

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

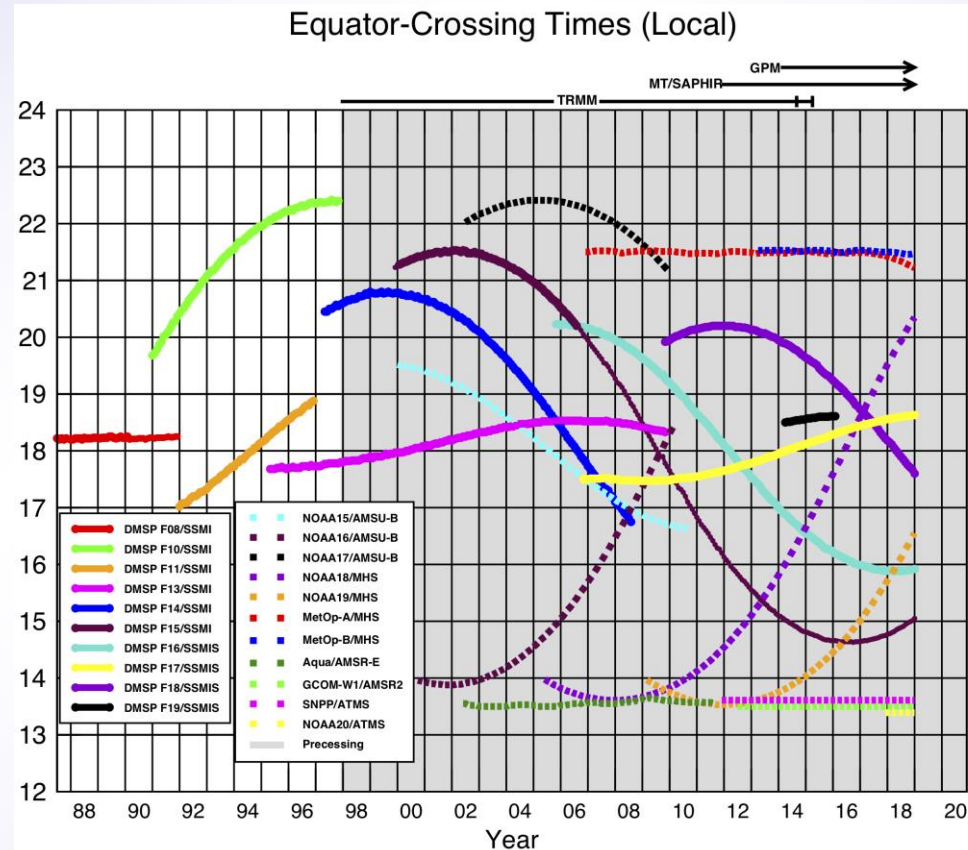
- sampling the diurnal cycle
- morphed microwave loses skill outside ± 90 min

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)
- 0.1° global CED grid
 - morphed precip, 60° N-S in V05, 90° N-S in V06
 - IR covers 60° N-S

	Half-hourly data file (Early, Late, Final)
1	<i>[multi-sat.] precipitationCal</i>
2	<i>[multi-sat.] precipitationUncal</i>
3	<i>[multi-sat. precip] randomError</i>
4	<i>[PMW] HQprecipitation</i>
5	<i>[PMW] HQprecipSource [identifier]</i>
6	<i>[PMW] HQobservationTime</i>
7	<i>IRprecipitation</i>
8	<i>IRkalmanFilterWeight</i>
9	<i>[phase] probabilityLiquidPrecipitation</i>
10	<i>precipitationQualityIndex</i>
	Monthly data file (Final)
1	<i>[sat.-gauge] precipitation</i>
2	<i>[sat.-gauge precip] randomError</i>
3	<i>GaugeRelativeWeighting</i>
4	<i>probabilityLiquidPrecipitation [phase]</i>
5	<i>precipitationQualityIndex</i>

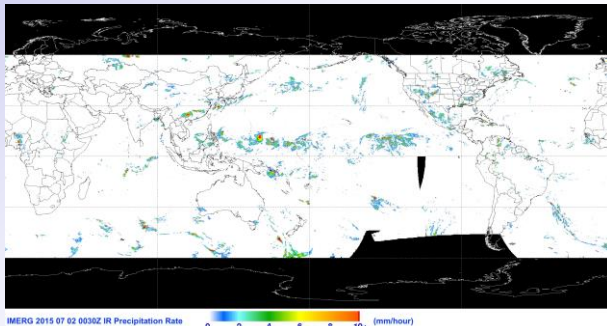
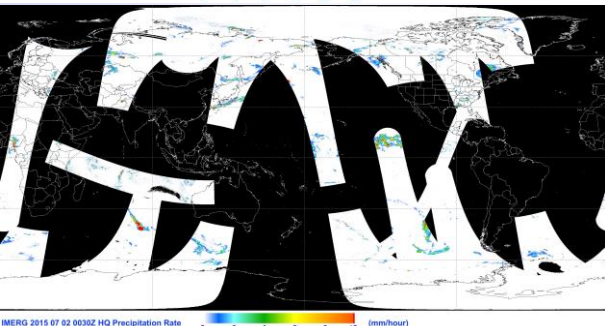
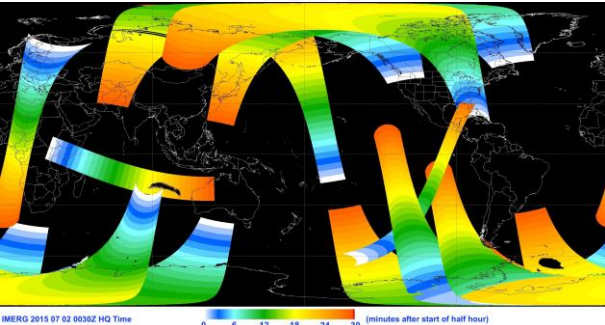
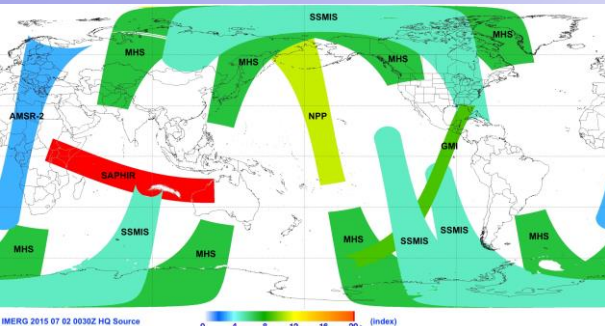
2. IMERG – Quick Description (2/2)

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	<i>[multi-sat.] precipitationCal</i>
2	<i>[multi-sat.] precipitationUncal</i>
3	<i>[multi-sat. precip] randomError</i>
4	<i>[PMW] HQprecipitation</i>
5	<i>[PMW] HQprecipSource [identifier]</i>
6	<i>[PMW] HQobservationTime</i>
7	<i>IRprecipitation</i>
8	<i>IRkalmanFilterWeight</i>
9	<i>[phase] probabilityLiquidPrecipitation</i>
10	<i>precipitationQualityIndex</i>
	Monthly data file (Final)
1	<i>[sat.-gauge] precipitation</i>
2	<i>[sat.-gauge precip] randomError</i>
3	<i>GaugeRelativeWeighting</i>
4	<i>probabilityLiquidPrecipitation [phase]</i>
5	<i>precipitationQualityIndex</i>

2. IMERG – Examples of Data Fields



PMW sensor

IR precip

cal precip

PMW time into half hour

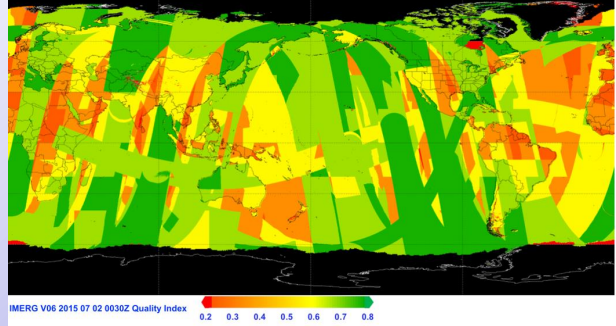
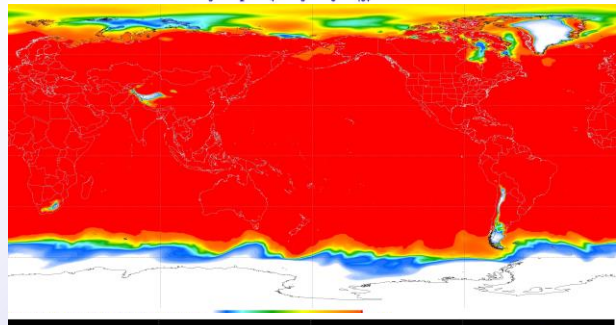
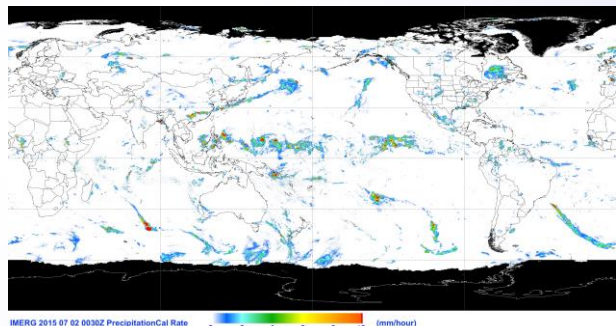
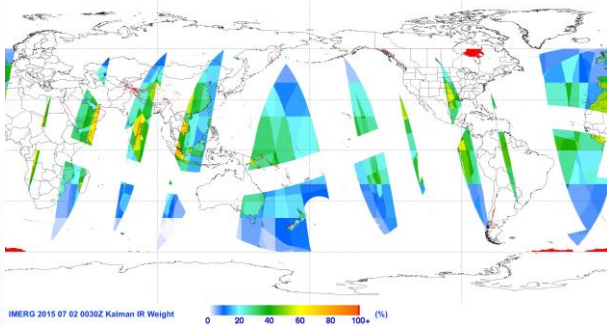
**2 July 2015
0030 UTC**

probability of liquid phase

PMW precip

IR weight

Quality Index



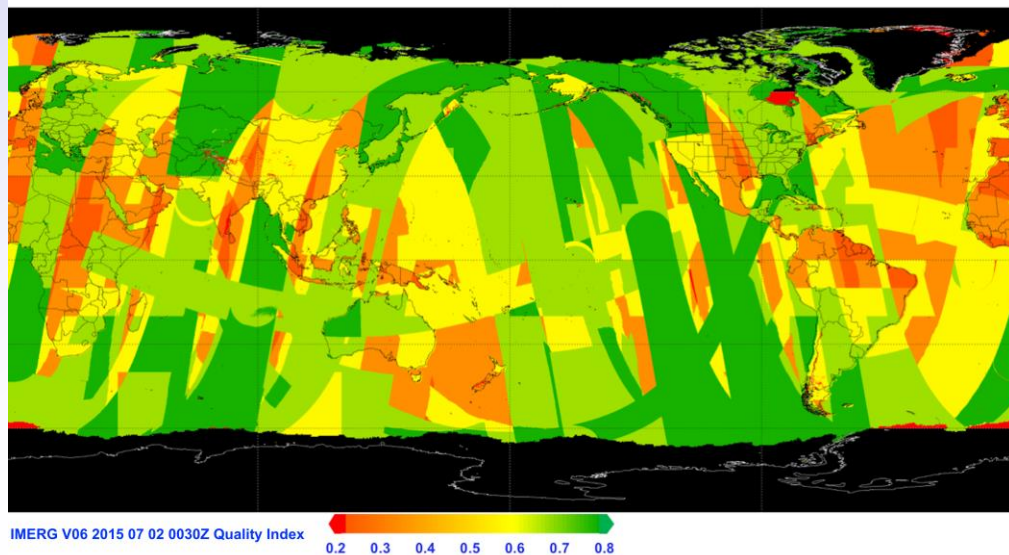
2. IMERG – Quality Index (1/2)

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 0.1° grid (0.25° in V05)
- thin strips due to inter-swath gaps
- blocks due to regional variations
- snow/ice masking will drop out microwave values



D.Bolvin (SSAI; GSFC)

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?

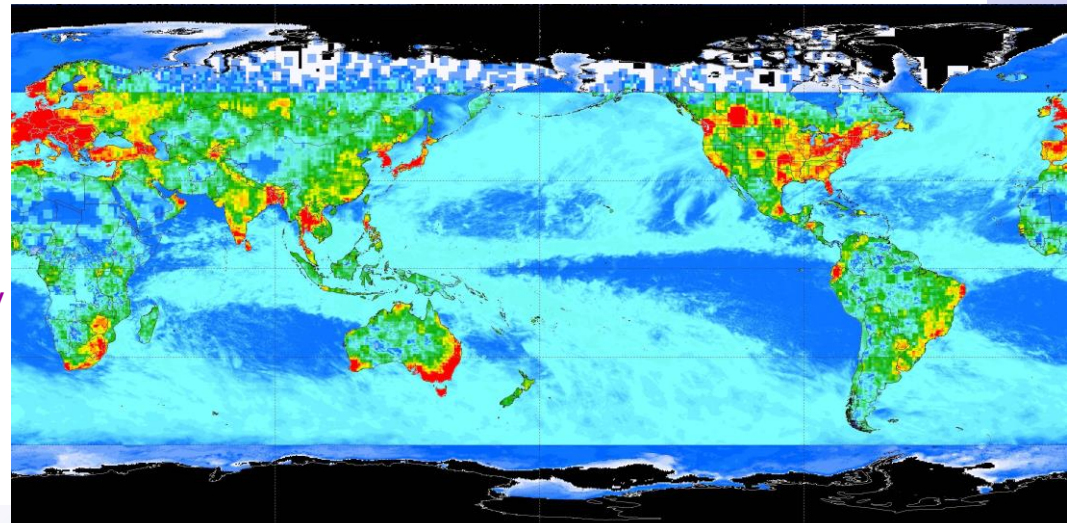
2. IMERG – Quality Index (2/2)

Monthly QI (unchanged)

- Equivalent Gauge (Huffman et al. 1997) in gauges / $2.5^\circ \times 2.5^\circ$

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

- 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

D.Bolvin (SSAI; GSFC)



2. IMERG – V06 Upgrades

Morphing vector source switched to MERRA-2/GEOS FP

Morphed precip extended from 60° N-S (V05 and earlier) to 90° 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 0.1° grid (0.25° 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 33°N-S and
 - blend with adjusted monthly climatological GPM-era microwave calibrations over 25°-90° N and S

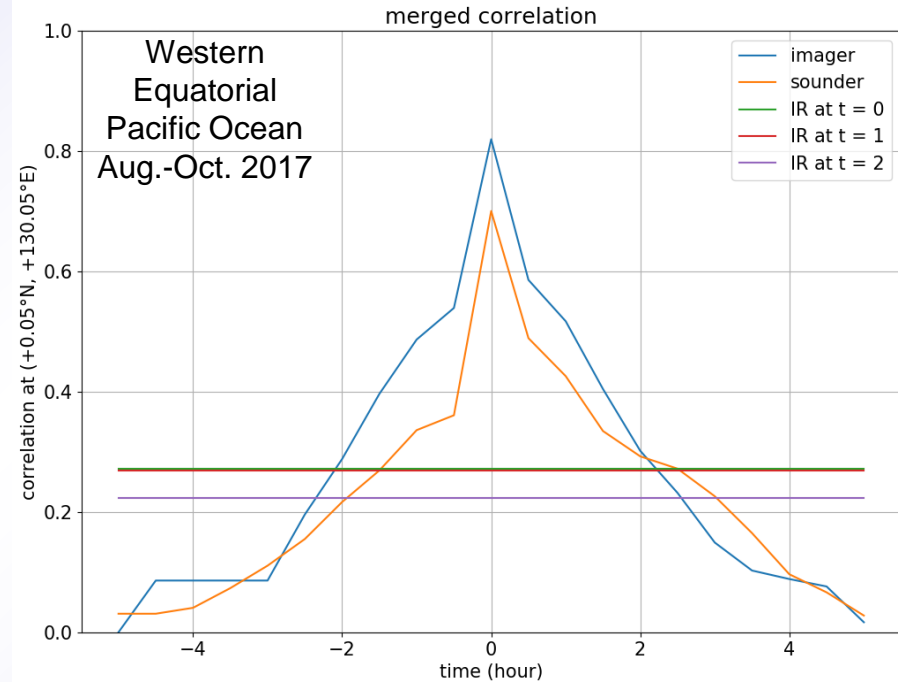
Revisions to internals raises the maximum precip rate from 50 to 200 mm/hr and no longer discrete

- 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)

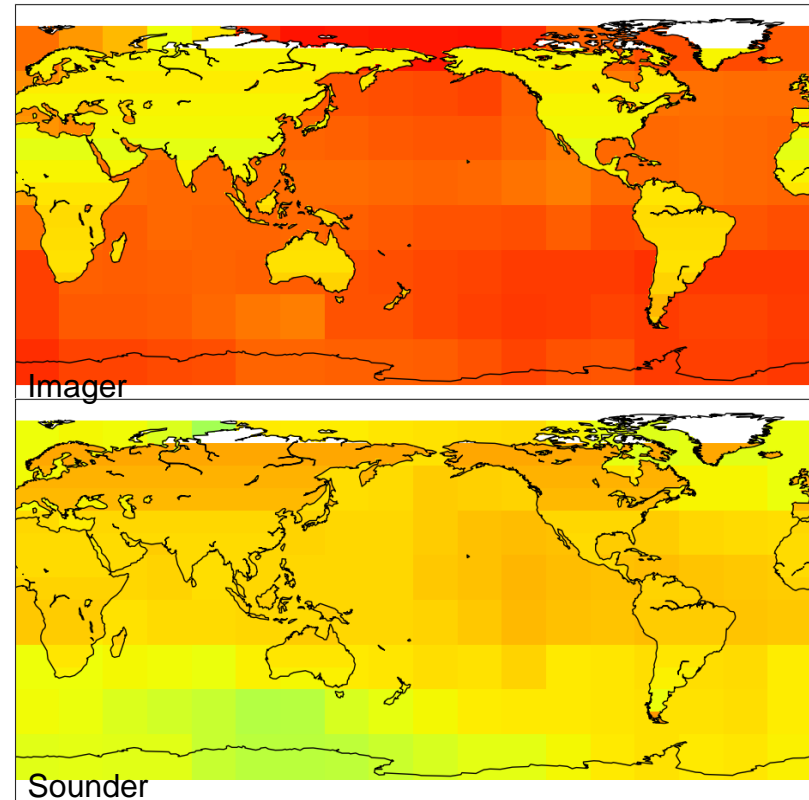


J. Tan (USRA; GSFC)

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

J. Tan (USRA; GSFC)

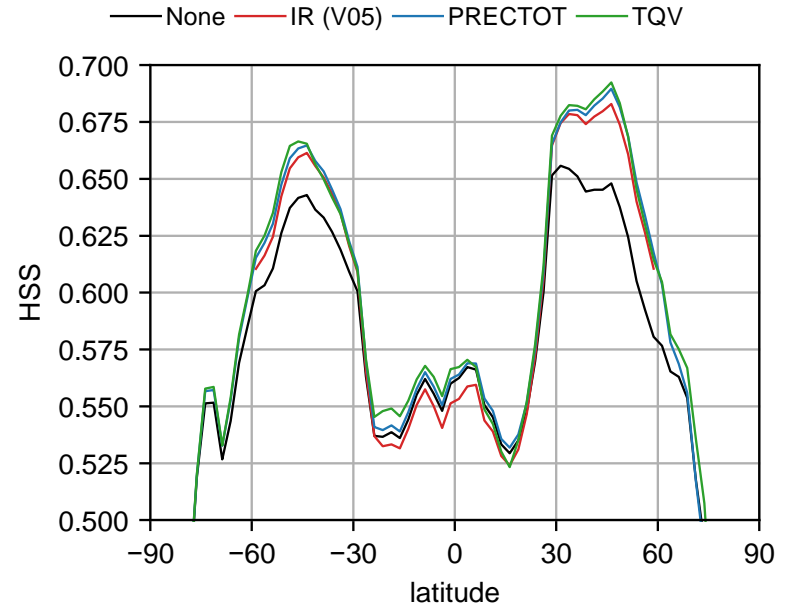
3. Some Details – Key Points in Morphing (3/3)

Tested vectors computed on a $5^\circ \times 5^\circ$ template every 2.5° , interpolated to $0.1^\circ \times 0.1^\circ$ 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



J. Tan (USRA; GSFC)

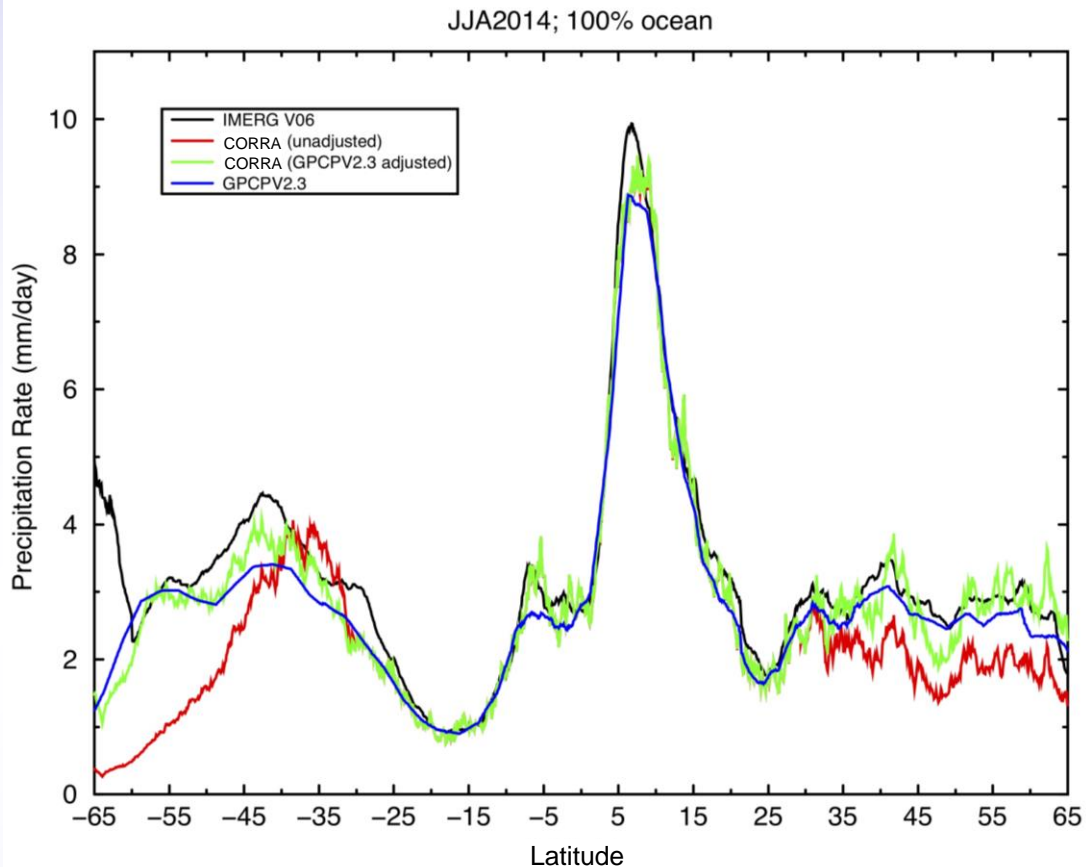
4. Early Results – Calibration

Calibration sequence is

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

Adjustments working roughly as intended

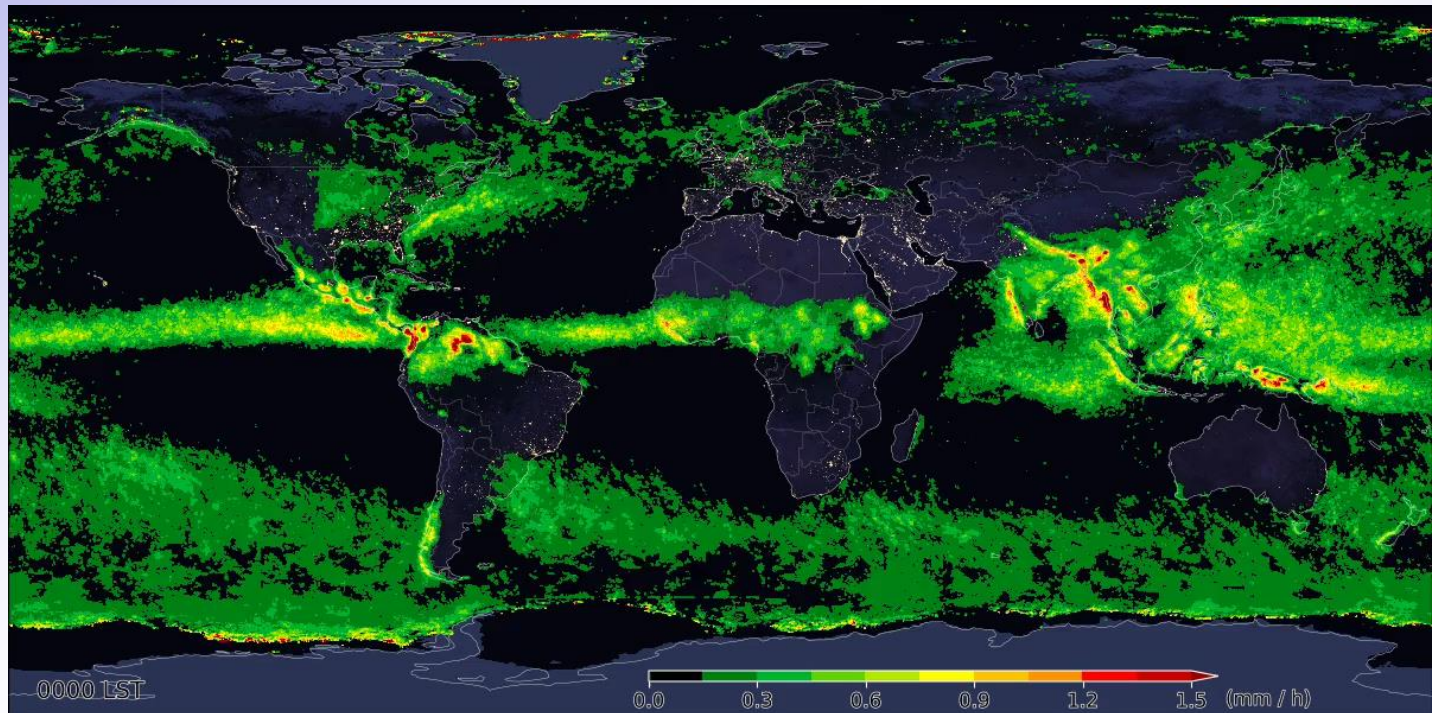
- CORRA is low at higher latitudes
- adjustments in Southern Ocean are large and need analysis
 - IMERG subsetted to coincidence with CORRA is much closer to CORRA



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



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)

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

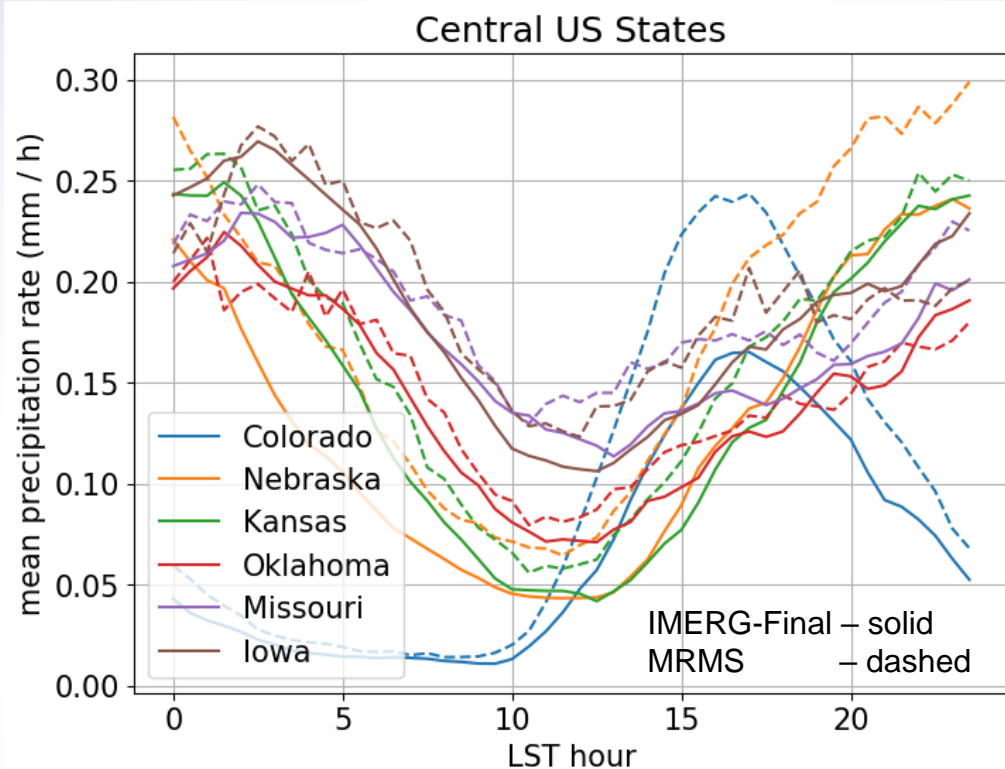
4. Early Results – JJA Diurnal Cycle in Central U.S. (GPM Era)

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

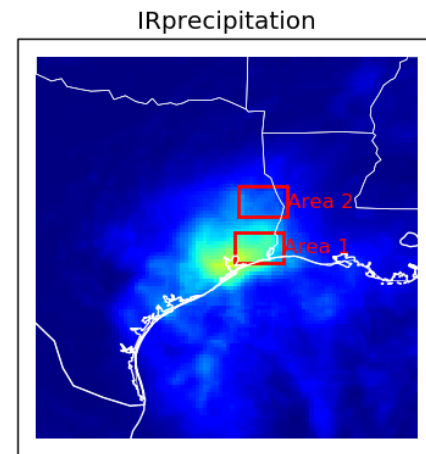
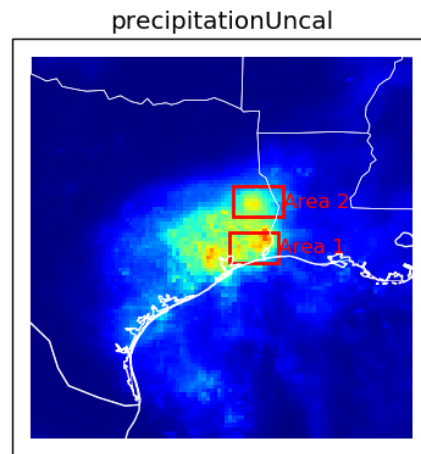
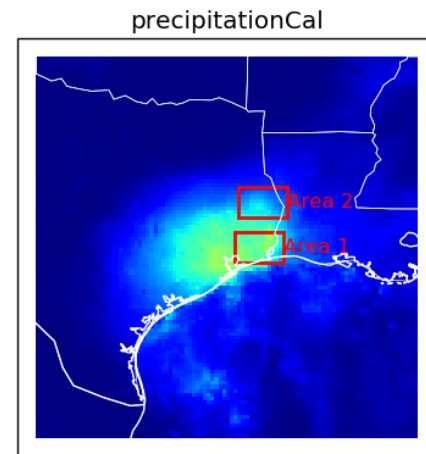
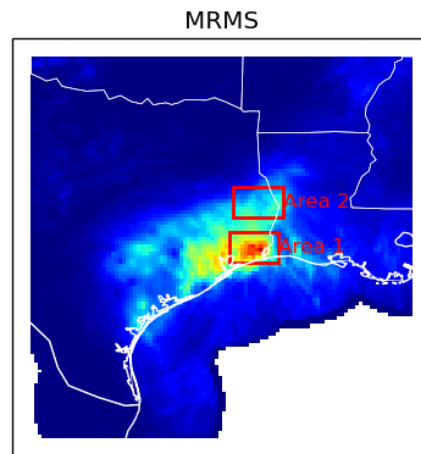


J. Tan (USRA; GSFC)

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

Harvey loitered over southeast Texas for a week

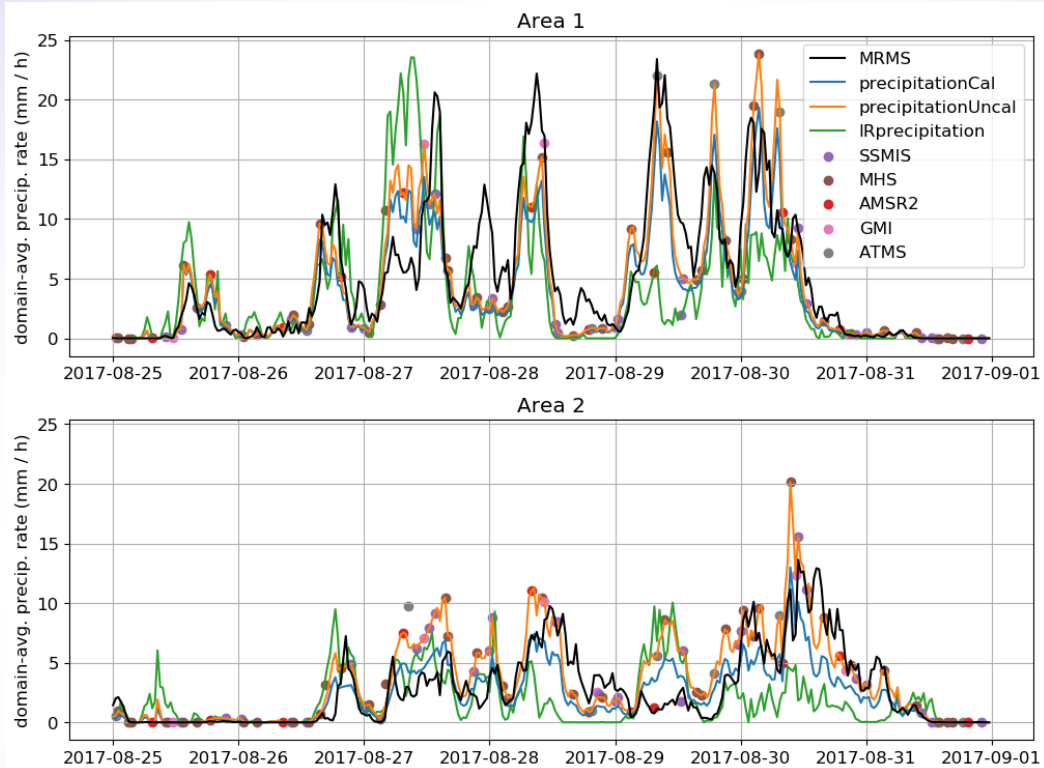
- Multi-Radar Multi-Sensor (MRMS) considered the best estimate
 - some questions about the details of the gauge calibration of the radar estimate
 - over land
- Uncal (just the intercalibrated satellite estimates) under(over)-estimated in Area 1(2)
 - should be similar in NRT Late Run
- Cal (with gauge adjustment) pulls both areas down
- microwave-adjusted PERSIANN-CCS IR has the focus too far southwest



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* \times factor)
 - short-interval differences show some cancellation over the whole event
 - but several-hour differences can be dramatic



J. Tan (USRA; GSFC)

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

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

V06(V05) is higher(lower) than TMPA

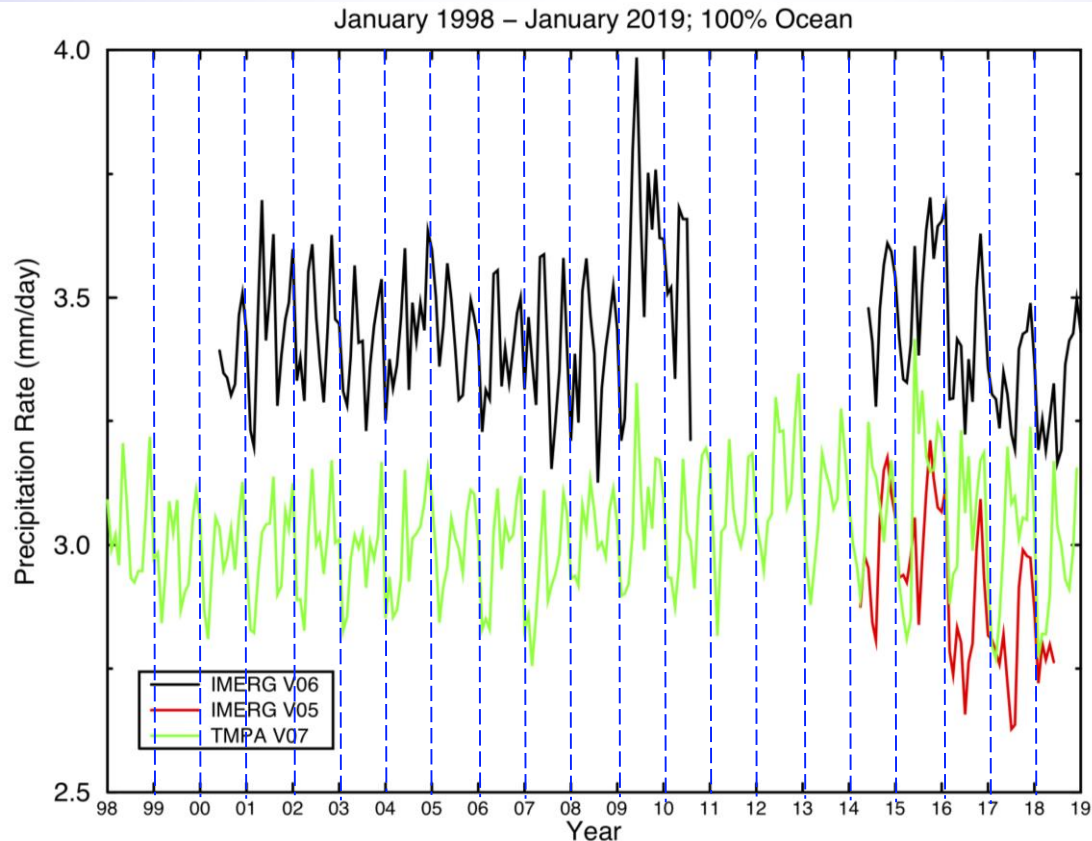
TMPA and TRMM-era IMERG have a strong semi-annual signal

- 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



5. Schedule and Final Remarks (1/3)

Early March 2019: began Version 9.5.1 Retrospective Processing

- the GPM era was launched for Initial Processing **done**
- the TRMM era Final Run reports are **underway**
 - 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 Initial Processing, so they come after Final Initial Processing
 - Final is always ~3.5 months behind, so the Early and Late Run Retrospective processing have to wait on Final Initial Processing to fill in the late data before they can be processed **coming**
- Early and Late Run Initial Processing is **underway** by May

5. Schedule and Final Remarks (2/3)

Development Work for V07

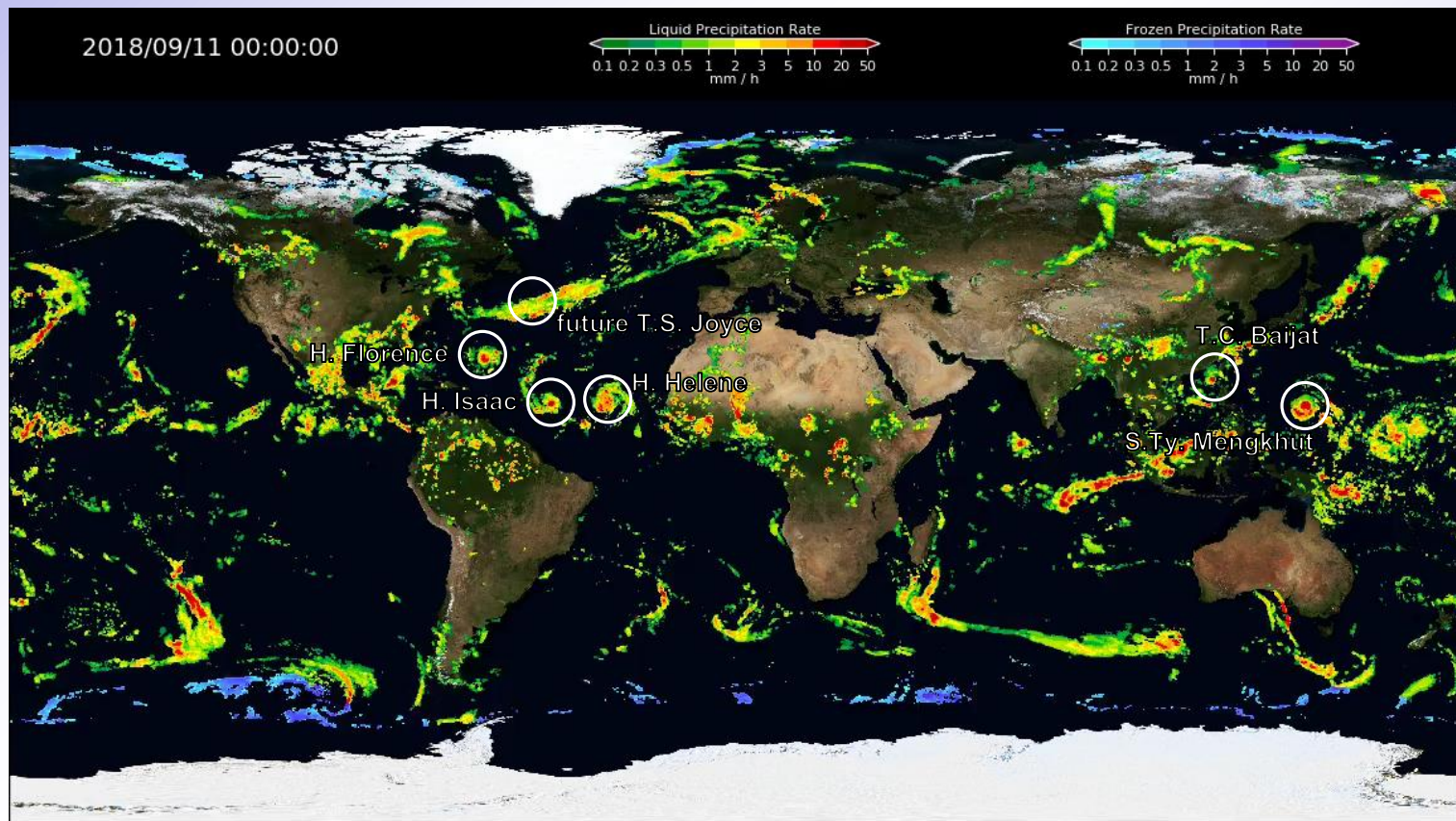
- multi-satellite issues
 - improve error estimation
 - develop additional data sets based on observation-model combinations
 - work toward a cloud development component in the morphing system
- general precipitation algorithmic issues
 - introduce alternative/additional satellites at high latitudes (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
 - 0.1°x0.1° half-hourly (and monthly in Final)
- new source for morphing vectors
- higher-latitude coverage
- extension back to 2000 (and eventually 1998)
- improved Quality Index



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

J. Tan (USRA; GSFC)