9.1 INFLUENCE OF SYNOPTIC AND MESOSCALE ENVIRONMENTS ON HEAVY OROGRAPHIC RAINFALL ASSOCIATED WITH MAP IOP-2B AND IOP-8

Yuh-Lang Lin*, James A. Thurman and Sen Chiao
Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC

1. Introduction

In studying several heavy orographic rainfall events that occurred over the southern Alps, Massacand et al. (1998) found that these events were accompanied by an upper-tropospheric high PV anomaly. They proposed that these high PV anomalies act as a precursor because they may: (i) enhance the southerly flow component toward the Alps, (ii) reduce the static stability beneath it, and (iii) trigger or enhance ascent on their forward flank to generate or enhance convection. In investigating heavy orographic rainfall events over the southern Alps, Buzzi and Foschini (2000) found that the following synoptic and mesoscale environments are conducive to heavy orographic rainfall over Alps: (1) strong low-level confluence over the western Alps between the post-frontal southwesterly flow and the pre-frontal southeasterly flow, (2) an 850 hPa pre-frontal low-level jet (LLJ) which serves as a warm conveyor belt, and (3) a deep trough approaching the Alps with an upper-tropospheric, quasi-stationary pressure ridge located to the east. In addition, the Atlas Mountain in North Africa, mountains in Sardinia and Corsica, the Appennines in Italy, and the coastal range to the east of the Adriatic Sea have also played important roles in forming LLJ's toward the Alps (Tripoli et al. 2000). Lin et al. (2001) proposed that these features belong to essential ingredients for heavy orographic rainfall, which have also been observed in other parts of the world, such as the U.S. and East Asia.

In this study, we adopt the PSU/NCAR MM5 model to simulate the heavy rainfall events associated with MAP IOP-2B and IOP-8 to help synthesize the synoptic and mesoscale environments conducive to heavy orographic rainfall over the Alps and understand their formation mechanisms. Three nested numerical experiments have been performed with grid resolutions of 45, 15, and 5 km. For IOP-2B, the simulation was initialized at 00UTC 19 September 1999 with NCEP reanalysis data, and ran for 48 h, while for IOP-8, simulations were initialized at 12UTC 19 October and ran for 60 h. The Kain-Fritsch cumulus parameterization and simple-ice microphysics parameterization schemes were used to represent moist processes, and the Blackadar scheme was used to parameterize the planetary boundary layer processes.

2. Flow Circulation and Rainfall Distributions

Numerical simulations for IOP-2B captured the low-pressure system off the west coast of Ireland (Fig. 1a) and a deep upper level trough over the eastern Atlantic (Fig. 1b). A broad 300 hPa jet was located over Spain with diffluence over the Alps. These simulated flow fields compare well with the NCEP reanalysis fields. When the deep short-wave trough with a strong positive PV anomaly approached the area, the low-level southeasterly, southerly, and southwesterly winds were strengthened. Fig. 2 shows the simulated 48 h accumulated rainfall (mm) for IOP-2B for the period 00UTC 19 September to 00UTC 21 September 1999. The simulated maximum accumulated rainfall is about 300 mm. The MM5 simulated rainfall distribution and amount compare well with observations. Part of the precipitation located to the south of the Alps was related to frontal rain associated with the short-wave trough passage. The precipitation over the southern slopes and the concave region of the Alps was associated with the orographic forcing of convectively unstable air and convergence of the low-level flow from east, south, and southwest.

In contrast to IOP-2B, the dominant moist flow for IOP-8 was more from the southeast off the Adriatic Sea. At 12UTC 19 October 1999, a low-pressure system was located to the west of the Alps over the Bay of Biscay. Twenty-four hours later (12UTC 20 October), a closed low was over the Bay of Biscay (not shown). At upper levels, a jet streak had formed along the Mediterranean coast of France with diffluence over the Lago Maggiore region at 00UTC 21 October. Twelve hours later, the right entrance region was just northwest of Lago Maggiore, possibly providing lifting via upper-level divergence or ageostrophic circulations (not shown). Rainfall totals were not heavy until 36 hours into the simulation (00UTC 21 October). As with IOP-2B, the heavy rainfall area then propagated eastward with the deep trough. The simulated maximum accumulated rainfall is about 140 mm (Fig. 2b), which is significantly smaller than IOP-2B. The simulated rainfall (50-100 mm) over Lago Maggiore region is larger than the observed amount of 20-50 mm. The rainfall extended farther upstream (south) from the Lago Maggiore region.

3. Upstream Orography and Low-Level Flow Characteristics

Fig. 3 shows the surface winds at 00UTC 20 September 1999. The surface winds came from 3 different origins: (i) the easterly low-level jet (LLJ) formed by the coastal mountains flanking the Adriatic Sea and then turned easterly toward the Lago Maggiore region, (ii) the southerly LLJ channeled by the North African Atlas Mountains, the Appennines, and mountains on Sardinia and Corsica surrounding the Tyrrhenian Sea, and (iii) the southwesterly LLJ behind the front (Fig. 3a). Rainfall over the southern slopes of the Alps was produced by convection triggered by convectively unstable flow forced by the orography, while

* Corresponding author Address: Yuh-Lang Lin, North Carolina State University, Box 8208, Raleigh, NC 27695
E-mail: yl_lin@ncsu.edu

the rainfall in the concave (Lago Maggiore) region and upstream (south) of the Alps was mainly produced by the convergence of these 3 LLJ's. The 5-km grid experiment indicates that a vortex formed in the concave area to the southwest of Lago Maggiore region, which may have affected local confluence (Fig. 3b).

A contributing factor to the convective instability associated with IOP-2B was the northward transport of a tongue of high θ_e 850 hPa air from northern Africa over the Lago Maggiore region that started at 12UTC 19 September, as shown from the north-south cross section passing through the Atlas Mountain and Lago Maggiore region (Fig. 4a). For example, this tongue of very hot air can be seen by looking at the contour of $q_e = 328\,K$. This pool of hot air reached Italy at 00UTC 20 September (Fig. 4b). The southern area of the rainfall was just west of this high θ_e flow. The observed and simulated CAPE were 50-100 J kg^{-1} in magnitude in northern Italy. This may imply that conditional instability played a less significant role than the convective instability. This deserves a further investigation.

As previously noted the rainfall for IOP-8 developed as southeasterly flow overran a surface cold layer. A model cross section (Fig. 5b) shows the surface cold layer over the same period as the rainfall (36-48 hours) (See Fig. 2 for the location of the cross section location). The flow coming off the Adriatic Sea rose over this stable cold-air layer on the southern Alpine slopes. The stable cold-air layer may act as an obstacle to the flow, which caused the effective slope and effective height of the mountain to be smaller, and help generate convection further upstream. This may explain why the rainfall amount is significantly less than that in IOP-2B, which has a much stronger convective instability (Fig. 5a). The vortex formed in the concave region of the southern Alps may also contribute partially to the rainfall upstream of the Lago Maggiore region in IOP-8. Another factor, which may affect the different rainfall distributions for IOP-2B and IOP-8, is the moist flow regime. Based on Chen and Lin's (2001) flow regime study, we hypothesize that IOP-8 belongs to the regime with upstream-propagating convective systems, thus helping produce more rainfall upstream of the Alps.

4.Upper-Level Forcing

As mentioned in the introduction, it has been proposed that the upper-tropospheric positive PV anomalies associated with the deep short-wave trough may help trigger ascent on their forward flank to generate or enhance convection produced by orographically induced upward motion (Massacand et al. 2000). The forward flank of the deep trough was able to induce the LLJ's, and the divergence associated with the upper-tropospheric trough or positive PV anomaly appears to be able to help strengthen the low-level upward motion (Fig. 1). The analysis of vertical velocity (w) along a cross section passing through the Lago Maggiore region indicates that the convective systems in both cases (Fig. 5) were developed from low levels over the southern upslope of Alps.

5. Concluding Remarks

In this study, we found that the deep short-wave trough and upstream mountains of the southern Alps helped induce three LLJ's. Strong convergence produced by these LLJ's and the orographic lifting of the convectively unstable flow were responsible for producing the rainfall in the vicinity of the Lago Maggiore region. A tongue of high q_e flow, which originated from North Africa, toward the southern Alps provided highly convectively unstable flow. The observed and simulated CAPE were low over northern Italy. A further study is needed to understand the role played by conditional instability due to the relatively low CAPE. The deep trough or positive PV anomaly seems to be able to induce the LLJ, but there was no apparent intrusion of the high PV air into the convection layer for both IOP-2B and IOP-8 cases. The convective systems developed from the low levels. One interesting connection between the trough system of IOP-2B and the remnants of Hurricane Floyd was found. We hypothesize that the outflow jet from Floyd strengthened the jet of the trough of IOP-2B.

Acknowledgments: This work is supported by the US NSF Grant ATM-0096876.

References

Buzzi, A., and L. Foschini, 2000: Mesoscale meteorologica features associated with heavy precipitation in the southern Alpine region. *Meteorol. Atmos. Phys.*, **72**, 131-146.

Chen, S.-H, and Y.-L. Lin, 2001: Regimes for conditionally unstable flow over an idealized three-dimensional mesoscale mountain. Preprints, MAP Newsletter, **15**.

Lin, Y.-L., S. Chiao, J. A. Thurman, M. L. Kaplan, and T.-A. Wang, 2001: Essential ingredients for heavy orographic rainfall and their potential application for prediction. Preprints, MAP Newsletter, **15.**

Massacand, A., H. Wernli, and H.C. Davies, 1998: Heavy precipitation on the Alpine south-side: An upper-level precursor. *Geophys. Res. Lett.,* **25**, 1435-1438.

Tripoli, G.J., G. Panegrossi, A. Mugnai, S. Dietrich, and E. Smith, 2000: Orographically induced flash floods on the northern Italian coast. *Preprints, Ninth Conf. on Mountain Meteorology,* Aspen, CO, Amer. Meteor. Soc.,336-339.

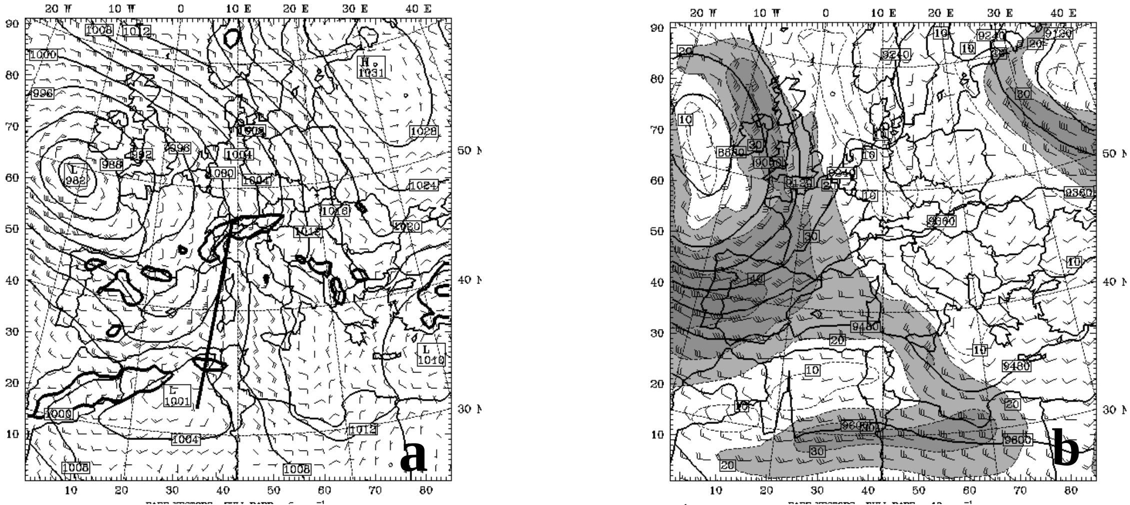

Fig. 1: (a) Sea level pressure (every 4 hPa) and winds (1 full barb=10 ms^{-1}), and (b) 300 hPa heights (every 120 m), isotachs (every 20 ms^{-1}) and winds (1 full barb=10 ms^{-1}) from MM5 45 km grid simulations for 00UTC 20 September 1999. The line in (a) is the location of the cross section for Figure 4.

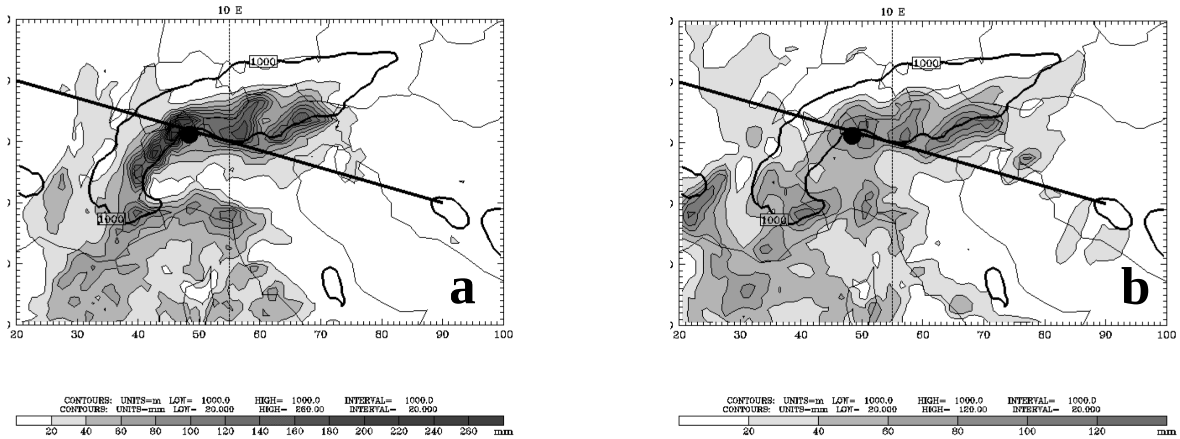

Figure 2. (a) Simulated 48 hour rainfall (mm) for the period 00 UTC 19 September to 00 UTC 21 September 1999 and (b) simulated 60 hour rainfall (mm) for the period 12 UTC 19 October to 00 UTC 22 October 1999. The bold contour represents the 1km terrain contour and the dot denotes the approximate location of the Lago Maggiore area. The line denotes location of cross section in Figure 5.

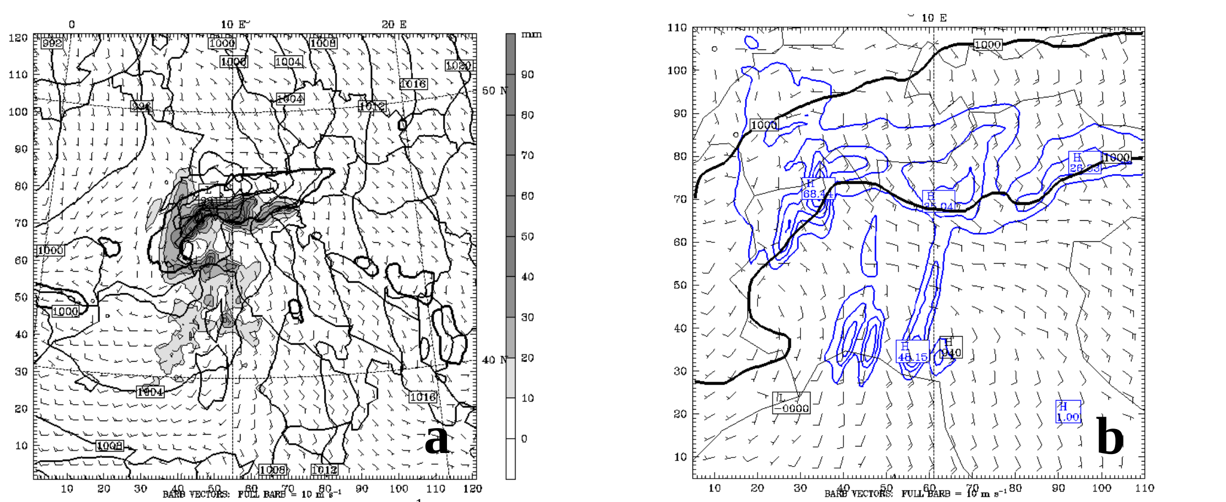

Figure 3. (a) Surface winds (1 barb=10ms^{-1}), sea level pressure (every 4 hPa) and 6-h accumulated rainfall (mm) at 12 UTC 20 September 1999 (IOP-2B) simulated by the 15-km grid, and (b) same as (a) except for 5-km grid and 3-hr accumulated rainfall. No sea level pressure is plotted in (b). Bold contour is 1km terrain contour for both (a) and (b).

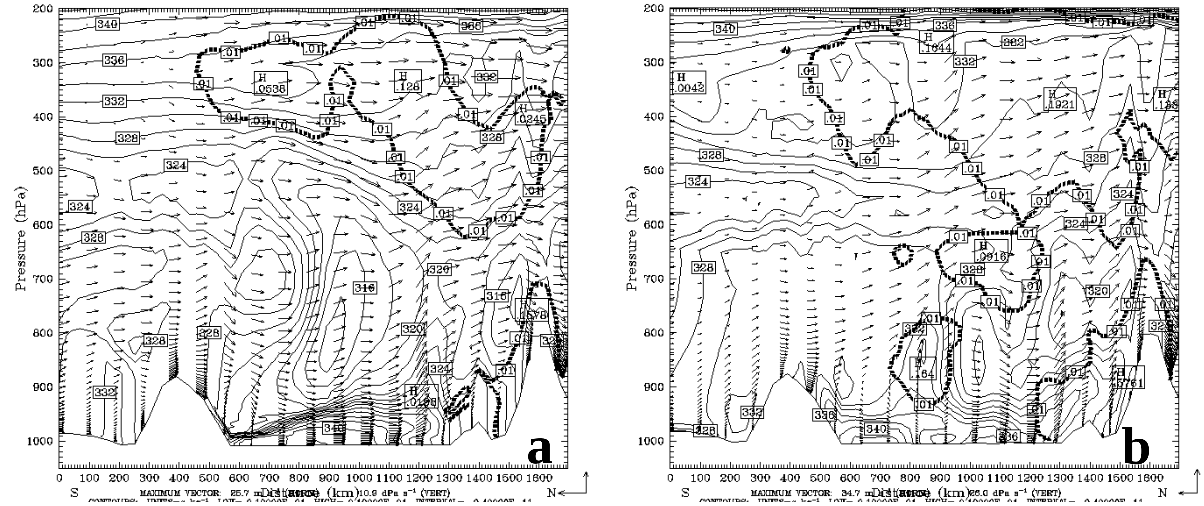

Figure 4. Circulation vectors, and θ_e (every 2K) along a cross section from North Africa to to the Lago Maggiore region (see Fig. 1) for (a) 12 UTC 19 September 1999 and (b) 00 UTC 20 September 1999. The cloud region ($q_v > 0.01$ gkg^{-1}) is denoted by heavy dashed curves.

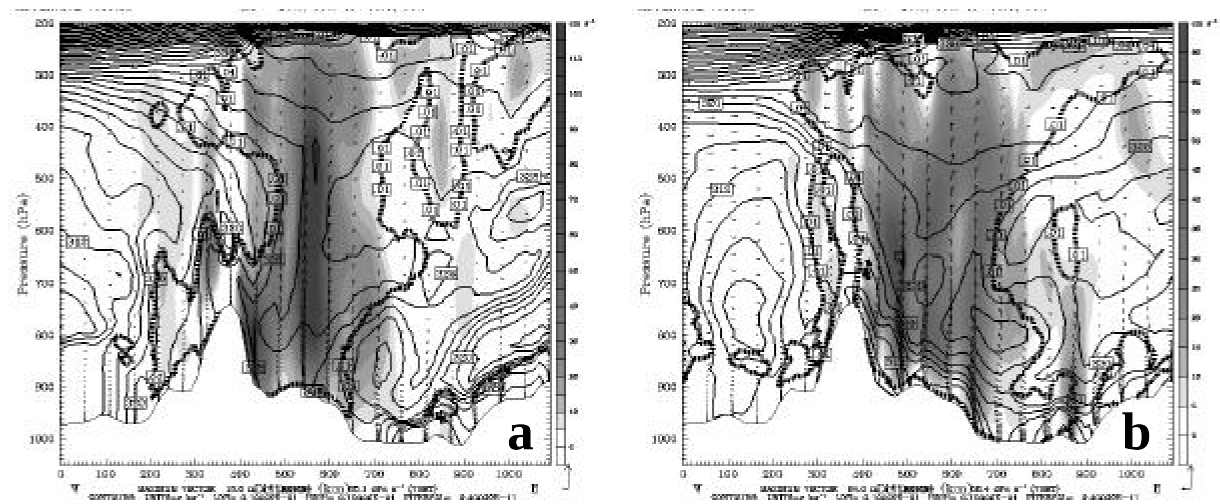

Figure 5. Circulation vectors, θ_e (every 2K), and vertical velocity (cms-1) for a cross section passing through Lago Maggiore (see Fig. 2 for cross section) for (a) 12 UTC 20 September 1999 and (b) 12 UTC 21 October 1999. The cloud region is denoted as in Figure 4.