JP7J.10 FORMATION AND MAINTENANCE MECHANISMS OF THE STABLE LAYER OVER THE PO VALLEY DURING MAP IOP-8

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1. INTRODUCTION

During the Mesoscale Alpine Programme (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 blocking of the cool easterly flow by the western flank of the Alps over the Po Valley led to the formation of the stable layer and differential advection along with blocking by the western and northern flanks of the Alps 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 cool 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 in the formation of the stable layer.

Early on 20 October 1999, the flow across northern Italy shifted to the south. A stability analysis shows these southerly airstreams, which originated over the Adriatic Sea, were characterized by relatively high static stability in the lowest 2 km. Consequently, these airstreams were blocked by the northern flank of the Alps and deflected into the Po Valley. A trajectory analysis for air parcels at Milan, shows that, above the stable layer, air parcels originated over the Mediterranean Sea, a region that was warmer and less stable than the low level air mass over the Adriatic Sea. This differential advection of a less stable air mass atop a more stable air mass appears to have also contributed to the longevity of the stable layer during IOP-8.

Composite radar analyses show that there was stratiform precipitation over the Po Valley on 20 and 21 October 1999. Evaporative cooling associated with this precipitation may have also helped to 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 (NOEV).

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, and domains 2 and 3 initialized six hours after domain 1. The simulation was run through IOP-8

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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). To test the hypotheses mentioned in section 2, a numerical sensitivity experiment was performed in which the western flank of the Alps was removed (NOWA), another sensitivity experiment was performed in which the northern flank of the Alps was removed (NONA), and a final sensitivity experiment was performed in which the thermal effects of evaporative cooling were suppressed (NOEV).

4. FORMATION AND MAINTENANCE MECHANISMS OF THE STABLE LAYER

4.1 Effects of the Western Flank of the Alps

In the NOWA simulation, the coldest air that moved across northern Italy during 18-20 October in the NOWA simulation (not shown) did not build up over the Po Valley to the same extent as was found within the control (CTRL) simulation, as it instead mostly remained in a rather narrow region along the slopes of the Alps. Therefore, without the presence of the western flank of the Alps to deflect the cool air towards the south, the NOWA stable layer did not extend as far to the south into the Ligurian Sea compared the CTRL simulation. 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 NOWA simulation in the direct path of that warm flow. The cool air began to be quickly advected towards the west and out of northern Italy. 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. As a result, the differential advection of warm air atop the cold dome was not present over the Po Valley to help enhance the inversion at the top of the cold dome and help to maintain the stable layer. Therefore, the NOWA stable layer eroded much faster (Fig. 1b), compared to the CTRL simulation (Fig. 1a). The precipitation maximum on 21 October within the NOWA simulation was 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 western flank of the Alps appeared to play a significant role in the formation of the stable layer by blocking the cool easterly flow which led to the build up of the cool, stable layer over the Po Valley. The western flank of the Alps also played a significant role in the maintenance of the stable layer by helping to retain the cool air across the Po Valley which led to differential advection.

4.2 Effects of the Northern Flank of the Alps

In the NONA simulation, the cool stable layer developed over the Po Valley during 18-20 October (not shown) in a manner similar to the CTRL stable layer since the western flank of the Alps was still present to block the incoming cool easterly flow, which led to a build up a cool air over the Po Valley. This indicates that the northern flank of the Alps did not play a role in the formation of the stable layer. However, when the warm southerly flow moved across the region late on 20 October and through 21 October, the lack of a northern barrier left the cool stable layer in the direct path of the warm flow which began to quickly advect the cool air towards the north and out of northern Italy. The approaching warm and moist southerly air of the NONA simulation then flowed through the Po Valley without experiencing any significant vertical lift, unlike within the CTRL simulation where the stable layer forced the incoming southerly flow to rise over the Po Valley. As a result, the differential advection of warm air atop the cold dome was not present over the Po Valley within the NONA simulation to help enhance the inversion at the top of the cold dome and help to maintain the stable layer. Therefore, the NONA stable layer eroded much faster (Fig. 1c), compared to the CTRL simulation (Fig. 1a), and there was generally light, if any, precipitation that fell across the Po Valley during 21 October within the NONA simulation (Fig. 2c). Overall, the northern flank of the Alps appeared to play a significant role in the maintenance of the stable layer across the Po Valley by helping to maintain the cool air over northern Italy which led to differential advection over the Po Valley.

4.3 Effects of Evaporative Cooling

In the NOEV simulation, the formation of the stable layer was very similar to the CTRL stable layer, but that was to be expected since the precipitation did not fully develop over the Po Valley until 20 October. During 20 and 21 October, when the moderate to heavy precipitation fell across the Po Valley, it was anticipated that the NOEV stable layer would become weaker and erode more quickly 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. The NOEV 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 NOEV and CTRL simulation, with the NOEV 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. CONCLUSIONS

Overall, the stable layer formation and maintenance appear to develop in a series of stages. First, the easterly flow associated with the stationary high pressure center over northeastern Europe advected the cool air across northern Italy and into the Po Valley. Second, the western flank of the Alps blocked that cool easterly flow and deflected it towards the Ligurian Sea. This blocked flow led to the build up of the cool air over the Po Valley. Third, the western flank of the Alps and the northern flank of the Alps both helped to retain the cool air over the Po Valley. As a result, the warm southerly flow approaching northwestern Italy was forced to rise up and over the cool stable layer leading to the differential advection of warmer and less stable air atop cool and stable air, which appeared to enhance the inversion and help to maintain the stable layer.

When evaporative cooling was suppressed within the model, there was very little change that occurred relative to the control simulation. More specifically, the stable layer continued to maintain the same depth and intensity as in the control simulation. Additionally, the accumulated precipitation of 21 October compared favorably to the control precipitation in both the distribution and amounts. Overall, it was shown that evaporative cooling played very little role in helping to develop and maintain the stable layer over northwestern Italy. It is known form previous work on Appalachian cold-air damming that evaporative cooling is important for cold-air damming maintenance. This mechanism, however, did not appear to be important for the maintenance of the IOP-8 stable layer. This leaves the question "Is the IOP-8 stable layer an anomaly?" If it is typically the case that evaporative cooling is not important for stable layer maintenance in the Po Valley, then it seems logical to wonder if it is also not important in other regions where blocking is frequent, such as along the south side of Alaska or in Greenland. Future work could be done to see what factors are climatologically important for stable layer maintenance, not just in the Po Valley, but in other places as well.

6. ACKNOWLEDGEMENTS

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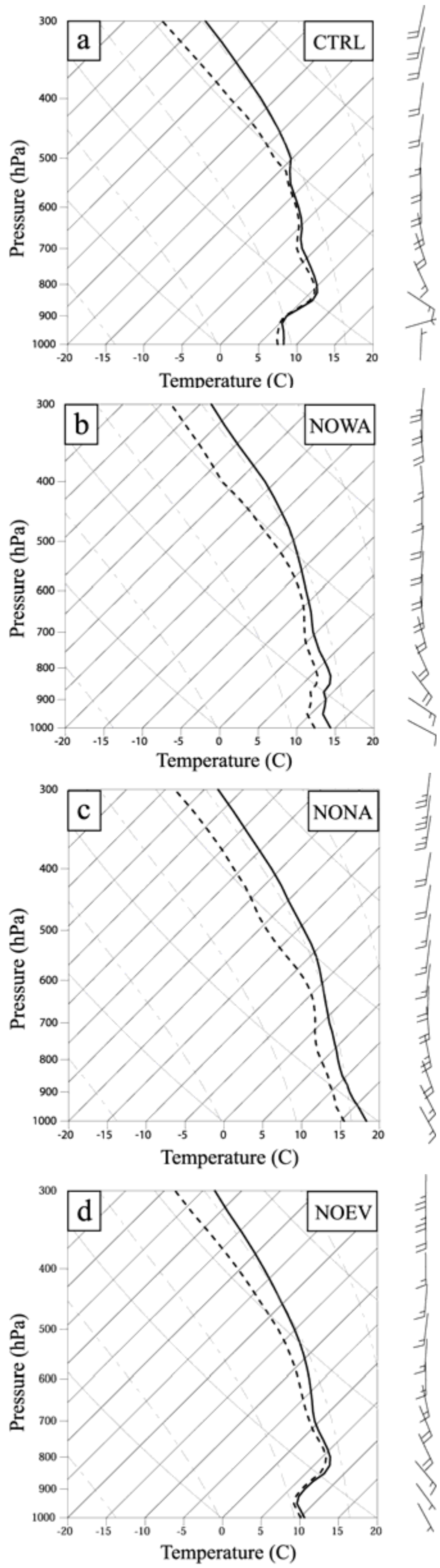

Fig. 1: MM5 domain 2 simulated soundings from Milan at 10/21/12Z for (a) CTRL, (b) NOWA, (c) NONA, and (d) NOEV. Temperature is given by the solid lines and dew point temperature by the dashed lines. Wind speed and direction are denoted by the wind barbs.

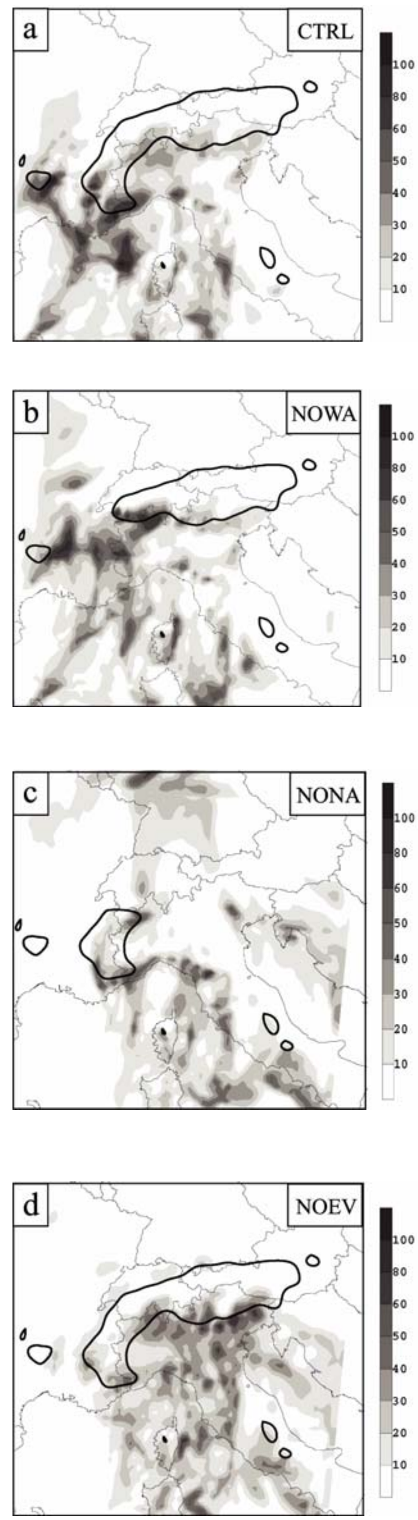

Fig. 2: MM5 domain 2 simulated 24 h accumulated precipitation (in mm; shaded as in legend) ending at 10/22/06Z for (a) CTRL, (b) NOWA, (c) NONA, and (d) NOEV.