The fifteenth session of the CAS/JSC Working Group on Numerical Experimentation (WGNE) was kindly hosted by the Naval Research Laboratory, Monterey, California, USA, from 25-29 October 1999. The session was held jointly with the third meeting of the GEWEX Modelling and Prediction Panel (GMPP). The list of participants in the (joint) session is given in the Appendix.

The session was opened at 0900 hours on 25 October 1999 with a warm welcome from the local host, Dr. P. Merilees, Superintendent of the Marine Meteorology Division of the Ocean and Atmospheric Science and Technology Directorate of the Naval Research Laboratory. Dr. Merilees introduced Captain J. Swaykos, Commanding Officer of the Fleet Numerical Meteorology Oceanography Centre (FNMOC) (with which the Marine Meteorology Division shared the site). Captain Swaykos added his welcome and outlined the main activities of FNMOC. He particularly noted that FNMOC was backing up NCEP operations with the Naval Operational Global Atmospheric Prediction System (NOGAPS) for an extended period of time (following the fire damage to the computer installation used by NCEP). FNMOC co-operated closely with the Marine Meteorology Division of the Naval Research Laboratory in relevant research activities.

Dr. Merilees briefly described the overall role of the Naval Research Laboratory which was the Department of the Navy's corporate laboratory with several specialized centres and laboratories conducting a wide range of both basic and applied research over a broad spectrum of disciplines. Research was undertaken in four directorates: systems, materials science and component technology, space technology, and ocean and atmospheric technology. The Marine Meteorology Division, as a component of the last of the above directorates, had the mission of: understanding and simulating the behaviour of the atmosphere on local, regional and global scales, including interaction with the ocean, land and cryosphere; applying new scientific knowledge to the development and implementation of objective analysis and prediction systems for the US Navy and other Department of Defense users; integrating new scientific knowledge with the analysis and prediction systems into automated weather interpretation systems for Navy and other Department of Defense operations, including the effect of atmospheric conditions on weapons systems. Dr. Merilees summarized a range of recent accomplishments by the Marine Meteorology Division in the area of data assimilation (e.g. use of high resolution geostationary cloud-tracked and water vapour-tracked winds operationally), tropical cyclone prediction, use of remotely-sensed data, mesoscale modelling, and boundary-layer phenomena. Presentations on a number of these items would be given by scientists from the Marine Meteorology Division at the appropriate time in WGNE discussions. Current research continued to be directed towards these areas as well as basic studies of atmospheric predictability and orographic and fetch-limited flows. Looking to the future, Dr. Merilees referred to the "telescoping strategy" being developed of global, regional, tactical and NOWCAST guidance.

Dr. Puri expressed on behalf of all participants thanks to Captain Swaykos and Dr. Merilees for the invitation to meet at the Naval Research Laboratory, and the excellent facilities offered and arrangements that had been made. He looked forward to a successful and productive meeting.

1. ROLE OF WGNE IN SUPPORT OF WCRP AND CAS

As a joint working group of the Joint Scientific Committee (JSC) for the World Climate Research Programme (WCRP) and the WMO Commission for Atmospheric Sciences (CAS), WGNE has the basic responsibility of fostering the development of atmospheric models for use in weather prediction and climate studies on all space and timescales. In the WCRP, WGNE together with the (WCRP) Working Group on Coupled Modelling (WGCM) are at the core of the climate modelling effort. There is evidently a need for close contact and co-ordination between WGNE and WGCM and, to this end, the Chairman of WGNE participated in the session of WGCM held in Hamburg, Germany, in September 1999. WGNE also works in close conjunction with the WCRP Global and Energy Water Cycle Experiment (GEWEX) in the development of atmospheric model parameterizations and studies of land surface processes. WGNE sessions are duly held jointly with the GEWEX Modelling and Prediction Panel.

With regard to its role in support of CAS, the initiation and build-up of the World Weather Research Programme (WWRP), aiming at improvement of predictions on all timescales with emphasis on “high impact” weather, is of particular interest to WGNE. The continuation of FASTEX-type research is now being considered by the WWRP and WGNE will join in the International Science Working Group to review this issue (see section 5.1).

The close relationship that exists between WGNE and operational (NWP) centres is extremely important in all aspects of WGNE work and it is the work of these centres that provides the major impetus for the refinement of atmospheric models. As usual, this WGNE session included reviews of progress at operational centres in all aspects of NWP including data assimilation, numerics and physical parameterizations, and in areas such as seasonal prediction, verification of precipitation and tropical cyclone track forecasts. WGNE also follows progress in various relevant national initiatives such as the Frontier Research Programme for Global Change in Japan, and steps being taken in the USA towards a unified weather prediction and climate simulation framework (see section 3.9).

In organizing the work of the session, the discussion of the GEWEX Modelling and Prediction thrust (encompassing the issues of cloud/radiation parameterization, studies of land-surface processes and soil moisture) was considered as constituting the GMPP session, and was moderated by Dr. D. Randall, Chair of the GMPP (see section 2 of this report). The review of the comparisons of features of atmospheric model simulations (see section 3), data assimilation and analyses (see section 4), and numerical weather prediction (see section 5) were considered formally as part of the WGNE session.

2. THE GEWEX MODELLING AND PREDICTION THRUST

2.1 The GEWEX Cloud System Study (GCSS)

Dr. D. Randall, Chair of GMPP (and the GCSS Science Panel), reviewed progress in GCSS. The primary objective is the development of refined parameterizations of cloud systems within atmospheric models used for numerical weather prediction and climate simulations through a better understanding of the coupled physical processes in different types of cloud systems. Five different cloud types are now being specifically studied: boundary layer; cirrus; extra-tropical layer clouds; precipitating convectively driven cloud systems; polar clouds. Five sub-working groups have been set up to deal with each of these cloud types. In each area, a series of case studies drawing on observations from various field experiments is being conducted to evaluate the simulations of cloud-resolving or cloud-system models and the treatment of relevant processes.

Boundary layer clouds (WG1)

Over the last two years, work has been focussed on the dynamics of shallow cumulus clouds. It has been found that various large-scale eddy simulation (LES) models are well able to reproduce conditions such as those observed during BOMEX. However, a large spread is apparent in the magnitude of the turbulent flux in the inversion layer. In an intercomparison of single column models for BOMEX cases, it was seen that both cloud cover and liquid water content were over-estimated by between two to five times. Following examination of the simulated lateral entrainment rates, new parameterizations of this effect have been formulated and included in atmospheric general circulation models such as that of the United Kingdom Meteorological Office. An intercomparison based on ATEX is now being undertaken, particularly to see if the findings in the BOMEX study could be reproduced for trade-wind cumulus and larger cloud cover. Advantage will also be taken of the European Project on Cloud Systems in Climate Models (EUROCS) that would begin in 2000 and investigate the diurnal cycle of marine stratocumulus and of cumulus clouds over land. Field experiments, exploitation of satellite data, and use/developments of cloud-resolving, single column, and general circulation models will be involved.

Cirrus clouds (WG2)

A comparison of the treatment of cirrus cloud models (including parcel, single-column, two-dimensional cloud-resolving, three-dimensional and large-scale eddy simulation models) of the idealized situations of cold (-60° to -70°C) and warm (-35° to -50°C) cirrus with a defined initial thermal stratification and vertical wind shear is being conducted. It is being found that the simulation of the vertical ice mass flux (or particle fall speed) is critical, leading to significant inter-model differences. Model comparisons are also being planned of well-observed cases of cold cirrus (in the ARM intensive observing period) and of warm cirrus (in EUCREX). The parameterization of anvil cirrus will also be assessed jointly with the precipitating convectively-driven clouds working group.

Extra-tropical layer clouds (WG3)

Attention has been given to the development of a methodology for testing parameterizations of relevant cloud processes in cloud-resolving and meso-scale models. Also, a statistical survey to compare extra-tropical layer clouds as simulated in NWP and climate models with the equivalent International Satellite Cloud Climatology Project (ISCCP) results has been undertaken. A case study based on data from the

Fronts and Atlantic Storm Track Experiment (FASTEX) is being planned. (This will include convective cirrus and boundary-layer clouds, so should additionally be useful to the other GCSS working groups, and is a first step towards a unified GCSS study). Another question being considered is the treatment of orographic clouds in models, particularly cloud processes related to sub-grid scale orography. Generally it is being found that mesoscale models underestimate the middle-level cloud generated by frontal systems but possibly overestimate the amount of high cloud. An outstanding question in this respect is whether sublimating cirrus is a trigger for pre-frontal descent that suppresses the middle cloud, and if so whether this effect is spurious or exaggerated.

Precipitating convectively-driven cloud systems (WG4)

Dr. S. Krueger, Chair of GCSS WG4, was able to participate in the session and presented in person the ongoing work. Crucial questions that had emerged were to develop a better representation of ice-phase microphysical processes in cloud system models, and to simulate more realistically the initiation of convection over land. The data gathered in TOGA-COARE have been particularly useful in studies of multi-scale convection and improving the understanding of the large-scale effects of tropical convection and its interaction with the ocean. A case study of continental deep convection is now also being planned, using data collected at the ARM Southern Great Plains experimental site during July 1997 during which a millimeter cloud radar was operational, providing vertical profiles of cloud properties. Measurements were also available from an extensive array of other meteorological instruments.

Polar clouds (WG5)

Data sets to force and validate single column or cloud resolving models over the entire annual cycle of the Surface Heat Budget of the Arctic Ocean (SHEBA) field campaign (1 Nov 1997-9 Oct 1998) as a basis for an extensive model intercomparison are being assembled. Specific studies of radiative transfer schemes, (polar) boundary layer clouds, and middle and upper-level clouds are also being planned.

GCSS workshop on "Cloud Processes and Cloud Feedbacks in Large-scale Models

A highlight in GCSS activities in the past year was the Workshop on "Cloud Processes and Cloud Feedbacks in Large-scale Models" at ECMWF, Reading, UK in November 1998. The purpose of this meeting was to bring together in a single forum a diverse group of scientists with strong common interests including global modellers with an interest in cloud parameterization, mesoscale and microscale cloud modellers (active in GCSS), as well as experts in radiative transfer and relevant specialists in remotely-sensed data. The workshop included a range of invited and contributed papers and posters. Time was also allocated for break-out discussions on: field experiments to aid large-scale modelling of clouds; use of cloud system models; use of numerical weather prediction to evaluate cloud schemes on large scales; cloud parameterization for the next 5-10 years. The workshop was very successful in producing good communication and interaction between the different groups, and, as a result, new expertise has been entrained into GCSS activities, and liaison between GCSS and radiation and satellite remote-sensing specialists is being further developed. Building on this, a new GCSS science plan is being prepared – in this it is particularly recognized that refining parameterizations requires the participation of large-scale as well as cloud-scale modellers. The full report of the workshop, including many of the invited and contributed papers, together with summaries of the break-out discussions would be produced in the WCRP report series in the first part of 2000.

2.2 Cloud-radiation parameterization

GCSS is a key activity in underpinning the refinement of cloud parameterizations in models. WGNE and GMPP took stock generally of the evolving status of parameterizations in this area. Problems continue to be associated with uncertainties in the treatment of cloud ice (e.g., the various processes involved in ice generation, supersaturation effects, range of particle sizes, optical properties). Differences of as much as 20 W/m^2 may result in the computed radiative effects of the cloud. In this context, field data collected in such programmes as ARM, SHEBA and FIRE are very important for verification. Also, it was noted that, in some regions, a considerable proportion of cloud and precipitation is at the mesoscale. Specific parameterizations are likely to be needed in general circulation models to avoid systematic biases. With regard to the computation of radiative transfer, the cost of schemes can be reduced significantly using neural net techniques. A clear-sky bias of the order of 10 W/m^2 is still apparent in the computed downward longwave. Another aspect is the need for more consistency in cloud radiation physics (e.g., between clouds and precipitation, cloud microphysics and optical properties).

2.3 Land-surface processes

Project for Intercomparison of Land-surface Parameterization Schemes (PILPS)

One of the main activities in assessing parameterizations of the interaction between the atmosphere and land-surface in models up to now has been the Project for Intercomparison of Land-surface Parameterization Schemes (PILPS), led by Professor A. Henderson-Sellers (Environment Division, Australian Nuclear Science and Technology Organization). Dr. Huqiang Zhang (Australian Bureau of Meteorology Research Centre) reviewed the latest developments in and results from PILPS on behalf of Professor Henderson-Sellers. Overall, the various phases (1-4) of PILPS have indicated the surprisingly poor closure of energy and water budgets in the treatment of the surface, large differences in simulations between different schemes, the strong sensitivity to soil moisture initialization, large divergences in “spin-ups”, and wide variation in the abilities to reproduce observations. Even when schemes are coupled to their own or a common host model, the range of differences is not reduced. At a PILPS “strategy forum” in February 1999, plans were set out for the further development of PILPS (a full report of this meeting is available on **http://cic.mq.edu.au/pilps-rice/**.) Ideas for the future include using improved tools and/or techniques, in particular the “Chameleon Surface Model” (CHASM), as constructed by Dr. C. Desborough, Macquarie University, Sydney, Australia, permitting runs with a wide variety of surface energy balance configurations (e.g., treatments of transpiration, soil evaporation, canopy interception) in large-scale models but where other aspects of the parameterizations are identical and all effective surface parameters can be controlled. A multi-criteria calibration optimization will also be employed, a tool designed to optimize the initial states of participating land-surface models. Furthermore, the range of application of PILPS studies will be extended to assessing carbon fluxes, and to intercomparisons of such aspects as plant respiration and the interaction between soil moisture and plant physiology in land-surface schemes (in view of the increasing importance of the “greening” of land surfaces to enable the biological properties of the surface to influence appropriately climate and the hydrological cycle). Liaison will be developed with relevant IGBP activities such as Global Analysis, Interpretation and Modelling (the regional interactions of climate and ecosystems) and the Biological Aspects of the Hydrological Cycle (parameterizations of land-atmosphere interaction). The earlier successful efforts of PILPS, especially phases 1 and 2 which introduced intercomparisons of land-surface schemes, and then compared the treatment of specific cases with observations (thereby identifying discrepancies between models and observations) will be continued with further studies of the Valdai region of Russia (mature and growing forests, and grass and agricultural steppe areas), of frozen catchments (in support of the WCRP Arctic Climate System Study), and of snow-cover in southern Ontario. Overall, there is clearly a need for PILPS projects to assess continuously new and old land-surface schemes as they are developed and refined. In this respect, useful input is being provided to the IPCC Third Assessment Report. An issue of concern is the explosion of the number of parameters in land-surface schemes and their increasing complexity.

Professor A. Robock (Department of Environmental Sciences, Rutgers University, NJ) gave more details of the project intercomparing land-surface schemes using the data for an eighteen-year period at a grassland site at Valdai, Russia (PILPS Phase 2(d)). This study was especially conducted to explore the treatment of snow and frozen soil processes and how these influence the prediction of summer soil moisture. This was the first time in PILPS that interannual variations, seasonal snow cover and frozen soil were included. Participants have found it a valuable test and basis for improving their land-surface schemes. Analysis of the results should enable conclusions to be drawn regarding the degree of complexity needed for various components of schemes and the effects of different physical parameterization choices. As noted above, further PILPS Phase 2 studies are being planned for mature and growing forests in the Valdai region of Russia, and for grass and agricultural steppe areas, and will illustrate how schemes react to the same forcing with different vegetation types. CHASM will be used as a tool, enabling switching between different parameterizations for evapotranspiration, snow, frozen soil, or run off within the modelling framework, thereby contributing to understanding reasons for differences in model performances.

Professor Robock also reported that six updated AMIP simulations had been examined to assess the impacts of model revisions, particularly land surface representations, on the treatment of soil moisture. No systematic improvement in the simulation of observed seasonal variations of soil moisture over the regions studied was apparent, with a continued strong tendency towards dry soil conditions during Northern Hemisphere summer months both globally and regionally. It is discouraging that there are no indications of conceptually more realistic land surface representations leading to better soil moisture predictions. However, as the seasonal cycle of regional precipitation is not correctly produced even in these revised models, it is not possible really to assess how the land surface schemes are performing. (This points to the need for continuing the PILPS Phase 2 type of off-line experiments as a means of evaluating and improving land surface schemes).

Dr. T.J. Phillips (PCMDI, Lawrence Livermore Laboratory) described more generally the validation of the treatment of land-surface processes in the AMIP simulations (as a specific AMIP sub-project carried out as an initiative of PILPS, Phase 3 - Comparison of the performance of land surface schemes in their host models). It has been found that a model's perceived performance depended on the land-surface variable assessed. The evaporation from the land-surface showed some sensitivity to the associated land-surface representation in that simple bucket representations tended to exhibit different spatio-temporal variability statistics than more complex treatments. However, a particular coupling of a simple bucket with an atmospheric model may yield global statistics that are nearly indistinguishable from those associated with more complex approaches, although some aspects of the simulation of the surface evaporation might be improved. The most marked divergence between bucket schemes and more complex representations is in the zonally asymmetric part of the land-surface evaporation field - but this may be a reflection of different choices of surface characteristics (e.g. albedo, surface roughness) more than intrinsic deficiencies of the bucket schemes. In any case, while there may be some improvements in the simulation of the global interannual variability of land-surface climate from the introduction of more refined land-surface schemes, the impact is limited by model shortcomings in other features such as the seasonal cycle of precipitation (cf. comments by Professor Robock above), as well as the overall effects of sensitivity to different initial conditions. However, the analysis so far has only been limited, there are shortcomings in the chosen reference data set, and these initial findings can only be regarded as tentative. In the future, alternative validation reference data will be employed, and energy/moisture partitionings and other diagnostics will be studied together with other assessments to try to determine better the relative influence of land-surface characteristics or the parameterization schemes themselves in the simulation of land-surface coupling in continental climates.

Global Soil Wetness Project

Another important activity enabling assessment of the treatment of land-surface processes in models is the Global Soil Wetness Project, led on behalf of GEWEX by the International Land Surface Climatology Project (ISLSCP). The goals of the project are: to produce state-of-the-art global data sets of soil moisture, surface flux and related hydrological quantities over land; provide a means of testing and developing large-scale validation techniques; enable a global comparison of a number of land-surface parameterizations, including a series of sensitivity studies with specific schemes that could aid future model developments. The results of a pilot phase in which global soil wetness data sets (on a 1°x 1° grid) for the period 1987-1988 were described at previous WGNE/GMPP sessions. These were based on the ISLSCP Initiative I CD-ROM, and the computed soil wetness fields appeared to be of higher quality than previously available products of this type, possibly as a result of the comparatively high horizontal resolution and use of observed precipitation forcing. Depending on the availability of ISLSCP Initiative II data sets (at a resolution of 0.5°x 0.5° over a ten-year period), revised, extended and higher resolution global soil wetness data sets will be produced in the near future. By such means, the Global Soil Wetness Project offers the possibility of comparing land-surface schemes at a resolution comparable to that of atmospheric models, of developing models and testing land-surface assimilation techniques. The soil moistures generated can also be directly verified against observations where these are available.

Development of land-surface parameterization activities

In order to review the overall framework and goals for the advancement of land surface models and analyses, and to promote the incorporation of improved land surface parameterizations into general circulation models, a workshop on “Modelling land-surface atmosphere interactions and climate variability” was organized in Gif-sur-Yvette, France in October 1999 on behalf of WGNE and GMPP by Dr. J. Polcher, with support from the Institut National des Sciences de l’Univers (INSU) of France. (This followed the proposal made by WGNE and GMPP at their joint session in October 1998.) The workshop included sets of presentations on the sensitivity of the mean climate to surface processes, the impact of land-surface processes on the sensitivity of climate perturbations, and validation of the variability of land-surface processes. Three break-out working groups addressed the following topics:

- implementation of land-surface schemes in general circulation models (such aspects as the approach to a modular structure in land-surface schemes and “plug compatibility”, benchmarking land-surface schemes, the need for an infrastructure to aid testing and validation, the treatment of sub-grid heterogeneity, extension to include carbon fluxes);

- validation of land-surface schemes and remote sensing (the planetary boundary layer feedback, the importance of frozen soil processes, the assimilation of remotely-sensed data in coupled land-atmosphere models, use of remote sensing to improve parameter specification); in respect to validation, the need for continuing PILPS Phase 2 experiments in different biome and climate regimes, checking the performance of land-surface schemes coupled to a common atmospheric column model, and work in the Global Soil Wetness Project with improved forcing data/parameters were all emphasized;
- sensitivity experiments for climate models (in particular to test the relative importance of land and ocean variability in determining climate, the strength of land-atmosphere coupling, the effects of modification of vegetation cover on climate).

Based on the recommendations of the workshop and the discussions at the WGNE/GMPP session, it was considered that a more general framework for the advancement of land-surface parameterizations and the incorporation of improved schemes into general circulation models in support of weather and climate predictions on all timescales was now needed. It was proposed that a comprehensive (GEWEX) Global Land-surface Parameterization Project* should be implemented, encompassing a set of four science activities in the form of a two-by-two matrix:

Local (point, plot, catchment) studies:	off-line	on-line
Large (continental and global) spatial scales:	off-line	on-line

The pioneering work of PILPS, the seminal studies and continuing work in local off-line land-surface parameterization and validations (as described above) made it the natural programme to undertake the “local, off-line” activities. The Global Soil Wetness Project represented the “large-scale, off-line” activity comprehensively. Two new activities, as put forward by the Gif-sur-Yvette workshop and the land modelling community, were also defined. The first of these, driven by the interest from operational modelling centres, would look at issues of heterogeneity and data assimilation. Secondly, through co-ordinated and organized coupled land-atmosphere modelling, the impact of land-surface processes on climate would be closely explored. In addition to these four scientific thrusts, a co-ordinated data and model infrastructure for advancing land-surface modelling and analysis would be developed. All these components would be complementary and interconnected under the umbrella of the GEWEX Global Land-Surface Parameterization Project, of which the detailed development will be overseen by a new GMPP Land-surface Parameterization and Coupling Panel (this organization is closely analogous to that of the GEWEX Cloud System Study, see section 2.1).

Simulation of the hydrological cycle for catchments of Russian rivers

Dr. V. Meleshko described a study at the Main Geophysical Observatory of the hydrological cycle and heat balance over the catchment areas of several large Russian rivers (Volga, Ob, Enisey, Lena) in twelve AMIP simulations from models having relatively high horizontal resolution. Similar biases appear in many of the simulations in these areas. In particular, the surface air temperature is found to be too high in the summer season, and the seasonal cycle of the total cloud amount in the models shows a minimum that is not seen in the observed data. Consequently, as a result of the positive feedback between surface radiative heating and surface evaporation, the model-simulated regime over the catchments is too dry. A possible reason is the heterogeneity of the land surface with numerous small-scale lakes and rivers that could be significant in the surface heat balance and evaporation, but which are not resolved in the models. This would seem particularly to be the case for the Ob catchment in the flat western Siberian region. The AMIP simulations are also characterized by a considerable spread in the snow mass in the March-April period (when accumulation reaches its maximum). This subsequently influences the time of complete melting of the snow, the water accumulation in the soil, and drying during the summer season.

3. COMPARISONS OF FEATURES OF ATMOSPHERIC MODEL SIMULATIONS

Organized model intercomparisons are a key element of WGNE activity in diagnosing shortcomings in model simulations, and form the basis of refining numerical techniques and the treatment of atmospheric physics processes required to improve climate representations and weather predictions. As well as the overarching Atmospheric Model Intercomparison Project (AMIP), WGNE reviewed a number of other relevant initiatives.

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* A science and implementation plan for this project is now being drawn up which has subsequently been named as the **"Global Land-Atmosphere System Study"** (GLASS).

3.1 General climate model intercomparisons

Atmospheric Model Intercomparison Project

A key element in WGNE efforts to identify errors in atmospheric models and their causes are organized model intercomparisons. The most important activity in this respect is the Atmospheric Model Intercomparison Project (AMIP), conducted on behalf of WGNE by the Programme for Model Climate Diagnosis and Intercomparison (PCMDI) at the Lawrence Livermore National Laboratory, USA, with the support of the US Department of Energy. Drs. P. Gleckler and K. Taylor (PCMDI) presented information on the status of this activity.

AMIP is now in its second phase (AMIP-II) which again calls for a community standard control experiment in conjunction with careful specific analyses of various aspects of the simulations. The experiment is over a longer period (January 1979-March 1996) than AMIP-I, with an initial spin-up period to quasi-equilibrium (designed to avoid the trends in deep soil moisture and temperature apparent in AMIP-I). As well as specified CO_2, sea surface temperature and sea-ice distributions, the solar constant and relevant orbital parameters that should be used have been indicated. Recommendations have also been made for a zonal monthly ozone climatology, land-sea mask and topography, concentrations of greenhouse gases such as methane, nitrous oxide (if considered separately), and a background monthly aerosol climatology. A much longer list of standard output has been defined. Over thirty groups have undertaken the required integrations and many have already submitted data to PCMDI. Again as for the first phase of AMIP, a range of diagnostic studies has been organized, including several that are new to AMIP-II. A number of generalised "experimental" projects looking at such aspects as AMIP ensembles and resolution sensitivity are also being undertaken. With all the experimental results being collected and the need for accessibility for research purposes, an efficient operational data management and analysis system has been developed at PCMDI. A "quick-look" set of diagrams and statistics, including particularly the standard WGNE set of diagnostics of mean climate, is now available routinely in respect of each participating model. The initiation of AMIP-II and the new sets of model results that have been assembled is certainly stimulating a new wave of AMIP research.

Looking to the future, it is foreseen that AMIP will become a "quasi-operational" community exercise in which modelling groups would periodically contribute revised model simulations (e.g. every four or five years). The experimental protocol will be updated annually by extending the sea surface temperature/sea-ice boundary conditions to near present and reviewing the standard output list.

A full description of AMIP (the AMIP-II experiment and the status of completed model integrations, list of diagnostic sub-projects, and results from AMIP-I) may be found on the AMIP Home Page (**http://www-pcmdi.llnl.gov/amip**).

"Transpose" AMIP

WGNE is continuing to investigate the feasibility of what is termed a "transpose" AMIP in which climate models would be run in NWP mode and then checked using the wide range of NWP verification techniques. Models would be run for 3-10 days from a number of analyses provided by one or more operational centres, and could be examined in terms of synoptic forecast quality, objective scores, weather parameters etc., as well as diagnostics of hydrological budgets, surface fluxes, clouds, diabatic heating etc. A preliminary study is being carried out by ECMWF and NCAR to look at issues such as the need for initialization, the transferability of initial fields from model to model, and a procedure to generate appropriate land surface/soil moisture conditions.

International climate of the twentieth century project

The International Climate of the Twentieth Century Project is being led by the Center for Ocean-Land Atmosphere Studies (COLA) and the UK Meteorological Office Hadley Centre for Climate Prediction and Research. The project utilizes standard sea-surface temperature and other boundary/forcing data sets to test the ability of atmospheric models to simulate the global climate over the past century or longer. Particular attention will be given to the analysis of multi-decadal variability demonstrated during the integrations. Some runs would also include the influence of natural and anthropogenic forcings (including the land surface).

A global monthly sea-surface temperature/sea-ice data set, compiled by the Hadley Centre (referred to as HadISST1) for 128 years (1870-1998) has now been made available to participants in the project. The real scientific work is expected to begin in a few months time when participants have carried out the proposed model integrations.

Review of model systematic errors

As apparent from several WGNE studies (e.g. AMIP-I and -II, model stratospheric simulations - see section 3.6), model systematic errors continue to be prevalent and affect several features of models' representations. WGNE organized a workshop on systematic errors eleven years ago (Toronto, September 1988). Although there has, of course, been substantial progress since that time, similar errors, especially in longer-term or seasonal forecasts that are now being increasingly widely prepared, are seen in different models (for example, in seasonal forecasts, the signal is usually no larger than the systematic error; excessive zonality is also seen frequently). WGNE therefore considered it timely to organize a new workshop to form an updated view of the status with regard to systematic errors and to consider future directions. Such issues as mean errors and their evolution in atmospheric models, sensitivity to physical parameterizations or model resolution, and differences between different models (drawing particularly on AMIP-II results) will be addressed. Diagnosis of such aspects as budget residuals, analysis increments, adjoint sensitivity will be welcome. As well as ensemble and time-mean errors, systematic shortcomings in computing atmospheric variability will be reviewed. Attention will also be given to new means of presenting errors and to alternative approaches that may provide further insights into the nature of systematic errors (many of which have persisted despite major model developments in recent years).

The workshop will be held from 16 to 19 October 2000 in Melbourne, Australia (in conjunction with the sixteenth session of WGNE). An organizing committee composed of Dr. K. Puri (Bureau of Meteorology Research Centre) (Chairman of WGNE), Dr. P. Gleckler (PCMDI), Dr. M. Miller (ECMWF), and Dr. D. Williamson (NCAR) was formed. An initial circular letter of announcement would be distributed early in 2000.

3.2 Standard climate model diagnostics

As noted above, the WGNE "Standard Diagnostics of Mean Climate" are the basis for the "quick-look" diagnostics provided to modelling groups upon submission of their AMIP simulations to PCMDI. (The list of diagnostics is available at **http://www-pcmdi.llnl.gov.amip**).

At its fourteenth session (November 1998), WGNE had suggested that further diagnostics describing the simulation of modes of climate variability (in particular ENSO and the Madden-Julian Oscillation) could be added to the standard set of diagnostics. The representation of the diurnal cycle was another question of interest. Dr. D. Williamson duly presented a list of proposed additional diagnostics/parameters including:

(i) General items such as temporal variance of global and regional averages and point values of key parameters on various timescales; monthly, seasonal, annual and decadal anomalies; angular momentum; seasonal variability.
(ii) Time series and low pass filters (>100 days) of the daily zonal mean 10°N-10°S averaged 200 hPa wind, and the 100 day running variance of the 20-100 day band-pass filtered zonal averaged 10°N-10°S average 200 hPa wind as an indicator of the Madden-Julian Oscillation; Hovmöller presentation of monthly average versus time precipitation and outward-going long-wave radiation for ENSO; all-India rainfall for the strength of the Indian monsoon; a blocking index; statistics on frequency and genesis regions of storm tracks (an unambiguous procedure is yet to be defined).
(iii) Information on simulated frequency of occurrence of hurricanes, tropical cyclone, floods and droughts.
(iv) Appropriate harmonics to show the diurnal cycle.

WGNE encouraged Dr. Williamson to continue the development of this list, suggesting that specific examples should be attached before it was released. The list will be circulated to WGNE members for comments/additions before finalisation.

3.3 Dynamical cores in atmospheric general circulation models

WGNE noted that, in numerical weather prediction models, there have been major advances in the speed of the basic integration resulting from algorithmic changes (semi-Lagrangian, semi-implicit methods, use of linear grids) which have allowed significantly higher resolution to be used without prohibitive increases in computing requirements (e.g. ECMWF has migrated from a T106L19 mainly tropospheric model in 1987 to a T319L60 model with comprehensive stratospheric representation in November 1999). On the other hand, atmospheric climate models continue to be run at relatively low resolutions (e.g. T42 is common) using conventional integration techniques, and advantage has not been taken of the economies in computer resources offered by the newer approaches. The reason for this may be that the benefits conferred by higher resolution are not always obvious in traditional climate model statistics. (This could be because many models were developed at a resolution of T42 with physical parameterizations that appeared to be effective at this resolution. (However, the net systematic error could be reduced by cancellation of errors of opposite sign: if increasing the resolution reduces only one error, the apparent net error increases). Moreover, climate models need particular characteristics, namely conservation over extended periods of integration, local flux based transport (non-linearly corrected to maintain certain physical properties), and locally consistent vertical velocities. Specifically, energy conservation to $0.2W/m^2$ or better is required, but this can only be achieved with non-linear flux-corrected schemes if energy is a predicted variable.

Eighth Workshop on the Solution of Partial Differential Equations in Spherical Co-ordinates

The general behaviour of the basic dynamical cores of atmospheric models and the sensitivity to the numerical schemes and grids employed would again be reviewed at the next periodic Workshop on the Solution of Partial Differential Equations in Spherical Geometry (the eighth) being held in San Francisco, CA, USA, 30 November-3 December 1999. Examples of techniques (in approximating the shallow water equations) on various grids were expected to be presented, including:

- latitude/longitude grids: applications of faster spectral methods; Fourier transforms of tensor fields on the sphere; pseudo-spectral methods versus dealiased high order finite differences; high order spatial discretization methods, optimal quadratic spline location, semi-Lagrangian semi-implicit schemes;
- use of other methods (e.g. reduced grid, composite meshes, icosahedral grids, cubed sphere or gnomonic mappings, Fibonacci grids, near-optimal interpolation of points on the sphere).

Recent developments in using baroclinic models were:

- Lin-Rood (NASA/GSFC - NCAR), a non-hydrostatic anelastic model in spherical geometry based on a two-time-level non-oscillatory forward-time Eulerian or semi-Lagrangian Navier-Stokes solver;
- Deutscher Wetterdienst, icosahedral grid, hybrid vertical co-ordinate;
- Colorado state University, icosahedral grid, isentropic vertical co-ordinate.

The performance of various vertical co-ordinate systems would also be compared.

Full details (including abstracts of presentations) are available at: **http://www.pcmdi.llnl.gov/conf/PDE/8th-workshop.html**.

Aqua-planet experiments as an AGCM test-bed

Various tests of model dynamical cores have been devised whose results have been discussed at previous sessions of WGNE (e.g. idealized forcings such as Held-Suarez or Boer-Dennis). These have given some indications of the differing behaviour of models with different dynamical cores or different time-stepping schemes (Eulerian or semi-Lagrangian) in representing an adiabatic, frictionless atmosphere. For examining the parameterization of individual physical processes, a single-column model has a valuable role. However, there seems to be missing a test-bed for the interaction of physics parameterizations with each other and with the dynamics. Professor B. Hoskins (Department of Meteorology, University of Reading, UK) described how a full general circulation model with very simplified surface conditions, in particular "aqua-planet" experiments with a basic sea surface temperature distribution, may be useful in this respect. The "correct" answers are, of course, not known for such experiments, but it is possible to investigate sensitivities and interactions.

Aqua-planet simulations have already been run by several groups for various applications (e.g. in investigating the organization of tropical convective systems, the Madden-Julian Oscillation, the characteristics of the atmospheric general circulation given idealized surface conditions). Professor Hoskins proposed that, under WGNE auspices, experiments should now be organized with four different zonal, hemispherically symmetric sea surface temperature distributions to examine the organization of tropical convection and the tendency for rain to occur on or off the equator. A further zonal profile would test the impact of an off-equatorial sea-surface temperature maximum. These would be supplemented by three experiments with zonally asymmetric sea surface temperature anomalies (i.e. longitudinally varying) superimposed on the basic sea surface temperature profile. The simulated zonal mean precipitation, Hadley cell, and zonal flow would all be of interest as well as a wave number/frequency decomposition of convective precipitation in the tropical belt (to explore the organization of this precipitation). In the zonally asymmetric experiments, the flow in the equatorial plane and in meridional sections at different longitudes and other such diagnostics would be required.

Full details of these experiments are still being developed, including definition of the model ouputs to be collected (in which PCMDI may assist). The further detailed organization of the initiative would be undertaken by Dr. R. Neale of the Department of Meteorology at the University of Reading.

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

The joint JSC/SCOR Working Group on Air-Sea Fluxes, with its responsibility of an overall appraisal of the strengths and weaknesses of surface-flux data sets from different sources, has asked WGNE to take up again the collection and intercomparison of flux products inferred from the operational analyses of the main global numerical weather prediction centres. Furthermore, the GCOS/GOOS/WCRP Ocean Observations Panel for Climate has underlined the requirement for high quality surface flux products that would have to be provided from routine operational analyses to meet its objective of implementing the ocean observing systems and assembling the data sets required for 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 temporal and spatial resolution, also has requirements for high quality global real-time products such as sea surface temperature (high resolution, multi-platform based), surface radiative fluxes and surface wind stress.

WGNE is duly planning an updated evaluation and intercomparison of surface flux products from NWP centres. This is being organized by Drs P. Gleckler (PCMDI) and J. Polcher (Laboratoire de Météorologie Dynamique) who have participated in WGNE discussions on this topic over the past few years. The "WGNE Surface Flux Analysis, SURFA" project will involve assembling at PCMDI full global fields of surface fluxes which will allow study at the same time of model-derived air-sea and land-surface fluxes (the latter are of growing interest in view of the proposed establishment of the GEWEX Global Land-Surface Parameterization Project described in the previous section). Dr. Gleckler's interests lie particularly in the study of the air-sea fluxes and Dr. Polcher's in land-surface fluxes. A spectrum of observational products ranging from high quality direct measurements (e.g., from the surface reference sites established as part of GODAE) to large-scale estimates will be used in validating the NWP surface flux products. These activities will allow the feasibility and utility of putting in place a (long-term) routine system for monitoring the evolution of the surface fluxes from operational analyses to be assessed. Initially, it is anticipated that surface flux and related fields will be collected at six-hourly intervals, but it would be essential that PCMDI data standard/formats be strictly followed. A variety of diagnostic tools are available at PCMDI that will be useful in evaluating the collected data, and results of analyses will be fed back routinely to the contributing operational centres. Documentation of the models and assimilation systems will also be built up. It is hoped to launch this activity early in 2000, with a preliminary report being given to the next annual session of WGNE. The first step was now to establish formal contact with operational centres willing to participate.

3.5 Snow Models Intercomparison Project (SNOWMIP)

SNOWMIP is being undertaken under WGNE auspices by Météo-France (Centre National de Recherches Météorologiques, Centre d'Etudes de la Neige, CNRM/CEN) and is aimed at evaluating the different types of snow models that have been developed for applications ranging from climate modelling, snow stability and avalanche forecasting. A number of groups, including several running climate models, are interested in participating. The first step will be the documentation of the various models including descriptions of how key parameters such as albedo, surface roughness, snow melt, internal state of the snow cover, heterogeneity etc. are specified or computed. The next stage will be the assembly of appropriate observed data sets, including relevant meteorological data and snow information such as surface temperature, snow depth/snow water equivalent, albedo, snow profiles. Three cases are being considered - mountainous, high elevation; mountainous, medium elevation; low altitude. Full technical details of the intercomparison will be worked out during 2000.

3.6 Model stratospheric intercomparisons

Comparison of Deterministic Predictions of Stratospheric Activity

The analysis of the results of the organized intercomparison of (deterministic) predictions of stratospheric activity at lead times of a few days during the period 1-25 October 1994 is now underway at BMRC. This interval includes a marked transition in the southern hemisphere stratospheric circulation and is therefore an interesting predictive test. Interested groups have been asked to provide 10-day forecasts from 1200 UTC on 10, 11, 12 October 1994 (using United Kingdom Meteorological Office stratospheric analyses). Results from multiple model configurations have also been sought in order to explore sensitivity to such factors as the location of the uppermost model level, vertical resolution and distribution of levels, parameterizations employed (e.g. of radiation, gravity wave drag).

Many models appear to have a common problem in that they show too rapid a movement and distortion in the shape of the polar vortex. It remains to be seen if this is linked to a problem in the initial analysis. Results do not appear to show much sensitivity to the location of the uppermost level. A more detailed study of the predictions (including quantitative diagnosis of rms errors/biases etc.) is being undertaken. However, some of the results are now relatively old and, in view of the increasing interest in the performance of models in the stratosphere, consideration is being given to defining an updated project.

SPARC-GRIPS

The experimentation of WGNE is well complemented by the intercomparison of stratospheric climate simulations being organized by the WCRP study of Stratospheric Processes and their Role in Climate (SPARC) (known as the GCM Reality Intercomparison Project for SPARC, GRIPS). The initial intercomparison of model stratospheric simulations has shown a wide range of skills, but almost all models suffer from a cold bias in the global mean temperature at all levels. Furthermore, the simulated planetary waves differ considerably between models as does the structure of the stratospheric polar vortex. There are significant systematic errors in zonal-mean zonal winds which are related to the drag due to resolved and parameterized waves in the models. In particular, the spectra of convectively-forced gravity waves resolved differs widely between models. These waves depend on the convective parameterization employed and the ability of numerical schemes to allow their propagation. These differences mean that models require varying amounts of forcing due to parameterized gravity waves. (The planned SPARC "Effects of Tropical Convection Experiment" being held over Northern Australia in 2002-2003 should be of considerable assistance in this respect). This first phase of GRIPS is now nearing completion and a summary of results is appearing in the Bulletin of the American Meteorological Society in March 2000. The second step in GRIPS, now being organized, involves further validation of models and carrying out controlled experiments to test parameterization schemes, including particularly investigation of radiative codes in use, of model responses to the formulation of mesospheric drag, and of gravity wave parameterizations. Other activities are being planned to clarify the understanding of the factors that determined the stratospheric state from 1979 to 1999, thought to be natural variability, lower boundary forcing, and variations in radiative forcing. This last effect will be studied by performing a series of perturbation experiments, imposing annual changes in solar forcing, ozone, and volcanic aerosols. The simulation of the quasi-biennial oscillation (QBO) remains another challenge. While a few models are now able to reproduce this feature (although differing more or less from that observed), in some cases, the QBO-like oscillation appears as the vertical resolution increases, in others it occurs as the representation of physical processes (in particular, the parameterization of gravity waves) is varied. A detailed evaluation of this question is also being planned as part of GRIPS.

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 most recent workshop in this series (the fourth), arranged jointly by WGNE and the IGAC Global Integration and Modelling (GIM) activity in 1998 was focussed on comparing model simulations of distributions of atmospheric aerosols (sulphates, soil, dust, soot etc.) and associated precursors with observations and on understanding the role of different processes (boundary-layer mixing, vertical convection, chemical/physical transformation, precipitation scavenging in determining the distribution. Preliminary results of this workshop were outlined at the fourteenth session of WGNE in November 1998 (see Report of Fourteenth Session of WGNE, section 3.7). The full report is expected to appear in the WGNE "blue-cover" publication series during the course of 2000.

Consideration is now being given to planning a further workshop, this time to assess how models treat and resolve the size distribution of multiple aerosol types. The planning of a standard comparative simulation, the procedures to be used in the evaluation of the results, and specification of the observational data needed are underway. The overall exercise is expected to begin late in 2000.

3.8 Regional climate modelling

At its fourteenth session in November 1998, WGNE had raised a number of technical issues that needed to be taken into account when constructing regional climate models. These included such aspects as the choices of domain for a regional climate model and its geographical extent, the potential problems with the lateral boundary conditions, and the scale dependency of parameterizations. The choices to be made and the relative role of various parameterizations were likely to be different in different parts of the world (i.e. in different climatological regimes). The importance of the simulation of the regional climate and key features such as the hydrological cycle being consistent with the large-scale behaviour of the driving (global) general circulation model was also stressed. The Joint Scientific Committee for the WCRP consequently asked WGNE, in co-operation with WGCM, to review further these questions and to consider how the scientific foundation for regional climate modelling could be strengthened. The JSC suggested that it might be appropriate for WGNE and WGCM to establish a joint ad hoc panel to consider outstanding questions and whether any organized or focussed numerical experimentation would be useful, possibly leading to a WCRP workshop on regional climate modelling in 2001.

A series of relevant presentations of work and reviews of activities in regional climate modelling was duly arranged at this session of WGNE. Dr. R.W. Arritt (Iowa State University, USA) summarized various possible approaches to regional climate modelling, particularly nested limited area models. There were many examples of implementation and applications of such models and the sensitivity to domain size, boundary locations, and physical parameterizations had been widely studied. The local and detailed information produced by these regional models was a basis for increasing co-operation with impacts assessment scientists. The quantification of uncertainties in regional climate simulations was thus becoming increasingly important, with a need for multiple realizations and the preparation of longer simulations to estimate interannual to interdecadal variability and the occurrence of regional "extreme events". Dr. Arritt recalled the role of the Project to Intercompare Regional Climate Simulations (PIRCS), conducted by Iowa State University, which had been designed to provide a common framework for evaluating the strengths and weaknesses of regional climate simulations through systematic comparative experiments by various groups using common initial and boundary data from the NCEP/NCAR reanalyses. Consistent comparisons of model results with observations had also been carried out (although, of course, like most of this type of intercomparison exercise, it was not usually possible to diagnose the sources of errors in individual models). Twelve modelling groups from Europe, Australia and North America had completed or were engaged in a pair of simulations (15 May-15 July 1988; 1 June-30 June 1993) focussed on the central USA. Preliminary results indicated that most models produce accumulated precipitation during the 1993 summer flood over the upper Mississippi River basin within about 10% of that observed. For the 1988 drought, the absolute magnitudes of differences among models are larger, as are the differences between models and observations (but the relative differences are smaller). Evaluation of the root-mean-square deviation of the models' 500 hPa heights versus the NCEP/NCAR reanalysis suggested that synoptic events are well handled by the models. Further analysis was underway to investigate model representations of the hydrological cycle and the relative importance of evaporation and moisture flux convergence in producing precipitation, and features such as the locally occurring nocturnal low-level jet and meso-scale precipitation patterns.

Dr. Arritt also noted that extended regional climate model intercomparisons were now underway using the NCEP/NCAR reanalysis for the period 1979-1988 as boundary conditions. The simulation of precipitation patterns was tending to show that orographic effects were well handled, but subtler dynamical processes less so. Several models systematically had problems in the deep south of the USA in the winter and in central USA in the summer, and in the treatment of snow and snow melt.

Professor B.J. Hoskins (University of Reading, UK) emphasized that, in regional simulations of long-term climate change, the crucial factor was the performance of the global driving model. At present, the prediction of modes of natural variability (e.g. ENSO, the North Atlantic Oscillation, the seasonal cycle of global monsoonal circulations) in most global models was far from realistic. The objective for regional climate models was to produce scenarios of local and regional climate on a smaller scale (including indications of extreme events, precipitation changes) consistent with the simulations of the large-scale model. Unless the large-scale variability was properly represented in the boundary forcing, there could be little confidence of the changes in local climate simulated by climate models. Professor Hoskins also pointed out that, as well as the finer horizontal resolution, a regional model should probably also have higher vertical resolution to resolve properly smaller scale structures. Embedding such a model may also involve problems. Finally, Professor Hoskins observed that embedding regional models in large-scale models was one technique to give local detail. Model output statistics (statistical downscaling) was another.

Dr. A. Lorenc (United Kingdom Meteorological Office) relayed comments relating to the issues raised by WGNE at its fourteenth session in November 1998 from the regional climate modelling group in the Hadley Centre for Climate Prediction and Research. It was emphasized that regional climate models were capable of producing realistic mesoscale distributions of, for example, precipitation, and run-off in climate simulations of ten years or more. Moreover, regional models generally did reproduce the large-scale behaviour of the driving general circulation model, provided the domain was not too large. However, it was necessary to check the resolution dependency of the model's parameterizations, and better agreement between the hydrological cycles simulated by the global and regional models could be obtained by using scale-dependent settings in cloud schemes. Extensive studies of the choice of an appropriate domain had been carried out and the WGNE suggestion that "the large-scale flow is stronger in winter so a larger regional domain may be required in this season" did not appear to be correct. The criteria for choosing a domain were that it should be small enough to prevent the large-scale circulation in the regional model diverging from driving model circulation, but large enough to prevent the development of mesoscale features from being damped by the lateral boundary forcing. It was further noted that several groups had run regional climate models for periods of a decade or more without finding long term trends in the hydrological cycle. Certainly, the hydrological cycle in the regional model could be different from that of the large-scale model especially if scale-dependent physics were not used, but the adjustment time for soil moisture was only about a year or so. This could pose problems in shorter timescale runs (e.g. as undertaken in PIRCS), but not in long climate simulations where the first year or two could be discarded if drift were apparent. In view of the foregoing, the Hadley Centre group considered that the computational robustness of the approach to regional climate modelling had been justified and "identical twin" experiments of the type suggested by WGNE were not seen as a high priority.

Dr. R. Laprise (University of Quebec at Montreal, Canada) reviewed several different aspects of regional climate modelling. Because of computational demands, global models could not be routinely integrated at high resolution. The basic aim of regional climate models was to provide a computationally affordable means to achieve high resolution for climate applications by limiting the high resolution area to the subset of the globe of interest in a particular application. Limited-area models nested within global models have been increasingly used for this purpose in the last decade following the seminal work of Giorgi. The working hypothesis is that, forced by the large-scale flow from a global model, a high resolution nested regional model would develop fine-scale features dynamically consistent with the large scales, thus effectively "down-scaling" global climate simulations. These fine scales could result from the interaction of the large-scale flow with fine-scale surface forcings (such as orography and surface heterogeneities) and, even in the absence of such surface forcing, from nonlinear processes (the simplest being the advection by sheared flow) or hydrodynamic instabilities. This process can be thought of as the large scales predisposing the development of fine scales coherently with the field equations, with the regional model serving as a nonlinear operator. Dr. Laprise noted recent (unpublished) results of numerical experiments carried out at the University of Quebec showing that the fine-scale features that develop in the course of the integration of a regional model are insensitive to initial conditions after an adjustment period of about 20 days. In the absence of strong surface forcings, the fine-scale features are entirely controlled by (large-scale) lateral boundary conditions. The robustness of these results lent some confidence to the regional modelling approach as a downscaling technique.

Dr. Laprise referred to the difficulties of handling the lateral boundary conditions in regional models which were compounded by the length of the simulations and the occurrence of possibly spurious budgets over the limited-area domain. In extreme cases, the flow in the regional model area could become inconsistent with the large-scale driving flow (reflected as a lack of correlation between the statistics of the regional and global models in the interior of the regional model domain). This problem has been perceived as casting doubt on the validity of regional model simulations. However, the lateral boundary condition in a limited-area model should be seen in the more general framework of the closure problem for numerical models. Because of their finite resolution, any model needs to parameterize the ensemble effect of unresolved sub-grid scale processes upon resolved scales. Unlike their global counterparts, limited-area models have an additional closure requirement at the largest resolved scale because of their finite domain size. This has traditionally been addressed as a physical-space boundary value problem. Dr. Laprise pointed out this question can also be considered in spectral space and Fourier filtering or judicious application of spatial filters (or so-called "nudging") may have the potential to ensure consistency between the large-scale features in the regional model and driving global model. In practice, this technique also reduced the numerical noise at the lateral boundaries.

Dr. Laprise reiterated that the final quality of the results from the regional climate model depended on the realism of the large scales simulated by the driving global models, which were the ultimate and most sophisticated tools for climate simulations. Regional climate modelling should be thought of as a useful approach in the arsenal of means to study climate change, climate processes and climate scenarios. Despite their inherent limitations and documented problems, use of regional climate models was no less defensible than other (imperfect) modelling tools and approaches (e.g. asynchronous coupling of atmosphere and ocean models, flux correction or adjustment in coupled ocean-atmosphere models, off-line atmospheric chemistry models). The proof of the validity of the regional climate modelling approach depended in the end on their ability to simulate regional climate realistically.

Dr. Laprise referred to experimentation aimed at validating the regional climate modelling approach in a perfect-model mode by first carrying out, as WGNE has suggested in the past, a long high resolution global model simulation to serve as a reference model climate. The resolution of the model data set is reduced (by spectral truncation or spatial filtering) to a typical (lower) global model resolution, and then used to drive a high resolution regional climate model whose simulation can be compared to the reference high resolution global integration over the same area. Global variable resolution models could be validated similarly. Such experiments are being undertaken at a few centres in the USA and in Canada. In this last case, a shallow water and baroclinic versions of the Canadian Global Environmental Multiscale (GEM) model will be employed, firstly forced as in the dynamical core experiments, then using full physics.

Another important issue that had been raised by WGNE at its session in 1998 had been the possibility that the unresolved scales in the driving general circulation model could effect the large-scale flow. This would not be compensated by any amount of downscaling in a regional climate model. Dr. D. Williamson (National Center for Atmosheric Research) reported in this regard on an analysis of simulations carried out at NCAR with the semi-Lagangian version of CCM3 (T63, T95, T127 spectral truncations with a linear transform grid and 26 levels in the vertical). In the analysis, the "large-scale flow" was taken to be the integral of moisture flux into regions of the size typical for nested climate models. Five year annual averages of the moisture flux into boxes 40°lat x 60°long, and of 60°lat x 90°long were computed. For boxes over the USA, differences between the T127 and T63 integral of moisture fluxes into the boxes were of the order of 0.3 and 0.2 mm/day rainfall equivalent for the smaller and larger boxes respectively (equivalent to 10 and 6 Wm^{-2} averaged over the regions). Differences of similar magnitudes were seen in other parts of the world. The differences between the T127 and T95 simulations were smaller (0.1 and 0.05 mm/day, or 3 and 1.5 Wm^{-2}). This suggests that the driving climate model may require a resolution of at least T95 in order to achieve a situation where the unresolved scales do not significantly impact the resolved scales. These results raise a question that needs to be generally evaluated, namely that, since the ultimate success of regional climate models depends on the proper and realistic simulation of the large scales by global circulation models, continued studies of the dependence of the simulated large scales on model resolution was of considerable importance. The proposed experimental "resolution" sub-project of AMIP-II provided a good opportunity for such studies.

A report of the discussions at the WGCM session in September 1999 on the topic of regional climate modelling was also given to WGNE. WGCM had concluded that a balanced view of regional climate modelling was required and that, although there were technical issues to be considered, there were very many successful applications and uses. The most serious problem to be tackled was the reduction of errors, systematic or otherwise, in the large-scale driving fields. Nevertheless, WGCM considered that a joint WGCM/WGNE review of the results being achieved by regional climate models, to clarify outstanding questions, to point to strengths and weaknesses, and to draw attention to the importance of the correct and careful use of regional climate models would serve a useful purpose. Techniques such as variable resolution models and non-dynamical (statistical) downscaling should also be taken up. Finally, the "added-value" given by different methods to regional detail and the validation of regional-scale results should be assessed.

In its overall review of the status of work in this area, WGNE reiterated that the technical issues that it had previously raised had to be considered very carefully when constructing a regional climate model. In particular, the question of an appropriate choice of domain size had been repeatedly mentioned, i.e., it should be large enough to prevent the development of regional-scale features being damped by lateral boundary forcing, but not so large that the larger scale circulation in the regional domain diverged from the driving model circulation. Generally, however, WGNE was encouraged by the reports of the research going on at several centres into refining the underlying approach to regional climate modelling and the results being achieved, and that a number of the points raised by WGNE are being addressed. On the other hand, the shortcomings in the large scales in global climate simulations must inevitably limit the credibility of any scenario inferred from regional climate models: this is a crucial point since regional models are already being applied in making statements about regional climate change scenarios. WGNE was pleased to see that "identical twin" experiments were being undertaken by a few groups as had been proposed by WGNE over the past two or three years and which would be a further means of assessing the skill and validity of the nested model (and variable grid) approaches. WGNE emphasized the importance of these experiments and encouraged further groups to consider conducting them.

WGNE took up the suggestion of a joint WGNE/WGCM panel on regional climate modelling with the basic objective of summarizing the current state of the art in this field and reviewing the outstanding questions. The panel should also consider whether any co-ordinated or focused experimentation (in addition to PIRCS and the "identical twin" experiments) would be useful in further investigating basic issues of regional climate modelling such as the choice of domain, potential problems with lateral boundary conditions, and scale-dependency of parameterizations. This could lead into the preparation of a joint WGNE/WGCM workshop later in 2001 that would be aimed at increasing the awareness of the community to the points that must be taken carefully into account when constructing regional climate models. Dr. R. Laprise and Dr. W. Wergen were nominated to represent WGNE on the joint panel. (WGCM had nominated

Dr. H. von Storch (Institute of Hydrophysics, GKSS Research Centre, Geesthacht, Germany) and Dr. R. Jones (United Kingdom Meteorological Office).

3.9 Other climate-related modelling initiatives

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

USA

Dr. T. Hogan (Naval Research Laboratory) described steps being taken in the USA towards a unified weather prediction and climate simulation framework and, more generally, what can be done to increase the involvement of the broader US research community in advancing US global modelling activities. Representatives from many NOAA-, NASA- and NSF-sponsored global numerical weather prediction and climate modelling centres and from the US navy global weather prediction group have agreed that closer collaboration would be beneficial and that global atmospheric model development for and application to climate simulation and weather prediction should be based on a “common modelling infrastructure” and “core models”. The modelling infrastructure should be flexible and designed to foster the exchange of technology between the various modelling groups in the USA, and should, moreover, be incorporated into national computing initiatives related to atmospheric modelling and prediction (such as the Department of Energy Climate Change Prediction Programme). All participating institutions have expressed their intent to work towards community standards for global weather and climate models.

To follow up these recommendations, a working group including all the leading USA modelling centres has been formed to design a modelling infrastructure, organize a framework and set down standards to be followed. Issues being addressed include plug compatibility, future coding languages, sharing dynamics modules and physical parameterizations, the development of flux couplers, ocean and land surface modelling standards, accuracy of physical constants, data formats and standards for meta-data.

Japan

Dr. T. Tsuyuki gave an update on the "Frontier Research Programme for Global Change" in Japan, an ambitious and far-reaching initiative co-ordinated by the Japanese Science and Technology Agency (see summary in Report of Fourteenth Session of WGNE, section 3.9). A key component is the development of a supercomputer a 1000 times faster than the CRAY C90. Construction of the computer (by NEC) has begun with installation expected in 2002. Plans call for 640 processor nodes (each having 8 processing elements with a peak performance of 8GFlops i.e. 64 GFlops at each node), and 10 Tbytes of memory (16 Gbytes per node) with, altogether, 3000km of cabling. Although the hardware development is well advanced, much work is still needed in the preparation of the comprehensive and complex Earth system models planned and of other software and methods of archiving.

4. DATA ASSIMILATION AND ANALYSES

4.1 Reanalysis projects

The outcome of the Second International WCRP Conference on Reanalyses, 23-27 August 1999, Wokefield Park, nr Reading, Berkshire, UK, which reviewed the status of reanalysis projects, the quality and characteristics of the reanalyses, and their use in a range of studies was reported to WGNE. The practical organization of and arrangements for the Conference were undertaken by ECMWF, whose efforts in this respect were greatly appreciated as well as the support of a number of other sponsors.

The event was a follow-up to the First WCRP International Conference on Reanalyses held in Silver Spring, Maryland, USA, 27-31 October 1997. That Conference had already identified several of the numerous benefits from the major reanalysis efforts that had been carried out by ECMWF, the USA NOAA National Centers for Environmental Prediction (NCEP) in collaboration with the National Center for Atmospheric Research (NCAR), and the USA NASA Goddard Space Flight Center Data Assimilation Office (DAO). The Second Conference reviewed the continuing progress in validation and exploitation of the reanalysis data sets. It was clear beforehand that there would be many successes to report across the entire spectrum of WCRP interest and beyond and this conference focussed far more on applications of reanalyses rather than their validation and intercomparison as had the first conference. In this regard, research requirements in the climate area and other domains, were placing increasing demands on the quality of the reanalysed data sets. Accordingly, the Conference was also a forum for setting out the requirements, assessing the extent to which they could be addressed in a new round of longer and more complex reanalyses, and providing comments or guidance to the reanalysis producers. The Conference was lively and productive including over 80 oral and 100 poster presentations.

The value of reanalyses for an impressive range of scientific studies and applications was demonstrated. Interesting and striking new results were shown of diagnostics of atmospheric behaviour and interactions with the ocean, land and cryosphere, the behaviour of El Niño, the occurrence of the Madden-Julian Oscillation, the polar circulation and stratospheric-tropospheric exchange, as well as in areas such as seasonal forecasting, the ocean circulation, ocean waves, hydrology, synoptic events, and geophysics. One novel application was in the determination of propagation loss of telecommunication signals. Examples were also given of the use of the reanalyses as a teaching tool.

The quality of the reanalyses was highly appreciated and, generally, the differences between the different reanalyses are approaching the level where they cannot be resolved by existing reference data sets. Nevertheless, there continue to be uncertainties in various aspects of the reanalyses, especially in terms of surface fields and fluxes. Improvements are needed in observations, data assimilation methods and models themselves to meet the requirements for a sufficiently accurate documentation of interactions between the different components of the climate system. The importance of having two or more state-of-the-art reanalyses as a basis for cross-comparison (e.g., of diagnostic results) and for indicating possible areas of shortcomings was strongly reaffirmed. The Conference duly encouraged the production of long reanalyses every 5-10 years, taking advantage of advances in operational systems, new data sets (e.g. from the continuing recovery of historical data) and the overall accumulated experience.

Despite their strengths, reanalyses can only be interpolations of the input observational data which have many gaps in time and space. Repeatedly during the Conference, the high priority to be attached to improving data quality, to filling in gaps in the observational data base, and to continuing efforts to obtain past data sets was emphasized. Because of the changes in observing systems and the available observational data base over the period of the reanalyses, the varying and often unknown biases in observing systems (which are not eliminated by reanalysis), it was noted that, although present reanalyses provide a good basis for studying interannual variability, they are not generally suitable for detection and assessment of long-term trends in climate variables, a key issue for CLIVAR. For trend analysis, it would be necessary to identify and document all the changing characteristics of data. This would require a major investment of resources whose availability is not apparent.

New reanalyses are now being planned and will form the basis for updated studies. These include:

- NCEP: a second reanalysis for a limited period 1979-1998 is being undertaken using an updated forecast model and data assimilation, improved diagnostic outputs, and including corrections for many of the known problems in the first NCEP/NCAR reanalysis. This will also provide the bridge to a much more advanced next generation reanalysis planned for about 2003 or later. A regional USA reanalysis is also being prepared.

- ECMWF: an ambitious and comprehensive 40-year reanalysis project (ERA-40) is in preparation for the period 1958-present. A much wider selection of data sources will be used in the ERA-40 reanalyses, but the reanalyses will then inevitably reflect the changes in the observing system since 1958. ERA-40 will employ a 3DVAR scheme, and a 60-level T159 forecast-model coupled with an ocean-wave model.

- NASA/DAO: major upgrades have been made to the data assimilation system (the Goddard Earth Observing System, GEOS) employed in NASA's first reanalysis,. These include a physical-space statistical analysis system and numerous improvements to the forecast model. The revised analysis scheme has the capability of assimilating TRMM and SSM/I precipitation observations. It is planned to produce a reanalysis for the TRMM period with the latest version of GEOS (see also section 4.2).

The Conference underlined that the reanalysis output needed to be made as widely available as possible, with access through the internet if possible. Availability of data sets on CD-ROMs was also very useful, especially for countries where the internet is not as yet fully developed, as well as for educational purposes. Reanalysis data sets needed to be supported by comprehensive documentation detailing the model used, the physical parameterizations, the input data, etc.

The full proceedings of the Reanalysis Conference were being published in the WCRP report series (WCRP-109, January 2000).

4.2 Developments in operational data assimilation/analysis systems

Overall view of status

As customary at its sessions, WGNE reviewed the latest developments in the implementation of data assimilation/analysis systems at the main operational centres, as well as the outcome of the Third WMO Symposium on Data Assimilation in Meteorology and Oceanography held in Québec City, Canada, in June 1999. The basic concept of assimilation is the process of absorbing and incorporating observed information into a prognostic model. However, the manipulation of the full background error covariance matrix, which is at the heart of the assimilation process, is much too expensive for practical use. The major differences between various assimilation methods can be seen in terms of different approximations in treating the error covariance. All are based on physical insights into the structure of important error processes, but there is a large spread of choices made, having consequences for the computational method needed. There is increasing interest in ensemble techniques to model the important growing error modes. Efforts also continue to be put into the appropriate means of assimilation of a wide variety of observations.

Despite overall progress, the assimilation of moisture remains an outstanding problem, with neither observations nor models yet providing the quality desired. Partly because of this, there is uncertainty as to the best assimilation method to adopt for the very high resolution models being planned for mesoscale numerical weather prediction in the next decade. WGNE has in the past discussed the organization of experimentation or studies to intercompare error covariance models, and has this question very much in mind (although the synoptic dependence of modern methods makes this intrinsically difficult).

Developments in data assimilation/analysis systems at operational centres

A number of attendees at the session gave information on the latest developments in the implementation of data assimilation/analysis systems at their centres, including in particular two presentations from scientists at the Naval Research Laboratory. Firstly, Dr. R. Daley described the Naval Research Laboratory Variational Data Assimilation System (NAVDAS). The main features are:

(i) Use of 3DVAR formulation. 4DVAR is only being developed more slowly in view of the still experimental nature of the algorithms involved, and the limited human and computer resources to tackle the problem.

(ii) 3DVAR can be used for global, regional and shipboard applications in the "telescoping strategy" being followed by the Naval Research Laboratory (see introduction by Dr. P. Merilees).

(iii) The 3DVAR system employed is set up in observation space, using pre-conditioned conjugate gradient descent. An observation space algorithm was chosen because it allows the use of more realistic background errors (the applications of data assimilation to meet naval requirements are more likely to suffer from a scarcity rather than overabundance of observations - and an observation-based algorithm is more suitable in these circumstances). Furthermore, the overall method is more like the current Naval Research Laboratory multi-variate optimal interpolation system, as well as giving the flexibility to be able to be used on a variety of processors ranging from workstations to massively parallel computers. Also there is little dependence on the forecast model and essentially the same code can be used for both shipboard and global applications.

Dr. R. Gelaro was the second scientist from the Naval Research Laboratory to give a presentation under this agenda item. He basically updated the information on his work on targeted observations presented at the fourteenth session of WGNE in November 1998, assessing the effectiveness of such observations based on the results of FASTEX and the North Pacific Experiment (NORPEX).

Dr. W. Wergen (Deutscher Wetterdienst) described how, in the context of estimating the potential benefits that could be realisable from a planned space-borne lidar instrument observing vertical profiles of the wind field, Deutscher Wetterdienst had carried out studies examining the impact of conventional radiosonde, pilot and aircraft data over the USA and Canada. Appropriate assimilations were performed for the period 21 January-10 February 1998, using the intermittent, optimum interpolation-based global T106 system at Deutscher Wetterdienst. The outcome from this limited study was:

- wind observations have a more pronounced impact on forecast quality in the medium-range than mass data

- aircraft data can successfully supplement the radiosonde and pilot network

- observations north of 52°N have a similar impact to the USA radio-sonde and aircraft data south of 52°N on forecast quality

- simulated single line-of-sight wind components could be assimilated and had a positive impact on forecast quality

As a result of this work, the European Space Agency was now planning an "Atmospheric Dynamics Mission" that would provide global coverage of line-of-sight wind components. An incoherent technique operating at 355 nanometres would be used based on Rayleigh and Mie scattering from molecules and aerosols, and would provide profiles throughout the troposphere.

Dr. A. Lorenc reported on the current status of the operational data assimilation system in the United Kingdom Meteorological Office. A 3DVAR scheme is used, similar in design to those at other centres, but set up so that it can be employed for both global and limited area grid-point models. There is also scope for developing a 4DVAR scheme. At present, the analysis increments are introduced (1/Nth at a time over N timesteps centred on the nominal analysis time) by means of an "incremental analysis update scheme" (this will change when the Meteorological Office unified model is updated to include a new dynamics core). In the limited-area version, visibility, cloud and rainfall rate analyses are also included. The cloud and rainfall rate data are assimilated via the analysis correction technique (as used for all variables prior to the introduction of 3DVAR). A "moisture observation preprocessing system" blends satellite imagery and surface cloud reports with radar observations to produce a three-dimensional cloud analysis, cloud fraction data then being converted into humidity increments through a relationship inferred from the model cloud scheme. A radar-based precipitation rate estimate is also assimilated via a technique of latent heat nudging. The constraint of zero analysis increments is specified at the lateral boundaries (possible because up-to-date boundary conditions are used operationally with assumption that there is no difference between the global and mesoscale analyses along this interface).

Dr. R. Atlas gave a comprehensive insight into the activities of the NASA Data Assimilation Office (DAO), which has the objectives of advancing the state-of-the-art of data assimilation so as to produce research quality assimilated data sets for addressing questions in studies of the Earth system and of global change, to make the best use of satellite data for climate assessment, and to assist Earth Observing System science and instrument teams. (This is in contrast to the other work reported in this section which is primarily aimed at preparing the best possible initial conditions for NWP). As noted in section 4.1, major upgrades have been made to the data assimilation system in use (GEOS), including development of a new version of the core atmospheric circulation model. As well as a revised software architecture (enabling a tropospheric configuration of 1°x 1° and 48 levels and a stratospheric configuration of 2°x 2.5° and 70 levels), a revised hydrodynamics core has been designed, and advanced parameterisations of physical processes adopted (e.g. a relaxed Arakawa-Schubert convective scheme, a Mellor-Yamada type moist turbulence parameterization, the land-surface model of Koster and Suarez, the long and shortwave radiation scheme of Chou and Suarez, and orographic gravity wave drag from Zhou et al). A particularly important aspect of GEOS is the physical space statistical analysis system providing a global analysis with minimal data selection questions, in grid-point space (equivalent to a 3DVAR scheme). Other features are interactive quality control, adaptive estimation of forecast error variance statistics, and non-separable forecast error correlation functions. The interactive quality control of observations enables extreme events to be better captured, with a demonstrable impact from data that would be otherwise rejected. Online forecast bias correction yields unbiased analyses (especially important for instrument teams). A rapid update cycle (one hour) being employed experimentally improves usage of all asynoptic data, eliminates a spurious tidal signal from analyses and is expected to improve the representation of the hydrological cycle in general (such a rapid update cycle is a cost-free partial alternative to 4DVAR). A parameterized Kalman filter is also employed. The main products of the system are:

- a first-look analysis, providing operational support to Mission to Planet Earth Satellites, especially AM-1, e.g. for developing instrument retrieval algorithms.

- multi-year assimilation or "reanalyses" (long assimilations with a non-varying system; reanalyses (from 1979 onwards) are planned approximately every four years, taking advantage of advances in assimilation systems as well as improving abilities to extract information from older data sets; the major research questions on impacts of changing observational systems will also be addressed.

- final platform analyses using the same information as the first-look analyses together with additional data from Mission to Planet Earth platforms: expected to change as the assimilation system and data availability from the platforms evolve.

Parallel analyses will also be carried out, including or excluding specific data sets as a means of assessing data impact.

In summarising recent results, Dr. Atlas noted the significant improvements in the representation of the hydrological cycle and atmospheric energetic terms in the GEOS analyses resulting from the assimilation of TMI and SSM/I rain-rates, as well as total precipitable water. In particular, better cloud, moisture, latent heating distributions in the tropics are apparent, and consequently reduced biases in radiative fluxes. Synoptic features are also better represented, and improved forecasts of tropical precipitation (beyond one day) and five-day forecasts generally in the tropics are obtained from the analysed states. Dr. Atlas also noted that initial tests using data from QuikSCAT (although not yet generally distributed) were showing great potential: this was yet a further example of the major role to be played by data assimilation in the use, retrieval and exploiting to the full all types of remotely-sensed data.

Dr. H. Ritchie summarized work at Recherche en Prévision Numérique (RPN) of the Atmospheric Environment Service* of Canada in further developing the 3DVAR data assimilation system, including preparations to assimilate directly satellite data (e.g. TOVS radiances, SSM/I total precipitable water). Assimilation will also be on model co-ordinate levels rather than pressure surfaces as hitherto. High priority is attached to the direct assimilation of TOVS radiances, since it appears that a degradation in the performance of the Canadian operational system may be attributable to a decline in the quality of SATEM retrievals. Additionally, emphasis has been given to using 3DVAR for a univariate analysis of stratospheric ozone (within the context of the "Middle Atmosphere Initiative"), and trials have been performed with TOVS total ozone data as the only input. In comparison with the Global Ozone Monitoring Experiment (GOME) data and TOMS analyses, the results from 3DVAR give realistic finer structure. Initial problems in the analyzed vertical distribution were reduced by the introduction of a basic ozone chemistry scheme in the assimilating model. Observing System Simulation Experiments have also been carried out as part of a feasibility study for a satellite-based ozone lidar and to assess the likely impact of an instrument being developed as a component of the "Ozone Research with Advanced Co-operative Lidar Experiment" (ORACLE). A one-month assimilation cycle has been prepared using a 3DVAR scheme and the global environmental multi-scale (GEM) model, with synthetic observations from a run with the RPN forecast model including stratospheric chemistry. The impact of the number of ozone profiles, of assimilating total ozone compared to ozone profiles, and of adding ozone chemistry in the assimilation cycle are being evaluated. Finally, it was noted that steps are being taken towards a 4DVAR scheme, with an efficient sequential analysis algorithm for an ensemble Kalman filter having been developed to enable the calculation of the 3DVAR background error covariances from an ensemble system. Furthermore, tangent linear and adjoint versions of the GEM model are being prepared.

Dr. P. Steinle (from the Australian Bureau of Meteorology Research Centre on a period of secondment to the Naval Research Laboratory) reported that the data assimilation at BMRC was being upgraded to a 3DVAR scheme in observation space (following the same formulation as that developed at the Naval Research Laboratory, see above). It was thought that this approach would be the most suitable in the context of the suite of BMRC's operational NWP models (global, regional, mesoscale). The approach was also preferred because of the ease with which the background error variance specification could be improved - in this respect the present optimum interpolation system being employed was known to be deficient. Additionally, the geographical variation of the vertical and horizontal error correlations, and the correlations between mass and moisture in the tropics could be readily included, and the variation of length scale with height, and variation of vertical correlations with horizontal scale allowed for. The design (like other variational systems) removes other major limitations of the existing scheme, such as the need for data selection and the inability to handle non-linear observation operators, as well as matching the available computing resources. It is the intention to adopt a unified assimilation for all the NWP models capable of incorporating most of the generalizations in the background error correlations. The next phase will be the use of non-linear observation operators, optimizing the iterative solver, and improving the specification of the background error correlations. The use of TOVS/ATOVS has been made a high priority with considerable attention given to implementing the appropriate observation operators, so that 1DVAR retrievals could be used. Initial results are very encouraging with substantial gains in forecast skill (from AMSU data in the short- and medium-term, and from 1DVAR TOVS mainly apparent in the medium-range). The improvement stems particularly from the attention paid to both the bias correction and the calculation of the scaling factors for the 1DVAR increments and observation errors. This has been accomplished by using the adjoint and forward model appropriate to each individual sounding, thereby automatically adjusting the weight given to the observation type as a function of retrieval type, variations in background and observation errors, different surfaces etc.

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* renamed Meteorological Service of Canada from 1 January 2000

Dr. M. Miller reviewed the latest developments in operational data assimilation at ECMWF, associated with the introduction of a new 50-level model in March 1999, providing a substantial upgrade to the vertical extent and resolution of the stratosphere, and in turn furnishing the accurate first-guess required for the assimilation of ATOVS raw radiances. This enabled a significant milestone to be passed in May 1999, with the direct assimilation in the 4DVAR system of ATOVS and TOVS 1c (raw) radiances. This is regarded as a major step forward since scientific results from ECMWF and elsewhere have clearly shown that satellite observations are best assimilated as engineering-calibrated geo-located measurements and that pre-processing of observations with a priori information should be avoided (since the assimilation system itself generally provides the most accurate information in this regard). At ECMWF, the use of the raw radiances had led to clear improvements in forecast quality that can be traced to the improved assimilation and the high quality of the radiances from AMSU-A. In July 1999, a new analysis of soil moisture and temperature was introduced (drawing on observations of temperature and humidity at 2 m). Other changes were also made in data usage, including revisions to the quality control of TOVS/ATOVS radiance data, use of frequent (90-minute) Meteosat winds and of EUMETSAT quality control information, use of US hourly profiler information at and above 700 hPa, blacklisting of ship humidity data, employing WMO tables for height assignment of ship wind data, and bias correction of radiosonde temperature observations (from the sonde-type information encoded in the TEMP message). The additional overall impact on forecast scores was small but positive. Further work is going ahead which will enable assimilation of radiances from METEOSAT and of wind information from SSM/I and QuikSCAT, and in the longer term, MSG and METOP. The new model and assimilation framework offers the prospect for marked improvements in stratospheric wind analyses, and, within about a year, when an ozone variable will be introduced, ozone analyses based on assimilation of ozone data from TOVS, SBUV and GOME. Work is also underway to develop the parameterization suite so that rain-rate data from SSM/I can be assimilated, together with the guidance provided by data from the Tropical Rain Measuring Mission (TRMM). The long-term goal is an integrated assimilation of all available data related to the physics and dynamics of rain-producing systems, including observations on clouds, rain-rate and dynamical fields above the clouds (much of these data are currently discarded).

Regarding the continuing development of the data assimilation system itself at ECMWF, Dr. Miller reported that ensembles of assimilations with perturbed observations have been used to estimate background error statistics (as an alternative to the "NMC method"). This should improve the statistical input to 3D and 4DVAR and provide refined quality control algorithms. Twelve-hour cycling of 4DVAR and increased resolution of the inner loops should also lead to marked increases in forecast skill. Economical upgrading of the inner-loop resolution requires the adjoint of the linearised form of the semi-Lagrangian time-integration scheme, and progress is being made in this. Together with the twelve-hour assimilation window, this will ensure that the reduced-rank Kalman filter, having benefits for both the assimilation and ensemble prediction systems, will be affordable. Further into the future, twenty-four hour cycling and improvements in the physics of 4DVAR will be explored.

Dr. T. Tsuyuki summarized the main upgrades in the JMA operational data assimilation system in recent months and those foreseen. ERS-2 scatterometer data had now been assimilated in the global analysis since July 1998. During the July-September 1999 period, assimilation of SATEM data from NOAA-15 in the global and regional analyses, of GOES visible cloud motion wind data in the global analysis, and of ACARS data over Europe in the global analysis were successfully implemented. From November 1999, NESDIS ATOVS/BUFR data would be assimilated. In March 2000, it was planned to initiate a 3DVAR scheme for the global analysis and direct assimilation of TOVS radiance data.

5. NUMERICAL WEATHER PREDICTION TOPICS

5.1 Short- and medium-range prediction

The World Weather Research Programme

Dr. R. Carbone, Chairman of the Scientific Steering Committee for the CAS World Weather Research Programme (WWRP) outlined the type of activities foreseen. WWRP is being organized on a project-oriented basis including "Research and Development Projects (RDPs) aiming to achieve real advances in forecast capability by combining elements of improved scientific understanding and the demonstration of these capabilities. These would be complemented by “Forecast Demonstration Projects” (FDPs) which would serve to exhibit and quantify the benefits derived from improved understanding and enabling technologies. Technology transfer and training would also be facilitated. The Mesoscale Alpine Programme (MAP) is the first RDP, with the objective of improving understanding of orographically-induced intense precipitation. A second RDP being considered is Tropical Cyclone Landfall with particular emphasis on extreme wind and rain hazards. Other topics being considered are aircraft inflight icing, hazardous weather and cyclones in the Mediterranean, predictability and optimal observing system experiments, and urban flooding. The first FDP is that in connection with the Sydney 2000 Olympics and is intended to demonstrate the capability of modern forecast systems and the associated benefits in delivering a real-time "now-cast" service (0-6 hours) in the context of the Olympics. There are clearly many significant challenges in the WWRP projects related to numerical modelling, data assimilation, observational strategies, verification techniques etc. Advances in NWP systems running at high resolution, non-hydrostatic modelling, treatment of flow over domains with steep complex terrain, as well as research to determine the best mix of observations and their spatial distribution for specialized forecasting systems, are needed. These topics are of direct concern to WGNE, which expects to contribute significantly in several respects.

Another subject now being actively discussed in the WWRP is the continuation of FASTEX-type research. (The "Fronts and Atlantic Storm Tracks Experiment", FASTEX, has provided the basis for studies and research in a number of areas related to the development and testing of data assimilation techniques such as targetted observations, singular vectors, breeding modes, forecast sensitivities etc.). However, there are questions regarding the ability of simulating accurately or validating the sensitivity to remotely-sensed data in the absence of in situ data. To obtain such data would require a complex and costly oceanic field campaign. It has been proposed that an International Science Working Group should be formed to define an appropriate programme of studies, with the initial emphasis to be placed on the synoptic scale aspects of short- to medium-range prediction of cyclones originating over the oceans. WGNE will nominate one or two representatives to participate in the International Science Working Group to consider co-ordinating/supervising any supporting or exploratory numerical experimentation that could be useful. However It was stressed that WGNE has not been involved in detailed planning of the observational phases of a field experiment and did not have expertise in this area. The prime responsibility for the organization of the observational component of any activity that might be proposed by the International Science Working Group would have to be taken by WWRP.

Performance of the main global operational forecasting models

WGNE reviewed the skill of daily forecasts from a number of the main operations 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. Generally, at three days and beyond, there appears to have a decrease in skill over the past year, with the notable exception of NCEP where the level of skill has improved especially in the past few months. This improvement at NCEP is particularly ascribed to the implementation of the physical initialization in the NCEP global data assimilation system making use directly of remotely-sensed data and information such as precipitation from SSM/I and GOES instruments.

WGNE was reminded of a potentially significant problem in the interpretation of verification scores, e.g., it is possible to obtain apparent large increases in scores by verifying against initialized as opposed to uninitialized analyses. Such a difference in scores can change a decision regarding the operational implementation of a revised operational system. It was suggested that WGNE should take up the issue of verification scores and review the various difficulties and uncertainties in verification of the skill of model forecasts.

Intercomparison of typhoon track forecasts

Dr. T. Tsuyuki presented the latest results from the ongoing intercomparison of forecasts of typhoon tracks in the western north Pacific conducted by JMA. Relevant data from operational forecasts have been made available from ECMWF, UKMO and the Canadian Meteorological Center, as well as from JMA itself. The improved performance of these models in predicting cyclone tracks and intensity over the past few years has been maintained. A feature of the most recent period (the 1998 season) was that the number of cyclones that formed in the western North Pacific was substantially lower than in the previous years (which limits the statistical significance of the latest results).

Dr. A. Lorenc noted the results of an intercomparison, carried out by the UKMO, of forecasts of hurricanes in the Atlantic domain by the UKMO and ECMWF models. This had indicated a superior performance of the UKMO model. On the other hand, a different conclusion had been reached in a similar comparison carried out at ECMWF.

Figure 1.

Figure 2.

Dr. J. Goerss from the Naval Research Laboratory summarized the findings from a verification of model hurricane predictions over the Atlantic Ocean undertaken at NRL. In particular, the results of extended-range forecasts of tropical cyclones using an ensemble of model outputs (NOGAPS, UKMO and JMA global models; GFDL, GFDN and JYTN nested grid models) showed that ensemble-mean tracks had significantly smaller errors on average than any individual model. Inclusion of ECMWF forecasts in the ensemble led to a further reduction in the error.

In view of the growing interest in prediction of tropical cyclones, it was proposed that the ongoing intercomparison conducted under WGNE auspices by JMA for the western North Pacific should now be extended to other areas. Three possible means of carrying out such an intercomparison will be considered:

- JMA to carry out the intercomparisons for all areas
- a common cyclone tracking programme could be used by all operational centres which would verify cyclone predictions on their own models: the results would be reported to one centre which would be responsible for presenting a combined view of the overall situation
- results from centres making (regional) comparisons (e.g. JMA for the western North Pacific, UKMO or NRL for the Atlantic) to be sent to one centre as above.

As a first step, Dr. T. Tsuyuki agreed to look into the possibility that JMA might undertake the comparisons for all the areas. WGNE will also need to review the verification methods in use to ensure consistency of comparisons in different domains if carried out by several different centres.

The "COMPARE" project

The current case study (the third) in the "COMPARE" project (Comparison Of Mesoscale Prediction And Research Experiments) is being led by JMA and is centred on a series of experiments based on the Tropical Cyclone Motion/SPECTRUM/TYPHOON Experiment (TCM-90) over the northwest Pacific (Tropical Cyclone "Flo"). A number of model integrations with varying resolutions and initial conditions (JMA and NCEP analyses) have been prepared. The validation and intercomparison of these various model runs show large differences in the predictions of the intensity of the cyclone, but smaller differences in the predictions of the track. The initial field used and whether this is with or without bogussing has a large impact on the forecast intensity. Some models have the capability of capturing to some extent the explosive development of the cyclone, and such models were superior in representing the inner structure of the typhoon. However, errors in the prediction of the intensity were still generally large. The overall conclusion is that a more realistic treatment of intensifying cyclones requires improvements in the ability of the numerical model in reproducing characteristic inner features of the typhoon including the concentrated rainfall from the cloud wall surrounding the eye of the typhoon. Supplemental experimentation has been carried out to see whether higher resolution models give more accurate predictions of cyclone intensity. Most models showed improvements to a greater or lesser degree with 10 km resolution. However, precipitation amounts in the range 100-300 km from the cyclone centre were systematically too small. Further diagnostic work was still needed to explain the large diversity among models, particularly with respect to the wide range of predictions of cyclone intensity. A workshop was being held in Tokyo in December 1999 to assess overall the results of this case.

WGNE was also informed that the originally planned fourth case study (Verification of the Origins of Rotation of Tornadoes Experiment, VORTEX 95) had to be dropped. Consideration was now being given to a case of severe flooding in China (which would be overseen by the China Meteorological Administration).

In discussing COMPARE, WGNE reiterated the view that the intercomparison cases needed to be designed to give a better understanding of the phenomenon that was the subject of the particular case, and to provide explanations for differences in model simulations. In this respect, the planned VORTEX 95 experimentation would have been very valuable, and it was unfortunate that the case had to be dropped (for reasons over which COMPARE had no control). Considering the diversity of results that had been obtained in the third COMPARE case (as noted above), WGNE felt it might be premature already to move to another case study. It was suggested that, taking parallels with AMIP, organization of a number of specific diagnostic sub-projects might be a good way to proceed. Furthermore, WGNE was not fully clear as to the objectives of the "severe flooding in China" case, particularly as short-term mesoscale forecasts would be highly dependent on initial conditions, adding to the difficulty of interpreting the results (cf. sensitivity to the initial conditions shown in the tropical cyclone case). WGNE saw little point in intercomparisons just centred on routine mechanical verification. The Chairman of WGNE agreed to relay these views to the Chairman of the COMPARE Panel (Dr. L. Leslie, University of New South Wales, Australia) and to ask that the points raised be considered at the COMPARE meeting in Tokyo in December 1999.

Verification and comparison of precipitation forecasts

Several centres continue to pursue activities in this area. At DWD, Dr. W. Wergen reported that quantitative global precipitation forecasts from CMC, DWD, ECMWF and NCEP continue to be verified against German and Swiss surface stations. Forecasts from Météo-France and UKMO have also been assessed since May 1998 and July 1998 respectively. The forecasts are interpolated bi-linearly to the more than 4000 locations of stations measuring precipitation in the German and Swiss networks. A series of scores (bias, a Heike skill score, equitable threat score and true skill statistics) are then computed. Relatively good performance is shown by Météo-France and UKMO compared to the longer-term participants in this exercise, but, in all cases, there is considerable room for improvement. On the scale from zero (for the skill of a chance forecast) to one (the perfect case), global models usually have a score around 0.4 for a twenty-four hour forecast (cf. persistence score of 0.3). The detailed results of the verification are available to the participating centres on a protected web-page. It is hoped in the future also to be able to include forecasts from JMA in the verification. It is planned to produce a full report on the procedures being used and overall findings.

Work on the verification of quantitative precipitation forecasts over Australia (carried out by Dr. E. Ebert, BMRC) was described to WGNE by the Chairman, Dr. K. Puri. On a daily basis, forecasts from six global and one regional model are verified against an objective analysis of raingauge data from 1000-1500 stations on a 0.25° grid over Australia. More detailed analyses, based on observations from nearly 6000 raingauges, are available after a few months and have been employed in most of the verifications summarized here. The precipitation forecasts and rainfall analyses are mapped onto a common 1° grid for verification purposes. It has been found that models generally perform well in mid-latitudes in the winter season, when the rainfall is primarily associated with frontal activity, with bias scores close to 1.0 for most, and equitable threat scores between 0.4 and 0.5 for the 00-24 hour forecasts, 0.35 to 0.45 for the 24-48 hour forecasts (using a rain threshold of 1 mm/day). RMS errors were typically less than 50% of the mean rain intensity, but both the mean and maximum rain intensities were generally underestimated. In mid-latitudes in summer, the extent of the forecast rain area appeared often to be too large. Equitable threat scores were somewhat lower than in the winter and showed little dependence on the length of the forecast (with values between 0.3 and 0.4). RMS errors were roughly 60% of the mean summer rain intensity. On the other hand, models were distinctly less skilful in predicting rainfall in the northern tropical region of Australia, where the winter season is extremely dry but there may be substantial convective rainfall in the summer in association with the seasonal Australian monsoon. In the dry season, there was very large variability among models in the bias score, with frequency underestimated by 50% in one model and overestimated by 50% in another (but not necessarily large errors in the predicted rainfalls because of the low rainfall values). The equitable threat score was in the range 0.2 to 0.3 for 00-24 hour forecasts falling by about 5% over the following 24-hour period. In the summer, all models overestimated the rain area, but average rain intensity was reasonably well predicted. One model (Deutscher Wetterdienst) gave too intense a mean rain intensity but was the only one to capture maximum intensities. The equitable threat score ranged from 0.2 to 0.3 for 00-24 hour forecasts but, surprisingly, increased by a few points for the 24-48 hour lead-time. Scores from the first and second years of the verification period (September 1997-August 1999) were compared to see whether any improvements had occurred during that time. Most of the differences from one year to the next seemed to relate to particular weather events. In particular, the skill of almost all models during the tropical winter decreased between 1998 and 1999 suggesting that tropical rainfall events may have been inherently more difficult to predict in the latter year. Improvements were noted in two models, namely the Australian GASP model (significant increases in equitable threat scores for both the tropical summer and winter mid-latitude predictions) and the JMA model (increases in all seasons and all regions).

WGNE was informed that verification of precipitation forecasts at NCEP was giving similar sorts of results. In reviewing overall the situation, based on equitable threat scores that were common to the various studies, WGNE noted that generally in middle latitude regions: models performed better in winter than in summer; scores were higher in the middle range of threshold values for precipitation (2-20 mm/day); predictions of heavy rainfalls were often poor, with consistent underestimation of the amounts. In the BMRC verification exercise, models were less skilful in predicting rainfall in the tropics. Preliminary work indicates that simple averaging of different models can give improvements in equitable threat scores. WGNE considered the studies of verification of precipitation where a comparative documentation of results would be valuable. Dr. E. Ebert would take the lead in preparing this material that could possibly lead to an article in, for example, the Bulletin of the American Meteorological Society. As a further extension to the work, the UKMO agreed to carry out verifications over the UK.

5.2 Long-range and seasonal forecasting

Dynamical long-range forecasting activities at JMA

An ensemble-based dynamical one-month forecast has been prepared since 1996 using a T63 30-level version of the JMA global spectral model. The ensemble comprises ten forecasts prepared with a combination of singular vector and lagged average methods. A model systematic bias (taken to be the average forecast error) was calculated from hindcast experiments for the period 1989-1994, and is removed from the forecast fields. Objective guidance for variance of forecast parameters is obtained from the ensemble forecast using a perfect prognosis method. Overall, the northern hemisphere (20°-90°N) 500 hPa height ensemble-mean anomaly correlation coefficient of the one-month forecast has been relatively stable since 1996 around 0.5 with peaks for certain months as high as 0.8 but close to 0.0 in some months.

Considerable efforts are also being devoted to El Niño monitoring and prediction through an Ocean Data Assimilation System (ODAS). This is built round an ocean general circulation model with a horizontal resolution of 2° in latitude and 2.5° in longitude (except near the equator where the latitudinal grid spacing is 0.5°), and 20 levels in the vertical (most of the upper 500m of the ocean). The model is forced with the daily averaged values of surface wind from the JMA operational data assimilation system and all available subsurface thermal data are analysed every five days using a two-dimensional optimal interpolation method. The model sub-surface temperature field is relaxed to the analysis field by nudging, and the sea surface temperature to an independent analysis. The model salinity is relaxed to climatology. ODAS, originally developed in 1995, is now being enhanced to assimilate TOPEX/POSEIDON altimetric measurements. The products obtained form the basis of a routine comprehensive monitoring of the evolution of the surface and sub-surface ocean conditions, including particularly ENSO-related events.

JMA has also implemented a coupled ocean-atmosphere model for prediction of ocean conditions and El Niños. This comprises a global spectral atmospheric model (T42L21) together with the ODAS general circulation model. No adjustment is made to reduce the imbalance between atmospheric and oceanic initial states (the latter obtained from ODAS), although heat and momentum flux corrections are applied to forecast fields in order to suppress climate drift in the predictions. Fifteen-month integrations are carried out twice a month and, in August 1999, JMA began to issue outlooks on El Niño (based on an ensemble of six members) every month. An encouraging degree of skill is apparent.

JMA is now aiming to introduce a dynamical seasonal forecast system. In preparation, a series of seasonal prediction experiments (to 120 days) with a T63L30 global atmospheric model forced by the observed sea surface temperature have been performed. These experiments provide an indication of the maximum skill of a seasonal forecast (i.e. when sea surface temperatures are predicted perfectly) that can be achieved using a coupled model. (This experimentation is also a contribution to the Seasonal prediction Model Intercomparison Project (SMIP) organized by the CLIVAR Working Group on Seasonal-to-Interannual Prediction (WGSIP)). As with all experiments of this type, the skill achieved is variable and also depends on the season (on average being higher in the winter and spring than summer and autumn). Nevertheless, the results are encouraging enough to begin the implementation of a full seasonal prediction system. This will comprise an atmospheric model for ensemble runs and a coupled ocean-atmosphere model that will provide the sea surface temperature for the atmospheric model runs. An experimental real-time ensemble seasonal prediction for 4-8 months ahead is carried out every month. With the acquisition of a new super-computer system (peak speed 768 Gflops) at JMA in March 2001, dynamical seasonal forecasting will be introduced operationally after an experimental period. This will then be based on a T106L40 global atmospheric model for the one month forecast, a T63L40 global atmospheric model for the 4-8 months forecast, this latter model being coupled to a 1°x 1°, 30-level ocean model for sea surface temperature predictions up to 18 months ahead.

Work on seasonal predictions at ECMWF

The skill of ECMWF seasonal predictions for the 1997/98 El Niño and 1998/99 La Niña was good overall. Analysis of the forecasts carried out continues to point to deficiencies in the atmospheric model, including shortcomings in handling the 30-60 Madden-Julian Oscillation in the tropics. A higher resolution version of the ocean component of the coupled model has been developed, and the vertical and horizontal mixing parameterizations have been altered and tuned. Although there has been a reduction in the overall cooling bias in the coupled model, some undesirable features in the east Pacific, east Atlantic and in the extratropics appeared. The European Union Programme on Prediction of Climate Variations on Seasonal and Interannual Timescales (PROVOST) has demonstrated benefits from using a number of models in seasonal forecasts with prescribed sea surface temperatures. Based on these positive findings, it is planned to develop a multi-coupled model system for seasonal prediction (with the acronym "DEMETER"), with funding from the European Union.

Experimental one-month forecasts at the Voeikov Main Geophysical Observatory

During 1999, experimental one-month forecasts continued to be conducted at the Main Geophysical Observatory, St. Petersburg. Initial fields of the main atmospheric variables were provided in quasi-operational mode from the main Russian Hydrometeorological Centre in Moscow. An eleven-member ensemble is produced (eleven slightly different initial states generated using a breeding technique), with the current observed sea surface temperature as a boundary condition. Over land, the Mintz-Serafini soil moisture "climatology" was employed, but in the first part of the summer, excessive precipitation was predicted systematically in Europe, Russia and western Siberia, when in point of fact, June and July 1999 were exceptionally dry. The forecasts were thus interrupted at the end of July in order to carry out a series of tests of sensitivity to the specification of the initial soil moisture. Regular experimental predictions were resumed in October 1999.

5.3 Recent developments at operational centres

As well as information on developments in operational data assimilation/analysis systems in section 4.2, and some details on progress in long-range and seasonal forecasting in section 5.2, a number of reports were given by participants in the WGNE session from the main operational centres. As usual, for most participants, this was a highlight of the session during which constructive discussions on problems or aspects of mutual interest took place.

Deutscher Wetterdienst

After a long parallel test, the new fourth generation NWP system at DWD was expected to become operational on 1 December 1999. From then, all forecasts would be produced by the new global model (triangular grid, horizontal resolution of 60 km, 31 hybrid vertical levels) and from the new hydrostatic local model (325 x 325 grid points, horizontal spacing 7 km, 35 layers, split time integration scheme). The initial conditions for the global model are obtained from an intermittent, optimum interpolation-based assimilation. Both models are run back-to-back on the T3E supercomputer. Three forecasts out to 48 hours are made each day from 00, 12 and 18Z analyses. Products are available to customers 210 minutes after the nominal start time.

UKMO

The atmospheric models used in UKMO for NWP and climate studies are derived from the so-called Unified Model System, but different formulations tend to be used in each configuration. Because of the requirement to meet operational deadlines, cheaper physics options may be used in NWP. The models are grid-point based, with a regular latitude-longitude grid in the horizontal and hybrid grid in the vertical (terrain-following near the surface but evolving to constant pressure surfaces at upper levels). The global operational model has a horizontal resolution of 0.83°x 0.56° and 30 levels (cf. 2.50°x 3.75° and 38 levels for the most recent climate model version, HadAM4). A split-explicit time-stepping scheme is used, conserving mass, mass-weighted potential temperature and moisture, and angular momentum. A zonal Fourier filter is applied at high latitudes in order to overcome the timestep limitations imposed by the use of a regular latitude-longitude grid. A number of alternative formulations for physical parameterizations are used. The Edwards-Slingo radiation scheme performs well in HadAM4, but does not appear to give significant advantages in the NWP model and so is not used in view of its expense. It is, nevertheless, employed in the mesoscale model as, together with a new boundary layer scheme (with stability-dependent surface exchanges based on Morin-Obukhov mixing length), it had a marked positive impact. The effects of penetrative convection are represented by an ensemble of buoyant entraining plumes with downdroughts taken into account (plus convective transport of momentum in the NWP model and HadAM4, radiative effects of anvils in HadAM4, and a CAPE closure in the NWP model). Land surface interactions are treated with a 4-level soil scheme in the NWP model, and the Meteorological Office Surface Exchange Scheme (MOSES) in the mesoscale model and in HadAM4. Operationally, after an early cut-off, the global model is run out to 48 hours to provide boundary conditions for the mesoscale model (12 km resolution, 38 levels), and then, from a later cut-off, to six days. The scores for the first global run are significantly worse than for the main run, a clear reflection of the reduced amount of available data at the earlier cut-off.

JMA

Experimental runs have been made with the hydrostatic mesoscale model (10 km horizontal resolution, 36 levels) since March 1998 using a physical initialization for assimilating precipitation data. Typhoon bogus data have been revised in order to reduce a negative bias seen in predicted winds. Since March 1999, an experimental 8-day 10-member ensemble prediction system has been run once per day with the T63L30 model. Perturbations are generated using the breeding method, but alternative means for increasing the amplitudes of the perturbations are being explored. Significant revisions to model physics are in hand including introduction of a prognostic cloud water scheme, updated Arakawa-Schubert convection, a modified cloud/radiation parameterization, a non-local planetary boundary layer, and refinement of the treatment of land-surface processes. As noted in section 5.2, the computer system will be replaced in 2001 and a complete upgrade of the NWP system will be made.

RPN

The horizontal resolution of the regional version of the Global Environmental Multiscale (GEM) model was increased to 24 km (from 35 km) in September 1998. In the move towards using a single operational code at the Canadian Meteorological Center, the T199L21 spectral finite element model was replaced by a 28-level version of GEM running on an equivalent uniform 400 x 200 horizontal grid for global data assimilation and medium-range forecasting. In the experimental ensemble forecast system, eight GEM members have now been added to the eight members from the spectral model. Another experimental activity, the "High Resolution Model Application Project" (HIMAP), produces higher resolution forecasts over the more populated areas of Canada. Consideration is being given to the incorporation of a generalized pressure co-ordinate that can also be used for a non-hydrostatic formulation.

BMRC

With the acquisition of the NEC Sx4 computer, the resolutions of both the global and regional models have been significantly increased (to T239 linear grid, 29 levels for the global model with effect from December 1998; 0.375°x 0.375°, 29 levels for the regional and tropical models from July and August 1999 respectively). The resolution of the mesoscale model would be increased from 0.25°x 0.25°, 19 levels to 0.125°x 0.125°, 29 levels in November 1999. The ECMWF land-surface/boundary-layer/vertical diffusion parameterizations have been implemented operationally in the regional models. The Edwards-Slingo radiation scheme has been incorporated into the global model.

ECMWF

An extensive upgrade of the ECMWF model's parameterization suite, for implementation before the end of 1999, was in preparation. The main changes were in the representation of sub-grid-scale orography fields, in the treatment of clouds, in the convection scheme, and in the resolution of the planetary boundary layer (which would lead to a 60-level model). Continuing work on the parameterization of land-surface processes for inclusion in the new ECMWF reanalysis project (ERA-40, see section 4.1) (and operational implementation in early 2000) will benefit from the recently introduced analyses of soil properties (see section 4.2). There are encouraging early results from using the reduced-rank Kalman Filter with the ensemble prediction system. There has also been collaboration with the United Kingdom in investigation of multi-analysis and multi-model ensembles; there are preliminary indications that most of the potential benefit is realisable by using analyses from several centres in the generation of initial perturbations. In studies of predictability at the extended range (days 10-30), skill appears to be marginal beyond day 10, but forecasts may benefit from use of a coupled atmosphere-ocean model (which would allow in particular an improved simulation of the Madden-Julian Oscillation and greater potential skill in predicting intra-seasonal variability).

In preparation for a major upgrade of the ECMWF system planned for late 2000, data assimilation and forecasts have been undertaken over three study periods (covering twelve weeks) with T_L511 resolution in the outer loops of the 4DVAR scheme and in the forecast model, and T106 resolution in the inner loops of 4DVAR. Both the results of the assimilation and forecasts are positive judged by a variety of measures of skill, and no unexpected meteorological or computing problems have appeared.

Dr. K. Puri reported on work he had carried out at ECMWF during his secondment there in 1999. With the availability of the forward and adjoint tangent models with linearised moist physics, it was now possible to derive tropical singular vectors enabling development of the ensemble prediction system to treat more satisfactorily certain tropical phenomena, especially tropical cyclones where the prediction of uncertainty in trajectory and intensity is of particular interest. With the present operational (extratropical) initial perturbations employed, there is only small spread of the predictions in contrast with the large spread of the predictions using targetted tropical singular vectors. Only in the latter case does the ensemble spread generally encompass the analysed track. The inclusion of stochastic physics provides a sufficiently large spread in values of central pressure.

6. OTHER WGNE ACTIVITIES AND FUTURE EVENTS

Publications

Two publications have been produced in the WGNE "blue-cover" numerical experimentation report series since the fourteenth session of the group, namely the latest annual summary of research activities in atmospheric and oceanic modelling (No. 28), and a report of a workshop on modelling the transport and scavenging of trace constituents by clouds in global atmospheric models in Cambridge, UK, August 1995 (No. 29) (this being one of the series of workshops aimed at assessing the capability of atmospheric models in simulating large-scale atmospheric transport, see section 3.7). WGNE was pleased to note that the Report No. 28, the annual summary of research activities in atmospheric and oceanic modelling, had, as has now become the custom, been printed in and distributed directly form Montreal, and was available early in 1999. The next publication in the WGNE report series (No. 30) would be the new annual summary of research activities and would again be printed and distributed directly from Montreal. WGNE expressed its appreciation to Dr. H. Ritchie for ably carrying forward the editorship of the report.

Next session of WGNE (and GMPP)

At the kind invitation of the Bureau of Meteorology, the next session of WGNE, the sixteenth, would be held in Melbourne, Australia, 23-27 October 2000 (in conjunction with the planned workshop on model systematic errors in Melbourne, 16-20 October 2000, see section 3.1). Information on detailed arrangements for the session would be distributed in due time. The session would be held jointly with the (fourth) meeting of the GEWEX Modelling and Prediction Panel.

7. CLOSURE OF SESSION

In his final remarks, the chairman of WGNE, Dr. K. Puri, reiterated gratitude on behalf of all participants to Dr. P. Merilees and the other staff of the Naval Research Laboratory for having hosted the session and the excellent support, facilities and hospitality that had been offered. The opportunity to interact with so many leading scientists at the Naval Research Laboratory, and to hear first hand of the excellent research and work going ahead had also been particularly appreciated and valued. Dr. Puri noted that this was the final session in which Dr. Meleshko would be participating as a member of WGNE. He thanked Dr. Meleshko for his many contributions over the years and the expertise that he had brought to the group in the area of climate model simulations, in particular the aspects of treatment of clouds and of polar regions. He wished Dr. Meleshko continuing success in the future.

The fifteenth session of WGNE was closed at 13.07 hours on 29 October 1999.

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