

Major Winter Weather Events during the 2013-2014 Cold Season

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Abstract:

The 2013-2014 cold season was marked by numerous winter storms and frequent, sustained outbreaks of Arctic air. A persistent upper-level trough remained in place through much of the season south of Hudson Bay, while upper-level ridging largely remained in place across the eastern north Pacific and the Gulf of Alaska. Seasonal low-level temperature anomalies of -1 to -4°C were observed across much of the north central and northeastern U.S., giving rise to public awareness of ‘the polar vortex’. Seasonal snowfall was above average across many of the same areas, and below average across much of the western U.S. Nineteen notable winter storms across the contiguous U.S. were documented, producing a total of 32 fatalities, 9 injuries, and \$263 million in damage. The five most substantial of these storms, based on damage and casualty data, are detailed in this article.

1. Introduction

Winter storms cause millions of dollars in damage and disrupt countless lives across the United States every year. They directly cause an average of 25 deaths in the U.S. each year (2003-2013 average), with an additional 27 deaths each year caused by cold temperatures (National Weather Service (NWS) Natural Hazard Statistics 2014). Winter storms produce a variety of precipitation including snow, sleet, and freezing rain, often with high winds, extreme cold, and coastal flooding in addition to the precipitation. Some parts of the U.S. are more prepared than others, and thus the impact of winter storms varies widely by region. Winter storm activity varies from year to year, in connection with large-scale atmospheric phenomena such as the North Atlantic Oscillation (NAO), Arctic Oscillation (AO), and El Niño-Southern Oscillation (ENSO).

The Weather Prediction Center provides winter storm specific forecasts for the U.S. These include quantitative precipitation forecasts (QPF), probabilistic heavy precipitation (rain, snow, freezing rain) forecasts, and forecast tracks of surface cyclones associated with winter weather. The WPC also issues Storm Summary products for high-impact winter weather events that affect multiple NWS county warning areas, commerce and transportation, and are likely to attract media attention. Storm Summaries contain information on the current location and intensity of a storm system, a summary of rain and snowfall accumulations, and a short term forecast for the storm system.

The purpose of this article is to provide an overview of the 2013-2014 cold season (Sep 15 – May 15), and a selection of the most notable winter weather events. Section two of the article describes the data used as well as the method for choosing which storms warranted the inclusion of a detailed description in this article. Section three of the article provides a seasonal

overview of the large scale patterns that affected North America during the cold season. Section four of the article discusses the individual details of the most substantial winter storms of the cold season. Finally, a summary is given in section five. Table 1 at the end of the article summarizes all the notable winter weather events for the season, including those that were, for brevity, not included in this article. Details on most of these other events, including their associated storm track overview images, can be found on the WPC website (<http://www.wpc.ncep.noaa.gov>) under the “Event Review” section.

2. Datasets

NCEP/NCAR Reanalysis data (Kalnay et al. 1996) were used to create the seasonal anomaly graphics referenced in section three. Snowfall analyses shown are interpolated snow analyses from the National Operational Hydrologic Remote Sensing Center (NOHRSC). The NOHRSC analyses are created using observed snowfall data received in SHEF (Standard Hydrometeorological Exchange Format) over AWIPS (Advanced Weather Interactive Processing System) (NOHRSC 2005). The data are then interpolated temporally using preprocessed RADAR (Radio Detection and Ranging) data (Stage II) as well as spatially using a weighting function (NOHRSC 2005). Snowfall data are not interpolated above 500 m in elevation in the eastern U.S. and above 1750 m in the western U.S. In northern Idaho, Washington, and Oregon snowfall data are not interpolated above 800 m. For further details on the data assimilation and interpolation schemes used in the NOHRSC snowfall analyses the reader is referred to NOHRSC 2005. Data for the North Atlantic Oscillation, Arctic Oscillation, and Pacific-North America Index plot are taken from the NOAA Climate Prediction Center (CPC) archive.

The five most substantial winter weather events of the season were chosen for inclusion in this article, based on monetary damage amounts and the numbers of deaths and/or injuries

directly attributed to the event (*Table 1*). Monetary damage and casualty data included in this article were taken from the official NWS Storm Data publication, *Storm Data and Unusual Weather Phenomena* (www.ncdc.noaa.gov/oa/climate/sd). Societal impact scales such as the Northeast Snowfall Impact Scale (NESIS, Kocin and Ucellini 2004) and Regional Snowfall Index (RSI, Squires et al. 2011) scales were considered, but for the purposes of this article official monetary damage amounts and deaths were chosen as a broader measure of impacts.

3. Seasonal Overview

The 2013-2014 winter weather season was a very active one for most of the contiguous U.S. The season was marked by numerous outbreaks of Arctic air across much of the central and eastern U.S., giving rise to media and public awareness of ‘the polar vortex’. Overall, areas of the Midwest, Mid-Atlantic, Northeast, and the Pacific Northwest received above average snowfall for the season, while much of the interior western U.S. received below average snowfall. The season began early and intensely with a blizzard in the northern Rockies and northern High Plains in early October 2013, which produced 3 to 4 feet of snow in some areas. The winter weather season ended late in some of the same areas, with a winter storm striking portions of the central Rockies and western High Plains in mid-May 2014.

The large-scale pattern was remarkably stable throughout most of the cold season, with upper-level ridging in place across the eastern North Pacific and western North America, and a persistent upper-level low in place south of Hudson Bay, as indicated by 500 hPa geopotential height seasonal anomalies (*Fig. 1*). The persistence of this large-scale pattern throughout most of the season allowed for numerous intrusions of Arctic air from the high latitudes of Canada into the central and eastern United States. The North Atlantic Oscillation (NAO, Barnston and Livezey, 1987) and the Arctic Oscillation (AO, Thompson and Wallace, 1998) were

predominantly positive throughout most of the season (*Fig. 2*). The Pacific-North America (PNA, Barnston and Livezey, 1987) index was negative throughout much of the season, but was strongly positive during January. During this period of positive PNA (aligned with a period of negative AO), the intensity of the ridge along the West Coast allowed for the most intense cold air outbreaks of the season, and a period of frequent winter storms across the central and eastern U.S.

250 hPa wind speed anomalies (*Fig. 3*) show two distinct jets – a Polar jet extending from northwestern Canada into the north central and northeastern U.S., and a weaker Subtropical jet extending from near Hawaii into the southwestern and south central U.S. before eventually merging with the polar stream across the Mid-Atlantic and the Northeast. These 250 hPa wind speed anomalies are suggestive of the predominant storm tracks for the season, as well as indicating the prospect of frequent phasing of northern and southern stream systems along the U.S. East Coast. The average storm tracks for the season are corroborated by viewing the 700 hPa relative humidity anomalies (*Fig. 4*), which suggest anomalously high 700 hPa relative humidity values from the eastern Pacific into the southeastern U.S. and across the northern plains and Great Lakes.

The intensity and duration of Arctic outbreaks across the central and eastern U.S. are evident from seasonal 850 hPa temperature anomalies (*Fig. 5*). Anomalies of -4 to -5 °C, representing the core of the anomalously cold air, were centered southwest of Hudson Bay, with anomalies of -1 to -4 °C common across much of the central and eastern U.S.

4. Most Notable Winter Weather Events of the Season

a. Southern plains to Ohio valley winter storm (5-7 December, 2013)

1) Meteorological Overview

Late on 4 December into early 5 December, a 500 hPa low developed near the North Dakota-Canada border and tracked northeastward, reaching northern Ontario by late on 5 December (*Fig. 6*). South of the low a positively tilted upper-level trough extended back into the Southwest. Embedded within the base of this broader trough, a shortwave trough moved across the Southwest on 5 December into early 6 December before reaching the southern plains later in the day.

During the evening of 4 December as the upper-level low formed and tracked to the northeast, a surface low tracked from the Upper Midwest through the Upper Great Lakes into southern Ontario by the morning of 5 December. A trailing cold front extended back through the Ohio valley into the lower Mississippi valley and southern plains early on 5 December. This front progressed farther to the south and east, reaching south Texas and the western Gulf Coast by that evening. Temperatures fell sharply behind the front. High temperatures on 5 December were below freezing in many areas across Oklahoma, northwest Arkansas and north Texas. On 6 December temperatures remained near or below freezing from central Texas to Ohio – 10 to 15°C below average for parts of the region and a stark contrast to the 15-20°C above average temperatures that were observed earlier in the week.

As the low-level winds increased ahead of the aforementioned shortwave trough moving through the Southwest, moisture from the Gulf of Mexico was advected north of the front. A weak surface low developed along the front and further enhanced the warm air and moisture advection east of the low track, while furthering the cold air advection to its southwest. In response to the enhanced warm air and moisture advection, precipitation began to develop on 5 December across north Texas, Oklahoma, Arkansas, southern Missouri and the Ohio valley. Moderate to locally heavy precipitation developed and continued into 6 December from

northeastern Texas and eastern Oklahoma into the Ohio valley as this moisture interacted with an area of strong low-level frontogenesis and upper-level divergence along the right-entrance region of an upper-level jet maximum.

Widespread snow accumulations of 4 inches, with local amounts of up to 13 inches, were observed from eastern Oklahoma to central Ohio (*Fig. 7*). South of the heavier snow accumulations, a wintry mix was reported, with sleet amounts of 1-3 inches recorded across parts of northeastern Texas, eastern Oklahoma, northern and central Arkansas and southeastern Missouri. Freezing rain, with ice accumulations greater than 0.25 inch, was reported across portions of northeastern Texas, southwestern Oklahoma, western Arkansas, western and central Tennessee, western and central Kentucky and southern Indiana and Illinois. Ice accumulations in excess of one inch occurred in some areas.

2) Impacts

Hundreds of thousands lost power due to the storm across the southern plains and portions of the Mississippi River valley. In North Texas alone, a quarter-million customers were left without power, causing many businesses to close. The weather also forced more than 1,000 cancellations at Dallas-Fort Worth International airport – one of the nation’s busiest airports. The Dallas Marathon, scheduled for the following Sunday and expected to draw 25,000 runners, was cancelled due to the storm’s impacts. Total monetary damage of \$81.1 million was reported for this event (making this event the most costly of the season), the large majority of which was due to excessive ice accumulations. One fatality was directly attributed to the event in Arkansas when a large limb weighed down by ice fell on a camping trailer, killing the occupant.

b. Southern plains to Northeast winter storm (20-23 December, 2013)

1) Meteorological Overview

An expansive and long-lived winter weather event affected areas from the southern plains to the Northeast from 20-23 December, 2013 (*Fig. 8*). At 12 UTC on 20 December, a quasi-stationary Arctic surface frontal boundary extended from the middle Mississippi valley eastward into northern New England. Across the central and southern plains, the Arctic front continued to move southward as a cold front. At this time, weak overrunning, resulting from 30 knot moist southwesterly flow at 850 hPa crossing the surface front across the Great Lakes and the Northeast, was causing scattered light snow, sleet, and freezing rain in the cold air north of the front. Concurrently, a vigorous and slow-moving mid/upper-level low from the Pacific was moving into northern Baja California. This feature would be responsible for the main event as it moved east over the coming days.

By 00-12 UTC on 21 December, as the mid/upper-level low and the associated surface low pressure system moved east, strengthening low-level southerly flow encountered the Arctic surface front across Texas, and resulted in the formation of an area of overrunning precipitation, which became larger and heavier over time, encompassing much of the southern and central plains and Ohio valley by 12 UTC. Precipitation in this large area fell as a mix of rain, sleet, and freezing rain. The very warm and moist air mass south of the Arctic front resulted in the formation of convective elements which became elevated as they moved across the front and above the shallow Arctic air. These elevated convective elements resulted in areas of very heavy sleet and freezing rain accumulations across portions of the southern and central plains. Additionally, a band of heavy snow from northern Texas to Iowa resulted in 6 to 12 inches of snow, with amounts as high as 15 inches in Kansas (*Fig. 9*).

During the day on 21 December the precipitation continued to expand across the Ohio valley and into the Northeast as low-level flow crossing the Arctic surface front continued to

strengthen ahead of the mid/upper-level low. As cold, shallow Arctic air moved into Maine, northern Vermont, and New York, substantial amounts of freezing rain fell in these areas. Many areas received more than one inch of ice accumulation. Farther north, where the cold air was deeper, 6 to 10 inches of snow fell in a band across northern Maine.

By 00 UTC on 22 December the slow-moving mid/upper-level low, which was still near the Mexico/Arizona border, began to accelerate northeastward as it started to become absorbed into an amplifying long wave trough across the northern plains. Between 12 and 18 UTC on 22 December, a band of heavy snow developed north and west of the surface low in an upper-level deformation zone. This area of heavy snowfall produced 6 to 10 inch accumulations from northern Illinois across eastern Wisconsin and into the northern Lower Peninsula of Michigan. Additionally, favorable low-level winds brought substantial lake-effect snows to the south shore of Lake Superior in Wisconsin, where up to 25 inches of snow fell. The deformation band over the Great Lakes diminished between 00 and 12 UTC on 23 December, bringing an end to the majority of the heavy winter precipitation across the Midwest and Great Lakes, although lake-effect snows lingered in the wake of the system. Snow persisted across northern Maine until the low-pressure system moved offshore during the evening of 23 December.

2) Impacts

The most substantial impacts from this event were extensive power outages resulting from freezing rain. Power outages were scattered from the southern plains to the Great Lakes in areas where substantial freezing rain occurred (exceeding 1"). The most substantial power outages were in the Northeast, where power outages persisted for weeks in some areas. Frigid temperatures in the wake of the event allowed snow and ice accumulations to linger. No fatalities

or injuries were directly attributed to the event. Monetary damage amounts of \$54.6 million were reported, primarily the result of heavy ice accumulations.

c. Central and eastern U.S. winter storm and Arctic outbreak (4-7 January, 2014)

1) Meteorological Overview

A major winter storm impacted much of the middle Mississippi and Ohio valleys and the Great Lakes during the first week of 2014. The multi-day snowfall event commenced late in the morning on 4 January, along a nearly stationary frontal zone extending from northern Missouri through the Upper Great Lakes. Precipitation began as light snowfall, the result of relatively weak vertical motion and an atmosphere that was relatively dry. Eventually warm air advection began to increase ahead of a southern stream shortwave moving through southern Kansas on 5 January (12 UTC) (*Fig. 10*) which helped moisten the low-levels of the troposphere, and increased upward vertical motion. The thermal gradient continued to strengthen across the Upper Great Lakes ahead of a deepening 850 hPa low which moved from southern Missouri into northwestern Ohio between 12-00 UTC on 5-6 January. This sharpening temperature contrast led to a layer of 850-700 hPa frontogenesis extending west and north of the 850 hPa low track where moderate to heavy snow began to fall. At this time, a pair of upper-level jets coupled across Illinois and Indiana by 18 UTC on 5 January. Eventually the baroclinic zone became more progressive in nature once the 500 hPa lows phased across the Upper Great Lakes by 12 UTC on 6 January which quickly carried the precipitation axis eastward. Behind the front in the central U.S., blowing snow and reduced visibilities were common.

During the height of the heavy snowfall, Chicago O'Hare airport saw wind chills below -15°C and visibilities dropped to less than two-tenths of a mile. In addition to the widespread snow, freezing rain fell early in the event on the morning of 5 January with at least a quarter inch

of ice reported across areas of the Mid-Atlantic. Southwesterly flow ahead of the upper-level trough between 950-800 hPa allowed warm air to overrun a surface layer which had decoupled and remained below freezing.

A widespread axis of 6 to 12 inches of snow fell from central Missouri northeastward through Illinois and Indiana and into Lower Michigan with isolated amounts nearing 18 inches across northern Indiana (*Fig. 11*). Additional heavy accumulations fell downwind of the Great Lakes as cyclonic flow and favorable lake trajectories set up over the region.

In addition to the wintry precipitation, some of the coldest temperatures in nearly 20 years affected the eastern two-thirds of the country, giving rise to media and public awareness of ‘the polar vortex.’ A large number of record low temperatures dating as far back as the 19th century were broken (*Tables 2 and 3, NCDC, Global Historical Climatological Network - Daily*). The upper-level flow was meridional the entire distance north to the Arctic Circle, providing a direct path for cold air advection toward the U.S. Windy conditions resulting from a strong surface pressure gradient led to some dangerously low wind chills. During the event, wind chill values plunged as low as -50°C across the northern High Plains.

2) Impacts

The combination of heavy snowfall, ice, and bitterly cold temperatures led to major disruptions to infrastructure and commerce. Accumulating ice caused a commercial aircraft to skid off the runway and into a nearby snowbank at John F. Kennedy International Airport (JFK). Thousands of flights in the affected area were canceled due to the inclement weather including at Chicago O’Hare International Airport (ORD) where jet fuel and deicing fluids froze in the -15°C temperatures. In addition to aviation, railway operations were severely hampered, with multiple lines experiencing cancellations and hours of delays. The historic cold outbreak also forced the

closure of all public schools in Minnesota on 6 January for the first time in 17 years. Further, Ohio State University in Columbus, OH, which had not been completely shut down since 1978, was closed from 6-7 January. Monetary damage from this event totaled \$5.6 million from a combination of the winter weather, high winds, and extreme cold. Ten fatalities were directly attributed to the event, all of which were due to exposure to the extremely cold temperatures and wind chill values, making this the deadliest event of the season.

d. Central to Northeast U.S. winter storm (4-5 February, 2014)

1) Meteorological Overview

A strong 500 hPa low moved south along the California coast and advanced into the desert Southwest late on 3 February, setting the stage for development of a winter storm across the southern and central plains. During the early morning hours of 4 February, a surface low and associated warm front formed along the western Gulf Coast ahead of the incoming 500 hPa low. As this storm moved northeastward, a comma-head developed on the northwest side and produced snow across Oklahoma, Kansas, and portions of Texas. Farther south in the transition zone, freezing rain and sleet impacted portions of the southern plains, middle Mississippi valley, and Tennessee valley. The wintry precipitation began to spread into the Ohio valley later on 4 February as the upper-level low continued to move northeastward into the central plains.

By 5 February, the upper-level low weakened as it moved over the Great Lakes, and its associated surface system filled as it advanced into the Ohio valley in favor of coastal cyclogenesis just off the Delmarva Peninsula (*Fig. 12*). As the strengthening surface low moved up the East Coast, snow fell west and north of it, covering most of the Northeast and Upper Great Lakes throughout the day. Along with the snow, the transition zone to the south impacted northern portions of the Mid-Atlantic with freezing rain and sleet. Snow continued to fall

throughout the night of 5 February and into 6 February across New England, then tapered off during the morning of 6 February as the surface low moved east over the Atlantic Ocean.

Over a foot of snow fell across multiple states from the central plains eastward toward the Northeast (*Fig. 13*). Up to 7 inches of snow fell across the southern plains and portions of the middle Mississippi, Ohio and Tennessee valleys. The majority of states across the Northeast received over a foot of snow with multiple areas in New York reporting 12-15 inches.

2) Impacts

Kansas and New York declared states of emergency due to severe impacts from the event. The state of Pennsylvania had over 600,000 people without power -- the largest power outage in that state since Post-Tropical Storm Sandy in 2012. Traveling was also treacherous; many automobile accidents occurred over these states and flight cancellations for this storm totaled over 3,000. Behind the front, a 1040 hPa Arctic surface high crossed the plains and moved over the East Coast, bringing record-breaking low temperatures and creating a dangerous situation for people without power during the frigid conditions. The event directly caused 4 deaths across the Midwest, resulting from exposure to the extreme cold and 1 injury in Pennsylvania, when a heavy ice-laden tree branch fell on a man. Total monetary damage of \$15.9 million was reported for the event.

e. Central Rockies and Front Range late-season winter storm (10-12 May, 2014)

1) Meteorological Overview

Over the Mother's Day weekend of 2014, a late season snowstorm impacted areas of the central Rockies and the central High Plains. While spring snows are not necessarily unusual for this region, this storm broke a record in Cheyenne, WY on 11 May for the heaviest calendar-day snow since records began in 1883. Snow began in the late morning of 10 May in the central

Rockies, and continued through the early evening hours of 12 May. The heaviest of the snow occurred during the afternoon and overnight hours of 11 into 12 May.

Around 00 UTC on 10 May, a closed upper-level low entered the Pacific Northwest. The low weakened slightly as it moved southward towards the Great Basin, but strengthened again as it crossed into southern Utah by 12 UTC on 11 May (*Fig. 14*). At this time, surface low pressure had organized in south central Utah, and moderate snow was falling across parts of the central Rockies in Colorado and southern Wyoming. Over the next 8 to 12 hours, the surface low drifted slowly eastward, but weakened as it reached the higher terrain of the central Rockies.

Concurrently, a second surface low formed in the lee of the Rockies and was strengthening as it moved into the central plains, which helped to advect the coldest air into the mountains and Front Range. This intense surge of cold air, combined with the dynamic lifting aloft, helped the heaviest snow form over the mountains of Colorado into the central High Plains.

Many areas received 4-12 inches of snow across the central Rockies and the central High Plains (*Fig. 15*). In the highest terrain of northern Colorado and southern Wyoming however, totals approached 2 feet, with a few places exceeding 3 feet. In addition to the heavy snow, high winds impacted much of the southwestern U.S. in the wake of the storm.

2) Impacts

Travel across the central Rockies was quickly compromised and became dangerous or impossible through the duration of the storm. Delays and cancellations were common at area airports, and numerous accidents blocked major roadways. In Wyoming, the storm prompted the shutdown of I-80, a major truck route, stranding thousands of motorists and causing overcrowding of rest stops along the interstate. Widespread power outages were also common across the central Rockies as heavy wet snow weighed down power lines and brought down

newly greened trees. No fatalities or injuries directly resulted from this event. However, total monetary damages were substantial, totaling \$45 million, primarily the result of the heavy snowfall impacting trees, power lines, and structures.

5. Summary

The winter weather season of 2013-2014 was very active. The five most substantial events described in this seasonal review directly resulted in a total of 15 fatalities and at least \$202 million in damage (*Table 1*). Across all notable events of the season, a total of 32 deaths, 9 injuries, and \$263 million in damage were reported. The number of deaths and injuries was an increase over the 2012-2013 season, while the total monetary damage amount was a decrease. The severity and widespread nature of unusually cold temperatures during several of the events during 2013-2014 is thought to have contributed to the higher number of casualties relative to the previous season.

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7. References

- Barnston, A.G., R.E. Livezey, 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Mon. Wea. Rev.*, **115**, 1083-1126,
doi: [http://dx.doi.org/10.1175/1520-0493\(1987\)115<1083:CSAPOL>2.0.CO;2](http://dx.doi.org/10.1175/1520-0493(1987)115<1083:CSAPOL>2.0.CO;2)
- Kalnay, E. and Coauthors, 1996: The NCEP/NCAR Reanalysis 40-year project. *Bull. Amer. Meteor. Soc.*, **77**, 437-471, doi: [http://dx.doi.org/10.1175/1520-0477\(1996\)077<0437:TNYRP>2.0.CO;2](http://dx.doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2)
- Kocin, P. J. and L. W. Uccellini, 2004: A Snowfall Impact Scale Derived from Northeast Storm Snowfall Distributions. *Bull. Amer. Meteor. Soc.*, **85**, 177-194,
doi: <http://dx.doi.org/10.1175/BAMS-85-2-177>.
- Menne, M.J., I. Durre, R.S. Vose, B.E. Gleason, and T.G. Houston, 2012: An overview of the Global Historical Climatology Network-Daily Database. *Journal of Atmospheric and Oceanic Technology*, **29**, 897-910, doi:10.1175/JTECH-D-11-00103.1.
- NOAA National Climatic Data Center. <http://doi.org/10.7289/V5D21VHZ> (3 November, 2015)
- NOHRSC Interactive Snowfall Maps, NOAA/NWS/OCWWS, 2005
(www.nohrsc.noaa.gov/technology/pdf/Snowfall_Maps.pdf)
- NOAA/NWS Natural Hazard Statistics, 2013
(http://www.nws.noaa.gov/om/hazstats/resources/weather_fatalities.pdf)
- Squires, M.F., J. H. Lawrimore, R.R. Heim Jr. D.A. Robinson, M.R. Gerbush, T.W. Estilow, L. Ross, 2011: Regional Snowfall Impact Scale. 27th IIPS, Seattle, WA.
- Storm Data and Unusual Weather Phenomena (www.ncdc.noaa.gov/oa/climate/sd)

Thompson, D.W.J., J.M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geo. Res. Lett.*, **25**, 1297-1300,

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Table 1:

Date	Event	Impacts	Deaths/Injuries	Damage (\$)
4-5 October, 2013	Northern Rockies and Northern Plains Winter Storm	Winter Storm/Heavy Snow, Blizzard	0/0	12.1 M
21-27 November, 2013	Southwest to Eastern U.S. Winter Storm	Winter Storm/Heavy Snow, High Wind	2/3	4.04 M
5-7 December, 2013	Southern Plains to Ohio Valley Winter Storm	Winter Storm/Ice Storm	1/0	81.1 M
6-9 December, 2013	Central and Northeast U.S. Winter Storm	Winter Storm/Ice Storm, High Wind, Cold/Wind Chill	0/1	726 K
14-15 December, 2013	Ohio Valley and Northeast Winter Storm	Heavy Snow/Winter Storm, Strong Wind, Coastal Flooding	0/0	605 K
20-23 December, 2013	Southern Plains to Northeast Winter Storm	Winter Storm/Ice Storm	0/0	54.6 M
1-3 January, 2014	Central and Eastern U.S. Winter Storm	Winter Storm/Heavy Snow, Blizzard, High Wind, Coastal Flooding, Cold/Wind Chill	2/0	2.64 M
4-7 January, 2014	Central/Eastern U.S. Winter Storm and Arctic Outbreak	Winter Storm, High Wind, Extreme Cold/Wind Chill	10/0	5.60 M
20-22 January, 2014	Midwest to Eastern U.S. Winter Storm	Cold/Wind Chill, Strong Wind	4/0	23.0 K
28-30 January, 2014	Gulf Coast and Southeast U.S. Winter Storm	Winter Storm, Extreme Cold/Wind Chill	1/1	6.08 M
2-3 February, 2014	Southern Plains to Northeast Winter Storm	Winter Storm, Cold/Wind Chill	3/0	22.0 K
4-5 February, 2014	Central to Northeast U.S. Winter Storm	Winter Storm/Heavy Snow/Ice Storm, High Wind	4/1	15.9 M
7-10 February, 2014	Western U.S. Winter Storm	Avalanche	2/0	40.0 K
11-14 February, 2014	Southern Plains to East Coast Winter Storm	Winter Storm/Ice Storm/Heavy Snow, High Wind, Cold/Wind Chill	3/0	2.95 M
1-3 March, 2014	Plains to Mid-Atlantic Winter Storm	Winter Storm/Heavy Snow, Debris Flow	0/3	3.57 M
6-7 March, 2014	Southern Appalachians Winter Storm	Winter Storm/Ice Storm	0/0	22.2 M
12-13 March, 2014	Midwest to Northeast U.S. Winter Storm	Winter Storm, Blizzard, High Wind	0/0	5.96 M
10-12 May, 2014	Central Rockies and Front Range Late-Season Winter Storm	Winter Storm	0/0	45.0 M
		Totals:	32/9	263 M

***Events shown in bold are those that were included in this article, denoted as the five most substantial events of the season based on monetary damage and/or direct casualties.**

Table 2: Top ten daily record low temperatures (ranked by longest standing) for 4-7 January, 2014. (NOAA National Climatic Data Center, Global Historical Climatological Network - Daily)

Top 10 Records by Longest Standing		
Location	Temperature (°F)	Previous Record Year
Federal Point, FL	27	1893
Howell WWTP, MI	-11	1896
Newark, NJ	3	1896
New York City (Central Park), NY	4	1896
Cape May, NJ	5	1904
Brockton, MA	-10	1904
Kokomo 3 SW, IN	-12	1904
Fredericksburg, TX	17	1910
Rolla, MO	-10	1912
Windsor, IL	-13	1912

Table 3: Top ten daily record low temperatures (ranked by lowest temperatures) for 4-7 January, 2014. (NOAA National Climatic Data Center, Global Historical Climatological Network - Daily)

Top 10 Records by Lowest Temperature		
Location	Temperature (°F)	Previous Record Year
Thorhult, MN	-40	1968
Mizpah 4 NNW, MT	-34	1991
Turtle Lake, ND	-34	1991
Ladysmith 3 W, WI	-33	1973
Willow Reservoir, WI	-31	1968
Albion 1 N, MT	-31	1968
Owatonna, MN	-30	1988
Mellen 4 NE, WI	-29	1973
Gurney, WI	-28	1968
Melrose, MN	-27	1988

Figure Captions:

Figure 1: 500 hPa geopotential height composite anomalies for the period of October 2013 to April 2014 (NCEP/NCAR Reanalysis).

Figure 2: The North Atlantic Oscillation (NAO), Arctic Oscillation (AO), and Pacific-North America Index values from October 2013 to April 2014 (CPC).

Figure 3: 250 hPa wind speed composite anomalies for the period from October 2013 to April 2014 (NCEP/NCAR Reanalysis).

Figure 4: 700 hPa relative humidity (%) composite anomalies for the period from October 2013 to April 2014 (NCEP/NCAR Reanalysis).

Figure 5: 850 hPa geopotential height composite anomalies for the period from October 2013 to April 2014 (NCEP/NCAR Reanalysis).

Figure 6: 500 hPa low (black L) track, surface low (blue) track, approximate area of 4 inch or greater snowfall (magenta) and 0.25 inch or greater ice (blue), surface frontal analysis valid at 12 UTC on 5 December, 2013.

Figure 7: Total observed snowfall (interpolated) during 48h preceding 12 UTC on 7 December, 2013 (NOHRSC).

Figure 8: 500 hPa low/trough (black), approximate areas of greater than 6 inches of snow (magenta) and 0.50 inch of ice (blue). Surface analysis shown is valid at 12 UTC on 21 December, 2013.

Figure 9: Total observed snowfall for the 72 hour period ending at 12 UTC on 23 December, 2013 (NOHRSC).

Figure 10: 500 hPa low track (black), surface low track (light blue), area receiving greater than 6 inches of snow (magenta), surface frontal analysis valid at 21 UTC on 5 January, 2014.

Figure 11: Total observed snowfall for the 72 hours ending at 18 UTC on 7 January, 2014 (NOHRSC).

Figure 12: 500 hPa low (black L) track, surface low (blue) track, area receiving greater than 6 inches of snowfall (magenta), surface frontal analyses valid at 06 UTC and 21 UTC on 5 February (the most intense point for each surface low).

Figure 13: Total observed snowfall for the 72 hour period ending at 12 UTC on 6 February, 2014 (NOHRSC).

Figure 14: 500 hPa low track (black), surface low pressure tracks (cyan and orange), approximate area receiving greater than 4 inch snowfall (magenta), surface frontal analyses valid at 18 UTC on 11 May and 00 UTC on 12 May, 2014.

Figure 15: Total observed snowfall for the 72 hour period ending at 12 UTC on 13 May, 2014 (NOHRSC).

Figures:

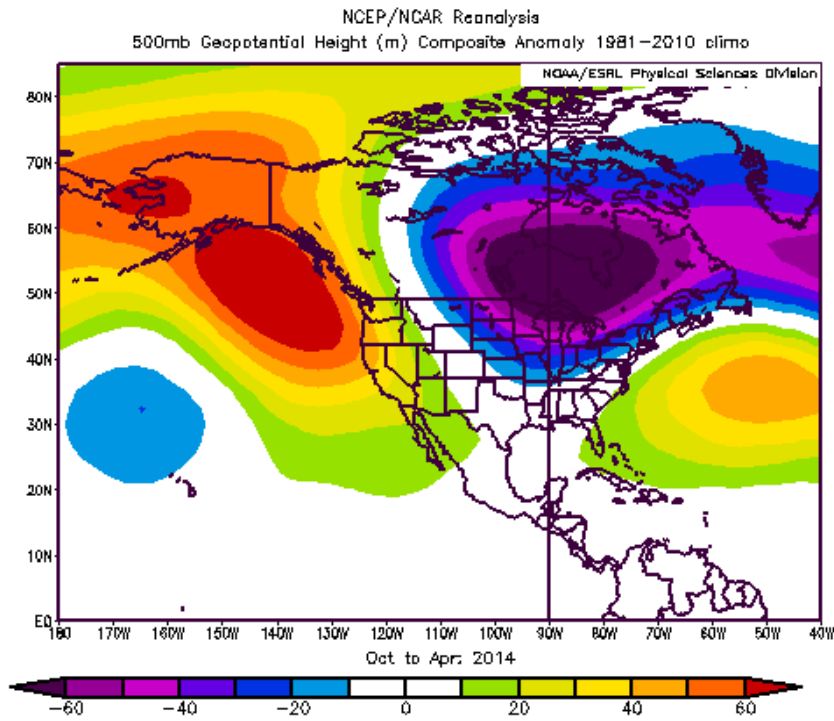


Figure 1: 500 hPa geopotential height composite anomalies for the period of October 2013 to April 2014 (Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at <http://www.esrl.noaa.gov/psd/>).

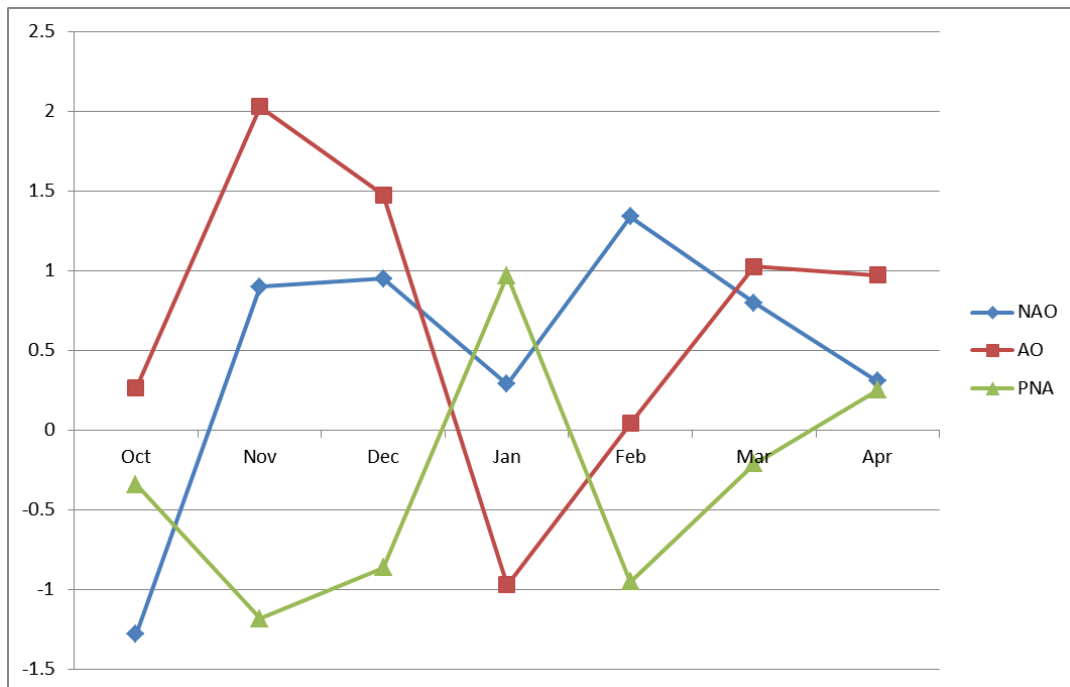


Figure 2: The North Atlantic Oscillation (NAO), Arctic Oscillation (AO), and Pacific-North America Index values from October 2013 to April 2014 (CPC).

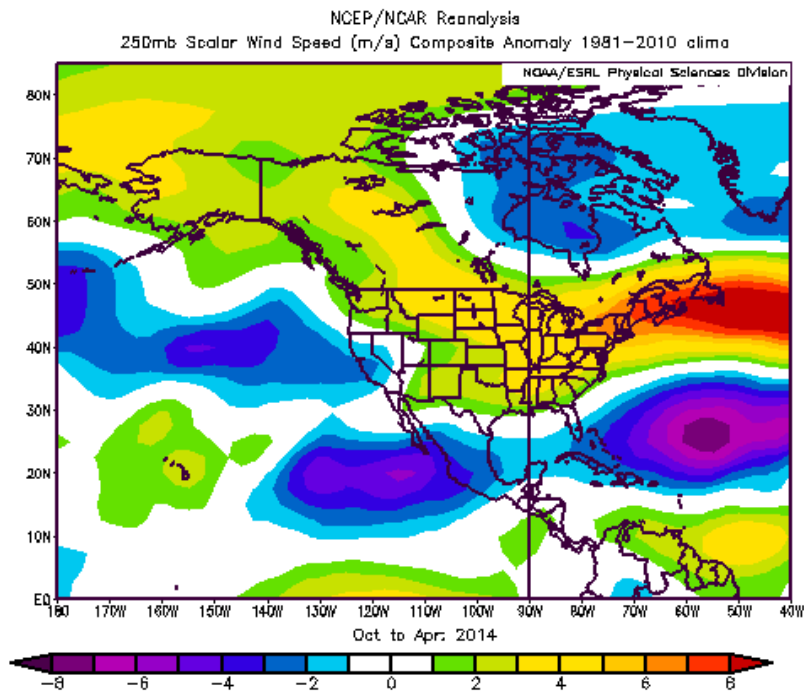


Figure 3: 250 hPa wind speed composite anomalies for the period from October 2013 to April 2014 (Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at <http://www.esrl.noaa.gov/psd/>).

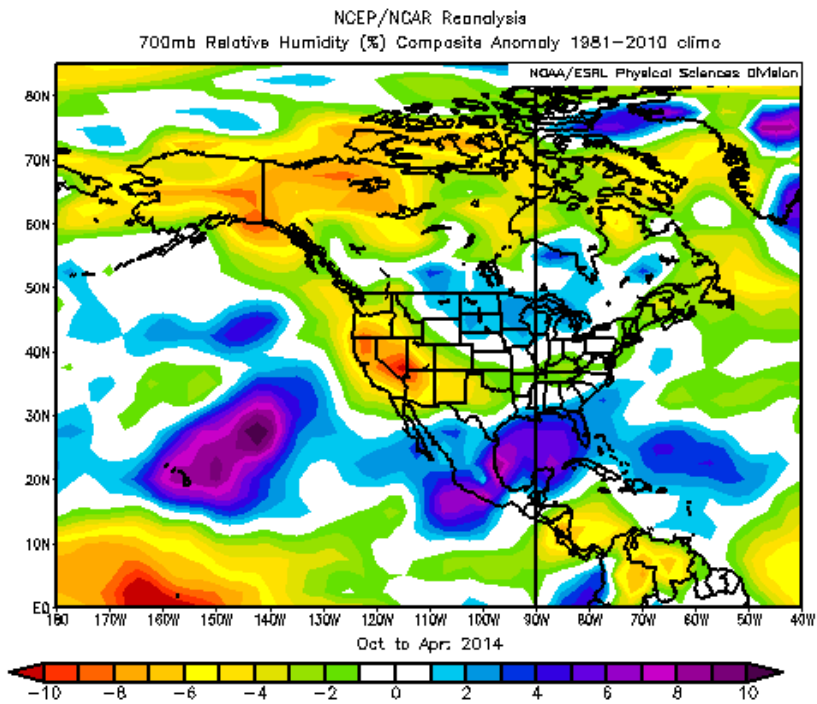


Figure 4: 700 hPa relative humidity (%) composite anomalies for the period from October 2013 to April 2014 (Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at <http://www.esrl.noaa.gov/psd/>).

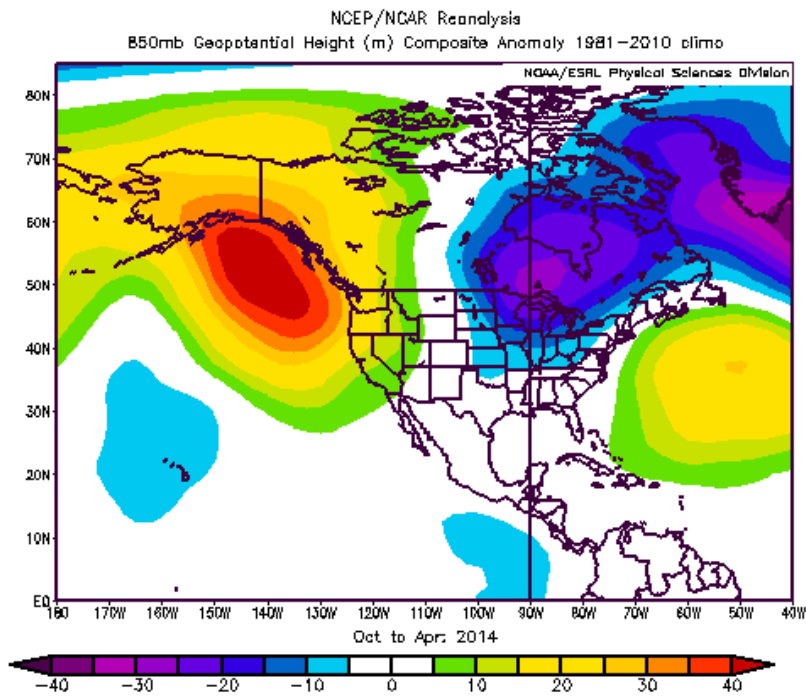


Figure 5: 850 hPa geopotential height composite anomalies for the period from October 2013 to April 2014 (Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at <http://www.esrl.noaa.gov/psd/>).

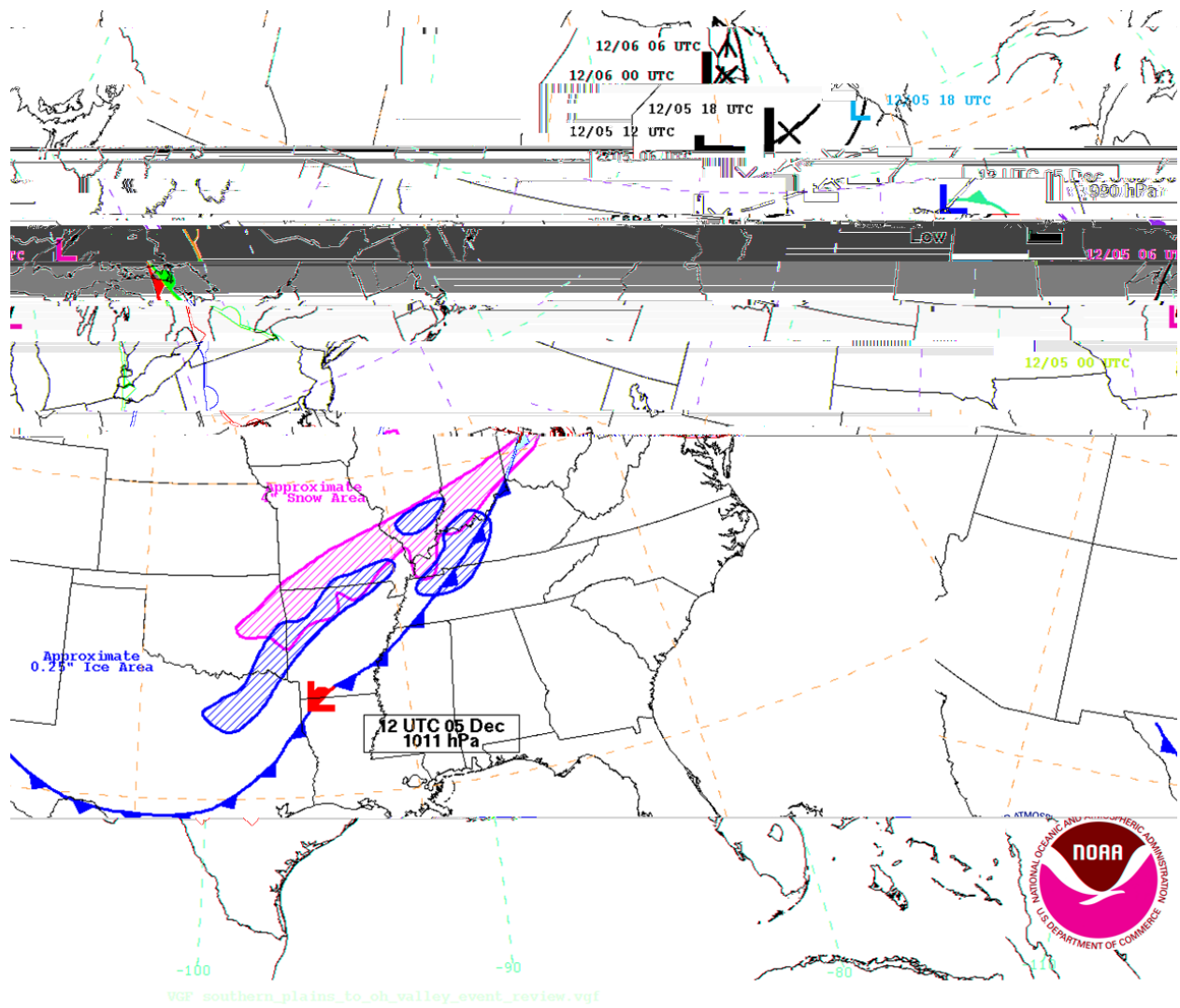


Figure 6: 500 hPa low (black L) track, surface low (blue) track, approximate area of 4 inch or greater snowfall (magenta) and 0.25 inch or greater ice (blue), surface frontal analysis valid at 12 UTC on 5 December, 2013.

Figure 7: Total observed snowfall (interpolated) during 48h preceding 12 UTC on 7 December, 2013 (NOHRSC).

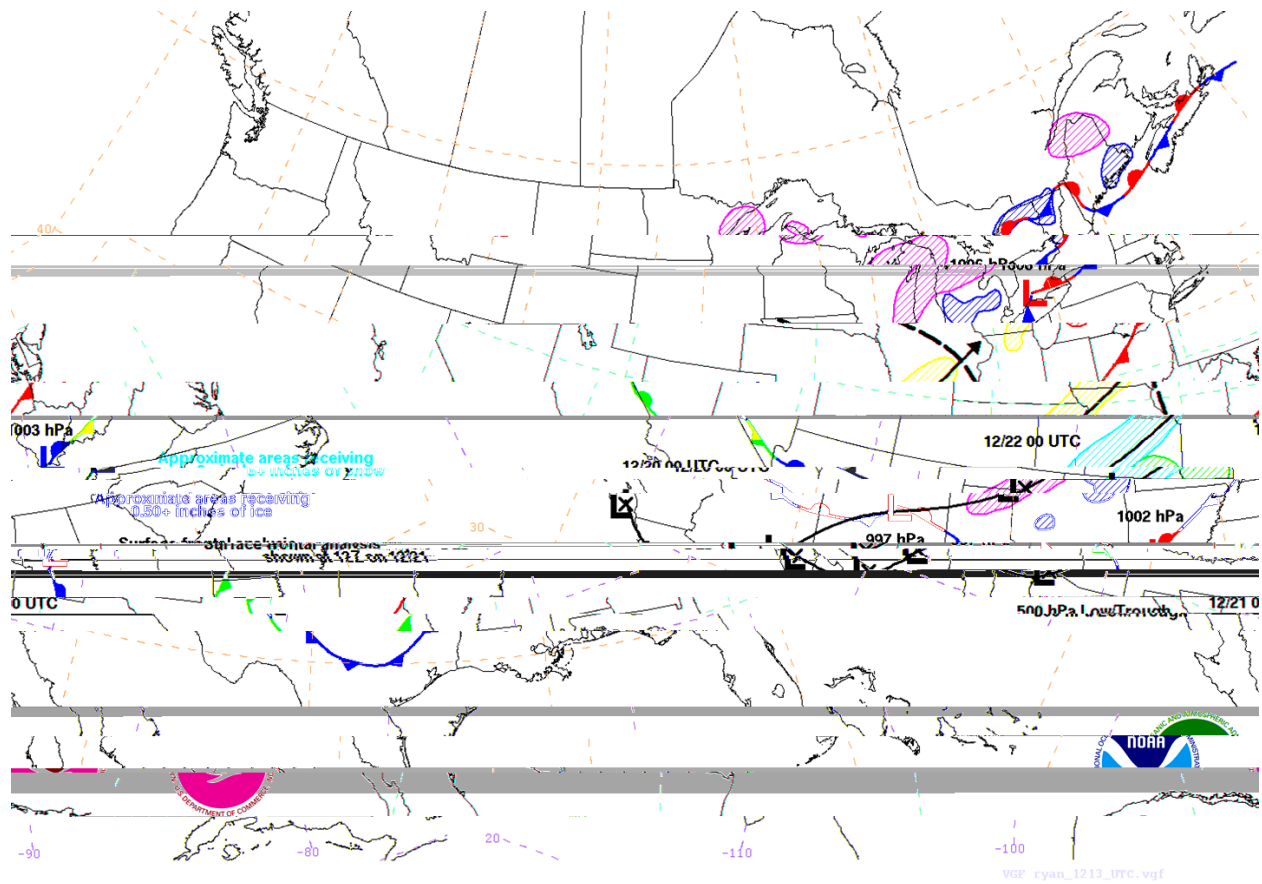


Figure 8: 500 hPa low/trough (black), approximate areas of greater than 6 inches of snow (magenta) and 0.50 inch of ice (blue). Surface analysis shown is valid at 12 UTC on 21 December, 2013.

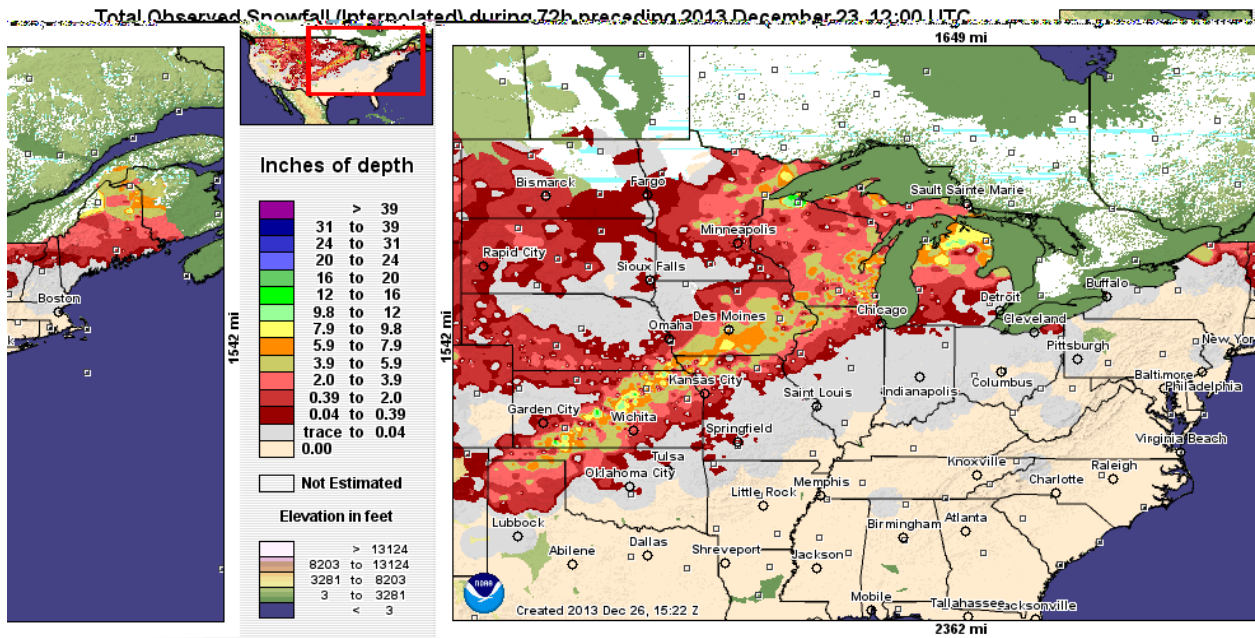


Figure 9: Total observed snowfall for the 72 hour period ending at 12 UTC on 23 December, 2013 (NOHRSC).



Figure 10: 500 hPa low track (black), surface low track (light blue), area receiving greater than 6 inches of snow (magenta), surface frontal analysis valid at 21 UTC on 5 January, 2014.

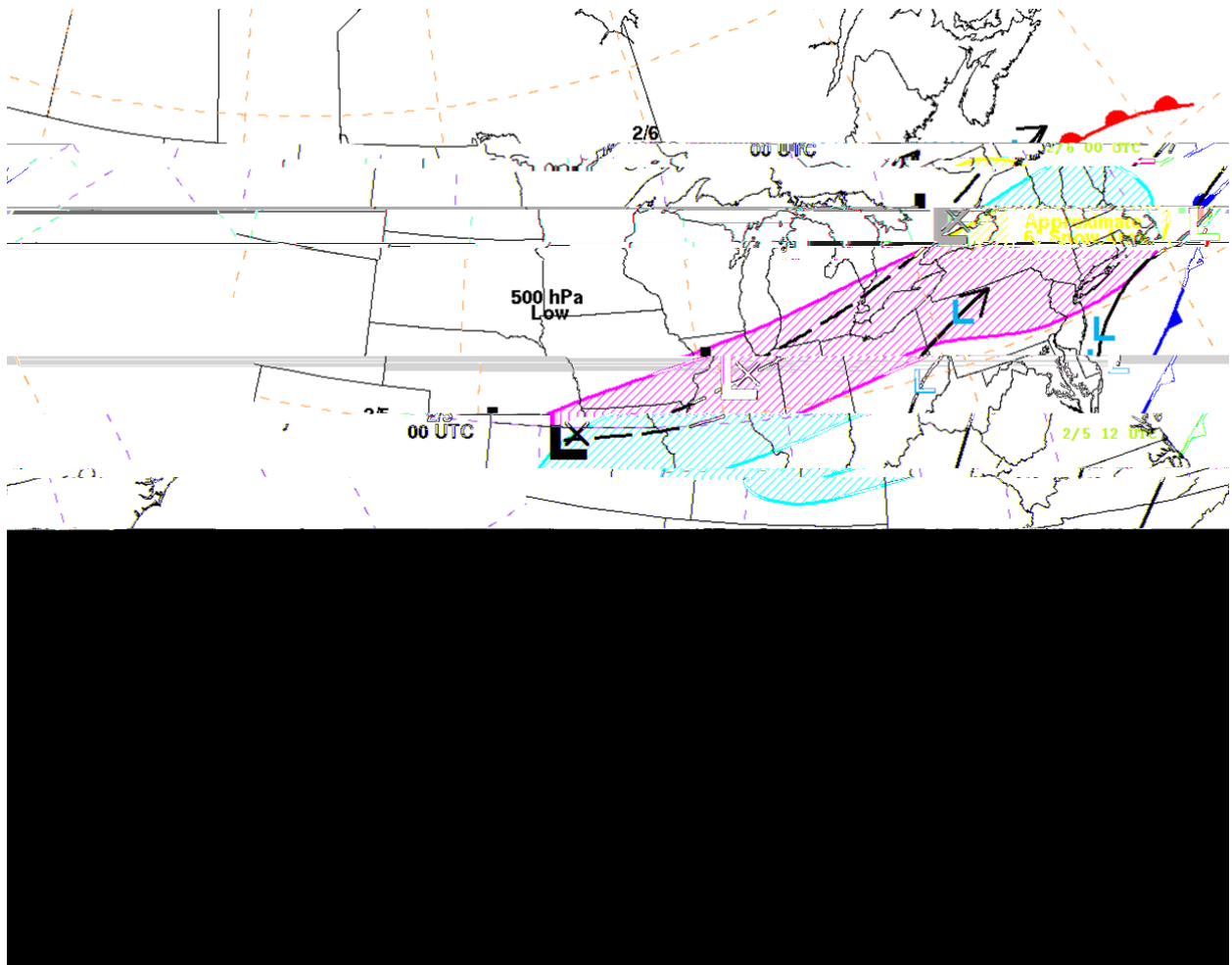


Figure 12: 500 hPa low (black L) track, surface low (blue) track, area receiving greater than 6 inches of snowfall (magenta), surface frontal analyses valid at 06 UTC and 21 UTC on 5 February (the most intense point for each surface low).

Figure 13: Total observed snowfall for the 72 hour period ending at 12 UTC on 6 February, 2014 (NOHRSC).

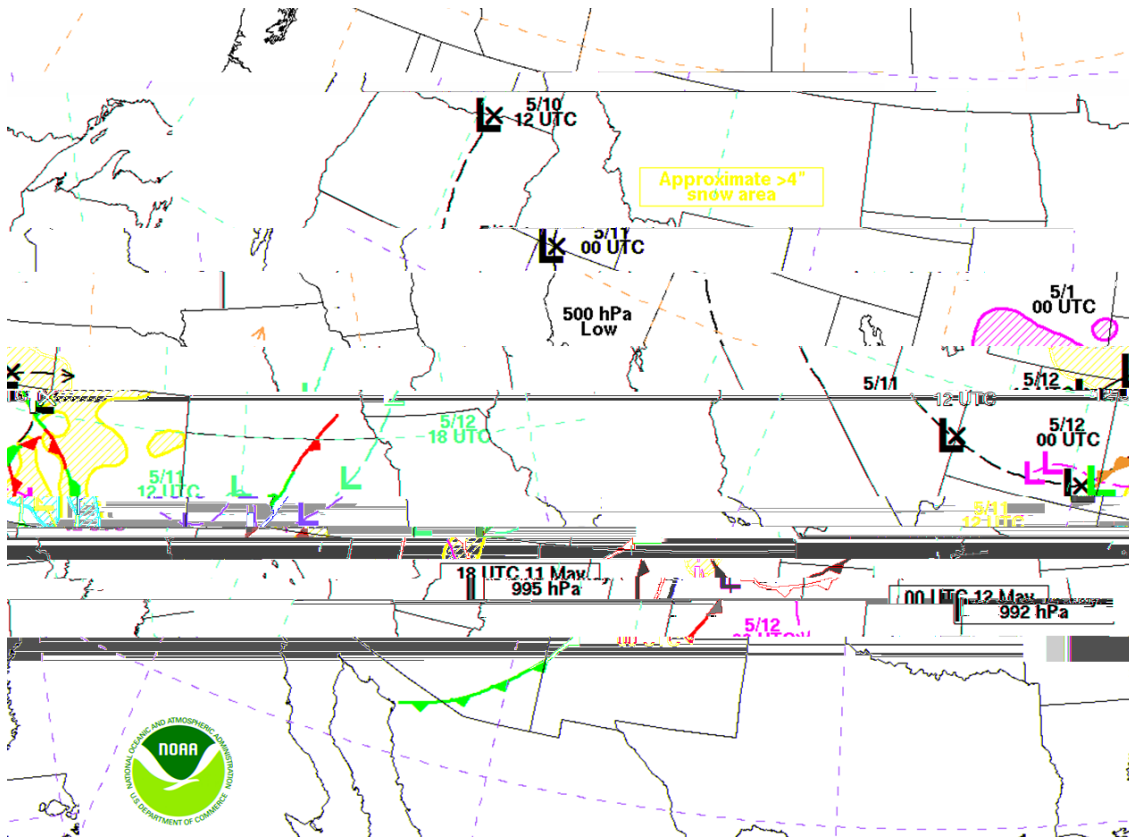


Figure 14: 500 hPa low track (black), surface low pressure tracks (cyan and orange), approximate area receiving greater than 4 inch snowfall (magenta), surface frontal analyses valid at 18 UTC on 11 May and 00 UTC on 12 May, 2014.

