

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

	<u>infrared</u>	<u>microwave</u>
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

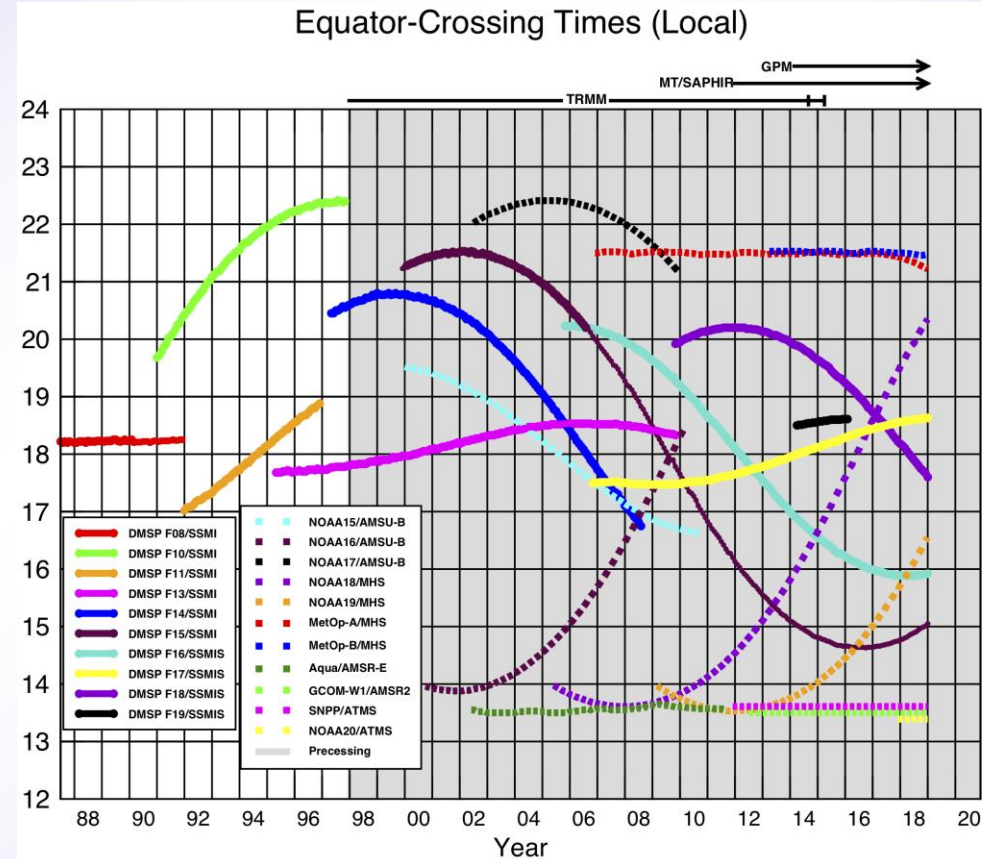
2. FROM DATA TO ESTIMATES – The constellation (1/2)

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)

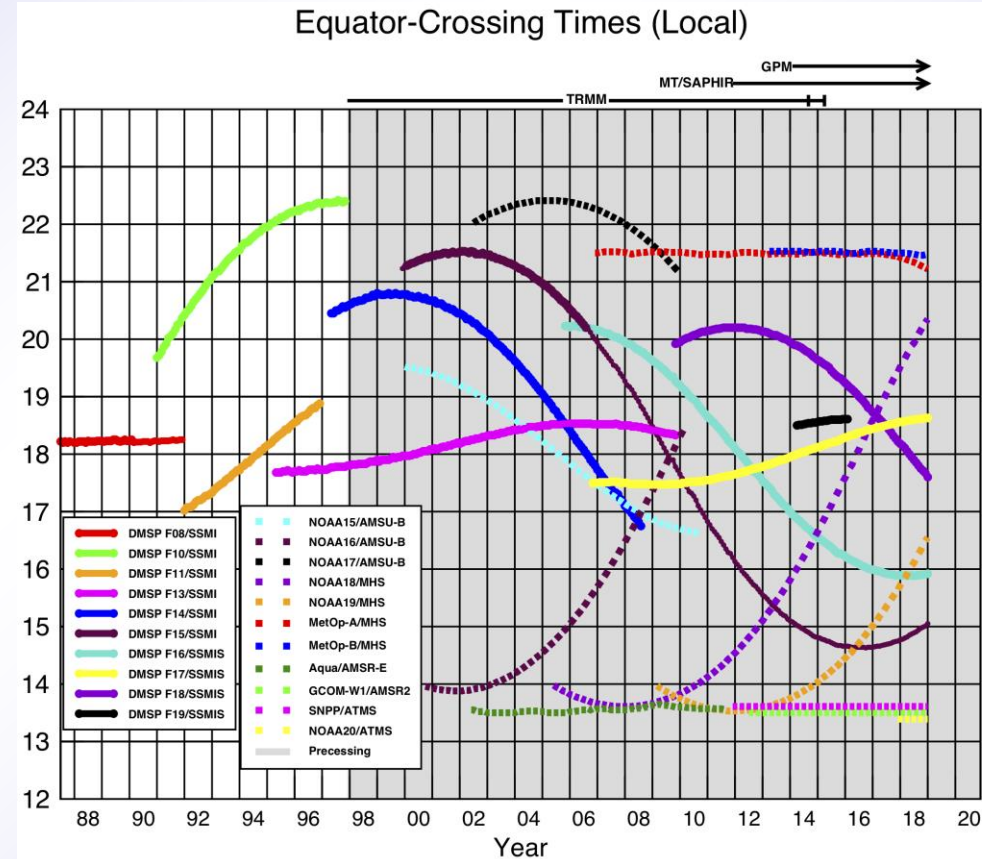


Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 30 January 2019, NASA/Goddard Space Flight Center, Greenbelt, MD.

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

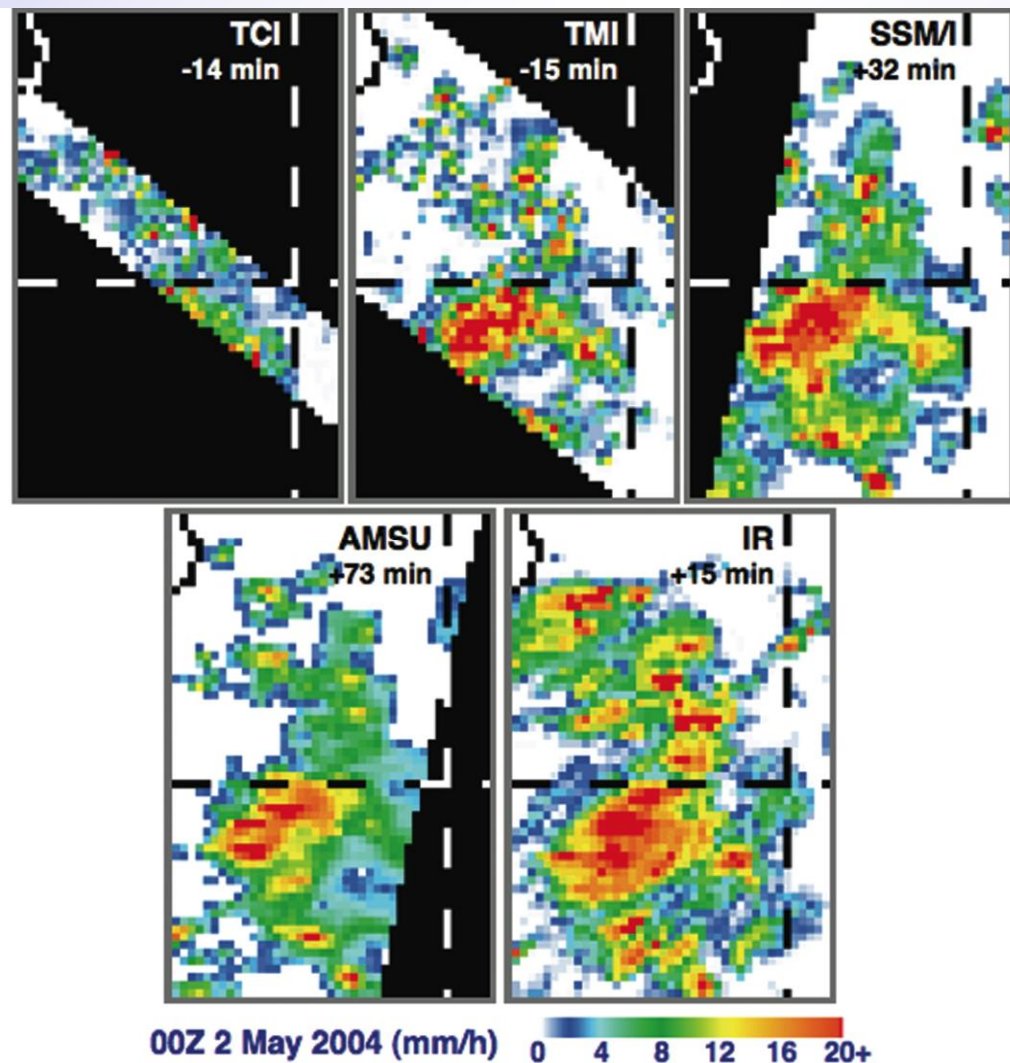
Nearly coincident views by 5 sensors
southeast of Sri Lanka

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)
- 0.1° 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>

3. IMERG – Quick description (2/2)

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

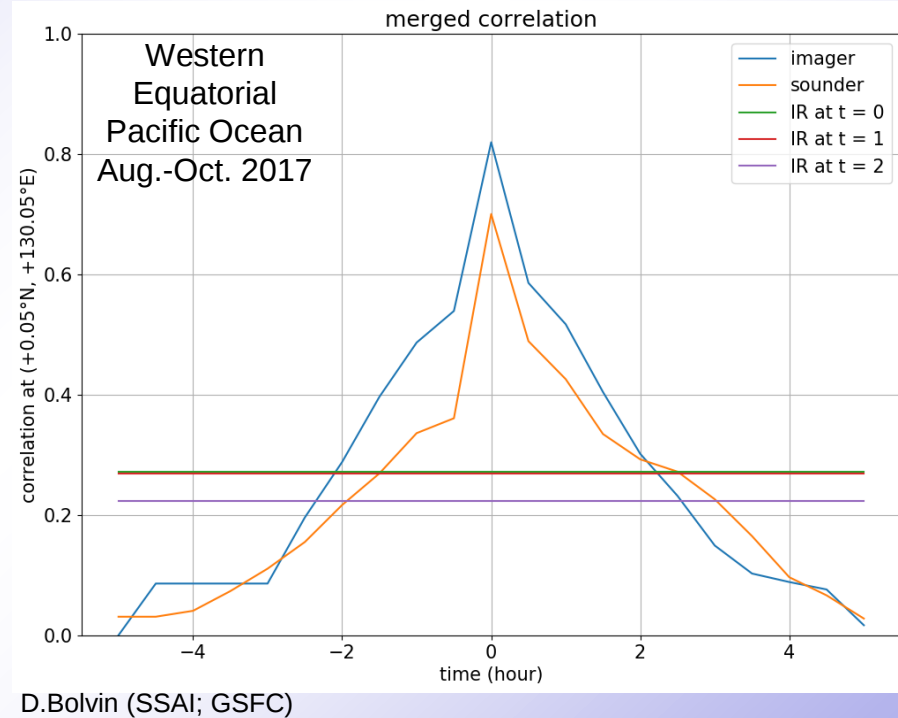
- Over Versions 04 to 06 the GPM core products have similar zonal profiles (by design)
 - these profiles are systematically low in the extratropical oceans compared to
 - GPCP monthly Satellite-Gauge product is a community standard climate product
 - Behrangi Multi-satellite CloudSat, TRMM, Aqua (MCTA) 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

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3. IMERG – Key points in morphing (1/2)

Following the CMORPH approach

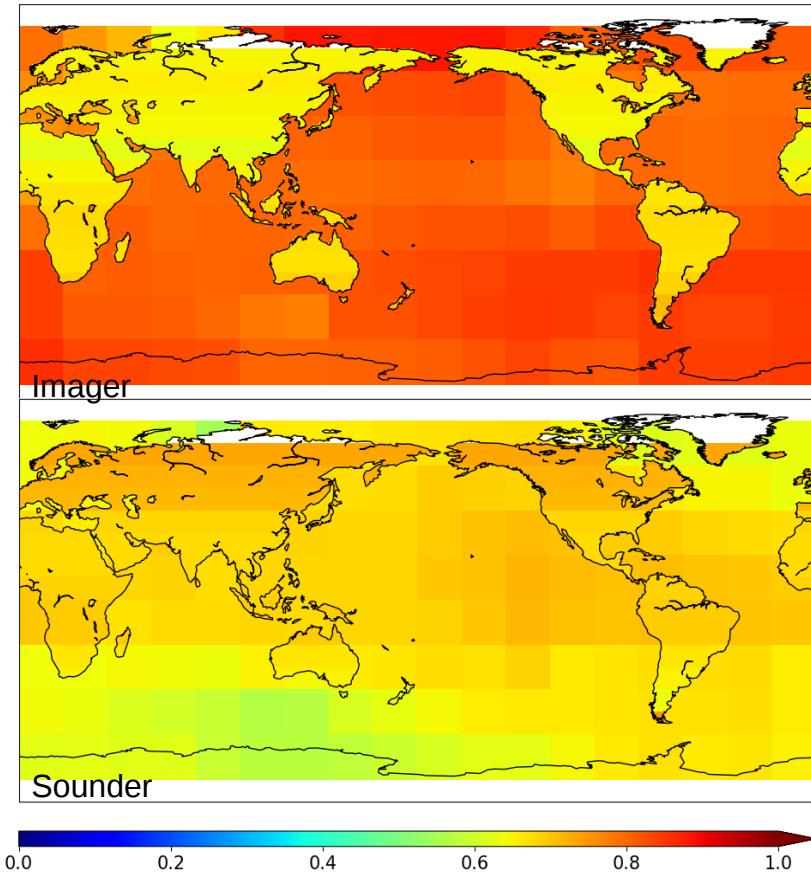
- for a given time offset from a microwave overpass
- compute the (smoothed) average correlation between
 - morphed microwave overpasses and microwave overpasses at that time offset, and
 - IR precip estimates and microwave overpasses at that time offset and IR at 1 and 2 half hours after that time offset
 - 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)



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

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- for a given time offset from a microwave overpass
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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

D.Bolvin (SSAI; GSFC)

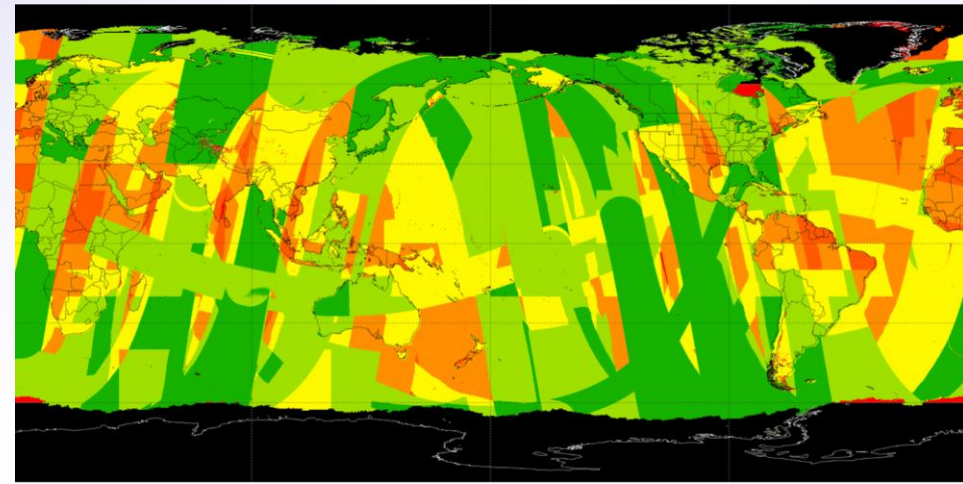
3. IMERG – Quality Index (1/2)

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



D.Bolvin (SSAI; GSFC)

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 the 4 km MERG Retrospective Processing

- the GPM era was **done** Final Intermediate Processing
- the TRMM era Final Intermediate Processing **underway** by May
 - complete data will take about 6 months
 - 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 past 3 months before May 2019 (i.e., until mid-August)
- Early and Late Run Initial Processing **coming** May

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

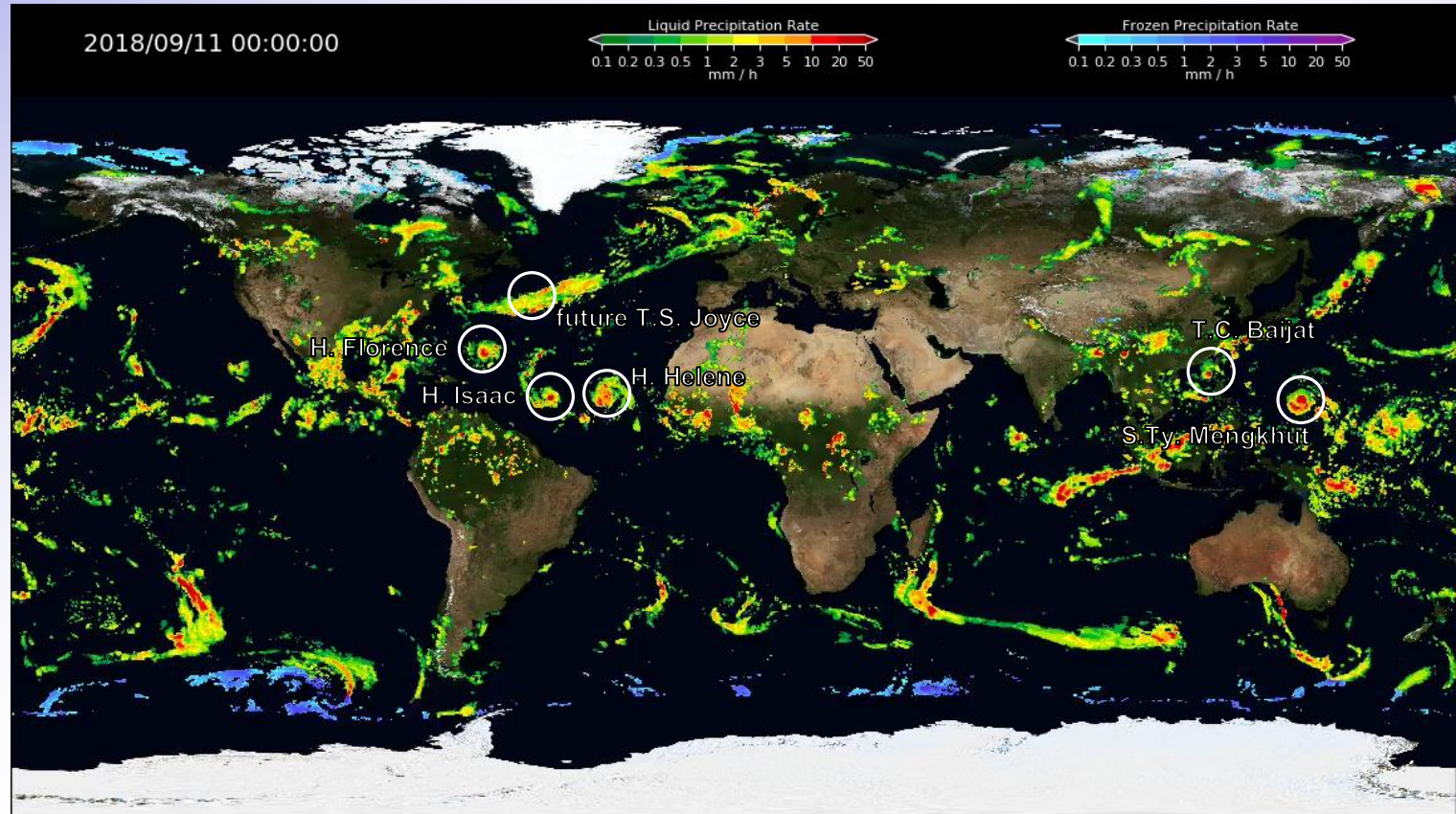
- Early, Late, Final
- $0.1^\circ \times 0.1^\circ$ half-hourly (and monthly in Final)

New source for morphing vectors

Higher-latitude coverage

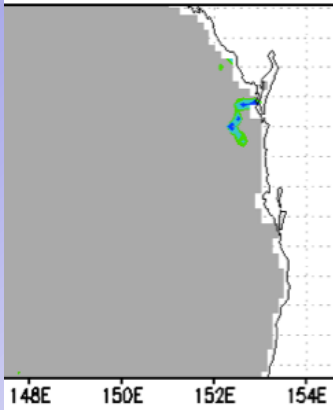
Extension back to 2000 (and eventually 1998)

Improved Quality Index

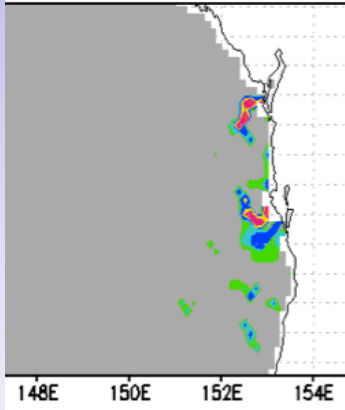


5. APPLICATION – Estimated flood evolution for 9-13 January 2011, Australia

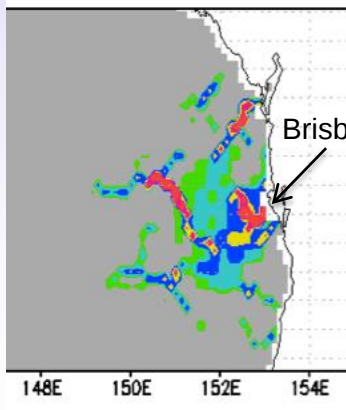
00 UTC 9 Jan



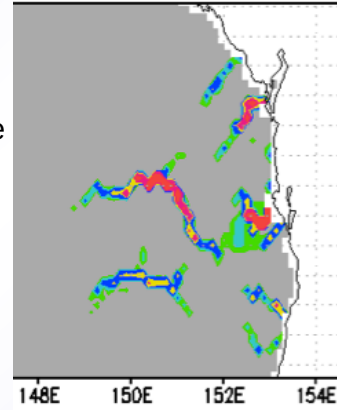
00 UTC 10 Jan



00 UTC 11 Jan



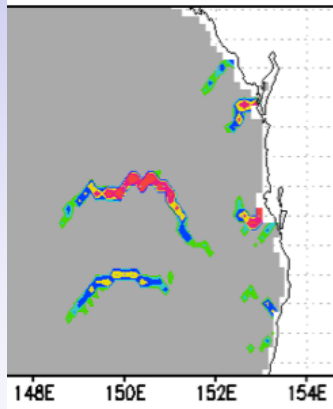
12 UTC 11 Jan



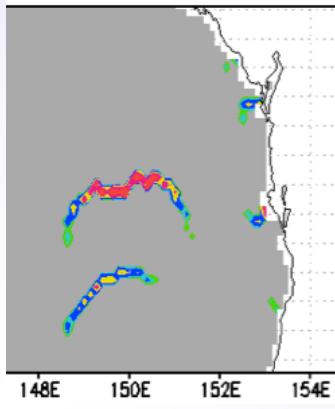
Relative Routed Runoff (mm)

Global Flood Monitor
Adler (U.Md.)

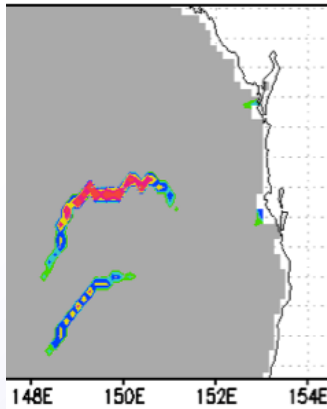
00 UTC 12 Jan



12 UTC 12 Jan



00 UTC 13 Jan

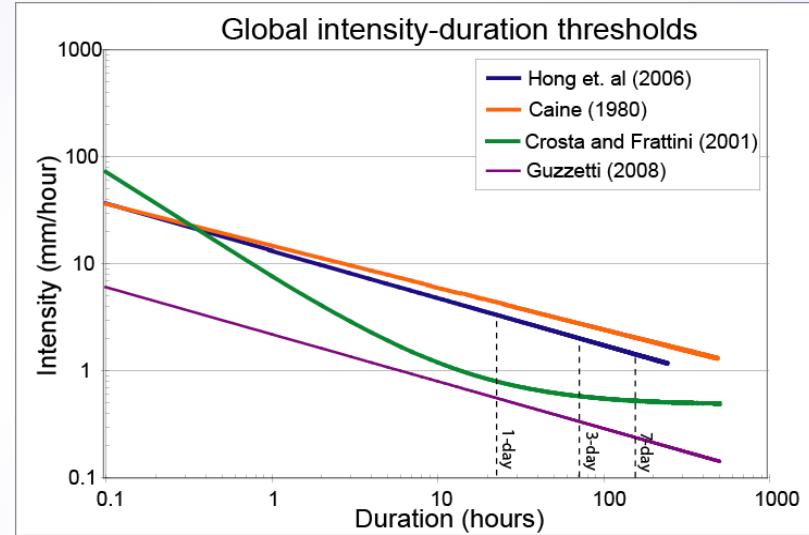
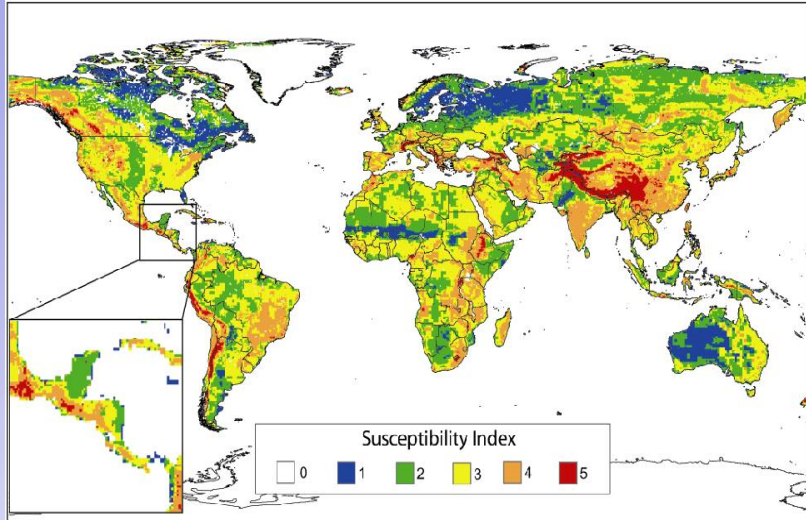


Individual events happen quickly; heavy localized rain events captured by satellite data

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
- 0.25°, 3-hourly resolution

Circles enclose small areas of estimated landslide locations

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, 50°N-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

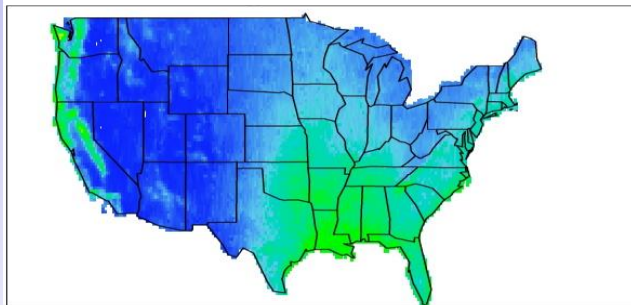
- GEV of annual maximum data for 65 years of CPC gauge
- previous GEV using annual maximum data for 14 years of TMPA

Satellite schemes match each other for short interval

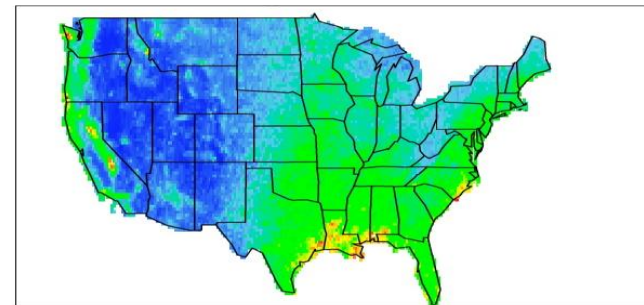
- and generally resemble CPC
- systematically high to the north

Event PP is closer to CPC at 25 years

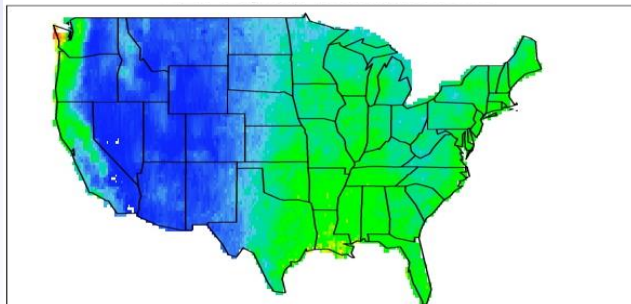
CPC 2 year return levels



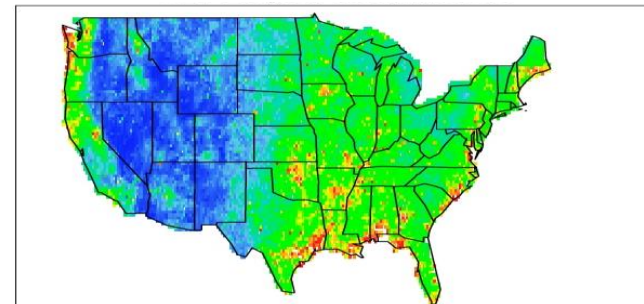
CPC 25 year return levels



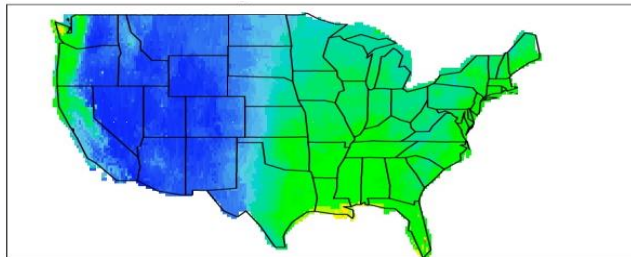
Annual GEV 2 year return levels



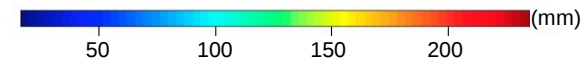
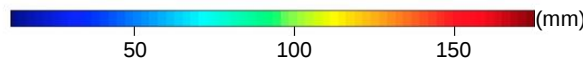
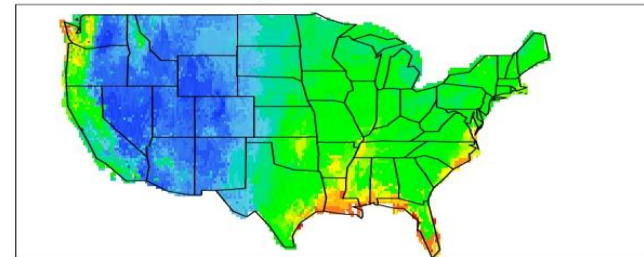
Annual GEV 25 year return levels



Event PP 2 year return levels



Event PP 25 year return levels



6. CONCLUDING REMARKS

Satellites provide the only practical global source of precipitation

- several “state of the art” combination algorithms, including IMERG
 - quasi-Lagrangian 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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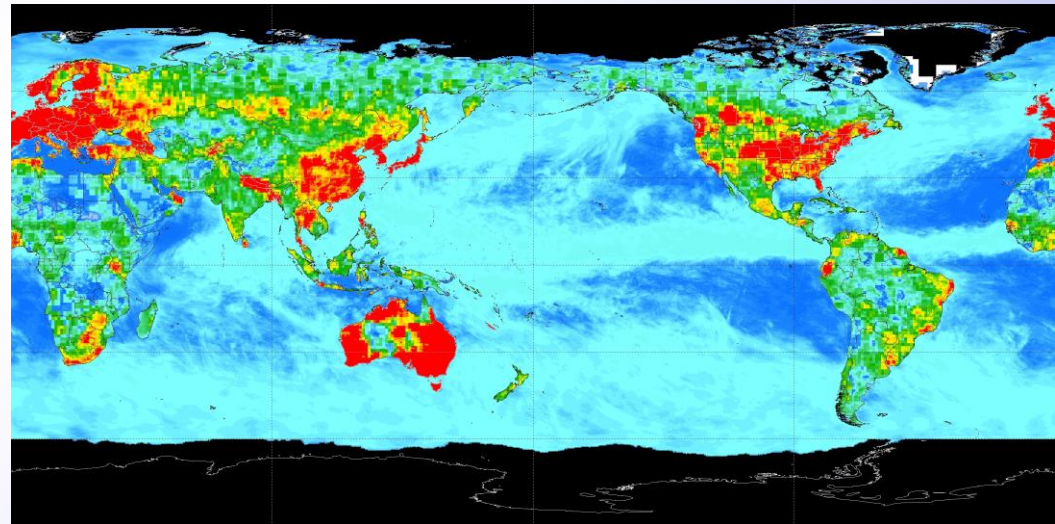
3. IMERG – Quality Index (2/2)

Monthly QI (unchanged from V05)

- Equivalent Gauge (Huffman et al. 1997) in gauges / 2.5°x2.5°

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

- 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)

