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Workshop Report

World Modelling Summit for Climate Prediction

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World Modelling Summit for Climate Prediction

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I. **PREFACE:**

The World Modelling Summit for Climate Prediction was co-sponsored by the World Climate Research Programme (WCRP), World Weather Research Programme (WWRP), and the International Geosphere Biosphere Programme (IGBP), "to develop a strategy to revolutionize the prediction of the climate to address global climate change, especially at regional scale." The primary emphasis of the Summit was on the simulation and prediction of the climate system, but the participants recognized similar challenges/opportunities in weather and other environmental simulation and predictions and that these fields can also benefit from the discussions and recommendations of the Summit. They acknowledged that challenges/opportunities in research, development and verification of climate models span across a wide range of time (intra- and inter-seasonal, decadal, centennial, and longer), and space (global, continental, regional, and other) scales that require immediate attention of climate, weather and environmental scientists, funding agencies and political leaders, globally. The Summit was very well organized and effectively hosted by the European Centre for Medium-Range Weather Forecast (ECMWF). The success of the Summit was due in large part to the major efforts of the organizers, host, sponsors and the participants. This Summit was indeed a major accomplishment in bringing the world leaders together and in defining a set of common objectives/priorities.

The participants identified four major objectives/priorities of: 1) developing models that represent realistically all aspects of the climate system; 2) confronting these models with observations to evaluate their adequacy, accuracy and shortcomings towards building confidence in their future projections; 3) obtaining computational capabilities that are three to four orders of magnitude greater than the best available capabilities today; and 4) establishing a world climate modelling project/programme that benefits from the expertise and investments of the nations around the world to achieve these priorities. The participants recognized all four objectives to be challenging beyond the resources and capabilities of any single nation, thus identified the opportunity for global coordination and cooperation as we move on towards accomplishing them. The participants called on the global environmental research programmes (IGBP, WCRP, WWRP, etc.) and their sponsoring organizations the International Council for Science (ICSU), United Nations Education, Science and Cultural Organization (UNESCO), Intergovernmental Oceanographic Commission (IOC), United Nations Environment Programme (UNEP), and the World Meteorological Organization (WMO), and their member countries to adopt and support these recommendations for implementation in the near-, intermediate- and long-term.

We believe the Summit was successful in achieving its primary goal of identifying the common priorities that are shared and endorsed by the participants, but the challenge of realizing them will be with us during the next decades. The Summit recommendations are quite timely as the world leaders are preparing to convene the World Climate Conference Three (WCC-3), in 2009, three decades after they established the climate research programme, WCRP, and the IPCC process, and two decades after the establishment of coordinated observations (GCOS) and the policy framework (UNFCC). The theme of WCC-3 is "climate information and prediction for decision making" which will depend to a large extent on our ability to predict and project reliably the state of Earth's climate system on seasonal, decadal and longer time scales, but more importantly to synthesize our best scientific knowledge about the climate variability and change and make it available to decision makers in a timely and effective manner. This implies establishing a climate information development and dissemination system that captures the outcome of climate observations, research, analyses and assessments in an end-to-end and seamless manner to serve effectively the providers and users of such information. This is indeed a multi-generations' challenge and opportunity that WCRP is pleased and privileged to embrace and support through its network of global partnerships with the national and international climate research programmes, and the network of its scientific experts from more than 190 countries around the world.

Ghassem R. Asrar
Director, World Climate Research Programme

II. BACKGROUND:

The Joint Scientific Committee (JSC) of the World Climate Research Programme (WCRP) introduced a new strategic framework in 2005 to integrate and synthesize activities of all its components (CLIVAR, GEWEX, CliC, SPARC) to obtain a holistic and predictive understanding of the total physical climate system. This strategic framework, Coordinated Observation and Prediction of the Earth System (COPES) has as its aim:

To facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical application of direct relevance, benefit and value to society.

To implement this new strategic vision of COPES, WCRP created two panels: WCRP Observations and Assimilations Panel (WOAP) and WCRP Modeling Panel (WMP). WMP consists of chairs of existing WCRP modeling panels. The main roles of WMP were to coordinate the activities of the existing WCRP modeling panels (WGNE, GMPP, TFSP, WGSIP, WGOMD, WGCM) and to identify problems and limitations of the existing models, data assimilations systems and computing facilities towards quantifying and harvesting the weekly-seasonal-decadal predictability of the physical climate system.

The WMP presented its report to the JSC at its 28th meeting held at Zanzibar, Tanzania on March 26-30, 2007. A summary of WMP discussions and conclusions is given below:

1. There is insufficient comprehensive model development effort globally. The effort is often under-funded, does not have sustained support, is considered unglamorous by some and scientists engaged in model development do not necessarily have a clear career path.
2. WGNE and WGSIP have pointed out serious limitations of low resolution climate models in simulating the current climate, especially the statistics of mid-latitude storms and blocking. It is therefore unlikely that such models can give sufficiently reliable estimates of changes in the statistics of regional climate to facilitate adaptation at the regional and local scale to climate change. It is essential and urgent that climate models are evaluated with respect to a comprehensive set of model metrics.
3. Use of high-resolution regional models to downscale regional climate change is questionable if the global models from which lateral boundary conditions for regional models are prescribed do not have reliable simulation of planetary waves and statistics of storms and blocking.
4. While there is a general acceptance that the traditional boundaries between weather and climate are somewhat artificial, there is as yet no world-wide organized and coordinated effort to implement the framework for seamless prediction of weather and climate variations. This framework requires that the decadal and multi-decadal predictions using IPCC-class models should move towards consideration of climate change as an initial value problem. This will ultimately require the state of the ocean-land-atmosphere-cryosphere system should be correctly initialized. It is recommended that the IPCC-class models

should be subjected to data assimilation and prediction of short-term weather and ENSO-type variations. Just as 1 day forecast errors are critical in determining the 10 day forecast errors in NWP, some elements of one season or one year predictions may be critical for decadal predictions.

5. The weather and climate modeling community does not have sufficient computing power to build and develop the next generation of cloud system resolving models. A significant fraction of computing power during the past 30 years has been used for running a large number of low resolution (cyclone scale resolving) model ensembles for long periods of time. It is essential that computing power be increased substantially (by a factor of 1000), and scientific and technical capacity be increased (by at least a factor of 10) to produce weather and climate information of sufficient skill to facilitate regional adaptations to climate variability and change.
6. While there has been considerable progress, physical climate system models continue to have serious limitation in simulating the space-time structure of the current climate (rainfall in the tropical forests, ITCZ, monsoons, dryness over deserts etc). Additional complexity (complex chemical and biological processes) must be being introduced in these models to address some issues. Careful studies are needed to quantify the best ways of improving models (e.g. realism versus complexity).
7. Lack of sufficient computing power and dedicated scientific staff to develop data assimilation systems for ultra-high resolution models has made it difficult to realize the maximum possible value from space measurements which are made at a significant cost.
8. There was a remarkable initial success in dynamical seasonal prediction of ENSO about 10-20 years ago. There is an apparent lack of further progress because of large errors in coupled ocean-atmosphere models, both in the initial conditions and in the evolution of the coupled system.
9. WCRP projects worldwide will be producing enormous amounts of data, both from observations and models. WCRP should begin to develop a common data management strategy for all WCRP activities.
10. WCRP, in collaboration with WMO/THORPEX and IGBP, and working with current centers, should initiate a major international effort in developing the next-generation Earth System models and establishing appropriate computing and data facilities.

The WMP report created a lively discussion among the JSC members which continued by e-mail even after the JSC meeting (the conclusions mentioned above represent the consensus approved by the chairman of JSC).

The JSC noted that the world recognizes that the consequences of global climate change constitute one of the most important threats facing humanity. The sustained, comprehensive and objective assessments by the IPCC have created a broad consensus that human activities are contributing to climate change. The climate science community is now faced with a major new challenge of providing society with reliable regional climate predictions. The peoples, governments, and economies of the world must develop mitigation and adaptation strategies, which will require investments of trillions of dollars, to avoid the dire consequences of climate change. Yet, the current generation of climate models have serious limitations in simulating and resolving the present climate and the regional weather variations. Use of high-resolution regional models to downscale regional climate change is questionable if the global models from which lateral boundary conditions are prescribed do not have reliable simulation. It is therefore unlikely that such models can give sufficiently reliable estimates of changes in the statistics of regional climate with a level of confidence required by society.

It is in this context that the Joint Scientific Committee of the WCRP asked the chair of WMP (J. Shukla) to organize the World Modelling Summit for Climate Prediction. The long-term vision for the Summit was to develop a strategy to revolutionize prediction of climate through the 21st century to help address the threat of global climate change particularly at regional scales.

The primary emphasis of the Summit was on the simulation and prediction of the physical climate system. However, since the prediction of regional climate change is strongly influenced both by weather fluctuations on short time scales, and bio-geo-chemical processes on long-time scales, the Summit was co-sponsored by WWRP and IGBP. The Summit brought together about 150 of the world's leading scientists from a number of disciplines to discuss what must be done to address society's urgent needs. The Summit was held at the ECMWF, Reading, UK on 6-9 May 2008.

The Summit consisted of several plenary presentations (see Agenda in appendix 1) and breakout group discussions around five themes lead by five theme leaders listed below.

Summit Themes:

1. Overview: societal drivers; current status of weather and climate modeling; strategies for seamless prediction; crucial hypotheses (B. Hoskins).

2. Prospects for next-generation modeling systems: balance between resolution and complexity; balance between multi-model and unified modeling framework; issues of parameterizing unresolved scales and regional models (M. Miller).

3. Prospects for current high-end computer systems and implications for model code design (J. Kinter).

4. Strategies for model evaluation, modeling experiments, and initialization for prediction of the coupled ocean-land-atmosphere climate system (M. Marotzke).

5. Strategies for enhancing human and computing resources: requirements and possible organizational frameworks (J. Slingo).

III. SCIENTIFIC QUESTIONS

A number of questions were formulated in advance to guide the discussions at the Summit. The questions are listed below.

Theme 1:

The WCRP Strategic Framework for 2005-15 "Coordinated Observation and prediction of the Earth System" and the Green paper "A Revolution in Climate and Weather Prediction - Towards a Seamless Process for the Prediction of Weather and Climate", discussed at the 2007 WCRP JSC meeting, provide the background for the discussion. The argument was made that the revolution was both possible and necessary. In the discussion of this, the notion of a seamless climate-weather problem was introduced.

- What are the crucial questions being asked of our community by society?
- Is a "revolution" both possible and necessary?
- A large body of evidence based on modeling experiments suggests that as models improve their parameterizations and increase their spatial resolution, the model's ability to simulate the current climate as well as the model's skill in predicting daily and seasonal fluctuations improves. What is the likelihood that if the spatial resolution of climate models is sufficiently increased so that deep convective cloud systems, ocean overflows and mesoscale eddies, and heterogeneous land surface processes can be explicitly resolved, and therefore, do not need to be parameterized, the fidelity of climate models in simulating the current climate will improve?
- How can we ensure that if we replace the traditional strategy of parameterizing unresolved small scale processes (viz deep convection in the atmosphere and mesoscale eddies in the oceans) by resolving the unpredictable scales, the rapid growth of the inherently unpredictable small scale systems does not overwhelm the predictable large-scale flow?
- To what extent is the notion of a seamless climate-weather problem valid and useful?
- How accurate must simulations of the physical climate system be to justify the extension of climate models to include additional complexity due to chemical and biological processes? What time and space scales of coupling are fundamental to the system? What are the appropriate metrics to evaluate climate models?
- What should be the approach to solving the problem?
- It is well recognized that if the global models, from which lateral boundary conditions for regional models are prescribed, do not have reliable simulation of planetary waves and the statistics of tropical and extratropical storms, blocking and other regional phenomena, the use of high resolution regional models to downscale regional climate change is questionable. Is there a less questionable alternative? Are time-slice experiments using very high resolution (as high as regional models) global atmospheric models with surface boundary conditions from global change experiments, less questionable than regional downscaling
- What can we promise to those who fund the venture?

Theme 2:

- What and how strong is the evidence for 'serious limitations' in current climate models?
- If there are serious limitations in simulating the physical climate system, should we be directing much more resources towards alleviating them e.g. better

parametrizations or higher resolution rather than massively increasing the complexity of the earth system simulation?
- Is the low resolution currently used due only to lack of computer and human resources or lack of understanding and 'cultural inertia'?
- Does the experience of NWP and early efforts with very high resolution climate simulations confirm that much higher resolution is essential?
- If the answer to the question above is yes then why are we not doing more?
- How strong is the evidence that resolving deep convection in large-scale models gives improvements to the forecasts and simulations, and hence fundamentally change the efficacy of climate prediction and projection?
- Is it possible that climate models will respond more nonlinearly to imposed climate forcing's in models which resolve deep convection, compared with the current generation of climate models?
- Do stochastic techniques provide an alternative to ultra-high resolution?
- Do Regional Climate Models (RCMs) necessarily improve the reliability of regional climate change forecasts? Is there a need for RCMs when deep convection is resolved in global climate models?

Theme 3:

- What is the best strategy to provide sufficient computational capability to enable the development and operation of dramatically higher resolution and higher complexity weather, climate- and Earth-system models in the next 10 years?
- Should partnerships between the modeling community and the chip/system design community be fostered toward the development of a specialized "climate computer"?
- What are the current status and current trends in high-end computing? What are the requirements for weather and climate modeling for the next decade?
- Are current plans by the commercial high-end computing vendors likely to produce systems capable of addressing those needs?
- What are the current status and current trends in petascale software?
- How can the weather and climate models take advantage of these developments?
- Are sufficient resources being dedicated to the development of software environments to support weather and climate modeling?
- What are the current status and current trends in global weather and climate model design?
- What advances in fluid dynamics modeling in other fields have been made or are anticipated and have the weather and climate model development groups taken advantage of these developments?

Theme 4:

- Can we define a strategy for model evaluation that spans a hierarchy of scales and processes?
- Can we identify key uncertainties for which this process-based evaluation is essential, and other key uncertainties for which it is less important?
- How do processes integrate into an overall model sensitivity?
- Can climate models or their components be initialized and used for "reanalysis" of observations and does this improve evaluations and insights for model improvements?

- What progress is required before we can initialize coupled climate prediction models?
- Is it sufficient to perform uncoupled initializations and then couple the initialized component models?
- We know several candidates that have the potential for carrying decadal climate predictability – the ocean, sea ice, soil moisture, and the stratosphere. How can we find out most effectively which of these candidates indeed leads to better predictions?
- Can we define a manageable set of metrics that allow us to quantify how well models fit observational data? What metrics map onto climate sensitivity?
- Can we map any metric onto a purpose for which it is defined?
- Do we have to take special measures to avoid that the metrics themselves, rather than model improvement, become the target?
- Do climate models correctly simulate major climate signals such as the retreat of Arctic summer sea ice during 2007?
- How much of the discrepancy is due to inherent predictability issues versus model deficiencies?
- How much is attributable to "external" forcing versus "internal" evolution? In the latter case, how critical are the initial conditions?
- Are there climate signals that models cannot be expected to simulate correctly even under the best circumstances?
- Can we attribute major climate signals to specific causes, thus explaining how they arose? What does ability to simulate immediate past events (or otherwise) map onto confidence in future predictions?
- Do we have an adequate strategy to investigate parameter sensitivity in models?
- Do we have the appropriate statistical framework?
- Do we know how to sample parameter space, both conceptually and efficiently enough?
- How does parameter sensitivity map onto model sensitivity?
- Given the large number of Model Inter-comparison Projects (MIP's) that have occurred so far, do we have an adequate MIP strategy?
- Is the MIP strategy comprehensive enough to give us insight both into how realistically or unrealistically models simulate the world, and insight into knowledge about how models differ from each other, thus pointing at key structural uncertainty?
- Is it time to stop treating all models as equals in the IPCC multi-model ensemble?
- How do MIP's lead to model improvement?

Theme 5:

- What is the strategy to ensure enhanced and sustained modeling efforts and computing power at the existing modeling centers of the world? Or, is the scale of the challenge so large that in addition to the current national efforts, a far more comprehensive, and internationally coordinated approach is needed?
- How can we convince governments and funding agencies of the immense economic value of an increased capability to produce information on regional and local changes and variations in climate, which are of sufficient accuracy to enable well-informed decisions on adaptation and mitigation options to be taken?

- Do we need a demonstration project and if so what form should it take? How or should such a project influence the structure and remit of the next IPCC assessment?
- What are the best strategies to foster collaboration and interaction among the weather/climate modeling community, computational fluid dynamics community and computer (and chip) manufacturers to achieve a million fold increase in the effective computing power for climate and weather modeling and prediction?
- What are the best strategies for fostering collaborations among existing centers around the world to tackle the intellectual challenge of achieving this step change in climate modeling and prediction? What role should the WCRP play in facilitating this?
- Has the time come for the climate modeling community of the world to establish a dedicated supercomputing facility and a collaborative research framework for climate and weather modeling and prediction that is beyond the capability of a single nation?

IV. REPORT OF THEME DISCUSSIONS

With the exception of Theme 1, for which all discussions were held in plenary session, there was a separate breakout group for each theme. A brief report of the discussion in the breakout groups is given below.

Theme 1 Report (Overview: societal drivers; current status of weather and climate modeling; strategies for seamless prediction; crucial hypotheses)

Theme 1 provided the context for the summit discussions, in terms of the relevant strategy procedures undertaken, the documents produced, the ideas developed in them and relevant developments in the community.

The WCRP 2005-15 Strategy, Coordinated Observation and Prediction of the Earth System introduced the notion of the seamless climate-weather problem, highlighting the lack of spectral gap, the intimate relationship between weather and climate and the importance of weather in the impact of climate. It also highlighted the range of challenges that are increasingly being faced in prediction, including the resolution, complexity, length and numbers of simulations and the requirement for observational data and the need to assimilate it in the context of models. Collaboration with WWRP THORPEX has led to a White Paper detailing the approach to topics of common interest, and also together with IGBP a contribution through the GEO process. The modeling coordination in WCRP and IGBP has led to a specification of a program of experimentation related to decadal time-scale projections of climate change.

The Japanese experience in running global climate models with resolution on scales of 10km has laid the basis for a wider experimentation and application of such very high-resolution models.

It was concluded that the societal need for a revolution in climate modeling is evident and that the science was in a sufficiently mature state to support such a revolution.

<u>Theme 2 Report</u> (Prospects for next-generation modeling systems: balance between resolution and complexity; balance between multi-model and unified modeling framework; issues of parameterizing unresolved scales and regional models)

This theme was allocated a wide range of topics for discussion. This included strategies for future modeling systems, issues of parameterization, regional modeling as well as the balances required and/or implied between resolution and complexity on the one hand and multi-models and unified modeling on the other. A list of possible questions had been tabled which was largely superseded by a draft for ingredients of a possible Climate Prediction Project provided just before the first round of discussions. As can be appreciated below, several of the group's main conclusions and concerns directly influenced the final Summit Statement.

The discussions focused first on the draft project ingredient list and can be summarized as follows:

The concept of a prediction project was generally accepted provided that it was understood to have a scientific focus and to be envisaged on a long enough timescale (e.g. 15years). Some concern was expressed that the distinction between 'prediction' and 'projection' was probably unclear to non-experts and might lead to misunderstandings if not careful.

It was noted that the key ingredient of 'seamlessness' was missing from the draft project component list and the group noted that this would sever the intimate links to the knowledge base of NWP. Strong views that this must be remedied in the final version were expressed. It was further noted that advances in our understanding of the climate system should be integral to the projects activities, once again underlining the overwhelming view of the group that the project must have a strong focus on science.

The most extensive and key discussion which also dominated part of the Plenary discourse concerned the role of the proposed world climate research facility. Despite many and varied ideas as to what type of experiments etc might be investigated, there was virtually unanimous agreement that the facility should have the character of a scientific enterprise rather than a prediction-dominated one. The group felt that it was the advancing of our understanding that was critical. Words such as 'demonstration' and 'dream' experiments were what inspired people.

It was the strong consensus view of the group that progress could be dramatically accelerated by focusing on experiments that are two or more generations ahead of national efforts and that might indicate what the most successful future model development directions should be. There was wide-ranging agreement that research at the facility should focus on complementary activities that support existing national/regional efforts but which cannot be carried out by individual centers (such as the grand challenge (dream) simulations (e.g., ultra-high resolution, uncertainty, increased complexity) rather than routine production of climate predictions. It was felt that these kinds of experiments would stimulate scientific and technological advances throughout the community and lay the foundation for future prediction efforts, just like the Human Genome Project laid the foundation for research into many branches of medicine that affect humankind today.

There was general agreement that much higher resolution of the major model components (atmosphere, ocean, land) is a fundamental prerequisite for a more realistic representation of the climate system and more relevant predictions (e.g., extremes, convection, tropical variability, regional and local applications).

Many people felt that improving the basic model physics should be a key part of any proposal whether through inspired development, much higher resolutions or stochastic concepts. It was noted several times that many of the national efforts at including more sophisticated model components (e.g., atmospheric chemistry and aerosols) are currently severely limited by the poor representation of some of the underlying physical processes (e.g., convection, clouds). It was noted that the Project's activities must support a rapid improvement of these representations if progress in climate prediction is to be made.

The excitement of addressing good science questions, identifying and tackling "road blocks", in part through the opportunities provided by a new super-facility was an essential part of any endeavor, and one to be preserved and nurtured not least for the engagement of the young scientists who might otherwise see modeling as unattractive.

The absence of some key communities in the discussion (e.g. cryosphere, land surface) was noted. It was envisaged that each of the absent communities would have their own set of possible "dream" or "demonstration" experiments to accelerate progress in their respective areas of research. However the group discussions could not consider in any detail what these experiments should be in the non-atmospheric components of the climate system. This was unfortunate.

There was an interesting if inconclusive discussion on how one would measure success of the project and the facility. However it was unanimously anticipated that very high-resolution studies would substantially improve the prediction of the tropical climate and its variability. If true, the consequences for predictions for some of the most populated and yet poorest areas of the globe would dramatically improve, a point strongly emphasized in the discussions.

The group also discussed ancillary matters such as:

1) Governance - concluding that at least part of the project and in particular the facility should involve an active component of proposal-based rather than executive-driven research
2) The implications of the 'Project' on young scientists and the supply of expert staff - concluding that this was a difficult and delicate issue especially in the formative years of any new initiative such as was being proposed.
3) The essential balance needed between any Track 1 supercomputer facility and the data archiving, retrieval and visualization.

In summary the group saw the following as its 'vision' that should be subscribed by the Statement

- To provide a quantum leap in the exploration of the limits in our ability to reliably predict climate and to support the needs of society to make decisions.

<u>Theme 3 Report</u> (Prospects for current high-end computer systems and implications for model code design)

The following topics were the focus for the Theme-3 discussion:

1. Prospects for high-end computing hardware in the next decade
    a. Conventional systems anticipated from commercial vendors
    b. Potential for hardware customization for climate simulation
2. Prospects for petascale software
    a. System-level software (compilers, etc.)
    b. Frameworks
3. Prospects for evolving climate model design
    a. Innovative numerical methods (adaptive mesh refinement, grids without singularities, etc.)
    b. Dynamic load balancing

The discussion was advised by the presentations given during the Theme-3 plenary session. Fig. 1 shows an estimated relationship between peak computation rates on large supercomputers and the grid sizes in climate models that could be used, assuming that a minimum threshold time-to-solution is achieved. During the discussion, the concern about how to work with exabytes of data was raised. The following summarizes the discussion in each category: strategy, hardware, software, models, and data.

Strategy

- A large, international facility for climate modeling must be programmatically viewed as analogous to a satellite mission in terms of scale, cost, "mission" organization, ambition.
- Climate prediction requires <u>dedicated</u> facilities, particularly if there will be a service component (delivering products), as national weather services perform.
- The target should be 100-1000 simulated days per wallclock day for whatever resolution model is used.
- The goal is to produce qualitatively better solutions.
- Because software and hardware must be developed hand in hand, there is a requirement for much more effective collaboration, including strategic partnerships, among the large labs, the university community and the vendor/compiler communities, including software engineers, model developers and tool builders.
- There is a need for increased investment in computational science, closely linked to the climate prediction enterprise.
- There needs to be a process to ensure balance among all components, especially between computing and data management and analysis. The scale of the problem is such that this may require new methodologies like on-the-fly processing and aspects such as are envisioned for the Data Curator.
- For both high-end computing and data management, what is not viewed as extraordinary effort needs to be made standard, i.e., there is a need to make the heroic routine.

- There is a critical need for more software engineers in the field. More generally, resources need to be invested in both computing infrastructure and trained personnel. There may be an underused resource of expertise in HEC to be exploited within the universities.

Hardware

- Flexible hardware that can support research on developing models with much higher (process-resolving) resolution is needed.
- Vendors currently deliver machines obtaining a given performance on benchmarks (e.g. LINPACK) that do not reflect the likely performance for current and future climate models. More realistic benchmarks should be used for a dedicated climate modeling platform. However, it is important to note that benchmarking new architectures with old codes is not necessarily a good approach.
- There are multiple issues related to the cost and power requirements for a multi-peta-flop climate computer. The consensus expressed by the vendors was that an "off the shelf" supercomputer would be more than sufficient for the community's needs.
- Heterogeneous (e.g, scalar/vector) architectures may be a workable solution, although the hardware cost may be higher and the programming model may be more difficult.
- Consensus of the question of customization of chips and/or system architectures:
  - The use of special floating point gate arrays (FPGA) processors to accelerate parts of models could be an area of experimentation, e.g., sparse matrix and multigrid solvers are coded efficiently on cell processors and accelerators already.
  - The use of probabilistic chips now in development could be a possibility for introducing stochastic processes into models at chip level.
  - A radical new design based on cell phone chip technology could be of interest for climate modeling – development of this idea would likely require over $500 million.
  - The problem with tailoring a specific machine for a particular class of algorithm is that it limits the ability to use the machine for possible future models and numerical methods.
  - The consensus was that this should not be emphasized, because memory per processor and speed of communications switch are critical elements, because the development cost is very high, and because currently-planned machines being delivered are likely to be serviceable for climate prediction in near future. However, because million-core machines are likely to be very different from today's computers (with MPI or OpenMP programming models), there should be some investment in this direction for longer term.

Software

- At millions of cores (or fewer), it is expected that new ways of expressing concurrency both for hardware elements and for model components will be required. There are languages on horizon (e.g. Titanium) that may simplify issues relating to parallelism, weak vs. strong scaling, and memory/memory-bandwidth issues.
- There is a requirement for more intelligent fault-tolerant methods with massively multi-core systems. Checkpointing to disk will become impractical.
- It may be possible to learn from the community's previous experience in making the transition from a vector programming model to a parallel programming model. It may also be advised to leverage the experience of the rest of the petascale community.
- The ratio of floating point computation rate to memory changes depending on the solver employed, e.g. algebraic multi-grid. The sorts of solvers and algorithms in use for climate modeling over next few years may change.

Models

- There are atmospheric GCMs currently in use at 50 km resolution that can run at 1,000 times faster than real time. Models with 25 km resolution are within reach within next three years or so. The dynamical core of CAM scales experimentally to 100,000 cores.
- Some ocean codes won't scale to high enough levels of parallelism, particularly due to the solution algorithm for the barotropic mode.
- The community should strive for global non-hydrostatic, cloud (or cloud system) resolving models of the atmosphere (with comparable resolution in the ocean). This is not likely to be attained within the next five years. Incremental progress is needed to work toward that goal.
- There is no definitive demonstration that resolving clouds or cloud systems will definitely lead to better climate predictions, so a demonstration project is needed, i.e., a run made at much shorter times than climate change simulation. A very (perhaps overly) ambitious target for climate modeling can help capture people's imaginations and make progress in this direction.
- It is not clear that the most appropriate organizational model one in which scientists write the code – a new "industrial computing" model may need to be adopted.

Data

- As models reach kilometer-scale resolutions, they will generate O(hundreds of exabytes) of output data.
- The output will likely be distributed – stored at individual modeling centers – and the metadata will be centralized. This is not the current model of data management in use for community climate modeling.
- There is a need to consider all aspects of data management and assessment: data archives, data stored on native grids, regression test suites, restart data saves, and the use of high-performance computing hardware for data analysis.
- Data mining (feature detection etc.), which is today an esoteric research problem, may become a necessity to work with exabyte data volumes. Similarly,

there may be a requirement for on-the-fly processing and visualization/animation.

- Accessibility to data by a much larger population (beyond modelers and climate scientists) may be problematic since data can be misused very easily.

Computing Capability & Model Grid Size (km)

Peak Rate:	10 TFLOPS	100 TFLOPS	1 PFLOPS	10 PFLOPS	100 PFLOPS
Cores	1,400 (2006)	12,000 (2008)	80-100,000 (2009)	300-800,000 (2011)	6,000,000? (20xx?)
Global NWP[0]: 5-10 days/hr	18 - 29	8.5 - 14	**4.0** - 6.3	**1.8 - 2.9**	**0.85 - 1.4**
Seasonal[1]: 50-100 days/day	17 - 28	8.0 - 13	**3.7** - 5.9	**1.7 - 2.8**	**0.80 - 1.3**
Decadal[1]: 5-10 yrs/day	57 - 91	27 - 42	12 - 20	5.7 - 9.1	**2.7** - 4.2
Climate Change[2]: 20-50 yrs/day	120 - 200	57 - 91	27 - 42	12 - 20	5.7 - 9.1

Range: Assumed efficiency of 10-40%
0 - Atmospheric General Circulation Model (AGCM; 100 levels)
1 - Coupled Ocean-Atmosphere-Land Model (CGCM; ~ 2X AGCM computation with 100-level OGCM)
2 - Earth System Model (with biogeochemical cycles) (ESM; ~ 2X CGCM computation)

* Core counts above $O(10^4)$ are unprecedented for weather or climate codes, so the last 3 columns require getting 3 orders of magnitude in scalable parallelization (scalar processors assumed; vector processors would have lower processor counts)

Thanks to Jim Abeles (IBM)

Figure 1. An estimate, based on the performance of the WRF atmospheric model, of the grid size (km) that could be used at various computational capability levels for problems ranging from numerical weather prediction (NWP) to climate change projection. A minimum threshold of time-to-solution is assumed in each category.

<u>Theme 4 Report</u> (Strategies for model evaluation, modeling experiments, and initialization for prediction of the coupled ocean-land-atmosphere climate system)

The Theme 4 discussions focused on the following topics:

- Process-based model evaluation
- Data assimilation, analysis, and initialization
- Detection and attribution of climate events
- Metrics
- Ensembles

The group tried in particular to identify issues within each topic that required computing resources significantly beyond what is currently available. In the following, these issues are characterized as grand (computational) challenges and marked bold.

Process-based model evaluation

Evaluation of model sensitivities should occur not only against "far downstream" variables, but also against intermediate processes and quantities. For example, the effects of varying cloud scheme parameters should be evaluated not only against global-scale satellite data, but also against what is known about basic cloud processes. The group classified as grand challenges the identification of relevant processes, which requires significantly enhanced model resolution, and high-resolution model experiments for developing and testing parameterizations. Other issues are the inclusion of more than ocean and atmosphere, the identification of data requirements including the uncertainties of data sets, an infrastructure for model-data comparisons, and the testing of the hypothesis that seasonal-to-interannual prediction is useful in evaluating shorter-timescale processes occurring in climate models.

Data assimilation, analysis, and initialization

One grand challenge identified in data assimilation is the initialization of coupled models for climate prediction, which is necessary to obtain physical consistency across the coupled prediction model but very difficult owing to the vastly different time scales that must be spanned. The presence of fast processes and the limits to predictability inherent in these short time scales imply that second-order statistics must be assimilated. Other grand challenges involve observing system experiments, required to develop rational strategies for defining the most effective and efficient data requirements; reduction and, if required, correction of model bias including dealing with model bias in assimilation; and the specification of model error covariance. Other issues comprise the provision of reanalysis datasets for model evaluation; improvements in the initialization of the ocean component of coupled forecast models; making inroads into the initialization of the cryosphere (sea ice, snow) and land surface (vegetation, hydrology) components of climate forecast models.

Detection and attribution of climate events

Do climate models correctly simulate major climate signals such as the retreat of Arctic summer sea ice during 2007? If there is a discrepancy between observed and simulated behaviour, how much is due to inherent predictability issues versus model deficiencies? Can we attribute major climate signals to specific causes, thus explaining how they arose? How does ability to simulate immediate past events map onto confidence in future predictions? This attribution of observed climate signals is crucial not only for scientific understanding per se, but also for the political and policy debate, as can clearly be demonstrated by the example of the shrinking Arctic summer sea ice: We as the scientific community face a serious crisis of credibility if, in the coming years, Arctic summer sea ice will be much more abundant than in 2007 and we cannot explain why.

Grand challenges arise from the search for proximate causes of climate signals, where the methodology for operational attribution is a research question; the near-real time attribution of short-term climate events (timescale of months); and the implication of attribution for the quality of operational climate prediction. Further research topics are the retrospective attribution of climate evolution and climate events during the last 100 years, and the connection between attribution and predictability and model performance.

Metrics

A number of criteria were specified for obtaining useful metrics for assessing model quality. Any metric should have discriminatory power; we must distinguish between customer-defined metrics and metrics characterizing model quality; metrics are needed not only for model performance of current climate, but also for the evaluation of long-timescale behavior against instrumental and palaeo-observations. It was noted that data assimilation routinely defines metrics through the definition of a cost function to be minimized. A grand challenge problem arises from the quest for proxy metrics – is it possible to define proxies that have the corresponding discriminatory power but are more readily evaluated? For example, can we identify metrics that map onto climate sensitivity? It was suggested to establish a task force to define metrics for decadal climate prediction, and to establish an infrastructure to ease the calculation of metrics.

Ensembles

Ensemble simulations are a fundamental tool in exploring the limits to climate predictability and assessing the quality of forecast skill. Grand challenge topics are the quantification of forecast skill, the experimental design for ensemble construction (e.g., fastest growing modes, likely to be very different in decadal prediction than in seasonal-to-interannual prediction or weather forecasting); and the experimental design for model perturbation and model intercomparison projects. In general terms, it is important to use ensemble techniques to explore consequences of uncertainty in initial conditions, parameters, and in structural model elements, both resolved and parameterized. Also, the role of boundary forcing vs. the influence of initial conditions must be quantified through ensemble approaches.

<u>Theme 5 Report</u> (Strategies for enhancing human and computing resources: requirements and possible organizational frameworks)

The purpose of the discussions was to consider the options for achieving the enhancement of resources necessary for a revolution in climate prediction, through national, international and/or global actions. The group considered both the hardware infrastructure requirements to deliver the computational power, as well as potential organizational frameworks that might facilitate greater intellectual firepower.

As a community we are committed to providing more advanced and reliable regional climate predictions to underpin local and regional adaptation needs with robust estimates of risk. We all agreed that the science is not complete; a clear statement to the UNFCCC and other bodies that current predictions are not adequate and why, should be made.

Important issues for the modeling community are reducing model biases and providing better estimates of uncertainty, not just in climate sensitivity, but also in terms of extremes and high impact climate and weather variations. There is general agreement that providing improved information at the regional and local level requires significant increases in model resolution, which are currently limited by insufficient computer power. We also noted the need to continue our drive towards representing the complex, multi-scale nature of the climate system more completely, and hence the requirement for an enhancement of intellectual firepower to attack these problems.

These challenges require a concerted, international response. Whilst it is imperative that national activities are enhanced significantly, we also recognized that 'business-as-usual' will not deliver the step change required to respond to societal needs. Alongside an ongoing enhancement of national activities, the proposal was made for a global facility (or federation) to be established, based around one or more dedicated high-end computing facilities, which would have a capability of 2-3 orders of magnitude above what is currently available nationally. This facility would act to accelerate progress, build global capacity in the underpinning science and technology base, and engage the global user community.

There was considerable discussion concerning the scope of this global facility and the question of whether it would deliver predictions or be primarily a research and capacity-building operation. Should it be science driven or service driven? There was a strong message from the national centers that their experience base of working with regional customers, often through NWP, means that predictions must continue to be made at the national level. There was also strong support for maintaining model diversity and that an element of competition was healthy!

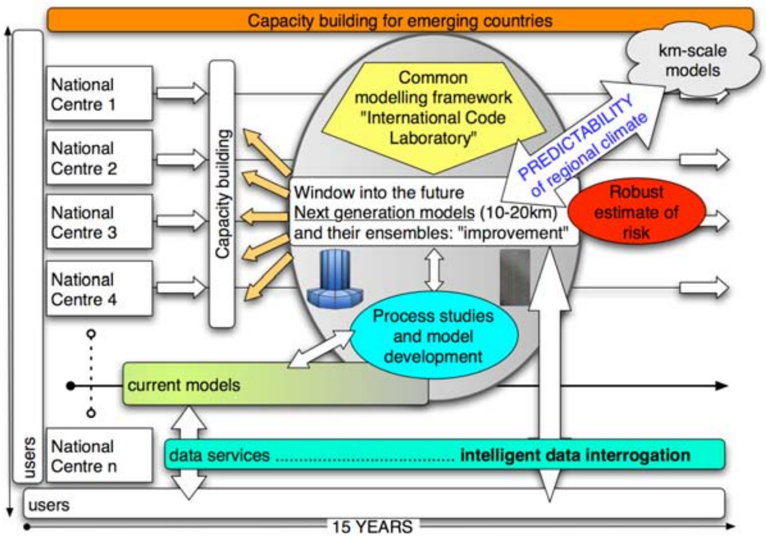
It was agreed that the following areas are where a global facility could have a real impact and provide substantial benefits to national activities:

- Developing next generation numerical cores that can exploit massively parallel computing architectures. This is a major challenge which all modeling centers face and for which a coordinated approach would be extremely beneficial. This might extend in the longer term to a common modeling framework.
- Provide a significantly enhanced computing capacity to scientists across the world so that they can perform simulations with an unprecedented level of detail and/or complexity ('windows into the future') required to advance

understanding and representation of the physical and biogeochemical processes in the climate system and thereby accelerate model improvement.

- Provide access to the level of computing resource necessary to perform climate predictions with a range of models at resolutions that are not possible on national facilities. This would contribute to a quantum leap in the exploration of the limits in our ability to reliably predict climate with a level of detail and complexity that is not possible now.
- Provide an enhanced data archive, analysis and visualization service for both observational and model data.
- Provide a portal for *global* users of climate predictions to access the most up-to-date information.
- Provide a focal point for advanced computational science that can follow closely the technology trends.
- Support a program of training and capacity-building in the use of climate models and climate predictions for developing countries. The role played by ICTP was noted as an example of the kind of function that could be offered.

These various functions are represented schematically in the following figure, which seeks to emphasize the important role that this central facility should play in the coming decade and beyond in enabling the national centers to achieve the end result of confident estimates of risk at the regional and local level over lead times from seasons out to a century.



There was some limited discussion on how to resource the project. The need for a clear statement of what the proposed investment will deliver and how success will be measured was emphasized. It also needs to be clear that there is no intention to compete with national centre funding i.e. government. Private sector and foundations were proposed as possible funders, but it was emphasized that foundations never support what governments will support, and the private sector may look for direct benefits. The importance of stressing the global, humanitarian aspects was noted when making the case for new and substantial investment.

V. THE MODELLING SUMMIT STATEMENT:

Based on the Summit deliberations the Theme leaders and the organizers, with substantial inputs from the members of the organizing committee, prepared a Summit Statement (see box).

The statement calls for the creation of a Climate Prediction Project, akin to the ITER or the Human Genome Project that can provide improved global climate information to underpin global mitigation negotiations and advise regional adaptation and decision-making in the 21st century. The Climate Prediction Project will require a two-pronged approach that both strongly enhances the capacity of the world's existing weather and climate research centers and establishes an international climate research facility for climate prediction that can help develop next-generation models, build global capacity, nurture a highly-trained workforce, and engage the global user community. The international facility will have at its heart a number of high-end computing facilities dedicated to climate that can enable climate prediction at the model resolutions and levels of complexity that are essential for producing accurate regional climate change information. Informed adaptation strategies are critically dependent on this kind of information, but the current generation of climate models cannot deliver it. The dream of those who attended the summit is to strive toward kilometer-scale modeling of the global climate system and take a quantum leap in the exploration of the limits of reliable climate prediction. A vigorous Climate Prediction Project with a number of international climate research and computing facilities would ensure that the goal of accurate climate predictions at the regional scale could begin to aid the global society in coping with the consequences of climate change.

The problem of climate change has riveted the attention of the peoples of the Earth. The WCRP must seize the moment and initiate Climate Prediction Project, which will enable and accelerate progress in climate modeling and prediction. It is also imperative that governments, foundations, and private sector provide substantial and sustained support for enhanced workforce and computing resources. There will always remain the need for much larger computing capability for climate prediction compared to weather prediction, because we must be able to run climate models at the same resolution as weather prediction models. The weather prediction models may have horizontal resolutions of 3-5 km within the next 5 years. Climate models at this resolution and decadal-century scale integrations will require computers with capability of about 10 petaflops by 2010 and 100 petaflops by 2025.

Summit Statement: The Climate Prediction Project

1. Considerably improved predictions of the changes in the statistics of regional climate, especially of extreme events and high-impact weather, are required to assess the impacts of climate change and variations, and to develop adaptive strategies to ameliorate their effects on water resources, food security, energy, transport, coastal integrity, environment and health. Investing today in climate science will lead to significantly reduced costs of coping with the consequences of climate change tomorrow.

2. Despite tremendous progress in climate modeling and the capability of high-end computers in the past 30 years, our ability to provide robust estimates of the risk to society, particularly from possible catastrophic changes in regional climate, is constrained by limitations in computer power and scientific understanding. There is also an urgent need to build a global scientific workforce that can provide the intellectual power required to address the scientific challenges of predicting climate change and assessing its impacts with the level of confidence required by society.

3. Climate prediction is among the most computationally demanding problems in science. It is both necessary and possible to revolutionize regional climate prediction: *necessary* because of the challenges posed by the changing climate, and *possible* by building on the past accomplishments of prediction of weather and climate. However, neither the necessary scientific expertise nor the computational capability is available in any single nation. A comprehensive international effort is essential.

4. The Summit strongly endorsed the initiation of a **Climate Prediction Project** coordinated by the World Climate Research Programme, in collaboration with the World Weather Research Programme and the International Geosphere-Biosphere Programme, and involving the national weather and climate centers, as well as the wider research community. The goal of the project is to provide improved global climate information to underpin global mitigation negotiations and for regional adaptation and decision-making in the 21st century.

5. The success of the **Climate Prediction Project** will critically depend on significantly enhancing the capacity of the world's existing weather and climate research centers for prediction of weather and climate variations including the prediction of changes in the probability of occurrence of regional high impact weather. This is particularly true for the developing countries whose national capabilities need to be increased substantially.

6. An important and urgent initiative of the **Climate Prediction Project** will be a world climate research facility for climate prediction that will enable the national centers to accelerate progress in improving operational climate prediction at all time scales, especially at decadal to multi-decadal lead times. This will be achieved by increasing understanding of the climate system, building global capacity, developing a trained scientific workforce, and engaging the global user community.

7. The central component of this world facility will be one or more dedicated high-end computing facilities that will enable climate prediction at the model resolutions and levels of complexity considered essential for the most advanced and reliable representations of the climate system that technology and our scientific understanding of the problem can deliver. This computing capability acceleration, leading to systems at least a thousand times more powerful than the currently available computers, will permit scientists to strive towards kilometer-scale modeling of the global climate system which is crucial to more reliable prediction of the change of convective precipitation especially in the tropics.

8. Access to significantly increased computing capacity will enable scientists across the world to advance understanding and representation of the physical processes responsible for climate variability and predictability, and provide a quantum leap in the exploration of the limits in our ability to reliably predict climate with a level of detail and complexity that is not possible now. It will also facilitate exploration of biogeochemical processes and feedbacks that currently represent a major impediment to our ability to make reliable climate projections for the 21st century.

9. Sustained, long-term, global observations are essential to initialize, constrain and evaluate the models. Well-documented and sustained model data archives are also essential for enabling a comprehensive assessment of climate predictions. An important component of the **Climate Prediction Project** will therefore be an accessible archive of observations and model data with appropriate user interface and knowledge-discovery tools.

10. To estimate the quality of a climate prediction requires an assessment of how accurately we know and understand the current state of natural climate variability, with which anthropogenic climate change interacts. All aspects of estimating the uncertainty in climate predictions pose an extreme burden on computing resources, on the availability of observational data and on the need for attribution studies. The Climate Prediction Project will enable the climate research community to make better estimates of model uncertainties and assess how they limit the skill of climate predictions.

11. Advances in climate prediction will require close collaboration between the weather and climate prediction research communities. It is essential that decadal and multi-decadal climate prediction models accurately simulate the key modes of natural variability on the seasonal and sub-seasonal time scales. Climate models will need to be tested in sub-seasonal and multi-seasonal prediction mode also including use of the existing and improved data assimilation and ensemble prediction systems. This synergy between the weather and climate prediction efforts will motivate further the development of seamless prediction systems.

12. The **Climate Prediction Project** will help humanity's efforts to cope with the consequences of climate change. Because the intellectual challenge is so large, there is great excitement within the scientific community, especially among the young who want to contribute to make the world a better place. It is imperative that the world's corporations, foundations, and governments embrace the **Climate Prediction Project**. This project will help sustain the excitement of the young generation, to build global capacity, especially in developing countries, and to better prepare humanity to adapt to and mitigate the consequences of climate change.

VI. ACKNOWLEDGEMENTS:

The Summit could not have been the successful event it has been without the scientific, organizational, financial and moral support received from numerous individuals and organizations.
Since it is impossible to name all individual scientists who contributed to the scientific aspects of this endeavor, the start of the revolution in climate prediction, we would like to thank the scientific community as a whole for all their expressions of support and good advice given.
The Summit was hosted by the European Centre for Medium-Range Weather Forecasts (ECMWF) in Reading. We would like to express our admiration for the outstanding technical organization of the event which was appreciated by all participants. We thank all involved ECMWF staff from Administration, Operations, and Research and especially Renate Hagedorn for her dedication in making the Summit such a productive and an enjoyable event.
The generous financial support of three computer vendors, CRAY, IBM, and NEC, made it possible to organize two evening banquets and to offer light lunch during the week to all participants. The numerous informal discussions encouraged by these social events contributed to the good working spirit the participants felt at the Summit.
The travel of a number of participants, in particular young scientists and scientists from developing countries was supported by co-organizers and further sponsors of the Summit. In particular we would like to thank the following organizations:
COLA, Center for Ocean-Land Atmosphere Studies;
DOE, US Department of Energy;
ESA, European Space Agency;
ICSU, International Council for Science;
IGBP, International Geosphere Biosphere Programme;
IOC, Intergovernmental Oceanographic Commission;
NASA, National Aeronautics and Space Administration;
NERC, Natural Environmental Research Council;
NOAA, National Oceanographic and Atmospheric Administration;
NSF, National Science Foundation;
MPIfM, Max-Planck Institute for Meteorology;
WCRP, World Climate Research Programme;
WMO, World Meteorological Organization;
WWRP, World Weather Research Programme.

List of Participants:

Faisal al Zawad, Myles Allen, Donald Anderson, Ghassem Asrar, Dave Bader, Johanna Baehr, Venkatramani Balaji, Helene Banks, Qing Bao, Len Barrie, Michel Béland, Lennart Bengtsson, Michaela Biasutti, David Blaskovich, Sandrine Bony, Olivier Boucher, Philippe Bougeault, Gilbert Brunet, David Burridge, Jim Caughey, John Church, Susanna Corti, Huw Davies, Pascale Delecluse, Mark Doherty, Leo Donner, Seita Emori, Veronika Eyring, Jay Fein, Greg Flato, Ned Garnett, Almut Gassmann, Larry Gates, Omar Ghattas, Marco Giorgetta, Chris Gordon, Renate Hagedorn, Ed Harrison, Hiroyasu Hasumi, Wilco Hazeleger, Olive Heffernan, Isaac Held, Tony Hirst , Greg Holland, Brian Hoskins, Trond Iversen, Christiane Jablonowski, Christian Jakob, Michel Jarraud, Emilia Jin, Sylvie Joussaume, In-Sik Kang, Al Kellie, Masahide Kimoto, Jim Kinter, Ben Kirtman, Chet Koblinsky, R. Krishnan, Ari Laaksonen, Peter Hjort Lauritzen, Hervé Le Treut, Peter Lemke, Elizabeth Lipiatou, Chris Llewellyn-Smith, Andrew Lorenc, Julia Manganello, Elisa Manzini, Dominique Marbouty, Jochem Marotzke, David Marshall, Alexia Massacand, Pierre-Philippe Mathieu, Taroh Matsuno, Robert Mechoso, Gerald Meehl, Martin Miller, John Mitchell, Mitch Moncrieff, Berrien Moore, Oliver Morton, James Murphy, Masashi Nagata, Antonio Navarra, Aida Diongue Niang, Nikos Nikiforakis, Per Nyberg, Kazutoshi Onogi, Franklin Opijah, Bartolomé Orfila, Tim Palmer, Hualu Pan, David Parks, David Parsons, Ari Patrinos, Fred Pearce, Matthew Piggott, Anna Pirani, Serge Planton, Vicky Pope, Kamal Puri, Venkatchalam Ramaswamy, Dave Randall, Richard Rood, Markku Rummukainen, Jeffrey Sachs, Takayuki Sasakura, Masaki Satoh, Paul Schopf, Bert Semtner, Cath Senior, Mel Shapiro, Xueshun Shen, Jagadish Shukla, Adrian Simmons, Julia Slingo, Lenny Smith, David Stainforth, Detlef Stammer, Bjorn Stevens, Max Suarez, Rowan Sutton, Hiroshi Takahara, Karl Taylor, Claudia Tebaldi, Tatsushi Tokioka, Kevin Trenberth, Carolina Vera, Pier Luigi Vidale, Duane Waliser, David Warrilow, Michael Wehner, Hilary Weller, Kent Winchell, Lee Woo-Jin, Kathy Yelick, Tianjun Zhou, Walter Zwieflhofer, Francis Zwiers.

APPENDIX 1 (AGENDA)

World Modelling Summit for Climate Prediction, 6 - 9 May 2008, Reading

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Tuesday, 6 May 2008

09:00-10:00	Registration & Coffee	
	Introductory Session:	chair: Jagadish Shukla (GMU/COLA)
10:00 - 10:10	Dominique Marbouty (ECMWF)	Welcome address
10:10 - 10:25	Jagadish Shukla (GMU/COLA)	Revolutionizing Climate Prediction: A Real Need and a Real Possibility
10:30 - 10:45	Michel Jarraud (WMO)	Reducing the Risk Associated with Climate Variability and Change and Severe Weather through Enhanced Prediction - The Need for International Cooperation
10:50 -11:00	Rajendra Pachauri (IPCC)	Keynote address
11:00-11:05	John Church (WCRP/JSC)	The WCRP view
11:05 - 11:10	Michel Beland (WMO/CAS/WWRP)	The CAS/WWRP view
11:10-11:15	Carlos Nobre (IGBP)	The IGBP view
11:20 - 11:45	Jeffrey Sachs (Earth Institute)	The Effects of Climate Change on International Migration, Trade, and the Distribution of Income
11:50-12:15	Chris Llewellyn-Smith (UKAEA)	The CERN experience
12:20 - 12:25	Renate Hagedorn (ECMWF)	Organizational announcements
12:30-14:00	*Lunch*	
	Theme-1:	chair: Brian Hoskins (Reading University)
14:00 - 14:25	Brian Hoskins (Reading University)	The development of the 2005-15 WCRP Strategic Framework
14:30 - 14:55	Gerald Meehl (NCAR)	Next generation climate models for coordinated climate change experiments
15:00 - 15:25	Mel Shapiro (UCAR)	The Socioeconomic and Environmental Benefits of a Weather, Climate and Earth-System Observations and Prediction Project for the 21st Century
15:30-	*Coffee/Tea*	

16:00		
16:00 - 17:00	Plenary Discussion for Theme-1 (including 20 min presentation by T. Matsuno)	Panellists: G. Brunet, B. Hoskins, T. Matsuno, J. Shukla
	Theme-2:	chair: Martin Miller (ECMWF)
17:00 - 17:25	Masaki Satoh (JAMSTEC)	Ongoing studies with the global cloud-resolving model, NICAM
17:30 - 17:55	John Mitchell (Met Office)	On resolution, complexity and uncertainty in climate change predictions
18:00-19:00	*ECMWF Icebreaker*	
19:00-22:00	*IBM Banquet*	

Wednesday, 7 May 2008

	Theme-2 (continued):	chair: Martin Miller (ECMWF)
09:00 - 09:25	Bjorn Stevens (UCLA)	Why aren't climate models getting better? (But forecast models are.)
09:30 - 09:55	Isaac Held (GFDL)	Attribution and prediction of regional climate change
10:00-10:25	Tim Palmer (ECMWF)	Towards the Probabilistic Earth-System Model
10:30-11:00	*Coffee/Tea*	
	Theme-3:	chair: Jim Kinter (COLA)
11:00 - 11:20	Walter Zwiefelhofer (ECMWF)	Trends in High-Performance Computing
11:25 - 11:45	Kathy Yelick (UC Berkeley and LBNL)	Petascale Meets Multicore: Programming Model Challenges and Opportunities
11:50 - 12:10	Omar Ghattas (Univ. Texas)	Towards advanced numerical algorithms for computational science on petascale systems: Dynamic mesh adaptivity, Newton-Krylov inverse solvers, and uncertainty quantification
12:15 - 12:25	T-3: David Parks (NEC)	The NEC perspective for Earth System Modelling
12:25 - 12:35	T-3: Per Nyberg (Cray)	Towards an Optimal Architecture for Earth System Modeling
12:35-12:45	T-3: Kent Winchell (IBM)	petaScale Computing: Capacity or Capability
12.45-14:00	*Lunch*	

	Theme-4:	chair: Jochem Marotzke (MPI-M)
14:00 - 14.25	Christian Jakob (Monash University)	Evaluating parametrizations in large-scale models - An integrated approach
14:30 - 14:55	Detlef Stammer (IfM-HH)	Initialization procedures for climate prediction models
15:00-15:25	Kazutoshi Onogi (JMA)	Evolution of Long-term Reanalysis
15:30-15:55	Kevin Trenberth (NCAR)	Exploiting and evaluating models with observations
16.00-16:30	*Coffee/Tea*	
	Theme-5:	chair: Julia Slingo (Reading University)
17:00-17:25	Ari Patrinos (Synthetic Genomics, Inc.)	The GENOME experience
17:30 - 17:55	Julia Slingo (Reading Univ.)	Where do we go from here? Possible ways forward for achieving a revolution in climate prediction.
18:00 - 18:30	Panel Discussion for Theme-5	
18:30 - 19:00	Transportation to Restaurant	
19:00-22:00	*NEC Banquet*	

Thursday, 8 May 2008

	Plenary:	
09:00 - 09:30	Briefing of Breakout Groups T2 - T5, including 10 min presentation by Mark Doherty (ESA)	
	Individual Breakout Groups:	Participants will have the opportunity to attend different breakout groups for session I and II
09:30-10:30	Breakout Groups T2-T5, session I	
10:30-11:00	*Coffee/Tea*	
11:00-12:30	Breakout Groups T2-T5, session I	
12:30-14:00	*Lunch*	
14:00-15:30	Breakout Groups T2-T5, session II	

15:30-16:00	*Coffee/Tea*	
16:00-17:30	Breakout Groups T2-T5, session II	
19:00-22:00	*Working Dinner for subgroup of OC responsible for drafting Summit Statement*	

Friday, 9 May 2008

	Plenary:	chair: Jagadish Shukla (GMU/COLA)
09:00-09:05	Introduction to Plenary Session	Jagadish Shukla (GMU/COLA)
09:05-09:20	Summary of Theme-1 plenary discussion	Brian Hoskins (Reading University)
09:20-09:40	Report from Theme-2 breakout group	Martin Miller (ECMWF)
09:40-10:00	Report from Theme-3 breakout group	Jim Kinter (COLA)
10:00-10:20	Report from Theme-4 breakout group	Jochem Marotzke (MPI-M)
10:20-10:40	Report from Theme-5 breakout group	Julia Slingo (Reading University)
10:40-11:00	*Coffee/Tea*	
11:00-12:30	Final Discussion & endorsement of Summit Statement	
12:30	**End of Summit**	
12.30-14:00	*Lunch*	
14:00-15:30	Internal meeting of the Organizing Committee	

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