

Major Winter Weather Events during the 2011-2012 Cold Season

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1 **1. Introduction**

2 Winter storms cause millions of dollars in damage and disrupt countless lives
3 across the United States every year. They directly cause an average of 24 deaths in the
4 U.S. each year (2002-2011 average), with an additional 27 deaths each year caused by
5 cold temperatures (NWS 2012). Winter storms produce a variety of precipitation
6 including snow, sleet, and freezing rain, often with high winds and extreme cold in
7 addition to the precipitation. Some parts of the U.S. are more prepared than others, and
8 thus the impact of winter storms varies widely by region. Winter storm activity varies
9 widely from year to year, in connection with large-scale atmospheric phenomena such as
10 the North Atlantic Oscillation (NAO), Arctic Oscillation (AO), and El Nino-Southern
11 Oscillation (ENSO).

12 Because winter storms cover spatial scales much larger than that of an individual
13 NWS office, WPC is positioned well to provide guidance on these storms. One role of the
14 WPC is to provide winter storm specific forecasts for the U.S. These include quantitative
15 precipitation forecasts (QPF), low-tracks, and probabilistic heavy precipitation (rain,
16 snow, freezing rain) forecasts.

17 The WPC issues Storm Summary products for high-impact winter weather events
18 that affect multiple NWS county warning areas, affect commerce and transportation, and
19 are likely to attract media attention. Storm summaries contain information on the current
20 location and intensity of a storm system, a summary of rain and snowfall accumulations,
21 and a short term forecast for the storm system. The purpose of this article is to provide an
22 overview of the 2011-2012 cold season and the season's most notable winter weather
23 events for which the WPC issued storm summaries. For the purposes of this article, the

24 cold season is defined as September 15 - May 15. These dates align with the dates that
25 the Winter Weather Desk at the NOAA/NWS Weather Prediction Center (WPC) is
26 active.

27 Section two of the article describes the data used for the images in the article.
28 Section three of the article provides an overview of the large scale patterns that affected
29 North America during the cold season. Climatological anomalies are examined, with the
30 goal being to show that the 2011-2012 cold season deviated substantially from
31 climatological averages. Section four of the article discusses the individual details of the
32 most significant winter storms of the cold season. Finally, conclusions are given in
33 section five.

34 **2. Datasets**

35 NCEP Reanalysis data (Kalnay et al. 1996) were used to create the seasonal and
36 monthly anomaly graphics shown in section three. Snowfall analyses shown are
37 interpolated snow analyses from the National Operational Hydrologic Remote Sensing
38 Center (NOHRSC). The NOHRSC analyses are created using observed snowfall data
39 received in SHEF (Standard Hydrometeorological Exchange Format) over AWIPS II
40 (Advanced Weather Interactive Processing System II) (NOHRSC 2005). The data are
41 then interpolated temporally using preprocessed RADAR (Radio Detection and Ranging)
42 data (Stage II) as well as spatially using a weighting function (NOHRSC 2005). Snowfall
43 data are not interpolated above 1640 feet in elevation in the eastern U.S. and above 5741
44 feet in the western U.S. In northern Idaho, Washington, and Oregon snowfall data are not
45 interpolated above 2625 feet. For further details on the data assimilation and interpolation
46 schemes used in the NOHRSC snowfall analyses the reader is referred to NOHRSC 2005.

47 **3. Seasonal Overview**

48 The cold season of 2011-2012 was quite unique, with significant climatological
49 anomalies across the majority of the contiguous U.S. (CONUS). Additionally, the cold
50 season was ‘book-ended’ by the two most notable winter storms of the season for the
51 Eastern U.S., in October and April. From 15 September, 2011 to 15 May, 2012, the WPC
52 issued Storm Summaries for seven notable winter storms across the CONUS. Table 1
53 provides an overview of these events, the dates they occurred, the impacts, and any
54 deaths or injuries directly attributed to the events. For most of the cold season, the
55 majority of the contiguous U.S. received anomalously low snowfall, along with
56 anomalously warm temperatures. Several climatological factors may have contributed to
57 the anomalous season, including a La Niña in the Pacific, as well as a strongly positive
58 North Atlantic Oscillation (NAO)/Arctic Oscillation (AO).

59 Average climatological anomalies for the cold season (Fig. 1) show substantial
60 deviations from climatological averages. 250 hPa wind speed anomalies (Fig. 1a) show a
61 pattern in which the upper-level jet stream was displaced to the north of its typical
62 location. Positive 250 hPa wind speed anomalies were observed across the Pacific
63 Northwest and across most of Canada, while negative anomalies were observed across
64 the majority of the CONUS. 500 hPa geopotential height anomalies for the same time
65 period (Fig. 1b) show an anomalous upper-level ridge centered across the Great Lakes. A
66 blocking pattern was dominant in the North Pacific during the season, with an anomalous
67 500 hPa low centered over Alaska and an anomalous high centered over the northern
68 Pacific Ocean, between Alaska and Hawaii. Seasonal temperature anomalies at 1000 hPa
69 for October through April (Fig. 1c) were positive across the majority of the CONUS. The

70 positive anomalies were maximized across the north central U.S., where positive
71 temperature anomalies of greater than 4 degrees C were noted at 1000 hPa. Finally, sea-
72 level pressure anomalies (Fig. 1d) show negative anomalies across Alaska and into most
73 of Canada, as well as the north central U.S. into the Great Lakes. These areas of negative
74 sea-level pressure anomalies are likely areas with a larger than average number of surface
75 lows tracking across them. Conversely, the positive sea-level pressure anomalies shown
76 across portions of the U.S. West Coast, as well as off the East Coast, indicate below
77 average surface low activity. As was shown by the 250 hPa wind speed anomalies, the
78 sea-level pressure anomalies also depict a dominant seasonal pattern in which storm
79 tracks were largely shifted north of climatological mean locations. Additionally, cyclone
80 activity along the U.S. east coast was substantially below average. Surface low tracks for
81 the season (Fig. 2) were largely focused across the central U.S., with only two major
82 episodes of cyclogenesis along the U.S. East Coast.

83 The NAO and the AO (Barnston and Livezey, 1987; Thompson and Wallace,
84 1998) remained in the positive phase for most of the cold season (Fig. 3), as indicated by
85 an anomalous low at 500 hPa across Greenland in the seasonal anomalies (Fig. 1b), with
86 an anomalously strong Azores high. The abnormally warm temperatures resulted in
87 below average snow depth across much of the nation. An image showing the snow depth
88 departure from normal on 31 January, 2012 (Fig. 4) shows that the majority of the
89 CONUS was experiencing below average snow depth, even during the climatologically
90 coldest month of the year. Seasonal outgoing longwave radiation (OLR) anomalies (Fig.
91 5) indicate above average OLR across a substantial portion of the nation, which
92 corresponds to below average precipitation (Liebmann et al. 1989). Seasonal correlations

93 using data back to 1949 (Fig. 6) demonstrate that above average temperatures and below
94 average 700 hPa relative humidity (and subsequent precipitation) across much of the
95 contiguous U.S. are both consistent with a strongly positive NAO/AO.

96 **4. Individual Event Summaries**

97 *a. Early-Season Mid-Atlantic and Northeast Winter Storm (29-30 October, 2011)*

98 1) Meteorological Overview

99 An October Nor'easter struck portions of the Mid-Atlantic and Northeast U.S. on
100 29-30 October, 2011. A surface low developed off the coast of the Carolinas on 29
101 October as a strong upper-level shortwave trough moved through the Ohio River Valley.
102 The surface low rapidly deepened and moved up the coast as the upper trough
103 approached the East Coast and became negatively tilted.

104 Precipitation began falling across the Mid-Atlantic states during the early morning
105 hours of 29 October in association with warm air advection east and north of the
106 developing low. Initially, the precipitation fell as snow only at the higher elevations,
107 well-inland. As the surface low moved northward up the coast, winds at the surface
108 backed from northeasterly to northwesterly across much of the Mid-Atlantic region,
109 allowing colder air to advect southeastward. This cold air advection changed the
110 precipitation from rain to snow in the foothills of Virginia, Maryland, and Pennsylvania.
111 Cooling of the atmospheric thermal profile as a result of melting in the bands of heavier
112 precipitation (Kain et al. 2000) likely accelerated the changeover to snow across the Mid-
113 Atlantic region. Farther north, precipitation began across New England by midday on 29
114 October. Cold air was already in place across interior New England, therefore
115 precipitation began as snow for all but the coastal areas.

116 Early in the event, a coastal front extended from the Virginia coast northward to
117 Cape Cod. This boundary weakened and was no longer analyzed in the WPC surface
118 analysis by 21 UTC on 29 October. A surface analysis from 00 UTC on 30 October (Fig.
119 7a) shows the surface low centered off the coast of New Jersey, with a pressure of 993
120 hPa. Isentropic ascent, as moisture from lower latitudes streamed northward and crossed
121 this coastal front may have enhanced precipitation in some areas. As the intensifying
122 surface low passed east of New England, wind gusts of more than 50 mph were recorded
123 along the coast. The highest wind gust of 69 mph was measured at Nantucket, MA. By 12
124 UTC on 30 October (not shown) the surface low had deepened to 977 hPa south of Nova
125 Scotia. The surface low reached its peak intensity of 976 hPa at 15 UTC on 30 October
126 just east of the southern tip of Nova Scotia.

127 Total snowfall exceeded a foot in areas from northeastern Pennsylvania to
128 southern Maine, with some areas of Massachusetts and New Hampshire receiving more
129 than 30 inches of snow (Fig. 7b). The heaviest snow was associated with intense 850-700
130 hPa warm frontogenesis, north of the surface low. Several snowfall records were broken
131 across the region, including in Central Park, NY, where the 2.9" accumulation was an all-
132 time snowfall record for the month of October.

133 2) Impacts

134 Because trees in many areas of the Mid-Atlantic and Northeast had not yet lost all
135 their leaves, many trees were downed, resulting in downed power lines and loss of power
136 for more than 3 million residents. Some locations were without power more than a week
137 after the storm ended. The storm resulted in one direct fatality due to a fallen tree (NWS
138 Storm Data). Additionally, air travel was severely disrupted with several planes stranded

139 on the tarmac at the Hartford airport for an extended period of time. Total reported
140 damage from the storm amounted to \$18.8 million from a combination of heavy snow,
141 high wind, and coastal flooding (NWS Storm Data).

142 *b. Eastern U.S. Heavy Rain and Snow (28-29 November, 2011)*

143 1) Meteorological Overview

144 A slow-moving low pressure system brought a rare November snowfall to the
145 central Mississippi River valley. Prior to the event on 26 November, a north-south
146 oriented cold front and a high amplitude upper-level trough moved eastward across the
147 Mississippi River valley. Upper-level flow was aligned nearly parallel to the lower levels,
148 therefore the eastward progression of the frontal boundary was rather slow. A ridge of
149 high pressure at the surface and aloft across the southeastern states, hindered the progress
150 of the front. The front was associated with a wide swath of rain from the onset. As time
151 progressed, energy became more consolidated near the base of the upper-level trough as
152 cyclogenesis commenced in the evening of 27 November over the southeastern U.S. The
153 cyclone quickly became occluded as the upper-level cut-off low deepened, while moving
154 generally northward into the Tennessee River valley by 00 UTC on 29 November (Fig.
155 8a). By early on 29 November, the core of the cold air associated with the upper-level
156 low began changing the rain to snow in the central Mississippi River valley on the back
157 side of the surface cyclone. After the snow ended the morning of 29 November, a few
158 inches of snow had accumulated in parts of northeastern Arkansas and southeastern
159 Missouri (Fig. 8b), with the highest amount of 8 inches reported at Paragould, Arkansas.
160 After delivering a rare snowfall in the central Mississippi River valley, the storm
161 continued north into the Ohio River valley on 29 November.

162 As the occluded cyclone continued moving northward, cold air advection from the
163 northwest during the afternoon of 29 November caused the rain across Lower Michigan
164 and northern Indiana to change to snow. In addition, a mesoscale band of snow organized
165 on the west side of the cyclone during the night, bringing a brief period of heavy snow
166 across the central portion of Lower Michigan where over 6 inches of snow were reported
167 (Fig. 8a). The highest amount was 9.0 inches in Lansing, MI.

168 2) Impacts

169 There were no known casualties and injuries directly related to the storm. Total
170 reported damage for the storm amounted to \$25 thousand from flooding in Arkansas and
171 Kentucky (NWS Storm Data).

172 *c. Southern Rockies to Central Plains Winter Storm (19-20 December, 2011)*

173 1) Meteorological Overview

174 A classic cut-off low drifted eastward across the southwestern U.S. then moved
175 northeastward toward the southern plains on 19-20 December, 2011. This upper low was
176 associated with a significant snowstorm accompanied by blizzard conditions in parts of
177 the south central and southwestern U.S. As the system moved northeastward, it
178 encountered milder temperatures, and became more of a rain producer from Kansas into
179 the Mississippi River valley and the Midwest.

180 Heavy snow was accompanied by strong winds which created blizzard conditions
181 in some locations. Clayton, NM, in the northeast corner of the state, reported 17.7 inches
182 on 19-20 December. Lamar, CO received 19.0 inches of snow on 20 December and set a
183 new record as the highest one-day snowfall total for any day in December. Total snowfall
184 (Fig. 9) shows widespread areas of greater than 12 inches. Additionally, snow drifts of 2

185 to 4 feet were reported. On the eastern fringes of the heavy snow swath, a mixture of rain,
186 sleet, and snow occurred in portions of central and south central Kansas creating some
187 slick and slushy spots on roads. The slow-moving low pressure system also produced
188 rainfall amounts of generally 1.5 to 2.5 inches across much of south central and
189 southeastern Kansas.

190 Surface analyses superimposed on satellite images on 19 December show the
191 distinct comma-shaped swirl of clouds associated with the developing storm, as an area
192 of surface low pressure consolidated over the panhandle of northern Texas to the south of
193 a sprawling area of high pressure moving eastward from the northern Rockies toward the
194 northern plains states (Fig. 10).

195 2) Impacts

196 For southeastern Colorado, northeastern New Mexico and western Kansas, this
197 was a debilitating snowstorm with high winds, low visibility and blowing snow, stranding
198 motorists at the start of the long holiday travel season. The primary impact of the storm
199 was to transportation. Total reported damage from the storm was \$53 thousand in New
200 Mexico, from heavy snow and blizzard conditions (NWS Storm Data). No known direct
201 fatalities or injuries were attributed to this storm.

202 *d. Western U.S. Winter Storm (14-20 January, 2012)*

203 1) Meteorological Overview

204 The period from 14-20 January was marked by numerous upper-level
205 disturbances along with an Arctic air outbreak over the northwestern U.S, which peaked
206 with historic snowstorms and ice storms over Washington State. The period began with a
207 shortwave trough embedded within the fast onshore flow to the south of an upper low

208 moving toward British Columbia. The shortwave moved southeastward through the
209 Pacific Northwest and helped to usher one of the coldest air masses of the season into the
210 region, in addition to producing snow showers across western Washington and Oregon.
211 Heavy snows were reported in the Olympic and Cascade Mountains, as well as some
212 lighter snows in the lower lying regions surrounding the Seattle-Tacoma metropolitan
213 region. A surface analysis from 00 UTC on 15 January (Fig. 11a) shows the cold air mass
214 advecting into the region.

215 The upper-level low and trough continued to move inland from 12 UTC on 15
216 January to 12 UTC on 16 January, with the leading edge of the associated low level cold
217 air plunging southeastward through the central Great Basin and Rocky Mountains.
218 Precipitation across the Pacific Northwest tapered off the morning of 16 January, with
219 scattered light precipitation advancing through the northern Rockies. Heavy snows
220 returned to the region including the Washington and Oregon coastal ranges and the
221 western slopes of the Cascades by the evening of 16 January as another shortwave trough
222 approached the coast. This shortwave along with a strong upper-level jet pushed across
223 the Pacific Northwest from 17-18 January, accompanied by a plume of subtropical
224 moisture. This moisture overrunning the preexisting cold air left in place by the previous
225 system resulted in heavy to near record snow amounts across portions of western
226 Washington. 11 inches of snow at the Olympia, WA airport and nearly 7 inches at the
227 Seattle-Tacoma International Airport on 18 January were the third and sixth highest,
228 respectively, on record. Up to 2 feet of snow occurred in the Oregon Coastal Range.
229 Heavy snows of near-record to record values were also reported further to the east across

230 the Blue Mountains in eastern Oregon and the Sawtooth and Bitterroot Ranges into the
231 northern Rockies.

232 As this system continued to the east from 12 UTC on 18 January to 12 UTC on 19
233 January the low level cold air over western Washington was reinforced by continued
234 precipitation and northerly flow at the surface. This set the stage for a historic freezing
235 rain event over western Washington, with a first ever ice storm warning for the region.
236 Ice accumulations of 0.5 to 0.75 inch were reported in the Seattle-Tacoma metropolitan
237 region, with an inch or more reported in areas further to the south and east. Heavy snows
238 falling along the Cascades spread to the south into northern California and along the
239 Rockies into the Tetons and northern Wasatch Mountains. Arctic high pressure at the
240 surface settled south through the northern Plains with the Arctic front banking up against
241 the eastern slopes of the northern Rockies (Fig. 11b). High winds were recorded across
242 and east of the mountains with gusts of up to 100 mph reported.

243 These systems impacted much of the northwestern U.S. with a combination of
244 heavy snow, rain, and ice. Snows from these storms (Fig. 12) covered areas from the
245 Pacific Northwest to the northern Plains. By 12 UTC on 20 January, 2 to 5 feet of snow
246 had been reported across the Cascades with the heaviest amounts centered near the
247 Mount Hood region. Over the northern Rockies, widespread accumulations of 1 to 3 feet
248 of snow were recorded, with the heaviest amounts falling along the Sawtooth Range
249 where 3 to 6 foot amounts were common and totals as high as 70 inches were reported.
250 Widespread rains of 3 to 6 inches with local amounts of 9 inches were observed along the
251 Northern California coast. Rainfall amounts as high as 15 inches were reported along the
252 Oregon coast. Freezing rain accumulations of 0.25 to 1 inch were reported across the

253 Columbia River Gorge east of Portland, with similar amounts observed across the
254 Seattle-Tacoma metropolitan area.

255 2) Impacts

256 Over 300 flights at SeaTac Airport were cancelled, costing the airline industry
257 millions of dollars. Total reported damage from this event amounted to \$24.5 million.
258 Three deaths and four injuries were directly attributed to the storm. Two of the deaths
259 occurred in Oregon when a car was swept into a swollen creek. One death and one injury
260 occurred in Washington, both the result of fallen trees under the weight of heavy ice.
261 Three injuries were also documented in Nevada as a result of trees blown down from
262 high winds associated with the storm system (NWS Storm Data).

263 *e. Central U.S. Winter Storm (3-4 February, 2012)*

264 1) Meteorological Overview

265 On 3-4 February 2012, a strong upper-level disturbance in the subtropical jet
266 stream resulted in a major winter storm over the central Front Range of the Rocky
267 Mountains and adjacent High Plains. Surface analyses at the height of the event on the
268 evening of the 3 February were indicative of a classic upslope snow event with strong
269 easterly winds on the north side of a strong surface low positioned over Oklahoma (Fig.
270 13b). An inverted trough from the low over the central Plains acted as another forcing
271 mechanism for the snow that fell over Kansas and especially south central Nebraska. At
272 500 hPa, a closed low was evident over eastern Colorado and the western parts of Kansas
273 and Nebraska, aiding in mid-level frontogenesis and ascent. A ridge of Canadian high
274 pressure over the northern Rockies and northern Plains reinforced the cold air advection.

275 Farther to the east over the Middle Mississippi River Valley, temperatures were
276 considerably warmer and rain was observed.

277 The greatest snowfall amounts (Fig. 13a) were concentrated in an area extending from
278 near Laramie, Wyoming to the Colorado foothills, and also east of Denver. There were a
279 few isolated reports of snow in the 3 to 4 feet range in the Colorado foothills from this
280 event, including 48 inches at Black Hawk, 46 inches at Pinecliffe, 37.7 inches at
281 Jamestown, and 36 inches at Evergreen. Over the state of Nebraska, a band of lighter but
282 still significant snowfall fell from North Platte eastward to near Omaha, with a localized
283 enhanced area of snow just to the north of North Platte. Winds gusted up to 40 mph over
284 the open plains of eastern Colorado and Nebraska.

285 2) Impacts

286 This snowstorm had significant impacts on transportation in the affected areas.
287 Interstate 70 was closed from Denver to the Kansas state line as heavy snow and strong
288 winds prevented snow removal crews from keeping the road adequately clear of snow.
289 About 600 flights were canceled in Denver as a result of the heavy snow in that region. In
290 Nebraska, the Interstate 80 corridor was most affected. The wet and compact nature of
291 the snow was enough to break large limbs and these frequently fell onto power lines,
292 causing over 15,000 people to lose power. There were no deaths or injuries directly
293 attributed to this storm. Total reported damage from this storm amounted to \$693
294 thousand, however this was primarily from flooding associated with the storm system
295 that occurred across the Southern Plains/Lower Mississippi River Valley, and not from
296 the winter storm (NWS Storm Data).

297 *f. Upper Midwest to New England Winter Storm (28 February - 1 March, 2012)*

298 1) Meteorological Overview

299 A significant winter storm impacted the north central to northeastern U.S. from 28
300 February to 1 March, 2012, producing heavy snow and blizzard conditions along with
301 minor to locally moderate accumulations of sleet and freezing rain. The winter storm
302 ended up being one of the most significant storms of the 2011 to 2012 winter season for
303 the north central U.S. and occurred toward the end of what had been a very quiet winter
304 season for the region up to that point. In fact, much of the region was experiencing a
305 moderate to severe drought at the time, but the storm managed to put a dent in the
306 precipitation deficit. Central Minnesota into northern Wisconsin were hit hardest in the
307 Upper Midwest with snowfall totals topping out at 20 inches (both at Clam Lake, WI and
308 Hinckley, MN). The Northeast also experienced a significant snowstorm with storm total
309 snowfall around a foot in many locations from central New York into central New
310 England (Figure 14a). The warmer side of this storm system was responsible for
311 hundreds of severe weather reports, stretching from the central Plains into the central
312 Appalachians.

313 Synoptically, the storm developed as a strong mid to upper level trough entered
314 the western U.S. on 28 February. At the surface, several disorganized areas of low
315 pressure consolidated into a single low pressure center during the evening of 28 February.
316 Snow began to overspread the Upper Midwest from late on 28 February into 29 February.
317 The upper-level trough translated eastward, acquiring a negative tilt at 00 UTC on 29
318 February, and closed off a mid-level center by 12 UTC on 29 February over the central
319 High Plains. The surface low subsequently continued to deepen on 29 February as it
320 tracked into Minnesota, reaching a peak intensity of 986 hPa that morning (Figure 14b),

321 while generating winds of 50 to 60 mph from portions of the Central Plains into the
322 Upper Mississippi River Valley. At the same time to the east, light to moderate snow
323 developed out ahead of a warm front into portions of the Northeast, with snowfall
324 intensity tapering off overnight. By the morning of 1 March, moderate snow began to
325 develop again as the main surface low from the Upper Midwest approached, and a
326 secondary low off developed off of the New England coast. 250 hPa winds on the
327 downwind side of the upper trough were in the 100 to 150 kt range, which helped to
328 enhance vertical motion within the left exit region of the strong upper jet and a region of
329 upper level diffluence, both directly over the regions which experienced the heaviest
330 snow. The upper trough had weakened by the time it reached the Northeast on 1 March,
331 partially explaining why the impacts on the Northeast were less intense than observed
332 over the Upper Midwest.

333 2) Impacts

334 The winter weather impacts from this storm were greatest across the Upper
335 Midwest with blizzard conditions causing widespread power outages and road closures,
336 along with the closure of numerous schools and businesses. State officials closed
337 Interstates 29 and 90 at one point during the storm due to the hazardous travel conditions.
338 State troopers reported hundreds of accidents on state highways. As less snow fell across
339 the Northeast, the impacts on school and business closures were reduced, but there were
340 many accidents attributed to blowing snow and icy roads. One fatality was directly
341 attributed to this event; a person in Minnesota died as a result of exposure to extreme
342 cold. A number of indirect injuries and fatalities also occurred due to traffic accidents

343 during the storm. Total reported damage from the event amounted to \$741 thousand from
344 the winter storm and associated high winds (NWS Storm Data).

345 *g. Late-Season Mid-Atlantic and Northeast Winter Storm (22-25 April, 2012)*

346 1) Meteorological Overview

347 Several key ingredients came together to create a favorable setup for this late-
348 season coastal storm. Shortwave energy moved into the Ohio and Tennessee valleys
349 Saturday night (00-12 UTC 22 April), while a shortwave in the subtropical jet moved
350 eastward through the northern Gulf of Mexico. A cutoff upper-level low formed over the
351 Ohio and Tennessee valleys, and the southern stream energy slowly weakened while
352 lifting east northeastward. These two systems, combined with divergence aloft from the
353 right entrance region of an upper jet and a sharp baroclinic zone set up along the Eastern
354 Seaboard, allowed a surface low to rapidly strengthen while tracking up the Carolina
355 coast by 12 UTC on 22 April (Fig. 15a). As the low deepened and tracked northward just
356 off the Mid-Atlantic coast on 22 April, an expansive area of precipitation developed from
357 North Carolina to Maine. Strong warm air advection and northerly moisture flux ahead of
358 the storm fueled bands of moderate to heavy rain along the coast.

359 The storm continued to track due north up the eastern seaboard Sunday night, and
360 by 12 UTC on 23 April, a 986 hPa surface low was analyzed near New York City (Fig.
361 15b). While the deep surface low along the coast brought gusty winds and drenching
362 rains to the coastal regions, the amplifying shortwave energy that closed off a low over
363 the Ohio River valley led to a secondary area of heavy precipitation farther inland (Fig.
364 16). The highest amounts were observed within the comma head that set up across
365 northeastern Pennsylvania and central New York. Northeasterly flow behind the storm

366 advected enough cold air to support snow in the higher elevations of the central
367 Appalachians Monday morning (12 UTC 23 April). The relatively high April sun angle
368 caused many locations to change back over to rain by Monday afternoon, however. The
369 surface low along the coast took a northwestward turn and started to slowly weaken while
370 tracking inland over New York State on 23 April. By 00 UTC on 24 April, the storm had
371 moved well into Quebec, and the strong winds and heavy precipitation over the Northeast
372 and Mid-Atlantic states had diminished. Coastal regions from North Carolina to Maine
373 reported widespread rainfall totals in excess of one inch from the event, and isolated
374 reports approaching five inches were observed across New England. New Boston, New
375 Hampshire exceeded five inches of rain, with 5.74 inches reported. Farther inland, the
376 late-season storm blanketed much of the central Appalachians with over four inches of
377 snow. A few sites over Western New York and Central Pennsylvania received over a foot
378 of snow, and one location, Laurel Summit, PA, measured 23.7 inches of snowfall.

379 2) Impacts

380 Travel was difficult throughout heavily populated cities along the I-95 corridor.
381 Travel conditions were particularly hazardous near the New England coast, where steady
382 rains combined with wind gusts of 40-50 mph. Thousands of power outages were
383 reported due to heavy wet snow falling on leafy tree branches. No reported deaths or
384 injuries were directly attributed to the storm. Total reported damage from the event
385 amounted to \$206 thousand, primarily from snow and strong winds (NWS Storm Data).

386 5. Conclusion

387 The 2011-2012 cold season featured an unusually low number of significant
388 winter precipitation events. Seven notable precipitation events were discussed in this

389 summary. The most significant winter weather events ‘book-ended’ the season, in
390 October and April. The events discussed in this summary directly caused a total of 5
391 fatalities with 4 additional injuries. A total of \$45 million in damage was attributed to
392 these events. Climatologically, the overwhelming majority of the CONUS experienced
393 well above average temperatures, with below average precipitation, for much of the
394 season. A La Niña in the Pacific as well as a positive phase of the NAO/AO for most of
395 the season may have contributed to the development and persistence of this pattern across
396 the U.S. Below average precipitation across much of the nation during the cold season
397 would set the stage for drought that would persist into the warm season across much of
398 the contiguous U.S.

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Storm Data and Unusual Weather Phenomena (www.ncdc.noaa.gov/oa/climate/sd)

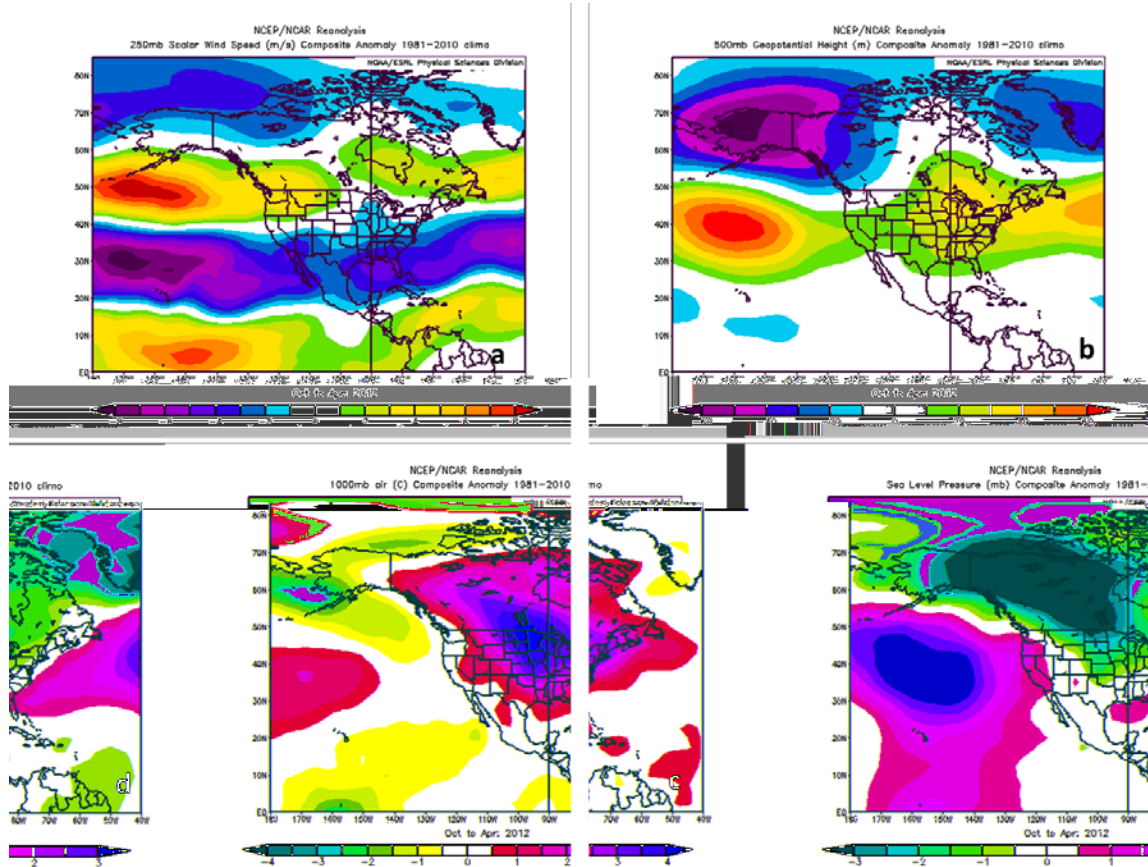
Thompson, D.W.J., J.M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geo. Res. Lett.*, **25**, 1297-1300.

Table:

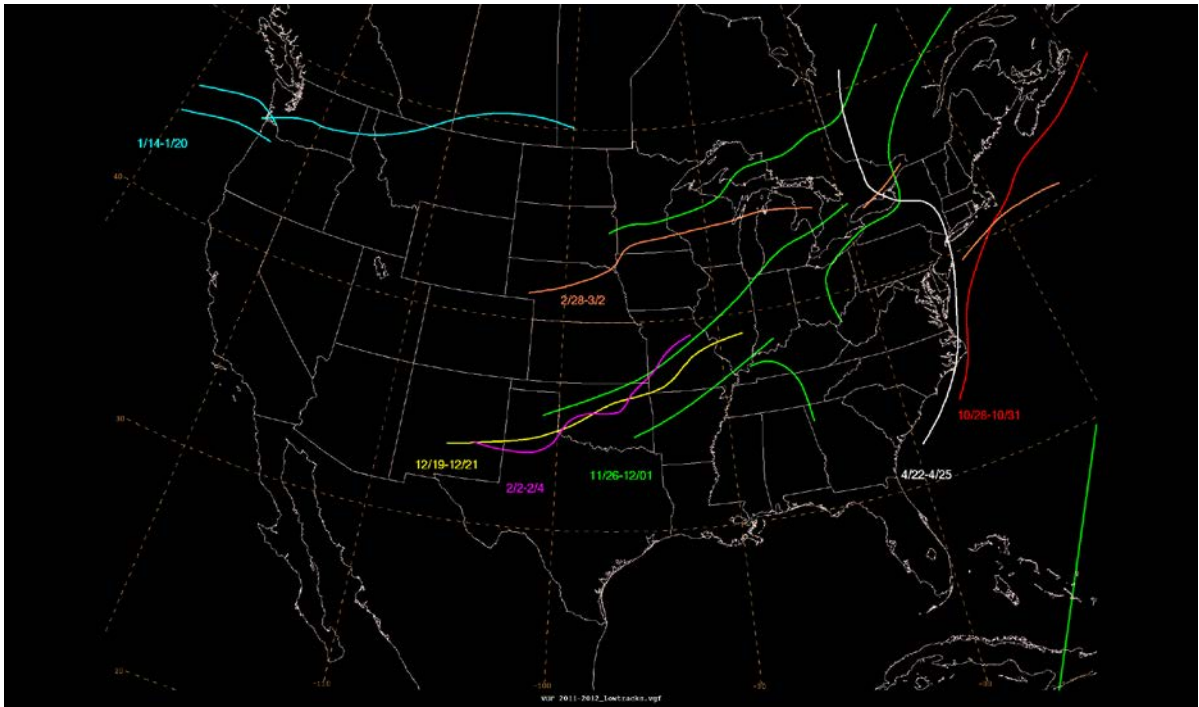
Date	Event	Impacts	Deaths/Injuries	Damage
29-30 October, 2011	Early-Season Mid-Atlantic and Northeast Winter Storm	Heavy Snow, High Wind	1/0	\$18.8 M
28-29 November, 2011	Eastern U.S. Heavy Rain and Snow	Flooding	0/0	\$25 K
19-20 December, 2011	Southern Rockies to Central Plains Winter Storm	Heavy Snow, Blizzard	0/0	\$53 K
18-20 January, 2012	Western U.S. Winter Storm	Winter Storm, Ice Storm, High Winds, Landslide, Flooding	3/4	\$24.5 M
3-4 February, 2012	Central U.S. Winter Storm	Winter Storm, Flooding	0/0	\$693 K
29 February - 2 March, 2012	Upper Midwest to New England Winter Storm	Winter Storm, Blizzard, High Winds, Cold/Wind Chill	1/0	\$741 K
23-24 April, 2012	Late-Season Mid-Atlantic and Northeast Winter Storm	Winter Storm, Lake-Effect Snow, Strong Wind	0/0	\$206 K

Table 1: Impacts, deaths/injuries, and damage amount (dollars) for the 2011-2012 Cold Season listed by event (NWS Storm Data).

Figures:



399 **Figure 1: 250 hPa wind speed anomalies (a), 500 hPa geopotential height anomalies (b), 1000 hPa air**
400 **temperature anomalies (c), and sea-level pressure anomalies (d), averaged from October 2011 to**
401 **April 2012 (NCEP Reanalysis).**

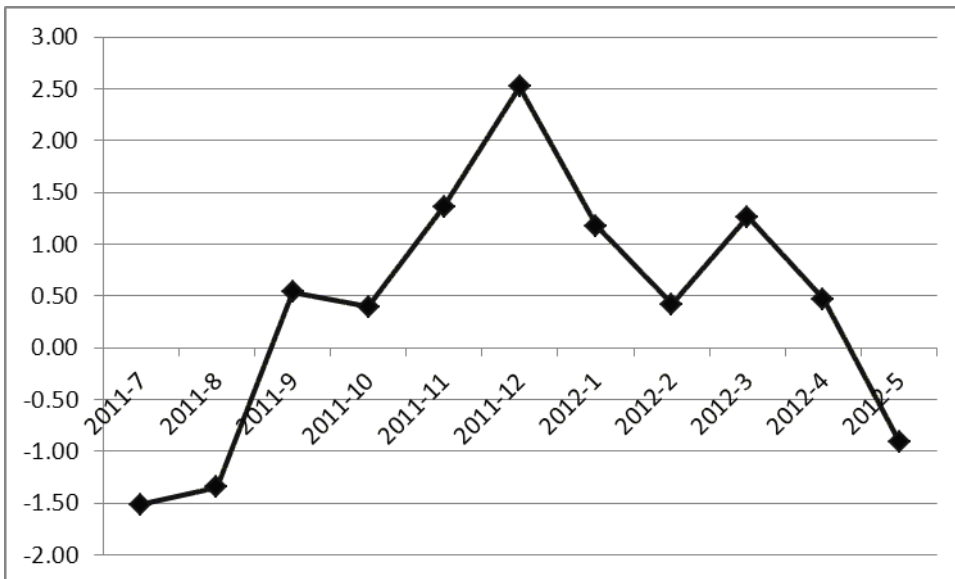


402

403 **Figure 2: Surface low tracks for all events discussed in this article. Note that some events consisted of**
 404 **multiple surface lows.**

405

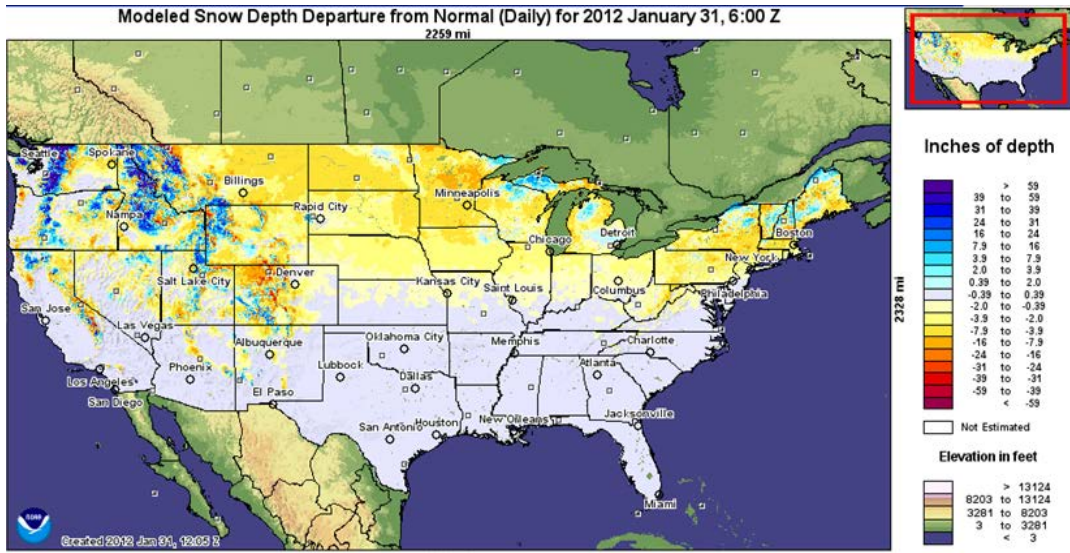
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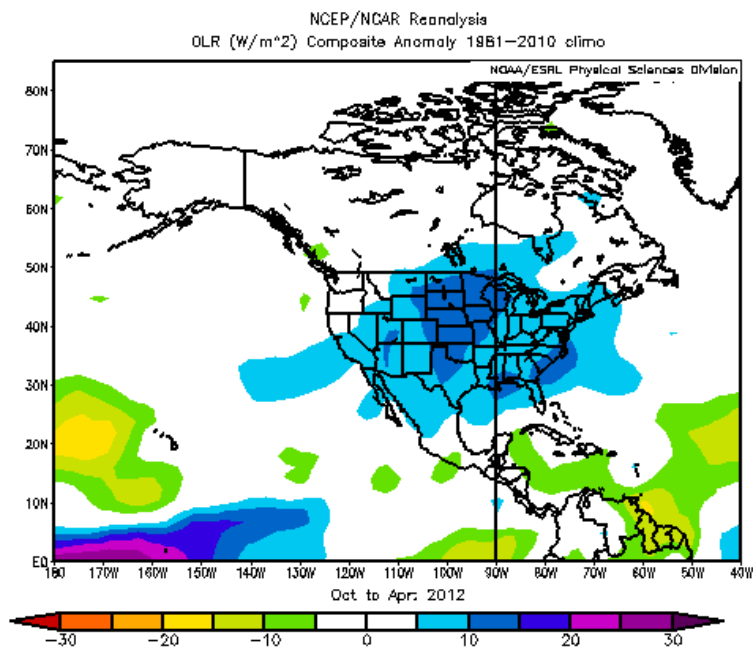
408 **Figure 3: NAO index for the months including the 2011-2012 cold season.**

409



410

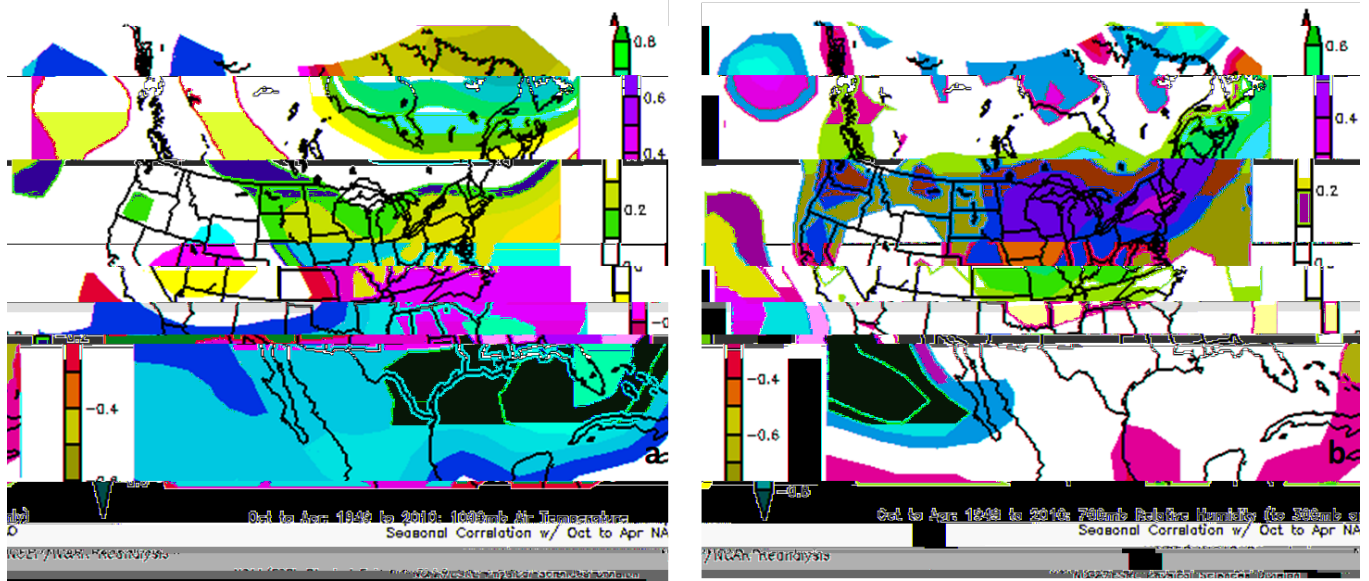
411 Figure 4: Snow depth departure from normal on 31 January, 2012 (NOHRSC).



412

413 Figure 5: Seasonal average (Oct 2011 to Apr 2012) outgoing longwave radiation (OLR) anomalies

414 (NCEP Reanalysis).



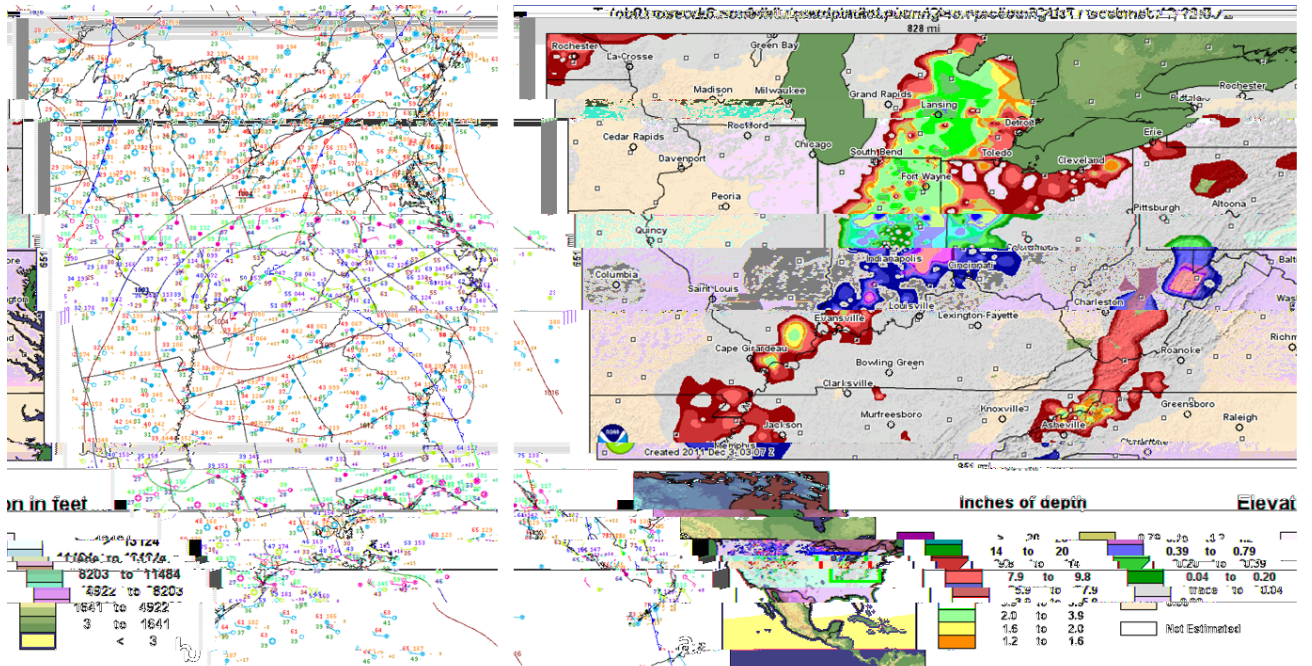
415

416 **Figure 6: Seasonal anomaly correlations (October to April) for 1000 hPa air temperature (a) and 700**
 417 **hPa relative humidity (b) with the NAO. Positive 1000 hPa temperature anomalies and negative 700**
 418 **hPa relative humidity anomalies are correlated with the positive phase of the NAO. (NCEP/NCAR**
 419 **Reanalysis)**

420

421

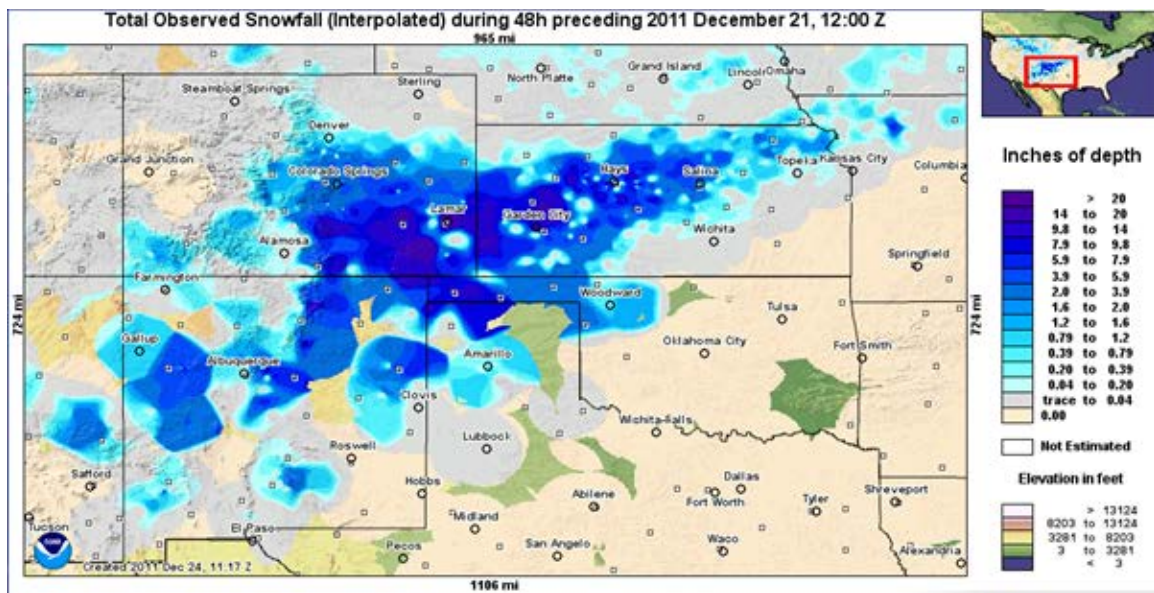
422 **Figure 7: (a) Surface analysis from 00 UTC on 30 October, 2011 (WPC/OPC) and (b) Total 48-hour**
 423 **snowfall accumulation ending at 12 UTC on 31 October, 2011 (courtesy of NOHRSC).**



424

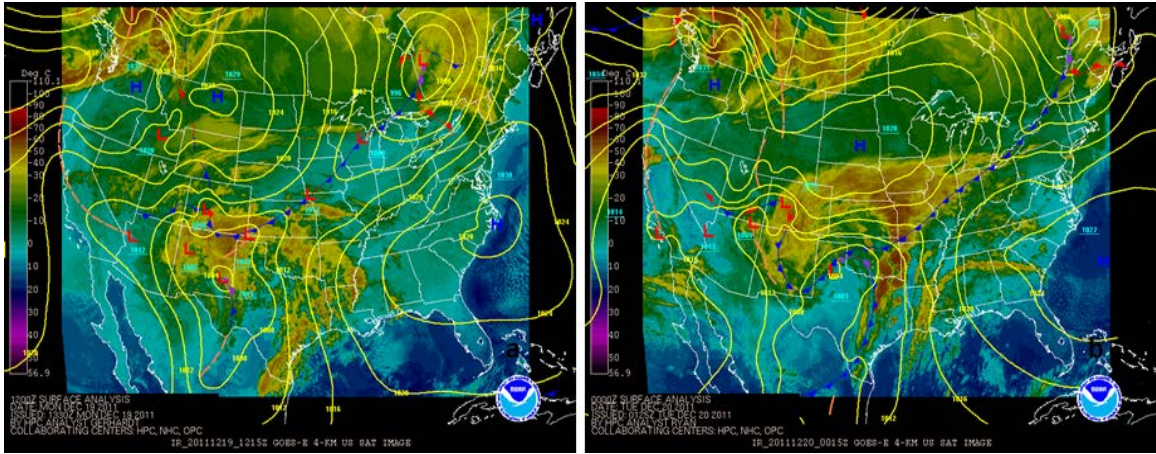
425 Figure 8: Observed 48-hour snowfall (interpolated) ending at 12 UTC on 1 December, 2011 (a)

426 (NOHRSC), and surface analysis from 00 UTC on 29 November (b).



427

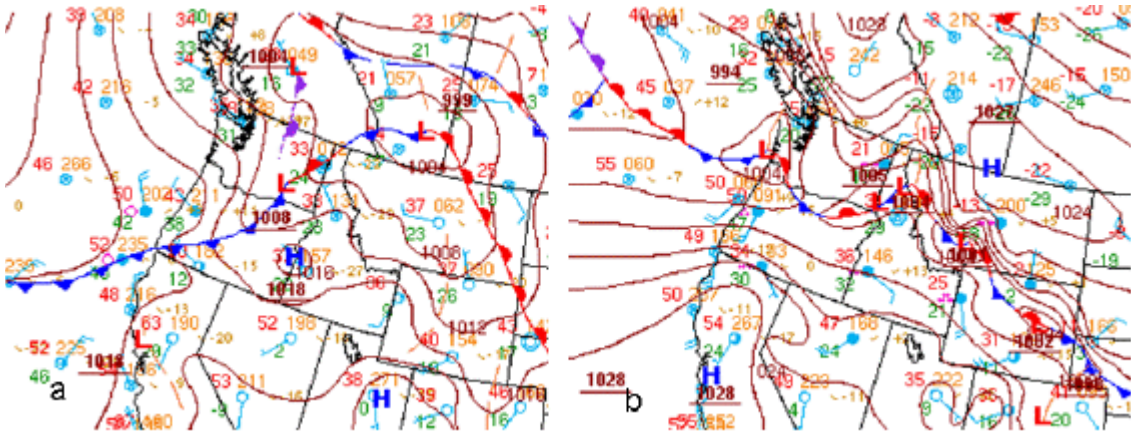
428 Figure 9: Observed 48-hour snowfall ending at 12 UTC on 21 December, 2011.



429

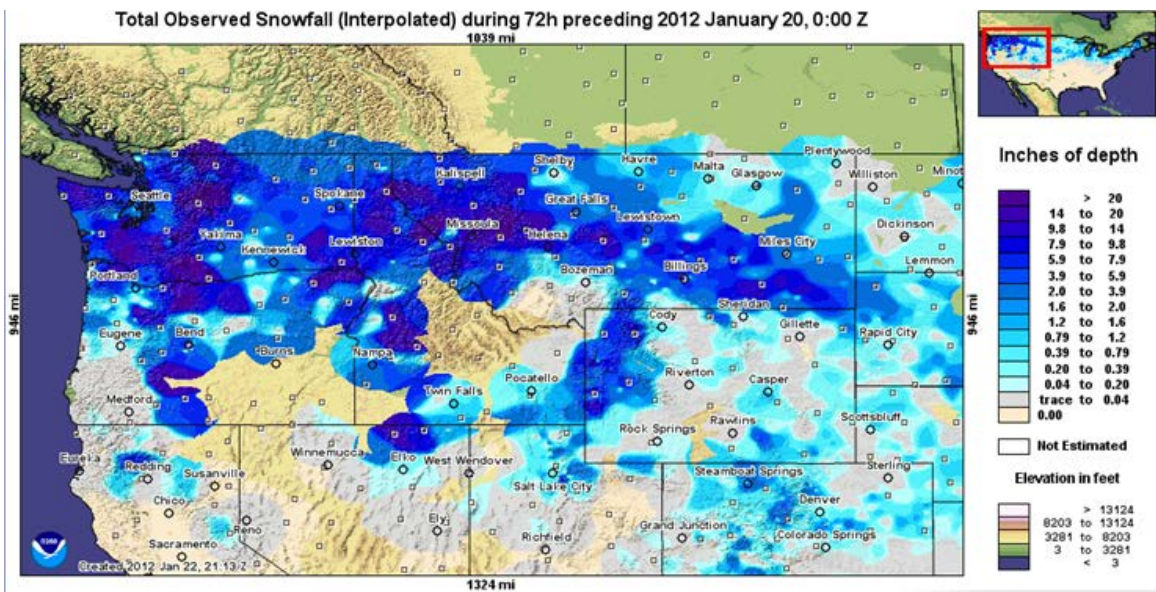
430 Figure 10: Surface analysis overlaid on infrared satellite imagery from 12 UTC on 19 December (a)

431 and 00 UTC on 20 December (b), 2011.



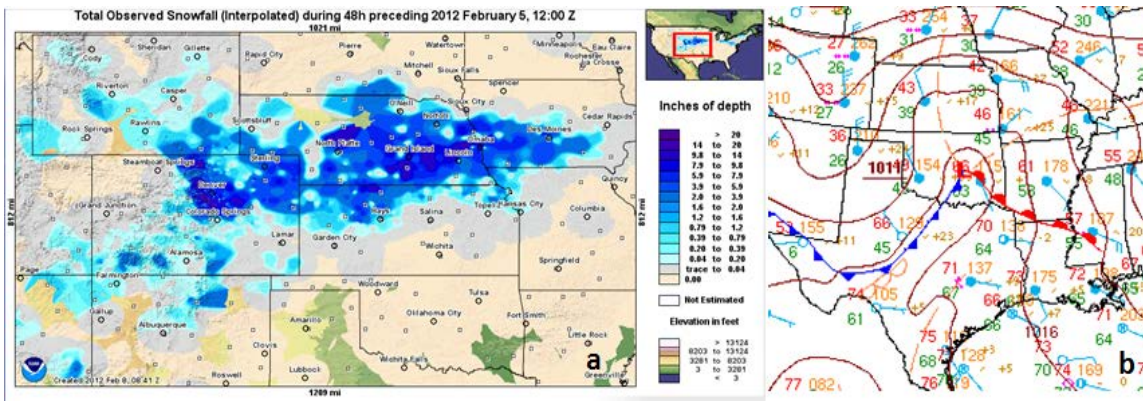
432

433 Figure 11: Surface analyses from 00 UTC on 15 January (a) and 00 UTC on 19 January, 2012 (b).

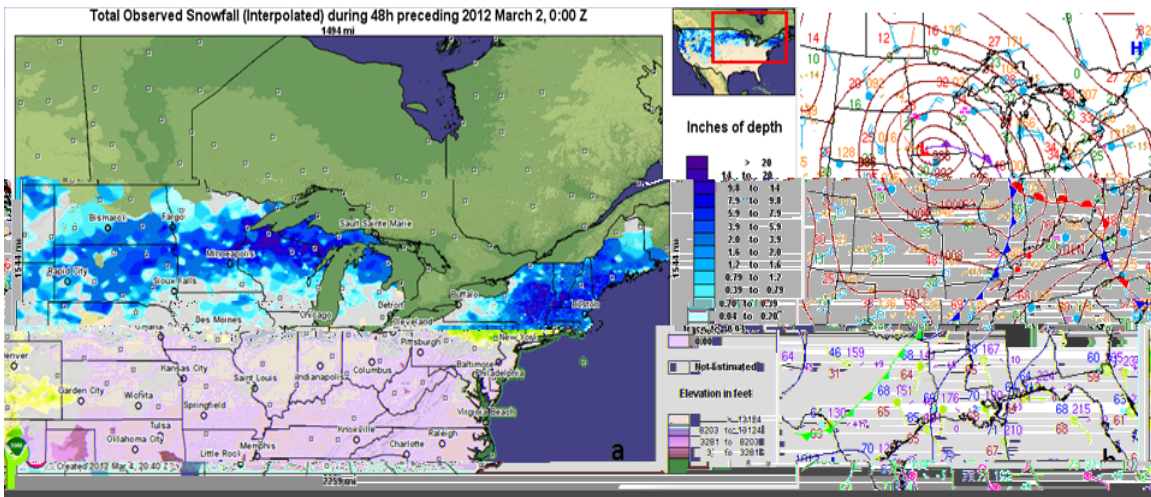


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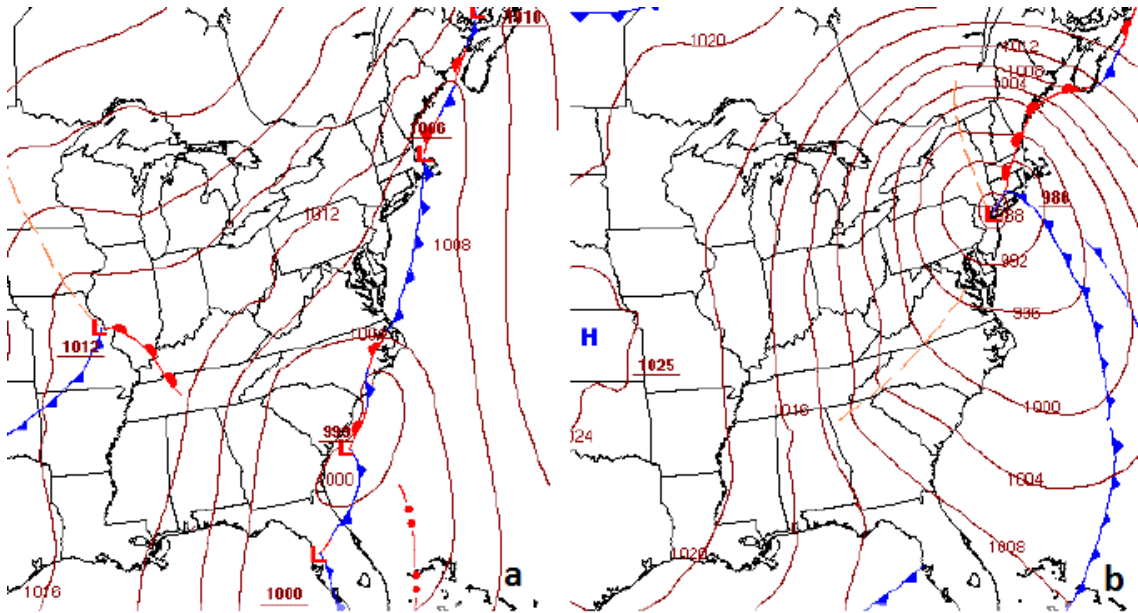
435 Figure 12: Total observed snowfall from 00 UTC 17 January to 00 UTC 20 January, 2012
 436 (NOHRSC).



437
 438 Figure 13: Total observed snowfall from 12 UTC on 3 February (a) (NOHRSC) and surface analysis
 439 from 00 UTC on 4 February (2012).



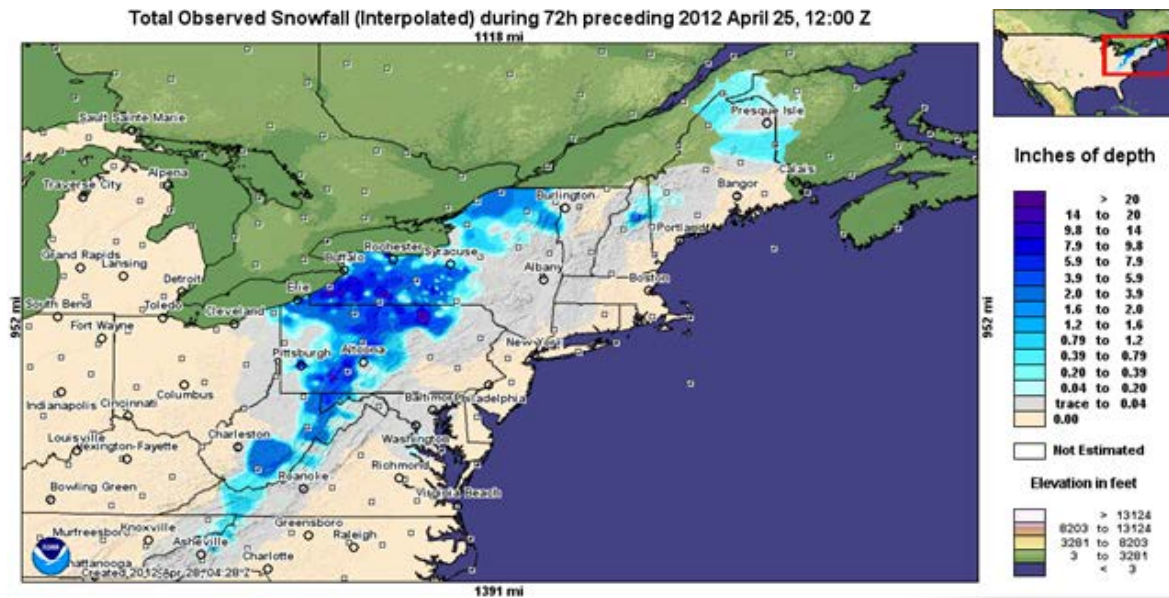
440
 441 Figure 14: Total observed snowfall from 00 UTC on 28 February (a) (NOHRSC) and (b) surface
 442 analysis from 12 UTC on 29 February, 2012.



443

444 **Figure 15: Surface analysis from 12 UTC on 22 April (a) and 12 UTC on 23 April (b), 2012.**

445



446

447 **Figure 16: Total observed snowfall from beginning at 12 UTC on 22 April and ending at 12 UTC on**

448 **25 April, 2012 (NOHRSC).**