# WHAT HAVE WE LEARNED FROM TRMM ON PRECIPITATION RETRIEVAL?

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**Abstract**

This paper is a brief summary of the experience gained since November 1997, exploiting the Tropical Rainfall Measuring Mission data sets arising from both the precipitation radar and the TRMM Microwave Imager. The text mostly reflects the activities conducted at CETP within the ABM group over a period that extends from 1994 to present. The author made a special effort to mention the work of other groups as often as possible, nevertheless this paper is not an exhaustive review on rain retrieval activities in the international community and no one should be offended of not figuring in this review.

## 1. Generalities on TRMM

The Tropical Rainfall Measuring Mission (TRMM) was placed on a 350 km altitude circular orbit in November 1997. It's a joint mission between NASA (US) and NASDA (Japan). The mission was designed for duration of 3 years. The actual mission duration is expected to be closer to 5 to 7 years under the condition that the satellite orbit be raised by about 50 km altitude before the end of August 2001. The decision to modify the orbit is currently under examination by NASA and NASDA.
The satellite carries onboard a series of 5 instruments (**Fig. 1**). Three instruments are part of the primary precipitation package (Kummerow *et al.* 1998):

- TRMM Microwave Imager (TMI) is a 5 frequencies conical scanning radiometer based on the SSM/I instrument. The 5 frequencies are 10.65, 19.35, 21.3, 37.0 and 85.5 GHz. All frequencies are polarized horizontally (H) and vertically (V), but the 21.3 GHz that is only vertically polarized. Swath width is about 700 km.
- Precipitation Radar (PR) is a 13.8 GHz radar. It is the first spaceborne radar dedicated to the study of precipitation. The swath width is 215 km. The radar provides reflectivity profiles between 0 and 20 km altitude with a 250 m vertical resolution.
- Visible-Infra-red Radiometer System (VIRS) is a five-channel spectroradiometer with bands in the wavelength range 0.6-12 μm.

But there are also two instrument, being part of the Earth Observing System-related package:

- Cloud and Radiant Earth's Energy System (CERES).
- Light Imaging System (LIS)

The paper hereafter focuses on the PR and the TMI exploitation only.

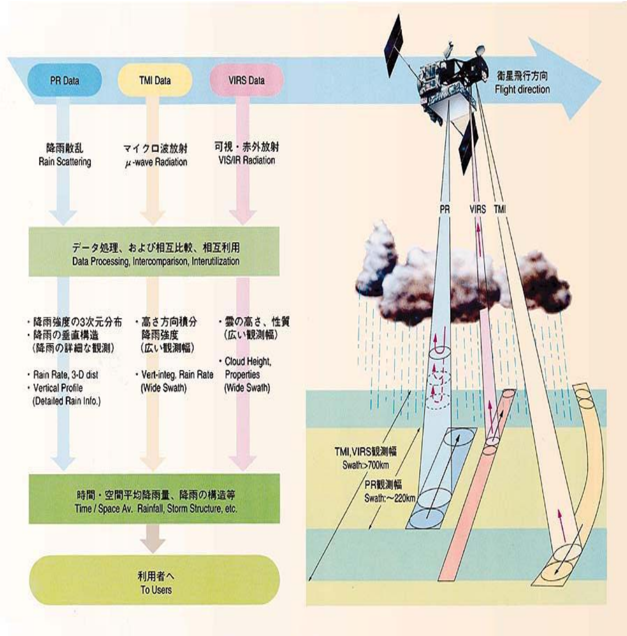


**Fig. 1**: Instruments geometry and configuration on TRMM. Only the PR, VIRS and TMI, being part of the precipitation package, are represented here. (courtesy NASA/NASDA)

The **Table 1** summarizes the characteristics of TMI as compared to the SSM/I. The two instruments are actually developed from the same core, the only differences being the additional 10 GHz for TMI and the footprint resolution due the difference in altitude between the two satellites.

| **Frequency (GHz)** | **10.65** | **19.35** | **21.3** | **37.0** | **85.5** |
|---|---|---|---|---|---|
| | | | **TMI** | | |
| Polarization | V, H | V, H | V | V, H | V, H |
| Wavelength (cm) | 2.81 | 1.55 | 1.35 | 0.81 | 0.35 |
| 3dB footprint (km²) | 60 x 36 | 30 x 18 | 27 x 16 | 16 x 10 | 7 x 4 |
| | | | **SSM/I** | | |
| Polarization | NA | V, H | V | V, H | V, H |
| Wavelength (cm) | NA | 1.55 | 1.35 | 0.81 | 0.35 |
| 3dB footprint (km²) | NA | 69 x 43 | 50 x 40 | 37 x 28 | 15 x 13 |

**Table 1:** TMI vs. SSM/I characteristics, the main difference being the footprint size due to the altitude difference (350 km vs. 833 km altitude).

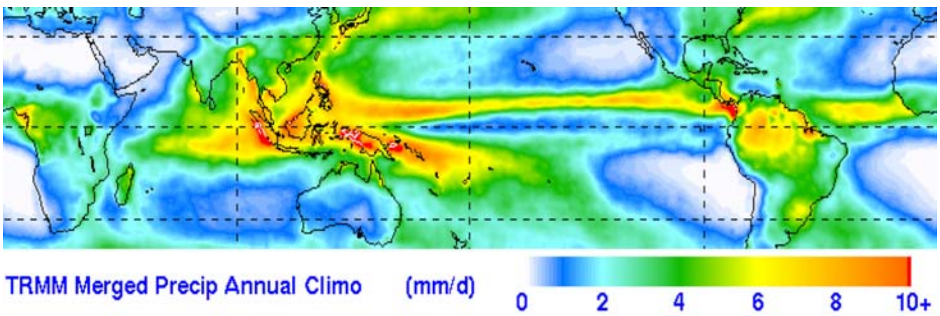


**Fig. 2.**: See text for explanation (Courtesy R. Adler/NASA-GSFC).

**Fig. 2** illustrates a 3 years (1998-2000) climatology of the surface rain as retrieved from different satellites and rain gauges data (Adler *et al.* 2000). This figure was obtained by merging the different rain estimates from the different satellites, completed with gauges data over land, the whole synergetic system being calibrated with TRMM. TRMM is nowadays estimated to be the best calibrated instrument flying. The need to merge TRMM data with other satellite estimates in this case is due to its orbitography: TRMM is not optimized for climatological products. The main source of error is the number of revisit over the same point that varies between 0 and 4 over a day, leading to a dramatic sensitivity to diurnal cycle for instance.

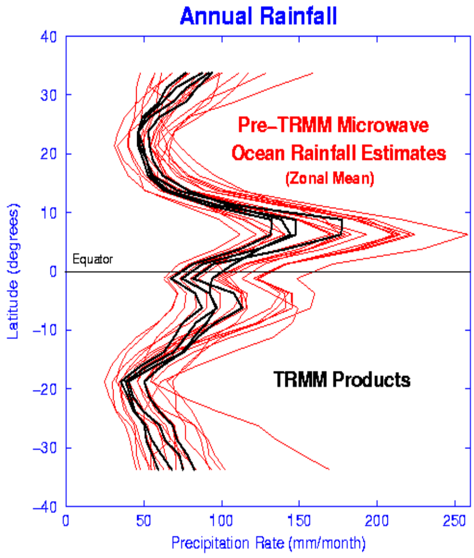


**Fig. 3**.: See text (courtesy of NASA)

**Fig. 3**. Shows the annual rainfall estimate presented as a zonal average. The solid grey lines are pre-TRMM era estimates, the solid thick black line are post-TRMM era estimates, corresponding to different TRMM standard products. The main feature to be noticed is the considerable reduction of the dispersion. One can notice that even the TRMM standard products are exhibiting some dispersion that is not completely explained at this point. The worst case being between the TMI-based estimate (2A12) and the PR based estimate (2A25) where the difference can be as high as 23%.

This discrepancy between the PR and the TMI is one of the primary sources of concern inside the community. On the one hand, the 2A12 algorithm is based on the Bayes' theorem (Kummerow *et al*., 1996, Viltard *et al*., 1996) and relies on cloud model simulation and probabilistic occurrences. On the other hand, the 2A25 algorithm is completely deterministic, being based on microphysics relationships. It was assumed for a long time that the PR might be providing slightly underestimated surface rain rates due to drop-size distribution sensitivity, while the TMI might be overestimating the rain rate due to intrinsic instrument /method biases. But at present, the answer is still unclear, and validation /comparison activities are continuing. Hereafter are presented some of the efforts continued at CETP to validate the PR rain estimates.

## 2. PR-Related Studies at CETP (Results on this section are extensively presented in F. Feirerra's PhD thesis).

### *1.1. Case study comparisons*

Two types of case studies comparison are conducted at CETP since 1997. The first approach is based on comparisons with ground-based radar data. The first series of data arises from the Darwin (Autralia) radar. Darwin radar is a polarized C-band radar (5 GHz) which sampling volume is typically 300m x 100m (at 2.5 km from radar) with a typical sampling time of about 10 minutes. A series of rain gauges and disdrometers measurements are also available nearby.

The standard product for this radar is available at the Goddard Distribution Active Archive Center (DAAC http://daac.gsfc.nasa.gov ), as the radar is an operational validation site for TRMM. This product does not account for attenuation effects and does not exploit the polarization capabilities of the radar. At CETP, a polarimetric algorithm was developed. This algorithm called the Zphi algorithm is described in Testud *et al.* (2000). It allows us to correct for attenuation and to retrieve the drop-size distribution slope parameter $N_0$ along a radar beam.

Quantitative and qualitative comparisons of both $N_0$ and reflectivity fields were performed (**Fig. 4**) and showed a good agreement. If the difference in terms of reflectivity is about .8 dB (s.dev. about 4.1, due mostly to sampling time differences), the rain rates exhibit a -0.69 mm.hr$^{-1}$ bias on the total rain ($R_{TRMM}$-$R_{Z-phi}$) but distributed as –1.96 mm.hr$^{-1}$ for convective rain and +4.99 mm.hr$^{-1}$ for stratiform rain (number of stratiform and convective occurrence is not the same !!). This emphasize the high sensitivity of the PR algorithm (and radar algorithms in general to the parameterized DSD characteristics in the $R=aZ^b$ relationship used.

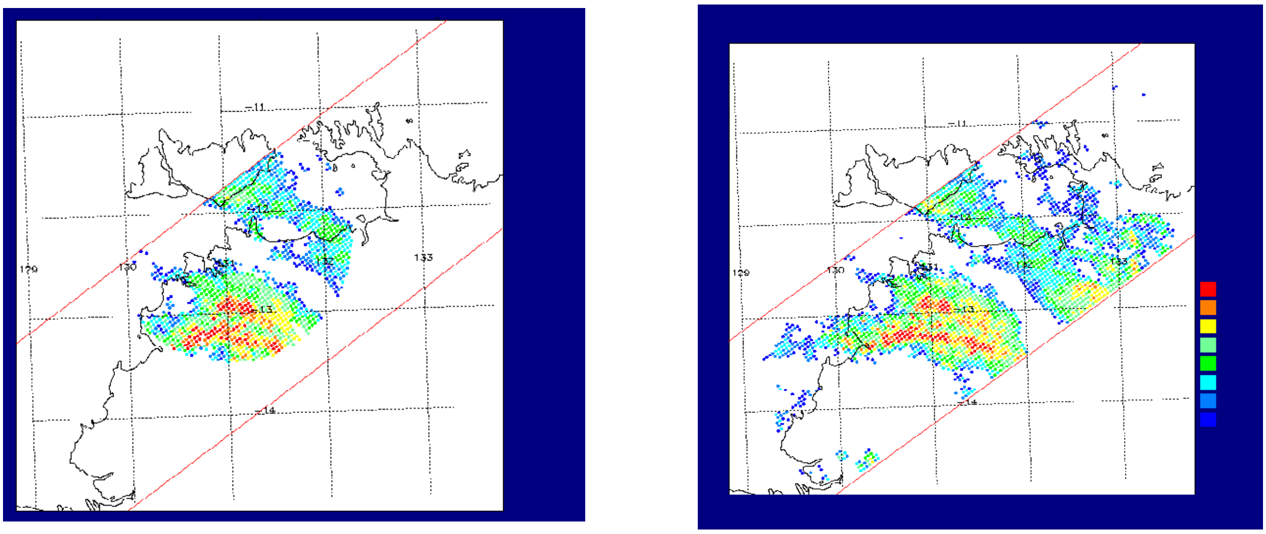

**Fig. 4**: On the left hand side is the ZPHI algorithm's corrected reflectivity at 2 km altitude as seen by the Darwin radar on 27 January 1998. On the right hand side, the same rain band at the same altitude, as seen simultaneously by the PR.

The second type of comparison was performed with airborne Doppler radar onboard the NOAA-P3 aircraft (http://www.aoml.noaa.gov/hrd/). The aircraft are equipped with X band (9.5 GHz) radar and flew into two interesting hurricane situations: Bonnie 1998 and Bret 1999. A close comparison of the TRMM and aircraft radar was performed over 10 minutes of airborne inside Bonnie, showing the excellent agreement in terms of reflectivity (bias of about 0.2 dB) and rain rate (bias about 0.2 $mm.hr^{-1}$). The Bonnie case is a particularly favorable case because it's mostly stratiform when all the sources of errors are minimal. For Bret, which offers a substantial proportion of convective profiles, the situation is more critical with differences of about 14.2 $mm.hr^{-1}$ for the convective profiles and 0.2 $mm.hr^{-1}$ for the stratiform cases. Up to now, no definite answer was found to explain such a poor performance in the intense convection. Hypotheses concerning the surface characteristics are under investigation.

### *1.2. Building up climatologies of profiles*

Another aspect of the exploitation of PR profiles is the possibility of studying the climatologies of the profiles (mean characteristics profiles) under different rain regimes. Fig. 5 is a preliminary illustration of this possibility where, "cyclone" represent the average profile found for Northern Atlantic hurricane cases, "Darwin" stands for coastal convection over Darwin in Australia, and "Pacifique" stands for oceanic mesoscale convective system in the middle of the Pacific Ocean in August 98.

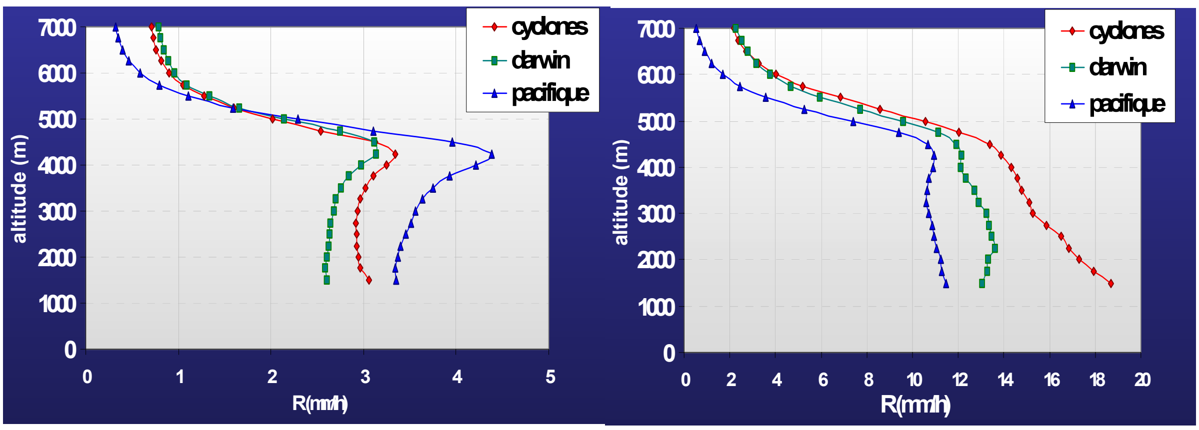


Fig 5: Left hand side: average profiles for stratiform rain under 3 different regimes. Right hand side, same, but for convective cases. See text for explanation.

These curves are of interest to see if some typical characteristics can be found depending on the latitude/longitude and/or the type of observed event (and **Fig. 5** seems to show such features). This could be extremely useful for further developments in model simulations or radiometric rain retrievals.

## 3. TMI-related activities

One of the main goals of the TRMM mission was give a tool to improve the rain retrieval algorithms from measured sets of brightness temperatures. The experience gained with SSM/I leaded to pretty decent estimates but with an error difficult to estimate and assumed to be rather high. The idea of calibrating the TMI algorithms based on the radar estimate was tempting. We presented above some results showing that the absolute radar calibration for PR is probably the best ever obtained on a rain radar (below 1dB).
Most rain retrieval methods nowadays are based on similar principles: a set of a-priori information on the atmospheric physics or on the relation ship between a given rain profile and the brightness temperature measured at the top of the atmosphere is built and set into a database. This database is made of cloud generated profiles, for instance, and their associated simulated brightness temperature. Fig. 6. Shows the flow diagram of this type of methods. Once the database built, the retrieval uses the measured $T_B$ (merging eventually with radar extra information) and digs out from the database the profile that is susceptible to generate such $T_B$ set. The way the "most probable profile" is found can be a neural network (Moreau *et al.* 2001), or any type of probabilistic approach like the Bayes theorem. The BAMPR (Panegrossi *et al*., 2001), the PATER (Bauer 2000), the Gprof (Kummerow *et al*, 1996) techniques are all using this type of approach.

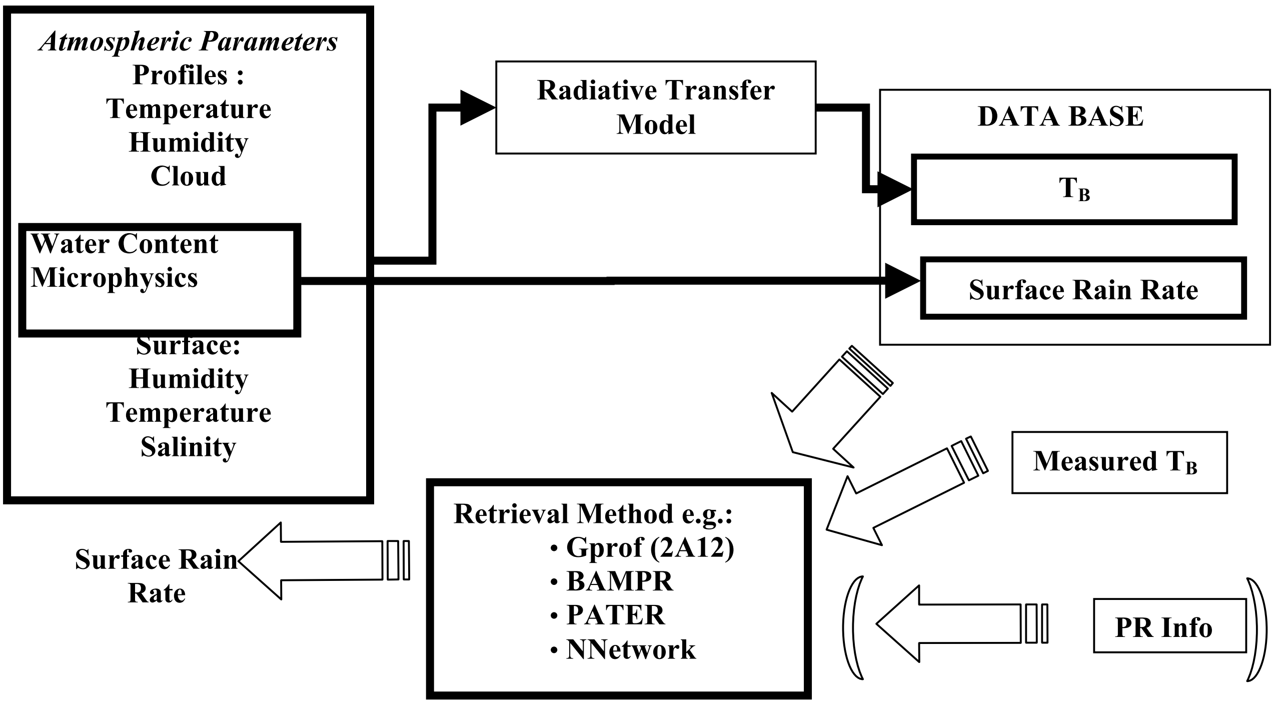


**Fig. 6**: Flow diagram of common rain retrieval techniques from measured brightness temperatures. See text for explanations.

One of the critical points when using such methods becomes then the quality of the database. When the database is built from cloud resolving model simulation, the necessarily limited number of available simulations counter balances somehow the high quality of the simulation. On the other hand, Numerical weather prediction models can provide a huge number of situations with a wide variety, but their spatial resolution is not so good and they do not contain any microphysics. A third way, developed at CETP, consists in using the co-located pixels of the TMI and the PR within the common swath of the instruments. This allows us to have a wide variety of situations and a set of measured brightness temperatures and rain profiles. It is obviously necessary, prior to any database building, to check the consistency between the two data sets. This is done in injecting the PR rain profiles into a forward radiative transfer model and comparing the simulated brightness temperatures with the observed ones (Viltard *et al*. 2000). Then it is possible to use the co-located observations within a database. This has proven to be an efficient technique also.

In parallel, the sensitivity to melting layer (Bauer *et al*., 1999) and to drop size distribution (Viltard et al. 2000) in forward radiative transfer calculation was estimated. Attention of the community was also drawn to the ice phase understanding, even if at this point no real progress have been accomplished in this domain.
Fig. 7 illustrates the rain retrieved over a pentad (8 to 12 February 1998), using both the neural network technique (lower left panel, Moreau, 2001) and the CETP co-located data algorithm (upper left panel). The two algorithms are compared with the Global Precipitation Index over the same period of time. The comparison shows that all the methods provide different estimates locally but the lower right panel shows that the zonal average are the same for the TMI only algorithms while the GPI (merging many sources of data) is giving a different result. This effect is probably mainly due to sampling errors with the TMI only.

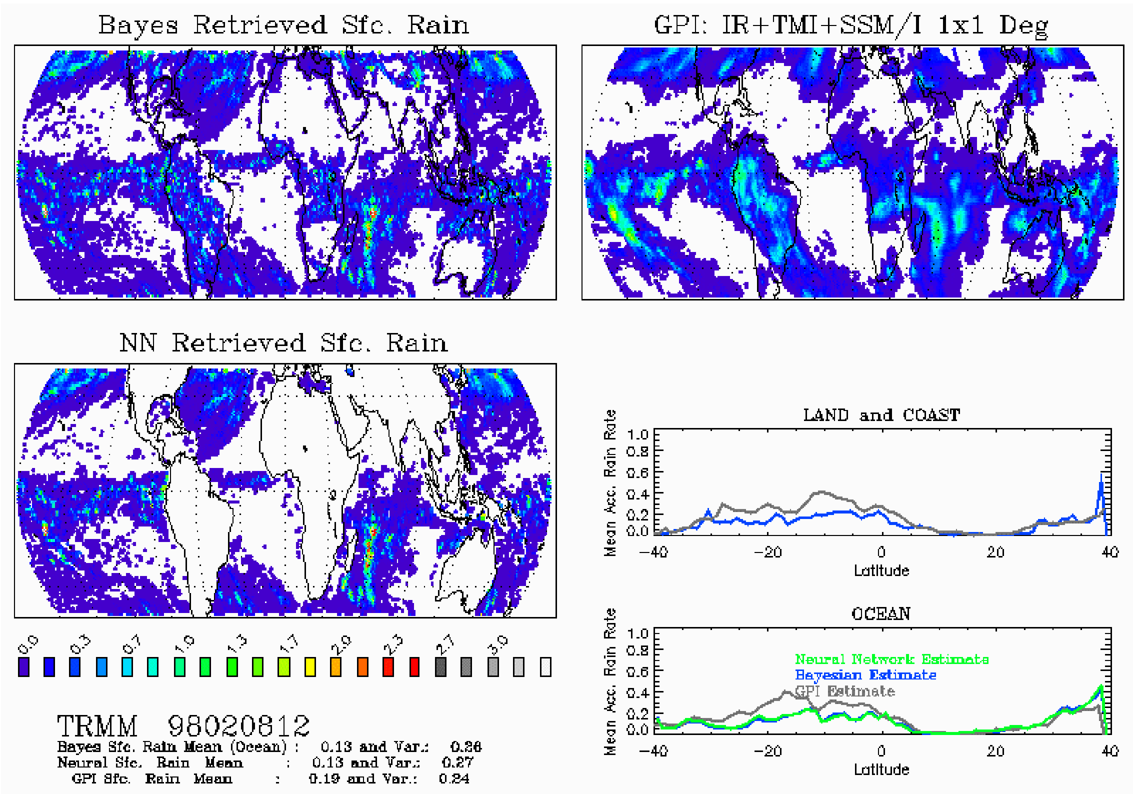


**Fig. 7**: Comparison of neural network (bottom left), co-located database algorithm (top left) and GPI (top right) over a pentad. The lower right panels stands for zonal means.

## 4. Conclusion

TRMM is already a major success but not necessarily the way it was anticipated to be. Certainly it appears today as a reference in terms of instrument design and quality of the rain retrievals. But the huge effort conducted around TRMM also raised a lot of new questions. The first one might be the problem of ice phase description and modelisation. This impacts not only the rain retrieval over ocean, but primarily over land, as the scattering signal is the only one available over the continental surface. The second problem identified is the need for a bigger number of cloud simulations to improve dramatically the retrievals. The third point could be the need to be able to handle the problem of the high dependence to microphysics parameters of the radar rain estimates.
What made TRMM so different from other missions previously launched with imager radiometers onboard? Without any doubts, the presence of the radar helped a lot to understand the small-scale structure of the rain and the way this small-scale structure interacts with the radiometric signal. The also increased resolution of the radiometer with respect to the SSM/I really allowed understanding the structure of the rain system and

particularly the spatial interaction of the convective and stratiform rain. This also raised questions on how to handle the different properties of each category.
Also the joint effort throughout many different communities to define and elaborate products that answer to the needs of future products and algorithms users. A lot of collaboration were indeed started within the framework of TRMM.

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