NASA GEOS-3/TRMM RE-ANALYSIS: CAPTURING OBSERVED TROPICAL RAINFALL VARIABILITY IN GLOBAL ANALYSIS

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ABSTRACT

Precipitation estimates from operational numerical weather prediction (NWP) systems are typically forecast products rather than “analyses” based on rainfall observations and model information. At NASA/GSFC, we have been pursuing an alternative strategy to precipitation analysis using observed rain rates to directly constrain model estimates in a statistical analysis procedure. A key issue in rainfall assimilation is that the model rain derived from parameterized moist physics can have significant biases, which must be rectified to make proper use of observations. Our variational time-continuous assimilation (VCA) scheme, in effect, acts as an online estimation and correction of forecast model biases in moisture tendency (therefore precipitation) within a 6h analysis cycle. We present results from a 5^+-year (1997-2002) reanalysis showing that assimilation of tropical TMI and SSM/I rain rates in the GEOS-3 global data assimilation system using this technique effectively captures the spatial and temporal variability of tropical precipitation systems in MJO signals, which in turn improves many aspects of the analysis including cloud/radiation fields in the tropics. Also presented are examples showing that the improved analysis can lead to better hurricane forecasts in the tropics.

1. INTRODUCTION

Understanding climate variability over a wide range of space-time scales requires a comprehensive description of the earth system. Global analyses produced by a fixed assimilation system (i.e., reanalyses) - as their quality continues to improve - have the potential of providing a vital tool for meeting this challenge. But at the present time, the usefulness of re-analyses is limited by uncertainties in such basic fields as clouds, precipitation, and evaporation (WCRP 1998) -especially in the tropics, where observations are relatively sparse.

Analyses of the tropics have long been shown to be sensitive to the treatment of cloud/precipitation processes, which remains a major source of uncertainty in current models. Yet, for many climate studies it is crucial that analyses can accurately reproduce the observed rainfall intensity and variability since a small error of 1 mm d^{-1} in surface rain translates into an error of ~ 30 W m^{-2} in energy (latent heat) flux. Currently, discrepancies between the observed and analyzed monthly-mean rain rates averaged to 100 km x 100 km resolution can exceed 4 mm d^{-1} (or 120 W m^{-2}), considerably larger than uncertainties on the order of ~ 10-20 Wm^{-2} in surface radiation flux analyses. Improving precipitation in analyses would therefore reduce a major source of error in the global energy budget. Uncertainties in tropical precipitation have been a major impediment in understanding how the tropics interact with other regions, including the remote response to El Nino/Southern Oscillation (ENSO) variability on interannual time scales, the influence of Madden-Julian Oscillation (MJO), and monsoons on intraseasonal time scales. A global analysis that can replicate the observed precipitation variability together with physically consistent estimates of other atmospheric variables provides the key to breaking this roadblock.

2. NASA GEOS-3/TRMM REANALYSIS

At NASA/GSFC, we have been exploring the use of satellite-based microwave rainfall measurements in improving global analyses (Hou et al. 2000, Hou et al. 2001). We have recently completed a multi-year, 1^{o} x 1^{o} "TRMM reanalysis", which assimilates 6-hourly TMI and SSM/I surface rain rates over tropical oceans using a 1D variational continuous assimilation (VCA) procedure in the GEOS-3 global data assimilation system (DAS). The scheme minimizes the distance between the 6h model rain and observations using moisture tendency corrections as the control variable (Hou et al., 2004). It acts as an online estimation and correction of biases in the precipitation observation operator to make more effective use of rainfall data. The analysis period extends from 1 November 1997 through 31 December 2002. The goal is to produce a multi-year global analysis that is dynamically consistent with available tropical precipitation observations for the community to assess its utility in climate applications and identify areas for further improvements.

3. RESULTS

Shown in Fig. 1 are the Madden-Julian Oscillation (MJO) signals in GPCP satellite-gauge rain rates compared with estimates from global analyses from the operational NCEP GDAS, the ECMWF reanalysis (ERA-40), and the GEOS-3/TRMM reanalysis. The NCEP GDAS operational system assimilates TMI and SSM/I rain rates using a 3DVAR algorithm from October 2001 onward, while the ERA-40 does not assimilate any precipitation data. Rainfall assimilation using the VCA scheme clearly enables the GEOS-3/TRMM reanalysis to better capture the intensity and propagation of tropical precipitation systems, which is confirmed by the error statistics shown in Fig. 2.

Results from a wavelet analysis show that the GEOS-3/TRMM precipitation analysis has a significantly higher correlation with GPCP observations over a wide range of temporal frequencies (Fig. 3). The Incremental Analysis Update (IAU) dynamical initialization scheme used in the GEOS-3 DAS allows the wind, temperature, and pressure fields to respond to the improved precipitation field within the 6h assimilation window to achieve dynamical consistency. The improved spatial and temporal distributions of tropical precipitation (and associated latent heating patterns) thus lead to improved vertical motion and humidity fields, as shown in Hou et al. (2001).

One measure of the overall quality of the analysis is terms of the top-of-atmosphere radiation. Figure 4 shows that the GEOS-3/TRMM reanalysis has smaller errors (over oceans) in the outgoing longwave radiation (OLR), as verified against CERES measurements. Note that the large OLR errors in vicinities of 60E and 60W in the GEOS-3 control (without precipitation data) reflect errors in the GEOS-3 system over land. Even though the GEOS-3/TRMM reanalysis assimilates only oceanic rain rates, the OLR errors over land are also substantially reduced over land.

We also performed hurricane forecast experiments using the GEOS-3/TRMM reanalysis as initial conditions. An example of the improved track forecast is shown in Fig. 5 for Hurricane Bonnie. Details of these experiments are reported in Hou et al. (2004).

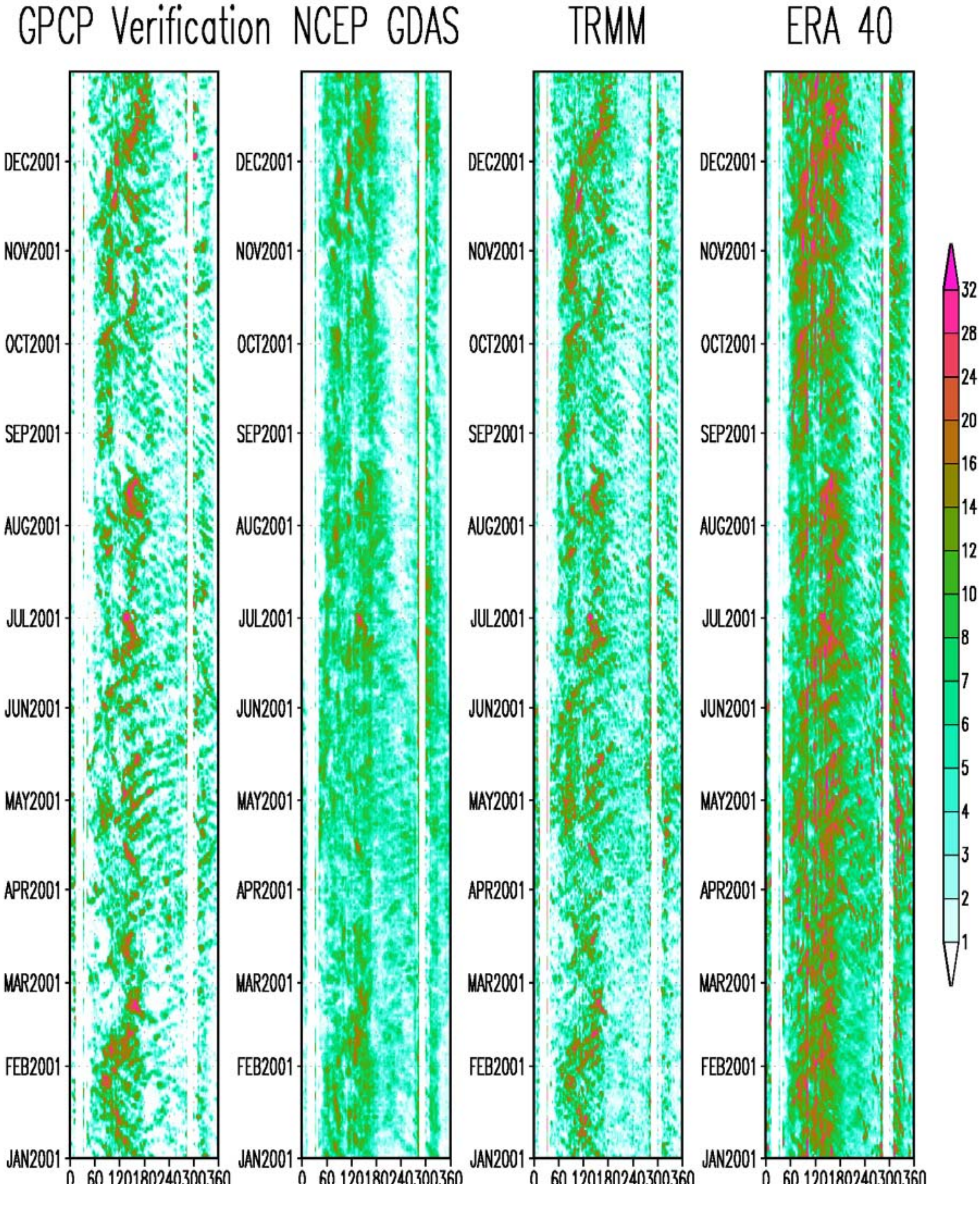

Figure 1. Precipitation over tropical oceans (10N-10S) for 2001. The TRMM analysis is produced by the NASA GEOS-3 global data assimilation system, which assimilates 6h TMI and SSM/I surface rain data using a 1D VCA scheme (Hou et al. 2004). The NCEP GDAS assimilates TMI rain rates from October 2001 using a 3DVAR scheme. The ECMWF ERA-40 is a reanalysis without using satellite rain rates. GPCP is the combined satellite-gauge rain estimate produces by the Global Precipitation Climatology Project (GPCP).

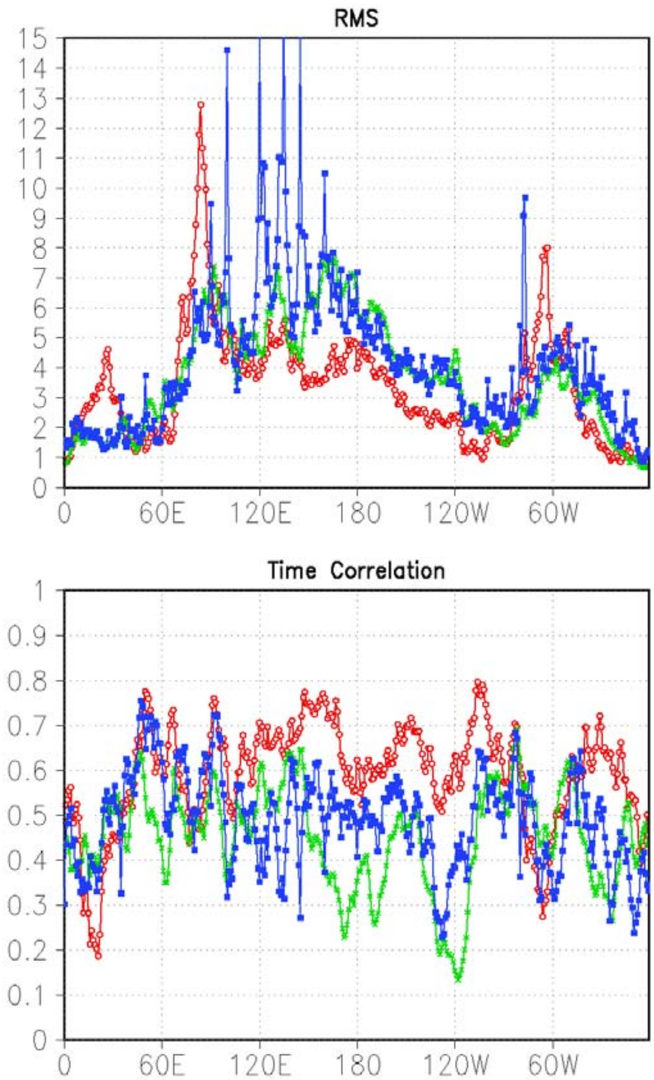

Figure 2. Precipitation errors relative to GPCP estimates for 2001 (see Fig. 1).

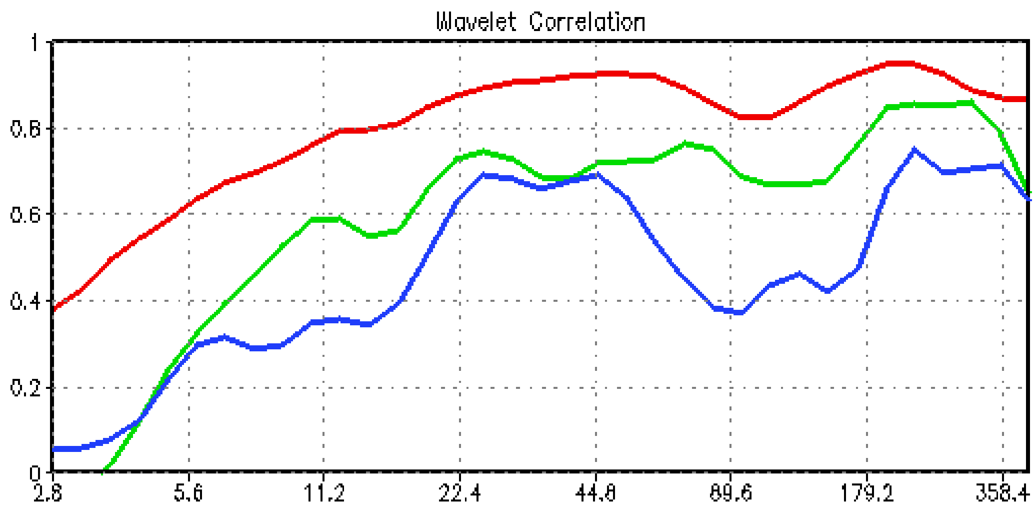

Figure 3. Wavelet correlation of precipitation analysis with GPCP data in temporal frequency space.

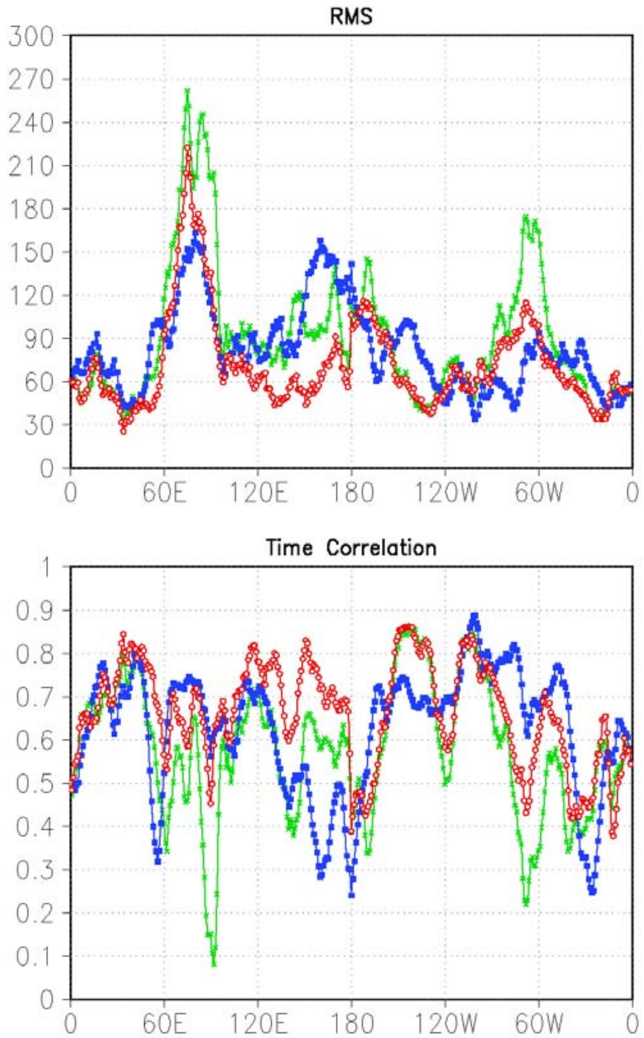

Figure 4. Errors in OLR relative to CERES TOA radiation measurements for May 1-Aug 31, 31,1998 Control is GEOS-3 analysis without rainfall data.

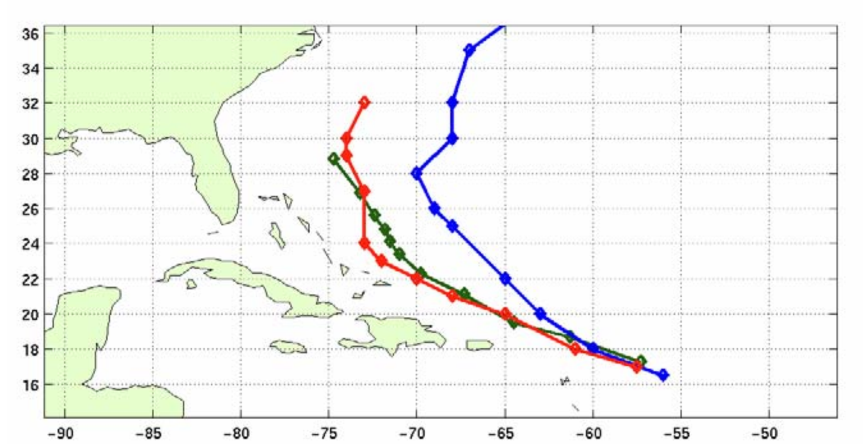

Figure 5. Five-day Hurricane Bonnie forecasts with and without TMI+SSM/I rainfall data initialized from 1200 UTC August 20, 1998. Also shown is NOAA's analyzed "best track".

4. SUMMARY

A unique feature of the GEOS-3/TRMM re-analysis is that its precipitation analysis is not derived from a short-term forecast (as done in most operational systems) but is given by a time-continuous model integration constrained by precipitation observations within a 6-h analysis window, while the wind, temperature, and pressure fields are allowed to directly respond to the improved precipitation and associated latent heating structures within the same analysis window.

These results show that rainfall assimilation using the VCA scheme enables the GEOS-3/TRMM reanalysis to better replicate the intensity and propagation of tropical precipitation systems and improves the associated climate signals ranging from a few days to interannual time scales.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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