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1. ANNUAL SESSION OF THE JOINT SCIENTIFIC COMMITTEE FOR THE WORLD CLIMATE RESEARCH PROGRAMME

The principal task of the annual session of the WMO/ICSU/IOC Joint Scientific Committee (JSC) for the World Climate Research Programme (WCRP) is to review the scientific progress in the programme during the preceding year. Through arrangements kindly made by Professor A. Sumi, the 2000 session of the JSC, the twenty-first, took place in the Earth Observation and Research Center of the Japanese National Space Development Agency (NASDA), Roppongi, Tokyo, Japan. The session was opened by the Chairman of the JSC, Dr. W.L. Gates, at 0900 hours on 13 March 2000. The list of participants is given in Appendix A. This report summarizes the information presented to the JSC on the progress in the WCRP during the preceding year and records the recommendations by the JSC for the further development of the programme (these recommendations are compiled for convenience in Appendix B).

Dr. Y. Takigawa, Director-General of the Japan Meteorological Agency and Permanent Representative of Japan with WMO, welcomed all participants and expressed his pleasure that this session of the JSC was being held in Japan. Dr. Takigawa referred to the increasing concern about and attention being given to the question of climate change. The WCRP was the key international scientific programme aiming to improve the understanding of the climate system needed for more confident projections of climate change. In this context, the work of the JSC was of the highest significance. Dr. Takigawa continued by summarizing the many notable contributions from Japan to WCRP, particularly to the Global Energy and Water Cycle Experiment (GEWEX), the study of Stratospheric Processes and their Role in Climate (SPARC) and the World Ocean Circulation Experiment (WOCE). He was especially pleased that the Japan Meteorological Agency was an active participant in the WCRP. Dr. Takigawa concluded by wishing all participants a pleasant and enjoyable stay in Tokyo.

The Chairman of the JSC thanked Dr. Takigawa for his welcome and expressed on behalf of all attending gratitude for the arrangements made for this session of the JSC in Tokyo, the first-class facilities provided, and the generous hospitality. He especially thanked Professor A. Sumi for all the work, time and efforts he had put into the organization of the session. The International Conference on the WCRP in Japan during the preceding week (8-10 March 2000), also arranged by Professor Sumi, had been much appreciated by all who had participated. The support to JSC members and WCRP project leaders who had attended the Conference was another very valuable contribution.

The Chairman extended his own greetings to participants in the JSC session. Among JSC members, he noted with regret that Dr. D. Cariolle, Dr. J.-F. Minster, Professor P. Schlosser, Professor V. Shannon and Dr. S. Solomon were unable to attend. In the case of Dr. Solomon, she was to receive during the week of the JSC session the US National Medal of Science, the highest scientific honour in the USA. On behalf of the JSC, the Chairman expressed the Committee's warmest congratulations for this achievement and extremely well-deserved recognition of her outstanding work and contributions to scientific research in recent years. It was gratifying that a scientist such as Dr. Solomon had also been willing to serve as a member of the JSC and contribute to the development of the WCRP.

The Chairman acknowledged with appreciation the participation of the WCRP sponsoring bodies. ICSU was represented by Dr. A. Larigauderie (ICSU Environmental Sciences Officer), IOC by Mr. A. Alexiou (IOC), and WMO by Mr. R. Newson (Acting Director of the WCRP). The Chairman also noted with pleasure the attendance of Professor B. Moore, Chair of the Scientific Committee for the International Geosphere-Biosphere Programme (IGBP). In view of the growing need for interactions between the global environmental change programmes (WCRP, IGBP and the International Human Dimensions Programme on Environmental Change, IHDP), the representation of these programmes in the sessions of the main scientific committees of the others was now essential. Dr. Whelpdale, as well as a JSC member, would speak on behalf of the WMO Commission for Atmospheric Sciences (CAS) as needed.

The Chairman voiced his gratitude for the customary participation of the chairs or representatives of WCRP steering or working groups who would brief the JSC on activities in their respective fields and advise on future actions to be taken. These included: Dr. R.G. Barry, Co-chair of the Cryosphere and Climate Task Group; Dr. L. Bengtsson, Chair of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM); Drs A. Busalacchi and J. Willebrand, Co-chairs of the CLIVAR Scientific Steering Group; Dr. H. Cattle, Chair of the ACSYS Scientific Steering Group; Dr. M.-L. Chanin and Professor M. Geller, Co-chairs of the SPARC Scientific Steering Group; Dr. P. Killworth, Co-chair of the WOCE Scientific Steering Group; Dr. K. Puri, Chair of the CAS/JSC Working Group on Numerical Experimentation (WGNE); Professor S. Sorooshian, Chair of the GEWEX Scientific Steering Group; Dr. P.K. Taylor, Co-chair of the JSC/SCOR Working Group on

Air-Sea Fluxes. Dr. M. Chahine, past Chair of the GEWEX Scientific Steering Group and Chief Scientist at the Jet Propulsion Laboratory, was participating in the capacity of invited expert/observer.

The Chairman was further pleased to note the attendance of Dr. J. Gould, Director of both the International WOCE and International CLIVAR Project Offices, and Dr. P. Try, Director of the International GEWEX Project Office. Dr. M.-L. Chanin, as well as Co-chair of the SPARC Scientific Steering Group, represented the SPARC Office.

The Chairman welcomed Professor P. Tyson, who was taking part in the session as Chair of the Scientific Steering Committee for the joint WCRP/IGBP/IHDP Global Change System for Analysis, Research and Training (START). The Chairman was particularly gratified that, at this session of the committee, Dr. K.D. Dawson, Chair of the Steering Committee for the Global Climate Observing System (GCOS) was able to be present, as well as Drs. M. Manton and N. Smith (both of the Bureau of Meteorology Research Centre, Australia) attending as, respectively, Chair of the joint WCRP/GCOS Atmospheric Observation Panel for Climate (AOPC) and Chair of the Ocean Observations Panel for Climate (jointly sponsored by the JSC and the Joint Scientific and Technical Committees for GCOS and the Global Ocean Observing System, GOOS).

The Chairman looked forward with anticipation to the scientific lectures that had been arranged and which would be given by leading Japanese scientists, namely the "Dome Fuji Project" by Professor T. Handoh, Institute for Low Temperature Science, Hokkaido University, and "Research Activities at the NASDA Earth Observation Research Center", by the Director of the NASDA Earth Observation and Research Center, Dr. T. Ogawa. Furthermore, a special presentation on the "Frontier Research System for Global Change" would be given by Professor T. Matsuno. The Chairman also observed with pleasure the participation of a number of Japanese scientists as observers (mainly active in the WCRP as members of project groups or leaders of WCRP-related activities).

Finally, the Chairman wished especially to greet Dr. D. Carson, Director-designate of the WCRP who had been able at short notice to come to the session as an observer. On behalf of the JSC, the Chairman congratulated Dr. Carson on his nomination and wished him every success when he took up his position in June.

2. REVIEW OF MAIN DEVELOPMENTS AND EVENTS SINCE THE TWENTIETH SESSION OF THE JSC

2.1 Thirteenth World Meteorological Congress

The review of the WCRP by the Thirteenth World Meteorological Congress (Geneva, May 1999) was favorable with expressions of support from many delegations. Appreciation was voiced for the organization of the Conference on the WCRP in August 1997. It was recognized that the message drafted by the Conference to the Third Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) highlighting concerns on the status of observational systems for climate purposes had directly stimulated the interest of UNFCCC in this question, providing motivation for the developments in relation to GCOS as described in section 3.4.

In specific comments on WCRP component activities, the remark was made (by the USA delegation) that “plans for various WCRP field programmes should be co-ordinated to integrate efforts to address common scientific problems”. The continuing production of the GEWEX global climatological data sets was welcomed, but Congress requested that steps should be taken to advertise these data more widely. A circular letter has subsequently been sent to the Permanent Representatives of Members of WMO, attaching the useful brochure on GEWEX data sets prepared by the International GEWEX Project Office.

Most importantly, Congress approved the continuation of the Agreement between WMO, ICSU and IOC on the conduct of the WCRP. However, in consideration of the overall WMO Programme and Budget for the period 2000-2003, the contribution approved from the WMO Regular Budget to the Joint Climate Research Fund was maintained at only zero nominal growth (in common with most WMO programmes). The net effect is that the sum available for WCRP activities for the period 2000-2003 is about CHF 1,430,000 per annum (compared to about CHF 1,500,000 for the period 1996-1999) (see also section 11.4).

2.2 ICSU/UNESCO World Conference on Science

ICSU and UNESCO jointly hosted a World Conference on Science, 26 June-2 July 1999, in Budapest, Hungary. The objective was to offer a major interdisciplinary forum for scientists, political decision-makers and representatives of society at large to come together to discuss the service that science needs to provide in the years and decades to come, and to establish what efforts were required for science to advance in response to the expectations and the challenges posed by human and societal development at the start of the twenty-first century. The output from the Conference was embodied in a "Declaration on Science and the Use of Scientific Knowledge" that underlined the importance of commitment to scientific endeavour and to the solution of problems at the interface between science and society, and a "Science Agenda-Framework for Action" that set down ideas for fostering partnerships in science and the use of science for development and the environment. These landmark documents were addressed to all partners and stakeholders in science, including the research community, government bodies, intergovernmental and non-governmental organizations, and the industrial sector.

As a specific item, the Conference reviewed "Science: Achievements, Shortcomings and Challenges" including a session on the "Scientific Approach to Complex Systems". This was designed to show how, with theoretical approaches and computational tools, progress was being made in understanding complex systems, and what were the current limitations and future prospects. The example of research on the climate system and climate change, involving interactive processes between atmosphere, oceans, land-surface, cryosphere and the biosphere was chosen, and WCRP organized, jointly with IGBP, an appropriate programme consisting of three presentations (climate variability predictions, Earth system models, and the disturbed carbon cycle) followed by a round-table discussion.

2.3 Intergovernmental Panel on Climate Change (IPCC)

Professor Y. Ding, in his capacity as co-chair of IPCC WG1, reported that the IPCC was now in the most intensive phase of its activities in the preparation of the Third Assessment Report. The timetable that had been set down for the preparation of the report was being observed and the report should be completed on schedule early in 2001. Very many in the WCRP research community (including several participants in the JSC session itself) had been involved as lead or contributing authors for various sections of the report, and have attended one or more of the series of drafting or lead author meetings.

The JSC reiterated its concern at the major demands placed on the available time of scientists by IPCC Assessments, in particular noting the comments of the Working Group on Coupled Modelling (WGCM) that the effort that can be given to the fundamental work needed in so many areas of climate research, including the development of climate models themselves, was being significantly diminished (see section 4.2.10). The JSC was also aware of the reservations expressed by WGCM on the approach to specifying emission scenarios. Nevertheless, the JSC appreciated the excellent work being carried out under the auspices of the IPCC and recognized that the assessment reports were landmarks in the overall progress of climate research. The JSC stressed the need for appropriate liaison and interaction with IPCC Working Group 1 in particular and asked Professor Ding to continue to undertake this role.

2.4 Highlights of activities in the WCRP

Detailed accounts of activities in the WCRP over the past year and the issues to be faced are included in the subsequent sections of this report, particularly those dealing with the component projects of WCRP. Specific highlights noted during the initial review of the main developments since the twentieth session of JSC were the steps towards the implementation of the GEWEX Co-ordinated Enhanced Observing Period (CEOP) and the involvement of other WCRP projects/activities (see section 5.2). Another important evolving aspect was the relationship between GEWEX and the wider hydrological community, especially in view of the considerable range of other initiatives being organized in this area and the numerous bodies involved. Whilst it was encouraging to see interest from many directions, care was required to avoid confusion among too many programmes whose separate purposes were not always clear to those outside the field (see further discussion in section 5.2).

The JSC was pleased to hear of progress in long-standing topics which had been discussed repeatedly at the JSC over recent years. A comprehensive science and implementation plan for the proposed new WCRP Climate and Cryosphere (CLIC) project had now been produced (see section 10.3.1). On this basis, it was hoped that the JSC could now move formally to confirm the establishment of CLIC and that steps towards concrete implementation could begin. The question of interface/interactions with other WCRP projects (e.g. with CLIVAR in respect to deep water formation in the Greenland/Iceland/Norwegian seas, and with GEWEX in cold-region hydrological studies) and the arrangements for the transition from ACSYS to CLIC also needed to be considered.

Understanding the role of cloud feedback in climate sensitivity is another issue which has often been raised (having been particularly highlighted by the Working Group on Coupled Modelling as one of the principal uncertainties in the projections of climate change). The GEWEX Radiation Panel is now undertaking a renewed consideration of this problem intended to lead to far more in-depth study of cloud and its dependence on the general circulation and temperature, and generally a more sophisticated approach looking at the feedback issue using the type of techniques available for analyzing highly non-linear complex systems. Aspects such as the precipitation efficiency of clouds and overlap assumptions in estimating total cloud cover will also be explored. The GEWEX Radiation Panel, together with the Working Group on Coupled Modelling, will arrange a workshop on the whole range of issues involved including analysis methods (see further discussion in section 5.3).

An advanced draft of the report of the JSC/SCOR Working Group on Air-Sea Fluxes assessing the present state of the art in regard to air-sea fluxes was also now available. The full report was a substantial document of more than 300 pages and was a comprehensive and authoritative account covering in depth the overall requirements for surface flux data of various scientific groups, the space-time variability of fluxes, data sources for fluxes and related variables, direct flux observation, parameterization of turbulent and radiative fluxes, random and sampling errors in flux fields, methods of evaluating fluxes and the flux-related products, and evaluation of fluxes. On this basis of the report, the JSC should consider how to proceed in the organization of future activities and studies in the area of air-sea fluxes (see section 7). The co-operation with SCOR in this work has clearly been very successful and beneficial, and continued joint sponsorship of activities certainly seems very desirable.

3. OVERALL WCRP ISSUES AND CO-ORDINATION AND INTERACTIONS WITH RELATED PROGRAMMES

3.1 Scientific direction of the WCRP, challenges and opportunities

The JSC reiterated what it saw as the basic task of WCRP. It was certainly not to manage and organize all climate science. The unique and primary role was the international co-ordination of those research-related activities and organization of projects that need and/or benefit from global scale or multi-national involvement/support. The basic ideas for such activities or projects (be they field experiments, planning of specific observing systems, model intercomparison studies) should stem from the scientific community. WCRP (or rather its scientific working groups) then had the responsibility of developing the basic scientific planning and implementation strategy. The projects and activities where WCRP has been most successful were where the particular community involved (and members of the WCRP project groups) had worked together in support of a specific activity (often where there was a clearly defined objective, or paradigm or hypothesis to be tested and which was usually limited in scope and time). The JSC noted that, with the increasing number of environmentally-related programmes of various types being proposed, there was increasing competition for limited resources and for the attention of policy makers. It was thus all the more important that WCRP projects be as specific, feasible, and distinctive as possible, with clear, tangible objectives that were convincing and could be easily "sold". As one step in this direction, the JSC suggested that timetables for WCRP projects/activities including implementation milestones should be established, periodic reviews taking stock of achievements prepared, and "sunset dates" (if applicable) set. The JSC requested that reports from all projects with this information be presented at the next session of the Committee.

As customary, a key task of the JSC was to recommend and agree on the further development of the WCRP and its component activities. The course to be taken had to be seen against the background that, as signals of climate change emerged more strongly, the issue of climate change would remain a major concern and a significant focus of public and political attention. There were likely to be increasing arguments regarding the application of the UNFCCC (Kyoto) Protocol and the requirements for (developed) industrialized nations to reduce emissions of greenhouse gases. This would place intensified pressure on WCRP (in co-operation with the IGBP) to understand more fully the carbon cycle and to quantify more exactly carbon sources and sinks (see section 3.2). There would, of course, be increasing demands for confident and quantitatively accurate projections of climate change, including possible modifications of the hydrological cycle and the impact on water resources, as well as growing requirements for predictions of climate variations on seasonal to interannual timescales for application in both water resource management and agriculture. Climate products would need to be tailored for regional use (in both developed and developing countries) and for climate impact assessment studies. The prediction of “ocean climate” (e.g. for fishery activities) would become increasingly important. Probabilistic statements (based on ensemble techniques) of, for example, extreme seasons or increased likelihood of storminess or hurricanes, would be required for industry, agriculture, water resources and insurance/reinsurance purposes. Above all, much more co-operation would be essential between the ever-growing array of environmental programmes/studies/activities to provide **solutions** (i.e., involving "end-to-end" projects) rather than just a piece of good new science.

There were also new opportunities, for example, that computing power and resources (through the further development of massively parallel-processing systems) would continue to grow rapidly, permitting much higher resolution models for climate simulations. Global coupled ocean/atmosphere climate models would be refined and become more sophisticated, including chemistry and biospheric processes, drawing on advances in individual discipline-oriented WCRP and IGBP activities for the realistic parameterization of essential processes in climate. As well as very high resolution simulations of climate, ensemble approaches would be increasingly developed (e.g., the "Earth Simulator" project in Japan in prospect for 2002 would enable a 100-member ensemble of 100-year integrations with a 60 km resolution global model to be prepared in 8 days). In the field of observations, the new satellite sensors, including advanced atmospheric sounders and active microwave instruments (scatterometers, radars, lidars) being launched by NASA, ESA and NASDA would provide the opportunity for an extensive range of improved global climate and environmental measurements (this era had already begun with TRMM and the successful launch of "TERRA" in December 1999, and "AQUA" later in 2000). The rapidly developing techniques in data assimilation/analysis (4DVAR, Kalman filtering) would lead to improved exploitation of conventional and novel remotely-sensed data. This, together with the technique of "targetted observations", were likely to modify the concept of the basic meteorological observing systems that were needed for numerical weather forecasting and hence that available for climate purposes. The continuing rapid advances in information technology would no doubt also have a major impact in many ways, in particular in facilitating access to data and products (assuming that the principle of free data exchange and access could be maintained). Possibilities included an alternative internet-based data system for the World Weather Watch, and distributed data serving systems providing seamless access to a range of observational and model data. The WCRP must clearly give this issue a high level of priority within its projects.

3.2 Co-operation and interactions between the Global Environmental Change Programmes

The Earth system science concept

Professor B. Moore presented the vision that had emerged at the recent meeting of the IGBP Scientific Committee (Mexico, February 2000). It had been recognized that the challenges of global environmental change required a treatment of the full Earth system and that scientific understanding of the Earth system was vital in helping human societies develop in ways that sustained global life support systems. The two critical messages that were becoming ever clearer were, firstly, that the Earth functioned as a system with properties and behaviour that were characteristic of the system as a whole. These properties included critical thresholds, "switch" or "control" points, strong nonlinearities, teleconnections, and unresolvable uncertainties. Understanding components of the Earth System was critically important but insufficient by itself to grasp the functioning of the system as a whole. Secondly, humankind was now a significant force in the Earth System, altering the rates of key processes and absorbing the impacts of global environmental changes. The environmental significance of human activities was now so profound that the term "Anthropocene" had been coined to describe the current era.

The scientific study of the whole Earth system now needed, taking into account its full functional and geographical complexity over time, was well beyond the scope of individual countries and regions and would depend on unprecedented international collaboration. Professor Moore believed that the three global environmental change programmes (IGBP, IHDP, WCRP) had built a solid base of sub-Earth system understanding and have developed and implemented effective and efficient strategies for studying global environmental change at the international level. The new challenge was to build, on the existing foundation, an international programme of Earth system science driven by a common mission and common questions, employing visionary and creative scientific approaches, involving ever closer collaboration across disciplines, research themes, programmes and nations. The ultimate goals of such an international effort in Earth system science would include: providing answers to fundamental questions such as how stable is the coupled Earth system in the face of major perturbations; the development of innovative and integrative simulation tools of varying complexity that can be used to tackle systematic questions; harmonization of social and biophysical information and data where appropriate; communicating vigorously the work on Earth system science to the broader scientific community, policy-makers, resource/environment managers and the public; and actively contributing to the development of sustainable management of the global environment. Professor Moore urged that IGBP, IHDP and WCRP work together towards a new era of Earth system science, the production of a joint paper on Earth system science, the preparation of a blueprint for the necessary collaborative international research, and a joint declaration to be made at the planned Global Change Open Science Conference in Amsterdam, July 2001.

As to IGBP itself, the study of global biogeochemical cycles would remain at the core of the programme, but there would be evolution to a more systematic structure in the domains of the atmosphere, oceans and land and in the interfaces between these. This approach was already becoming apparent in the IGBP with, for example, the Land-Ocean Interactions in the Coastal Zone (LOICZ) core project and the emerging Surface Ocean Lower Atmosphere Study (SOLAS). Thought was being given to how to integrate the science appropriately between other IGBP core projects. Likewise, a stronger bridge between the scientific agendas of various IGBP and WCRP core projects (e.g. the Biospheric Aspects of the Hydrological Cycle, BAHC, and GEWEX; the International Global Atmospheric Chemistry, IGAC, Project and SPARC) was needed. The Global Analysis, Interpretation and Modelling (GAIM) activity was being re-oriented to integrate across the whole structure. The Past Global Changes core project would provide the essential longer time context for the dynamics of the Earth System.

Professor Moore also referred to the establishment of three possible new IGBP/IHDP/WCRP joint projects on cross-cutting issues of major societal relevance - the global carbon cycle, water resources, and an initiative on global change and food and fibre. These projects would depend critically on research in the various IGBP, IHDP, and WCRP core projects already being undertaken or planned. However, considerable co-ordination would be needed to bring the elements into a more integrated framework, with new work to be initiated where gaps were identified. Strategic partnerships would be developed with other research institutions outside the three programmes and with policy and management bodies to ensure that the overall effort is designed and implemented in ways to facilitate the application of results. The global carbon cycle project was the most advanced with a series of activities planned during 2000, leading to the definition of a common international framework to help guide research at national, regional an global scales. For the food and fibre project, a scoping meeting with IGBP, IHDP and WCRP representatives had been held in early March 2000 which laid out an overall structure for activities (see below), with further planning meetings being proposed during 2000 and early 2001 to draw up a scientific and implementation strategy. An initial co-ordination meeting for the water resources project was expected later in 2000 or the first part of 2001.

Review of existing co-operation and linkages between WCRP and the other global environmental change programmes and their development

The JSC was impressed by the vision offered by IGBP and the developing opportunities to work together in global change research (or Earth system science), the possibilities of establishing new IGBP/IHDP/WCRP joint projects and building a stronger bridge between the scientific agendas of various IGBP and WCRP core projects. However, in this overall context, the JSC recalled that, at its twentieth session, there had been considerable discussion of several areas where interactions between WCRP and the other global environmental change programmes (especially IGBP) would be valuable. A joint WCRP/IGBP approach to the carbon cycle was thought to be of high priority and suggestions had been made how co-ordination in this area could be reinforced, in particular in the organization of joint WCRP/IGBP activities on the representation of the carbon cycle in climate models (through WGCM and GAIM). As noted above, IGBP had been pushing ahead strongly in the planning of a global carbon cycle project, but the hoped-for collaboration between WCRP and IGBP had not developed (see below for further discussion of this topic as one of the new IGBP/IHDP/WCRP joint projects). Also at the twentieth session of the JSC, a detailed joint assessment of tropospheric chemistry in relation to climate change had been proposed and ideas put forward regarding the WCRP involvement in and contribution to the Global Change Open Science Conference in Amsterdam in 2001 (in which IGBP was taking the lead planning role). Neither had there been much progress or action in these areas at the time of the twenty-first session of the JSC.

On the other hand, the JSC was pleased that formal and informal links and joint activities had continued to grow between individual WCRP and IGBP projects. In particular the co-operation between SPARC and IGAC in studying upper tropospheric/lower stratospheric chemistry processes and the penetration of UV radiation into the stratosphere and upper troposphere (see section 6.3.3), as well as that between CLIVAR and the Past Global Changes (PAGES) project in refining and extending the past climate record, were notable. WCRP should also certainly contribute to the planned IGBP Surface Ocean-Lower Atmosphere Study (SOLAS) (see detailed discussion of this aspect in section 7.2). More generally, there had been several ad hoc meetings (or meetings of opportunity) between the directors or representatives of WCRP, IGBP and IHDP, as well as the Director of START. At these meetings, a range of issues, including increasing co-operation, the crosscutting initiatives, and a common approach to funding issues (see below) had been discussed.

In order to ensure the appropriate co-operation, the JSC firstly proposed that the Chairman of the Committee and the Director of the WCRP consider how, in conjunction with their IGBP counterparts, expanded levels of collaboration could be brought about, possibly including the organization of joint projects and/or bringing together more closely existing separate WCRP and IGBP core projects that had a close relation, as well as developing new areas of collaboration (e.g. joint WGCM/GAIM model intercomparisons). The JSC also suggested the establishment of a joint WCRP/IGBP "co-ordination committee" (that could comprise the Director of the WCRP, the Executive Director of IGBP, two other representatives each of WCRP and IGBP) to examine an overall strategy for closer linkages between WCRP and IGBP. This idea could be further explored at the meeting of the chairs and directors of the global environmental change programmes (planned to be held in Geneva, August 2000). Additionally, the JSC reiterated its call for a detailed joint assessment of the tropospheric chemistry and climate issue, centred round the organization of one or two workshops over the next two years. The invitation to Dr. Solomon to lead this activity on behalf of WCRP, in conjunction with IGBP, particularly IGAC, would be reconfirmed.

In a slightly different area, the JSC also recognized the importance of closer ties between WCRP and IGBP in many aspects of ocean-related activities. It was noted that IGBP, together with the Scientific Committee on Oceanic Research, SCOR, were planning a workshop in September 2000 on "Future Directions in Ocean Biogeochemistry". This would particularly review the results of the IGBP/SCOR Joint Global Ocean Flux Study (JGOFS) (now running down) in conjunction with the results of WOCE and other related IGBP programmes. The JSC urged that WCRP be involved in this workshop.

IGBP/IHDP/WCRP crosscutting initiatives

The JSC took up further the proposed crosscutting initiatives between IGBP, IHDP and WCRP. The JSC fully endorsed the basic approach that an overall study of Earth system science was needed jointly by the three programmes rather than individual disciplinary activities and taking into account that humankind was also an interactive part of the overall system. Such efforts could obviously additionally be seen as a contribution to sustainability (see below).

In respect to the carbon cycle, IGBP had taken the lead, but the JSC saw that the WCRP had a fundamental contribution to make to work in this area, particularly in following up the possibilities of inferring atmospheric CO_2 concentrations from remotely-sensed (MSU and AIRS) data in the future. This opened up the prospect of operational assimilation and analyses at the main NWP centres that would give a far more comprehensive and dynamic view of changes in regional and global atmospheric CO_2 concentrations on all timescales (and hence the magnitudes of regional sources and sinks), and thus be a potentially powerful tool for verifying post-Kyoto CO_2 emissions. The JSC nominated a small ad hoc group to outline the WCRP contribution to carbon-cycle studies (in particular in preparation for the IGBP-organized international workshop on the Framework for Carbon Cycle Research being held in October 2000). Dr. M. Chahine (Chief Scientist, Jet Propulsion Laboratory) agreed to serve as the convener of the group. The other members proposed were Dr. A. Hollingsworth (bringing the variational data assimilation expertise) and Dr. H. Le Treut (bringing the all important coupled modelling perspective). Moreover, an oceanographer to advise on what insights WCRP could provide regarding quantitative observations of marine fluxes of carbon dioxide should be included (ensuring liaison as necessary with the WCRP/GCOS/GOOS Ocean Observations Panel for Climate, see also section 3.4).

Concerning a crosscutting "food and fibre" initiative, the JSC was informed that an initial scoping meeting had taken place in Paris at the beginning of March 2000 at which WCRP, IGBP, IHDP and ICSU had all been represented. The proposal was made to develop the "Global Environmental Change and Food Systems" initiative under the sponsorship of the three global environmental change programmes. The overall theme would be the impact of global change (environmental and socio-economic) on food production, supply and accessibility, and feedback to the Earth system. Three main foci would be encompassed:

- global change impacts on food systems, including climate variability (embracing CLIMAG-type studies, see section 3.3), change in atmospheric inputs and pollution, changes in regional production patterns resulting from non-agricultural land uses, changes in regional production resulting from changing management;
- environmental and socio-economic consequences of increasing food production, including climate forcing, impacts of freshwater quality and quantity and wetlands, carbon sequestration in productive soils and biomass, impacts of changed genetic variability and emerging biotechnologies;
- consequences of changing environmental and socio-economic conditions on accessibility to food and fibre, including differential and changing vulnerability of humankind and institutions, structural changes (including urbanization) and food security, impacts of global change on carrying capacity.

It was planned to establish from the outset strategic partnerships with such bodies or groups as FAO, WMO, and the Consultative Group on International Agricultural Research (CGIAR). A series of meetings or workshops would be set up during 2000 and 2001.

The JSC welcomed this initiative, and endorsed WCRP's involvement in and contribution to the activity. Dr. D. Whelpdale agreed to represent the WCRP in the (six-person) group that was being set up to guide the planning phase during 2000/2001, and would participate in the initial international planning workshop that was being arranged to take place in Reading, UK, 20-21 July 2000. Further representatives from GEWEX and CLIVAR would be nominated as the overall scope of the project was elaborated.

The definition of a "crosscutting" water resources activity had not yet been considered in depth. The JSC saw that the WCRP had a major responsibility in this area, but substantial contributions would be made by IGBP in terms of water quality and biogeochemical aspects and by IHDP in the effects on and interactions with human activities. It was proposed that WCRP should take the lead in organizing an overall scoping/planning meeting (with GEWEX to be very much at the centre of the effort).

The JSC noted that the "land surface" may be another specific area where crosscutting efforts would be valuable in exploring the evolving vegetative and hydrological nature of the land surface and modification of land use as an essential component of global change (perhaps as part of the "water" initiative). The new Global Land-surface Atmosphere System Study (GLASS) now being undertaken in GEWEX (and which would also serve as a tool for the International Satellite Land-Surface Climatology Project and the IGBP/BAHC (see section 5.4.2) would be a key contribution to such an effort.

Joint funding initiative

Another issue being jointly considered by WCRP, IGBP and IHDP was ensuring sufficient stable core financial resources to enable the successful development of the programmes. A common strategy for fund raising was being considered, including attempting to identify new opportunities and approaches to obtain resources. Ideas in this respect had been included in a document prepared by the directors of the international global environmental change programmes submitted to the ICSU Executive Board session in Cairo (September 1999). The ICSU Board had supported the approach outlined and passed a resolution giving ICSU the mandate to support the ideas within the International Group of Funding Agencies (IGFA). Subsequently, the question of new funding mechanisms for global science had been discussed with IGFA. Attention is now being given to considering the ways that the required core funding might be obtained from the public (IGFA) and private sectors and how to proceed in practice. A joint "Resource Development Committee" was being set up. The JSC agreed that the Director of the World Climate Research Programme and Dr. J. Gould (Director of the International CLIVAR Project Office) should serve as WCRP representatives on this committee (see also discussion in section 11.4 on WCRP resources).

"Sustainability Science"

The increasing interest of ICSU in and emphasis given to "Sustainability Science", and the steps needed in pursuing a science agenda for sustainability were reported to the JSC. ICSU programmes and scientific committees had, over the years, contributed significantly to sustainable development, but the scientific community was now being asked to intensify, refocus and co-ordinate efforts across programmes to respond to the urgent need for more knowledge for a transition to sustainability. The JSC saw that the international global environmental change programmes together had an important role here and should jointly consider with ICSU how they could assist. It was clear that this would require and depend on joint or crosscutting initiatives in areas such as water, and global environmental change and food systems referred to above. The jointly-sponsored WCRP/IGPB/IHDP START initiative (see section 3.3) would also have a key role.

WCRP contribution to Global Change Open Science Conference, Amsterdam, July 2001

IGBP had taken the initiative in proposing and leading the organization of the Global Change Open Science Conference to be held in Amsterdam in July 2001. At the Conference, the intention is to present the latest scientific understanding of global environmental change at three levels: firstly, an integrated view of IGBP; secondly, crosscutting research involving IGBP, IHDP, WCRP, as well as regional scientific studies co-ordinated by START and other groups; and, thirdly, review of the status of individual IGBP, IHDP and WCRP projects which provide the scientific base on which the overall integrated approach to global environmental change envisaged would be built. The Conference would also look forward to the new insights for studying the critical thresholds, nonlinearities and teleconnections of the highly complex Earth system in which human activities are intimately interwoven with natural processes. The final objective would be to set a research programme for the current era of increasing human domination of many global-scale processes. The Conference is aimed towards the global change science community, leaders of government and industry and interested citizens. Many aspects would be relevant to policy and resource managers, as well as to segments of the private sector which are becoming increasingly interested in global environmental change.

The JSC agreed that WCRP participation in the Conference was essential. Suggestions of topics where WCRP would be a lead contributor were, for example, in climate prediction and variability, the land surface and the climate system, and studies of palaeo-climate (jointly with PAGES). The JSC requested the Chairman urgently to take steps to ensure that WCRP had an appropriate and visible role in the Conference, that WCRP be represented on the Conference Organizing Committee, and duly take part in a critical Conference planning meeting taking place in the Netherlands in mid-May.

3.3 Development of regional contributions to global change research programmes

Global Change System for Analysis, Research and Training (START)

Professor P. Tyson briefed the JSC on the continuing implementation of and plans for the WCRP/IGBP/IHDP Global Change System for Analysis, Research and Training (START). He recalled that the basic remit of START was the establishment of regional research networks of collaborating institutions to undertake studies of regional aspects of global change, assess regional impacts and to provide regionally important information to policy makers and governments. These activities underpinned the enhancement of scientific capacity in developing countries by strengthening and connecting existing institutions and by training scientists. Substantial efforts were also made in mobilizing the resources necessary to augment scientific capabilities and infrastructure in developing countries. The "end products" of START are intended to be: increased understanding of global change issues at a regional level; increases in regional research initiatives and publications; increase in the number of scientists trained in global change research; improved regional infrastructure for global change research; development of regional data bases and improved access to data; and enhanced regional co-operation in global change research and training. Regional networks providing frameworks for these activities have been initiated so far in Northern Africa, Southern, Central and Eastern Africa, the Mediterranean, Southeast Asia, Southern Asia, and temperate East Asia. A parallel intergovernmental effort in the Americas, the Inter-American Institute for Global Change Research (IAI), is a close partner of START and there has been collaboration in a number of projects. Two other intergovernmental bodies involved in global change science are the Asia-Pacific Network for Global Change Research (APN) and the European Network for Research in Global Change (ENRICH), and START also works closely with these.

Professor Tyson noted that the global change research activities conducted under the auspices of START fell into four major categories:

- land use change and the impacts on terrestrial ecosystems
- regional climate variability and change
- changes in atmospheric composition and its impacts
- global change and coastal zone, land-ocean interactions and international water.

Professor Tyson highlighted areas in which enhanced WCRP-START collaboration would be important, namely regional climate variability and change, regional analyses of climate data, identification of indices for climate change detection, and monitoring trends in climate extremes. The JSC encouraged the Director of the WCRP and WCRP project groups to make efforts to establish contact with START regional committees and to develop co-operation in these areas. An excellent example of the type of activity of value were the APN Asia-Pacific Workshops on Indicators and Indices for Monitoring Trends in Climate Extremes, organized under the leadership of Dr. M. Manton at the Australian Bureau of Meteorology Research Centre in December 1998 and December 1999. The workshops brought together scientists from fourteen countries in the South East Asia-Western Pacific region. During the second workshop, participants carried out a practical analysis of rainfall and temperature data from stations in their home countries, producing trends in indicators such as the frequency of daily rainfall exceeding the mean 99^{th} percentile, frequency of days with maximum/minimum temperatures above/below the mean $99^{th}/1^{st}$ percentile. The results of the analysis have been submitted for publication in an international journal and have been taken into account in the IPCC Third Assessment Report. Overall, this was a unique exercise with a group of countries in a geographical region joining together to analyse climate data in a homogeneous manner, thereby providing a consistent picture of trends in climate in the South East Asia-West Pacific region, as well as establishing a network of scientists with a mutual interest in the analysis of climate data. This stimulating approach to regional capacity building is now also being followed by other groups, in particular the Working Group on Climate Change Detection (jointly sponsored by CLIVAR and the WMO Commission for Climatology).

Climate Prediction and Agriculture (CLIMAG)

Professor Tyson also outlined the further steps in the implementation of CLIMAG, which had originally stemmed from a proposal made by the JSC in 1996 for an initiative to foster the use of climate variability predictions for agriculture. START was leading the development of this capacity building project (now jointly sponsored by START/WCRP/IGBP/IHDP). Specific efforts were being aimed at enhancing the interfaces between meteorological, agricultural and social sciences communities, developing the capability in tropical regions for the integrated use of climate and agricultural modelling in order to improve techniques for forecasting yields, and to assess the type of climate prediction information needed by regional and national decision-makers and the means by which such information can be used. This requires insights into the socio-economic feasibility of the project, the technical possibilities and relevant climate processes. A series of planning workshops had been held, the most recent of which was the International CLIMAG Workshop in Geneva, September 1999, where experts in meteorology, agronomy and social sciences reviewed the overall state of the science, and identified the further steps to be taken for the implementation of a regional demonstration project. A CLIMAG Steering Group (chaired by Professor H. Grassl) has now also been established to co-ordinate the planning and implementation of regional demonstration and pilot projects, to identify the strategic research challenges posed by CLIMAG, and to ensure that these were taken up by WCRP, IGBP and IHDP. Additionally the Steering Group had the task of fostering partnerships between the stakeholder communities and resource agencies.

The JSC welcomed the establishment of the CLIMAG Steering Group and emphasized especially the need for CLIMAG to promote the end-to-end projects that highlighted the value of climate predictions to making decisions relevant to crop production at the farm level. The JSC saw that CLIMAG could thereby offer a significant opportunity of showing that the strategic research carried out by global environmental change programmes was directly applicable to practical questions. The JSC noted that CLIMAG would be a fundamental element in the global environmental change and food systems initiative now also being developed (see section 3.2).

3.4 Climate monitoring and co-operation/liaison with global climate observing initiatives

Global Climate Observing System (GCOS)

Dr. K. Dawson, Chair of the GCOS Steering Committee, presented a report on GCOS, focussing particularly on the interactions with the United Nations Framework Convention on Climate Change (UNFCCC), and its Subsidiary Body for Scientific and Technical Advice (SBSTA). Following the statement drafted by the Conference on the WCRP in August 1997 to the Third Conference of the Parties (COP-3) of UNFCCC (Kyoto, Japan, December 1997) highlighting the concerns on the status of observational systems for climate research, a resolution on the "Development of Observational Networks of the Climate System" had been unanimously adopted. In response, the GCOS Secretariat prepared for COP-4 (Buenos Aires, Argentina, November 1998) a “Report on the Adequacy of Global Observing Systems” (which included input from the JSC and various WCRP project groups). The report concluded that, while many of the observational requirements were known and documented, and several observing components were in place, substantial augmentations and enhancements were needed to meet fully climate purposes. It was emphasized that what was urgently required was a commitment by nations to provide a global coverage of the key climate variables, to halt and reverse the degradation of existing observing systems, and to exchange information more effectively. COP-4 consequently adopted a decision on Research and Systematic Observation (Decision 14/CP.4) urging Parties to: undertake programmes of systematic observations; to exchange data freely; to support relevant capacity building; and to build up actively national meteorological, atmospheric and oceanographic observing systems. Parties were requested to submit information on national plans and programmes related to their participation in global observing systems for climate. The COP-4 decision also invited the agencies participating in the “Climate Agenda”, through the GCOS Secretariat, to “initiate an intergovernmental process for addressing the priorities for action to improve global climate observing systems for climate ....”.

Following this, GCOS undertook the preparation of guidelines for reporting on national plans and programmes. As a follow-up to its Decision 14/CP.4 and taking into account the material provided by GCOS, COP-5 took two further decisions:

- Decision 4/CP.5: adopted revised guidelines for the preparation of national communications related to research and systematic observation as developed by GCOS and requested (Annex I) Parties to provide a detailed report on their activities in relation to systematic observation in accordance with these guidelines (in conjunction with their third national communications) by 30 November 2001.

- Decision 5/CP.5: urged Parties to address deficiencies in climate observing networks and invited them, in consultation with GCOS, to bring forward specific proposals for that purpose, and to identify the capacity-building needs and funding required in developing countries to enable them to collect, exchange and utilize data on a continuing basis in pursuance of the Convention. Further, GCOS was invited, in consultation with relevant regional and international bodies, including the Global Environmental Facility, to organize regional workshops on this issue, and to continue to assist and facilitate the establishment of an appropriate intergovernmental process to identify priorities for action to improve global observing systems for climate and options for their financial support.

The question of establishing an "appropriate intergovernmental process" for GCOS was of particular interest to the JSC, and it had been observed at the twentieth session of the JSC (March 1999) that some involvement by WCRP in such a process was important in underlining research requirements for climate data and to provide scientific support for global climate monitoring. Such a mechanism could also offer a means of wider presentation of WCRP results and discussion of needs with relevant government agencies. However, in a recent development, Canada hosted an informal meeting devoted to considering an intergovernmental mechanism or process for GCOS (Toronto, February 2000). Unfortunately, there had been no opportunity to present directly to this meeting the interface between GCOS planning and the needs of the climate research community. However, several participants at the Toronto meeting were certainly aware of the complementary roles of the WCRP and GCOS, and pointed out the importance of developing co-operation between the two programmes. In the event, the Toronto meeting had considered that there were already in existence a number of intergovernmental mechanisms that could be engaged in the implementation of GCOS, and that relevant constituent or other bodies of the sponsoring agencies could be utilized in building up the links with, and the involvement of, governments in all aspects of GCOS. The interactions with UNFCCC and SBSTA in ensuring systematic observations of climate were encouraged. Advice had also been offered that a number of "operational" and/or senior governmental representatives should be added to the GCOS Steering Committee. The need for the further refinement of the implementation strategy for GCOS was stressed in order to demonstrate clearly how GCOS was responding to the policy requirements of UNFCCC, and the needs of climate research and of predictions, climate impact assessments etc. The costs and benefits of maintaining and enhancing observing systems should be analyzed. The urgent need of the GCOS Secretariat for additional resources was recognized.

Possible follow-up actions were now being considered, including commitment and resource mobilization, building up a sense of ownership by national governments especially by making full use of reporting through UNFCCC, addressing known deficiencies with regionally focussed action plans, pursuing joint activities with WCRP and IGBP, and continuing active liaison with user groups. In particular, it was planned to organize a series of regional workshops to identify the capacity-building needs of developing countries (in response to Decision 5/CP.5 of the UNFCCC). Analyses of deficiencies in existing systems based on available data by expert panels would also be organized. The comments of the Toronto meeting on how an intergovernmental process could be engaged would be reported to UNFCCC/SBSTA.

The JSC hoped that the efforts spent by GCOS in developing the dialogue with UNFCCC and the other steps being taken would bear fruit in providing extra resources needed for a genuine and effective global climate observing system. The JSC agreed that the WCRP should continue to co-operate and interact as appropriate with GCOS and support the GCOS implementation strategy in view of the complementarity and interdependence of the two programmes and to ensure that full account was taken in GCOS of the priorities and requirements of climate research.

WCRP/GCOS Atmospheric Observation Panel for Climate (AOPC)

Dr. M. Manton, Chair of AOPC, reported how the work of the panel was developing. Particular attention was being given to building up an effective GCOS Surface Network (GSN) and GCOS Upper Air Network (GUAN). Operational monitoring of GSN performance was now being undertaken by Deutscher Wetterdienst and JMA, and of GUAN by the United Kingdom Meteorological Office, the US National Climatic Data Centre, and ECMWF. Discrepancies in station dictionaries and between GSN and Regional Basic Synoptic Network Stations, and incorrect formats (in about 40% of messages) were being found. GSN CLIMAT reports were being received from about 60% of stations, and CLIMAT TEMP (GUAN) reports from about 75%. It was apparent that much remained to be done to ensure the quality and consistency of these data, and direct project support for GSN and GUAN was a priority. The JSC urged that GCOS reports to UNFCCC highlight the support necessary for global baseline observations such as GSN and GUAN, and that this point should be brought out forcefully at the planned GCOS regional workshops. The JSC also noted, that while AOPC was making progress in establishing global baseline networks for in situ measurements, it was important to obtain appropriate complementary observations from satellites. The JSC encouraged the

AOPC to work with relevant groups and agencies to secure these observations. The JSC additionally encouraged the efforts taken to collect historical and meta data from GSN stations.

AOPC had also established, with the Ocean Observations Panel for Climate (see below), a joint task group to examine and evaluate differences between various sea surface temperature and sea-ice analyses, to identify sources of discrepancies, and to recommend steps to be taken to ensure quality and consistency of the analyses. Eleven sea surface temperature products were being studied at NCAR where difference fields were being computed. The JSC emphasized the need to include additionally a comprehensive assessment of the sea-ice analyses. Among other ocean issues being considered by AOPC was the data coverage provided by drifters, in particular measurements of sea-level pressure. The JSC concurred fully with AOPC that maintaining sea-level pressure sensors on (sea surface temperature) drifting buoys was of the utmost importance especially for climate analysis and monitoring. It was noted that the WGNE Surface Flux Analysis (SURFA) project (see section 4.1.5) in which full global fields of surface fluxes over land and oceans inferred from operational NWP products are being intercompared and evaluated (including validation against surface reference sites) was also of considerable interest to AOPC.

Finally, Dr. M. Manton, as illustration of the difficulties to be faced in climate monitoring, recalled the recent review produced by the USA National Research Council of the National Academy of Science, "Reconciling Observations of Global Temperature Change". The differences between surface and Microwave Sounding Unit (MSU) measurements had been analysed, but had not been fully explained (although the disparity in no way invalidated the conclusion that surface temperature has been rising). The JSC observed that this work brought to the forefront issues of the quality of remotely-sensed and in situ data, and underscored the need for AOPC to ensure that appropriate international mechanisms were put in place for processing and analysis of satellite data for climate purposes.

WCRP/GCOS/GOOS Ocean Observations Panel for Climate (OOPC)

Dr. N. Smith, Chair of OOPC, noted that one of the most important events for OOPC in recent months was the major international Conference on the Ocean Observing System for Climate, held at St. Raphael, France, 18-22 October 1999. The Conference was successful and opened the door to a new era in oceanography with the prospect of global, integrated and sustained ocean observations. A multi-purpose system was envisaged increasing efficiency and offering a broader investment base, and in which research and operations would work together. A schedule of action and priorities had been set out. Moreover, the mechanisms to move forward now seemed to be in place with the creation of the Joint (WMO/IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM), the establishment of the forum "Partnership for Observations of the Global Oceans" (POGO) which should provide the means for ocean institutions to work together more closely in the future, the activities of the Integrated Global Observing Strategy (IGOS) Partners in fostering remotely-sensed observations of the ocean, and the initiation of several related projects such as the Global Ocean Data Assimilation Experiment (GODAE) and the assembly of surface reference data sets in conjunction with the work of WGNE on surface flux analysis (see section 4.1.5).

With respect to GODAE, Dr. Smith reported that a strategic plan had been distributed and potential national contributions were being consolidated. The components required for implementation from point of measurement through to the final assimilation and delivery of products to user communities were being assessed, including measurement networks (in situ and remote), telecommunications and data assembly networks, assimilation centres, application groups or service providers etc. The mechanisms to be put in place (prototype systems, pilot projects, directed tasks) were being identified. The main phases of GODAE now foreseen (following concept elaboration 1998-1999) were: development/pre-operational phase, 2000-2002; operational phase, 2003-2005; post-operational consolidation phase, 2006-2007. A key element of GODAE was the "ARGO" proposal, the deployment of a global array of profiling floats. ARGO would complement and greatly enhance the global ocean and climate observing system. An implementation plan had been prepared and political issues were being addressed. Significant commitments had been indicated and it appeared realistic to expect around 400-600 deployments annually from 2001 onwards. (At the planned nominal resolution of 250-300 km, a total of approximately 3000 floats is required for global coverage). The overall distribution that would be achieved was still an open issue, with the Southern Ocean possibly an area of concern.

Another essential component of GODAE was the development of high resolution sea surface temperature products. These would be of broad application and were intended to serve purposes ranging from climate to NWP, as well as GODAE itself. High resolution (~10 km), at least daily, fields were planned with account being taken of the diurnal cycle if possible, using as input data the "raw" sea surface temperature radiances from different satellites, other remotely-sensed measurements, analysed sea surface temperatures from satellite and in situ observations. Allowance would be made for the different characteristics of the various measurements (i.e. whether skin, bulk or "thin"). A data team was also being established and a centralized data server would be set up. Resources were being sought to populate the data server, set up a data archive, define the required data pathways, co-ordinate the various data-specific servers (e.g. for satellite products), and to develop products and derived fields for GODAE. Yet another important issue was that of ocean modelling and data assimilation and a working group was being constituted on this topic.

Finally, Dr. Smith referred to the opportunity and potential offered by information technology (as noted in section 3.1). However, leadership and appropriate co-ordinated research and development either for application in oceanography or a more general multi-purpose approach serving climate research as a whole (e.g. a "climate information technology and management" project) were needed.

In reviewing Dr. Smith's report, the JSC was particularly pleased at the success of the Conference on the Ocean Observing System for Climate and the encouraging future for global, integrated and sustained ocean observations that now seemed feasible. In the area of ocean data assimilation, the JSC recognized that GODAE had an important role in providing leadership and focus. With respect to the potential of information technology, the JSC considered that this represented a challenge to be taken up by the WCRP as a whole.

In considering this last item, the JSC saw as an important first step that information and available expertise in data management activities should be freely exchanged across the whole WCRP. Data assembly/management activities in the various WCRP component projects had so far been conducted more or less independently. The JSC encouraged increased interaction and liaison between project offices in this area, and suggested that a meeting of leaders of data management activities should be arranged. Representatives of GCOS (AOPC and OOPC) should also be invited to participate in order particularly to ensure that research and operational data activities were conducted and brought together as far as possible, or were carried out in a complementary manner.

3.5 Relationship between WCRP and the space agencies

With the continuing development of the WCRP, there were, of course, growing data requirements, especially for remotely-sensed data. It was essential to discuss these requirements at the earliest possible stage with space and/or satellite-observing agencies, in view of the lead-time in planning missions and the intense competition among different scientific disciplines to attract the attention of the space agencies. Hitherto, the relationship between WCRP and the space agencies has been mainly through GEWEX (the major space agencies involved in Earth observation participate regularly in the annual sessions of the GEWEX Scientific Steering Group). The SPARC Scientific Steering Group (which has very contrasting data needs) has also built up a direct and effective relationship with the space agencies. However, the JSC considered that a more co-ordinated approach at the level of the WCRP itself may now be necessary, with regular contacts (visits, correspondence) to review WCRP needs, the prospects for new missions, and how WCRP can influence these.

Another serious related issue was that of ensuring the continuity of the time series of climate parameters inferred from remotely-sensed data. With several new research satellites and data streams coming on line in the next few years, this question was becoming more and more pressing. These research systems will continue to be the mainstay of climate observations and monitoring (at least in the WCRP) for the foreseeable future. It was essential to ensure systematic overlap of new types of observations and validation of systems to enable the possibility of genuine climate monitoring. This in turn required real resources and efforts to be devoted to careful processing and systematic and comparative analysis of the data streams from old and new satellites. However, funding and resources for this type of work appeared to be very scarce and limited. The JSC agreed that it was important to draw the attention of the Committee on Earth Observing Satellites (CEOS) and perhaps also the Integrated Global Observing Strategy (IGOS) Partnership to these questions. In this context, it was suggested that CEOS should be formally invited to participate in the next session of the JSC.

4. CLIMATE MODELLING

Climate modelling activities in the WCRP are organized round two main working groups: the joint CAS/JSC Working Group on Numerical Experimentation (WGNE) concerned with the refinement of the atmospheric component of climate models and the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) overseeing the development of fully coupled atmosphere/ocean/land/cryosphere models to study climate variations on time-scales from several years to a century and to provide confident projections of climate change resulting from natural and anthropogenic causes. The Chairman of WGNE, Dr. K. Puri, described the main activities related to atmospheric modelling being undertaken by or under the auspices of his group (section 4.1), and Professor L. Bengtsson, Chairman of WGCM, the status of WGCM projects (section 4.2). Furthermore, responding to the request from the JSC at its twentieth session, WGNE and WGCM had jointly reviewed a number of issues related to regional climate modelling (section 4.3).

4.1 Atmospheric modelling activities in support of the WCRP

4.1.1 Organization of WGNE work

In view of their respective roles at the core of climate modelling in the WCRP, there is evidently a requirement for close co-ordination between WGNE and WGCM and, to this end, the Chairman of WGNE participated in the session of WGCM held in Hamburg, Germany, in September 1999. WGNE also works in close conjunction with the Global Energy and Water Cycle Experiment (GEWEX) in the development of atmospheric model parameterizations and studies of land surface processes. In this respect, WGNE sessions are held jointly with the “GEWEX Modelling and Prediction Panel” (GMPP). Likewise, WGNE co-operates with the SPARC “GRIPS” project (focussed on the intercomparison of model stratospheric simulations) in the effort to refine the stratospheric component of atmospheric models (see section 6.1.1).

WGNE additionally has an important role in support of the WMO Commission for Atmospheric Sciences (CAS), in reviewing the development of atmospheric models for use in weather prediction on all timescales. The close relationship between WGNE and operational (NWP) centres by virtue of the CAS connection underpins many aspects of WGNE work and provides a strong impetus for the refinement of the atmospheric component of climate models. WGNE sessions duly include reviews of progress at operational centres in topics such as data assimilation, numerics, physical parameterizations, ensemble prediction and, more recently, seasonal prediction, and the verification of precipitation forecasts. WGNE also follows progress in various relevant national initiatives such as Frontier Research System for Global Change in Japan.

The following paragraphs review the main activities of WGNE in support of WCRP objectives, including particularly several items of interest and recommendations arising at the fifteenth session of the group kindly hosted by the Naval Research Laboratory, Monterey, CA, USA, in October 1999.

4.1.2 WGNE model intercomparison activities

Atmospheric Model Intercomparison Project

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

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

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

"Transpose" AMIP

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

Snow Models Intercomparison Project (SNOWMIP)

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

Comparison of deterministic predictions of stratospheric activity

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

Many models appear to have a common problem in that they show too rapid a movement and distortion in the shape of the polar vortex. It remains to be seen if this is linked to a problem in the initial analysis. Results do not appear to show much sensitivity to the location of the uppermost level. A more detailed study of the predictions (including quantitative diagnosis of rms errors/biases etc.) is being undertaken. However, some of the results are now relatively old and, in view of the increasing interest in the performance of models in the stratosphere, consideration is being given to defining an updated project. (This work of WGNE is complemented by the SPARC "GRIPS" activity, see section 6.1.1).

Review of model systematic errors

As apparent from several WGNE studies (e.g. AMIP-I and -II, model stratospheric simulations), model systematic errors continue to be prevalent and affect several features of models' representations. WGNE organized a workshop on systematic errors in 1988 and, although there has, of course, been substantial progress since that time, similar errors, especially in longer-term or seasonal forecasts that are now being increasingly widely prepared, are seen in several models. In seasonal forecasts, the signal is usually no larger than the systematic error, and excessive zonality is also seen frequently. WGNE therefore considered it timely to organize a new workshop to form an updated view of the status with regard to systematic errors and to consider future directions. Such issues as mean errors and their evolution in atmospheric models, sensitivity to physical parameterizations or model resolution, and differences between different models (drawing particularly on AMIP-II results) will be addressed. Diagnosis of such aspects as budget residuals, analysis increments, adjoint sensitivity will be welcome. As well as ensemble and time-mean errors, systematic shortcomings in computing atmospheric variability will be reviewed. Attention will also be given to new means of presenting errors and to alternative approaches that may provide further insights into the nature of systematic errors (many of which have persisted despite major model developments in recent years). The workshop would be held in October 2000 in Melbourne, Australia.

4.1.3 Dynamical cores in atmospheric general circulation models

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

Aqua-planet experiments as an AGCM test-bed

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

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

4.1.4 Atmospheric model parameterizations

The refinement of atmospheric model parameterizations is the basic objective of the GEWEX modelling and prediction thrust with which WGNE works in close association. The discussion of the GEWEX modelling and prediction thrust at the joint meeting of WGNE and GMPP, encompassing the GEWEX Cloud System Study (GCSS), the issue of cloud/radiation parameterizations, and studies of land surface processes and soil moisture is described in detail in section 5.4. It is particularly noted that the concept of a new framework for the advancement of land surface parameterizations, and the incorporation of more complex second generation parameterization schemes into general circulation models was adopted at the joint WGNE/GMPP session in October 1999 (the "Global Land-Atmosphere System Study", GLASS).

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

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

The joint JSC/SCOR Working Group on Air-Sea Fluxes, with its responsibility for an overall appraisal of the strengths and weaknesses of surface-flux data sets from different sources (see section 7.1), 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 (see section 3.4) has underlined the requirement for high quality surface flux products that would have to be provided from routine operational analyses to meet its objective of implementing the ocean observing systems and assembling the data sets required for climate studies. The Global Ocean Data Assimilation Experiment (GODAE), aiming to provide a practical demonstration of real-time global ocean data assimilation as a basis for complete synoptic descriptions of the ocean circulation at high temporal and spatial resolution, also has requirements for high quality global real-time products such as sea surface temperature (high resolution, multi-platform based), surface radiative fluxes and surface wind stress.

WGNE is duly planning an updated evaluation and intercomparison of surface flux products from NWP centres. The "WGNE Surface Flux Analysis" (SURFA) project will involve assembling at PCMDI full global fields of surface fluxes which will allow study at the same time of model-derived air-sea and land-surface fluxes (the latter are of growing interest in view of the proposed establishment of the Global Land-surface Atmosphere System Study). A spectrum of observational products ranging from high quality direct measurements (e.g., from the surface reference sites established as part of GODAE) to large-scale estimates would be used in validating the NWP surface flux products. These activities would allow the feasibility and utility of putting in place a (long-term) routine system for monitoring the evolution of the surface fluxes from operational analyses to be assessed. Initially, it is anticipated that surface flux and related fields will be collected at six-hourly intervals, but it would be essential that PCMDI data standard/formats be strictly followed. A variety of diagnostic tools are available at PCMDI that will be useful in evaluating the collected data, and results of analyses will be fed back routinely to the contributing operational centres. Documentation of the models and assimilation systems would also be built up. Formal contact was being established with operational centres willing to participate.

Strong interest was expressed in SURFA by the JSC, particularly by the representatives of the oceanographic community.

4.1.6 Modelling large-scale atmospheric transport

A series of workshops to assess the ability of atmospheric models to simulate the global distribution of inert or chemically interacting matter has been organized under WGNE auspices. The most recent workshop in this series (the fourth), arranged jointly by WGNE and the IGAC Global Integration and Modelling (GIM) activity in 1998 was focussed on comparing model simulations of distributions of atmospheric aerosols (sulphates, soil, dust, soot etc.) and associated precursors with observations and on understanding the role of different processes (boundary-layer mixing, vertical convection, chemical/physical transformation, precipitation scavenging) in determining this distribution (as reported at the twentieth session of the JSC). The full report of this workshop was expected to be published in the CAS/JSC WGNE "blue-cover" report series during 2000.

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

4.1.7 Reanalyses

The Second International WCRP Conference on Reanalyses was held at Wokefield Park, near Reading, Berkshire, UK, 23-27 August 1999. The Conference reviewed the status of reanalysis projects, the quality and characteristics of the reanalyses, and their use in a range of studies. The practical organization of and arrangements for the Conference were undertaken by ECMWF, whose support in this respect was gratefully acknowledged by the JSC.

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

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

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

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

New reanalyses were now being planned and would form the basis for updated studies. These included:

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

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

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

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

The full proceedings of the Reanalysis Conference have been published as WCRP-109 (WMO/TD-No. 985).

4.1.8 Status of data assimilation/analysis systems

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

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

4.1.9 Other activities

WGNE conducts a number of other activities or projects, which, although primarily related to weather prediction research, certainly have interest for the WCRP. These include an intercomparison of typhoon track forecasts, and verification and comparison of precipitation forecasts. Both these studies have reached an advanced stage and the results are being written up for publication. These topics are of considerable relevance in the context of the growing attention to the frequency and impact of severe weather events in the NWP community and from the climate perspective. WGNE collaboration with the CAS World Weather Research Programme (WWRP) is also starting to develop. WWRP is targetted on improving predictions of "high impact" weather events, to exploit progress in scientific understanding in relevant national and international programmes (including WCRP activities, in particular GEWEX), and to advance the knowledge of atmospheric processes of importance to weather forecasting through the organization of focussed projects. In this last respect, efforts were being made to energise resource commitments for research initiatives such as the Mesoscale Alpine Programme (MAP) and the Fronts and Atlantic Storm Track Experiment (FASTEX). WGNE is co-operating with WWRP in setting up an International Science Working Group to define a programme of research and forecast demonstration projects that could be taken up in a continuation of FASTEX-type research.

WGNE also reviews at its annual sessions the increasing use of ensemble prediction techniques at operational centres, and the growing application in seasonal forecasting and climate prediction - and this would now become a separate item on the WGNE agenda.

4.2 Progress in coupled modelling

4.2.1 Overall scope of work of WGCM

WGCM endeavours to maintain a broad overview of modelling activities in the WCRP in its basic task of building up climate models. In particular, there were many fundamental modelling issues where close interaction with WGNE (concerned with the development of atmospheric circulation models for use in climate studies and weather prediction on all timescales) was necessary. These included questions related to basic numerical methods (e.g., application of semi-Lagrangian techniques or linear grids which offer major advances in the speed of the integration) as well as parameterization of various physical processes. Noting the advances in numerical methods (which allow higher resolutions to be used without prohibitive increases in computing requirements), the JSC encouraged WGCM to examine exploitation of these new techniques in climate modelling.

In other areas of WCRP modelling, the results of the Sea-Ice Model Intercomparison Project conducted by the ACSYS Numerical Experimentation Group (see section 10.1.7), namely that a two-level dynamic/thermodynamic model with a viscous plastic sea-ice rheology was judged to give the best results at present and to be adequate and appropriate for climate models, were of particular interest to WGCM. The availability of this new generation of ice models that could be incorporated into global climate models was an important step forward and WGCM has strongly encouraged modelling groups to review their existing treatments of sea ice with a view to making use of a more advanced representation of the type recommended by ACSYS-NEG. In respect to the work on model simulations of the stratosphere undertaken in SPARC-GRIPS (see section 6.1.1), WGCM recognized that progress in the questions being addressed was important in refining projections of climate change. In particular, a full representation of the stratosphere was needed in climate models in order to be able to simulate realistically chemistry-climate coupling and solar forcing. WGCM has duly stressed that all climate models need to incorporate an adequately resolved stratosphere.

WGCM has continued to be very conscious of the large uncertainties in the representation in models of the climate feedback associated with clouds and water vapour. An appropriate dialogue was now being established with the GEWEX Radiation Panel on this subject (see also section 5.3).

The following paragraphs summarize the specific activities being undertaken by WGCM itself, including the main items of interest and recommendations from the most recent session of the group, kindly hosted by the Max Planck Institute for Meteorology, in Hamburg, Germany, in September 1999. A good introduction to the work of the group at this session had been provided by the Fourth International Conference on Modelling Global Climate Change and Variability that had been organized by the Max Planck for Meteorology in Hamburg the preceding week. The Conference had included focussed sessions on the development and validation of comprehensive climate models, modelling seasonal to interannual variability, modelling decadal to centennial climate variability, and the prediction and detection of anthropogenic climate change.

4.2.2 Coupled Model Intercomparison Project (CMIP)

CMIP is one of the most important and long-standing initiatives of WGCM, having been started in 1995. It comprises two components: CMIP1 to collect and document features of global coupled model simulations of present-day climate (control runs); CMIP2, to document features of climate sensitivity experiments with CO_2 increasing at 1% per year. CMIP1 and CMIP2 data bases have been established at PCMDI.

Data from the control runs of global coupled models (CMIP1) have been collected from twenty modelling groups in eight countries (representing virtually every group in the world with a functioning coupled model), and from transient climate integrations from sixteen groups (all that are expected). The model documentation for CMIP1 was now fairly complete (and accessible via the web) and CMIP2 model documentation was in progress. PCMDI was also compiling an atlas of CMIP results including overview figures and various statistical summaries, mean maps of basic parameters (surface pressure, surface air temperature and precipitation for December, January, February and June, July, August), time series of global mean surface air temperature, power spectra of the time series of surface air temperature, measures of interannual variability, and specific summaries of ENSO, the North Atlantic Oscillation and monsoons. Using the PCMDI data bases, ten CMIP1 and eleven CMIP2 diagnostic subprojects were currently in progress on a wide range of subjects:

CMIP1: analysis of variance in CMIP coupled models; North Atlantic Oscillation variability; documentation of interannual variability and coupled processes; simulation of the cryosphere; potential predictability at long timescales; autocorrelation of hemispheric control-run temperature data; East Asian climate; southern mid-to-high latitude variability; coupled model variance; effect of flux adjustments and interannual and decadal variability.

CMIP2: East Asian climate change; signal detection; dynamic response of the ocean to global warming; climate change in northern Europe; energetics of coupled models and role of oceanic heat transport; correlation between oceanic structure, ocean circulation and heat transport; biospheric carbon cycle response to global warming; effect of climate sensitivity; ocean thermal expansion and heat uptake in climate change experiments; vertical structure of warming in CO_2 climate change experiments; analysis of climate variability and change using simple global indices.

In addition, a pilot project to study the Madden-Julian Oscillation in coupled models, requiring collection of additional data from CMIP participants, has been proposed. The modelling community has not so far responded to the request for additional specific data subsets, presumably since extracting data on ad hoc basis is very labour-intensive.

More information on CMIP is available at **http://www-pcmdi.llnl.gov/cmip/**. A paper describing the status of CMIP at the time of a workshop on CMIP in Melbourne, Australia, in October 1998 (the main results from which were reported at the twentieth session of the JSC in March 1999) has been published in the Bulletin of the American Meteorological Society, and various other CMIP-related publications are appearing in the refereed literature.

WGCM has given careful thought to how CMIP should now be developed. Firstly, it was agreed that the existing data base should be maintained and should respond as required to specific requests for data (e.g., from IPCC). It was also agreed that consideration should be given to extending the range of data collected in CMIP1 and CMIP2 so that additional processes, as simulated in coupled models, especially such aspects as feedback mechanisms and ocean mixing could be investigated in more detail. The CMIP Panel would poll the scientific community and diagnostic sub-project leaders to assess the additional fields that would be most useful. PCMDI would be ready and able to help in this regard, and software already written for AMIP would greatly reduce the effort needed to accept, undertake quality control of, and archive data. (Alternatively, groups could make fields available on a local device.)

WGCM has additionally proposed that the initiation of a third phase of CMIP (CMIP3) should be explored. This would focus specifically on twentieth and twenty-first century coupled model simulations, but the exact approach to be followed is complicated by the numerous scenarios employed and lack of agreement on forcing data sets. The activity would be linked to that of IPCC Data Distribution Centres which were also archiving data from these runs. The CMIP Panel would examine the questions involved, including the possibility of agreeing on a single forcing data set, the collection of just a single (100-year) integration from each modelling group; the range of variables to be provided and data set formats. A further issue arising in terms of technical logistics was whether a distributed archival structure may now be appropriate. In this, each modelling group would make available locally the required data fields that could then be accessed (electronically) by those interested in comparative analyses (rather than each group compiling the requested data which are then transmitted to and archived at PCMDI). Nevertheless, PCMDI would still have a key role to act as clearing house, a data referral centre, and to hold subsets of data from groups not willing or able to offer direct access.

4.2.3 Idealized sensitivity experiments

Intercomparison of results from equilibrium doubled CO_2 experiment (in which the atmosphere is coupled to a simplified slab ocean, thus not involving the complexity of the ocean response) have revealed interesting differences in the inferred cloud feedbacks. This feedback and that linked to upper tropospheric water vapour remain among the largest uncertainties in climate sensitivity. The Cess et al. studies a few years ago have hitherto been the only such intercomparison of a single component of model climate sensitivity, but even in this work, there was no detailed investigation of the sensitivity of, for example, cloud feedbacks to specific model parameterizations. There was now increasing evidence to suggest that the strength of the response of a climate model to radiative forcing (controlled by feedbacks) was much more sensitive to parameterizations employed than to the ability of the model to simulate the current climate. Also, the artificial nature of the Cess et al. experiments made it difficult to relate the global feedback coefficient found to the general climate change problem. Feedback parameters have been computed by individual groups, but the lack of uniformity in experimental conditions and widely differing methodologies prevented any clear overall view of the current status of cloud and water feedback. It was therefore considered important to undertake a systematic intercomparison of these feedbacks in models, including the link between feedback and the ability of a model to simulate the seasonal cycle.

The approach that would now be followed was an extension of the perturbation techniques of Cess and was designed to throw light on the sensitivity of cloud feedback to the parameterization of cloud optical properties. Interested modelling groups would be invited to perform ten-year integrations using AMIP sea-surface temperature and sea-ice distribution with an atmospheric concentration of 345 ppmv CO_2 as a "control", and the sea surface temperature and sea-ice distribution from a doubled CO_2 (690 ppmv) simulation (probably as provided by the Hadley Centre) in which the cloud optical properties would be the "best estimate" of each group. A further pair of experiments should then be carried out with a perturbation in the water-ice transition (via a change in a key internal parameter or combination of parameters). The minimum set of data fields required would be monthly means of: all components of the top-of-the-atmosphere radiation budget (cloudy and clear); all components of surface energy and surface radiation budgets (cloudy and clear); 2m air temperature, precipitation and three-dimensional distributions of clouds, temperature, humidity, cloud-liquid water and cloud-ice. (Ideally the full set of AMIP-I upper-air low frequency (monthly mean) standard model output would be useful.) The ten annual means of cloud forcing for the doubled CO_2 simulation, separated into long- and short-wave components (both global means and zonal averages) would then be computed, and analyzed and compared. It would be hoped in some areas to decompose the top-of-the-atmosphere flux in order to explore cloud feedback in more detail and to investigate upper and lower tropospheric water vapour feedback. This type of work would also certainly simplify some of the effort needed in IPCC assessments. A few outstanding questions remained to be resolved. Firstly, unlike the original Cess et al. experiments, the surface albedo feedback would not be suppressed in the intercomparison now being proposed. However, independent studies have suggested that albedo feedback is of considerably less importance than that due to cloud and water vapour and can be more readily diagnosed. Secondly, the sea surface temperature and sea-ice data to be used in the control and doubled CO_2 simulations needed to be more carefully evaluated, e.g., the aspect of significant reduction in sea ice, adjusting the land/sea mask to different grids. It might be appropriate to use instead a +2K perturbation of the AMIP sea-surface temperature. A small pilot experiment (involving at least two different models) would be initiated to check whether these questions were important. It was also noted that the amount of computation involved was far more than for the original Cess et al. work, but it was certainly not out of proportion to the large increase in availability of computer resources since that time. It was also considered that use of a single column model for this study would not be adequate since it is important to evaluate the geographical distribution of feedback. The same type of experimental technique could be extended to study other key issues such as the parameterization of convection and even the effect of vertical resolution.

It was is planned to present the results from a pilot study at the European Geophysical Annual Assembly in Nice, 25-29 April 2000 (a symposium on "feedbacks" was planned as part of this event) and then to establish firm experimental plans.

4.2.4 Standardized forcing scenarios

An IPCC Report on Emission Scenarios (SRES) has proposed four new "marker scenarios" based on different demographic and technological developments. A particular feature of these scenarios was that the rise in sulphur dioxide emissions was cut dramatically by 2030 and fell below 1990 levels by 2070. These scenarios, each of which assumed distinctly different changes in levels of population, economic growth, etc., were currently under government and expert review and would be considered by the IPCC Plenary in 2000. In the meantime, some centres were already performing experiments with these scenarios. IPCC has indicated that the older emissions scenario (IS92a) would be maintained in parallel with the SRES scenarios to provide continuity.

The question of stabilization scenarios was also being actively considered (by IPCC Working Group III), initially for CO_2 only. Account was being taken of the probable change in gross domestic product, but not population.

The JSC noted the concern expressed by WGCM at the approach to considering emission scenarios in IPCC, and the lack of consultation with the modelling community. In order to be able to compare results from different and/or new versions of models, it was important to maintain some sort of continuity in the emission and concentration scenarios employed. (Model radiation codes ultimately use concentrations so standardized values for these would be of benefit in comparative modelling studies.) Moreover, the estimation of emission scenarios cut across all the IPCC Working Groups and co-ordination, and consistent methods and assumptions, between the three groups were essential. Also, if new scenarios were to be produced as part of the IPCC effort, the timing should be such that new climate model simulations and analyses can be prepared for the IPCC report.

In the context of forcing scenarios, the work of SPARC to identify the current best estimates of relevant parameters that determine recent time-varying climate forcing in the stratosphere was also important (see section 6.1.3).

4.2.5 Initialization of coupled models

Although there has been no organized work by WGCM on the initialization of coupled models, it is a topic that has been kept under close review. An appropriate initialization was essential for a realistic control integration, and for subsequently being able to assess the signal versus noise in transient climate change experiments. The satisfactory initialization of the ocean component was the key and was a particular scientific challenge as well as being potentially demanding in terms of computer resources because of the long timescales involved. There was, of course, a close relationship between initialization and flux adjustment (if this were used). One approach to ocean initialization now being increasingly attempted was to use the observed (three-dimensional) state (such as that compiled by Levitus). This had the advantage of being straightforward and requiring little computer time (and thus facilitating tests of revised models). Moreover, the initial coupled model state was near to that observed. On the other hand, the ocean initial state might not strictly be in balance (perhaps because of deficiencies in data and their analysis and/or since the present climate was changing). Also, ocean models did not correctly simulate the state of the ocean and thus drifted away from even perfect initial conditions. The situation might additionally be complicated since, when the initial conditions for the atmosphere and ocean were not obtained in a coupled mode (i.e., by a sufficiently long coupled integration), there was potential for shock when the individual components were brought together. This was associated with imbalances in surface fluxes which could take on values greatly different from those in the separate atmosphere or ocean runs, and leading to unphysically large variability.

Nevertheless, several modelling groups have recently carried out integrations from atmosphere and ocean observed initial states (and not employing flux adjustment). A particular example was the latest version of the Hadley Centre coupled model (HadCM3). In an AMIP integration (i.e., with present-day sea surface temperature and sea-ice distributions and present-day radiative forcing), the atmospheric component had a global radiative imbalance of 2 Wm^{-2} (implying a 1-2 K drift annually in global mean surface air temperature when coupled). However, when pre-industrial greenhouse gas concentrations and aerosol loadings were used in the atmospheric component, coupled with a Levitus ocean state (i.e., new present-day sea-surface temperature and ice distributions and **pre-industrial** radiative forcing), the radiative balance was close to zero and there would be little drift in the global mean surface air temperature.

Generally, there were still problems in initializing coupled model integrations with observed data sets, although the results achieved with HadCM3 and other groups were encouraging. However, more work was needed before the initialization of coupled models was fully understood.

4.2.6 Ocean modelling

Working Group on Ocean Model Development

A joint WGCM/WOCE Working Group on Ocean Model Development (WGOMD) has now been formally established to give specific attention to a number of questions on the performance of ocean models and to the refinement of the ocean component of coupled models. The group met for the first time in early March 2000, and particularly recognized a need for documenting the status of and progress in ocean modelling for climate studies. Collection of information from major climate modelling centres, ocean modelling development groups and the sea-ice community (through ACSYS) has begun, with a special interest in such aspects as significant advances in ocean model physics and numerics.

In discussing specific activities to be undertaken, WGOMD took particularly into account the further development of ocean modelling needed to meet the objectives of WOCE and various issues of concern raised by the ocean modelling community in this respect (see section 8.1). WGOMD agreed that co-ordinated programmes of experimentation with basin- to global-scale ocean models were indispensable to examine the effects of numerical schemes and physical parameterizations. However, regarding a possible ocean model intercomparison project, WGOMD considered that such an exercise would only be meaningful if conducted as a component of studies of the representation of critical processes, with models run in strictly defined configurations. There were, nevertheless, a growing number of intercomparisons, typically initiated between a few groups and models, although these sometimes established a baseline for assessments of other models or parameterizations. Ongoing work of this type included a comparison of four global ocean models using as identical a forcing as possible, studies of different models and their sensitivity to resolution and various parameterizations for the North Atlantic, the treatment of dynamics of eddies and mean flows in the Southern Ocean by various models, and an international effort (DOME) involving groups from about ten institutions to assess the performance of ocean models and parameterizations schemes in representing the intense mixing and bottom boundary layer processes in overflow regimes such as the Denmark Strait or the Straits of Gibraltar. WGOMD recommended that attention should be specifically focussed on model behaviour in the Southern Ocean and the treatment of the North Atlantic thermohaline circulation because of the potentially critical role of the dynamics of these oceans in perturbations of the coupled system. Systematic investigations of the representation of the formation of subtropical and intermediate waters in ocean models and the dependency on resolution and parameterizations were also considered important because of the impact on the uptake and sequestration of anthropogenic trace gases. WGOMD had finally proposed that, in order to enhance the interaction between the climate and ocean modelling communities, and to further collaborate in assessing the performance of ocean models against observations and the further requirements fur such observations, a workshop should be held in 2001 on the theme of effects of ocean model resolution on climate studies. (This would be about three years after the workshop in Boulder, CO, USA in 1998, which had reviewed ocean modelling for climate studies and whose results were reported at the twentieth session of the JSC).

The JSC welcomed the initial ideas put forward by WGOMD, in particular the need to address the realistic representation of ocean physics critical for modelling the response of the coupled climate system. The JSC also agreed that investigations of model simulations of the Southern Ocean and North Atlantic thermohaline circulation and of the formation of subtropical mode and water formation were important. However, the JSC emphasized that the strategy for the development of ocean models should not be confined to an ocean-only context, but that appropriately designed experiments with fully coupled models to test the impact and relevance to the representation of the overall climate system were needed. For example, the apparent sensitivity of the meridional heat flux in ocean-only model simulations to the horizonzal resolution implied a marked change in the surface heat flux, which would clearly affect the simulation of the fully coupled system. As noted below, tests with coupled models up to at least eddy-permitting resolution were now being undertaken. The JSC pointed to the need for strong collaboration between WGCM and WGOMD in this regard, and co-operation with centres running high resolution coupled models. A more structured approach to coupled model experimentation than had so far been possible in CMIP was also required, and this should be considered jointly by WGCM and WGOMD. The proposed workshop in 2001 appeared to offer an opportunity for mapping the way forward.

High resolution coupled ocean/atmosphere integrations

In view of the concerns that the relatively coarse resolution ocean models used for climate research have shortcomings that may result in systematic errors in ocean simulations, principal coupled modelling groups have been encouraged (by WGCM) to carry out a reasonably long integration with a high resolution coupled ocean/atmosphere model as a means of identifying such errors and assessing their significance. Although substantial computer resources were needed to perform this experimentation, the rapid advances in computer power in recent years (particularly parallel processing capability) meant that this was no longer as serious an obstacle as it once was. The Hadley Centre has duly commenced an integration with a 1º atmospheric and 1/3º resolution ocean model. NCAR was planning an integration with a T85 atmosphere and 1/3º resolution global ocean model. A high resolution experiment was also being considered by the Southampton Oceanography Centre (with a high resolution ocean model coupled to the CSIRO atmospheric model). However, only relatively few such runs would be possible in the next few years, and WGCM had an important role in encouraging collaboration between groups who undertook such runs, and in fostering co-operation between groups in drawing lessons from the results.

4.2.7 Detection and attribution of climate change

In recent years, the focus has shifted from detection methods, which assessed the pattern similarity between observed and model simulated “fingerprints”, to optimal detection techniques, which estimated the amplitude of model-simulated climate change signals in observations. This technique showed whether significant anthropogenic and naturally forced signals were apparent, whether a simulation was consistent with observations and indicated a scaling factor by which the model simulation may be scaled for the best fit with observations. For the most reliable results, fingerprints for all relevant natural and anthropogenic climate change signals should be used (this approach was basically a multi-regression technique applying a best fit linear unbiased estimator). However, amplitude estimates resulting from optimal fingerprint techniques reflected similarity of the largest spatial scales rather than small-scale pattern information, and care needed to be taken to make sure only reliable large-scale information from models was used. Methods have been developed to assess the reliability of the model climate variability used in detection, and the technical details important in obtaining reliable results are being formalized (see Allen and Tett, 1999: Checking for model consistency in optimal fingerprinting. Climate Dynamics, **15**, 419-434). Also, to work well, the optimal detection approach needed a control simulation of the order of a thousand years or longer and ensembles of anthropogenically and naturally forced climate change predictions over the observed period in question. In a sense, optimal detection was a model validation exercise and would provide a rigorous answer only if model simulations over large timescales were consistent with observations. Thus, valuable information was provided for modellers in return for the admittedly rather substantial effort in producing the various simulations.

Typical results from optimal detection studies showed that the time-space evolution of surface temperature observations over the recent five decades was inconsistent with internal climate variability (as inferred from coupled model simulations), and with the simulated climate response to estimated changes in natural forcing. This was evidence for a significant and detectable anthropogenic influence on climate. Furthermore, most major models, forced with greenhouse gases and sulphate aerosols, showed a space-time evolution of temperature similar to that observed. However, certainly not all simulations were consistent with observations in all aspects, but some of the differences might, at least in part, be caused by errors in the model treatment of climate forcing, e.g., in the indirect effect of sulphate aerosols.

The application of optimal detection techniques remained subject to the caveat of the limited knowledge of intrinsic internal climate variability and that which was naturally forced, and the realism of the simulation of these variabilities by models. Accordingly, a very conservative approach was used in detection and attribution studies, namely only using models whose variance was similar to or greater than observations. Some detection results held even if model variance was inflated by a factor of four. However, differences between different coupled models pointed to the importance of validation of the internal climate variability in long timescale model simulations. Palaeo-data might be useful in this regard, but the climate response to naturally occurring climate forcings (solar irradiance fluctuations, volcanism) (and the mechanism of some of these forcings, e.g., the importance of ozone feedback in natural forcing) needed to be better understood.

It was also noted that detection and attribution studies applying fingerprints from different coupled models as an estimate of green house gas and sulphate aerosol forcing showed somewhat different results. Patterns from the same model with different forcing were often more similar to each other than those from different models with the same forcing. Also, whereas the Hadley Centre and MPI models gave a significant underestimation of the early twentieth century warming when anthropogenic forcing only was used (but agreed better if natural forcing was also applied), one of the members of an ensemble of GFDL anthropogenic climate change simulations produced similar warming to that observed. There was clearly a need to understand why different coupled models reacted differently to similar forcing, and a comparison of model simulations over recent history could be valuable in assessing the range of forcings and model simulations that provided results that were consistent with observations. This might be an activity that could be taken up by CMIP.

Other issues relevant in the detection and attribution of climate change included the apparent discrepancy between instrumental surface temperature observations and lower tropospheric temperature measurements by satellite data and radiosondes (see section 3.4). Recently, the focus has shifted from questions of data reliability to the interpretation of a physically interesting low-frequency variability in the difference between surface and lower tropospheric temperatures (larger than fluctuations seen in coupled model simulations). Furthermore, changes in modes of variability, for example, in the Arctic Oscillation in climate extremes, were important, not only for model validation, but also for assessing the potential impact of climate change on man. Work in these areas was in an early stage, and was expected to become more important in the future. For validation of model-simulated changes of climate extremes, reliable daily data on a dense observational grid were needed.

Overall, WGCM has reiterated the need for as complete, accurate and long a climate record as possible for validating climate models and assessing their capability of simulating climate variability. As well as maintenance of existing observing systems, continued efforts on “data archeology” were necessary, as well as extension of palaeoclimatic data as far as feasible.

4.2.8 Palaeoclimatic modelling

As part of the Palaeoclimate Modelling Intercomparison Project (PMIP), organized by the Laboratoire de Modélisation du Climat et de l’Environnement (CE-Saclay) in France and PCMDI, co-ordinated experimentation to study the simulation of the climates of the mid-Holocene (6000 BP) and last Glacial

Maximum (21000 BP) has been undertaken as reported at the twentieth session of JSC. A number of complementary experiments and analyses have now been carried out.

In the case of the mid-Holocene, whereas PMIP experiments were focussed on the mean climate change in the middle of the period, some coupled models have since been used to investigate changes on interannual to interdecadal timescales. Although some palaeo-environmental evidence has hinted that short-term climate variability associated with ENSO was reduced during the early to mid-Holocene, this was not found in comparative runs of the NCAR CSM coupled model with present and 6000 BP forcing, or in runs with the Institute Pierre-Simon Laplace model. On the other hand, a reduction of about 20% in the frequency and intensity of El Niño was seen in the FOAM coupled model in an integration with the stronger insolation conditions of 11000 BP. This may have been a consequence of the intensified Asian summer monsoon in the simulation which enhanced the Walker circulation and tended to cool the central and eastern Pacific. Whether this effect would have occurred in this model with 6000 BP insolation conditions remained to be investigated. Although ENSO variability was not affected in the NCAR CSM mid-Holocene experiment, there were indications of important changes in the teleconnections between Sahel precipitation and ENSO sea-surface temperature anomalies.

With respect to the Last Glacial Maximum, PMIP results indicated that, in the tropics, models using the relatively warm CLIMAP sea surface temperatures underestimated the terrestrial cooling. Models that computed sea surface temperatures showed a better approximation to the cooling, but decreases in ocean temperatures as a whole were overdone. Over the western half of Europe, in particular, all the simulations tended to give too little winter cooling. Another diagnostic of model response that has now been investigated was ice-sheet mass balance. The global ice volume reached a maximum around 21,000 BP and thus the net budget of the Laurentide and Eurasian ice sheets would have been expected to be close to zero. Three models had close to zero or positive net budgets, but most produced negative budgets, the deficit being worse in the experiments with CLIMAP sea-surface temperature and coarser resolution models. Some of the discrepancies seen in the Last Glacial Maximum experimentation may be linked to missing feedbacks (e.g., all simulations omit possible vegetation change due to climate-induced shifts in the biomes, and CO_2-induced changes in vegetation and leaf conductance). Some experiments to test the sensitivity to this effect have now been carried out, and, in particular, in a new generation coupled atmosphere-vegetation model (GENESIS-IBIS), it was indicated that, over much of Eurasia, forests would be replaced by tundra and steppe, contributing to cooler conditions (although still not cool enough). However, in the tropics, areas of warming (rather than cooling) were found as a result of simulated deforestation. Another factor was that mineral aerosol (dust) concentrations were many times higher than today, especially in the polar stratosphere and this could have provided an extra cooling effect. Taking into account the climate and CO_2-induced vegetation changes to infer the dust distribution (which was in fairly good agreement with proxy data), computations indicated a small positive change in radiative forcing in high latitudes, but a larger negative change in the tropics; this was another feedback mechanism that could amplify the effects of changed CO_2 forcing.

A workshop on PMIP was held near Montreal, Quebec, Canada, 4-8 October 1999. A full synthesis of the results obtained including model-to-model and model-to-data comparison was compiled, and recent PMIP studies and analyses including data updates, sensitivity experiments, and recent work with coupled ocean-atmosphere and/or atmosphere-vegetation models in simulating the mid-Holocene and Last Glacial Maximum periods reviewed. The future of PMIP was also considered. WGCM has strongly encouraged continuing efforts on PMIP lines, perhaps for example over periods of extreme events.

On a different topic, WGCM noted that there have been relatively few comparisons of the natural climate variability simulated in coupled models to palaeo-records over the last millennium. It has been found that the level of decadal-scale variability is underestimated in long MPI and GFDL long control coupled model runs compared to summer palaeo-temperature proxies. However, the GFDL model did show centennial timescale variability bearing some similarity to proxy data. The Hadley Centre model (HadCM2) appeared to produce only decadal-scale variability. However, there was evidence that inadequate simulation of variability at decadal to centennial scales in these long historical runs could be due to missing external forcings. Efforts have been made to improve the reconstructions from proxies, and better estimates of forcing over the last millennium are becoming available. Further progress resulted from the joint CLIVAR/PAGES workshop reviewing climate variations over the last 1000 years (Venice, Italy, November 1999). WGCM has reiterated the requirement for a much higher resolution of climate variability over the past 1000 years (in particular for the reconstruction of ENSOs and the North Atlantic Oscillation). There was clearly scope for co-operation between modellers and the palaeo-data community in this area.

4.2.9 Atmosphere-ocean predictability on decadal timescales

New results from experimentation related to decadal predictability were becoming available. Using an uncoupled atmospheric general circulation model driven with prescribed (observed) sea-surface temperature and sea-ice distributions over several decades, low-frequency variations in mid-latitudes appear to be reproducible in some integrations. In particular, observed decadal variations in the North Atlantic Oscillation are simulated. This would suggest some long timescale atmospheric predictability **if** sea surface temperatures can be predicted far ahead.

Relevant studies have also been carried out with coupled models. Following the classical predictability approach, initial states were chosen from long control integrations and the coupled model then restarted with small perturbations superimposed. Such studies have indicated that at least some sub-surface (oceanic) variables may be predictable several years ahead. Real forecasts/hindcasts can also be used to address the question of decadal predictability (e.g., running a coupled model from an appropriate initial state and examining the indicated evolution of the coupled system). There were only a few examples available so far, in one of which (with a simple hybrid coupled model for the North Pacific), upper ocean heat content changes appeared to be predictable at least five years in advance.

WGCM has put forward proposals for an informal co-operative investigation of decadal predictability, involving collecting general information on both "diagnostic" and "prognostic" predictability. There has been considerable interest in the community in this topic, and it has been proposed that a workshop on decadal climate predictability should be organized under WGCM auspices in conjunction with the next session of WGCM (La Jolla, CA, USA, October 2000). The workshop would take up available evidence from oceanic and atmospheric, observation-and model-based studies of decadal climate predictability. The main focus was expected to be the investigation of decadal predictability using both "diagnostic" and "prognostic" approaches. The objective would be to form an assessment of the state of the art in the field of decadal climate predictability and to identify future research topics or co-ordinated model experimentation that should be undertaken internationally.

4.2.10 Liaison with IPCC Working Group 1

The preparation of the IPCC Third Assessment Report, in particular the scientific review ("The Science of Climate Change"), under the responsibility of IPCC Working Group I, was being pursued by means of an intensive programme of activities that would continue until the beginning of 2001. Many members of WGCM were involved and were having to devote a substantial fraction of their time in drafting texts, participating in drafting meetings, etc. WGCM has again expressed concern at the demands on scientists' time, when there was so much fundamental work needed in the development of climate models themselves. As noted in section 4.2.4, the approach to defining emission scenarios in IPCC and consultation with the modelling community on this matter could also be improved.

4.2.11 Carbon-cycle modelling

At the 1998 session of WGCM, it had been agreed that efforts would be undertaken jointly with the Global Analysis, Integration and Modelling (GAIM) element of IGBP aimed at modelling the observed interannual variations in CO_2 and assessing the relative contributions of the atmosphere, ocean and terrestrial components of the Earth system to these variations. As a first step, it was proposed that appropriate atmospheric and surface fields from AMIP integrations be used to force off-line runs of carbon cycle models in simulating CO_2 uptake or release by the terrestrial biosphere. Likewise, using surface and oceanic fields from CMIP, the amount of carbon sequestered or released by the ocean could be computed. A second more ambitious step would be to carry out transient integrations with coupled atmosphere-land-ocean-carbon models in which the fossil fuel emission would be specified, and the simulated change in carbon dioxide concentration, dependent on the carbon flux parameterizations, computed, which would then interact with the model's physical climate. However, the planned joint activities had not progressed (although a CMIP2 project on the response of the biospheric carbon cycle to global warming had been initiated).

Nevertheless, several of the groups represented on WGCM were already proceeding to incorporate the carbon cycle into their models. At the Max Planck Institute, modelling work evaluating various terms in the global cycle of carbon dioxide was underway. At the Institute Pierre-Simon Laplace, off-line forcing of a continental carbon model and of an ocean carbon model have shown that climate change could reduce the carbon dioxide uptake by up to 20%. In view of the potential importance of this feedback, a coupled carbon cycle/climate experiment has been set up. The climate model has been initialized by a 200-year run in the pre-industrial period, this then being used to initialize the full carbon cycle model (in a state where the airborne carbon fraction is about 50%). Two experiments were now in progress corresponding respectively to unperturbed pre-industrial emissions on one hand and anthropogenically modified emissions on the other. A group of European modelling groups had also jointly put forward a proposal for appropriate systematic experimentation under the European Framework V programme.

These activities are of considerable interest, but there remains a definite need for co-operation with GAIM. One possibility was to try and build up an interested group of scientists by organizing a workshop on the incorporation of the carbon cycle into coupled models.

4.2.12 Requirements for resources for coupled modelling

The JSC noted the comments made by WGCM on the requirements for the development of coupled models and carrying out the multiple long integrations required (it is essential to perform ensembles of integrations in estimating the response of the climate system to anthropogenic forcing and to obtain a clear indication or the signal-to-noise ratio, noise in this case being natural climate variability). As well as significant increases in manpower to develop models and to analyse results, continuous enhancement of computing resources was needed. Several of the centres represented on WGCM were acquiring or had access to substantially increased computing power and parallel processing capability (e.g., MPI would have a twenty-fold increase early in 2000; NCAR had available an SGI-2000 128 processor, and IBM/SP 128 processor equipment and access to an SGI at the Los Alamos National Laboratory; the Institute Pierre-Simon Laplace was acquiring an NEC/SX5; BMRC and CCCma were now using NEC/SX4 computers). These developments were encouraging, but generally computing resources still fell far short of what was required.

4.3 Regional climate modelling

At its twentieth session, the JSC noted a number of technical issues raised by WGNE that needed to be taken into account when constructing regional climate models. These included such aspects as the choices of the domain for a regional climate model and its geographical extent, the potential problems with the lateral boundary conditions, and the scale dependency of parameterizations. The choices to be made and the relative role of various parameterizations were likely to be different in different parts of the world (i.e. in different climatological regimes). The importance of the simulation of the regional climate and key features such as the hydrological cycle being consistent with the large-scale behaviour of the driving (global) general circulation model was also stressed. The JSC asked WGNE, in co-operation with the WGCM, to review further these questions and to consider how the scientific foundation for regional climate modelling could be strengthened. The JSC suggested that it might be appropriate for WGNE and WGCM to establish a joint ad hoc panel to consider outstanding questions and whether any organized or focussed numerical experimentation would be useful, possibly leading to a WCRP workshop on regional climate modelling in 2000 or 2001.

Review by WGCM

WGCM took up the topic of regional climate modelling at its session in Hamburg in September 1999. As background to the discussion, a number of presentations were given. These included several examples of the fine detail added by regional climate models which coarser resolution global models are incapable of simulating. In particular, the skill of a regional European model (using reanalyses as boundary conditions) in accurately reproducing such features as the mean precipitation climatology over the United Kingdom, realistic river run-offs into the Baltic and precipitation extremes in the Alps was demonstrated. The same model gave results that were consistent with the large-scale forcing simulations with only minimal deviations in 500 hPa fields. The stability of the simulations was indicated by the lack of long-term drift in the modelled precipitation. Furthermore, the simulated precipitation patterns appeared insensitive to domain size, with no spurious sources or sinks. On the basis of these results, regional climate models could be regarded as well-proven tools adding substantial value to coarse driving data and of use in a wide variety of climate applications.

Additional results were also presented illustrating how regional climate modelling techniques produced high resolution simulations which seemed to take account realistically of the effects of resolved small scale features within areas of interest. However, it was emphasized that reliable indications of regional climate changes could only be achieved if there were improvements and reductions in the substantial systematic errors in the (global-scale) driving models. As progress was made in these respects, more confidence could be placed in the results of regional climate models. It was also pointed out that it was essential to run regional climate models over sufficiently long time-slices, especially in regions such as Europe that were characterized by large low-frequency (decadal) variability in order to obtain statistically significant climate changes over the scale of the domain covered by the regional model.

The potentially wide range of important applications of regional climate models (which held the prospect of becoming "regional environmental models" featuring regional oceans and lakes, river catchments, the local vegetative cover and ecosystems) was also reviewed. More specifically, regional climate models could be valuable in downscaling global climate change simulations, in inferring detailed local information from palaeoclimatic reconstructions, studies of regionally-induced and limited climate change, analysis and scenarios of transboundary pollution, and regional reanalysis for risk assessment (e.g. ocean wave changes). However, to work satisfactorily, the domain size should not be too large. It was foreseen that regional climate models would always be an indispensable tool even as computing capabilities increased. Longer integrations would be needed (e.g. for palaeoclimatic studies) and there would always be a demand for finer and finer detail (i.e. higher resolution).

In considering the means of linking a regional model to the driving large-scale model, a technique known as "spectral nudging" was presented. This is based on the idea that regional-scale climate statistics are conditioned by the interplay between continental-scale atmospheric conditions and such regional features as marginal seas and mountain regions. The regional model is forced to satisfy not only these boundary conditions, but also the large-scale flow conditions inside the integration area. It was illustrated how spectral nudging succeeded in keeping the simulated state close to the driving state at larger scales, while permitting smaller-scale features to be generated (whereas with standard boundary forcing methods the regional model could develop internal states inconsistent with the large-scale flow). In this context, spectral nudging could be regarded as a sub-optimal and indirect data assimilation technique.

It was furthermore noted that regional climate modelling was being reviewed in the IPCC Third Assessment Report currently in preparation. The report was expected to give an optimistic view of the state of the art of the work in this area, but to acknowledge the need for further systematic testing and improvements.

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

Review by WGNE

Presentations of work and reviews of activities in regional climate modelling were also arranged at the WGNE session in Monterey in October 1999. The various approaches to regional climate modelling, particularly nested limited area models, were summarized. There were many examples of implementation and applications of such models and the sensitivity to domain size, boundary locations, and physical parameterizations had been widely studied. The local and detailed information produced by these regional models was a basis for increasing co-operation with impacts assessment scientists. The quantification of uncertainties in regional climate simulations was thus becoming increasingly important, with a need for multiple realizations and the preparation of longer simulations to estimate interannual to interdecadal variability and the occurrence of regional "extreme events". The role of the Project to Intercompare Regional Climate Simulations (PIRCS), conducted by Iowa State University, which had been designed to provide a common framework for evaluating the strengths and weaknesses of regional climate simulations through systematic comparative experiments by various groups using common initial and boundary data from the NCEP/NCAR reanalyses, was noted. Consistent comparisons of model results with observations had been carried out (although, of course, like most of this type of intercomparison exercise, it was not usually possible to diagnose the sources of errors in individual models). Twelve modelling groups from Europe, Australia and North America had completed or were engaged in a pair of simulations (15 May-15 July 1988; 1 June-30 June 1993) focussed on the central USA. Preliminary results indicated that most models produce accumulated precipitation during the 1993 summer flood over the upper Mississippi River basin within about 10% of that observed. For the 1988 drought, the absolute magnitudes of differences among models are larger, as are the differences between models and observations (but the relative differences are smaller). Evaluation of the root-mean-square deviation of the models' 500 hPa heights versus the NCEP/NCAR reanalysis suggested that synoptic events are well handled by the models. Further analysis was underway to investigate model representations of the hydrological cycle and the relative importance of evaporation and moisture flux convergence in producing precipitation, and features such as the locally occurring nocturnal low-level jet and meso-scale precipitation patterns.

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

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

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

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

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

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

It was reported that experimentation aimed at validating the regional climate modelling approach in a perfect-model mode by carrying out, as WGNE has suggested in the past, a long high resolution global model simulation to serve as a reference model climate, was now being undertaken at a few centres in the USA and Canada. The resolution of the model data set was reduced (by spectral truncation or spatial filtering) to a typical (lower) global model resolution, and then used to drive a high resolution regional climate model whose simulation can be compared to the reference high resolution global integration over the same area. Global variable resolution models could be validated similarly.

Another important issue raised by WGNE in its report to the JSC in 1999 had been the possibility that the unresolved scales in the driving general circulation model could effect the large-scale flow. This would not be compensated by any amount of downscaling in a regional climate model. In this regard, simulations carried out at NCAR with the semi-Lagangian version of CCM3 (T63, T95, T127 spectral truncations with a linear transform grid and 26 levels in the vertical) have been analyzed. The “large-scale flow” was taken to be the integral of moisture flux into regions of the size typical for nested climate models. Five year annual averages of the moisture flux into boxes 40°lat x 60°long, and of 60°lat x 90°long were computed. For boxes over the USA, differences between the T127 and T63 integral of moisture fluxes into the boxes were of the order of 0.3 and 0.2 mm/day rainfall equivalent for the smaller and larger boxes respectively (equivalent to 10 and 6 Wm^{-2} averaged over the regions). Differences of similar magnitudes were seen in other parts of the world. The differences between the T127 and T95 simulations were smaller (0.1 and 0.05 mm/day, or 3 and 1.5 Wm^{-2}). This suggested that the driving climate model may require a resolution of at least T95 in order to achieve a situation where the unresolved scales did not significantly impact the resolved scales. These results raised a question that needed to be generally evaluated, namely that, since the ultimate success of regional climate models depends on the proper and realistic simulation of the large scales by global circulation models, continued studies of the dependence of the simulated large scales on model resolution was of considerable importance. The proposed experimental “resolution” sub-project of AMIP-II (see section 4.1.2) provided a good opportunity for such studies.

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

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

Comments by the CLIVAR Working Group on Seasonal-to-Interannual Prediction (WGSIP)

WGSIP at its session in Bologna, Italy in November 1999 (see section 9.4) pointed out the strong interest in the application of regional models in seasonal prediction (i.e., limited area models nested in a global seasonal prediction). As well as the technical issues reviewed by WGCM and WGNE and the concern related to the simulation of the large-scales in the global models, the question was raised regarding the extent to which regional models added predictive value or detail to the global seasonal prediction that might not be more simply inferred by statistical downscaling. WGSIP welcomed the prospect of a joint WGNE/WGCM panel on regional climate modelling, but hoped the aspect of downscaling in the context of seasonal-to-interannual prediction would be considered.

Establishment of a joint WGNE/WGCM ad hoc panel on regional climate modelling

The JSC noted with interest the WGCM and WGNE reviews of regional climate modelling, and the various points and issues discussed. The JSC itself additionally raised the question of the predictability/reproducibility of the smaller scales simulated in regional climate models. The JSC therefore endorsed the establishment of a joint WGNE/WGCM ad hoc panel on regional climate modelling, including the members nominated by WGNE and WGCM, namely:

R. Laprise (Convener), University of Québec at Montréal, Canada
R. Jones, United Kingdom Meteorological Office
H. von Storch, GKSS Research Centre, Geesthacht, Germany
W. Wergen, Deutscher Wetterdienst

It was also agreed that Dr. B. Kirtman, Center for Ocean-Land Studies (COLA), USA, should be invited to represent the interest of the CLIVAR Working Group on Seasonal-to-Interannual Prediction in the application of regional models in seasonal prediction.

The JSC agreed that the panel should undertake the basic task of summarizing the current state of the art in the field of regional climate modelling and reviewing the outstanding questions, particularly those raised by WGNE. The work that had gone into the IPCC Third Assessment Report on this topic could be a good starting point. The panel should also consider, as suggested by WGNE, whether any co-ordinated or focussed experimentation (in addition to PIRCS and the "identical twin" experiments) could be useful in further investigating basic issues of regional climate modelling such as choice of domain, scale dependency of parameterizations etc. It would be useful to discuss whether it would be worthwhile to organize an international workshop in 2001 or 2002, with the objective of reviewing and increasing the awareness of the community to the questions to be borne in mind when using regional climate models, and to look forward to progress that can be expected in this area in the coming years. The JSC asked the chairs of WGNE and WGCM to be fully involved in the discussions of the panel and to keep breast of the views formulated. The JSC anticipated that most of the initial discussions, exchange of ideas, scoping out in detail aspects to be taken up could be conducted by e-mail or at meetings of opportunity.

5. THE GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (GEWEX)

Professor S. Sorooshian, Chair of the GEWEX Scientific Steering Group, led a general review of GEWEX activities, giving special emphasis to the importance of developing the applications of the results being achieved. Supporting presentations were given by Dr. P. Try, Director of the International GEWEX Project Office, who highlighted some of the main highlights in the practical implementation of GEWEX in the past year (including the organization of the Third International Conference on GEWEX, in Beijing, June 1999), and Dr. T. Koike, University of Tokyo, on the progress in the planning the Co-ordinated Enhanced Observing Period (CEOP).

GEWEX continues to be organized in three main thrusts: hydrometeorology (as described in section 5.2); radiation studies (section 5.3); modelling and prediction (section 5.4). In addition, an overall activity is planning and collection of the global observations required for GEWEX, and the assembly of a range of global climatological data sets (as described in section 5.1).

5.1 GEWEX global observations

Scientific requirements

The existing array of operational meteorological satellites (the NOAA series of polar orbiters and geostationary satellites, the European METEOSATs and the Japanese GMS spacecraft) are fundamental sources of the atmospheric data needed by GEWEX. The maintenance of this array and continuity of observations, the benefits expected from instrument development and the ongoing international support for the processing of satellite data for GEWEX climatological data projects (e.g., the International Satellite Cloud Climatology Project, the Global Precipitation Climatology Project) are essential elements in meeting the requirements for GEWEX global data fields. The other key element is the launching of several Earth observation platforms in the next few years, namely: the European environmental satellite, ESA’s ENVISAT; ESA/EUMETSAT METOP-1 (the first operational polar orbiter from Europe); the new NASA Earth Observing Satellites, AQUA and TERRA; and the Japanese National Space Development Agency (NASDA) ADEOS series.

The above systems will go a long way to meeting the requirements of GEWEX for global observations (and those of the WCRP as a whole). However, particularly critical requirements are:

- vertical profiles of atmospheric radiative fluxes;
- quantitative details of cloud microphysical properties and dynamics;
- the ageostrophic component of the atmospheric circulation;
- soil moisture and other information on land surface characteristics from a focussed land surface observation project

The above list encompasses specific gaps in the observations of concern to GEWEX specified earlier (namely global three-dimensional distributions of clouds, soil moisture in the surface layer, upper tropospheric wind profiles). The requirements as now set down are parallel to those of the large-scale atmospheric modelling community (both for NWP and climate simulations) which is seeking high quality data on key processes such as radiation and clouds and forcing boundary conditions.

Following discussions between the GEWEX Scientific Steering Group and the space agencies, significant steps to meet these requirements have been taken. In this respect, the Tropical Rainfall Measuring Mission (TRMM) is a good example of the type of international effort that is useful to GEWEX. TRMM has provided unprecedented coverage of the horizontal and vertical structure of tropical rain systems which are already being exploited in parameterization and assimilation studies. The continuity of these measurements is important and follow-on missions and other complementary proposals such as the Global Precipitation Mission are certainly needed. Another example of a potentially valuable mission is "Cloudsat", that would carry a cloud-profiling radar capable of studying the three-dimensional structures of (thick) clouds important to weather and climate and their effect on radiative transfer.

These types of missions, drawing together national and international partners, directed towards answering specific climate- and environmental-related scientific questions, when added to the other Earth Observing Platforms, offer exciting prospects for an improved understanding of the dynamics and energetics of the Earth's atmosphere in support of WCRP and GEWEX scientific goals. The JSC expressed its appreciation to space agencies for the efforts being made to meet these requirements, but stressed the need to continue to explore possibilities for further relevant missions needed by GEWEX and other components of the WCRP. As already noted in section 3.5, the JSC considered that a more co-ordinated approach to space agencies at the level of the WCRP itself may now be necessary, especially to ensure the full engagement of space agencies and to influence the development of all types of observing systems and the planning of new missions.

Management of GEWEX global climatological data sets and plans for exploitation of new data

GEWEX is responsible for several global climatological projects* based on merging satellite data with current in situ (atmospheric, land/ocean surface) measurements. This involves close interaction with space agencies in tracking the status of global environmental observing systems, monitoring retrieval procedures and data quality control, organizing data archiving and data distribution on the appropriate media, and assisting (through workshops, symposia and data management meetings) in the international co-ordination of projects.

Attention is now being given to the continuation and development of these projects beyond 2000, when the new Earth observing platforms begin to come on line. The set of observations required to close the global water and energy cycles and the availability of these data both in the past and the future will be assessed. This should enable a judgement to be made whether the new observing systems and new data products meet the requirements, or whether refined analysis techniques should be developed. However, such new data sets will require validation and interpretation against existing (longer-term) data sets to ensure continuity. Thus, support to the GEWEX global data projects (as they exist at present) must be maintained, as well as finding additional resources for systematic comparisons of old and new data sets (see also section 3.5). In this context, the GEWEX Scientific Steering Group has recommended that the GEWEX climatological data projects should be extended for at least another five years. The Director of the WCRP has been duly requested to draft letters to the major space agencies and other involved institutions urging continuation of support of the climatological data projects. It would also be pointed out that the participating centres needed to calibrate, control the quality of, and adopt processing software to data from the changing operational systems, and should duly establish levels of support adequate for all these tasks to be carried out.

5.2 Hydrometeorology

The building blocks of the GEWEX hydrometeorology thrust, overseen by the GEWEX Hydrometeorology Panel, are the “continental-scale experiments” which are regional initiatives to investigate energy and water budgets over large river basin/drainage areas and to study the physical processes that determine surface fluxes of energy and water over land. There are currently five such projects: the GEWEX Continental-scale International Project (GCIP) in the Mississippi River Basin; the Baltic Sea Experiment (BALTEX); the MacKenzie GEWEX Study (MAGS), the Large-scale Biosphere-Atmosphere (LBA) Experiment in Amazonia; and the GEWEX Asian Monsoon Experiment (GAME). A further experiment, the Coupling of the Tropical Atmosphere and Hydrological Cycle (CATCH), a 3-5 year study in Sahelian Africa to evaluate and develop the present capability of predicting the impact of climate variability on water resource management and crop production, is now being planned. Overall, progress is manifest in the data bases that have been built up, the supporting process and modelling studies carried out, and the increasing recognition of the importance of the role of continental-scale hydrometeorology in the climate system. A further major step forward will be the implementation of the Co-ordinated Enhanced Observing Period (CEOP) in 2002-2003, as well as the assembly of global land surface data bases for modelling studies and setting out guidelines for model transferability and global applications studies.

GEWEX Continental-scale International Experiment (GCIP)

GCIP is the most mature of the GEWEX continental-scale experiments. Particular findings have included the marked influence of vegetation on evapotranspiration rates and on the quantity and distribution of convective precipitation in summer months, the importance of taking into account soil moisture anomalies in prediction of summer precipitation, the effects of winter snow cover and its melting pattern on the spring hydrology with possible feedbacks on springtime precipitation, the successful representation of sub-grid scale precipitation variability using downscaling techniques, and how land surface heterogeneity can significantly affect local moisture recycling. GCIP has also been able to demonstrate the utility of climate forecasts in the management of water resources and has provided significant insights and results in this area. Within the framework of one specific reservoir management scheme in the USA, it was shown that an annual benefit of US$ 2M could be realised by appropriate application of forecasts in decision making. The priority focus in 2000 will be the northwest regional area of the Mississippi River Basin lokking at regional coupled model subcomponents, and hydrometeorological predictions and water resources over a full annual

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* These include the International Satellite Cloud Climatology Project, the Surface Radiation Budget, the Global Precipitation Climatology Project, the Water Vapour Project and the Global Aerosol Climatology Project. For a full description of the status of these various data sets, see section 5.3.

cycle. Over the following two or three years, GCIP is expected to evolve into the "GEWEX Americas Prediction Project" (GAPP), which would extend the GCIP scientific and strategy approach to other climatic regions in the USA, and place additional emphasis on understanding how land surfaces can influence the climate system and predictability.

The Baltic Sea Experiment (BALTEX)

The central observational and modelling phase of BALTEX (known as "BRIDGE") began in October 1999 (after a six-month pilot phase April-September 1999), and will span two annual cycles and three winter seasons, finishing in early 2002. A follow-up intensive analysis period is being planned (to be carried out from early 2002 up to 2005).

GEWEX Asian Monsoon Experiment (GAME)

As reported at the twentieth session of the JSC, the GAME intensive observing period was successfully conducted from April to September 1998. Since then efforts have been devoted to assembling the data gathered and beginning appropriate analyses. The GAIM Archive and Information Network (GAIN) is now active. Work has been carried forward on the (GAME) Asian Automatic Weather Station Network (AAN) which will remain operational up to 2004; this comprises about ten stations measuring surface meteorological data in a variety of regions ranging from the Arctic to the tropical rainforest, as well as a series of surface radiation monitoring sites (following BSRN standards). Several studies related to understanding and predicting the characteristics of the Asian monsoon over various GAME regions have been undertaken. Preparations are also in hand for "GAME-Siberia" with an intensive observation period planned in 2000, which should throw light on the seasonal evolution of the water and energy cycles over the forests which dominate Siberia.

The MacKenzie River GEWEX Study (MAGS)

Studies in MAGS have provided an understanding of the advective processes which are source of most of its moisture and precipitation and which may be depicted as a "conveyor belt" of moisture moving across the coastal mountain ranges. The amount of water vapour being transported in this way gives an indication of the snow accumulation in the winter season and thence a measure of expected snow melt and run-off during the summer. At this latter time of year, local evaporation of water from vegetation and open water surfaces, not advection, appears likely to be the major source of atmospheric moisture over the MacKenzie basin. A proposal for a second phase of MAGS for the period 2001 to 2005 has been submitted.

Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA)

The LBA field phase began at the end of 1998 with a first intensive observing period in January/February 1999 based on two closely coupled exercises, namely a wet season atmospheric mesoscale campaign and a ground-validation experiment for TRMM. A further intensive observing period in southwest Amazonia from October to December 1999 was designed to study the transition from dry to wet seasons. Seventy research projects are now in various stages of implementation covering all the main LBA foci (physical climate, carbon cycle dynamics, biogeochemistry, atmospheric chemistry, land surface hydrology and water chemistry, land use and land cover changes, remote sensing studies and human dimensions). LBA will continue to 2003, taking advantage of TRMM measurements, EOS "TERRA", ENVISAT, the Chinese-Brazilian Earth Resources Satellite, and Landsat 7.

Coupling of the Tropical Atmosphere and Hydrological Cycle (CATCH)

Progress is continuing to be made in the planning of CATCH, a continental-scale experiment in West Africa. The basic objective is to undertake a 3-5 year study in the Sahel region to evaluate and develop the present capability of predicting the impact of climate variability on water resource management and crop production. Emphasis is being planned on multi-scale observational systems and modelling in order to relate large-scale circulation patterns to the life cycle of meso-scale convective systems down to the characterization at fine resolution of rainfields at the ground. There are indications that drought periods are linked to a significant decrease in the number of convective systems observed each year. Two major steps so far are the collection of a ten-year (1989-1999) high resolution, high quality rainfall data set over the Niamey area and the installation of a hydrometeorological network in the Oueme catchment area. The future support that can be given to CATCH is in course of discussion.

Water and Energy Budget Closure Task (WEBS)

WEBS is now being undertaken as a specific activity within the GEWEX hydrometeorological thrust with the purpose of using observations and model analyses to close the water and energy budget on a regional scale for each of the continental-scale experiments. Issues to be taken up are: the assembly of high temporal resolution data sets, essential for accurately quantifying the water budget; the sensitivity of the spatial resolution of the sampling; the use of runoff as an independent variable for testing closure; development of high resolution four-dimensional data assimilation with the appropriate input to provide the best products for determining budgets; process studies of precipitation, clouds, soil moisture/run-off etc. in order to improve model treatments of the water and energy cycle.

The Co-ordinated Enhanced Observing Period (CEOP)

CEOP was originally conceived as a co-ordinated enhanced observing period by four of the continental-scale experiments, involving a year-long effort to collect common data sets from which the impact of soil moisture in the climate system on a global scale could be evaluated and several fundamental land surface/atmospheric interactions could be better understood. It has now evolved into an important activity in the WCRP that could underpin major progress in understanding and predicting the climate system, to be undertaken in conjunction with other components of the WCRP, focussing particularly on the source and sink regions forcing or modifying the atmospheric circulation.

The basic scientific strategy of CEOP was presented at the twentieth session of the JSC (March 1999). The JSC considered that CEOP was likely to be a valuable opportunity for studying a range of climate features at a global scale and the extent to which these depended on local atmospheric and hydrological processes, as well as assessing the predictability of useful hydrological parameters. A significant change in the plans as described at that time is that the CEOP data collection phase has now been extended by a year to cover the period 2001-2003.

CEOP will evidently depend heavily on success in the WEBS task outlined above and the assembly of a range of suitable data sets relevant to land surface process and modelling studies. The priority activities in the CEOP data collection phase are:

(i) Assembly of reference site data sets for studies of land/hydrology/atmosphere coupling: a number of reference datasets comprising atmospheric, hydrological and land surface characteristic variables distributed over the land areas of the globe and covering the same time period of at least one year are necessary.

(ii) Coupled hydrological/atmospheric model transferability experiments: the overall objective is to evaluate the performance of coupled hydrological/atmospheric models in different geographical and climate regions, as well as over the same region at a different scales/resolutions.

(iii) Use of validation of satellite data and derived or inferred products: relevant data sets of hydrometeorological variables or products available directly or by inference from remotely-sensed data will be needed to improve coverage in data-sparse regions outside the in situ (nominally) data-rich continental-scale experiment areas. The in situ data can be used to validate the satellite products (as well as the fields of hydrometeorological variables provided by the GEWEX climatological data projects, see sections 5.1, 5.3).

(iv) Regional co-ordinated experiment in the Asian/Australian monsoon region: a co-ordinated study of characteristics of the Asian/Australian monsoon during a common time frame aimed at understanding and modelling seasonal to interannual variations of the monsoon and its influence on water resources is considered as an essential component of CEOP. This will involve bringing together a number of relevant research projects which are already ongoing and planned within the Asian/Australian monsoon region (including in Mongolia, Tibet, the Bay of Bengal, Thailand, the eastern Indian Ocean, Indonesia and western Pacific Ocean), as well as the exploitation of data from a number of the Earth observing platforms now coming on line.

Overall, CEOP will thus contribute to a number of issues of importance in WCRP. The study of the Asian/Australian monsoon, already underway as a part of GAME, will be closely co-ordinated with CLIVAR activities in this area. Likewise, CEOP, through GCIP and LBA, will provide essential input for the CLIVAR investigation of the Variability of the American Monsoon System (VAMOS), and, through CATCH, will be likely to lead to improved understanding of the West African monsoon. Other data collected in CEOP from GAME, GCIP, MAGS, BALTEX will be valuable in studying climate forcing on seasonal timescales associated to anomalies in land-surface conditions, and the degree to which such anomalies may be linked on seasonal and annual or even interannual timescales.

The JSC expressed interest in the progress in planning CEOP. The JSC urged that special or additional data sets assembled in CEOP should be made available in real time on the WMO/WWW Global Telecommunications System, and also that a cleat time-line for production of the various data sets be established. Some members of the JSC remained uncertain of the overall guiding goal of CEOP and the "added value" that would be provided by CEOP as a co-ordinated "global" project beyond the proposed synchronous observing periods of the continental-scale experiments. Nevertheless, the JSC reiterated its request to all WCRP project groups to take note of CEOP, to take advantage of the potential prospect of studying certain climate features synchronously at a global scale, and to consider appropriate supporting activities.

Real-time access to data from GEWEX field studies/regional experiments

The JSC fully agreed with the position taken by the GEWEX Scientific Steering Group that the various observations made in GEWEX field studies/regional experiments should be made available in (near) real-time in the appropriate standard format on the WMO/WWW Global Telecommunications System, in order to permit the earliest possible access by the major modelling and analysis centres (see also above). This was especially important for CEOP. Not only was real-time operational data assimilation an immediate and searching test of the quality of the data being gathered, but data would feed into forecasts for the continental-scale experiment catchment areas which would be valuable in planning the day-to-day observational programme in these regions.

Relationship between the GEWEX hydrometeorology thrust and the wider hydrological community

As noted in section 2.4, the relationship between GEWEX and the wider hydrological community is of considerable importance in view of the range of activities being undertaken in this area and the numerous bodies involved. Care was particularly required to avoid confusion among programmes and activities whose separate purposes were not always clear to those outside the field.

Amongst the initiatives more closely related to GEWEX was the UNESCO "Hydrology for Environment, Life and Policy" (HELP) programme, intended to provide the scientific basis for improved land and water management through a global network of experimental basins, and aiming to deliver social, economic and environmental benefits through integrated catchment management and sustainable and appropriate use of water. This would involve studies of important local hydrological processes with research directed towards hydrological variability and change, biophysical processes affecting the movement of water, hydrochemical pathways and processes, development and application of models, and use of remotely-sensed data. It was planned to select initially five to ten demonstration drainage basins (10^4-10^6 km^2) where the most critical water policy issues could be addressed. In the next stage, a further 100-200 catchments of similar dimensions would be selected worldwide. Interfaces between HELP and GEWEX were foreseen at two levels:

- for basins of common interest, complementary work should be defined and carried out
- data and expertise would be sought by HELP in documenting relevant aspects of climate variability and change.

It was understood that HELP was seeking to exploit, not duplicate, the work of and data collected by the science-driven programmes (such as GEWEX) to contribute to the resolution of policy management and development issues. Conversely, since HELP would document not just hydrological but also bio- and eco-systems and socio-economic parameters for a worldwide network of catchments, scientific programmes may expect some benefits.

The work in GEWEX to improve regional hydrological models and downscaling is the main common scientific element of interest between GEWEX and HELP. A workshop may be arranged to consider how best to establish collaborative links, at which the opportunity could also be taken to discuss interactions with the broader hydrological and water resources management community, and other relevant hydrological initiatives, including particularly the connections with WMO Hydrological and Water Resources Programme and the World Hydrological Cycle Observing System (WHyCOS).

In the same context as the foregoing, it is noted that the GEWEX Hydrometeorology Panel has a clear objective to promote the participation of the hydrological modelling community and supporting operational environmental services in the task of developing improved and more accurate hydrometeorological predictions. A "Water Resources Application Project" (WRAP) is therefore being initiated to take up questions relating to the influence of local versus non-local controls on precipitation over land, the extent to which controls vary from region to region, what are the feedback mechanisms in the hydrological cycle, how they may affect wet and dry spells, and how well the soil moisture field can be determined in collaboration with water resource agencies. Another objective is how better to use improved information related to water resources that is expected to be provided by GEWEX and to develop closer working relationships with water resource managers. There is a need to co-ordinate a number of parallel initiatives in this area including the "Model Parameter Estimation Exercise" (MOPEX), and the individual activities in this are underway within each continental-scale experiment, as well as the ACSYS hydrological model intercomparison (see section 10.1.7).

International Satellite Land-Surface Climatology Project (ISLSCP)

ISLSCP has the task of advising GEWEX on the use of satellite remote-sensing and other techniques to advance the understanding of the physical and biological processes controlling interactions between vegetated land and the atmosphere, and assists in the assembly of relevant regional and global satellite data sets and accompanying in situ measurements. In this respect, a ten-year “Initiative II” (1986-1995) multi-disciplinary land surface/vegetation climatology data set on a uniform 0.5º x 0.5º grid is being constructed. The preparation of this data set has taken into account feedback from users and problems noted with the earlier 1ºx1º two-year (1987-1988) data set (“Initiative I”). However, progress in issuing this data set has been slow, and this has delayed progress in the Global Soil Wetness Project (see section 5.4) which intends to use the ISLSCP Initiative II data sets in preparing revised and higher resolution global soil wetness data sets.

ISLSCP is also expected to make a significant contribution to WEBS (see above) through the provision of flux measurements from Fluxnet towers at several locations in continental-scale experiment domains, as well as characterizations of vegetative cover. Work on a seasonal-to-interannual leaf area index and dynamics could also be important, as well as information on the occurrence of shallow convection, turbulence and local rainfall linked to land-surface heterogeneity. From modelling activities in ISLSCP, useful information may also be obtained from high resolution atmospheric models coupled to land-surface schemes of varying complexity, and results of studies of the sensitivity of the energy and water balance at a range of time and space scales to changing vegetation cover.

5.3 Radiation

The overall broad goal of the GEWEX atmospheric radiation physics thrust, led by the GEWEX Radiation Panel, is an improved assessment of cloud-climate feedback, essential in achieving more confident projections of climate change. The general approach being followed is to use existing and new data sets to quantify the extent to which clouds affect the radiative heating of the atmosphere; this then influences the atmospheric circulation and feeds back to clouds.

Cloud feedback and climate forcing

At its twentieth session, the JSC commented that activity in the GEWEX radiation thrust did not appear sufficiently directed towards understanding the role of cloud feedback in a model's climate sensitivity. At this session, therefore, the JSC welcomed the renewed consideration being given to this topic by the GEWEX Radiation Panel which would involve a far more dynamic study of cloud and its dependence on interacting atmospheric parameters (temperature, moisture, circulation) (the last of these has previously been very much neglected). The strategy proposed would be bipolar, firstly exploiting observations from all available sources to define the state of the atmosphere and determine the fluxes, and secondly improving the formulation of cloud processes/radiative transfer and interaction in models. The latter element should particularly draw on recent progress in developing new parameterizations and would also include an updated "Intercomparison of Radiation Codes in Climate Models" (ICRCCM). An integrated approach will be followed in understanding climate forcing and feedback and use will be made of the techniques now available for analysing highly non-linear complex systems. Aspects such as the precipitation efficiency of clouds and overlap assumptions in estimating total cloud cover will also be explored. An article outlining the overall strategy is being prepared (for publication in a suitable scientific journal) which will then form the basis for organizing a workshop on cloud feedbacks in the climate system in the next year or so. In view of the uncertainties in cloud feedback in climate models repeatedly emphasized by the Working Group on Coupled Modelling, this group would be closely involved in planning the workshop and the detailed definition of the specific tasks to be undertaken.

International Satellite Cloud Climatology Project (ISCCP)

ISCCP has now completed more than sixteen years of data collection. Radiances from operational meteorological satellites, with the exception of INSAT, continue to be collected by the relevant Sector

Processing Centres and delivered to the ISCCP Global Processing Centre at the NASA Goddard Institute for Space Studies in New York in accordance with the defined procedures. Currently operating satellites are NOAA-14, NOAA-15, GOES-8, GOES-10, GMS-5, METEOSAT-5 and METEOSAT-7. NOAA-15 replaced NOAA-12 in the "morning" position in December 1998, but budget shortfalls have delayed delivery of these data, as well as from NOAA-12 and NOAA-14. Problems with data formats have also delayed deliveries of much of the GOES data. METEOSAT-5 has been operating over the Indian Ocean since July 1998, where it is now expected to remain until the end of 2001. If the launch of the METEOSAT Second Generation craft to replace METEOSAT-7 is successful and either METEOSAT-6 or METEOSAT-7 is still healthy, one of these will move to replace METEOSAT-5. The launch of MTSAT to replace GMS-5 failed; actions are being taken to extend the life of GMS-5.

Regarding the status of the ISCCP cloud product data sets, full details are presented on the ISCCP home page **http://isccp.giss.nasa.gov**. The new reanalyzed products (D1/D2) up to the end of 1998 should be available by mid-2000, when a CD-ROM (D2 data) covering the period 1994-1998 will be issued, complementing the earlier releases for 1983-1988 and 1989-1993. Looking to the future, attention must be given to restoring the funding shortfalls affecting the delivery of NOAA polar orbiter data referred to above. Beyond this, in line with the discussion in section 5.1, it is foreseen that production of ISCCP data sets will be continued for at least another five years. Certain enhancements are expected, including the development of techniques for the improved identification of thin cirrus and multi-layer clouds, and for the determination of effective particle sizes for both liquid and ice clouds. In support of GEWEX Cloud System Study (see section 5.4.1), methods for identifying and tracking specific types of clouds and following the lifecycles of different dynamical systems are being explored. Modifications to the ISCCP analysis system are being examined to enable exploitation of higher measurements from other satellites for experimental uses.

Surface Radiation Budget

The NASA Langley Research Center is preparing for the production of a refined global data set of surface short-wave and long-wave radiative fluxes, with a start shortly to be made on processing and archiving a twelve-year data set (also including a top-of-the-atmosphere radiative budget climatology) (designated “Release 2”). As well as new versions of the algorithms to infer short- and long-wave fluxes, ISCCP pixel-level data will be used, improved gap filling strategies have been developed and a revised background aerosol loading employed. The use of meteorological parameters from reanalyses has been examined. Assistance has been obtained from the Langley Atmospheric Sciences Data Center for data processing and archiving.

Baseline Surface Radiation Network (BSRN)

The objective of the BSRN is to observe surface short- and long-wave radiative fluxes at the highest attainable accuracy in a number of contrasting climatic regions. These measurements are valuable in assessing theoretical treatments of radiative transfer in the atmosphere (including particularly validation of the GEWEX surface radiation budget climatology), verifying climate model computations, and for monitoring regional trends in surface radiation. Nineteen sites are currently active in a variety of locations (polar regions, mid-latitude forested and plain areas, mountain massifs, tropical rainforest, deserts) and are submitting data to the central BSRN archive at the Swiss Federal Institute of Technology in Zurich. A further 18 sites have indicated that they wish to be considered as BSRN stations, but are as yet only partially producing BSRN quality data. Furthermore, several of these sites are not complying with BSRN standards for timely submission of the relevant measurements.

GEWEX Water Vapour Project (GvaP)

The implementation of the next stage of GvaP, aimed at improving knowledge of the variability of water vapour, its radiative effects, feedbacks and change due to human activities is now being considered. A workshop during 1999 reviewed relevant scientific and technical issues and the opportunities offered by new observations or observing techniques, based on which a plan is being drawn up for a new version of a global water vapour climatology data set. At the same time GvaP needs to be placed on a more international footing, the approach being employed should be assessed and linkages developed with other relevant initiatives, in particular the SPARC work aimed at refining the water vapour climatology in the lower stratosphere and upper troposphere and the comprehensive Water Vapour Assessment (WAVAS) (see section 6.2.3).

Global Precipitation Climatology Project (GPCP)

The basic monthly mean GPCP product on a 2.5°x 2.5° grid now covers the period July 1987 until the present. A "version 2" data set has been created, in which the 2.5°x 2.5° monthly mean record has been extended back until 1979, by making use of TOVS data to fill in the polar regions and values inferred from an OLR-based algorithm. The basic satellite data themselves are now collected at 1°x 1° three-hourly space/time resolution, and are used in the preparation of the 2.5°x 2.5° product and, recently, trial 1°x 1° daily fields. This latter data set (for the period January 1997 to April 1999) is being evaluated. It has been designed so that it scales appropriately to the 2.5°x 2.5° monthly mean values. Daily gauge analyses are being developed by the Global Precipitation Climatology Centre (hosted by Deutscher Wetterdienst) and will be incorporated into the 1°x 1° analysis as they become available.

GPCP products are primary input to the GEWEX hydrometeorology thrust, in particular CEOP and the WEBS task (see section 5.2). The error estimates that are included in the GPCP data base (for the infrared and microwave satellite data and the gauge analyses) are especially valuable in giving a quantitative indication of the confidence to which the water budgets may be closed. To meet the requirements of the continental-scale experiments, the possibility of preparing satellite-based regional precipitation data sets at considerably higher spatial (0.25°) and temporal (one-hour) resolutions is being considered. In the other direction, data from the continental-scale experiments will be of value in validating precipitation estimates based on remotely-sensed data.

GEWEX aerosol studies

The principal activity under this heading is the GEWEX Global Aerosol Climatology Project, set up in 1998, to analyse satellite radiance data, supplemented with available surface observations and ground validation measurements to infer the global distribution of aerosols, their properties, radiative forcing effects and seasonal and interannual variations.

Intercomparison of Radiation Codes in Climate Models (ICRCCM)

After a gap of some years, new activity in ICRCCM is being planned. As noted at the start of this section, this will be a key element of the intensified attention being given to cloud feedback and climate forcing in the GEWEX radiation thrust. Studies of the performance of codes in both clear and cloudy conditions and comparisons with observations will be organized, and will be extended to include examples of clear-sky computations with water vapour conditions typical of the tropics and of polar regions. Analyses will be particularly directed to test the assumptions embedded in different codes, systematic errors that may be introduced in the computation of fluxes, and the use of fractional cloudiness as a means of dealing with three-dimensional effects. This exercise will also establish the range of radiative flux and heating rate estimates from one-dimensional models in the presence of identical cloud descriptions and provide a means of testing and developing parameterizations of sub-grid scale variations of cloud/radiation effects suitable for use in climate models.

Ocean Surface Turbulent Fluxes

The possibility of obtaining estimates of global ocean evaporation, the diurnal variation of sea surface skin temperature and the surface heat flux from satellite data at high-resolution space and time-scales is being actively explored by the radiation science community (although this is not formally an approved GEWEX or WCRP project). As well as drawing on satellite radiance measurements as in the past, the use of scatterometer and ocean altimetric data offers the prospect of significant refinement to the type of algorithms that could be employed. A workshop was organized in Boulder, CO, USA in July 1999 to review the development of methods for determining ocean surface sensible and latent heat fluxes from satellite data and to organize comparisons with available detailed high temporal resolution observed surface data sets. It was particularly noted that progress would depend on close collaboration with the oceanographic community where most of the expertise in validating ocean surface fluxes and experience in using them resided. A further workshop was planned during 2000 to examine the results of comparisons and to consider the implications for future work in this area.

The JSC reiterated the importance of close co-ordination of this activity with the surface flux efforts in WCRP (particularly that of the JSC/SCOR Working Group on Air-Sea Fluxes in producing a detailed assessment of surface flux and flux-related data sets, see section 7.1, and the WGNE SURFA project, see section 4.1.5). The consideration of the overall organization of work on surface fluxes in the WCRP by the JSC is summarized in section 7.

5.4 Modelling and prediction

The modelling and prediction thrust of GEWEX has the objective of developing and evaluating improved interactive model formulations of atmospheric and land-surface processes that regulate the global hydrological and energy cycle. This thrust, which includes specifically the GEWEX Cloud System Study (GCSS) and the new Global Land-Atmosphere System Study (GLASS), is conducted by the GEWEX Modelling and Prediction Panel (GMPP). In view of the close relationship between the activities of the Modelling and Prediction Panel and those of WGNE, as noted in section 4.1.1, the two groups meet jointly.

5.4.1 The GEWEX Cloud System Study (GCSS)

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

Boundary layer clouds (WG1)

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

Cirrus clouds (WG2)

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

Extra-tropical layer clouds (WG3)

Attention has been given to the development of a methodology for testing parameterizations of relevant cloud processes in cloud-resolving and meso-scale models. Also, a statistical survey to compare extra-tropical layer clouds as simulated in NWP and climate models with the equivalent International Satellite Cloud Climatology Project (ISCCP) results has been undertaken. A case study based on data from the Fronts and Atlantic Storm Track Experiment (FASTEX) is being planned. (This will include convective cirrus and boundary-layer clouds, so should additionally be useful to the other GCSS working groups, and is a first step towards a unified GCSS study). Another question being considered is the treatment of orographic clouds in models, particularly cloud processes related to sub-grid scale orography. Generally it is being found that mesoscale models underestimate the middle-level cloud generated by frontal systems but possibly overestimate the amount of high cloud. An outstanding question in this respect is whether sublimating cirrus is a trigger for pre-frontal descent that suppresses the middle cloud, and if so whether this effect is spurious or exaggerated.

Precipitating convectively-driven cloud systems (WG4)

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

Polar clouds (WG5)

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

Revision of GCSS science and implementation plan

As reported at the twentieth session of the JSC, a workshop on cloud processes and cloud feedbacks in large-scale models, organized by GCSS and WGNE took place at ECMWF in November 1998. Stemming from recommendations from this workshop, the GCSS science and implementation plan is being updated. A specific strategy for dealing with issues in cloud process modelling is being added, as well as ideas on how GCSS can contribute to the renewed consideration of cloud/radiative feedbacks in the climate system in the GEWEX radiation thrust (see section 5.3).

5.4.2 Land-surface processes

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

One of the main activities in assessing parameterizations of the interaction between the atmosphere and land-surface in models up to now has been the Project for Intercomparison of Land-surface Parameterization Schemes (PILPS). Overall, PILPS has indicated the surprisingly poor closure of energy and water budgets in the treatment of the surface, large differences in simulations between different schemes, the strong sensitivity to soil moisture initialization, large divergences in “spin-ups”, and wide variation in the abilities to reproduce observations. Even when schemes are coupled to their own or a common host model, the range of differences is not reduced. Ideas for the future include runs with a wide variety of surface energy balance configurations (e.g., treatments of transpiration, soil evaporation, canopy interception) in large-scale models but where other aspects of the parameterizations are identical and all effective surface parameters can be controlled. A multi-criteria calibration optimization will also be employed, a tool designed to optimize the initial states of participating land-surface models. Furthermore, the range of application of PILPS studies will be extended to assessing carbon fluxes, and to intercomparisons of such aspects as plant respiration and the interaction between soil moisture and plant physiology in land-surface schemes (in view of the increasing importance of the “greening” of land surfaces to enable the biological properties of the surface to influence appropriately climate and the hydrological cycle). Liaison will be developed with relevant IGBP activities such as Global Analysis, Interpretation and Modelling (the regional interactions of climate and ecosystems) and the Biological Aspects of the Hydrological Cycle (parameterizations of land-atmosphere interaction). The earlier successful efforts of PILPS, especially phases 1 and 2 which introduced intercomparisons of land-surface schemes, and then compared the treatment of specific cases with observations (thereby identifying discrepancies between models and observations) will be continued. Overall, there appears to be a need for PILPS to assess continuously new and old land-surface schemes as they are developed and refined. In this respect, useful input is being provided to the IPCC Third Assessment Report. An issue of concern is the explosion of the number of parameters in land-surface schemes and their increasing complexity.

Also, as part of PILPS, a specific AMIP sub-project has studied the treatment of land-surface processes in AMIP simulations. A model's perceived performance depended on the land-surface variable assessed. The evaporation from the land-surface showed some sensitivity to the associated land-surface representation in that simple bucket representations tended to exhibit different spatio-temporal variability statistics than more complex treatments. However, a particular coupling of a simple bucket with an atmospheric model may yield global statistics that are nearly indistinguishable from those associated with more complex approaches, although some aspects of the simulation of the surface evaporation might be improved. The most marked divergence between bucket schemes and more complex representations is in the zonally asymmetric part of the land-surface evaporation field - but this may be a reflection of different choices of surface characteristics (e.g. albedo, surface roughness) more than intrinsic deficiencies of the bucket schemes. In any case, while there may be some improvements in the simulation of the global interannual variability of land-surface climate from the introduction of more refined land-surface schemes, the impact is limited by model shortcomings in other features such as the seasonal cycle of precipitation, as well as the overall effects of sensitivity to different initial conditions. However, the analysis so far has only been limited, there are shortcomings in the chosen reference data set, and these initial findings can only be regarded as tentative. In the future, alternative validation reference data will be employed, and energy/moisture partitionings and other diagnostics will be studied together with other assessments to try to determine better the relative influence of land-surface characteristics or the parameterization schemes themselves in the simulation of land-surface coupling in continental climates.

Six updated AMIP simulations have also been examined to assess the impacts of model revisions, particularly land surface representations, on the treatment of soil moisture. No systematic improvement in the simulation of observed seasonal variations of soil moisture over the regions studied was apparent, with a continued strong tendency towards dry soil conditions during Northern Hemisphere summer months both globally and regionally. However, as the seasonal cycle of regional precipitation is not correctly produced even in these revised models, it is not possible really to assess how the land surface schemes are performing. (This again points to the need for continuing PILPS off-line experiments as a means of evaluating and improving land surface schemes).

Global Soil Wetness Project

Another important activity enabling assessment of the treatment of land-surface processes in models is the Global Soil Wetness Project, led on behalf of GEWEX by the International Land Surface Climatology Project (ISLSCP) (see section 5.3). The goals of the project are: to produce state-of-the-art global data sets of soil moisture, surface flux and related hydrological quantities over land; provide a means of testing and developing large-scale validation techniques; enable a global comparison of a number of land-surface parameterizations, including a series of sensitivity studies with specific schemes that could aid future model developments. In a pilot phase, global soil wetness fields (on a 1°x 1° grid) for the period 1987-1988 (based on the ISLSCP "Initiative I" data set) have been computed, and appear to be of higher quality than previously available products of this type, possibly as a result of the comparatively high horizontal resolution and use of observed precipitation forcing. Depending on the availability of ISLSCP Initiative II data sets (at a resolution of 0.5°x 0.5° over a ten-year period), revised, extended and higher resolution global soil wetness data sets will be produced in the near future. By such means, the Global Soil Wetness Project offers the possibility of comparing land-surface schemes at a resolution comparable to that of atmospheric models, of developing models and testing land-surface assimilation techniques. The soil moistures generated can also be directly verified against observations where these are available.

Development of land-surface parameterization activities

In order to review the overall framework and goals for the advancement of land surface models and analyses, and to promote the incorporation of improved land surface parameterizations into general circulation models, a workshop on “Modelling land-surface atmosphere interactions and climate variability” was organized in France in October 1999 under the auspices of GMPP and WGNE. Challenges such as the "greening" of land-surface parameterizations, and a more comprehensive treatment of soil freezing have to be taken into account, and this will bring new prognostic variables into land-surface schemes. Also, whereas the first generation of land-surface treatments were characterized by a highly detailed representation of vertical processes and simple assumptions on horizontal variability, the new generation would need to increase horizontal complexity and include a representation of the sub-grid scale variability of surface properties.

The workshop concluded that the development of improved land surface parameterization schemes and encouraging their incorporation into general circulation models should be supported by a new structure of complementary scientific activities. The "greening" of land-surface parameterizations, requiring international intercomparisons to validate representations of new features will continue to depend fundamentally on PILPS and its pioneering work in local off-line validation of land-surface schemes (as described above). The Global Soil Wetness Project is another essential element, enabling comparisons of new schemes at a global scale and identification of critical regions in which inadequate treatments and lack of data lead to divergence of results. Two further elements would be, firstly, study of issues of heterogeneity and data assimilation (of particular interest for operational modelling centres), and, secondly, exploration of the impact of land-surface processes on climate through carefully organized and co-ordinated coupled land-atmosphere modelling. In addition to these four scientific activities, a co-ordinated data and model infrastructure for advancing land-surface modelling and analysis should be developed. All these components would be complementary and interconnected under the umbrella of a new "**Global Land-Atmosphere System Study**" (GLASS). The detailed planning of GLASS would be overseen by a new GMPP "GLASS" scientific panel (this organization is closely analogous to that of GCSS, see section 5.4.1). A science and implementation plan would be drawn up during 2000. GLASS would be conducted in close association with ISLSCP and other related initiatives (particularly BAHC, for which GLASS will be well suited to assist in intercomparing models used).

The JSC agreed that GLASS appeared to be a useful, innovative and consistent new approach for fostering research into land-surface processes, and looked forward to being informed of the development of work in this area.

5.5 The Third International Conference on GEWEX

The Third International Conference on GEWEX was kindly hosted in Beijing, China, from 16 to 19 June 1999 by the China Meteorological Administration (in conjunction with the fourth GAME study conference). The Conference was regarded by all who attended (two hundred and eighty-two scientists from twenty-four countries) as a major success. Two hundred and ninety-two papers were presented (two hundred and twenty-four oral, sixty-eight posters). All participants appreciated the excellent arrangements made and hospitality offered.

Extensive meteorological and hydrological data sets have now been collected by the continental-scale experiments, and many new results based on these observations were presented at the Conference. Examples were shown of refined physical parameterizations of land-surface processes and of cloud-radiation interaction. Many notable developments in hydrological and land-surface models were reported. These models are now demonstrating the ability to be coupled with global and regional climate models, improving the overall simulation and/or prediction performance. Many new diagnostics of global energy and water cycles were described - in this respect, results from the Intensive Observing Period of the GEWEX Asian Monsoon Experiment (GAME) in 1998 (co-ordinated also with the South China Sea Monsoon Experiment, SCSMEX) were a particular focus of attention. Many contributions at the conference demonstrated the role of the coupled land-atmosphere system in climate variability through anomalies in soil moisture, land-surface characteristics and radiation processes. The findings will further support the development of climate and hydrological predictions on monthly, seasonal and interannual timescales which are so essential in water resource management. Other topics taken up included the variability and predictability of Asian/Australian and African monsoonal circulations, heavy precipitation and cloud systems in the tropics and sub-tropics, the connection between the water and carbon cycles, high latitude and high-altitude hydrology, and climate change and its impact on water resources and on the intensity of the hydrological cycle on global and regional scales. During the Conference, the potential importance of CEOP bringing together all the GEWEX atmospheric and hydrological process studies was repeatedly stressed.

6. STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE (SPARC)

Dr. M.-L. Chanin and Professor M. Geller, Co-chairs of the SPARC Scientific Steering Group, reviewed the main developments and events relevant to SPARC during the last year, as described in the following paragraphs. SPARC has been operating since 1992 in what might be called its "first phase" and adjustments to the strategy laid out in the SPARC Implementation Plan (WCRP-105, June 1998) are now being considered (see, in particular, section 6.5).

6.1 Modelling stratospheric effects on climate

6.1.1 Intercomparison of stratospheric models

The "GCM Reality Intercomparison Project for SPARC" (GRIPS) has grown both in the number of research groups involved and the range of tasks being tackled. An account of results from the first phase of GRIPS and their scientific implications appeared recently in the Bulletin of the American Meteorological Society. In summary, the first phase of GRIPS, a simple intercomparison of model stratospheric simulations, has shown that there is a wide range of skills in the simulations, but almost all show a cold bias in the global mean temperature at all levels. Furthermore, the simulated planetary waves differ considerably between models as does the structure of the stratospheric polar vortex. There are significant systematic errors in zonal-mean zonal winds which are related to the drag due to resolved and parameterized waves in the models. In particular, the spectra of convectively-forced waves resolved differs widely between models. These waves depend on the convective parameterization employed and the ability of numerical schemes to allow their propagation. These differences mean that models require varying amounts of forcing due to parameterized gravity waves and work on improved parameterizations together with a better understanding of gravity wave morphologies and sources are needed. As well as experimentation with GCMs, progress will depend on interaction with the SPARC gravity wave initiative (in which the “Effects of Tropical Convection Experiment” being held over Northern Australia in 2002-2003 is a major ingredient) (see section 6.3.1).

The second phase of GRIPS, now being organized, involves further validation of models and carrying out controlled experiments to test parameterization schemes, including particularly investigation of radiative codes in use, of model responses to the formulation of mesospheric drag, and of gravity wave parameterization. Other activities are being planned to clarify the understanding of the factors that determined the stratospheric state from 1979 to 1999, thought to be natural variability, lower boundary forcing, and variations in radiative forcing. This last effect will be studied by performing a series of perturbation experiments, imposing interannual changes in solar forcing, ozone and volcanic aerosols. (The solar forcing experiments have been taken up specifically in response to the request of the JSC at its twentieth session in March 1999 when discussing the issue of solar forcing and climate variability- see also section 6.4.2.) It is hoped that the results of the SCOSTEP International Solar Cycle Studies project that is studying the time-variation of solar UV and total irradiance can be made available for input to modelling activities.

As still a further step, experimentation will be organized imposing climate change scenarios and comparing ensembles of transient runs. This will have the objective of demonstrating the impacts of middle atmospheric change on climate. These activities in GRIPS will draw on two projects related to SPARC which the European Commission has recently agreed to support, namely Solar Influence on Climate and Environment (SOLICE) and (the European) Stratospheric Processes and their Impacts on Climate and the Environment (EuroSPICE). SOLICE will attempt to determine the mechanisms by which solar changes have an impact on climate, organize investigative model runs and intercompare results, and extend and improve existing data analyses. EuroSPICE will involve model simulations for the period 1980-2000 to assess the impact of stratospheric ozone trends, and for the period 2000-2020 (using the best possible predictions of trace gas concentrations).

The simulation of the quasi-biennial oscillation (QBO) remains another challenge. While a few models are now able to reproduce this feature (although differing more or less from the observed), in some cases, the QBO-like oscillation appears as the vertical resolution increases, in others it occurs as the representation of physical processes (in particular, the parameterization of gravity waves) is varied. A detailed evaluation of this question is also being planned as part of GRIPS.

6.1.2 Stratospheric reference climatology

A refined climatology of the means and variabilities of basic stratospheric parameters is needed for GRIPS, as well as a number of other SPARC initiatives. A series of monthly global climatologies of temperature, zonal winds, and various atmospheric trace constituents (N_2O, O, CH_4, H_2O, O_3, NO_2, HNO_3, etc.) have been assembled from UARS and other data. Monthly and daily stratospheric circulation statistics have been inferred from available stratospheric analyses or reanalyses including those from NCEP, UKMO, Free University of Berlin, and NASA/GSFC. Other data compiled include upper-level radio-sonde winds from Singapore (as an indicators of the phase of the QBO) and statistics on tropopause height.

Attention is now being given to setting up these data sets in accessible form at the SPARC data centre (see section 6.8). It is also planned to produce a technical report during 2000 describing the data sets, comparing stratospheric circulation statistics, and quantifying uncertainties and interannual variability**.**

6.1.3 Climate forcing in the stratosphere

Under the auspices of SPARC, a review of stratospheric aspects of climate forcing has been undertaken in order to provide, for the use of the climate modelling community, the current best estimates of the relevant parameters. The approach has been to consolidate existing information and assemble time-varying distributions from 1880 to the present together with indications of uncertainties.

The work has now been completed and a full report was included in SPARC Newsletter No. 14 (January 2000). With respect to ozone, a composite climatology as a function of latitude and height has been recommended based on the data set compiled by Randel and Wu (1999) in the stratosphere (using SAGE and ozonesonde data), and the data set of Kiehl, Portman and Solomon (1999) in the troposphere. Time variations are taken from the SPARC ozone trends assessment (as now incorporated in the latest WMO/UNEP Assessment, 1998). For stratospheric aerosols, the Sato (1993) distribution as a function of height and time is proposed. The perturbations resulting from a “typical”: (e.g., Pinatubo) volcanic eruption could be drawn from the work of Robock and Stechnikov (1998). As for variation of the solar constant since 1880, and changes of the solar spectrum during a typical solar cycle, the best estimate was considered to be that in Chapter 6 ("Radiative Forcing of Climate") in the draft IPCC Third Assessment Report now in course of preparation. All the relevant data are available at the SPARC data centre (see section 6.8).

6.1.4 Stratospheric data assimilation

The SPARC Scientific Steering Group recognized that data assimilation is one of the foundations of climate research, being the means by which observational data are combined with the output from a dynamical model to give an optimal representation of the evolving state of the atmosphere (or other components of the climate system). At the same time, data assimilation provides an objective quality control of observational data, the basis for combining different types of data in a consistent manner, error estimates, extrapolation of background fields and observations over data-sparse regions, and can be used as a tool in assessing the design of observing systems. Data assimilation very much depends on co-operation and interaction between modellers, observationalists/instrument experts, and scientific users. The whole field is undergoing rapid development at present with optimal interpolation (OI) techniques being superceded by three- and four-dimensional variational approaches. Against this background, focussed stratospheric data assimilation efforts are likely to offer good opportunities to encourage interdisciplinary exchange within the stratospheric community and links to numerical weather prediction centres. This is especially important in view of the new streams of stratospheric data coming on line from (research) satellites in the next few years (e.g., ENVISAT, the NASA EOS series, etc.). As well as these data, full access is required to the operational meteorological data sets compiled at the main global numerical weather prediction centres.

Accordingly, the SPARC Scientific Steering Group agreed that it would be useful and timely to review the status of stratospheric data assimilation and specific related problems (including stratospheric data availability). Consideration is being given to planning a workshop to gather information on current activities and to discuss developments in stratospheric data assimilation that may be needed. This initiative will be closely co-ordinated with the Working Group on Numerical Experimentation which has overall responsibility in the WCRP for data assimilation questions.

6.2 Long-term changes in the stratosphere

6.2.1 Stratospheric temperature trends

The original objectives of SPARC activities in this area were to intercompare various data sets and assess the temperature trends apparent in the lower stratosphere and up to the level of mesosphere, as well as to evaluate the extent to which these trends could be explained by specific causes. As reported at previous sessions of the JSC, work undertaken includes the assembly of a range of relevant data sets (radiosondes, lidars, rocketsondes, satellite soundings (from MSU) and stratospheric soundings (from SSU)), and supporting modelling, i.e., simulations of the temperature response to changes in radiatively active species and forcing with observed trends. The results of the first phase of this initiative have formed the basis of Chapter 5 in the latest WMO/UNEP Ozone Assessment (published in 1999) on stratospheric temperature trends. A summary would also be published in Reviews of Geophysics in January 2001, and a full account would be prepared as a SPARC Report. The work carried out is also proving valuable input to the IPCC Third Assessment Report in particular for the discussion of radiative forcing of climate change, climate processes, and detection and attribution.

In view of the important questions involved, and especially the probability of further changes in stratospheric temperatures due to internal and external forcing, SPARC efforts in this area are continuing. Firstly, data sets will be updated until the end of 1999, and the trends and uncertainties recalculated. Additional work will be put in to resolve the discrepancies in the satellite and radio-sonde trends, and the "raw" data will be compared with the latest reanalyses (in particular the planned ECMWF 40-year reanalysis). Examination of rocket- and radio-sondes data will continue with a number of cross-checks being carried out in order to consolidate previous findings. All data sets will be analysed for seasonal trends and variability, with particularly close attention being given to northern hemisphere polar winter/springtime changes. The sensitivity of the trend calculations to spatial and temporal inhomogeneities in data and to the time period being examined will be explored.

New model investigations of the possible causes of the observed seasonal and mean stratospheric temperature trends (e.g., the potential effect of interannual changes in water vapour concentrations) and examination of trends over specific regions are also being planned. As a complement to the linear trend experiments carried out so far, sources of perturbations will be assessed by carrying out transient model simulations with the appropriate time-varying forcings (e.g., Pinatubo volcanic aerosol): the simulations will then be compared to observations. In all cases, comparisons with data will be more rigorous. Also, with an increasingly long data record, it may be possible to make more definite deductions on questions of detection and attribution.

It is noted that the overall objectives of this SPARC initiative are becoming broader than those set originally, with plans also in hand to analyze temperature trends above the middle stratosphere in collaboration with the International Commission of the Middle Atmosphere (ICMA), and the Scientific Committee on Solar Terrestrial Physics (SCOSTEP) (as recommended by the International Workshop on Long-term Changes and Trends in the Atmosphere, Pune, India, February 1999). Furthermore, trend estimates near the tropopause will be refined (including a better determination of tropopause height), the solar cycle signature in observations and models explored, and stratosphere-troposphere coupling investigated. Specific efforts focused on climate variability and long-term change, and research on the major unresolved issues to have become apparent in the stratospheric temperature trends study in the past few years will also be undertaken. Beyond this, it is clear that temperature trends are closely linked with changes in other stratospheric parameters (ozone, water vapour, dynamical activity, etc.), and activities will have to become increasingly integrated with the SPARC studies in these areas.

What has been strongly emphasized by the different groups of scientists who have been involved in this work has been the value of the SPARC umbrella under which coherent international research into stratospheric temperature trends (using both observations and models) has been carried out and plans for the future drawn up. It is viewed as important to keep the international “expert” SPARC temperature trends sub-group, comprising observationalists, modellers and diagnosticians together.

6.2.2 Understanding ozone trends

After the major effort in 1998 to finalize the work or the assessment of trends in the vertical distribution of ozone (published as SPARC Report No. 1 in May 1998) and which was also an essential foundation for the latest WMO/UNEP Ozone Assessment, thought is being given to the further development of studies in this area. Topics that will be taken up include attribution of past stratospheric ozone trends and to explore whether the effect of the Montreal Protocol can yet be detected. There is a need to consolidate existing work and to foster more research by promoting contact between research groups. The aim is to assemble relevant updated results as a set of peer-reviewed papers and/or SPARC reports (or in other appropriate format), to be available in 2002, which could feed into the next WMO/UNEP Ozone Assessment in 2002-2003.

In this research area also, it was stressed by the scientists involved that SPARC has provided an ideal context for encouraging the type of international co-operative research and cross-disciplinary discussions needed by bringing small groups of working scientists into contact. In the longer term, an evolution to study of trends in stratospheric parameters in general (including temperature) could be foreseen (see also sections 6.2.1, 6.2.3 and 6.5).

6.2.3 Stratospheric and upper tropospheric water vapour

SPARC work in this area originally set out with the intention of refining the water vapour climatology in the lower stratosphere and upper troposphere. It has now developed into a comprehensive SPARC Water Vapour Assessment, which is specifically investigating the concentration, distribution and variability (long-term change or trends) of water vapour in the upper troposphere and lower stratosphere. The processes controlling the present distribution of upper tropospheric/lower stratospheric water vapour are also being studied to the extent possible. The Assessment comprises:

- reviews of techniques of measurement of water vapour, descriptions of measurement systems and error estimates; identification of the most recent accurate data sets available;
- assessment of the quality of available data sets (taking into account limitations in data coverage and accuracy, and including data intercomparisons);
- best estimates of water vapour distribution and variability based on the above.

Urgency was attached to this assessment since the water vapour question represents the single largest uncertainty for accurate prediction of global and regional warming likely to result from the increases in atmospheric CO_2 concentrations. Neither the global and regional distribution of water vapour nor its seasonal variation is known with an accuracy that allows climate models to be validated. Intensive effort has duly been devoted to the preparation of the Assessment during the past year, and a first draft was sent out for peer review in November 1999. A full review meeting was held in Paris in January 2000 which agreed on the more or less final version of the Assessment, which would be printed and published by the end of 2000. The basic finding is that measurements of water vapour in the upper troposphere/lower stratosphere indicate an upward trend. However, useable data only extend back about twenty years and uncertainties are large. Routine meteorological soundings of water vapour appear not to be useful at these levels and in the upper troposphere, the main source of information is satellite measurements (available since 1979); these show a small but weakly significant trend (+0.04% per year in the averaged 60°N-60°S relative humidity). The uncertainty in specific humidity values (inferred from measurements of relative humidity and temperature) are too large to be able to identify any significant trend with confidence. In the lower stratosphere, the longest continuous reliable data set is of balloon measurements at a single location (Boulder, CO) since 1981. These data show consistently positive water vapour trends (1% per year at all levels between 10 and 28 km, the increases being statistically significant above 16 km). Regarding satellite measurements in the lower stratosphere, the SAGE-II record, although from 1985, has been badly affected by volcanic aerosols and it cannot be used for trend studies. HALOE has offered continuous stable measurements since 1991, which, although over a much shorter period, show globally an increase of about 2% per year between 20 and 70 km (cf 1% for the balloon record). However, there is a puzzling change in the trend from 1996 (this points to the limitations of using records of only a few years in this type of study). Understanding of factors controlling the long-term changes in upper tropospheric/lower stratospheric water vapour is not adequate either to explain the trends or to make projections into the future (e.g., the trend in the Boulder record is about twice that expected from methane oxidation alone; an increase in the average saturation mixing ratio at the tropical tropopause would be a simple explanation, but, although estimates are difficult and uncertain, trends in this appear to be in the opposite direction). The overall sobering conclusion is that the present set of observations are not adequate to provide answers to several of the fundamental questions about the influence of upper tropospheric/lower stratospheric water vapour on climate. The Assessment recommends a comprehensive and organized approach to monitoring water vapour in these regions of the atmosphere. A summary of the main findings has been submitted to and would appear in the IPCC Third Assessment Report.

6.3 Stratospheric processes

6.3.1 Gravity wave processes and their parameterization

The construction of a stratospheric gravity-wave climatology based on high-resolution radio-sonde data was considered at a workshop in Abingdon, UK in July 1999, where the results from an initial analysis were reviewed. Issues taken up included quality control of radio-sonde data, possible errors associated with the horizontal drift of the soundings from the original station location, the range of height covered in the stratosphere, averaging intervals, the effects of gaps in spatial coverage and intermittency of observations. The use of the theory and modelling to aid in the interpretation of observations was also discussed. It was agreed that gravity-wave climatologies should now be produced including monthly-mean values of kinetic and potential energy, the directions of propagation of gravity waves in the horizontal, wave spectral/frequency characteristics, ratio of upward propagating to downward propagating energy and mean vertical wavelengths. The climatology would cover a 7 km layer in the lower stratosphere (the lower boundary of which would be determined by the mean height of the tropopause) and would extend over as many years as possible in order to be able to study the interannual variability of gravity-wave activity. The feasibility of deriving other parameters for research purposes such as intrinsic frequencies, horizontal wavelengths, phase velocities and, possibly, momentum fluxes will also be examined. The climatologies were expected to be available for review by participants in the work in the first half of 2000. It is planned later to submit for publication a series of articles describing the research efforts that have gone into the generation of the climatologies.

The planning of the international field experiment to investigate the gravity-wave field forced by tropical convection (now known as the “Effects of Tropical Convection Experiment”, ECTE) is progressing. During the six-week intensive observation period (late October-early December 2002) the intense diurnal convection that occurs over the Tiwi Islands, north of Darwin, Australia, will be studied in detail. The objectives are to obtain a hitherto unprecedented detailed picture of the development of tropical deep convection in three dimensions, to investigate the generation of stratospheric gravity waves by convection, to assess the effects of convection on transport and mixing in the upper troposphere and lower stratosphere and on the transformation of ozone precursors in the upper troposphere, to observe the generation and subsequent dynamical and microphysical evolution of tropical anvil cirrus, and to study the effects of deep convection in stratosphere/troposphere exchange, particularly the injection of water into the stratosphere. The role of tropical convection as an excitation mechanism for gravity waves is particularly important in understanding and modelling stratospheric dynamics since a significant component of the eddy-driving of the mean flow is due to sub-synoptic scale gravity waves (i.e., wavelengths 10-2000 km). Many key resources required for the experiment will be available in principle, including: polarized Doppler radars from BMRC, Australia and NSF/NCAR, USA; the USA NSF/NCAR Electra aircraft with Eldora radar; the USA NSF WB-57 high altitude aircraft. Australia is providing the basic infrastructure needed (with strong backing from the Australian Bureau of Meteorology and various Australian universities). As well as the Doppler radar and aircraft, the USA may offer a cloud radar, a lightning mapping system, airglow imagers, a lidar and a barograph network. France, the United Kingdom, New Zealand, Canada and Republic of Korea are also participating with contributions to the observational programme, or supporting modelling studies.

A detailed plan of the scientific objectives and instrumentation to be deployed during the field campaign may be viewed at **http://www.princeton.edu/~kph/EXP2**.

6.3.2 Lower stratospheric/upper tropospheric processes

Transport and mixing in the lower stratosphere and upper troposphere are fundamental to SPARC, and hold the key to many issues, e.g., the upper tropospheric/lower stratospheric ozone budget; mid-latitude water vapour distribution and tropical dehydration, However, there is still no overall strategy and theoretical framework for studying stratospheric-tropospheric exchange, paradigms that can be tested, or an obvious common measurement/diagnostic approach. Thus, the role played by SPARC in this area up to now is to keep under review the basic questions that need to be addressed and to bring the different communities involved in this subject together in various focussed workshops. In view of the importance of the tropopause (where climate/ozone issues come together), consideration is now being given to planning a “tropopause workshop” during 2001. The workshop would take up topics such as:

- what is the tropopause, how well is it known, why does it take the form that is observed?
- what is the role of the tropopause in upper tropospheric/lower stratospheric physical/chemical/dynamical processes and the implications for tropospheric chemistry/climate?
- how may the tropopause be expected to change in the future?

As well as the above initiative, joint SPARC-IGAC studies of chemical processes in the upper troposphere/lower stratosphere are going forward, including work on the quantum yield of ozone photolysis reactions. Recent laboratory measurements have been carefully reviewed, and a paper is expected to be published during 2000 in which evaluated data will be presented in a form accessible to atmospheric chemists. Analysis of atmospheric chemistry data on small organic peroxy radicals (CH_3O_2, $C_2H_5O_2$, $CH_3C(O)O_2$) is also proceeding. This type of joint SPARC-IGAC activity is extremely beneficial to both projects and crucial in the evaluation of important upper tropospheric/lower stratospheric chemical reactions.

6.3.3 Penetration of UV radiation into the lower stratosphere and troposphere

There is already strong evidence of the effect of decreases of stratospheric ozone on the chemical composition of the troposphere. This occurs as a result of increasing UV flux into the troposphere enhancing the photodissociation of chemical species, leading in turn to greater tropospheric concentrations of the hydroxyl radical and perturbations in the distribution and lifetimes of species such as CO, O_3, CH_4, H_2O_2, HCFCs, HFCs, etc. It is essential to know the actinic flux distribution in the lower stratosphere and troposphere and to determine the climatology of photodissociation rate constants (J values) for various radicals as a function of altitude, and to make marked progress in model calculations. A joint SPARC-IGAC initiative is being launched with the objectives of evaluating existing data (including J values and actinic flux measurements), considering the requirements for new instrumentation and organizing validations of computations of radiative transfer at UV wavelengths. This activity fits well with and complements the joint SPARC-IGAC studies of chemical processes in the upper troposphere and lower stratosphere (see section 6.3.2). A workshop on UV measurements and radiative transfer modelling has been proposed and studies will be made of how to achieve a better synergy of ground-based and satellite observations (in co-operation with the WMO Global Atmosphere Watch Scientific Committee on UV Monitoring). This work will also be relevant to the newly proposed IGBP Surface Ocean and Lower-Atmosphere Study (SOLAS) (in which a principal question is to understand whether changes in the spectrum and intensity of solar radiation could affect the production of trace gases from the surface of the ocean) (see section 7.2).

6.4 Other scientific issues

6.4.1 Dynamical coupling of the stratosphere and troposphere

Two (somewhat speculative) aspects of what are thought to be manifestations of the dynamical coupling of the stratosphere and troposphere were noted. Firstly, an extensive review of the quasi-biennial oscillation (QBO) and its role in coupling the stratosphere and troposphere has been completed and published in Reviews of Geophysics in October 1999. This authoritative and substantial work had been based on the results of the SPARC workshop in March 1998 where the current state of research into all aspects of the QBO had been assessed. The QBO, which dominates the variability of the equatorial stratosphere, appears as downward propagating easterly and westerly wind regimes, with a variable period averaging approximately 28 months. The QBO seems to be an example (perhaps the premier) of a coherent oscillating mean flow that is driven by vertically propagating waves with periods unrelated to that of QBO. Although a tropical phenomenon, the QBO affects the stratospheric flow planet-wide by modulating the effect of extra-tropical waves and the variability of the mesosphere by selectively filtering waves that propagate upward through the equatorial stratosphere. A quasi-biennial signal is even apparent in the strength of Atlantic hurricanes. Neither are the effects of the QBO confined to atmospheric dynamics – chemical constituents such as ozone, water vapour and methane, act as tracers and can be modified by the circulation changes (in both hemispheres) induced by the QBO. Also, through modulation of extra-tropical wave propagation, the QBO may have an effect on the breakdown of wintertime stratospheric polar vortices and the magnitude of high-latitude winter ozone depletion. More recently, a symposium (held during the IUGG Assembly, in Birmingham, UK, in July 1999) reviewed the latest results relating to the QBO and internal gravity waves. The SPARC Scientific Steering Group has noted and encouraged work being carried out using data from radio-sondes, rocket-sondes, the Stratospheric Sounding Unit (SSU) and UARS HRDI to estimate zonal equatorial winds in the stratosphere and mesosphere over the period 1963-1999.

The reference to a possible relationship between the QBO and the Arctic Oscillation opens up the consideration of a linkage between the Arctic Oscillation and North Atlantic Oscillation as a manifestation of dynamical coupling between the stratosphere and troposphere. Among the key questions is that it is not known whether the Arctic Oscillation actually propagates or just appears to propagate into the troposphere: it may be possible that the tropospheric Arctic Oscillation is largely independent of the stratosphere and when the anomalies are in alignment, they amplify or reinforce each other. Equally, whether there is upward influence from the troposphere (i.e., upward wave propagation) is not known. The possible forcing of the Arctic Oscillation by the QBO is another question. There is fundamental disagreement as to whether the Arctic Oscillation is zonally symmetric or asymetric and, for example, whether an aqua-planet would have an Arctic Oscillation. Another tantalising speculation is that, if low-latitude zonal wind anomalies in the upper troposphere are caused by solar/UV influence, these anomalies could propagate northward (and downward), and interact with the Arctic Oscillation (and could thus be a mechanism for solar influence on climate!). More and more ideas are continuing to develop in this field (e.g., as reported at the special session at the American Geophysical Union meeting in December 1999 on the Arctic Oscillation, and as would no doubt be reported at a Chapman Conference on the North Atlantic Oscillation in October 2000 and the Second SPARC General Assembly in November 2000 (see section 6.7)). The SPARC Scientific Steering Group will assess carefully the scientific developments in this aspect of the dynamical coupling of modes of variability of the stratosphere and troposphere and consider periodically whether or not any co-ordinated research initiative in this area would be of benefit. The questions involved will also be discussed with CLIVAR.

6.4.2 Solar forcing and climate variability

As requested by the JSC, SPARC is keeping under review research on solar forcing, its variability as a source of variations in climate and possible underlying mechanisms (the CLIVAR Scientific Steering Group was asked to summarize evidence for past climate variability that could be explained by solar effects). The SPARC Scientific Steering Group noted that, although changes in the solar spectrum are known to affect ozone, temperature and the actinic flux in the middle atmosphere, there is still no consensus on whether tropospheric climate is influenced in any way by these changes. The data analysis planned in the European project SOLICE, and the modelling activities in GRIPS and SOLICE (see section 6.1.1) may help throw further light on this issue.

The JSC reiterated the importance of examining solar effects on climate, with emphasis to be given to assessing the various suggested mechanisms (see discussion on solar forcing and climate variability at the twentieth session of the JSC during the consideration of SPARC), in order that observed changes might be properly attributed to cause. This was another example of a cross-cutting activity in the WCRP where SPARC would be involved in studying the mechanisms involving the stratosphere, GEWEX on possible cloudiness variations linked to changes in solar output/cosmic rays, and CLIVAR in a rigorous interpretation of the observed climate signals.

6.4.3 Stratospheric monitoring

Continuing progress in stratospheric science depends on basic measurement programmes such as the WMO Global Atmosphere Watch and the Network for the Detection of Stratospheric Change (as well as the WMO World Weather Watch for basic dynamical stratospheric observations and the Global Climate Observing System). The monitoring of ozone in particular is a crucial issue in order to follow the recovery of stratospheric ozone consequent to the implementation of the Montreal protocol and it is essential to ensure the continuity and quality of ozone measurements. In this respect, the SPARC Scientific Steering Group strongly stressed the fundamental importance of the Global Atmosphere Watch ground-based ozone instrument and ozonesonde observations. It was recalled that it was through the Dobson network that the Antarctic ozone hole was originally discovered and that confidence had been developed in satellite-derived ozone trends. Ground-based measurements are still vital in complementing the increasing range of satellite measurements of ozone. The continuation of well-calibrated Global Atmosphere Watch observations was thus regarded as of high priority. This support of SPARC for the Global Atmosphere Watch has been communicated to WMO.

The SPARC Scientific Steering Group also noted that, faced with a possible gap in the continuity of global space-based measurements of total ozone, a mission “QuikTOMS” will be launched by NASA (planned for August 2000). The SPARC Scientific Steering Group has written to NASA thanking the agency for its responsiveness in this respect, and drawing attention to the need for similar responsiveness in addressing the looming gap in SAGE measurements, needed for determining the trend in the vertical ozone profile at mid- and low latitudes. However, there remains a compelling requirement to establish an internationally recognized suite of satellite "primary monitoring instruments" for measuring total ozone and the ozone vertical profile. SPARC is assisting in the definition of a CEOS-IGOS strategy in this respect.

6.5 <u>Review of overall SPARC strategy and status of implementation</u>

After seven years of activity, SPARC has made substantial progress in many of the tasks undertaken, including GRIPS, the compilation of a stratospheric reference climatology, assessment of stratospheric temperature trends, understanding ozone trends, refining estimates of upper tropospheric and lower stratospheric water vapour, and establishing a stratospheric gravity wave climatology (as described in the earlier sections of this document). The SPARC Scientific Steering Group is giving consideration to the overall strategy that has so far been followed and assessing whether any reorganization of the programme is now appropriate. Hitherto, SPARC initiatives have been fairly focussed and dealt with individually (by sub-project working groups). Although some of the scientific issues taken up obviously still need specific continuing efforts, it appeared that it may now be timely to integrate the knowledge acquired across SPARC in order to progress towards the goal of an overall understanding of all aspects of stratospheric variability and change, its interactions with the troposphere, and its role in climate.

Areas where concerted efforts are still clearly needed are: refinement of the gravity wave climatology and understanding the role of gravity waves in stratospheric dynamics; upper tropospheric/lower stratospheric chemistry and microphysics; the tropopause; solar forcing and climate variability. SPARC also saw the need to assess observations of stratospheric aerosols (jointly with IGAC). Additionally, there is a range of specific modelling questions such as the parameterization of gravity waves and others identified in the first phase of GRIPS (see section 6.1.1) as well as the topic of stratospheric data assimilation (see section 6.1.4).

The sort of basic structure foreseen for SPARC in the future would involve integration or synthesizing the understanding of stratospheric trends of temperature, ozone and water vapour, and solar effects through modelling studies. These would be particularly aimed at elucidating upper tropospheric/lower stratospheric variability, and its role in the overall climate system by building on the modelling work already carried out in the stratospheric trends study and GRIPS. However, additional models (e.g., two-dimensional, chemical transport) which have not so far been exploited in SPARC would also be required, as well as developing the use of data assimilation techniques. Furthermore, although the number of climate models which include the stratosphere is increasing, there is currently insufficient contact between the SPARC community and tropospheric climate modelling groups. The new SPARC efforts on stratospheric data assimilation and UV penetration could help in building bridges. Within this framework, the main priority for SPARC is to continue generally to facilitate research on stratospheric processes and their role in climate by providing a forum or umbrella for international co-operation and encouraging inter-disciplinary exchanges. SPARC will thus remain science-driven, but, at the same time, it should be in a position to provide the best available information on relevant stratospheric questions for the periodic international assessments such as those of IPCC and WMO/UNEP. This requires a forward-looking approach to identify new questions that could arise.

This topic will be taken up further at the next session of the SPARC Scientific Steering Group.

6.6 Interactions with other programmes and activities

As noted at several points in the preceding text, SPARC maintains strong links and/or interacts widely as appropriate and necessary with several other programmes (both through the medium of joint working groups and participation of other programme representatives in an ex officio capacity in sessions of the SPARC Scientific Steering Group). Particularly noteworthy is the co-operation with IGAC (the joint SPARC-IGAC activity on upper tropospheric/lower stratospheric chemical processes, see section 6.3.2; the proposed joint initiatives on the penetration of UV radiation into the lower stratosphere and troposphere, see section 6.3.3; the possible joint assessment of observations of stratospheric aerosols, see section 6.5). Reference is also made to the planned collaboration with ICMA, IAGA and SCOSTEP on upper stratospheric temperature trends (see section 6.2.1).

6.7 Planning for the second SPARC General Assembly

The Second SPARC General Assembly would be held in Mar del Plata, Argentina, 6-10 November 2000. Professor A. O'Neill (University of Reading, UK) is serving as chair of the Scientific Organizing Committee. The organization of the scientific programme is aimed not only to consolidate the research SPARC has undertaken to date, but also to identify where new initiatives or activities are needed. The four principal themes of the Conference will be:

- stratospheric processes and their role in climate
- stratospheric indicators of climate change
- modelling and diagnosis of stratospheric effects on climate
- UV observations and modelling radiative transfer.

A more detailed description may be seen on the Conference web site (**http://www.sparc2000.at.fcen.uba.ar/)**.

A Local Organizing Committee (chaired by Dr. P. Canziani, University of Buenos Aires) has also been established with arrangements for conference facilities, hotel accommodation, etc., now well advanced (see web site referenced above).

It was gratifying that numerous sponsors have been attracted, and that it would be possible to offer travel support to a number of students and young scientists.

6.8 The SPARC Data Centre

The SPARC data centre, supported by NASA, has been established at the State University of New York at Stony Brook, a manager appointed, and a significant start made on assembling key stratospheric data sets in a readily accessible form. Information available includes the USA high resolution radio-sonde data, NCEP reanalyses from 1978-1998, the observed 1979-1997 climatologies of stratospheric and trace gases derived from UARS observations. A list of SPARC sub-projects and of acronyms frequently used in SPARC is also maintained (see **http://www.sparc.sunysb.edu/**).

6.9 The SPARC Office

As well as its regular responsibilities of compiling and editing SPARC Newsletters, updating the SPARC mailing list, maintaining contacts with the SPARC community of scientists, organizing various SPARC meetings and periodically revising the SPARC home page, particular support has been given to the preparation of the SPARC water vapour assessment report (see section 6.2.3). Substantial efforts have also been devoted to seeking sponsors for the Second SPARC General Assembly, and assisting in the arrangements for the Assembly would be a major task during 2000. The JSC was very encouraged that a full-time support position in the SPARC Office had now been offered by the French Centre National de Recherche Scientifique. A suitable candidate has been found and would begin work in June 2000. This positive development was the result of the steps taken in France by one of the French members of the JSC, whose support was sincerely acknowledged.

7. AIR-SEA FLUXES

7.1 Activities of the JSC/SCOR Working Group on Air-Sea Fluxes

Dr. P.K. Taylor, Co-chair of the joint JSC/SCOR Working Group on Air-Sea Fluxes, summarized the progress in the work of the group, which had been set up by JSC and SCOR to foster interdisciplinary consultations in the area of air-sea fluxes, to review the requirements of different scientific disciplines for surface flux data, and to compile a catalogue and assess the quality of available surface flux and flux-related data sets. A principal objective was the preparation of a report reviewing these various topics.

As requested by the JSC at its twentieth session, an accelerated schedule had been followed during the past year in compiling the report. Two meetings of the group had been held (De Bilt, Netherlands, April 1999 where a first draft had been carefully considered and developed, and Southampton, UK, December 1999, where an advanced draft had been reviewed and the main conclusions and recommendations agreed). A substantively final version, representing a comprehensive assessment (over 300 pages) of the present state of the art in regard to air-sea flux determination, was available and could be accessed at **http://www.soc.soton.ac.uk/JRD/MET/WGASF** (to be published in the WCRP report series later in 2000). The report included an extensive evaluation of flux products, ranging from in situ data sets to those inferred from remotely-sensed data, and model-based fields (i.e. from reanalyses or operational analyses). Major discrepancies between different types of data sets were still apparent. The main conclusions from the working group are summarized in the final chapter of the report (Chapter 12), supplemented by a number of specific recommendations. Among these, noting that the present reanalyses are far from perfect when it comes to air-sea fluxes, support was expressed for continuing reanalysis efforts (every 5-10 years by at least two centres). It was recognized that evaluation of fluxes or flux-related variables from global operational NWP systems would benefit future reanalyses as well as providing essential guidance and estimates of uncertainty in flux fields. The WGNE SURFA project (see section 4.1.5) to collect and study relevant flux data sets from a number of global operational centres was thus of considerable importance. The requirement for high quality in situ data for verification and calibration of model- or satellite-derived flux estimates was highlighted, e.g. a network of flux reference platforms (a combination of long-term moorings and ships) capable of delivering the most accurate measurements possible of stress and all components of air-sea heat fluxes. Alongside this, air-sea interaction experiments to improve flux (and boundary layer) parameterizations continued to be necessary (but it was essential to provide adequate resources to ensure a complete analysis of the data collected and realisation of the full potential benefits of such experiments). Resources were also needed for the assembly of data sets, data mining/archeology and cataloguing (e.g. the continuing development of flux and flux-related data sets such as COADS based on Voluntary Observing Ships and other historical data, efforts to remove non-stationary observational biases in historical data, maintenance of a comprehensive catalogue of flux data sets on the Internet). Finally, the Working Group pointed out that work must be continued to obtain new flux products, to compare and assess the quality of fluxes from various sources, and to evaluate the parameterizations used. Work to enhance the reliability of momentum, net heat and freshwater fluxes by combining the best estimates from the various sources should also be fostered.

Attention was now being given to the organization of a (WCRP/SCOR) Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields in 2001. The workshop would be intended to bring together the different scientific communities interested in air-sea fluxes and, as a first step, review the Working Group report, collect feedback from the community as a whole, and provide a wide opportunity to comment on and debate as appropriate the conclusions and opinions of the Working Group. The latest developments in obtaining flux and flux-related parameters from in situ and remotely-sensed data, and from model output fields would also be presented. Further studies of uncertainties inherent in various fields were also anticipated. Although primarily concerned with global-scale flux climatologies, the elaboration of flux parameterizations, and ideas for field experiments and collection of high quality flux data would also be taken up. Most importantly, the Workshop would, like the earlier WCRP Workshop on Air-Sea Flux Fields in 1995, be intended to promote further inter-disciplinary consultations, and to encourage feedback and dialogue between the producers and users of surface fluxes and related data. This would be a basis for agreeing on the strategy and internationally co-ordinated initiatives needed to make progress in studying, determining more accurately and making appropriate use of air-sea fluxes.

Dr. Taylor recalled that the existing JSC/SCOR Working Group on Air-Sea Fluxes had been established for a limited period of produce a report on the state of the art of air-sea fluxes, and to organize an interdisciplinary workshop (of the nature outlined above). However, a new or follow-up group in this same area would certainly be needed. In particular, the collaboration that had developed between the different communities involved should be fostered, and the requirements, as well as the contributions, of biologists, chemists, brought together with those of the existing physical ocean and atmospheric communities. Projects such as CLIVAR, the Surface Ocean-Lower Atmosphere Study (SOLAS) (see section 7.2) and GODAE all required accurate fluxes with specified uncertainties. This could generate stronger grounds for soliciting more broadly resources for the support of air-sea flux research. Efforts were needed to bring these diverse interests (but common needs) together. Furthermore, the expertise and collaboration between atmospheric and ocean scientists, and modellers and observationalists that was established during the Coupled Ocean-Atmosphere Response Experiment (COARE) should be preserved and extended, in particular to pursue the crucial problems of boundary layer parameterization that had to be solved to achieve accurate coupled-model representation of air-sea fluxes on time- and space-scales important in climate variability. (As reported at the twentieth session of the JSC, the major Conference on COARE in 1998 strongly recommended continued study of coupled ocean-atmosphere boundary layer phenomena in the WCRP, using field data from COARE and other experiments aiming at the development of new algorithms for incorporation into NWP and climate forecasting models). This was allied to the overall requirement to review ongoing research into flux parameterizations and their implementation in data assimilation and satellite retrievals (e.g. to assess the work on ocean surface turbulent fluxes reported in section 5.3 which was primarily based on satellite estimates and oriented towards tropical regions). Other areas where work was needed was on flux variability and the role of this variability in interannual to centennial fluctuations such as the North Atlantic Oscillation, ENSO etc. There also remained much to do in evaluating the quality of surface fluxes (their "strengths and weaknesses"), and organization of specific efforts to resolve uncertainties in time-mean magnitudes of fluxes. New directions should be explored (e.g. to provide tools to assist in determining bio-chemical fluxes) and the specification of the Earth observing system(s) needed to give a comprehensive coverage of surface fluxes.

The JSC was greatly impressed by the summary of the Working Group on Air-Sea Fluxes that had been presented, and acknowledged the outstanding efforts and hard work of the Working Group over the past year in preparing the report to the accelerated schedule requested by the JSC. Particular credit was due to the Co-chairs of the group, Dr. P.K. Taylor (Southampton Oceanography Centre, UK), for his remarkable contribution in compiling and editing the complete document, and Dr. S. Gulev (Shirshov Institute of Oceanology, Russian Federation) who has steered the group through a virtually word-by-word review of the text at its meeting in December 1999. The JSC urged that the report now be published and the follow-up workshop to gather the general views of the community be organized as rapidly as feasible. The Working Group web site (including a flux product catalogue) should be built up and maintained. The JSC agreed that the present Working Group should formally continue in existence until the workshop was held. The future organization of WCRP activities in the area of air-sea fluxes (in particular the establishment of a new group to continue to oversee the efforts required) would be considered at the next session of the JSC (March 2001).

7.2 Surface Ocean-Lower Atmosphere Study (SOLAS)

The Surface Ocean-Lower Atmosphere Study (SOLAS) is a potential new IGBP core project with the primary goal of addressing the interactions between the atmosphere, climate and marine biogeochemistry that might be linked to global change. SOLAS would aim to bring together both physical and biogeochemical atmospheric and marine research scientists as well as atmospheric chemists, building on the foundation laid by JGOFS, IGAC, PAGES and WOCE. Emphasis would be placed on an improved understanding of the basic processes and mechanisms and a "hypothesis-testing" approach.

A SOLAS Open Science Conference took place in Germany in February 2000 to discuss the basic SOLAS ideas and concepts with as wide a group of interested scientists as possible. There were more than 250 participants from 22 countries in the fields of chemical, biological and physical oceanography, marine ecology, atmospheric chemistry and physics, remote sensing, air-sea interaction, and biogeochemical modelling. A very wide range of scientific topics was discussed and the Conference certainly contributed to the objective of developing communications between the atmospheric and oceanographic biogeochemical communities. The Conference recommended that SOLAS basic hypotheses and goals needed to be more sharply focussed. In particular, the aspects of carbon cycle research to be covered within SOLAS should be closely defined and targetted on the air-sea flux of CO_2 (including studies of gas exchange), relevant upper ocean process studies, and building up atmospheric time series related to air-sea CO_2 exchange (e.g. measurements of O_2/N_2). The results and recommendations from the Conference would be used in developing the scientific blueprint for SOLAS that would then be submitted to IGBP and SCOR (and other interested programmes such as WCRP) as a basis for approval and implementation.

The JSC reiterated its interest in SOLAS and the outcome of the recent Conference. The JSC observed that the support of the physical science community would be essential to make progress in many of the issues being considered. SOLAS would also need to make the step from local measurements to large-scale fields of fluxes, i.e. parameterizations have to be developed in terms of widely available measurements such as O_2, pH, partial CO_2 uptakes. SOLAS would then be faced with similar problems of sampling and mapping biogeochemical fluxes as with (physical) heat, water and momentum fluxes.

The JSC recognized the importance of the work of the JSC/SCOR Working Group on Air-Sea Fluxes as described being fully available to and being taken into account in SOLAS planning. To achieve the needed broadening of SOLAS in the direction of physical fluxes, Dr. Taylor agreed to participate in a meeting in May 2000 that would further elaborate SOLAS science planning. The JSC looked forward to the opportunity of reviewing the SOLAS plan (expected to be released and circulated later in 2000) at its next session in March 2000. The consideration of future WCRP activities in air-sea fluxes at that time could then also include assessment of the support that might be given to SOLAS (as well as taking into the other requirements for continuing work on air-sea fluxes summarized in section 7.1).

8. WORLD OCEAN CIRCULATION EXPERIMENT (WOCE)

Dr. P. Killworth, Co-chair of the WOCE Scientific Steering Group, and Dr. J. Gould, Director of the WOCE International Project Office, reviewed progress in WOCE. The observational programme (1990-1997) had now been completed, and the Analysis, Interpretation, Modelling and Synthesis (AIMS) activity was well underway and expected to continue until 2002. Overall, WOCE has been recognized as a unique and highly successful experiment, and there may well never again be such a comprehensive global oceanic survey. As WOCE was now in its final stages, the presentations to and discussions at this session of the JSC focussed on the achievements of WOCE, in particular illustrating the importance of ocean effects in properly understanding the behaviour of the coupled ocean-atmosphere system.

8.1 Review of progress towards WOCE objectives

Ocean model development

For the period 1990-1998, WOCE was primarily an ocean observational programme. In the AIMS phase, now that the WOCE data set was largely complete, the development of ocean modelling has necessarily come very much to the forefront. The joint WGCM/WOCE Working Group on Ocean Model Development (WGOMD) (see section 4.2.6) will have a crucial role in this respect.

Among issues of concern is that ocean model development has not generally been carried out in close conjunction with atmospheric and coupled modelling groups (e.g. ocean components are simply handed over to (coupled) climate modellers). Neither the atmospheric nor oceanic representations are "correct" and both need improvement - but development of each component in isolation cannot solve the problem. This is an unsatisfactory situation which WGOMD, with its close connection with WGCM, should be able to resolve.

In recent years, the move towards increasing horizontal and vertical resolution has brought ocean models to a position in which they are capable of representing much better the state of the interior of the ocean and its variability. Thus, progress should be possible in the treatment of key ocean processes in coupled models provided higher resolution can be used. From an ocean standpoint, weaknesses of the present (relatively low-resolution) coupled models and their ocean components include significant underestimation of oceanic heat and fresh water fluxes and long-term errors in the oceanic temperature/salinity structure. Refinements in the parameterization of ocean processes and phenomena are being pursued by several groups which may have significant benefits in coupled models when the processes cannot be adequately represented in detail. Examples are:

- mixing in gravity flows: the entry of water masses from marginal seas into the global ocean is controlled by gravity flows particularly in the North Atlantic (and in the Nordic seas represent a key element of the thermohaline circulation). Even a simple parameterization of mixing processes in gravity flows improves the simulated transfer of water masses;

- mixing over topography: evidence is accumulating regarding tidally-induced mixing over mid-ocean ridges, and whilst the magnitude may be small, its impact has not yet been assessed. However, it could induce significant modifications to water mass distributions (comparison with WOCE measurements will help in research on this topic);

- flows between basins: many connections between basins are narrow and hence comparable to or smaller than the model grid. It is impossible to reach a realistic equilibrium state with respect to water mass properties or circulation strengths unless these inter-basin flows can be better represented. Effective parameterizations are needed - the present generation of (coarse-resolution) coupled models are simply wrong;

- deep convection and ventilation: water mass properties are determined to a considerable extent in regions where deep winter convection occurs in the ocean (often also near the edge of ice-covered regions): the largest air-sea heat fluxes also occur in these regions. Deep convection (and marginal ice zone processes are poorly represented in ocean models, but attempts are being made to reproduce the deep convection seen during the latter phases of WOCE in the Labrador Sea, and the more widespread seasonal subduction of surface-modified water mass into the ocean interior;

- role of mesoscale processes in ocean heat and freshwater transports: this is a key element in internal ocean variability and is receiving increasing attention as model resolution improves.

WGOMD is duly taking these aspects into account in planning activities to be undertaken in the development of ocean models and fully coupled models (see section 4.2.6).

A separate issue in the development of ocean models is the limitation imposed by computing resources, particularly the estimation of the ocean state (or assimilation process). The capability of describing the time-varying ocean circulation and transport processes on a global scale has been demonstrated and it is technically feasible to assimilate the entire suite of relevant in situ ocean and remotely-sensed data using a full ocean circulation model, but only at a very coarse resolution (2°x 2°). Over the next five years, assimilation at a ¼ ° resolution over a fifteen-year time period is envisaged, requiring at least a thousand-fold increment in computer capacity (compared to the current barely possible 2° resolution experimentation and to permit multiple assimilation runs). Dedicated high capacity computers are required but are not currently available to ocean modelling groups.

WOCE observations and syntheses

Very large amounts of WOCE data are already available, including approximately 10,000 one-time hydrographic stations and most of the associated tracer measurements as well as almost 100% of surface drifter and 90% of current meter data, and 70% or more of other data streams. This has stimulated a flurry of analysis and synthesis activities ranging from studies using single in situ data sets to sub-basin scale syntheses and inverse analyses of all the oceans covered by WOCE, exploiting both in situ and remotely-sensed data (particularly altimetry). As noted above, state estimations and inverse analyses are very demanding in terms of computer resources and can take several months even at coarse resolution. In this regard, it is essential that the assimilating model employed runs close to reality - but this is best achieved with a high resolution model. The more limited analyses of a particular basin or section are proceeding in an ad hoc manner and co-ordination is needed.

It is noted that many of these syntheses have been produced outside the USA in countries in which no dedicated WOCE AIMS funding is available. In the USA, where funding is available, it is disappointing that there have been relatively few bids to carry out such work.

8.2 The "success" of WOCE

Refereed scientific papers based on WOCE observations or on modelling carried out as part of WOCE are appearing at a rate of approximately 200 per year. This evidently represents a significant increase in our knowledge of the ocean, but few papers have directly addressed the originally stated objectives of WOCE, firstly, to develop models useful for predicting climate change and to collect the data necessary to test them, and, secondly, to determine the representativeness of the specific WOCE data sets for the long-term behaviour of the ocean and to find methods for observing long-term changes in the ocean circulation. Contributions in these areas depend on basin scale and global syntheses and inverse analyses (with the attendant difficulties noted above), which are as yet far from complete.

A comprehensive view of the achievements of WOCE would be provided later in 2000 by the publication of the WOCE 1998 Conference Book "Ocean Circulation and Climate", based on the papers presented at the Conference. A wide range of topics, including the ocean and climate, new ways of observing the ocean, the global flow field, formation and transport of water masses, and large-scale fluxes, all based on the work carried out in and developments resulting from WOCE would be covered. A further important project is the preparation of a series of WOCE Atlases for each ocean based on the one-time hydrographic survey data. The addition of a volume for the Arctic Ocean including ACSYS data has also been discussed. Partial funding to meet the costs of this exercise will be forthcoming from US and German sources. However, WOCE would wish to make the series of atlases available free of charge to those who collected the data and to oceanographic libraries as has been done for past surveys (e.g. the International Geophysical Year). This would require funding of the order of US$ 100k, and possibilities to find such a sum (e.g. from private foundations) are being explored.

In some senses, more progress has been made towards the second goal of WOCE than the first. Comparisons made between temperature and salinity distributions from WOCE and pre-WOCE sections have started to indicate the magnitude and spatial scale of long-term variations in the ocean, although the causes of these or their significance in relation to either circulation changes or to interactions with the atmosphere are far from being identified. The capability of documenting changes in the ocean in detail from frequently repeated trans-ocean sections and time series is (and will remain) limited by the very small number of ocean areas for which such data sets are available.

A major technological advance stimulated by WOCE was the development and widespread use of profiling (PALACE) floats which were extensively deployed in the second part of the field phase of the Experiment. This experience has led to PALACE floats forming the basis of the planned global ARGO array, a key element in GODAE (see section 3.4) as well as the sustained oceanic observations for CLIVAR and GOOS. The accuracy of salinity measurements from PALACE floats is being actively assessed using WOCE data. Beyond this, the exploitation of the WOCE PALACE data set is still very much in its infancy, in particular taking advantage of the symbiotic relationship between PALACE data and high quality remotely-sensed altimetric data.

8.3 The final phase of WOCE

Much still remains to be done to achieve WOCE objectives and for the full expected contribution to be made to the overall WCRP goal of improving the understanding of the climate system. To advance, it is essential to ensure continued funding of WOCE AIMS activities at a national level, secure commitments to follow through the planned activities in the AIMS phase, and maintain an appropriate international infrastructure. In respect to the first of these, specific WOCE funding has ceased in most countries. Although the opportunities presented by the availability of WOCE data sets attract (on a piece-meal basis) the resources needed for limited relatively coarse-resolution regional analyses, as noted above, it appears difficult to obtain the substantial funding and computing capacity for basin and global-scale syntheses, particularly where this would benefit from multi-national collaboration. The particular problem of the shortfall in computer resources for global scale ocean data assimilation was specifically pointed out in section 8.1, the solution for which lies beyond WOCE alone. This is an issue which should be taken up by the JSC and in CLIVAR.

Central to the WOCE AIMS strategy has been the organization of a series of regional and specific subject-based workshops. In the former category, the first workshop on the Pacific was held in 1996, followed by workshops on the South Atlantic and Southern Ocean in 1997, on the Indian Ocean in 1998, and on the North Atlantic in August 1999. These workshops have had significant impact in encouraging collaborative regional analysis and interpretation projects, and in accelerating publication of specific basin results. In respect to special scientific topics, a workshop on "The representativeness of the WOCE data set" (addressing the second goal of WOCE) would be held in Japan in October 2000 and on "Global Ocean Fluxes" (dealing with the technical and scientific aspects of computing property transports from WOCE hydrographic sections and central to the first goal of WOCE) in mid-2001. An overall final WOCE Conference is being planned for 2003.

The WOCE system of Data Assembly Centres (in general, one for each WOCE data stream) and the two Special Analysis Centres (for Air-Sea Fluxes and for Hydrographic Data) will need to continue to function. The level of funding for these centres is well below ideal, as it has always been. Most of the WOCE Data Assembly Centres have now been endorsed by the CLIVAR Data Task Team (see section 9.2) as being required to play an essential role in handling delayed-mode ocean data for CLIVAR. It is hoped that the CLIVAR endorsement may help in obtaining continuing (and improved) resources. The supporting WOCE Data Information Unit has the responsibility of identifying missing data and meta-data required to complete the overall WOCE data set. A second version of the WOCE data on CD-ROM would be distributed in 2000, together with a comprehensive inventory of WOCE observations compiled by the Data Information Unit and WOCE International Project Office (a first version was issued in 1998). The production of the CD-ROMs is being funded by the US National Oceanographic Data Center, but support remains to be found for printing and distribution of the data inventory by the WOCE International Project Office.

8.4 The WOCE International Project Office

WOCE continues to be overseen on a day-to-day basis by the International Project Office (co-located with the International CLIVAR Project Office in Southampton, UK - see section 9.6) with a staffing level of 2.3 full-time equivalent scientific positions and 0.75 full-time equivalent secretarial support. Activities include production and distribution of reports of meetings and workshops and of the International WOCE Newsletter, assembly of a bibliography of WOCE-related papers, and maintaining the WOCE web site. Shortage of funds would result in a reduction to three issues of the Newsletter in 2000. The efforts needed to ensure an orderly conclusion of WOCE in 2002 (namely, monitoring the assembly of the WOCE data set, publication of the atlases, production of a further (final) version of CD-ROMs, the ongoing monitoring of the scientific success of WOCE, and ensuring a smooth transition to CLIVAR) will clearly fall to the WOCE International Project Office, and hence continuing funding of the Office is required. Another very substantial task will be the planning and organization of the final WOCE Conference, probably in 2003.

9. CLIMATE VARIABILITY AND PREDICTABILITY (CLIVAR)

The Co-chairs of the CLIVAR Scientific Steering Group, Drs A. Busalacchi and J. Willebrand, together with the Director of the International CLIVAR Project Office, Dr. J. Gould, summarized the main highlights in the development of CLIVAR during the past year.

9.1 Anthropogenic climate change and extreme climatic events

Increased atmospheric temperatures continue to be observed worldwide. As noted in section 3.4, the recent review produced by the USA National Research Council of the National Academy of Science, "Reconciling Observations of Global Change", has gone some way towards resolving apparent inconsistencies between temperature trends based on in situ data compared to those inferred from satellite measurements (the inconsistency in no way invalidates the conclusion that surface temperature has been rising). Reconstructions based on proxy records from palaeoclimatic data show that the rise in northern hemisphere surface temperature is unprecedented within at least the past 1000 years. The basic study of anthropogenic climate change in the WCRP/CLIVAR is the task of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) (see section 4.2.7) but many elements of CLIVAR contribute directly or indirectly through their efforts to observe and/or assess the natural variability of the climate system.

Various seasonal climate anomalies and extreme events such as the flooding in Venezuela and Mozambique, the European "hurricane" in December 1999, continue to make headlines worldwide. These types of events and their socio-economic impacts, point to the relevance and importance of the CLIVAR efforts to improve the understanding of climate variability and predictability.

9.2 CLIVAR observational requirements

As well as relying on routine global meteorological, hydrological and oceanographic measurements, regional observations and those from process-related campaigns will contribute to the overall global array of CLIVAR data. However, it is a major challenge to find the resources and gain the commitments to ensure that key observations can be sustained for multi-year periods and that homogeneous records of acceptable quality can be maintained. These objectives of CLIVAR are parallel to those of GCOS and GOOS (see section 3.4) and CLIVAR therefore works in close concert with these programmes. The major international Conference on Ocean Observations for Climate held in France in October 1999 (see section 3.4) reviewed the wide range of ocean observations required for both climate research and operational purposes and identified, in a series of multi-authored papers, an optimal observing framework. From these, it should be possible to constitute a blueprint for sustained ocean observations of climate. The remit of the CLIVAR Upper Ocean Panel may then be extended to consider all sustained ocean observations. The relationship between such a modified CLIVAR Panel, the Ocean Observations Panel for Climate (OOPC) (see section 3.4) and the newly-formed WMO/IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) needs to be defined. Additionally, a panel for the Atlantic basin has been formed. While this will mainly consider questions related to the North Atlantic Oscillation, thermohaline circulation and tropical Atlantic variability, requirements for CLIVAR African research, for the study of the Variability of the American Monsoon System, VAMOS (see section 9.3), and for an improved understanding of the role of the South Atlantic will not be overlooked. Plans to consider the implementation of needed observing systems for the Pacific Ocean, Southern Ocean and Indian Ocean would be taken up at various workshops during the course of 2000. Generally, however, it should be noted that the oceanographic measurement programmes to collect the data essential are already underway in all ocean basins (but not necessarily as part of CLIVAR). The key observational elements must be identified and steps taken to ensure that the relevant data are captured by CLIVAR data systems.

More specifically, the principal elements of the sustained (atmospheric and oceanic) observational data set required for CLIVAR include:

- meteorological data: in situ information is provided by the WWW network of operational surface and upper air stations. However, there are known gaps in the operation of this network. It is also essential for CLIVAR that all the data collected are freely available to research groups - this is particularly important for the investigation of seasonal-interannual variability, for instance in monsoonal regions;

- tropical ocean moored arrays: to meet CLIVAR requirements, the existing (operational) Pacific Tropical Atmosphere Ocean (TAO) array should be extended to cover the global tropical oceans. Progress is being made in this respect, one development being that of the full integration of the Japanese TRITON array with TAO as from 1 January 2000. Atlas moorings, phased out of the western Pacific along 137°E, 147°E, 156°E in 1999, have been replaced with JAMSTEC TRITON buoys. Data from several side-by-side deployments of TRITON and ATLAS systems were compared over a period of several months to ensure interchangeability of the mooring measurements. Real-time and delayed mode TAO/TRITON data are available via the GTS. Additionally, PIRATA, which can be regarded as an Atlantic extension of TAO, was completed during 1999 with the deployment of twelve Atlas mooring sites jointly by Brazil, France and USA. The partner countries have agreed to extend this pilot array for a further three years. Other data are obtained from profiling floats and satellites: these complement the in situ arrays but cannot replace them and long-term fixed buoy deployments will necessarily remain a key source of data;

- upper ocean measurements: the two primary sources of these data are, firstly, the fleet of Voluntary Observing Ships (VOS) deploying XBTs (furnishing temperature data to 750m) along the routes of the WOCE/TOGA network together with, in some cases, surface temperature and salinity; secondly, the rapidly expanding fleet of floats delivering profiles of temperature and salinity from approximately 2000m to the surface every ten days or so. These floats will become the basis of the operational global ARGO array (see section 3.4) providing data in real time. Both these data sources are essential to the global and regional objectives of CLIVAR. ARGO is especially important for data coverage in remote areas away from shipping lanes and in areas of severe winter weather. Regrettably, the USA (NOAA) may be reducing its support for high latitude XBT lines, which would be a significant loss to the global upper ocean network. The global array of TOGA/WOCE drifters also continues to provide valuable information on surface currents, temperatures (and, in some cases, salinity) as well as measurements of atmospheric pressure;

- full depth hydrography and tracers: while CLIVAR cannot approach the 10,000 stations distributed and occupied in an organized manner in the global oceans during the eight-year WOCE global survey, it will be necessary to carry out repeats of the key WOCE sections in a systematic manner (typically every 5-10 years) for the purposes of monitoring oceanic fluxes of heat and fresh water and to document changes in temperature and salinity. Information on these changes is vital to the understanding of the stability of the thermohaline circulation. Sections across major inter-ocean channels need to be occupied more frequently and several (e.g., across the Drake Passage, between Australia and Antarctica, and across the North) are currently surveyed approximately every two years. Trans-ocean sections should also be made in order to construct an updated inventory of oceanic CO_2 (following that made jointly by WOCE and JGOFS in the period 1990-1997). Validating models of the oceanic uptake of anthropogenic CO_2 depends on such an inventory. The Conference on Ocean Observations for Climate revealed a high level of commitment for trans-ocean sections in the Atlantic and Southern Ocean but relatively little interest in much of the Pacific;

- satellite observations: remotely-sensed data have become the mainstay of all aspects of climate monitoring and research and are, of course, essential for CLIVAR. Whilst the array of operational meteorological satellites offers the prospect of continuity in remotely-sensed atmospheric data, there is no such guarantee for most oceanographic satellite systems, particularly for altimetry and scatterometer winds. For altimetric measurements, reliance is still being placed on the eight-year old TOPEX/POSEIDON satellite (together with the less accurate data from ERS-2). A replacement satellite (JASON) was expected to be launched in late 2000. QuickSCAT (carrying the Seawinds radar instrument) was placed in orbit in June 1999; this new stream of scatterometer data offers an important monitoring capability for CLIVAR. The joint USA/Japan Tropical Rainfall Measuring Mission (TRMM), launched in November 1997, also provides valuable data for CLIVAR studies and the uncertainty in rainfall in the tropics inferred from remotely-sensed data have been significantly reduced (see also section 5.1).

- palaeoclimatic data: an essential element of CLIVAR is the refinement and extension of the past climate record in order to gain an improved understanding of climate change and as a basis for studies of seasonal and interannual variability. The instrumental record of climate is short and reliance has therefore to be placed on the reconstruction of past climate from proxy indicators. Close collaboration has been established with IGBP/PAGES in this respect to exploit and make readily available to the climate research community the numerous proxy records of temperature and precipitation variability, many with annual resolution, prior to the start of the instrumental record. These proxy records include but are not limited to documentary evidence, ice cores, tree rings, temperatures in boreholes, lake sediments and coral. As well as individual climate parameters, occurrences of major dynamical phenomena can be inferred - for example, it has been possible to reconstruct variations in Southern Oscillation Index and the phase for the North Atlantic Oscillation with a monthly resolution as far back as 1675. Analysis of air trapped in ice cores enables a record of changes in greenhouse gas levels to be built up.

- data management: a CLIVAR Data Task Team has been established to review the data streams and products needed to support CLIVAR research and to consider data delivery and quality control mechanisms and whether these are adequate for CLIVAR. This is evidently a substantial task that will take some time to complete, but the ground covered will also be of relevance to other WCRP projects and the other global climate observing systems (GCOS, GOOS, GTOS). In this connection, the recommendation of the JSC that information on data management activities in the different components of the WCRP should be freely exchanged across the whole WCRP and that a meeting of leaders of data management activities should be arranged (see section 3.4) is of importance. Liaison with the global climate observing systems in this activity would be ensured by the Chair of the CLIVAR Data Task Team, Professor F. Webster, who was also chairman of the Joint (global climate observing systems) Data and Information Panel (JDIMP). Another important factor which is certain increasingly to affect the accessibility of required data sets is the continuing rapid advances in information technology and the growth of web-based distributed data sets and distributed data servers (see also section 3.1). So far, the CLIVAR Data Task Team has only considered the use of existing data systems (such as the WOCE delayed mode Data Assembly Centres, see section 8.3) or the (real-time) operational data bases for meteorological and oceanographic observations.

9.3 Studies of regional climate variability

Asian-Australian monsoon system

The role of the Indian Ocean in the predictability of the Asian-Australian monsoon system continues to be a key question. Current hypotheses suggest that the predictability of the Asian-Australian monsoon depends on forcing from the adjacent oceans and land masses as well as (large-scale) anomalies in sea surface temperature in remote ocean basins (e.g. those linked to ENSO). Recent findings from field experiments exploring the onset of the monsoon and indications that regional climate modes (in addition to ENSO) may also have a role in the variability of the monsoon have provided new foci for monsoon modelling and process studies, and stimulated consideration of the development of a long-term "Monsoon Observing System".

CLIVAR Africa study

In large areas of Africa, food production and water resources depend fundamentally on the strength of seasonal precipitation events and can be very adversely affected by climate anomalies. The CLIVAR Africa panel has produced a report "Climate Research for Africa" outlining the scientific scope and conceptual design for an international project to investigate the variability and predictability of the African climate and to assess climatic factors which contribute to phenomena such as desertification. The report, which has now been widely distributed, highlights the need to study African climate both in a global context and through regional modelling initiatives, and for a greatly improved collection of basic meteorological and climate-related observations over the continent and the adjacent oceans. The basic infrastructure and scientific capacity in Africa must be reinforced in order to be able to begin and sustain the activities necessary. Africa duly represented an excellent opportunity for CLIVAR to work in co-ordination with CLIPS, the climate fora, etc., to establish the foundation required and to build up a network linking those involved in African climate research. A CLIVAR Africa implementation plan was now being prepared.

Variability of the American Monsoon System (VAMOS)

Planning for VAMOS is in full swing, with a great interest being shown by research scientists in Latin and North America (although funding is still primarily from US sources). VAMOS will include a number of phenomenologically based programmes:

- a study of marine stratocumulus in the southeastern Pacific (with a field phase in 2002-2004);
- a joint CLIVAR/GEWEX investigation of American monsoon systems beginning with a study of American low level jets in the period 2001-2003;
- a hydroclimatology project in the La Plata River Basin (plan in preparation)
- research into the role of the Altiplano in driving the American monsoon (may not begin until 2001).

All these initiatives are severely resource-limited. Support for a moored buoy array off the west coast of Chile is being sought from the Global Environment Fund.

9.4 Modelling activities in support of CLIVAR

Modelling activities of interest to and in support of CLIVAR are conducted by the joint JSC/CLIVAR Working Group on Coupled Modelling (WGCM), the Working Group on Seasonal-to-Interannual Prediction (WGSIP), and the joint WGCM/WOCE Working Group on Ocean Model Development. The work of WGCM was reported in detail in section 4.2 (including that of the Working Group on Ocean Model Development in section 4.2.6). Several specific issues of concern in the development of ocean models are also outlined in section 8.1.

JSC/CLIVAR Working Group on Coupled Modelling

Among aspects of high priority for CLIVAR in the work of WGCM is the study of atmosphere-ocean predictability on decadal timescales. A workshop on this topic was being organized in October 2000 (see section 4.2.9), and the CLIVAR Scientific Steering Group has asked that recommendations on the efforts needed to advance towards CLIVAR objectives in this area in both modelling and observations be formulated. Another key issue is that of the detection and attribution of climate change (see section 4.2.7) and WGCM is being encouraged to undertake specific activities in modelling climate change, in particular as to why different coupled models show significantly different responses to similar forcing. A further question is the rapid climate change that can be seen in the palaeoclimatic proxy record and that may be indicative of strong non-linearity in the dynamics of the climate system. For example, the abrupt Younger-Dryas cold event (11000 to 12000 BP) appeared to be global but with different phasing in different locations. The most widely accepted explanation at present is that these climatic instabilities result from changes in the thermohaline circulation induced by freshwater pulses into the northern North Atlantic fed by changes in continental ice-sheets. However, the mechanisms for such rapid changes are poorly understood and are not adequately simulated by the current generation of coupled climate models. Of particular interest also are the results of the Palaeoclimate Modelling Intercomparison Project and the simulations of the climates of the mid-Holocene (climate optimum) 6000 BP, and the Last Glacial Maximum 21000 BP (see section 4.2.8). The efforts of palaeoclimate modellers in employing intermediate complexity models, fully coupled ocean-atmosphere models, and even ocean-atmosphere-vegetation models to generate long time series that could be compared with the proxy record is another important activity.

Working Group on Seasonal-to-Interannual Prediction (WGSIP)

WGSIP reports directly to CLIVAR and has the responsibility of considering how operational seasonal-to-interannual predictions can be further refined, the improvements that can be made in the skill of probabilistic seasonal forecasts (e.g. by exploiting ensemble predictions and/or multi-model ensembles), examining the dependence of model predictions on the data used for forecast initialization and the way the data are assimilated, and the assessment of relevant observing systems and their effectiveness. These activities need to be supported by research into relevant modes of climate variability and predictability on seasonal to interannual timescales and seasonal effects interacting with monsoonal flows.

In considering the status of operational seasonal-to-interannual predictions, WGSIP reviewed further the reasons for the limited levels of skill achieved in forecasts of the 1997/1998 El Niño. As reported at the twentieth session of the JSC, WGSIP had earlier reached the sobering assessment that models had demonstrated only relatively limited ability in exploiting the predictability of El Niño. Generally, neither the onset nor the amplitude of the event were well predicted and the overall treatment of the evolution (growth, decay) was mixed. WGSIP has subsequently reconfirmed various aspects of its original diagnosis, namely:

- westerly wind bursts appear to have played an important role in the development of the event and that inadequate treatment of these disturbances partly contributed to the failure of some models adequately to predict the event;

- the specification of the initial ocean conditions was important in determining the quality of the predictions, pointing to the need for the development of improved data assimilation strategies;

- shortcomings in the treatment of the annual cycle adversely influenced the predictive skill;

- deficiencies in the treatment of the Pacific/Indian Ocean exchanges deserve greater attention.

A key element of WGSIP work in understanding shortcomings in present models and the basis for making improvements is a series of intercomparison projects. Among these is the intercomparison of ENSO simulations in coupled models (ENSIP), drawing on the data base of simulations assembled in the WGCM Coupled Model Intercomparison Project (CMIP) (see section 4.2.2). ENSIP has now been completed and has demonstrated that many models are severely flawed in representing the basic sea surface temperature climatology and annual cycle, and in simulating ENSO realistically in terms of equatorial sea surface temperature anomalies. In the companion study of the variability of the tropical oceans on seasonal and interannual timescales other than ENSO (STOIC), substantial (mainly cool) biases are apparent in sea surface temperature. As in ENSIP, there were generally large differences between the simulated and observed changes in sea surface temperatures, and even the basic annual cycle was not usually well reproduced. Zonal wind stress fields have also been examined and there is seen to be a scatter in model simulations in the Pacific ranging from much too strong easterlies to much too weak for the annual mean in the 5°N-5°S equatorial strip. In the Indian Ocean, the easterlies were too weak in all models, as in most models in the Atlantic. STOIC is also nearing completion and a full report is in preparation.

A dynamical seasonal prediction study has been undertaken to assess the predictability of the mean circulation and rainfall up to a season in advance. Participating groups have been invited to produce five- or nine-member ensembles of four-month forecasts from four winter and four summer periods in different years using observed initial conditions from successive days and prescribed boundary conditions. Results show that, as would be expected, the skill varies significantly from model to model and case to case. The skill of the multi-model ensemble is nearly the same as that of the best available model, except for cases when some members have a very low degree of performance (anomaly correlation coefficient less than zero). Models reproduce the northern hemisphere 500 hPa geopotential anomaly for the winter 1982/1983 better than other winters (1986/87, 1987/88, 1992/93), this apparently being attributable to the very strong El Niño conditions in that winter. Generally, lower levels of skill are seen in the summer cases. The accuracy of precipitation forecasts is limited except in regions directly affected by ENSO.

Yet another intercomparison being undertaken is aimed at evaluating the capabilities of the current generation of tropical ocean models to simulate interannual variability when driven by the "best" available surface forcing (including particularly wind-stress products from the multi-year atmospheric reanalyses). This should help in understanding better the deficiencies noted in the coupled model results in ENSIP and STOIC.

9.5 CLIVAR links to other programmes

The scope of CLIVAR is very large by any standards and there are therefore links and intersections with most other projects and activities in the WCRP. The strongest linkages are as follows:

- WOCE: there is close collaboration on data issues between WOCE and CLIVAR (as indicated in sections 8.3 and 9.3), and frequent co-sponsorship of workshops on ocean topics. CLIVAR depends on WOCE results to provide a baseline for assessing change in the ocean and the promotion of four dimensional oceanographic data assimilation;

- ACSYS/CLIC: the Arctic Ocean, Nordic Seas and Southern Ocean are key elements in the global thermohaline circulation and also sensitive indicators of long-term climate change. CLIVAR has no formal programme in the Arctic, but is liasing with ACSYS/CLIC to ensure that information on exchanges between the Arctic and the global ocean is available to CLIVAR. The implementation of CLIVAR in the Southern Oceans will be developed in collaboration with CLIC;

- GEWEX: the hydrological cycle is a principal component of monsoonal circulations, and there is thus extensive commonality of interest between GEWEX and CLIVAR in studying the seasonal-to-interannual variability of these features. The GEWEX Combined Enhanced Observing Period

(CEOP) (see section 5.2) will provide important input to CLIVAR for many studies. Conversely, CLIVAR wishes to take advantage of the potential prospect of studying aspects of the climate system at a global scale and will consider appropriate supporting and/or complementary activities which should mutually benefit both programmes.

9.6 The International CLIVAR Project Office

As a direct result of the considerable interest shown in CLIVAR by the nations participating in he CLIVAR Conference (December 1998), the International CLIVAR Project Office has developed links with many national CLIVAR programmes and has kept abreast of a range of national and multi-national developments. Over the past year, the Project Office has worked closely with the CLIVAR Scientific Steering Group, working groups and panels to assist in the organization of CLIVAR meetings. The Office has also published the reports of many of these meetings. Information on CLIVAR has been disseminated by means of a regularly produced newsletter ("Exchanges"), a series of posters designed and printed by the Project Office, and through the Web. A major recent initiative (in collaboration with the Joint Planning Staff in Geneva) has been the construction of Web-based CLIVAR project descriptions (down to the level of individual national contributions). Furthermore, the initial elements of a searchable bibliography (viewable at **http://www.clivar-search.cms.udel.edu**) have been established based on accessions to the UK Meteorological Office library.

New CLIVAR panels to oversee various aspects of implementation of the programme are being formed, and closer collaboration with other activities (e.g., PAGES, GCOS/GOOS) is required, and thus the ability of the International CLIVAR Project Office to provide a satisfactory level of support to CLIVAR will decline unless new staff and funding are forthcoming. Additional support (i.e. staff secondments or funding to hire staff) is constantly being sought, for instance, to hire an appropriate person to work in South America (or to undertake an intensive mission for a period of a few months) to help with regional implementation, particularly of VAMOS. The assistance of the JSC members in encouraging financial support from their countries, as well as looking into the possibility of finding suitable staff secondments, was urgently requested.

10. THE ARCTIC CLIMATE SYSTEM STUDY (ACSYS) AND POLAR CLIMATE

The Chairman of the Scientific Steering Group for the Arctic Climate System Study (ACSYS), Dr. H. Cattle, summarized the progress in the implementation of ACSYS (sections 10.1.1 to 10.1.7) and WCRP Antarctic Sea-Ice Research Projects (section 10.2). Dr. R. Barry, Co-chair of the WCRP Climate and Cryosphere (CLIC) Task Group, introduced the Science and Co-ordination Plan for CLIC as prepared by the Task Group, as a basis for acceptance of CLIC as a new WCRP project (see section 10.3).

10.1 The Arctic Climate System Study

ACSYS is specifically focussed on the Arctic (in comparison with the broader CLIC programme that has now been framed). The overall aim of ACSYS is to determine the role and sensitivity of the Arctic in the global climate system, i.e. on one hand, whether the Arctic climate is as sensitive to global change as model simulations appear to suggest, and, on the other hand, the sensitivity of global climate to Arctic processes. Studies in ACSYS are therefore directed to: improving the understanding of interactions between the Arctic Ocean circulation, ice cover, the Arctic atmosphere and hydrological cycle; describing the key processes in Arctic climate and providing a more accurate representation of these processes in global climate models; and attempting to estimate Arctic climate variability and trends. The principal activities undertaken within ACSYS are concerned with the Arctic ocean circulation (hydrographic survey, shelf studies, assessment of variability, establishing an historical Arctic Ocean climate data base); developing the Arctic sea-ice climatology and research; characterising the Arctic atmosphere and hydrological cycle in the Arctic region; and modelling Arctic processes. Quantifying the Arctic Ocean freshwater balance is an overall cross-cutting target of the work. An updated description of the full scope of these activities is included in the latest revised version of the ACSYS Implementation Plan, compiled by the International ACSYS Project Office (and now to be relabelled "ACSYS Implementation and Achievements"). This document is available on the ACSYS web site **http://www.npolar.no/acsys/impplan/index.htm**. An ACSYS "glossy brochure" was also being prepared.

The latest developments in the various components of ACSYS are outlined in the following paragraphs.

10.1.1 Arctic Ocean circulation

A survey of channels in the Barrow Strait-Lancaster Sound using conductivity-temperature depth (CTD) instruments was carried out in 1999 as part of the Barrow Strait "Flow-Through" study. A model to simulate the (barotropic) flow driven by a 10 cm higher elevation of the Beaufort Sea relative to Baffin Bay is being developed. Elsewhere, in the Greenland Sea, transient tracer measurements indicate that, despite the absence of open-ocean deep convection and driven up-slope convection off Spitzbergen, deep water renewal does occur. A follow-up programme during 2000 will investigate whether the roughness of the Greenland continental slope is able to generate downslope flow perpendicular to the East Greenland current. A new initiative, the Study of Environmental Arctic Change (SEARCH) with the objective of understanding the environmental changes in northern high latitudes over recent decades, is also now being planned by the US National Science Foundation Arctic System Science Programme. These changes include the general warming, the shifts in atmospheric circulation manifested in a tendency towards positive modes of the Arctic and North Atlantic Oscillations, the increased areal extent and warming of Atlantic-derived waters in the Arctic Ocean, reductions in sea-ice extent, and terrestrial snow-cover, the decrease of permafrost zones and alterations in terrestrial ecosystems. A supporting effort will explore shelf-basin exchange in the Arctic. International collaboration in SEARCH is recognized as important, and links with ACSYS and CLIC are being discussed.

10.1.2 Arctic sea-ice climatology

The range and accessibility of sea-ice data and products continues to increase. The US National Ice Center has now released a converted version of a CD-ROM containing all Arctic and Antarctic weekly ice charts prepared by the Center for the period 1972-1994. The Canadian Ice Service has also transferred their ice-chart archive (covering the Canadian East Coast and Hudson Bay, the eastern Canadian and western North American Arctic for the years 1968-1997) to CD-ROM. New information is being added every year to the WMO Global Digital Sea-Ice Data Bank. The principal Arctic data sets that have been accumulated will be presented in a joint Russian-American Atlas of Arctic sea-ice on CD-ROM during 2000. The Radarsat Geophysical Processing System in Alaska is now quasi-operational, providing a weekly snapshot of Arctic ice at a resolution of 200m. Derived products from the imagery are being evaluated.

In respect to ice-draft, data from nuclear submarines (both as ice-draft profiles and statistics) are now being archived at the USA National Snow and Ice Data Center and can be accessed at **http://www-nsidc.colorado.edu/NSIDIC/CATALOG/ENTRIES/nsi-0061.html**. Data are available for eight cruises (five US, three UK) made during the years 1976, 1987, 1991-1994 and 1996-97, and include 870 statistical ensembles over 40,000 km of track (within the central Arctic Ocean outside the EEZs of Canada, Denmark and Russia). Based on these data, a dramatic thinning of ice is apparent in the central Arctic in the 1990s. Other ice-draft observations using ice-profiling sonars are being made in the Fram Strait. This activity, which began in 1987, is continuing as part of the European Variability of Exchange in the Nordic Seas (VEINS) initiative. Typically four locations on the East Greenland continental slope near 80°N have been instrumented. In the Beaufort Sea, Canada maintains four ice-draft monitoring sites along the margin of the perennial pack ice. Furthermore, weekly measurements of ice thickness and on-ice snow depth have been collected at 195 sites on fast ice across Canada as far back as the 1940s (these data are available via **http://www.cis.ec.gc.ca/cia/icesnow.html**).

Sea-ice movement is another key parameter in understanding the evolution of the Arctic ice-cap. The International Arctic Buoy Programme (IABP) is the principal source of information for an ACSYS sea-ice motion climatology. In November 1999, twenty-seven, buoys were active. So far, with the present deployment strategy in IAPB, ice-drift data have only obtained for about half the total area of Arctic sea-ice cover. Major efforts have been made in IPAB, but the ACSYS SSG nevertheless hoped to see the extension of the network of buoys to marginal seas (Chukchi Sea, Balfin Bay, Sea of Okhotsk etc.), although EEZ sensitivities and the difficulties of working in the seasonal sea-ice zone must be recognised. A different technique to measure the transport of sea ice through the Canadian Archipelago is being evaluated by Canadian scientists. This is based on a combination of ice-profiling and Doppler sonars for point measurements, and of Radarsat to support extrapolation across the complex system of interconnecting channels in the Canadian Arctic.

10.1.3 The Arctic atmosphere

In its studies of the Arctic atmosphere, ACSYS draws on a range of other activities in the WCRP, especially the global reanalyses from ECMWF, NCEP/NCAR and the NASA Goddard Space Flight Center (see section 4.1.7). ACSYS has been particularly involved in assessing the reanalysis products in polar regions and the Second WCRP International Conference on Reanalyses, held at Wokefield Park, near Reading, Berkshire, UK, 23-27 August 1999 (see full account in section 4.1.7) included a session specifically devoted to polar applications of reanalyses. Among examples of these applications were evaluation of hydrological budgets in the Arctic, driving sea-ice and regional Arctic atmospheric models, diagnosis of air-sea interactions, and investigation of high-latitude climate variability. Changes associated with the North Atlantic and Arctic Oscillations, and ENSO, could also be identified. The availability of accurate values for the water vapour flux convergence over northern high latitudes was an especially useful result from the reanalyses. However, reanalyses do have deficiencies in various aspects hampering their exploitation for some applications, namely in surface flux fields such as evaporation, radiation and precipitation - these shortcomings are particularly marked in data-sparse southern high latitudes. ACSYS has been working closely with ECMWF in the preparation of the 40-year ECMWF reanalysis project (ERA-40) in discussing the use of improved sea-ice data sets and a refined representation of sea ice.

The study of polar clouds and radiation being conducted as part of the GEWEX Cloud System Study (GCSS) (see section 5.4.1) (drawing on the data sets collected in Surface Heat Budget of the Arctic Ocean, SHEBA, experiment) will also be a fundamental contribution to an improved understanding of the Arctic atmosphere and knowledge of cloud processes and their optical properties in polar regions.

10.1.4 The Arctic hydrological cycle

The major components of the ACSYS hydrological programme are the compilation of an Arctic hydrological data base, and the development of Arctic hydrological modelling. In respect to the former item, particular attention is being given to the assembly of research-quality Arctic run-off and precipitation data sets, including supporting studies of the adequacy of measurements of solid precipitation. The ACSYS Arctic run-off data base, being constructed by the Global Run-off Data Centre (GRDC) in Koblenz, Germany, contains mean monthly discharge data from 235 stations or rivers flowing into the Arctic Ocean. During 1998, no new data were submitted, but data sets were received in 1999 from Canada, the USA and Scandinavian countries. The availability of run-off data for the 1990s from Russia remains a problem. River run-off information contained in a "Pan-Arctic" run-off data base released by Russia under license is being used as a stop-gap. Release of the full set of Russian data to the GRDC is being requested under the terms of Resolution 25 (WMO Cg-XIII) concerned with the exchange of hydrological data and products.

The Arctic precipitation data archive, organized by the Global Precipitation Climatology Centre in Offenbach, Germany, continues to build up both daily and monthly uncorrected and corrected precipitation data (point and gridded) from all measuring stations within the Arctic catchment area for the period 1950-2000, as well as available supporting satellite and model information. The work being undertaken has recently been reviewed, and new directions proposed. These include, in particular, the preparation of a monthly precipitation climatology for the ACSYS hydrological region. It was further recommended that products from the Arctic precipitation data archive should be based on the highest quality possible station/gauge information, since precipitation inferred from remotely-sensed data in the ACSYS region seems unlikely to be very useful in the near future being in mind the limitations of current sensors and retrieval algorithms. Consideration should also be given to how support can be best provided to CLIC in the future.

A new and significant development is the possible establishment of an Arctic regional component (ARCTIC-HYCOS) of the World Hydrological Cycle Observing System (WHyCOS). The main objective of ARCTIC-HYCOS would be to monitor fresh water inflow to the Arctic Ocean. The concept will be discussed with the Hydrological and Water Resources Department of WMO.

10.1.5 ACSYS data and information flow management

The preparation of an ACSYS data and information management plan is in hand. Steps are also being taken to improve the visibility of the ACSYS Data and Information Service (ADIS) by way of extensions to and modifications of the ACSYS web-site. Information on available Arctic hydrological, meteorological, sea-ice, glaciological, oceanographic, radiation, remotely-sensed and modelling data sets can be consulted at the ADIS web site **http://www.npolar.no/oelke/adis.html**.

More generally, the objective of ACSYS data and information flow management is to facilitate the assembly and archiving of ACSYS data sets in designated data centres, and to establish feedback between users and providers. An additional target is to set up a centralized and accessible high quality cryospheric data set. Criteria for archiving model data are also being considered.

10.1.6 ACSYS observational products

The ACSYS Scientific Steering Group has identified a need to focus on specific observational products based on both remotely-sensed and in situ data. A panel has been established to assess requirements for such merged observational products and data, and to review the means by which these can be derived. Initially, particular attention is being given to assessing techniques for inferring sea-ice thickness, ice concentration and type, ice drift, surface albedo and temperature from remotely-sensed data. Many of these fields can now be provided with sufficient accuracy, and spatial and temporal resolution for wide application in ACSYS-related research, including model validation and development of parameterizations. Satellite-based estimates of sea-ice extent have in fact been produced since 1979, but problems still exist in estimating sea-ice concentrations in the summer when melt ponds influence the surface characteristics. Promising analyses of sea-ice motion have recently been obtained from passive microwave, scatterometer, advanced very high resolution radiometer, and synthetic aperture radar data (and will be extended back in time to 1979). The Radarsat Geophysical Processing System (see also section 10.1.2) is now producing estimates of the age of sea ice and the thickness distribution of thin ice by combining motion fields (the shear and patterns of divergence/convergence) with simple ice growth models. It is with respect to sea-ice thickness where additional information is particularly needed. This cannot at present be determined directly from satellites, although measurements of ice freeboard using radar altimetry show some promise. The ACSYS SSG has requested the observational products panel to consider the feasibility of deriving a sea-ice thickness climatology for ACSYS and CLIC by combination of a range of measurements including electromagnetic observations from ships, upward-looking sensors (moored and carried by submarines) and remotely-sensed data (see section 10.1.2). Overall, the increasing availability of remotely-sensed observations of sea ice are providing valuable new perspectives on the interannual variability in sea-ice concentration, extent and motion, and homogeneous compilations of historical observations of sea-ice extent (again as described in section 10.1.2) are beginning to reveal the long-term record of sea-ice cover.

10.1.7 ACSYS modelling activities

Significant steps forward continue to be taken in the type of modelling needed to support ACSYS. In particular, consideration has been given to the data sets and management of these data sets to support sea-ice/ocean modelling activities, the modelling strategies to make the optimal use of available data, and the requirements for future observations for model validation. Among the recommendations that have been made are:

- gridded annual and seasonal mean climatological sea-ice thickness fields, based on all available measurements, should be produced (for both hemispheres) in view of the importance of these fields for evaluating the performance of sea-ice models (and other cryospheric research applications);

- data sets on run-off from the Greenland (and Antarctic) ice sheets/shelves were needed (these could be based on a modelling approach using a simple degree-day concepts, high resolution digital elevation data, and, for example, relevant parameters from ECMWF analyses/reanalyses);

- information on iceberg calving from the Greenland (and Antarctic) ice sheets/shelves was important (and could be inferred from ship-borne data held by the Norwegian Polar Institute and ice-margin observations from satellites);

- the WCRP International Programme for Antarctic Buoys (see section 10.2.2) should be continued as the data collected were not available from any other source and were essential for validating sea-ice models in the southern hemisphere.

The ACSYS Numerical Experimentation Group continues to organize sea-ice model studies and intercomparisons, and is now planning a simulation over an annual cycle with one-dimensional atmosphere/sea-ice/ocean (column) models, forced by the SHEBA atmospheric and oceanic data sets. This will be carried out in collaboration with the GCSS polar clouds and radiation component. An intercomparison of Arctic regional climate models is also being considered.

In the development of Arctic hydrological modellling, an intercomparison is being jointly planned by ACSYS and GEWEX to assess the performance of hydrological models in treating cold-region water and energy cycles. A PILPS Phase 2 experiment (off-line validation of land-surface models using local forcing data sets (see section 5.4.2)) will be organized based on data sets from the Torne River basin, Sweden. At a later stage, data from the GEWEX Continental-scale Experiment in the MacKenzie River basin (MAGS, see section 5.2) and from the Lena River basin in Russia (to be collected by GAME-Siberia) would be utilized.

10.2 WCRP Antarctic Sea-ice Research Activities

10.2.1 Antarctic sea-ice thickness project

At present, there are five moorings with upward-looking sonars deployed by the Alfred Wegener Institute for Polar and Marine Research, Germany, in the Weddell Sea, and two deployed by the Antarctic Co-operative Research Centre, Australia, off east Antarctica. The Alfred Wegener Institute moorings are due for recovery in 2001 and those of the Antarctic Co-operative Research Centre during 2000. Overall in the period 1990-1999, 51 upward-looking sonars were deployed under the auspices of the WCRP Antarctic sea-ice thickness project (by the Alfred Wegener Institute, the Antarctic Co-operative Research Centre, and the Norwegian Polar Institute). Evidently, the deployment and recovery of buoys in such a remote area poses major logistic problems and involves considerable expense. Moreover, twelve moorings were lost (mainly due to icebergs), and of the thirty-one instruments recovered up to now, only seventeen have yielded good quality data. More detailed information on the project's activities and results is available at **http://www.awi-bremerhaven.de/Research/ansitp/index.html**.

In a development which may point the way to the future, the first trial of a British automatic submarine with an upward looking sonar was expected to be conducted later in 2000. The submarine would run under floes to provide profiles of thicknesses in the marginal ice zone.

10.2.2 WCRP International Programme for Antarctic Buoys (IPAB)

IPAB is a co-operative effort of nineteen agencies and institutions from twelve different countries with interests in near-surface meteorology and oceanography in the Antarctic and Southern Ocean. A particular objective is to foster and maintain a network of drifting buoys (as well as logistic support for the deployment of buoys, data acquisition and processing, data communication services, archiving, scientific and technical advice) south of 55°S, encompassing the maximum Antarctic seasonal sea-ice extent. The programme is strongly research-oriented and the majority of buoy deployments are made for specific research purposes (e.g. the movement of Antarctic sea-ice) rather than for operational monitoring.

Since the inception of the programme in 1995, a total of 106 drifting buoys have been deployed. These have been concentrated in the Weddell Sea and off the coast of East Antarctica, but recently a number have been placed in the Ross and Bellinghausen Sea region. Most of the buoys report through Service Argos, and hence the data are available for use operationally by meteorological services as well as for a variety of other studies such as the validation of techniques for determining sea-ice motion from remotely-sensed data. A detailed account of IPAB activities is available at **http://www.antcrc.utas.edu.au/antcrc.buoys/buoys.html**.

10.3 The WCRP Climate and Cryosphere (CLIC) study

10.3.1 The development of the CLIC Science and Co-ordination Plan

At its session two years ago, the JSC, after careful consideration, endorsed the proposal for a broader programme on the climate and cryosphere in the WCRP. As well as the compelling scientific arguments for such a programme and the obvious need to bring together a range of existing cryospheric activities within a global climate research framework, there were many requests from other involved bodies for WCRP to undertake an overall co-ordinated global study on the role of all components of the cryosphere in the global climate system. The JSC agreed that a WCRP Climate and Cryosphere (CLIC) Task Group should be established to develop a science and implementation plan for CLIC. An interim report was delivered to the twentieth session of the JSC in which the principal scientific questions to be addressed in CLIC and how they might be tackled had been discussed in some detail. This included ideas for the range of observational studies required to explore interactions of the cryosphere with various components of the climate system on global, regional and process-level scales, as well as for investigations of several cryospheric processes.

In the past year, attention has been given to setting out a full science strategy for CLIC, comments on the draft science and implementation plan collected, links with other programmes identified, steps needed for implementation specified, and possibilities of national commitments to CLIC sounded out. The final draft "CLIC Science and Co-ordination Plan" was presented to the JSC at its twenty-first session (available electronically at **http://www.npolar.no/acsys/CLIC/clic_may.pdf.**

In the plan, the main scientific questions to be taken up are treated under the following headings:

- Interactions between the atmosphere, snow/ice and land
- Interactions between land ice and sea level
- Interactions between sea ice, oceans, and the atmosphere, and
- Cryospheric interactions with the atmosphere and the ocean on a global scale

The cryosphere is also considered as an indicator of climate variability and change.

Atmosphere-snow/ice-land interactions are concerned with the role of the terrestrial cryosphere (i.e. snow, lake- and river-ice, glaciers and frozen ground/permafrost) within the climate system. Specific issues include the interactions and feedback of terrestrial snow and ice in the current climate and their variability, in land surface processes and in the hydrological cycle, as well as the response and feedback of permafrost to changes in the climate system. Improved knowledge is required of the amount, distribution, and variability of solid precipitation on a regional and global scale, and its response to a changing climate.

The primary concern regarding the relationship of the cryosphere and sea level is the past, present and future contribution of land ice to sea level change. The extent to which sea level rise over the last 100 years can be explained by changes in land ice volume needs to be clarified. This means it is essential to measure and explain the current state of balance of glaciers, ice caps and ice sheets, and especially to resolve the present large uncertainties in the mass budgets of the Greenland and Antarctic ice sheets.

In the interactions between atmosphere and ocean in high latitudes, sea ice has a major modulating role, whose details and consequences for the global climate system are not yet fully known. Improved knowledge is needed of the broad-scale time-varying distributions of the physical characteristics of sea ice, particularly ice thickness and the overlying snow-cover thickness, in both hemispheres, and the dominant processes of ice formation, modification, decay and transport which influence and determine ice thickness, composition and distribution. The representation of much of the physics is incomplete in many models, and it will be necessary to improve coupled models considerably to provide the capability of predicting the response of sea ice to climate change and potential feedbacks.

Key issues on the global scale are understanding the direct interactions between the cryosphere and atmosphere, correctly parameterizing the processes involved in models, and providing improved data sets to support these activities. In particular, improved interactive modelling of the atmosphere-cryosphere surface energy budget and surface hydrology, including fresh-water runoff as well as better formulations and data sets on surface albedo and its dependence on surface type, vegetative cover, underlying surface albedo, and surface temperature are required. Other important global issues are the impact of cryospheric anomalies on the atmosphere, and the sensitivity to variability and change of atmospheric moisture transport, which controls snow accumulation and thus the mass balance of ice sheets. Another important aspect of the cryosphere for global change concerns the ice-albedo feedback. The cryosphere also has the potential for influencing the global ocean through changes in sea level, modulation of the thermohaline circulation, which affects meridional heat and fresh-water transport, and impacts on the efficiency of carbon uptake and exchange. The fundamental interactive processes and feedback between large-scale ocean circulation and the cryosphere must be better understood.

Because of its response to regional and global variations in the climate system, the cryosphere is not only an integrator of climate processes, but also a strong indicator of change. Cryospheric change indicators are particularly valuable in regions where conventional observations are of short duration or completely lacking. Existing time series of the extent of sea ice, snow cover, and permafrost, and of glacier geometry and mass balance, should continue to be monitored for change. Records of past climatic variability at the multi-decadal and longer time-scales are available from historic and geomorphologic records of glacier fluctuations, borehole temperatures and ice cores. These data complement the existing instrumental records of temperature and precipitation and can improve both temporal and spatial coverage. The longer perspective can indicate how significant recent changes are in relation to natural variability.

In each of the foregoing areas, a combination of measurements, analysis and monitoring, field process studies and modelling at a range of time and space scales will be required. The observational framework for CLIC will be built on the achievements of ACSYS, the existing WMO meteorological and hydrological networks, the continuing WCRP Arctic and Antarctic buoy and sea-ice thickness projects, and elements of GCOS/GTOS/GOOS relating to the cryosphere. Remotely-sensed data will obviously be of special importance, and foreseen new missions (e.g. ESA-CryoSat or NASA's Geoscience Laser Altimeter) would provide much valuable information. CLIC implementation will complement other initiatives already going ahead in the cryosphere; co-ordination will be needed to ensure that together a global perspective on cryospheric research will be obtained. Many issues addressed in CLIC are also relevant to aspects of

CLIVAR and GEWEX, and there must be strong links between the programmes to ensure that science initiatives within CLIC are co-ordinated with and are complementary to those initiated or planned in CLIVAR and GEWEX.

10.3.2 The establishment of CLIC as a WCRP project

The JSC commended the work of the WCRP CLIC Task Group in developing a comprehensive science and co-ordination plan that mapped out clearly the scientific questions that needed to be tackled, and that set down the observational and modelling strategy to be followed. The JSC duly endorsed CLIC as a new project in the WCRP focussed on an in-depth study of the role of the cryosphere in climate.

It was foreseen that ACSYS would continue for a further few years as an important component of CLIC, and the JSC considered the arrangements for the transition from ACSYS to CLIC. Firstly the ACSYS Scientific Steering Group was re-established as the "ACSYS/CLIC Scientific Steering Group" with the following terms of reference:

(i) Formulate and guide the ACSYS observational and modelling programmes for determining Arctic climate processes and realistic representation of the Arctic region in global climate models.

(ii) Formulate and guide the CLIC observational and modelling programmes for determining the role of the cryosphere in global climate and realistic representation of the cryosphere in global climate models.

(iii) Formulate in particular the implementation plan for CLIC.

(iv) Stimulate exchange and analysis of data relevant to ACSYS and CLIC, and the dissemination of scientific results.

(v) Use the advice of experts and expert groups as necessary in order to assist with the development and implementation of the ACSYS and CLIC projects.

(vi) Establish scientific liaison and logistic co-operation with other WCRP projects and with appropriate programmes/organisations/groups and activities relevant to ACSYS and CLIC.

(vii) Advise the JSC on progress achieved in the implementation of the ACSYS and CLIC projects and advances in the understanding of polar and cryospheric processes.

Appropriate members would be added to the existing ACSYS Scientific Steering Group in place of those retiring in 1999 (and later years), chosen particularly to provide links and co-ordination with activities or programmes/groups/organizations relevant to CLIVAR (see section 11.2).

It was furthermore agreed that the existing ACSYS Numerical Experimentation Group should become the ACSYS/CLIC Numerical Experimentation Group, with an expanded role in support of CLIC. The terms of reference for the ACSYS/CLIC Numerical Experimentation Group are:

(i) In liaison with other NEGs within the WCRP:

- to address cryospheric modelling issues of the coupled system (atmosphere, sea ice, ocean, ice sheets, ice shelves, ice caps, glaciers, and land hydrology including snow cover, frozen ground, permafrost, and lake and river ice) relevant to ACSYS/CLIC;
- to promote the investigation and improvement of the parameterisation of specific cryospheric processes in climate models;
- to distribute the improved parameterisations.

(ii) To advise the ACSYS/CLIC SSG on data requirements for model development, validation and optimisation, and on archiving model output, and

(iii) To develop, review and update as appropriate the ACSYS and CLIC implementation plans on a regular basis.

(iv) To create temporary task groups where required to:

- promote the improvement and evaluation of models of individual components of the cryosphere;
- investigate coupling processes and techniques in models whose representations of cryospheric components are interactively connected in part or in combination, and
- advise the ACSYS/CLIC SSG on the use of data assimilation techniques applied to individual components and coupled models.

The International ACSYS Project Office would become the International ACSYS/CLIC Project Office, with appropriately modified terms of reference. The specific tasks of the Office included co-ordination of national commitments of resources and logistic support required to implement ACSYS and CLIC, developing data management for ACSYS and CLIC and ensuring the timely flow of scientific data, and assisting in the organization of ACSYS/CLIC meetings, workshops and conferences. The JSC was gratified to learn that the Norwegian Polar Institute would continue to host and support the International ACSYS/CLIC Project Office until at least 2003 (the planned date for the completion of ACSYS), and might be willing to host an International CLIC Project Office after this date. However, other support to the Office was extremely limited. The Alfred Wegener Institute for Polar and Marine Research had funded a position up until July 1999, and JAMSTEC continued to make some contribution towards operational costs. There was a pressing need to obtain further resources for the International ACSYS/CLIC Project Office and the assistance of JSC members in encouraging and arranging suitable secondments/financial support from their home countries was urgently requested. The JSC noted that the post of Director of the International ACSYS/CLIC Project Office was vacant, but that candidates had been interviewed and that the position would be filled in June 2000.

11. ADMINISTRATIVE MATTERS

11.1 Election of Officers of the JSC

The terms of all the existing Officers of the JSC (i.e. that of Dr. W.L. Gates, Chairman; Dr. R.T. Pollard, Vice-chairman; Professors Y. Ding, B. Hoskins, and P. Lemke, Officers) all expired on 31 March 2000. It was noted that Dr. W.L. Gates and Dr. R.T. Pollard expected to step down from the Committee at the expiry of their current terms of membership (31 December 2000), and it would thus be necessary to nominate a new Chairman and Vice-Chairman. The JSC unanimously agreed to invite Professor P. Lemke to serve as Chairman and Professor B. Hoskins as Vice-Chairman, both with effect from 1 April 2000 for a term of two years. Furthermore, the JSC unanimously invited Professor Y. Ding to serve a further two-year term as an Officer (1 April 2000-31 March 2002). Dr. J. Church and Professor A. Sumi were unanimously nominated to fill the two remaining Officer positions for terms of two years.

11.2 Organization and membership of WCRP scientific and working groups

The membership of various scientific and working groups and the changes made by the JSC at its twenty-first session are listed below.

CAS/JSC Working Group on Numerical Experimentation (WGNE)

Membership of the WGNE is determined by consultation between the Chairman of the JSC and the President of CAS. Of the members whose terms were expiring, Dr. V. Meleshko now wished to leave WGNE after many years of service. It was proposed that Dr. V. Kattsov (Voeikov Main Geophysical Observatory, St. Petersburg, Russia), be invited to serve in place of Dr. Meleshko for an initial term up to 31 December 2003. It was further agreed that the term of membership of the Chairman of WGNE, Dr. K. Puri, and those of Drs P. Bougeault, A. Lorenc, M. Miller, W. Wergen, and D. Williamson should be extended for a further two years. The composition of WGNE is thus:

Membership	Expiry of appointment		
K. Puri (Chair)	31	December	2001
P. Bougeault		"	2001
Chen Dehui		"	2001
V. Kattsov		"	2003
S. Lord		"	2001
A. Lorenc		"	2001
M. Miller		"	2001
H. Ritchie		"	2001

T. Tsuyuki	"	2001
W. Wergen	"	2001
D. Williamson	"	2001

JSC/CLIVAR Working Group on Coupled Modelling

The term of the membership of the current Chair of the Working Group on Coupled Modelling, Professor L. Bengtsson, together with those of several members, expired on 31 December 1999. The JSC agreed, in consultation with the Co-chairs of the CLIVAR Scientific Steering Group, that the appointment of Professor Bengtsson would be extended by a further year (until 31 December 2000). In order to institute rotation in the membership of the Working Group on Coupled Modelling, Drs T. Delworth (Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA) and A. Weaver (School of Earth and Ocean Sciences, University of Victoria, BC, Canada) were nominated to serve for initial terms of four years (i.e. up to 31 December 2003) in place of Drs G. Boer and R. Stouffer. It was nevertheless hoped that Drs Boer and Stouffer would continue to take an active part in WGCM work and to participate in WGCM sessions, in particular in their capacity as members of the CMIP panel. The terms of membership of Drs S. Joussaume, H. Le Treut, B. McAvaney, G. Meehl, J. Mitchell and D. Webb were extended by two years. In addition, Dr. J. Mitchell was nominated as Vice-chair of the group with immediate effect in the expectation that he might take up the Chairmanship of the Working Group on Coupled Modelling when the term of Professor Bengtsson came to an end. The composition of the Working Group on Coupled Modelling duly becomes:

Membership	Expiry of appointment		
L. Bengtsson (Chair)	31	December	2000
J. Mitchell (Vice-chair)		"	2001
C. Boening		"	2002
T. Delworth		"	2003
G. Hegerl		"	2002
S. Joussaume		"	2001
H. Le Treut		"	2001
B. McAvaney		"	2001
G. Meehl		"	2001
A. Noda		"	2001
A. Weaver		"	2003
D. Webb		"	2001

WOCE Scientific Steering Group

As WOCE would come to its formal end in 2002, it was decided at the twentieth session of the JSC that the membership of the WOCE Scientific Steering Group should be fixed for the remaining duration of the Experiment . The composition of the group thus continues as:

Membership	Expiry of appointment		
P. Killworth (Co-chair)	31	December	2002
W. Large (Co-chair)		"	2002
S. Imawaki		"	2002
W. Jenkins		"	2002
P. Killworth		"	2002
K. Speer		"	2002
D. Stammer		"	2002
L. Talley		"	2002
E. Tziperman		"	2002

CLIVAR Scientific Steering Group

Since the annual session of the CLIVAR Scientific Steering Group closely followed that of the JSC, changes in or renewal of membership to take effect from 1 January 2000 were agreed in advance by the Chairman of the JSC on behalf of the Committee. Drs. J. Jouzel and Dr. Martinson were invited to serve a further period of two years, and Dr. K. Trenberth one year. Drs. Guoxiang Wu (Chinese Academy of Sciences) and F. Zwiers (Canadian Centre for Climate Modelling and Analysis) were invited to join the group for initial terms of three years (i.e. until 31 December 2002). The membership of Dr. Chongyin Li (Chinese Academy of

Sciences) came to an end on 31 December 1999. The composition of the CLIVAR Scientific Steering Group is now:

Membership	Expiry of appointment		
A. Busalacchi (Co-Chair)	31	December	2002
J. Willebrand (Co-chair)		"	2001
J. Jouzel		"	2001
K. Hanawa		"	2000
D. Martinson		"	2001
J. Mitchell		"	2000
N. Nicholls		"	2000
T. Palmer		"	2000
E. Sarachik		"	2000
K. Trenberth		"	2000
R. Weller		"	2002
G. Wu		"	2002
F. Zwiers		"	2002

ACSYS/CLIC Scientific Steering Group

As noted in section 10.3.2, following the establishment of CLIC as a new project in WCRP, the ACSYS Scientific Steering Group was re-established as the ACSYS/CLIC Scientific Steering Group. It was firstly agreed to invite Dr. H. Cattle, Chair of the ACSYS Scientific Steering Group, to serve as Chair of the ACSYS/CLIC Scientific Steering Group with immediate effect until 31 December 2001. Dr. I. Allison (Antarctic Co-operative Research Centre, Hobart, Tasmania, Australia) and Dr. R. Barry (University of Colorado, Boulder, USA) were proposed as Vice-chairs for an initial term up to 31 December 2001. Dr. B.A. Goodison (Atmospheric Environment Service of Canada) and Dr. T. Fichefet (Université Catholique de Louvain, Belgium) would be invited to join as new members. These nominations took very much into account the transition now under way from ACSYS to CLIC. The other members of the former ACSYS Scientific Steering Group whose terms did not expire until 31 December 2000 (that is Drs G. Alekseev, E. Fahrbach, T. McClimans, H. Melling, T. Takizawa, and V. Vuglinsky) would be invited to serve as members of the ACSYS/CLIC Scientific Steering Group until 31 December 2000. Three members of the old ACSYS Scientific Steering Group (Drs J. Curry, P. Lemke, and D. Lettenmaier) would now step down following the expiry of their terms on 31 December 1999. The initial composition of the ACSYS/CLIC Scientific Steering Group is thus:

Membership	Expiry of appointment		
H. Cattle (Chair)	31	December	2001
I. Allison (Vice-chair)		"	2001
R. Barry (Vice-chair)		"	2001
G. Alekseev		"	2000
E. Fahrbach		"	2000
T. Fichefet		"	2001
B. Goodison		"	2001
P. Jones		"	2000
T. McClimans		"	2000
H. Melling		"	2000
T. Takizawa		"	2000
V. Vuglinsky		"	2000

GEWEX Scientific Steering Group

No changes in membership were due to be made at this session of JSC. Members and dates of expiry of appointments are:

Membership	Expiry of appointment		
S. Sorooshian (Chair)	31	December	2000
R. Atlas		"	2002
R. Curran		"	2002
Y.H. Ding		"	2000

A. Hollingsworth	"	2000
M. Moncrieff	"	2000
J. Noilhan	"	2000
W. Rossow	"	2000
U. Schumann	"	2002
I.A. Shiklomanov	"	2000
R.E. Stewart	"	2000
B. Wilkinson	"	2000
T. Yasunari	"	2000

Working Group on Radiative Fluxes/GEWEX Radiation Panel

Several terms of membership on this group expired on 31 December 1999, but proposals for renewal of appointments or replacements of members were not available at the JSC session. The Committee requested the Officers, in consultation with the Chair of the GEWEX Scientific Steering Group and the Chair of the GEWEX Radiation Panel, to consider renewals of terms of membership or nomination of new members. The composition of the group at the time of the JSC session was:

Membership	Expiry of appointment		
G. Stephens (Chair)	31	December	1999
P. Arkin		"	2001
J. Curry		"	1999
R. Ellingson		"	1999
J. Harries		"	2001
V. Khvorostyanov		"	1999
W. Krajewski		"	1999
J.-J. Morcrette		"	1999
T. Nakajima		"	1999
V. Ramaswamy		"	1999
R. Stuhlmann		"	1999
D. Tanré		"	2001
S. Tjemkes		"	1999
B. Wielicki		"	2001

SPARC Scientific Steering Group

No changes were due to be made at this session of the JSC. Members and dates of expiry of appointments are:

Membership	Expiry of appointment		
M.-L. Chanin, Co-chair	31	December	2000
M. Geller, Co-chair		"	2000
C. Granier		"	2000
K. Hamilton		"	2000
D. Karoly		"	2000
V. Khattatov		"	2000
P. McCormick		"	2002
A.J. O'Neill		"	2000
T. Peter		"	2000
U. Schmidt		"	2000
T. Shepherd		"	2000
S. Yoden		"	2002

JSC/SCOR Working Group on Air-Sea Fluxes

As noted in section 7.1, the JSC agreed that the joint JSC/SCOR Working Group on Air-Sea Fluxes should continue in existence until the Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields in 2001 to oversee the organisation of the workshop. The membership remains as:

- S. Gulev, P.P. Shirshov Institute of Oceanology, Moscow, Russian Federation (Co-chair)
- P. Taylor, Southampton Oceanography Centre, Southampton, UK (Co-chair)
- B. Barnier, Laboratoire des Ecoulements Géophysiques et Industriels, Institut Mécanique de Grenoble, France
- F. Bradley, CSIRO Centre for Environmental Mechanics, Canberra, Australia
- T. Charlock, NASA Langley Research Center, Hampton, VA, USA
- P. Gleckler, Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA, USA
- K. Kutsuwada, School of Marine Science and Technology, Tokai University, Japan
- D. Legler, US CLIVAR Office, Washington, DC, USA
- R. Lindau, Institut für Meereskunde, Kiel, Germany
- D. Rothrock, Polar Science Center, University of Washington, Seattle, WA, USA
- J. Schulz, Max Planck Institut für Meteorology, Hamburg, Germany
- A. da Silva, NASA Goddard Space Flight Center, Greenbelt, MD, USA
- A. Sterl, Royal Netherlands Meteorological Institute, De Bilt, Netherlands
- G. White, NOAA National Centers for Environmental Prediction, Washington, DC, USA

WCRP/GCOS/GCOS Ocean Observations Panel for Climate

The membership of the Ocean Observations Panel for Climate, jointly sponsored by the JSC and the Joint Scientific and Technical Committees for GCOS and GOOS, is:

- N. Smith, Bureau of Meteorology, Melbourne, Australia (Chair)
- G. Griffiths, Southampton Oceanography Centre, UK
- E. Harrison, NOAA Pacific Marine and Environment Laboratories, Seattle, USA
- P. Haugan, University Courses on Svalbard, Longyearbyen, Norway
- J. Johanesson, ESTEC, Noordwijk, Netherlands
- M. Kawabe, Ocean Research Institute, University of Tokyo, Japan
- J.R. Keeley, Marine and Environmental Data Service, Fisheries and Oceans, Ontario, Canada
- G. Needler, Bedford Institute of Oceanography, Dartmouth, Canada
- J. Picaut, ORSTOM, France (temporarily at NASA/GSFC)
- R. Reynolds, NCEP, Washington, DC, USA
- R. Weller, Woods Hole Oceanographic Institution, Massachusetts, USA
- W. Zenk, Institut für Meereskunde, Kiel, Germany

No changes in the membership of this group were proposed.

WCRP/GCOS Atmospheric Observation Panel for Climate

The membership of the group is:

- M. Manton (Bureau of Meteorology Research Centre, Melbourne, Australia) (Chair)
- P. Arkin (International Research Institute for Climate Prediction, Palisades, NY, USA)
- A. Baede (Royal Netherlands Meteorological Institute, De Bilt, Netherlands)
- V. Barros (Department of Atmospheric Sciences, University of Buenos Aires, Argentina)
- R. Fleming (NOAA Office of Global Programs, Boulder, CO, USA)
- E. Harrison (NOAA Pacific Marine Environmental Laboratory, Seattle, WA, USA)
- P. Jones (Climatic Research Unit, University of East Anglia, Norwich, United Kingdom)
- T. McElroy (Meteorological Service of Canada)
- R. Okoola (Department of Meteorology, University of Nairobi, Kenya)
- D. Parker (Hadley Centre for Climate Prediction and Research, Bracknell, United Kingdom)
- T. Peterson (National Climatic Data Center, Asheville, NC, USA)
- N. Sato (Office of Meteorological Planning, Japan Meteorological Agency, Tokyo, Japan)

The JSC noted that Dr. M.-L. Chanin (Co-chair of the SPARC Scientific Steering Group) had recently tendered her resignation from the Atmospheric Observation Panel for Climate. Dr. Chanin had been particularly aware of WCRP interests in and requirements for atmospheric observations and it would be important that her place be filled by a member familiar with WCRP. It was proposed that Dr. G. Stephens (Colorado State University) and currently Chair of the GEWEX Radiation Panel (see above) would be an excellent candidate in this respect, and would be fully aware of links needed between GCOS and the research community, as well as with space agencies.

11.3 Publications

The following reports were produced by the Joint Planning Staff for the WCRP in various series between the twentieth and twenty-first sessions of the JSC:

WCRP Report Series

WCRP-108 Proceedings of the International CLIVAR Conference (Paris, France, 2-4 December 1998) (WMO/TD-No. 954)

WCRP-109 Proceedings of the Second WCRP International Conference on Reanalyses (Wokefield Park, near Reading, UK, 23-27 August 1999) (WMO/TD-No. 985)

WCRP-110 Workshop on Cloud Processes and Cloud Feedbacks in Large-scale Models (Reading, UK, 9-13 November 1998) (WMO/TD-No. 993)

Informal WCRP Reports and Documents

4/1999 Climate and Cryosphere (CLIC) (Summary report of first session of the Task Group, Utrecht, The Netherlands, 8-11 July 1998)

5/1999 WCRP International Programme for Antarctic Buoys (Report of the second session of Programme Participants, Naples, Italy, 11-13 May 1998)

6/1999 Stratospheric Processes and their Role in Climate (SPARC) (Report of sixth session of the Scientific Steering Group, Nagoya, Japan, 26-29 October 1998)

7/1999 Global Energy and Water Cycle Experiment (GEWEX) (Report of eleventh session of the Scientific Steering Group,Tucson, Arizona, USA, 26-29 January 1999)

8/1999 CAS/JSC Working Group on Numerical Experimentation (Report of fourteenth session, Dorval, Québec, Canada, 2-6 November 1998)

9/1999 CLIVAR Variability of the American Monsoon System (VAMOS) (Report of second session of Panel, Buenos Aires, Argentina, 15-18 March 1999) (also ICPO Report No. 30)

[10/1999 ----]

11/1999 CLIVAR Upper Ocean Panel (UOP) (Report of fourth session, Woods Hole, Massachusetts, USA, 21 May 1999) (published jointly with report of GCOS/GOOS/WCRP Ocean Observations Panel for Climate as GOOS Report No. 75, GCOS Report No. 78, ICPO Report No. 31)

12/1999 ACSYS Hydrology Models Intercomparison (Report of planning meeting, Koblenz, Germany, 27-29 March 1999)

13/1999 Cold Regions Hydrological Modelling (Report of GEWEX/ACSYS workshop, Quebec City, Canada, 25-27 August 1998)

14/1999 Status and Directions for the ACSYS Arctic Precipitation Data Archive (Report of workshop, Offenbach, Germany, 30 March-1 April 1999)

15/1999 Arctic Climate System Study (ACSYS) (Report of seventh session of Scientific Steering Group, Tokyo, Japan, 2-6 November 1998)

16/1999 Climate Research for Africa (Report of the CLIVAR Africa Study Group) (also ICPO Report No. 29)

1/2000 JSC/CLIVAR Working Group on Coupled Modelling (Report of third session, Hamburg, Germany, 20-22 September 1999) (also ICPO Report No. 32)

2/2000 CLIVAR Working Group on Seasonal-to-Interannual Prediction (previously CLIVAR NEG-1) (Report of fourth session, Bologna, Italy, 9-12 November 1999) (also ICPO Report No. 33)

3/2000 Global Energy and Water Cycle Experiment (GEWEX) (Report of fifth session of Hydrometeorology Panel, Hamburg, Germany, 13-17 September 1999)

Special WCRP Reports

- Annual Review of the World Climate Research Programme and Report of the Twentieth Session of the Joint Scientific Committee (Kiel, Germany, 15-20 March 1999) (WMO/TD-No. 976)

CAS/JSC Working Group on Numerical Experimentation Report Series

No. 29 Proceedings of WCRP Workshop on Modelling the Transport and Scavenging of Trace Constituents by Clouds in Global Atmospheric Models (Cambridge, UK, 1-4 August 1995) (edited by P. Rasch) (WMO/TD-No. 950)

No. 30 Research Activities in Atmospheric and Oceanic Modelling (edited by H. Ritchie) (WMO/TD-No. 987)

Technical Documents

- Sea-ice Charts of the Arctic (Proceedings of workshop, Seattle, USA, 5-7 August 1998) (WMO/TD-No. 949) (also IAPO Report No. 3)

- Arctic Regional Climate Models (Proceedings of workshop, Bracknell, UK, 4-6 November 1996) (edited by H. Cattle) (WMO/TD-No. 981)

The following documents were produced in WCRP Project Offices:

- Arctic Buoy Programme (Proceedings of Conference, Seattle, USA, 3-4 August 1998) (IACPO Report No. 4)

- World Ocean Circulation Experiment (WOCE) (Report of twenty-fifth session of Scientific Steering Group, Brest, France, 5-9 October 1998) (WOCE Report No. 163/99)

- World Ocean Circulation Experiment (WOCE) (Report of Indian Ocean workshop, New Orleans, USA, 22-25 September 1998) (WOCE Report No. 164/99)

- Ocean Modelling for Climate Studies (Report of WOCE/CLIVAR workshop, Boulder, USA, 10-13 August 1998) (WOCE Report No. 165/99, ICPO Report No. 28)

- WOCE/CLIVAR Data Products (Report of committee, Bidston, UK, 12-15 April 1999) (WOCE Report No. 166/99, ICPO Report No. 29 (sic))

- Ocean Tracers (Report of WOCE-AIMS workshop, Bremen, Germany, 22-26 February 1999) (WOCE Report No. 167/99)

- World Ocean Circulation Experiment (WOCE) (Report of twenty-sixth session of Scientific Steering Group, San Diego, USA, 18-22 October 1999) (WOCE Report No. 168/99)

- World Ocean Circulation Experiment (WOCE) (Report of North Atlantic workshop, Kiel, Germany, 23-27 August 1999) (WOCE Report No. 169/00)

Other reports/documents available are listed on and are accessible through the WCRP Home Page: **http://www.wmo.ch/web/wcrp/otherwcrpreports.htm**.

11.4 WCRP resources

As noted in section 2.1, the sum available for WCRP activities supported by the Joint Climate Research Fund would be about CHF 1,430,000 per annum for the period 2000-2003 (compared to about CHF 1,500,000 for the period 1996-1999). Thus, there would continue to be severe shortfalls in WCRP financial resources (as well as staffing). The JSC strongly reiterated the need for all members to act strongly as spokepersons in their home countries and to stress to national funding agencies the importance of increased financial contributions for WCRP activities. The secondment of staff to aid the operation of the Joint Planning Staff of the WCRP and the various Project Officers should also be vigorously explored. Furthermore, members were urged to investigate all possibilities for obtaining national or institutional resources to cover the costs of attendance of themselves in sessions of the JSC, and of other individual national participants in WCRP meetings, working groups sessions etc.

The JSC also recalled the planned funding initiative being jointly considered by WCRP, IGBP and IHDP and the proposal to set up a "Resource Development Committee" (see section 3.2). The JSC was of the view that fund-raising initiatives of the type being envisaged needed to be linked to an overall WCRP communications strategy. This should emphasize the "added-value" given by WCRP, promote the WCRP image and visibility, and emphasize "deliverables". Full advantage should be taken of the electronic communication capabilities now available. However, it was recognized that this was not just an extra task to be loaded onto the already severely overstretched JPS. Ideas, assistance and initiatives were required of all JSC members and WCRP project offices.

12. DATE AND PLACE OF NEXT SESSION

The JSC gratefully accepted the kind invitation put forward by Dr. K. Trenberth to host the twenty-second session of the Committee in Boulder, CO, USA, from 19 to 24 March 2001.

13. CLOSURE OF THE SESSION

The Chairman thanked all participants for their contributions to the session. He felt that the level of scientific discussions had been particularly high. He especially acknowledged the excellent scientific presentations that had been given to the Committee by Professor T. Handoh on the "Dome Fuji Project" and by Dr. T. Ogawa on research activities at the NASDA Earth Observation and Research Center, as well as the special presentation on the impressive Frontier Research System for Global Change in Japan by Professor T. Matsuno. The Chairman reiterated his gratitude to Professor A. Sumi for the outstanding arrangements made for the JSC session, the first class facilities, and generous hospitality.

This was the last session of the JSC which Dr. Gates would chair (see section 11.1), and the Chairman-elect, Professor Lemke expressed, on behalf of all members of the Committee and participants, thanks for the excellent manner in which he had led the work of the JSC over the past six years. Dr. Gates had made many notable contributions to the WCRP during this period. Professor Lemke looked forward to the continuing interest and support of Dr. Gates.

The twenty-first session of the WMO/ICSU/IOC Joint Scientific Committee for the WCRP was closed at 15.00 hours on 17 March 2000.

APPENDIX A

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