The fourteenth session of the CAS/JSC Working Group on Numerical Experimentation (WGNE) was kindly hosted by Recherche en Prévision Numérique (RPN), Environnement Canada, Dorval, Québec, Canada, from 2-6 November 1998. The session was held jointly with the second 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 2 November 1998 with a warm welcome from Dr. M. Bélin, Director of the Meteorological Research Branch of Environnement Canada (in which RPN is a division), and with best wishes for a successful meeting. The Chairman of WGNE, Dr. K. Puri, expressed thanks to RPN for the excellent facilities, the support given and arrangements that had been made.

Dr. Puri continued by voicing his pleasure at having been appointed as Chairman of WGNE in May 1998 in succession to Dr. D. Williamson. Dr. Puri acknowledged the outstanding contributions made by Dr. Williamson to the work of WGNE, particularly in the development of the WGNE association with GEWEX which had given new impetus to activities in the area of atmospheric model parameterizations. Dr. Puri particularly welcomed those attending as recently appointed members of WGNE, namely Dr. Chen Dehui (National Meteorological Centre, China State Meteorological Administration), Dr. S. Lord (National Centers for Environmental Prediction, National Weather Service, USA), Dr. H. Ritchie (Recherche en Prévision Numérique, Environment Canada), and Dr. T. Tsuyuki (Numerical Prediction Division, Japan Meteorological Agency). He also expressed gratitude for the major work carried out in support of WGNE by those members who had recently retired (Dr. E. Kalnay, Dr. D. Randall, Mr. N. Sato, Dr. A. Staniforth). He was pleased that Dr. Randall would continue to participate in WGNE sessions in his capacity as Chairman of GMPP.

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 in WCRP. 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 that had been held from 18 to 19 October 1998 in Melbourne, Australia. 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 a particular challenge. WWRP is encouraging regional research initiatives such as the Mesoscale Alpine Programme (MAP) and further studies like the Fronts and Atlantic Storm Track Experiment (FASTEX), and tackling problems common to many countries (e.g. tropical cyclone landfall, detailed forecasts for urban areas) (see also section 5.1). WGNE is certainly expected to contribute to the WWRP, particularly, for example, in seeing how relevant GEWEX results and process studies could be exploited.

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 in the traditional domains of data assimilation, numerics and physical parameterizations, as well as recently developing areas such as ensemble prediction, seasonal prediction, verification of precipitation and tropical cyclone track forecasts. WGNE also follows progress in various relevant national initiatives such as the Earth Simulator project in Japan, and the Climate Change Programme and Accelerated Climate Prediction Initiative in the USA (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 of the GCSS Science Panel), reviewed progress in GCSS. The overall objective is the development of refined parameterizations of cloud systems within atmospheric models used in NWP and climate simulations through a better understanding of the coupled physical processes within different types of clouds. The emphasis is on determining the effects of clouds acting as systems rather than as individual clouds or processes, especially since it is often impossible to isolate single processes and study them separately. GCSS makes use of cloud-resolving or cloud-system models to study the relevant processes. These models are developed and evaluated using observations from regional field experiments, and then employed as experimental test-beds to increase overall understanding and to provide synthetic four-dimensional data sets. Single-column models (as derived from full general circulation models) are also valuable tools for work in this area and can also be forced with the same data sets used to drive cloud system models. Comparison of results and observations is valuable in assessing the strengths or weaknesses of different parameterizations. In GCSS, four different cloud types are being specifically studied in this way: boundary layer clouds; cirrus; extra-tropical layer clouds; precipitating convectively driven cloud systems. Four sub-working groups have been set up to deal with each of these cloud types. As described below, plans to examine Arctic clouds and radiation processes within GCSS are also being considered.

Boundary-layer clouds (WG1)

A series of intercomparisons of the behaviour of boundary-layer cloud models has been conducted based on observations from FIRE 87, ASTEX, BOMEX and ATEX, as well as idealized cases designed to isolate key physical processes. It is apparent that very high vertical resolution is needed for the treatment of entrainment. New parameterizations of entrainment driven by cloud-top cooling have been formulated. The next case study will be based on July 1997 data (also selected for a study of precipitating convectively-driven clouds, see below) and will be carried out in collaboration with the ARM single-column modelling group.

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 is being 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 is being 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.

A presentation on other GCSS activities in this area was given by Dr. P. Yau, McGill University, Montréal. Based on simulations of a cold frontal change in Southeast Australia, it was noted that the generation of middle- and high-level frontal clouds still appears to be a serious problem in both mesoscale and general circulation models. This is linked to the inadequate representation of the sub-grid scale vertical velocity structure. When one cloud type is not correctly modelled, this in turn leads to “false” coupling and feedback between the various components of the overall frontal cloud mass (e.g. sublimation of cirrus triggers mesoscale descent suppressing the development of medium-level cloud). There are also still significant differences between the modelled cloud optical properties and those observed. On the other hand, cloud-resolving models with increased horizontal resolution and employing explicit cloud schemes did give improved generation of middle-level cloud ahead of the front. Methodologies to apply these results to give better simulations in general circulation models have been explored but problems were encountered in trying to scale up from 20-30 km to 300 km.

Precipitating convectively-driven cloud systems (WG4)

Again a number of case studies have been carried out. The first of these involves one-, two- and three-dimensional modelling of a squall line on a timescale of a few hours, using initial conditions and verification data sets collected during the intensive observation period of TOGA-COARE. Generally, all the seven participating cloud-resolving models were able to simulate the gross observed features of the squall-line including the mean precipitation structure and speed of propagation. A parameterization of the ice phase appeared to be necessary to achieve the type of development of stratiform cloud observed. The second case again includes one-, two- and three-dimensional modelling of the evolution of convective systems in response to imposed (observed) time-varying large-scale forcing over a period of a week. The initial conditions for these simulations, the varying large-scale forcing and data for verifying the domain and time-averaged statistics of convective cloud systems were obtained by taking averages over the TOGA-COARE intensive flux array. Results are available from five two-dimensional cloud-resolving models, one three-dimensional cloud resolving model, one three-dimensional mesoscale model, and five single-column models. There were general similarities in the simulation of temperature, precipitable water, outward-going longwave radiation, ice-water path, cloud mass flux and other quantities, indicating that the large-scale advection is a principal factor in determining the bulk characteristics of convection. The models, as well as producing “observable” parameters (e.g. time-series of large-scale temperature, water vapour mixing ratio profiles, precipitation etc.), also provide quantities that are not available from observations such as the fractions of convective and stratiform clouds, large-scale profiles of cloud water, cloud-ice, rain and snow, solar and infrared heating rates, cloud updrafts and downdrafts and convective momentum transfer. These data will be a useful resource for comparing with other convective parameterizations. Also, as a complement to this case, an off-line radiation code intercomparison has been organized to examine and compare surface heat fluxes, radiative heating rates and fluxes, and various relevant microphysical fields from the cloud-resolving and single-column models at one particular moment of time.

A third case study is now being planned over the continental USA using measurements taken at the ARM Southern Great Plains Experimental site during July 1997 (together with a boundary-layer clouds study as noted above), and also in collaboration with the ARM single-column modelling group. A millimeter cloud radar was operational at the ARM site in July 1997, providing vertical profiles of cloud properties. Measurements are also available from an extensive array of other meteorological instruments.

Arctic cloud and radiation processes

Dr. J. Curry (University of Colorado) described the special problems in understanding and simulating Arctic clouds. There were, for example, very large variations in the distribution of clouds in Arctic regions in the AMIP integrations. Difficulties in treating Arctic clouds (and optically important ice crystal suspensions) are linked to the unique atmospheric and surface characteristics in this part of the world (e.g. common temperature inversions). Determining the optical properties of Arctic clouds is another outstanding concern. Progress in this area now looks possible following the major field campaign in the Arctic in 1997/1998, the Surface Heat Budget of the Arctic Ocean (SHEBA) (to which ARM and FIRE also contributed). A range of measurements of Arctic clouds, radiative fluxes and sea ice have been collected and these could form the basis for the study of Arctic clouds in GCSS, focussing on microphysical processes including mixed phase clouds, the stable atmospheric boundary layer, (three-dimensional) radiative transfer, and cloud-radiative feedback processes. A series of case studies suitable for large-scale eddy simulation boundary layer experiments and longer time series of observations for single-column model integrations would be prepared. In co-ordination with the SHEBA-ARM-FIRE communities, these would be utilized in experimentation with single column models to improve parameterizations of clouds and radiation. In particular, benefit could be taken from use of a feedback analysis being developed to compare single-column model simulations with observations. The opportunities for useful single-column modelling in this area will also be extended as a result of the ARM programme undertaking a multi-year time series of observations at Barrow, Alaska, in 1998.

Overall conclusions

Participants in the WGNE/GMPP session were impressed by the developing activities in GCSS in tackling challenging problems and the extensive use being made of real data to refine models and parameterizations. The extension of these activities to polar clouds as proposed by Dr. J. Curry was considered timely and valuable. The importance of increasing the interaction between those involved in GCSS, large-scale (general circulation) modelling groups, the radiation and remote sensing communities was stressed. (An opportunity for this would be provided by the workshop on cloud processes and cloud feedbacks in large-scale models at ECMWF, Reading, the week following the WGNE/GMPP session). Regarding the issue of cloud feedback, a three-dimensional simulation of deep tropical convective clouds has been provided by GCSS/WG4 and a three-dimensional large-eddy simulation of boundary layer clouds by GCSS/WG1 for use in three-dimensional radiative calculations. (The issue of large-scale cloud feedback in the climate system, of major concern to climate change modelling groups, would also be taken up at the ECMWF workshop).

GMPP and WGNE agreed that further work was needed to make GCSS case study data sets generally available (e.g. on CD-ROM). It was also noted that shortfalls continued in the resources (e.g. research grants to cover manpower and computational costs) required for the development of GCSS, and GMPP and WGNE encouraged efforts to find funding and resources. Furthermore, it was pointed out that international participation in GCSS should be increased in order to be able to take full advantage of the relatively limited resources and number of scientists working in this field.

2.2 Cloud/radiation parameterization

Based on a presentation made by Dr. M. Miller, WGNE and GMPP took stock more generally of parameterizations of cloud and radiation in atmospheric models. Cloud treatments were now evolving rapidly after several years of fairly slow progress. There was a transition from “integrating” to process-oriented schemes, direct links to convection, improved specification of cloud properties and inclusion of more complicated microphysical processes. Generally in forecast models, realistic cloud patterns and distributions are now produced and verification scores have improved. It was noted that ice fall speed is emerging as a critical parameter in cloud treatments and also has a strong influence on convection. Regarding the computation of radiative transfer, methods are still expensive and a neural networking approach may have to be employed to gain efficiency without loss of accuracy.

As noted in section 2.1, a workshop “Cloud processes and cloud feedbacks in large-scale models”, jointly organized by WGNE and GCSS, was taking place at ECMWF, Reading, UK, 9-13 November 1998. The workshop would bring together general circulation modellers, the mesoscale/microscale cloud modelling community (active in GCSS) as well as experts in radiative transfer, relevant satellite and aircraft observation data specialists and aim to increase the interaction between these different groups. The workshop would focus on the capabilities of current cloud model parameterizations and what gaps needed attention. Another issue would be to consider how to deal with the macro-scale problem of cloud forcing and feedback in the climate system, and indeed how this forcing (and cloud radiative properties) might be modified in a changed climate (an aspect that has been repeatedly emphasized by the Working Group on Coupled Modelling in its task of studying long-term climate change projections).

Also under this agenda item, Dr. V. Meleshko presented the results of a study to assess the sensitivity of the Voeikov Main Geophysical Observatory coupled atmospheric/mixed-layer ocean model to cloud-radiation forcing in simulations of CO_2-induced climate warming and the dependence of the forcing on the treatment of atmospheric convection. When cloud-radiation feedbacks did not operate, the treatment of convection made little difference, with the climate response being predicted as a warming of 2.1°C in the case of CO_2-doubling with a Kuo-type scheme and 2.4°C with an Arakawa-Schubert scheme. When included, cloud-radiation feedbacks are positive and produced an enhancement of the warming, but the magnitude then depended significantly on the way convective processes were parameterized (e.g. predicting warming became 2.7°C with a Kuo scheme, 4.3°C with Arakawa-Schubert). It was postulated that, with the Arakawa-Schubert scheme, more water vapour is taken from the lower troposphere and transported to the upper troposphere as compared to Kuo, favouring the formation of more higher and middle layer clouds. In a warming climate, the amounts of high and middle-layer clouds decrease, with consequent radiative cooling of the troposphere, intensification of convection and enhancement of water vapour feedback. With the Kuo scheme, the extent of high clouds increases slightly and that of low clouds decreases slightly (in the tropics), thereby reducing convection and evaporation from the surface, and in return reducing the cloud-radiation feedback.

2.3 Land-surface parameterization schemes

WGNE and GMPP reviewed the two main activities in this area at present: the Project for Intercomparison of Land-surface Parameterization Schemes (PILPS) and the Global Soil Wetness Project.

PILPS

Dr. A. Henderson-Sellers presented recent work in PILPS, which has the goal of assessing parameterizations of the interaction between the atmosphere and the land surface in models. There have now been four phases of PILPS, the first two of which concentrated on comparing and validating land-surface parameterization schemes in off-line mode. Phase 1 set minimum standards that schemes should fulfil, and allowed a general comparison of schemes, demonstrating surprisingly poor closure in some, and significant sensitivities and large differences. Phase 2 highlighted substantial discrepancies in the description of seasonal and annual cycles, strong sensitivity to initial conditions, major variations in spin-up time and considerable shortcomings in the ability to reproduce observed land-surface situations. Subsequent phases of PILPS have been aimed at exploring the behaviour of land surface schemes when coupled to their host models (Phase 3) and a common host atmospheric general circulation model (Phase 4(a)) and limited area model (Phase 4(b)). Phase 3 was conducted as an AMIP diagnostic sub-project, but the outcome was ambiguous because of the lack of consistency in initialization of soil moisture in AMIP-I. For phase 4(a), using the NCAR CCM3 at resolution T42, two integrations with different land-surface schemes show significant differences in predicted anomalies of monthly precipitation and in average surface temperature and in the magnitude of simulated interannual variability of these quantities. However, the T42 resolution employed may be too coarse. Differences in simulations could also be dominated by the choice of input variables for the land surface schemes and the specification of land surface and soil moisture conditions. In phase 4(b), an initial evaluation of the impact of different land surface schemes on 48-hour forecasts from the BMRC Limited Area Prediction System has been completed. Effects appear to be a function of the intensity of weather systems involved and the initialization of the soil moisture. Further PILPS studies are being planned including a further off-line Phase 2 test using Oklahoma/GCIP data. In this, techniques developed by the University of Arizona will be exploited to optimize the initial states of all participating land surface schemes prior to intercomparison. Also, a study of the sensitivity of general circulation models to land-surface schemes using specialized techniques applied to satellite data (as an AMIP-II sub-project) is being undertaken. A new tool, the so-called Chameleon Surface Model (CHASM) (as implemented by Dr. C. Desborough, Macquarie University, Sydney, Australia) will be employed, 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 meeting of the PILPS Advisory Committee was being held in February 1999 to consider the future strategy for PILPS, the objectives to be achieved, and plans for reports summarizing PILPS findings and results.

Global Soil Wetness Project

Information on the Global Soil Wetness Project, led on behalf of GEWEX by the International Satellite Land Surface Climatology Project (ISLSCP), was presented by Dr. P. Dirmeyer. The goals are: to produce state-of-the-art global data sets of soil moisture, surface fluxes over land and related hydrological quantities; provide a means of testing and developing large-scale validation techniques over land; serve as a means of assessing ISLSCP Initiative I data sets; enable a global comparison of a number of land-surface parameterizations, including a series of sensitivity studies of specific parameterizations that could aid future model development. Pilot global soil wetness data sets on a 1° x 1° grid during the period 1987-1988 have been prepared at a number of centres by integrating one-way uncoupled land-surface process models with externally specified surface forcings and standardized soil and vegetation distributions (from the ISLSCP Initiative I CD-ROM). The computed soil wetness fields have more detail and appear to be of higher quality than previously available products of this type, apparently as a result of the comparatively high horizontal resolution and use of observed precipitation forcing. There is, however, a large variation in the mean soil wetness between different models, although the evapotranspiration climatologies are similar. This may be a consequence of land-surface process schemes having been used in climate models, where they are tuned to produce “climatological” fluxes whatever the typical mean model soil wetness parameter. Not all the uncertainties are due to model shortcomings; for example, the accuracy of the simulated mean run-off computed for river basins seems to be directly related to the number of rainfall observations that went into producing the original ISLSCP Initiative I data set. Nevertheless, the use of soil moisture product as a specified boundary condition improves climate simulations, especially for precipitation. With the planned release of the ISLSCP Initiative II data set at a global resolution of 0.5° x 0.5° for a ten-year period, revised extended global soil wetness data sets will be produced.

GMPP and WGNE noted that the Global Soil Wetness Project offers the possibility of comparing land-surface schemes at a resolution comparable to that of atmospheric models, of model development, and testing land-surface assimilation techniques. Another valuable feature is that the soil moistures generated can be directly verified against observations where these are available. GMPP and WGNE agreed that the Global Soil Wetness Project provided a potentially useful tool for refining land-surface models. Accordingly, the importance of producing revised extended global soil wetness data sets using the higher resolution ISLSCP Initiative II data set, in which several of the shortcomings in the Initiative I data were addressed, was emphasized. However, progress in issuing the ISLSCP Initiative II data has been slow. It was recommended that the Director of the WCRP should write to NASA on behalf of WGNE and GMPP encouraging support for the rapid processing and release of the improved ISLSCP data set.

Development of land-surface parameterization activities

WGNE and GMPP agreed that the overall framework and goals for the advancement of land-surface parameterizations, their incorporation into general circulation models in support of improved weather and climate predictions at all timescales and related activities needed to be developed. Two recent workshops had identified aspects that needed to be taken into consideration. A GEWEX/IGBP workshop in February 1997 had recognized the importance of the “greening” of land surfaces to enable the biological properties of the surface to interact with climate and the hydrological cycle. This means that plant respiration and the carbon cycle should be represented in land-surface schemes, “dynamical” vegetation is needed, the interaction between soil-moisture and plant physiology needs to be simulated, and naturally occurring heterogeneities accounted for. Furthermore, attention should be given to the horizontal complexity of hydrological processes, involving a better treatment of sub-grid scale heterogeneities (essential for an improved simulation and run-off). A joint ECMWF/GMPP workshop in July 1998 on modelling and data assimilation for land-surface processes had concluded that, in the short term, snow and albedo schemes definitely needed to be refined, while, in the longer term, inclusion of geographically variable vegetation properties, addition of sub-grid scale variability for some processes and improving the representation of biophysical processes were all important. The elaboration of land-surface schemes in this way would require new data including long-term flux measurements for evaluating the simulated physiology and evolution of vegetation, and statistics of horizontal heterogeneities. Observations should be focussed round catchment areas as the basic unit and techniques for assimilation of remotely-sensed data in appropriate land-surface models were necessary.

However, there was little agreement between atmospheric modellers how to proceed towards these objectives and it was felt that land-surface modellers needed to examine in greater depth the problems in this area and give clearer guidance to large-scale atmospheric circulation modellers. It was duly proposed that a (joint WGNE/GMPP) workshop be organized in the second half of 1999 for a comprehensive review of the status of the relevant science, to collect the views of the community how activities should be advanced, and what internationally co-ordinated projects would be useful. Dr. J. Polcher agreed to undertake the organization of the workshop on behalf of WGNE and GMPP (which is now planned to be held in Paris, 4-8 October 1999). It was foreseen that activities based on the Global Soil Wetness Project would be an important element of the type of land-surface modelling and analysis necessary. PILPS is likely to be another important component of these activities, but some realignment of PILPS analyses would probably be necessary. The meeting of the PILPS Advisory Committee in February 1999 was asked to take this into account in discussing the future of PILPS.

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.

3.1 General climate model intercomparisons

Atmospheric Model Intercomparison Project (AMIP)

AMIP, conducted 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, is a key element in WGNE efforts to identify errors in atmospheric models and their causes. Dr. P. Gleckler (PCMDI) provided a report on the status of the project, which is now well into its second phase (AMIP-II). This is again centred around 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 temperature and moisture 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 larger list of standard output has been defined. All modelling groups that took part in the original experiment have expressed their interest in being actively involved in AMIP-II as well as several new groups, and at the time of the WGNE session, nine completed model runs had been received at PCMDI. Overall scientific guidance and co-ordination continues to be provided by the WGNE AMIP panel.

A “quick-look” diagnosis and intercomparison of AMIP simulations, including particularly the standard WGNE set of diagnostics of mean climate, will be made available by PCMDI within a month of receiving a model run. With regard to diagnostic sub-projects, these are being subject to more stringent review than in AMIP-I, and, based on AMIP-I experience, there will be several improvements and clarifications in project protocol. At the time of the WGNE session, twelve diagnostic sub-projects had been approved. Consideration will also be given to co-ordinated systematic sensitivity experiments (e.g. to explore the variability revealed in multiple simulations, and to study further the sensitivity to model horizontal and vertical resolution).

WGNE recognized that AMIP was continuing to play a vital role in revealing the strengths and weaknesses of atmospheric models and providing an important yardstick in gauging their improvement. AMIP also provided a very valuable infrastructure for organized model intercomparisons, for a range of model diagnoses, and for modelling groups to judge the performance of their model compared to others. WGNE underlined the importance it placed on the continuation of AMIP as an evolving benchmark exercise, with periodic standard control experiments with updated boundary conditions etc. As more advanced/refined integrations become available, so could the diagnostic projects become more elaborate and the range of output parameters collected should be periodically enhanced. In this context, careful consideration also needed to be given to procedures for submitting data and data formats, in particular for example for providing updated integrations with later model versions, required to assess progress overall. Protocols were being discussed by the WGNE AMIP panel and would be described at the next session of WGNE. The approach adopted in this will set the standard for all WCRP modelling intercomparison projects and could thus have far-reaching consequences. Concerning the AMIP panel itself, WGNE agreed with the proposal that Dr. M. Miller be invited to replace Dr. D. Randall.

Two suggestions for fairly substantial and important AMIP-related projects were brought up during the WGNE session. The first, from Dr. S. Schubert, NASA/Goddard Laboratory for Atmospheres, would be designed to examine the connection between the climate of a free-running general circulation model and the climate of the same model when employed in data assimilation mode. It would attempt to assess the impact of model systematic errors on the climatology of the assimilation and whether the data constraints could affect the behaviour of the physical parameterizations. The aim would be to throw light on the interpretation of analysis products in validating model simulations. Interested groups should carry out (as a minimum) a one-year assimilation and one-year simulation using the identical model with co-ordinated (AMIP) output and comparing whether budgets were balanced differently, how bias might impact various diagnostics etc. NCEP and ECMWF already had plans to run “parallel” simulations as part of their reanalysis efforts (see section 4.1), but, as well as co-ordination of output, additional fields needed to compute full budgets were needed. Ideally these runs (and those from other major centres) should be for the same period for a current year (e.g. 1999/2000) when verification data from TRMM and scatterometers could also be used.

The second project was presented by Dr. Miller, the basic idea being what was termed a “transpose” AMIP in which climate models would be run in NWP mode and could then be 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 (e.g. a set of ten-day forecasts once or twice a month, three-day forecasts for special periods such as the ARM IOP). The runs 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. This could be seen as complementing and augmenting the current AMIP efforts. ECMWF would be able to supply a number of the basic data sets but it would be necessary to generate fields at various horizontal and vertical resolutions, to consider the question of initialization and to define a procedure for land-surface fields. It was agreed that ECMWF and NCAR would carry out a pilot project looking at these issues and present results at the next session of WGNE. This could then be the basis for formulation of a formal project on these lines.

Finally, in its discussion of AMIP and related topics, the general question of systematic errors (as highlighted by AMIP) was raised. It was recalled that WGNE had organized a workshop on systematic errors ten years earlier (Toronto, September 1988) which had at that time, provided a useful review of the status of the problem. Although there has, of course, been substantial progress since then, there still appears to be a number of common errors especially in the longer-term or seasonal forecasts that are now being prepared increasingly widely (for example, in seasonal forecasts, the signal is usually no larger than the systematic error; excessive zonality is also seen frequently). It was suggested that it would be timely to organize a new workshop on this subject to be held in 2000 or 2001. A sub-group (the Chairman of WGNE, Dr. K. Puri; P. Gleckler; M. Miller; D. Williamson) was asked to consider the possibility further and, if appropriate, to put forward proposals at the next session of WGNE.

International Climate of the Twentieth Century Project

The International Climate of the Twentieth Century Project has been developed under the leadership of the Center for Ocean-Land Atmosphere Studies (COLA) and the UK Meteorological Office Hadley Centre for Climate Prediction and Research. The project utilizes the GISST 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).

In view of the interest of these century or longer integrations to the WCRP Climate Variability and Predictability Study (CLIVAR) in its investigations of longer-term variability, the Working Group on Coupled Modelling (WGCM) had already proposed that it was appropriate for the project to be recognized as a WCRP-sponsored activity. However, as it involved co-ordinated integrations of atmospheric models forced by specified boundary conditions, the project was akin to AMIP and WGCM suggested that it could be more suitable for WGNE to follow this activity in parallel with AMIP. WGNE agreed that the results from the International Climate of the Twentieth Century Project were of interest in this context and hoped in the future to review the results being achieved as a complement to AMIP. All information and findings that could help in understanding interannual to multi-decadal variations would be relayed to WGCM and CLIVAR.

WGNE was aware of the range of modelling intercomparison activities being undertaken not only by itself, WGCM and the CLIVAR Working Group on Seasonal-to-Interannual Prediction (ex CLIVAR NEG-1), but also a monsoon predictability study organized by the CLIVAR Asian-Australian Monsoon Panel and other experimentation such as the International Climate of the Twentieth Century Project. WGNE expressed its concern at the large number of projects and considered that greater co-ordination of these activities was necessary.

Standard climate model diagnostics

Following their adoption at the twelfth session of the working group, 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 standard diagnostics is available at <**http://www-pcmdi.llnl.gov/amip/**>).

It was suggested that further diagnostics describing the representation 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 agreed to put forward an appropriate supplemental list of diagnostics/parameters that could also be collected.

Comparison of dynamical cores of atmospheric general circulation models

The dependence of errors in atmospheric models on their basic dynamical cores and the sensitivity to the numerical schemes employed and spatial resolution are still unresolved questions. Various test cases have been devised and have given useful hints but there remain uncertainties in the application of these tests and there continues to be a need for procedures that are more discriminating with regard to accuracy. Under WGNE auspices, an informal working group including 20 members from 14 organizations in five countries has been set up to consider the formulation of suitable tests and/or experimentation. A workshop involving the group was held in Gatlinburg, TN, USA, 29 April-1 May 1998, in conjunction with the Sixth Workshop on Numerical Solutions of Fluid Flow in Spherical Geometry. It was agreed that results from the available test cases (those of Held and Suarez; Boer and Denis) should be collected centrally as a basis for comparison, and a set of standard variables and averaging required were defined. Again, it is PCMDI who will take role of centre for assembling and analyzing the various data sets. Full details are available on the web site <**http://www-pcmdi.llnl/gov/dc**>.

The workshop also reviewed a range of issues that test cases might address, for example: the domain of integration and gridding (including effects of poles and other grid inhomogeneities and boundaries); the treatment of advection, conservation, gravity-wave propagation; maintenance of balanced flow, orographic forcing (and specification of pressure gradient term); cascades to unresolved scales; non-hydrostatic effects, etc. Further discussions on this topic are expected to be held in conjunction with the next workshop on numerical solutions of fluid flow in spherical geometry planned for 28 November-2 December 1999 in San Francisco.

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 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 fully recognized the importance of OOPC activities and the GODAE initiative, and wished particularly to see appropriate liaison and dialogue with GODAE as this effort developed in view of its interest to operational NWP centres.

WGNE will duly take up the implementation of a regular verification of surface flux products from NWP centres. Comparison with observations from selected sites will be very useful in this respect, and WGNE specifically supported the establishment of a series of surface reference sites as planned in GOOS and GODAE. Representatives of operational centres at WGNE expressed their willingness to participate in the type of validation of surface flux products that was being sought. PCMDI also voiced interest in this activity and in collecting the data sets needed. A variety of diagnostic tools were available at PCMDI that would be useful in evaluating the NWP products, but it would be essential that the data be forwarded in appropriate (PCMDI/AMIP) formats. It was planned to collect full global fields of the surface fluxes which would allow, at the same time as the verification of air-sea fluxes, a study of the land-surface fluxes, also of considerable interest in view of the growing importance attached to this topic as described in section 2.3. Drs P. Gleckler and J. Polcher agreed jointly to draft a plan for a pilot study aimed at a routine evaluation and intercomparison of surface fluxes. The plan would then be presented to NWP centres to assess their interest and to ensure that the required surface flux fields could be easily submitted. Available observationally-based data sets (both historical and operational) of both ocean and land surface fluxes would be documented (in particular in co-ordination with the JSC/SCOR Working Group on Air-Sea Fluxes).

Model treatment of snow and ice-fields

The main item discussed under this heading at this session of WGNE was an interesting new project proposed by Météo-France (Centre National de Recherches Météorologiques, Centre d'Etudes de la Neige, CNRM/CEN) 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, had already expressed interest in participating. The first step would 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. were specified or computed. The next stage would 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. Data sets would generally need to span a complete winter and longer periods would be useful as a basis for assessing the simulation of interannual variability. Initially, the focus would be on a limited number of data sets (e.g. those from Weissflujoch, Switzerland, or Col de Porte, France), and these would be used as the basis for an (off-line) intercomparison of snow models. Variables common to all or a majority of models would be collected such as start/end of snow cover, maximum snow depth and snow water equivalent, date of maximum snow cover, surface temperature, snow melt etc. Studies of sensitivity to changes in key variables such as air temperature, incoming long wave radiation would also be carried out. Additionally, from participating detailed snow models, internal variables (e.g. temperature profiles, snow density and settlement, description of the granular structure of the snow) should be submitted. At a later stage, consideration would be given to a (one-dimensional or three-dimensional) on-line intercomparison. To define the intercomparisons in detail, to set up the required practical co-ordination and to review such aspects as data formats and management, a workshop would be organized during 1999 to bring together potential participants, data set producers, etc. WGNE endorsed this activity.

Model stratospheric intercomparisons

Comparison of Deterministic Predictions of Stratospheric Activity

WGNE has been exploring for some years the possibility of an organized intercomparison of (deterministic) predictions of stratospheric activity at lead times of a few days during the period 1-25 October 1994. This interval includes a marked transition in the southern hemisphere stratospheric circulation and is therefore an interesting predictive test. A series of pilot experiments has been conducted by the Australian Bureau of Meteorology Research Centre (BMRC) and the Japan Meteorological Agency (JMA) from which preliminary results were presented at earlier sessions of WGNE (and are available on the web site <**http://www.ho.bom.gov.au/bmrc/regncoll.html**> under the section “WGNE – pilot study”). Subsequently, an overall co-ordinated project has been defined, with participants being asked to prepare 10-day forecasts from 1200 UTC on 10, 11, 12 October 1994 (using United Kingdom Meteorological Office stratospheric analyses). A series of model fields, together with a general description of the model used and resolution, should be submitted to BMRC, which will act as focal point for this work under the guidance of Drs W. Bourke and K. Puri (Chairman of WGNE). Results from multiple model configurations are also being 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). BMRC will use a common software package in the diagnosis and validation of results.

SPARC-GRIPS activity

The experimentation being undertaken by WGNE complements 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 objectives of GRIPS are to assess the capability of modelling the climate and variability on a range of timescales in the middle atmosphere and the interactions with the troposphere, to investigate the relative roles of different forcing mechanisms in maintaining the stratospheric climate, and to examine the climate response to changes in the composition of the middle atmosphere using the appropriate models. In the first phase of the project, diagnostics of thirteen model stratospheric simulations have been collected. All models reproduce to a certain extent the zonally-averaged latitudinal and vertical structure of the stratosphere. However, many important discrepancies are apparent including (sometimes large) systematic temperature errors, the strength and location of major jets and the position of the tropical tropopause. It has also been noted that the stationary planetary waves in the northern winter troposphere and stratosphere often differ widely from those observed and the simulation of low-frequency oscillations in the tropical stratosphere is generally deficient (e.g. no QBO). The second phase of GRIPS is a set of more controlled experiments designed to examine certain processes in detail and including “off-line” tests of such aspects as radiative schemes. Tests to assess the effect of gravity wave parameterizations have also been formulated. Looking ahead, an experimental sub-project in AMIP-II is being planned to elucidate the sensitivity of model climates to the distribution of ozone.

Development of global operational assimilation for stratospheric ozone at the Canadian Meteorological Centre

Dr. S. Edouard, RPN, referred to work to implement a self-consistent global operational data assimilation system for stratospheric ozone. The capability was being developed to assimilate conventional observations in real time, as well as to be prepared for the next generation of observations. Prerequisites for this task are revising the configuration of the Canadian Meteorological Centre's Global Environmental Multi-scale (GEM) model (see section 5.3) for the stratosphere and the introduction of an appropriate chemistry component to be able to simulate the evolution of the background ozone fields. The effects of varying vertical and horizontal resolution are being investigated, as well as the possibility of improved representation of physical mechanisms such as gravity wave phenomena that could be obtained with higher resolution and studying their impacts during the generation of background fields in the data assimilation cycle. It will probably be necessary to use a hybrid vertical co-ordinate to avoid the problems seen in stratospheric winds associated with the use of the sigma-coordinate.

Modelling large-scale atmospheric transports

Comparison of model simulations of distributions of atmospheric aerosols

A series of workshops to assess the ability of atmospheric models to simulate the global distribution of inert or chemically interacting gases has been organized under WGNE auspices. Dr. R. Leaitch (Atmospheric Environment Service of Canada) reported on the results of the latest workshop in this series (the fourth), arranged jointly by WGNE and the IGAC Global Integration and Modelling (GIM) activity, that took place in Halifax, NS, Canada, 19-21 October 1998. The workshop 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. As with earlier workshops in the series, atmospheric climate and chemical transport modellers interested in large-scale simulation of atmospheric trace constituents, modellers and theoreticians involved in parameterizing the relevant processes, and scientists with detailed expert knowledge in these areas were brought together. A standardized numerical test was designed to examine the ability of dynamical/chemical models to represent transport of sulphur from various source regions both horizontally to remote locations and in the vertical.

Twelve modelling groups had carried out this test and reported results at the workshop. Considerable differences were apparent between models. Over the global domain, the fraction of sulphur removed by precipitation ranged from 50-80%. The transformation of sulphur dioxide into sulphate aerosol in clear air (in contrast to internally in clouds) also varied greatly from model to model (10-50%). There were large differences in model treatments of transport of sulphur from the anthropogenic source regions of North America, Europe and Southeast Asia. The most consistent results were in the simulated distribution of sulphur in the lower troposphere in the latitude zone 30°N-60°N, with least consistency in the tropics and Arctic. Comparing modelled and observed distributions of sulphur at ground level at 25 sites showed that most model values were on average within 50% of the observed seasonal mean, but that several models had values that were 100% or more too high, a reflection of the differences in the ability of models to transport and disperse sulphur in the vertical. Further analysis of the results obtained is underway, but it is clear that models generally fell well short in the test, and significant refinements are needed. A full report of the workshop is expected to be published in the WGNE "blue-cover" report series during 1999.

Looking to the future, the workshop recommended continuing activity in the comparison of large-scale dynamical/chemical models and observations. Atmospheric aerosols are a major uncertainty in radiative forcing, and sulphate aerosols are but one of a number that should be taken into account in climate simulations. Moreover, to ensure accurate computation of the radiative effect of aerosols, the size distribution should be represented. Thus, a further useful study could be to examine how models would treat and resolve the size distribution of multiple aerosol types. However, this would depend on the availability of the appropriate observations. A proposal to undertake such an activity has been made by the Brookhaven National Laboratory, NY, USA, with a standard comparative numerical test being organized during 2000, and a fifth workshop in this series in 2001. A suggestion to study the chemistry of the combination of oxidants and aerosols was also made.

Use of “mean age of air” as a diagnostic

Dr. D. Williamson noted that the mean age of air had become a popular diagnostic for studying stratospheric transport. For a (passive) tracer of this type whose mixing ratio increases linearly with time, the lag between the occurrence of a particular mixing ratio value in the stratosphere and of that value in the troposphere gives the mean age at that stratospheric location. Recent experimentation with a forty-level version of the GFDL SKYHI general circulation model shows that a wide range of distributions of the mean age of stratospheric air can be obtained in the same model depending on the passive tracer transport treatment. Among schemes tested were several different Eulerian grid-point methods, and a semi-Lagrangian and fully Lagrangian schemes (all implemented on-line within the model). Relative to other methods, and also in comparison with atmospheric estimates, the semi-Lagrangian approximation resulted in extremely young ages. Other experiments with the NCAR CCM3, which is very different from the GFDL in terms of dynamical approximations and physical parameterizations, also yielded a similarly young age of air in the stratosphere when semi-Lagrangian tracer transport was employed. These results are not well understood and additional experimentation and analyses are being undertaken. However, it would appear that age of air could be used to develop an idealized test of the long-term statistical behaviour of dynamical cores and transport models for stratospheric simulations, especially in conjunction with an idealized forcing such as that of Held and Suarez modified to produce a reasonable stratosphere (see section 3.3). This might require the inclusion of surface topography to enable polar stratospheric variability to be reproduced.

Regional climate modelling

Project to Intercompare Regional Climate Simulations

Drs W. Gutowski and R. Arritt from Iowa State University, co-Directors (with Dr. E. Tackle) of the Project to Intercompare Regional Climate Simulations (PIRCS), presented an update to WGNE on progress. The objective of PIRCS is to provide a common framework for evaluating the strengths and weaknesses of regional climate models through systematic comparative simulations. An initial pair of simulations (15 May-15 July 1988; 1 June-30 July 1993) focussed on the central USA using lateral boundary conditions from NCEP reanalyses have been completed by eight modelling groups from around the world. The ability of the regional models to simulate mesoscale dynamical features such as the locally occurring nocturnal low-level jet and regional-scale precipitation patterns has been examined. The frequency and (to a lesser extent) magnitude of observed synoptic-scale precipitation events were reproduced, as were episodes of mesoscale and convective precipitation, but in a more stochastic sense with significant differences on spatial and temporal scales. The skill in treating the large-scale 500 hPa flow was also examined: this was reasonable during periods dominated by a ridge or zonal flow, but mixed in periods characterized by the development and migration of short-wave lows or troughs. Other ongoing work includes assessment of sensitivity to features such as model domain size, parameterization schemes and the initial soil moisture. Comparisons are also being made with other approaches to regional climate modelling such as stretched grids over a particular region in a global model, uniform high resolution models and statistical downscaling.

WGNE endorsed PIRCS as a comprehensive project making a valuable contribution to the evaluation of regional climate simulations and offered its scientific support. In this context, a number of issues were raised, in particular regarding the treatment of the moisture budget. The PIRCS organizers are looking into these questions. Dr. A. Staniforth has acted in the past few years as WGNE liaison to PIRCS. Now that Dr. Staniforth had left WGNE, it was suggested that Dr. B. Bougeault take up this role.

Review of regional climate modelling questions

Generally, in respect to regional climate modelling, WGNE stressed that efforts to intercompare or validate models needed to consider carefully the way in which they are to be used – a good model for one purpose might not be satisfactory for another. Bearing in mind that the main use of regional climate models is to add higher resolution detail to, but keep the large-scale features of global model integrations particularly in the context of climate change, attention was drawn to several points:

(i) Regional climate models should realistically represent the mesoscale meteorological phenomena which are important for their contribution to local climate, but which may not be properly represented in a larger-scale general circulation model;

(ii) Regional climate models should, in their domain, reproduce the large-scale behaviour of the general circulation model providing the boundary conditions. This should be checked by scaling up regional model results to the global model scale, and comparing over a large range of conditions (i.e. across the seasonal cycle, different geographical regions, perturbed climates), to ensure that the regionally-simulated response is indeed a down-scaled global model simulation;

(iii) The dependency on resolution of the model's parameterizations needs to be carefully assessed to verify that they do not result in large-scale deviations between the regional model and the forcing model (e.g. the more intense and localized vertical motion in a high resolution model leading to more efficient and intense precipitation, hence lower mean-humidity and greater run-off from the land surface). These aspects are most important when a higher resolution version of essentially the same model is nested. Dependency on timestep should also be checked.

(iv) The role of boundaries in determining the large-scale flow of a nested regional model should be explored, and hence an appropriate domain for the regional model chosen. The large-scale flow is stronger in winter, so a larger regional domain may be required if the model is used in this season.

(v) The lack of conservation at the boundary should not significantly affect the energy and water cycles in the regional model (e.g. a spurious source or sink in moisture at the boundary of the regional model should not be reflected in a spurious trend in the soil moisture budget).

In addition, questions remain concerning the computational robustness of the underlying approach. As previously pointed out by WGNE, the most straightforward approach may be the "identical twin" paradigm with a very high resolution (comparable to the regional model) global simulation as a control and a simulation with a regional model identical to that of the global model. The regional model should then be run, firstly, with boundary conditions from the full resolution global simulation and, secondly, with boundary conditions from the global simulations that have been degraded to the type of resolution expected in practice. The first test should expose computational problems such as noise generation by the boundary conditions or suppression of the signal from extra smoothing. In the second, the statistics of the smaller scales of the global simulation should be reproduced if the basic nesting approach is correct. However, there is additionally the issue of how the large-scale flow in the global model is determined by unresolved scales – this cannot be compensated by downscaling using a regional model. One way this could be investigated in the framework of the above tests is to compare the results using a lower resolution version of the global model and nested regional model with those from the matching resolution global and regional model control integrations. All these studies need to be carried out for a range of climatic regimes (e.g. mid-latitude, tropics, summer and winter) and applied similarly to other techniques such as variable-mesh models that are sometimes employed as an alternative to nested regional models.

WGNE emphasized that, since the ultimate success of regional models is dependent on the realism of the large-scales simulated by global models, it attached great importance to the continuing investigation of the convergence of both the basic dynamical and complete model solutions with resolution (the former is the objective of the WGNE-sponsored comparison of dynamical cores of atmospheric general circulation models, see section 3.3).

Other climate-related modelling initiatives

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

USA

In the USA, the Department of Energy Climate Change Prediction Programme, developed from the integration of the Computer Hardware Advanced Mathematics and Model Physics (CHAMMP) programme and the climate research element of the Carbon Dioxide Research Programme, is focussed on developing, testing and applying climate and prediction models at the leading edge of scientific knowledge and computational technology, and will exploit a distributed or virtual climate modelling centre with three primary sites: a model development centre at the Los Alamos National Laboratory, exploring computational and numerical methods on the next generation of supercomputers; a model testing and evaluation centre at PCMDI; a model application centre at NCAR, using a variant of the NCAR Climate System Model with

Department of Energy supported computational improvements for Department of Energy applications. The overall goal is to construct models, based on definitive theoretical foundations and taking advantage of improved computational methods, that will run efficiently on future generations of high performance supercomputers. This should dramatically increase both the accuracy and throughput of computer model-based predictions of the climate response to the growing atmospheric concentrations of greenhouse gases. The set of reference benchmarks and model diagnostics needed to assess model computational performance and the realism of simulations will also be enlarged (building on the test cases developed under CHAMMP). The programme will continue to support the CHAMMP-initiated series of Workshops on Numerical Solutions of Fluid Flow in Spherical Geometry, the next of which will be held in San Francisco in late 1999 where the issue of test cases for dynamical cores will be further discussed (see section 3.3). Other activities being supported include:

- continuation/enhancement of activities previously funded under CHAMMP;
- studies of theoretical limits of climate prediction having accuracy at subcontinental and smaller domains over decade to multi-century time-scales;
- development of improved mathematical techniques, model formulations and computer algorithms for atmospheric, oceanic and coupled global circulation models that will describe and predict the behaviour of the global climate system more accurately and efficiently for the type of climate predictions described above, exploiting advanced parallel-processing supercomputers;
- development of refined parameterizations of key climate processes;
- compilation and analysis of long-term observation-based climate data sets that can be used to test the ability of climate models to simulate and predict the climate system realistically.

Another important development in the USA is the Accelerated Climate Prediction Initiative (ACPI). The concept document published in June 1998 calls for accelerated progress in model improvement and application to climate simulation, a substantial reduction in the uncertainties in decade-to-century model-based projections of climate change, and an increase in the availability and usability of these projections by the broader climate change research and assessment communities. It is anticipated that major advances in climate simulations and projections would come from high spatial resolution and refined physical parameterizations in models, as well as use of ensembles. A serious limitation at present is the computing resources for multi-decadal-to-centennial projections. Thus, improvements in models must be accompanied by increases in computing throughput, requiring marked enhancements of the computational efficiency of model codes and of parallel operation, and hardware having a (peak) capability of 40 TFLOPS and 20 Tbytes of memory. The ACPI implementation plan will be elaborated so as to complement the US Department of Energy Strategic Simulation Initiative (part of the Accelerated Strategic Computing Initiative, ASCI).

Consideration is also being given in the USA to working towards a unified weather prediction and climate simulation framework and, more generally, to 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). An informal working group has been tasked to design an infrastructure, organize a framework and set down standards as a basis for moving ahead.

Japan

An update was given on the plans for the ambitious and far-reaching global change research in Japan. At the heart of this activity is the development of the “Earth Simulator”, based on a strategic approach to the Earth as “one system”. An extensive range of studies of atmospheric, oceanic, cryospheric, land and biological processes is envisaged together with a strong observational programme using satellites and research ships. Building on this foundation, in the area of atmospheric and oceanographic science, a high performance comprehensive global coupled climate change prediction model (with a resolution of 10 km and plug-in schemes) and a regional numerical weather prediction model (with a resolution of 1 km) will be developed, studies on material transfer in the atmosphere and ocean undertaken, and an approach made towards the integrated utilization of Earth observation data using 4D VAR and Kalman filter techniques. Simulations of the Earth's interior dynamics are also planned, involving development of a global model of crust and mantle dynamics able to represent earthquake generation mechanisms and to predict strong ground motion, and studies of material transfer in strata. The "Frontier Research Programme for Global Change", which will use the Earth Simulator as a research tool, is a component of this work. Intensive computer hardware development will be undertaken aiming at achieving a processing capability many times that of the existing fastest supercomputer to support these programmes (peak performance of 40 Gflops and 10 Tbytes of memory envisaged).

4. DATA ASSIMILATION AND ANALYSES

4.1 Reanalysis projects

ECMWF

The plans for a forty-year reanalysis at ECMWF (ERA-40) are well advanced. The model used will be basically the ECMWF operational configuration as at May 1998 with a resolution of T_L159 and 60 levels, employing a 3D VAR assimilation scheme. The whole stratosphere will be included with an associated ozone analysis and evolving humidity. A coupled atmosphere ocean-wave model will also be incorporated. Relative to the first (fifteen year) ECMWF reanalysis (ERA-15), better use will be made of island observations, ship and buoy winds, soil wetness information, snow data (unavailable to ERA-15) employing a new snow model, improved orography, and refined parameterizations of a variety of physical processes (as developed in the ECMWF operational model in recent years). Considerable quantities of extra data have been received and are being processed including NCAR's holding of TOVS 1b data and a number of years of surface and upper air data. The correction of sonde bias is a concern. Particular attention has also been given to the boundary conditions to be used and the specification of the atmospheric composition to correct known deficiencies in ERA-15, and especially to take account of suggestions made by the WCRP polar research community. The GISST 4 sea-surface temperature data set and a new 2D VAR NCEP sea surface temperature analysis from 1981 will be employed. A working group including representatives from NCEP and UKMO has been set up to advise on the approach to be taken in generating sea-ice concentrations and ensuring consistency with the sea surface temperature data sets. ERA-40 is planned to start during 1999 and will be run in two streams covering the 1990s and 1957-1978, with the 1980s being done last. Provision is being made to repeat the period 1957-1978 if necessary to be sure that the relatively limited data available are exploited to the optimum extent.

NCEP/NCAR

At NCEP, the fifty-year NCEP/NCAR global reanalysis has been completed. There were no model changes during the whole period of the assimilation, for which a more comprehensive data base was available than for the original operational analyses for the same time. The series of (homogeneous) analyses provided represents a unique research resource (which can be accessed through the internet: <**nic.fb4.gov:8000**> and then linking to the reanalysis home page). Despite the value of the global reanalysis data set, there are various shortcomings, in particular the coarse resolution (200 km), excessive summer precipitation over the south-east USA, and not directly assimilating TOVS radiances (the assimilation of radiances rather than TOVS retrievals resulted in the largest single improvement of forecast scores on its introduction in the operational system). Thus, it is now being planned to carry out a regional USA analysis using an updated assimilation system and the NCEP limited area ETA model aiming to provide a superior product at high resolution over an area of interest. As well as the many advances incorporated in the operational system since the global reanalysis, the model will be forced during the assimilation with the observed precipitation. Following this, the possibility of an updated global reanalysis will be considered.

Second International Conference on Reanalyses

Following the first very successful Conference on Reanalyses in Washington, DC, in October 1997, WGNE agreed at its thirteenth session (November 1997) that a second International Conference on Reanalyses should be held later in 1999. WGNE reviewed the steps taken in the planning of the second Conference which would take place at Wokefield Park near Reading, UK, 23-27 August 1999. ECMWF had kindly offered to supervise the organization of the Conference. WGNE stressed the urgency of now proceeding rapidly with the arrangements, in particular distributing an initial announcement of the Conference and call for papers. WGNE agreed that fundamental themes to be taken up should include the improved understanding of low frequency variability as a result of reanalyses, the validation of coupled models, and assessment of predictability from the medium-range through seasonal and interannual to decadal timescales. Sessions at the Conference would be centred round:

- Global reanalysis data sets, analysis methodology, impact of data inhomogeneities, estimation of data bias, evaluation against independent observational data sets.

- Diagnosis from reanalyses of global and regional aspects of the hydrological energy, and momentum cycles

- Diagnosis from reanalyses of the mechanisms of atmosphere and ocean phenomena such as the Madden-Julian oscillation, stratospheric variability, interannual variability of monsoons, tropical cyclone frequency, and ENSO

- Use of reanalyses for driving ocean, land, sea-ice and chemistry models, and for development and validation of climate system models

- Medium-range, seasonal-to-interannual and decadal predictability studies using reanalyses

- Future requirements and plans.

Full details on the Conference are available on the web site <**http://www.ecmwf.int/conf/sicra/index.html**>**.**

4.2 Observing system experiments and observation assessment

WGNE has been regularly reviewing progress in data assimilation and analysis, particularly the rapid development and operational implementation of variational assimilation schemes in recent years, permitting more effective exploitation of all types of observational data including satellite radiance measurement and scatterometer winds (see section 5.3 for reports on recent developments in operational systems at various centres by members of WGNE). At this session of WGNE, discussions were particularly centred round observing system experiments and observation assessment.

WGNE appreciated the increasing experimentation taking place related to the assessment and design of observing systems. This ranged from preliminary study of the feasibility and impact of new observations and techniques to the exploration of how composite operational observing systems could be optimized. WGNE reiterated that substantial effort in terms of computer resources (similar to those required for NWP) and organization of the experimentation (involving many cases) is necessary to obtain a statistically significant result and to avoid misleading conclusions. Results may depend on the assimilation technique employed, the forecast range, and the means of assessment of forecast accuracy. As assimilation schemes develop further (e.g. the 4D VAR approach), conclusions may alter. The evaluation of new satellite systems is difficult because like observations often do not exist, and because the lead-time for decisions is so long that assimilation methods will have altered by the time the system is operational. For new observations, observing system simulation experiments can be carried out, but these are more expensive than basic observing system experiments, since an additional high resolution run with a different model is required to generate “observations”. This introduces further problems of interpretation. WGNE emphasized that, in view of these issues, observing system experiments cannot be considered a simple tool: close collaboration with relevant experts in observational technology was essential (for example with groups such as NAOS or COSNA).

Other interesting work in this area is the exercise co-ordinated by the United Kingdom Meteorological Office in looking at and intercomparing the response of data assimilation to single isolated observations (see <**http://www.met-office.gov.uk/sec5/NWP/DA-intercomparison/index.html**>). WGNE urged that this project be continued and encouraged interested groups to participate. However, in the latest assimilation systems such as 4DVAR, the response to an isolated observation can strongly be influenced by the flow and the likely errors of the day. Extending the intercomparison to take this into account would require centres also to use the same atmospheric state for the chosen case. The analysis intercomparison would have to be linked to related intercomparisons of singular vectors, breeding modes, forecast sensitivities etc. The “Fronts and Atlantic Storm Tracks Experiment” (FASTEX), which is providing the basis for a number of studies in these areas, could offer possibilities for appropriate test cases (see also section 5.1 on targetted observations). The design of a useful set of experiments should be a topic for a specialized workshop.

WGNE agreed that it should keep this whole subject under careful review and that it should be included as a specific agenda item at future sessions, including reviews of recent observing system/impact experiments.

4.3 Third WMO Symposium on Data Assimilation in Meteorology and Oceanography

WGNE was informed of the plans for the third WMO Symposium on Data Assimilation in Meteorology and Oceanography to be held in Québec City, Canada, 7-11 June 1999 (the first symposium was in Clermont-Ferrand, France, in July 1990, the second in Tokyo, Japan, in March 1995). The principal goal of the symposium is to give a comprehensive view of progress in data assimilation relevant to operational applications in meteorology and oceanography, recognizing the common problems that exist such as the effect of dynamical instabilities on the data assimilation and the wide-range of scales that are important. The challenge of exploiting new satellite data (e.g. from ENVISAT, the EOS-AM and -PM platforms, the ADEOS and METOP series) would also be discussed, as would methodological aspects. The increasing range of applications of data assimilation in climate and upper air research, atmospheric mesoscale studies (including chemistry), seasonal prediction (initialization of coupled ocean/atmosphere models), large-scale oceanography, and meso-scale ocean simulation and prediction (including ocean biogeochemistry) would be considered.

WGNE looked forward to receiving a summary of the main findings, conclusions and recommendations for future research efforts from the symposium at its next session in 1999.

5. NUMERICAL WEATHER PREDICTION TOPICS

5.1 Short- and medium-range prediction

The CAS World Weather Research Programme

Dr. F. Delsol noted that the mission and objectives of the World Weather Research Programme (WWRP) had now been formally agreed by the WMO Commission for Atmospheric Sciences and Executive Council. WWRP will be organized on a project-oriented basis including “Research and Development Projects” (RDPs) aiming to achieve real advances in forecasting 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. MAP would include a Special Observation Period from 7 September-15 November 1999. A second RDP being considered is Tropical Cyclone Landfall with particular emphasis on extreme wind and rain hazards. Other topics that could be taken up 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 would be able to contribute significantly in several respects. WGNE expressed its willingness to provide support and assistance as required. The communication (including requests to WGNE from WWRP for appropriate activities) and co-ordination would be assured by the membership of Drs P. Bougeault and T. Tsuyuki in both WGNE and the Science Steering Committee for the WWRP.

Performance of the main global operational forecasting models

WGNE reviewed the skill of daily forecasts from a number of the main operational centres as presented to the session by Dr. M. Miller. Examples of the twelve-month running means of verification scores (root mean square error) for 500 hPa geopotential height in the northern hemisphere at lead-times of one and three days, and five and seven days, are shown respectively in Figures 1 and 2. Generally, there appears to have been a distinct improving trend over the past year (compared to the hiatus noted at the last session of WGNE). It is not clear the extent to which these variations in trends are due to intrinsic changes in the predictability of the atmospheric circulation from year to year, or a reflection of changes in observational data. Improvements are probably resulting also from the advances in and implementation of the new assimilation techniques.

Intercomparison of typhoon track forecasts

A report on the latest results from the intercomparison of forecasts of typhoon tracks in the western north Pacific Ocean conducted by JMA was given. Data in this respect from operational forecasts have been made available from ECMWF, UKMO, and the Canadian Meteorological Center, as well as JMA itself. The error in distance (as verified against best-track data produced by JMA) continues to show a reduction with both northward and eastward biases decreasing substantially (the errors at 48 and 72 hours are now around 200 and 400 km respectively).

The “COMPARE” project

Activities in the “COMPARE” project (Comparison of Mesoscale Prediction and Research Experiments), aimed at carrying out comparative experiments with regional mesoscale models in a collaborative manner in order to further understanding and predictive capability at this scale, continue. The current case study (the third), being led by JMA, 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, NCEP analyses with and without GFDL, JMA bogussings) have been prepared. Preliminary results suggest that the predictions of the cyclone track were generally reasonable, although initial analysis and whether or not bogussing was used had a larger impact on the forecast track than employing different models. With regard to the prediction of the intensity of the cyclone, there was a large diversity among models, with some capable of capturing the explosive development of the cyclone to a certain degree. Models successful in simulating the explosive development were also generally superior in representing the inner structure of the typhoon. Consequent to these findings, it is being proposed that a further experiment be carried out at high resolution (10 km), by groups able to do so, to see whether this would give improved predictions of cyclone intensity.

Planning is well advanced for a further COMPARE case, sponsored by the Center for Analysis and Prediction of Storms, Norman, Oklahoma, USA, designed to examine the treatment of the onset of strong convection and to improve the understanding of the origin and evolution of tornadic storms, using data from VORTEX 95 (Verification of the Origins of Rotation in Tornadoes Experiment). Experimentation will be conducted for up to 18 hours using resolutions of 27, 9 and 3 km. The representation of the convection as a function of horizontal resolution will be explored, as well as the question whether 3 km resolution is sufficient to simulate rotation in the supercell. Supplementary experiments will be carried out to assess sensitivity to soil moisture and radiation.

A further experiment being considered is a case from FASTEX to investigate the representation of frontal zones lying across the North Atlantic and secondary cyclogenesis, but there has been little detailed planning so far.

Verification and comparison of precipitation forecasts

Several centres have been pursuing activities in this area. At DWD, precipitation forecasts from CMC, DWD, ECMWF and NCEP have now been assessed over Germany for more than two years and from Météo-France and UKMO since May 1998 and July 1998 respectively. The forecasts are interpolated bi-linearly to the more than 4000 locations of stations in the synoptic and climatological network measuring precipitation in Germany and Switzerland. A series of scores (bias, a Heike skill score, equitable threat score and true skill statistics) are then computed. A full description is available on <**http://www.dwd.de/research/wgne**>.

At NCEP, quantitative precipitation forecasts over the USA from CMC (global and regional models), DWD, ECMWF and NCEP (medium-range forecast, Eta, and nested grid models) are being examined. The verification data set is comprised of twenty-four hour accumulated precipitation reports provided by the USA National Weather Service's River Forecast Centers. There are approximately 10000 stations in this network with good spatial coverage and resolution east of the Rockies, but gaps further west. Some of the gaps are filled in with radar reports from which bogus observations are created using the observed rainfall intensities. Since the model quantitative precipitation forecast is an areal average over the (model) grid box, the value for verification is also taken as the areal average over the grid box on which the model forecast was provided (except for the Eta model). For a set of eight thresholds, counts of the number of points where the forecast value is greater than particular thresholds, of the number of points where the observed value is greater than these thresholds, and of the number of points with both forecast and observed values greater than these thresholds are made. These are then used as a basis for calculating an equitable threat score.

A report was also given of the verification of NWP quantitative precipitation forecasts (00-24 hours) over Australia from DWD, ECMWF, Australian Bureau of Meteorology (global and regional models), NCEP, UKMO and JMA for a twelve-month period September 1997-August 1998. Forecasts were remapped to a standard 1°x1° grid and verified against a gridded surface analysis of daily rainfall. The rain area, volume, average and maximum rain rates were evaluated, and several categorical statistics (bias score, probability of detection, false alarm ratio, equitable threat score, and Hanssen and Kuipers score) were computed. The verification focusssed on the treatment of the Northern tropical monsoon and the southeastern subtropical regimes. For both, the operational models tended to overestimate rainfall in summer and to underestimate it in winter. In the southeastern region, the models had Hanssen and Kuipers scores ranging from 0.5 to 0.7, and easily outperformed persistence. On the other hand, model skill appeared to be relatively limited in the Northern monsoon regime with Hanssen and Kuipers scores of only 0.2 to 0.6. During the summer wet season, the low skill is associated with an inability to simulate the behaviour of tropical convective rain systems. During the winter dry season, it is associated with the low probability of detection of the occasional rainfall event. Model skill generally fell dramatically for rain rates greater than 10 mm/day. This implies that the models are much better at predicting the occurrence of rain than they are at predicting the magnitude and location of the peak values.

Targetted observations

Dr. R. Gelaro (Naval Research Laboratory, Monterey, CA, USA) led an interesting review at the WGNE session of the effectiveness of targetted observations based on the results of FASTEX and the North Pacific Experiment (NORPEX). Several targetted observing strategies were proposed and tested by different groups during these experiments with the general conclusion that targetted observations could be used successfully to improve forecasts of weather events at lead-times of one to three days. However, there remains considerable debate over the design of these strategies as well as over the expected degree of forecast improvements and the overall cost effectiveness of their use.

The possibility of using targetted observations has opened up through the development of singular vector/adjoint methods and ensemble transform and quasi-inverse linear techniques. The basic hypothesis is that the early stages of error growth in numerical forecasts are dominated by a relatively small number of unstable structures and that preferentially reducing the analysis errors that project onto these structures can lead to improved forecast skill. It is not an issue of correcting the largest analysis errors but, rather, focussing limited observational resources where the growth of analysis error may be particularly large. These "targets" tend to be highly correlated with the locations of the leading singular vectors of the linearized forecast model. During FASTEX and NORPEX, the most successful examples of targetting resulted in forecast error reductions of 10-40% (based on a variety of measures) in the 24-48 hour time range. In contrast, in those cases where well designed null experiments were possible (in which only observations outside the primary target area were assimilated), error reductions of only a few per cent were apparent. However, in general, there was large case-to-case variability with impacts (positive and negative) depending on many factors, particularly adequate sampling of the target area and the ability of the assimilation scheme to make appropriate use of the special observations. Much additional research in these areas is required.

In the context of the foregoing, it must also be noted that the conventional observing network has changed significantly over the few years that work on objective targetting has been going on. High density geostationary satellite wind data are now an important contributor to the network, and, in NORPEX, targetted dropsonde data did not lead to a mean increase in forecast skill at two days compared to forecasts in which all available geostationary satellite winds were used at each six-hour analysis cycle (only 10 out of 26 cases were improved). Assimilation of satellite winds alone was responsible for a reduction of the mean forecast error by more than 20% over the (45-day) NORPEX period, suggesting that it may be increasingly difficult to extract additional useful information from, for example, intermittent dropsonde observations over relatively limited areas. Nevertheless, there would seem to be exciting potential to improve the impact of targetted observations by identifying situations where satellite wind data are not able to reduce the analysis error in sensitive locations, by optimizing sampling strategies, and by improved data assimilation procedures. In summary, an a priori identification of specific meteorological situations where forecasts would benefit from both remotely-sensed and in situ observations is a key challenge.

Dr. S. Lord referred specifically to the NCEP results using NORPEX data. Parallel runs with and without dropsondes showed overall an encouraging improvement in the majority of forecasts when the dropsonde data were included.

5.2 Long-range and seasonal forecasting

Dr. P. Bougeault reviewed the highlights of the WMO Workshop on Dynamical Extended Range Forecasting hosted by Météo-France in Toulouse in November 1997. Some eighty participants from twenty-nine countries had been treated to fifty oral presentations and two panel discussions. The presentations included descriptions of the systems in use to produce long-range and/or seasonal forecasts (20 days to one year), namely, coupled ocean-atmosphere models (with ensemble techniques), empirical methods based on long time series, and a combination to exploit the complementary nature of the dynamical and empirical approaches. Issues linked to the exploitation of ensemble techniques were also reviewed such as the generation of perturbations to obtain a true random sampling of future states, the spread of forecasting skill, and the correlation between skill and spread (even in a perfect ensemble, the correlation may not be high). Techniques of blending dynamical and statistical approaches were discussed including taking advantage of statistical predictors of sea surface temperature to force a dynamical model and relaxation (nudging) dynamical model variables towards a statistical prediction. Reports were given of predictions of the 1997/1998 El Niño (those produced dynamically by BMRC, ECMWF, COLA, JMA and by the stochastic oscillator approach of KNMI). It was observed that the models generally predicted a weak El Niño as early as late 1996, and then a more intense El Niño following strong westerly wind bursts early in 1997. However, on the whole, the development of the event was underpredicted and the phase was too late throughout. Whilst showing some promise, forecast performance appears to have been affected by model biases. The monitoring of and taking into account intense synoptic wind events definitely seemed important in obtaining more accurate predictions of El Niño and its intensity (see also “Review of predictions of the 1997/1998 El Niño, section 2, Report of the Third Session of the CLIVAR GOALS Numerical Experimentation Group, November 1998, WCRP Informal Report No. 3/1999, ICPO Publication Series No. 24, also available on <**http://www.dkrz.de/clivar/neg1 3.html**>). A final topic taken up at the WMO Workshop was that of standardized evaluation and comparison of forecasts. A lot of work was likely to be required in reaching a consensus on the scores that should be used (deterministic versus probabilistic, local versus spatially averaged, tropical versus extra-tropical, meteorological value versus value for impact assessment). It was proposed that an ad hoc committee be formed to develop specific recommendations. WGNE asked to be informed of the work undertaken in this respect at its next session.

Dr. M. Miller reported on the European Union (EUROCLIVAR) Programme on Prediction of Climate Variations on Seasonal and Interannual Timescales (PROVOST). Results of (multi-centre) seasonal predictability experiments (using prescribed observed sea surface temperatures) had been archived at ECMWF. Preliminary verification scores showed an advantage for multi-model ensembles.

Dr. V. Meleshko described activity at the Voeikov Main Geophysical Observatory in long-range weather prediction. In collaboration with the Russian Hydrometeorological Centre (Moscow) which provided initial fields of the main atmospheric variables in quasi-operational mode, experimental one month forecasts had been produced once weekly using the Main Geophysical Observatory atmospheric general circulation model (T42L14 version) over a period of one year (May 1997-May 1998). The initial fields of mass and wind (prepared independently) were not in balance, and a digital filtering procedure was applied to time series of the model variables generated by forward and backward integrations from the initial time. An ensemble of eleven members was prepared from eleven slightly different initial states (generated using a “breeding” technique) forced by the current observed sea surface temperature. Evaluation of forecast skill showed that the correlation of monthly anomalies of computed 500 and 1000 hPa heights was greater than that for persistence forecasts over the northern hemisphere as a whole in all seasons, but not over Siberia in the winter. (See section 5.3 for information on developments in long-range and/or seasonal forecasting at operational centres as presented by members of WGNE).

5.3 Recent developments at operational forecasting centres

A number of participants gave information on recent developments in or extensions of their operational activities. Taking advantage of the venue of the WGNE session in Montréal, there were several presentations by scientists from the Canadian Meteorological Centre, in particular RPN (the modelling research division of the Canadian Meteorological Centre).

Canadian Meteorological Centre

Dr. P. Dubreuil, Chief of RPN, gave an overview of the impressive scope of the current operational systems at the Canadian Meteorological Centre and plans for future research and development at RPN. Despite cutbacks in staff, the quality and quantity of research being conducted were being maintained, in particular in the area of numerical aspects in which RPN has a long-standing reputation of excellence. The Canadian Meteorological Centre was well equipped with computing power, currently 3 NEC SX4 (one with 32 processors, two with 16 processors each). More details of developments in data assimilation and of the Global Environmental Multiscale (GEM) model are given below. In summary, in respect to the former, priority was being given to the improvement of the 3DVAR system and the capability of assimilating new data types, preparations for 4DVAR and Kalman filtering. Refinement of model physical processes including the treatment of the land surface and clouds and radiation, as well as looking forward to coupling with appropriate environmental models, were also being given attention. The ensemble approach was being actively developed, based on eight-member ensembles generated by perturbing observations. Long-range forecast ensembles are being prepared, comprised of six members produced by the global operational model and six by the Canadian Meteorological Centre climate model. Dr. Dubreuil also referred to the work on forecast post-processing including the refinement of the “model output statistics” approach, the preparation of advanced work station tools for forecasters (such as the “Advanced Weather Element Display”, AWED) and the generation of “environmental” predictions of near-surface ozone concentrations, ultra-violet irradiance and atmospheric pollution/air quality. Finally, it was noted that an Atlantic Environmental Prediction Research Initiative had been established in Halifax to explore regional maritime aspects.

Dr. L. Fillion presented, on behalf of a number of scientists at RPN, a description of the strong effort in data assimilation. Over the past year, significant work had been undertaken in preparation for the operational introduction of an improved 3DVAR data assimilation scheme in May 1999. One of the main features of the new version was that the 3DVAR analysis would be carried out directly on the (28) vertical co-ordinate levels of the GEM forecast model, instead of on the (16) pressure levels in the current operational 3DVAR scheme. This would avoid the problem of interpolating analysis increments from pressure surfaces to the model’s vertical co-ordinate system. The spectral (T108) Helmholz stream function and velocity-potential increments would still be computed, but the unbalanced geopotential would be replaced by more appropriate baroclinic mass variables (unbalanced temperature and surface pressure). The logarithm of specific humidity would replace dew point depression as the analyzed humidity variable. Refined background-error covariances (based on a lagged average forecast method) would be used, also taking into account specific weaknesses seen in the current model in some regions of the operational domain. Balanced and unbalanced components of the analysis increments of divergence would be produced (non-divergent currently). Tangent-linear operators would be used with special treatments of data outside the vertical analysis domain. A variational quality control scheme was also being developed. The overall improved 3DVAR scheme would additionally rapidly give the opportunity for other important extensions in the data assimilation at RPN, namely replacement of SATEM by TOVS and ATOVS data, the exploitation of SSM/I estimates of precipitation rates and total precipitable water, and scatterometer observations. Work was also proceeding on 4DVAR assimilation with the tangent-linear and adjoint codes for the GEM forecast model having been prepared and related studies of GEM numerics such as the linearization of iterative processes and use of a digital filter for controlling spurious gravity-wave noise underway.

Dr. P. Houtekamer from RPN, described other work in the area of 4D data assimilation involving an ensemble Kalman filter to estimate the forecast error covariances from a (Monte-Carlo) ensemble of short-range forecasts. The approach worked well in an experiment with a low-resolution quasi-geostrophic model, a simulated observational network and model-error covariances of a known statistical form.

Dr. J. Côté presented the overall GEM model strategy and numerics. A single 28-level model is now run operationally for the short-range (up to 48 hours) (variable resolution, minimum 0.22°) and the long range (72-240 hours) (at a uniform resolution of 0.9°). This model is also used in the data assimilation cycle (see above) and the spin-up cycle for the regional model (a mesoscale version with a focussed window with resolution of 15 km). GEM employs an implicit two time-level semi-Lagrangian integration scheme on a rotated variable resolution latitude-longitude grid, with the Phillips terrain-following vertical co-ordinate (top level 10 hPa). A simple cell integrated finite element formulation is used, explicit in the horizontal (variable Arakawa C-grid) and implicit in the vertical (no staggering). The grid is varied smoothly outside the uniform 0.22° resolution window to eliminate spurious wave reflection. The overhead involved in running a global model for regional forecasting is not excessive because of the technique of increasing the resolution in a fixed-size window. The model has also been formulated in terms of hydrostatic pressure allowing non-hydrostatic terms to be switched on. Preliminary tests of the non-hydrostatic version are encouraging - at low resolution the hydrostatic forecast is essentially reproduced. Another area to which attention has been given is the development of the tangent linear and adjoint versions of GEM as required for the 4DVAR assimilation (see above). Substantial work has also been needed for the recoding of a distributed version of GEM. Other current efforts are directed towards improving various aspects of model formulation, including physics/dynamics coupling, Lagrangian Coriolis terms, and a truly hybrid vertical co-ordinate. In the near future, the time-stepping algorithm, vertical staggering and horizontal diffusion will be re-examined. It is also planned to develop a nested version of GEM and to make comparison with the variable resolution version.

Dr. A. Tremblay outlined the conception of a mixed-phase cloud scheme for use in numerical weather prediction models designed to improve the forecasts of various weather elements. The scheme was based on a single prognostic equation for total water content and included parameterization of key cloud microphysical processes. (Three-dimensional) output fields are, typically, solid particles, liquid and supercooled cloud droplets and different precipitation types. Results compare favourably with available observational data. A novel aspect is the explicit inclusion of processes involved in the formation of supercooled liquid water, enabling freezing precipitation and supercooled cloud droplets to be modelled in the absence of the classical ice melting mechanism. This has significantly increased the probability of representing freezing precipitation and improved the bias score over that achieved using the classical melting ice algorithm only.

Dr. R. Benoit summarized work being undertaken to provide real-time ultra-fine numerical predictions for the MAP Special Observing Period. The development of the Canadian non-hydrostatic mesoscale ("MC2") model optimized for massively parallel processors offers the prospect of solving very large weather forecast problems in sufficiently short time to envisage real-time daily computations over a domain covering an area such as the Alps. Such forecasts would evidently be invaluable in the MAP Special Observing Period (e.g. for planning flights of research aircraft) and will be made available to the MAP Operations Centre. A horizontal grid of 490 x 400 at 2km resolution, with 35 levels in the vertical (possibly more), is being considered. The performance of the model in reproducing such aspects as orographic condensation and breaking upper tropospheric gravity waves is being examined. Forecasters at the Swiss Meteorological Institute will also conduct a systematic evaluation of MC2 forecasts in comparison to the operational Swiss model.

In the field of seasonal prediction, Dr. G. Brunet discussed a hybrid multi-model approach. Forecasting seasonal mean conditions a few months in advance is commonly done with either relatively complex general circulation or coupled models and/or statistical techniques. The interest in the latter is motivated by the useful forecasts on monthly/seasonal scales that can be obtained from an empirical approach which may currently be competitive with or even in some cases superior to those from dynamical models. The Canadian Climate Research Network CLIVAR group has carried out a series of historical ensemble forecasts for the period 1969-1994 using, firstly, the model developed by the Canadian Centre for Climate Modelling and Analysis (centred in Victoria, BC) (primarily designed for climate simulations) and, secondly, a reduced resolution version of the RPN global spectral model. Empirical forecasts were produced for the same period with a canonical correlation analysis method and a two-step model. The geographical distribution of the skill of the models (dynamical and empirical) shows inhomogeneous intermodel differences, from which the inference may be drawn that a hybridization of the different model outputs might improve the overall skill of prediction. Hybrid forecasts for different seasons, lead times and variables are obtained by exploiting the "best linear unbiased estimator" technique, a general method for blending outputs from different models to optimise forecast skill.

Deutscher Wetterdienst

Dr. W. Wergen noted that the new fourth generation NWP-system at DWD was at an advanced stage of development. The upgraded global model (horizontal resolution 55km, 31 levels) is based on a triangular grid with physical parameterizations taken from the current limited area model and a gravity wave scheme from ECMWF. A sequential optimum interpolation data assimilation technique is used. The complementary limited area model which runs at a resolution of 7 km with 35 levels has a non-hydrostatic formulation. The physics package is similar to the global model, but a refined surface and boundary layer parameterization will be included. The initial states for the limited area model are prepared using a “continuous nudging” assimilation. Results of trials of both models (on a CRAY T3E computer) have been encouraging. Evaluation of the new system will continue in parallel with the existing operational suite until the second half of 1999.

BMRC

With the acquisition of the NEC SX4 computer, the resolution of both the global and limited area models is being increased, and physics and data assimilation/analysis components updated. The global model (GASP, T239L29) will use a three-dimensional semi-Lagrangian time integration (non-interpolating in the vertical). The Gaussian grids for the dynamics and physical process are on a linear 240x480 grid with poleward thinning, while the analysis is implemented on the non-thinned grid with increments at full resolution. The limited area prediction system (LAPS, horizontal resolution 0.375°, 29 levels) will employ a two time-level explicit scheme (although a two time-level semi-implicit/semi-Lagrangian approach is being tested in research mode). The physical parameterizations are the same in both LAPS and GASP except that the former has the ECMWF land surface, boundary layer and vertical diffusion schemes, the latter a bucket-type method. Final testing is underway before operational implementation. Analyses for both the global and limited area systems are prepared by multi-variate statistical interpolation (MVSI), this having been substantially upgraded to include high resolution structure functions, increased flexibility in dealing with different data types, and multi-tasking. For GASP, the prediction errors have been updated based on comparing observed minus first guess statistics in radiance space. Significant efforts have also been devoted to refining the 1D VAR scheme, with the new version to be implemented operationally in the near future. The MVSI code (already implemented) has been generalized, and the 1DVAR scheme is to be incorporated in this to provide a 3DVAR radiance analysis.

For seasonal prediction, BMRC has developed a coupled atmosphere-ocean model and accompanying ocean data assimilation. The atmospheric component is an R21L9 version of the BMRC atmospheric model, and the ocean model is the GFDL MOM model with a resolution of 2° longitudinally and varying from 0.5 to 5.8° latitudinally, and 25 levels in the vertical (unevenly spaced). A thermodynamic sea-ice model has also been incorporated. The whole is initialised with the BMRC optimum interpolation scheme with a ten-day ingestion window. Sixty one-year forecasts (starting from the last day of February, May, August and November from 1981-1995) have been performed, demonstrating reasonable skill for lead times out to about nine months. Operational trials should begin during 1999.

The BMRC intermediate coupled model has also been used operationally for a number of years for seasonal prediction. Confidence measures based on ensemble spread (from ensembles produced using singular vector techniques) and on the amplitude of the dominant normal mode in the initial conditions have been developed and should be put into operations in 1999. Additionally, experimental seasonal predictions are being made with the BMRC atmospheric climate model (R31L17). Six-member ensembles of 120-day integrations with persisted sea surface temperature are being prepared. The results are verified in terms of a “linear error probability space” skill score of anomalies at one, two and three month lead times. Precipitation forecasts only show limited skill mainly confined to the tropics, particularly where there are large sea surface temperature anomalies. A greater degree of skill is apparent in larger-scale fields (e.g. 200 hPa height), but this is again mainly confined to the tropics.

ECMWF

4DVAR was implemented operationally at ECMWF in November 1997, with two outer loops and linearized physics in the second loop. Since then changes in the use of satellite data and a fully coupled wave model have been introduced, a new statistical formulation of the background error constraint implemented (resulting in significant improvements in tropical analyses and forecasts, ocean wave forecasts and benefits in the extra-tropics), and the variational quality control extended to all data used in the atmospheric analysis. A simplified Kalman filter, based on the singular vectors of the linearized forecast model and on the 3DVAR Hessian, has been developed and is being evaluated for cycling the 4DVAR error statistics. Preliminary results are encouraging, but further study is needed to determine the most effective configuration for operational use. Looking to the future, 4DVAR will be enhanced with an increased inner loop resolution (T_L159 instead of T63 as currently), a time window of 12 hours (6 hours currently), a simplified Kalman filter, outer loop resolution of T_L639 (T_L319 currently), and assimilation of ATOVS data (including the ozone channel), METEOSAT water vapour radiances, and SBUV, TOMS and GOME ozone observations.

With respect to the operational model, a more accurate and stable two time-level semi-Lagrangian scheme, a T_L319 linear grid, and new orography were introduced in April 1998. As well as marked forecast benefits, the computational economies subsequently permitted extension to 50 levels in the vertical and the incorporation of an extended model stratosphere and ozone as a prognostic variable. A second-order accurate semi-Lagrangian treatment of physics has also been implemented. Extensive revisions of convection (a CAPE-type convective closure), clouds (an improved representation of cloud overlap and refined source terms for both convective and large-scale clouds), and radiation (benefitting from recent laboratory measurements) were made in December 1998. Extended comparisons of the assimilations and forecasts from T_L639, T_L319 and T213 models are being undertaken in the prospect of operational use of a $T_L639L60$ model in 1999 or 2000 (also including an improved surface analysis and physical parameterizations).

The ensemble prediction system is now run at $T_L159L31$ (with a one-hour time step and two time-level semi-Lagrangian scheme). An ensemble of 50 forecasts is prepared every night, and since March 1998, evolved singular vectors and stochastic physics forcing have been used as well as standard singular vector perturbations in trying to span a greater range of phase space with the ensembles. The stochastic physics forcing has resulted in an improvement of prediction skill for precipitation in the ensemble system. Further refinements foreseen include use of an extended Kalman filter for a T21L3 quasi-geostrophic model for simulating ensemble prediction in idealized situations, and development of singular vectors in the tropics using linear physics. A multi-model, multi-analysis system is being explored with comparisons with DWD and NCEP being undertaken. Other studies include use of a high resolution ensemble prediction system for giving warning of, for example, Alpine flood events, and severe storms such as that in October 1987. Experiments with ensembles based on initial singular vector perturbations with growth targetted on Europe have also begun.

The seasonal forecast system, now based on a T63L31 version of the ECMWF atmospheric model and HOPE ocean model, is run daily, thus allowing an ensemble to be built up. However, model systematic errors are proving to be an important problem, as the drift is comparable in magnitude to the signal (i.e. the seasonal anomaly) being forecast. The revised parameterizations of convection, radiation and clouds referred to above appear to reduce the magnitude of the drift in sea surface temperature in a six-month coupled ocean-atmosphere integration, and thus offers hope of improvement in the future.

Japan Meteorological Agency

Dr. T. Tsuyuki noted several upgrades in the operational suite at JMA since July 1997 including introduction of asymmetric typhoon bogussing in the regional analysis, revision of the bias correction system for radiosonde data, assimilation of ERS-2 scatterometer data in the global analysis and revision of the quality control system for sea-level pressure and surface pressure data. Over the next year or so, it is planned to begin assimilation of ATOVS cloud-cleared radiance data and, in March 2000, to implement a global 3DVAR assimilation scheme.

With regard to NWP operations themselves, twelve-hour forecasts have been produced twice a day since March 1998 using an experimental mesoscale model (horizontal resolution 10 km, 36 levels). Also, using the Koo-kai coupled ocean-atmosphere model, seventeen month forecasts have been prepared twice a month on an experimental basis; a significant spin-up problem is being investigated. Future plans include eight-day global ensemble forecasts (10 members using a breeding method) (beginning in 1999). A major computer upgrade is foreseen in March 2001 which will enable further significant development of the operational NWP system and routine dynamical seasonal forecasting, and, looking even further ahead, implementation of 4DVAR for mesoscale analysis in 2002.

NCEP

Among a range of continuing innovations, Dr. S. Lord drew special attention to the development of physical initialization in the NCEP global data assimilation system, which, in particular, makes use of satellite precipitation data from SSM/I and GOES instruments. From the adjoint forms of relevant model physical parameterizations, the modification of the background thermodynamic and divergence profiles needed to produce model-generated precipitation nearer to that observed is determined. Weight is given to the suppression of model precipitation when observations indicate there are no clouds. Preliminary results are very encouraging with a distinct improvement in three-day wind forecasts in the tropics and more accurate placement of precipitating systems. At present, the initialization procedure is not capable of dealing with regions where the model does not produce precipitation but observations indicate that is raining.

Météo-France

Dr. P. Bougeault described changes in the past year which included a new background cost function introduced in December 1997. This had resulted in an improved planetary boundary layer. An ISBA land surface scheme had been implemented in March 1998. The availability of a Fujitsu VPP 700 (enhancing computer capacity by a factor of five) in the second quarter of 1998 provided the opportunity for significant increases in model resolution. ARPEGE is now run in a T199L31C3.5 version with an effective resolution ranging from 14.2 km over Europe to about 175 km elsewhere. The limited area model ALADIN now has a resolution of 7.5 km and an enlarged domain. In October 1998, new error statistics were introduced in the data assimilation. In the future, it was expected that TOVS radiances would be assimilated by the end of 1998 and ERS winds in early 1999 (the latter accompanied by an increase in the vertical resolution of the planetary boundary layer in ALADIN). A 4DVAR scheme should be introduced in the ARPEGE assimilation cycle by the end of 1999.

National Meteorological Centre/Chinese State Meteorological Administration

Dr. Chen Dehui noted that the current computing facilities at the National Meteorological Centre of the Chinese State Meteorological Administration were centred round a Cray C90 and IBM SP2. These would be upgraded to produce a performance of about 30 GFlops and 100 GFlops respectively during 1999, with a further enhancement to 300 GFlops for the IBM system in 2000. There would be commensurate increases in resolution in the operational models, with the current global model going from T106L19 to T239L31 and the mesoscale limited area model from 15 km to 5-10 km in 2000. An optimum interpolation analysis is in use for both systems at present, but it is planned to move to a 3DVAR scheme in 2000. Twelve-member ensemble (lagged average) longer-range forecasts are being prepared with a T63 model. Plans call for sixty-member ensembles (based on singular vector perturbations) in 2000.

United Kingdom Meteorological Office

Dr. A. Lorenc described the significant changes in the United Kingdom Meteorological Office modelling strategy at the beginning of 1998 with the implementation of a new unified model for NWP and climate studies. Operational NWP was now based on two model versions – global with resolution of 60 km and 30 levels (i.e. a grid of 432x325x30) and mesoscale with resolution 12 km and 38 levels (grid of 146x182x38). Upgrades to the physics included a new cloud parameterization (only used in the climate version), mixed phase precipitation (in the mesoscale and climate versions, leading to improved forecasts of visibility in the mesoscale model), the Meteorological Office Surface Exchange Scheme (MOSES), a new boundary layer treatment (in the climate version and being implemented in the mesoscale model in November 1998), and the Edwards-Slingo radiation scheme (only in the climate model). Vertical transport of momentum by convection and a CAPE convective closure were implemented initially in the global NWP model but were later removed because of problems in treating a tropical cyclone. Dr. Lorenc also looked forward to the incorporation of 3DVAR assimilation in the global forecast system early in 1999 and in the mesoscale system in June 1999. A new dynamics package would be included in the climate model version in December 1998, but only in the NWP version in March 2000 (no changes are being implemented in the Meteorological Office systems in the second half of 1999 because of the potential Y2K problem).

6. OTHER WGNE ACTIVITIES AND FUTURE EVENTS

Publications

Only one publication had been produced in the “blue-cover” numerical experimentation report series since the thirteenth session of the group, namely the latest annual summary of research activities in atmospheric and oceanic modelling (N° 27). This again had been printed and distributed directly from Montréal, and the report had been available early in 1998. The next publication in the WGNE report series (N° 28) would be the new annual summary of research activities in atmospheric and oceanic modelling and would again be printed and distributed directly from Montréal, and was expected to be available in February or March 1999. WGNE expressed its appreciation to Dr. H. Ritchie for agreeing to take over the editorship of “Research Activities in Atmospheric and Ocean Modelling” in succession to Dr. A. Staniforth. This would maintain the now traditional role of RPN in undertaking this task (begun by Dr. A. Robert in 1972 on behalf of WGNE under the auspices of the Global Atmospheric Research Programme).

Next session of WGNE (and GMPP)

At the kind invitation of the Naval Research Laboratory, the next session of WGNE, the fifteenth, would be held in Monterey, CA, USA, 25-29 October 1999. Information on detailed arrangements for the session would be distributed in due time. The session would be held jointly with the (third) meeting of the GEWEX Modelling and Prediction Panel.

7. CLOSURE OF SESSION

In closing the session, the Chairman of WGNE, Dr. K. Puri expressed gratitude on behalf of all participants to Recherche en Prévision Numérique and the Atmospheric Environment Service of Canada for having hosted this session of WGNE, and the excellent support, facilities and hospitality that had been provided. The opportunity to interact with a number of leading scientists at RPN, and their contributions to the WGNE session itself, had also been particularly appreciated and valued.