10.12 AIRBORNE DOPPLER RADAR OBSERVATIONS OF THE MAP SOP IOP14 (3 NOVEMBER 1999) CONVECTIVE STORMS OVER THE APENNINE MOUNTAINS

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1. INTRODUCTION

Heavy rain producing slow moving mesoscale convective systems (MCSs) over mountainous terrain can produce disastrous flooding events. The interactions between convective storm circulations and complex topography that produce heavy precipitation are largely undocumented. During the MAP SOP on November 3, 1999 (IOP14) both the NOAA P-3 and NCAR Electra aircraft (both equipped with airborne Doppler radar, Jorgensen et al. 1983) observed convective storms and stratiform precipitation along the coastal plain and inland slopes of the Apennine Mountains in east-central Italy. Analyses of storm kinematic and radar reflectivity structure are presented which illustrate the basic system airflow and dynamics.

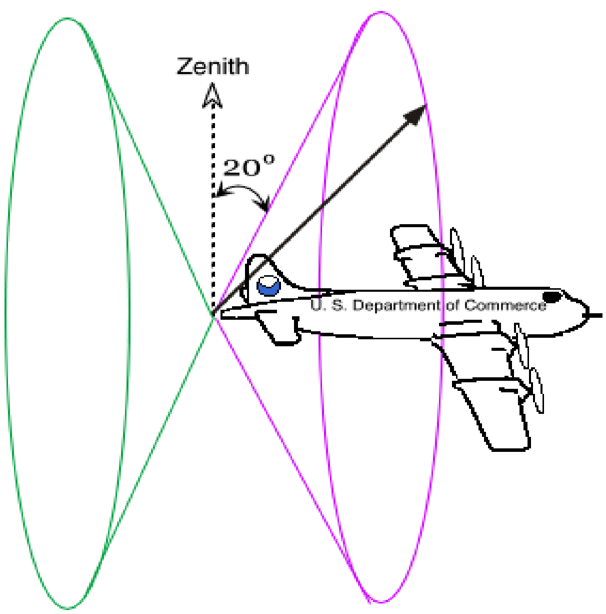

Fig. 1. Scanning geometry of the NOAA P-3 Doppler radar. The antenna scans alternatively looking forward and then aft 20° from the aircraft. Aircraft motion caused the beams to intersect. Where the beams intercept, a horizontal wind estimate can be made.

The NOAA P-3 aircraft's airborne Doppler radar (Fig. 1) is an X-band, vertically scanning radar (using the French-built "flat plate" antenna) that uses a batch-mode "staggered pulse-repetition frequency (PRF)" technique to extend the unambiguous radial (Nyquist) velocity using two PRFs (Jorgensen et al. 2000). The two PRFs used in this study were 3200 and 2133 s^{-1}, which produced an extended Nyquist interval of 51.4 m s^{-1}. Processor dealiasing mistakes and second-trip ground return were removed using the NCAR SOLO radar editing software package. Ground clutter was removed using an automated procedure that compared the locations of each range bin to a high-resolution (30 second) digital topographic database (Yu, personal communication). Following SOLO editing, three-dimensional winds were constructed using the pseudo-dual-Doppler methodology described in Jorgensen et al. (1996). The Doppler data was interpolated to Cartesian grids with a spacing $\Delta x = \Delta y = 1.5$ km and $\Delta z = 0.5$ km. The vertical grid levels were constructed relative to mean sea level (MSL). Vertical velocity is estimated from vertical integration of horizontal divergence estimates. The integration is from the top of the echo (where w=0 is assumed) to the surface, which is defined by the high-resolution digital topographic database. An O'Brien (1970) divergence correction is made to the vertical column to insure that w=0 at the ground.

The maximum range of the radar is about 45 km, which represents a maximum time displacement between intersecting fore and aft scans of about 4 minutes. During that time, as well as for the duration of each flight leg that comprises the complete volume scan, the weather within the analysis domain is assumed to be "stationary". For IOP14, the P-3 flew 16 flight leg segments in and around precipitation region during the day of 3 November. The typical flight leg lengths were about 10-15 minutes, which represents about 80-120 km in horizontal distance. Prior to beginning the box patterns the aircraft deployed a dropwindsonde over the Ligurian Sea upstream of precipitation. During the flight the strongest storms moved down the coast at about 5 m/s, presumably associated with the advancing cold front.

2. KINEMATIC STRUCTURE DETERMINED BY THE AIRBORNE DOPPLER RADAR

The P-3 flew "box" flight patterns roughly centered on the crest of the Apennine mountains.

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Figure 2 shows the topography of the Apennine mountains along with the P-3 track from 1200-1214 UTC, a flight track that ran nearest to the strongest convective cells and down the mountain slope. This flight track segment was close to the cold frontal location. Highest topographic within the psuedo-dual-Doppler analysis domain was about 2.2 km MSL.

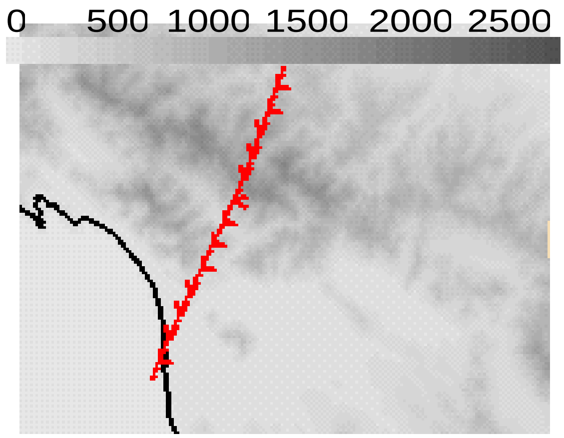

Fig. 2. P-3 flight track overlayed on the topography (m) of the Apennine Mountains within the dual-Doppler analysis domain shown in Fig. 3. Topography scale is at top.

Ground relative horizontal winds and reflectivity derived from the airborne pseudo-dual-Doppler analysis at 2 km MSL is shown in Fig. 3. A broken convective line was present near the P-3s flight track running roughly NE to SW. Substantial low-level convergence was seen along the leading edge of this convective line. At 2 km, the flow was generally from the south to southeast into the line, although the flow was perturbed near the leading edge. To the rear of the convective line (to the NW of the flight track) the flow was predominantly southerly, although as the flow approached the higher terrain it was again perturbed and tended to flow around the highest terrain near x=40, y=90. Maximum reflectivity in the convective cells was generally confined to the lowest levels and was ~52 dBZ, typical for thunderstorms of moderate intensity.

A vertical cross section (Fig. 4) is shown to illustrate the low level flow as it interacted with the topography. The cross section runs approximately north-south from near the coast to the higher terrain. Strong convective cells were seen along the coast and the coastal plain and again near the foothills of the mountains. Along the crest of the mountain ridge more stratiform rain, characterized by a "bright band" of enhanced reflectivity near the freezing level, was seen. Predominant flow was onshore, with the winds strengthening with height until the very top of the clouds. There was a weak indication of off shore, or downslope flow at the lowest levels. Wind vectors of 3-5 m/s are seen at the first grid level moving away from the mountains. This magnitude of flow is qualitatively similar to what was seen at 500 m MSL by the aircraft in-situ data during its descent sounding just off shore. Since there were storms along the coast, indeed offshore at times, this convection was not due to orographic lifting. It is probable that the precipitation near to the steep slopes of the Apennines were aided by orographic lifting of the onshore. General upward motion is seen in the flow below 2 km MSL as it impinged on the mountains. General lifting of the air is seen near the slopes to about the cloud tops.

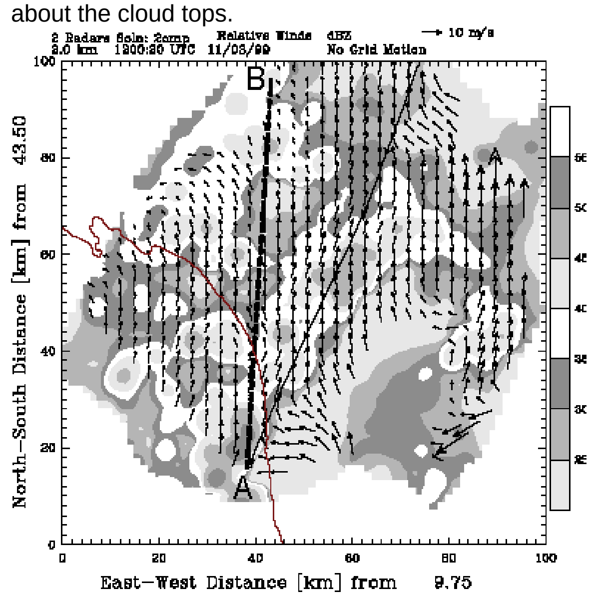

Fig. 3. Horizontal earth-relative winds and reflectivity field at 2.0 km AGL from the airborne pseudo-dual-Doppler analysis. P-3 flight track is shown as the solid line running through the center of the plot from roughly NNE to SSW. Thick solid line labeled "A-B" represent the location of a vertical cross section shown in Figs. 4.

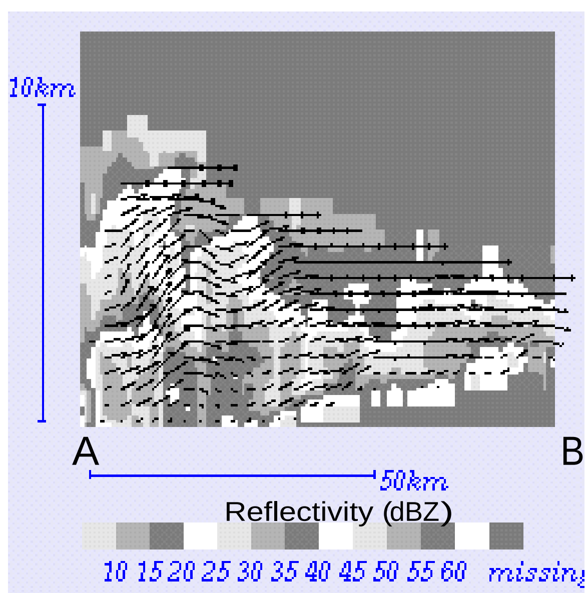

Fig. 4. Vertical cross section of ground relative wind and reflectivity along the line marked "A-B" in Fig. 3. The cross section runs from the Ligurian Sea on the left through the mountain crest on the right.

3. PARTICLE TRAJECTORIES, SCHEMATIC STRUCTURE, AND A POSSIBLE FEEDER-SEEDER MECHANISM

We hypothesize that airflow and precipitation particles detrained from the convective cell tops from the strong storms along the coast move northward in the prevailing southerly flow and perhaps contributed to the precipitation generation on the mountain slopes and crest. This type of precipitation generation mechanism is similar to “seeder-feeder” (Houze et. al. 1981) mechanisms in warm-frontal rainbands since the upper particles seed the lower layer of cloud, which, in this case, is presumably being generated by orographic lifting. Air and hydrometeor trajectories (Fig. 5) were calculated from the Doppler-derived 3-D wind fields to illustrate the feasibility of the “seeder-feeder” mechanism. Air parcel motion was traced over an hour from a region entering the convective storm at low levels to exiting at upper levels. From the exit region, particle trajectories were traced to where they intersected the ground. With realistic terminal fallspeed-radar reflectivity relationships (Jorgensen et al 1996), Fig. 5 illustrates the feasibility of hydrometeors originating in the upper level detrainment region of the convective storms along the coast falling through the orographic cloud producing a seeding effect which would act to enhance the precipitation.

A schematic illustration of the hypothesized air and hydrometeor motions based on the Doppler wind analysis is shown in Fig. 6. The top panel is a hypothesized horizontal depiction of the topography (700 m elevation contour shown in purple) and precipitation cell locations. A vertical cross section from approximately south to north along the line labeled A-B is shown in the bottom panel. Shallow downslope (and offshore) flow aids the development of convective storms along the coast.

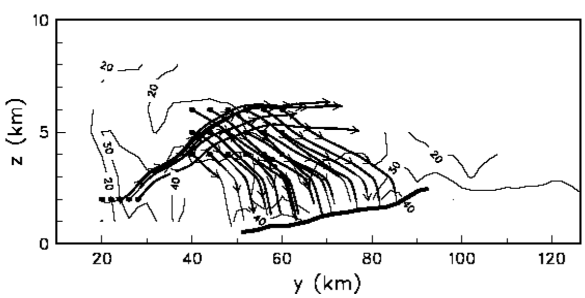

Fig. 5. Vertical cross section of rising air trajectories initiated at x=44 km, z=2 km, that rose up to at least 4 km. Downward lines are hydrometeor trajectories using a terminal fall speed-reflectivity relationship from Jorgensen et. al (1996). Background contours are radar reflectivity (dBZ). The thick solid line indicates topography.

4. SUMMARY

Airborne Doppler radar data collected by the NOAA P-3 during the MAP SOP IOP14 (November 3 1999) flight mission has been analyzed to illustrate the structure of the precipitating convection. It is possible that heavy precipitation on the southern Apennine slopes and higher terrain crests was aided by a “seeder-feeder” mechanism from the outflow of precipitation particles from the storms along the coast and near the slopes.

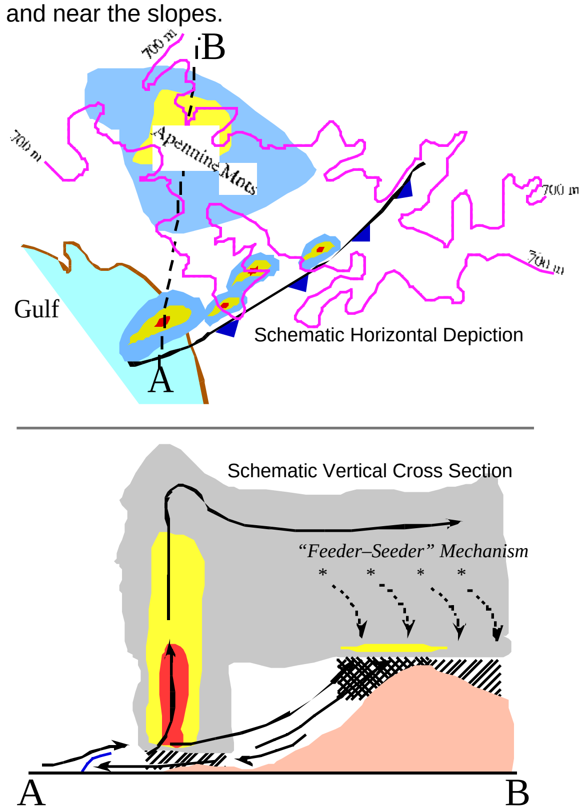

Fig. 6. Schematic illustration of the “Feeder-Seeder” mechanism.

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