A New GHP/GLASS Crosscutting Project: Human Regulation of the Water Cycle (HRWC)

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The continental water cycle is not only governed by climate and its fluctuations, but also by human activities intended to maximize water resources for mankind's benefit. For instance, it is estimated that dams control 48% of the world's rivers and that these reservoirs store about 7000 km^3 of water on the continents (Hanasaki et al., 2006). The majority of dams provide water for agriculture to increase crop yields. Not only are societies regulating and altering the water flows at the surface, but they are also extracting groundwater in many regions at unsustainable levels. It is a major challenge for society to ensure sustained water availability for human activities in a changing climate. Thus, if it is the ambition of GEWEX and the World Climate Research Programme to address the Grand Challenge of Water for the Food Baskets of the World, then human interventions into the water cycle on the continents need to be explicitly taken into account in these studies.

To develop a strategy towards this aim, the GEWEX Hydroclimatology Panel (GHP) and the Global Land/Atmosphere System Study (GLASS) Panel organized a workshop from 28–30 September 2016 in Gif-sur-Yvette, France on the campus of the University Paris-Saclay and the Centre National de la Recherche Scientifique. The overall objective of the workshop was to establish a strategy that addresses the various aspects of human activities within the GEWEX program, centering on a crosscutting study that combines the modeling activities of GLASS and the regional expertise of GHP. The workshop discussions were structured by invited talks and proposed contributions.

Representation of the Flow Regime Downstream of a Dam or Reservoir

The discussions on the first day were centered on available observations and those needed to better understand key processes. The most common variables observed are river discharge and flow regimes, or extremes (high and low flow conditions) described by time series that can be extracted from a hydrograph. Observed river discharge accounts for human impacts, including water abstractions and intakes (see Figure 1). Information on naturalized flow conditions (i.e., streamflows from which manageable and quantifiable human influences have been removed) is generally not available. Some exceptions to this are measurements from very small undisturbed rivers.

Rules characterizing reservoir operation schemes are essential to the representation of the flow regime downstream of a reservoir or dam, but are only available for a few large dams. Global Hydrological Models (GHMs) make use of generic operation schemes derived either from observations of inflow and outflow of a reservoir (or dam) or from existing rules. Information on water rights and water allocation (priorities) are difficult to collect and implement in models. To express water demand, data on sectorial water abstraction (i.e., potential demand) is needed but difficult to obtain. Even fewer data exist on actual water consumption for different sectors. Information on inter-basin transfers, water use efficiencies of irrigation or return flows is very limited and often only accessible in an indirect way. The discussion also tried to establish how well human water regulation could be observed from space. In principle the reservoir levels, irrigation areas and periods should be observable, but it could not be established how far this information can be estimated reliably and made available systematically at the global scale with current or planned satellite missions.

Anthropogenic Influences on the Water Cycle

The human processes that need to be observed and understood in more detail are those directly affected by climate or that will be unsustainable in the future. The understanding of the water cycle gained within GEWEX should inform societies on how the water available in the food baskets of the world will evolve. Thus, water consumption and withdrawals for irrigation need to be differentiated between sources like surface water or groundwater. Reservoir management for agricultural production, as well as hydropower, needs to be better understood to create simulations of river discharge and predict the propagation of anomalies. The observations should also cover correlated processes, such as land use and/or land cover changes and urbanization. As socio-economic processes are the main drivers, links need to be established within these communities for process understanding and validation.

The current state of water management in land-surface models (LSMs) is relatively nascent (Nazemi and Wheater, 2015a,b). Irrigation is generally based on water stress thresholds that are easy to implement but likely are not very realistic since they lack the human control element and do not satisfy water conservation. Attempts at modeling groundwater have been done by extending model soil depths vertically, but this neglects lateral subsurface flow processes and hydrogeology. More LSMs are coupled to river routing schemes, but relatively few model dams and storage reservoirs. Some groups have made estimates of anthropogenic water with satellite-based computations of evaporation, or by assimilating satellite leaf area index (LAI), soil moisture or total column water to try and constrain anthropogenic water use at large scales. However, assimilating observations related to human processes that are not simulated may help in numerical weather forecasting but will be problematic for climate change simulations.

Improving Anthropogenic Hydrological Processes in LSMs

Moving forward, what are the main issues and challenges for improving anthropogenic hydrological processes in LSMs? Great care must be taken since there is a danger of includ-

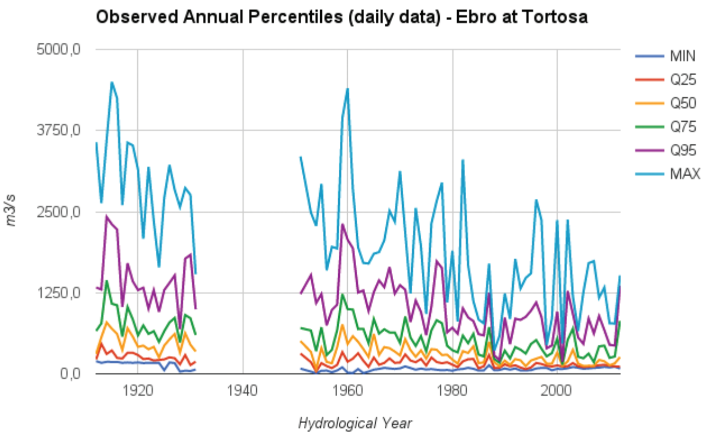

Figure 1. Evolution over the last century of the annual percentiles of discharge at the Tortosa Station in the Ebro River in Northern Spain. This figure is based on river flow data from the Spanish Ministry of Agriculture, Fisheries, Food and the Environment (MAPAMA). Quintana Seguí, personal communication.

ing processes that are under-constrained. This would lead to over-fitted parameterizations, which would have erroneous sensitivities or miss some feedbacks. One of the main issues is estimating water demand. Some LSMs use a simple estimation for water demand, however the most promising way forward is likely to be based upon projecting water demands and allocations using generic hydro-economic modeling. This consists of separate calculations of water exchange value and use value (i.e., the impact of water use) and then the separation of these into different needs (irrigation, hydropower, municipal uses and ecological flows). Such approaches are designed to be globally applicable; however, they are limited by available data and their complexity, which makes their general use by LSMs more difficult. Access to governing rules of centralized water management, water rights, reservoir release, environmental flow regime and river and ground water extractions (which is extremely heterogeneous and depends on local regulations) is essential. In some cases, water managers do not follow pre-established rules rigorously, which makes the problem even more difficult. Even if the data is public, the information is often hard to access by nonlocal scientists, due to language and cultural barriers, or badly designed data sharing mechanisms. Water demand, withdrawal and actual use are often treated synonymously, but are clearly very different. As this is an interdisciplinary endeavor, terminological and conceptual differences among the different scientific communities involved can also hinder progress. Nevertheless, some very promising approaches from the hydro-economic community were presented at the workshop and thus strong collaborations need to be established.

Improved modeling of anthropization in LSMs is theorized to induce potential feedbacks owing to human interventions. Using an offline-modeling system with irrigation, researchers have simulated the long-term reduction in the volume of the Aral Sea and showed that future projections can be made on the expected desiccation of this natural reservoir. An example from a recent coupled modeling study over the central U.S. showed that precipitation is enhanced downstream of irrigated areas and demonstrated how regional scale low-level circulation patterns could be modified (Huber et al., 2014). Other potential irrigation feedbacks included increased evapotranspiration (ET) in the irrigated crop tiles of LSMs, which sometimes leads to overall ET decrease in grid cells due to atmospheric feedback through increased humidity on other tiles. Convection can occur upstream of irrigated areas near the dry/wet soil boundary triggered by sea breeze type phenomena (Figure 2, Sato et al., 2007; Kawase et al., 2008); thus the effect is not necessarily just local, and can mitigate or dampen local and regional heat extremes. It is therefore important to encourage the GEWEX community to explore these feedbacks and how they affect our ability to predict weather and climate.

Quantifying Water Resources

In the workshop's final discussions, it was concluded that GEWEX should take on the scientific challenge of better quantifying water resources available for agriculture and other activities by accounting for explicitly human intervention in our geophysical view of the water cycle. The topic needing most urgent attention is the human regulation of the water cycle. Driven by climate potentials, water is stored in reservoirs, and governed by agronomic needs it is adducted to irrigate areas. When the climate does not allow this, water is pumped from deep aquifers of which the characteristics are often not fully known. As these are significant perturbations to the continental waters, it was proposed that human water regulation be prioritized in our research and that the notion of water value be progressively integrated into our approach.

Potential Study Regions

Semi-arid climates are of the greatest interest as their low climatic potential is most critical for human activities. Depending upon the local characteristics of the water cycle and the socio-economic conditions, very different solutions may be implemented for water regulation, offering a wide range of situations

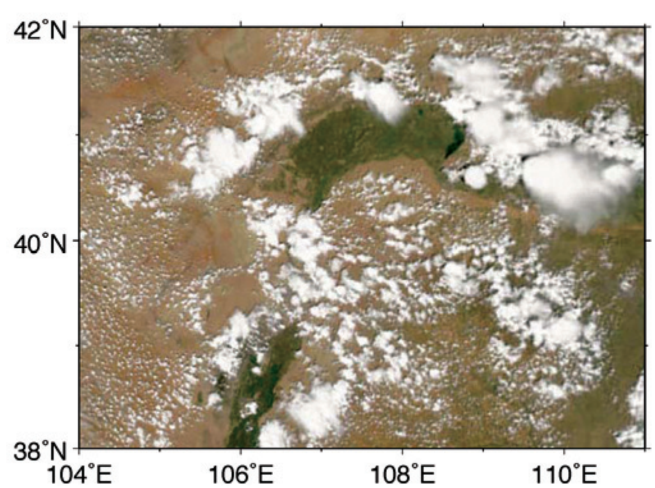

Figure 2. Clouds forming around the Heato irrigation district on the Yellow river in China. MODIS/AQUA true color image provided by T. Sato (personal communication).

to be analyzed. Furthermore, these are areas where atmospheric feedbacks from the enhanced evaporation over reservoirs or irrigated areas can be expected and thus we urgently need to understand the climatic consequence of water usage there.

Human Regulation of the Water Cycle (HRWC) Project

A number of regions were identified that could make excellent test cases for a crosscutting project because of their locations in data rich areas: (i) the Ebro River Basin in Spain within the HYdrological cycle in the Mediterranean EXperiment (HyMeX) region of study; (ii) the Murray Darling River Basin in the Australian Energy and Water Exchanges (OzEWEX) domain; and (iii) the Arkansas-Red River Basin within the U.S. Atmospheric Radiation Measurement Program where GLASS has conducted studies. Other areas, such as the Saskatchewan River Basin in Canada or the Chao Phraya River Basin in Thailand were discussed and also offer interesting perspectives. Test cases will gather expertise and organize model comparisons to evaluate their ability to reproduce the water cycle as it is today and its evolution with increasing human regulation.

Land-surface products derived from remote sensing data, including the impacts of human activities and products for monitoring the human footprint on the water cycle, were identified as priorities. The involvement of the GEWEX Data and Assessments Panel (GDAP) would greatly benefit this project.

Because of the project's multidisciplinary approach, GEWEX should strengthen its collaborations with international organizations, including the Food and Agronomy Organization (FAO) for the exchange of geophysical and agronomic views on the water cycle, and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) and Agricultural Model Intercomparison and Improvement Project (AgMIP) for assistance in modeling human activities in land-surface models. The GHP/GLASS crosscuttting project on the Human Regulation of the Water Cycle will build upon these collaborations and the observational and modeling activities within GEWEX to work towards understanding the continental water cycle as a system that is strongly driven by human activities.

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Research Highlights

Robust Response of Global Mean Precipitation to Anthropogenic Aerosols

Reference: Salzmann, Marc, 2016. Global Warming Without Global Mean Precipitation Increase? *Sci. Adv.,* Vol. 2, No. 6, e1501572. DOI: 10.1126/sciadv.1501572.

Science: Climate models suggest that precipitation decreases by about 3–4% per Kelvin for aerosol cooling. This is about twice as much as the precipitation increase of about 1.5–2% per Kelvin for carbon dioxide warming, and helps to explain why, thus far, global mean precipitation has not increased markedly in spite of a net global warming caused by greenhouse gases.

Impact: It is shown that the observed 20th century temperature increase can be used as a constraint on 20th century global mean precipitation simulated in climate models, and a robust aerosol effect on precipitation is identified. This helps to more easily interpret historical changes of global mean precipitation and to reconcile climate model results with observations.

Summary: Some regions have experienced an increase in precipitation while other regions have seen a precipitation decrease. At the same time, extreme rain events have become more frequent. Yet some observations as well as global climate models suggest that the global mean precipitation has neither increased nor decreased notably until recently. While greenhouse gas warming due to carbon dioxide has long been known to increase global mean precipitation in climate models by about 1.5–2% per Kelvin warming, here it is shown that cooling by aerosols in state-of-the art global climate models decreases precipitation by 3–4% per Kelvin. Due to this robust effect of aerosol on precipitation, global mean precipitation has not increased notably in spite of a net global warming (based on global climate models that simulate a realistic 20th century warming). In the future, however, an increase of global mean precipitation close to the well-known 1.5–2% per Kelvin is anticipated as greenhouse gas warming is expected to become more important.

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http://advances.sciencemag.org/content/2/6/e1501572

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