1B.6 AIRBORNE DOPPLER OBSERVATIONS OF A COLD FRONTAL SYSTEM ENCOUNTERING THE EASTERN ALPS DURING MAP IOP5

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1. INTRODUCTION

Earlier studies have suggested the ability of orographic effects to produce precipitation in both prefrontal and postfrontal regions (Browning et al. 1974; Hobbs et al. 1975). Owing to the precipitation produced by the orographic effects usually embedded within the large-scale frontal precipitation, one of the major difficulties for these earlier studies was to distinguish orographically induced precipitation from the precipitation that was associated with baroclinic forcings. This in turn prevented from a clear identification of mesoscale processes resulting in the modification of frontal precipitation by topography. With the recent observations of dual-Doppler radars, the detailed three-dimensional airflow and precipitation structure in the vicinity of fronts have been revealed. Several articles have further provided observational evidence that the distortion of the low-level frontal zone by mountains as well as the orographic blocking effect played an important role in strongly modify precipitation at and ahead of the fronts (Braun et al. 1997; Colle et al. 1999; Yu and Bond 2002). However, given the variability of environmental conditions associated with fronts and topography, our understanding on this scientific topic is still largely incomplete.

In this study, airborne Doppler radar measurements from the Special Observing Period of the Mesoscale Alpine Programme (MAP) was used to examine the detailed airflow and precipitation structure associated with a south-north oriented cold frontal system as it moved eastward and encountered the eastern Alps near the border of northeastern Italy and Slovenia on 4 October 1999. Topography over the study region is oriented approximately northwest-southeast (with a peak mountain height of ~2500 m), and exhibits, however, significant variation in terrain height along the mountain ranges (cf. Fig.1). A distinction of the present case from foregoing mentioned studies is that its accompanying prefrontal environment at low levels was characterized by a more convectively unstable atmosphere. We will show the different types of precipitation occurring within the frontal system, which were highly related to the orographic features and their interaction with synoptic flow.

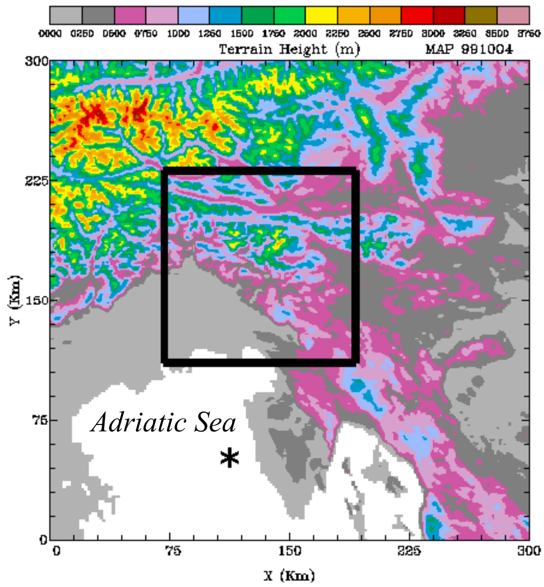

Fig. 1. Topography (shading scale at top) over the eastern Alps. The box outline (120 X 120 km^2) marks dual-Doppler analysis domain.

2. PRECIPITATION AND AIRFLOW STRUCTURE IN THE VICINITY OF FRONT

The airborne Doppler radar data processing in this study is following the procedures outlined by Yu et al. (2001). The detailed three-dimensional airflow and precipitation in the frontal and mountainous region is obtained by use of a pseudo-dual-Doppler synthesis derived from multiple-view radial velocity data as described by Jorgensen and Smull (1993). The horizontal and vertical analysis grid spacing were set to 1.5 km and 0.25 km, respectively, over a volume encompassing 120 ×120 km^2 in the horizontal and 12 km in the vertical. The location of dual-Doppler analysis domain is shown by the inset box in Fig. 1.

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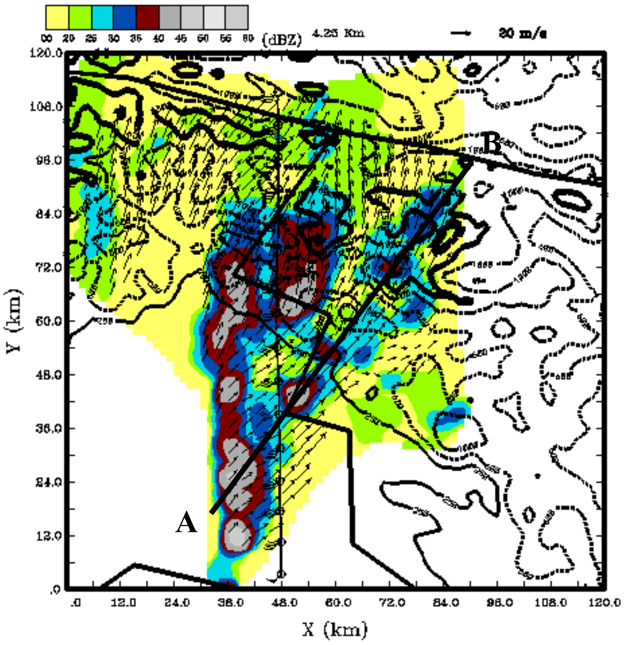

Fig. 2. Ground-relative wind vectors and radar reflectivity (dBZ, shading key at upper left) at 4.25 km MSL derived from the airborne dual-Doppler analysis at 0720 UTC 4 October 1999. NCAR Electra flight track is shown as the solid line and selected flight-level measured winds indicated by wind flag are also shown. Thick line segment A-B marks location of vertical cross section shown in Fig.3.

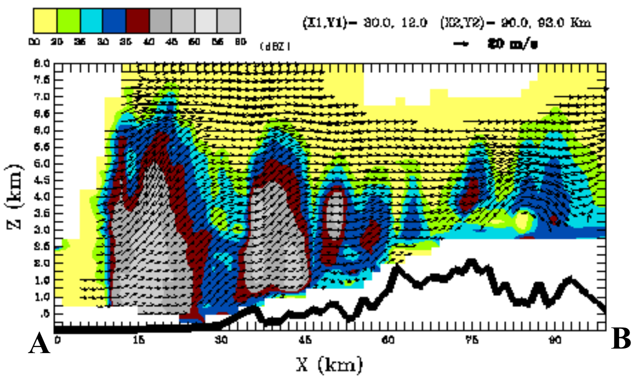

Fig. 3. Vertical cross section of dual-Doppler-derived ground-relative winds and radar reflectivity (dBZ, shading key at upper left) along A-B in Fig. 2. Heavy solid line in lower-right portion of the figure indicates height of topography along the section.

As viewed by a sequence of ground-based radar observations at Fossalon (location near the lower left corner of the analysis domain), precipitation associated with the frontal systems rapidly intensified after ~0500 UTC 4 October 1999 while the upper-level deep trough approached the eastern edge of the Alps. About 2-3 hours later, the frontal precipitation developed into a highly organized feature, characterized by a narrow but intense band extending from the inland sloped terrain to a location well far upstream of topography over the northern Adriatic Sea. During this period, dual-Doppler synthesis results indicated that the mesoscale precipitation pattern over the northern portion of the front (i.e., near the southern slope of eastern Alps) exhibited two primary modes. One was oriented south-north, with a narrow zone of high radar reflectivities marked by multiple centers of very heavy precipitation (maximum ≧ 45 dBZ). This narrow band coincided with the low-level frontal wind shift zone and was thus interpreted to be a narrow cold-frontal rainband (NCFR). However, as revealed by dual-Doppler synthesis results derived from a series of flight legs, the NCFR became disorganized and dissipated rapidly in the following 2 hours as the eastward-moving front encountered the relatively low terrain (i.e., the lower right portion of the analysis domain), where was occupied by the cold northerly flow. The second distinct mode of precipitation evident in Fig. 2 was located ahead of the front and oriented approximately parallel to the prevailing southwesterly flow. This precipitation band was less organized (compared to the narrow cold-frontal rainband), and the convective cells along the band were present upwind of the highest terrain and in regions of steepest windward slopes. A vertical cross section running through these prefrontal cells and the narrow cold-frontal rainband indicated the convective nature of these convective activities (Fig. 3). In particular, low-level winds associated with the prefrontal convective cells were predominately upslope flow. The position of the prefrontal cells was also found to roughly coincide with that of calculated maximum vertical motions forced by the mountains slopes (not shown). The results suggest the significance of upslope lifting on the triggering of these prefrontal convective cells.

3. STRATIFORM PRECIPITATION OVER MOUNTAINS

As evident in Fig. 2, a wide region of stratiform precipitation was present over the higher terrain near the northern end of the narrow cold-frontal rainband. Observations indicate that this stratiform rain persisted about 4 hours during and after the passage of the surface front. As shown by dual-Doppler synthesis results from a later time at 1027 UTC (Fig. 4), widespread stratiform precipitation still existed over the windward slopes and mountain crests. A vertical cross section approximately normal to the orientation of mountain ranges indicated that the stratiform precipitation was associated with the low-level mesoscale convergence between southwesterly flow and the northerly flow originated to the north side of the Alps (Fig. 5). The region of heaviest stratiform precipitation was just located slightly downstream of this flow boundary. Examination of other vertical cross sections over the dual-Doppler analysis domain indicates not all of the northerly flow from the north of the Alps could flow over the mountain ridges and meet the southwesterly flow south of the Alps (not shown). It is suggested that such variation of the northerly flow over the windward slopes contributed to different intensity of observed precipitation [i.e., enhanced (reduced) reflectivities over the lower (higher) terrain] as evident in Fig. 4.

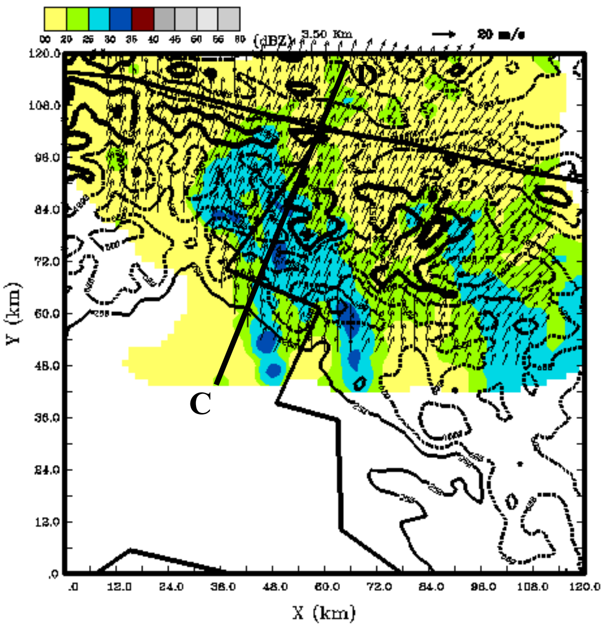

Fig. 4. As in Fig. 2 except showing dual-Doppler synthesis results at 1027 UTC 4 October 1999. Thick line segment C-D marks location of vertical cross section shown in Fig. 5.

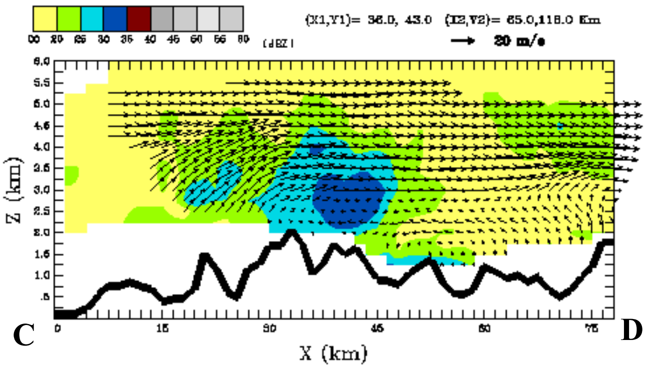

Fig. 5. As in Fig. 3 except showing vertical section along C-D in Fig. 4.

4. CONCLUSIONS

Analyses of airborne Doppler radar measurements collected during MAP IOP5 have suggested at least two distinct types of precipitation mechanism, as illustrated schematically in Fig. 6. The "upslope triggering" mechanism contributed to the triggering of relatively short-lived deep convective cells in the prefrontal region. The observed location of these prefrontal cells was closely related to the steepness of the mountain slopes. Over the regions of the prefrontal convective cells, the northerly flow appeared to be blocked locally north of the mountains and thus no obvious northerly downslope flow was observed over the windward slopes. The other precipitation mechanism, "windward slope convergence", contributed to the maintenance of a more persistent and widespread stratiform precipitation over the mountainous region during and after the passage of the surface front. This type of forcing appeared to be more pronounced and caused stronger precipitation rate in regions of less steep and lower mountains which permits the northerlies to flow over mountain and converge with the low-level prevailing southwesterly flow over the windward slopes.

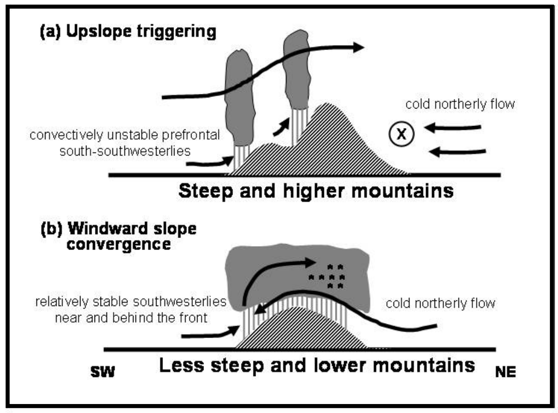

Fig. 6. Schematic vertical cross section depicting two different precipitation mechanisms ("upslope triggering" in upper panel and "windward slope convergence" in lower panel) identified by airborne Doppler observations on 4 October 1999 during MAP IOP5. This section is oriented approximately southwest-northeast normal to the orientation of the mountain barrier.

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REFERENCES

Braun, S. A., R. A. Houze, Jr. and B. F. Smull, 1997: Airborne dual-Doppler observations of an intense frontal system approaching the Pacific Northwest coast. *Mon. Wea. Rev.*, **125**, 3131-3156.

Browning, K. A., F. F. Hill, and C. W. Pardoe, 1974: Structure and mechanism of precipitation and the effect of orography in a wintertime warm sector. *Quart. J. Roy. Meteor. Soc.*, **100**, 309-330.

Colle, B. A., C. F. Mass, and B. F. Smull, 1999: An observational and numerical study of a cold front interacting with the Olympic Mountains during COAST IOP 5. *Mon. Wea. Rev.*, **127**, 1310-1334.

Hobbs, P. V., R. A. Houze, Jr, and T. J. Matejka, 1975: The dynamical and microphysical structure of an occluded frontal system and its modification by orography. *J. Atmos. Sci.*, **32**, 1542-1562.

Jorgensen, D. P., and B. F. Smull, 1993: Mesovortex circulations seen by airborne Doppler radar within a bow-echo mesoscale convective system. *Bull. Amer. Meteor. Soc.*, **74**, 2146-2157.

Yu, C.- K., F. Roux, and D. P. Jorgensen, 2001: Airborne Doppler observations of a convective system over the eastern Alps during MAP IOP5. *Preprints*, 30th International Conference on Radar Meteorology, Munich, Germany, 530-532.

Yu, C.- K., and N. A. Bond, 2002: Airborne Doppler observations of a cold front in the vicinity of Vancouver Island. *Mon. Wea. Rev.*, **130**, 2692-2708.