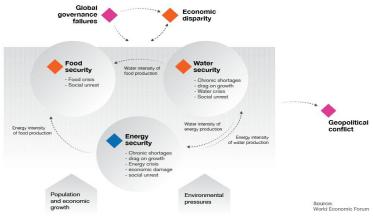
Precipitation Metrics and the Energy-Food-Water Nexus: Challenges and Opportunities

J. Marshall Shepherd (University of Georgia) Steve Burian (University of Utah) Menglin Jin (University of Maryland) Chuntao Liu (TAMU-CC)

UNIVERSITY OF GEORGIA

Contact me: marshgeo@uga.edu

Background

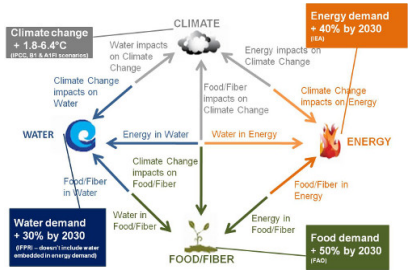


This work is pushing PMM science further into the realm of societal benefit at a critical time in water and food security—Dr. Marshall Shepherd

Thanks to Dr. Ramesh Kakar and the PMM science team.

The economy of food-water security risk is manifested by the following numbers (UN Report): global projections for a 50% increase in food demand, 30% increase in water demand, and 40% increase in energy demand by 2030. Such demands are, in part, driven by urbanization and population increases.

Villamayor-Tomas et al. (2015) note that many frameworks have been used to study the Energy-Water-Food-Network *(EWFN), however, there has been very little attention to the hydroclimate implications and interactions*. Much of the attention has focused on greenhouse gas emission, landuse, resource management efficiency, or societal facets. The complicated interconnections of Energy-Water-Food systems have emerged as critical areas of research. We approach (EWFN) from the perspective of NASA's Precipitation Measurement Mission (PMM).



Our motivation is to describe emerging efforts to link satellite based precipitation data and other NASA data to support the EWFN nexus related to urban transitions and interconnections to agriculture. As a part of our broader research portfolio, satellite-based precipitation estimates are being exploited to develop scientifically rigorous but stakeholder accessible metrics. The basic questions guiding the research are: *Can precipitation per urban capita or per individual be quantified using PMM datasets? If so, can spatio-temporal trends in the metric be useful in the assessment of the EWFN capacities and vulnerabilities?*

It is important to caveat that the focus on this emerging thread of research is the urban catchment scale. Most major urban areas have catchment basins that extend well beyond the city itself. Further, groundwater sources can augment water supply in an urban environment and broaden the catchment region as well. While the work herein focuses on precipitation contributions, it is not our intent to assume it is the only contributor to urban water supply budgets. Although Mitchell et al. (2003) did find that mean annual rainfall was three times greater than potable water for Canberra, Australia. than the output from A daily model was used to quantify the components of the total urban water balance of the Curtin catchment, Canberra, Australia. They concluded that variations in climate (rainfall) were significant factors in the water balance components of an urban catchment. Precipitation is also vital to groundwater recharge, and the literature suggests that urbanization can actually increase recharge rates through the combination of precipitation, storm drainage, and infrastructure leakage (Lerner, 2002).

Progress in Year 2 on Research Themes

1. Research Theme 1: Metrics for Precipitation within the EWFN framework

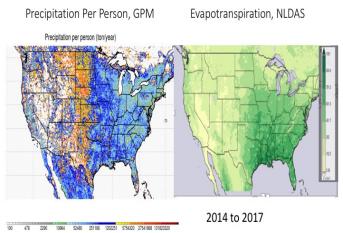
Can precipitation per urban capita or per individual be quantified using PMM datasets?

If so, can spatio-temporal trends in the metric be useful in the assessment of the EWFN capacities and vulnerabilities?

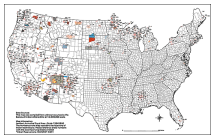
How vulnerable is urban agriculture to hydroclimate variability and extreme events?

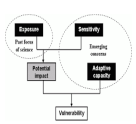
Shepherd and C. Liu submitted a paper to Environmental Research Letters documenting the first every Precipitation Per Person (PPP) metrics from the GPM satellite. The paper also hypothesized that PPP could be used as a proxy for global water stress. The initial reviews suggest that a longer data record would be more compelling. The authors are currently working to extend the PPP data record back by producing a TRMM-based version as well. GPM Outreach Scientist Dr. Dalia Kirschbaum also used materials provided by Dr. Shepherd and Dr. Liu in a GPM achievements paper to go into a special issue for IPWG.

Figure: Precipitation Per Person from 2014 to 2017 (left) and Evapotranspiration from NLDAS (right)

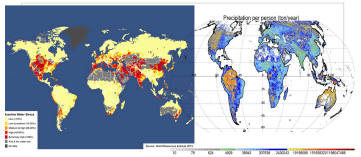


Shepherd and Graduate Student Ansley Long (supported on this grant) have refined a dissertation topic investigating precipitation and water stress in the 4-corners region of the southwest United States. This is a region that has a highly vulnerable native American population. The region is also topographically rigorous and sparsely instrumented for rainfall measurement. Her dissertation outline is as follows: A Satellite-Based Assessment of Hydroclimate Vulnerability and Implications in the Arid, Four Corners Region of the United States



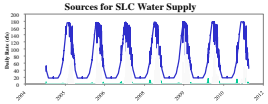


Is PPP a Proxy For Water Stress?



High water stress (red-orange)–LOW PPP (green-light blue)?

Shepherd and C. Liu are also working to explore the concept of P-E (Precipitation – Evapotranspiration) Per Person as a more accurate accounting of global water stress. Figure 1 shows PPP from 2014 to 2017 (left) and Evapotranspiration from NLDAS (right). The idea is to ultimately combine the two and conduct statistical analyses of P-E per person and global water stress. Figure 2 is a from a talk given by Dr. Shepherd at the Georgia Water Resources Conference in April, 2017. It is a baseline, qualitative comparison of PPP and Global Water Stress. There are some compelling relationships, but there are also some inconsistencies. Professor Aris Georgokakis is a well-known engineer and hydrologist. He suggested the P-E per Person as this meeting. This is a significant goal of Year 2 to Year 3 activities. The UGA College of Agriculture and Water Resources Faculty have expressed interest in learning more about the value of such NASA products.



2. Research Theme 2: Ecosystem Services and Water

What is the potential for precipitation-driven food production and other ecosystem services in cities and how do they vary spatially and temporally globally?

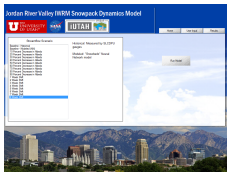
How can precipitation metrics be used to assess water vulnerability

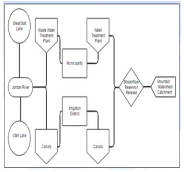
UU PhD Student Ryan Johnson started on the project in August 2017. For his work in the upcoming years, he will focus on two activities. First, he will develop and apply regional metrics of energy, water, and food to relate to the new Precipitation Metrics from the UGA graduate student. The work will seek to develop relationships between Precipitation Metrics and energy, water, and food impacts. Second, Ryan will develop approaches to apply satellite data in a systems model of water vulnerability in the Salt Lake City metropolitan area that can seek to operationalize the relationships between Precipitation Metrics and EWFN impacts for forecasting. In the process, he will apply hydroinformatics tools to solve the problem of big data for systems analysis and EWFN forecasting. UU PhD Student Ryan Johnson has completed preliminary literature review on the EFWN and integration of satellite data into EFWN systems modeling. The household will supply the base for regional consumption modeling framework as papers integrating household to region support this methodology. EWFN modeling approaches cover EFW demand, optimization management, and predictive modeling which will be accepting of remote sensing data. Investigation indicates use of satellite data for water productivity; specifically, in the nearby Wasatch mountains and adjacent watersheds influencing water availability and quality to the greater SLC area. This review provides the foundation for a deeper modeling study of relationships between Precipitation Metrics based on the approach of UGA and water vulnerability in SLC.

Figure Connections between mountain streamflow (e.g. from historical gaged records, outputs from watershed models, or calculated via snowmelt Neural Network models) and the water suppliers and the River Network (municipalities and receiving waters)

Research Themes (Continued)

UU PhD Student Carly Hansen has advanced the ability to model drivers of EWFN outcomes in Utah using the GoldSim model. The connection between streamflow and the water system is represented in a systems model of the Greater Salt Lake City metropolitan area. This model represents each of the municipalities and water suppliers as nodes, and the transport between the suppliers and users is based on urban and irrigation demands. Other supplies, from stormwater and irrigation canals are transferred from municipal storm drains to receiving waters. The performance of the system (measured through vulnerability to failures (shortages or flooding) and amount of water used from different sources (which have different associated costs) are calculated for the system at each time step of the model simulation.





An example of this output is shown for the baseline scenario used in the snowmelt modeling research

Other important outputs of the systems model include daily volumes of waste water discharge and streamflow diversions to receiving water bodies. These outputs are an important component of analyses of effects of development and the urban system on water quality of the receiving bodies of water. Simulations of future system operation will be used for forecasting water quality conditions and as inputs for a decision support tool for water resource managers. A paper for Environmental Modeling and Software, which summarizes this work, is in preparation.

3. Research Theme 3: Urban-Agricultural Interactions

How do the urban-induced surface and boundary-layer meteorological changes affect farms near cities?

How can the satellite observations, in particular, NASA GPM data, help to enhance a land surface model to capture the urban impact on agriculture?

Some of this work is being presented as a separate poster at the 2017 PMM Meeting so we will not present results in detail here but here are some major points:

a. We concluded that the NPP products from both MODIS and NPP are not good enough for our original research idea, which was to assess the urban UHI impact on NPP in the nearby urban regions. This is because we need daily observations to understand Tskin impact on cropland products. Unfortunately, the existing NPP products are inconvincible at daily scale. We are searching another approach to study urban impact on agriculture, which is still within the overall scope of the proposal. b. Green Roofs are our current focus. What kind of green vegetable or foods are proper for urban conditions. What temperature and moisture conditions are needed for such Green Roof products. Evapotranspiration work from the modeling part of this project will also help inform Shepherd and Liu P-E analyses. c. Assess Tskin and Tair over urban building roofs and their relations with urban size, building height, and building materials. Simulate these surface temperature relations using WRF/Single-column urban model and WRF/Multiple urban model. The figure below shows that airport 2-m air temperature is lower than the building roof temperature about 5 F at night, but during the daytime from the morning 10 AM to 18 PM the 2-m temperature at these two regions are very similar. Nevertheless, WRF simulated 2-m temperature is close to the observations from 9 AM-18 PM, but overestimated the surface temperature at night about 8-10 ° F. Further analysis shows that the modeled urban heat anthropogenic flux from building to surrounding urban environment is too high. We are developing a new building scheme to improve urban simulation.

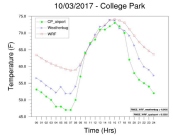
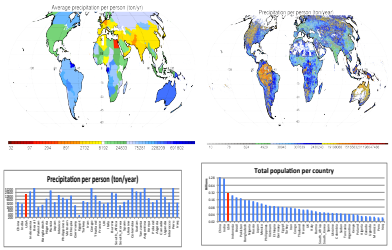


Figure Diurnal variations of surface air temperature for College Park, MD, from (a) airport located in College Park, MD (CP-airport), (b) from WeatherBug instrument installed on the building roof in College Park, MD, and (c) WRF/multiple-urban-canopy model simulated. The model boundary conditions are using NOAA GFS forcing.

Final Thoughts

We have produced the first precipitation per person metrics derived from GPM. We used the Ku-band radar to derived a three-year mean precipitation rate at 0.25ox0.25o grids (figure 2) from April 2014 to March 2017 for the globe.



Papers published, submitted, or in development

Shepherd et al (2016) Earthzine (published)

Shepherd and Liu, Environmental Research Letters (revised for resubmission

Burian et al, Environmental Modeling and Software (In preparation)

Zhang, H. M. Jin, M. Leach, 2017: A Study of the Oklahoma City Urban Heat Island Effect Using a WRF/Single-Layer Urban Canopy Model, a Joint Urban 2003 Field Campaign, and MODIS Satellite Observations. Climate 2017, 5(3), 72; doi:10.3390/cli5030072.

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