Freezing Rain in Medford, Oregon: Analysis of a High-Impact Event

National Weather Service

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Introduction

Any amount of freezing rain can be a high-impact event, especially for regions that are not accustomed to this type of precipitation. At a glance, Medford, Oregon, in the Rogue Valley, looks conducive to freezing rain events (Figure 1). Its high-latitude location at 42° North, valley topography, mountain blocking and distance from the moderating influence of the Pacific Ocean suggest that it would be a prime candidate for trapping cold air near the surface, leading to episodes of freezing rain. However, historical data indicate that ice events in the Rogue Valley are rare. According to climate data for Medford's Rogue Valley International Airport, freezing rain has been reported only 6 calendar days since 1984 (NCDC). Before 1984, records combined freezing drizzle and freezing rain into one term called "glaze", so these records were not included in this study.

On December 11 and 12, 2009, Medford International Airport (MFR) reported a total of 0.13 inches of precipitation with periods of rain, sleet, and freezing rain. This relatively small amount of precipitation caused over 140 accidents in the Rogue Valley on the 11th and the morning of the 12th (Mail Tribune, 2009). Specifically, 20 accidents occurred during the afternoon and evening of Friday December 11, and 125 accidents occurred overnight on December 11 through the morning of Saturday December 12. Many factors contributed to this high-impact weather event, including local terrain, soil temperatures, and well-below normal antecedent temperatures. In this study, I will explore the cold air outbreak that preceded the wintry precipitation, the factors involved in the freezing rain event, a comparison to past Rogue Valley freezing rain situations, and the precipitation type forecasting tools we have available. It is my hope that the lessons learned from examining this event will provide increased situational awareness and highlight the forecasting tools to use during future icing events.

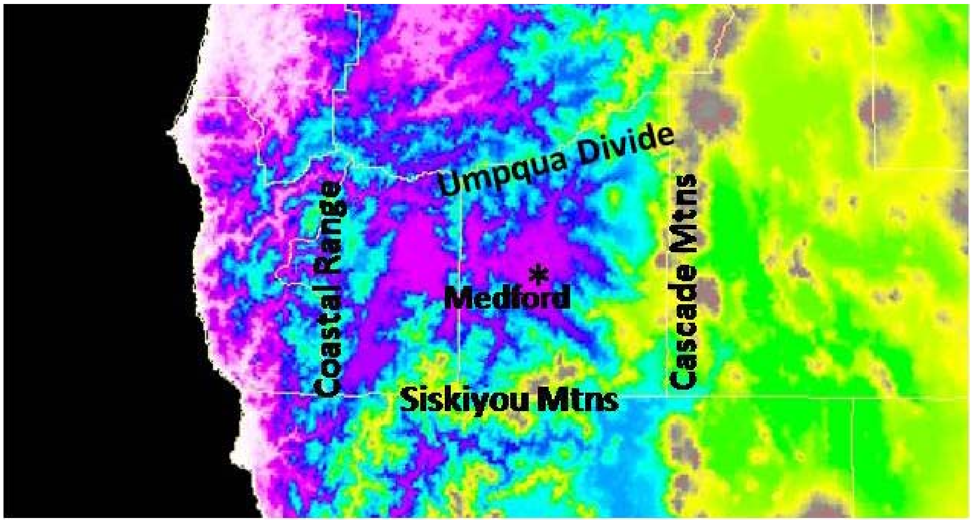

Figure 1. Southwestern Oregon Terrain Map

Synoptic Pattern During Cold Air Outbreak

A high amplitude upper ridge over the Northeast Pacific Ocean with broad northwesterly upper level flow over Oregon was present at 1200Z 8 December 2009, the beginning of the cold air event (Figure 2). This flow shared some common characteristics with historic polar and modified arctic outbreaks in the region. December 1990 was an example of one of the coldest periods in the Rogue Valley, historically. The 500 mb re-analysis for the beginning of that event is depicted in Figure 3. Note that the scales and associated colors of the two charts are different. Although the 1990 pattern featured a stronger northerly wind component at 500 mb, lower heights over Oregon, and correspondingly lower surface temperatures, one can draw similarities between the two cold event upper-air patterns. Both feature high amplitude upper ridges over the Gulf of Alaska and ridge axes near 140W. In comparing the severity of these two events, I looked at the number of consecutive low temperatures that reached 15° F or lower. (A low of 15° F at Medford, Oregon is 16° below average for December low temperatures). The December 1990 cold air outbreak had six such consecutive lows of 15 degrees F or lower while the 2009 event had three. Using this criteria, the 1990 event ranks as the third most significant cold air event in Medford's history while the 2009 event ties for sixth (xmACIS). This string of three very cold mornings with high temperatures only reaching the mid 30s F dropped soil temperatures well below freezing which likely contributed to the accumulation of ice later in the week. Gradually the flow aloft shifted to a more zonal westerly direction as the upper ridging began to tilt negatively, moderating the air mass over Southwest Oregon and ending the cold snap (Figure 4).

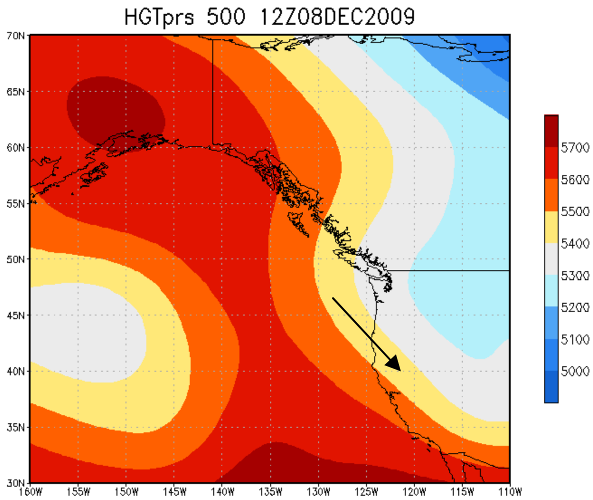

Figure 2. 500 mb Reanalysis 12Z 8 Dec 2009

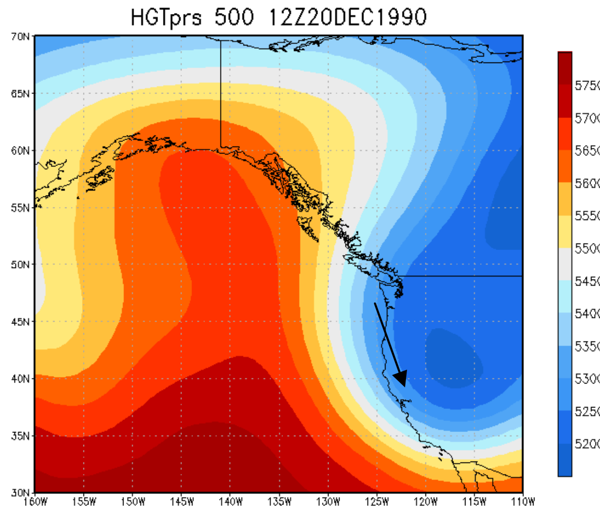

Figure 3. 500 mb Reanalysis 12Z 20 Dec 1990

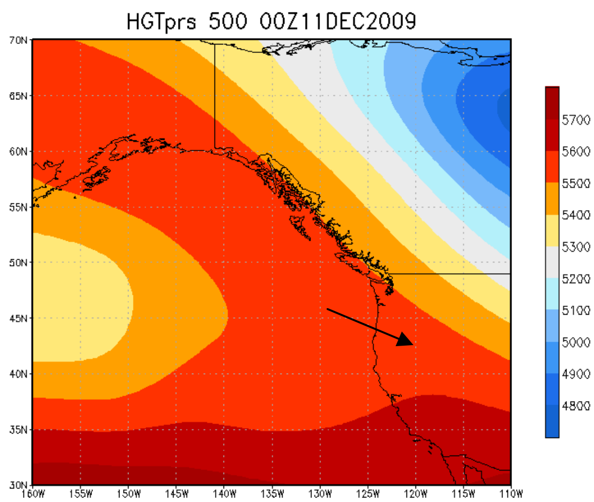

Figure 4. 500 mb Reanalysis 00Z 11 Dec 2009

Infrared satellite imagery with surface analysis and 500 mb winds overlaid clearly depicts a transition towards a warmer air mass (Figure 5). A low pressure center can be seen near 40N 130W on Figure 5, and the image shows Southern Oregon in the transition zone between the colder northwesterly 500 mb flow in Eastern Oregon and warmer westerly flow over the offshore waters. Even though significant warming was occurring aloft due to the approaching low pressure and synoptic regime transition, cold air was still entrenched in the Rogue Valley, and the evolution of this near-surface cold air layer would prove to be critical to developing freezing rain.

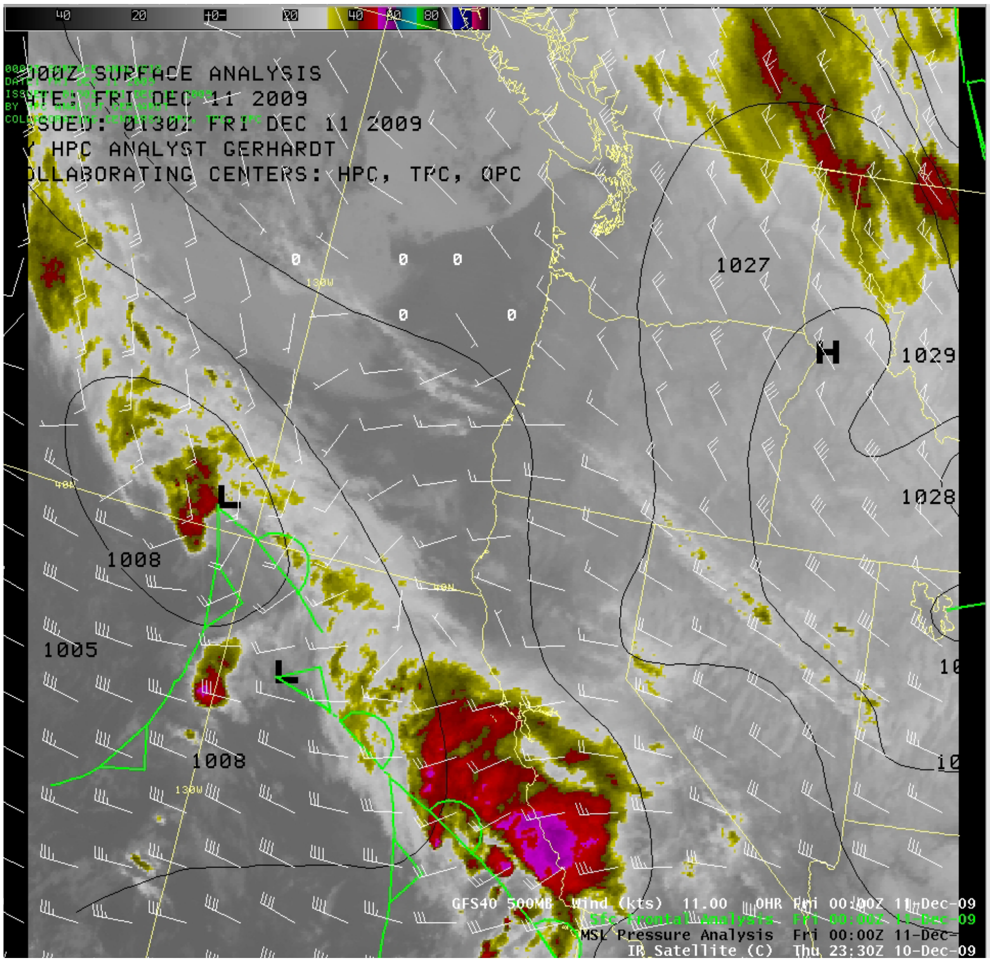

Figure 5. IR Image and 500 mb winds 00Z 11 Dec 2009

Pattern During the Onset of Precipitation

On December 11 at 1800Z the synoptic pattern featured a surface high pressure area over the Great Basin and a 1008 mb low pressure center at 41N 130W (Figure 6). Overlaid on the IR satellite image are the GFS 290K pressure and wind fields. Pressure is drawn at 50 mb increments. Over Northern California 15 kt winds are blowing perpendicular to this gradient toward lower pressure. This suggests that the band of enhanced clouds and precipitation over northern California was the result of weak isentropic up glide. This overrunning was the source for the mix of light freezing rain and sleet that fell in Medford during the day of December 11. By 0000Z on 12 Dec 09, Figure 7 shows a band of high clouds beginning to move north of Medford, while the low center and associated surface convergence and enhanced clouds lags behind over Northwestern California and the offshore waters. Around this time, freezing precipitation ended and skies cleared, allowing solar heating to melt some of the ice on the road surfaces. This was short-lived as sunset brought a return to the sub-freezing surface temperatures. Finally, Figure 8 depicts the frontal cloud band reaching Southern Oregon and the Rogue Valley. This area of clouds dropped more freezing rain overnight on December 11 and into the early morning hours of December 12. Surface temperatures finally climbed above freezing during the day on December 12. Subsequent precipitation from the upstream frontal system over the offshore waters on Figure 8 fell as a cold rain.

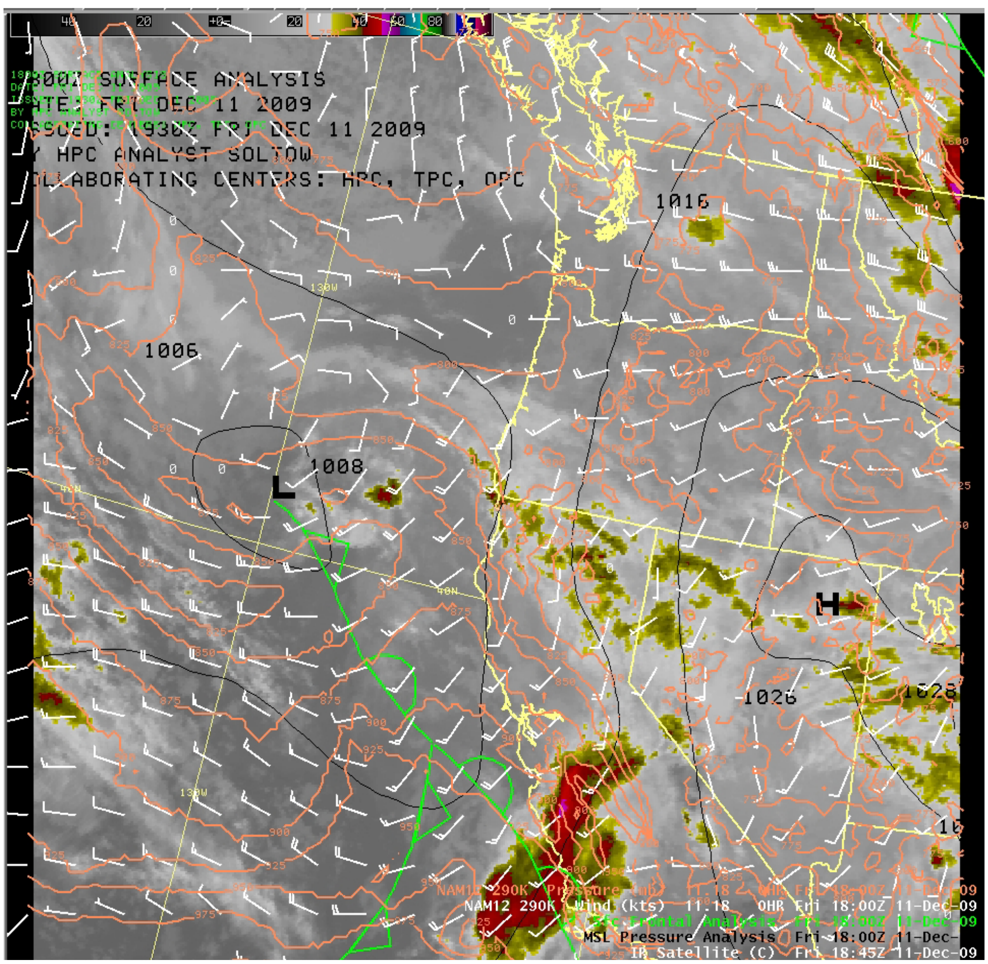

Figure 6. IR Image/290K Pressure and Winds 1800Z 11 Dec 09

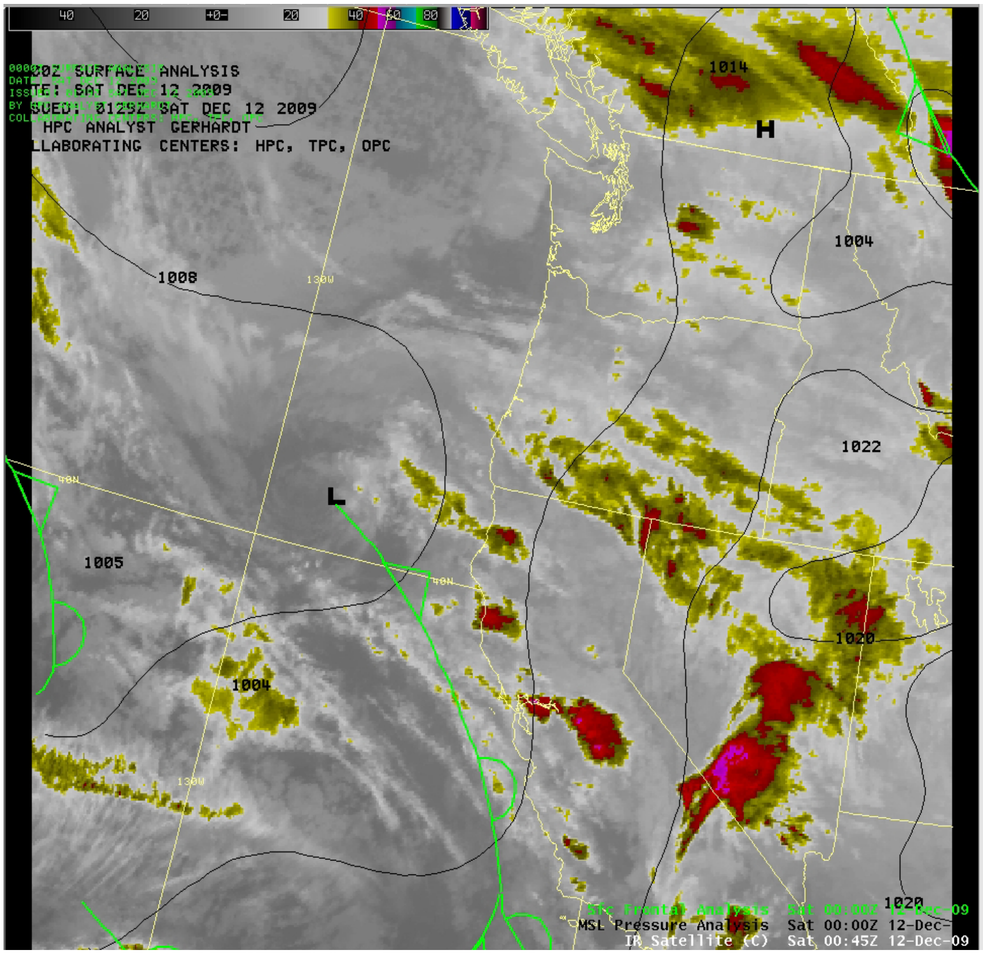

Figure 7. IR Image/Surface Analysis 0000Z 12 Dec 09

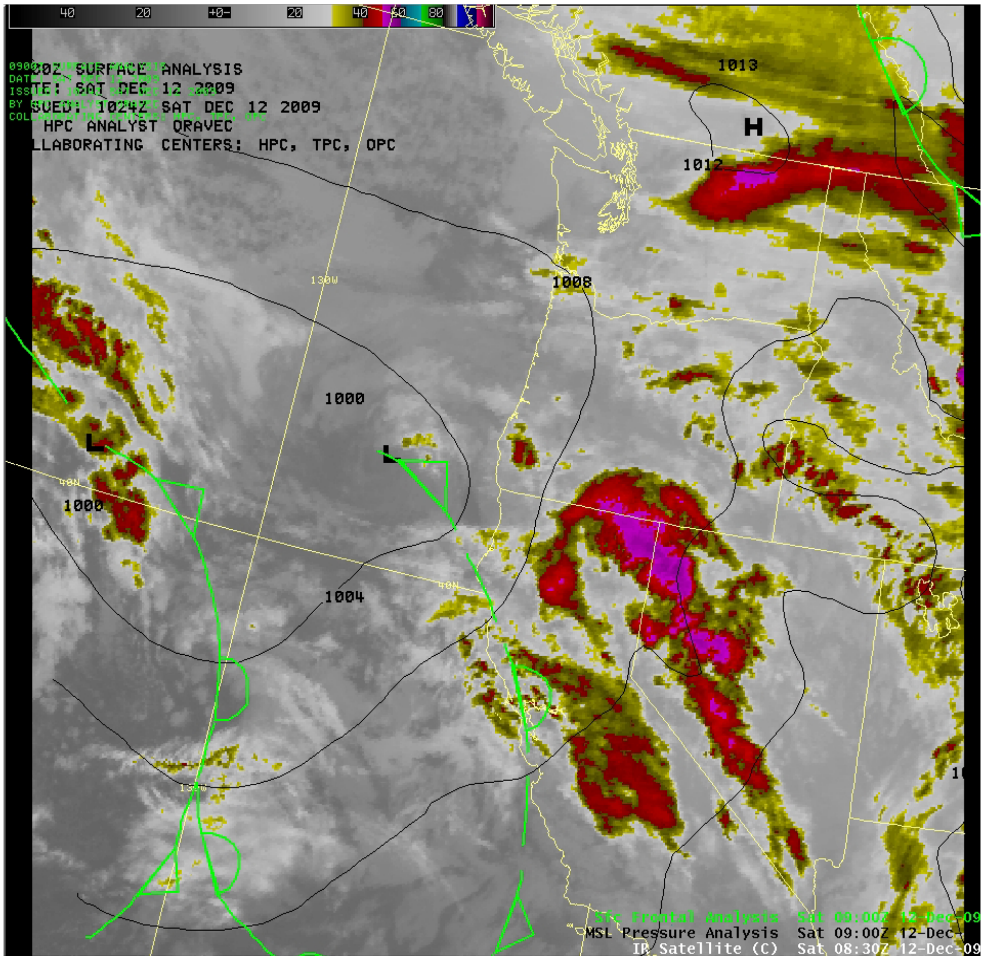

Figure 8. IR Image/Surface Analysis 0900Z 12 Dec 09

Mesoscale Setup

Medford and the Rogue Valley are surrounded by terrain on all sides with the Coastal Range to the west, Siskiyou Mountains to the south, Cascade Mountains to the east, and the Umpqua Divide to the north (Figure 1). Unlike Portland, Oregon and its Columbia River gorge that can provide continental polar or modified arctic air drainage from the east, the Rogue Valley has no nearby linear gap in the Cascade Mountains to allow shallow cold air to drain towards Medford. Therefore, it seems that a continental polar air mass must be anomalously deep to affect Medford. The critical depth of this cold air will briefly be discussed in the forthcoming Bufkit examples. Once cold air settles in the Rogue Valley, it can become entrenched, which was the case in the December 11 and 12, 2009 freezing rain event.

A progression of five MFR soundings beginning December 9 at 1200Z and continuing through December 12 at 1200Z highlight four important aspects of the cold air and subsequent freezing rain event. It gives a thorough understanding of the magnitude of the cold air that preceded the freezing rain, a visual depiction of the evolution of the warm tongue aloft and cold surface temperatures, the magnitude of southerly flow associated with the approaching low, and the dry air involved that resulted in evaporational cooling, limiting the warming of the temperature profile.

Figure 9 includes the coldest temperature profile (green) of the continental polar air mass, December 9, 1200Z as well as an overlay of the December 10, 1200Z (orange) sounding when the cold air began to moderate as westerly flow aloft increased. On the coldest sounding, 850 mb temperatures were -7° C, and the temperature profile was generally isothermal from surface to 8,000 feet MSL. The warmer, orange profile shows temperatures aloft warming with an 850 mb reading of -2° C. The low-level flow at 925 mb is noticeably weak on both soundings, with easterly and northerly directions.

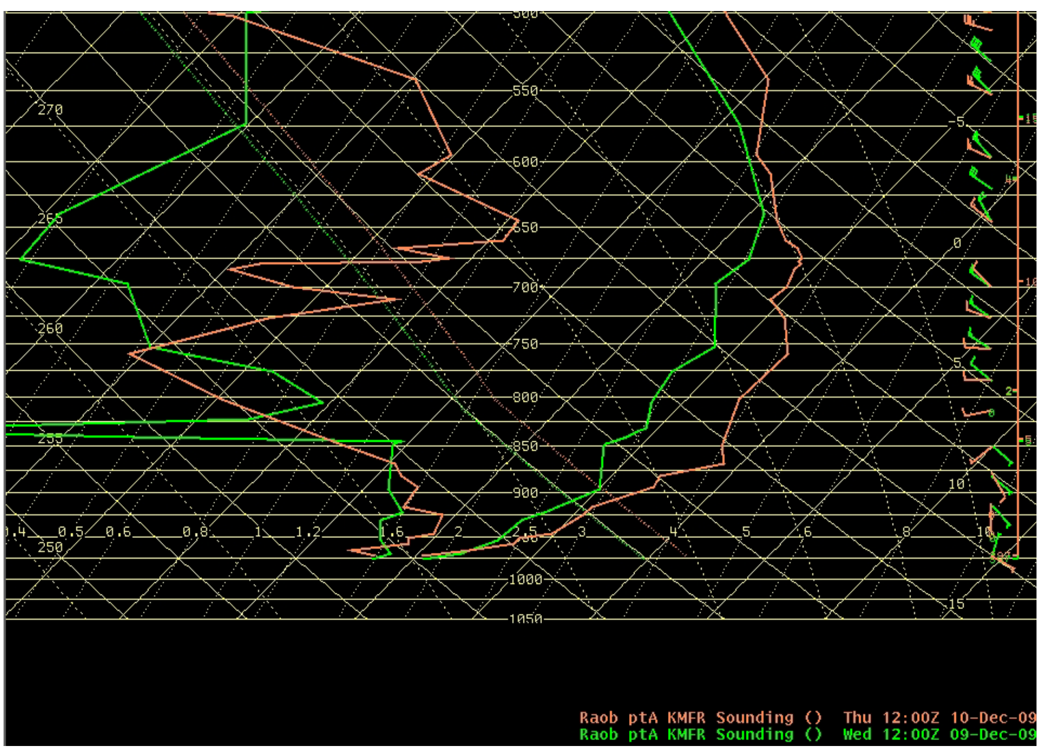

Figure 9. 1200Z 9 Dec (Green) and 1200Z 10 Dec (Orange) 2009 Soundings.

Figure 10 depicts all the soundings with temperature profiles that supported the freezing rain event. The December 11, 1200Z sounding (green) shows the warm tongue of air at 850 mb reaching 3° C. Also, the image indicates deepening and strengthening of westerly flow above 5000 feet, and continued sub-freezing temperatures below 925 mb. Even as onshore flow aloft increases, 925 mb winds remain very light, not strong enough to mix out or moderate the significant amount of low-level cold air. Finally, this sounding clearly displays the dry air near the surface with 7 degree C dew point depressions common from the surface to 900 mb. When applying the wet-bulb temperature functionality in AWIPS or Bufkit software, cooling by evaporation lowers the temperature profile near the surface, likely offsetting any warm advection associated with upstream weak shortwave troughs (Figure 11). The orange sounding from December 12 at 0000Z shows a mostly saturated profile from the surface through about 8000 feet MSL. The temperatures of the warm tongue have actually decreased, likely due to evaporational cooling. Flow near the surface is still very weak, so any warm advection that is occurring is likely aloft, and surface temperatures are still below freezing. The blue sounding from December 12 at 12Z shows conditions at the end of the freezing rain event. Increasing warm advection raised the surface temperatures above freezing shortly after this time.

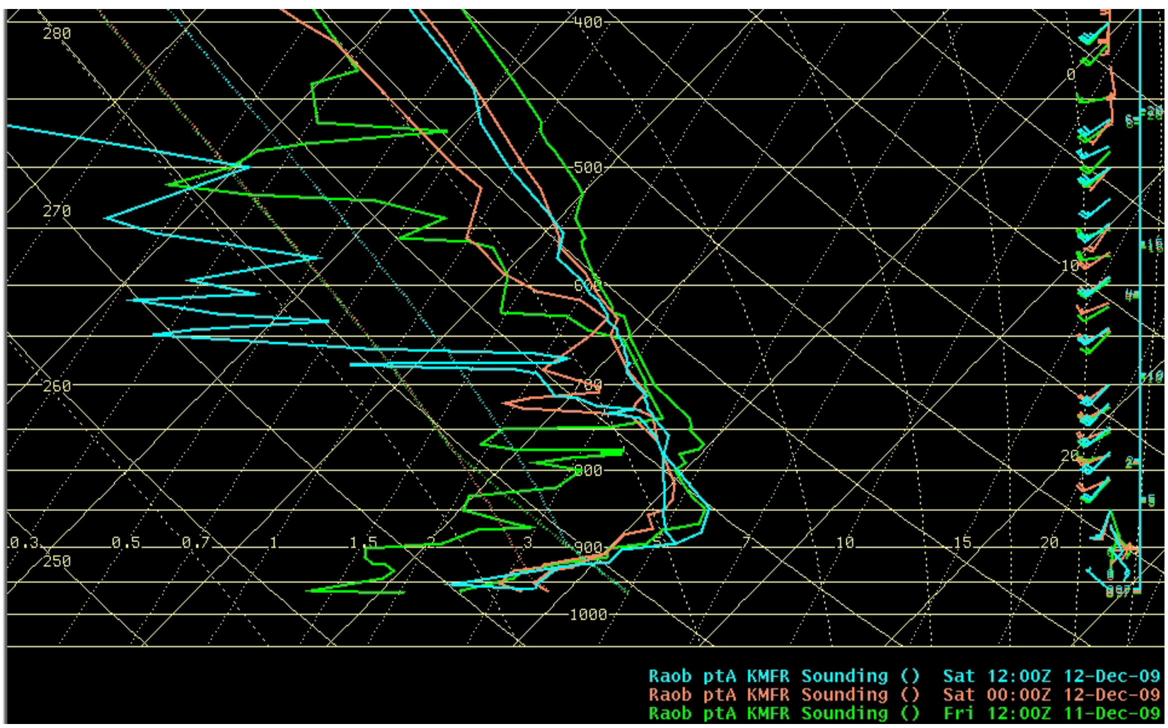

Figure 10. 12Z 11 Dec (Green), 00Z 12 Dec (Orange), 12Z 12 Dec (Blue) 2009 Soundings.

Wet-Bulb Temperature Profile

Finally, Figure 11 again displays the December 11, 1200Z sounding as precipitation began to approach Medford, this time using the wet-bulb temperature profile functionality of AWIPS. Dry air is depicted near the surface with 7° C dew point depressions common from the surface to 900 mb. When applying the wet-bulb temperature profile in AWIPS or Bufkit software, evaporational cooling lowers the temperature profile at least 2° C from the surface to 800 mb, offsetting any warm advection associated with upstream weak shortwave troughs.

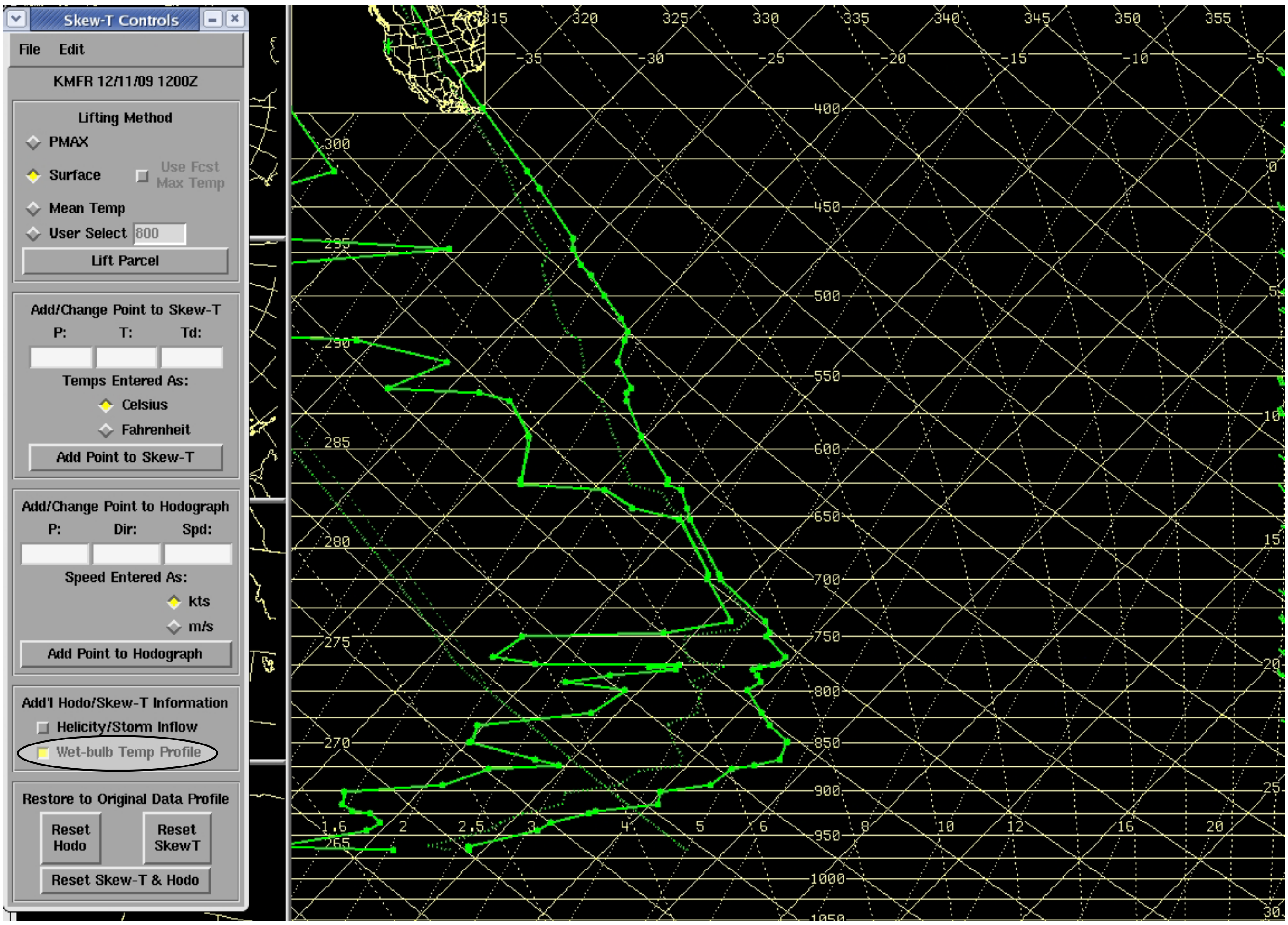

Figure 11. 1200Z 11 Dec 09 Sounding (Thick Green Line) With Wet-bulb Temperature Profile (Dotted Green Line).

Soil Temperatures

When examining any winter weather event, soil temperature should be considered. It makes sense that upward conduction of above-freezing 2-inch soil temperatures will slow the rate of or prevent the accumulation of freezing rain or snow on the ground. However, it is difficult to determine what soil temperatures are required to allow a high-impact event to occur. This study will not answer that question definitively for the Rogue Valley, but it will provide a rough correlation to serve as a basis for future studies. Days with freezing rain reported were correlated to local newspaper weather headline archives to determine which days with freezing rain caused the greatest societal impacts. Besides the event that is the focus of this study, a high-impact freezing rain event occurred on December18-19, 2005 where a dozen traffic accidents occurred on highly-traveled Interstate 5 (Mail Tribune). On December 24, 2008 freezing rain was observed and winter weather made the headlines, but no traffic accidents or significant impacts were reported (Mail Tribune). Figure 12 is a table listing these dates and a comparison of the number of accidents reported with the mean soil temperatures for the event day(s):

Date of Freezing Rain Event	Number of Accidents Reported	Mean Soil Temperature (°F/°C)
11-12 Dec 2009	145	29.87/-1.2
18 Dec 2005	12	33.95/1.1
24 Dec 2008	0	35.75/2.1

Figure 12. Soil Temperatures and Traffic Accidents Associated With Freezing Rain

Though the sample size is small, it is clear that colder soil temperatures result in a higher number of traffic accidents when freezing rain is occurring. While there are a myriad of other variables that influence the impact of a freezing rain event, such as the timing of the event, subfreezing soil temperatures enhance the probability that freezing rain will result in icy roads and traffic accidents.

Forecast

The NAM12 model forecast sounding with initial time of December 11 at 1200Z is compared to the actual sounding data below to quantify how the model verified against the actual evolution of low level temperatures and winds. Note that the main shortcoming of the model output was the evolution of surface temperatures from the December 11 through December 12.

	12Z Dec 11 09	00Z Dec 12 09	12Z Dec 12 09
Surface Temp (°F/°C)	**Actual: 22/-6** *Model: 29/-2*	**Actual: 30/-1** *Model: 37/3*	**Actual: 29/-2** *Model: 35/2*
850mb Temp (°F/°C)	**38/3** *37/3*	**34/1** *33/1*	**38/3** *35/2*
850mb Wind Spd (dddff Kt)	**16007/***20008*	**20010/***23011*	**20013/***22020*
925mb Wind Spd (dddff Kt)	**01005/***17004*	**05006/***13004*	**09002/***15008*

Figure 13. NAM12 KMFR model data in italics. Actual data in bold.

Throughout the 24-hour forecast, the NAM12 model verified well at the 850 mb level, resolving the warm tongue and wind flow aloft. However, the lowest levels of the model forecast verified poorly. This began with the initialization of surface temperatures 7° F warmer than were observed December 11 at 1200Z. The 7° F warm bias associated with this model run continued through the freezing rain event. Additionally, the actual low-level northerly and easterly wind was not forecast by the NAM12. Instead, southerly winds were forecast, likely contributing to the warm bias of the model. Though the GFS model is not detailed here, its output verified poorly as well, with a warm bias near the surface. It is clear that, especially in freezing rain situations, emphasis should be placed on actual 1200Z and 0000Z soundings versus the less accurate model soundings.

Precipitation Type Algorithms

There are many methods to determine precipitation type based on the temperature and moisture profiles of the atmosphere. Two different methods available in Bufkit are explored below. Data from the actual RAOB soundings are ingested into Bufkit, and the Bourgoin and Thickness algorithms are applied to the soundings. It makes more sense to verify the precipitation type algorithms against actual data than against forecast soundings in this event because of the poor model performance in the lowest levels.

Bourgouin Area Technique

Applying this method, when there are multiple freezing levels in the temperature profile, two areas of the sounding are calculated to determine precipitation type (Figure 14). First, the area of temperatures greater than 0° C is computed. Second, the near-surface area of temperatures less than 0° C is computed. These areas correspond to the melting and freezing energies in J/kg, respectively. Utilizing this method for the December freezing rain event, the algorithm predicted freezing rain from Dec 11 at 1200Z through December 12 at 1200Z. Figure 15 shows that all three soundings, represented by red dots, lie in the freezing rain portion of the algorithms output.

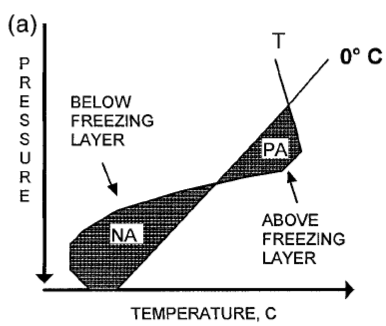

Figure 14. Bourgouin Area Technique

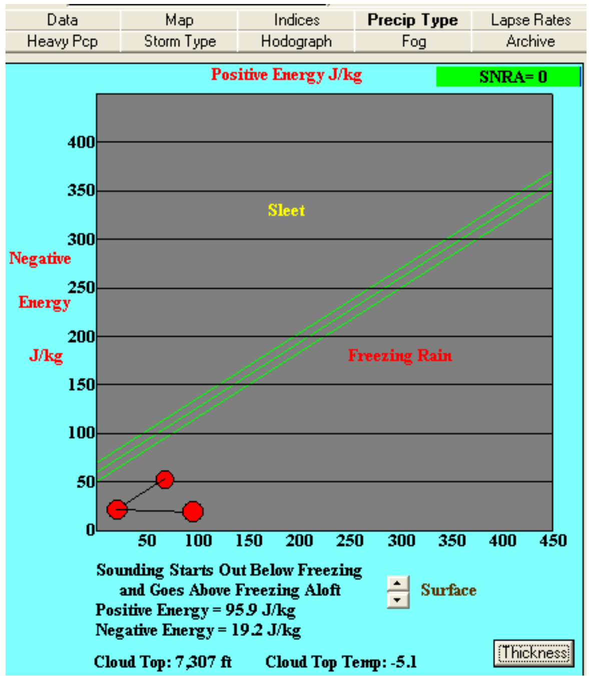

Figure 15. Bourgouin output for 12Z Dec 11 – 12Z Dec 12 09

Figure 16 compares the negative energies, or lowest subfreezing layers, from the December 11, 2009 event with the December 18, 2005 event. The highest impacts occurred in the 2009 event (refer to Figure 12), which had larger negative energy values. Computing the negative energy quantity may be a useful predictor of precipitation type in the Rogue Valley, as it quantitatively represents the depth of the cold air trapped at the surface. This should correlate well with the duration and severity of freezing rain episodes. In the case of the high-impact December 2009 freezing rain event, that value was 52.7 J/kg.

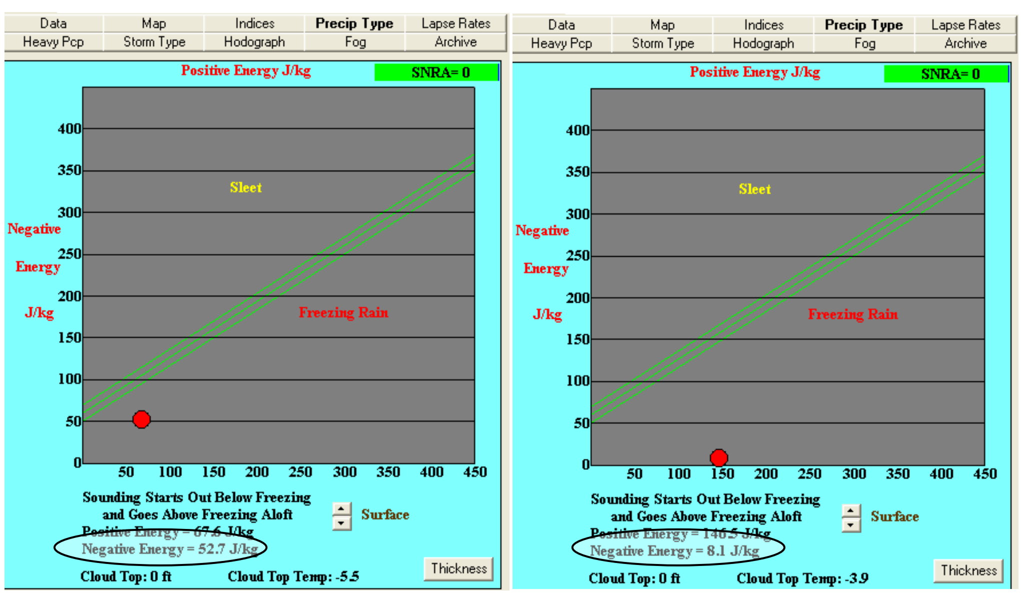

Figure 16. Comparison of Subfreezing Layer Depth 11 Dec 09 (left-highest impact) and 18 Dec 05 (right-less impact)

Thickness Method:

The TREND website states, "The Partial Thickness Universal Nomogram evolved from site-specific nomograms created according to the experimental design and developmental strategies described in Keeter and Cline (1991)". In this method, the 1000mb-850mb and 850mb-700mb thicknesses are calculated and a precipitation type is determined. The nomogram can be applied using Bufkit software, and the results for the December 2009 event are shown in Figure 17. The output for the December 12, 1200Z sounding was in the snow-rain area, which is not consistent with the freezing rain that was observed at that time. This method may not be suited for Medford, Oregon because the station pressure at Medford is usually less than the 1000 mb pressure level that is used in this algorithm. Additionally, it does not quantify the depth of cold air like the Bourgouin technique.

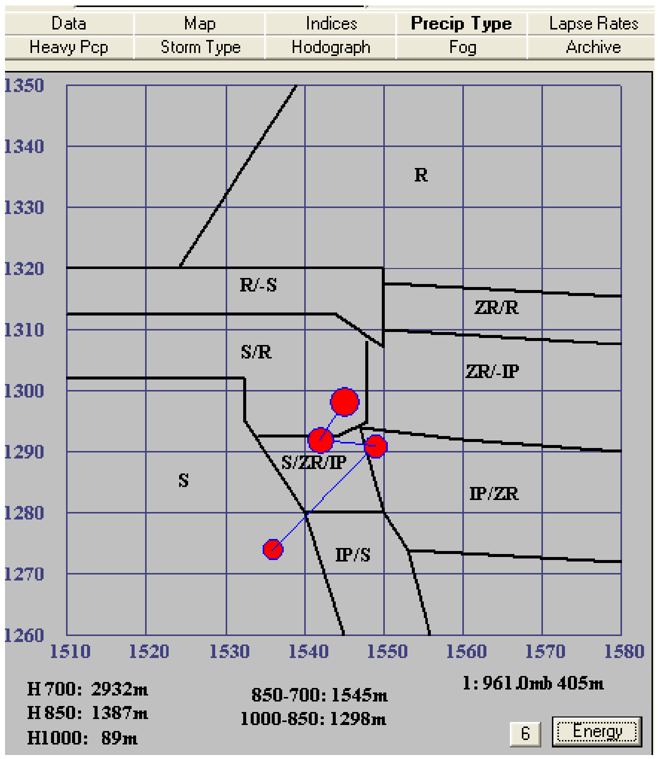

Figure 17. Partial Thickness Output for 12Z 10 Dec – 12Z 12 Dec

Lessons Learned

When analyzing rare meteorological events, such as freezing rain in the Rogue Valley, being aware of various forecast and observational phenomena can produce a good forecast. Recognizing favorable antecedent conditions, understanding model shortcomings and strengths, and becoming familiar with forecasting tools will enhance the forecasting process. Below is a list of insights gained from studying freezing rain potential in the Rogue Valley. Although these conclusions are derived from a limited number of freezing rain occurrences, most if not all these ideas will likely apply in future events.

1. Models have difficulty in complex terrain.
    a. The NAM12 and GFS did not accurately resolve the evolution of cold air in the Rogue Valley.
    b. The NAM12 over-forecast the magnitude of southerly low level winds and likely warmed the valley too much as a result.
    c. Emphasis on actual 12Z and 00Z soundings in freezing rain events is crucial.
2. Anomalously cold air can produce anomalous weather events.
    a. Freezing rain and sleet are rare in the Rogue Valley, but so are multiple days of 15° F low temperatures.
3. Monitoring soil temperatures enhances situational awareness and readings are likely related to event impact.
    a. A Tactical Decision Aid page with soil temperatures and other winter weather critical values would be helpful to monitor winter weather threats for the Rogue Valley.
    b. Future winter weather studies that include soil temperature can build upon the limited number of events analyzed in this study.
4. Bufkit is a good tool to use for precipitation type forecasts.
    a. The Bourgouin method performed well in the December 11-12, 2009 freezing rain event.
    b. A simple method to ingest real-time soundings into Bufkit is possible and would likely enhance situational awareness and forecasts during freezing precipitation events.
    c. Wet-bulb temperature profile should be monitored as it may offset any weak warm air advection.
5. Monitoring upstream shortwave intensity is important.
    a. Be aware of isentropic up glide.
    b. Monitor strength of warm air advection associated with shortwave energy.
    c. Determine whether the shortwave or frontal system is strong enough to mix out the low-level cold air in the valley.

Acknowledgements

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