FORMATION AND MAINTENANCE MECHANISMS OF THE STABLE LAYER OVER THE PO VALLEY DURING MAP IOP-8

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Abstract: During Mesoscale Alpine Program (MAP) IOP-8, a strong stable layer formed over the Po Valley and northern Ligurian Sea. Based on observations, reanalysis data and prior studies, we hypothesize that differential advection (Lin et al., 2005) led to the formation of the stable layer and differential advection along with blocking of cool easterly flow by the western flank of the Alps over the Po Valley played significant roles in the maintenance of the stable layer. Numerical sensitivity tests with the MM5 model were performed to examine these possible formation and maintenance mechanisms of the IOP-8 stable layer. When the western flank of the Alps was removed, the stable layer still formed, but eroded more quickly and became much shallower and narrower at the later stage of IOP-8, which is consistent with the hypothesis. It was also found that the Dinaric Alps and evaporative cooling did not play significant roles in forming and maintaining the stable layer.

Keywords *– ICAM, MAP, Alps, IOP-8, Stable Layer, MM5, Po Valley, Dinaric Alps, Evaporative Cooling*

1. INTRODUCTION

During MAP IOP-8, a strong stable layer formed over the Po Valley and northern Ligurian Sea. This stable layer has been shown in previous research to be important for the formation of convection over the Ligurian Sea and the lack thereof over the Po Valley and southern slopes of the Alps (Bousquet and Smull, 2003; Rotunno and Ferretti, 2003; Medina and Houze, 2003). Lin et al. (2005) found that differential advection played an important role in the maintenance of the IOP-8 stable layer. In this study, we hypothesize that differential advection led to the formation of the stable layer and differential advection along with blocking of cool easterly flow by the western flank of the Alps over the Po Valley played dominant roles in the maintenance of the stable layer. We will examine these formation and maintenance mechanisms through inspection of observed data as well as numerical simulations.

2. SYNOPSIS OF THE IOP-8 ENVIRONMENT

Observations and reanalysis data showed that stable layer formation occurred as relatively cool, moist air associated with a high pressure system over northeast Europe was advected into the Po Valley on 17 October 1999. The westward progression of this air mass appeared to be blocked by the north-south leg of the Alpine ridge, thus resulting in an accumulation of cold air in the Po Valley during the ensuing 60 h. It appears that blocking of cool easterly flow by the western flank of the Alps over the Po Valley played a significant role, along with differential advection (Lin et al. 2005), in the maintenance of the stable layer. To examine the impact of blocking by the western flank of the Alps, a sensitivity experiment was performed where the western Alps were removed (NOWALP).

Analyses showed that the air entering the Po Valley from the east had to first cross the Dinaric Alps. The lee side warming and drying experienced by these air parcels as they crossed this mountain range may have acted to reduce the build up of the cold pool in the Po Valley. To examine the impact of the Dinaric Alps on the cool air of the stable layer, the Dinaric Alps were removed within a sensitivity experiment (NODINA).

Observations and reanalysis data also indicated that a variety of forcings may have contributed to the maintenance of the stable layer. For example, there was eastward advection of warm air over the western

Alps that appeared to have strengthened the temperature gradient at the top of the cold dome. Additionally, composite radar analyses show there was stratiform precipitation over the Po Valley on 18 October 1999. Evaporative cooling associated with this precipitation may have also helped maintain the stable layer. To examine the impact of evaporative cooling on stable layer maintenance, a sensitivity experiment was performed where the thermal effects of evaporative cooling were suppressed (NOEVAP).

3. EXPERIMENT DESIGN

Numerical simulations were performed by using the Penn State/NCAR MM5 model. Three nested domains, with two-way interaction, were used for the simulations. Domain 1 used a 45-km grid spacing with 91x85 grid points in the horizontal, domain 2 used a 15-km grid spacing with 121x121 grid points and domain 3 used a 5-km grid spacing with 142x142 grid points. Forty-five unevenly spaced full-sigma levels were used in the vertical with the maximum resolution in the boundary layer. The time steps for Domains 1, 2 and 3 were 90s, 30s, and 10s, respectively. The ECMWF ERA40 2.5º x 2.5º reanalysis data was used to initialize the model and update the boundary conditions every six hours. Since the cool air began to advect across northern Italy at 12 UTC 17 October 1999, the model was initialized twelve hours earlier at 00 UTC 17 October 1999, with Domains 2 and 3 initialized six hours after Domain 1. The simulation was run through IOP-8 until 06 UTC 22 October 1999. The control simulation performed for this case agreed well with the observations and reanalysis data on the development and maintenance of the stable layer over the Po Valley along with the associated precipitation during IOP-8 (not shown).

4. MODEL SENSITIVITY TESTS

In the NOWALP simulation, the cool stable layer still developed over the Po Valley during 18-20 October with a fairly similar width and depth to that of the control (CTRL) simulation. However, the development took a greater amount of time since there was no western barrier to help provide some protection for the cool air across the Po Valley to pool up against. When warm southerly flow moved across the region late on 20 October and through 21 October, the lack of a western barrier left the cool stable layer in the direct path of that warm flow which led to a much faster erosion of the NOWALP stable layer compared to the CTRL simulation. Throughout 21 October, the NOWALP stable layer was very shallow and confined in a narrow band adjacent to the southern face of the Alps (Fig. 1b), which was quite different from the CTRL stable layer (Fig. 1a). This allowed the approaching warm and moist southerly air to flow through most of the Po Valley before experiencing a vertical lift along the slope of the Alps, unlike in the CTRL simulation where the stable layer forced the incoming southerly flow to rise over the Po Valley. The weaker and shallower NOWALP stable layer led to a precipitation maximum area located over the Lago Maggiore Target area (Fig. 2b), which was shifted to the north of the CTRL precipitation maximum that was located over the Po Valley (Fig. 2a). Overall, the blocking of the cool easterly flow by the western flank of the Alps appeared to play a significant role in the maintenance of the stable layer across the Po Valley.

In the NODINA simulation, the air advected into the Po Valley was slightly cooler compared to the CTRL simulation since less warming and drying occurred over the region where the Dinaric Alps had been located. Also, without the Dinaric Alps present, the easterly flow moved across northern Italy at a speed that was about 5 m s^{-1} faster than the CTRL easterly flow, which allowed the NODINA simulation to advect slightly cooler temperatures further into the Po Valley. Due to the cooler advection, when the warm southerly flow began to erode the stable layer late on 20 October and throughout 21 October, the cooler stable layer base of the NODINA simulation helped to slow down its erosion. As a result, the stable layer depth was slightly deeper over the Po Valley during 21 October (Fig. 1c), which led to more vertical lift over the Po Valley and in turn produced a greater amount of precipitation in that region in comparison to the CTRL simulation (Fig. 2c). Thus, the Dinaric Alps appeared to have warmed the cool easterly flow and slightly hindered the speed of the easterly flow which prevented more of the cool air from being advected further into the Po Valley and the Ligurian Sea. However, based on the NODINA results, the Dinaric Alps did not play a significant role in the formation and maintenance of the IOP-8 stable layer.

In the NOEVAP simulation, the development and maintenance of the stable layer was very similar to that of the CTRL stable layer. During 18 October, when a light batch of precipitation fell across the Po Valley, it was anticipated that the NOEVAP stable layer would become less intense than the CTRL stable layer if evaporative cooling had been a major maintenance mechanism. However, there was little to no difference between the two stable layers. Even during the period of heavier precipitation on 20-21 October when it should have become weaker and eroded more quickly, the NOEVAP stable layer (Fig. 1d) was still maintained and eroded in a manner similar to that of the stable layer from the CTRL simulation. The precipitation that fell on 21 October matched fairly well between the NOEVAP and CTRL simulations, with the NOEVAP precipitation amounts being only slightly less in certain areas across the Po Valley (Fig. 2d). Due to the fact that turning off the evaporative cooling within the model produced a simulation in which the stable layer was almost identical to that of the CTRL simulation, it showed that evaporative cooling did not aid the maintenance of the stable layer.

5. CONCLUSION

In this study, the Penn State/NCAR MM5 mesoscale model was used to simulate the MAP IOP-8 event and numerical sensitivity tests were performed to examine the impact of differential advection, the western flank of the Alps, the Dinaric Alps and evaporative cooling on the formation and maintenance of that stable layer. The results demonstrated that blocking of the cool, easterly flow by the western flank of the Alps had a significant impact on the stable layer maintenance. Although the cool easterly flow was able to produce a stable layer that was at a similar depth to that of the control stable layer during the first half of the simulation, without the western flank of the Alps present within the simulation, the cool stable air that developed over the Po Valley was quickly eroded when warm southerly flow approached the region. As a result, heavier precipitation fell along the southern slope of the Alps over the Lago Maggiore Target Area. In the simulation without the Dinaric Alps, advection of cooler air into the Po Valley produced a stable layer that took slightly longer to erode. However, the Dinaric Alps did not appear to play a significant role in the IOP-8 stable layer formation and maintenance. When the evaporative cooling was deactivated, it did not affect the maintenance of the stable layer. Overall, we conclude that differential advection led to the development of the stable layer and blocking of cool easterly flow, along with differential advection, played significant roles in the maintenance of the IOP-8 stable layer.

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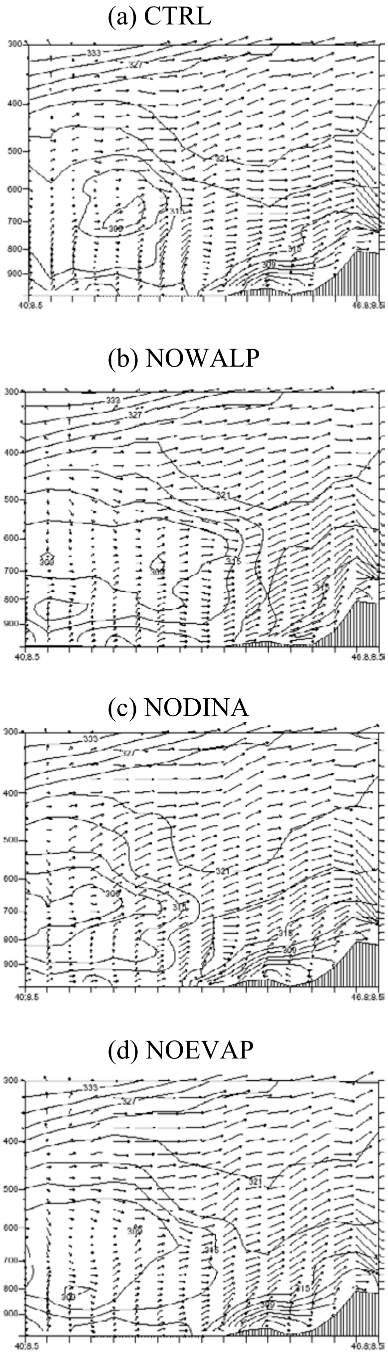

Figure 1: MM5 Domain 2 output showing a S-N cross-section of θ_e (K) and wind vectors at 8.5ºE from 40ºN to 46.8ºN at 12 UTC 21 October 1999 for (a) CTRL, (b) NOWALP, (c) NODINA, and (d) NOEVAP.

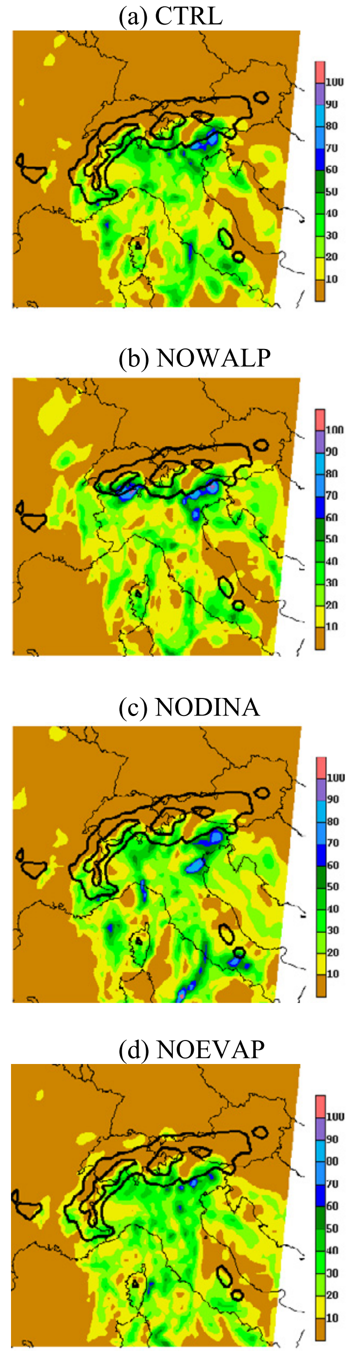

Figure 2: MM5 Domain 2 output showing 24 h accumulated precipitation (in mm) from 06 UTC 21 October to 06 UTC 22 October 1999 for (a) CTRL, (b) NOWALP, (c) NODINA, and (d) NOEVAP.