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February 2015: A Month to Remember in New England for Record Cold

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Abstract

February 2015 was one of the coldest months on record across the Northeast U.S., and in a number of locations was the all-time coldest month observed. Some of the possible causes of this extreme cold air outbreak are shown to be ENSO, MJO, positive SST anomalies, and persistent cyclogenesis along the east coast of the U.S. A review of the offical National Weather Service Climate Prediction Center's temperature forecasts and Heidke skill scores for February along with two climate models that provided temperature forecast guildance for such an extreme event are examined. Lastly, a comparison with previous extreme cold months since 1948 across the Northeast U.S. showed that 500 hPa geopotential height composite anomalies had different distributions; however, the 500 hPa geopotenital height composite means all had an upper level trough across the Northeast U.S. This event review will hopefully provide forecasters with more confidence in predicting or assessing the potential for future extreme cold air outbreaks.

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1. Introduction

An extreme cold air outbreak affected all of the Northeast U.S. during February 2015 (Northeast Regional Climate Center (NRCC) 2015). In some locations it was the all time coldest month ever observed. This was in sharp contrast to the start of the winter that featured well above normal temperatures in December 2014 (Fig. 1). Temperatures in January 2015 averaged below normal across the Northeast U.S. (Fig. 2), but there was not a persistent extreme cold air outbreak. The mild start to the winter made the conditions more harsh in February 2015, which was one of the coldest, and in some locations the all-time coldest month of record in parts of the Northeast U.S. (NRCC; Figs. 3, 4 and Table 1). The extreme cold led to ice buildup on waterways and made navigation difficult, slowed commerce, and forced ferry services to be suspended. Boat traffic was restricted as far south as parts of the upper Chesapeake Bay for about a week due to icy conditions, and the start of maple season was delayed by up to three weeks in New England, New York, and Ohio because the extreme cold kept sap from flowing (Quarterly Climate Impacts and Outlooks 2015).

The first section of this paper will examine the temperature records that were established in a historical context. Next, the surface and upper air patterns associated with the February 2015 extreme cold outbreak will be examined. The upper air patterns associated with the top 5 coldest outbreaks since 1948 will also be examined. The possible causes of the record cold will be discussed, and finally a review of the offical forecast and forecast skill from the Climate Prediction Center (CPC), along with the forecasts from two climate models will be presented.

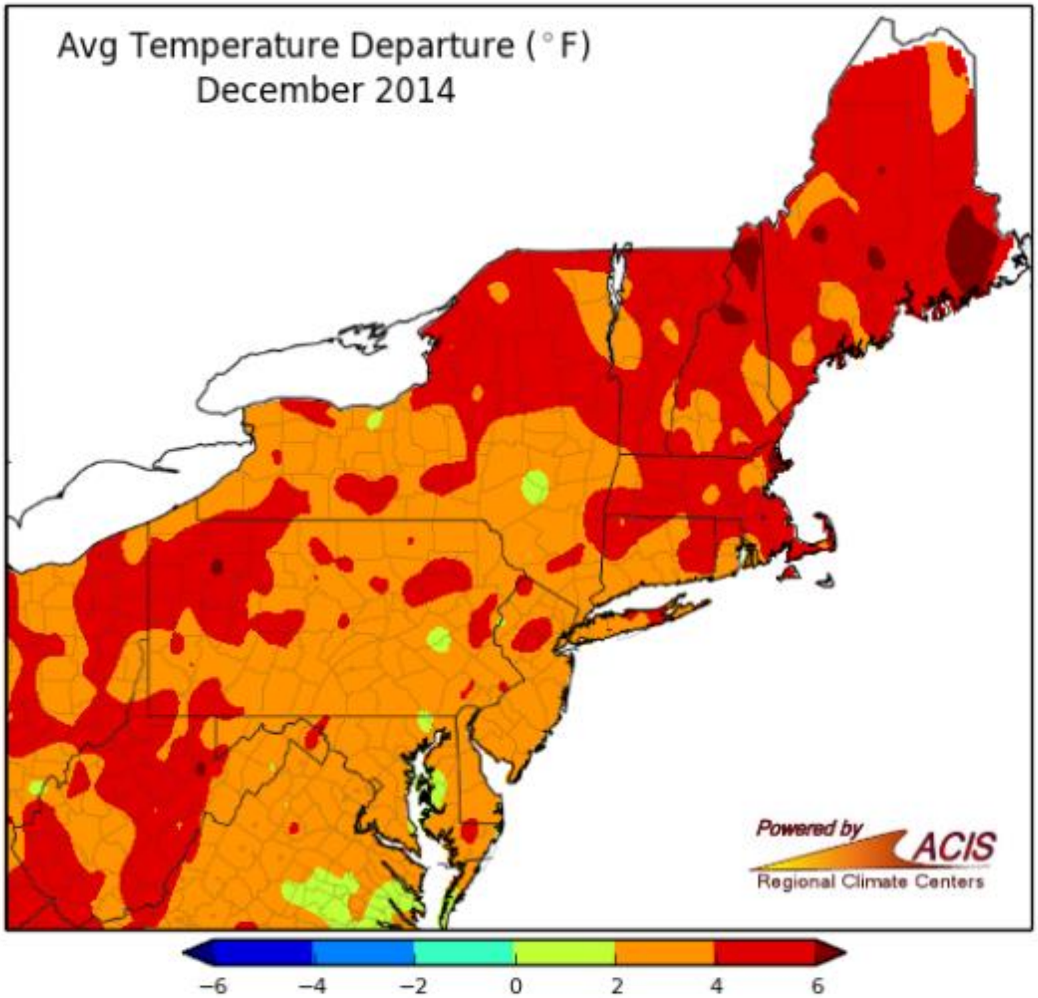


Figure 1. December 2014 departure from normal temperature (°F) from the *Northeast Regional Climate Center*.

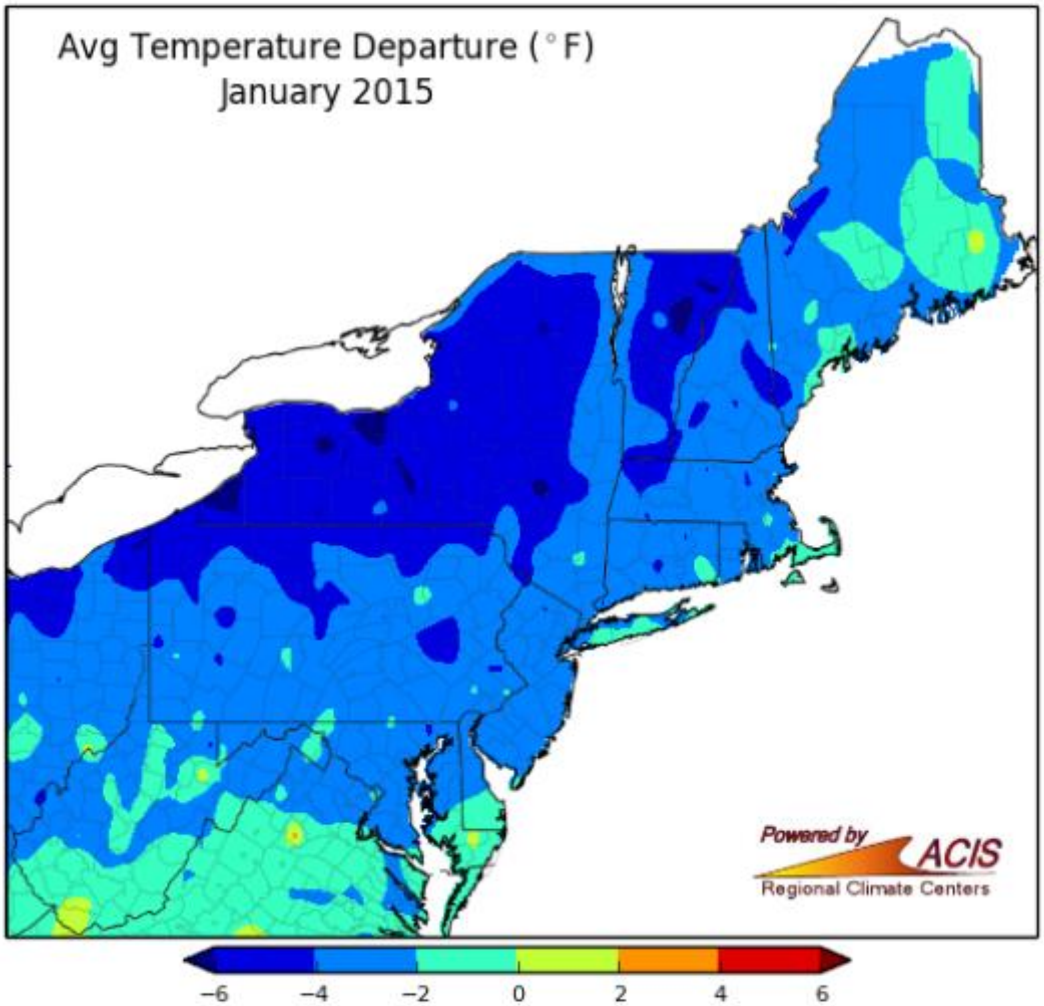


Figure 2. January 2015 departure from normal temperature (°F). Figure from the *Northeast Regional Climate Center*.

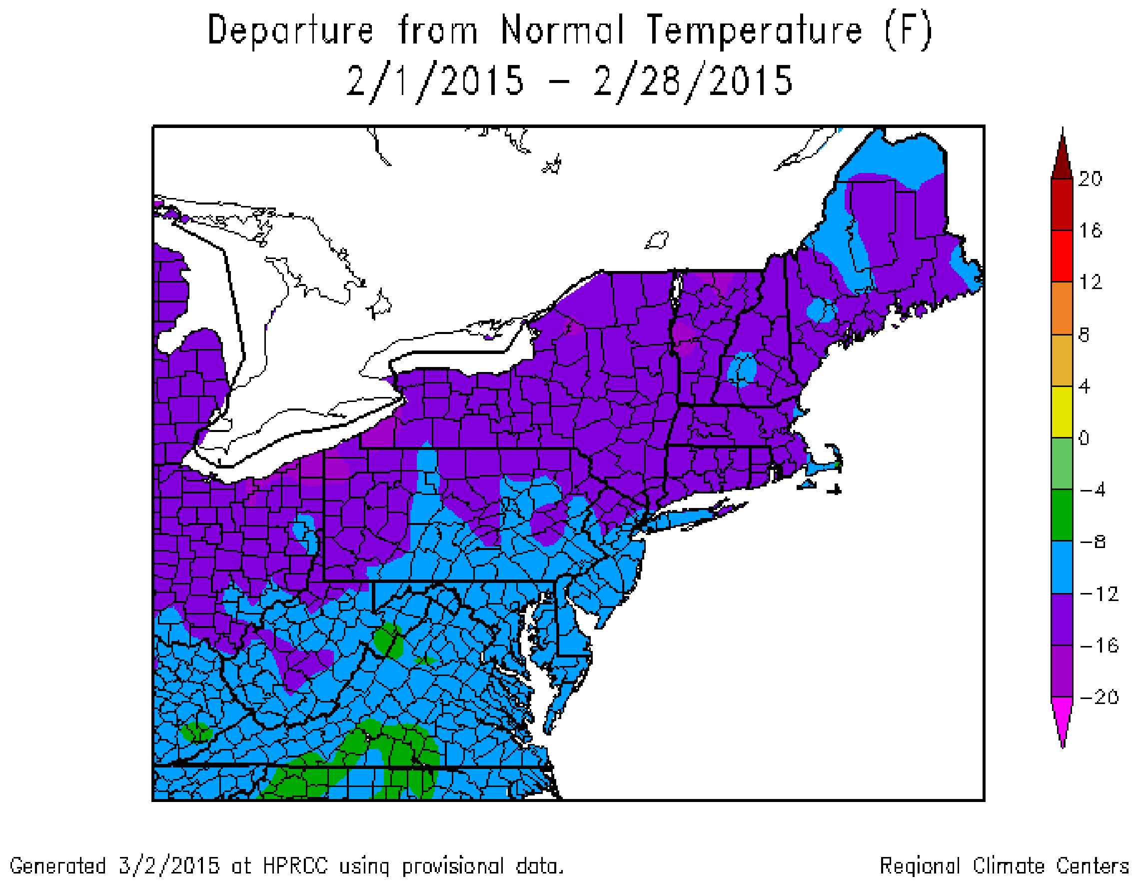


Figure 3. February 2015 departure from normal temperature (°F). Figure from the *Northeast Regional Climate Center*.

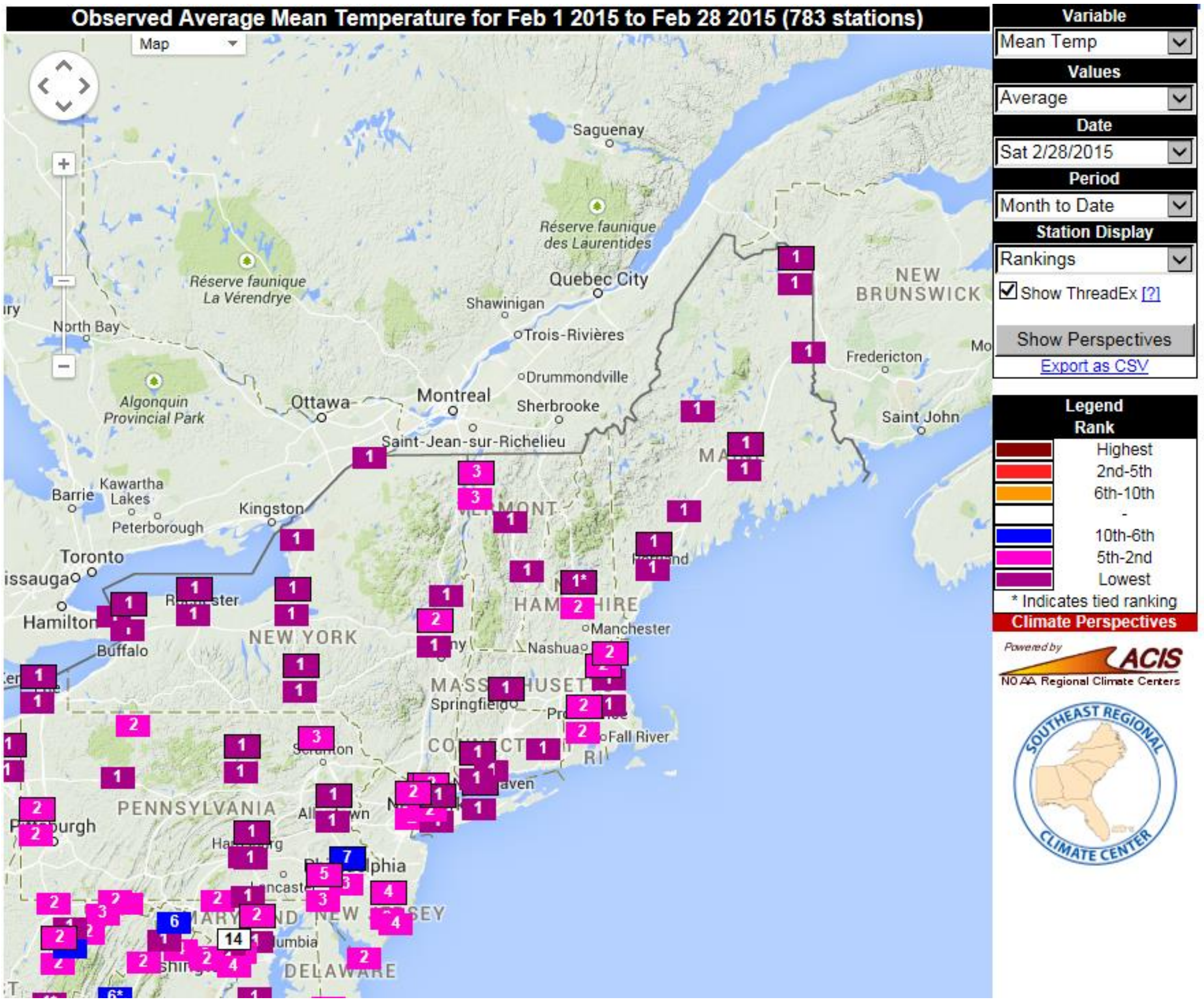


Figure 4. The observed average mean temperature rankings for February 2015. Figure *from the* *Southeast Regional Climate Center*.

Table 1. February 2015 temperature rankings (°F) across the Northeast U.S. *Source* - *Northeast Regional Climate Center*.

Area	Feb. 2015	Normal	Departure	Feb. Rank (coldest)	All-Time Rank (coldest)
Syracuse, NY	9.0	25.9	-16.9	1	1
Buffalo, NY	10.9	26.3	-15.4	1	1
Erie, PA	13.1	28.3	-15.2	1	2
Rochester, NY	12.2	26.4	-14.2	1	1
Hartford, CT	16.1	29.7	-13.6	1	1
Worcester, MA	14.2	27.0	-12.8	1	1
Binghamton, NY	12.2	24.7	-12.5	1	2
Bridgeport, CT	19.9	32.4	-12.5	1	1
Concord, NH	12.1	24.3	-12.2	1	8
Harrisburg, PA	20.9	32.9	-12.0	1	4
Portland, ME	13.8	25.5	-11.7	1	2
Williamsport, PA	18.1	29.7	-11.6	1	3
Caribou, ME	2.8	14.1	-11.3	1	4
Islip, NY	21.6	32.8	-11.2	1	1
Kennedy Ap, NY	24.5	34.9	-10.4	1	2
Providence, RI	18.4	32.0	-13.6	2	2
Albany, NY	12.7	25.9	-13.2	2	4
Pittsburgh, PA	18.3	31.1	-12.8	2	4
Boston, MA	19.0	31.7	-12.7	2	2
Elkins, WV	20.1	32.2	-12.1	2	7
Charleston, WV	25.7	37.7	-12.0	2	5
Huntington, WV	25.2	37.2	-12.0	2	8
Newark, NJ	22.6	34.6	-12.0	2	3
Allentown, PA	18.9	30.7	-11.8	2	3
LaGuardia Ap, NY	24.2	35.3	-11.1	2	3
Dulles Ap, VA	25.4	36.2	-10.8	2	5
Baltimore, MD	25.3	35.8	-10.5	2	4
Burlington, VT	7.6	21.5	-13.9	3	7
Central Park, NY	23.9	35.3	-11.4	3	5
Scranton, PA	17.5	28.8	-11.3	3	5
Beckley, WV	23.2	34.4	-11.2	4	9
Atlantic City, NJ	24.4	35.3	-10.9	4	7
Wilmington, DE	24.8	35.1	-10.3	4	9
Philadelphia, PA	25.8	35.7	-9.9	7	20
Washington, DC	30.3	39.0	-8.7	14	

2. The Record Cold

February 2015 was one of the coldest Februaries on record, and in some locations the all-time coldest month on record across the Northeast U.S (NRCC). For the purposes of this event review the Northeast U.S. includes the six New England States, along with Delaware, Maryland, New Jersey, New York, Pennsylvania, and West Virgina. Average temperatures were 9° to 15° F below normal (Fig. 3). February 2015 ranked as the 2nd coldest month across the Northeast U.S. since 1948 behind only January 1977 (NRCC). It was the coldest month across the Northeast U.S. since January 1994, which was the 4th coldest month on record (NRCC). In Maine, Caribou observed its all-time coldest February on record with an average temperature of just 2.8° F, which surpassed 1993 when the average temperature was 4.1° F. Bangor, Maine set an all-time coldest monthly record. The average temperature at Bangor of 6.1° F smashed the previous record for February of 11.3° F in 1993, and also broke the all-time coldest month record by more than 2° F. The old record of 8.4° F was established in January 1994.

Across New England and the greater Northeast U.S., there were many impressive monthly temperature records broken. Portland, Maine, observed its coldest February on record, and the 2nd coldest month of all-time. Boston, Massachusetts, and Providence, Rhode Island, each had their 2nd coldest February and 2nd coldest month of all time. Hartford and Bridgeport, Connecticut, as well as Syracuse, New York, observed their coldest month ever. Elsewhere in the Northeast U.S., Buffalo, Rochester, and Islip, New York, observed their coldest months on record (Fig. 4).

Fifteen long term climate sites had a record cold February, and seven long term climate sites had their all-time coldest month on record. Most of the climate sites in the Northeast U.S. had either their coldest or 2nd coldest February on record (Table 1). What was remarkable was the persistence of the cold weather. While not unusual to have a week or two with below normal temperatures, every day featured below and in many cases well below normal temperatures at Bangor, Maine (Applied Climate Information System (ACIS); Fig. 5). A similar temperature pattern was noted at Syracuse, New York (ACIS; Fig. 6). Boston, Massachusetts, had only one day with above normal temperatures, and Buffalo, New York, experienced above average temperatures on just 2 days during the entire month of February (ACIS).

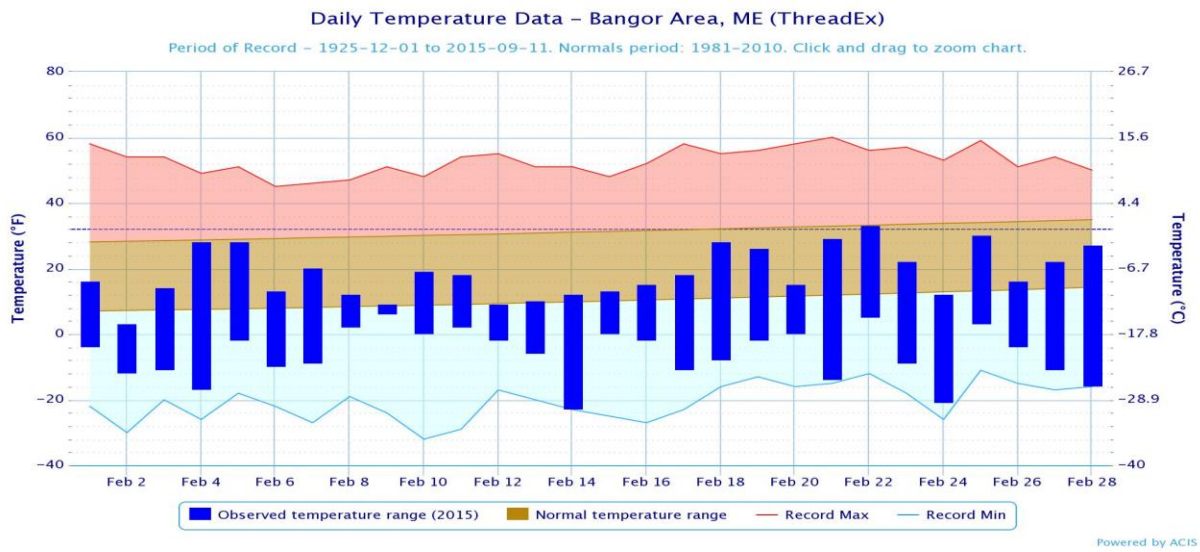


Figure 5. Daily temperature data (°F) for Bangor, Maine for February 2015.

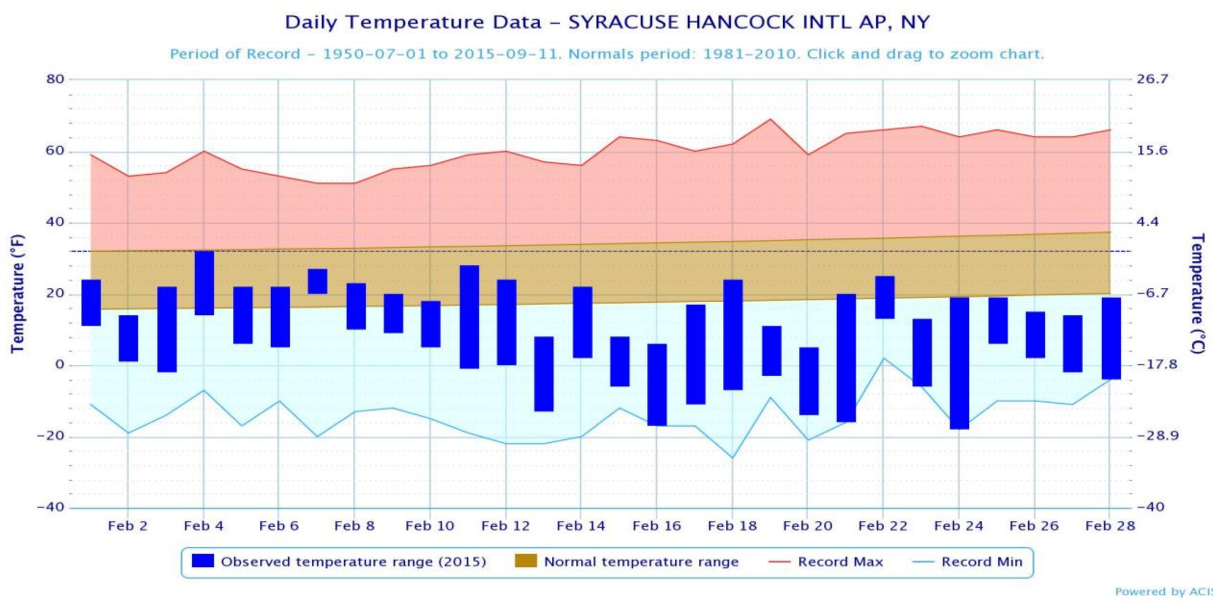


Figure 6. Daily temperature data (°F) for Syracuse, New York for February 2015.

3. Upper Air and Surface Patterns

The upper air and surface weather patterns that produced the persistent cold weather across all of the Northeast U.S. were investigated to provide a synoptic overview of the event. In order to do this, a reanalysis of upper air and surface patterns were examined using the NCEP/NCAR Reanalysis courtesy of NOAA's Earth System Research Laboratory (ESRL; Kalnay et al. 1996).

The winter began in December 2014 with positive 500 hPa geopotential height anomalies across the Northeast U.S. (Fig. 7).

By January 2015, weakly negative 500 hPa geopotential height anomalies were observed across the Northeast U.S; however, strong positive anomalies were noted across the Pacific Northwest as well as the Bering Sea and strong negative anomalies were noted in the vicinity of the Davis Strait (Fig. 8). By February 2015, there were persistently low 500 hPa heights across central Siberia, northern Canada, and into the Great Lakes and Northeast U.S. Examining the 500 hPa composite anomalies (1981-2010 climatology), negative anomalies on the order of 90 to 120 meters were noted across the greater Northeast U.S. including all of New England (Fig. 9a). At the same time, strong positive height anomalies were observed west of the Continental Divide. The 500 hPa composite mean for February 2015 (Fig. 9b) showed strong ridging along the west coast of the U.S. with a deep trough across the eastern U.S. In the Northeast U.S., the persistence of the upper air pattern led to well below normal temperatures at the surface, which corresponded well with the upper air anomalies (Fig. 10).

Next, the surface patterns in February 2015 were examined. The sea level pressure composite anomaly showed that surface pressures were lower than the climatological mean just off the Northeast U.S. coast (Fig. 11). This was due to a series of surface lows that moved toward the Northeast U.S. coast from the west and intensified across the Canadian Maritimes (Weather Prediction Center's surface analysis archive, http://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php). The persistence of this pattern led to favorable conditions for pulling cold Canadian air into the Northeast U.S. on the back side of the surface lows.

Lastly, a comparison with the top five coldest months is shown. February 2015 ranked as the second coldest month across the Northeast U.S. since 1948 (NRCC). The top 5 coldest months across the Northeast U.S. in order since 1948 were; January 1977, February 2015, December 1989, January 1994, and January 1970 (Fig. 12a-c). The 500 hPa geopotential height composite mean and anomalies associated with these other extreme cold months are shown in Figs. 13-16. In all cases, the 500 hPa geopotential height composite mean showed a similar pattern of an upper level trough across the Northeast U.S. The 500 hPa geopotential height composite anomalies had different distributions with cold anomalies showing up across the Great Lakes, the Northeast U.S., and in some cases off the New England coast.

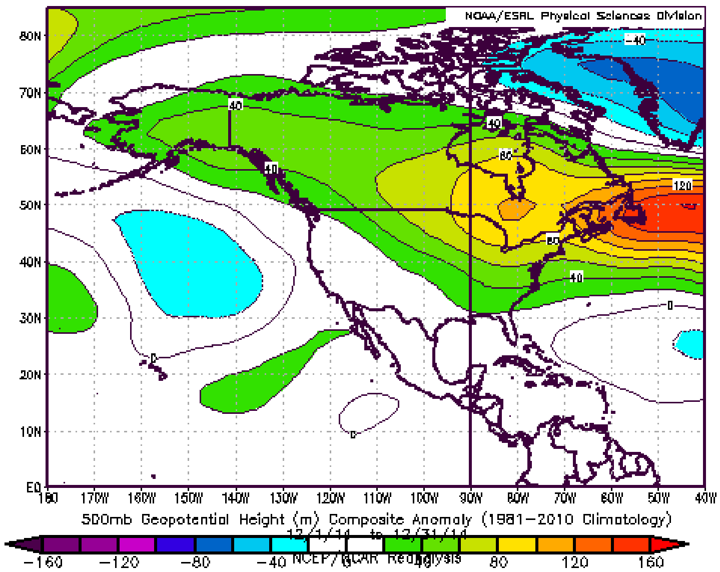


Figure 7. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during December 2014. Figure *from NOAA's Earth System Research Laboratory*.

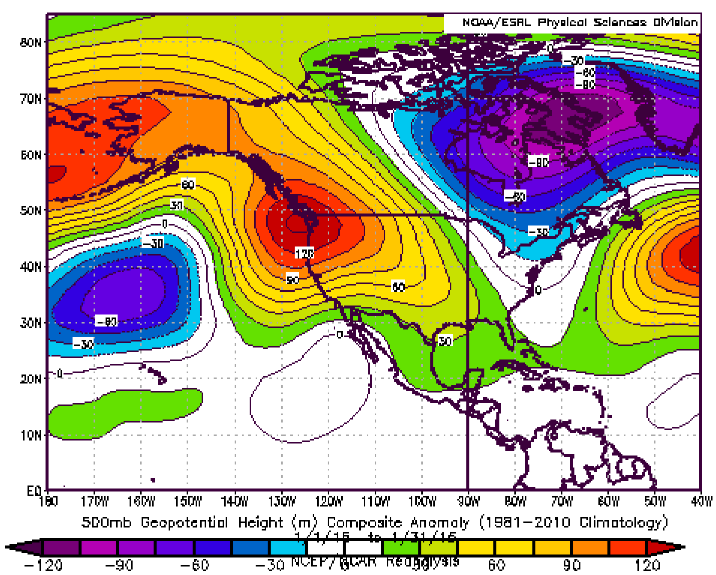


Figure 8. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during January 2015. Figure *from NOAA's Earth System Research Laboratory*.

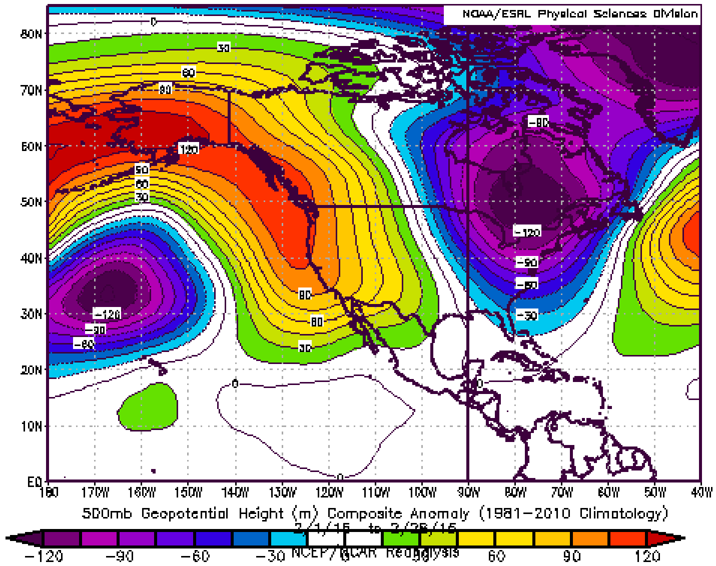


Figure 9a. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during February 2015. Figure *from NOAA's Earth System Research Laboratory.*

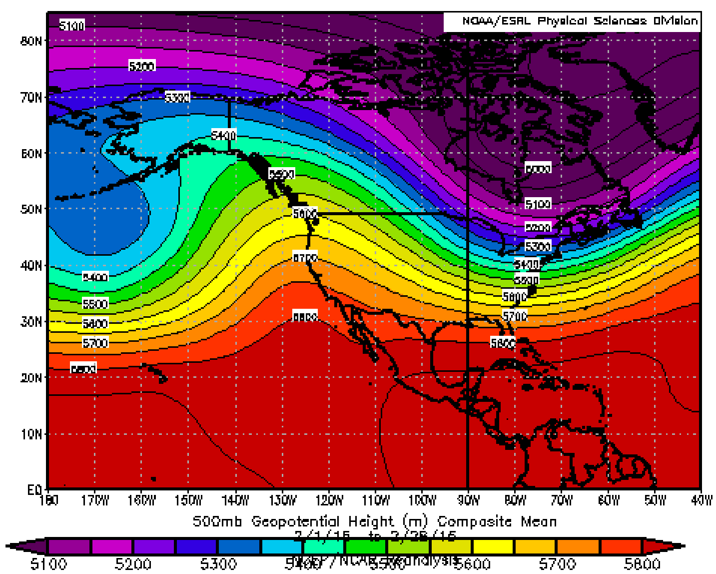


Figure 9b. 500 hPa geopotential height composite mean (m), from the 1981-2010 climatology, during February 2015. Figure from NOAA's Earth System Research Laboratory.

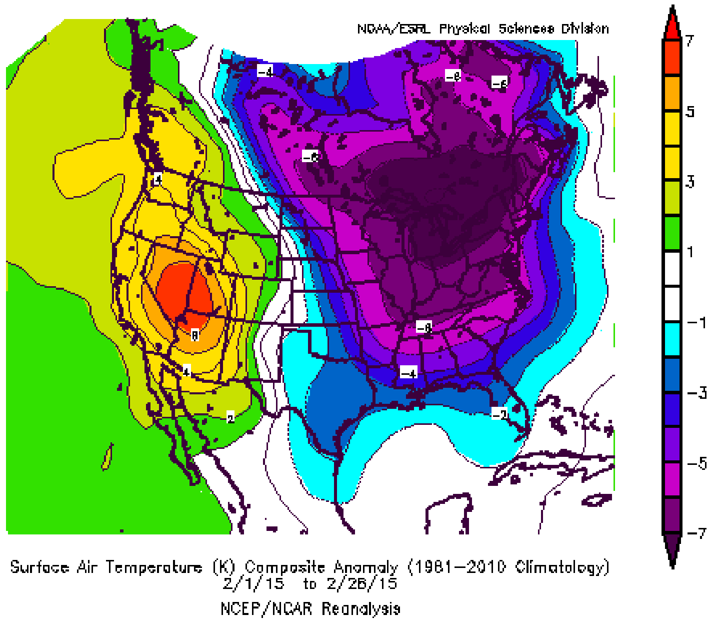


Figure 10. Surface air temperature composite anomaly (K), from the 1981-2010 climatology, during February 2015. Figure *from NOAA's Earth System Research Laboratory*.

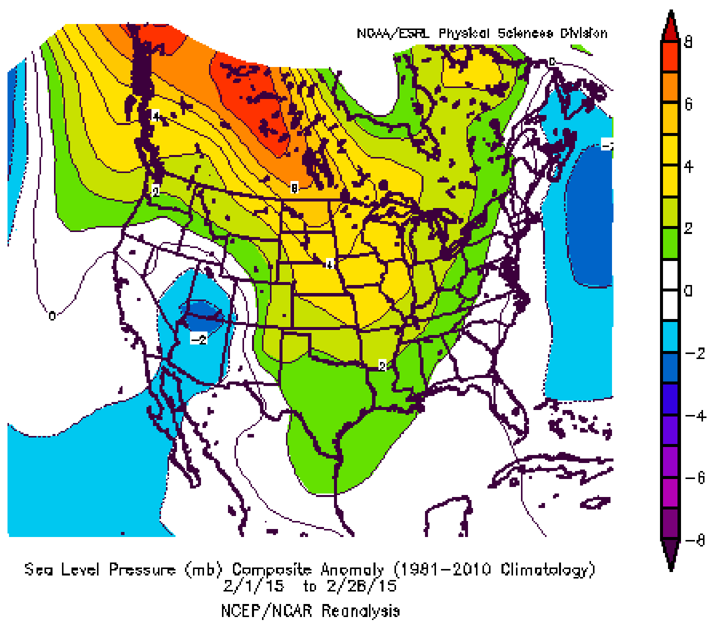
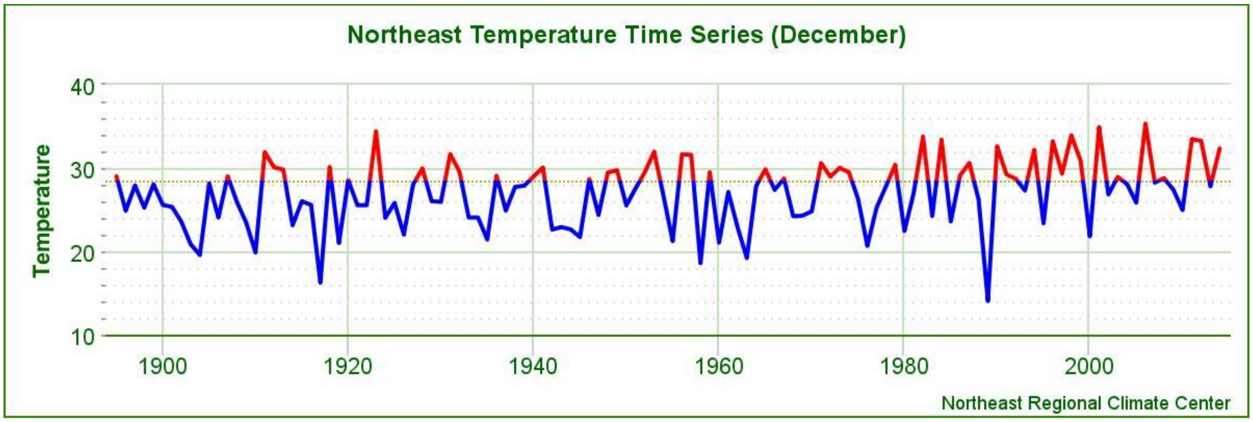
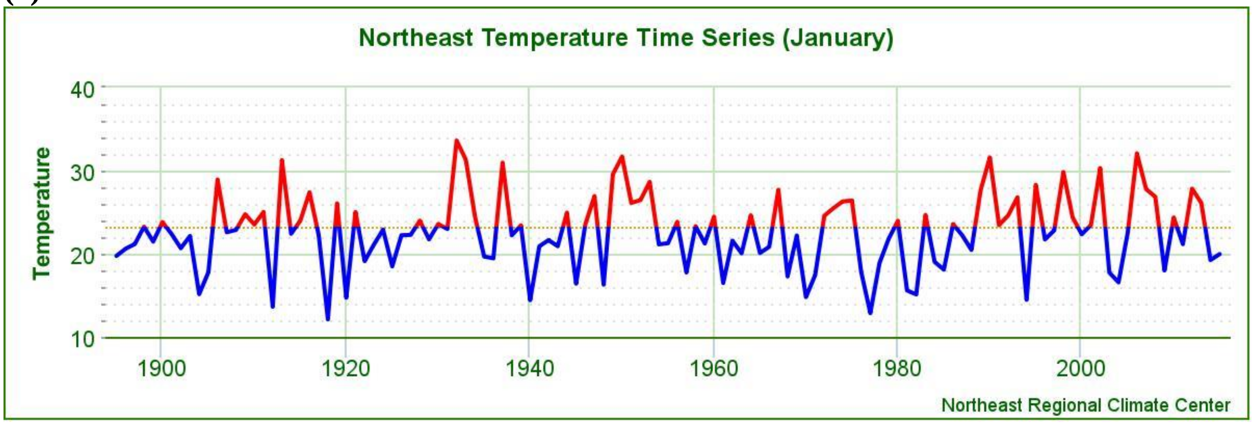


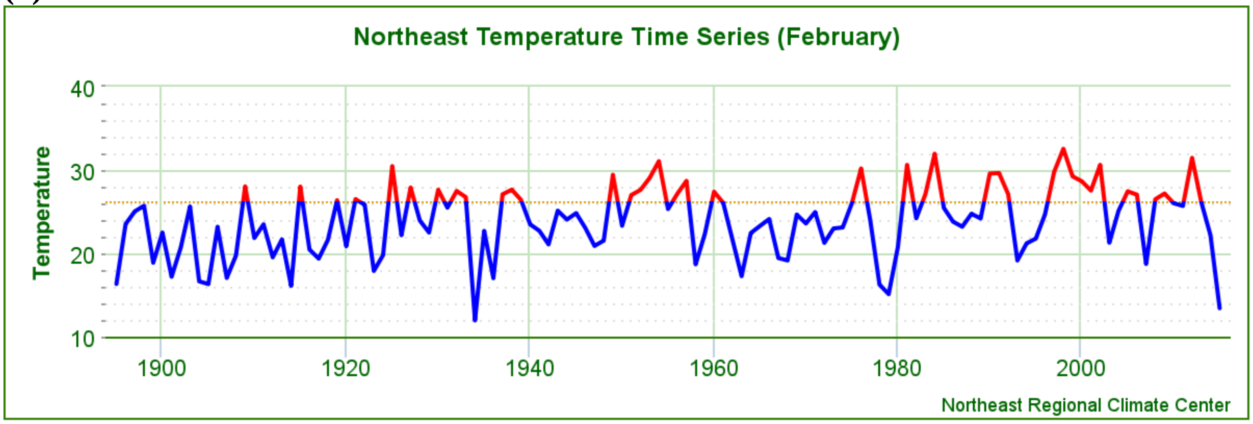
Figure 11. Sea level pressure composite anomaly (mb), from the 1981-2010 climatology, during February 2015. Figure *from NOAA's Earth System Research Laboratory*.



(a)



(b)



(c)

Figure 12. The average monthly temperature (°F) across the Northeast U.S. during (a) the month of December, (b) the month of January, (c) the month of February. Figure from the *Northeast Regional Climate Center.*

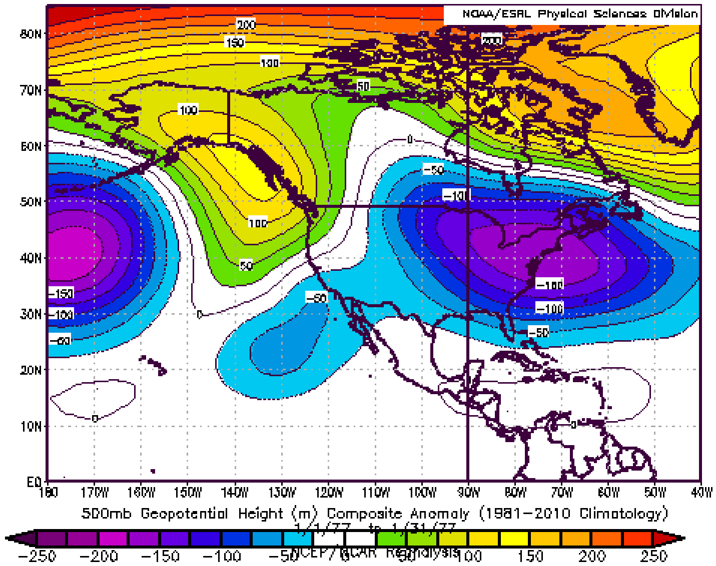


Figure 13a. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during January 1977. Figure from *NOAA's Earth System Research Laboratory*.

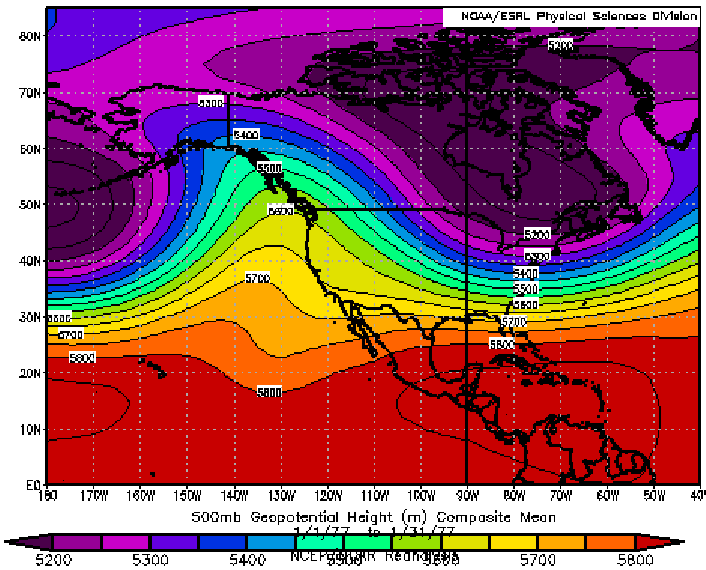


Figure 13b. 500 hPa geopotential height composite mean (m), from the 1981-2010 climatology, during January 1977. Figure from *NOAA's Earth System Research Laboratory*.

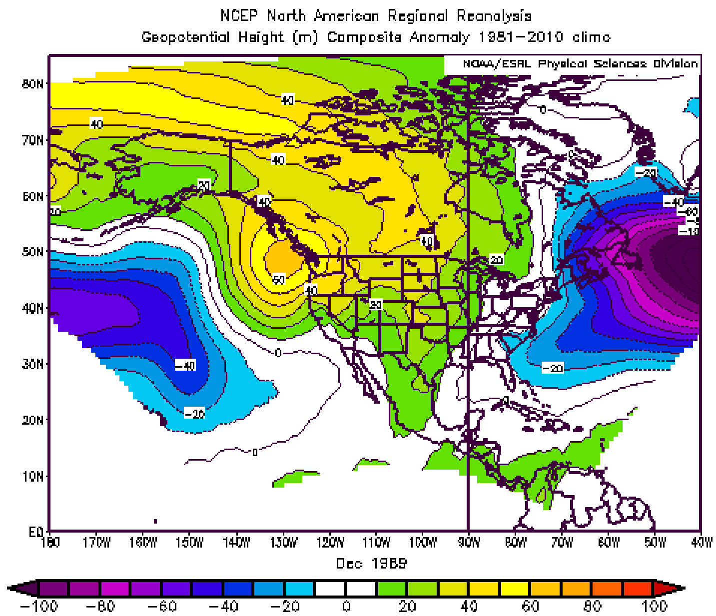


Figure 14a. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during December 1989. Figure *from NOAA's Earth System Research Laboratory.*

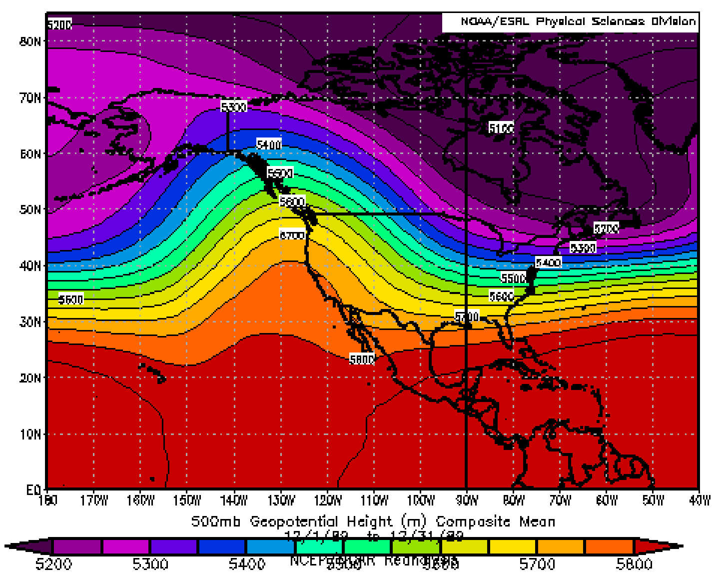


Figure 14b. 500 hPa geopotential height composite mean (m), from the 1981-2010 climatology, during December 1989. Figure *from NOAA's Earth System Research Laboratory.*

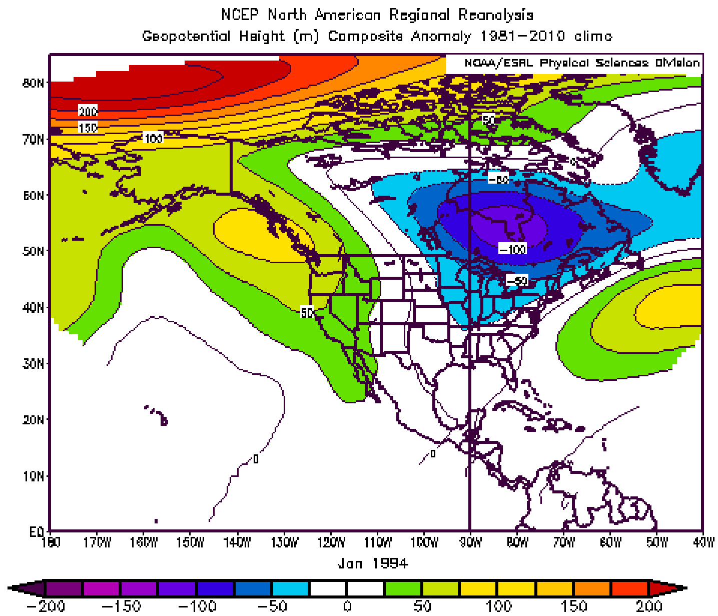


Figure 15a. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during January 1994. Figure *from NOAA's Earth System Research Laboratory*.

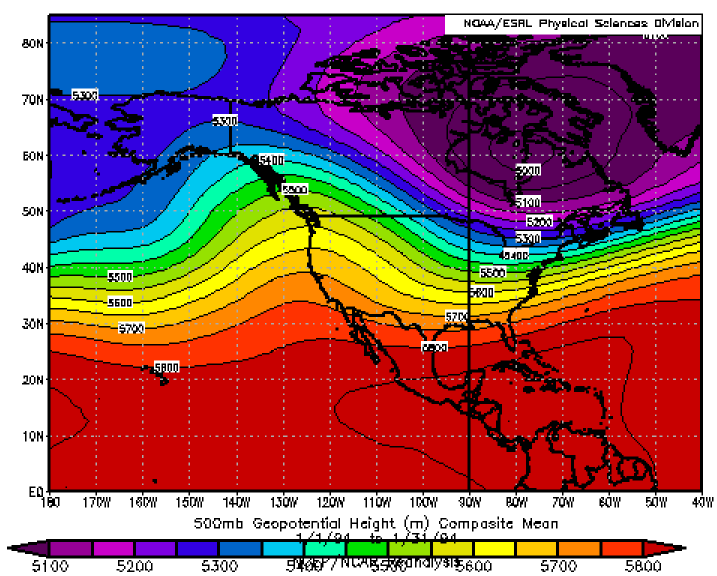


Figure 15b. 500 hPa geopotential height composite mean (m), from the 1981-2010 climatology, during January 1994. Figure from NOAA's Earth System Research Laboratory.

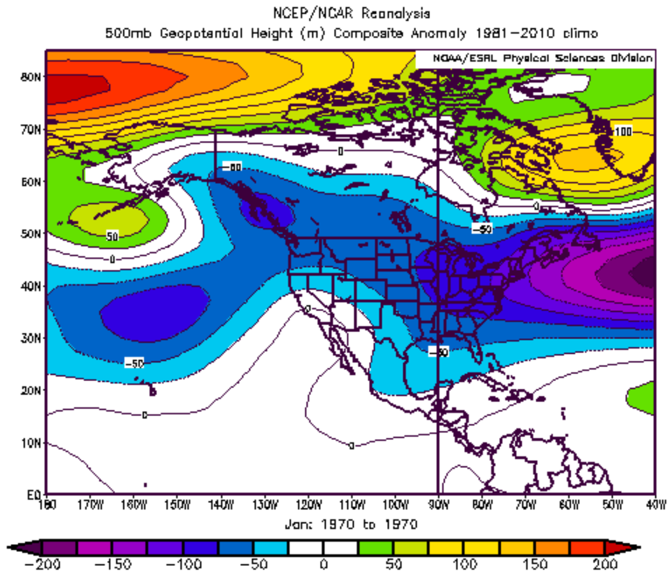


Figure 16a. 500 hPa geopotential height composite anomaly (m), from the 1981-2010 climatology, during January 1970. Figure *from NOAA's Earth System Research Laboratory.*

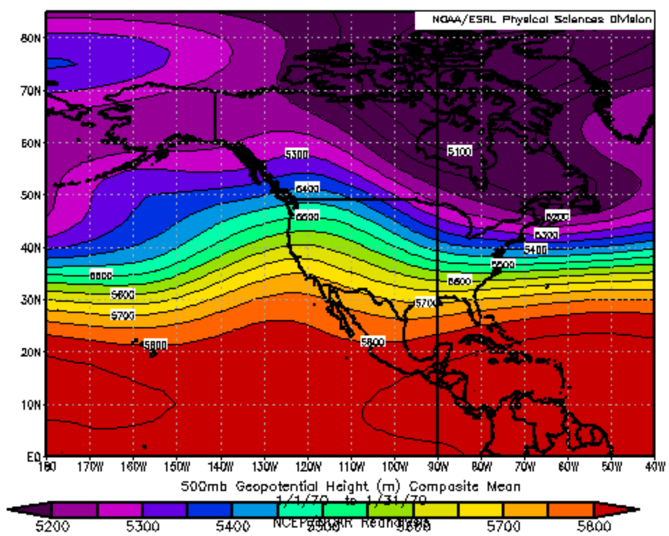


Figure 16b. 500 hPa geopotential height composite mean (m), from the 1981-2010 climatology, during January 1970. Figure from NOAA's Earth System Research Laboratory.

4. Possible Causes of the Record Cold

To help determine possible causes of the record cold, atmospheric and oceanic conditions were examined for February 2015 as well as the CPC's forecaster reasoning behind the montly forecasts. A comparison is made to January 1977, which was the all-time coldest month across the Northeast U.S. since 1948.

During February 2015, weak El Niño conditions were observed (CPC's monthly

El Niño/Southern Oscillation (ENSO) diagnostic discussion, www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_disc_feb2015/). Above average sea surface temperatures (SSTs) were observed across the western and central equatorial Pacific, and the low level easterly trade winds remained weaker than average across much of the equatorial Pacific (CPC). The above average SSTs may have become weakly coupled to the tropical atmosphere. The largest postive SST anomaly of +0.75 °C (CPC's indices page, www.cpc.ncep.noaa.gov/data/indices/sstoi.indices)) was observed in Niño region 4 (5N-5S, 160E-150W), with near zero temperature anomalies in the Niño 1+2 regions (Figs. 17-18). Positive SST anomalies were also noted along the west coast of North America and across parts of the north Atlantic Basin (Fig. 19). The positive SST anomalies along the west coast of North America potentially helped to amplify the mean long wave ridge over the western North America coast, and were likely a significant factor in the long wave pattern at mid and upper latitudes. The Climate Prediction Center indicated in their monthly discussion for February 2015 issued on 15 January 2015 that there was "a continued lack of a robust atmospheric response to the near to above average equatorial pacific SSTs." The positive SST anomalies in the north Atlantic may have been an additional source of latent heat for enhanced east coast cyclogenesis for the New England coast. Additional reinforcing shots of cold air followed the passage of the cyclones and also likely aided in keeping the cold air in place throughout the month.

The Madden-Julian Oscillation (MJO) was weak with no coherent MJO pattern observed during the month of February (CPC's MJO discussion, www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/ARCHIVE/). The upper air pattern slowly retrograded during the month (Fig. 20). Arctic air extended from central Siberia and across the Canadian Archipelago and into New England. What was remarkable was the persistence of this pattern during the entire month. The fact that the MJO was not coherent and did not disrupt the quasi-stationary position of anomalous convection across the western equatorial Pacific may have been a driver in the persistence of the upper air pattern, but this is beyond the scope of this manuscript and would be worthy of future research by the climate research community. There was also a lack of well organized convection across the eastern equatorial Pacific. Strong negative OLR anomalies indicative of the enhanced convection were observed across the western Pacific with much weaker anomalies across the central and western equatorial Pacific (Fig. 21). These strong anomalies across the western Pacific may have become weakly tied to the tropical atmosphere and potentially played a role in the persistent ridge that was centered along the west coast of North America and the downstream trough across the Eastern U.S.

Konrad and Colucci (1989) investigated the cold outbreak of January 1977, which was the only month in the Northeast U.S. to be more severe than the February 2015 cold outbreak since 1948. They investigated a total of 17 strong cold air outbreaks and found that the strongest outbreaks were associated with rapid surface cyclogenesis which followed the outbreak onset. This is consistent with what was noted in February 2015 when reinforcing shots of cold air followed the passage of offshore cyclones, and likely aided in keeping the cold air in place throughout the month on a large scale across all of the Northeast U.S.

Examining the CPC's archive of Nino region SST anomalies, a similar analog was found with January 1977. Both February

2015 and January 1977 featured nearly identical values in the Nino 3 and 3.4 regions across the west central and central tropical north Pacific with less warming noted in the far eastern tropical Pacific in Nino region 1+ 2 (CPC, Table 2).

Most, if not all, past literature regarding impacts of El Nino on North America winters only reference stronger El Nino events where significant positive SST anomalies are distributed across all Nino regions. During these events, enhanced convection further east energizes the Hadley Cell circulation over a large portion of the central and eastern tropical North Pacific Ocean. This in turn energizes the subtropical jet originating from the south side of a stronger sub-tropical ridge over these regions, resulting in an injection of wave train energy into the Pacific polar jet stream. This enhanced Pacific polar jet enters the west coast of the U.S. during the winter, resulting in a split flow pattern over North America, displacing a more northern jet stream along with deep arctic air further north than average into northern Canada, frequently resulting in the observance of a negative Tropical Northern Hemisphere (TNH) teleconnection pattern (CPC, www.cpc.ncep.noaa.gov/data/teledoc/teleco ntents.shtml).

It is proposed that the more western displaced Pacific equatorial positive SST anomalies and associated enhanced convection observed during February 2015 and January 1977 potentially resulted in a more regional (rather than basin wide) enhancement of the Hadley Cell circulation over the west central and central tropical north Pacific. Namias et al. (1978) noted that a strengthened Hadley circulation transports high-level momentum so as to increase the extratropical westerlies. During the January 1977 extreme cold outbreak Namias et al. (1978) noted that there was a quasi-stationary long wave pattern, similar to February 2015, that developed from the North Pacific eastward through North America, which was in phase with the climatological normal flow pattern, although greatly amplified. This helped lock in the anomalous pattern because seasonal forcing did not oppose the factors leading to the abnormal forcing. This in turn, may have resulted in an enhanced sub-tropical jet that resulted in wave energy into a polar jet stream tied with the maintenance of anomalously strong Aleutian mid tropospheric vortex, rather than a Pacific polar jet stream entering the U.S. west coast and continuing eastward across the country. Subsequently, the downstream impacts on the long wave pattern over North America become quite different, with anomalously deep mid tropospheric ridging along all of the North America west coast resulting in anomalously deep troughing over eastern North America. This then results in the observance of very positive Pacific-North America (PNA) and/or East Pacific (EP-NP) teleconnection patterns rather than the negative TNH patterns seen with strong, more distributed equatorial SST anomalies across all Nino regions (CPC Teleconnection page, www.cpc.ncep.noaa.gov/data/teledoc/teleco ntents.shtml). Highly positive PNA and especially EP-NP patterns result in deep mid-tropospheric northeast anomalous component flow (Nouhan 1999) over significant portions of the arctic source region of North America extending into the CONUS. This leads to a much greater supply of arctic air into the eastern U.S., via an anomalously meridional component of the jet stream. Walsh et al. (2001) noted that the trajectories of the coldest air are southward or southeastward over North America during extreme cold outbreaks in the United States. Meanwhile, an anomalously northward displacement of a single mean jet stream well north of California and the southwest U.S. results in above normal temperatures and below normal precipitation. The weak El-Nino conditions mostly indicated in Nino regions 3.4 and 4 during February 2015 did not match the conceptual model of winter impacts of typical (especially strong) basin wide (with positive SST anomalies affecting all Nino regions) El-Ninos on California, the southwest U.S., and across the northern tier of the U.S. El-Nino conditions occurring with February 2015, however, did significantly resemble weak El-Nino conditions that occurred in January 1977, another month that featured bitterly cold temperatures for New England (as well as other portions of the eastern U.S.) and very dry conditions for California and the southwest U.S. To further examine the varying magnitudes of different El-Ninos on winter impacts across New England and other portions of the U.S. is beyond the scope of this manuscript, but would be worthy future research within the climate modeling community.

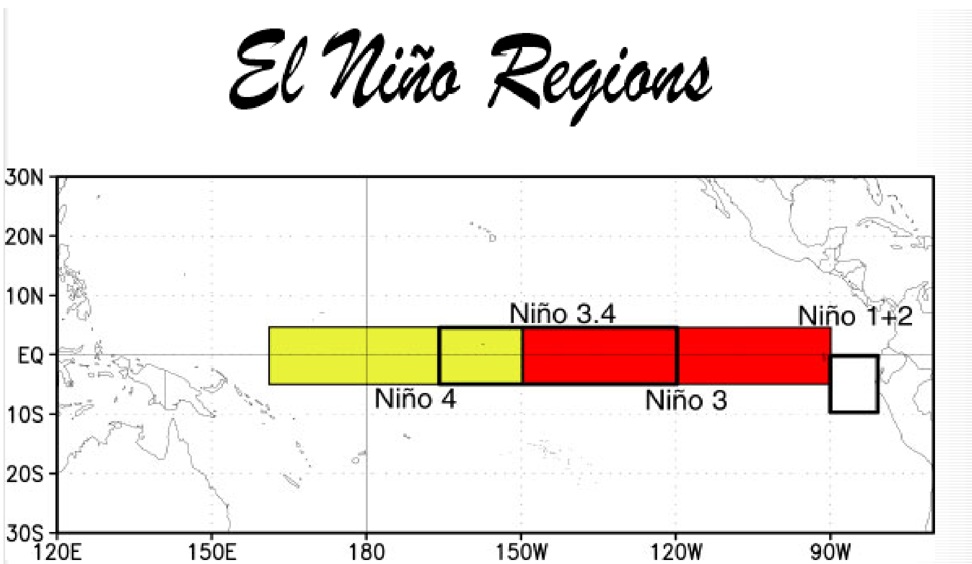


Figure 17. El Niño regions. *Figure from the CPC.*

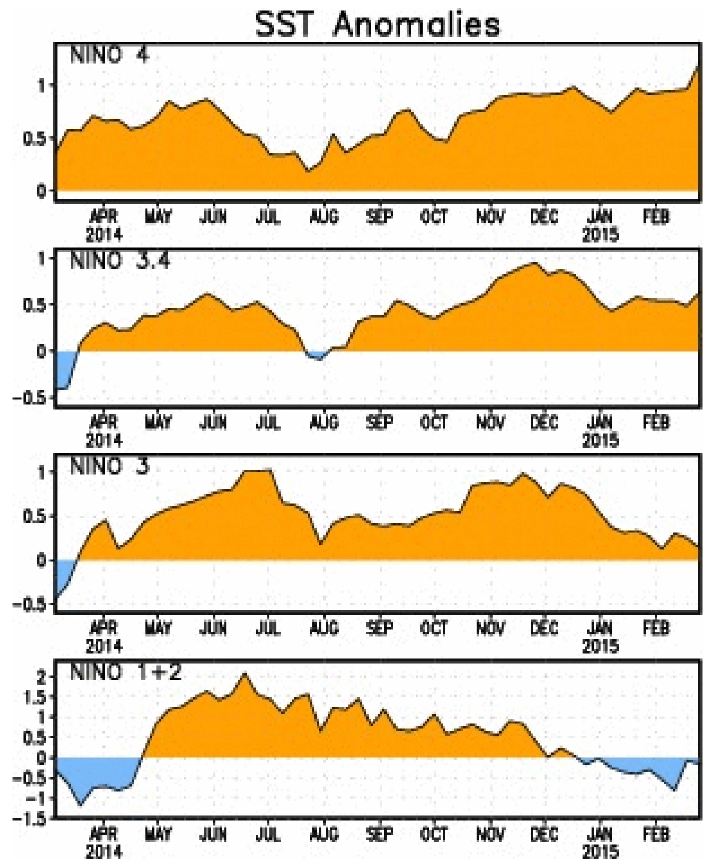


Figure 18. Niño Region SST Departures (°C). *Figure from the CPC*.

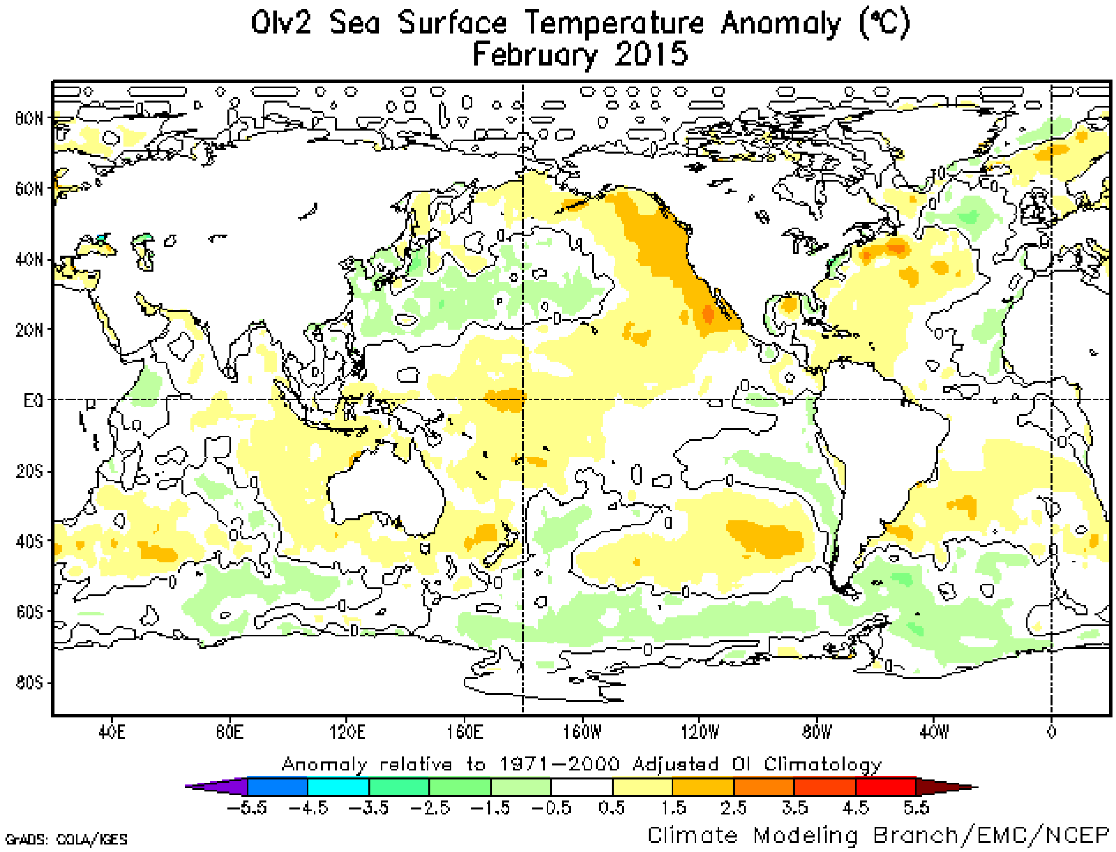


Figure 19. Global sea surface temperature anomalies (°C) during February 2015. *Figure from NCEP -* http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/images/archive/monthly_anomaly/monanomv2_201502.png.

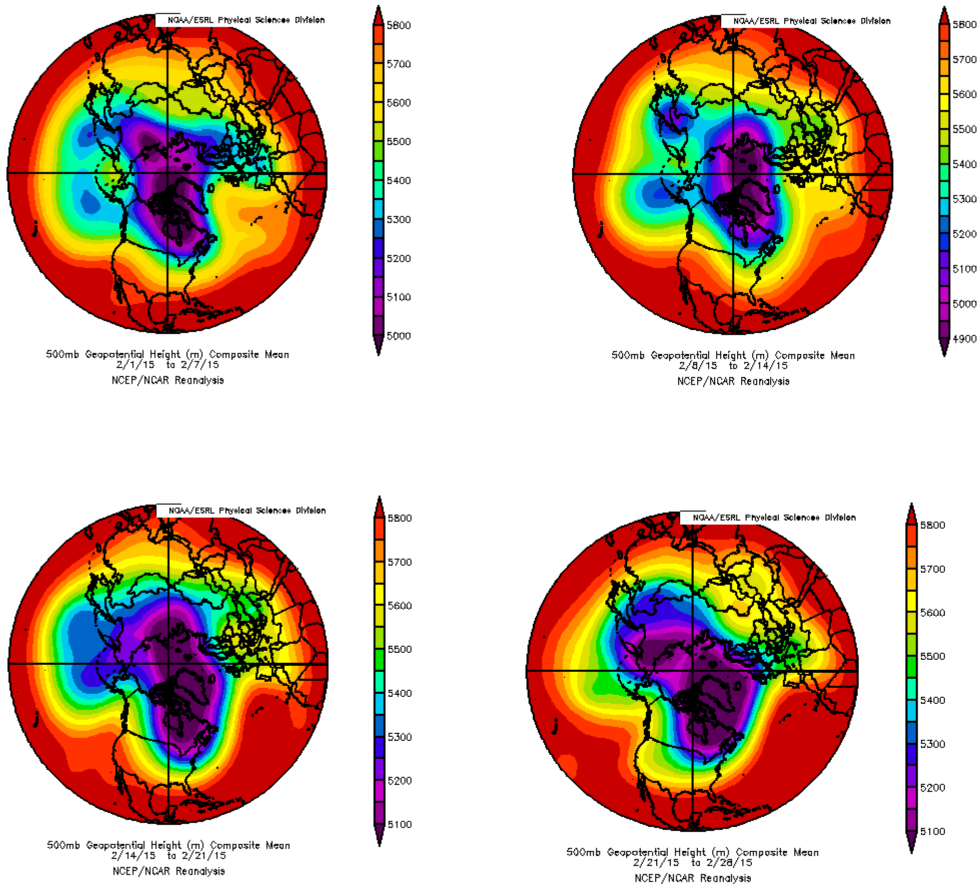


Figure 20. Clockwise, the composite 500 hPa geopotential heights (m) across the northern hemisphere for February 1-7, 8-14, 14-21, and 21-28. . Figure *from NOAA's Earth System Research Laboratory.*

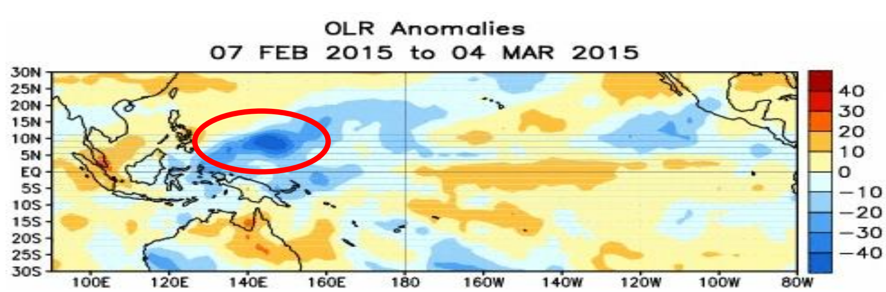


Figure 21. ORL anomalies Feb 7-Mar 04, 2015. *Figure from the CPC.*

Table 2. SST anomalies January 1977 versus February in the Nino 1+2, Nino 3, Nino 4, and Nino 3.4 regions.

Month/Year	Nino 1+2	Nino 3	Nino 4	Nino 3.4
January 1977	+0.20	+0.67	-0.06	+0.66
February 2015	-0.03	+0.46	+0.75	+0.50

5. Case Review: Climate Models and the CPC Forecast

The North American Multi-Model Ensemble (NMME) is an experimental multi-model seasonal forecasting system consisting of coupled models from US modeling centers including NOAA/NCEP, NOAA/GFDL, IRI, NCAR, NASA, and Canada's CMC (Kirtman et al. 2014). The forecast graphics are updated on the 9th of each month and are based on the models that are run before the 8th of the month. The NMME lead 2 monthly forecast for February 2015 was thus available on 9 December 2014, and is displayed in terciles (Fig. 22). The Northeast U.S. was in an area where above normal temperatures were favored. The next outlook issued on 9 January 2015, indicated that no one class was dominant, and thus there was no strong signal that pointed toward February being a record cold month (Fig. 23). However, there was a month over month trend toward a colder forecast indicated.

The CFSv2 is run once daily at NCEP and is comprised of 16 ensemble members (Saha et al. 2014). The forecast that was issued closest in time to the issuance of the NMME and was based on initial conditions from 1-10 January 2015 indicated cold anomalies on the order of 1-2 degrees (K) across the Northeast U.S. (Fig. 24). Figures 25 & 26 are the CFSv2 forecast based on the initial conditions from 12-21 January 2015, and the final forecast that was issued for February based on the initial conditions from 22-31 January 2015. There was a clear trend toward increased cold anomalies, which by the final outlook were on the order of 4+ degrees (K). The daily CFSv2 2-m temperature anomalies from 23-31 January 2015 showed that by late January the model indicated that there was a high likelihood that February would have significantly below normal temperatures across the Northeast U.S. (Fig. 27). There was a strong trend during the month of January that pointed toward warmer temperature anomalies in February across western North America. It is not possible to discern from the CFSv2 that this would necessarily be an indication that all-time record cold monthly temperatures were forecast by the model across the Northeast U.S.

The official NWS forecast from the CPC that was issued on 15 January 2015, indicated that there were no strong climate signals that would point toward an unusually cold February (Fig. 28). The February outlook "reflects a fairly high amount of uncertainty, given significant differences among the various climate models, and the continued lack of a robust atmospheric response to the near to above average equatorial pacific SSTs." The Heidke skill score of the CPC forecast was zero (Fig. 29), which indicated no skill compared to a random forecast. The final issuance of the monthly outlook for February that was issued on 31 January 2015 was significantly different from the previous 0.5-month lead outlook and indicated an increased likelihood that temperatures would average below normal across the Northeast U.S. during the month of February (Fig. 30). The CPC forecaster noted that there were "enhanced odds of below normal temperatures for much of the eastern third of the continental U.S. which was well supported by most of the long range tools, and was consistent with the idea that a large scale trough would dominate the mid-tropospheric circulation in the east." The Heidke skill score of the revised CPC forecast (Fig. 31) was 100, which indicates a perfect forecast. It seems likely that during the 2nd half of January 2015 that the climate models, and in particular the CFSv2, picked up on the idea that an upper trough would dominate during the month of February across the Northeast U.S.

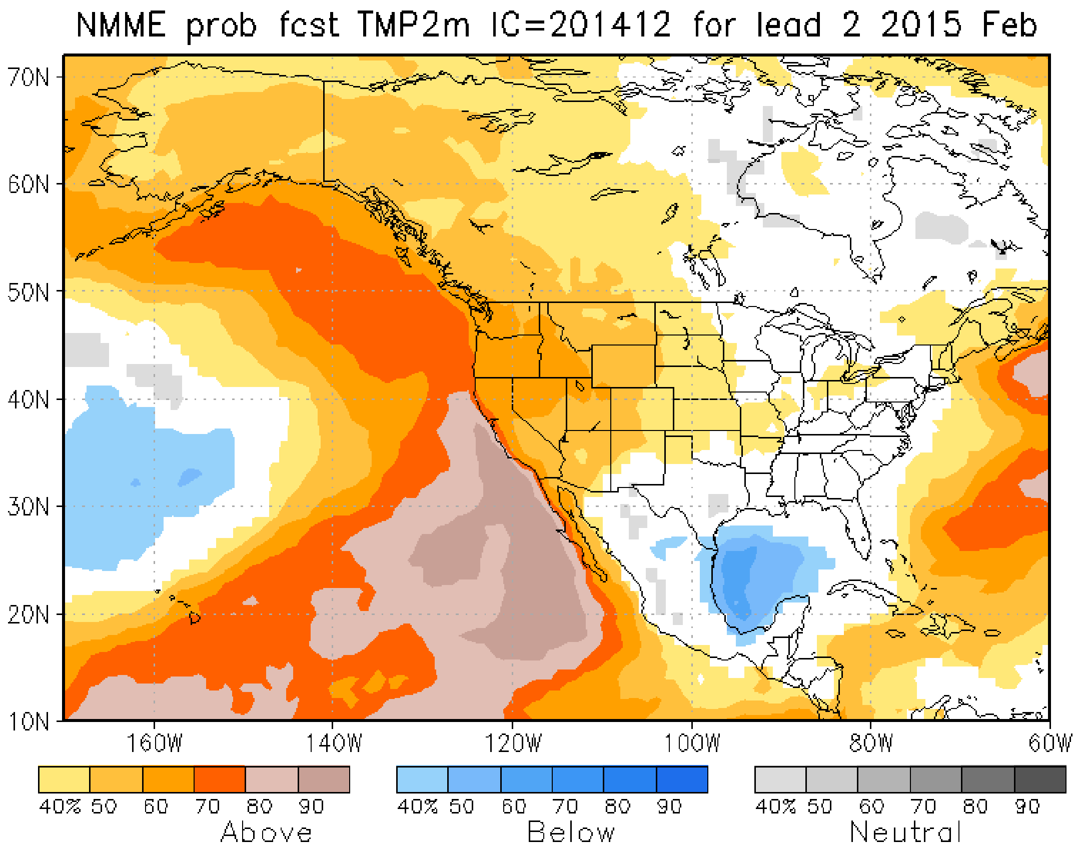


Figure 22. NMME forecast issued December 9, 2014, valid for February 2015. 2-m temperature tercile probabilities.

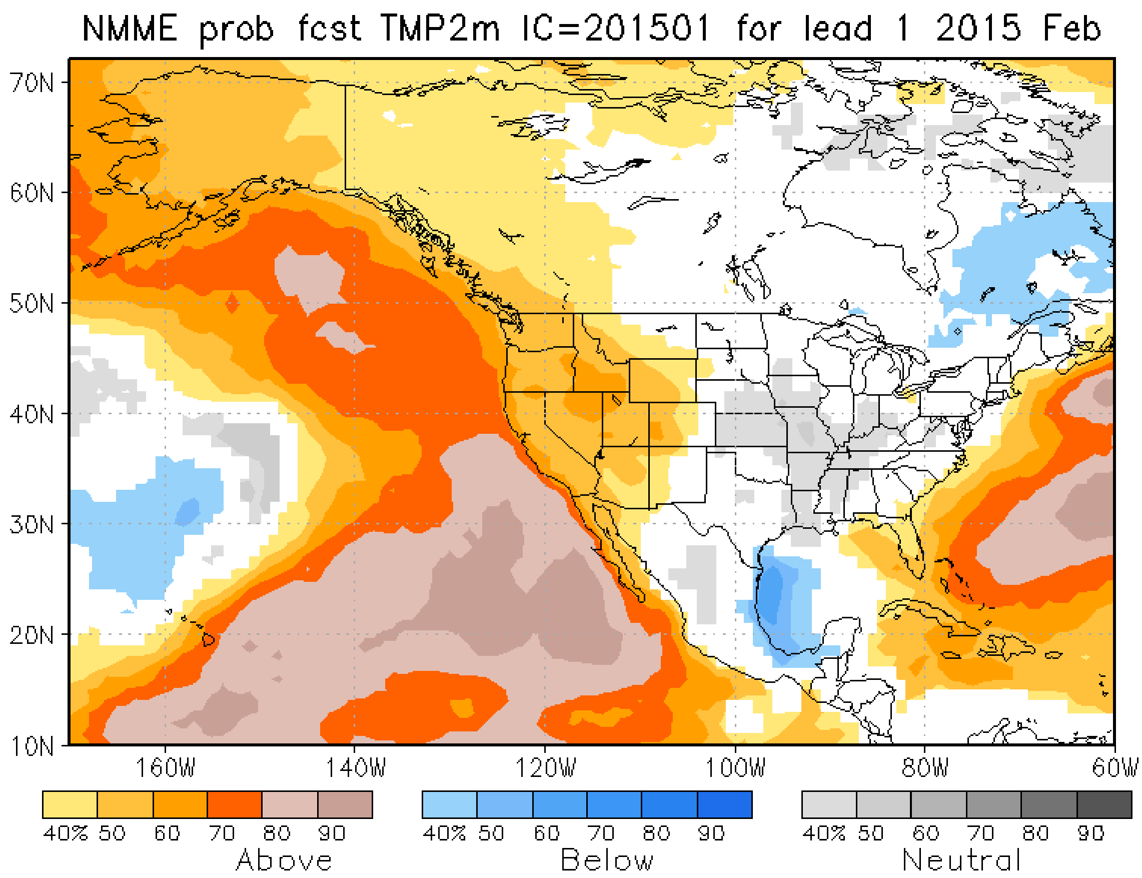


Figure 23. NMME forecast issued January 9, 2015, valid for February 2015. 2-m temperature tercile probabilities.

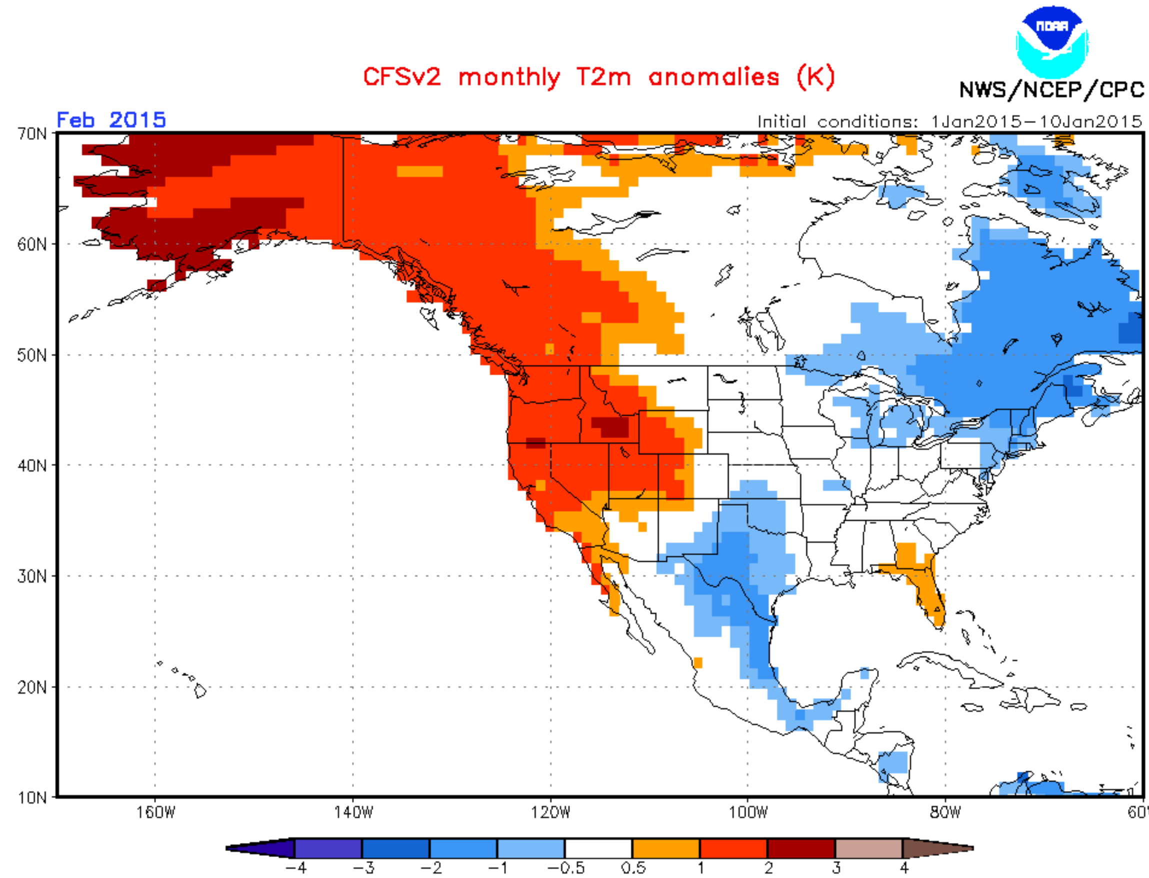


Figure 24. CFSv2 2-m temperature anomalies (K) based on initial conditions from January 1-10, 2015.

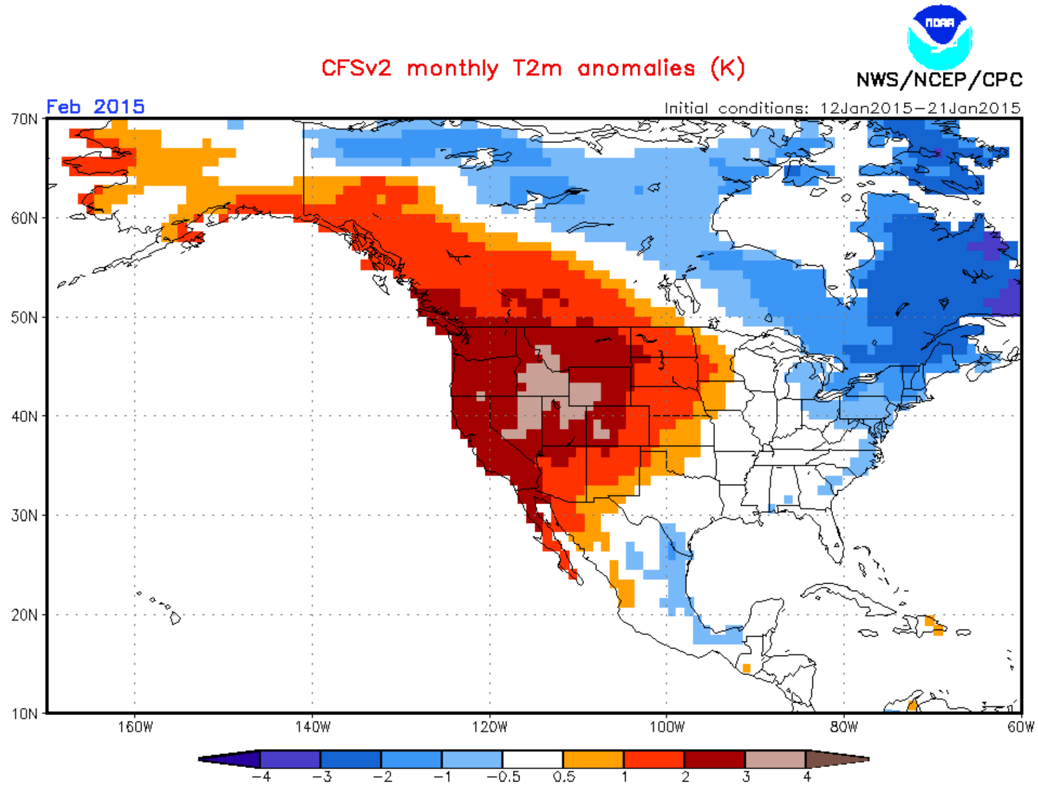


Figure 25. CFSv2 2-m temperature anomalies (K) based on initial conditions from January 12-21, 2015.

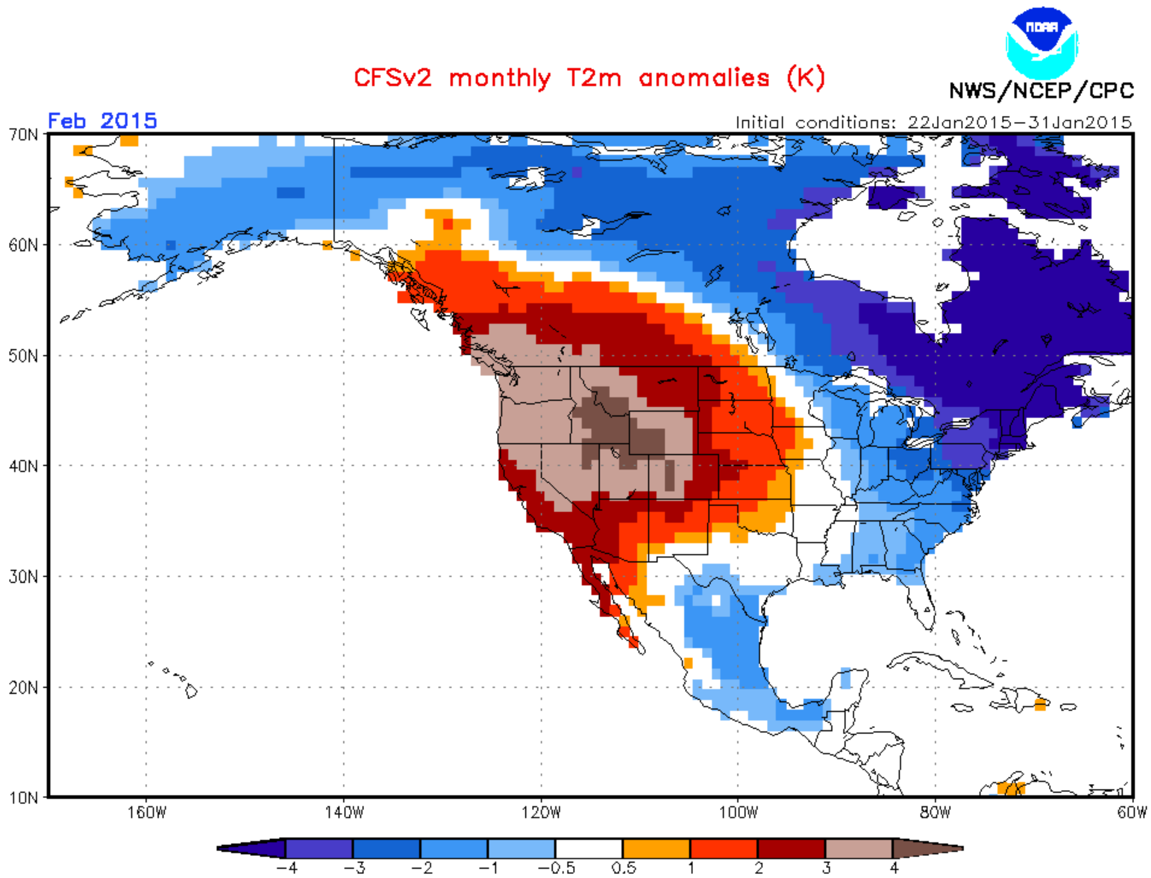


Figure 26. CFSv2 2-m temperature anomalies (K) based on initial conditions from January 22-31, 2015.

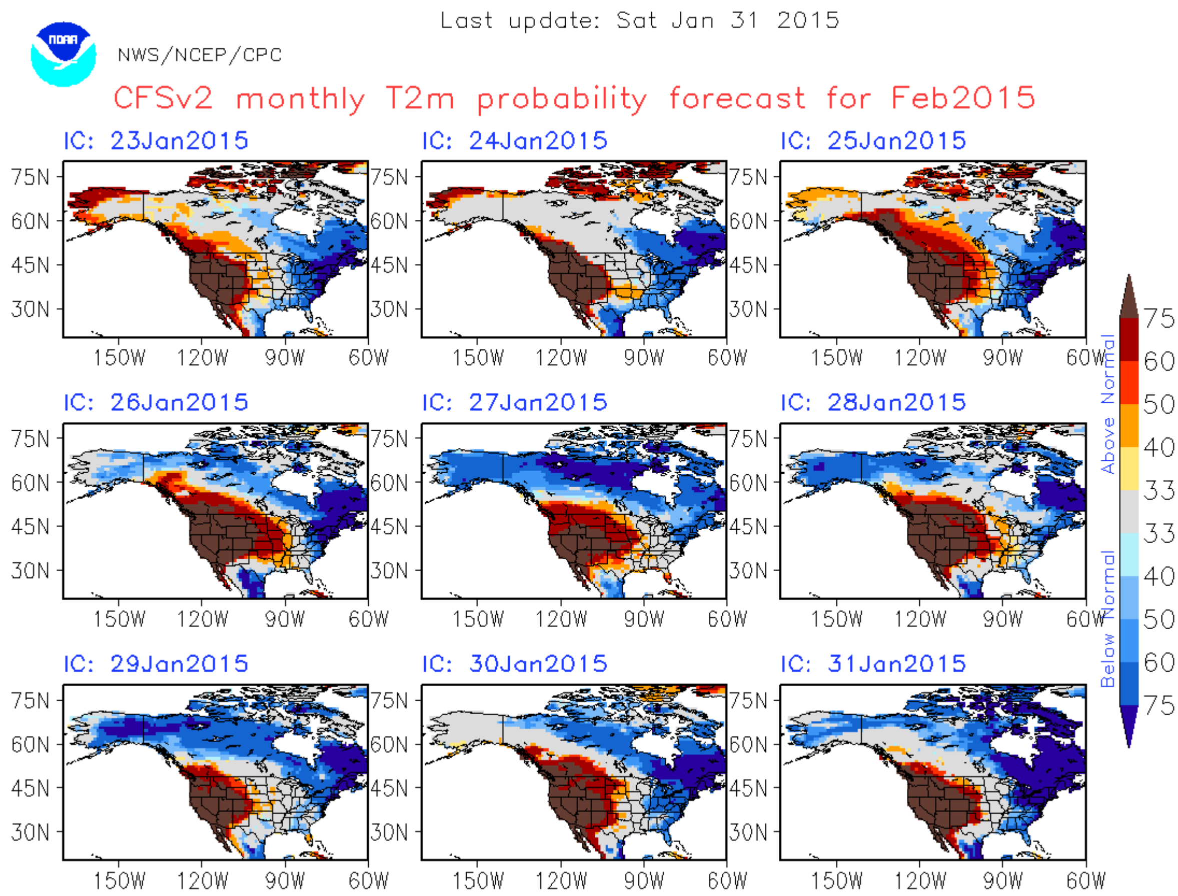


Figure 27. The daily CFSv2 2-m temperature anomalies (K) from January 23-31, 2015.

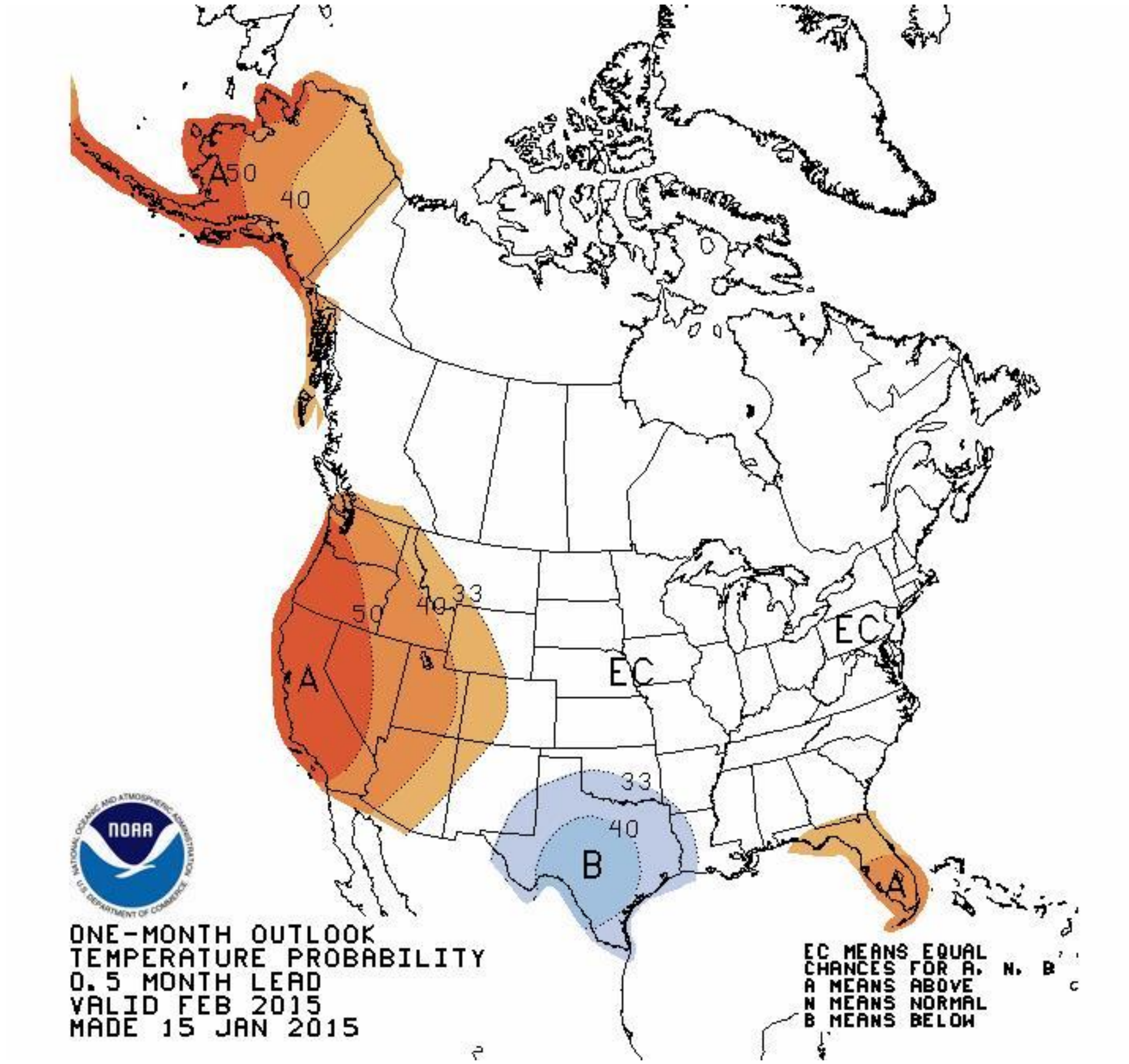


Figure 28. The official National Weather Service's Climate Prediction Center temperature forecast for February 2015 from the CPC that was issued January 15, 2015

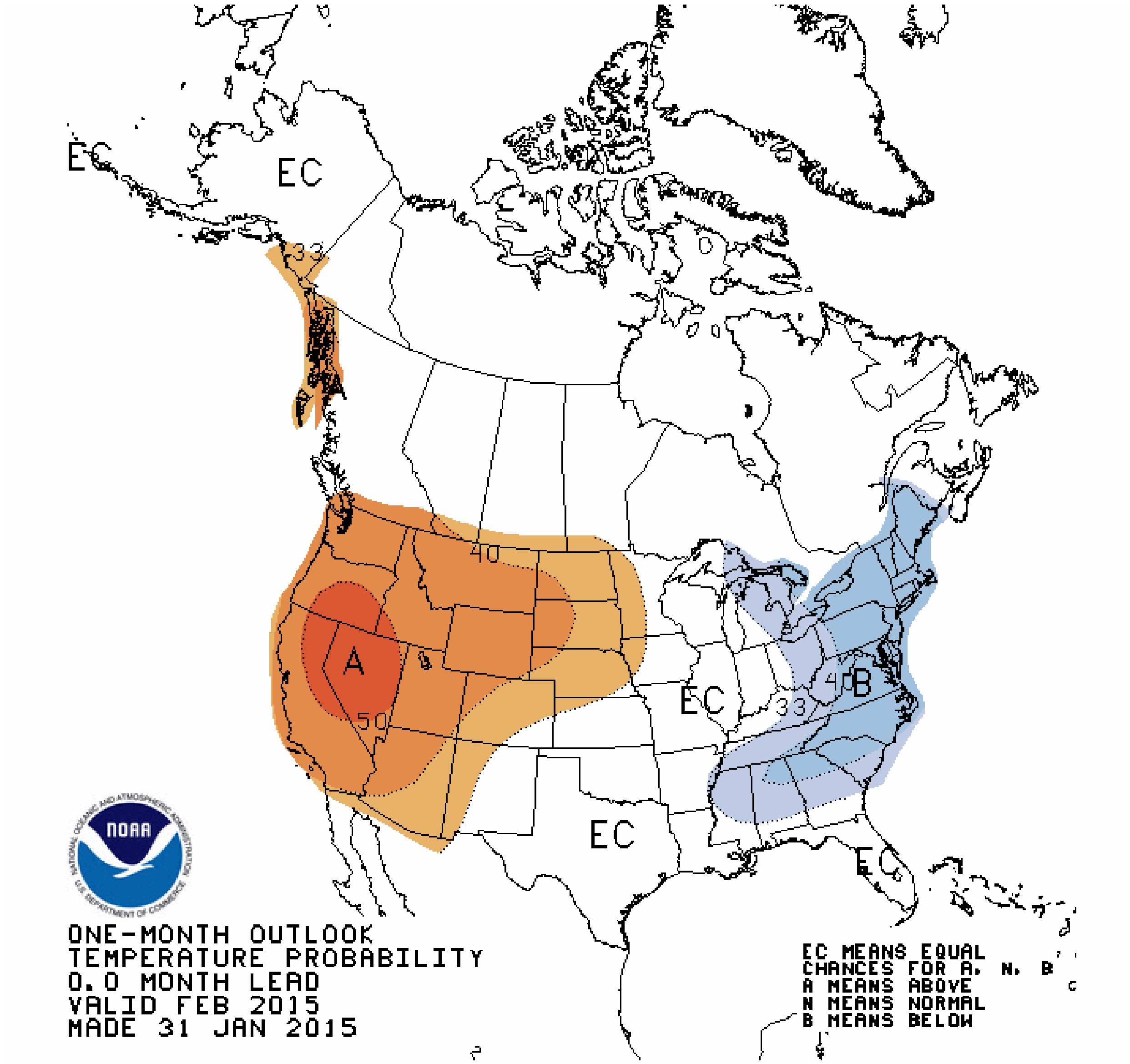


Figure 29. The final official National Weather Service's Climate Prediction Center temperature forecast for February 2015 from the CPC that was issued January 31, 2015.

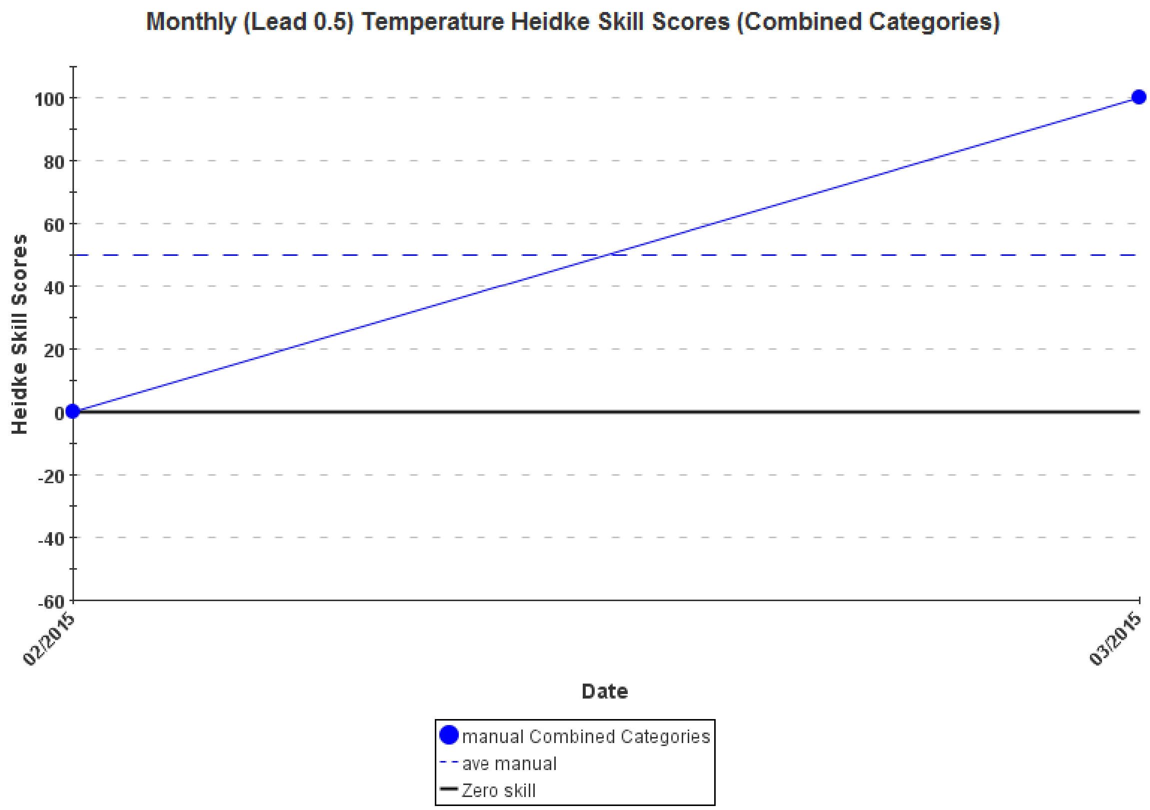


Figure 30. Heidke Skill Scores for February 2015 from the CPC forecast for Climate Division 1-9 (excluding 6) issued on January 15, 2015. Source http://www.vwt.ncep.noaa.gov/

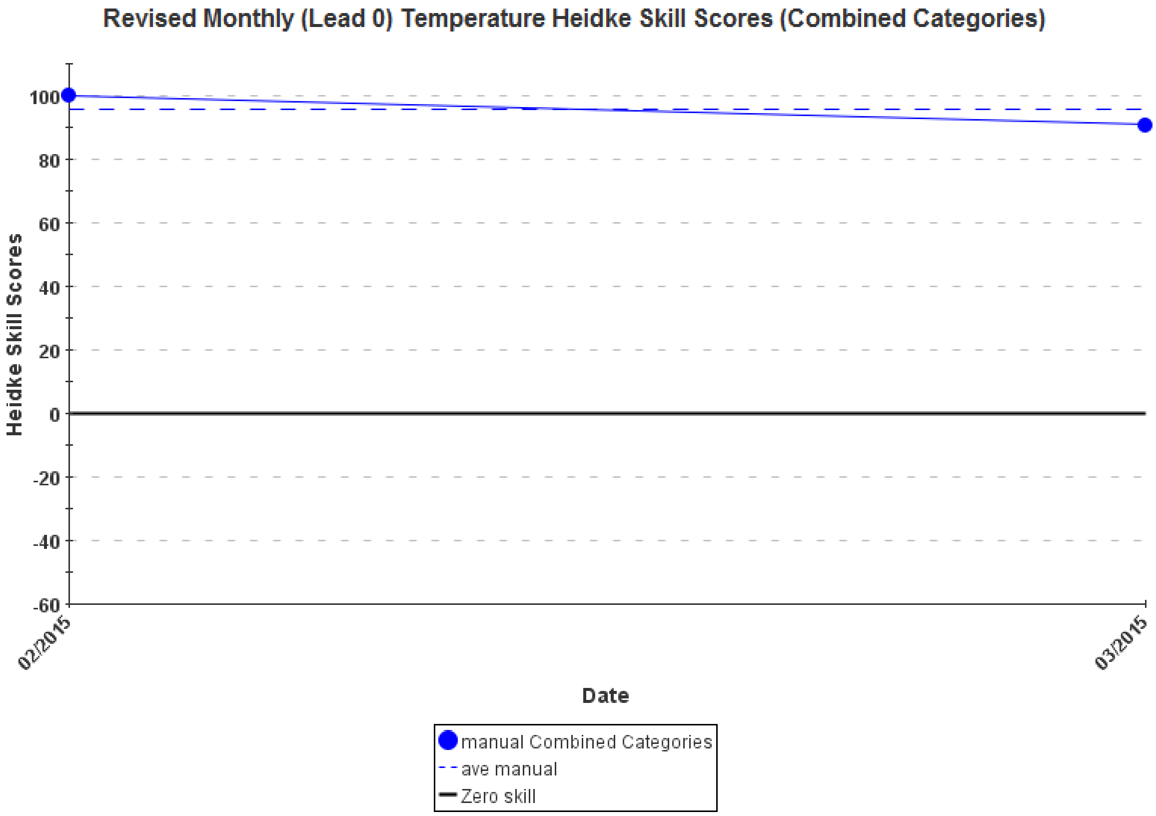


Figure 31. Heidke Skill Scores for February 2015 from the CPC forecast for Climate Division 1-9 (excluding 6) issued on January 31, 2015. Source http://www.vwt.ncep.noaa.gov/

6. Conclusion

This paper showed that February 2015 was one of the coldest Februaries on record across the Northeast U.S., and in some locations the all-time coldest month on record. An upper air analysis showed that there was a very persistent pattern during the month with a strong ridge along the west coast of North America, and a strong downstream trough that extended from the Canadian Archipelago into the Northeast U.S. The pattern retrograded during the month, but only very slowly. This kept a fresh supply of cold arctic air across the Northeast U.S. all month. The lack of a well defined MJO, enhanced convection across the tropical west Pacific, and positive SST anomalies along the west coast of North America may have all played a role in the persistence of the upper air pattern. Surface cyclogenisis along and off the Northeast U.S. coast also likely played a role in keeping the cold air in place across the region.

Prior extreme cold months did not have a similar distribution to February 2015 in the 500 hPa geopotential height composite anomalies across North America. There is therefore not one common composite anomaly pattern in the 500 hPa geopotential heights that forecasters can look for when attempting to determine whether a month has the potential for being record cold, but rather different ditributions in the 500 hPa geopotential heights may lead to such exteme outcomes. The mean 500 hPa patterns did, however, show a mean trough in all cases across the Northeast U.S. Futher evaluation of the composite anomalies associated with extreme cold months would be a worthy endevour. Rapid surface cyclogenesis along and off the Northeast U.S. coast does appear to play an important role in reinforcing the cold air.

The NMME did not have a signal pointing toward an unusually cold February, and in fact the lead 2 outlook in December indicated an increased likelihood of above normal temperatures. The CFSv2, which is one of the component members of the NMME, did have an increasing cold signal during the month of January. The offical NWS forecast from the CPC issued on 15 January 2015 had no skill compared to a random forecast; however, the CPC forecast issued on 31 January 2015, accurately forecasted an increased likelihood of below normal temperatures in February. The climate models gave little lead time for such a significant event, and were unable to provide any guidance to the forecaster as to whether the anomalies would be record breaking. There are still a significant amount of unknowns that affect monthly climate forecasts and more work is needed to better predict these events.

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