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# SHALLOW RAIN FROM THE TRMM PR: A FIVE-YEAR CLIMATOLOGY

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## 1. INTRODUCTION

The Precipitation Radar (PR) aboard the Tropical Rainfall Measuring Mission (TRMM) Observatory is the first space-borne radar designed for observing precipitation (Kozu et al. 2001), with an emphasis on moderate-to-heavy rain from deep convective systems over tropical land and ocean. Short and Nakamura (2000, hereafter SN) noted that light, shallow rain observed by the PR occurred predominantly over the oceans. They estimated that rain from shallow systems comprised about 20% of oceanic rainfall. The purpose of the present study is to examine the PR performance at the lower limit of its design specifications and to use statistical methods to estimate the amount of light rainfall from shallow precipitating clouds that may have been missed due to those limitations. Because PR algorithms continue to be refined in preparation for the next reprocessing cycle (version 6) this paper also anticipates some important algorithm changes that are expected to significantly increase the rainfall attributed to shallow clouds.

The diurnal cycle of rainfall in regions dominated by shallow radar echoes will also be documented along with rainfall corrections attributable to PR limitations.

## 2. PR CHARACTERISTICS AND LIMITATIONS

The PR has a range resolution of 250 m, a field-of-view (FOV) of 4.3 km and a minimum detectable reflectivity of about 17 dBZ, giving it sufficient sensitivity and resolution to detect rainfall rates as low as ~0.4 mm/hr. The PR beam is scanned electronically from nadir to +/- 17°, making a swath width of about 220 km with 49 FOVs.

The 17 dBZ sensitivity is sufficient to detect more than 98% of total tropical rainfall. However, the regional percentages can be substantially greater in areas where instantaneous rainfall intensities are in the light to very light categories. Examples are the marine stratocumulus and trade wind cumulus regimes over the oceans.

At the outer edges of the PR swath, the radar scattering volume becomes significantly tilted with respect to the earth's surface and one edge of the main lobe is scattered by the surface. This produces severe contamination for the range bins closest to the surface. The contamination is eliminated by filtering procedures at the expense of missing shallow rain echoes near the edges of the swath. Figure 1 illustrates the under-sampling of shallow "storms," adopting the terminology in TRMM PR Product 3A25 version 5, by comparing storm height distributions from the near-nadir FOVs (dashed line +) to the storm height distribution from the full swath (solid line x).

Fig. 1 also shows that shallow storms, defined here as echoes with radar tops < 3 km, are predominantly classified as stratiform. Schumacher and Houze (2003) have shown that a re-classification of shallow, isolated echoes as convective leads to a more reasonable pattern of stratiform rain contribution across the tropics.

Five years of TRMM PR data for the years 1998 to 2002 has been examined to determine a five-year climatology of shallow rain. The method of Short and Nakamura (2000) has been extended to include correction procedures for the following:

- Under-sampling of shallow storms
- Re-classification of shallow storms from stratiform to convective
- Very light rain missed by the 17 dBZ cutoff
- Missing "warm" rain in product 3A25

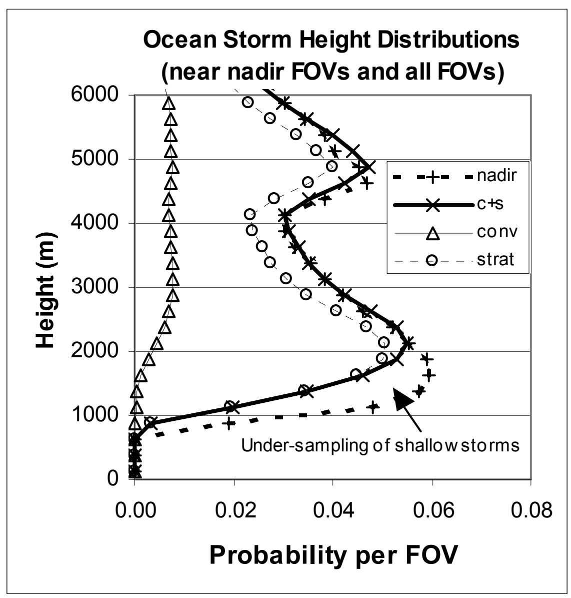


**Figure 1.** Storm height distributions over the oceans from product 2A25, Version 5. The near nadir distribution was derived from the inner 7 FOVs, nadir +/- 3. An under-sampling of shallow storms below 2000 m is clearly evident. The under-sampling is due to geometric effects associated with the PR scan pattern.

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## 3. CORRECTIONS TO SHALLOW RAINFALL

Corrections to shallow rainfall have been implemented by a combination of one or more of the following 4 methods: 1) A parameterization of rainfall rate in terms of storm height, developed by Short and Nakamura (2000) and refined here; 2) Adjustment of the Z-R relation used for shallow stratiform rain based on the 2A25 product; 3) Modeling of PR rainfall rate histograms with the lognormal distribution to estimate the amount of rain below the 17 dBZ sensitivity threshold, and 4) Use of a conditional mean rainfall rate for missing “warm” rain.

### *3.1 Under-sampling of shallow storms*

Annually averaged storm height histograms, similar to Fig. 1 were computed from product 3A25 for each 5°x5° latitude/longitude cell from 40N to 40S. The number of rainy pixels in each cell was increased by applying gain factors for each height bin below 3 km. The gain factors were derived from an analysis of 2A25 orbit-by-orbit data (see also Fig. 1). A rainfall rate was then assigned to the added pixels, based on a height-rainfall rate parameterization, updated from SN.

The parameterization is:

$R_c$ = 0.16 (mm/hr)*(H – 7.3), where H is in hundreds of meters.

Fig. 2 shows the geographic pattern of rainfall added by the correction for under-sampling. A local maximum >50 mm/year occurs southeast of Hawaii near the mean position of the eastern Pacific ITCZ. This region has been the focus of previous investigations aimed at understanding discrepancies between estimates of rainfall based on satellite and surface based observations (Janowiak et al. 1995). The PR under-sampling correction indicates a relatively high concentration of shallow echoes, compared to most other regions. This result is consistent with the Janowiak et al. (1995) interpretation of discrepancies between rainfall climatologies. Another maximum of similar magnitude lies east of Japan. A maximum of 40 mm/yr occurs over the southern Indian Ocean.

The average value of the under-sampling correction over the oceans is 21.1 mm/yr. The correction is typically less than 5 mm/yr over the continents. A notable exception is southeastern China, where it is greater than 10 mm/year.

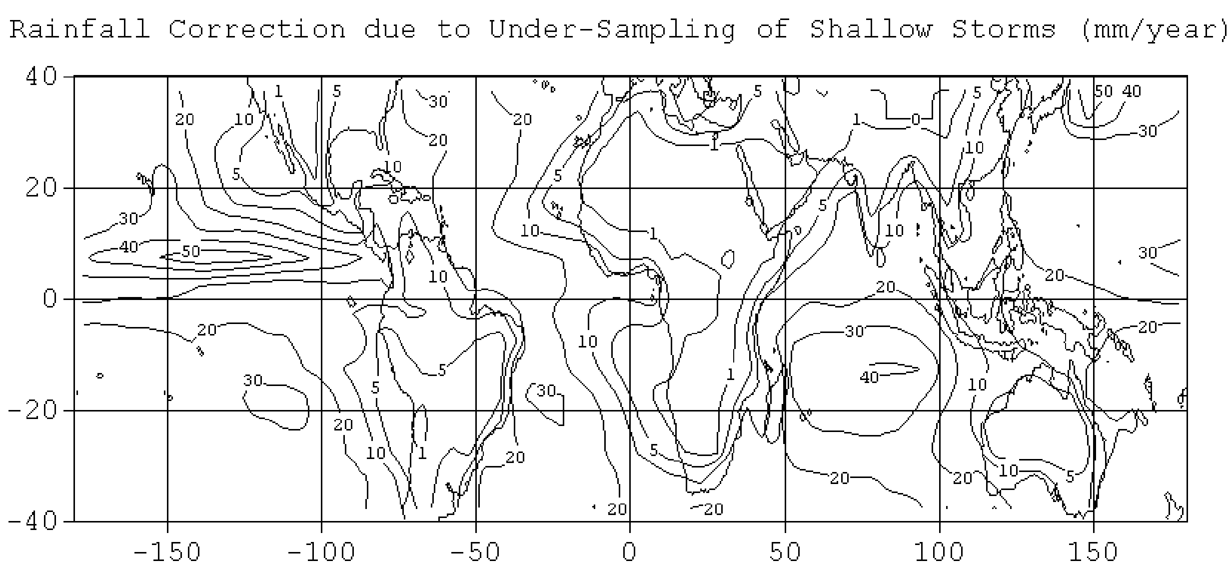


**Figure 2.** Estimated rainfall (mm/year) attributed to the under-sampling of shallow storms.

### *3.2 Re-classification of shallow storms*

SN noted that the predominant TRMM PR classification of shallow echoes was stratiform in regions where rainfall was known to be primarily from trade-wind cumulus and marine stratocumulus. Schumacher and Houze (2003) thoroughly examined this problem and found that a re-classification of shallow isolated echoes as convective would result in more reasonable patterns of stratiform rainfall contributions across the tropics. It is expected that the version 6 reprocessing will incorporate the Schumacher/Houze recommendation.

The impact of this re-classification was estimated by the following procedures: A 5-day sample of 2A25 and 2A23 orbit-by-orbit data was examined to determine the Z-R relationship applied to shallow stratiform and convective echoes. The ratio of retrieved rainfall rates was 1.38 at the same reflectivity, with the convective rate being higher.

The TRMM PR data was used to develop a parameterization of rainfall rate as a function of echo top height for stratiform echoes. For each 5°x5° cell the storm height histogram was used to determine the fraction of pixels classified as stratiform for each height below 3 km. They were re-classified as convective and their rainfall rate was increased by a factor of 1.38. Figure 3 shows the geographic pattern of the rainfall correction due to re-classification of shallow stratiform storms as convective.

As in Fig. 1, the two dominant maxima are over the east Pacific ITCZ and just east of Japan. Some caution should be used in interpreting the magnitude of the correction pole-ward of ~30N and ~30S, because winter precipitation systems in these regions may have freezing levels at or below 3 km, making the stratiform classification reasonable. The average correction over the oceans is 53.1 mm/year. The average correction over the continents is about 10 mm/year. Notable exceptions are over eastern China, eastern USA, northern South America and the southern fringes of Australia.

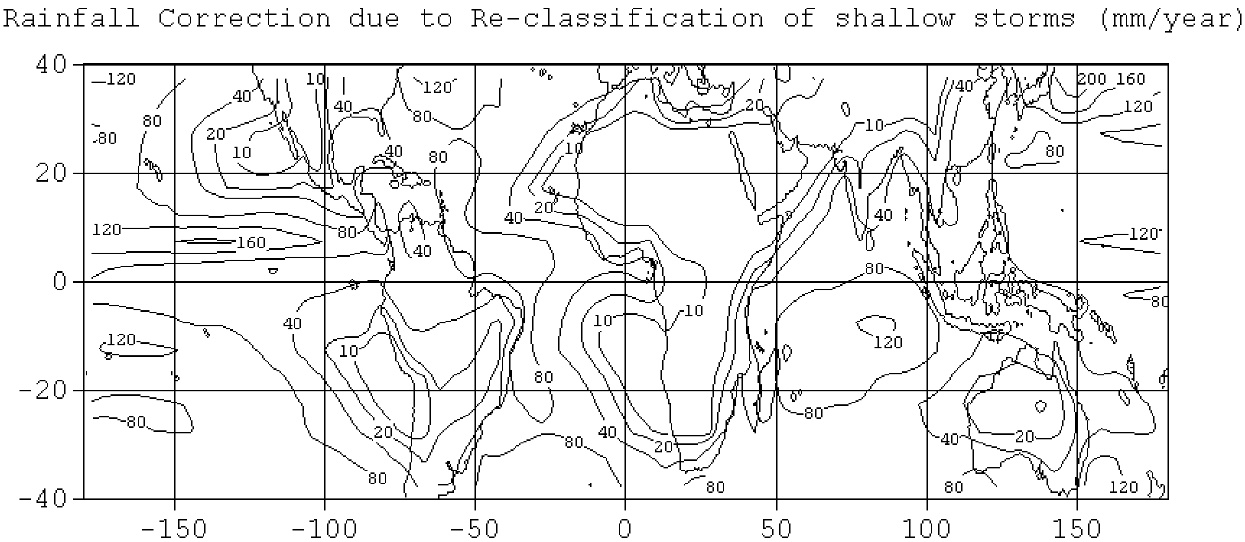


**Figure 3.** Estimated rainfall (mm/yr) attributed to re-classification of all shallow storms to be convective.

### *3.3 Missing very light rain and "warm" rain*

Short (1998) found that with a minimum detectable reflectivity of 18 dBZ the PR would have enough sensitivity to detect approximately 98% of total tropical rainfall. Once on orbit, the PR sensitivity was found to be about 17 dBZ and that level was maintained until the TRMM orbit was boosted to 400 km in August 2001. At the higher altitude the PR sensitivity has decreased by 1.2 dBZ (to about 18.2 dBZ).

To estimate the amount of rainfall being missed by the sensitivity cut-off, near-surface rainfall rate histograms were obtained from the 3A25 product and zonally averaged for ocean cells. A log-normal distribution was fit to the portion of the histogram where rainfall rates exceed 0.49 mm/hr, corresponding to the lower bound of the 5th bin in the PR rainfall rate histograms found in product 3A25. This threshold corresponds approximately with the minimum detectable reflectivity. The fitted distribution was used below that level to estimate the missing very light rain.

Rainfall for the 3A25 special category "warm" has been estimated from a limited analysis of 2A25 and 2A23 data. Approximately 6% of rainfall occurrence was found to be "warm." The 3A25 version 5 product indicates less than a 1% occurrence due to a computer glitch in the data processing (J. Kwiatkowski; personal communication). The conditional mean rainfall rate for the "warm" rain was found to be 1.1 mm/hr.

Table 1 lists zonal averages of rainfall over the oceans directly from the 3A25 product and for the 4 correction procedures outlined above.

Table 1. Zonally averaged annual rainfall (mm) from product 3A25 and corrections for the following:
A) Under-sampling; B) Re-classification;
C) 17 dBZ Sensitivity and D) "Warm" rain

| Latitude | 3A25 | A | B | C | D | Total |
|---|---|---|---|---|---|---|
| 37.5 | 1116 | 25 | 80 | 21 | 29 | 155 |
| 32.5 | 919 | 23 | 62 | 18 | 24 | 127 |
| 27.5 | 692 | 18 | 43 | 14 | 18 | 93 |
| 22.5 | 513 | 17 | 40 | 11 | 14 | 82 |
| 17.5 | 603 | 18 | 43 | 10 | 17 | 88 |
| 12.5 | 906 | 20 | 49 | 11 | 24 | 104 |
| 7.5 | 1682 | 29 | 76 | 16 | 41 | 162 |
| 2.5 | 1156 | 19 | 50 | 11 | 29 | 108 |
| -2.5 | 915 | 16 | 43 | 9 | 24 | 92 |
| -7.5 | 1051 | 21 | 53 | 12 | 26 | 112 |
| -12.5 | 759 | 22 | 52 | 11 | 20 | 105 |
| -17.5 | 536 | 24 | 50 | 11 | 16 | 101 |
| -22.5 | 489 | 22 | 44 | 13 | 15 | 93 |
| -27.5 | 593 | 20 | 44 | 15 | 17 | 97 |
| -32.5 | 733 | 22 | 56 | 19 | 21 | 118 |
| -37.5 | 781 | 21 | 65 | 19 | 22 | 127 |
| Average | 840 | 21 | 53 | 14 | 22 | 110 |

The total correction is 13% of the 3A25 result.

Fig. 4 shows the zonally-averaged annual rainfall after the corrections listed in Table 1 were applied. A break-down for rainfall from shallow and deep echoes is also shown. Rainfall from shallow echoes comprises

34% of total rainfall, a substantial increase from the 20% estimate by SN.

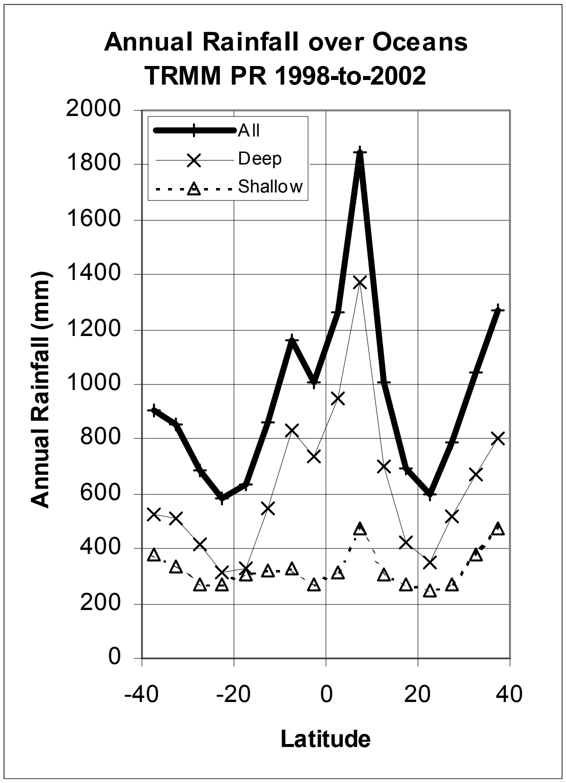


**Figure 4.** Zonally averaged annual rainfall over the oceans with separate estimates for shallow (dashed Δ ) and deep echoes (solid x) observed by the TRMM PR.

## 4. DIURNAL CYCLE AND PR CORRECTIONS

Although corrections for PR limitations impact the global oceanic rainfall by only 13% (see Table 1), the regional impact can be substantially greater in areas where shallow echoes produce most of the rainfall.

The diurnal cycle in shallow rainfall was determined from product 3G68 over two regions in the southeastern Pacific and Atlantic regions where >85% of PR echoes have tops less than 3 km. The areas are between 5°S and 20°S and 5°W-to-20°W(south Atlantic) and 100°W-to-115°W (south Pacific).

Figure 5 shows the composite diurnal cycle in shallow rainfall for the months of July for the years 1998-2002. The average PR rainfall for the month is 0.4 mm/hr per month, or 9.6 mm/month. The average rainfall from the TRMM Microwave Imager is 5.0 mm/month.

Corrections to the PR rainfall totals in these regions are: Under-sampling, 1.8 mm/month; Re-classification 3.2 mm/month; Sensitivity 0.5 mm/month; missing warm rain 0.6 mm/month. The total correction is 6.1 mm/month, bringing the monthly rainfall to 15.7 mm, a 66% increase over that shown in Figure 5.

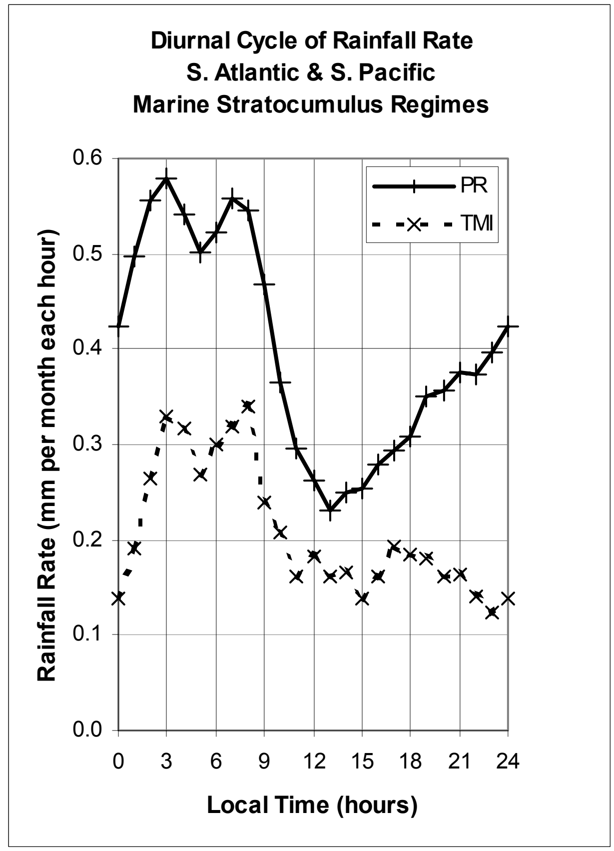


**Figure 5.** Diurnal cycle in rainfall in from the PR and the TRMM Microwave Imager (product 3G68) in regions dominated by shallow echoes over the southeast Pacific and Atlantic Oceans.

## 6. REFERENCES


Janowiak, J. E., P. A. Arkin, P. Xie, M. L. Morrissey and D. R. Legates, 1995: An examination of the east Pacific ITCZ rainfall distribution. *J. Climate*, **8**, 2810-2823.

Kozu, T., T. Kawanishi, H. Kuroiwa, M. Kojima, K. Oikawa, H. Kumagai, K. Okamoto, M. Okumura, H. Nakatsuka, and K. Nishikawa, 2001: Development of precipitation radar onboard the Tropical Rainfall Measuring Mission (TRMM) satellite. *IEEE Trans. Geosci. Remote Sensing*, **39**, 102–116.

Schumacher, C. and R. A. Houze, Jr., 2003: The TRMM Precipitation Radar's view of shallow, isolated rain. *J. Appl. Meteor.*, to appear.

Short, D. A., 1998: Monthly rainfall comparisons from the TRMM PR (3A25) and TMI (3A11) in the lower mid-latitudes of the winter hemisphere. Proceedings of the Symposium on the Observation of Rainfall from Non-sun-synchronous Orbit. Nagoya University, Japan, 14–16 December 1998, pages 120 - 125.

Short, D. A. and K. Nakamura, 2000: TRMM radar observations of shallow precipitation over the tropical oceans. *J. Climate*, **13**, 4107-4124.