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# RAINFALL ESTIMATES ON THE ALTIPLANO USING RADAR AND PASSIVE MICROWAVE DATA FROM TRMM

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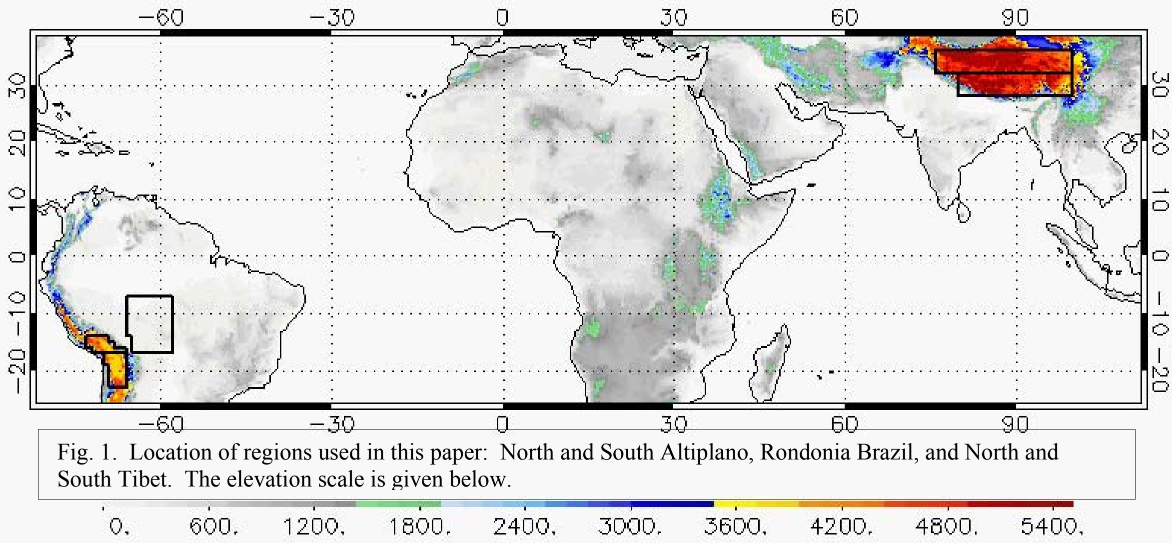

Fig. 1. Location of regions used in this paper: North and South Altiplano, Rondonia Brazil, and North and South Tibet. The elevation scale is given below.

Table 1. Average rainfall for summer season (mm/month) from TRMM radar in above boxes

| | Rondonia DJF | Northern Altiplano DJF | Southern Altiplano DJF | Northern Tibet JJA | Southern Tibet JJA |
|---|---|---|---|---|---|
| No ice | 30.4 | 13.2 | 8.2 | 6.6 | 18.7 |
| With ice | 73.7 | 40.5 | 24.8 | 18.3 | 39.8 |
| With MCS | 103.7 | 12.9 | 8.2 | 7.4 | 16.6 |
| **Total** | **207.8** | **66.6** | **41.1** | **32.2** | **75.0** |

## 1. INTRODUCTION

Rainfall estimation for most of the world is a very difficult problem. In regions without dense rain gauge networks, it is necessary to rely on remote sensing, and in regions without high quality weather radars, satellite algorithms may be the only option. Unfortunately, even the best such algorithms are far from perfect, but in high altitude regions such as the Altiplano the problems are compounded. The “calibrations” with rainfall observations used to develop algorithms require ample radars and rain gauges, and the Altiplano has neither. As Mota (2003) found, the widely-used Global Precipitation Index overestimates rain over the Altiplano by a factor of 2-3, most likely because cirrus anvils and other high clouds often have little precipitation reaching the surface there compared with other regions. The TRMM satellite offers an opportunity to use its radar data from space to study precipitating systems over the Altiplano. The purpose of this paper is to present these data, comparing properties of systems over the Altiplano with those over the Tibetan Plateau, and with the adjacent Rondonia lowlands. Table 1 shows how the estimated summer rainfall is distriibuted between systems with MCSs, with ice,

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and without ice. We focus on the summer rainy season because it is the largest contributor to annual rainfall, but also because it minimizes contamination of the passive microwave channel at 85 GHz. In this paper, we use the data from this channel to separate precipiation features (PF) into 3 types: With MCS (see Nesbitt et al. 2000), with ice, and without ice.

## 2. FRACTION OF RAINFALL FROM PF TYPES

The following tables summariize results from 8 years of TRMM data during the summer seasons in each box. First we sum all rainfall observed by the TRMM radar, partitioned into the 3 types of PFs. We can immediately see that there are strong similarities between the 4 high plateau regions, and strong differences between the Altiplano and the Rondonia lowlands a short distance to the east. Rondonia has 50% of its rain volume (Table 2) from PFs with MCSs. In contrast, each of the 4 plateau regions has by far the largest fraction of its rain from PFs with ice. rate 2 mm hr$^{-1}$). As expected, virtually all MCSs exceed this rain volume, as well as most rain from As a “sanity check”, in Tables 3 and 4 we show the rain volume and percent of the total in each category from PFs large enough to have 1000 mm km$^2$ hr$^{-1}$ (*e.g.* rain area 500 km$^2$ with mean rain PFs with ice. PFs “without ice” contribute about 13% (75/570) of Rondonia’s rain, with 49% of that (37/76) above the threshold rain volume, showing that these are likely small, shallow rain showers without significant ice scattering. It is not at all surprising that the Altiplano and Tibet have very little of their rainfall from such clouds. We expect that the non-zero fraction of “without ice” rain in Tibet represents artifacts, representing inability of the 85 GHz passive microwave channel to distinguish precipitating ice from surface ice and snow cover. This is a significant issue in precipitation retrievals that requires a major research effort.

Table 2. Total volumetric rain * $10^5$ mm km$^2$ hr$^{-1}$
Volumetric rain > 0, elevation >3000 m (except for Rondonia)

| | Rondonia DJF | Northern Altiplano DJF | Southern Altiplano DJF | Northern Tibet JJA | Southern Tibet JJA |
|---|---|---|---|---|---|
| No ice | 75.6 | 3.5 | 4.6 | 36.5 | 36.6 |
| With ice | 210.6 | 18.3 | 19.7 | 165.5 | 134.1 |
| With MCS | 283.5 | 5.0 | 6.9 | 76.2 | 47.9 |

Table 3. Total volumetric rain * $10^5$ mm km$^2$ hr$^{-1}$
Volumetric rain ≥ 1000 mm km$^2$ hr$^{-1,}$ elevation ≥ 3000 m (except for Rondonia)

| | Rondonia DJF | Northern Altiplano DJF | Southern Altiplano DJF | Northern Tibet JJA | Southern Tibet JJA |
|---|---|---|---|---|---|
| No ice | 36.9 | 0.4 | 0.8 | 3.3 | 7.5 |
| With ice | 207.5 | 15.2 | 16.9 | 120.3 | 100.6 |
| With MCS | 283.5 | 5.0 | 6.9 | 72.9 | 47.3 |

Table 4. Percent of total volumetric rain from PFs with volumetric rain ≥ 1000 mm km$^2$ hr$^{-1}$

| | Rondonia DJF | Northern Altiplano DJF | Southern Altiplano DJF | Northern Tibet JJA | Southern Tibet JJA |
|---|---|---|---|---|---|
| No ice | 48.8% | 10.7% | 17.8% | 9.1% | 20.5% |
| With ice | 98.5% | 83.1% | 85.6% | 72.7% | 75.1% |
| With MCS | 100.0% | 100.0% | 100.0% | 95.7% | 98.7% |

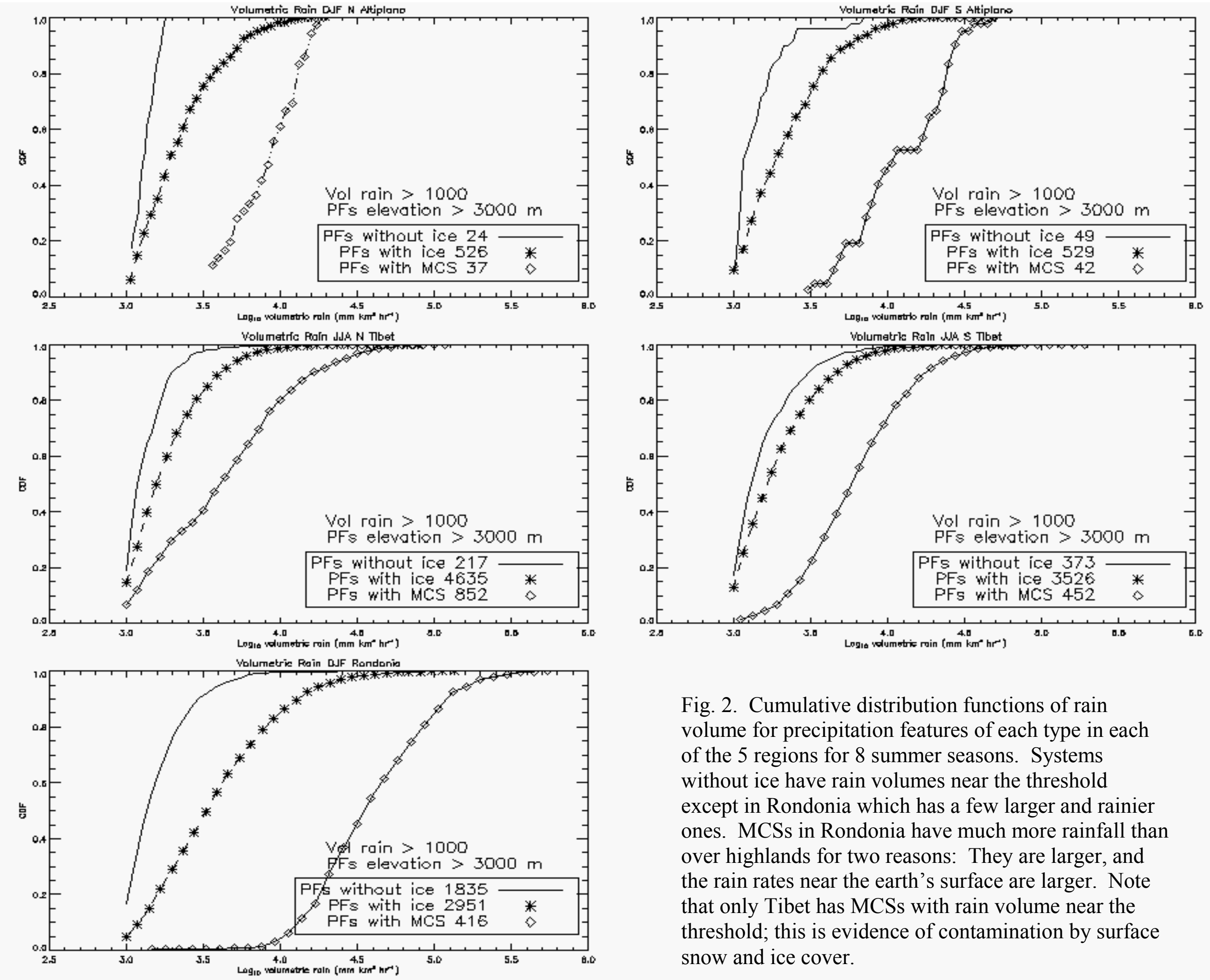

Fig. 2. Cumulative distribution functions of rain volume for precipitation features of each type in each of the 5 regions for 8 summer seasons. Systems without ice have rain volumes near the threshold except in Rondonia which has a few larger and rainier ones. MCSs in Rondonia have much more rainfall than over highlands for two reasons: They are larger, and the rain rates near the earth's surface are larger. Note that only Tibet has MCSs with rain volume near the threshold; this is evidence of contamination by surface snow and ice cover.

We now compare the properties of PFs with ice and PFs with MCSs in different regions. We already know that MCSs contribute a large fraction of the Rondonia precipitation, a smaller fraction of highland precipitation. PFs with ice contribute the largest fraction over highlands, so it is of interest to compare their properties with each other (i.e., Altiplano vs. Tibet) but also with Rondonia, where the TRMM-LBA field campaign acquired considerable knowledge of precipitation features. Since a rather large fraction of MCSs have at least one lightning flash (detected by the LIS instrument on TRMM), we compare MCSs with at least one flash. For both MCSs and PFs with ice, we use the rain volume threshold of 1000 mm km$^2$ hr$^{-1}$.

Table 5. Properties of PFs with Rain Volume 1000 mm km$^2$ hr$^{-1}$ and at least one flash (medians)

| Parameter | Rondonia | Altiplano (N & S) | Tibet (N & S) |
|---|---|---|---|
| Minimum 85 GHz $T_b$ (°K) [colder means larger ice water path) | 165 | 198 | 187 |
| Minimum 37 GHz $T_b$ (°K) | 258 | 259 | 254 |
| Max height 20 dBZ echo (km) | 13.5 | 13.0 | 13.5 |
| Max height 40 dBZ echo (km) | 5.75 (!) | 7.5 | 8.25 |
| Max echo at z = 6 km (dBZ) | 39 | 40 | 42 |
| Max echo at z = 9 km (dBZ) | 28.5 | 32.3 | 35.3 |
| Volumetric rain (mm km$^2$ hr$^{-1)}$ | 42000 | 11500 | 8800 |
| Max near-surface echo (dBZ) | 46 | 43.3 | 43.8 |

Table 6. Properties of PFs with ice with Rain Volume 1000 mm km$^2$ hr$^{-1}$ (medians)

| Parameter | Rondonia | Altiplano (N & S) | Tibet (N & S) |
|---|---|---|---|
| Minimum 85 GHz $T_b$ (°K) | 223 | 225 | 224 |
| Minimum 37 GHz $T_b$ (°K) | 272 | 267 | 264 |
| Max height 20 dBZ echo (km) | 10.25 | 11.5 | 11.0 |
| Max height 40 dBZ echo (km) | 5.0 (!) | 7.0 | 7.5 |
| Max echo at z = 6 km (dBZ) | 33 | 37 | 35 |
| Max echo at z = 9 km (dBZ) | 23.7 (!) | 29.6 | 29.0 |
| Volumetric rain (mm km$^2$ hr$^{-1)}$ | 3920 | 2080 | 1860 |
| Max near-surface echo (dBZ) | 41.7 | 39.8 | 38.0 |

## 3. SUMMARY

The current state-of-the-art in estimating precipitation from satellites is disappointing in high altitude regions, and confidence is low in these estimates over the Altiplano. However, the TRMM radar database can be used to describe the properties of precipitating systems. These properties are very similar in Tibet and the Altiplano, lending some confidence to the results. Comparing Altiplano to Rondonia PFs, surface rain rates are higher over lowlands, as expected. However, radar echoes are equally intense in the upper troposphere for MCSs, and more intense for PFs with ice over the Altiplano and Tibet compared with Rondonia. The implication is that a large fraction of summer rainfall over these high plateaus comes from small but moderately intense convective storms.