WCRP Grand Challenge:

Changes in Water Availability

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WCRP Grand Challenge – **Global Water Resources**

How can we better understand and predict precipitation variability and changes, and how do changes in land surface and hydrology influence past and future changes in water availability and security? *These questions focus on the exploitation of improved data sets of precipitation, soil moisture, evapotranspiration, and related variables such as water storage and sea surface salinity expected in the coming five years to close the water budget over land and provide improved information for products related to water availability and quality for decision makers and for initializing climate predictions from seasons to years ahead. The improvements will come from ongoing and planned satellite missions as well as greater use of in situ observations; their evaluation and analysis to document mean, variability, patterns, extremes and probability density functions; their use to confront models in new ways and to improve our understanding of atmospheric and land surface processes that in turn feed into improved simulations of precipitation; and new techniques of data assimilation and forecasts that can lead to improved predictions of the hydrological cycle across scales, from catchments to regional to global, including hydrogeological aspects of ground water recharge. In particular need of attention is the use of realistic land-surface complexity with all anthropogenic effects taken into account, instead of a fictitious natural environment. This encompasses all aspects of global change, including water management, land use change, and urbanization. The ecosystem response to climate variability and responsive vegetation must be included, as must cryospheric changes such as permafrost thawing and changes in mountain glaciers. These results should all lead to improved understanding and prediction of precipitation and water variability, enhance the evaluation of the vulnerability of water systems, especially to extremes, which are vital for considerations of water security and can be used to increase resilience through good management and governance.*

Context

The 21st century poses extreme challenges for the sustainable management of water resources at all levels from the local to the global scale. Water is a basic requirement for life and effective water management is needed to provide some of society's most basic needs. However, demand for water resources is increasing, due to population growth and economic development, while water resources are under pressure globally from over-abstraction and pollution. This is increasingly leading to competition for water, at local, regional and international levels. Environmental change is adding addition pressures. Anthropogenic influences are changing land

and water systems, redefining the state of drainage basins and the rivers and groundwater aquifers that supply the bulk of renewable freshwater supply to society. Widespread land use changes, associated with population increases, urbanization, agricultural intensification and industrialization, are changing hydrological systems in complex ways, and on many of the world's major rivers, water management is changing flows, often with severe effects on downstream users, aquatic ecosystems and freshwater discharges to the world's seas and oceans. Superposed on these pressures, expected climate change and climate variability can combine to create extreme and perhaps unprecedented conditions which have high impact consequences for human populations, economic assets and critical physical infrastructure. This unique combination of pressures has exposed weaknesses in current water governance and management. It has increased the awareness of uncertainties, the complexity of the systems to be managed, and the need for profound changes in policy and management paradigms, as well as governance systems.

WCRP has a unique role to play in developing the new scientific understanding and modeling and prediction tools needed for a new era of global water management. WCRP via GEWEX is well poised to motivate a new generation of land surface and global hydrological models, building on recent developments in earth observations, that represent the dynamics of managed waters. CLIVAR has an equally important role in motivating a new generation of weather-resolving climate models that are capable of simulating and potentially predicting the basic modes of variability, whether arising from sea surface temperature and ocean, land surface moisture, sea ice, or other sources that are known to drive global precipitation variability and extremes on seasonal to decadal time scales. Such prediction systems are increasingly necessary to address regional impacts of climate change.

The vast majority of water comes from precipitation – either directly, or indirectly through runoff from distant locations. From a climate perspective, it is therefore an imperative to understand the natural variability of precipitation in the system, as well as its susceptibility to change from external forcings. Because of its inherently intermittent nature, it is a major challenge to determine precipitation amounts reliably with a few instantaneous observations of rates such as from available satellites. Improved observations and analysis products related to precipitation and the entire hydrological cycle, and their use in evaluating and improving weather, climate and hydrological models is important and tractable over the next 5 to 10 years.

The specific questions that will be addressed over the next 5-10 years include:

How well can precipitation be described by various observing systems, and what basic measurement deficiencies and model assumptions determine the uncertainty estimates at various space and time scales? Despite a continuous improvement in observing systems, the uncertainty in precipitation estimates lies not only in the measurement error itself, but in the space/time interpolation of a naturally discontinuous and intermittent field and/or in the assumptions needed to convert a physical measurement from remote sensing into a precipitation amount. Critical water source regions often reside in complex terrain where sampling issues, remote sensing artifacts, and limitations are compounded. The errors are not static but instead depend on the nature of the precipitation itself. Focusing on the large scale environment responsible for the precipitation therefore holds hope to build not only better rainfall products, but characterizing the uncertainties in a verifiable manner as well. Regional hydroclimate projects provide detailed understanding that translate the large-scale information into usable information at decision making scales.

How do changes in climate affect the characteristics (distribution, amount, intensity, frequency, duration, type) of precipitation – with particular emphasis on extremes of droughts and floods? Increased temperatures, and associated increases in lower tropospheric water vapor, by making more water vapor available to storms, will very likely increase the intensity of rains and snows, increasing risk of severe floods. Changes in seasonality, shifts in monsoons, changes in snow melt and runoff, and so on are also part of this question which is elaborated on in the "extremes" science question.

How do models become better and how much confidence do we have in global and regional climate predictions and projections of precipitation? A challenge to the community is to develop improved global models. Scientists are beginning to run global climate models at sub 10km resolution, resolving meso-scale weather including the most extreme tropical storms. These need to be coupled to the ocean and land, and will require a new generation of parameterizations that better reflect what is and is not resolved. These models can potentially revolutionize our ability to correct long-standing model biases, minimize the need for downscaling, and provide predictions of regional impacts and changes in extremes from months to decades ahead. There is great need to quantify the uncertainty in precipitation projections and predictions at regional scales. Starting with improved uncertainties in the climate observations of precipitation, new and improved diagnostics must be developed to test the robustness of model predictions in different regimes. Knowing the uncertainties is critical if predictions of the mean precipitation and its distribution are to be used in local planning efforts.

How do changes in the land surface and hydrology influence past and future changes in water availability and security? While the land surface has small heat capacity, and heat moves slowly via conduction, the water storage varies enormously and water flows. Land has a wide variety of features, slopes, vegetation, and soils and is a mixture of natural and managed systems. Land plays a vital role in carbon and water cycles, and ecosystems. Of particular need of attention is use of realistic land surface complexity with all anthropogenic effects included instead of a fictitious natural environment. This includes all aspects of global change including water management, land use change and urbanization, and their feedbacks to the climate system. There is a need to address terrestrial water storage changes and close the water budget over land through exploitation of new datasets, data assimilation, improved physical understanding and modeling skill across scales, from catchments to regional to global with links to the entire hydrological cycle.

How do changes in climate affect terrestrial ecosystems, hydrological processes, water resources and water quality, especially water temperature? The ecosystem response to climate variability and responsive vegetation must be included but is mostly neglected in today's climate models. Cryospheric changes such as permafrost thawing, changes in the duration and depth of seasonal snowpacks, and changes in mountain glaciers must also be included. Feedbacks, tipping points, and extremes are of particular concern. The results should enhance the evaluation of the vulnerability of water systems, especially to extremes, which is vital for considerations of water security and can be used to increase their resilience through good management and governance.

How can new observations lead to improvements in water management? Over the last few decades, in situ observations of land surface hydrologic variables, such as streamflow, have generally been in decline. Regional estimation of evapotranspiration remains a significant challenge. At the same time, new observation methods, such as weather radars, flux towers, and satellite sensors have led to different types of measurements, and challenges for their incorporation in the hydrologic models used for hydrologic prediction and water management. One example is soil moisture, which in most models essentially acts as a buffer between the land forcings (mostly precipitation and evapotranspiration) and runoff, and whose characteristics are defined by the internal model parameterizations that control runoff production.

How can better climate models lead to improvements in water management? Regional precipitation predictions and projections remain a challenge at all timescales from seasonal forecasting out to centennial climate change. However, there are limited regions with forecast skill on seasonal timescales, associated mainly with ENSO, and broad scale, zonally-averaged precipitation changes associated with climate change appear to be detectable. The challenge now is to maximise the skill and reliability of predictions of regional rainfall changes on all timescales. This requires better understanding and model simulation of the teleconnections and drivers of regional climate such as changes in the oceans and cryosphere that are relevant to regional precipitation. Subsequent improved climate prediction systems and better dissemination of climate prediction information must be developed to deliver the benefit to society.

Prospects for advancements are excellent on this question because of new observations already underway and planned and the growing interest in climate predictions on all timescales. Key areas of development include:

1. A new Global Precipitation Mission as detailed at http://pmm.nasa.gov/GPM. *"Through improved measurements of precipitation globally, the GPM mission will help to advance our understanding of Earth's water and energy cycle, improve forecasting of extreme events that cause natural hazards and disasters, and extend current capabilities in using accurate and timely information of precipitation to directly benefit society."* The joint NASA/JAXA mission's Core Observatory is scheduled for launch in 2014. Most of the world's major space agencies will participate in this mission through the contribution of constellation satellites used to reduce revisit times to roughly 3 hrs.
2. Closely related missions such CloudSat (a NASA mission with components from the Canadian Space Agency to measure clouds and light precipitation), and EarthCARE an ESA mission (http://www.esa.int/esaLP/SEM75KTWLUG_LPearthcare_0.html) to advance our understanding of the role that clouds and aerosols play in the climate system), due for launch late 2015, that will make important contributions to the global precipitation estimates.
3. New satellite sensors such as SMOS(an ESA mission to map soil moisture and sea surface salinity), Aquarius (a NASA/Space Agency of Argentina mission to improve Sea surface salinity),and future SMAP data (A NASA mission dedicated to measuring soil moisture and the freeze/thaw cycle), produce or will produce estimates of near-surface soil moisture that can be used to diagnose or update model estimates, and GRACE (a joint NASA/DLR mission to map gravity anomalies and thus detect changes in water storage), now provides a nearly decade-long record of total water storage, albeit at coarse spatial resolutions. The planned Surface Water and Ocean Topography (SWOT) mission will provide observations of lake and reservoir surface area and levels, from which changes in storage of over 7000 km^3 of the estimated 8000 km^3 of reservoir storage globally will be available at one to two week

intervals. In addition in situ observations from buoys and ARGO floats will help close the water and energy budgets over the oceans.

4. Improvements in communication and data exchange policies to help create higher resolution global surface maps of precipitation based upon both local very dense networks of high-resolution precipitation measurements as well as surface radar networks where these are available. Significant gains are expected from high resolution gridded products based on in-situ data as well as inventories of long-term in-situ precipitation time series focused on engagement of these data into validation, error estimation and intercomparison efforts. The use of improved error statistics to develop new blending algorithms and fusion techniques capable of bringing together precipitation measurements with distinct error characteristics (e.g., gauges, radar, satellites and models) into a consistent physical framework. Advances in data assimilation techniques that allow more precipitation information to be incorporated into Numerical Weather Prediction models.
5. Surface fluxes of moisture are improving through the use of flux tower and other observations over land, feeding into improve estimates of evapotranspiration as part of the GEWEX Landflux project.
6. The production of an Integrated Water and Energy product by the GEWEX GDAP panel that can be used to explore linkages between hydrology and energy variables in the Earth System that in turn provides a much improved basis for evaluating models on all aspects of the water cycle. Advanced diagnostic methods that use the observed variables and their covariability to diagnose not only problems in the model output, but assess model processes and potential improvements to these processes in order to better represent the observed climate behavior.
7. Incorporation of more realistic land surface hydrology into land surface models, including water management, land management and land use change, as well as improved process representation (including cryospheric processes). The new information coming available is expected to be revolutionary in terms of the management of trans-boundary rivers, but current climate models have no mechanisms for use of this information, since most do not represent the effects of water management.
8. New methods must be developed to address system vulnerability, particularly to extremes. Quantification of the uncertainty in each of the elements of the global water-balance, including the managed aspects, in a consistent manner is required. Further there is a need to communicate uncertainties, manage expectations, address management under uncertainty (e.g., building resilience).
9. Several other developments in modeling are progressing and advances appear likely. These include development of improved precipitation downscaling methods, particularly for mountainous and arid regions; evaluation of the hydrologic dynamics of land surface models with newly available data; prediction of stream temperature as a diagnostic in land surface models; improving freshwater fluxes to the world's seas and oceans; and including the known climate feedbacks in off-line land-surface change assessments. Water demand models and assessments to land surface and hydrological models must be linked at the global scale.
10. Demonstration of the usefulness of GEWEX data products and new tools such as cross-scale modeling, ensemble hydrological prediction, data assimilation, and data provision in water resource management.

There are multiple benefits and the results are important for society.

As well as greatly improved knowledge about land water resources and ocean salinity, and the causes of their variations, much improved models will allow better predictions and projections on all time scales from seasonal to centennial and from global to continental to basin scales. Predictions, with quantified uncertainties provide invaluable information for water managers and users, including decision makers at many levels associated with food and water security. These developments would naturally serve to push WCRP research and development priorities, as users provide feedback on weaknesses and further needs.

The information provided also feeds into the development of a "Global Drought Information System". Such a system would provide a user anywhere in the world access to information on our current understanding of drought in that region (e.g., role of ENSO, PDO, global warming, etc), the history of drought in that region (with access to various data, time series, indices, etc), current conditions (monitoring results), the results of near real time attribution (our understanding of the current conditions), and regularly updated forecasts from months to years ahead (with consistent estimates of (uncertainties). The system would naturally build on the various investments we are making in observations (including reanalysis), drought research, and modeling/forecasting capabilities (e.g., the various national and international MME efforts such as the WMO lead center for long range forecasts: www.wmolc.org). The system would be built hand-in-hand with the user community, and would have to be sustainable and refreshable as new datasets, better understanding and better modeling capabilities become available. It would naturally serve to push WCRP research and development priorities, as users provide feedback on weaknesses and further needs (analogous to how the weather community is continuously being pushed for better weather forecasts).

Appendix: Implementation

Within GEWEX, 4 Grand Science Questions have been identified, two of which are blended in the above and a third deals with extremes, which is partly included in the above. Separate descriptions of these are available and all of the science questions posed are linked to panels within GEWEX for actions. For instance GDAP will play a major role in GPM and the development and assessment of precipitation and related products. GDAP and GASS will be engaged in Cloudsat and EarthCARE projects. GLASS and GHP will be very involved with soil moisture and the new satellite products that are anticipated. Improved datasets and their assessment will involve GDAP and GHP, while model evaluation and development will be led by GASS and GLASS, along with hydrological modeling in GHP. Together the projects will use data with models to better assess uncertainties and products.

Plans will be advanced not only within the Panels, but also in crosscutting workshops that help focus the dataset development, evaluation and assessment. This will afford the opportunities for all projects under WCRP to become engaged and to formulate new activities.