

The TRMM Precipitation Radar's View of Shallow, Isolated Rain

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ABSTRACT

The Tropical Rainfall Measuring Mission (TRMM) 2A23 convective–stratiform separation algorithm applied to the TRMM satellite's precipitation radar identifies shallow, isolated precipitation over much of the tropical oceans. The shallow, isolated rain elements dominate the outer fringes of the tropical rain area but give way to deeper, more organized convective systems and associated stratiform areas toward heavy-rain regions. The majority of the shallow, isolated radar echoes are classified as stratiform by version 5 of the 2A23 algorithm. Because the shallow, isolated echoes probably represent warm rain processes, they should be classified as convective. This reclassification leads to a more reasonable pattern of stratiform rain contribution across the Tropics.

1. Introduction

The Tropical Rainfall Measuring Mission (TRMM) satellite produces a set of precipitation products, which includes a subdivision of the rain detected by the TRMM precipitation radar (PR) into convective and stratiform components. An algorithm designed by Awaka et al. (1997) is routinely applied to the TRMM radar data to make this subdivision (i.e., TRMM product 2A23¹). The algorithm designates each pixel of radar echo as convective, stratiform, or other based on the horizontal and vertical echo structure. After assigning a pixel of radar data to one of these three categories, the radar echo can be further identified as shallow and isolated. We have found that version 5 of the 2A23 algorithm apparently misclassifies much of the shallow, isolated echo as stratiform when it should be convective and that this misclassification leads to potential errors in the PR convective–stratiform statistics. In this note, we will examine the mapping of the shallow, isolated radar echo category over the whole Tropics and infer from this mapping a meaningful view of the overall ensemble of precipitating convection in the Tropics.

¹ The TRMM 2A23 algorithm has been further described online at <http://tsdis02.nascom.nasa.gov/>.

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2. Definitions

There are two main classifications of tropical precipitation: *convective* and *stratiform*. These classifications are based on the microphysical growth processes of precipitation particles and on the vertical distribution of latent heating associated with precipitation processes (Houze 1997). The convective classification refers to regions where precipitation is falling from young, active convection (i.e., regions of strong, nonhydrostatic vertical motions). Numerous updrafts on the order of meters per second refresh the cloud liquid water content such that the droplets and ice particles growing in these regions increase in mass through collection processes, namely, coalescence and/or riming. The stratiform classification refers to regions of older, less active convection, where weaker vertical air motions predominate and precipitation particles increase in mass primarily through vapor deposition. By this definition, the stratiform region must contain ice. Airborne Doppler radar data show that convective and stratiform regions of tropical precipitation areas have distinct dynamical structures, such that the convective regions distribute heating throughout the depth of the troposphere and stratiform regions heat the upper troposphere and cool the lower troposphere (Houze 1982, 1989, 1997).

According to the *Glossary of Meteorology* (Glickman 2000), *warm rain* is “rain formed from a cloud having temperatures at all levels above 0°C, and resulting from the droplet coalescence process.” For rain to fall from a cloud with a top below the 0°C level, the amount of

collision-coalescence required would need to occur in a convective cloud (Houze 1993, chapter 6). Stratus or stratocumulus would be insufficient for any precipitation other than drizzle. The glossary distinguishes warm rain from the *warm rain process*, which is defined as “growth by collision-coalescence and limitations to growth by drop breakup.” Moreover, the warm rain process “occurs in clouds having sufficient liquid water, updraft, and lifetime to sustain collision-coalescence” and “is found to be active in both shallow and deep convection.” Thus, warm rain is produced by the warm rain process, but the process may occur in deeper convective clouds. From these definitions, it follows that the warm rain process is likely associated with convective clouds. Stratiform precipitation, as described above, occurs in the deep ice-cloud regions of previously more active convective cloud. The warm rain process does not occur in such cloud regions.

3. The TRMM PR convective-stratiform separation algorithm

The TRMM PR rain-type classifications (TRMM product 2A23) are made by merging convective-stratiform separation methods based on vertical structure (brightband identification, echo-top height, and maximum reflectivity in the vertical profile; Awaka et al. 1997) and on horizontal variability of the echo (peakedness and local echo intensity; Steiner et al. 1995). The PR algorithm classifies the PR echoes into three categories: convective, stratiform, and other. The three categories are subdivided according to level of certainty based on the agreement between the horizontal and vertical methods. There are 6 stratiform subcategories, 10 convective subcategories, and 2 other subcategories (Table 1). The category labeled “other” is assigned when there is no bright band detected, the convective reflectivity threshold is not met, and any of the observations below the 0°C level are noise. Thus, the “other” category represents either noise or regions of precipitation aloft with no precipitation near the surface. Because of the ambiguity of the “other” category and its very small contribution to total rain (<0.2% when using a 17-dBZ threshold, the sensitivity limit of the PR), it is not discussed further.

The last stratiform subcategory (rain-type 15) and the last four convective subcategories (rain-types 26–29) have an additional designation of shallow and isolated. A pixel is designated as shallow and isolated when the echo top is lower than the climatological 0°C level by at least 1.5 km and the rain pixel is separate from other rain-certain areas. We suggest that the stratiform shallow, isolated subcategory (rain-type 15) is likely warm rain and, as such, should be considered to be a convective subcategory based on the physical arguments above. In section 4 we will see that the spatial pattern of rain-type-15 echoes across the Tropics is consistent

with these echoes being convective rather than stratiform.

The misclassification of rain-type-15 echoes is likely a combination of the PR’s sensitivity and horizontal resolution. The PR algorithm is based partially on the horizontal-texture method of Steiner et al. (1995), which assumes a pixel of radar echo is convective only if it exceeds a specified high intensity or it stands out against the background echo intensity. Convective cells are normally on the order of 1–2 km in horizontal dimension, such that they would appear less intense when observed with the PR’s 4-km footprint,² making an isolated convective cell observed by the PR less likely to meet the specified high-intensity criteria. In addition, the Steiner et al. (1995) technique assumes that if there are no surrounding “background” pixels with detectable echo, the pixel is not convective because the echo fails the peakedness criteria. The sensitivity of the PR (~17 dBZ) most likely causes the PR algorithm to alias weak, isolated convection into the stratiform category because pixels with substantial rain rates are often left without a background with which to compare their intensities. The horizontal method of Steiner et al. (1995) was based on the assumed availability of ground radar data with higher horizontal resolution and a full range of sensitivity to weak rain (~0–5 dBZ). It remains an issue to be able to tune the algorithm to classify echo unambiguously as convective at lower reflectivities and lower horizontal resolution.

Data from the Kwajalein Atoll (~9°N, 168°E) ground radar [see Schumacher and Houze (2000) for details on the Kwajalein radar dataset] were used to assess the performance of the convective-stratiform algorithm when reflectivity <17 dBZ is excluded and when the Kwajalein radar data are interpolated to varying resolutions. Kwajalein is in the eastern edge of the west Pacific warm pool and receives moderate amounts of rain-type 15 (Fig. 1d). Two versions of the convective-stratiform algorithm were applied to the entire month of ground radar data for December of 1999. The first version uses all of the echo observed by the Kwajalein radar, and the second version uses only echo >17 dBZ. Approximately 7% fewer pixels were classified as convective cores and 2% fewer pixels were classified as convective when the 17-dBZ threshold was applied. These decreases led to a 1% increase in the percent of total rain that was stratiform. These results do not change when data were interpolated to 2 km × 2 km or 4 km × 4 km horizontal resolution. When the Kwajalein radar data are interpolated to 4 km × 4 km horizontal resolution instead of 2 km × 2 km, the stratiform rain fraction increases by approximately 10%. Note that the convective-stratiform separation algorithm was not specifically tuned for the 4 km × 4 km resolution. These tests are only an indirect measure of the effect that lower

² The PR’s horizontal resolution became ~5 km after the increase in operating altitude in August of 2001, exacerbating this problem.

TABLE 1. TRMM version-5 2A23 rain-type classifications. Here, V and H are vertical and horizontal methods, respectively; sf is stratiform; conv is convective; and BB is bright band.

2A23	Stratiform	2A23	Convective	2A23	Other
10	V = sf (BB exists) H = sf	20	V = conv (no BB) H = conv	30	V = other H = other
11	V = sf (BB exists) H = other	21	V = other H = conv	31*	V = other H = other
12	V = other (BB possible) H = sf	22	V = conv H = other		
13	V = sf (BB exists) H = conv	23	V = conv (BB exists) H = conv		
14	V = other (no BB) H = sf	24	V = conv H = sf		
15*	V = other H = sf	25	V = sf (BB possible) H = conv		
		26*	V = conv H = conv		
		27*	V = conv H = other		
		28*	V = other H = conv		
		29*	V = conv H = sf		

* Shallow, isolated designation.

sensitivity and lower horizontal resolution would have on classifying shallow, isolated echo, but they are consistent with the physical reasoning made in the previous paragraph and highlight possible areas of improvement for the TRMM 2A23 algorithm.

4. Alternative treatment of the stratiform shallow, isolated rain subcategory

For each $2.5^\circ \times 2.5^\circ$ grid element in the TRMM PR domain, a histogram was compiled that shows the number of pixels containing each convective and stratiform subcategory listed in Table 1 for 1998–2000. The histograms were created from the version-5 TRMM product 2A23. Only pixels with near-surface reflectivities ≥ 17 dBZ were included in the histograms. From these histograms, convective and stratiform maps of the annually averaged pixel count were constructed with the shallow, isolated subcategories excluded (Figs. 1b and 1c). The convective and stratiform subcategories of shallow, isolated pixel counts were combined to obtain Fig. 1d. The PR annually averaged rain for the 3-yr period is shown for reference in Fig. 1a.

These maps show how the population of precipitating clouds varies over the Tropics. Figures 1b and 1c show that the stratiform and convective patterns are qualitatively similar to each other throughout the Tropics. Both patterns resemble the tropical rainfall pattern in Fig. 1a; regions of maximum stratiform and convective pixel counts occur in regions of high rain accumulation. These similarities are consistent with the greatest rain accumulations being produced by mesoscale systems that contain both deep convection and stratiform precipitation. The shallow, isolated pattern (Fig. 1d) is very different from the stratiform and convective patterns, with

maximum pixel counts over ocean regions where the rain accumulation is low. This category gives an illuminating indication of where the precipitating cloud population consists mainly of shallow convective clouds (probably cumulus congestus and isolated cumulonimbus). A comparison of Figs. 1b–d shows how the regime of primarily shallow precipitating convective clouds populating the outer edges of the tropical rain region gives way to deeper convection toward the center of the tropical rain region. A comparison of Figs. 1b and 1c shows further that stratiform precipitation is intimately connected to the deeper convection.

Additional evidence in support of the reclassification of the shallow, isolated echo as convective can be found in the 38-yr low-cloud climatological classification based on synoptic surface observations presented by Norris (1998). The shallow, isolated echo population represented in Fig. 1d is very similar to the cumulus cloud populations depicted by Norris, whereas there is very little similarity to the bad-weather stratus (or nimbostratus) population. In addition, the reclassification addresses the occurrence of anomalously low stratiform echo heights that Short and Nakamura (2000) found in their study of TRMM-observed shallow precipitation.

Figure 2a shows the average stratiform rain fraction (i.e., the percent of total rainfall accounted for by stratiform precipitation) for 1998–2000, based on version-5 TRMM 2A23 convective–stratiform classification. The rain fraction is obtained by using the TRMM 2A25 near-surface reflectivities and converting them to rain using the TRMM PR's version-5 initial convective and stratiform Z–R relations (Iguchi et al. 2000). Figure 2a indicates high (>60%) stratiform rain fractions in regions of low rain accumulation over northern Africa,

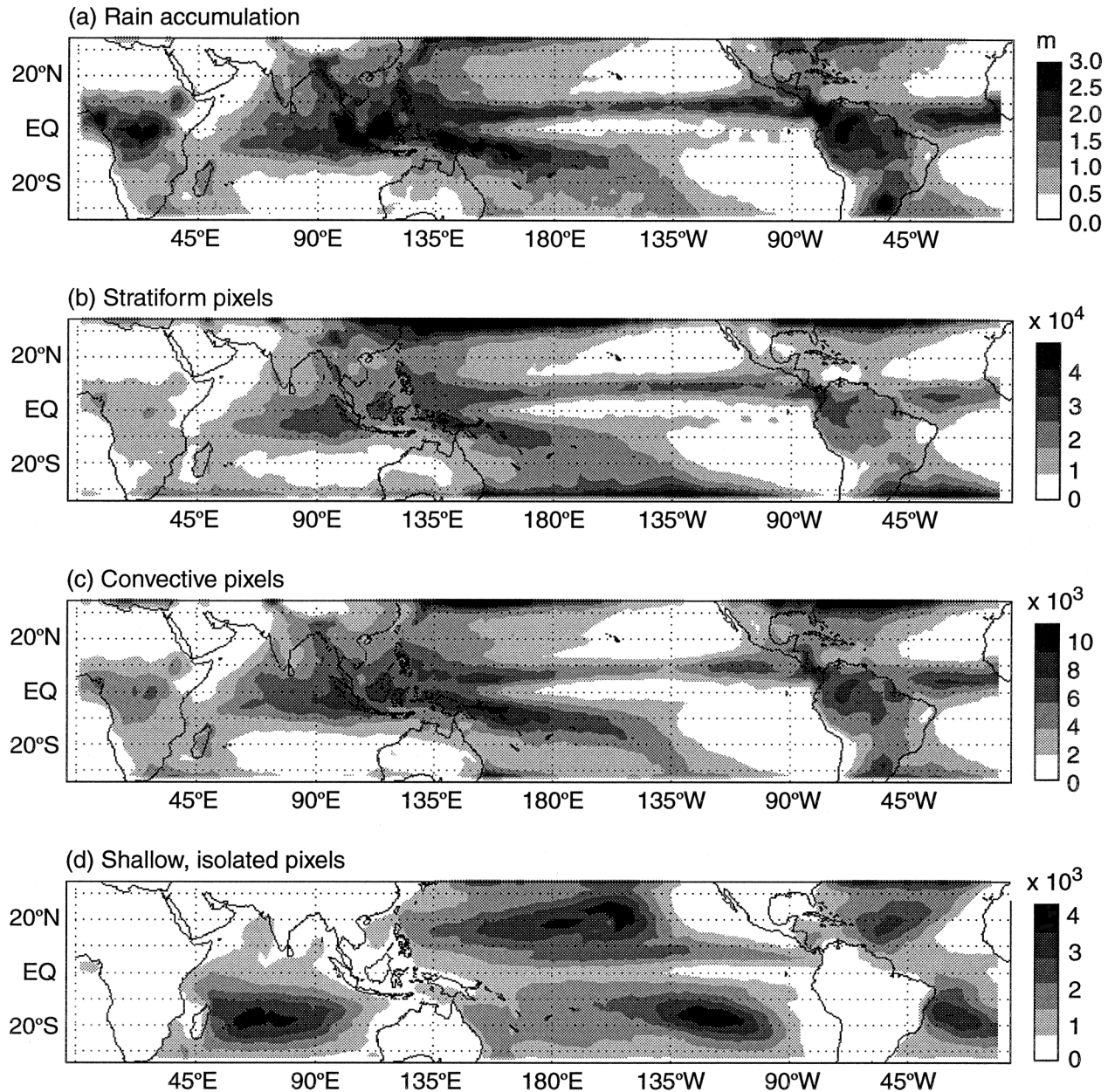


FIG. 1 TRMM version-5 PR 2.5° observations from 1998 to 2000 for annually averaged (a) rain, (b) stratiform pixel count (rain-types 10–14), (c) convective pixel count (rain-types 20–25), and (d) shallow, isolated pixel count (rain-types 15, 26–29).

the southeast Indian Ocean, the equatorial central Pacific, the northeast Pacific off of the coast of Baja, the southeast Pacific off of the coast of South America, and the South Atlantic. This pattern is strange, because we would not expect high stratiform rain fractions outside the main precipitation zones but rather in the centers of the rainy areas, where deep convection and mesoscale convective systems thrive. Also notable is the tendency for high stratiform rain fractions along the northern and southern edges of the TRMM orbital domain (25–35°N and 25°–35°S). These regions are also low in rainfall accumulation, but the high stratiform rain fractions

might be real because midlatitude baroclinic systems occasionally intrude into these latitudes.

Figure 2b is the same as Fig. 2a except that it has been modified by placing the shallow, isolated stratiform subcategory (rain-type 15) in the convective classification. The maxima over the low rain accumulation regions of the tropical oceans have all been reduced substantially (although very high stratiform rain fractions remain over northern Africa and the northeast Pacific, most likely artifacts of the very low rain accumulation in those regions). Thus, the gradient of stratiform rain fraction has been reversed in these areas and appears to

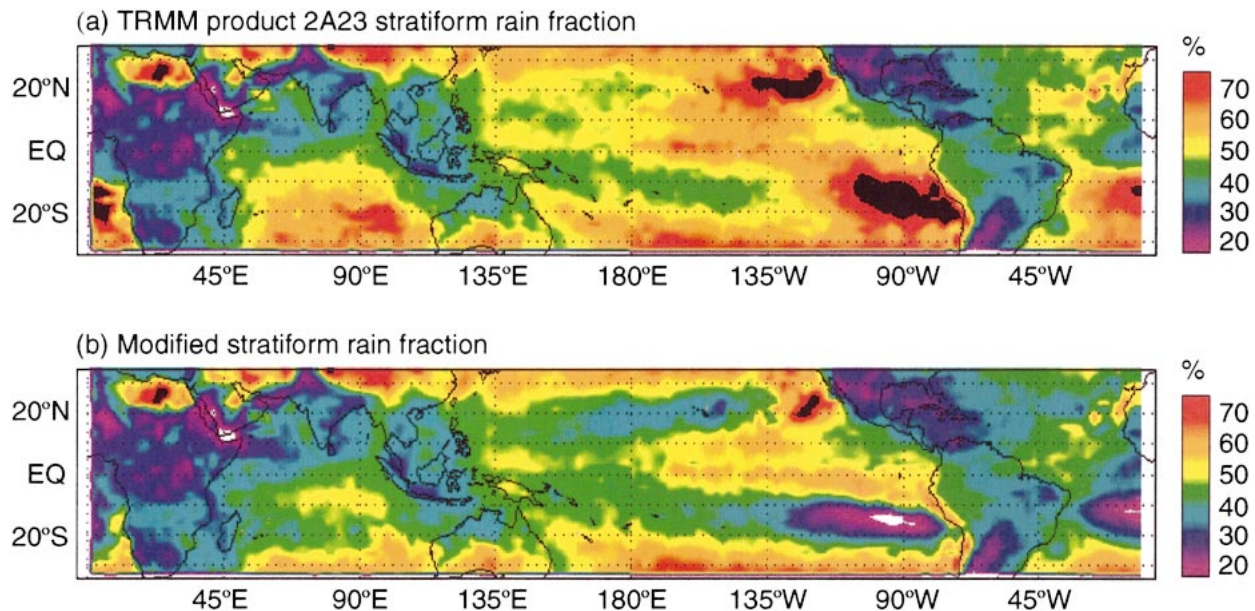


FIG. 2. TRMM PR 2.5° average stratiform rain fraction from 1998 to 2000, based on (a) TRMM version-5 2A23 stratiform (rain-types 10–15) and convective (rain-types 20–29) classifications and (b) TRMM version-5 2A23 convective–stratiform classifications with the stratiform shallow, isolated pixels (rain-type 15) considered as convective. The color bar represents stratiform rain fractions between 15% and 75%, black indicates values of $> 75\%$, and white indicates values of $< 15\%$.

be more reasonable because we do not expect large mesoscale convective systems in these areas peripheral to the main precipitation zones of the Tropics. The ITCZ has more moderate stratiform rain fractions and is more clearly delineated from regions outside of the ITCZ. The double ITCZ structure in the central-to-eastern Pacific is more sharply defined. The oceanic stratiform rain fractions poleward of 20°N and 20°S remain high but have become distinct from precipitation regions closer to the equator. This separation by latitude is reasonable because the belts of high stratiform fraction poleward of 20°N and 20°S appear to be caused by extratropical frontal systems, which are probably more stratiform, as indicated, even though the validity of the convective–stratiform separation algorithm (tuned for tropical convection) is questionable at these latitudes.

The comparison of Figs. 2a and 2b shows that although the shallow, isolated precipitation does not contribute much to overall rain accumulation, it can substantially affect the pattern of the relative contributions of convective and stratiform rain throughout the Tropics. For reasons noted in section 2, the proportion of rain that is stratiform is a direct indicator of how the vertical profile of heating varies over the Tropics. An error in this stratiform proportion leads to an error in the pattern of the vertical profile of heating over the Tropics. An incorrect convective–stratiform classification can also lead to errors in other convective–stratiform rain-based statistics (e.g., storm-height distributions and rain-rate intensities).

5. Conclusions

When the shallow, isolated radar echoes are extracted from the TRMM PR version-5 2A23 algorithm output and mapped separately, the pattern formed by this category of precipitation gives a meaningful view of the ensemble of precipitating clouds across the Tropics. Shallow, isolated rain elements dominate the outer fringes of the tropical rain area but give way to deeper, more organized convective systems and associated stratiform areas toward the heavy-rain regions of the near-equatorial Tropics. The shallow, isolated echoes seen by the TRMM PR probably represent warm rain processes and, as such, should therefore be classified as convective. Making this change in the version-5 TRMM 2A23 algorithm leads to a more reasonable pattern of stratiform rain contribution across the Tropics and hence to a more latent reasonable heating pattern and more accurate statistics for convective and stratiform precipitation. Version 6 of the algorithm will reflect this reclassification (J. Awaka 2002, personal communication).

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