P2.6 A NEW SATELLITE DERIVED PRECIPITATION DATA SET FOR STUDYING TRENDS IN EXTREME EVENTS

[1,2]Ralph Ferraro*, [1,2]Tom Smith, [2]Matt Sapiano, [2]Renu Joseph and [1,2]Huan Meng

[1]NOAA/NESDIS Center for Satellite Applications & Research, College Park, MD

[2]The Cooperative Institute for Climate Studies (CICS), College Park, MD

1. INTRODUCTION

While several data sets of precipitation developed from in-situ, satellite, numerical weather prediction and climate models, or blended analysis have emerged over the past decade (and focused on studying the long term/large scale trends in the global rainfall), much less attention has been placed on the possible trends in the distribution of short-term rainfall which contribute to longer-term drought and flood conditions. In the most recent climate studies, many investigators conclude that this sort of change is more likely to be attributed to the global warming scenario rather than trends averaged over long temporal and spatial scales (Trenberth et al. 2003; Trenberth et al. 2007). In this project, a new passive microwave satellite-based daily, 0.25 degree resolution data set has been developed using all available sensors with a common retrieval scheme. Currently, the time period of the data set is 1998 – 2006 (9 years in length), however, plans are to extend the time series for the period 1993 - 2007. It has been developed based on hourly rainfall estimates from the satellites, combined using an optimal interpolation scheme. Preliminary analysis indicates that the global rainfall from this new data set is comparable to the average from more established techniques such as the GPCP (Adler et al. 2003) and CMORPH (Joyce et al. 2004) data sets. Because the global daily data set is based on hourly "snapshot" input data (which is preserved in the final product generation), this intermediate product can be used to estimate probability distribution functions (PDF's) of near-instantaneous rain rates at any 0.25 degree grid box on the earth. Thus, changes in the PDF's over time can be investigated and related to other annual to inter-annual climate forcing. Additionally, the data set will offer the ability to examine the diurnal cycle of precipitation and any changes that might be occurring over the 15-year period.

It is the purpose of this paper to highlight the first version of this new data set (hereafter referred to as the OI product) and show comparisons with some of the other merged global precipitation data sets. In addition, areas of concern are noted and possible solutions for the second version are discussed. Finally, some preliminary ideas on utilization of the data for other applications are discussed.

*Corresponding author address:
Ralph Ferraro
Cooperative Institute for Climate Studies/ESSIC
University of Maryland; 2207 Computer & Space Sciences Bldg.
College Park, MD 20742
Ralph.R.Ferraro@noaa.gov

2. DATA AND METHODOLOGY

Since passive microwave (MW) retrievals of rainfall are superior to their IR counterparts in terms of their physical connection to cloud microphysics/rainfall processes (Ebert el al. 1996), the new precipitation time series has focused on the use of such data. However, it was recognized that there are several algorithm versions that exist in the various satellite time series (see Table 1), so one of the primary aims of this study was to reprocess as much of the satellite orbital data using both a common retrieval technique, and its most recent version. For passive MW "imagers", the Goddard Profiling Algorithm (GPROF, Kummerow et al. 2001) was adopted. In theory, the biases between the GPROF retrievals for each of the individual satellite sensors should be close to zero, with the caveat being the observation time of the satellite (i.e., diurnal cycle affects) as well as the sensor characteristics (i.e., footprint size, channel availability, etc.). For example, it's expected that TRMM and AMSR-E should exhibit similar rainfall amounts over long time periods since they both contain a similar set of channel measurements with high spatial resolutions. On the other hand, TRMM was designed to sample the earth at all times of the day over the course of a year whereas the AMSR-E observes the earth at approximately 2 am and 2 pm each day, thus, it only samples a portion of the diurnal cycle. This will likely result in regional rainfall biases.

Table 1 – Characteristics of the input data sources used in the OI precipitation time series. I denotes "imager"; S denotes "sounder. The references are the most relevant that describe the algorithm and data set used.

Sensor	Satellite	Type	Years	Reference
SSM/I	DMSP F11, F13, F14, F15	I	1998 - 2006	Kummerow et al. (2001)
TMI	TRMM	I	1998 - 2006	Kummerow et al. (2001)
AMSR	Aqua	I	2002 - 2006	Wilheit et al. (2003)
AMSU	NOAA-15, 16, 17, 18	S	2000 - 2006	Vila et al. (2007)

The Advanced Microwave Sounding Unit (AMSU), first placed into orbit on the NOAA-15 satellite in July 1998, has provided a unique set of measurements from a passive MW "sounder" that has become vital to the retrieval of global rainfall (Vila et al. 2007). Despite the difference in the retrieval algorithm as compared to

GPROF (due to the AMSU being a cross-track scanner, having frequencies between 23 and 183 GHz, etc.), the nearly 4-hour global rainfall information (since 2002 when three satellites were in operation), plus, the increased sensitivity to lighter rainfall over land, helps reduce the diurnal sampling error and contributes significantly to global rainfall. In fact, its utilized by several other merged rainfall techniques (e.g., CMORPH, TMPA, etc.). In this project, an improved AMSU rainfall algorithm was developed (Vila et al. 2007) and the entire AMSU time series was reprocessed using this retrieval technique. Further details on the algorithms, satellites, etc. are also found in Table 1.

Unlike other "merged" satellite rainfall products, this data set does not utilize infrared measurements or rain gauge data, nor does it attempt to normalize each measurement to some sort of "reference". It uses an Optimal Interpolation (OI) scheme to combine the various input data sources. First the individual sensor type are gridded onto an hourly, 0.25 degree grid. The relative noise to signal variance of each type of data is estimated and the hourly data are then analyzed using OI. The OI produces an analysis value and an error estimate for each hourly 0.25 degree region. These satellite data typically allow analysis for six to twelve hours of each day. In addition to the hourly OI, a daily product and error estimate is produced by averaging the hourly OI.

The OI is essentially using two retrieval techniques (e.g., GPROF and AMSU) from four different sensors and up to 10 different satellites over the nine year period (see Table 1). This approach should reduce the number of degrees of uncertainty in the time series; however, in this initial version of the OI data set, no attempt has been made to inter-calibrate the input radiances from the various sensors to a common reference. Thus, its possible that systematic biases will remain.

Each retrieval algorithm has its own set of "screens" for anomalous surfaces such as snow and ice. However, despite the best efforts put forth in each algorithm, these methods due not work in every situation (Ferraro et al. 1998). Thus, after each daily rain field is generated, a common snow/ice mask is applied to the final product which is constructed as follows. Oceanic ice estimates from the NOAA daily, 0.25˚ OI sea surface temperature analysis (Reynolds et al. 2007) were merged with weekly 1˚ Northern Hemisphere snow data from the Rutgers Global Snow Lab data (GSL; Robinson and Frei 2000) where the same snow data was used for each day in a week and for each 0.25˚ box within the 1˚ GSL boxes. Areas with elevation greater than 3km were also masked as well as the whole of the Antarctic where a fixed land mask was used. All these components were merged onto a single 0.25˚, daily grid which was then spatially smoothed slightly to avoid issues around the ice/snow edge.

3. RESULTS

The initial data set developed is nine years in length (1998 – 2006) and occurs during the passive MW "data rich" era: a period where the TMI was in operation, at least 3 SSM/I sensors were operating, AMSU data became available (2000), and finally, AMSR-E (2002). Prior to 1998, only SSM/I were in operation, severely limiting the diurnal sampling of precipitation.

To illustrate the overall behavior of the global time series and the impact of the various input data sets being utilized, Figure 1 shows the zonal mean rainfall difference from 2006 (e.g., 2006 zonal mean minus 1998 zonal mean, etc.). The differences have been normalized by the actual mean rainfall for the entire nine years. Year to year consistency is found, especially after 2002, with most differences being attributed to interannual variations in the rainfall. However, larger differences are found before 2002, and much of this can be explained due to the lack of AMSU (only two satellites in operation in 2002 vs. three afterwards; no AMSU prior to 2000) and AMSR-E data in the time series. Prior to 2000, the largest differences are found, where two primary features are detected. The first is the lesser amount of rain in the mid and high latitudes. Apparently, a bias between the GPROF retrievals and the AMSU retrievals exists over the oceans. The larger differences over the tropics in 1998 and to some extent, 1999, can be explained by the transition from strong El Nino to strong La Nina conditions in the tropical Pacific.

It is important to see how the OI data set compares with that from other similar products. Figure 2 shows a comparison with the GPCP monthly precipitation product, where the OI has been accumulated from the daily estimates. Shown are the monthly precipitation anomaly features, stratified by land and ocean, which describe seasonal to interannual variations in precipitation. Over land, there is excellent agreement between the OI, the GPCP merged and the GPCP merged satellite (MS) products. The OI and the MS appear to agree the closest. Some apparent noise is evident at the highest latitudes in the OI, most likely attributed to inadequate screening of snow cover. Over ocean, larger differences are found, in particular, during the first two years of the OI data set, where SSM/I and TRMM were the only data sources. In the regions poleward of 35 degrees latitude (i.e., outside the TRMM domain), the OI shows improper negative rainfall anomalies. Apparently, the SSM/I retrievals in these regions are less than those contributed from the other data sources. Within the TRMM domain, all three data sets are in relatively good agreement. These results are consistent to those found in Figure 1.

Another way to evaluate the robustness of the OI is to look at regional, high time/space scale rainfall (e.g., see Sapiano et al. 2008). Shown in Figure 3 is an example of 24-hour (00 UTC – 00 UTC) accumulated rainfall for 29 August 2005, the day Hurricane Katrina made landfall in the United States. As can be seen, the OI is comparable to CMORPH and the gauge-corrected mosaiced radar Stage IV products in terms of the large scale rain patterns. Detailed analysis reveals subtle differences in the magnitudes and locations of the heaviest rainfall within particular rain systems. An evaluation of the rainfall associated with Katrina over a nine day period showed excellent agreement between the OI, CMORPH and Stage IV.

4. SUMMARY AND FUTURE PLANS

In this study, a new merged passive MW rainfall product utilizing all possible sensors and the most recent retrieval algorithms has been assembled for the period of 1998 – 2006. Preliminary comparisons against other products such as the GPCP and CMORPH have demonstrated the robustness of the new product. Plans are to expand the data set to include the years of 1993 – 2007. It is envisioned that the OI data set will be made publicly available during the latter half of 2008.

There are some problem areas that need to be addressed in the second version of the product, which include a possible bias correction for the AMSU vs. the imager products. Additionally, intersatellite calibrations being developed under the auspices of the Global Precipitation Measurement Mission (GPM) need to be included in the product. Finally, the reliability of product in the pre-TRMM era needs to be properly addressed.

Because of the way the OI data set has been assembled, it will be useful for the investigation into possible trends in rainfall extremes, shifts in the diurnal cycle of rainfall, etc.

The views, opinions, and findings contained in this report are those of the author(s) and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

4. REFERENCES

Adler, R. F., G. J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, and E. Nelkin, 2003: The version 2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979-present), *J. Hydromet.*, **4**, 1147-1167.

Ebert, E.E. & Manton, M.J., Arkin, P.A., Allam, R.E. & Gruber, A., 1996: Results from the GPCP algorithm intercomparison programme, *Bull. Amer. Meteor. Soc.,* **77,** 2875-2887.

Ferraro, R.R., E.A. Smith, W. Berg, and G. Huffman, 1998: A review of screening techniques for passive microwave precipitation retrieval algorithms. *J. Atmos. Sci.,* **55**, 1583-1600.

Joyce, R. J., J. E. Janowiak, P. A. Arkin, and P. Xie, 2004: CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution.. *J. Hydromet.,* **5**, 487-503.

Kummerow, C., Y. Hong, W. S. Olson, S. Yang, R. F. Adler, J. McCollum, R. Ferraro, G. Petty, D.-B. Shin and T. T. Wilheit, 2001: The evolution of the Goddard Profiling Algorithm (GPROF) for rainfall estimation from passive microwave sensors. *J. Appl. Meteor*., **40**, 1801-1820.

Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax, 2007: Daily High-Resolution-Blended Analyses for Sea Surface Temperature. *J. Clim.*, **20**, 5473-5496.

Robinson, D.A. and A. Frei, 2000: Seasonal Variability of Northern Hemisphere Snow Extent Using Visible Satellite Data. *Professional Geographer*, **51**, 307-314.

Sapiano, M. R. P. and P. A. Arkin, 2008: An inter-comparison and validation of high resolution satellite precipitation estimates with three-hourly gauge data. *In preparation.*

Smith, T.M., P.A. Arkin, J.J. Bates, and G.J. Huffman, 2006: Estimating bias of satellite-based precipitation estimates. *J. Hydromet.,* **7,** 841-856.

Trenberth, K.E., A. Dai, R. M. Rasmussen, D. B. Parsons, 2003: The changing character of precipitation. *Bull. Am. Meteorol. Soc.*, **84**, 1205–1217.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Vila, D., R. Ferraro, R. Joyce, 2007: Evaluation and Improvement of AMSU Precipitation Retrievals. *J. Geophys. Res.,* **112**, D20119, doi:10.1029/2007JD008617.

Wilheit, T., C. Kummerow and R. Ferraro, 2003: Rainfall algorithms for AMSR-E. *IEEETrans. Geosci. Rem. Sens.,* **41,** 204-214.

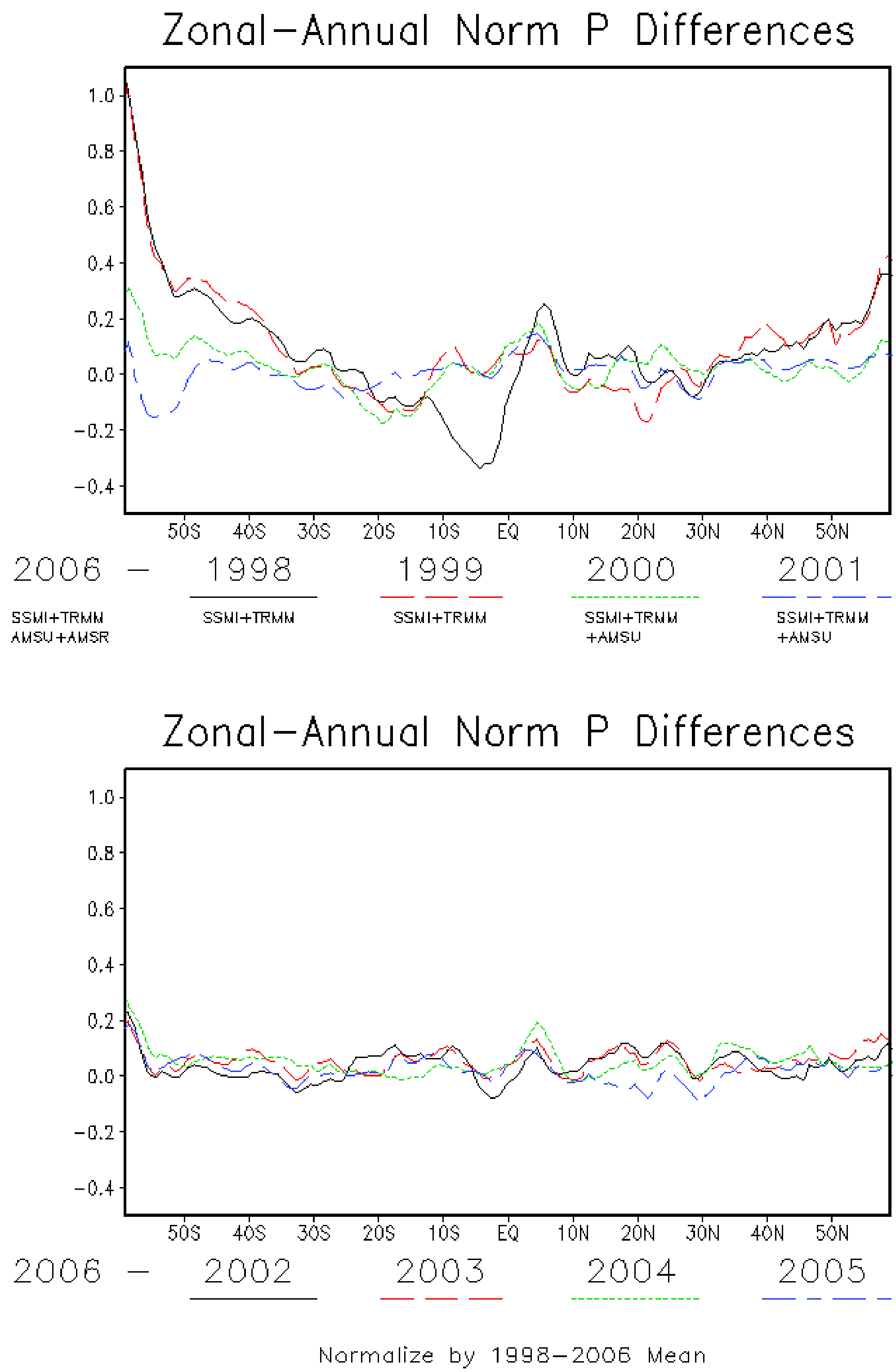

Figure 1 – Zonal mean precipitation differences (percent) for 2006 minus the year indicated (1998 through 2005) for the OI precipitation data set. Also noted are the sensors that were available in the analysis each year (note that beginning in 2002, all satellite data sources are available).

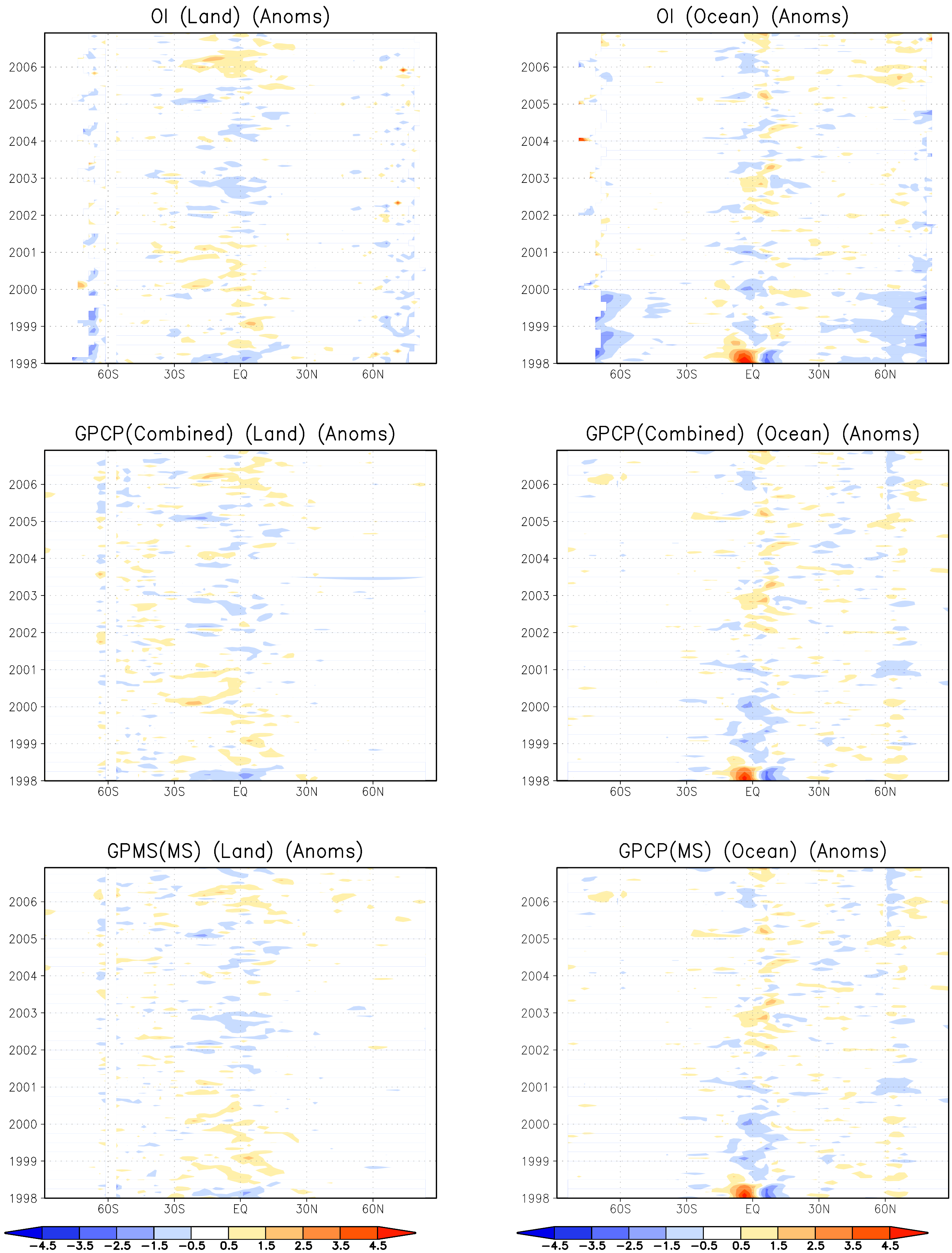

Figure 2 – Daily zonal mean precipitation anomalies (mm d^{-1}) for the OI (top), GPCP combined (middle) and GPCP merged satellite (bottom).

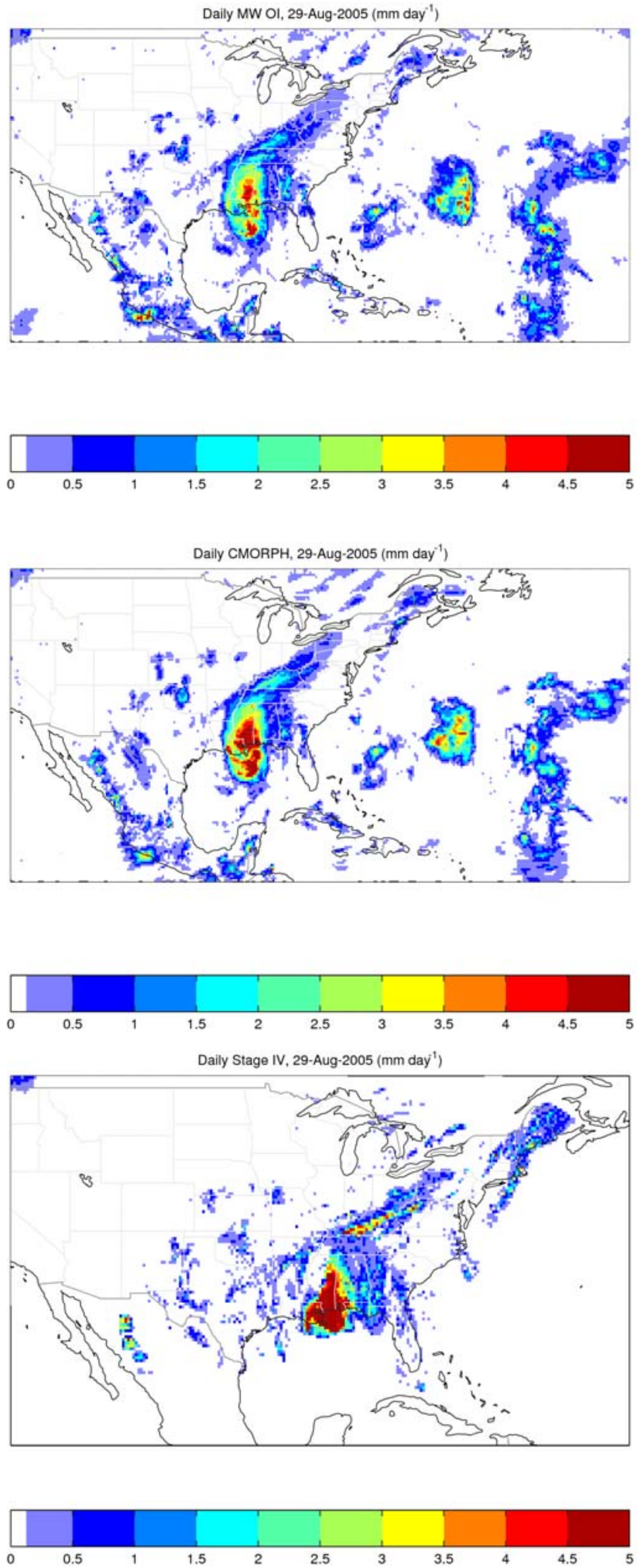

Figure 3 – Daily rainfall (mm d^{-1}) for 29 August 2005 for the OI (top), CMORPH (middle) and the Stage IV (radar/gauge analsyis). This was the day that Hurricane Katrina made landfall in Louisiana.