**13A.11** HIGH RESOLUTION REFLECTIVITY PROFILES IN VARIOUS CONVECTIVELY GENERATED PRECIPITATION SYSTEMS

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This brief paper illustrates some profiles of radar reflectivity in various precipitation systems observed during the 1998-99 Tropical Rainfall Measuring Mission (TRMM) field campaigns. The profiles were collected by a nadir-viewing radar on the NASA ER-2, flying around 20 km altitude. This paper focuses on hurricane environments.

## 1. TRMM FIELD CAMPAIGNS

A common objective in the TRMM field campaigns is to validate TRMM reflectivity and passive microwave data over convection and convectively-generated stratiform precipitation regions. One, TEFLUN-A (Texas-Florida Underflight) experiment, focused on springtime mesoscale convective systems (MCSs) mainly in southeast Texas. TEFLUN-B was conducted in August-September in central Florida, in coordination with CAMEX-3 (Convection and Moisture Experiment). The latter focused on hurricanes, especially during landfall, whereas TEFLUN-B concentrated on central Florida convection, which is largely organized by sea breeze circulations. Thirdly, TRMM-LBA (Land-Biosphere-Atmosphere interaction in the Amazon) took place in Jan-Feb '99 in the southwestern quadrant of the Amazon Basin. All experiments were amply supported by surface data, in particular a dense raingauge network, a polarization radar, wind profilers, a mobile radiosonde system, a cloud physics aircraft penetrating the overflown storms, and, for TEFLUN, a network of 10 cm Doppler radars (WSR-88D).

## 2. ER-2 DOPPLER RADAR

Of key importance to TRMM Precipitation radar (PR) validation is ER-2 Doppler radar (EDOP). EDOP is a non-scanning instrument with two antennas, one pointing to the nadir, the other pointing 33.5° forward (Heymsfield et al. 1997). The forward pointing beam receives both the normal and the cross-polarized echoes, so the linear depolarization ratio field can be monitored. EDOP has a wavelength of 3.12 cm (9.6 GHz), compared to 2.17 cm (13.8 GHz) for the TRMM PR, a vertical resolution of 37.5 m (vs 125 m for TRMM PR, at least in the core swath 48 km wide), and a horizontal along-track resolution of about 100 m (vs 4.4 km for TRMM PR). The EDOP beamwidth is 2.9°, which in the nadir translates to about 500 m at 10 km altitude and 1000 m at the ground. The 2-D (along-track) airflow field can be synthesized from the radial velocities of both beams. It is primarily the superb horizontal and vertical resolutions that distinguishes EDOP from other ground-based or airborne radars. Therefore we focus on the EDOP nadir reflectivity data.

## 3. EXAMPLES OF REFLECTIVITY PROFILES

A variety of precipitation systems have been sampled in the TRMM field experiments, including isolated thunderstorms, small or decaying MCSs, and hurricanes. Large MCSs (not associated with a tropical cyclone/depression) were not sampled in any of the experiments. Stratiform rainfall (not associated with a hurricane) was relatively undersampled, but especially in TRMM LBA several vigorous convective cells were overflown, as well as some shallow precipitating convection.

In this paper we focus on profiles of EDOP nadir reflectivity on a flight over Hurricane Georges while it made landfall on Hispaniola. Georges was a mature category 3 hurricane but rapidly decayed to a category 1 system while the ER-2 was overhead. Figure 1 is a contoured frequency by altitude diagram (CFADs, Yuter and Houze 1995) of a feeder band south of Georges' eye. The peak bright band reflectivity of 50 dB is higher than in other stratiform regions around Georges. The reflectivity factor (Z) is high in rain, and the spectrum of Z values narrow, implying uniformity along this 60 km long leg. Above the bright

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band Z decays rapidly, as has been shown for other hurricanes (e.g. Figure 11 of Szoke et al. 1986).

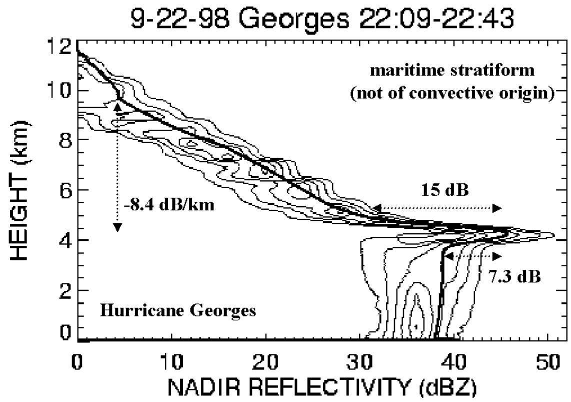


**Figure 1**. *CFAD for a 60 km long leg of EDOP nadir reflectivity, south of Hispaniola, over an inflow band of Hurricane George. George had made landfall over Hispaniola. No attenuation correction has been applied. The solid line is the mean reflectivity computed from Z (not dBZ) values.*

Deep convection developed within the eye of Georges as it passed over the Hispaniola mountains. These mountains are between 0.8 and 2.1 km high below this flight leg, but a 3,093 m high peak is nearby. A CFAD of this convection is shown in Figure 2. This CFAD consists of three convective cores, each overshooting the surrounding anvil by up to 5 km. Another ER-2 pass along the same track about 15 minutes later suggests that these cores were about to mature. They were sustained by three updrafts, each peaking at over 15 m/s, located between 9-15 km altitude. One of the cores has an updraft over 20 m/s and 35 dB at 12.5 km. The cores become unidentifiable at and below the freezing level. A bimodal Z distribution is apparent above the freezing level: the upper curve corresponds with three overshooting convective cores, and the lower more stratiform curve represents the interstitial precipitation.

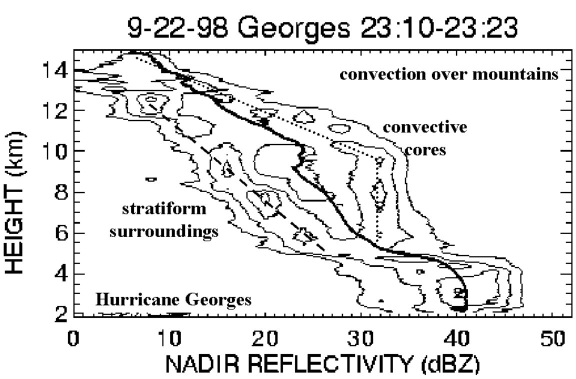


**Figure 2**. *CFAD for a 30 km long leg of EDOP nadir reflectivity, over deep convection over the Cordillera Central of Hispaniola. This section covers the center of the circulation of Hurricane Georges, i.e. it extends across the previously well-defined eye. The interstitial reflectivity profile (highlighted by the dashed line) is distinct from that of the convective cores (highlighted by the dotted line), and it appears stratiform. The solid line is the mean. No attenuation correction has been applied.*

The increase in Z from ~33 to ~40 dB across the freezing level in the convective cores reveals that graupel was prevalent: graupel changes little in size when it starts to melt, but its wet coating increases its index of refraction by 6.7 dB. This right-shift in hurricane convection is highlighted in Figure 3 (lower left). A cross section shows that the interstitial regions (between the cores) have a weak bright band, suggesting the presence of some snow crystals and little riming.

The strength of the bright band in the offshore feeder band of Georges becomes more obvious in a comparison with the bright band of an eyewall of Georges over Hispaniola, and a bright band of a trailing stratiform region in the Amazon (Figure 3). Over land the hurricane stratiform region shows not only a weaker bright band, but also a broader Z spectrum, and a slower decay with height above the bright band. In other words their characteristics are close to those of stratiform regions of convective origin (e.g. in the MCS over the Amazon), except for the broadening of the Z profile and the maintenance of high Z values below the bright band. Reflectivity often decays below the freezing level in MCS stratiform regions, on account of the mesoscale subsidence there.

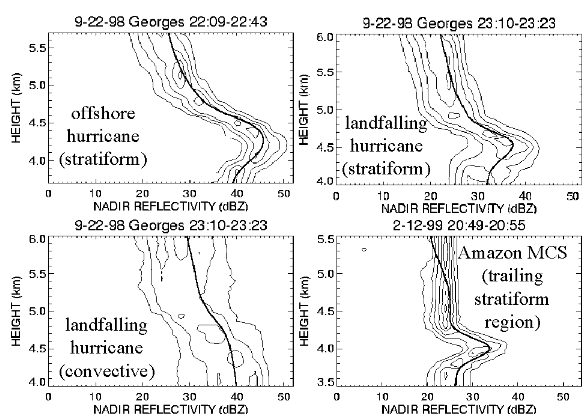


**Figure 3**. *Bright band comparisons. The height range of these CFADs is just 2 km. The upper two CFAD profiles are from hurricane Georges, offshore (left) and onshore (right). The left upper and lower profiles correspond with Figures 1 and 2, respectively. The*

*lower right profile is based on the trailing stratiform region of a small MCS in Rondonia, Brazil.*

## 4. SUMMARY OF RESULTS

### 4.1 Stratiform regions

These examples of Georges, and data from other flights over Georges and Bonnie, suggest that in a maritime environment, far from deep convection in the eye-wall or in spiral bands, hydrometeor concentrations above the freezing level are much lower than those below, indicating weak updrafts and a dominance of warm rain processes. There is a linear, rapid decay of Z of about -7 dB/km above the bright band. This explains the observed high minimum 85 GHz brightness temperatures, above 220 K, over offshore hurricane rainbands (as in stratiform regions of marine MCSs [McGaughey and Zipser 1996]). The Z spectrum is narrow and the melting layer is very bright (e.g. a 14 dB decrease above the bright band, and a 7 dB decrease below).

Upon landfall, Z profiles are still 'bottom-heavy', but deeper, more curved, broader and decaying less rapidly. In the case of Bonnie on 8/26/98 (just prior to landfall), a poorly defined double eyewall was present, and a CFAD of both eyewalls shows a blend of stratiform and (less prevalent) convective signatures. Also, the melting layer becomes less bright upon landfall (e.g. a decrease of 10/5 dB above/below the bright band).

### 4.2 Convective regions

Convective regions as sampled in Georges as well as in Brazil (not shown) not only have high Z values aloft and higher cloud tops (implying a low 85 GHz brightness temperature), but also a broad Z distribution spectrum between the freezing level and the anvil. This spectrum is often bimodal, blending convective-core and stratiform ice size spectra. The convective cores have a curved Z profile, while the immediate surroundings have stratiform characteristics, such as a linear Z profile and a weak bright band. This bimodal distribution is present in many very short sections, as short as 4.5 km (the TRMM PR footprint). Many updraft cores near the eyewall of Georges and Bonnie, especially at upper levels, appear to be close to the resolution of EDOP in diameter. Therefore a significant portion of the vertical drafts is not included in updraft statistics such as those for intense hurricanes by Jorgensen et al. (1985). Another implication is that TRMM PR pixels labeled as convective may contain a mixture of truly convective and more stratiform parts. This has implications on the interpretation of precipitation and cloud microphysical algorithms. This will be illustrated by means of a comparison of several TRMM PR pixels with similar Z profiles over hurricane Bonnie. In reality these pixels range from weakly convective to stratiform.

It remains to be determined how the high-reflectivity cores (above the freezing level) correlate to the vertical motion at the resolution of EDOP. Using ground-based radar data over central Florida, Yuter and Houze (1995) suggest that updrafts and high reflectivities tend to coincide at high levels, but the correlation is weak.

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