Urban-snow relationships: Process studies and a new framework for optimizing and managing global urban water systems in the GPM era

J. Marshall Shepherd and Brad Johnson, University of Georgia) Steve Burian (University of Utah), and Menglin Jin (San Jose State University)

The University of Georgia

Contact me: marshgeo@uga.edu

Background

The PIs are three of the most cited authors on urban climatology, urban hydrometeorology and water management, and precipitation processes, so it is the ideal team to break new ground beyond the "rainfall" problem, which is the essence of NASA-sponsored research.

- Progress continues at the University of Georgia to (1) Evaluate and validate snowfall climatologies in urban and non-urban regimes and (2) Advance the Urban Climate Archipelago Concept (*Shepherd et al 2013*)
- This work fits in a broader context to

-provide, perhaps for the first time, a comprehensive study of urban-snow (fall, melt, and cover) relationships using a fusion of in-situ, remote sensing, and modeling technique

-provide new GPM snowfall product validation as an implicit outcome of (i)

-situate such processes within the continuum of short-term climate variability and broader climate change, and

-establish a framework incorporating urban-snow relationships and utilization of GPM era precipitation data for optimizing and managing urban water systems.

Atlanta Snow Jam 2014 and Urbanization

Key Accomplishments

Key results over the 3 year period include:

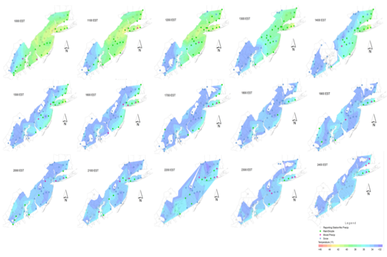
(i) a comprehensive study of urban-snow (fall, melt, and cover) relationships using a fusion of in-situ, remote sensing, and modeling techniques,

(ii) GPM IMERG-based analysis of urban snowfall

(iii) New understanding of urban aerosol-snowfall relationships

(iv) Emergence of the Urban Archipelago Concept (Shepherd et al. 2013)

(iv) a framework incorporating urban-snow relationships and utilization of GPM era precipitation data for optimizing and managing urban water systems.

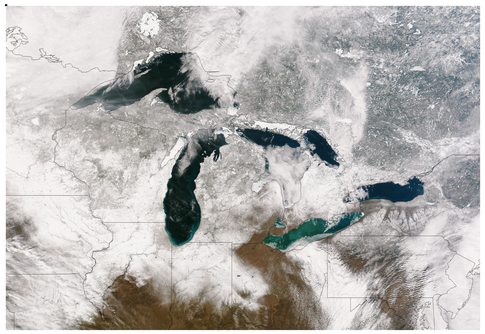


UGA Graduate Student Brad Johnson is using surface data, NARR, profiles, and IMERG to understand the role of urban landscapes and Archipelagos on winter precipitation type in Nor'Easters.

Research Objectives (2013-2016 Period)

1. Urban Snowfall Climatology

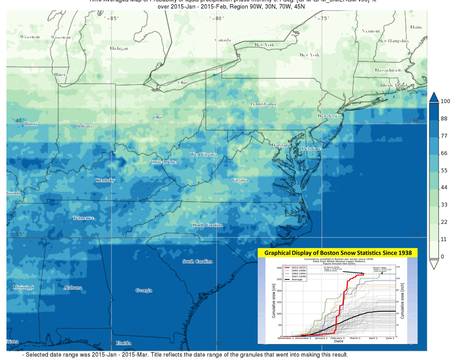
We evaluated and validated snowfall climatologies, in urban and non-urban regimes. We hypothesize that urban regions affect spatio-temporal snowfall patterns (see below) primarily due to the following mechanisms explored in objective 2 such as: warm surface (e.g. UHI) induced thermal instability (mesocirculations), urban buildings (via mechanical turbulence and convergence) lifting air - similar to mountains, urban aerosols providing more CCN for cloud microphysical processes, and urban aerosol reductions of surface insolation (note: this may actually have a negative effect on urban-induce-snowfall). Such processes may lead to urban-influenced snowfall distributions under certain conditions. Like urban-influenced summer convective rainfalls (Shepherd 2013) urban snowfall effects do not occur under every situation and this research seeks to distinguish when it may occur and under what set of conditions. As a secondary objective, our analysis of snowfall climatologies provided high-quality validation datasets (using new satellite, radar, and in-situ products) for validating the next-generation GPM snowfall algorithms.



3. Water management

We utilized observed urban-snow relationships and GPM era precipitation data for optimizing urban water systems, specifically frozen precipitation and linkages to water supply/quantity/quality. We propose to extend the results from a. and b. to investigate the implications of observed land cover and aerosol effects on snowfall, snowcover, and snowpack on hydrologic response, water system reliability, vulnerabilities, and decision making for urban water supply systems. In addition, working with a group of state and local water management professionals, the team advanced the use of GPM era frozen precipitation data to reduce the uncertainty of short-term hydrologic projections.

Boston Snowfall and IMERG Probability of Frozen Precipitation (0.1 deg) Winter 2015



2. Urban snow mechanisms with climate modeling

We quantified any urban land cover and aerosol effects on snowfall, snowcover, or snowmelt using numerical models. We hypothesize that three mechanisms are related to urban-snow effect: (a) both urban aerosols and the urban modification of the surface roughness length contribute to downwind enhancement of snowfall; (b) the urban heat island effect reduces snowfall and snow accumulation; and (c) urban aerosols (for example, soot) darken snow surface and thus reduce surface albedo, leading to earlier and more rapid snow melt. The melted area may result in a higher albedo than snow covered conditions leading to a positive feedback on snowmelt (the so-called positive snow-albedo feedback).

To quantitatively identify the net effect of the above three competing mechanisms and to know the relative importance of each mechanism, first, we analyzed TRMM, GPM and MODIS snow observation. Second, we used NASA Unified WRF and NCAR urban-enhanced Community Land Model (CLM4) to examine snowfall over urban regions. We expect that such urban effect is a function of location, city size and atmospheric conditions of urban regions and a quantitative description is reachable from this project.

MODIS SNOTEL Comparison

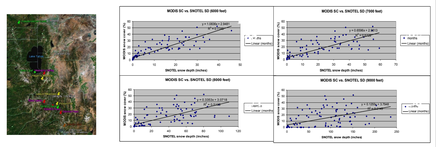


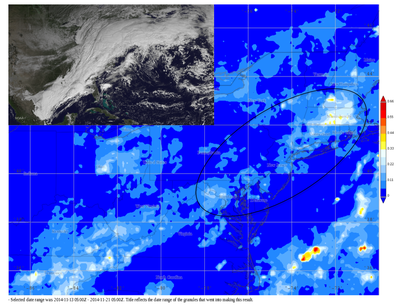
Figure 13: Correlation of MODIS snow cover and SNOTEL snow depth for all 120 months of data.

Snow Telemetry (SNOTEL) stations have been recording the monthly snowpack since the 1970's. However, these stations are sparse with only 26 total stations over the entire area. MODIS, has better spatial resolution.

Key Highlights and Results

1. Major Snow Events and GPM Data: During the period November 13-21, a significant snowstorm impacted much of the Eastern United States. A major Headline was 5-7 feet of snow in the Buffalo, NY area due to a vigorous lake effect snow (LES) mechanism

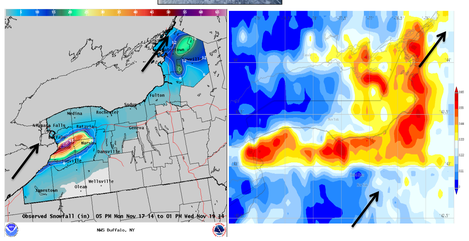
GPM IMERG based estimates were able to resolve the historical LES event over and downwind of Buffalo.



Instantaneous, High Quality Precipitation from IMERG at 0.1 deg resolution 11/13-11/21, 2014

NWS (in)

GPM Imerg (mm/hr)

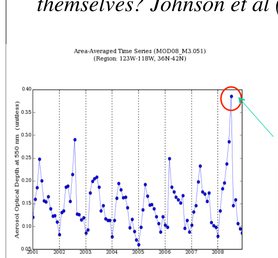


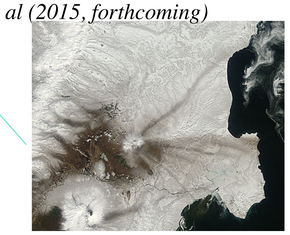
Qualitatively, the IMERG 0.1 degree, high quality instantaneous product **captured significant bands near Buffalo (downwind of Lake Erie) and east of Lake Ontario** but does appear to **over-estimate** along the southern border of Lake Ontario.

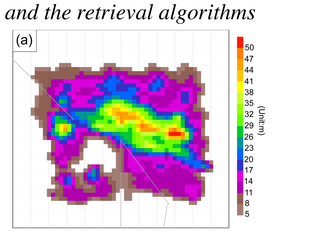
2. Urban Archipelagos and Snow Storms

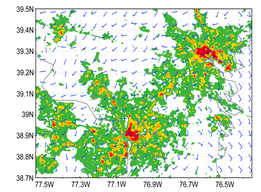
Nor'easters and winter storms impact the distribution of winter precipitation. IMERGE is able to discern clear signatures of snowfall from DC, Baltimore, Philadelphia, and Boston. This demonstrates the capacity to provide climatologies like the work of B. Johnson at UGA.

- UGA PhD Student Brad Johnson and Dr. Shepherd are currently merging ground, radar, and satellite assets to understand urban interactions with snowfall and snowcover in the Northeast United States Megalopolis or Urban Climate Archipelago (Shepherd et al 2013)
- Precipitation 11/13-11/21, 2004 (Above). *How do urban aggregates around DC, Baltimore, Philadelphia, and NYC affect snowfall rates, snow cover, and the retrieval algorithms themselves? Johnson et al (2015, forthcoming)*



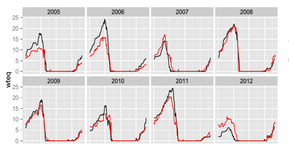






3. Urban aerosols and land cover. Jin et al. continued to advance our understanding through observations (top left) and modeling (top right) of the role of urban aerosols and land cover/building morphology on snowfall and related dynamic process. Model simulations by Jin for DC part of Urban Archipelago (Shepherd) using Burian lidar dataset

Figure 1: K-fold cross validation of Albedo-Snow Water Equivalent (A-SWE) model



The development of the Random Forest model, the integration of an existing model (e.g., SNICAR), and incorporation of satellite data analysis are being used to explore the relative impact of urban air quality and subsequent deposition on snowmelt and streamflow in the Salt Lake City, Utah, USA area. As an example, a new A-SWE model was built using the Random Forest machine learning technique (figure 1).

4. Hydrology and Water Management

The Utah group has made particular progress addressing potential complex influence of urban air quality, deposition of black carbon on snow, snowmelt dynamics, and resulting urban water supply implications.

- Thanks to Ramesh Kakar and NASA/PMM for funding our research. We also leverage funding from an IDS grant with NASA GSFC.