Validation of Satellite Snowfall Measurements in Contiguous United States (CONUS)

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Objective and Motivation

The Global Precipitation Measurement (GPM) Core Observation satellite, launched in February 2014, was developed in partnership with the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA). The satellite anchors a global network of satellites from the US and other countries that also collect precipitation measurements.

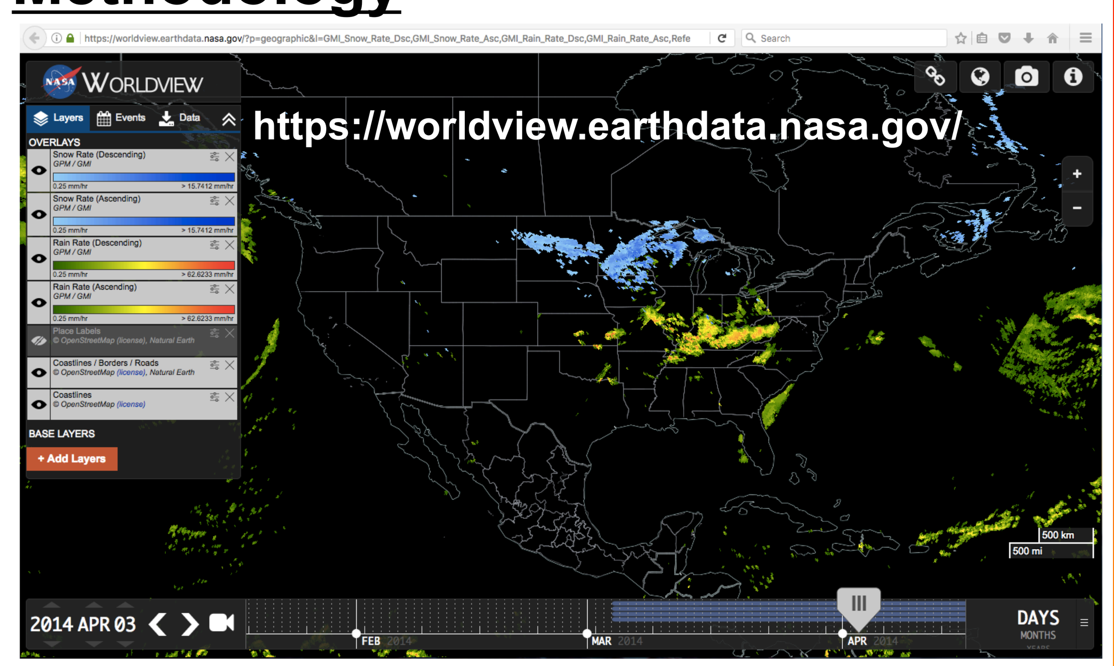
One requirement of the satellite is to detect falling snow. The goal of this study was to use data from surface observations to validate falling snow events as detected by GPM's Dual-Frequency Precipitation Radar (DPR) . If GPM can detect falling snow and classify it as such, then it could lead to increased knowledge of fresh water resources. GPM can lead to a better understanding of the full picture of the water cycle. This could result in identifying patterns of precipitation systems over land.

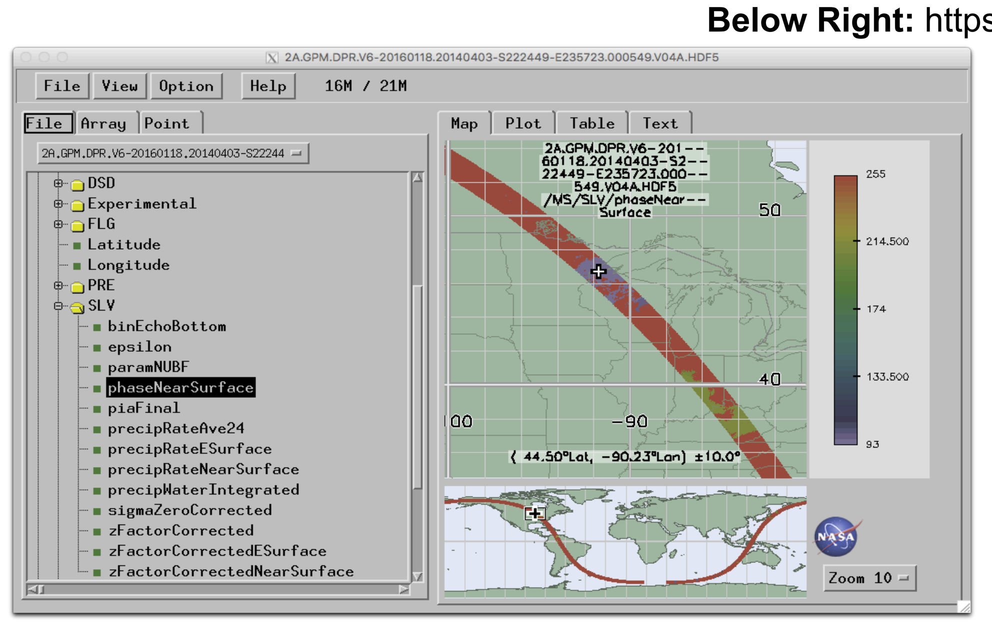
Background

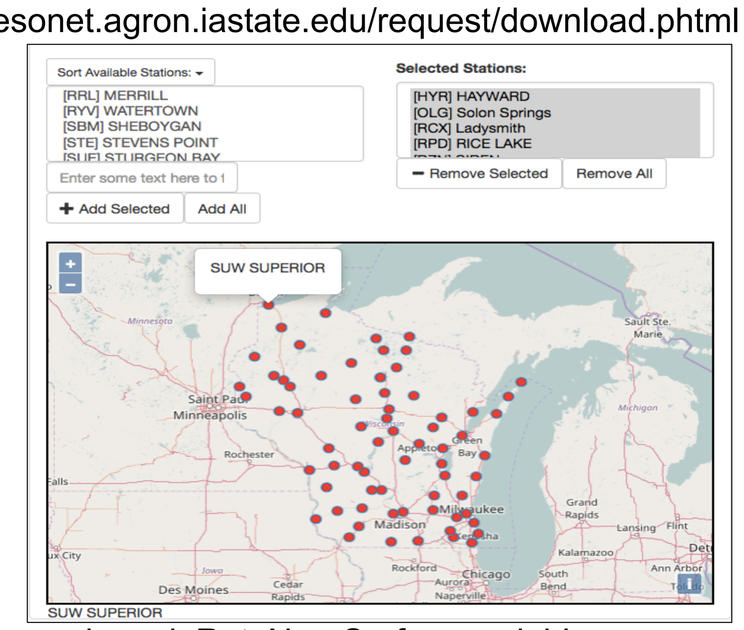
- GPM mission is an international effort to collect precipitation measurements from a constellation of satellites
- GPM core satellite builds off the success of the Tropical Rainfall Measuring Mission (TRMM)
- Can measure light to heavy precipitation as well as microphysical properties of precipitation particles
- Satellite is equipped with a dual frequency phased array precipitation radar (DPR) and microwave imager (GMI)
- DPR has two bands, *Ka* and *Ku*, with scan widths of 120 and 245 km respectively whereas GMI has scan width of 880 km
- DPR can give a 3-D image of a storm's structure and gives more direct measurements than GMI
- GPM can measure rain rates as low as 0.2 mm h^{-1}
  - Expected to detect liquid equivalent rates of 0.5 mm h^{-1} for snow
- Obtaining falling snow (rate) measurements can be a difficult challenge for both satellite and ground platforms
  - Snow can have variable fall speeds due to different sizes and shapes
  - Also has different melted water equivalents from system to system
  - Near surface air temperatures vary in time and space with topography, atmospheric, and surface conditions
- Has been shown that ice-phase precipitation algorithms using satellite passive radiometer observations are useful for studying snow

Methodology

- Used Worldview to collect events (right)
  - Events occurred in CONUS, east of the Rocky Mtns during Mar. 2014 through Feb. 2016
- Viewed GPM DPR files using NASA's Tool for High-resolution Observation Review (THOR) (bottom left)
  - Viewed Matched Scan (MS) and Normal Scan (NS)
  - MS = *Ka* and *Ku* bands overlaid
  - NS = *Ka* and *Ku* bands offset
- Obtained ground observations (ASOS/AWOS) from Iowa Environment Mesonet database (bottom right)
  - Variables: Precipitation (mm), Visibility (miles), Lat/Lon







Below Left: Tool for High-resolution Observation Review (THOR)
Below Right: https://mesonet.agron.iastate.edu/request/download.phtml

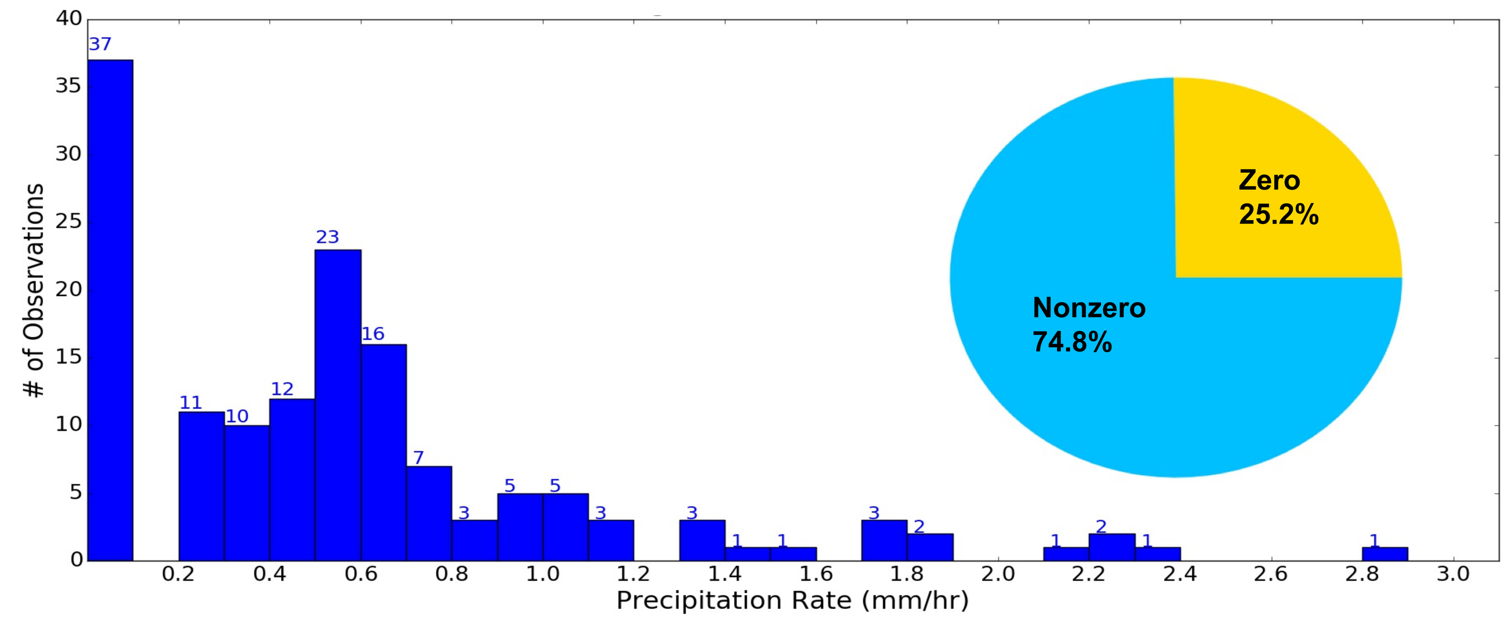
- Compared observations reporting snow to DPR's phaseNearSurface and precipRateNearSurface variables
  - Observations of light, moderate, and heavy snowfall
  - <u>Observed snowfall intensity is based on visibility</u>
    - Light Snow: Visibility > 0.75 miles and Moderate Snow: Visibility between 0.25 and 0.75 miles
- Using the distance formula:

$$d = R * \cos^{-1}(\sin(lat_1)\sin(lat_2) + \cos(lat_1)\cos(lat_2)\cos(lon_1 - lon_2))$$

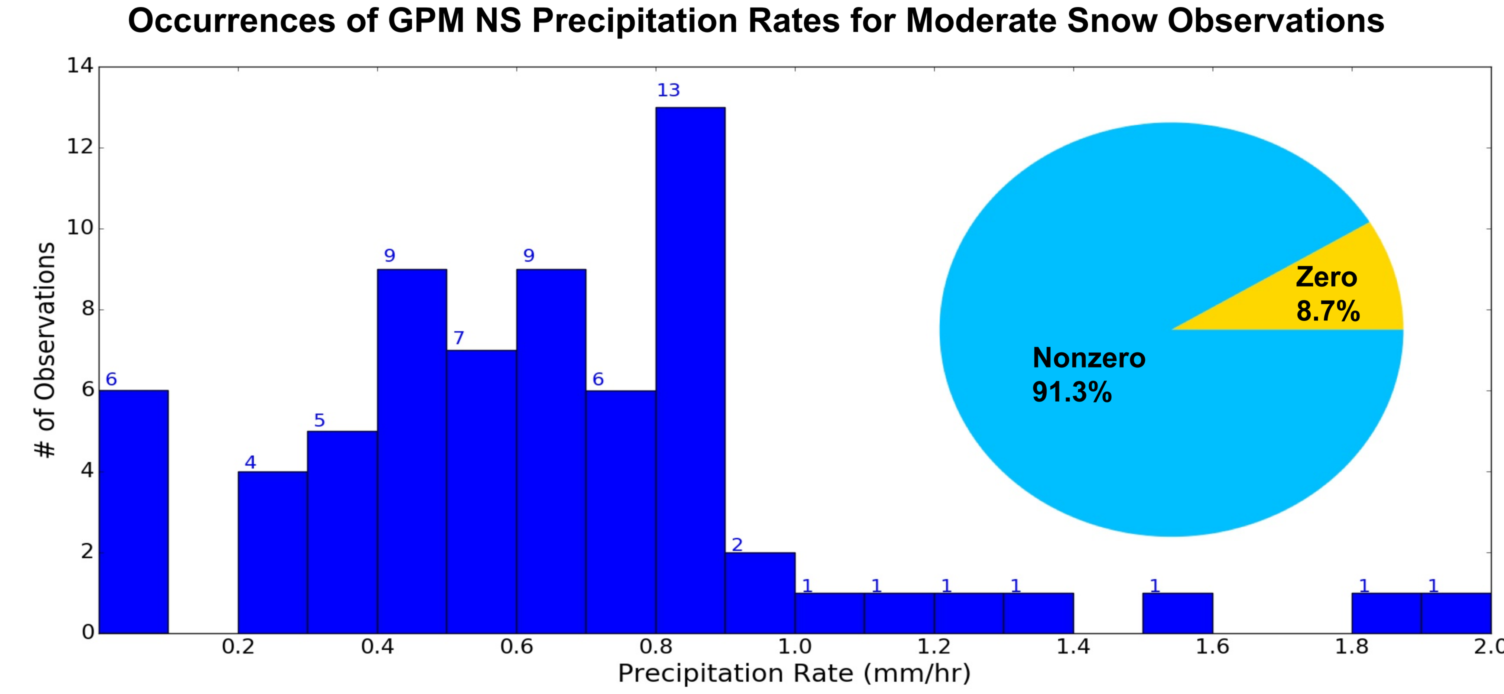
Comparable data were only considered when *d* between GPM data point and observation point was less than or equal to 5 km

Results

Occurrences of GPM NS Precipitation Rates for Light Snow Observations



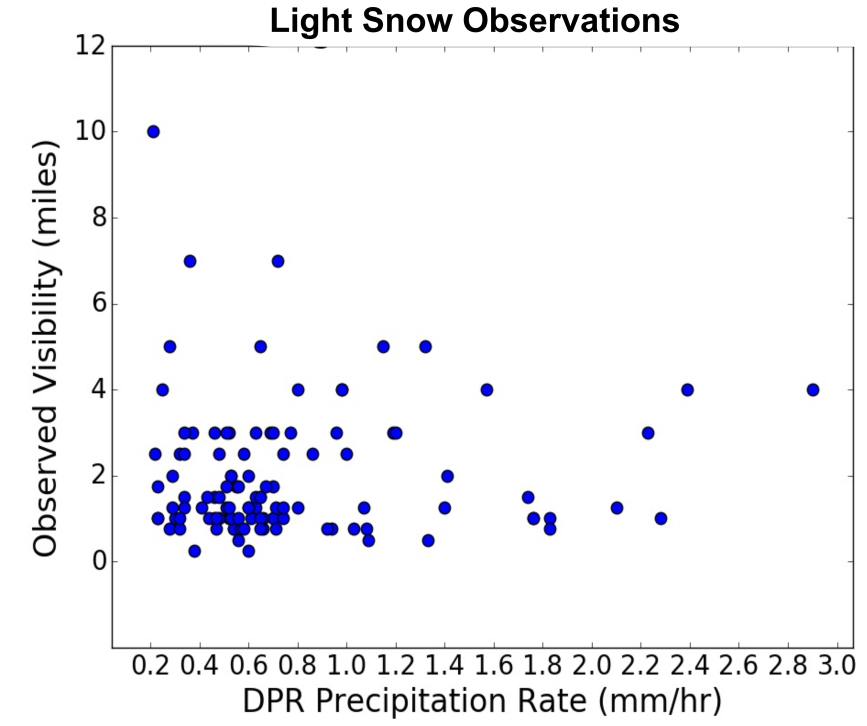
Occurrences of GPM NS Precipitation Rates for Moderate Snow Observations



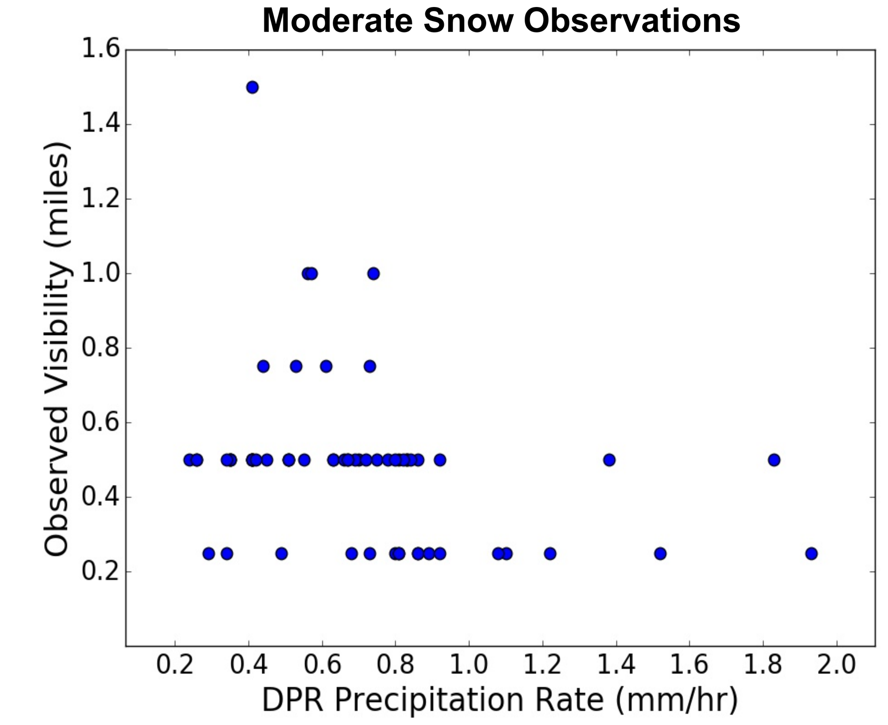
Above Plots: Light and moderate snowfall observations depend on observed visibility. Snowfall intensity increases with increasing precipitation rates. Majority of light snow events around 0.5 mm h^{-1} whereas majority of moderate snow events closer to 0.8 mm h^{-1}. Note that an observation with a precipitation rate greater than 8 mm h^{-1} is not shown on the moderate snow plot.
Insets: Percentage of zero and nonzero precipitation rates as detected by DPR.

Cases where DPR reported 0 mm h^{-1} can be explained by a few factors. The first reason is that there could be missing data at a specific point. Another possible reason is that DPR cannot pick up shallow events as observed in lake effect snow events. DPR minimum detection signal12 dBZ limit of the *Ka* band could be an additional explanation as many snow events can occur below that boundary. It is also possible that there is error in the ground observation. For example, what a human observer sees as light snow could actually just be blowing snow.

GPM NS Precipitation Rate vs Observed Visibility for Light Snow Observations



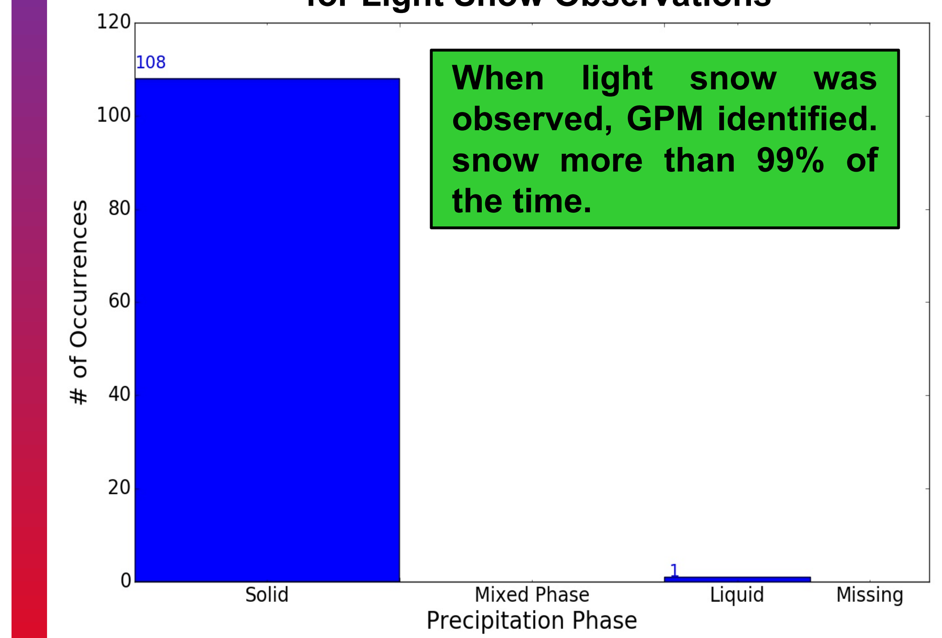
GPM NS Precipitation Rate vs Observed Visibility for Moderate Snow Observations



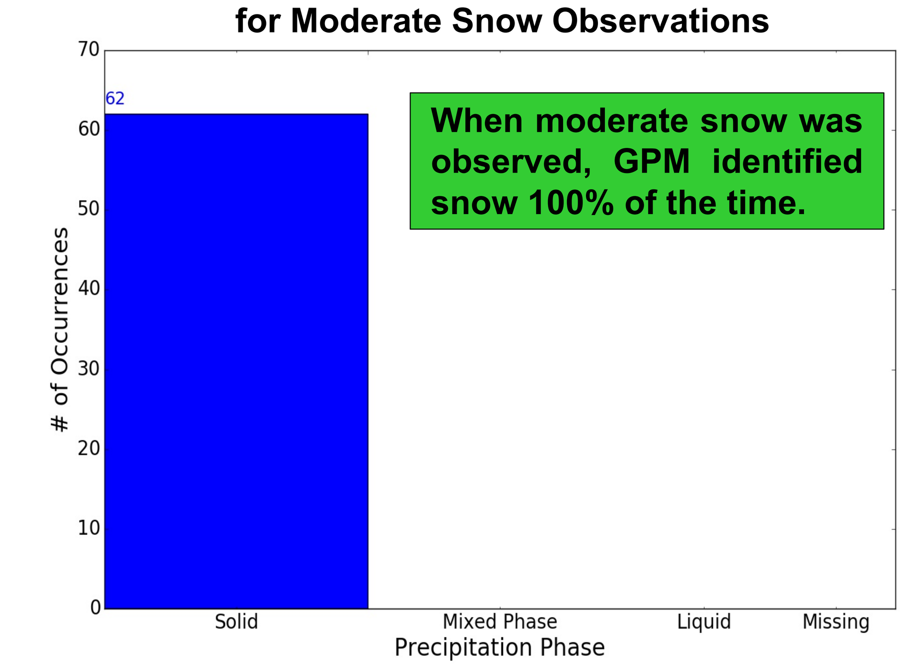
Recall from **Methodology**, observed snowfall intensity is based on visibility.
Left: Most visibilities fell within the threshold for light snow. Some observations had clearer visibilities despite occurring in higher precipitation rates.
Right: Most observations had visibilities inside the threshold. Overall, observations fit well with what would be expected.
Both: 0 mm h^{-1} estimates were omitted. Other factors besides precipitation can affect visibility.

Results Continued

Occurrences of GPM NS Precipitation Phase for Light Snow Observations



Occurrences of GPM NS Precipitation Phase for Moderate Snow Observations



Above: When GPM detected precipitation, it correctly classified observed snow at the ground as solid phase precipitation. There was one case for a light snow observation that GPM classified the precipitation as liquid. Due to time constraints during this summer project, it was not investigated why there was the misclassification.

Discussion and Conclusions

- Main goal of project achieved: GPM can correctly classify precipitation as snow as shown above
  - Should note that GPM does well classifying precipitation when the satellite actually detects it
  - Majority of light snow cases and all of moderate snow cases correctly classified
  - Too small of sample size to make conclusions about heavy snow
- GPM can detect liquid equivalent snowfall rates 0.2 mm h^{-1}
  - Smaller threshold than originally expected
- Snowfall intensity generally increases with increasing precipitation rates
- Visibility usually decreases with increasing precipitation rates
  - Not the case for light snow intensity
  - Could be errors in observations, GPM estimates, or both
  - Could be other weather present

Future Work and Acknowledgements

Using a similar methodology, current and future work is focusing on validating GPM estimates of solid and liquid phase precipitation over all of CONUS. To compare GPM estimates and observations, a skill score will be used to determine how often the GPM satellite correctly classifies precipitation phases. It is important to see how well GPM performs in all areas and determine if there are geographical biases.

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References

- Hou, A. Y., and Coauthors, 2014: The Global Precipitation Measurement System Mission. *Bull. Amer. Meteor. Soc.*, **95**, 701-722.
- Huffman, G. J., D. T. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, P. Xie, 2014: Precipitation Measurement Systems: GPM Integrated Multi-Satellite Retrievals for GPM (IMERG) Algorithm Theoretical Basis Document (ATBD) v4.5. NASA. Accessed July 29, 2016. https://pmm.nasa.gov/resources/documents/gpm-integrated-multi-satellite-retrievals-gpm-imerg-algorithm-theoretical-basis-
- IEM, 2016: ASOS Network / ASOS-AWOS-METAR Data Download. Accessed July 8, 2016. https://mesonet.agron.iastate.edu/request/download.phtml
- Kulie and Bennartz, 2009: Utilizing Spaceborne Radars to Retrieve Dry Snowfall. *J. Appl. Meteor. Climatol.*, **48**, 2564-2580.
- NASA, 2016: Worldview (online interactive application). Accessed July 29, 2016 https://worldview.earthdata.nasa.gov/
- National Weather Service, 2012: ASOS & Climate Observations Fact Sheet. Accessed December 21, 2016 http://www.weather.gov/media/lmk/pdf/educational_pages/ASOSandClimateObservations__What_Is_ASOS.pdf
- Skofronick-Jackson, G., 2011: Precipitation Measurement Systems: Global Precipitation Measurement. NASA. Accessed July 26, 2016. https://pmm.nasa.gov/GPM
- Skofronick-Jackson, G., and Coauthors, 2015: Global Precipitation Measurement Cold Season Precipitation Experiment (GCPEX): For Measurement's Sake, Let It Snow. *Bull. Amer. Meteor. Soc.*, **96**, 1719-1741.
- Skofronick-Jackson, G., S. J. Munchak, S. Ringerud, 2016: Performance of the Falling Snow Retrieval Algorithms for the Global Precipitation Measurement (GPM) Mission. *Proc. IEEE Int. Conf. on Geoscience and Remote Sensing Symp. 2016*, Beijing, China, Institute of Electrical and Electronics Engineers, In Press (as of July 2016).