7.3 THE MESOSCALE METEOROLOGY OF THE COLUMBIA RIVER GORGE

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1 INTRODUCTION

The Cascade Mountain range, located about 250 km inland from the Pacific Ocean, extends from north to south through Washington and Oregon. The barrier is continuous except for a handful of gaps, with the Columbia Gorge being the only near sea-level conduit (the topography of the Gorge is illustrated in figure 3 in the modeling section). As a result, gap flow is common in the Columbia Gorge and plays a profound role in defining the climate of the surrounding region, which includes the city of Portland. Examples of phenomena associated with Columbia Gorge gap flow are damaging winds, frigid cold, snowfall, and freezing rain.

The aim of this study is to improve understanding of the relative importance of the Gorge and the dynamical processes occurring within it. An additional goal is to improve forecasting of weather events in which gap flow through the Gorge plays a role. Three separate things are being done to achieve this. First, a detailed climatological study accesses more quantitatively the influence of gap flow through the Gorge on weather phenomena in the study area. Second, synoptic composites for different Gorge weather events are being produced to identify and analyze canonical synoptic patterns leading to such events. These composites are created by combining NCEP re-analysis data for all days for which particular weather event occurs in Portland (for example, days when two inches of snow falls). Finally, the Gorge is being modeled using the Penn State MM5 mesoscale model. The purpose of the modeling part of the study is twofold. The first objective is to verify that the Columbia Gorge region can be modeled using a high-resolution mesoscale model and determine what vertical and horizontal resolution is required to accurately represent the airflow through it. The second is to use model output in tandem with observational assets to perform a case study analysis of a Gorge event. This will provide insight into the dynamics occurring in the Gorge.

2 CLIMATOLOGY STUDY

Data from Washington and Oregon stations participating in the NWS COOP network was used for the analysis. These stations contain a number of Surface Airways Observation sites that provided more detailed fields than the standard temperature and precipitation set. The period of record used was 1948 to 1998.

2.1 Gorge Influence On Portland Airport Climate

Portland International Airport (PDX) is the station nearest the eastern exit of the Gorge with a comprehensive historical time series of meteorological variables like daily weather, and wind speed and direction in addition to the primary climate fields (temperature maxima and minima, precipitation and snowfall). The daily climate data for Portland was broken up according to the wind speed and direction on each day in the record. This decomposition was done using the daily peak gust speed and direction as well as the daily resultant wind speed and direction. The data was then recombined by month and season. Both decompositions yielded similar results. Samples of some of the results from the analysis using the peak gust speed record are presented below.

In figure 1 (a) the PDX wind distribution is broken down by direction and speed for each season. The cold season plot clearly illustrates the importance of easterly flow through the Gorge. At the regional level the wind at this time of the year is predominately southerly ahead of approaching storms and westerly behind them. However, at PDX the prevailing winds, and also the strongest winds, are easterly to southeasterly as a result of gap flow through the Gorge. Such easterly flow is induced by the pressure gradients that develop across the Cascades as storms approach from the west and/or cold core high pressure builds to the east.

The importance of this easterly flow is vividly shown in figure 1 (b) which decomposes winter snowfall and freezing rain climatology by wind direction. The top plot shows that snowfall at PDX is strongly correlated with easterly winds. The lower plot of freezing rain distribution is even more conclusive. The skew towards south-easterly wind in the case of freezing rain is probably due to the fact that the easterly flow is shallower in these cases and southerly momentum is mixing down from aloft.

2.2 Along Gorge Results

The decomposition of climate variables by wind direction and speed was extended to stations within the Gorge. Astoria, which is well to the west of the Gorge on the coast, was also included for comparison purposes. Since detailed wind data was only available for PDX, the wind at this location was used in the analysis of all the locations.

In figure 1 (c), the top plot shows the average wintertime temperature at various stations along the Gorge for all days, as well as days when the wind at PDX was in a particular quadrant. As expected there is a strong correlation between days with easterly flow and the

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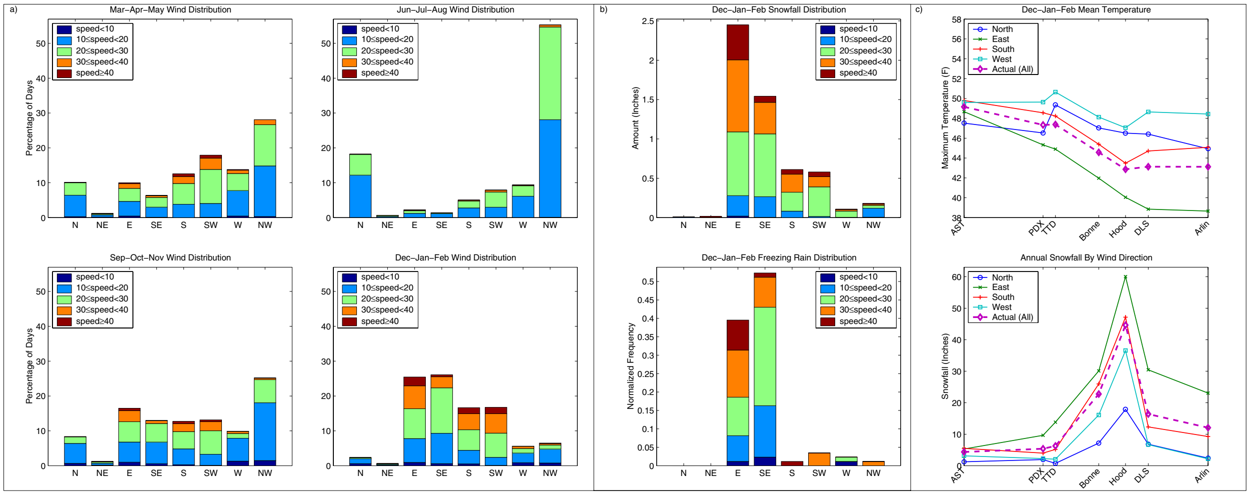

Figure 1: Climate statistics for PDX and along the Columbia Gorge, broken down by peak gust direction and speed at PDX. (a) Seasonal distribution of wind direction and speed at PDX. (b) Wintertime distribution of snowfall and freezing rain at PDX. (c) Wintertime mean temperature and annual snowfall at stations along the Gorge as a function of the wind direction at PDX.

occurrence of colder than average temperatures. Easterly flow at PDX implies generally easterly flow throughout the Gorge, which in turn indicates that the source of the air is continental.

The bottom plot in figure 1 (c) shows the annual snowfall at locations across the Gorge as a dashed line. The solid lines show the expected snowfall at each location if the wind at Portland was in the given quadrant every day. Again there is a correlation between snowfall and easterly flow.

3 COMPOSITE STUDY

Composite analysis is useful to identify synoptic patterns that are associated with particular weather events. For example, Ferber et al (1993) used composites to identify the synoptic pattern that typically leads to snowfall in the Puget Sound lowlands. The reader is directed to Ferber's paper for more details on the compositing technique as the same methodology and dataset are used here.

The objective of the composite study is to identify the synoptic evolution that is typically associated with a particular type of Gorge weather event. Three types of phenomena are discussed here; a temperature of 20°F or more below normal, snowfall of more than 2" in 24 hours, and freezing rain. All of these have been shown to be correlated strongly with easterly flow through the Gorge. Days meeting the above criteria were selected based on observations at PDX.

Composites of 500 mb height, 850 mb temperature and sea-level pressure were produced for each of the three types of event. Corresponding weighted climatology fields were also produced to allow calculations of the deviation of the composite from climatology and of the statistical significance of the deviation using the two-tailed Student's t-test (Panofsky and Brier, 1968). Time periods every 24 hours from 72 hours prior to the event to 48 hours following the event were analyzed.

Figure 2 shows a snapshot of the synoptic evolution on the day of the event for each event type. Each of the three types of event show marked deviations from climatology in the study region and immediately upstream. Statistical significance of these deviations was high. The composites exhibit similarities that further validate the claim that the Columbia Gorge plays a significant role on the local climate. In all cases the 500 mb flow is higher amplitude than normal with the Pacific Northwest downstream of a ridge over the Gulf of Alaska. Temperatures at 850 mb are colder than normal as would be expected in this cold advection regime. Finally, in all cases there is a substantial pressure gradient between the Northwest coast and the western interior. This general synoptic situation is conducive to the eastward flow of cold continental air through the Columbia Gorge. However, the three types of events do have distinct characteristics. Note, in particular, differences in the position and amplitude of the 500 mb ridge-trough pattern, the orientation of the surface pressure gradient and the extent of intrusion of cold air in the 850 mb thermal plot.

4 MODELING STUDY

This part of the project sets out to achieve two things. First, to establish that the meteorological fields within and close to the Gorge can be modeled accurately. Secondly, to use this validated simulation to evaluate in more detail the structures present and better understand them.

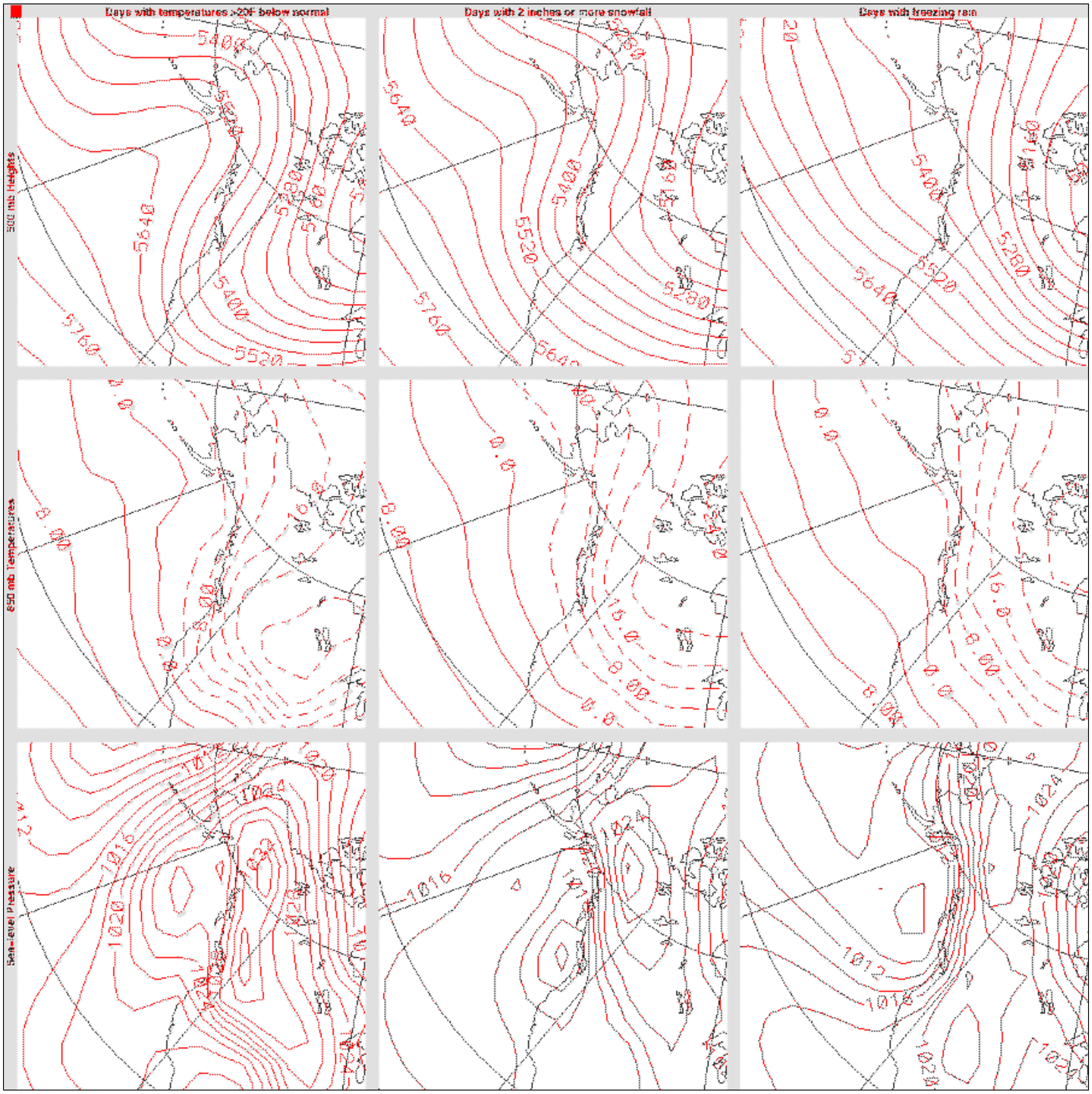

Figure 2: Composite 500 mb height, 850 mb temperature and sea-level pressure fields, for three types of weather event associated with the Columbia Gorge. The plots are valid for the time of the event. They are produced by averaging the respective fields for each day, between 1948 and 1994, on which the event type was observed at PDX.

The case chosen for investigation in the modeling study was a winter weather event which occurred between the 12th and 15th of December 2000. During this period Arctic air became entrenched in Eastern Washington and there was sustained moderate to strong easterly flow through the Gorge, which was enhanced as a series of weak systems approached the west coast. The cold outflow from the Gorge resulted in several days of mixed wintry precipitation in the Portland area.

4.1 Effect Of Horizontal Resolution.

The simulation of this case with the MM5 uses five one-way nests. The outer nest has a grid point spacing of 36 km and each subsequent nest employs a scaling factor of three to yield 12 km, 4 km, 1.33 km and 0.444 km. The highest resolution domain utilizes the maximum resolution of the terrain data, which has a 30 second interval.

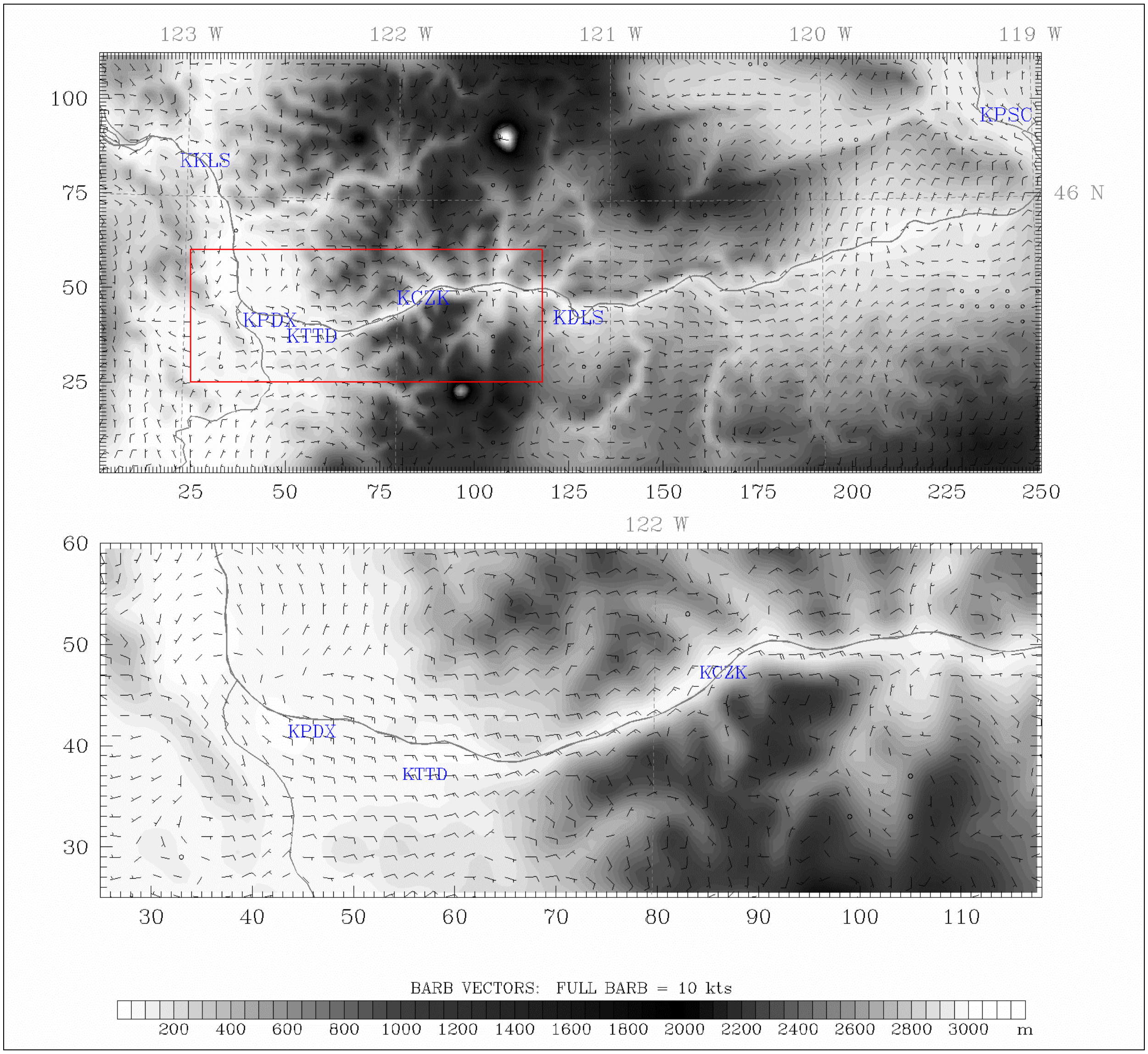

Figure 3: Topography of the Columbia Gorge and surrounding region, as represented in the 1.33 km domain, with location of SAO stations in the vicinity. Model output from the 1.33 km for 2000121300F18 nest is overlaid. The top figure shows wind barbs on sigma=0.997 plotted every four grid points. The boxed area is shown in close up in the bottom figure where barbs are plotted every two grid points revealing the detailed structure of the wind field.

At 36 km, 12 km and 4 km the Gorge appears as a progressively lower pass through the Cascades. Because of this, the atmospheric structures that the model develops in response to the terrain, especially in the 36 km and 12 km nests, are not consistent with those found in reality. At 4 km grid point spacing a broad channel flow is seen to develop and the model forecast, if correctly interpreted, can be useful. However, there is a dramatic improvement when a resolution of 1.33 km is used. The overall topography is well resolved and the structures that develop are physically reasonable. The verification of wind and temperature at locations in the Gorge and close to the exit also improve radically. Figure 3 provides an example of output from this nest. It shows lowest sigma level winds plotted over the model terrain. There is additional improvement when the resolution is again tripled to 0.444 km grid spacing but this improvement is not as significant as between 4 km and 1.33 km and may not be worth the enormous amount of extra computation resources required.

4.2 Effect Of Vertical Resolution

Analysis of ACARS data from aircraft landing and taking off at PDX shows that the gap flow through the Columbia Gorge rarely exceeds 1 km in depth and is frequently much shallower. There is often an abrupt transition zone between the channel flow and the free air above. Thus, the vertical resolution used for these simulations is important in defining the location of this interface and accurately representing the strong vertical gradients present. These factors affect the entrainment of air into the gap flow. This entrained air may have very different temperature, momentum, moisture content and other characteristics. Therefore, how much air is entrained, and how quickly this air mixes downward, play an important role in defining the properties of the gap flow.

Runs were performed using 32, 38, 44 and 50 vertical sigma levels. The additional levels were used to gradually increase the vertical resolution in the lowest 1.5 km with the greatest concentration of levels being added close to the surface.

As vertical resolution was increased, low level wind speeds in the Gorge and its exit region increased. The effect was most pronounced at around 140 to 200 meters above the surface. Temperatures on the lower sigma levels decreased within the Gorge and around the exit region, while on the same sigma levels along higher terrain, they increased. Both these results indicate that increasing vertical resolution may reduce vertical mixing and strengthen the capping inversion, which produces a stronger, more decoupled flow.

4.3 Cloud Microphysics

Although initial simulations produced reasonable wind fields within the Gorge, more detailed verification revealed that temperatures within the Gorge were too low at night and too warm during the day. More importantly, temperatures in Eastern Washington, the source of the air moving into the Gorge, were found to be too cold. It was established that the initialization of much of the Columbia Basin was poor. In addition, temperatures in the Columbia Basin fell far too rapidly after sunset. This resulted in gross errors, especially around sunrise. The initialization errors were largely corrected by running the Little_R objective analysis program. However, temperatures still plummeted at nighttime.

Observations showed that most of the Columbia Basin was under a low to mid-level cloud deck. However, the model was not creating these clouds. This was leading to excessive radiational cooling. Repeating the simulation using cloud water initialization did little to resolve the problem, as the resulting clouds rapidly dissipated. It is thought that the reason for this rapid cloud loss is related to the use of the Simple Ice microphysics scheme. This scheme considers all clouds at a temperature below 0°C to be composed of ice. Thus, since temperatures in the Columbia Basin were well below freezing, the clouds were considered to be composed of ice particles. Because the MM5 tends to precipitate ice quickly, the clouds were rapidly eradicated. By switching to the Reisner2 cloud microphysics scheme and initializing with cloud water it was found that a thin cloud layer could be maintained and net cooling at the ground was reduced to rates similar to those found in reality.

4.4 Future Research – A Case Study and Dynamical Analysis Of Model Output

Model output, together with all observational assets available, will be used to perform an in-depth analysis of the December 2000 case. The evolution of the flow through the length of the Gorge, and in particular, its behavior in the Gorge exit region will be examined. The vertical structure will be considered, especially the boundary at the top of the channel flow where air with quite different properties interacts and momentum may be transferred into or out of the flow.

5 References

Ferber, G. K., C. F. Mass, G. M. Lackmann and M. W. Patnoe: Snowstorms over the Puget Sound Lowlands. *Weather and Forecasting,* **8,** 481-504.

Panofsky, H. A., and G. W. Brier, 1968: *Some Applications of Statistics to Meteorology*. The Pennsylvania State University, 224 pp.