# ACTIVITIES OF THE CAS/JSC WORKING GROUP ON NUMERICAL EXPERIMENTATION (WGNE)

The JSC/CAS Working Group on Numerical Experimentation (WGNE) has the central responsibility in the WCRP for the development of the atmospheric component of climate models and, together with the Working Group on Coupled Modelling (WGCM), lies at the core of the climate modelling effort in WCRP. Close co-ordination is duly maintained between WGNE and WGCM. Furthermore, WGNE works in conjunction with the WCRP Global Energy and Water Cycle Experiment (GEWEX) in the development of atmospheric model parameterizations and, in this respect, WGNE sessions are held jointly with the "GEWEX Modelling and Prediction Panel". Liaison is also maintained with the SPARC "GRIPS" project (focussed on the intercomparison of model stratospheric simulations) and will be developed with the new SPARC initiative on stratospheric data assimilation.

WGNE additionally has an important role in support of the WMO Commission for Atmospheric Sciences (CAS) in reviewing the development of atmospheric models for use in weather prediction and climate studies on all timescales. The close relationship between WGNE and operational (NWP) centres by virtue of the CAS connection underpins many aspects of WGNE work and provides a strong impetus for the refinement of the atmospheric component of climate models. WGNE sessions duly include reviews of progress at operational centres in topics such as data assimilation, numerics, physical parameterizations, ensemble predictions, seasonal prediction, forecasting tropical cyclone tracks, and the verification of precipitation forecasts. WGNE maintains close co-ordination with the CAS World Weather Research Programme. A particularly strong area of collaboration is in the planning and development of THORPEX: A Global Atmospheric Research Programme.

The following paragraphs review the main activities of WGNE in support of WCRP objectives, including especially items of interest and recommendations arising at the eighteenth session of the group kindly hosted by Meteo-France, Toulouse, France, 18-22 November 2002.

## 1. MODEL INTERCOMPARISON PROJECTS

A key element in meeting the WGNE basic objective to identify errors in atmospheric models, their causes, and how they may be eliminated or reduced, is a series of model intercomparison exercises.

### Atmospheric Model Intercomparison Project

The most important and far-reaching of the WGNE-sposored intercomparisons is the Atmospheric Model Intercomparison Project, conducted by the Programme for Climate Model Diagnosis and Intercomparison (PCMDI) at the Lawrence Livermore National Laboratory, USA, with the support of the US Department of Energy. AMIP, based on a community standard control experiment simulating the period 1979 – 'near present', is now reaching the end of its second phase (AMIP-II). Approximately twenty-five modelling groups have submitted simulations and much of the data from these runs are available for a wide range of diagnostic sub-projects. In addition to the standard runs, ensembles and runs at varying horizontal resolutions are being archived for specific research sub-projects. Regular updates of the overall status of AMIP, model integrations, diagnostic subprojects are posted on the AMIP home page http://www-pcmdi.llnl.gov/amip. On the technical side, PCMDI now has a powerful open source software system which enables efficient management of the voluminous AMIP data sets. An automatic system is now in place which can organise simulations, perform extensive quality control, and make the data accessible (via ftp) to interested users. Most importantly, the facility is now able to rapidly provide a detailed diagnostic report on a model simulation.

Following the recommendation of the WGNE, an International AMIP Workshop was held in Toulouse from 12-15 November 2002. The WGNE-appointed AMIP panel served as the Scientific Organising committee which was chaired by Dr. Peter Gleckler of PCMDI. A key decision made by the committee was to have a focus on innovative diagnostics and have a strong representation from the observational communities. The workshop program and abstracts are available at: http://www.cnrm.meteo.fr/amip2/. Model diagnostic sessions were broken into the General Circulation, Tropical Variability and Monsoons, Fluxes and Cloud-Radiative effects, the Hydrological Cycle, Land Surface Processes and Phenomena and Extra-Tropical Variability. Keynote speakers included: M. Miller (ERA40), B.J. Hoskins (Dynamical approaches), J.-F. Royer (West African Monsoon), T. Koike (Co-ordinated Enhanced Observing Period, CEOP), S. Krueger (GEWEX Cloud Systems Study), R. Koster (GLASS poor man's LDAS), and J.-J. Morcrette (use of ARM data for model diagnosis). Several discussion forums were devoted to refining the experiment and prioritizing future activities.

Some key conclusions of the Conference included –

- Despite limitations, the idealised AMIP SST experiment is still a powerful diagnostic test,
- A ‘mean AMIP model’ generally outperforms any individual model and is a useful reference,
- Diagnostic Subproject analysis has become an increasingly useful exercise,
- There was an encouraging synergism with the GEWEX modelling projects,
- There was strong support by conference attendees to see AMIP continue in some form.

The conference proceedings will be published as a WCRP report.

The WGNE session immediately following the AMIP Conference discussed future directions for AMIP. The discussions included recommendations from an AMIP panel meeting held in Reading in February 2002 namely, comprehensive diagnostic reports should be made available to modellers soon after they submit a simulation to PCMDI; AMIP should be exploited as a diagnostic tool of the coupled system with WGNE and WGCM working towards integrating AMIP and CMIP; and process studies should become an increasing diagnostic focus. It was also noted that (i) there was an external review of PCMDI in March 2002, which provided encouraging support for the continuation of systematically evaluating AMIP runs; (ii) diagnosis of coupled models is now a higher priority project at PCMDI than AMIP, and (iii) PCMDI will soon have a new director which would have a significant bearing on the future directions for the project. As with previous WGNE discussions on this topic and in line with the Workshop conclusions, WGNE continues to strongly support the continuation of AMIP as an experimental protocol providing an independent evaluation of atmospheric models and facilitating increasingly advanced diagnostic research. The Group recommended that the AMIP panel should meet again to discuss and provide advise on future directions for the project.

"Transpose" AMIP

Operational Numerical Weather Prediction has proven to be an excellent platform for examining parameterization methods as it allows direct comparison of the parameterized variables (e.g. clouds, precipitation) with observations early in the forecast while the modeled state is still near that of the atmosphere, but after initial transient computational modes are damped. Forecast centers report that such an approach is very useful in developing and evaluating parameterizations. Climate modeling groups not associated with an NWP centre generally have not been able to take advantage of such an approach because of the large amount of work involved in developing data ingest and assimilation systems. The question is how to obtain the benefits conferred by application of a model operationally in forecasting and assimilation for developing the parameterizations in climate models. The basic idea of a "transpose" AMIP and a companion project CCPP-ARM parameterization Testbed (CAPT) being undertaken by PCMDI and NCAR is to apply climate models to forecasts and examine how well the models predict the detailed evolution of the atmosphere at the spatial scales resolved by these models. Comparison with state variables from analyses and reanalyses and with estimates of parameterized variables from field campaigns should yield insight into the errors in parameterizations and lead to improved formulations.

The critical aspect is the initialization of the model for the forecasts. The basic approach is to map the climate scales as represented in analyses onto the climate model grid, eliminating the unresolved scales. The mapping of atmospheric state variables is reasonably straightforward as long as changes in orography and vertical coordinate system are accounted for. The mapping of parameterized atmospheric variables which have a time history (e.g. cloud water) is less obvious, but might be possible by considering the details of the parameterizations in both the climate model and analysis model. However, these variables are often related to fast process so their initialization might be less critical. Land model variables are more problematic because it is difficult to map the discrete/discontinuous land variables between different grids, there may be different dominant land types in the two systems, and there is no uniform definition of land model state variables. One approach currently being tried to obtain appropriate initial land values is to spin-up the land, and possibly atmospheric parameterized variables, over a period of time by having them interact with the atmosphere model constrained to follow the analyses in time by either periodically (e.g. 6-hourly) updating the atmospheric state or by adding a term to the model to force the state to follow the analyses to some degree (nudging). Both approaches may be more successful if poorly predicted atmospheric variables which drive the land, such as precipitation, are replaced by observed estimates as they are exchanged. Alternative approaches will also be considered. These include mapping reanalysis soil moisture profile to climate model by maintaining equivalent soil moisture availabilities, off-line land initialization (as in GSWP) driven with global observations, and inversion of observed surface fluxes.

WGNE is duly developing a project on these lines. Although a number of questions need to be resolved, the work to date is promising. Appropriate contacts will be taken with potential participants in discussing how to proceed. Advantage will also be taken of the experience in the Global Land-Atmosphere System Study (GLASS) where the planning of global scale interactive integrations has faced similar difficulties in the initialization of land surface and soil variables.

Snow Models Intercomparison Project (SNOWMIP)

SNOWMIP is being undertaken by Météo-France (Centre National de Recherches Météorologiques, Centre d'Etudes de la Neige, CNRM/CEN) under the auspices of WGNE and the International Snow and Ice Commission (ICSI) of the International Association of Hydrological Sciences. Liaison is also maintained with the GLASS. The objective of this project is to compare snow models of various complexity at four sites belonging to various climatic regions. A total of 24 models from 18 teams are involved. The models vary from simple models used for hydrology to sophisticated ones for snow physics research. The data for the runs were released in November 2000. After a workshop in July 2001 some teams were allowed to re-submit their results and the analysis began in January 2002. Some models show a good ability to correctly simulate the snow pack features for all of the sites, whereas other models are more adapted to particular conditions. The high alpine site is the best simulated site, because the accumulation and melting periods are distinct. The current analysis shows that when looking at a specific parameterisation (e.g. albedo, water retention…) the results are highly variable and some show discrepancies between observations and models. For instance an albedo parameterisation based on age only give bad results for the onset of melting at some sites. In 2003, the project intends to submit several papers and begin intercomparisons of detailed snow models. More information is available at http://www.cnrm.meteo.fr/snowmip/.

Comparisons of stratospheric analyses and predictive skill in the stratosphere

In the past two or three years, there has been growing interest in the representation of and prediction in the stratosphere and several major global operational centres have significantly increased the vertical extent and resolution of their models and associated data assimilation and predictions in the stratosphere and into the mesosphere. WGNE is thus undertaking a new intercomparison of stratospheric analyses initially, followed subsequently by an intercomparison of model predictive skill in the stratosphere. This work closely complements that carried out in SPARC "GRIPS".

Data from five NWP models (BoM, ECMWF, NCEP, NOGAPS and Met Office) have been received for the northern hemisphere component of this study. The target period was January - February 2000 which was an active period for the northern hemisphere polar vortex. The analyses were found to be relatively similar though there were distinct differences in the polar night jet magnitude, extent and location as well as the size and shape of the polar vortex low temperature regions between the models. All the available model forecasts were found to provide reasonable forecasts but were also found to have difficulty with certain days associated with large changes in the polar vortex. These days were generally linked to the rapid elongation of the polar vortex. Some models were found to cope with these days better than others. This study has now been extended to the southern hemisphere and similar datasets will be examined for the polar vortex splitting event in September - October 2002.

International Climate of the Twentieth Century Project (C20C)

The objective of the International Climate of the Twentieth Century Project, developed under the leadership of the Center for Ocean-Land Atmosphere Studies (COLA) and the UK Met Office Hadley Centre for Climate Prediction and Research, is to assess the extent to which climate variations over the past 130 years can be simulated by atmospheric general circulation models given the observed sea surface temperature fields and sea-ice distributions and other relevant forcings such as land-surface conditions, greenhouse gas concentrations and aerosol loadings. The initial experimentation being undertaken has involved carrying out "classic" C20C/extended AMIP-type runs using the observed sea surface temperature and sea ice as the lower boundary conditions (the HadISST 1.1 analyses provided by the Hadley Centre) for the period 1949-1997, with a minimum ensemble size of four members.

A workshop was convened in Calverton, MD, USA in January 2002 jointly by the Hadley Centre and COLA to review the results that had so far been obtained from the C20C model integrations and to plan a more highly structured C20C project. At the workshop the results from ensembles of runs forced with HadISST from the recent informal phase of C20C were summarised. Besides a number of diagnostic methods and new results on simulating 20th century climate, a presentation was made on the question of how limited AGCMs may be in simulating the variance of climate adequately. A specially designed experiment was created whereby the Hadley Centre HadAM3 AGCM was forced in ensemble mode with daily SSTs from part of a very long control run of the CGCM HadCM3. The initial conclusion is that the variance of those quantities looked on seasonal to decadal time scales are not significantly less in the AGCM than in the CGCM. Small differences that did occur were, however, consistent with the notion of excessive thermal damping in AGCM simulations. This supports the general validity of the AGCM approach for many types of climate predictability and trend studies. However an unresolved issue is whether some specific modes are missing in the AGCM that are present in the CGCM due to the lack of coupling. This work is being extended to include another AGCM/CGCM pair. The workshop decided that more emphasis should be placed on including forcings in addition to SST. Because of uncertainties in some forcings, and their tendencies to partially cancel, it was agreed to use (i) data from the Hadley Centre on changes in carbon dioxide since 1871, (ii) volcanic stratospheric forcing from 1950 only, and (iii) changes in tropospheric and stratospheric ozone. Participants will carry out a set of six integrations for 1871-2002 and a further set of 10 from 1950-2002. The HadISST will soon be updated in near real-time to make this possible. Participants will carry out a further 100-year control run with the 1961-1990 climatology of HadISST in order to study the role of naturally occuring modes.

Given that AMIP and C20C have a number of common features, WGNE expressed the view that both projects would gain by closer collaboration. C20C could, for example, follow AMIP in establishing a tighter experimental protocol and adapt some AMIP procedures, while AMIP should consider using the HadISST for any future phases.

## 2. STANDARD CLIMATE MODEL DIAGNOSTICS

The WGNE standard diagnostics of mean climate have now been in use for a number of years and, in particular, were the basis for the "quick-look" diagnostics for AMIP simulations computed by PCMDI (see section 1). (The list of these standard diagnostics is available at http://www.pcmdi.llnl.gov/amip/OUTPUT/ WGNEDIAGS/wgnediags.html.)

The standard diagnostics of mean climate included traditional variance and eddy statistics, but additional diagnostics of large-scale variability are also needed to characterize models. Over the past three years WGNE members have developed a list of standard diagnostics of variability focusing on the troposphere. These diagnostics have been demonstrated to be useful by individual developers and include measures of intraseasonal variability, Madden-Julian Oscillation (MJO), El Nino - Southern Oscillation (ENSO), blocking, seasonal cycle, diurnal cycle, atmospheric angular momentum, and modes of variability. They also include wavenumber-frequency plots, and histograms of precipitation. Examples of these diagnostics calculated from simulations with the NCAR Community Atmosphere Model (CAM2) can be seen at: http://www.cgd.ucar.edu/cms/mstevens/variability/index.html. They will also be included in the PCMDI "quick-look" diagnostics mentioned above. Code for the diagnostics will be available from both centres in the future.

## 3. DEVELOPMENTS IN NUMERICAL APPROXIMATIONS

The range of approaches being followed in numerical approximations for integrating partial differential equations on a sphere, and the types of grids being tried, were well illustrated by the scope of presentations at the 2001 Workshop on the Solution of Partial Differential Equations on the Sphere in Montreal, Canada, May 2001, the International Workshop on the next generation Climate Model in Tokushima, Japan, March 2002, the Second Hybrid-isentropic Modeling Workshop in Louisville, USA, April 2002, and the 2002 Workshop on the Solution of Partial Differential Equations on the Sphere in Toronto, Canada, August 2002. Examples included, for the shallow water equations, techniques for using icosahedral, cubed sphere, and spherical grids. Likewise for baroclinic systems to which much more attention was now being given, methods using isosahedral, cubed sphere, spherical grids with variable resolution, and adaptive meshes were described. In the vertical, although an example of the application of finite elements was presented, traditional "sigma" co-ordinates are still very much in use. Several new vertical approaches are being developed including the use of cubic spline in the vertical advection with the semi-Lagrangian scheme coupled with cubic finite-element in the vertical at ECMWF, and spectral element vertical and horizontal discretization coupled with semi-lagrangian transport at the Naval Research Laboratory. Additional studies in this area (e.g., to take advantage of isentropic co-ordinates) are now definitely needed.

Specific consideration is also being given to the development of new methods for application in climate models, and for simulation of atmospheric transport (e.g., of aerosols, trace chemicals) where local conservation and preservation of the shape of distributions are essential. Energy conservation in climate models is of particular importance. In practice, conservation of better than 0.1 $wm^{-2}$ is needed, whereas schemes with nonlinear intrinsic diffusion (e.g., Lin-Rood, monotonic semi-Lagrangian) can lose energy at a rate of 1.5 $wm^{-2}$, as can explicit diffusion schemes. This loss should be converted to heat, but this might not be the correct approach. This is still a basic uncertainty in model formulation that must be kept in mind. One possible approach being pursued is to move away from spectral to local grid point based methods with local conservation and shape preservation without polar filters.

The numerical representation of orography and transport modelling remain particular issues which WGNE intends to follow. Another important component of activities in this area is the development of tests of the various numerical schemes/grids in a baroclinic system before introduction into complete models where complex feedbacks can obscure effects of new schemes. Two new related tests were presented at the 2002 Workshop on the Solution of Partial Differential Equations on the Sphere which were based on the growth of baroclinicly unstable modes. These were developed by L.M. Polvani (Princeton University) and and R.K. Scott (Columbia University) and by C. Jablonowski (University of Michigan). Due to the nonlinear interactions of the growing modes the true solution is not known and reference solutions were computed with very high resolution dynamical cores. Details will be published in the future.

In addition to tests of dynamical cores in isolation, the interactions of physics parameterizations with each other and with the dynamics need to be examined. Stripped down versions of atmospheric models with very simplified surface conditions, in particular "aqua-planet" experiments with a basic sea surface temperature distribution, offer a useful vehicle in this regard, with considerable potential to understand the performance and effects of different dynamical cores and different representations of physical processes. For example, at NCAR, aqua-plant simulations with Eulerian and semi-Lagrangian dynamical cores coupled to the CCM3 parameterization suite produced very different zonal average precipitation patterns. Analysis showed that the contrasting structures were caused primarily by the different timestep in each core and the effect on the parameterizations rather than by different truncation errors introduced by the dynamical cores themselves. When the cores were configured to use the same time step, and same three time-level formulation and spectral truncation, similar precipitation fields were produced.

WGNE has recognized that aqua-planet experiments could have wide application in testing basic model numerics and parameterizations in the way described above and has duly endorsed the proposal for an "aqua-planet intercomparison project". This would be led by the University of Reading together with NCAR and PCMDI. The objective would not just be to assess current model behaviour and to identify differences, but to establish a framework to pursue and undertake research into the differences. An experimental design and data to be collected has been developed and a list of diagnostics to be computed and compared was being considered. Details of experimental design are available at :
http://www.met.reading.ac.uk/~mike/APE/ape_home.html

## 4. REGIONAL CLIMATE MODELLING

The Chairman of the WGNE/WGCM RCM panel, Prof. R. Laprise, reported on the second meeting of the PRUDENCE consortium that took place on 2-4 October 2002 in conjunction with the Second ICTP Conference on ‘Detection and Modelling of Regional Climate Change’, held at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy. The PRUDENCE activities that relate directly to WGNE and WGCM include the coordinated use of several climate models to assess, in a controlled manner, a number of numerical modelling uncertainties associated with climate-change projections. These include the use of several low resolution coupled GCMs (CGCM), atmosphere only GCMs (AGCM) and nested RCMs. AGCMs are usually run at medium resolutions, as time slices of high resolution uniform resolution models, or as variable resolution AGCMs. These models are driven with sea states based on recent climate analyses to which are added the climate change from CGCM simulations. RCMs are usually nested in AGCM simulated atmospheric states rather than CGCM atmospheric fields in order to reduce systematic biases.

Experimentation continues at the University of Quebec at Montreal (UQAM) following the so-called ‘Big Brother Experiment’ (BBE) perfect model protocol to assess the ability of nested regional climate models to reproduce with fidelity fine scales features. Earlier work using BBE focussed on the winter season over an eastern North American region where surface forcing is not dominant (Denis et al., 2002 and 2003). Further experiments have been carried out over a western North American region where there is a strong forcing exerted by orography (Antic et al., 2003), and for the summer season when surface processes exert a significant influence (Dimitrijevic et al., 2003). The overall conclusions of these perfect model experiments are as follows. One-way nesting RCMs can simulate quite accurately climate in terms of both large and fine scale components of stationary and transient eddies, when driven by large scale information in midlatitude winter.

The results are improved by the presence of strong surface orographic forcing. The RCMs' ability to reproduce accurately fine scale features is substantially reduced in summer, due to less effective large scale control by lateral boundary nesting. Additional findings of these studies concern the acceptable jump in spatial resolution between the driving and nested models and the acceptable time interval for providing lateral boundary conditions. For a 45-km grid RCM, it appears that a maximum jump of 6 (or possibly 12) is acceptable, which corresponds to an equivalent GCM spectral resolution of T60 (or possibly T30). The maximum acceptable update interval of the lateral boundary conditions for the nesting of a 45-km grid RCM appears to be around 6 hours. It is noteworthy that the maximum acceptable values of resolution jump and boundary update interval are mutually dependent.

In the ensuing discussions some further concerns on RCMs were expressed by WGNE members such as possible problems at boundaries due to the response of the land surface scheme and the ability to simulate the variability of extreme events. It was agreed that relevant WGNE members would provide Prof. Laprise with a write up of their concerns that would then be considered by the RCM panel. Following satisfactory resolution of these concerns, the RCM report will be finalised and submitted for publication in a general journal such as the Bulletin of the American Meteorological Society.

A number of options for the proposed WGNE/WGCM sponsored RCM Workshop have been considered, including holding a special session at an already scheduled RCM-related meeting. The favoured alternative currently being considered is for a joint WGNE/WGCM/IPCC RCM Workshop in early 2004. This is expected to be the recommendation of the RCM panel Chair to WGNE.

## 5. MODEL-DERIVED ESTIMATES OF OCEAN-ATMOSPHERE FLUXES AND PRECIPITATION

Evaluation and intercomparison of global surface flux products (over ocean and land) from the operational analyses of a number of the main NWP centres (the "SURFA" project) remains a high priority for WGNE. As well as the increasing concern in NWP centres with improving the treatment of surface fluxes, this activity responded to the request of the joint JSC/SCOR Working Group on Air-Sea Fluxes and the GCOS/GOOS/WCRP Ocean Observations Panel for Climate for a WGNE initiative to collect and intercompare flux products inferred from operational analyses. Moreover, the intercomparison of land-surface fluxes is of importance in the context of GLASS.

The atmospheric and coupled modelling communities and oceanographers have very strong interest in advancing SURFA, which could provide a good opportunity for real progress in estimating and determining surface fluxes. Some NWP fluxes are already being accumulated at PCMDI. Unfortunately, a committed funding source has yet to be identified for SURFA. Given the importance of this effort for a variety of research communities, it is hoped that this issue can be resolved soon.

Air–sea fluxes are directly important for a number of WCRP projects. Therefore, a background paper on 'WCRP and Fluxes' has been prepared by JPS/WCRP and WGNE was invited to comment on it. WGNE was also requested to consider the need to setup a 'WCRP Coordinating Committee on Air-Sea fluxes', given the very wide and varied requirements for air-sea fluxes within WCRP, and closely related programmes (eg. GODAE, GCOS). WGNE supported the idea and suggested that the proposed committee should have a nominee from WGNE whose contributions to the new group will be in validation of surface fluxes and through AMIP subprojects.

## 6. ATMOSPHERIC MODEL PARAMETERIZATIONS

The GEWEX "modelling and prediction" thrust, with which WGNE works in close association, is devoting efforts to the refinement of atmospheric model parameterizations, notably those of clouds and radiation, land surface processes and soil moisture, and the atmospheric boundary layer.

### Clouds

One of the main activities supporting refinement of model cloud parameterizations is the GEWEX Cloud System Study (GCSS) being conducted as a component of the GEWEX modelling and prediction thrust.The goal of GCSS is to improve the parameterization of cloud systems in atmospheric models through improved physical understanding of cloud system processes. The main tool of GCSS is the cloud-resolving model (CRM), which is a numerical model that resolves cloud-scale (and mesoscale) circulations in either two or three spatial dimensions. The large-eddy simulation (LES) model is closely related to the 3D CRM, but resolves the large turbulent eddies. The primary approach of GCSS is to use single-column models (SCMs), which contain the physics parameterizations of GCMs and NWP models, in conjunction with CRMs, LES models, and observations, to evaluate and improve cloud system parameterization.

GCSS is composed of five working groups, relating to boundary-layer cloud systems, cirrus cloud systems, extratropical layer cloud systems, precipitating convective cloud systems, polar cloud systems. C. Bretherton and P. Brown began serving as WG chairs during 2002, respectively for the boundary-layer and the cirrus groups.

The GCSS workshop held at Kananaskis in May 2002 reflected the increasing interest of the GCM community in GCSS activities and the increasing interaction of GCSS with the radiation, microphysics, aerosol, and cloud-remote sensing communities. The following scientific advances are expected in the GCSS WGs during the next several years:

- rapid progress on the representation of sub-grid scale cloud overlap and inhomogeniety due to the combination of CRMs, cloud radar observations, and faster methods of calculating radiative fluxes for arbitary cloud configurations;
- steady progress in the understanding and representation of cloud microphysical, formation, and dissipation processes due to integrated use of LES (large-eddy simulations) models, CRMs, SCMs, GCMs, and cloud-scale observations, plus insights from recent and upcoming field experiments; and
- use of super-parameterizations (i.e., CRMs used as parameterizations) in some GCMs will provide more physically realistic representations of cloud processes, to increase knowledge and understanding of interactions between cloud processes and large-scale processes (including cloud feedbacks), and to help improve conventional parameterizations.

Land-surface processes

The GEWEX Global Land-Atmosphere Study (GLASS) project is progressing through the various actions which were defined in the implementation plan. Under PILPS (Project for Intercomparison of Land Surface Parameterization Schemes), a set of simulations at the local and regional level was finalised over the Rhône basin, a new local study including carbon fluxes was initiated over a forested land in the Netherlands, and a third off-line intercomparison of land surface models is starting for the first time in a semi-arid region (San Pedro catchment in the southwestern U.S.).

The Global Soil Wetness Project 2 (GSWP-2) will start in early 2003 and first results should be available by the end of the year. Its goals are to:

- Produce state-of-the-art global data sets of surface fluxes, of soil wetness and related hydrologic quantities.
- Develop and test large-scale validation, calibration, and assimilation techniques over land.
- Provide a large-scale validation and quality check of the ISLSCP data sets.
- Compare Land Surface Schemes and conduct sensitivity studies of specific parameterizations which should aid future model development.

A major product of GSWP-2 will be a multi-model land surface analysis for the ISLSCP II period.

In order to assess our knowledge on the role surface moisture and temperature states play in the evolution of weather and the generation of precipitation, a new study called GLACÉ will address the problem of the relative role of land-surfaces in the variability of the climate system. This will be based on a series of GCM experiments using coupled free and forced land-surface schemes.

Atmospheric boundary layer

The "GEWEX Atmospheric Boundary Layer Study" (GABLS) has the principal objective of improving the representation of the atmospheric boundary layer in regional and large-scale models, based on advancing the understanding of the relevant physical processes involved. GABLS will also provide a framework in which scientists working on boundary layer research issues at different scales can interact. The first focus of GABLS is on stable boundary layers (SBL) over land. Much of the warming predicted by climate models is during stable conditions over land (either in winter or at night), while at the same time the understanding and parameterization of the SBL is still very poor. GABLS aims to provide a platform in which scientists working on boundary layers at different scales will interact.

A GABLS workshop on Stable Boundary Layers was held at the European Center for Medium-Range Weather Forecasting (ECMWF) in Reading, UK, on March 25-27, 2002 with a balanced participation of process modellers, observation specialists and GCM modellers.

Three task groups were defined on the following topics: the analysis of existing observations, in order to provide data sets to validate LES results and to help scope out the parameterization problem, large eddy simulations to help guide and evaluate proposed parameterizations, and GCM studies to provide feedback on updated parameterizations.

## 7. GEWEX CO-ORDINATED ENHANCED OBSERVING PERIOD (CEOP)

In the joint discussions with the GEWEX Modelling and Prediction Panel, the status of the planning and steps towards implementation of the GEWEX Co-ordinated Enhanced Observing Period (CEOP) were reviewed. CEOP has requested the WGNE community to provide comprehensive gridded output from global data assimilation systems. This requested output includes not only standard meteorological output but also output allowing study and analysis of water and energy processes in the atmosphere and land surface. In particular, detailed Model Output Location Time Series (MOLTS) have been requested at 41 international reference sites, where there are extensive in situ measurements and where extensive satellite products are being developed. This small data set will be complemented by more comprehensive 3 dimensional globally gridded data. Minimum output will include analysis variables, every 6 hours, as well as variables every 3 hours from a 6 hour forecast made every 6 hours as part of the analysis cycle. Every day at 1200 UTC, a corresponding 36 hour forecast is also requested, since this will provide some measure of how the models are adjusting (spinning up) to the initial state. This data will be archived initially by the individual meteorological centers and then later sent to MPI, which will develop a model output archive. NWP Centers are only being asked for comprehensive analysis and forecast output for the period Jul. 1, 2001-Dec. 31, 2004.

Most of the centres represented on WGNE were in principle ready to assist but raised questions concerning the complexity and long-term nature of the request, how the model data would be used in practice, and how CEOP would be useful for NWP centres. The need was expressed for a clearer exposition of the scientific strategy that would be followed by CEOP to exploit the in situ, remotely-sensed, and model output data to meet CEOP objectives. The point was reiterated that potential benefits of CEOP can be fully exploited by operational centres only if the data collected are available in real time. WGNE members were asked to consider carefully what recommendations could be made to CEOP so that it could better serve NWP centres. These recommendations were later communicated to CEOP.

Dr. John Roads made a presentation on the current status of CEOP and also responded to concerns that had previously raised by WGNE and communicated to CEOP namely,

1. *CEOP has not yet fully defined its objectives and modus operandi*

CEOP is developing a revised implementation plan, which will be made available soon.

2. *Why simultaneous observations?*

It is problematic to base global observations and modelling on single site observations. CEOP wants to develop the best possible global hydroclimatological 3-dimensional synoptic snapshot to provide the basis for future global hydroclimatological research in a wide variety of climate regimes. CEOP's hope is that these simultaneous observations could be continued beyond the initial CEOP period. It should be stressed that CEOP is a pilot project that could become the basis for an even longer-term experiment.

3. *Will there be a central archive or even a small number of distributed and coordinated archives?*

University of Tokyo will archive the satellite data, UCAR will archive the in situ data, NASA GLDAS will archive the GLDAS and US LDAS products, as well as pertinent satellite data, MPI will archive the model output. MOLTS will be mirrored at all data centers.

4. *Improved interaction needed with climate modellers, some key people claim they have not heard CEOP.*

There is growing community awareness.

5. *Some of the Executive blurb seems to envisage large-scale budget-type studies. However the data exchange is not in place and future long-period analyses would be required. Such studies and the making available of global data sets are a vastly bigger undertaking with nothing in place to make a coordinated program.*

This is a pilot study. If the data set does prove to be of value then it can be discontinued. CEOP believes the data sets will be continued and extended.

WGNE members were pleased to see that CEOP had responded to their concerns and that progress had been made. There was still some reservation concerning the request for 3-dimensional fields and some members felt that it might be better for CEOP to concentrate on relevant 2-dimensional fields with possibly higher resolution.

## 8. REANALYSES

ECMWF

The ambitious and comprehensive 40-year reanalysis project at ECMWF (ERA-40, August 1957 to December 2001), with support from the European Union, is progressing well. The assembly of a merged data set of conventional observations carried out in collaboration with NCEP and NCAR is complete. A surprisingly large amount of extra data is available compared to the earlier 15-year reanalysis (ERA-15), with, in particular, a significant increase in the number of radiosonde and pilot wind soundings from the NCEP data base. EUMETSAT is also reprocessing wind products from METEOSAT-2 from 1983-1988. The collection of observations is almost complete and the observational archive is itself a valuable resource that will be shared with NCEP and JMA for future reanalysis. Many problems with observations have been resolved although others remain, especially biases in radiance data.

The data assimilation is based on the system that was operational from June 2001 to January 2002 and includes 3DVAR analysis, T159 L60 resolution model, direct assimilation of raw radiances, analysis of ozone, a coupled ocean-wave model and enhanced set of post-processed products. Additional products include cloud statistics from TOVS radiance processing, fields from the physical parametrizations to support chemical-transport modelling, comprehensive outputs for selected grid points and catchment basins, vertically-integrated fluxes and data on isentropic and constant-PV surfaces. The reanalysis itself is being undertaken in three streams covering the periods 1987-2001 when TOVS, SSM/I, ERS, ATOVS and CMW data were available, 1972-1988 with VTPR, TOVS and CMW data, and 1957-72 (the pre-satellite era).

Tests of the assimilation of SBUV and TOMS ozone data have proceeded in parallel, and have given satisfactory results. SBUV and TOMS assimilation was thus added to the production system from January 1991 onwards. Ozone analyses for 1989 and 1990 will be produced off-line. In this connection, the ERA-40 experience has been invaluable in the development of operational assimilation of ozone at ECMWF.

A number of assessments of the ERA-40 analyses for the late 1980s and early 1990s have been made by the partners in the project (from ECMWF Member States and NCAR). In almost all respects, the quality of the ERA-40 analyses appeared to be superior to that of the ERA-15 analyses. The validation studies have identified some deficiencies especially with the tropical hydrology, and mixed results for the pre-1979 period.

ERA-40 data will be (i) available to all Member States via direct access (free), (ii) condensed onto CD with limited levels and parameters, (iii) available nationally via specific data centres such as NCAR, MPI, BADC, IPSL, (iv) available to non Member States via ECMWF (with handling charges), and (v) available in small subsets on the ERA-40 website (public).

Comprehensive information on ERA-40, including the current status of production and archiving and monitoring plots can be consulted via **http://www.ecmwf.int/research/era**.

NCEP

The original NCEP/NCAR reanalysis from 1948 is continuing to be carried forward to the present in a quasi-operational manner (two days after data time). The reanalyses distributed through NCAR, CDC and NCDC are readily available either electronically or on CD-ROM. A joint NCEP/DOE reanalysis (NCEP-2) for the period 1979-1999 has also been produced (available electronically). This was based on an updated forecast model and data assimilation with corrections for many of the problems seen in the original NCEP/NCAR reanalysis and also improved diagnostic outputs.

The current initiative is the preparation of a regional reanalysis over the USA for the period 1979-2004 to be continued later in near-real time. This should provide a long-term consistent data set for the North American domain, superior to the global reanalysis in both resolution and accuracy. The regional reanalysis will be based on the Eta model and the Eta data assimilation system with the global reanalysis used as boundary conditions. Model resolution will be 80km with 38 layers in the pilot stage and 32km with 45 layers in the production stage. Important features will be direct assimilation of radiances and assimilation of precipitation (over the USA), as well as recent Eta model developments (refined convective and land-surface parameterizations). Free forecasts will be carried out to 72 hours every 2.5 days. A range of data (including all those used in the global reanalysis, various precipitation data sets, TOVS-1B radiances for certain periods, profiler measurements, and lake surface data) has been assembled and a large number of pilot runs carried out. Considerable improvements are apparent in the precipitation patterns which look very similar to the observed precipitation patterns in summer, especially in runs where precipitation was assimilated. The fit to the upper air temperatures and vector winds (as observed by radio-sondes) and surface temperatures are also notably better than that of the global reanalysis.

The production of the regional reanalysis is now in progress and two streams will be run when the Class VIII machine becomes available. It is planned to complete most of the production by 31 August 2003, the last date that Class VIII machine will be available. A Users' Workshop is planned for 2003.

Japan Meteorological Agency (JMA)

The Japanese Reanalysis Project, JRA-25 is a five-year joint project of JMA, which is providing the operational data assimilation and forecast system, and the Central Research Institute of Electric Power Industry (CRIEPI), a private foundation providing computer resources. The objective of the project is to provide a comprehensive data set for the period 1979-2004 which will form the basis for a dynamical seasonal prediction project and global warming study, for advanced operational climate monitoring services at JMA, and for various activities in climate system studies. A 3DVAR system (operational since 2001) with a model resolution of T106 and 40 levels in the vertical will be employed. As well as data archived at JMA from 1975 to present, the NCEP/NCAR data used in the NCEP reanalysis and the merged ECMWF/NCEP data sets in ERA40, a range of satellite observations (including reprocessed GMS cloud motion wind data), and 'bogus' wind data surrounding tropical cyclones will be assimilated. The project is expected to be completed by 2005, with the products available to scientific groups contributing to the evaluation of the reanalysis and who provide feedback on improvements that could be made. Some recent developments include provision of TC bogus data by PCMDI/LLNL and two-year sample data of ERA-40 by ECMWF. The first announcement of invitation for evaluation group members was made in October 2002 and the second meeting of the JRA-25 Advisory Committee is planned for February 2003.

In the discussions following the presentations WGNE members reiterated that the JSC needs to seriously consider making reanalysis an ongoing effort, given the importance and strong support for the project. The current situation is unsatisfactory and wasteful because expertise built up for a reanalysis is lost when a phase is completed and then has to be reassembled with a new phase. A further advantage of an ongoing exercise is that it would facilitate research that is relevant to WCRP projects.

## 9. PERFORMANCE OF THE MAIN GLOBAL OPERATIONAL MODELS

As usual at its sessions, WGNE reviewed the changes in skill of daily forecasts produced by a number of the main operational centres over the past year. For most centres, a marked increase in skill (as indicated by the verification scores of root mean square error of 500 hPa geopotential in the northern and southern hemisphere at various lead times out to seven days) was again apparent; this increase has now been sustained since the first part of 1999. Improvements were particularly notable in the case of ECMWF, NCEP and the Met Office. At all time ranges, the advance in skill of ECMWF forecasts was outstanding. In the southern hemisphere too, there were distinct increases in skill in forecasts from several centres, with levels sometimes approaching those seen in the northern hemisphere. WGNE ascribed this to the increasing capability of using variational data assimilation schemes and an incremental improvement in the exploitation of observational data in the southern hemisphere.

## 10. INTERCOMPARISON OF TYPHOON TRACK FORECASTS

An intercomparison of forecasts of typhoon tracks in the western North Pacific has been conducted by the Japan Meteorological Agency on behalf of WGNE for a number of years. The intercomparison has now been extended to cover also the North Atlantic and eastern North Pacific regions. The operational centres submitting forecasts now include ECMWF, the Met Office, the Canadian Meteorological Center, Deutscher Wetterdienst, and the Japan Meteorological Agency. Results show continuing improvements in the track forecasts although there is considerable variability from year to year and from basin to basin. A report summarizing the results of the intercomparisons over the period 1991-2000 has being prepared by the Japan Meteorological Agency and published as a WMO report.

## 11. VERIFICATION AND COMPARISON OF PRECIPITATION FORECASTS

As a principal contribution to WGNE activities in this area, NCEP, DWD and BMRC have been verifying twenty-four and forty-eight hour quantitative precipitation forecasts from eleven operational NWP models for a six-year period against rain gauge observations over the USA, Germany, and Australia in order to assess the skill in predicting the occurrence and amount of daily precipitation. It has been found that quantitative precipitation forecasts have greater skill in mid-latitudes than the tropics where the performance was only marginally better than persistence. The best agreement among models, as well as the greatest ability in discriminating rain areas, occurred for a low rain threshold of 1-2 mm/day. In contrast, the skill for forecasting rain amounts greater than 20 mm/day was generally low, pointing to the difficulty in predicting precisely where and when heavy precipitation may occur. In spite of the impressive progress made in numerical weather prediction, quantitative precipitation forecasts have only shown marginal improvement over the five to six year period examined. A paper documenting this work has been accepted for publication in the Bulletin of the American Meteorological Society.

The validation of precipitation forecasts has become an increasingly important activity. Accordingly this WGNE project has expanded significantly and the Met Office, Meteo-France, JMA and CMA have also started verifying precipitation forecasts in their regions. Of particular interest is the Met Office study which will attempt to verify precipitation in 3-h periods. This should shed light on model performance during the spin-up period and diurnal variation of precipitation, in addition to the daily rainfall amounts. WGNE was prominently involved in the organization of the International Conference on Quantitative Precipitation Forecasts that was held in Reading, UK in September 2002.

## 12. THORPEX: A GLOBAL ATMOSPHERIC RESEARCH PROGRAMME

At the invitation of WGNE, Prof Alan Thorpe made a comprehensive presentation on THORPEX: A Global Atmospheric Research Programme. A key change in the past year has been the change in focus from a hemispheric to global experiment. Prof. Thorpe described THORPEX as a ten-year international research programme designed to accelerate improvements in short-range (up to 3 days), medium-range (3 to 7 days) and extended-range (week two) weather predictions, and in the societal and economic value of advanced forecast products. The programme builds upon ongoing advances within the basic research and operational forecasting communities and it will make progress by enhancing collaboration between these communities. THORPEX core scientific objectives are to:

- advance basic knowledge of global-to-regional influences on the evolution and predictability of high-impact weather;
- contribute to the development of dynamically-interactive forecast systems, which will include the concept of targeting;
- develop and apply new methods for assessing the economic and societal value of weather information;
- carry out THORPEX Observing-Systems Tests (TOSTs) and THORPEX Regional Campaigns (TRCs);
- demonstrate the full potential of THORPEX research results for improved operational forecasts of predictable high-impact weather events on time scales out to two weeks and beyond. This demonstration, the THORPEX Prediction Experiment, will last for up to one year.

The themes proposed are of major interest to WGNE, and the studies of predictability and observing system issues being taken up will have benefits throughout the WCRP. The international coordination of THORPEX is under the auspices of the WMO, WWRP and WGNE. The THORPEX International Science Steering Committee (ISSC) defines the core research objectives with guidance from the THORPEX International Core Steering Committee (ICSC) whose members are selected by national permanent representatives to the WMO.

WGNE reiterated its support for THORPEX as a collaborative WWRP/WGNE experiment. At the WGNE session, a joint WWRP/WGNE draft resolution concerning the current status and the next steps in the development of THORPEX was reviewed and finalised in consultation with the Chair of the WWRP, Dr R. Carbone. The committees agreed that the essential next step is the development and submission of the detailed THORPEX Science plan for review and consideration by WWRP and WGNE.

## 13. REVIEW ON STATUS OF MESOSCALE NUMERICAL WEATHER PREDICTION

Mesoscale models have grid spacings of around 50 km, most around 10 km, and a few special purpose models have smaller grids. A limit on resolution of mesoscale models is given by the resolution of global uniform models, some of which are being run at 40 km (eq ECMWF). Mesoscale models are being used for operational forecasting, urban air quality, dynamical adaptation, quantitative precipitation forecasting, ensemble prediction, aviation, research and development etc. There are two types of lateral boundary conditions: variable resolution and limited-area. Variable resolution is well posed, two-way interactions are allowed but it is more expensive and slower. Limited-area models use a variety of boundary conditions: the most commonly used are Perkey-Kreisberg and Davies which allow one-way interactions only but are cheaper and faster. Research is being carried on more transparent boundary conditions for limited-area models. This is motivated by the fact that as the grid spacings get smaller so do integration domains and the sensitivity to boundary conditions gets larger. The principles for model design can vary but an example is given by DWD/COSMO model which uses non-hydrostatic dynamical equations, efficient numerical method of solution, comprehensive physics package, flexible choice of initial and boundary conditions, mesh-refinement techniques, ability to focus on regions of interest, handles multi-scale phenomena, and uses high-resolution data sets for external parameters. Some commonly used basic design options that are being used for the dynamics include Eulerian / semi-Lagrangian advection, grid-point / spectral discretization, latitude-longitude / Lambert grid.

Some key issues in mesoscale modelling that are the subject of current and future work include –

- What is the relation between resolution and grid spacing?
- What is the appropriate physics for a given grid spacing?
- Should physics be chosen with resolved wave or grid spacing?
- What is the robustness or sharpness of a given physics parameterisation?
- How far can we go with a given physical parameterisation?
- Should stationary forcings be filtered and by what amount?
- What is the limit of integration time for a useful forecast with one-way nesting and a given domain?
- Is ensemble forecasting preferable to increased resolution?
- Should dynamics and physics timesteps be the same?
- Is increased vertical resolution needed?
- Where should the top of mesoscale models be?
- Should special care be taken about formal conservation?

## 14. VERIFICATION TECHNIQUES FOR MESO-SCALE MODELS

Whilst rms errors, anomaly correlations, skill scores etc. are objective indicators of large-scale model performance, consideration needs to be given to providing measures for the much higher resolution and/or mesoscale models now increasingly employed and for verifying predictions of weather elements and severe events. Work is now being undertaken in this area for parameters such as quantitative precipitation forecasts, two-metre temperature and humidity, ten-metre winds, cloudiness etc. For verification purposes, the basic observational data used are SYNOPs, with data from automatic and climate network stations also increasingly important. Additionally, radar data and high resolution satellite observations have significant potential in this area. There is general consensus that new methods are needed for the verification of mesoscale models, that there should be enhanced international exchange of the relevant data, and that intercomparison of model scores can be useful if done thoroughly and consistently. The issue has been actively discussed at the past two WGNE sessions.

In its 13th session, the WMO/Commission for Atmospheric Science tasked WGNE to prepare a position paper on high-resolution model verifications, oriented towards weather elements and severe weather events (item 5.3.10 of the abridged final report, document WMO-N°941). This recognizes the specific difficulty of traditional verification methods in providing a useful measure of model performance at high resolution and for intense events. First, the verification of mesoscale events is limited by the insufficient density and quality of the observing networks. Second, the related weather elements may be on the edge of predictability, or entirely stochastic from the perspective of current NWP models. As such, the traditional verification methods based on instantaneous comparison of analyzed and predicted fields may not yield useful information, and new methods are needed. Third, there is a great expectation that mesoscale models will deliver products of direct relevance to end-users, and consequently much work is done on the development of user-oriented verifications, but the needs are not the same for user-oriented and developers-oriented verifications.

The verification of numerical models against observations has several purposes. For instance: (i) provide a measure of the progress of the forecast skill over the years; (ii) compare the merits of two versions of a forecasting system in order to decide which is the best for operations; (iii) understand where the problems are and what aspects of the system need refinements; (iv) compare the relative value of two different systems for a specific category of users. No single verification system can be optimal for all of these tasks and there is a need to issue guidance on what methods are good for what purpose.

A position paper on verification has now been prepared by Dr. Philippe Bougeault on behalf of WGNE and is included in the current issue. The purpose of the present paper is to report on a survey of methods currently in use or under development in many operational NWP centers, and to provide guidance on desirable features for verification methods, based on shared experience.

In recognition of the importance of verification in general, there is now a proposal to form a joint WGNE/WWRP Working Group on Verification.

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