UNDERSTANDING THE TRIPLE POINT

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A column called "Triple Point" is an apt venue for an essay on some of the biggest challenges in geosciences research today. The triple point of water is the intersection of the stability fields of vapor, solid, and liquid water, and understanding the processes governing the distribution, transport, and storage of water in all its forms is one of the most compelling research challenges facing our community. The extent to which the water cycle varies in space and time is inextricably linked to other parts of the climate system, as well as to land- and water-use decisions. Hence, the confluence of three divariant fields at the triple point is a powerful reminder of the nexus of water-cycle research, climate-change prediction, and the healthful sustainability of the human environment.

Consider, for a moment, the dilemmas of our generation: the world's population has doubled to over 6.5 billion in the last century; water use has accelerated about six fold over the same time frame; our climate is undoubtedly changing, although regional- and decadal-scale changes remain uncertain; and—a sobering reality—human impact now rivals natural processes in affecting mass transfer at the Earth's surface. The flip side of these changes is the increasing demand for more precise prediction of water sustainability, ecosystem and soil quality, and human hazards (e.g. floods) on a regional scale and at human time frames. Is our community poised to make precise predictions about the response of the water cycle to our changing environment? Are our predictions sufficiently reliable to guide policies and plans for society?

> "The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights."
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> —U.N. Committee on Economic, Social and Cultural Rights

So, yes, there are reasons for concern and urgency. The great majority of today's active geoscientists were trained to be specialists and reductionists. We break down complex systems into fundamental component parts and we understand them at that level, and then we understand the whole by probing the summative interactions of the component parts. Traditional disciplinary field boundaries have developed in the science of the component parts. In the case of water, for example, meteorologists focus their attention on atmospheric phenomena affecting precipitation; hydrologists study water sources and transport on and beneath the ground; soil scientists focus on the reaction of water with weathered rocks; biogeochemists and ecologists worry about the coupled cycles of water, organic components, and nutrients; sedimentologists track water transport and deposition of soil and sediment particles; and geomorphologists are primarily concerned with the sculpturing of landscapes by water. Programs at research institutions have generally mirrored this intellectual alignment, and funding agencies have provided support for understanding the core science. This approach has served us well in the past and will continue to be the foundation of important discoveries in the future. But large-scale issues need a sophisticated understanding of the non-linearly interacting parts. The difficulty of upscaling behavior and properties known at smaller scales has challenged traditional reductionist approaches, and we are only beginning to recognize the full complexity and emergent properties of larger Earth systems (e.g. large watersheds, regional basins).

The Earth's surface is complex and dynamic, and a holistic understanding of its interacting parts is required if we are to make precise predictions of future water balance in any region of the world, under scenarios of changing climate and land use. This paradigm shift requires new tools and approaches, and regional-scale observatories and modeling of the coupled climate–water cycle at a compatible scale are at the core of the needed approach.

We must continue to make observations at many temporal and spatial scales to help drive our emerging theoretical understanding. Regional observatories focused on water balance and cycles are examples of an emerging large-scale observatory approach supported by the National Science Foundation of the U.S.A. For example, Earthscope is a downward-looking observatory that assesses surface movement and stress release at the subcontinental scale. Both the Ocean Observatory Initiative (OOI) and the National Ecological Observatory Network (NEON) will likewise be deploying cyber-accessible, interactive, remote systems to observe interconnected processes in the Earth's ocean and terrestrial ecosystems, respectively. We use the word "telepresence" to indicate that such systems are here for all, and, in building these observing systems, we are accelerating our journey from sampling science to network science.

Terrestrial observatories (e.g. NSF-funded critical zone observatories and WATERS test beds) are in their infancy, but they are critical testing grounds for the development and deployment of new observational methods to predict coupled atmosphere–land processes and water balance in terrestrial environments at watershed-to-regional scales. These observatories are platforms for studying the fundamental water and surface processes in real time (i.e. hours, seasons, years, decades), and they are designed to uncover both long-term trends and abrupt or extreme events. They will complement time-continuous remote observations that are already in place, as well as the observations of ecological processes that will be the focus of NEON. The deployment of such observation systems is also designed to study interconnected processes (atmosphere, hydrosphere, biosphere, pedosphere), and this will feed much-needed data to validate and constrain coupled, regional models of climate and the water cycle. Terrestrial observatories are purposely networked at the national scale in order to aid in understanding regional, continental, and global patterns. Hence, the key output of terrestrial observatories is a fundamental understanding of the interlinked parts: regional climate; spatial and temporal patterns of precipitation distribution; and the partitioning of precipitation among runoff, evapotranspiration, soil moisture, and groundwater recharge. This partitioning is specific to the regional landscape, ecology, soil lithology, development and land use, season, prior soil saturation, and the time–space heterogeneity of the precipitation events. This is important, challenging science.

Large-scale terrestrial observatories are unlikely to be a panacea for our current limitations in predicting the complex response of the water cycle to climate change and land- and water-use decisions. At the very least, however, they will be a major step towards understanding the improvements needed in our predictive capabilities and towards the development of strategies to reduce predictive-model uncertainties. Region-specific models and mechanistic generalizations derived from such models will be our main tools for predictions that need to be made at the scales required to inform policy and water-resource-management decisions. Ralph Waldo Emerson said: "Nothing great has ever been accomplished without enthusiasm." We are going to need all our collective enthusiasm to succeed in solving these tough scientific challenges.

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