Biases and Uncertainties in GPROF Precipitation due to Channel Failures and Sensor Information Content

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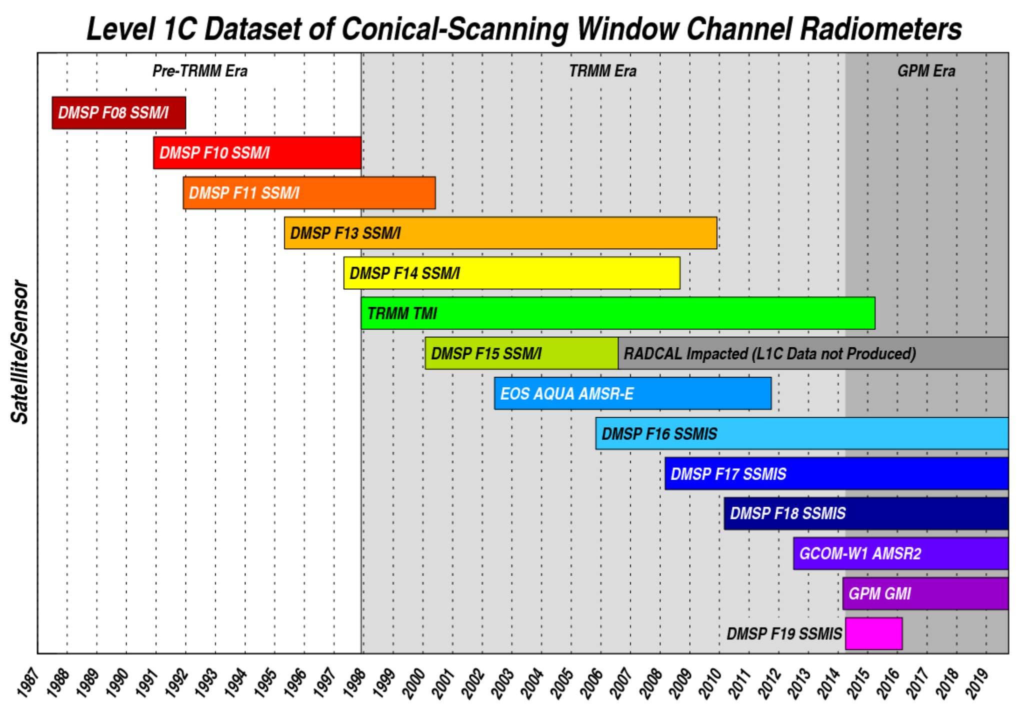
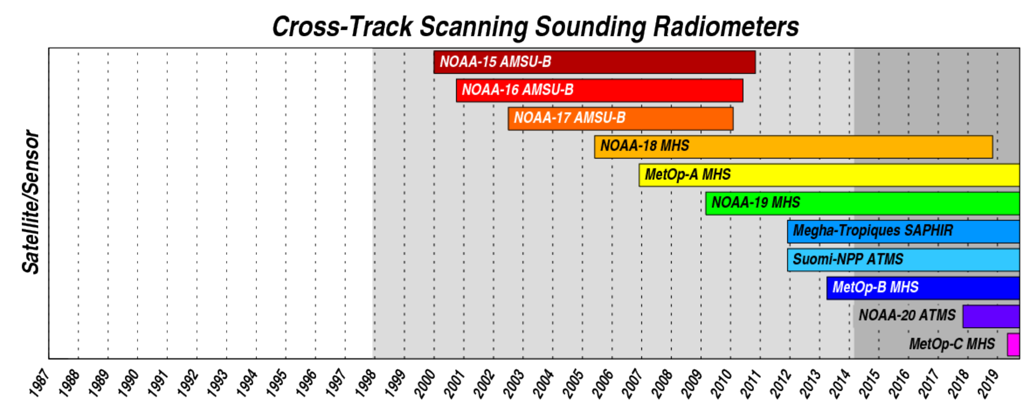
Introduction



Quantifying uncertainties in the GPROF radiometer precipitation estimates is a challenging, yet critical task for many applications. Accurate uncertainty estimates are needed to better integrate microwave estimates into the IMERG precipitation product as well as well as for developing long-term precipitation climate data records. The plot on the left shows the current availability of intercalibrated Level 1C data from the conical-scanning window channel radiometers, and the plot on the right shows the availability for the cross-track sounding radiometers.

Ground-based validation datasets, such as MRMS over the continental U.S., are incredibly valuable to identify problem issues, but have significant limitations for assessing global uncertainties. Fortunately, precipitation estimates from the combined GMI-DPR and long-term high-resolution reanalysis dataset help augment these data for assessing global uncertainties. Two main aspects of this work include the following.

1. Quantifying uncertainties in accumulated daily and monthly mean precipitation estimates.
2. Identifying and mitigating errors due to channel failures and/or degradation, or other calibration-related issues.

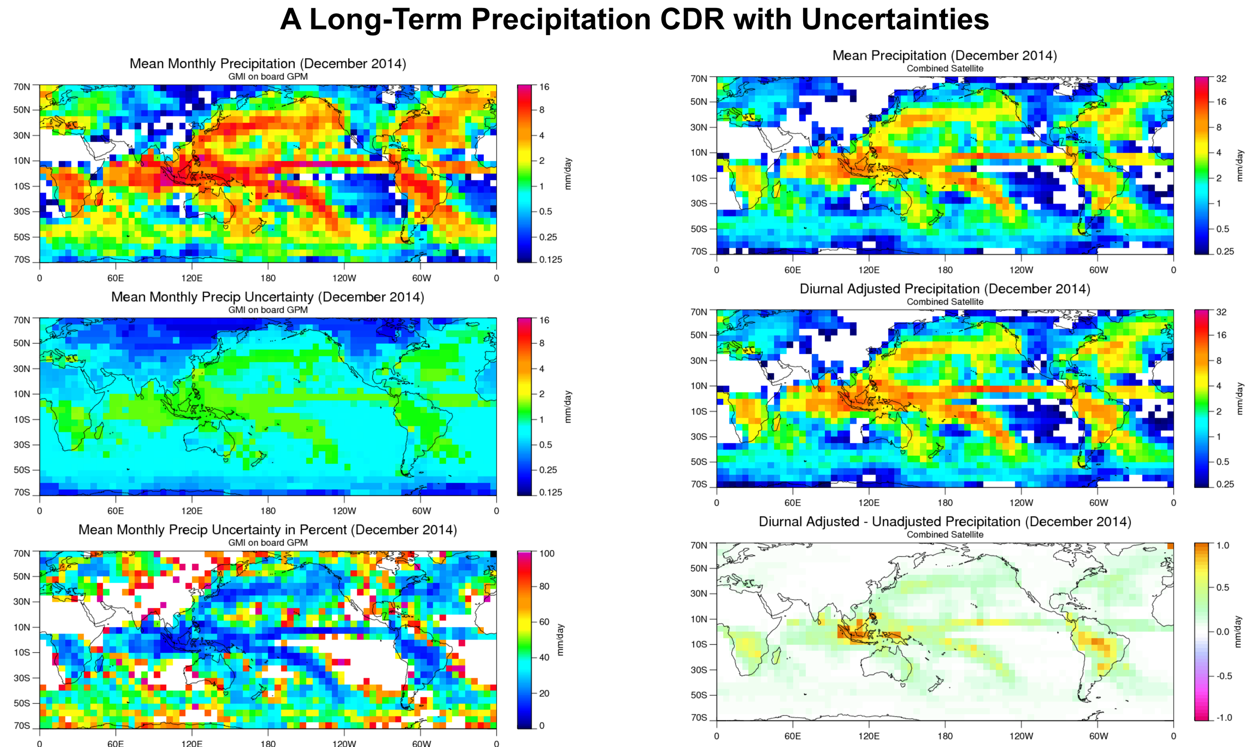


Sources of Uncertainty Computed for Precipitation CDR

1. Systematic errors due to storm morphology (convective versus stratiform)
2. Sampling (satellite sensors typically fly over given scene 1-2X/day)
3. Diurnal cycle errors (residual errors after diurnal cycle adjustment)
4. Information content errors resulting from less channels/resolution vs. GMI
5. Bayesian retrieval errors in pixel-level retrieval estimates

Uncertainties in Monthly 5x5 Degree Estimates

A Long-Term Precipitation CDR with Uncertainties

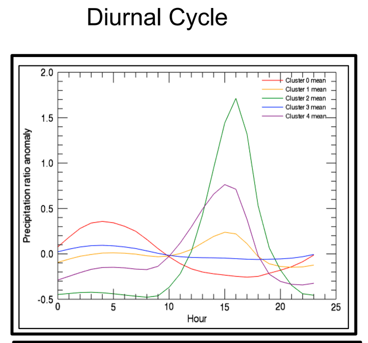


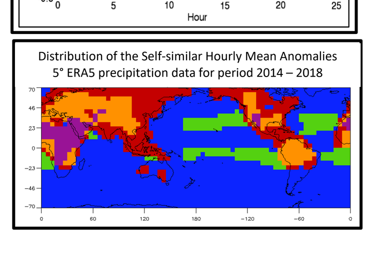
A long-term precipitation climate data record (CDR) has been produced from the conical-scanning microwave imagers shown in the figure in the top left of the introduction panel. The monthly gridded estimates in this CDR are at 5x5 degree resolution and use the current operational V05A Level 2 GPROF estimates. A key feature of this dataset is the inclusion of uncertainty information, including uncertainties from systematic error sources. The figure on the above left shows the monthly mean precipitation and associated uncertainties (both in mm/day and %) for GPM GMI from December 2014. The figure on the above right shows the original monthly mean precipitation as well as the mean precipitation after adjusting for the diurnal cycle. The figure on the right is also a composite of data from six sensors including GPM GMI, TRMM TMI, GCOMW1 AMSR2, and SSMIS on board F16, F17 and F18.

Sources of Uncertainty in Monthly Estimates

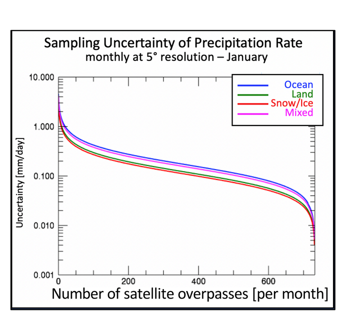
The total uncertainty in the monthly 5x5 degree precipitation estimates includes uncertainty estimates from five different sources. These are 1) Storm morphology (i.e. convective vs. stratiform), 2) diurnal cycle, 3) sampling, 4) information content in the available channels vs. GMI, and 5) the Bayesian or pixel-level retrieval uncertainty.

Diurnal Cycle



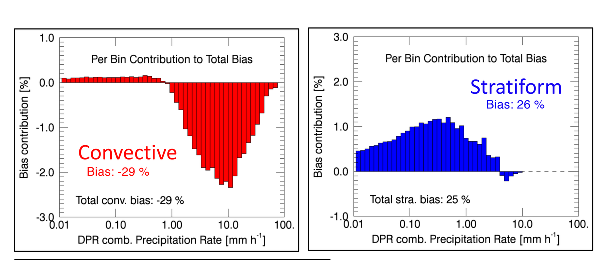


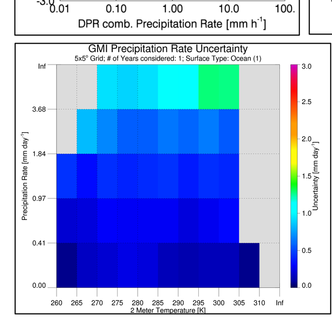
Sampling



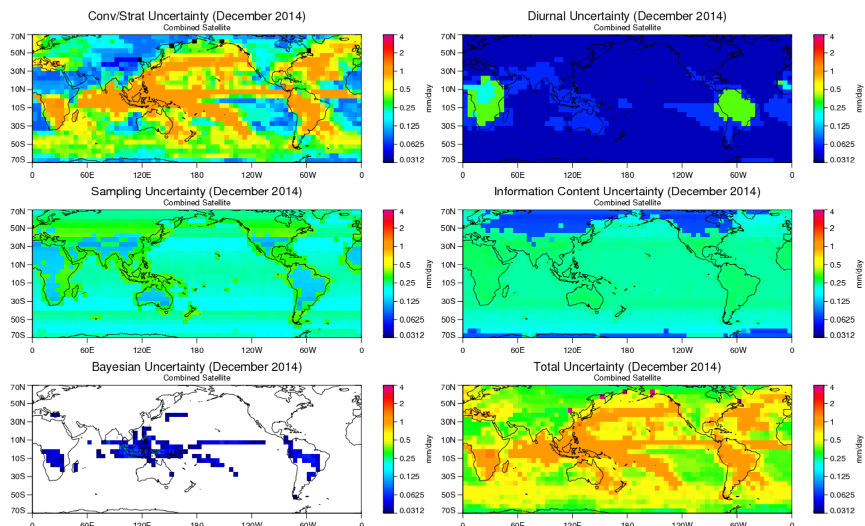
The diurnal cycle is clustered into five types (above left) based on ERA5 reanalysis data. The mean distribution of these clusters is shown in the figure on the lower left. Sampling errors (above) are also calculated using hourly ERA5 data.

Storm Morphology





Biases in GPROF retrieval estimates are highly correlated with storm morphology. Biases based on combined DPR-GMI estimates are shown above for convective and stratiform pixels. Using precipitation intensity and 2m temperature as proxies, we can assign uncertainties associated with these systematic biases.



Estimates of the five individual uncertainty contributions along with the total uncertainty are shown in the figure on the left for the December 2014 combined satellite estimate. The Bayesian, or pixel-level retrieval errors, are random and thus have a small contribution when composited over 5x5 degree monthly grids. Residual diurnal cycle errors (after adjustment for diurnal sampling is applied) are also generally small, with the largest values over tropical rain forests where the diurnal cycle is largest. Convective/stratiform morphology errors are largest in arears with the most precipitation, while sampling errors depend on both satellite sampling and precipitation variability. The information content errors are computed using synthetic data (i.e. GMI with SSM/I sampling and channel availability) to determine the impact of reduced information from GMI on the precipitation estimates.

Sensor Channel Failures and/or Degradation

Failed and/or Degraded Channels on the SSMIS Sensors

Satellite/Sensor	Channel	Start Date/Time	End Date/Time	Flag
F16 SSMIS	91 V-Pol	24 Apr 2014	26 Aug 2015	Caution
F16 SSMIS	91 H-Pol	25 Apr 2014	Ongoing	Caution
F16 SSMIS	150 H-Pol	01 May 2015	26 Aug 2015	Channel set to missing
F16 SSMIS	183+/-1 H-Pol	01 May 2013	26 Aug 2015	Channel set to missing
F16 SSMIS	183+/-3 H-Pol	01 May 2013	26 Aug 2015	Channel set to missing
F16 SSMIS	183+/-7 H-Pol	01 May 2013	26 Aug 2015	Channel set to missing
F17 SSMIS	37 V-Pol	05 Apr 2016	18 May 2016	Channel set to missing
F17 SSMIS	37 V-Pol	03 Aug 2016	Ongoing	Channel set to missing
F18 SSMIS	150 H-Pol	14 Feb 2012	Ongoing	Channel set to missing

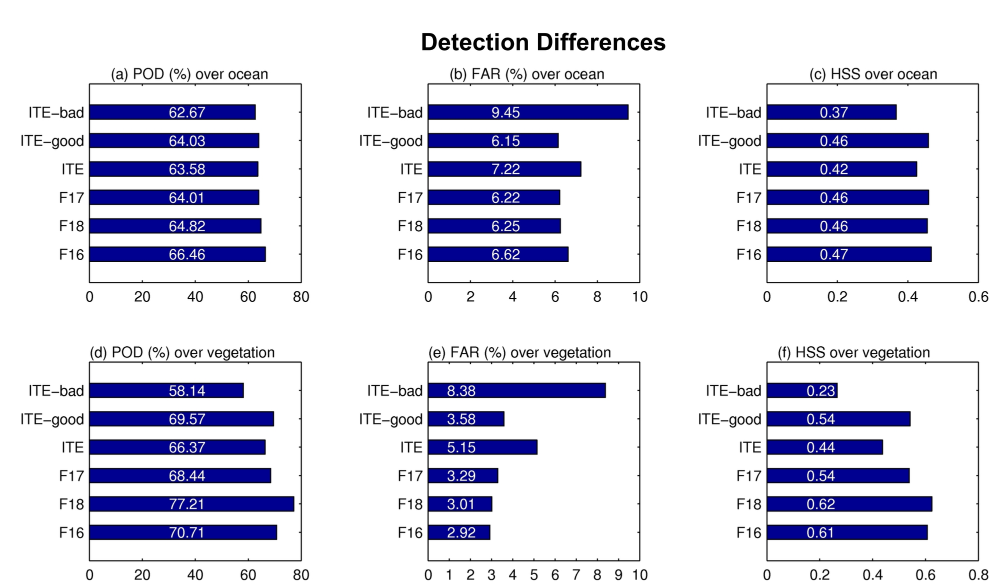
The table on the left shows the various channels on the DMSP SSMIS sensors that have either failed, or have degraded performance. The coverage of the SSMIS sensors is important for IMERG given the coverage from the three instruments on board F16, F17 and F18 in both space and time. Failed channels, however, can have unexpected consequences as detailed below.

Investigating GPROF Performance for F17 with Failed 37v Channel

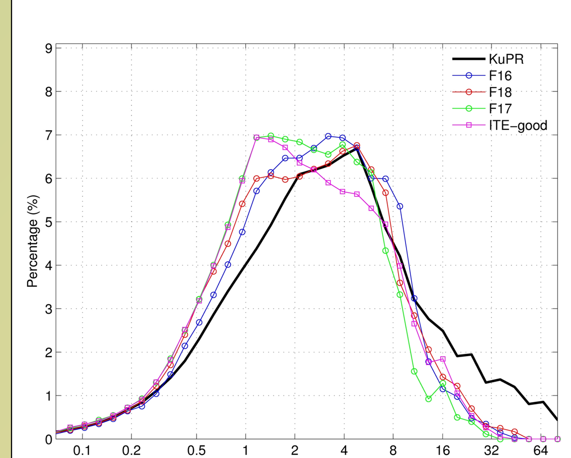
The detection and intensity performance was compared to estimates from the GPM KuPR for six different SSMIS retrievals including the three SSMIS sensors as well as modified versions of the F17 SSMIS data. All data are from the period from April 2015 through November 2018.

- Operational F16
- Operational F18
- Operational F17 (without 37 V-Pol channel)
- F17-ITE (with 37 V-Pol, all swathes)
- F17-ITE-good (with 37 V-Pol, but only low NEDT orbits)
- F17-ITE-bad (with 37 V-Pol, but only high NEDT orbits)

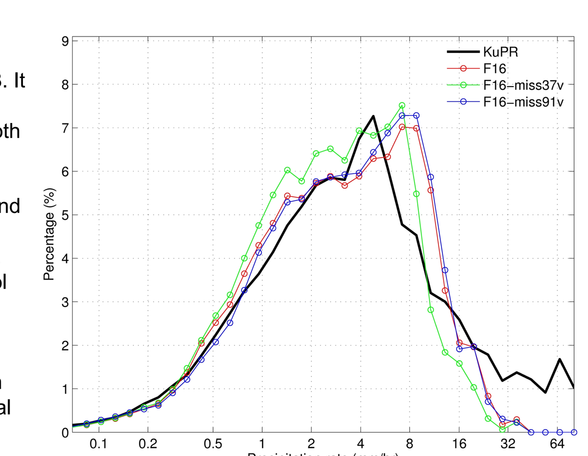
Detection Differences

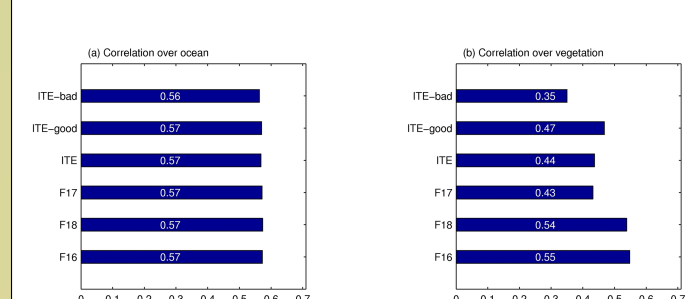


Intensity Differences



- F17 (green line) shifts left, compared with F16 and F18. It shows that there is less heavier rainfall from F17 (both left and right figures).
- ITE-good is similar to F16 and F18, only when the precipitation rate > 8 mm/hr. This is because the 37 V-Pol Tb respond mainly to heavy precipitation (left figure).
- Loss of 91 V-Pol channel on F16 appears to have minimal impact on F16 intensity histogram (right figure).





The loss of the 37 V-Pol channel seems to have almost no impact over ocean, but it significantly degrades the correlation with KuPR over vegetated land. Including the high-NEDT orbits results in an even lower correlation than simply dropping the use of the 37 V-Pol channel in the retrieval.

Conclusions

Detection

- Comparing F17 and F17-ITE-good,it appears that the loss of the 37 V-Pol channel has negligible impact on precipitation detection.
- ITE-bad has significantly degraded detection performance over both land and ocean, indicating the importance of not using this channel with elevated NEDT.
- A potential reason for the degraded detection performance of F17 is the warmer Tb at 91 GHz for moderate to heavy precipitation (not shown).

Intensity

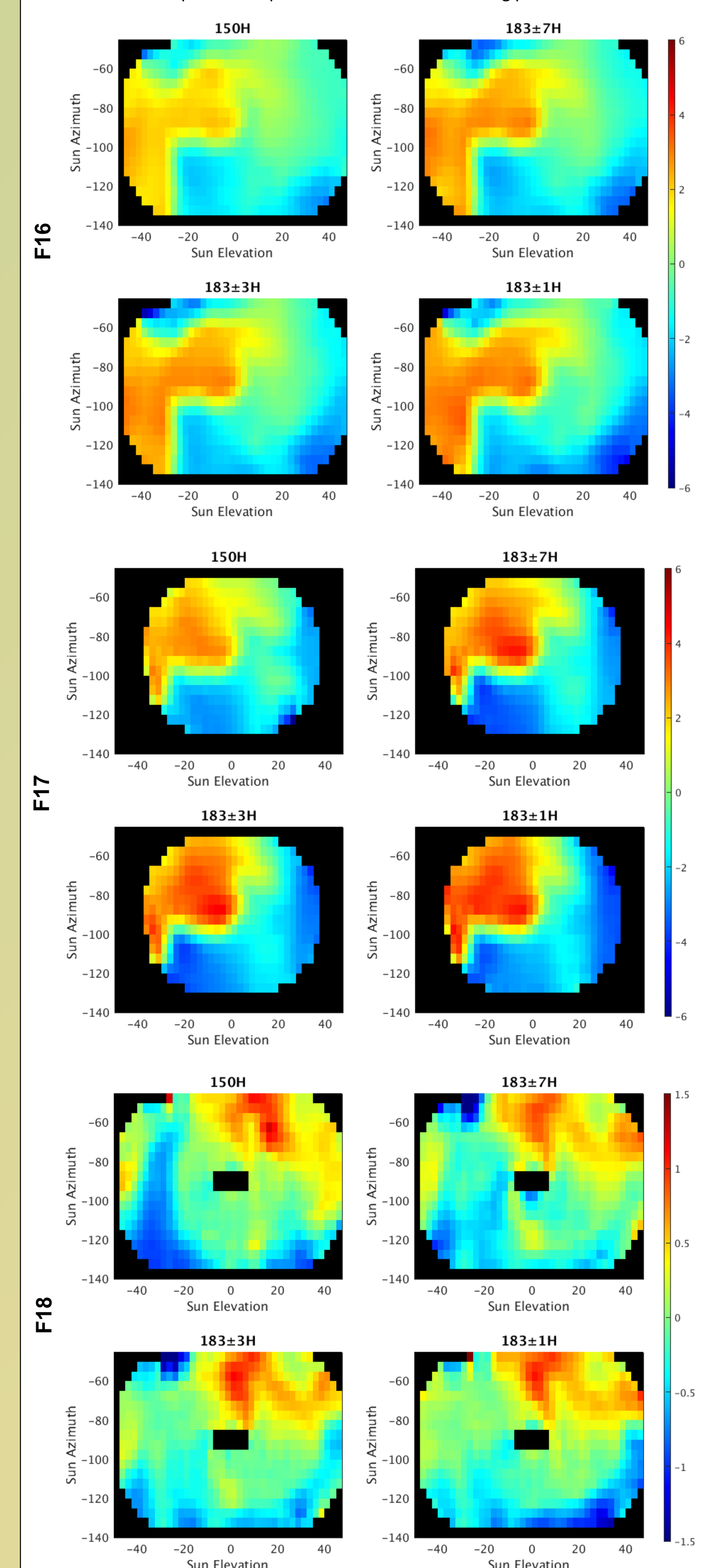
- Losing the 37 V-Pol channel results in the "intensity" histogram shifting towards lighter precipitation over vegetated land. left (**more light rain, less heavy rain**)
- Losing the 91 V-Pol channel appears to have a negligible impact.

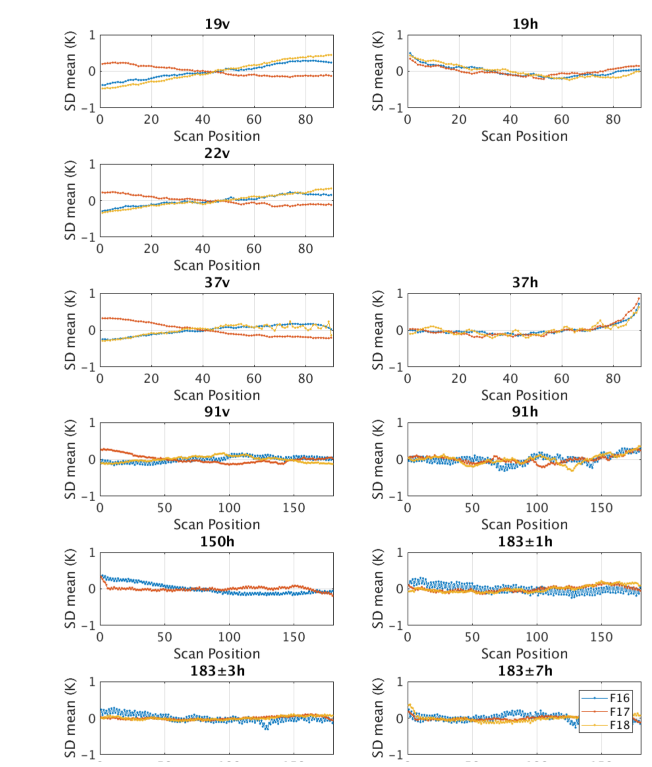
SSMIS Calibration Errors

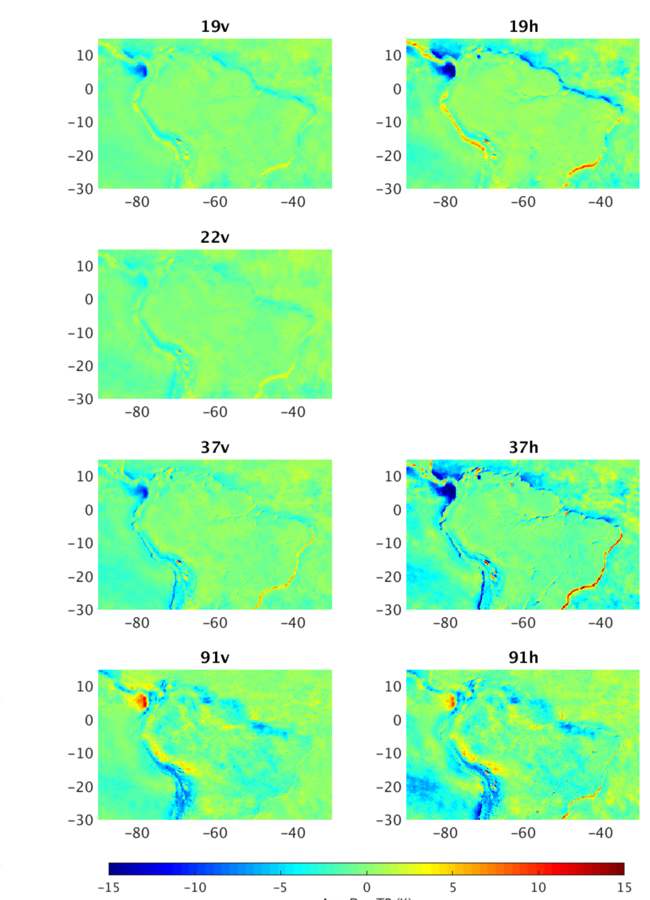
Sun-Angle Calibration Corrections for High-Frequency SSMIS Channels

The SSMIS radiometers on board the DMSP F16, F17, F18 and F19 spacecraft suffer from several significant calibration issues. Of particular concern are an emissive main reflector on F16 and F17, solar intrusions into the warm load, and other solar heating-related issues. Since there is insufficient information available to solve for all of these sun-related issues on orbit, a sun-angle dependent correction was developed using intercalibration techniques. Results are shown below for the high-frequency SSMIS channels used in the precipitation retrieval. Corrections for the lower-frequency channels were implemented prior to the Level 1C data being produced.

Another issue impacting the SSMIS calibration as well as subsequent retrievals involves feedhorn mounting offsets, which impact the geolocation and the view angle. Radiative transfer model simulations are very sensitive to view angle errors. Errors in the knowledge of the feedhorn pointing in the spacecraft roll/pitch direction result in a slope/arc in the resulting cross-scan biases. Pointing errors also result in geolocation errors, which can be assessed by difference gridded Tbs from ascending versus descending scans (see figure below).







Summary

Precipitation CDR with Uncertainties:

- A precipitation climate data record (CDR) is being produced for the conical-scanning microwave imagers over a 30+ year period starting with SSM/I on board DMSP F08. It will include 5x5 degree monthly, 1x1 degree daily, and global-monthly gridded estimates with uncertainties.
- It uses the Climate version of latest operational GPROF V05A retrieval algorithm
- Uncertainty estimates include 1) Storm morphology (i.e. convective vs. stratiform), 2) diurnal cycle, 3) sampling, 4) information content vs. GMI, and 5) Bayesian or pixel-level retrieval uncertainty.

Assessing the Impact of Channel Failures:

- Failure and/or degradation of multiple SSMIS channels has occurred in recent years, impacting the precipitation retrievals.
- As assessment of the impact versus GPM KaPR estimates shows a significant impact on precipitation intensity estimates from F17 over vegetated land surfaces resulting from the loss of the 37 V-Pol channel.
- Somewhat surprisingly, the loss of the 91 V-Pol channel appears to have a negligible impact.
- The bottom line is that retrieval impacts are highly dependent on the channel, the surface type, and the type of precipitation.

SSMIS Calibration Issues:

- There are significant calibration issues with SSMIS due to emissive reflectors on F16 and F17 as well as solar intrusion and heating issues.
- Previous attempts have been made to develop corrections for these impacts, however, we are revisiting these issues.
- This will include updates to sun-angle corrections, particularly for high-frequency channels, along with updated cross-scan bias and geolocation corrections due to pointing errors.

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