Measurement Uncertainty of Satellite-based Precipitation Sensors

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ABSTRACT

Uncertainties associated with satellite-based multi-sensor precipitation products are from two sources: (1) *the upstream sensors used* and (2) *the algorithms to merge the sensor retrievals*. Several satellite-based precipitation products, generated from disparate merging algorithms, share remarkable similarities in error characteristics, this suggests these errors can be traced back to their upstream sensor inputs. Knowledge of error characteristics of these satellite sensor inputs is useful, especially when the scheduled Global Precipitation Measurement (GPM) Mission plans to provide high resolution multi-sensor precipitation products at global scale. In this study, a comprehensive assessment of the measurement uncertainty associated with satellite precipitation sensors is performed . Several Passive Microwave (PMW) precipitation sensors have been studied, including TMI, AMSR-E, SSMIS and AMSU-B and MHS. The next generation multi-senor QPE (Q2) data over the contiguous U.S. is used as the ground reference. From our results, PMW sensor retrievals exhibit fairly systematic bias varying by seasons and rain rates, with overestimates in summer at intermediate rain rates and underestimates in winter at high-end rain rates. This feature is also observed in the merged products, suggesting the dominant contribution of the sensor errors to merged products.

Objectives, Study Data, Region, and Time Period

❑ *Objectives*

- To quantify the uncertainties in satellite-based precipitation sensor Earth Science Data Records (ESDRs)

- To identify the propagation of their systematic and random errors into merged multi-sensor precipitation measurements

❑ *Study Data, Region and Time Period*

-Study data: ESDRs from conical scanning sensors TRMM TMI, Aqua AMSR-E, DMSP F series SSMIS, and cross track scanning sensors AMSU-B (from NOAA-15,16,17) and MHS (from NOAA 18,19, and MetOp-A)

-Study region: Continental US

-Time period: three years (2009 ~ 2011)

Table 1. Major precipitation sensor data records

Precipitation Sensor ESDRs	Data Period	Horizontal Resolution (km)	Swath width (km)	Scan Pattern
TRMM PR	Dec.1997-present	5	247	Cross track
TRMM TMI	Dec.1997-present	14	878	Conical
EOS AMSR-E	Jun.2002-Oct.2011	15	1450	Conical
DMSP-F13 SSM/I	May 1995-Nov.2009	15	1700	Conical
DMSP-F14 SSM/I	May 1997-Aug.2008	15	1700	Conical
DMSP-F15 SSM/I	Jan.2000-Sep.2010	15	1700	Conical
DMSP-F16 SSMIS	Nov.2005-present	12.5	1707	Conical
DMSP-F17 SSMIS	Mar.2008-present	12.5	1707	Conical
DMSP-F18 SSMIS	Mar.2010-present	12.5	1707	Conical
NOAA-15 AMSU-B	Jan.2000-Sep.2010	16	2343	Cross track
NOAA-16 AMSU-B	Oct.2000-Apr.2010	16	2343	Cross track
NOAA-17 AMSU-B	Jun.2002-Dec.2009	16	2343	Cross track
NOAA-18 MHS	May 2005-present	17	2156	Cross track
NOAA-19 MHS	Feb.2009-present	17	2156	Cross track
MetOp-2/A MHS	Dec.2006-present	17	2156	Cross track

Ground Reference

❑ *Ground Reference*

NOAA National Severe Storms Laboratory's next generation multi-sensor QPE (*Q2*) data over the contiguous US (*resolution: 5 minutes and 1 km*).

❑ *QA/QC*

Q2 data has been corrected using radar gauge merged product *NEXRAD Stage IV data* (*resolution: hourly and 4 km*). Corrected Q2 data was used as ground "truth" to validate satellite-based rainfall retrievals from different sensors.

(*Corrected Q2 data are available for sharing upon requests*)

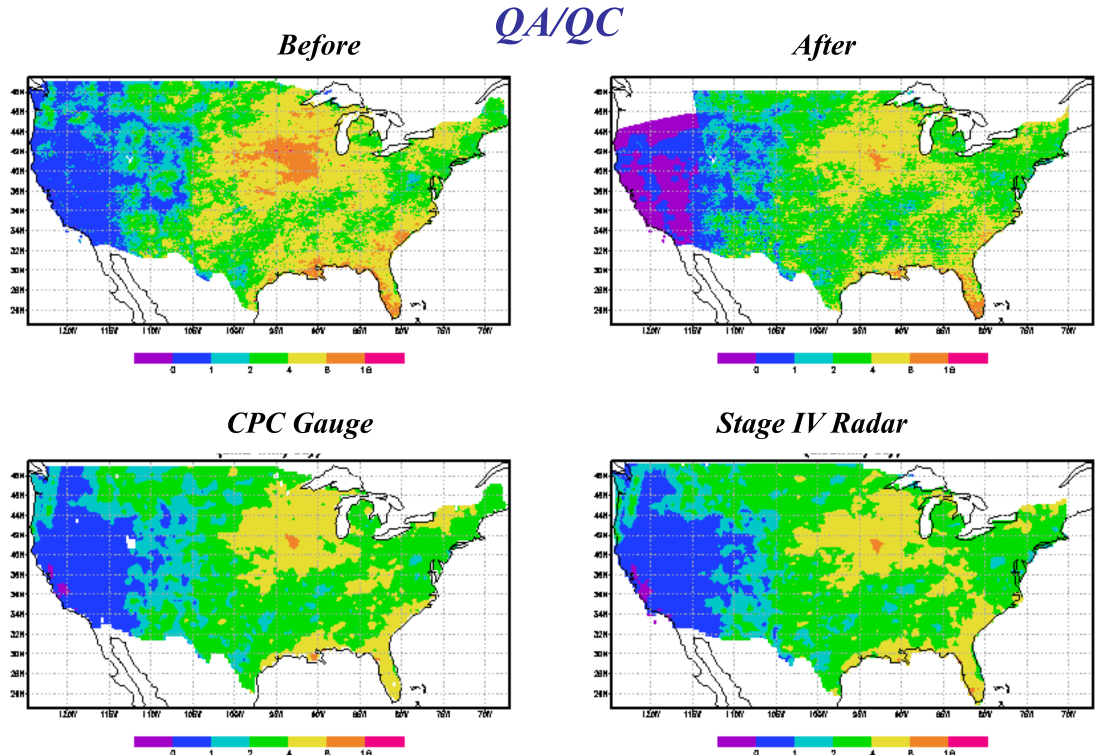


Figure 1. Comparisons of Q2 data before and after QA/QC with CPC gauge data and NEXRAD Stage IV data. Upper left: original Q2 data; Upper right: corrected Q2 data; Lower left: CPC gauge data; Lower right: Stage IV radar data.

Methodology

❑ *Coincident Spatially Averaged Observations*

The instantaneous rainfall pixel data are first horizontally averaged to 0.25° for each satellite separately. When any one of the satellite sensors overpass a 0.25° by 0.25° grid box within 5 minutes with Q2 matched data, consider that they are sampling the same rain/non-rain event.

❑ *Rainfall Retrievals from microwave instruments: AMSR-E, TMI, SSMI, SSMIS, AMSU-B and MHS*

The microwave rainfall retrievals used for AMSR-E, TMI, SSMI, and SSMIS are all based on the most recent version of the NASA's Goddard profiling (GPROF) algorithm. The rainfall retrievals from AMSU-B and MHS are from NOAA's Microwave Integrated Retrieval System (MIRS). *SSMIS data (beta version) being used, because official data is unavailable.*

Sample Size (2009-2011) -At least 1000 samples for most satellites

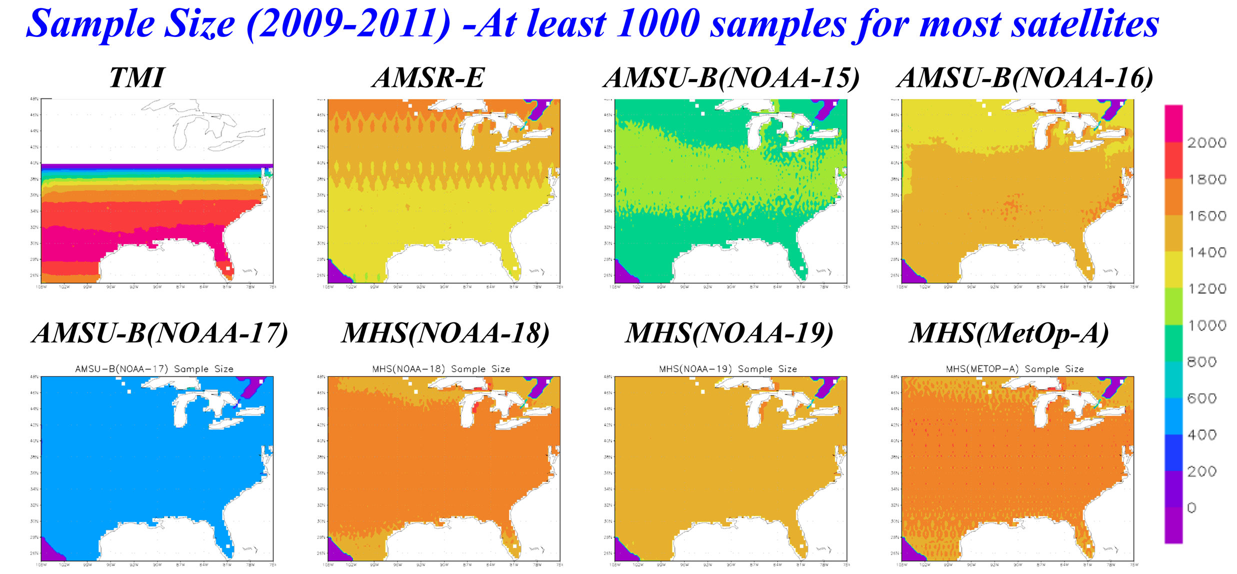


Figure 2. Accumulated coincident sample numbers of AMSR-E, TMI, AMSU-B and MHS versus corrected Q2 over three years from 2009 to 2011 in continental US.

Statistical Analysis

Mean Precipitation confirms spatial- dependent error structure

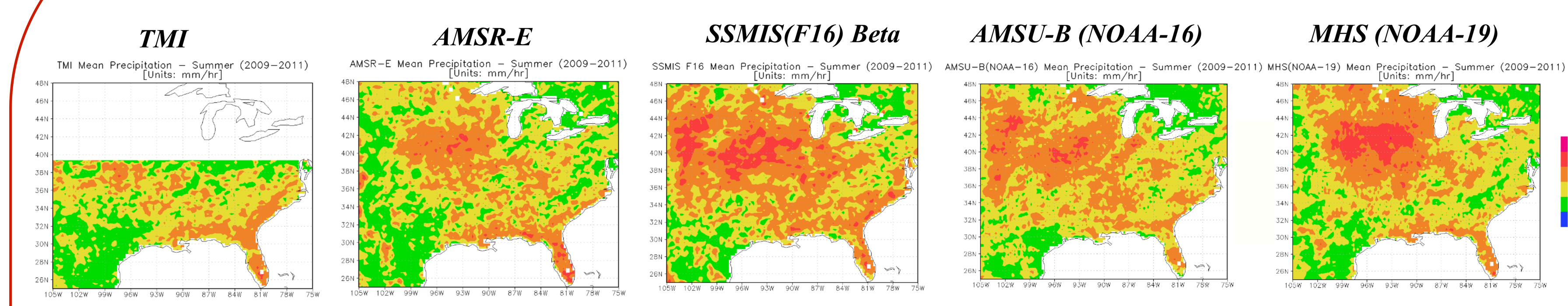


Figure 3. Mean precipitation for summer shows spatial dependent

PDF Comparisons confirm season-dependent error characteristics

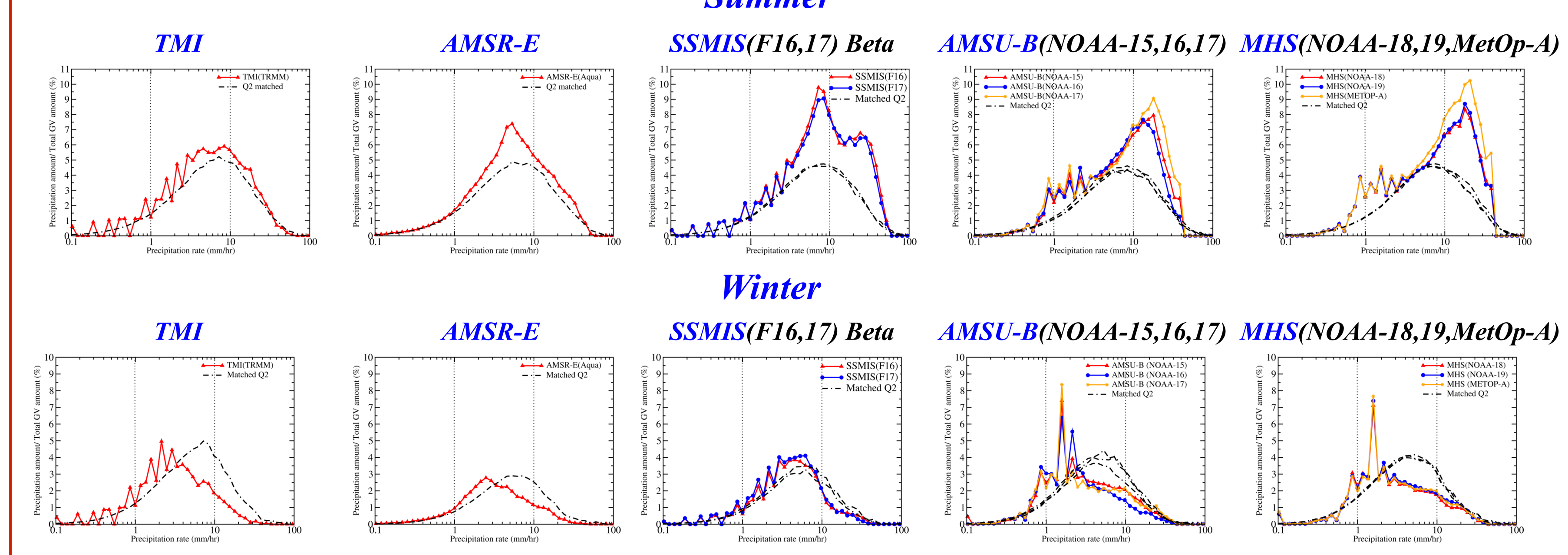
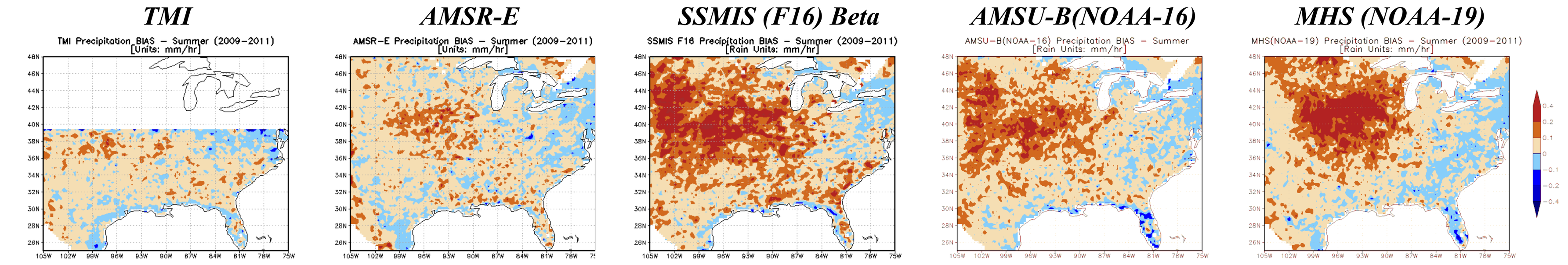


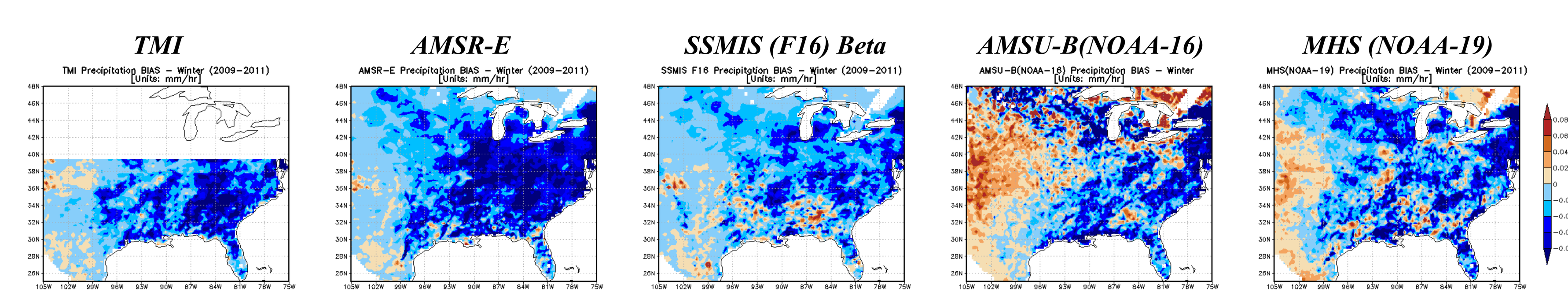
Figure 4. PDF comparisons between satellite sensor rainfall retrievals and Q2 matched data. TMI and AMSR-E have better matching in Summer, but underestimate rainfall in Winter. SSMIS, AMSU-B, and MHS overestimate rainfall at intermediate to large rain rates in Summer , but underestimate intermediate to large rain rate in Winter.

BIAS

Summer BIAS - More overestimates in sounders for summer



Winter BIAS - More underestimates in imagers for winter



Level 2 to 3 Error Propagation

❑ CMORPH rainfall estimates from each individual sensor, were compared with corrected Q2 data. All the sensors overestimate rainfall in summer, and underestimate intermediate and large rainfall in winter.

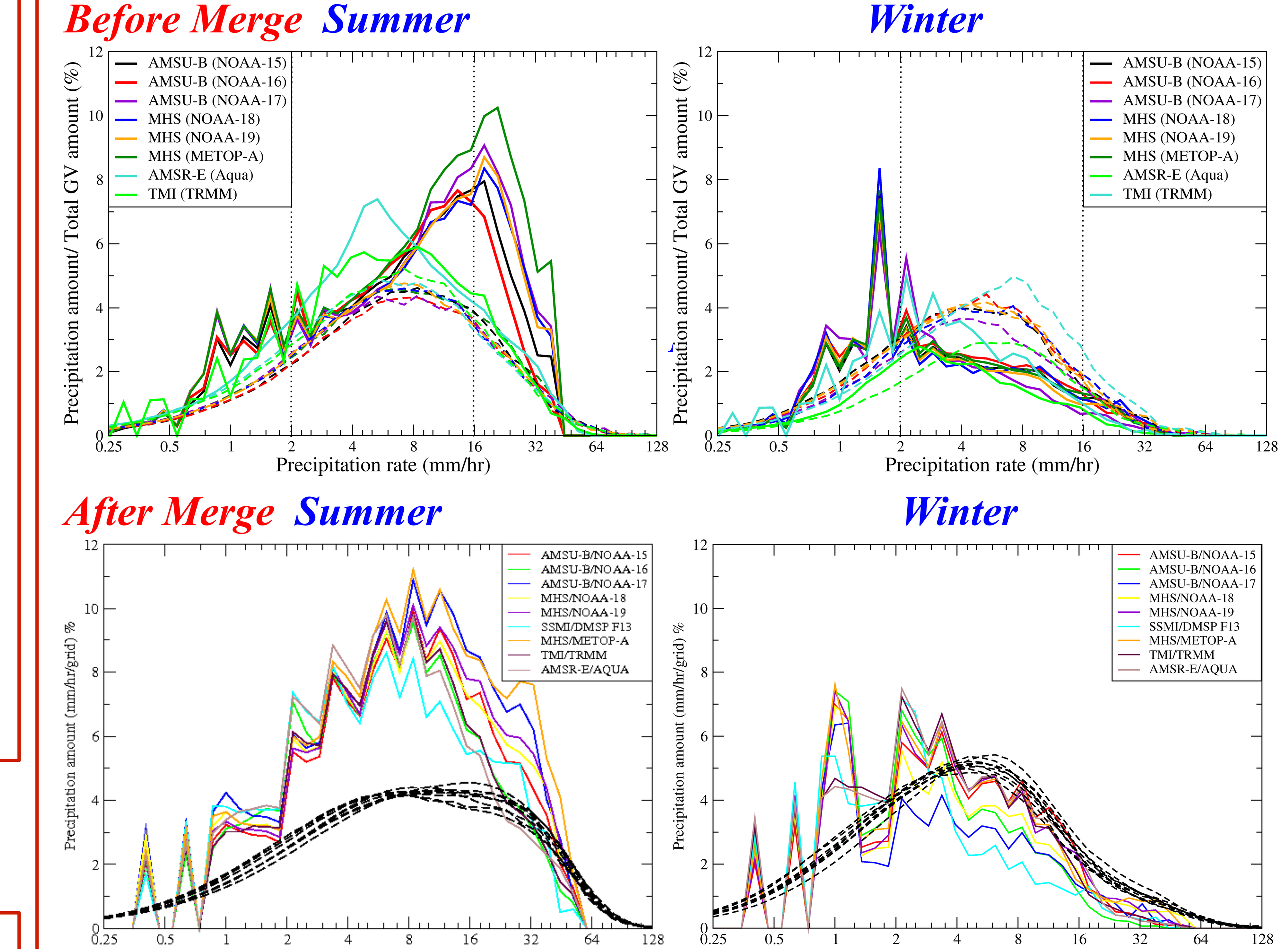


Figure 5. Upper: PDF comparisons before the merge; Lower: After the merge, CMORPH satellite sensor components compared with collocated Q2 corrected data. (Time period:2009-2011)

Conclusions and Future Work

❑ Sensor biases have seasonal and rain-rate dependency: summer – overestimate; winter – underestimate. This feature is also observed in the merged products, suggesting the dominant contribution of the sensor errors to merged products.

❑ AMSR-E and TMI perform better in summer; SSMIS, AMSU-B and MHS in winter.

❑ Future work:

1. Continue systematic and random error analysis in precipitation measurements from passive microwave sensors, over both land and ocean.
2. Study of error propagation from single sensor measurements to merged products.
3. Investigate error modeling of both systematic error and random error.

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