

**Western U.S. to Northern Plains Winter Storm
December 28th, 2010 – January 1st, 2011
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Overview:

A multi-feature winter weather event impacted locations from the West Coast to the Mississippi River Valley during the final days of 2010. The event lasted from December 28th, 2010 through January 1st, 2011 and consisted of a Pacific front that moved inland across the Western U.S., a strong Arctic boundary that plunged southward from Canada, and two low pressure centers that strengthened over the Upper Midwest. The combination of these systems caused widespread heavy snow, high winds, and sub-freezing temperatures across much of the western half of the country (Fig. 1). Some localized flooding, icing, and a severe weather outbreak also resulted from this event (Fig.1).

The Pacific front that initially moved into the West Coast on Tuesday, December 28th, brought 1 to 3 inches, with isolated higher amounts, of precipitation into the coastal regions of Oregon and Northern California as well as the favored upslope regions of the Sierra Nevada ranges and the Columbia Plateau (Fig. 2). Although precipitation totals were not necessarily extreme with this event, the ground was well saturated from significant rainfall events earlier in the month (see HPC Event Review, "[Western U.S. Heavy Precipitation Event](#)"), and some localized flooding was reported along the California-Oregon border and portions of California's Central Valley. As the front progressed inland across the Central Great Basin and Southwest, it caused heavy snow and gusty winds along the higher elevations of the Sierra Nevada, Wasatch, Mongollon Rim, and Southern Rockies (Table 1 and Fig. 1).

While the Pacific cold front moved eastward, an Arctic boundary dropped southward from Canada, causing winds to increase and temperatures to plummet throughout the western half of the country. By 12 UTC on January 1st, sub-freezing temperatures were observed across the Middle Mississippi Valley, the Southern Plains, and as far south as the New Mexico-Mexico border (Fig. 3). Over the Northern and Central Plains, -20°C to -10°C (-4°F to 14°F) temperatures combined with strong sustained winds in excess of 15 knots (17 mph), to create bitter New Year's Day wind chill temperatures near -26°C (-15°F).

Finally, two low pressure centers strengthened over the Upper Midwest and brought two rounds of high wind and heavy snow across Minnesota and the eastern Dakotas, less than 24 hours apart. Locations from central South Dakota to northern Minnesota reported 6-10 inch snowfall totals, with a few snow reports exceeding 15 inches. The second of the two lows led to the more memorable outcome of the event which was a New Year's Eve severe weather outbreak across the Middle and Lower Mississippi Valley. 39 hail, 66 tornado, and 90 wind reports were recorded during the final day of 2010 (Fig. 4).

Location	Wind Gust (mph)
Squaw Valley, CA	109
Pyramid Lake, NV	106
Mammoth Lakes, CA	105
Alpine Meadows, CA	95
Red Mountain Pass, CO	95
Castaic Lake, CA	94
Park City, UT	90
Ogden, UT	89
Independence, CA	85

Table 1: Local storm reports of peak non-thunderstorm wind gusts (in mph) during the event. (Data provided by numerous local Weather Forecast Offices).

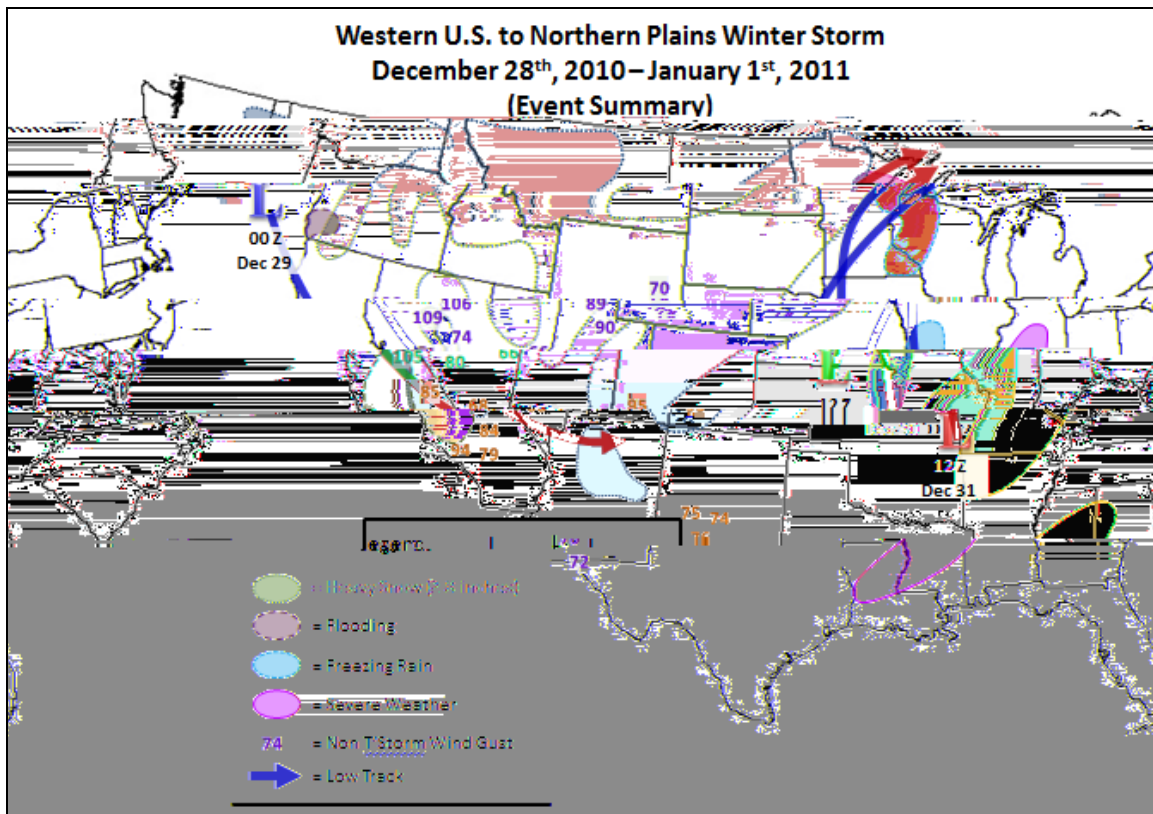


Figure 1: Summary of event impacts, including area of heavy snow, flooding, freezing rain, severe weather, non-thunderstorm wind gusts, and low tracks.

Q2 [All Gauge] 48hr QPE Accumulation

Valid Period: 12/28/2010 00:00:00 – 12/30/2010 00:00:00 UTC

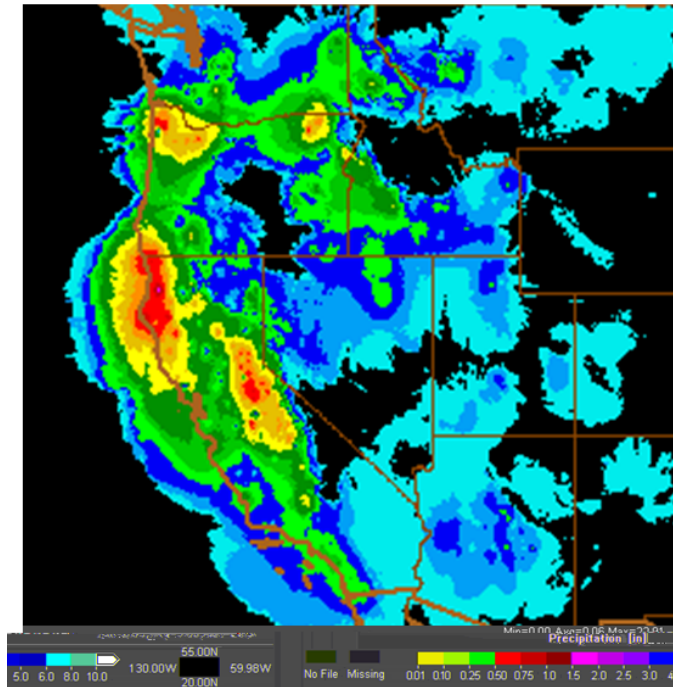


Figure 2: 48 hour precipitation totals across the Western U.S. ending at 00 UTC on December 30th, 2010 (Image provided by the National Mosaic and QPE (NMQ)).

TMPsfc [K] – uvbarb3 [] at 12Z Sat 01jan2011

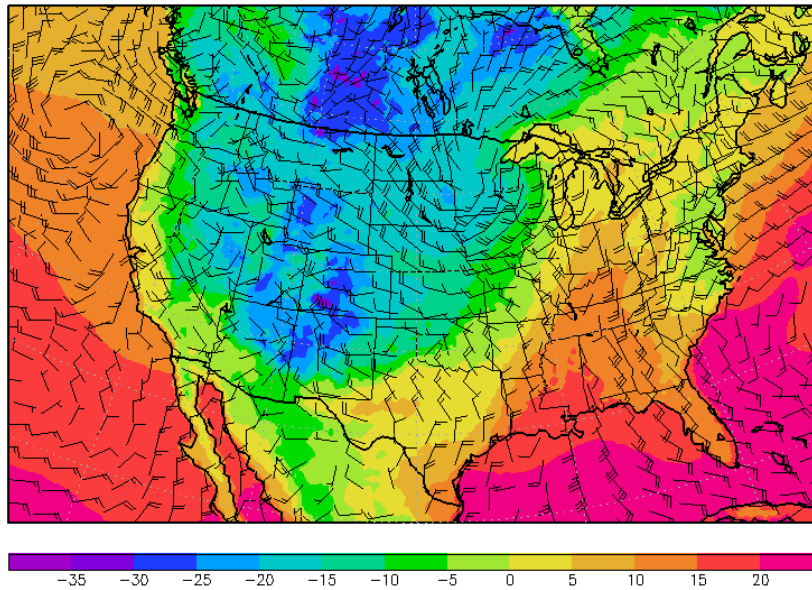


Figure 3: Surface Temperature (°C) and 1000 mb Wind Barbs at 12 UTC on Saturday January 1st, 2011 (Image provided by NCDC).

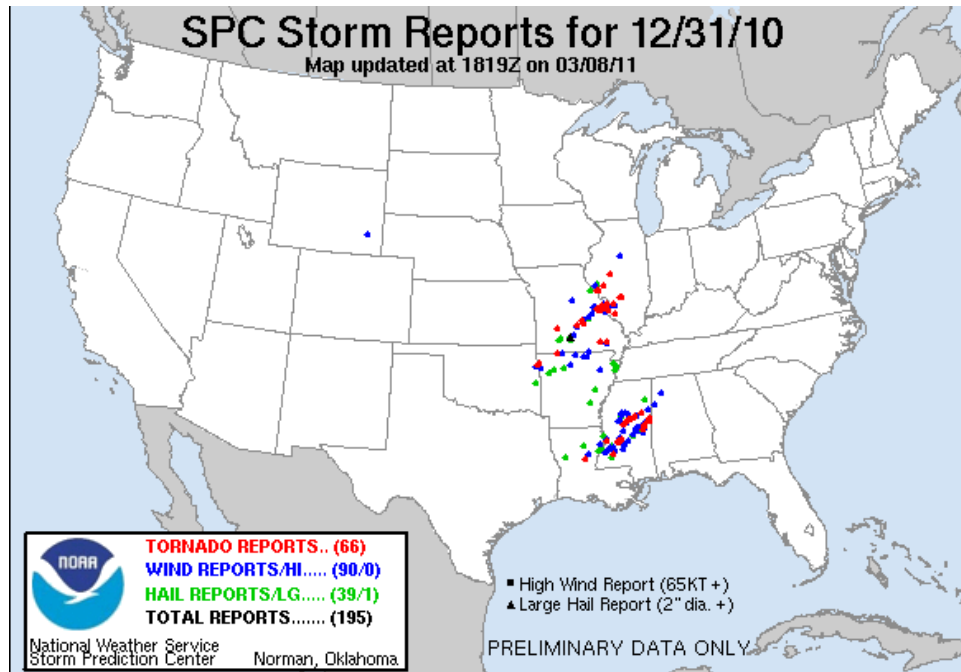


Figure 4: Tornado, wind, and hail reports recorded by the Storm Prediction Center (SPC) on December 31st, 2010 (*Image provided by the SPC*).

Synoptic Setup:

Multiple large scale ingredients played a role in amplifying the effects of an anomalous 500 mb trough that moved into the western half of the country during the last few days of December 2010.

At 00 UTC on December 29th, height falls were just beginning to reach the Pacific coast as an upper level trough approached the Western U.S. (Fig. 5 a.). The surface low and cold front associated with the trough remained offshore on the 29th, but low-level westerly winds ahead of the surface features brought plenty of Pacific moisture inland along the coastline (Fig. 6 a.). A distinct plume of moisture, or atmospheric river, stretched from the Hawaiian Islands to the southern Oregon and northern California coast. This feature, also known as the “Pineapple Express”, in conjunction with the onshore flow into steep terrain allowed for heavy precipitation along much of the Oregon and California coastline Tuesday evening and into early Wednesday morning. By 00 UTC on December 30th, the 500 mb trough had slid inland over the Intermountain West, and the surface cold front had progressed southeastward from the Pacific coast to the central Great Basin and Desert Southwest (Fig. 5 b. and 6 b.). Positive vorticity advection along with orographic lift helped precipitation continue with this system as it moved eastward. Behind the Pacific front, much cooler air moved in and lowered snow levels across the region. Freezing level heights over much of California and Nevada dropped roughly 1 km in 24 hours.

Between 12 UTC on December 30th and 00 UTC on December 31st, a weak short wave out of the main trough ejected northeastward from the Central High Plains to the Upper

Midwest, allowing a surface wave to develop along an Arctic boundary that dropped southward across the Northern and Central Plains (Fig. 5 c. and 6 c.). The surface low tracked northeastward from eastern Nebraska on Thursday morning to northern Wisconsin by early Friday morning. A tight pressure gradient and warm air advection northwest of the low track led to strong sustained winds and periods of heavy snow across eastern South Dakota and into central Minnesota (Fig. 6 c. and 7). Less than 24 hours later, the main trough axis had swung eastward of the Rockies (Fig. 5 d.) and a second surface low developed over the Plains and tracked trough the Upper Midwest (Fig. 6 d). Divergent flow aloft increased within the left exit region of a strengthening 250 mb jet max streaking from the Southern Plains to the Midwest (Fig. 8). In response to the increased positive vorticity advection, the surface low strengthened as it tracked northeastwards across the Upper Midwest and eventually dropped to 989 mb over extreme northeastern Minnesota by 12z on January 1st.

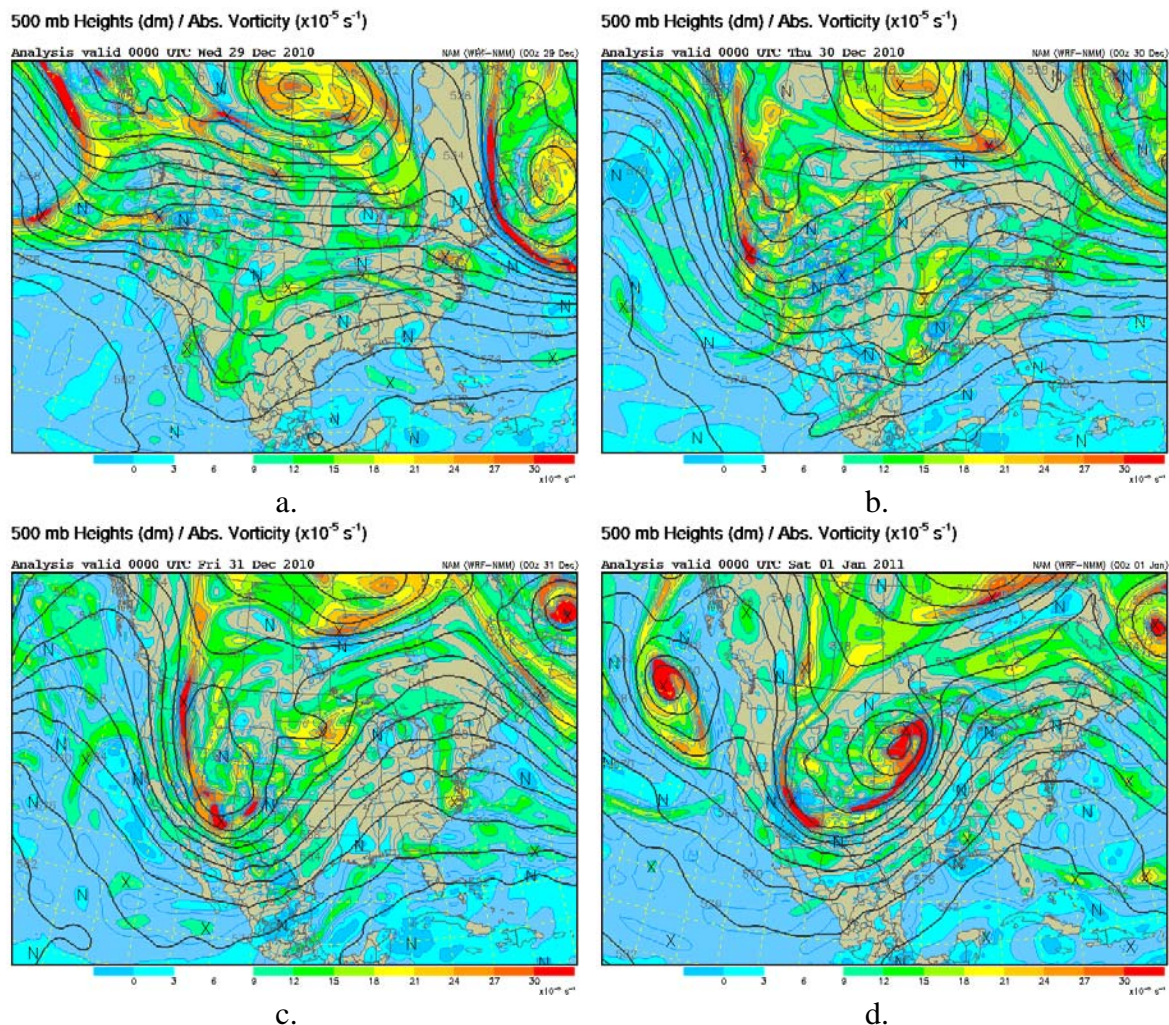


Figure 5: 500 hPa heights (dm) and absolute vorticity from (a) 00 UTC on the 29th, (b) 00 UTC on the 30th, (c) 00 UTC on the 31st of December 2010, and (d) 00 UTC on the 1st (d) of January 2011 (*Images provided by UCAR*).

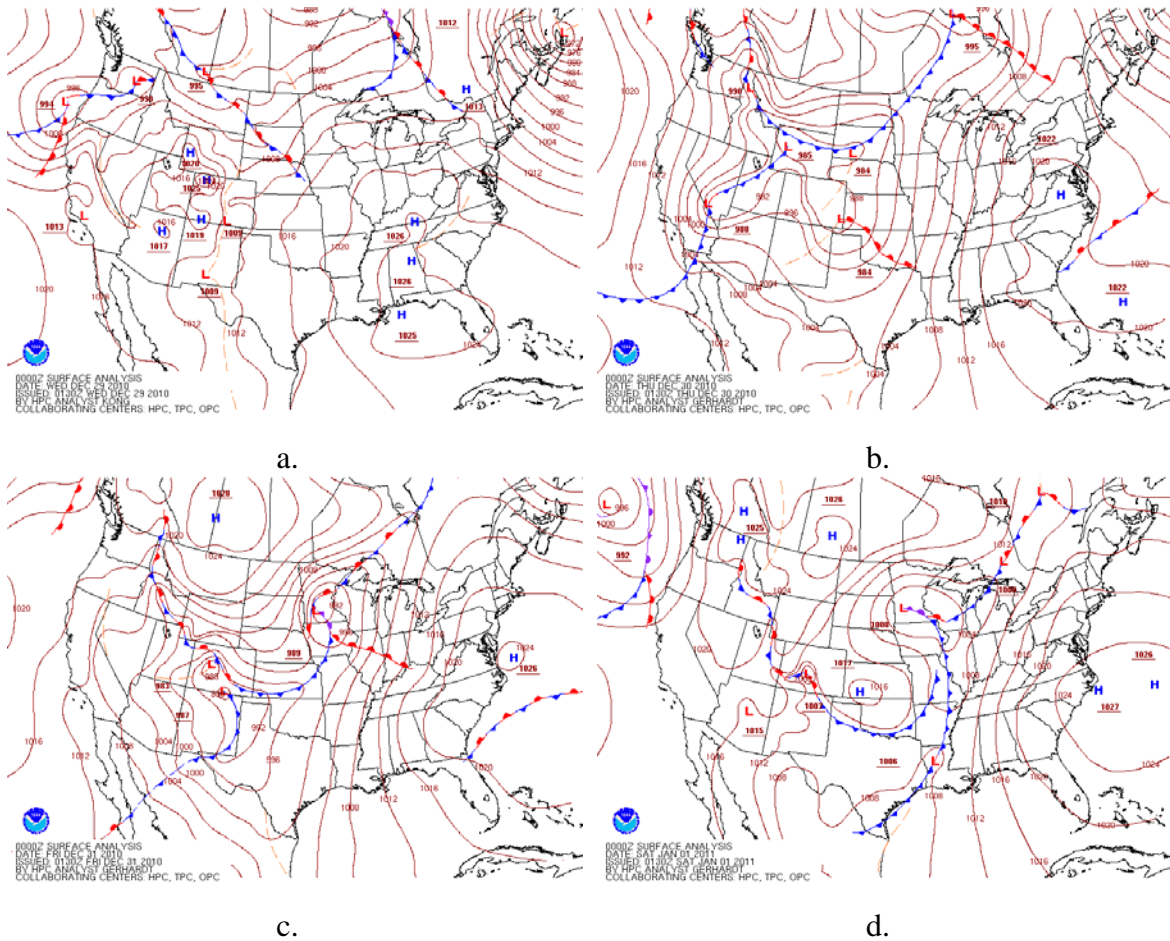


Figure 6: Analyzed surface pressures (every 4 mb) and fronts from (a) 00 UTC on the 29th, (b) 00 UTC on the 30th, (c) 00 UTC on the 31st of December 2010, and (d) 00 UTC on the 1st (d) of January 2011 (*Images provided by HPC*).

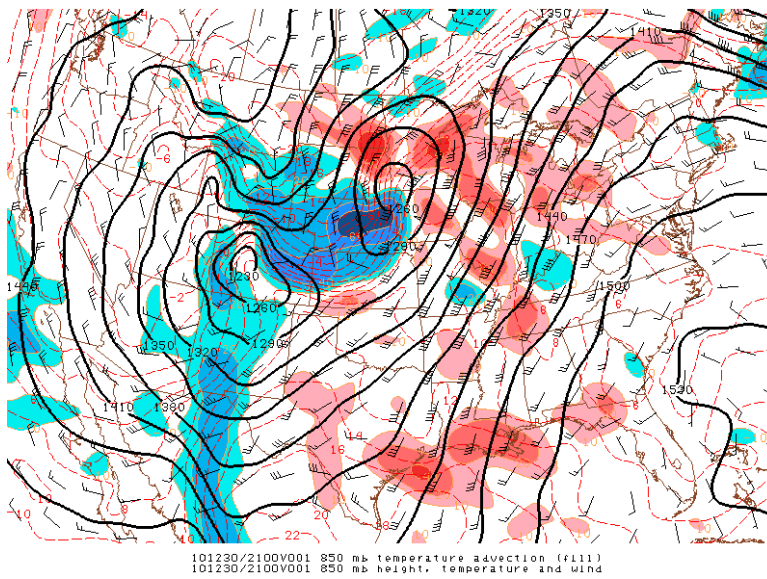


Figure 7: 850 mb heights, temperature, wind, and temperature advection from 21 UTC on December 30th, 2010 (Image provided by SPC).

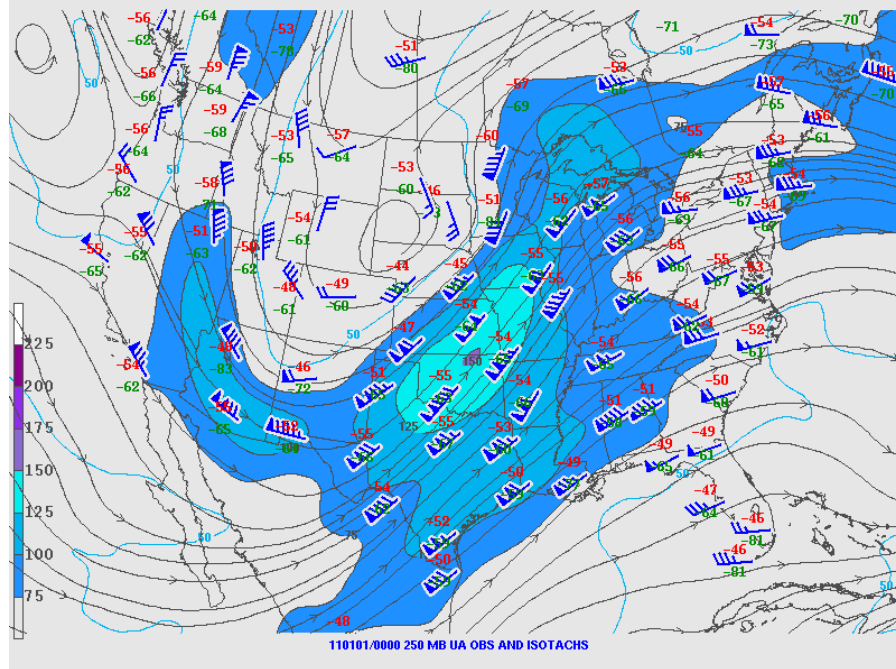


Figure 8: 250 hPa observations and isotachs (knots) from 00 UTC on January 1st, 2011 (Image provided by SPC).

Mesoscale Features:

As the event unfolded across the U.S., smaller scale features within the synoptic pattern impacted localized areas with intense snowfall rates, freezing rain, and severe weather.

While the cold front along the California coast moved inland over the Southwestern U.S. on Wednesday, December 29th, moisture from the Pacific became limited. However, upslope flow against the terrain combined with the strong large scale lift associated with the 500 mb trough and brought periods of heavy snow to localized areas. Over two feet of snow was observed across regions of Arizona where strong southwesterly flow ahead of the cold front led to periods of intense snowfall rates along portions of the Mogollon Rim (Fig. 9). Additionally, locations surrounding the Salt Lake City area measured more than 20 inches of snow from this event. Strong northwesterly flow behind the advancing cold front caused heavy snow along the western slopes of the Wasatch Range (Fig. 9).

By 12 UTC on the December 31st, the Pacific front had moved well into the Southern Plains and the Arctic boundary dropping southward from Canada had made it halfway into Missouri and across Northern Oklahoma and North Texas. The main energy from the upper trough had swung eastward out of the Rockies, and allowed the surface low over southeast Kansas to strengthen and move northward. Despite the sub-freezing surface temperatures in place behind the Arctic front, the increased southerly flow at 850 mb, due to the strengthening surface low over southeast Kansas, led to a pocket of warm

air aloft and resulted in freezing rain over isolated areas of western Missouri and eastern Kansas (Fig. 10 and 11).

While the 500 mb trough and cold front nudged eastwards, conditions became ideal for a severe weather outbreak over the Mississippi River Valley. The strong low level jet ahead of the surface cold front brought warm Gulf of Mexico moisture northward into the Lower and Middle Mississippi Valleys. PW values in excess of 30 kg/m^2 (1.2 inches) were observed from Louisiana to Illinois. By 12 UTC on December 31st, the increased southerly flow and moisture over the Lower Mississippi Valley led to modest CAPE values of 500-1000 J/kg, 40-50 kts (46-57 mph) of vertical wind shear (0-6km), and effective storm-relative helicity values exceeding $450 \text{ m}^2/\text{s}^2$. The abundance of shear and instability allowed a line of thunderstorms containing tornadoes to develop over eastern Oklahoma, ahead of the advancing cold front (Fig. 12). The storms stayed within a favorable environment of strong shear and helicity as they propagated northeastwards New Year's Eve, causing severe weather across Arkansas, Missouri, and Illinois (Fig. 12). Farther south, a second line of storms developed ahead of the cold front by 00 UTC January 1st, 2011. This second line formed over Louisiana and also propagated northeastwards into a favorable environment, bringing severe weather and heavy downpours to the Lower Mississippi Valley and Southeast (Fig. 12).

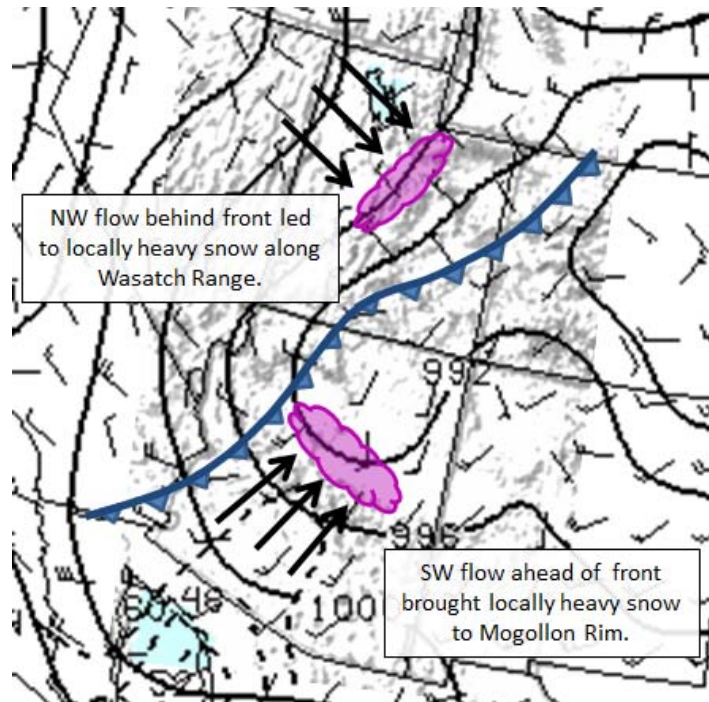


Figure 9: MSL Pressure and surface wind, location of the surface cold front, and ingredients for heavy snow at 09 UTC December 30th, 2010.

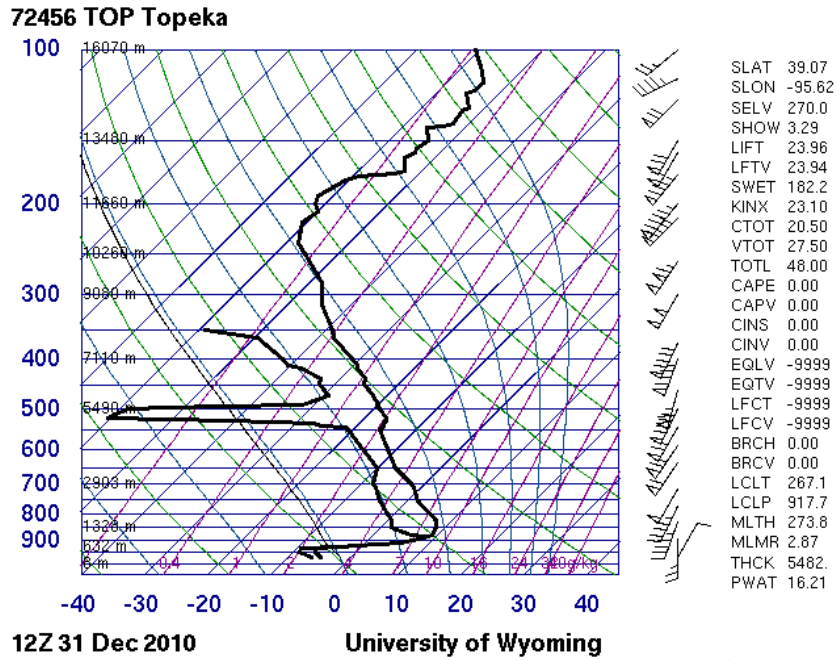


Figure 10: Sounding from Topkea, KS at 12 UTC on December 31st, 2010 (Image provided by University of Wyoming).

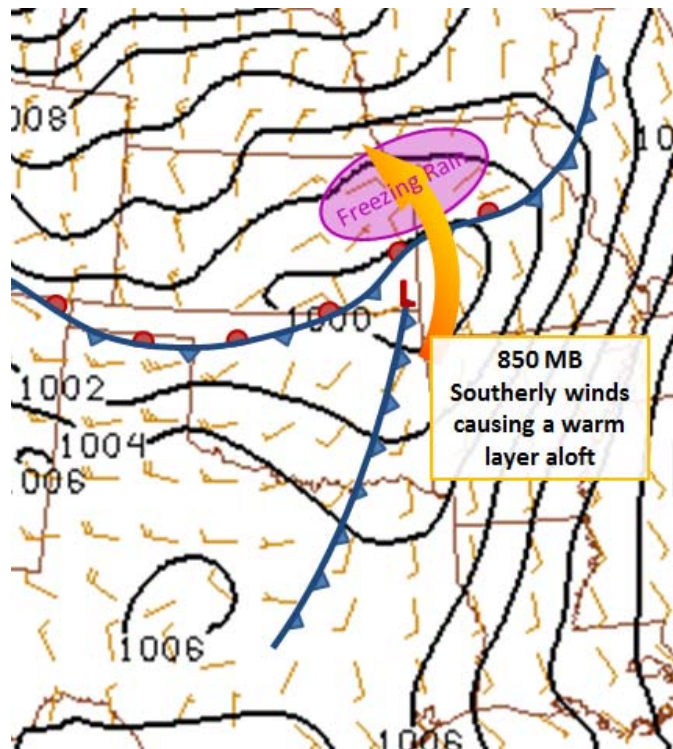


Figure 11: MSL pressure and surface winds, location of surface fronts, and ingredients for freezing rain at 12 UTC on December 31st, 2010.

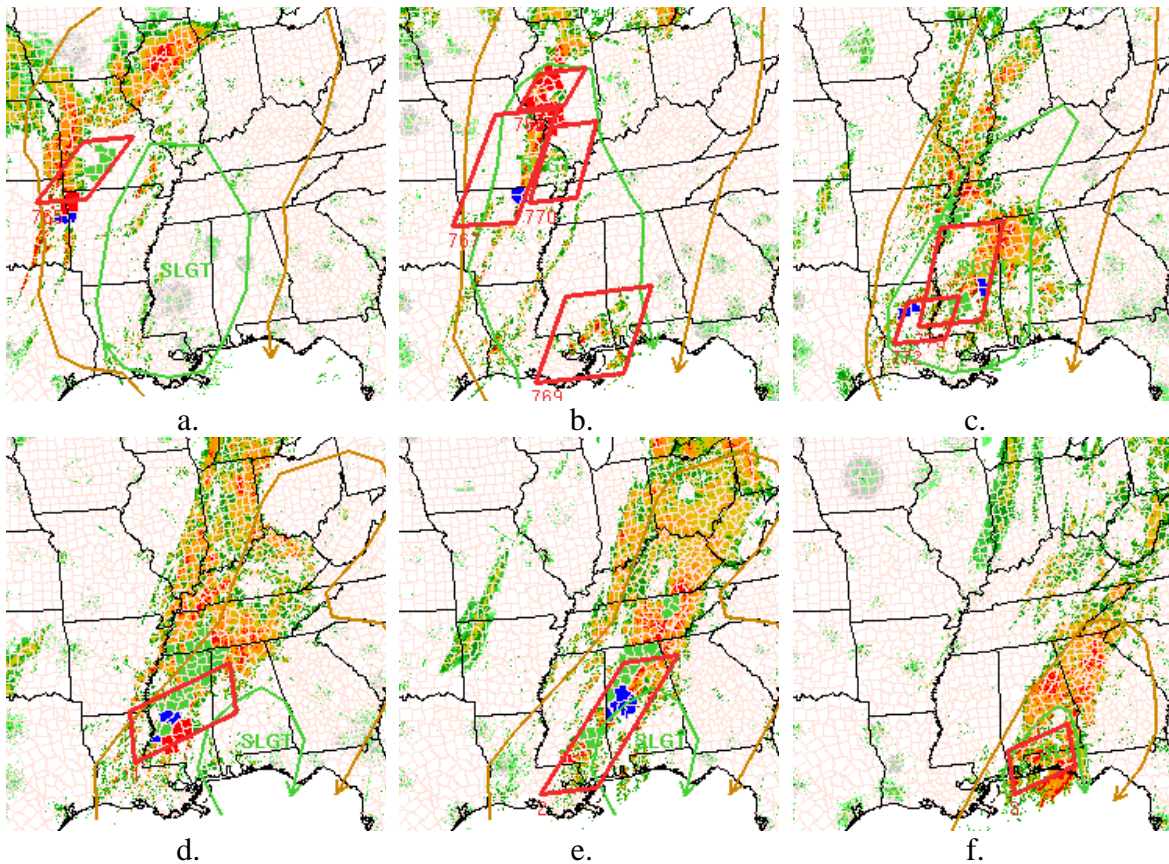


Figure 12: Radar reflectivity overlaid with the SPC day 1 outlook, watches, and warnings over the Mississippi River Valley from 12 UTC (a), 18 UTC (b), 00 UTC (c), 06 UTC (d), 12 UTC (e), and 18 UTC (f) on December 31st, 2010 through January 1st, 2011 (*Images provided by SPC*).

Summary:

In the final days of 2010 and first day of 2011, a multi-feature winter weather event impacted locations from the Pacific coast to the Mississippi River Valley. Heavy snow, high winds, sub-freezing temperatures, flooding, icing, and severe weather were all reported while an anomalous 500 mb trough moved across the Western half of the country. As an associated surface low and cold front approached the West Coast, westerly winds ahead of the system brought Pacific moisture inland leading to 1-3 inches of precipitation over portions of Oregon and northern California. Precipitation continued, winds gusted, and snow levels dropped as the cold front progressed southeastward over the Sierra Nevada and into the Southwest. While the Pacific front moved farther inland, an Arctic boundary dropped southward from Canada and brought sub-freezing temperatures to much of the western half of the country. A weak short-wave ejecting out of the main trough axis, allowed a surface wave to develop along the Arctic boundary and track northeastwards across the Upper Midwest. Once the main trough swung out of the Rockies, a second low strengthened over the Upper Midwest. These two surface lows, less the 24 hours apart, brought gusty winds and 6-10 inches of snow from central South

Dakota to northern Minnesota. Smaller scale features from the event impacted some localized areas. Over 20 inches of snow was observed along the Mogollon Rim and western slopes of the Wasatch Range, where upslope flow combined with the large scale lift of the 500 mb trough to create intense snowfall rates. Periods of freezing rain were recording in eastern Kansas and northwestern Missouri due to a low-level jet carrying a wedge of warm air above sub-freezing temperatures. Finally, a New Year's Severe Weather Outbreak occurred while southerly flow ahead of the advancing cold front increased shear and instability over the Lower and Middle Mississippi Valleys.