Reaching for 20 Years with the IMERG Multi-Satellite Products

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1. IMERG – Quick Description

IMERG is a single integrated code system for near-real and post-real time

- "Early" – 4 hr (flash flooding)
- "Late" – 14 hr (crop forecasting)
- "Final" – 3 months (research)
- half-hourly and monthly (Final only)
- 0.1º global CED grid
  - morphed precip, 60º N-S in V05, 90º N-S in V06

Combined product (calibrator) adjusted to GPCP V2.3 seasonal climatology zonally for reasonable bias

- GPM core products have similar bias (by design)
  - these profiles are systematically low in the extratropical oceans compared to
    - GPCP V2.3 SG product
    - Behrangi Multi-satellite CloudSat, TRMM, Aqua (MCTA) product
- over land GPCP adjustment provides a first cut at the adjustment to gauges used in the Final

	Half-hourly data file (Early, Late, Final)
1	*[multi-sat.] precipitationCal*
2	[multi-sat.] precipitationUncal
3	*[multi-sat. precip] randomError*
4	[PMW] HQprecipitation
5	[PMW] HQprecipSource [identifier]
6	[PMW] HQobservationTime
7	IRprecipitation
8	IRkalmanFilterWeight
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*

1. IMERG – V06 Upgrades

Morphing vector source switched to MERRA-2/GEOS FP

Morphed precip extended from 60º N-S (V05 and earlier) to 90º N-S, *but*

- masked out for icy/snowy surfaces

Half-hourly Quality Index modified

- t=0 values estimated (set to 1 in V05)
- shifted to 0.1º grid (0.25º in V05)

Full intercalibration to Combined Radar-Radiometer Algorithm (CORRA)

- V05 took shortcuts

Modifications for TRMM era

- compute calibrations for older satellites against TRMM
  - compute TRMM-era microwave calibrations in the band 33ºN-S and
  - blend with adjusted monthly climatological GPM-era microwave calibrations over 25º-90º N and S

Revisions to internals raises the maximum precip rate from 50 to 200 mm/hr and no longer discrete

- files bigger due to less compressibility
- allows really tiny numbers

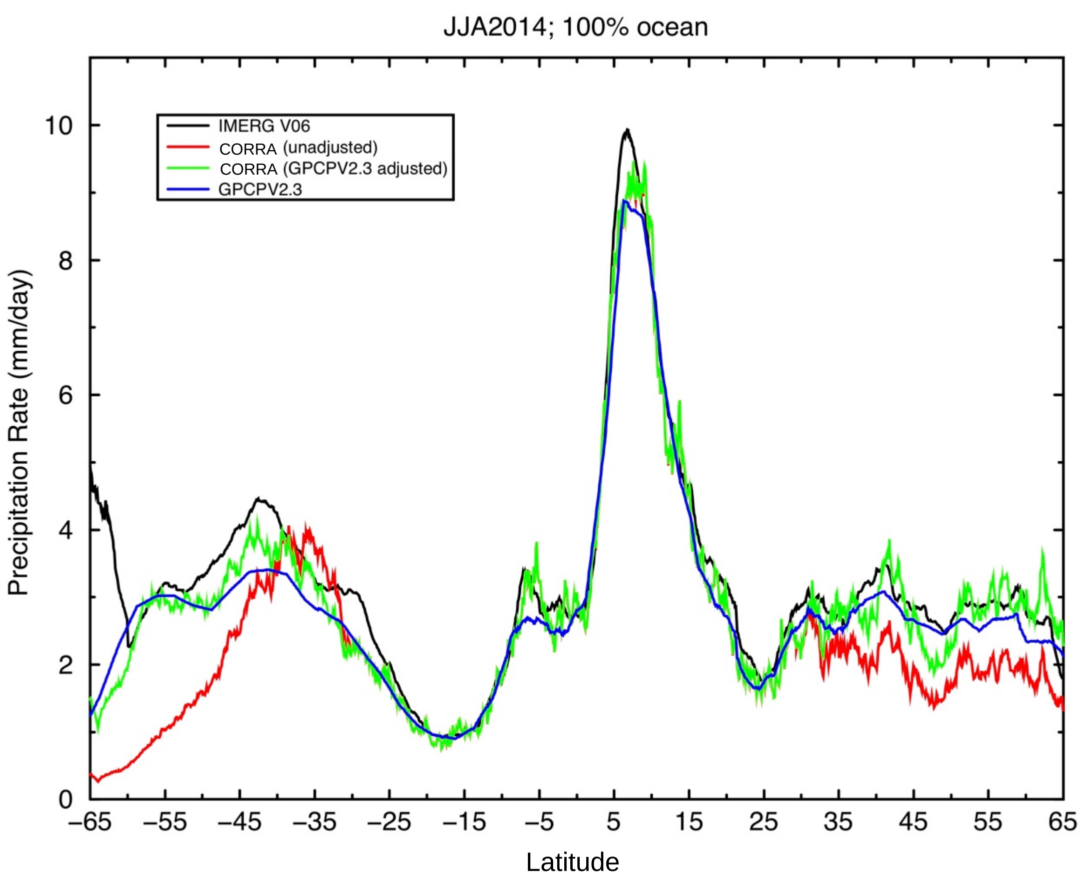
2. Early Results – Calibration

Calibration sequence is

- CORRA climatologically calibrated to GPCP over ocean outside 30ºN-S
- GMI calibrated to monthly CORRA
- GPM constellation climatologically calibrated to 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 (adjusted) CORRA



D. Bolvin (SSAI; GSFC)

2. Early Results – Ocean (50ºN-S) Precip Timeseries

V06 Final Run starts June 2000

V06 is higher than 3B43 (TMPA) and GPCP over ocean

TRMM-era IMERG has a strong semi-annual signal

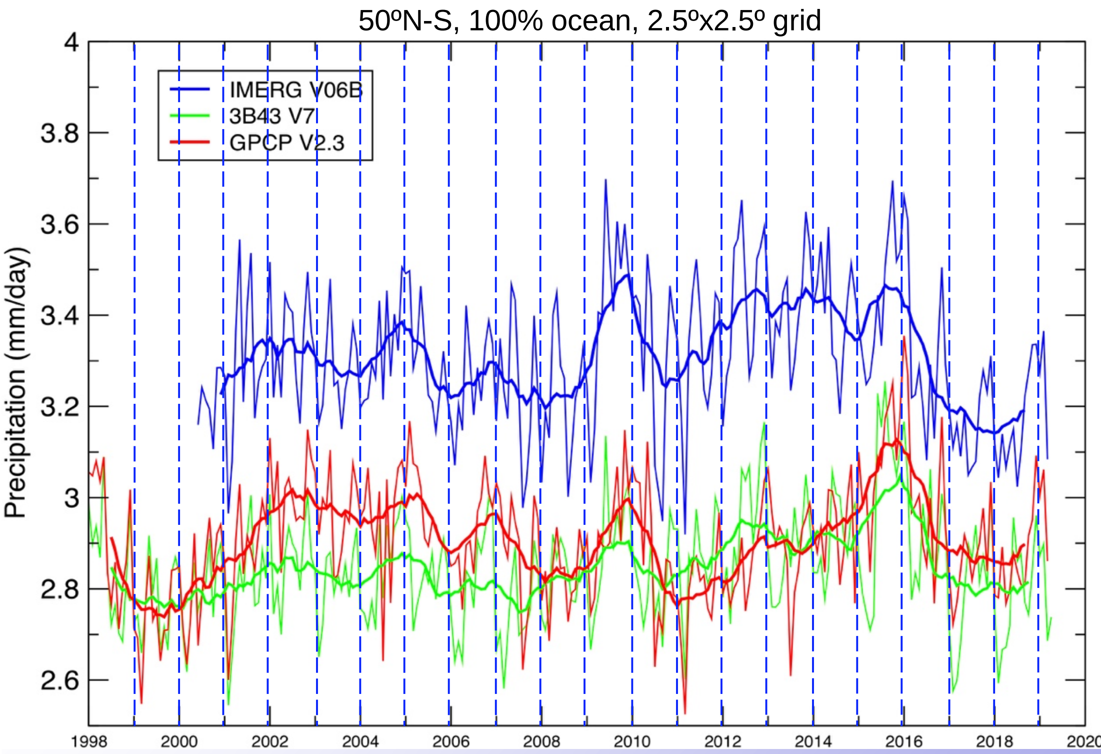
- GPM-era IMERG and 3B43 dominated by the annual cycle

Interannual variation

- has similar peaks/troughs for all datasets
- GPCP (passive microwave calibration) lags phase of 3B43 (through 2013), IMERG (both PMW/radar calibration)
- after September 2014, 3B43 (PMW calibration) matches GPCP phase

Additional multi-year variations

- IMERG and 3B43 are High Resolution Precipitation Products, not CDRs



E. Nelkin (SSAI; GSFC)

2. Early Results – Tropical Ocean (20ºN-S) Monthly Precip Histogram Timeseries

Histogram of Final Run monthly tropical oceanic precip on 0.1º grid, 20º N-S (top)

- log(counts) to help draw out small values

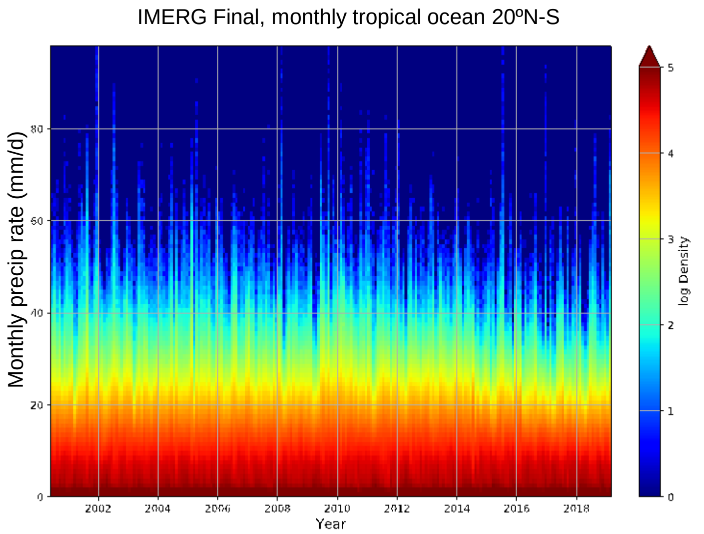
Anomaly helps guide interpretation (bottom)

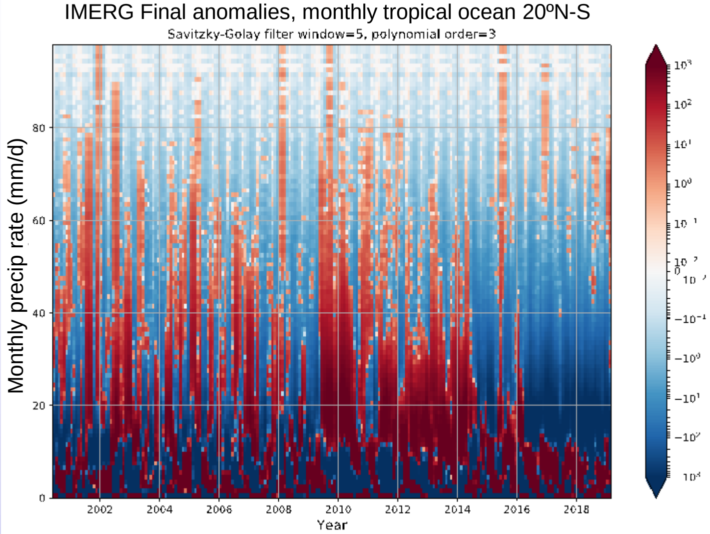
- log scale in both directions from zero
- filtered in time to emphasize main features

Initial impressions

- mid-to-high rates sometimes (2009-10) vary together, but not always (2006-07)
- lower rates tend to vary in the opposite direction
- start of GPM calibration (June 2014) seems to shift the PDF to lower rates
- persistent mid-range positive anomalies in 2009-14 remain to be explained

This discussion will help determine reliability for trend analysis





G. Potter (USRA; GSFC)

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

Average September-November for 2001 to 2018, Late Run

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

Reminiscent of IMERG V05, but

- less “flashing” due to inter-satellite differences and morphing
- better data coverage at higher latitudes (not seen here)

J. Tan (USRA; GSFC)

Reminiscent of TMPA, but

- more detailed, broader spatial coverage
- no interpolations between the 3-hourly times
- less IR-based precip used (which tends to have a phase lag)

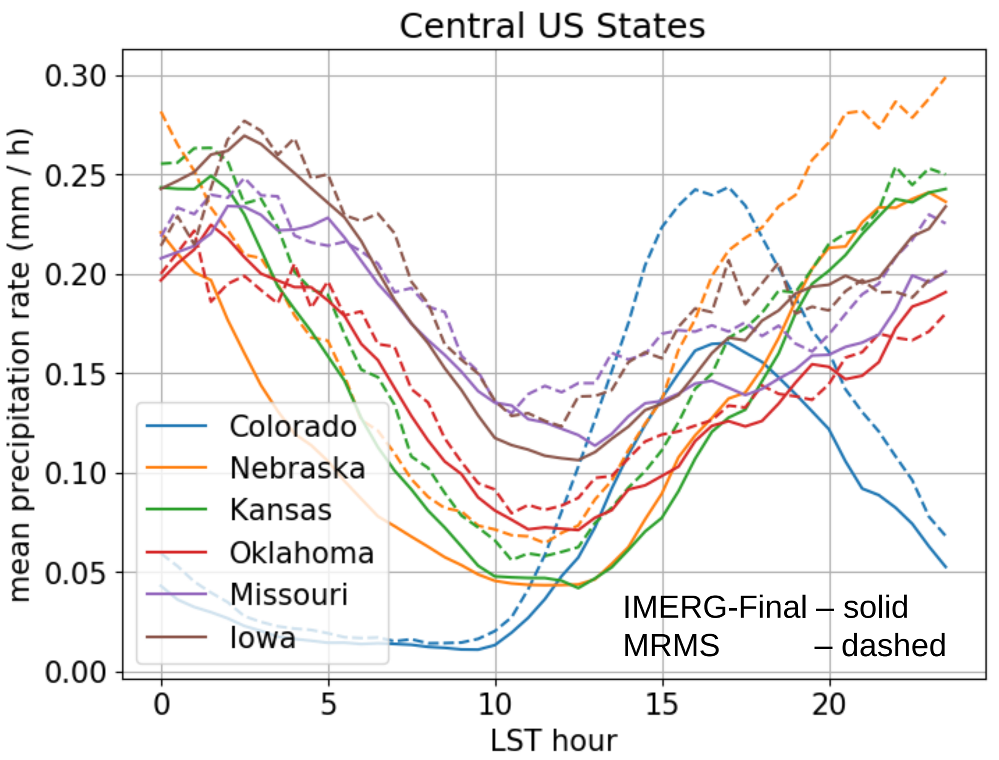
2. Early Results – Final Run, June-August Diurnal Cycle in Central U.S. (GPM Era)

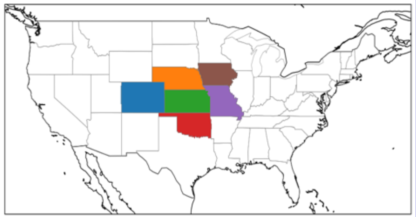
Average June-August for 2014 to 2018 (5 summers) for 6 states, Final Run

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





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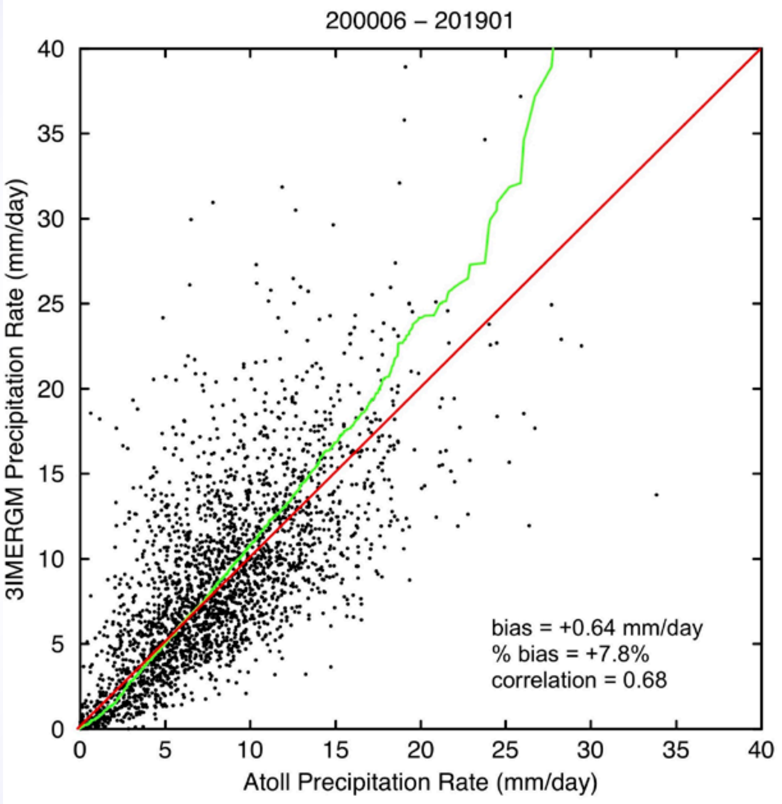
2. Early Results – IMERG Final, Monthly for Atolls

Monthly accumulations for tropical Pacific <u>atolls</u>

- Pacific Rainfall Database (PACRAIN)
- match of gauge to encompassing 0.1º grid box
- all useful months
    - stations have various periods of record (potentially changing the regions sampled)
    - 53 “good” atolls, averaging ~11/month
- bias varies with precip rate
    - IMERG under-(over-)estimates at low(high) rates
    - atoll gauges lack undercatch correction
        - likely ~5-10%, so overall IMERG bias is (amazingly) good, but rate biases remain



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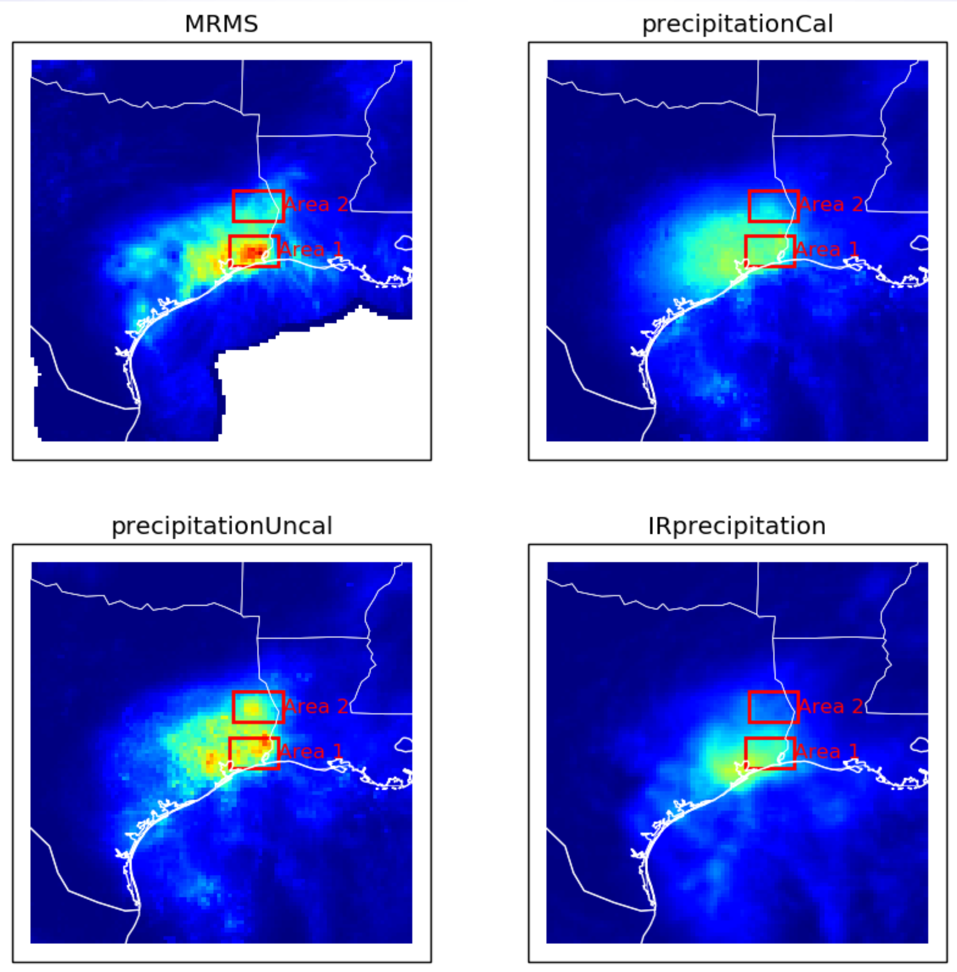
2. Early Results – Hurricane Harvey, 25-31 August 2017, IMERG and MRMS (1/2)

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) under(over)-estimated in Area 1(2)
  - should be similar to Late Run
- Cal (with gauge adjustment) pulls both areas down
- microwave-adjusted PERSIANN-CCS IR has the focus too far southwest



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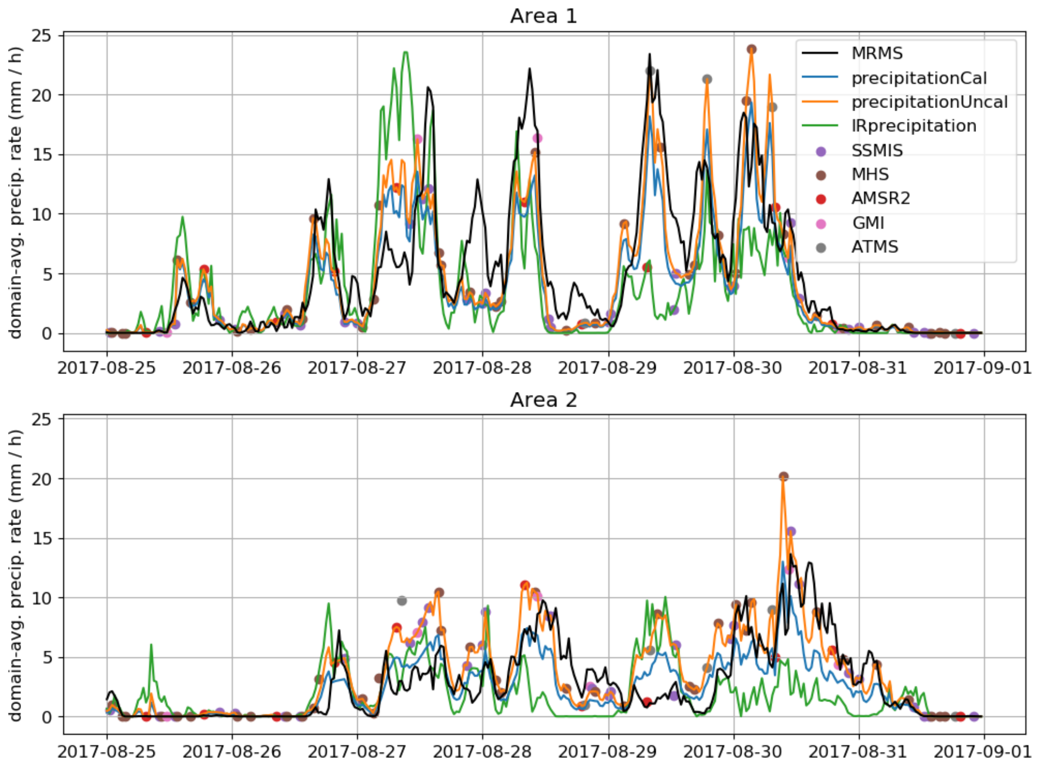
2. Early Results – Hurricane Harvey, 25-31 August 2017, IMERG and MRMS (2/2)

IMERG largely driven by microwave overpasses (dots)

- except duplicate times
- not just time interpolation
  - systems move into / out of the box between overpasses
- satellites show coherent differences from MRMS
  - microwave 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



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3. Schedule and Final Remarks (1/2)

IMERG V06B is fully operational

- 19+ years, starting June 2000
- TMPA will end with December 2019

Development Work for V07

- multi-satellite issues
  - improve error estimation
  - develop additional data sets based on observation-model combinations
  - work toward a cloud development component in the morphing system
- general precipitation algorithmic issues
  - introduce alternative/additional satellites at high latitudes (TOVS, AIRS, AVHRR, etc.)
  - evaluate ancillary data sources and algorithm for Prob. of Liq. Precip. Phase
  - work toward PMW retrievals that work over snow/ice
  - work toward improved wind-loss correction to gauge data
  - more-advanced IR algorithm

Version 07 release should be in “about 2 years” (2022?)

3. Schedule and Final Remarks (2/2)

IMERG is now V06B

- the product structure remains the same
  - Early, Late, Final
  - 0.1^{o}x0.1^{o} half-hourly (and monthly in Final)
- new source for morphing vectors
- higher-latitude coverage
- extension back to 2000 (and eventually 1998)
- improved Quality Index
- TMPA ending in December

See https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4285

1. Introduction – The Constellation

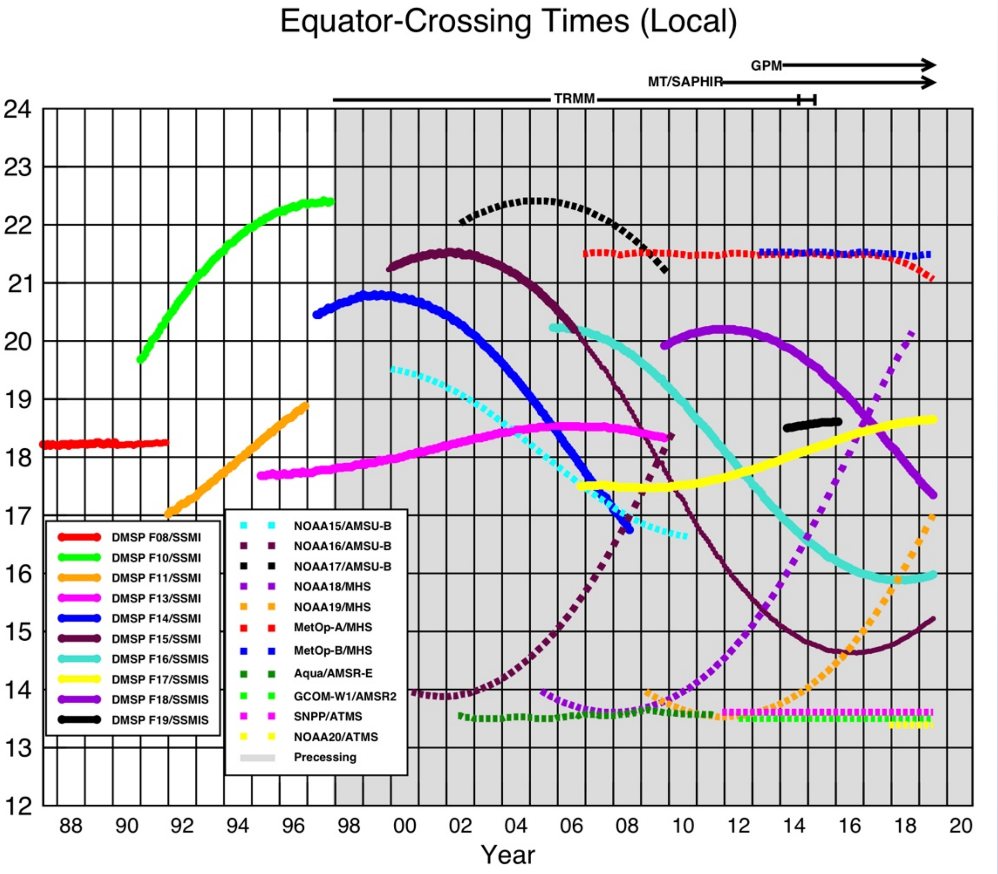
Presently 3-hourly observations >90% of the time, globally

The current GPM constellation includes:

- 5 polar-orbit passive microwave imagers
- 5 polar-orbit passive microwave sounders
- input precip estimates
    - GPROF (LEO PMW) + PRPS (SAPHIR)
    - PERSIANN-CCS (GEO IR)
    - CORRA (combined PMW-Ku radar)
    - GPCP SG (monthly satellite-gauge)

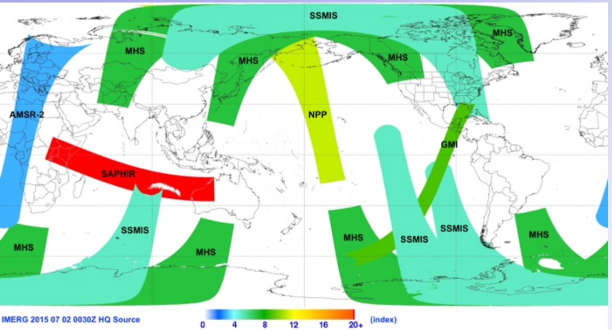
The constellation is evolving

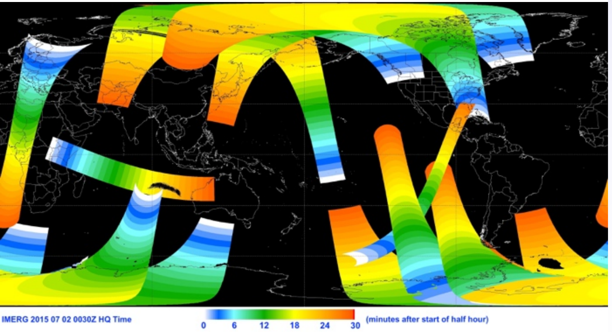
- launch manifests are assured for sounders, sparse for imagers

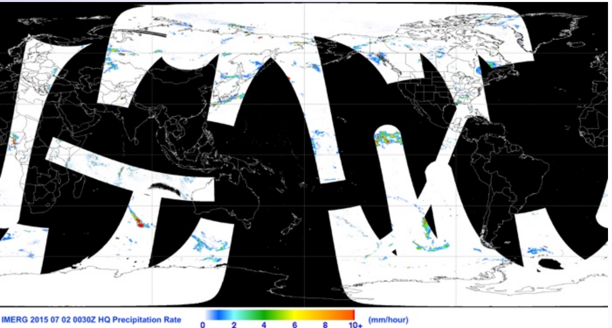


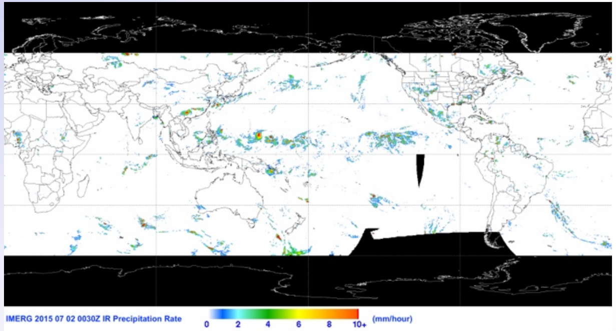
Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 19 July 2019, NASA/Goddard Space Flight Center, Greenbelt, MD.

2. IMERG – Examples of Data Fields





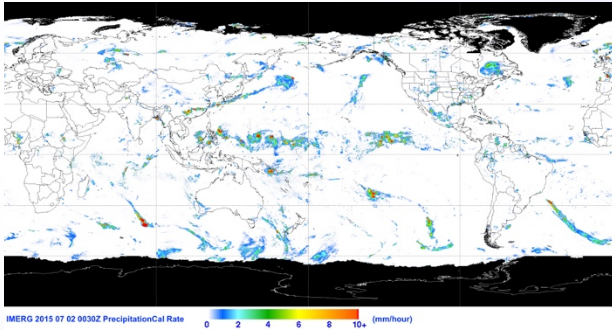


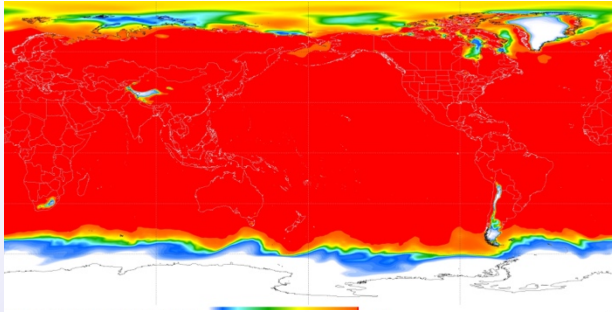


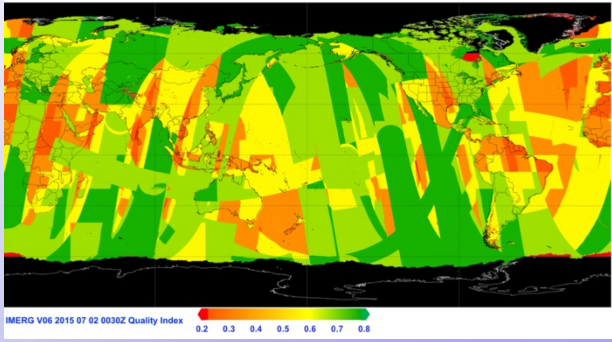
PMW sensor | IR precip | cal precip (uncal precip)

PMW time into half hour | **2 July 2015 0030 UTC** | probability of liquid phase

PMW precip | IR weight | Quality Index







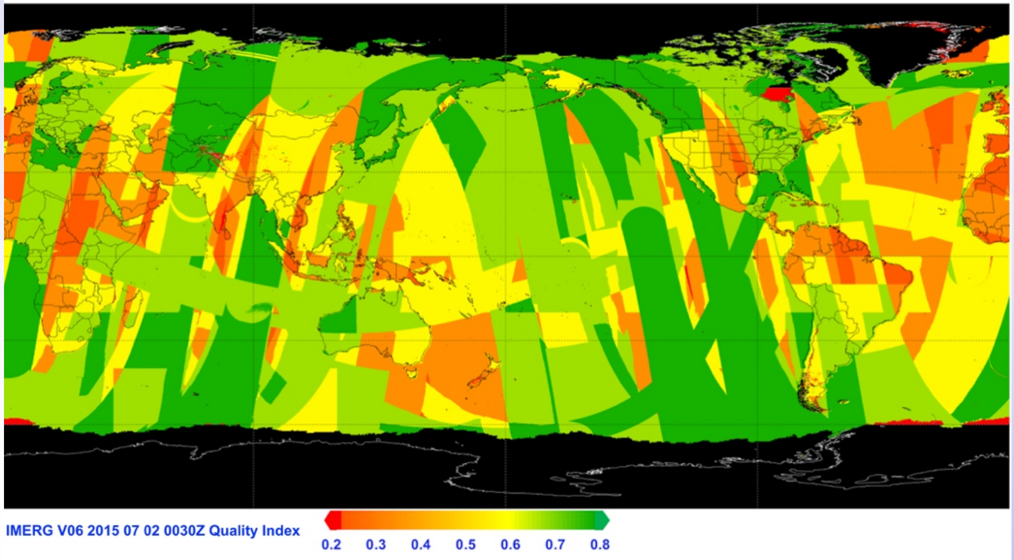
2. IMERG – Quality Index (1/2)

Half-hourly QI (revised)

- approx. Kalman Filter correlation
  - based on
    - times to 2 nearest PMWs (only 1 for Early) for morphed data
    - IR at/near time (when used)

$$QI_h = tanh\left(\sqrt{\sum arctanh^2(r_i)}\right)$$

  - where *r* is correlation, and the *i*'s are for forward propagation, backward propagation, and IR
  - or, an approximate correlation when a PMW is used for that half hour
- revised to 0.1º grid (0.25º in V05)
- thin strips due to inter-swath gaps
- blocks due to regional variations
- snow/ice masking will drop out microwave values



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The goal is a simple "stoplight" index

- ranges of QI will be assigned
  - good 0.6-1
  - use with caution 0.4-0.6
  - questionable 0-0.4
  - is this a useful parameter?

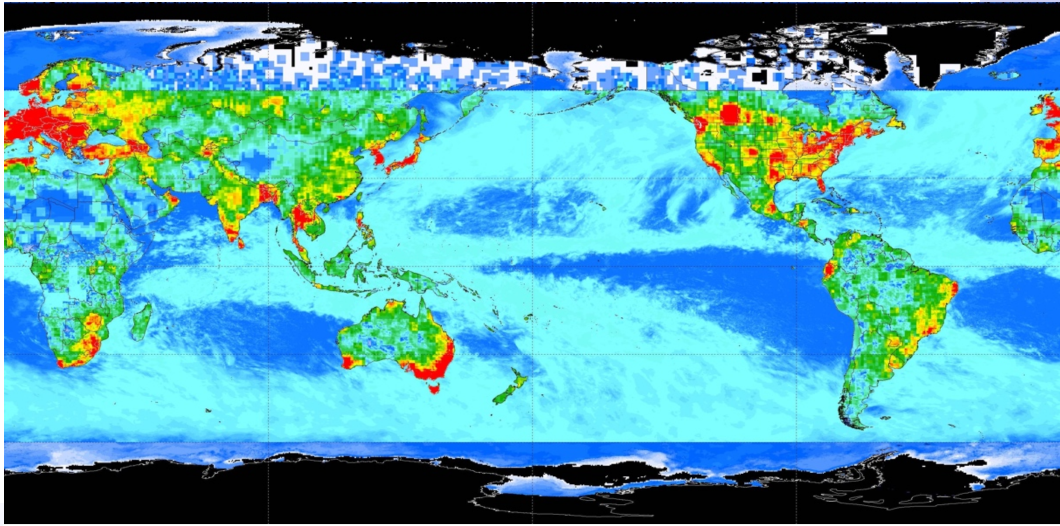
2. IMERG – Quality Index (2/2)

Monthly QI (unchanged)

- Equivalent Gauge (Huffman et al. 1997) in gauges / 2.5ºx2.5º

$$QI_m = (S + r) * H * (1 + 10 * r^2)/e^2$$

  - where r is precip rate, e is random error, and H and S are source-specific error constants
- invert random error equation
- largely tames the non-linearity in random error due to rain amount
- some residual issues at high values
- doesn't account for bias
- the stoplight ranges are
  - good > 4
  - use with caution 2-4
  - questionable < 2
  - note that this ranking points out uncertainty in the values in light-precip areas that nearly or totally lack gauges (some deserts, oceanic subtropical highs)



Month Qual. Index Dec 2016

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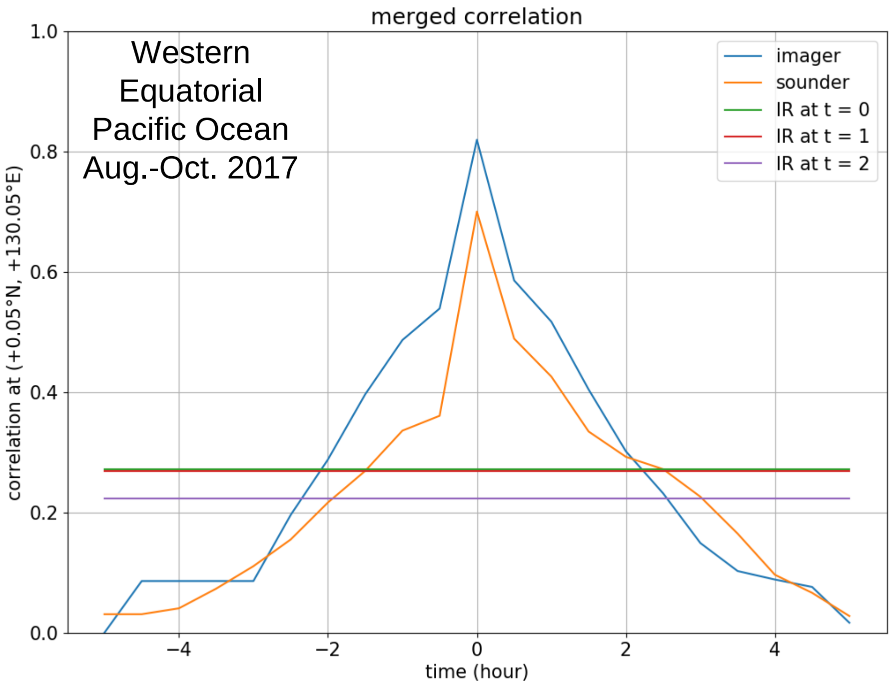
3. Some Details – Key Points in Morphing (1/3)

Following the CMORPH approach

- for a given time offset from a microwave overpass
- compute the (smoothed) average correlation between
  - morphed microwave overpasses and microwave overpasses at that time offset, and
  - IR precip estimates and microwave overpasses at that time offset and IR at 1 and 2 half hours after that time offset
  - for conical-scan (imager) and cross-track-scan (sounder) instruments separately
- the microwave correlations drop off from t=0, dropping below the IR correlation within a few hours (2 hours in the Western Equatorial Pacific)



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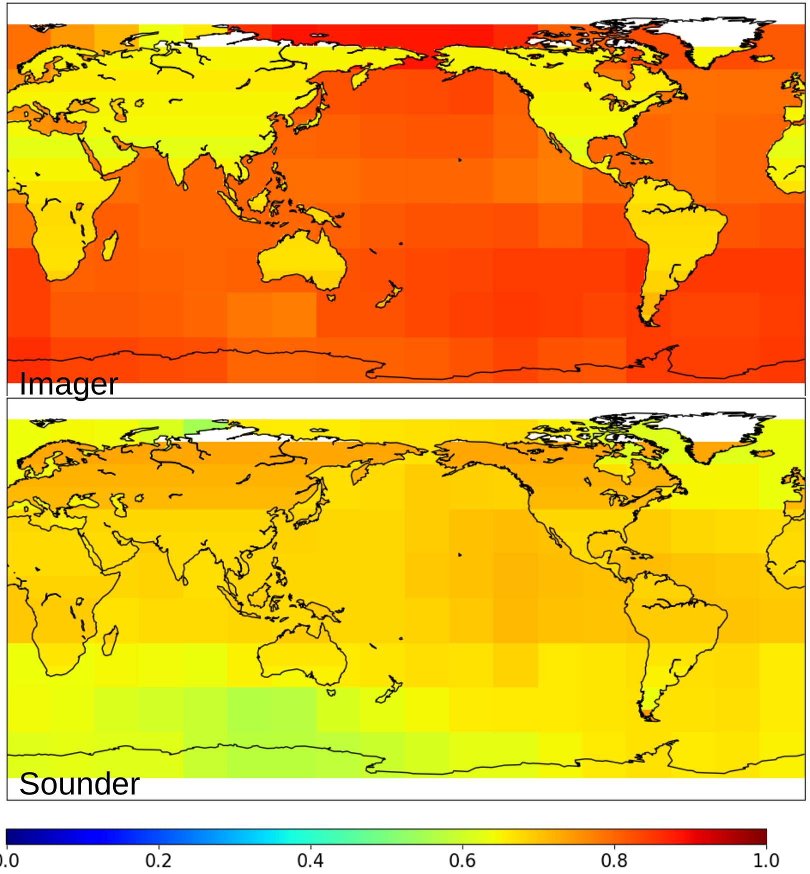
3. Some Details – Key Points in Morphing (2/3)

Following the CMORPH approach

- for a given time offset from a microwave overpass
- compute the (smoothed) average correlation between
  - morphed microwave overpasses and microwave overpasses at that time offset, and
  - IR precip estimates and microwave overpasses at that time offset and IR at 1 and 2 half hours after that time offset
  - for conical-scan (imager) and cross-track-scan (sounder) instruments separately
- the microwave correlations drop off from there, dropping below the IR correlation within a few hours (2 hours in the Western Equatorial Pacific)
- at t=0 (no offset), imagers are better over oceans, sounders are better or competitive over land



L2 correlation at t=0 Aug.-Oct. 2017

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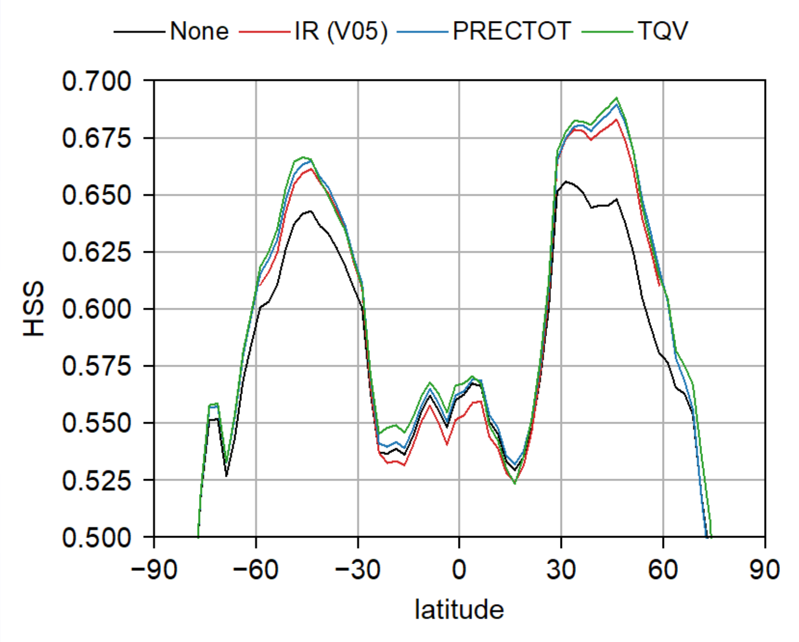
3. Some Details – Key Points in Morphing (3/3)

Tested vectors computed on a 5ºx5º template every 2.5º, interpolated to 0.1ºx0.1º based on

- MERRA2 TQV (vertically integrated vapor)
- MERRA2 PRECTOT (precip)
- CPC 4-km merged IR Tb (as in V05 IMERG)
- NULL (no motion)

On a zonal-average basis, compute the Heidke Skill Score for

- merged GPROF precip (HQ) propagated for 30 min.
- compared to HQ precip observed in the following 30 min.
- TQV is consistently at/near the top
- further research is expected for V07



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