

# The Use of a High-Resolution Modeling System during the Orographic

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## Storms Laboratory Intensive Observing Period (IOP)

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### ABSTRACT

This paper focuses on the use of a mesoscale model to predict daily fluctuations of temperature, relative humidity, wind speed, and wind direction at the Storm Peak Lab, located at Steamboat Springs, CO. The key research focus is on model resolution, i.e. does increasing resolution lead to improved forecasts. Another focus of this paper is extreme weather events that occurred during the IOP. The first event is a snow storm that produced over 15 inches of snow at the lab in 12 hours. The second event is a wind storm that produced a peak wind gust of 55 mph. Mesoscale simulations are shown for both these events, along with a discussion of their causes. Verification of modeled mountain weather is often quite challenging because of the complex terrain. The IOP provides a unique opportunity to study the accuracy of these model simulations.

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## 1. INTRODUCTION

Weather influenced by mountainous and very complex terrain, such as the Rocky Mountains, can often be very destructive and hard to predict. For example, Cotton et al. discusses a 3 July 1993 downslope wind storm that produced 82kt winds at Fort Collins, Colorado (1995). This storm caused extensive tree and roof damage. Verification of mountain weather predictions are also quite challenging, mostly due to the sparse number of observation stations.

The Orographic Storms Laboratory IOP was held from 11 March – 18 March 2006. This field program provides a unique opportunity to take accurate measurements of atmospheric conditions in an area of very complex terrain. The research lab is located on Mt. Werner near Steamboat Springs, Colorado with an elevation of 10,500ft. The Storm Peak Laboratory (SPL) is operated by the Desert Research Institute (DRI) Division of Atmospheric Sciences (DAS).

The first primary goal of this paper is to simulate basic meteorological variables, such as temperature, relative humidity, wind speed, and wind direction. Model resolution is the key focus of these simulations, i.e. can increased resolution

produce more accurate results. The second goal is to simulate two extreme weather events that occurred during the IOP, including a severe snow storm and wind storm.

## 2. MESOSCALE MODELING

The University of Wisconsin Non-Hydrostatic Modeling System (UW-NMS) is used for all of the simulations in this paper. The UW-NMS is the preferred model because of its ability to accurately simulate flow in areas of complex terrain. The UW-NMS uses a unique terrain following system that is able to capture both subtle and steep topography changes. Tripoli gives various examples of complex flows that are accurately modeled by the UW-NMS (1992).

Past research often focuses only on extreme weather events. For example, a damaging wind storm is studied by Canes and Corey using the fifth –generation Pennsylvania State University/ National Center for Atmospheric Research Mesoscale Model (2003).

Das et al. has shown that model resolution is very important for accurate mountain weather predictions (2003). As resolutions decrease from 10km to 1km, with the appropriate model physics, better weather forecasts are produced. High resolution simulations are often not possible because of computer limitations. Das et al. commonly used model resolutions of 10km. Higher model resolution is an important factor because atmospheric forcing is better resolved with increased resolution (Leung, 2003).

The next section simulates basic meteorological variables, with a focus on the impact of increasing resolution. These simulations use resolutions as high as 500m.

### 3. RESOLUTION SENSITIVITY

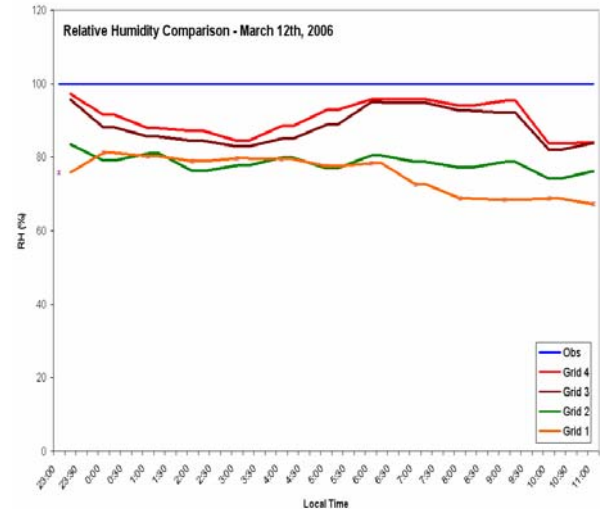
Three 12-hour simulations are produced during the IOP. The simulation times include:

- a. 23:00 10 March 2006 – 11:00 11 March 2006
- b. 23:00 11 March 2006 – 11:00 12 March 2006
- c. 11:00 13 March 2006 – 23:00 13 March 2006

The UW-NMS simulations use a four grid nested structure with resolutions of 32km, 8km, 2km, and 500m. Basic meteorological variables, including temperature, relative humidity, wind speed, and wind direction are predicted every hour.

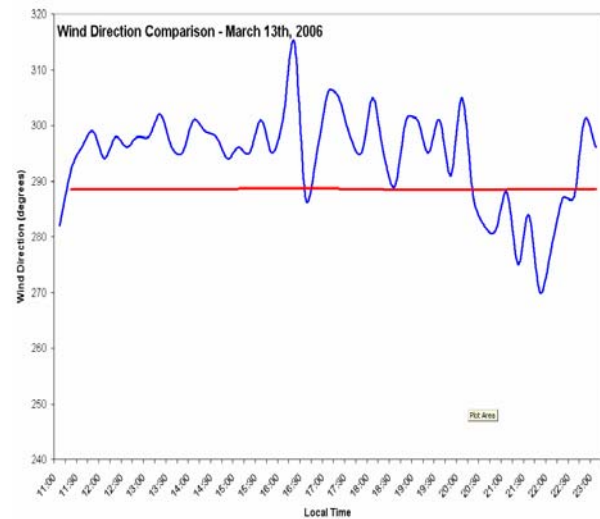
The model results are compared against observations taken at the SPL. These observations are available at 15 minute intervals.

The following figure shows a comparison between the four UW-NMS resolutions and the SPL measurement of relative humidity. Grid 4 corresponds to the 500m simulation, grid 3 to the 2km simulation, etc. As shown in figure 1, the model is fairly accurate predicting relative humidity. Also, it is evident that increasing resolution improves the model result. The average RH for the 32km grid is 78 percent, and the average for the 500m grid is 96 percent.



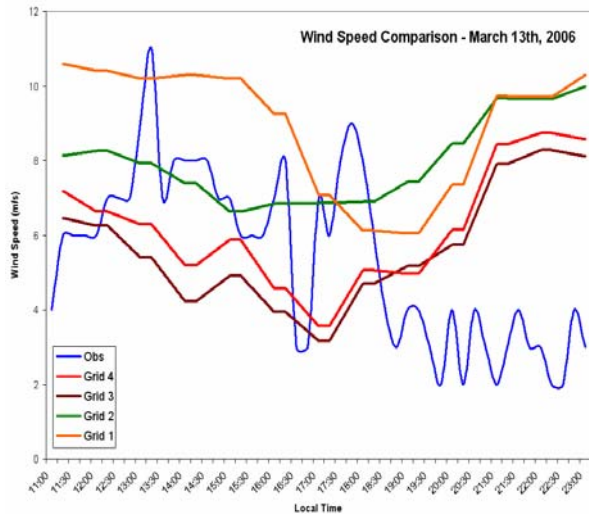
**Figure 1.** Comparison of UW-NMS and SPL relative humidity estimates. This plot shows results from 23:00 11 March 2006 – 11:00 12 March 2006.

The simulations of relative humidity are the most accurate of all the variables predicted. The next most accurately predicted variable is wind direction. Figure 2 shows a comparison between the average wind direction from all 4 resolution grids and the observed SPL measurements. An average of wind direction is used from the UW-NMS because all grids had very similar wind directions. For this variable, increasing the model resolution had little impact. This suggests that the local flow direction is influenced by the large scale flow and not complex local topography features, as the terrain is not completely resolved at lower resolutions.



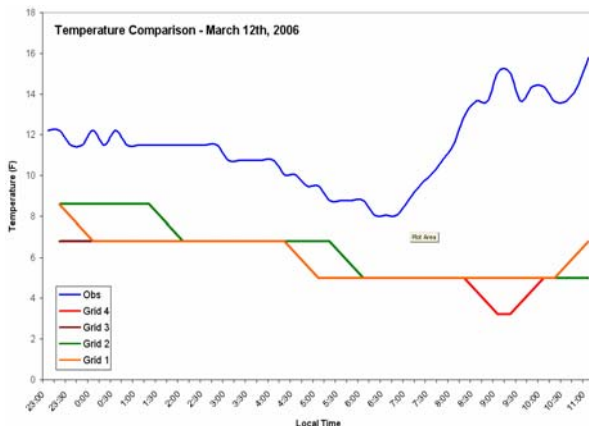
**Figure 2.** Comparison of average UW-NMS and SPL wind direction estimates. This plot shows results from 11:00 13 March 2006 – 23:00 13 March 2006.

The next figure shows the comparison for wind speed measurements and predictions. For this period, the UW-NMS predicts wind speed accurately within 4mph. The highest resolution grids produce the best simulation of wind speed.



**Figure 3.** Comparison of UW-NMS and SPL wind speed estimates. This plot shows results from 11:00 13 March 2006 – 23:00 13 March 2006.

Finally, temperature measurements and predictions are compared from 23:00 11 March 2006 to 11:00 12 March 2006. The temperature simulations were the most surprising result. For all of the simulations, temperature estimates are not very different, as shown in figure 4. Also, the observed temperatures are consistently higher than the model predictions by around 5 degrees Fahrenheit.



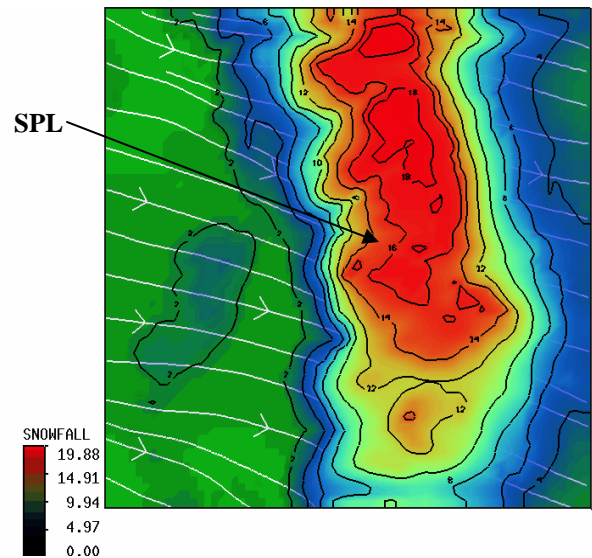
**Figure 4.** Comparison of UW-NMS and SPL temperature estimates. This plot shows results from 23:00 11 March 2006 – 11:00 12 March 2006.

Inaccurate estimates of surface snow cover and radiation effects may be the cause for underestimation of surface temperature. As shown in figure 4, the changes in resolution have little impact.

This section shows the advantage of using higher resolution simulations. For wind speed and relative humidity the accuracy of predictions are increased by using higher resolution.

#### 4. EXTREME WEATHER EVENTS

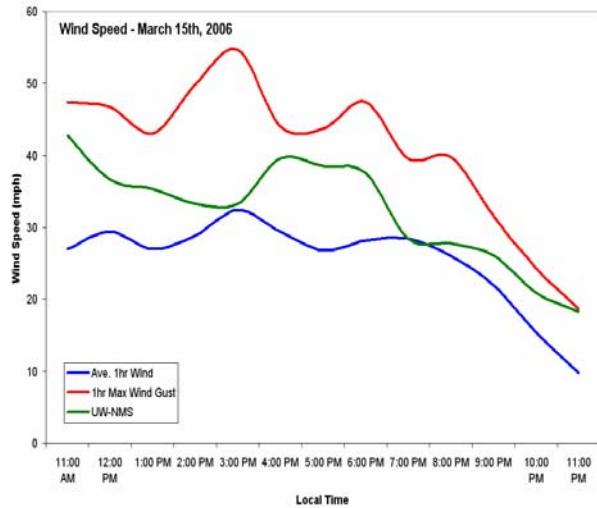
The following section focuses on two extreme weather events. First, a severe snow storm impacted the SPL from 23:00 13 March 2006 to 11:00 14 March 2006. At the lab, 15.1 inches of snow was recorded. Figure 5 shows the 12-hour snowfall prediction from the inner grid of the UW-NMS. The highest resolution (500m) grid is the most accurate for this case.



**Figure 5.** 12-Hour snowfall prediction (inches) from the 500m grid of the UW-NMS. 23:00 13 March 2006 – 11:00 14 March 2006. Also, the average 3-km streamline flow is shown.

For the 500m grid, the UW-NMS predicted 15 inches of snow at the SPL. The simulation is extremely accurate. Also, the orographic nature of the precipitation is very evident. At the base of the mountain only 2 inches of snow was recorded. Orographic snowfall at SPL is often observed when winds flow from the northwest.

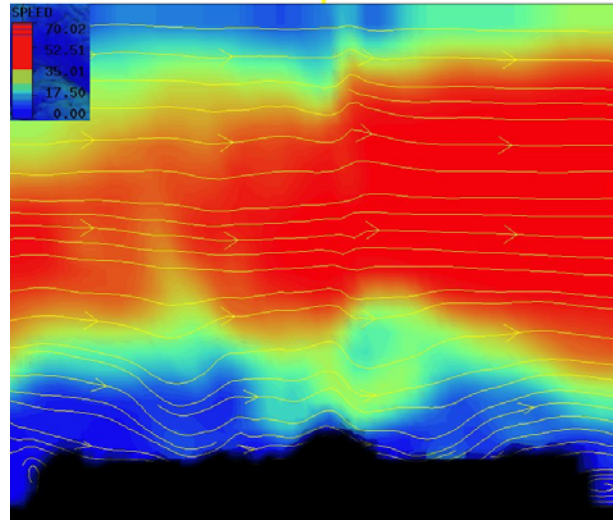
The next extreme weather event is a wind storm. The peak wind gust at the SPL was 55mph, which occurred around 15:00. This event occurred from 11:00 15 March 2006 to 23:00 15 March 2006. The following figure shows the average 1-hour wind at SPL, the peak 1-hour wind gust, and the UW-NMS wind speed prediction at each hour. This figure is from the inner grid of the UW-NMS simulations. The highest resolution (500m) grid is the most accurate for this case.



**Figure 6.** Average 1-hour wind at SPL (blue), peak 1-hour wind gust at SPL (red), and UW-NMS wind speed prediction (green). These measurements are in miles per hour (mph).

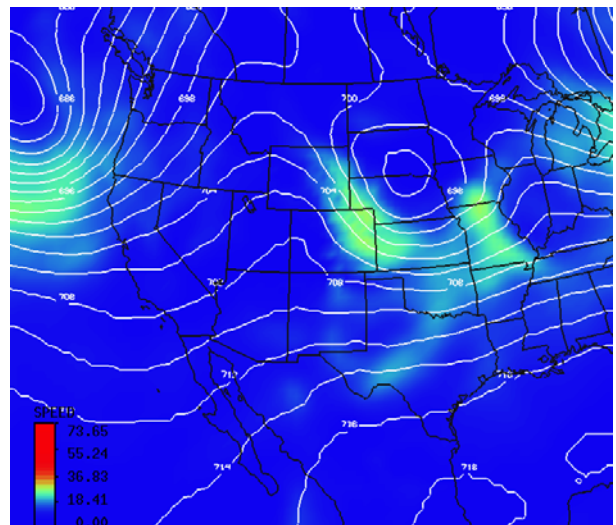
As seen in figure 6, the UW-NMS simulation is very accurate. As desired, the predicted wind lies between the average wind speed and max wind speed. The UW-NMS predictions are the instantaneous wind measurements at each hour.

The cause of the extreme wind storm is from two separate events, downward mixing of westerly momentum and a strengthening pressure gradient force over SPL. The following figure shows the downward mixing of momentum. This vertical cross section shows that stronger winds aloft are being transported to the surface. This image is taken from the outer grid of the UW-NMS (32km resolution).



**Figure 7.** Vertical cross section of wind speed (m/s), colored and contoured. This image is taken at 14:00 15 March 2006.

The other mechanism for this extreme weather event is a strengthening pressure gradient force. During this time period, a strengthening low pressure is moving to the southeast with a strong high pressure ridge developing near SPL. The following figure, taken from the outer grid of the UW-NMS, shows the isobars around 3km, along with wind speed contoured. At the time shown (18:00) the speed maximum has passed SPL to the east/southeast.



**Figure 8.** 3km pressure contours (mb) and speed (m/s) at 18:00 15 March 2006

Both extreme weather events are predicted very well with the UW-NMS. The most accurate simulations are from the highest resolution grids. As shown in the previous section and this section, increased resolution can lead to more accurate simulations.

## 5. CONCLUSIONS

This paper has shown the advantages of using a high resolution mesoscale model. When using the UW-NMS, while increasing resolution of grid domains, many types of meteorological conditions can accurately be predicted. These model simulations are necessary to warn the public of upcoming severe mountain weather.

Three 12-hour simulations are conducted with the UW-NMS for “normal” atmospheric conditions, i.e. no extreme or dangerous weather. These simulations show that the highest resolution grids tend to be the most accurate. The best improvements are seen with relative humidity and wind speed predictions.

Two extreme weather events are modeled with the UW-NMS, including a severe snow storm that impacted the SPL on 14 March 2006 and a wind storm that caused white out conditions on 15 March 2006. The snow storm produced over 15 inches of snow in less than 12 hours at SPL. The wind storm produced a peak wind gust of 55mph at SPL. Both of these events are predicted accurately with the UW-NMS. Also, the highest resolution grids are the most accurate for these two events. In both “normal” and “extreme” weather cases increased resolution seems beneficial.

## 6. REFERENCES

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