P8.24 ANALYZING THE ERROR COMPONENTS IN BLENDED SATELLITE PRECIPITATION ANALYSES

F. Joseph Turk, Robert J. Joyce[1], and John E. Janowiak[2]

Naval Research Laboratory, Marine Meteorology Division, Monterey, CA 93943
Tel: (831)-656-4888; FAX (831)-656-5025; Email: turk@nrlmry.navy.mil
[1]Climate Prediction Center, NCEP/NOAA, Camp Springs, MD, and RS Information Systems (RSIS), McLean, VA
[2]Climate Prediction Center/NCEP/NWS/NOAA, Camp Springs, MD 20746

1. INTRODUCTION

In recent years the capability to quantify precipitation from space has been greatly enhanced with the addition of several new measurement capabilities, most notably from passive radiometric (PMW) sensors such as the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and its companion Precipitation Radar (PR), and the EOS-Aqua Advanced Microwave Scanning Radiometer (AMSR-E). Additionally, the requirements in climate modeling, precipitation data assimilation, and hydrologic applications have necessitated the need for daily (and sub-daily) precipitation analyses and their associated accuracy. Owing to intermittent PMW orbit coverage, this has necessitated the blending of these data with the rapid-time capability of geostationary-based thermal infrared (IR) observations. The types of blending schemes can be subdivided into two main categories, those that utilize the IR observations to advect precipitation in between PMW revisits, and those that utilize the PMW to calibrate the IR observations in-between satellite revisits. While capturing more of the underlying cloud evolution and areas of extreme precipitation intensification, the blending operation does introduce a complicated error that has several components. Common to all schemes is the error that is introduced from the instantaneous PMW rainfall estimates. A related error results from the inter-sensor bias between each PMW sensor type, which is primarily a function of the sensor field-of-view, rainfall rate, latitude, season, and the background surface type. A more complex error is related to the revisit schedule of the underlying PMW satellite constellation. Other more scheme-specific errors result from the way that the IR data are used to maintain temporal persistence in-between satellite revisits. Since extreme precipitation events are often associated with orographic conditions, the extreme events (the tail of the rainfall distribution) may be under-represented unless terrain and environmental conditions are taken into account. The overall combined error characterization is complicated by the fact that it is constantly changing due to the PMW overpass schedule (and may involve periods of missing data), and where these observations lie with respect to the space and time scales of the blending process.

2. SATELLITE OMISSION

In this presentation, we examine the performance degradation of two blended satellite precipitation techniques, the “advection-type” Climate Prediction Center (CPC) Morphing (CMORPH; Joyce et. al 2004) and the “quantitative-type” NRL-Blend (Turk et. al, 2003), when the underlying PMW satellite constellation is modified by omission of one or more satellites. The study is meant to examine one of the error components mentioned in Section 1, that which is due to the revisit schedule of the underlying PMW satellite constellation. The CMORPH uses the PMW-derived rainfall overpass sequence propagated by motion vectors derived from geostationary satellite data to derive rain products at half-hourly intervals. The NRL-Blend uses a histogram-matching relationship between the most recent PMW-derived rainfall (it also uses the TRMM PR radar-derived rainrates) and its time/space coincident geostationary satellite 11-µm infrared (IR) data, to produce an IR-calibrated rain product at the update cycle of the geostationary satellite. Both of these techniques depend upon the underlying PMW-based satellite constellation and its associated overpass schedule. If a particular PMW satellite were to fail, or be otherwise unavailable, it is constructive to know how the resultant gap in PMW temporal coverage (and the rain estimation characteristics of that particular sensor type) will affect the overall performance of these (or other) blended satellite rainfall techniques. In the discussions to follow, the “all-satellites” constellation is composed of TRMM TMI/PR, three DMSP/SSMI (Special Sensor Microwave Imagers active on F-13/14/15), and three NOAA/AMSU-B (Advanced Microwave Sounding Unit active on NOAA-15/16/17) satellites (the

AMSR-E was not yet available for these studies). This seven-satellite constellation has a worst-case revisit time of about six hours in the tropics, slightly less at latitudes near 40N/S. To examine the impact of satellite data outages, these techniques were also run in parallel for three configurations where satellite(s) were omitted: (2) Omission of NOAA-16, (3) omission of NOAA-17, and (4) omission of NOAA-17 and TRMM. The NOAA-16 satellite is in a sun-synchronous local afternoon crossing time orbit (1420 Local Time of Ascending Node, or LTAN), and the TRMM is a non sun-synchronous satellite with coverage limits of ±38 degrees latitude. The remainder of these satellites are in the more common sun-synchronous morning/night orbits (e.g., NOAA-17 LTAN is 2220).

To examine the performance (and relative degradation) of CMORPH and NRL-Blend due to the PMW overpass schedule, parallel runs of the two techniques were coordinated between 7 June and 9 July 2004 over the continental United States (CONUS), where the CPC Realtime Precipitation Validation (Available online at **http://www.cpc.ncep.noaa.gov/products/janowiak/us_web.shtml**) is ongoing. A total of 18 days were analyzed by the two techniques and validated against the CPC realtime gauge validation (Higgins et. al, 2000). The three panels of Figure 1 depict the time series of the average (non-zero) rainrate, the maximum rainrate, and the percent of raining pixels over the CONUS for each of these days (the red bar indicates the average over the interval).

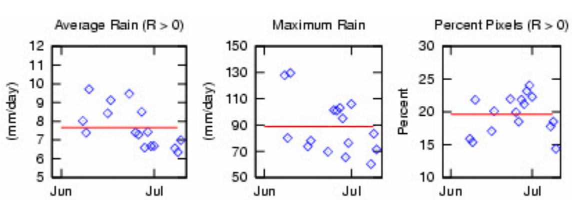

Figure 1. Average (non-zero rain pixels only) rainrate, maximum rainrate, and percent rainy pixels over the CONUS domain, extending over the 24-hour period ending at 12 UTC each day. The red bar indicates the average over the entire interval.

To examine how both CMORPH and NRL-Blend are affected by these changes to the underlying satellite constellation, Figures 2-3 depict the results using two basic threshold statistics, the probability of detection (POD) and the false alarm rate (FAR), and the overall spatial correlation shown in Figure 4. One would expect that constellation (2) would have the most noticeable degradation on both techniques performance, since NOAA-16 is the only synchronous satellite in the early afternoon orbit. Its loss interrupts the only constant afternoon PMW observation, and could lead to inaccuracies when morphing the PMW-derived rainfall between two overpasses separated by perhaps 8 hours or more, where the rainfall undergoes substantial evolution in space and time. The NRL-Blend would continue to operate during these satellite outages, but would default to using successively older PMW rainfall data to calibrate the incoming geostationary data, which are less representative of the current state of the rainfall evolution, so it is likely to degrade also.

The results show that for these summer 2004 cases, the CMORPH is the superior technique, as noted by the across-the-board higher POD and improved correlation scores compared to NRL-Blend (and also in other scores not depicted). Both techniques dropped about 0.05 in average POD when NOAA-16 was omitted. The FAR scores are not substantially different and hover near 0.3 for all satellite conditions, suggesting that something other than the makeup of the PMW satellite constellation is causing the incorrect characterization of the precipitation. The CMORPH correlation score drops from near 0.68 to 0.61 when NOAA-16 is omitted (bottom leftmost figures in Figures 2-4), whereas NRL-Blend drops less, from 0.53 to 0.50 (upper rightmost figures).

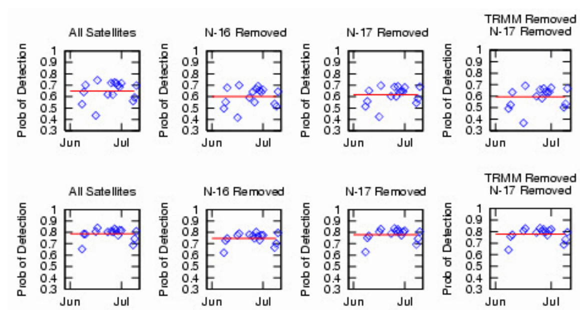

Figure 2. Probability of Detection (POD) of the NRL-Blend Technique (top row) and CMORPH (bottom row). Each data point represents the POD of the 24-hour rainfall accumulations (threshold= 1 mm/day) ending at 12 UTC for 18 days between 7 June and 9 July 2004. The effect of satellite omission is shown from left to right in each row. (1) The left-most column is the "all-satellites" or "reference" PMW configuration (one TRMM, three DMSP/SSMI, and three NOAA/AMSU-B), followed by, (2) when NOAA-16 is omitted, (3) when NOAA-17 is omitted, (4) when both NOAA-17 and TRMM are omitted.

The omission of NOAA-17 (third column in Figures 2-4) is not as noticeable, presumably since there are other PMW satellites near the same LTAN of NOAA-17 (e.g., the DMSP satellites and also

NOAA-15). The loss of NOAA-17 and TRMM together (fourth column) shows similar results as the NOAA-17 only omission. This is likely due to several factors; one being that TRMM does not cover the northernmost half of the United States, so there are no TRMM data represented in the latitudes above 38N. Also, above (below) 30N (30S) degrees latitude, there is oftentimes TRMM TMI coverage from several successive orbits (depicted below) about 90 minutes apart, but on some days these data arrive near the same local time as the DMSP or NOAA satellites, where they are not as useful. Since these statistics represent only represent a limited number of days, there is probably not enough data here to make a clear judgment on the effect of TRMM omission to the daily rainfall accumulations.

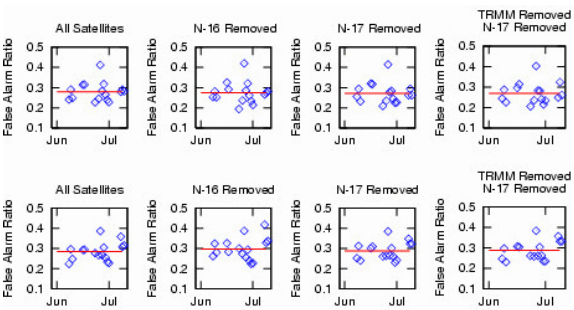

Figure 3. Same as Figure 2, but for the False Alarm Rate (FAR).

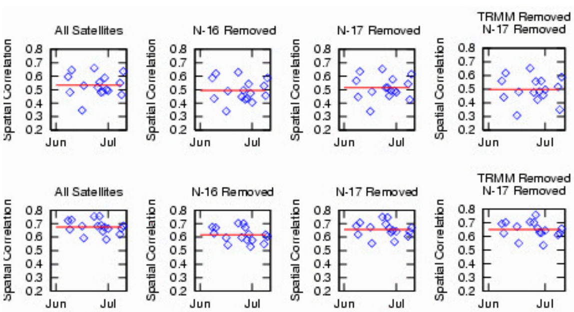

Figure 4. Same as Figure 2, but for the spatial correlation.

These results suggest that the timing of the local overpasses from the PMW satellite data, and how they are "phased" with regards to the time evolution of the underlying precipitation, are more important than the overall number of PMW-based satellite sensors. There will be invariably cases where the rainfall evolution and occurrence is well synchronized with a sequence of PMW overpasses, and other cases where the satellite overpass timings "miss" the precipitation. This is especially true of TRMM, since its crossing times change from day to day. This is not too problematic if one desires to monitor precipitation over a long enough period of time (e.g., monthly time scale). However, if the precipitation has a diurnal component, having a sun-synchronous satellite (like NOAA-16 or EOS-Aqua for rain regions with an afternoon maximum) appears to be most desirable.

3. RAIN EVOLUTION ON 9 JUNE 2004

The results of Section 2 showed skill scores and statistics for both NRL-Blend and CMORPH over 24-hour periods. This was done to compare with the daily CPC radar/raingauge analysis products. Given the insights gained from analysis of the satellite removal in Section 2, it is worth further dissecting several of these 18 days into smaller time periods in order to examine the impact of the satellite omission at time scales shorter than one day. We have chosen 9 June 2004 as a date for analysis, since the TRMM orbit pattern on this day was such that there were four successive passes over the state of Texas in the United States over a five hour period ending near 13 UTC (7 AM local time). Figure 5 lists the PMW satellite overpass schedule, and Figure 6 shows the coverage of the TRMM TMI for these four overpasses. The red lines in each panel of Figure 6 indicates the swath width of the TMI instrument, and the red symbols overlaid on the image indicate lightning flashes within ±5 minutes of the satellite overpass time, as recorded by the National Lightning Detection Network (NLDN).

Satellite Overpass Schedule 9 June 2004
Centered at 32N 98W (Texas USA)

DATE	TIME (UTC)	SAT	KM
2004/06/09	00:35:01	NOAA-15	74
2004/06/09	00:59:02	F-13	497
2004/06/09	01:59:03	F-14	543
2004/06/09	07:54:13	TRMM	366
2004/06/09	08:05:27	AQUA	476
2004/06/09	08:33:07	NOAA-16	945
2004/06/09	09:31:49	TRMM	245
2004/06/09	11:09:40	TRMM	297
2004/06/09	12:47:20	TRMM	219
2004/06/09	12:55:44	NOAA-15	588
2004/06/09	13:24:44	F-13	63
2004/06/09	14:24:38	F-14	135
2004/06/09	16:40:41	F-15	815
2004/06/09	17:48:33	NOAA-17	741
2004/06/09	19:06:19	AQUA	886
2004/06/09	19:54:48	NOAA-16	778
2004/06/10	00:11:30	NOAA-15	617
2004/06/10	00:44:59	F-13	168
2004/06/10	01:44:44	F-14	210

Figure 5. Satellite overpass schedule for June 9, 2004, relative to the location at 32N 98W. The distances in km represent the closest distances between the satellite subpoint and the on-Earth location at 32N 98W (near the center of the state of Texas).

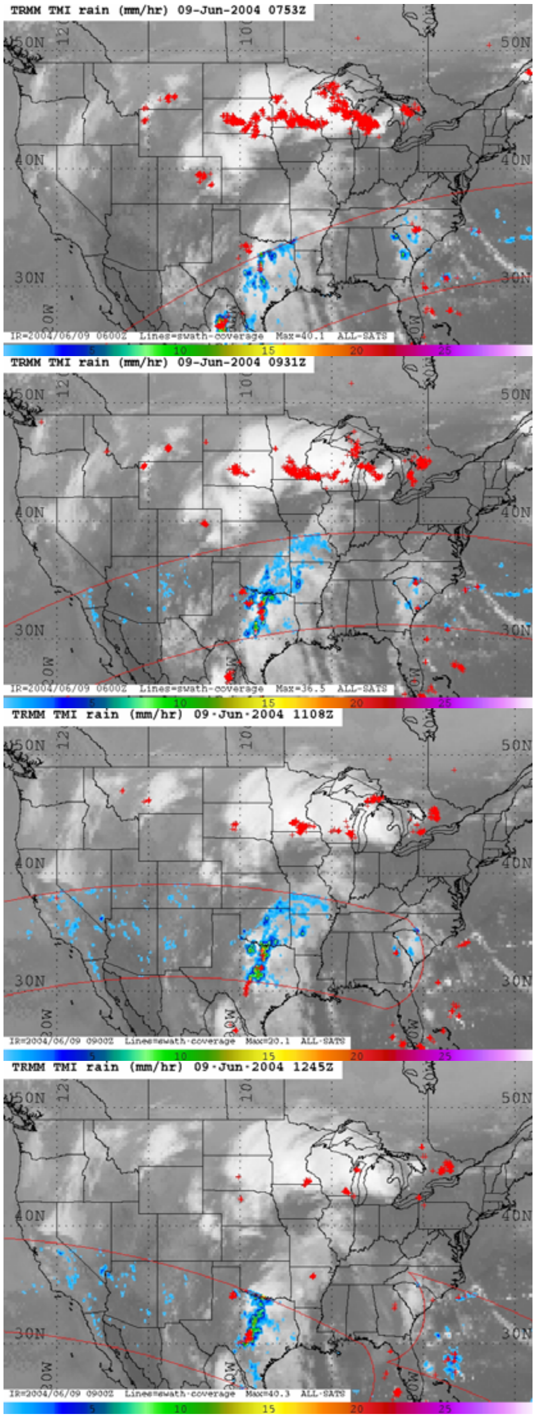

Figure 6. TMI-derived rainfall rates from four sequential TRMM overpasses over the southern United States on 9 June 2004 (red entries in Figure 5, depicted in sequence from top to bottom. The times on these images represent the time that the TRMM subpoint passed closest to the center of the CONUS, so the overpass times printed on these images are a few minutes different than the corresponding entries in Figure 5. The red lines in each panel indicate the swath width of the TMI instrument, and the red symbols overlaid on the image indicate lightning flashes within ±5 minutes of the satellite overpass time, as recorded by the National Lightning Detection Network (NLDN).

Figure 7 shows the rainfall totals recorded by the NEXRAD radar data and compiled by the West Gulf River Forecast Center, for the 6-hour period ending at 12 UTC on 9 June. The heaviest rain totals were between 50-100 mm over central Texas. In Figures 8 and 9, the rainfall totals during this same time interval as estimated by the NRL-Blend are depicted for the entire CONUS. Figure 8 represents the accumulations where (seven satellites) all-satellites PMW configuration was used, and Figure 9 represents the accumulations when both NOAA-17 and TRMM were omitted from the all-satellites constellation. Since there was an abundance of TRMM data during this time, one would expect the degradation between Figures 8 and 9 to be noticeable. Figures 10 and 11 show the identical figures for the CMORPH technique.

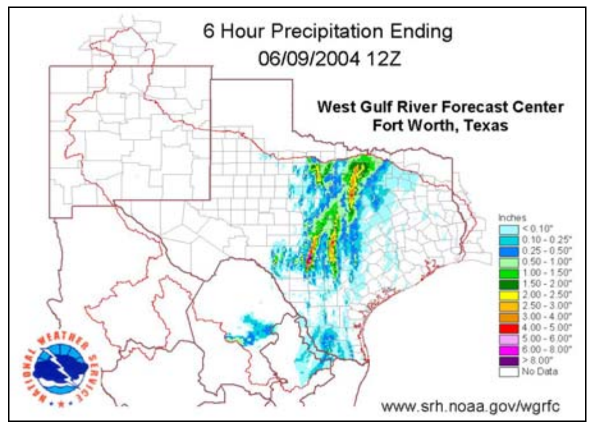

Figure 7. 6-hour rainfall accumulations over the state of Texas in the United States, ending at 12 UTC on 9 June 2004. Figure courtesy of the West Gulf River Forecast Center.

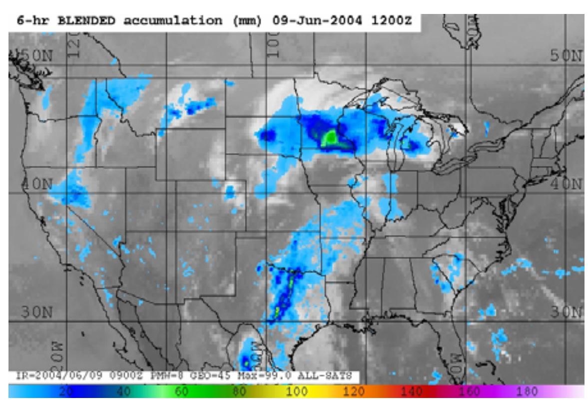

Figure 8. 6-hour rainfall accumulations from the NRL-Blend over the CONUS, ending at 12 UTC on 9 June 2004. The PMW satellite constellation used was the all-satellites configuration.

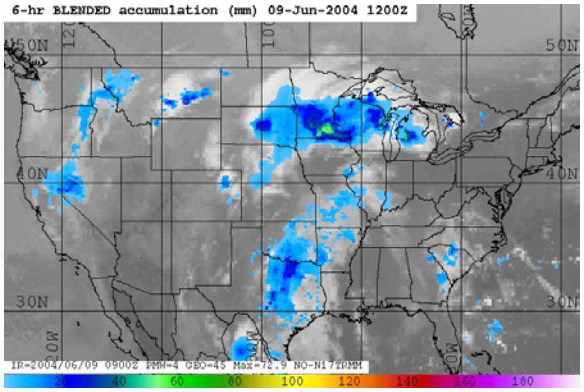

Figure 9. 6-hour rainfall accumulations from the NRL-Blend over the CONUS, ending at 12 UTC on 9 June 2004. The PMW satellite constellation used had both NOAA-17 and TRMM omitted.

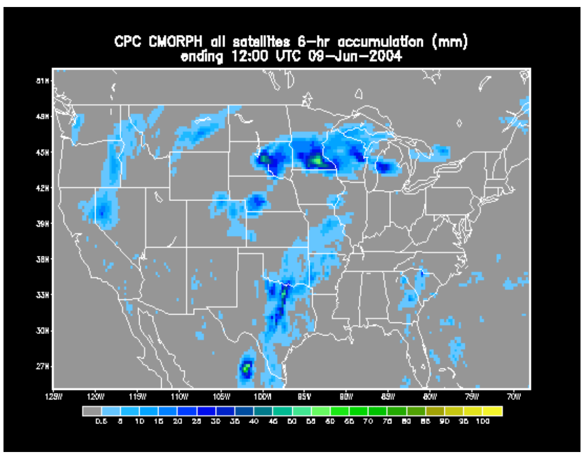

Figure 10. Same as Figure 8, but for the CMORPH technique.

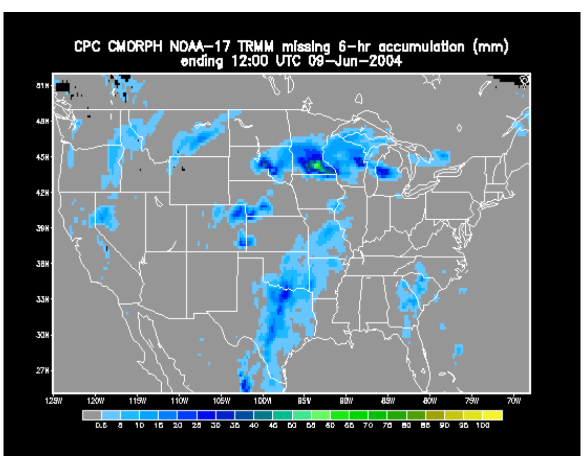

Figure 11. Same as Figure 9, but for the CMORPH technique.

For both techniques, the all-satellites configuration was able represent both the pattern and the total accumulation much more accurately than for the case when NOAA-17 and TRMM were omitted. In this case, the timing of the TRMM overpasses and the onset of the heavy precipitation were closely synchronized in time, so the impact of TRMM omission is substantial to both techniques.

To depict the opposite situation where the PMW satellite overpass schedule was not so favorable, we show in Figures 12-16 a sequence of images identical to Figures 7-11, but for the 6-hour period ending at 18 UTC on 9 June. From Figure 5, there was one TRMM pass, but there were three different SSMI passes during this time. Under these conditions, the difference between the two NRL-Blend estimates (Figures 13 and 14) is not very noticeable, and the peak rainfall totals (over 150 mm during this six hours) are underestimated. The corresponding CMORPH estimates (Figures 15 and 16) also show similar characteristics and a general underestimate of the peak rainfall totals during this time. The underestimate can be attributed to a number of factors, but a major factor is the coarser horizontal resolution rainfall retrievals from the SSMI or AMSU-B instruments, compared to the TMI instrument.

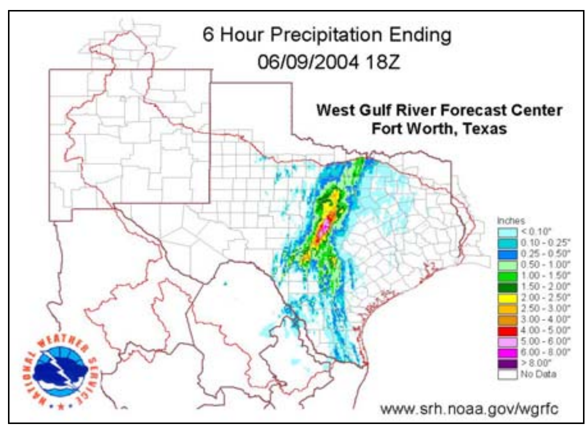

Figure 12. 6-hour rainfall accumulations over the state of Texas in the United States, ending at 18 UTC on 9 June 2004. Figure courtesy of the West Gulf River Forecast Center.

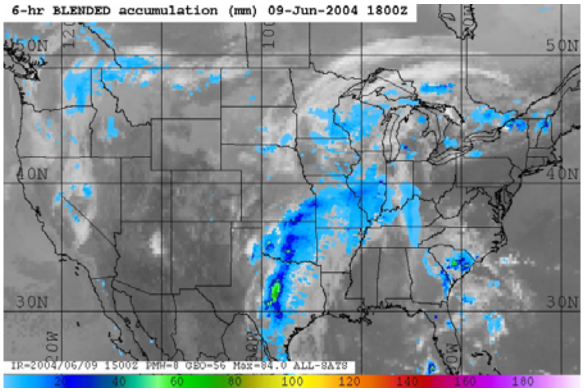

Figure 13. 6-hour rainfall accumulations from the NRL-Blend over the CONUS, ending at 18 UTC on 9 June 2004. The PMW satellite constellation used was the all-satellites configuration.

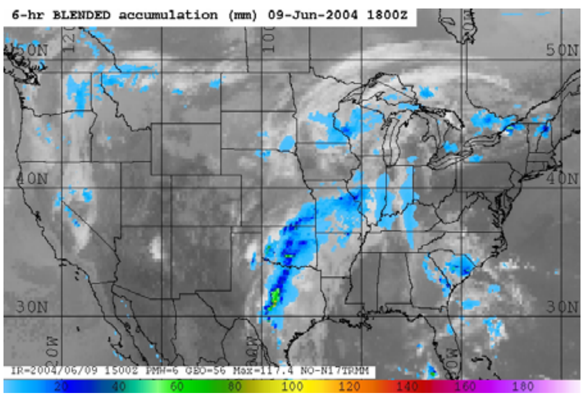

Figure 14. 6-hour rainfall accumulations from the NRL-Blend over the CONUS, ending at 18 UTC on 9 June 2004. The PMW satellite constellation used had both NOAA-17 and TRMM omitted.

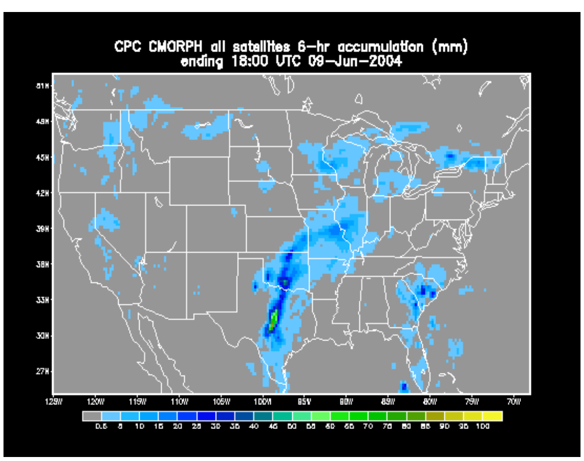

Figure 15. Same as Figure 13, but for the CMORPH technique.

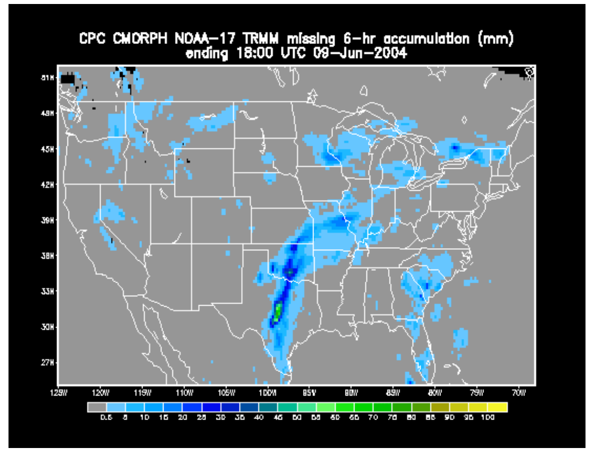

Figure 16. Same as Figure 14, but for the CMORPH technique.

4. CONCLUSIONS

This study has examined the impact of how changes to the PMW satellite constellation affect the overall performance of two types of blended satellite precipitation retrieval techniques. The reference or "all-satellites" PMW constellation was composed of the TRMM satellite, three DMSP/SSMI sensors onboard F-13, 14 and 15, and three AMSU-B sensors onboard NOAA-15, 16 and 17. Each sensor has specific PMW-based rainfall rate retrieval algorithms whose estimates are blended with the rapid-time capabilities of geostationary satellites. This study examined how the performance of two blended satellite techniques, the NRL-Blend and the Climate Prediction Center (CPC) CMORPH, were impacted by the loss of one or more PMW satellites. Three modifications were examined: Omission of NOAA-16 (the current afternoon-orbit NOAA satellite), omission of NOAA-17, and omission of both NOAA-17 and TRMM. The performance was judged by examining statistical scores against ground truth rainfall estimates, which were taken from the daily CONUS radar/gauge dataset produced by CPC. The loss of NOAA-16 was found to have the greatest impact, even more than the loss of NOAA-17 and TRMM together. Overall, the CMORPH performed better than NRL-Blend for probability of detection (POD) and spatial correlation scores (and also for other types of validation scores which were not presented). Both techniques suffered the most degradation in performance when the local afternoon-crossing NOAA-16 satellite was removed from the PMW constellation. It was found that the timing of the PMW overpass schedule relative to the time evolution of heavy precipitation events was critical to determining the overall degradation of any particular blended satellite precipitation technique.

In the near future, the Aqua/AMSR-E satellite sensor (similar LTAN as NOAA-16) will be added to the PMW constellation, and its finer spatial resolution and capability for improved light rainfall precipitation estimation is expected to positively impact these (and other) blended satellite techniques. Other PMW sensors, such as Windsat/Coriolis, will also augment the PMW coverage (although it lacks the 85 GHz channel needed for over-land rain sensing capabilities). While it would be desirable to have a PMW sensor onboard a geostationary satellite in the future, next-generation geostationary sensors (SEVIRI on Meteosat Second Generation, ABI on GOES-R, etc.) have expanded spectral as well as temporal capabilities, which will be exploited to overcome longstanding limitations from typical longwave IR observations. The expanded spectral coverage has already been examined in the EURAINSAT project (Levizzani et.al, 2004), for such characteristics as rain/no-rain screening, rain evolutionary stage, rain typing, etc.

This study represents a first attempt at examining the individual error components in blended satellite precipitation analyses, and has not attempted to further quantify the error in the resultant rainfall rate produced by each of these techniques (e.g., in terms of an accuracy within a given rainrate interval). The study used only 18 days over the summer United States season, whereas a complete error budget analysis should consider further separation into land/ocean backgrounds, season, and latitude. Since the satellite revisit schedule and overpass times change from day to day, the resultant error characterization should be dynamic and (ideally) produced at the same time as the rainfall estimate itself.

ACKNOWLEDGMENTS

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5. REFERENCES

Higgins, R.W.,W. Shi, E. Yarosh, and R. Joyce, 2000: Improved United States Precipitation Quality Control System and Analysis. Available online at http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/7/index.html.

Joyce, R.J., J.E. Janowiak, P.A. Arkin, P. Xie, 2004: CMORPH: A Method that Produces Global Precipitation Estimates from Passive Microwave and Infrared Data at High Spatial and Temporal Resolution. *J. Hydrometeor*., **5**, 487-503.

Levizzani, V., and A. Mugnai, 2004: Rainfall measurements from space: Where are we? *Proc. 14th Int. Conf. on Clouds and Precipitation*, Bologna, Italy, 18-23 July.

Turk, F. J., Ebert, E.E., Sohn, B.-J., Oh, H.-J., Levizzani, V., Smith, E.A., and R. Ferraro, 2003: Validation of a global operational blended-satellite precipitation analysis at short time scales. *12th AMS Conf. on Sat. Meteor. and Ocean.*, CD-ROM, 13-17 February, Long Beach.