



Atmospheric Correction Module: QUAC and FLAASH User's Guide



Atmospheric Correction Module
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Chapter 1

Introduction to QUAC and FLAASH

This **chapter** covers the following topics:

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The QUAC Model	9	Input Data Requirements	12

About Atmospheric Correction

The nature of remote sensing requires that solar radiation pass through the atmosphere before it is collected by the instrument. Because of this, remotely sensed images include information about the atmosphere and the earth's surface. For those interested in quantitative analysis of surface reflectance, removing the influence of the atmosphere is a critical pre-processing step. To compensate for atmospheric effects, properties such as the amount of water vapor, distribution of aerosols, and scene visibility must be known. Because direct measurements of these atmospheric properties are rarely available, there are techniques that infer them from their imprint on hyperspectral radiance data. These properties are then used to constrain highly accurate models of atmospheric radiation transfer to produce an estimate of the true surface reflectance. Moreover, atmospheric corrections of this type can be applied on a pixel-by-pixel basis because each pixel in a hyperspectral image contains an independent measurement of atmospheric water vapor absorption bands.

The Atmospheric Correction Module provides two atmospheric correction modeling tools for retrieving spectral reflectance from multispectral and hyperspectral radiance images: QUick Atmospheric Correction (QUAC) and Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH). With the Atmospheric Correction Module, you can accurately compensate for atmospheric effects.

QUAC and FLAASH were developed by Spectral Sciences, Inc., a world leader in optical phenomenology research, under the sponsorship of the U.S. Air Force Research Laboratory. Spectral Sciences has been an integral part in the development of modern atmospheric radiation transfer models, and has worked extensively on MODTRAN since the model's inception in 1989.

About QUAC

QUAC is a visible-near infrared through shortwave infrared (VNIR-SWIR) atmospheric correction method for multispectral and hyperspectral imagery. Unlike other first-principles atmospheric correction methods, it determines atmospheric compensation parameters directly from the information contained within the scene (observed pixel spectra), without ancillary information. QUAC performs a more approximate atmospheric correction than FLAASH or other physics-based first-principles methods, generally producing reflectance spectra within approximately +/-15% of the physics-based approaches. QUAC is based on the empirical finding that the average reflectance of a collection of diverse material spectra, such as the endmember spectra in a scene, is essentially scene-independent. All of this means significantly faster computational speed compared to the first-principles methods.

QUAC also allows for any view or solar elevation angle. Should a sensor not have proper radiometric or wavelength calibration, or the solar illumination intensity be unknown (such as when a cloud deck is present), this approach still allows the retrieval of reasonably accurate reflectance spectra.

QUAC provides the following:

- Automated atmospheric correction of MSI and HSI data in the solar reflective spectral region (~0.4-2.5 μm).

- Support for AISA, ASAS, AVIRIS, CAP ARCHER, COMPASS, HYCAS, HYDICE, HyMap, Hyperion, IKONOS, Landsat TM, LASH, MASTER, MODIS, MTI, QuickBird, RGB, and unknown sensor types.

QUAC creates an image of retrieved surface reflectance, scaled into two-byte signed integers using a reflectance scale factor of 10,000.

About FLAASH

FLAASH is a first-principles atmospheric correction tool that corrects wavelengths in the visible through near-infrared and shortwave infrared regions, up to 3 μm . (For thermal regions, use the **Basic Tools** → **Preprocessing** → **Calibration Utilities** → **Thermal Atm Correction** menu option.) Unlike many other atmospheric correction programs that interpolate radiation transfer properties from a pre-calculated database of modeling results, FLAASH incorporates the MODTRAN4 radiation transfer code.

Note

The version of MODTRAN4 incorporated into ENVI FLAASH was modified to correct errors in the HITRAN-96 water line parameters. See Matthew et al. (2000) for details.

You can choose any of the standard MODTRAN model atmospheres and aerosol types to represent the scene; a unique MODTRAN solution is computed for each image.

FLAASH also includes the following features:

- Correction for the adjacency effect (pixel mixing due to scattering of surface-reflected radiance)
- An option to compute a scene-average visibility (aerosol/haze amount). FLAASH uses the most advanced techniques for handling particularly stressing atmospheric conditions, such as the presence of clouds.
- Cirrus and opaque cloud classification map
- Adjustable spectral polishing for artifact suppression.

FLAASH supports hyperspectral sensors (such as HyMAP, AVIRIS, HYDICE, HYPERION, Probe-1, CASI, and AISA) and multispectral sensors (such as ASTER, IRS, Landsat, [RapidEye](#), and SPOT). Water vapor and aerosol retrieval are only possible when the image contains bands in appropriate wavelength positions (see “[Input Data Requirements](#)” on page 12 for details). In addition, FLAASH can correct images collected in either vertical (nadir) or slant-viewing geometries.

References

For detailed scientific descriptions of the model employed by QUAC, see the following references:

Bernstein, L. S., S. M. Adler-Golden, R. L. Sundberg, et al, 2005. *Validation of the Quick Atmospheric Correction (QUAC) algorithm for VNIR-SWIR multi- and hyperspectral imagery*. SPIE Proceedings, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XI. Vol. 5806, pp. 668-678.

Bernstein, L. S., S. M. Adler-Golden, R. L. Sundberg, and A. Ratkowski, 2006. *Improved Reflectance Retrieval from Hyper- and Multispectral Imagery without Prior Scene or Sensor*

Information. SPIE Proceedings, Remote Sensing of Clouds and the Atmosphere XI. Vol. 6362.

For detailed scientific descriptions of the model employed by FLAASH, see the following references:

Adler-Golden, S. M., M. W. Matthew, L. S. Bernstein, R. Y. Levine, A. Berk, S. C. Richtsmeier, P. K. Acharya, G. P. Anderson, G. Felde, J. Gardner, M. Hoke, L. S. Jeong, B. Pukall, A. Ratkowski, and H.-H. Burke, 1999. *Atmospheric Correction for Short-wave Spectral Imagery Based on MODTRAN4*. SPIE Proceedings on Imaging Spectrometry, Vol. 3753, pp. 61-69.

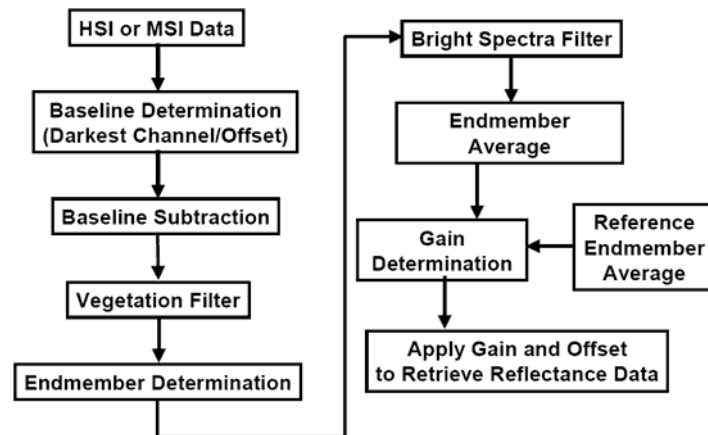
Berk, A., L. S. Bernstein, G. P. Anderson, P. K. Acharya, D. C. Robertson, J.H. Chetwynd, and S. M. Adler-Golden, 1998. *MODTRAN Cloud and Multiple Scattering Upgrades with Application to AVIRIS*. Remote Sensing of the Environment, Vol. 65, pp. 367-375.

Berk A., L. S. Bernstein, and D. C. Robertson, 1989. *MODTRAN: a moderate resolution model for LOWTRAN7*. GL-TR-89-0122. Air Force Geophysical Laboratory, Hanscom AFB, MA. p. 38.

Matthew, M. W., S. M. Adler-Golden, A. Berk, S. C. Richtsmeier, R. Y. Levine, L. S. Bernstein, P. K. Acharya, G. P. Anderson, G. W. Felde, M. P. Hoke, A. Ratkowski, H.-H. Burke, R. D. Kaiser, and D. P. Miller, 2000. *Status of Atmospheric Correction Using a MODTRAN4-based Algorithm*. SPIE Proceedings, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VI. Vol. 4049, pp. 199-207.

The QUAC Model

The QUAC data processing scheme is outlined below.



QUAC performs a fast and fairly accurate atmospheric correction with the following conditions:

- There are at least 10 diverse materials in a scene.
- There are sufficiently dark pixels in a scene to allow for a good estimation of the baseline spectrum.

The FLAASH Model

This section is a brief overview of the atmospheric correction method used by FLAASH.

FLAASH starts from a standard equation for spectral radiance at a sensor pixel, L , that applies to the solar wavelength range (thermal emission is neglected) and flat, Lambertian materials or their equivalents. The equation is as follows:

$$L = \left(\frac{A\rho}{1 - \rho_e S} \right) + \left(\frac{B\rho_e}{1 - \rho_e S} \right) + L_a \quad (1)$$

where:

ρ is the pixel surface reflectance

ρ_e is an average surface reflectance for the pixel and a surrounding region

S is the spherical albedo of the atmosphere

L_a is the radiance back scattered by the atmosphere

A and B are coefficients that depend on atmospheric and geometric conditions but not on the surface.

Each of these variables depends on the spectral channel; the wavelength index has been omitted for simplicity. The first term in Equation (1) corresponds to radiance that is reflected from the surface and travels directly into the sensor, while the second term corresponds to radiance from the surface that is scattered by the atmosphere into the sensor. The distinction between ρ and ρ_e accounts for the adjacency effect (spatial mixing of radiance among nearby pixels) caused by atmospheric scattering. To ignore the adjacency effect correction, set $\rho_e = \rho$. However, this correction can result in significant reflectance errors at short wavelengths, especially under hazy conditions and when strong contrasts occur among the materials in the scene.

The values of A , B , S and L_a are determined from MODTRAN4 calculations that use the viewing and solar angles and the mean surface elevation of the measurement, and they assume a certain model atmosphere, aerosol type, and visible range. The values of A , B , S and L_a are strongly dependent on the water vapor column amount, which is generally not well known and may vary across the scene. To account for unknown and variable column water vapor, the MODTRAN4 calculations are looped over a series of different column amounts, then selected wavelength channels of the image are analyzed to retrieve an estimated amount for each pixel. Specifically, radiance averages are gathered for two sets of channels: an absorption set centered at a water band (typically 1130 nm) and a reference set of channels taken from just outside the band. A lookup table for retrieving the water vapor from these radiances is constructed.

Note

For images that do not contain bands in the appropriate wavelength positions to support water retrieval (for example, Landsat or SPOT), the column water vapor amount is determined by the user-selected atmospheric model (see [“Using Water Retrieval”](#) on page 22 for details).

After the water retrieval is performed, Equation (1) is solved for the pixel surface reflectances in all of the sensor channels. The solution method involves computing a spatially averaged radiance image L_e , from which the spatially averaged reflectance ρ_e is estimated using the approximate equation:

$$L_e \approx \left(\frac{(A + B)\rho_e}{1 - \rho_e S} \right) + L_a \quad (2)$$

Spatial averaging is performed using a point-spread function that describes the relative contributions to the pixel radiance from points on the ground at different distances from the direct line of sight. For accurate results, cloud-containing pixels must be removed prior to averaging. The cloudy pixels are found using a combination of brightness, band ratio, and water vapor tests, as described by Matthew et al. (2000).

The FLAASH model includes a method for retrieving an estimated aerosol/haze amount from selected dark land pixels in the scene. The method is based on observations by Kaufman et al. (1997) of a nearly fixed ratio between the reflectances for such pixels at 660 nm and 2100 nm. FLAASH retrieves the aerosol amount by iterating Equations (1) and (2) over a series of visible ranges, for example, 17 km to 200 km. For each visible range, it retrieves the scene-average 660 nm and 2100 nm reflectances for the dark pixels, and it interpolates the best estimate of the visible range by matching the ratio to the average ratio of ~0.45 that was observed by Kaufman et al. (1997). Using this visible range estimate, FLAASH performs a second and final MODTRAN4 calculation loop over water.

Reference

Kaufman, Y. J., A. E. Wald, L. A. Remer, B.-C. Gao, R.-R. Li, and L. Flynn, 1997. *The MODIS 2.1- μm Channel-Correlation with Visible Reflectance for Use in Remote Sensing of Aerosol*. IEEE Transactions on Geoscience and Remote Sensing. Vol. 35, pp. 1286-1298.

Input Data Requirements

Input data requirements differ between QUAC and FLAASH. In general, QUAC does not require the input data to meet as many requirements as FLAASH.

QUAC Input Requirements

The input data for QUAC can be in radiance, apparent reflectance, or raw/uncalibrated units. QUAC supports band interleaved by line (BIL), band interleaved by pixel (BIP), and band sequential (BSQ) formats and all data types. Spatial subsets, spectral subsets, and masking are allowed as QUAC input. QUAC input files must have at least three bands and valid wavelengths.

QUAC supports atmospheric correction of visible near-infrared through shortwave infrared (VNIR-SWIR) hyperspectral or multispectral imagery. For multispectral and hyperspectral sensors, wavelength values must be available in the ENVI header file or in separate ASCII files.

FLAASH Input Requirements

The input image for FLAASH must be a radiometrically calibrated radiance image in band-interleaved-by-line (BIL) or band-interleaved-by-pixel (BIP) format. The data type may be floating-point, 4-byte signed integers, 2-byte signed integers, or 2-byte unsigned integers. To perform water retrieval, the image bands must span at least one of the following ranges at 15 nm spectral resolution or better:

- 1050-1210 nm
- 770-870 nm
- 870-1020 nm

Additional wavelength coverage is required for aerosol retrieval (see [“Using Aerosol Retrieval”](#) on page 23). For hyperspectral sensors, wavelengths and full width half maximum (FWHM) values must be available in the ENVI header file or in separate ASCII files. Known multispectral sensors require only wavelength values, while unknown (custom) multispectral sensors also require spectral response filter functions (see [“Multispectral Settings”](#) on page 27).

FLAASH requires input data to be floating-point values in units of $\mu\text{W}/\text{cm}^2 \cdot \text{nm} \cdot \text{sr}$. If the input radiance image is not already in floating-point format, you must also know the scale factor (or factors) used to convert radiance data into these units. The scale factors are division factors that satisfy the following relationship:

$$\left(\frac{\text{integer radiance image}}{\text{scale factor}} \right) = \text{floating point radiance image } [\mu\text{W}/(\text{cm}^2 \cdot \text{nm} \cdot \text{sr})]$$

If the scale factor is not a constant for all bands, a scale factor for each band must be provided in an ASCII file. An example of a scale factors file that is appropriate for 1995-2002 AVIRIS data is available in `\Data\flaash\hyperspectral\input_files\AVIRIS_1998_scale.txt` on the ENVI Resource DVD.

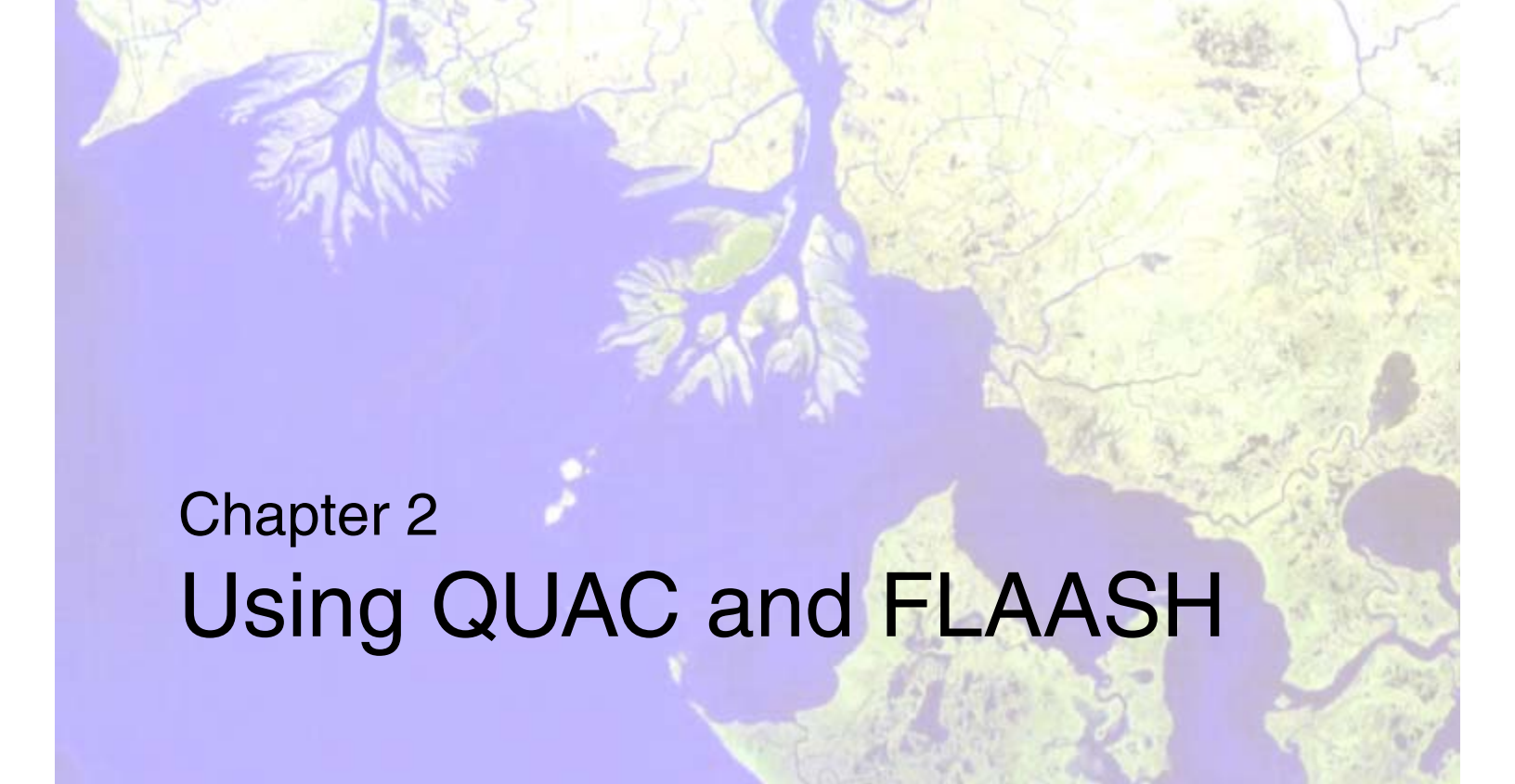
Preparing ASTER Data

ENVI automatically calibrates and applies scale factors to ASTER Level 1A and 1B data when you first read them. You do not need to perform these steps separately. Because ASTER Level 1A bands are not coregistered, you cannot directly input Level 1A VNIR or SWIR datasets into QUAC and FLAASH. A recommended approach is to coregister visible near-infrared (VNIR) and shortwave infrared (SWIR) bands, then use ENVI's Layer Stacking tool to combine them into a single dataset to input into QUAC and FLAASH.

Tip

See the ENVI Tutorials on the [ITT Visual Information Solutions website](#) (or on the ENVI Resource DVD that shipped with your ENVI installation) for step-by-step examples.

It is not recommended to retrieve visibility (aerosols) with ASTER data. See “[Using Aerosol Retrieval](#)” on page 23. While ASTER bands cover the region required for the dark-land pixel-retrieval method, the bandwidth for Band 2 is fairly wide (660 nm) and will likely include the vegetation red edge, which could significantly bias the visibility estimate.



Chapter 2

Using QUAC and FLAASH

This **chapter** describes how to use the Atmospheric Correction Module: QUAC and FLAASH, including detailed descriptions of the parameters and instructions for setting them. It covers the following topics:

Using QUAC	16	Starting the Processing	37
Standard FLAASH Input Parameters	17	Saving and Restoring FLAASH Run Parameters (Templates)	38
FLAASH Advanced Settings	31	FLAASH Output Files	39

Using QUAC

The parameters for QUAC include selecting an input file, specifying a sensor type, and setting output file defaults.

1. From the ENVI main menu bar, select one of the following:
 - **Basic Tools** → **Preprocessing** → **Calibration Utilities** → **QUick Atmospheric Correction**
 - **Spectral** → **QUick Atmospheric Correction**
 - **Spectral** → **Preprocessing** → **Calibration Utilities** → **QUick Atmospheric Correction**

The Input File dialog appears.

2. Select an input file and click **Open**. The file is added to the top of the Select Input File dialog.
3. Perform any optional spatial or spectral subsetting or apply a mask. For subsetting details, see [Subsetting Data](#) in the *ENVI User's Guide*.
4. Click **OK** on the Input File dialog. The QUick Atmospheric Correction Parameters dialog appears.
5. Specify a sensor type. If you do not know the sensor type of the input file or the sensor type is not available in the drop-down list, select **Unknown**. ENVI will handle the input file in a generic way.
6. Select output to **File** or **Memory**.
7. Click **OK** to process the file. Click **Queue** to prepare multiple functions in advance for processing. For more information see [Queuing ENVI Processes](#) in *Getting Started with ENVI*.

Standard FLAASH Input Parameters

The parameters for ENVI FLAASH include selecting an input radiance image, setting output file defaults, entering information about the sensor and scene, selecting an atmosphere and aerosol model, and setting options for the atmosphere correction model.

Advanced settings, such as setting the azimuth and zenith for instruments that use a non-nadir viewing geometry and entering a CO₂ mixing ratio are described in “[FLAASH Advanced Settings](#)” on page 31.

- From the ENVI main menu bar, select one of the following:
 - Basic Tools** → **Preprocessing** → **Calibration Utilities** → **FLAASH**
 - Spectral** → **FLAASH**
 - Spectral** → **Preprocessing** → **Calibration Utilities** → **FLAASH**

The FLAASH Atmospheric Correction Model Input Parameters dialog appears ([Figure 2-1](#)).

- Set the input parameters as described in the following sections.

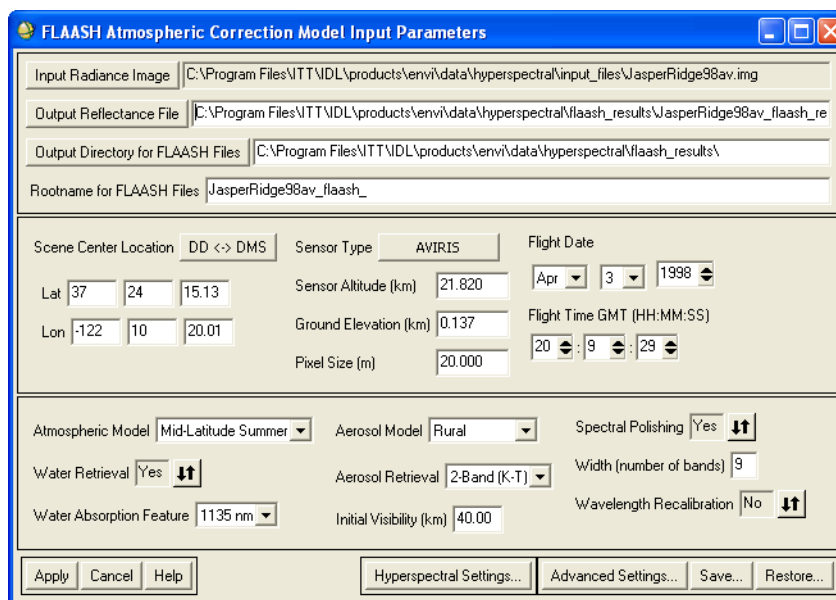


Figure 2-1: FLAASH Atmospheric Corrections Model Input Parameters Dialog

Specifying Input and Output File Information

- In the FLAASH Atmospheric Corrections Model Input Parameters dialog, click **Input Radiance Image** to open the FLAASH Input File dialog.

The input radiance image should contain calibrated radiance data in a floating-point, long integer (4-byte signed), or integer (2-byte signed or unsigned) data type, and the

interleave must be BIL or BIP. To convert between different interleaves, select **Basic Tools** → **Convert Data (BSQ, BIL, BIP)** from the ENVI main menu bar.

2. Select the input file and any spatial subsetting (see the *ENVI User's Guide* for subsetting instructions), then click **OK**. If you select a spatial subset, you can make adjustments to it later by using the FLAASH Advanced Settings dialog (see “[FLAASH Advanced Settings](#)” on page 31).

If wavelengths are not defined in the input image header file, FLAASH prompts you to read these values from an ASCII file using ENVI's Input ASCII File dialog.

The ASCII file should contain data in columns (for example, the wavelengths are in one column). Be sure to correctly specify the wavelength column and units when reading the ASCII file.

The Radiance Scale Factors dialog appears ([Figure 2-2](#)).

3. Select whether to enter a single scale factor (a constant) for all bands, or to read an array of scale factors (one per band) from an ASCII file.
 - If you select **Read array of scale factors (1 per band) from ASCII file**, a file selection dialog appears. Select the input ASCII file.
 - If you select **Use single scale factor for all bands**, the **Single scale factor** text box appears. Enter a scale factor.

Be sure to specify the correct column for the scale factor. For convenience, you can apply a multiplication factor and/or inverse. If you specify both, the multiplication factor is applied before the inverse. If necessary, you can redefine the scale factors later using the FLAASH Advanced Settings dialog (detailed in “[FLAASH Advanced Settings](#)” on page 31). An example of an appropriate scale factors file for 1995-2002 AVIRIS data is available in `\Data\flaash\hyperspectral\input_files\AVIRIS_1998_scale.txt` on the ENVI Resource DVD.

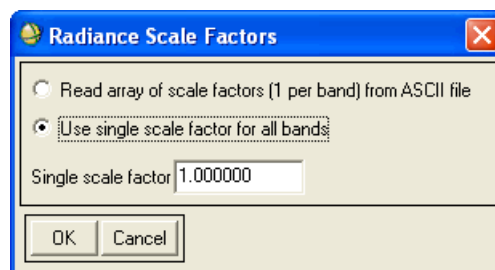


Figure 2-2: Radiance Scale Factors Dialog

Choose scale factors such that the input pixel values divided by these factors converts the data into floating-point radiance values in units of $\mu\text{W}/\text{cm}^2 \cdot \text{nm} \cdot \text{sr}$. If the input image is already in floating-point radiance in the correct units, then set the scale factors to 1 for all bands.

After you select the input file and radiance scale factors, the top three text boxes are populated with the input filename and directory information, the default output filename and path, and the default output directory.

Output Filename

1. To change the output filename, in the FLAASH Atmospheric Corrections Model Input Parameters dialog, click **Output Reflectance File**. The Select Output File dialog appears.
2. Navigate to the desired output directory and enter the new filename in the text box.
3. Click **Open**. The new directory and output name appears in the **Output Reflectance File** text box.
 - Alternatively, you can enter the path and filename directly into the text box. If you choose to enter a filename, but do not enter a directory path, the reflectance file output is saved in the directory that is designated in the **Output Directory for FLAASH Files** text box.

Output Directory

1. To change the output directory, click **Output Directory for FLAASH Files**. The Browse for Folder dialog appears. This setting is the location where all FLAASH files (except the output reflectance file) are written. The FLAASH files that are output to this directory include the column water vapor and cloud map images, the journal file, and optionally the template file.
2. Navigate to the desired output directory and click **OK**. The new directory information appears in the **Output Directory for FLAASH Files** text box.
 - Alternatively, you can enter the path directly into the text box. Be sure to include the full directory path.

Root Name

In the **Rootname for FLAASH Files** text box, enter the prefix to add to each FLAASH file produced during a FLAASH session. Do not include a directory path.

The root name is the prefix that is appended to the output FLAASH filenames. ENVI automatically adds an underscore character to the rootname. For example, a rootname of `MyHymapImage` produces a cloud map output image called `MyHymapImage_cloudmask.dat`.

Entering Scene and Sensor Information

Scene and sensor information include the scene center location (lat/lon), the average ground elevation of the scene, the sensor type, the sensor altitude, and the flight date and time. These data let FLAASH determine where the sun was in the sky and the path of sunlight through the atmosphere to the ground and back to the sensor.

1. In the **Lat** and **Lon** fields, enter the latitude and longitude of the scene center, respectively, using negative values for Southern and Western Hemispheres. To toggle between decimal degrees and degrees/minutes/seconds, click **DD <-> DMS**.

- Click **Sensor Type** and select the name of the sensor that collected the input radiance image. The input parameters dialog changes slightly when switching between **Multispectral** and **Hyperspectral** sensor types. For spaceborne sensors, a default **Sensor Altitude (km)** is automatically set according to the sensor type.

Note

For multispectral sensors, the sensor type is used to automatically assign the correct spectral response functions for the image bands. FLAASH uses ENVI's filter functions for the named multispectral sensors.

- In the **Sensor Altitude (km)** field, enter the altitude of the sensor when the image was collected, in kilometers above sea level. For spaceborne sensors, the sensor altitude is automatically set when you select the sensor type.
- In the **Ground Elevation (km)** field, enter the average scene elevation, in kilometers above sea level.
- In the **Pixel Size (m)** field, enter the image pixel size in meters. The pixel size value is used for the adjacency effect correction. An approximate value is adequate. For non-nadir looking sensors (or any sensor with non-square pixels) enter the largest pixel dimension.
- Click the **Flight Date** drop-down lists, select the month and date the scene was collected. Use the arrow increment buttons to select a year, or enter the four-digit year in the text box.
- In the **Flight Time GMT (HH:MM:SS)** fields, enter the Greenwich Mean Time when the scene was collected.

Selecting Atmospheric Model Settings

Use the **Atmospheric Model** drop-down list to choose one of the standard MODTRAN model atmospheres.

For the best results, select a model whose standard column water vapor amount is similar to, or somewhat greater than, that expected for the scene. The standard column water vapor amounts (from sea level to space) for each model atmosphere are given in [Table 2-1](#).

If no water vapor information is available, select an atmosphere according to the known or expected surface air temperature, which tends to correlate with water vapor. If the temperature is unknown, select an atmosphere from [Table 2-2](#), which is based on a seasonal-latitude surface temperature model.

Model Atmosphere	Water Vapor (std atm-cm)	Water Vapor (g/cm ²)	Surface Air Temperature
Sub-Arctic Winter (SAW)	518	0.42	-16 °C or 3 °F
Mid-Latitude Winter (MLW)	1060	0.85	-1 °C or 30 °F
U.S. Standard (US)	1762	1.42	15 °C or 59 °

Table 2-1: Column Water Vapor Amounts and Surface Temperatures for the MODTRAN Model Atmospheres

Model Atmosphere	Water Vapor (std atm-cm)	Water Vapor (g/cm ²)	Surface Air Temperature
Sub-Arctic Summer (SAS)	2589	2.08	14 °C or 57 °
Mid-Latitude Summer (MLS)	3636	2.92	21 °C or 70 °
Tropical (T)	5119	4.11	27 °C or 80 °

Table 2-1: Column Water Vapor Amounts and Surface Temperatures for the MODTRAN Model Atmospheres (Continued)

Latitude (°N)	Jan.	March	May	July	Sept.	Nov.
80	SAW	SAW	SAW	MLW	MLW	SAW
70	SAW	SAW	MLW	MLW	MLW	SAW
60	MLW	MLW	MLW	SAS	SAS	MLW
50	MLW	MLW	SAS	SAS	SAS	SAS
40	SAS	SAS	SAS	MLS	MLS	SAS
30	MLS	MLS	MLS	T	T	MLS
20	T	T	T	T	T	T
10	T	T	T	T	T	T
0	T	T	T	T	T	T
-10	T	T	T	T	T	T
-20	T	T	T	MLS	MLS	T
-30	MLS	MLS	MLS	MLS	MLS	MLS
-40	SAS	SAS	SAS	SAS	SAS	SAS
-50	SAS	SAS	SAS	MLW	MLW	SAS
-60	MLW	MLW	MLW	MLW	MLW	MLW
-70	MLW	MLW	MLW	MLW	MLW	MLW
-80	MLW	MLW	MLW	SAW	MLW	MLW

Table 2-2: Selection of MODTRAN Model Atmospheres Based on Latitudinal/Seasonal Dependence of Surface Temperature

Water Vapor Units

The “atm-cm” unit is specific to the atmospheric science community, which typically uses one of two units to measure the total amount of a gas in the atmospheric column from the ground to the top of the atmosphere (where 200 to 300 km is generally a good number for the location of the top).

When you use units of “atm-cm,” think of it as bringing all the water molecules down to a thin layer of pure water vapor at the Earth’s surface, at 1 atm of pressure and 0 degrees C. That layer has a thickness measured in centimeters, so the water column is described in atmosphere-centimeters. If the pressure were doubled, then the thickness would be halved. Thus, the units of atm-cm (not just cm) are used to describe the amount of gas in the atmospheric column to emphasize that the height and pressure are interdependent.

Of course, it is not physically possible to bring these molecules into such a condensed layer. All of the molecules in the layer would condense into a liquid under these conditions, even if they could be gathered in such a way. The layer is imaginary.

The second set of units, gm/cm², is more easily understood as the mass of water molecules in the atmospheric column over each cm² of ground surface. Since liquid water has a 1 gm/cm² density, this value is numerically equal to the number of centimeters of water on the ground if all the atmospheric water rained out at once.

Using Water Retrieval

To solve the radiative transfer equations that allow apparent surface reflectance to be computed, the column water vapor amount for each pixel in the image must be determined. FLAASH includes a method for retrieving the water amount for each pixel. This technique produces a more accurate correction than using a constant water amount for the entire scene. To use this water retrieval method, the image must have bands that span at least one of the following ranges at a spectral resolution of 15 nm or better:

- 1050-1210 nm (for the 1135 nm water feature)
- 870-1020 nm (for the 940 nm water feature)
- 770-870 nm (for the 820 nm water feature)

For most of the multispectral sensor types, the **Water Retrieval** setting is **No** because these sensors do not have the appropriate bands to perform the retrieval.

The **Water Retrieval** options are as follows:

- **Yes:** Perform water retrieval. From the **Water Absorption Feature** drop-down list, select the water feature you wish to use. The 1135 nm feature is recommended if the appropriate bands are available. If you select 1135 nm or 940 nm, and the feature is saturated due to an extremely wet atmosphere, then the 820 nm feature is automatically used in its place if bands spanning this region are available.

Tip

When performing a water retrieval on multispectral image data, use the Multispectral Settings dialog to manually set the water bands (see [“Multispectral Settings”](#) on page 27 for details).

- **No:** Use a constant column water vapor amount for all pixels in the image. In this case, the column water vapor amount is determined according to the standard column water vapor amount for the selected Atmospheric Model, multiplied by an optional **Water Column Multiplier**. See [Table 2-1](#) for the standard column water vapor amounts for each Atmosphere Model. Set the **Water Column Multiplier** value accordingly.

Selecting an Aerosol Model

Click the **Aerosol Model** drop-down list and select one of the standard MODTRAN aerosol/haze types.

Note

The choice of model is not critical if the visibility is high (for example, greater than 40 km).

The model choices are as follows:

- **Rural:** Represents aerosols in areas not strongly affected by urban or industrial sources. The particle sizes are a blend of two distributions, one large and one small.
- **Urban:** A mixture of 80% rural aerosol with 20% soot-like aerosols, appropriate for high-density urban/industrial areas.
- **Maritime:** Represents the boundary layer over oceans, or continents under a prevailing wind from the ocean. It is composed of two components, one from sea spray and another from rural continental aerosol (that omits the largest particles).
- **Tropospheric:** Applies to calm, clear (visibility greater than 40 km) conditions over land and consists of the small-particle component of the rural model. For more details on MODTRAN aerosol models, see Abreu and Anderson (1996).

Using Aerosol Retrieval

FLAASH includes a method for retrieving the aerosol amount and estimating a scene average visibility using a dark pixel reflectance ratio method based on work by Kaufman et al. (1997). The dark-land pixel-retrieval method requires the presence of sensor channels around 660 nm and 2100 nm. A dark-land pixel is defined to be one with a 2100 nm reflectance of 0.1 or less and a 660:2100 reflectance ratio of approximately 0.45. If the input image contains bands near 800 nm and 420 nm, an additional check is performed, requiring the 800:420 radiance ratio to be 1 or less, which eliminates pixels likely to be shadows and water bodies.

Click the **Aerosol Retrieval** drop-down list: and select an option:

- **None:** When you select this option, the value in the **Initial Visibility (tm)** field is used for the aerosol model (described in the following section).
- **2-Band (K-T):** Use the aerosol retrieval method. If no suitable dark pixels are found, then the value in the **Initial Visibility** field is used.

Tip

When performing an aerosol retrieval on multispectral image data, use the Multispectral Settings dialog to manually set the aerosol bands (see “[Multispectral Settings](#)” on page 27 for details).

Note

It is not recommended that you scene-average visibility with ASTER data (see “[Using Aerosol Retrieval](#)” on page 23). While ASTER bands cover the region required for the dark-land pixel-retrieval method, the bandwidth for Band 2 is fairly wide (660 nm) and will likely include the vegetation red edge, which could significantly bias the visibility estimate.

Entering an Initial Visibility Value

In the **Initial Visibility** field, enter an estimate of the scene visibility in kilometers. The initial visibility value is assumed for the atmospheric correction if the aerosol is not being retrieved.

Table 2-3 lists approximate values based on weather conditions.

Weather Condition	Scene Visibility
Clear	40 to 100 km
Moderate Haze	20 to 30 km
Thick Haze	15 km or less

Table 2-3: Approximate Scene Visibility Values

The visibility, V is defined as the 550 nm meteorological range and is related to extinction coefficient β (base e) by the equation $V = 3.912/\beta$. The extinction coefficient β is defined as the horizontal optical depth per km. A related value, the aerosol optical depth (AOD) is measured vertically (from the ground to space). To convert the AOD to β , divide AOD by the effective aerosol thickness layer, which typically has a value of around 2 km, but varies with the visibility, elevation, and other factors.

Note

Enter an **Initial Visibility (tm)** value even if you have set the **Aerosol Retrieval** parameter to **2-Band (K-T)**, as FLAASH uses the **Initial Visibility (tm)** value if the aerosol cannot be retrieved.

Using Spectral Polishing

Polishing is a term used by Boardman (1998) for a linear renormalization method that reduces spectral artifacts in hyperspectral data using only the data itself. The basic assumptions are as follows:

- The artifacts may be removed by applying a uniform linear transformation (that is, channel-dependent gain factors and offsets) to the spectra.
- Spectrally smooth reference pixels (for example, soil or pavement) can be found within the scene from which the transformation can be derived.
- The true spectra of the reference pixels can be approximated by applying a spectral smoothing operation.

The gains and offsets are generated from the reference pixels by performing a linear fit of the smoothed spectra to the original spectra. Boardman's original algorithm, which smooths by Legendre polynomial fitting, is found in the ENVI main menu bar under **Spectral** → **EFFORT Polishing**.

The FLAASH polishing algorithm yields similar results with less input data. The smoothing is performed with a running average over n adjacent channels (where n is defined as the polishing width). Spectrum endpoint and missing-channel complications are limited if only a modest amount of smoothing is desired (n is low). For example, a polishing width of 2 is

useful for removing residual sawtooth noise caused by a dark current offset between odd-numbered and even-numbered channels, as seen in early AVIRIS data. A wider polishing width (for example, 5 to 11) is better for removing larger-scale artifacts such as atmospheric absorption band residuals.

1. Click the **Spectral Polishing** toggle button to select one of the following options:
 - **Yes:** Spectrally polish the reflectance image.
 - **No:** Output the unaltered modeled reflectance.
2. In the **Width (number of bands)** field, enter the width of the smoothing window to be used in the FLAASH spectral polishing algorithm.

The reference pixels are selected as follows:

1. For each pixel, a smoothed spectrum is calculated.
2. The difference between the smoothed spectrum and the unsmoothed spectrum is calculated for each measured wavelength.
3. The RMS of the smoothed-unsmoothed difference at each wavelength is calculated, and normalized by dividing by the mean reflectance over all wavelengths for the pixel.
4. The pixels with the lowest ten percent of normalized RMS differences are selected from among the cloud-free, non-blank, and non-vegetated pixels.
5. The normalized RMS differences for the selected pixels are histogrammed and the pixels that fall into the lower half of the histogram are selected to be reference pixels for the calculation of the gain factor. This eliminates artifacts often found using EFFORT with a vegetated scene.
6. The gain factor for the linear transformation is computed as the ratio of the RMS smoothed to RMS un-smoothed spectrum for these pixels. There is no offset in the transformation. For this reason, very dark pixels such as water are essentially unaffected by the FLAASH polishing.

A larger number generates more smoothing. A value of 9 is recommended for typical 10 nm-resolution hyperspectral sensors (such as AVIRIS). A value of 2 provides minimal smoothing but removes odd-even spectral band imbalances. Odd polishing widths are slightly more computationally efficient. Spectral polishing requires hyperspectral input data, and is therefore disabled when a multispectral sensor type is selected.

Recalibrating the Input Wavelengths

An accurate wavelength calibration is critical for atmospherically correcting hyperspectral data. Even slight errors in the locations of the band center wavelengths can introduce significant errors into the water retrieval process, and reduce the overall accuracy of the modeled surface reflectance results. To minimize such errors, FLAASH includes a method for identifying and correcting wavelength miscalibrations.

Click the **Wavelength Recalibration** toggle button to select one of the following options:

- **Yes:** Automatically adjust the wavelength calibration prior to computing the water retrieval.
- **No:** Use the input file's wavelengths.

AVIRIS, HYDICE, HYMAP, HYPERION, CASI, and AISA sensors are automatically supported for wavelength recalibration. All other hyperspectral sensors require a spectrograph definition file (see the “[Selecting a Spectrograph Definition File](#)” on page 31 for more details).

When a wavelength recalibration is performed, an additional output file is created which summarizes the results. The output file is saved to the FLAASH output directory and named *rootname + wl_recalibration.txt*. In addition, a message summarizing each spectrograph's wavelength correction is written in the journal file under the heading “Determined Wavelength Shift Using NODD Algorithm.” One shift and variance value exist for each spectrograph. The shift value indicates the average wavelength shift in channels, as computed from a number of pixels near the centerline of the image; the variance value indicates the uncertainty in the shift determination. In some cases, both the shift and variance are zero. This can occur when wavelength calibration errors are not present, or when no absorption feature is available within the spectral range of the spectrograph, preventing a wavelength correction from being performed. The FLAASH reflectance output file contains the new wavelength assignments.

If you find that the corrected wavelengths are an improvement after the FLAASH processing is complete, you may want to apply them to the original input radiance image. To do this, select **File** → **Edit ENVI Header** → **Edit Attributes** → **Wavelengths** from the ENVI main menu bar. You can automatically import the new wavelengths using the FLAASH output file called *rootname + wl_recalibration.txt*. If you choose to do this, then any further processing of the radiance file in FLAASH should be done with the **Wavelength Recalibration** toggle button set to **No**, which speeds processing time.

For algorithm details, see the following reference:

Felde, G. W., G. P. Anderson, S. M. Adler-Golden, M. W. Matthew, and A. Berk, 2003. *Analysis of Hyperion Data with the FLAASH Atmospheric Correction Algorithm*. Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery IX. SPIE Aerosense Conference, Orlando. 21-25 April 2003.

Hyperspectral Settings

The **Hyperspectral Settings** button appears at the bottom of the FLAASH Atmospheric Correction Model Input Parameters dialog when you select a hyperspectral sensor from the **Sensor Type** button menu. This option allows you to choose how bands are selected for water vapor and/or aerosol retrieval.

Note

If the input data is from a named hyperspectral sensor (listed under the **Sensor Type** button menu on the FLAASH Atmospheric Corrections Model Input Parameters dialog), and neither water nor aerosol is being retrieved, it is unnecessary to check the hyperspectral settings before applying FLAASH.

Click **Hyperspectral Settings**. The Hyperspectral Settings dialog appears. Select one of the following options:

- **File**: Specify a channel definition file. Click **Channel Definition File**, navigate to the desired channel definition file, and select the file. The correct format for a channel definitions file is described in “[Hyperspectral Channel Definitions File](#)” on page 27.

- **Automatic Selection:** FLAASH automatically selects the channel definitions. Channel definitions are automatically assigned by FLAASH based on the spectral characteristics of the data. This is the default setting and is recommended.

Hyperspectral Channel Definitions File

The channel definition file follows a simple format where each line contains one channel definition in the form:

```
channel_type = band_number
```

The valid channel_types are listed below, and must be included in the file verbatim:

```
water channels reference
water channels absorption
cirrus channel
KT upper channels
KT lower channels
alternate water channels absorption
alternate water channels reference
```

The alternate water channels are used in case the selected water channels are saturated.

The first band in the file is referred to as band number 1. If more than one band is appropriate for a channel_type, the bands should be enclosed in curly brackets {} and separated with white space. Comments can be included as long as they are preceded with a semi-colon character. You only need to include channel definitions for those processing steps that are being requested.

The following text is an example channel definition file for an AVIRIS sensor:

```
; Standard AVIRIS channels
; Channels are counted starting at 1.

water channels reference = {73 74 75 87 88 89} ; wings must be
; symmetric on absorption center channel
water channels absorption = {80 81 82} ; absorption band
cirrus channel = 109 ; no {} needed for single number

; optional channels. Can leave these out, but will lose some
; functionality. KT is needed for automatic visibility
; determination.
; Kaufman-Tanre method channels
KT upper channels = { 184 185 186 187 188 }
KT lower channels = { 29 30 31 32 33 34 }

alternate water channels absorption = { 49 50 } ; 0.82 micron band
alternate water channels reference = { 44 45 54 55 }
```

FLAASH produces a channel definition file for each processing run (both multispectral and hyperspectral). The file, named *rootname_channel_definition.txt*, is saved when the **Output Diagnostic Files** option is set to **Yes** in the FLAASH Advanced Settings dialog.

Multispectral Settings

The **Multispectral Settings** button appears at the bottom of the FLAASH Atmospheric Correction Model Input Parameters dialog when you select a multispectral sensor from the **Sensor Type** button menu. When applying the FLAASH atmospheric correction model to a

multispectral dataset, it is critical to properly choose the bands that are used for water vapor and/or aerosol retrieval. In addition, if the input data is from an unknown multispectral sensor, it is necessary to define the sensor's spectral response functions.

1. Use the FLAASH Multispectral Settings dialog to define the bands for water vapor and aerosol retrieval.

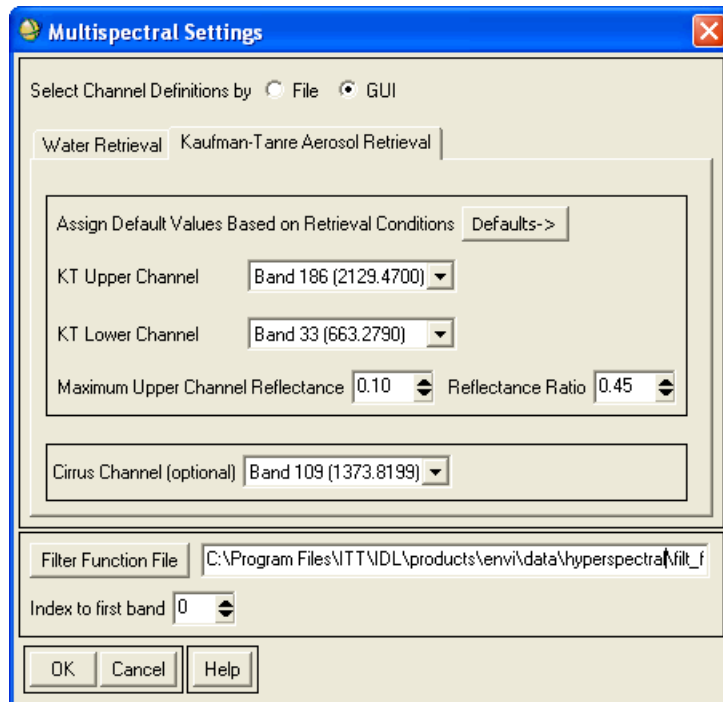


Figure 2-3: Multispectral Settings Dialog

Note

If the input data is from a named multispectral sensor (listed under the **Sensor Type** button menu on the FLAASH Atmospheric Corrections Model Input Parameters dialog), and neither water nor aerosol is being retrieved, it is unnecessary to check the multispectral settings before applying FLAASH.

The channel definitions are used to assign bands from the input file for use in the water and aerosol retrieval process. If a FLAASH template file was restored before opening the Multispectral Settings dialog, then the channel definitions are set according to the information saved in the template file. Otherwise, FLAASH selects default bands according to pre-defined wavelength ranges (defined below). If bands within the pre-defined ranges are not available, then the channel is left undefined.

2. Click **Multispectral Settings**. The Multispectral Settings dialog appears. Select from the following options:
 - **File**: Specify a channel definition file. Click **Channel Definition File**, navigate to the desired channel definition file, and select the file. The correct format for a

channel definitions file is described in “[Multispectral Channel Definitions File](#)” on page 30.

- **GUI:** Interactively select the channels using the Multispectral Settings dialog:
 - Select either the **Water Retrieval** or the **Kaufman-Tanre Aerosol Retrieval** tabs to choose the retrieval category (water or aerosol).
- A. Within each active retrieval category, use the drop-down lists to select the desired band.
- B. In the **Kaufman-Tanre Aerosol Retrieval** tab, set the **Maximum Upper Channel Reflectance** and the **Reflectance Ratio** values. These settings identify dark pixels used for the visibility estimate. Recommended values are assigned automatically by choosing one of the options under the **Defaults** drop-down list. For more information about the Aerosol Retrieval algorithm and these settings, see “[The FLAASH Model](#)” on page 10 or the following reference:

Y. J. Kaufman, A. E. Wald, L. A. Remer, B.-C. Gao, R.-R. Li, and L. Flynn, 1997. *The MODIS 2.1- μ m Channel-Correlation with Visible Reflectance for Use in Remote Sensing of Aerosol*. IEEE Transactions on Geoscience and Remote Sensing. Vol. 35, pp. 1286-1298.

Note

If you are using the Over-Water Retrieval default settings, the KT Upper and Lower bands are reversed. This is done by design. Applying a maximum reflectance threshold to the 880 nm band tends to better discriminate clear water from turbid or wet areas, leading to more accurate visibility retrievals.

You only need to define channels for the processing that is being requested. For example, if you are requesting an aerosol retrieval, but not a water retrieval, then you may leave the water channels undefined, but both the KT Upper and KT Lower channels have to be defined.

The recommended wavelength ranges for each channel are as follows:

Water Retrieval	1135 nm	absorption	1117 - 1143 nm
		reference upper wing	1184 - 1210 nm
		reference lower wing	1050 - 1067 nm
	940 nm	absorption	935 - 955 nm
		reference upper wing	870 - 890 nm
		reference lower wing	995 - 1020 nm
	820 nm	absorption	810 - 830 nm
		reference upper wing	850 - 870 nm
		reference lower wing	770 - 790 nm

Table 2-4: Recommended Wavelengths for Channel Definitions

Aerosol Retrieval	KT upper	2100 - 2250 nm
	KT lower	640 - 680 nm
Cloud Masking	cirrus clouds	1367 - 1383 nm

Table 2-4: Recommended Wavelengths for Channel Definitions (Continued)

- C. If the input image is from an unknown multispectral sensor type, the sensor's spectral response functions must be defined using a filter function file. Click **Filter Function File** and select the multispectral sensor's filter function file. The filter function file must be an ENVI spectral library format file, and contain the sensor's filter functions consecutively, one for each band in the sensor. However, the filter function for the sensor's first band need not be the first function in the file.
- D. In the **Index to first band** field, enter the index into the filter function file (beginning at zero) where the sensor's filter functions begin.

Note

When using a known multispectral sensor (i.e., one whose name is listed under the **Sensor Type** button menu), the filter function file and index are automatically set properly to use the filter function files included in the ENVI distribution.

Multispectral Channel Definitions File

The channel definition file follows a simple format where each line contains one channel definition in the form:

```
channel_type = band_number
```

The valid `channel_types` are listed below, and must be included in the file verbatim:

```
water channels reference
water channels absorption
cirrus channel
KT upper channels
KT lower channels
KT band cutoff
KT band ratio
```

The first band in the file is referred to as band number 1. If more than one band is appropriate for a `channel_type`, the bands should be enclosed in curly brackets `{ }` and separated with white space. Comments can be included as long as they are preceded with a semi-colon character. You only need to include channel definitions for those processing steps that are being requested. For example, a channel definition file for applying FLAASH to Landsat TM with aerosol retrieval but a fixed water vapor amount could include the following text:

```
; FLAASH channel definition for Landsat TM
KT upper channels = 6
KT lower channels = 3
```

FLAASH produces a channel definition file for each processing run (both multispectral and hyperspectral). The file, named `rootname_channel_definition.txt`, is saved when the **Output Diagnostic Files** option is set to **Yes** in the FLAASH Advanced Settings dialog.

FLAASH Advanced Settings

The FLAASH advanced settings are arranged into three categories: modeling parameters, viewing geometry, and FLAASH processing controls. Use the Advanced Settings dialog to modify the defaults, enter additional data, or to make changes to previous settings.

To access the advanced settings, click **Advanced Settings** in the lower-right corner of the FLAASH Atmospheric Correction Model Input Parameters dialog. The FLAASH Advanced Settings dialog appears.

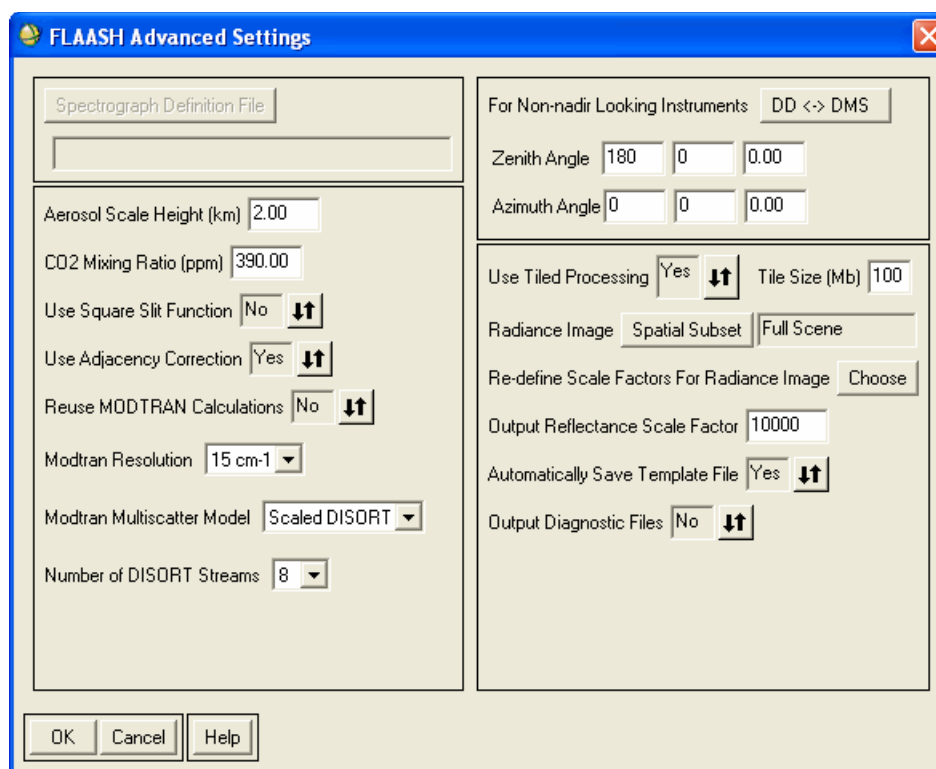


Figure 2-4: FLAASH Advanced Settings Dialog

Selecting a Spectrograph Definition File

The spectrograph definition file is used to assign the spectral features that are used to correct the wavelength calibration for hyperspectral input images. FLAASH includes built-in spectrograph definitions for the AVIRIS, HYMAP, HYDICE, HYPERION, CASI, and AISA sensors. If the input image is from another hyperspectral sensor, or you wish to customize the built-in spectrograph definitions you must provide your own spectrograph definition file.

To select a file, click **Spectrograph Definition File** and navigate to the file on disk.

The Spectrograph Definition file is an ASCII text file which contains one line for each spectrometer in the sensor. Each spectrometer's line contains the following information:

- The wavelength (in nanometers) of the reference absorption feature being used to correct the wavelength calibration. If no reliable absorption feature is contained within the span of the spectrometer, then no correction can be made and this value should be set to zero.
- The full-width half-maximum (FWHM) factor for the reference absorption feature. A wavelength span equal to:

$$4 * (\text{FWHM factor}) * (\text{mean FWHM})$$

on each side of the reference absorption feature is used to find the bands needed for identifying the feature. The exact value of the FWHM factor is not critical for a successful wavelength recalibration. Values between 0.5 and 1.5 tend to work well for hyperspectral sensors with critical sampling (where the FWHM is approximately equal to the band spacing). If no reference absorption feature exists for the spectrometer, then set this factor to zero.

- The first band number in the spectrometer relative to the first band in the sensor (starting at band number 1).
- The last band number in the spectrometer relative to the first band in the sensor.

The required format of the file is illustrated in the following example, which depicts the default Spectrograph Definition File for the AVIRIS sensor:

```
; FLAASH spectrograph definition for AVIRIS
spectrograph = {0., 0., 1, 32}
spectrograph = {760.17, 0.6, 33, 96}
spectrograph = {0., 0., 97, 160}
spectrograph = {2058.7, 1.5, 161, 224}
```

The first line in the file is a comment (comments can be placed anywhere in the file, but must be preceded with the semi-colon character). Each of the next four lines contain a spectrograph definition for one of the AVIRIS instrument's four spectrometers.

The first spectrometer contains instrument bands 1-32, but does not span any known absorption feature that can be used to recalibrate the wavelengths (so the first 2 values are set to zero). The second spectrometer contains instrument bands 33-96, and the oxygen feature at 760.17 nm is used as the reference absorption feature, with a FWHM factor of 0.6. The third spectrometer contains instrument bands 97-160, but does not contain any reliable features. The fourth spectrometer contains bands 161-224, and the CO₂ feature at 2058.7 nm is used, also with a FWHM factor of 1.5.

Note

For CASI and AISA, the built-in spectrograph definition file assumes that the collected bands span the 760 nm oxygen feature.

Setting Modeling Parameters

Set the following modeling parameters:

1. In the **Aerosol Scale Height (km)** field, enter the effective $1/e$ height of the aerosol vertical profile in km. Typical values are 1 to 2 km. The default value is 1.5 km.

Note

The aerosol scale height is used only for the calculation of the adjacency scattering range.

2. In the **CO₂ Mixing Ratio (ppm)** field, enter the carbon dioxide (CO₂) mixing ratio in parts per million by volume. In 2001, the value was approximately 370 ppm. For best results, add 20 ppm to the actual value.
3. Click the **Use Square Slit Function** toggle button to select **Yes** for images that were derived by averaging together adjacent bands (for example, LASH). This better models the spectral response of the derived bands.
4. Click the **Use Adjacency Correction** toggle button to specify whether or not to use adjacency correction. Unlike most atmospheric correction models, the FLAASH model accounts for both the radiance that is reflected from the surface that travels directly into the sensor and the radiance from the surface that is scattered by the atmosphere into the sensor. The distinction between the two accounts for the adjacency effect (spatial mixing of radiance among nearby pixels) caused by atmospheric scattering. More accurate reflectance retrievals result when adjacency is enabled; however, there may be occasions when it is desirable to ignore this effect. Turning adjacency correction off sets $\rho_e = \rho$ in Equation (1) (see “[The FLAASH Model](#)” on page 10 for more information).
5. Click the **Reuse MODTRAN Calculations** toggle button to specify whether or not to reuse previous MODTRAN calculations. Reusing previous MODTRAN calculations is useful for rapidly processing multiple images taken under essentially identical conditions; the identical illumination, viewing geometries, and visibility are assumed, but the water vapor retrieval is performed again. It is also useful for rapidly generating images with and without polishing, or with different polishing widths. Following is an explanation of the options:

No: FLAASH computes a new set of MODTRAN radiative transfer calculations for the selected image and model parameters

Yes: FLAASH performs the atmospheric correction using the MODTRAN calculations from the *previous* FLAASH run. This change causes FLAASH to perform a water retrieval; therefore, the **Water Retrieval** toggle button on the main FLAASH Input Parameters dialog is automatically set to **Yes**. You cannot reset **Water Retrieval** to **No** until you set **Reuse MODTRAN Calculations** to **No**.

Following each FLAASH run, the MODTRAN calculations are stored in a file called `acc_modroot fla`, and a copy is saved in both the FLAASH output directory as well as in ENVI’s temporary directory (defined in the ENVI preferences file). If you set **Reuse MODTRAN Calculations** to **Yes**, ENVI first looks in the current FLAASH output directory for the `acc_modroot fla` file. If the file is present, it is used. Otherwise, ENVI uses the copy that is in the temporary directory. Therefore, you can force FLAASH to use the MODTRAN calculations from any previous run by copying the desired `acc_modroot fla` from the desired run into the FLAASH output directory for the current run.

6. In the **Modtran Resolution** drop-down list, select a resolution. The **Modtran Resolution** setting controls the MODTRAN spectral resolution and the trade-off of speed versus accuracy for the MODTRAN4 portion of the calculation. Lower

resolution yields proportionally better speed but less accuracy. The main differences in accuracy are seen near 2000 nm and beyond. The 5 cm^{-1} resolution is the default value when you select a hyperspectral sensor as input, but it changes to 15 cm^{-1} when you select a multispectral sensor. If aerosol is being retrieved, there are two MODTRAN4 runs performed at 15 cm^{-1} resolution followed by one MODTRAN4 run at the resolution you select. If aerosols are not being retrieved, the first two runs are omitted.

7. In the **Modtran Multiscatter Model** drop-down list, select a multiple-scattering algorithm to be used by MODTRAN4. FLAASH offers three options for multiscatter models: **Isaacs**, **Scaled DISORT**, and **DISORT**. The default is **Scaled DISORT** with eight streams.

The DISORT model provides the most accurate short-wave (less than $\sim 1000\text{ nm}$) corrections, however it is very computationally intensive. The Isaacs 2-stream method is fast but oversimplified. The Scaled DISORT method provides near-DISORT accuracy with almost the same speed as Isaacs. In the Scaled DISORT model, DISORT and Isaacs calculations are performed at a small number of atmospheric window wavelengths. The multiple scattering contributions in each method are identified and ratios of the DISORT and Isaacs methods are computed. This ratio is interpolated over the full wavelength range, and finally, applied as a multiple scattering scale factor in a spectral radiance calculation performed with the Isaacs method. This procedure yields near-DISORT accuracy at window wavelengths, and also improves the accuracy in absorbing regions.

8. If you select **DISORT** or **Scaled DISORT** as the multiscatter model, specify the number of streams: 2, 4, 8, or 16. The number of streams is related to the number of scattering directions evaluated by the model. Calculations with two or four streams are not recommended, as they dramatically increase computation time (over **Isaacs**) with little or no improvement. Increasing the number of streams for the Scaled DISORT model should not significantly increase processing time.

Use of the DISORT multiscatter model dramatically increases FLAASH processing time, and is rarely necessary for accurate atmospheric corrections. The magnitude of multiple scattering in any scene is dependent on the amount of haze (water vapor and aerosols) that are present. Moreover, scattering preferentially affects the shorter (visible) wavelengths; longer (near infrared) wavelengths are minimally affected. You should only consider using the DISORT model in the most severe cases, when haze is very strong and critical correction of the shortest wavelengths is required. Computation times vary with system resources, but typical relative computation times are:

Isaacs: DISORT-2: DISORT-4: DISORT-8: DISORT-16 = 1: 22: 24: 30: 60

That is, running DISORT with 8 streams usually takes about 30 times longer than using Isaacs. In addition, a combination of DISORT (with any number of streams) and a MODTRAN resolution of 1 cm^{-1} is extremely computationally intensive.

References

- K. Stamnes, S.-C. Tsay, W. Wiscombe, and K. Jayaweera. *Numerically Stable Algorithm for Discrete-Ordinate-Method Radiative Transfer in Multiple Scattering and Emitting Layered Media*. Applied Optics. Vol. 27. 1988. pp. 2502-2509.
- R. G Isaacs, W. C. Wang, R. D. Worsham, and S. Goldenberg. *Multiple Scattering LOWTRAN and FASCODE Models*. Applied Optics. Vol. 26. 1987. pp. 1272-1281.

Setting Viewing Geometry Parameters

For instruments that use a non-nadir viewing geometry, you must specify the zenith and azimuth angles. The zenith angle is defined *at the sensor* as the angle between the line of sight and the zenith (180 for nadir-viewing sensors). Zenith angles must be positive and between 90 and 180 degrees. The azimuth angle is defined as the azimuth (the angle between the line of sight and due North) of the sensor as viewed from the ground. This angle is arbitrary for nadir-viewing sensors. Azimuth values must be between -180 and 180 degrees. For example, if your azimuth from the sensor is 90 degrees (due east), then the azimuth from the ground is -90 degrees (due west).

In the **Zenith Angle** and **Azimuth Angle** fields, enter the correct angles.

Note

To toggle between degrees/minutes/seconds and decimal degrees, click the **DD <-> DMS** button.

Setting FLAASH Processing Controls

Set the following parameters for processing:

1. Click the **Use Tiled Processing** toggle button to specify whether or not to use tiled processing. Like all ENVI processing routines, FLAASH processes the input data in pieces (called tiles), then reassembles the tiles after processing is complete to produce the final result. Using tiled processing allows FLAASH to run on images of any size, regardless of system resources (that is, available memory).

The default setting in FLAASH is to use tiled processing (**Yes**). Tiled processing is highly recommended; however, some cases occur when FLAASH runs faster without tiling.

If you select **Yes**, then enter a value (in megabytes) in the **Tile Size** field. The default tile size is set to the larger of your ENVI Preferences Cache Size or 100 MB. When processing, FLAASH ensures that the largest piece of the image that is read into memory at any time never exceeds the tile size. It is recommended that the tile size be set to the largest value that does not leave the rest of the computer system deprived of memory for essential functions. For single user machines, a reasonable estimate is about 75% of the installed RAM.

Large datasets that contain many pixels with values of 0 (such as a projected Landsat scene) may cause the FLAASH process to fail because the tile can return all “0” pixels. An error message may appear in a popup window and in the file `journal.txt` that is created in the output file directory specified in the FLAASH Atmospheric Corrections Model Input Parameters dialog.

To work around this problem, increase (or even *double*) the **Tile Size** value so that each tile contains some image data.

2. Click **Spatial Subset** to re-define the spatial subset you selected during original input file selection. You can also use the information displayed in the **Spatial Subset** field to verify the spatial subset that was defined when the input image was selected.

3. Click **Choose** to re-define the scale factors you selected during the original input file selection. When the Radiance Scale Factors dialog appears, select a scale factor method (see [“Specifying Input and Output File Information”](#) on page 17 for details).
4. In the **Output Reflectance Scale Factor** field, enter the value used to scale the output reflectance image from floating-point into 2-byte integer data space.

Signed integers have an absolute data range between -32768 and +32767. The recommended scale factor is 10,000. This value is stored as the Reflectance Scale Factor Attribute in the header file of the output image.

5. Click the **Automatically Save Template File** toggle button to specify if you want to automatically save FLAASH parameters to a template file in the FLAASH output directory. For details about template files, see [“Saving and Restoring FLAASH Run Parameters \(Templates\)”](#) on page 38. The filename is `template.txt` appended to your defined root name.

Tip

It is recommended you leave this setting at **Yes** (default), as it can be helpful to retain a copy of each run’s parameters for later reference.

6. Click the **Output Diagnostic Files** toggle button to specify whether or not to create intermediate data files, including the channel definition files used for both hyperspectral and multispectral corrections. The intermediate files can be helpful in diagnosing runtime problems.

It is recommended you leave this setting at **No** (the default) unless instructed otherwise, or if you want to see the channel definition file used by FLAASH.

Starting the Processing

When all FLAASH parameters are set, click **Apply** in the FLAASH Atmospheric Model Input Parameters dialog to begin processing.

Saving and Restoring FLAASH Run Parameters (Templates)

You can save a complete set of FLAASH run parameters, including input and output file names, to a template file. You can then use the FLAASH template to restore the run settings at a later date. This can be quite useful for quickly re-defining the model settings, or for checking to see how the parameters were set in a previous run. For convenience, the template file is in an ASCII format, so it can easily be read outside of ENVI using any text editor. Template files can also be used to share FLAASH run details with colleagues who also have FLAASH; just send the template file to them to restore.

Saving the Template

To save the FLAASH run settings to a template file at any time, click **Save** in the lower-right corner of the FLAASH Atmospheric Model Input Parameters dialog.

If you set the **Automatically Save Template File** toggle button to **Yes** in the FLAASH Advanced Settings dialog, a template file is automatically saved into the FLAASH output directory when you click **Apply** in the FLAASH Atmospheric Model Input Parameters dialog.

Restoring a Template File

To restore a FLAASH template file, click **Restore** in the lower-right corner of the FLAASH Atmospheric Model Input Parameters dialog.

The template file stores the full path names of the input and output files (that is, the file names include the directory names). If the input file is not already opened in the current ENVI session, it is automatically opened. If any of the files or directories cannot be located on the computer where FLAASH is running, the corresponding fields in the FLAASH dialogs will not be filled in, but ENVI reads the rest of the parameters. This process allows template files to be shared between users working in different locations.

FLAASH Output Files

The FLAASH atmospheric correction model produces the output files described in the following sections.

Surface Reflectance

FLAASH creates an image of retrieved surface reflectance, scaled into two-byte signed integers using the scale factor defined in the FLAASH Advanced Settings dialog. (To set the scale factor, see “[Setting FLAASH Processing Controls](#)” on page 35.) The name and location for this output file is defined in the FLAASH Atmospheric Correction Model Input Parameters dialog, in the **Output Reflectance File** field. The reflectance image bad bands are set according to the bad bands defined for the input radiance image, as well as those for which the atmospheric transmission, as determined by FLAASH, is too low for an accurate reflectance calculation.

Water Vapor

FLAASH creates an image of retrieved column water vapor in units of (atm • cm). This file is written to the FLAASH output directory with the name `water.dat` appended to your specified root name.

Cloud Map

FLAASH creates a cloud map classification image is written to the FLAASH output directory with the name `cloudmask.dat` appended to your specified root name. The cloud determinations are used during FLAASH processing to refine the estimate of ρ_e in equation (1). This quantity defines the magnitude of the adjacency effect.

Log File

The log file is an ASCII file containing a detailed description of the FLAASH processing. This file is written to the FLAASH output directory with the name `journal.txt` appended to your specified root name.

FLAASH Template File (Optional)

If you set the **Automatically Save Template File** toggle button to **Yes** in the FLAASH Advanced Settings dialog, a template file is automatically saved into the FLAASH output directory when you click **Apply** in the FLAASH Atmospheric Model Input Parameters dialog. The name `template.txt` is appended to your specified root name.



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