Orographic Precipitation in Potentially Unstable Alpine Storms: MAP IOPs 2b, 3, and 5

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1. Introduction

Many intense autumn Alpine storms occur ahead of strong baroclinic troughs. This pattern is commonly associated with large precipitation amounts over the southern Alpine slopes since it tends to produce flow with southerly component around 850 mb, i.e. flow perpendicular to the terrain (Massacand et al. 1998). MAP-SOP IOP2b occurred under this synoptic pattern, exhibiting precipitation amounts of more than 250 mm over the western slopes of the Lago Maggiore (LM) area. Medina and Houze (2003) analyzed IOP2b and proposed a conceptual model of the mechanisms that must have accounted for the enhancement of precipitation that occurred on the lower windward slopes of the Alps. They suggested that the weak moist stability of the air approaching the Alps allowed the flow to rise easily and suddenly over the first major rise of terrain. In addition to this rapid rise, the release of the potential instability of the flow produced overturning and caused precipitation particles over the first major peak of terrain to grow rapidly and fallout, thus making the orographic precipitation enhancement very efficient (Smith 1979). The purpose of this paper is to test this conceptual model by determining if similar precipitation mechanisms occurred in IOPs 3 and 5, which also had air of slight potential instability approaching the Alpine barrier.

2. Review of IOP2b

Medina and Houze (2003) found that in IOP2b the atmosphere was potentially unstable below $\sim$700 mb. A Milan sounding taken at 1200 UTC 20 September 1999 showed that the equivalent potential temperature decreased from the surface up to $\sim$700 mb, except in a thin stable layer centered around 800 mb (Fig. 1, solid line). The NCAR S-Pol polarimetric radar showed the detailed precipitation and airflow structures. Figure 2a-c shows a vertical cross section of mean S-Pol radar data during IOP2b (1300 UTC 19 September - 0100 UTC 21 September 1999) in the direction approximately parallel to the low-level wind. The radial velocity exhibited a jet rising abruptly over the first peak of the terrain (Fig. 2a). Thus, the entire layer of the atmosphere rose over the Alpine barrier, efficiently advecting and condensing low-level moisture. A low-altitude precipitation maximum formed over the first peak of the terrain, suggesting that raindrops grew by coalescence (Fig. 2b), probably in the manner suggested by Neiman et al. (2002). In addition, Medina and Houze (2003) found evidence that riming growth occurred above the 0°C level, further promoting the rapid growth and fallout of precipitation on the lower windward slopes. This result was obtained by applying particle identification algorithms to the polarimetric radar data (Vivekanandan et al. 1999). Contours of frequency of occurrence of identified particle types show that graupel tended to occur above the first peak of the terrain, directly above the low-level reflectivity maximum and at the exit of the radial velocity jet (Fig. 2c). The vertically pointing OPRA radar (Yuter and Houze 2003) showed updrafts > 2 m/s, suggesting that the existing potential instability was released when the air was lifted over the mountains, and that convective cells were triggered. With simple model calculations Yuter and Houze (2003) showed that these cells further enhanced the growth of particles by coalescence and riming. Thus, the orographic precipitation enhancement in IOP2b was seen to be the result of air with slight potential instability rising rapidly and forming embedded convective cells over the first sharp rise in the terrain.

3. Other potentially unstable cases: IOPs 3 and 5

MAP-SOP IOPs 3 and 5, like IOP2b, occurred ahead of baroclinic troughs. According to a Milan sounding taken at 0000 UTC 26 September 1999 during IOP3 the atmosphere was potentially unstable from $\sim$975 to 700 mb (Fig. 1, dashed line). The mixing ratio and temperature of IOP3 below $\sim$800 mb were very similar to the values observed in IOP2b (not shown). A cross section of S-Pol radar data

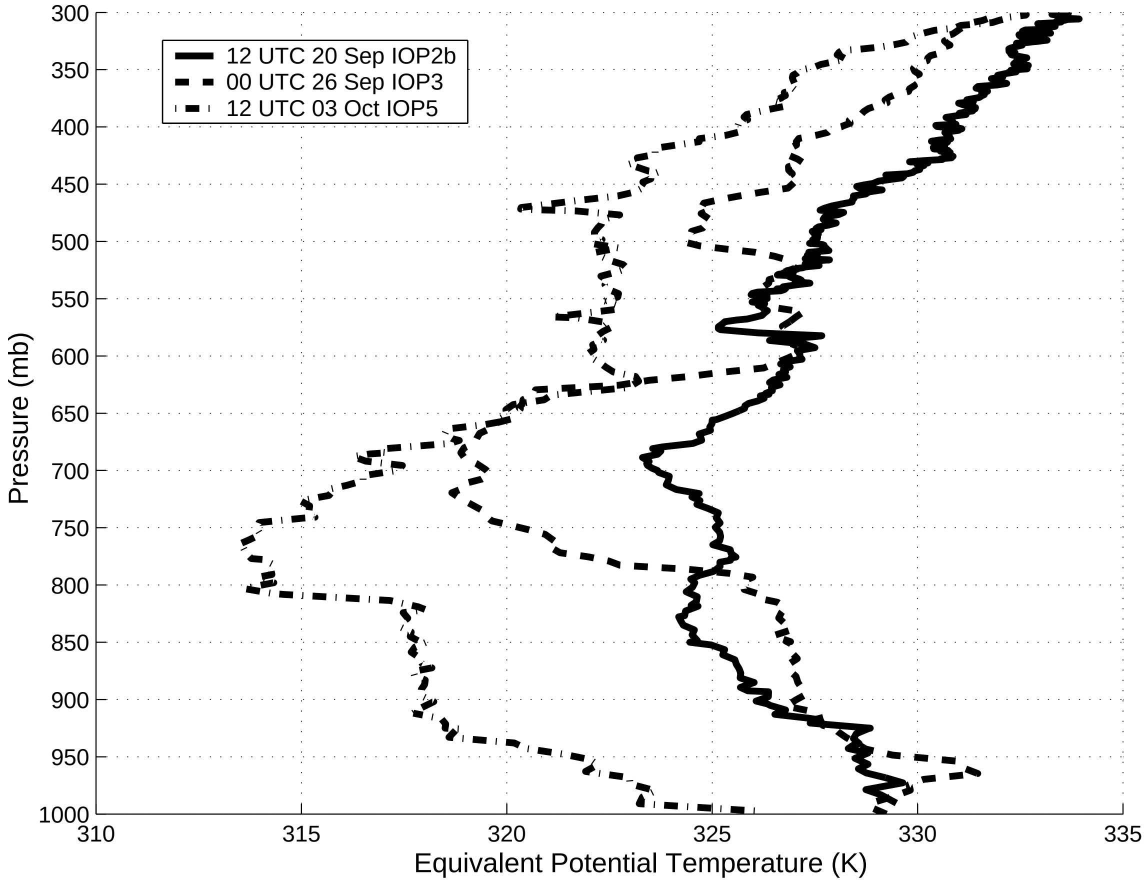

Figure 1: Equivalent potential temperature profiles calculated from Milan soundings taken at 1200 UTC 20 September 1999 during IOP2b (solid line), 0000 UTC 26 September 1999 during IOP3 (dashed line), and 1200 UTC 3 October 1999 during IOP5 (dash dotted line).

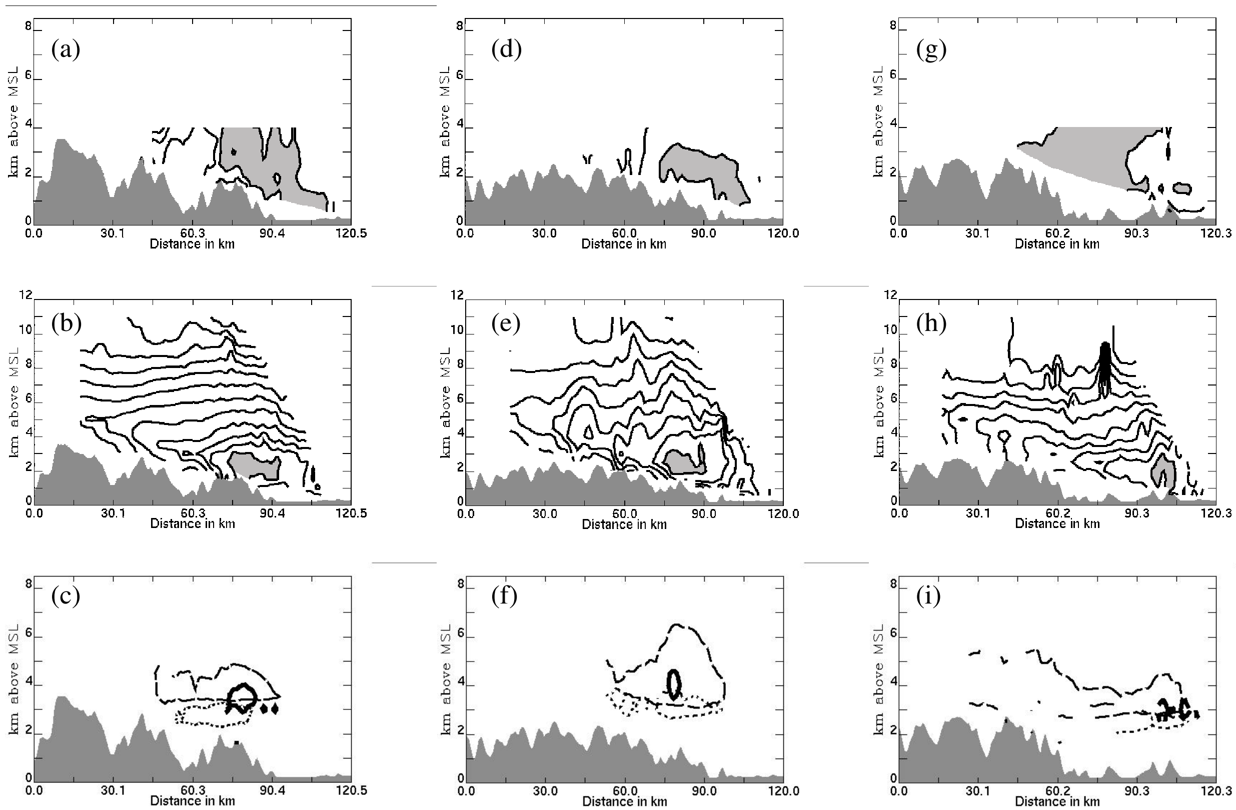

Figure 2: Vertical cross sections of NCAR S-Pol radar data extending from the radar site, located on the lower right corner of the panels, across the Alps to the (a)-(c) north-northwest, (d)-(f) north-northwest, (g)-(i) north. The fields in the panels have been either accumulated or averaged during (a)-(c) IOP2b, (d)-(f) IOP3, and (g)-(i) IOP5. (a) Mean radial velocity contoured every 3 m/s, values between 12-15 m/s shaded. (b) Mean reflectivity contoured every 5 dBZ, values 36 dBZ shaded. (c) Frequency of occurrence of particle types: 0.5 contour of dry snow (long-dashed), 0.3 contour of wet snow (short dashed), and 0.02 contour of graupel (solid). (d) Mean radial velocity contoured every 3 m/s, values 9 m/s shaded. (e) Mean reflectivity contoured every 7 dBZ, values 34 dBZ shaded. (f) Frequency of occurrence of particle types: 0.1 contour of dry snow (long-dashed), 0.03 contour of wet snow (short dashed), and 0.017 contour of graupel (solid). (g) Mean radial velocity contoured every 3 m/s, values between 9-12 m/s shaded. (h) Mean reflectivity contoured every 6 dBZ, values 32 dBZ shaded. (i) Frequency of occurrence of particle types: 0.1 contour of dry snow (long-dashed), 0.05 contour of wet snow (short dashed), and 0.005 contour of graupel (solid).