White Paper on WCRP Grand Challenge #1

Regional climate information:

Can we provide skilful regional climate predictions at seasonal to decadal time scales and reliable and actionable long term regional climate change projections?

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Context

Many aspects of human societies, such as food production, water availability and management, health, energy production and consumption etc., depend critically on climate variability and change. While some countries have the resources and infrastructure necessary to respond to the variability of climate, others are more vulnerable, to the point that large climate anomalies and extremes can cause enormous loss of life and resources, thereby constituting a substantial societal and environmental stress. It is thus important that climate information is provided to relevant stakeholders in order to allow them to properly design and implement response policies. This increasing recognition has given impetus to the development of many climate service activities in different countries and, on the global scale, to the launch of a Global Framework for Climate Services (GFCS) by the World Meteorological Organization (WMO).

In order to be useful and actionable, reliable climate information needs to be available at scales that can vary from sub-continental to regional and even local. The temporal horizon also spans a wide range of scales. For some applications, say crop planning, information is needed at intra-seasonal to seasonal scale (e.g. will there be a delayed monsoon onsets? Will the next monsoon be weaker than normal?). Others may require information at decadal scales, for example in planning infrastructure with lifetimes of 10-20 years. Finally, long term (century-scale) climate change information is needed to develop national or regional adaptation and mitigation policies.

During the last several decades, strong research activities have taken place in the areas of seasonal to interannual prediction and long term climate change projection, while more recent is the development of activities in decadal predictability and predictions. Despite these efforts, to date the use of regional climate information at different temporal scales has been quite limited, in part because of the (sometimes perceived) poor skill of the prediction systems and in part because of a communication gap between the scientific and stakeholder communities. However, the inception of the GFCS and of numerous new programs in climate prediction/projection not only have allowed substantial recent progress in these areas of research, but have offered the opportunity for a true leap in the quality and use of regional climate information, laying the grounds for this Grand Challenge.

The Grand Challenge

Over the next 5-10 years, four scientific frontiers will need to be pushed substantially forward:

Frontier 1: Intraseasonal and seasonal predictability and prediction. **Identify and understand phenomena that offer some degree of intra-seasonal to inter-annual predictability, and skilfully predict these climate fluctuations and trends.**

Framing the problem: Advances in climate and forecasting research during the past decade have lead to the understanding that modeling and predicting a given seasonal climate anomaly over any region is incomplete without a proper treatment of the effects of sea surface temperature (SST), sea ice, soil wetness, snow cover, vegetation, stratospheric processes, and chemical composition (carbon dioxide, ozone, etc.). The feasibility of seasonal prediction rests on the existence of slow, and predictable, variations in the Earth's components that force atmospheric variability. The potential for skilful forecasts thus depends on the ratio of externally forced signals relative to the atmospheric natural “noise”. The majority of external variance is known to originate from SST variations, while less is known about the seasonal signals due to soil moisture, land use, sea ice, atmospheric chemical composition and aerosols. Additional skill due to atmospheric initial conditions is also expected for certain modes of the atmosphere (for instance, annular modes), but, with the possible exception of the stratospheric quasi-biennial oscillation, there is little evidence that atmospheric initial conditions contribute to skill for lead time forecasts beyond a few weeks. Identifying and understanding the sources of predictability and the limit of predictability are active areas of research that need to be strengthened. Gaps in knowledge remain in understanding coupled processes, scale interactions and teleconnections in the climate system as well as in resolving key model deficiencies such as the double intertropical convergence zone (ITCZ), the Pacific Cold Tongue bias, the Atlantic Gulf Stream cold bias and warm biases in the eastern Atlantic and Pacific Oceans. Forecast skill has increased over the past ten years and it is expected to continue to improve as errors in forecasting systems and initialization techniques are improved. To complement improvements in forecasting systems, new seasonal prediction strategies have also emerged, largely based on multi-model ensemble, multi-institutional international collaborations. For example the WMO Lead Centre for Multi Model Ensemble forecasts at www.wmolc.org is coordinating regular monthly and seasonal forecasts from 12 leading centres worldwide and this will form a key component of the WMO GFCS.

Scientific Questions**:** What is the regional predictability and prediction skill at intra-seasonal to seasonal scales? How can we best realise this predictability in future forecast systems? What are the key model errors that currently limit forecast skill? How important is the initialization of land conditions (e.g. soil moisture) for seasonal predictions? How important is the inclusion of coupled climate system components? How does seasonal predictability change under changing global climate conditions? How skilful are the predictions of those intra-seasonal aspects most relevant for impacts (e.g. monsoon onset)? How to best combine seasonal forecasts from multi-model ensembles?

Frontier 2: Decadal variability, predictability and prediction. **Identify and understand phenomena that offer some degree of decadal predictability and skilfully predict these climate fluctuations and trends.**

Framing the problem: Decadal prediction is an emerging field of climate science with associated high expectations from society to deliver information for regional adaptation in the next years and decades. Scientifically meeting this challenge requires identifying and understanding phenomena that offer some degree of decadal predictability, and in turn developing prediction systems able to realistically and accurately capture such forms of predictability. More precisely, a key aim is to quantify sources of climate predictability on up to decadal to multi-decadal time scales, and to provide probabilistic regional forecasts with skill sufficient for planning and decision making purposes. The intermediate decadal to multi-decadal time scales are perhaps the most complex and least understood from a prediction perspective. At these scales external (e.g. anthropogenic) forcings are superimposed on natural modes of internal climate variability, particularly as driven by the slow components of the climate system, and therefore the problem has both initial conditions and boundary conditions aspects. At these scales the role of the oceans, including the deep ocean, is fundamental, and coupled interactions amongst the various components of the climate system play important roles in setting the space-time scales of fluctuations. The evaluation of decadal simulations must address the reliability and skill of the simulations as well as the representation of mechanisms of decadal variability. This evaluation is limited by the fact that the climate system has conditional predictability and it is non-stationary due to external forcings, and that the observational record relative to decadal variability is relatively short. The accurate simulation of case study events, such as the 1970s climate shift of the Pacific, the rapid warming of the North Atlantic sub-polar gyre in the 1990s, or the 1990s shift in increased North Atlantic hurricane activity, is a key measure of model performance. Among key topics to consider in order to improve decadal predictions are: the identification of the best initialization strategies for decadal predictions; the availability of sufficiently dense and accurate ocean observations networks and the development of ensemble techniques to disentangle the effects of anthropogenic forcings and the low frequency natural climate fluctuations. Similar to seasonal prediction, the use of large multi-model ensembles is a necessary approach to improve the assessment of the prediction quality and characterize related uncertainties.

Scientific Questions: Is there decadal (out to 10 years) predictability and prediction skill at regional scales? How do we improve the representation of mechanisms which give decadal prediction skill in models? What are the regions where such predictability and skill is maximum? How to disentangle the role of external forcings from that of internal decadal variability of the climate system? How to optimize the ensemble prediction approach, for example in terms of ensemble size, model resolution, and post-processing (e.g. bias correction)? What is the best ocean initialization strategy and what is the uncertainty associated with such initialization? Are current ocean observations sufficient for an effective initialization?

Frontier 3: Reliability and value of long term regional climate change projections. **Provide reliable regional climate projections for the 21st century and beyond for use in Impact, Adaptation and Vulnerability (IAV) studies as a basis for the development of response (adaptation, mitigation) strategies to climate change**

Framing the problem: To date, little confidence has been placed on regional climate projections obtained from Global Climate Models (GCMs), as for example evident from the most recent assessment reports (TAR, AR4) of the Intergovernmental Panel on Climate Change (IPCC). This is because of the coarse resolution of the models, the lack of inclusion of key Earth system processes and feedbacks (e.g. carbon cycle) and the model systematic errors. Different downscaling and post-processing techniques have been developed to regionally enhance the GCM information and derive fine scale climate information but, perhaps with the exception of some multi-insitutional European projects, their use so far has been too limited to provide robust regional projections, and a deep understanding of their advantages and limitations. A key issue in assessing the credibility of long term regional projections is the identification of suitable criteria to measure such credibility. Differently from weather and seasonal/decadal prediction, long term projections cannot be validated against observations. The credibility of projections thus needs to be assessed through multiple lines of evidence, such as the agreement across models and methods, the performance of models in representing observed climates, trends and key processes, understanding of the effects of systematic model biases and, perhaps above all, understanding of the processes that underlie the projected responses. The careful and critical evaluation of model-produced projections and a full characterization of underlying uncertainties are prerequisites for the provision of useful information for IAV application, and much research needs to be devoted to this issue. In this regard, the latest generation GCMs (e.g. used in CMIP5) are characterized by increased resolution and more and improved components of the climate system, and their performance in reproducing observed sub-continental scale climate and key modes of variability has improved. In addition, international coordinated programs such as the "Coordinated Regional Downscaling Experiment" (CORDEX) provide new frameworks to better and more extensively evaluate the added value and usefulness of the fine scale climate information provided by different downscaling tools. It is thus expected that these new international programs will provide better quality and more robust regional and local scale projections, improved characterization of uncertainties and stronger interactions with the community of users of climate information.

Scientific Questions: How to define, quantitatively assess and enhance the credibility of regional climate projections? How to extract regional forced signals from the underlying natural variability? How do model systematic errors affect regional climate projections? What is the added value of regional downscaling and post-processing techniques? How to best assemble the information from ensembles of model projections? How to characterize the uncertainty in regional climate projections given a finite and often sparse matrix of model simulations? How to increase understanding of the interplay across the different drivers, processes and feedbacks that characterize regional climate at different spatial and temporal scales ?

Frontier 4: Definition of usefulness: informing the risk management and decision making space.

Provide information that constitutes a solid and targeted basis for decision making concerning risk management and response options in specific sectors and contexts, also through active and two-way involvement with stakeholders.

Framing the problem: Traditionally, there has been a strong disconnect between the information provided by the climate science community and the information needs for IAV research in support of the decision making process, be it at the seasonal/decadal or longer time scale. It is difficult to actually define what constitutes useful, and in fact actionable, information. Often, information on changes in mean climatology or interannual variability does not provide sufficient background for informed decision making. In most cases the information provided directly by climate models needs to be post-processed in order to be tailored for specific IAV applications. In particular, uncertainties in regional climate predictions or long term projections need to be properly quantified and communicated for use in risk assessment and management studies. In this regard, it is important to establish and communicate the theoretical limit to predictability and how close the information provided by present systems is to this theoretical limit. Ultimately, users at the regional level are primarily interested in the value of the forecast information in terms of economic, social or other aspects, which is distinctly different from its quality. For example, although regional centers throughout the world can take pride in the fact that they have produced some skilful seasonal forecasts in terms of quality over the past one or two decades, in many cases the actual value is not immediately evident. This is a major challenge that will require a strong interaction between the climate science and stakeholder communities, well beyond the level that has occurred so far.

A related issue is that of communication of climate information. Much of the climate data that is commonly made public comes from a climate perspective, chosen, collated and structured by climate scientists. Moreover, the data are most often presented in terms of time and/or spatial averages and, if viewed from the perspective of the needs by decision makers, such information may address poorly the user community requirements. This poses three key interrelated issues for the development of tailored information. First is the question of formulating the climate data in relation to the relevant attributes of the stakeholder knowledge needs. Central to this question is that of scales -- providing information on temporal and spatial scales relevant to the stakeholder sectors' activities. In this respect the stakeholder needs may often be represented by derivative expressions of the fundamental climate data. Second is the need to formulate climate information in the context of the discernable signal with respect to expected variability. In particular, stakeholders need the information in terms of probability or likelihood that the change differs from natural variability that is already accounted for in their planning. This relates to the risk management approach where the climate information is factored in along with non-climate factors influencing the response decisions. Thirdly, the data needs to be contextualized in terms of consequence. What may be a significant climate change in meteorological terms may not always be relevant to a societal sector. Stakeholder activities are nominally optimized within climate and non-climate thresholds, which may be hard limits (e.g. environmental limits for a particular crop), or soft limits that relate to progressive degradation (e.g. an anomalous high recurrence of extreme events degrading disaster response capacity). Often thresholds may also be present as compound constraints, where change in each factor individually might not cross a threshold, but in combination exceed some system limit.

Scientific Questions: How to best post-process climate data to provide targeted information for IAV applications within the context of risk management? How to convey credibility and uncertainty to users of the climate information? How to assess the value of the information in relation to its quality? How to contextualize the climate information within climate and non-climate thresholds of relevance for IAV applications? How to best engage the stake-holder community in a fruitful dialogue with the science community in order to maximize the usefulness of climate information?

Opportunities for rapid progress

As mentioned, to date relatively little confidence has been placed on regional seasonal to decadal predictions and long term projections, and very limited use by stake-holders of these products has occurred. However, a number of developments offer the opportunity of rapid progress in the next 5-10 years.

The Climate system Historical Forecast Project (CHFP): The WCRP Working Group on Seasonal to Interannual Prediction (WGSIP) is coordinating a multi-model, multi-institutional set of hindcast experiments – the Climate system Historical Forecast Project (CHFP). The CHFP aims to explore provide a large set of hindcast experiments for use by the research community and to document changes in skill over time. It also assesses untapped sources of predictability on seasonal to interannual timescales due to interactions and memory associated with all the elements of the climate system (Atmosphere-Ocean-Land-Ice). The CHFP experiments provide a baseline assessment of current seasonal to interannual prediction capabilities using the best available models of the climate system and data for initialisation. They provide a framework for assessing current and planned observing systems, and a test bed for integrating process studies and field campaigns into model improvements.

The Climate Model Intercomparison Project (CMIP5): The WCRP Working Group on Climate Modeling (WGCM) is coordinating a large multi-model, multi-institutional program, CMIP5, aimed at producing a new set of decadal (10-30 years) hind-casts and predictions using the initialized climate system (at minimum the oceans) as a starting point along with uninitialized climate projections for the 21st century and beyond under a range of Representative Concentration Pathways (RCP) specifying both greenhouse gas and aerosol emissions for earth system models and concentrations for AOGCMs as well as land use/land cover. CMIP5 has produced an ensemble of experiments of unprecedented size, scope, quality and ready access which is allowing the exploration of the scientific frontiers outline above with much greater depth than ever before.

The Working Group on Regionl Climate (WGRC) and the COordinated Regional Downscaling EXperiment (CORDEX): The WCRP has recently established the WGRC which will serve to prioritize and coordinate regional research within the WCRP and serve as the conduit for two-way information exchange between the WCRP, the rest of the GFCS, and the various institutions and coordinating bodies that provide climate services in various regions. The Terms of Reference include oversight of specific WCRP regional climate research activities, in particular CORDEX. CORDEX is the first international multi-model, multi-institutional program aimed at producing a coordinated set of high resolution decadal predictions and long term projections for regions worldwide with the use of dynamical and statistical downscaling models. It will allow a better than ever exploration and understanding of the advantages, limitations and usefulness of the fine scale climate information produced by downscaling tools.

A new generation of models: The rapid increase in computing power has allowed the development of models with increasingly high resolution and inclusion of more comprehensive physics and more components of the climate system, such as atmosphere, oceans, carbon cycle, cryosphere, biosphere and chemistry/aerosol. The performance of the models has steadily improved, both in terms of mean climatologies and higher order moments of variability. This progress in models is expected to continue and provide increased robustness to predictions and projections.

***Coordinated model analysis**:* Increased transparency and thoroughness in the model evaluation process is being embraced by the climate modeling community as a means for progress. The WCRP Metrics Panel is leveraging the experience of different communities (CFMIP, CCMval, WGOMD, NWP, MJOWG, etc) to guide as thorough a model evaluation process as possible with emphasis on broad participation (online multi-model evaluation results, an online repository for diagnostic codes) and process-based evaluation.

***Observations**:* Increased accessibility to observational datasets and cooperation between the observations and modeling communities. There are various initiatives aimed at enhancing the use of observations by the climate modeling community (Obs4MIPs, ESA CUMG initiative, GEWEX datasets), the development of observation simulators (COSP, CALIPSO) to evaluate models directly with satellite and in situ observations. In turn, the modeling community can issue recommendations on what is required of the Earth observing system.

Global Framework for Climate Services: The WMO has recently launched the Global Framework for Climate Services (GFCS). The overarching purpose of the GFCS is to enable better management of the risks of climate variability and change through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale. The pillars of GFCS are a user interface platform; a climate services and information system (CSIS); observations and monitoring; research, modeling and prediction (WCRP); and capacity building. Four thematic areas have been identified as initial foci of the plan: food security and agriculture, water resource management, disaster risk reduction and human health. The CSIS is the component of the GFCS most concerned with the generation and dissemination (data flow) of climate information. It comprises global, regional and national centres and entities that generate/process climate information, and promote the exchange of data and products to agreed standards and protocols. Global Producing Centers (GPCs) generate global (seasonal) climate updates which are collected at the WMO lead centre (www.wmolc.org), regional climate centers produce regional outlooks by means of the Regional Climate Outlook Fora (RCOFs), from which national met and hydro services produce national updates through National Climate Outlook Fora. RCOFs include formal sessions that involve climate scientists, key user groups, decision makers as well as media, for identification of impacts and implications, and the formulation of response strategies. Outreach sessions are held involving sector specialists as well as media experts to develop effective communications strategies.

A new impetus for enhanced interactions between the climate science and stakeholder communities : To date, the interactions between the scientific and stakeholder communities have been poor. However, because of the realization that the actionable use of climate information (in particular under the threat of global warming) requires a better understanding between these two communities, a new impetus in improving communication is under way and is expected to continue in the next years, particularly within the framework of climate service activities.

Initiatives

To be further expanded after input from CLIVAR and WGRC.

Note: The WGRC is still being established, and the new committee has yet to meet for the first time. The proposed initiatives in Frontiers 3 & 4 are thus a provisional framing from the co-chairs of WGRC to fall within the grand challenge.

Initiative 1: Developing exemplar studies on using multi-model, multi-method climate data in identifying and analysing climate change signal versus noise. This initiative would build on ongoing and future programs aimed at producing large multi-model ensembles of climate projections using both GCMs and dynamical and statistical downscaling methods, such as CMIP5, CORDEX and other intercomparison projects. Research is needed on how to best evaluate and assemble information from multi-model, multi-method ensembles in order to i) produce probabilistic regional information usable in risk assessment and management work; and ii) increase the credibility of the projection information through multiple evidence and better process understanding. This initiative would gain from the development of regional analysis teams and frameworks that would tap on local know-how and maximize the usefulness of the information produced through active engagement of the IAV community.

Initiative 2: Facilitation of dialogue and sustained interaction between the communities engaged in modelling / downscaling, climate analysis, observations, interface organizations engaged in climate services, and users / stakeholders in the policy and stakeholder communities related to adaptation and risk management. The objective of this initiative is to facilitate the co-exploration by scientists and users of multiple information streams to achieve robust, relevant, defensible, and where appropriate, actionable understanding within the context of uncertain information. The implementation can be through multiple modalities; workshops, training opportunities, new methodologies, etc. As there are multiple complementary activities already underway, this initiative would optimally be in partnership where appropriate. A key emphasis would be on enabling communities to address the inherent specificities of different user knowledge needs, while recognizing that priority sectors of agriculture, health, water, and food security would likely be dominant initially. In support of this initiative, targeted research would be fostered to address the key scientific questions identified in Frontier 3, and communication and dialogue would be strengthened between key agencies, including among others national and regional climate service activities, the GFCS, research institutions, etc. Guidance for the research community would be provided, in partnership with other authorities (such as GFCS and the IPCC DDC), focused on identifying research priorities on regional information, managing uncertainty and contradiction in climate information, recommending new directions, and addressing issues of scales.

Strategy of coordination and integration

- ***This Grand Challenge will have a joint leadership. CLIVAR will lead activities within the frontiers F1 and F2, while the WGRC will lead the activities within the Frontiers F3 and F4.*** Strong collaborations are expected with GEWEX, SPARC, CLIC, WGCM and WGSIP as well as the **WMAC** (WCRP Modeling Advisory Council) and **WDAC** (WCRP Data Advisory Council). Overall progress and achievements of the GC will be reported and discussed annually at WGCM meetings.

- To strengthen the coordination and integration of the initiatives, a ***Grand Challenge Joint Steering Committee (GC-JSC)*** will be organized including representatives of the key groups involved and key expertise (global and regional climate modelling, seasonal to decadal prediction, climate services). A first goal of the GC-JSC will be to associate each initiative with a clear goal and co-chairs to lead it. The committee will insure that the initiatives will interact effectively with related ongoing or planned WCRP projects.

- As a first step to provide impetus to this GC, ***a series of workshops may be organized*** to articulate goals and sharpen the activities planned for the initiatives, and to maximize the coordination across these activities and their relevance towards pushing forward the scientific frontiers identified in this GC.