Heading for 20 years of Quasi-Global Precipitation with the new Version 06 IMERG

George J. Huffman(1), David T. Bolvin(1,2), Eric Nelkin(1,2), Jackson Tan(1,3),

and Dan Braithwaite(4), Kuolin Hsu(4), Robert Joyce(5,6), Christopher Kidd(1,7), Soroosh Sorooshian(4), Pingping Xie(6)

(1) NASA/GSFC Earth Sciences Division – Atmospheres
(2) Science Systems and Applications, Inc.
(3) Univ. Space Res. Assoc.
(4) Univ. of California Irvine
(5) Innovim
(6) NOAA/NWS Climate Prediction Center
(7) Univ. of Maryland / ESSIC

george.j.huffman@nasa.gov

1. Introduction – The Constellation

We want 3-hourly observations, globally

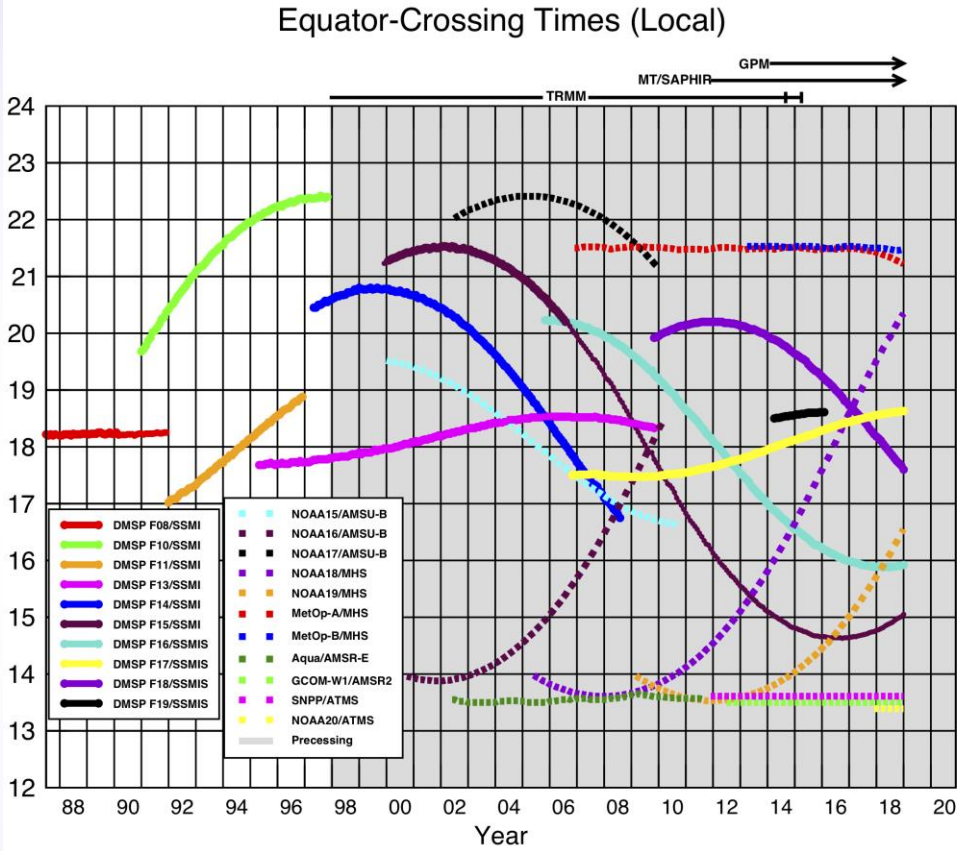
- sampling the diurnal cycle
- morphed microwave loses skill outside ±90 min

The current GPM constellation includes:

- 5 polar-orbit passive microwave imagers
  - 3 SSMIS, AMSR-2, GMI
- 6 polar-orbit passive microwave sounders
  - 3 MHS, 2 ATMS, SAPHIR*
- input precip estimates
  - GPROF (LEO PMW)
  - 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), 30 January 2019, NASA/Goddard Space Flight Center, Greenbelt, MD.

2. IMERG – Quick Description (1/2)

IMERG is a unified U.S. algorithm based on

- Kalman Filter CMORPH – NOAA/CPC
- PERSIANN CCS – U.C. Irvine
- TMPA – GSFC
- PPS (GSFC) processing environment

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

- multiple runs for different user requirements for latency and accuracy
  - "Early" – 4 hr (flash flooding)
  - "Late" – 14 hr (crop forecasting)
  - "Final" – 3 months (research)
- time intervals are half-hourly and monthly (Final only)
- 0.1º global CED grid
  - morphed precip, 60º N-S in V05, 90º N-S in V06
  - IR covers 60º N-S

	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*

2. IMERG – Quick Description (2/2)

IMERG is adjusted to GPCP V2.3 monthly climatology zonally to achieve a bias profile that we consider reasonable

- GPM Version 04, 05, 06 core products have similar zonal profiles (by design)
  - these profiles are systematically low in the extratropical oceans compared to
    - GPCP V2.3 monthly Satellite-Gauge product
    - Behrangi Multi-satellite CloudSat, TRMM, Aqua (MCTA) product
- over land GPCP adjustment provides a first cut at the adjustment to gauges that the final calibration in IMERG enforces
- similar bias concerns apply during TRMM

	Half-hourly data file (Early, Late, Final)
1	*[multi-sat.] precipitationCal*
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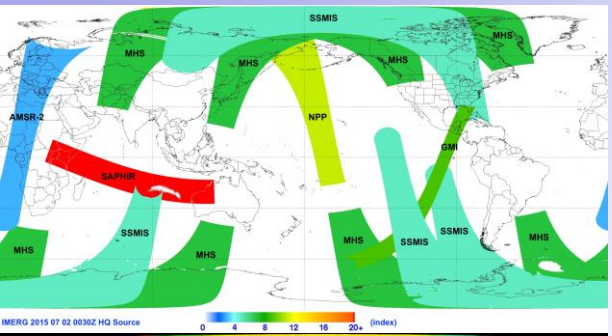
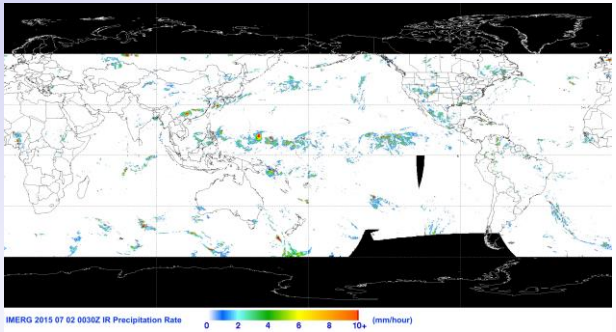
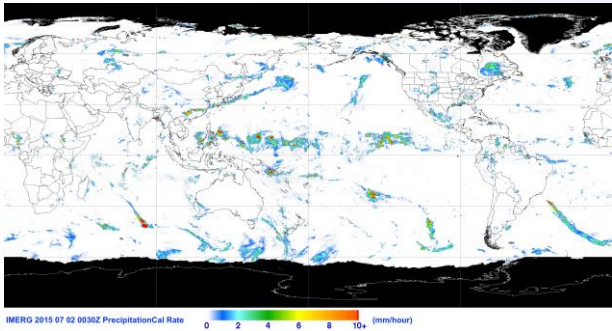
2	*[sat.-gauge precip] randomError*
3	GaugeRelativeWeighting
4	*probabilityLiquidPrecipitation [phase]*
5	*precipitationQualityIndex*

2. IMERG – Examples of Data Fields



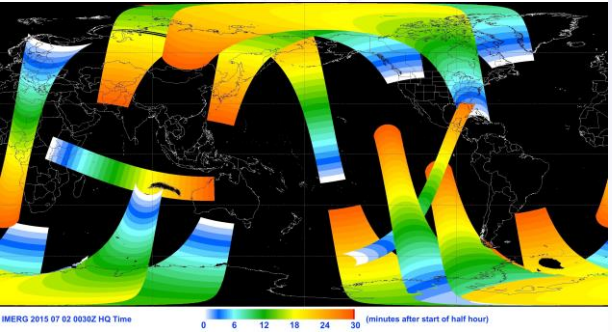




PMW sensor

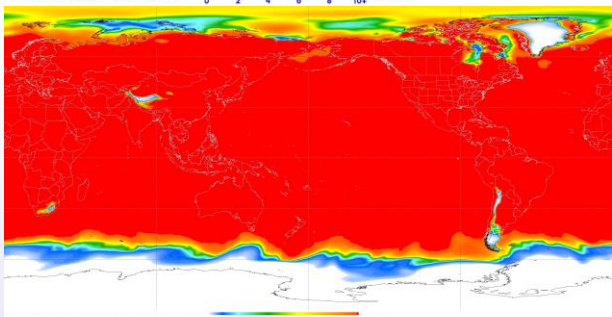
IR precip

cal precip

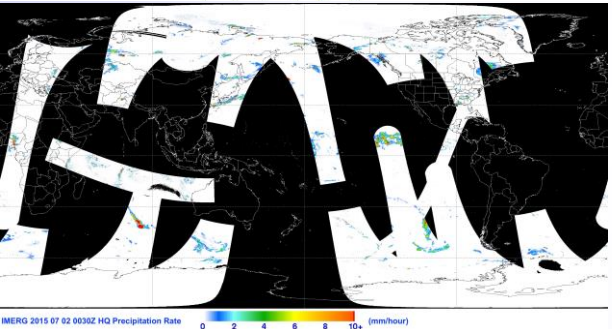


PMW time into half hour

2 July 2015 0030 UTC

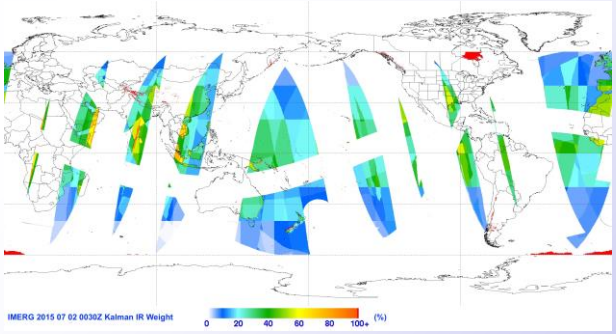


probability of liquid phase

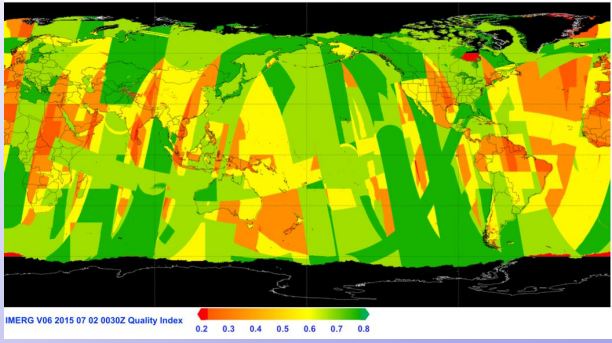


PMW precip

IR weight



Quality Index



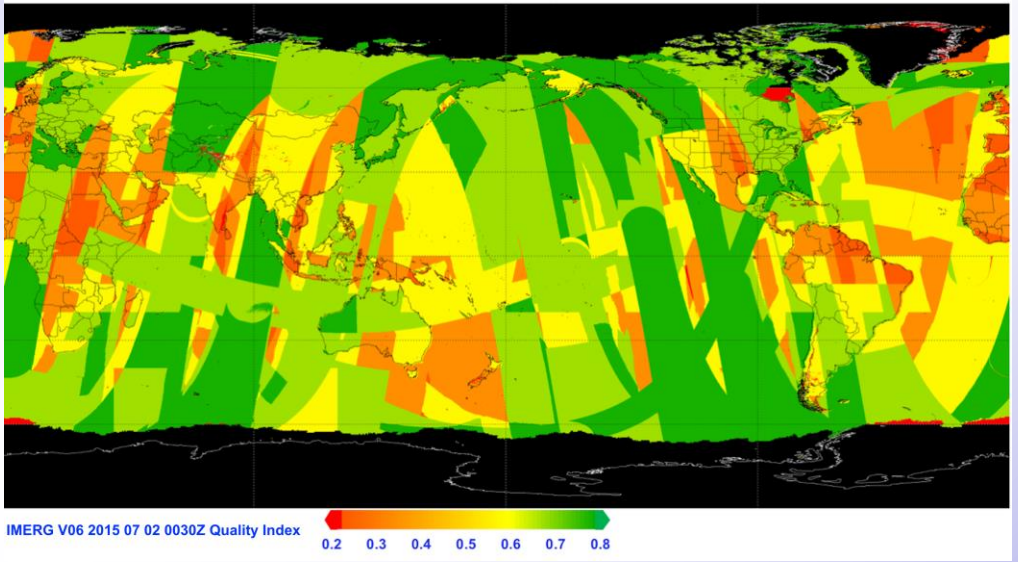
2. IMERG – Quality Index (1/2)

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?

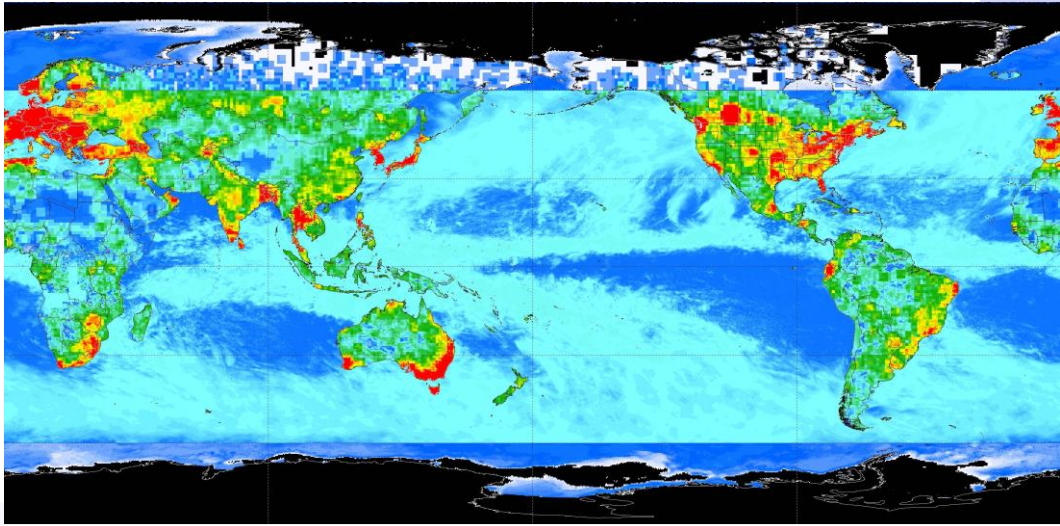
2. IMERG – Quality Index (2/2)

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)



2. 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 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

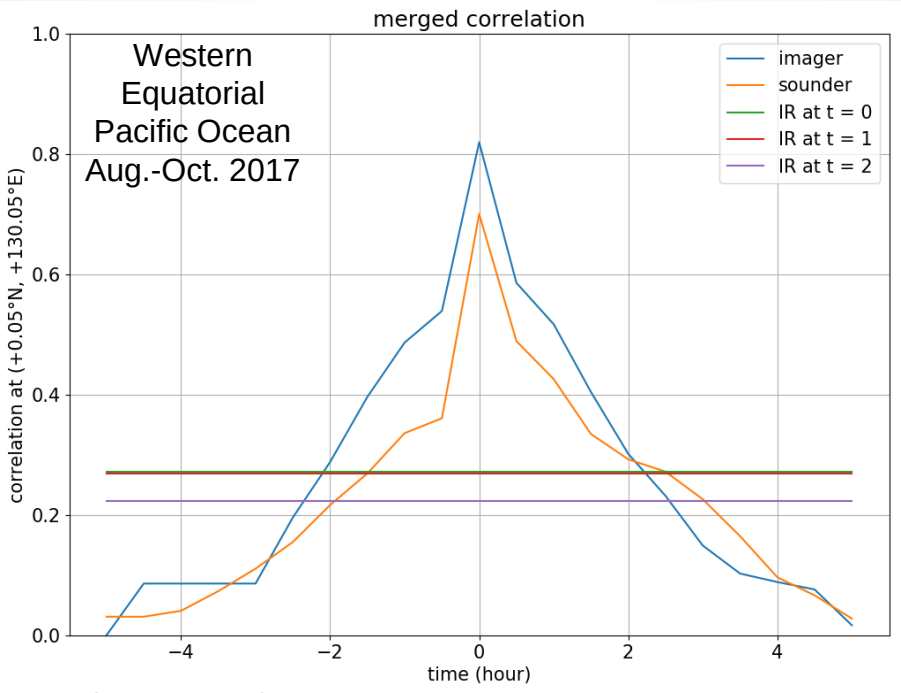
Revisions to internals raises the maximum precip rate from 50 to 200 mm/hr and no longer discrete

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

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)

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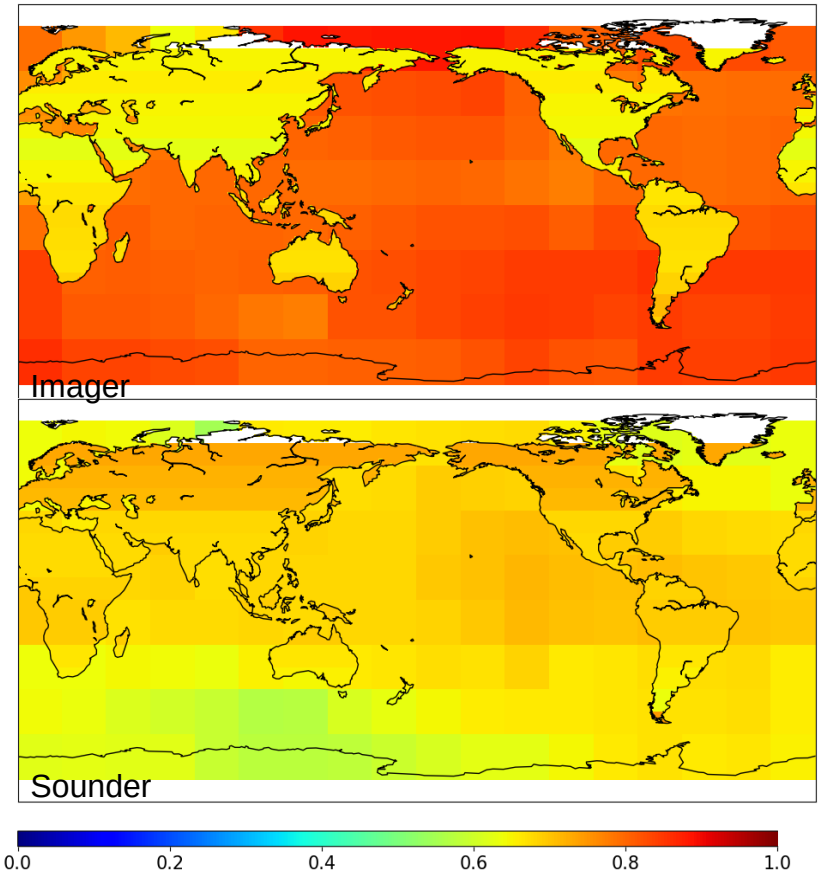
  - IR precip estimates and microwave overpasses at that time offset and IR at 1 and 2 half hours after that time offset
  - for conical-scan (imager) and cross-track-scan (sounder) instruments separately
- the microwave correlations drop off from there, dropping below the IR correlation within a few hours (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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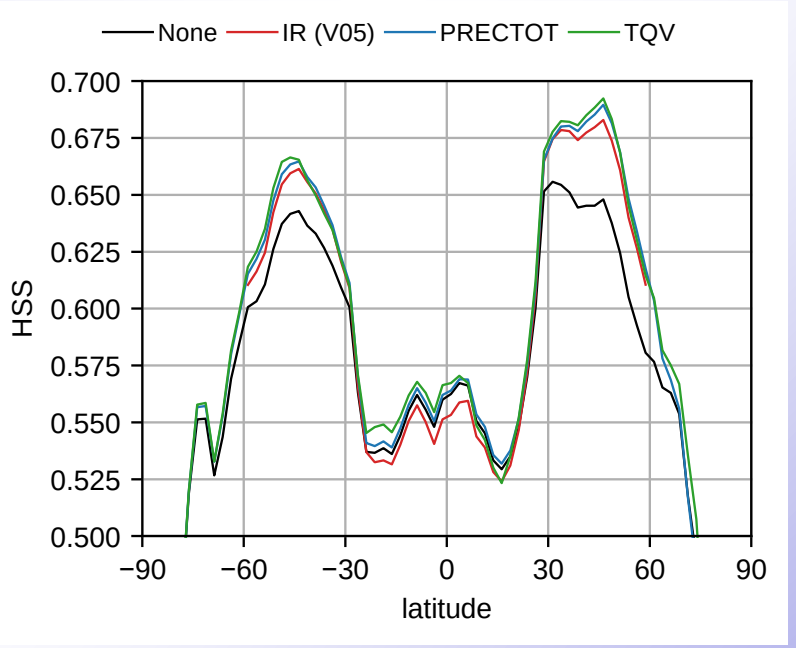
3. Some Details – Key Points in Morphing (3/3)

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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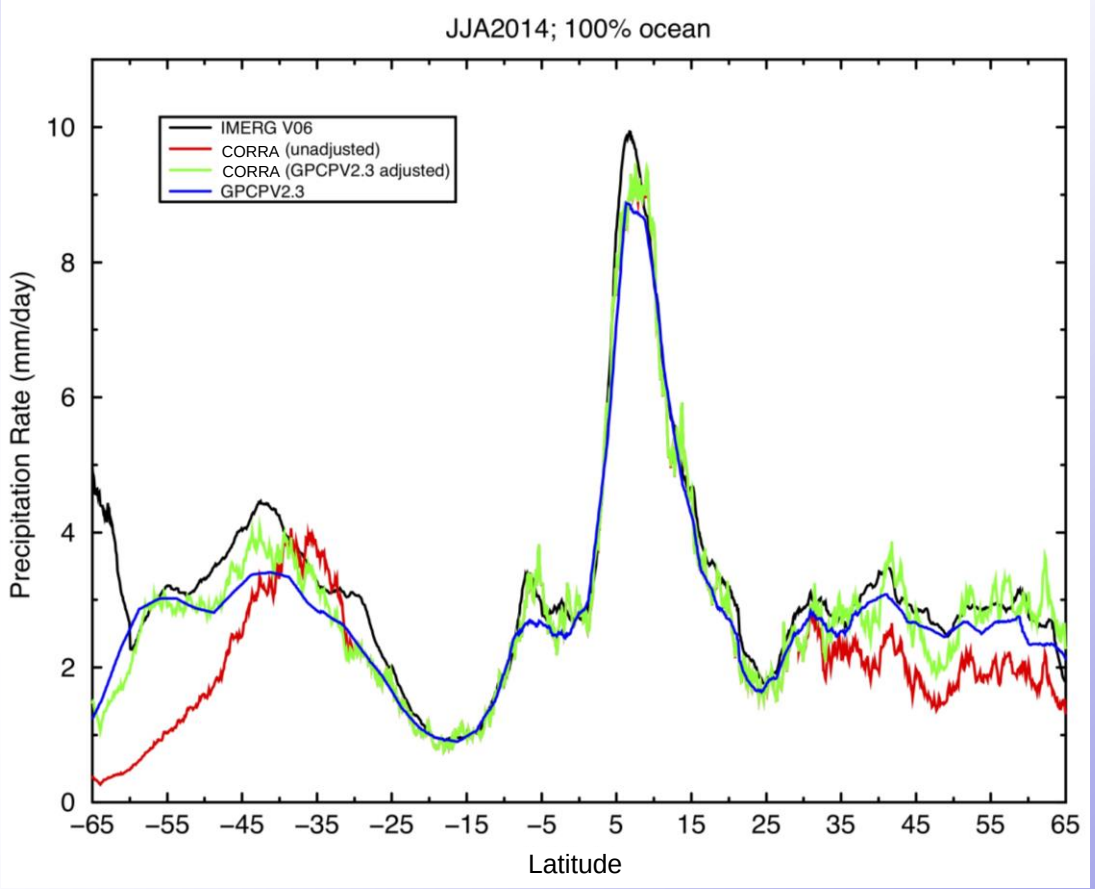
4. Early Results – Calibration

Calibration sequence is

- CORRA calibrated to GPCP over ocean outside 30ºN-S
- GPM constellation calibrated to CORRA

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



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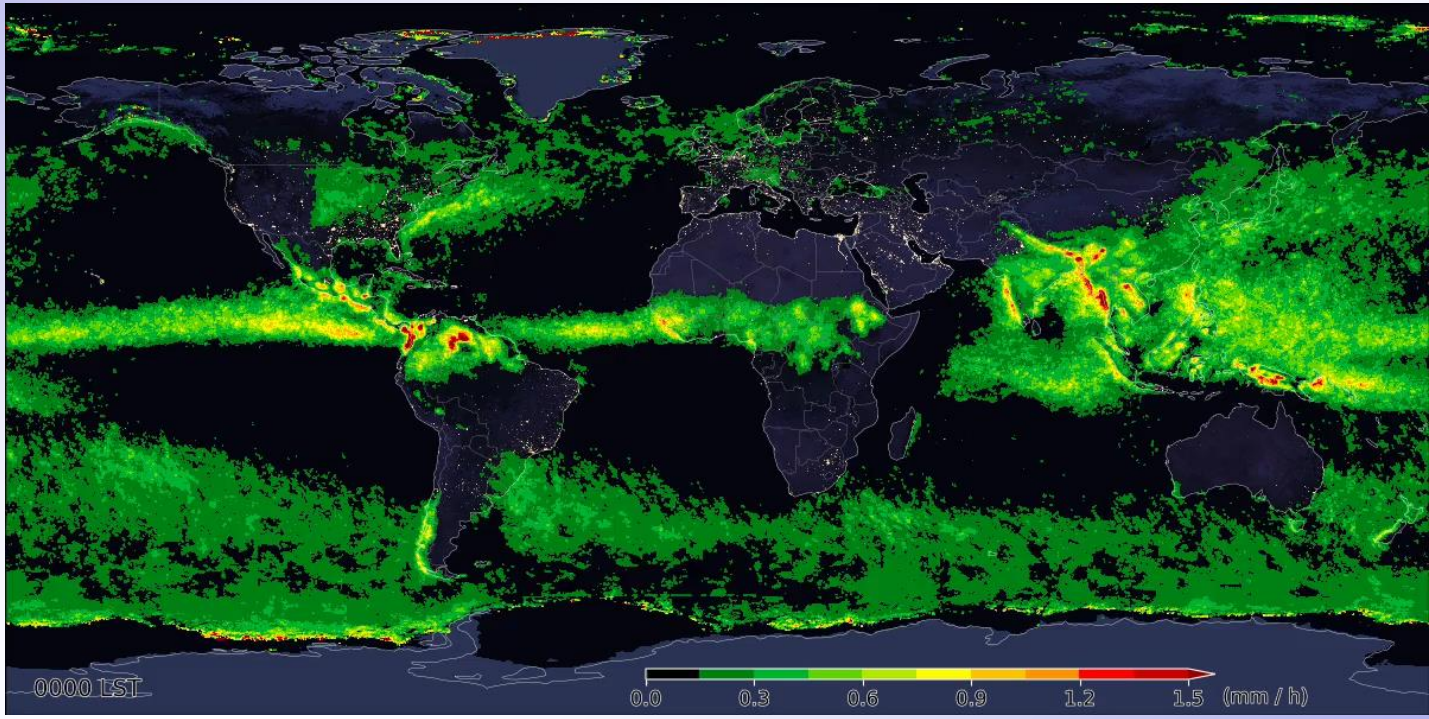
4. Early Results – JJA Diurnal Cycle (GPM Era)

Average June-July-August for 2014 to 2018

- data re-sorted to give the same LST over the whole globe
- surface cycles between Blue Marble and Night Lights
- adding the TRMM era will smooth out the results



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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)

Reminiscent of IMERG V05, but

- better data coverage at higher latitudes
- less “flashing” due to inter-satellite differences and morphing
- and still have artifacts along ice edges

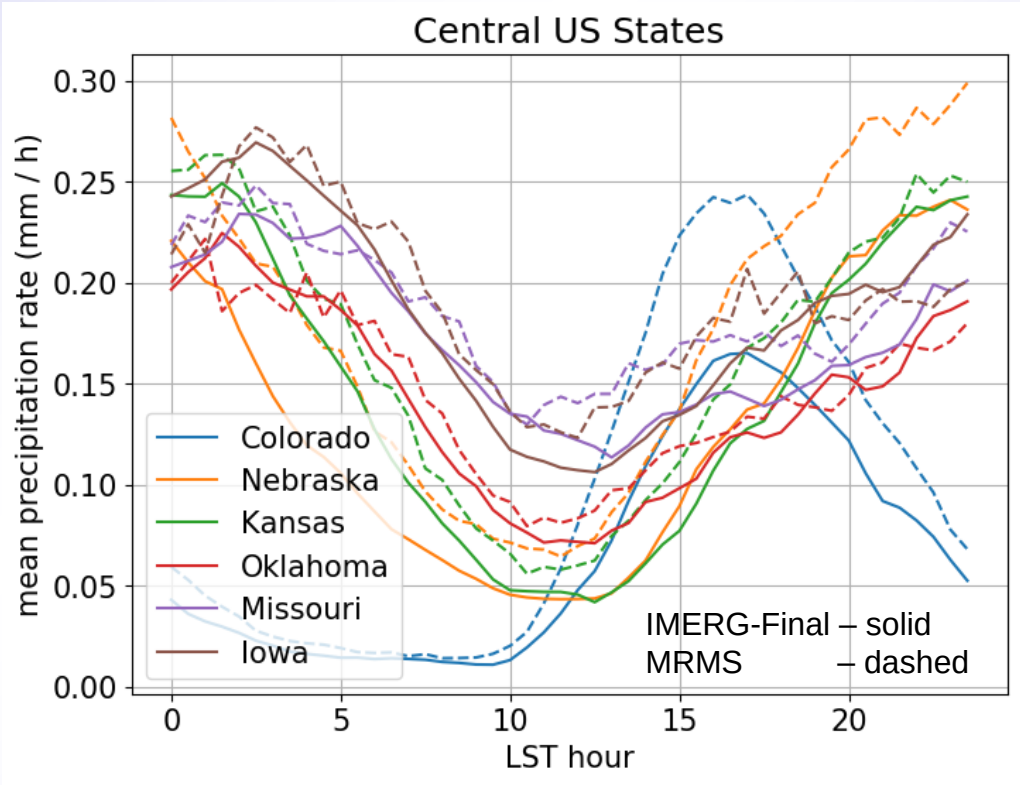
4. Early Results – JJA Diurnal Cycle in Central U.S. (GPM Era)

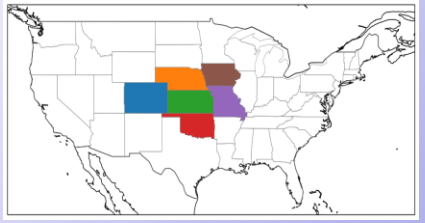
Average June-July-August for 2014 to 2018 (5 summers) for 6 states

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

- lower averages
- 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 would have to use different data





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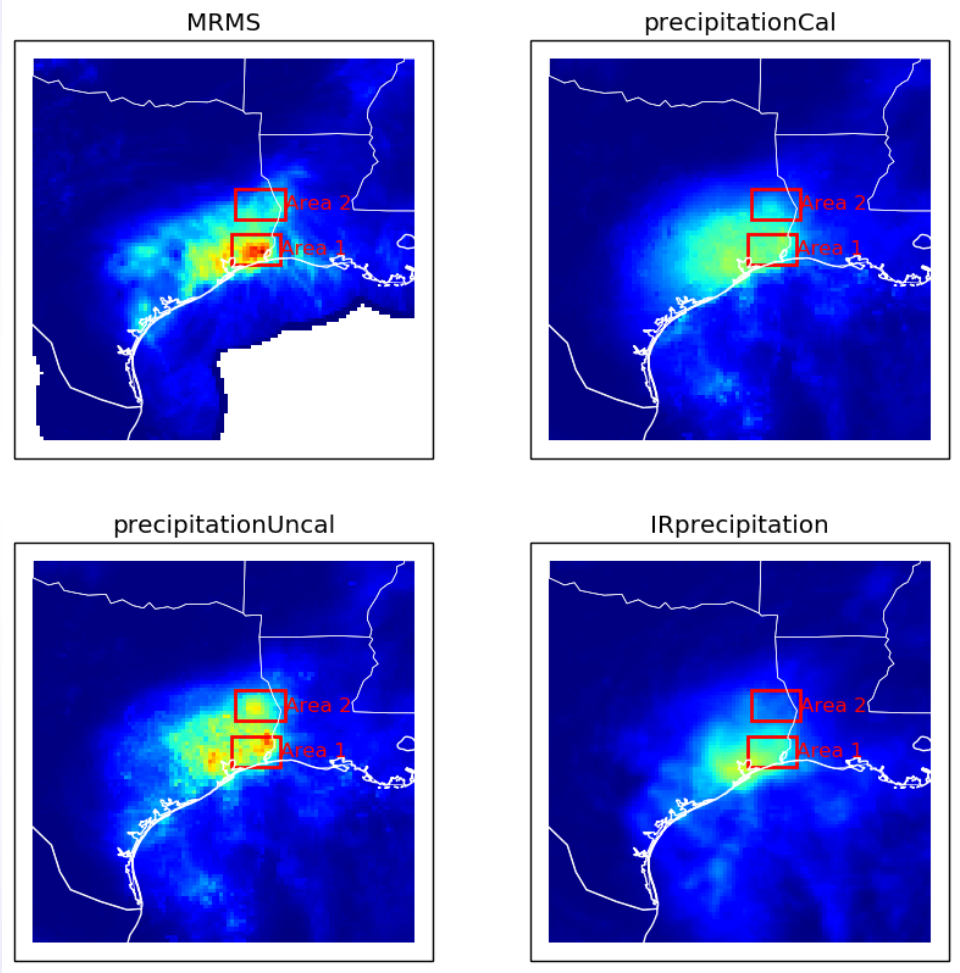
4. Early Results – Hurricane Harvey, 25-31 August 2017, IMERG and MRMS (1/2)

Harvey loitered over southeast Texas for a week

- Multi-Radar Multi-Sensor (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 in NRT 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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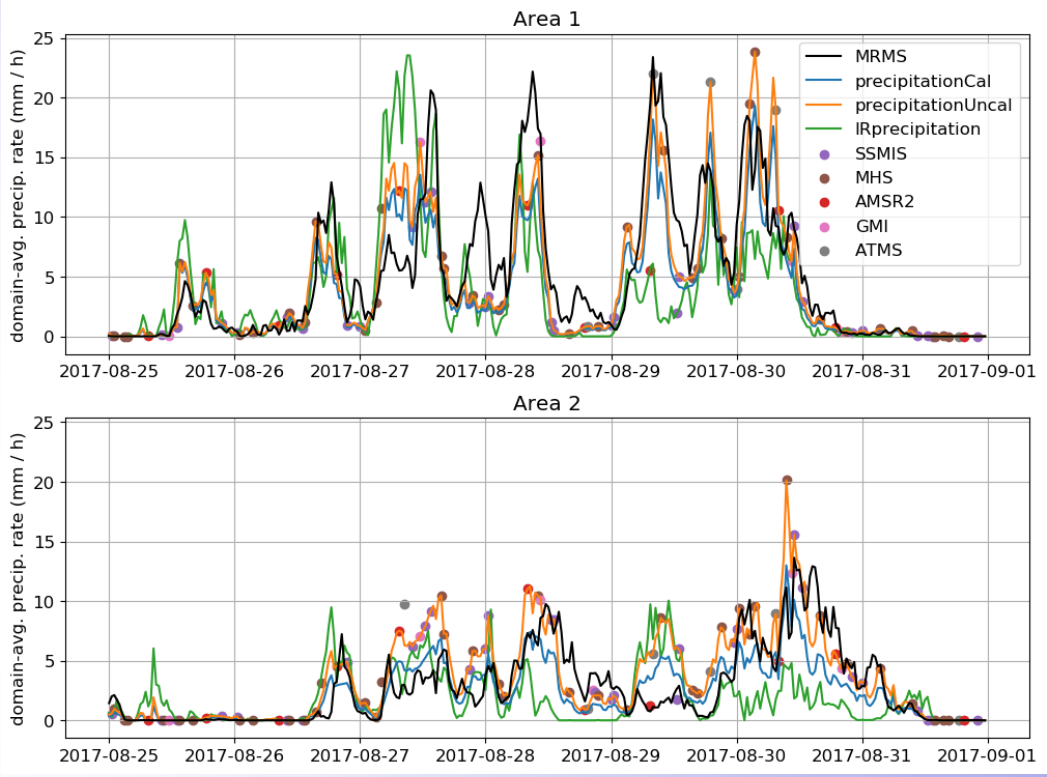
4. Early Results – Hurricane Harvey, 25-31 August 2017, IMERG and MRMS (2/2)

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

V06 Final Run starts June 2000, currently processed into 2010, plus the GPM era

V06(V05) is higher(lower) than TMPA

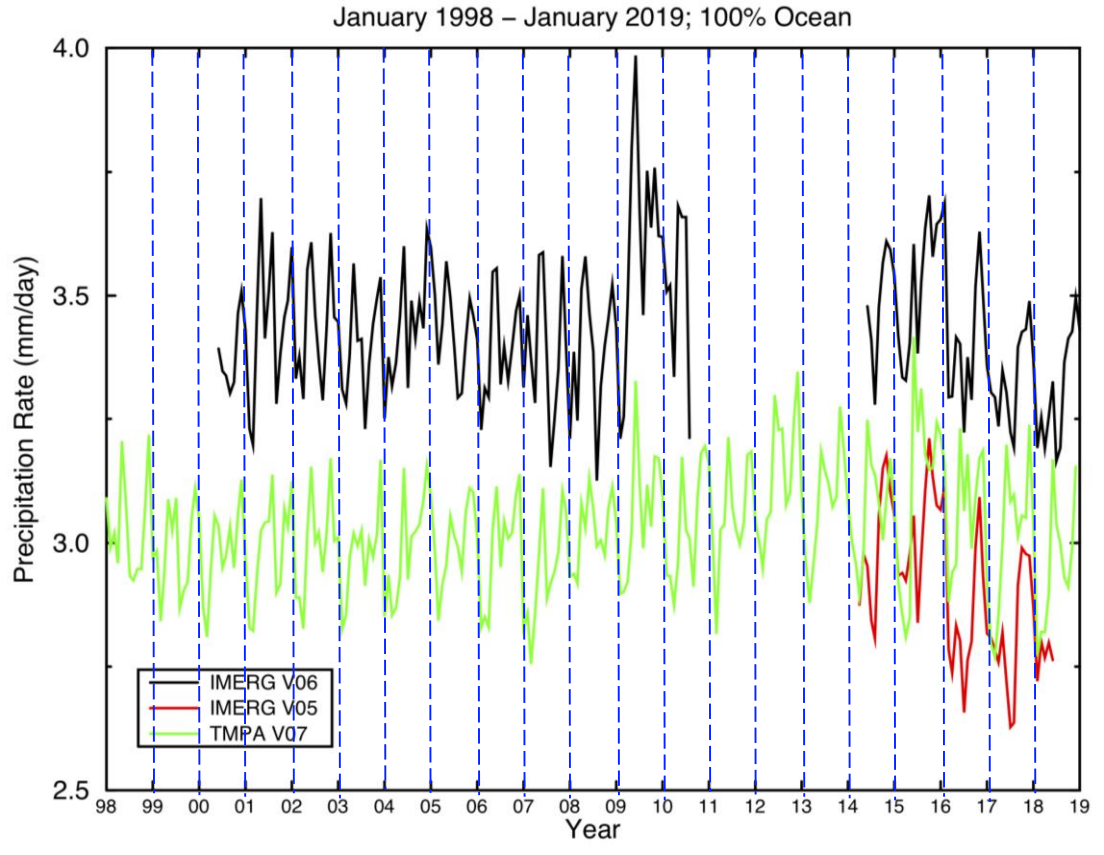
TMPA and TRMM-era IMERG have a strong semi-annual signal

- GPM-era IMERG is dominated by the annual cycle

Short-term “trend”

- similar for all GPM-era datasets
- flatter for IMERG than for TMPA in TRMM era

Behavior in 2009-10 is under review



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5. Schedule and Final Remarks (1/3)

Early March 2019: began Version [illegible] Retrospective Processing

- the GPM era was launched fu[illegible]
- the TRMM era Final Run rep[illegible]
  - complete data should finish in May
  - 4 km merged global IR data files continue to be delayed for January 1998-January 2000
    - the run builds up the requisite 3 months of calibration data starting from February 2000
    - the first month of data is for June 2000
    - the initial 29 months of data will be incorporated when feasible
- Early and Late Run Retrospective Processing uses Final in[illegible]s, so they come after Final
  - Final is always ~3.5 months behind, so the Early and La[illegible]e processing have to wait on Final Initial Processing to fill in the l[illegible]s before [illegible]
- Early and Late Run Initial Processing [illegible]ay

done

underway

coming

underway

5. Schedule and Final Remarks (2/3)

Development Work for V07

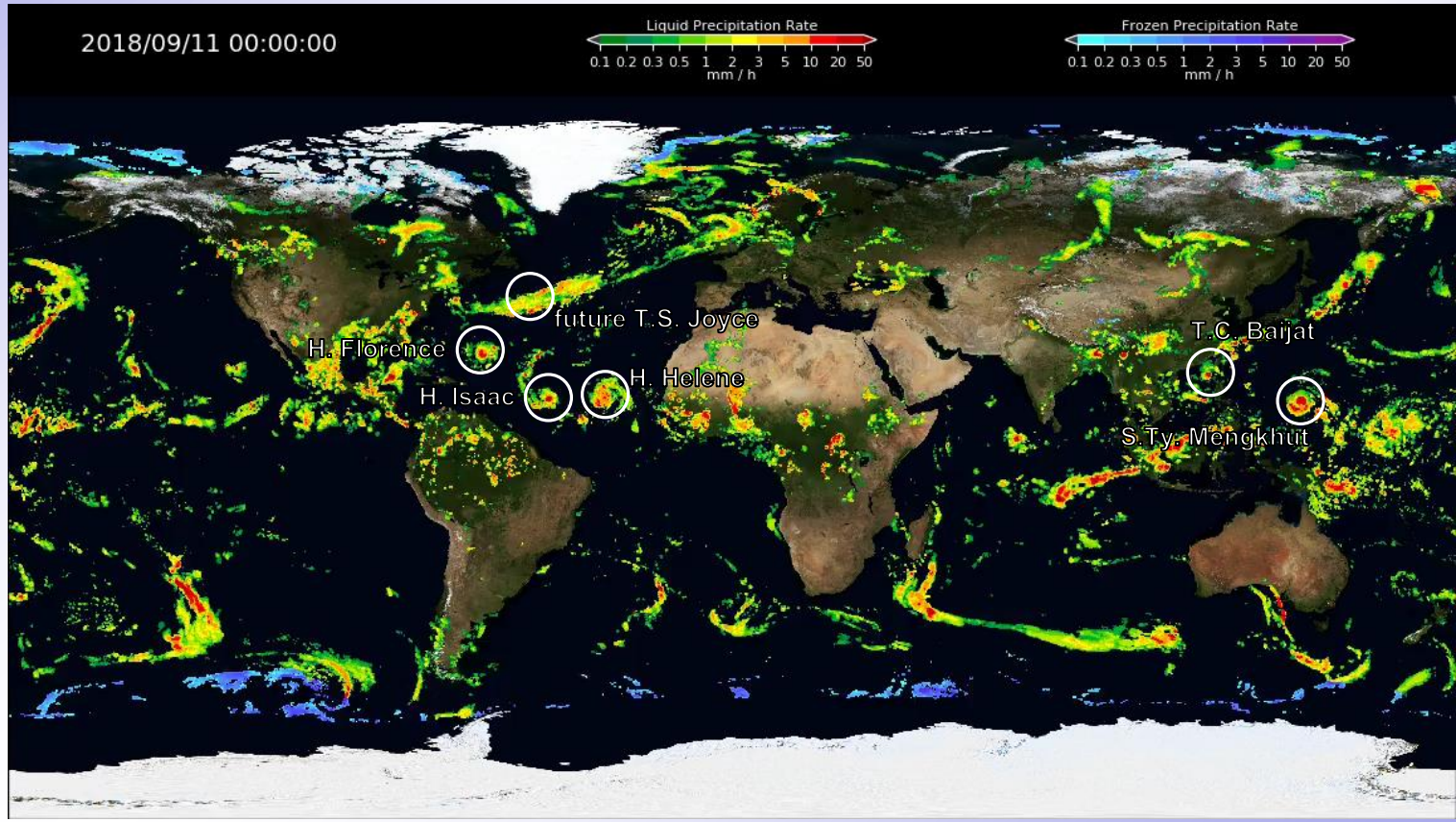
- multi-satellite issues
  - improve error estimation
  - develop additional data sets based on observation-model combinations
  - work toward a cloud development component in the morphing system
- general precipitation algorithmic issues
  - introduce alternative/additional satellites at high latitudes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

Version 07 release should be in about 2 years (2021-22?)

5. Schedule and Final Remarks (3/3)

IMERG is being upgraded to V06 in Spring 2019

- the product structure remains the same
  - Early, Late, Final
  - 0.1ºx0.1º half-hourly (and monthly in Final)
- new source for morphing vectors
- higher-latitude coverage
- extension back to 2000 (and eventually 1998)
- improved Quality Index



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