

# **Documentation for the GAMIT GPS Analysis Software**

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## 1. Overview of GAMIT Processing

GAMIT is a comprehensive GPS analysis package developed at MIT and Scripps for the estimation of three-dimensional relative positions of ground stations and satellite orbits. The software is designed to run under any UNIX operating system supporting X-Windows; we have implemented thus far versions for Sun (OS/4 and Solaris 2), HP, IBM/RISC, DEC, and LINUX on Intel-based workstations. The maximum number of stations and sessions allowed is determined by dimensions set at compile time and can be tailored to fit the requirements and capabilities of the analyst's computational environment. The primary output of GAMIT is a loosely constrained solution (H-) file of parameter estimates and covariances which can be passed to GLOBK for combination of data to estimate station positions and velocities and orbital and Earth-rotation parameters. With Release 9.9 GAMIT and GLOBK can be run with little effort or intervention by the analyst using a new suite of processing scripts described in Chapter 10. In order to diagnose problems with the processing, however, the new user will want to understand both the theory and organization of each of the GAMIT modules, and hence should spend some time reading through this manual and executing the program in a more deliberate manner than is required in routine processing.

At the start of processing the analyst has available a preliminary set of station coordinates (L-file), the broadcast ephemeris (E-file or RINEX navigation file) for the satellites observed, an ensemble of phase and pseudo-range observations, and auxiliary information available from the log sheets (tracking scenarios, antenna heights, and meteorological data). This information should be organized into *sessions*, defined as spans during which a group of stations tracks simultaneously the phases of two or more satellites. In order to accommodate combination with continuously operating stations, sessions are today usually organized into 24-hr spans covering a single UTC day. It is not difficult, however, to organize a session across a day boundary if that is more efficient for a particular local survey (see Chapter 4). The data and other information are prepared in the proper formats, and each session is analyzed individually or combined with other sessions to yield estimates of improved station coordinates and orbital parameters.

The analysis software is composed of distinct modules, which perform the functions of preparing the data for processing, generating reference orbits for the satellites, computing residual observations (O-C's) and partial derivatives from a geometrical model, detecting outliers or breaks in the data, and performing a least squares analysis. Although the modules can be run individually, they are tied together through the data flow, particularly file-naming conventions, in such a way that most processing is best done with shell scripts and a sequence of batch files set up by two driver modules—MAKEXP ("make experiment") for the data preparation and FIXDRV ("fixed-table driver") for the modeling, editing, and estimation. Though much of the data editing is performed automatically, the solution residuals can be displayed or plotted so that manual editing of problematical data can be performed. The primary steps in the data analysis are summarized below, with reference to the modules used in each step. Details are given in Chapter 4–6, and a summary table in Appendix 1.

## 1) Setup the program and processing directories

The software is distributed with a top-level directory (which must be aliased to `gg` for your login) containing shell scripts ( `/com` ), source code ( `/gamit`, `/kf`, and `/libraries` ), tables ( `/tables` ), documentation ( `/doc` and `/help` ), map grids ( `/maps`, for GMT plotting), and example command files and tables (`/templates`). Within the main source directories are sub-directories for each of the main modules of GAMIT or GLOBK and `/bin` directories containing executables. Your Unix path must contain `~/gg/com`, `~/gg/gamit/bin`, and `~/gg/kf/bin` in order to run the software anywhere on your system.

You should create an "experiment" directory that will contain a subdirectory for the RINEX files, a subdirectory for experiment-specific tables, and subdirectories for each session to be processed (see Section 4.1 for details of the directory structure).

## 2) Prepare the data.

Generate an L-file of *a priori* coordinates for the experiment epoch from an existing GLOBK apr file (`gapr_to_l`) or by performing a fit to the pseudoranges on the RINEX file (`sh_rx2apr`).

Enter antenna and receiver occupation information (from log sheets) into table `station.info` using templates and an editor.

Create all of the other data-preparation input files using program `MAKEXP`.

Execute the programs `MAKEJ` and `MAKEX` (and possibly `MAKEK`) to read the receiver data files (in RINEX or FICA format) and generate the clock (J- and K-) and observation (X-) files to be used in the analysis.

Obtain initial conditions (G-file) for GAMIT's orbital integrator (ARC) by copying a G-file from SOPAC, executing script `sh_sp3fit` to fit the ARC model to an IGS "sp3" file, or executing the script `sh_bcf` to fit the ARC model to the broadcast elements in a RINEX navigation file.

## 2) Set up and execute batch processing.

Edit templates to create control files `sittbl` and `sestbl` for the batch analysis run.

Execute program `FIXDRV` to create batch files for the analysis.

Execute the batch job to perform processing.

ARC creates a T-file by numerical integration of the initial conditions in the G-file.

MODEL computes the theoretical values of the observations ("observables") and partial derivatives of these observations with respect to the parameters to be estimated, and writes them to an output (C-) file for editing and estimation.

AUTCLN performs automatic (batch) editing of cycle slips and outliers in the phase observation.

CFMRG writes a (M-) file defining the way observations are to be combined, and SOLVE performs the least squares analysis, writing the "print" output to a Q-file and the adjustments and covariance matrix to an H-file for combination with other sessions and experiments using GLOBK.

3) Evaluate the solution by examining the output (Q-file) from SOLVE (chi-square value and size of parameter adjustments) and the phase rms for each station from AUTCLN (autcln.post.sum ). If a station shows problem you may need to look at sky-plots of the phase residuals, created by sh\_oneway from the .DPH files produced by AUTCLN, or use CVIEW to look at the phase residuals in more detail on the screen.

The standard processing sequence for unedited data includes one or two passes through MODEL, AUTCLN, and SOLVE. If you have good a priori coordinates and orbits, a single pass usually sufficient for a good solution, but a second pass using AUTCLN in postfit mode will allow better handling of poor data and provide quality statistics for each of the stations in the network. produce . If the a priori coordinates and orbits are not highly accurate, then the additional pass is also necessary to improve these to the level at which the automatic editing is robust and the adjustments are within a linear range. With poorly behaved data, it may also be necessary to examine with CVIEW the phase residuals from the initial solution and to add instructions for deleting data to the AUTCLN command file, or, more rarely, to fix remaining small cycle slips interactively.

Chapter 2 presents a brief summary of the theoretical elements of GPS data analysis. It introduces GAMIT nomenclature and includes references that describe in greater detail the algorithms used by the program. Chapter 3 describes in detail the files used and their naming conventions; it need not be read carefully the first time through. Chapter 4 describes the steps in data preparation. The details of running FIXDRV and executing and interpreting the batch analysis runs are given in Chapter 5. Chapter 6 describes the procedures for automatic and interactive editing. Chapters 7–9 are included for reference but need not be read to carry out most processing tasks. Chapter 7 describes the individual modules in more detail. Chapter 8 the various options available for modeling the tropospheric delay; and Chapter 9 the various utility programs and auxiliary data files, only a few of which need concern most analysts. Chapter 10 describes how to use the new automatic processing scripts. Finally, the Appendices provide a summary of the processing and file names, information on antenna specifications, data formats, and a rarely used procedure for handling non-simultaneous sampling times under SA.

*Note on manual style:* All of the programs in the GAMIT and GLOBK (kf) directories are named for Unix in lowercase. For emphasis, however, and to distinguish (Fortran) programs from (C-) shell scripts, we have written them in uppercase in this manual.

## 2. Data Analysis: Theory

### 2.1 Introduction to GPS Measurements

High-precision geodetic measurements with GPS are performed using the carrier beat phase, the output from a single phase-tracking channel of a GPS receiver. It is the difference between the phase of the carrier wave implicit in the signal received from the satellite, and the phase of a local oscillator within the receiver. The carrier beat phase can be measured with sufficient precision that the instrumental resolution is a millimeter or less in equivalent path length. For the highest relative-positioning accuracies, carrier beat phase observations must be obtained simultaneously at each epoch from several stations (at least two), for several satellites (at least two), and at both the L1 (1575.42 MHz) and L2 (1227.6 MHz) GPS frequencies. The dominant source of error in a phase measurement or series of measurements between a *single* satellite and ground station is the unpredictable behavior of the time and frequency standards ("clocks") serving as reference for the transmitter and receiver. Even though the GPS satellites carry atomic frequency standards, the instability of these standards would still limit positioning to the several meter level were it not for the possibility of eliminating their effect through signal differencing.

A second type of GPS measurement is the pseudo-range, obtained using the 300-m-wavelength CA ("coarse acquisition") code or 30-m-wavelength P ("protected") code transmitted by the satellites. Pseudo-ranges provide the primary GPS observation for navigation but are not precise enough to be used alone in geodetic surveys. However, they are useful for synchronizing receiver clocks, resolving ambiguities and repairing cycle slips in phase observations, and as an adjunct to phase observations in estimating satellite orbits.

For a single satellite, differencing the phases (or pseudo-ranges) of signals received simultaneously at each of two ground stations eliminates the effect of bias or instabilities in the satellite clock. This measurement is commonly called the between-stations-difference, or single-difference observable. If the stations are closely spaced, differencing between stations also reduces the effects of tropospheric and ionospheric refraction on the propagation of the radio signals. If the ground stations have hydrogen-maser oscillators (with stabilities approaching 1 part in  $10^{15}$  over several hours), then single differences can, in principle, be useful, as they are for VLBI. In practice, however, it is seldom cost effective to use hydrogen masers and single difference observations in GPS surveys. Rather, we form a double difference by differencing the between-station differences also between satellites to cancel completely the effects of variations in the station clocks. In this case the observations are just as accurate with low-cost crystal oscillators as with an atomic frequency standard (though the use of the latter may make editing a bit easier).

Since the phase biases of the satellite and receiver oscillators at the initial epoch are eliminated in doubly-differenced observations, the doubly-differenced range (in phase units) is the measured phase plus an *integer* number of cycles. (One cycle has a wavelength of 19 cm at L1 and 24 cm at L2 for code-correlating receivers; half these values for squaring-type receiver channels.) If the measurement errors, arising from errors in the

models for the orbits and propagation medium as well as receiver noise, are small compared to a cycle, there is the possibility of determining the integer values of the biases, thereby obtaining from the initially ambiguous doubly differenced phase an unambiguous measure of doubly differenced range. Resolution of the phase ambiguities allows a more precise measure of the relative positions of the stations (see, e.g., *Blewitt* [1989], *Dong and Bock* [1989]).

GAMIT incorporates difference-operator algorithms that map the carrier beat phases into singly and doubly differenced phases. These algorithms extract the maximum relative positioning information from the phase data regardless of the number of data outages, and take into account the correlations that are introduced in the differencing process. (See *Bock et al.* [1986] and *Schaffrin and Bock* [1988] for a detailed discussion of these algorithms.) An alternative, (nearly) mathematically equivalent approach to processing GPS phase data is to use formally the (one-way) carrier beat phases but estimate the phase offset due to the station and satellite clocks at each epoch. This approach is used by AUTCLN to compute one-way phase residuals for editing and display.

In order to provide the maximum sensitivity to geometric parameters, the carrier phase must be tracked continuously throughout an observing session. If there is an interruption of the signal, causing a loss of lock in the receiver, the phase will exhibit a discontinuity of an integer number of cycles. This discontinuity may be only a few cycles ("cycle-slips") due to a low signal-to-noise ratio, or it may be thousands of cycles, as can occur when the satellite is obstructed at the receiver site. Initial processing of phase data is often performed using time differences of doubly differenced phase ("triple differences", or "Doppler" observations) in order to obtain a preliminary estimate of station or orbital parameters in the presence of cycle slips. The GAMIT software uses triple differences in editing but not in parameter estimation. Rather, it allows estimation of extra free bias parameters whenever the automatic editor has flagged an epoch as a possible cycle slip or, in the program "quick" mode, whenever there is a gap in the data. Various algorithms to detect and repair cycle slips are described by *Blewitt* [1990], and also in Chapter 6 of this document.

Although phase variations of the satellite and receiver oscillators effectively cancel in doubly differenced observations, errors in the *time* of the observations, as recorded by the receiver clocks, do not. However, the pseudo-range measurements, together with reasonable a priori knowledge of the station coordinates and satellite position, can be used to determine the offset of the station clock to within a microsecond, adequate to keep errors in the doubly differenced phase observations below 1 mm.

General background and an error analysis for the carrier-beat phase observable may be found in Chapter 5 of *King et al.* [1985] and Chapter 2 of *Feigl* [1991].

## 2.2 Dual-Band Processing

A major source of error in single-frequency GPS measurement is the variable delay introduced by the ionosphere. For day-time observations near solar maximum this effect

can exceed several parts per million of the baseline length. Fortunately, the ionospheric delay is dispersive and can be reduced to a millimeter or less (at mid-latitudes) by forming a particular linear combination (LC, sometimes called L3) of the L1 and L2 phase measurements:

$$\phi_{LC} = 2.546 \phi_{L1} - 1.984 \phi_{L2}$$

(See, e.g., *Bender and Larden* [1985], *Bock et al.* [1986], or *Dong and Bock* [1989]) Forming LC, however, magnifies the effect of other error sources. On short baselines where the ionospheric errors cancel in between-station (single) differencing, it is preferable to treat L1 and L2 as two independent observables, rather than form the linear combination. For baselines longer than a few kilometers, on the other hand, on which ionospheric errors are uncorrelated, it is preferable to form LC and completely eliminate the effects of the ionosphere. In the general case, the optimal choice of dual-band observable must lie somewhere between these two extremes [*Bock et al.*, 1986; *Schaffrin and Bock*, 1988]. That is, one must balance the amplification in noise introduced by forming LC against the benefits gained by eliminating ionospheric effects. In practice, most networks of extent greater than a few kilometers are processed using the LC observable.

In examining phase data for cycle slips, it is often useful to plot several combinations of the L1 and L2 residuals. Single-cycle slips in L1 or L2 will appear as jumps of 2.546 or 1.984 cycles, respectively, in LC. Single-cycle slips in both L1 and L2 (a more common occurrence) appear as jumps of 0.562 cycles in LC, which, though smaller, may be more evident than the jumps in L1 and L2 because the ionosphere has been eliminated. If the L2 phase is tracked using codeless techniques, the carrier signal recorded by the receiver is at twice the L2 frequency, leading to half-cycle jumps when it is combined with full-wavelength data. Hence, a jump of a "single" L2 cycle will appear as 0.892 in LC and simultaneous jumps in (undoubled) L1 and (doubled) L2 will appear as 1.654 cycles in LC. Another useful combination is the difference between L2 and L1 with both expressed in distance units:

$$\phi_{LG} = \phi_{L2} - 0.779 \phi_{L1}$$

sometimes called "LG" because the L2 phase is scaled by the "gear" ratio ( $f_2/f_1 = 60/77 = 1227.6/1575.42$ ). In the LG phase all geometrical and other non-dispersive delays (e.g., the troposphere) cancel, so that we have a direct measure of the ionospheric variations. One-cycle slips in L1 and L2 are of course difficult to detect in the LG phase in the presence of much ionospheric noise since they are equivalent to only 0.221 LG cycles.

If precise (P-code) pseudorange is available for both GPS frequencies, then a "wide-lane" (WL) combination of L1, L2, P1, and P2 can be formed which is free of both ionospheric and geometric effects and is simply the difference in the integer ambiguities for L1 and L2:

$$WL = n_2 - n_1 = \phi_{L2} - \phi_{L1} + (P1 + P2) (f_1 - f_2)/(f_1 + f_2)$$

The WL observable can be used to fix cycle slips in one-way data [Blewitt, 1990] but should be combined with LG and doubly differenced LC to rule out slips of an equal number of cycles at L1 and L2.

Using wide-lane observations averaged over a satellite pass is the most efficient approach to resolving the wide-lane ( $n_2 - n_1$ ) phase ambiguities (see, e.g. Blewitt, 1989; Dong and Bock, 1989) though clock jumps and inter-channel receiver biases can sometimes produce spurious results. To provide a check the algorithm used by GAMIT employs both the pseudoranges and the "phase wide-lane" with ionospheric constraints to resolve the wide-lane ambiguities [Bender and Larden, 1985; Dong and Bock, 1989; Feigl et al., 1993].

### 2.3 Modeling the Satellite Motion

A first requirement of any GPS geodetic experiment is an accurate model of the satellites' motion. The (3-dimensional) accuracy of the estimated baseline, as a fraction of its length, is roughly equal to the fractional accuracy of the orbital ephemerides used in the analysis. The accuracy of the Broadcast Ephemerides computed regularly by the Department of Defense using pseudorange measurements from 5 stations is typically 5-10 parts in  $10^7$  (10-20 m), well within the design specifications for the GPS system but not accurate enough for the study of crustal deformation. By using phase measurements from a global network of over 50 stations, however, the International GPS Service for Geodynamics (IGS) [Beutler et al., 1994a], is able to determine the satellites' motion with an accuracy of 2-10 parts in  $10^9$  (5-20 cm). For GPS surveys prior to about 1991, the global tracking network was much smaller but can still be used to achieve accurate results for regional surveys. If we include in our analysis observations from widely separated stations whose coordinates are well known (from VLBI, SLR, or global GPS measurements), the fractional accuracy of the baselines formed by these stations is transferred through the orbits to the baselines of a regional network. For example, a 10 mm uncertainty in the relative position of sites 2500 km apart introduces an (approximate) uncertainty of only 1 mm in the components of a 250 km baseline. This scheme can be used successfully even with regional fiducial sites, transferring, for example, the relative accuracy of 250-500 km baselines to a network less than 100 km in extent.

The motion of a satellite can be described, in general, by a set of six initial conditions (Cartesian position and velocity, or osculating Keplerian elements, for example) and a model for the forces acting on the satellite over the span of its trajectory. To model accurately the motion, we require knowledge of the acceleration induced by gravitational attraction of the sun, moon, and higher order terms in the Earth's gravity field, and some means to account for the action of non-gravitational forces due, for example, to solar radiation pressure and gas emission by the spacecraft's batteries and attitude-control system. For GPS satellites non-gravitational forces are the most difficult to model and have been the source of considerable research over the past 15 years (see Colombo [1986] Lichten and Bertiger [1989], Beutler et al. [1994b] for more discussion).

In principle, a trajectory can be generated either by analytical expressions or by numerical integration of the equations of motion; in practice, numerical integration is almost always used, for both accuracy and convenience. The position of the satellite as a function of time is then read from a table (ephemeris) generated by the numerical integration. The equations of motion and numerical integrator used by GAMIT were adapted from the Planetary Ephemeris Program, developed originally at MIT's Lincoln Laboratory. A detailed description of the equations and algorithms may be found in *Ash* [1972].

In modeling the phase and pseudorange observations, we must take into account not only the motion of the center of mass of the satellite but also meter-level offsets between the center of mass and the phase-center of the transmitting antenna. These offsets are negligible for regional networks but can introduce centimeter-level errors for baselines approaching an Earth radius. Also important are temporary phase excursions of several decimeters lasting up to a half-hour during the maneuvers the satellites execute to keep their solar panels facing the Sun when the orbital plane is nearly aligned with the Earth-Sun direction. For the satellites in each orbital plane, this alignment occurs for several weeks twice a year, the so-called "eclipse season". Yoaz Bar-Sever and colleagues at JPL have spent considerable effort developing models of the satellites' orientation, even to point of making the behavior more predictable by getting DoD to apply a small bias about the yaw axis—a change that was implemented gradually between June, 1994, and November, 1995. See *Bar-Sever* [1996] for a complete discussion.

#### 2.4 Estimation by Least Squares

GAMIT incorporates a weighted least squares algorithm to estimate the relative positions of a set of stations, orbital and Earth-rotation parameters, zenith delays, and phase ambiguities by fitting to doubly differenced phase observations. Since the functional (mathematical) model relating the observations and parameters is non-linear, the least-squares fit for each session may need to be iterated until convergence, i.e., until the corrections to the estimated station coordinates and other parameters are negligible. Data can be viewed and edited interactively without iteration since CVIEW uses the pre-fit residuals, partial derivatives, and parameter adjustments to compute and display "predicted" post-fit residuals (see Section 6.5). Automatic editing is more effective near convergence, however, since AUTCLN uses pre-fit residuals.

In current practice, the GAMIT solution is not usually used directly to obtain the final estimates of station positions from a survey. Rather, we use GAMIT to produce estimates and an associated covariance matrix of station positions and (optionally) orbital and Earth-rotation parameters ("quasi-observations") which are then input to GLOBK [*Herring*, 1997] or other similar programs to combine the data with those from other networks and times to estimate positions and velocities [*Feigl et al.*, 1993; *Dong et al.*, 1997]. In order not to bias the combination, GAMIT generates the solution used by GLOBK with only loose constraints on the parameters, defining the reference frame only at the GLOBK stage by imposing constraints on station coordinates. Since phase ambiguities must be resolved

(if possible) in the phase processing, however, GAMIT generates several intermediate solutions with user-defined constraints before loosening the constraints for its final solution. These steps are described in detail in Section 5.4.

The most rigorous way to handle the phase ambiguities is to keep them free for an initial combination of all of the data to be used in the study, and then use the estimated uncertainties (appropriately scaled) of station coordinates and possibly orbital parameters from the combination as constraints in an iteration in which the GAMIT processing is repeated. In practice, however, it is often possible to avoid the iteration by applying in the initial solution sufficiently tight, but statistically conservative constraints on coordinates and orbital parameters and using conservative criteria for assigning the phase ambiguities to integer values. These issues are discussed in *Dong and Bock* [1989] and *Blewitt* [1989] and Chapter 5 of this manual.

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### 3. File Structure and Naming Conventions

#### 3.1 Introduction

Before running GAMIT it is necessary to understand its file naming conventions. All the program modules adhere to specific conventions for the naming of files for a particular experiment. This assures a unique definition of each experiment, facilitates data file management, and allows for ease of interactive processing and troubleshooting. There are four types of files:

- 1) site-occupation-specific
- 2) solution-specific
- 3) experiment-specific
- 4) global

Each file is distinguished either by its first character (types 1 and 2) or a unique name (type 3). Type 1 files are named using 4-character station codes and the day of the observations. Type 2 and 3 files have an experiment (survey) or solution name, chosen by the analyst, embedded within the file name. Type 4 files have specific names that are hard-wired in the software (though these names are often elaborated using links). These naming conventions allow the software to perform the bookkeeping necessary to process large quantities of data.

The remaining sections of this chapter describe the contents and format of the files of each type, and how the file is created and used by the software. A summary of all the file names is also given in Appendix 1, and templates for user-created files may be found in the `gamit/example` directory that accompanies the software distribution. Although file names will sometimes be shown in upper-case for clarity, lower-case is the preferred standard for UNIX operating systems.

#### 3.2 Site-occupation-specific Files

**X-file :** Observation data file containing the L1 and L2 carrier beat phases and pseudo-ranges, signal amplitudes, initial station coordinates and antenna offsets, start and stop times, and the identification of the satellites tracked in each receiver channel.

**Format :** `xsitey.day`

**Example :** `xvndn7.002`. This X-file has been created by program MAKEX from the data recorded at station VNDN (Vandenberg) on day 2 of 1987.

**Notes :** X-file names correspond directly to four-letter station codes used in the L- and throughout the software. The X-file names that appear in the D-file (see below) define all subsequent site-specific names.

**Type :** ASCII

**Created by :** MAKEX, utilities CTOX, XTOX, XUP

**Input to :** MODEL, and optionally MAKEK, BCTOT, FIXDRV, and CVIEW

- C-file : Primary file for data analysis, created by MODEL from an X-file and used as input to AUTCLN, SINCLN, DBLCLN, CVIEW, and SOLVE; contains observations (O's), prefit residuals (O-C's, observed-computed values), partial derivatives, and auxiliary information.
- Format : *csitey.day*  
 Example : *cvndn7.002*  
 Notes : Direct correspondence to X-files but binary and with partials. Once the data on the C-files have been cleaned, program CTOX is run to make clean X-files for further processing.  
 Type : Binary  
 Output of : MODEL, AUTCLN, SINCLN, DBLCLN, CVIEW  
 Input to : AUTCLN, SINCLN, DBLCLN, SCAN, CVIEW, SOLVE
- E-file : Broadcast Ephemeris data in either RINEX or FICA format. It is used by BCTOT to create an initial G-file and/or a T-file from the broadcast ephemeris parameters, and by MAKEJ and MAKEK to generate satellite and receiver clock files.
- Format : *esitey.day* or *sitedayn.yyn*  
 Example : *evndn7.002* or *vndn0020.87n*  
 Notes : The parameters and format of the E-file are described in Appendix 4.  
 Type : ASCII  
 Output of : RINEX translators or utility FICACHOP  
 Input to : BCTOT, MAKEJ, MAKEK
- K-file : Receiver clock data computed by MAKEX or MAKEK using nominal site coordinates, broadcast ephemeris, and pseudo-range. It is used by FIXDRV to estimate the coefficients of a linear or cubic polynomial model for clock behavior during the session.
- Format : *ksitey.day*  
 Example : *kvndn7.002*  
 Notes : The parameters and format of the station-specific K-file are described in 4.9. For receivers which do not record the broadcast ephemeris, there is a *session* - specific K-file of different format; this file is described in Section 9.4.  
 Type : ASCII  
 Output of : MAKEX, MAKEK  
 Input to : FIXDRV and utilities CALCK and PLOTK.

- P-file : <P>rint file for a MODEL run - provides a record of the run.
- Format : *psitey.day*  
 Example : *pvndn7.002*  
 Notes : Direct correspondence to X- and C-files  
 Type : ASCII  
 Output of : MODEL
- V-file : Print file for a SINCLN run - contains a record of the editing performed.
- Format : *vsitey.day*  
 Example : *vvndn7.002*  
 Notes : Direct correspondence to C-file  
 Type : ASCII  
 Output of : MODEL
- W-file : <W>eather file - contains meteorological data for modeling the effect of tropospheric refraction on the satellite signals.
- Format : *wsitey.day*  
 Example : *wvndn7.002*  
 Notes : This file is optional and is described in Section 9.5. If not available, default meteorological data are used.  
 Created by : User  
 Input to : MODEL
- Z-file : Water Vapor Radiometer (WVR) file - contains WVR data for modeling the effects of wet tropospheric delay on the satellite signals.
- Format : *zsitey.day*  
 Example : *zvndn7.002*  
 Notes : This file is optional and is described in Section 9.5.  
 Created by : User  
 Input to : FIXDRV, MODEL

### 3.3 Solution-specific Files

These files are specific to a particular experiment and should be unique with regards to all other experiments in order to facilitate efficient data management.

D-file : FIXDRV file - defines the number of sessions in each experiment, the number of receivers per session, the coordinate (L-) file, the ephemeris (T-), station-clock (I-), satellite-clock (J-), and data files (X- or C-) per session, and the order in which the sessions should be processed.

Format : `dxxxxy.day` where `xxxx` is the solution name. The rest of the filename is arbitrary but FIXDRV looks at the sixth character to set up the default value of the year. The three characters of the extent may be the beginning day of the experiment, but this is not necessary.

Example : `dcalf7.002`

Notes : The D-file is the primary input file to FIXDRV. As such, its name defines all subsequent experiment-specific files. The user can identify the experiment name in any manner. Prior to executing FIXDRV, the user creates the D-file, using program MAKEXP or manually. See Section 5.2.

Type : ASCII

Created by : MAKEXP or user

Input to : FIXDRV

Session Control Table : Input control file for FIXDRV, specifying the type of analysis and the *a priori* measurement errors and satellite constraints. See Section 5.2.

Format : `sestbl`.

Notes: : The file name is hard-wired, but links may be used to define different versions of the table.

Type : ASCII

Created by : User from template

Input to : FIXDRV

Site Control Table : Input control file for FIXDRV, specifying for each site the clock and atmospheric model to be used, and the *a priori* coordinate constraints. See Section 5.2

Format : `sittbl`.

Notes: : The file name is hard-wired, but links may be used to define different versions of the table.

Type : ASCII

Created by : User from template

Input to : FIXDRV

AUTCLN (detailed) output file: Complete record of the editing process; can be ignored and deleted if the solution completed successfully. See sections 6.2 and 7.6.

Format : autcln.out  
 Type : ASCII  
 Created by : AUTCLN

AUTCLN summary file: Summary of editing; useful for evaluating results. See sections 6.2 and 7.6.

Format : autcln.pref.sum or autcln.post.sum  
 Type : ASCII  
 Created by : AUTCLN

A-file : ASCII version of the T-file, optionally generated for scrutiny by the analysis or for export.

Format : *axxxy.day*  
 Type : ASCII  
 Output of : TTOASC  
 Input to : None

B-file : Primary <B>atch file - controls the batch (automatic) mode of data processing.

Format : *bxxxxx.bat* where *xxxxx* are the first five characters of the D-file name.  
 Example : *bcalf7.bat*  
 Notes : The primary B-file contains a sequence of secondary B-files which execute in an order prescribed by FIXDRV the individual modules of the software. Its name corresponds to that of the D-file.  
 Type : ASCII  
 Output of : FIXDRV

B-file : Secondary <B>atch file - controls the execution of one program module.

Format : *bxxxxx.nnn* where *xxxxx* are the first five characters of the D-file name and *nnn* is the sequence number of the batch file.  
 Examples : *bcalf7.001*, *bcalf7.015*  
 Notes : Each secondary batch files contains the input stream for one execution of a program module. For example, the first line of *bcalf7.bat* might be *arc < bcalf7.001* . That is, the program module ARC will receive its instructions from *bcalf7.001* .  
 Type : ASCII  
 Output of : FIXDRV  
 Input to : ARC, MODEL, CFMRG, SOLVE, DBLCLN

- G-file : A file of orbital initial conditions for all satellites on the T-file.
- Format : *gxxxxy.day*
- Example : *gcalf7.002*
- Notes : The G-file contains initial conditions and nongravitational force parameters for each GPS satellite at a particular UTC epoch. The G-file initial conditions serve as starting points for a numerical integration of the satellite orbits and the generation of a T-file. The name of the G-file is arbitrary but would normally include the day and year of the initial conditions as in the example above (day 002, 1987); in any case it should match the name of the corresponding T-file. The filename of the G-file created by SOLVE is the same except that the 6th character is incremented by one letter. The format of the G-file is described in Section 4.10
- Type : ASCII
- Output of : BCTOT, TTOG, SOLVE
- Input to : ARC, SOLVE
- H-file : Covariance matrix and parameter adjustments for solution generated with loose constraints, used as input to GLOBK.
- Format : *hxxxxy.day*
- Example : *hcalf7.002*
- Type : ASCII
- Output of : SOLVE
- Input to : HTOH, HTOGLB, HTOSNX
- I-file : <I>ite file - contains a site by site, session by session record of the station clock offset, rate, and acceleration, used optionally by MODEL.
- Format : *ixxxx.xxx*
- Example : *icalf7.002*
- Notes : The I-file name is specified in the D-file.
- Type : ASCII
- Output of : MAKEI, FIXDRV, SOLVE
- Input to : MODEL, SOLVE

- J-file : Satellite clock parameters transmitted by the satellites and recorded by the receivers.
- Format : *jxxxxy.day*  
 Example : *jcal7.002*  
 Notes : This file is used by MODEL to compute the receiver clock corrections epoch-by-epoch, and also to correct the modeled phase for large satellite clock drifts (e.g., under SA conditions) when observations are not recorded simultaneously at all sites.  
 Type : ASCII  
 Created by : MAKEJ  
 Input to : MODEL
- M-file : <M>erge file - sets up the data and parameters for the least-squares analysis in SOLVE.
- Format : *mxxxx1.day, mxxxxa.day*  
 Example : *mcal1.002, mcalfa.002*  
 Notes : The M-file name is derived from the D-file name. The initial M-file is created by CFMRG (using a FIXDRV-written batch file) to set up the initial SOLVE, SINCLN, DBLCLN, or CVIEW run. After estimating adjustments to the parameters, SOLVE writes a new M-file with the same name and with the adjustments included. In the usual processing sequence generated by FIXDRV, the 6th character of the M-file name for the "quick" solution is "1", and for standard solutions "a". If there are multiple solutions of a given type, the M-file is overwritten (re-created by CFMRG) each time.  
 Type : Binary  
 Output of : CFMRG  
 Input to : SOLVE, SINCLN, DBLCLN, SCAN, CVIEW
- N-file : <N>oise file contains station-specific, elevation-dependent values used to reweight phase observations in SOLVE after postfit editing by AUTCLN.
- Format : *nxxxx1.day nxxxxa.day*  
 Example : *ncal1.002, ncalfa.002*  
 Notes : The file has the structure of the `error model:` section of the SOLVE batch file. SOLVE reads it to overrides the batch-file input.  
 Type : ASCII  
 Output of : Shell-script `sh_sigelv`  
 Input to : SOLVE

- O-file : Solution output file for a SOLVE run, an abbreviated form of the Q-file used for plotting, statistics, and input to GPSNET.
- Format : *oxxxx1.day oxxxxa.day*
- Example : *ocalf1.002, ocalfa.002*
- Notes : This file is designed to be interfaced with a network adjustment program or the BSL series of programs to calculate statistics. Its use is optional but strongly recommended for detecting blunders. The name of the O-file corresponds directly to the Q-file from which it was copied.
- Type : ASCII
- Output of : SOLVE
- Input to : Network-adjustment, statistics, and plotting programs
- Q-file : Print file for a SOLVE run - contains a record of the analysis.
- Format : *qxxxx1.day, qxxxxa.day*
- Example : *qcalf1.002, qcalfa.002*
- Notes : The Q-file naming conventions are identical to those of the M-files. For a batch run, the file *qcalf1.002* in our example will be created by the "quick" solution of SOLVE (see Chapter 5), *qcalfa.002* by the "regular" solution. As for M-files, multiple passes through SOLVE (to iterate parameter estimates or editing) will cause the Q-files from the previous iteration to be overwritten.
- Type : ASCII
- Output of : SOLVE
- T-file : <T>abular ephemeris file for all satellites in a session or series of sessions - contains satellite state vectors at equally-spaced intervals (default 15 minutes for ARC) for later interpolation in MODEL. The name should match that of the G-file.
- Format : *txxxxy.day*
- Example : *tcalf7.002*, this T-file is associated with a G-file with initial conditions on day 002 of 1987
- Type : Binary
- Output of : ARC, BCTOT, NGSTOT, *sh\_bctot*, *sh\_sp3fit*
- Input to : FIXDRV, MODEL, TTONGS, TTOASC
- U-file : Ocean tide components for all stations in the session, created by OCTTAB from a global file of station components (*stations.oct*) or a grid of components by latitude and longitude (*grid.oct*).
- Format : *uxxxxxy.day*
- Type : ASCII
- Output of : OCTTAB
- Input to : MODEL

- V-file (1) : Print file for DBLCLN - contains a record of the editing performed.
- Format : vdblcln.out  
Type : ASCII
- V-file (2) : Print file for SCANM (one of two files for SCANRMS -contains a summary of rms values and jumps for each double-difference combination.
- Format : *vxxxx 1.day.sort*, *vxxxx a.day.sort*, *vxxxx 1.day.worst*, *vxxxx a.day.worst*  
Type : ASCII
- Y-files : <Y>aw files, of two types. An ASCII version (6th character is last digit of year) giving times of eclipses and yaw rates for each satellite observed during the session is written by ARC from information in the global file *svnav.dat* and computed eclipse information. A binary version (6th character is *t*) giving the angle of departure from nominal yaw at the epochs of the observations in the session is written by YAWTAB, using the T-file and ASCII y-file as input for the computations. Both of these files are discussed in Section 7.2
- Format : *yxxxxy.day*  
Example : *ypgga5.267*  
Type : ASCII  
Output of : ARC  
Input to : YAWTAB
- Format : *yxxxxy.day*  
Example : *ypggat.267*  
Type : Binary  
Output of : YAWTAB  
Input to : MODEL

### 3.4 Experiment-specific Files

These files contain information collected for a particular experiment, such as antenna heights and time-dependent site coordinates.

Session information or scenario file : Satellites and times to be processed (Section 4.5).

Format : session.info (formerly makex.sceno)  
 Type : ASCII  
 Created by : User or MAKEXP  
 Input to : MAKEX, FIXDRV

Station information file : Receiver, antenna, and occupation-time information for each session (see Section 4.3)

Format : station.info  
 Notes : Prepared from site logs (replaces files hi.raw and sited., no longer used)  
 Type : ASCII  
 Created by : User, or HI2STNFO from hi.raw  
 Input to : MAKEX, FIXDRV, MODEL

L-file : Station coordinate file - contains a list of the best available coordinates of the sites occupied during a particular experiment (see Section 4.2).

Format : lxxxx.day in the working directory, where xxxx is the solution name from the D-file name.

Example : lsv4x7.002

Notes : The L-file stores *thea priori* coordinates for a particular date, determined by reading a file of positions and velocities from, e.g., VLBI, SLR, or a global GPS analysis. An updated L-file is written by SOLVE.

Type : ASCII  
 Created by : User, GLBTOL, SVTOL, SOLVE  
 Input to : MAKEX, MAKEK, FIXDRV, MODEL

Site description file : Antenna phase center offsets to be applied to the site coordinates. (Supplanted by station.info but still usable if the latter does not exist.)

Format : sited. in the working directory; in general, *expmt.makex.sited*.  
 Example : trex18.makex.sited  
 Type : ASCII  
 Created by : HI  
 Input to : MAKEX, FIXDRV, MODEL

### 3.5 Global Files

These files are global in the sense that they can be used for many experiments over the time interval for which they are valid (usually for at least a year). The name of the files must be exactly specified as indicated below. There must be a copy of these files (or a link of the same name) in each working directory.

gdetic.dat:	Table of parameters of geodetic datums
Format	: gdetic.dat
Notes	: The format of this file is described in Section 9.8. It can be augmented at any time to include additional datums.
Type	: ASCII
Created by	: User
Input to	: FIXDRV, MODEL, SOLVE
svnav.dat	: Table giving NAVSTAR numbers, block number (I or II), spacecraft mass, and yaw parameters for each GPS satellite (listed by PRN number)
Format	: svnav.dat
Notes	: See Section 9.8
Type	: ASCII
Created by	: User
Input to	: MAKEX, ARC, MODEL
antmod.dat	: Table of antenna phase center offsets and, optionally, variations as a function of elevation and azimuth.
Format	: antmod.dat
Notes	: See Section 4.3, 5.2 and Appendix 7
Type	: ASCII
Created by	: MIT
Input to	: MODEL
rcvant.dat	: Table of correspondences between GAMIT 6-character codes and the full (20-character) names of receivers and antennas used in RINEX and SINEX files.
Format	: rcvant.dat
Notes	: See Section 4.3 and Appendix 7
Type	: ASCII
Created by	: MIT, SIO, or user from IGS standards
Input to	: MODEL (eventually XTORX and HTOSNX)

- ut1 . : UT1 table - contains TAI-UT1 values in tabular form.for interpolation in MODEL and ARC, and BCTOT
- Format : ut1. in the working directory; ut1.iers, e.g., in the tables directory
- Notes : Should be updated regularly. See Section 9.8.
- Type : ASCII
- Created by : SIO, MIT, or user from, e.g., IERS, USNO
- Input to : FIXDRV, MODEL, ARC, BCTOT, NGSTOT, TTONGS
- 
- pole. : Pole table - contains polar motion values in tabular form for interpolation in MODEL and ARC, and BCTOT
- Format : pole. in the working directory; pole.iers, e. g., in the tables directory
- Notes : Should be updated regularly. See Section 9.8.
- Type : ASCII
- Created by : MIT, SIO, or user from e.g., IERS, USNO
- Input to : FIXDRV, MODEL, ARC, BCTOT, NGSTOT, TTONGS
- 
- leap.sec : Table of jumps (leap seconds) in TAI-UTC since 1 January 1982.
- Format : leap.sec
- Notes : See Section 9.8.
- Type : ASCII
- Created by : SIO, MIT, or user from, e.g., IERS, USNO notices.
- Input to : FIXDRV, MODEL, ARC, BCTOT, NGSTOT, TTONGS
- 
- nutabl. : Nutation table - contains nutation parameters in tabular form for interpolation in MODEL, ARC, and BCTOT
- Format : nutabl. in the working directory; nutabl.91, e.g., in the tables directory
- Notes : See Section 9.8.
- Type : ASCII
- Created by : MIT
- Input to : MODEL, ARC, BCTOT, NGSTOT, TTONGS

luntab . : Lunar tabular ephemeris

Format : luntab. in the working directory; luntab.95.J2000 , e. g., in the tables directory

Notes : Inertial reference frame (B1950 or J2000) must batch input controls. Linked by links.com or links.tables. See Section 9.8.

Type : ASCII

Created by : MIT

Input to : ARC

soltab . : Solar tabular ephemeris

Format : soltab.in the working directory; soltabl.95.J2000 , e. g., in the tables directory

Notes : Inertial reference frame (B1950 or J2000) must batch input controls. Linked by links.com or links.tables. See Section 9.7.

See Section 9.7.

Type : ASCII

Created by : MIT

Input to : ARC

stations.oct . : Ocean tide components by stations.

Type : ASCII

Format : stations.oct in both the day and tables directories.

Created by : Hans-Georg Scherneck at Onsala Space Observatory

Input to : OCTTAB

grid.oct . : Ocean tide components by latitude and longitude.

Type : Binary

Format : grid.oct in both the day and tables directories.

Created by : DAF2DA from the ASCII ".daf" files created by Hans-Georg Scherneck at Onsala Space Observatory

Input to : OCTTAB

## 4. Creating Data Input Files

### 4.1 Introduction and file organization

The first, and in many ways most difficult step in analyzing GPS data, is organizing the data, both field notes and receiver output, in such a way that it can be handled efficiently by the processing programs. It is during this process that you must make tentative decisions about how many days to analyze, what stations should be included and over what time span, and how frequently to sample the data. In short, this is the time to start taking careful notes and to plan your analysis strategy. This is also the time when you discover that you are missing log sheets, data files, or *a priori* coordinates for particular stations, and you must send frantic e-mail to fill in the holes.

The main GAMIT modules (beginning with FIXDRV, ARC, and MODEL) require seven types of input:

- Raw phase and pseudo-range data in the form of ASCII X-files (one for each station within each session)
- Station coordinates in the form of an L-file
- Receiver and antenna information for each site (file station.info)
- Satellite list and scenario (file session.info)
- Initial conditions for the satellites' orbits in a G-file (or a tabulated ephemeris in a T-file)
- Satellite and station clock values (I-, J-, and K-files)
- Control files for the analysis (sestbl. and sittbl.)
- "Standard" tables to provide lunar/solar ephemerides, the Earth's rotation, geodetic datums, and spacecraft and instrumentation information (see below).

The X-files are the key organizational structure because all X-files for a given session are written with the same start and stop times, selection of satellites, and sampling interval. This imposed rigidity has certain advantages. The primary one is that the process of creating the X-files (program MAKEX) acts as a filter, catching most of the problems with missing or invalid data, mismatched time tags, and poorly behaved receiver clocks that would cause greater loss of time if discovered later.

The first step is to create working directories for the processing. The recommended organization (and the one used by `sh_gamit`) is a "survey" or continuous network directory (e.g., `emed98`, `scec99`, `scign99`) under which you will have "day" directories for each day or session (e.g. `/312` for day 312). Parallel to the day directories are directories containing the RINEX files (e.g., `/rinex`), orbit files (e.g. `/brdc` for navigation files and `/igs` for IGS SP3 files), and the GAMIT tables relevant to the survey (`/tables`). (The directories for GLOBK processing of the survey, `/gsoln` and `/glbf`, can also go at this level.)

You begin the pre-processing by creating links within the day directory to the data files and tables necessary to set up the batch processing. The first step is to create links to the GAMIT global files: geodetic datums (gdtic.dat), lunar and solar ephemerides (luntab. and soltab.), nutations (nuttab.), Earth rotation (ut1. and pole.), ocean tides (stations.oct and grid.oct), leap seconds (leap.sec), and spacecraft, receiver, and antenna characteristics (svnav.dat, antmod.dat, rcvant.dat). This is usually accomplished in two steps. First, in the /tables directory, execute script links.tables, which will create links for the global files to ~/gg/tables. Then from each day directory you execute links.day, which will create links for global files and survey-specific files to ../tables. Links.day will also create links from the day directory to ../tables for the six control and survey-specific files needed by GAMIT: station.info, session.info, .sestbl., sittbl., autcln.cmd. and lfile. Hence, you can keep a single copy of these files in /tables, avoiding the possibility of processing different sessions with different input controls. If you are simply performing a test with a single day's data, you execute links.com to link tables directly to ~/gg/tables and copy all the other files into the day directory. The link scripts, like all the scripts in /com are self-documenting—simply type the name with no arguments to see the proper syntax.

We describe the linking of the RINEX files in Section 4.5, preparation of the L-file, station.info, and session.info Sections 4.2–4.4, and the control files for FIXDRV (sestbl. and sittbl.) in Chapter 5. The navigation file is simply a RINEX "n" file, named either *aaaannn.YYn* or *aaaaY.DDD* and should be linked or copied into the day directory from the /rinex or /brdc directory or directly from an IGS Data Center.

#### 4.2 Preparing the coordinate (L-) file

The L-file contains the coordinates of all the stations to be used in the experiment. Only geocentric (spherical) coordinates are supported, in the following format:

```
VLBI FIDUCIALS:      GLB223 (1987.0) + TIES CONVERTED TO SV4
Created by mhm 10/1/90
END
FTOR FORT7266      N36  29   8.22850      W121  46   23.7842      6370574.9754      noam 1990.238
ONSA ONSAGPS      N57  13  13.29164      E 11   55   31.84348      6363045.6176      eura 1990.238
OVRO OVRO7114     N37   2   50.52769      118   17   37.65749      6371527.9644      noam 1990.238
```

You may include as many comment lines as you wish, terminated by "END". The format is (A12,5X,A1,I2,1X,I2,1X,F8.5,1X,A1,I3,1X,I2,1X,F8.5,F12.3). The plate name and reference epoch at the end of each line are comments and not used by the program. Within each day directory, the usual name of the L-file is the same as the D-file except for the first character(i.e., *lproj.ddd*), with a link provided to an experiment-wide L-file (lfile.) in ../tables.

The L-file is usually created by program GAPR\_TO\_L from a GLOBK apr file, which has Cartesian coordinates and velocities in free format:

```
* EPHEMERIS INFORMATION FROM ITRF97_GPS.SNX
VILL_GPS 4849833.7942 -335049.1753 4116014.8279 -0.0071 0.0187 0.0110 1997.291
MADR_GPS 4849202.4770 -360329.1322 4114913.0865 -0.0069 0.0197 0.0121 1996.222
REYK_GPS 2587384.4941 -1043033.5012 5716563.9714 -0.0201 -0.0035 0.0083 1997.299
FORT_GPS 4985386.6406 -3954998.5817 -428426.5071 -0.0006 -0.0047 0.0098 1996.497
```

Note that the first column must be blank (except for comments). For GAMIT purposes, you may set the velocities to 0. and omit the date. There is an apr file containing precise coordinates for all of the IGS stations in /templates/itrf97.apr.

The syntax is

```
gapr_to_l <globk.apr> <lfile> <full names> <date>
```

where <globk.apr> is the name of the input GLOBK *a priori* file,

<lfile> is the name of the output -L-file

<full names> is the name of a file which gives the full site name for each of the

GAMIT four character site codes. You can usually omit this file by substituting using double quotes (" ") since the full site name for GAMIT is taken from file station.info, not the L-file

< date > is the date to which the L-file coordinates should be referred. The date may be specified in one of three ways:

- (1) If a single value is given, then decimal years is assumed,
- (2) If two values are given, they are assumed to be year and day of year.
- (3) If three values are given, they are assumed to be year, month, day.

(NOTE: The program will *only* pick up sites with \_GPS in the site name. This convention is used in the GLOBK .apr files in order to distinguish VLBI and GPS sites. In translating GAMIT h-files to GLOBK binary files, HTOGLB automatically adds the \_GPS to the GAMIT site codes.)

You can obtain coordinates for new stations in your network using the script sh\_rx2apr, which invokes programs SVPOS and SVDIFF to perform a an iterative pseudorange solution from RINEX files:

```
sh_rx2apr -site <site> -nav <nav> -ref <ref> -apr <apr> -chi <val>"
```

where <site> is the name of the RINEX file for the station for which you need coordinates, <nav> is a RINEX navigation file, <ref> is the name of a RINEX file for a known station (preferably but not necessarily close by), <apr> is the name of an apr file containing the coordinates of the reference station, and <val> is the chi-square value below which the SVPOS (point-position) solution is considered converged. The SVDIFF step may be skipped by entering only the <site> and <nav> files. Note that the <site> file must be within or linked in the current directory (no pathname allowed). The outputs of sh\_rx2apr are both a GAMIT L-file (default name lfile.<site>) and a GLOBK a priori file (<site>.apr), which you can append to existing files (sh\_gamit does this automatically; see Chapter 10).

It behooves you to exert some effort to get good a priori coordinates for processing. The first consideration is to generate pre-fit residuals sufficient for AUTCLN to perform robust editing of the data. For this purpose, errors up to 10 m will usually allow enough data to pass through to allow a decimeter-level solution that can be iterated; errors up to 1 m allow good editing. The second consideration is linearity of the least-squares adjustment. The convergence rate for station coordinates is (conservatively) 1/1000, so 1 m errors in the a priori values contribute no more than 1 mm error to the final value. The most exacting requirement is the coordinates used for the fiducial stations, which if constrained in the final solution define the reference frame of the network. If you are using GLOBK for your final solution, then the first two of these requirements (editing and linearity) should be met in the GAMIT L-file, and the last two (linearity and fiducial coordinates) should be met in the GLOBK a priori (.apr) station file. GLOBK apr files of ITRF coordinates can be obtained from /updates/tables in the MIT ftp directory.

### 4.3 Creating the station information file

All of the receiver and antenna information specific to a particular site occupation is recorded in file station.info, which is read by MAKEXP, MAKEX, and MODEL. The values entered correspond to a single occupation, of either one day or a series of days. The format of station.info is shown below:

```
chin pggg
(A,A4,1X,A4,1X,A8,F6.3,2(1X,F6.3),1X,A6,1X,A6,1X,A5,1X,F5.2,1X,I4,1X,I3,2X,I1,6(1X,I2))
TRCK SITE Stn name Ant Ht Ant N Ant E Rcvr AntCod HtCod Vers Yr Doy SN Start Stop
#
# IGS and related stations used in regional analysis
TAIW TAIW Taiwan 1.719 0.000 0.000 TRMSST TRMSST SLTGP 4.53 1991 22 0 00 00 00 00 00 00
TAIW TAIW Taiwan 1.768 0.000 0.000 ROGSNR ROGAQA DHBGR 2.31 1992 117 0 00 00 00 00 00 00
USUD USUD Usuda 0.000 0.000 0.000 ROGSNR ROGSNR DHPAB 7.00 1992 303 0 00 00 00 24 00 00
USUD USUD Usuda 0.000 0.000 0.000 ROGSNR ROGSNR DHPAB 7.30 1993 021 0 00 00 00 24 00 00
#
# Regional stations
BHC3 BHC3 Lijiang 1.027 0.000 0.000 TRMSST TRMSST SLBGP 4.64 1993 161 1 01 0 0 10 30 00
BSC1 BSC1 Mojiang 1.237 0.000 0.000 TRMSST TRMSST SLBGP 4.64 1993 169 1 01 00 00 03 30 00
BSC1 BSC1 Mojiang 1.377 0.000 0.000 TRMSST TRMSST SLBGP 4.64 1993 169 1 04 00 00 05 30 00
THZ1 THZ1 Xichang 1.405 0.000 0.000 TRMSST TRMSST SLBGP 4.64 1993 116 1 20 00 00 24 00 00
THZ1 THZ1 Xichang 1.405 0.000 0.000 TRMSST TRMSST SLBGP 4.64 1993 117 1 00 00 00 02 00 00
THZ1 THZ1 Xichang 1.210 0.000 0.000 TRMSST TRMSST SLBGP 4.64 1993 117 1 02 30 00 08 00 00
```

The two 4-character strings on the first line specify respectively the experiment name and orbit (G- or T-) file names to be used by MAKEXP (see Section 4.5) in setting up the processing directory. The second line is a Fortran-readable format for the station entries beginning on line 4. The third line is comment but is required for proper reading of the file. After this line, any line with a non-blank first character is treated as a comment. In the station entries, the first two columns are redundant for static surveying but describe the receiver track (TRCK) and monument occupation (SITE) for kinematic or dynamic surveying. The 16-character station name (squeezed to 8 characters in the example in order to get the entire line on the page) will be written on the X-file and used throughout GAMIT whenever full names are printed. The antenna height, given in meters, refers to the measured distance (vertical or slant) between the monument and a physical point on the antenna specified by the 5-character keyword under AntCod, as described below. The Ant N and Ant E values

refer to the offsets of the center of the antenna from the monument. The `station.info` values are *added* to the coordinates of the monument in computing the antenna phase-center position.

For static surveying, the appropriate entry in `station.info` is selected by matching the station id (`TRCK`), the year (`Yr`), day-of-year (`DOY`), and the `start` and `stop` times in `station.info` with the station and time requested by `MAKEX` or `MODEL`. You must observe the following rules:

1) If the start and stop times are 0 0 0 0 0 0 or 0 0 0 24 0 0, the antenna information entered for a day will be used throughout the day and for all days following until a later entry is encountered in the table. Thus, in the example, the initial entry for `TAIW` is valid from 0h UTC on day 22 of 1991 until 0h UTC on day 117 of 1992.

2) If the start and stop times are any other values, the information is valid only within the listed times. The example shows for the regional stations five specific cases. `Lijiang` is the simplest, with a single set of values used for a single session, 0100–1030 on day 161. `Mojiang` was observed on day 169 with two different antenna setups, to be combined into a single session for processing. Finally, `Xichang` was observed in two sessions, the first of which crosses a day boundary. Since the epoch entries do not allow for a different day number to be entered for the start and stop times (a deficiency we will eventually correct), you must make two entries for the first session. The start time for a station *must be at or before the beginning of its X-file as specified by session.info, not the setup time listed on the log sheet* (the program does not look within the X-file to note that the actual beginning of tracking was later in the session). Note that the session number currently has no meaning in the context of `station.info` entries.

3) Multiple entries for a station need not be contiguous but must be in chronological order (Release 9.44 will detect this for you, but earlier releases will pick up without warning the last entry before one later than the date of your session).

4) After the first two lines, any entry with a non-blank character in column one will be treated as a comment, allowing you to document the history of a tracker or experiment.

Besides documenting the analysis, the receiver type (`RCVR`) and firmware/software version (`VERS`) are used by `MAKEX` in filtering the sample time (some receivers have offsets from the even minute) and determining whether a receiver has full- or half-wavelength L2 observations. Note that the firmware codes used by `GAMIT` are numerical and do not necessarily correspond to the manufacturer's designations; for correct processing, the firmware version does not always need to be strictly correct and in some cases is defined artificially in `GAMIT` to account for non-standard or erroneous sampling (see Section 4.7).

Most important among the entries in `station.info` are the antenna type and specification of how the height-of-instrument (`HI`) was measured in the field since this directly affects the estimated heights from the analysis. This information is typed into `station.info` in the form of keywords and later converted by `GAMIT` to L1 and L2 phase-center offsets. For example, in the `station.info` given above, station `BHC3` on day 161 used a Trimble SST (`TRMSST`) antenna whose slant-height to the bottom of the outer edge of the ground plane

(SLBGP) was measured as 1.027 m. For historical reasons, all measurements to the antenna reference point (ARP) are specified as DHPAB ("direct height to pre-amp base"), as shown in the example for IGS station USUD. Complete descriptions of all of the antennas allowed by GAMIT and the models used to compute their effective phase centers are given in Appendix 2. To verify current information for your version of the software, see subroutines `hisub.f` and `ant_alias.f` in `gamit/lib` and `rvant.dat` and `antmod.dat` in `gg/tables`.

In most cases the entries in `station.info` for a field survey must be entered manually from the log sheets, using as a template, e.g., `gg/tables/station.info`. A current `station.info` for all of the continuous stations processed by SOPAC can be found on the SOPAC web page and in `updates/tables` in the MIT GAMIT/GLOBK ftp directory. If you are processing RINEX files generated elsewhere and all of the header information is completely correct, then `sh_gamit` will perform updates of the template `station.info` for you automatically. If you want to merge several `station.info` files created for different surveys, you can use the program `MSTINF`:

```
mstinf -f <infile> -w <outfile> -s <file_list> -l <sites_list>
```

where `<infile>` is a reference `station.info` file with definitive information, `<outfile>` is the name of the merged output `station.info` file, `<file_list>` are the names of one or more `station.info` files to be merged, and `<sites_list>` are the names of one or more stations to include in the merged file. Only the first two arguments are required. If `<sites_list>` is omitted, then all of the stations in the reference file will be included in the output file. The option `-u <site_list_file>` may be used, where `<site_list_file>` is a file containing the stations to be included (one name per line, with the first column blank).

#### 4.4 Creating a scenario file

The scenario file (`session.info`) contains the start time, sampling interval, number of observations, and satellites (PRN #s) to be used in generating the X-files for each day. It does *not* correspond to the time-dependent scenarios used to program some receiver software, but rather includes all the satellites that you want to use in the analysis—generally all available from any receiver since you can delete satellites later on in the processing. To find out what satellites are available on the raw data files, use the shell scripts `rxscan` and `ficascan`. An example of a `session.info` file is given below:

```
* session.info: free format, non-blank first column is comment
*Year Day Sess# Interval #Epochs Start hr/min Satellites
1986 278 1 30 900 14 04 3 6 9 11 12 13
1986 350 1 30 900 8 10 3 6 9 11 12 13
1986 351 1 30 900 8 06 3 6 9 11 12 13
1987 144 1 120 225 22 52 3 6 8 9 11 12 13
```

(Older versions of `session.info` used a formatted read, with the format in the second line of the file. These versions can be read successfully by current releases.) The `session.info` file can be specific to a given experiment or contain all of the scenarios used for all the

experiments processed at your facility. An experiment-specific file can be generated automatically by program MAXEXP (see below) using the input start/stop time and the satellites available on the navigation file.

#### 4.5 Using MAKEXP

Once you have assembled the RINEX observation and navigation files and created station.info and (optionally) session.info you can run program MAKEXP in the day directory to generate most of the additional files you will need to complete preprocessing. MAKEXP determines the stations to be included in a session from the RINEX or X- files present in the day directory. For RINEX, it is usually most convenient and efficient not to copy the files into the day directory, but rather to create links to one or more parallel directories in which groups of data files have been collected by source or region. For example, in processing a survey from central California, you might have collected several days of data from the Southern California Continuous Integrated GPS Network (SCIGN), the Bay Area Regional Deformation (BARD) network, and global IGS stations, stored for several days in ../rinex/scign, ../rinex/bard, and ../rinex/igs, respectively. You can then use the script sh\_link\_rinex or sh\_link\_rinex1 to link from each day directory to these data directories. If you know the day and session number(s) of the RINEX files you need to link, the first script is more efficient:

```
sh_link_rinex -year <yr> -days <doy> -sess <sessions> -dir <dir>
    <yr> is the 4 char year of observations
    <doy> are the 3 char days of the year to be linked
    <sess> are the 1 char rinex session numbers to be linked [default 0]
    <dir> the absolute or relative path to the rinex files [default ../rinex]
```

Example : sh\_link\_rinex -year 1996 -days 016 017 -sess 0 1 -dir ../rinex/scign

The second script is more sophisticated, invoking program RXSCAN to scan every RINEX file in the directory to determine which ones have data for the requested day:

```
sh_link_rinex1 -year <yr> -day <doy> -dir <dir>
    <yr> is the 4 char year of observations
    <doy> is the 3 char day of the year to be linked
    <dir> the absolute or relative path to the rinex files [default ../rinex]
```

Example : sh\_link\_rinex1 -year 1996 -day 247 -dir ../rinex/igs

When you run sh\_link\_rinex1 for the first day of an experiment, it may a long time to run (1 minute per file on a Sun Sparc1) as it creates a .summary list for each station, but once the list is created, the script will run quickly for subsequent days.

To run MAKEXP, you may type the program name and answer the queries or, for automatic processing, use command-line arguments or the shell script sh\_makexp

```
sh_makexp -yr <yr> -doy <doy> -nav <file> -sinfo < int hh mm nepoch >
```

in which the required entries are year (yr), day-of-year (doy), navigation file (file), and the session span information—sampling interval (int), hour (hh), minute (mm), and number of epochs (nepoch) (a more complete list of options is given as help when you type the name of the shell-script). In interactive use, you will be asked to enter the year, day-of-year, session number, and navigation file. When invoked, MAKEXP will then the working directory for RINEX or X-files with the input date, compare the 4-character station names and date with the TRCK codes and dates in station.info, and write to the screen a summary of the available stations. If a scenario file (session.info) exists, MAKEXP will use it to determine the start and stop times and the satellites to be used in the session. If the session.info file has only a single entry in it, MAKEXP will "edit" the entry to set the year and day-of-year but keep the start time, sampling interval, number of epochs and the satellite list intact. If there is no scenario file, you will be asked to input the sampling interval, number of epochs, and start time; the program will generate a satellite list from the navigation file. With the shell script, editing of an existing scenario file is invoked by omitting the -sinfo option. If you have used sh\_link\_rinex1 to include in the day directory only files with data you need for processing, then you can enter 999 and 99 for day and session, respectively, telling MAKEXP that you want to use all the RINEX files present to generate the list of stations to be processed. If you enter either 0 or 1 for the session number, MAKEXP will search for both in compiling its station list (GAMIT changes all session numbers of 0 to 1 internally). New options (Release 10.05) with command-line or sh\_makexp input are -srin to search all RINEX files in the directory for data matching the input date; -xver <char> to use X-files with a 6th character other than the last digit of the year (useful to select previously cleaned X-files). Type sh\_makexp to see a complete list of options and examples.

The screen output of MAKEXP contains a summary of the stations found (X-files to be created), satellites included, and the session times. It concludes with instructions for the next steps:

Now run, in order:

```
sh_sp3fit -f <sp3 file> OR sh_bcfrit bctot.inp OR copy a g-file from SOPAC
sh_check_sess -sess 278 -type gfile -file <g-file>
makej <nav-file> <jfile> OR copy a j-file from SOPAC
sh_check_sess -sess 278 -type jfile -file jvent7.278
makex <makex-batchfile>
fixdrv <dfile> OR run interactively
```

The script sh\_sp3fit generates satellite initial conditions (G-file) by fitting the ARC model to the tabulated ephemerides in "SP3" format from an IGS analysis center. The input <sp3 file> must be present or linked in the local directory (pathnames are not allowed). Alternatively you can create these files from the broadcast ephemeris on a RINEX navigation file or copy GAMIT-format files directly from SOPAC. The second step (sh\_check\_sess) is optional but assures that the satellites requested in session.info are available on the orbital (G- and T-) files. Program MAKEJ creates a (J-) file of satellite clock values from the navigation message. Then you may again use sh\_check\_sess to

assure that the satellites requested in `session.info` are available on the J-file. Program MAKEX creates the GAMIT observation (X-) files from the RINEX files. Each of these steps is described in the following sections of this chapter. Finally, program FIXDRV reads the analysis controls, described in Chapter 5, and creates a batch file for GAMIT processing.

Creating the input files for MAKEJ, MAKEX, and FIXDRV from templates is not difficult and may be necessary for experiments with multiple sessions or a mixture of RINEX and FICA files. For large experiments or permanently operating arrays, however, using MAKEXP can save a great deal of time and manual effort. (Yet one more level of sophistication is provided by the new shell script `getready`, which runs the complete GAMIT sequence from a small set of input files. The script, written by Eric Calais while at SIO, is internally well documented and can be found in `gamit/com`.)

Although MAKEXP is usually run from RINEX files, you can use it again at a later stage of processing from X-files simply to generate a new station list (D-file) for FIXDRV. In this case, you do not need to have present or linked either the RINEX observation files or a navigation file.

#### 4.6 *Creating T- and G-files from External Ephemerides*

Orbital information is input to GAMIT in the form of a tabular ephemeris (T-) file, which contains the positions of all the satellites at 15-minute intervals throughout the observation span, or a G-file of initial conditions which are integrated by ARC (in the batch run) to create a T-file.

If the satellite orbits are to be adjusted to fit the observations, then the T-file must also contain partial derivatives of position (as a function of time) with respect to six "initial conditions" and other parameters describing the orbit of each satellite. ARC generates the partials by numerically integrating their force equations (termed "variational equations") simultaneously with the equations of motion. If the G-file of initial conditions was obtained from a global orbit solution performed using GAMIT with a compatible version of ARC (e.g., by SOPAC), it can be used directly in ARC to produce a T-file consistent with the solution. Integration of instantaneous position and velocity values obtained by evaluating the broadcast message parameters or extracted from an external Earth-fixed ephemeris (in SP #3 format) produced by another software package or an incompatible version of ARC will *not* reproduce the original accuracy since model differences will cause the orbit to deviate from the original orbit as the integration proceeds away from the initial epoch. The original accuracy can be obtained, however, by estimating initial conditions for ARC using externally derived positions and velocities over the full session as pseudo-observations. The most accurate and reliable method of obtaining a starting T-file is to follow this procedure using the shell script `sh_sp3fit` and an SP #3 file from an IGS analysis center:

```
sh_sp3fit -f <sp3 file> -d <yr doy> -o <orbit name> -i <equator prec> -r <radmod> -t
```

where `<sp3 file>` is the name of the external file (e.g., `igs08523.sp3` for day 3 of week 852). The year and day-of-year may be omitted if your `session.info` contains only a single entry (i.e., continuous-array style), but if you have a single `session.info` for an entire survey, then you must specify the requested year and day in the command line. `<orbit name>` is the 4-character name for the G- and T-files, nominally read from the first line of `station.info`. `<equator prec>` specifies the inertial reference frame and precession constant for the G- and T-files; the defaults are the conventional J2000 IAU76, but you may specify B1950 IAU68 for compatibility with older GAMIT and SOPAC processing (see the discussion of inertial frame in Section 5.2). `<radmod>` specifies the radiation-pressure (non-gravitational force) model to be used with the orbit; the default is BERNE (see sections 5.2 and 7.2). The final argument ( `-t` ), if entered, causes `sh_sp3fit` to create (integrate) a T-file from the initial conditions (G-file) estimated from the fit. The default is to skip this step, deferring the integration to the first step of the GAMIT batch run. In addition to a G- and (optionally) T-file, `sh_sp3fit` will generate two print files (`sp3fit.fit` and `sp3fit.rms`) summarizing the quality of the fit, and a Y-file of satellite yaw parameters for the orbital span (see Section 7.2).

An alternative but less accurate means of generating an initial orbit is to use the script `sh_bcfrit` to perform a fit of the GAMIT model to the broadcast elements in a navigation file. Before doing so, you should run the program BCCHECK to determine the consistency of the elements and to filter outliers:

```
bccheck <RINEX nav file> <yr> <day>
```

will produce a new navigation file ( `<RINEX nav file>.bcchecked` ) containing only elements whose differences from the elements at the midpoint of the day are less than 1000 m. The print file `bccheck.out` will give you a summary of the times and differences of the elements in the file, with any deleted marked by an asterisk. Next execute

```
sh_bcfrit <input file>
```

where `<input file>` is the `bctot.inp` produced by MAKEXP:

<code>b</code>	indicates batch input
<code>auto2360.94n.bcchecked</code>	RINEX navigation file
<code>xpver4.236</code>	X-file to determine session scenario
<code>tvent4.236</code>	output T-file
<code>y</code>	'yes' to transform the orbit to an inertial frame
<code>J2000</code>	designation of the inertial frame

If you don't have an X-file or wish to create a T-file for a longer span, you can do so by changing the input file to match an alternate set of questions asked by BCTOT:

<code>b</code>	indicates batch input
<code>auto2360.94n.bcchecked</code>	RINEX navigation file
	blank line to indicate no X-file
<code>tvent4.236</code>	output T-file

Y	'yes' to input the start and stop epochs
94 8 24 1 0 0.	start epoch yy mm dd hh mm sec. in free format
900	tabular interval of the T-file in seconds
94 8 25 19 0 0.	stop epoch
Y	'yes' to transform the orbit to an inertial frame
J2000	designation of the inertial frame

sh\_bcfrit will create four files: an earth-fixed T-file (*tproje.ddd*) obtained by evaluating directly the broadcast elements; an inertial T-file obtained either by rotating this file to an inertial frame (B1950 or J2000); a G-file (*gprogy.ddd*) obtained by interpolating from the inertial T-file for the epoch requested; and a Y-file of satellite yaw parameters (see Section 7.2).

The G-file consists of two formatted header lines, one or more comment lines, and initial conditions and force parameters for one or more satellites. Shown below is a typical G file:

```

86 279 12 00 00                GPST B1950 IAU68 SPHRC
8 X   Y   Z   XDOT YDOT ZDOT DRAD YRAD ZRAD
G-file generated from ebrdc6.279    1-10-1987  18:16:20
ANY OTHER COMMENT LINES
END
PRN 06
-.24748600267000D+05
0.88024642750000D+04
0.47948566210000D+04
-.11532236900000D-01
-.18622397472000D+01
0.33736392796000D+01
0.10000000000000D+00
0.00000000000000D+00
0.00000000000000D+00
PRN 09
-.21643530559117D+05
-.15228859494884D+05
-.17710854977416D+04
0.11606424294013D+01
-.12653416265926D+01
-.34787168623116D+01
0.10000000000000D+00
0.00000000000000D+00
0.00000000000000D+00
END

```

The first line gives the epoch of the ICs in GPST or UTC (year, day-of-year, hours, minutes, seconds), followed by the time type (GPST or UTC), the inertial frame for the ICs (J2000 or B1950), the precession constant used (IAU76 or IAU68), and the model for non-gravitational ("radiation") accelerations (SPHRC for "spherical" in the example shown (see Section 5.2). The second line gives the number of ICs plus force-model parameter to be read from the G-file. This is followed by one or more comment lines, terminated by END. The initial conditions for each of the satellites are given as Cartesian components of the position and velocity vectors in units of km and km/s. The last three ICs of each group

in this example are dimensionless coefficients multiplying the modeled direct solar radiation force (DRAD) and forces along the y- (YRAD) and z- (ZRAD) axes of the spacecraft. The coefficients RAD2 and RAD3 express these forces as fractions of the nominal direct solar radiation force.

#### 4.7 Creating satellite (J-) clock -files

In order for MODEL to account properly for clock effects in the phase observations, additional information must be supplied about the behavior of the satellite and station clocks. How these effects are computed and tabulated depends on the level of dithering imposed by selective availability and whether the ground stations are sampling the phase simultaneously. For normal processing you run MAKEJ by typing the name of the program followed by the navigation file and the output J-file name:

```
makej auto2980.98n jcalif8.298
```

Alternatively, you can run the program interactively. The first question will ask you to choose the source of the satellite clock information:

```
Choose source of SV oscillator frequency corrections:
 1 E-file broadcast message.
 2 Second order fit to C-file from site with H-maser
Pick a number.
```

For networks with simultaneous sampling, it is sufficient to create a satellite clock (J-) file using simply the coefficients transmitted in the broadcast message. These can be obtained from the RINEX navigation file, or the Block 9s of a TI FICA file (see program FICACHOP), from any station that observed for most of the session or from the combined files distributed by IGS analysis centers. Select option 1 at the prompt and then enter in response to prompts the name of the output J-file, the name of the RINEX navigation file or GAMIT E-file (RINEX or FICA format), and the interval at which you want to tabulate the clock values. Once per hour (3600 s) is usually a sufficient interval. If SA is on, then the difference in the signal propagation time to different sites (up to ~10 ms) or, more seriously, several-second differences in the nominal sampling times can introduce significant errors if the oscillator variations are not modelled on the time-scale of the sampling differences. A technique for generating such a model using the phase residuals computed for sites with atomic oscillators is described in *Feigl et al.* [1991] and more extensively in Chapter 2 of *Feigl* [1991]. This option is invoked by selecting 2 at the prompt and is described in more detail in Appendix 4.

Part of a sample J-file is shown below:

```
SV clock corrections written by king Program: 6.1 of 90/05/18 01:58:50 (apollo)
YR DOY HR MN SEC(UTC) WKNO SOW(GPST) PRN XEAF0 XEAF1 XEAF2
(I4,1X,I3,2I3,1X,F5.2,3X,I3,1X,F9.2,2X,I2,2X,3D16.8)
1988 311 17 59 55.00 461 64800.00 3 0.39050030E-03-0.68212103E-12 0.00000E 00
1988 31117 59 55.00 461 64800.00 13 0.37502684E-03 0.23874236E-11 0.00000E 00
1988 311 18 59 55.00 461 68400.00 3 0.39049797E-03-0.68212103E-12 0.00000E 00
```

The first line is a header constructed by MAKEJ, and the second line contains titles to guide the analyst. The third line is a format statement used to read the entries that follow. Each data line contains the coefficients transmitted by the satellite for its own clock. The formula to be used in computing the SV clock offset is

$$\Delta t_s = t_s' - t_s = a^{(0)} + a^{(1)}(t-t_0^{(c)}) + a^{(2)}(t-t_0^{(c)})^2$$

where  $t_s'$  is the time read by the satellite's clock and  $t_s$  is "true" GPS time. The coefficients  $a^{(0)}$ ,  $a^{(1)}$ ,  $a^{(2)}$  are given in the last three columns (XEAF0, XEAF1, XEAF2) and refer to the reference epoch  $t_0^{(c)}$  given in columns 6 and 7 as GPS week number and seconds of week. The numbers in the first 5 columns give the reference time in GPST (or UTC prior to Release 9.28) using conventional units.

The J-file is also used by MAKEX to generate a K-file of station clock offsets, used in turn by FIXDRV to generate an I-file of station clock coefficients for MODEL.

#### 4.8 Running MAKEX

Program MAKEX takes as input the scenario file (session.info), station information file (station.info), satellite clock (J-) file, Broadcast ephemeris (RINEX nav or GAMIT E-) file, station coordinates (L-) file, and raw data files (in RINEX or FICA format), and creates X- and K-files for input to FIXDRV and MODEL. K-files, though normally created by MAKEX can be re-created later if necessary by program MAKEK (Section 4.10).

To run MAKEX after running MAKEXP, you need type only `makex <control-file>` where `<control-file>` is the name of a control file with name `day.makex.batch`, where `day` is the day of year designating the session to be processed. The control file contains pointers to the input files and a list of station-days to be processed. An example for RINEX input is shown below:

```
infor 1
sesfo 1 ./session.info
rinex 1 ./
ficaf 0
coord 1 ../tables/lfile.
stnfo 1 ./station.info
xfile 1 ./x
svclk 1 ./jtrex0.091
clock 1 ./k
extra 0
rdorb 1 ./vndn0911.90n
extra 0
site year doy sn sw ver
(a4,1x,a4,1x,a3,1x,a1,2x,a3,1x,f4.2)
vnd2 1991 091 1 GES 1.9
yknf 1991 091 1 GES 1.9
mojm 1991 091 1 COR 4.8
```

```
vndn 1991 091 1 TRM 3.25
```

The first 12 lines indicate which of the input and output files are to be used and the directories in which they reside. The first six columns are not read by the program but provide hints to the users (all lines must be present in the order given). A "1" following the name indicates that the file is to be used (input or output), a "0" that it will not be used. Complete file names are useful for documentation, but if the file (or link) is in the working directory (i.e., the one in which MAKEX is being run), an abbreviated filename may be used (see, e.g., the `rinex` and `stnclk` entries above). For the input RINEX or FICA files, no filename is given since MAKEX constructs the filename from the station and day names which follow in the input stream. FICA files must be named `[site][y].[day].fic` (note that only the last digit of the year is used, with no session number), and RINEX files `[site][day][f].[yr]o`, where `f` is the file sequence number and `o` indicates that it is an "observation" file. Similarly, for X- and K- files, only the first letter is given. In the above example, if the input data file were FICA, the `rinex` entry would have been "0" and `../` (or directory path) would appear after `ficaf`. The GAMIT E-file (`rdorb` above) is simply an orbit file in either RINEX nav-file format or FICA Block 9 (TI4100) format (created with FICACHOP). The first line gives the information file, a log of MAKEX runs written to the current directory with name `dd.makex.infor` (`091.makex.infor` in the example given).

Line 13 of the batch input is a comment that provides column headers for the list of station files which follow. Line 14 gives the format for reading the key characters of the site file name. The format shown in the example allows reading of a four-character site code (`VND2`), the year (1991), session number (1), and the day number (091). In the current GAMIT release, the session number should always be 0 or 1 (treated equivalently inside GAMIT) since the software does not yet support multiple sessions in the naming of X-files (multiple sessions can be combined by SOLVE in estimation, but that's another story—see Section 5.6). Beginning with GAMIT release 9.6 (MAKEX version 9.57), MAKEX will scan all RINEX or FICA files for data within the span requested in `session.info`, so you can include within the day directory multiple RINEX filenames with arbitrary session numbers. If you have not used one of the `sh_link_rinex` scripts and want to have MAKEX search for data, you can specify one or more directories in the `rinex` or `fica` lines of the batch file; e.g.,

```
rinex 1 ../rinex/scign/ ../rinex/bard/ ../rinex/igs/
```

The receiver software (or firmware) and version in the last two fields of the MAKEX batch input file are required in order to have time tags correctly matched. The 3-character software ID is derived by MAKEXP from the receiver type and software version entered into `station.info`. Designators for software versions currently supported, and their sampling times are listed in Table 4.1 and documented in subroutine `gamit/makex/settim.f`. In several cases, we have arbitrarily added an additional digit to the version number in order to distinguish time tags set by the operator.



Table 4.1 Receiver software designations used by MAKEX

Receiver	Software	Abbrev.	Version	Sampling time (seconds after the GPST minute)
TI 4100	GESAR	GES	1.0-1.9	59.08
			CORE	COR
	4.1	59.08		
	4.7	59.08		
	4.11	59.00		
	4.12*	59.08		
	4.13	59.00 and 59.08 in same file		
	4.8	0.08		
	5.7	59.08		
	ROM	ROM		59.08
		1.11	59.00	
	GSM	GSM	59.08	
MACROMETER II		MAC		58.475 - (GPST-UTC)
MINI-MAC		MIN	1.49	0.001
			1.50	0.001 - (GPST-UTC)
			1.59	59.001
			1.61-1.64	0.000
			1.89	59.001 **
TRIMBLE 4000 SLD,SST 4000 SST/SSE	NAV+SIG	TRM	3.11-3.25	variable
			4.1 ff	0.0
ASHTECH XII, TOPCON		ASH	1.0, 2.0, 6, 7, 8***	0.0
ROGUE SNR 8		ROG	1.51, 2.30	0.0 - (GPST-UTC)
			2.31 ff	0.0
MINI-ROGUE			1.11, 1.50, 2.31, 2.4, 5.5, 5.6, 5.61 6.11, 7.00ff	0.0
TURBO-ROGUE SNR-8000		TRB	1.0, 2.00-3.20	0.0
SERCEL TR5S NR52		SRT		0.0
		SRN		0.0
LEICA SR299/399/9500		LEI	1.13 - 5.2	0.0
GEOTRACER 2000/2200		GEO	8.0 (L1), 9.0 (dual)	0.0
UNAVCOL1		CMC	2.0	0.0

\* COR 4.12 indicates one of two anomalous frequency plans used during GOTEX and at Yellowknife during March 1990.

\*\* MIN 1.89 indicates MiniMac data sampled at 59.001 but tagged in the RINEX file as 59.000. The time tags are corrected in MAKEX and software version gets changed to 1.59 in XTORX.

\*\*\*The Ashtech software designations are somewhat arbitrary: 1.0 indicates a codeless receiver; for the P-XII, 2.0 indicates the alpha version of the software, 6.0 the beta version, 7.1 the 7A software, and 7.2 the 7B software; Z-12 software is designated 8.0ff (see comments in gamit/makex/settim.f).

## 4.9 Description of the X-file

A sample X-file created by MAKEX is shown below:

```

GPS Phase & Pseudorange from TI 4100 receivers

MAKEX (Apollo 92-06-01)          run on 1991-06-17 16:50:44

                                GESAR/PHASER HEADER INFORMATION

UNPACK 1.3 of 87/10/06   mill7.007a.fic          1987-10-15 18:04:23
BLK   13   0   3   0

END

                                COORDINATE FILE INFORMATION
STATION_NAME_____  LATITUDE      LONGITUDE  HEIGHT          RCVR  SWVR
                   _DG MN SS.SSSSS _DG MN SS.SSSSS ____ (M) ____
MILLER CADT          N34 19 50.33849  W120 13 48.02332 6371422.962  GES  1.0

ANT OFFSETS (M) L1  UP    NORTH  EAST  L2  UP    NORTH  EAST
                   1.491    0.000  0.000    1.466  0.000  0.000

6 SATELLITES
CHANNEL 1 PRN# 3 NAVSTAR          DATA TYPES          1    2    3    4
CHANNEL 2 PRN# 6 NAVSTAR          LAMBDA -1 -1 1 1
CHANNEL 3 PRN# 9 NAVSTAR          LAMBDA -1 -1 1 1
CHANNEL 4 PRN# 11 NAVSTAR         LAMBDA -1 -1 1 1
CHANNEL 5 PRN#12NAVSTAR 10 LAMBDA -1 -1 1 1
CHANNEL 6 PRN# 13 NAVSTAR         LAMBDA -1 -1 1 1

FIRST EPOCH (UTC)          GPST-UTC= 4.0
YR DAY HR MN SECS  INTERVAL(SECS)  DATA INTERVAL  SESSION
87  7  6 41 55.080  120          30          1

225 EPOCHS

EXPANDED DATA FORMAT STATIC
EPOCH # FLG CH  L1 PHASE          AMP          L2 PHASE          AMP          L1 PSEUDORANGE          L2 PSEUDORANGE

1  0

2  11987  7  6  43  55.080  0 MILL N34 19 50.33849 W120 13 48.02332 6371.422.962 1.4910 0.0000 0.0000 1.466
   0 2 0.209327782121811E+08 7 -0.263626960264358E+08 6 0.242673706688020E+08 0.242673708548

3  21987  7  6  45  55.080  0 MILL N34 19 50.33849 W120 13 48.02332 6371.422.962 1.4910 0.0000 0.0000 1.466
   0 1 0.283412097505112E+08 7 -0.354413610923080E+08 6 0.249617918581700E+08 0.249617931178
   0 2 0.233529585203629E+08 8 -0.244768413617021E+08 7 0.238068262469650E+08 0.238068256365

```

The first group of records (to END) are header lines, accumulated by the succession of programs that have handled the data up to this point. These are followed by the name of the station, its coordinates as read from the L-file, and the antenna offsets read from station.info (or sited.) file. The list of satellites given next specifies the order in which they appear in the X-file (not necessarily the channel assignments in the receiver). DATA TYPES specifies which of the allowable types of observations are present:

- 1 = L1 phase
- 2 = L2 phase
- 3 = L1 P-code pseudorange
- 4 = L2 P-code pseudorange
- 5 = L1 C/A code pseudorange

The LAMBDA, or "wavelength" codes given for each channel indicate, for each data type, whether it is ambiguous and whether the ambiguity spacing is full or half wavelength. All phase observables are converted to full wavelength on the X-file.

- 0 = observable is not present for this channel
- 1 = ambiguity spacing is one wavelength (e.g., 19 cm for L1 phase)
- 2 = ambiguity spacing is one-half wavelength
- 1 = no ambiguity
- 2 = no ambiguity (original observable was half wavelength)

The usual value of LAMBDA is -1 (code-correlating receivers) or -2 (L2 from codeless receivers) for phase observations, 1 for pseudo-range observations. X-file data are required to be evenly spaced, so the observation times are specified by a start epoch, an observation interval, and the number of epochs. INTERVAL is the actual interval on the X-file; DATA INTERVAL refers to the raw data file interval (usually the receiver sampling interval) and is used by the editing routines to determine if gaps in the X-file are due to sparse sampling or missing data. The observations at each time are identified by an epoch number, an integer which specifies the number of satellites for which there are data at that epoch, and the GPS time (or UTC prior to Release 9.28). The station coordinates and antenna offsets are repeated at each epoch to allow for kinematic processing. For static processing with a change of antenna height during the session, the X-file will also reflect the change, but values read from station.info during actual processing (by program MODEL) override those in the X-file. Then for each channel, there are eight numbers given: a flag indicating whether the data are valid (=0) or have been flagged (set non-zero—see gamit/includes/errflg.h for a key) by other modules; the channel number; the L1 phase (cycles); the amplitude of the L1 signal using RINEX conventions; the L2 phase; the L2 amplitude; the L1 pseudo-range (meters); and the L2 pseudo-range. Note that phases in the X-files are in the "Doppler" convention (increasing phase is *decreasing* range), and therefore have the opposite sign to phases in the corresponding RINEX files.

#### 4.10 Creating station clock (K- and I-) files

The offset from GPS time (or UTC) of each receiver's clock must be accounted for in modeling the theoretical value of the phase observations at each epoch. If the positions of the receiver and a satellite are known, along with the offset of the satellite's clock, then the pseudorange observation provides a direct measure of the receiver clock offset:

$$\Delta t_r = \frac{p_1 - \rho}{c} + \Delta t_s$$

where  $\rho$  is the calculated range to the satellite,  $p_1$  is the observed pseudo-range and  $c$  is the speed of light. Recall (Section 2.1) that an accuracy of about one microsecond in receiver-clock offset is necessary to achieve an accuracy of one millimeter in the estimated baseline vector. In order to achieve this accuracy, the computation is performed in MODEL using the station and satellite positions (from the L- and T-files) calculated for the theoretical phase observable. In this case, one microsecond (300 m) in the theoretical values is easily

achieved. Sufficient accuracy in the measured pseudorange is also achieved easily if P-code range is available. If only C/A code is available, and particularly under conditions of selective availability (SA), some care must be exercised. At present, MODEL computes the receiver-clock offset using an average of values calculated from all of the satellites visible at each epoch, detecting and removing anomalous values caused by pseudorange outliers or bad SV clock values.

Strictly speaking, it is not necessary to provide GAMIT with any more information about a receiver's clock than that incorporated in the pseudoranges at each epoch. There are a few practical reasons, however, why it is useful to generate a more explicit model of the receiver-clock behavior at an earlier stage in the processing. Doing so provides a way of detecting poor receiver performance, for example. Also, for receivers with poor and unmodeled clocks numerical problems are sometimes created in SOLVE when there are several-hour gaps between observations. Hence we input to MODEL tables of coefficients which effectively model these variations. For the receiver clock, MAKEX generates an estimate of the offset at an epoch interval of 120s for Ashtech and Trimble receivers, whose clocks reset often, and 600s for other receivers, using satellite elements from the broadcast ephemeris. These estimates are written into the K-file:

RDRK	14	1992	73	19	43	53.0000	0.07132594	0.00018337	0.00007289
RDRK	18	1992	73	19	43	53.0000	0.07109620	-0.00000169	0.00007330
RDRK	19	1992	73	19	43	53.0000	0.07405061	0.00000424	0.00007332
RDRK	14	1992	73	19	45	53.0000	0.07153746	0.00018337	0.00001910
RDRK	18	1992	73	19	45	53.0000	0.07095191	-0.00000169	0.00001955
RDRK	19	1992	73	19	45	53.0000	0.07389223	0.00000424	0.00001934
RDRK	14	1992	73	19	47	53.0000	0.07175308	0.00018337	0.00096434
RDRK	18	1992	73	19	47	53.0000	0.07080949	-0.00000169	0.00096493
RDRK	19	1992	73	19	47	53.0000	0.07373656	0.00000424	0.00096463
RDRK	14	1992	73	19	49	53.0000	0.07197269	0.00018337	0.00090899
RDRK	18	1992	73	19	49	53.0000	0.07066900	-0.00000169	0.00090950
RDRK	19	1992	73	19	49	53.0000	0.07358361	0.00000424	0.00090935

The first column gives the station code, followed by the satellite PRN number, year, day of year, hours, minutes, and seconds (always UTC). The eighth column is the observed pseudo-range to the satellite at the time given, in units of seconds, followed by the offset of the satellite clock (from GPS time) computed from the transmitted clock corrections. The final number is the receiver clock correction computed using the formula above.

Any differences in receiver clock values computed using the data from different satellites at the same time are due to errors in the pseudo-range measurements, the satellite clock models, or the geometrical models (station coordinates and satellite ephemeris). In the above K-file, for example, the corrections computed at 19<sup>h</sup> 43<sup>m</sup> 53.<sup>s</sup> using data from satellites 14, 10, and 19 differ by up to 0.4 microseconds, equivalent to a radial position error of 120 meters (probably due to errors in the broadcast ephemeris). Differences between receiver clock values computed for a given satellite at different times could reflect model errors but are usually dominated by actual receiver clock drift. In our example, there is a change between 19<sup>h</sup> 43<sup>m</sup> and 19<sup>h</sup> 45<sup>m</sup> of 54 microseconds, indicating a drift in the receiver oscillator of 4.5 parts in 10<sup>7</sup> ( $54 \times 10^{-6} / 120$ ). This high drift rate is typical of the crystal oscillators in many of today's lightweight receivers (the above example was a

Trimble 4000 SST). More stable (thermally controlled) crystals can achieve stabilities of 1 part in  $10^8$  (TI 4100) or better (Macrometer II). Rubidium, cesium, or hydrogen-maser oscillators can achieve even higher stabilities ( $10^{-11}$  to  $10^{-15}$ ).

The ~1 ms jump in clock value at 19<sup>h</sup> 47<sup>m</sup> 53.<sup>s</sup> is a feature of the Trimble 4000 SST and Ashtech P12 receivers, indicating that the clock has been reset to keep it within 1 ms of the nominal sampling time. Both the recorded sampling time and the pseudorange measurement will show a discontinuity of exactly 1 ms. Some RINEX translators can be set to remove the discontinuity at translation, but this is not necessary since MODEL will account for it in its epoch-by-epoch estimate of the receiver clock offset, and FIXDRV will remove the discontinuities in fitting the low-order polynomial used in modeling the phase observations.

It is possible to have anomalous ("bad") values in the K-file—computed clock offsets that are many milliseconds off due to bad pseudorange measurements. The presence of these anomalous blunder points will be indicated by very large residuals (> 500 microseconds) in the polynomial clock fit done by FIXDRV. You can tabulate and plot the fit residuals using the script `sh_plotk`, but usually the quickest way to find the problem is just to scan visually the last column of the K-file; most often the bad values are among the first few of the session. If `sh_plotk` or the polynomial fit in FIXDRV shows the clock behavior to be bad, and you determine that the problem is not a bad K-file, then you should proceed but be on the alert for a problem with this station in the analysis. Rapidly drifting clocks are more likely to cause an abnormal number of cycle slips (see the `autcln.sum` file, described in Section 6.2). Large jumps in the clock or rapid drift accompanied by several-hour gaps in the data may cause the residuals to get large, introducing numerical problems in SOLVE. The best remedy for this is to use the `apply_phase_clk` option in AUTCLN (see Section 6.2).

FIXDRV will read the K-file for each site and create a session I-file, similar to the J-file for satellite clocks, tabulating the coefficients of a low-order polynomial for each receiver's clock. If you want to recreate a K-file after running MAKEK, you can do so easily by running MAKEK, which will prompt you for the name of input E-, L-, and X-files and for the tabulation interval.

## 5. Batch Processing

### 5.1 Introduction

Batch processing is accomplished by invoking sequentially and with appropriate input files the GAMIT modules that perform the required computations. The command or "batch" files to invoke the modules are created, for each standard type of analysis, by program FIXDRV. The batch run set up by FIXDRV would typically go through the following steps:

- generation of an orbital ephemeris with partials (ARC)
- generation of residuals and partials (MODEL)
- automatic edit of residuals (AUTCLN)
- solution (CFMRG/SOLVE)
- regeneration of residuals and partials with an improved model (MODEL)
- automatic edit of residuals (AUTCLN)
- solution (CFMRG/SOLVE)

The double pass through MODEL and SOLVE serves two purposes: 1) the model obtained from the first solution can be used to flatten the residuals, allowing for improved editing and also the display of post-fit (one-way) residuals for evaluation; 2) adjustments to station coordinates are reduced to a few centimeters, assuring that non-linearities do not degrade the final estimates. In most cases, the results of your processing can be assessed through inspection of the print output (Q-file) of the final solution and the data statistics compiled by AUTCLN (autcln.sum.post). If there are problems, then one or more steps of the batch job can be run individually, or FIXDRV (and occasionally MAKEX) can be run to repeat the complete processing sequence.

If you have prepared the data in a "day" directory as described in Chapter 4, then you should have available as files or links all of the tables necessary to run FIXDRV and to execute the GAMIT batch run: station and scenario tables (station.info and session.info), ephemerides (G- and T-files), raw observations (X-file), satellite and station clock values (J- and K-files), *a priori* station coordinates (L-file), lunar and solar ephemerides (luntab. and soltab.), and tables for earth rotation values (nutabl., ut1., and pole.), TAI-UTC (leap.sec), geodetic datums (gdetic.dat), ocean tides (stations.oct and grid.oct), antenna phase-center offsets or models (antmod.dat), receiver and antenna names (rcvant.dat), and satellite yaw parameters table (svnav.dat). Three additional files are needed: the list of X-files to be processed (D-file), and control tables for the analyses (sestbl. and sittbl.) These can be easily created from templates (from gamit/example), as described below. If you have used MAKEXP for data preparation, you will have already a D-file.

## 5.2 Running FIXDRV

FIXDRV has three primary inputs: 1) a D-file containing the names of the satellite ephemeris (T-), clock (I- and J-), and observation (X- or C-) files to be used; 2) a session control table (sestbl.) containing analysis commands; and 3) a site control table (sittbl.) specifying *a priori* constraints for coordinates and station-specific models.

An example of a D-file (named dvent7.278) is given below, with comments added at the right:

```

1           number of solutions
2           number of sessions
lvent7.278  L-file for all sessions
tvent7.278  T-file for all sessions
ivent7.278  I-file for all sessions      (end of global files)
jvent7.278  J-file for session 1
3           number of stations (x-files) in session 1
xcato7.278
xsafe7.278
xlove7.278
jvent7.279  J-file for session 2
2           number of stations (x-files) in session 2
xcato7.279
xsafe7.279

```

The integer on the first line gives the number of independent solutions to be performed; if greater than one, it indicates that you have concatenated essentially independent runs for serial processing. The integer on the second line indicates the number of sessions in this solution; in the example the data from two sessions (days) are to be used simultaneously to estimate the station coordinates and orbital parameters. With widespread use of GLOBK, GAMIT runs involving more than one session or solution are rare, so in most cases the first two lines of the D-file will each contain "1" and the last four lines shown above will be omitted. Lines 3–6 contain the name of the coordinate (L-) file to be read, the ephemeris (T-) file to be read or created, and the name of the I-file to be read or created. The I-file is now optional and can be left blank or set to 'NONE' if you don't have K-files readily available from which to calculate clock rates. In this case, you must specify 'Use I-file = N' in the sestbl. (see below). The use of an I-file is recommended because modeling of the dominant drift in the receiver clock minimizes the danger of numerical problems in SOLVE due to large jumps across gaps of several hours. For each session there is the name of the satellite clock (J-) file to be used, an integer giving the number of stations, and the names of all of the X- or C-files for that session. The names of other files to be read or created are assigned by FIXDRV: the G-filename from the T-file name; the K- and P-file names from the X- (or C-) file name; and the H-, M-, O-, Q-, and V-file names from the D-file name.

A session control table (sestbl.) with only the required and commonly used entries is shown below. (See Table 5.1 for a complete list of entries.)

```

Session Table
-----

Processing Agency = MIT

Station Number = *
Satellite Number = *

Station Constraint = Y      ; Y/N
Satellite Constraint = Y   ; Y/N (next two lines free-format but 'all' must be present)
  all   a   e   i   n   w   M   rad1 rad2 rad3 rad4 . . . rad9
        0.01 0.01 0.01 0.01 0.01 0.01 5   5.   1.   1. . . . 1.

Choice of Observable = LC_HELP ; L1_SINGLE/L1&L2/L1_ONLY/L2_ONLY/LC_ONLY/
                       ; L1,L2_INDEPEND./LC_HELP
Choice of Experiment = Relax. ; BASELINE/RELAX.
Initial ARC = Yes          ; Default Yes
Type of Analysis = 0-Iter  ; Prefit / Quick / 0-Iter/1-Iter/2-Iter
Data Status = Raw         ; RAW/CLN
AUTCLN Postfit = R        ; (N/Y/R) Run an extra AUTCLN and SOLVE; R causes repeat

AUTCLN Command File = autcln.cmd ; Default none (use default options in AUTCLN)
Use N-file = Yes          ; Reweight data using AUTCLN summary model; default = No
Quick-pre decimation factor = 10 ; Decimate in SOLVE on AUTCLN pre-solution
Quick-pre observable = LC   ; No ambiguity resolution for AUTCLN pre-clean
Delete AUTCLN input C-files = Yes; Yes / No / Intermediate; default = No
Delete eclipse data = Post  ; All/Post/No; default Post

Zenith Delay Estimation = Yes ; Yes/No
Number Zen = 4              ; number of zenith-delay parameters
Atmospheric Gradient = Yes  ; Yes/No (default no)
Elevation Cutoff = 15.     ; Applied in SOLVE, overrides MODEL and AUTCLN values

Antenna Model = ELEV       ; NONE/ELEV/AZEL default = NONE
Tide Model = 15            ; Binary coded: 1 earth 2 freq-dep 4 pole 8 ocean default = 7

Estimate EOP              ; Binary coded: 1 wob 2 ut1 4 wob rate 8 UT1 rate; default 15
Wobble Constraint         ; [pole] [pole rate] default = 3. 0.3 (arcsec) (arcsec/day)
UT1 Constraint           ; [UT1] [UT1 rate] default = 0.00002 0.02 (sec) (sec/day)

Ionospheric Constraints = 0.0 mm + 8.00 ppm ; default = 1 ppm
Ambiguity resolution WL   ; default = 0.15 0.15 1000. 10. 500.
Ambiguity resolution NL   ; default = 0.15 0.15 1000. 10. 500.

```

Each command is recognized by the keywords at the beginning of the line. They must begin in column one and be spelled out completely and correctly but are not case sensitive. The keyword answer must begin exactly one space after the equal sign. The order of the commands in the files is not important except for the satellite constraints, which must follow the Satellite Constraint keyword. After the semi-colon on each line is a summary of keywords for all the options available. These are simply comments in the session table.

In the example shown, the first input is a 3-letter code for the analysis group. This is required in order to force identification of a solution on the h-file. The next two entries,

giving the number of stations and satellites (the \* means to use all stations or satellites). are required but currently serve no useful function since the exclusion of stations and satellites must be accomplished by editing the SOLVE batch file (see Section 7.5) . (We hope to reinstate this feature in FIXDRV and the sestbl. in the future.)

Next, the user specifies whether *a priori* constraints are to be used for stations and satellites. The station constraints are applied globally (not session by session); the actual constraints are set in the site control (sittbl.) file. For satellite constraints, if ALL is found in the header line, as shown in the example, only one entry is required, with values applied to all satellites. If you need to specify different constraints for different satellites, there must be entries for all satellites in the scenario, in the following format:

```
Satellite Constraint = Y          ; Y/N
  ch#   a   e   i   n   w   M   rad1 rad2 rad3 rad4 . . . rad9
NO.1 = 0.01 0.01 0.01 0.01 0.01 0.01 0.01 5   5.   1.   1. . . . 1.
NO.2 = 0.01 0.01 0.01 0.01 0.01 0.01 0.01 5.   5.   1.   1. . . . 1.
....
NO.30= 0.01 0.01 0.01 0.01 0.01 0.01 0.01 5.   5.   1.   1. . . . 1.
```

In both examples, there should be entries for 9 non-gravitational force ("radiation-pressure") parameters (only 5 are shown because of the limited page width). The constraints are given in parts per million (ppm) for the initial conditions and percent for the non-gravitational force parameters (in contrast to GLOBK which expects m and m/s for initial conditions and a fraction of unity for the non-gravitational force parameters). The values shown (0.01 ppm or 20 cm for initial conditions, 5% for the direct radiation-pressure and y-bias coefficients, and 1% for the third axis coefficient and the once-per-rev parameters) are roughly appropriate for SOPAC or IGS orbits since late 1994. The orbital constraints to be applied are one of most important decisions you have to make in setting up the analysis. In deciding upon constraints, remember that SOLVE will perform two sets of solutions—one ("constrained" or "tight") which uses directly the input constraints and one ("loose") which uses hard-wired, loose constraints (10 ppm). The "tight" solution is displayed in the Q-file, used for updating the L- (station-coordinate) and G- (orbital parameter) files and for writing the M-file of parameter adjustments that is used for scanning and manually editing the post-fit residuals. If you are not using GLOBK, this GAMIT-produced "tight" solution provides the final estimates of parameters. The "loose" solution is not displayed in the Q-file (except for its constraints and statistics, at the bottom), but is written into the H-file for input to GLOBK. If you are using GLOBK for your final analysis, you set the orbital (and station) constraints there, and the GAMIT sestbl. values have no direct effect on the GLOBK solution. They can have an important indirect effect, however, since resolution of phase ambiguities ("bias-fixing") is performed by SOLVE as part of the constrained solution, with the resolved integer values carried forward to the loose solution. So in deciding what values to use in the sestbl. for orbital constraints, you need to consider both the expected accuracy of your *a priori* orbit and the strategy you plan to use for your analysis. Moreover, you will probably want to perform several different analyses, using chi-square, coordinate uncertainties, and success in resolving ambiguities to determine the optimal value of the orbital constraints for the

GAMIT solution. See Chapter 2, Section 5.4 below, and *Feigl et al.* [1993] for further discussion.

The six command lines beginning with `Choice of Observable` establish basic structure of the batch run according to the size of the network:

```
Choice of Observable = LC_HELP
Choice of Experiment = RELAX
Initial ARC = Yes
Data Status = RAW
Type of Analysis = 0-ITER
AUTCLN Postfit = R
```

`Choice of Observable = LC_HELP` means that the observable is the ionosphere-free linear combination ("LC" or "L3") and that the regular SOLVE solution attempts to resolve phase ambiguities using both an ionospheric constraint and pseudorange data if available. For networks extending over less than a few kilometers, you can set `Choice of Observable = L1,L2_INDEPEND` to use the L1 and L2 phase observations directly, which will result in smaller measurement noise as long as the ionospheric contribution is negligible. For orbit determination with only widely spaced stations, setting `Choice of Observable = LC` (no ambiguity resolution attempted) will save computation time.

`Choice of Experiment = RELAX` means that you are solving for both station coordinates and orbital parameters, a reasonable approach even for short-range networks provided you apply appropriate constraints to the orbital parameters. You can suppress orbital parameters completely by setting `Choice of Experiment = BASELINE`.

`Initial ARC` determines whether or not ARC is run as the first step in your batch processing. If you have a T-file from earlier analyses or from running `sh_sp3fit`, you do not need to regenerate it in your data processing. If on the other hand you have only a G-file (from SOPAC or earlier as the output of earlier analyses), you should set `Initial ARC = YES`.

`Data status` specifies either the normal case (`raw`) or the special situation (`clean`) in which you have obtained data in which all the cycle slips have been removed by previous editing. We use this option primarily with data acquired before 1990 that were edited manually with `CVIEW`.

The next two commands are used to control the number of passes through `MODEL`, `AUTCLN`, and `SOLVE` to obtain a final solution. `Type of analysis = 0-ITER` is somewhat of a misnomer since paired with `AUTCLN Postfit = R` it implies at least one iteration of the initial solution. In the first pass `AUTCLN` operates on prefit residuals, and in the second one uses the adjustments written on the M-file by `SOLVE` to perform a "postfit" edit. Since in postfit editing `AUTCLN` estimates clock parameters, this mode allows you to see and compute statistics of the one-way residuals for individual stations (rather than just double differences), which can be especially helpful for characterizing station performance, weighting the data for each station appropriately, and understanding

problems in the solution. With `AUTCLN Postfit = R` (for "redo"), as opposed to simply `Yes`), if the quality of fit improves significantly between these two solutions (ratio of `nrms` values  $> 1.5$ ), a third one is performed to insure linearity in the adjustments. Other options for `Type` of analysis, described later, are useful mainly for primary orbit determination (at SOPAC) and specialized solutions.

`AUTCLN Command file` allows you to input controls for `AUTCLN`. The `autcln.cmd` file should be present and contain the `postfit` controls `apply_phs_clk`, `use_postfit`, and (usually) `pf_remove_bf` described in Section 6.2. The command `Use N-file = Yes` invokes the shell-script `sh_segelv` to read the summary file from the `postfit` `AUTCLN` run and write into a file to be read by `SOLVE` values of coefficients of an elevation-dependent model for the a priori errors assigned to the data from each station (see [Data Weighting](#) later in this section, but note that if `Use N-file` is specified, you do not need to also specify `Station Error`—and in fact, you should not do so because you likely want uniform weighting to be used in the pre-fit `SOLVE` run).

To reduce the computational cost of using the post-fit mode, you can reduce the sampling rate (`Quick-pre decimation factor = 10`) and by-pass ambiguity resolution (`Quick-pre observable = LC`) in the initial solution. The next controls determine whether `C`-files are saved or regenerated. To take full advantage of the iterative scheme, you should set `Delete AUTCLN input C-files = Yes`. This option is also most conserving of disk space but will increase run time a small amount compared with the saving the initial `C`-files temporarily (`Intermediate`) or permanently (`No`). Unless you suspect a problem with `AUTCLN` and want to examine all the input and output `C`-files, there is no need to elect this last option.

The `AUTCLN` command file is also the mechanism for explicitly removing from the solution data which might be corrupted by satellite rotations during or after eclipses or by a bad clock determination. These features are implemented by `Delete eclipse data` and `Edit AUTCLN command file`, explained below Table 5.1. In Release 9.6 both of these options, as well as `postfit` editing are commanded in the batch file using the new script `sh_autedit` (replacing `sh_autedt` and `avedit`). The script reads the "base" `autcln.cmd` file and edits it appropriately to incorporate eclipse and clock editing, creating for the batch run the `AUTCLN` input file(s) `autcln.cmd.prefit` and (optionally) `autcln.cmd.postfit`.

The most appropriate way of handling the atmosphere depends on the size of the network and the accuracy desired. For networks less than a few kilometers in extent, the atmospheric delay effectively cancels between stations, so you do not want to estimate any atmospheric parameters. For larger networks, you should estimate one or more zenith delay parameters for each station (`Zenith Delay Estimation = Y`). The zenith delay parameters for regional stations will be highly correlated, but there is sufficient precision in the estimation algorithm that these high correlations will not degrade your estimates of station coordinates and the differences in zenith delay between stations will be well determined. (If you wish to see in the output the uncertainty of the differences, then you can add tight constraints to one of the zenith delays in the `SOLVE` batch file; see Section

7.5). The default is to estimate a single zenith delay for each station with an a priori constraint of 0.5 meters. You may allow a variation in the zenith delay during the observation span by specifying a piecewise-linear model with stochastic constraints. `Number Zen` is the number of "knots" in the model; hence, for a new value every 3 hrs of a 24-hr session, you would set `Number Zen` = 9. A knot spacing between 1 and 4 hours is reasonable for most situations, the trade off being resolution versus program size and run time. The allowed variation between tabular points in the estimation is defined by a Gauss-Markov process with a default value of  $0.02 \text{ m} / \sqrt{\text{hr}}$ . The default correlation time is set to 100 hr, making the process effectively a random walk. Specification of these parameters is documented in Table 5.1 and discussed further in Section 8.3. A new feature with release 9.58 is the ability to estimate a north-south and an east-west gradient in atmospheric delay, given as the differences in meters at 10 degrees elevation (see Section 8.4). The final entry for atmospheric modeling is the minimum elevation angle for accepting observations. In the presence of modeling deficiencies for the atmospheric delay or the phase-center variations of the antenna, estimated station heights can be quite sensitive to this cutoff angle.

`Antenna Model` refers to the use an elevation-dependent or elevation-and-azimuth-dependent model for the effective phase center of the receiver antenna. The default is to use no model, but elevation-dependent models have now been developed by NOAA (<http://www.grdl.noaa.gov/GRD/GPS>) for most commonly used antennas and are included in the GAMIT file `antmod.dat` (see also `rcvant.dat`).

`Tide Model`, used to apply models for the time-variable displacements in station coordinates due to tides, is a binary-coded variable, allowing you to easily select any combination you want to use or test. The first (1) and second (2) bits control the IERS/IGS standard models for diurnal and semi-diurnal Earth tides [*IERS Conventions 1996, IERS Tech. Note 21*, Observatoire de Paris, July, 1996] and should always be set. The third (4) bit controls the pole tide, also coded according to IERS standards. This component is not always applied in GAMIT, however, because it has only long-period (primarily annual and 460 days) effects on station coordinates and can be added by GLOBK. (GLOBK will detect whether it has been applied in GAMIT and apply it or not, as instructed, to make the H-files from different processing compatible.) The most complicated part of the tide model is loading due to ocean tides because this effect must be computed (external to GAMIT) using a convolution of a model of the ocean tides themselves and the geometry of the land-sea interface. With Release 10.0 we have implemented corrections based on the model developed by Hans-Georg Scherneck of Chalmers University (Sweden). These are applied in one of two ways—by reading from a table (`stations.oct`) containing corrections for 465 global tracking stations (GPS/SLR/VLBI), or by interpolating from a  $0.5 \times 0.5$  degree global grid (`grid.oct`). In either case, program OCTTAB obtains the horizontal and vertical amplitudes and phases of 11 tidal constituents for each station in the session (D-file), and writes these into a U-file that has a format similar to the Scherneck station table. The values from the station table will be used if the station being processed is within 10 km of a station given in the table; otherwise they will be interpolated from the grid. The file `octtab.out` records the source of

tides for each station in the session. The Scherneck station table (`stations.oct`) and the U-file are relatively small and can be easily examined. The grid table (`grid.oct`), however, is large and has been formatted (at MIT) as a direct-access binary file to conserve space and allow for efficient reading. The version distributed with the software is written with big-ENDIAN binary representation (used by Sun and HP), but OCTTAB automatically converts it to little-ENDIAN when it is read on a little-ENDIAN (Intel or DEC) machine.

By default corrections to Earth rotation parameters are estimated for each session (`Estimate EOP = 15`). If your solution includes 24-hr tracking from a global set of stations, then you can estimate well pole ("wobble") position and UT1 rate but not a UT1 offset since this is perfectly correlated with the nodes of the satellites' orbits. In order to have a full covariance matrix available for GLOBK, however, it is preferable (and necessary in versions prior to January, 1995) to turn on all six EOPs but with tight constraints on the UT1 offset in the GAMIT solution. The default constraints for UT1 rate and pole position and rate are rather loose, so these should be tightened to match the uncertainty in your a priori tables (~ 0.0001 sec/day, 0.001 arcsec, 0.0005 arc/day for IERS Bulletin A or B finals) if you have only a regional network and want to assess carefully the results of the GAMIT analysis.

The final set of the `sestbl.` inputs shown control resolution of phase ambiguities in the solution. Unfortunately, no GPS analysis group or software package (to our knowledge) has automated ambiguity resolution to the point where you can uncritically apply a particular algorithm to all situations. GAMIT uses a combination of pseudo-range observations, if available, and phase observations with an ionospheric constraint to provide flexibility and redundancy. This approach, together with some fairly conservative threshold criteria makes the process reasonably but not perfectly failsafe for most networks. Tuning the algorithm for your particular network and evaluating the results is discussed in Section 5.5.

There are a number of optional entries in the `sestbl.` that may be invoked for special cases and to exercise greater control over the processing. These are summarized in Table 5.1 and further discussed below.

Table 5.1 Summary of *sestbl*. entries

---

Processing Agency	Required –
Station Number	see discussion
Satellite Number	above
Station Constraint	
Satellite Constraint	
 <i>Analysis controls</i>	
Type of Analysis	0-ITER: ARC (optional), MODEL, AUTCLN (optional), SOLVE, SCANDD 1-ITER: Two sequences of 0-ITER, the first using "Quick" SOLVE 2-ITER: Three sequences PREFIT: 0-ITER but without SOLVE QUICK: 0-ITER but with "Quick" SOLVE
SOLVE-only = YES	YES/NO default = NO
Data Status	RAW: Include AUTCLN before each SOLVE run CLEAN: Do not include AUTCLN in the processing sequence
Choice of Observable	LC_HELP: Ambiguity-free and ambiguity-fixed solutions with LC LC_RANGE: Same as LC_HELP but with pseudo-range priority LC_ONLY: Ambiguity-free solution with LC L1_ONLY: Ambiguity-free and ambiguity-fixed solutions with L1 L2_ONLY: Ambiguity-free and ambiguity-fixed solutions with L2 L1,L2_INDEPEND: Ambiguity free and fixed solutions with L1 & L2 L1&L2: (see notes below)
Choice of Experiment	RELAX: Include station, orbital, and Earth-rotation parameters BASELINE: Do not include orbital or EOP parameters
 <i>Data weighting</i>	
Station Error	UNIFORM [sigma] : Weight all phase data equally, [sigma] = 1-way L1 or L2 in mm, default = 10. BASELINE [a] [b] : Weight proportional to baseline length $a^{**2} + (b^{**2})(L^{**2})$ in mm, ppm, def 10. 0. ELEVATION [a] [b] [elev] : Weight by elevation angle; 1-way $a^{**2} + b^{**2}/\sin(\text{elev})^{**2}$ in mm, deg; def= 4.3 7.(
Satellite Error	UNIFORM [sigma] : Satellite error added quadratically to station error; default = 0.
Use N-file	YES : Reweight the data in the final solution using the ELEVATION model with coefficients estimated by AUTCLN in postfit editing
 <i>Ambiguity Resolution</i>	
Ionospheric Constraints	0.0 mm + 1.00 ppm [see below and Section 5.5]
Ambiguity resolution WL	default = 0.15 0.15 1000. 10. 500. [see below]
Ambiguity resolution NL	default = 0.15 0.15 1000. 10. 500. [see below]
Type of Biases	EXPLICIT Necessary for ambiguity resolution (default) IMPLICIT Default for Quick solution

Atmospheric Parameters

Zenith Delay Estimation	Yes/No to estimate zenith delay parameters; default = No
Elevation Cutoff	Give value in degrees; applied in SOLVE; default = 15.
Number Zen	Number of zenith-delay parameters per station; default = 1
Zenith Model	PWL: Piecewise-linear ( default for Number Zen > 1 ) CON: Constant from time of knot (i.e., step model)
Zenith Constraints	Overall a priori constraint in m; default = 0.5
Zenith Variation	[var] [tau] : Variation and correlation parameters in Gauss
Markov model; default =	0.02 m/sqrt(hr) and 100 hrs.
Atmospheric Gradients	Yes/No to estimate a N-S and E-W gradient; default = No
Num Grad	Number of E-W or N-S gradient parameters in PWL model; default = 1
Gradient Constraints	Gradient at 10 deg elevation in meters; default = 0.03 m
Tropospheric Constraints	YES/NO: Spatial constraints, default = No (see Sec 8.3)

Orbit parameters

Initial ARC	YES: Integrate G-file ICs to get a T-file (default for RELAX) NO: Use existing T-file (default for BASELINE)
Final ARC	YES: Re-integrate the final estimated ICs NO: Suppress re-integration of the final estimated ICs (default)
Inertial frame	J2000: T-file & calculations in J2000 (default & current SOPAC) B1950: Old T-file and SOPAC frame
Radiation Model for ARC	BERNE: 9-parameter model (GAMIT and SOPAC default) BERN1: same as BERNE but with AIUB 1997 non-adjustable terms BERN2: 6-parameter AIUB 1997 model SPHRC: 3-parameter model (old GAMIT and SOPAC default) SRDYB: same as BERNE but with no once-per-rev terms added SVDYZ: 3-parameter direc/y/z model with ROCK4 x/z terms added SVXYZ: 3-parameter x/y/z model with ROCK4 x/z terms added
Reference System for ARC	IGS92: Gravitational constants from IGS 1992 standards (default) WGS84: Gravitational constants from WGS84 standards (BC ephemeris)
Tabular interval for ARC	Output interval on T-file in seconds; default = 900.
Stepsize for ARC	Integration stepsize in seconds; default = 75.
Export Orbits	YES/NO: Create or not an Earth-fixed SP3 file for export (def = No)
Orbit id	4-char code for export orbit
Orbit Format	SP1/SP3 (NGS Standard Products), default = SP3
Orbit organization	3-char code for processing agency for export orbits
Reference System for Orb	5-char code for Earth-fixed reference system for export orbits

MODEL parameters

Antenna Model	NONE: No model for phase-center variations (default) ELEV: Elevation-dependent model in antmod.dat. AZEL: Elevation- and azimuth-dependenet model in antmod.dat
Tide Model	Binary coded: 1 earth 2 freq-dep 4 pole 8 ocean default = 7
Earth Rotation	Diurnal/Semidirunal: Binary coded: 1=pole 2=UT1 4=Ray model default=7
Yaw Model	SV yaw used from svnav.dat; YES/NO default = YES
Use I-file	Reference clock polynomial; YES/NO default = YES

SOLVE parameters

Estimate EOP	Binary coded: 1 wob 2 ut1 4 wob rate 8 UT1 rate; default 15
Wobble Constraint	[pole] [pole rate] default = 3. 0.3 (arcsec) (arcsec/day)
UT1 Constraint	[UT1] [UT1 rate] default = 0.00002 0.02 (sec) (sec/day)
Select Epochs	[start] [stop]
Decimation Factor	[factor] Default = 1 (no decimation)
H-file solutions	LOOSE-ONLY: Write only the loose solutions on the H-file (default) ALL: Write both the constrained and loose solutions on the H-file
Correlation print	Threshold for printing parameter correlations (default 0.9999)

Cleaning parameters

Clean Option	AUTCLN: Use kf program AUTCLN for cleaning (default) SINCLN: Use GAMIT program SINCLN DBLCLN: Use GAMIT programs SINCLN plus DBLCLN
AUTCLN Command File	[filename] Default none (use default options in AUTCLN)
Quick-pre decimation factor	Set (e.g. 10) to save time in autcln-pre SOLVE
Quick-pre observable	Options same as Choice of Observable; set = LC to save time
Quick-pre elevation cutoff	Set lower to see get low-el residuals flatter in AUTCLN postfit
AUTCLN Postfit	Yes/No to invoke postfit editing (requires an extra solution)
Edit AUTCLN Command File	Add delete commands to autcln.cmd for bad clocks Y/N default = NO
Delete eclipse data	POST: Add delete commands for 30 min after eclipse (default) ALL: Add delete commands for eclipse and post-eclipse
Iteration	XFILES: On iteration, run AUTCLN on original data (default) CFILES: On iteration, run AUTCLN on previously cleaned data NO: Do not delete data during or after eclipse.
SCANDD control	BOTH: Run SCANDD after each solution (default) IFBAD: Run SCANDD only if the nrms > 1.0 FIRST: Run SCANDD only after the quick solution FULL: Run SCANDD only after the full solution NONE: Do not run SCANDD at all.

File handling

X-compress = YES	Uncompress/compress X-files default = NO
Delete all input C-files	YES/NO default = NO
Delete MODEL input C-files	YES/NO default = NO
Delete AUTCLN input C-files	YES/NO/Intermediate default = NO
Update T/L files	T_AND_L (default), T_ONLY, L_ONLY, NONE (Applies only to update for full solution after quick)
Update tolerance	Minimum adjustment for updating L-file coords, default 0.3 m
Run CTOX = YES	Make clean X-files from C-files default = NO

Analysis controls. The Type of Analysis, as discussed above, is almost always 0-ITER or 1-ITER. The most common use of 2-ITER would be in determining orbits, where high correlations require multiple iterations to achieve convergence. In this case the initial solution would be performed using the "quick" algorithm in which SOLVE estimates (implicitly) an extra bias parameter at each gap or flagged (by AUTCLN) point in the double-difference observations, rendering the parameter estimates less accurate but also less sensitive to cycle slips. If you iterate, you must decide whether you want to update coordinates only, orbit only, or both for the second solution (see Update T/L files under File handling in the explanation of Table 5.1). PREFIT will generate batch files for ARC, MODEL, and AUTCLN, but not CFMRG or SOLVE. It is a convenient way to generate C-files for inspection with CVIEW, trial editing with AUTCLN, or for input to MAKEJ when you have mismatched time tags in the presence of SA. QUICK will generate the standard 0-ITER sequence but set SOLVE for a "quick" solution. A separate command, SOLVE-only, allows you to set up a batch run from C-files, executing only CFMRG and SOLVE. As discussed above, Data Status determines whether AUTCLN (or SINCLN/DLBCLN) is included in the run. Among the Choice of Observable selections, the only one not already explained is L1&L2. With this choice ambiguities are resolved simultaneously for L1 and L2 (as in the L1,L2\_INDEPEND option) but with an ionospheric constraint which remains in the final solution. This option has not been recently tested and so should be used with caution. Choice of Experiment is discussed above.

Data weighting. For analysts who wish to experiment with non-uniform weighting of the phase data, several options are available. If you are not estimating orbital parameters and expect a non-negligible contribution from orbital errors, you may wish to weight the observations according to baseline length, as described by *Bock et al.* [1986] —see Chapter 2 for references]. In this case you specify `Station error = BASELINE a b`, where  $a$  is the constant component in mm and  $b$  the baseline-length component in parts per million; the two terms are combined quadratically. A second (and mutually exclusive) approach is to assign errors according to elevation angle: `Station error = ELEVATION a b`, where  $a$  is again a constant and  $b^2$  multiplies a term inversely proportional the sine of the elevation angle. The default values (4.3 and 7. ) are chosen (rather arbitrarily) such that an observation at  $40^\circ$  (the median elevation of a typical session at mid-latitudes) has the same weight as with UNIFORM option with the one-way L1 sigma equal to 10 mm, and an observation at  $20^\circ$  has half the weight. This option can be invoked on a station-by-station basis by editing the SOLVE batch file (see Section 7.5) but can only be invoked uniformly for all stations from the `sestbl`. The most powerful and now recommended option is to use weight the data by elevation angle based on the actual scatter of the residuals from each station. This option is implemented via a (new) N-file in which the coefficients  $a$  and  $b$  of the ELEVATION model have been estimated by AUTCLN from postfit editing. To invoke this option, specify `AUTCLN postfit = Yes` and `Use N-file = Yes` in the `sestbl` and insert the appropriate postfit-edit commands in the `autcln.cmd` file, as described earlier in this chapter. With any of the three station-weight options, you can specify an additional term by which a particular satellite's observations can be downweighted. Set `Satellite error = UNIFORM a`, where  $a$  is a constant in mm to be added quadratically to the station error.

Ambiguity resolution. These inputs allow you significant control over the criteria used to resolve phase ambiguities. `Ionospheric Constraints` specifies the constraint applied to the ionosphere in estimating the wide-lane (L2–L1) phase ambiguity. In this input, unlike most of the others in the `sestbl`, you must follow the format to the right of the = sign exactly. The two `Ambiguity resolution` entries specify the decision-function and chi-square search parameters to be used for widelane (WL) and narrow-lane (NL) resolution. The fourth parameter is the maximum baseline length (in km) over which you want to attempt to resolve ambiguities. Strategies for choosing these parameters are discussed in Section 5.5. The `Type of Biases` entry specifies whether ambiguity parameters are carried through explicitly or solved for implicitly. Selecting `IMPLICIT` reduces the size of the SOLVE output (Q-) file but precludes resolving ambiguities.

Atmospheric parameters. Most of the entries for this group were explained in the standard setup. The only additional entry is `Tropospheric Constraints`, which allows you to assume a spatial correlation among zenith delay parameters using the structure function described by *Treuhaft and Lanyi* [1986] (see Section 8.6). We have tested this constraint in only a limited way (with slightly positive results). It is currently coded only for a single zenith-delay parameter per station.

Orbit parameters. The first two entries control whether or not ARC is run to create a T-file prior to the first MODEL run (*Initial ARC*) and after the final SOLVE (*Final ARC*). As indicated above, you may suppress the initial integration if you already have a T-file. You do not need to create a T-file from the estimated orbital parameters unless you need it for further processing or wish to create an SP3 file for export. The next entry sets the inertial frame for the orbital integration in ARC, the orbital ephemerides themselves (T-file), and the calculation of the theoretical observable in MODEL. In a fundamental sense the frame is arbitrary; as long as you transform coordinates and ephemerides consistently between the Earth-fixed and inertial frames, the choice of inertial frame matters only if you are combining inertial orbital parameters with those from an external source. The current convention for astronomical and IGS use is the equator and equinox of Julian epoch 2000.0, designated J2000 and corresponding to 0h UTC on 1 January, 2000. If you plan to use G- or T-files from SOPAC and/or you are starting anew in you processing and want to be consistent with the rest of the world, you should specify J2000, which is the current GAMIT default. The default for releases 9.4 or earlier was 'B1950', designating Bessilian epoch 1950.0. You should specify this if you wish to repeat a solution you have previously run. If you specify J2000 but have a B1950 G-file (or vice versa), ARC will automatically convert the G-file before integrating, saving the old file with an additional extent (.B1950 or .J2000). The next two entries specify the dynamical model to be used in the integration of initial conditions. The default gravitational field (*Reference system for ARC = IGS92*) is from the IGS/IERS 1992 standards (see *McCarthy* [1992] in the references in Chapter 2), but you can specify the WGS84 field if you wish to perform comparisons with a DoD orbit. There are two commonly used models for non-gravitational ("radiation pressure") accelerations on the satellites. Prior to mid-1995, GAMIT and SOPAC orbits were generated with "spherical" or "flat-plate" model that had three adjustable parameters: coefficients representing a "direct" (Sun-facing), "y-bias" (along the spacecraft y-axis), and "z" (along the Earth-facing spacecraft axis) accelerations. A more comprehensive and demonstrably better model uses 9 adjustable parameters including both constant and once-per-revolution accelerations (as described by *Colombo* [1986]). The particular form of this model we employ is close to that described by *Beutler et al.* [1994] and hence is designated BERNE. These and two other models available are described in Section 7.2. The last two entries in this group control the integration stepsize and T-file tabular interval. The default from release 9.2 forward is a 75-second stepsize and 900-second (15-minute) tabular interval. These are reduced from the former 168-second and 1350-second (22.5-minute) intervals to provide consistency with IGS standards. There are differences between a 75-second and 168-second integration stepsize for eclipsing satellites—up to 20 cm over 1 day ( $\pm 12$  hrs from a midpoint epoch) and up to 60 cm over 3 days. The differences (errors) for some eclipsing satellites in the 75-second integration compared with one with a 150-second stepsize are less than 5 cm over 1 day but up to 30 cm over 3 days. The tabular spacing can remain at 15 minutes for these smaller stepsizes providing the former is an integer multiple of the latter. The final group of entries are used if you wish to create an NGS SP#1 or SP#3 format ephemeris file from the final ARC integration (done routinely at SOPAC processing but rarely elsewhere). The 4-character *Orbit id* gets used in the export file name. The *Orbit organization* and *Reference*

system for `Orb` are written onto the header of the file (see the `SP#1` and `SP#3` format descriptions). Since these are Earth-fixed orbits, the reference system refers to the terrestrial frame used to define the station coordinates in the GAMIT or GLOBK solution (e.g. `ITR94` for `ITRF94`).

MODEL parameters. Besides the antennas phase-center model (Antenna model), discussed above, there are controls to specify the model used for solid-Earth tides, Earth rotation, satellite yaw, and receiver clocks. `Tide Model` is binary coded to allow inclusion of constant-Love-number tides ("1" bit), the frequency-dependent ( $K_1$ ) radial tide ("2" bit), pole tide ("4" bit), and ocean-loading effects ("8" bit), all modeled according to IGS 1992 standards. The default (= 7) is to include the direct solid-Earth tide, including the frequency-dependent term, and the pole tide. We do not yet have ocean-tide components for a sufficient number of stations to include these in the model. `Earth Rotation` allows you to disable the addition of diurnal and semi-diurnal terms to the `UT1` and pole angles read from tables. With Release 9.8, we have changed from an older model [Herring and Dong, *J. Geophys. Res.*, 99, 18071, 1994] to a more recent one [J. Ray, private communication, 1998]. In order to distinguish these models in the GAMIT output (including h-files for GLOBK), we added a third bit ("4"), so that the current default value is 7. `Yaw Model` allows you to disable modelling of satellite yaw (rotation of the antenna away from the Earth-pointing position). With the modifications in Release 9.7 of the yaw code to have all stations read a common table of yaw values, we have found no cases for which the yaw model degrades the solution (which occasionally occurred before in regional processing due to different stations getting different yaw angles because of different satellite rise times). Finally, you have the option (`Use I-file`) of not including in the theoretical observable a piece-wise polynomial model of the station clock, computed by `FIXDRV` from the K-file samples written into the I-file. Since the receiver clock rate cancels in double differences (all channels are sampled simultaneously), it does not need to be modeled. However, using the I-file is recommended to prevent numerical problems which sometimes occur in `SOLVE` if there is a large station clock drift and a long gap in the data from a satellite (from its setting and then rising again). The only time you might want to omit the I-file is if you have inadvertently deleted it or the K-files and don't want to recreate them using `MAKEK` or `MAKEX`.

SOLVE parameters. Estimation of Earth rotation parameters (`Estimate EOP`) should be considered in most analyses, as discussed above. The estimation control is binary coded, with the "1" bit used for pole position, the "2" bit for `UT1` offsets, the "4" bit for pole rate, and the "8" bit for `UT1` rate. The units of the a priori constraint are arcseconds and arcseconds per day for pole and (time) seconds and (time) seconds per day for `UT1`. By default, corrections to the constant and rate of `UT1` and pole position are estimated for each session (`Estimate EOP` = 15) but you may want to tighten the constraints if you have only regional data in your analysis. The two remaining commands for `SOLVE` allow you to use only part of the data, either for sensitivity tests or to reduce the run time. To use a partial span, enter the stop and start epoch numbers (determined from the X-file or using `CVIEW`) after `Select epochs =` . To use only every  $n$ th point set `Decimation factor = n`. These two controls may be used together. `H-file` solutions controls what

solutions are written into the H-file for use by GLOBK. The default is now to write only the two (biases free and biases-fixed) loosely constrained solutions, not the solutions produced by the input GAMIT constraints, in order to reduce the size of the H-files. If you need to have the constrained solutions in the H-file (e.g., for debugging or post-processing with FONDA), then you should specify H-file `solutions = ALL`.

Cleaning parameters. There are eight controls for cleaning the data—seven listed here and one under File Control. `Clean Option` specifies what programs are used. `AUTCLN` is the default and recommended in all cases, but the use of the old GAMIT-directory programs `SINCLN` and `DBLCLN` is explained in Appendix 6. The use of `AUTCLN Command File`, `AUTCLN Postfit`, and the File Control entry `Delete AUTCLN input C-files` has been discussed earlier in this section. `Edit AUTCLN Command File` invokes an option for script `sh_autedit` to extract messages about clock errors from the P-file created by `MODEL` and to add commands to `autcln.cmd` to delete these data in cleaning. With the current `AUTCLN`, this option should never be needed. There are three options for handling eclipse data, implemented by edits to the `AUTCLN` command file invoked by `sh_autedit`. The default is `Delete eclipse data = POST`, which will unweight observations occurring during the first half-hour following an eclipse, the period during which the yaw model always fails. `ALL` will unweight data during the eclipse as well, and `NO` will keep all of the data. The `Iteration` command controls whether the second `MODEL/AUTCLN` sequence in a 1-ITER or 2-ITER run uses the original X-files (default) or the C-file created from the last run. Finally, since a `SCANDD` run is one of the most time-consuming parts of the processing and may be useful only at the end, and then only when the normalized rms from `SOLVE` suggests the presence of cycle slips, `SCANDD control` allows you to specify when in the batch sequence `SCANDD` gets executed. For unclean data, `FIXDRV` always writes a line for `SCANDD` into the batch file after each solution, but `SCANDD control` determines whether or not it is dummied by a comment character (`#`). With `SCANDD control = BOTH` (the default), `SCANDD` will be executed unconditionally after the quick and full solutions. Option `FIRST` causes execution after the quick solution only, `FULL` after the full solution only, and `NONE` after neither. Option `IFBAD` will write into the batch file `cs`h commands to look at the normalized rms in the Q-file; only if the `nrms` is greater than 1.0 will `SCANDD` be run.

File handling. These entries allow you some control over the files used or created in your batch run, and hence the amount of disk space required to process a survey. If `x-compress = yes`, then the batch script will expect the X-files to be compressed at the beginning of the run and will compress them again at the end. The next group of entries allows you to delete the input C-files from one or more processing steps. The default is to save all C-files so that you check the editing for each iteration. At the other extreme, setting `Delete all input C-files = yes` will assure that no more than two sets of C-files are resident at the same time and will leave only the last set on the disk at the end. The `update T/L files` command allows you to use the adjusted values of coordinate and/or orbital parameters in successive iterations. The most common case for most users occurs when you want to update the coordinates for new stations for postfit editing and in order to achieve final adjustments are within a linear range for least-squares estimation (see Section

4.2). In this case you would set `update T/L files = L-ONLY` and use the `update tolerance` command to limit the updates to those stations with large adjustments (default is 0.3 m). Finally `Run CTOX = yes` creates at the end of the run a set of X-files with cleaned data, allowing you in principal to delete the last set of C-files if you have no further need to re-run SOLVE with different constraints or to examine the post-fit residuals with SCANDD or CVIEW. The correctly edited data on these X-files can be used as subsequent inputs to GAMIT processing with `Data status = clean`.

The form of the site control table ( `sittbl.` ) is shown below. The columns occupied by each entry are indicated by the keywords and dashes at the top of the file, and since these are used to read the entries, the order is arbitrary. Most of the entries are also optional, with the required information picked up from defaults or from corresponding (station-independent) entries in the `sestbl.` The example below shows the most commonly used entries; the omitted ones specify the atmospheric models and are described in Chapter 8.

STATION	FIX	--COORD.	CONSTR.-	--EPOCH--	CUTOFF	CLK	KLOCK	CLKFT	APHS
SAFE San Fernando	NNN	100.	100.	100.	001- *	10.0	NNN	3	NONE
WSFD WSFD GPS	NNN	0.01	0.01	0.01	001- *	10.0	NNN	3	L NONE
YKNF YELLOWKNIFE	NNN	0.01	0.01	0.01	001- *	10.0	NNN	3	L NONE
RICH RICHRPA	NNN	0.05	0.05	0.10	001- *	10.0	NNN	3	L ELEV
TROM TROMGPSM	YYY	5.00	5.00	5.00	001- *	10.0	NNN	3	L AZEL

The table may contain any number of stations, whether used in the experiment or not. The 4-letter code must match that used in the D-file; the 12-letter descriptor is arbitrary and not used (the full station names for the q-file are read from `station.info`). The third column (in the example shown) indicates which, if any, of the three station coordinates are to be fixed/free (Y/N) in the solution. Deleting the data from a station that appears in the D-file done must be done by using the `exclude` command, inserted into SOLVE batch file (see Section 7.5). Any *a priori* coordinate constraints are given under `COORD.CONSTR.` in units of meters for latitude, longitude, and radius. Whether one uses coordinate constraints or not is specified in `sestbl.` (as described earlier). You should think carefully about this entry since this is your opportunity to define the reference system for the analysis by constraining the coordinates of one or more fiducial stations. If you plan to use GLOBK for your final analysis, you should avoid absolute *fixing* of any stations, but rather use *a priori* constraints.

You can restrict the number of observations to be used from one or more stations by specifying a range of epochs ( `EPOCH` ) or changing the elevation cutoff ( `CUTOFF` ). In the current version of the software any modifications to `EPOCH` or `CUTOFF` will apply globally to all sessions.

The next three entries control the way the receiver clock is handled. The `CLK` entry indicates whether or not an offset, rate, or acceleration term is to be estimated by SOLVE. Almost always the answer is "No" ( `N` ). `KLOCK` selects the way the clocks are modeled and can be quite important for certain receivers. For all receivers except MiniMacs you should normally select option 3 to indicate that the receiver clock offset is to be estimated epoch-by-epoch using the pseudorange (see Section 4.7), and that the effect of oscillator

variations on the phase is to be modeled with a low-order polynomial. Since the MiniMac receivers keep their clocks synchronized with the GPS satellites, it is preferable to assume an offset of 0. by selecting option 1. The third option ( 2 ) uses the low-order polynomial for both the epoch offset and oscillator variations. This approach will model receiver clock offsets as well as will Option 3 if the receiver clock stability is sufficient (better than  $\sim 10^{-8}$ ) to keep deviations from the polynomial less than 1 microsecond throughout the observation span. The crystals in the TI 4100 and MACROMETER II usually meet this requirement but those in the newer low-power receivers do not unless they are locked to an external atomic oscillator (as at some IGS tracking stations). The order of the polynomial to be used by FIXDRV may be specified under CLKFT as linear ( L ) or cubic ( C ), or left for FIXDRV to decide from the fit by leaving this column blank. If KLOCK is not specified, the way the clock is handled is determined by the receiver type, with all receivers except MiniMacs set to option 3 (epoch-by-epoch estimation).

The final column shown in the example is for invoking a model for variations in the phase center of the receiving antenna ( APHS ). The use of a model for all stations can be controlled using the sestbl. entry, but the sittbl. entries override the sestbl. if the former are present. So to avoid confusion, you may want to omit this column from the sittbl. except for those analyses in which you need to control the model separately for each station.

The usual way to run FIXDRV is to give the name of the D-file as a command-line argument. In this case, there are no further prompts necessary. If an I-file exists, it will be used; if not, it will be created by fitting polynomials to the clock values given in the K-files. If you wish to choose an alternate I-file, or recreate the I-file even though it exists, you should run FIXDRV interactively by not specifying the D-file as a command-line argument. In this case, FIXDRV will prompt you for the name of the D-file. It will then ask what you want to do about the I-file: use the old one, save the old one and create a new one, or overwrite the old one. Most of the time you probably want to "Use the old one" (option 3) and avoid a time-consuming recalculation of all the clock coefficients, but if you have added a station to the D-file since last running FIXDRV or have updated the K-file by rerunning MAKEX or MAKEK with improved station coordinates, you should create a new I-file.

When you run FIXDRV to create an I-file, you will get a display for each station indicating how well the station clock (as represented by the values in the K-file) fits a linear polynomial and a cubic polynomial that also includes "steps" representing unexpected clock jumps or, for many receivers, programmed resets of 1 or 2 milliseconds to keep the sampling time synchronized with GPS time. Typical rms values for field receivers are several milliseconds for the linear fit (without jumps) and 50-1000 microseconds for the cubic fit with jumps. See the discussion in Chapter 4.10 to determine whether larger values may cause problems in your processing.

### 5.3 Executing the Batch Run

The output of FIXDRV is a command file (shell script) named `b{expmt}.bat` which invokes the GAMIT modules in the appropriate order for the type of analysis you have requested (see the example on the following page). To execute the analysis run in foreground type `cs {batch file name}`; in background type `gbat {batch file name}`. (If your system recognizes the batch file as a command file [use `chmod +x` under UNIX], you can of course omit the `cs` when running in foreground.) All of the required modules will then be executed automatically to perform the processing sequence you have defined with FIXDRV. Beginning with release 9.5, the first lines of the batch file remove any existing files logging the status of the batch run (`GAMIT.status`) and warnings (`GAMIT.warning`) or aborts (`GAMIT.fatal`). Most messages generated by the GAMIT modules and AUTCLN are now written into these files instead of directly to the screen (or `b{expmt}.bat.log` if the job was executed using the `gbat`). They provide a convenient method of determining if a GAMIT run executed successfully. During execution, you can monitor the progress of a background job by typing `tail GAMIT.status`. The first code now executed by ARC, MODEL, CFMRG, and SOLVE is a check for the existence of `GAMIT.fatal`; if it's found, indicating that the previous step in the batch sequence has failed, the current module will terminate also. This feature is designed to avoid the common problem of overlooking the failure of a previous step in evaluating the success of a run.

For most of the modules, the command references a secondary B-file containing the input stream for one execution of the specified module. Each input stream contains replies to all the queries that the user would encounter when running the module interactively. In the case of AUTCLN, there are command-line arguments rather than a secondary batch file given. For AUTCLN, these arguments are the command file name (optional), a character indicating whether input C-files are overwritten ('.') or the 6th character incremented ('+'), and the name of a D-file (to be read for the C-file names) and the 6th character of the input C-files (which may be different from the names in the D-file). (See Chapter 7 for more detail.).

The sequence of program executions is listed in the primary B-file and the individual responses are listed in the secondary B-files. An example of a primary B-file for a 1-ITERATION analysis with postfit editing by AUTCLN is shown below. It is usually more efficient for regional networks to perform a 0-ITERATION analysis, repeating it if necessary to correct problems, we show the 1-ITERATION case here to document this feature of GAMIT. In this example, we have set `Update T/L files = L_ONLY` since we do not expect to improve the orbit from the regional data; and we have set `Delete input AUTCLN C-files = I`, indicating that the only time a second set of C-files is retained is for the postfit editing step, avoiding an unnecessary rerun of MODEL.

bvent7.bat

```

#!/bin/csh
# Remove any existing GAMIT.status, .warning, .fatal files
/bin/rm GAMIT.status
/bin/rm GAMIT.warning
/bin/rm GAMIT.fatal
#
# Initial orbital intergration
arc < bvent7.001
#
# Generation of yaw file
yawtab yvent7.278 tvent7.278 yventt.278 120
# Initial O-Cs and editing
model < bvent7.002
model < bvent7.003
model < bvent7.004
model < bvent7.005
model < bvent7.006
model < bvent7.007
model < bvent7.008
sh_autedit -base autcln.cmd -autecl arcout.278 278 N 30
autcln autcln.cmd.prefit . dvent7.278 7 >! autcln.out
mvcf 7 a
#
# Quick solution
cfmrg < bvent7.010
solve < bvent7.011
sh_check_soln quick 1.0
#scandd < bvent7.012
model < bvent7.013
model < bvent7.014
model < bvent7.015
model < bvent7.016
model < bvent7.017
model < bvent7.018
model < bvent7.019
autcln autcln.cmd + dtest7.278 b >! autcln.out
#
# Full solution
cfmrg < bvent7.021
solve < bvent7.022
#
# Post-fit editing and solution
mvcf b d
/bin/rm c????c.???
sh_autedit -base autcln.cmd -autecl arcout.278 278 N 30
autcln autcln.cmd.postfit . dvent7.278 d >! autcln.out
mvcf d e
/bin/cp mventa.278 mventa.278.autcl
cfmrg < bvent7.024
solve < bvent7.025
#
# Scan the residuals
scandd < bvent7.026

```

Listed below are explanations for each module execution in the batch file.

**ARC** Generate an orbital ephemeris (T-file) with partials using as initial conditions a G-file produced by `sh_sp3fit`, `sh_bctot`, or copied from SOPAC. This step can be skipped if you've already created a T-file using `sh_sp3_fit` or `sh_bcfite` or copied one from SOPAC.

**YAWTAB** Generate a table of yaw values for each SV at each observation epoch using as input the T-file and short table of yaw values written by ARC.

**MODEL** Compute prefit residuals ("O-C's") and partial derivatives for the observations on each X-file; create C-files with the same names (except for the first letter) as the X-files.

**AUTCLN** Read the C-files output by MODEL and search for cycle slips and outliers in the pre-fit one-way and double-difference residuals, inserting extra biases at all questionable gaps; create the "a" series C-files (i.e., with the year digit replaced by "a") with these corrections to the phase data and prefit residuals.

**CFMRG** Set up the M-file for the least squares fit: define and select the parameters to be adjusted and the C-files to be read.

**SOLVE** Perform a least-squares estimate of station coordinates and orbital parameters; update the M-file with the parameter adjustments (in order to edit post-fit residuals); write the "a" L-file with an adjusted set of coordinates and the "a" G-file with an adjusted set of orbital initial conditions. The M-file and Q-file from quick solutions are always named with the sixth character "1".

**SCANDD** Using the updated M-file to create predicted post-fit residuals, scan all double-difference combinations to produce a summary of potential cycle slips remaining. This step has been commented out by `FIXDRV` since we set `SCANDD control = FULL` to indicate that SCANDD (a time-consuming step) should be executed only at the end of the full solution.

**MODEL** Recompute O-C's and partials from the original X-files using the new L-file. Create "b" series C-files.

**AUTCLN** Re-clean the data using the flatter residuals obtained from the iterated coordinates and orbits. Output "b" series C-files.

**CFMRG** Create a new M-file with the names of the "b" series C-files; the "regular solution" M-file always has "a" as its sixth character.

**SOLVE** Perform a least-squares estimate of station coordinates and orbital parameters, attempting to resolve phase ambiguities if specified by the type of analysis. This execution of SOLVE will also update the M-file with the parameter adjustments in order to view or edit the post-fit residuals. It will also write overwrite the "a" L-file and create a "b" G-file. Like the M-file, the Q-file from this solution is named with the sixth character "a".

**AUTCLN** Re-clean the data using residuals flattened by the 'predicted' parameter adjustments on the M-file. The input C-files are those generated by the MODEL run input to the last AUTCLN and SOLVE runs (the "b" series now renamed "d").

**CFMRG** Regenerate the "a" M-file for the final solution.

**SOLVE** Repeat the full solution with the re-edited data.

The shellscript executed just before each AUTCLN run copies a "base" AUTCLN command file (specified by `autcln_cmd` in the `sestbl.`, usually `autcln.cmd`) into either `autcln.cmd.prefit` or `autcln.cmd.postfit`, uncommenting in the latter case the commands for post-fit editing (see Section 6.2) and in both cases adding (optionally) commands to exclude data corrupted by eclipses (`Delete eclipse data` in the `sestbl.`).

There are two important principles to remember using batch files to carry out an analysis. The first is that you often need to exert control over the execution by commenting out (with # signs) certain lines of the primary B-file. When you execute your initial batch run, you may want to comment all of the command lines after the first SOLVE in order to inspect the quick solution before reintegrating the orbit, re-MODELing the observations, and performing the regular solution. There are many things—some beyond your control, some you should have caught but didn't—that can cause the quick solution to be bad (see Section 5.4). Another example of the need to comment command lines is when you have previously run ARC and don't want to repeat the integration at the beginning of the batch solution, or when you want to postpone the final ARC integration until after you have inspected the Q-file from your solution (though both of these controls can be implemented using `sestbl.` commands). Finally, if your batch run fails in the middle for any reason, you can comment the command-lines that have executed successfully and continue the run after the interruption.

The second important principle concerns the naming conventions for the various files. Of most concern are the C-file names. `FIXDRV` will establish a sequence which increments the sixth character each time a new C-file is written. In the cleaning sequences (`QUICK`, `1-ITER`, or `2-ITER`) the C-files written by the first MODEL run will begin with the year number, e.g., "7" for 1987, and the sequence will continue "a", "b", etc. (With AUTCLN the incrementing is done using a "+" rather than a "." in the command line if you do not wish to delete the input C-files, or using the `mvcf` (or `copyc`) script to rename the files.) If, for example, you choose to by-pass AUTCLN (by commenting the command line) and perform manual editing with `CVIEW`, then you should request `CVIEW` to write output C-

files with the sixth character incremented (this is an easy and natural procedure—see Chapter 6). Then you can continue the batch sequence without having to edit the names of the C-files in the secondary B-files for MODEL and CFMRG. Special rules apply for 0-ITER with clean data runs, in which only one set of new C-files is created. In order to accommodate multi-session solutions within a single day, the output C-file from MODEL is the same as the input X-file. Thus if your input X-files are named with 6th character "a" and "p", for example, designating "am" and "pm" sessions, these letters will be retained in the C-file. The 0-ITER options with clean data (only) also allow for C-files rather than X-files in the D-file; in this case the C-files output by MODEL will be incremented by one letter (e.g. "a" => "b", "p" => "q"). It is partly because of the inherent complication of file naming (but also to reduce processing time) that many analysts prefer to use always 0-ITER (no quick solution), just repeating it with updated coordinates or orbits if the a priori values of these are sufficiently bad to cause problems for AUTCLN or adjustments that are outside of the linear range (see the discussion in Section 4.2).

Table 5.2 below summarizes the assignment of the sixth character and disposition of the C-files for the most common processing sequences. The input files for MODEL are assumed to be X-files and hence always have the last digit of the year as their sixth character.

Table 5.2 6th character and disposition of C-files in batch processing

Type of Analysis:		QUICK	1-ITER	2-ITER	0-ITER
<i>Initial O-C and edit</i>					
MODEL	in (X)	yr	yr	yr	[usually yr]
	out	yr	yr	yr	[same as X]
					[incremented if C]
AUTCLN	in	yr	yr	yr	yr
	out	a	a	a	a
<i>Quick solution</i>					
CFMRG, SOLVE	in	a	a	a	
<i>1st iteration</i>					
MODEL	in			yr	
	out			b	
AUTCLN	in			b	
	out			c	
CFMRG, SOLVE				c	
<i>2d iteration and/or final solution</i>					
MODEL	in		yr	yr	
	out		b	d	
AUTCLN	in		b	d	
	out		c	e	
CFMRG, SOLVE			c	e	a [yr if no AUTCLN]
<i>Postfit editing and repeat solution</i>					
MODEL	in		yr	yr	yr
	out		d	f	b
AUTCLN	in		d	f	b
	out		e	g	c
CFMRG SOLVE			e	g	c

Finally, we display the contents of the secondary B-files created in our example:

File BVENT7.001 (ARC)

```

PRN 3
PRN 6
PRN 9
PRN 11
PRN 12
PRN 13
END
IGS92 BERNE 900.0 75.0

```

arcout.002  
gvent7.002

87 23 21 37 23.00000  
87 9 16 37 23.00000

Y  
tvent7.002

#### File BVENT7.002 (MODEL)

S	Static mode
pvent7.002	Print file
ivent7.002	Station clock polynomial (I-) file
lvent7.002	Coordinate (L-) file
xcato7.002	Input X or C file
ccato7.002	Output C-file
N	Delete input C-file?
tvent7.023	T-file
I	Inertial frame
N	Use W-file?
N	Use Z-file?
jvent7.002	Satellite clock polynomial (J-) file
0 7 7	Geodetic datum / Tide model / SP Earth rotation
15.0 NONE	Elevation angle cutoff / Antenna model
2 yventt.278	Clock model / Yaw file
1013. 25 20.0 50.0	Pressure, temp, humidity
SAAS SAAS CFA CFA	

#### File bvent7.021 (CFMRG)

BATCH

cato	4 letter station code
love	4 letter station code
moja	4 letter station code
pver	4 letter station code
safe	4 letter station code
wsfd	4 letter station code
yknf	4 letter station code

3 6 8 9 11 12 13 Total PRN Numbers

ccatoe.278	C-file
clovee.278	C-file
cmojae.278	C-file
cpvere.278	C-file
csafee.278	C-file
cwsfde.278	C-file
cyknfe.278	C-file

END

EEEEEEEE

mventa.278	M-file
Y	coordinate partials?
Y	atmospheric partials? This should be hard wired
4 4 4 4 4 4 4	Number zenith delay parameters
Y	orbital partials?

```

Y          SV antenna offset partials?
Y          gradient parameters estimated? (Y/N)
  1  1  1  1  1  1  1  Number of gradient parameters - Session 1

```

### File bvent7.022 (SOLVE)

```

=====
*   << key-word-controlled batch file format >>           *
* symbol ":" must exist in command lines as separator      *
* any non-blank character at first column means comment line
* empty after ":" means comment line too                  *
=====
*
----- Part 1 -- Files and Global Controls
operation mode:   batch
owner:           MIT
Q-file name:     qventa.278
H-file mode:     0
datum code:      0
M-file name:     mventa.278
quick solution choice: full
biases:          explicit
phase difference options: double difference
combination mode: LC_HELP
  bias search approach: decision function
  search path:       narrow lane
  search criteria:   0.15  0.15 1000.00  10.00  500.
start and end epochs: 1 225 1
set cutoff_elevation:
  cutoff: all _sites 15.0
error model:
  stn_error: all_sites uniform 10.0
  sat_error: all_sats 0.0
*
----- Part 2 -- Parameters
set parameters:
  estimate: all_sites all_parameters
  fix:      all_sites clock
  fix:      all_sites grad
  estimate: all_sats all_parameters
  fix:      all_sats clock radiation
  fix:      global all_parameters
exit set:
*
----- Part 3 -- A priori Constraints
set apriori constraints:
  tight_apr_coord: cato 100.000 100.000 100.000
  tight_apr_coord: love 100.000 100.000 100.000
  tight_apr_coord: moja 100.000 100.000 100.000
  tight_apr_coord: pver  0.010  0.010  0.010
  tight_apr_coord: safe 100.000 100.000 100.000
  tight_apr_coord: wsfd  0.010  0.010  0.010

```

14 February 2002

```

tight_apr_coord: yknf 0.010 0.010 0.010
loose_apr_coord: all_ 100. 100. 100.
zenith delays: all_sites 4 PWL
tight_apr_zenith: cato 0.500 0.005 100.0
loose_apr_zenith: cato 0.500 0.005 100.0
tight_apr_zenith: love 0.500 0.005 100.0
loose_apr_zenith: love 0.500 0.005 100.0
tight_apr_zenith: moja 0.500 0.020 100.0
loose_apr_zenith: moja 0.500 0.020 100.0
tight_apr_zenith: pver 0.500 0.020 100.0
loose_apr_zenith: pver 0.500 0.020 100.0
tight_apr_zenith: safe 0.500 0.020 100.0
loose_apr_zenith: safe 0.500 0.020 100.0
tight_apr_zenith: wsfd 0.500 0.020 100.0
loose_apr_zenith: wsfd 0.500 0.020 100.0
tight_apr_zenith: yknf 0.500 0.020 100.0
loose_apr_zenith: yknf 0.500 0.020 100.0
tight_apr_grad: cato 0.030 0.030
loose_apr_grad: cato 0.030 0.030
tight_apr_grad: love 0.030 0.030
loose_apr_grad: love 0.030 0.030
tight_apr_grad: moja 0.030 0.030
loose_apr_grad: moja 0.030 0.030
tight_apr_grad: pver 0.030 0.030
loose_apr_grad: pver 0.030 0.030
tight_apr_grad: safe 0.030 0.030
loose_apr_grad: safe 0.030 0.030
tight_apr_grad: wsfd 0.030 0.030
loose_apr_grad: wsfd 0.030 0.030
tight_apr_grad: yknf 0.030 0.030
loose_apr_grad: yknf 0.030 0.030

* units are ppm for elements, percent for rad parms (The next two lines are truncated here by page width )
tight_apr_orbit: all_ 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E-03 1.E-03 1.E-03 . .
loose_apr_orbit: all_ 10. 10. 10. 10. 10. 10. 1000. 1000. 1000. 1000. 1000. 1000. 1000. . .
exit set:
*
-----Part 4 -- Session Options
set session_1 options:
include: all_sites all_sats
error model
stn_error: all_sites uniform 10. 0.0
sat_error: all_sats 0.0
noise file name:
atmosphere constraint: N
ionosphere constraint: 0.0 1.0
wide lane ambiguity criteria: 0.15 0.15 1000.0 10.00 500.0
pseudorange ambiguity criteria: 0.05 0.05 1000.0
exit set:
*
----- Part 5 -- Solution Options
set tight_free solution option:
print out solution: q-file ofile

```

```

update file option:    m-file l-file g-file
input_m file name:   mventa.278
output_m file name:  mventa.278
input_l file name:   lvent7.278
output_l file name:  lventa.278
coord_upd_tol:       0.03
input_g file name:   gvent7.278
output_g file name:  gventa.278
correl_prt:          0.999900
exit set:
*
set tight_fix solution option:
  print out solution:  q-file ofile
  update file option:  m-file l-file g-file
  input_m file name:   mvent1.278
  output_m file name:  mvent1.278
  input_l file name:   lvent7.278
  output_l file name:  lventa.278
  coord_upd_tol:       0.03
  input_g file name:   gvent7.278
  output_g file name:  gventa.278
  correl_prt:          0.999900
exit set:
set loose_free solution option:
  update file option:
exit set:
set loose_fix solution option:
  print out solution:
exit set:

```

#### 5.4 Evaluating the Solutions

There are two first-order criteria for determining if a solution is acceptable: 1) are there adequate data to perform a reasonable estimate, and 2) do the data fit the model to their noise level. The primary indicator that the first criterion has been met is the magnitude of the uncertainties of the baseline components. If these are larger than you expect with the *a priori* constraints you have applied to station coordinates and orbital parameters, then a quick look in the Q-file or autcln.sum file will usually reveal that large quantities of data have been discarded by AUTCLN. For the second criterion, the primary indicator is the "normalized rms" (nrms) of the solution; i.e., the square root of chi-square per degree of freedom. If the data were randomly distributed and the *a priori* weights were correct, the nrms would be close to unity. In practice with the default weighting scheme, a good solution usually produces a nrms of about 0.25. Anything larger than 0.5 means that there are cycle slips that have not been removed or associated with extra bias parameters (see Sections 2.1 and 6.1), or that there is a serious modeling problem (e.g., bad coordinates of the fixed stations or an unmodeled satellite "burn"). If the final solution of a batch sequence meets these two criteria, there is usually no need to look carefully at any other

output, though rms of (one-way) residuals in autcln.sum.post will tell you the relative quality of stations in your network.

To illustrate the information available from the Q-file, we use as an example an analysis of data obtained with 120s sampling over 8 hrs using TI4100 receivers in a 7-station network in North America on day 278 of 1987. (This is the "standard" example provided in the gamit/example directory; though the results are less accurate than with modern data, we retain it here for consistency.) In this solution the coordinates of three fiducial stations (Palos Verdes, Yellowknife, and Westford) were given *a priori* constraints of 10 mm.

Program SOLVE Version 9.88 99/04/16 09:30:00:00 (SunOS)

SOLVE Run on 1999/ 5/26 15:52: 2  
OWNER: MIT OPERATOR: rwk

Geocentric Coordinates Option

Epoch interval: 1 - 225

Decimation interval: 1

LC solution with ionosphere constraint bias-fixing

Tracking stations:

1	CATO	Castro Peak
2	LOVE	Loma Verde P
3	MOJA	MOJAVE GPS
4	PVER	PVER7268
5	SAFE	San Fernando
6	WSFD	WSFD GPS
7	YKNF	YELLOWKNIF

Satellites observed:

1..	PRN	3
2..	PRN	6
3..	PRN	8
4..	PRN	9
5..	PRN	11
6..	PRN	12
7..	PRN	13

Cutoff elevation angle in SOLVE batch file (degrees):

Station		Cutoff angle
1	CATO Castro Peak	15.00
2	LOVE Loma Verde P	15.00
3	MOJA MOJAVE GPS	15.00
4	PVER PVER7268	15.00
5	SAFE San Fernando	15.00
6	WSFD WSFD GPS	15.00
7	YKNF YELLOWKNIF	15.00

A priori receiver measurement error models and std devs in mm

Station		Model	Std dev	Elev
1	CATO Castro Peak	uniform	10.00	0.00
2	LOVE Loma Verde P	uniform	10.00	0.00
3	MOJA MOJAVE GPS	uniform	10.00	0.00

4	PVER	PVER7268	uniform	10.00	0.00
5	SAFE	San Fernando	uniform	10.00	0.00
6	WSFD	WSFD GPS	uniform	10.00	0.00
7	YKNF	YELLOWKNIF	uniform	10.00	0.00

A priori satellite measurement error std devs in mm

Satellite		Std dev
1	PRN 3	0.00
2	PRN 6	0.00
3	PRN 8	0.00
4	PRN 9	0.00
5	PRN 11	0.00
6	PRN 12	0.00
7	PRN 13	0.00

A priori coordinate errors in meters

Station		Latitude	Longitude	Radius
1	CATO Castro Peak	100.000	100.000	100.000
2	LOVE Loma Verde P	100.000	100.000	100.000
3	MOJA MOJAVE GPS	100.000	100.000	100.000
4	PVER PVER7268	0.010	0.010	0.010
5	SAFE San Fernando	100.000	100.000	100.000
6	WSFD WSFD GPS	0.010	0.010	0.010
7	YKNF YELLOWKNIF	0.010	0.010	0.010

A priori zenith delay Model = PWL

Station		ZEN_APR (m)	ZEN_VAR (m/sqrt(hr))	Correlation time (hrs)	# of delays
1	CATO Castro Peak	0.500	0.005	100.000	4
2	LOVE Loma Verde P	0.500	0.005	100.000	4
3	MOJA MOJAVE GPS	0.500	0.020	100.000	4
4	PVER PVER7268	0.500	0.020	100.000	4
5	SAFE San Fernando	0.500	0.020	100.000	4
6	WSFD WSFD GPS	0.500	0.020	100.000	4
7	YKNF YELLOWKNIF	0.500	0.020	100.000	4

A priori atmospheric gradient error in meters at 10 degrees elevation angle

Station		North-South	East-West
1	CATO Castro Peak	0.01000	0.01000
2	LOVE Loma Verde P	0.01000	0.01000
3	MOJA MOJAVE GPS	0.01000	0.01000
4	PVER PVER7268	0.01000	0.01000
5	SAFE San Fernando	0.01000	0.01000
6	WSFD WSFD GPS	0.01000	0.01000
7	YKNF YELLOWKNIF	0.01000	0.01000

Keplerian a priori orbital errors (dimensionless except semi-major axis (km))

Sat#		Semiaxis	Eccen.	Inclin.	Asc.node	Perigee	M.anom.	rad1	rad2	..	rad9
1	PRN 3	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05
2	PRN 6	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05
3	PRN 8	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05
4	PRN 9	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05
5	PRN 11	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05
6	PRN 12	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05
7	PRN 13	260.0000	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-02	1.0E-05	1.0E-05	..	1.0E-05

```

Apriori SV antenna offset errors (m)
Sat#   dX      dY      dZ
      1      2      3
1      0.100  0.100  0.100
2      0.100  0.100  0.100
3      0.100  0.100  0.100
4      0.100  0.100  0.100
5      0.100  0.100  0.100
6      0.100  0.100  0.100
7      0.100  0.100  0.100

```

```

A priori pole position errors in arcs and arcs/day
Xp      Xp_rate      Yp      Yp_rate
0.003000  0.000100  0.003000  0.000100

```

```

A priori earth rotation errors in sec and sec/day
UT1      UT1_rate
0.000020  0.000100

```

Session 1

Stations used

```

1  2  3  4  5  6  7
Y  Y  Y  Y  Y  Y  Y

```

Satellites used

```

1  2  3  4  5  6  7
Y  Y  Y  Y  Y  Y  Y

```

Assumed ionosphere error

```

constant :      0.0 ppm :      1.00

```

	C-file	Elev	Number of double differences for each satellite PRN						
			Cutoff	3	6	8	9	11	12
OBS	1 CCATO7.278	15.00	142	191	33	199	137	55	191
OBS	2 CLOVE7.278	15.00	291	457	93	420	306	110	391
OBS	3 CMOJA7.278	15.00	220	46	26	26	21	96	207
OBS	4 CPVER7.278	15.00	299	508	112	444	318	110	397
OBS	5 CSAFE7.278	15.00	211	301	48	321	234	55	332
OBS	6 CWSFD7.278	15.00	61	350	126	259	263	35	164
OBS	7 CYKNF7.278	15.00	0	223	68	181	139	35	88

Fix dependent bias param. of index 223

Fix dependent bias param. of index 258

```

Number of good oneway phases:  4240
Number of single differences:    0
Number of double differences:  2335

```

Inspection of the observation summary will reveal whether or not there were adequate data obtained from each of the satellites to determine its orbit. Often there are not from a single session, particularly if it is less than 24 hours long or has only a continental-scale fiducial network. In the example shown, no double differences could be formed with Yellowknife for PRN 3, so that its orbital parameters are poorly determined from the data. The summary of double difference observations is also important because a small number for a given station or satellite may prevent resolution of ambiguities for combinations involving that station or satellite. The message near the end Fix dependent bias parm. means that the

absence of data for certain station/satellite combinations forced SOLVE to "fix" (remove from the solution) one or more ambiguity parameters that it had defined prior to reading in the data. The message is no cause for concern.

The next part of the Q-file begins the display of information associated with ambiguity resolution. The procedure invoked by `Choice of Observable = LC_HELP` is a modification of the one discussed by *Dong and Bock* [1989] (see Chapter 2 for references), the primary differences being the constraint of orbital and station parameters and the simultaneous use of pseudo-ranges in determining the wide-lane biases. This procedure has six steps:

- 1) Use the LC observable to estimate all parameters, including (real-valued) "biases" for each independent double difference combination. This solution becomes the "biases-free" solution recorded in the Q-file.
- 2) Fix all geodetic parameters at the values estimated in step 1), and estimate only the "wide-lane" (L2-L1) biases, this time using the L1 and L2 observations separately with constraints on the ionosphere.
- 3) Using the algorithms described below, fix as many of the wide-lane biases as possible to integer values.
- 4) With the wide-lane biases determined in step 3) held fixed, use the LC observations to estimate geodetic parameters and "narrow-lane" (L1) biases.
- 5) Using algorithms similar to those used in step 3, fix as many of the narrow-lane biases as possible to integer values.
- 6) With the narrow-lane biases determined in step 5) held fixed, use the LC observations to estimate geodetic parameters. This step produces the "biases-fixed" solution recorded in the Q-file.

Each of these steps can be best understood by reference to the Q-file output. If precise P1 and P2 pseudoranges are not available, then the wide-lane ambiguity parameters are separated from ionospheric effects by constraining the differential ionosphere at each epoch. The value of 1 ppm is appropriate for a relatively quiet ionosphere, as might be present in the daytime at mid-solar cycle, or at night near solar maximum (as was the case here). Values of the ionospheric constraint as large as 8 ppm can be effective in resolving wide-lane ambiguities and are realistic for daytime observations near solar maximum. Using the ionospheric constraints and precise pseudoranges, if available, SOLVE estimates real-valued wide-lane ambiguity parameters ("biases"). These parameters are then "fixed" to integer values using the decision function and chi-square search algorithm described by *Dong and Bock*.. The parameters (input or default) and specific algorithm used are echoed in the Q-file:

```
Wide-lane bias-fixing criteria
deviation : 0.15 sigma : 0.15 decision func. : 1000.0 ratio : 10.0

==== estimate and fix wide-lane (L2-L1) ambiguities ====

Algorithm: LC_HELP
```

L2-L1 biases estimated from phases and ionospheric constraint using the decision function and chi-square search. If a bias is not fixed using the decision function and P2 pseudo-range (PR) is available, the PR wide-lane estimate is used with the PR decision function if

$$|\text{PR estimate} - \text{phase estimate}| < 0.4 \text{ cycle}$$

Finally, for biases fixed with the decision function, the PR estimates overrides if PR estimate is a factor of two closer to an integer than the phase estimate. For codeless receivers, half-integer values are allowed.

L1,L2 estimate of biases with 1.0 ppm ionosphere constraint  
All orbit, site and atmosphere parameters forced from LC

Chi2= 0.32487E+05 Normalized rms= 0.26569E+01 parameters= 68

--- bias uncertainties scaled by nrms !

The three decision-function parameters are the deviation from an integer (*cutdev*) and standard deviation (*cutsig*) that define the rounding area described in *Dong and Bock* (Figure 4 and Appendix A). The third parameter (decision function) is the inverse of the probability for making a type 1 error (fixing the ambiguity at the wrong integer value). The decision-function rounding algorithm is sensitive primarily to the value chosen for *cutdev*. Decreasing or increasing it from the default value of 0.15 cycles has the effect of making your resolution of ambiguities more or less conservative. Though the algorithm is less sensitive to *cutsig*, it makes sense to change it to match the value of *cutdev* when specifying these parameters in the *sestbl*. The fourth parameter displayed (*wlrat*) is the cutoff ratio for the chi-square searching algorithm that is invoked after rounding. The current coding of this algorithm ignores correlations among the ambiguity parameters; hence the value of the ratio that represents a significant increase in chi-square is very sensitive to the number of parameters in the solution (i.e., the size of the network). The default value of 10. is moderately conservative for most networks.

If a wide-lane ambiguity is not resolved with the decision function and precise pseudoranges are available, the pseudorange estimate is also used. The criteria for fixing a real-valued estimate to an integer are that the uncertainty (*sigma*) of the estimate be less than 0.15 cycle, that the estimate be within 0.3 cycles or 3-sigma of an integer, whichever is smaller, and that the difference of the pseudorange and phase estimate be less than 0.8 cycles. This last requirement is to guard against a spurious pseudorange estimate that might be fortuitously close to an integer. The pseudorange estimate is allowed to override the decision-function estimate if the former has an uncertainty less than 0.1 cycles and is a factor of two closer to an integer. This situation would occur if a high ionosphere degraded to phase estimate. A warning is printed if both the phase and pseudorange estimates are apparently good but close to different integers.

If you want to give higher priority to the pseudorange estimate, you can specify a slightly different algorithm identified as *LC\_RANGE* in the *sestbl*. input. With this algorithm, the wide-lane bias is fixed from the pseudorange estimate if the deviation is within 0.4 cycle and not greater than 3-sigma. If these criteria are satisfied, no check against the ionosphere-constrained estimate is made. If not, then the decision function is invoked to attempt to resolve the ambiguity.

The uncertainties obtained for the biases in the wide-lane solution are scaled by the nrms (unlike the uncertainties estimated in the complete solutions), so the ability of the decision function to fix the biases is reduced if the ionospheric constraint is too tight. In the example shown, the nrms is 2.66, a reasonable value for moderate ionospheric conditions. On the other hand, if the constraint is too loose, the wide-lane uncertainties will also go up because the estimator will be unable to separate the wide-lane and ionospheric parameters. For receivers that have no P-code range, the widelane ambiguities can assume half-wavelength values, making separation more difficult. The uncertainties from the pseudo-range solution are not influenced by the level of ionospheric error and should be reliable if the pseudorange observations are sufficiently precise (when averaged over the session) and not corrupted by multipath.

Next follows a lengthy summary (truncated in this documentation) of the estimation of the biases from the ionosphere-constrained L1 and L2 observations. In this solution, the station and orbital parameters have been fixed at their values from an LC, biases-free solution which SOLVE has performed but does not write to the Q-file until later. First in the summary are the narrow-lane (L1) biases (designated B1L1), which should theoretically be integers but may not be close to integers in this solution due to ionospheric errors. Following these are the wide-lane (L2-L1) biases (designated B1L21), which because of their larger wavelengths are more likely to be close to integers even in the presence of ionospheric errors. (The B1 in the designation refers to "biases from session 1".) For brevity, we show below only the values for the 19-km baseline between Loma Verde and San Fernando (SAFE) and the 32-km baseline between Castro Peak and San Fernando.

Label (units)	L1,L2 est.	Uncertainty	PR est.	Uncertainty
196*B1L1 LOVE-SAFE	6- 3	31.933	0.037	
197*B1L1 LOVE-SAFE	6- 8	151.945	0.046	
198*B1L1 LOVE-SAFE	6- 9	31.982	0.029	
199*B1L1 LOVE-SAFE	6-11	-6.996	0.029	
200*B1L1 LOVE-SAFE	6-12	31.905	0.044	
201*B1L1 LOVE-SAFE	6-13	0.006	0.031	
202*B1L1 CATO-SAFE	6- 3	11.925	0.038	
203*B1L1 CATO-SAFE	6- 8	66.810	0.049	
204*B1L1 CATO-SAFE	6- 9	11.987	0.030	
205*B1L1 CATO-SAFE	6-11	-4.196	0.030	
206*B1L1 CATO-SAFE	6-12	11.936	0.045	
207*B1L1 CATO-SAFE	6-13	-0.132	0.032	
...				
231*B1L21LOVE-SAFE	6- 3	-4.986	0.053	-5.949 0.123
232*B1L21LOVE-SAFE	6- 8	-34.007	0.065	-34.306 0.163
233*B1L21LOVE-SAFE	6- 9	-5.006	0.040	-5.233 0.127
234*B1L21LOVE-SAFE	6-11	3.005	0.041	2.748 0.130
235*B1L21LOVE-SAFE	6-12	-5.012	0.062	-6.095 0.151
236*B1L21LOVE-SAFE	6-13	0.012	0.044	-0.704 0.123
237*B1L21CATO-SAFE	6- 3	-0.962	0.054	-1.240 0.188
238*B1L21CATO-SAFE	6- 8	-16.014	0.070	-16.751 0.238
239*B1L21CATO-SAFE	6- 9	-0.978	0.042	-1.316 0.174
240*B1L21CATO-SAFE	6-11	0.989	0.043	0.698 0.182
241*B1L21CATO-SAFE	6-12	-0.926	0.063	-1.243 0.202
242*B1L21CATO-SAFE	6-13	-0.006	0.045	-0.428 0.174
Fix No. 234 bias from	3.01	to	3.0	
Fix No. 233 bias from	-5.01	to	-5.0	

```

Fix No. 242 bias from -0.01 to 0.0
Fix No. 240 bias from 0.99 to 1.0
Fix No. 236 bias from 0.01 to 0.0
Fix No. 231 bias from -4.99 to -5.0
Fix No. 245 bias from 6.02 to 6.0
Fix No. 248 bias from 0.01 to 0.0
Fix No. 247 bias from 4.99 to 5.0
Fix No. 232 bias from -34.01 to -34.0
Fix No. 238 bias from -16.00 to -16.0
Fix No. 239 bias from -0.97 to -1.0
Fix No. 235 bias from -5.02 to -5.0
Fix No. 237 bias from -0.96 to -1.0
Fix No. 243 bias from 6.02 to 6.0
Fix No. 246 bias from -1.95 to -2.0
Fix No. 244 bias from 16.05 to 16.0
Fix No. 241 bias from -0.92 to -1.0

```

--- bias uncertainties scaled by nrms!

In the example shown, SOLVE resolved all of the wide-lane ambiguities for LOVE-SAFE (Nos. 231–236) and CATO-SAFE (Nos. 237–242) using the decision function with the ionosphere-constrained phase estimate. In four cases the phase and pseudorange estimates are inconsistent; in each of those the phase estimate was closer to an integer and hence took precedent. The uncertainties in the pseudorange estimates would have been a factor of two smaller had we used 30-s rather than 120-s sampling.

Next in the Q-file is a summary of both the narrow-lane and wide-lane biases after the resolution of as many as possible of the wide-lanes. The narrow-lane bias estimates are slightly changed, and have smaller uncertainties, but will be close to integers in the separate L1 and L2 solution only if ionospheric effects are small (as is in fact the case for this experiment). The main purpose of this summary is to highlight the wide-lane biases that have been fixed at integers and those for regional baselines that remain unresolved. Using this summary and the preceding one, you should evaluate whether or not it may be possible to resolve the remaining (regional) wide-lane ambiguities by changing the ionospheric constraint or editing the data. You can use CVIEW to inspect the residuals for the station-satellite combinations in question to see whether, for example, the departure from an integer is due to an excursion in only part of the pass—in the phase estimate due to the ionosphere or in the pseudo-range estimate due to multipath—in which case you could unweight the offending data. Note that the pseudorange estimate is made using the full one-way span of data for each station and satellite so that multipath corruption of the wide-lane combination may not be visible if you display only double differences in CVIEW. (The use of one-way, rather than doubly differenced pseudorange was instituted to handle the high pseudorange noise of early P-code receivers. Future versions of SOLVE will provide the option of using doubly differenced pseudorange to reduce the influence of receiver range biases and to make the phase and pseudoranges for each double-difference ambiguity parameter consistent.)

== summary of wide-lane biases after fixing ==

Label (units)	L1,L2 est.	Uncertainty	PR est.	Uncertainty
...				
196*B1L1 LOVE-SAFE 6- 3	31.940	0.026		
197*B1L1 LOVE-SAFE 6- 8	151.942	0.033		
198*B1L1 LOVE-SAFE 6- 9	31.979	0.020		
199*B1L1 LOVE-SAFE 6-11	-6.993	0.021		
200*B1L1 LOVE-SAFE 6-12	31.899	0.031		
201*B1L1 LOVE-SAFE 6-13	0.012	0.022		
202*B1L1 CATO-SAFE 6- 3	11.944	0.027		
203*B1L1 CATO-SAFE 6- 8	66.803	0.035		
204*B1L1 CATO-SAFE 6- 9	11.998	0.021		
205*B1L1 CATO-SAFE 6-11	-4.202	0.022		
206*B1L1 CATO-SAFE 6-12	11.973	0.032		
207*B1L1 CATO-SAFE 6-13	-0.135	0.023		
...				
231 B1L21LOVE-SAFE 6- 3	-5.0		-5.949	0.123
232 B1L21LOVE-SAFE 6- 8	-34.0		-34.306	0.163
233 B1L21LOVE-SAFE 6- 9	-5.0		-5.233	0.127
234 B1L21LOVE-SAFE 6-11	3.0		2.748	0.130
235 B1L21LOVE-SAFE 6-12	-5.0		-6.095	0.151
236 B1L21LOVE-SAFE 6-13	0.0		-0.704	0.123
237 B1L21CATO-SAFE 6- 3	-1.0		-1.240	0.188
238 B1L21CATO-SAFE 6- 8	-16.0		-16.751	0.238
239 B1L21CATO-SAFE 6- 9	-1.0		-1.316	0.174
240 B1L21CATO-SAFE 6-11	1.0		0.698	0.182
241 B1L21CATO-SAFE 6-12	-1.0		-1.243	0.202
242 B1L21CATO-SAFE 6-13	0.0		-0.428	0.174

After determining as many as possible of the wide-lane ambiguities, SOLVE fixes these at integer values and performs an LC (ionsphere-free) solution for all of the geodetic parameters and the narrow-lane bias parameters. This solution is identified by the keyword summary preceding it:

```

USER SOLN DIFF PHASE CONSTRAINTS BIASES PARAMETERS H-FILE
KEYS: DEFLT FULL DBLE LC NOION ATM FREE STN ORB ZEN NOCLK GCR

```

Then follows a list of the original X-files and the C-files created by the run, and the data statistics:

```

Ephemeris and survey data files          (qventa.278      1998/ 5/13   9: 9:18)
TVENT7.278      XCATO7.278      CCATO7.278
                  XLOVE7.278      CLOVE7.278
                  XMOJA7.278      CMOJA7.278
                  XPVER7.278      CPVER7.278
                  XSAFE7.278      CSAFE7.278
                  XWSFD7.278      CWSFD7.278
                  XYKNF7.278      CYKNF7.278
MERGE File: mventa.278

```

```

Double-difference observations: 2335
Epoch numbers 1 to 225 Interval: 120 s decimation: 1
Start time: 87 10 5 14 37 59.080

```

```
Total parameters: 265 live parameters: 208
```

```

Prefit nrms: 0.11483E+03 Postfit nrms: 0.29527E+00
-- Uncertainties not scaled by nrms

```

```
Channels used: 1 2 3 4 5 6 7
```

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568 568 311 753 765 338 937

Correlation coefficients greater than 0.999900: None

The predicted postfit nrms for this solution was 0.29, about the level expected for the assigned *a priori* measurement error and the typical performance of the TI4100 receiver. (If the data from each baseline were used independently, then you could use this nrms value, along with the assigned measurement error [nominally 10 mm in L1, implying 64 mm, or 0.3 cycles in LC] to compute the average rms of the residuals; e.g.,  $\sim 0.29 \times 0.3 = 0.09$  cycles [18 mm] in this case. AUTCLN in postfit mode computes the rms values on a station-by-station basis—see Section 6.2.)

Next follows a listing of all the estimated parameters with their adjustments and uncertainties from the bias-free solution. The station coordinates have the form

Label (units)	a priori	Adjust (m)	Formal	Fract	Postfit
1*CATO GEOC LAT (dms)	N33:54:26.75445	-0.0050	0.0127	-0.4	N33:54:26.75429
2*CATO LONG (dms)	W118:47:08.75979	0.0078	0.0266	0.3	W118:47:08.75948
3*CATO RADIUS (km)	6372.2845106000	0.0225	0.0434	0.5	6372.28453315

The parameter adjustments and formal uncertainties are given in units of meters. *Fract* is the adjustment as a fraction of the formal error. Scanning these values in the solution is useful to spot anomalous adjustments and also tells you whether you need to iterate in order to achieve adjustments unaffected by non-linearities in the partial derivatives (see Section 4.2). The uncertainties are the formal errors of the least squares fit based on the assigned data weighting. They have not been scaled by the *a posteriori* variance of unit weight (the nrms) since (temporal) correlations among phase observations usually renders this value unduly optimistic. The uncertainties of the coordinates of station CATO (Castro) with respect to the nearest fixed station (Palos Verdes, 50 km away, in this example) are of order 1-4 cm, acceptable values for a single-session solution with a relatively weak fiducial network (Palos Verdes – Yellowknife – Westford). We should expect from this result that a multi-day solution with phase ambiguities resolved would produce uncertainties of 1 cm or less.

Next are given the adjustments to the atmospheric zenith delays for each station, either a constant over the session or the tabular points of a piecewise linear function. In this example, we are estimating 4 tabular points over the 7.5-hr session, so that the tabular points are 2.5 hr apart. The adjustments in this case are less than 3 cm and less than the uncertainties of 8–12 cm. The O-file includes with the zenith delay estimates the time of each tabular point so that they may be easily plotted.

22*CATO ATMOS- 1 1	2.2123446029	-0.0286	0.0820	-0.3	2.18376533
23*CATO ATMOS- 2 1	2.2123446029	-0.0275	0.0817	-0.3	2.18482288
24*CATO ATMOS- 3 1	2.2123446029	-0.0256	0.0815	-0.3	2.18675445
25*CATO ATMOS- 4 1	2.2123446029	-0.0042	0.1150	0.0	2.20815916

Also listed are the north-south and east-west atmospheric gradients for each station. The units of these are such that they represent the difference between the north-looking and south-looking (or east- and west-) atmospheric delays at 10 degrees elevation angle (see Section 8.4).

```

50*CATO N/S ATMOS GRAD      0.0000000000      0.0019      0.0268      0.1      0.00185385
...
57*CATO E/W ATMOS GRAD      0.0000000000      0.0043      0.0275      0.2      0.00425886

```

In this case the gradients are small compared to their uncertainties and did not need to be estimated.

In the main parameter list, as in the G-file, the orbital elements are given in terms of the Cartesian initial conditions in km and km/s. The adjustments and uncertainties, however, are given in m and m/s for ease of interpretation:

```

85*ORBIT X      km      PN03-13976.9094676840      3.5308      39.6752      0.1      -13976.90593688
86*ORBIT Y      km      PN03 22548.1011499110      9.8227      13.3860      0.7      22548.11097262
87*ORBIT Z      km      PN03 3693.2210527633      -6.6175      41.2866      -0.2      3693.21443523
88*ORBIT Xdot   km/s    PN03 -1.1970220165      -0.0005      0.0073      -0.1      -1.19702249
89*ORBIT Ydot   km/s    PN03 -1.3320686827      0.0018      0.0060      0.3      -1.33206685
90*ORBIT Zdot   km/s    PN03 3.3985770848      -0.0001      0.0020      -0.1      3.39857696
91*RAD PRES DIRECT PN03 1.0000000000      0.0000      0.0000      0.0      1.00000000
92*Y AXIS BIAS  PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
93*B AXIS BIAS  PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
94*COS DIRECT   PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
95*SIN DIRECT   PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
96*COS Y BIAS   PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
97*SIN Y BIAS   PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
98*COS B BIAS   PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000
99*SIN B BIAS   PN03 0.0000000000      0.0000      0.0000      0.0      0.00000000

```

In this example, the initial position for PRN 3 adjusted (from the broadcast orbit) by about 10 m and has an uncertainty of about 50 m. Since Cartesian initial conditions are difficult to interpret, particularly for multi-day arcs, a summary of orbital uncertainties in terms of Keplerian elements is given at the bottom of the Q-file:

Post-fit Keplerian orbital errors in parts in 10\*\*7

	a	e	I	Node	Perigee	M Anom.	w+M
PRN 3	10.665	3.841	10.641	8.898	531.261	547.271	24.331
PRN 6	7.268	4.582	3.660	4.544	464.397	470.174	13.205
PRN 8	7.492	2.385	5.302	4.516	771.625	786.808	18.819
PRN 9	4.748	1.460	2.657	4.325	200.566	205.830	6.432
PRN 11	4.050	1.567	4.521	6.120	161.344	157.834	6.005
PRN 12	20.925	13.281	9.373	13.161	1164.316	1188.594	24.964
PRN 13	6.571	1.795	4.695	4.524	1858.325	1857.855	6.552

This summary shows that the semi-major axes,  $a$ , (representing the orbital period, in accordance with Kepler's third law) is determined with an uncertainties of 1–2 ppm, not unreasonable for the analysis of a single (~5 hr) pass, less than half an orbital period. The orientations of the orbital plane, given by the inclination,  $I$ , and the longitudes of the ascending node, are all determined to about 1 ppm. The next two elements, the argument of perigee and mean anomaly are intrinsically poorly defined for a near-circular orbit; hence, the more meaningful measure of the along-track uncertainty is their sum, indicated here by  $w + M$  (since  $w$  is the usual symbol for argument of perigee). This component is almost always the least well determined, so the uncertainty in  $w + M$  will match closely the largest uncertainty in the Cartesian initial conditions; here the uncertainties are 0.6–2.5 ppm or 15–65 m of position at the GPS orbital radius (26,000 km).

Below the orbital parameters are Earth orientation parameters (EOP)—pole position and UT1 and their rates of change. The units are arc-seconds and arc-second per day. Since we have used data from a weak global network, these parameters have all been constrained tightly to their a priori values, obtained in this case from IERS Bulletin B. With a large global network, all of these can be estimated accurately from GPS observations except for UT1, which is perfectly correlated with the ascending nodes of the satellites.

190*X POLE (arcs)	-0.0558591603	0.0000	0.0030	0.0	-0.05585730
191*X POLE RATE (arcs/d)	-0.0006000000	0.0000	0.0001	0.0	-0.00060000
192*Y POLE (arcs)	0.3016859381	0.0000	0.0030	0.0	0.30169137
193*Y POLE RATE (arcs/d)	0.0013425023	0.0000	0.0001	0.0	0.00134251
194*UT1-TAI (sec)	-23.4900699616	0.0000	0.0000	0.0	-23.49006996
195*UT1-TAI RATE (sec/d)	-0.0016590442	0.0000	0.0001	0.0	-0.00165916

The last group of parameters are the biases, of which we show only the L1 estimates for the two baselines discussed above and for which the widelane biases were resolved.

196*B1L1 LOVE-SAFE 6- 3	0.0000000000	31.8825	0.4043	31.88247512
197*B1L1 LOVE-SAFE 6- 8	0.0000000000	151.9709	0.1379	151.97088168
198*B1L1 LOVE-SAFE 6- 9	0.0000000000	32.0019	0.1557	32.00194728
199*B1L1 LOVE-SAFE 6-11	0.0000000000	-7.0142	0.1227	-7.01419035
200*B1L1 LOVE-SAFE 6-12	0.0000000000	31.9471	0.3680	31.94708296
201*B1L1 LOVE-SAFE 6-13	0.0000000000	-0.0367	0.2209	-0.03666700
202*B1L1 CATO-SAFE 6- 3	0.0000000000	11.7906	0.5686	11.79058587
203*B1L1 CATO-SAFE 6- 8	0.0000000000	66.8599	0.1798	66.85989321
204*B1L1 CATO-SAFE 6- 9	0.0000000000	11.9096	0.1738	11.90961172
205*B1L1 CATO-SAFE 6-11	0.0000000000	-4.1569	0.1845	-4.15694811
206*B1L1 CATO-SAFE 6-12	0.0000000000	11.6759	0.4143	11.67586633
207*B1L1 CATO-SAFE 6-13	0.0000000000	-0.1115	0.2805	-0.11150922

After the summary of parameter estimates SOLVE lists the components of each baseline for the biases-free solution:

Baseline vector (m):	CATO(Site 1) to	SAFE(Site 5)
X 22126.3867 Y(E) 5021.4762 Z 22600.1150	L 32024.3253	
+- 0.0279 +- 0.0351 +- 0.0238 +- 0.0122	(meters)	
correlations (x-y,x-z,y-z) =	0.20228 -0.68451 -0.72699	
N 27155.5488 E 16974.1265 U 112.2888	L 32024.3253	
+- 0.0099 +- 0.0267 +- 0.0420 +- 0.0122	(Meters)	
Correlations (N-E,N-U,E-U) =	-0.51360 -0.12804 0.01121	

Baseline vector (m):	LOVE(Site 2) to	SAFE(Site 5)
X 299.0178 Y(E) -12367.2768 Z -14970.5286	L 19420.4962	
+- 0.0238 +- 0.0313 +- 0.0210 +- 0.0133	(meters)	
correlations (x-y,x-z,y-z) =	0.16977 -0.67687 -0.75822	
N -18401.3186 E 6195.4832 U 403.8989	L 19420.4962	
+- 0.0076 +- 0.0235 +- 0.0371 +- 0.0133	(Meters)	
Correlations (N-E,N-U,E-U) =	-0.60197 -0.13845 0.06462	

The baseline vectors are given both in a geocentric reference frame (XYZ) and in local coordinates (north, east, up) tangent to the reference ellipsoid (changed from spherical with Release 9.92) at the first station of each pair. The sense of the vector is (second station – first station). This presentation of uncertainties is particularly helpful in evaluating the baseline uncertainties for closely spaced stations, neither of which was held fixed in the solution, since in this case the estimates of their coordinates will be highly correlated.

From these estimates, SOLVE then attempts to resolve the narrow-lane ambiguities using first the decision-function criteria for rounding :

```
Narrow-lane bias-fixing criteria: deviation : 0.15  sigma : 0.15
                                decision func. : 1000.0 ratio : 10.0
                                maximum distance : 500.0
```

```
Fix No. 199 bias from -7.01 to -7.0
Fix No. 198 bias from 32.02 to 32.0
Fix No. 201 bias from -0.04 to 0.0
Fix No. 197 bias from 151.97 to 152.0
Fix No. 204 bias from 11.92 to 12.0
Fix No. 205 bias from -4.07 to -4.0
```

In this case, only six of the 12 narrow-lane ambiguities on the two selected baselines were resolved using the decision-function algorithm. The primary reason for this poor performance is the relatively large uncertainties due to the weak fiducial network and large orbital uncertainties. For the ambiguities not resolved by the decision function, SOLVE evaluates the chi-square ratio for a series of solutions generated with different values of the ambiguity parameters, tested five at a time beginning with those with the lowest uncertainties.

```
Lowest chi-squares: 187. 211. 217. 217. 217. 221. 225. 227. 231 234.
(chi2/chi20 - 1.)*sqrt(df): 0.00 5.82 7.20 7.30 7.32 8.37 9.21 9.76 10.72 11.42
```

Parameter biases:

```
196 32.0 32.0 32.0 32.0 32.0 31.0 32.0 33.0 32.0 32.0
200 32.0 32.0 32.0 31.0 33.0 32.0 32.0 32.0 32.0 32.0
203 67.0 67.0 66.0 67.0 67.0 67.0 67.0 67.0 67.0 67.0
207 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 -1.0
210 -26.0 -27.0 -26.0 -26.0 -26.0 -26.0 -26.0 -26.0 -25.0 -26.0
```

In this set of test solutions, none of the bias parameters has the same value for all combinations producing a chi-square ratio less than the specified input value (10.0); hence, no additional ambiguities are resolved.

The last section of the Q-file gives the estimates of all of the geodetic parameters from an LC solution in which the resolved wide-lane and narrow-lane bias parameters are held fixed at integer values. Again we list only the estimates for our two sample baselines:

```
USER SOLN DIFF PHASE CONSTRAINTS BIASES PARAMETERS H-FILE
KEYS: DEFLT FULL DBLE LC NOION ATM FIXED STN ORB ZEN NOCLK GCX
```

```
Total parameters: 265 live parameters: 202
Prefit nrms: 0.11467E+03 Postfit nrms: 0.29555E+00
```

Label (units)	a priori	Adjust (m)	Formal	Fract	Postfit
1*CATO GEOC LAT (dms)	N33:54:26.75445	-0.0031	0.0120	-0.3	N33:54:26.75435
2*CATO LONG (dms)	W118:47:08.75979	0.0034	0.0236	0.1	W118:47:08.75966
3*CATO RADIUS (km)	6372.2845106000	0.0239	0.0431	0.6	6372.28453448
4*LOVE GEOC LAT (dms)	N34:19:00.91886	-0.0019	0.0122	-0.2	N34:19:00.91880
5*LOVE LONG (dms)	W118:40:07.17484	-0.0097	0.0278	-0.3	W118:40:07.17522
6*LOVE RADIUS (km)	6372.0437766000	0.0363	0.0408	0.9	6372.04381294
...					
196*B1L1 LOVE-SAFE 6- 3	0.0000000000	31.9798	0.1791		31.97982595
197 B1L1 LOVE-SAFE 6- 8	0.0000000000	152.0000			

```

198 B1L1 LOVE-SAFE 6- 9 0.0000000000 32.0000
199 B1L1 LOVE-SAFE 6-11 0.0000000000 -7.0000
200*B1L1 LOVE-SAFE 6-12 0.0000000000 32.0096 0.1921 32.00959292
201 B1L1 LOVE-SAFE 6-13 0.0000000000 0.0000
202*B1L1 CATO-SAFE 6- 3 0.0000000000 11.9340 0.3684 11.93399708
203*B1L1 CATO-SAFE 6- 8 0.0000000000 66.9070 0.1686 66.90696645
204 B1L1 CATO-SAFE 6- 9 0.0000000000 12.0000
205 B1L1 CATO-SAFE 6-11 0.0000000000 -4.0000
206*B1L1 CATO-SAFE 6-12 0.0000000000 11.7622 0.2186 11.76219392
207*B1L1 CATO-SAFE 6-13 0.0000000000 0.0222 0.1654 0.02221374
...
Baseline vector (m) :          CATO(Site 1) to          SAFE(Site 5)
X  22126.3909 Y(E)  5021.4656 Z  22600.1115 L  32024.3240
+- 0.0201 +- 0.0312 +- 0.0232 +- 0.0073 (meters)
correlations (x-y,x-z,y-z) = 0.71316 -0.83524 -0.92637
N  27155.5418 E  16974.1353 U  112.2929 L  32024.3240
+- 0.0057 +- 0.0126 +- 0.0415 +- 0.0073 (Meters)
Correlations (N-E,N-U,E-U) = -0.21910 -0.09942 -0.01708

Baseline vector (m) :          LOVE(Site 2) to          SAFE(Site 5)
X   299.0201 Y(E) -12367.2820 Z -14970.5286 L  19420.4995
+- 0.0168 +- 0.0275 +- 0.0206 +- 0.0068 (meters)
correlations (x-y,x-z,y-z) = 0.74743 -0.85979 -0.92168
N -18401.3206 E   6195.4877 U   403.9018 L  19420.4995
+- 0.0053 +- 0.0100 +- 0.0366 +- 0.0068 (Meters)
Correlations (N-E,N-U,E-U) = -0.30682 -0.09924 0.01790

```

You'll note that resolving ambiguities for these two baselines improved the uncertainties in the horizontal components by up to a factor of two. An important check on whether the phase ambiguities have been resolved correctly may be obtained by comparing the biases-free and biases-fixed estimates of the baseline vectors. In this example the biases-free and biases-fixed estimates from the two solutions agree for all components within the (larger) biases-free uncertainties.

After SOLVE has completed the biases-fixed solution, it repeats both the biases-free and biases-fixed solutions with very loose constraints on all of the parameters in order to obtain an unbiased set of adjustments and covariance matrix for input to GLOBK. These two solutions are saved in the H-file. The details of the loosely constrained solution are written to the screen or log file but not saved in the Q-file. The Q-file does record, however, the station, zenith-delay, and orbital constraints used and the normalized rms for the biases-free and biases-fixed solutions:

Loose constraints. All solutions and covariance matrix are stored in H-file.

A priori coordinate errors in kilometers

			Latitude	Longitude	Radius
1	CATO	Castro Peak	0.10000	0.10000	0.10000
2	LOVE	Loma Verde P	0.10000	0.10000	0.10000
3	MOJA	MOJAVE GPS	0.10000	0.10000	0.10000
4	PVER	PVER7268	0.10000	0.10000	0.10000
5	SAFE	San Fernando	0.10000	0.10000	0.10000
6	WSFD	WSFD GPS	0.10000	0.10000	0.10000
7	YKNF	YELLOWKNIF	0.10000	0.10000	0.10000

Keplerian a priori orbital errors (dimensionless except semi-major axis (km))

Sat#	Semiaxis	Eccen.	Inclin.	Asc.node	Perigee	M.anom.	rad1	rad2	.. rad9
1 PRN 3	0.2600	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E+01	1.0E+01	.. 1.0E+01
2 PRN 6	0.2600	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E+01	1.0E+01	.. 1.0E+01

```

3 PRN 8 0.2600 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E+01 1.0E+01 .. 1.0E+01
4 PRN 9 0.2600 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E+01 1.0E+01 .. 1.0E+01
5 PRN 11 0.2600 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E+01 1.0E+01 .. 1.0E+01
6 PRN 12 0.2600 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E+01 1.0E+01 .. 1.0E+01
7 PRN 13 0.2600 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E-05 1.0E+01 1.0E+01 .. 1.0E+01

```

A priori zenith-delay errors in meters

1	CATO	Castro Peak	0.500	0.005	100.000
2	LOVE	Loma Verde P	0.500	0.005	100.000
3	MOJA	MOJAVE GPS	0.500	0.020	100.000
4	PVER	PVER7268	0.500	0.020	100.000
5	SAFE	San Fernando	0.500	0.020	100.000
6	WSFD	WSFD GPS	0.500	0.020	100.000
7	YKNF	YELLOWKNIF	0.500	0.020	100.000

A priori pole position errors in arcs and arcs/day

Xp	Xp_rate	Yp	Yp_rate
3.000	0.300	3.000	0.300

A priori earth rotation errors in sec and sec/day

ut1	ut1_rate
3.000	0.300

A priori atmospheric gradient error in meters at 10 degrees elevation angle

Station	North-South	East-West
1 CATO Castro Peak	0.01000	0.01000
2 LOVE Loma Verde P	0.01000	0.01000
3 MOJA MOJAVE GPS	0.01000	0.01000
4 PVER PVER7268	0.01000	0.01000
5 SAFE San Fernando	0.01000	0.01000
6 WSFD WSFD GPS	0.01000	0.01000
7 YKNF YELLOWKNIF	0.01000	0.01000

```

Total parameters: 265 live parameters: 207
Prefit nrms: 0.11480E+03 Postfit nrms: 0.29258E+00

```

```

Total parameters: 265 live parameters: 202
Prefit nrms: 0.11467E+03 Postfit nrms: 0.29274E+00

```

Normal stop in SOLVE

## 5.5 Multi-session Solutions

The capability to perform multi-session solutions in GAMIT was developed to enhance ambiguity resolution by combining the information from multiple days or networks at a time when continental- or global-scale tracking networks were capable of determining orbits only at the level of 50–100 ppb (see, e.g., *Dong and Bock [1989]*). The multi-session feature is seldom used today and may not work properly with recent program enhancements. Resolution of ambiguities for a regional network can almost always be accomplished today using a single session in conjunction with tight constraints on orbits obtained from global tracking. Once ambiguities are resolved, GAMIT will loosen the constraints and create an H-file that can be combined in GLOBK with H-files from a global solution and from regional solutions for other sessions (days). This process might involve some iteration: resolution of ambiguities in GAMIT can be enhanced by putting tight (but realistic) constraints on the station coordinates and orbital parameters from a previous GLOBK solution which was performed using the "biases-free" output of GAMIT.

If a multi-session GAMIT run is necessary, some thought should be given to file naming and the organization of the data. The current restriction of X- and C-files to 9 characters limits the analyst's ability to differentiate between sessions within the same day. This problem can be avoided in preparation and cleaning of the data by using separate directories for each session. When finally combining the clean data in a multi-session solution, you can then rename the X- (or C-files) so that the 6th character is different ("a" for "am" and "p" for "pm" is one such scheme). It is also usually convenient to run the multi-session solutions in a new directory, with links made to the input X- (or C-) files in the original session directories.

## 6. Data Editing

### 6.1 Introduction

Continuously tracked, doubly differenced carrier phase observations provide an extraordinarily precise data set for estimating GPS orbital parameters and relative site positions; but the strength of the data can be realized only if it is edited properly to be free of cycle slips within each tracking session. Sometimes this is impossible, and we are forced to introduce additional "bias" (offset) parameters that effectively break the phase data into shorter and thus weaker segments. The goal of the analyst (and/or the analysis software) is to remove cycle slips while introducing as few additional parameters as possible. Too many additional bias parameters weakens the solution, but residual cycle slips not absorbed by bias parameters produce erroneous estimates of the important geodetic parameters. To put the problem in perspective, recall that the most common slip in the ionosphere-free linear combination (LC), corresponding to one-cycle slips in L1 and L2, is 0.52 cycles, or 10 cm in equivalent pathlength. Since our usual goal is few-*millimeter* estimates of station positions, a single undetected slip can be (but not always is) quite serious.

Strictly speaking, we require only that all cycle slips be fixed (or covered by bias parameters) in the *doubly differenced* phases since those are the data used by SOLVE in its estimation. As a practical matter, however, the editing process is much simpler if cycle slips can be identified and repaired in the data from a single station and satellite. This "one-way" observable is dominated by variations in the station and satellite oscillators ("clocks"), which must be removed in the editing process. Analysis programs use two approaches to accomplish this task. With modern receivers the pseudoranges at both the L1 and L2 frequencies can be combined with the phases to produce a "wide-lane" observable that is free of both oscillator and ionospheric effects (see the paper by *Blewitt* [1990] referenced in Chapter 2). This approach breaks down when the pseudoranges are noisy (from multipath or a poorly functioning receiver) and for equal slips in the L1 and L2 phases, which show no break in the wide-lane. A second approach, used in conjunction with the widelane, determines the source and size of a cycle slip by comparing a number of double difference combinations.

With the large number of satellites and stations now used in most surveys, automatic editing is essential for the sanity of the analyst. Fortunately, AUTCLN, the automatic editor developed by Tom Herring, has reached a level of maturity that it can handle both regional and global networks with only occasional manual intervention. In its postfit mode it can remove clock effects and provide reliable statistics for the performance of each station. The key to efficient processing is learning to use the outputs of SOLVE, AUTCLN, and the scanning routines to determine quickly if a problem exists, and then to use the interactive editor, CVIEW, together with AUTCLN to perform an effective fix. In

the next three sections we describe the most important features of these programs and how to run them. Then in Section 6.5, we discuss efficient strategies for editing.

## 6.2 Automatic editing using AUTCLN

AUTCLN uses the residuals written to the C-file by MODEL, performs automatic editing, and writes an output C-file with outliers removed, cycle-slips repaired, and extra bias flags inserted for slips that cannot be reliably repaired. A new feature in AUTCLN 3.0 estimates station and satellite oscillator variations ("phase clocks") and allows reading of an M-file updated by SOLVE so that editing can be performed on (one-way) predicted postfit residuals (see the formula in Section 6.4). AUTCLN is invoked with four command-line arguments:

```
autcln [ command-file ] [ out C-file series ] [ D-file ] [ input C-file series ]
      or [ list of C-files ]
```

The first argument gives the AUTCLN command-file name. The command file can be omitted by substituting ' ' for the file name, and AUTCLN will use the default values for all parameters. For a GAMIT batch run, FIXDRV invokes the script `sh_autedit` which will always create a command file of the name `autcln.cmd.prefit`, even if there is no "base" command file present, and optionally a command file of the name `autcln.cmd.postfit`. The second command-line argument is a single character used to determine the name(s) of the output C-files. If an alphameric character is given (e.g., `a`), then the output C-file names will be the same as the input but with this character substituted for the 6th character of the input series (usually the last digit of the year or a letter). Two special characters are used: `.` to keep the same 6th character as the input files, overwriting the input files; `+` to create new files with the 6th character incremented (i.e., `[ yr ] => a, a => b`). If no character is given (i.e., ' ' used), then no updated C-files will be written. The input C-files are specified either by a D-file name followed by a character indicating the series (6th character of name), or by a complete list of the C-files to be used. FIXDRV creates one of two forms of the AUTCLN command-line:

```
autcln autcln.cmd.prefit . dvent7.278 7
```

if the input C-files are to be deleted (overwritten and then incremented using the `mvcf` script), or

```
autcln autcln.cmd.prefit + dvent7.278 7
```

if the old C-files are to be retained.

The following is a sample autcln.cmd file, listing the options most often invoked. This example is kept current in pub/gps/updates/templates in the GAMIT/GLOBK ftp directory.

```

* Command file for AUTCLN version 3.125 to be used for global and regional data
* Default values are listed with comment flag (non-blank first character)
* Last edited by tah/rwk/scm 000928

* Don't use any GAMIT edits
  use_gamit no

* Remove more bias flags by allowing a base satellite if multiple slips
  allow_one_bg yes

* Set minimum elevation for editing and output: 15 10 better for older receivers
* also sets minimum SNR
  site_param all 10 10 0 0

* Set the ionospheric tolerances so you don't throw out too much data.
* These are the current defaults and will work under both low and high
* ionospheric conditions with well-behaved receivers. For poorly tracking
* receivers and low ionosphere, you can improve the editing using
* 240 4 0.3 0.8.
* ion_jump all 30 6 2 5

* Criteria for detecting slips (initial bias flags). Defaults shown.
* First three are for WL, irrelevant for codeless L2 receivers
* Second three (LC) might be set tighter (e.g. 4 0.2 0.5) to catch
* partial-cycle jumps with poorly performing receivers
* dd_fit_tol 5 2 10 3 0.35 0.8

* The following three commands control the repair of cycle slips and subsequent
* removed of bias flags. The default values are conservative in the sense
* that they retain the most data. They are optimal for global networks but
* will work ok also for regional networks. However, for better ambiguity
* resolution in regional networks, different values are optimal.
*
* Set the tolerances used in trimming the one-way data to remove small
* segments between bias flags. The following are defaults:
* trim_oneway 120 8 0.1 24
* For regional networks use
* trim_oneway 1000 10 0.2 50
* The first two parameters are the minimum times in seconds and minimum
* epochs for attempting to remove a bias flag; the last two are the minimum
* fraction of total span and minimum number of epochs allowed after last bias
* flag. To strengthen ambiguity resolution for regional data, increase the
* last two parameters. For fewer bias flags in 24-hr data increase the first
* two parameters.
*
* Number of data used to repair cycle slips. Defaults are ok for all data but
* all values could be reduced for data sampled less often than 30s.
* dd_return_site 100 50 10 10
*

```

```

* DD criteria for removing bias flags: chi-sq ratio  chi-sq min  max gap  gap scale
* For global networks use
*   remove_bias 10  3  1800  5
* For regional networks use
*   remove_bias 10  3  3600  5
* For fewer flags but more risk over small gaps, decrease the first value (see
* autcln.out).  For fewer flags and more risk over large gaps, increase the
* third and decrease the fourth,

* Maximum number of bias flags per SV before deleting all the data.
* Default infinite (not checked).
  max_scan_edit  30

* To enhance numerical stability in SOLVE (but be careful in interpreting
* one-way residuals)
  apply_phs_clk 1

* Set the summary filename to agree with the command file produced by FIXDRV
  summary autcln.prefit.sum

* Commands to be used if post-fit editing invoked in the sestbl.
POST  summary  autcln.post.sum
POST  apply_phs_clk 30
POST  use_postfit
POST  postfit_edit 10 4.0
* Remove biases in one-ways after postfit edit
POST  pf_remove_bf
* Possibly allow patching over larger gaps
* POST  remove_bias 10  3  3600  2
* Output phase residuals for sky plots
POST  phs_res_root DPH

* Explicit edits added by sh_autedit or the analyst
x edit_site_sv algo 0 1 2800
x edit_site_sv all 23 1 400
x edit_site_sv trom 15 451 460

```

The first command (`use_gamit no`) tells AUTCLN to ignore any loss-of-lock indicators inserted by the receivers. Selecting this option is a change from past practice, made necessary by the large number of bogus slips flagged by some receivers.

The second command (`allow_one_bg`) deals with the case where all channels of a receiver slip at nearly the same time, preventing AUTCLN from patching unambiguously in the one-way observations. By specifying `yes` to this command, you allow AUTCLN to select one channel (satellite) as 'base', patch it roughly in one-ways, and then patch all other channels with respect to it. Since this option applies only to multiple-satellite slips, not multiple-station slips, allowing the patch will not create problems if the data are later combined in a different network configuration. The default for this command is `no`, but

`yes` will usually provide better editing. Occasionally, however, AUTCLN will make a mistake in using this mode (`yes`) when the slips are at slightly different epochs.

The next command sets the minimum elevation angles for AUTCLN to examine (first value) and retain (second value) the data. Additional commands, with `all` replaced by the station code, can be added to raise the cutoff for poorly functioning receivers or lower it for modern receivers in cases where you want to examine very low elevation data.

The next four commands control the removal of bad data. The `ion_jump` criteria are applied to the undifferenced ("one-way") LG observations in attempting to detect noise from bad receiver performance. The thresholds must be set high enough so that LG noise from high ionospheric fluctuations is not confused with receiver noise. The default values (shown) are set high enough that the ionosphere does not trigger rejection even for polar and equatorial stations near solar maximum, and thus they provide only a loose filter for bad data. If you need a tighter filter to detect problems with older receivers tracking in mid-latitude regions, you may reset the the `ion_jump` parameters to `[station] 240 4 0.3 0.8`.

If you find from CVIEW or your scan output that AUTCLN is failing to detect some cycle slips, then you should alter the parameters of the `dd_fit_tol` command. The first three (`5 2 10`) apply to the widelane (WL) observable and are thus relevant only for P-code receivers; the second three (`3 0.35 0.8`) apply to the doubly differenced LC observable. They specify, respectively, the ratio of an allowed jump to the rms of the segment of data being examined, the minimum value of a jump that will be flagged, and the maximum value above which all jumps will be flagged. The tolerance of the maximum jump allowed without incurring a bias flag will fall between the minimum and maximum specified with the intermediate values set by the ratio times the local rms. Thus the default values for LC allow for a maximum jump between 0.35 and 0.8 cycles. Values this high imply that the receiver is not likely to allow one-cycle slips in L1 and L2 (leading to 0.5 in LC). To detect these small slips, which often occur in older receivers, you should reset the LC values to `4 0.2 0.5`.

The `trim_oneway` command is used to remove small segments of data that may encumber the repair of cycle slips or the resolution of the overall phase ambiguity. The first two values (`120 8`) are the minimum time in seconds and the minimum number of epochs between bias flags. If you find segments (using CVIEW) for which a single gap of, for example, 5 or 10 minutes would result in a more reliable cycle slip repair than would multiple smaller gaps, then you should increase these values. The second two values (`0.1 24`) are the minimum fraction of the total span and the minimum number of epochs allowed after the last bias flag. Since SOLVE attempts to resolve the ambiguity using only the last segment of data, removing even a fairly long but noisy segment of data at the end

may result in lower parameter uncertainties by allowing resolution of additional ambiguities.

The next group of entries control the repairing of cycle slips and subsequent removal of bias flags. They provide your primary control for the final stage of editing. The `dd_return_size` command sets the number of data used on each side in the repair; the default values (100 50 10) imply segments of 50 minutes, 25 minutes, and 5 minutes for one-way WL and doubly differenced LC and LG, respectively, for data sampled at 30s intervals. For 120s sampling you probably want to reduce these values by factors of 2 to 4. The `remove_bias` command sets the actual criteria used to remove a bias flag. The algorithm uses a comparison of the chi-square for the data segment (set by `dd_return_size`) for the "best" choice of integer with the chi-square for the next best choice. The first value ( 10 ) gives the threshold ratio and the second ( 3 ) a minimum value used to make the comparison more robust (see the description of the command in Section 7.6). Increasing the first value provides a more conservative edit (fewer bias flags removed), and decreasing it a more aggressive one. The last two values control how large gaps are treated. The third ( 3600 seconds ) sets the maximum gap for which a bias flag will be removed; the fourth ( 5.0 ) is a "gap factor" that scales the computed chi-square such that it becomes harder to remove a bias flag for large gaps (see the exact definition in Section 7.6). In Section 7.6 we describe how you can use the AUTCLN output to determine why a bias flag was inconveniently or improperly left or removed and how you can tune the `remove_bias` values to change the action.

The `max_scan_edit` command sets limit on the number of bias flags added to the data for a particular station and satellite before AUTCLN decides it would be better off deleting all of the data from that combination.

The `apply_phs_clk` command invokes estimation of satellite and station oscillator variations epoch by epoch. Its primary use in AUTCLN is in 'postfit' mode (see below), in which the adjustments from SOLVE are used to flatten the residuals on which AUTCLN works to repair cycle slips. The phase-clock estimation is performed iteratively, with the argument of the command indicating how many iterations may be performed. A dozen or more iterations may be necessary to get a good estimate, but if you are not invoking postfit editing, you should use `apply_phs_clk` with a single iteration, which will serve to remove large jumps the data that often create numerical problems in SOLVE. Keep in mind, however, when you use `apply_phs_clk` with only one iteration that errors in the clock estimates will produce artifacts (fractional-cycle jumps) in the one-way (undifferenced) phase residuals in CVIEW. These cancel in double differences and of course are no more a problem than the much greater clock noise present when you do not remove part of the clock terms at all—it's just that in the latter case the one-way residuals are so large (> 100 cycles) that you don't expect to use them for editing. (Note that the default number of

iterations for `apply_phs_clk` is 30, appropriate for post-fit editing, so the `1` is required if you want to save computation time in the pre-fit mode.)

Finally in this section we have an explicit entry for the AUTCLN summary file (discussed below). This assures that the pre-fit and post-fit summaries will be saved with different file names.

As discussed in Section 5.2, we now recommend using the `postfit` feature of AUTCLN even though this will increase computation time by 30 to 80% and the `postfit` AUTCLN will occasionally fail with bad data. The situations most likely to be helped are the recovery of low-elevation data for estimating atmospheric parameters and the need to detect and remove data affected by systematic, low-amplitude errors resulting from poorly modeled satellite yaw, multipathing, or severe short-period tropospheric water vapor. Equally important, however, is the ability to examine one-way residuals (in the `autcln.sum` file and with `CVIEW`) generated by `apply_phs_clk` and `use_postfit` to study the performance of stations at all levels of quality and to isolate a problem station or satellite when the pre-fit edit has failed to produce satisfactory results. There are two new controls in `postfit` mode. The command `postfit_edit` allows removal of data based on its deviation from the mean of the series, rather than just point to point changes. The first argument indicates at what iteration you want AUTCLN to start this process, the second the sigma criterion to apply, and the third the maximum residual (in cycles) for which a data point can be restored if it was previously removed because it was close to a bias flag. The defaults are to start editing at the 10th iteration, to use a 4-sigma criterion, and not to restore any previously deleted data. The command `pf_remove_bf` allows AUTCLN to remove bias flags in one-way residuals after editing. It is reasonable to forego the threshold editing (to avoid lopping the tops off large oscillations) but still invoke `postfit` bias-flag removal.

The final set of commands in the example, `edit_site_sv`, allow you to control the results by asking AUTCLN explicitly to delete (unweight) certain segments of data that you have identified by `CVIEW` to be problematic or have determined from other information (station or satellite logs) should be ignored. The first argument is the station 4-character code, or `all`; the second is the satellite PRN number, with `0` signifying all satellites; the third and fourth are the range of epochs over which data should be unweighted. The shell command `sh_audit` written into the batch file by `FIXDRV` creates additional `edit_site_sv` commands for `autcln.cmd.pre` and `autcln.cmd.post` in response to `sestbl.` entries controlling the use of data during and after satellite eclipses.

Other entries in the `autcln.cmd` file are described in Section 7.6. Note in particular the commands which allow you to use flags inserted by `CVIEW` (`use_cvview_edit`), control the tolerance for clock resets (`clk_reset_tol`), specify station-specific editing (`site_params`), and remove extra bias flags at the beginning of a station-satellite data segment (`remove_first_bi`).

AUTCLN produces two output files which are quite useful for diagnosing problems. Usually you will need to examine only the summary file, `autcln.sum`. The first two tables provide a compact indication of whether one or more stations or satellites are anomalous. The first is a summary of the clock behavior :

```

Clock and Range noise statistics at iteration 3
Site/PRN      Allan SD@100 #      Range rms      #
              sec  (ppb)          (mm)
BRLD          19.761493  2832          596.9  16210 TRM
KAIN          19.931665  2879          675.1  15939 TRM
KIT3          .527232     2879          729.9  16307 TRB
KUM6          10.105467   719           2061.0  3462 TRM
. . .
PRN_01        .384611     1188
PRN_02        .411166     1039
PRN_05        .422517     984

```

The Allen standard deviation at 100s is given (in parts per billion) for each station and satellite. Station clock values in excess of 50 ppb (5 parts in 10<sup>8</sup>) indicate variations larger than those expected for well-tuned crystal oscillators in any of the commonly used receivers. Atomic oscillators (Rubidium, Cesium, or Hydrogen-maser) should show values below 1 ppb. A bad clock does not necessarily mean bad phase data but increases the chances of cycle slips and degrades the ability of AUTCLN to perform a proper edit. The fourth column gives the rms of range noise in millimeters for each station. For P-code receivers under non-AS conditions, these values should be under a meter; under AS, some will increase to 1000–2000 mm. Values larger than this usually mean lots of bad range data or bad prefit residuals (station coordinate errors > 10 m). The 3rd and 5th columns of the list are simply the number (#) of observations used in the calculation.

Following the clock summary is a listing of the number of bias flags added during the initial double-difference scan:

```

DDScan bias flags added report for pass 1
SITE PN01 02 05 06 07 09 14 15 16 22 23 24 25 26 27 28 29 31
BRLD 6 2 10 8 14 18 6 4 10 6 4 12 7 0 2 2 0 0
KAIN 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0
KIT3 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0
KUM6 0 2 0 0 2 4 0 0 0 0 0 2 0 0 0 0 0 0
KUMB 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0
LHAS 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1

```

In this example station BRLD is performing poorly relative to the others but may not have fatal errors. Many bias flags added can mean either bad prefit residuals or bad phase data. Too many flags for a satellite at more than one station usually represents the effect of an unmodeled acceleration of the satellite (e.g., unmodeled thrusting).

If you have selected postfit editing in AUTCLN, the next four tables give the actual postfit phase statistics for each station and satellite after correcting the residuals for adjustments in

the parameters (using the M-file from the first SOLVE solution) and estimating station and satellite clocks epoch-by-epoch from the phases. The most useful of the tables is the first, containing the rms scatter of the one-way residuals:

```
ONE-WAY POSTFIT RESIDUAL STATISTICS: Pass 20
-----
RMS by site and satellite (mm): Pass 20
RMS IT Site All 01 02 03 04 05 06 07 09 10 14 15 16 17 18 19 21 22 ...31
RMS 20 IISC 5.9 6 5 7 6 6 5 5 6 4 6 8 6 5 6 6 6 5 ... 6
RMS 20 KIT3 4.9 4 4 5 5 6 4 5 5 5 4 6 5 4 5 4 5 4 ... 5
RMS 20 LHAS 4.6 4 4 5 4 7 5 3 6 3 6 5 6 3 5 4 4 4 ... 5
RMS 20 NAGA 6.0 5 6 6 8 6 5 5 6 6 6 6 7 6 6 6 5 7 ... 5
RMS 20 NAMC 3.5 3 3 4 3 0 0 3 4 0 4 4 4 4 3 4 3 4 ... 4
RMS 20 SHAO 3.9 4 4 3 3 4 5 4 4 4 5 4 4 4 4 4 4 4 ... 4
RMS 20 TAIW 4.2 4 4 4 3 5 5 4 4 4 5 4 4 4 4 4 5 4 ... 4
RMS 20 TSKB 3.9 4 5 4 3 4 5 3 3 3 3 3 4 4 4 4 4 4 ... 3
RMS 20 USUD 3.7 4 5 4 3 3 4 3 3 3 4 3 3 3 4 4 4 4 ... 4
RMS 20 ALL 4.6 4 5 5 5 5 5 5 4 5 4 5 5 5 4 5 5 5 ... 4
```

From this table you can see at a glance if there is a station or satellite whose residuals are significantly higher than the others. Values between 3 and 5 mm for "clean" stations, and 6 and 10 mm for stations with larger than average multipath are typical. Values larger than this suggest a problem that may affect your solution. Since the calculation of one-way residuals requires explicit estimation of the station clock, it is possible that this calculation in AUTCLN will fail even though you have obtained a good solution in SOLVE using double differences. In this case, the values in the table will be large, most likely overflowing their field (\*\*\*\*\*). The cause is almost always bad ranges near the beginning of a satellite's pass, when AUTCLN needs these to obtain an initial estimate of the phase clocks. You can identify the culprit station by `grep`'ing on 'JMP BIAS' in the `autcln.out` file:

```
JMP BIAS flag added at 1770 Site BRLD PRN 22          90744182.40    1000.0
...
Updating at 1771 site BRLD PRN 04 cycles by 113430205.0 88387170.0 Pass 1
...
JMP BIAS flag added at 1771 Site BRLD PRN 06          75620154.59    1000.0
JMP BIAS flag added at 1771 Site BRLD PRN 22          75620154.59    1000.0
```

There will always be some messages of this type in the file, and most of the time AUTCLN has handled the clock jump correctly. However, if you see a string of these messages together, associated with several satellites or stations and with very large values, this is a good indication that AUTCLN has miscalculated the clock at an epoch just prior to the ones shown. You can identify the problem by displaying the wide lanes in CVIEW, and fix it by adding explicit edits to `autcln.cmd` using the `edit_site_sv` command. The other three tables associated with postfit editing are described in Section 7.6.

In addition to the rms (RMS) statistics, there are also tables of the mean (AVG) and 25-point-averaged rms (AMS) values, and the rms as a function of elevation angle. The AMS table also includes the ratio of the 25-point average rms to the single-point rms (RMS) and is useful for

determining whether the scatter is dominated by random, short-term noise or long-period variations. Random variations should be reduced by a factor of 5.0; typical values are between 1.5 and 2.0; values near 1.0 indicate a stronger-than-usual dominance of long-period variations.

RMS of 25-point averages by site and satellite (mm): Pass 20

AMS	IT Site	All Ratio	01	02	03	04	05	06	07	09	10	14	15	16	17	18	19	21	22	...	31
AMS	20 IISC	3.3 1.77	4	2	4	4	3	3	3	4	2	4	5	3	2	3	3	3	2	...	2
AMS	20 KIT3	2.8 1.70	2	3	2	4	5	2	4	2	4	3	3	3	2	3	2	3	2	...	3
AMS	20 LHAS	2.6 1.76	2	2	3	2	4	1	2	2	2	4	3	3	1	3	2	3	2	...	2
AMS	20 NAGA	4.3 1.39	3	5	4	7	2	4	3	4	4	3	4	5	4	5	5	3	5	...	3
AMS	20 NAMC	2.0 1.74	1	2	2	2	0	0	2	2	0	1	2	2	2	2	2	3	2	...	2
AMS	20 SHAO	2.3 1.67	3	2	2	2	2	3	2	2	3	3	3	2	2	2	2	2	3	...	2
AMS	20 TAIW	2.6 1.59	2	3	3	2	3	2	2	2	2	3	3	2	2	2	2	4	3	...	2
AMS	20 TSKB	2.2 1.74	2	3	3	2	2	3	2	2	2	2	2	2	2	2	1	2	3	...	2
AMS	20 USUD	2.2 1.70	2	3	2	2	2	3	2	1	2	2	2	1	1	1	2	2	3	...	3

The table of rms as a function of elevation angle will also always show that the scatter is higher at low elevations, but since almost all error sources (orbital errors as well as multipath and tropospheric effects) show this pattern, you should view the phase residual plots (DPHS) and make careful comparisons between stations and between successive days before drawing conclusions. The values in this table are used by script `sh_sigelv` to produce elevation-dependent weightings (N-file) for SOLVE.

Elevation angle dependent RMS statistics.MODEL:  $RMS^2 = A^2 + B^2/(\sin(\text{elv}))^2$

ATELV Site	A	B	0-05	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	...	85-90
ATELV IISC	4.3	1.8	0.0	0.0	8.6	8.1	7.8	7.0	5.8	5.3	4.5	4.2	...	4.3
ATELV KIT3	3.5	1.7	0.0	0.0	7.9	7.2	6.5	4.9	5.4	4.6	4.1	3.8	...	3.2
ATELV LHAS	2.9	1.7	0.0	0.0	7.4	7.8	6.5	4.7	4.7	3.7	3.6	3.3	...	0.0
ATELV NAGA	7.8	0.0	0.0	0.0	9.4	7.2	5.9	4.9	4.5	3.9	3.8	4.2	...	17.6
ATELV NAMC	2.3	1.2	0.0	0.0	5.4	5.5	4.7	4.0	3.4	3.3	3.0	2.7	...	1.3
ATELV SHAO	2.5	1.2	0.0	0.0	5.9	5.1	4.3	4.4	3.9	3.7	2.7	2.9	...	2.4
ATELV TAIW	3.4	1.2	0.0	0.0	5.7	6.6	5.4	4.6	3.9	3.7	3.6	3.7	...	4.6
ATELV TSKB	2.7	1.4	0.0	0.0	6.5	6.3	4.6	3.7	3.4	3.1	2.9	2.9	...	4.0
ATELV USUD	2.4	1.4	0.0	0.0	6.6	5.6	4.2	3.9	3.2	3.2	3.2	2.9	...	3.5

A good edit of the data should not only produce a small rms scatter but also leave few extra bias flags in gaps or associated with repaired cycle slips. The `DATA AMOUNTS` table of `autcln.sum` reports this information for both pre- and post-fit runs:

DATA AMOUNTS (Good: # good data; Gap: # deleted in gaps; BF: # bias flags < 2\*max separation)

SITE	PRN	Good	Gap	BF	PRN	Good	Gap	BF	PRN	Good	Gap	BF	PRN	Good	Gap	BF
FORT	PN01	657	0	0	PN02	699	4	0	PN04	649	0	0	PN05	681	0	0
	PN06	945	0	0	PN07	133	7	0	PN09	648	0	0	PN14	477	0	1
	PN15	444	0	1	PN16	1119	2	2	PN17	813	0	0	PN18	782	0	0
	PN19	1047	0	0	PN20	470	6	2	PN21	962	0	0	PN22	1125	0	0
	PN23	659	0	0	PN24	573	0	1	PN25	0	0	0	PN26	1132	0	0
	PN27	1058	0	1	PN28	640	0	0	PN29	1032	0	0	PN31	1128	0	0

For each one-way sequence, the table shows the number of good data in the one-way sequence (`Good`), the number of data deleted in gaps between closely spaced bias flags (`Gap`), and the number of remaining bias flags that might be resolved (`BF`) (i.e., the number separated by less than twice the maximum size over which a flag would be removed). A

number greater than a few dozen in the `Gap` column and/or greater than 3 in the `BF` column usually means bad prefit residuals or noisy data.

If all of the data from a station have been deleted by AUTCLN, the reason can usually be assessed from the editing report:

```

EDITING REPORT AND SITE PARAMS
SITE  MnCLN  MnOUT  SNR   LSNR  GF03  RCLK  GF02  BEND  BCLS  NPED  GF-1  GF04  DDSC  PFED  GFUN  BDL2  NODD  ELEV  EDI
      (deg)  (deg)  L1  L2
OBSV  10.00  10.00  0  0    0    0    0    0    31   0    0    0  3640  83    0    0    83    0    0
RCUT  15.00  15.00  0  0    0    0    0    0    0   0    0    0    0    0    0    0    0    0    0    0
UCL1  15.00  15.00  0  0    0    0    0    0    56   0    0    0    0  5567  0    0    2   589  0

```

In this case the data for station `OBSV` were removed due to double difference scanning errors (`DDSC`). This usually means that there are large slopes in the double difference residuals, most likely due to bad apriori coordinates. The AUTCLN output file (`autcln.out`) can be scanned to see how large these scanning jumps were, and if they are not too large `DD_FIT_TOL` can be increased to allow the data through. `sh_svdif` can also be used to improve the apriori coordinates.

The summary for `RCUT` suggests that AUTCLN never saw the data at all, as you can confirm by looking at the top of the file for the number of data used in the range clock estimates. The most common reasons for this to occur are no valid L2 range/phase data even though the RINEX header said these data were available (check the RINEX header and data file), or all the range data are so bad (pre-scan range errors) that none of them were accepted in the solution. The autcln tolerances can be reset to allow very bad range data to get through the cleaning, but these range data are used to compute the clock epoch corrections in MODEL, so if the range data are corrupted (AVCLK errors in MODEL) then the epoch of the phase measurement is not computed correctly. Double difference phase residuals can still look smooth (but systematic) in these cases but the position determination will probably not be good (i.e., several centimeters of error). Ideally, we want the epoch of phase measurement known to 1 micro-seconds which corresponds to 300 meters of range error. Allowing ranges error too much larger than this can corrupt the position estimates.

The data for `UCL1` were deleted due to the postfit residuals being too large (`PFED` column). A check of the AUTCLN messages in the `GAMIT.status` file shows that when the station was removed, the RMS was 2.7 meters:

```

STATUS :991127:0714:11.0 AUTCLN/main: +Phase clock and bias estimation pass 14
STATUS :991127:0714:11.0 AUTCLN/pf_check_rms: Removing UCL1 Postfit RMS 2766.1 mm too large. Num 4920

```

(The AUTCLN output file can be `grep'd` for `^RMS ..` to get the RMS of all stations as a function of iteration.) Sometime these large residuals are due to the prefit GAMIT run being bad (i.e., large `nrms`), which corrupts the residuals in the postfit run. If the `settbl` contains `AUTCLN Postfit = R`, then the postfit solution will be run twice if the pre-fit

GAMIT solution is bad. Check the P-file for AVCLK errors, and then possibly the I- and K-files to pinpoint the time and cause, and the Q-file for the sizes of the adjustments. In the case shown here, the prefit AUTCLN run detected many DD scan errors, so most likely the a priori coordinates for the site are bad.

The other tables in the `autcln.sum` file and the use of the `autcln.out` file for tracing problems are discussed in Chapter 7.

If you have the `setenv` variable of your `.login` file referencing the `stdrel/help` directory, you can take advantage of an extensive on-line help file for AUTCLN. To view the current parameter defaults, type `autcln defaults`.

### 6.3 Scanning the residuals to identify slips

With the postfit editing capability of AUTCLN, it is seldom any longer necessary to perform a separate scan of the phase residuals to identify problematic data. Several programs and scripts are available, however. All take as input the M-file from a quick or full solution and operate on the predicted postfit LC doubly differenced residuals. The most commonly used program, an optional part of the batch sequence, is SCANDD. You can run it directly by typing the program name and the M-file from the SOLVE solution:

```
scandd mventa.278
```

Omitting the M-file will put SCANDD into an interactive mode, allowing you to select only certain stations, scan pre-fit (rather than post-fit) residuals, or scan a set of C-files with different 6th character.

SCANDD calculates the LC root-mean square (rms) of each double-difference series and searches for jumps in the doubly differenced LC residuals. It also identifies all possible cycle slips and compiles a list of corrections that can be used directly as input to CVIEW. SCANDD produces three output files, each with a slightly different summary of the doubly differenced residuals. The file most analysts find easiest to use in identifying potential cycle slips is called `vscan.out`, which lists the largest LC "jumps" for each double-difference series. A distinction is made between jumps that are associated with bias flags ("flagged"), which do not corrupt a "full" or "regular" SOLVE solution, and those that have not had extra bias flags assigned ("unflagged"). You can obtain a sorted version of this file by running the shell script `sortv` to sort the file `vscan.out` by epoch and produce two additional files, one listing the largest slip for every double difference combination, the other (more useful for large networks) listing only the 80 worst slips. Shown below is the output of the second of these files, named `vxxxx1.ddd.worst`, where the experiment name (`xxxx`), type of solution (1), and day number (`ddd`) are taken from the M-file name.

```

80 worst jumps
  CHAN1 CHAN2 SIT1  SIT2  NDATA  RMS  EPOCH(F)  FLAGGED  EPOCH(U)  UNFLAGD
    2     4     6     7   496   0.27   712     -1.02    713     -1.41
    2     4     7     9   441   0.45   712     +1.23    713     +1.40
    2     4     3     7   517   0.26   712     -1.21    713     -1.40
    2     4     7     8   529   0.40   712     +1.05    713     +1.38
    2     4     7    10   531   0.40   712     +1.38    713     +1.37
    2     4     1     7    21   1.16   712     -0.99    713     -1.34
    2     4     2     7   530   0.40   712     -1.07    713     -1.32
    2     4     4     7   532   0.40   712     -1.14    713     -1.30
    2     4     5     7   517   0.31   712     -1.13    713     -1.27
    1     3     7     9   165   0.20   423     -1.29    360     -0.40
... 68 lines deleted ...
    3     4     7    10   392   0.12   503     -0.19    366     -0.27

```

```

Created vshiml.350.sort
Created vshiml.350.worst
Print with: enscrip -fCourier7 vshiml.350.sort
Print with: enscrip -fCourier7 vshiml.350.worst

```

This file can be used as a guide to interactive editing using CVIEW since the epoch of the largest jump, and the double-difference combination affected, are shown. In the list shown above, for example, the repeated appearance of the same computed unflagged ( U ) LC jump at epoch 713 indicates that a cycle slip occurred at site 7 in either channel 2 or 4. If renamed to cview.list, it can also be read into CVIEW and used to skip directly to the potential cycle slips in the list.

A second summary of potential slips is file scan.dd. It differs from vscan.out in listing all of the potential slips (not just the largest in each series) and suggesting the number of L1 and L2 cycles to be added or subtracted to fix them. It also includes an indicator for bias flags on each of the channels. By including all flagged and unflagged slips, however, scan.dd provides a larger and more complicated file than one usually needs after running AUTCLN. To use scan.dd it is usually best to sort it by epoch by running program SORTER, which will ask you to select for inclusion slips associated with series with rms values above a given value:

```

% sorter
CHOOSE A LOWER BOUND TO SORT SCAN.RMS (e.g. 0.8) : 0.1

```

An rms below 0.1 cycle usually indicates that there are no slips in the series. You may also exclude from the sorted list a satellite and/or station:

```

ENTER SAT AND SITE TO EXCLUDE (e.g. 3 0 or CR to skip) :

```

An abbreviated example of the output file, dd.srt, is shown below. The column headers are not printed by the program but have been added here for clarity.

	Epoch	LC full rms							Predicted slip	
			Chan 1	Chan 2	Site 1	Site 2	L1	L2		
1	199	0.05	4	2	8	1	1.00	0.00		
2	199	0.05	4	2	9	1	1.00	0.00		
3	199	0.06	4	2	5	1	1.00	0.00		
4	199	0.06	4	2	6	1	1.00	0.00		
5	199	0.06	4	2	10	1	1.00	0.00		
6	199	0.07	4	2	3	1	1.00	0.00		
...										
127	476	0.13	6	5	14	6	0.00	-1.00		
128	477	0.12	6	5	14	5	1.00	1.00		
129	477	0.13	6	5	14	9	-1.00	-2.00		
130	477	0.15	6	5	14	4	-1.00	-2.00		

In this example, the repeated appearance of the same computed L1 jump at epoch 199 indicates that a cycle slip occurred at site 1 in either channel 4 or 2. The combinations shown for epochs 476 and 477 paint a less clear picture, but probably indicate multiple slips—at both epochs and/or more than one satellite or station.

The third output of SCANDD is file `scan.rms`, which gives for each series the rms value calculated three different ways: 1) "full" (as in `vscan.out` and `scan.dd`), in which implicit biases are inserted when explicitly flagged by `AUTCLN` or `CVIEW`; 2) "quick" in which an implicit bias is inserted at all gaps; and 3) "total", in which no implicit biases are removed—i.e, the rms value will include all jumps in the phase. This file is most helpful in identifying stations with receiver problems or satellites experiencing unmodeled translations (from, e.g., non-gravitational forces) or rotations (mis-modeled yaw during eclipse or "noon turn"). Like the `scan.dd` file, `scan.rms` file is sorted by program `SORTER`, producing three output files:

```
rms.quick - LC-RMS for quick solution (any gap/flag starts a new rms)
rms.full  - LC-RMS for full  solution (any flag starts a new rms)
rms.total - LC-RMS of the entire series (as in CVIEW).
```

An abbreviated example of the file `rms.full` is shown below, where the rms information (for "quick", "full", and "total") has been sorted in order of decreasing size of the "full" rms:

	Quick	Full	Total	No obs.	Chan 1	Chan 2	Site 1	Site 2
1	0.18	0.18	0.18	21	5	1	2	1
2	0.10	0.17	0.17	27	7	6	7	6
3	0.16	0.16	0.16	12	6	4	3	1
...								
66	0.10	0.11	0.40	52	7	2	2	1
67	0.10	0.11	0.11	39	4	1	5	1
68	0.10	0.11	0.11	34	6	4	7	6

In this example, the smaller quick than full rms for series 2 indicates that there is an unflagged gap that may still have a slip. The large (0.40 cycle) total rms for series 66 indicates that there is a flagged jump (probably at a gap) which could not be patched by

AUTCLN. With a largest full rms of 0.18 cycles, this solution is probably free of slips or unmodeled effects.

A way of determining better whether the presence of cycle slips or bad modeling at a particular station or satellite is causing the high rms values for certain series is to run SHOWRMS. The input is one of the sorted rms lists (from SORTER), and the output is a normalized distribution of the contribution of each station/satellite pair to the overall rms of the predicted postfit residuals:

```
% showrms

Enter 1 for rms.qui 2 for rms.ful 3 for rms.tot
2
RMS DISTRIBUTION (total rms = 1000) example: 234 = 23.4%

stn|sum|-----
 1: 227:  33  44   3  47  47  14  36
 2: 132:  22  25   7  18  22  11  25
 3: 139:  29  14  14  11   0  36  33
 4: 125:  22  22   7  18  25  11  18
 5:  80:  18  11   0  11  14   7  18
 6:  88:   0  18   7  14  22  11  14
 7: 205:   0  55  18  33  36  11  51
-----
sum --> 125 191  58 154 169 102 198
chn -->   1  2   3  4   5  6   7

Enter 1 fix, 2 new, 0 quit, otherwise help
2
```

Selecting 2 ('new') allows you to see the redistributed rms contributions after a station or satellite is removed. Selecting 1 ('fix') is similar but doesn't redistribute the contributions—that is, they no longer add up to 100%. In this example, four of the highest contributions are from station 1 (channels 1,2,4, and 5), so we may want to see what happens to the distribution if we remove station 1 from the computation:

```
Enter channel #s to be removed (- for all sites)
0
Enter site #s to be removed (- for all channels)
-1

RMS DISTRIBUTION (total rms = 1000) example: 234 = 23.4%

stn|sum|-----
 1:  0:   0  0   0  0   0  0   0
 2: 88:  11 18   7 11  11  11  18
 3:102:  22 14  14  3   0  25  22
 4: 88:  14 18   7  7  14   7  18
 5: 44:  11  0   0  3   7   7  14
 6: 58:   0 11   7  7  11  11  11
 7:161:   0 40  14 25  29  11  40
-----
```

```

sum -->  58 102  51  58  73  73 125
chn -->   1   2   3   4   5   6   7

```

Now channels 2 and 7 from station 7 stand out as the largest contributors to the overall rms. The results of SHOWRMS should not by themselves lead you to remove a satellite or station from the solution since a higher rms value for a particular satellite or station may just indicate a longer span of observations. The summary can, however, be used effectively as a guide for inspecting the residuals using CVIEW.

#### 6.4 Interactive editing using CVIEW

Program module CVIEW is the primary interactive tool of the analysis software. It allows the analyst to display to the screen almost every imaginable combination of phase and pseudo-range residuals, as well as clock behavior and the sky tracks of the satellites. For editing, it has a number of features which allow rapid and effective repairing of cycle slips, insertion and removal of additional bias parameters, and the unweighting of questionable data. CVIEW also accepts as input RINEX or X-files, allowing inspection of raw data when you suspect a receiver problem or want an early look at the ionosphere (LG) or widelane (WL) observables, neither of which depend on modeling the geometry. Any analyst new to GAMIT should take the time to become proficient at using CVIEW. In our 15 years of experience we have seen no data set which can be completely understood without some examination of the residuals.

By giving you a choice of the C-files to be viewed and (optionally) a particular set of parameter adjustments to be removed, CVIEW allows you to examine the results of different stages of the processing. In the most common case (at least before the advent of post-fit editing by AUTCLN), you will want to examine the doubly differences residuals as they are predicted to be after parameter adjustments in the final SOLVE. CVIEW obtains these residuals by correcting the (pre-fit) residuals on the C-files using the partial derivatives and the parameter adjustments written by SOLVE on the M-file, according to the following formula

$$r'_i = r_i + \sum_{j=1,m} (\Delta p_j \cdot \partial c_i / \partial p_j)$$

where  $r_i$  is the prefit O – C ("observed – computed") at epoch  $i$   
 $\Delta p_j$  is the adjustment to parameter  $p_j$   
 $\partial c_i / \partial p_j$  is the partial derivative of the observation with respect to  $p_j$   
and  $m$  is the number of adjusted parameters

To invoke CVIEW in this mode, type

```

cview m[ expt]a.ddd

```

If you have used AUTCLN in its post-fit mode, you have a choice of two sets of residuals to examine. With the “a” M-file, you will get the doubly differences residuals from the final SOLVE solution, just as before. In this case the one-way residuals made available by AUTCLN’s corrections to phase clocks will be “nearly” flat but will in fact not represent the actual post-fit residuals because the corrections for parameters adjustments have been taken from the final SOLVE M-file whereas in correcting clocks AUTCLN used parameter adjustments from the previous (“AUTCLN pre-”) SOLVE solution, recorded on the M-file now named with “p” as the sixth character (see the batch-file sequence in Section 5.3). To best evaluate the one-way residuals, you should give CVIEW the name of this earlier M-file. Since this M-file will contain the names of versions of the C-files (the “b” versions with a 0-ITER run, whereas the final “a” M-file has the “d” versions), you will need to have saved these earlier C-files or substitute the later ones (which are equivalent for this purpose). This can be accomplished easily by using additional optional command-line arguments when invoking CVIEW:

```
cview m[ expt]p.ddd ddd d
```

The last argument (d) corresponds to the version of the C-files that are currently present in your day directory. The day number is also included because it was added as a second command-line argument to earlier versions of CVIEW for use with multi-session processing (in which a single M-file may have C-files from more than one day). Invoking CVIEW in this mode is usually the best way to examine the data if you have used AUTCLN in post-fit mode since you can see problems directly in the one-way residuals without having to infer from the double differences the station and satellite at fault. The doubly differenced residuals, however, will not be those from the final SOLVE—though they will usually be very close—so if there is a question about systematic signatures, you may have to invoke CVIEW a second time with the “a” M-file. This is usually unnecessary.

There is one additional mode for CVIEW that is sometimes useful; namely viewing the (doubly differenced) residuals as they are passed to AUTCLN from MODEL or to SOLVE from AUTCLN. The first case is interesting if AUTCLN has performed poorly for one or more stations or satellites and you want to determine why (e.g. poor *a priori* coordinates leading to large pre-fit residuals and deletion by AUTCLN of most or all of the data). The second is interesting if the solution nrms and SCANDD output suggests mismodeling of a satellite (e.g., from “burn”) and you want to see the effect before SOLVE has “smeared” it into the residuals of other satellites in the least squares adjustment. To view pre-fits, as well as to select a sub-set of C-files, you must invoke CVIEW with no arguments on the command line. In this case, the program will prompt you for the name(s) of an M-file or C-file(s). Responding with the M-file name results in a display of all the C-files, giving you the opportunity to select a subset of the files and/or to change the sixth character of the

C-file names listed to as to read in a different set. Then CVIEW will then ask if you want to view post-fit residuals. Responding Y (“yes”) will give you the standard post-fit mode, just as if you had used an M-file on the command line.

Regardless of how many command-line argument you use, CVIEW will ask if you wish to read in one of the lists of rms values and cycle slips generated by SCANDD, SORTER, or sortv. An affirmative answer gives you the opportunity to go move quickly to the problematic double-difference combinations using the LIST command in CVIEW, as described below. Almost always you will want to choose rms.ful, the output of SORTER order in decreasing rms. The filenames vscan.out and scan.out.worst are not currently included among the choices listed by CVIEW, but the file format can still be read—the user need only rename these files to view.list.

As each C-file is read, header information is displayed, including parameters indicating the data types present. Once all the C-files are read, CVIEW will display the first of several interactive menus used in plotting:

```

L1  L2  LC  LG  WL  NO POLY  TIME SERIES  STACK[ ]  MOVIE[ ]  STOP

SEEK  PLOT  LIST  1-WAY  2 PRN06  3 PRN08  1 BLHL  2 VNDN  FILE  SEEK-FORW

```

For most of the boxes on the screen there is a stack of allowable commands, which can be selected by clicking on the box with the mouse. The left button moves you backward in the stack, the right button moves you forward, and the center button selects the pre-programmed default shown in the illustration above. The first four boxes in the top panel select up to five observables to be plotted. The default is plots of the L1, L2, LC, LG phase residuals and the wide-lane combination of phase and pseudo-range. Many analysts prefer to use the fifth plot not for wide-lane by to show the time span of each one-way combination contributing to the double difference. This give you the best opportunity to infer quickly the likely station and satellite responsible for a gap, extra bias parameter, or large residuals stemming for low-elevation data. The complete list of allowable data types is given below in the order they appear in the menu stack:

```

AZ    azimuth from station to satellite (degrees, clockwise from north )
EL    elevation angle (degrees)
..    nothing plotted
L1    L1 phase
LG    geometry-free linear combination phase ( L2 - g*L1 )
LC    ionosphere-free linear combination phase ( 2.546 L1 - 1.984 L2 )
L2    L2 phase
P1    L1 pseudorange (cycles)

```

<b>P2</b>	L2 pseudorange (cycles)
<b>WL</b>	widelane combination (constant integer in cycles)
<b>W*</b>	widelane combination with large jumps removed (constant integer in cycles)
<b>PG</b>	geometry-free linear combination pseudorange ( $P2 - g \cdot P1$ )
<b>BG</b>	$LG - PG$ (cycles)
<b>I1</b>	pseudorange ionosphere at P1 ( $-g/(1-g^2) PG$ )
<b>I2</b>	pseudorange ionosphere at P2 ( $-1/(1-g^2) PG$ )
<b>CL</b>	computed receiver clock correction (microseconds)
<b>DT</b>	horizontal display of all four one-ways in a double-difference combination

The sixth box in the top panel selects the order of polynomial to be removed from the plot, or the order of derivative to be taken. For example, to plot the rate of change of double differences (akin to "triple differences") you would select **DERIV 1** (the units are cycles per second), and to plot the derivative with a first-order polynomial removed, select **D1 + P 1**. The most useful selections are **P 1** and **P 2**, in connection with the **SPAN** command described below, allowing you to remove a first or second order polynomial from a short segment of data. The next box selects **TIME SERIES**, **SKY PLOT**, or **SPECTRUM**, defining the type of axes to be drawn for the plot. The next two boxes, **STACK** and **MOVIE**, allow you to stack a series of plots on the same screen and/or to cause them to be displayed automatically in sequence without intervention as explained below. The brackets **[ ]** indicate that these two boxes are toggles, not stacks; clicking with any mouse button in the brackets introduces an asterisk **[\*]** and turns on the feature. The final box **STOP**s the CVIEW display and returns you to the control menu in the operating system window, at which point you can resume the display (and editing) or exit the program. Returning to the operating system menu without exiting the program is useful if you need to check files or available disk space, for example.

The bottom menu panel contains the satellite(s) and station(s) being displayed. The default is the first double-difference combination (as shown here), but you may display one-way or single-difference combinations by making the second box of one or both pairs blank. Clicking on the fourth box (**1-WAY**) plots the one-way observable for the satellite and site shown in the first box of each pair. As for the upper panel, the selection is changed by clicking on the box to rotate forward (right mouse button) or backwards (left button) in the stack. The first three boxes on the left contain the commands allowing you to move from one screen to another. To change to a particular combination of satellites and stations, rotate (either backward or forward) to the selections in the right four boxes and click on **PLOT**.

To select the next available double difference, click (with any mouse button) on **SEEK**. The default is to "seek-forward", in increasing order of satellites and stations, but you can reverse the process (e.g. to return to a problematic combination) by clicking on the last box to change **SEEK-FORW** to **SEEK-BACK** and then using **SEEK**. To move through the SCANDD list you have read in, select **SEEK-LIST** and then **SEEK**. Clicking on **LIST** with

the left or right buttons will display in the bottom right corner of the screen the last or next combination, respectively, but will not plot it.

Finally, a hard copy of the screen plot may be obtained by clicking on **FILE** to write a file and then using the shell script `sh_cvview_panel`.

Time series are displayed with the mean removed and the value indicated to the left of the vertical axis as `Y: 0 @ [mean value]`. Also shown is the rms (" s") of the series about the mean. The time (X-) axis is marked in hours and minutes (hh:mm) but without resetting to zero if the series goes over midnight. Unless **SHOW MARGINAL** has been selected, the display will include only those observations weighted in the solution. Continuous observations (no gap) are indicated by lines connecting each point. The epoch number of any point can be displayed by clicking on the point. The presence of an extra bias parameter is indicated by vertical bars, with "semaphores" attached to indicate (in single or double differences) which satellite(s) and station(s) have the bias flags; e.g.

$\begin{array}{c}   \\ / \end{array}$	station 1 satellite 1	$\begin{array}{c} / \\   \\ \end{array}$	station 2 satellites 1 and 2
---------------------------------------	-----------------------	--	------------------------------

Stations are indicated by semaphores to the left (station 1) or right (station 2) (*memory tool*: stations are separated *horizontally* on the Earth); satellites by semaphores at the bottom (satellite 1) or top (satellite 2) (satellites rise or *severtically*).

When one or more time series are plotted on the screen, the top and bottom menu panels change to display the following:

```

SLIP [ ]  MOVE  PATCH  FIND  SAVE  UNWT  REWT  BIAS (-!?!+)  UNDO  ELIM
SAVE  ABORT  SPAN[*]  ALL[ ]  <<T>>  >>T<<  MARG[ ]  HIDE[ ]  <<  >>

```

The boxes in the bottom panel (except for the first two) control the display of the plots. The most useful command is **SPAN**. Toggled on it automatically expands and contracts the horizontal axis to fit the time series being displayed. Toggled on after selecting a range of points on the screen (by simply clicking on any of the displayed plots), it adjusts the horizontal scale to fit the span selected. Toggled on after selecting a single point, it expands the scale and moves the selected point to the center of the screen. **ALL** returns the horizontal scale to the complete interval of the session. The next two boxes ( `<<T>>` and `>>T<<`) directly expand or contract the time axis. The final two boxes ( `<<` and `>>`) move the origin to the left or right, expanding the time scale if appropriate. For short (e.g., 225-point) series, the same effect can be accomplished with any one of several different selections of these six boxes. The seventh box is a toggle between showing **MARGINAL** (unweighted) points and hiding them. Toggled on **[\*]**, unweighted points are displayed as

open circles or, if they were unweighted because they were below the elevation cutoff, as open squares. At present CVIEW does not distinguish between slightly and grossly bad residuals, so that with marginals displayed the vertical scale is often distorted, masking variations in weighted points. The **HIDE** box is a toggle between hiding bias flags that occur in one-way observations that fall in gaps in the double-difference combination being displayed (SOLVE will remember the flags and insert an extra bias parameter in the solution; we term these "pushed" biases.) **ABORT** quits the plot with no changes to the series; **SAVE** quits and saves any editing that has been done to that series.

Most repairing of cycle slips is accomplished with the **PATCH** and **MOVE** selections of the top panel. For either box, you must first select a single point in the series you wish to have moved to connect smoothly with the immediately preceding segment. You do this by placing the cursor on the point and clicking with the left button on the mouse. (The use of the middle and right buttons will invoke more powerful features, described below.) Then, clicking on **PATCH** will cause the program to calculate automatically the number of cycles needed to repair the slip and to move selected point and all points beyond it. If you have clicked on and L1 or L2 plot, **PATCH** will move the points in that plot only by the number of integer cycles that best connects the phase. If you have clicked on LC, LG, or WL the program will calculate the number of L1 and L2 cycles necessary to best fit two combinations (with an appropriate weighting based on their respective scatters) and will display in the lower right corner the statistical confidence level of the fit. Clicking on LC, invokes use of LC and LG; clicking on LG invokes use of WL (!) and assumes the change in LG = 0.; clicking on WL invokes use of WL and LG. The **PATCH** algorithm is discussed further below in the context of editing strategies. **MOVE** works only on L1 and L2 and allows you to adjust these series by integer or half-integer cycles using additional menu boxes that will appear:

**0.25 0.5 1 2 5 10 50 100 500 1000 Add 0.0**  
**CANCEL M PERFORM R**

For each of the boxes of the top panel, clicking on the left mouse button will decrement (subtract from), and clicking on the right button will increment (add to), the value shown by the unit for that box. Clicking on the middle button will choose the unit value. The value selected will appear in the upper right corner of the screen (shown here as **0.**). Then clicking **PERFORM** or the **right mouse button** with the cursor in the plot area will execute the move; clicking **CANCEL** or the **middle mouse button** will cancel the selection. The value of 0.5 is primarily for L2 with squaring-type receiver channels where a one-cycle slip in the original signal corresponds to a half-cycle in the displayed phase. (The value of 0.25 [or 0.5 with full-wavelength signals] should be used sparingly and is included only to check for 180° phase shifts, usually temporary, of the signal in some receivers.) **MOVE** is primarily useful to test for phase repairs when the visual impression implies a different

number of cycles than the number calculated by **PATCH**. Most of the time **PATCH** alone will do the trick.

The **BIAS** box allows you to add ( **right mouse button** ), remove ( **left mouse button** ), or locate ( **center mouse button** ) extra bias parameters at epochs with questionable cycle slips. It can be used with a single epoch or a range of epochs (the latter being useful primarily in *removing* bias flags). **ELIM** will eliminate bias flags in all one-way data in series displayed unless a narrower span is defined by brackets. **FIND** will attempt to assist you in locating the (one-way) satellite and station combination associated with a cycle slip or extra bias parameter following a gap by changing the display to put as the first satellite and station the one in which the gap occurred. Clicking on **SAVE** or **ABORT**, followed by **PLOT** or **SEEK** will restore the original sequence. (Be careful here, though, because you may end up using intervening commands that erase CVIEW's memory of the last combination. It's a good idea to jot down on paper the combination on the screen before invoking **FIND**, so that when you're finished editing a particular epoch you can return to the right place in the search sequence. ) **UNWEIGHT** flags data points to be omitted from the solution by SOLVE; **REWEIGHT** removes the flag. All of these commands are to be executed after you have selected a point or range of points on the screen by clicking on them with the mouse.

Note that for double differences, the corrections you make are applied to the first satellite and first station displayed for the double-difference combination. The importance of being aware of this feature is discussed in the next section.

The eighth and ninth boxes allow you to reverse your immediately previous action. **UNDO** reverses the effects of **PATCH**, **MOVE**, **WEIGHT**, **REWEIGHT**, **BIAS**, and **ELIM**, all of the commands that actually change the data. **CANCEL** simply removes the selection of points you have made in anticipation of a move. The **SLIP** box is unused at present.

The **MOVIE** function is useful for viewing an entire set of residuals quickly to infer its character, locate a problem, or verify at the end of editing that everything is clean. If **STACK** is invoked, all of the plots will be superimposed on the screen. This is a powerful feature for discerning the nature of the residuals but it can become a mess if there are too many series. Once you start the MOVIE, you can stop it by clicking anywhere on the screen with the *middle* mouse button (click *once* only and wait for the current frame to finish being written to the screen). Following this by **PLOT** will show you the series that was on the screen when you stopped, allowing you to hit the panic button when you see something you don't like. If you start the MOVIE with the **right button**, plotting will stop at the first series with LC RMS > 1.0.

When you have exercised all of the commands and gained some experience in data editing, you can use CVIEW in a more automatic mode, using the mouse buttons to reduce the

number of hand motions required. When the cursor is in the plot area of the screen, the mouse buttons take on different functions. The **left button** puts brackets on the data as described above. The **middle button** acts as SEEK or ABORT according to command displayed at the bottom. The **right button** executes the sequence FIND + PATCH, with PATCHing being performed only if the correct satellite and station was "found"; a second click on the right button will SAVE and re-PLOT. To UNDO the PATCHing, use the **left button** .

Fixing cycle-slips in double differences is straightforward if you remember certain rules. If a particular receiver channel slips one or more cycles, a break will appear in all data combinations that include that channel. For example, a slip in the L2 phase at station 1 received from satellite 3 will appear in all double difference plots LC, LG, and WL that include station 1 and satellite 3. *The first step is to identify the station and satellite for which the slip occurred* . One way to do this is to make use of the sorted output of SCANDD (e.g., vscan.out.worst ), marking on the printout or in the file displayed by an editor the satellite and station common to all occurrences of the slip at a particular epoch (see Section 6.3). If you have run AUTCLN in post-fit mode, you can identify the source(s) of the slip by viewing each of the one-ways contributing to the double difference. In the case where there is a gap or extra bias flag in only one station and satellite combination of the double difference, then the **FIND** command will identify for you the combination and move it to the ( 1, 1 ) position in the display. With this display, you can use **PATCH** (or **MOVE**) to fix the slip, and then return to the original order of the double difference combination by clicking on **SAVE** or **ABORT**. If there is no gap or several gaps, then you should check all four one-way series. Multiple slips are not uncommon since a satellite or receiver may "hiccup", affecting multiple stations or channels, respectively. In cases of very high noise in the one-ways (due to bad clocks or ionosphere), you may have to deduce the culprit channel by displaying several combinations of double differences. For example, suppose that for three stations and three satellites the following combinations had a cycle-slip at a particular epoch of observation:

- (station 1 - station 2) - (satellite 1 - satellite 3)
- (station 1 - station 2) - (satellite 2 - satellite 3)
- (station 2 - station 3) - (satellite 1 - satellite 3)
- (station 2 - station 3) - (satellite 2 - satellite 3)

It is clear that the cycle-slip occurred at station 2 and satellite 3. Thus the slip should be fixed with satellite 3 and station 2 appearing first when the double difference combination is selected in the menu. In some cases the location of the cycle-slip is ambiguous. For example, if only two stations are observing, it is impossible to determine at which site a slip occurred. In this case, the slip can be fixed at either site. The only requirement is that all double-difference plots be free of cycle slips, i.e, that the cycle-slips are fixed consistently.

*Remember: All editing operations are applied only to the **first** satellite and station in the double difference combination, so if the edit is made in double differences, you may have to switch the order before executing the operation (bias, unweight, reweight, patch, move)*

Once the correct satellite and station are identified as responsible for a cycle slip, the next step is to determine its size and whether it occurred in L1 or L2. If the ionospheric fluctuation between epochs is much less than a cycle (or a half-cycle with codeless tracking channels), it will be obvious in the separate plots of L1 and L2 how many cycles slipped in each channel. If the ionospheric fluctuations are large, however, only LC may be sufficiently smooth to discern the size of the slip. In the most difficult cases, it may be necessary to examine all four phase series (L1, L2, LC, and LG) to deduce the combination of L1 and L2 cycles (and/or half-cycles) responsible for the LC jump. Table 6.1 gives the most common residual LC and LG jumps that occur for combinations of slips in L1 and L2 for the cases of full-wavelength and half-wavelength L2. The bold-faced entries, representing LC jumps of less than one cycle, are the most dangerous since they can escape detection if the fluctuations in L1 and L2 due to the ionosphere are very large.

Using **PATCH** in CVIEW allows you to avoid computing the L1 and L2 combinations explicitly. Used with LC or LG, **PATCH** will make a best estimate of the jumps by examining these two time series and apply integer corrections to L1 and L2. The statistical confidence of the estimate is displayed, allowing you to assess whether to retain or add a free-bias flag at the break. This is a useful feature even when you believe that there is no slip, in order to reinforce your subjective judgement of the confidence of the connection made by AUTCLN. **PATCH** uses up to 15 points on either side of the slip (usually also a gap) in estimating its correction. Its estimate and confidence level are reliable as far as the LC and LG residuals are concerned. There are times, however, when the analyst is justified in raising the confidence level based on the appearance of L1 and L2. If LC and LG are noisy compared with L1 and L2 (which can occur if multipathing dominates ionospheric fluctuations), then using **PATCH** or **MOVE** on L1 and L2 separately is more convenient. In this case Table 6.1 is particularly useful.

Table 6.1 LC and LG jumps for L1 and L2 slips

$$LC = 2.546 L1 - 1.984 L2 \qquad LG = L2 - 0.779 L1$$

<u>L1</u>	<u>L2</u>	<u>LC</u>	<u>LG</u>
<i>All combinations <math>\leq \pm 1</math></i>			
-1	-1	-0.56	-0.22
-1	-0.5	-1.55	0.28
-1	0	-2.55	0.78
-1	0.5	-3.54	1.28
-1	1	-4.53	1.78
0	-1	1.98	-1.00
0	-0.5	0.99	-0.50
0	0.5	-0.99	0.50
0	1	-1.98	1.00
1	-1	4.53	-1.78
1	-0.5	3.54	-1.28
1	0	2.55	-0.78
1	0.5	1.55	-0.28
1	1	0.56	0.22
<i>Positive combinations <math>\leq \pm 5</math> with <math>LC &lt; 1.0</math> or <math>LG &lt; 0.1</math></i>			
2	1.5	2.12	-0.06
2	2.5	0.13	0.94
2	3	-0.86	1.44
3	4	-0.30	1.66
4	5	0.26	1.88

In data sets with many gaps (from. e.g., a poorly performing receiver), there may be a large number of bias flags inserted by AUTCLN and you would like to perform the entire edit manually. In this case, you can use the **BIAS** function to remove all bias flags which are in the first satellite and station displayed or the **ELIM** function to remove bias flags in all satellites and stations associated with the series. If a data set has many small gaps but few actual cycle slips, it is sometimes easier to remove all the bias flags before starting and then add back the ones you need. This strategy is facilitated by program RMBIAS, which is run from a batch file ( `rmbias.bat` ). To create this batch file run the script `mk.rmbias` , responding to the prompt with the 6th character of the input C-files. The script will then create in `rmbias.bat` an RMBIAS command for each C-file in your directory with that 6th character. The output C-files will always have 6th character "x". You can rename them using the scripts `mvcf` or `copyc`. If you are using AUTCLN, there should never be a large number of bias flags remaining and you should have no need for RMBIAS.

After you have completed all editing for the session, click on **STOP** and answer positively the query to write out corrected C-files. The names of the new C-files are created by incrementing the sixth character of the old C-file names. Whenever you select STOP while

editing, CVIEW will give you the opportunity to continue editing and/or to save the edited C-files by issuing the following prompt:

You may:

- 1 Write new C-files, incrementing series letter
- 2 Write new C-files, incrementing series letter and deleting old C-files
- 3 Overwrite input C-files
- 4 Not write any C-files
- 5 Not write any C-files but save vcview.out

Only 1 and 4 will let you continue editing

Pick a number

With modern data sets, for which any editing is can usually be accomplished by adding `edit_sv_site` commands to AUTCLN, you will have used CVIEW only for diagnosing problems and you may select 4 or 5 to avoid writing out the C-files. If you have performed edits, particularly cycle-slip repair, which you wish to keep, then you should select 1, 2, or 3. The simplest course is to overwrite the input C-files, but if you have spent a long time editing and don't want to chance a (rare) system problem, then 1 is the safest option. In this case you may need to rename the C-files (change 6th character) to match what SOLVE is expecting (from the M-file) using the script `mvcf` after finishing with CVIEW. If you select options 1 or 4, you will get the prompt

Do you wish to continue editing (Y/N)

A "yes" (Y) reply will return you to the editing screen, after performing an interim save of the C-files if you have chosen option 1. A "no" ( N) reply will exit the CVIEW, either directly if you have selected option 4, or after writing out the C-files if you have selected option 1. When you are engaged in a long editing sessions, it is prudent to **STOP** editing periodically to save the C-files. (Neither the hardware we have used nor the software we have written is immune to unexpected crashes.)

Option 5 at the end of editing will write out a file ( `vcview.out` ) of all the edits you have made in the session. Running the (interactive) program AUTEDT or (better) the shell script `sh_cvedt` extracts from `vcview.out` the information about which data you have unweighted and appends to the `autcln.cmd` file the appropriate `edit_site_sv` commands for AUTCLN.

### 6.5 Strategies for Editing

When used in its postfit mode, AUTCLN will usually produce a near-optimal editing of the data from almost any survey, including those performed in the 1980s and 1990s with first or second generation receivers. For these older surveys, or modern ones spanning only a few hours and including only two or three stations, it is efficient to view all of the data with CVIEW to satisfy yourself that AUTCLN has recovered all of the useful data and not left any unnecessary bias flags. If you find problems, you may elect to perform the edit manually, especially with small data sets, but most of the time you can induce AUTCLN to do the right thing by changing its input parameters and/or pre-deleting (with the `edit_site_sv` command) short spans of noisy data. This approach has two advantages over manual editing: 1) it transfers the burden of editing from the (expensive, slow, and fallible) analyst to the (cheap, fast, and slightly less fallible) cpu; 2) the `autcln.cmd` file now maintains the record of all edits, so that you can reprocess the data, from RINEX files if necessary, as modeling and editing algorithms improve.

The preferred strategy for networks with more than two or three stations is to first examine the outputs of SOLVE (q-file) and AUTCLN ( `autcln.post.sum` and the sky-plots of phase residuals [DPHS] produced with `sh_gamit`) to determine if there were any problems with the run. If so, then you can use the outputs of SCANDD (sorted versions of `vscan.out` and `scan.rms`) with CVIEW to identify the station or satellite and cause of the problem and add controls to `autcln.cmd` to fix it. Since SCANDD is fairly time-consuming to run, it's usually most efficient to omit it from the standard batch solution and repeat the run if you suspect problems.

The most obvious indicator of a bad solution is the `nrms` value in the Q-file. As discussed in Section 5.4, values above 0.3 usually signify a problem, and for many surveys you should expect most values to be near 0.2. If you are processing several days of a survey at one time, `grep'ing` on `nrms` for all of the q-files will give you an indication of problem days. If the `nrms` is abnormally high, you should then look at the `scan.rms` output of SCANDD (or `rms.ful` after running SORTER) to see if a single satellite or station is causing a problem. If you find values greater than about 0.2 cycles, you should examine the residuals visually with CVIEW to understand the cause of the problem.

Even without a high `nrms`, you should examine the `autcln.sum` file to ascertain whether there are problems with a station or satellite. If a receiver or clock is malfunctioning, or if you have a bad a priori coordinate for the station, AUTCLN may have deleted large quantities of data or added an excessive number of bias flags. The first three tables in the summary file will tell you quickly if there is a major problem. With postfit editing, the table of one-way phase residuals will characterize precisely the performance of each station and satellite. With either postfit or prefit editing, you should also make sure that in the DATA AMOUNTS listing there are small numbers in the `Gap` (data deleted in gaps) and `BF`

(bias flags remaining) columns and that the number of data retained ( `Good` column) are comparable to those for other stations. If you find anomalies, the other tables in the file and `CVIEW` can help you determine the source of the problem. If you have run `AUTCLN` in post-fit mode, there will a summary of the rms of the residuals for each station and satellite, allowing quick identification of outliers. (See the explanation for these tables in sections 6.2 and 7.6 and the on-line help for `AUTCLN`.)

If you suspect problems at a station from its postfit rms, you should run `sortv` on the `vscan.out` file from `SCANDD`. Usually, looking at `vxxxxa.ddd.worst` will tell you if there are any potential slips. It would be unusual for there to be more than one or two of these (if any) after `AUTCLN` unless there is a station with a malfunctioning receiver.

For regional networks, there is one additional and very important editing consideration if you plan to attempt ambiguity resolution in the analysis. The present version of `SOLVE` assigns the (one allowed) explicit ambiguity parameter to the last segment of the double-difference series; that is, the data after the last extra bias parameter (shown by a bar in `CVIEW`). This is because the extra bias parameters are all estimated implicitly. In order to maximize the probability that the ambiguity for a series will be resolved, you want to have the last segment as long as possible. This means that for stations in a regional network you *should not leave an extra bias parameter in the latter part of an otherwise continuous series, but rather unweight the data at the end containing these extra biases*. The last entry in the `trim_oneway_tol` command for `AUTCLN` gives you some control over this, but it's still possible to have a too-short segment at the end of a double difference sequence. For widely spaced fiducial stations where there is no chance to resolve ambiguities, leaving an extra bias parameter associated with a few points at the end is of little consequence. The important thing in this case is to avoid breaking up with bias flags long segments of data, wherever they are located in the observing span.

Once you have identified any editing problems with the solution, you should make take corrective action and then rerun the solution from the appropriate step. If the problem is bad data from station or satellite you can begin with `AUTCLN`, after removing the bad data from consideration using the `edit_site_sv` command in the (base) `autcln.cmd` file (taking advantage of `CVIEW`'s ability to generate these entries automatically for short segments removed using the `UNWT` command—see the last paragraph of Section 6.4). If the problem is a bad a priori station coordinate, you should begin with `MODEL` after updating the L- or T-file. If you suspect a bad orbit, you can first repeat the `SOLVE` run with the satellite excluded ( `exclude: PN04`, e.g., in the `Session Options` ) to test your hypothesis, and then add `edit_site_sv` entries to the `autcln.cmd` file to provide a permanent record and assure exclusion in future runs. Occasionally the appearance of bad data can be traced back to a problem with the information in the RINEX file (e.g., named incorrectly) or the auxilliary files of `GAMIT` ( `UT1.`, `pole.`, `station.info` ).

## 7. Running the Modules Individually

### 7.1 Introduction

Each module can be run individually using the batch files created by FIXDRV, edited if necessary to change input controls. To run the modules from a batch file, use the operating system option for the redirection of standard input devices. This option allows the user to redirect the input from a batch file rather than from the keyboard. For example, to run MODEL from batch input file bvent7.002, type

```
model <bvent7.002
```

and the program will take responses from the input file. This is the basis of the batch mode of processing. An examination of the primary and secondary input files output by FIXDRV will make these concepts clearer (Section 5.3).

### 7.2 Running ARC

The function of ARC is to create a T-file of tabulated ephemerides of the satellite coordinates and the partial derivatives of these coordinates with respect to initial conditions and the other adjustable parameters (just the three non-gravitational force parameters in the current version). Below is a sample batch file from the example network discussed in Chapter 5:

File bvent7.001 (ARC)

```
PRN 3
PRN 6
PRN 9
PRN 11
PRN 12
PRN 13
END
IGS92 SPHRC 900.0 75.0 GPST INERTIAL B1950
arcout.002
gvent7.002

87 23 21 37 23.00000
87 9 16 37 23.00000
Y
tvent7.002
```

The first five lines list the "names" of the satellites to be integrated (ARC expects names of the form PRN *nn* or NAVSTAR *nn*), terminated by END. The next line specifies the models and integration controls, read under format control. The preferred gravitational model is IGS92, invoking the IGS standard for GM and an 8x8 truncation of the GEM-T3 gravity

field. However, most GAMIT analyses prior to release 9.25, including the GARNER orbits generated at SIO, have used MERIT standards, so if you are reintegrating a G-file for regional analysis but combining the H-files with those generated elsewhere, be careful that the gravitational models are consistent. In multiyear analysis for station positions and velocities, there is no serious problem in having used different gravitational models to generate the orbits since the adjustments of initial conditions will absorb most of the model differences.

The only radiation pressure model available in the past has been a "flat-plate" or "spherical" (SPHRC) model in which adjustable parameters were defined for the Sun direction ("direct"), spacecraft y-axis ("y-bias"), and the Earth-pointing (spacecraft z) axis ("z-bias"). Only the first two of these are well determined and usually estimated. A better geometric model is defined by the Sun-pointing axis, y-axis, and a third axis orthogonal to both of these. Investigators at AIUB (Berne) (*Beutler et al.*, [1994]; see references in Chapter 2) have termed this third axis "x", but we designate it the "b-axis" to distinguish it from the spacecraft x-axis. This parameterization is available by specifying SRDYB, which allows three adjustable parameters, or BERNE, which allows the three constants plus once-per-rev accelerations (sine and cosine terms) along each of these three axes, for a total of 9 parameters. *Beutler et al.* [1994] (and the AIUB standard processing) incorporate into these formulations the ROCK4 model described by Fliegel et al. [*J. Geophys. Res.*, 97, 559–568, 1992], modified to lump the "X" and "Z" forces into a single "direct" force (M. Rothacher, personal communication, 1994). Tests carried out at MIT thus far have shown no improvement (in fact, a slight degradation) using the ROCK4 model, so we do not include it in BERNE or SRDYB. A second difference between the GAMIT and Bernese formulations is that we include shadowing only in the constant, direct solar term, whereas Berne includes it for all 9 terms. Two additional parameterizations are available: SRDYZ uses the same adjustable parameters as SPHRC but includes the original formulation of the ROCK4 model, with the additional forces applied along the X and Z axes. Finally, SRXYZ uses adjustable parameters and ROCK4 forces along the spacecraft x, y, and z axes. The details of these formulations may be found in the code and documentation of subroutine `ertorb.f` in the `/arc` directory.

The next two entries on the same line are for the T-file tabular interval and integration step-size, both given in seconds. The nominal values are 900 (15 minutes) and 75 seconds, respectively. The tabular interval must be an even multiple of the integration step-size. The final three entries give the time type (GPST or UTC) desired for the T-file (GPST is now default), and the reference frame, which in the current version must be 1950.0 inertial.

The next two lines give the filenames of the ARC printed output and the input G-file containing the initial conditions and initial values of the non-gravitational force parameters. There is then a blank line (for historical reasons), followed by the start and stop times of the integration, given as (2-digit) year, day-of-year, hours, minutes, seconds. The times

given are the times between which interpolation can occur; the actual values on the T-file will extend five epochs beyond the limits given. The last two lines of the ARC input contain a single control ( Y or N ) indicating whether the variational equations (partial derivatives with respect to initial conditions and parameters) are to be integrated, and the name of the output T-file.

The ARC print output file (ARCOUT.ddd ) summarizes the input controls and also records the times when each satellite is being eclipsed by the Earth. This information is useful in evaluating the level of stochastic variation (Markov parameters) to be allowed with multisession T-files in GLOBK. A sample output file is given below but with the summary for only one satellite included:

```

Output archive file: arcout.278
Input ICs file: ggpst7.278

9.16 of 94/07/26 14:40:00 (SunOS)

Standard spherical radiation pressure model used

Epoch of ICs, read from: ggpst7.278
Yr Mn Dy   Hr  Min Sec  JD      Sec of Day (GPST)
87 10  5    18 22 59. 2447074 66179.00000000

Input start time for observations:
Yr Mn Dy   Hr  Min Sec  JD      Sec of Day (GPST)
87 10  5    13  7 59. 2447074 47279.00000000

Input stop time for observations:
Yr Mn Dy   Hr  Min Sec  JD      Sec of Day (GPST)
87 10  5    23 37 59. 2447074 85079.00000000

TDT-GPST at IC epoch   = 51.1840 sec

***** PRN 9 *****
PRN 9 is a block 1 satellite and has a mass of 462600.0 grams

ICs found in the g-file:  X    Y    Z    XDOT YDOT ZDOT RAD1 RAD2 RAD3

Satellite and ICs: PRN 9
-0.256749494345660D+05 0.415313921343370D+04 0.565073203730440D+04
-0.104843035787760D+01 -0.158739652566680D+01 -0.336546540194340D+01
0.100000000000000D+01 0.000000000000000D+00 0.000000000000000D+00

Sat   Se  mimjr Ax  Eccen'ty  Perigee      Incl'n      Ascen.Node  Mn Anomaly
      _____  DDD MM SS.S  DDD MM SS.S  DDD MM SS.S  DDD MM SS.S
PRN 9  26560.651  0.012882  66 23 29.5  63 59 40.5  356 53 45.0  98 29 17.0

PRN 9 Radiation pressure, Y-Bias, Z-Bias: 0.100000D+01 0.000000D+00 0.000000D+00

IERS92/IGS Standards for model constants

Times written to T-file header (GPST)
IC epoch:      87 10  5 18 22 59.000000
Start   : 1987 10  5 11 22 59.000000
Stop    : 1987 10  6  1 22 59.000000
No. epochs:    57
Tabular interval: 900.0  Integration interval: 75.0000

```

```

          PJD      LAMBDA  YR DOY  MO  DY  HR MIN PRN
Start eclipse: 2447074.56631 0.161 87 278 10 5 13 35 PRN 9
Eclipsing:    2447074.54027 0.010 87 278 10 5 12 57 PRN 9
Eclipsing:    2447074.53940 0.912 87 278 10 5 12 56 PRN 9
End eclipse:   2447074.53853 1.000 87 278 10 5 12 55 PRN 9

Start eclipse: 2447075.03940 0.432 87 279 10 6 0 56 PRN 9

Output yaw file:  yvent7.278
Output ephemeris file: tvent7.278

```

The identification of the satellite as "Block 1" or "Block 2" is relevant to select the nominal direct acceleration in the radiation-pressure models. These are further modified by the nominal mass of the satellite, read from `filesvnav.dat`. This nominal direct acceleration also becomes the unit for the (smaller) estimated accelerations along the x-, y-, z-, and b-axes.

For the eclipse summary, the first line printed (`Start eclipse`) gives the first integration epoch for which the shadow factor ( `LAMBDA`; 1.0 = full sunlight ) is less than 1.0; this is followed by all epochs for which the factor is less than 1.0 (only one in this case) and the first epoch for which the factor is again 1.0 (`End eclipse`).

During the integration ARC will combine the eclipse information with the history of spacecraft yaw biases given in `svnav.dat` to create a session-specific Y-file of predicted spacecraft attitude for the span covered by the T-file. An example of a Y-file a span in late 1995 is shown below:

```

PRN  YAW_RAT  BIAS  YR MO DA  HR MN  ECLIPSE
 39  NOMINAL  yaw rates  - explanation of file in read_yaw.f
  1   0.123  P    95 10 30  9 15
  2   0.113  N    95 10 30  9 15
...
  9   0.128  P    95 10 30  9 15
  9   0.128  P    95 10 30  9 37  E
  9   0.128  P    95 10 30 15 37
  9   0.128  P    95 10 30 21 36  E   -134.4   9.7
  9   0.128  P    95 10 31  3 36
12   0.199  U    95 10 30  9 15
...
31   0.097  P    95 10 30  9 15

```

Examples are given for satellites with positively-biased ( `P` ), negatively-biased ( `N` ), and unbiased ( `U` ) yaw, and for satellites with no eclipses (PRNs 1, 2, 12, and 31) and two eclipses and a noon maneuver during the span ( PRN 9 ). The extra values given for the second eclipse of PRN 9 are the yaw and beta angles at the start of the eclipse; these are not written into the original Y-file by ARC but rather added by MODEL during processing. For an explanation of the history and importance of yaw modeling see Section 2.3 and *Bar-Sever* [1996]. See Section 9.8 for a listing of `svnav.dat` giving the history of yaw biases for all of the GPS satellites.

### 7.3 Running MODEL

The function of MODEL is to create a C-file containing the observation residuals (O-Cs) and partial derivatives to be used in SOLVE to estimate adjustments to parameters. Below is a sample batch file from the example network discussed in Chapter 5:

#### File bvent7.002 (MODEL)

```

S                Static Mode
pcato7.278       Print file
ivent7.278       Station clock polynomial (I-) file
lvent7.278       Coordinates (L) file
xcato7.278       Input X or C-file
ccato7.278       output C-file
N                Delete input C-file?
tvent7.278       T-file
I                Inertial frame
N                use W-file?
N                use Z-file?
jvent7.278       Satellite clock polynomial (J-) file
0 7 7           Geodetic datum / Tide model / SP Earth rotation
0.0 NONE        elevation angle cutoff (now ignored in MODEL) / antenna model
3 yventt.278     Clock model / Yaw file
1013.25 20.0 50.0 pressure, temp, humidity
SAAS SAAS NMFH NMFH

```

The first line indicates the type of experiment—static (S), kinematic (K), or dynamic (D)—and is used to guide MODEL in the reading of the X-file. There is an additional key-letter input possible ('O') if the X-file is 'old-style', written prior to October, 1991, and doesn't itself have an identifier for the type of experiment. The "hooks" for kinematic and dynamic processing have been put in MODEL (and most of the other modules), but these features are not yet operational.

The second line gives the name of the print (P) file that records the file-header and model information for the run. The P-file name is normally the same as the X-file name except for the first character, but any name can be used for test purposes.

The third line gives the name of the receiver-clock (I) file, which should have been created by FIXDRV. The I-file name is normally the same as the D-file name except for the first character, but again is arbitrary.

The fourth line gives the name of the site-coordinate (L) file. The L-file name is normally the same as the D-file name except for the first character, but again is arbitrary.

The fifth line gives the name of the input X- or C-file. MODEL will use the first character to determine the file type. The sixth line gives the output C-file name. This is followed by

an input ('Y' or 'N') indicating whether the input C-file should be deleted at the end of the MODEL run. If the the input data file is an X-file, MODEL will not delete it regardless of the entry on the seventh line.

The eighth line gives the name of the satellite ephemeris (T) file. The T-file name is arbitrary except for the first character. For single-day T-files, use of the last digit of the year and the day of year are convenient.

The ninth line indicates whether the MODEL computations are to be performed in an earth-fixed ('E') or inertial ('I') coordinate system. At present, only inertial frame computations are supported by ARC and MODEL.

The next group of questions tell MODEL whether you wish to use an input table for surface meteorological data (W-file) or water-vapor-radiometry data (Z-file). If the response to either of these questions is "Y", the name of the file should be added as an additional line following the question response. Use of these tables is relatively untested.

The next line gives the name of the satellite clock (J) file. The name is arbitrary but is usually the same as the D-file except for the first letter. The J-file should have been created from an E-file using MAKEJ. With Selective Availability invoked, a large J-file, computed using observations at a site with an atomic frequency standard, may be necessary.

Line 13 has three integers designating the geodetic datum and the models to be used for solid-earth and ocean tides and short-period (diurnal and semidiurnal) oscillations of UT1 and pole. The current version of GAMIT works properly only in spherical (internally Cartesian) coordinates, so ' 0' should always be specified for the datum. The integer controlling the tide model is binary coded—the first (1) bit for the default frequency-independent model for solid-earth tides, the second (2) bit for a frequency-dependent model for the K1 solid-earth tide, the third (4) bit for the pole tide, and the fourth (8) bit for ocean tides. The default (7) is to apply the first three models. Previous versions of GAMIT did not use the pole tide, but GLOBK will detect this and add it when combining h-files. Application of ocean tides requires an additional input table (tide.) and is still being tested

Line 14 was formerly used for the elevation cutoff angle, but this can no longer be controlled in MODEL; hence the zero entry. The other entry on this line is a keyword indicating the model to be used for antenna phase-center variations. The default is NONE, but a table ( antmod.dat ) may be used to provide an elevation-dependent ( ELEV ) or elevation-and-azimuth-dependent ( AZEL ) model. See Appendix 7 for the current state-of-knowledge of the mean and time-variable locations of the L1 and L2 phase centers for commonly used GPS antenna.

The next line has two unrelated entries. The first (integer) specifies the way in which the receiver clock is determined. A value of 1 indicates no correction is to be calculated—the time-tag on the X- (or C-) file is accepted as correct; this option is used for a receiver that keeps its clock synchronized with GPS time. A value of 2 indicates that the first or second order polynomial estimated from pseudoranges in FIXDRV and stored in the I-file is used to model the clock throughout the session; this option is valid for clocks that maintain continuity and have a stability of better than 1 part in  $10^{-8}$  over the session, such as the TI4100 or any receiver attached to an atomic frequency standard. A value of 3 forces a clock estimate from pseudoranges at each epoch; this is the most general option and can be used under all circumstances except when the clock is synchronized but the pseudoranges are corrupted, as was the case with early MiniMac data. The second entry is the name of the satellite yaw file to be read to determine the spacecraft attitude.

The last two lines allow you to select the default (fixed) values for surface meteorological data and the models to be used in computing the atmospheric delays. The default models are shown; see Chapter 8 for a more detailed discussion.

A summary of the MODEL run is contained in the P-file. A typical P-file is shown below. It records, successively in divided sections, 1) the version and files used, 2) the X-file header information, 3) T-file header information, and 4) the information actually used by MODEL and recorded on the output C-file header. In reading a P-file, be careful not to confuse X-file header values (for, e.g. antenna height or station coordinates) with the values read at run-time and used by MODEL. At the end of the P-file are warnings issued by MODEL regarding the calculation of receiver-clock corrections.

```
-----
** ** MODEL VERSION AND INPUT FILES SUMMARY **
```

```
      Program MODEL Version 9.78 of 98/06/04 17:25:00 (SunOS)
```

```
MODEL Run on 1998/ 6/ 5 14:53:11 by rwk
```

```
Receiver-clock (I-) File : ivent7.278
```

```
Site Coordinate (L-file) File : lvent7.278
```

```
Input Observation File: xcato7.278
```

```
Output C-file       : ccato7.278
```

```
Ephemeris (T-) File : tvent7.278
```

```
SV clock (J-) File  : jvent7.278
```

```
-----
** X-FILE HEADER INFORMATION **
```

```
GPS Phase and Pseudorange for GAMIT Processing
```

```
MAKEX v. 6.31 of 89/08/18 20:47:
```

```
Run by brad           on 1989-08-23 14:21:23
```

```

MADE FROM FILE: //bullen/data/gps/trex9/y87d278/cato7.278.fic
HEADER FROM SOURCE FICA FILE:
UNPACK 1.7      MIT GPS 1988021413:52:03   cato7kurt      MEMTEC
Operator input site code          CATO
Operator initials                  FW
Operator input receiver serial num UN02
Operator input antenna height (m) 1.0000
Operator input humidity (%)        75.0000
Operator input temperature (deg C) 150.0000
Operator input pressure (Mb)       980.0000
Software version number            1.2000

```

CVIEW run  
CVIEW run

X-File written from C-File : ccatoc.278

END

```

Site: Solstice Cyn
Coordinates (lat,lon,rad): 33 54 26.00037 118 47 4.92878 6372399.996000
Receiver software: GES 1.20 Antenna: TI4100
Antenna offsets (Up North East) L1: 1.3410 0.0000 0.0000 L2: 1.3160 0.0000 0.0000 meters
Start time: 1987 10 5 14 37 55.080 UTC

```

Channels= 7 Epochs= 225 Interval= 120

Original data interval= 0 Session= 1

Partials= 0 IDUAL= FRQFAC=

Channel	PRN	Data type:	1	2	3	4
		LAMBDA				
1	3		-1	-1	1	1
2	6		-1	-1	1	1
3	8		-1	-1	1	1
4	9		-1	-1	1	1
5	11		-1	-1	1	1
6	12		-1	-1	1	1
7	13		-1	-1	1	1

-----  
\*\* T-FILE HEADER INFORMATION \*\*

Tabular ephemeris file generated from gvent7.278 4- 6-1998 16:52:45 15

```

Epoch of initial conditions: 10 5 87 18. 22. 59.000
Ephemeris start : 10 5 1987 12. 7. 59.000
Ephemeris end : 10 6 1987 0. 37. 59.000
Tabular interval (sec) : 900.000
T-file epochs : 51
Comments :

```

```

GPST INERTIAL B1950 IAU68 IAU80 IGS92 BERNE
X Y Z XDOT YDOT ZDOT DRAD YRAD BRAD DCOS DSIN YCOS YSIN BCOS BSIN

```

```

Number of satellites : 7
NINTRS : 48
Orbital parameter types : X Y Z XDOT YDOT ZDOT DRAD YRAD BRAD DCOS DSIN
YCOS YSIN BCOS BSIN

```

```

Satellite name and ics :
PRN 3 -13976.909468 22548.101150 3693.221053 -1.1970 -1.3321 3.3986 1.0000 ... 0
PRN 6 -24301.947288 -3636.941639 -10053.296475 1.5332 -1.6140 -3.1724 1.0000 ... 0

```

...

-----  
 \*\* INPUT MODELING INFORMATION \*\*

## SVs selected

Channel: 1 2 3 4 5 6 7  
 PRN #s : 3 6 8 9 11 12 13

## SV type and antenna offset from center of mass

PRN #	Blk id	DX	DY	DZ (m)
3	1	0.2100	0.0000	0.8540
6	1	0.2100	0.0000	0.8540
8	1	0.2100	0.0000	0.8540
9	1	0.2100	0.0000	0.8540
11	1	0.2100	0.0000	0.8540
12	1	0.2100	0.0000	0.8540
13	1	0.2100	0.0000	0.8540

## Input I-file clock ploynomial coefficients

Epoch (seconds) 0.117102D-04  
 Rate (seconds/second) -0.420373D-08  
 Acceleration (1/SEC) 0.000000D+00  
 Cubic term (1/S/S) 0.000000D+00

Rcvr firmware from X or C-file ( 1.20) does not match station.info ( 0.00)---  
 station.info value written on C- and H-file

## Datum read from file GDETIC.DAT

Title reads: Geodetic Datums yb/rwk 87.4.21  
 Datum selected: a 1/f DX DY DZ  
 WGS84 6378137.000 298.257223563 0.000 0.000 0.000

## Tidal corrections applied are: 3

The value is decoded as:

- 1 = solid earth tides
- 2 = frequency dependant K1 model
- 4 = pole tide
- 8 = ocean tides

The corrections are applied as per the binary option

That is a value of 15 implies all corrections

## Short period earth orientation corrections applied are: 3

The value is decoded as:

- 0 = no short period corrections
- 1 = short period pole corrections
- 2 = short period ut1 corrections

The corrections are applied as per the binary option

That is a value of 3 implies all corrections

## Antenna type from station.info: TI4100

Standard code: TI4100 Full name: TI 4100

Offset from monument (code, U,N,E): SLPAB 1.1170 0.0000 0.0000

equivalent to ARP offset: 1.1138 0.0000 0.0000

--constant throughout session

Phase center model requested: NONE Used: G1\_GAMIT\_9.2\_\_\_\_ Code: NOG1

TI4100 L1 phase center offsets from ARP from antmod.dat [UNE] (mm): 227.0 0.0  
 0.0

TI4100 L2 phase center offsets from ARP from antmod.dat [UNE] (mm): 202.0 0.0  
 0.0

Mean L1 offset from monument [UNE] (m): 1.3408 0.0000 0.0000

Mean L2 offset from monument [UNE] (m): 1.3158 0.0000 0.0000

```

Atmospheric models
Sea-level pressure =          1013.250 mb
Sea-level temperature=        20.0 degs C
Relative humidity =           0.50 (fractional)
Zenith delay models and mapping functions:
  DRYZEN WETZEN DRYMAP WETMAP
  SAAS  SAAS  NMFH  NMFH

```

```
-----
** OUTPUT C-FILE HEADER INFORMATION **
```

GPS Phase and Pseudorange for GAMIT Processing

```

MAKEX v. 6.31 of 89/08/18 20:47:
Run by brad          on 1989-08-23 14:21:23

```

```

MADE FROM FILE: //bullen/data/gps/trex9/y87d278/cato7.278.fic
HEADER FROM SOURCE FICA FILE:
UNPACK 1.7      MIT GPS 1988021413:52:03   cato7kurt      MEMTEC
Operator input site code          CATO
Operator initials                  FW
Operator input receiver serial num UN02
Operator input antenna height (m)  1.0000
Operator input humidity (%)        75.0000
Operator input temperature (deg C) 150.0000
Operator input pressure (Mb)       980.0000
Software version number            1.2000

```

```

CVIEW run
CVIEW run

```

X-File written from C-File : ccatoc.278

```

Model 9.78 of 98/06/04 17:25:00 (SunOS)
Run on 1998/ 6/ 5 14:53:  by rwk

```

Record 2 :

Site: Castro Peak

```

Rcvr, SN:  TI 4100
Ant, SN:    TI 4100
Rcvr, SW:   GES 0.00

```

Coordinates (lat,lon,rad): 0.59179633 -2.07320273 radians 6372.284511

```

Antenna offsets (Up North East) ARP:
1.1138 0.0000 0.0000 L1: 1.3408 0.0000 0.0000 L2: 1.3158 0.0000 0.0000 meters

```

SKD=S MTIME= 2 NEPOCH= 225 INTER= 120 IRCINT= 120

Start time: 87 5 10 14 37 59.080 (GPST) Session: 1

```

Channel PRN  Data type:  1  2  3  4
                      LAMBDA
   1      3             -1 -1  1  1
   2      6             -1 -1  1  1
   3      8             -1 -1  1  1
   4      9             -1 -1  1  1
   5     11             -1 -1  1  1

```

12 October 2000

```

6      12      -1 -1  1  1
7      13      -1 -1  1  1

```

Raw data file: XCATO7.278 T-file: TVENT7.278

J-file: jvent7.278

Bias flags ( 1) : 0 0

Models: B1950 IAU68 IAU80 IGS92 BERNE

Ephemeris epoch (PEP JD, sec GPST) : 2447074 66179.000

Earth rotation

```

Epoch (PEP JD, sec GPST) : 2447074 66119.080
UT1-TAI, UT1dot (s, s/d) : -23.49007 -0.00166 UT1 type: 2
xp, xpdot (arcs, arcs/d) : -0.05586 -0.00060
yp, ypdot (arcs, arcs/d) : 0.30169 0.00134
psi, psidot (arcs, arcs/d) : -1.09850 0.00000
eps, epsdot (arcs, arcs/d) : 9.74699 0.00000

```

Met data (series binary flag) : 7

Zenith delay (m) : 2.2123

Station weight = 1.0

NPART=26 NLABEL=20 NEXTRA 1

EXTRA= 0.00

Record 3 :

```

RLABEL, ISLOT, IDMS =SITE # LAT. (DMS)      1  1
                      SITE # LONG.(DMS)     11  1
                      SITE # RADIUS (KM)     21  0
                      ATMOSPHERE             31  0
                      SITE # CLK EPOCH       41  0
                      ORBIT X km             101 0
                      ORBIT Y km             111 0
                      ORBIT Z km             121 0
                      ORBIT Xdot km/s        131 0
                      ORBIT Ydot km/s        141 0
                      ORBIT Zdot km/s        151 0
                      RAD PRES DIRECT        161 0
                      Y AXIS BIAS            171 0
                      B AXIS BIAS            181 0
                      COS DIRECT             191 0
                      SIN DIRECT            201 0
                      COS Y BIAS            211 0
                      SIN Y BIAS            221 0
                      COS B BIAS            231 0
                      SIN B BIAS            241 0

```

```

PREVAL= 0.59179632565998D+00 -0.20732027318210D+01 0.63722845106000D+04
        0.22123446029015D+01 0.11710230000000D-04 -0.42037335000000D-08
        0.00000000000000D+00 -0.13976909467684D+05 0.22548101149911D+05
        0.36932210527633D+04 -0.11970220164939D+01 -0.13320686827172D+01
        0.33985770848327D+01 0.10000000000000D+01 0.00000000000000D+00
        0.00000000000000D+00 0.00000000000000D+00 0.00000000000000D+00
        0.00000000000000D+00 0.00000000000000D+00 0.00000000000000D+00
        0.00000000000000D+00 -0.24301947287728D+05 -0.36369416390653D+04
        -0.10053296474502D+05 0.15331794338002D+01 -0.16140243063355D+01
        -0.31724316986411D+01 0.10000000000000D+01 0.00000000000000D+00
        0.00000000000000D+00 0.00000000000000D+00 0.00000000000000D+00

```

```

0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 0.26708660387432D+04 -0.21097415555649D+05
0.16134956701078D+05 0.23822396282475D+01 -0.16491869581020D+01
-0.25422889115928D+01 0.100000000000000D+01 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 -0.25674949434566D+05 0.41531392134337D+04
0.56507320373044D+04 -0.10484303578776D+01 -0.15873965256668D+01
-0.33654654019434D+01 0.100000000000000D+01 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 -0.81237872687489D+04 -0.98838109221874D+04
0.23389414394361D+05 0.20904296667312D+01 -0.31751918542911D+01
-0.66573089221972D+00 0.100000000000000D+01 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 -0.14938585132190D+05 0.10564066754801D+05
0.19579413854459D+05 -0.31835280614272D+01 -0.82201988393225D+00
-0.19824156922850D+01 0.100000000000000D+01 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 -0.15948840452290D+05 0.93986557781736D+04
0.19029837926710D+05 0.52050149665399D+00 -0.32470509987392D+01
0.20508523425603D+01 0.100000000000000D+01 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 0.000000000000000D+00 0.000000000000000D+00
0.000000000000000D+00 -0.55859160277778D-01 -0.600000000000003D-03
0.30168593809399D+00 0.13425022500666D-02 -0.23490069961604D+02
-0.16590441639308D-02

```

-----  
\*\* END HEADER INFO -- BEGIN PROCESSING MESSAGES

```

No valid data for RCLOCK at epoch 50
No valid data for RCLOCK at epoch 65
No valid data for RCLOCK at epoch 199
MODEL warning in EPOCH_CLK:
  receiver clock correction from PRN03 at epoch 202 is enormous: 1.2030E+02 seconds!
MODEL warning in EPOCH_CLK:
  receiver clock correction from PRN03 at epoch 202 is enormous: 1.2030E+02 seconds!

```

```

PRN  Ngood
03   109
06   89
08   33
09  137
11  113
12   61
13  165

```

### 7.4 Running CFMRG

The purpose of CFMRG is to create an M-file to control the combination of C-files and selection of adjustable parameters to be input to the estimation module SOLVE. SOLVE rewrites the M-file, adding adjustments to the parameters; this updated M-file is then read by CVIEW to calculate predicted postfit residuals. A sample input batch file follows:

```
BATCH
cato          4 letter site code
love          4 letter site code
moja          4 letter site code
pver          4 letter site code
safe          4 letter site code
wsfd          4 letter site code
yknf          4 letter site code

   3   6   8   9  11  12  13      Total PRN Numbers
ccatod.278    C-file
cloved.278    C-file
cmojad.278    C-file
cpverd.278    C-file
csafed.278    C-file
cwsfdd.278    C-file
cyknfd.278    C-file
END
EEEEEEEE
mventa.278    M-file
Y             coordinate partials?
Y             atmospheric partials? This should be hard wired
   4   4   4   4   4   4   4      Number zenith delay parameters
Y             orbital partials?
Y             SV antenna offset partials?
Y             gradient parameters estimated? (Y/N)
   1   1   1   1   1   1   1      Number of gradient parameters - Session 1
```

The structure of the batch file is rather archaic, with many entries present for historical rather than logical reasons. The first line of the input file specifies batch mode for CFMRG; interactive mode is no longer supported. This is followed by a site of the 4-letter site codes for the run, a blank line, and a list of the satellites appearing on the C-file. Next is a list of the C-files to be included, terminated by 'END'. The next line, a string of 'E's, one for each station, specifies that explicit, rather than implicit biases are to be used. Next is the M-file name, which must match the name given in the SOLVE batch file. The 'Y' ('yes') for coordinate partials may be changed to 'N' if sites coordinates are not to be included in the SOLVE parameter menu (for 'ORBIT' mode in SOLVE)). The 'Y' for atmospheric or gradient partials should not be changed. The number of zenith-delay parameters or gradient parameters to be used may be changed, but must match the values in the SOLVE batch file and must be the same for all sites. The 'Y's for orbit and satellite antenna offset partials may be changed to 'N' if no orbital parameters are to be adjusted and you do not wish to have them appear in the SOLVE menu.

### 7.5 Running SOLVE

The principal inputs to SOLVE are the C-files and an M-file. The phase data, the O-C's, and the partial derivatives are read from the C-files; the parameter menu and pointers are read from the M-file. The adjusted values are output to the M-file in order to compute the post-fit residuals in SINCLN, DBLCLN, or CVIEW, and adjusted station, orbital, and (optionally) clock parameters are written to new L-, G-, and I-files, respectively, for use in subsequent processing.

SOLVE was originally designed to be interactive in order to facilitate manual intervention in resolving phase ambiguities. With the increasing size of GPS networks, interactive use is less tractable, and this feature is no longer supported. With SOLVE version 9.33 we have radically changed the input batch file to replace commands designed originally for interactive operation with commands more easily understood and edited by the user. The batch file generated by FIXDRV for the 'full' (not 'quick') solution for the sample network discussed in Chapter 5 is shown below with comment lines added to document additional controls.

```

=====
*   << key-word-controlled batch file format >>                               *
*   symbol ":" must exist in command lines as separator                       *
*   any non-blank character at first column means comment line               *
*   empty after ":" means comment line too                                   *
=====
*
----- Part 1 -- Files and Global Controls
operation mode:      batch
Q-file name:        qventa.278
H-file mode:        0
datum code:         0
M-file name:        mventa.278
quick solution choice:  full
biases:             explicit
phase difference options: double difference
combination mode:   LC_HELP
  bias search approach: decision function
  search path:      narrow lane
  search criteria:  0.15  0.15 1000.00  10.00
start and end epochs:  1  225  1
set cutoff_elevation:
  cutoff: all_sites 15.0
error model:
  stn_error: all_sites uniform 10.0
  sat_error: all_sats 0.0
*
----- Part 2 -- Parameters
set parameters:
  estimate: all_sites all_parameters
  fix:     all_sites clock
#  fix:    all_sites zenith
  fix:    all_sites grad

```

```

estimate:  all_sats all_parameters
fix:       all_sats clock radiation
fix:       global all_parameters

exit set:
*

----- Part 3 -- A priori Constraints
set apriori constraints:
tight_apr_coord:  cato 100.000 100.000 100.000
tight_apr_coord:  love 100.000 100.000 100.000
tight_apr_coord:  moja 100.000 100.000 100.000
tight_apr_coord:  pver  0.010  0.010  0.010
tight_apr_coord:  safe 100.000 100.000 100.000
tight_apr_coord:  wsfd  0.010  0.010  0.010
tight_apr_coord:  yknf  0.010  0.010  0.010
loose_apr_coord:  all_ 100. 100. 100.
zenith delays: all_sites 4 PWL
tight_apr_zenith:  cato 0.500 0.005 100.0
loose_apr_zenith:  cato 0.500 0.005 100.0
tight_apr_zenith:  love 0.500 0.005 100.0
loose_apr_zenith:  love 0.500 0.005 100.0
tight_apr_zenith:  moja 0.500 0.020 100.0
loose_apr_zenith:  moja 0.500 0.020 100.0
tight_apr_zenith:  pver 0.500 0.020 100.0
loose_apr_zenith:  pver 0.500 0.020 100.0
tight_apr_zenith:  safe 0.500 0.020 100.0
loose_apr_zenith:  safe 0.500 0.020 100.0
tight_apr_zenith:  wsfd 0.500 0.020 100.0
loose_apr_zenith:  wsfd 0.500 0.020 100.0
tight_apr_zenith:  yknf 0.500 0.020 100.0
loose_apr_zenith:  yknf 0.500 0.020 100.0
tight_apr_grad:   cato 0.030 0.030
loose_apr_grad:   cato 0.030 0.030
tight_apr_grad:   love 0.030 0.030
loose_apr_grad:   love 0.030 0.030
tight_apr_grad:   moja 0.030 0.030
loose_apr_grad:   moja 0.030 0.030
tight_apr_grad:   pver 0.030 0.030
loose_apr_grad:   pver 0.030 0.030
tight_apr_grad:   safe 0.030 0.030
loose_apr_grad:   safe 0.030 0.030
tight_apr_grad:   wsfd 0.030 0.030
loose_apr_grad:   wsfd 0.030 0.030
tight_apr_grad:   yknf 0.030 0.030
loose_apr_grad:   yknf 0.030 0.030
tight_apr_orbit:  PN03 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
tight_apr_orbit:  PN06 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
tight_apr_orbit:  PN08 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
tight_apr_orbit:  PN09 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
tight_apr_orbit:  PN11 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
tight_apr_orbit:  PN12 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
tight_apr_orbit:  PN13 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.0E+04 1.E+03
loose_apr_orbit:  all_ 10. 10. 10. 10. 10. 10. 1000. 1000. 1000.

```

```

exit set:
*
-----Part 4 -- Session Options
set session_1 options:
  include:          all_sites all_sats
  atmosphere constraint:      N
  ionosphere constraint:      0.0  1.0
  wide lane ambiguity criteria: 0.15  0.15  1000.0  10.00
exit set:
*
----- Part 5 -- Solution Options
set tight_free solution option:
  print out solution:      q-file ofile
  print out solution:      q-file ofile
  update file option:      m-file l-file g-file
  input_m file name:      mventa.278
  output_m file name:      mventa.278
  input_l file name:      lvent7.278
  output_l file name:      lventa.278
set tight_fix solution option:
  print out solution:      q-file ofile
  update file option:      m-file l-file g-file
  input_m file name:      mventa.278
  output_m file name:      mventa.278
  input_l file name:      lvent7.278
  output_l file name:      lventa.278
  input_g file name:      gvent7.278
  output_g file name:      gventa.278
  g_line:  By FIXDRV          qventa.278          rwk          12/22/1993
17:07:50
set loose_free solution option:
  update file option:
exit set:
set loose_fix solution option:
  print out solution:
exit set:

```

With the new batch file, almost all of the SOLVE options and constraints can be changed simply by editing the command lines. In Part 1, for example, you can rerun SOLVE with a different observable or ambiguity-resolution options, for example by changing combination mode, bias search approach, and search criteria. The combination mode keywords are the same as in thesestbl. for Choice of observable as explained in Section 5.2. The only ambiguity resolution schemes that have been exercised with recent data are the range-priority algorithm selected by combination mode = LC\_RANGE and tuning of the deviation and sigma of the search criteria as discussed in Section 5.5. However, other approaches, including simple rounding and use of an expectation function, are coded and could be invoked by users interested in further research in this area (see *Blewitt [1989]*, *Dong and Bock [1989]*, and SOLVE subroutine bisopt.f) The algorithm and parameters for the wide lane resolution are specified in the batch file under Session Options since these depend on instrumentation and ionospheric activity.

Editing the batch file is particular convenient for running quickly different subsets of the data. To change the span or sampling, edit `thstart` and `end epoch$line`, in which the first value is the start epoch, the second the end epoch, and the third the decimation factor. To the low-elevation cutoff, edit the numerical value and/or add additional lines:

```
cutoff: all_sites 15.0
cutoff: cato 20.0
```

The `error model` keywords and values are analogous to those in the `sestbl`. (Section 5.2), in which you can chose uniform, baseline-length-dependent (`baseline`), or elevation-angle-dependent (`elevation`) weights for any or all stations, and/or different weights for individual satellites. For example,

```
error model:
  stn_error: all_sites uniform 10.0
  stn_error: cato elevation 4.3 7.0
  sat_error: all_sats 0.0
  sat_error: PN09 20.
```

To fix a parameter, add its name to the list in Part 2; i.e.,

```
fix:          all_sites clock cato long
```

to fix the longitude of site 'CATO' (Castro Peak). In Part 3 are given the a priori constraints for sites, orbital parameters, and zenith-delays for both the tight (user-specified, in `sestbl`.) and loose (default, for GLOBK) solutions. The units for all of these inputs are meters for position and meters/second for velocity. Note that for zenith delays, it is best to use the same constraints for the loose solution as for the tight, since GLOBK does not estimate these parameters.

To unweight stations or satellites in the solution, use the `exclude` command in Part 4; e.g.,

```
exclude:      cato pver pn03
```

Part 5 specifies mainly the output files for the run. You can change the names of any of these if you want, e.g., to make multiple runs with the same data.

When SOLVE runs it writes output both to standard output (screen or the `.log` file) and to the Q-file. The screen output is almost the same as the Q-file but includes also a record of every 50 epochs as the program is running plus and indication of when additional (implicit) bias parameters are inserted as the data are read and the normal equations formed. An explanation of the Q-file is given in Chapter 5.

## 7.6 Running AUTCLN

AUTCLN operates on one or more C-files to flag and/or patch cycle slips and unweight questionable data, using all combinations of the available phase and pseudorange data. The program is executed using a single runstring:

```
autcln <command file> <out of series> [...list of cfiles...] OR
      [dfile name] <in cf series>
```

where <command file> is an optional command file (commands are given in the ctogobs.hlp file). If no command file is given (default file generation) then " should be used as a place holder in the runstring. If defaults is given as the command file then the defaults will be printed. The program will not act on the rest of the runstring.

<out of series> is a single character to denote the new cfile series to be written out. If no character given (i.e., ' ' used) then no updated cfiles will be written. Special characters that can be used are:

- . -- Overwrite the input C-files
- + -- Increment the C-file series letter, converting numeric series values to a.

[...list of cfiles...] is the list of cfiles to be cleaned

or

[dfile name] is the name of a D-file with the list of C- (or X-) files

<<in cf series> when the dfile form is used this optional argument can be used to change the input cfile series from that in the D-file.

A sample AUTCLN command file is given in Chapter 6 and copied below.

```
AUTCLN Command File
remove_bias_cond 10.0 3.0 1800.0
allow_one_bg yes
use_gamit_elev yes
use_cview_edit yes
remove_first_bia yes
dd_return_size 100 25 5 10.
* Site dependent ion parameters
ion_jump fair 120 6 2 5
ion_jump kour 120 6 2 5
ion_jump yell 120 6 2 5
ion_jump darw 120 6 2 5
ion_jump mcmu 120 6 2 5
ion_jump trom 120 6 2 5
```

A non-blank character in the first column denotes a comment. All commands are case insensitive. A complete list, copied nearly verbatim from the on-line help file (kf/help/autcln.hlp ) is given below:

end Last command issued. An end-of-file (EOF) will have the same effect.

use\_postfit <mfile name>

Used to invoke postfit editing. The argument may be all or part of the m-file updated with adjustments by SOLVE. If no argument is given then the name is assumed to be `m[dfnm]a.ddd` where `[dfnm]` are the four characters from the D-file name given in the AUTCLN runstring. If one character is given this is assumed to be the series name (i.e., a, b..). If less than seven characters are given these are used as the beginning of the name of the M-file; if 7 or more, they are assumed to be the complete M-file name. If the M-file cannot be opened, then a warning message is printed and prefit residuals will be used. The M-file does not need to contain all of the stations being used by AUTCLN. Note: Care should be taken that the M-file goes with the current C-files (i.e., that MODEL has not been re-run using different parameter values since the M-file was created).

apply\_phs\_clk [MAX Iter] [Non-int] [Converged %] [Over shoot]

This command will invoke a new feature in which will generate one-way phase residuals which should have all the clock effects from the ground sites and satellites removed. The process is done iteratively with the arguments allowing the user some control. `MAX Iter` is the maximum number of iterations (default 30). `Non-int` is the number of iterations before a non-integer bias parameter will be used in estimating the clock offset (default 3). `Converged %` gives the percent change in the rms of the one-way residuals between iterations that will be taken to mean the solution has converged (default 0.1 %). `Over shoot` can be used to speed convergence. At each iteration, the mean offsets of the one-way residuals are computed and removed. The overshoot is a multiplier used so that more than the mean is removed at each iteration. The default is 1.5, and values greater 2 seem to cause solutions to diverge. All of the arguments are optional with the default being used for any values not passed. Invoking this option will normally double the AUTCLN runtime. The solution will not be affected unless there are pathological clocks that cause numerical problems in SOLVE, in which case `apply_phase_clk` will usually fix the problem. With this option on, the RMS scatters of the one-way residuals are computed and added to the summary file. These can be useful when attempting to diagnose problems. *Caution:* The one-way residuals will look flat in CVIEW only when the same M-file is used in AUTCLN.

postfit\_edit [Start Iter] [Nsigma] [Max Restore] [Max rms]

This commands allows editing of phase residuals using an n-sigma criterion. `Apply_phs_clk` is invoked when this option is used. `Start Iter` denotes the iteration number in `apply_phs_clk` before editing starts. Several iterations should be made before editing. The default is 9. `Nsigma` is the multiplier threshold in sigma

units for deleting data. The sigma used is the RMS scatter of the LC phase data from each site. The default is 4.0. LC residuals that are less than  $n\text{-sigma}$  and have been flagged due to close bias flags can be restored provided they are less than `max_restore` (default 0.5 cycles). If a station's RMS is greater than `Max rms`, its data will be completely removed from the solution (default 0.5 cycles)

```
rng_jump_tol [n-allan sd] [min jump(μsec)]
```

This command specifies the size of a discontinuity in the range O-C that will be considered a clock jump. The first value `n-allan sd` is the multiplier of the clock stability given by the Allan standard deviation and the second value (`min jump (μsec)`) is the minimum, in microseconds, that will be considered a jump in microseconds; .i.e., both numbers must be exceeded for a clock jump to be flagged. The default values are 100.0 and 0.95, but to better detect bad ranges that cause problems with postfit editing, values of 20. and 0.1 may be preferred.

```
clk_reset_tol [jump difference(μsec)]
```

Tolerance for jump to be taken as a millisecond reset in the clock ( $\mu\text{sec}$ ). A typical value is 10  $\mu\text{sec}$ , but it may need to be increased if a priori clock polynomial (from FIXDRV) does not match the data well (for example due to bad a priori station coordinates or satellite orbits). The default is set to 100  $\mu\text{sec}$  to account for low quality crystal clocks in many receivers.

```
rng_resid_tol [n-sigma] [min error (m)] [max error (m)]
```

Tolerance for bad range residuals. Range residuals are computed after satellite and station clocks are estimated. They are equivalent to doubly differenced range residuals are affected by poor station coordinates and satellite orbits. The maximum value before a point will be deleted is  $n\text{-sigma}$  times the rms of the range residuals, but the value tolerance value cannot be less than `min error` nor more than `max error`, both in meters. The defaults are 10. 190. 380 and should not be overridden unless many BAD Pre-RNG data for messages appear.

```
ion_jump_tol [Receiver code/ALL] [max gap (sec)] [Multiplier]
             [Min dIon (cyc)] [Max dIon (cyl)]
```

Lets user set the tolerances for detection cycles slips in the ionospheric delay (LG). The maximum jump allowed is set by minimum of the `Max dIon` and the maximum of the `[multiplier]` by the last change in the ion delay and the `Min dIon (cyc)`. That is tolerance will fall somewhere between `Min dIon` and `Max dIon` with the intermediate values set by the `Multiplier` by the change in the previous two data points. The test will be done for all data points separated by `[max gap]` or less and all contiguous data. The default values are 30. 6. 2.0 5.0, which work well with modern receivers even in polar and equatorial regions. With older receivers and a quiet ionosphere, the first three values should be 240. 4. 0.8 to provide more sensitive detection of cycle slips.

`rng_noise` [Receiver code/ALL] [noise (mm)]

Lets user specify the apriori values for the standard deviation of the range measurements by site (initial values only). They will be updated during the AUTCLN run and the updated values reported in the clock and range statistics in the output and summary file.

`max_rclk_iterations` [max iterations]

Maximum number of range clock iterations. The solution for the estimate of the satellite and station clocks is iterated to determine the statistics of the range noise and clock Allan standard deviations. The iteration stops either at [max iterations] or until the convergence criteria are met.

`rel_clk_weight` [weight]

Weight to be given to the clock noise model based on previous iteration's estimate of the Allan standard deviations of the clocks relative to data noise while estimating the clocks. Typical value is to down weight the clock statistics by a factor of 10 relative to the data.

`rng_clk_root` [range clock root of file names]

Lead part of the name to be given to the range clock solution output. If no root is given then the range clock solution will not be output. For example `crng` will produce output files named `crng.PIN1` and `crng.PRN_21`. A `cplot` command file will also be generated called `<root>.plt`

`phs_clk_root` [phase clock root of file names]

Lead part of the name to be given to the phase clock solution output. If no root is given then the phase clock solution will not be output. See `rng_clk_root`.

`phs_res_root` [phase residual root of file names]

Lead part of the name to be given to the one-way phase residual (to the prefit model) output. If no root is given then the phase will not be output. See `rng_clk_root` and `residual_site`

`sng_diff_root` [single difference file root]

Lead part of the name for single difference between stationsfiles (These may be used with the program `mon_data` to processing single difference kinematic data). The single differences are between first site and subsequent sites. The `residual_site` list is used select which sites to write to single difference files, which are only generated if C-files are written out.

`residual_site` [List of four character codes/ALL/NONE]

Lets the user specify which sites should be output to the phase residual or single difference files

`summary_file` [Name of summary file/6]

Name of a summary file. If the command is not given, the summary is written to a file named `autcln.sum`. If 6 is given as the file name then the summary is written to standard out.

`rcv_allan_sd [site code/ALL] [Allan standard deviation (ppb@100sec)]`

Allows the user to specify the Allan standard deviations of the clocks at each site. These are updated during AUTCLN run.

`remove_bias_cond [Chi**2 Ratio] [min chi**2] [max gap] <large gap scale>`

Sets the constraints for removing biases. A bias flag is removed if

$$X = C2/(C1 + \min * \exp(-C1/\min)) > \text{ratio}$$

where C1 is the smallest chi\*\*2 obtained during trial fixes to integer values; C2 is the next smallest; min is min chi\*\*2 in the command; and ratio is Chi\*\*2 Ratio in the command. In addition, the gap must be smaller than max gap. The default values of Chi\*\*2 Ratio, min chi\*\*2, and max gap are 12., 3., and 3600. (sec), respectively. The final argument large gap scale is optional; if it is specified, then the value of X computed from the data is reduced by  $1 + \text{large gap scale} * \text{atan}(\text{gap}/\text{min data})$  where gap is the gap in the data and min data is the smaller of the number of data in the left and right segments about the gap. The default value of large gap scale is 5.0

`allow_one_bg [yes/no]`

Deals with the case where all channels of a receiver slip at nearly the same time. By specifying yes you allow AUTCLN to select one channel as a base, patch it roughly in one-ways, and the patch all other channels with respect to it.

`use_gamit_elev [yes/no]`

If yes is specified (default), then the cutoff angle specified in the C-file will be used in editing and outputting data, the safest approach for rerunning old data (cutoff passed from the C-file to the X-file via CTOX). With new data a better approach is to use the min\_elev command of AUTCLN and to control use of data by SOLVE with the GAMIT sestbl. input.

`use_cview_edit [yes/no]`

Allows user to specify if the CVIEW unweight flag (-1) should be used or not. If yes is specified then the CVIEW unweight flag will not be overridden by AUTCLN. The default is no.

`use_mm_range [yes/no]`

Allows user to specify if MiniMac range measurements should be used. The default is not to use them (no). (If ranges are not used then MiniMac should be connected to a very good clock.)

`ignore_gaps [yes/no]`

Lets user specify that gaps should be ignored when forming acceptable double differences during cleaning. The default is no; this option should only be used for cleaned data when the GAMIT elevation cutoff and CVIEW edits are used.

`flag_gaps` [yes/no]

Lets user specify if gaps in the one-way data should be flagged with a bias flag. The default is `no`, but is automatically set to `yes` when the `allow_one_bgyes` is given

`gap_size` [cf\_code/ALL] [number of epochs]

Lets user specify the number of epochs allowed in a gap so that it will not be flagged. At setting of 1 (default) will cause all gaps to be flagged. Specifying `gap_size` automatically turns on the `flag_gaps` option.

`remove_ms_jump` [yes/no]

Lets user decide if millisecond jumps in the clock are removed when C-files are written. The default is to remove the jumps (`yes`).

`remove_first_bia` [yes/no]

By default AUTCLN puts a bias flag at the beginning of each one-way sequence as part of its internal bookkeeping. This has no influence on the SOLVE solution, but the extraneous flags will be removed before C-files are written if `yes` is specified for this command. The writing of single-difference files requires the initial bias, so `yes` should not be specified when single difference files are to be written.

`edit_site_sv` [Site Code] [PRN] [Start Epoch] [Stop Epoch]

Allows user to specify site/satellite combinations over specific epoch ranges to be edited and not used in determining clock behavior and double difference editing. Useful for treating bad satellite range data. `ALL` may be used delete all sites for a specified specified satellite; 0 may be used for the PRN number to delete all satellites over the specified epoch range.

`phs_fit_tol` [4 values all in cycles]

Tolerances in deciding if a cycle slip has occurred in the pre-fit clock fit to the one-way phase data. The values and their defaults are as follows:

- (1) deviation of mean phase residual from range solution in pass 1 (1000.);
- (2) deviation of worst phase residual from range solution in pass 1 (500.);
- (3) deviation of pass 2 mean phase from pass 1 phase solution (200.);
- (4) deviation of pass 2 worst phase residual from pass 1 phase solution (100.).

Values 3 and 4 are normally much less than values 1 and 2. The actual deviations being flagged can be viewed by setting `status_report Pass1_slips Pass2_slips`

`status_report` [List of options]

Allows user to tailor the output of the program by selecting which quantities will be output in `autcln.out`. The options come from the following list:

- `CLK_JMP_PROC` - possible clock jump detection
- `CLK_JMP_VAL` - value of clock jump when one is found
- `BIAS_ADDED` - BIAS flag added during one-way phase processing
- `PASS1_SLIPS` - Number of cycles added in Pass 1 one-way clean
- `PASS2_SLIPS` - Number of cycles added in Pass 2 one-way clean

DD\_TRIALS - List each double difference combination tried  
 DD\_ESTIMATES - Estimates of cycle slip during the DD fix.  
 DD\_SCAN - Details of scan flag showing sites and svcs used.  
 ELEV\_DIST - Distribution of final (weighted) data by elev  
 RUN\_PARAMS - Dump of parameters used in run.

ALL may also be used, and then `-option` to turn off particular output; e.g.,  
`status_report all -clk_jmp_proc` The status reports are sent to standard out.

`dd_report [DD Report file name] [option]`

Allows user to specify a file of the format readable by CVIEW and to specify which types of double differences should be output to this file (i.e. ALL, FIXED, NOT\_FIXED). If the file name `dd.sr` is used then the file can be directly read into CVIEW to allow checking of the cleaning results.

`min_elevation [Min clean elevation (deg)] <Min output elev (deg)>`

Minimum elevation to which data will be cleaned. Once this value has been set in AUTCLN, the data below this elevation will not be useable later without further cleaning. The minimum output elevation is optional and is the elevation cutoff to be applied when the C-files are written. This command is ignored if `use_gamit_elev = yes`

`trim_oneway_tol [min_dtl_bias] [min_good_bias] [min_dtr_end] [min_good_end]`

Set the tolerances used in trimming the one-way data to remove small segments of data (defaults in parentheses):

`min_dtl_bias` - minimum time in seconds between bias flags (120 s)

`min_good_bias` - minimum epochs between bias flags and maximum epochs over which a bias flag will be removed in one-way data (8)

`min_dtr_end` - Fraction of total duration of data allowed for a bias flag at the end of the one-way sequence (0.1)

`min_good_end` - Number of epochs of data allowed after last bias flag (24)

`dd_return_size [Max WL] [Max LC] [Max LG] <One way fix tol>`

Set the number of data to be used for cycle skip repair (defaults in parentheses):

Max WL - widelane estimates (100), applies to one-ways

Max LC - LC (50), applies to double differences

Max LG - LG (10), applies to one-ways or double differences

These values should be decreased if there is significant curvature in the data, which might apply particularly to LG with a high ionosphere. They cannot be set less than 5. `One way fix tol` is an optional argument that sets the maximum duration over which one-way L1/L2 range data will be patched using the widelane and LG.

`dd_fit_tol` [WL Ratio] [WL Min] [WL Max] [LC Ratio] [LC Min] [LC Max]

Set the tolerances for flagging cycle slips in wide-lane [WL] and LC double differences [LC] (defaults in parentheses):

`Ratio` - Ratio allowed for jump compared to local rms or last change (WL 5, LC 3.)

`Min` - Minimum value for a jump that will be flagged (cyc) (WL 2., LC 0.5)

`Max` - Maximum value above which all jumps will be flagged (cyc) (WL 10., LC 0.8)

(The tolerance on the maximum jump allowed will fall between Min and Max with the intermediate values set by [local rms]\* [ratio])

`scan_site` [All/None/list of site names]

Lets user specify which sites should be scanned before double difference cleaning. If unflagged slips are found during double difference cleaning this command should be used. All will set all sites to be scanned; clear will set no sites to be scanned. A minus sign before a site name will remove this site from list (e.g., -PIN1 will remove PIN1 from the scan list.)

`max_scan_edit` [number]

Lets user set the threshold for the number of double difference bias flags that can be added during scanning before the complete station/satellite set of one-way data is edited. (The default is not to apply this editing condition). For non-AS data the number can be set small (~10). For AS data, <50 will excessively delete old Rogue data. This control is used to automatically delete bad stations and satellites experiencing burns.

`np_set` [size (epochs)] [Start (epochs)]

Form normal points with phase and range data using groups of [size (epochs)] points. For 30 second data, size=15 forms 7.5 minute normal points. The value must be odd. [Start (epochs)] sets the starting epoch for forming normal points. If the value is negative then normal points will not be formed but the editing necessary to form the normal points will be applied to the data. (This feature is useful for testing the effects of the approximations inherent in the normal point formation.)

`site_params` [site/ALL] [Min Clean El] [Min Out El] [Min L1 SNR] [Min L2 SNR]

Allow site specific parameters to be specified:

[Min Clean El]- minimum elevation angle to which data will be cleaned (degs)

[Min Out El] - minimum elevation angle to be used for output of C-files (deg).

[Min Out El] must be greater than or equal to [Min Clean El] (By cleaning to a lower elevation angle, more data are available for detecting and fixing cycle slips)

[Min L1 SNR]- minimum SNR value to be used at L1. Setting this to 0 will allow all initially into the solution. (same as Pre 2.13 Versions of AUTCLN).

[Min L2 SNR] - minimum SNR value to be used at L2.

The default values for these parameters is set based on receiver type. If the `min_elevation` command is used after the `site_params` command all stations will be given the cut-off elevation angles specified in the `min_elevation` command.

`igs_clk [clock-file name] [min rms ]max rms] [List of reference clocks]`

Write out one-way clock values in the standard IGS clock format. The clock-file name is arbitrary but is the name has only three characters, AUTCLN will construct a name of the form `[name]WWWD.clk` where `WWWD` is the GPS week and day number (e.g., `mit10452.clk`). The `[min rms]` sets the upper limit for a clock to be used as a reference if no reference clock list is given; the units are cycles, and 20 is typical for a hydrogen maser. The `[max rms]` is the largest rms a station clock can have for it to be included in the output file (200 cycles will include most stations). You may optionally list stations to be used to define the reference (e.g. `ALGO WTZR`). A small program `diff_igs` has been added to the `ctogobs` directory to compute differences between clock files.

AUTCLN produces two output files, a step-by-step log of the editing process (`autcln.out`) and summary (`autcln.sum`). In order to interpret either of these, it is necessary to understand the algorithms used in the editing. Since the steps are made in sequence with results from previous steps used, errors in one stage of the processing usually cause errors in later stages. Also errors at one station or on one satellite can effect the results from other stations and satellites. There are seven major steps in the process:

(1) Clock error estimates for sites and satellites based on range data. This analysis is iterated until there is convergence between iterations for the estimates of clock statistics. The maximum number of iterations can be set. Range data can be edited by the analyst if they is not consistent with data from other sites and satellites. In the default settings for `autcln`, bad range data are typically un-deleted in the second iteration if there are lots of bad range measurements.

(2) Clock error estimates for sites and satellites based on phase data The clock errors from the range data are used as a priori values for estimates from phase data. During this analysis, large jumps in the phase data can be detected and the number of cycles of phase needed to make the range and phase consistent are computed. Changes in the ionospheric delay estimates from phase data are also used to detect jumps in the data. When jumps are detected, bias flags are added. Bad range or bad prefit residuals can cause an excessive number of bias flags to be added at this stage. The adding of bias flags and the number of cycles removed with each bias flag are reported in the output of AUTCLN. The default ionospheric jump detector parameters are too tight for polar and equatorial regions and can be changed by station in the command file.

(3) The default action next is to add bias flags to all gaps in the data. This can be changed in the command file, but is not recommended.

(4) The default action next is to scan all contiguous one-way data and to form double differences with triplets of the data to see if there are jumps in the double differences. When a jump is found, more double differences are formed to assess if the one-way data being analyzed have the jump. (This is done by switching the satellite and station to see if the jump persists.) Bad prefit residuals can cause many biases to be added at this stage. Unmodeled accelerations of the satellites can also cause many bias flags to be added at different stations.

(5) Cleaning of data using as many observables as possible. This step involves trying to assess the number of cycles of slip at each bias flag in the one-way data and whether the bias flag can be reliably removed. Small segments of data (i.e., closely spaced bias flags) are removed before any attempt is made to resolve biases. Three criteria are used to compute the number of cycles: (1) continuity of LC, (2) continuity of LG, and (3) continuity of the widelane. Different number of data are used in each of these with the widelane typically being the longest and LG the shortest. The sequence AUTCLN uses is to first try to resolve the integers in one-ways if P-code L1 and L2 range data are available using the widelane and LG continuity. If this fails then double differences are used and LC continuity is also considered. The default setting in autcln is to not allow one-way bias flag removal because this became unreliable once AS was turned on. To patch in double differences, AUTCLN finds another station and satellite combination which does not have a bias flag or gap around the time of the flag which is being evaluated. Stations and satellites are scanned in sequence until AUTCLN finds a combination that can be used to remove the bias flag or runs out of stations and satellites to try. The default is to output a line for each combination tried. The last one output is the one which was used to determine the number of cycles. A common occurrence is that all satellites at a station have bias flags at or near the same time (due to a power failure for example). In these cases, there is an optional feature to "allow one bias or gap" (the `allow_one_bg` command) at this time. In this case, autcln first determines if bias flags can be removed if it ignores the bias flags on both satellites being used in the double difference. If the bias flag can be removed, then it resolves the cycles slips on the first one-way data sequence to be tested and removes the bias flag. When later bias flags are encountered at this time for this station, they will be patched relative to the first one-way sequence where the bias flag was removed. "Force? T" appears in autcln.out for those bias flags removed this way. (There is no explicit book keeping to ensure that this happens). When data are very "broken up" with many bias flags and gaps, AUTCLN can make mistakes in this procedure, so this is normally the most unreliable part of the cleaning process. Only loss of lock on all satellites at a station is treated in this way. If all stations lose lock on a satellite at the same time then the bias flags will be not removed unless they can be patched in one-ways. While data are being used for patching, they are also checked for jumps. When a jump is found, autcln scans each of the

one-way sequences, checking to see if there are cycle slips in them. Because more data are used than when the jumps were first detected, this test is more sensitive than the original scanning and sometimes detects jumps that had not been previously detected. In many cases, these jumps are noisy data and the added bias flag is later removed (and sometimes added back again later). Jumps detected this way can be found in the output by grepping on LCDD. If they are large, then AUTCLN has become confused about where a slip is located and this can cause problems. The cleaning loop is iterated four times since data with bias flags resolved late in the cleaning loop may be used to resolve biases on data looked at earlier. There are some differences between the iterations. In the first iteration, `allow_one_bg` is not used. This is so that as many bias flags as possible are resolved before it is attempted. On subsequent iterations `allow_one_bg` is invoked on increasingly larger gaps in the one-way sequence. It starts at about 10% on the maximum gap size over which biases will be removed, and increases by about 5% each iteration. After the first iteration, large gaps in the data are no longer considered (i.e., we will never be able to remove these bias flags).

(6) Data trimming. In this step, short sequences of data between bias flags are removed and the length of data after the last bias flag on each one-way sequence is checked as a percentage of the total number of data on the sequence. If this percent is too small then the data are removed and the process repeated. This is done so that SOLVE will have a long sequence of data for resolving biases. (Double differences are not checked at this point, so it is possible to get bias flags which have only a small number of data available for their determination.)

(7) Normal pointing (optional). Normal points can be formed at this point.

The tables in the `autcln.sum` file summarize the results of these steps:

### Clock Statistics

```

Clock and Range noise statistics at iteration 3
Site/PRN      Allan SD@100 #      Range rms      #
              sec (ppb)              (mm)
ARAK          1.610128    905          1344.1    5452 LEI
AYVA          1.635893    864           695.8    5261 LEI
...
ERDT          100.000000  1199         190.3     7729 TRM
MATE          0.010000    2879         6707.6   17717 ROG
ONSA          0.030619    2859         2179.0   18710 TRB
WETT          0.010000    2879         2253.7   18020 ROG
PRN_01        0.434580    1097
PRN_02        0.441315    1054
PRN_04        0.438818    1130

```

This table gives estimates of the clock Allan standard deviation (in parts-per-billion) and range noise rms for each receiver. These clock statistics are based on range data only. The example shown is typical for AS conditions with SA active. With AS off, the range noise

for a Rogue SNR-8 or TurboRogue will approach that of the Trimble SSE ( $< 1$  m). Values much larger than a few meters usually mean lots of bad range data or bad prefit residuals (station coordinate errors of  $>10$  m). Very bad range data can be seen with `AVCLCK` errors in the MODEL output P-file. Also `autcln.out` will list bad range measurements (but sometimes here the station or satellite may be incorrectly listed especially when there are a lot of bad data). If there are `AVCLCK` errors, then the `edit_site_sv` command can be used to pre-edit these values in AUTCLN. With each clock and range statistic is also the number of data used to calculate it. For the example here, the two regional stations (ARAK and AVYA) observed for only 8 hours whereas the three IGS stations (MATE, ONSA, and WETT) observed for 24 hours.

Scanning Summary

```

DDScan bias flags added report for pass 1
SITE PN01 02 04 05 06 07 09 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
ARAK      0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
AYVA      0  3  0  0  0  1  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0
...
MATE      3  0  1 13  0  0  0  0  0  0  0  2  4  0  0  0  0  4  0  2  0  0  2
ONSA      3  0  0  1  0  0  1  0  0  3  1  0  0  0  3  6  2  0  3  0  0  0  2
WETT      2  2  0  0  0  2  0  0  1  1  1  0  0  0  0  0  0  0  2  0  0  0  1

```

This summary lists the number of bias flags added by site and satellite during double difference scanning of the phase data. Large values here can mean either bad prefit residuals or bad phase data. The `max_scan_edit` command can be used to automatically delete all data on a station/satellite combination which has too many bias flags added during double difference scanning. Many bias flags being added to a satellite at many stations usually represents the effects of an unmodelled acceleration of the satellite. Rogue SNR-8 often have many bias flags added when AS is on. (Note that in the current version of AUTCLN the clock statistics and scanning summaries are given twice, once for each of two initial passes through the data.)

One-way Residual Statistics

When AUTCLN is run in post-fit mode, the next four tables give a summary of the phase residuals for each station and satellite after correcting the data for adjustments in the parameters (using the M-file from the first SOLVE solution) and estimating station and satellite clocks epoch-by-epoch from the phase residuals. The two tables give the rms values and the number of data used in the calculation for each station or satellite.

ONE-WAY POSTFIT RESIDUAL STATISTICS: Pass 22

-----  
RMS by site and satellite (mm): Pass 22

```

RMS IT Site All 01 02 04 05 06 07 09 12 14 15 16 17 18 19 20 21 22 ... 31
RMS 22 ARAK 7.2 0 6 7 7 0 8 7 6 8 0 7 0 6 6 0 0 15 ... 0
RMS 22 AYVA 6.7 0 6 7 13 0 5 7 8 7 0 6 0 6 5 0 0 12 ... 0
...
RMS 22 MATE 5.1 5 4 6 4 4 6 5 4 4 5 6 5 5 6 5 4 4 ... 5
RMS 22 ONSA 5.5 5 6 6 5 5 6 3 4 5 5 6 6 5 6 6 5 7 ... 5
RMS 22 WETT 6.3 6 7 6 5 5 7 5 5 7 7 7 6 6 8 5 6 5 ... 6
RMS 22 ALL 6.0 6 6 6 5 5 6 6 6 6 5 6 6 6 6 5 5 7 ... 6

```

Number of data by site and satellite: Pass 22

```

NUM IT Site All 01 02 04 05 06 07 09 12 14 15 16 17 18 19 20 21 22 ... 31
NUM 22 ARAK 5385 0 587 311 84 0 224 177 228 199 0 507 0 534 631 0 0 118 ... 0
NUM 22 AYVA 5224 0 552 306 48 0 195 139 195 220 0 509 0 535 631 0 0 142 ... 0
...
NUM 22 MATE 17346 825 507 539 728 638 775 736 788 764 673 695 636 761 660 762 633 575 ... 640
NUM 22 ONSA 17276 820 734 846 668 619 782 346 609 697 631 834 717 682 744 676 651 733 ... 664
NUM 22 WETT 17739 868 734 701 735 637 846 652 746 716 684 732 624 689 619 726 695 595 ... 663

```

The values here (5–8 mm overall) for the five stations shown are typical for well-performing receivers in a good solution. The only rm value over 10 mm is for PRN 13 at

station AYVA; the second table indicates that there were few data (48) compared to the other satellites, suggesting either that AUTCLN deleted a number of bad observations (which can be checked below) or that the satellite's pass was short and low on the horizon and therefore with a larger fraction of data corrupted by high multipath or atmospheric fluctuations.

The next table gives the average one-way residuals, a useful addition that may help you distinguish between systematic, long-period errors and high receiver noise or multipathing

Average OW residuals by site and satellite (mm): Pass 22

AVG	IT	Site	RMS	01	02	04	05	06	07	09	12	14	15	16	17	18	19	20	21	22	...	31
AVG	22	ARAK	7.2	0	1	0	0	0	0	0	-1	0	0	-1	0	0	-1	0	0	0	...	0
AVG	22	AYVA	6.7	0	1	0	1	0	0	0	0	-1	0	0	0	0	1	0	0	-1	...	0
...																						
AVG	22	MATE	5.1	0	0	0	0	0	1	0	0	1	-1	-1	0	-1	1	0	0	0	...	0
AVG	22	ONSA	5.5	0	1	0	0	0	0	0	1	0	0	1	-1	0	-1	0	0	0	...	0
AVG	22	WETT	6.3	0	-1	0	-1	0	0	0	-1	-1	1	-1	1	0	1	0	0	-1	...	0

In this case the averages are all less than about 1 mm, indicating no significant systematic residuals. The last table shows the rms values as a function of elevation angle, a potential tool for deciding whether elevation-angle-dependent weighting of the data might be useful (an analysis approach we are currently investigating).

Elevation angle dependent RMS statistics. MODEL:  $RMS^2 = A^2 + B^2 / (\sin(\text{elv}))^2$

ATELV Site	A	B	0-05	5-10	10-15	15-20	20-25	25-30	30-35	35-40	...	75-80	80-85	85-90
ATELV ARAK	5.5	2.1	0.0	0.0	8.2	12.6	10.8	8.2	6.7	5.4	...	5.5	5.0	8.1
ATELV AYVA	3.7	2.6	0.0	0.0	11.9	11.1	8.1	7.9	6.2	5.7	...	3.3	3.7	2.9
...														
ATELV MATE	2.6	2.1	0.0	0.0	9.8	8.0	7.1	5.6	4.8	3.8	...	3.4	3.9	3.7
ATELV ONSA	2.7	2.1	0.0	0.0	9.8	8.3	6.6	5.6	5.0	4.6	...	3.3	3.0	2.6
ATELV WETT	3.7	2.4	0.0	0.0	11.5	9.4	7.9	6.8	5.8	5.0	...	4.1	4.8	5.8

### Data Editing and Bias Flags Remaining

DATA AMOUNTS (Good: # good data; Gap: # deleted in gaps; BF: # bias flags < 2\*max separation)

SITE	PRN	Good	Gap	BF	PRN	Good	Gap	BF	PRN	Good	Gap	BF	PRN	Good	Gap	BF
ARAK	PN01	0	0	0	PN02	587	0	0	PN04	311	0	0	PN05	84	0	0
	PN06	0	0	0	PN07	224	1	1	PN09	177	0	0	PN12	228	0	0
	PN14	199	4	0	PN15	0	0	0	PN16	507	0	0	PN17	0	0	0
	PN18	534	0	0	PN19	631	1	0	PN20	0	0	0	PN21	0	0	0
...																
MATE	PN01	825	1	0	PN02	507	0	0	PN04	525	34	0	PN05	728	13	0
	PN06	645	0	1	PN07	776	2	1	PN09	736	0	0	PN12	788	0	0
	PN14	764	0	0	PN15	659	2	0	PN16	696	0	0	PN17	636	1	0
	PN18	761	3	0	PN19	660	0	0	PN20	762	0	0	PN21	633	0	0
...																

These lists (one per station) show by satellite the number of good data in the one-way sequence, the number of data deleted in gaps between closely spaced bias flags, and the number of remaining bias flags that might be resolved (i.e., number bias flags separated by less than twice the maximum size over which bias flags would be removed). Large numbers in the gap columns and/or large numbers of remaining bias flags usually mean bad prefit residuals or noisy data. Usually, the numbers inGap column increase when AS is on

especially for SNR-8 receivers. More than 3 bias flags remaining usually indicates that the data is noisy and broken up into small pieces. (Bad data at one site can often lead to additional biases at other sites, so it usually the site with the most bias flags that is causing the problems.)

### Elevation-angle Statistics

ELEVATION ANGLE HISTOGRAM														
SITE	0- 5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	...	80-85	85-90	Min (dg)
ARAK	0	0	0	505	502	591	429	437	537	361	...	40	15.01	
AYVA	0	0	0	575	499	545	419	436	511	323	...	40	15.01	
...														
MATE	0	0	0	1415	1643	1704	1400	1448	1249	1383	...	54	15.00	
ONSA	0	0	0	1834	1789	1621	1419	1500	1467	1058	...	79	15.00	
WETT	0	0	0	1641	1624	1650	1529	1468	1441	1073	...	208	15.01	

This table shows the number of good data or good normal points in elevation bins. Correctly operating receivers should have about the same number in 15-20 degree bin as in the 20-25. (The above example is for 24 hours with 15-point normal points).

### Bias Flag Report

This report provides an overall summary of the number of bias flags in the clean data and why they were added.

BIAS FLAG REPORT: Types																																
SITE	ORG-Original							JMP-Big Jump							ION-Ion Jump				GAP-Data Gap				DDS-DD scan				WLS-Wide Lane				DDC-DD c.	
	# Flagged							# Remaining							# Edited				# with jump													
	ORG	JMP	ION	GAP	DDS	WLS	DDC	ORG	JMP	ION	GAP	DDS	WLS	DDC	ORG	JMP	ION	GAP	DDS	WLS	DDC	ORG	JMP									
ARAK	10	0	0	8	2	0	2	0	0	0	1	0	0	0	1	0	0	2	1	0	1	9	0									
AYVA	9	0	0	1	8	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	9	0									
...																																
MATE	63	0	0	12	33	0	0	8	0	0	1	0	0	0	26	0	0	6	28	0	0	29	0									
ONSA	4	0	0	138	36	0	6	1	0	0	16	0	0	0	2	0	0	55	29	0	1	1	0									
WETT	65	0	0	11	13	0	2	10	0	0	2	1	0	0	31	0	0	5	10	0	0	24	0									

The report is in four sections:

# Flagged are the numbers of bias flags added or encountered during cleaning (Entries explained below).

# Remaining are the numbers of bias flags left in the cleaned data.

# Edited are the numbers of bias flags removed by deleting the data affected by the bias flag (as opposed to the bias flag removed by reliably resolving the integer number of cycles at the flag).

# with jump are the numbers of bias flags which were resolved to non-zero integer values. The difference #Flagged - (#Remaining+#Edited+#with jump) gives an idea of the number of bias flags added that were not really needed. (It is not possible to tell how many real jumps were in the edited data).

When data are normal pointed the number of remaining bias flags will not necessarily be the same as the sum of the values shown in the "Data Editing and Bias Flags Remaining" report because this latter report is generated before normal points are formed, and some bias flags reported in the #Edited columns are not present if the data are deleted during the normal point formation.

Within each of these categories, the reasons for adding the bias flags are given:

ORG is the number of original bias flags in the data (loss-of-lock indicator set in the rinex file). There is not much the user can do about these if they are large, other than to conclude that the receiver itself was not very happy.

JMP is the number added due to large jumps between the phase and range estimates of the clocks. Large values here can indicate very bad prefit data (e.g. when site positions are 100's km in error) but most often indicate bad range data. Very bad ranges (>300 m) will generate AVCLCK errors in MODEL, and smaller range errors can be detected by the reports of biases added in the one-way phase fitting. The tolerances for these fits can be increased to stop the bias flags being added, or the initial range data can be deleted. (These are often low elevation data that will not be used in the final analysis anyway.)

ION is the number of bias flags added in the ionospheric jump detector. Again the tolerances can be increased so that these jumps are not detected. This jump detector is independent of both the range and prefit model quality. For equatorial and polar sites the detector tolerances should be loosened. (e.g., ion\_jump\_tol yell 30 6.0 2.0 5.0)

GAP is the number added due to gaps in the data. There is not much that the user can do about these since they result from gaps in the data. If the SNR is being used to flag data, reducing the SNR limit can make these values smaller.

DDS is the number of bias flags added due to discontinuities in the double difference data. Large values here indicate poor quality phase data or bad prefit residuals.

WLS is the number of bias flags added due to jumps in the widelane observable. The widelane jump detector should be loosened for AS data. (In the example used here all these values were zero, so the WLS column has been cut out to reduce the table width.)

DDC is the number of bias flags added during cleaning. Large values here are very bad because all the jumps in the data should have been detected before cleaning starting. Grep'ing on LCDD in autcln.out will show the magnitudes of the jumps. Most often these are just above the tolerances for detection and simply reflect the increased sensitivity of the detector used during cleaning. Large jumps usually mean that AUTCLN has become confused as to which one-way a jump occurs on and is trying to patch it in the wrong place. Often deleting some of the data around these times is sufficient to remove the problem. Grep'ing on the epoch number (with a space on either side) shows the manipulations of all data at this epoch, including which stations and satellites were used to do the patch. This can be useful in tracing what happened during the cleaning.

## Editing Report

This report shows the parameters used at each station for the editing and why data were eliminated from the analysis.

```

EDITING REPORT AND SITE PARAMS
SITE MnCLN MnOUT SNR LSNR GF03 RCLK GF02 BEND BCLS NPED GF-1 GF04 DDSC PFED GFUN BDL2 NODD ELEV :
      (deg) (deg) L1 L2
ARAK 10.00 15.00 1 1 0 0 0 2 0 36 0 0 0 0 58 0 0 0 6 6.
AYVA 10.00 15.00 1 1 0 0 0 0 0 0 0 0 0 0 37 0 0 0 11 6.
...
MATE 10.00 15.00 1 1 0 0 0 0 79 77 0 0 0 0 266 0 0 28 1605 21
ONSA 10.00 15.00 1 1 0 0 0 0 249 167 0 0 0 0 260 0 0 1050 4180 21
WETT 10.00 15.00 1 1 0 0 0 0 142 17 0 0 0 0 255 0 0 11 2347 19

```

MnOUT is the minimum elevation angle to be used when writing out the C-files.

MnCLN is the minimum elevation angle used during cleaning. By including lower elevation data for cleaning, there is more chance of finding double differences. The disadvantage is that low elevation angle data can be of very poor quality for some receivers. Also we have seen cases where the low elevation angle data appears to be values generated by the model in the receiver and therefore is very smooth but inconsistent with the real data. This really confuses AUTCLN because the data appear very good and often autcln will remove the real data because they are so much noisier than the "model" data.

SNR L1 and L2 are the signal-to-noise ratio (snr) limits used by station. There is some inconsistency in the snr limits used by different RINEX translators especially for Rogue SNR-8 data. The values above (for KIT3 which is a TurboRogue) are for Rogues translated by JPL's SRX program. (Strictly, 4 means SNR<0 in the SRX converter, but there seem to be lots of good data with snr of 4 so we accept these data. RGRINEX running on SNR-8 data will have snr values as low as 2 and these are often good data. An snr of 1 in the RINEX standard means bad data and hence the limits should never be less than 2. 0 or blank in the RINEX file for SNR will NOT be edited by AUTCLN since by definition these values mean no information is available.

The meaning of each column is the number of points (before normal pointing, but after data for normal pointing has been selected) edited for the given reason. Data points can have multiple reasons for being edited.

LSNR -- SNR value at either L1 or L2 below the set limit

GF03 -- GAMIT low amplitude flag (rarely if ever set by the current MAKEX).

RCLK -- Large difference between autcln's estimates of the station clock and the value actually used in model (not implemented currently and cut from table displayed here to reduce the table width )

- GF02 -- GAMIT bad data flag. Indicates that the receiver is not tracking; usually denoted by an L2 SNR of 2. This flag may be set by MAKEX but also set by AUTCLN if the L1 and L2 range values are exactly equal. (All were zero in the table displayed here so they have been cut to reduce the width.)
- BEND -- Bias flags were too close to the end of the data.
- BCLS -- Bias flags were too close together.
- NPED -- Data could not be used in normal point but was OK otherwise (usually about 10% of the total amount of good data for 15-point normal points).
- GF-1 -- GAMIT marginal flag. Usually zero for raw data but is set when data are cleaned in CVIEW. Reprocessing of AUTCLN output C-files with `edit_site_sv` used in the command file will set this flag.
- GF04 -- GAMIT elevation cutoff flag (set in MODEL).
- DDSC -- Too many bias flags were added during double difference scanning so the whole one-way sequence was deleted.
- PFED -- Postfit AUTCLN edits (`postfit_edit` command).
- INTR -- Interactive edits (not implemented and not shown in the displayed table).
- GFUN -- GAMIT flag of unknown type (should be zero; not shown in the displayed table).
- BDL2 -- SNR edits for L2 only (i.e., L1 SNR was good).
- NODD -- Data for which no double differences could be formed (not implemented, but should be flagged if separate AUTCLN runs are to be combined).
- ELCL -- Data edited below cleaning elevation angle.
- EDIT -- Data edited by `edit_site_sv` command
- MMRB -- Data flagged with the `use MiniMac range = n` command.
- ELEV -- Data flagged below the output elevation angle.
- Good -- Number of good data remaining that will be used in the SOLVE analysis.

At the end of the `autcln.sum` file is a list of the parameter values used in the run.

The information written in `autcln.out` can sometimes be helpful in determining how AUTCLN handled data at a particular epoch. Given below is an explanation of the lines appearing in the file:

#### DD Trials line

```
.....
Ep 114   S1/C1 2 13   S2/C2 1 2   dL1/2 slip 0.0  0.0 cycles   NumLR 23 18
EpLR 111 114   dchi, Chiqual 1.7 102.9  30.3
```

`Ep` is the epoch number

`S1/C1` is site number and channel for one way

`S2/C2` is site number and channel for double difference. If these values are zero then there was no double difference formed.

`dL1/2 slip` is the change in number of cycles at L1 and L2

`NumLR` is the number of data in left and right segments (May actually be less than this if unflagged bias found).

`EpLR` is the epoch numbers across the gap or bias flag being patched

`dchi, Chiqual` are the lowest two  $\chi^2$  increments when integer cycles are tried, and the ratio used to see if bias flag can be used.

#### Bias Flag line (always printed)

```
Epoch 114   Site MOJ1 PRN 20   L1 from  0.0 to  0.0  L2 from  0.0 to  0.0
Reliable?  T   30.44   BFLG   OneBG F   Force F
```

where the first line designates the epoch, site, satellite and cycles added in L1 and L2

`Reliable? T` indicates that the bias flag was removed, and the value following is `Chiqual`

`BFLG` or `GAP` says whether a bias flag or gap is being patched

`OneBG T` or `F` gives the value of the `OneBG` flag (see commands)

`Force` indicates whether (`T`) or not (`F`) the one-ways were forced to have the bias flag removed so that other combinations could have one bias or gap.

## 8. Atmospheric Delay Models

### 8.1 Description of the atmospheric delay

As the GPS signal travels from the satellite to the receiver, it propagates through the atmosphere of the earth, where it is retarded and its path changed from a straight line to a curved one. If we take the simplified mathematical model for the observable to be one in which the signal is assumed to be propagating in a straight line and at the speed of light in vacuum, then the "atmospheric delay" is defined to be the difference between the true electrical path length and this assumed straight-line length. Using this definition, the atmospheric delay is a term to be added to the simplified model.

The atmospheric delay in the zenith (i.e., vertical) direction varies from about 6 to 8 nanoseconds (190 to 240 cm, or 10-12 cycles of phase at L1-band) depending on meteorological conditions and site location. The atmospheric delay increases with decreasing elevation angle approximately with the cosecant of the elevation angle, so that the atmospheric delay at an elevation angle of 20 degrees may be from 30-36 cycles of L1 phase.

The atmospheric delay is usually broken down into two components. The first component is due to the mixture of all constituents, but it is assumed that the mean molar mass of these constituents is equal to the mean molar mass of only the "dry" (all except water vapor) constituents. Assuming that the atmosphere is in hydrostatic equilibrium, the "zenith delay" due to these components is very well modeled (standard deviation of approximately 0.5 mm) using the surface pressure, which represents the total weight of the atmosphere. This component of the atmospheric propagation delay is usually termed the "dry" or "hydrostatic" delay, and accounts for nearly all (90-100%) of the atmospheric propagation delay.

The second component of the atmospheric delay is due to water vapor, and includes a correction for the "dry mean molar mass" assumption used to derive the dry delay (see above). This component of the atmospheric propagation delay is called the "wet delay" and is equal to zero if there is no water vapor present anywhere along the path of the signal. However, there usually *is* water vapor present along the path of the signal and it is poorly predicted using measurements of conditions at the site alone. This difficulty is caused by the "unmixed" condition of atmospheric water vapor, which means that the water vapor is present in "blobs" throughout the troposphere. Because of this condition, models for the wet delay are notoriously inaccurate and can have RMS errors of several cm (zenith), out of a total (zenith) wet delay of 0-40 cm.

## 8.2 Algorithms for the atmospheric propagation delay

The atmospheric propagation delay is implemented in the following manner:

$$\text{ATDEL}(\text{EL}) = \text{DRYZEN} * \text{DRYMAP}(\text{EL}) + \text{WETZEN} * \text{WETMAP}(\text{EL})$$

where EL is the elevation angle of the satellite, DRYZEN is the dry zenith delay, WETZEN is the wet zenith delay, DRYMAP is the "mapping function" for the dry delay (see below) and WETMAP is the mapping function for the wet delay. A mapping function is a mathematical model for the elevation dependence of the respective delays. The mapping functions (for both the dry and the wet terms) are approximately equal to the cosecant of elevation, but there are significant deviations from this "cosecant law" due both to the curvature of the earth and the curvature of the path of the GPS signal propagating through the atmosphere.

Many expressions for the four terms DRYZEN, DRYMAP, WETZEN, and WETMAP appear in the scientific literature. For microwave observations there is little controversy about the expressions for the dry zenith delay. Since the wet zenith delay cannot be accurately modeled from surface measurements, the expressions used are not critical. The choice of mapping function can be important, however, particularly for elevation cutoff angles below 15 degrees. The model to be used in GAMIT for each of the four terms is specified by keywords in the `sittbl`. (see Section 5.2), a portion of which is shown below with the default choices and values of the surface pressure, temperature, and relative humidity.

```
SITE          FIX  --COORD.CONSTR.-  DZEN  DMAP  WMAP  ---MET._VALUE---  WFILE
CATO Castro Peak  NNN  100.  100.  100.  SAAS  NMFH  NMFW  1013.25  20.0  50.0  NONE
```

### DZEN:

The default model [ SAAS ] for the dry zenith delay is that described by *Saastamoinen* [1972]. If there is a W-file of meteorological data, the actual pressure at the station, as interpolated from the file is used to determine the delay. If there is no W-file ( NONE, the default) the model takes the surface pressure given in the `sittbl` and reduces it to pressure at the station using the station's height and small corrections for gravitational variations with latitude. You can also input directly a constant value for the dry zenith delay by specifying the model as `CMMN` where `MNN` is the range-equivalent of the delay in centimeters; e.g., `C230` sets the delay as 230 cm. This feature is useful mainly for error analysis.

### WZEN:

The default model [ SAAS ] for the wet delay is also from *Saastamoinen* [1972]. It makes use of both the surface temperature and the relative humidity/dewpoint, either from the

meteorological data file or from the default values. The default values of temperature and humidity (20 degrees C and 50%) serve to make the a priori delay "reasonable" for temperate climates. As for the dry zenith delay, you may set a constant value using `gNMN` as the input model except that the constant delay is given in millimeters (NOT centimeters). This feature is useful because, as mentioned above, the true wet zenith delay is often not correlated with surface measurements. You can use `C000` (i.e., zero wet zenith delay) and estimate a zenith delay correction which, if the correct pressure was used for the dry zenith delay, will represent the mean wet zenith delay. An additional option for the wet delay is to determine the value from water-vapor radiometer data, as described in Section 8.5 below; in this case set the `WZEN` code to `WVR`.

#### DMAP and WMAP:

Beginning with GAMIT release 9.6, the default mapping functions for both the hydrostatic ("dry") and water-vapor ("wet") delays are the those developed recently by Arthur Niell of the MIT's Haystack Observatory [ *Niell, 1996*]. If these are entered explicitly into the `sittbl`, the codes are `NMFH` and `NMFW` for `DMAP` and `WMAP`, respectively. These replace the `CfA-2.2` [ `CFA`] model developed at the Harvard-Smithsonian Center for Astrophysics [ *Davis et al., 1985*] for analysis of VLBI data. You should expect no significant difference between the Niell and CfA mapping functions for observations above 15 degrees elevation angle. (The other recent mapping function is the MTT model developed by *Herring* [1992], but this has not yet been coded in GAMIT.) GAMIT also supports two older mapping functions which were commonly used for analysis of microwave observations prior to 1985—one developed by *Marini and Murray* [1974] [ `MARI` ] and one by *Chao* [1972] [ `CHAO` ]

### 8.3 Estimating a zenith delay parameter

Since the water vapor contribution to atmospheric delay is poorly modeled using surface meteorological data, GAMIT allows estimation of corrections to the zenith delay. The partial derivative of phase or pseudorange with respect to the zenith delay parameter is simply the mapping function, approximately equal to the cosecant of the elevation angle of the satellite as viewed from the station. For stations in a regional network the elevation angles viewing a particular satellite will be nearly equal, producing high correlations among the estimated zenith delays. Even for stations a few meters apart, however, separate zenith delays can be estimated without causing numerical problems in `SOLVE`; although the uncertainties in all of the zenith-delay parameters will be large, the relative values of the estimates themselves can be trusted. To extract from the solution the uncertainties of the differences, however, you should fix or tightly constrain one of the values.

The model for zenith delay can take the form of a single parameter for each station and session, or a piecewise linear function of zenith-delay over the session. In the latter case, the tabular points of the function can be constrained using a first-order Gauss-Markov process. Controls for estimation of zenith delay are input via the `sestbl.` and/or `sittbl.` The `sestbl.` inputs, adopted as common to all stations are as follows:

```
Zenith Delay Estimation = YES ; YES/NO
Number Zen = 4 ; number of zenith-delay parameters
Zenith Model = PWL ; PWL (piecewise linear)/CON (step)
Zenith Constraints = 0.50 ; zenith-delay a priori constraint in meters
Zenith Variation = 0.02 100. ; zenith-delay variation, tau; units m/sqrt(hr), hrs
```

Specifying `Number Zen = 1`, and either `PWL` or `CON` for `Zenith Model` will invoke a single parameter for the zenith delay over the session. The best representation of zenith-delay variations is usually accomplished with a new zenith delay parameter for every 2–6 hours during the day (the gain from 6 hrs to 2 hrs is usually small and will increase running time for SOLVE considerably); thus with an 8-hr observation span, you might set `Number Zen=3` to get two 4-hr segments (the `PWL` representation includes tabular points on each end of the observation span), or with a 24-hr span, set `Number Zen=9` to get 3-hr segments. The overall zenith constraint should be set loose enough to encompass comfortably any error in the wet delay; 0.5 meters is the default and reasonable. The variation is specified as parameters of a first-order Gauss-Markov process. The first value in `zenith variation` is the point-to-point variation allowed, in units of meters. The second value is the correlation time ( $\tau$ ) in hours. Setting  $\tau$  long compared to the observation span results in a random walk process, which is both reasonable and easy to interpret (and has the practical advantage of persistence with large error bars for spans with few observations). the easiest to understand The default value of 100. hrs accomplishes this for 24-hr spans. Setting  $\tau$  equal to a value short compared with the tabular point interval will result in a white-noise process for the variation in tabular points; in this case the constraint will be applied with respect to the default model value rather than the value of the last tabular point.

There is an additional entry in the `sestbl.`,

```
Tropospheric Constraints = NO ; YES/NO
```

which invokes a spatial constraint on the zenith-delay parameters. This constraint can be useful for tying together the zenith-delay adjustments for closely-spaced sites in a network. This feature was coded originally for a single zenith delay, however, and does not yet work for time-dependent models.

Different values for the zenith constraints can be invoked using `sittbl.` entries, shown below:

SITE	DZEN	DMAP	WMAP	---MET.	VALUE----	WFILE	ZCNSTR	ZENVAR	ZENTAU
CATO Castro Peak	SAAS	NMFH	NMFW	1013.25	20.0 50.0	NONE	0.5000	0.005	100.
LOVE Loma Verde	SAAS	NMFH	NMFW	1013.25	20.0 50.0	NONE	0.5000	0.005	100.

PVER	PVER7268	SAAS	NMFH	NMFW	1013.25	20.0	50.0	NONE	0.5000	0.020	100.
SAFE	San Fernando	SAAS	NMFH	NMFW	1013.25	20.0	50.0	NONE	0.5000	0.020	100.
YKNF	YELLOWKNIFE	SAAS	NMFH	NMFW	1013.25	20.0	50.0	NONE	0.5000	0.020	100.
AROG	ARO GPS	SAAS	NMFH	NMFW	1013.25	20.0	50.0	NONE	0.5000	0.020	100.
RICH	RICHFRPA	SAAS	NMFH	NMFW	1013.25	20.0	50.0	NONE	0.5000	0.020	100.
TROM	TROMGPSM	SAAS	NMFH	NMFW	1013.25	20.0	50.0	NONE	0.5000	0.020	100.

It is currently a requirement that the number of zenith delays in the session be the same for all stations.

#### 8.4 Estimating gradients

The effects of azimuthal asymmetry in the atmospheric delay are not included in MODEL but may be estimated in SOLVE. The coded partials imply a model of the form

$$\text{ATDEL}(\text{EL}, \text{AZ}) = \text{GRADNS} * \text{AZMAP}(\text{EL}) * \text{COS}(\text{AZ}) + \text{GRADEW} * \text{AZMAP}(\text{EL}) * \text{SIN}(\text{AZ})$$

where EL is the elevation angle, AZ the azimuth, and AZMAP the mapping function for gradients, given by

$$\text{AZMAP} = 1. / ( \text{SIN}(\text{EL}) * \text{TAN}(\text{EL}) + \text{C} )$$

and C is a constant equal to 0.003 [ *Chen and Herring* , 1997]. Since the gradient parameters, GRADNS and GRADEW, have small and non-intuitive values near the zenith (i.e., for AZMAP = 1 ), we rescale them to represent the difference between the the north (or east) and south (or west) delay at 10 degrees elevation. At 10 degrees the rms scatter of gradients observed from VLBI observations are about 5 mm. Our default a priori constraint is 30 mm.

#### 8.5 Water vapor radiometer (WVR) data

A water-vapor radiometer is a multichannel radiometer which measures the brightness temperatures of the atmosphere. The main contributions to this radiation below 100 GHz are atmospheric oxygen, water vapor, and liquid water. The several frequencies of the WVR are used to solve for these various components and the wet delay. The algorithm for the delay currently implemented is

$$\text{Wet delay} = \text{A} + \text{B} * \text{T1} + \text{C} * \text{T2}$$

where A, B, and C are user-defined constants, and T1 and T2 are the brightness temperatures (*not* linearized) at two frequencies. The name of the WVR data file (Z-file) must also be entered. The Z-file is of the format:

This is a comment line

.

This is the last comment line

END

Header line #1

Header line #2

YYYY DDD HH MM YYYY DDD HH MM SITE

Header line #3

Header line #4

YYYY DDD HH MM SS AZ EL T1 T2 TS

.

The actual entries are free format. They include the year, day-of-year, hours, minutes and seconds for the WVR observation, the azimuth and elevation (in degrees) of the observation, the brightness temperatures (in Kelvins), and the surface temperatures (in degrees Celsius). In order to interpolate the brightness temperatures, they must be converted to equivalent zenith brightness temperatures. This is done in the following manner: Saturation effects are taken into account by determining the optical depth using

$$T_i = T_0 \exp(-\tau_i) + T_{\text{eff}} [1 - \exp(-\tau_i)]$$

where  $\tau_i$  is the optical depth at the frequency of the brightness temperature  $T_i$ ,  $T_0=2.9$  K is the big-bang background temperature, and  $T_{\text{eff}}$  is the "effective" temperature of the atmosphere [*Chandraesker*, 1960; *Wu*, 1979]. We use the approximations

$$T_{\text{eff}} = 0.94 * T_s$$

where  $T_s$  is the surface temperature in Kelvins [ *Wu*, 1979]. The optical depth is then mapped to the zenith using

$$\tau = \tau(\text{zen}) * \text{WETCHAO}(\text{elevation})$$

where the function WETCHAO is the wet Chao mapping function given above. The zenith brightness temperatures are then calculated from the zenith opacities using the expression above. These zenith brightness temperatures are then interpolated to the epoch of the GPS measurement, and the zenith delay is calculated using the user-defined WVR constants. The wet delay away from the zenith is computed using the Chao wet mapping function. Note: For consistency with the interpolation scheme, the user must choose 'CHAO' for the

wet mapping function if WVR is chosen for the zenith wet delay. If this is not done, the program will display a warning and the wet mapping function will be changed to 'CHAO'.

### 8.6 References

Chandrasekhar, S., *Radiative Transfer*, Dover, New York, 1960.

Chao, C. C., A model for tropospheric calibration from daily surface and radiosonde balloon measurements, *Tech. Mem. 391-350*, Jet Propulsion Laboratory, Pasadena, California, 1972.

Davis, J.L., T.A. Herring, I.I. Shapiro, A.E.E. Rogers, G. Elgered, Geodesy by radio interferometry: Effects of atmospheric modeling errors on estimates of baseline length, *Radio Science*, 20, 1593-1607, 1985.

Chen, G., and T. A. Herring, Effects of atmospheric azimuth asymmetry on the analysis of space geodetic data, *ournal of Geophysical Research*, 102, 20489–20502, 1997.

Herring, T. A., Modeling atmospheric delays in the anlysis of space geodetic data, *Proceedings of the Symposium on Refraction of Transatmospheric Signals in Geodesy*, Publications on Geodesy, No. 36, ed. by De Munck and Spoelstra, 247, Netherland Geodetic Commission, Delft, Netherlands, 1992.

Marini, J.W., C.W. Murray, Correction of radio range tracking data for atmospheric refraction at elevations above 10 degrees, unpublished memorandum, 1974.

Niell, A. E., Global mapping functions for the atmospheric delay at radio wavelengths, *Journal of Geophysical Research*, 101, 3227–3246, 1996.

Treuhaft, R. N., and G. E. Lanyi, The effect of the dynamic wet troposphere on VLBI measurements, Geodesy and Geophysics Preprint No. 141, Jet Propulsion Laboratory, Pasadena, 1986.

Saastamoinen, J., Atmospheric correction for the troposphere and stratosphere in radio ranging of satellites, in *The Use of Artificial Satellites for Geodesy*, *Geophys. Monogr. Ser.*, Vol. 15, edited by S.W. Henriksen et al., pp. 247-251, American Geophysical Union, Washington, D.C., 1972.

Wu, S.C., 1979: Optimum frequencies of a passive microwave radiometer for tropospheric path-length correction. *IEEE Trans. Ant. Prop.*, AP 20, 181-187.

## 9. Utility Programs and Auxiliary Tables

### 9.1 Plotting and computing statistics from GAMIT solutions

The most useful way to view the results of a GAMIT analysis is by examining the baseline repeatability from day-to-day. The shell script `sh_gamit_baseline` will do this from the `o`-files produced by SOLVE. The instructions for running the script can be generated by typing its name with no arguments; these are reproduced below:

Use GMT to make a multiple panel GAMIT baseline plots with uncertainty scaling. It also creates inputs for `wrms/nrms` scatter plots, which can be plotted with `/stdrel/com/sh_globk_scatter`

```
Requirements  : GMT(netcdf/gmt/ghostscript)
               : gamit/bin/poly01  (linked to gamit/utils)
```

```
USAGE :      sh_gamit_baseline  <options>.
```

```
EXAMPLES: for time-series plots
```

```
sh_gamit_baseline  -o o* -b PIN2_VNDP PIN2_YAM2
```

```
sh_gamit_baseline -u 1 -o o* -b PIN2_VNDP PIN2_YAM2
```

```
====OPTIONS====
```

```
-o[files]      list      : ofile names. MUST have this.
-f[file]       file      : Baseline names.
-b[aseline]    list      : command line argument for baselines. If -f and
                        -b are both omitted, all baselines are plotted.
-free          : Biases free solution--Default.
-fixed         : Biases fixed solution.
-d[delete]     <sites/baselines etc> : names of unwanted sites.
-df            file      : file contains the names of unwanted sites.
-[delete_file] : Makes life easier for -d
-u[nc_scale]   value     : scale all uncertainties by this.. Default =1.
-y[scale]     min max    : vertical scale. If not issued it will be calculated.
-x[scale]     min max    : horizontal scale. If not issued it will be calculated.
-frame        value     : gmt border day-axis frame ticks. Default =1.
-annot        value     : gmt border day-axis label intervals. Default =1
-a            ext       : Add more descriptors to postscript file name.
                        Default is psgamit.#
```



The program WBSLFILT ("Weighted BaSeLine Filter") can be used to scan the O-files from the observation sessions of an experiment and compute the mean and weighted rms scatter of the estimated baseline vectors. You can choose the estimates you wish to use by keying on the characters in columns 19-21 of the baseline summary in the O-file; i.e.

```
'R N'  bias-free  NE U
'X N'  bias-fixed NE U
'R X'  bias-free  X Y Z
'X X'  bias-fixed X Y Z
```

To get the NEU, components from the bias-fixed solution out of a group of O-files, try:

```
grep -h _ o*.*?? | grep 'R N' | sort | wbslfilt >! mine.r.neu.wbsl
```

Note that WBSLFILT must have *\*sorted\** input to work properly.

Here is some example output:

```
-----
ALS0_AROO RMS 11 N 45242.5761 +- 0.0082 E 11595.5381 +- 0.0408 U -263.6538 +- 0.0838 L 46705.6390 +- 0.0131
ALS0_AROO PPB 11 N 45242.5761 +-174.6840 E 11595.5381 +-874.4694 U -263.6538 +-***** L 46705.6390 +-279.9606
ALS0_AROO SIG 11 N 45242.5761 +- 0.0072 E 11595.5381 +- 0.0083 U -263.6538 +- 0.0571 L 46705.6390 +- 0.0073
ALS0_AROO CORR 11 N-W 0.0187 N-U 0.0883 W-U -.0225 ST DEV OF UNIT WGT 8.6480
ALS0_AROO 1991.315 N 0.0008 +- 0.0092 E -0.0112 +- 0.0124 U 0.1420 +- 0.0703 L -0.0029 +- 0.0098
ALS0_AROO 1991.316 N -0.0073 +- 0.0095 E 0.0096 +- 0.0173 U 0.0667 +- 0.0646 L -0.0051 +- 0.0101
ALS0_AROO 1991.317 N -0.0002 +- 0.0058 E 0.0237 +- 0.0058 U -0.0246 +- 0.0553 L 0.0058 +- 0.0058
ALS0_AROO 1991.318 N 0.0047 +- 0.0124 E -0.0015 +- 0.0297 U 0.1081 +- 0.1006 L 0.0035 +- 0.0141
ALS0_AROO 1991.319 N -0.0122 +- 0.0069 E 0.0191 +- 0.0135 U -0.0104 +- 0.0556 L -0.0071 +- 0.0075
ALS0_AROO 1991.320 N 0.0070 +- 0.0052 E -0.0355 +- 0.0055 U 0.0998 +- 0.0487 L -0.0027 +- 0.0055
ALS0_AROO 1991.320 N 0.0165 +- 0.0147 E 0.0508 +- 0.0115 U 0.1145 +- 0.0738 L 0.0279 +- 0.0147
ALS0_AROO 1991.321 N -0.0019 +- 0.0086 E -0.0082 +- 0.0222 U 0.0143 +- 0.0816 L -0.0040 +- 0.0075
ALS0_AROO 1991.321 N 0.0069 +- 0.0210 E 0.0424 +- 0.0749 U -0.0172 +- 0.0850 L 0.0172 +- 0.0334
ALS0_AROO 1991.322 N -0.0030 +- 0.0066 E -0.0279 +- 0.0058 U 0.0839 +- 0.0577 L -0.0103 +- 0.0069
ALS0_AROO 1991.322 N 0.0293 +- 0.0153 E 0.1458 +- 0.0144 U -0.1193 +- 0.0712 L 0.0652 +- 0.0156
-----
```

The RMS denotes the standard deviation of one measurement (a.k.a., the square root of the sample variance). This is what most people mean by "repeatability". This RMS value is expressed as parts per billion on the PPB line. The SIG value is the standard error of the mean. The weighted mean value is available on all three of these lines. The 11 in this example denotes the 11 individual day measurements. The correlations follow. The individual day entries are deviations from the weighted means, with their uncertainties from the input file.

Here is a script to generate a bunch of statistics and plot them using gnuplot, the local XY plotter at IGP. You could use your own.

```
#!/bin/csh
# generate repeatability statistics
#
# collect the O-files:

# $1 is name of run
```

```

set files = ../3*/o$1??.???

#grep Normalized $files

# collect the baselines in NEU

if (-e tmp.bsl) then
  /bin/rm tmp.bsl
endif

# Get the bias free solution
grep -h _ $files | grep 'R N' | sort >! $1\r.neu.bsl

# Get the bias free solution XYZ
grep -h _ $files | grep 'R X' | sort >! $1\r.xyz.bsl

# Get the bias fixed solution
grep -h _ $files | grep 'X N' | sort >! $1\x.neu.bsl

cat $1\r.neu.bsl | wbsfilt >! $1\r.neu.wbsl
cat $1\x.neu.bsl | wbsfilt >! $1\x.neu.wbsl

cat $1\r.neu.wbsl | grep RMS | colrm 132 | sort -rn +14 >! $1\r.neu.rms
cat $1\x.neu.wbsl | grep RMS | colrm 132 | sort -rn +14 >! $1\x.neu.rms

#Plot files for free solutions
cat $1\r.neu.rms | awk '{print $17/1000. , $7*1000.}' >! $1.r.n
cat $1\r.neu.rms | awk '{print $17/1000. , $11*1000.}' >! $1.r.e
cat $1\r.neu.rms | awk '{print $17/1000. , $15*1000.}' >! $1.r.u
cat $1\r.neu.rms | awk '{print $17/1000. , $19*1000.}' >! $1.r.l

#Plot files for fixed solutions
cat $1\x.neu.rms | awk '{print $17/1000. , $7*1000.}' >! $1.x.n
cat $1\x.neu.rms | awk '{print $17/1000. , $11*1000.}' >! $1.x.e
cat $1\x.neu.rms | awk '{print $17/1000. , $15*1000.}' >! $1.x.u
cat $1\x.neu.rms | awk '{print $17/1000. , $19*1000.}' >! $1.x.l

#plot on screen
cat rep.gnu | sed s/NAME/$1/ | sed s/F/r/ | sed s/TITLE/"Repeatability for $1 (free) `date`"/
>! r.gnu; gnuplot r.gnu
cat rep.gnu | sed s/NAME/$1/ | sed s/F/x/ | sed s/TITLE/"Repeatability for $1 (fixed)
`date`"/ >! x.gnu; gnuplot x.gnu

#plot on paper
grep -v continue r.gnu >! r.lgnu; lasergnu -b -f r.lgnu -p -Psparc
grep -v continue x.gnu >! x.lgnu; lasergnu -b -f x.lgnu -p -Psparc

```

## 9.2 Creating RINEX or FICA Files from NGS ARGOS Files

Prior to May, 1992, CIGNET tracking data were aggregated at NGS by GPS Week in the ARGOS format. There are three files for each station (each week), one containing phase and pseudo-range data (usually called a "data" or "tape" file), one containing broadcast ephemeris and satellite clock information ("orb" file), and one containing the meteorological data ("met") file. There may also be a fourth file of descriptive information. The first step in using the CIGNET data is to FTP or transfer from tape at least the "data" and "orbit" files. Once transferred, the file names should contain the (4-character) standard station identifier plus the GPS week; e.g., for Yellowknife in week 437, the two required files should be named yknf437.dat and yknf437.orb.

A sample data (.dat) file is shown below:

```
YELLOWKNIFE          437 143 198    5 22
 88  5 24 21 51 59.0800000 251519.080000 1 6
    -69283.6838536321073582.10107 53744718.7507536299753069 .45818 40.5 39.5
 88  5 24 21 51 59.0800000 251519.080000 1 6
    -69283.6838536321194922.50099 53744718.7507536299753069 .45818 40.5 39.5
```

The first (title) record gives the station name, GPS week number, and the calendar date of the first day of the week. For each set of simultaneous observations, there is a time-tag record, with the epoch given in calendar date, (GPS) hours, minutes, seconds, and GPS seconds-of-week, followed by the number of satellites at that epoch and their pseudo-random noise (PRN) code numbers. For each epoch there are one or more measurement records containing (in order) L1 phase (cycles), L1 pseudo-range (meters), L2 phase, L2 pseudo-range, L1 carrier power-to-noise ratio (dB-Hz), and L2 carrier power-to-noise ratio (dB-Hz).

A sample orbit (.orb) file is shown below:

```
437 : GPS WEEK #

6 88  5 25  0  0  0.0 -.116699375212D-03 -.192130755750D-10 -.277555756156D-16
    .122880000000D+05    -.925000000000D+01    .101825670448D-08    .183378419704D+00
    -.586733222008D-06    .531821721233D-02    .104252249002D-04    .515364718437D+04
    .259200000000D+06    -.111758708954D-07    .192736365505D+01    -.726431608200D-07
    .111949619933D+01    .254187500000D+03    .202961194281D+01    -.621168731314D-08
    -.232152527227D-10    .100000000000D+01    .437000000000D+03    .000000000000D+00
    .100000000000D+01    .000000000000D+00    .000000000000D+00    .430080000000D+05
6 88  5 25  1  0  0.0 -.116767827421D-03 -.192130755750D-10 -.277555756156D-16
    .163840000000D+05    -.687500000000D+01    .101647091580D-08    .708491445227D+00
    -.396743416786D-06    .531794375274D-02    .104773789644D-04    .515364661980D+04
    .262800000000D+06    .186264514923D-08    .192734131190D+01    -.614672899246D-07
    .111949607937D+01    .253406250000D+03    .202958492564D+01    -.621847331009D-08
    -.292869342041D-10    .100000000000D+01    .437000000000D+03    .000000000000D+00
    .100000000000D+01    .000000000000D+00    .000000000000D+00    .430080000000D+05
```

The first (title) record contains only the GPS week number. Satellite clock and ephemeris information are listed as they are received. The first line gives satellite PRN number, GPS date and time, clock bias (seconds), clock drift (sec/sec), and clock drift rate (sec/sec<sup>2</sup>). The following four or six lines contain the standard ephemeris information, similar to that

given in the GAMIT E-file. A description of each value may be found in the NGS documentation distributed with the tape. Note that there was a change at Week 424.

The meteorological data (.met) file gives simply the temperature (°C), pressure (mb), and relative humidity (percent) at hourly intervals. A sample is shown below:

```
YELLOWKNIFE  GPS WEEK  437
 88 5 22 0 0 0.00      3.60    978.00    37.39
 88 5 22 1 0 0.00      3.70    979.00    39.53
 88 5 22 2 0 0.00      3.50    982.00    40.41
 88 5 22 3 0 0.00      3.40    985.00    41.01
 88 5 22 4 0 0.00      2.90    984.00    42.49
```

To convert an ARGO data (.dat) file into a RINEX observation (.YYO) file, use the shell script sh\_argo2rx :

```
sh_argo2rx -f < ARGO-file > -apr < apr file > [ -o ]
```

where the ARGO file name must begin with the 4-character station ID; apr-file is the name of a GLOBK file of a priori station coordinates; and the optional final argument ( -o ) signifies that an existing RINEX file of the same name will be overwritten. If available, station.info and rcvnt.dat will be read to get the RINEX header information.

To convert an ARGO orbit (.orb) file into a RINEX navigation (.YYn) file, use the program ARGO2NAV, which takes as a single command-line argument the name of the ARGO orbit file; viz: argo2nav algo537.orb

To convert ARGO data and orbit files into FICA files, use the program ARGO2FIC. To run the program simply type its name followed by the filename prefix (station and week number) and the receiver software version used to collect the data (CORE 4.1, 4.7, or 4.8 for the TI4100, 1.49, 1.50, or 1.61 for the MINI-MAC):

```
argo2fic      yknf437      4.1
```

ARGO2FIC will read the weekly .dat and .orb ARGO files and open and write a FICA file for each calendar day, naming the file by the station and day number. (If a .orb file is not available for a site, you can create one to satisfy ARGO2FIC by renaming the orbit file from another site since the orbital information is the same.). For Yellowknife in week 437, seven files will be created, named yknf8.143.fic, yknf8.144.fic, ....., yknf8.149.fic. The number of FICA blocks of each type will be displayed on the screen and written to an information file named, for the example shown, yknf437.inf. Note that both (week-long) ARGO files and (daily) FICA files are large compared to (daily) X-files, so some planning of disk space should be done before beginning the conversions.

### 9.3 *Creating RINEX files from FICA files*

Program FIC2RX (in the /makex directory) can be used to create RINEX observation and navigation files from FICA files. It has been tested for TI4100 blocks 101, 6, and 9 (all from GESAR), and is coded (but untested) for the TI4100 using CORE or ROM software, and for MiniMac, Rogue, and Trimble receiver blocks, as well as the short (RINEX-like) blocks (70, 80, 1080, 1180, 1280, 1380) created for all receivers near the end of FICA's useful lifetime. To run the program type

```
fic2rx <fica-file name> <l-file name>
```

If either of the command-line arguments is omitted, the program will prompt you to enter them. Omission of the L-file is allowed but will result in zeroes being entered for the approximate station coordinate in the RINEX header. FIC2RX is currently coded (MAKEX version 9.58 of March, 1997) to remove the nearest integer of the initial phase as per RINEX standards, but this feature of the code may be easily commented out.

### 9.4 *Creating X-files from C-files (Utility CTOX)*

In order to conserve disk space and maintain "clean" archival data files, it is useful to convert edited C-files back to X-files whenever possible. This is done using the program CTOX. It can be run from a single C-file or a list of C-files contained in a D-file. When you invoke the program, it will prompt you for the name of the input C- or D-file. If a D-file is used as input, CTOX will give you the opportunity to change the series letter associated with the input C--files. Finally, you will be prompted for the series letter to be associated with the output X-files.

### 9.5 *Creating RINEX files from X- and E-files*

Whenever data are exchanged with another institution, they should be transcribed in to RINEX format. This is easily accomplished using the program XTORX (in the /makex directory). XTORX accepts two command-line arguments: the first is the name of the input X-file or D-file containing a list of X-files; the second, used only in the case of a D-file, gives the series letter associated with the X-files (which might have a different series letter in the D-file list).

*(Program ETORX to write RINEX navigation files from FICA Blk 9 files to be written)*

### 9.6 *Converting a hi.raw file to sited. or station.info*

Prior to release 9.0, antenna height information was recorded by the analyst in a "raw" file read by program HI, which converted the actual measurements into L1 and L2 offsets, written in the "station description" (sited.) file. The sited. file can still be read by MAKEX, FIXDRV, and MODEL, but it is recommended that these files be converted into a

station.info file, which provides a more direct connection between the original measurement and the offsets used in modeling the site coordinates (see Chapter 4). (There is a loss of information in the new scheme since the hi.raw file provided for input measurements in both meters and inches and both before and after the observations. Most of the time, however, the analyst will make a judgement about the validity of the antenna measurements when he/she transcribes the values from the log sheet.) The format of the current hi.raw file,

(A4,A2,A1,1X,A3,1X,A16,2(1X,F5.3,1X,2I2),2(1X,F6.3),1X,A6,1X,A5), is shown below:

```
ALGO871.003 ALGONQUIN      1.175 0000  1.175 0000  0.000  0.000  TI4100SLPAB
ALGO871.004 ALGONQUIN      1.175 0000  1.175 0000  0.000  0.000  TI4100SLPAB
DEVL871.004 DEVILS PEAK,SCI 1.272 0000  1.271 0000  0.000  0.001  TI4100SLPAB
DEVL871.004 DEVILS PEAK,SCI 1.271 0000  1.272 0000  0.000  0.001  TI4100SLPAB
```

(The hi.raw file in use prior to {date} had one fewer decimal places in the height and offsets in meters. These files can be converted into the current format using program HI2HI92.) The first entry is the session identifier: 4-character station name, year, session number, and day. The second entry is the complete station name. Then follow seven entries giving measured values of antenna height and offset: height before the observations in meters, height before the observations in inches and 32nds of inches, height after the observations in meters, height after the observations in inches and 32nds of inches, east offset in meters, and north offset in meters. The final two columns give the antenna type and measurement scheme.

You need enter only the measurements that are available; any entry with a value of zero will be ignored. HI converts slant or vertical heights with respect to the antenna structure to the heights of the phase centers (L1 and L2) and computes an average of the "before" and "after" values entered in meters. Values entered in inches are used only as a check (unless no meters value is entered); large discrepancies between the English and metric measurements are indicated by the program.

The output of HI is a station description file in the format shown below:

```
ID YR.DAT SITE DESCRIPTION  L1_HT  L1_N  L1_E  L2_HT  L2_N  L2_E
(A4,A2,A1,1X,A3,1X,A16,4X,6F8.3)
ALGO871.003 ALGONQUIN      1.399  0.000  0.000  1.374  0.000  0.000
ALGO871.004 ALGONQUIN      1.399  0.000  0.000  1.374  0.000  0.000
DEVL871.004 DEVILS PEAK,SCI 1.496  0.001  0.000  1.471  0.001  0.000
OVRO871.003 OVRO-7114      1.387  0.000  0.000  1.362  0.000  0.000
OVRO871.004 OVRO-7114      1.890  0.000  0.000  1.865  0.000  0.000
```

To convert a hi.raw file into a station.info file, run program HI2STNFO. Since the station.info file contains the receiver software version, which is not in hi.raw, this information must be provided to effect a complete translation. HI2STNFO will prompt you for the name of a makex.batch file to provide the receiver information. If you have already created X-files (the usual case if you're running HI2STNFO), you may choose to leave the receiver information out of the station.info file since it is used only by MAKEX.

### 9.7 Creating K-files from Clock Log Information

For a codeless receivers the offsets between receiver clocks in the network are measured by bringing the receivers together at a common point. This procedure is usually performed both before and after a survey, and the offsets recorded in the observer's log. Prior to processing the data, the analyst must enter these offsets into a session- or campaign-specific K-file of the format shown for the example below:

```

FT ORD MACROMETER II   CLOCK DAYS 147-149
END
SERIAL NUMBER          UNIT CODE
    919                 S
    922                 T
END

```

CLOCK LOG TABLE

B E F O R E					A F T E R				
RECEIVER S/N					RECEIVER S/N				
HHMM	DAY	REFER.	REFER.	DIFF.	HHMM	DAY	REFER.	REFER.	DIFF.
(UTC)		A	B	( $\mu$ S)	(UTC)		A	B	( $\mu$ S)
2149	147	919	922	0.300	0559	148	919	922	17.10
2049	148	919	922	0.300	0542	149	919	922	3.000
1924	149	919	922	0.300	0600	150	919	922	3.000

At the top of the table are one or more header records and the serial numbers corresponding to the receiver unit numbers that might be used in identifying the observation files. Then each clock comparison performed in the field is tabulated. FIXDRV uses the differences recorded before and after observations to compute an offset and rate for each receiver with respect to a reference (designated in FIXDRV) for each day. In the example the clock for receiver serial number 919 was used as a reference for each comparison, but it is not necessary to use the same reference each time. On day 147 the clock for receiver 922 was synchronized with 919 to within 0.3 microseconds ( $\mu$ s) before observations began (at 2149 UTC) but had drifted by 17  $\mu$ s by the end of the session (0559 the next day). On days 148 and 149 the two clocks were also synchronized at the beginning, and the drift by the end was only 3  $\mu$ s.

### 9.8 Creating W-files from Weather Log Information

Meteorological data is entered for each site into a W-file, an example of which is shown below:

```

Static met file for FOR2 Brush 2 1988 Day 148
END
1988 148 2100 1988 149 0600 FOR2
Time (UTC)          TEMP  PRES      REHUMID
                   LOCAL  LOCAL      LOCAL
YR  DAY  HR  MN  DEG C  MB      PER CENT
  (free format)
88 148 21 00          17.9    979.0    70.0
88 149 06 00          17.9     97      70.0

```

One or more header lines are terminated by END. Then follows a line giving the total span of the file (to facilitate interpolation and to avoid reading beyond the end) and three lines of header information that is read by the program to determine the type and units of met values entered. Temperature and pressure are always entered in units of degrees Celsius and millibars, respectively, but the water vapor values may be relative humidity in per cent (as shown) or partial pressure of water vapor in millibars. All three measurements may be for the site itself (LOCAL) or at sea level (SEALEVEL). The tabulated times and met values are in free format.

### 9.9 Creating and Maintaining Datum, Time, Spacecraft, and Ephemeris Tables

Many of the modules of GAMIT require a table giving the parameters of geodetic datums. ARC and MODEL require tables for TAI-UTC, TAI-UT1, pole position, nutation, and spacecraft parameters. ARC also requires tables for the positions of the sun and moon. The data for these tables are available from MIT or Scripps but may also be obtained from national astronomical and geodetic agencies or the International Earth Rotation Service (IERS). In this section, we describe how these data should be formatted for use by GAMIT.

#### Geodetic Datums ( gdetic.dat )

Table 9.1 is a example of the geodetic datum file. There is a one-line header followed by descriptions, not read by the program, of the columns of the table. Five-character names are used to denote each datum, which is then specified by the standard ellipsoid parameters, semi-major axis (in meters) and inverse flattening, and cartesian offsets (in meters) from the geocenter.

*Table 9.1*

Geodetic Datums						last updated by rwk 96.10.30
Datum	a	1/f	DX	DY	DZ	
WGS84	6378137.	298.257223563	0.	0.	0.	
NAD83	6378137.	298.257222101	0.	0.	0.	
WGS72	6378135.	298.26	0.	0.	4.5	
NAD27	6378206.4	294.9876982	-12.01	-162.97	189.74	
CLK80	6378249.145	293.465	0	0	0	English Clarke
CLI80	6378249.2	293.4660208	0	0	0	Clarke 1880 IGN
INT24	6378388.	297.	0	0	0	

#### Spacecraft parameters ( svnav.dat )

The file svnav.dat gives the correspondences between spacecraft (Navstar) numbers (NSN) and pseudo-random noise (PRN) numbers for each GPS satellite, its mass, and its yaw

parameters. The tables is updated after each launch or change in yaw status, usually by Paul Tregoning of ANU based on data supplied by Yoaz Bar-Sever of JPL. The begining and end of the current (Dec 96) table is shown below:

```

NSN/PRN #s, masses, and yaw rates satellites. Updated by R. King 4 Jun 98
PRN SV BLK MASS(G) BIASED YAW RATE YR MO DY HR MN DX DY DZ (see key at bottom)
4, 1 1 453800. U 0.1990 78 02 22 00 00 0.210 0.0 0.854
6, 3 1 453800. U 0.1990 78 10 06 00 00 0.210 0.0 0.854
...
2, 13 2 878200. U 0.1130 89 06 10 00 00 0.279 0. 0.9519
2, 13 2 878200. Y 0.1130 93 01 01 00 00 0.279 0. 0.9519
2, 13 2 878200. N 0.1130 95 07 05 01 10 0.279 0. 0.9519
2, 13 2 878200. P 0.1130 95 11 17 00 00 0.279 0. 0.9519
14, 14 2 887400. U 0.0870 89 02 14 00 00 0.279 0. 0.9519
...
13, 43 4 1100000. P 0.1230 97 07 23 00 00 -0.0031 -0.0012 0. -- yaw values provisiona
8, 38 2 972900. P 0.1230 97 11 06 00 20 0.279 0. 0.9519 -- yaw values provisiona
BLK: 1=Blk I 2=Blk II 3=Blk IIA 4=Blk IIR
Temporary: Blk IIA (SV 23-30) set =2 for backward compatibility (releases < 9.63 )
BIASED (yaw): Y=normal A=anti-normal P= +ive only, N= -ive only U=unbiased
SVANT-DXYZ: Antenna offsets from center of mass (m)

```

The mass, along with the block number, is used to calculate non-gravitational accelerations. The block number is used to determine the offset of the transmitter antenna phase center from the center of mass of the spacecraft. The yaw "bias" and rate determine how MODEL treats the spacecraft attitude during eclipse. Prior to June, 1994, all of the GPS satellites had unbiased ( U ) yaw when in sunlight, leading to difficult-to-predict behavior during eclipse. Under these conditions GAMIT does not attempt to model the eclipse orientation. In June, 1994, DoD added a small (0.5 degree) bias to the nominal yaw of some satellites, increasing the number to the entire constellation by November, 1995. The bias causes a satellite to yaw at a predictable rate and direction during eclipse. There are four direction "conditions" that have been in effect for at least a short period on some satellites since June, 1994: positive (clockwise) ( P ), negative ( N ), "normal" ( Y , positive or negative, depending on the angle between the orbit plane and the Sun, and "anti-normal" ( A , opposite of normal). For a complete discussion of the yaw history and the model, see *Bar-Sever* [1996] (referenced in Chapter 2). The last three columns contain the offsets of the spacecraft (LC) antenna phase-center from the center of mass. The values shown here and hardwired into the code prior to Release 9.71 are nominal offsets determined by DoD and its contractors. We expect to change these in the near future to values estimated from global data analyses.

### TAI-UTC ( leap.sec )

Although GAMIT files and internal calculations are now mostly GPS time, UTC is used for some old X-files and is useful for informational purposes. The conversion from one system to another is performed by reading the table `lap.sec` which gives leap seconds since

1 January 1982, at which time TAI-UTC was 20.0 seconds. The format of the table is given below:

*Table 9.2*

```
LEAP SECOND TABLE      CREATED 87-12-15   UPDATED 98-01-08
(1X,F9.1)                2449169.0 JUN 30 1993
2445151.0                !JUNE 30, 1982 LEAP SEC INCREMENT
2445516.0                !JUNE 30, 1983 LEAP SEC INCREMENT
2446247.0                !JUNE 30, 1985 LEAP SEC INCREMENT
2447161.0                !DEC 31, 1987 LEAP SEC INCREMENT
2447892.0                !DEC 31, 1989 LEAP SEC INCREMENT
2448257.0                !DEC 31, 1990 LEAP SEC INCREMENT
2448804.0                !JUN 30, 1992 LEAP SEC INCREMENT
2449169.0                !JUN 30, 1993 LEAP SEC INCREMENT
2449534.0                !JUN 30, 1994 LEAP SEC INCREMENT
2450083.0                !DEC 31, 1995 LEAP SEC INCREMENT
2450630.0                !JUN 30, 1997 LEAP SEC INCREMENT
2451179.0                !DEFAULT LATER DATE (Guess: Dec 31 1998)
```

The first line of the table is a comment. The second line gives the format of the tabular entries to follow and the last date for which the current table is valid. If a date beyond that given on line two is requested by the program, a message will be printed and execution will stop. The tabular entries are simple the PEP Julian dates (PJD) for each leap second ( $PJD = MJD + 2400001$ ; see the discussion with the lunar table below). The calendar dates to the right of each entry are comments not read by the program.

### TAI-UT1 Table :

Table 9.3 shows a UT1 table, which consists of a two-line descriptive header and a series of values as a function of time modified Julian date (MJD). In the example shown, the comments on the first line indicate that the values in the table came from IERS Bulletins A and B. The second line includes the format of the data lines, an integer ("2" in the example) indicating whether the values are TAI-UT1 (UT1 type = 4) or TAI-UT1R (UT1 type = 2), the PEP Julian days over which the table is valid, the number of values per line ("6"), the spacing of the values in days ("5"), and the factor to be used to convert the tabulated values to the units required by the program (seconds of time). The designation "UT1R" means that TAI-UT1 has been "regularized" (smoothed) by removing the effects of zonal tides with periods shorter than 35 days, which can introduce short-period variations up to 2.5 milliseconds. MODEL and ARC add these terms back in from conventional models when computing the angular orientation of the earth. If UT1 values are computed and tabulated at intervals of 5 days, as in IERS Bulletin B, it is useful to use UT1R to avoid errors in interpolation. If values are computed at intervals of 1 day or less, however, unregularized values are preferred. GAMIT UT1 tables are constructed from

IERS circulars on a regular basis at Scripps to support PPGA operations and may be copied from the public directories. Users should note whether the values for recent dates are "predicted" (IERS Bulletin A or B), "rapid service" (Bulletin A), or "final" (Bulletin B) and consider whether errors in the values are important for your particular analysis.

*Table 9.3*

```
TAI-UT1R: IERS Bull. B, BULL. A Rapid Service from 44444; Updated 2/10/88 (5X,I5,6(I8,1X),14X,I2)
2446824 6 5 1.E-5
45499 2122110 2123100 2123990 2124790 2125540 2126250
45529 2126940 2127620 2128280 2128940 2129680 2130490
45559 2131350 2132230 2133100 2133960 2134770 2135580
45589 2136420 2137310 2138270 2139300 2140360 2141410
```

### Pole Position Table:

Table 9.4 shows a pole-position table, which, like the TAI-UT1 table, consists of a two-line header and a series of values as a function of time. The first line is a comment describing the source of the table. The second line has exactly the same form as the TAI-UT1 table except for the "type" parameter, giving the format, span, number of values per line, tabular interval in days, and the factor to be used to convert the tabulated values to the units required by the program (seconds of arc). The pole position values are stored in pairs, with the  $x$  position given as the first value of each pair and the  $y$  position the second. As for UT1, the pole-position values from the IERS can be "predicted", "rapid service", or "final", with different levels of accuracy. For the highest accuracy in your analysis, you should use a set of pole-position values estimated from VLBI and/or GPS data simultaneously with your site coordinates. If you do not estimate these values in your own analysis (using GLOBK), you can copy the MIT tables `/sites/vg_ yymmdd` and `/tables/pole.vlbi_ yymmdd`

*Table 9.4*

```
BIH79 WOBBLE: UPDATED WCB 01/05/87 RAP.SER. FROM 46744, PRED. FROM 46794 (1X,I9,12I5,8X,I2)
2446824 6 5 1.E-3
45499 222 497 238 480 252 462 265 444 276 425 287 405
45529 298 384 309 363 319 341 326 319 330 298 333 277
45559 333 256 331 235 328 214 322 193 314 172 304 151
45589 293 131 280 112 265 95 249 80 231 66 211 54
45619 189 43 167 34 145 27 123 22 100 18 77 17
45649 55 18 33 19 12 22 -9 26 -29 32 -47 39
```

Lunar Table:

Table 9.5 shows the beginning section of a Lunar table, which has the same format as the UT1 and pole tables except that there is an additional character entry at the end of the second header line indicating whether the ephemeris is in a B1950 or J2000 inertial frame.

Important note on Julian Day numbers: In the lunar, solar, and nutation tables, we have followed the convention of the MIT Planetary Ephemeris Program (PEP) and designated a day, beginning at midnight, by conventional Julian Day which begins the following noon. Thus, the PEP JD (PJD) is the conventional Julian Date + 0.5. The Modified Julian Day (MJD) used by the IERS in the earth rotation tables is one day (plus 240000) less than the PEP Julian Day, i.e.,  $PJD = MJD + 1 + 240000$ .

For each following line of the table, the first number is the PEP Julian day number of the table entry minus 2400000. (Note that the time interval spacing between table entries is 0.5 day. Therefore, two table entries will have the same Julian day number.) The second, third and fourth numbers are the x, y and z of the Moon's position on that Julian date. The units are meters and the values are with respect to the mean equator and equinox of 1950.

*Table 9.5*

```
J2000 Lunar ephemeris for 1995 Nov 94 - Mar 96  rwk/MIT  95/6/16
(1x,i5,6i11)      0 2449641 2450200  3 -1      1.E-03 J2000
 49641  338866941 -190113511 -44831903
 49641  359853304 -154961265 -30778560
 49642  376410611 -117854817 -16331906
 49642  388399920 -79273638  -1673630
 49643  395737251 -39701958  13016720
 49643  398392214   376099   27563394
```

Solar Table:

Table 9.6 shows the beginning section of a Solar table (which is actually a tabulation of the position of the Earth with respect to the Sun). The header entries are at 4 day intervals, the PEP Julian day number has 2400000 subtracted, and the x,y,z position components are in kilometers.

*Table 9.6*

```
J2000 Earth ephemeris for 1995 Nov 94 - Mar 96  rwk/MIT  95/6/16
(1x,i5,6i11)      0 2449641 2450197  3  4      1.E+00 J2000
 49641  138814695   50128193  21733554
 49645  134547714   58751821  25472708
 49649  129639597   67095038  29090431
 49653  124109860   75118738  32569486
```

Nutation Table:

Table 9.7 shows the beginning section of a nutation table. The first line is again a comment line describing the table. That comment line indicates that the table is good from the 335th day of 1984 to the 180th day of 1985 and that the table was generated March 26, 1985. The second line gives the format of each table line and then five numbers. The start and stop Julian day numbers of the table are the first two. The third number indicates that each line will contain four pairs of table values. The fourth number (-1) indicates that the tabular interval is 0.5 (i.e.  $2^{-1}$ ) day. The fifth number indicates the value that the table values must be multiplied by to get the proper units (arc seconds) for the program. Only the start and stop Julian day numbers are actually used from these headers. On each following line of the table, there is the PEP Julian day number - 2400000, followed by four pairs of values of  $\Delta\psi$  and delta  $\Delta\epsilon$ , the conventional angles describing the nutation in longitude and obliquity (in units of  $10^{-4}$  arcseconds, according to the fifth entry in the second header line). Note that the table lines are at time intervals of two days, which means that each pair of nutation angle values is 0.5 days apart.

*Table 9.7*

Nutation ephemeris for 1995		Nov 94 - Feb 96		rwk/MIT		94/10/4	
(1x,i5,8i8,8x,i2)		2449641	2450200	4	-1		1.E-04
49641	117182 -59269 116620	-59240	116001	-59247	115344	-59290	
49643	114671 -59373 114000	-59494	113350	-59652	112738	-59843	
49645	112180 -60063 111686	-60305	111267	-60564	110928	-60832	
49647	110672 -61104 110499	-61372	110406	-61630	110385	-61872	
49649	110429 -62092 110527	-62286	110667	-62450	110835	-62582	
49651	111016 -62680 111193	-62745	111351	-62777	111473	-62780	

## 10. Automatic Batch Processing

### 10.1 Overview

Once you understand the file structure and analysis tools of GAMIT, you can save significant time in processing large quantities of data by using the automatic processing script `sh_gamit` and the related scripts `sh_glred`. `Sh_gamit` takes you, with a single command, from raw or RINEX data over a range of days to a solution and sky plots of phase data as a record of the GAMIT analysis. `Sh_glred` uses the GAMIT results to produce time series of day-to-day repeatability and a solution (h- or SINEX) file that may be combined with those from other epochs to estimate station velocities. The only preparation required is setting up the control files, most of which are common to all analyses of a particular era, and assembling the non-IGS data in one or more directories on your system.

The first step in running the scripts is to create an experiment directory and then to copy into it the templates directory from the GAMIT/GLOBK source directory. You will then need to edit one or more files in this directory to tailor the processing to the configuration of your computer system and GPS network:

`process.defaults` : Edit to specify your computation environment, sources for internal and external data and orbit files, start time and sampling interval, and instructions for archiving the results.

`sites.defaults` : Edit to specify which local and IGS stations are to be used and how station log data are to be handled.

`station.info` : Make sure that this file is current (from SOPAC) for all IGS stations you will use in your analysis. If the RINEX files for your local network contain IGS-standard receiver and antenna codes and the correct height information refers to the ARP, then no further entries are required. If not, then you must manually enter the GAMIT codes and height values into the file. You can give `station.info` priority over the RINEX headers using the `xstnfo` option in `sites.defaults`.

`lfile.` and `.apr` files : The template files will contain accurate coordinates for IGS stations, and the script will attempt to calculate coordinates for any new station via a pseudorange solution, or (if you say so) use the coordinates in the RINEX header. When GAMIT runs, these coordinates will be updated from the phase solution so that for successive days on which the same station is observed, the accurate coordinates will be used.

`sestbl.` and `sittbl.` : Edit these to set the appropriate options for your analysis. Make sure that any station for which you specify tight constraints in `sittbl.` has accurate coordinates in the `apr` file (`apr.f` in `process.defaults`).

You may also choose to create under the experiment directory a `/rinex` directory and to copy into it all of your local RINEX files. Alternatively, you can specify in `process.defaults` the directory structures for searching for raw and RINEX files on your

local and remote systems, as explained in Section 10.3. All other directories and files required by GAMIT will be created by the script.

Once you have edited appropriately the template files, you can start the processing from within the experiment directory by giving `sh_gamit` simply the 4-character code for the experiment and a range of days to process:

```
sh_gamit -expt emed -d 1999 235 236 237 238 >&! sh_gamit.log
```

The time span can also be specified using `-s <start_day> <stop_day>` to indicate a range of consecutive days, or `-r <days>` to indicate that you want to process a single day `<days>` before the current date. You may also override some of the parameters specified in `process.defaults`:

```
-orbit <type>  Type of orbit (IGSP IGSR IGSF SIOP SIOR SIOF)
-eops <name>  EOP series to be used ( usno [default], bull_b )
-c           Do not compress X-files and RINEX files when done (default compress)
-archive     Copy solution files to an archive and remove the day directory (default no)
-e           Do not erase C-files when done (default is to erase)
-pres       Plot phase residuals as postscript skyplots (default no)
-nogifs     Do not create gif files of sky plots (default is to create from postscript)
-netext <char> Add network specific suffix (character) to day directory names (e.g.035r )
-sessinfo   Sampling interval, #epochs, start time (HH MM) (e.g. 30 2880 0 0 )
-mailto     User name and machine (e.g. simon@chandler.mit.edu)
```

Most of the time the parameters may be omitted in favor of the values you have specified in `process.defaults` for the whole experiment. The overrides are useful, however, if you wish to test the effect of processing a day with a different orbit, EOP table, or session length, in which case you can create a directory for the same day by appending a character to its name (e.g., `-netext t`). Finally, you may launch `sh_gamit` from anywhere on the system by specifying the full path name of the processing directory with `-dir <path>`. When the script runs, it will write to the screen a record of each step, which you may choose to redirect to a file (e.g., `>&! sh_gamit.log`). Though the current version of this log is cryptic in parts, you should be able to use it together with `GAMIT.fatal` file, and the source code for `sh_gamit` to identify the point and reason for failure should that occur. We welcome user feedback to improve the displayed information.

When processing of each day is completed, `sh_gamit` will send a mail message to you giving the number of stations used, the nrms values from the Q-file, the rms of the one-way phase residuals for the two best and two worst stations from the AUTCLN postfit summary file, and a list of any large adjustments to station coordinates. These statistics will let you know whether you need to examine the GAMIT output further for possible reprocessing.

A collateral benefit of the automatic processing development is that we have cleaned up many of the utility shell scripts so that they can be easily used in non-automatic or customized processing. The most useful of these are `sh_make_rinex`, `sh_get_nav`, `sh_get_rinex`, `sh_get_orbits`, `sh_update_eop`, `sh_link_rinex`, and `sh_make_sky_gifs`. Instructions for running each of these may be obtained by typing the name with no arguments.

## 10.2 Template files

Following are annotated copies of the two new control files used by `sh_gamit`.

### process.defaults

```
# Do not remove any of these entries.  To by-pass a function, set the
# value to null:  ""
#
## LOCAL DIRECTORIES
# Directory for translation of raw data (may have links to /rawfnd)
set rawpth = "/data13/simon/mitnet/raw"
# Directory path for raw archives (search all levels); e.g. /data18/simon
set rawfnd = ""
# Input files for RINEX translators
set mpth = "$procdir/mkrinex"
# RINEX files directory
set rpth = "$procdir/rinex"
# Directory path for RINEX archives (search all levels); e.g. /data18/simon
set rnxfnd = ""
# Broadcast orbit directory
set bpth = "$procdir/brdc"
# IGS files directory
set ipth = "$procdir/igs"
# G-files directory
set gpth = "$procdir/gfiles"
# GAMIT and GLOBK tables directory
set tpth = "$procdir/tables"
# Globk solution directory (required but not yet used)
set glbpth = "$procdir/soln"
# Globk binary h-file directory (required but not yet used)
set glfpth = "$procdir/glbf"
# Output gifs directory
set gifpth = "$procdir/gifs"
# Template files
set templatepth = "$procdir/templates"
# Place to store temporary control files
set cpth = "$procdir/control"
# Archive root directory (cannot be null)
set archivepth = "$procdir/archive"

## FTP INFO FOR REMOTE FILES
# Raw data archive
set rawarchive = 'chandler.mit.edu'
set rawdir = 'pub/continuous/mitnet'
set rawlogin = 'anonymous simon@chandler.mit.edu'
# Addresses for CDDIS, SOPAC, IGSCB, and USNO are given in /com/ftp_address
```

```

## GAMIT
# Set sampling interval, number of epochs, and start time for processing
set sint = '30'
set nepc = '2880'
set stime = '0 0'
# New variables for updating tables (see sh_upd_stnfo)
set stinf_unique = "-u"
set stinf_nosort = "-nosort"
set stinf_slthgt = "2.00"
# Set "Y" to use RINEX header coordinates if not in lfile or apr file
set use_rxc = "N"
# 4-character code for broadcast orbits
set brdc = 'brdc'
# Minimum x-file size to be processed (Def. 300 blocks)
set minxf = '300'
# Set search window for RINEX files which might contain data for day
set rx_doy_plus = 1
set rx_doy_minus = 1

## RESOURCES
# Minimum raw disk space in Kbytes
set minraw = '30000'
# Minimum RINEX disk space in Kbytes
set minrinex = '30000'
# Minimum archive disk space in Kbytes
set minarchive = '20000'
# Minimum working disk space in Kbytes
set minwork = '200000'

## SYSTEM-DEPENDENT SETTINGS
# UNIX df command must be set to return the correct form
set udf = 'df -k'
# UNIX mail command
set umail = 'mailx -s'
# Mail address for the processing report
set mailto = 'simon'
# Host name for email and anonymous ftp password use
set machine = 'wegener.mit.edu'
# Ghostscript path
set gspath = '/usr/bin'
# ImageMagick path for gif conversion
set impath = '/usr/bin/X11'
# Web interface .html file.
set htmlinfo = 'mitnet.html'

```

#### sites.defaults

```

# File to control the use of stations in the processing
#
# Format: site  expt  keyword1  keyword2  ....
#
#   where the first token is the 4- or 8-character station name (GAMIT
#   uses only 4 characters, GLOBK allows only 4 unless there are earth-
#   quakes or renames); the second token is the 4-character experiment
#   name, and the remaining tokens, read free-format, indicate how the

```

```

# station is to be used in the processing. All stations for which
# there are RINEX files in the local directory will be used auto-
# matically in the GAMIT processing and do not need to be listed.
#
#
# GAMIT:
# ftprnx = sites to ftp from rinex data archives.
# ftpraw = sites to ftp from raw data archives.
# xstinfo = sites to exclude from automatic station.info updating.
# GLOBK:
# glrepu = sites used in the GLRED repeatability solution
# glreps = sites used for reference frame definition (stabilization) in
#          GLORG for the GLRED repeatability solution
# glts = sites to plot as time series from GLRED repeatability
solution
mate_gps tubi ftprnx xstinfo glrepu glreps
ankr_gps tubi ftprnx xstinfo glrepu glreps glts
kit3_gps tubi ftprnx xstinfo glrepu glreps
nssp_gps tubi ftprnx xstinfo glrepu glreps
graz_gps tubi ftprnx xstinfo glrepu glreps
noto_gps tubi ftprnx xstinfo glrepu glreps
nico_gps tubi ftprnx xstinfo glrepu
sofi_gps tubi ftprnx xstinfo glrepu
zeck_gps tubi ftprnx xstinfo glrepu
zwen_gps tubi ftprnx xstinfo glrepu glreps
bahr_gps tubi ftprnx xstinfo glrepu
tela_gps tubi ftprnx xstinfo glrepu
tubi_gps tubi ftpraw xstinfo glrepu glts
mert_gps tubi ftpraw glrepu glts
kant_gps tubi ftpraw glrepu glts
# may use the following:
# all_sites tubi xstinfo

```

### 10.3 Using *sh\_gamit*

Before you start, review carefully all of the entries in `process.defaults`. In particular, make sure that the system-dependent UNIX commands are correctly specified. The `df` and `mail` commands are set in `process.defaults`. A form of `df` must be used that produces a return of the form

```
Filesystem 1024-blocks Used Available Capacity Mounted on
shida:/shida/data34 13573771 11711318 1156800 91% /tmp_mnt/data34
```

Some systems also return different units with the `ls -s` option (e.g., kilo-bytes vs 128-word blocks, so the minimum sizes of the X-files should be checked to make sure that the limits represent truly small files. A POSIX-compliant version of `awk` must be specified with a link in your path (e.g., in `/gamit/bin`). (An alias in your `.cshrc` file will not work with the `sh_gamit` scripts.)

The most complex feature of `sh_gamit` is the procedure by which raw and RINEX files are gathered for each day of a survey. The simplest situation is when you have all of the data on your local system in RINEX form and placed into the `/rinex` directory under the experiment directory before you start. In this case, you should leave blank all of the variables associated with collecting additional data: `/raw, /rawfnd, /rnxfnd` in

`process.defaults` and the `ftp`raw and `ftp`rxnxtokens of `sites.defaults`. If you need to acquire global RINEX files from an IGS data center, you may specify the stations using `ftp`rxn in `sites.defaults`. `sh_gamit` will invoke `sh_get_rinex` for both the CDDIS and SOPAC archives and `ftp` to your `/rinex` directory all stations specified that are available. A more complicated situation arises when you have a mixture of raw and RINEX data, which may be archived in multiple directories on your system or at a remote data center. The `/raw` and `/rxn` variables of `process.defaults` specify a path to multiple-level raw and RINEX directories which will be searched for any data files available for the day being processed. In this case, `sh_gamit` will create links within the experiment `/raw` and `/rinex` directories to the files in the `/raw` and `/rxn` paths. Any case-folding or renaming necessary to create standard file names for raw files will be done for the links in `/raw`, leaving the original names in `/raw` unchanged. Whatever the mix of raw and RINEX files available, `sh_gamit` will compare the lists of X-, RINEX, and raw files available, and perform translations only when the product file is not available. If you wish to force retranslation of raw to RINEX, or RINEX to X, you must remove the product files before you start.

If you expect `sh_gamit` to generate `station.info` entries from the RINEX header information, you should review the antenna and receiver names used in all of the headers before you start (e.g., by `grep`'ing on the RINEX files for 'REC #' and 'ANT #'). If any non-standard names have been used, make sure that a unique string representing these names appears in `/templates/guess_rcvant.dat`. If you know that all of your receivers and/or antennas are of the same type, you can force their use by specifying them as `ant default` and `rcv default` in this file. Antenna heights can also be problematic. In the RINEX standard, the height is supposed to be a vertical height to antenna reference point, but often a slant height is actually given in the file. If the latter is the case, then `stinf_slthgt` in `process.defaults` can be set to a height above which the height will be assumed to be a slant height to the outside edge of the ground plane. (Setting `stinf_slthgt` to 0 or a large number will make all heights interpreted as direct height measurements.) Running from raw data can be problematic because the antenna type is not usually stored in the raw files and must be supplied by the user. The UNAVCO TEQC program is used for converting to RINEX. The `sh_make_rinex` script assumes an antenna type and adopts a generic (not IGS standard) name based on the receiver type: Trimble --> TRIMBLE\_4000SST, TurboRogue-->AOAD/M\_T, Ashtech --> ASH701933\_M. If the wrong height is used in the GAMIT processing, but the antenna type is correct, then the `station.info` file can be updated and program `htupd` used to correct the binary H-file without the need to rerun GAMIT. Note that sites that are listed in `sites.defaults` with the `xstinfo` ("exclude `station.info` update") entry should have `station.info` entries. This entry should be used for all IGS stations since the `templates/station.info` file has the information for these stations corrected specified whereas their RINEX headers, particularly for older data, may be incorrect. If `sh_gamit` cannot determine the receiver or antenna type from an existing `station.info` or from the RINEX headers, it will terminate with one of several messages that make this clear (see `GAMIT.fatal` or the screen or log-file output of the script).

If you are processing a session which does not cover a single UTC day, there can be problems in automatically updating the entries in `station.info`. If there have been changes in antenna height during the session, then you will need to create the `station.info` entries manually. Otherwise, the processing should go smoothly as long as you instruct the script to look for RINEX files on all of the days covered by the session using the `rx_doy_minus` and `rx_doy_plus` entries in `process.defaults`. Since the date in a RINEX file is supposed to reflect the time of the first measurement, for single-day processing, the `rx_doy_plus` entry should be 0 (since no data from the next day should be needed). For RINEX files which cross the day boundary, `rx_doy_minus = 1` should capture these data correctly. If RINEX files are longer than 24-hours then `rx_doy_minus` may be set larger to ensure that all data are processed.

A common mode of failure for `sh_gamit` is having a station or all of its data removed from the solution. If the station does not appear at all, the problem is usually a missing RINEX or incomplete RINEX file. If the station appears but has no data, then the data have most likely been removed by AUTCLN. The most common reason for the removal is that too many bias flags were added (DDSC column of the editing report of the AUTCLN summary file), either because of poor a priori coordinates or poor receiver performance.

If a priori coordinates for a station are not available in the L-file (or apr file) from previous processing, `sh_gamit` will by default invoke the `sh_rx2apr` script to perform a pseudorange solution. Coordinates good to 10-20 m can usually be obtained from the data at the station of interest (better if SA is off), but the preferred approach is to perform the solution differentially, using also a RINEX file from an IGS station with known coordinates. To make sure this happens, you should specify `ftp_rnx` in `sites.default` and have present in the `/rinex` directory or available via ftp from an IGS data archive the RINEX files for each day from one or more IGS stations. To by-pass `sh_rx2apr` and use the coordinates from the RINEX header, set `use_rxc = Y` in `process.defaults`. This option should be used only if you know that the header values are always present and accurate.

`Sh_gamit` can also fail if it is unable to ftp required global RINEX files or orbital information from an IGS archive (usually SOPAC or CDDIS). The `GAMIT.fatal` message will usually make clear what file is missing. In this case, check the ftp connection manually and restart the processing.

When you rerun a day after a previous failure, you need to exercise some care to avoid repeating the failure. The easiest solution is to remove the day directory completely and to remove any bad entries in the L-file in `station.info` in the `/tables` directory. If you do not remove the day directory, then note the following protocols: (a) Any existing X-file in a directory will be used again and the script assumes that there is a valid `station.info` entry for this file (if not, the process will fail). (b) Any existing RINEX file linked in the day directory will be assumed to exist. If the link is now empty because you have renamed or remove the file in the remote directory, this may not be detected correctly on all systems. (c) A previously added `station.info` entry will be used (and not replaced) if it applies to the

day being processed. (d) Coordinates in the L-file will be used if they exist (so if the entry has been corrupted it should be removed).

#### 10.4 Using *sh\_glred*

This script provides an efficient way to generate time series from a combination of regional and global data. The input is a specified set of regional and/or global networks, a total span of days to be processed, and the number of days to be combined in each solution. The script then collects all the available ascii h-files, generates binary h-files using `htoglb`, combines all of these for each day or group of days, runs `glred` and `glorg` to produce a solution for each group, and generates repeatability plots. The search areas for h-files may include GAMIT day directories, any number of other local directory trees, and the SOPAC archive. Though you can customize the command files for `glred` and `glorg` for special tasks, command files for a standard loose combination, with or without global tracking data, will be generated automatically if they are not available.

`Sh_glred` is not designed to generate repeatabilities from daily binary h-files that have already been combined or to estimate velocities from h-files spanning several years. Templates for using `glred` and `globk` for these tasks, however, may be found in the `/templates` directory; see `run_repeat`, `run_combine`, `run_velocity`, `globk_rep.cmd`, `globk_comb.cmd`, `globk_vel.cmd`, `glorg_vel.cmd`.

Once you have edited appropriately the template files, you can start the processing from within the experiment directory:

```
sh_glred -s <yr1 doy1 yr2 doy2> -expt <expt> -net <networks> -local
        -netext <char> -yrest <year> -ncomb <num> -stnfo <station.info> -cmd
        -opt <A F H L U G E K C R>
```

where `-s` is used to specify the start ( `yr1 doy1` ) and stop ( `yr2 doy2` ) year and day-of-year for the processing, `-expt` is the 4-character experiment name for the H-files in local day directories ( `ddd[char]` ), and `-net` indicates the SOPAC H-files to be included. The options for SOPAC are ALL (default), or some combination of the solutions in the archive, currently `igs1 igs2 igs3 net1 net2 net3 net4` ). If `-local` is specified, the script will process only days within the span for which local data are available; otherwise, it will process all days within the span for which it can find SOPAC H-files. The days to be processed can also be specified explicitly using `-d yr doy1 doy2 doy3 ..`, or with `-r days` to indicate that processing should commence a certain number of days ( `days` ) before the current date and continue until there are no more local or SOPAC files to include.

The local directories are searched by default with the day-of-year, but can be restricted by specifying a network suffix (e.g. `035r` ) with `-netext` or a year prefix (e.g. `1997_` ) with `-yrest`. The optional argument `-ncomb` is used to specify the number of days to include in

each combination. The default is 1 day, but you can also use the script to produce weekly or monthly averages of local or global files. The argument ( `-stnfo` ) is the name of the station.info or SINEX file to be read by program `hfupd`; the default is `../tables/station.info` .

The following processing tasks are available, listed in the order in which they are performed:

- <R> Remove old `h*.gl?` files from the `glfpth` directory prior to starting.
- <F> Ftp global h-files from the SOPAC archive, search names given by `<networks>` .
- <H> Run `htoglb` on all ascii files present or linked within `glfpth` (usually `procdir/glb`).
- <LA> Link locally archived ascii H-files (all `h[net|expt]?.yyddd`) for inclusion in the combination.
- <LB> Link locally archived binary H-files (all `hyymmdd????_[net|expt].gl?`) for inclusion in the combination.  
Searches are from `hfnd` down, where `hfnd` is by default `procdir/glb` but may be specified as multiple paths in `process.defaults`.
- <LC> Link locally generated combined binary H-files (
- <U> Run `hfupd` on binary h-files (*not yet tested*).
- <G> Run `glred` for combination or repeatabilities.
- <E> Run `ensum` and `sh_baseline` for plots.
- <C> At the end compress the ascii H-files, remove any links, and copy the ascii and binary H-files to `glbpth/ascii_yyyy` and `glbpth/bin_yyyy` , respectively, where `glbpth` is specified by `process.defaults` [default `glb`]
- <A> Do all options.

The stations to be used in each part of the processing are specified by tokens in `sites.defaults`, as shown in Section 10.2. Stations included in the `glred` combination are accompanying by token `glrepu`, those used to define the reference frame in `glorg` by `glreps`, and those for which time-series plots are to be generated by `glts`. The default for `glred` and plots is to use all stations. For `glorg` stabilization, there is a default list of IGS stations built into the script, but for regional networks, you probably want to specify explicitly the stations to be used.

The script uses command files named `globk_comb.cmd` and `glorg_comb.cmd` , which it looks for in the solution (not `/templates` ) directory. If these files do not exist, they will be created with the appropriate commands to do a loose combination with `glred` and a `glorg` stabilization. If you wish to alter any of the `globk` or `glorg` commands, for example to constrain orbits in a regional solution, change the default EOP constraints, or omit the `glorg` solution, you can run `sh_glred` initially with only the `-cmd` option to create the command files for editing.

To avoid overwriting useful h-files or using obsolete ones, it is important to keep in mind the precedence rules of the script. For local data (`sh_gamit` day directories), specifying the `H` option will force `htoglb` to be rerun for all directories within the time span indicated, whether or not a binary file exists in the searched directories (nominally `glb` and

glbf/bin\_yyyy). Omitting H will cause no new binary files to be created, so it is not possible to retranslate only a selected group of ascii H-files. This is not an important limitation, however, because retranslated htoglb runs quickly. For remote data (locally linked or ftp'd from SOPAC), setting H will also force htoglb to be rerun on any ascii H-files present or linked (by LA) in the H-file (glbf) directory, but you can safely set F since the script will not re-ftp any remote (ascii) H-files that are present.

Output H-files from the combination are named HYYMMDD\_[expt][netext].GLX and written in to the solution directory. The script creates a separate .gdl file for each day with a similar name, each pointing to the combined GLX H-file in the solution directory. When ensum is run, it will create SUM. and VAL. files by concatenating all .org files present, so you can run sh\_glred separately for different time spans and create plots that combine the spans.

### Examples

Combine regional files from sh\_gamit with global files from SOPAC, one day at a time and generate repeatability plots:

```
sh_glred -d 1999 235 1999 250 -net igs1 igs2 igs3 -netext r -expt emed -opt F H G E C
```

Regenerate repeatability plots from existing binary h-files (e.g with different stabilization):

```
sh_glred -d 1999 235 1999 250 -net igs1 igs2 igs3 -netext r -expt emed -opt G E
```

Combine existing regional and global binary h-files into monthly averages:

"

```
sh_glred - d 1999 235 2000 120 -ncomb 30 -net igs1 igs2 igs3 -expt emed -opt G LB
```

## **Appendix 1. Summary of GAMIT Processing (without sh\_gamit)**

### *A.1.1. Data Preparation*

Create an experiment directory with subdirectories for tables and each session (day)

Run links.tables in the tables subdirectory

Assemble RINEX (or FICA) files from diskettes, tape, and/or ftp

Prepare an L-file -- see Section 4.2

Enter antenna heights and receiver software versions in station.info

Enter scenarios in session.info (optional if running MAKEXP)

Edit the template sestbl. and sittbl. to set the controls for the analysis

For each day:

Run links.day

Run MAKEXP to get a D-file and batch file for MAKEX

Run MAKEJ to get a J-file

Run MAKEX with [day].makex.batch to get X- and K-files

Create a G-file and T-file from IGS or broadcast information -- see Section 4.10

### *A.1.2. Create and execute a batch file to obtain a solution*

Run FIXDRV with the D-file as input

Run b[expt].bat which executes ARC, MODEL, AUTCLN, CFMRG, and SOLVE to obtain a solution for station and orbital parameters, written to q[expt]a.day, o[expt]a.day, and h[expt]a.day ), and updates g[expt]b.[day] , l[expt]a.[day] , and m[expt]a.[day]

Check q[expt]a.[day] for good nrms (<0.3), small station and orbital parameter adjustments, and good ambiguity resolution; and autcln.post.sum for number of observations and rms of residuals for each station.

Delete the C-files to save disk space; compress and/or backup RINEX and X-files

### A.1.3 File-naming conventions

- A - file: ASCII version of the T-file (tabular ephemeris)
- B - file: controls the batch mode of data processing
- C - file: observed – computed (O-C's), partial derivatives
- D - file: driver file of sessions and receivers
- E - file: broadcast ephemeris, in FICA Blk 9 or RINEX navigation file format
- G - file: orbital initial conditions and non-gravitational parameter values
- H - file: adjustments and full variance-covariance matrix for input to GLOBK
- I - file: receiver clock polynomial input
- J - file: satellite clock polynomial coefficients
- K - file: values of receiver clock offset during observation span, from pseudorange
- L - file: station coordinates
- M - file: controls merging of data (C-) files for SOLVE and editing programs
- N - file: data-weight overrides for SOLVE created from autcln.sum.postfit
- O - file: record of the analysis (reduced form of Q-file) for post-processing analysis
- P - file: record of a MODEL run
- Q - file: record of the analysis (SOLVE run)
- S - file: station coordinates and antenna offsets —*no longer used*
- T - file: tabular ephemeris
- U - file: ocean tide constituents
- V - file: editing output of SINCLN, DBLCLN, and SCANRMS
- W - file: meteorological data
- X - file: input observations
- Y - file: satellite yaw parameters
- Z - file: water-vapor radiometer data

## A.1.4. Summary of input and output files

	<b>INPUT</b>	<b>OUTPUT</b>
<b>MAKEXP</b>	<ul style="list-style-type: none"> <li>- RINEX (or X-) files</li> <li>- station.info</li> <li>- session.info</li> </ul>	<ul style="list-style-type: none"> <li>- D-file</li> <li>- session.info (optional)</li> <li>- Input batch files for MAKEX, MAKEJ, BCTOT</li> </ul>
<b>MAKEJ</b>	<ul style="list-style-type: none"> <li>- E-file (RINEX nav file)</li> <li>- C-file (optional--See 4.6)</li> </ul>	<ul style="list-style-type: none"> <li>- J-file (satellite clock file)</li> </ul>
<b>MAKEX</b>	<ul style="list-style-type: none"> <li>- raw observations (RINEX or FICA)</li> <li>- station.info (ant hts, rcvr software)</li> <li>- session.info (scenario file)</li> <li>- E-file (RINEX nav file)</li> <li>- J-file (satellite clock file)</li> <li>- L-file (coordinates of stations)</li> </ul>	<ul style="list-style-type: none"> <li>- K-file (receiver clock)</li> <li>- X-file (input observations)</li> </ul>
<b>ARC</b>	<ul style="list-style-type: none"> <li>- arc.bat (batch input file)</li> <li>- G-file (orbital initial conditions)</li> </ul>	<ul style="list-style-type: none"> <li>- arcout.ddd (output print file)</li> <li>- T-file (tabular ephemeris for all sat. ses.)</li> </ul>
<b>FIXDRV</b>	<ul style="list-style-type: none"> <li>- D-file (defines the input and output)</li> <li>- sestbl. (session control)</li> <li>- .sittbl. (site control)</li> <li>- T, J, L, X (or C) input</li> </ul>	<ul style="list-style-type: none"> <li>- B-file (bexpy.bat : primary batch file)</li> <li>- B-file (bexpy.nnn : secondary batch files)</li> <li>- I-file (rcvr clock polynomials)</li> </ul>
<b>MODEL</b>	<ul style="list-style-type: none"> <li>- L-file (site coordinates)</li> <li>- station.info (ant heights)</li> <li>- X-file or C-file</li> <li>- T-file</li> <li>- I-file</li> <li>- J-file</li> </ul>	<ul style="list-style-type: none"> <li>- C-file (upgrade if input C-file)</li> </ul>
<b>AUTCLN</b>	<ul style="list-style-type: none"> <li>- C-file</li> </ul>	<ul style="list-style-type: none"> <li>- C-file (cleaned)</li> </ul>
<b>CFMRG</b>	<ul style="list-style-type: none"> <li>- C-file</li> </ul>	<ul style="list-style-type: none"> <li>- M-file (points to the C-files)</li> </ul>

<b>SOLVE</b>	- C-file - M-file	- Q-file - G-file - H-file - L-file
<b>CVIEW</b> <b>SCANDD</b>	- M-file and C-files	- C-files (CVIEW only)

<b>MAKEK</b>	- E-file - J-file - L-file - X-file	- K-file
<b>NGSTOT</b>	- SP3-file	- G-file - T-file
<b>BCTOT</b>	- E-file	- G-file - T-file

## Appendix 2. Antenna Specifications

### A.2.1 Introduction

Accurate and consistent modeling of the antenna phase centers continues to be one of the most vexing problems in GPS analysis. For purposes of discussion it is useful to divide the problem into horizontal and vertical effects, and to consider for the latter the "absolute" and relative models.

For most of the antennas there are horizontal offsets of a few millimeters of the L1 and/or L2 phase centers from the mechanical center of the antenna. These are sometimes not repeatable among individual antennas of a particular type and can be over 5 mm for analyses using the ionospheric-free (LC) combination of L1 and L2 phase. These offsets can be determined by measurements of the antenna phase pattern in an anechoic chamber [Schupler *et al.*, 1991; Rocken *et al.*, 1995] or by analysis of short baseline field measurements in which the antennas are rotated between sessions [Braun *et al.*, 1996].

The vertical positions of the phase centers of all GPS antennas show significant elevation-dependent motions, which if not modeled make estimated station heights dependent on the elevation cutoff angle of the observations at each station. The size of the effect can vary from a few millimeters for matched antennas in a regional network in which all stations have nearly the same horizon, to several centimeters for some combinations of mismatched antennas. The vertical phase center, as a function of elevation angle, can be mapped for individual antennas using anechoic chamber measurements [Schupler *et al.*, 1991] or differentially for pairs of antennas by estimating coefficients of a polynomial or spherical-harmonic model [Mader and McKay, 1996; Rothacher *et al.*, 1995]. When the "absolute" models determined from anechoic chamber measurements are used in analyses of global tracking data, station heights differ 6-12 cm from values inferred from SLR and VLBI data, implying a GPS scale error of  $\sim 10^{-8}$ . More likely, there is some aspect of the anechoic chamber measurements that is not yet understood. The difference in elevation-dependent variations from anechoic chamber measurements of pairs of antennas, however, agree reasonably well (25%) with those inferred from estimated from field measurements over short baselines, allowing inference of the vertical phase center, independent of elevation-angle cutoff, at the level of about 5 mm for some antennas. For others, the agreement is poorer, presumably indicating significant effects that depend on the electrical environment of the measurements. For example, Elosequi *et al.* [1995] demonstrated centimeter-level effects from the pillar used to support the antenna.

Although an effective "absolute" model for vertical offsets remains illusive, the IGS issued in June, 1996, a provisional differential model that represents usefully the mean vertical and horizontal offsets for many of the commonly used antennas [Rothacher and Mader, 1996]. This model, designated IGS\_01, arbitrarily assumes no elevation-dependent terms for the Dorne-Margolin choke ring antennas used in the global network and applies elevation-dependent variations for other antennas. Since the release of IGS\_01, the US National Geodetic Survey and Geodynamics Research Division of NOAA have carried out

an extensive program of determining differential models for many antennas. The results of these tests are available on the GRD web page ([www.grdl.noaa.gov/GRD/GP](http://www.grdl.noaa.gov/GRD/GP))

GAMIT computes the instantaneous position of an antenna's phase center from the geodetic monument in three pieces. File `station.info` records the vertical or slant distance from an accessible point on the antenna structure (specified in the entry) to the monument, and also any horizontal offsets of the center of antenna from the monument deriving from a setup error. Subroutine `lib/hisub.f` converts these field measurement to an offset of the IGS-defined antenna reference point (ARP)—usually the bottom center of the pre-amp—from the monument using mechanical specifications hard-wired into the subroutine. Finally, the instantaneous positions of the L1 and L2 phase centers with respect to the ARP are computed by subroutine `model/phasecc.f` using the constant or elevation and/or azimuth dependent model specified in table `antmod.dat`.

In deciding how to handle phase centers in your processing, you should recognize that millimeter-level accuracy in the vertical for mismatched antennas or long baselines is not yet possible, and therefore consistency may be more important than accuracy. We currently recommend one of two options: use of table `antmod.dat.mit` (in `updates/tables`), which has no elevation-dependent terms and constant offsets that are (mostly) consistent with prior GAMIT use and have been employed by SOPAC for the current (1995–99) processing and reprocessing; or table `antmod.dat.igs`, which has the June, 1996, IGS\_01 model of constants and elevation-dependent terms for many commonly used antennas and current (December, 1999) model from NGS, designated NGS\_02, for many others. If you specify (in `station.info`) an antenna for which there is no model, GAMIT will warn you and use 0. for the offset of the phase centers from the ARP. Note two important features of phase center offsets: 1) elevation-dependent variations are highly correlated with the atmospheric zenith delay and are thus most important to model correctly when this parameter is being estimated; 2) elevation-dependent terms in the model are closely coupled with the constant offset and should be matched correctly in the table ( see, e.g., *Rothacher et al.*, [1995]). We tested rigorously, with short baselines, only the IGS\_01 model for the microstrip antennas used with the Trimble SST, SSE, and SSi receivers. In all other cases, you will have to verify with your own tests which, if any, model is appropriate to use.

The next seven sections describe the mechanical dimensions of antennas used with TI4100, Trimble, Rogue, Ashtech/Topcon, Macrometer, Sercel, and Leica receivers. Section A.2.9 lists references for this appendix.

### A.2.2 TI 4100 Antennas

#### TI 4100 Conical Spiral

In field operations there are two conventional points on the antenna structure to which height measurements are referred: the center and the outside edge of the base of the pre-amp. Vertical measurements to the center of the base are designated `DHPAB` and are simply

added to the table values to get the L1 and L2 phase centers. Slant height measurements to the edge of the base are designated `SLPAB` and converted to vertical heights using the pythagorean rule and a base radius of 0.8415 m.

The values given in the `antmod.dat.mit` for the early series 100 and 2000 antennas, designated `TI_100` and `TI2000`, respectively but both aliased to `TI4100`, are taken from *Sims* [1985]. For the newer and more common 4000 series antennas, designated `TI4000`, the values were determined by *Schupler et al.* [1992] and confirmed by our own analysis. Use of the *Schupler et al.* variable phase-center model will increase the heights (relative to other antenna types) estimated from LC observations by about 15 mm.

### TI 4100 FRPA-2 microstrip

These antennas have been used only at the CIGNET fiducial stations at Richmond (Florida), Mojave (California), and Kauai (Hawaii). The offsets given in `antmod.dat.mit` are based on UNAVCO short baseline tests (personal communication, John Braun, 21 May 1994). They are untested in MIT or SOPAC analyses.

## A.2.3 Trimble Antennas

### Trimble 4000 SST

The 4000 SST antenna (`TRMSST`), part # 145321 and usually designated "4000ST L1/L2 Geodetic", is a microstrip which has a round ground plane with horizontally scalloped and vertically beveled edges. Below the ground plane is a small square box containing the pre-amp. Field height measurements are commonly made to the outer edge of the ground plane—either the top, middle, or bottom of the beveled edge. Subroutine `hisub` is coded to accept slant height measurements to the top (`SLTGPF`, radius 0.2403 m), middle (`SLMGP`, radius 0.2413 m), or bottom (`SLBGP`, radius 0.2403 m) of the ground plane, and also a direct height to the bottom of the ground plane (`DHGBP`). If the Trimble measuring rod is used, the height measurement is usually made to the inside of one or more of the notches (radius 0.2334), on either the top (`SLTGN`) or bottom (`SLTBGN`) of the ground plane. The bottom of the ground plane is 0.060 m, the middle 0.0615 m, and the top 0.063 m above the ARP (base of pre-amp).

With no elevation-dependent model, Trimble specifications and UNAVCO tests put the L1 phase center 6.2 mm above, and the L2 phase center 4.7 mm above the top of the ground plane. Use of the variable phase-center model will increase heights estimated from LC observations by about 15 mm. Rotation tests and anechoic chamber measurements suggest that there are differences of at least several millimeters, in both the vertical and horizontal directions (C. Rocken, personal communication, 1995; *Rothacher and Mader*, 1996). The `IGS_01` model reflects these differences.

### Trimble 4000 SSE

The antenna accompanying all but the first SSE receivers, and also SSi receivers, is different from the SST antenna in having separate microstrips for L1 and L2; it is part # 22020.00, is usually designated "Geodetic L1/L2", and carries the GAMIT code `TRMSSE`. Subroutine `hisub` allows the same types of measurements but uses slightly different dimensions. The bottom of the ground plane is 0.0556 m, the middle 0.0574 m, and the top 0.0591 above the ARP. The radius to the edge of the ground plane (top, middle, or bottom) is 0.2415, and to the inside of the notches 0.2335 m.

The no-model offsets given in `antmod.dat.mit` are currently set to be the same as for the SST antenna, as indicated by the manufacturer, but anechoic chamber and field measurements suggest that there are differences of at least several millimeters, in both the vertical and horizontal directions (C. Rocken, personal communication, 1995; *Rothacher and Mader*, 1996).

### Trimble 4000 SL

The 4000 SL antenna, part # 10877.10, is a microstrip which has a round ground plane with a smooth edge. In release 9.8 we changed the 6-character code for this antenna from `TRMSLD` to `TRSLMC` to avoid confusion with the square-ground-plane antenna (part # 12562.10) which Trimble calls 4000 SLD and which is not supported by GAMIT. Below the ground plane is a square box containing the pre-amp. Field measurements of the slant height are commonly made to the top (`SLTGP`) or bottom (`SLBGP`) edge of the ground plane or the bottom corner of the pre-amp base (`SLPAC`). The bottom of the ground plane is 0.0529 m, and the top 0.0512 m above the pre-amp base, the ARP. The ground plane has a radius of 0.2413 m, and the diagonal from the center to the corner of the pre-amp is 0.0991 m.

According to the manufacturers specifications, the L1 phase center is 6.1 mm above the top of the ground plane or 0.0573 m above the ARP, and the L2 phase center 4.5 mm above the top of the ground plane or 0.0557 m above the ARP, with no variable phase center model applied (UNAVCO communication from B. Perin, 6 February, 1991).

### Trimble 4000 SXD

The 4000 SXD antenna (`4000SX`, part # 10877.10) is a microstrip which has a square ground plane with rounded corners. Below the ground plane is a square box containing the pre-amp. Field measurements of slant height are commonly made to the bottom of the ground plane at one of the corners (`SLCGP`) or to the bottom corner of the pre-amp base (`SLPAC`). The ground plane is 3.4 mm thick and the bottom is 0.048 m above the pre-amp base, the ARP. The side of the ground plane is 0.3048 m and the diagonal (rounded) corner (the measurement point) 0.4153 m from the center. The pre-amp has a half-width of 0.0984 m and a diagonal of 0.1391 m.

According to the manufacturers specifications, the L1 phase center is 6.2 mm above the top of the ground plane or 0.0574 m above the ARP, and the L2 phase center 4.6 mm above the top of the ground plane or 0.0558 m above the ARP, with no variable phase center model applied (UNAVCO communication from B. Perin, 6 February, 1991).

#### A.2.4 *Rogue Antennas*

##### Dorne-Margolin with Choke Ring

There are three antennas used with Rogue, MiniRogue, and TurboRogue receivers, all variations of a Dorne-Margolin element mounted with the circular ground plane and choke rings based on a JPL design. The antennas used with the original Rogue SNR-8 were built at JPL and are designated model "R" ( ROGSNR , DMRCHR , or ROGDMR ); the early models built by Allen Osborne Associates (AOA) are designated model "B" ( ROGAOA , DMBCHR , or ROGDMB ); and the AOA models currently distributed with the TurboRogue are designated model "T" ( TRBROG , DMTCHR , or ROGDMT , ). If the antenna is mounted on a tripod, height measurements are usually made to the bottom of the choke ring or an underlying baseplate. If the antenna is spike-mounted on the ground, the measurement is made to the bottom of the baseplate. In some permanent mounts surveyed by theodolite, the direct height may be specified to the the top of the choke rings (HTCR).

For the "R" model, the ARP is the bottom of a base plate, 0.381 mm in diameter and 6 mm thick. The choke ring above is 64 mm high, so that the top of the choke ring is 70 mm above the ARP. Measurements made to the bottom of the assembly are all to the ARP, whether designated "pre-amp base" (HPAB) or "bottom of choke ring" (HBCR or SLBCR).

The "B" model replaced the thin baseplate with one 11 mm high and 351 mm in diameter, and increased the choke ring height to 70 mm. For this model the ARP is the bottom of the choke rings, not the bottom of the baseplate, so that the top of the choke rings is still 70 mm above the ARP.

The "T" model has a choke ring 67 mm high including the baseplate and a pre-amp 35 mm high. The ARP is the bottom of the pre-amp, so that the top of the choke rings is 102 mm above the ARP. The width of the choke rings is 381 mm.

According to the manufacturers' nominal specifications, with no variable model, the L1 phase center is 8 mm, and the L2 phase center 26 mm above the top of the choke rings for all three models.

#### A.2.5 *Ashtech Antennas*

There have been primary three models, with several variations each, of the Ashtech dual-frequency micro-strip antennas. The first two models (both part #700228) both use a Ball Corporation microstrip patch and have a 28-cm ground plane but have different amplifiers

and different configurations of ground planes. The third model has a different microstrip patch and a larger ground plane. The Ashtech choke-ring antenna is patterned after the TurboRogue (DM-T) antenna but has had several revisions and has been used with and without one of several radomes.

### Ashtech L

The early models of the 700228 antenna have been used mostly with the MD-XII (codeless) receiver and are designated the "Geodetic L1/L2" or "L" model (ASHL12). They have a 28-cm ground plane with closed holes near the edge for measuring height and an external low noise amplifier (LNA). The two versions (700228A and 700228B) both had a leveling bubble but used different LNAs. The third (700228C) removed the leveling bubble. GAMIT allows different designations for these revisions (ATGEOB and ATGEOC, respectively), does not yet have phase-center models to distinguish them, but currently treat. Field measurements are commonly made by placing a measuring rod through holes 115 mm from the center near the outer edge of the ground plane (SLHGP or SLAGP). The ground plane itself is rounded on the edge, with bottom outer edge 142.4 mm from the center. The top of the ground plane, where the holes are located, is 64 mm above the base of the pre-amp (ARP). Subroutine hisub also supports slant height measurements to the outermost part of the bevel on the bottom of the ground plane (SLBGP). There is a provision for adding extender sections to the ground plane, but this configuration has rarely been used and is not supported by hisub.

### Ashtech P/Topcon P

The later model (D) of the 700228 has been used chiefly with the Ashtech P12 and Topcon GP-RIDP receivers (but possibly also with the Ashtech Z-12 and Topcon GP-RIDY) and is designated the "Geodetic II L1/L2 REV B" or "P" (ASHP12/TOPPP12). It also uses a 28-cm ground plane but with the holes open and at the edge, at a distance of 131.8 mm from the center, and no ability to extend the ground plane. The allowable measurement codes are the same as for the "L" model.

### Ashtech III/Topcon

The "Geodetic Antenna III" antenna (ASHGD3 part #700718A or TOPGD3 part #700779) uses a different micro-strip patch and a larger (34-cm) ground plane (sometimes termed the "Whopper") with open holes. It has been used with the Ashtech Z-12 and Topcon GP-RIDY receivers. The antenna has an internal LNA in the center hub. The US Coast Guard version has a radome and is designated ASHGDR and has part #700829. As for the L and P models, the top of the ground plane is 64 mm above the base of the pre-amp (ARP). The radius of the ground plane is 173.7 mm, and the pre-amp 40.0 mm. GAMIT supports measurement of the direct height to the top of the ground plane (DHTGP) and slant height to the outside of the holes (SLHGP or SLLGP).

At the present time, the effective phase centers of the Ashtech microstrip antennas is uncertain. Short baseline GPS and anechoic chamber measurements give inconsistent results. In table `antmod.dat.mit` we have maintained the offsets determined for Release 9.2, which place the L1 phase center ~33 mm, and the L2 phase center ~13 mm above the ground plane. Previous GAMIT releases assumed that both L1 and L2 phase centers are in the ground plane. The IGS\_01 model in `antmod.dat.igs` gives elevation-dependent models for these antennas but they are based on limited, non-redundant tests and do not have the reliability of the models for the Trimble microstrip or the choke-ring antennas

### Ashtech Dorne-Margolin with Choke Ring

There have been 14 different versions of the Ashtech choke-ring antenna, some trivially different and some with changes that might affect the phase pattern. All have been designed to be mechanically and electrically equivalent to the Turbo-Rogue ("T") antenna, and in the current version of `antmod.dat` are assigned the same (null) model as the D-M T. To allow tracking of small potential changes, however, each of these models is assigned a different name, both by the IGS and in GAMIT (see `rcvant.dat`). One possibly important difference arises when the antenna is used with the Ashtech-supplied conical radome. Tests at UNAVCO [ *Rocken et al.*, 1995] and MIT [ *Niell et al.*, 1996] suggest that the phase center changes in vertical by 5–15 mm when this radome is used, but similar tests at AIUB (Bern) and NGS obtain differences less than 3 mm [ *Rothacher and Mader*, 1996]. The use of a centered spherical radome of the type currently employed by SCIGN produces no significant change in the phase pattern.

## A.2.6 MACROMETER Antennas

### Min-Mac 2816 AT

The Macrometer antenna used with the Mini-Mac 2816 AT is a crossed dipole above a thick square ground plane ( `MINXDP` or `MIN6AT` ). The ARP is the base of the ground plane structure, which contains the pre-amp. GAMIT supports only direct height measurements to the ARP (`DHPAB`) or reference to the L1 phase center (`L1PHC`).

According to the manufacturer's specifications, the L1 phase center is 107.1 mm, and the L2 phase center 91.7 mm above the ARP [J. Ladd, private communication, 1989]. Use of an elevation-dependent model corrects this by several centimeters.

## A.2.7 SERCEL Antennas

For the SERCEL TR5S and NR52 antennas, we have only scant information conveyed by K. Feigl from the log sheets for the Djibouti 1991 observations. There are no mechanical dimensions coded in `hisub`, so that only measurements to the ARP (`DHPAB`) are allowed. The difference between the L1 and L2 phase centers is unknown. In `antmod.dat`, we

currently give for the TR5S (SRTR5S) phase center offsets from the ARP of 264 mm for the TR5S (SRTR5S) and 210 mm for the NR52 (SRNR52).

### A.2.8 Leica Antennas

The Leica SR299/SR399 "Sensor", AT201/302, and AT303 antennas are attached directly to a rotating bubble level ("carrier"; e.g. GRT44), or a "stop/go" kinematic pole via a screw hole on the bottom of the antenna. The ARP is defined as the bottom of the antenna housing, coincident with the top of the carrier. With the carrier mount and tripod, measurements are commonly made using a pull-down tape measure attached to a "height-hook", with the top of the tape measure (the read point) located 0.350 m below the ARP. You can specify a direct height to the ARP ( $\phi_{HPAB}$ ) or a direct height read from the height-hook tape ( $\phi_{HHK}$ ). In using values recorded on field logsheets, be aware that the height hook tape suggests to the operator adding 0.449 m to the measured value to account for both the offset to the ARP (0.350 m) and the nominal L1 phase center (0.091 m above the ARP). Be sure that you understand what value has been recorded. Also, the Sensor antennas may be used with a "ranging pole" (different from a "stop/go kinematic pole") via an "adaptor with 5/8-in thread"; in this configuration the ARP, corresponding to the top of the pole, is 12 mm lower with respect to the phase centers. The range-pole configuration is not coded in GAMIT. With the choke-ring antennas (AT303 and AT504), you may also specify slant-height measurements to the outside bottom edge of the choke rings ( $\phi_{BCR}$ ).

The IGS\_01 phase-center model in antmod.dat.igs has three elevation-dependent models for the phase center, corresponding respectively to the SR299 or SR399 internal antennas ( $LC299I$  or  $LC399I$ ), and the series 200 external antenna with ( $LC202G$ ) or without ( $LC202N$ ) a ground plane. The AT303 was intended by Leica to be slightly different from the IGS standard (DM-T TurboRogue antenna), so antmod.dat includes the NGS\_02 model for this antenna. The AT503 ( $LC_503$ ) is assumed be the same as the DM-T.

### A.7.8 References

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### Appendix 3. Description of Data Exchange Formats

Two formats (FICA and RINEX) have been used to distribute GPS phase and pseudorange data from single tracking sessions, and a third (ARGOS) used by NGS to distribute week-long data from CIGNET stations prior to 1992. In addition, each of these formats has a file or blocks defined to contain ephemeris and clock information broadcast by the satellites. Finally, orbital ephemerides in tabular (XYZ per epoch) format are distributed in the SP1 or SP3 ("Standard Product") format developed by NGS and now used by the IGS. The ARGOS format is described in Chapter 9 (section 9.2); the others are described below.

#### A.3.1 RINEX

The Receiver INdependent EXchange format for GPS data provides the current IGS standard for the distribution of phase and pseudorange data ("o" file) and the navigation message ("n" file) recorded by a receiver. There is also a less used file for meteorological data. Version 1 of the RINEX formats is described in ["A Common Exchange Format for GPS Data by Gurtner, W., G. Mader, and D. MacArthur, in *Proceedings of the Fifth International Geodetic Symposium on Satellite Systems*, Las Cruces, New Mexico, 1989] and reprinted in *CIGNET Bulletin 2 (3)*, May–June, 1989. Version 2 is described in *CIGNET Bulletin 3 (3)*, September–October, 1990. A sample of a Version 1 RINEX navigation file is given in the section A.3.3.

#### A 3.2 FICA

TI4100 data prior to 1989 were usually distributed in the Floating-Integer-Character-ASCII (FICA) format devised by the Applied Research Laboratory at the University of Texas. A description of the format and definitions of the standard TI 4100 blocks and (ad hoc) MIT-defined blocks used to create an acceptable input file for MAKEX from NGS ARGO format, see the comments in subroutines `blknnn.f` in `gamit/makex`.

#### A.3.3 Description of the E-file

The E-file consists of one or more "blocks" of Broadcast Ephemeris data as recorded by the receiver from the satellites' transmissions. For convenience we have not introduced a new format for these data; rather, they may be either in RINEX navigation file format (preferred) or in FICA format as defined by GESAR Block 9 for the TI 4100. To create an E-file for from a TI FICA file, use the program FICACHOP and specify Block 9.

An example of a RINEX navigation file, with an ephemeris block for only one satellite, is given below:

```

1          NAVIGATION DATA          RINEX VERSION / TYPE
MAKEX v. 7.1 of 90/07/09 apollo king 1990-07-06 19:16:30 PGM / RUN BY / DATE

8 88 11 8 4 8 59.10.323700718582E-03 0.171894498635E-09 -0.277555756156E-16
0.102400000000E+05 0.104687500000E+02 0.177400246575E-08 -0.199337541371E+01
0.603497028351E-06 0.530868989881E-02 0.652857124805E-05 0.515373352242E+04
0.194400000000E+06 -0.856816768646E-07 0.108490472307E+01 0.186264514923E-07
0.110755363248E+01 0.330250000000E+03 -0.584334212505E+00 -0.634633577893E-08
0.274297139863E-09 0.100000000000E+01 0.461000000000E+03 0.000000000000E+00
0.700000000000E+01 0.600000000000E+02 0.000000000000E+00 0.102400000000E+05

```

The first line is a header giving the RINEX version number (1) and the type of file (the "N" in column 21 is the critical character). The second line is a comment describing how the file was created. Additional comment lines can be added by putting "COMMENT" in columns 61-67. A blank line separates the header from the data blocks.

The first line of each data block has the PRN number (8 here), epoch in GPST, and the three satellite clock polynomial coefficients (see Section 4.6). The next 24 describe the ephemeris of the satellite. Their definition and use is given, e. g., in *King et al.*, Chapter 7. The correspondences are listed in Table A.3.1 below.

An example of one block of a FICA-type E-file is given below. The first line indicates that there are 60 floating point numbers in the block (and no integers or character strings).

```

BLK      9    60    0    0
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 3.850000000000E+02 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 1.300000000000E+01
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 2.625000000000E+00 2.0854440099709E-09
-2.4993916368254E+00 1.8067657947540E-07 2.7529464568943E-03 6.5285712480545E-06
5.1537107257843E+03 1.152000000000E+05 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 -5.5879354476929E-08 -2.0695827239133E+00 1.0058283805847E-07
1.0937269895249E+00 3.200312500000E+02 -4.2112338394786E-01 -6.4691980394937E-09
0.000000000000E+00 2.1822337559381E-10 0.000000000000E+00 0.000000000000E+00
0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00

```

For the most part, the numbers in the FICA Blk 9 are the same as those used in the RINEX-type E-file but in a different order.

Table A.3.1 Broadcast ephemeris values in RINEX and FICA E-files

<u>Description</u>	<u>RINEX file Line #, Index</u>	<u>FICA Blk 9 Index No.</u>
Clock drift rate ( sec/sec <sup>2</sup> )	SV Clk 3	14
Clock drift (sec/sec )	SV Clk 2	15
Clock bias (sec)	SV Clk 1	16
Age of ephemeris data (GPS sec of week)	Orb 1 1	26
Radial sine correction (CRS) (meters)	Orb 1 2	27
Correction to mean motion (radians/sec)	Orb 1 3	28
Mean anomaly at epoch (radians)	Orb 1 4	29
In-track cosine amplitude (CUC) (radians)	Orb 2 1	30
Eccentricity	Orb 2 2	31
In-track sine amplitude (CUS) (radians)	Orb 2 3	32
Square root of the semi-major axis (metet <sup>1/2</sup> )	Orb 2 4	33
Time of epoch (GPS seconds of week)	Orb 3 1	34
Inclination cosine correction (CIC) (radians)	Orb 3 2	46
Right ascension of ascending node (radians)	Orb 3 3	47
Inclination sine correction (CIS) (radians)	Orb 3 4	48
Inclination (radians)	Orb 4 1	49
Radial cosine adjustment (radians)	Orb 4 2	50
Argument of perigee (radians)	Orb 4 3	51
Rate of change of right ascension of ascending node (rad/s)	Orb 4 4	52
Rate of change of inclination (radians/sec)	Orb 5 1	54
Codes on L2 channel	Orb 5 2	
Full week number (GPS weeks)	Orb 5 3	6
L2 P data flag	Orb 5 4	
SV accuracy	Orb 6 1	8
SV health	Orb 6 2	9
Receiver channel		19
Satellite PRN number		20
Clock epoch (GPS sec of week)		13
HOW word (GPS seconds of week)		3
Age of ephemeris data (GPS sec of week)		53

A 3.2 SP3 Orbit File

A complete description of the NGS standard GPS orbit products is given by Remondi [NOAA Tech. Rep. NOS 133 NGS 46, 1989]. The one most commonly used and adopted by the IGS for distribution of earth-fixed ephemerides is SP#3; an example for the official IGS orbit is shown below:

```
#aP1996 4 21 0 0 .00000000 96 ORBIT ITR93 HLM IGS
## 850 .00000000 900.00000000 50194 .000000000000000
+ 25 1 2 3 4 5 6 7 9 14 15 16 17 19 20 21 22 23
+ 24 25 26 27 28 29 31 18 0 0 0 0 0 0 0 0 0 0
+ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
+ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
++ 5 5 6 5 5 5 5 5 5 5 8 5 6 5 5 5 5
++ 5 5 5 6 5 5 5 5 8 0 0 0 0 0 0 0 0 0
++ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
++ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
++ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
%c cc cc ccc ccc cccc cccc cccc cccc cccc cccc cccc cccc
%c cc cc ccc ccc cccc cccc cccc cccc cccc cccc cccc cccc
%f .00000000 .0000000000 .000000000000 .0000000000000000
%f .00000000 .0000000000 .000000000000 .0000000000000000
%i 0 0 0 0 0 0 0 0 0 0 0 0 0 0
%i 0 0 0 0 0 0 0 0 0 0 0 0 0 0
/* RAPID SERVICE ORBIT COMBINATION FROM WEIGHTED AVERAGE OF:
/* cod emr esa gfz jpl ngs sio
/* REFERENCED TO GPS CLOCK AND TO WEIGHTED MEAN POLE:
/*
* 1996 4 21 0 0 .0000
P 1 -20844.049743 16468.077022 682.661913 53.575584
P 2 12944.844539 -10393.087331 -20299.519500 -249.520521
P 3 -8227.617128 20375.326181 -15102.650518 4.597767
P 4 13744.791940 -9683.391414 20694.419314 22.047268
P 5 -12352.621960 -20060.938827 12297.360719 36.113385
P 6 -19546.655943 -1100.613728 18148.758754 8.140737
P 7 20712.125279 -16356.600000 -518.876248 719.138221
P 9 -17764.134276 -16037.093050 -11757.505817 -18.951339
P 14 12179.034086 18588.450559 14478.113351 13.465001
P 15 19057.231547 15809.204514 -9780.269336 293.252400
P 16 -1083.799746 -26408.146377 2349.366780 8.084014
P 17 -24486.194361 -4762.735719 -9703.838269 -112.969182
P 19 25533.173686 3886.160764 -6400.473223 459.005144
P 20 -15478.615183 -9745.065423 19106.255998 14.598467
P 21 -12024.261423 12964.155803 -19620.557712 -19.797230
P 22 -3194.548377 24157.840245 10016.934756 301.593609
P 23 -15229.612960 -1727.102967 -21438.845352 9.526407
P 24 544.423674 -15500.071774 21780.182095 -179.844909
P 25 -11610.793056 11908.640383 20691.294205 -1.623070
P 26 -3511.667947 -15876.253008 -20761.862582 -183.285168
P 27 21532.343236 -3952.280131 -15530.087869 26.271555
P 28 -12532.981692 20254.408891 -11879.931632 78.225844
P 29 12432.222182 9589.973773 21587.240169 8.991759
P 31 4170.173983 15571.909204 -21199.804060 447.486131
P 18 21074.399097 -2889.491428 15694.503544 999999.999999
* 1996 4 21 0 15 .0000
P 1 -20941.140297 16195.390001 -2157.407872 53.634533
...
```

The characters in columns 1 and 2 indicate the type of line. The first line (#a) includes the GPST date and time (year, month, day, hour, minute, second) of the start of the orbital information, the number of epochs (96 in the example), the terrestrial coordinate system used (ITR93, for ITRF-93) and the agency computing the the orbit (IGS). The keyword in

columns 41–45 indicates the type of data used to compute the orbit. For individual analysis centers this will indicate, e.g. doubly differenced carrier phase ( d ), but for the IGS combined orbit the orbits of the individual analysis centers are the "observations". The second line ( ## ) repeats the start time but in terms of GPS week ( 850 ) plus seconds of week and Modified Julian Day plus fraction-of-day; it also gives the interval of the tabulated ephemerides in seconds (00).

The third to the seventh lines ( + ) have the number of satellites followed by their respective PRN numbers. The 8th to the 12th lines ( ++ ) indicate the accuracy of the orbit of each satellite, given by the exponent of 2 in millimeters; e.g., 5 implies an accuracy of  $2^5$  mm, or 3.2 cm. Lines 13–18 are reserved for addition of character (%c), floating-point (%f) or integer (%i) variables to the format. Lines 19–22 have free-form comments (\*).

For each epoch there is a header line ( \* ) and data lines ( P ) for each satellite. The data lines contain Cartesian coordinates in kilometers and the clock offset in microseconds.

## Appendix 4. Modeling Satellite Clock Variations due to SA

For precise geodesy, the most troublesome aspect of the policy of "selective availability" (SA) is the dithering of the frequency of the satellite oscillators. Between March and August of 1990, the level of dithering reached 1-2 Hz ( $\sim 1$  part in  $10^{-9}$ ), making the oscillators of the Block II satellites appear to be no more stable than the better crystal oscillators used in field receivers. Dithering is a problem because receivers do not generally sample the phase of the same transmitted wavefront. Even if the nominal sampling time is the same, receivers separated by intercontinental distances sometimes sample wavefronts transmitted at times different by a few tens of milliseconds due to the difference in propagation time. For the level of SA active in 1990, the phase error in the case of simultaneously sampling sites at intercontinental distances is only a few millimeters in equivalent distance. For receivers that sample at times differing by  $\sim 1$  second (e.g. TI 4100 and MiniMac 2816 or Trimble 4000SST), the error can reach a cycle or more (see *Feigl et al.* [1991] for a more complete discussion).

The satellite oscillator phase (or frequency) variations can be determined rather easily from the carrier-beat phase residuals from a station using an atomic oscillator (Rubidium, Cesium, or Hydrogen-maser). Program MAKEJ performs this task using the phase-residuals from one or more C-files to compute satellite clock corrections at each epoch and to write these into a J-file which has the same form as the J-file created from the broadcast clock polynomial (see Chapter 4). The only complication is the need to clean the phase data and to use the residuals from several stations in order to avoid gaps. A reasonable strategy is to process the data from a global network of 3–10 atomic-oscillator stations using `Type of Analysis = QUICK` and to perform only minimal manual editing in order to get a set of C-files to be used as input to MAKEJ. If you start with enough stations, you can afford to omit problematic C-files.

To invoke this mode of MAKEJ, choose option 2 at the first prompt and then enter the name of the J-file to be created:

```
Choose source of SV oscillator frequency corrections:
 1 E-file broadcast message. [OK for MAKEX and MODEL without S/A]
 2 Second order fit to C-file from site with H-maser [best for S/A]
Pick a number.2
```

```
Enter output J-file name >: jtrex0.086
Opened J-file: jtrex0.086
```

MAKEJ will then ask you whether you want to see extra (debug) information (usually not) and display a list of the C-files available in the directory:

```
Wanna debug? (Y/N) n
```

```
Choose one or more C-files from stations with atomic standards
```

Available files:

- 1 carot0.086
- 2 cblhl0.086
- 3 ccent0.086
- 4 cjp110.086
- 5 clock.doc
- 6 cmadc0.086
- 7 cmojm0.086
- 8 covro0.086
- 9 cpver0.086
- 10 cricm0.086
- 11 ctoc.bat
- 12 cvndn0.086
- 13 cwsfm0.086

Enter file names or pick numbers:

1 7 10 13

In this example, we have chosen C-files from four VLBI sites (Algonquin, Mojave, Richmond, and Westford) all equipped with Hydrogen-maser frequency standards.

You will next be asked to provide as input the J-file used by MODEL in the analysis that produced the C-files. Since the phase residuals were generated with the satellite-clock terms from this J-file, it is crucial that you use this file as reference in generating the new epoch-by-epoch J-file.

Choose as input reference the J-file used by MODEL to produce the C-files

Available files:

- 1 jrefj0.086
- 2 jtrex0.086

Enter a file name or pick a number:1

MAKEJ will then read the time and phase residuals from all of the C-files and estimate a series of satellite-clock coefficients defined in the same way as for the broadcast J-file. The clock-offset term (units = seconds) is taken from the input J-file directly. MAKEJ will estimate from three successive values of the phase residuals at each station a frequency-offset coefficient (dimensionless) and frequency rate (or clock acceleration) coefficient (1/seconds). The values from each station are then averaged, with outliers detected and removed, and written on the J-file. Part of a J-file for day 86 of 1990 is shown below:

SV clock terms from C-file rwk					9.14 of 92/07/15 13:00 (sun)			sun		
YR	DOY	HR	MN	SEC(UTC)	WKNO	SOW(GPST)	PRN	XEAF0	XEAF1	XEAF2
(i2,1x,i3,2i3,1x,f6.7,3x,i3,1x,f9.2,2x,i2.2,2x,3d16.8)										
90	86	0	44	24.000	533	175470.00	02	-0.44736080D-05	-0.38595080D-09	-0.72672011D-13
90	86	0	44	54.000	533	175500.00	02	-0.44736080D-05	-0.37723562D-09	0.21328450D-12
...										
90	86	3	44	54.000	533	186300.00	02	-0.44619665D-05	-0.18795949D-09	0.13967074D-11
90	86	3	45	24.000	533	186330.00	02	-0.44619665D-05	-0.67060934D-10	0.61826852D-12
90	86	3	45	54.000	533	186360.00	02	-0.44619665D-05	-0.29081758D-10	0.14717717D-13
90	86	3	46	24.000	533	186390.00	02	-0.44619665D-05	-0.75677689D-10	-0.79131662D-12
90	86	3	46	54.000	533	186420.00	02	-0.44619665D-05	-0.34106051D-12	0.00000000D+00
90	86	3	47	24.000	533	186450.00	02	-0.44619665D-05	-0.34106051D-12	0.00000000D+00

The estimates can be made, of course, only if the satellite is visible from the station whose C-file is being used, so if a non-global network is used, you will obtain many messages of the form

```

Estimate failed for PRN 19 at epoch 2; using reference values
Estimate failed for PRN 19 at epoch 3; using reference values
.....
Estimate failed for PRN 19 at epoch 20; using reference values

```

As long as at least one "good" station is available in the region of your primary network, you will have a valid estimate for most or all of the epochs of interest. Use of a global network and an observation span longer than that of your primary data session will avoid endpoint problems, which arise inevitably since phase data from three epochs are needed to estimate frequency and its rate of change (see Chapter 2 of *Feigl* [1991]). If a good estimate cannot be obtained at any epoch, the coefficients from the input J-file are written. In the example shown above, broadcast coefficients have been used after 3 46<sup>m</sup> 24<sup>s</sup>, when PRN 2 is no longer visible from any of the four stations. Note the difference in the stability of the clock as reported by the satellite (3 parts in 10<sup>3</sup>) and as actually measured (3 parts in 10<sup>10</sup>) (although part of this difference might be attributed to time period of averaging—hours versus minutes).

After writing the complete J-file, MAKEJ will display a summary:

```

J-File written for 9 satellites

  Start: 90  86  0 44
  Stop  : 90  86  8 42

Valid estimates  PRN:   2    3    6    9   11   13   14   16   19
                   362  433  542  562  832  710  499  159  369

Outliers   PRN:   2    3    6    9   11   13   14   16   19
carot0.086      0    0    0    0    0    0    0    0    0
cmojm0.086     0    0    0    0    0    0    0    0    0
cricm0.086     0    0    0    0    0    0    0    0    0
cwsfm0.086     0    0    0    0    0    0    0    0    0

Jfile: j4stn0.086 contains PRNs 02 03 06 09 11 13 14 16 19

```

In estimating the clock coefficients, MAKEJ uses only phase residuals which are flagged as "good" for SOLVE and not flagged as a cycle slip requiring an extra bias parameter. If the data have been completely cleaned no outliers will be detected.