NASA VISION QUEST
2010-2025: LONG-TERM CLIMATE

WHAT IS THE FUTURE OF WATER RESOURCES, IN THE U. S. AND THE WORLD?

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Abstract – Water resources in the United States and the world in general are coming under increasing pressure as population rises, and industrial needs increase. In addition, the likelihood of substantial future climate change will likely compound the problem by leading to substantial changes in water availability. Our ability to provide global observations of the hydrologic cycle on a regional scale is quite poor, and our ability to predict likely water changes due to climate warming is practically non-existent. Given the global aspects of the problem, NASA should take the lead in improving our observing and forecasting capability.

I. WATER RESOURCES AND SOCIETAL FUNCTIONS AT RISK

The world's water resources are currently undergoing increasing stress as population grows and industrial demands increase. Population pressures are already causing water problems in countries such as Algeria, Kenya, Rwanda, Tunisia, and many in the Middle East. It is estimated that future population growth will cause water problems in additional countries such as Egypt, South Africa, Iran, Somalia and Ethiopia, among others. Water problems have been evident for some time in the southwest and western states in the U.S., but now they are appearing in normally moist regions such as Florida, Alabama and Georgia, again due to increasing demand. Water may well be the limiting factor to growth in many regions as the century progresses.

The forecast climate change for this century will likely intensify these problems and create others. Societies have normally adapted in a somewhat optimal fashion to available water, through demographics, commerce, treaties and a whole host of intangible customs. The prospective warming may well be so large and rapid as to disrupt many of these practices, with widespread consequences for the local regions affected, and the world. Environmental refugees have already been created by droughts in Africa and Asia, provoking conflict and terrorism in countries unable to handle their influx, with obvious global consequences.

A warmer world is likely to have a much more variable hydrologic cycle – when it rains it will rain harder; where it is not raining, it will be hotter, with more evaporation, amplifying drought conditions. The impact will be especially hard on third world countries, where studies have shown agriculture is at risk. The current melting of mountain glaciers, a water resource during summer, is already affecting a region of some 500 million people, most importantly Pakistan. As we have seen, the United States is not immune from disruptions in this part of the world.

Drought scenes like this from Afghanistan may become more common as climate warms and the hydrologic cycle changes.

Even in the U.S., water allocation disagreements are occurring throughout the country, between regions, and between farmers, cities and the environment. A likely reduction in snowfall will limit the natural reservoir of snowmelt in spring, of great importance for portions of the western U.S. Amplification of the hydrologic cycle will mean more intense floods in overpopulated floodplains; an increase has already been seen in the intensity of rainfall events in this country. Hotter conditions will mean greater energy and water demands during summer, when energy use normally maximizes. An example of the entwined nature of the issue occurred during the summer of 1988, when drought in the northern United States resulted in complete loss of the waste water used to remove heat from power plants – and plants had to shut down entirely, just when the energy for air conditioning was most needed. A warmer climate and water stress will mean increased health risk in an aging population.

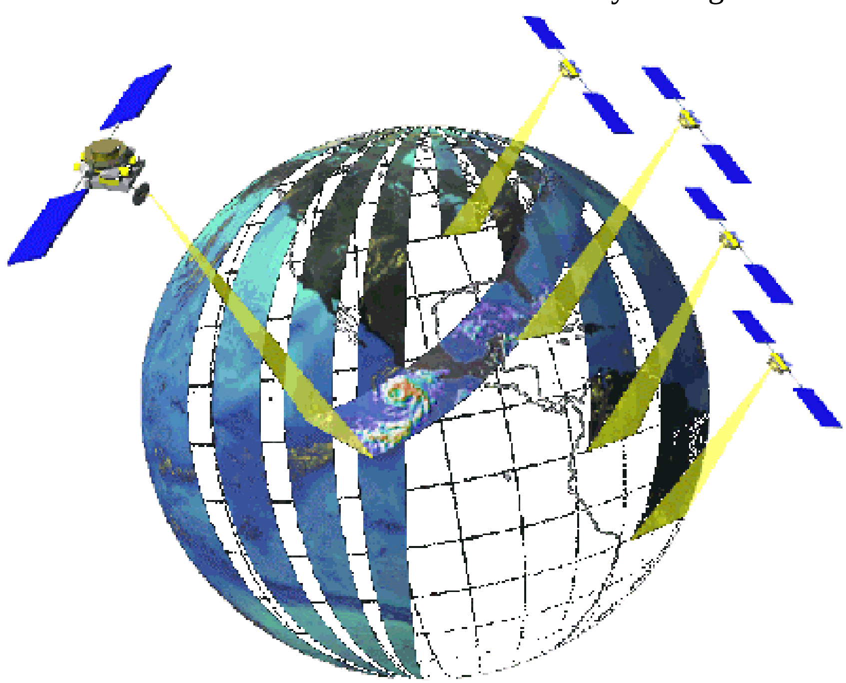
II. OUR ABILITY TO PREDICT SPECIFIC CHANGES IS POOR

Ideally, we would be able to predict the potential climate change impacts on water availability, added to projections of water usage associated with expected population changes. However, outside of the few likely differences already noted, our ability to specify whether water will increase or decrease in specific regions is nonexistent. Climate models (GCMs) differ in their forecasts of regional water availability changes. GCMs also produce inconsistent changes compared with the "climate impact" models used to evaluate regional affects (e.g., climate models find little increase in water stress in the tropics, while impact models show maximum increase there). For the U.S. there is no consistency even in predictions of whether the eastern portion of the country will get wetter or drier. This lack of ability to forecast water changes with confidence limits the possibility of the long-term planning needed to mitigate them, and also inhibits sensible calculations of cost/benefit ratios used to determine what we should do now to reduce climate change.

III. THE NASA ROLE IS OF GLOBAL IMPORTANCE

The problem of water resources, even on a regional level, is really a global problem. The hydrologic cycle is globally connected: we see that warming of a few degrees in the tropical east Pacific Ocean during El Nino events can have large consequences for precipitation in California and the rest of the United States. Furthermore, climate change impacts are global; climate-induced changes in wheat production in Argentina and Russia will affect wheat prices obtained by U.S. farmers. As noted above, water resource changes are a potential source of global geopolitical instabilities. Remote sensing is needed to provide the relevant global hydrologic observations.

NASA's observations are and will be used to provide better knowledge of the current hydrologic state and its variability, as well as to help in understanding the processes. For example, the Global Precipitation Mission (GPM) and the Gravity Recovery and Climate Experiment (GRACE) will contribute to this effort.



GPM will be a constellation-type mission involving a fleet of several satellites; instrumentation includes a multi-channel polarized passive microwave radiometer and a radar system for measuring rainfall.

NASA's observations would be used to improve climate models so as to help in the predictions of future water availability being made with NASA's Global Climate Model and other models. Our lack of understanding of current conditions on a regional scale inhibits our understanding of the proper physics, leading to divergent choices among modeling groups, and divergent predictions. With continuing global observations, we could assess progress in prediction capability through comparison of forecast and observed trends.

IV. WHAT NASA NEEDS TO DO

A. Observations

Water availability changes are a very practical matter, and as such cannot be the exclusive province of researchers; the observations that are most needed must be decided upon in active communication with water managers, who therefore have to be explicitly involved in the process. The most useful observations may be scale-dependent, with different quantities needed on the watershed, ecosystem and field scale. We already know that precipitation is a challenging retrieval on a regional scale, and should continue to receive high priority. Soil moisture down to rooting depth is the needed quantity for practical use and models, but it is currently unavailable. Ground wetness to 10 cm depth is obtained through microwave observations, but the deeper in-ground retrievals require longer wavelengths that conflict with radio frequencies and require bigger antennae, among other problems. It may never be obtainable, hence the need to focus on truly quantifiable criteria. Evaporation over broad scales is a calculated quantity that requires near-surface observations, a goal for remote sensing, but again not readily retrievable currently. Runoff, in the form of streamflow, is monitored in many regions but not everywhere.

This brief assessment also emphasizes that a surface network is a necessary component of any serious attempt to improve our hydrological understanding. A recent WMO document[1] describes plans for such a network. Ideally NASA would cooperate in this venture, supplying the remote sensing components which can help in area averaging; the surface network could help in validation of NASA retrievals. In combination with such a network, NASA could help establish a "Supersite" at one location, to be used to assess the sensitivity of needed observations and define the required processes on the relevant scales. The goal would be to be in position by 2010 to prioritize measurements and scale-sizes for both ground-based and remote sensors.

Whatever observations are decided upon, it is mandatory that they be maintained over the long-term (decades). They will be used for monitoring changes as well as improving models, and so must be continued sufficiently long to observe trends for comparisons with model predictions. While monitoring is less glamorous than exploring new research technologies, the two can go together, as improved observing techniques are allowed to overlap with the previous technology so as to maintain a continually calibrated record.

B. Models

Precipitation is associated with rising motion, and hence atmospheric dynamics that responds to gradients in temperature. During winter months in the extratropics it is associated with storm systems, which gain their energy and have their path influenced by such temperature gradients. Evaporation is associated with the absolute temperature and wind. Therefore, it is impossible to produce better predictions of the hydrologic cycle change without improved prediction of future changes in temperature and temperature gradients. The prime goal for future models is to provide better assessments of such quantities. Since that encompasses the whole spectrum of model processes, it emphasizes the need to put resources into climate models in general, not just their hydrologic component. Model computations must be made on the scales at which hydrologic processes function, which requires finer horizontal resolution than that currently employed for climate change projections.

The land surface parameterizations help partition rainfall changes into evaporation and runoff, leading to altered water availability. To improve these models requires defining the relevant physiognomic units and properties on the various scales that must be included to make models more realistic. Global data bases of these relevant land characteristics, including the human influence on the land surface, must be prepared. This too will require working with experts 'on the ground' in various countries; NASA's involvement would then be not only global but international.

Continual comparisons between observed and modeled trends should allow us to evaluate how different models are doing, and learn which are most successful, and why. This will provide confidence for future assessments, something which is now totally lacking[2].

V. THE BENEFITS OF NASA RESEARCH

Such research would have many practical benefits, likely paying for itself many times over. Better observations would help improve our understanding of the current hydrologic cycle and water availability, of great importance today given the growing societal pressures already in evidence. They would help improve our water management, including long-term planning (e.g., reservoir storage, water transfer or treatment facilities), and floodplain management. Better forecasts of future hydrologic changes would help us understand the geopolitical implications of climate change, and the likely consequences. And for this and other, more local reasons (what will happen in the U.S., and when) they would allow for more accurate assessments of the economic benefits of various policy options relative to the costs. Both increased population and climate change are likely to be dominant characteristics in the 21st century, and the corresponding water availability changes may well be the biggest issue we face.

VI. RELATION TO OTHER NASA VISION QUEST TOPICS

The long-term climate change research proposed here is highly synergistic with the other NASA vision quest research topics. Sea level rise will affect water quality and ecosystem health. Improved understanding of tropical storm processes will help in forecasting how hurricane frequency and intensity will change in the future, affecting water availability especially along the U.S. east coast. Better understanding of sub-seasonal weather predictors that affect water availability today, will allow for better forecasts of their future effects. And water availability changes will have important consequences for ecosystems and biodiversity. Water is the unifying element for many aspects of society, and its future availability is the most important result long-term climate change research could provide.

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