A comparison between tropical rainfall maps: TRMM and ERA40, 1998 to 2001

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1 Introduction

1.1 Subject

The purpose of this study is to perform an initial qualitative and quantitative comparison between tropical rainfall values via multiple data sets, primarily ERA40 rainfall and TRMM rainfall. Rainfall information from GPCP and CMAP will be included in the analysis at a later time.

The Tropical Rainfall Measurement Mission (TRMM) satellite provides a unique view of the Earth’s tropical precipitation patterns. TRMM’s combination of diurnal coverage, multiple instruments on a single platform, and flight longevity allow for a powerful addition to the currently available measures of precipitation and related meteorological fields. The objectives of the TRMM mission are to “measure rainfall and energy (i.e., latent heat of condensation) exchange of tropical and subtropical regions of the world”[3].

ERA40 is a reanalysis data set generated by ECMWF. Data are available at 2.5° x 2.5° grid spacing or higher resolutions, with monthly mean 6-hourly values for most available fields[1]. While the ERA40 data product does provide surface precipitation as part of its output, it does not include rainfall observations in its assimilation process, nor does include constraints to maintain a balanced hydrological budget. Despite this limitation, ERA40 provides one of the most advanced global meteorology data sets available for the modern era and as such plays an important role in ongoing climate, modeling and other meteorological studies.

1.2 Objectives

A comparison between TRMM and ERA40 will provide a more detailed look at the strengths and weaknesses of ERA40’s precipitation handling in the tropics and subtropics. With the majority of the surface being ocean, “precipitation over the global tropics can be measured satisfactorily only from space”[3]. With the rainfall and the associated atmospheric diabatic heating focused in the tropics it is important to have as accurate an image of these for this region of the globe as possible. TRMM’s meteorological observations provide uniquely constructed views of the tropical and subtropical rainfall and diabatic heating, which combined with the now approaching ten year lifespan of the satellite allow for some of the most reliable remotely sensed observations currently available. These observations can be used as both a comparative check against the ERA40 reanalysis results, as well as a complimentary data set to augment ERA40’s strengths in pressure structure derived fields such as winds.

Relationships between precipitation differences and other fields will be used as aids to hypothesize the reasons behind the differences between the data sets. Precipitation differences conditioned on precipitable water may be used to provide some insight in to how realistically ERA40 is using the water it has available. Other conditioning variables will be added in the future.

2 Required data sets

2.1 TRMM

There are three primary instruments on the TRMM satellite platform[3]:
1. TRMM Precipitation Radar (PR) is a rain profiling radar with a frequency of 13.8GHz. This instrument provides rainfall measurements from approximately 37°N to 37°S. The active sensing nature of the PR allows for sampling at several height levels within the atmosphere, providing a view of the three-dimensional rainfall structure within its field of view. With a wavelength of 2.2cm, PR’s signal is able to effectively penetrate heavily precipitating systems which occur often in the deep tropics.

2. TRMM Microwave Imager (TMI) is a nine channel passive microwave radiometer. TMI provides passive rainfall measurements, as well as some measure of inferred vertical structure.

3. Visible and Infrared Radiometer System (VIRS) is a visible and infrared passive radiometer. VIRS provides cloud-top temperatures as well as contextual cloud top structure.

Both TMI and PR have their own range of available data products, while VIRS is used primarily as a calibration aid in combined precipitation data products. VIRS also provides a base for comparison with geostationary visible and infrared satellite instruments.

The TRMM satellite flies with a 35° inclined orbit, causing it to precess during its orbits, seeing the same geographic location at different local times during each orbit. Over time this provides a diurnal view of the precipitation patterns for a given location.

Each of the TRMM data products mentioned here, as well as several others, along with their associated documentation are available from the NASA Goddard Space Flight Center Data and Information Service Center http://daac.gsfc.nasa.gov/precipitation/TRMM_README/.

2.1.1 3B42
TRMM 3B42 is not used directly in this project. However, it serves as the base for the main TRMM data set used here: 3B43. TRMM 3B42 provides 3-hourly combined PR, TMI, VIRS and geostationary visible and infrared satellite combined best-estimate gridded total rainfall product[2].

2.1.2 3B43
The TRMM 3B43 data set is a monthly mean version of the TRMM 3B42 data set, with additional rain gauge station data used for verification and adjustment of rainfall biases[2]. Coverage runs from 50°S to 50°N and from 180°W to 180°E with a 0.25° x 0.25° grid spacing. Total surface rainfall values are provided for each grid box in units of mm/hour. Data are available from January 1998 through the present.

2.2 ERA40
The University of Maryland Department of Atmospheric and Oceanic Science in-house copy of the ERA40 data set provides a monthly time scale, with global coverage on a 2.5° x 2.5° grid and 23 vertical pressure levels ranging from 1000hPa to 1hPa.

2.2.1 Surface rainfall
Surface rainfall values are provided for each grid box, separated in to convective and stratiform components, in units of meters per 6 hours.

2.2.2 Precipitable water, from specific humidity
Specific humidity values are provided for each grid box at each of the 23 pressure levels in units of kg/kg. Precipitable water is found from a vertical integral of the specific humidity from the surface pressure to 250mb and is in units of mm.

2.2.3 Diagnosed diabatic heating
Diabatic heating values are provided for each grid box at each of the 23 pressure levels in units of K/sec. These data are not yet utilized in this analysis.
3 Methodology

TRMM data are regridded to ERA40 spatial resolution in order to ease comparison between the two data sets. Units for individual fields are selected based on convention and the units used in TRMM’s data products, and are as follows:

- Surface rainrate: mm/day
- Precipitable water: mm
- Diabatic heating: K/hour

3.1 Regridding

TRMM data are regridded to match the ERA40 2.5° x 2.5° resolution using a simple area average. Each TRMM grid value within a given 2.5° x 2.5° grid box is summed, then this sum is divided by the number of TRMM grid boxes within the ERA40 grid box to get the area average. No latitude-based weighting is used for the results presented here.

3.2 Difference maps

The difference maps shown in figures 1 and 4 are a simple point-by-point difference.

4 Results

4.1 TRMM vs ERA40

ERA40’s combined surface rainfall values (convective plus stratiform) tend to reconstruct general rainfall patterns on a global scale which are comparable to observations. However, the strength, location and spatial extent of several large scale features, such as the ITCZ, are notably different between the two data sets.

4.1.1 Total rain rate, January climatology

For the January climatology difference, shown in figure 1, ERA40 shows larger rainrates throughout the equatorial Pacific. Corresponding TRMM and ERA40 precipitation maps can been seen in figures 2 and 3 respectively. The ERA40 ITCZ off of the South American coast out in to the eastern Pacific is both wider in extent to the north and south with respect to TRMM as well as having much larger peak rainrate values. ERA40 shows rainrates more than 11 mm/hour greater than reported by TRMM’s 3B43 data product on the South American equatorial coast and in several areas a few degrees south of the equator out in to the Pacific. The differences are larger in the western Pacific where throughout the region from 30°S to the equator and 120°E to 130°W the ERA40 rainrate values are 3 mm/day to over than 11 mm/day larger than those shown by TRMM. A similar pattern exists over the equatorial Atlantic, with tropical precipitation which is too strong and widely spread latitudinally when compared with TRMM.

Differences over land are overall smaller in magnitude and vary between which data set shows the greater precipitation values. The Gulf Coast states in the US show 2 to 4 mm/day more rainfall in TRMM’s view, while the west and east coasts of the US show approximately 2 mm/day difference, with ERA40 precipitating more in the west and TRMM in the east. ERA40 shows more rainfall than TRMM in the US’s Pacific Northwest by 2 to 3 mm/hour, but comparisons at this latitude may be somewhat less reliable than at lower latitudes due to TRMM’s latitudinally limited view.

In South America, Brazil and portions of Peru have one of the largest TRMM land rainrate surpluses in both magnitude and extent. TRMM ranges from 2-4 mm/hour greater than ERA40 throughout the center of the South American continent in this area, likely indicating an underrepresentation of the convective processes in this region. A notable distinction here is that while ERA40’s tropical ocean rain rate maxima tend to fall in similar locations to ERA40’s precipitable water maxima (see figure 7 for a map of the ERA40 precipitable water), this same relation does not hold over land. There is a precipitable water maximum in this South American region which is similar is spatial coverage to the Brazil and Peru TRMM rainrate surplus.
4.1.2 Total rain rate, July climatology

The July climatology difference map is shown in figure 4. The picture here is notably different than that of the January climatology. ERA40’s tropical precipitation signal is shifted too far to the north throughout almost the entire western hemisphere, resulting in a north-south ERA40-TRMM dipole effect. The precipitation difference magnitudes are larger overall in this region than they were in the January climatology due to there being a difference in location of the rain maxima in addition to the differences in strength and extent seen in January. The west Pacific again shows large relative ERA40 precipitation values, with the focus now shifted in to the northern hemisphere following summer.

Land rainrate differences also shift to follow the change in seasonal rain patterns. The western hemisphere land masses show generally smaller differences than those seen in the January climatology, though TRMM does show more rainfall than ERA40 in the central US by 2 to 3mm/day. In the eastern hemisphere the differences are now large with the onset of the monsoon. TRMM shows a 3 to 9mm/day higher rainrate than ERA40 throughout most of India and China below 30°N, with the exception of a strip of 4 to 7 mm/hour higher rainrate in ERA40 over TRMM in a band around 100°E, running up to the Tibetan Plateau where ERA40’s rainrate exceeds TRMM’s by between 4 and greater than 11mm/hour.

4.1.3 (TRMM - ERA40) total rainrate histogram

Each of the histograms shown in figures 9 and 10 show histograms representing the distribution of TRMM - ERA40 surface rain rate across the 50°S to 50°N latitude belt for January and July climatologies, respectively. Each count represents one grid box which falls within a given histogram bin.

Figure 9 shows a histogram illustrating the distribution of (TRMM - ERA40) precipitation differences. There is a clear logarithmic curve to either side of the 0-difference bin peak. The ERA40 tail of the distribution - the negative side - has a longer and larger in magnitude tail than the TRMM tail on the positive side of the histogram. This gives the distribution a skew of -3.43 and a mean value of -0.993. The distribution comes to a sharp point at the 0-bin, with a kurtosis of 25.8. The result is that, for this 50°S to 50°N band, ERA40 produces more surface rainfall than TRMM observes.

The July (TRMM - ERA40) histogram shown in figure 10 is similar to the January case, but July shows a significantly less distinct form on the ERA40 end of the curve than seen in the January curve. The TRMM tail of the distribution, to the positive side, has a similar shape to the January histogram TRMM tail, with a similarly clear logarithmic curve. The ERA40 end of the curve has a less distinct shape than in the January climatology. This follows the picture shown in the July climatology map (figure 4), with more offset in the locations of rainfall patterns in July rather than the larger magnitudes but similar spatial distribution of rainfall seen in the January map. The July distribution has a skew of -2.39 and a mean of -1.05. The less distinct shape of the distribution histogram leads to a kurtosis of 12.3, much lower than the January distribution.

4.1.4 (TRMM - ERA40) rainrate distribution conditioned on precipitable water

Figure 11 shows the distribution of January climatology (TRMM - ERA40) surface rain rate differences conditioned on ERA40’s January climatology of precipitable water (figure 7). The rain rate differences, which correspond to grid points with the precipitable water values between 15mm and 35mm, are clustered close to zero, generally ranging between 1 and -1 mm/hour. For precipitable water values below 15mm, ERA40 tends to have rain rate values which are larger by between 1 and 2 mm/hour. Both TRMM rain rates and ERA40 rain rates individually (figures 12 and 13) conditioned on ERA40 precipitable water show a bulge in this region. The reason for this is unknown, but may be due to some modeling artifact in the ERA40 production process. External validation from NVAP or other observed precipitable water data sets will be neede for further clarification of what this feature may be.

A more striking feature of figure 11 is the growth in differences for precipitable water values greater than 35mm. Overall, ERA40 grows more quickly with rising precipitable water values in this range. These large precipitable water values all fall in the tropics, where ERA40 tends to rain more than TRMM, so this fits well with the January climatology map (figure 1).

References


Figure 1: TRMM - ERA40 total surface rainfall difference for 1998 through 2001 January climatology
Figure 2: TRMM total surface rainfall for 1998 through 2001 January climatology
Figure 3: ERA40 total surface rainfall for 1998 through 2001 January climatology
Figure 4: TRMM - ERA40 total surface rainfall difference for 1998 through 2001 July climatology
Figure 5: TRMM total surface rainfall for 1998 through 2001 July climatology
Figure 6: ERA40 total surface rainfall for 1998 through 2001 July climatology
Figure 7: ERA40 precipitable water for 1998 through 2001 January climatology
Figure 8: ERA40 precipitable water for 1998 through 2001 July climatology
Figure 9: TRMM - ERA40 surface rain rate distribution histogram for 1998 through 2001 January climatology
Figure 10: TRMM - ERA40 surface rain rate distribution histogram for 1998 through 2001 July climatology
Figure 11: TRMM - ERA40 surface rain rate distribution conditioned on ERA40 precipitable water, January climatology
Figure 12: TRMM surface rain rate distribution conditioned on ERA40 precipitable water, January climatology
Figure 13: ERA40 surface rain rate distribution conditioned on ERA40 precipitable water, January climatology