MAINTENANCE OF A MOUNTAIN VALLEY COLD POOL AND THERMAL BELT: A NUMERICAL STUDY

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Abstract: A mountain valley cold pool was simulated with the Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model version 5 (MM5) to determine the effects of snow cover, planetary boundary layer (PBL) parameterizations, spin-up time, vertical and horizontal resolution, and horizontal diffusion on the maintenance of a cold pool. The simulation was of a cold pool that remained in the Yampa Valley of northwestern Colorado throughout 10 January 2004. Results of model runs were verified by a mesonetwork of weather stations located on the western slope of the valley. The presence of snow cover improved the simulation results, but was not sufficient to retain the cold pool in the valley. Increasing the model spin-up time, vertical resolution, and the PBL parameterization had little effect on the model results. However, increasing the horizontal resolution from 1 km to 100 m did improve the results and retained a weak inversion in the valley. Using the horizontal diffusion scheme of Zängl (2002) had an effect similar to that achieved by increasing the horizontal resolution.

Keywords – Cold air pools, numerical simulations

1. INTRODUCTION

Whiteman et al. (2001) define two types of cold pools. A diurnal cold pool forms during the evening or night and decays following sunrise the next day. A persistent cold pool lasts longer than one diurnal cycle. Persistent cold pools can have significant effects on human activities (Whiteman et al. 1999). Air pollution can accumulate to unacceptably high levels, liquid precipitation falling into the cold pool can produce freezing rain or drizzle, and cold pools can delay the melting of snow and the breakup of ice on rivers. Despite their significant impact, forecasting the buildup and removal of persistent cold pools remains a challenging problem (Zhong et al. 2001).

The temperature inversion associated with a valley cold pool may not extend to the ridges. This will result in a band of relatively warmer temperatures known as a “thermal belt” partway up the sidewalls. If the thermal belt exists in mountain slope surface temperatures, it is possible to identify the presence of cold air pool without the use of upper-air soundings.

In this study, we investigate a cold pool and thermal belt that persisted in the Yampa Valley of Colorado throughout 10 January 2004. The purpose of this study is to assess the importance of various factors on numerical model simulations of cold pools and thermal belts. These simulations are compared to observations that were taken during a field research course in the Yampa Valley.

2. METHODOLOGY

2.1. Topography, observing sites, and dataset

The upper Yampa Valley of northwestern Colorado (south of Steamboat Springs, CO) is a roughly north-south oriented valley that cuts through the western slope of the Rocky Mountains for a distance of approximately 90 km (Fig. 1). At the top of the eastern summit, at an elevation of 3210 m MSL is the Desert Research Institute's (DRI) Storm Peak Laboratory (SPL) (Borys and Wetzel 1997), which serves as the operations center for a field research course offered by the University of Nevada-Reno and DRI.

The observational network for this study consists of a line of automated surface stations along the eastern wall of the valley. All stations report temperature and relative humidity, but only stations at higher elevations report wind data. Unfortunately, this precludes comparisons of winds above and below the inversion. Additionally, none of the stations report pressure, so the potential temperature cannot be calculated. In this study we use only measured temperatures for model verification. The temperature sensors have a range of -40°C to +60°C and are accurate to ±0.3°C at 0°C.

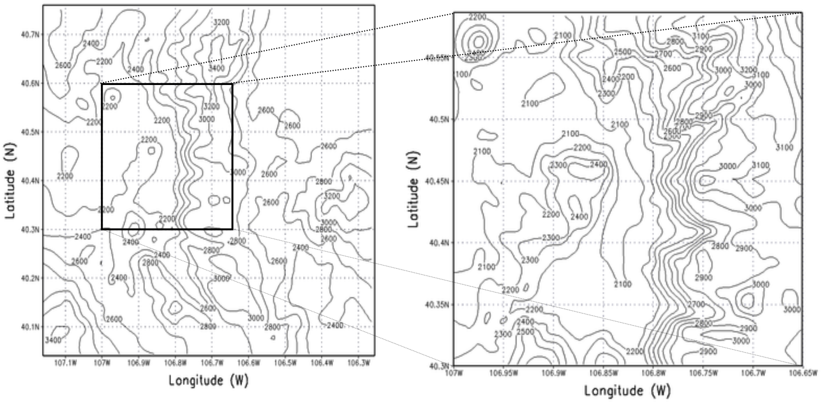

Figure 1 Left: Topography of the upper Yampa Valley from the model domain with 1 km grid spacing. Contours are shown every 200 m. Right: Insert of the upper Yampa Valley from the 300 m domain. Contours are shown every 100 m.

2.2. Synoptic overview

For the first week of January 2004, a series of shortwaves created a significant snowfall over the Yampa Valley. A high-pressure ridge, which began to build over the area on January 8, reached the maximum amplitude on January 9. The high pressure remained over the area throughout January 10. While the ridge of 8-10 January had cleared skies aloft, the stagnant flow and recent snowfall led to widespread dense fog. Clearing began at higher elevations in the early evening hours of January 10, and the valley fog dissipated shortly after sunrise. The remainder of the day had clear skies and calm winds. The cold pool formed in the valley in the early evening hours of January 8 and remained in place during January 10. Due to the calm synoptic conditions, we have selected this event for our numerical study of the persistent cold pool.

2.3. Model description

The model used in this study was the Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model version 5 (MM5) (Grell et al. 1994). The baseline run contained four nested two-way interactive domains, all roughly centered over the field site, with resolution of 27, 9, 3, and 1 km. In the vertical, fifty-one sigma levels were used, with finer resolution in the lowest levels of the atmosphere. Terrain elevation, land-water mask, and vegetation data were taken from the U.S. Geological Survey dataset of the corresponding resolutions. Initial and boundary conditions and snow cover data were provided by the National Center for Environmental Prediction Global Forecast System model reanalyses. All of the runs used the MM5's Grell cumulus parameterization, Dudhia simple ice microphysical scheme, and cloud-radiation scheme.

The time period for the baseline model run was 12 UTC (05 LST) 10 January 2004 to 00 UTC 11 January (17 LST 10 January) 2004. To verify the importance of snow cover on cold pool maintenance, two sets of runs were performed with and without snow cover. For this, five model runs were performed with the following PBL schemes: the Burk-Thompson PBL, the Mellor-Yamada PBL as used in the Eta model, the Hong-Pan PBL as used in the former Medium Range Forecast (MRF) model, the Gayno-Seaman PBL, and the Pleim-Chang PBL. Based on the results of these simulations, additional sensitivity tests were performed, in which we varied the vertical resolution, start time of the simulation, the horizontal resolution, and the method for calculating horizontal diffusion.

3. RESULTS

Typically, the thermal belt, an indicator of the temperature inversion on top of the cold air pool, would reach a maximum intensity just prior to sunrise. Then, solar heating would lead to the increase of temperatures on the lower side of the belt until temperatures in the valley exceed the mid slope temperatures, and the temperature profile decreases with increasing elevation. However, in this case, the thermal belt remained in the same location with a similar intensity throughout the day. The observations showed that the thermal belt was still in place at mid-day at 21 UTC (14 LST) January 10. On the other hand, none of the simulations were able to maintain the thermal belt on the eastern slope that is seen in the observations. Varying the PBL parameterization had very little effect on the results. Without snow cover, the temperature is very elevation dependent, with a maximum at the floor of the Yampa Valley and a minimum at the eastern summit. With snow cover, the maximum at the valley floor is considerable flattened relative to the eastern summit of the valley.

For the run with increased vertical resolution, the results are nearly identical to those obtained with the same PBL scheme and snow cover analysis at much coarser vertical resolution. While lengthening the model spin up time, by initializing the model twelve hours earlier to allow for additional spin up of the model physics, did have a more sizable effect on the model solutions than varying the PBL parameterization, it did not produce the desired improvement either. Therefore, it appears that the vertical resolution and the model spin up time had little effect on the simulation of the cold air pool in this case.

The next parameter that was modified was the horizontal resolution. First, a 300 m domain was nested inside the fourth domain of the previous model setup. With the increased horizontal resolution, a weak thermal belt was retained in the model solutions in nearly the same location as shown by the mesonet observations. The finest horizontal resolution that could be achieved with a reasonable computation time was 100 m. Near the warmest part of the day, at 21 UTC (14 LST), the temperature structure is similar to the results of the 300 meter run, with a very weak cold pool and thermal belt still in the valley.

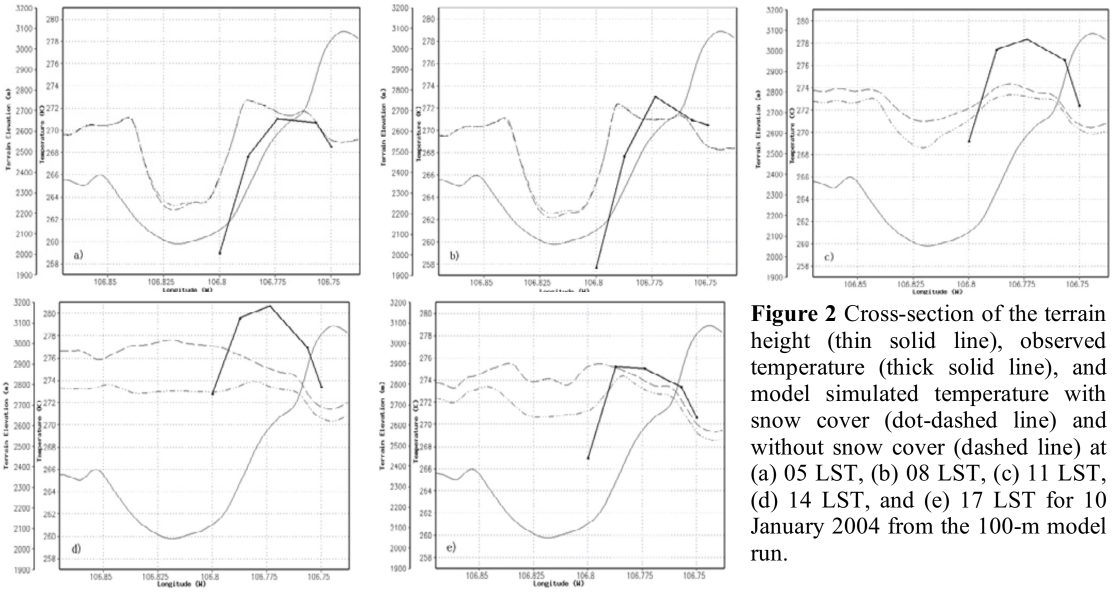

Figure 2 Cross-section of the terrain height (thin solid line), observed temperature (thick solid line), and model simulated temperature with snow cover (dot-dashed line) and without snow cover (dashed line) at (a) 05 LST, (b) 08 LST, (c) 11 LST, (d) 14 LST, and (e) 17 LST for 10 January 2004 from the 100-m model run.

We have also conducted a simulation at 1 km horizontal resolution with a diffusion scheme developed by Zängl (2002) that calculates horizontal diffusion on horizontal surfaces instead of sigma surfaces. The improvement achieved with Zängl scheme at 1 km resolution was similar to that achieved by increasing the horizontal resolution to 300 m with horizontal diffusion calculated along sigma surfaces. This is consistent with Zängl's (2002) findings, and emphasizes the importance of proper representation of horizontal diffusion in steep terrain.

4. CONCLUSIONS

On 10 January 2004, a persistent cold pool and thermal belt were observed in the upper Yampa Valley of western Colorado. The ability of the numerical model to simulate these features was found to be dependent on several critical factors: i) the use of snow cover data in the model runs, ii) the horizontal resolution, and iii) the proper representation of horizontal diffusion. The planetary boundary layer parameterization, vertical resolution, and the model spin-up time were found to be less important in improving the simulation results. The model simulations only started to retain the cold pool when the horizontal resolution was reduced to 300 m.

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REFERENCES

Borys, R. D., and M. A. Wetzel, 1997: Storm Peak Laboratory: a research, teaching, and service facility for the atmospheric sciences. *Bull. Amer. Meteor. Soc.*, **78**, 2115–2123.

Grell, F. A., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). NCAR tech. Note, NCAR/TN-398 + STR, 122 pp. [Available from NCAR, P.O. Box 3000, Boulder, CO 80307.]

Whiteman, C. D., 1999: Wintertime evolution of the temperature inversion in the Colorado Plateau Basin. *J. Appl. Meteor.,* **38,** 1103–1117.

Whiteman, C. D., 2001: Cold pools in the Columbia Basin. *Wea. Forecasting,* **16,** 432–447.

Zängl, G., 2002: An improved method for computing horizontal diffusion in a sigma-coordinate model and its application to simulations over mountainous topography. *Mon. Wea. Rev.*, **130**, 1423–1432.

Zhong, S., C. D. Whiteman, X. Bian, W. J. Shaw, and J. M. Hubbe, 2001: Meteorological processes affecting the evolution of a wintertime cold air pool in the Columbia Basin. *Mon. Wea. Rev.,* **129,** 2600–2613.