P4.11 ANALYSIS OF TRMM 3-HOURLY MULTI-SATELLITE PRECIPTATION ESTIMATES COMPUTED IN BOTH REAL AND POST-REAL TIME

George J. Huffman[*1,2], Robert F. Adler[1], Erich F. Stocker[3], David T. Bolvin[1,2], Eric J. Nelkin[1,2]

1: NASA/GSFC Laboratory for Atmospheres
2: Science Systems and Applications, Inc.
3: NASA/GSFC Global Change Data Center

1. INTRODUCTION

Satellite data form the core of the information available for estimating precipitation on a global basis. While it is possible to create such estimates solely from one sensor, researchers have increasingly moved to using combinations of sensors in an attempt to improve accuracy, coverage, and resolution. The first such combinations were performed at relatively coarse scale to ensure reasonable error characteristics. For example, the Global Precipitation Climatology Project (GPCP) satellite-gauge (SG) combination is computed on a monthly 2.5°x2.5° lat./long. grid (Huffman et al. 1997). Subsequently, users requested that the estimates be made available at finer scale, even at the cost of higher uncertainties. Examples from the GPCP include the Pentad (Xie et al. 2003) and One-Degree Daily (Huffman et al. 2001) combination estimates of precipitation. This paper reports on a data set at the 3-hourly, 0.25°x0.25° lat./long. resolution that is being computed for the Tropical Rainfall Measuring Mission (TRMM).

2. INPUT DATA SETS

The majority of the input data is based on two different sets of sensors. First, microwave data are being collected by a variety of low-Earth-orbit (LEO) satellites, including the TRMM Microwave Imager (TMI) on TRMM, the Special Sensor Microwave/Sensor (SSM/I) on Defense Satellite Meteorology Program (DMSP), the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) on Aqua and the Advanced Earth Observation Satellite II (AdEOS-II), and Advanced Microwave Sounding Unit (AMSU) on the National Oceanic and Atmospheric Administration (NOAA) satellite series. These data have a strong physical connection to the hydrometeors that result in surface precipitation, but each individual satellite provides a very sparse sampling of the time-space occurrence of precipitation. Even taken together, there are significant gaps in the current coverage by microwave estimates.

In contrast, the infrared (IR) data that are being collected by the international constellation of geosynchronous-Earth-orbit (GEO) satellites provide excellent time-space coverage. Recently, access to these data has been greatly facilitated by the Climate Prediction Center (CPC) of the National Weather Service/NOAA, which is merging the geo-IR data into half-hourly 4x4-km-equivalent lat./long. grids. The IR brightness temperatures (T_b) are corrected for zenith-angle viewing effects and inter-satellite calibration.

For post-real-time estimates before the start of the CPC data in early 1999, we use a GPCP data set that provides 24-class T_b histograms of GEO-IR data on a 3-hourly, 1°x1° lat./long. grid covering the latitude band 40°N-S. We zenith-angle-correct the data, convert them to box-average T_b, and bilinearly interpolate them to the 0.25° grid. This data set also provides grid-box-average Geosynchronous Operational Environmental Satellite (GOES) Precipitation Index (GPI; Arkin and Meisner 1987) estimates computed from LEO-IR data recorded by the NOAA satellite series. These data are used to fill holes in the GEO-IR coverage, most notably in the Indian Ocean sector before Meteorological Satellite 5 (METEOSAT-5) began providing observations there in June 1998.

The drawback to all IR-based precipitation estimates is that the T_b's sense cloud-top temperature, and implicitly cloud height. Arkin and Meisner (1987) showed that such information is poorly correlated to precipitation at the fine scales, but relatively well-correlated at scales larger that about 1 day and 2.5°x2.5°.

The project also makes use of the TRMM Combined Instrument (TCI) product, which is a multi-sensor estimate based on TMI and TRMM Precipitation Radar (PR) data. Finally, two sources of monthly rain gauge analyses are used, the GPCP analysis developed by the Global Precipitation Climatology Centre (GPCC), and the Climate Assessment and Monitoring System (CAMS) analysis developed by CPC.

In the course of developing the 3-hourly estimates, the authors realized that they could obtain (restricted) access to the requisite microwave and IR data within a few hours of observation time. Knowing

* *Corresponding author address*: George J. Huffman, NASA/GSFC Code 912, Greenbelt, MD, 20771; e-mail: huffman@agnes.gsfc.nasa.gov

that "real-time" (or more strictly, near-real-time) production could make the estimates useful to several new classes of users, a two-track approach was developed. A real-time product that only depends on microwave and IR data is computed a few hours after real time, then a post-real-time product is computed a few days after the end of the month. The two approaches are sufficiently similar that a single description is given in the next section, with differences pointed out as needed.

3. THREE-HOURLY ESTIMATION

The 3-hourly estimates are produced in three stages; (1) the microwave estimates are combined, (2) infrared estimates are created with microwave calibration, and (3) the microwave and IR are combined. Figure 1 presents a block diagram of the estimation procedure. Each 3-hourly data field is intended to represent the precipitation rate at the nominal observation time.

High Quality (HQ) Microwave Estimates

All of the available microwave data are converted to precipitation estimates. At the present this is achieved by applying the Goddard Profiling Algorithm (GPROF; Kummerow et al. 1996) to TMI, SSM/I, and AMSR-E (real-time only) pixel data, and averaging each to the 0.25° resolution over the time range ±90 minutes from the nominal observation time. All of these estimates are adjusted to a "best" estimate using probability matching of rain rate histograms assembled from coincident data. In the post-real-time system the calibrating data source is the TCI, while for the real-time system it is the TMI, since the TCI are unavailable in real time.

For the post-real-time estimates, the calibration month is a calendar month, and the resulting adjustment is applied to <u>all</u> of the microwave data for the same calendar month. This is not possible in the real-time system, so the calibration month is a trailing accumulation of 6 pentads, updated at the end of each pentad. A pentad is a 5-day period, except when Leap Day is included in the pentad that encompasses it; there are 73 pentads in each year.

Variable Rain Rate (VAR) IR Estimates

The CPC Merged IR data are averaged to 0.25° resolution and combined into hourly files as ±30 minutes from the nominal time. The amount of imagery delivered to CPC varies by satellite operator, but international agreements mandate that full coverage is provided for the 3-hourly synoptic times (00Z, 03Z, …, 21Z). Histograms of time-space matched HQ rain rates and IR T_b's, each represented on the same 3-hourly 0.25° grid, are accumulated for a month, and then used to create calibration coefficients for IR precipitation rate that vary in space. By design, there is no rain when the T_b is greater than a threshold value that matches the frequency of precipitation in the IR to that of the microwave, and increasingly colder T_b's have increasingly large rain rates. The calibration coefficients are then applied to the entire hourly IR data set.

As with the HQ, the post-real-time calibration month is a calendar month, and the resulting coefficients are applied to the same calendar month of <u>all</u> IR data. In the real-time system the calibration month is a trailing accumulation of 6 pentads, updated at the end of each pentad.

Combined HQ and VAR Estimates

As a first step, we currently combine the HQ and VAR estimates with the simplest possible scheme, namely the physically-based HQ estimates are taken "as is" where available, and the remaining grid boxes are filled with VAR estimates. This scheme provides the "best" local estimate in each grid box, at the expense of a time series with heterogeneous statistics. If homogeneous statistics are important to the user, either the HQ or VAR estimates may be accessed, depending on the application.

It is highly advantageous to include rain gauge data in combination data sets (Huffman et al. 1997, among others). However, experience shows that on any time scale shorter than a month there is not sufficient gauge data available and reported on consistent observation intervals to warrant direct inclusion in a global algorithm. We solved this issue in the 1DD by scaling the short-period estimates to sum to a monthly estimate that includes monthly gauge data. Here, we take a similar approach with the post-real-time estimates. All available 3-hourly HQ+VAR estimates are summed over a calendar month to create a monthly multi-satellite (MS) product. The MS and gauge are combined as in Huffman et al. (1997) to create a post-real-time monthly SG, which is a TRMM product in its own right. Then the field of SG/MS ratios is computed (with controls) and applied to scale each 3-hourly field in the month. Of course, such a gauge adjustment is not possible for the real-time system.

4. DATA SET STATUS

The real-time system has been running routinely on a best-effort basis in the TRMM Science and Data Information System (TSDIS) since late January 2002. For simplicity, a fixed latency of 6 hours after nominal observation time has been used to run the processing. The HQ, VAR, and HQ+VAR estimates, which are labeled 3B-40RT, 3B-41RT, and 3B-42RT, respectively, are available from ftp://aeolus.nascom.nasa.gov or http://precip.gsfc.nasa.gov. The post-real-time system has been developed as the Version 6 algorithm for the TRMM operational product 3B-42, although that product only provides the final gauge-adjusted HQ+VAR field. The Version 6 TRMM 3B-43 product has been developed as the post-real-time monthly SG sketched out above. At press time it was planned that these data will be reprocessed back to the first full month of TRMM (January 1998) in Spring 2003, as well as starting to process then-current data.

5. EXAMPLES

Figure 2 provides a snapshot of the merged microwave (HQ, top) and microwave-calibrated IR (VAR, middle) precipitation estimates for 18Z on 24 September 2002 from the real-time 3-hourly algorithm. The combined HQ+VAR field is sufficiently similar to the VAR that it is not displayed. The corresponding product identifiers are 3B40RT and 3B41RT. The HQ panel shows a typical amount of coverage by the F13, F14, and F15 SSM/I's and the TMI; AMSR-E was not yet available and AMSU was not yet incorporated. In contrast, the IR coverage is essentially complete for this particular observation time. Visual inspection of the two images shows general agreement in the location of major precipitation features, even though there is considerable variation in the small-scale details. Note the rain systems associated with hurricanes Isadore (in the Gulf of Mexico) and Lili (in the eastern Caribbean Sea). A mid-latitude low-pressure center and trailing front are located north of Hawaii, and late-afternoon convection is taking place in central Africa.

The difference field (Fig. 2, bottom) facilitates a comparison of the two fields. The convective systems, such as the African thunderstorms and hurricanes tend to show local differences, most likely due to the delay in time between the occurrence of precipitation and the growth of cirrus at the top of the storm. The mid-latitude system shows a larger-scale offset, which is believed to result from the frontal-scale offset between high-level cirrus ahead of the system and precipitation, which is located closer to the low-pressure center and frontal zone. Some of the offsets shown in the difference field could also be due to the 3-hour window for HQ data. Future work will minimize this problem by more closely matching up the HQ and IR times.

The individual 3-hourly VAR fields show large RMS differences from corresponding HQ fields, but they are designed to reproduce the monthly histograms of HQ rain rates. Thus, at least in a probabilistic sense the time series of precipitation is representative. The advantage of the 3-hourly 0.25° detail is that users are free to tailor averages or composites of the data to their own needs.

The results of the 3-hourly algorithm are best viewed as movie loops, which are beyond the scope of this preprint. Readers are urged to visit http://trmm.gsfc.nasa.gov and click on the button labeled "See More Images, Movies, & Accumulation Maps". A variety of instantaneous and cumulative images and movies are available for viewing and downloading, with larger movies available in lower resolution for users with limited-bandwidth network connections.

6. FUTURE DEVELOPMENT

The first task for the authors is to further characterize the performance of this approach and explore differences between the real-time and post-real-time results. At the same time, we expect to start integrating AMSU precipitation estimates into the HQ product. Thereafter, we will extend the estimates to the poles by incorporating fully global precipitation estimates based on Television Infrared Operational Satellite (TIROS) Operational Vertical Sounder (TOVS) and Advanced Infrared Sounder (AIRS) data. Both TOVS and AIRS fly on LEO satellites. The best approach to combining the HQ and VAR estimates is also a topic for future research. It would be helpful to develop a better IR-based algorithm so that the combination would not have to reconcile the strong fine-scale differences that currently exist between HQ and VAR. Finally, the study of precipitation in general needs a succinct statistical description of how fine-scale precipitation estimates perform over the range of scales up to global/monthly.

On the instrumentation side there is a concerted effort to provide complete 3-hourly microwave data. Most of this effort is focused on the National Aeronautics and Space Administration's proposed Global Precipitation Measurement (GPM) Mission. Besides simply increasing the frequency of coverage, it is planned to provide a TRMM-like "core" satellite to calibrate all the passive microwave estimates on an on-going basis. We expect a permanent role for the geo-IR in filling the inevitable gaps in microwave coverage, as well as enabling sub-3-hourly precipitation estimates at fine spatial scales.

7. REFERENCES

Arkin, P.A., and B.N. Meisner, 1987: The Relationship Between Large-Scale Convective Rainfall And Cold Cloud Over The Western Hemisphere During 1982-1984. *Mon. Wea. Rev.*, **115**, 51-74.

Huffman, G.J., R.F. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A. McNab, B. Rudolf, and U. Schneider, 1997: The Global Precipitation Climatology Project (GPCP) Combined Precipitation Data Set. *Bull. Amer. Meteor. Soc.*, **78**, 5-20.

Huffman, G.J., R.F. Adler, M. Morrissey, D.T. Bolvin, S. Curtis, R. Joyce, B McGavock, J. Susskind, 2001: Global Precipitation at One-Degree Daily Resolution from Multi-Satellite Observations. *J. Hydrometeor.,* **2**, 36-50.

Kummerow, C., W.S. Olsen, and L. Giglio, 1996: A simplified scheme for obtaining precipitation and vertical hydrometeor profiles from passive microwave sensors. *IEEE Trans. Geosci. Remote Sens.*, **34**, 1213-1232.

Xie, P., J.E. Janowiak, P.A. Arkin, R.F. Adler, A. Gruber, R. Ferraro, G.J. Huffman, and S. Curtis, 2003: GPCP Pentad precipitation Analyses: An Experimental Data Set Based On Gauge Observations And Satellite Estimates. *J. Climate,* in revision.

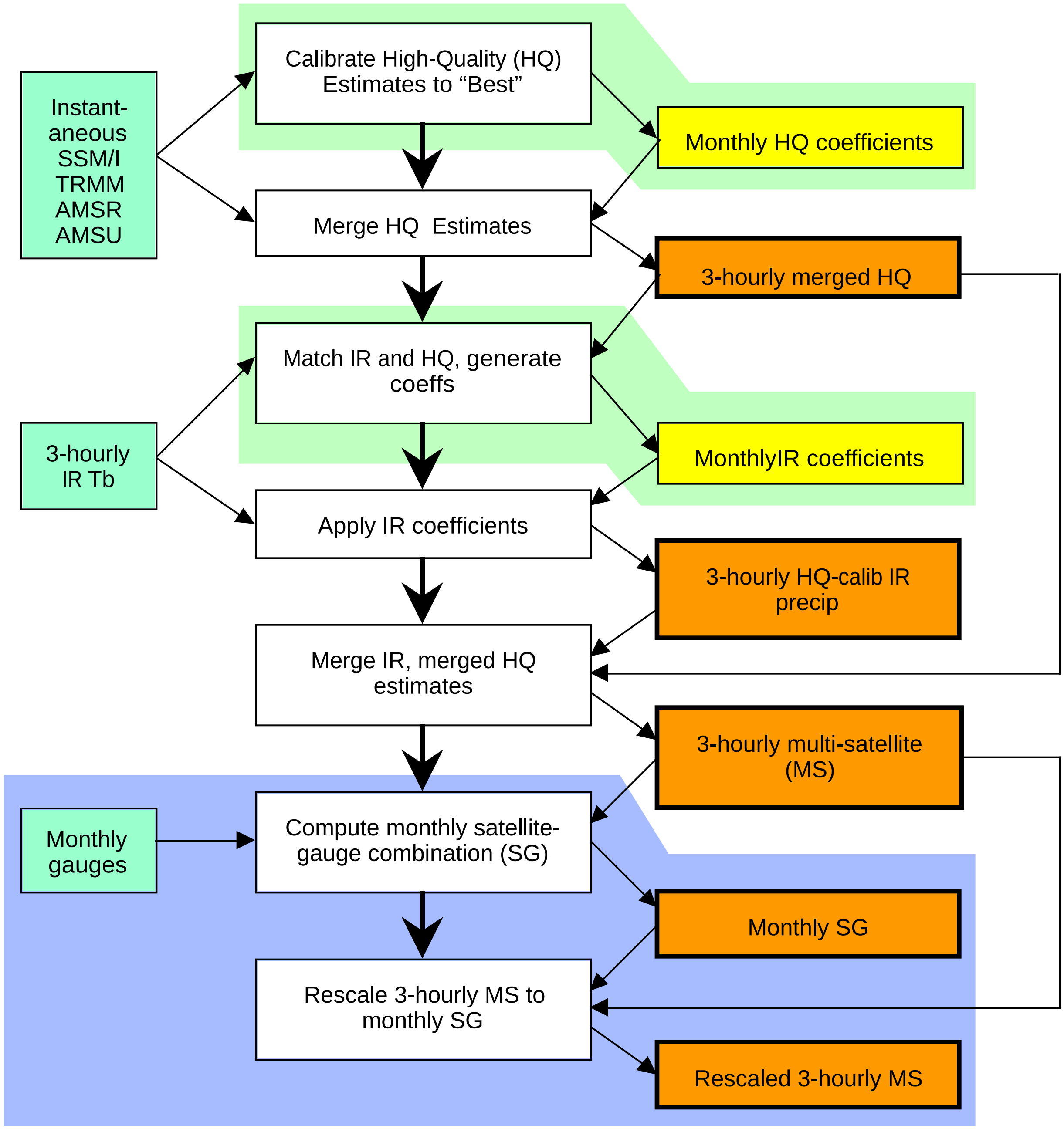

Figure 1 Block diagram for both the real-time and post-real-time 3-hourly algorithms, showing input data (left side), processing (center), output data (right side), data flow (thin arrows) and processing control (thick arrows). The items on the green shading run asyncronously for the real-time algorithm, and the items on the blue shading are only performed for the post-real-time algorithm. “Best” in the top center shaded box is the TMI GPROF precipitation estimate for the real-time algorithm and the TMI-PR combined algorithm precipitation estimate for the post-real-time algorithm.

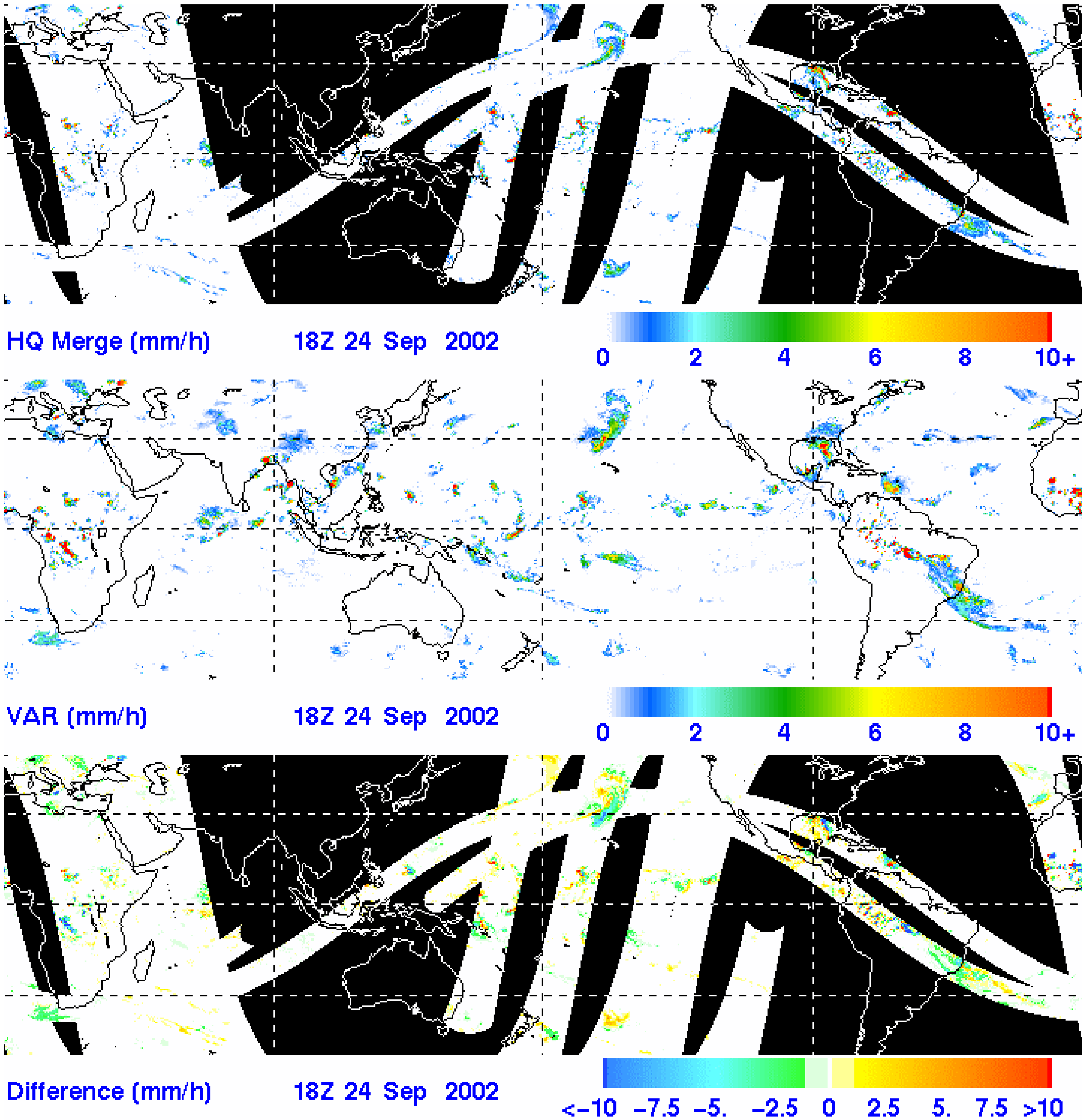

Figure 2 Example of output from the real-time 3-hourly algorithm, showing the merged microwave field (HQ, or 3B40RT; top), microwave-calibrated geo-IR (VAR, or 3B41RT; middle), and the difference (bottom) for the nominal observation time 18Z on 24 September 2002. Blacked-out areas lack data for the calculation.