Integrated Multi-Satellite Retrievals for GPM (IMERG)

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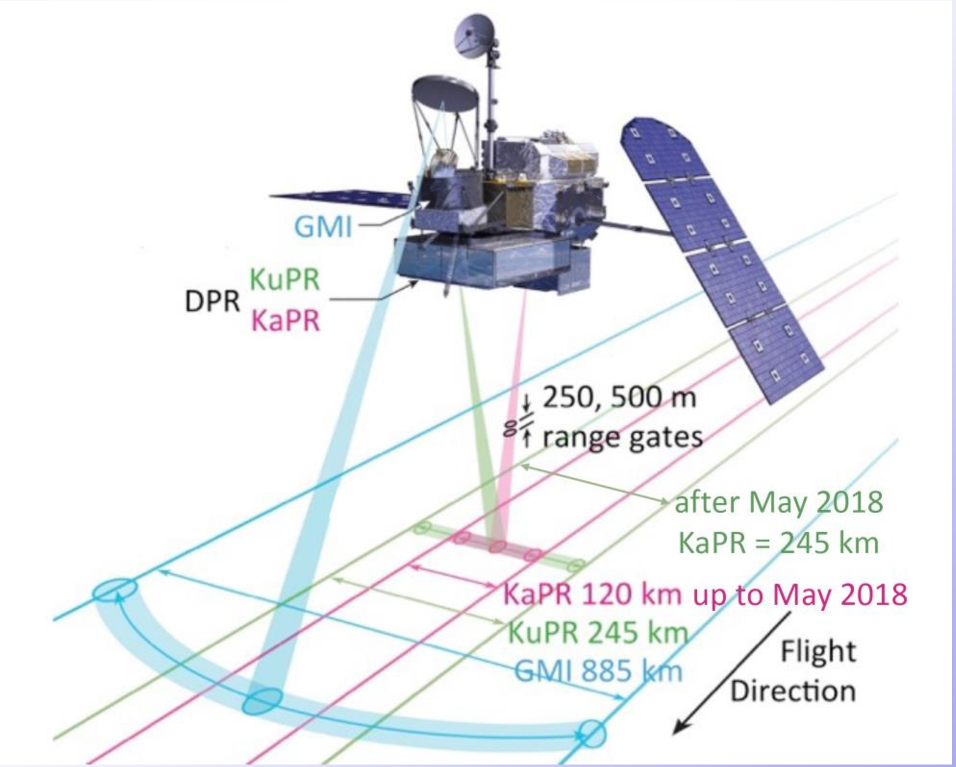
1. Basics – GPM Core Observatory

13-channel GPM Microwave Imager (GMI) provided by NASA

- passive radiometer with excellent calibration
- 10VH, 19VH, 23, 36VH, 89VH, 166VH, 183±3, ±7
- provides observations of precipitation (rain and snow) intensity and distribution over 885 km swath
- high spatial resolution (down to ~5 km footprints)

Dual-frequency Precipitation Radar (DPR) provided by JAXA

- KuPR similar to TRMM, KaPR added for GPM
- provides 3D observations of precipitation structure, precipitation particle size distribution
- high spatial resolution (5 km horiz.; 250 m vertical)



1. Basics – The GPM Constellation

The Core Observatory alone gives really sparse coverage

- DPR gives 1-2 snapshots every 3 days
- GMI gives 1-2 snapshots per day

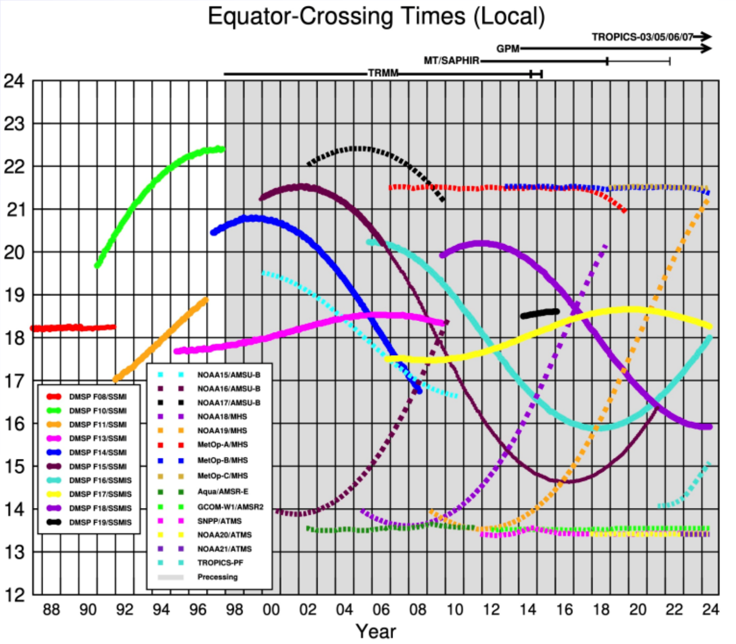
So, we asked other agencies to contribute data

- currently 11 passive microwave sensors
    - includes SSMIS, AMSR2, ATMS, MHS
    - ~3-hourly observations
    - preparing to add new sensors as they are launched – AMSR3, MetOp SG, WSF-M MWI

And then we do interpolation to fill in the gaps

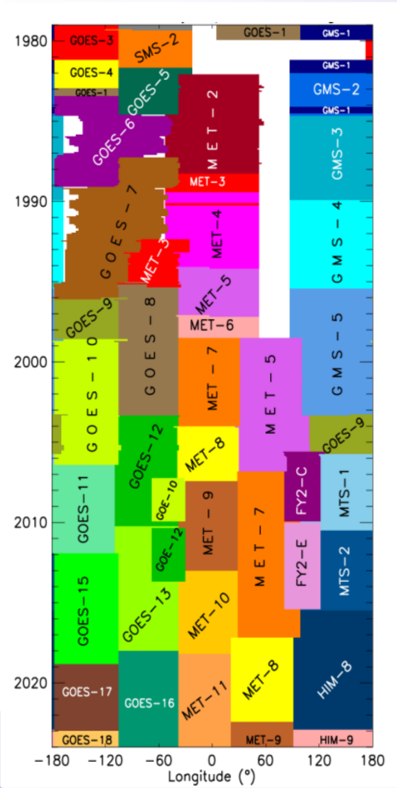
- also global geosynchronous infrared observations as a back-up fill-in

LEO Passive Microwave



Ascending passes (F08, TROPICS-PF descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 24 June 2024, NASA/Goddard Space Flight Center, Greenbelt, MD.
https://gpm.nasa.gov/resources/images/gpm-constellation-overpass-times

GEO IR



Ken Knapp (NCEI)

1. Basics – Single-satellite estimates

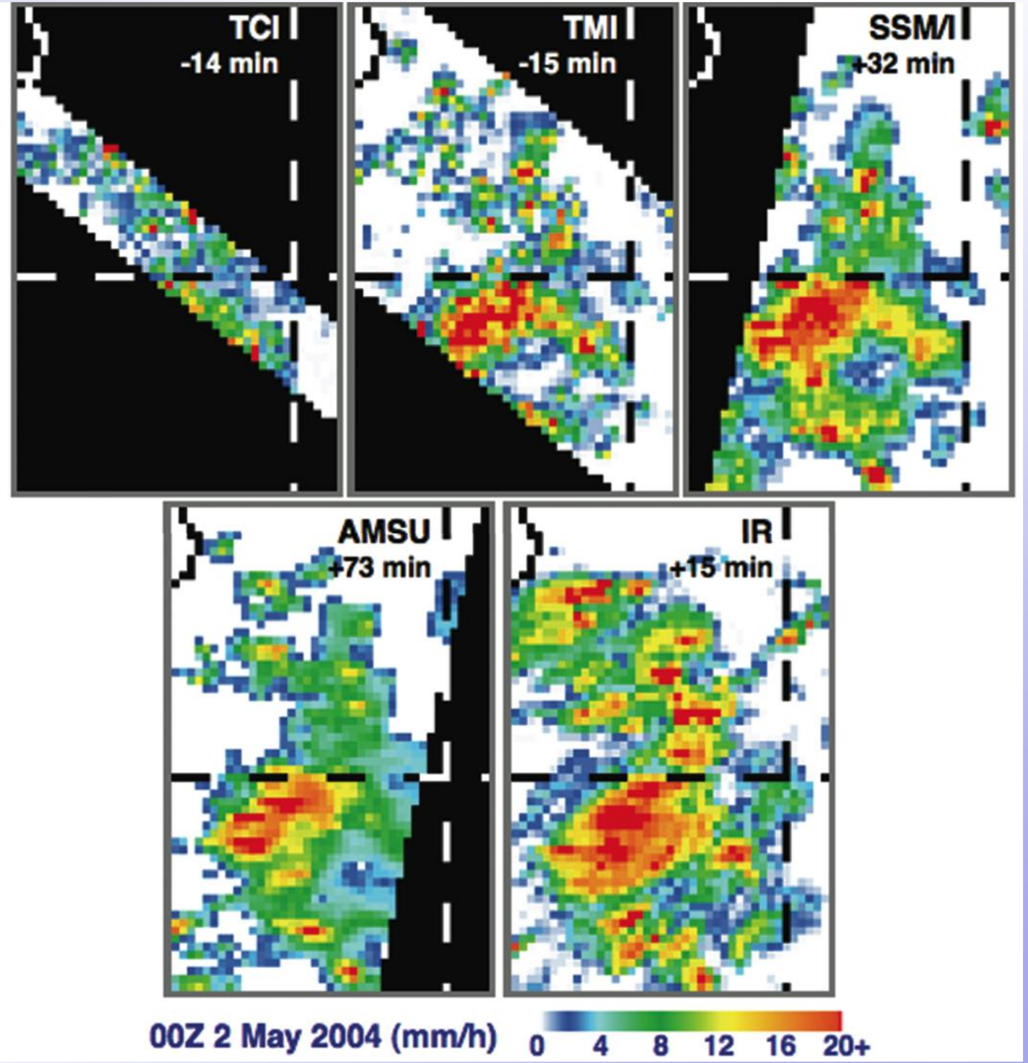
Nearly coincident views by 5 sensors southeast of Sri Lanka

The offset times from 00Z are below the "sensor" name

The estimates are related, but differ due to

- time of observation
- resolution
- sensor/algorithm limitations

Combination schemes try to work with all of these data to create a uniformly gridded product



2. IMERG – Quick description (1/2)

IMERG is a unified U.S. algorithm

- based on code from NASA, NOAA, and U.C. Irvine
- processed at PPS (GSFC)

IMERG is a single integrated code system

- multiple runs for different user requirements for latency and accuracy
  - "Early" – 4 hr (flash flooding)
  - "Late" – 14 hr (crop forecasting)
  - "Final" – 4 months (research)
- time intervals are half-hourly and monthly (Final only)
- 0.1º global CED grid
  - morphed precip 90º N-S
  - IR covers 60º N-S

Datasets listed in *https://gpm.nasa.gov/data/directory*

- access to alternate formats at PPS, GES DISC
- documentation

	Half-hourly data file (Early, Late, Final)
1	*[multi-sat.] precipitation*
2	[multi-sat.] precipitationUncal
3	*[multi-sat. precip] randomError*
4	MWprecipitation
5	MWprecipSource [identifier]
6	MWobservationTime
7	IRprecipitation
8	IRinfluence
9	*[phase] probabilityLiquidPrecipitation*
10	*PrecipitationQualityIndex*
	Monthly data file (Final)
1	*[sat.-gauge] precipitation*
2	*[sat.-gauge precip] randomError*
3	gaugeRelativeWeighting
4	*probabilityLiquidPrecipitation [phase]*
5	*PrecipitationQualityIndex*

2. IMERG – Quick description (2/2)

Overall calibration is provided by TRMM and GPM Combined Radar-Radiometer Algorithm (CORRA)

- TRMM June 2000-May 2014, GPM thereafter
- TRMM-era microwave calibrations over 33ºN-S and
- blend with adjusted monthly climatological GPM-era microwave calibrations over 25º-90º N and S

IMERG is adjusted to GPCP monthly climatology zonally in high-latitude oceans to achieve a “reasonable” bias profile

- the GPM CO product biases are similar (by design)
  - these profiles are systematically low in the extratropical oceans compared to
    - GPCP monthly Satellite-Gauge product, a community standard climate product
    - Behrangi Multi-satellite CloudSat, TRMM, GPM (MCTG) product
- similar issue in the TRMM era

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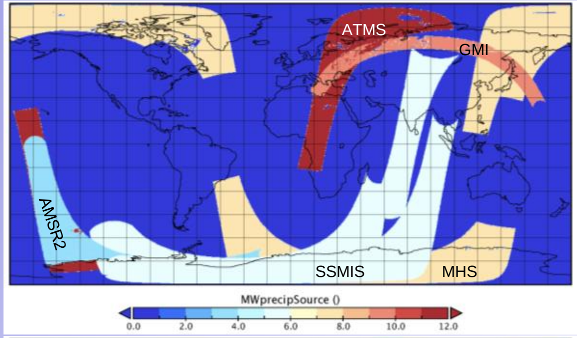
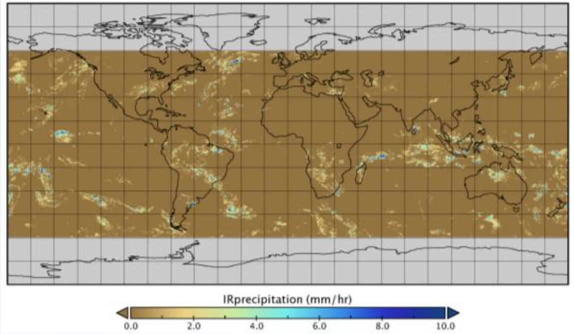
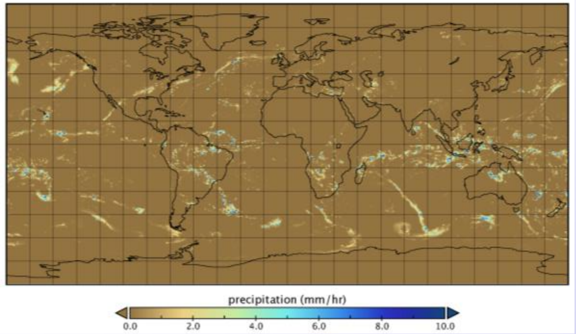
2. IMERG – Examples of Data Fields



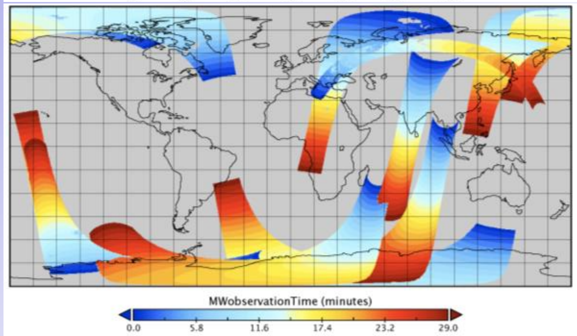




PMW sensor

IR precip

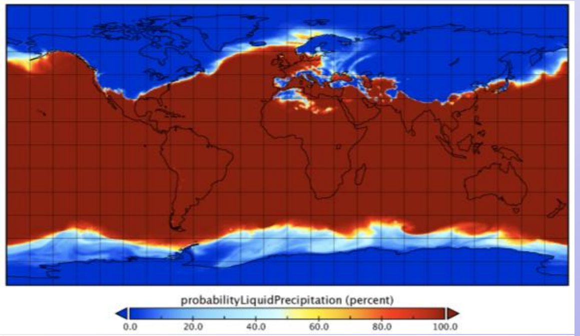
precip (uncal precip)



PMW time into half hour

1 Feb. 2023 00:00-00:30 UTC

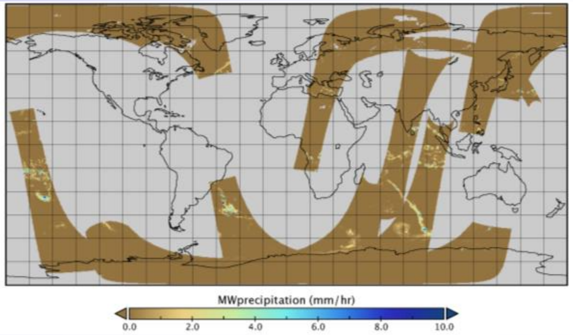
probability of liquid phase

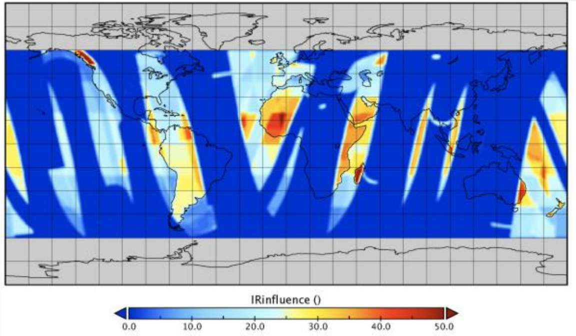


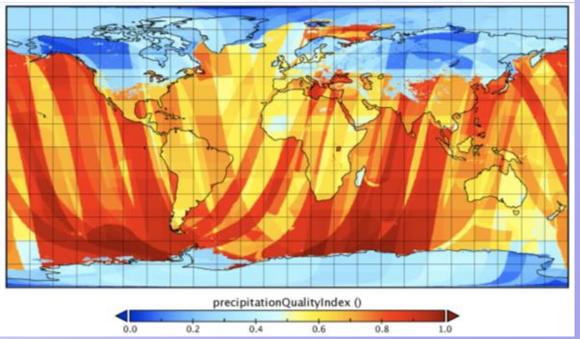
PMW precip

IR weight

Quality Index



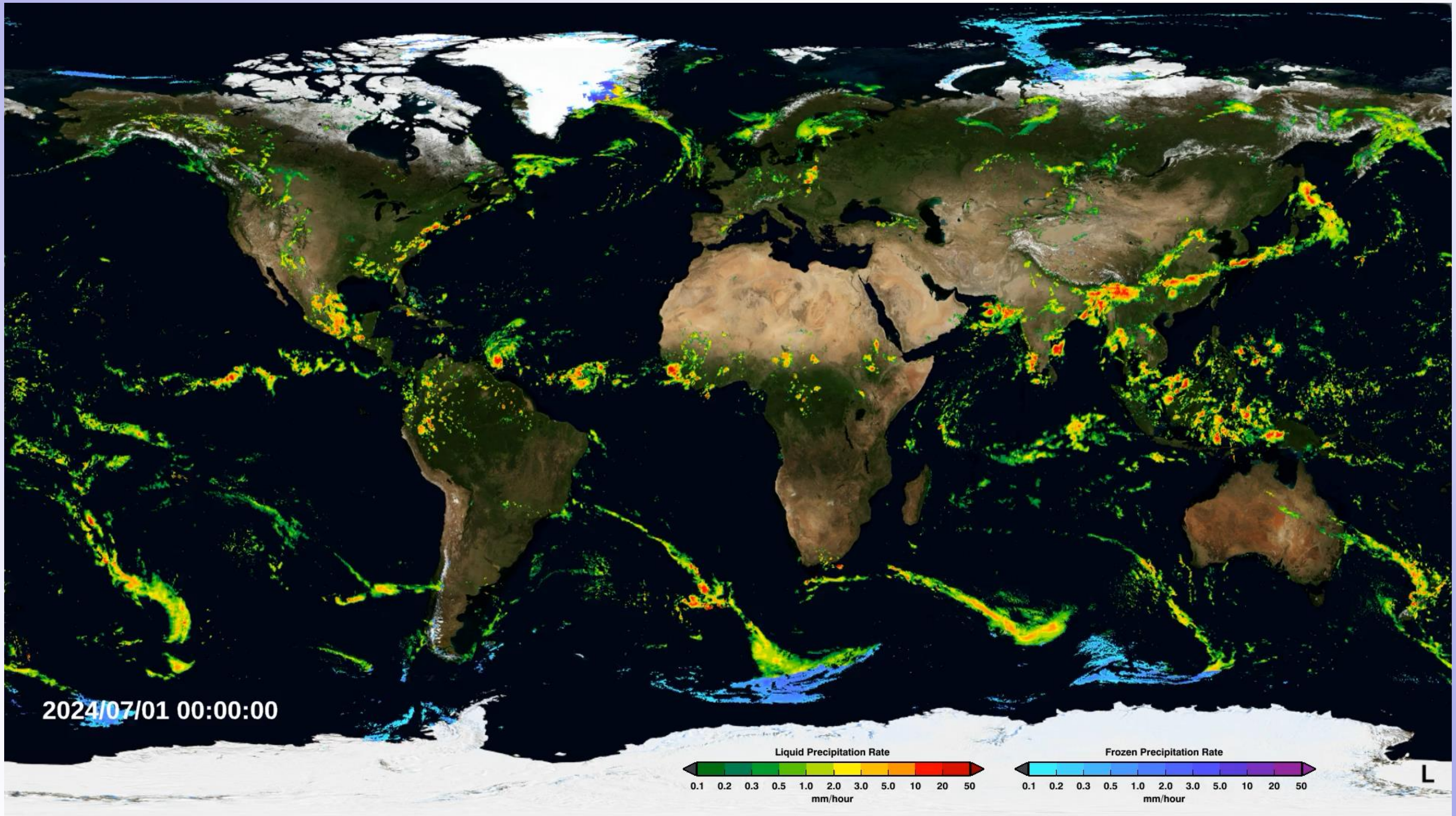




2. IMERG – Recent week visualization

Updated on the web every hour: *https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4285*

Rain/snow determined with 50% threshold on probabilityLiquidPrecipitation



2. IMERG – Data Access

NASA resources require a free, automatic registration

Datasets listed in *https://gpm.nasa.gov/data/directory*

- the page gives access to the various data levels of GPM and "related" data
- IMERG is under the "Level 3" tab
- documentation
- access to the native-format (HDF5) and all "value-added" variants of the datasets through NASA sites

Spatial and variable subsetting for native-format datasets

Giovanni provides an on-line display and analysis capability for IMERG and other NASA data

- download analysis graphics or data
- excellent check on your custom code's ingest of IMERG data

"Contact Us" link at the bottom of each web page

Level 3 | Level 2 | Level 1 | Related Datasets

Geophysical parameters that have been spatially and/or temporally resampled from Level 1 or Level 2 data.

IMERG Early Run

Near real-time low-latency gridded global multi-satellite precipitation estimates

IMERG Late Run

Near real-time gridded global multi-satellite precipitation estimates with quasi-Lagrangian time interpolation

IMERG Final Run

Documentation:

- IMERG V07 Release Notes
- IMERG V07 Technical Documentation
- IMERG V07 ATBD
- IMERG GIS / GeoTIFF Documentation
- File Specification for GPM Products

Data Source	Instruments	Primary Unit / Variable	Data Format(s)	Temporal Resolution	Instructions / Notes	Download URL
GES DISC	Multisatellite	Precipitation Rate (mm/hr) / precipitationCal	Visualization, GeoTIFF, HDF5, NetCDF, OPeNDAP	30 Minute, 1 Day	• On GES DISC site, see gray "Data Access" box in top right for download links • To generate data visualizations, click the blue "Giovanni" button • Allows for data subsetting	30 Minute: https://disc.gsfc.nasa.gov/datasets/GPM 1 Day: https://disc.gsfc.nasa.gov/datasets/GPM_3II
PPS Near Real-time	Multisatellite	Precipitation Rate (mm/hr) / precipitationCal	HDF5	30 Minute	• Click here to register for PPS data access • Files located in ./[yyyymm]/ • Data access is also available via FTPS, click here for instructions.	https://jsimpsonhttps.pps.eosdis.nasa.gov/imerg/ea
PPS Near Real-time	Multisatellite	Precipitation Accumulation (mm)	GeoTIFF	30 Minute, 3 Hour, 1 Day	• Click here to register for PPS data access • Read documentation for using IMERG GeoTIFF + Worldfiles • 30 minute, 3 hour, and 1 day files are all available in the same directory, with the timespan indicated within the filename (e.g. 3B-HHR-	https://jsimpsonhttps.pps.eosdis.nasa.gov/imerg/gis

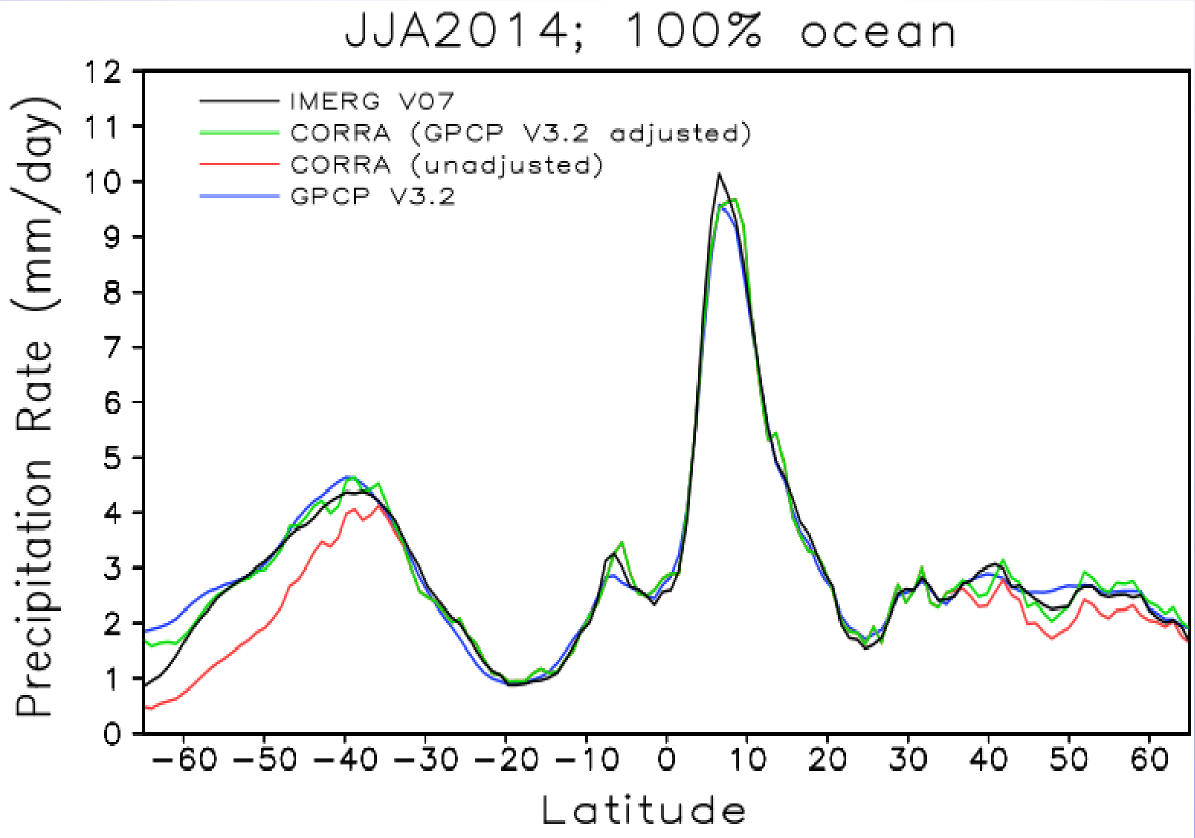
3. Results – Calibration

Calibration sequence is

- CORRA climatologically calibrated to GPCP over ocean outside 30ºN-S
- TMI/GMI calibrated to CORRA on 45-day rolling matchups
- GPM constellation climatologically calibrated to TMI/GMI

Adjustments working roughly as intended

- CORRA is low at higher latitudes
- adjustments in Southern Ocean are large and need analysis
    - IMERG subsetted to coincidence with CORRA is much closer to CORRA

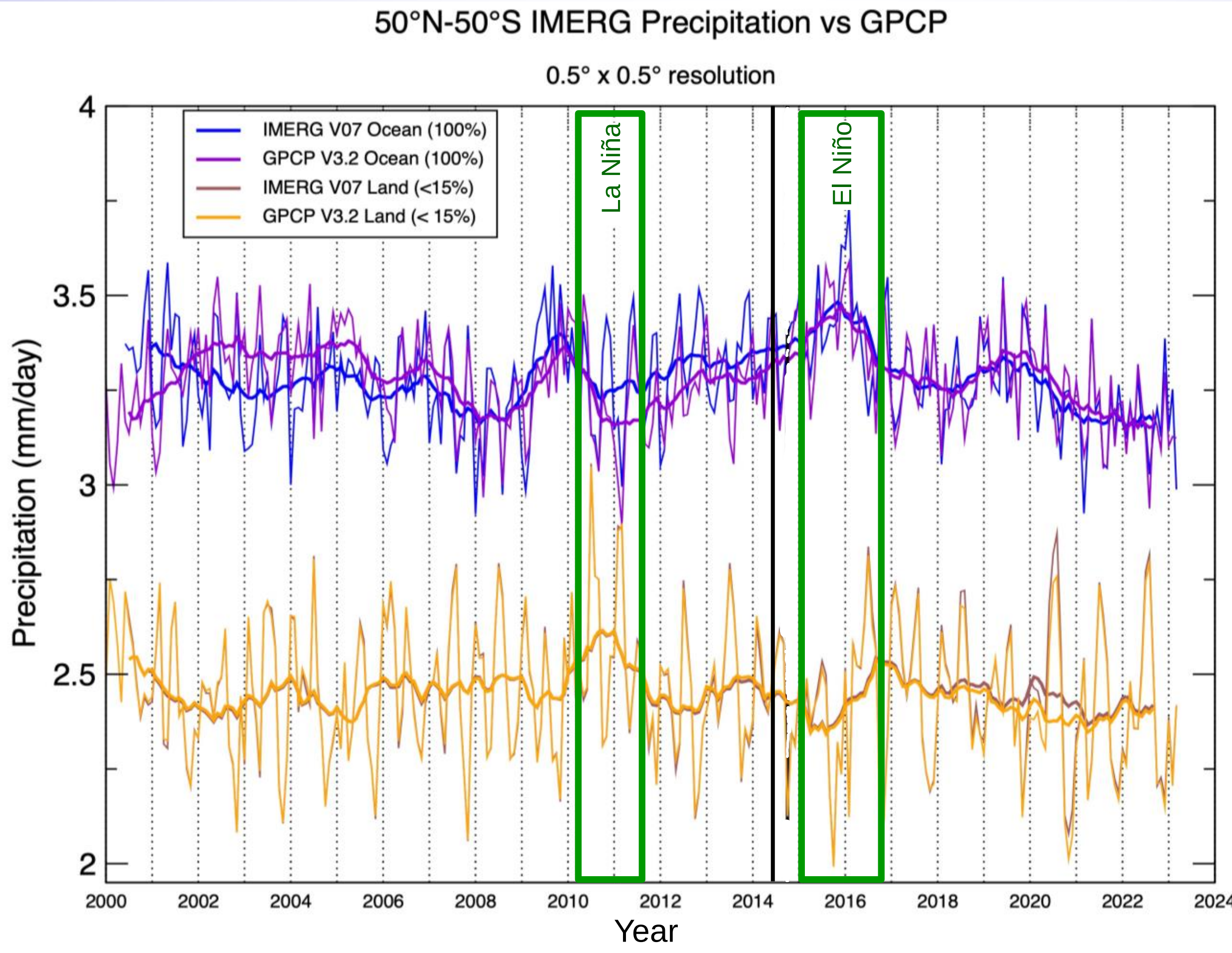


R. Joyce (SSAI; GSFC)

3. Results – Time series for land and ocean averaged each month over 50ºN-S

GPCP and IMERG-Final for 2000-2023, 50ºN-S

- the solid line in 2014 is the shift from TRMM to GPM calibration
- the heavy line has a running 13-month boxcar smoother
- land curves are very similar because
  - they use the same gauge information
  - gauges tend to dominate
- ocean is rather similar despite vastly different algorithms
  - interesting interannual differences
- land and ocean move in opposite directions in ENSO events
- GPCP is preferred for climate analysis – more homogeneous



Eric Nelkin (SSAI; GSFC)

3. Results – Histogram time series

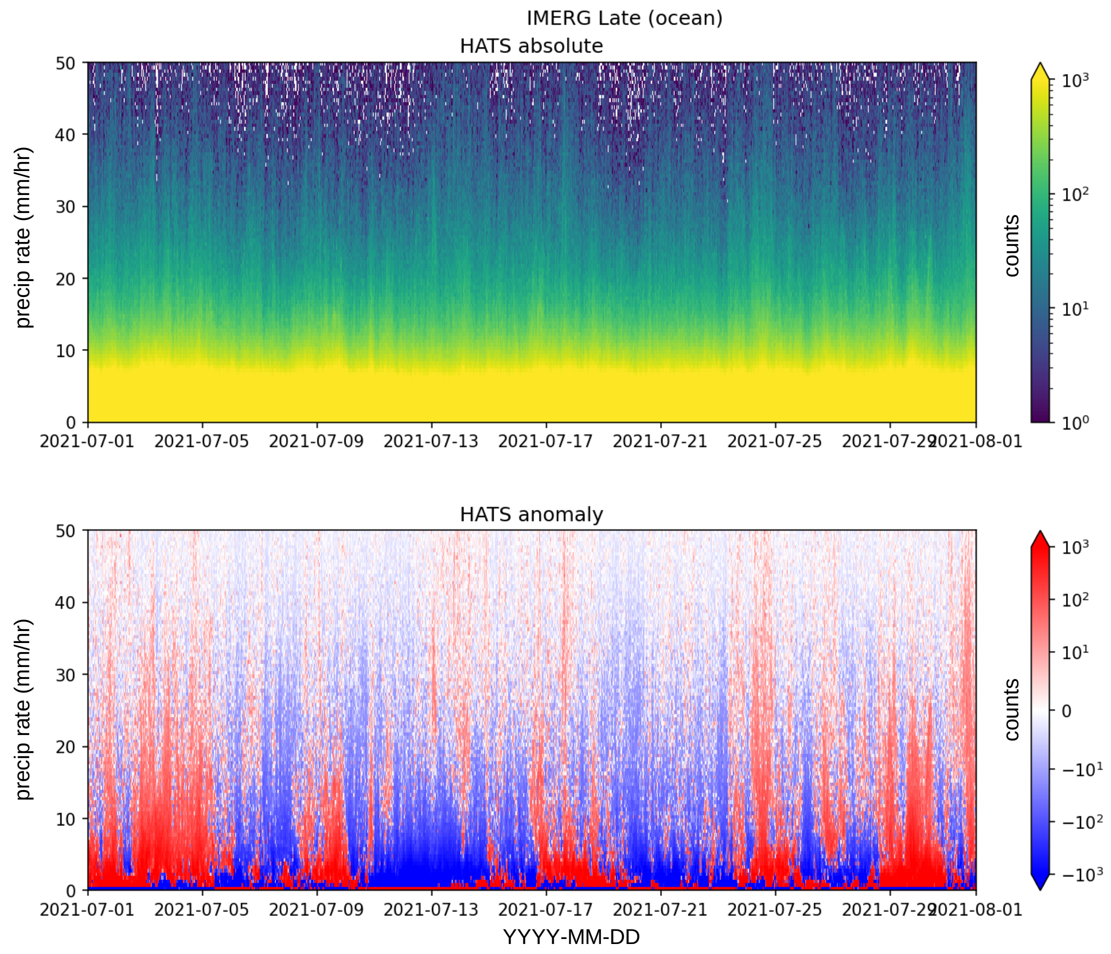
The time series of histograms gives more information about fluctuations

- counts per histogram bin are colorized logarithmically

The behavior is much clearer for anomalies from the time-average counts in each bin

- counts are again logarithmic (except close to zero)
- Histogram Anomaly Time Series (HATS)
- Potter et al., 2020, *BAMS*, 10.1175/BAMS-D-20-0130

This example is for V06 IMERG Late half-hourly data over ocean, 50°N-S, July 2021



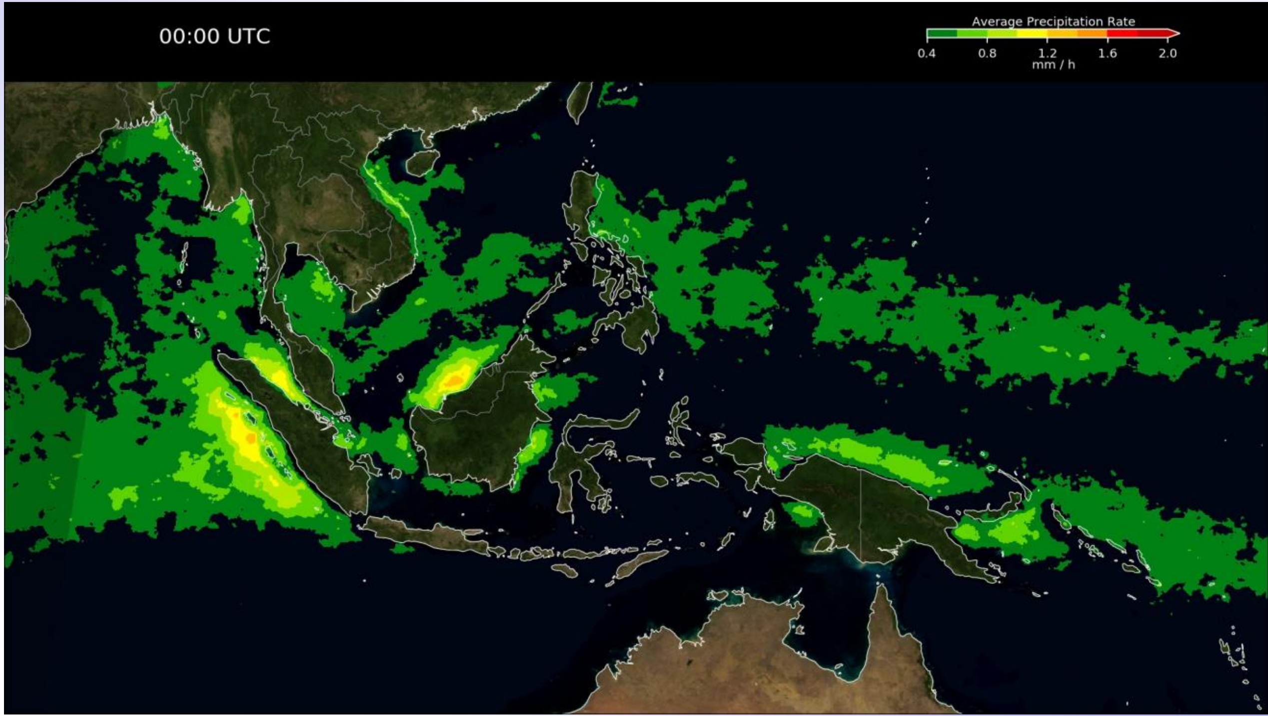
3. Results – Late Run, September-November Diurnal Cycle, Maritime Continent

Average September-November for 2001 to 2018, V06 Late Run

- day/night shading
- Blue Marble land
- smoothed in space and time
  - even 18 years of seasonal data still has lumps

Interesting behavior that spans land and ocean thanks to using satellite data

- coasts show systematic propagation
- but it dies out and the open ocean has an early morning maximum
- note maxima in concave coastal areas (western Papua New Guinea)



J. Tan (UMBC; GSFC)

3. Results – Final Run, June-August Diurnal Cycle in Central U.S. (GPM Era)

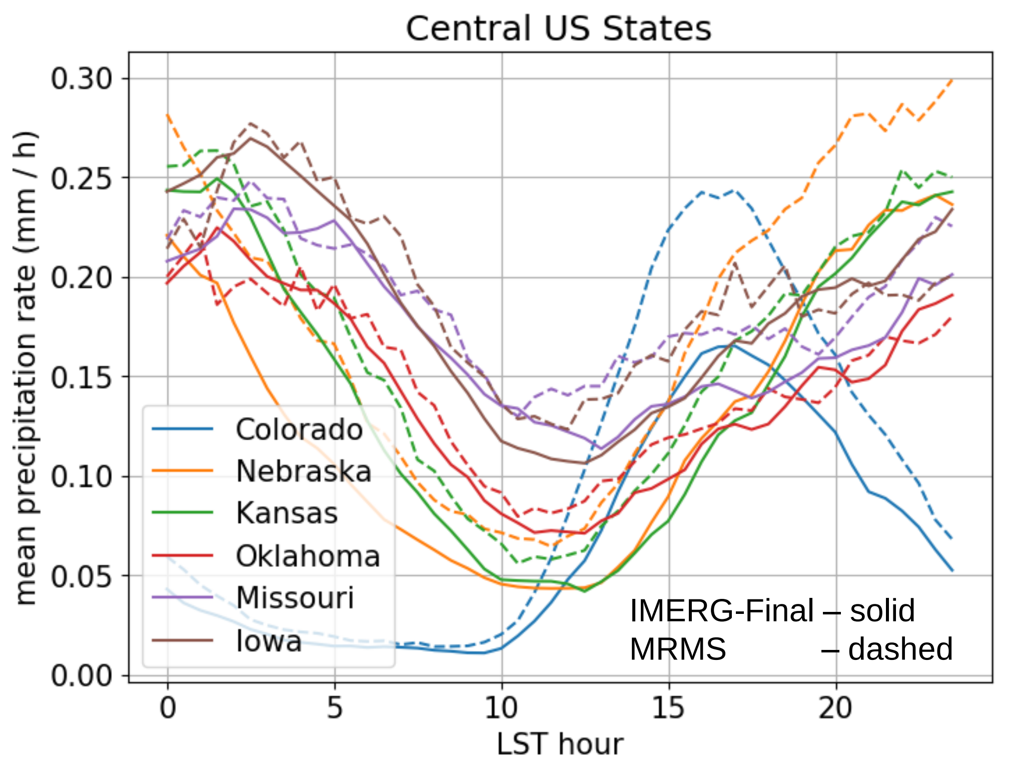
Average June-August for 2014 to 2018 (5 summers) for 6 states, V06 Final Run

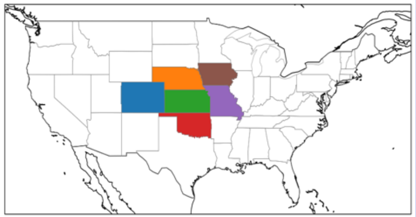
- V07 not yet analyzed

Compared to Multi-Radar Multi-Sensor (MRMS, dashed), Final (solid) shows:

- lower averages (despite use of gauge data)
- lower amplitude cycle in Colorado
- higher amplitude cycle in Iowa
- very similar curve shapes, peak times

This version of MRMS only starts in 2014, so an extended comparison requires different data



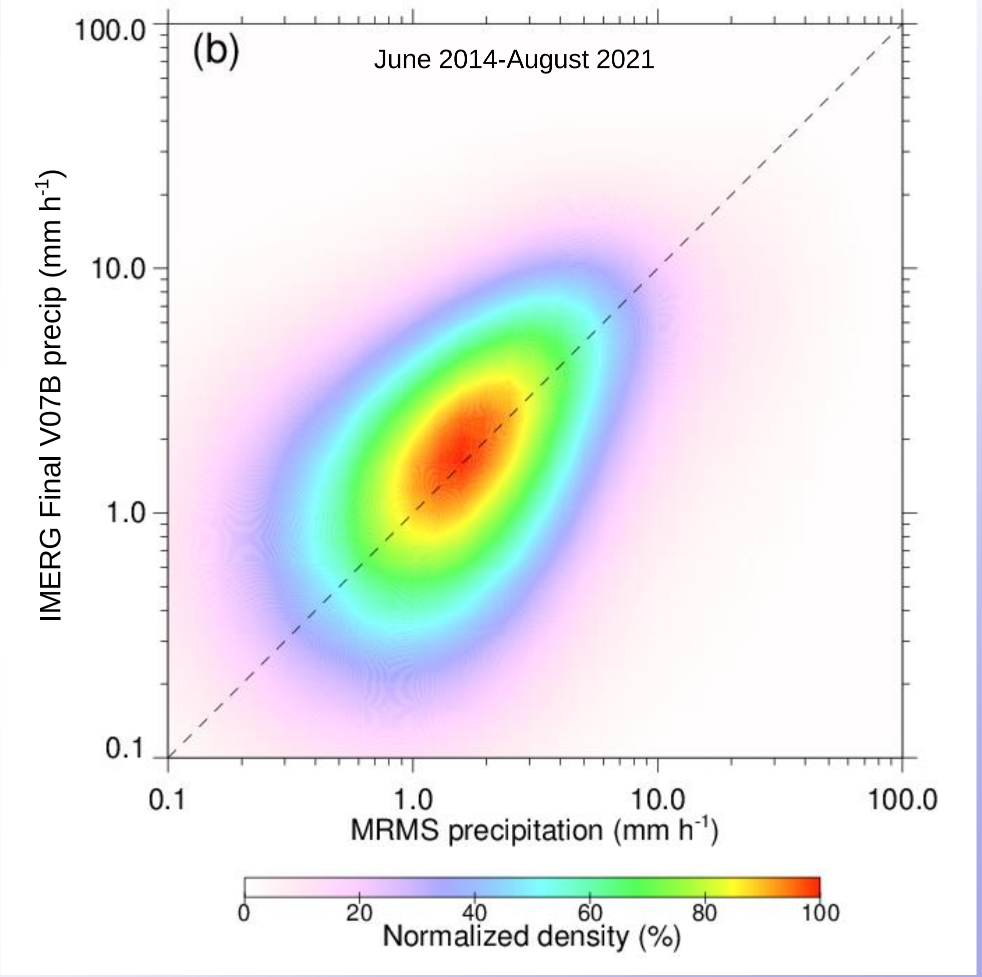


J. Tan (UMBC; GSFC)

3. Results – IMERG Final V07 Over CONUS

IMERG bias varies by location and weather regime, but in general

- comparison to MRMS over CONUS at half-hourly 0.1° scale
- June 2014-August 2021 without January-May 2016, August 2017-February 2018 (12 months of missing/bad MRMS out of 87)
- relative bias = -8.10%
- NMAE = 0.8140 (mm/h)
- NRMSE = 1.7331(mm/h)
- corr = 0.345

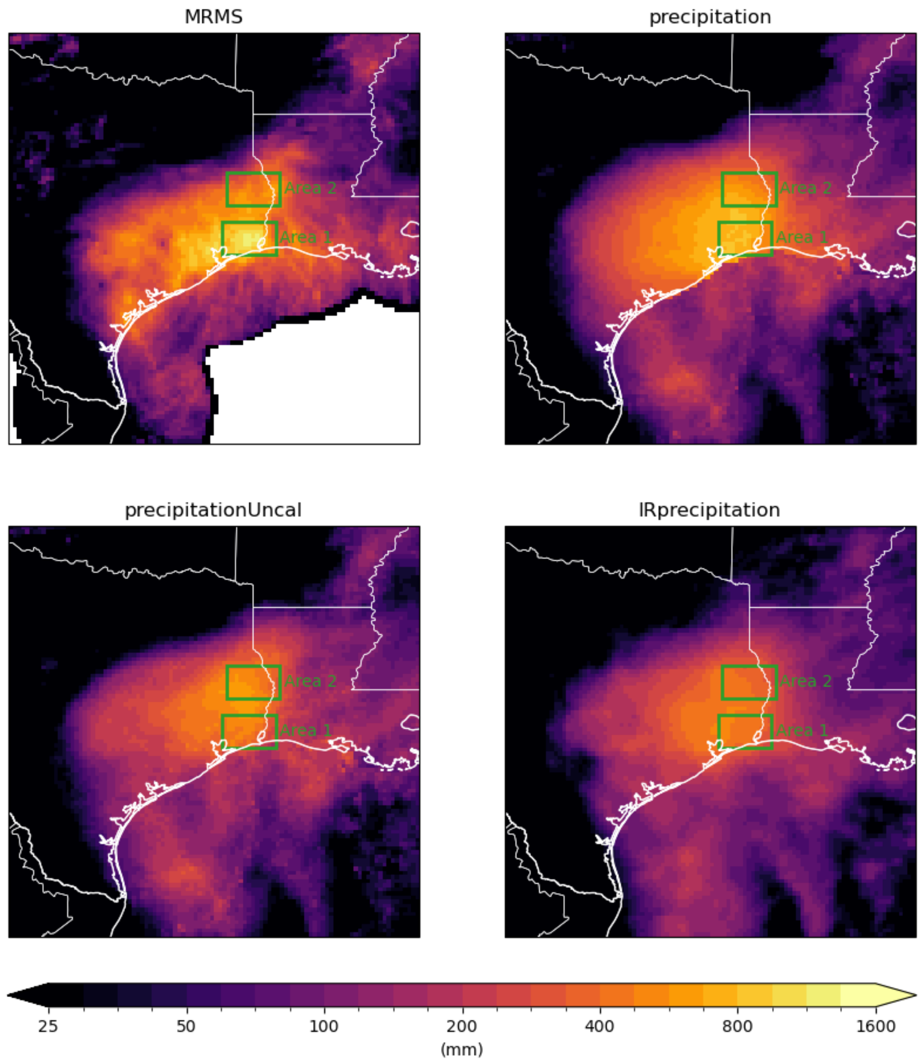


Jianxin Wang (SSAI; WFF)

3. Results – Hurricane Harvey, 25-31 August 2017, V07B IMERG Final and MRMS (1/2)

Harvey loitered over southeast Texas for a week

- MRMS considered the best estimate
  - some questions about the details of the gauge calibration of the radar estimate
  - over land
- Uncal (just the intercalibrated satellite estimates)
  - Area 1 underestimate of ~50%
  - Area 2 overestimate of ~4%
- Cal (with gauge adjustment) boosts values in both areas
  - Area 1 underestimate of ~14%
  - Area 2 overestimate of ~ 15%
- microwave-adjusted PERSIANN-CCS IR has the focus too far west

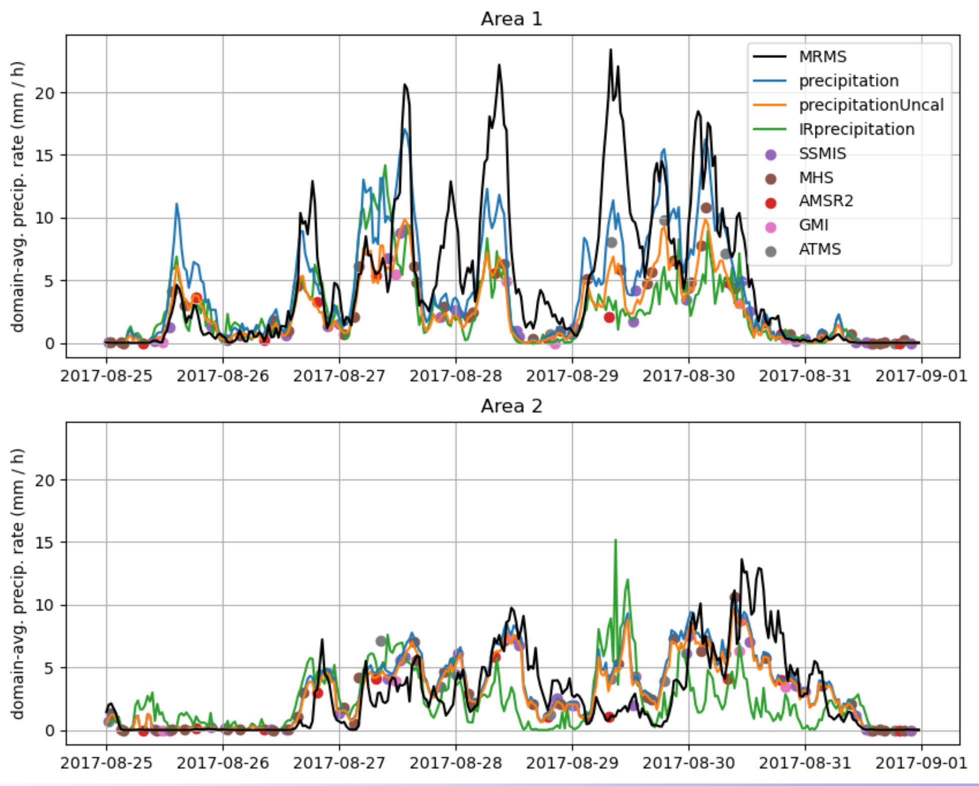


J. Tan (UMBC; GSFC), after Huffman et al. (2020)

3. Results – Hurricane Harvey, 25-31 August 2017, V07B IMERG and MRMS (2/2)

IMERG largely driven by microwave overpasses (dots)

- except only use 1 of multiple swaths in a ½ hour
- not just time interpolation
  - systems move into / out of the box between overpasses
- satellites show coherent differences from MRMS
  - PMW only "sees" the solid hydrometeors (scattering channels), since over land
  - IR looks at Tb within "clustered" data
  - both are calibrated to statistics of time/space cubes of data
    - Cal is basically *(Uncal x factor)*
  - short-interval differences show some cancellation over the whole event
    - but several-hour differences can be dramatic

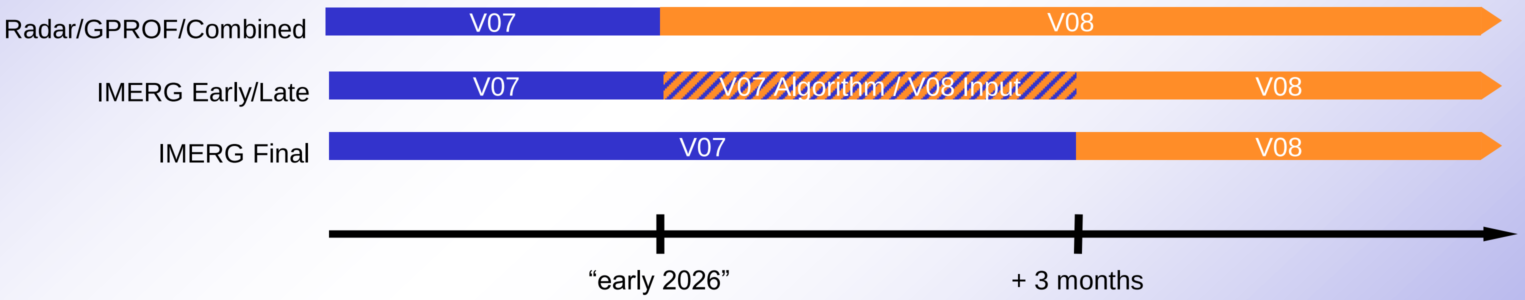


J. Tan (UMBC; GSFC), after Huffman et al. (2020)

4. Looking Ahead to Version 08 – Schedule

The Version 08 release is scheduled for "early 2026"

- radar, GPROF, and Combined reprocessings start first
- at the same time:
  - IMERG Early and Late Runs must shift from V07 to V08 GPROF and Combined near-real-time inputs
  - IMERG Final Run is suspended to maintain homogeneous inputs
- 3 months later: IMERG Final Run reprocessing starts for V08
- 3-4 months later (after Final is done): IMERG Early and Late Runs shift to V08, with retrospective processing at about the same time



Questions? george.j.huffman@nasa.gov

5. References

Bolvin, D.T., G.J. Huffman, E.J. Nelkin, J. Tan, 2021: Comparison of Monthly IMERG Precipitation Estimates with PACRAIN Atoll Observations. *J. Hydrometeor.*, **22**, 1745-1753. *doi:10.1175/JHM-D-20-0202.1*

Huffman, G.J., D.T. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, C. Kidd, E.J. Nelkin, S. Sorooshian, E.F. Stocker, J. Tan, D.B. Wolff, P. Xie, 2020: Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement (GPM) mission (IMERG). Chapter 19 in *Adv. Global Change Res., Vol. 67, Satellite Precipitation Measurement*, V. Levizzani, C. Kidd, D. Kirschbaum, C. Kummerow, K. Nakamura, F.J. Turk (Ed.), Springer Nature, Dordrecht, ISBN 978-3-030-24567-2 / 978-3-030-24568-9 (eBook), 343-353. *doi:/10.1007/978-3-030-24568-9_19*

Potter, G., G.J. Huffman, D.T. Bolvin, M.G. Bosilovich, J. Hertz, Laura E. Carriere, 2020: Histogram Anomaly Time Series: A Compact Graphical Representation of Spatial Time Series Data Sets. *Bull. Amer. Meteor. Soc.*, **101**, E2133-E2137. *doi:10.1175/BAMS-D-20-0130*

Rajagopal, M., E. Zipser, G.J. Huffman, J. Russell, J. Tan, 2021: Comparisons of IMERG Version 06 Precipitation At and Between Passive Microwave Overpasses in the Tropics. *J. Hydrometeor.*, **22**(8), 2117–2130. *doi:10.1175/JHM-D-20-0226.1*

Tan, J., G.J. Huffman, D.T. Bolvin, E.J. Nelkin, M. Rajagopal, 2021: SHARPEN: A Scheme to Restore the Distribution of Averaged Precipitation Fields. *J. Hydrometeor.*, **22**(8), 2105–2116. *doi:10.1175/JHM-D-20-0225.1*

Tan, J., G.J. Huffman, Y. Song, 2024: Automated Quality Control Scheme for GPM Satellite Precipitation Products. *Geophys. Res. Lett.,* in revision.

Watters, D.C., G.J. Huffman, P.N. Gatlin, D.T. Bolvin, R. Joyce, P. Kirstetter, E.J. Nelkin, J. Tan, D.B. Wolff, 2024: Error Tracing of IMERG-GMI Oceanic Precipitation. *J. Hydrometeor.*, submitted.

Questions? george.j.huffman@nasa.gov

Supplementary slides

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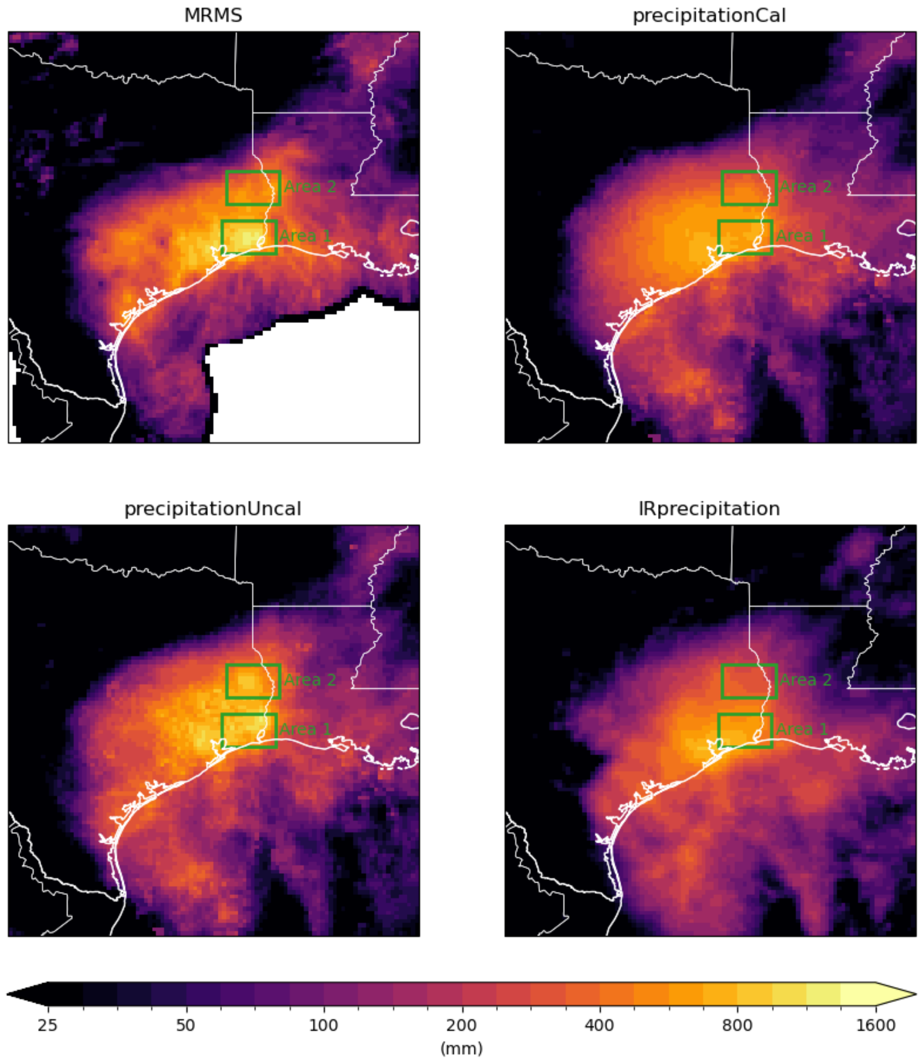

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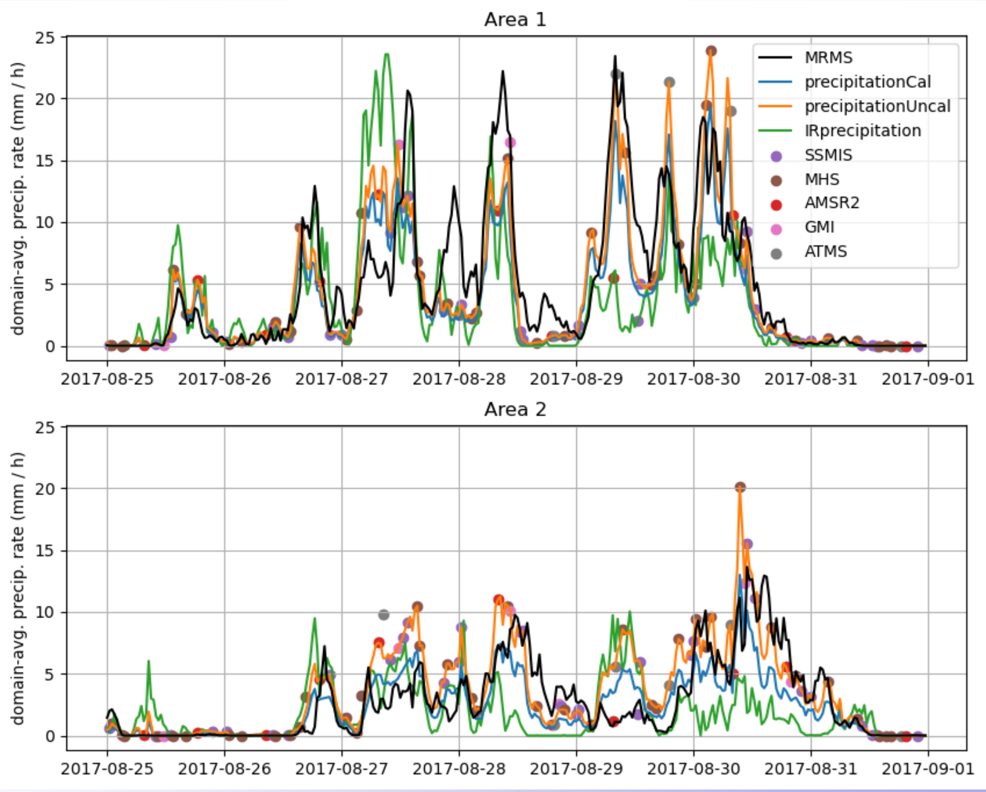

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