Southern Stream Storm 11-17 February 2003:
Presidents Day Weekend Snow Storm

By
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1. Introduction

The East Pacific Pattern (EP) showed the development of split flow over the eastern Pacific in early February. The EP index, used to measure this pattern went negative in early February. The EP is an excellent measure of the character of the pacific jet as it enters North America. Similar to the North Atlantic Oscillation (NAO), which quantifies how the Atlantic jet flows into Western Europe. The split flow in early February allowed Pacific energy to move into northwestern North America and drag cold arctic air, and a massive arctic anticyclone, into eastern North America. The split then allowed southern stream energy to move across the eastern Pacific into southern North America. The ideal scenario for potential snow storms development with a strong slow moving anticyclone and a vigorous southern stream short-wave.

A series of weak waves traversed the southern United States. These waves led to some snow and ice in the eastern United States on the 6-7th and 10-11th of February. Then a strong arctic surge with an anomalous surface anticyclone took grip of eastern North America. On the 11th of February a strong eastern Pacific storm moved on shower under the block along the western Canadian coast. This storm brought heavy rains and mountain snows to southern California. A surge of 4-5 standard deviation precipitable water anomalies surged into southern California on the 11th and 12th with 3-4 SD anomalous low-level 850 hPa winds. Though the rain caused flooding, it was welcome to the drought stricken areas of the southwest.

This potent Pacific wave, actually two distinct waves, began to progress eastward setting the stage for a record snowstorm from the Mississippi and Ohio Valleys to southern New England as it interacted with a retreating arctic air mass. This storm would produce snowfall in the top-ten for the major Metropolitan areas from Washington DC to Boston. This would be Baltimore, MD largest single record snowfall. This would be Baltimore, MD largest single record snowfall and Boston's single day largest snowfall. It should be noted that the first impulse on 14-15 February produced 1-4 inches of snow and this snowfall total was added to the Baltimore storm total from the second impulse on Sunday. It could be argued that these were two separate events; counted this way Baltimore barely misses the record. The National Centers for Environmental Predictions (NCEP) Medium Range Ensemble forecast system (MREF) showed a strong east-west baroclinic zone, an anomalous surface anticyclone over New England an Quebec, and an anomalous low-level easterly jet over the Ohio Valley and mid-Atlantic region on the 16th and 17th of February. Model quantitative precipitation forecasts (QPFs) implied the potential for a major winter storm from as early as the 11th of February. There were some problems farther north and several MREF runs did not push the precipitation shield far enough to the north to produce the heavy snow in central New England and the Boston area. The NCEP precipitation verification page showed this problem. http://wwwt.emc.ncep.noaa.gov/mmb/ylin/pcpverif/daily/.

The Canadian Meteorological Center (CMC) model provided useful guidance as to the potentially more northward precipitation shield. The CMC model was blended with the MREF and this blend showed a potentially more northward precipitation shield than earlier MREF runs.

As the storm unfolded, NCEP short range ensembles (SREF), stepped terrain model (Eta), and the medium range forecast output from the global forecast system (GFS) showed low-level pressure anomalies of +4 and -5SDs for the surface anticyclone to the north and the low-level easterly jet between the surface cyclone to the south. This, along with anomalous precipitable water anomalies to the south implied the potential for a record breaking snow storm along the eastern US. This storm had many features in common with the last major East Coast storm of 6-7 January 1996.

This paper will examine the conditions associated with the record snow storm of 16-17 February 2003. Of critical importance was the interaction of a strong pacific wave and a slowly retreating surface anticyclone. The resulting anomalous jet entrance

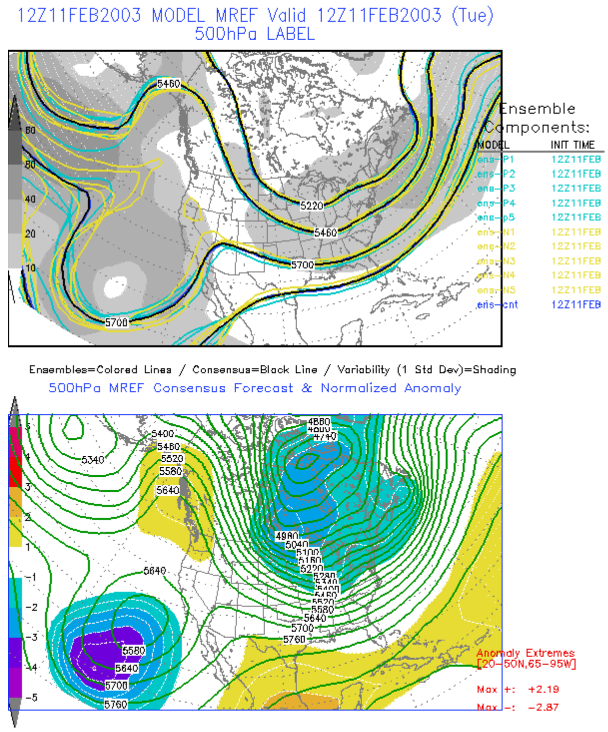

Figure 1. MREF 500 hPa heights (m) and departures from the 30-year climatologies in standard deviations from normal valid at 12Z 11 February 2003.

circulation would produce record snows in the Mid-Atlantic Region and ice in the Carolina's. Model forecasts and anomalies will be shown with an emphasis on the value of climatic anomalies to predict record events.

2. Methods

All model data were collected in real-time from the NCEP ftp site. The climatic anomalies were extracted from the database as in Hart and Grumm (2001). For comparison purposes, the NCAR-NCEP re-analysis data were used to compare the January 1996 storm to this storm.

Other data used include satellite and radar data taken off the World Wide Web in real time.

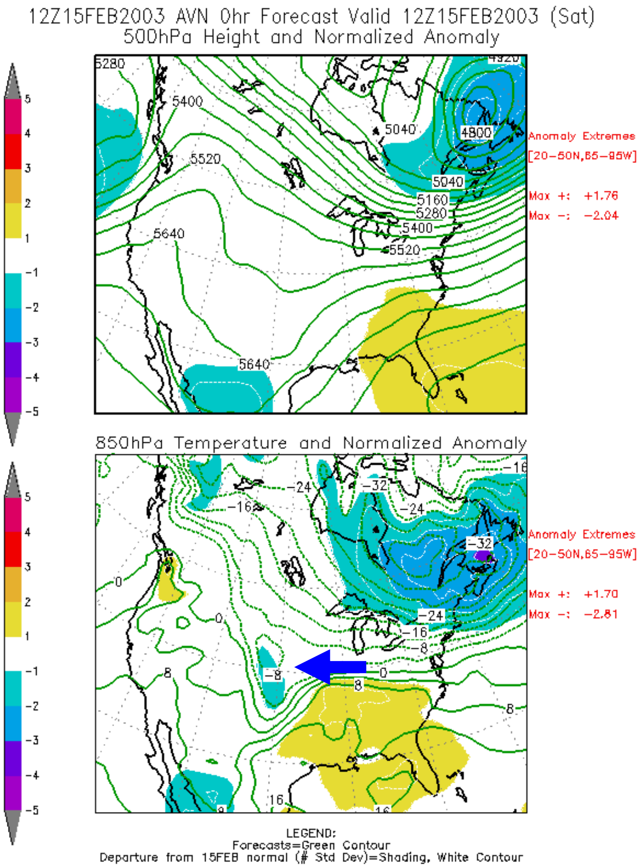

Figure 3. As in Figure 2. Except showing 00-hour GFS 500 hPa heights and anomalies and 850 hPa temperatures and anomalies. The blue arrow shows the axis of the 850 hPa wind anomaly maxima.

3. Overview

The split flow over North America and the strong pacific wave entering southwestern North America on 11 February 2003 in the NCEP MREF data from 1200 UTC is shown in Figure 1. Of particular interest is the deep 500 hPa low off the California coast (-3.5SD below normal) moving under the ridge in southern Alaska.

As the storm moved onshore, the low-level southerly wind anomalies were on the order of +3 SDs above normal with some areas of +5 SDs above normal in southern California. The PWAT anomalies were as large as +5 SDs

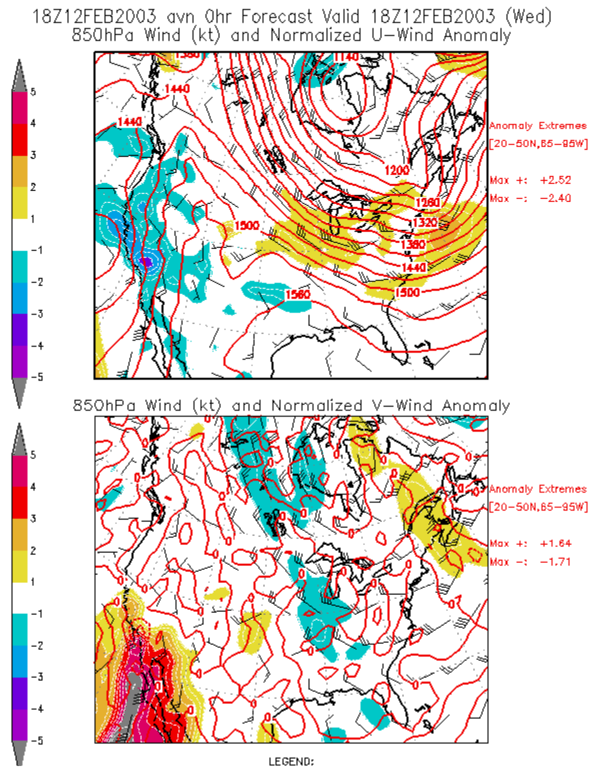

Figure 2. As in Figure 1 except GFS 00-hour forecast of 850 hPa winds valid at 1800 UTC 12 February 2002 showing a) U-winds, anomalies, and 850 hPa heights and b) V-winds and divergence.

above normal in the same areas. The output from the GFS valid at 1800 UTC 12 February is shown in Figure 2. These data imply a strong surge of anomalously strong southerly flow and moisture (PWAT not shown) into the region. Not surprisingly, flash floods and heavy rains impacted southern California. Long Beach, CA, the site of the 2002 *American Meteorological Society Annual meeting* had 2-3 inches of rainfall from the 11th to the 13th of February. Heavier rain was observed farther inland as the storm moved eastward.

By 1200 UTC 15 February, the upper level wave was east of the Rocky Mountains and began to interact with arctic air mass which had moved across eastern North America 24 hours earlier. This resulted in the strong baroclinic

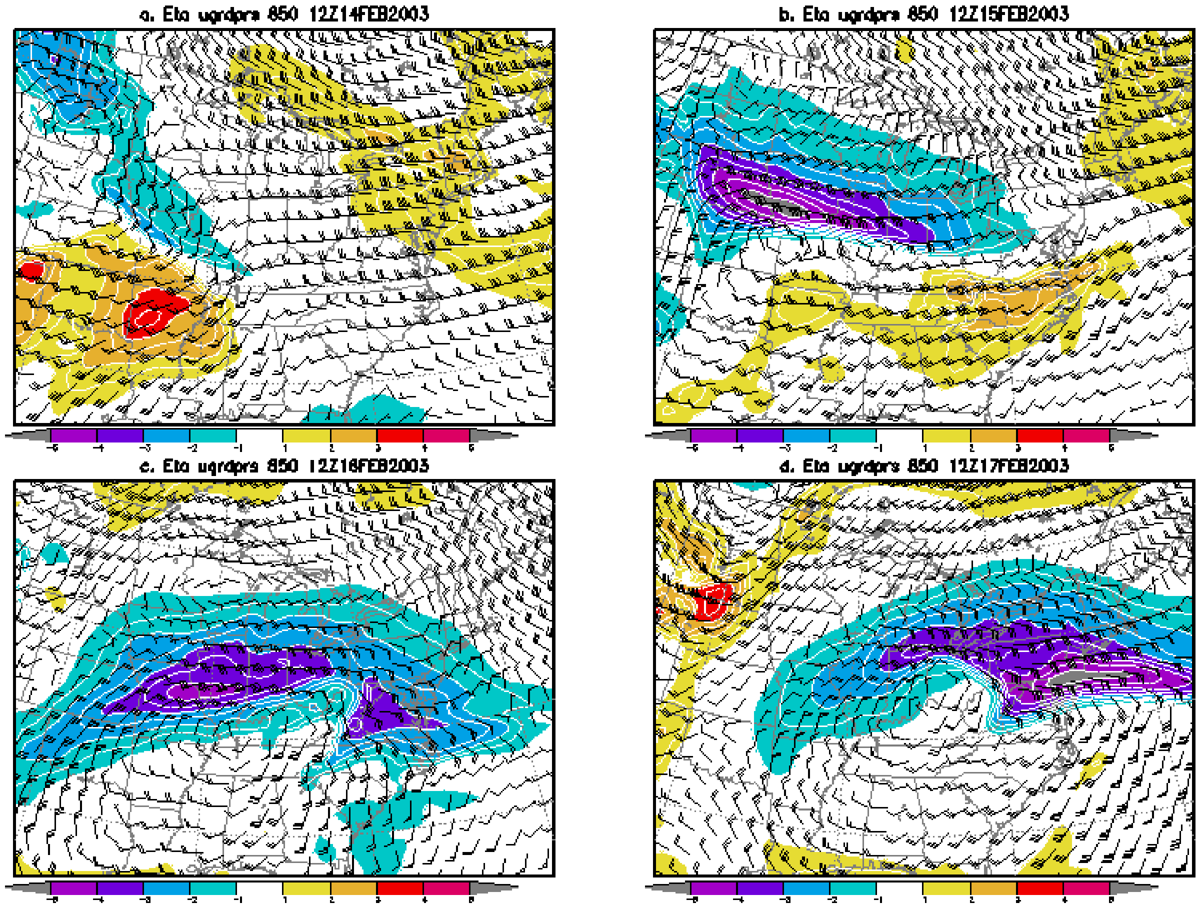

Figure 4 Eta 00-hour forecasts of 850 hPa winds and the u-wind anomalies valid at the times specified in the labels.

zone shown in Figure 3. Of key interest is the -1 to -1.5 SD trough over Mexico and the strong east-west baroclinic zone from the southern plains to the east coast. Note the pocket of -32C air at 850 hPa over New England and the warm anomaly over the Gulf States. The implies confluence in the 500 hPa contours suggested a broad jet entrance region over the region. Two features which stood out at this time in the jets were a +2.5 SD anomalous westerly jet over then northeastern US and a -4.2 SD easterly 850 hPa jet over the central plains (not shown). The low-level jet anomaly axis is shown by the arrow in Figure 3. At the surface, an anomalous 1030 hPa anticyclone was present over the Great Lakes. The central pressure of this anticyclone was on the order of +2.5 SDs above normal, with a modest surface cyclone to the south (not shown). Forecast implications about this are discussed below. The evolution of the low-level 850 hPa jet from the Eta initial analysis is shown in Figure 4. These data show the initial low-level jet (LLJ) over the central plains on the 14^{th}. By the 15^{th} this LLJ had strengthened and move eastward into the Midwest. By the 16^{th} a secondary LLJ had developed along the Mid-Atlantic coast and it moved northward up the coast on the 17^{th}. Snow developed in the cold air associated with this LLJ over the plains on the 14^{th} with heavy rains and thunderstorms to the south in the warm air. The LLJ which developed rapidly

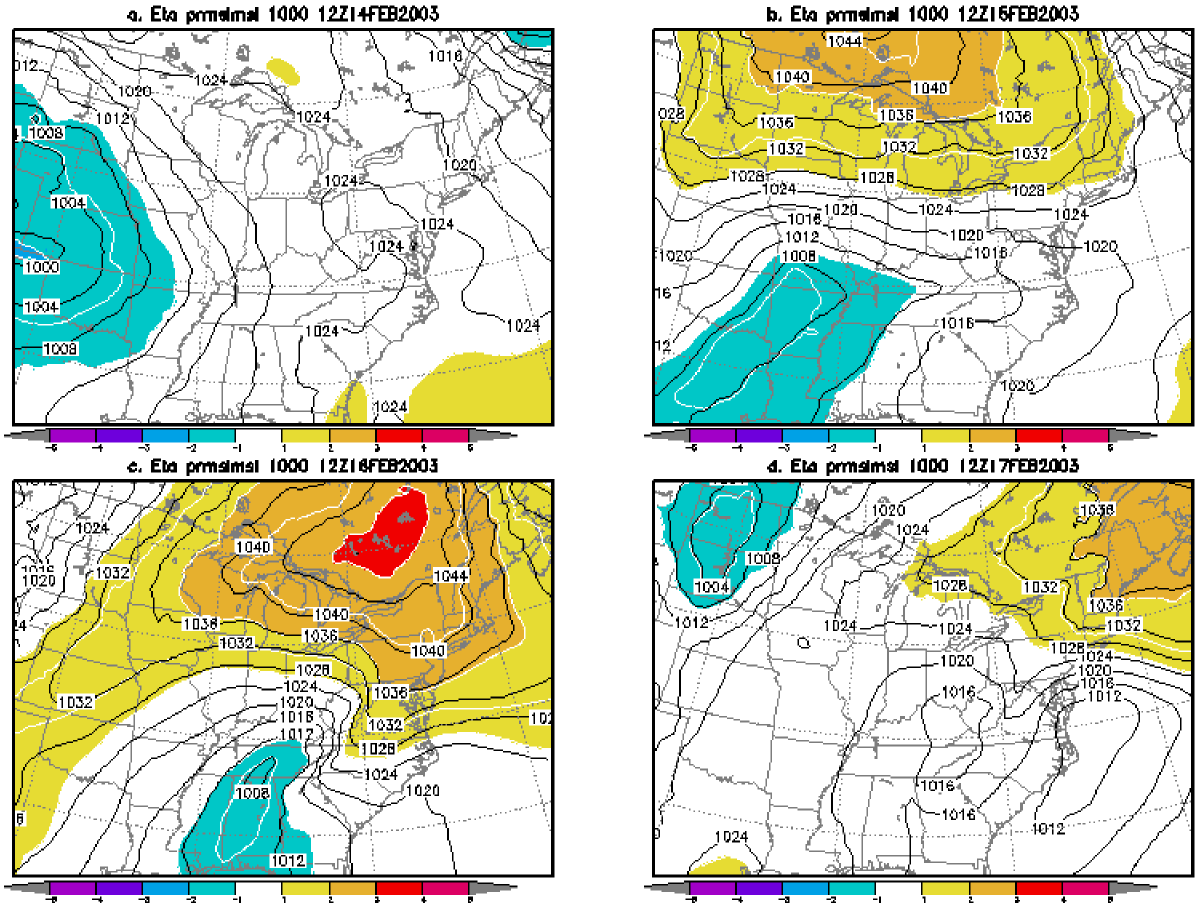

Figure 5 As in Figure 4 except Eta forecast of mean-sea level pressure (hPa) and standardized anomalies.

along the Mid-Atlantic coast early on the 16th moved very slowly northward, this led to the long and persistent snowfall in Maryland, Virginia, and Pennsylvania. This jet was in excess of -5SDs below normal by the mooring of the 14th (Fig 4d). This LLJ disrupted air traffic over the mid-west and along the Mid-Atlantic region on Saturday 15 February as moderate snow fell over a large area. The system began to deepen and the low-level jet strengthened. By 1200 UTC 16 February (Fig 4c) there was a -4.22 SD 850 hPa jet over the Illinois just north of the 850 hPa low center and a secondary jet of about -3.5 SDs below normal over Virginia and Maryland. Heavy snow was observed in both locations on Sunday morning at the nose of each low-level jet. Eta forecasts at this time implied a -5.5 SD low-level jet to develop in the Mid-Atlantic region by 1200 UTC Monday 17 February 2003. This jet was aimed at central Maryland and southern Pennsylvania implying a potential record storm by Presidents Day. Hard to imagine since over 12 inches of snow had already fallen by 1800 UTC 16 February over most of this region.

The Eta MSLP 00-hour forecasts show the evolution of the persistent and anomalous surface anticyclone which moved into the Great Lakes region on the morning of the 15th. By the 16th, the central pressure was over +3.5 standard

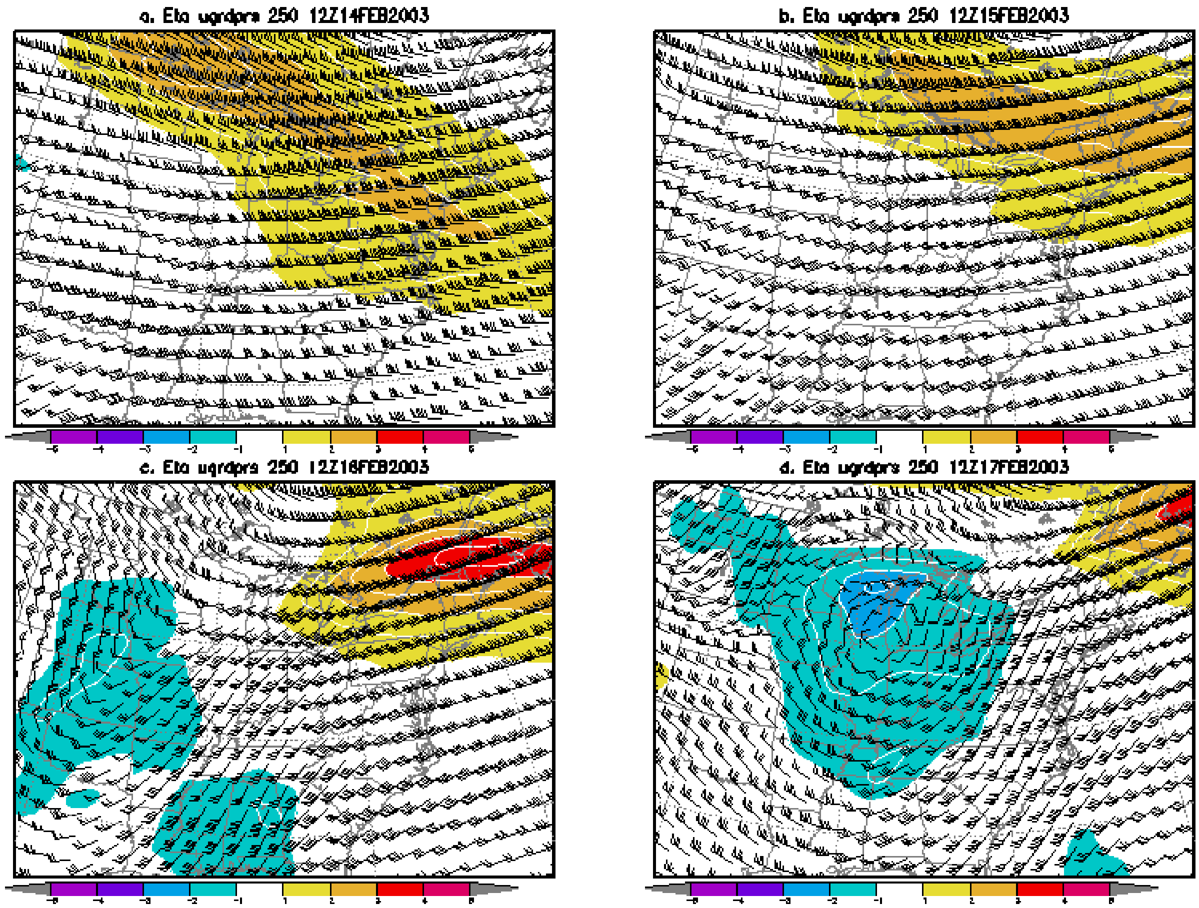

Figure 6 As in Figure 4 except 250 hPa winds and U-wind anomalies.

deviations above normal. The anticyclone slowly began retreating to the northeast on the 17th. The surface cyclones (primary died in southern Appalachians and secondary along coast) associated with this storm were nondescript in relation to more notable storms and relative to the anomalous anticyclone. It should be noted that the Christmas 2002 snow storm had a central pressure less than 970 hPa off Long Island and was about -4SD below normal. Critical to this ***snow event*** was the strong baroclinic zone and persistent jet entrance circulation, as the surface cyclones was not of any particular note.

The 250 hPa winds and U-wind anomalies for the period of 1200 UTC 14 February 2003-1200 UTC 17 February 2003 are shown in Figure 6. These data are for the same times as Figures 3 and 4. Of key interest is the +3.5 SD wind anomaly associated with the jet entrance region on the morning of the 16th. It is interesting how the wind anomalies define the jet and provide a feel for how significant this jet streak feature was on the morning of the 16th. The baroclinic zone associated with this jet is not shown. However, these data showed a pocket of -40C air at 850 hPa moving across Ontario, which is about -3.5SDs below normal. South of the frontal boundary, 850 hPa temperatures were on the order of +1SD above normal (see Figure Appendix). The maintenance of the surface anticyclone and the baroclinic zone were critical in this event.

4. Forecasts

i. Overview

There are many forecasts aspects one can take on this storm. A focus on QPFs would lessen the significance of the model success in forecasting this storm. However, it was clear that the NCEP MREF suite pointed toward a major precipitation event for the eastern half of the United States well in advance. The key to this overall successful forecast were the well forecast arctic anticyclone and the Pacific short-wave in the southern stream. This resulted in MREF and eventually GFS, Eta, and SREF forecasts of the anomalous LLJ. One could argue that the initial QPFs were a bit too far south and the models were slow to adjust for the more northward extent of the precipitation shield.

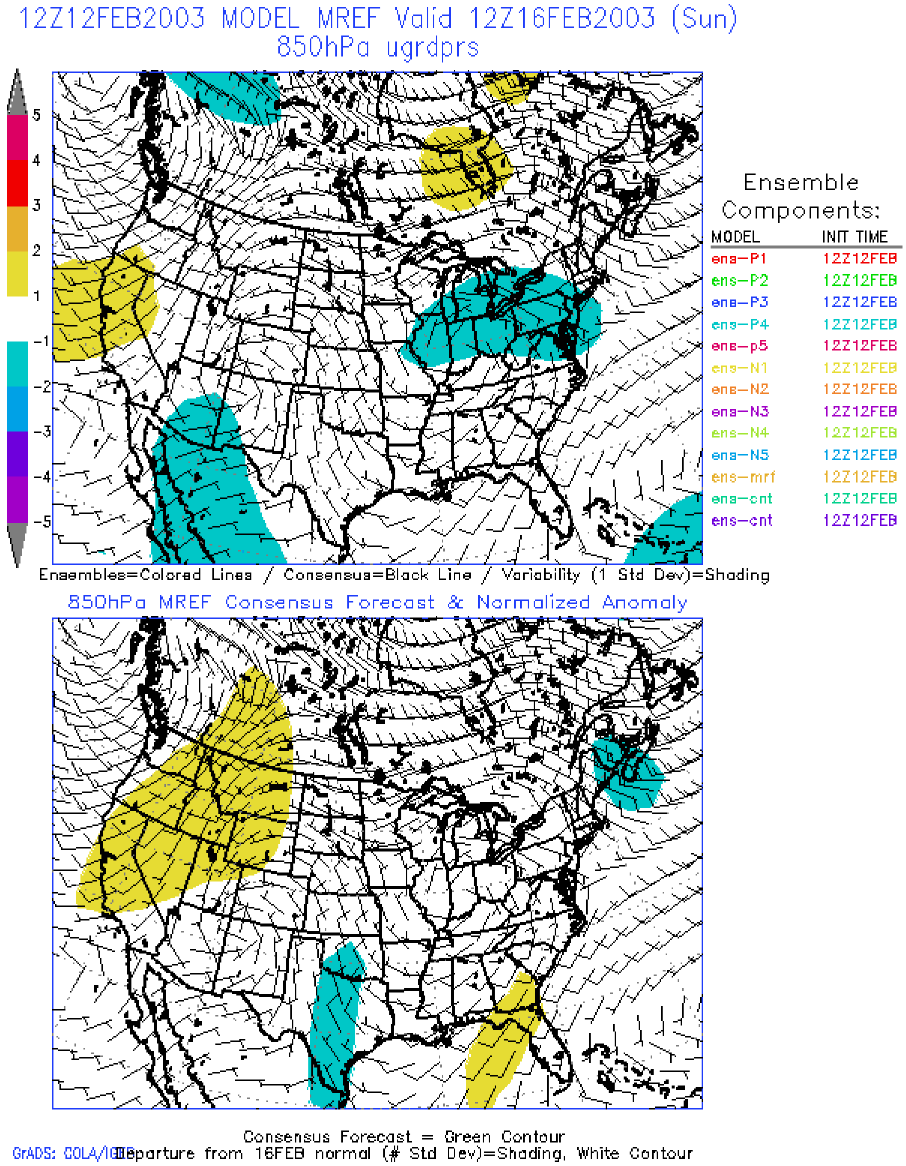

Figure 7. As in Figure 6 except MREF 850 hPa winds and a) U-anomaly and b) V-anomaly valid at 1200 UTC 16 February 2003.

ii. MREF

MREF forecasts by the 12th of February began locking on to the potential for anomalous easterly flow and cold air from the mid-Atlantic region and northward. Earlier forecasts show the potential for precipitation, but lacked the jet structures in the anomalies.

Forecasts from 1200 UTC 12 February showed an anomalous anticyclone over the Great Lakes, a strong low-level baroclinic zone over the Mid-West to the Mid-Atlantic region and a weak surface cyclone in the Tennessee Valley by 1200 UTC 16 February. The 24-hour QPF forecasts ending at 1200 UTC 16 February showed a very high probability of 0.2, and 0.50 inches of QPF from New Jersey to Missouri and to the Gulf States.

The 850 hPa winds and anomalies are shown in Figure 7. These data show the U-wind anomaly form New Jersey back to Missouri, a large part of the area in the cold air, north of the baroclinic zone, where the model was forecasting significant QPF amounts. A more N-S band was in the model QPFs in response to the warm moist southerly jet which was forecast to be over Florida and Georgia by 1200 UTC 16 February (lower panel).

Successive MREF forecasts continued to show the potential development of a significant precipitation event and at shorter ranges, the anomalies grew in size due to decreased dispersion amongst forecast members at shorter forecast ranges. By 1200 UTC on the 13th, MREF forecasts of 850 hPa winds were pointing toward a -3SD U-wind anomaly.

iii. Short Range

Due to the lack of blending, NCEPs Eta and GFS had the strongest signal for the strength of the LLJ and how anomalous it was. However, the SREFs did an incredible job forecasting this feature too. Despite being comprised of 10-12 members, the SREF wind anomalies forecast the double jet structure and LLJ very well. This feature was well forecast by both the 0900 UTC SREFs on both 14 and 15 February 2003. These forecasts, enhanced by the operational Eta and GFS are shown in Figure 8.

The SREF probabilities of 0.60 and 1.00 inch QPF is shown in Figure 9. Figure 9a shows that the SREFs forecast a high probability of heavy snow in the Mid-Atlantic region on the 16th from forecasts initialized at 0900 UTC 14 February. This was consistent with previous MREF QPF forecasts. Twenty

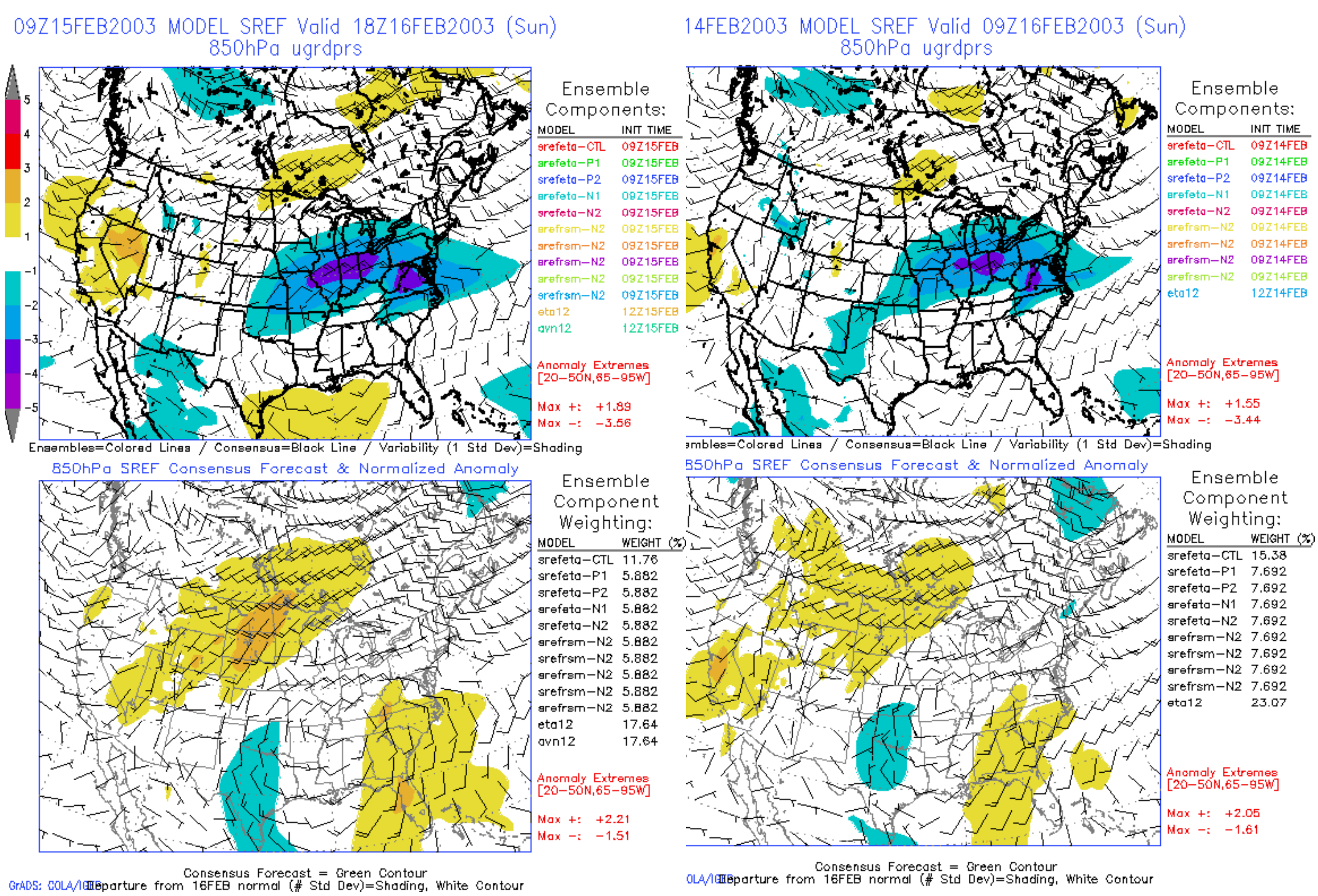

Figure 8 As in Figure 7 except SREF forecasts of 850 winds showing U and V wind anomalies. Forecasts are valid at 1800 and 0900 UTC 16 February 2003.

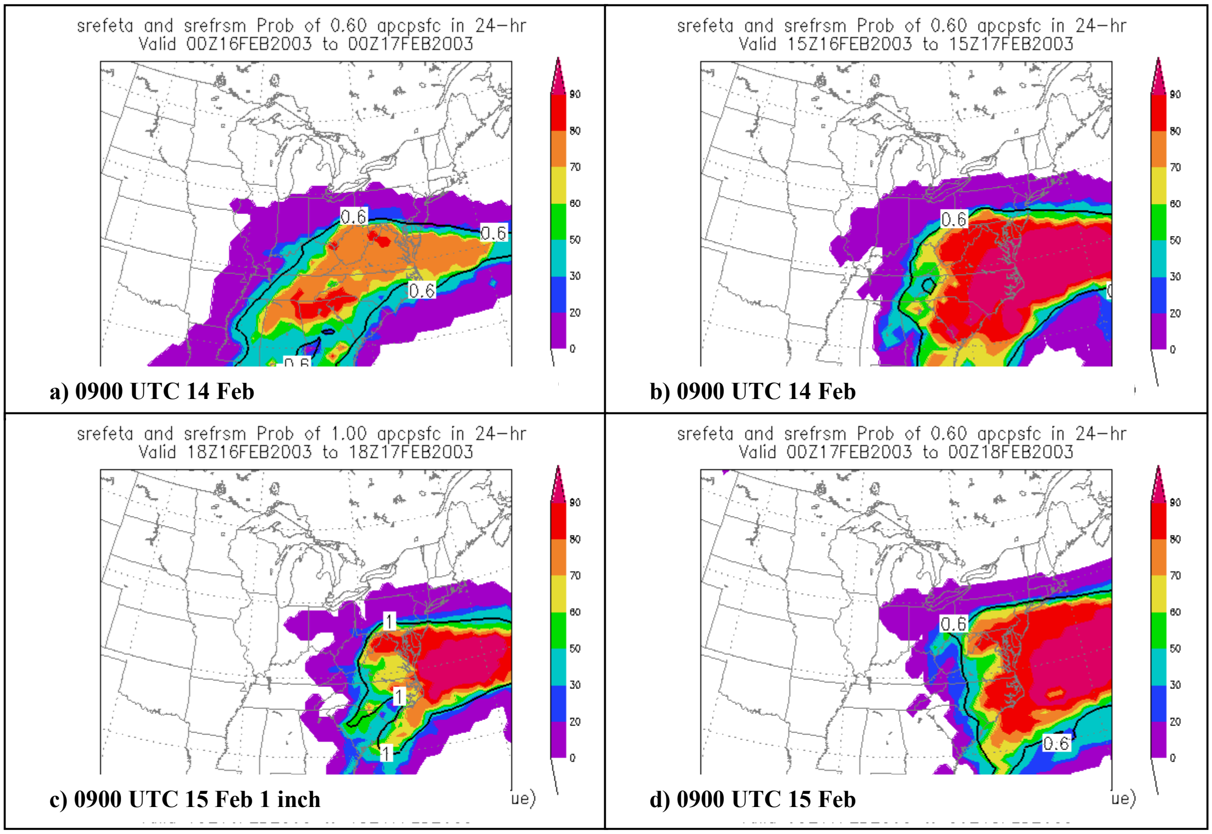

Figure 9 SREF 24-hour QPF 0.60 probabilities ending at the specified times. Model cycles are a) 0900 UTC 14 February, b) 0900 UTC 15 February c)) 0900 UTC 15 February and b)) 0900 UTC 15 February.

four hours later, the 0900 UTC 15 February SREF continued to focus the POPS in the Mid-Atlantic region. At this time, the model forecast a high probability of at least 1.00 inches of QPF in the Mid-Atlantic area (Fig. 9c) and a wide area of heavy snow (using a simple 10:1 ratio) for a broader area. The heavier QPF amounts were not forecast to reach the New York area until the 24-hour period of 0000 UTC 17-18 February (Fig. 9d). The 12-hour POPS gave more accurate timing, however the images below show how well the models forecast the high threat areas and outlined the timing quite well.

The SREFs did show nearly a 100% chance of at least 1.00 inches of QPF in the Mid-Atlantic region between 0900 16-0900 17 February. This included the cities of Washington and Baltimore. This provided excellent guidance as to where heavy snow was likely and with the wind anomalies that the potential for record snows were evident. Although not shown, the 850 hPa temperatures supported snow. However, the 700 hPa temperatures showed a brief period of about 0^{o}c air reaching to Baltimore implying the potential for some warm air aloft to create mix late on the 16^{th}.

Later forecasts from the SREFs at 2100 UTC 15 and closer to the event provided even better guidance and are not shown.

iii) Eta forecasts

The Eta performed quite well with this event, as did the SREF system, which include an Eta component. Although not

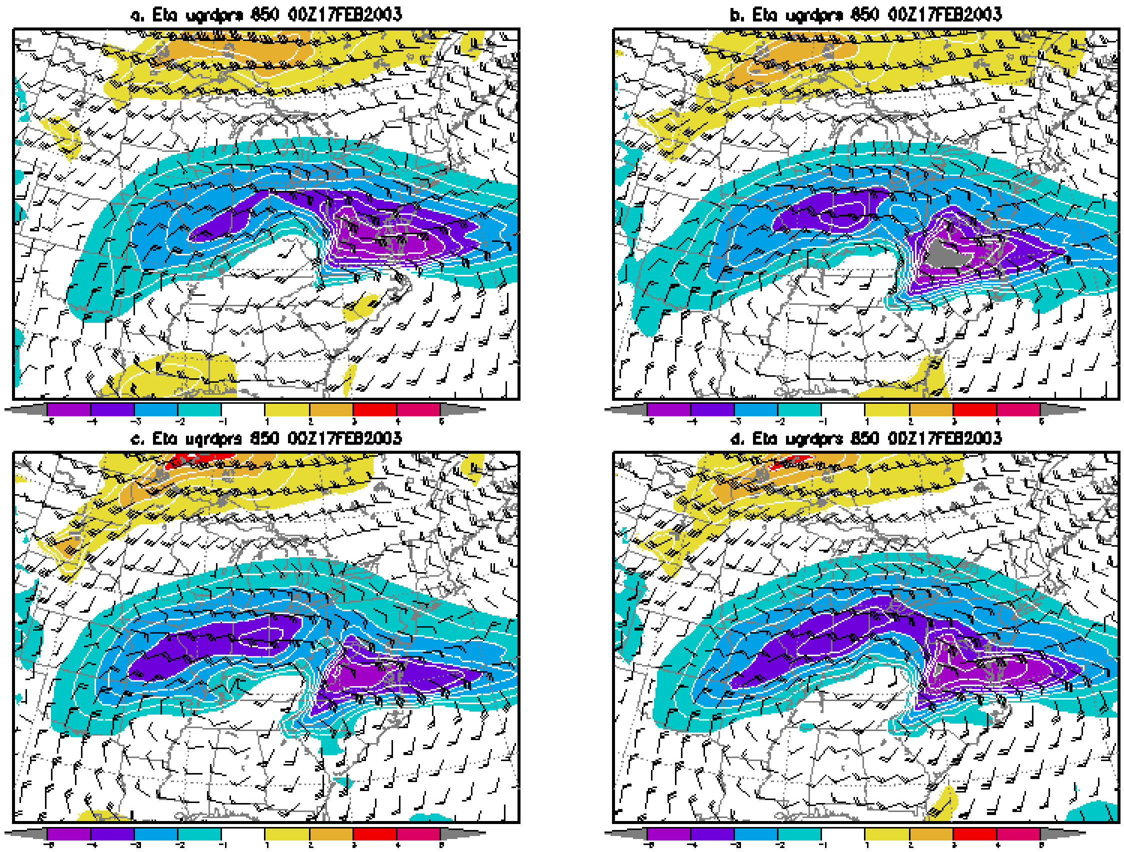

Figure 10 Select Eta 850 hPa jet forecasts all valid at 0000 UTC 17 February 2003 from forecasts initialized at a) 1200 UTC 14 Feb, b) 0000 UTC 15 Feb, c) 1200 UTC 15 Feb, and d) 0000 UTC 16 Feb 2003.

shown, the POP forecasts in Figure 9 include the operational Eta and GFS forecasts. The spaghetti plots showed that the Eta did quite exceptional with the area of heavier QPF. However, the focus here was on the Eta's excellent forecast of the LLJ which fed the Atlantic moisture into the Mid-Atlantic region, producing the heavy snow.

The Eta 850 hPa winds and anomalies are shown in Figure 10. These data are from the Eta every 12-hours beginning at 1200 UTC 14 February through 0000 UTC 16 February showing the forecast valid at 0000 UTC 17 February 2003. The key forecasts included the anomalous LLJ over the Mid-West and the secondary LLJ which developed in-situ in the Mid-Atlantic region. This anomalously strong low-level flow directed the low-level moisture into the Mid-Atlantic region and provided a hint as to the strength of the jet entrance circulation, thus producing the heavy snowfall.

Earlier studies of heavy rains and snow (Hart and Grumm 2001) have shown that the anomalous 850 hPa LLJ is a critical predictor of these features. The Eta produced an incredibly accurate forecast of this system. Although not shown, the GFS had a similarly successful forecast.

In addition to the anomalous low-level jet, the models also forecast a surge of anomalous moisture over the arctic air mass. This concept is illustrated by the Eta precipitable water (PWAT) forecasts valid on the 15th and 17th of February shown in Figure 10. These forecasts

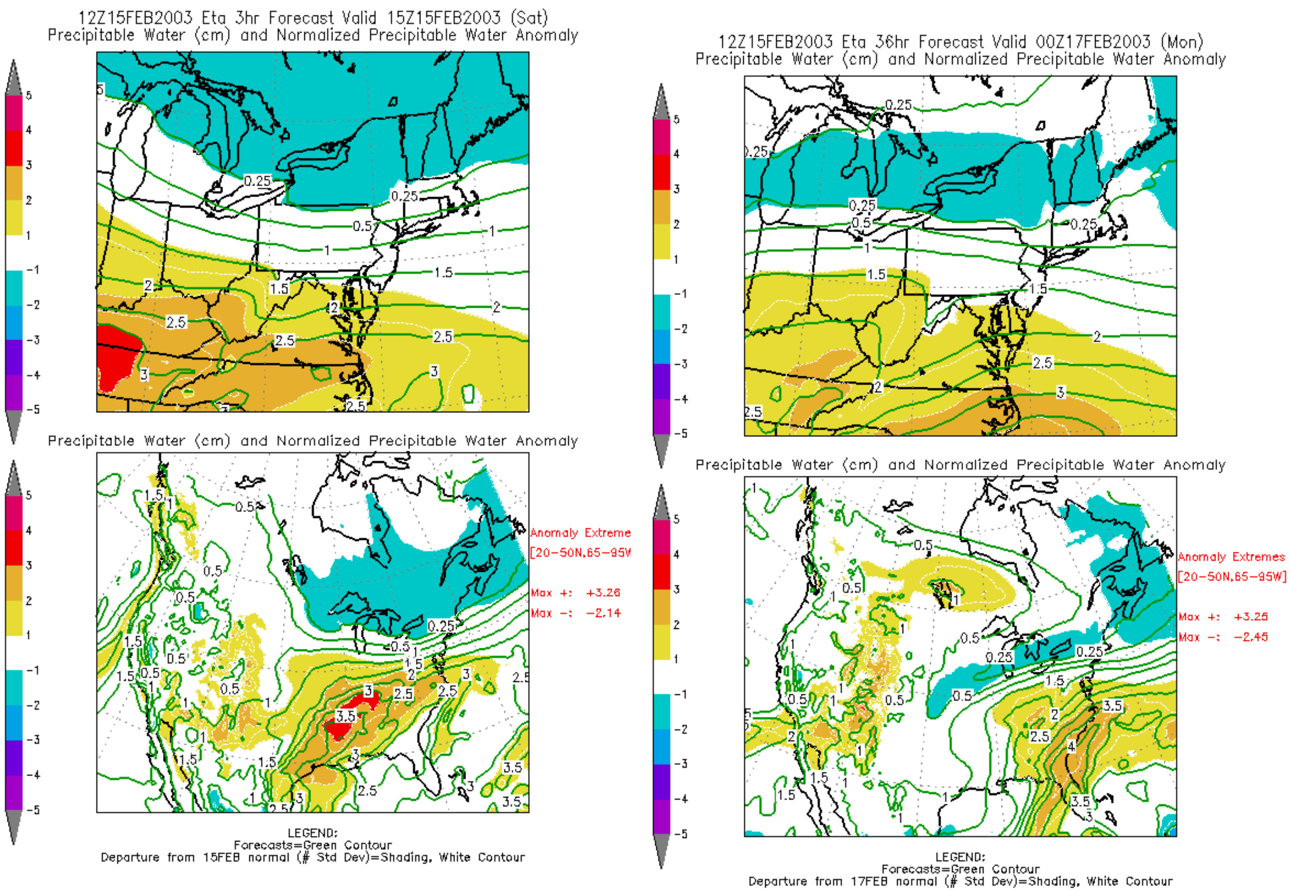

Figure 11 Eta forecasts of precipitable water (cm) and anomalies from 1200 UTC 15 February 2003 valid at a) 15Z 15 Feb and b) 00Z 17 February 2003.

showed the highly anomalous (+3.26SD) PWAT over Tennessee on the 15th. This likely contributed to the flooding in this area. On the 17th, anomalously moist air was attempting to move over the colder air. The pattern at 0000 UTC 17 February clearly showed the persistent influx of anomalous moisture into the region, supporting moisture for the heavy snowfall.

In the Washington, DC and Baltimore, MD area, the Eta model sounding (Fig. 12) valid at 0000 UTC 17 February showed that the warmest temperatures (-0.5C at 720 hPa) and the highest mixing ratios were in the warm, moist southwesterly air stream near 700 hPa. This moisture aloft likely contributed to the anomalous precipitable water values despite the extremely shallow low-level cold air. Note the sharp veering of the winds near 800 hPa. This implies that the high PWAT values were a reflection of the surge of Gulf moisture over the shallow low-level cold air. This sounding, combined with the Eta anomalies suggest how important the southern stream wave was in pumping tropical moisture into the region of the anomalous jet entrance region, which forced the low-arctic air southward (comments from Dr. Michael Fritsch, Stephen Jascourt and Dr. Lance Bosart).

5. Conclusions

The Presidents Day weekend storm of 2003 was a record breaking event. It produced heavy snow over a large portion of the densely populated megalopolitan corridor of the eastern United States and westward into the Mid-West (Fig. 13,additional views are in the Appendix). It was a classic example of the interaction of a potent southern stream Pacific wave forcing tropical moisture poleward and a slow moving arctic anticyclone, providing the necessary conditions for snow and sleet at low-levels. No doubt slightly blocked flow over the North Atlantic contributed to the persistence of the surface anticyclone and low-level baroclinic zone. The slow moving anticyclone was critical to the long duration of the snow and the maintenance of the strong low-level baroclinic zone.

Key features associated with this event included the southern stream wave, the anomalous arctic anticyclone, the resulting anomalous jet entrance region, and the resulting anomalous jet entrance circulation, estimated by the anomalous LLJ which was in excess of -5SDs below normal at times as it crept up the Mid-Atlantic coast. *One thing absent in this event, especially in the early stages, was a well developed surface cyclone*. The so-called storm was more of a prolonged and persistent snow event due to the ideal jet entrance circulation which was slow to move. Most of the snow in the Mid-Atlantic region was virtually unrelated to a significant surface cyclone. Clearly, a more pronounced cyclone developed with time and could be attributed to the heavy snow, in about half the time, in southern New England and Boston proper.

The anomalies and the relative position of the LLJ were relatively well forecast by the MREF, SREF, Eta, and GFS models. The climatic anomalies clearly played a critical role in identifying the snowfall potential of this winter storm. As shown by Grumm et. al (2002) the impact of high precipitable water anomalies is often associated with heavy precipitation. Grumm and Hart (2001b) and Hart and Grumm (2001) showed the importance of anomalous low-level easterly flow associated with heavy precipitation in the eastern United States. These examples showed both the climatic implications and the forecast implications. Grumm and Hart (2001a) showed how climatic anomalies can be related to East Coast Snow storms. This storm shared many of the common characteristics associated with east coast snowstorms (Kocin and Uccellini, 1990) and the climatic anomalies known to accompany these storms (Grumm and Hart 2001a). Clearly, the climatic anomalies forecast by the NCEP models, MREF and SREF systems allowed forecasters to readily visualize the potential for this significant snow storm.

Clearly, it was the confluence in the jet entrance region that kept the models predicting the developing storm and precipitation shield to from extending farther north. Overall, the models were also under estimated the depth of the trough in the southern stream when compared to model initial analyses.

The deeper than forecast southern stream trough and the slightly weaker confluence that verified allowed the precipitation shield and the eventual coastal cyclone to move farther north along the coast. The NCEP MREF forecasts were slow to pick up on the slightly weaker confluence and likely led to some earlier forecasts suggestion that significant snowfall would occur north of New York City. Therefore, this forecast was a great success in the Mid-Atlantic region but at longer ranges was not as well forecast in the northeastern United States.

This storm represents yet another in a succession of MREF and SREF forecast skill, with some noted exceptions. Both systems properly forecast the anomalous surface anticyclone and the southern stream wave. The former brought cold air into the region, favoring snow and the latter brought warm air and moisture into the region, favoring heavy QPF amounts. The warm air aloft also contributed to a major ice event in the Carolinas. The QPFs form the ensemble systems were sufficient to forecast heavy snow. One might argue that they missed the maximum amounts, which is always problematic. One problem with blending models is that the small disagreements in location make determining the maximum QPF difficult. Perhaps the maximum and its estimated location could be estimated from the ensemble member with the closest solution to the consensus forecast? However, the large agreement and well forecast anomalies suggested that this would be a record event. A job well done by the NCEP forecast suite.

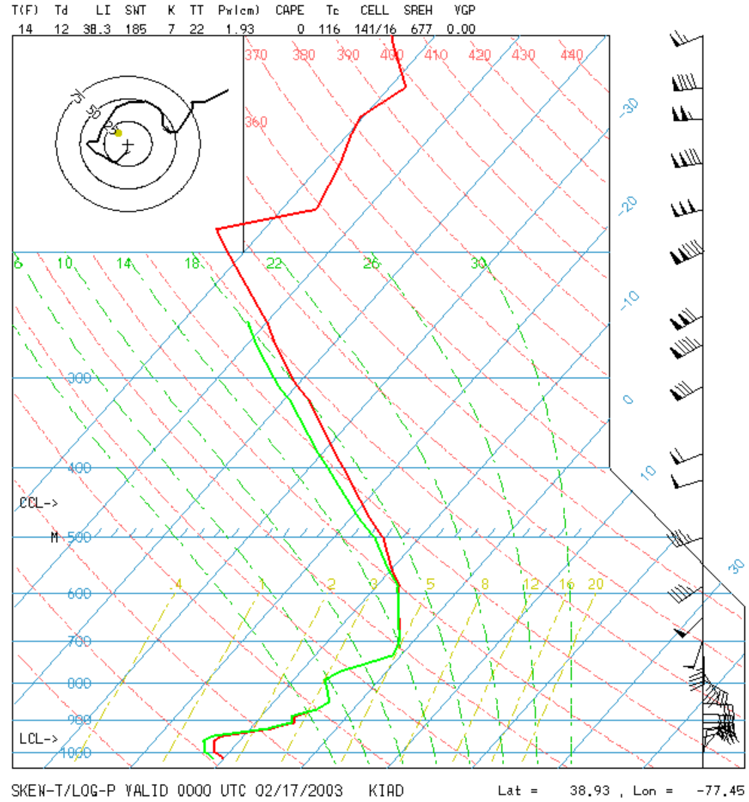

Figure 12. Eta model sounding for KIAD valid at 0000 UTC 17 February 2003. Courtesy of Dr. Michael Fritsch.

6. Acknowledgements

Data feed and GrADS support is provided by Dr. Robert Hart of the Pennsylvania State University. Climatic anomaly forecast use and encouragement is supported by the NWS Offices in State College, Washington DC, and Wakefield Virginia and Mr. Paul Knight of the Pennsylvania State University.

Comments suggested to improve the original are reflected in this document from Dr. Louis Uccellini (NCEP) who

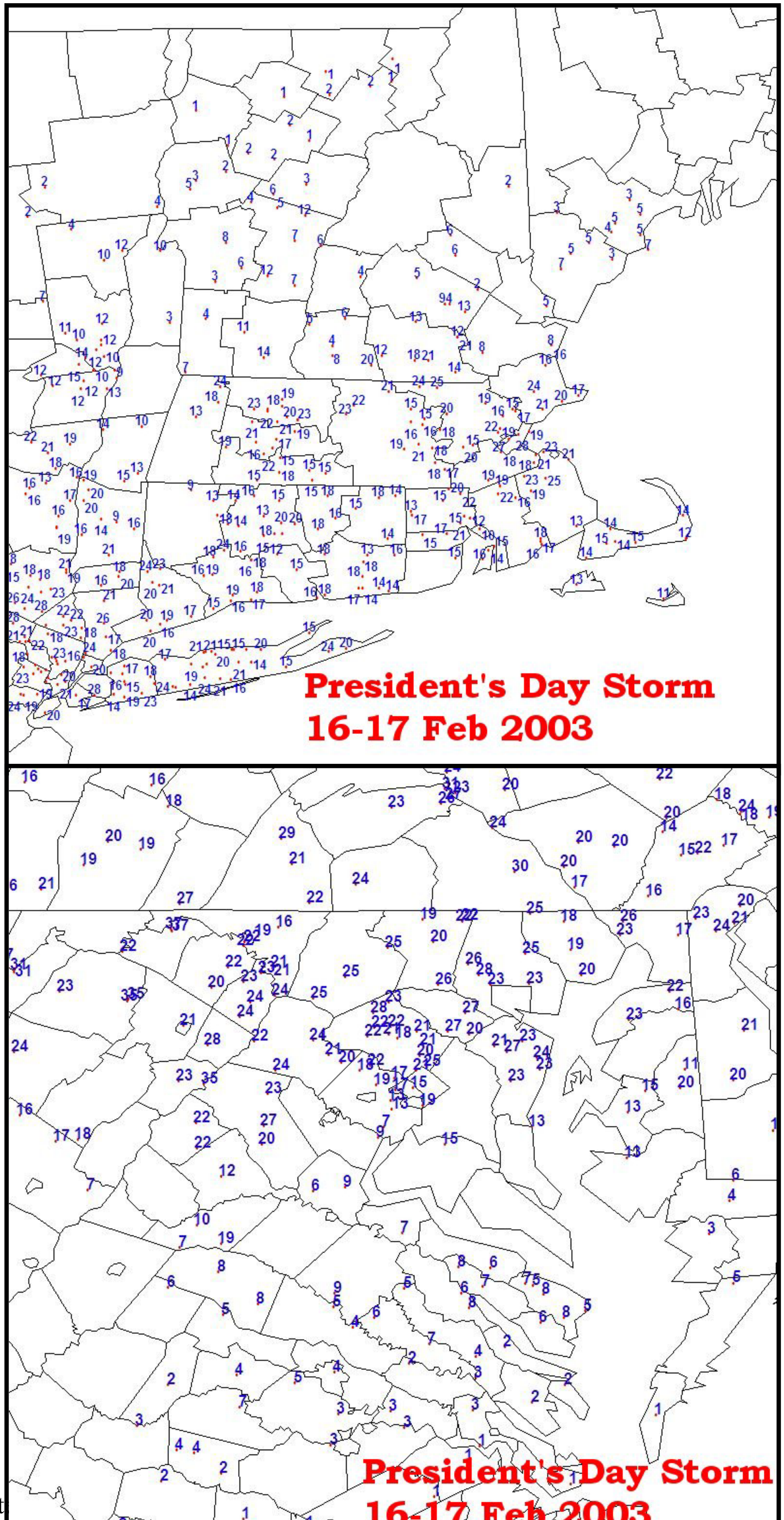

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Figure 13 Snowfall (inches) from spotters and cooperative observers showing the Mid-Atlantic (lower) northeastern United States. Courtesy John LaCorte.

entrance was critical, Dr. J. Michael Fritsch (PSU) for comments about the low-level cold air and the surge of warm air loft. He contributed Figure 12 to make the points cleare. Dr. Stephen Jascourt (NCEP) for many edits and suggestions about the importance of the flow of warm air over the cold air and model errors related to the trough intensity and over forecasting of the jet entrance region circulation, and Dr. Lance Bosart (SUNYA) for comments on the events. Hope Albany gets a Bronze metal for snow by getting 5.4 more inches to reach 100! Another foot and a half and it's a Gold Metal, 112.5 in 970-71 look out.

Snowfall analyses were provided by John LaCorte (NWS-State College) using data from varied NWS offices showing how important data sharing is. Ron Holmes (NWS-State College) for web access to these reports and studies.

7. References

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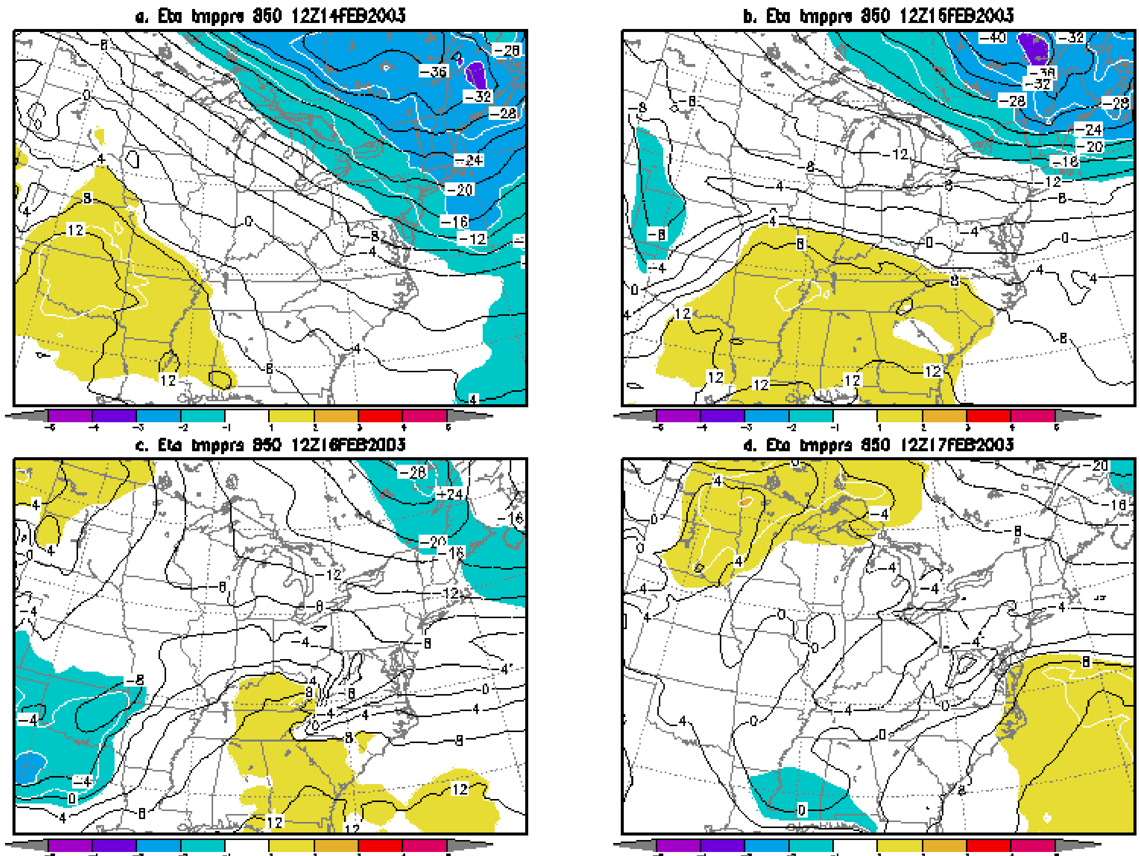
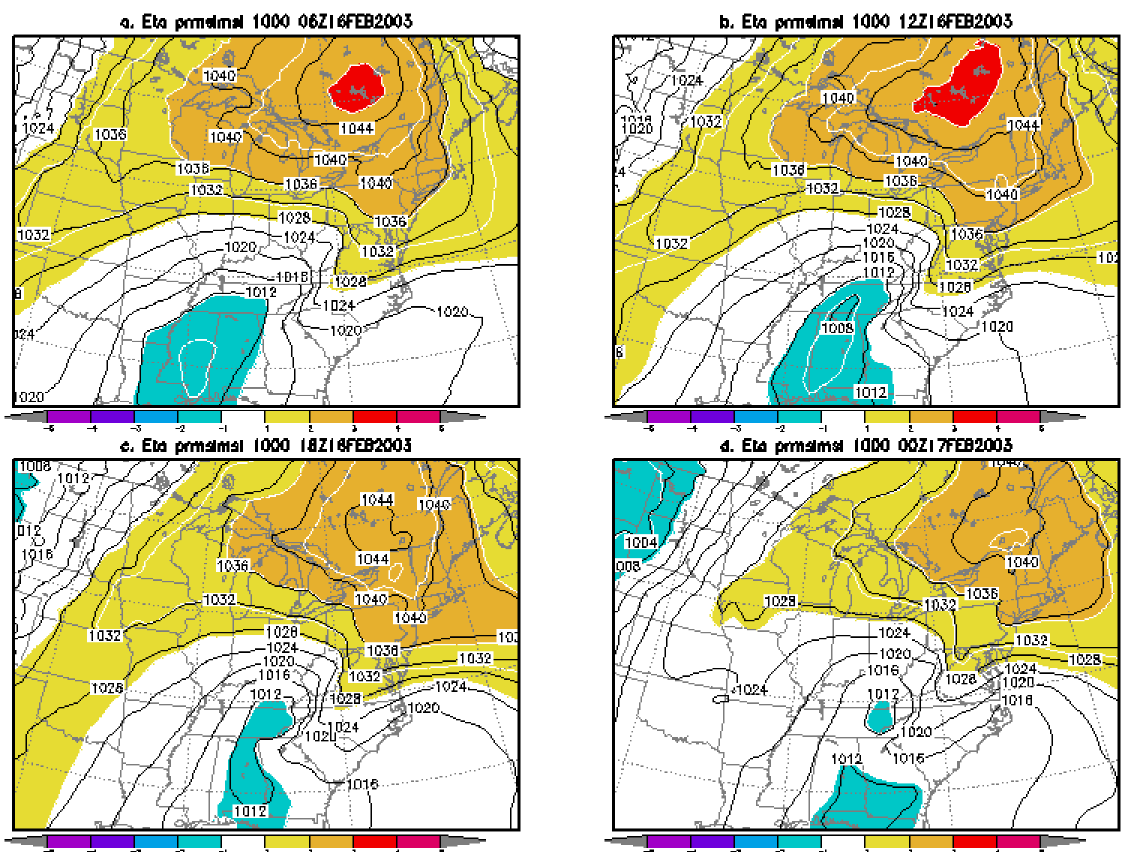
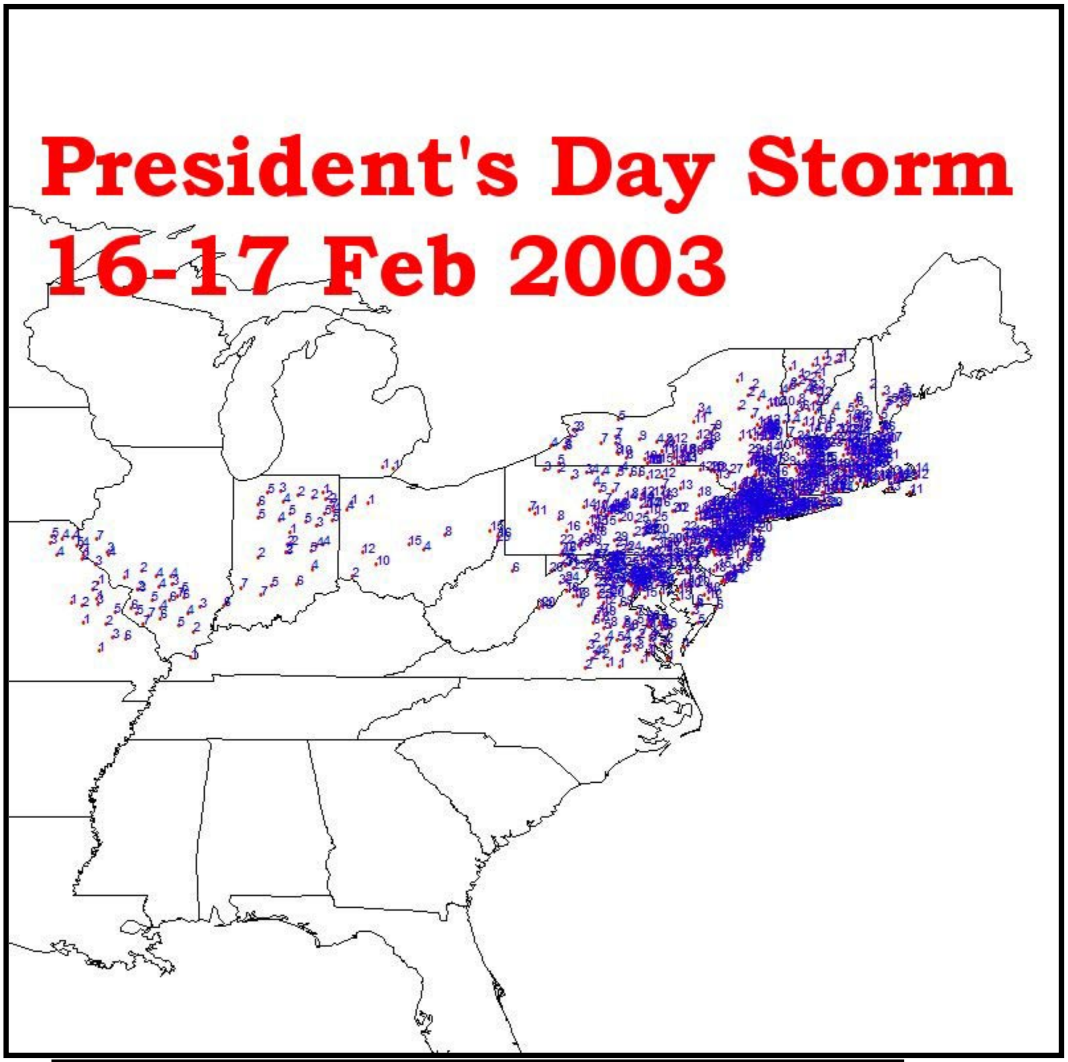
Appendix Figures






President's Day Storm
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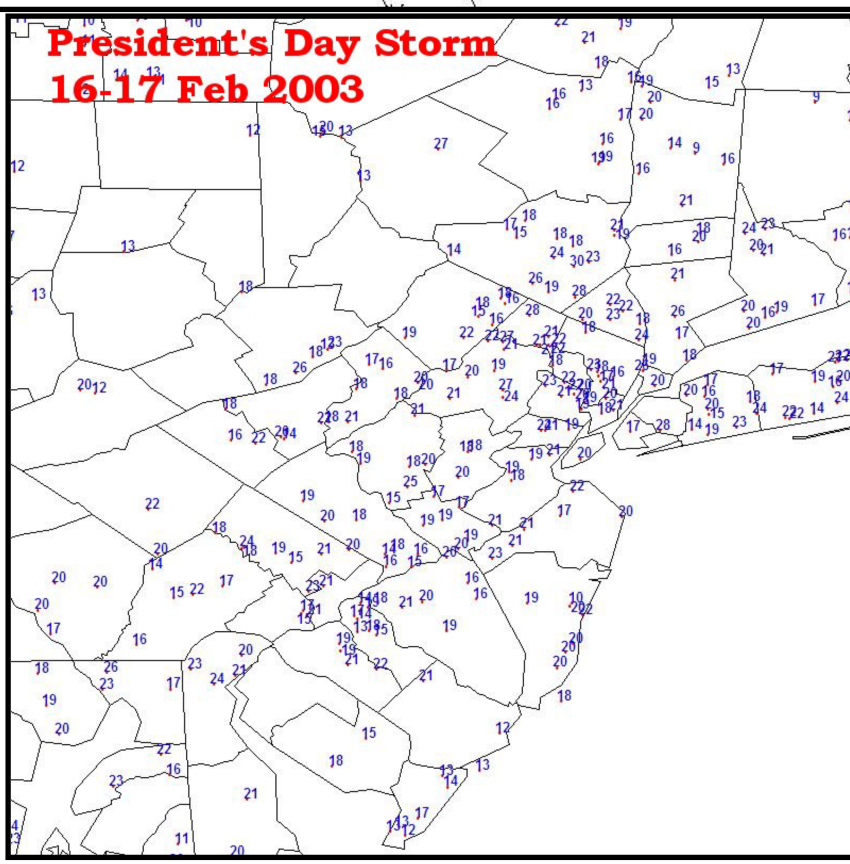
President's Day Storm
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Albany Snow Records as of Feb 2003:

1) 112.5" 1970-71
2) 110.0" 1887-88
3) 99.6" 1890-91
4) 97.1" 1981-82
5) 94.7" 1915-16
**6) 94.4" 2002-03
7) 94.2" 1992-93
8) 94.2" 1886-87
9) 92.4" 1977-78
10) 90.0" 1947-48