Lessons Learned in Building Long-Term Multi-Satellite Global Precipitation Records

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Efforts to construct long-term global precipitation data sets from the decades-long record of satellite (and other) data historically have fallen into one of two categories. Climate Data Records (CDR), such as the Global Precipitation Climatology Project (GPCP), prioritize homogeneity over fine-scale accuracy. On the other hand, High Resolution Precipitation Products (HRPP), such as the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA), emphasize the use of data from all available satellites. For both types of products, experience has shown that it is critical to choose the appropriate reference standard to intercalibrate an ever-evolving constellation of satellite sensors. Towards this end, we have used passive microwave (PMW) in developing GPCP, and combined PMW-radar in TMPA.

The launch of the TRMM follow-on Global Precipitation Measurement (GPM) mission in 2014 gave birth to several nearly-global HRPP's, including the Integrated Multi-satellitE Retrievals for GPM (IMERG). Our strategy in refining IMERG has been to first focus on the tropics and mid-latitudes, where we have relatively high confidence, and only more recently begin to expand into the lower-confidence high latitudes. Similarly, although GPCP has provided nearly-global estimates since its inception in the early 1990's, the advent of sensors such as CloudSat has facilitated new efforts to modernize its estimates at high latitudes.

For each of these data sets, it is expected that the final merged estimate should tend to track along with its respective calibration standard. Time series depicting GPCP, TMPA, and IMERG will be presented, in order to demonstrate the extent to which this is so. Additionally, comparisons amongst the products will show areas of agreement and highlight areas where further improvements are needed.

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1: NASA/Goddard Space Flight Center
2: Science Systems and Applications, Inc.
3: GESTAR/USRA

Forty Years of Eyes on the Planet: An Uninterrupted Record of Earth Remote Sensing with Satellite Passive Microwave Instruments

AGU 100 FALL MEETING
Washington, D.C. | 10–14 Dec 2018

Background

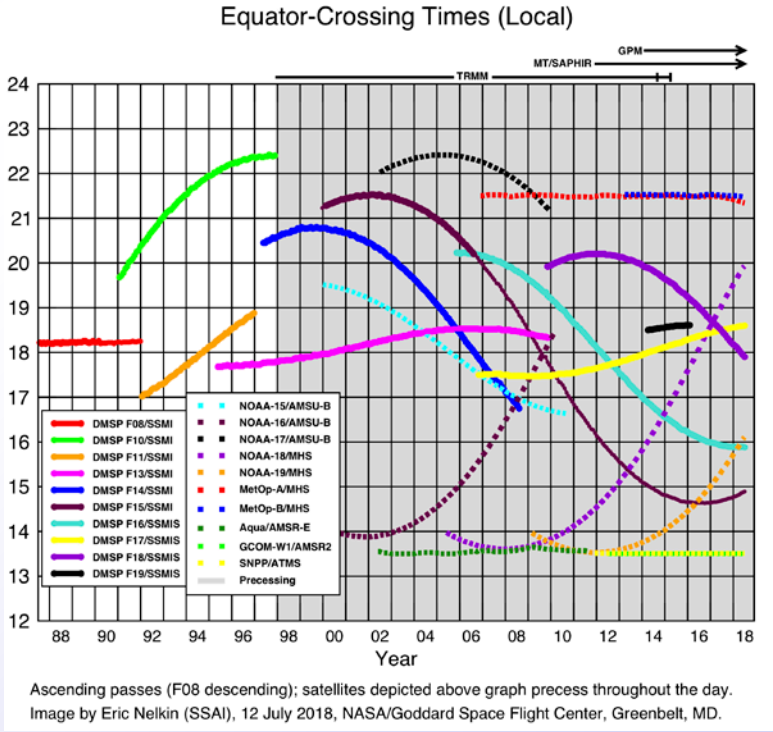
A diverse, changing, uncoordinated set of input precipitation estimates, with various

- periods of record
- regions of coverage
- sensor-specific strengths and limitations

Seek the longest, most detailed record of "global" precipitation

Two types of products:

HRPP and CDR



Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 12 July 2018, NASA/Goddard Space Flight Center, Greenbelt, MD.

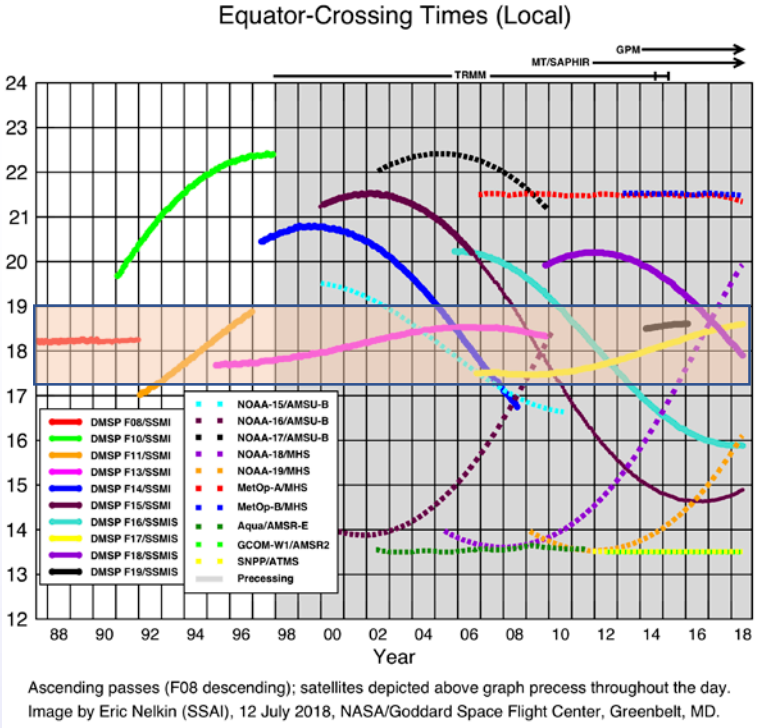
HRPP vs. CDR

HRPP – High-Resolution Precipitation Product

- emphasize use of data from all available satellites
- varying diurnal sampling in long-term record
- examples: TMPA, IMERG, GSMaP, CMORPH, …

CDR – Climate Data Record

- prioritize homogeneity over fine-scale accuracy
- stricter standards than HRPP
- examples: GPCP, PERSIANN-CDR, …



Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 12 July 2018, NASA/Goddard Space Flight Center, Greenbelt, MD.

Intercalibration is key!

For any merged-satellite product, whether HRPP or CDR, it is critical to choose a reference standard.

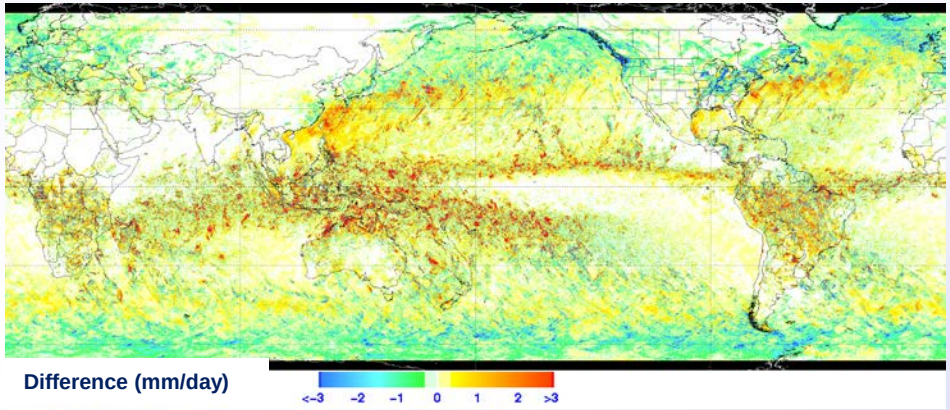
All other sensors are then calibrated against the standard prior to merging.

The goal is to achieve stability:

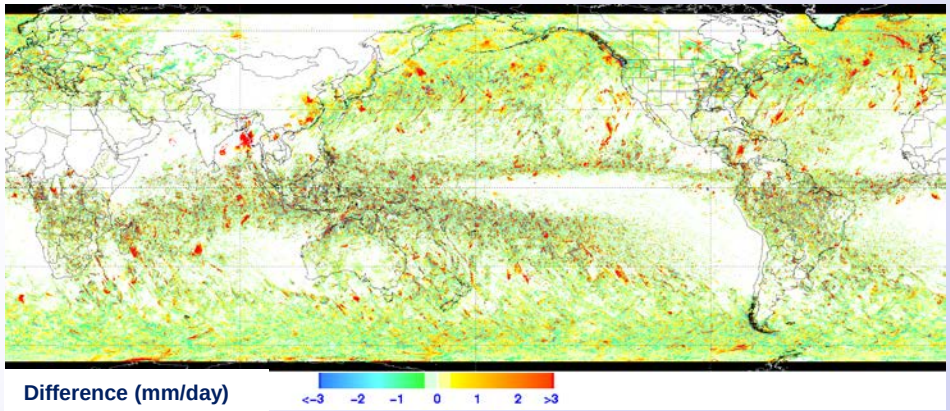
- HRPP: control fluctuations in sampling
- CDR: continuity in long-term record

In IMERG, the combined-instrument (radar + PMW) is the standard against which other sensors are calibrated. Example at right shows improvement in GMI for Jan-Feb 2018 after intercalibration.

"Before": Combined minus **uncalibrated** GMI



"After": Combined minus **calibrated** GMI



(David Bolvin, SSAI; GSFC)

Near-Real-Time Processing

Near-real-time versions of satellite products are always vulnerable to anomalies in the input data. Unfortunately, by the time the issue is noticed, inevitably the output is already “contaminated”.

It is impossible to anticipate every possible way that input data can affect the output product.

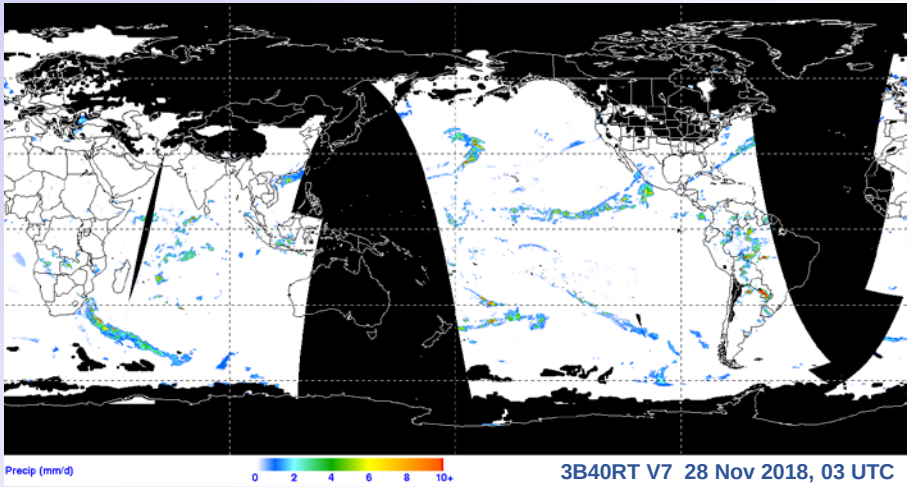
Nevertheless, “It is not your duty to complete the work, but neither are you free to desist from it.”

Near-Real-Time products are often our “canary in the coal mine”, alerting us to issues that can be cleaned up without slipping into the post-real-time research-quality product.

The following slides demonstrate examples of how things can go wrong, and in some cases, offer solutions.

Products examined are **TMPA-RT** (latency: ~8 hours), **IMERG Early** (~4 hours), and **IMERG Late** (~14 hours).

Post-processing Quality Control (1/2)



Above: Typical 3-hourly TMPA-RT combined-MW precipitation

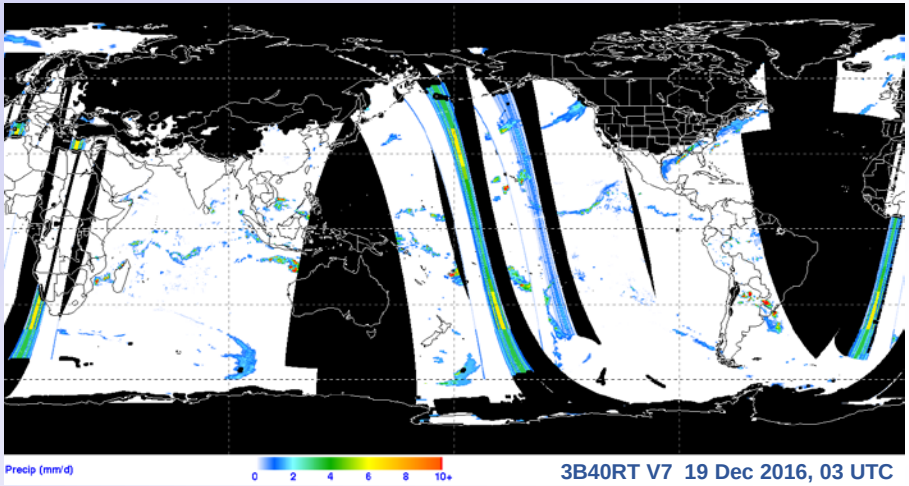
Right: Excerpt from nominal QC report produced by daily script, examining the eight 3-hourly files from previous day

```
Got data from trmmrt.gsfc.nasa.gov
/snow/nelkin/V7TMPA-RT/3B40RT/201811
/snow/nelkin/V7TMPA-RT/3B41RT/201811
/snow/nelkin/V7TMPA-RT/3B42RT/201811
Done gunzipping 3B40,41,42 files
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112803.7.bin
WARNING: 15 values of   113 in box with upper left at i =  741, j =  216
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112803.7.bin
WARNING: 17 values of   127 in box with upper left at i =  471, j =  276
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112803.7.bin
WARNING: 18 values of   100 in box with upper left at i =  351, j =  566
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112803.7.bin
WARNING: 15 values of   100 in box with upper left at i =  346, j =  571
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112803.7.bin
WARNING: 25 values of   100 in box with upper left at i =  346, j =  576
SUMMARY OF FREQUENTLY-OCCURRING VALUES IN 18112803.7.bin:
   1 instances of 5x5 boxes with 15+ values of   75
   0 instances of 5x5 boxes with 15+ values of  104
   0 instances of 5x5 boxes with 15+ values of  109
   4 instances of 5x5 boxes with 15+ values of  150
   0 instances of 5x5 boxes with 15+ values of  162
   0 instances of 5x5 boxes with 15+ values of  200

SUMMARY OF FREQUENTLY-OCCURRING VALUES IN 18112806.7.bin:
   0 instances of 5x5 boxes with 15+ values of   75
   0 instances of 5x5 boxes with 15+ values of  104
   0 instances of 5x5 boxes with 15+ values of  109
   8 instances of 5x5 boxes with 15+ values of  150
   2 instances of 5x5 boxes with 15+ values of  162
   0 instances of 5x5 boxes with 15+ values of  200

SUMMARY OF FREQUENTLY-OCCURRING VALUES IN 18112809.7.bin:
   0 instances of 5x5 boxes with 15+ values of   75
   0 instances of 5x5 boxes with 15+ values of  104
   3 instances of 5x5 boxes with 15+ values of  109
   6 instances of 5x5 boxes with 15+ values of  150
   0 instances of 5x5 boxes with 15+ values of  162
   0 instances of 5x5 boxes with 15+ values of  200

WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112812.7.bin
WARNING: 17 values of    50 in box with upper left at i =  571, j =  591
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201811/3B40RT.2018112812.7.bin
WARNING: 15 values of    50 in box with upper left at i =  576, j =  596
SUMMARY OF FREQUENTLY-OCCURRING VALUES IN 18112812.7.bin:
   0 instances of 5x5 boxes with 15+ values of   75
   0 instances of 5x5 boxes with 15+ values of  104
   0 instances of 5x5 boxes with 15+ values of  109
   8 instances of 5x5 boxes with 15+ values of  150
   0 instances of 5x5 boxes with 15+ values of  162
   0 instances of 5x5 boxes with 15+ values of  200
```

QC searches 5x5 0.25°x0.25° grid boxes, reporting on instances of repeating precipitation rates, to try to catch anomalies

Easy to become desensitized to these messages!

Post-processing Quality Control (2/2)




```
Done gunzipping 3B40,41,42 files
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 18 values of   155 in box with upper left at i =   21, j =   56
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 25 values of   342 in box with upper left at i =  686, j =  131
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 19 values of   342 in box with upper left at i =  686, j =  136
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 24 values of   342 in box with upper left at i =  691, j =  136
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 15 values of   130 in box with upper left at i =  681, j =  146
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 17 values of   342 in box with upper left at i =  696, j =  156
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 24 values of   342 in box with upper left at i =  701, j =  156
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 17 values of   130 in box with upper left at i =  696, j =  161
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 25 values of   342 in box with upper left at i =  701, j =  161
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 17 values of   130 in box with upper left at i =  691, j =  166
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 20 values of   342 in box with upper left at i =  701, j =  166
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 20 values of   342 in box with upper left at i =  706, j =  166
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 22 values of   342 in box with upper left at i =  706, j =  171
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 24 values of   342 in box with upper left at i =  706, j =  176
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 15 values of   342 in box with upper left at i =  706, j =  181
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 22 values of   342 in box with upper left at i =  711, j =  181
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 25 values of   342 in box with upper left at i =  711, j =  186
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 18 values of   342 in box with upper left at i =   21, j =  191
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 22 values of   342 in box with upper left at i =  711, j =  191
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 15 values of   342 in box with upper left at i =  716, j =  191
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 25 values of   342 in box with upper left at i =   21, j =  196
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 22 values of   342 in box with upper left at i =  716, j =  196
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 19 values of   644 in box with upper left at i =   21, j =  201
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 25 values of   644 in box with upper left at i =  716, j =  201
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
WARNING: 15 values of   644 in box with upper left at i =   16, j =  206
WARNING! File: /snow/nelkin/V7TMPA-RT/3B40RT/201612/3B40RT.2016121903.7.bin
```

Vigilance is required to overcome desensitization.

99+% of the time, reports are nominal. Maps are not routinely generated and examined.

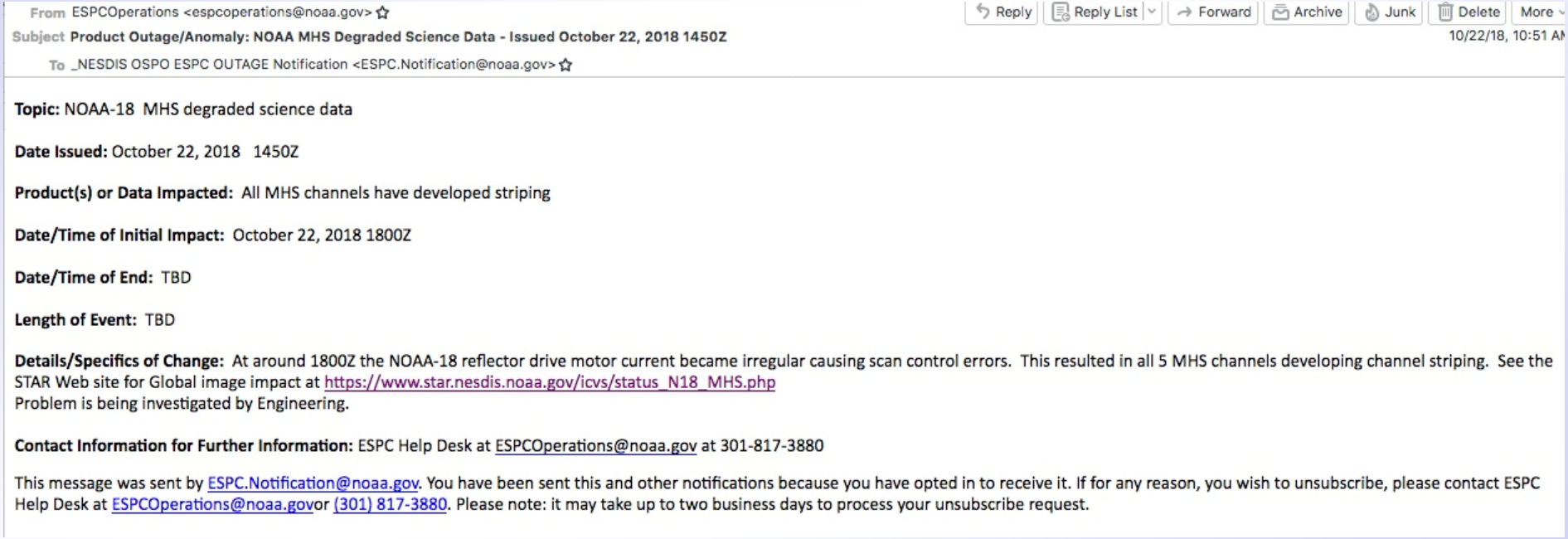
Here, numerous **“WARNING!”** statements indicated the need to produce a map (above), revealing unphysical streaks.

Further investigation of the component estimates revealed the culprit here was F16/SSMIS.

NOAA Notifications (1/2)

A valuable resource for learning of satellite anomalies is the **NOAA ESPC Operations mailing list**.

These messages specify the start and end date/time, and the impact on science, allowing us to make informed decisions on whether to exclude a particular instrument from our combined products, and whether reprocessing is feasible.



From ESPCOperations <espcoperations@noaa.gov>
Subject **Product Outage/Anomaly: NOAA MHS Degraded Science Data - Issued October 22, 2018 1450Z**
To _NESDIS OSPO ESPC OUTAGE Notification <ESPC.Notification@noaa.gov>

Reply | Reply List | Forward | Archive | Junk | Delete | More
10/22/18, 10:51 AM

Topic: NOAA-18 MHS degraded science data

Date Issued: October 22, 2018 1450Z

Product(s) or Data Impacted: All MHS channels have developed striping

Date/Time of Initial Impact: October 22, 2018 1800Z

Date/Time of End: TBD

Length of Event: TBD

Details/Specifics of Change: At around 1800Z the NOAA-18 reflector drive motor current became irregular causing scan control errors. This resulted in all 5 MHS channels developing channel striping. See the STAR Web site for Global image impact at https://www.star.nesdis.noaa.gov/icvs/status_N18_MHS.php
Problem is being investigated by Engineering.

Contact Information for Further Information: ESPC Help Desk at ESPCOperations@noaa.gov at 301-817-3880

This message was sent by ESPC.Notification@noaa.gov. You have been sent this and other notifications because you have opted in to receive it. If for any reason, you wish to unsubscribe, please contact ESPC Help Desk at ESPCOperations@noaa.govor (301) 817-3880. Please note: it may take up to two business days to process your unsubscribe request.

NOAA Notifications (2/2)

However, as NOAA reports on many satellites, it is common to receive a dozen-plus emails per day.

Since most of these concern instruments we do not use, **desensitization** is again a challenge.

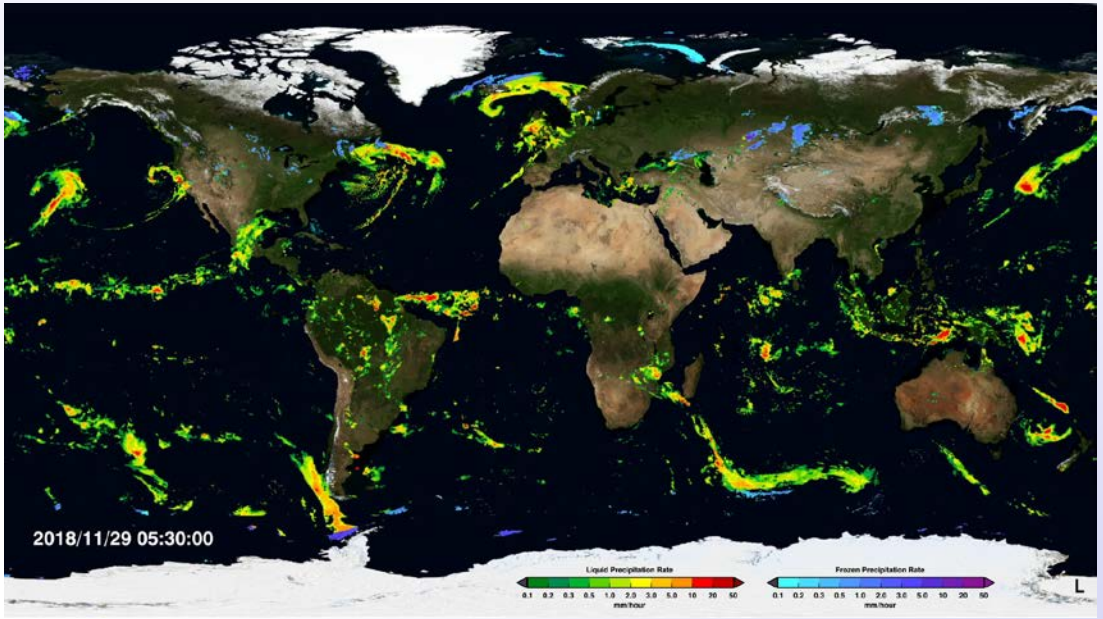
•	ESPCOperations	Administrative: GOES-16 MDS Request for Meso-2 scheduled for November 27, 2018- Issued: November 27, 2018...	• 11/27/18, 8:55 AM
•	ESPCOperations	Administrative: GOES-16 MDS Request for Meso-1 scheduled for November 27, 2018- Issued: November 27, 2018...	• 11/27/18, 9:20 AM
•	ESPCOperations	Administrative: Update #1: GOES-17 for Meso-2 scheduled for November 26, 2018 - Issued: November 27, 2018 1...	• 11/27/18, 11:35 AM
•	ESPCOperations	Administrative: GOES-17 for Meso-1 scheduled for November 27, 2018 - Issued: November 27, 2018 1640Z	• 11/27/18, 11:49 AM
•	ESPCOperations	Product Anomaly: PDA OPS anomaly during Oracle patching. November 27, 2018 1810Z	• 11/27/18, 1:09 PM
•	ESPCOperations	Product Outage/Anomaly: GOES-15 LRIT Broadcast outage. November 27, 2018 - Issued: November 27, 2018 1855Z	• 11/27/18, 1:56 PM
•	ESPCOperations	Product Outage/Anomaly: Loss of GOES-16 products and their distribution to AWIPS, PDA and over the GRB. Nove...	• 11/27/18, 1:56 PM
•	ESPCOperations	Product Outage/Anomaly: Loss of numerous GOES-16 products and their distribution to PDA. November 27, 2018 ...	• 11/27/18, 2:16 PM
•	ESPCOperations	Product Outage/Anomaly: (Update #1) GOES-15 LRIT Broadcast outage. November 27, 2018 - Issued: November 2...	• 11/27/18, 5:20 PM
•	ESPCOperations	Product Outage/Anomaly (Update #1): Loss of numerous GOES-16 products and their distribution to PDA, Novem...	• 11/27/18, 5:20 PM
•	ESPCOperations	Administrative: GOES-17 for Meso-1 scheduled for November 28, 2018 - Issued: November 28, 2018 0258Z	• 11/27/18, 9:59 PM
•	ESPCOperations	Administrative: Update #1 GOES-17 for Meso-1 scheduled for November 28, 2018 - Issued: November 28, 2018 16...	• 11/28/18, 11:10 AM
•	ESPCOperations	Administrative: Update #2: GOES-17 for Meso-2 scheduled for November 26, 2018 - Issued: November 28, 2018 1...	• 11/28/18, 11:21 AM
•	ESPCOperations	Product Outage/Anomaly: SNPP Product Outage/Delay Issued: November 28, 2018 1732Z	• 11/28/18, 12:32 PM
•	ESPCOperations	Administrative: Update #3: GOES-17 for Meso-2 scheduled for November 26, 2018 - Issued: November 28, 2018 1...	• 11/28/18, 1:31 PM
•	ESPCOperations	Administrative: GOES-17 for Meso-2 scheduled for November 28, 2018 - Issued: November 28, 2018 1840Z	• 11/28/18, 1:40 PM
•	ESPCOperations	Administrative: GOES-16 MDS Request for Meso-2 scheduled for November 29, 2018- Issued: November 29, 201...	• 9:04 AM
•	ESPCOperations	Administrative: GOES-17 for Meso-2 scheduled for November 28, 2018 - Issued: November 29 2018 1538Z	• 10:37 AM
•	ESPCOperations	Administrative: GOES-17 for Meso-2 scheduled for November 29, 2018 - Issued: November 29, 2018 1545Z	• 10:44 AM
•	ESPCOperations	Administrative: Eumetsat Weekly Operations Schedule - Weekly Operations Schedule - Week 49 - Issued: Novem...	• 11:09 AM
•	ESPCOperations	Product Outage/Anomaly: DMSP Data delay, Issued: November 29, 2018 1805Z	• 1:04 PM
•	ESPCOperations	Administrative: GOES-17 for Meso-1 scheduled for November 29, 2018 - Issued: November 29, 2018 1853Z	• 1:52 PM
•	ESPCOperations	SARSAT Outage/Anomaly:Update#1 Florida Medium Earth Orbit (MEO) Ground Station Data Delay, Issued: Novem...	• 2:06 PM
•	ESPCOperations	Product Outage/Anomaly: Update#1 DMSP Data delay, Issued: November 29, 2018 1947Z	• 2:47 PM
•	ESPCOperations	Administrative: GOES-15 Visible Calibration Update for the Month of November 2018 Issued: November 29, 2018 ...	• 3:47 PM

IMERG: Disappearing IR!

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

In transitioning from the last “Late” image to the initial “Early” image at the next half-hour, areal coverage **markedly decreases**.

Note the loss of frozen precipitation over Eurasia, Canada, and the Arctic, and of light rain over the tropical and subtropical oceans!



Culprit: IR data arrived later than usual, missing the 4-hr cut-off for inclusion in the Early product.

Solution: none for Early. GSFC coordinates with NOAA/CPC to ensure full IR is included in “Final”.

IMERG: Disappearing IR!

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

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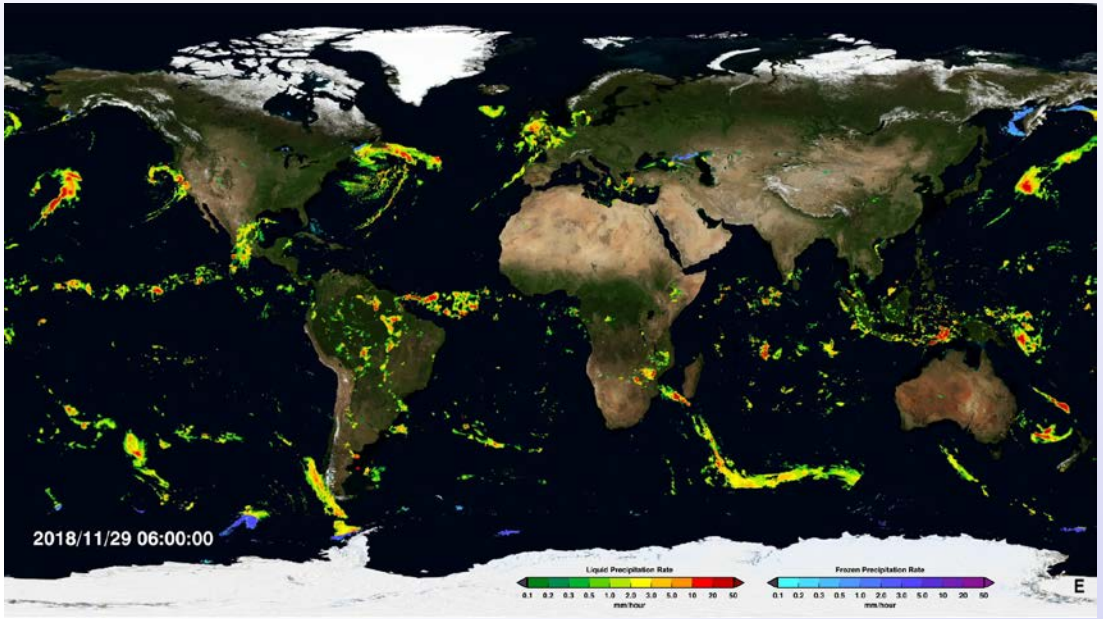
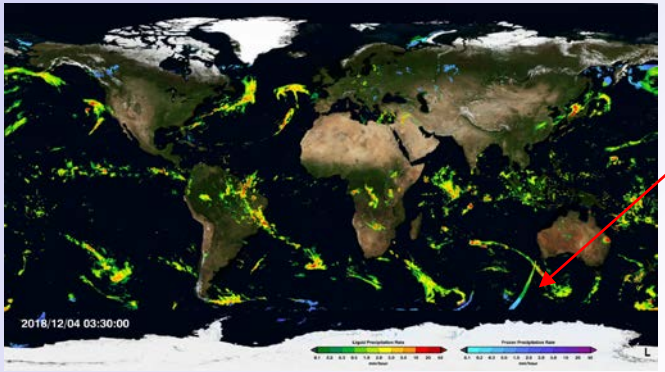


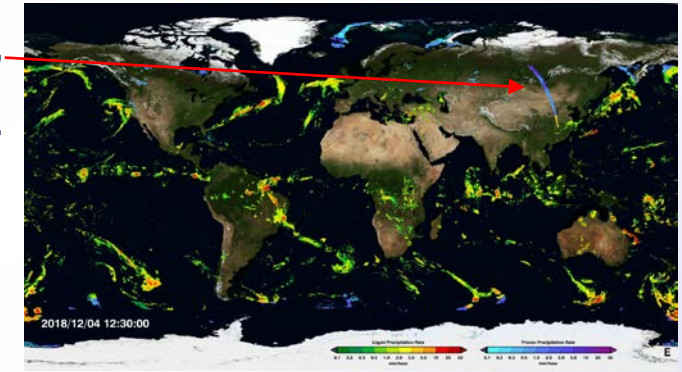
Culprit: IR data arrived later than usual, missing the 4-hr cut-off for inclusion in the Early product.

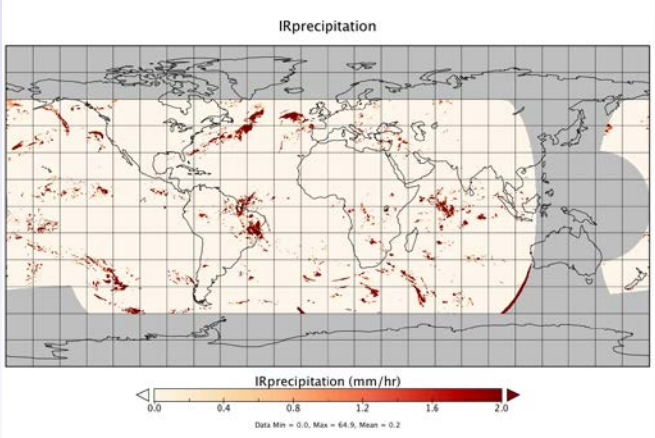
Solution: none for Early. GSFC coordinates with NOAA/CPC to ensure full IR is included in “Final”.

Precipitation Arcs in IMERG-L, IMERG-E

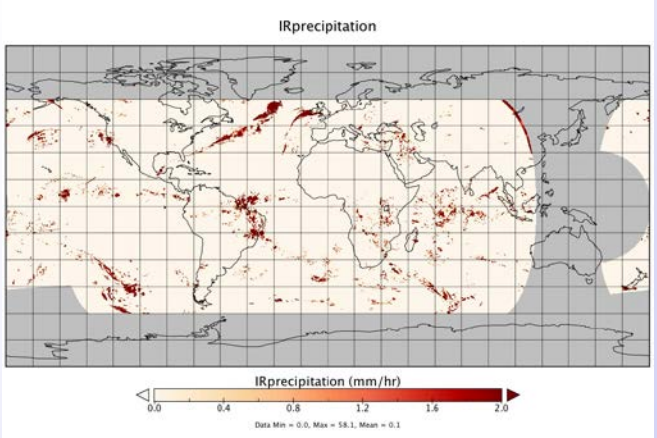


Ephemeral “precipitation” arcs occasionally appear.





These are attributable to the underlying IR input, where bogus arcs appear at the edge of coverage.



Solution: TBD; in development.

Automated Quality Control

Post-real-time research-quality products (IMERG Final, TMPA, CDR's such as GPCP, etc.) provide the opportunity for analysis before release to the public.

Near-real-time HRPP products (IMERG-E, IMERG-L, TMPA-RT, etc.) generally have not had the capability to catch problems on the fly. Instead, the data are released as is.

Reprocessing may occur depending on:

(1) resources and
(2) whether the issue is noticed quickly enough.

A long-sought, but elusive, goal has been automated quality control.

Toward this end, IMERG V06 computes the granule(orbit)-average conditional precipitation rate for each of the component PMW sensors, at the front-end gridding stage.

If the resulting value exceeds a user-specified threshold, the entire gridded granule is **excluded** from the downstream merger code. A threshold of 4 mm/hr appears to work well.

IMERG Quality Index

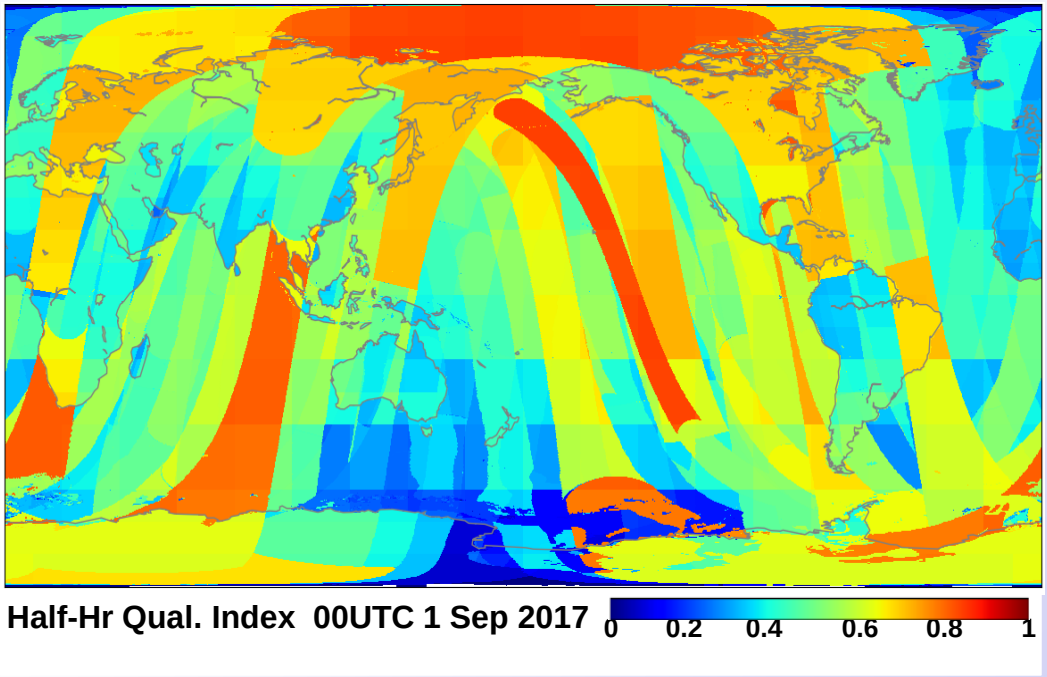
Another long-sought, but elusive goal, has been development of a useful output field to quantify uncertainty.

The **IMERG Quality Index** was introduced in V05 and improved in V06.

For the half-hourly products (Early, Late, and Final), it is based on the "types" of estimates against GMI, the calibration standard.

Categorical guidance (e.g., "good", "use with caution", "poor") is being developed.

Feedback is welcomed!



(David Bolvin, SSAI; GSFC)

Summary

- HRPP combine information from as many satellites as possible; CDR emphasize homogeneity
- For both, **intercalibration** is vital to achieve stability and continuity
- Satellite data can ”go bad” in more ways than one can possibly imagine
- Real-time products are often our first indication of an issue
- Quality control of input data is critical; **automated QC** is the ideal
- IMERG V06 outputs a Quality Index field to aid in evaluation of precipitation estimates

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