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WATER IN A CHANGING CLIMATE

GEWEX/iLEAPS Conferences and Joint Sessions

24–28 August 2009
Melbourne, Australia

For latest conference information and programs:

http://gewex.org/2009gewex_ileaps_conf.html

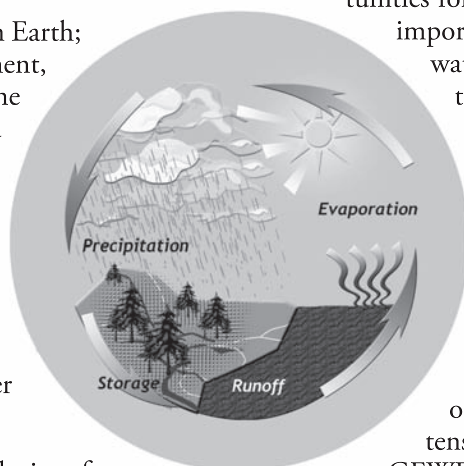
Commentary

GEWEX Conference Highlights Water Research Challenges and Strategies

Peter J. van Oevelen
Director, International GEWEX Project Office

GEWEX and the Integrated Land-Ecosystem-Atmosphere Processes Study (iLEAPS) with the support of Monash University (Prof. Christian Jakob) are holding parallel conferences with joint sessions in Melbourne, Australia on 24–28 August 2009. This issue of the newsletter is dedicated to the overall theme of the conferences, "Water in a Changing Climate."

Water is not only an essential part of life on Earth; to me it is also the most fascinating element, substance and medium. It is both medicine and poison, it both gives and takes life, and there is hardly a process on Earth where water is not involved in some form or another. As physical scientists we tend to focus on the mechanics of water movement, the phase changes, and the transportation and energy conversion involved in these processes. However, we must realize that this is only a small part of the water in our environment and in our lives.



Water and Energy Cycle.

As the general understanding of the complexity of our Earth system increases and the general public better understands its impact on these processes, we as hydrologists, meteorologists, geophysicists and engineers must engage and interact with the public more closely. One step is involvement with other science disciplines (e.g., economics, social science, the humanities). Another step is to interact more closely with users and stakeholders, which means addressing the sometimes conflicting requirements of these different and diverse groups. GEWEX has an obligation as a community to provide the best possible information, knowledge, predictive capability and tools necessary to deal with the issues related to our most precious resource—water. We have to realize however that we are a science program delivering science output to first and foremost other scientists, science disciplines and science-related activities; and that our interactions with users beyond those are preferably through other channels more suitable to interfacing with the users and better capable in translating the users' problems and needs into useful product/application requirements and, consequently, science requirements. At the same time we have to assure that support for basic climate science is seen as an intrinsic part of the solution in providing adaptation and mitigation strategies to society.

The articles in this newsletter issue highlight the challenges ahead in dealing with "Water in a Changing Climate" and should be considered visionary as they address the various authors' opinions on the subject. These articles offer also some critical notes on current research and a different perspective of research activities related to Water in a Changing Climate. Some of the ideas presented can be considered controversial and I welcome any commentaries on them but also on the other issues raised. Many of the articles acknowledge the increased emphasis on uncertainty in our predictions and how this influences our strategies related to adaptation and mitigation to a changing climate. Suggestions are given for where research should be focused in the future to better address these issues from both a hydrologic and climatologic scientific point of view, as well as those of decision and policy makers. Personally, I am pleased that many of the suggestions provide opportunities for GEWEX to grow and play an increasingly important role in science related to the energy and water cycle at all scales (both temporal and spatial). They also show that the science as represented by the GEWEX community has played an important role in increasing our understanding of energy and water-related processes as part of the Earth system.

The complexity of GEWEX activities has evolved tremendously over the past 20 years to address the science of climate, from a small core project dealing with a handful of activities to the current project with an extensive number of activities. The International GEWEX Project Office's responsibilities have grown along with it and that by itself poses challenges in maintaining the necessary resources to meet the project's demands.

The issues raised in this newsletter and others will be discussed at the upcoming conference in Melbourne. We have planned an interesting program and side activities, including a special "Media Meets Science" event on Tuesday evening where two important "water" documentaries will be shown with introductions followed by a public panel discussion. I look forward to welcoming you to Melbourne.

GEWEX NEWS

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Water in a Changing Climate: Challenges for GEWEX

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At its conception (Phase I, from 1990 to 2002), GEWEX was guided by four main objectives related to water and energy cycles in the climate system (WCRP, 1990):

- Determine the Earth's hydrologic cycle and energy fluxes using global measurements;
- Model the global hydrologic cycle and assess its impact on the atmosphere, oceans, and land surfaces;
- Develop the ability to predict variations in global and regional hydrologic processes and water resources as well as their responses to environmental change;
- Foster the development of observing techniques, data management, and assimilation systems for operational application to long-range weather forecasts, hydrology, and climate predictions.

In Phase II (2003–2012), GEWEX set forth four principal scientific questions that are related to climate variability and change (see *http://www.gewex.org/gewex_overview.html*):

- Are the Earth's energy budget and water cycle changing?
- How do processes contribute to feedback and causes of natural variability?
- Can we predict these changes on seasonal to interannual time scales?
- What are the impacts of these changes on water resources?

Phase II is essentially intended to utilize GEWEX "prediction capabilities, data sets and tools for assessing the consequences of global change," particularly as they relate to water resources and the related applications communities, to address these questions. Furthermore, the transition from Phase I to Phase II is characterized by a stronger emphasis on water resources and on the impact of a changing climate on the water cycle and water resources.

We focus here on the challenge GEWEX faces in moving forward its research agenda in three critical areas of water cycle research that directly impact the design and management of water resource systems. How GEWEX can best succeed in this ongoing transition is not entirely clear. As a mature organization with many legacy activities, how will GEWEX develop a clear and compelling scientific agenda that addresses the evolving needs of global change science? We argue that after a decade or so of attention, a major focus of Phase II on seasonal climate prediction has borne little fruit, particularly as evaluated with respect to any reasonable measure of prediction skill in the extratropics. While we don't imply that some focus on seasonal prediction is not justified—where the rubber meets the road so to speak in water resource applications, there are demonstrable and potentially large benefits if seasonal prediction skill can be demonstrated. However, in our experience, most of the actual land hydrologic (and hence water resources) seasonal prediction skill comes not from an ability to forecast climate, but rather from hydrologic initial conditions (see e.g., Wood and Lettenmaier, 2008; Li et al., 2008). These include knowledge of soil moisture and snow water storage. Furthermore, this skill is often at the shorter end of the seasonal time scale (e.g., weeks). This suggests to us that land data assimilation (not just land surface modelling, which GEWEX Global Land Data Assimilation System activities now emphasize) may well be a more fruitful path of inquiry than seasonal climate prediction.

If seasonal prediction is not to be the golden bullet for GEWEX, where does its future lie? We argue that water in a changing climate, and more specifically, providing the basis for understanding the impacts of changes in the water cycle on land surface hydrology and water resources, should constitute a central research vision for GEWEX. We believe that based on its past successes in the land-atmosphere domain (GEWEX is the only WCRP program that has successfully integrated the land surface and atmospheric communities, and it should justifiably take pride in this as a major accomplishment), GEWEX could make major contributions to three problems outlined below.

Stationarity is Dead

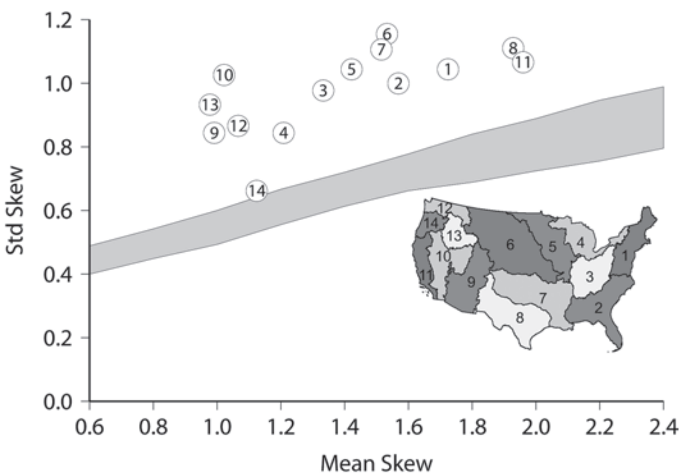
In a recent paper of that title, Milly et al. (2008) argue that statistical stationarity, which is the central premise behind the design and management of water-related structures, ranging from small road culverts and urban stormwater detention to the design and operation of huge reservoirs on the world's largest rivers, is no longer tenable. The stationarity assumption has commonly been applied to streamflow observations, but as the capability of hydrological models has advanced, it is now applied as well to surface atmospheric variables, such as precipitation, temperature, and surface radiative fluxes, among other variables that serve as forcings to hydrological models. In either case, ample evidence exists that the stationarity assumption is no longer valid. Among the well known examples of ongoing hydrologic change (nonstationarity) are western U.S. snow observations (mostly decreasing), observations of low flows in U.S. streams (mostly increasing), and pan evaporation in the U.S. and former Soviet Union (mostly decreasing). In our view, the overriding issue is no longer to identify cases of nonstationarity, or even to address the more interesting scientific question of attribution, but rather, what methods should replace the time honored hydrological analysis methods that assume stationarity? Are our climate models up to the task of estimating the future mean and variability of water cycle variables sufficiently for design life times (which typically are in the 25 to 100 year range)? Milly et al. (2008) suggest that an effort similar to the Harvard Water Program of the 1950s and 1960s (Maass et al., 1962), which was the genesis of many of the methods currently in use in the water resources community today, will be required to develop the tools needed by the next generation of planners. We are somewhat surprised that research agencies have yet to come to grips with this problem, or even to frame it scientifically. In our view, GEWEX could play a key role in shaping a research agenda in this area.

Fat-tailed Statistical Distributions of Extremes

A recent paper by Weitzman et al. (2009) has generated considerable interest in the climate adaptations community. Among other things, Weitzman argues that in a changing climate, the probability distributions of extremes of natural hazards (e.g., floods and droughts) may have heavier ("fat" in his terms) tails than the distributions that are commonly used in practice (such as the extreme value family). In a slightly different context, this is a problem that was given considerable attention by the hydrologic community in the 1970s and 1980s.

In a seminal paper, Matalas et al. (1975) identified what they termed the "condition of separation." The condition of separation is a reflection of their observation that over essentially all hydrologic regions of the U.S., the standard deviation of the coefficient of skewness is larger relative to the (regional) mean than would be expected from many commonly used probability distributions (see figure below). The condition of separation can be viewed as evidence that the "true" probability distribution of hydrologic extremes is more heavy tailed than would be expected from the distributions of extremes commonly used in practice. While the Matalas et al. (1975) conclusion is similar to that of Weitzman et al. (2009), it is based on extensive analysis of many thousands of flood observations. Furthermore, the Matalas et al. (1975) work motivated a series of papers over the following decade that examined alternative probability distributions and regional fitting methods that were able to capture the observed heavy-tailed behavior. However, all of the work in this area, most of which had appeared in print by the 1980s, was based on observed streamflow records.

Given the current interest in the possibility of heavy-tailed distributions, a number of obvious questions present themselves to which the expertise of the GEWEX community could be applied. These include the extent to which nonstationarity might contribute to heavy-tailed behavior; whether climate models are able to reproduce, via some sequence of downscaling steps, observed heavy-tailed behavior in past observations; and how, and to what extent, this behavior is likely to be propagated into a non-stationary hydrologic future. Given the GEWEX interest in assessing the consequences of global change, we envision a research agenda that assesses the ability of climate projections to represent the statistical characteristics of future extreme events.



Condition of separation, showing relationship of standard deviation over regions of skew coefficient of annual maximum flood series of 30 years length as related to regional mean skew coefficient, computed at U.S. Geological Survey stream gauges across the continental U.S. Gray shaded area represents range of synthetic values from Monte Carlo simulations with commonly used probability distributions of extremes. Numbers correspond to U.S. hydrological regions as shown in inset. Figure replotted from Figure 4 of Matalas et al. (1975) by E. Clark, University of Washington.

Hydrologic Persistence in Climate Models

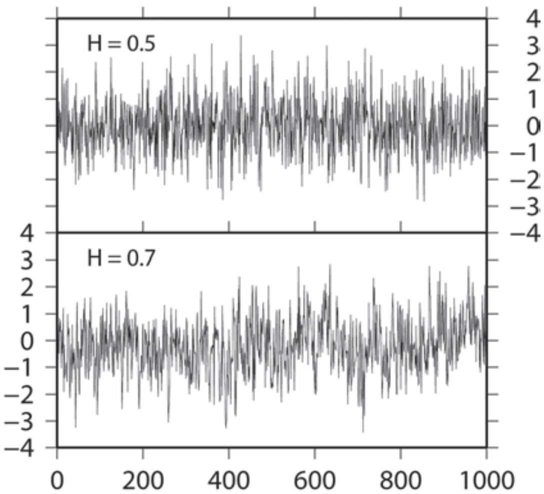
In the 1960s and 1970s, there was a great deal of interest in the hydrologic community in the so-called "Hurst Effect" in hydrologic time series. The Hurst Effect was the observation, based on a lifetime of work by H.E. Hurst in the Nile River basin (Hurst, 1951), that streamflows (and other geophysical time series) tended to have more persistence than would be expected in random sequences. This observation was formalized in a series of papers by Mandelbrot and Wallis (see e.g., Mandelbrot and Wallis, 1968), and a set of models that captured this behavior (see figure on page 5).

In short, models with a Hurst coefficient H (the calculation of which is based on the dependence of the range of a time series rescale by its standard deviation on the record length of the time series) equal to 0.5 are short term persistent (white noise is one example), whereas models with H>0.5 (bounded by one) have progressively longer term persistence. Estimates over many geophysical records typically have average values of H of around 0.7. In a recent paper, Rutten et al. (2009) analyzed global gridded observed precipitation records from the 20th Century, and 20th Century runs from four global climate models. They found that the observations had H values that were considerably larger than the values computed from GCM precipitation sequences, and that this was true for all of the GCMs tested. This implies that climate model simulations may not adequately reflect the low frequency behavior of precipitation observed in historical records. Because droughts effectively are manifestations of low frequency climate behavior, this implies that climate models may be unable to reproduce droughts with severity and length consistent with historic observations, and calls into question their ability to predict future drought statistics. Further, the reliability of water supply reservoirs is closely related to the persistence of below average inflows.

We believe that the GEWEX community should bring its expertise to bear to understand the reasons why climate models appear to systematically under-predict low frequency variations, and should assess the implications for drought projections that are necessary for the future performances of water resource systems.

Summary

Changes in climate will result in changes in water resources. Central to these changes will be the ability to estimate the statistical characteristics of the water cycle variables that control the design and reliability of water resource systems. GEWEX has identified as one of its central scientific objectives assessing the consequences of global change on water resources. Our vision is that GEWEX should embrace a scientific agenda that addresses the three issues outlined above that are critical to the design and reliability of water resource systems—specifically,



One thousand year synthetic sequences of Fractional Gaussian Noise. H=0.5 corresponds to short-term persistence, H=0.7 to long-term persistence. The role of low frequency in H=0.7 sequence is apparent. Figure courtesy of K. Andreadis and E. Clark, University of Washington.

addressing time series non-stationarity in a changing climate; assessing the statistical characteristics of hydrologic extremes (floods and droughts) in climate projection models and their implications for future design; and understanding the apparent under-persistence in water cycle variable time series generated from climate models and the associated implications for the reliability of water resource systems. If GEWEX could motivate progress in these areas, it would assume a central role in global change science.

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Collateral Damage from the Death of Stationarity

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In February 2008, a group of authors writing in *Science* declared that insofar as water management is concerned, stationarity is dead (Milly et al., 2008). What they mean by this claim is that water management decisions can no longer proceed under the assumption that "the idea that natural systems fluctuate within an unchanging envelope of variability." The authors assert that both scientists and decision makers have long been aware of human disturbances and climate variations and their effects on the water cycle, but have historically considered these effects "to be sufficiently small to allow stationarity-based design." Such assumptions allowing for stationarity-based design, they argue, are no longer valid. Stationarity is dead.

The authors of the *Science* article assert that the cause of the death of stationarity is human-caused climate change resulting from the emission of greenhouse gases. However, some scholars have argued that treating natural systems as stationary has always been a mistake. Such arguments are frequently found in relation to the water cycle, for instance, in discussion of the often misused notion of the 100-year flood. Stationarity, these scholars might say, has always been dead. But whether or not natural systems are stationary in the absence of greenhouse gas emissions misses the larger point that the assumptions of stationarity that have underpinned water management for many decades are increasingly viewed as flawed. Consequently, there is a need to consider alternatives to stationarity-based policies.

One implication that the authors of *Science* draw from the death of stationarity is that more attention should be paid to modelling and observations of natural processes. They argue that "we need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems." In other words, we have to improve our ability to anticipate the future, because relying on the statistics of the past will no longer be a useful guide to what is to come. Of course, more attention to models and observations was often the same recommendation found when stationarity was thought to be alive and well.

Here I suggest a far more consequential implication of the death of stationarity for the role of science in water management decision making than a need for better models and observations. Rather than basing decision-making on a predict (probabilistically of course) then act model, we may have to face up to the fact that skillful prediction of variables of interest to decision makers may simply not be possible. And even if it were possible, we would not be able to identify skill on the same time scales as decisions need to be made. The consequence of this line of argument is that if stationarity is indeed dead, then it has likely taken along with it fanciful notions of foreseeing the future as the basis for optimal actions. Instead, it may be time to rethink how we make decisions in the face of not simply uncertainty, but fundamental and irreducible ignorance. Rather than focus on optimal decisions guided by prediction, we may need instead to focus on robust decisions guided by recognition of the limits of what can be known.

Why Skillful Predictions are Not Possible: The Guaranteed Winner Scam Meets the Hot Hand Fallacy

A skillful prediction is one that improves upon a prediction based on a naive baseline. For weather and climate forecasts the naive baseline that is typically used is climatology. Two simple dynamics associated with the production and interpretation of predictions help to explain why the death of stationarity makes the prospects for skillful predictions less likely in the future. By contrast, conventional wisdom holds that nonstationary processes are often more amenable to skillful prediction.

The first involves the consequence of the availability of a multitude of predictions for most any variable of interest to decision makers. The second dynamic involves a well-known, but nonetheless common, bias in decision making.

The first of these dynamics might be called the "guaranteed winner scam," after the following analogy. Select 65,536 people, and tell them that you have developed a methodology that allows for 100% accurate prediction of the winner of next weekend's big football game. You split the 65,536 people into two equal halves and send one half a guaranteed prediction of victory for one team, and the other half a guaranteed win on the other team. You are guaranteed that your prediction will be viewed to be correct by the 32,768 people who received your correct prediction.

Each week you can proceed in this fashion. By the time 8 weeks have gone by there will be 256 people anxiously waiting for your next week's selection because you have demonstrated remarkable predictive capabilities, having provided them with 8 perfect picks. Presumably they will now be ready to pay a handsome price for the predictions you offer in week 9.

Now instead of predictions of football match winners, think of real-time predictions of natural processes, such as precipitation, floods, or the state of the El Niño Southern Oscillation (ENSO). In such a situation, predictions that build in considerations of nonstationarity will (by definition) differ from predictions based on a stationary climate. With enough of a diversity of predictions and predictive methodologies, there will be a very wide spread of forecasted events for any particular phenomenon. And for almost any phenomena of interest, meteorological services, management agencies, scientific literature, as well as pronouncements by individual scientists, will generally provide a wide range of predictions.

Consider for example, Jewson et al. (in press), which presents a suite of 20 different models that lead to predictions for 2007–2012 hurricane landfalls in the United States. The suite of models produce forecasts that span a range from more than eight percent below the 1900–2006 mean to 43 percent above that mean, with 18 values falling in between. Over the 5-year period it is virtually certain that one or more of these models (and there are of course other models and predictions from other sources) will have provided a prediction that will be more accurate than the long-term historical baseline (i.e., will be skillful). And of course, this refers only to the analysis found in a single paper; a broader survey of relevant predictions would arrive at a substantially wider spread.

With such diversity of predictions, the user of these forecasts has no way of knowing whether the skill was the result of true predictive skill or just chance given a very wide range of available predictions. And because the scientific community is constantly introducing new methods of prediction, the "guaranteed winner scam" can go on forever with little hope for certainty. Nonstationarity makes this problem even more intractable, because even if skill could be demonstrated for one set of predictions, nonstationarity could easily mean that such demonstrated skill is not stable and the same methodology may not continue to generate skillful forecasts as relationships evolve and change over time.

Complicating the issue is a second dynamic, the "hot hand fallacy" which was coined by behavioral pschyologists to describe how people misinterpret random sequences, based on how they view the tendency of basketball players to be "streak shooters" or have the "hot hand" (Gilovich et al., 1985). The "hot hand fallacy" holds that the probability in a random process of a "hit" (i.e., a made basket or a successful hurricane landfall forecast) is higher after a "hit" than the baseline probability. (The "gambler's fallacy" is also relevant. It posits that the odds of a miss are higher after a run of "hits.") In other words, people often see patterns in random signals that they then use, incorrectly, to ascribe information about the future.

1972 Melbourne flood – Elizabeth Street. Photo courtesy of the Commonwealth of Australia 2009, Bureau of Meteorology (ABN 92 637 533 532).

The "hot hand fallacy" can manifest itself in several ways with respect to predictions of Earth system processes. First, as argued above, the wide range of available predictions essentially spanning the range of possibilities means that some predictions for the next years will be shown to have been skillful. Even if the skill is the result of the comprehensive randomness of the "guaranteed winner scam" there will be a tendency for people to gravitate to that particular predictive methodology that appears to succeed for future forecasts, much like the person who receives eight consecutive weeks of correct football winners will pay close attention to that issued for week nine. Second, a defining feature of climatology is persistence, suggesting that nature does sometimes really exhibit a "hot hand." However, nonstationarity means that an over-reliance on persistence will eventually lead one astray, even when skill has been shown to exist.

As a result of these dynamics, robust predictive skill can be shown only over a fairly long term, offering real-time predictions and carefully evaluating their performance. For predictions that are issued and evaluated frequently, such as daily weather forecasts, useful determination of skill is possible. But as the time scale of the phenomenon stretches to longer timescales, such as seasonal or interannual predictions, the time period necessary to demonstrate skill necessarily is many decades, far beyond the timescale of any decision process. For even longer term forecasts, such as decadal and longer, determination of skill in forecasting simply cannot be done on human timescales. Consequently, judgments of skillful predictive methodologies on shorter time scales must be based on guesswork or other factors beyond empirical information on predictive performance.

Alternatives to Prediction

Fortunately, decision makers have alternatives to prediction. Such alternatives depend no less on science, but they will depend on science beyond predictions generated from sophisticated models. Individuals and organizations commonly take actions without accurate predictions of the future to support them. They manage the uncertainty by making decisions or establishing decision processes that produce satisfactory results in the absence of good predictions. In recent years, a number of researchers have begun to use climate models to provide information that can help evaluate alternative responses to climate change, without necessarily relying on accurate predictions as a key step in the assessment process. The basic concept rests on an exploratory modelling approach in which analysts use multiple runs of one or more simulation models to systematically explore the implications of a wide range of assumptions and to make policy arguments whose validity is unaffected by uncertainties.

As a key step, such analyses use climate models to identify potential vulnerabilities of proposed adaptation strategies. These analyses do not require accurate predictions of future climate change from cutting edge models. Rather they only require a range of plausible representations of future climate that can be used, for instance, to help the water agencies better understand where their vulnerabilities may lie and how they can be addressed. Even without accurate probability distributions over the range of future climate impacts, such information can prove very useful to decision makers.

A robust decision is one that leads to success or avoids failure regardless of circumstances, rendering specific knowledge of the future much less important. Robust strategies perform well compared to the alternatives over a wide range of assumptions about the future. In this sense, robust strategies are "insensitive" to the resolution of the uncertainties.

A focus on robust decision making in recognition of the limited ability to demonstrate predictive skill does not imply that climate model development should cease; further model development can and should inform the plausible ranges used in robust decision-making. However, we must give up fantasies of being about to accurately predict the future, and as importantly, to even know how well we can anticipate the future before it arrives.

By avoiding an approach that places climate prediction at its heart, successful adaptation strategies can be developed in the face of this deep uncertainty. Decision makers should systematically examine the performance of their adaptation strategies over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political and cultural factors. They should choose a strategy that they find sufficiently robust across these alternative futures. Such an approach can identify successful adaptation strategies without accurate and precise predictions of future climate.

The death of stationarity may very well have taken with it notions of our ability to skillfully predict the future. As a consequence, it casts serious doubts on the viability of a predict-and-decide mode of connecting science with decision making. Rather than despair this situation, we should embrace it, as the death of stationarity has been long overdue.

Acknowledgements: The last section of this article is based on Dessai et al., 2009.

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Precipitation in a Changing Climate—More Floods and Droughts in the Future

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Evidence is building that human-induced climate change—or global warming—has a direct influence on changes in precipitation and the hydrological cycle. While precipitation amount is most commonly considered, even bigger changes occur in its intensity, frequency and type (rain vs. snow). A warmer climate increases risks of both drought and flood, but at different times and/or places. These aspects have enormous implications for agriculture, hydrology and water resources, yet they have not been adequately appreciated or addressed in many studies of climate change impacts. Because natural variability in weather provides resilience, the biggest impacts occur through changes in extremes.

The conceptual basis for changes in precipitation is given by Trenberth (1998, 1999), Allen and Ingram (2002), Trenberth et al. (2003), Neelin et al. (2006) and Held and Soden (2006). Increased heating accelerates land-surface drying as heat goes into the evaporation of moisture; this increases the potential incidence and severity of drought, and has been observed in many places worldwide (Dai et al., 2004). However, the water-holding capacity of air increases by about 7 percent per 1° Celsius warming, and moisture in the atmosphere has been widely observed to be increasing. This moisture then gets carried around by atmospheric winds to a point where storms are favored. Typical storms reach out a distance of about four times the radius of the rain dimension, and gather in water vapor to produce precipitation (Trenberth, 1998; 1999). As heavy rainfall rates typically exceed local surface evaporation rates greatly, precipitation depends primarily on low-level moisture convergence. The convergence of increased water vapor therefore leads to more intense precipitation and risk of heavy rain and snow events. This is widely observed to occur in all storms, whether they be individual thunderstorms, extratropical rain or snow storms, or tropical cyclones and hurricanes. But this convergence may also lead to reductions in the duration and/or frequency of rain events, given that total amounts do not change much and dry spells in between such events also increase in duration. Hence, basic theory, climate model simulations and empirical evidence all confirm that warmer climates, owing to increased water vapor, lead to more intense precipitation events even when the total annual precipitation is reduced slightly. This in turn increases the risk of flooding.

Observations of Change

Observational evidence reviewed by Trenberth et al. (2007) is noted here very briefly. Relative humidity has tended to remain about the same, from the surface throughout the troposphere, and thus actual moisture amounts in the atmosphere increase at the same rate that the Clausius-Clapeyron equation gives, or about 7 percent per Kelvin over the oceans where moisture supply is not limited or slightly less over parts of land. Other changes occur as the patterns of where storms form and track change, and thus global atmospheric circulation plays a key role in the distribution of precipitation (Vecchi et al., 2006). Generally dry areas are becoming drier (mostly throughout the subtropics) and wet areas are becoming wetter, especially in mid-to-high latitudes and in the monsoon trough in the tropics during the wet season. The snow season has become shorter by up to 3 weeks in parts of the boreal high latitudes over the last 50 years, owing to an earlier onset of spring.

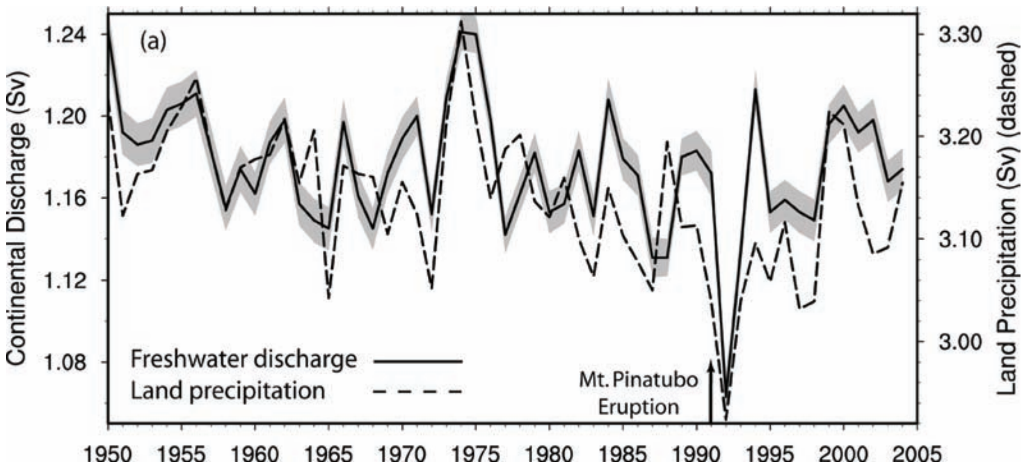
There is also clear evidence of changes in the extremes of precipitation. Globally averaged over the land area with sufficient data, the percentage contribution to total annual precipitation from very wet days (upper 5 percent) has increased during the past 50 years, even in places where mean precipitation amounts are not increasing. For the contiguous United States, Groisman and Knight (2008) show that even as the top 0.3 percent of heavy rains has increased by 27 percent from 1967 to 2006, so have dry spells increased in most places. The distribution and timing of floods and droughts is most profoundly affected by the cycle of El Niño events, particularly in the tropics and over much of the mid-latitudes of Pacific-rim countries. While enhanced rainfall rates increase the risk of flooding, mitigation of flooding by local councils and government bodies is continually occurring and flooding records are often confounded by changes in land use and increasing human settlement in flood plains. Nevertheless, great floods have been found to be increasing in the twentieth century (Milly et al., 2002).

Increases in drought are associated with a drying trend over many land areas that has taken place since the mid-1950s that is partly associated with decreases in precipitation over land (see figure on page 9) and an overall decrease in runoff and river discharge into the ocean (Trenberth and Dai, 2007; Dai et al., 2009). Large surface warming has also likely contributed to the drying by increasing atmospheric demand for moisture.

Future Prospects

Expectations for changes in overall precipitation amounts are complicated by aerosols. Because particulate aerosols block the sun, surface heating is reduced. Absorption of radiation by some aerosols, notably carbonaceous, directly heats the aerosol layer which otherwise may have been heated by latent heat release in precipitation following surface evaporation. Hence, these aerosols reduce the hydrological cycle. The largest decrease recorded in global land precipitation took place in the year after the Mount Pinatubo volcanic eruption, owing to cooling from aerosols deposited in the stratosphere (Trenberth and Dai, 2007; see figure on page 9). Even as the potential for heavier precipitation occurs from increased water vapor amounts, the duration and frequency of events may be curtailed, as it takes longer to recharge the atmosphere with water vapor.

A very robust finding in all climate models with global warming is for an increase in potential evapotranspiration. In the absence of precipitation, this leads to increased risk of drought, as surface drying becomes enhanced. It also leads to an increased risk of heat waves and wildfires; once the soil moisture



Annual water year (October–September) continental freshwater discharge (solid line; shading indicates ± one standard error, 1 Sv=10^6 m^3 s^{-1}) into the global oceans during 1950–2004 estimated using streamflow records from the world's largest 925 rivers supplemented with simulated streamflow using a land surface model forced with observed precipitation and other atmospheric forcing. Dashed line is observed precipitation integrated over global land areas. The correlation between the two curves is 0.65. The timing of the Mount Pinatubo eruption is given by the black arrow at the bottom. From Trenberth and Dai (2007).

is depleted, all of the heating goes toward raising temperatures and wilting plants.

The global increase in precipitation closely matches the increase in surface evaporation, which depends on the energy available. The evaporation rate is much less than the 7 percent per 1° Celsius increase in water vapor, although Wentz et al. (2007) suggest that this may be underestimated in models. A consequence is that the characteristics of precipitation must change (Trenberth et al., 2003); it is the intensity and duration that are thus most affected. The increase in intensity can even exceed this value because the additional latent heat released feeds back and invigorates the storm that causes the rain in the first place, further enhancing the convergence of moisture. The total precipitation amount increases at a much lower rate, however, so there must be a decrease in light and moderate rains and/or a decrease in the frequency of rain events. We might call this the "it never rains but it pours" syndrome (see figure below)! In addition, as heat is transported upwards during precipitation, greater latent heat is released with the additional moisture and thus there is less need for the overall circulation to be vigorous (Held and Soden, 2006; Vecchi et al., 2006). Another implication is that large-scale overturning circulations, such as the Hadley and Walker cells, are apt to weaken.

Based on model results, the Intergovernmental Panel on Climate Change (IPCC) (2007) found that there is a tendency for an increase in heavy daily rainfall events in many regions, including some in which the mean rainfall is projected to decrease. In the latter cases, the rainfall decrease is often attributable to a reduction in the number of rain days rather than the intensity of rain when it does occur. An analysis of future climate simulations by the latest generation of coupled climate models (Sun et al., 2007) shows that for each 1° Celsius of surface warming globally, atmospheric precipitable water increases by about 9 percent, daily precipitation intensity increases by about 2 percent, and daily precipitation frequency decreases by 0.7 percent. For very heavy precipitation (>50 mm day^{-1}), the percentage increase in frequency is much larger than in its intensity (31.2 vs. 2.4 percent) so that there is a shift towards increased heavy precipitation. Thus, extreme weather events such as heavy rainfall and flooding are projected to become much more frequent as climate warms, but with fewer events overall.

Climate model results (IPCC, 2007) have become more consistent with regard to projected changes in the patterns of precipitation and can now simulate recent observed patterns of change. Increases in the amount of precipitation are very likely at high northern latitudes, but decreases in precipitation are projected for tropical and subtropical regions outside of the monsoon trough. This is the "rich get richer and the poor get poorer" syndrome (Neelin et al., 2006). However, extratropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns, continuing the broad pattern of observed trends over the last half-century. Along with a poleward expansion of the subtropical high-pressure systems, this movement leads to a drying tendency in the subtropics that is especially pronounced at the higher-latitude margins of the subtropics.

Future tropical cyclones (typhoons and hurricanes) will also likely become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures (IPCC, 2007). Because an intense tropical cyclone takes heat out of the ocean and mixes the ocean, leaving behind a much stronger cold wake than a more modest storm, there may be fewer tropical cyclones as a whole. Possible increases in static stability also lead to fewer tropical cyclones. Nonetheless, increased risk of flooding is a likely outcome from land-falling tropical storms.

As temperatures rise, the likelihood of precipitation falling as rain rather than snow increases, especially at the beginning and end of the snow season and in areas where temperatures are near freezing. Such changes lead to increased rains and, along with earlier snowmelt and greater evaporation and ablation, the result is a reduced snow-pack. In mountain areas, the winter snowpack forms a vital freshwater resource in the spring as the snow melts. A diminished snow-pack results in subsequent lower soil moisture, which likely contributes to summer drought due to the importance of re-cycling of moisture.

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Increasing Greenhouse Gases Impact Local Water Supplies

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Life on Earth is a water-processing system and humans have found many uses for water to support a technology-based life. With population and standards of living increasing, demand for water is beginning to exceed supply in some places. In a constant climate, long-range plans for meeting this increased demand can be made. In a changing climate, if we do not know the details of the changes, good plans cannot be made.

There are two conceptual difficulties in understanding water supply. The first is that the amount of water in any given local reservoir at any given location is the result of the balance of fluxes in and transports by the whole climate system. Consequently, the availability of water at one location and time is dependent on a global water circulation system in which local variations are affected by distant changes. Hence local water problems may arise from global-scale variations but global variations can be induced by large local changes. The second difficulty is that, in a complex system like the climate, the amount of water in a reservoir does not necessarily behave in an intuitive or simple way: as examples, reducing our demand for water in response to a drought does not necessarily lead to an increase of water in the reservoir or increasing precipitation does not necessarily produce an increase of water in the reservoir either. Moreover, even small changes of the global atmospheric or oceanic circulations can produce local changes in a local reservoir that are not proportional.

The part of the climate water cycle that is most important for people, animals and plants is the net transport of evaporating ocean water by the atmospheric circulation to precipitation over land. However, the net transport of a small amount of water away from the oceans is a consequence of a large energy transfer between the ocean (heated by the sun) and the atmosphere (cooled by thermal radiation to space) and a redistribution of freshwater by the atmospheric and oceanic circulations. The former constitutes the main part of the energy balance of Earth; subtle changes in the latter can affect the ocean biosphere and chemistry. A substantial fraction of the water precipitating onto the land is lost to evaporation and almost all of the net import of water to the land is returned to the ocean by runoff. Between the time water is temporarily stored near the land surface (a smaller part of the water is stored for longer time periods at greater depths) and its eventual return to the ocean, water passes through the biosphere or through other human usages.

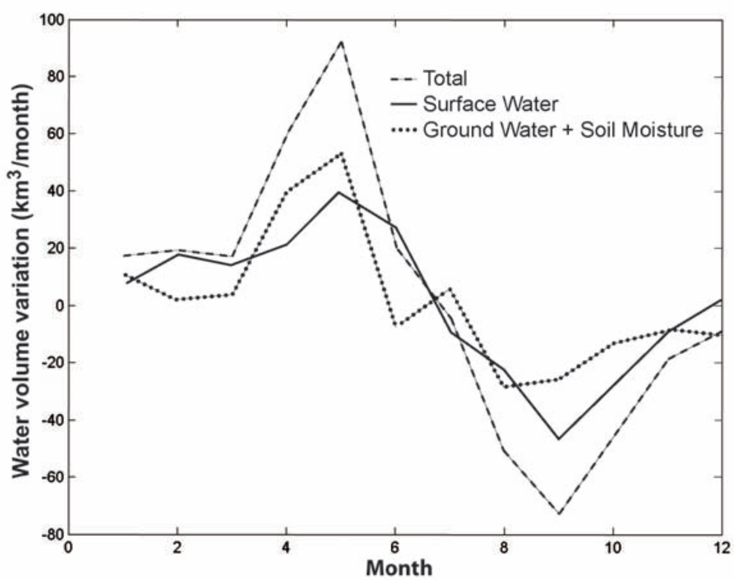
Solar heating of the surface is regulated by clouds; thermal radiative cooling of the atmosphere is regulated by clouds and water vapor. The surface is cooled mostly by evaporation of water vapor into the atmosphere and the atmosphere is heated mostly by precipitation back to the surface. Thus, the water cycle constitutes the main surface-atmosphere exchange of energy. From this description, it is easy to see the many ways in which water-cloud-precipitation processes can alter the heating-cooling that drives the atmospheric and oceanic circulations. All of these processes depend, in turn, on the atmospheric circulation: evaporation rate depends on near-surface windspeed, precipitation rate depends on the speed of vertical motions, transport of water vapor from near the surface to the upper atmosphere depends on smaller-scale convective motions, and water vapor transport from lower to higher latitudes and from ocean to land depends on larger-scale horizontal winds. Consequently there is a grand, multi-path (complex) climate feedback loop between the water cycle and the atmospheric and oceanic circulations that operates on all scales, from weather scales (primarily atmospheric variations over hours to days) through seasonal to decadal scales (oceanic variations).

Changes in greenhouse gas abundances (or other human induced changes of the surface) alter the distribution of heating and cooling within the climate system, so even though the total solar heating of the Earth remains the same, adjustments of the heat exchanges and transports by the atmospheric and oceanic circulations are required to maintain balance. Even over a relatively short period of time, changing greenhouse gas abundances will activate the fast feedback processes involving the water cycle, bringing about changes in local water supplies.

Over the past few decades, with contributions from national weather services and space agencies, as well as from several projects of the World Climate Research Program (GEWEX, the Climate Variability and Predictability Project, the Tropical Ocean Global Atmosphere Project and the World Ocean Circulation Experiment), the development of global, long-term data products and their analysis—as well as general research on atmospheric processes through modelling and field campaigns—has nearly completed the quantitative description of the weather-scale to decadal-scale variations of the atmospheric and oceanic circulations and of the diabatic heating forcing these circulations (radiation heating/cooling, sensible heat exchanges and water phase conversions). These efforts have also better characterized all the processes that affect the exchanges of energy and water in the global climate. There is still much work to do, the completion of which is the main research goal for the next few years. With such detailed observational analyses available, work can also begin in earnest on understanding the fast feedback processes that operate to influence these variations, as well as the early climate response to forcing changes like increasing greenhouse gas abundances.

There are a number of tasks that must be completed, including reprocessing the global observations to improve their detail and accuracy, and employing these observations to verify in much greater detail how our models represent the main processes influencing the circulation and fast feedback processes (water vapor transports, clouds, precipitation, radiation). Currently, the weakest aspects of our understanding of the global water cycle involve smaller-scale convective motions in both the atmosphere and ocean and the precipitation produced by atmospheric storms, especially when both ice and liquid phases are involved. These problems concern the creation and evolution of atmospheric convective storms, especially the mesoscale systems, and of the oceanic downwelling regimes that occur at relatively small scales.

What next? Completion of the quantitative description of the global energy and water cycle and diagnosis of the fast climate feedback processes that influence its variations will enhance our ability not only to explain so-called natural climate variations on decadal time scales but also to predict the changes in water cycle in more detail. However, this only sets the stage for answering our questions about what will happen to water



The annual cycle of total water mass variations in the Rio Negro River Basin from the Gravity Recovery and Climate Experiment (GRACE) mission and the annual cycle of surface water volume changes obtained from the combination of open water extent from a Special Sensor Microwave Imager (SSM/I)-based analysis and water levels from the TOPEX/POSIDEN altimeter—the difference is the soil moisture and deep water storage (Frappart et al., 2008).

supplies. Future research efforts must quantify the partitioning of water among the near-surface systems of the climate freshwater in the ocean and water on land, especially in the rapidly evolving cryosphere. These reservoirs have both fast and slow components that need to be understood to better predict changes in the water supply in a changing climate. This requires development of new capabilities to measure the amounts of water in various reservoirs (after quantifying precipitation and surface evaporation rates).

Continued expansion of the upper-ocean buoy system will increase the detail available on variations of upper ocean characteristics. Adding satellite salinity measurements to surface stress and surface topography measurements already available, along with sea surface temperature and precipitation and evaporation rates, will allow for a more detailed treatment of freshwater changes in the upper ocean. Particular attention needs to be given to coastal regions, especially near melting ice sheets, and to developing methods for detecting downwelling cold, freshwater.

Over land, analysis of combined measurements of many sensors (old and new) can provide measures of soil moisture (correcting for vegetation effects); open water extents (inundation fraction); water levels, which can be combined with the extent variations to provide estimates of river basin discharge, and total water volume changes from gravity anomalies. The figure on page 11 shows the results of an early version of such an analysis for the Rio Negro River Basin, where satellite determination of the total water mass variation over a year is compared with surface water volume changes obtained from the combination of open water extent and water level—the difference is the soil moisture and deep storage (Frappart et al., 2008). In addition, the characterization of the properties and variations of land vegetation have to be expanded to better constrain their role in influencing surface water partitioning (in combination with surface skin temperature diurnal cycles, radiation, precipitation and evaporation rates). Our models of surface water processes need to evolve, too, especially with new observations becoming available. In particular, models are needed that combine the detailed physical landscape aspects of traditional hydrology with the detailed biological aspects of land vegetation to improve representation of the partitioning of water and to capture the response of the biosphere to changes in this partitioning.

As these research tasks are completed and new capabilities developed, more detailed studies and models of human interactions with water supply will be necessary to achieve the goal of translating predictions of climate change in the next few decades into reliable forecasts of water supply changes to allow for planning our response.

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Recent Achievements in Macroscale Hydrological Modelling

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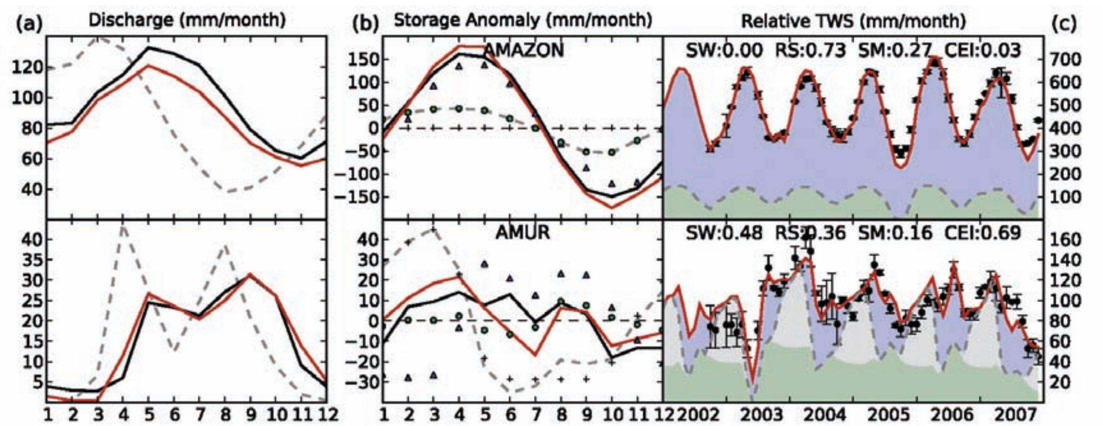
In the early 1990s, during the planning stage of the GEWEX Asian Monsoon Experiment (GAME), the topic of "how to develop macroscale hydrological models" was seriously discussed among Japanese scientists related to land-atmosphere interaction studies. Two approaches for this were identified by this group. The first approach was to expand a conventional microscale rainfall-runoff hydrological model into a macroscale model that could run on the continental scale with a detailed energy balance and vegetation representation. The alternative approach was to enhance hydrological processes in land surface models (LSMs) and couple them with horizontal water flow processes, particularly with river flow.

The river routing scheme, "Total Runoff Integrating Pathways (TRIP)" (Oki and Sud, 1998; Oki et al., 1999), was developed with a global flow direction map. This scheme can be coupled with any LSM, and also used as a post-processor by integrating the runoff estimated by LSMs into river discharge. The first version of TRIP adopted a primitive fixed velocity scheme (Miller et al., 1994). A variable velocity version was later developed (Ngo-Duc et al., 2007). TRIP was coupled with some of the Global Circulation Model (GCM) projections used in the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) to identify the impact of climate change on hydrological cycles (Faloon and Betts, 2006), and there have been some studies of future assessment on the world water resources and global flood disasters utilizing the TRIP model as well (Oki and Kanae, 2006; Hirabayashi and Kanae, 2009). Further, Kim et al. (2009) underscored the importance of river components in terrestrial water storage (TWS) variation over global river basins. To reduce simulation uncertainty, ensemble simulations were performed with multiple precipitation data, and a localized Bayesian model averaging technique was applied to the TRIP simulation.

The figure on page 13 shows that river storage not only explains different portions of total TWS variations, but also plays different roles in different climatic regions. It is the most dominant water storage component in wet basins (e.g., Amazon, Brazil) in terms of amplitude, and it acts as a "buffer" which smoothes the seasonal variation of total TWS especially in snow-dominated basins (e.g., Amur, Russian and China). It signifies that the model simulation of TWS may not be able to properly reproduce the amplitude and seasonal pattern of observed TWS variation by GRACE (the Gravity Recovery And Climate Experiment, see Tapley et al., 2004) without an appropriate representation of river storage component. The dominant role of river storage had already been indicated in a pilot study which compared total TWS changes estimated by the atmospheric water balance method and a GCM simulation coupled with TRIP in the Amazon River Basin (Oki et al., 1996). However, the message was not fully convincing until recent years when satellite-observed GRACE data became available. Using a geodesy approach, Han et al. (2009) em-



(a) Seasonal variations of gauged discharge (black solid line), discharge routed by TRIP (red solid line) and runoff without routing (gray dashed line). (b) Seasonal variations of GRACE observed Terrestrial Water Storage Anomalies (TWSA) (black solid line), simulated TWSA with river storage (red solid line), simulated TWSA without river storage (gray dashed line), and the major water storage components in TWS. Gray crosses (+), green circles, and blue triangles represent the individual storage component of snow water, soil moisture, and river storage, respectively. (c) Interannual variations of relative TWS: the GRACE observation (black dots), simulation with river storage (red solid line), and simulation without river storage (gray dashed line). Each area shaded by blue, gray, and green indicates the portion of river storage, snow water, and soil moisture in the simulated relative TWS, respectively.

ployed a fixed velocity version of TRIP in the Amazon River Basin and its vicinity, and compared the model simulations to the residual of GRACE raw measurements derived from removing all the gravity-influencing factors except for the horizontally moving water. They demonstrated that the optimal flow velocity of TRIP in the Amazon varies between rising and falling water levels.

Macroscale hydrological models have also been developed in response to societal expectations for solving current and future world water issues. There is an increasing demand for information on water resources and the future prediction of these. Conventionally, available freshwater resources are commonly defined as annual runoff estimated by historical river discharge data or water balance calculation (Baumgartner and Reichel, 1975; Korzun, 1978). Such an approach has been used to provide valuable information on the annual freshwater resources in many countries. Atmospheric water balance using the water vapor flux convergence data could alternatively be used to estimate global distribution of runoff owing to the advent of atmospheric reanalysis and data assimilation system (Oki et al., 1995).

Simple analytical water balance models have been widely used to estimate global-scale available freshwater resources in the world since the beginning of this century (Alcamo et al., 2000; Vörösmarty et al., 2000). Later, LSMs were used to simulate global water cycles (Oki et al., 2001; Dirmeyer et al., 2006), and to assess global water resources by estimating the water demand under future climate change scenarios (Shen et al., 2008). Some of those estimations were calibrated by multiplying an empirical factor for the river basins where observed discharge data are available. However, recent model simulations with advanced climate forcing data can estimate global runoff distribution with adequate accuracy without the need for calibration (Hanasaki et al., 2008a).

Several recently developed macroscale hydrological models for water resources assessment also include a reservoir operation scheme (Haddeland et al., 2006; Hanasaki et al., 2006) to simulate the "real" hydrological cycles that are significantly influenced by anthropogenic activities and modified from "natural" hydrological cycles on the global scale in "Anthropocene" (Crutzen, 2002). An integrated water resources model is further coupled with a crop growth submodel, which can simulate the timing and quantity of irrigation requirement, and a submodel, which can estimate environmental flow requirement (Hanasaki et al., 2008a). Such an approach is able to assess the balances of water demand and supply on a daily time scale. A gap in the subannual distribution of water availability and water use can be detected in the Sahel, the Asian monsoon region and southern Africa, where conventional water scarcity indices such as the ratio of annual water withdrawal to water availability and available annual water resources per capita (Falkenmark and Rockström, 2004) can not properly detect the stringent balance between demand and supply (Hanasaki et al., 2008b).

Numerical models can be associated with a scheme tracing the origin and flow path as if tracing the isotopic ratio of water (Yoshimura et al., 2004). Such a flow tracing function of water in the integrated water resources model (Hanasaki et al., 2008a) with the consideration on the sources of water withdrawal from stream flow, medium-size reservoirs and nonrenewable groundwater in addition to precipitation to croplands enabled the assessment of the origin of water producing major crops (Hanasaki et al., 2009). See figure at the top of page 16. Areas highly dependent on nonrenewable groundwater are detected in the Pakistan, Bangladesh, western part of India, north and western parts of China, some regions in the Arabian Peninsula and the western part of the United States through Mexico. Cumulative nonrenewable groundwater withdrawals estimated by the model are corresponding fairly well with the country statistics of total groundwater withdrawals, and such an integrated model has the ability to quantify the global virtual water flow (Allan, 1998; Oki and Kanae, 2004) or "water footprint" (Hoekstra and Chapagain, 2007) through major crop consumption (Hanasaki et al., 2009).

It seems that these achievements illustrate how the framework of global offline simulation of land surface models coupled with lateral river flow model and/or anthropogenic activities, driven by best estimates of meteorological "forcing" data, such as precipitation and downward radiation, is relevant for estimating global energy and water cycles, validating the estimates and sometimes the quality of "forcing" data with independent observations, and improving the models. There are attempts to utilize this framework for assessing the impacts of climate change on future hydrological cycles, which would demand adaptation measures in water resources management, flood management and food production. For such purposes, it is necessary to develop reliable "forcing" data for the future based on GCM projections probably with bias corrections and spatial and temporal downscaling, as well as developing best estimates for the future boundary conditions for hydrological simulations such as vegetation type and land use/land cover. It should be also examined how much the framework can be applied to finer spatial and temporal scales, such as 1-km grid spacing and hourly simulations. For such researches, observational data from regional studies provide significant information, and efforts to integrate data sets from various regional studies should be promoted. It is for sure that cooperation among Global Environmental Change Programs under ICSU, including WCRP, is and will be accelerating the macro-scale hydrological studies effectively.

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(please see http://gewex.org/gewex_nwsltr.html for complete listing)

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Meeting/Workshop Reports

Third Meeting of the International Soil Moisture Working Group (ISMWG)

Lisbon, Portugal
10–11 March 2009

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The primary focus of the meeting, which was hosted by the Institute of Meteorology in Lisbon, Portugal, was to review the reorganization of the working group, which was recently placed under the umbrella of the GEWEX Radiation Panel (GRP). In addition, the status of current activities was reviewed and plans for near-future activities discussed. A three-tiered structure for the ISMWG was proposed to better address the GRP requirements:

1. Validation, with a main focus on the development of a global *in situ* soil moisture network and data sets to support validation of satellite soil moisture retrieval and assimilation, as well as the validation of satellite soil moisture products and soil moisture intercomparison projects.
2. Assimilation, with a main focus on the assimilation of soil moisture and satellite data (both active and passive) into numerical weather prediction and hydrological modelling for both forecasting and process studies.
3. Product fusion and merging, with a main focus on the development of long-term consistent global soil moisture products (and their derivatives).

The new structure will also address the ISMWG responsibilities for the Group on Earth Observations (GEO) and the Global Terrestrial Network–Hydrology (GTN-H). Volunteers are being sought for each of the three tiers. If you are interested, please send an email to *gewex@gewex.org*.

In 2007, with the support of the European Space Agency (ESA) through the Soil Moisture and Ocean Salinity (SMOS) mission project, an initiative was approved and money allocated to start a data-hosting center. It is hoped that in 2009 this data-hosting center will kick off to support the soil moisture data collection activities.

As a first start the Institute of Photogrammetry and Remote Sensing of the Technical University of Vienna along with the International GEWEX Project Office and with support from GEWEX Coordinated Energy and Water Cycle Observations Project (CEOP) will start with developing and consequently sending out a questionaire to all those who run soil moisture measurement network sites.

During the meeting, presentations on the various soil moisture *in situ* measurement sites, as well as the soil moisture estimates from space and soil moisture applications, were covered. More information about ISMWG, as well as the presentations given at this meeting, can be found at: *http://gewex.org/ismwg_3rdmeeting.html*.

5th World Water Forum

Istanbul, Turkey
16–22 March 2009

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An estimated 33,000 people participated in broad discussions on water at the 5th World Water Forum (WWF). The Forum is held every 3 years and brings together international experts with interests in all aspects of water. The theme of this Forum was "Bridging Divides for Water," a goal that was symbolized by holding sessions at venues on both sides of the Galata bridge that crosses the Golden Horn. In order to address the broad range of concerns and interests in water, the program was broken down into themes and regional discussions.

The theme presentations of most interest to the GEWEX community included: Theme 1 – Global Changes and Risk Management; Theme 3 – Managing and Protecting Water Resources and their Supply Systems to Meet Human and Environmental Needs; and Theme 6 – Education, Knowledge and Capacity Development. Theme 1 dealt with issues related to the GEWEX Extremes activity while Theme 6 dealt with data issues of concern to the World Climate Research Programme, the World Meteorological Organization (WMO) and the Group on Earth Observations (GEO). Regional presentations were useful for providing an overview of water problems in each geographical area. Those wishing to get more information about these needs can access the regional and theme summaries at *http://content.worldwaterforum5.org/files/*.

The program also featured a number of side events, including some training sessions, a science fair and a large number of impressive technical exhibits by countries, regional projects, publishers and engineering firms. My primary involvement with this WWF came through a GEO side event organized by Dr. Douglas Cripe of the GEO Secretariat. This session, entitled "Virtual Constellation for Water," featured presentations and discussions on different aspects of GEO as well as a talk on the use of altimetry to estimate water levels and flows. Although the number of attendees was smaller than had been hoped for due in part to a conflict with a popular WMO session on data, those who attended were enthusiastic about the potential benefits of Earth Observations in the water sector. More details on the session are available on the GEO website at *http://www.earthobservations.org/*.

András Szöllösy-Nagy, UN Educational, Scientific and Cultural Organization (UNESCO) is shown holding the Third World Water Development Report, which outlines actions to address future water challenges.

Other side events of interest to the GEWEX community included a special event to mark the launch of the second phase of the Terrestrial Initiative in Global Environment Research (TIGER), a European Space Agency sponsored capacity-building effort in Africa, and a training event sponsored by the Arab Water Council with considerable National Aeronautics and Space Administration (NASA) involvement on "How to Use Remote Sensing for Improved Water Management."

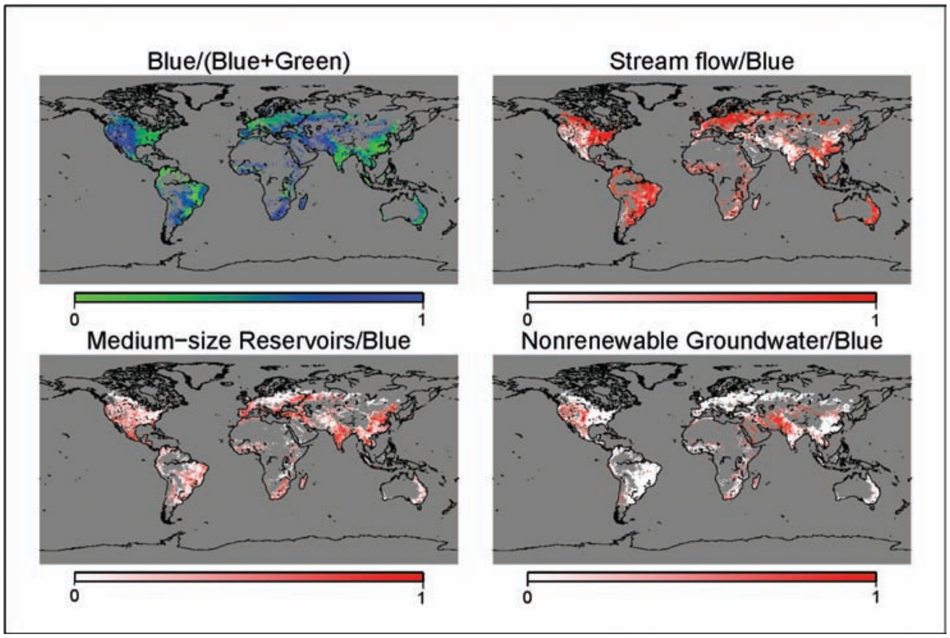
The WMO exhibit focused on the hydrological aspects of its program. The United Nation (UN) was very active at the WWF and all its agencies dealing with water related interests, including UN Water itself, had exhibits. One of the UN highlights was a special event to mark the release of the latest World Water Development Report. The report can be downloaded at *http://www.unesco.org/water/wwap* or purchased at *http://www.earthscan.co.uk/?tabid=74799*.

Since this is the third WWF that I have had an opportunity to attend, I am taking the liberty of making a few remarks about trends in these events. On the positive side, it is clear that the WWF events are generating increasing interest by members of national governments. For example, there was a ministerial conference held concurrently with the main forum events (although it was not on the conference site), with substantial interaction between the ministerial and the technical events. In addition, the Forum has grown so that it now provides an excellent means of meeting people with different perspectives on water, a place for obtaining a very concentrated update on the latest water issues and new programs, and an excellent audience for distributing information about science programs such as GEWEX and GEO.

On the negative side, it is evident that difficulties in mobilizing action on water issues remain. For example, one issue that was raised frequently, especially in the regional themes of Africa and the Arab Water Council, related to "water as a human right" has not yet received a clear response from governments. At a more practical level, another negative trend was the decrease in the number of physical scientists that have engaged with this process in more recent years. For example, 6 years ago at the 3rd WWF in Kyoto, the discussions on climate change and disasters were led by the academic sector. At this forum the agendas of the events seemed to be heavily managed by the government sector.

In summary, the resource materials provided through the presentations, handouts and summaries provided at the WWF provided a good overview of the state of programs aimed at managing water resources around the world. The experience of trying to inform this community of the benefits of Earth observations through a side event and handouts provided glimpses of "what might be" although we did not reach our full potential in this area. In the future more could be accomplished with a larger and more focused effort, stronger links to the main WWF program, and more advance planning.

Origin of Water Assessments in Producing Major Crops is Now Feasible



The top left panel illustrates the ratio of blue water to total evapotranspiration during a cropping period in irrigated croplands. The "blue" water is defined as that part of evapotranspiration originating from irrigation, whereas the "green" water is from precipitation (see Falkenmark and Rockström, 2004). This panel also shows a distinctive geographical distribution in the dependence on blue water. The ratios of the source of blue water for stream flow include the influence of large reservoirs (top right panel), medium-size reservoirs (bottom left panel) and nonrenewable groundwater (bottom right panel). See article by T. Oki, et al. on page 12.

GEWEX/WCRP Meetings Calendar

For a complete listing of meetings, see the GEWEX web site: http://www.gewex.org

25–28 May 2009—International Conference on Climate Change: The Environmental and Socio-economic Response in the Southern Baltic Region—Szczecin, Poland.

10–12 June 2009—EarthCARE Workshop—Kyoto, Japan.

15–19 June 2009—AGU Chapman Conference on Abrupt Climate Change—Columbus, Ohio, USA.

22–24 June 2009—NASA Earth System Science at 20: Accomplishments, Plans, and Challenges—NAS, Washington, DC, USA

22–24 June 2009—GEWEX/Global Land/Atmosphere System Study (GLASS)/QUEST Workshop—Exeter, United Kingdom.

26–27 June 2009—GEWEX Atmospheric Boundary Layer Study (GABLS) Workshop—Boulder, Colorado, USA.

5–10 July 2009—2009 Gordon Research Conference on Radiation and Climate—New London, New Hampshire, USA.

13–15 July 2009—WCRP/WWRP-THORPEX Year of Tropical Convection ImplementationWorkshop—Honolulu, Hawaii, USA.

19–29 July 2009—IAMAS/IAPSO/IACS 2009 Joint Assembly (MOCA-09) on Our Warming Planet—Montreal, Canada.

20–24 July 2009—3rd International AMMA Conference—Ouagadougou, Burkina Faso.

16–22 August 2009—2009 World Water Week in Stockholm—Stockholm, Sweden.

19–21 August 2009—Third GEWEX Coordinated Energy and Water Cycle Observations Project (CEOP) Meeting—Melbourne, Australia.

20–22 August 2009—iLEAPS/GEWEX Early Career Scientists Workshop—Melbourne, Australia.

22 August 2009—GEWEX/Global Land/Atmosphere System Study (GLASS) Meeting—Melbourne, Australia.

23 August 2009—GEWEX/iLEAPS Workshop on Landflux—Melbourne, Australia.

24–28 August 2009—6th Int'l Scientific Conference on the Global Energy and Water Cycle and 2nd iLEAPS Science Conference—Melbourne, Australia.

9–15 September 2009—International Workshop on the Northern Eurasia Mountain Ecosystems and Regional (High Elevations) NEESPI Science Team Workshop—Bishkek, Kyrgyz Republic.

16–18 September 2009—GEWEX/GRP Working Group on Data Management and Analysis—College Park, Maryland, USA.

22–25 September 2009—Milutin Milankovitch Anniversary Symposium: Climate Change at the Eve of the Second Decade of the Century. Inferences from Paleoclimate, and Regional Aspects (sponsored by GEWEX)—Belgrade, Serbia *(http://www.sanu.ac.rs/English/Milankovic2009/Milankovic.aspx)*.

24–28 September 2009—13th Session of the Working Group on Coupled Modelling—San Francisco, California, USA.

13–16 October 2009—GEWEX Radiation Panel Meeting—Bonn, Germany.

3–7 November 2009—24th Session of the Working Group on Numerical Experimentation (WGNE) to be held with the 10th Session of the GEWEX Modelling and Prediction Panel (GMPP)—Montreal, Canada.

9–12 November 2009—ECMWF/GLASS Workshop on Land Surface Modelling and Data Assimilation and the Implications for Predictability—ECMWF, Shinfield Park, Reading, United Kingdom

18–20 November 2009—ESA/EGU/ISPRS/GEWEX Conference on Earth Observation and Water Cycle Science: Towards a Water Cycle Multi-Mission Observation Strategy—ESRIN, Frascati, Italy *(http://www.congrex.nl/09C16/)*.