Improving snow and streamflow simulation in the National Water Model by leveraging advanced mesonet observations from the mountains of New York State

jminder@albany.edu

Justin R Minder[1], Patrick W Naple[1], Theodore W Letcher[2], David Gochis[3], Arezoo RefieeiNasab[3], Aubrey Dugger[3]

1. *University at Albany, Albany, NY, USA*
2. *Cold Regions Research and Engineering Lab, Hanover, NH, USA*
3. *National Center for Atmospheric Research, Boulder, CO, USA*

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Overview

Background/Motivation: Accurate representation of snowpack is crucial for hydrological forecasting as it can impact flooding and water resource management. The National Water Model (NWM; http://water.noaa.gov/about/nwm) is a physically based hydrological modeling system, built on the WRF-hydro framework, that aims to improve hydrological forecasting across the US with streamflow forecasts at millions of locations. However, its representation of snow needs to be evaluated and improved, especially over the Eastern US, where routine snow observations are limited and snow in the NWM has seen minimal evaluation. Currently, snow physics in the NWM are parameterized based on the Noah-MP land surface model (e.g., Livneh et al. 2010) and there is no snowpack data assimilation.

Goal: Improve the snow state initializations and prediction within the NWM by taking advantage of observations from New York State Mesonet (NYSM), through two pathways:

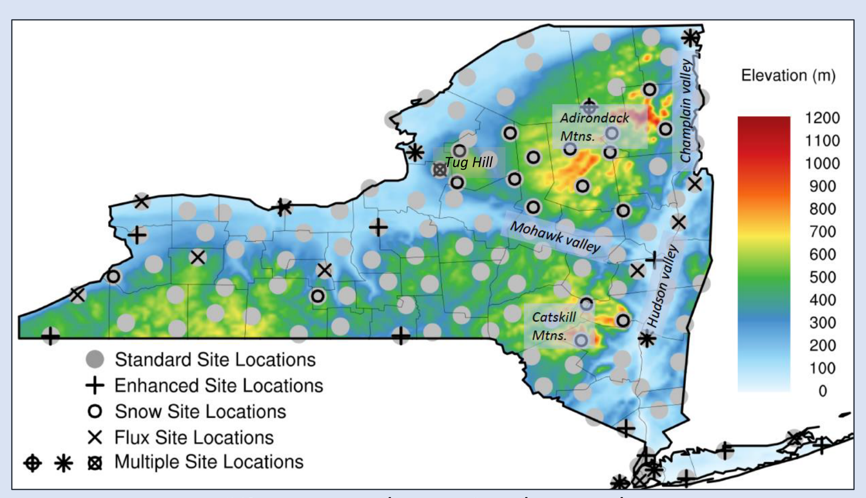
1) Optimization of the snow physics parametrization suite in the NWM
- Perform point simulations with the NWM forced with meteorological observations from the NYSM
- Vary Noah-MP snow parameterizations options and evaluate against NYSM and manual snowpack depth and snow water equivalent (SWE) observations
- Use these results to optimize configuration for the NWM snow model for the rest of the Northeastern United States.

2) Implementation and demonstration of snow data assimilation (DA)
- Work within the ensemble Kalman filtering framework of NCAR's Data Assimilation and Research Testbed
- Assimilate point snowpack observations (depth, SWE) into the NWM analysis cycle
- Improve upon current deterministic analysis by producing ensemble analyses that aid in quantifying uncertainty

Run retrospective, distributed simulations with the NWM to evaluate improvements to medium-range (1-10 day) streamflow forecasts

Observations

New York State Mesonet (NYSM)



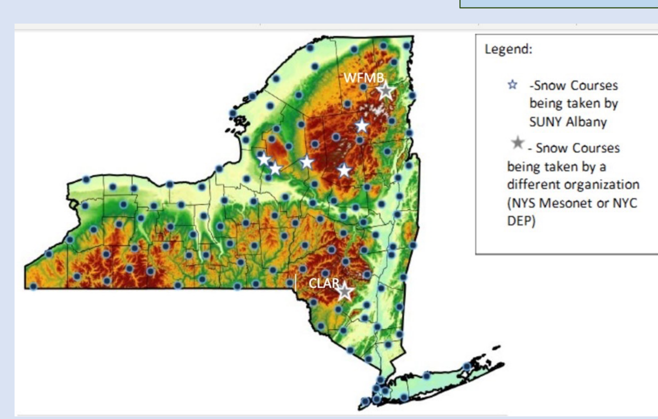
NYS Mesonet observational network

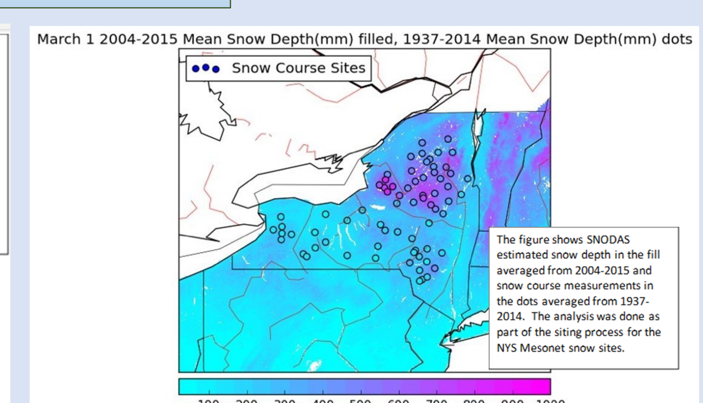
- 126 weather stations spread around New York State. All sites measure: precipitation (weighing gauge w/ double-Alter shield), **snow depth**, soil moisture and temp., 2-m & 9-m temperature, 2-m humidity, incoming solar radiation, 10-m winds, photos
- Snow subnetwork measures **snowpack SWE** at 20 sites
- Surface energy budget (SEB) subnetwork measure surface fluxes
- 5-min data collection frequency
- Extensive metadata

Campbell Scientific SR50-A sonic distance sensor (NYSM snow depth sensor)

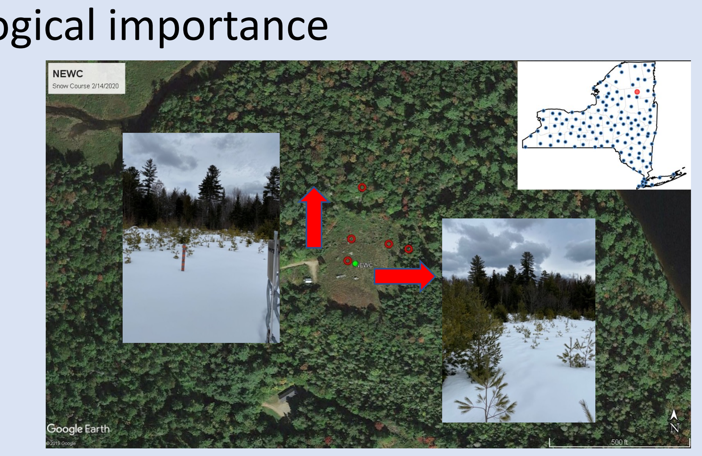
Campbell Scientific CS725 Gamma Radiation Sensor (NYSM SWE sensor)

Snow Courses





- Monthly snow courses at 5 NYSM snow sites to evaluate local snowpack variations to inform DA and model evaluation
- Survey sites focus on areas of substantial snowpack and hydrological importance



An example of our snow course layout at the NEWC NYSM station

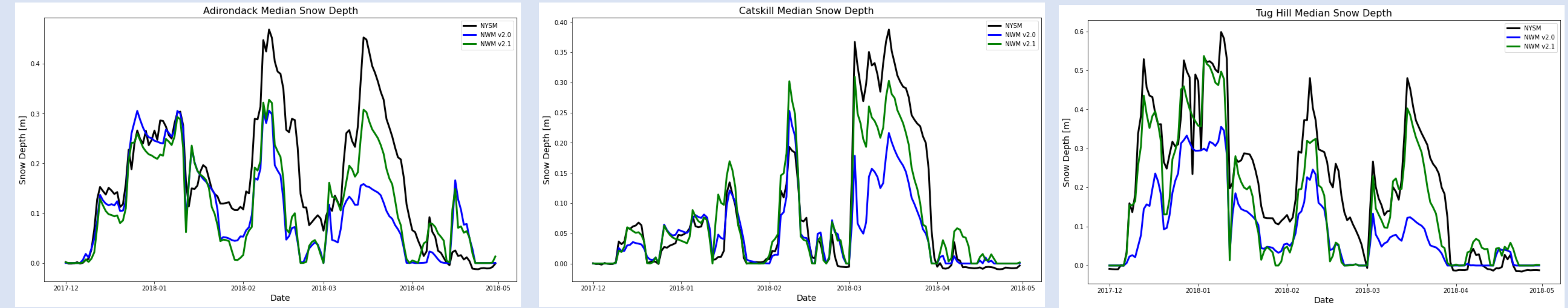
- *2 transects through clearings and into the surrounding forest*
- *20 snow depth measurements are taken at each core location*
- *Snow core taken to measure SWE at the median snow depth value*

- Data from the snow courses will be used to quantify observational uncertainty and inform our model-observation comparisons

Initial Results

NWM Retrospective Runs

- NWM retrospective runs are multi-decadal runs of different NWM versions, forced with meteorological analysis datasets.
- Comparison with retrospective runs gives a baseline NWM performance in simulating snowpack over the mountains of NY State.



Snow depth time series from the 2017-2018 winter comparing outputs from NWM retrospective runs v2.0 and v2.1 with NYSM measure snow depth. Snow depth values are averaged over all station that fall in the Adirondack Mountains (left), Catskill Mountains (middle), and Tug Hill Plateau (right)

- NWM snow depth is negative biased in 2017-2018; bias grows throughout the snow season
- NWM v2.1 reduces bias relative to v2.0. Possible causes:
  - *Improved atmospheric forcing ? (v2.0: NLDAS-2 vs. v2.1: AORC)*
  - *Calibration of model parameters ? (fractional snow cover parameterization)*

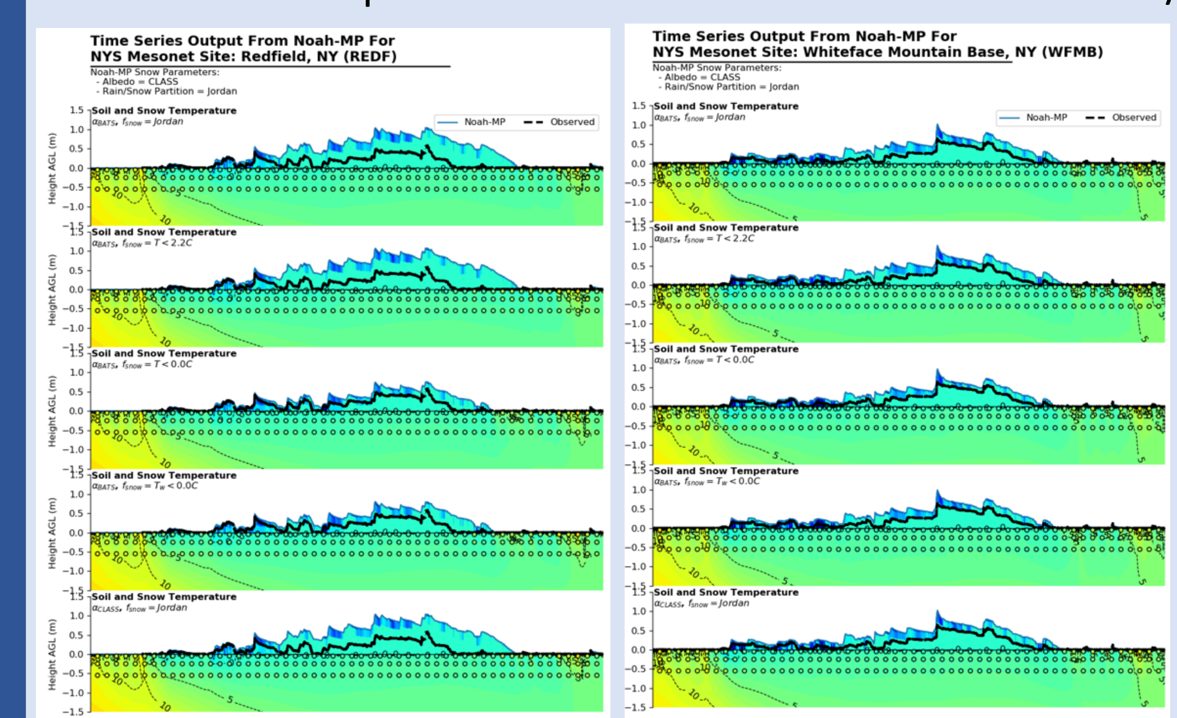
Point Simulations at NYSM sites

- Used to evaluate physical parameterization choices

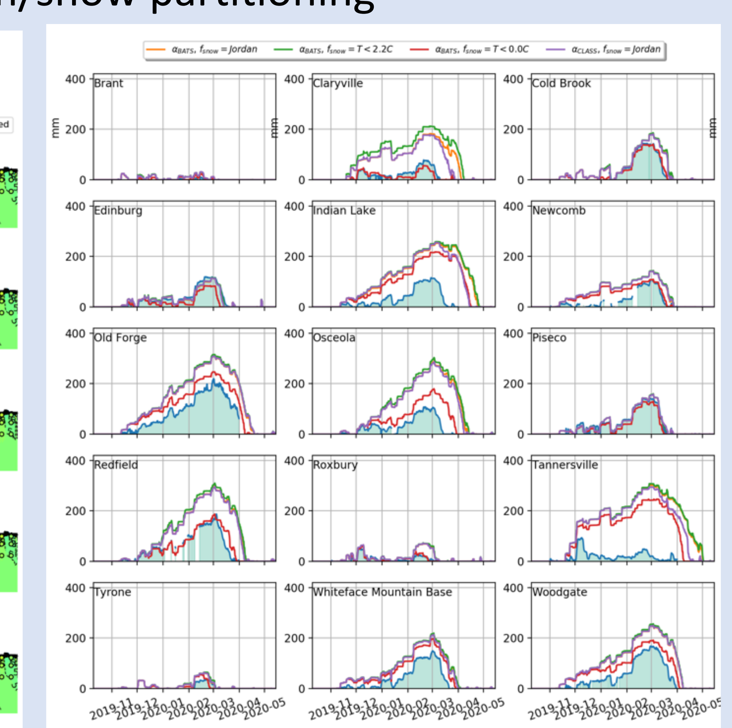
Model Configuration
- 5-min forcing data from NYSM observations
- Soil temperature / moisture is initialized from NYSM
- 5-min time-step
- LW forcing from the HRRR
- Model initialized October 1 of each year
- 6-hour output
- Initial experiments focused on snow albedo & rain/snow partitioning

Simulation Name	Albedo Parameterization	Rain/Snow Partitioning
BASELINE	BATS	Jordan*
PRECIP1	BATS	BATS (T < 2.2 C)
PRECIP2	BATS	T < 0 C
PRECIP3	BATS	T_W < 0 C
ALBEDO1	CLASS	Jordan*
ALBEDO2	CLASS	T < 0 C

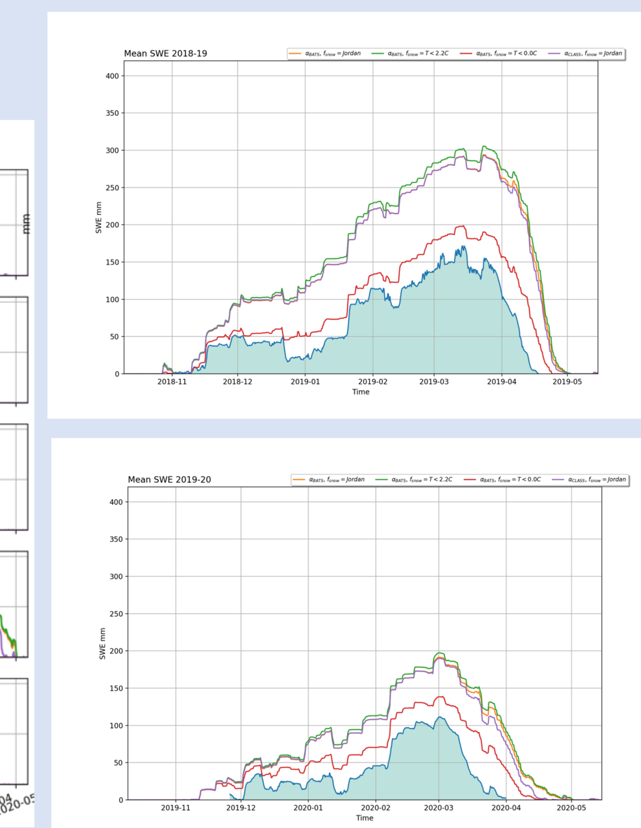
**Jordan (1991) scheme determines precipitation phase based on a linear function of 2-m air temperature per the SNTHERM model*



Snow depth time series from the 2019-2020 winter comparing the different sensitivity experiments to NYSM snow depth measurements at REDF(left) and WFMB (right)



SWE timeseries from the 2019-2020 winter comparing the sensitivity experiments to observed SWE at NYSM SWE sites



Site mean SWE timeseries for the 2018-2019 winter (top) and 2019-2020 winter (bottom) comparing the sensitivity experiments to observed SWE form the NYSM

- 0-deg. C temperature threshold for rain/snow instead of using Jordan leads to large improvements in model performance
- CLASS albedo performs slightly better, than BATS, but impacts are small compared to precipitation partitioning. Evaluation against albedo observations at SEB sites is underway.

Next steps

- Directly evaluate precip. partitioning against snow depth observations and camera images
- Evaluate sensitivity to additional snow physics parameters
- Check of overall improvements with distributed simulations given results from the point simulations
- Use snow course data to characterize spatial variability and vegetation impacts
- Begin work on data assimilation

References
- Livneh, B., Y. Xia, K.E. Mitchell, M.B. Ek, and D.P. Lettenmaier, 2010: Noah LSM snow model diagnostics and enhancements. Journal of Hydrometeorology, 11, 721-738
- Jordan, R., 1991: A one-dimensional temperature model for a snow cover: Technical documentation for SNTHERM. 89. No. CRREL-SR-91-16. Cold Regions Research and Engineering Lab, Hanover NH