Satellite Precipitation Estimates, GPM, and Extremes

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1. Introduction
2. From Data to Estimates
3. IMERG
4. Schedule
5. Application
6. Concluding Remarks

1. INTRODUCTION – Rain is easy to measure, hard to analyze

The physical process is hard to represent:

- rain is generated on the microscale
- the decorrelation distance/time is short
- point values only represent a small area & snapshots only represent a short time
- a finite number of samples causes problems

Image courtesy of the University Corporation for Atmospheric Research

1. INTRODUCTION – Instrumentation strong points

Knowledge of precipitation is key to a wide range of users

Data sources have recognized strengths:

- microwave imagers — good instantaneous results
- geo-IR — good sampling
- satellite soundings — some information in cold-surface conditions
- precipitation gauge — near-zero bias
- model — complete coverage and "physics"

Different data sources are best in different regions

All have bigger errors in

- mountains
- snowy/icy regions

1. INTRODUCTION – But …

Instruments have characteristic errors:

- raingauge
  wind losses — splashing
  evaporation — side-wetting
  interpolation
- radar
  raindrop population changes
  anomalous propagation
  beam blockage by surface features
  sidelobes
- satellite
  physical retrieval errors
  beam-filling errors
  time-sampling
- numerical prediction models
  computational approximations
  initialization errors
  errors in other parts of the computation

Sensor-specific strengths and limitations

	infrared	microwave
latency	15-60 min	3-4 hr
footprint	4-8 km	5-30+ km
interval	15-30 min (up to 3 hr)	12-24 hr (~3 hr)
"physics"	cloud top weak	hydrometeors strong

- additional PMW issues over land include
  - scattering channels only
  - issues with orographic precip
  - estimates not currently useful over snow and sea ice

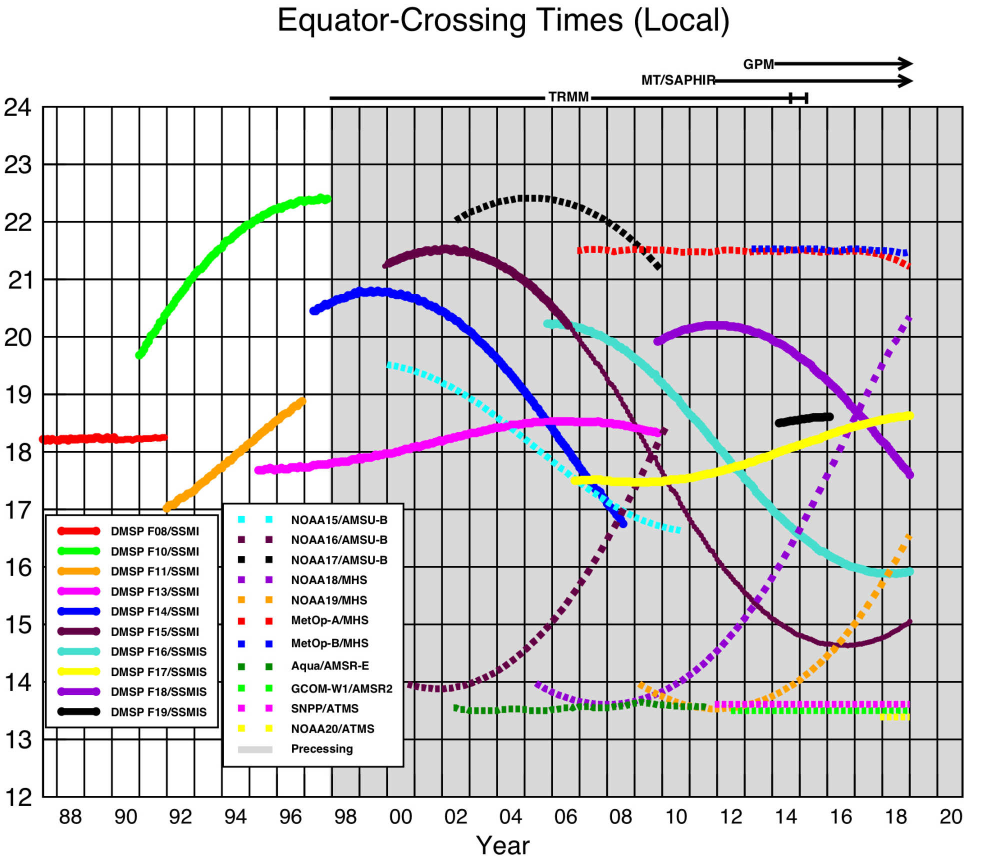
2. FROM DATA TO ESTIMATES – The constellation (1/2)

We want 3-hourly observations, globally

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

The current international 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) & PRPS (SAPHIR)
  - PERSIANN-CCS (GEO IR)
  - 2BCMB (combined PMW-radar)
  - GPCP SG (monthly satellite-gauge)

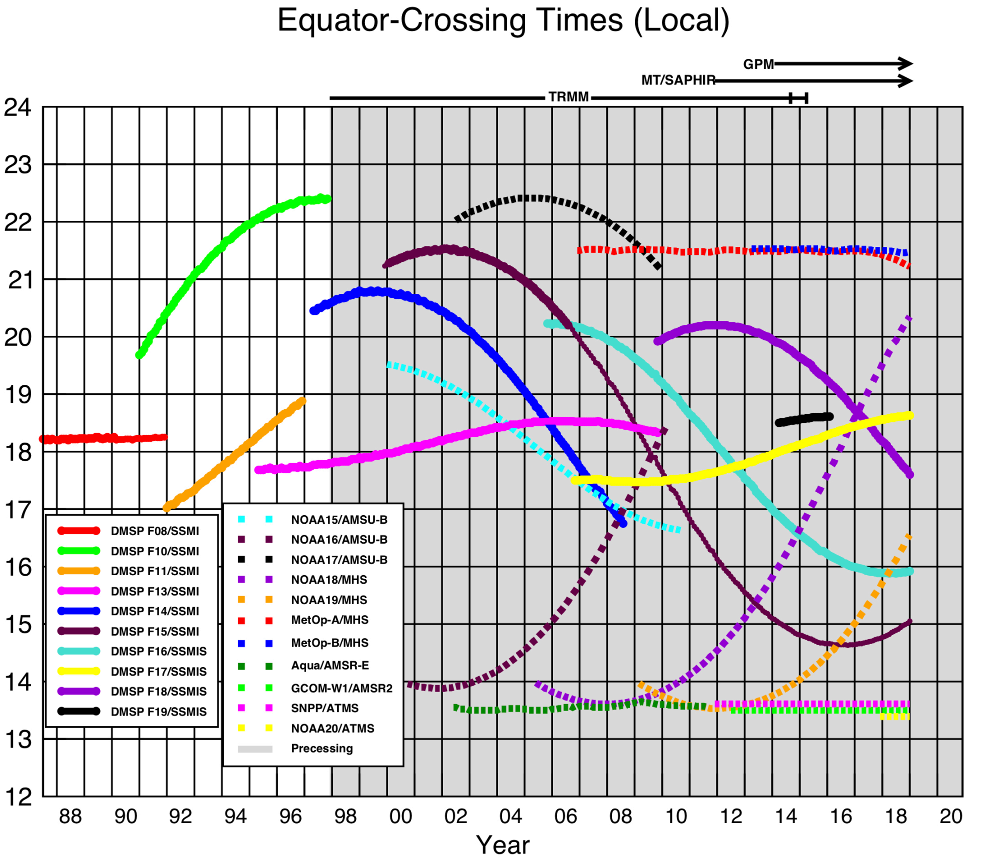


Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 30 January 2019, NASA/Goddard Space Flight Center, Greenbelt, MD.

2. FROM DATA TO ESTIMATES – The constellation (2/2)

The constellation is evolving

- legacy satellites are allowed to drift
  - exact coverage is a complicated function of time
  - duplicate orbits aren't very useful for getting 3-hourly observations
- launch manifests tend to show fewer satellites in the next decade



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. FROM DATA TO ESTIMATES – Single-satellite estimates

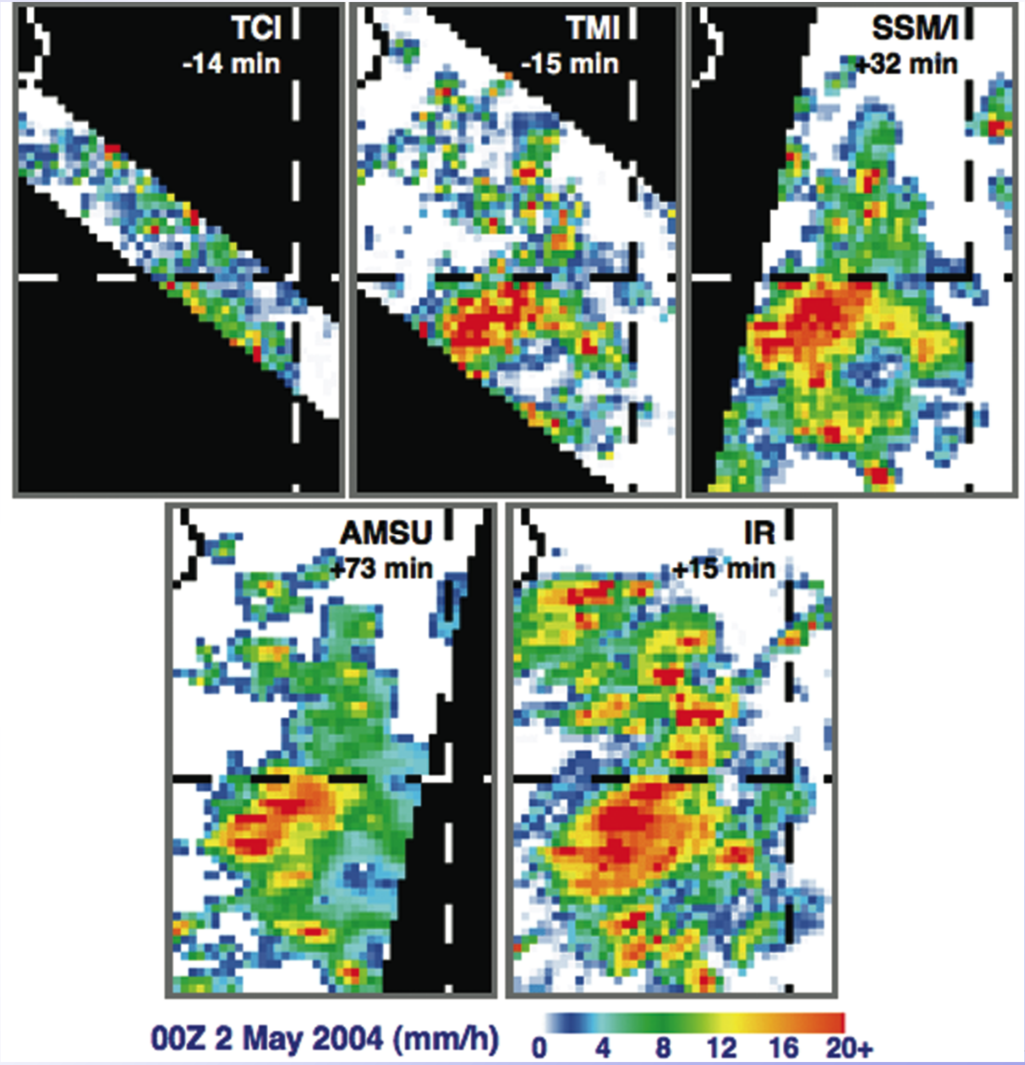
Nearly coincident views by 5 sensors southeast of Sri Lanka

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. FROM DATA TO ESTIMATES – There are numerous choices out in public

The International Precipitation Working Group (IPWG) web site

- http://www.isac.cnr.it/~ipwg/
- a concerted effort in the next biennium to beef up user-oriented information
  - “fitness for use”
  - http://www.isac.cnr.it/~ipwg/data.html
- tables listing publicly available, long-term, quasi-global precipitation data sets
  - http://www.isac.cnr.it/~ipwg/data/datasets.html
  - combinations with gauge data
  - satellite-only combinations
  - single-satellite
  - gauge analysis

And I have a dog in this show …

3. 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*

3. IMERG – Quick description (2/2)

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

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

	Half-hourly data file (Early, Late, Final)
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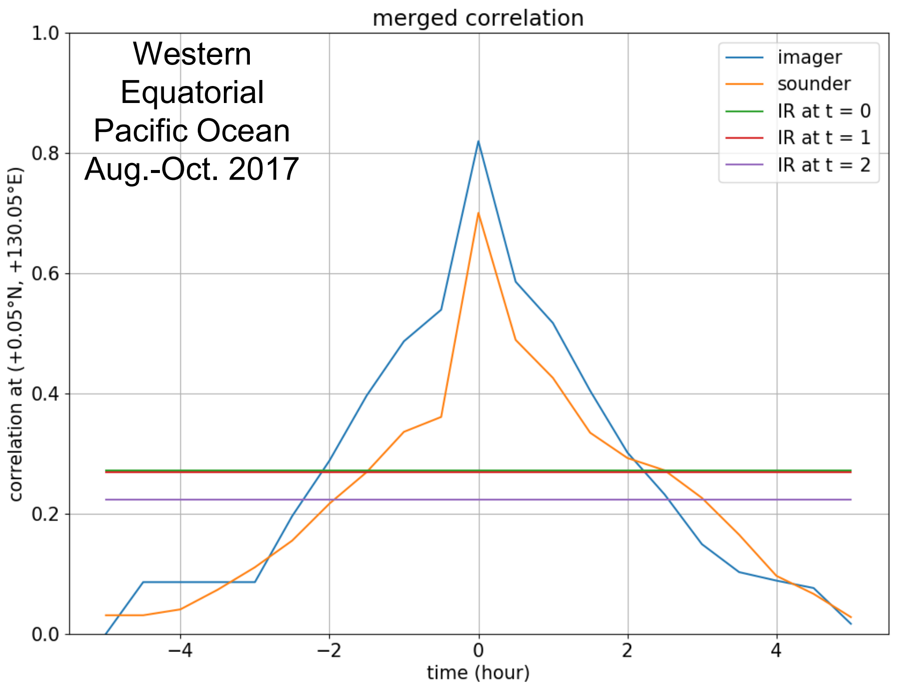
3. IMERG – Key points in morphing (1/2)

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
  - by season and regional blocks
- the microwave correlations drop below the IR correlation within a few hours (2 hours in the Western Equatorial Pacific)



D.Bolvin (SSAI; GSFC)

3. IMERG – Key points in morphing (2/2)

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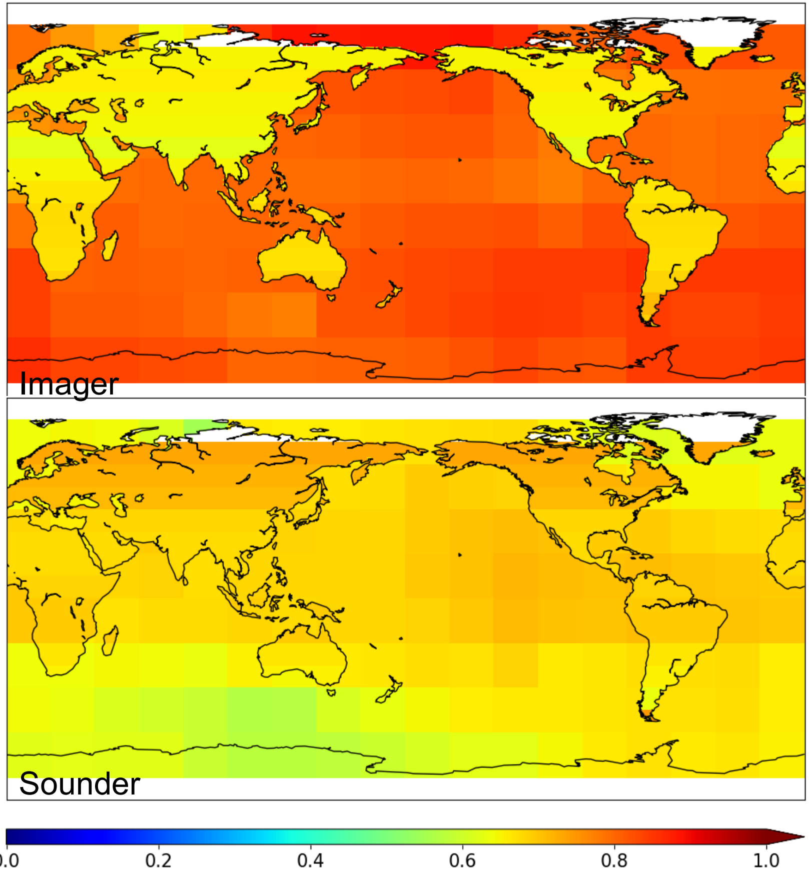
  - for conical-scan (imager) and cross-track-scan (sounder) instruments separately
  - by season and regional blocks
- the microwave correlations drop below the IR correlation within a few hours (2 hours in the Western Equatorial Pacific)
- at t=0 (no offset), imagers are better over oceans, sounders are better or competitive over land



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

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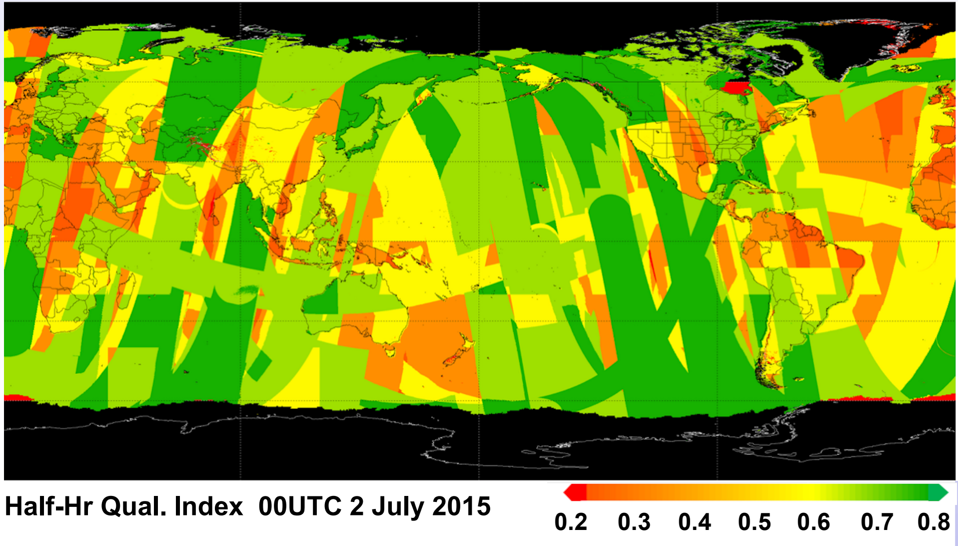
3. IMERG – Quality Index (1/2)

Half-hourly QI (revised)

- approx. Kalman Filter correlation
  - based on
    - times to 2 nearest PMWs (only 1 for Early)
    - IR at 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
  - approximate *r* when a PMW overpass is used
- 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



Half-Hr Qual. Index 00UTC 2 July 2015

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The goal is a simple "stoplight" index

- ranges of QI are considered to be:
  - > 0.6 good
  - 0.4–0.6 use with caution
  - < 0.4 questionable
- is this a useful parameter?

4. SCHEDULE – Version 06 in the GPM era

Early March 2019: began Version 06 IMERG Retrospective Processing

- the GPM era was launched first, Final Run first ← done
- the TRMM era Final Run reprocessing is underway ← underway
  - complete data will take about a month
  - 4 km merged global IR data files continue to be delayed for January 1998-January 2000
    - the run will build up the requisite 3 months of calibration data starting from February 2000
    - the first month of data will be for June 2000
    - the initial 29 months of data will be incorporated when feasible
- Early and Late Run Retrospective Processing uses Final intermediate files, so they come after Final
  - Final is always ~3.5 months behind, so the Early and Late retrospective processing have to wait on Final Initial Processing to fill in the last 3 months before May 2019 (i.e., until mid-August)
- Early and Late Run Initial Processing will start ~1 May ← coming

4. SCHEDULE – Development work for V07

Multi-satellite issues

- improve error estimation
    - field seems to be headed toward posting quantile values
- develop additional data sets based on observation-model combinations
- work toward a cloud system 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 (late 2021?)

4. SCHEDULE – Version 06 summary

The product structure remains the same

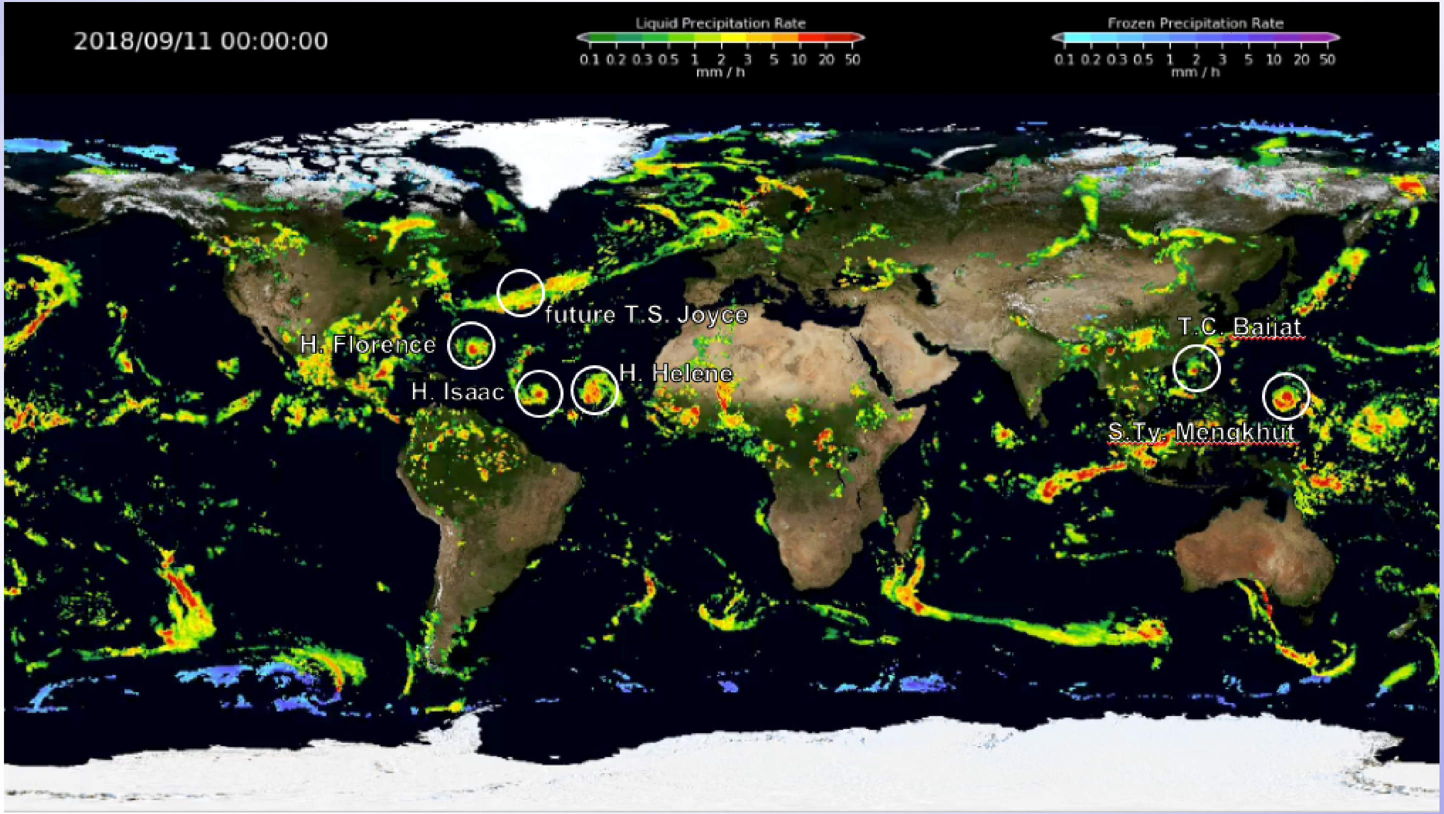
- Early, Late, Final
- 0.1°x0.1° half-hourly (and monthly in Final)

New source for morphing vectors

Higher-latitude coverage

Extension back to 2000 (and eventually 1998)

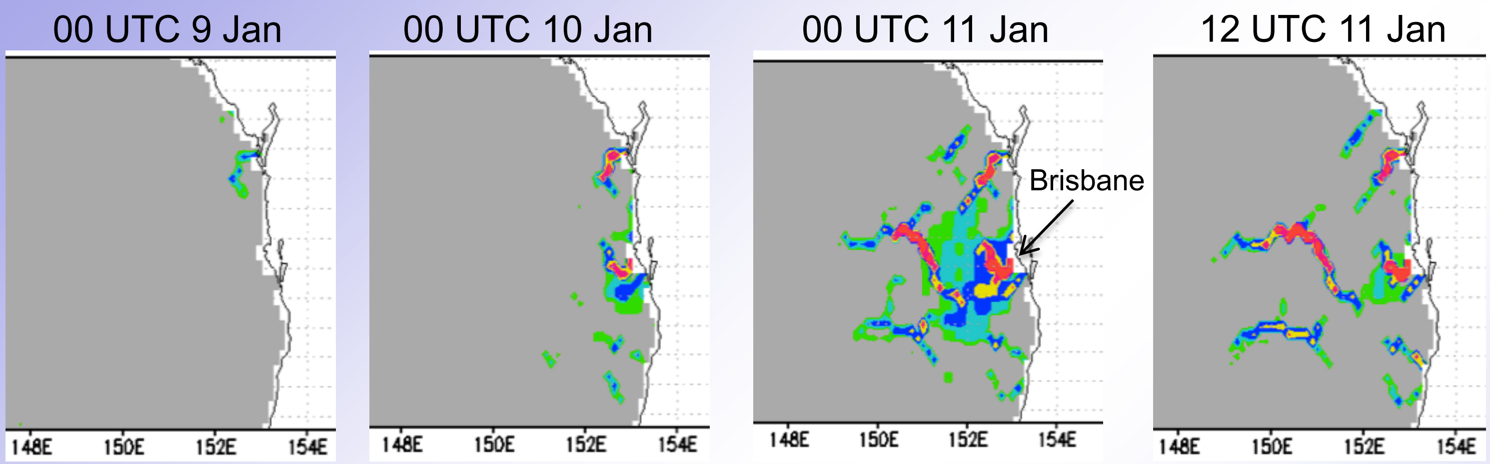
Improved Quality Index

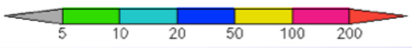


see 1C-1-Huffman_NASA_SatPrecipslides_Video.mp4

J. Tan (USRA; GSFC)

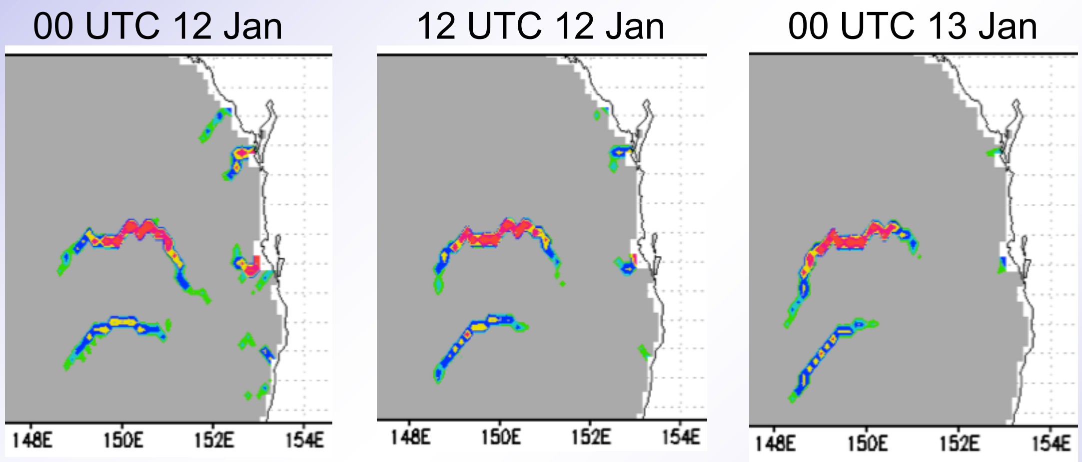
5. APPLICATION – Estimated flood evolution for 9-13 January 2011, Australia





Relative Routed Runoff (mm)

Global Flood Monitor
Adler (U.Md.)

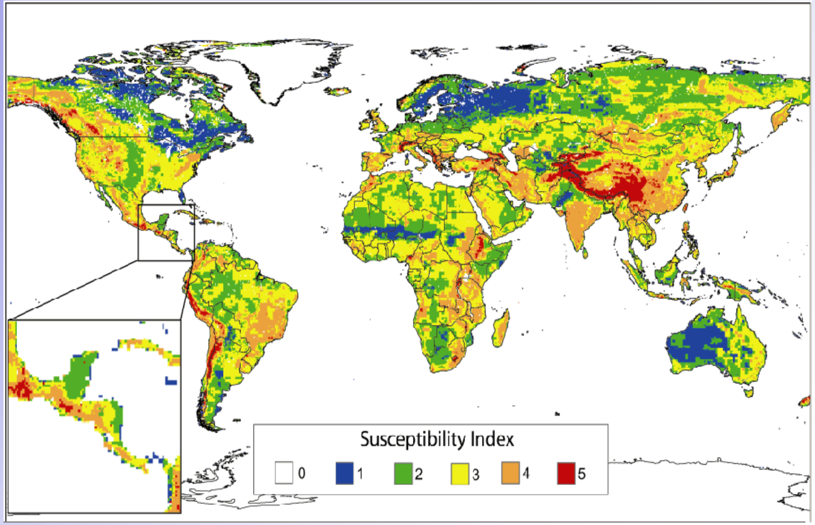


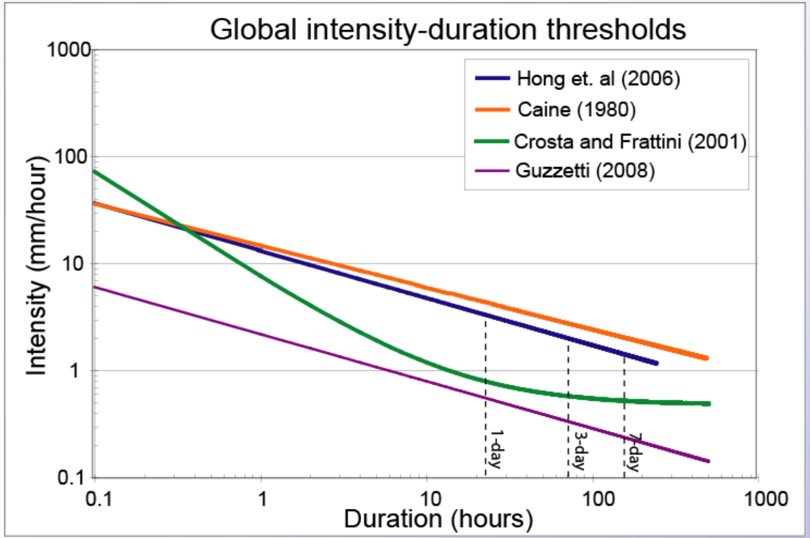
Individual events happen quickly; heavy localized rain events captured by satellite data

Flood models estimate flood evolution

- Brisbane area floods peak on 11 Jan. then subside
- To the west another flood area develops from the same rain system
- high water levels move downstream into relatively unpopulated areas

5. APPLICATION – Global landslide occurrence algorithm





Surface Data:

- topographic variables
- land cover
- soil type and texture
- drainage density

Rainfall Data:

- TMPA
- 0.25º, 3-hourly resolution

Circles enclose small areas of estimated landslide locations

D. Kirschbaum (GSFC)

5. APPLICATION – Extreme precipitation

Fu et al. (2010) examined long-term behavior of ”extreme” precip in Australian gauge data

- computed 7 measures of “extreme”
- all measures roughly tracked together
- all measures of “extreme” showed strong multi-time-scale variability
    - a strong interdecadal component is present over the entire record
- provides a strong cautionary statement about reliability of fitting to a few decades of data

Adler et al. (2010) show only modest trends in global mean precip over 1979-2014

- but regional trends are substantially larger
- the global change seems to mostly manifest as wetter/drier in wet/dry areas

Adler, R.F., G. Gu, M. Sapiano, J.-J. Wang, G.J. Huffman, 2017: Global Precipitation: Means, Variations and Trends during the Satellite Era (1979-2014). *Surv. Geophys*., 21 pp. *doi:10.1007/s10712-017-9416-4*

Fu, G., N.R. Viney, S.P. Charles, J. Liu, 2010: Long-Term Temporal Variation of Extreme Rainfall Events in Australia: 1910-2006. *J. Hydrometeor*., **11**, 950-965. *doi:10.1175/2010JHM1204.1*

5. **APPLICATION –** Estimate Average Recurrence Interval for precipitation (1/2)

Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) dataset

- predecessor to IMERG
- 15 years, 50ºN-S

Approach builds on a previous avg. recurrence study

- domain partitioned into ~28,000 non-overlapping clusters using recursive k-means clustering
- peak-over-threshold classification as extreme if gridbox day value exceeds a (regional, seasonally varying) 99% threshold
- only the maximum day's value is retained in a run of over-threshold days
- analysis is a generalized extreme value (GEV) fitted with maximum likelihood estimation (MLE)

Demirdjian, L., Y. Zhou, G.J. Huffman, 2018: Statistical Modeling of Extreme Precipitation with TRMM Data. *J. Appl. Meteor. Climatol*., **57**, 15-30. *doi:10.1175/JAMC-D-17-0023.1*

5. APPLICATION – Estimate Average Recurrence Interval for precipitation (2/2)

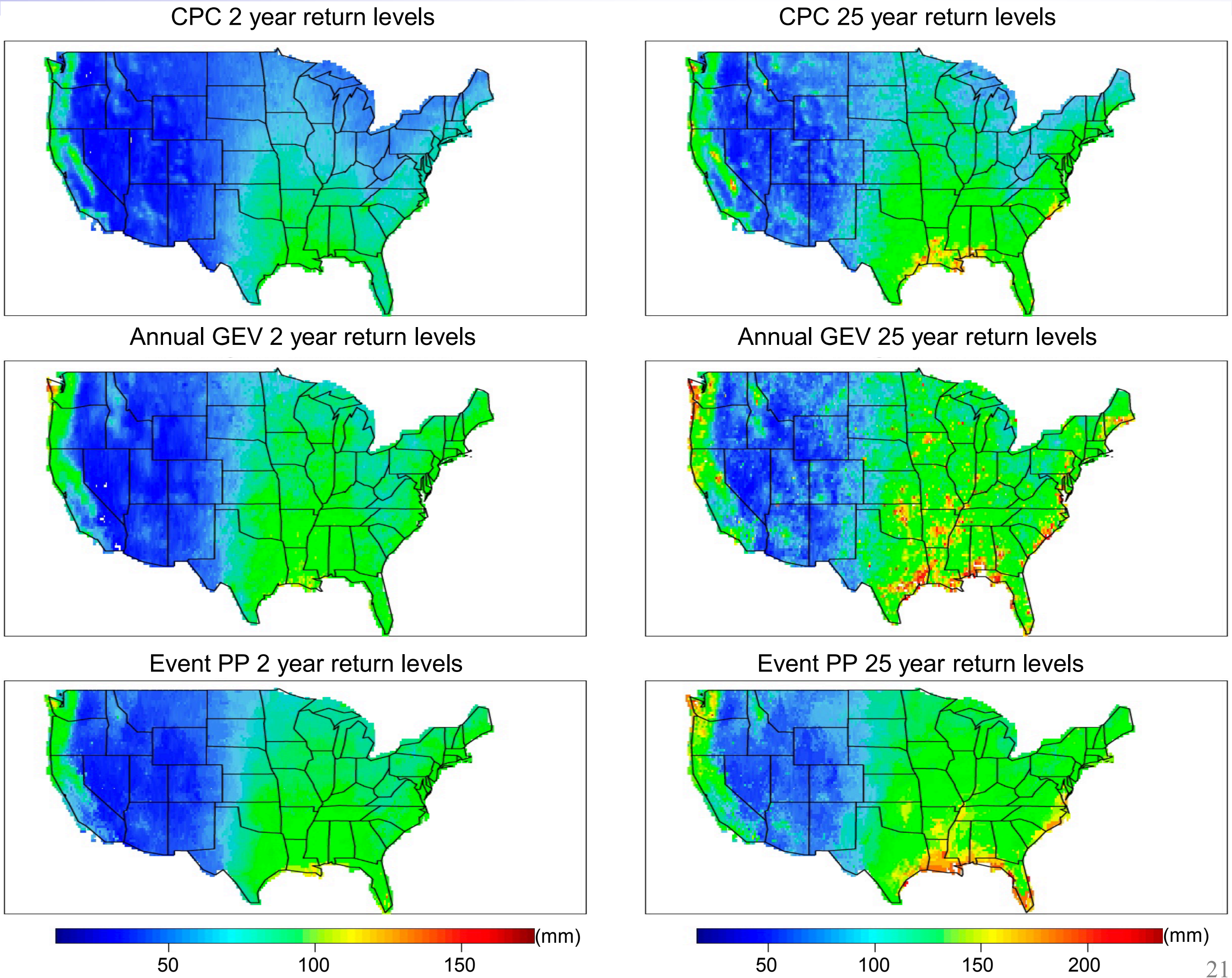
Compare Event PP to

- GEV of annual maximum data for 65 years of CPC gauge
- previous GEV using annual maximum data for 14 years of TMPA

Satellite schemes match each other for short interval

- and generally resemble CPC
- systematically high to the north

Event PP is closer to CPC at 25 years



6. CONCLUDING REMARKS

Satellites provide the only practical global source of precipitation

- several “state of the art” combination algorithms, including IMERG
  - quasi-Langrangian interpolation between passive microwave overpasses to populate a fine time grid
  - but algorithms are still mostly tuned to means, not extremes

Satellite datasets are being used to estimate extremes

- flooding
- landslides
- return period precipitation values

Precipitation extremes exhibit strong interdecadal fluctuations, but the influence of global change is still under study

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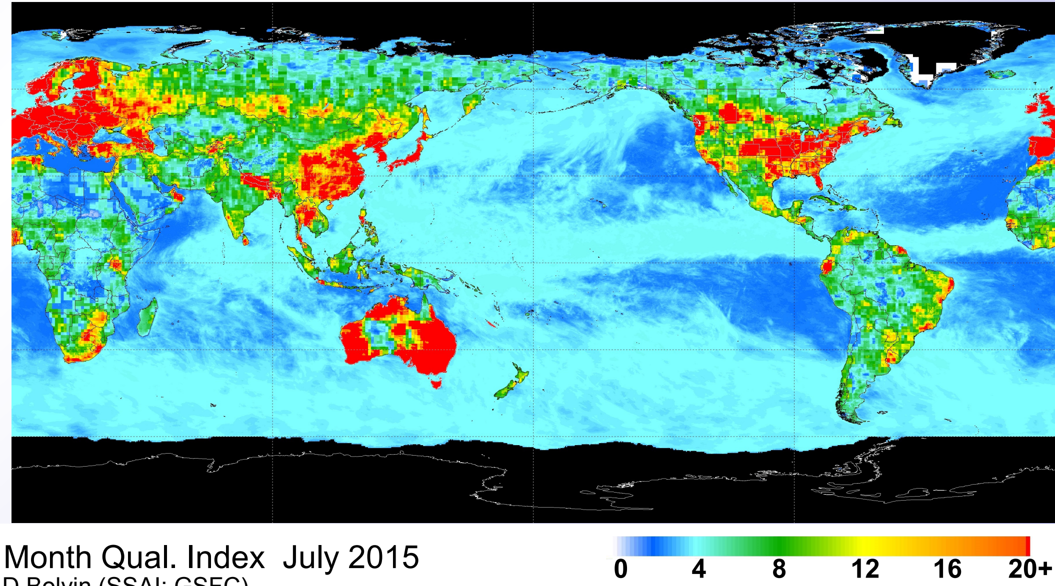
3. IMERG – Quality Index (2/2)

Monthly QI (unchanged from V05)

- 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
- $QI_m \geq 4$ is "good"
- $2 \leq QI_m < 4$ is "use with caution"
- $QI_m < 2$ is "questionable"



Month Qual. Index July 2015

D.Bolvin (SSAI; GSFC)