A Comparison of Four Downslope Windstorm Events in Southeast Washington and Central and Northeast Oregon

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Downslope windstorms associated with mountain waves are not uncommon in NWS Pendleton's County Warning Area (CWA). The Cascade Range, the Blue Mountains, and the Wallowa Mountains can act as mountain barriers under certain upper level flow patterns. Forecasting strong winds at the surface based on mountain waves can be challenging, and predicted wind speeds may also be underestimated if a forecaster fails to closely look at forecast soundings and cross sections along the mountain barrier. The higher grid resolution of the latest numerical models has improved the capability of early detection of mountain waves.

The synoptic and mesoscale patterns of four downslope windstorm events that have occurred since November 2007 in southeast Washington and central and northeast Oregon will be compared in this study: the November 12, 2007 windstorm in the Wallowa Valley; the January 4, 2008 windstorm along the Blue Mountain foothills; the January 1, 2009 windstorm in Central Oregon; and the January 6-7, 2009 windstorm across the Kittitas and Yakima Valleys and the Lower Columbia Basin (fig. 1). Analysis will include MSL pressure and upper level winds; forecast soundings; and model cross sections of winds, potential temperature and omega. The 1.6 rule-of-thumb that can determine the likelihood of vertically amplified mountain waves will also be examined with these events.

Geographical Description of NWS Pendleton's County Warning Area

The Cascade Range runs north to south and divides Washington and Oregon with a considerable difference in climate west of the Cascades compared to east of the Cascades. The Cascade Range not only acts as a barrier to precipitation in westerly flow patterns but also winds. Winds over eastern Washington and eastern Oregon can vary significantly compared to the west side of both states. The east side of the Cascade Range slopes down into the vast area of the Columbia Basin plateau. NWS Pendleton provides forecasts for the lower portion of the Columbia Basin which includes the Kittitas Valley, the Yakima Valley, the eastern Columbia River Gorge, north central Oregon, and the Columbia Deschutes Plateau of central Oregon. The lower Columbia Basin and the Columbia Deschutes Plateau rise sharply to the east into the forested areas of the Blue Mountains, the Ochoco Mountains, and the Wallowa Mountains. The topography becomes very complex in this area with steep rugged terrain, deep canyons, and valleys. Figure 1 demonstrates the geographical topography of NWS Pendleton's CWA.

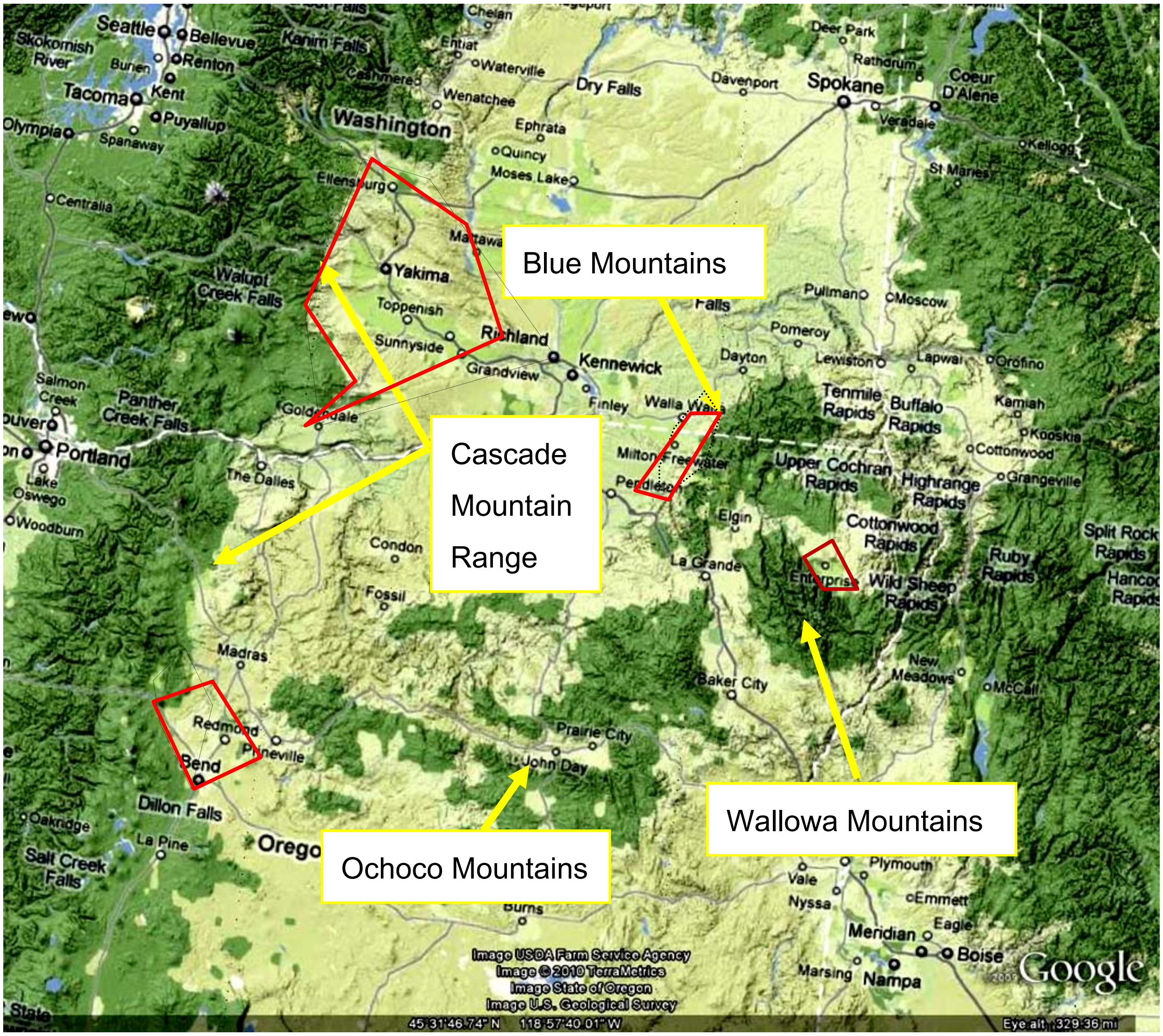

Figure 1 Geographical map of eastern Washington and eastern Oregon. The areas highlighted in red outline the windstorm damage of the four events of this study.

Characteristics of Mountain Waves that Form Downslope Windstorms

One of the first indications of the presence of mountain waves is a strong wind that is perpendicular to the mountain barrier in a stable atmosphere. Stable air that flows over a mountain range is cooled and becomes denser than the air around it, and the stable air sinks downward by the force of gravity on the lee side of the mountain to its equilibrium level. The air mass will oscillate about its equilibrium level and will form waves. (Whiteman 2000). Studies have shown (e.g. Brinkmann 1974; Klemp and Lilly 1975) that mountain waves may propagate vertically and create severe downslope windstorms when a stable layer exists along the ridge top with a less stable layer aloft.

In addition, there is a weak or negative shear of the cross-barrier component of the wind. These conditions will force air to accelerate downward creating surface winds that may be much stronger than the winds aloft. Mountain waves that do not propagate vertically are called trapped lee waves. Trapped lee waves form in a smooth horizontal flow with strong wind shear and a deep stable layer aloft.

Determining the amplitude of gravity waves and whether winds will accelerate down along the lee side of a mountain barrier is a challenge. However, improved resolution of the NWP models can help forecasters provide a longer lead time of high wind warnings in these mesoscale events by utilizing cross sections and forecast soundings. The 1.6 rule, as will be discussed later, may help forecasters predict trapped lee waves compared to vertically propagating mountain waves.

November 12, 2007, Wallowa Valley

Surrounded by mountains with peaks over 9000 feet, the Wallowa Valley can be sheltered from winds but can also receive damaging downslope winds. The Wallowa State Park is located at the base of Mount Howard (elevation 8020 feet) just south of Enterprise and Joseph. The storm on November 12 blew down trees throughout the state park, forcing the park to close through the end of December. In Joseph, a wind gust of 78 mph was observed.

Synoptic Overview

A deep upper low and an associated occluded front moved across southern British Columbia and the Pacific Northwest on November 12. Moist stable air spread across Washington and Oregon, as evident on infrared satellite (fig.2). NWP models showed increasing southerly winds aloft as well as a tight surface pressure gradient. At 850 mb, winds as strong as 60 knots were indicated by the models, including the 12-km NAM (fig. 3). The 12-km NAM also placed a lee side low over Wallowa Valley with strong cross-barrier SLP gradients and boundary layer winds of 55 knots (fig. 4).

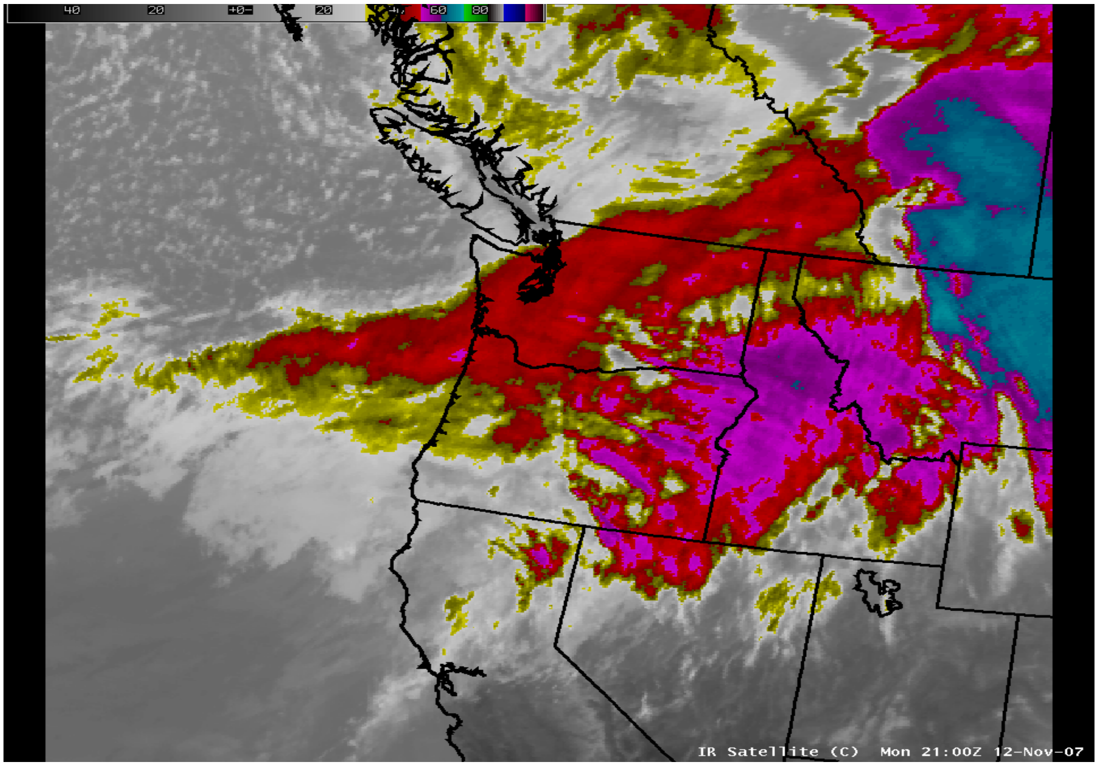

Fig.2 Infrared satellite at 2100 UTC 12 November 2007

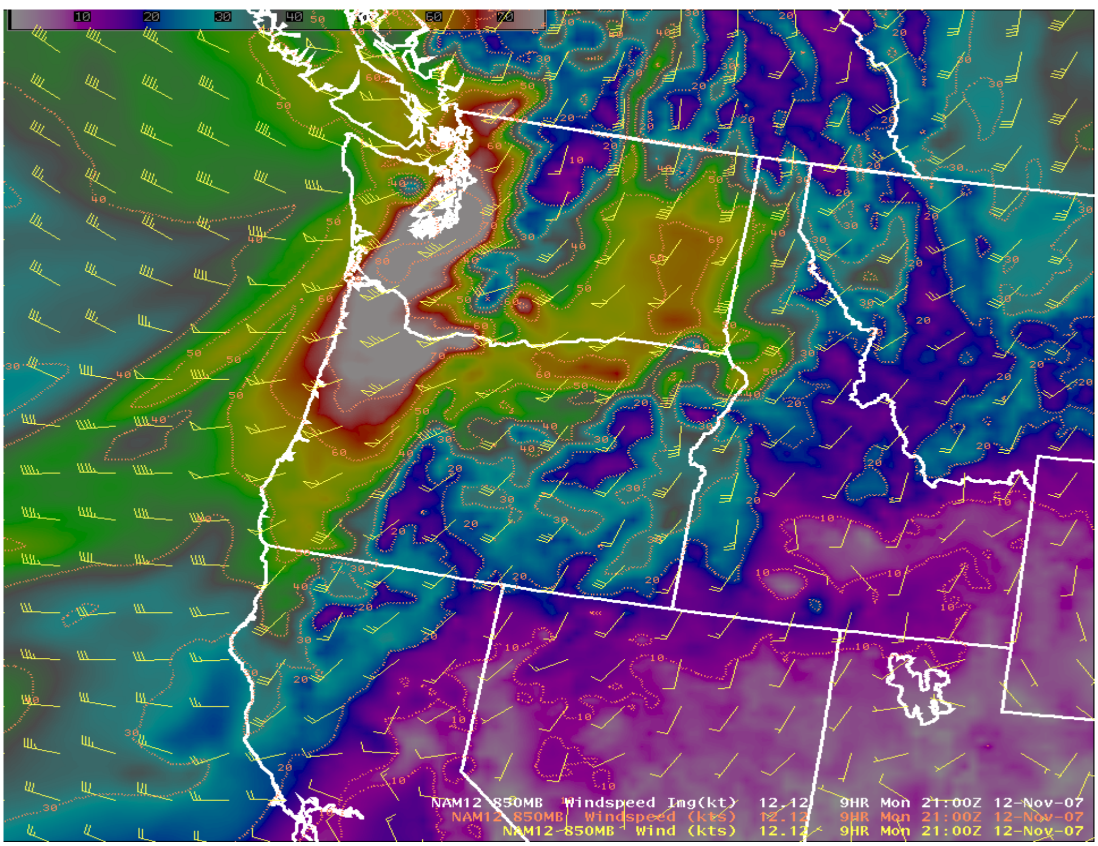

Fig. 3. NAM12/12Z 850mb winds at 2100 UTC 12 November 2007

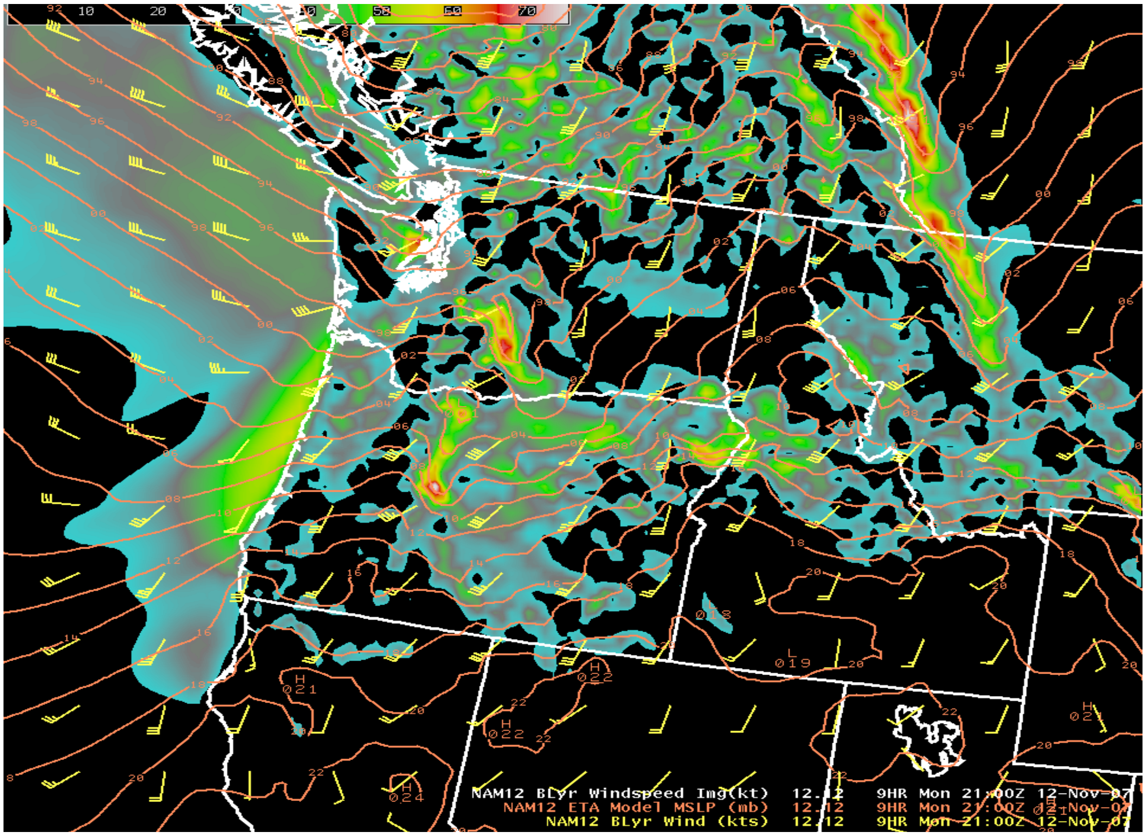

Fig. 4: NAM12/12Z MSLP gradients and boundary layer winds at 2100 UTC 12 November 2007. Image highlights wind speeds ≥ 35 knots.

Mesoscale Overview and 1.6-Rule of Thumb

The strength of the surface pressure gradients and upper level winds are obviously first clues to predicting strong winds in the Wallowa Valley, but the main question will be whether winds aloft will actually reach the surface. It is not uncommon for strong winds above the ridge tops to become trapped and not propagate to the surface in this area of complex terrain. That is why it is important to look closely at mesoscale features. Observing cross sections of potential temperature, winds and omega may help a forecaster determine whether lowering of isentropes and downward omega contribute to downslope winds. The 12-km NAM did an excellent job showing a mountain wave above the peaks of the Eagle Cap Wilderness along with downward omega (fig. 5).

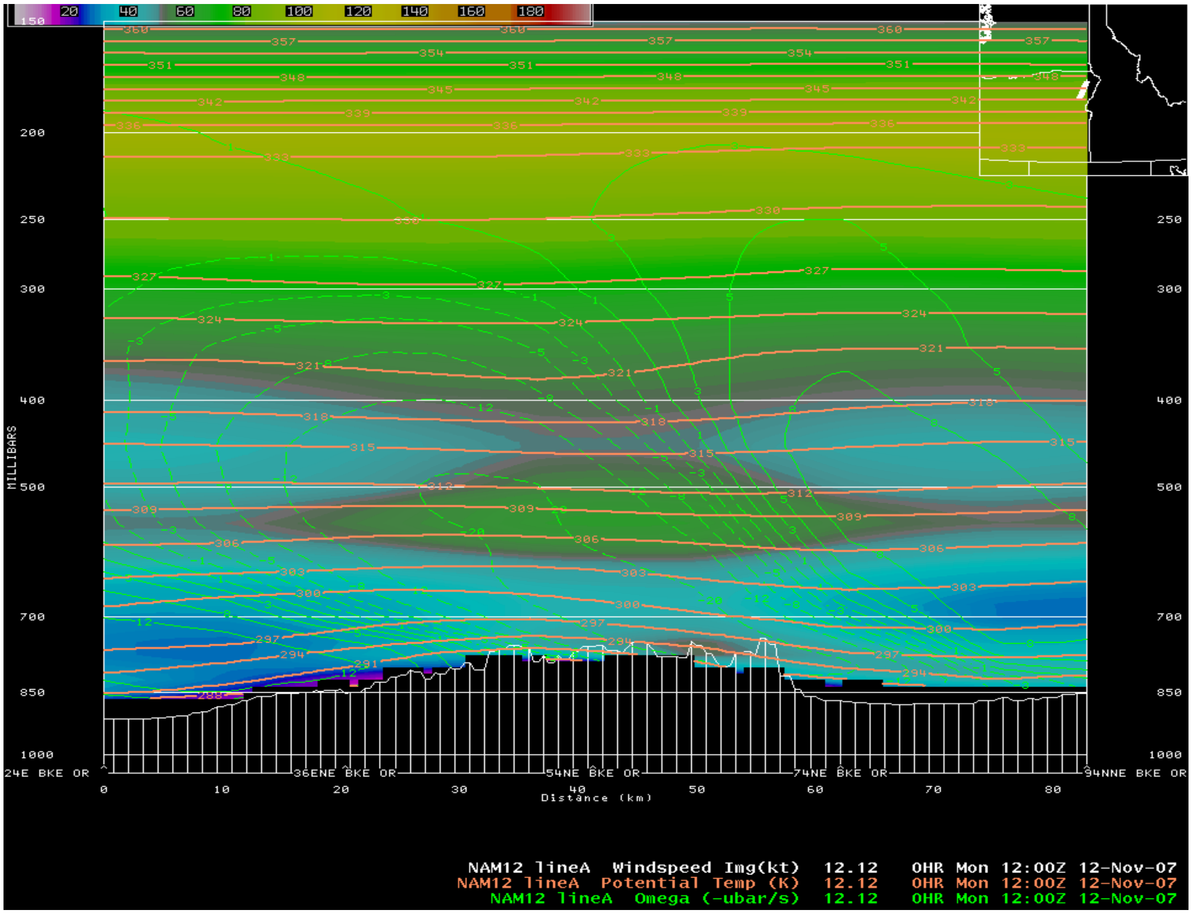

Fig.5 NAM12/12Z 00hr run on 12 November 2007. Potential temperature and omega cross section in the Eagle Cap Wilderness area of the Wallowa Mountains.

A simple 1.6-Rule of Thumb (UCAR's Meteorological Education and Training website www.meted.ucar.edu) can be used as a tool for anticipating vertically-propagating waves compared to trapped lee waves. If the winds at 2 kilometers above the ridge top are stronger than 1.6 times the ridge top winds, there is a better potential for trapped lee waves. On the other hand, if the winds at 2 kilometers above the ridge top are weaker than the ridge top winds multiplied by 1.6, there is a better potential for vertically propagating waves. Simply stated, trapped lee waves occur when there is a strong wind shear that inhibits energy from propagating vertically. A forecast sounding showing the 1.6-rule is shown on figure 6. The 12-km NAM forecast soundings were analyzed postmortem when the damaging winds were observed in the Wallowa Valley from 1200 to 2100 UTC on November 12, 2007, and each forecast sounding indicated the potential for vertically-propagating waves.

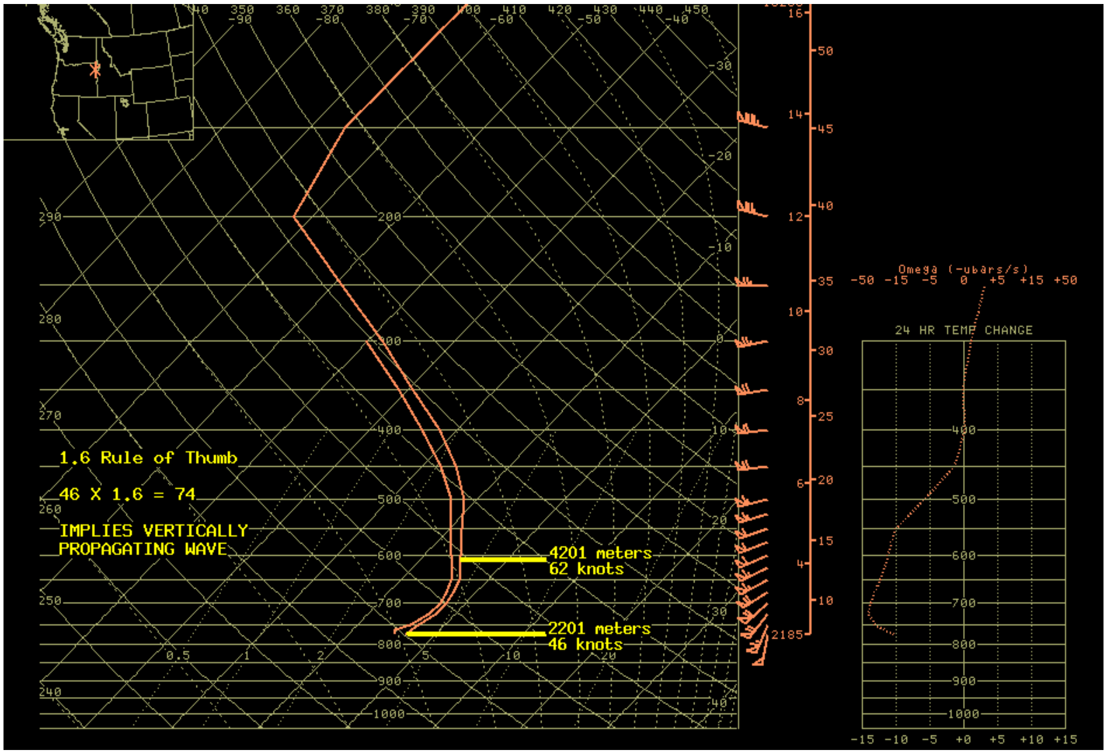

Fig. 6 NAM12/12Z forecast sounding for 2100 UTC 12 November 2007 model run

January 4, 2008, Blue Mountain Foothills

Severe southeast downslope winds were observed along the Blue Mountain foothills in the vicinity of Pendleton and Walla Walla. Upper Wild horse (near Tollgate, OR) observed the strongest winds with a gust of 80 mph. The Walla Walla Airport reported sustained winds of 55 mph and gusts to 78 mph. Umatilla County reported $3.6 million in damage, and Walla Walla County reported $4.9 million in damage. Contrary to the belief that the strength of downslope winds generated by mountain waves depends on the steepness along the lee side of a mountain slope, the west slopes of the Blue Mountains are not as steep as, for example, the east slopes of the Rockies and yet were capable of producing this extreme event on January 4, 2008.

Synoptic Overview
(Note: The 12-km NAM for this particular study is not available). A broad upper level trough off the Eastern Pacific provided widespread precipitation throughout Washington and Oregon on January 3rd and 4th. A moist subtropical tap and a southwest flow ahead of the trough indicated considerable warm air advection aloft (fig. 7 and fig. 8). A 959 mb surface low moved across British Columbia on January 4th. Meanwhile, a strong surface high developed in the Snake River Valley of southern Idaho (fig 9). A sharp pressure minimum was created within the lee-side low which was associated with the peak winds that afternoon.

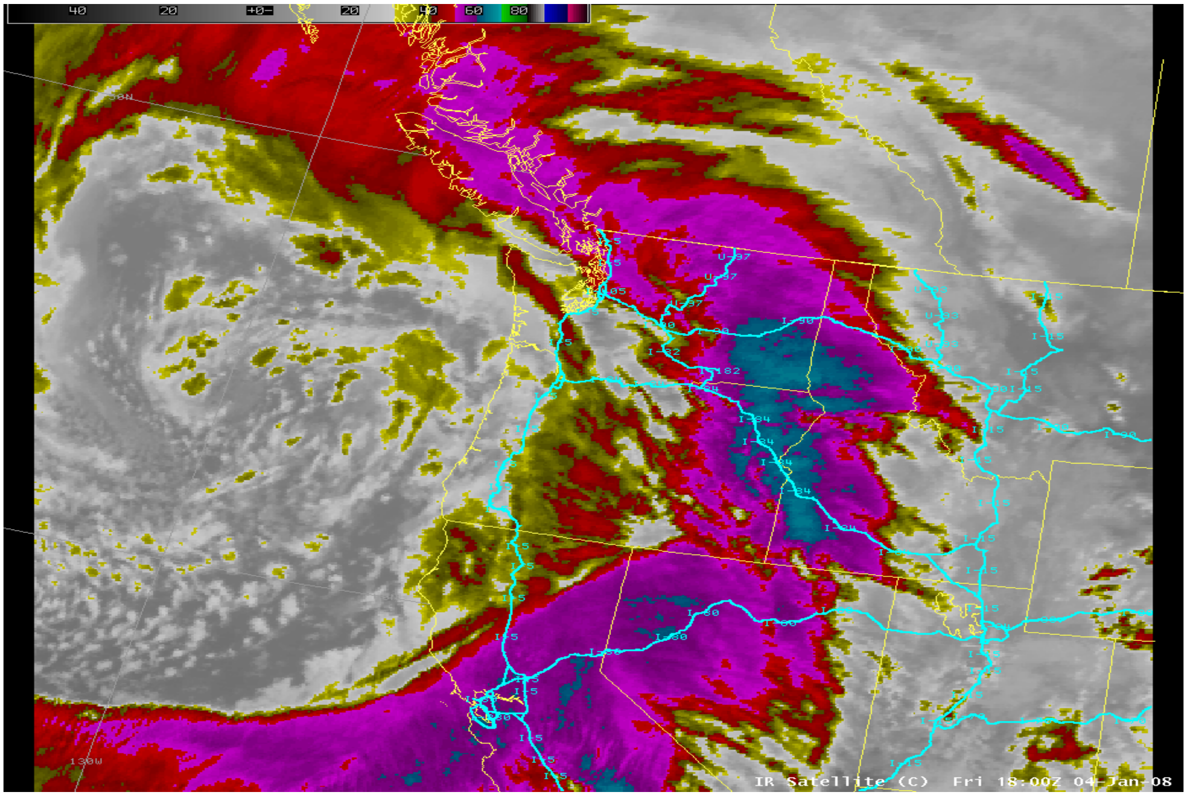

Fig. 7 Infrared satellite at 1800 UTC on 4 January 2008

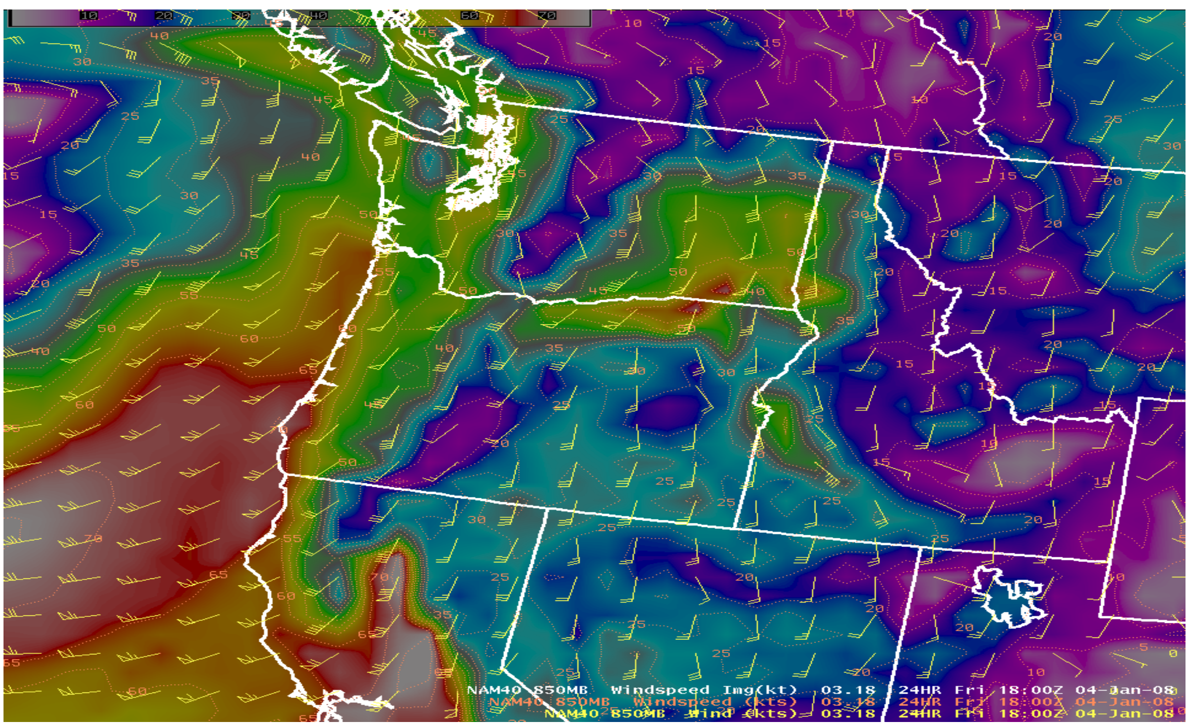

Fig. 8 NAM40/18Z 24HR 850mb winds at 1800 UTC 4 January 2008

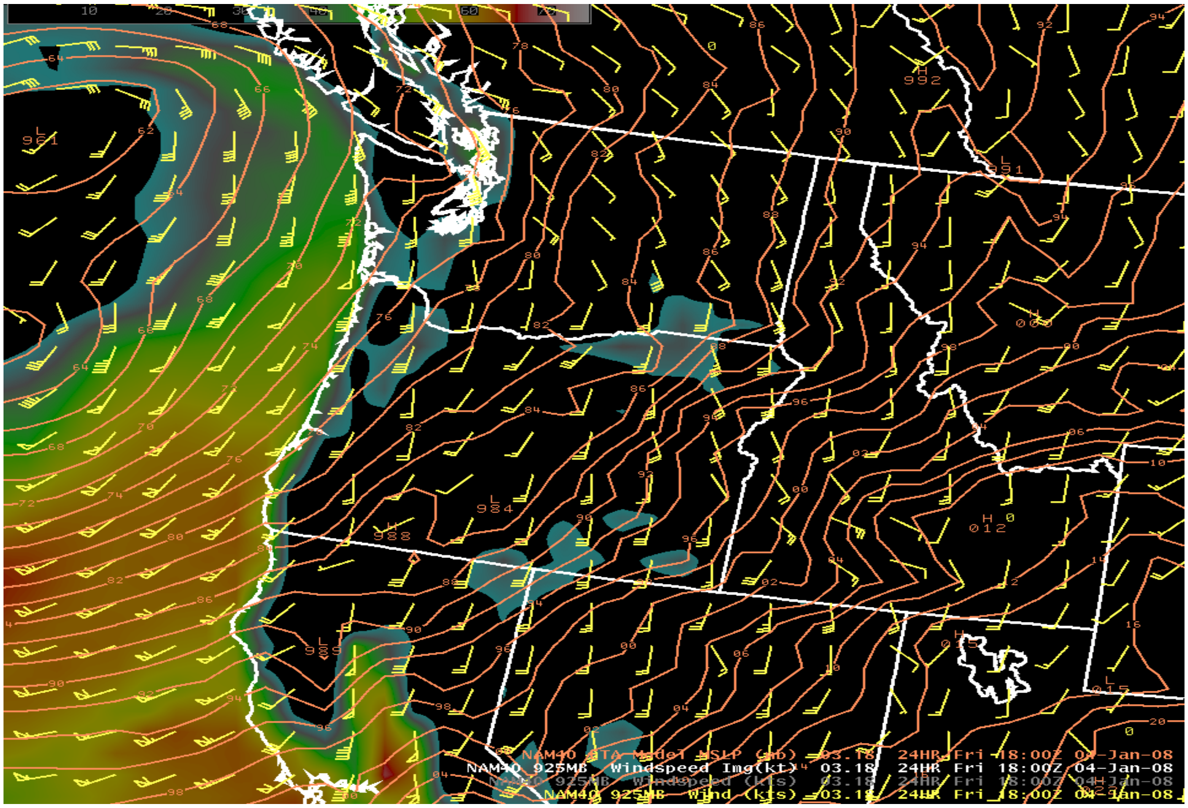

Fig. 9: NAM40/18Z 24HR MSLP gradients and 925-mb winds at 1800 UTC 4 January 2008. Image highlights wind speeds ≥ 35 knots.

Mesoscale Overview and the 1.6-Rule of Thumb

As stated in the synoptic overview, a lee-side low developed over the west side of the Blue Mountains. This was identified by the 2.9-km NMM (not available) that also indicated strong surface winds in the Walla Walla vicinity. The accurate position and strength of low level winds from the NMM helped forecasters provide lead time with high wind watches and warnings ahead of the event. Figure 10 shows the cross section of potential temperature and omega from the 40-km NAM. Although the NAM40 does not identify strong winds along the peaks of the Blue Mountains, it does show impressive downward motion looking at omega and potential temperature surfaces.

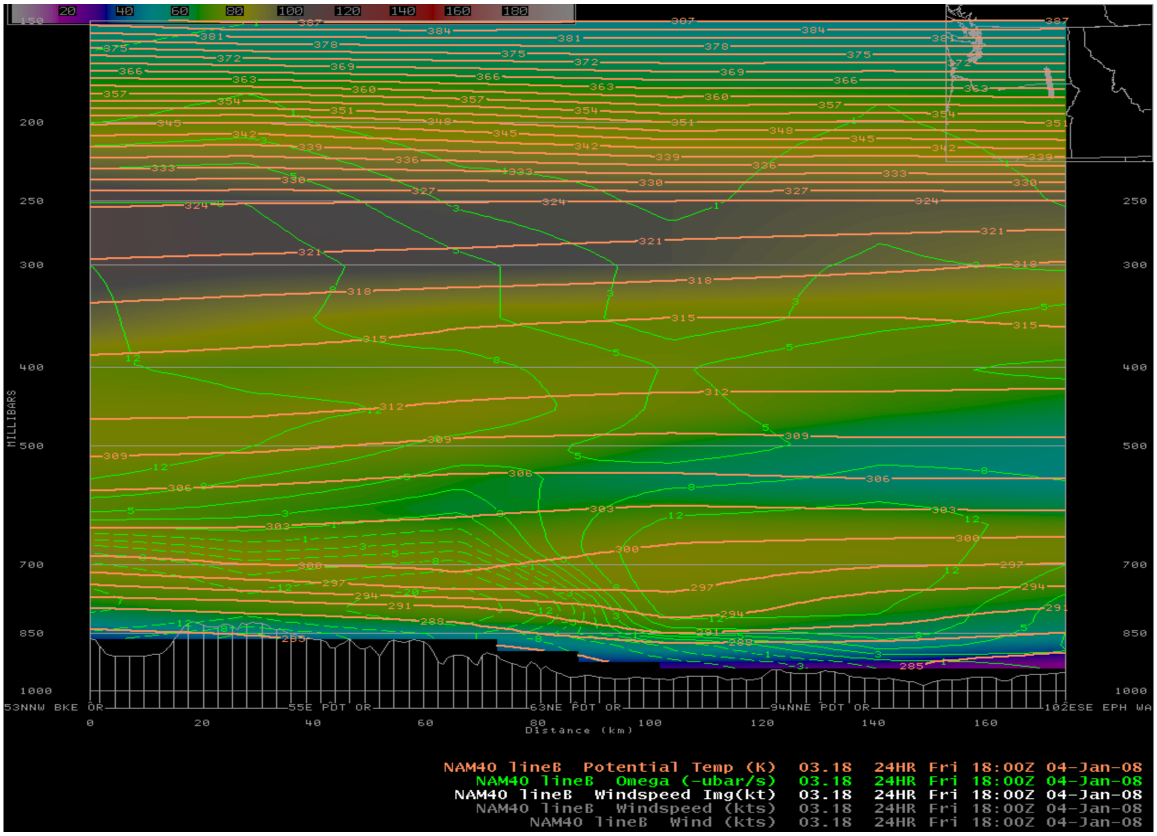

Fig.10 NAM40/18Z 24HR 1800 UTC 4 January 2008. Potential temperature and omega cross section.

The 1.6-Rule of Thumb did not work for the NAM40 model run (fig. 11), but was noted in the forecast soundings of NAM12. This proves to show that the higher resolution models have made improvements to mesoscale forecasting of downslope winds.

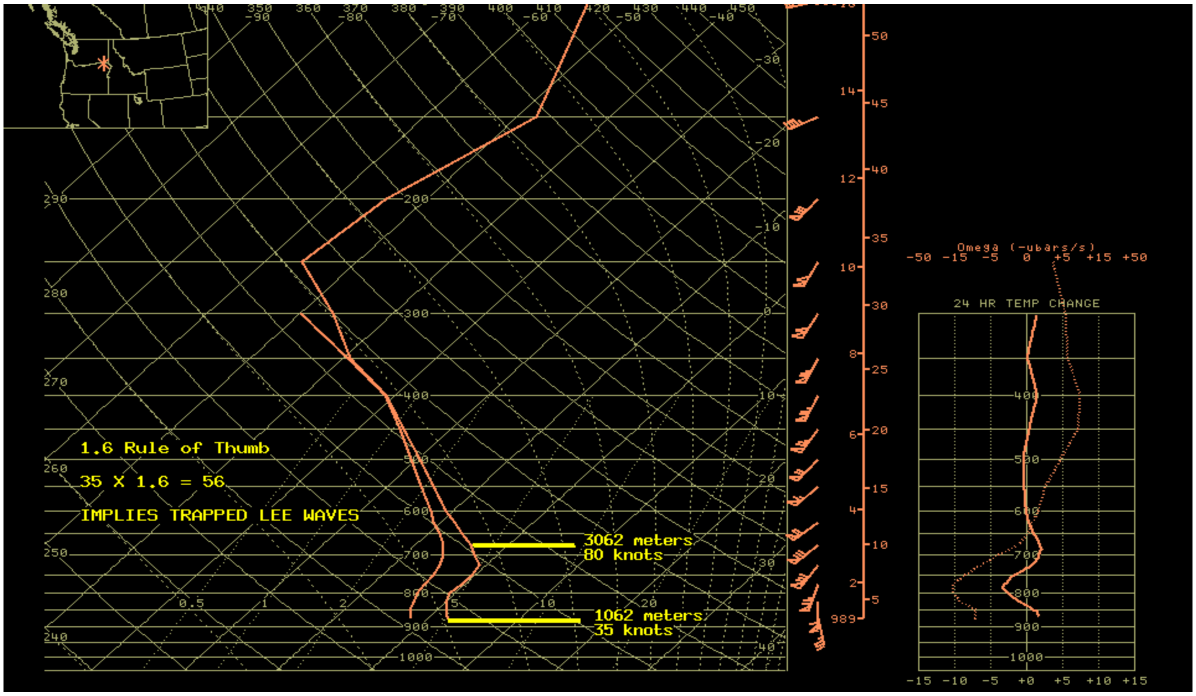

Fig. 11 NAM40/18Z 24HR forecast sounding for 1800 UTC 4 January 2008. The 40-km resolution implied trapped lee waves unlike the higher resolution 12-km NAM.

January 1, 2009, Central Oregon

Numerous downed trees and power lines were observed in Deschutes County on New Year's Day, 2009. The strongest wind gust observed was 68 mph at Tumalo Ridge RAWS site. The greatest concentration of damaging winds occurred in and near the Bend and Sisters, Oregon, area.

Synoptic Overview

Similar to the two previous windstorm events, a moist warm front and strong winds aloft were observed on the morning of New Year's Day 2009 (fig.12 and 13). The low level jet was directed over the Oregon Cascades with 850mb winds around 65 knots. Although winds aloft were very strong with this event, SLP gradients were not very significant (fig 14).

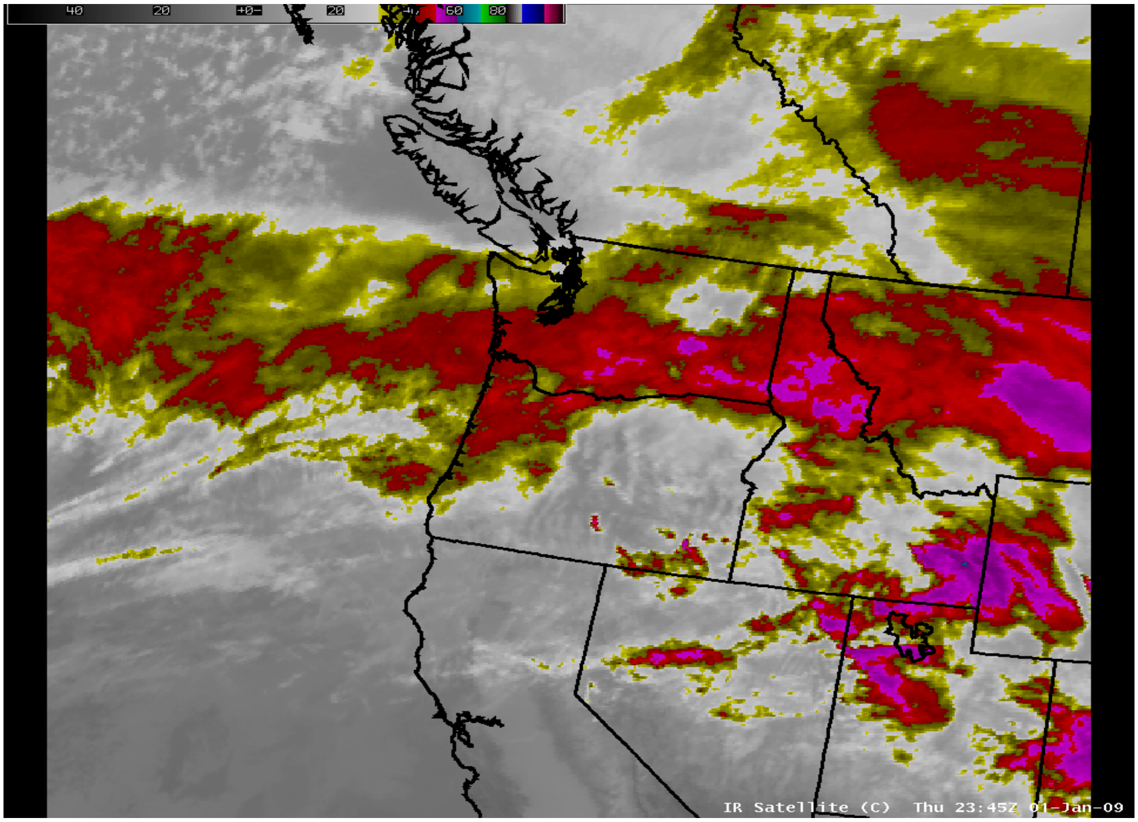

Fig. 12 Infrared satellite at 2345 UTC on 1 January 2009

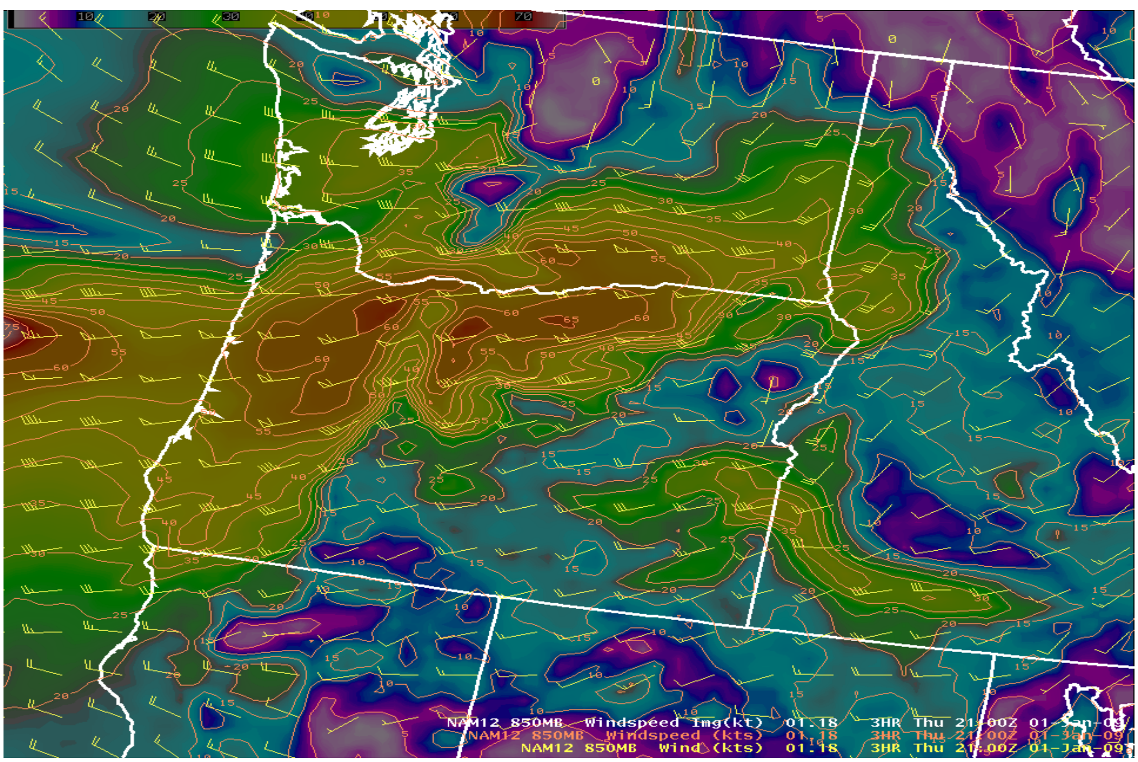

Fig. 13 NAM12/18Z 850mb winds at 2100 UTC 1 January 2009

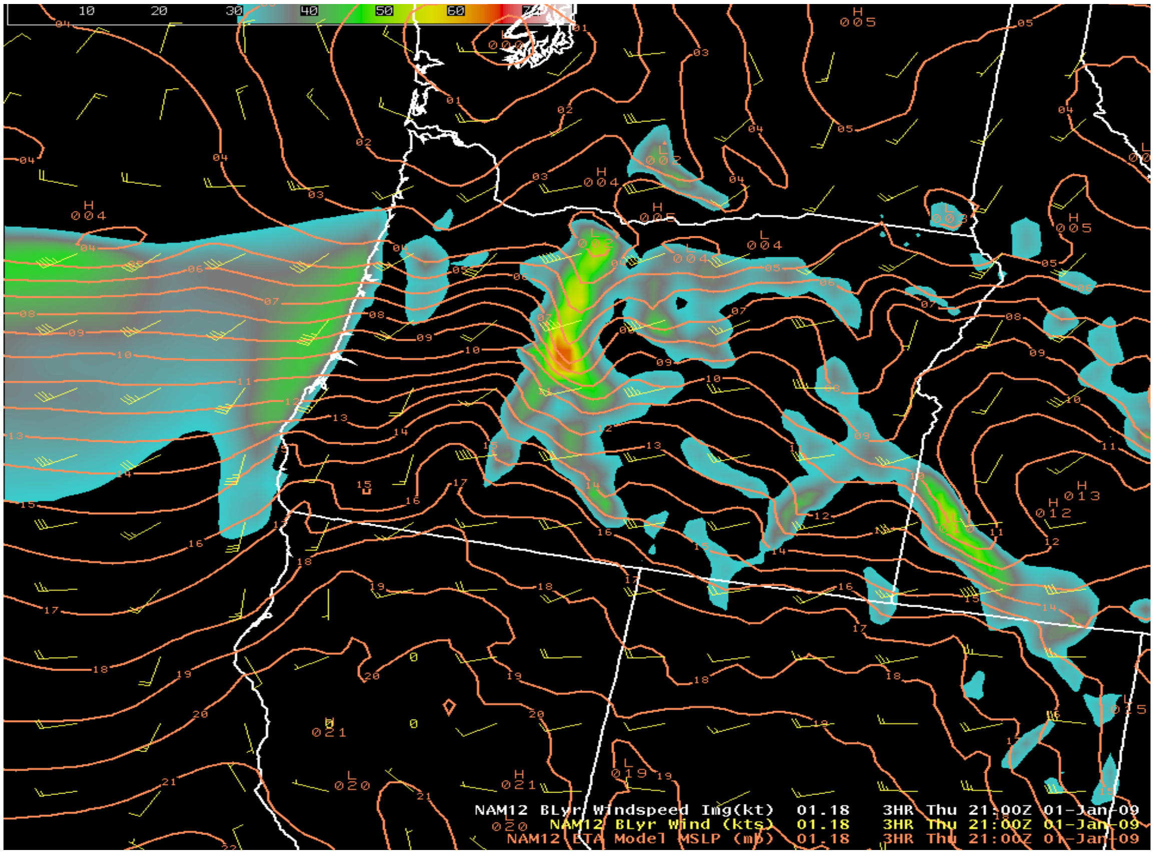

Fig. 14: NAM12/18Z MSLP gradients and boundary layer winds at 2100 UTC 1 January 2009. Image highlights wind speeds ≥ 35 knots.

Mesoscale Overview and 1.6-Rule of Thumb

A lee-side trough over the east side of the Oregon Cascades can be seen in figure 14. Boundary layer winds near 60 knots were also detected by the 12-km NAM. This was probably the biggest factor in deciding on the high wind watch and warning that was issued for Central Oregon. A cross section also reveals strong downward omega (fig. 15). The 1.6-rule also worked well in this case (fig. 16).

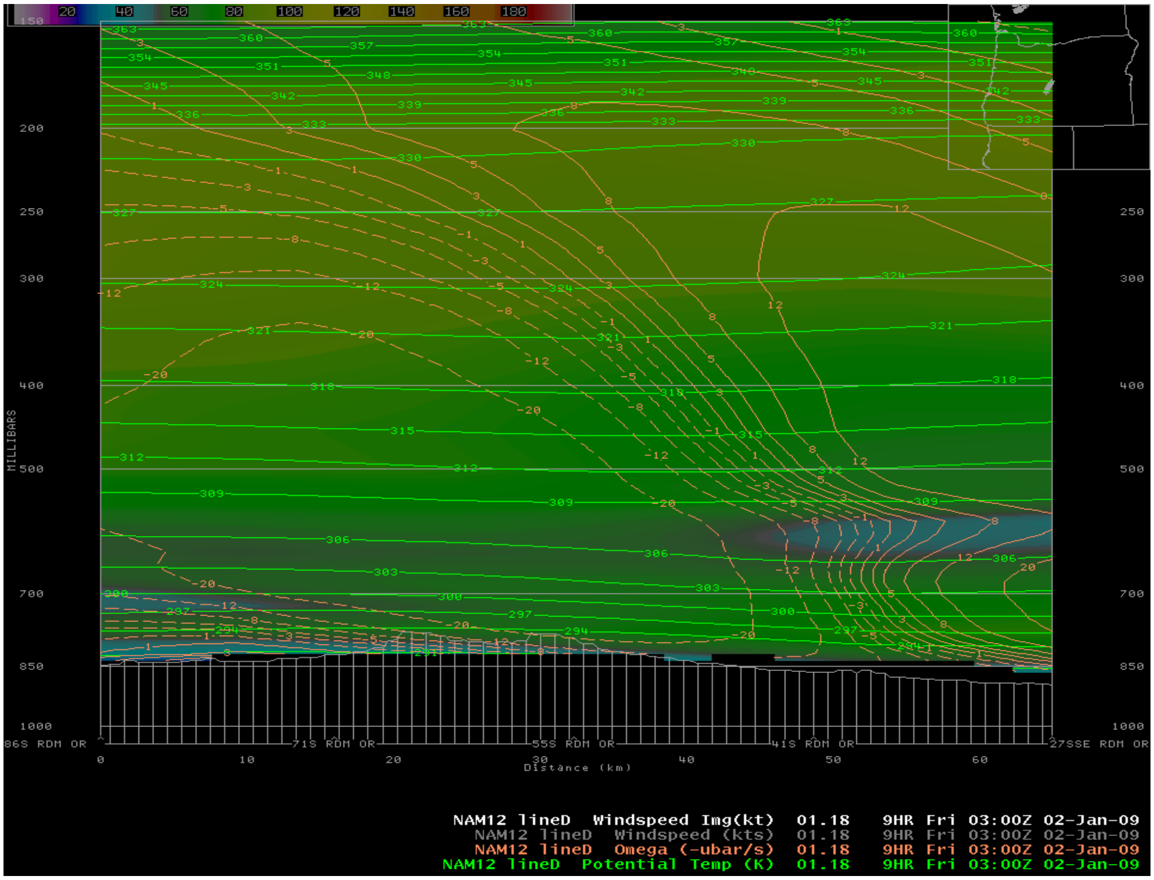

Fig.15 NAM12 0300 UTC 2 January 2009 from the 18Z January 1, 2009 run. Potential temperature and omega cross section.

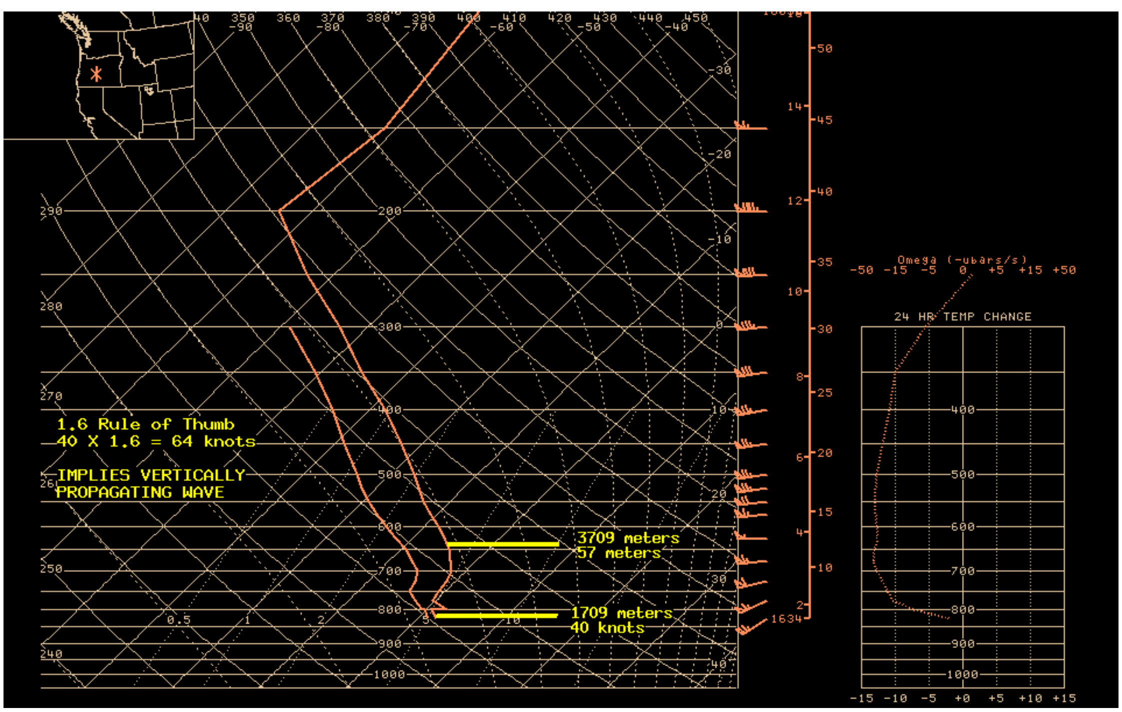

Fig. 16 NAM12/18Z forecast sounding for 0300 UTC 2 January 2009

January 6-7, 2009, South Central and Southeast Washington

Several days after the windstorm event in Central Oregon, strong winds surfaced along the east slopes of the Washington Cascades, the Kittitas and Yakima Valleys, and the Lower Columbia Basin. A gust to 76 mph was measured along South Umtanum Ridge in the Yakima Valley, and to 80 mph in Goldendale, WA. Sedge Ridge RAWS site (elevation 4300 feet) reported frequent gusts of 69-79 mph with the strongest gusts of 114 mph.

Synoptic Overview
In this wind event, cold air remained trapped in the Lower Columbia Basin and surrounding valleys ahead of the Pacific storm system. There was significant warm air advection aloft, and it took hours before the strong upper level winds mixed down to the surface. Infrared satellite shows the storm system directed over Washington State. There is also evidence of strong westerly winds on the infrared satellite by the wave clouds on the lee side of the Cascades (fig. 17). The upper level and low level jet were directed over Washington (fig. 18). NWP models advertised a lee side surface low (fig 19) over western Yakima county.

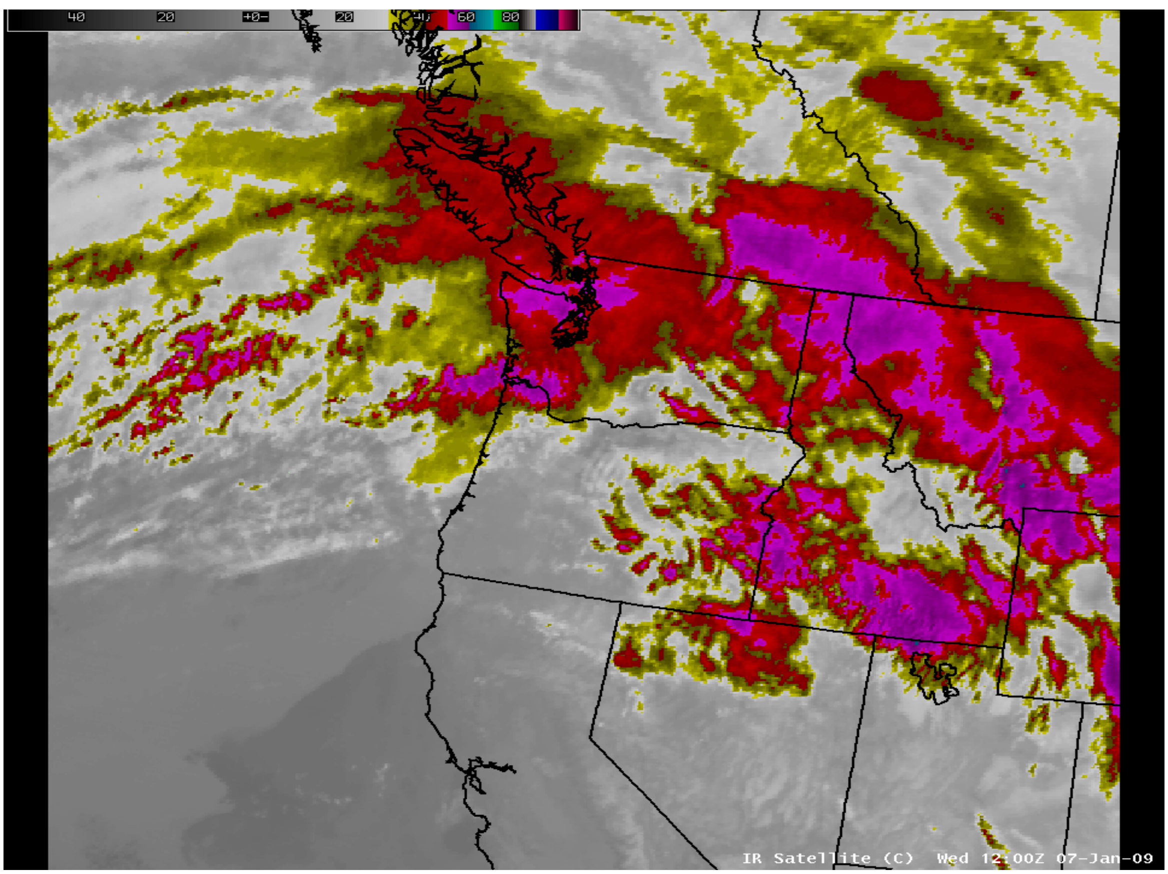

Fig. 17 Infrared satellite at 1200 UTC on 7 January 2009

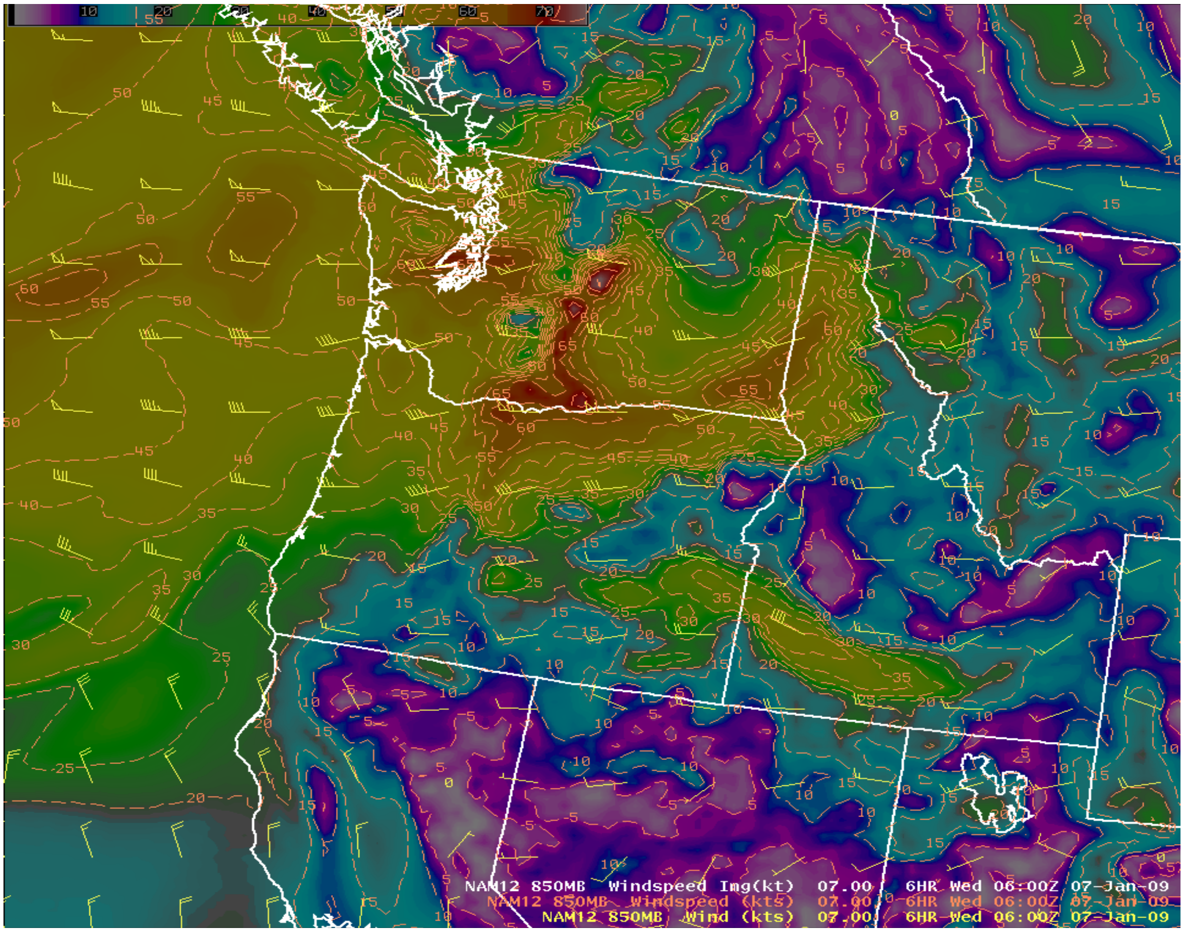

Fig. 18. NAM12/00Z 850mb winds at 0600 UTC 7 January 2009

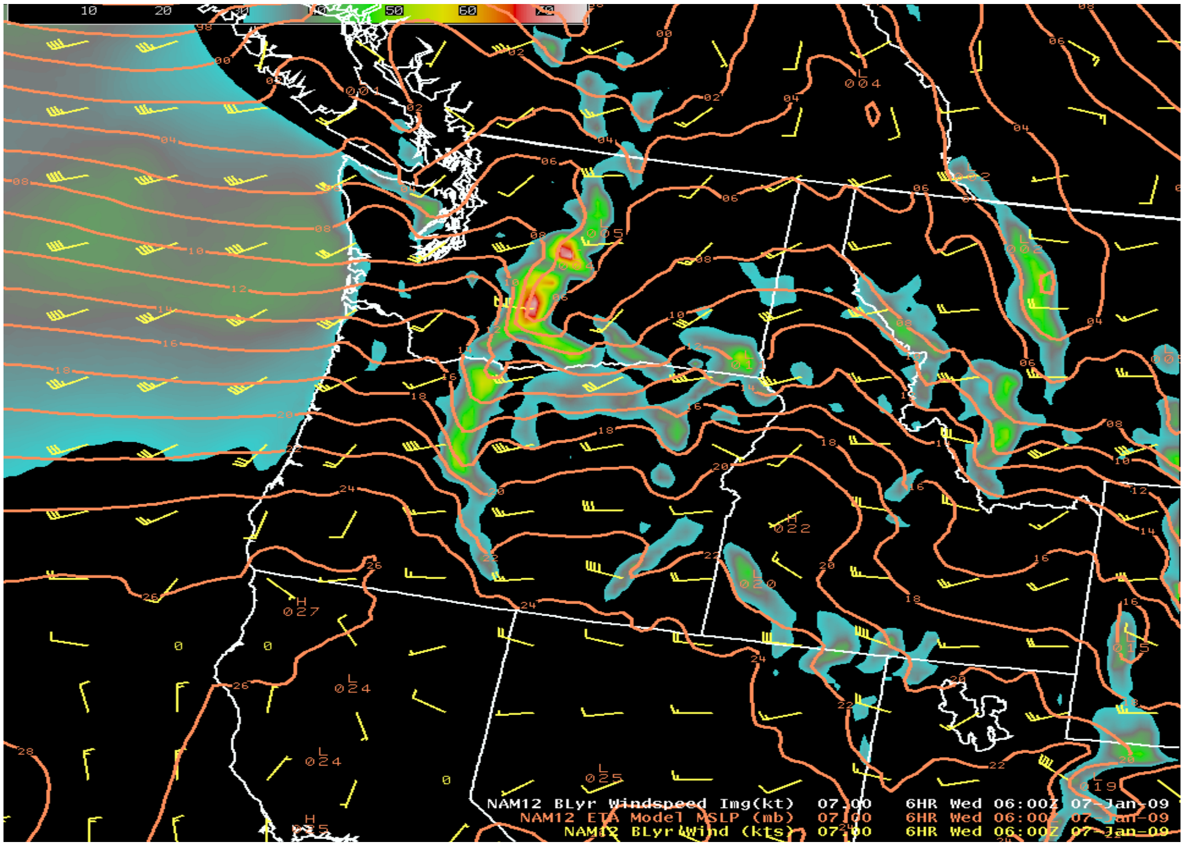

Fig. 19: NAM12/00Z MSLP gradients and boundary layer winds at 0600 UTC 7 January 2009. Image highlights wind speeds ≥ 35 knots.

Mesoscale Overview and the 1.6-Rule of Thumb

Similar to the wind event in Central Oregon on New Year's Day, a strong lee side trough was evident on the east side of the Washington Cascades. NAM12 showed both 850mb winds and boundary layer winds around 65 knots. One challenge in forecasting the potential for severe downslope winds using model cross sections and soundings is to determine *where* to place the cross section and exact location of a sounding. It may take several attempts to get good detail for the mesoscale event. A postmortem analysis of the cross section through Mount Adams showed a well defined mountain wave and descending air into the Yakima Valley (fig. 20). A forecast sounding was placed along the ridge top in this same area, and the 1.6-rule identified a vertically amplified mountain wave.

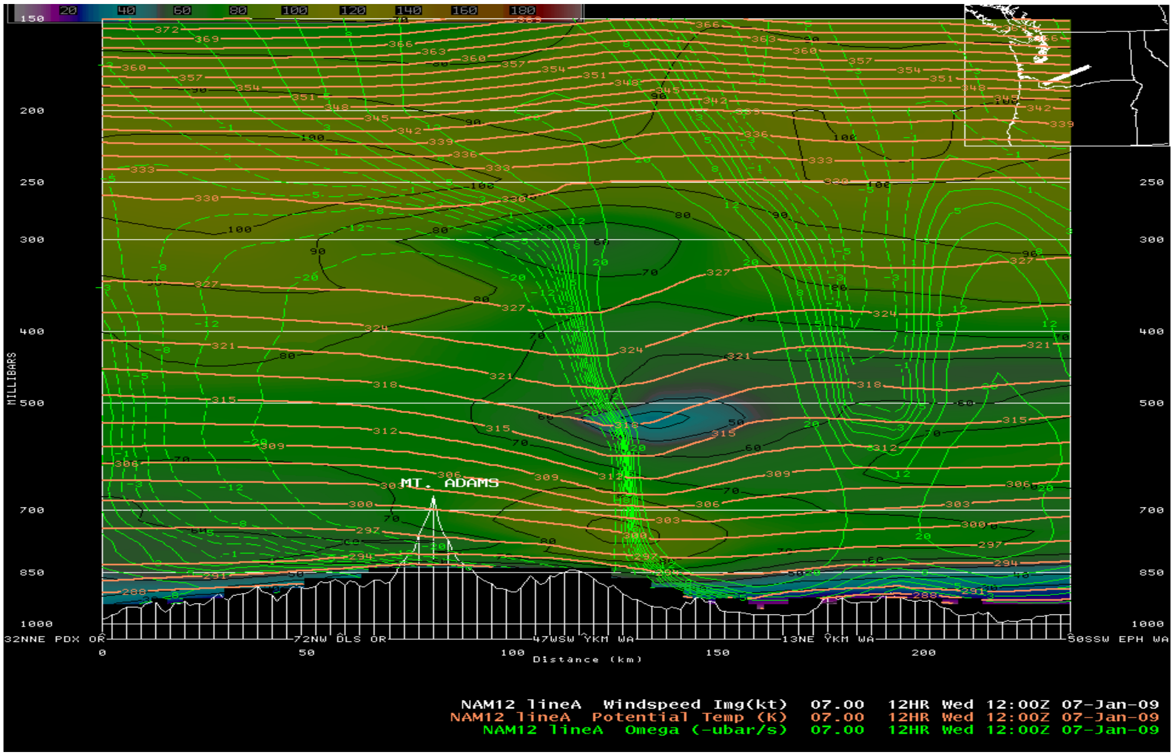

Fig.20 NAM12 1200 UTC 7 January 2009 from the 00Z January 6, 2009 run. Potential temperature, wind speeds and omega cross section.

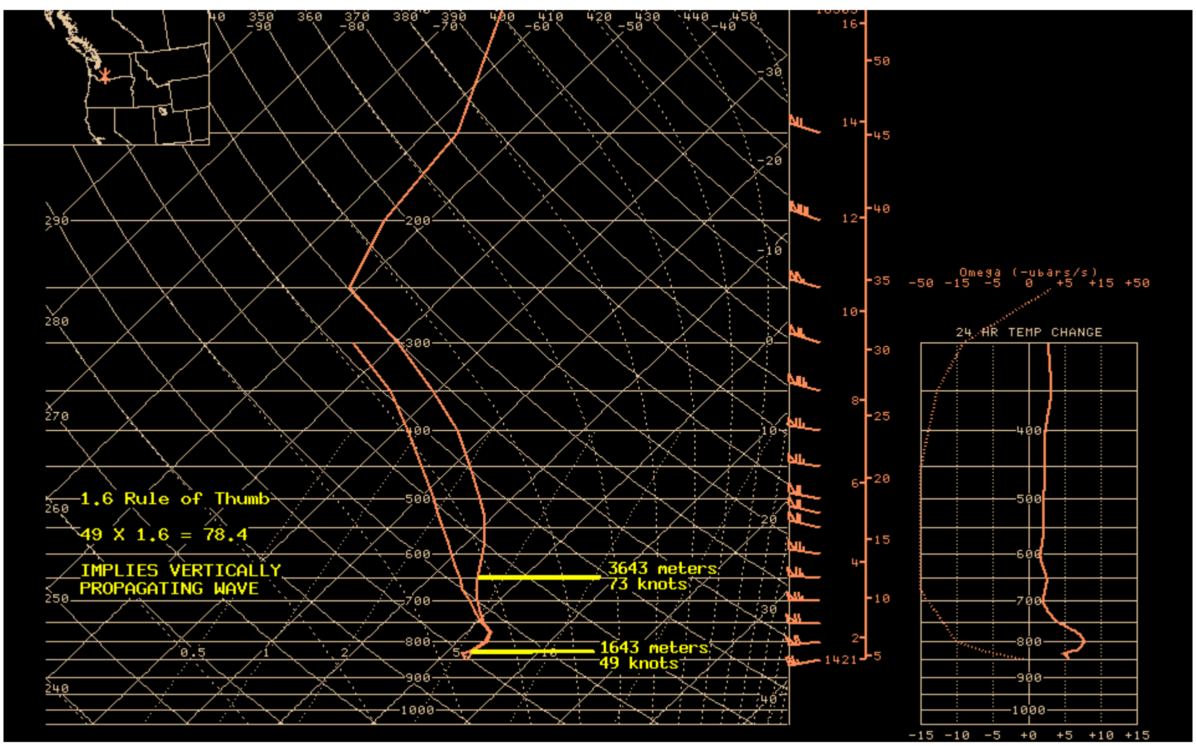

Fig. 21 NAM12/00Z forecast sounding for 1200 UTC 7 January 2009

Conclusion

Forecasting downslope winds can be challenging in areas of complex terrain. While some mountain waves remained "trapped" and do not accelerate winds down a mountain slope, others can propagate to the surface and cause severe winds that may even be stronger than the low level jet. As noted by the University Corporation for Atmospheric Research (UCAR) in the training website *Mountain Waves and Downslope Winds,* downslope winds can occur any time of the day but typically occur at night when the air mass is more stable. Informing the public of the impending threat of sudden damaging winds at night is critical with an early lead time. Utilizing the high resolution models and focusing on the mesoscale details of the event is essential to determine if mountain waves will vertically propagate to the surface.

The combination of a stable layer at the ridge top, a less stable layer aloft, and a weak or negative shear aloft was necessary for the damaging winds that developed in each of these case studies. A strong wind perpendicular to the mountain barrier and a lee side trough were also present during each event. The only differences were the steepness of the mountain slopes and the time of occurrence (i.e. diurnal wind storms compared to nocturnal wind storms). While the events that occurred in central Oregon and south central Washington were associated with the Cascade Mountain Range, the mountains just south of the Wallowa Valley are more isolated in nature. The wind storm along the foothills of the Blue Mountains was associated with a less steep mountain slope. Most research studies regarding downslope wind storms are associated with the more common mountain ranges such as the Cascades and the Rocky Mountains. By exploring the synoptic and mesoscale features related to damaging downslope winds in NWS Pendleton's CWA, it becomes easier to recognize the potential of a downslope event advertised by the high resolution models, even for smaller scale areas.

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