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The seventeenth session of the CAS/JSC Working Group on Numerical Experimentation (WGNE), held jointly with the fifth session of the GEWEX Modelling and Prediction Panel (GMPP), was kindly hosted by Deutscher Wetterdienst, Offenbach, Germany, from 29 October to 2 November 2001. The session was opened at 0905 hours on 29 October by the Chairman of WGNE, Dr. K. Puri, and of GMPP, Dr. D. Randall. The list of participants in the (joint) session is given in the Appendix.

Mr. U. Gärtner, President of Deutscher Wetterdienst and Permanent Representative of Germany with WMO welcomed all participants to the headquarters building of Deutscher Wetterdienst and Offenbach. Mr. Gärtner spoke of the importance of the agenda to be taken up at the session which should lead to valuable results for meteorological services. He particularly stressed the need to improve predictions of extreme events.

On behalf of all participants, Dr. K. Puri expressed gratitude to Mr. Gärtner and Deutscher Wetterdienst for hosting the joint session of WGNE and GMPP and the excellent arrangements made. He voiced his appreciation to Dr. W. Wergen, ably assisted by Ms. A. Bierman, for the efforts and time they had put into the organization of the session.

Dr. G. Adrian, Director of Research at Deutscher Wetterdienst added his welcome to participants and reviewed the range of activities undertaken by Deutscher Wetterdienst especially in the research and development area. As well as a strong meteorological analysis and modelling programme, including global circulation and meso-scale models (which would be presented in greater detail during the course of the WGNE/GMPP session - see section 6.4), Deutscher Wetterdienst made a significant contribution to climate and environmental studies, in particular by hosting the German National Climate Data Centre, the (EUMETSAT) Satellite Application Facility for Climate Monitoring, as well as the data centre for the Baltic Sea Experiment (BALTEX) and the Global Precipitation Climatology Centre (also presented in greater detail during the course of the WGNE/GMPP session - see section 6.1). Deutscher Wetterdienst also supported a range of environment- or climate-related observations (for example, a WCRP Baseline Surface Radiation Network station, a reference station for the GEWEX Water Vapour Project, the RA VI Dobson Centre, and a Global Atmospheric Watch Station). The relevance of a number of these activities for GEWEX was noted.

1. RELEVANT RECOMMENDATIONS FOR THE DEVELOPMENT OF WGNE/GMPP ACTIVITIES

At the WGNE/GMPP session in October 2000, a proposal for an atmospheric boundary-layer study to be undertaken within GEWEX, under the auspices of GMPP, had been introduced (the GEWEX Atmospheric Boundary Layer Study, GABLS). This proposal had been endorsed by the GEWEX Scientific Steering Group at its session in January 2001. In its turn, the Joint Scientific Committee (JSC) for the WCRP recognized the need for activities in this area but stressed the cross-cutting nature of the questions involved which were of wide interest in the WCRP. The development of work in GABLS is described in section 2.4: the initial focus would be a study of the stable atmospheric boundary layer over land.

The WGNE/GMPP session was reminded that the thirteenth session of the Commission for Atmospheric Sciences (CAS) would take place in February 2002, where WGNE activities would be discussed. The Commission viewed collaboration between WGNE and the developing World Weather Research Programme (WWRP) as of considerable importance (see section 5.1 for description of the status of WWRP). One of the key WWRP initiatives was THe Observing System Research and Predictability Experiment (THORPEX) being undertaken as a "Research and Development Programme" of WWRP in collaboration with WGNE for numerical aspects. WGNE/GMPP would be invited to consider how to assist in the further development and implementation of THORPEX (see section 5.1). The session would also be called on to review and contribute to the policy statement that CAS had been requested to provide on the "scientific basis and limitations of forecasting weather and climate", indicating the limits of predictability and what useful information forecasts could be expected to provide (see section 5.1).

2. PHYSICAL PARAMETERIZATIONS IN MODELS

The development of improved interactive formulations of a variety of physical processes in models (including cloud systems, land-surface processes, and the atmospheric boundary layer) was a key objective of the GEWEX modelling and prediction thrust.

2.1 <u>Review of radiative processes and their parameterization</u>

Dr. H. Barker, representing the GEWEX Radiation Panel, presented the status and highlighted a number of the outstanding issues in the parameterization of radiative transfer. Firstly, it was noted that surface irradiances measured in the US Department of Energy Atmospheric Radiation Measurement (ARM)

Program at the site in the Southern Great Plains provided a good benchmark for radiation computations. In particular, close agreement was now being found with line by line models (although for gaseous transmission the "correlated-k distribution" (CKD) paradigm has almost entirely replaced other methods). In respect to aerosols, there still remained many uncertainties as to global sources and sinks and the distribution of constituents. Mostly, the composition was unknown with consequent lack of knowledge of optical properties. There was only limited understanding of processes such as mixing with cloud droplets. There were still numerous outstanding questions in the estimation of surface albedo e.g., over water: dependence on wind speed (Fresnel reflection), enhancement by suspended sediment and breaking waves. Over land, such aspects as shadowing of snow over mountains, and masking and interception of snow by vegetation were problematic. In determining cloud optical properties, a spectral integration was often made over droplet size distributions whereas, in reality, properties depended on the spectral distribution, a function of the distribution of photon paths. However, in computing fluxes, idealized scattering phase functions were usually adequate for clouds. Dr. Barker noted that an updated intercomparison of short-wave radiation codes in climate models (ICCRM) was now being undertaken (ten years since the last exercise). The objectives would be to assess how well one-dimensional codes interpreted and handled unresolved clouds, and to compare one-dimensional and three-dimensional solar flux estimates for clear sky and overcast (plane-parallel homogeneous clouds) conditions. For simple cases, most one-dimensional codes underestimated atmospheric absorptance (typically by 20 Wm^{-2}, up to half of which could be a consequence of a lack of water vapour continuum). In the case of long-wave radiation, new schemes for scattering by cloud droplets and for treating cloud overlap and horizontal variability were coming into use, as well as techniques for taking into account unresolved clouds.

2.2 Cloud parameterizations

One of the principal activities aimed at refinement of parameterizations in models was the GEWEX Cloud System Study (GCSS). The aim was to achieve a better understanding of the coupled physical processes at work within different types of cloud, the overall emphasis being on determining the effects of clouds acting as systems rather than individual clouds or the role of individual cloud processes. Dr. S. Krueger, Chair of the GCSS Science Panel, recalled that five different cloud types were being specifically studied: boundary layer; cirrus; extra-tropical layer clouds; precipitating convectively driven cloud systems; polar clouds. In each area, a series of case studies drawing on observations from various field studies was being conducted to evaluate the simulations of cloud-resolving or cloud-system models and the treatment of the relevant processes. Single-column models were also valuable tools particularly in making connections between general circulation models and data collected in the field, thereby facilitating observationally based evaluations of new parameterizations in isolation from the large-scale dynamics. Ultimately, cloud parameterizations must, of course, be tested in full climate simulations or in numerical weather prediction models and the organization of such activity was being considered. Attention was also being given to parameterization development, and assessing new treatments and their performance in single-column or cloud system models. Full details of the scientific issues being addressed in GCSS and the studies carried out or underway were included in the GCSS Science and Implementation Plan (**http://www.gewex.com/gcss_sciplan.pdf**). A general GCSS meeting was being planned in Canada in May 2002 (jointly with an ARM workshop).

Dr. G. Tselioudis (NASA/GISS), leader of GCSS Working Group 3 dealing with extra-tropical layer clouds, outlined the results of studies of the representation of mid-latitude layer clouds in global circulation models. Firstly, it was seen that cloud optical depths were too large in regions of both ascending or descending air currents: it appeared that cloud water content was probably overestimated in the water budget calculations. There was too little cloud cover in desert regions, perhaps linked to the boundary layer being too dry or subsidence too strong. Also, cloud-top heights were too low in regions of descent, possibly suggesting that turbulent mixing or shallow convection was too weak. Higher resolution global models had distinctly better simulations of mid-latitude clouds and their properties (although not much improvement was apparent for resolutions finer than about 2°x 2° with the type of parameterizations currently in use).

Dr. D. Randall presented preliminary results from a short climate simulation with a two-dimensional cloud resolving model installed in each grid column of the NCAR Community Climate System Model. The cloud resolving model replaced the conventional convective and stratiform cloud parameterizations and allowed for explicit computation of the global cloud fraction distribution for use in the computations of radiative transfer. Clearly the embedded cloud system model increased greatly the computational cost of running the model (by about a factor of 180), and this has meant that the length of the simulation with the combined model (with a 2.8°x 2.8° resolution) has so far had to be limited to two months. However, the simulated distributions of total rainfall, precipitable water, cloud cover and the Earth's radiation budget were very realistic. In detail, deep convection, including mesoscale organization, downdrafts and anvils, fractional cloudiness, cloud overlap, three-dimensional cloud-radiation effects and convectively generated gravity waves were all explicitly represented. Microphysics, radiative transfer, and turbulence and small-scale convection had still to be parameterized but this was facilitated with the high resolution of the cloud resolving model. There were a number of technical issues that also had to be dealt with such as the consistency between the cloud resolving model and the host general circulation model, coupling methods, and the incorporation of the planetary boundary layer and land surface. Nevertheless, this approach of combining models was potentially an important new path towards the goal of climate simulation with physically realistic cloud processes and cloud feedbacks. The advent of massively parallel processing and distributed architectures opened the door to the approach, since it appeared that the hybrid cloud/general circulation model could use thousands of processors with a high degree of computational efficiency.

Dr. K. Puri reported on the initiation of a joint BMRC/CSIRO/ARM programme in the Darwin area aimed at linking atmospheric radiation measurements with parameterization issues. Specific targets were the long-term monitoring of the four-dimensional structure, evolution and associated radiative properties of coastal maritime and continental tropical cloud systems, formulation and validation of model parameterizations, assessment of the importance of the vertical structure of aerosols at Darwin on aerosol products retrieved using a combination of instrumental measurements, and clarifying the effect of thin cirrus clouds on aerosol retrievals. A new Bureau of Meteorology observing office was opened in August 2001, ARM instruments/equipment delivered, and installation/testing had begun. The site was expected to be operational by March or April 2002.

Dr. Puri also drew attention to the Darwin Area Wave Experiment (DAWEX) in progress at the time of the WGNE/GMPP session. Stemming from an initiative of the WCRP study of Stratospheric Processes and their Role in Climate (SPARC), the experiment involved scientists from Australia, Japan and the USA, and was designated to characterize the wave field in the middle atmosphere over northern Australia excited by intense diurnal convection in this area (known locally as "Hector"). The experiment included three five-day intensive observation periods in October, November and December 2001 during which there were three-hourly radio-sonde observations from three north Australian locations. In addition, ground-based air-glow imagers provided by groups in Japan and the USA, radars to monitor winds in the mesosphere and lower thermosphere, and a Doppler radar were deployed. The findings and results of DAWEX will help in the preparation of a larger-scale "Effects of Tropical Convection Experiment" (ETCE) in 2005 or later.

2.3 Land-surface processes

Global Land-Atmosphere System Study (GLASS)

Dr. J. Polcher reviewed the progress being made in the planning and implementation of GLASS which has been designed to encourage the development of a new generation of land-surface schemes for incorporation into general circulation models. As reported at the WGNE/GMPP session in 2000, extensive intercomparisons of land-surface models ranging from local to global scales and from off-line experiments to fully coupled are being co-ordinated.

Recent specific local-scale/off-line intercomparisons (a continuation of activities initiated by the Project for Intercomparison of Land-surface Parameterization Schemes, PILPS) included a study of simulations of the surface hydrology in land-surface models in high latitudes. The key processes involved were the snow regime, turbulent fluxes in cold climates, and frozen soil and surface water storage. It was found that the main differences between the simulations were caused by uncertainties in the rate of sublimation from a snow-covered surface. Large differences in land-atmosphere sensible heat flux were also noted, a consequence of the decoupling of the atmosphere and surface in stable conditions. Another local-scale/off-line intercomparison in preparation was aimed at evaluating the ability of land-surface models to simulate carbon fluxes over a forested area (in the Netherlands) and to represent both the biophysical and biogeochemical processes involved, and to examine how well observed carbon sinks were captured. At a larger scale, experimentation was being planned to assess the performance of land-surface models in reproducing the discharge for a number of sub-basins in the Rhone Valley over several annual cycles ("Rhone-AGG" organized by Météo-France/CNRM as a contribution to GLASS). Questions to be investigated were the extent to which the sub-grid run-off and drainage parameterizations were scale dependent, how various aggregation methods employed compared, and the impact of grid resolution on simulated surface water exchange and snow-melt run-off.

Global scale/off-line experiments were being undertaken using ISLSCP-II data to check model representation of interannual variability over a ten-year period. The sensitivity to errors in the forcing data would be explored, whether land-surface models could be satisfactorily validated at the global scale with remotely-sensed data, the comparability of drying-out cycles in different models, and the simulation of carbon dioxide fluxes at the global scale.

Coupled, local-scale experiments were beginning to indicate the importance of coupling, in particular that the effects of feedback from the planetary boundary layer could be significant. At the global-scale, experimentation was being designed to assess benefits that could result from more realistic precipitation values in improving the behaviour of land-surface schemes and the simulated climate. The role of surface initial conditions was also being investigated based on a multi-model ensemble. Soil moisture was being initialized over a three-to-four month period using observed precipitation amounts, by when it was assumed that the model soil moisture would be realistic. In the integration phase, soil moistures would be free to evolve and diverge.

WGNE and GMPP agreed that, overall, GLASS was advancing satisfactorily. Activities in the coupled, local-scale area needed to be enhanced as this would underpin interactions with GCSS in examining the effects of an improved land-surface treatment in cloud experiments, with the "GEWEX Atmospheric Boundary Layer Study" (GABLS) (see section 2.4) in searching for better ways of forcing land-surface schemes outside atmospheric models, and with data assimilation studies for appropriate refinements to land surface models.

Development of a European Land Data Assimilation System (ELDAS)

Dr. M. Miller outlined the scope foreseen for ELDAS as a research/demonstration European Union project. The intention was to bring together European-wide expertise in the area of assimilation of soil moisture and to provide a major European contribution to a global land data assimilation system. A particular objective would be to prepare and exploit remotely-sensed data (Meteosat/MSG thermal/visible; SMOS and AMSR microwave) in soil moisture assimilation in combination with observed precipitation (gridded analyses of daily gauge totals, merged with model precipitation fields in data-sparse areas).

2.4 Atmospheric boundary layer

The WGNE/GMPP session in October 2000 reviewed a proposal for a "GEWEX Atmospheric Boundary Layer Study" (GABLS). The principal objective would be to improve the representation of the atmospheric boundary layer in general circulation models, based on advancing the understanding of the relevant physical processes involved. GABLS should also provide a framework in which scientists working on boundary layer research issues could interact.

Dr. B. Holtslag summarized the progress so far in planning GABLS. The initial focus would be the treatment of the stable atmospheric boundary layer over land, for which understanding and parameterizations were limited (e.g. see reference to issue noted in section 2.3 concerning decoupling of the atmosphere and surface in stable conditions). Details of the work needed would be developed at a workshop at ECMWF, Reading, UK, in March 2002, in which process-oriented experts and large-scale modellers would be brought together.

2.5 The Mesoscale Alpine Programme (MAP)

Dr. P. Bougeault summarized scientific studies being undertaken in the Mesoscale Alpine Programme (MAP) (formally a World Weather Research Programme project) and the results being found. The basic objectives set out for MAP were to improve the understanding and prediction of:

- orographically influenced precipitation events and related floods, involving deep convection, frontal precipitation and run-off;
- the life cycle of Föhn-related phenomena, gap flows, gravity-wave breaking and the Alpine wake in general;
- the turbulent boundary layer within Alpine valleys.

The MAP Special Observing Period took place from 7 September to 15 November 1999 with the participation of many European and North American meteorological services and science agencies. In terms of ground systems, MAP was probably one of the largest field experiments ever conducted in Europe. In the special Observing Period of 70 days, there were also seventeen Intensive Observing Periods totalling 42 days. Statistical evaluation has shown that 1999 was a very good year from the perspective of the frequency and distribution of MAP-relevant atmospheric events (all occurred more frequently than expected compared to the average over the last ten years).

Since then, using the data collected, research has been undertaken into a range of scientific topics including:

- orographic precipitation mechanisms involving studies of the small scale dynamics of precipitating systems and their interaction with topography, and of the detailed growth mechanisms of precipitation particles;
- incident upper-tropospheric potential vorticity anomalies ("PV-streamers"), focussing on the dynamics of such anomalies approaching the Alps from the west at tropopause level and their role as precursors of severe precipitation events in the Alps;
- hydrological measurements and flood forecasting, assessing the near-real time forecasting capabilities of hydrological flood models, soil moisture monitoring techniques, the significance of soil moisture initial conditions, and the utility of information on water storage for hydro-electric power companies;
- dynamics of gap flow, investigating the three-dimensional velocity distribution at the Brenner Pass and within the Wipp Valley, its space-time variability in relation to flow above the mountain top, and key questions of stratified fluid dynamics such as the possible formation of a hydraulic jump downstream of the gap;
- non-stationary aspects of the Föhn in a large valley, specifically examining the four-dimensional variability of the Föhn flow in the Rhine valley (upstream of Lake Constance) and the dynamical processes involved, in particular those responsible for the removal of the pool of cold surface air frequently present in the Rhine valley at the onset of Föhn;
- three-dimensional gravity wave breaking, seeking answers to basic questions such as its role in clear-air turbulence, its space-time distribution, the predictability of gravity waves in meso-scale models, the vertical distribution of momentum fluxes in the presence of breaking gravity waves, and the associated potential vorticity generation;
- potential vorticity banners, including examination of the high resolution structure of the Alpine wake at or below mountain-top level, and documenting the existence and cross-stream spatial flow of well-defined potential vorticity banners extending downstream over several hundred kilometers (as suggested in modelling studies);
- structure of the planetary boundary layer over steep orography, including its depth, the three-dimensional distribution of turbulent fluxes within a steep valley, the interaction of boundary layer turbulence and local winds, and the exchange of air mass and atmospheric constituents between the boundary layer and the free atmosphere.

A detailed description of the MAP Special Observing Period and the scientific questions being investigated was published in 2001 in the Bulletin of the American Meteorological Society, 82, 433-461.

3. STUDIES AND COMPARISONS OF ATMOSPHERIC MODEL SIMULATIONS

3.1 General model intercomparisons

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, was a series of model intercomparison exercises. These encompassed a number of fairly general wide-ranging intercomparisons as outlined in this section, as well as more specific efforts, e.g., evaluation of snow models as employed in atmospheric circulation models (see section 3.5), or assessment of stratospheric analyses and predictions (see section 3.6).

Atmospheric Model Intercomparison Project

The most important and far-reaching of the WGNE-sponsored intercomparisons was the Atmospheric Model Intercomparison Project (AMIP), 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. Dr. P. Gleckler reviewed the status and progress of the project, which, based on a community standard control experiment simulating the period 1979-1996, was now reaching the end of its second phase (AMIP-II). Twenty-three modelling groups have submitted simulations and much of the data from these runs were available for a wide range of diagnostic sub-projects. A few further groups might provide integrations before the end of the year, the time limit recommended by WGNE for the current phase of AMIP. In addition to the standard runs, ensembles and runs at varying horizontal resolutions were being archived for specific research sub-projects. Climatological comparisons have been made available for nearly every standard AMIP model output field, and probably represented the most comprehensive source of the climatologies of atmospheric circulation models. AMIP research has been structured round a series of diagnostic sub-projects and a clear view of how models have evolved since AMIP began nearly a decade ago has emerged. Overall, there has been a general improvement both in terms of the "median" model as well as for many of the individual models. The simulation of interannual variability and performance in specific geographical regions, as measured by global climatological statistics, also appeared to be more realistic.

Regular updates of the overall status of AMIP, model integrations, and diagnostic subprojects were posted on the AMIP home page **http://www-pcmdi.llnl.gov/amip**.

On the technical side, PCMDI had now completed an open source software system which enables much more efficient management of the voluminous AMIP data sets. An automatic system has been put in place to organize the simulations, perform extensive quality control, and make the data accessible (via FTP) to interested users. Most importantly, modellers could now access a "quick-look" summary of the performance of submitted runs, thus enabling PCMDI to turn towards developing increasingly advanced climate model diagnostics.

In its review of AMIP, WGNE noted that the project had become a well-defined experimental protocol for testing global atmospheric circulation models. However, although useful, model intercomparison by itself left many questions unanswered. Thus, the "I" in AMIP might now also stand for "Infrastructure" in view of the powerful capabilities PCMDI has built for handling model integrations, and so effectively facilitating the diagnosis and display of many characteristics of the results. Efforts were also underway to increase co-ordination with the Coupled Model Intercomparison Project (CMIP), in particular to encourage the preparation of an AMIP simulation using the atmospheric component of coupled models, as has been recommended by WGNE. The plan to hold the Second International AMIP conference in Toulouse, France, 12-15 November 2002 (in conjunction with the next session of WGNE) was welcomed and endorsed. The conference would highlight the results from the AMIP-II diagnostic sub-projects and provide an opportunity for activity reports from the participating modelling groups.

Looking beyond the conference, WGNE strongly supported the continuation of AMIP as an experimental protocol providing an independent evaluation of atmospheric models and facilitating increasingly advanced diagnostic research. It was considered that AMIP should evolve from a "snapshot" exercise (such as AMIP-I and AMIP-II had been) into an ongoing activity, with modelling groups submitting updated runs with new versions of their models every few years (at a time of their choosing) and that a centralized library of these simulations (including a model median) should continue to be maintained as a gauge of progress in atmospheric modelling. A number of other suggestions were put forward which would be taken up by a session of the AMIP panel in February 2002 to draw up a blueprint for the future of AMIP as well as detailed plans for the AMIP Conference in November 2002 (the WGNE-appointed AMIP panel advises on the practical implementation of AMIP).

The type of valuable overview of characteristics of models provided by AMIP was well illustrated by a brief report from Dr. V. Kattsov on the performance of climate models in high latitudes (this in fact drew on AMIP, CMIP and the IPCC Data Distribution Centre data bases). It was firstly noted that the inter-model variance of the simulated air temperatures was larger in coupled than uncoupled models, this being at least partially a consequence of extra degrees of freedom in the variation of sea-ice coverage in coupled models. Uncoupled models were seen to be warmer than coupled (and warmer than the NCEP reanalysis) by several degrees over the Arctic ocean during the winter half-year. The simulated precipitation exceeded observational estimates particularly over the terrestrial watersheds of the Arctic Ocean, the bias being strongest in the cold season and larger in coupled than uncoupled models. The inter-model mean of annual net surface moisture flux (P-E) in the AMIP-II simulations was close to the one available estimate for the terrestrial watershed (although this was uncertain because of lack of real information on evaporation). Both coupled and uncoupled models suffered from a systematic error in the Arctic sea-level pressure that adversely affected the simulated sea-ice motion and thickness distribution, and the freshwater transport in the form of sea ice. This appeared as a shift of mass from the Beaufort Sea to Siberian coastal waters (stronger in coupled models). There were indications of some improvement between AMIP-I and AMIP-II in the simulation of cloud coverage over the Arctic Ocean, manifested in a reduction of inter-model scatter and also in a slightly more realistic annual cycle of the cloud fraction, but the surface radiative fluxes varied widely especially in cloudy conditions. The overall variations of clear-sky and cloudy-sky radiative fluxes, taking into account discrepancies in the simulated Arctic cloudiness suggested that the surface energy budget was not likely to be correctly represented in simulations of climate change, and not even in present-day climate.

"Transpose" AMIP

Dr. D. Williamson outlined the basic concept underlying a "transpose" AMIP as proposed by himself and Dr. M. Miller, and a similar exercise "CCPP-ARM GCM analysis of Tendency Errors" (CAGATE) now being considered by PCMDI. In operational NWP, models used for forecasting and data assimilation were tested against reality routinely, sometimes several times a day. The requirement to provide as accurate analyses and forecasts as possible was a powerful stimulus to careful refinements of the parameterization of physical processes in operational models. It appeared unlikely in general that use of an atmospheric climate model (at the type of resolutions typically employed) in an operational system would approach the level of skill and realism of a state-of-the-art NWP model. The question was 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 was to examine how well climate models predicted the detailed evolution of the atmosphere at the spatial scales resolved by these models, and to explore whether errors occurring in short-range forecasts (six hours up to a few days) with climate models might suggest how the physical parameterizations could be improved. How best to take advantage of field programme data (e.g., from the Atmospheric Radiation Measurement programme, ARM) to refine models, and elucidation of the possible relationship between initial (forecast) errors and long-term systematic errors were other key aspects. Forecasts from operational analyses and/or reanalyses using (atmospheric) climate models needed to be prepared and compared (on a climate scale) with verifying analyses in regions with adequate data (so that the background operational model forecast did not dominate the analysis). The climate model forecasts could also be compared with data collected in, for example, ARM field campaigns, although care was required to allow for the different spatial scales involved.

The initialization and spin-up of forecasts were likely to be critical aspects. The basic approach would be to map the climate scales as represented in the analyses onto the climate model grid. In principle, such a mapping of atmospheric variables of state was straightforward except insofar as changes in orography and the vertical co-ordinate system were required. The handling of other physical parameters which had a time history (e.g., cloud water) was less obvious, but might be possible if details of the parameterizations in both the climate model and analysis model were known. Land-surface variables were even more problematic in face of the difficulties of mapping discrete/discontinuous variables, different representations of land surfaces in different models, and the lack of a uniform definition of land-surface variables. It would be necessary to spin up the land surface variables and possibly certain other key variables in atmospheric parameterizations for a period of a few months. In the case of the former, a start would be made from a land model climatology with attention given to achieving appropriate values for those variables affecting surface fluxes (deep, slowly evolving soil layers near to climatology would probably not present a problem). During this process, either the atmospheric state could be updated with analyses periodically (e.g., six-hourly), or a term added to the model variables to relax the predicted state towards the analysis.

WGNE and GMPP encouraged the development of the project on these lines, but recognized that there were a number of questions to be resolved. Appropriate contacts would be taken with potential participants in discussing how to proceed. Advantage would also be taken of the experience in the Global Land-Atmosphere System Study (GLASS) (see section 2.3) where the planning of global scale interactive integrations had faced similar difficulties in the initialisation of land surface and soil variables.

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, was to assess the extent to which climate variations over the past 130 years could 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. Some participating institutions began the experiments from an earlier date (HadISST 1.1 extends back to 1871). A small common set of diagnostics has been saved from the integrations to facilitate comparison and quantitative analysis. The project was complementary to other internationally co-ordinated numerical experimentation projects, notably AMIP, and the general guidelines were similar to these activities. Fifteen groups were participating.

A second (optional) ensemble of experiments was being planned with specified values of most of the known external forcings, both natural and anthropogenic (again ensembles of at least four members starting from 1871 or 1949). A third set of experiments (also optional) was being designed to explore the role of the land surface in recent climate change and variability, particularly at the regional scale, probably beginning from 1970.

A workshop was being 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 (mainly the first set of runs).

3.2 Standard climate model diagnostics

Dr. D. Williamson recalled that the WGNE standard diagnostics of mean climate had now been in use for a number of years and were attracting widening interest, in particular being the basis for the "quick-look" diagnostics computed by PCMDI for the AMIP simulations (see section 3.1). The list of these standard diagnostics was available at **http://www.pcmdi.llnl.gov/amip/OUTPUT/WGNEDIAGS/wgnediags.html**).

The diagnostics of mean climate did include certain variance and eddy statistics, but additional parameters to describe large-scale climate variability at a range of frequencies were needed. Over the past two years, attention has thus been given to preparing a list of "WGNE standard diagnostics of variability". For the present, these were focussed on summarising the variability simulated in the troposphere of atmospheric climate models. The diagnostics being considered should already have been used and demonstrated (with examples from a specific model), easily computed (perhaps with code supplied), and stable (in the sense of not being strongly influenced by natural variability so that representative values could be obtained from a single AMIP simulation without ensembles being required). The proposed list of variability or phenomenological diagnostics encompassed intraseasonal variability, the Madden-Julian Oscillation, ENSO, blocking, wavenumber-frequency power spectra, precipitation rates, the seasonal cycle, and atmospheric angular momentum. AMIP modelling groups and those taking part in AMIP diagnostic sub-projects have been invited to comment on the proposal.

3.3 Developments in numerical approximations

Dr. D. Williamson led the discussion of this item. 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. 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 icosahedral, 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 were still very much in use. Additional studies in this area (e.g., to take advantage of isentropic co-ordinates) were now definitely needed. The problem of representation of the "pressure gradient" term also remained somewhat neglected.

Specific consideration was 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 were essential. Energy conservation in climate models was of particular importance. In practice, conservation of better than 0.1 wm^{-2} was needed, whereas schemes with non-linear intrinsic diffusion (e.g., Lin-Rood, monotonic semi-Lagrangian) could lose energy at a rate of 1.5 wm^{-2}, as could explicit diffusion schemes. This loss should be converted to heat, but this might not be the correct approach. This was still a basic uncertainty in model formulation that must be kept in mind.

There was considerable continuing activity in this area with various workshops in the course of the coming year that should bring together the atmospheric modelling and the computer science communities, but these links needed to be reinforced. The numerical representation of orography and transport modelling remained particular issues which WGNE intended to follow. Another important component of activities in this area was 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. In this respect, two new baroclinic tests have been devised, firstly a polar vortex test including complex dynamical features (a primary potential vorticity tongue and secondary instability causing roll-up into five sub-vortices) and, secondly, the simulation of a growing baroclinically unstable wave. As well as these tests, the interactions of physics parameterizations with each other and with the dynamics needed 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, offered 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 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 (Dr. R.B. Neale, Professor B. Hoskins, Dr. M. Blackburn) together with NCAR (Dr. D. Williamson) and PCMDI (Dr. P. Gleckler). 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.

3.4 Model-derived estimates of ocean-atmosphere fluxes and precipitation

The WGNE "SURFA" project

The updated WGNE evaluation and intercomparison of global surface flux products (over ocean and land) from the operational analyses of the main NWP centres ("SURFA") was being organized on behalf of WGNE by Dr. P. Gleckler (PCMDI) whose interests lay particularly in the study of air-sea fluxes, and Dr. J. Polcher (Laboratoire de Météorologie Dynamique) whose interests lay in the study of land-surface fluxes. 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 for a WGNE initiative to collect and intercompare flux products inferred from operational analyses. Furthermore, the GCOS/GOOS/WCRP Ocean Observations Panel for Climate has underlined the requirement for high quality surface flux products that need to be provided from routine operational analyses to meet the objective of implementing the ocean observing systems and assembling the data sets for the purposes of climate studies. The Global Ocean Data Assimilation Experiment (GODAE), aiming to provide a practical demonstration of real-time global ocean data assimilation as a basis for complete synoptic descriptions of the ocean circulation at high spatial and temporal resolution, also had requirements for high quality global real-time products. Moreover, the intercomparison of land-surface fluxes was of importance in the context of the Global Land Atmosphere System Study (GLASS) (see section 2.3).

In an initial pilot study, eleven operational NWP centres were invited to submit global fields (for 1999) of a number of various surface products and related parameters at various time intervals to PCMDI. Several groups provided the requested fields, but it was apparent that extracting historical data presented a number of difficulties. Because of this and since the real interest lay in the performance of current operational systems, a "near real-time" approach for collecting data was being adopted, with a near real-time link being established with interested centres. The primary objective would be to make the data collection from the centres and the handling of the data at PCMDI as easy and efficient as possible and "real-time" data were now being received by PCMDI from NCEP and ECMWF. Efforts were being made to extend this to other operational centres. At the same time, steps were being taken to have available relevant oceanographic data (e.g., from the TAO/Triton array) for comparing with and validating model-based estimates of surface fluxes.

WGNE stressed the high priority now to be given to rapidly advancing SURFA in which the atmospheric and coupled modelling communities and oceanographers all have very strong interest, and which was a good opportunity for real progress jointly in estimating and determining surface fluxes. Attention was drawn to the need to collect a range of ancillary variables to enable extended diagnostics/analyses of surface flux fields. Careful examination of the land-surface fluxes was also important particularly in view of problems of model spin-up.

Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields

WGNE recalled that more general and comprehensive work on air-sea fluxes in the WCRP was led by the JSC/SCOR Working Group on Air-Sea Fluxes (WGASF). A comprehensive and authoritative assessment of the state of the art in regard to air-sea flux determination was produced in 2000 (published in the WCRP report series, WCRP-112, Intercomparison and Validation of Ocean-Atmosphere Energy Flux fields, also available at **http://www.soc.soton.ac.uk/JRDMET/WGASF**). This report has proved to be very useful and has been widely appreciated in the interested scientific community. WGASF subsequently organized a major workshop (Washington, DC, May 2001) bringing together the different scientific communities interested in air-sea fluxes to review the Working Group Report and to consider what needed to be done in determining surface fluxes more accurately. The workshop was a considerable success with well over 100 participants from 15 countries. After an initial keynote address reviewing the WGASF report, sessions at the workshop were devoted to modelling and data assimilation, validation of flux products, flux fields inferred from remote sensing, and flux measurements and parameterizations. Break-out groups then took up the issues of how parameterizations could be refined and measurements necessary, how flux estimates could be validated, and how flux products could be improved in the future. In the area of parameterizations and measurements, the case was made for an airflow distortion experiment involving suitable reference platforms and a research ship with sonic anemometers distributed around the vessel. A flux-profile study over the ocean, a radiation measurement comparison experiment, and coastal ocean studies in carefully chosen, contrasting regions conducted in a standard manner were also proposed. Regarding verification, strong encouragement was expressed for the WGNE "SURFA" project. The importance of developing error estimates for air-sea fluxes and near-surface fields from NWP was stressed, as well as the need to investigate new methods of direct precipitation measurement over the ocean and to expand and improve the on-line catalogue of air-sea flux data sets and their evaluation established by WGASF. Looking to the improvement of flux fields in the future, combination of flux and meteorological products would certainly be required (this would depend on more timely delivery of flux products and including meta data with all flux data sets), detailed studies of error estimates should be undertaken as a means of quantifying and then reducing imbalances in regional estimates in flux climatologies, and parameterizations valid over a wider range of environmental conditions (e.g. low and high winds) should be developed. The planned Global Precipitation Mission was seen as providing an essential step in obtaining higher temporal and spatial resolution fields of atmospheric and ocean basic variables and air-sea fluxes. The full report of the workshop including all the main findings, conclusions and recommendations and extended abstracts of the presentations has been published as WCRP-115, Intercomparison and Validation of Ocean-Atmosphere Flux Fields (and can also be accessed via the web at **http://www.soc.soton.ac.uk/JRDMET/WGASF/workshop/report/html**).

The JSC/SCOR Working Group on Air-Sea Fluxes formally came to the end of its mandate following the workshop in Washington in May 2001. However, in view of the number of outstanding questions relating to physical air-sea interactions in the WCRP and follow-up required to the work of WGASF, the JSC has recognized that a new WCRP "air-sea interactions" group will need to be established.

3.5 Snow Models Intercomparison Project (SNOWMIP)

Dr. P. Bougeault reported on the progress of SNOWMIP 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 was also maintained with the Global Land-Atmosphere System Study (GLASS). The project was aimed at intercomparing and evaluating the variety of snow models that have been developed for applications ranging from climate modelling, hydrological simulations, snow stability and avalanche forecasting. The basic approach was the point validation of the simulation of several properties of the snow-mantle (snow depth, snow water equivalent, snow temperature profile, and in some cases the fine scale characteristics of the snow). Initial conditions and forcing data from four sites at various altitudes (Col de Porte, France; Weissflujoch, Switzerland; Sleepers River, Appalachians, USA; Goose Bay, Canada) were supplied to participating groups at the end of 2000. In accord with WGNE advice, the snow models could also be run coupled with underlying soil models rather than with the prescribed heat fluxes from the ground. Twenty different groups have submitted simulations from twenty-four snow models, with preliminary results being discussed at the IAMAS Scientific Assembly (Innsbruck, Austria, July 2001). A large scatter in results from different models was apparent and further detailed analysis was being undertaken. However, there was little difference in using an underlying soil model or prescribed heat flux (the heat flux from the ground was very small anyway). More information is available at **http://www.cnrm.meteo.fr/snowmip/**.

WGNE appreciated the progress made and looked forward to a fuller analysis of the results at its session next year.

3.6 Model stratospheric representation

In the past two or three years, there has been growing interest in the model representation of, and data assimilation and prediction in, the stratosphere and several major global operational centres have significantly increased the vertical extent and resolution of their models in the stratosphere and into the mesosphere (50-60 km). At the last WGNE/GMPP session in October, it was decided to undertake a new intercomparison of stratospheric analyses and of model predictive skill in the stratosphere. At the same time, the WCRP study of Stratospheric Processes and their Role in Climate (SPARC) established a working group to review and co-ordinate the development of data assimilation in the stratosphere. The intercomparison of stratospheric climate simulations (known as the GCM Reality Intercomparison Project for SPARC, GRIPS) was also continuing.

Comparisons of stratospheric analyses and predictive skill in the stratosphere

This activity was being led on behalf of WGNE by Dr. G. Roff (BMRC). A number of groups have expressed interest in participating, and were being invited to submit their stratospheric analyses for the period January-February 2000. Subsequently, centres would be asked for forecasts (based on their analyses) to at least ten days, and preferably up to twenty days in order to be able to assess the limit of useful predictability in the stratosphere. Fields at daily intervals of u, v, z, T, RH on pressure levels (1000, 850, 500, 200, 100, 70, 50, 30, 10, 1 hPa) on a 2.5° x 2.5° latitude/longitude grid in netCDF or GRIB format, as well as sea-level pressure and isentropic potential vorticity at 500K, would be collected. A general description of the model, resolution and parameterizations employed should also be provided. Comparisons would be made with Met Office analyses (in pressure co-ordinates). The proposal was being further discussed with interested users.

SPARC activities in stratospheric data assimilation

The objective of SPARC activities in this area was to ensure that the advances in data assimilation techniques in many operational centres were exploited to obtain global quality-controlled, internally consistent data sets of the dynamic and chemical state of the stratosphere (as well as, where possible, the upper troposphere and mesosphere). The data sets would be especially designed to support SPARC-related studies of chemistry-climate interactions, with attention initially being given to making full use of the data becoming available from the ENVISAT and EOS/AURA satellites. A range of error statistics related to the utilisation and/or validation of instruments and for validation of models would also be produced. The type of effort undertaken would include comparisons of global analysed data sets complementing the WGNE work, assembly of documentation on data production methods and data quality at the SPARC Data Centre, and organization of workshops to consider how the methodology of data assimilation in the stratosphere could be refined (e.g. to include new variables such as aerosol loadings). It was also the intention to draw on analysed data sets to prepare reports on aspects of particular interest (e.g. stratospheric water vapour and its evolution). A small SPARC working group bringing together representatives from several of the active leading centres preparing stratospheric analyses has been formed to guide the work necessary. Close co-ordination and liaison would be maintained with WGNE.

SPARC-GRIPS

SPARC has been undertaking for a number of years an intercomparison of model stratospheric simulations(SPARC-GRIPS). Major progress was made in 2000 in collecting and summarizing the results of the first phase of GRIPS which included an intercomparison of basic features of model stratospheric simulations. Findings have been published in the Bulletin of the American Meteorological Society and the Journal of Geophysical Research. The past year has been one of consolidation. A number of activities within the first phase remain to be completed (e.g. studies of the treatments of sudden warmings, tropospheric-stratospheric interactions). In the second phase of GRIPS (impacts of different parameterization schemes), tests of radiative codes were underway and this would lead to an investigation of gravity wave parameterizations. Studies of model response to formulations of mesospheric drag have been completed. The third phase of GRIPS would be concerned with explaining the observed variability in the stratosphere taking into account natural variability and the forcing by changes in aerosol loading, in solar radiation, and in atmospheric concentrations of ozone and carbon dioxide). A few groups have begun the experimentation required (some in connection with the European projects "Solar Influence on Climate and the Environment" (SOLICE) and "Stratospheric Processes and their Impacts on Climate and the Environment" (EUROSPICE)).

3.7 Modelling large-scale atmospheric transport

A series of workshops to assess the ability of atmospheric models to simulate the global distribution of inert or chemically interacting matter has been organized under WGNE auspices. The planning of a further workshop aimed at assessing how models treat and resolve the size distribution of multiple aerosol types by examining the results of a standard comparative simulation was only moving ahead slowly. The Brookhaven National Laboratory of the US Department of Energy has agreed to act as the focal point for the work, to specify the observational data required, and to evaluate the model results obtained, but the funding needed to conduct the exercise has not so far been secured. The earliest that progress could now be expected was 2002, with the final workshop not being foreseen before 2004.

3.8 Regional climate modelling

Following the reviews carried out by WGNE and WGCM in respect to regional climate modelling at their respective 1999 sessions, the JSC established a joint WGNE/WGCM ad hoc panel to summarize the current state-of-the-art in the field of regional climate modelling and to take up the questions that had been raised. These included technical items noted by WGNE (choice of domain size, scale dependency of model parameterizations, consistency of simulated energy and water budgets in inner and outer models, the care needed in handling the lateral boundary conditions) as well as aspects emphasized by the JSC itself (the limitations imposed by the performance of the global driving model, and the predictability/reproducibility of smaller scales simulated in regional climate models, RCMs). On behalf of the panel, the convener, Dr. R. Laprise (Université of Québec in Montréal) outlined the main points in the draft report of the group.

There was no doubt that dynamical atmospheric RCMs have matured over the past decade and now allowed (and were used in) a very wide spectrum of applications. At horizontal scales of 300km and larger, simulations were consistent with the nesting (driving) data. At fine spatial and temporal scales, the RCM-simulated patterns of important surface variables, such as precipitation and winds, often had demonstrable skill. However, grid spacing was currently often constrained by computing resources to typically about 50km, which limited the amount of detail available at the finest scales. Future increases in computer power and applications of multiple nesting techniques would be likely to allow increases in resolution to grid spacing of order of 1km (this would require the use of fully non-hydrostatic models and scale-dependent parameterisations).

It was recognised that RCMs had deficiencies and improvements were required. The sensitivity of RCM-simulated results to computational domain size, to the jump in resolution between the nesting data and the RCM, to errors or deficiencies of nesting data, and to nesting techniques, needed further investigation. Moreover, the added value provided by regional modelling should be assessed relative to simpler statistical post-processing of coarse-grid data. An assessment of the performance of an RCM required climate data on much finer spatial and temporal scales than traditionally used for validating global models. In some regions such data were available but not necessarily easily accessible, and appropriate gridded analyses have not been prepared. Where such data were not available, methods of validation other than comparison with standard climatological variables ought to be developed or applied. The performance of different RCMs should be compared both in their simulation of current climate and in their use as a dynamical downscaling tool to provide high-resolution climate-change information. This was necessary both to guide future developments in regional climate modelling and to contribute to the assessment of uncertainty in regional climate simulations and projections.

The Panel reiterated that the final quality of the results from a nested RCM depended on the realism of the large scales simulated by the driving general circulation model. The reduction of errors, systematic or otherwise, in general circulation models must therefore remain a priority for climate modellers.

The various recommendations made by the Panel included the following points:

(i) Obviously, all numerical models suffered from various defects and were a reduced image of a considerably more complex reality. In this sense, all models should be made more realistic in very many different ways, but the process of improving models should be guided by the needs of the specific applications.

(ii) An international RCM workshop should be organised bringing together, not only RCM modellers, but also global climate modellers, diagnosticians and dynamicists, users of RCM results, research managers and funding agencies, under the theme "the added value of regional climate model simulations in many applications". The Panel suggested holding the workshop during 2003 in the Southern Hemisphere, possibly in Buenos Aires, Argentina, where there was growing community of scientists who could contribute to the essential local arrangements.

(iii) The assessment of RCM climate simulations continued to be hampered by the lack of high-resolution observed gridded climate data over many regions of the globe. Regional re-analysis projects using observations from national archives should be encouraged.

(iv) Long, multi-decadal RCM simulations nested within an ocean-atmosphere model and forced by observed SST could be made to assess RCM skill in reproducing fine-scale features associated with large-scale year-to-year anomalies. This would constitute a "Regional (climate) Model Intercomparison Project", RMIP, analogous to AMIP, for global circulation models. The recently-completed European project MERCURE has delivered such simulations for the European region using three RCMs and could act as a model for such an exercise.

(v) When intended for climate-change projections, the RCM should be validated in different climate regimes in order to establish their general applicability. It would be valuable to organize a co-ordinated international modelling effort to nest a number of global model-simulated data sets over a few regions. This would be a major undertaking requiring strong international support and convincing funding agencies of the importance of such a project. The new European project "Prediction of Regional scenarios and Uncertainty for Defining European Climate-change risks and Effects" (PRUDENCE) which would compare simulations and climate change over Europe from several general circulation models and RCMS could be an important component in such a project.

WGNE expressed appreciation to Dr. Laprise and to his group for their work and the wide-ranging review of regional climate modelling that had been produced. WGNE agreed with most of the points made, including the proposal for an international RCM workshop in the next 1-2 years and saw merit in a regional climate model intercomparison project if an appropriate exercise could be designed. WGNE recommended that the report be forwarded to the JSC*. It was suggested that the report could be further extended to include or expand discussion of the following points:

- the risk of "blind application" of a regional climate model and the need to educate less experienced users of models and the data produced, in particular advice on the limitations of regional climate model results consequent to the shortcomings in skill of the simulations of the forcing general circulation in representing large-scale circulation features (oscillations, seasonal variability)
- the differing vertical resolution between a regional climate model and the driving general circulation model, and the interpolation (in the vertical) from the outer grid to the nested grid
- the role of regional climate models in testing and paving the way for the next generation of high resolution general circulation models and testing model parameterizations (e.g. land-surface schemes)
- the importance of checking conservation properties
- the need to test the regional climate model physics in different "climates"/geographical regions
- comparison of model results with a statistical down-scaling approach.

The final version of the report would probably be submitted for publication as a review article in the Bulletin of the American Meteorological Society or similar journal.

WGNE agreed that in view of the various outstanding questions and the progress and developments continuing to be made, regional climate modelling should continue to be an item on the agenda of the annual WGNE session.

Testing the down-scaling ability of one-way RCMs

Although the report of the joint WGNE/WGCM ad hoc panel had not specifically proposed co-ordinated experimentation as a means of further investigating basic issues in regional climate modelling, Dr. Laprise reported on a "big-brother" experiment undertaken in Canada by the University of Québec and RPN, Montréal. This experiment was designed to test the ability of a RCM to reproduce fine-scale features realistically, and to assess how robust such features were to the resolution jump between the nesting and nested models. The experiment involved establishing a reference climate using a large-domain high-resolution regional climate model simulation (the "big brother"), which was then degraded by removing scales shorter than those resolved in the atmospheric models normally used in climate simulations. The degraded fields were then used to drive a nested regional climate model integrated at the original high resolution except that it was embedded in the big brother domain. The climate statistics were compared to those of the big brother simulation over the same area. The differences should be attributable to errors associated with the down-scaling, not to model errors or observational limitations. Using the University of Québec regional climate model of Caya and Laprise at 45km resolution, big brother and nested simulations were carried out for a period of one month (in winter) for a domain over the east coast of North America. The results indicated that, even with a twelve-fold resolution jump, the large-scale features were well preserved. Transient mesoscale features were also successfully reproduced up to a twelve-fold resolution jump but, whilst the representations of stationary systems (in terms of pressure, precipitation, temperature) over small-scale stationary forcings were well maintained, discrepancies were apparent over the oceans (although these should average out to zero with longer simulations). The inference, based on this one-month winter case, was that the nesting approached was reliable, although a twelve-fold resolution change seemed to be the upper limit.

3.9 Other climate-related modelling initiatives

WGNE noted with interest reports of developments in climate modelling activities in Japan and the USA.

Japan

Dr. T. Tsuyuki gave an update on the "Frontier Research Programme for Global Change" in Japan, the ambitious and far-reaching initiative co-ordinated by the Japanese Science and Technology Agency.

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* report would also be reviewed by the session of WGCM in February 2002 (postponed from September 2001).

An extensive range of studies in the fields of climate variability, the prediction of droughts and floods on the seasonal to interannual time range, global warming, atmospheric composition, and ecosystem change was envisaged centred round strong modelling (the "Earth simulator") and supporting observational programmes. Fifty research scientists have now been recruited. A key element was also the computer development required, involving a massively parallel system with computing nodes (vector-type multi-processors) tightly connected by sharing main memory. Assuming an efficiency of 12.5%, a peak performance of 40 Tflops was expected (640 processor nodes each with 8 processing elements with a peak performance of 8 GFlops i.e. 64 Gflops at each node). The total main memory was 10 Tbytes (shared memory per node of 16 G bytes). The "Earth Simulator" site has been established in Yokohama (the Yokohama Institute for Earth Sciences), and the initial activity with the Earth Simulator was planned to begin in March 2002. A particular target would be to complete a highly advanced global warming prediction for the next IPCC assessment (probably 2006).

USA

Dr. D. Williamson reported on the continuing steps in the USA towards achieving a more unified approach to global climate modelling activities and increasing the involvement of the broader US research community. As part of the Department of Energy initiative "Scientific Discovery through Advanced Computing" (SciDac), a project for the collaborative design and development of the NCAR Community Climate System Model for tera-scale computers was being undertaken as a follow-on to the DOE Accelerated Climate Prediction Initiative (ACPI) "Avant Garde" pilot project. As well as the Climate and Global Dynamics and Scientific Computing Divisions of NCAR, the NASA/GSFC Data Assimilation Office, and six other DOE Laboratories were involved. The objectives were to expand the scientific scope of the Community Climate System Model and to improve the software engineering in order to achieve a high performance portable modular system and to bring all components into conformity in a comprehensive software framework (i.e. machine-specific, utility, library and model-code layers) (see also section 5.4, "NCEP", regarding the project "Earth System Modelling Framework" to set up a common infrastructure for weather and climate modelling).

Concerning data standards, agreed NetCDF Climate and Forecast (CF) Metadata Conventions have now been released. These have been designed to promote processing and sharing of NetCDF files in which the metadata provide a definitive description of what each variable represents and the spatial and temporal properties of the data, so as to facilitate extraction, regridding and display capabilities. The new conventions were simpler, whilst continuing to emphasize conformity and backwards compatibility. Several forecasting and climate modelling groups have also been discussing an initiative "PRISM" aiming to facilitate co-operation between modelling groups by planning common interfaces to facilitate coupling components from different models, at the same time maintaining and drawing benefit from model diversity.

Dr. R. Petersen described the planning of the USA "Weather Research and Forecast" (WRF) project with the goals of developing an advanced mesoscale forecast and assimilation system and building closer ties between research and operations (and running research and operational models with a common model infrastructure). One of the principal motivations was to enhance significantly the range of products for forecasters needed to predict phenomena such as individual thunderstorms, and squall lines, lake-effect snow storms, down-slope wind storms, sea-breeze convection, coastal stratocumulus decks, and post-frontal rainbands. This required models running at very high spatial resolution (1-3 km), making use of the highest resolution observations available, handling terrain effectively, and representing key physical processes, especially microphysics and land-surface interactions, as realistically as possible. Fundamental scientific issues to be taken up included the range of predictability of storm-scale events and the effect of resolving fine-scale details on this predictability, identification of the most crucial observations and whether high resolution data from national networks (e.g. from WSR-88D) could be used to initialize NWP models in real time, the type of physical representations required, exploiting ensembles for storm-scale prediction, the verification techniques needed for storm and mesoscale forecasts, the networking and computational infrastructures to support such high resolution NWP, and how to generate useful decision-making information from model output. Operational and research centres were collaborating on issues such as the appropriate design for a 1-10 km grid, portable and efficient models/model components, elaborating advance data assimilation methods and refining model physics. The principal partners were NCEP, the NCAR Mesoscale and Microscale Meteorology Division, the NOAA Forecast Systems Laboratory, the Oklahoma University Center for Analysis and Prediction of Storms, the Air Force Weather Agency and the Federal Aviation Administration. Other collaborators included GFDL, NASA/GSFC Atmospheric Sciences Division, the NOAA National Severe Storms Laboratory, the NRL Marine Meteorology Division, the Atmospheric Modelling Division of the US Environmental Protection Agency, and a number of university groups. Development teams looking at numerics and software, data assimilation, analysis and validation, community involvement and operational implementation have been established.

4. DATA ASSIMILATION AND ANALYSIS

4.1 Reanalysis projects

ECMWF

Dr. M. Miller reported that the ambitious and comprehensive 40-year reanalysis project at ECMWF (ERA-40), with support from the European Union, was progressing well. The assembly of a merged data set of conventional observations carried out in collaboration with NCEP and NCAR was complete. A surprisingly large amount of extra data was 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. Discussions were also in hand with EUMETSAT regarding the reprocessing of wind products from METEOSAT-2. The reanalysis itself was 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), using a 60-level, T159 forecast model coupled with an ocean-wave model. Nearly seven years of analysis starting from September 1986 have been prepared. Two years of analysis from July 1957 and one year from January 1972 have also been completed, with VTPR radiance data being successfully assimilated towards the end of the latter period. However, serious deficiencies in the analysed hydrological cycle were noted. These have been traced to an error in encoding some of the SYNOP data for the period, and problems with the time assignment of certain radiosonde data used in the assimilations in both the 1950s and 1970s have also been detected. Corrected data sets have been prepared and production has recommenced.

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 would 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; the extent of these in the longer time series of analyses that were gradually emerging as production progressed would be carefully assessed.

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

Dr. R. Petersen reviewed the status of reanalysis activities at NCEP. The original NCEP/NCAR reanalysis from 1948 was continuing to be carried forward to the present in a quasi-operational manner (two days after data time) and has now been extended to a total period of nearly fifty-four years. The recent period March 1997-September 2001 has been reanalysed to correct for a modification in the processing of TOVS data. The reanalyses distributed through NCAR, CDC and NCDC were 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. In particular, hourly fields were provided to support the compilation of the International Satellite Land-Surface Climatology Initiative II data set. An additional initiative was the preparation of a regional reanalysis over the USA for the period 1982-2003 (perhaps 1979-2003). 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 would be based on the ETA model (and the ETA data assimilation system) (with the global reanalysis used as boundary conditions). Important features would 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). 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 some pilot runs carried out. Considerable improvements were apparent in the monthly precipitation fields produced over the contiguous USA, especially in runs where precipitation was assimilated. However, some unrealistically intense episodic precipitation events occurred in the summer period in locations off the Mexican coast (now remedied). The fit to the geopotential heights (as observed by radio-sondes) was also notably better than that of the global reanalysis.

Japan Meteorological Agency (JMA)

WGNE welcomed the exciting news, relayed by Dr. T. Tsuyuki, of the planning of a 25-year reanalysis by JMA (JRA-25) for the period 1979-2004. This would form the basis for a dynamical seasonal prediction project and global warming study, advanced operational climate monitoring services at JMA, and various activities in climate-system studies. The reanalysis was a five-year joint initiative of JMA, which is providing the data assimilation expertise and forecast system, and the Central Research Institute of the Electric Power Industry, a private foundation, furnishing the computer resources. A 3D-Var system (operational since September 2001) with a model of resolution of at least T106 and 40 levels in the vertical would be employed. As well as data archived at JMA from 1975 to the present, the NCEP/NCAR data set used in the NCEP reanalysis and the merged ECMWF/NCEP data sets in ERA-40, a range of satellite observations (including reprocessed GMS cloud motion wind data) would be assimilated. The project was expected to be completed by 2005, with the products available to scientific groups contributing to the evaluation of the reanalyses and who provided feedback on improvements that could be made.

4.2 Observing system and observation impact studies

WGNE noted information provided by Dr. A. Lorenc concerning the activities of a number of international groups considering the future shape of World Weather Watch observing systems. In particular, under the CBS Open Programme Area Group on Integrated Observing Systems, (OPAG-IOS), an expert team on data requirements and the redesign of the global observing system had suggested a number of exploratory observing system experiments including assessments of the impact of hourly SYNOPS, the impact of denial of radiosonde data globally above the tropopause, the information content of the Siberian radiosonde network, the impact of AMDAR data over Africa (through data denial in a 4D-Var analysis and forecasting system), the impact of tropical radiosonde data, the impact of three LEO-AMSU-like sounders (NOAA-15 and -16, AQUA), and the impact of AIRS data. A number of the main operational centres had "volunteered" to undertake experimentation in these various areas (with the exception of denial of radiosonde data above the tropopause).

Regular exchange of information on observing system and observing system simulation experiments was being fostered through a series of workshops under the auspices of WMO/CBS (two so far, in April 1997 and March 2000). Consideration was now being given to the organization of a further workshop involving the expert team on data requirements and the redesign of the global observing system, those responsible for observational networks, and modellers. WGNE welcomed the suggestion that it should also play a part in the planning of the workshop and asked Dr. Lorenc to represent WGNE on the organizing committee.

Dr. Lorenc also summarized the results of recent observing system experiments carried out in the Met Office. Firstly, parallel assimilations and forecasts had been run for one month to study the impact of various groups of observations (based on denial of those observations). Preliminary results (which needed to be confirmed by experimentation for another month in another season) indicated that all data have a positive impact. Satellite data were very important in the southern hemisphere and also increasingly so in the northern. Overall, the findings agreed with those from similar experiments at ECMWF, although the relatively larger emphasis on short-period surface forecasts caused surface observations to appear more valuable in the Met Office results. Secondly, in contrast to the parallel runs used for the global studies, efforts have been made to select significant cases where observations appear to have had a large impact on operational short-period forecasts of rainfalls, identifying those observations which had the biggest effect. This approach thus took into account user concerns with major weather events, and indicated a statistically significant signal, but evidently did not necessarily measure the "average" impact of observations. Again, all observation types studied gave a significant benefit in one case or another.

4.3 Co-ordinated Enhanced Observing Period

The GEWEX Co-ordinated Enhanced Observing Period (CEOP) was an important activity which should provide a wealth of data to enable further extensive testing of atmospheric model parameterizations. The basic objective was to collect synchronous common data sets from all the regional GEWEX hydrological-atmospheric studies for a period from 2001 to 2003. The regional studies being undertaken, aiming to characterize energy and water budgets on the scale of continents, included the USA Continental-scale International Project, GCIP; the Baltic Sea Experiment, BALTEX; the GEWEX Asian Monsoon Experiment, GAME; the MacKenzie River GEWEX Study, MAGS; the Large-scale Biosphere-Atmosphere Experiment in Amazonia, LBA. Progress was being made in the organization of an investigation of the Coupling of the Tropical Atmosphere and Hydrological Cycle, CATCH, in the Sahel region of West Africa with the objective of improving predictions of the impact of climate variability on water resources management. Australia was now also planning the "Murray-Darling Basin Water Project" - see below).

The primary objectives of CEOP were to:

- document, better understand and improve the simulation and prediction of water and energy fluxes and reservoirs over land for water resource applications
- document the seasonal march of the monsoon systems and better understand their physical driving mechanisms and their possible connection.

In summary, the plan was to create a database of in situ and remotely-sensed measurements, including those from a number of carefully selected reference stations closely linked to observing sites in the GEWEX hydrological-atmospheric studies as well as model output. A pilot global hydro-climatological data set would be compiled to assess and improve the representation of water and energy cycle processes in global and regional models. Full details can be found at **http://www.gewex.com/ceop.html**.

In respect to CEOP planning, a particular issue taken up by WGNE and GMPP was the request that had been made to main operational centres to supply an extensive range of model gridded output in a highly specific format. Most of the centres represented on WGNE were in principle ready to assist, but several questions were raised concerning the complexity and long-term nature of the request. There was also little indication of how model data would be used in practice, what feedback, if any would be provided, or indeed indication how CEOP would be useful to NWP centres. The need for close co-ordination with WGNE and the various NWP and modelling centres to clarify the scientific strategy that would be followed in CEOP to exploit the in situ, remotely-sensed, and model output data was strongly emphasized. The point was also reiterated that the potential benefits of CEOP could be fully realized by operational centres only if the data collected were available in real time. WGNE members were asked to consider further ideas that could be put forward to CEOP so that it might better serve NWP centres.

The Murray-Darling Basin Water Balance Project

Dr. K. Puri outlined plans being drawn up by the Australian Bureau of Meteorology, including BMRC, and the University of Melbourne for a water balance project in the Murray-Darling Basin. The objectives were to:

- enhance the capability of the operational systems of the Bureau of Meteorology to provide accurate and reliable estimates of the real-time surface water budget across the Murray-Darling Basin;
- measure the spatial and temporal variability of soil moisture and temperature across one part of the basin;
- identify and reduce key limitations in the representation of soil moisture and temperature in BMRC atmospheric models;
- develop products for water authorities in the Murray-Darling Basin.

The project would involve a range of observational and modelling studies drawing on the hydrological expertise of the University of Melbourne, and the atmospheric modelling experience of BMRC. The core of the observational programme would be detailed observations of soil moisture and temperature at 18 sites in the Murrumbidge River Basin (a tributary of the Murray-Darling), providing a unique data set for the evaluation and development of numerical models.

The Tibetan Plateau Field Experiment (TIPEX)

Dr. Chen Dehui informed WGNE and GMPP of the successful organization and conduct of TIPEX in the period 10 May-10 August 2001, a second field experiment over the Tibetan Plateau (following on the Qinghai Xizang Plateau Meteorological Experiment in 1979, undertaken as a component of FGGE and MONEX). The main goal was to obtain more detailed information on the structure of the planetary boundary layer over the Tibetan Plateau and an improved understanding of regional atmospheric physical and dynamical mechanisms. Intensive observations were taken at three special stations using an array of specialized instruments (Bowen ratio systems, fluctuating hygrothermoscopes, infrared thermometers, an optical raingauge, ultrasonic anemometers and thermometers, various radiometers, Döppler radars, wind profilers, low-level radiosondes, tethersonde profilers). Among the main findings so far were the identification of a significant humidity inversion over the planetary boundary layer. The reasons for this remained uncertain, but it suggested the existence of weak moisture transport in mid-to-upper levels above the planetary boundary layer. Solar irradiance was very intense over the Plateau, often higher than the solar constant - this phenomenon, seldom found elsewhere, was related to the distribution of cumulus clouds and their radiative effects. Active meso-scale convection was often observed, with characteristics of the meso-scale cells shown by the temporal variation of the observed rainfall intensities. The values of bulk transfer coefficients were found to vary greatly as a function of the local topography and landscale (drag coefficients between 10^{-3} and 10^{-2} in unstable conditions). During the summer, the cumulus that often developed in the central Tibetan Plateau would move to join with the Meiyu front and could be associated with heavy rainfalls in the Yangtze river basin.

5. NUMERICAL WEATHER PREDICTION TOPICS

5.1 Short- and medium-range weather prediction

Preparation of policy statement on the "scientific basis for, and inherent limitations of, weather forecasting"

WGNE and the WWRP Science Steering Committee had been asked to provide input for a WMO policy statement on the "scientific basis for, and inherent limitations of, weather forecasting". In particular, WGNE was expected to review and contribute to sections on medium-range and seasonal prediction. In the latter respect, the Chair of the CLIVAR Working Group on Seasonal-to-Interannual Prediction (Dr. S. Zebiak) had forwarded material. WGNE examined the composite text as it stood, which had also been considered at the session of the Science Steering Committee for the WWRP the previous week. A number of comments were made, notably that the draft appeared too long and did not contain enough specific information. Little emphasis had been given to such concepts as error growth, predictability as a function of scale, and the behaviour of chaotic systems. The steady improvement in recent years in medium-range prediction also deserved to be particularly highlighted.

Dr. A. Lorenc undertook to prepare a revised statement which would then be further circulated by e-mail to WGNE for additional comments. The final WGNE input would then be considered at the session of the WMO Commission for Atmospheric Sciences in February 2002*.

The World Weather Research Programme

Dr. R. Carbone, Chair of the Scientific Steering Group for the WWRP, recalled that the overall goals of WWRP were to improve forecasts of "high impact" weather through research, experimental forecast demonstration, technology transfer and training, and offering broadly shared benefits to all nations. WWRP was now moving ahead strongly on many fronts. Among activities undertaken were the Mesoscale Alpine Programme which had provided high quality data from the Special Observing Period (7 September-15 November 1999) enabling research on a range of topics related to the effects of orography (see section 2.5), the Sydney 2000 Forecast Demonstration Project which, consistent with its aims, had demonstrated that advanced nowcasting systems were robust an transferable and could be used successfully in an operational environment, and the Aircraft In-Flight Icing Project, which had played an important role in co-ordinating and consolidating numerous national and regional efforts concerned with understanding icing conditions in water and mixed phase clouds. A further range of projects addressing tropical cyclone landfall, THe Observing System Research and Predictability Experiment (THORPEX) (in collaboration with WGNE, see detailed description below), and the Mediterranean Experiment (investigating cyclones that produced high impact weather in the Mediterranean) were being actively developed. Other projects being considered were Athens 2004 (a follow-on from Sydney 2000 particularly concerned with urban air quality and nowcasting storms in connection with the Olympic Games in Athens), a study of warm season and rainfall and flooding, urban weather and flood prediction, and sand and dust storms.

THe Observing System Research and Predictability Experiment (THORPEX)

As noted above, THORPEX, one of the most important research and development projects of WWRP was being undertaken in collaboration with WGNE which would take the lead in the numerical experimentation aspects. THORPEX themes were of major interest to WGNE, and the studies of predictability and observing system issues being taken up would have far-reaching benefits and impact throughout the WCRP. THORPEX was particularly targetted on the outstanding challenge of the skilful prediction of high impact weather associated primarily with synoptic-scale systems which often contain significant embedded mesoscale features. Activities would include:

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* At the Commission session, the text was substantially revised and the new version (as attached as Annex II to report of the Commission session) would be forwarded to and discussed by the fifty-fourth session of the WMO Executive Council in June 2002.

- observing system experiments with real and "virtual" observations to determine optimal observing and data assimilation strategies for improved predictions of high impact weather;
- diagnostic studies of life-cycles of high impact weather systems;
- establishing the relative importance of errors in models and initial conditions on forecasts;
- assessing the potential of advanced ensemble prediction systems to indicate the probability of high impact weather events;
- identifying regions where new observations (in situ or remotely-sensed) would have the greatest impact;
- an ambitious field campaign testing possible enhancements to the operational observing system and providing guidance for the design of permanent and targetted components of the observing system;
- regional field tests to study specific predictability issues and new observing systems;
- determining economic and societal benefits of improved forecasts of high impact weather.

WGNE reiterated its support for THORPEX as a collaborative WWRP/WGNE experiment. At the WGNE session, the next steps in the development of THORPEX were reviewed in conjunction with Dr. R. Gall (NCAR) and Dr. M. Shapiro (NOAA/ERL), two of the leading scientists involved in framing THORpex plans, and Dr R. Carbone. Firstly, it was suggested that a focussed science plan was now required, laying out a schedule of activities and resource requirements. To oversee the preparation of the plan and its implementation, an international science committee should be established, to be supported later by an international management committee to secure and guide the use of resources (WGNE would take part in these committees). Questions had been raised on the capacity of atmospheric/meteorological research communities to carry out THORPEX as described, and whether it would be possible to conduct the proposed rapid sequence of field programmes in several distinct geographical regions. Bearing in mind the primary goal of forecasting cyclones originating over the ocean and remote continental regions taking advantage of new technologies, targetted observations, and advanced data assimilation methods, it was agreed that THORPEX should initially focus on the North Pacific region, and observing/analysing developing mid-latitude baroclinic waves. This could have an immediate impact on short-range forecasts in North America and medium-range forecasts in Europe. Subsequently, an area for attention should be the western Pacific, to explore tropical cyclone track prediction. The importance of collaboration with the World Weather Watch and other projects requiring sustained observations in remote regions (such as CLIVAR-Pacific) was stressed.

Dr. M. Miller drew attention to the developing European interest in THORPEX. Several countries had made statements in support of an "Euro-THORPEX" as well as two European-wide organizations (ECMWF and EUCOS). The requirements and objectives of European groups were fed into the overall THORPEX proposal as summarized above and suggestions made for observational components, including European North Atlantic Experiments over the Atlantic and Canadian Arctic. Specific European Commission funding was being sought under Framework 6.

Performance of the main global operational forecasting models

WGNE reviewed the skill of daily forecasts from a number of the main operational centres as presented to the session by Dr. M. Miller. Examples of the twelve-month running means of verification scores (root mean square error) for 500 hPa geopotential in the northern hemisphere at lead-times of one and three, and five and seven days, are shown respectively in Figures 1 and 2. For most centres, a marked increase in skill was again apparent: this increase has now been sustained since the first part of 1999, particularly in the cases of ECMWF, NCEP and the Met Office. At all time ranges, the advance in skill of ECMWF forecasts was striking. 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.

Verification techniques for meso-scale models

Whilst rms errors, anomaly correlations, skill scores etc. (as used above) were objective indicators of large-scale model performance, consideration needed 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. Dr. P. Bougeault described work that was now being undertaken in this area for parameters such as quantitative precipitation forecasts (an excellent prototype), two-metre temperature and humidity, ten-metre winds, cloudiness etc. For verification purposes, the basic observational data used were SYNOPs, with data from automatic and climate network stations also increasingly important. Additionally, radar data and high resolution satellite observations had significant potential in this area.

A basic question was how the model should be compared to the observational data. Whilst, currently, a "nearest grid point" or "interpolation from model grid to observation location" approach was common, upscaling techniques were developing rapidly. These latter techniques appeared to improve verification scores especially for large grids and when small rainfall amounts were involved. However, there could be difficulties in comparing models with different horizontal resolutions, and a "double penalty effect" might come into play at high resolutions. To avoid this, errors needed to be partitioned between displacement, amplitude and pattern, or higher moments of the distribution of parameters computed, or a Fourier decomposition attempted to separate errors in various scales. Another method might be the use of the "observation operators" from variational data assimilation to infer a "synthetic radar reflectivity" or "satellite radiances" from model fields for comparison with observations. In looking at two-metre temperature and humidity and ten-metre winds, additional difficulties arose including the need for altitude corrections, accounting for wind exposure effects, and representivity problems. For models with tile surface schemes, there was the option of using the temperature of the appropriate tile rather than that at the grid-point, but in this case, knowledge of the observational environment was needed (soil, vegetation type etc.).

Other questions concerned the actual scoring method (e.g. percentage correct, Heidke, frequency bias, threat or equitable threat) - all had different advantages and drawbacks which needed to be taken into account depending on the parameter and characteristic being verified. Further outstanding points were the requirement to standardize definitions/notation etc., providing the statistical significance of the results, and comparison with known references such as climatology, persistence or chance.

There was general consensus that new methods were needed for the verification of mesoscale models, that there should be enhanced international exchange of the relevant data, and that intercomparison of model scores could be useful if done thoroughly and consistently. WGNE agreed to consider this topic in greater depth at its next session.

Performance of models in high latitudes

Under item 3.1, Dr. V. Kattsov summarized the performance of atmospheric circulation models in high latitudes on the basis of AMIP simulations. WGNE recommended that the performance of NWP products in high latitudes should also be assessed. Dr. V. Kattsov undertook to examine various approaches in this regard and to lead an e-mail correspondence with other members of WGNE on what could be done, with a view to providing an initial report at the next session of WGNE.

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. Dr. T. Tsuyuki noted that the intercomparison has recently been extended to cover also the North Atlantic and eastern North Pacific regions. The operational centres submitting forecasts now included ECMWF, the Met Office, the Canadian Meteorological Center, Deutscher Wetterdienst, and the Japan Meteorological Agency. Results showed considerable variability from year to year and from basin to basin in the distance error of the forecast. Overall, over the ten-year period 1991-2000, a significant reduction in the distance error in the predicted tropical cyclone position in the western North Pacific was apparent. In recent years, some models have outperformed the persistence forecast even at twenty-four hours. Bias error in tropical cyclone positions was also reduced before recurvature, but not afterwards. Improvements in the forecasts of the tracks of tropical cyclones could be expected to continue with the use of advanced data assimilation methods, refinements in the parameterization of physical processes, and enhancements in spatial resolution. In this context, it would be interesting to add the verification of tropical cyclone intensity to the intercomparison. A report summarizing the results of the intercomparisons over the period 1991-2000 was being prepared by the Japan Meteorological Agency.

Dr. T. Rosmond introduced results obtained by the Naval Research Laboratory in a comparison of errors in forecasts of Atlantic hurricanes homogeneously for the period 1995-1998 at 24, 48, 72, 96 and 120 hours obtained from NOGAPS, GFDL, UKMO and the "consensus" of the three. The last showed distinctly less error than the contributing results. Dr. Rosmond also presented a comparison of forecast results for 2000 in the western North Pacific from five operational systems (NOGAPS, Met Office, JGSM, AVN and ECMWF). Again the consensus forecast, used by the Joint Hurricane Forecast Centre, had the least error.

The "COMPARE" project

The results of the third and most recent study (a series of experiments centred on the Tropical Cyclone Motion/SPECTRUM/TYPHOON Experiment, TCM-90 and tropical cyclone "Flo", over the Northwest Pacific) have been made available on the web. Otherwise, there were no new developments to report concerning the "COMPARE" project (Comparison of Mesoscale Prediction And Research Experiments). No leader or organizing body has been found for a further COMPARE case (experimentation based on data sets collected in the Meso-scale Alpine Programme, MAP was being considered).

The Chair of WGNE agreed to approach the Chair of the COMPARE Steering Committee, Dr. L. Leslie (University of New South Wales, Australia) to ascertain the future plans.

Verification and intercomparison of precipitation forecasts

Several centres represented on WGNE have been pursuing activities in this long-standing WGNE activity. Dr. E. Ebert (BMRC) has compiled the verification results of twenty-four and forty-eight hour quantitative precipitation forecasts from eleven operational NWP models for a five-year period against rain gauge observations over Australia, Germany and the USA to obtain a comprehensive view of the skill in predicting the occurrence and amount of daily precipitation. It has been found that quantitative precipitation forecasts had 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. Location errors for rain systems, determined using pattern matching with observations, were typically about 100 km for twenty-four hour forecasts with smaller errors for the heaviest rain systems.

Overall, quantitative precipitation forecasts did not appear to have improved significantly over the four to five year period examined. Certainly, as new model versions were introduced, the skill in the various aspects of precipitation forecasting assessed changed - but not always for the better. This finding underlines the complexity of juggling improved model numerics and physical parameterizations. Unless the accurate prediction of rainfall is made a top priority by NWP centres, only slow advances could be expected in the skill of model precipitation forecasts.

The work described above was now being written up for publication under the title "The WGNE assessment of short-term quantitative precipitation forecasts from operational numerical weather prediction models" (probably for submission to the Bulletin of the American Meteorological Society). The draft would be circulated to participating centres for comments and agreement on publication. WGNE offered strong commendations to Dr. Ebert for her excellent work in this area. It was noted that Dr. Ebert's paper would also be presented at the International Conference on Quantitative Precipitation Forecasts to be held in Reading, UK, September 2002 (the WGNE activities in verification and intercomparison of precipitation forecasts would together be a major contribution to this Conference).

WGNE received reports of other activities in precipitation verification at several centres. Dr. U. Damrath outlined the results of verification of quantitative precipitation forecasts for several global models at Deutscher Wetterdienst against rainfall measurements at about 4000 stations in Germany (these results were drawn on by Dr. E. Ebert in her work outlined above). Forecasts and observations were compared by means of contingency tables and calculations of traditional scores (frequency bias, Heidke, equitable threat). It was specifically confirmed that the skill of quantitative precipitation forecasts was highly dependent on model resolution, with, in general, better results with finer resolution. Low precipitation amounts were overestimated by nearly all models at all times of year but especially during the March-May period. High precipitation amounts were often underestimated especially by models with coarse resolution. There had been a positive experience of using "super-observations" for verification, which would thus be included in the future in this work at Deutscher Wetterdienst. Outstanding questions requiring further study were the definition of a verification grid, and interpolation of model output to this grid in a consistent manner.

Dr. R. Petersen summarized the routine verification of precipitation undertaken at NCEP. Quantitative precipitation verification began in late 1992 (over the continental USA) with operational model outputs being compared to 24-hour raingauge totals. Features added over the years include a high resolution multi-sensor analysis, verifying other centres' results, verification over sub-regions of the continental USA and over shorter periods (less than twenty-four hours) using hourly precipitation analyses.

Dr. A. Lorenc reported that the Met Office was using radar- and gauge-based analyses of precipitation from its Nimrod nowcasting system for verification of large-scale model precipitation forecasts over the UK. The better coverage in space and time provided by the Nimrod system enabled higher statistical significance to be attached to the results, and the averaging scale better matched that of the model allowing a more informative diagnosis of model performance. Verification of global model precipitation forecasts over the UK was still at a preliminary stage with only five models (BMRC, DWD, JMA, NCEP, Met Office) having been checked for about a year (ECMWF and Météo-France would be added shortly).

Dr. P. Bougeault noted that, in Météo-France, work was also under way to be able to contribute to the WGNE project. Sample results had been received from DWD, JMA, MSC, NCEP and the Met Office and would be verified against 3500 rainfall observation stations from the French climatological network. The routine production of scores for the various models was expected to begin soon.

The Global Precipitation Climatology Centre (GPCC)

The activities described above in the verification of precipitation forecasts have mainly involved the intercomparison of the forecasts with relatively fine-scale national or regional precipitation data sets drawn from national collections of rain-gauge observations. The Global Precipitation Climatology Centre (GPCC), operated by Deutscher Wetterdienst, produced global gridded precipitation data sets based on observational data. These global data sets were essential for verifying global climate models, the investigation of climate anomalies and variability, and the overall determination of the Earth's water balance and hydrological budgets.

Dr. B. Rudolf, Manager of the GPCC, highlighted the main efforts of the centre, which was originally established in 1989 on the invitation of WMO as a contribution of Germany to the WCRP (and, later, also the Global Climate Observing System, GCOS). The GPCC was also one of the major components of the Global Precipitation Climatology Project (GPCP) which incorporated not only the raingauge-based data sets prepared by GPCC, but also information inferred from remotely-sensed infrared and microwave data, TOVS and OLR. However, conventionally measured data from raingauge networks were still the most reliable for obtaining area-averaged precipitation for the land surface. Thus, the initial task of GPCC was to establish a global precipitation data base including synoptically observed weather reports (with at least daily resolution) and monthly climatic data, distributed worldwide as SYNOP and CLIMAT messages via the WWW Global Telecommunications System. These sources provided nearly 7000 stations in near real-time, which were the basis for the GPCC monthly monitoring of global precipitation. Additional data have been supplied on a voluntary basis following WMO requests and bilateral negotiations, so that the entire GPCC data base comprises monthly precipitation totals for 30-40,000 stations. Careful procedures have been instituted for quality control of the data and correction of errors, and in the subsequent computation of the monthly gridded area-mean precipitation for the Earth's land surface. The two main data sets finally produced were the GPCC "Monitoring Product", available monthly on a routine basis (within a delay of about two months) (Jan 1986-present), land surface only, on 1.0°x 1.0° and 2.5°x 2.5° lat/long grids (based on observed data from 6000-7000 raingauge stations) and the "Full Data Product", available monthly in delayed mode (January 1986-December 1995) would be published shortly, land surface only on a 0.5°x 0.5° lat/long grid (based on observed data from 30,000-40,000 raingauge stations). Special activities were also undertaken in support of the WCRP Arctic Climate System Study (ACSYS)/Climate and the Cryosphere (CliC) project, notably the establishment and operation of the Arctic Precipitation Data Archive, for which daily precipitation and snow depth for the Arctic hydrological basin were collected. The data were analysed and evaluated and the liquid water equivalent estimated. The gridded total precipitation, snow depth and river discharge for the large rivers of the Arctic hydrological catchment area were intercompared. Full details of the activities and operation of the GPCC can be consulted via the GPCC website: **http://gpcc.dwd.de**.

Dr. Rudolf finally noted that, in collaboration with the University of Frankfurt, GPCC was undertaking a new German project related to the WCRP Climate Variability and Predictability (CLIVAR) study, namely the development of a European and global data basis for the German climate programme (DEKLIM) and related statistical analysis on climate variability on decadal to centennial timescales. GPCC's role was the collection, quality control and evaluation of all available historical, precipitation and air temperature data globally over the full observational period. Another new project was the analysis and modelling of climate-related processes in the Arctic in co-operation with the Alfred-Wegener Institute, and the Universities of Bonn, Hamburg and Kiel. This involved an extension of the Arctic Precipitation Data archive, collection and evaluation of all available snow depth and liquid water equivalent data and estimates, and development of an improved precipitation and snow climatology of the Arctic hydrological basin.

In relation to the observations of high-latitude precipitation that were being collected by GPCC, Dr. V. Kattsov pointed out severe errors in gauge measurements especially those of solid precipitation under windy conditions. Depending on partitioning between falling and surface wind-blown snow, there could be a significant "undercatch" to significant "overcatch". For this reason, global precipitation climatologies based on archived gauge measurements without use of a comprehensive bias correction could be misleading. At the Main Geophysical Observatory, St. Petersburg, such a bias correction procedure had been developed and applied to daily precipitation observations from Russian North Pole drifting stations during the period from the early 1950s up to the 1990s. Observations from Russian land meteorological stations have been similarly corrected for bias over the same period. These observational time series should be a basis for improvement of existing precipitation climatologies in high latitudes.

5.2 Ensemble prediction

Recent developments in the use of ensemble prediction techniques were presented by a number of participants in the session. Dr. A. Lorenc described the development of a "poor-man's" ensemble prediction system (PEPS) and the future plans. The preliminary system was based on nine low-resolution (5°x 5°) models, run daily but twenty-four hours "late". Products included "spaghetti charts" and Brier skill scores using the ECMWF ensemble prediction system as a reference were computed. Results for four-months of forecasts from early February 2001 to early June 2001, in which several different PEPS configurations (e.g. all available models, one model removed, all together with six members from the ECMWF ensemble prediction system) were tested, showed consistently better Brier skill scores than an ensemble prediction system over the short-range except in the southern hemisphere. The greatest benefits seemed to be in the cases of more extreme events. The reliability was good, and rank histograms indicated good coverage of the forecast uncertainties at all time ranges out to five days. Enhanced tests were being planned with larger ensembles and including lagged members. Nine centres have agreed to supply forecast data: ensemble charts and fields for their local areas will be offered in return.

Dr. K. Puri reported that the BMRC Medium-range Ensemble Prediction System (BoM-EPS) had been running in research mode since May 2000, and had now been transferred to a BoM operational trial system, running daily in the BoM operational schedule since 5 July 2001. The system consisted of a 33-member ensemble of 10-day forecasts from the BoM global assimilation and prediction system. The perturbation strategy used in generating ensemble members followed the singular vector approach pioneered by ECMWF. Perturbations were scaled linear combinations of the sixteen fastest growing 48-hour T42L19 adiabatic singular vectors, localized from 20°S-90°S. In July, BoM-EPS was upgraded from the previous T79L19 resolution with Eulerian advection to T_L119L19 semi-Lagrangian. Northern hemisphere perturbations were added in December and the suite extended to run twice daily (00Z, 12Z), the latter so that output was available for BoM forecasters around 9 am local time when the medium-range forecast guidance was prepared. A range of products was routinely available to forecasters as part of the operational trial, including individual ensemble member charts, animated spaghetti plots, tubing charts and ensemble significant weather probabilities. An intercomparison of the performance of the ECMWF and BoM ensemble systems for the southern hemisphere over the five-month period April to August 2001 has been carried out. The ECMWF products appeared to have an advantage in skill of 12-36 hours compared to those of BoM in the medium-range, although the overall characteristics of the two sets of ensembles were similar.

Dr. H. Ritchie informed WGNE of recent developments in the ensemble prediction system of the Meteorological Service of Canada. Initial perturbations were generated by the "breeding of growing modes" approach. A ten-day forecast ensemble of 16 members, 8 from the global forecast spectral model and 8 from globally configured versions of the global environmental multi-scale model, was prepared with different dynamical and/or physical parameterization options for each member to reflect model errors or uncertainties. Recently, the horizontal grid was increased from T95 to T149 for the spectral model members, and, equivalently, from 192 x 96 points to 300 x 150 for the global environmental multi-scale model. During the pre-implementation tests early in 2001, it was found that this increase in resolution gave reduced rms errors in the 500 hPa fields, expanded beneficially the spread of the ensemble, and produced better relative scores for precipitation forecasts over Canada.

Dr. M. Miller highlighted the main developments in the ECMWF ensemble prediction system. In particular, the relative advantages of an increased-resolution ensemble prediction system and an increased-size system for extreme weather prediction have been examined. The impact of increasing ensemble size had a much larger impact on economic value for users with small cost/loss ratio and it was apparent that decisions whether to implement increases in resolution compared to increases in ensemble size needed ideally to be made with a knowledge of the requirements of forecast users. A number of studies have been undertaken for cases when the performance operationally of the ensemble prediction system was unsatisfactory. Results have underlined the importance of the initial perturbations, sufficient ensemble size and ensemble resolution (an increase to T255 produced members that were very close to the analysis in both intensity and position). Regarding the application of ensemble prediction in the tropics, diabatic singular vectors have proved a useful tool in generating initial perturbations when tropical cyclones were present: this technique was in pre-operational trial. In other work, errors in the application of stochastic physics have been detected and corrected, whilst it has been found that twenty-four hour singular vectors did not have a beneficial effect in the ensemble prediction. A multi-analysis ensemble prediction system was also being tried, with the 12Z analyses of NCEP, Météo-France, the Met Office and DWD used to initialise the forecasts which were then run with the same model configuration as the control ensemble predictions.

Dr. R. Petersen referred to the implementation of the "Short-range Ensemble Forecast (SREF) project" at NCEP, based on the development of a multi-regional model and 0-3 day ensemble prediction system that would provide operationally relevant and useful guidance on the probability distribution of weather elements or events, including quantitative precipitation prediction, winter storms, storm tracks, aviation weather and extreme or rare events. The system was built round the NCEP "ETA" model (with a 48km horizontal resolution), ten members (regionally-bred initial state perturbations), and twice daily runs out to 60 hours. Products included ensemble mean and spread charts, and "spaghetti" and probability diagrams. Among questions being addressed were the perturbation strategies (both in the initial conditions and model version), potential advantages of increased resolution, the trade-offs in different model configurations (resolution, ensemble size, domain etc.), and product development.

5.3 Long-range and seasonal forecasting

Developments in long-range and seasonal forecasting at various centres were reviewed. These forecasts are, of course, now mainly prepared using coupled models, and Dr. K. Puri described the work in this respect at BMRC where a new coupled ocean/atmosphere model for seasonal forecasting was being constructed. The ocean component was based on the second version of Australian Community Ocean Model developed by CSIRO Marine Research, in turn derived from the GFDL MOM model. There was an enhanced tropical resolution of 0.5°N/S and 2°E/W, and 25 levels in the vertical, half in the top 200 metres. The model included a parameterization of tidal mixing in the Indonesian through-flow region and improvements in vertical mixing. The atmospheric component was based on the BoM unified atmospheric model with a resolution of T47L17. The ocean was initialised in real time by assimilating the latest ocean data every three days using an optimum interpolation scheme: during the assimilation cycle, the ocean model was forced by the latest six-hourly surface stresses, heat and fresh water fluxes from the NWP model so that the most recent activity in the Pacific Ocean would be captured. The model would run operationally at the National Meteorological and Oceanographic Centre, with an eight month coupled model forecast performed every three days. In preliminary hindcasting tests, the evolution of observed anomalies were captured reasonably well, notably the onset of the 1997 El Niño, although the magnitude of warm events was underestimated. Like most coupled models, drift was apparent. No correction was made during the forecast, but the drift was estimated a posteriori and removed from the forecast diagnostics. Nevertheless, it appeared that the drift had a negative impact on forecasts, and its reduction by the appropriate refinement of the ocean and atmosphere models and improved parameterizations was a high priority. Another area for future research is ensemble prediction, in particular to explore sample errors in the initial conditions and to generate optimally growing modes in the ensemble forecasts.

Dr. M. Miller informed WGNE of the development at ECMWF of a "System-2" version of the coupled model for seasonal prediction, incorporating a T95 resolution atmospheric component, a higher resolution ocean-circulation model and an ocean-wave model. Some refinements have also been made to the ocean data assimilation system, with a five-member ensemble of ocean analyses being generated to reflect uncertainty in the fields used to drive the ocean model. Each of the analyses was additionally perturbed as a means of accounting for uncertainty in the sea surface temperature, so generating sets of initial conditions from which a forecast ensemble of 40 members was generated. Significant short-range forecast errors in sea surface temperature persisted in System-2 as with System-1, and, overall, in predictive skill, no clear advantage with System-2 was apparent. ECMWF was also playing a leading role in the "DEMETER" project aimed at developing a European multi-model ensemble prediction system for seasonal to interannual prediction. Two of the six participating coupled models were already installed and running at ECMWF. The DEMETER system used ERA-40 reanalysis data for initializing the integrations, and the progress of the experimentation would thus advance at the speed of ERA.

Dr. V. Kattsov spoke of an intercomparison in progress of experimental one-month weather forecasts (April 2001-April 2002) prepared by the Russian Hydrometeocentre and the Voeikov Main Geophysical Observatory. The Hydrometeocentre forecasts comprised a five-member ensemble obtained from a T42L15 model for the first ten days and then regression for the second and third ten-day periods. The Main Geophysical Observatory produced an eleven-member ensemble of forecasts (with perturbations from breeding initial errors) from a T30L14 model for the three ten day periods. It was also noted that experimental seasonal forecasts were being carried out at the Main Geophysical Observatory. The goal was to assess the potential predictability in Russian mid-latitudes. Using the T30L14 model, sets of six member ensemble forecasts had been prepared for the period 1979-2000 (four forecasts per year). Preliminary results indicated only limited predictability beyond one month (0.2-0.3 anomaly correlation).

5.4 Recent developments at operational forecast centres

Further to the information on progress in ensemble prediction systems presented in section 5.2, and some details on long-range/seasonal forecasting activities in 5.3, reports were given by participants in the session from the main operational forecasting centres on recent developments/extensions/improvements in systems. As usual, constructive discussions on problems of mutual interest took place. A summary of the status of models (global and regional) now in use, and those foreseen in the next three to five years, as well as computing resources is shown in Table 1 (compiled by Dr. P. Merilees).

Bureau of Meteorology (K. Puri)

The current suite of global and limited area models at the Australian Bureau of Meteorology consisted of:

- the global assimilation prediction (GASP) system, horizontal resolution T_L239 and 29 levels;
- the limited area prediction system (LAPS), horizontal resolution 0.375^o x 0.375^o and 29 levels;
- the tropical limited area prediction system with the same resolution;
- the mesoscale limited area prediction system, horizontal resolution 0.125^o x 0.125^o and 29 levels;
- the tropical cyclone limited area prediction system, horizontal resolution 0.15^o x 0.15^o and 19 levels.

In addition a 0.05^o x 0.05^o version of the model was run operationally twice a day for domains covering Melbourne and Sydney, with hourly output then being used to drive a CSIRO photochemical model. Results in the form of two-dimensional fields, time series and time-height cross sections were provided to the environmental protection authorities.

The optimal use of satellite soundings was the driving force for present assimilation research strategies within BMRC; the 3D-Var software has been developed to support the global and limited area systems and to allow assimilation of a diverse range of data. A particular feature of the BMRC approach was much enlarged data selection and improved quality control. Recent research has concentrated on the optimum utilisation of the current ATOVS AMSU-A radiance data, the assimilation of QuikSCAT scatterometer data and refined usage of cloud drift winds.

Complementing this, an extended version of the global system (50 vertical levels with the top level at 0.1 hPa) has been developed which allowed the full forward calculation of ATOVS radiance first-guess values in the 1D-Var retrieval scheme. Extensive global assimilation experiments have been conducted and medium-range prediction performance in the stratosphere has been substantially improved. The QuickSCAT scatterometer data were now being assimilated on an experimental basis, and have shown a modest positive impact on medium-range prediction in the Southern Hemisphere. Quality control procedures have been supplemented with background checks of wind direction to remove incorrectly de-aliased data. The scatterometer data were expected to be included into the operational global system as part of the next major upgrade.

With regard to LAPS, planned upgrades included 1D-Var assimilation of satellite radiances together with hourly radiation calculations (instead of three-hourly currently) and soil moisture nudging. The system has been extensively tested through parallel running over several months and has shown a positive impact over the current operational system.

It was also noted that the ECMWF Meteorological Archival and Retrieval System (MARS) had been made available to the Bureau late in 1998. MARS has now been implemented in the Bureau and was currently being used to archive selected global model and global ensemble system output, in addition to research experimental data. It was expected that it would gradually replace the Bureau's existing operational real time database as the repository for archived NWP model and observational data.

China Meteorological Administration (Dr. Chen Dehui)

Recent developments in the implementation of numerical weather prediction systems at the National Meteorological Centre of the China Meteorological Administration were summarized. The operational models have now been moved from a CRAY/C92 to an IBM/SP, and testing of an upgraded global medium-range forecast system (T213L31 instead of T106L19) was under way. The supporting ensemble system for medium-range forecasting was based on 32-member ten day forecasts (at resolution T106L19), with perturbed initial conditions obtained by a singular vector method. A nested meso-scale model had been developed for forecasts of intense meso-scale rainfall events in northern China. Looking to the future, a comprehensive development programme of the NWP system over the next five years was being elaborated.

In this last context, reference was made to work at the Institute of Atmospheric Physics of the Chinese Academy of Sciences on the design of a new framework for a global meteorological model. Increasing the horizontal resolution of a global model had, of course, a major penalty in terms of the amount of computing required. Thus the technique of using separate meshes for computing and physics was being examined. The computing mesh was even so that no false refraction phenomena were produced during the integration. The physical mesh was uneven, dense in the equatorial region and sparse around the pole. This reduced the difference in computational stability between these regions and damped high frequency modes at the pole. New numerical methods were also being explored.

Meteorological Service of Canada (Dr. H. Ritchie)

The regional configuration of the Global Environmental Multiscale (GEM) model had a uniform high resolution window over North America and the adjacent oceans, with a smoothly degrading resolution moving away to the remainder of the globe. In September 2001, a major change in the parameterization of land surface processes was implemented. The former force-restore land surface scheme was replaced by the Interactions Soil Biosphere Atmosphere (ISBA) scheme together with a sequential assimilation based on model error feedback of low-level air temperature and humidity to generate the soil variables (soil temperature and soil moisture at two levels). This new system provided an improved treatment of surface processes using a mosaic-type approach for vegetated land with possible snow pack, ice-free and ice-covered oceans and lakes, and glaciers. In pre-implementation testing this modification was found to produce a greatly improved diurnal cycle in the surface air temperature and a significant reduction in the objective verification errors in the lower atmosphere. Objective precipitation scores were also much better. Model resolution changes and a new condensation package were planned to be implemented in early 2002. The horizontal resolution over the uniform high resolution area would be refined from the present 24 km to a value in the 12-15 km range, the number of vertical levels increased from 28 to 45-50, and the time step reduced from 12 to 7.5 minutes. The Fritsch-Chappell scheme for deep convection would be replaced by the Kain-Fritsch scheme, and the Sundqvist condensation scheme by a mixed phase cloud microphysics treatment. A more scale selective horizontal diffusion would also be introduced.

For the uniform resolution global configuration of the GEM model used for global data assimilation and medium-range forecasts at CMC, the Lott and Miller subgrid-scale orographic drag parameterization had been found to produce a large reduction in the errors of all the dynamical fields throughout most of the atmosphere. This modification was expected to be implemented in the near future. The model vertical coordinate has also been generalized to the Laprise and Girard formulation that asymptotes more rapidly to a pressure-type coordinate in the upper atmosphere. Work was in progress to refine the horizontal resolution from the present 100 km to about 35 km and to increase the number of model levels from 28 to 52, together with a reduction in time step from 45 to 15 minutes. This change would be combined with a more scale selective horizontal diffusion and changes in the convection and condensation schemes as in the regional configuration.

In the 3D-Var scheme, changes have been made to permit direct assimilation of surface pressure and temperature, and RAOB data as temperatures rather than geopotential, as well as significant level temperatures and winds. It was also now possible to assimilate many new types of data including dropsondes, ACARS/AMDAR/AIREP temperatures, and additional ATOVS satellite channels. The former OI module for quality control of observations had been replaced by a background check followed by a variational quality control. This combination of modifications had a very strong positive impact on the accuracy of the medium range forecasts throughout the atmosphere and was expected to be implemented in the near future.

	GLOBAL "NOW"	GLOBAL 3-5 YEARS	REGIONAL "NOW"	REGIONAL 3-5 YEARS	COMPUTING "NOW"	COMPUTING 3-5 YEARS
BMRC	T_L239 L29	T_L479 L60	0.125^o L29	0.05^o L60	40 GFLPS NEC SX-5	800 GFLPS ?
CMA	T106 L19	T213 L31	0.50^o L20	0.25^o L31	75 GFLPS IBM	750 GFLPS ?
CMC	0.9^o L28	0.3^o L60	15KM L42	WINDOWS 2KM L60	200 GFLPS NEC SX-5/SX-6	UNDER REVIEW
DWD	60KM L31	30KM L35	7KM L35	2.8KM L45	240 GFLPS IBM	500 GFLPS IBM
ECMWF	T_L511 L60	T_L799 L90	N/A	N/A	400 GFLPS FUJITSU	2400 GFLPS IBM
JMA	T213 L40	T_L1000 L60	10KM L40	5KM L60	80 GFLPS HITACHI	2400 GFLPS ?
METEO-FRANCE	T199 L31	T403 L41	9.5KM L31	UNDER REVIEW	250 GFLPS FUJITSU	750 GFLPS ?
UKMO	60KM L30	40KM L48	12KM L38	2KM L48	150 GFLPS T3E	1500 GFLPS ?
NCEP	T254 L64	T400 L70	12KM L50	6KM L70	2 at 75GFLPS IBM	750 GFLPS ?
FNMOC/NRL	T239 L36	T400 L60	9KM L40	3KM L60	100 GFLPS 03K	400 GFLPS ?

GFLPS = Indicator in Gigaflops of sustained computing capacity
"NOW" = Actually operational or within a few months

Table 1. METRICS FOR OPERATIONAL NWP CENTERS AS REPORTED TO WGNE - NOVEMBER 2001

The 4D-Var software had been adapted to the new multi-processor version of the GEM code. Adjoints had been prepared for simplified physical parameterizations including vertical diffusion, gravity wave drag, and large-scale condensation. Incremental sensitivity analyses were now being performed on a routine basis. A complete incremental 4D-var prototype was expected to be available in spring 2002 with implementation in 2003.

Deutscher Wetterdienst (Dr. D. Majewski)

The operational models and systems supported by Deutscher Wetterdienst included:

- a global hydrostatic model on an icosahedral-hexagonal grid, 60 km mesh size, 31 layers, 164,000 grid points/layer: an intermittent data assimilation technique was employed based on an optimum interpolation scheme: forecasts were made up to 174 hours from 00 and 12Z each day, and up to 48 hours from 18Z;
- a local non-hydrostatic, fully compressible model (Euler equations) on a rotated latitude/longitude grid with a mesh size of 7 km, 35 layers, 325 x 325 grid points/layer; data were assimilated continuously based on a nudging scheme: forecasts up to 48 hours were produced from 00,12 and 18Z;
- a high resolution hydrostatic regional model (used by ten services worldwide) on a rotated latitude/longitude grid, capable of being run over various domains with mesh sizes ranging from 7 to 28 km, from 20 to 31 layers; initial and lateral boundary data were derived from the global model: forecasts up to 78 hours were prepared from 00 and 12Z;

In the coming months, the NWP system would migrate to a new IBM/SP (80 nodes each with 16 processors). Changes that would be made in the systems themselves were introduction of prognostic ozone as a basis for a UV-B forecast in the global model, prognostic cloud ice in the global, local and regional models, and a six-layer soil model in the local model. Looking further ahead, it was planned to run a version of the global model with a 35 km mesh size and 35 layers on the ECMWF Fujitsu VPP 5000, to increase the resolution of the local model to 2.8 km and 45 layers in the vertical and to include an explicit simulation of deep convection, and to use the ECMWF upper air analysis with a Deutscher Wetterdienst surface analysis as initial conditions for the global model.

ECMWF (Dr. M. Miller)

A number of major changes had been implemented in the ECMWF operational system over the past year or so. In September 2000, a twelve-hour 4D-Var time-window was implemented in the then T319/T63 operational system. This required careful refinement of many aspects of the 4D-Var, particularly in quality control and in areas affecting the accuracy of the inner-loop trajectory. Subsequent verifications of the trajectory against frequently-reporting observations indicated that the mismatch between the resolution of the inner and outer loops was still an important problem.

In November 2001, the 4D-Var system was upgraded to T511 outer loops and T159 inner loops and the resolution of the deterministic model to T511. The spectral resolution of the wave model was upgraded to 30 frequencies and 24 directions. Observational verification showed that the new 4D-Var assimilation system was clearly better because of the greater accuracy of the overall system and the reduced mismatch between the inner and outer loops. The forecast performance of the new system has been highly satisfactory. Wave forecasts have also shown marked improvement.

In June 2001, AMSU data were used over land for the first time, as well as being used more extensively over sea-ice. Hourly, instead of 3-hourly, calls to the radiation code were implemented in the data assimilation cycle and a revised ozone chemistry model was implemented.

Other work has included further study of the application of a reduced-rank Kalman filter. This has not delivered consistently positive results, partly through limitations of the 4D-Var system, and partly perhaps for more fundamental reasons related to the space of the (singular) vectors used to describe the dynamical component of the analysis and forecast error. The work on the reduced-rank Kalman filter and other elements of the assimilation system showed there was still much scope for improvement in 4D-Var.

Many studies continued to show a clear positive impact of the effective assimilation of satellite data on the skill of the forecasts subsequently carried out. Improved means of using satellite thus continued to be a central element of ECMWF efforts. Extensive preparations have been made for calibration, validation and assimilation of the many new instruments to be launched in the next eighteen months including those of ENVISAT (five instruments, measuring ozone and waves), JASON (sea-level), ADEOS-2 (SeaWinds scatterometer), DMSP (SSMI/S), MSG (SEVIRI), EOS-AQUA (AIRS advanced sounder).

A new finite-element representation in the vertical has been developed and was in pre-operational testing in the forecast model and in the assimilation system. It appeared to reduce markedly the level of computational noise in the stratosphere. Further work on the semi-Lagrangian scheme was delivering further gains in accuracy.

Research on physical parameterizations has relied heavily on a wide range of field experiment data to check quantitatively the accuracy and realism of the parameterization. For example, radiation measurements at a moored buoy in the south eastern Pacific were used to identify problems in boundary and cloud parameterizations. Increasing attention has been paid to the numerics of the physics-dynamics interface. Good progress has also been made on the assimilation of rain-rate and cloud.

JMA (Dr. T. Tsuyuki)

Major upgrades had been introduced in the NWP system following the acquisition of a powerful new supercomputer (a Hitachi SR8000E1 with 80 nodes, main memory 640 Gbytes, peak performance 768 Gflops). In the global spectral model, the number of vertical levels had been increased from 30 to 40, with model top at 0.4 hPa instead of 10 hPa. Extensive refinements had also been made to the cumulus convection and radiation schemes. The forecasts made from 12Z data had been extended to 9 days (from 8 days) and those made from 00Z to 90 hours (from 84 hours). In the regional spectral model, the vertical resolution around the tropopause had been enhanced by increasing the number of levels from 36 to 40, the domain size had been extended by about 50% to reduce the detrimental influence of the lateral boundary, and the analysis interval decreased from twelve to six hours. As to the typhoon model, the horizontal resolution had been increased from 40 to 24 km, and the number of levels from 15 to 25. Additional runs at 00 and 12Z had been introduced to complement those at 06 and 18Z.

The opportunity had also been taken to enhance the operational suite with a mesoscale model having a resolution of 10 km. Forecasts out to 18 hours were being prepared four times a day. Each run was completed within 1½ hours of the time of the initial conditions, these being obtained from a three-hour pre-run during which data were assimilated by means of optimum interpolation and physical initialization techniques at one-hour intervals. Further, a medium-range ensemble prediction system had been implemented, with a 25-member ensemble produced every day using a T106 version of the global spectral model. Initial perturbations were generated by the "breeding of growing modes" approach.

Further upgrades were continuing to be made. In the area of data assimilation, JMA wind profiler data had been assimilated since June 2001 with notable improvements in forecasts of heavy rainfall events from the mesoscale model. A 3D-Var assimilation scheme was put in place for the global analysis in September 2001, and a 4D-Var scheme would be introduced in the coming months for the analysis for the mesoscale model. Steps were being taken to assimilate SSM/I precipitable water data and QuikSCAT sea surface wind observations in the global and regional analyses, and Döppler radar wind measurements from the two Japanese airports in the mesoscale analysis. Regarding model improvements, the cumulus convection, land-surface process and radiation schemes in the global spectral model were being upgraded, a prognostic cloud water scheme would be implemented in the regional spectral model, and perturbations to tropical initial conditions introduced for the medium-range ensemble prediction system.

Météo-France (Dr. P. Bougeault)

The development of the ARPEGE/ALADIN mixed global/limited area spectral model continued in collaboration with the ECMWF and a number of countries from Eastern Europe. The current operational version featured a T199C3.5L31 global model (where T=199 was the horizontal truncation, C=3.5 the stretching factor, and L=31 the number of levels). This provided an equivalent horizontal resolution of 20 km locally over western Europe. As a result of the intensive optimisation of the physical parameterizations over several years, systematic biases were now very small. The complementary ALADIN limited-area model ran at a resolution of 9.5 km over a domain of 2000 km x 2000 km. Forecasts were produced at 00, 06, 12 and 18Z every day. A 4D-Var assimilation system was used with a six-hour time window, a multi-incremental method comprising three external loops with increasing resolution for the internal loops at T42, T63 and T95. The exploitation of satellite data was rapidly increasing with NESDIS pre-processed radiances from NOAA-16 (HIRS and AMSU-A) and NOAA-15 (AMSU-A only) being assimilated together with cloud winds from geostationary satellites (except along the western part of Atlantic storm tracks where they appeared to degrade results).

Several enhancements were planned in 2002 or early 2003, including a major change (increased low-level mixing) in the planetary boundary layer scheme in the near future. A new semi-Lagrangian model version, based on that at ECMWF but with several in-house modifications to account for differences in the physics/dynamics interfaces at Météo-France, would be introduced enabling an increase in resolution to T_L298C3.5L41 (a linear grid and 41 levels) and subsequently T_L403C2.7L41 after further testing. The 4D-Var might also be upgraded by going to just two external loops, with respectively T_L107 and T_L161 in the internal loops. The objectives for satellite data assimilation would be to use raw radiances from the NOAA satellites as soon as possible, as well as radiances received directly (and early) at the Center for Space Meteorology in Lannion, in short cut-off runs. Work was also continuing on the assimilation of data from AIRS, IASI, and SSM/I. The computer system was presently a Fujitsu VPP5000 with 31 vector processors, delivering a sustained power of 250 Gflops. The expectation was that this would be replaced in 2003.

UK Met Office (Dr. A. Lorenc)

The Met Office's new Unified Model, including both the new, non-hydrostatic, semi-implicit, semi-Lagrangian, dynamical core and upgraded physics has been the main focus of recent modelling development. It was expected to go operational in the second quarter of 2002. The majority of improvements to the current operational system have come from better data assimilation and more use of satellite data. Careful attention to detail in the selection and use of data has maintained the recent good rate of improvement in most global forecast scores. The biggest impact was due to the change to two ATOVS satellites (from TOVS + ATOVS). Intelligent thinning in cloudy areas, the use of AMSU-B, and better use over land were other significant improvements in this area. Surface wind speeds from a second SSM/I satellite, wind profilers, a reduction in the weight given to winds from satellite imagery, and a change to the error covariances assumed for moisture also contributed. Increases in the mesoscale forecast scores have been harder to achieve; correction of land surface temperatures in the assimilation, wider use of radar data from Europe, and refinements to the diagnosis of visibility gave a noticeable improvement. The operational stratospheric assimilation system was upgraded to 3D-Var (based on the main global system), with a view to eventual merger of the two systems.

NCEP (Dr. R. Petersen)

Dr. R. Petersen outlined NCEP's far-reaching plans for 2002. The existing "AVN" and "MRF" model runs would be consolidated into a new Global Forecasting System providing forecasts to 16 days four times daily. The basic global model would be run at T254L64 from 0 to 3.5 days, at T170L2 from 3.5 to 7.5 days, and T126L28 to 16 days. The resolution of the model used in the ensemble prediction system would be T126L28 up to 7.5 days and T62L28 to 16 days. A new long-wave radiation scheme and a refined dynamical core were under preparation. In the area of analysis, revised background error estimates would be introduced, a grid-point 3D-Var scheme was being tested, and an updated daily sea-surface temperature analysis implemented. Ocean data assimilation would be undertaken to support the seasonal forecast system, together with the development of a coupled model for sea-surface temperature forecasts. At the national level in the USA, a project to produce a common infrastructure for weather and climate modelling was under consideration (the "Earth System Modelling Framework"). The principal institutions involved were, as well as NCEP, NASA/DAO, NASA/NSIPP, NCAR, MIT and GFDL. NCAR would lead the principal development of the framework, MIT its application to coupled climate models, and NCEP and NASA/DAO the data assimilation aspects.

Extensive changes have also been made, and more are planned, to the NCEP ETA analysis and forecasting system, including particularly an increase of resolution to 12 km and 60 levels, assimilation of WSR-88D radial velocities and GOES cloud data, and an upgrade to cloud microphysics, grid-scale precipitation and the radiation scheme. The ETA forecasts were complemented by various "Threats" runs. In the summer season, the highest priority was the GFDL hurricane model, but at other times, when there were few tropical storms, forecasts were prepared with a nested meso-scale version of the ETA model (with resolution of 10 km hitherto, but to be increased to 8 km following the increase in resolution of the ETA model). The higher resolution produced better guidance overall in surface winds and temperatures particularly where driven by complex terrain or coastlines and was particularly useful for threatening local weather phenomena such as locally heavy rains and flash flooding, heavy winter and lake effect snows, rain-snow line, local freezing temperature events, and fog. A series of fixed domain nests were run at specific times each day (00Z: Alaska and Hawaii; 06Z: western USA and Puerto Rico; 12Z: central USA and Hawaii; 18Z: eastern USA and Puerto Rico), although it might be necessary to shrink the domains or shorten the forecasts to fit within the same time schedule following the increase in resolution from 10 to 8 km.

Naval Research Laboratory - Monterey/Fleet Numerical Meteorology Oceanography Centre (FNMOC) Dr. T. Rosmond)

At the end of October 2001, FNMOC formally began running on two SGI Origin 3000 systems (a 512-processor 500 MHZ, a 128-processor 400 MHZ), representing a twenty-fold increase in computational power over the two previous CRAY C90s. The operational suite (the global system, NOGAPS; the meso-scale system, COAMPS; the 3D-Var analysis, NAVDAS) were being upgraded to take advantage of the increased capability.

Initially, NOGAPS resolution would be increased from T159L24 to T239L36. A semi-Lagrangian version to replace the present Eulerian formulation should be ready in 12-16 months, which would enable a T500L60 resolution on the large SGI system. Other enhancements included a new land-surface parameterization and extending the top of the model to 0.01 hPa. For COAMPS, which was currently run over seven nested domains around the world, at 81/27/9 km horizontal resolution and 30 levels, the plan was to move to a 27/9/3 km and 60 levels configuration. NAVDAS, designed and developed by the late Dr. R. Daley, was expected to be operational for both regional and global applications. NAVDAS, built round an observation space algorithm unlike most other 3D-Var implementation, was particularly attractive for US Navy applications because many of the areas covered were data sparse. The transition to a four-dimensional analysis capability was also being developed.

Dr. T. Rosmond also referred to two active research areas at the Naval Research Laboratory. In relation to atmospheric predictability, tangent linear and adjoint dry dynamics versions of NOGAPS have been written and extensive singular vector experimentation conducted, including in support of aircraft targetting during FASTEX and NORPEX. In this context, an important extension of the exploitation of singular vectors was the development of an analysis variance norm, which, unlike the often used total energy norm, incorporated information on observation distribution. This was particularly helpful for targetting experiments since the area of maximum singular error growth was shifted towards data sparse areas, where extra observations should have more impact on analysis error reduction and thus improved forecasts. The analysis variance norm was based on the error variance estimates produced by the NAVDAS, which also provided the formal adjoint of the 3D-Var algorithm, enabling computation of adjoint sensitivities in terms of the treatment of actual observations by the NOGAPS/NAVDAS data assimilation system. This represented a significant enhancement in observation targetting and should be a powerful tool during THORPEX. A next-generation ensemble prediction system was also being developed to replace the rudimentary breeding mode system currently in use. Two possible methods for generation of initial perturbations were being considered, either use of a rotated singular vector, or an analysis error variance approach.

The other active research area was in coupled data assimilation. Hitherto, computational requirements have often restricted oceanic data assimilation to relatively simplified demonstrations compared to the high resolution global assimilation in near real-time that is really required by oceanographers. The Naval Research Laboratory has constructed a simple three-dimensional optimum interpolation data assimilation system for the ocean and atmosphere, with the NOGAPS model for predicting the atmosphere, and an ocean model. The twenty-four hour forecast from the ocean model was used as the background for each ocean analysis cycle, and six-hour forecasts from NOGAPS for the atmospheric cycle. All available ocean observations were used, including altimeter and synthetic data. It was noted that the ocean background forecasts occasionally predicted a change of more than 60% during the twenty-four update periods in dynamically active western boundary currents (cf. persistence backgrounds in some ocean data assimilation applications). So far the ocean model has been run at the relatively coarse resolution of 0.5° to allow a wide range of data impact experiments: these would be repeated at finer resolutions (0.25°, 0.15°) in the coming months. The plan was to have the full coupled data assimilation system available for operational testing in the 2004-2005 timeframe.

6. OTHER WGNE ACTIVITIES AND FUTURE EVENTS

Publications

One publication had been produced in the WGNE "blue-cover" numerical experimentation since the sixteenth session of the group, namely the annual summary of research activities in atmospheric and oceanic modelling (No. 31, produced in April 2001), again printed and distributed directly by RPN, Montreal.

In the call for contributions for the April 2001 report (mailed out in hard-copy form) at the end of 2000, recipients had been requested to confirm addresses and to provide electronic co-ordinates. The intention was that, in future, calls for contributions to "Research Activities in Atmospheric and Oceanic Modelling", as well as other communications from WGNE such as notification of workshops, conferences, etc., would be distributed electronically. The acceptability of the publication in electronic form had also been canvassed - although many had replied that they preferred to continue receiving the hard copy version.

The call for contributions for the next report in the series (No. 32) would be distributed (electronically) before the end of 2001 requesting electronic submission of reports either as an attachment via an e-mail message or via a web site: **http://www.cmc.ec.gc.ca/rpn/wgne**. The assembled report would then be available electronically at this web site in about April 2002. The required number of copies would also be printed and mailed to those who had so requested in the survey of the WGNE mailing list at the end of 2000.

WGNE appreciated the significant changes that had been made in the collection of material for and preparation of "Research Activities in Atmospheric and Oceanic Modelling". It was suggested that an automatic response be instituted to those who submitted their contributions electronically, and that the availability of the report on the web be notified automatically to those who had submitted texts. WGNE observed that "Research Activities in Atmospheric and Oceanic Modelling" was still a very effective means of giving notice of and keeping abreast of current work and results in the field of numerical modelling and should thus definitely be continued. However, it was considered that effort needed to be given to advertising/promoting the report in view of the somewhat reduced mailing list following the survey at the end of 2000. It was also recommended that the scope and interest of the report could be broadened by including articles on WGNE activities/results/events (e.g. an account of the work in quantitative precipitation forecasting, a description of the verification of tropical cyclone tracks).

Next session of WGNE and GMPP and other events

As noted in section 2.1, it was planned to hold the Second International AMIP Conference at the Météo-France/CNRM site in Toulouse, France, 12-15 November 2002. An invitation was also kindly offered to hold the next session of WGNE and GMPP in Toulouse in conjunction with the Conference i.e. the following week, 18-22 November 2002. WGNE and GMPP accepted this invitation with thanks. Information on detailed arrangements for the session would be distributed in due time.

A data assimilation conference in memory of Dr. R. Daley, who had for so long been a leading scientist in this area with unique insight into basic atmospheric dynamics and physics, had been proposed by the Naval Research Laboratory and other groups in Canada where Dr. Daley had worked. WGNE agreed wholeheartedly that this would be a very appropriate and richly deserved memorial for Dr. Daley and wished to be involved fully in and contribute strongly to the organization of the Conference. This might be held later in 2002 or in 2003. In the latter case, WGNE would certainly wish to consider holding its session in 2003 in association with the Conference (possibly in Victoria, BC, Canada). In any case, WGNE as a group as well as its individual members, would be strong and active supporters to and participants in the Conference.

7. CLOSURE OF SESSION

On behalf of all participants, Dr. K. Puri, Chair of WGNE, and Dr. D. Randall, Chair of GMPP, expressed deep appreciation to Deutscher Wetterdienst for hosting the session of WGNE and GMPP, and the excellent facilities and hospitality offered. The opportunity of interacting with many scientists and experts at Deutscher Wetterdienst and hearing first hand of the research and work going ahead had been very valuable. Sincere gratitude was voiced to Dr. Wergen and supporting staff for the excellent arrangements, unstinting assistance, and refreshments that had been provided.

The joint seventeenth session of WGNE/fifth session of GMPP was closed at 12.15 hours on 2 November 2001.

APPENDIX

LIST OF PARTICIPANTS

1. <u>Members of the CAS/JSC Working Group on Numerical Experimentation</u>

Dr. K. Puri (Chairman)
Bureau of Meteorology Research Centre
GPO Box 1289K
Melbourne, Victoria 3001
Australia
Tel: +61-39-669-4433
Fax: +61-39-669-4660
e-mail: K.Puri@bom.gov.au

Dr. P. Bougeault
Centre National de Recherches Météorologiques
Météo-France
CNRM/GMME/D
42, Avenue Coriolis
F-31057 Toulouse Cedex
France
Tel: +33-5-61-07-93-58
Fax: +33-5-61-07-96-26
e-mail: philippe.bougeault@meteo.fr

Dr. Chen Dehui
National Meteorological Centre
China State Meteorological Administration
46 Baishiqiaolu Road
Western Suburb
Beijing 100081
China
Tel: +86-10-6840-8074
Fax: +86-10-6217-2016
e-mail: chendh@rays.cma.gov.cn

Dr. V. Kattsov
Voeikov Main Geophysical Observatory
7 Karbyshev Street
194021 St. Petersburg
Russian Federation
Tel: +7-812-247-8668
Fax: +7-812-247-8661
e-mail: kattsov@main.mgo.rssi.ru

Dr. A.C. Lorenc
Forecast Research Division
Met Office
London Road
Bracknell, Berkshire RG12 2SZ
United Kingdom
Tel: +44-1344-856-227
Fax: +44-1344-854-026
e-mail: Andrew.Lorenc@metoffice.com

Dr. M. Miller
European Centre for Medium-Range Weather Forecasts
Shinfield Park
Reading, Berkshire RG2 9AX
United Kingdom
Tel: +44-1189-499-070
Fax: +44-1189-869-450
e-mail: mmiller@ecmwf.int

Dr. H. Ritchie
Recherche en Prévision Numérique
Meteorological Service of Canada
West Isle Office Tower 500
2121 Trans-Canada Highway
Dorval, Québec H9P 1J3
Canada
Tel: +1-514-421-4739
Fax: +1-514-421-2106
e-mail: Hal.Ritchie@ec.gc.ca

Dr. T. Tsuyuki
Numerical Prediction Division
Forecast Department
Japan Meteorological Agency
1-3-4 Otemachi
Chiyoda-ku, Tokyo 100-8122
Japan
Tel: +81-3-3212-8341
Fax: +81-3-3211-8407
e-mail: tsuyuki@npd.kishou.go.jp

[now at:
Meteorological Research Institute
1-1 Nagamine
Tsukuba, Ibaraki, 305-0052
Japan
Tel: +81-298-53-8638
Fax: +81-298-53-8649
e-mail: ttsuyuki@mri-jma.go.jp]

Dr. W. Wergen
Deutscher Wetterdienst
Frankfurter Strasse 135
D-63067 Offenbach am Main
Germany
Tel: +49-69-8062-2713
Fax: +49-69-8062-3721
e-mail: werner.wergen@dwd.de

Dr. D. Williamson
National Center for Atmospheric Research
Climate and Global Dynamics Division
P.O. Box 3000
Boulder, CO 80307-3000
USA
Tel: +1-303-497-1372
Fax: +1-303-497-1324
e-mail: wmson@ncar.ucar.edu

UNABLE TO ATTEND

Dr. S. Lord
NCEP/Environmental Modelling Center
Rm 207, World Weather Building
5200 Auth Road
Camp Springs, MD 20746
USA
Tel: +1-301-763-8000 ext. 7202
Fax: +1-301-763-8545
e-mail: Stephen.Lord@noaa.gov

2. Members of the GEWEX Modelling and Prediction Panel

Dr. D.A. Randall (Chairman)	Department of Atmospheric Science Colorado State University Fort Collins, CO 80523-1371 USA Tel: +1-970-491-8474 Fax: +1-970-491-8428 e-mail: randall@redfish.atmos.colostate.edu
Professor B. Holtslag	Wageningen University Meteorology and Air Quality Section Duivendaal 2 NL-6701 AP Wageningen The Netherlands Tel: +31-31-748-5519 Fax: +31-31-748-2811 e-mail: Bert.Holtslag@user.metair.wag-ur.nl
Dr. S. Krueger	Department of Meteorology University of Utah 135 South 1460 East, Room 819 Salt Lake City, UT 84112-0110 USA Tel: +1-801-581-3403 Fax: +1-801-585-3681 e-mail: skrueger@met.utah.edu
Dr. J. Polcher	Laboratoire de Météorologie Dynamique du CNRS Tour 25, 5ème étage BP 99, 4 Place Jussieu 75252 Paris Cedex 05 France Tel: +33-1-4427-4763 Fax: +33-1-4427-6272 e-mail: Jan.Polcher@lmd.jussieu.fr

3. Invited experts and observers

Dr. G. Adrian	Deutscher Wetterdienst Frankfurter Strasse 135 D-63067 Offenbach am Main Germany Tel: +49-69-8062-2720 Fax: +49-69-8062-3731 e-mail: gerhard.adrian@dwd.de
Dr. H. Barker	Meteorological Service of Canada 4905 Dufferin Street Downsview, Ontario M3H 5T4 Canada Tel: Fax: e-mail: howard.barker@ec.gc.ca

Dr. R. Carbone	Mesoscale and Microscale Meteorology Division, NCAR P.O. Box 3000 Boulder, CO 80307-3000 USA Tel: +1-303-497-8926 Fax: +1-303-497-8181 e-mail: carbone@ucar.edu
Dr. R. Gall	National Center for Atmospheric Research P.O. Box 3000 Boulder, CO 80307-3000 USA Tel: +1-303-497-8160 Fax: e-mail: gall@ucar.edu
Dr. P. Gleckler	PCMDI Lawrence Livermore National Laboratory P.O. Box 808, L-264 Livermore, CA 94558 USA Tel: +1-925-422-7631 Fax: +1-925-422-7675 e-mail: gleckler@pcmdi.llnl.gov
Dr. R. Laprise	Department of Earth and Atmospheric Sciences UQAM PO Box 8888, Station Downtown Montréal, Québec Canada H3C 3P8 Tel: +1-514-987-3000 ext. 3302 Fax: +1-514-987-4277 e-mail: laprise.rene@uqam.ca
Dr. D. Majewski	Deutscher Wetterdienst Frankfurter Strasse 135 D-63067 Offenbach am Main Germany Tel: +49-69-8062-2728 Fax: +49-69-8062-3721 e-mail: detlev.majewski@dwd.de
Dr. P. Merilees	Naval Research Laboratory 7, Grace Hopper Avenue Monterey, CA 93943-5502 USA Tel: +1-831-656-4721 Fax: +1-831-656-4031 e-mail: merilees@nrlmry.navy.mil
Dr. R. Petersen	NCEP/Environmental Modelling Center 5200 Auth Road Camp Springs, MD 20746 USA Tel: +1-301-763-8000 ext. 7200 Fax: +1-301-763-8545 e-mail: Ralph.Petersen@noaa.gov

Dr. T. Rosmond

Naval Research Laboratory
7, Grace Hopper Avenue
Monterey, CA 93943-5502
USA
Tel: +1-831-656-4736
Fax: +1-831-656-8031
e-mail: rosmond@nrlmry.navy.mil

Dr. B. Rudolf

Deutscher Wetterdienst
Global Precipitation Climatology Centre
Postfach 10 04 65
D-63004 Offenbach-Am-Main
Germany
Tel: +49-69-8062-2765
Fax: +49-69-8062-3759
e-mail: bruno.rudolf@dwd.de

Dr. M. Shapiro

NOAA/ETL
325 Broadway
Boulder, CO 80303
USA
Tel: +1-303-497-8965
Fax:
e-mail: mshapiro@ncar.ucar.edu

Dr. G. Tselioudis

NASA/GISS
Columbia University
2880 Broadway
New York, NY 10025
USA
Tel:
Fax:
e-mail: gtselioudis@giss.nasa.gov

4. Secretariat Staff

Mr. F. Delsol

Director, Atmospheric Research and
Environment Programme Department
World Meteorological Organization
Case Postale No. 2300
CH-1211 Geneva 2
Switzerland
Tel: +41-22-730-8212
Fax: +41-22-730-8049
e-mail: delsol_f@gateway.wmo.ch

Mr. R.L. Newson

Joint Planning Staff for the World Climate Research Programme
World Meteorological Organization
Case Postale No. 2300
CH-1211 Geneva 2
Switzerland
Tel: +41-22-730-8418
Fax: +41-22-730-8036
e-mail: newson_r@gateway.wmo.ch