Examination of the Intense Cold Frontal Passage of 19 November 2003 and Associated Low Elevation Snow Event in Southwest Washington and Northwest Oregon using the NWS Weather Event Simulator

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Introduction

Cold fronts pass across the Pacific Northwest with increasing frequency during the month of November, but few in recorded history have had the intensity of the frontal passage of 19 November 2003. This cold front was marked by a nearly 20F degree temperature difference across the frontal zone, deep frontal trough and sharp wind shift. Heavy rain fell in advance of the front below the 6000 foot melting level. After the surface front passed, moderate to heavy stratiform precipitation continued, a rarity for cold fronts in the Pacific Northwest, and precipitation turned to snow all the way to the floor of the Northern Willamette Valley near sea level (Map1). Large, wet, "silver dollar" sized, conglomerate snow flakes fell in the Portland and Vancouver metro areas in one of the earliest snows ever recorded (Photo 1).

Cold fronts which move across the Pacific Ocean and reach the Washington and Oregon coasts are generally weak in surface features. This can be attributed to the moderating influence of the Pacific Ocean and the complexity of the terrain once the fronts make landfall. Low elevation snow in western Oregon and Washington is relatively infrequent and thus one of the more difficult, yet critical, forecast problems faced by forecasters in the Portland Weather Forecast Office. An examination of this front with the NWS Weather Event Simulator (WES) will help our understanding of the processes acting during some low elevation snow events. This should ultimately lead to more accurate forecasts in the future.

Synopsis

On 18 November 2003, a 300 MB ridge extended across the Pacific Northwest with a subtropical jet transporting warm moist air into western Oregon and Washington (Figure 1). Flood watches and warnings were posted across areas of western Oregon and Washington due to the high freezing levels and anticipated heavy precipitation. The AMSU (Advanced Microwave Sounding Unit) total precipitable water image from 18 November 2004, at 18Z shows values of around 1 inch along the front off the Oregon coast (Figure 2). At the same time, a cold upper trough was over the Queen Charolette Islands with a polar jet driving south toward the Pacific Northwest (Figure 1).

Examination of the Cold Front

On 19 November 2003, a strong cold front had developed as cold polar air collided with and moved under, moist subtropical air. Strong frontogenesis occurred as the front moved south as seen in the 10Z AWIPS MSAS analysis (Figure 3). Note the temperature difference across the front seen in the MSAS surface analysis and observational data from 12Z on the 19th (Figure 4). Portland, Oregon and areas to the south had temperatures in the mid to upper 50s while areas of northern Washington were in the upper 30s.

The MSAS surface pressure analysis and surface data indicate an intense front lies in a sharp surface trough as it passes south over Portland (Figure 4). A local weather spotter's thermograph showed an 8F degree temperature drop in 20 minutes as the front passed. As the front passes, winds shift from southwest to northwest. At 11Z the front aloft can easily be seen in the KRTX (Portland) radar 0.5 degree velocity data as a dramatic wind shift extending from the radar at around 1200 feet, to the sloping frontal surface at around 2400 feet (Figure 5). By 18z surface temperatures had cooled into the 30s and the front aloft could still be seen in the radar velocity data but at a much higher level (not shown).

Examination of the Low Level Snow Event

A feature which is common to low level snow events in the Northern Willamette Valley is the existence of a sub freezing, sometimes sub zero, low level air mass in the Columbia Basin east of the Cascades and an easterly pressure gradient. The easterly gradient forces the cold air through the Columbia River Gorge resulting in strong gap flow and cooling of the near surface and boundary layer air by advection and latent heat of evaporation. In the present case, an easterly pressure gradient did exist through the Gorge. However, note the surface temperatures in the Columbia Basin of around 60 degrees F (Figure 3). In fact, the Columbia basin was in the warm sector of the frontal system with strong warm frontogenesis occurring to the north across northern Washington (Figures 3 and 4). Therefore, the process of cold advection through the Columbia River Gorge and evaporative cooling were not a contributing factor to producing low level snow in the northern Willamette valley in this case.

Forecasters in the Pacific Northwest typically forecast freezing level heights using relationships of the 500-1000mb and the 700-1000mb layer thickness values. The snow level is derived by subtracting 1000 feet from the freezing level. These relationships, developed from regression equations, normally work reasonably well for mountain snow events because the lapse rates typically don't vary greatly from storm to storm. However, examination of the data used in developing the regressions show that the relationships break down for the very low level snow events. This is an indication of the complicated and important physical and thermodynamic process that occur in these cases.

Using the thickness relationships, a freezing level for 18Z on November 19 of around 2500 feet can be forecast using the Eta model data from 18Z November 18 run. Applying the normal relationship, a snow level of 1500 feet can be forecast in the Northern Willamette Valley. Normally, it is very difficult to lower the snow level in the lowest 1500 feet of the boundary layer across the Pacific Northwest west of the Cascades. This is due the moderating influence of the Pacific Ocean, numerous rivers, warm ground and the heat island of the urban areas, all which must be overcome.

So what were the processes which resulted in snow falling to sea level, about 1500 feet lower than would normally be expected? First, we can look at the initial observed freezing level as it lowered after the frontal passage. Aircraft assent and decent data from Portland Airport, only recently made available to the forecasters in the NWS AWIPS system, showed the frontal inversion and the presence of cold advection and northwest flow below the front at 1259Z (Figure 6). Only 14 minutes later another aircraft sounding shows the freezing level has lowered and significant cooling has occurred in the entire profile (Figure 7). By 15Z an aircraft sounding and the radar velocity data from the KRTX WSR-88D radar near Portland showed the sloping frontal boundary aloft over Portland around 2500 feet. The strong convergence aloft seen in the velocity data (Figure 8) also indicated that frontogenesis aloft was continuing, as forecast by the Eta Model from the previous day at 18z.

Temperatures in the area of lift above the front were around -5C. Southwest flow of high dewpoint air through a deep layer of the atmosphere continued to transport moisture north over the frontal boundary. Lift generated by the sloping frontal surface along the isentropes can been seen in the circulation streamlines from the model forecast. This combined with lift generated by the continued frontogenesis produced an environment favorable for heavy precipitation to continue to fall north of the surface front into the deepening layer of cold air.

A process which is significant in cases were precipitation occurs in areas of cold advection, or in areas of little or no warm advection, is the cooling contribution of snowflakes melting as they fall through a relatively shallow layer of already cool, but above freezing, air. Even when the air is already saturated the latent heat absorption involved in the melting process can be enough to cool the air to the 0C isotherm of a vertical profile. The process normally begins at the top of the above 0 layer where the air is cooled and moisture is condensed and precipitated out, until the temperature reaches that of the falling snow around 0C. The process is most efficient in heavy precipitation, and proceeds lower and lower as long as precipitation persists, and can produce a 0C isothermal layer through several thousand feet all the way to the surface.

In the case at hand, all the key ingredients for this process were present. Radar velocity data, surface reports and aircraft data showed the presence of strong cold advection below the frontal surface as it passed around 12Z. This layer of cold advection continued to deepen with time as the front progressed south. Heavy precipitation continued to fall after the frontal passage. The Portland ASOS reported 0.82 inches of precipitation between 12Z, after the front had passed, to 17Z when snow began. An additional 0.45 inches fell between 17Z and the end of the event around 20Z. Kain et al. (Weather and Forecasting, 2000) have shown the following equation can be used to represent the temperature change in a layer due to the melting process:

delta T = -193 D/delta p

where: delta T is the temperature change in degrees C
D is the water equivalent depth of the precipitation in cm
delta p is the depth of the above freezing layer in mb

The aircraft sounding at 1313Z (Figure 7) showed the depth of the above 0C layer was around 200 mb. The water equivalent depth of precipitation which fell after frontal passage and before snow began at the surface was 2.0828 cm. Inserting these numbers into the above equation yields a temperature decrease in the layer of 2C. Examination of the 1313Z aircraft sounding (Figure 7) shows that the average temperature in the layer was only around 2.5C. Additionally, the strong cold advection, as seen in the backing of wind with height in the aircraft sounding, that began near the surface after the frontal passage and progressed higher and higher as time went on easily could have been responsible for an addition 0.5C of cooling.

The latent heat of melting from the heavy snowfall at the top of the above zero layer to the north of the front, combined with strong cold advection, gradually cooled the air toward the 0C isotherm resulting in a nearly isothermal layer from the surface to 2000 feet as seen in later aircraft soundings. The size of the snow flakes insured their survival to the surface.

Forecasts and Forecast Procedures

Forecasts for the 19th issued during the afternoon and evening before the frontal passage indicated snow levels would fall to around 2500 feet and maximum temperatures would be in the lower 50s. MOS equation forecasts for this day indicated similar values. The snow level actually fell to near sea level and maximum daytime temperatures only achieved the upper 30s. However, a close look at the available forecast models in AWIPS indicates a much better forecast was possible by careful examination of the non-routine data sets (e.g data sets other than 500mb heights, vorticity advection, 700mb omega and 700-1000mb thickness values) and by a understanding of the physical processes which can lead to the lowering of the snow level in heavy precipitation events where warm advection is not present.

Conclusion

The front that passed across the Pacific Northwest was atypical of most frontal passages in the region. Heavy precipitation which occurred after the frontal passage produced significant cooling due the process of latent heat absorption in a layer of the lower troposphere severl thousand feet deep. This combined with strong cold advection was responsible for very low snow levels.

This missed event, while uncommon, is significant due to its great impact to life, property and the economy that the NWS is mandated to protect. Forecasters need to be vigilant of the meteorology and call in extra staff to deal with the increased workload, especially in the short term where forecaster impact can be the greatest. Forecasters must also understand the physical processes that lead to these low level snow events and carefully examine appropriate data available in the AWIPS system.

Map 1

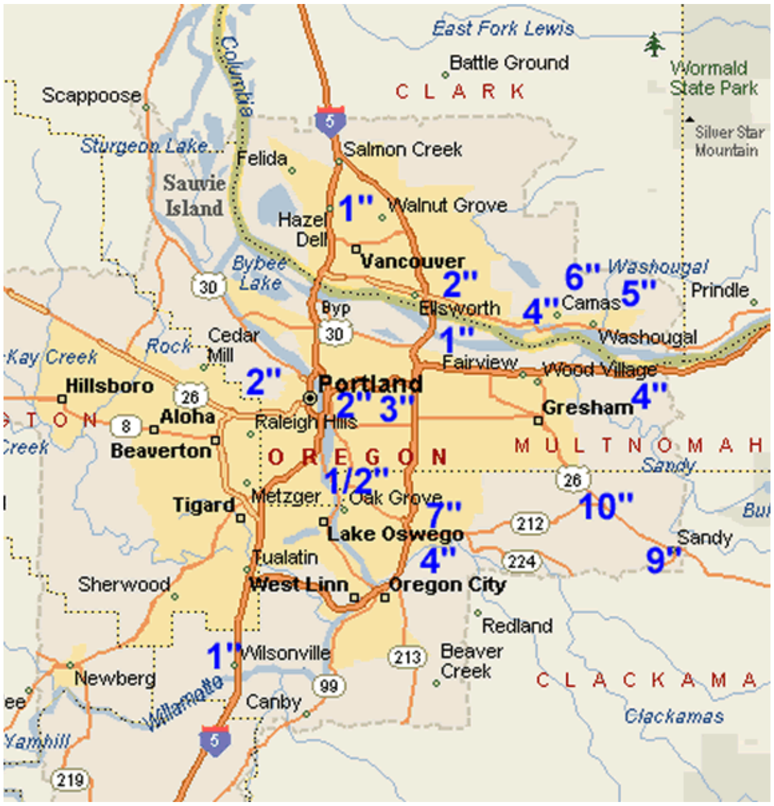
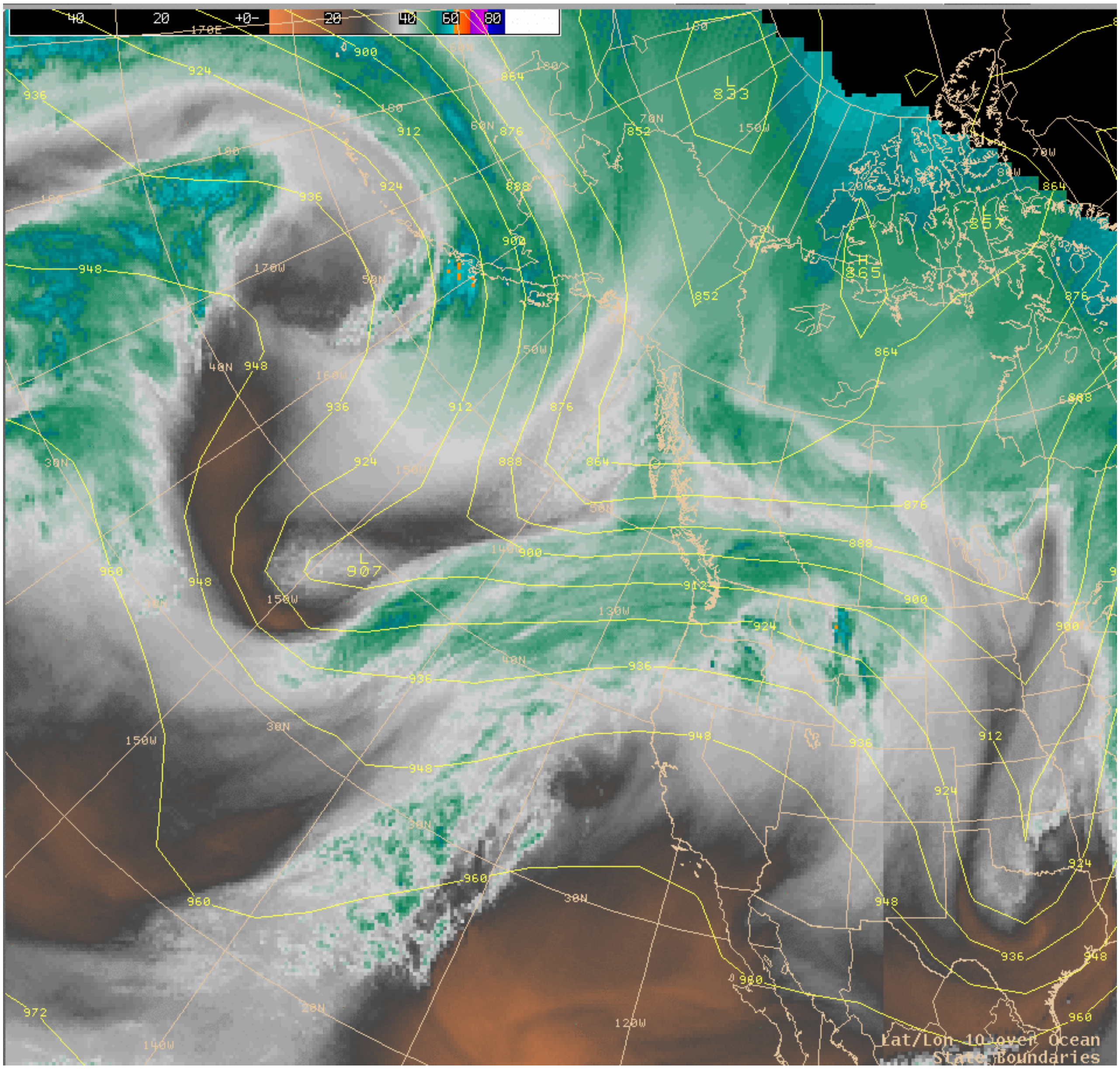


Photo 1

Figure 1



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Lat/Lon 10 over Ocean
State Boundaries

Figure 2

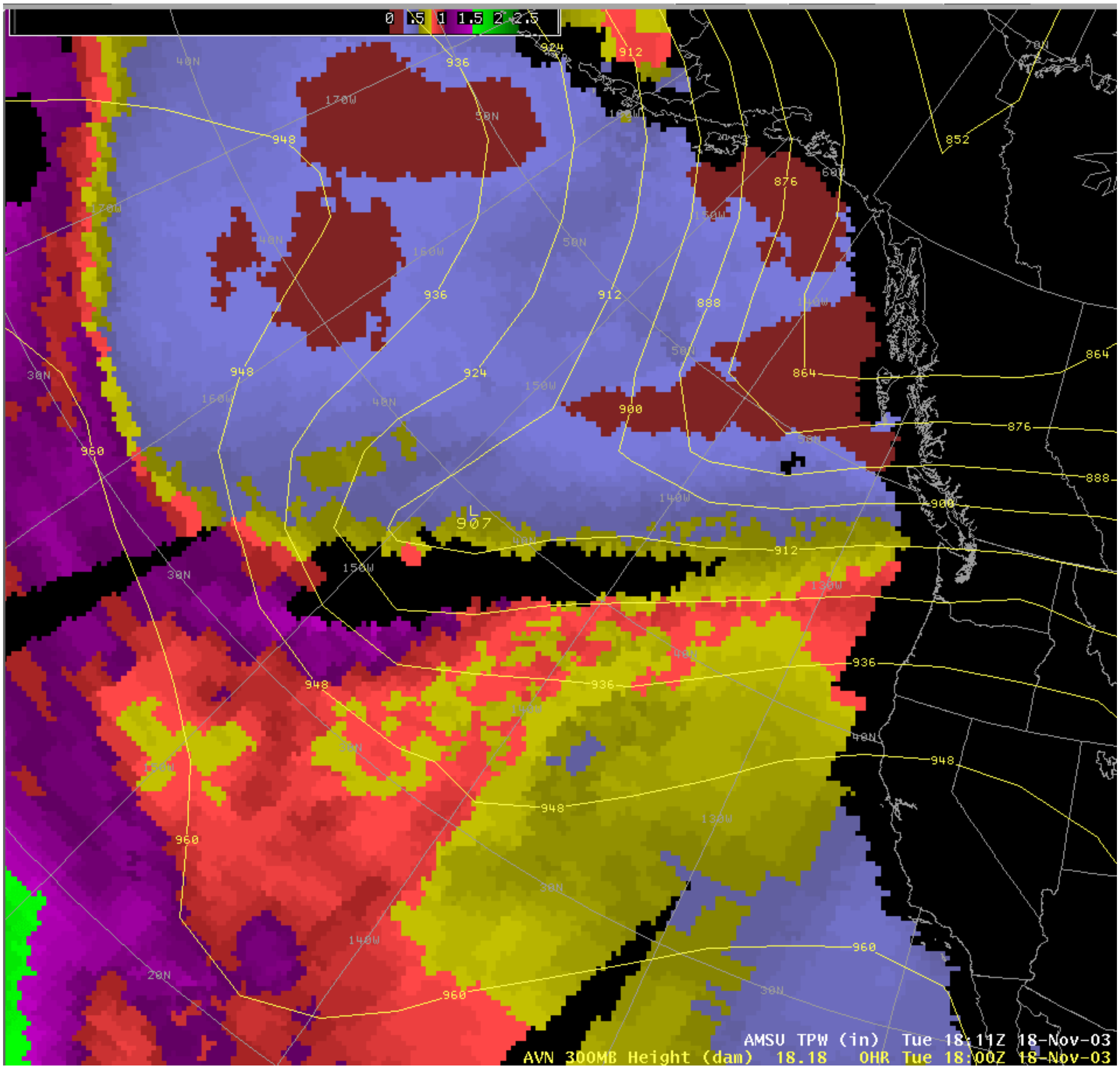
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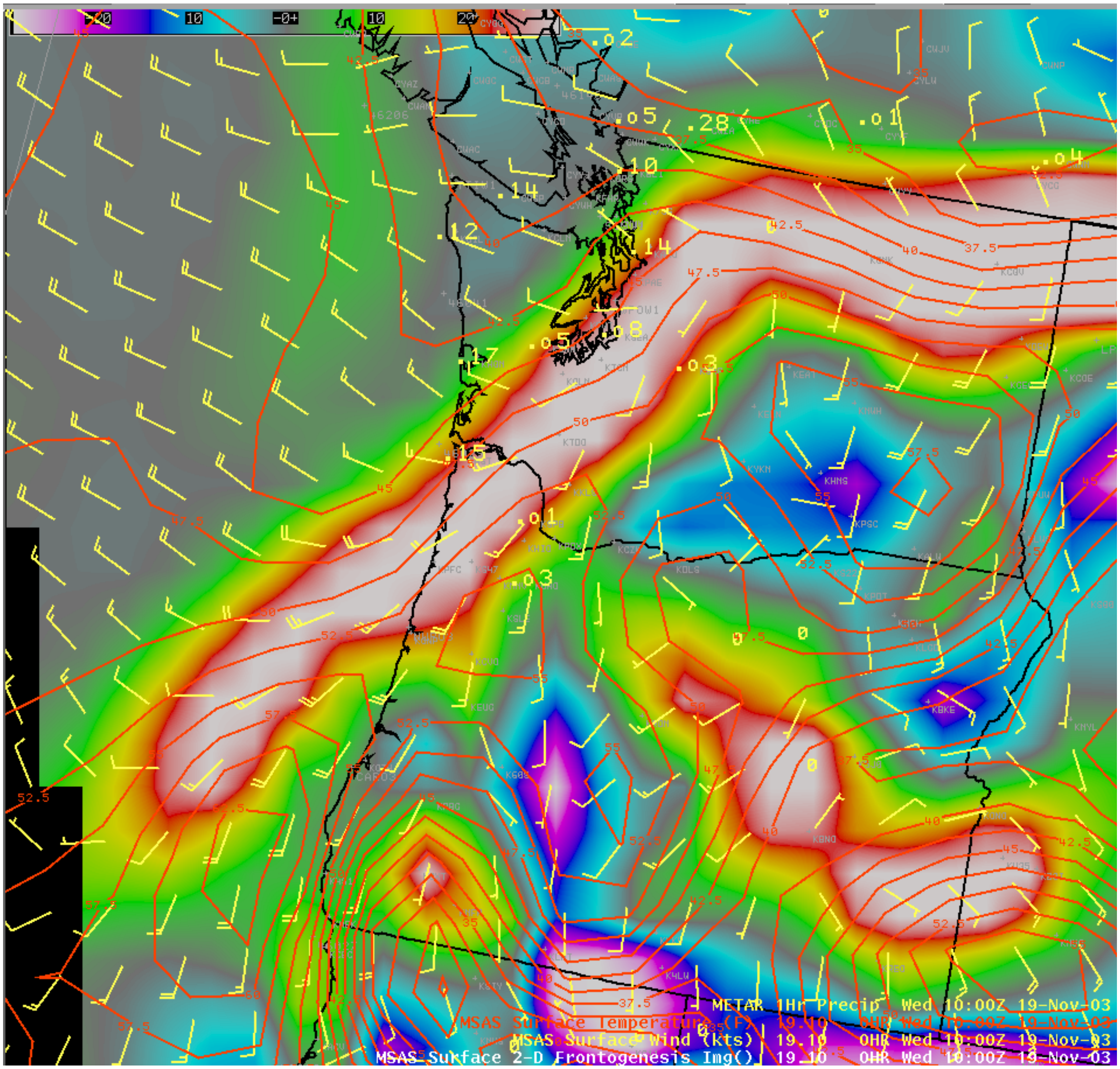
Figure 3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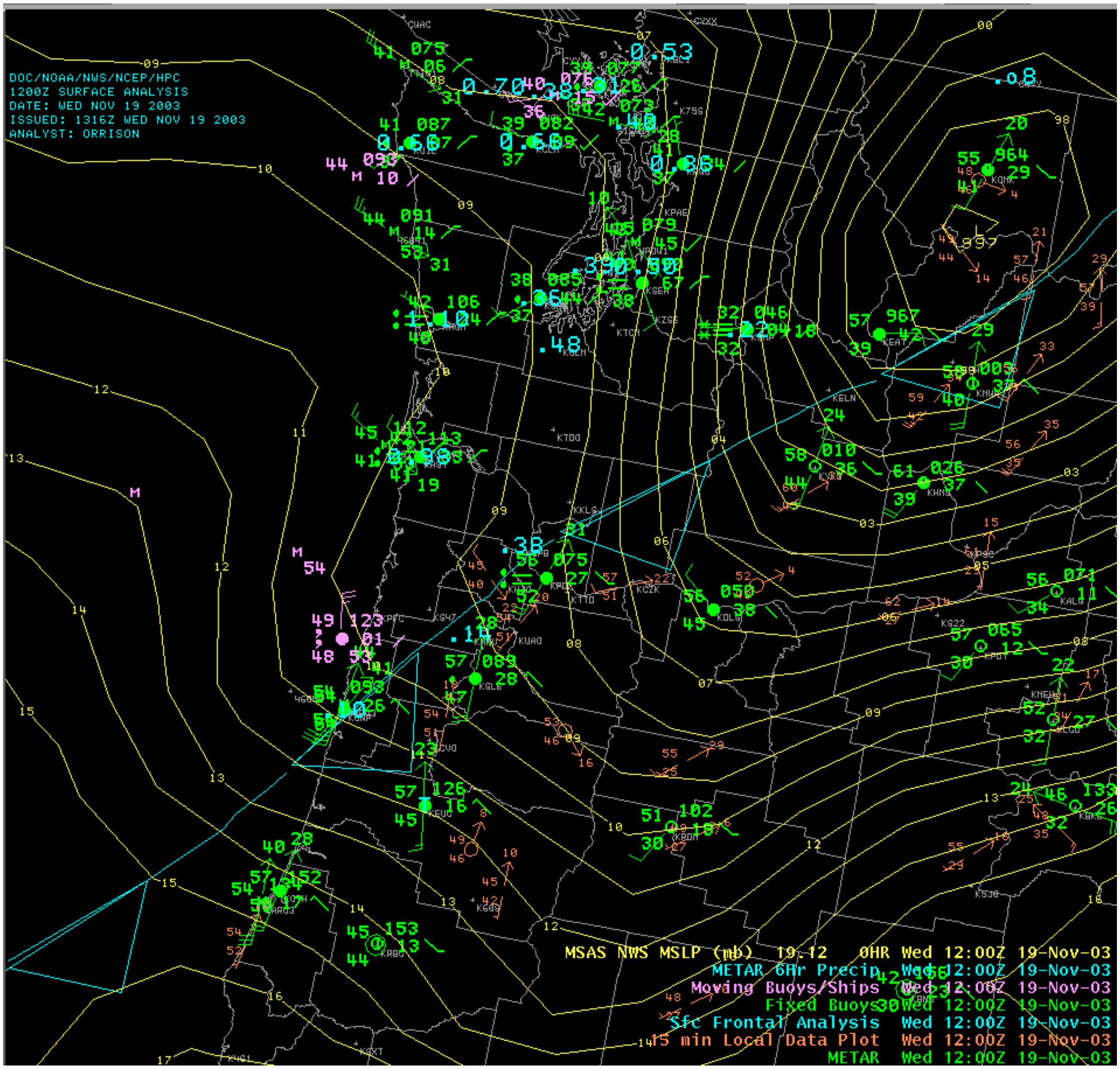
MSAS Surface Temperature (F) 19.10 0HR Wed 10:00Z 19-Nov-03
MSAS Surface Wind (kts) 19.10 0HR Wed 10:00Z 19-Nov-03
MSAS Surface 2-D Frontogenesis Img() 19.10 0HR Wed 10:00Z 19-Nov-03

Figure 4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ANALYST: ORRISON
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METAR 6Hr Precip Wed 12:00Z 19-Nov-03
Moving Buoys/Ships Wed 12:00Z 19-Nov-03
Fixed Buoys Wed 12:00Z 19-Nov-03
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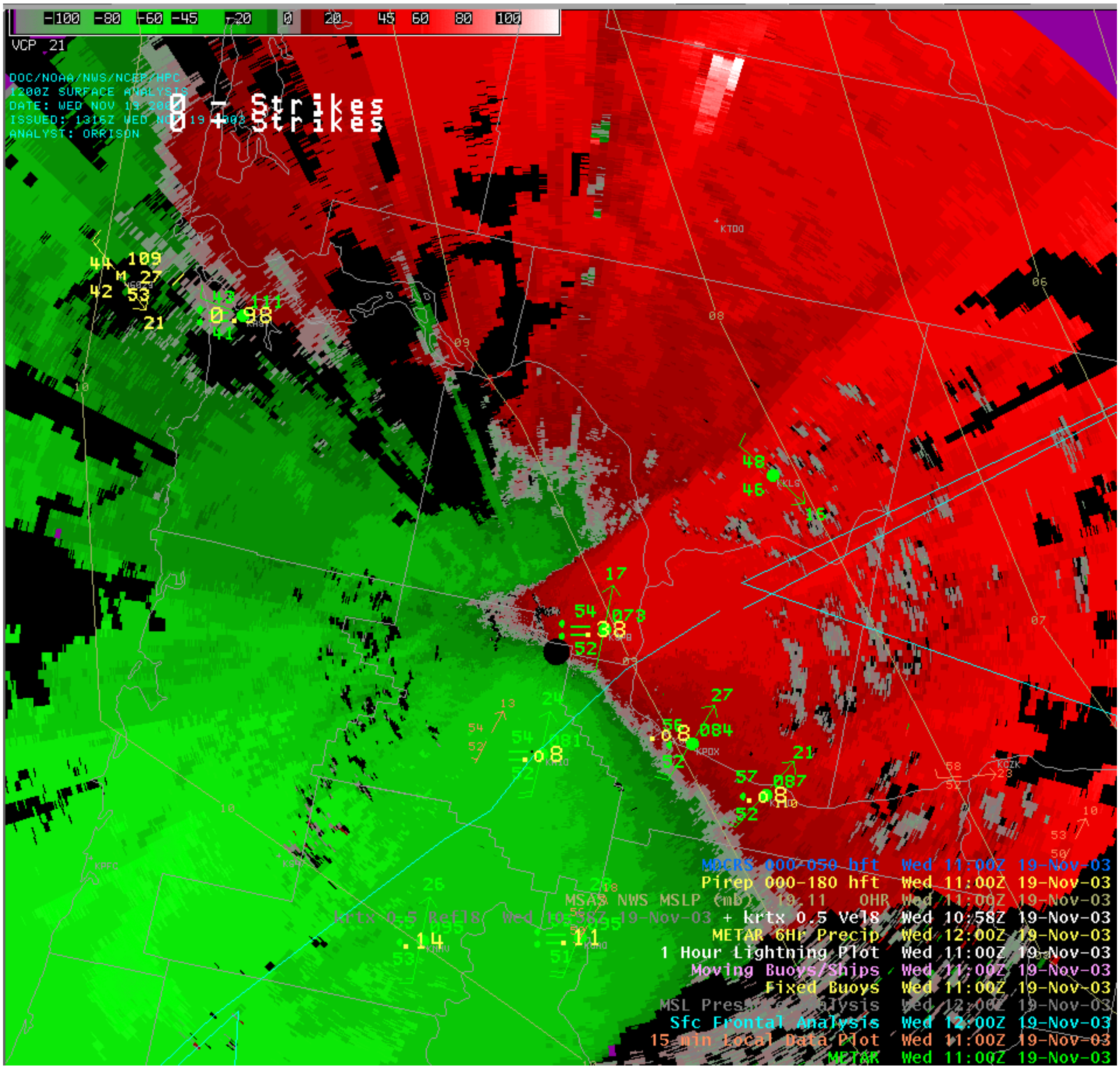
METAR Wed 12:00Z 19-Nov-03

Figure 5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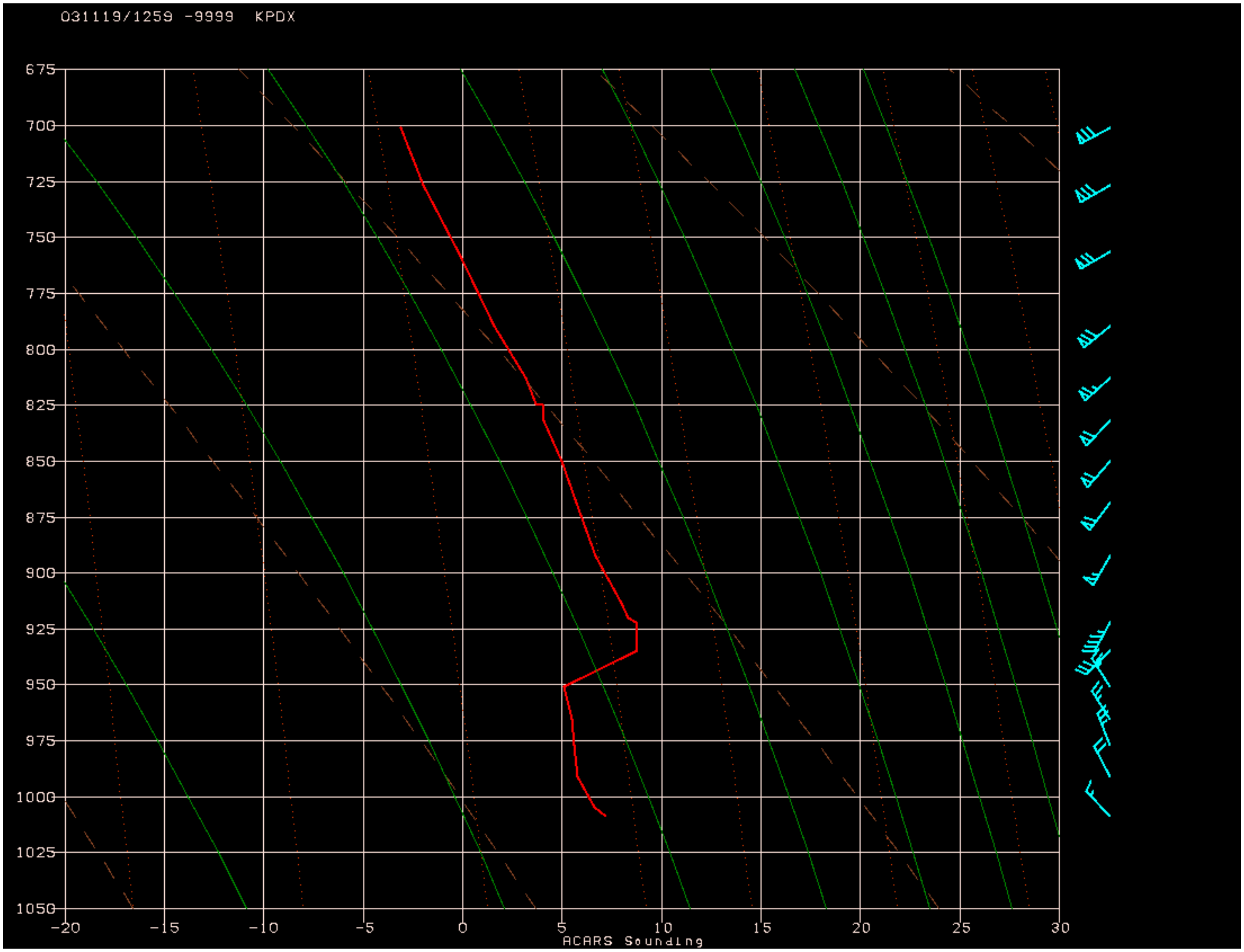
VCP 21
DOC/NOAA/NWS/NCEP/HPC
1200Z SURFACE ANALYSIS
DATE: WED NOV 19 2003
ISSUED: 1316Z WED NOV 19 2003
ANALYST: ORRISON
0 - Strikes
0 + Strikes
MDCRS 000-050 hft Wed 11:00Z 19-Nov-03
Pirep 000-180 hft Wed 11:00Z 19-Nov-03
MSAS NWS MSLP (mb) 19 11 OHR Wed 11:00Z 19-Nov-03
krtx 0.5 Refl8 Wed 10:58Z 19-Nov-03 + krtx 0.5 Vel8 Wed 10:58Z 19-Nov-03
METAR 6Hr Precip Wed 12:00Z 19-Nov-03
1 Hour Lightning Plot Wed 11:00Z 19-Nov-03
Moving Buoys/Ships Wed 11:00Z 19-Nov-03
Fixed Buoys Wed 11:00Z 19-Nov-03
MSL Pressure Analysis Wed 12:00Z 19-Nov-03
Sfc Frontal Analysis Wed 12:00Z 19-Nov-03
15 min Local Data Plot Wed 11:00Z 19-Nov-03
METAR Wed 11:00Z 19-Nov-03

Figure 6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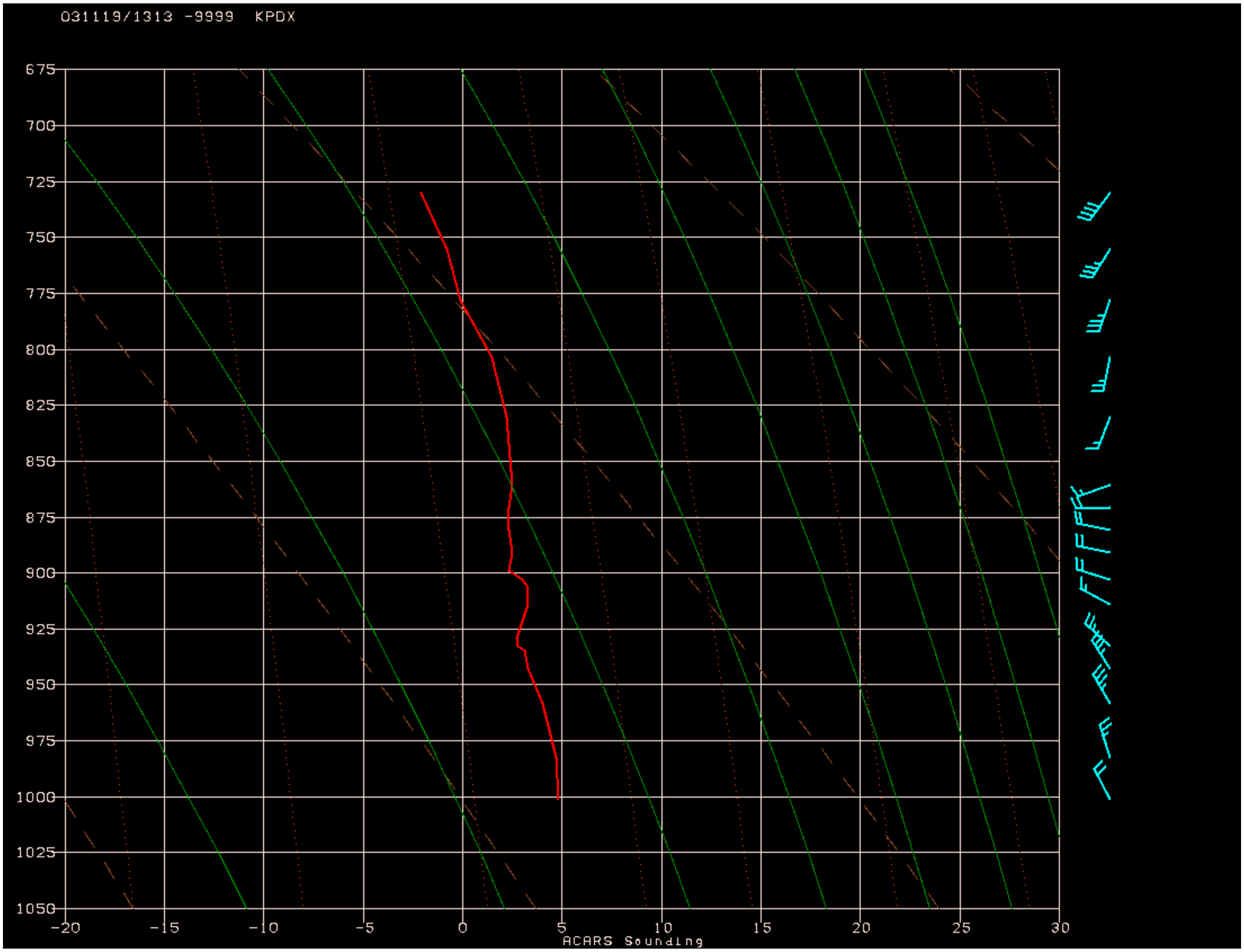
ACARS Sounding

Figure 7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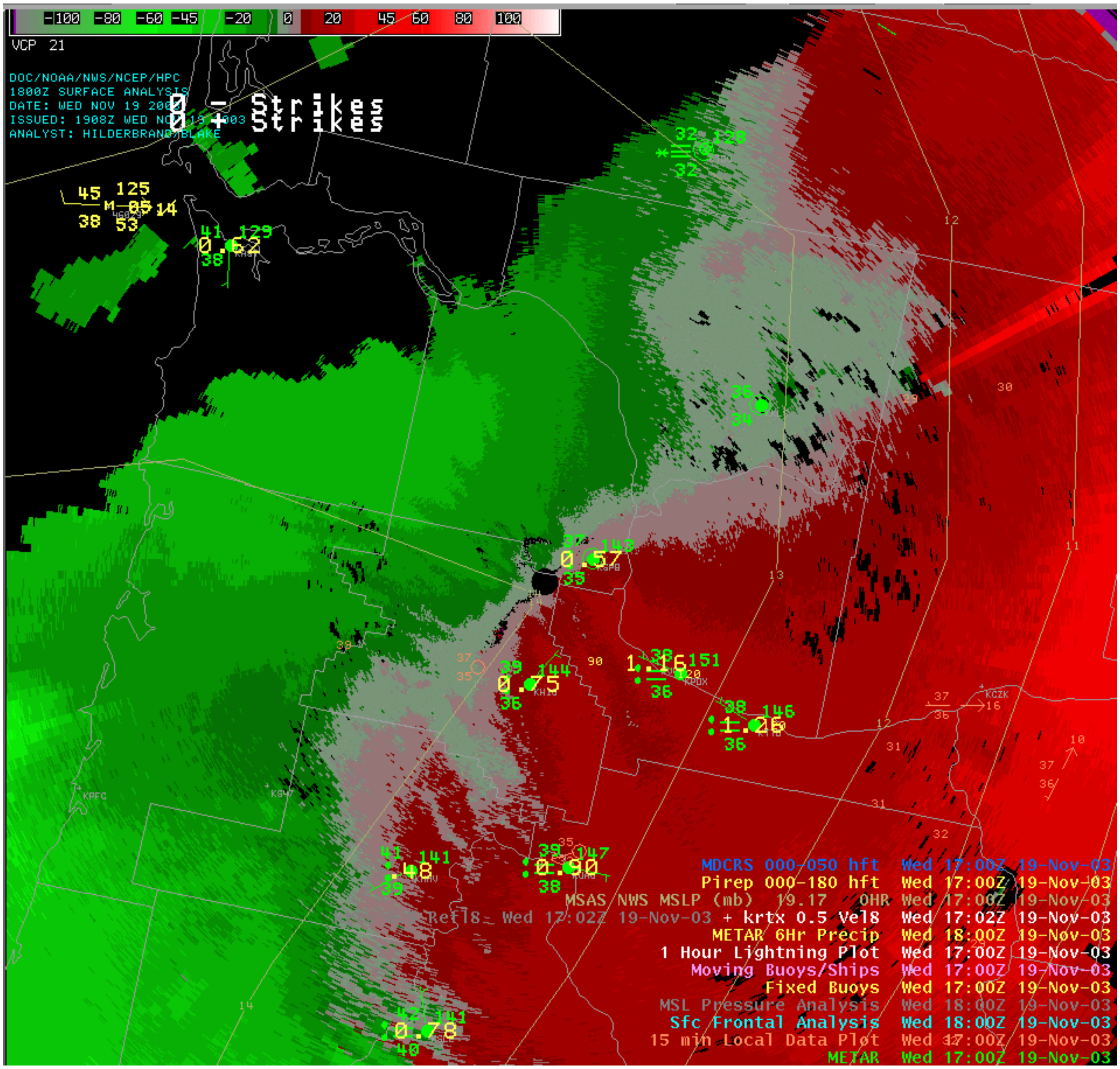
ACARS Sounding

Figure 8


-100 -80 -60 -45 -20 0 20 45 60 80 100
VCP 21
DOC/NOAA/NWS/NCEP/HPC
1800Z SURFACE ANALYSIS
ANALYST: HILDERBRAND/BLAKE
0 - Strikes
0 + Strikes
MDCRS 000-050 hft Wed 17:00Z 19-Nov-03
Pirep 000-180 hft Wed 17:00Z 19-Nov-03
MSAS NWS MSLP (mb) 19.17 0HR Wed 17:00Z 19-Nov-03
Refl8 Wed 17:02Z 19-Nov-03 + krtx 0.5 Vel8 Wed 17:02Z 19-Nov-03
METAR 6Hr Precip Wed 18:00Z 19-Nov-03
1 Hour Lightning Plot Wed 17:00Z 19-Nov-03
Moving Buoys/Ships Wed 17:00Z 19-Nov-03
Fixed Buoys Wed 17:00Z 19-Nov-03
MSL Pressure Analysis Wed 18:00Z 19-Nov-03
Sfc Frontal Analysis Wed 18:00Z 19-Nov-03
15 min Local Data Plot Wed 17:00Z 19-Nov-03
METAR Wed 17:00Z 19-Nov-03