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Raindrop Size Distributions and Radar Bright Bands in California Coastal Orographic Storms

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1. INTRODUCTION

Profiling radar observations of precipitation in northern California's coastal mountains by the CALJET experiment during the strong El Niño winter of 1997-98 revealed new insights about microphysical properties of the region's orographically-forced precipitation. Data from S-band precipitation profilers showed that, although these storms extended above and below the freezing level, they often did not exhibit the radar melting layer bright band (BB) that is usually characteristic of midlatitude winter storms. Yet these non-bright band (NBB) situations contributed substantially to the region's record-breaking winter precipitation that year, even though they were generally shallow and commonly passed beneath the coverage of the nearest NEXRAD radars.

PACJET, the ongoing follow-on to CALJET, collected new S-band profiler data in 2003 in the same area, this time augmented with raindrop disdrometer and polarimetric scanning radar measurements. This article presents preliminary analyses of the 2003 observations, which corroborate and clarify some of the earlier findings.

2. CALJET FINDINGS

White et al. (2003) correlated data from a tipping bucket rain gauge and a collocated S-band precipitation profiler at Cazadero, CA, during the 1997-98 El Niño winter. The site is in the coastal mountains at 0.475 km MSL and about 10 km from the coastline. Two distinctly different precipitation regimes were observed, which produced similar rainfall rates (~ 4 mm/h) that winter. Using the S-band reflectivity and vertical Doppler velocity measurements, an objective criteria categorized the half-hourly data into periods that did and did not exhibit a well-defined melting layer bright band.

Figure 1, from the White et al (2003) article shows the full-season compilation of S-band data for these two regimes, in terms of normalized contoured frequency by altitude diagrams. Profiles from the BB cases are distinguished by a sharp increase of Doppler velocity and a peak of reflectivity just below the 0°C level, while the NBB cases show only gradual changes with height. The BB profile is a common characteristic of mid-latitude storms where melting snowflakes produce the bright band.

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The implication is that a markedly different precipitation formation process is at work in the NBB cases, where either ice is entirely absent aloft or, at least, large snowflakes are absent.

White et al (2003) showed further that the NBB cases contributed 28% of the record breaking winter season rainfall at this coastal mountain site, and although average rainfall rates were the same, the NBB rain exhibited about 8 dB less radar reflectivity than the BB cases. This, and the observed weaker Doppler velocities, implies that the NBB rainfall was composed of fewer large drops and greater concentrations of small raindrops, a situation for which the standard Z-R relation used by the WSR-88D (NEXRAD) surveillance radars underestimates rainfall. The NBB cases were also shallower, often existing entirely below the lowest sweeps of the nearest NEXRAD radars located about 150 km away. Thus, these important rain producing NBB cases are typically mis-handled or missed entirely by NEXRAD and represent a handicap for operational forecasters.

3. PACJET-2003 OBSERVATIONS

The same S-band profilers were operated in January-March 2003 at the Cazadero mountain site and on the coastline at Fort Ross, CA, about 12 km farther south. The profiler is an enhanced version (White et al. 2000) of the original, with an expanded dynamic range to avoid saturation in heavy rain and to detect a substantial portion of non-precipitating cloud. Joss-Waldvogel raindrop disdrometers operated along side the profilers at both locations. A scanning, polarimetric X-band radar (Martner et al. 2001) also operated at Fort Ross, in addition to rain gauges, a surface meteorological station, and a radiosonde launch station.

Figure 2 shows unedited data from the S-band profiler and disdrometer for a 24-h period at Fort Ross on 13 January 2003, during a four-day storm that dropped 5 inches of rain at this coastline site. Three periods between 0000 and 1100 UTC have a well-defined BB near 3 km MSL in the profiler's time-height image of signal-to-noise ratio. Simultaneous data from the disdrometer shows that these BB periods were characterized by larger but less numerous raindrops compared with the period after 1200 UTC when the larger drops disappeared but small drops were far more numerous. Rainfall rates computed from the measured drop size spectra show that about 40 mm of rain accumulated from four bursts of heavier (10-20 mm/h) rain associated with the BB periods. An additional 20 mm accumulated much more gradually over the last 12 hours in a prolonged period of 1-3 mm/h of NBB rainfall.

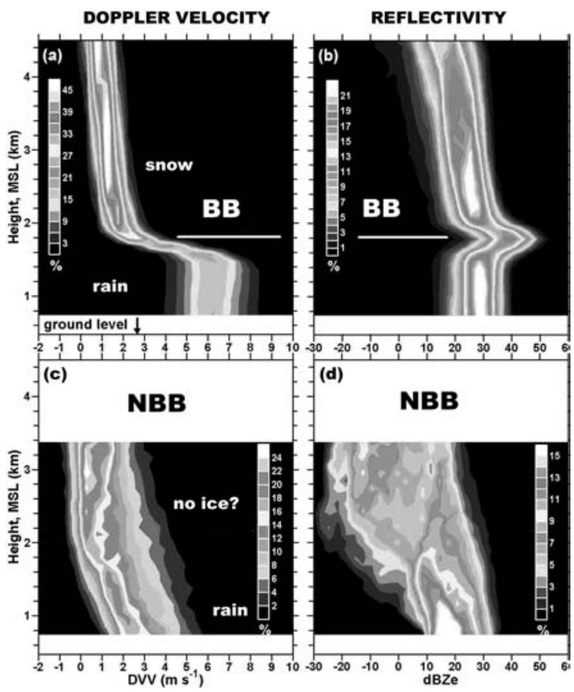

Figure 1. Height-normalized composite of S-band profiles of reflectivity and vertical Doppler velocity from the entire CALJET winter season showing distinct differences in bright band (top) and non-bright band (bottom) cases. The average rain rate was 4 mm hr^{-1} for each composite. After White et al. (2003).

Figure 3 compares drop size spectra for 1-minute periods of BB and NBB rainfall to illustrate the microphysical differences. The bright band spectra contained considerably larger drops. However, the NBB spectra had much greater concentrations of small drops. This agrees with the inferences drawn by White et al (2003) based on Doppler spectra data from the profiler, but without the corroborating evidence of drop size spectra from a disdrometer. In the ongoing analysis, all of the 2003 data and disdrometer data from some earlier years will be stratified into BB and NBB categories using the objective profiler data criteria of White et al (2003) to more fully quantify the relationship between drop sizes and bright bands in these storms.

Meanwhile, other noteworthy features were immediately observed in the field in 2003. The X-band polarimetric radar at Fort Ross interrupted its scans every 12 minutes to obtain 1 minute of high temporal resolution (8 beams/s) vertical data for comparison with the S-band (1 beam /15 s). Figure 4 shows consecutive time-height images from the X-band real-time display, separated by 12 minutes. It can be seen that the bright band appears (and later vanished) over two cycles (24 minutes). The bright

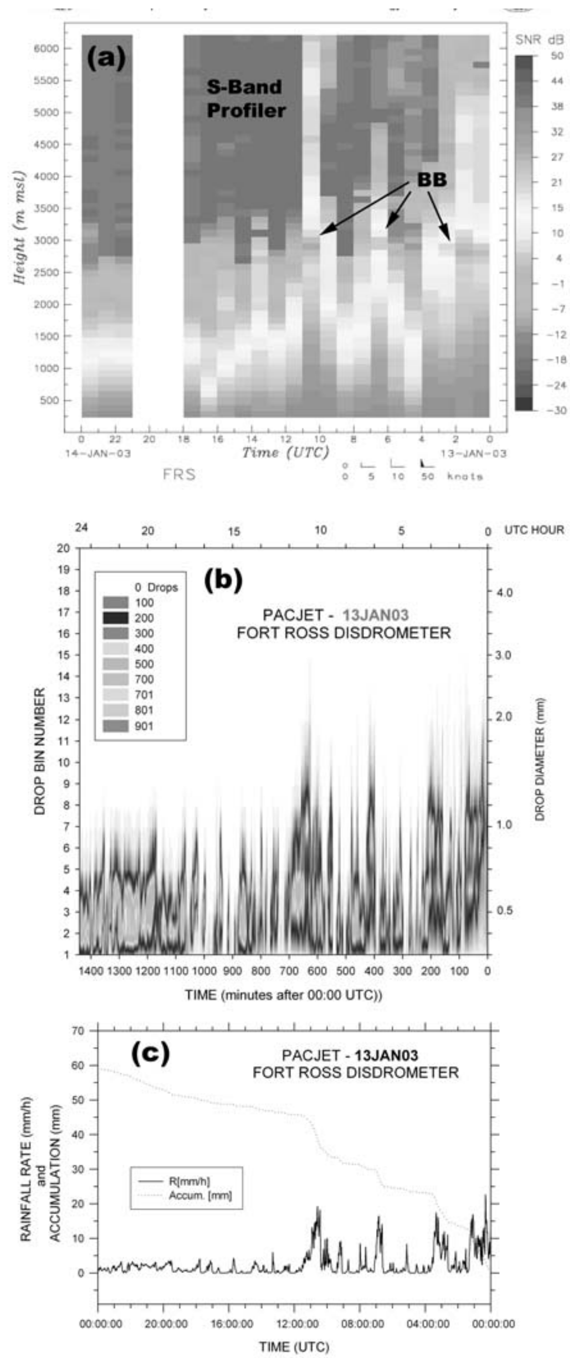

Figure 2. Twenty-four hours of data from the Fort Ross site on 13JAN03, including (a) time-height image of signal-to-noise ratio from the S-band profiler, (b) contours of the number of drops as function of diameter and time from the disdrometer, and (c) rainfall rate and accumulation from the disdrometer.

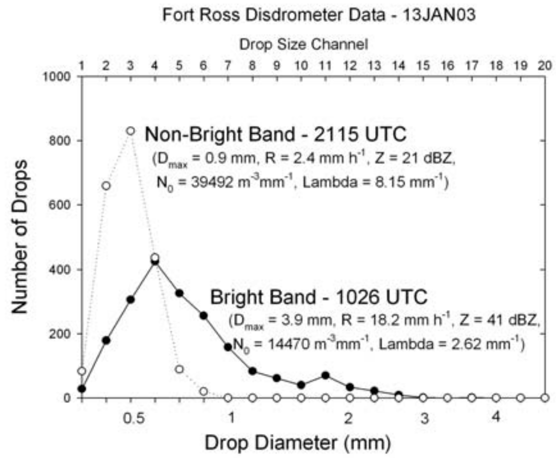

Figure 3. Drop size spectra from the disdrometer for two 1-minute periods during bright-band and non-bright-band periods of rainfall.

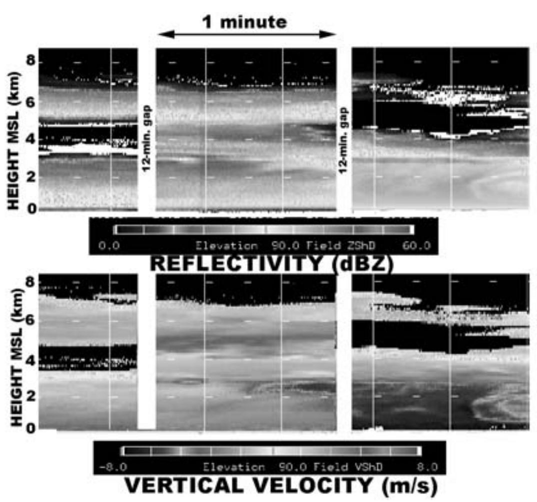

Figure 4. Three short periods of vertical data from the X-band radar on 13JAN03 between 1002 and 1029 UTC showing rapid development of the bright band as a higher cloud moved over the persistent lower stratus at Fort Ross. Time proceeds from left to right in each panel.

band was present during and just after the passage of deeper echo tops. The transient and deeper character of the BB periods were common features in the 2003 X-band vertical data. Furthermore, the X-band's RHI scans (not shown) revealed that the most pronounced bright bands were located beneath fall streaks originating from higher echo layers or cells.

From these observations, we suggest that bright bands arise in these coastal storms, at least some of time, from a seeder-feeder situation. When a higher cloud layer drops ice crystals into an underlying shallow, but supercooled, stratiform cloud, the precipitating crystals from aloft grow in the lower layer by riming and deposition and melt as they continue downward through the 0°C level. In the absence of an overpassing seeded cloud, the persistent but shallower underlying feeder cloud layer generally lacks the larger ice crystals needed to produce a radar bright band and larger raindrops. In this scenario, the NBB is simply a period when the feeder cloud lacks a seeder cloud partner. From the CALJET evidence, this happened frequently during El Niño storms. Deep, contiguous clouds also provide the necessary conditions for BB formation. Future analysis of data from three PACJET winters will determine whether the CALJET statistics were typical or unusual.

The X-band radar's polarimetric capabilities will also be used with data from its RHI scans to classify particle types over the S-band/disdrometer sites in 2003. The primary goal of this work will be to determine whether or not ice crystals are present in the NBB cloud echoes above the 0°C level. The analysis will examine particle identification using differential reflectivity (Z_{DR}) and/or a new method for estimating circular depolarization ratio (CDR) from this radar's polarimetric basis of simultaneous transmission- simultaneous reception of horizontal and vertical polarizations, as described by Matrosov (2003). Figure 5 is an example of the application of this method to data from an RHI scan through a deep, bright-band-producing cloud at Fort Ross on 16 February 2003. The decreasing CDR values with increasing elevation angle are characteristic of rimed dendritic crystals, which are very suitable for producing prominent bright bands upon melting.

Another feature noted from the X-band radar's realtime data displays during the Pacjet-2003 was the fact that the nearest NEXRAD radars commonly failed to detect the shallower precipitation echoes approaching the Fort Ross area from the ocean. Figure 6 is a clear example of

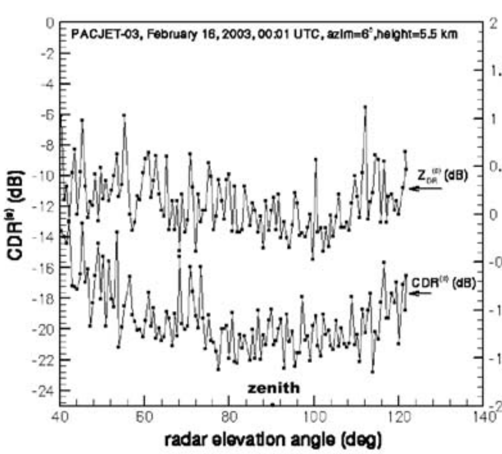

Figure 5. Differential reflectivity (Z_{DR}) and circular depolarization ratio (CDR) estimate for an RHI scan by the X-band radar through a deep BB-producing cloud .

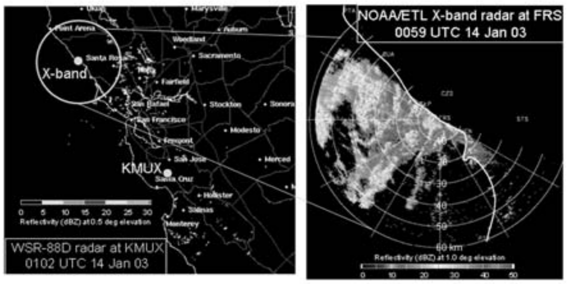

Figure 6. Comparisons of scan images from the San Francisco NEXRAD (left) and the PACJET X-band radar (right) at Fort Ross showing the shallow precipitation echoes that passed beneath the NEXRAD coverage.

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this on 14 January 2003. The San Francisco NEXRAD (KMUX) detected no precipitation in the area, while the X-band radar, from its close-proximity vantage point at Fort Ross, detected widespread showers moving onshore. As noted by White *et al.* (2003), this problem occurs because the nearest NEXRADs (San Francisco, Sacramento, and Eureka) are so far away that their lowest sweeps (0.5° elevation) are more than 3 km above sea level in this area. Intervening mountains worsen the situation by blocking the low beams of the Sacramento radar.

Unfortunately, as has been shown, these shallow echoes, which are often NBB situations, cannot be safely neglected by forecasters. They are persistent and produce significant amounts of rain, even exceeding flood warning thresholds in some cases. Deficiencies in NEXRAD coverage at lower altitudes is caused by the wide spacing of radars, Earth curvature, and by terrain blockage. It is a common problem, especially in the western states (Westrick et al. 1999). One solution is to add relatively inexpensive "gap-filler" Doppler radar systems to fill these coverage holes in crucial locations. The X-band radar at Fort Ross demonstrated this possibility in an area of especially poor NEXRAD coverage that is also prone to flooding, and it begins to reveal the magnitude of the precipitation missed in these voids.

4. SUMMARY AND CONCLUSIONS

PACJET-2003 disdrometer and S-band profiler data are being partitioned into rainfall periods with and without a radar melting level bright band (BB and NBB, respectively). Preliminary analysis of data from the Fort Ross coastline site corroborates the earlier CALJET diagnosis based on radar data alone, in that the appearance of a bright band is usually associated with relatively sparse concentrations of larger raindrops at the surface, whereas the NBB periods have much greater concentrations of small drops. The NBB rainfall is less intense but more steady and prolonged, and it usually falls from regions with shallower echo tops. The X-band data show that a bright band can appear, vanish, and reappear in a matter of minutes. It is suggested that NBB periods often arise when a persistent, shallow feeder cloud is not receiving larger ice crystals falling from over-passing seeder cloud cells. It is commonplace for extensive rain echoes in NBB situations to arrive at the coastline beneath the coverage of the regional NEXRAD radars, thereby eluding the attention of NWS forecasters.

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