Summary of V07 Reprocessing, Conversion of OS to Red Hat 8, and Impact on Data of the GPM Core Satellite Boost

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GPM Orbit Boost (November 2023)

Background

The most fundamental change in the Global Precipitation Mission (GPM) since the core satellite's launch in March 2014 was the boost of the satellite to a higher altitude in November 2023. Solar activity modeling indicated that increasingly strong solar activity might cause the GPM core satellite to begin controlled re-entry procedures as early as 2027. A re-entry date this early would mean no observation-period overlap with subsequent missions, such as the NASA Atmosphere Observing (AOS) mission.

The Japan Aerospace Exploration Agency (JAXA) had an interest in maintaining an overlap between the Dual-frequency Precipitation Radar (DPR) on the GPM core satellite and JAXA future missions. JAXA planned a future mission carrying a Ka-band precipitation radar that was scheduled for launch in 2029. JAXA requested that the GPM project scientist investigate the possibility of raising the altitude of the GPM core satellite to extend the GPM operational mission. NASA and JAXA jointly investigated options for an orbit boost. These analyses along with an analysis from the NASA Mission Operations Center (MOC) determined that ~435 km would be the best target altitude for an orbit boost. Using these studies, the GPM Project Scientist approached NASA headquarters with a request to approve an altitude boost. Further discussions between NASA and JAXA management concluded that a GPM core-satellite boost was in the interest of both agencies.

The decision was made to raise the altitude of the core satellite to ~435 km from the original ~405 km altitude. Based on solar activity modeling, such a boost would enable GPM to maintain its orbit until 2030. After that, the satellite would begin a 1.5 to 2.5 year drift-down period. During part of the drift down, DPR could continue to collect science data, whereas during the entire drift down, the GMI Microwave Imager (GMI) would collect science data. November 7 and 8, 2023, were selected as the earliest dates for carrying out the orbit boost.

On November 7, 2023, the altitude of the GPM core satellite was raised to ~435 km, but the orbital eccentricity was outside of specifications. On November 8, several additional maneuvers corrected the eccentricity, bringing it into the optimum range for DPR operations.

DPR

Fig. 1.

Pre-boost month, Dec. 2022

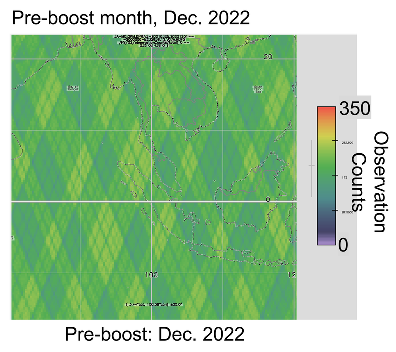
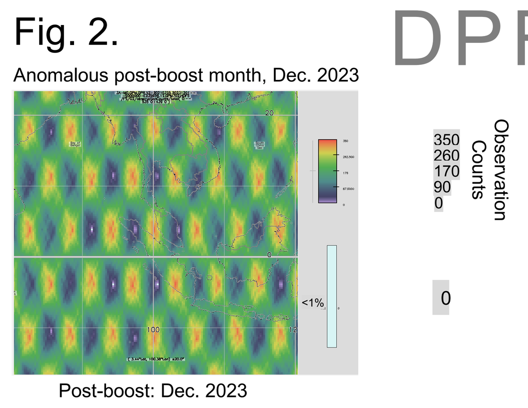


Fig. 2.

Anomalous post-boost month, Dec. 2023



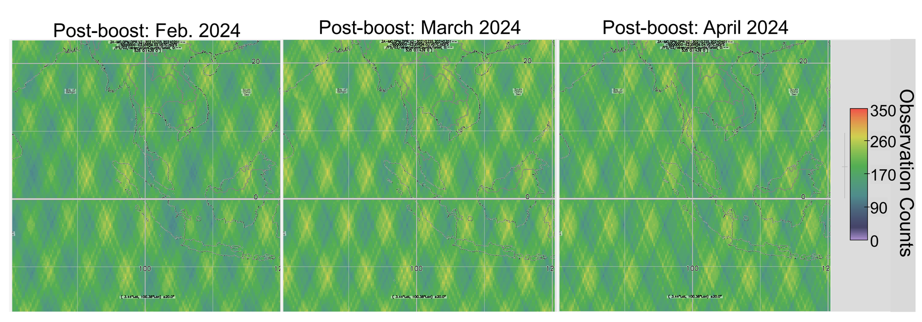


Fig. 3.

3 normal post-boost months Comparing Pre-boost December 2022 and Post-boost December 2023 Gridded Ku Observation Counts. Data source: 0.25°× 0.25° monthly DPR product, subset showing 40° by 40° region crossing the Equator. Data for December 2023 is anomaly month due to gaps in the GPM satellite during December 2 to 5. During December 2023, some grid boxes have zero observations for the month.

Fig. 4.

DPR sensitivity change over ocean

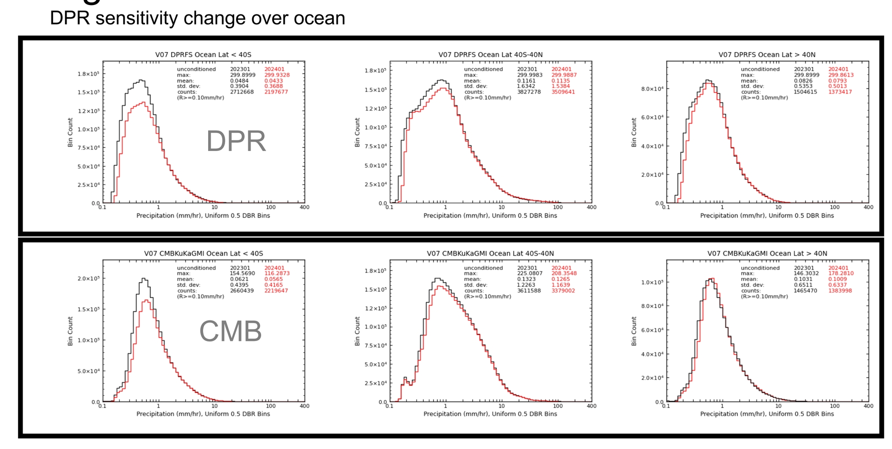
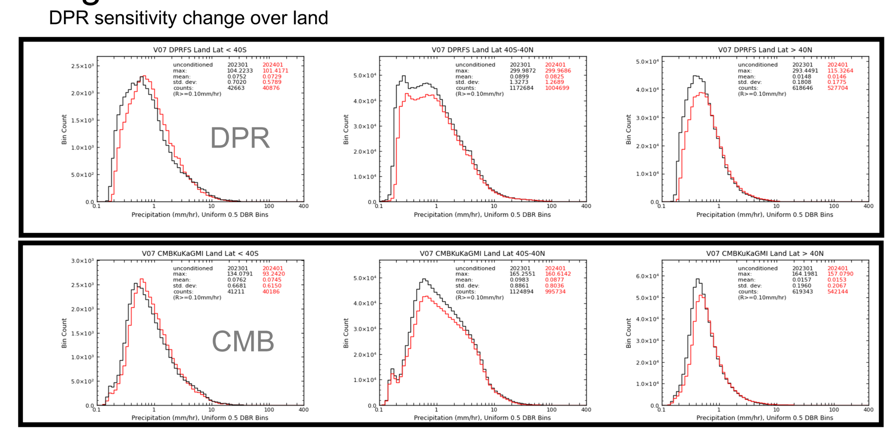


Fig. 5

DPR sensitivity change over land



GMI

Mean Earth Incidence (Zenith) Angles
At 407 km, Swath 1: 52.8°, Swath 2: 49.2°
At 442 km, Swath 1: 53.2°, Swath 2 :49.5°

Mean Ground Track Speed:
~ 7.22 km/sec pre-boost
~ 7.16 km/sec post-boost

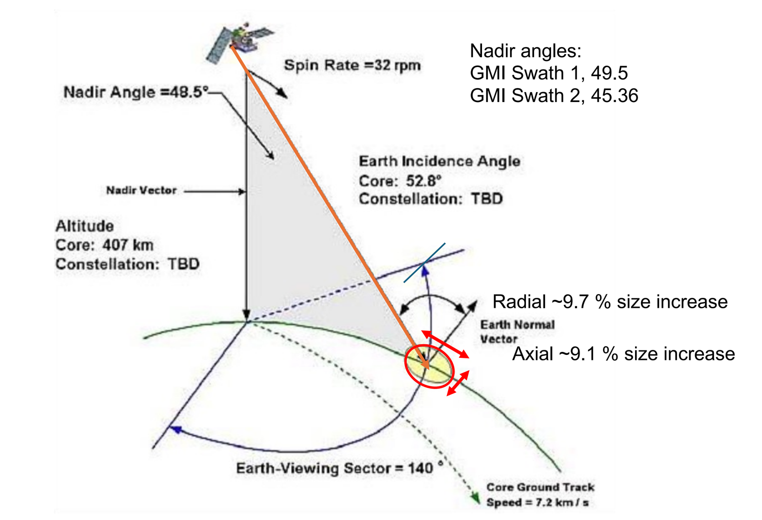


Fig. 6

Altitude boost impact on footprint size. Schematic from slides "GMI Footprint Changes Due to 35 km Altitude Boost" Stephen Bilanow and Rachael Kroodsma 2023-11-07. https://pps.gsfc.nasa.gov/Documents/GMI_boost_footprint_Notes_2023_11_07.pdf. This diagram is also included on this web page: https://pps.gsfc.nasa.gov/gpminstruments.html. The main impact on the footprint size is from increased distance to the surface, which is about 9% farther away. Because of the curvature of the Earth, the Earth Incidence Angle at the footprint center increases by a mean value of about 0.39 degrees in Swath 1 (low frequency channels) and about 0.34 degrees in Swath 2 (high frequency channels).

Fig. 7

Maximum (red), mean (black), and minimum (blue) orbit altitude for the GPM satellite during the first eight years of the mission.

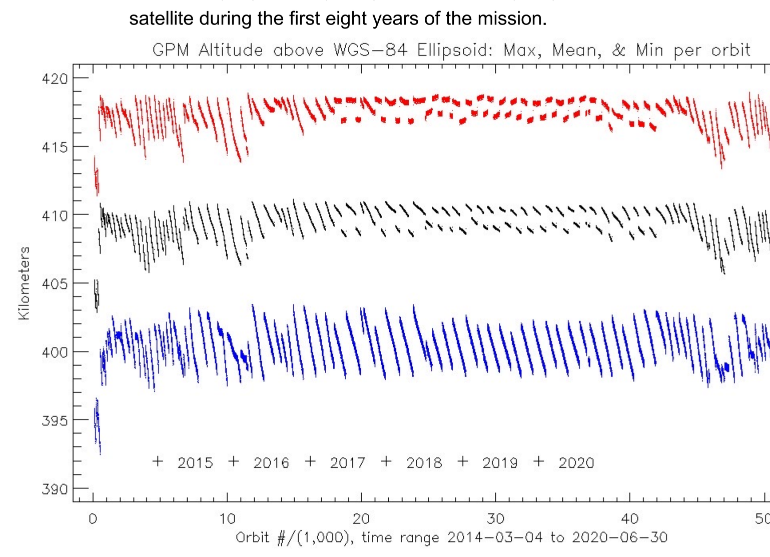


Table 1

Pre-boost and post-boost orbit altitudes of the GPM core-satellite

GPM Geodetic Height Range	Pre-Boost	Post-Boost +35	Proportional Height Increase
Maximum	419	454	8.35 %
Median	408	443	8.58 %
GMI Spec	407	442	8.60 %
Minimum	397	432	8.82 %

Boost Impact on DPR

Immediately after the boost, there was concern that the new altitude might have an impact on the revisit times of the GPM instruments: DPR and GMI. **Figure 1** shows revisit time prior to the November 2023 orbit boost. **Figure 2** shows revisit time in December 2023, that contains areas with long revisit times. The GPM flight operations team (FOT) subsequently changed the schedule for altitude maintenance that shortened the post-boost revisit time to close to the pre-boost values. **Figure 3** shows February-April 2024 revisit time and its similarity to pre-boost values.

The November 2023 orbit boost increased the Ku/Ka-band radar field of view (IFOV), the swath width, and the DPR's sensitivity.

1. IFOV size increased from 5.0 to 5.3 km
2. Swath width increased from 245 to 260 km
3. Instrument sensitivity decreased by ~0.64 dB

Figure 4 provides an example of the DPR post-boost sensitivity change that impacted precipitation detection over ocean. It also provides the impact that this sensitivity change has on the combined radar/radiometer product. The plots compare level 2 IFOV land precipitation (absolute counts) in the DPR FS swath and the CMB Ku-Ka-GMI combined swath, both in 3 latitude bands. Top plots show Dual-frequency Precipitation Radar (DPR) estimates. Bottom plots show DPR+GMI combined estimates (CMB). Black line shows January 2023, and red line shows January 2024. Figure 4 shows a small decrease in light-rain DPR counts due to the boost in November 2023. **Figure 5** provides the same information as Figure 4, except over land.

Boost Impact on GMI

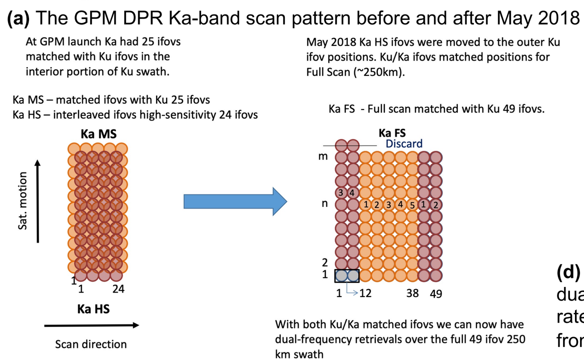
In both swaths of the GMI radiometer, the footprint increased by ~9 km. The details of the impact on footprint size are provided in **Figure 6.** The actual geodetic height relative to the Earth's surface varies during each orbit, and so the footprint size varies proportionally by about 5% during each orbit. Maximum, mean, and minimum altitude over the first 8 years of the mission are shown in **Figure 7** in red, black, and blue, respectively. The actual mean altitude has generally been a little higher than the 407 km referenced in the GMI design specifications.

The planned range of operating altitudes pre-boost and post-boost are shown in **Table 1**. The altitude increase causes a proportional increase pixel size at nadir as a first-order approximation. The pixel size increases are a little larger for the GMI beams than DPR beams due to the Earth's curvature. The GMI change estimates are based on adding 35 km to the GMI specification value of 407 km.

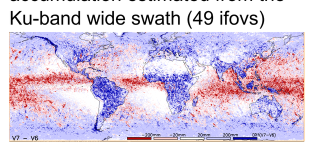
Version V07 Reprocessing

Fig. 8. DPR

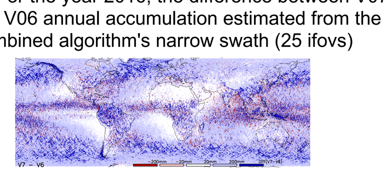
(a) The GPM DPR Ka-band scan pattern before and after May 2018



(b) For the year 2016, the difference between V07 and V06 annual accumulation estimated from the Ku-band wide swath (49 ifovs)



(c) For the year 2016, the difference between V07 and V06 annual accumulation estimated from the Combined algorithm's narrow swath (25 ifovs)



(d) December 2019, the difference in the DPR's dual-frequency V07 near-surface precipitation rate when the monthly average is calculated from only narrow-swath ifovs vs. all ifovs

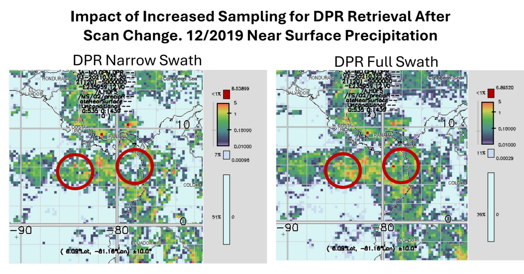
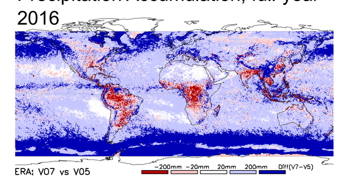
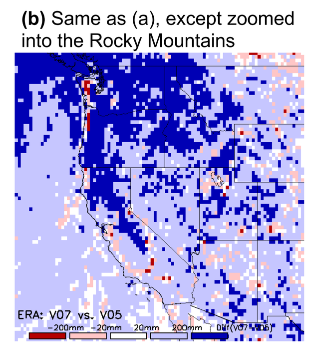


Fig. 9. GMI

(a) V07 vs. V05 Difference (mm) of GPROF GMI ERA Surface Precipitation Accumulation, full-year 2016



(b) Same as (a), except zoomed into the Rocky Mountains



(c) ERA vs. GANAL Difference (mm) of GPROF GMI V07 Surface Precipitation Accumulation, full-year 2016

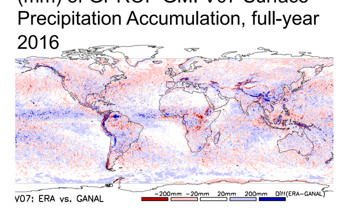
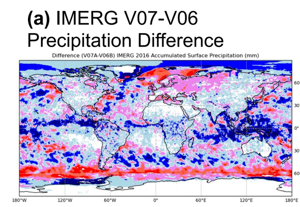
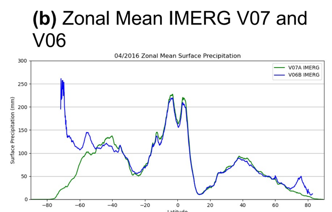


Fig. 10. IMERG

(a) IMERG V07-V06 Precipitation Difference

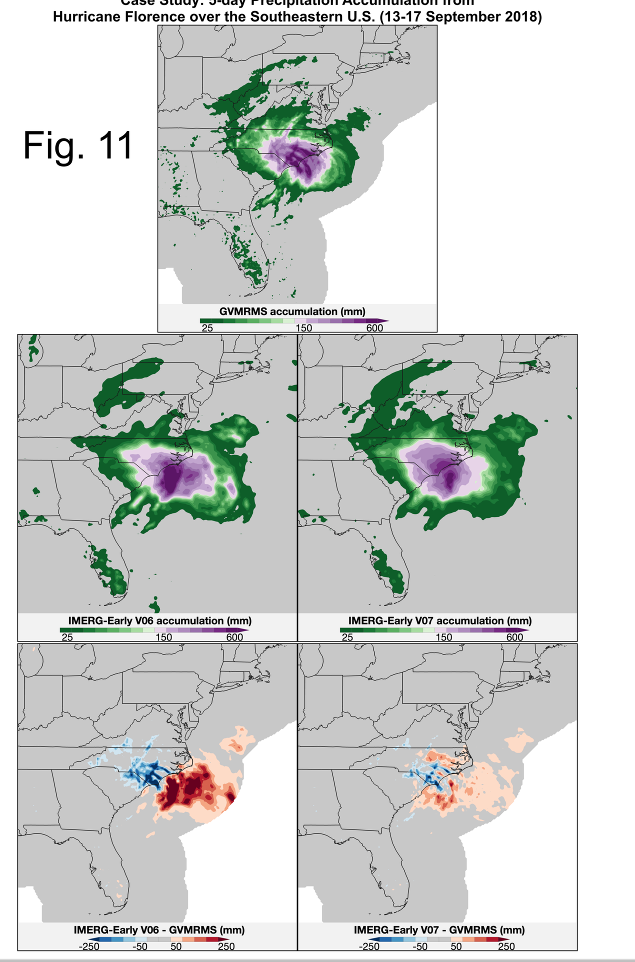


(b) Zonal Mean IMERG V07 and V06



Case Study: 5-day Precipitation Accumulation from Hurricane Florence over the Southeastern U.S. (13-17 September 2018)

Fig. 11



Version V07

The GPM radar algorithms have been updated from version V06 to V07. The update occurred after the Joint Precipitation Measurement Missions (PMM) Science Team (JPST) approved the change. V07 radar processing began in December 2021. **Figure 8** provides an analysis of differences between V06 and V07 in the radar algorithm retrievals.

The level-2 radiometer products have also been upgraded to version V07. **Figure 9** shows the changes between V05 (there was no public V06 radiometer version) and V07 in this product.

For the IMERG algorithm, the switch to version V07 occurred in the Production system before occurring in the Near Real-Time system. The GPM Production system began producing V07 Final IMERG in June 2023. Reprocessing occurred for the entire data record, which currently covers June 2000 to through the end of 2023. **Figure 10** shows differences between versions V06 and V07 Final IMERG.

The IMERG algorithm team included a number of improvements in the Version V07 Final IMERG algorithm. They developed full GMI/TMI swath calibrations to CORRA/[T]. They determined that the GMI/TMI estimates outside of the CORRA/[T] swath did not have the same precipitation-rate distribution as inside the CORRA/[T] swath.

In addition, the IMERG algorithm team made progress in correcting the precipitation-rate distribution issues between the 5-km CORRA/[T] and GMI/TMI precipitation. They accomplished this improvement by averaging CORRA/[T] to the GMI/TMI footprint.

The case study shown in **Figure 11** demonstrates the improvement in Final IMERG version V07 over V06. The MRMS ground-validation radar data is used as a reference to demonstrate this improvement. The case study examines Hurricane Florence on September 13-17, 2018, over the eastern United States. One can see that IMERG V07 matches more closely the reference MRMS data for this event.

Red Hat 8 Conversion

Production

It was decided that before the GPM radiometer and the combined products were updated to version V07, the GPM Production system would be upgraded to Red Hat 8 (IT security requirement). This operating-system upgrade required recompilation of all the algorithms including the V07 radar algorithms that had started running under CentOS 7. Differences between algorithm output generated under CentOS 7 and Red Hat 8 had to be investigated and data product correctness verified. In a few cases, algorithms were discovered to have issues that prevented comparable CentOS 7 and Red Hat 8 results. All these issues were corrected before the decisions were made to upgrade the Production system to Red Hat 8 and to start V07 reprocessing after that upgrade.

The Red Hat 8 update occurred in 4 steps with the last one the most difficult:

1. Conversion of the online data fileserver where the public retrieves GPM data
2. Conversion of the Science Data Processing Segment (SDPS) that obtains spacecraft data from the GPOM MOC and distributes it to JAXA, NRT, and Production
3. Conversion of the Science Data Subsystem that includes the Production, development, and testing servers
4. Conversion of GPM near real-time (NRT) subsystem. The NRT update involved operating system, hardware, and conversion to Python 3.

The conversion of the SDPS and online fileserver to Red Hat 8 actually occurred before the conversion of the radar to data product version V07. This sequence was necessary because these servers were outward facing servers and therefore a higher security risk. NASA IT Security required these servers be updated to an approved OS. These servers were converted to Red Hat 8 in mid-2021. This update did cause some problems for users whose machines were running an outdated version of CentOS 6. The security ciphers of Red Hat 8 didn't include the older ciphers used by earlier Linux systems.

At the beginning of May 2022, once the V05 radiometer products for April were completed, the production subsystem was upgraded to Red Hat 8 and also to run version V07 radiometer products. The V07 radar and combined algorithms were also recompiled under Red Hat 8. The V07 radar products were restarted under Red Hat 8 on May 5, 2022, but starting with data from May 1, 2022.

On the same day as the radar products, the radiometer V07 products started being produced under Red Hat 8. The first day of observations that were processed was May 1, 2022. As required, reprocessing began with 1987 SSMI data. An important aspect of the radiometer products was that it went from V05 to V07. No version V06 radiometer product was ever distributed to the public. At the same time, the V07 combined radiometer/radar products began to be processed under Red Hat 8. All combined products were reprocessed to the beginning of TRMM data record that starts in January 1998.

Near Real-Time

The last and most difficult conversion of the GPM data processing system was the conversion of the GPM Near Real-Time (NRT) system. The challenge was that three aspects needed upgrading: operating system, hardware, and switching from Python 2 to Python 3. The NRT operating system update had been tested in detail during the update of the Production system.

The Red Hat 8 conversion of the NRT began on June 3, 2024. Half the NRT processing nodes were removed from the operational NRT cluster and were updated to Red Hat 8. The updated nodes became the operational component of the NRT system and the old CentOS 7 nodes were removed from the cluster. New network switches were installed into the racks, and some rewiring was carried out.

Python 2 dependence was removed during the update to Red Hat 8. This also was an IT security requirement because the Python 2 language is no longer maintained. The NRT data and process-control code have for years been written in Python 2. This code also used many public domain programs that were never upgraded to Python 3. In anticipation of the conversion to Red Hat 8, PPS updated these programs to run under Python 3 when possible. When not possible, PPS wrote programs to accomplish the tasks using Python 3. These changes were largely implemented long before June 3, 2024. The NRT Python programs contain tens of thousand of lines of code in the form of utilities, services, data management, and program management. Much of this modified code could be tested before the conversion took place on June 3, 2024. Unfortunately, some key components could be tested only within an operational NRT.

As part of the June 2024 operating system update, IMERG V07 code compiled under Red Hat 8 was installed on the Red Hat 8 operational NRT. IMERG NRT includes the Early and Late IMERG HDF5 half-hour products and the associated IMERG GIS products. These IMERG V07 algorithms had been extensively tested in the NRT test environment. The IMERG V07 NRT processing started on June 3, 2024, but started processing with data from June 1.

Issues with input-data ingest from partners (not testable except in operations) as well as configuration issues presented startup problems during the conversion/update. These ingest issues had to be corrected before the necessary inputs were available for IMERG V07 processing to begin. This occurred on June 6, 2024.

Forward processing of version V07 IMERG included Early and Late IMERG and IMERG GIS. After these algorithms were running in the NRT system, the NRT fileserver was updated with retroprocessed version V07 IMERG files for dates prior to June 2024. These retrospectively created V07 IMERG files had been created in the production subsystem. Currently, all V07B NRT IMERG files for June 2000 through December 2023 are available for downloading from the NRT fileserver. As data latency and processing latency requirements allow, V07B NRT IMERG data for January 2024 through May 2024 will also be retroprocessed and made available on the NRT fileserver.

Conclusion

The entire GPM data processing system is now running Red Hat 8. In addition, Python 3 scripts have replaced all Python 2 scripts. All products, whether research grade or near real-time, are running at data product version V07.

Questions and comments: Erich.F.Stocker@nasa.gov