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PRECIPITATION IN THE SOUTH EAST ALPS – MAP SCIENTIFIC CONCLUSIONS REVIEW

Tomaž Vrhovec*, Jože Rakovec
University of Ljubljana, FMF, Slovenia

Gregor Gregorič
Environmental Agency of Slovenia, Meteorological Office, Ljubljana, Slovenia

Stéphanie Pradier, Michel Chong, Frank Roux
Laboratoire d' Aérologie CNRS- UPS Toulouse, France

Stefano Micheletti
Osservatorio Meteorologico Regionale dell'ARPA FVG, Visco UD, Italy

ABSTRACT

The main results concerning orographic precipitation in the SE Alps can be summarized:

1. The majority of precipitation in the SE Alps is often recorded before the cold front reaches the area as heavy convection is triggered by forced ascent over steep southern slopes of the Alps and as the warm air lifts above the level of free convection. This situation is persistent (from some hours to one or two days). The precipitation maximum of the whole Alps is located in the SE Alps (the Julian Alps in Friuli Venezia Guilia and Slovenia) and it exceeds the maximum in Ticino and northern Piedmont
2. The cold front from the west was – in the most expressed MAP case IOP 5 – marked by a squall line. At the same time as the cold front was moving across the Po plain, the cold air was already flowing around the eastern Alps in the lower layers of the atmosphere and over the ridges of the Julian and Dinaric Alps. With two cold fronts (a shallow one from the East and a "deep" one from the West, the warm air was orographically occluded and squeezed out towards the south.
3. A very dense network of recording rain gauges (about 10 km distance) was a big improvement in comparison to the operational setup, but in the areas of the highest precipitation accumulation gradients it should be still denser. Spatial interpolation methods for precipitation were tested on MAP data and for daily values the statistical methods gave good results while for hourly precipitation their results were not better than simple mathematical interpolations. Additional data would be needed especially in the areas of the maxima and of the strongest gradients.
4. Fossalon radar in Friuli Venezia Giulia proved to be a very useful tool for monitoring the precipitation in the SE Alps but the radar shadows from the first Alpine ridges lead to heavy underestimation of precipitation in the core region of the Julian Alps.
5. The aircraft missions revealed the wind structure of the cold air from the east moving across the Alpine ridges and its contribution to the forced ascent of the SW warm conveyor belt in front of the cold front from the West. The squall line of the IOP 5 (Oct. 5. 1999) is a good example of orographically modified leading edge of cold flow moving along the south side of the Alps.
6. Several modeling studies revealed that meso-beta processes(~ 100 km) contribute a great deal to the precipitation distribution the South of the Alps and that topographic convergence in this scale is responsible for location of the precipitation maxima. The smaller scale topography, its slopes and altitudes, is further modifying the precipitation distribution. The location of triggering regions for convection is determined with even smaller scale (~1 – 3 km) and use of the radar data can help with nonhydrostatic modeling for lead times up to some hours.

* Corresponding author address: Tomaž Vrhovec, University Ljubljana, FMF, Dept. Physics, Jadranska ul 19, SI1000 Ljubljana, e-mail tomaz.vrhovec@uni-lj.si

1. INTRODUCTION

During MAP SOP (Sept. 7. – Nov. 15. 1999) the South East Alps were chosen as secondary - "mission" area for the »wet« MAP (P1 – Orographic precipitation). The area of the Julian and Karnic Alps is known (Frei and Schaer 1998) as an area of climatological precipitation maximum in the Alps. During MAP SOP in the SE Alps area there was a network of additional automatic rain gauges and the Friuli Venezia Giulia radar in Fossalon was operational (Kastelec and Vrhovec 2000). Several research flights with P3 and Electra research aircraft were performed (Pradier et al. 2002). In MAP SOP one excellent and several good precipitation cases occurred in the area. The time distribution of precipitation during MAP SOP is depicted on Figure 1. Comparing the MAP SOP precipitation with the climatology (September – November, 1961 – 1990) for the area (Table 1) we can deduce that MAP SOP in 1999 was close to the climatological pattern.

Table 1. Number of days with precipitation exceeding daily threshold in the SE Alps for September – November 1961 – 1990 and MAP SOP.

Daily	climatology		MAP SOP
	mean	max.	
1 mm	32	58	25
20 mm	12	21	15
40 mm			9
80			6

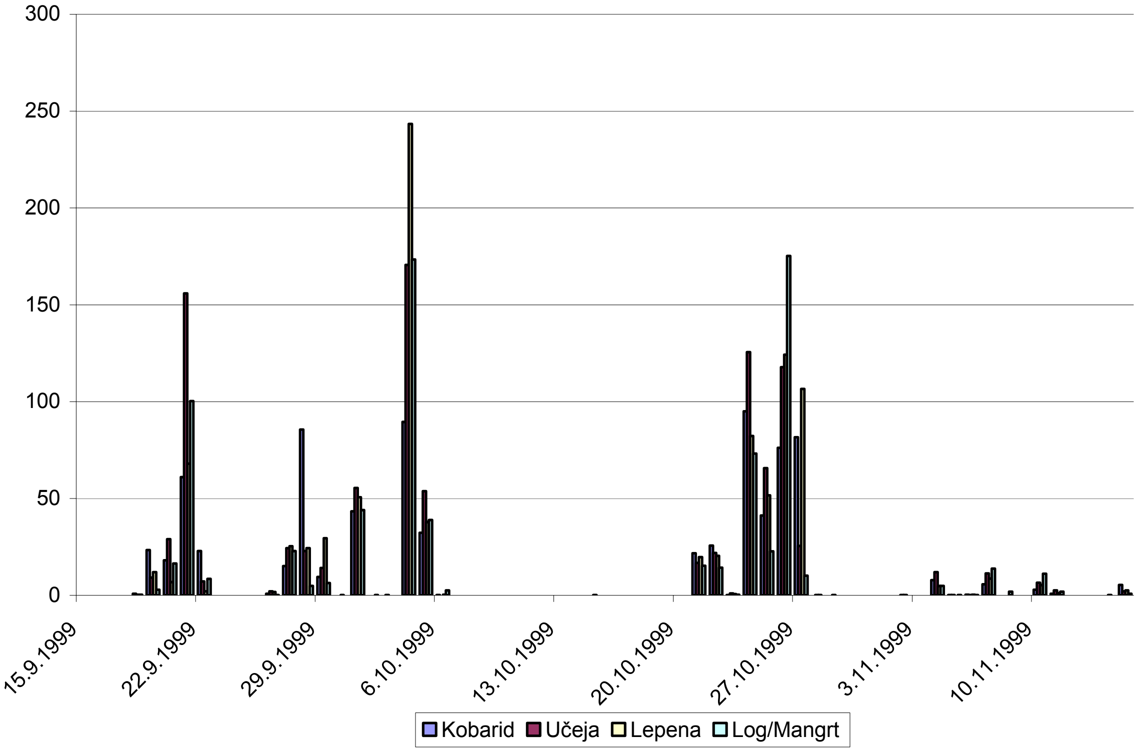

Figure 1. Daily accumulations of precipitation for 4 stations in the SE Alps for MAP SOP.

The most intense precipitation event in the SE Alps during MAP SOP was IOP 5 (Oct. 3-4. 1999), but also IOPs 2b (Sept. 22.), 9 and 10 were strong. Detailed studies of MAP IOP 5 were published by Cheng et al. (2001), Pradier et al. (2002) and Vrhovec et al., (2004a). Several other studies concerning MAP SOP in the SE alps were published in the proceedings of various MAP – meetings (2000 - 2004), International Conferences on Alpine Meteorology (2001, 2003) and AMS Mountain Meteorology Conferences (2000, 2002).

2. LOCATION OF PRECIPITATION MAXIMUM

The climatic precipitation maximum of the whole Alps is located in the SE Alps (the Julian Alps in Friuli Venezia Guilia and in Slovenia) and it exceeds the “western” maximum in Ticino and northern Piedmont (Frei and Schaer 1998). But the Ticino mountains are higher - up to 4500 m – while the SE Alps reach up to 3000 m. Both regions have steep south mountain slopes and both regions have concave topography. There is also a convex shape of Trentino mountains bulging soutwards between them (Figure 2).

The majority of precipitation in the SE Alps is often recorded before the cold front, associated with the Mediterranean cyclone, reaches the area (Vrhovec et al. 2001, Vrhovec et al., 2004a). Heavy prefrontal convection is triggered by forced ascent over steep southern slopes of the SE Alps and as the warm and moist air lifts above the level of free convection. This situation is persistent (from some hours to one or two days).

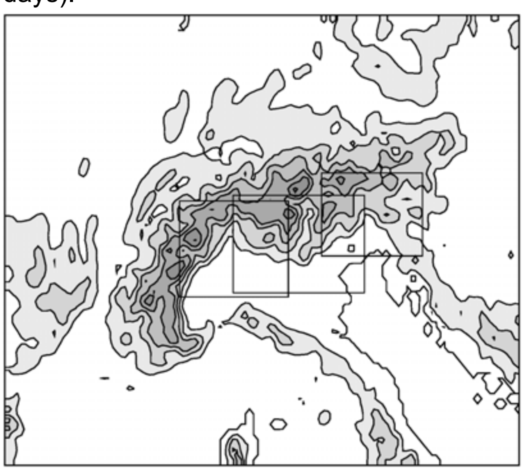

Figure 2: Relief of the Alps in a 10 km resolution and with 500m-spaced isohypses and the three sub-regions at Alps south side: Ticino (west), Trentino (centre), and Julian Alps (east) (from Rakovec et al. 2004)

The stable flow characteristics were studied (Rakovec et al. 2004) for idealized Alpine topography (as in Figure 3), similiar to the topographies used by Schneidereit and Schaer (2000), but with or without the southwards protruding bulge of Trentino Mts. and with or without Dinaric Alps (Figure 3), as well as for the similar modifications of the realistic relief (Figure 2).

In simulations with idealized relief with both, the Dinaric Alps and the Trentino Mts. (Figure 3, upper panel), the stable SW flow splits before reaching the Trentino Mts. and flow converges into Ticino and somewhat less intense also into the SE Alps. Due to the Dinaric Alps there is a perpendicular deflection of basic SW flow along the winward Dinaric slopes creating a barrier jet. There is no deflection if the Dinarides are removed (Figure 3, bottom panel). So the W Alps and Trentino Mts. cause convergence of stable south flow into Ticino and the Dinaric Alps and the Trentino Mts. are the main factor of flow convergence in the SE Alps.

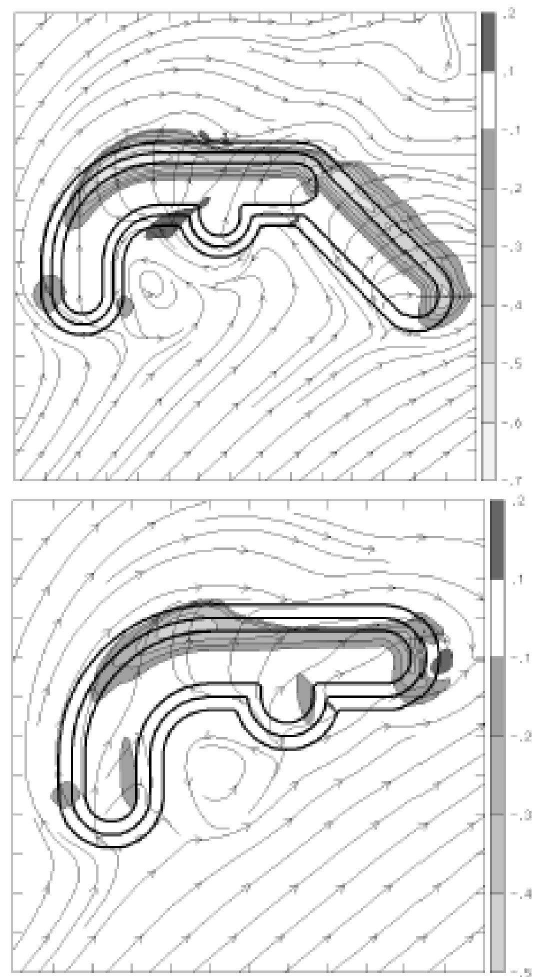

Figure 3. Vertical velocity (shaded contours, c.i. 0.1 m/s) and streamlines at z=50 m for stable southwesterly flow for two different idealized Alps. Height contours every 500 m (from Rakovec et al. 2004).

For less stable cases the effect of concavity and of horizontal convergence is less evident. The majority of precipitation events on the south side of the Alps are associated with weakly stable moist S to SW flow. There were 15 such cases during MAP SOP and all of these days were simulated using hydrostatical models (like ALADIN) or nonhydrostatical models (like MM5 or Meso-NH). Simulating these 15 events with a nonhydrostatic model MM5 and aggregating precipitation we showed (Vrhovec et al. 2004b) that simulated precipitation corresponds well with the observed ones (Figure 4).

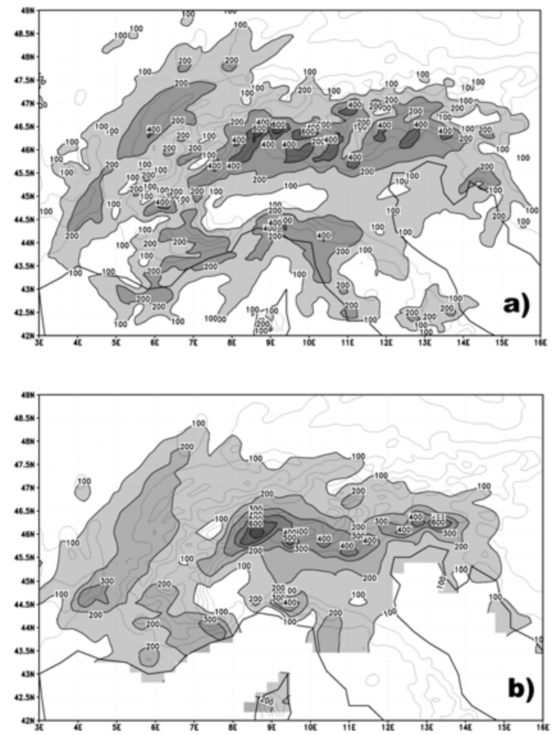

Figure 4. Total precipitation accumulation for the selected 15 days of MAP SOP a) simulated for real topography, b) observed and interpolated into 25 grids (from Vrhovec et al. 2004b).

The influence of topography shapes was studied in the scale above 200 km using both, idealized and real relief (Vrhovec et al. 2004). The case of idealized arc-shaped Alps including the Trentino Mts. (as in Figure 3, lower panel) causes a precipitation maximum in Ticino and to the south of Trentino with a drier gap in-between. Adding further the Dinaric Alps (1000 m lower than the Alps proper, as in Figure 3, upper panel), precipitation in concave region of the Julian Alps was significantly increased.

Also the real topography was modified with removal of either the Trentino Mts. or the Dinaric Alps.

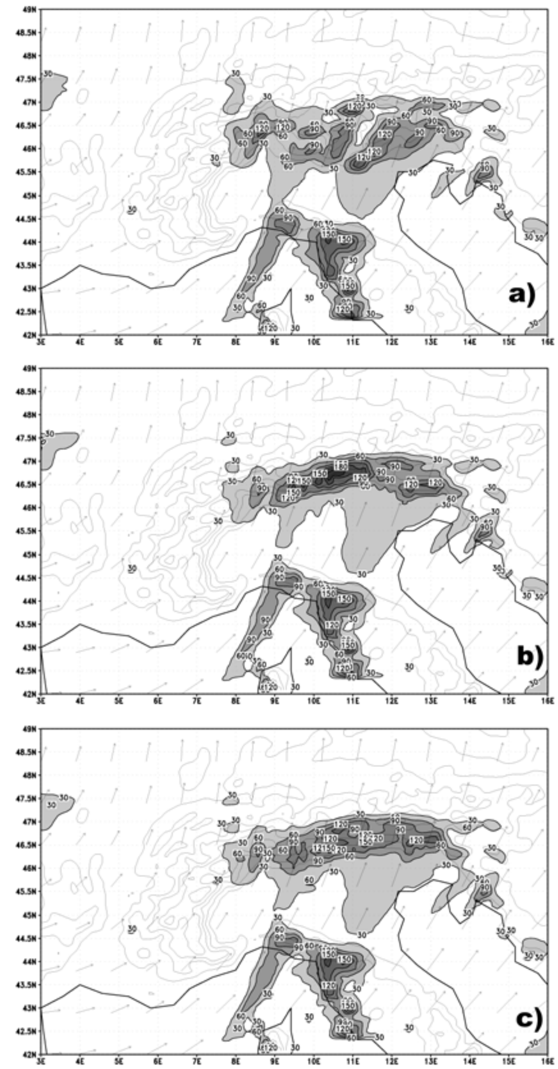

Figure 5. Simulated 24 h precipitation accumulation for IOP 2b Sept. 20. 1999 a) for real topography, b) for the Trentino Mts. removed with steep slopes, c) same as b) but with twice as gentle slope in Trentino. The wind vectors denote 24 h mean wind at every tenth grid point at 500 hPa (from Vrhovec et al. 2004b).

When the convex Trentino Mts. are removed (Figure 5b) new uniform and concave slopes form all along the south Alps. This modification cause a significant increase of precipitation in the modified shape of topography. To test the influence of the steepness of the slopes were the slopes of the modified area made in two versions: one with twice as steep slopes as original and the other with the same topography gradient as the original. Precipitation is weaker for approximately one third over the gentler slopes (Figure 5c), while convergence of the horizontal wind becomes organized in an elongated belt ahead of the foothills in both cases. On that basis we estimate that about one third of precipitation increase in the new Trentino can be attributed to the increased, and the rest to the removal of the convex bulge.

The removal of the Dinaric Alps replaced concave region of the original topography with a convex. In this case the precipitation maximum located in the Julian Alps disappeared, as flow was no more forced to converge in this region. When we were using the real topography, both concave regions on the south side of the Alps (Ticino and the Julian Alps) got their precipitation maxima.

The 15 MAP SOP cases are representing a typical autumn sample of precipitation periods for the Northern Mediterranean and the Alps with unstable vertical stratification, so flow-over is not inhibited for the most of the atmosphere and just for some days at lower levels some blocking could be expected.

Flow-over regime was strongly modified by a convective activity - for majority of 15 events, especially for the events with the heaviest precipitation like IOP 2b, IOP 5 and IOP 8 thunderstorms and squall line were reported (Rotunno and Ferretti 2003, Pradier et al. 2002, Richard et al. 2003, Vrhovec et al. 2004a). The convective activity was limited to the locations where direct lifting to the level of free convection was enabled (the mountain crests must be high enough) and so precipitation accumulation was limited to the southern Alpine slopes. It is important to stress that at a 10 km resolution the slopes are still very moderate (10 – 25 m/km) while the slopes in a 1 km resolution are an order of magnitude higher.

To attain lifting of SE flow up to the level of free convection the mountains must be higher than this level. During MAP IOP 5 (Oct. 4-6 1999) the level of free convection was about 1500 m, so the first ridges of the SE Alps were not high enough to trigger the convection and the precipitation accumulation in the Friuli foothills of the Alps was of an order of magnitude lower than it was in the higher Alps, where convection was triggered (Figure 7).

Continous triggering of convection and advection of these thunderstorms across SE Alps was excellenty documented by OSMER FVG radar in Fossalon (Figure 6.)

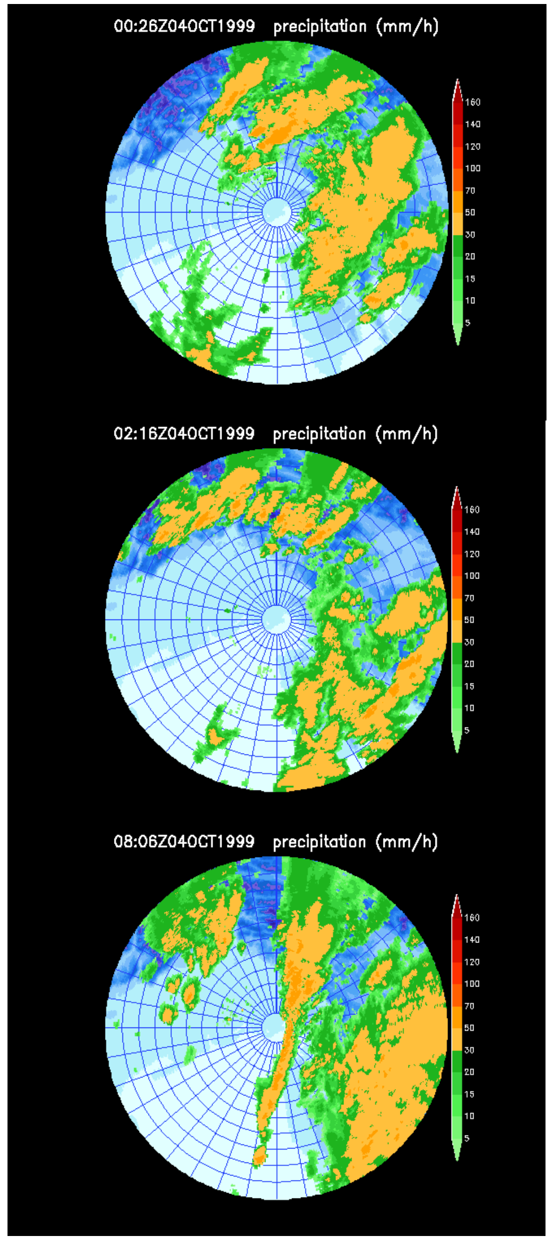

Figure 6. Radar picture from Fossalon radar: upper panel for 4 Oct. 1999 00:26 UTC when prefrontal convection was the most intense, middle for 02:16 UTC with convection limited just to the highest ridges and lower panel when squall line was passing (09:06 UTC).

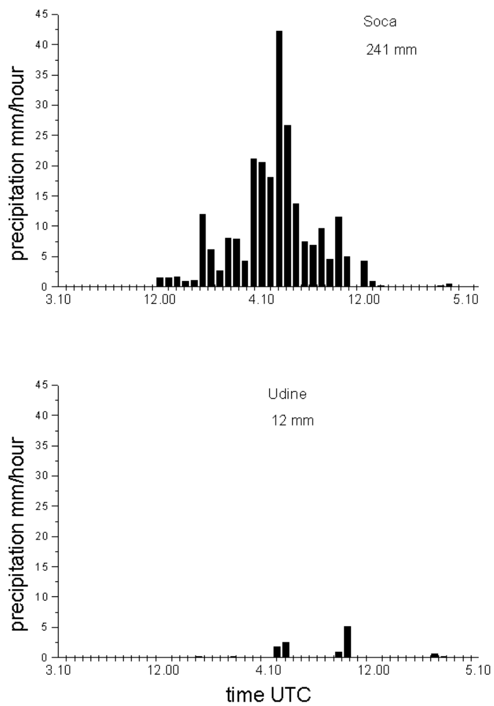

Figure 7. Hourly precipitation accumulation for the stations Soča and Udine for duration of MAP IOP 5, Oct 3 and 4 1999. Udine is located at the foothills of the SE Alps, Soča is in the Alps, along flow distance between the two stations is 40 km (from Vrhovec et al 2004a)

The summarised reasons why the precipitation maximum of the Alps is located in the SE Alps are:

a) Synoptic scale forcing of SW flow associated with the Mediterranean cyclones and their fronts.

b) Steep winward slopes of the mountains

c) No orographic obstacles on the winward side of SE Alps (while to the south of Ticino – before S or SW flow reaches the Alps – are the Apennines).

d) In stable flow cases convergence due to convex shape of topography.

e) In unstable cases convection triggered due to sufficient high mountains so that the level of free convection is attained.

f) The SE Alps are exposed to the SW conveyor belt for longer period of time than Ticino, as the cyclone is formed at the W rim of the Alps and it then moves towards E.

3. INFLUENCE OF FINE SCALE TOPOGRAPHY ON FLOW AROUND THE ALPS

The role of the topography in fine scale was evaluated by examining the airflow and precipitation structure of MAP IOP 5 associated with the convective line from both airborne Doppler radar observations and numerical simulations (Pradier et al. 2002). The north-south Electra flight track between 0720 and 0735 UTC during the early stage of the line clearly identifies two flow regimes consisting of the warm south-southwesterly flow over the flat Friuli-Giulia plain and the Alpine windward slopes, and a cold northerly-to-northeasterly flow confined below 3-km altitude and descending the sloped terrain of the Julian Alps to the north.

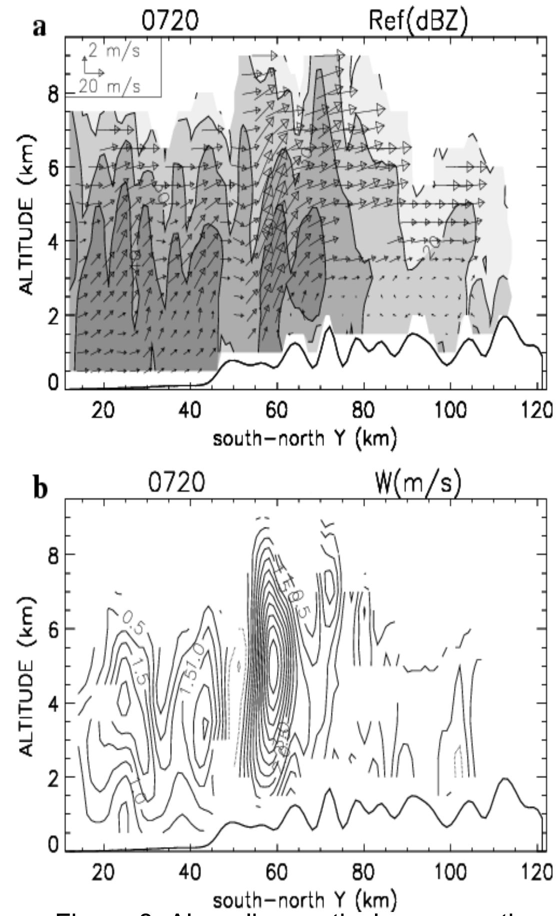

Figure 8. Along-line vertical cross section of (a) radar reflectivity (contours every 10 dBZ) and wind vectors, and (b) vertical velocity (contour interval of 0.5 m s^{-1}) as deduced from airborne Doppler radar observations at 0720-0735 UTC (from Pradier et al. 2002).

The south-southwesterly flow prevailed within the heavy precipitation line over the plain and the apparent effect of the complex orography was to favor more active cells above the windward slope regions (Figure 8a, upper panel).

The vertical organization of the air motion and precipitation along the convective line reveals a cellular precipitation structure with three well-marked and regularly spaced (~20 km) updraft cores (Figure 8b, bottom panel). The two northernmost updraft cores (at y = 40 and 60 km respectively) occurred over the upslope regions slightly a few kilometers ahead of the maximum slopes of the terrain, and they peaked at 3.5-4 km above the surface. The predominant core at y = 60 km exceeded 5 ms^{-1} at 5-km altitude. These cores resulted from combined effects of low-level convergence of southerly and northerly flow and of orographic forcing. To the north of the most active cell, i.e., to the north of the first elevated mountain peak with the steepest slope at *y* = 72 km, there was an abrupt change in the precipitation and wind. The increase of horizontal flow is a well-known manifestation of orographic effects on airflow passing over a mountain (e.g., Grossman and Durran 1984), but this occurred at upper levels. The updraft outflow air that could detrain northwards may contribute to the observed relatively strong and stratified horizontal flow, in addition to the environmental pressure gradient forces aloft accelerating the flow along parcel trajectories. The transition to stratiform precipitation appears to be due to detrainment of ice particles in the southerly flow and subsequent fallout to the north.

Figure 9 shows the near-surface winds obtained from two 1-km resolution numerical simulations within a domain centered on the Friuli region, but with two different resolutions of the orography, using the Meso-NH model (Lafore et al. 1998). The CTRL experiment (Figure 9a) uses a 1-km topography, while the EXP experiment (Fig. 9b) considers a smooth 9-km topography interpolated onto the model grid.

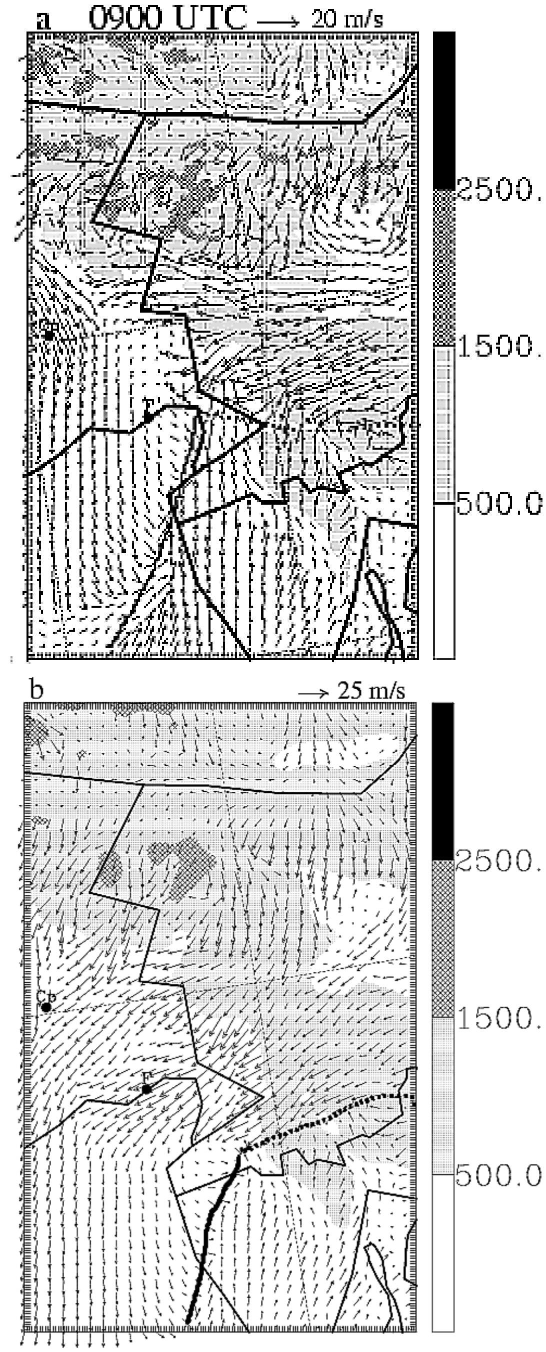

Figure 9. Model-derived fields of near-surface winds at 0900 UTC over the Friuli and Slovenia region, with (a) high 1-km, and (b) smooth 9-km topography resolution. Shaded regions represent terrain heights above 500, 1500, and 2500 m. Heavy solid and dashed lines indicate the cold and warm front locations, respectively (from Pradier et al. 2002).

The flow organization at 0900 UTC and the frontal boundaries marking the eastern and southern edges of the cold air in CTRL and EXP appear quite different, although both experiments predict the line structure of the heavy precipitation (not shown) along the marked narrow convergence line associated with the surface cold front to the south of the Alpine chain. The differences mainly result from the evolution of the convergence line and hence the associated precipitation band depends on the southwestward progression of the cold air that descends from the easternmost Alps. This has an evident impact on the cold front motion. The westward expansion of this northeasterly cold flow, which is an orographically-induced flow wrapping around the eastern end of the Alps, dramatically modifies the cold and warm front positions which are located more eastward and southward in EXP than in CTRL. CTRL and EXP clearly suggest that the finest topography acts as a retarding factor for the northeasterly flow and for the eastward progression of the cold front, and that scales down to 1 km can have a non-negligible influence on the dynamics of frontal systems. These simulation results are confirmed by surface wind analysis performed by Vrhovec et al. (2004a).

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