Report of a Workshop on "High Resolution Climate Modeling"

10-14 August 2009

Abdus Salam International Centre for Theoretical Physics (ICTP)

Trieste, Italy

Executive Summary

An International Workshop on "High Resolution Climate Modeling" was held on 10-14 August 2009 at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy. The workshop was cosponsored by National Aeronautics and Space Administration (NASA) Global Modeling and Assimilation Office (GMAO) and the Center for Ocean-Land-Atmosphere Studies (COLA). Financial support was provided by the GMAO and ICTP. The workshop was organized by In-Sik Kang, F. Kucharski, S. Schubert, and J. Shukla. The workshop consisted of invited speakers, posters, and panel discussions. The total attendance was 95, with 30 invited speakers.

In the following we provide a summary report of the workshop. This includes summaries of the workshop goals, highlights of the presentations and discussions, progress by the various groups on carrying out high resolution climate simulations, and most importantly, a set of recommendations for advancing high resolution modeling for weather and climate applications. In brief, it is recommended that:

1) existing high-resolution climate model simulations be summarized, and efforts be made to make subsets of the output available to the general community;

2) the community coordinate on carrying out and analyzing high resolution climate model simulations with a focus on demonstrating an ability to reproduce recent tropical storm activity;

3) as an extension of the Year of Tropical Convection (YOTC) project, a limited number of global simulations be carried out at very high resolution (at order 4km) for a full season to demonstrate the impact of enhanced resolution on the monsoon, the MJO, and other subseasonal variability during 2008/2009;

4) key people from the global and meso-scale modeling communities get together for a workshop to discuss lessons learned and possibilities for future collaboration.

Additional recommendations and further details are provided in the body of the report.

Organization

The report is organized as follows:

All the presentations are available at: http://gmao.gsfc.nasa.gov/pubs/docs/Schubert404.pdf

A. Background and Goals

The workshop brought together some of the key scientists and students involved in high resolution modeling and provided a forum for exchanging their experiences and their results, and for discussing the future direction of climate modeling, particularly for high impact weather and climate events.

A specific focus of the workshop was on the simulation of tropical storms in global high-resolution climate models. This is at a time when the climate science community is being asked to explain unprecedented tropical storm activity yet our understanding of how such events are affected by global warming, or decadal variability, or whether they are just an expression of the tails of the distribution of statistically stationary weather variability, is at best incomplete. It is fortunately also a time when our computational capabilities are reaching a level that will allow us to begin running our climate models at weather-resolving scales so that we can simulate the climate-weather linkages that are fundamental to answering these basic questions about long term changes in tropical storm behavior.

'The specific goals of the workshop were to:

1. To report the most up-to-date understandings in the scientific community on the high resolution climate models and to discuss the future direction of climate modeling for prediction of high impact weather and climate events and for the changes of those events in the 21st century associated with global warming.
2. To identify how SST controls tropical storm activity on interannual and longer time scales, and the potential modulation of that activity by the MJO on subseasonal time scales, as well as the sensitivity of the results to model formulation.
3. To identify the major problems that those climate models have in simulating the tropical cyclones and MJO and to discuss the possible solutions to overcome those problems.

4. To discuss ways of sharing the high-cost simulation data sets from high-resolution models of various institutions not only among the scientists generating the data but also with the scientists from developing countries.

The workshop also provided an opportunity to assess progress and make further plans on an international effort to carry out coordinated high resolution simulations of tropical storms and the impacts of sea surface temperature (SST) anomalies and the Madden Julian Oscillation (MJO). This effort (initiated by the NASA co-organizer of this workshop, Dr. Siegfried Schubert), entitled "High Resolution Climate Model Simulations of Recent Hurricane and Typhoon Activity: The Impact of SST and the Madden Julian Oscillation" has been endorsed by the World Climate Research Program, Climate Variability Programme (CLIVAR) in recognition of the importance of high resolution modeling, particularly in high impact weather events and tropical cyclones. The workshop also builds on a US workshop sponsored by NASA and held at the Center for Ocean-Land-Atmosphere Studies (COLA) in August of 2007 to assess progress and outstanding issues for high resolution climate modeling of tropical storms.

B. Workshop Presentations and Discussion

Monday, August 10

J. Shukla gave an introduction to the workshop by reviewing the goals of the workshop and stressing the importance of resolution in achieving improved weather and climate simulations. **Fred Kucharski** addressed some of the workshop logistics and welcomed the group to Trieste and the ICTP.

Masaki Satoh gave an overview of the NICAM model and recent global experiments run at cloud-resolving scales on the Earth Simulator. A number of seasonal and shorter runs (resolution ranges from 3.5 to 14km) have been carried out and results were presented showing successful simulations of the MJO (including embedded meso-scale features and multi-scale interactions), typhoon/cyclone genesis and the impact of the MJO, Asian summer monsoon variability, diurnal precipitation variations, and cloud properties (including ice). The talk concluded with an overview of future developments including advances in the cloud microphysics scheme, aerosol interaction, and coupling to the ocean.

Next, **Tim Palmer** addressed the issue of how to assess the reliability of precipitation simulations of climate change. The question was posed of whether 20th Century SI information about where the model is most unreliable can be used to "predict" where the 21st Century model climate change signal is most inaccurate. He suggested and provided evidence that there exists a sequence of links that connect various components of the system that are necessary for a seamless prediction of climate change. He concluded that there is an urgent need for more substantial assessments of the impact of resolution in time-slice mode on the climate-change signal for weather-related variables, and to determine at what resolution there is "convergence" of the synoptic-scale climate-change signal.

Kerry Emanuel discussed high resolution modeling of the response of tropical storms to climate change. He pointed out that current global models and even regional models are too coarse to simulate high intensity (category 4 and 5) tropical cyclones (TCs). He further noted that since most of the storm damage is caused by the high intensity storms, current models do not simulate those storms most relevant to society. He described an alternative technique for downscaling in which they drive a simple but very high resolution, coupled ocean-atmosphere TC model using boundary conditions supplied by the global model or reanalysis data set. The model shows high skill in capturing spatial and seasonal variability of TCs, has an excellent intensity spectrum, and captures the impacts of well known climate phenomena such as ENSO and the effects of warming over the past few decades.

Shian-Jiann Lin talked about recent advances in tropical cyclone simulations with GFDL's prototype global cloud-resolving model (HIRAM). He described HIRAM, and presented results of ultra-high resolution (100m-1 km) adiabatic simulations on an idealized very small planet, results from 50km and 25km simulations of recent (1981-

2005) tropical cyclone characteristics, and results of deterministic forecasts at 25 km and 13km resolutions. At 50km, the model does well in simulating the climatology of tropical storm tracks, as well as the interannual variability of storm counts in the various ocean basins. The model also performed very well in hindcasting several hurricanes (Katrina, Wilma, and Ike). Ongoing and future work includes, running C360 (25km) IPCC AR5 time slice experiments, coupling to the ocean, running global "cloud-resolving" mulit-year simulations at C2000 (4-5km), and preparing the model to run globally at 1-km.

Bill Putman presented results from high-resolution simulations with experimental versions of the GEOS-5 model that includes a non-hydrostatic, cubed sphere, finite volume dynamical core. Simulations were done at horizontal resolutions ranging from approximately 55km to 1.7 km (with some runs done both with and without parameterized convection). Various results were presented on efforts to improve the scaling of the model with the goal of running efficiently on massively-parallel (10^4-10^5 processors) peta-flop computers . Results were shown on the impact of high resolution on resolving such features as Pacific marine stratus, cloud streets in the North Atlantic associated with cold air outbreaks, the Saharan air layer, tropical storms, and the overall kinetic energy spectrum.

In-Sik Kang discussed the need for improvements in the parameterization of moist physics in high-resolution atmospheric models with a focus on horizontal resolutions of the order 10km at which cumulus parameterizations are still needed, but current schemes developed for coarser resolutions are not appropriate. The talk outlined an approach consisting of a bulk cumulus model and PDF-based turbulence ensemble cloud scheme and semi-explicit cloud microphysics, and the need to take advantage of cloud resolving models to develop the appropriate statistics.

Dave Randall presented an overview of the design and testing of a global cloud-resolving model. He outlined current approaches to achieving high resolution including non-hydrostatic GCMs (developed with cyclone-scale physics), a multi-scale modeling framework (MMF), and global cloud resolving models (GCRMs). In designing a GCRM, he presented the advantages of developing the governing equations in terms of the unified system (e.g., in filtering sound waves, accuracy, global applicability) and the advantages of the vector vorticity equation (e.g., pressure-gradient force is eliminated, weather systems dominated by vorticity). They are currently working on a non-hydrostatic geodesic dynamical core, with "off the shelf "local" physics, with a second non-hydrostatic geodesic dynamical core nearing completion.

Tuesday, August 11

Mitch Moncrieff talked about organized multi-scale precipitating convection and the global circulation. He noted that the amount and distribution of precipitation is strongly affected by convective organization, and that while we know much about convective organization as a process, we know much less about its large-scale effects, especially, how it is represented in global models. He concluded, however, that the scale-gap of traditional convective parameterization has been bridged, with realistic mesoscale circulations now occurring in explicit models even with 10-km-grids. This is relevant for seamless climate prediction, especially in terms of the distribution of precipitation and the diurnal cycle, and as an important element of the "upscale cascade". The key challenge is representing meso-convective organization in traditional parameterizations.

Wei Kuo Tao 'presented an overview of the Goddard Multi-Scale Modeling System with Unified Physics. The key components consist of the fvGCM and follow-on GEOS GCM, the Goddard Cumulus Ensemble (GCE) Model, the Weather Research Forcast (WRF) Model, and the Land Information System (LIS) model. WRF is used as the center-piece of an integrated modeling of aerosol, cloud, precipitation and land processes at the high resolutions commensurate with satellite observations. The current NASA MMF consists of the GCE (2-D) imbedded in the fvGCM. The MMF is being used to conduct long-term integrations to examine the physical processes associated with the diurnal variation of clouds and precipitation over land, to examine the explicit cloud-aerosol-radiation interactions (using GOCART), and to investigate the flood/drought and hurricane events impacting the continental United States.

Cristiana Stan's presentation (given by Jim Kinter) focused on the representation of cloud processes in the simulation of climate. It was noted that current climate GCMs tend to have common biases including a split ITCZ, excessive precipitation distribution over the Indo-Pacific Warm Pool, unrealistic ENSO, weak ENSO-monsoon connections, and unrealistic MJOs. In addressing the role of increased resolution and improved physics she compared several different versions of the CCSM consisting of a control (T42), a high-resolution version (.47X.63), and an MMF version with an embedded CRM (SP-CSRM). The results showed that, on intra-seasonal time-scales, the SP-CCSM simulates a more realistic MJO with more realistic alternating "active" periods of enhanced convection and "break" periods of reduced convection over the Indian Ocean, and better simulation of the high-frequency stochastic forcing acting at the air-sea interface (e.g., wwb) that produces more realistic ENSO variability. It was concluded that high resolution and explicit representation of cloud processes are both needed.

Wojciech W. Grabowski addressed the question of high-resolution modeling and cloud microphysics: why should we care? The answer is that we should care because of the tight coupling between the cloud microphysics and cloud dynamics, and important effects of cloud microphysics on the atmospheric part of the hydrologic cycle, on radiative processes, on the coupling with the surface, and on cross-tropopause transport. He concluded in particular that cloud microphysics has important but poorly understood effects on cloud system dynamics, and that this impact is most likely the strongest for boundary-layer clouds, which require the highest spatial resolution. The effects on deep convection (and arguably on frontal cloudiness) are unclear. For indirect effects of aerosols on climate, contemporary large-scale climate models (i.e., GCMs with tens of km gridlength) are not appropriate. From the cloud-scale processes point of view, efficient algorithms for aerosol-processing by clouds need to be developed.

Pier Luigi Vidale described the frontiers of UK climate modelling. He noted that current (IPCC AR4) global climate models lack many of the skills required to answer societal needs for predicting climate risks and their attribution at the regional scale. He presented a hierarchy of models (HiGEM (coupled), HadGAM (135km atmos-only), HiGAM, (90km atmos only), NUGAM (60km atmos only), HadGEM3-H (stratosphere), comprising a range of grid spacing in the atmosphere (see above) and ocean (1 1/3° - 1/3°). The results show that cyclones emerge at all scales, but their intensity is sensitive to (increases with) resolution. The coupled model (HiGEM) reveals some interesting scale interactions between 1) TIWs and equatorial Pacific SSTs, which help to support a more realistic ENSO, and 2) ENSO and tropical cyclones. He also notes that their participation in the next IPCC, with the submission of near-term, high-resolution decadal predictions to CMIP5, marks the shift to a new level of collaboration between NERC and the Met Office, under the auspices of the Joint Climate Research Programme (JCRP).

Kazuyoshi Oouchi described the results of a summer seasonal simulation and a global warming experiment with NICAM with a focus on tropical cyclones and multi-scale precipitation events. These runs differ from previous NICAM experiments in that the time range is extended to seasonal length while also exploiting the strength of the global cloud-system resolving (7-km and 14-km mesh) framework. The design of the global warming experiment consists of a run forced with the control-case (2004) SST plus a CMIP3-based ΔSST (future- present). The results of the global warming run show an increased intensity and decreased frequency of tropical storms over the globe, with the decreased frequency occurring preferentially over the Atlantic. Results of the summer (Asian monsoon) simulation show that precipitation variability ranging from diurnal to intraseasonal scales is captured well, particularly over land areas. An Indian Monsoon Index shows encouraging skill of the model in predicting activity of a monsoon cycle (monsoon trough) for about 30 – 40 days, though the model tends to over-predict precipitation over the Indian Ocean.

Tim Miller compared the effects of the RAS and Kain-Fritsch convective schemes on Katrina Forecasts with GEOS-5 run at 0.25° horizontal resolution. The results show that replacement of the RAS convective scheme with the K-F scheme results in a much stronger and compact Katrina, closer to reality by those measures. In terms of maximum wind for example the gap with respect to observed values was closed by 50%. The Kain-Fritsch scheme permits development of an effective secondary circulation, resulting in a well-developed warm-core storm. The suppressed storm development in the RAS case seems to be due to the RAS scheme drying out the boundary layer and lower free troposphere, thus hampering the grid-scale secondary circulation and attending cyclone development. It is noted that further simulations of other tropical cyclones are needed before general conclusions can be made.

Oreste Reale discussed methods for assessing the representation of tropical cyclones in global models. The problem being addressed in this work is the optimal representation of a tropical cyclone at a given model resolution. The idea is to compare the structure of cyclones in a resolution-independent matter to assess the degree of `efficiency' that a model has in representing a tropical cyclone at a given resolution. Key aspects addressed include storm intensity, vertical structure, warm core characteristics, and horizontal compactness (future work includes assessing tropical cyclogenesis and extratropical transitions). Regarding intensity, it was noted that excessively high drag in the marine boundary layer seems to occur in global models when winds exceed 30m/s: the 10m wind is often about 60% of the 850hPa wind (unlike 90% in real world). It was suggested to use 850mb winds instead. Regarding horizontal compactness, a proposed metric is the ratio of radius of maximum wind over the radius of wind greater than the environmental wind of a given threshold, which can be considered the radius of the tropical cyclone (TC) in the model. Results were presented summarizing the various TC features in a number of current global climate and weather models.

Tony Rosati presented an overview of high resolution coupled model activities at GFDL. He noted that the key questions being addressed at GFDL are: 1) What intra-seasonal to decadal predictability exists in the climate system, and what are the mechanisms responsible for that predictability? 2) To what degree is that predictability (and associated climate impacts) dependent on model formulation? 3) Is the identified predictability of societal relevance? He then described the latest versions/resolutions of the GFDL atmospheric and coupled model (CM2.1-CM2.6) that exist or are in development, and gave examples of how they are being used to address variability and predictability on time scales ranging from intraseasonal to decadal. A number of results were shown (e.g., improved MJO, reduced subsurface temperature, SST, and precipitation bias in the latest versions) to support the idea that both higher resolution and improved physics is important for addressing predictability, including that associated with the connections between climate variations and high impact weather phenomena.

HuaLu Pan talked about convection parameterization for the NCEP Weather and Climate model. He noted that parameterization of convection is still needed for the next 5-10 years, and that therefore there is a need to continue to develop and improve the physical basis for coded algorithms determining current performance. These improvements need to perform as well (or better) for both weather and climate models. He gave several examples of recent work (e.g., improvements in the diurnal cycle) and identified key areas that need improvement involving, the convective trigger (+PBL), convective momentum transport, refining the physical basis for closure, better cloud model within the convection scheme, and a mass flux based shallow convection scheme. Furthermore, he emphasized that the approach must be physically-based, noting that CRMs can be useful for specific problems.

Myong-In Lee described the results of a series of simulations of tropical storms with high-resolution (25km and 50km horizontal resolution) versions of the GEOS-5 model. In particular, experiments were conducted to assess the sensitivity of tropical variability to the cumulus parameterization (the Relaxed Arakawa Schubert – RAS) scheme: this was done by gradually decreasing the level of convective adjustment by increasing the relaxation time scale in RAS. The results showed that at resolutions of 25-50 km, the convective parameterization is still required, in that it plays a dominant role in dictating the mean climate and temporal variability. Results were also presented from runs in with RAS was modified to include a new stochastic formulation to determine cumulus entrainment (based on Tokioka 1988). It was shown that this produces improved tropical variability for both tropical storm and subseasonal (MJO) time scales. It also results in improved tropical storm structure (intensity, warm core, compactness). The results of a series of seasonal simulations forced with SST for the years (1997, 1998, 1999, 2004, 2005,2006,2007), indicates that the modified GEOS-5 model (run at 50km horizontal resolution), produces a very realistic annual cycle and interannual variability in Atlantic tropical storm characteristics (e.g., counts, tracks, genesis region), though it does not reproduce the high intensities of category 4 and 5 hurricanes.

Wednesday – August 12

Siegfried Schubert gave an overview of a proposal on "High Resolution Climate Model Simulations of Recent Hurricane and Typhoon Activity: The Impact of SSTs and the Madden Julian Oscillation". The intent of the proposal (endorsed by CLIVAR/AAMP) is to provide a framework for a coordinated international effort to carry out and analyze high-resolution (and companion coarser resolution) climate simulations of tropical storm activity with a number of state-of-the-art global climate models (targeting 20-100km horizontal resolution). The approach involves simulating selected years/seasons including some with highly unusual tropical storm activity (both in

AMIP and coupled mode); addressing physical mechanisms, and resolution/physics dependence and impact of physics through coordinated experimentation; and developing/deciding on a common set of diagnostics (e.g., tropical storm metrics, basic climate diagnostics, tracking tools) for evaluation and validation. An example was presented from simulations made with the SNU model run at 25km and 125km resolution for the years 1997 and 1999. The results showed that the model is able to reproduce some of the key differences in Typhoon activity during those two years. An example was also shown about how runs with idealized SST anomalies might be used to learn more about how the different ocean basins can impact tropical storm activity. The issue of validation and the use of new high-resolution reanalysis products was also discussed.

Jae-Kyung Schemm presented results from dynamic hurricane season prediction experiments with the NCEP CFS CGCM (T382/L64). She noted that this is one of the FY08/09 CTB internal projects – a collaborative effort between the NCEP CPC and EMC. All runs were initialized with NCEP/DOE R2 and NCEP GODAS Initial conditions at 0Z, Apr. 19-23 for 1981-2008, and forecasts extended to December 1. Output was provided at every 6 hours. The results show that the CFS exhibits a robust climatological seasonal cycle of tropical cyclones over the three NH basins. The hindcasts also capture the observed warming trend and intensification of hurricane activity in the Atlantic basin. In addition, the results show a fair level of skill in predicting interannual variability of seasonal storm activities for the Atlantic and West. N. Pacific basins. It was noted that they provided input for the 2009 CPC Hurricane Season Outlook with real time prediction runs.

Frederic Vitart presented his work on the simulation of the MJO and its impact on tropical storms in the ECMWF monthly forecasting system. He started by reviewing the recent improvements in the simulation of MJO and TCs at ECMWF. The model changes included a new formulation of convective entrainment, and a new formulation of the relaxation timescale used in the massflux closure. The hindcasts consist of 15-member ensemble 46-day forecasts starting on the 15th of each month from 1989 to 2008. The model is Cycle 32R3 run at T399 (50 km) uncoupled till day 10 and T255 (80km) coupled after day 10. The perturbations for the atmosphere consisted of singular vectors + stochastic physics, while for the ocean they were wind stress perturbations generated during data assimilation. The results show that the MJO and Tropical Cyclone activity are more realistic since 32R3, though the MJO suffers from a too slow propagation and has difficulties to cross the Maritime Continent. The model simulates a realistic impact of the MJO on model tropical storms, although the impact tends to be weaker than observed.

Akio Kitoh discussed the future projections of precipitation extremes, tropical cyclones, extratropical cyclones and blockings. The results are based in part on the MRI/JMA Atmospheric GCM run at TL959 (20km) with 60 layers (0.4 hPa). Runs were made for 1) present-day (1979-2003), in which the model was run with the observed sea surface temperature (SST) and sea-ice concentration, and 2) near future (2015-2039) and future (2075-2099). For the future runs the SST and sea-ice anomalies of the CMIP3 multi-model ensemble mean were added to the observations, retaining the present interannual variability**.** Additional runs were done at 60km resolution (using SST from individual CMIP3 models) and different initial conditions. The results of the 20km runs for present day showed that there is skill in reproducing interannual variation in TC frequency associated with ENSO. For the future (2075-2000) runs, the TC frequency is predicted to decrease in the western North Atlantic and increase in the eastern North Atlantic. Also, frequencies of Euro-Atlantic and Pacific blockings are projected to decrease. In the next 2 years they plan to improve the model for TC and precipitation. The AOGCM (ESM) CMIP5 runs will be done with TL159 AGCM + 1x0.5 OGCM with TL95 aerosol model + T42 chemistry model. The AGCM time-slice will be run at TL959 (20-km). After that, the full AOGCM + ESM will have the Atmosphere at 20-km, and the Ocean at 1/8x1/12, plus a lower resolution aerosol and chemistry model.

Lennart Bengtsson talked about tropical and extra-tropical cyclones in high resolution climate predictions. He presented results from a series of climate modeling experiments using high resolution versions of the ECHAM5 atmospheric model run at T213 and T319 resolution. The ocean boundary conditions were obtained from a coupled climate run by the ECHAM5/OM at T63 resolution. Results were calculated from the 20th century 1960-1989 (using observed GHG) and for 2070-2099 (using scenario A1B). The effect of reduced resolution (T63 versus T213) is that extratropical storms intensities are underestimated. The results for the warmer climate runs are that accumulated precipitation around extra tropical cyclones increases by some 11%. Extreme precipitation increases by more than 30% in some areas, in the storm track region by more than 50%. Extreme winds are likely to fall within the range of the present climate. The number of tropical cyclones in a warmer climate are reduced by some 10% at the end of the 21st century. The stronger storms become more intense (cyclones with wind speeds >50m/s increase from 12 to 17 per year compared to the end of the 20th century). Intensification occurs in all tropical storm regions.

William K. Lau presented results from modeling the impacts of Saharan Air Layer, and radiative effects of Saharan dust on tropical cyclogeneses and hurricanes. This included results from forecasting convective organization of tropical systems using the NASA GEOS4 global meso-scale model, an examination of the impacts of Saharan Air Layer (SAL) and Saharan dust on tropical Atlantic weather and climate, and an assessment of the impacts of absorbing aerosols (dust and BC) on the water cycle of the Asian monsoon. Regarding the SAL impact, they investigate two waves - one developing (W2), while the other (W1) does not. They show that W1 failed to develop into a TC (even though initial voriticity development is favorable), in part because of entrainment of dry air from SAL. A strong thermal dipole is associated with the SAL in W1 case, suggesting possible signature of radiative effect of Saharan dust. A much weaker dipole is found for the SAL associated with W2, which eventually developed into hurricane Helena. For future experiments, they propose to run GEOS-5 at ¼ x ¼ degree (or higher) both with and without interactive aerosols (using GOCART) with specified SST for 2005 and 2006. They also plan to use HR global GEOS-5 as boundary conditions to run multiple-embedding WRF (with indirect effects of aerosols) over complex terrain of IGP/Himalayas to study regional aerosol-hydroclimate interactions.

T.N. Krishnamurti presented results from downscaled multi-model super-ensemble forecasts of seasonal rains over the Asian Monsoon belt. The methodology consisted of taking coarse resolution precipitation data from 16 coupled climate models (resolution 2.5 degree) and bi-linearly interpolating them to a 0.5 degree grid to conform with the APHORDITE observations. Regression coefficients were obtained (using a cross validation technique) by least square linear fit of the model interpolated precipitation with that of the high resolution observational data sets. The final outcome of the methodology is precipitation forecast at 0.5 degree grids over the South Asian region from 18 coupled models for forecast on monthly basis. Examining the performance of the various coupled models for the Monsoon Asia, they found that none of model's forecast match with observations on the basis of year to year forecast over Monsoon Asia. For a particular year or region some models performed better than others. The major findings of the study are that the use of the downscaled multimodel superensembles provides better forecasts in terms of rms errors, anomaly correlations and the equitable threat scores compared to all member models, the ensemble mean, and the bias removed ensemble mean for the monsoon region.

Filippo Giorgi discussed producing a new generation of regional climate model projections: The CORDEX framework. He noted that the resolution of GCMs is still too coarse to capture regional and local climate processes, and one approach to downscaling is to nest regional Climate Models (RCMs) within a GCM in order to locally increase the model resolution. In this "one way nesting" the initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM or analyses of observations. He cited a number of review publications and projects that discuss this approach, and gave some examples of the benefits of the enhanced regional resolution (e.g., improvements in topographic forcing, extreme events, east Asia monsoon). He then discussed the WCRP COordinated Regional climate Downscaling Experiment (CORDEX). The goals of CORDEX are to evaluate and possibly improve different regional downscaling techniques, design a common framework for the next generation RCD-based climate change projections for input to impact/adaptation work, and to facilitate the engagement of the end-user community and the scientific community from developing countries.

Suzana Camargo talked about diagnostics of tropical cyclone activity and associated environmental conditions in observations and models. She presented results that showed that the Genesis Potential Index (GPI) fits very well the annual cycle of the number of tropical cyclones in each basin. The results also showed that the GPI reproduces the modulation of tropical cyclones (TCs) by ENSO and the MJO. The QBO relationship with Atlantic hurricane activity appears to be robust until 1980s robust, however, the relationship disappeared in more recent years. It was suggested that ENSO has an influence on the QBO & Atlantic TC relationship, and that ENSO could also be playing a role in the other basins where the relationship is very weak or not significant. Finally, it was shown that Potential intensity theory cannot explain the secular trends in measures of "hurricane activity" and no formal theory is in place to understand frequency and track changes

Kevin Walsh discussed the intercomparison of high resolution climate models of tropical cyclones. In particular, he reviewed TCMIP – the Tropical Cyclone climate Model Intercomparison Project. The project currently has about 30 members. The initial goals are to: use common metrics to compare simulations of TCs in coarse-resolution

CMIP3 model output, an dto solicit contributions of high-resolution climate model output for intercomparison, using standard metrics. The ultimate goal is improvement of high-resolution TC climate models (global and regional) through systematic intercomparison. He discussed the use of consistent detection routines for all simulations: –your detection and tracking routine but with detection thresholds adjusted for consistency with common metrics. He showed results indicating that biases in TC patterns of formation at low resolution tend to persist when downscaled to higher resolution. As a result, nested model can give very different TC formation if forced by different models. He noted that TCMIP is now accepting data submissions, and results. The aim is to meet the IPCC AR5 deadline for papers in press (2012) so that analysis should be completed by 2011.

Emilia Jin presented results about two flavors of El Niño and its role on the forecast of MJO and tropical cyclone. The two flavors of El Niño consist of: (1) maximum SST anomalies in the warm pool region, (2) maximum SST in the cold-tongue region. Using CFS hindcast results, she showed that with an increase of the lead month, the forecast ENSO mode progressively approaches the model intrinsic mode in free coupled run and departs from the observed. With increasing forecast lead month, CGCMs fail to distinguish between the two flavors of El Niño because models tend to simulate the one mixed flavor of El Niño. Further results show that, the CFS Genesis Potential Index **(**GPI) is in agreement with the warm-pool and mixed-mode El Niño, but not with the cold-tongue El Niño. Also, CFS can reproduce a realistic MJO-tropical cyclone genesis relationship globally. However, because of unrealistic the ENSO-MJO relationship, the actual prediction of cyclone genesis is not realistic. This suggests that improvement of ENSO, and ENSO-MJO relationship is important for improving the simulation of tropical cyclones in coupled models.

Tianjun Zhou addressed the issue of how well Atmospheric General Circulation Models simulate the inter-annual and interdecadal variability of Asian monsoon. The talk focused on 1) Interannual variability of Asian monsoon, 2) Global monsoon precipitation change, and 3) East Asian monsoon circulation change. An analysis of the results from a number of different AGCMs forced with observed SST lead to the following conclusions. The AMIP MME captures the leading modes of monsoon variability with a skill that is comparable to reanalysis in terms of the seasonally evolving spatial patterns and the corresponding temporal variations, as well as their relationships with ENSO. The skill of AMIP simulation is season-dependent. The DJF (JJA) has the highest (lowest) skill. Over the East Asia, extra-tropical western North Pacific and South China Sea, the MME shows nearly no skill in JJA. The topical Ocean warming is one mechanism for the weakening tendency of global land monsoon rainfall and E. Asian Monsoon Circulation. The decadal scale westward extension of WPSH is partly driven by the warming of Indian Ocean. The AGCMs succeed in simulating the EA monsoon circulation change, but fail in simulating the EA monsoon rainfall change.

Thursday – August 13

Jim Kinter examined the prospects for petascale climate modeling: can kilo-processors, exa-flops and peta-bytes make a difference in simulation of Earth's climate? He discussed the following 10 points: 1) Climate change is most difficult and important problem. 2) Scientific consensus: humans contribute to climate change. 3) World, urgently engaged in global mitigation and regional adaptation strategies, needs detailed regional information. 4) IPCC AR4: considerable uncertainty in predictions of magnitude of global change, 5) … and uncertainties in regional climate are even bigger , 6) Climate prediction is very computationally demanding, 7) Climate spatial scales span 10 decades, but current models resolve less than 4 decades, 8) Within 6 years, peak capability of 100 petaflops, 10^7 computing units, 9) Parallel computation means new software, algorithms and models, and 10.… and new methods in workflow management, data management, and visualization. A discussion of each of the 10 points lead to the following conclusions: There has been considerable progress in weather & climate modeling over the past 45 years along with a 10^9-fold increase in computing. Breakthroughs in the next decade will require huge increases in model resolution & complexity →' 10^{3+} X increase in computing capability, along with work on an entire spectrum of issues in high-end computing and model & code development. We are not currently organized as a community to step up to this challenge. This problem may be larger than any single nation can address … international cooperation is required to accelerate progress and productively use petascale computing for climate prediction

Panel Discussion: Computational and High Resolution Modeling Challenges Chair: J. Shukla

Shukla posed the question: What are the factors that currently limit the ability to run very high-resolution simulations? The answers varied considerably and include the following issues and concerns:

1) lack of institutional support and resources

2) need for dedicated computers; reliability issues (large number of processors – some will fail)

3) insufficient disk space; I/O limitations (need parallel I/O); code scalability

4) code reliability ("bugs"); insufficient data storage (not now, but soon)

5) data management issues - no analysis/visualization capabilities on same machine so need to move large amounts of data to another machine

6) lack of reproducibility

7) need for skilled "manpower"

More general but related issues:

8) Need to define a goal on resolution (what is practical and what is scientifically useful) – should aim for 10km resolution –to close the climate/weather gap

9) Concerning climate sensitivity (clouds and convection), there is a need to compare with space-based observations, so the model resolution should be commensurate with that of the observations

10) Should take advantage of data assimilation increments to isolate model deficiencies (improving processes – e.g., the quality of the cloud schemes)

11) Need to strive for unbiased models – large model bias does not allow accessing benefits of observations

12) Need to weigh the benefits of resolution increases against the benefits gained by developing more comprehensive climate models (e.g., chemistry, aerosols, carbon cycle) - need buy in from the larger climate community

13) Need to weigh the benefits of resolution increases against the benefits gained by increasing the ensemble size of simulations (e.g., in time slice experiments)

14) Also need to improve the physics (parameterization) – develop synergy between resolution increases and physics improvements

15) Need to consider deliverables: improved simulation of water cycle, droughts, seasonal forecasts, hurricane intensities, tracks etc.

There was also some discussion of a lead center for high-resolution modeling/World Climate Center. Both Saudi Arabia and China were mentioned as possible candidates.

Panel Discussion: Link to YOTC, IPCC, APCC, TCMIP, coordination on experiments, etc. (S. Schubert, I.-S. Kang, J. Shukla, F. Kucharski, Woo-Jin Lee, Mitch Moncrieff, and Kevin Walsh).

Mitch Moncrieff (see Thursday ppt) gave an overview of the Year of Tropical Convection (YOTC): Multi-scale Organization of Tropical Convection and its Interaction with the Global Circulation: Time-scales up to Seasonal. He noted that the Science Plan, Implementation Plan, and meeting reports, are available at http://www.ucar.edu/yotc . Research areas include, attribution and experimentation (high-resolution prediction); modeling (parameterized and explicit convection); and theoretical/simplified models. The science elements consist of: MJO and convectively coupled equatorial waves, Monsoons and intraseasonal variability, Easterly waves and tropical cyclones, Tropical-extratropical interaction, and the Diurnal cycle of precipitation. Key High-Resolution Analysis & Forecast Archives are being produced by ECMWF T799 – ~25km, on-line; NASA/GEOS-5 - ~25km, in progress; and NCEP - ~40km, in progress.

Shukla suggested that the groups in a position to do so, consider an extension of YOTC hindcasts. Namely, to carry out a limited number of global hindcasts/ simulations at order 4km resolution for a full season to address monsoon, MJO and other longer term variability during the YOTC "year" (2008-2009).

Kevin Walsh (see Thursday ppt) outlined the Tropical Cyclone Model Intercomparison Project (TCMIP) (http://www.earthsci.unimelb.edu.au/~kwalsh/tcmip_index.html)

He discussed the key science issues being addressed: What are the factors that govern simulated formation rates? What governs the regional variation in tropical cyclone simulation (i.e. usually too few in N.Atlantic, too many in S. Atlantic, poor in E. N. Pacific)? What governs the relationship between empirical indices like SGP and simulated low formation? How well can models simulate the relationship between MJO and tropical cyclone formation, and why? He also discussed current and future issues, including the analysis of climatological performance in existing climatological SST or AMIP-style runs, CMIP5 data specification (needs to be checked to see what issues will arise for applying TCMIP diagnostics), and common future experiments performed specifically for TCMIP.

Woo-Jin Lee (see Thursday ppt) gave an overview of APCC goals and activities, highlighting the importance of providing benefits to society. He provided some examples of recent results from the operational MME forecasts, and outlined some of the on-going efforts in model diagnostics, in developing a testbed on extreme climate prediction, and in data and information sharing. APCC participates in the Climate Historical Forecast Project (CHFP) data distribution center. He noted that as of January 2009, experimental monthly 3-month and 7-month lead drought/flood predictions have been carried, and a global hydrological extreme drought/flood monitoring service was launched (http://www.apcc21.net/climate/climate03_11.php). He then discussed future extensions of APCC's activities to include, extreme event predictability experiments, long lead and ISV predictability, the development of observational and derived indices, and high-resolution climate model output. He in particular expressed a willingness to consider having APCC be one of the distribution centers for high-resolution simulations.

Siegfried Schubert outlined a number of goals for collaboration involving data sharing, common analysis metrics and coordination on model simulations. He proposed that groups coordinate on the basic problem of assessing the ability of models to simulate recent tropical storm activity. This is an emerging requirement for both IPCC and seasonal forecasting. The necessary runs are already being done by a number of groups, and the effort would be consistent with the goals of a CLIVAR project on high-resolution climate model simulations of tropical storms. This includes two sub-projects involving 1) assessing the sensitivity to and improving model physics (further discussed by In-Sik Kang), and 2) additional experimentation to improve our understanding of the physical mechanisms that determine the variability of tropical storms from subseasonal to seasonal and longer time scales (discussed further by S. Schubert). It was suggested to include 2008 and 2009 in the years to simulate (minimum set of key years are then 1997, 1998, 1999, 2004 - 2009; if possible would ideally include all years 1979-2009).

He also emphasized the need to summarize existing high-resolution simulations, as an initial step in improving coordination among the various groups and in making high resolution simulations available to the general community (focusing on runs at 20-100km and coarse resolution runs that demonstrate a capability to reproduce tropical storm characteristics).

Kerry Emanuel summarized (via email) a number of issues that came up during the workshop regarding current efforts to run global climate models at very high resolution, noting that many of these issues have already been faced by meso-scale modelers. He, in particular, suggested that key people from the global and meso-scale modeling community get together for a workshop to discuss lessons learned. These lessons include:

•Paying attention to the formulation of surface fluxes at high wind speeds

•Converting all dissipated kinetic energy back into heat

•Being aware that hurricane eyewalls are strongly frontogenetical and will collapse down to the smallest scale permitted by your horizontal resolution and/or your formulation of horizontal diffusion (including artificial diffusion owing to your numerics)

•The need to couple to the ocean (if you have not already done so). Specifying SSTs does not guarantee that the model atmosphere will produce the correct TC climatology. Hurricanes are sensitive to the thermal disequilibrium between the sea surface and the air just above it, and this can be strongly influenced by the distribution of radiatively active gases and aerosols and by the mean surface wind speed, as well as by SST

He also suggested that we open up a channel of communication with the people who are deciding what variables to produce and store for the AR5 climate simulations. In particular, it would be nice if a subset of the workshop participants could meet and decide on a uniform tropical cyclone detection algorithm that could be applied to instantaneous model output, say 4 times per simulated day.

C. Recommendations

Here we summarize the key recommendations and associated action items that came up during the workshop.

1) Summarize key existing high-resolution simulations, and look into the possibility of making these (subsets) available to the general community

a. See Appendix B of this report for a current summary

b. Assess whether APCC can play a role as a data holding and distribution center (Woo-Jin Lee)

c. Assess whether TCMIP can play a role as a data holding and distribution center (Kevin Walsh)

2) Collaboration on high resolution climate modeling should focus on demonstrating an ability to reproduce recent tropical storm activity (1979-2009)

a. At a minimum should cover years (1997-2009)

b. Coordinate on developing common storm metrics and detection schemes (see also below)

c. Build on TCMIP and CLIVAR high resolution modeling project

d. Focus on what is currently feasible to run (20km -100km resolution), and relevant to IPCC and short –term climate prediction.

e. Link to YOTC

f. Consider possible coordinated mechanistic experiments: e.g., idealized SST

g. Consider possible coordinated model sensitivity experiments

3) Extend the YOTC hindcasts by carrying out a limited number of global hindcasts/simulations at order 4km resolution for a full season to address monsoon, MJO and other longer-term variability during YOTC "year" (2008-2009). The groups in a position to do that are (GMAO, GFDL, NICAM).

4) Open up a channel of communication with the people who are deciding what variables to produce and store for the AR5 climate simulations. In particular, it is suggested that a subset of the workshop participants could meet and decide on a uniform tropical cyclone detection algorithm.

a. Kevin Walsh has taken as an action item to contact the relevant people and modeling groups regarding the variables saved

b. Kevin Walsh and Suzana Camargo will look into the possibility of a common tracking tool (at least some key aspects of the tools)

5) Key people from the global and meso-scale modeling community should get together for a workshop to discuss lessons learned and possibilities for future collaboration

D. Appendix A: Agenda

Monday, August 10

8:30 9:30 ***Registration***: Adriatico Guesthouse, Lower Level 1

9:30 - 10:00 *Welcome and logistics*: ***J. Shukla*** *and* ***F. Kucharski***

Overview talks: Chair: S. Schubert

10:00 - 11:00 **Masaki Satoh**: "Overview of NICAM: global cloud-resolving simulations and development"

11:00 - 11:30 **Break**

11:30 - 12:15 **T.N. Palmer** & M. Matsueda: "Simulations of climate change at low and high resolution: testing the seamless prediction concept"

12:15 - 13:00 **Kerry Emanuel**: "High resolution modeling of the response of tropical cyclones to climate change"

13:00 - 14:00 **Lunch**

Follow-up to Reading meeting – progress on ultra-high resolution climate modeling Chair: Shukla

14:00 - 14:30 **Shian-Jiann Lin**: "Tropical cyclone simulations with the prototype GFDL global cloud resolving model"

14:30 -15:00 **Bill Putman**: "Global Non-Hydrostatic Simulations with the Goddard Earth Observing System, Version 5 (GEOS-5) Model & the Finite-Volume Dynamical Core"

15:00 - 15:30 **Break**

15:30 - 16:00 **In-Sik Kang**: "Moist Physics Parameterization for High Resolution Climate Models"

16:00 - 16:30 **Dave Randall**: "Design and testing of a global cloud-resolving model"

Tuesday, August 11

Multi-scale modeling, physics and resolution issues Chair: I.-S. Kang

9:00 9:30 **Mitch Moncrieff** : "Organized Multiscale Precipitating Convection and the Global Circulation"

9:30 - 10:00 **Wei Kuo Tao** : "A Goddard Multi-Scale Modeling System with Unified Physics"

10:00 - 10:30 **Cristiana Stan (given by Jim Kinter)**: "The role of cloud processes representation in the simulation of climate"

10:30 - 11:00 **Break**

11:00 - 11:30 **Wojciech W. Grabowski** and Hugh Morrison: "High-resolution modeling and cloud microphysics: why should we care?"

11:30 - 12:00 **Pier Luigi Vidale**: "Frontiers of UK climate modelling: resolving processes and scale interactions"

12:00 - 13:30 **Lunch**

Multi-scale modeling, physics and resolution issues (cont'd) Chair: Akio Kitoh

13:30 - 14:00 **Kazuyoshi Oouchi**: "Tropical cyclone & multi-scale precipitation events in the summer seasonal simulations and global warming experiments with NICAM"

14:00 - 14:30 **Tim Miller**: "Comparison of the Effects of RAS vs. Kain-Fritsch Convective Schemes on Katrina Forecasts with GEOS-5"

14:30 - 15:00 **Break**

15:00 - 15:30 **Oreste Reale,** Siegfried Schubert and Myong-In Lee: "Assessing the representation of Tropical Cyclones in global models"

15:30 - 16:00 **Tony Rosati**: "High Resolution Coupled Model Activities at GFDL"

16:00 - 16:30 **HuaLu Pan**: "Convection parameterization for the NCEP Weather and Climate model"

16:30 - 17:00 **Myong-In Lee**, Siegfried Schubert, Max Suarez, Julio Bacmeister and Oreste Reale: "Simulation of Tropical Storms with High Resolution Versions of the GEOS-5 Model"

Wednesday – August 12

Current simulations of tropical storms and climate variability Chair: F. Kucharski

9:00 - 9:30 **Siegfried Schubert, In-Sik Kang** & Oreste Reale: Overview of Proposal: High Resolution Climate Model Simulations of Recent Hurricane and Typhoon Activity: The Impact of SSTs and the Madden Julian Oscillation

9:30 - 10:00 **Jae-Kyung E. Schemm** & Lindsey Long: "Dynamic Hurricane Season Prediction Experiment with the NCEP CFS CGCM"

10:00 - 10:30 **Frederic Vitart**: "Simulation of the MJO and its impact on tropical storms in the ECMWF monthly forecasting system"

10:30 - 11:00 **Break**

11:00 -11:30 **Akio Kitoh**: "Projections of precipitation extremes, tropical cyclones, extratropical cyclones and blockings"

11:30 - 12:00 **Lennart Bengtsson**: "Tropical and extra-tropical cyclones in high resolution climate predictions"

12:00 - 13:30 **Lunch**

Current simulations of tropical storms and climate variability (cont'd) Chair: S. Schubert

13:30 - 14:00 **William K. Lau**, Oreste Reale, Eric Wilcox, Kyu-Myong, Kim and Donglian Sun: Modeling the impacts of Saharan Air Layer, and radiative effects of Saharan dust on tropical cyclogeneses and hurricanes

14:00 - 14:30 **T.N. Krishnamurti** and V. Kumar: "Downscaled Multimodel Superensemble Forecasts of seasonal rains over the Asian Monsoon belt"

14:30 - 15:00 **Filippo Giorgi**: "Producing a new generation of regional climate model projections: The CORDEX framework"

15:00 - 15:30 **Break**

15:30 - 16:00 **Suzana Camargo**: "Diagnostics of tropical cyclone activity and associated environmental conditions in observations and models'"

16:00 - 16:30 **Kevin Walsh**: "Intercomparison of high resolution climate models of tropical cyclones"

16:30 - 17:00 **Emilia Jin**: "Different flavors of ENSO and its impact on the forecast of MJO and tropical cyclone"

17:00 - 17:30 **Tianjun Zhou**: "How well do Atmospheric General Circulation Models simulate the inter-annual and interdecadal variability of Asian monsoon?"

Thursday – August 13

Computational and High Resolution Modeling Challenges Chair: J. Shukla

9:00- 9:45 Jim Kinter: "Prospects for Petascale Climate Modeling: Can Kilo-Processors, Exa-Flops and Peta-Bytes Make a Difference in Simulation of Earth's Climate?"

9:45 - 10:30 ***Panel Discussion*** (include modeling issues/future directions)

10:30 - 11:00 **Break**

11:00 - 12:30 ***Panel Discussion continued***

12:30 - 14:00 **Lunch**

14:00 - 15:30 ***Panel Discussion (S. Schubert, I.-S. Kang, J. Shukla, F. Kucharski, Woo-Jin Lee, Mitch Moncrieff, and Kevin Walsh.*** Link to YOTC, IPCC, APCC, TCMIP, coordination on experiments, etc

Poster Session: Chair- Fred Kucharski

15:30 - 18:00 **Break and poster session** (Area outside the Kastler Lecture Hall)

E. Appendix B: Summary of Existing High Resolution Simulations

The following lists various runs that have been made at high resolution. The list is not meant to be comprehensive (it is to a large extent limited to the groups represented at the workshop) nor have the groups agreed to make all these runs available to the general community. Together, these runs provide a good sense of the level of interest and the considerable effort made, and resources already expended by the various modeling groups in running global (in some cases regional) climate models at high resolution. The runs (as described in the presentations) represent an emerging capability to use climate models to advance a number of issues, in particular those related to climate/weather interactions and extreme events. As such, we do hope to be able to make some subset of these runs available to the broader science and applications communities for further analysis (see recommendations).

•NASA/Global Modeling and Assimilation Office (GMAO):

(see also presentation by Myong-In Lee)

GEOS-5 AGCM with modified moist physics, 0.5 degrees horizontal resolution, 15 May – 01 Dec, 1997,1998, 1999, 2004, 2005, 2006, 2007, 5 ensemble members; will repeat these experiments (and extend to cover all years from 1997-2009) at 0.25 degrees and the latest version of GEOS-5.

•Seoul National University (SNU):

(information provided by Sung-Bin Park/see also presentation by S. Schubert)

SNU AGCM, 0.25 degrees horizontal resolution, 1997(Elino case), 1999(LaNina case), from 14 Apr. to 31 Oct., six ensemble members.

•NOAA/National Centers for Environmental Prediction (NCEP):

(see also presentation by Jae Schemm)

CFS AOGCM, April 19-23 ICs, run thru 01 Dec, 1981-2008, 5-member ensemble

- AGCM: 2007 operational NCEP GFS in T382/L64 resolution, LSM: Noah

  OGCM: GFDL MOM3

- All runs initialized with NCEP/DOE R2 and NCEP GODAS.

- Output at every 6 hours

- Plan to repeat for July initial conditions

•NOAA/Geophysical Fluid Dynamics Laboratory (GFDL):

(see also presentation by Shian-Jiann Lin)

AM2.1 AGCM with modified moist physics, 0.5 degree horizontal resolution, 4 realizations of the period 1981-2005, observed SST.

•National Center for Atmospheric Research (NCAR):

(info. provided by Ruby Leung of Pacific Northwest National Laboratory)

Simulations carried out with the Nested Regional Climate Model (NRCM) using the WRF model, a tropical channel simulation (from 30/45S - 45N) at 36 km resolution driven by the NCEP/NCAR global reanalysis for 1996-2005; for selected years did 36 km resolution with a 12 km two-way nest over the Atlantic, and over the Maritime Continent; several simulations at 36 km and 12 km resolution over North America and the Atlantic driven by the CCSM current and future climate.

Also North American Regional Climate Change Assessment Program (NARCCAP) simulations driven by the NCEP/DOE global reanalysis (1979-2005) and AOGCM runs of current (1970-2000) and future climate (2040-2070).

• Japan Marine Science & Technology Center/Center for Climate System Research (JAMSTEC/CCSR):

(see also presentation by Masaki Satoh)

NICAM model: Boreal Summer 2004 consisting of June-Oct. at 14km (2member); June-Aug. at 7km; Future Boreal Summer for climatology of 2070-2099 using average SST of AR4 models; May-Oct. at 14km; Perpetual July exp: 1month spin-up + 2month to get a quasi-statistically stable state at 14km, 7km; 1month, Dec 2006 - Jan 2007, at 7, 14km; 1 week (25-31) Dec 2006, at 3.5km (MJO experiment); 1month, Nov 2006, at 7, 14km (MISMO experiment); 1month, Apr-May 2008, 5 members (Myanmar cyclone).

'Quantities archived for the 2004 boreal summer experiments include:

3-hrly 3d (40 levels) prognostic, instantaneous variables, and

1.5 hr 2d (single level) time-averaged variables.

The data size is 1.5TB/mo from 14-km and 6 TB/mo from the 7-km runs.

• Japan Meteorological Agency-Meteorological Research Institute (MRI/JMA):

(see also presentation by Akio Kitoh)

MRI/JMA Atmospheric GCM: one 20km run for 1979-2003 with observed SST and sea ice concentration; several scenario simulations for the near future (2015-2039) and future (2075-2099) run at 60km horizontal resolution, with 4 different SST anomalies based on (CMIP3 average, MRI-CGCM2.3.2, MIROC_hires, CSIRO) and 3 initial conditions.

• European Centre for Medium-Range Weather Forecasts (ECMWF):

(see also presentation by Frederic Vitart)

- Operational Seasonal Forecasts:

  - 1981-present starting on the 1st of each month

  - 11 members (41 members after 2007)

  - 7 months coupled integrations (5 members of the forecasts starting on 1st

November/Feb/May/August have been extended to 13 months)

- resolution: T159L62 (about 1.125 degrees or 125 km).
- IFS cycle 31r1 (was operational in 2006)

- Operational Monthly Forecasts:
  - Hindcasts are produced each week starting the same day and month as the real-time forecasts for the past 18 years
  - 5 members for hindcasts, 51 members for real-time forecasts
  - 32 day integrations forced by persisted SST anomalies until day 10 and coupled after day 10
  - Resolution : T399L62 (about 50 km resolution) until day 10 and T255L62 (about 80 km resolution) after day 10
  - Latest version of IFS.
- Extended Monthly Forecasts Hindcasts (Research experiment):
  - 1989-2008 starting the 15th of each month
  - 15 members
  - 46-day integrations forced by persisted SST anomalies until day 10 and coupled after day 10
  - Resolution : T399 (about 50 km resolution) until day 10 and T255 (about 80 km resolution) after day 10
  - IFS cycle 32R3 (was operational in from Nov 2007 until June 2008).

• **University of Reading/United Kingdom-Japan Climate Collaboration (UJCC):**

(see Pier Luigi Vidale's presentation for status of runs)

1a) Control coupled Model Simulations – present day

HadGEM1-3 (135km) - 3X100years

NUGEM (60km) – 20 years (paused)

1b) Atmos-only simulations (AMIP SSTs)

HadGAM (135km) – NX25 years

HiGAM (90km) - NX25 years

NUGAM (60km) - NX25 years

HadGEM3-H (60km) stratosphere – 2X25 years

2a) Control coupled– present day

HiGEM (90km, 1/3 ocean) – 2X150 years

2b) Atmos-only simulations (HiGEM SSTs)

HadGAM (135km) – 30 years

HiGAM (90km) - 30 years

NUGAM (60km) - 30 years

3a) 2XCO2 coupled–warm stabilised

HiGEM (90km, 1/3 ocean) – 30 years

3b) Atmos-only simulations (HiGEM SSTs 2XCO2)

HadGAM (135km) – 30 years

HiGAM (90km) - 30 years

NUGAM (60km) - 30 years

4a) 4XCO2 coupled–warm stabilised

HiGEM (90km, 1/3 ocean) – 30 years

4b) Atmos-only simulations (HiGEM SSTs 4XCO2)

HadGAM (135km) – 30 years

HiGAM (90km) - 30 years

NUGAM (60km) - 30 years