Global Precipitation Measurement Mission (GPM) : Connecting Science and Engineering

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GPM: Science to Engineering

- TRMM (past) and GPM (present)
  - TRMM summary
  - GPM goals and their implications

- GPM/GMI Innovations
  - GMI improved engineering – calibration subsystem
  - Radiometer intercalibration

- Summary and Next Steps
The Precipitation Measurement Missions (PMM): TRMM and GPM Science
GPM Predecessor Mission: TRMM

- Tropical Rainfall Measurement Mission (November 27, 1997 – April 15, 2015)
  - Tropical rainfall is responsible for ~3/4 of energy driving global atmospheric circulation – driver of weather, climate as key part of water cycle
  - TRMM Goals:
    - Characterize amount, distribution of tropical rainfall
    - Test, improve satellite precipitation estimation techniques
- Mission consists of ground, airborne and spaceborne elements
  - TRMM spaceborne elements:
    » TRMM Microwave Imager (TMI),
    » Precipitation Radar (PR),
    » Visible and Infrared Sensor (VIRS),
    » Lightning Imaging Sensor (LIS),
    » Clouds and the Earth’s Radiant Energy System (CERES)

- Global Precipitation Measurement mission (February 27, 2014 - Present)
  - Similar goals to TRMM, but expanded …
GPM Goals: Evolution of TRMM

• GPM is follow-on to TRMM with improvements:
  – Global distribution
  – Cover all phases of precipitation
  – Improved accuracy, dynamic range for precipitation products
  – Improved understanding of link between precipitation and climate
  – Insights in storm structure, large-scale atmospheric processes
  – Improved water cycle knowledge and precipitation system evolution
  – Improve ability to observe weather including severe weather
  – Measure rain microphysics

• GPM spaceborne elements:
  – GPM Microwave Imager (GMI)
  – Dual-frequency Precipitation Radar (DPR)
Top Level Implications of GPM Goals

1 of 2

- **Global vs. Tropical**
  - From low inclination to high inclination orbit
    - TRMM at 35 degree orbital inclination, GPM core at 65 degree orbital inclination

- **Rain vs. Precipitation**
  - Measure hydrometeors in all phases
    - Must add high frequency channels to radiometer pick up snow

- **Improved accuracy precipitation retrievals**
  - Use microwave instruments with improved calibration
    - Microwave means low-Earth orbit …

- **Climate study**
  - Add to climate record by tying GPM measurements to past measurements
    - Need methods of intercalibrating multiple instruments
Top Level Implications of GPM Goals 2 of 2

• Storm structure study
  – Requires improved resolution
    • Need larger apertures on radiometer
      – TRMM Microwave Imager (TMI): 0.6 m
      – GPM Microwave Imager (GMI): 1.2 m

• Large scale processes
  – Requires improved spatial coverage
    • Wider swath widths
    • Intercalibration of multiple instruments

• Weather, precipitation process study
  – Requires improved revisit time (goal: 3 hours)
    • Use constellation of multiple instruments
    • Need method of intercalibration

• Rain microphysics
  – Dual frequency radar to infer drop size distributions
GPM Constellation

GPM Constellation Status

- MetOp B/C (EUMETSAT)
- Suomi NPP (NASA/NOAA)
- GPM Core Observatory (NASA/JAXA)
- Megha-Tropiques (CNES/ISRO)
- NOAA 18/19 (NOAA)
- GCOM-W1 (JAXA)
- TRMM (NASA/JAXA)
- JPSS-1 (NOAA)
- DMSP F17/F18/F19/F20 (DOD)

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GPM Core Satellite
Passive Microwave Observations of Precipitation and GMI Innovations
Hydrometeor Observations

• Hydrometeors seen in contrast to underlying surface signal
  – Over cold ocean: hydrometeor emission seen as increase in brightness temperature over cold ocean
    • Rain emission a function of rain rate, frequency
    • Liquid hydrometeor emission largely unpolarized in contrast to polarized ocean surface
  – Over land: hard to see emission in contrast to warm land, so look for precipitation scattering seen as decrease in brightness temperature:
    • Ratio of absorption/emission vs. scattering a function of index of refraction and size parameter
      – Absorption/scattering efficiency comparable when \( \pi D/\lambda \sim 1 \)
      – Hydrometeor sizes:
        » Cloud drop: \( \sim 15 \) microns water, \( \sim 25 \) microns ice
        » Rain drop: \( \sim 0.5 – 5 \) mm; snow: \( .1 – 1 \) cm, hail: \( 0.5 – 1 \) cm
    – So we must go to higher frequencies (mm-wave) to see precip scattering
    – Microwave wavelengths in cm: \( \sim 30/(\text{frequency in GHz}) \)
GMI Incorporates Additional Channels Relative to TMI
Rain over Ocean: Rain Rate/Frequency dependence
Precipitation over Land
Radiometer Calibration: Cold Space and Warm Load Views
Known Issues with Radiometers

• Though robust, past conical scanning radiometers have had issues leading to calibration/observation problems:
  – Emissive reflector
  – Sunlight on hot load, hot load temperature gradients
  – Intrusions in cold sky view – sun, moon, Earth
  – Antenna Pointing offsets – incidence angle angle impact
  – Inaccuracies in prelaunch characterization
    • Sidelobes, spill-over, s/c interference, cross-polarization leakage, non-linearity

  – Driving requirement for GPM: improve retrieval precision, accuracy
    • Must improve calibration accuracy, radiometer stability
      → GMI design and GPM data processing incorporate many innovations to address these issues
Innovations to Address Issues

• Though robust, past conical scanning radiometers have had issues leading to calibration/observation problems:
  – Emissive reflector
    → pre-launch coating tests, thermistors on reflector
  – Sunlight on hot load, hot load temperature gradients
    → Hot load shield, additional thermistors in hot load
  – Intrusions in cold sky view – sun, moon, Earth
    → Shaping and position of cold sky reflector, spacecraft structure
  – Antenna Pointing offsets – incidence angle impact
    → On-orbit analysis to estimate, correct for offsets
  – Inaccuracies in prelaunch characterization
    • Sidelobes, spill-over, s/c interference, cross-polarization leakage, non-linearity
    → On-orbit maneuvers, noise diodes, back-up calibration methods
GPM Microwave Imager - GMI
GMI Cold Sky Reflector and Warm Load
GMI Noise Diodes

• Unlike past conical scanning radiometers, GMI uses not only a hot load and cold sky reflector, but also noise diodes for 10 – 36 GHz channels.
  – Inject a stable source of brightness used as back-up calibration and to compute receiver non-linearity
  – If cold sky reflector or warm load data are corrupted, can use other calibration point plus noise diode as back-up two-point calibration
  – Based on success of GMI diodes, now being used as sole source of warm calibration on multiple missions
GMI Four-Point Calibration
Antenna Offsets and Beam Spoiling: WindSat

Cold After Attitude, Beam Spoiling Correction

Before Attitude, Beam Spoiling Correction
GMI Calibration: Beam Spoiling and Magnetic Interference

Before Correction

After Correction

Cold

Warm

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Intercalibration: Resolving Radiometer Disagreements

Once known calibration issues are addressed, we compare observations from multiple radiometers:

- Observations may not be identical
  - Differences due to known issues (differing frequencies, incidence angles, resolution)
  - Differences may due to unknown issues (calibration issues not tracked down yet)
  - We need a way to compute differences and adjust to develop radiometer to radiometer consistency: \( \rightarrow \) intercalibration

Double Difference (DD) method:

\[
DD = (Obs - Sims)_{\text{Target}} - (Obs - Sims)_{\text{Reference}}
\]

- Obs come from variety of methods – UM method uses vicarious calibration
- Use GMI as reference radiometer
  - Non sun-synch orbit means GMI crosses orbits of all other constellation radiometers
- Simulations use radiative transfer model with parameters from NWP analysis fields
## Vicarious Double Differences with GMI

All values in Kelvins

<table>
<thead>
<tr>
<th>Channel</th>
<th>TRMM TMI</th>
<th>GCOM-W1 AMSR2</th>
<th>DMSP F16 SSMIS</th>
<th>DMSP F17 SSMIS</th>
<th>DMSP F18 SSMIS</th>
<th>DMSP F19 SSMIS</th>
<th>Coriolis WindSat</th>
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<tbody>
<tr>
<td>10v</td>
<td>2.36 (166)</td>
<td>2.46 (284)</td>
<td>-3.51 (158)</td>
<td>0.25 (290)</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<tr>
<td>10h</td>
<td>2.20 (87)</td>
<td>2.53 (292)</td>
<td>-2.98 (83)</td>
<td>0.26 (288)</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<tr>
<td>18v</td>
<td>-0.19 (181)</td>
<td>0.41 (285)</td>
<td>-4.60 (174)</td>
<td>0.62 (290)</td>
<td>-0.38 (174)</td>
<td>1.42 (285)</td>
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<td>18h</td>
<td>0.06 (129)</td>
<td>0.29 (283)</td>
<td>-2.49 (99)</td>
<td>0.86 (289)</td>
<td>0.29 (99)</td>
<td>2.89 (283)</td>
<td>0.41 (99)</td>
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<tr>
<td>23v</td>
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<td>-0.55 (291)</td>
<td>0.56 (188)</td>
<td>1.67 (286)</td>
<td>0.64 (188)</td>
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<tr>
<td>36v</td>
<td>1.93 (204)</td>
<td>1.86 (283)</td>
<td>-2.38 (201)</td>
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<td>2.01 (283)</td>
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<tr>
<td>36h</td>
<td>0.81 (136)</td>
<td>1.77 (282)</td>
<td>-4.37 (130)</td>
<td>-0.08 (287)</td>
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<td>2.74 (282)</td>
<td>0.53 (130)</td>
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<td>89v</td>
<td>1.08 (271)</td>
<td>*</td>
<td>-0.76 (235)</td>
<td>-0.02 (289)</td>
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<td>1.80 (286)</td>
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<td>89h</td>
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<td>-2.24 (177)</td>
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<td>89hb</td>
<td>*</td>
<td>*</td>
<td>-1.74 (177)</td>
<td>-0.22 (289)</td>
<td>*</td>
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</tr>
</tbody>
</table>
Impact of Intercalibration on Science: Mean Global TPW, 1988 - Present

From Wes Berg, Colorado State University
The GPM mission was conceived as the next step in precipitation science beyond TRMM

- Goals are to tie precipitation process on global scale in all phases (liquid, ice) to weather and climate processes
- These goals drive both the design of the GMI instrument as well as how the data are processed
  - GMI includes numerous innovations to improve calibration and stability
  - Data processing focuses on developing a long-term, high temporal resolution dataset by combining multiple instruments through intercalibration
- Though the innovations move forward both the science and engineering of GPM quite a bit, issues remain
  - Future research will focus on eliminating additional sources of radiometer instability as well as refining the intercalibration process to reduce/better quantify uncertainties