P2.2 ATTRIBUTION OF EXTREME VARIABILITY OF TEMPERATURE TO MAJOR TELECONNECTIONS AND DEVELOPMENT OF PROBABILISTIC AIDES FOR DECISION MAKING USING LOGISTIC REGRESSION: A CASE STUDY OF A FLORIDA FROST HOLLOW

Bartlett C. Hagemeyer, CCM*
NOAA/National Weather Service, Melbourne, Florida

1. INTRODUCTION

Hagemeyer (2007) provided an update of the continuing efforts to predict extreme storminess, rainfall, and temperature variability during the Florida Dry Season (1 November - 30 April) from major teleconnections, and offered a philosophical discussion of predictability and attribution issues that might lead to the development of seasonal outlooks of extreme localized events. The extreme events of most significance during the Florida dry season are excessive stormy periods, excessive rainy and dry periods, and extreme cold weather outbreaks.

Hagemeyer (2007) stated that" *...a wide variety of users might benefit from predictions of the occurrence of extreme weather within a season of means. Extremes of weather that are most impacting are typically hidden in the mean seasonal conditions. The author is in favor of forcing the issue of forecasting extreme weather from larger climatic signals and identifying strengths and weaknesses to focus future research. Extremes of seasonal measures of temperature and rainfall are made up of extreme weather events. If the deviations from the means are correlated, it is likely the actual events contributing to the deviation may well be correlated. Interestingly, a seasonal forecast of 3-6 months is theoretically more accurate, as defined by the predictor/predictand relationships, than is a forecast of extreme weather, say 10 to 14 days in advance. But that doesn't always mean the existing predictor/predictand relationships are the most relevant. It is the author's opinion that seasonal forecasts should focus more on variables that define extreme events for a given area rather than above/below normal mean temperature and rainfall."*

The author was intrigued by trying to develop extreme weather predictions of a probabilistic nature out of climate forecasts and large-scale teleconnections. The goal was to determine whether the exceptional relationships between some teleconnections and the probability of occurrence of extreme weather for Florida using Logistic Regression (LR) techniques (Wilks 1995) could be adapted for much smaller areas such as specific work or "impact" sites. The inherently probabilistic nature of LR is appealing, and it can be used to identify a very specific extreme weather scenario and correlate the database produced for that variable with major teleconnections.

The primary purpose of this paper is to stimulate interest in pushing the envelope in seasonal forecasting into unique impact variables relevant to specific areas and users. There are certainly potential benefits as well as risks to such approaches, but society continues to become more sophisticated in its ability to understand the interrelationships of weather and climate and the underlying uncertainties. The goal should be to broaden the constituency that can make educated decisions to exploit the evolving knowledge of climate and weather by taking advantage of benefits and by reducing risks.

A unique opportunity to test the use of logistic regression in developing seasonal forecast decision aides for a very specific user, location, and critical forecast problem came to light in November 2007. Jerry Conrad, the National Weather Service (NWS) Cooperative (COOP) Observer at Plymouth 3N (PLTF1) in northwest Orange County, Florida (Fig. 1), reported to the supervising NWS office in Melbourne, Florida, the occurrence of a minimum temperature of 30°F and a damaging freeze/frost at his camellia nursery on 17 November 2007 (Figs. 2a-b). Mr. Conrad noted the rarity of such an early freeze and damaging frost at his and surrounding nurseries. Mr. Conrad is well known among horticulturists in Central Florida and is considered an innovator (http://cstaf.ifas.ufl.edu/casestudy4.pdf). He is also well known to the NWS in Melbourne and has been a dedicated official COOP weather observer since 1 December 2001. Mr. Conrad has taken daily maximum and minimum temperatures and rainfall observations at his location since 11 January 1981. Bud Dietzmann, Hydrometeorological Technician (HMT) and Climate Data Program Leader at NWS MLB had recently obtained and transcribed the daily observations from Mr. Conrad's record books into a spreadsheet and quality controlled the data. Thus, the three things needed to test the concepts of Hagemeyer (2007) were available: a specific user (horticulturist), a specific critical problem (early season freezes in November), and a very specific database of minimum temperature taken at the location of the forecast problem.

2. CHARACTERISTICS OF THE PLYMOUTH 3N OBSERVATION SITE

Mr. Conrad's COOP minimum temperature observations are well known to NWS MLB as typically the coldest in their area of responsibility. Indeed, the Plymouth COOP site is in a classic frost pocket or frost hollow (AMS

Corresponding author address: Bart Hagemeyer, National Weather Service, 421 Croton RD, Melbourne, FL 32935; e-mail: bart.hagemeyer@noaa.gov

Glossary http://amsglossary.allenpress.com/glossary/search?id=frost-hollow1), although the use of these terms in Florida may be debatable as the term "cold pocket" is often used colloquially (Attaway, 1997). Figure 3a shows the location of the historic Plymouth observation sites in a large depression that includes present day Lake Victor at an elevation of approximately 60' with terrain rising to 100-120' within 1/2 km on all sides and no physical outlet. This is rather exceptional topography for Central Florida. The author (Hagemeyer 1985) had investigated the influence of terrain in producing local circulations in the Ozark Mountains making this case study particularly intriguing. Figure 3b. illustrates a typical frost hollow and development of katabatic drainage wind. It is likely that the entire low area extending around Lake Victor on Figure 3 was, in the distant past lakebed covered in water and/or marsh. Indeed, Mr. Conrad stated that Lake Victor had been quite large and had been a fishing lake in the 1930s. As late as the 1970s abandoned docks remained along the shores of the current day "depression." Lake Victor and the surrounding depression formed thousands of years ago as parts of the Central Florida ridge underlain with porous limestone collapsed into a giant sinkhole. USDA soil maps indicate the soil in the area is generally sandy and excessively drained. It is likely that cool air would drain down the depression into the area around present day Lake Victor (57' elev.), making the Conrad nursery one of the coldest locations within the larger depression. Adding further to the complexity of the microscale environment of the observation site is the surprising variability of surface water content of the depression on the scale of years. The estimation of water area on Figure 3 is from July 1985. Figures 4a-c show aerial views of the area on 25 January 1999 (Fig. 4a) with open water on Lake Victor and the smaller depression near to the actual observation site, on 26 April 2002 (Fig. 4b) with no open water at all (winter 1999, 2000, and 2001 were quite dry in central Florida), and most recently in early 2007 (Fig. 4c) with water and vegetation in Lake Victor.

In December 2007, Mr. Conrad reported no standing water at all in Lake Victor or surrounding areas within the depression. The region has gone through several wet and dry cycles since 1985, and the state of surface moisture in the depression would have a significant impact on the radiation balance relative to frost/freeze occurrence. However, a detailed consideration of this aspect is beyond the scope of the current paper. A close-up view of the PLTF1 site (Fig. 5) also shows a tree line and forested area that has grown up south of the observation site during the period of observation record which would affect the radiation balance and drainage flow from the south. Drainage flow from the north and west is not significantly affected by trees and this could lead to micro-scale cold air damming over the clear area of the observation site north of the tree line. The picture that emerges is that of a very complex micro-scale environment where very sensitive horticultural operations take place. Thus, the PLTF1 site makes an excellent case study to apply the methods outlined in Hagemeyer (2007) to "push the envelope" in providing probabilistic seasonal "impact" forecasts for very specific operations from large-scale teleconnections.

A closer look at the most recent frost/freeze event of 17 November 2007 that motivated this case study further reveals the uniqueness of the Plymouth location. The low temperature recorded on the morning of the 17th was 30°F at T3. Pictures of frost on the ground and damaged vegetation (Figs. 2a-b) leave no doubt that the temperature was at least that low in mid-November and that a camellia-damaging frost occurred. The synoptic scale surface map for the morning of the 17th (Fig. 6) shows that the surface freezing line analyzed from first order synoptic observation stations was limited to extreme North Florida. A high-resolution mesoanalysis of the lowest temperatures for the morning of the 17th at 1215 UTC (Figs. 7a-b) shows that freezing temperatures had penetrated much deeper into Florida to around Ocala, but still well northwest of Plymouth, and indicated a temperature of ~41° F at Plymouth. This clearly illustrates the sub-mesoscale controls over minimum temperature at this test observation site.

3. FREEZE DATABASE DEVELOPMENT

Mr Conrad began taking routine daily measurements of highs, lows, and rainfall at his house (T1 on Fig. 3, elev. ~72'), which was under a heavy tree canopy, on 11 January 1981. Beginning 1 January 1983, daily low temperature readings were also taken at a site near the growing operations euphemistically named the "pit" (T2) at a height of about 2' above the ground (Fig. 3, elev. ~58') and continued until 31 December 2001. Mr. Conrad became an official NWS COOP Observer on 1 December 2001, and a standard temperature sensor was installed further away from the "pit" site where trees had begun to encroach (T3 on Fig. 3, elev. ~63') and observations at T2 were discontinued. COOP observations have been recorded at T3 from 1 December 2001 until present. This makes for a continuous daily record of minimum temperatures at Plymouth for 27 years, long enough to make meaningful statistical analyses and forecasts. The challenge was deciding on freeze threshold criteria from three different sites in close proximity during 27 Novembers from 1981 through 2007. It is important not to miss freezes in the historical record to produce a data set to develop seasonal probabilistic forecasts using LR. It is equally important not to include cases that were not significant as they could seriously dilute the value of the forecasts.

The mean monthly November minimum temperatures for the years when simultaneous observation were taken at T2 and T1 from November 1983 to November 2001 were calculated to be 52.8° F and 56.3° F, respectively. On average, the minimum November temperature at T2 was 3.5° degrees colder than T1. There is no overlapping data for T2 and T3, but generally the T2 site would be colder than the T3 site as it is approximately 9 feet lower at the sensor (58 +2' T2 and 63+6' for T3).

Only in November 1981 and 1982 were there no temperature readings in the vicinity of T2. In November 1981 there was a freeze with low temperatures of 27° F and 28° F at T1 implying a freeze with an even lower temperature at T2. In November 1982 the temperature at T1 did not go below 44° F, and it could not have been reasonably expected to be below freezing at the T2 site. The 30° F reading of 17 November 2007 at T3 was known to cause frost and freeze damage in the vicinity of T3 and at T2 (Fig. 3). Observations were only taken at T3 from November 2002 through November 2007. A tentative decision and forecast criteria of the occurrence of a minimum temperature reading of 30° F or less at any historical observation site (T1, T2, and T3) during the month of November from 1981 through 2007 was decided upon for the development of logistic regression forecasts. These criteria would reasonably ensure that the minimum temperature was always at least 30° F or less at T2. These criteria resulted in nine freeze cases in 27 years, or a 33% chance of climatological occurrence. Pertinent details of each freeze event are shown on Table 1. Only two of the nine cases were right at the criteria of 30° F; the other seven were below 30° F. Of the non-freeze cases, three Novembers saw lows of 31° F and only one of 32° F. If these cases were included, that would be 13 freezes in 27 years or 48% of the time. This is not a rare enough event, and is less likely to be damaging and dilute the forecast development and raising the specter of too many false alarms. Thus, the final nine cases were comprised of minimum temperatures at or below 30° at any observing site, with the assumption that a reading of 30° F or less at either T1 or T3 would clearly result in a temperature of 30° F or less in the vicinity of T2.

4. ATTRIBUTION OF NOVEMBER FREEZES AND DEVELOPMENT OF PROBABILISTIC GUIDANCE

Logistic Regression analyses were performed on the relationship of the occurrence of a November freeze event at PLTF1 to the major teleconnections on Table 1 in a manner similar to that of Hagemeyer (2007) for all of Florida. Table 2 shows the measures of significance for LR of November freeze occurrences on November mean Arctic Oscillation (AO), North Atlantic Oscillation (NAO), Pacific North American (PNA) oscillation, and NINO 3.0. LR was also computed using mean November through January (NDJ) AO, October through December (OND) NINO 3.0, and the combinations of November AO and PNA and November NAO and PNA.

Generally, as was found with Florida minimum temperatures in Hagemeyer (2007), the results for AO, NAO, and PNA were significant, while those of NINO 3.0 were not. The best single predictor was mean November AO, followed by November PNA. The NAO was slightly less significant than AO, while NINO 3.0 was not significant at any level (p = .49). The results for broader seasonal measures such as NDJ AO and OND NINO 3.0 were worse than for November variables alone, although NDJ AO was still highly significant. The multiple LR combination of November mean AO and PNA was remarkably significant (p = .001). November NAO and PNA were slightly less significant.

The plotted results for November AO LR (Fig. 8) show the probability distribution of a November freeze given the mean November AO index. Plots of the actual AO values for the freeze (1) and no-freeze (0) cases are shown to help assess the veracity of the LR probability results. In only one of nine freeze cases was the AO index >0 (0.3), and in only 3 of 18 non-freeze cases was AO <0. The Probability of Detection (POD) is quite high (89%), and the False Alarm Rate (FAR) is relatively low (3 of 11 <0, or 27%).

The plotted LR results for November PNA on freezes and the actual values of PNA for the freeze (1) and no-freeze (0) cases are shown on Figure 9. The probability relationship is somewhat weaker for the PNA compared to the AO. In only one of nine freeze cases was the PNA index <0 (-.8) giving a POD the same as the AO (89%). However, the FAR was much higher at 47% (8 of 15 >0) as seven times the PNA was >0 and a freeze did not occur.

The plotted LR results for November NINO 3.0 on freezes and the actual values of NINO 3.0 for the freeze (1) and no-freeze (0) cases are shown on Figure 10. The probability relationship is very weak and only slightly better than climatology. Indeed, three freezes have occurred in El Niños and four in La Niñas, and it is only slightly more likely to have a freeze in a La Niña as an El Niño, resulting in no demonstrable skill for November freezes.

The results for multiple LR on AO and PNA were very strong (p=.001, chi square 14.5). A plot of the November AO index versus November PNA index for the nine freeze events (Fig. 11) shows the paired AO- and PNA+ nature of the freeze occurrences in seven of nine cases (78%). In only two cases the relationship is not evident, one with negative PNA and one with positive AO (and PNA close to zero). Another way to assess the strength and reliability of the relationship of AO and PNA to freezes in the context of the full LR results is shown on Figure 12. On Figure 12, the occurrence and nonoccurrence of freeze events are plotted at 1 and 0, respectively, at the computed LR probability of the event, and the AO and PNA indices are plotted against the LR computed probability of a freeze. At high probabilities of a November freeze, the LR modeled results always give a negative AO coupled with a positive PNA. The two “Xs” plotted at “0” at high probability are non-freeze events where they should not be and they represent the only two forecast false alarms in the data set. Likewise, the two “Xs” plotted at “1” at low probability on Figure 12 are the only two forecast misses in the data set. Of course, forecast misses should be considered the worst-case scenarios for the customer as mitigation would not generally be attempted at these low probabilities of impact occurrences. This type of reliability diagram can be useful to supplement and better understand the underlying probability information for the customer.

The two false alarms were November 1997 and

1998 when AO and PNA were -0.7 and +0.9 (73% probability of freeze) and -1.4 and +0.7 (87% probability of freeze), respectively. Interestingly, the 1997 false alarm was during the strongest El Niño on record, and the 1998 false alarm was during a strong La Niña. The two misses were in November 1991 (El Niño) and November 1995 (La Niña) when AO and PNA were 0.3 and 0.2 (18% probability of freeze) and -.7 and -.8 (26% probability of freeze) respectively. These two cases constitute a near normal AO and PNA miss and a PNA miss. Because of their importance to the customer, these four cases will be reviewed later in the paper.

5. SYNOPTIC SETTING OF FREEZE EVENTS - PHYSICAL RELATIONSHIPS TO PROBABILITSTIC FREEZE OUTLOOKS

Probabilistic statistical decision tools are only useful if they can be put into a real life context of the physical processes in the atmosphere that lead, in this case, to an early dry season (November) freeze at PLTF1. Hagemeyer (2006 and 2007) discussed the general relationship of the AO, PNA, NAO, and Pacific SSTs to Florida temperature. Statistically, the AO/NAO is the primary dry season influencer on Florida temperature. Figure 13 shows the historic range of the AO index that typically peaks in January (see Hagemeyer 2007 for extreme AO map examples) and reaches a minimum in July. The influence of the AO begins to increase significantly in November as the transition into the dry season takes place; it is during those Novembers when it is significantly and persistently negative that early season cool weather outbreaks are most likely to affect Florida.

Figure 14a shows the mean sea level pressure (MSLP) analysis for November 1994, the month that the LR model gave the absolute lowest probability of a freeze at PLTF1 (0%, AO +1.8 and PNA -1.7). With a November average minimum temperature of 61.5° F versus a normal of 55.4° F; this was the second warmest November in the 27 years of the study databases. A persistent, strong ridge of high pressure extending from the Atlantic to the southeast U.S. north of Florida would bring maritime air masses and generally easterly flow to the state, ensuring warmer than normal temperatures, especially at night, with virtually no chance of a freeze.

The mean MSLP analysis for November 2002, the month that the LR model gave the highest probability of a freeze at PLTF1 (94%, AO -1.4 and PNA +1.5), is shown as Figure 15a. A mean surface trough off the eastern seaboard is found in a weakness in the subtropical ridge, and mean surface flow is continental from the northwest. Indeed, November 2002 was the coldest November of the 27-year database with an average minimum temperature of 49.3° F versus a mean of 55.4° F, and 12.2° F colder on average than November 1994 (Fig. 14a).

The most noteworthy large-scale differences between Figures 14a and 15a are the strength of the Aleutian low, intermountain ridge and arctic high, and the extension and strength of the Atlantic subtropical ridge. At 500 mb the differences between the positive AO and negative PNA and negative AO and positive PNA scenarios (Figs. 14b and 15b) are even more striking with an anomalously strong ridge over the southeast in the highest probability of warm scenario (14b) and an anomalously intense Hudson Bay low and strong west coast ridge in the highest probability of cold scenario (15b). What's most instructive is that these two extreme examples were found by data and probability analyses of mircoscale impacts. The reasons for expectation of colder weather with the high amplitude negative AO and positive PNA scenario are obvious on a broad scale, and closer consideration of the freeze cases is needed.

6. COMPOSITE FREEZE WEATHER MAPS

Composite daily analyses of select meteorological variables for the nine freeze cases were completed to more clearly understand actual weather conditions leading to freezes and the linkage of individual extreme weather events and climate scale mean conditions. The composite daily MSLP analysis for the nine freezes (Fig. 16) displays a negative AO and positive PNA pattern, as should be expected. A 1024 mb high is centered over the Georgia/Florida border (Fig. 16.), and a cold front and trough of low pressure extends southward from a 998 mb low over the Canadian Maritime Provinces to the east of the Bahamas. This mean cold front had moved through the PLTF1 area on the day before the freeze in all cases so that on the morning of the freeze, the cold front was typically well to the east and high pressure was settling over the area. Indeed, none of the nine November freezes were advection freezes immediately following cold front passage. Figure 17 shows the distinctive 1000 mb height anomalies at low levels associated with the southeast high (+30m) and the northeast low (-90m). It is also noteworthy that in all nine cases there was no measurable rainfall in the 48 hours prior to the freeze and no rainfall with the cold frontal passage preceding the freeze (i.e. "dry fronts"). This lack of rainfall would tend to enhance radiational cooling in the depression.

The composite 500 mb analysis and height anomalies (Figs. 18a-b) for the freeze events display a strong ridge over Western North America with a positive 75m height anomaly over Western Canada and a strong trough off the eastern seaboard with a negative 180m height anomaly over New England. This clearly illustrates the resulting high amplitude flow that results in negative AO and positive PNA bringing cold airmasses into the southeastern United States. The sensible weather resulting from this type of weather pattern is shown by the surface temperature anomaly analysis (Fig. 19).

However, the generally obvious cold weather pattern set on the broad stage of the composite pressure/height maps for the nine freezes does not explain the extreme relative cold of the PLTF1 microclimate. The average minimum temperature at Tallahassee (TLH, ~200 miles northwest), Jacksonville (JAX, ~120 miles north), and Orlando International Airport (MCO, ~25 miles southeast) for the nine freeze events was 27.6° F, 30.6° F, and 42.1° F, respectively, (from Table 1). The average low temperature at PLTF1 was 27.4º F or about equal to TLH, 3.2º F colder than JAX, and 14.7º F colder than MCO. This temperature distribution clearly illustrates the non-advection nature of the November freeze events – they were all radiation freezes at PLTF1. A brief review of the November 1981 freeze case is instructive. On 20 November a vigorous cold front moved through central Florida followed by strong winds through the night. On the morning of the 21st, the minimum temperatures at TLH and JAX were 28° and 31° respectively while the temperatures at PLTF1 and MCO were 38° F and 40° F respectively. On 22 November, after the front had moved well south and winds had died down to calm the minimum temperatures at TLH, JAX, and PLTF1 were 26° F, 30° F, and 27° F respectively, while the minimum temperature at MCO was 36° F.

Freezing temperatures associated with continental airmasses have rarely penetrated into Central Florida in November. MCO has only reached 32º F on one November morning since 1952. The Orlando Executive Airport eight miles north of MCO has only reached freezing four times since 1948 (only once below 30º F), the lowest being 29º F in November 1950. Attaway (1997) noted the importance of relatively rare November and March/April freezes at the transition in and out of the traditional dry or cool season that are severe enough to affect the citrus crop. He noted that a frost/freeze somewhere in Florida is common in November, but that large-scale advective cold air outbreaks (which may or may not be followed by radiation freeze events) that affect the citrus growing areas of Florida are extremely rare. The most recent notable large-scale November freeze was on 24-25 November 1970 when freezing temperatures reached south of Lake Okeechobee and TLH reached an unprecedented November low of 13 º F with Tampa falling to 23 º F. It is likely that the low at PLTF1 was similar to that of TLH. A truly historic large scale November freeze.

The composite mean surface wind vector (Fig. 20) and 850 mb RH and RH anomaly analyses (Figs. 21a-b) for the nine freeze cases more clearly illustrate the necessary conditions to achieve an environment favorable for a damaging freeze at the unique PLTF1 site. The center of the surface high (Fig. 20) characterized by calm winds is over south Alabama and the Florida Panhandle, resulting in weak (<3 m/s) northerly surface flow right down the Florida Peninsula. These light winds would favor the formation of drainage flow and enhance the flow down the much larger Lake Victor depression (katabatic winds) toward PLTF1 with no outlet. Note that the composite daily wind calculations are averaged over an entire day, and it is likely that the winds are even lighter at the time of morning minimum temperatures.

The composite mean 850 mb RH and RH anomaly analyses (Figs. 21a-b) illustrate the incredible dryness of the low level airmass over North Central Florida for the freeze events. 850 mb RH is approximately 10%, and the relatively small negative anomaly region is centered right over the PLTF1 site. The 850 mb specific humidity analysis (Fig. 22) indicates that this region has the absolute lowest specific humidity (<.001kg/kg) of anywhere on the entire map domain of the continental U.S. and surrounding areas and illustrates the high latitude source region of the overlying cold, dry airmass. Thus, following the cold front that produces initially cold and dry air advection flowing right down the peninsula, the post-frontal continental high pressure systems settle over the southeast and the very light winds and extreme dryness of the airmass results in the right meteorological conditions to produce a damaging radiation freeze due to the unique physical geography of the PLTF1 site.

During interviews with Mr. Conrad he was well aware of the importance of tracking upstream dew points and wind flow to make short-term (<12 hour) predictions of a freeze at his site. This case study not only verifies and quantifies anecdotal experience at the microclimate site, but also shows that the freezes are the end result of teleconnections and weather patterns on the scale of synoptic climatology that could be used to predict micro-scale damaging freezes with considerable accuracy. Having shown the importance of wind and moisture to the development of freezes at PLTF1**,** it is now instructive to return those cases of false alarms and misses of the LR forecast scheme to see what information can be gleaned for the user to help in decision making.

7. FALSE ALARMS AND MISSED FORECASTS OF IMPACT EVENTS

The two freeze false alarms in November 1997 and 1998 were reviewed for insights into why a freeze did not occur despite a forecast of a high probability of a freeze based on LR results of the AO and PNA indices. The strongest El Nino on record in November occurred in 1997 and November 1998 was during a strong La Nina. This reinforces the finding that ENSO generally has no skill at predicting freeze occurrence in Florida. A cold front did move through Central Florida on 16 November 1997 and the minimum temperature did reach 34 ° F at PLTF1 on the morning of the 17th (coldest of the month) missing the forecast criteria by 4°. Minimum temperatures of 32° F were reported at both TLH and JAX with 44° F reported at MCO. Figures 23a-b show the mean surface wind vector and 850 mb RH for 17 November 1997. The surface winds are considerably stronger (~7 m/s) and the minimum 850 RH area considerably smaller and with higher values (20-25%) than in the mean freeze cases. It is also likely that surface moisture conditions in the Lake Victor depression were higher than normal in November 1997 as 6.70" of rain fell in October and November. All of these factors would act to limit radiational cooling.

A cold front moved through central Florida on 27 November 1998 and the minimum temperature at PLTF1 reached 40° F (coldest of the month) on the morning of 28 November missing the forecast criteria by 10°. Minimum temperatures of 39° F at TLH and 42° F at JAX and 51° F at MCO were well above those of the mean freeze cases indicating the airmass was simply not cold enough (no freezing temperatures in Southeast U.S.) to allow freeze development even though Figures 24a-b show that on 28 November the mean surface wind vector was very light (<3 m/s) and down the peninsula and 850 mb RH was quite low (~15%), similar to the mean freeze cases. Also, in this case the depression floor was undoubtedly very moist with Lake Victor at a high level and likely standing water in much of the depression as record rainfall of 29" fell from July through November. Note that Figure 4a from January 1999 shows Lake Victor and the depression near PLTF1 full of water. This case was also characterized by short-term 500 mb ridging over the Gulf of Mexico. In summary, November 1998 was simply too warm to produce a damaging freeze despite favorable mean AO and PNA patterns.

Forecast misses are of course the most concern as the worst case scenario of total loss of economic value of crop and even failure of business could occur if mitigation or bet hedging actions are not taken based on a forecast of a low probability of a freeze and then a freeze occurs. In this study the main concern is the seasonal or longer range forecasts of freeze at least a month in advance and thus longer term actions that could be taken to benefit or avoid loss relating to extreme temperature variability. The customer would have a last chance to take short-term protective actions in advance of an imminent freeze, thus this study addresses both long-term predictability and the physical characteristics of the atmosphere through case studies of the freeze events so as to be as much benefit as possible to the customer.

The freeze events that occurred at PLTF1 with a low probability of occurrence predicted by the AO and PNA relationship (forecast misses) were 25-26 November 1991 and 23 November 1995. Interestingly, the November 1991 event was during a weak El Nino (NINO 3.0, +1.0) and the 1995 event was during a weak La Nina (NINO 3.0, -0.9). Hagemeyer (2007b) noted that during extreme phases of ENSO freezes were less likely in Florida than when ENSO was relatively weak as in these cases. It is also noteworthy that the two false alarms where freezes did <u>not</u> occur, <u>were</u> during extreme El Nino and La Nina conditions.

A cold front moved through central Florida on 24 November 1991 and on 25 and 26 November the low temperature at PLTF1 was 28° F and 27°. The low temperature was 25° F both days at TLH and 30° F and 29° F at JAX and 43° F and 42° F at MCO (AO and PNA near neutral 0.3 and 0.2). Figures 25a-b show the mean surface wind vector and 850 RH for 26 November 1991. The wind mean wind is light (<5 m/s) and down the peninsula and 850 mb RH is 10 to 15% (25 November not shown, but similar) like the mean freeze cases. November 1991 was also the driest November in the 27 year record of PLTF1 with only 0.43" of rain recorded and only 4.84" of rain fell in the normally wet months of September and October combined which was near a record low. Thus it is likely that the surface moisture in the depression was near a record low and would have resulted in much more effective loss of heat through radiation in the clear and dry airmass.

Figures 26a-b show the mean surface wind vector and 850 mb RH for the case of 23 November 1995. AO was negative for this case (-0.7), but the negative PNA (-0.8) resulted in a low probability of a freeze. The cold front moved through central Florida on the 21st and the temperature fell to 32° on the morning of the 22nd. By the morning of the 23rd the high pressure system had settled right over north Florida and the mean wind speed was near calm on Figure 26a (<2m/s) over PLTF1, the lowest of any case and 850 mb RH was 10 to 15%. November 1995 was also very dry (the 4th driest in the PLTF1 record at 0.68"), but rainfall was above normal in the preceding wet season. With the drainage characteristics of the sandy depression soil it may well be that very dry conditions through the later half of October and November are critical and lead to rapid drying of the soil allowing greater radiational cooling in the very dry and clear airmass under light winds.

This study's significant finding is that the large-scale circulation pattern resulting from the mean state of AO and PNA plays the major role in setting the stage for a November freeze at PLTF1 with a high degree of confidence. The actual occurrence of a freeze at the PLTF1 site depends on the movement of a cold continental airmass over the Southeast U.S. with light winds, no clouds, and very dry air over the site. The physical characteristics of the depression also play a critical role with below normal rainfall in the weeks or months preceding a freeze, low lake levels, and the lack of significant rain with cold frontal passage leading to dryness of the top layer of sandy soil acting to increase the radiational cooling.

In general false alarms in freeze forecasts could result from higher than normal surface moisture in the depression, especially significant rainfall with the frontal passage, stronger than expected surface winds, and unexpected clouds most likely in the form of jet stream cirrus or stratocumulus moving inland from the east coast as low-level flow around the surface high pressure center veers northeast. Forecast misses are most likely when the depression is very dry; the surface winds are calm and the overlying airmass extremely dry and cloud-free.

From interviews with Jerry Conrad it was determined that he was well aware his operation is in a cold spot and that radiation, not advection, was the most common cause of a freeze. He has not observed freezes during stormy or windy conditions with, or immediately following, a frontal passage. A 28 degree temperature or frost is the critical event for blooming camellias. For short-term monitoring of freeze potential he watches dry bulb and dew point temperatures reported to the north, even into South Georgia. He has observed that low temperatures at his site can drop below standard indicated dew points to the north. He also watches for light surface winds and dry upper air flow from the northwest and the potential for any cloud cover. He is aware that the development of a tree canopy along the south border of his site over the years has an effect on the microclimate and that the state of ground moisture has a significant impact on radiational cooling. He has not documented lake levels or soil moisture conditions over time. Mr. Conrad is of the opinion that long term planning for temperature sensitive operations has value. Some of the issues he raised in addition to direct damage to blooming camellias were the need to protect expensive pressurized watering systems from rupture due to freezing and planning for use of heaters which are very expensive to operate. It is likely that once experimental long-term outlooks are available more applications will be realized.

8. CONCLUDING REMARKS

This study has demonstrated that much more detail in probabilistic seasonal forecasting for unique impact variables relevant to specific areas and users is possible. There are two very significant issues to overcome to be successful in broader application of these principles. First, and foremost, is the simple fact that the major teleconnections such as used in this study are not predictable at long range with any reasonable skill other than Pacific sea surface temperatures that measure ENSO. Unfortunately, the state of ENSO has been given far too much credit for extreme climate variability in some cases and is mentioned all the time in the popular press because it is relatively easy to explain and monitor, and there are a multitude of forecasts of its future state, some with skill (see for example: http://iri.columbia.edu/climate/ENSO/currentinfo/SST_table.html). About half the time ENSO is neutral, and it is neutral or weak ~75% of the time, and as the author has documented for Florida over the years, when ENSO is neutral or weak the other teleconnections are especially important to extreme events and climate variability. Unfortunately, not near as much effort is being expended on developing long-range predictions for the NAO, AO, and PNA which are often responsible for extreme climate variability, and in particular, temperature variability. It is extremely important that research in this area be done. As Hagemeyer (2007) stated: *the impact of a consistent and strongly negative AO/NAO pattern for the winter in Florida is potentially so great that some critical customers could take action based on a low seasonal confidence forecast based on a prevailing negative AO.*

The other significant issue is that a database of observations are needed for unique impact variables for specific areas and users to be of most benefit in developing long-range forecast schemes such as demonstrated here. This study demonstrates that the results for one critical site and customer such as PLTF1 could not be easily extrapolated to another customer even in relatively close proximity due to the uniqueness of the physical characteristics of the operations site. Comparison sampling, proxy variables and conversion factors would have to be developed for a site based on the nearest reliable long term observation site and this has the potential to introduce significant error. It is most important that customers concerned about weather and climate critical operations make the necessary effort to document the environmental conditions at their operations site, or at least document the most significant impact variables.

Another issue that relates to the actual short-range forecasting of extreme temperature variability such as freezes at PLTF1 is that the operational resolution of the NWS's National Digital Forecast Database (NDFD, http://www.weather.gov/ndfd/) is too course to capture the details of local weather conditions modified by terrain. A side benefit of this study on long-term forecasting of freezes is the quantification of the influence of topography on the difference in minimum temperatures of low-lying areas in northwest Orange County, Florida compared to the prevailing "zone" forecast. Wording to the effect that minimum temperatures could be as much as 10° colder in low lying area than in the area as a whole could be added to the forecast, but the inclusion of such information in gridded forecasts will have to wait for future increases in grid resolution and bandwidth.

9. ACKNOWLEDGMENTS

Jerry Conrad provided the original PLTF1 data used for this study. Bud Dietzmann transcribed all the data from the original hand written observer logbooks from PLTF1 into a spreadsheet for this study and quality-controlled the data. Without Bud's hard work this study would not have been possible**.** Shirley Leslie provided invaluable editorial assistance in the preparation of the manuscript.

10. DISCLAIMER

The views expressed are those of the author and do not necessarily represent those of the National Weather Service or its parent agency NOAA.

11. REFERENCES

Please see: http://www.srh.noaa.gov/mlb/research.html for a complete list of references.

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Freeze	Date	T1	T2	T3	D	TLH	JAX	MCO	AO	NAO	PNA	NINO 3.4
1	11/22/1981	27	-	-	-	26	30	36	-0.2	-0.4	1.3	0.0
	11/23/1981	28	-	-	-	30	32	38				
2	11/18/1983	33	28	-	5	29	32	39	-0.7	-1.0	1.8	-0.9
3	11/14/1984	33	27	-	6	28	31	42	-1.0	-0.1	0.4	-1.1
	11/30/1984	36	29	-	7	29	31	46				
4	11/22/1987	35	30	-	5	27	32	47	-0.5	0.2	1.3	1.5
5	11/25/1991	35	28	-	7	25	30	43	0.3	0.5	0.2	1.3
	11/26/1991	33	27	-	5	25	29	42				
6	11/23/1995	37	29	-	8	29	33	43	-0.7	-1.4	-0.8	-0.9
7	11/21/2000	35	26	-	9	32	35	45	-1.6	-0.9	0.7	-0.7
	11/22/2000	29	20	-	9	23	25	40				
	11/23/2000	32	25	-	7	32	28	42				
8	11/29/2002	-	-	29	-	25	31	41	-1.4	-0.2	1.5	1.8
9	11/17/2007	-	-	30	-	26	30	45	-0.5	0.6	0.7	-1.5

Table 1. November freeze (≤30ºF) data at the PLTF1 observation site from 1981 to 2007. The T1, T2, and T3 observation sites are indicated on Figure 3. The temperature difference between T1 and T2 is shown in column “D”. Corresponding minimum temperatures (ºF) for Tallahassee (TLH), Jacksonville (JAX), and Orlando International Airport (MCO) are indicated in the columns TLH, JAX and MCO, respectively. The mean teleconnection indices for each November case are indicated by AO, NAO, PNA and NINO3.4 respectively.

Predictor Teleconnection(s)	***df***	**Chi Sq**	***p*-value**
NOV AO	1	9.8	0.002
NOV NAO	1	5.9	0.015
NOV PNA	1	9.2	0.003
NOV NINO 3.0	1	0.5	0.486
NDJ AO	1	7.1	0.008
OND NINO 3.0	1	0.0	0.838
AO+PNA	2	14.5	0.001
NAO+PNA	2	12.9	0.002

Table 2. Measures of significance of results of Logistic Regression analyses of teleconnection indices in first column on the occurrences of November freeze events (≤30º F) at PLTF1 documented on Table 1.

Figure 1. Location of Plymouth 3N (PLTF1) NWS COOP observation site is indicated by the red push pin.

Figure 2a.

Figure 2b.

Figures 2a-b. Photographs of frost on ground (2a) and damaged Elephant Ear Plants (2b) at Plymouth 3N COOP site early on the morning of 17 November, 2007 (Photos courtesy of Jerry Conrad).


Image courtesy of the U.S. Geological Survey
m 200 400 500
yds 200 400 600
100
100
ROCK SPRINGS
ROAD
T1
T3
T2
Lake Victor
75
75
120'
115
134'
ZELLWOOD

Figure 3a.

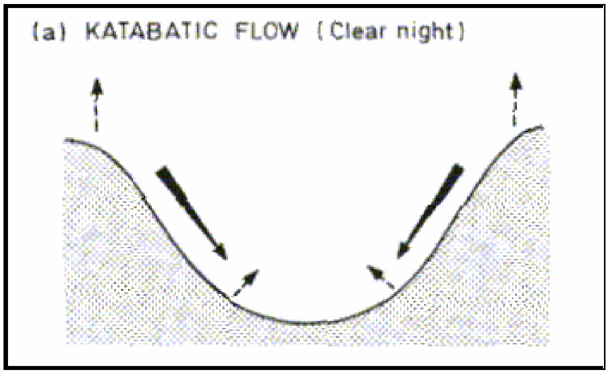


Figure 3b.

Figures 3a-b. U.S. Geological Survey topographic map from July 1985 of the area surrounding the Plymouth 3N observation site (3a). The ~10 acre horticulture site of Mr. Conrad is outlined by the red rectangle in the center of the map. The 75' contour is outlined in black and the 100' contour in blue. The house observation site is shown as T1, the “Pit” observation site by T2, and the current day COOP site by T3 on Figure 3a (refer also to Table 1). A schematic of the typical development of drainage flow into a frost hollow is shown on Figure 3b.

Figure 4a.

Figure 4b.

Figure 4c.

Figures 4a-c. Aerial photographs of the area surrounding the PLTF1 observation site (yellow “X”) on 25 January 1999 (4a), 26 April 2002 (4b), and in early 2007 (4c).

Figure 5. Close-up of the PLTF1 site shown in Fig. 4c. illustrating the complex small-scale physical environment that influences the minimum temperature observations.

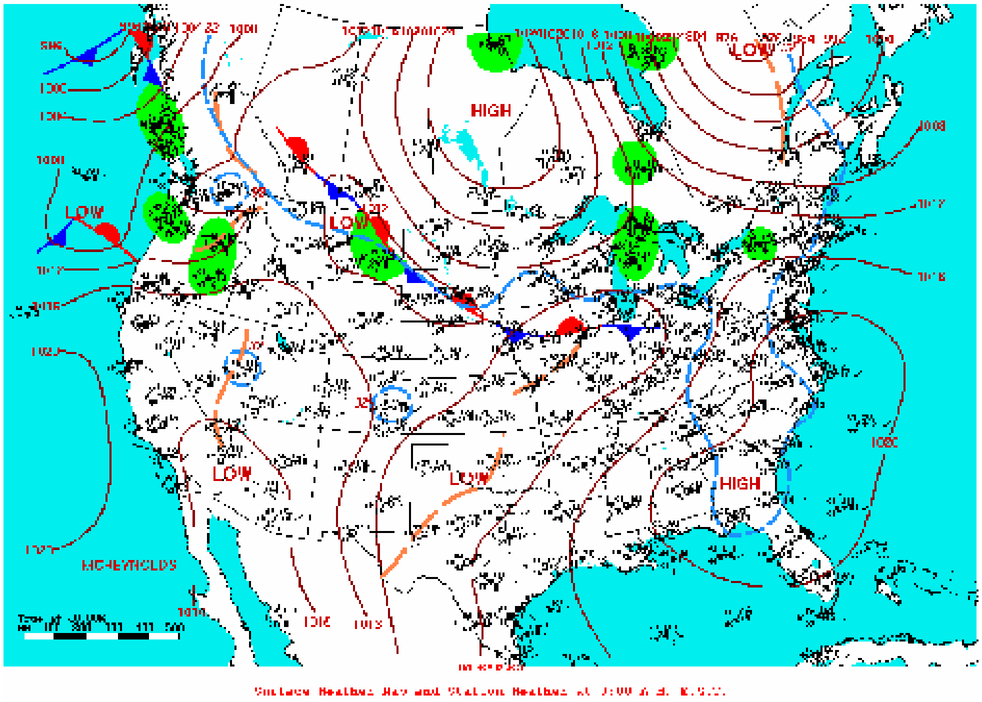


Figure 6. Daily Weather Map for the morning of 17 November 2007. Freezing temperatures at the surface are enclosed by the dashed blue line.

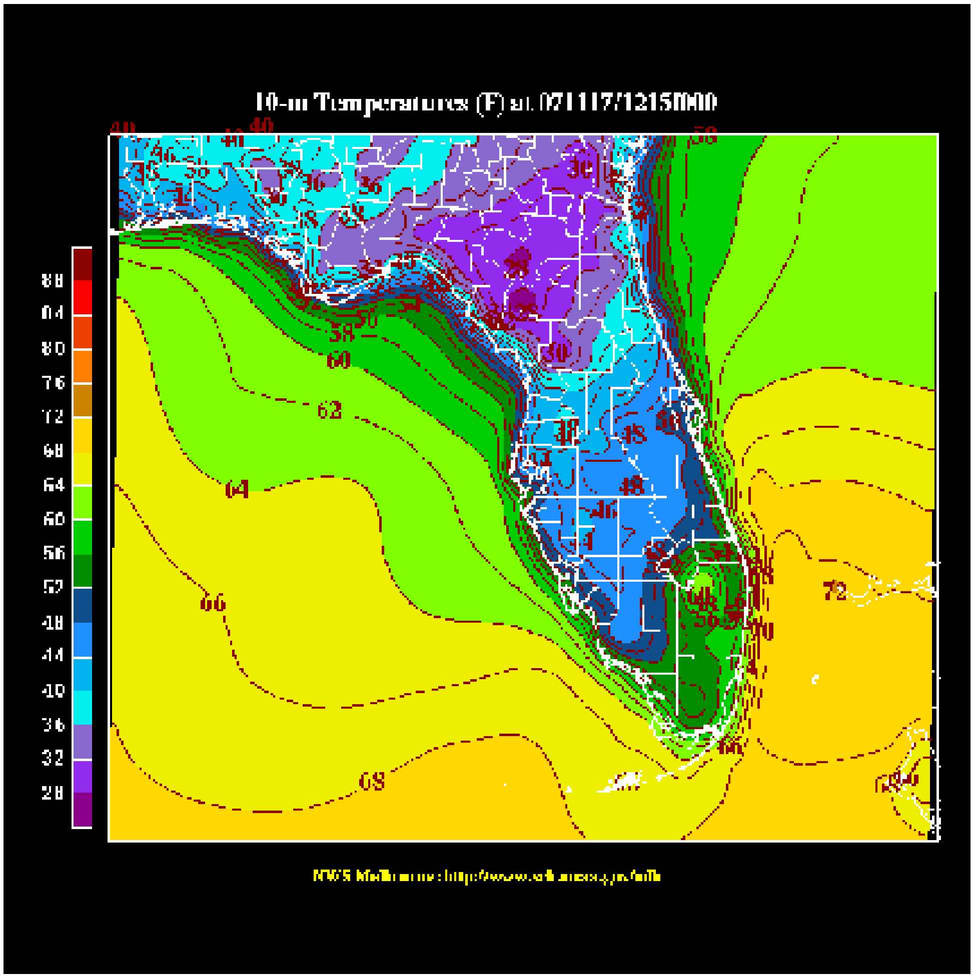


Figure 7a.

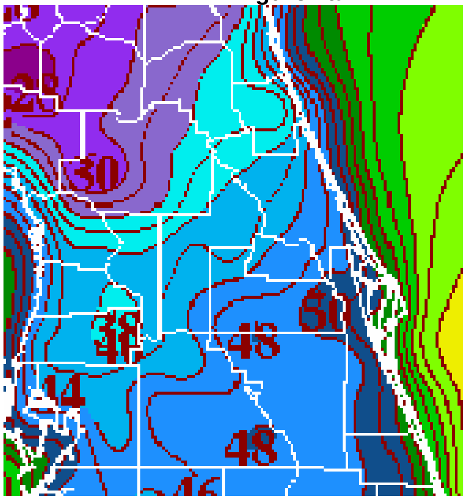


Figure 7b.

Figures 7a-b. Florida temperature mesoanalysis at 1215 UTC on 17 November 2007 (a) and an enlargement of analysis over Central Florida (b). Maps courtesy of Peter Blottman, NWS Melbourne, Florida.

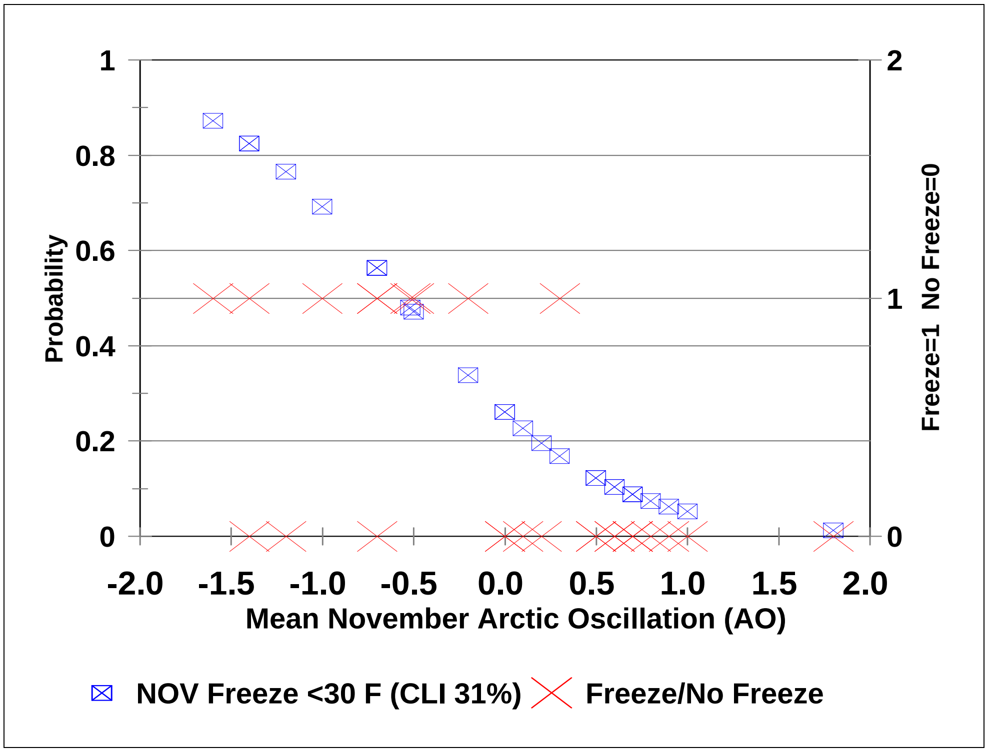


Figure 8. Plot of logistic regression probability results for November AO on November freezes at PLTF1 (blue), and plots of November AO values (red Xs) for freeze (1) and no-freeze (0) events.

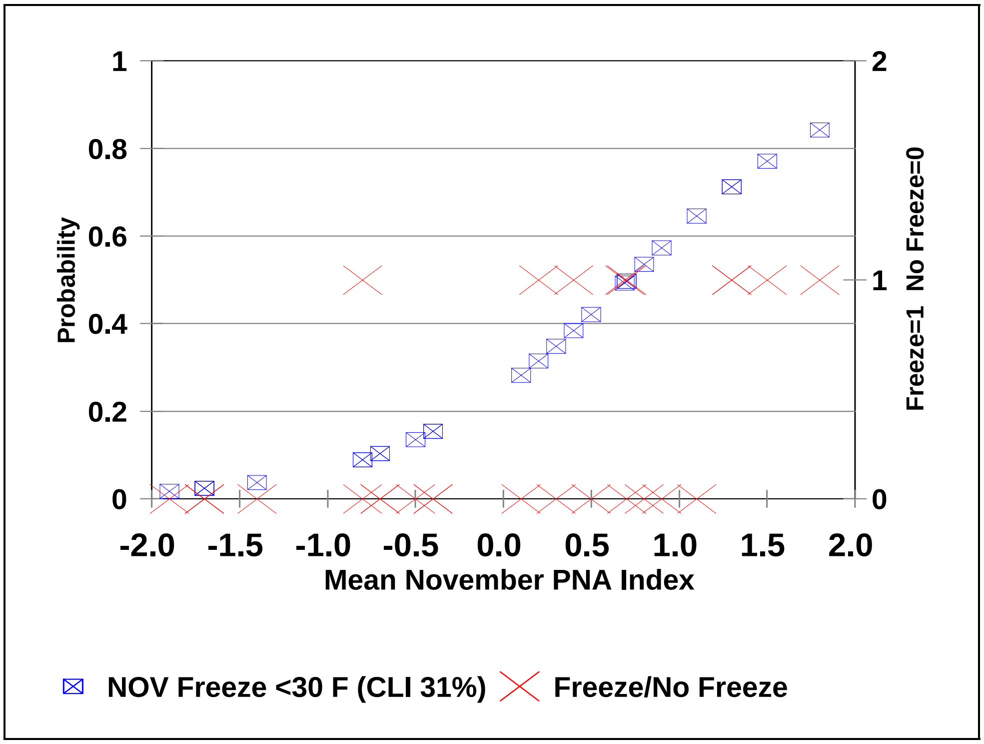


Figure 9. Plot of logistic regression probability results for November PNA on November freezes at PLTF1 (blue), and plots of November PNA values (red Xs) for freeze (1) and no-freeze (0) events.

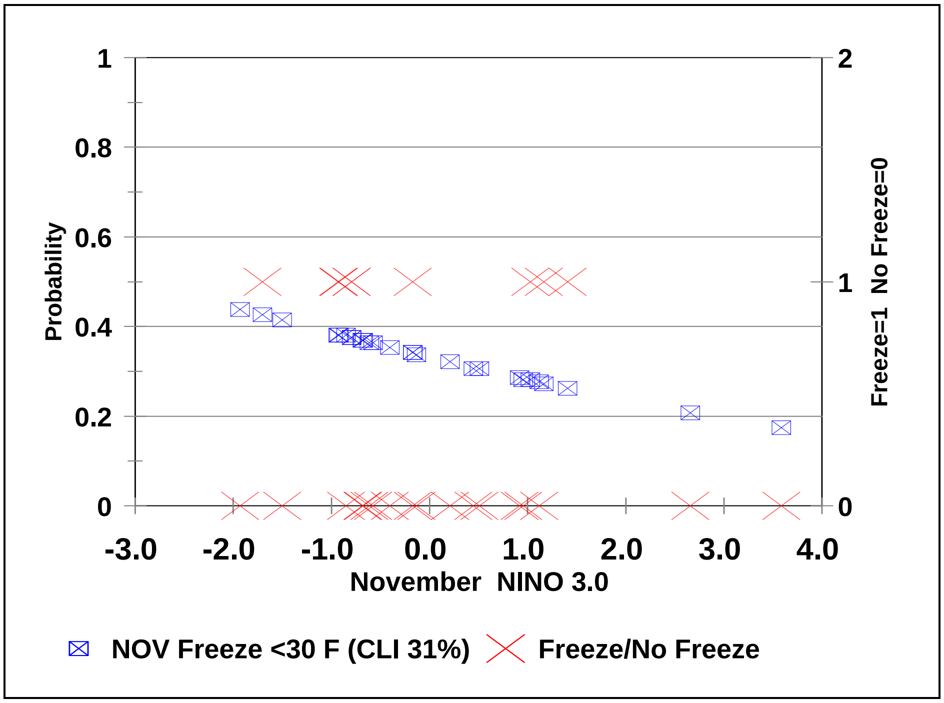


Figure 10. Plot of logistic regression probability results for November NINO 3.0 on November freezes at PLTF1 (blue), and plots of November NINO 3.0 values (red Xs) for freeze (1) and no-freeze (0) events.

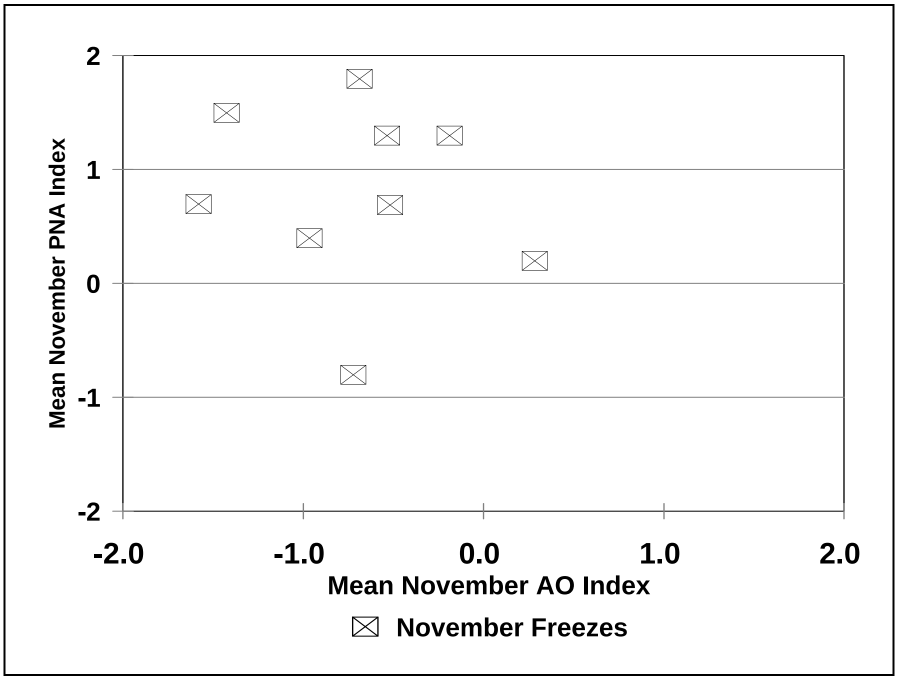


Figure 11. Plot of November AO versus November PNA indices for the nine freeze cases at PLTF1.

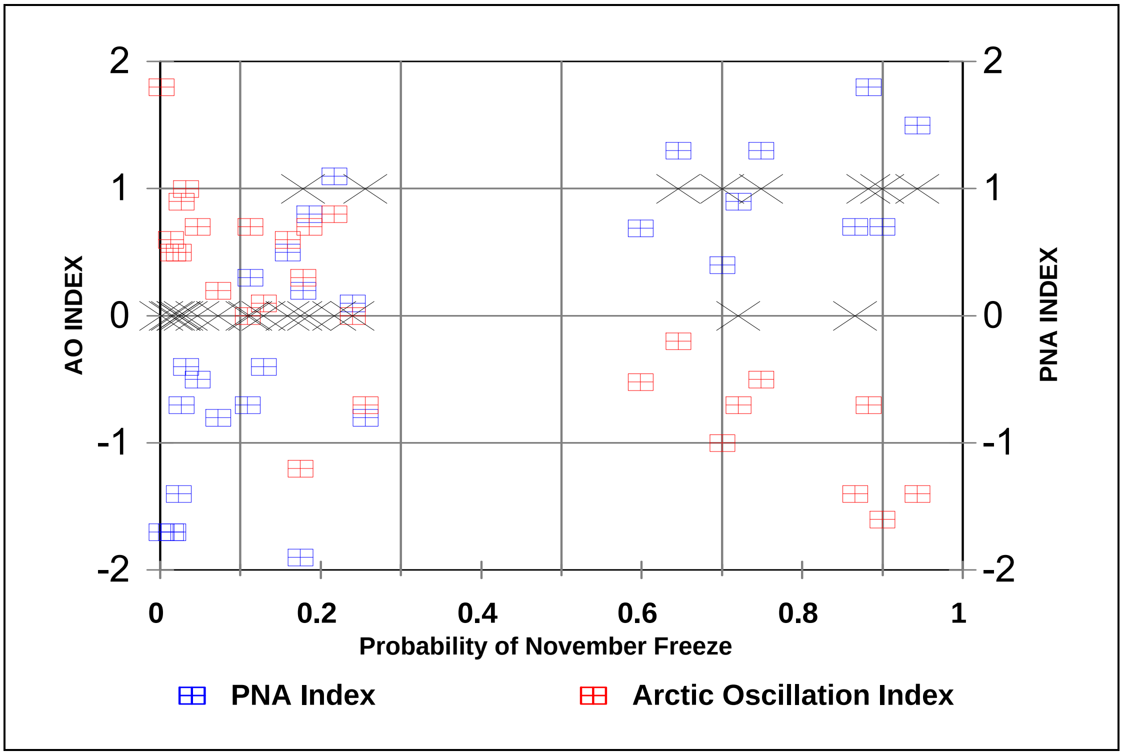


Figure 12. Plots of November PNA (blue box) and AO (red box) and freeze (X at 1) and no-freeze (X at 0) events against theorectical LR computed probabilities of a freeze event.

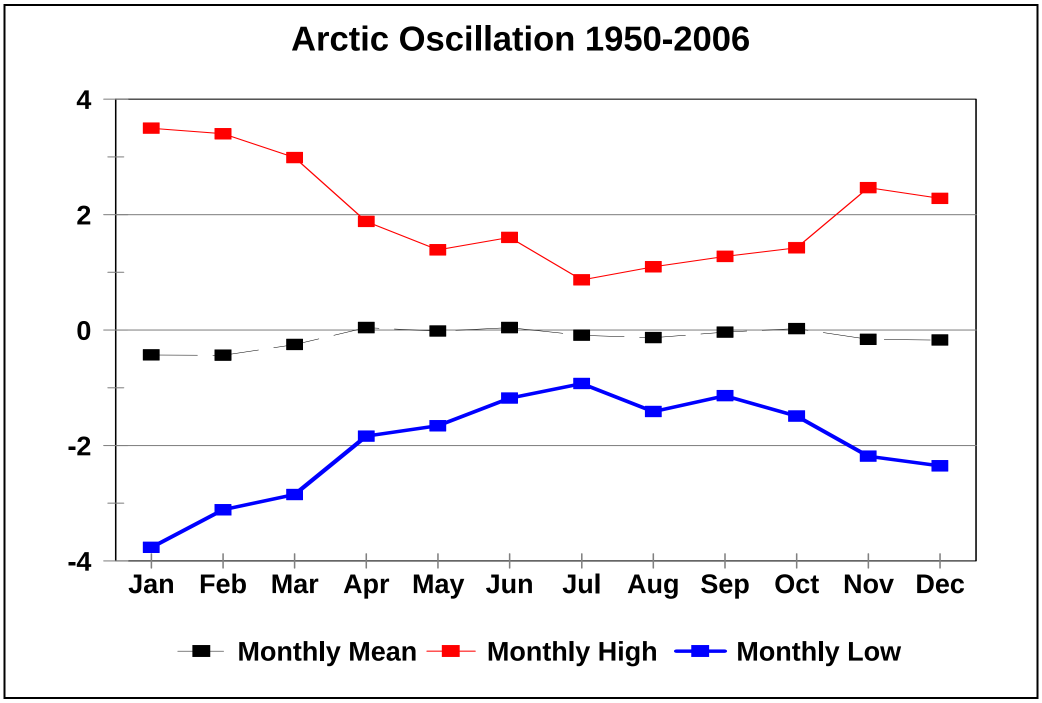


Figure 13. Historical ranges of the Arctic Oscillation index (1950-2006). Normal monthly vales are indicated in black, record monthly lows in blue and record monthly highs in red.

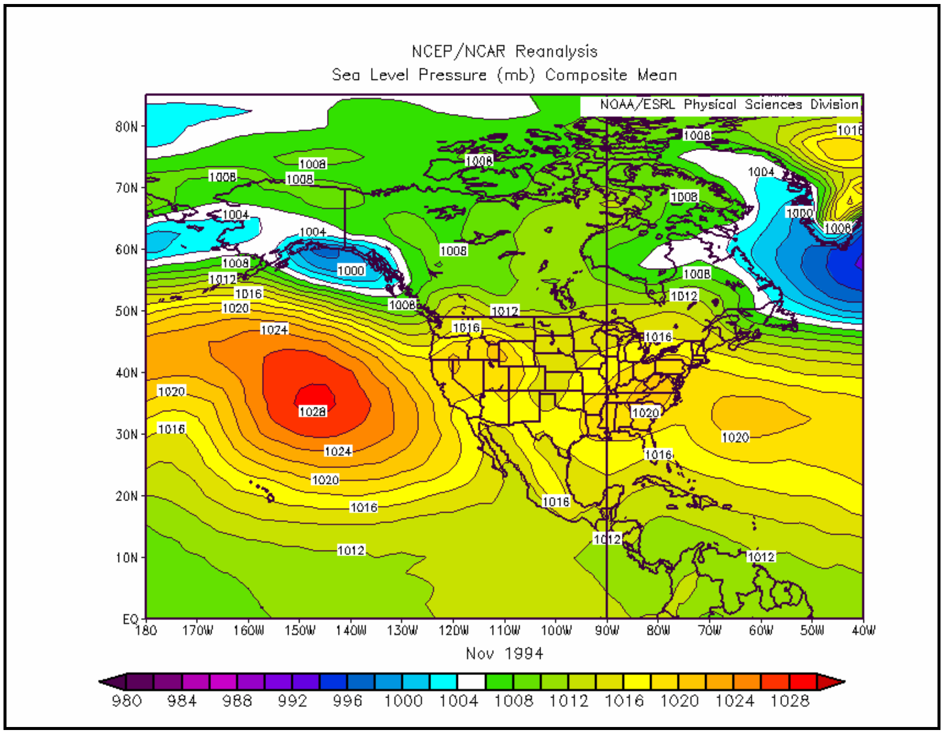


Figure 14a

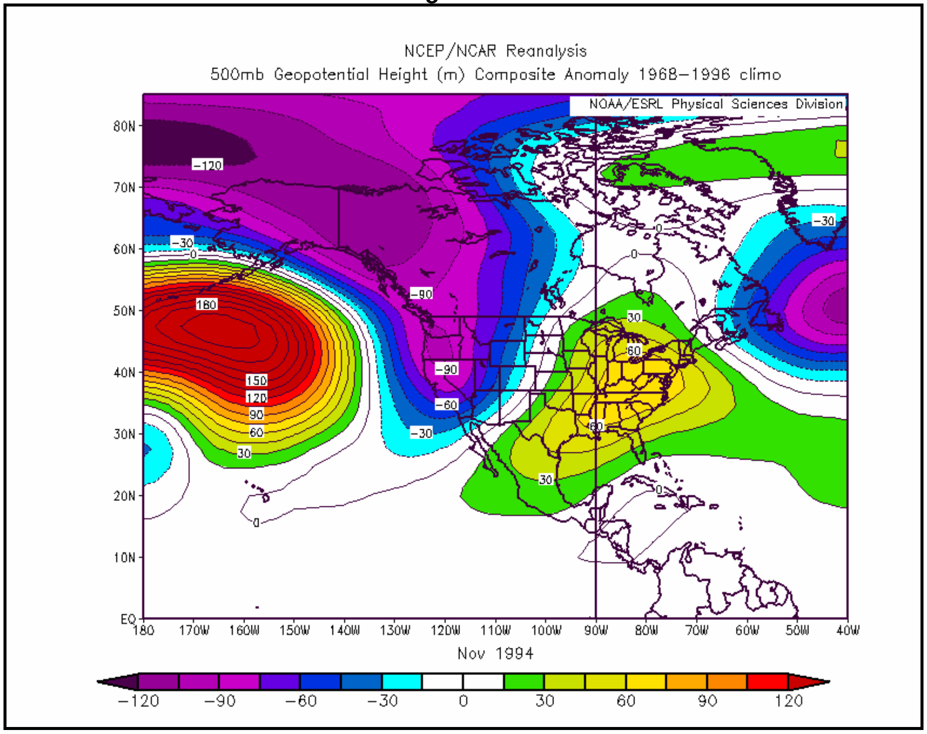


Figure 14b

Figures 14a-b. Mean November 1994 MSLP in mb (14a) and mean November 1994 500 mb geopotential height anomaly (m) analyses representative of the lowest probability of a freeze at PLTF1.

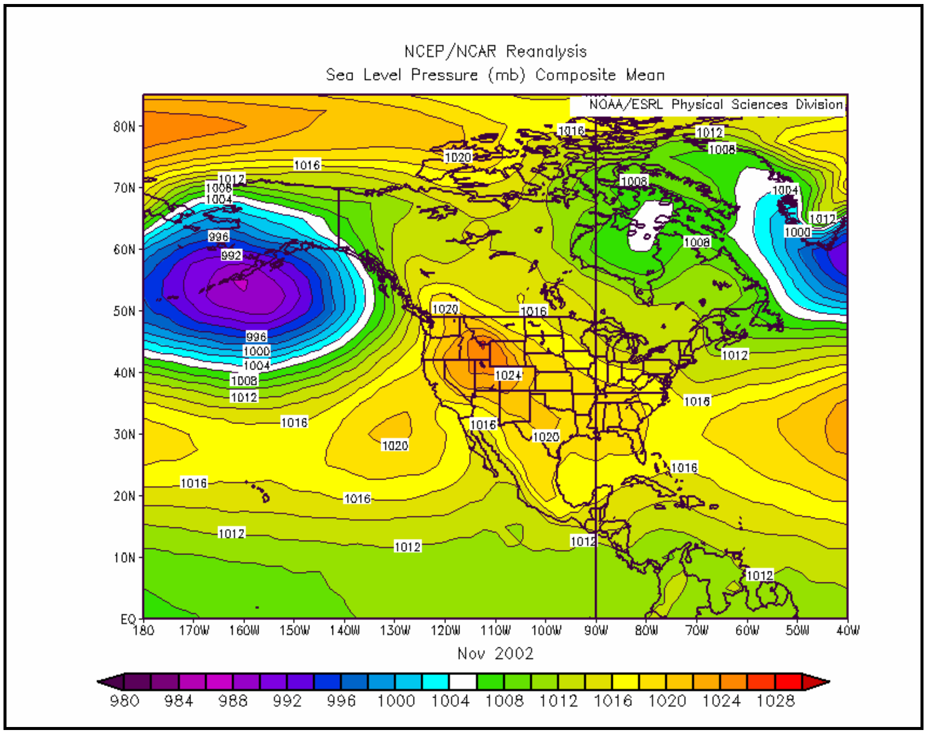


Figure 15a.

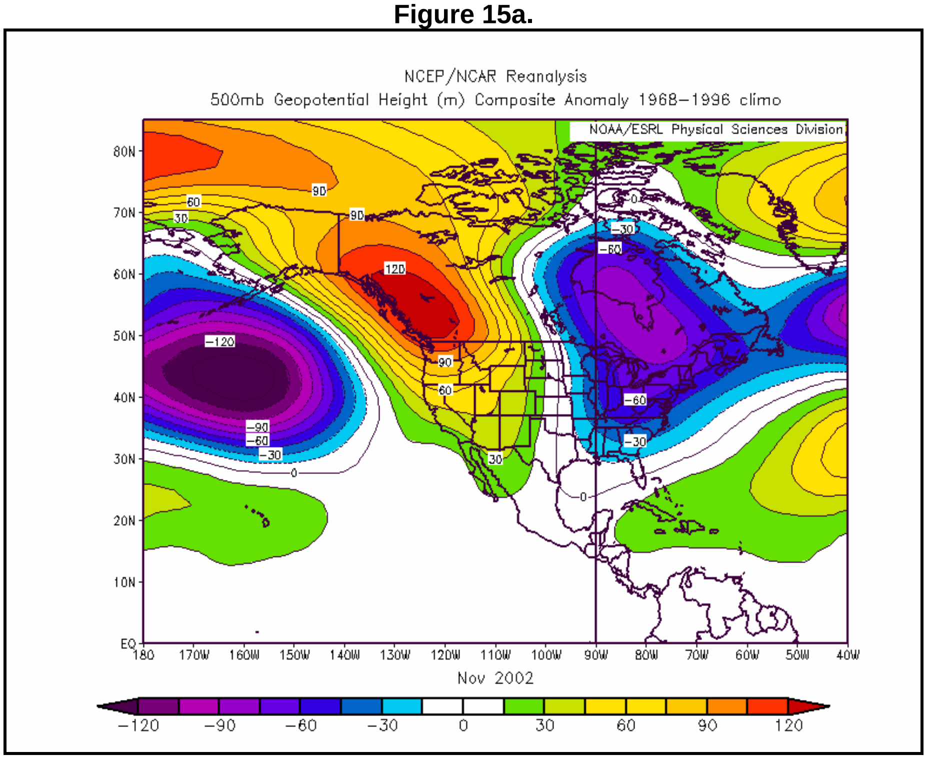


Figure 15b.

Figures 15a-b. Mean November 2002 MSLP in mb (15a) and mean November 2002 500 mb geopotential height (m) anomaly analyses (15b) representative of the highest probability of a freeze at PLTF1.

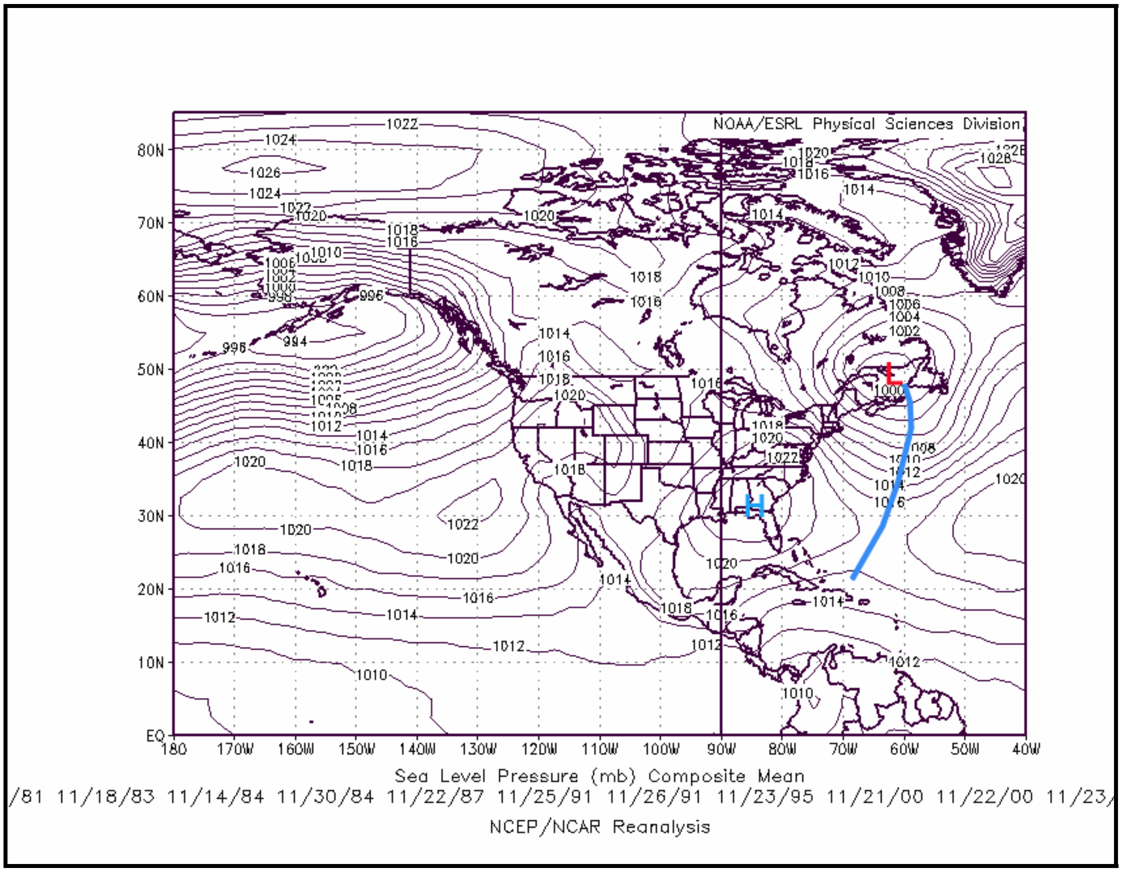


Figure 16. Composite mean MSLP analysis for the nine freeze cases shown on Table 1.

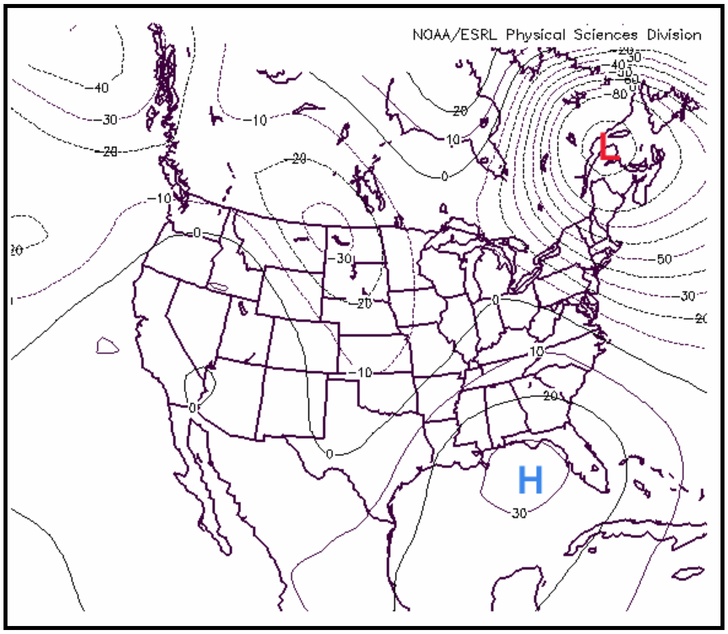


Figure 17. Composite mean 1000 mb height anomaly (m) for the nine freeze cases shown on Table 1.

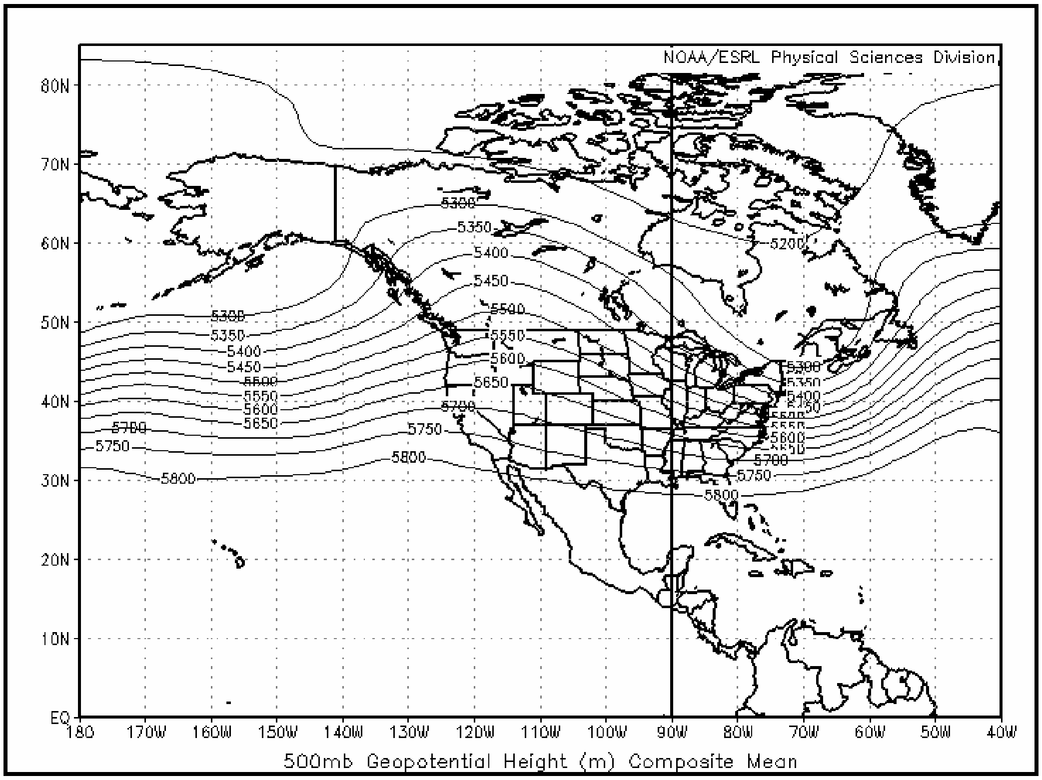


Figure 18a.

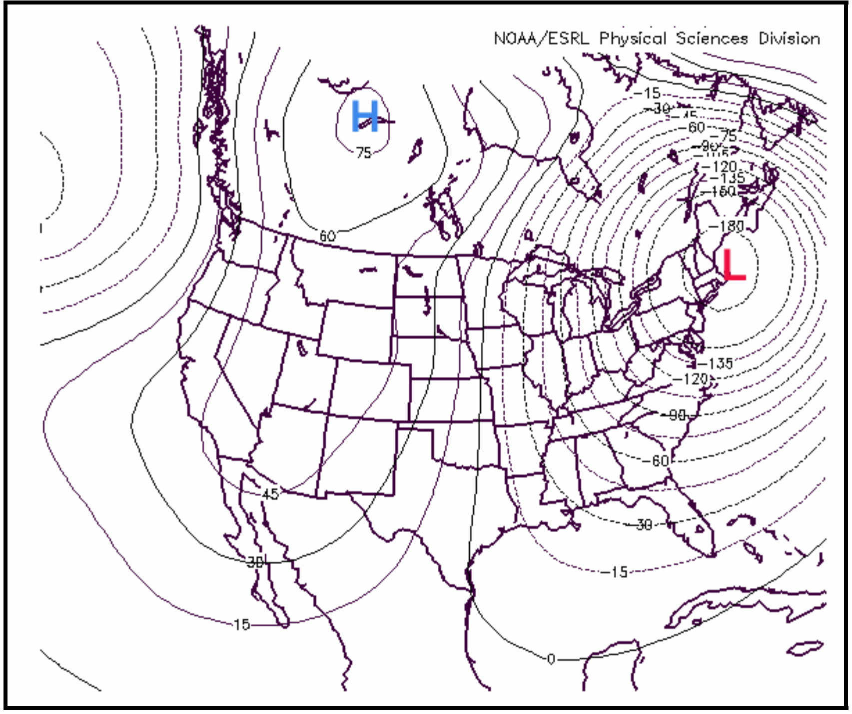


Figure 18b.

Figures 18a-b. Composite 500 MB geopotential height (18a) and height anomaly (18b) analyses for the freeze cases.

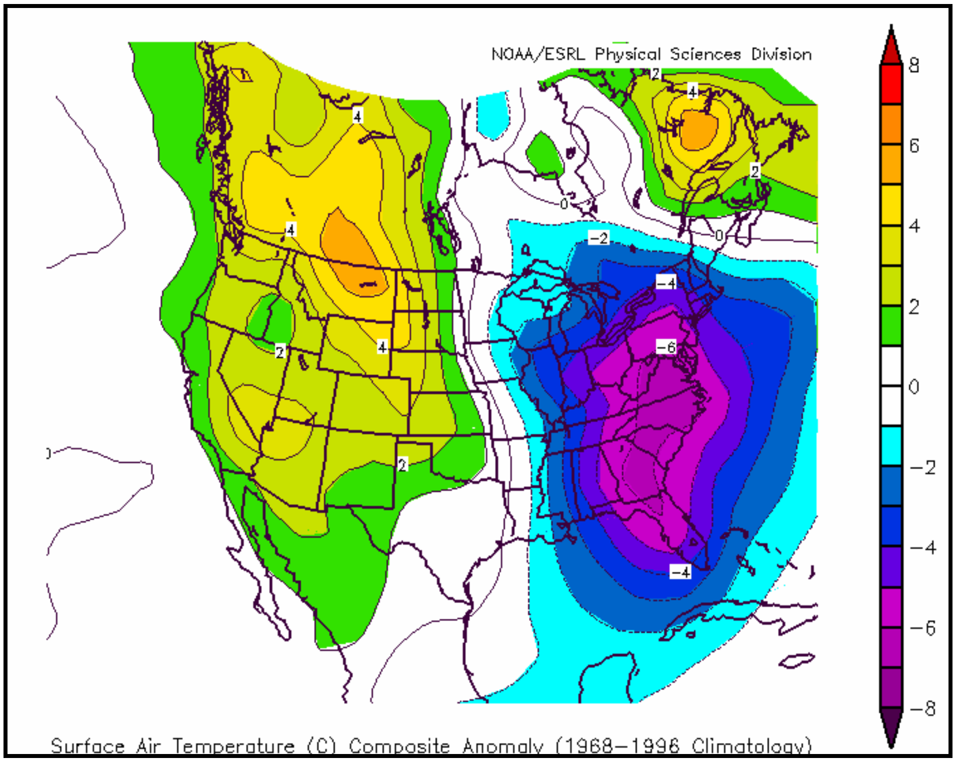


Figure 19. Composite daily surface air temperature anomaly (C) for the freeze events.

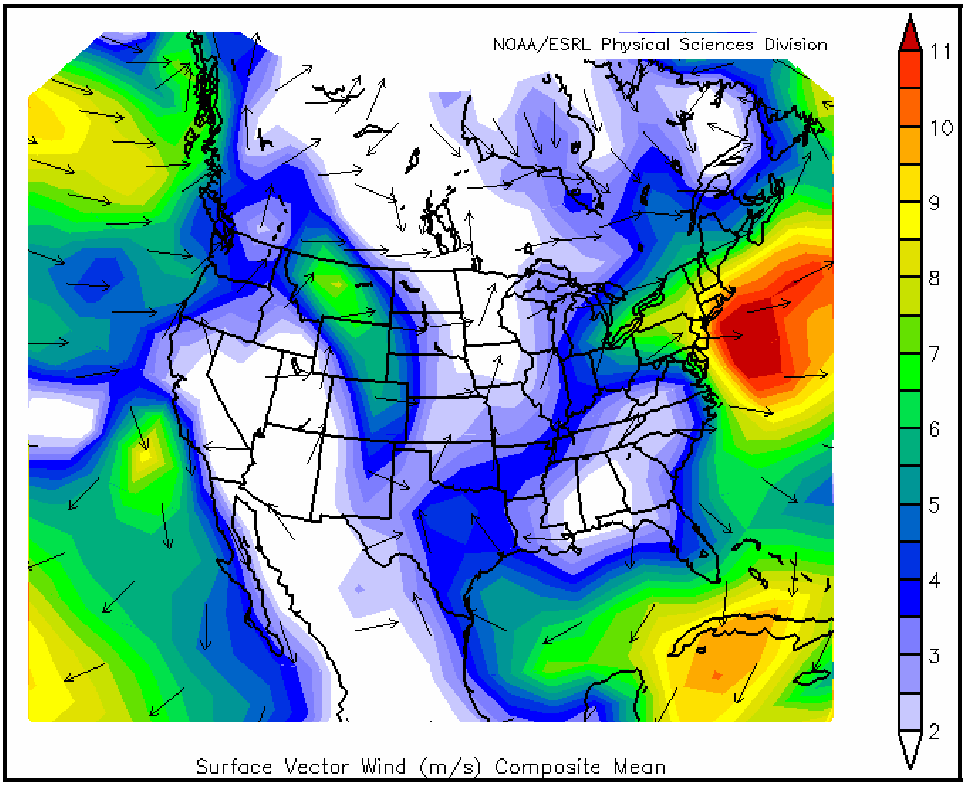


Figure 20. Composite daily surface wind vector analysis (m/s) for PLTF1 freeze events.

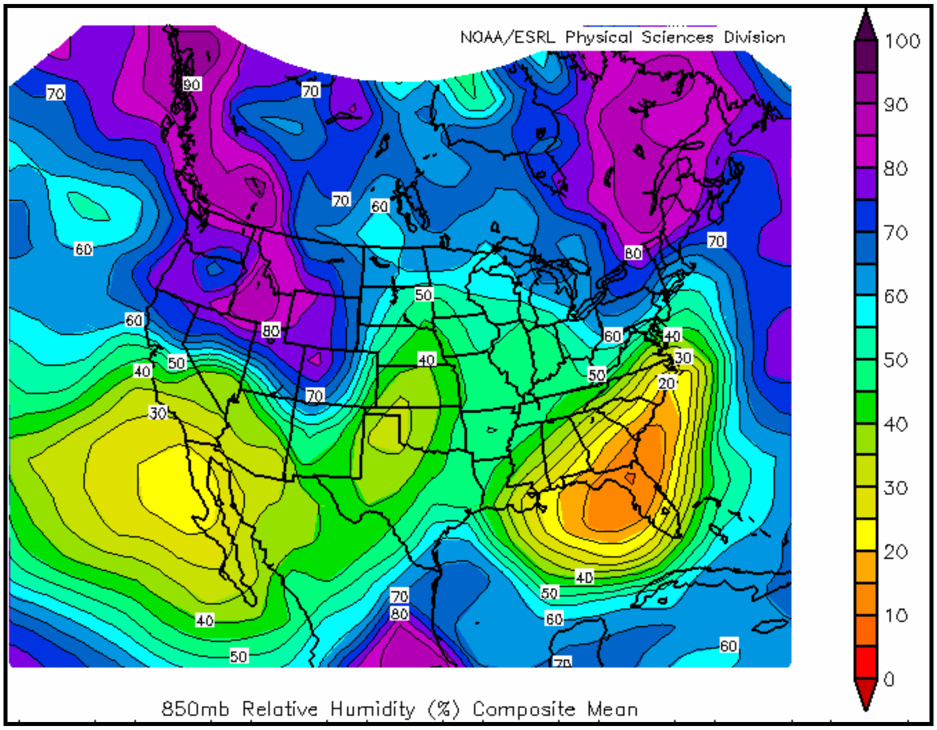


Figure 21a.

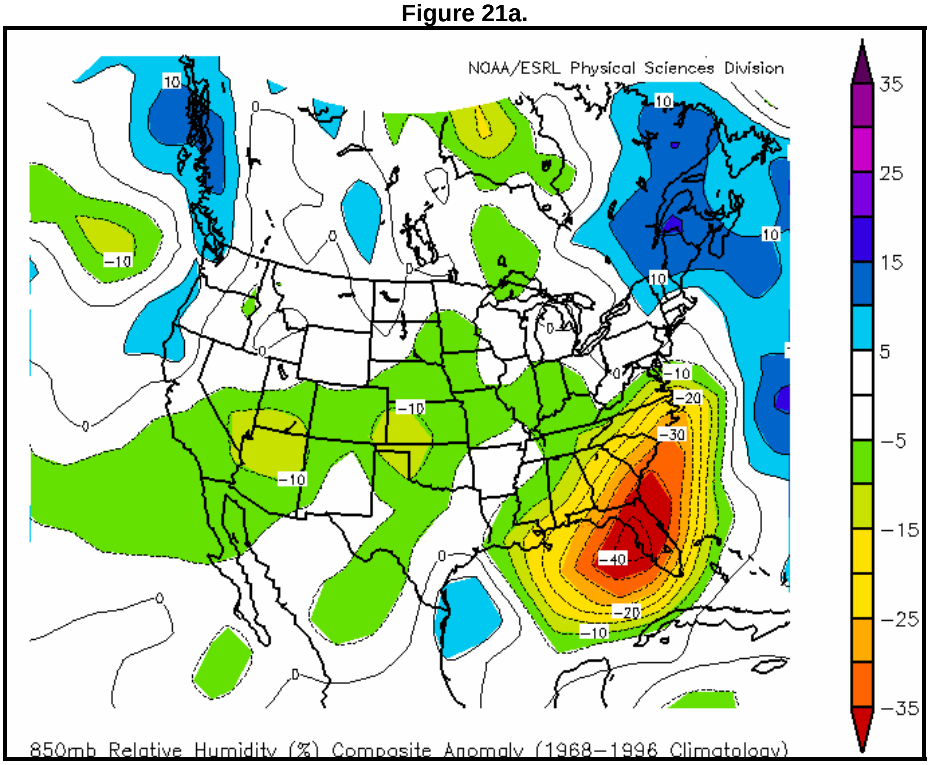


Figure 21b.

Figures 21a-b. Composite mean daily 850 mb relative humidity (21a) and 850 mb RH anomaly (21b) analyses for November freeze events at PLTF1.

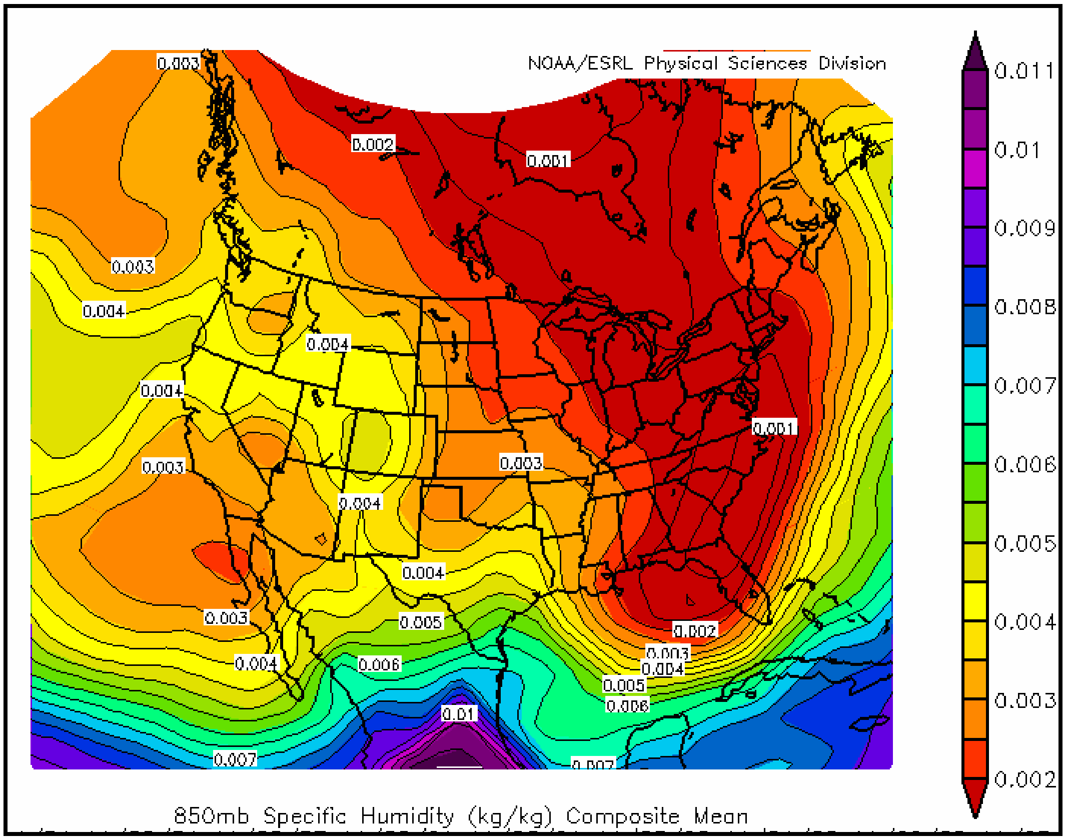


Figure 22. Composite daily mean 850 mb specific humidity analysis for PLTF1 freeze events.

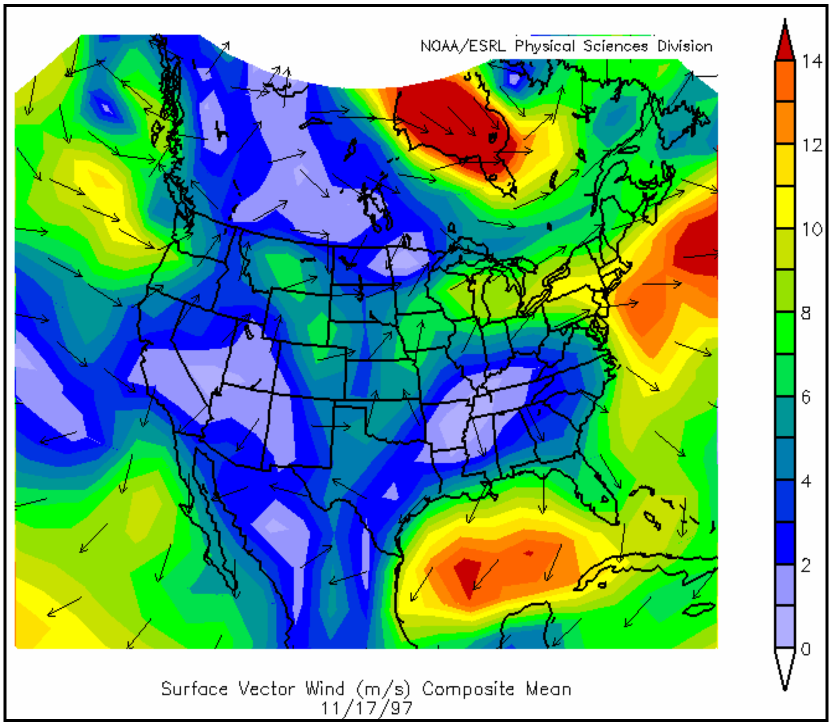


Figure 23a.

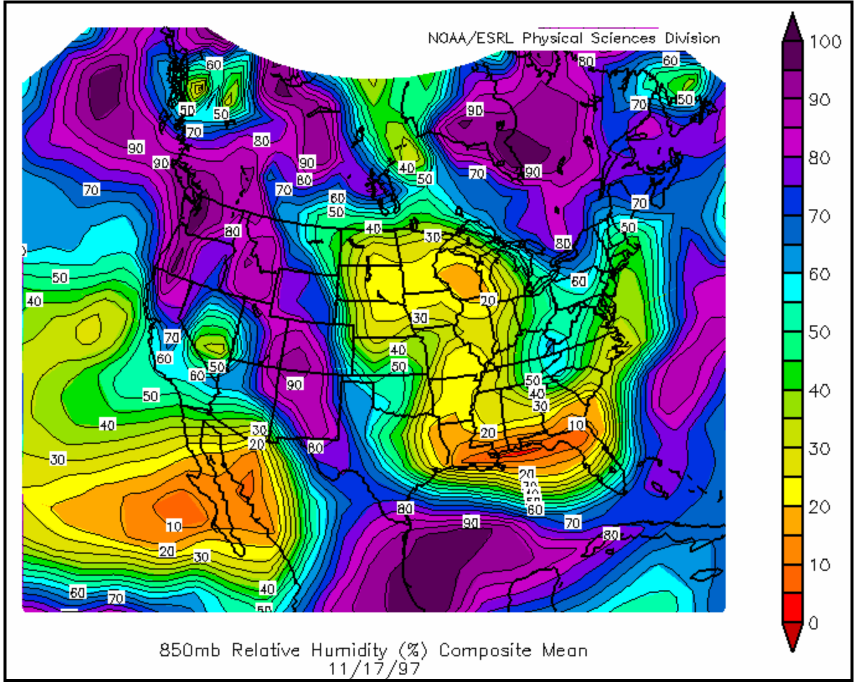


Figure 23b.

Figures 23a-b. Composite daily surface wind vector (23a) and 850 mb RH (23b) analyses for 17 November,1997.

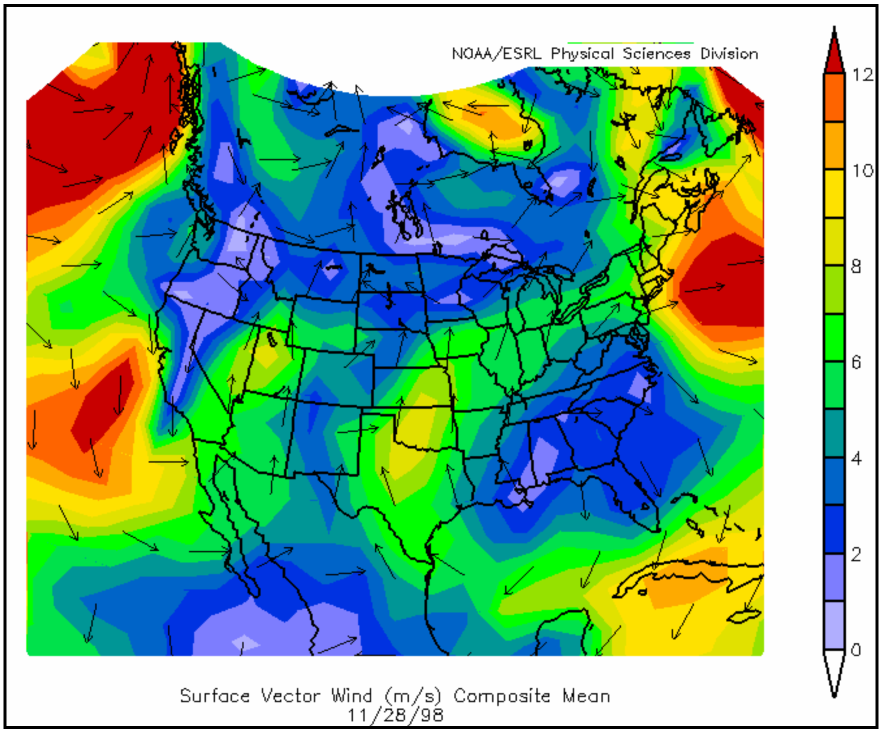


Figure 24a.

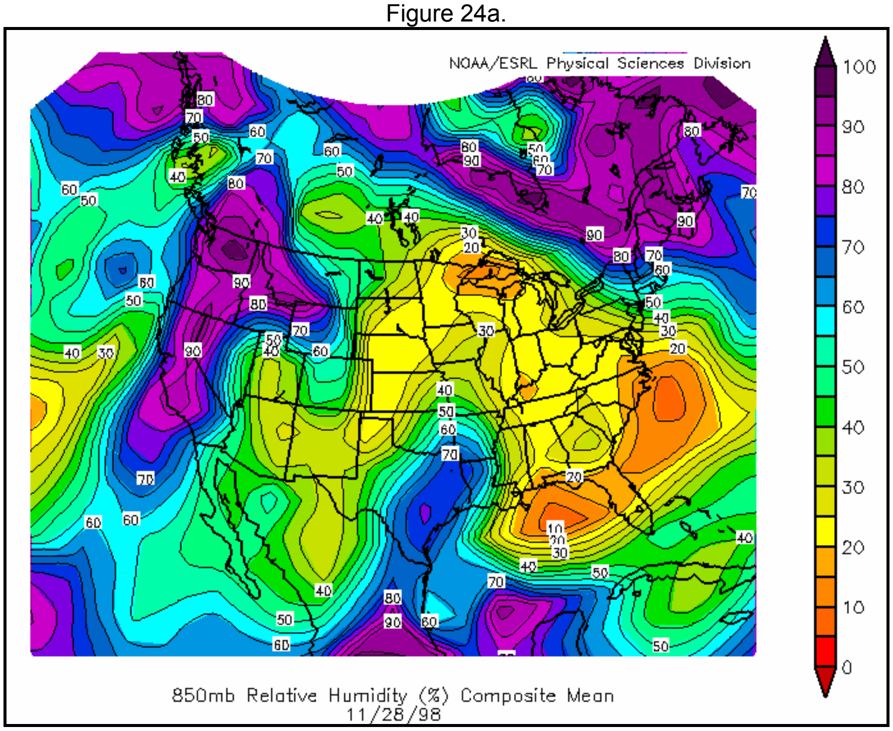
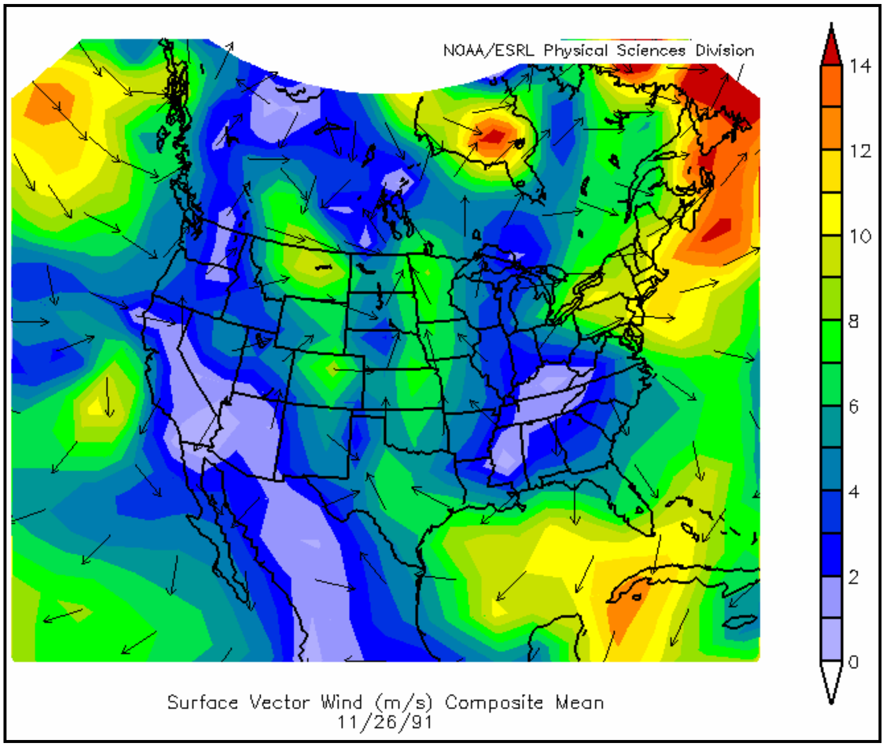


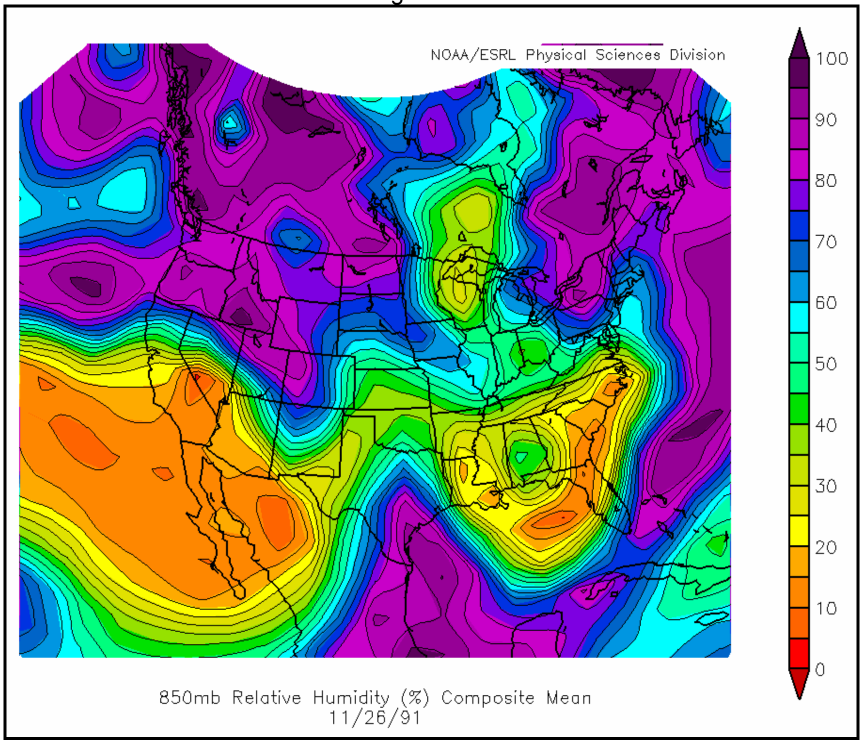
Figure 24b.

Figures 24a-b. Composite daily surface wind vector (24a) and 850 mb RH (24b) analyses for 28 November 1998.



Surface Vector Wind (m/s) Composite Mean
11/26/91

Figure 25a.



850mb Relative Humidity (%) Composite Mean
11/26/91

Figure 25b.

Figures 25a-b. Composite daily surface wind vector (25a) and 850 mb RH (25b) analyses for 26 November 1991.

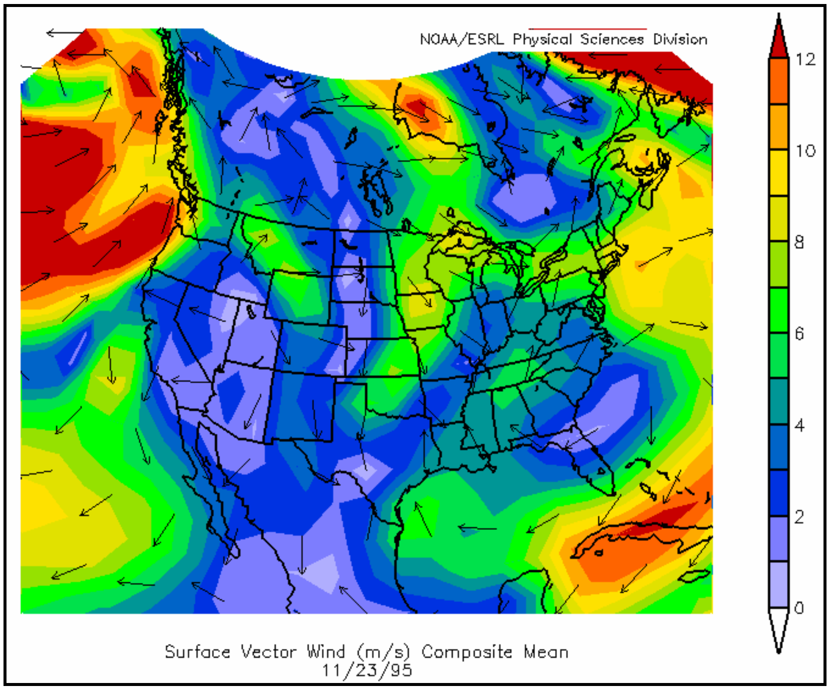


Figure 26a.

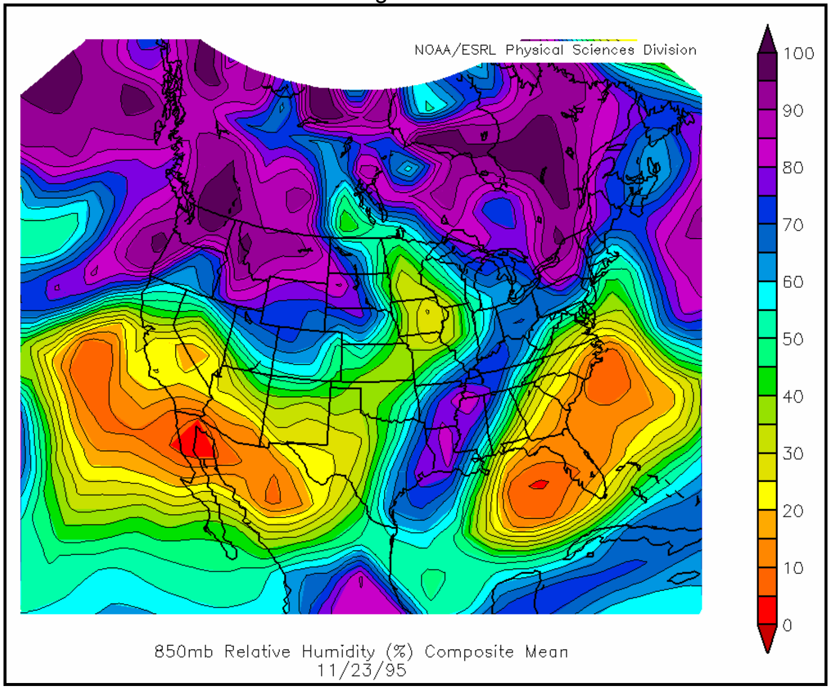


Figure 26b.

Figures 26a-b. Composite daily surface wind vector (26a) and 850 mb RH (26b) analyses for 23 November 1995.