P10.9 AIRBORNE RADAR AND PASSIVE MICROWAVE-BASED CLASSIFICATION AND CHARACTERIZATION OF TROPICAL PRECIPITATION PROFILES

Bart Geerts
University of Wyoming, Laramie, USA

1. INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) has improved our understanding of precipitation processes, and quantitative precipitation estimation, by a quantum leap, especially over the tropical oceans, but *there is still a large discrepancy between instantaneous rainrate estimates based on radar and those based on upwelling microwave radiation* (Kummerow et al 2000). This implies a lack of understanding of fine-scale precipitation processes and storm dynamics, mainly at low latitudes. What are the characteristic sizes and vertical depths of tropical precipitation systems? Is precipitation generated mostly above or below the freezing level? How does rainfall intensity vary spatially? We aim to shed some light on these questions by studying the detailed vertical profiles of hydrometeors, vertical motion, and associated upwelling microwave signatures, in a range of tropical precipitation systems. We are analyzing all ER-2 nadir reflectivity profiles, obtained from EDOP, along level flight legs during the TRMM GV field campaigns conducted in 1998, '99, and possibly 2001, as well as all coincident upwelling microwave radiances, as measured by AMPR on the ER-2. This dataset will be used to contrast convective and stratiform hydrometeor profiles in isolated and organized convective systems over Florida and Brazil to those in oceanic tropical cyclones. Shown here are composite reflectivity and velocity data, plus microwave brightness temperatures, for land-based and oceanic systems. We compare these composite data to a TRMM-based climatology.

2. CONVECTIVE VS. STRATIFORM PRECIPITATION

We are using data from a series of field experiments to characterize some clearly-defined tropical precipitation types that are well-recognized as distinct. The characterization primarily uses vertical profiles of radar reflectivity and vertical motion, at an unprecedented vertical resolution. These data are supplemented with passive microwave data recorded from the same zenith vantage point, and in situ cloud microphysical data. The vantage point is the same as that of TRMM Precipitation Radar (PR), but the horizontal and vertical resolutions are at least one order of magnitude higher (**Fig 1**).

In essence *there is a distinction between convective and stratiform precipitation*. The distinction is important because of differences in Z-R (reflectivity-rainrate) relationships, and different profiles of in-cloud latent heat release. The TRMM PR rainfall products discriminate between the two types. Prior to TRMM (launched in 1997) the separation between the two rain types was based on ground-based radars (Steiner et al 1995, Biggerstaff and Listemaa 2000). The discrimination is based on rather circumstantial arguments, namely the intensity and relative isolation of the echo pattern. The main problem with these side-looking radars is that they often miss the presence and structure of the bright band (melting layer). This is because at range the beamwidth is much larger than the gate spacing (Fig 1). A deep rain system is considered stratiform when a bright band is present.

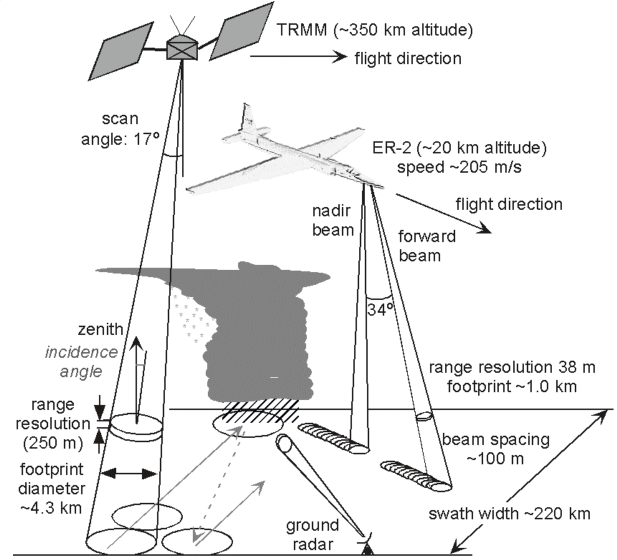

Fig 1. The ER-2 Doppler radar (EDOP) assumes the same vantage as the TRMM Precipitation radar, but it observes precipitating systems at much higher resolution.

Geerts (2000) developed a discrimination algorithm based on high-resolution profiles of reflectivity. These profiles are derived from the EDOP nadir radar antenna; similar profiles can be obtained from ground-based 915 GHz profilers or a vertically-pointing ground radar, however aircraft traverses have the advantage covering entire storms nearly simultaneously. The EDOP data were collected in a series of TRMM Ground Validation (GV) campaigns in 1998-'99, namely CAMEX-3, TEFLUN-B, and TRMM LBA. Additional EDOP profiles may be obtained in CAMEX-4 (Aug-Sept 2001), which, as its predecessor, focuses on hurricanes. The classification method by Geerts (2000) is designed to be similar to the 'V-method' used to classify TRMM PR rainfall, to allow comparison and to isolate misinterpretations due to sampling resolution. The V-method ignores horizontal echo patterns. It uses individual reflectivity profiles in isolation of adjacent profiles. The misinterpretations in spaceborne rain classification obviously imply errors in rainfall estimation, because different Z-R relations are used for convective and stratiform rain. They are due either to horizontal or vertical resolution problems.

Firstly, the characteristic diameter of tropical convection is smaller than the TRMM PR footprint of ~4.3 km (e.g. Sauvageot et al 1999), and typical reflectivity gradients are at least two orders of magnitude larger in reality than can be derived from TRMM PR data. Therefore TRMM PR reflectivity profiles underestimate core storm intensities and the TRMM PR classification of small convective towers is biased towards stratiform, because of insufficient intensity (Heymsfield et al 2000). Stratiform rain only develops in the later stages of evolution of large thunderstorm complexes (Houze 1993). Intensity underestimation, compounded by limited PR sensitivity (18 dBZ), may render small convective towers invisible to the PR. Secondly, the vertical resolution of the TRMM PR is 250 m in the nadir and worse at higher incidence angles (Fig 1), which is inadequate to sample thin bright bands that identify stratiform precipitation according to the V-method.

3. PRELIMINARY RESULTS

We are analyzing all EDOP data along straight and level ER-2 flight legs during the TRMM GV field campaigns, and contrast convective and stratiform hydrometeor profiles in isolated and organized convective systems over Florida and Brazil to those in oceanic tropical cyclones. Convective/stratiform classification is controversial in hurricanes, because of the dominance of stratiform precipitation (defined either by the H method, Steiner et al 1995, or the V method) even in areas that are generally assumed to be convective, such as the eyewall. Z-R relations are well-known to be different in hurricane environments. An example of EDOP data along a flight leg over a small, vigorous thunderstorm is shown in **Fig 2**. The convective /stratiform classification is shown as well. A profile is considered stratiform when a bright band is present. It is considered convective if the maximum layer-mean reflectivity is 42 dB. A layer of 1 km is assumed to exclude bright band contamination. If neither conditions apply, the rain type is considered inconclusive. Both a convective and a trailing stratiform region can be distinguished in Fig 2. The leading anvil is not classified because the hydrometeors do not reach the ground. The convective portion has a high reflectivity above the freezing level, which is only possible through upward advection of hydrometeors, while the stratiform region has a well-defined bright band where settling snowflakes melt.

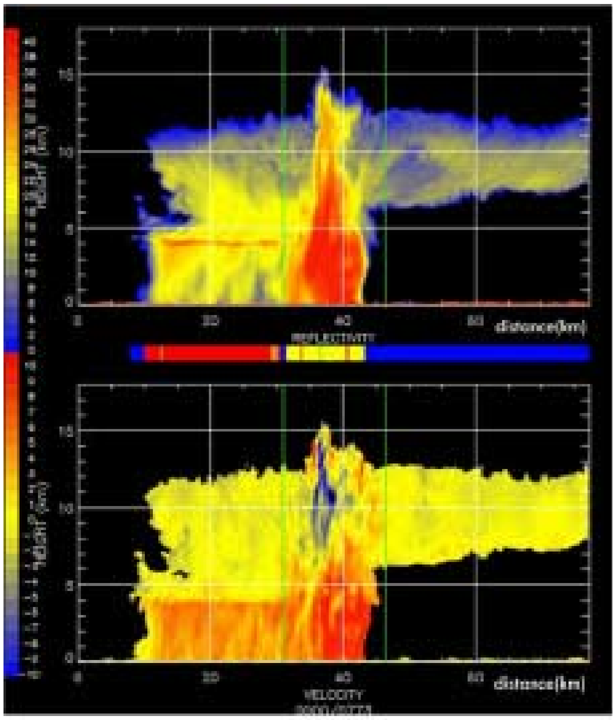

Fig 2. Cross section of a thunderstorm in Brazil on 12 Feb 1999 during TRMM LBA. Top image shows reflectivity (dBZ) and bottom image vertical hydrometeor motion (ms^{-1}), negative values indicate upward motion. The precipitation is classified as stratiform (red), convective (yellow) or inconclusive (blue) between the two images.

The variation of reflectivity frequency by altitude is shown in **Fig 3**, for the stratiform and convective regions shown in Fig 2. The bright band at the freezing level in the upper left panel is consistent with the velocity discontinuity from snow to rain, in the lower left panel; these are characteristics of stratiform precipitation. Convective precipitation is marked by stronger echoes above the freezing level, and a broader spread in reflectivity and velocity values at any level.In addition to spectra of radar reflectivity profiles, we will show the nadir beam radial velocities to estimate profiles of the vertical displacement of hydrometeors, as well as the local or mesoscale vertical motion, assuming a Z-V_t (fall speed) relationship or the technique by Heymsfield and Tian (2000), respectively. Clearly the estimation of vertical velocity profiles is subject to much uncertainty. Other variables in our classification include echo top and near-surface reflectivity (or surface rainrate).

We further present the coincident microwave upwelling radiation, measured by AMPR nadir beams, where available. AMPR, the Advanced Microwave Precipitation Radiometer, was on the ER-2 during most TRMM GV campaigns. Much effort has been spent in the last decade on the retrieval of surface rainrate from the microwave radiation upwelling from cloud tops (e.g. Kummerow and Giglio 1994). The technique commonly used is based on a database of hydrometeor profiles (as derived from a cloud-resolving model run for various environments) coupled with microwave brightness temperatures at various frequencies (as estimated from a radiative transfer model). It turns out that upwelling microwave radiation is quite sensitive to ice crystal shape, the amount of riming, and the characteristics of the melting layer (Evans and Vivekanandan 1990), aspects which depend to some extent on the radar reflectivity profile. We will show microwave brightness temperature spectra for all composite reflectivity profiles. The composite radar reflectivity profile and microwave brightness temperature data are presented as frequency-by-altitude displays, as in Fig 3, as well as in probability density functions. These are compared against TRMM data, in particular 3A25 (PR reflectivity) and 3B31 (TMI) for the same region and month, as well as to the climatology presented in Shin at al (2000).

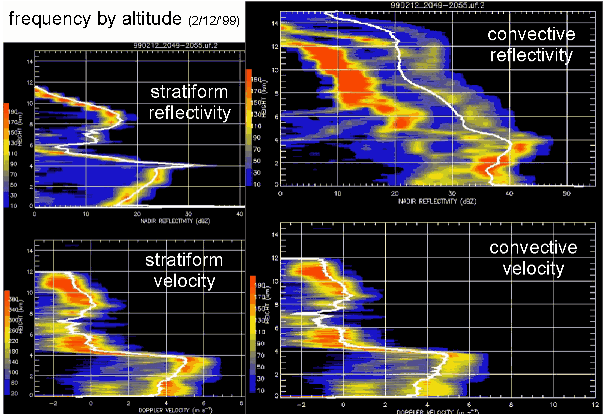

Fig 3. Frequency-by-altitude display of the reflectivity and vertical velocity of the stratiform (right) and convective (left) parts of the storm shown in Fig 2.

4. FURTHER WORK

For some select flight legs we plan to supplement the reflectivity profiles with in situ measurements taken by the UND Citation at various altitudes in cloud below the ER-2. These measurements include drop size distribution (which may be different for identical reflectivity values), liquid water content, vertical air motion, and ice characteristics (amount of riming, shape). To determine the representativeness of proximity in situ data, we do not use specific time/space limits, but rather examine mapped radar reflectivity fields for each case.

We will further mine the complete EDOP dataset for some objectively-defined *specific precipitation types*, mainly because they have proven to be a major challenge for the microwave or radar rainrate estimation. First we distinguish between oceanic tropical precipitation, associated with tropical cyclones or depressions, and land-based systems in Florida or Brazil (again either convective or stratiform). Other specific types include warm rain events (shallow convection) and vigorous convection (convective 'beast' or 'hector'), such as shown in Fig 2. Much effort will be devoted to warm rain events, because little is known about the dynamics and rain-growth mechanisms of shallow tropical convection, which according to TRMM PR estimates accounts for a very large proportion of events (up to 40%) and a significant proportion (> 20%) of rain accumulation (Ziad Haddad, pers. comm.). EDOP and other data suggest that numerous warm rain events have been overflown by the ER-2 during the TRMM GV campaigns but in a fortuitous way, not as a target of coordinated efforts. A bimodal storm cloud top distribution appears present. Tops of tropical precipitating systems are found most commonly just below the tropopause; a secondary peak frequency occurs near the freezing level (Shin et al 2000). Underestimation of the significance of shallow convection and a biased latent heating profile impact our capability to simulate the general circulation.

References

Biggerstaff, M.I., and S.A. Listemaa, 2000: An Improved Scheme for Convective/ Stratiform Echo Classification Using Radar Reflectivity. *J. Appl. Meteor*, **39**, 2129–2150.

Evans, K.F., and J. Vivekanandan, 1990: Multiparameter radar and microwave radiative transfer modeling of nonspherical atmospheric ice particles. *IEEE Trans. Geosci. Remote Sens*., **28**, 423-437.

Geerts, B., 2000: Reflectivity and velocity profiles in tropical precipitation systems, derived from nadir-viewing X-band airborne radar. Preprint Volume, *13th International Conference on Clouds and Precipitation*, Reno, NV, 14-18 August, 254-255.

Heymsfield, G.M., B. Geerts and L. Tian, 2000: TRMM Precipitation radar reflectivity profiles compared to high-resolution airborne and ground-based measurements. *J. Appl. Meteor.*, **39**, 2080–2102.

Heymsfield, G.M., and L. Tian, 2000: Fallspeeds and vertical air motions in stratiform rain derived from ER-2 Doppler radar observations. Preprint Volume, *13th International Conference on Clouds and Precipitation*, Reno, NV, 14-18 August, 303-305.

Houze, R.A. Jr., 1993: *Cloud Dynamics*. Academic Press, 573 pp.

Kummerow, C., and L. Giglio, 1994: A passive microwave technique for estimating rainfall and vertical structure information from space. Part II: Applications to SSM/I data. *J. Appl. Meteor*., **33**, 19-34.

Kummerow, C., et al, 2000: The Status of the Tropical Rainfall Measuring Mission (TRMM) after Two Years in Orbit. *J. Appl. Meteor*, **39**,1965–1982.

Sauvageot, H., F. Mesnard, and R.S. Tenorio, 1999: The relation between the area-average rain rate and the rain cell size distribution parameters. *J. Atmos. Sci*., **56**, 57-70.

Shin, D., G. R. North, and K. P. Bowman, 2000: A summary of reflectivity profiles from the first year of TRMM radar data. *J. Climate*, **13**, 4072–4086.

Steiner, M., R.A. Houze Jr., and S.E. Yuter, 1995: Climatological characterization of three-dimensional storm structure from operational radar and raingauge data. J. *Appl. Meteor.*, **34**, 1978-2007.