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An Applied Climatology of Low Visibility Over the Coastal Waters of New Hampshire and Southern Maine

James C. Hayes
NOAA/National Weather Service
Gray, ME

Abstract

An applied climatology of low visibility has been developed for the coastal waters of southern Maine and New Hampshire. Low visibility, defined as 450 meters (¼ nautical miles (NM)) or less, can pose a significant hazard to marine operations. An examination of low visibility over the coastal waters of southern Maine and New Hampshire was performed using hourly observations from selected Gulf of Maine Ocean Observing System (GoMOOS) buoys in the Gray, ME (GYX) coastal waters for the period 2001 through 2007.

From these data, frequency distributions and composite maps were constructed. The highest percentage of hourly observations with low visibility occurred across the coastal waters of central Maine, with the lowest percentage across the coastal waters of New Hampshire. A south to southeast wind was favored for low visibility at all buoy locations. July had the highest number of low visibility observations at all buoy locations, with a general maximum occurring June through August. This coincides with the highest dew point temperatures of the year over the coastal waters.

For GoMOOS buoys closer to shore, the number of hourly observations with visibilities of 450 meters or less reached a minimum in the late afternoon and early evening. The maximum occurred just before sunrise. For GoMOOS buoys further offshore, the differences between the maximum and minimum were less distinct.

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1. Introduction

Low visibility (defined as a surface visibility of 450 meters (¼ NM) or less) over the coastal waters has a significant impact on commercial and recreational activities. The primary restriction to visibility over the coastal waters is fog. The most common type of fog for the coastal waters of New Hampshire and southern Maine is advection fog (also referred to as sea fog). This is caused by the movement of moist air over colder water, and the consequent cooling of the air to its dew point (Binhua 1985).

Advection fog tends to prevail in locations where two ocean currents with different temperatures flow next to each other (Ahrens 1994). The cold Labrador Current flows south off the coast of Newfoundland and Nova Scotia, while the Gulf Stream flows almost parallel to the Labrador Current well south of the Gulf of Maine (Fig. 1). Warmer air flowing north from the Gulf Stream results in advection fog development over the relatively cool Gulf of Maine. This flow produces fog two out of three days during the summer across the Labrador Current (Ahrens 1994).

The Labrador Current feeds colder water southwest around Labrador into the Nova Scotian Current (labeled in Fig. 1), which flows south of Nova Scotia into the Gulf of Maine. The Nova Scotian Current splits in the Gulf of Maine into the Eastern Maine Coastal Current and the Western Maine Coastal Current (Fig. 2).

While sea fog is a common occurrence across the Gulf of Maine, especially during the summer months, no comprehensive climatology of fog for the Gulf of Maine exists. The goal of this study is to provide forecasters with a preliminary climatology of low visibility over the coastal waters of New Hampshire and southern Maine. The information derived here will give forecasters some understanding of the frequency and extent of low visibilities across the coastal waters. This should, in turn, result in better forecaster awareness and improved visibility forecasts.

2. Data and Methodology

Until recently, visibility over the coastal waters was inferred from ASOS and AWOS observations near the coast, since no other marine visibility observations were available. However, the deployment of buoys by GoMOOS provided a network of real-time visibility observations. GoMOOS is a national pilot program designed to offer real-time meteorological and oceanographic data for the Gulf of Maine.

GoMOOS deployed its first 10 buoys in 2001. Among its sensors, each GoMOOS buoy is equipped with a Mira 3544 EX visibility sensor, which has an operational range of 20 to 3000 meters (AADI 2009). Each buoy collects and transmits meteorological and oceanographic data each hour. The data is accessible on the GoMOOS web site (available at http://www.GoMOOS.org). In addition to real-time data, the GoMOOS web site offers access to historical data back through 2001.

Hourly air temperature, sea surface temperature (SST), wind direction, speed, gusts and visibility were collected for each of the GoMOOS buoys in the Taunton, MA (BOX), Gray, ME (GYX) and Caribou, ME (CAR) coastal waters (Fig. 3) for the study period (2001-2007). Hourly observations for selected ASOS and AWOS sites were collected from the National Climatic Data Center (NCDC) website for the study area in order to supplement the visibility observations near the coast (NCDC 2009).

In order to develop pattern recognition for low visibility over the Gulf of Maine (due primarily to sea fog), a synoptic climatology was created, using data from the Daily Average NCEP NARR composites [available at http://www.esrl.noaa.gov/psd/cgi-bin/data/narr/plotday.pl]. Average meteorological conditions for days with hourly observations with low visibility were examined using this dataset. The daily composites are averages of the 0000, 0600, 1200, and 1800 UTC data, and the anomalies are based on means computed between 1979 and 2006. The NARR dataset was used to build a climatology of mean sea level pressure (MSLP) and 2 meter dew point for the Gulf of Maine for the study period.

Additionally, in order to determine the frequency distribution of wind direction and speed for the spring and summer months at the GoMOOS buoys locations, comprehensive wind rose plots were constructed using the WindPro software (available at http://www.emd.dk/WindPRO).

Finally, monthly SST values were collected for the Gulf of Maine. SST products are created from data collected from the Advanced Very High Resolution Radiometer (AVHRR), located onboard the NOAA polar orbiters. The data from the AVHRR is processed through the Pathfinder program, a collaborative effort among the National Oceanographic Data Center (NODC), the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (RSMAS), and NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC). AVHRR Pathfinder SST version 5 offers 4 km resolution for the period 1985 to the present (NASA 2009). Monthly SST climatologies for the Gulf of Maine for the period 1985 through the present were created from locally stored AVHRR Pathfinder SST products, using temporal averaging, at the Satellite Oceanography Lab, located at the University of Maine (available at www.seasurface.umaine.edu).

3. Results

The percentage of hourly observations with low visibility was calculated for each GoMOOS buoy, as well as selected ASOS and AWOS sites in the study area. The percentage values were plotted in ArcMAP (Harlow and Pfaff 2004). A gridded map was created from the percentages across the study area utilizing inverse distance weighted (IDW) interpolation (Fig. 4).

The highest percentage of hourly observations with low visibilities was located over the eastern Maine coastal waters, with values approaching nine percent. This is likely due, at least in part, to lower SST values over the coastal waters of eastern Maine. The colder water associated with the eastern Maine Coastal Current serves as a colder surface over which warmer air rides, cools to its dew point, and forms sea fog over the eastern Maine coastal waters.

Over the GYX coastal waters, the highest percentage of hourly observations with low visibility occurred over the central Maine coastal waters, closest to the colder eastern Maine Coastal Current. A much lower percentage occurred over the New Hampshire coastal waters, near the mouth of the Merrimack River. This is close to the southern terminus of the warmer western Maine Coastal Current.

a) Monthly distributions

All GoMOOS buoy locations in the GYX coastal waters showed a broad maximum of low visibility between May and October. The broadest maximum occurred at GoMOOS Buoy B, spanning from May through October, with a peak in July (Fig. 5). A similar pattern occurred at GoMOOS Buoy C. However, the maximum stretches from May through August, with a more pronounced peak in July. The July peak is even more prevalent at GoMOOS Buoy E and F, with a less expansive overall maximum.

While the maximum of low visibility occurred over slightly different time periods for each GoMOOS buoy location, all buoy locations showed a peak in July. This may be attributed to the prevailing flow over the coastal waters during the summer months. During this time, surface high pressure is typically located well east of the mid Atlantic coast (often referred to as the Bermuda High) (Fig. 6). The clockwise flow around the expansive high produces a south to southwest flow over the coastal waters (Fig. 7). The flow draws higher dew point temperatures northward over the Gulf of Maine (Fig. 8).

Mean 2 m dew point temperatures for the GYX coastal waters for July were highest near the New Hampshire coast (about 18 °C) and lowest near the mouth of the Penobscot Bay. Mean SST for the GYX coastal waters for July ranged from 19° C near the New Hampshire coast to 15° C near the mouth of the Penobscot Bay (Fig. 9). Even though the differences between the mean surface dew point temperatures and composite SST values for July were small, the mean dew point is actually lower than the composite SST value at GoMOOS Buoy B, when compared to GoMOOS Buoy F, where the values are about the same.

While composite SST values were lower in June, the mean dew point temperatures over the coastal waters were also lower (Fig. 10). This may account for the lower number of hourly observations with low visibility in June (when compared to the July peak). In August, the composite SST values are nearing their highest values for the year (Fig. 11). The composite SST values were, in most locations, above the mean dew point temperatures over the coastal waters. This may explain the lower number of hourly observations with low visibility in August (again, when compared to the July peak).

b) Hourly distributions

The trend of hourly observations with low visibility generally followed a diurnal pattern. The number of hourly observations with low visibility peaked during the early morning hours and reached a minimum in the mid to late afternoon. The maximum occurred with diurnal cooling near the time of low temperature over the coastal waters. This can be attributed to cooling and moistening of the lowest portion of the marine layer. The timing of the maximum is roughly the same for all GoMOOS buoy locations.

The minimum in low visibility generally occurred during the mid to late afternoon. This is due to warming and drying of the boundary layer over land, due to solar insolation. The prevailing south to southwest surface transports the drier air from land to the near shore waters, allowing dew point temperatures to lower and help dissipate the sea fog. This occurred more quickly at GoMOOS buoys B and C. Since these buoys are closer to land, the prevailing surface flow more effectively brings the drier air to these locations (Fig. 12). After the heating maximizes, the number of hourly observations with low visibility begins to increase.

The diurnal trend in hourly observations with low visibility was also apparent at GoMOOS buoys E and F. However, the diurnal trend was not as distinct for these buoy locations, with a much broader maximum and a less distinct minimum. The prevailing south to southwest surface flow at these locations is not land based, and the drier air from land does not typically reach these buoys.

c) Air-sea temperature difference

As might be expected, the difference between air temperature and SST for hourly observations with low visibility was close to zero for all GoMOOS buoys. There were, however, a very small number of observations where the air temperature was more than 14° C cooler than the underlying SST. The largest number of observations occurred at GoMOOS Buoy B, but all other GoMOOS buoys showed at least a few observations with very large air-SST differences (Fig. 13). While the sample size is very small, these occurrences appear to coincide with episodes of arctic sea smoke over the near shore waters.

4. Case Study - 4 August 2009

A typical pattern for low visibility over the GYX coastal waters developed during the early morning hours of 4 August 2009. High pressure located well east of the mid Atlantic coast produced a south to southwest flow over the coastal waters (Fig. 14). The flow transported surface dew points between 16° C and 19° C over the Gulf of Maine (Fig. 15). High sea surface temperatures over the coastal waters ranged from about 19° C along the New Hampshire to about 15° C near the mouth of the Penobscot Bay (Fig. 16) The higher dew points advected over the cooler SST aided in the formation of sea fog over a large portion of the GYX coastal waters during the early morning hours of 4 August 2009 (Fig. 17). The visibility at GoMOOS buoy E (located in marine zone ANZ152) dropped to 450 meters (1/4 NM) at 0800 UTC, and the visibility at GoMOOS buoy F (located at the mouth of the Penobscot Bay) dropped to 450 meters one hour earlier (about 0700 UTC).

With little in the way of cloudiness over land, heating commenced quickly after sunrise. The heating resulted in convective mixing, which brought drier air from above to the surface. As the light surface flow veered to the southwest over southwest Maine, the drier air was entrained into the marine layer over the coastal waters. The drier air help erode the western edge of the sea fog across Casco Bay (ANZ153) and the western portions of ANZ152 (Fig. 18).

However, the visibility at GoMOOS buoys E and F did not improve during the day. This was likely due to the southerly flow, since that trajectory did not allow drier air to be entrained into the marine layer and help dissipate the fog.

5. Summary

An operational climatology of low visibility over the Gray ME coastal waters was constructed using visibility data from GoMOOS buoys. The highest percentage of hourly observations with low visibility occurred over the eastern portion of the coastal waters, near the mouth of the Penobscot Bay. A much lower percentage occurred over the southern coastal waters, near the mouth of the Merrimack River.

A broad maximum of low visibility extended from May through October for all GoMOOS buoys. This is due, at least in part, to warmer air drawn north over the Gulf of Maine in the spring and summer months by high pressure anchored off the mid Atlantic coast. In this scenario, the warmer air rides over the cooler sea surface temperatures transported into the Gulf of Maine by the cold Labrador Current (via the eastern Maine Coastal Current). The warmer air is then cooled to its dew point, forming sea fog.

Since the coldest sea surface temperatures typically reside over the coastal waters of central and eastern Maine, the highest frequency of low visibility occurred in the eastern portion of the Gray ME coastal waters. All GoMOOS buoy locations showed a peak in low visibility in July. This may be attributed to higher dew point temperatures being transported north over the still cool sea surface temperatures. While sea surface temperatures are cooler in June, the mean dew points over the coastal waters are about the same as the sea surface temperatures, resulting in fewer hourly observations with low visibility. By August, the mean sea surface temperatures are higher, but so are the mean dew point temperatures, resulting in fewer hourly observations with lower visibility.

A diurnal trend in low visibility was evident at all GoMOOS buoy locations. The maximum of low visibility during the early morning hours can be attributed to cooling and moistening of the lowest portion of the marine layer. The timing of the minimum is roughly the same for all GoMOOS buoy locations. The minimum of low visibility generally occurs in the mid to late afternoon. It is thought that this is due to warming and drying of the boundary layer over land. In this scenario, the drier air is then entrained into the marine layer over the near shore waters, allowing dew points to lower and help dissipate the sea fog. For GoMOOS buoys B and C, the minimum is pronounced in the mid to late afternoon. For GoMOOS buoys E and F, where the entrainment of drier air from land is not as pronounced, the minimum is less distinct.

As might be expected, almost all hourly observations with low visibility occurred with an air-sea surface temperature difference of ± 2° C. However, all GoMOOS buoys (most notably Buoy B) had low visibility when the air temperature was more than 14 °C colder than the underlying SST. While the sample size is very small, these occurrences appear to coincide with episodes of arctic sea smoke over the near shore waters.

Using these results, marine forecasters should be able to identify times of day and year when low visibility is likely, and add this information to the marine forecast products.

Acknowledgments

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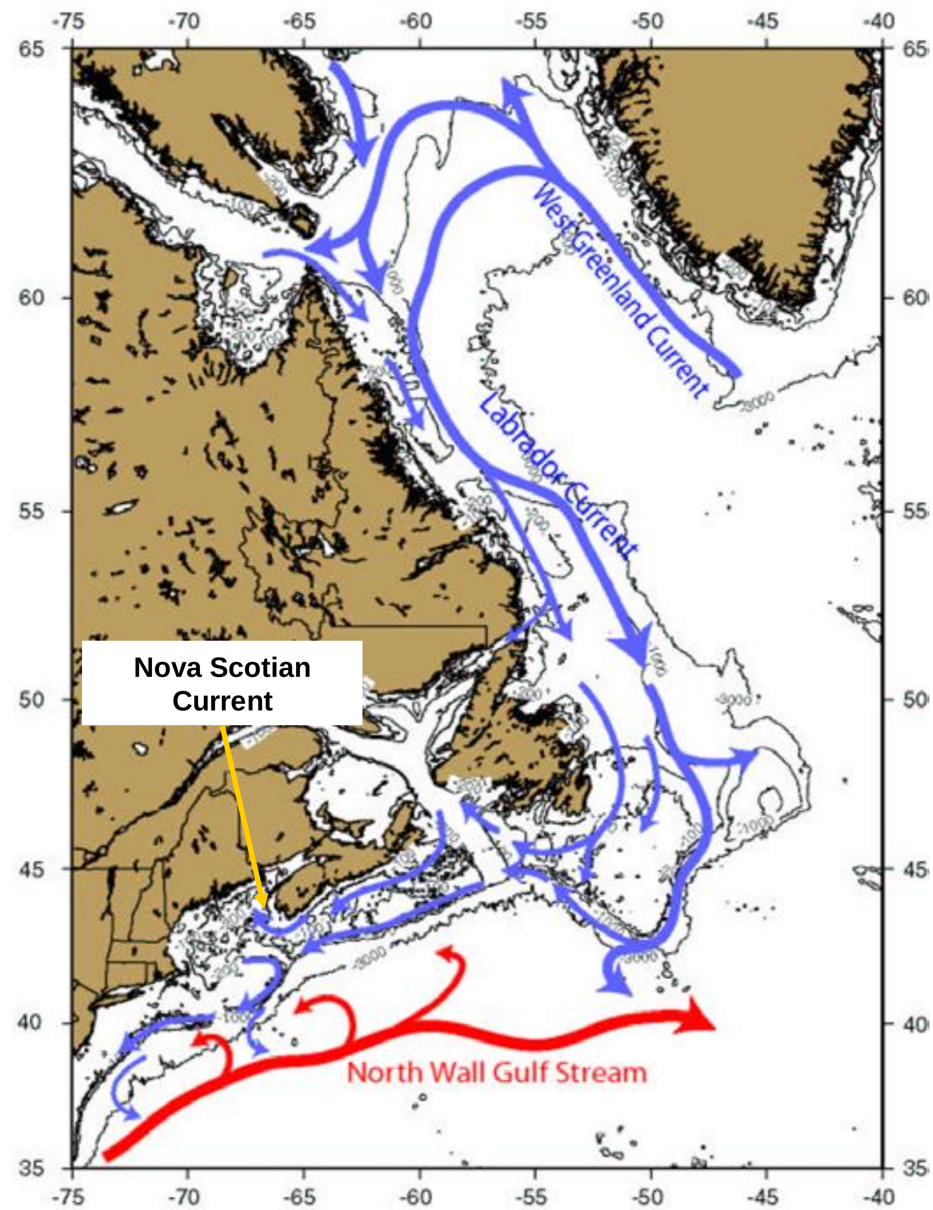


Figure 1. The Labrador Current feeds cold water southwest toward the Gulf of Maine, while the Gulf Stream passes to the southwest (from Townsend and Ellis 2008). The Nova Scotian Current is denoted by the yellow arrow.

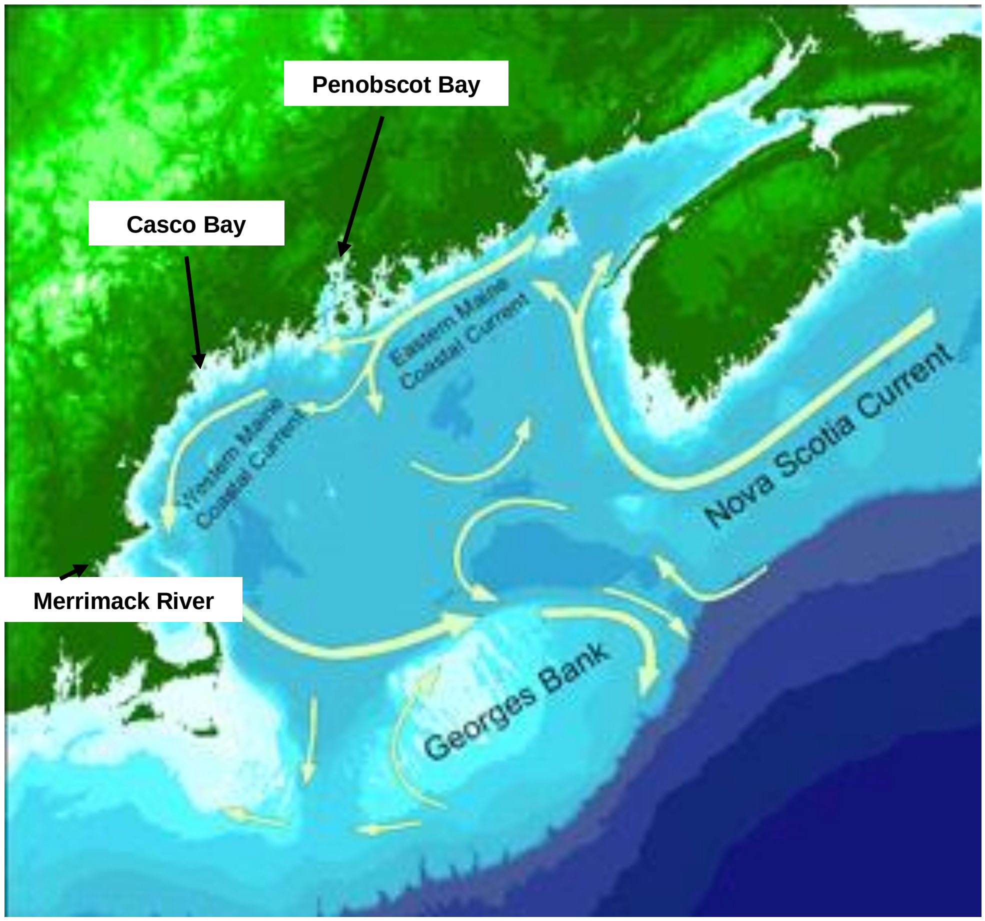


Figure 2. Currents in the Gulf of Maine (from Pettigrew et al. 2005)

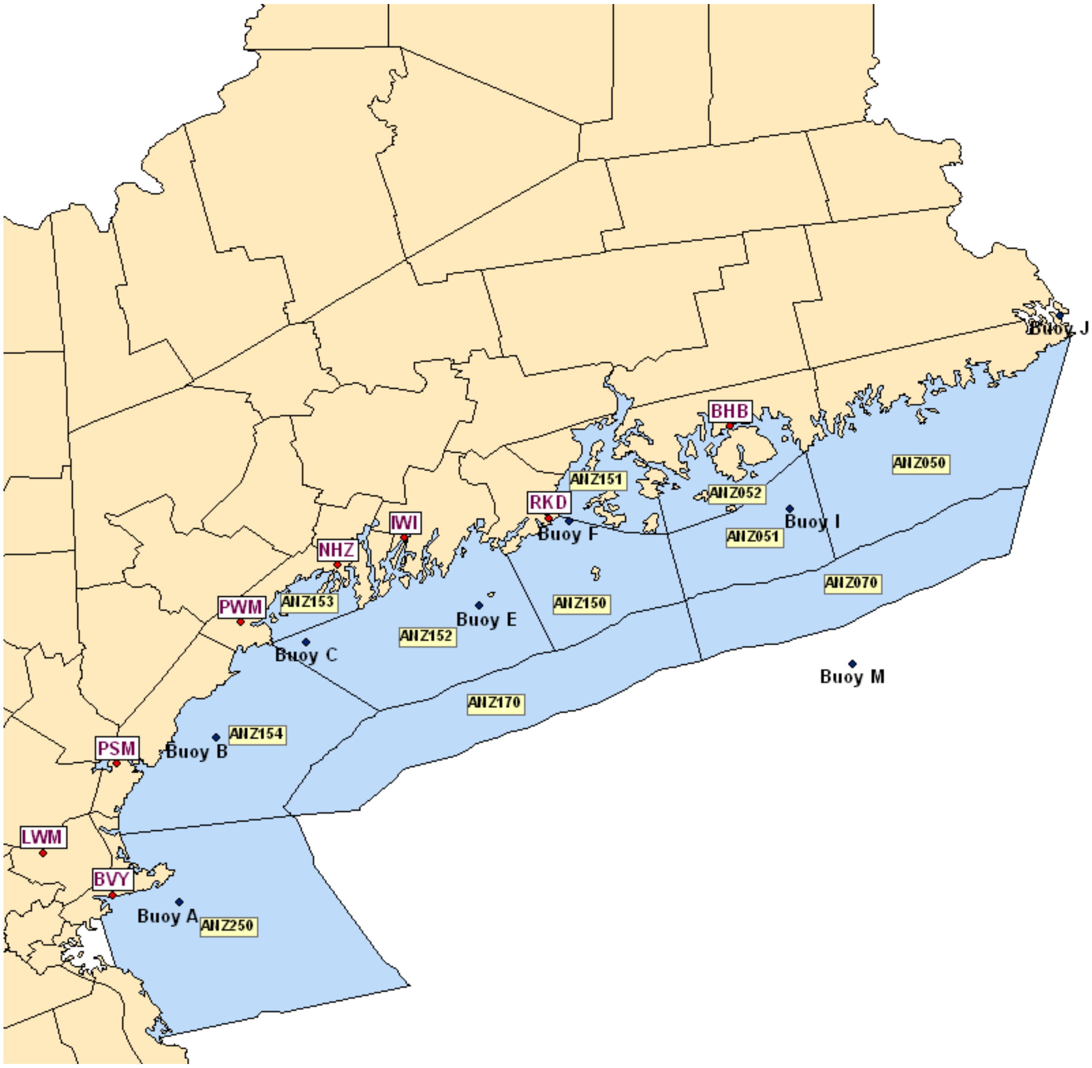


Figure 3. Locations of the GoMOOS buoys and ASOS/AWOS surface observations used in the study. The marine zones are also labeled.

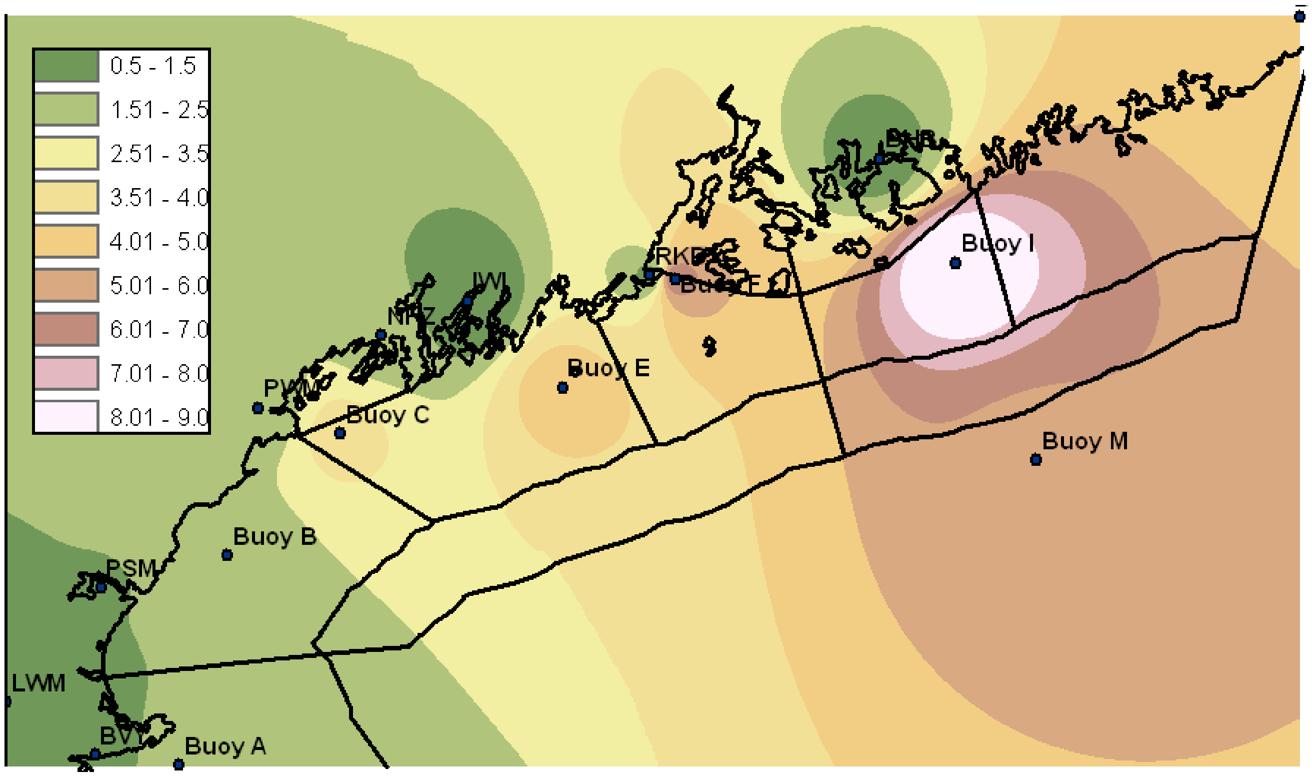


Figure 4. Percentage of hourly observations with visibilities of 450 m (¼ NM) or less, 2001-2007. GoMOOS buoys and ASOS/AWOS observations were used to construct the map.

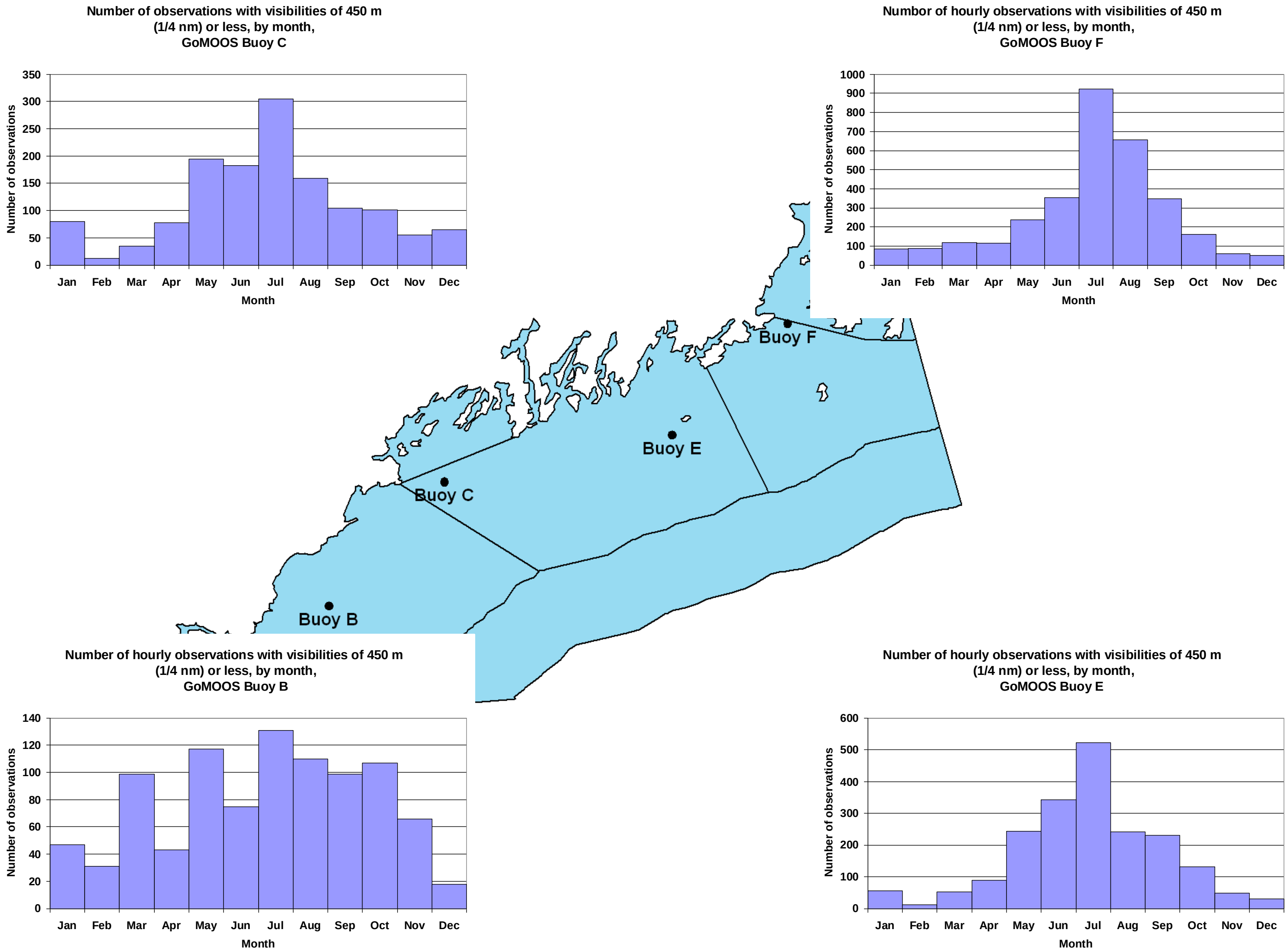


Figure 5. Number of hourly observations with low visibility, by month of the year, for each of the GoMOOS buoys in the GYX coastal waters.

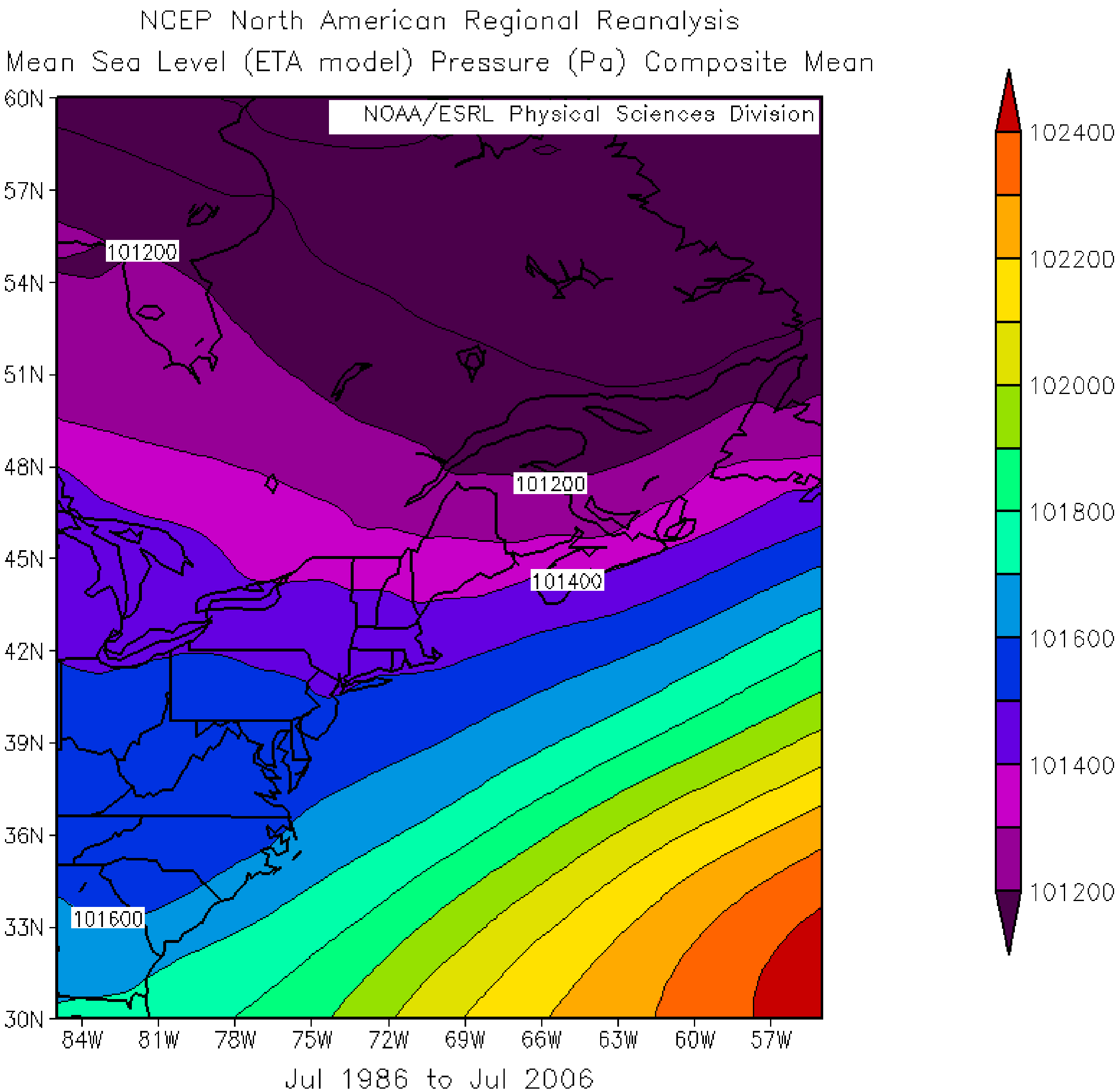


Figure 6. NARR July Mean sea level pressure composite (pascals).

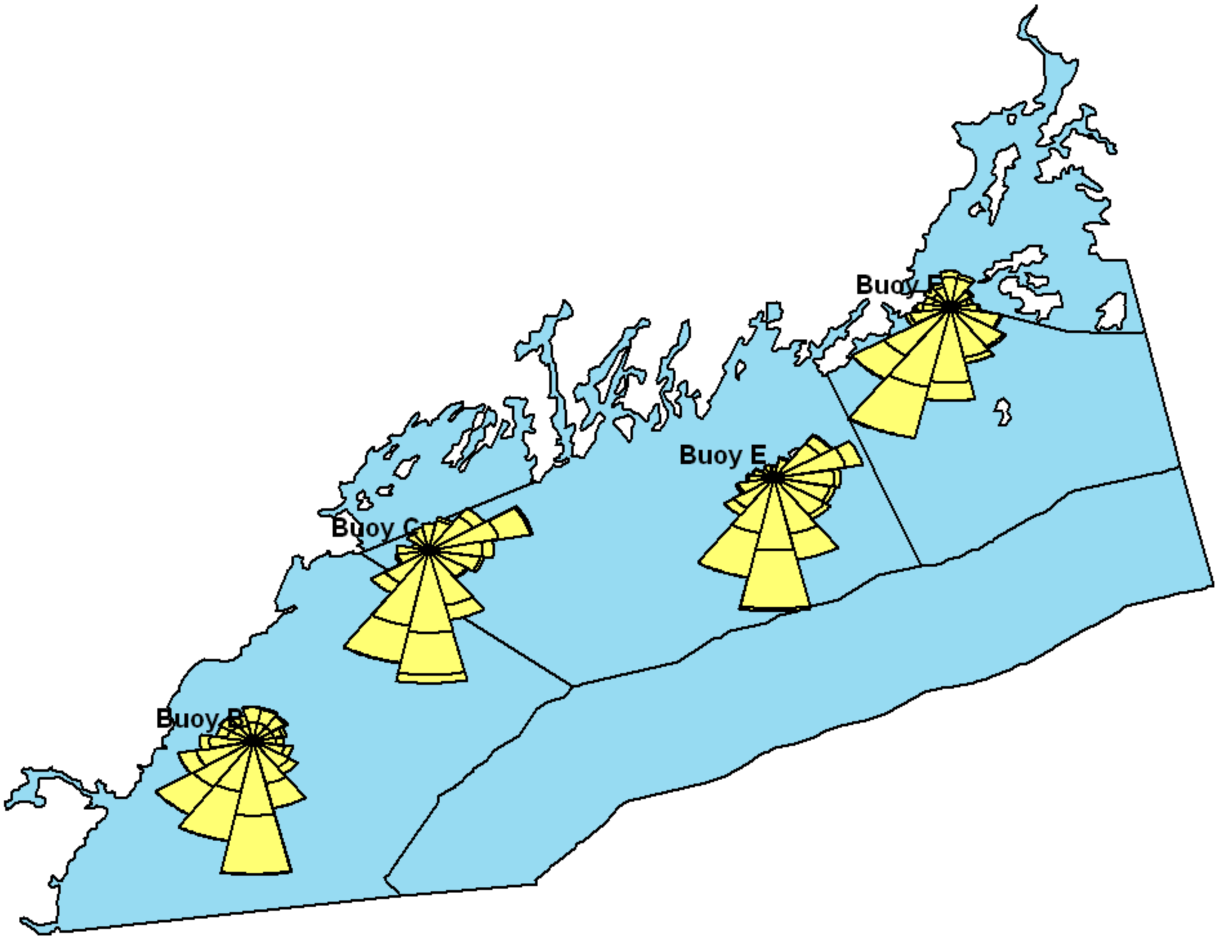


Figure 7. July wind roses for the GoMOOS buoys in the GYX coastal waters

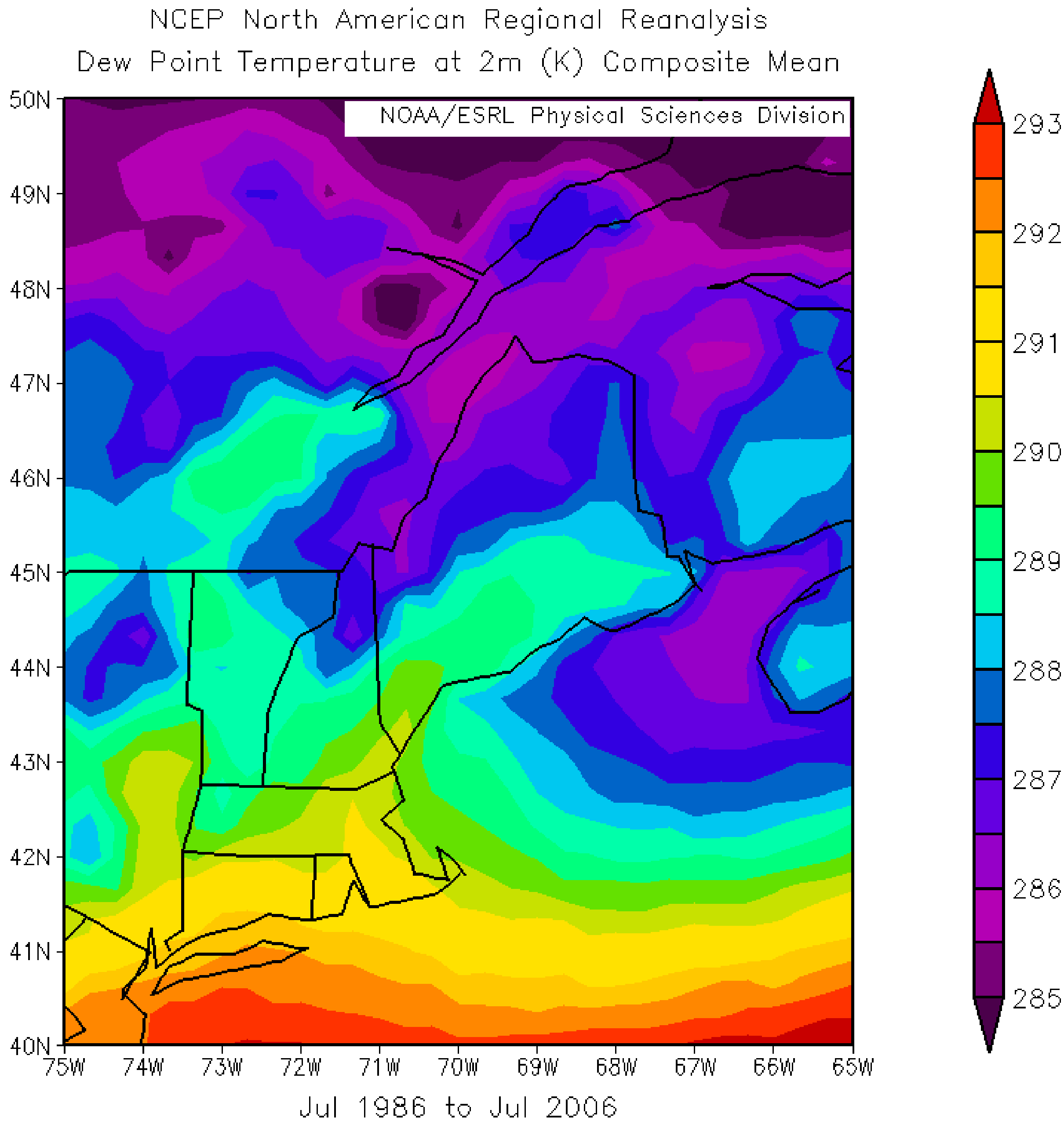


Figure 8. NARR composite 2 meter dew point for July (K).

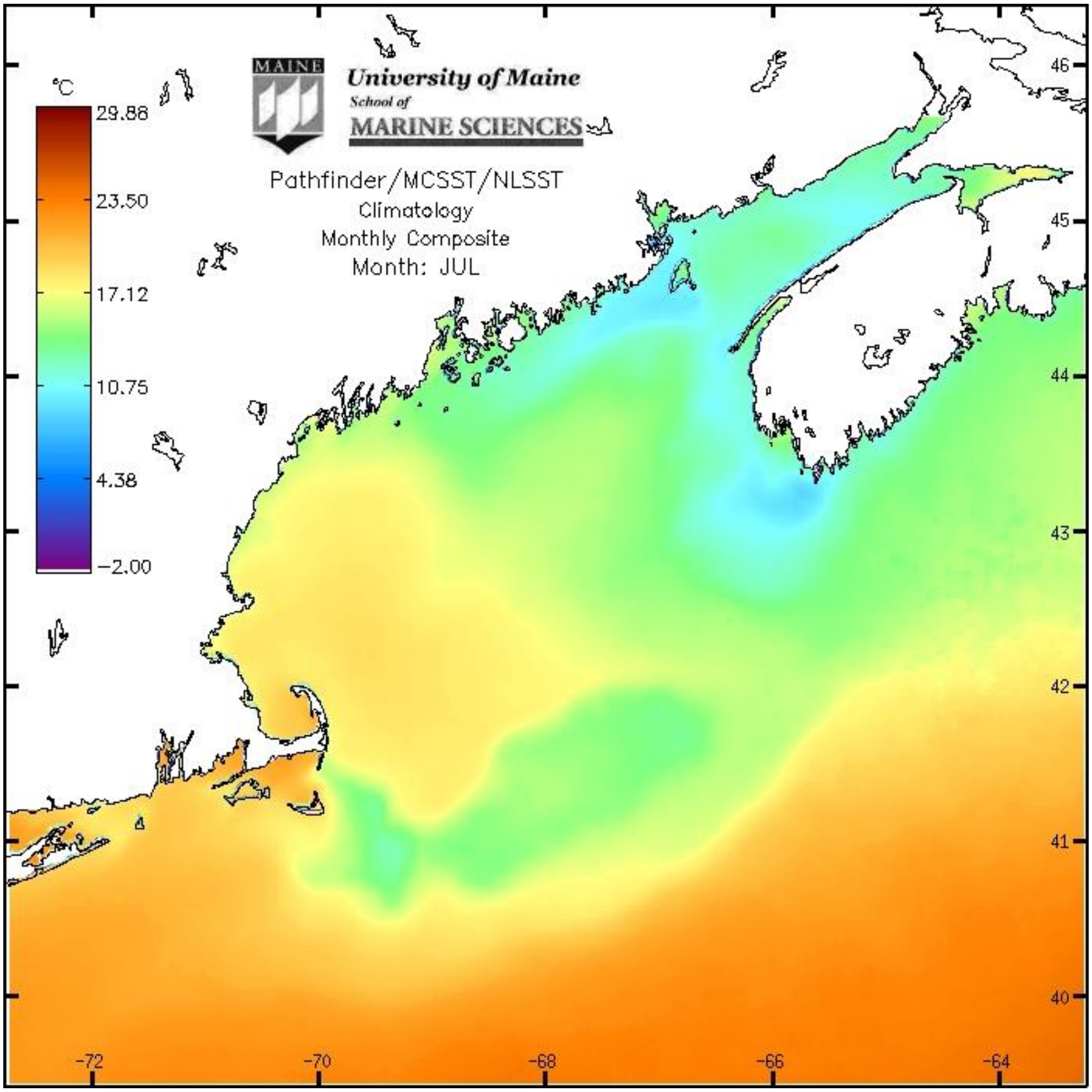
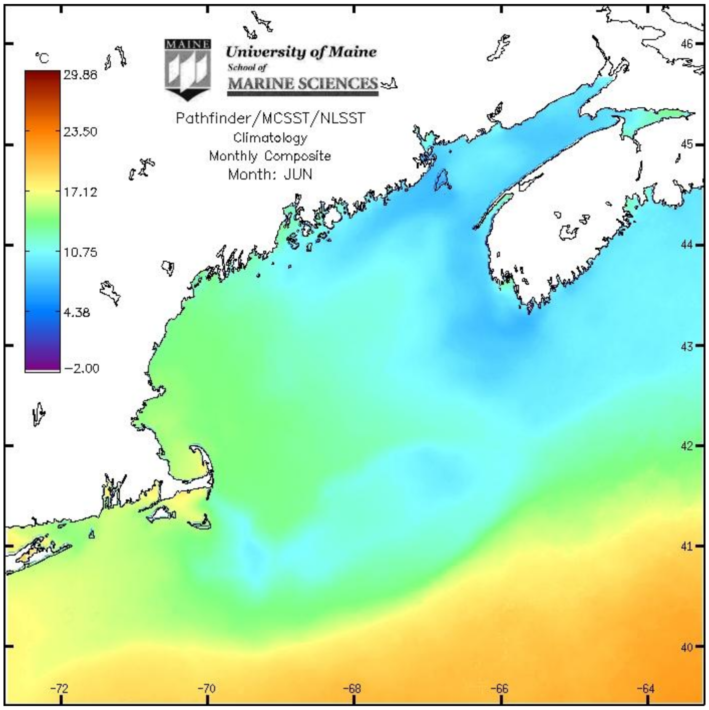


Figure 9. Monthly composite sea surface temperature (SST) for July for the Gulf of Maine (°C). The 4km monthly composites were constructed from locally stored AVHRR Pathfinder SST products, using temporal averaging, at the Satellite Oceanography Lab, located at the University of Maine.

a)



b)

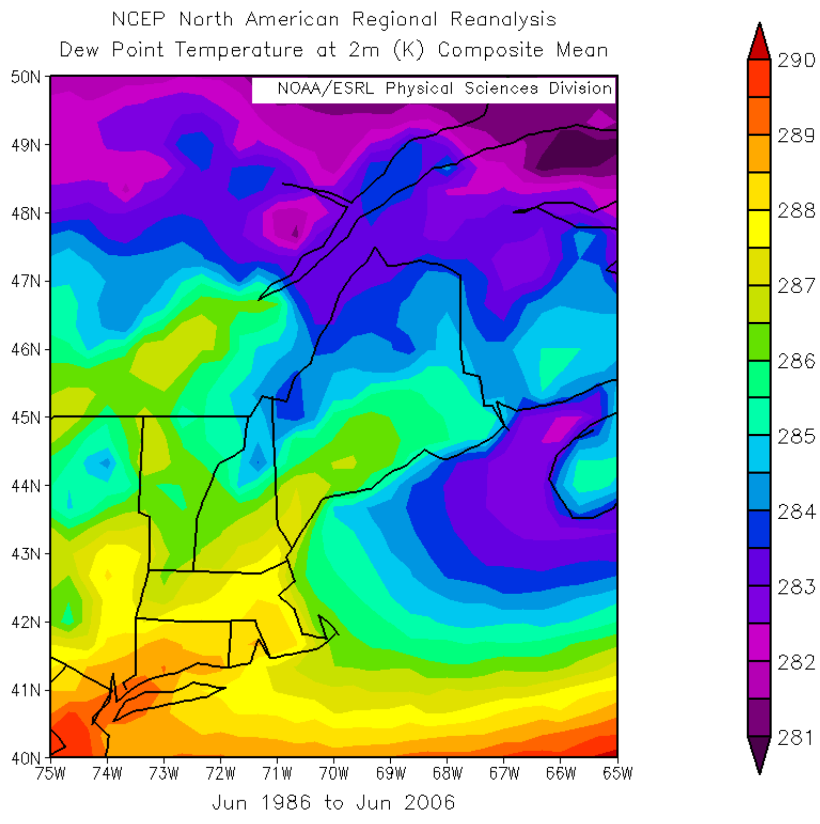


Figure 10. (a) Monthly composite SST for June (°C), and (b) NARR composite 2 meter dew point for June (K).

a)

b)

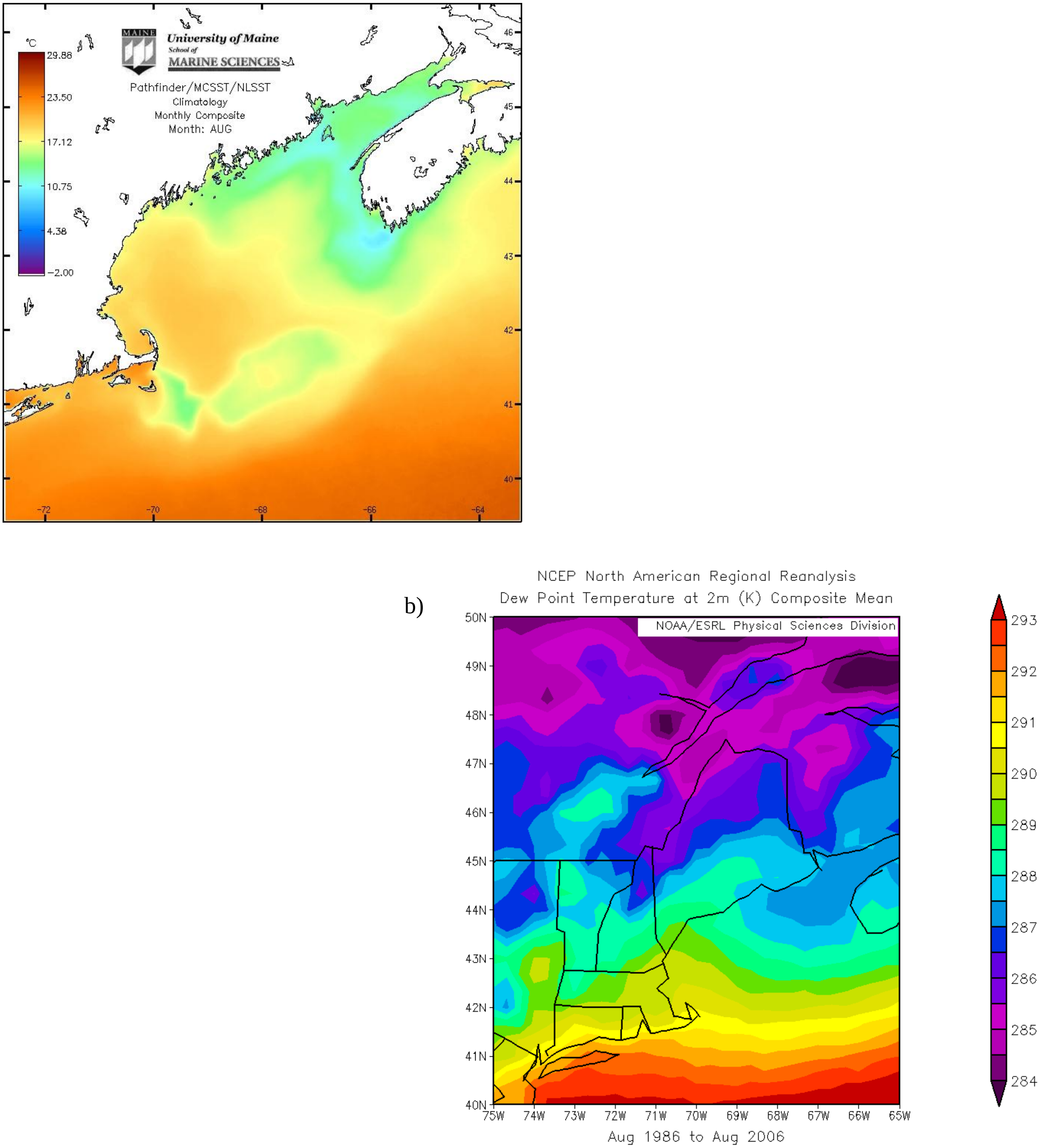


Figure 11. (a) Monthly composite SST for August (°C) and (b) NARR composite 2 meter dew point for August (K).

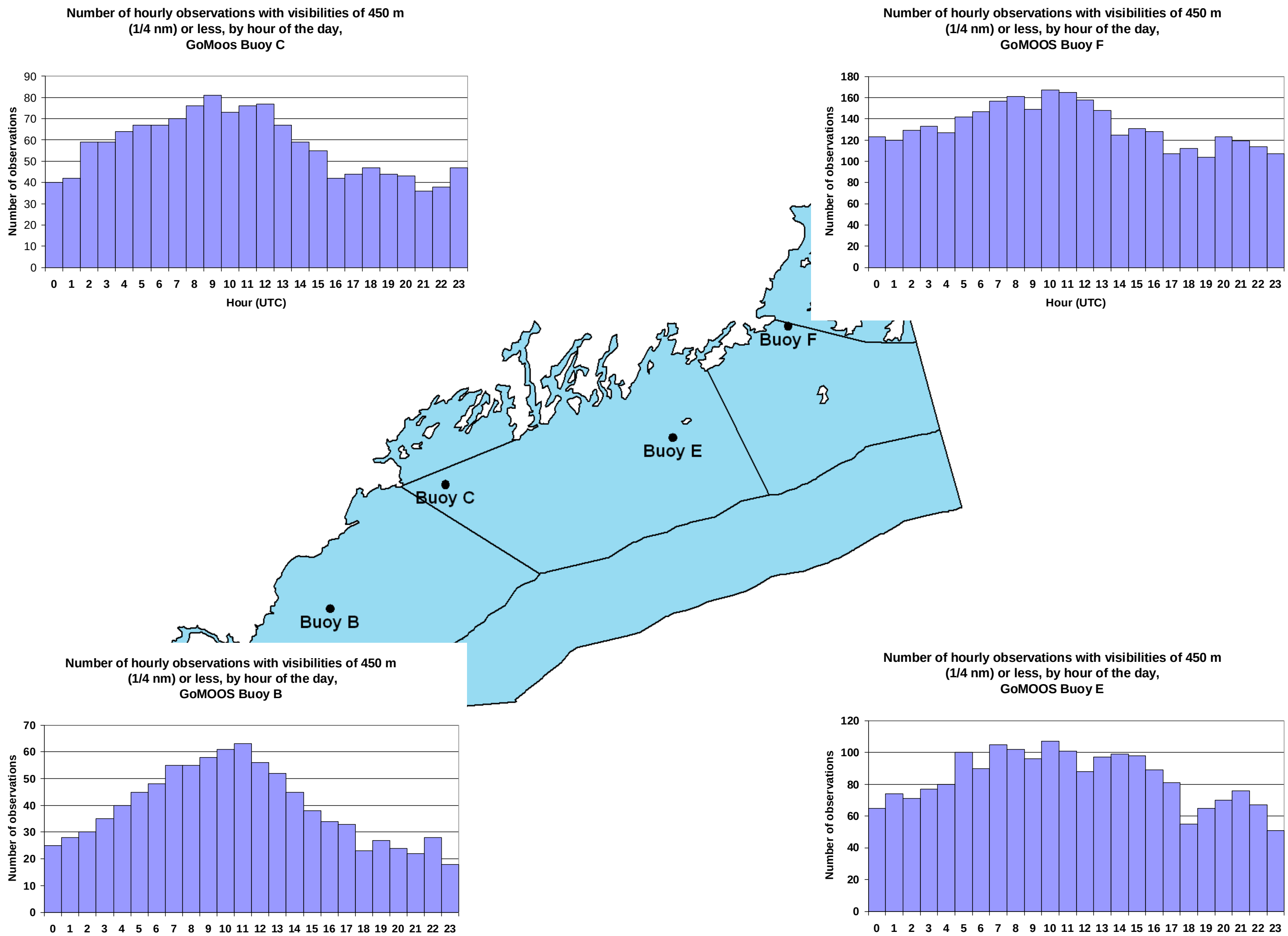


Figure 12. Number of hourly observations with low visibility, by hour of the day (UTC), for each of the GoMOOS buoys in the GYX coastal waters.

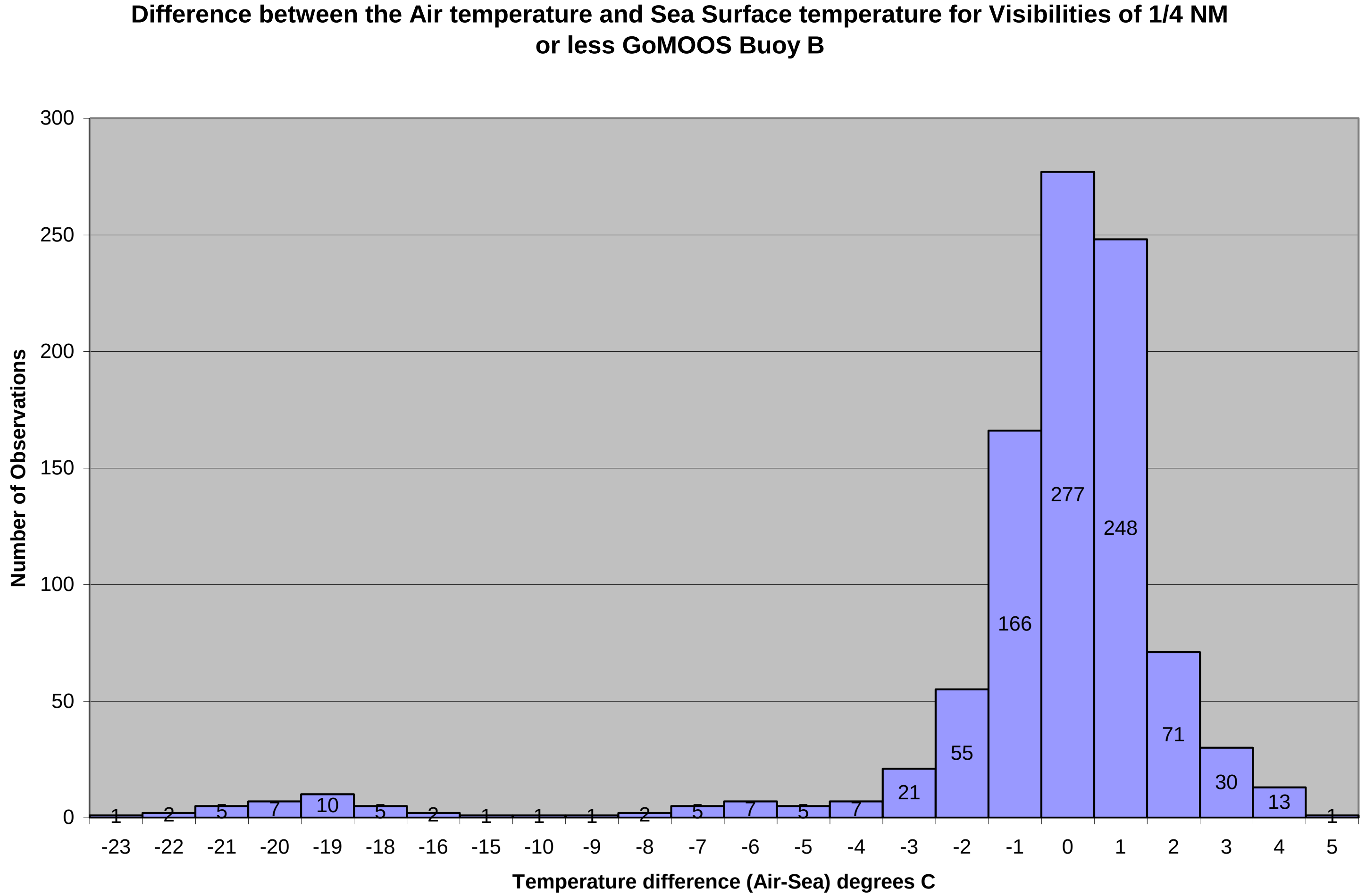


Figure 13. Distribution of the air-sea surface temperatures for hourly observations with low visibility at GoMOOS Buoy B.

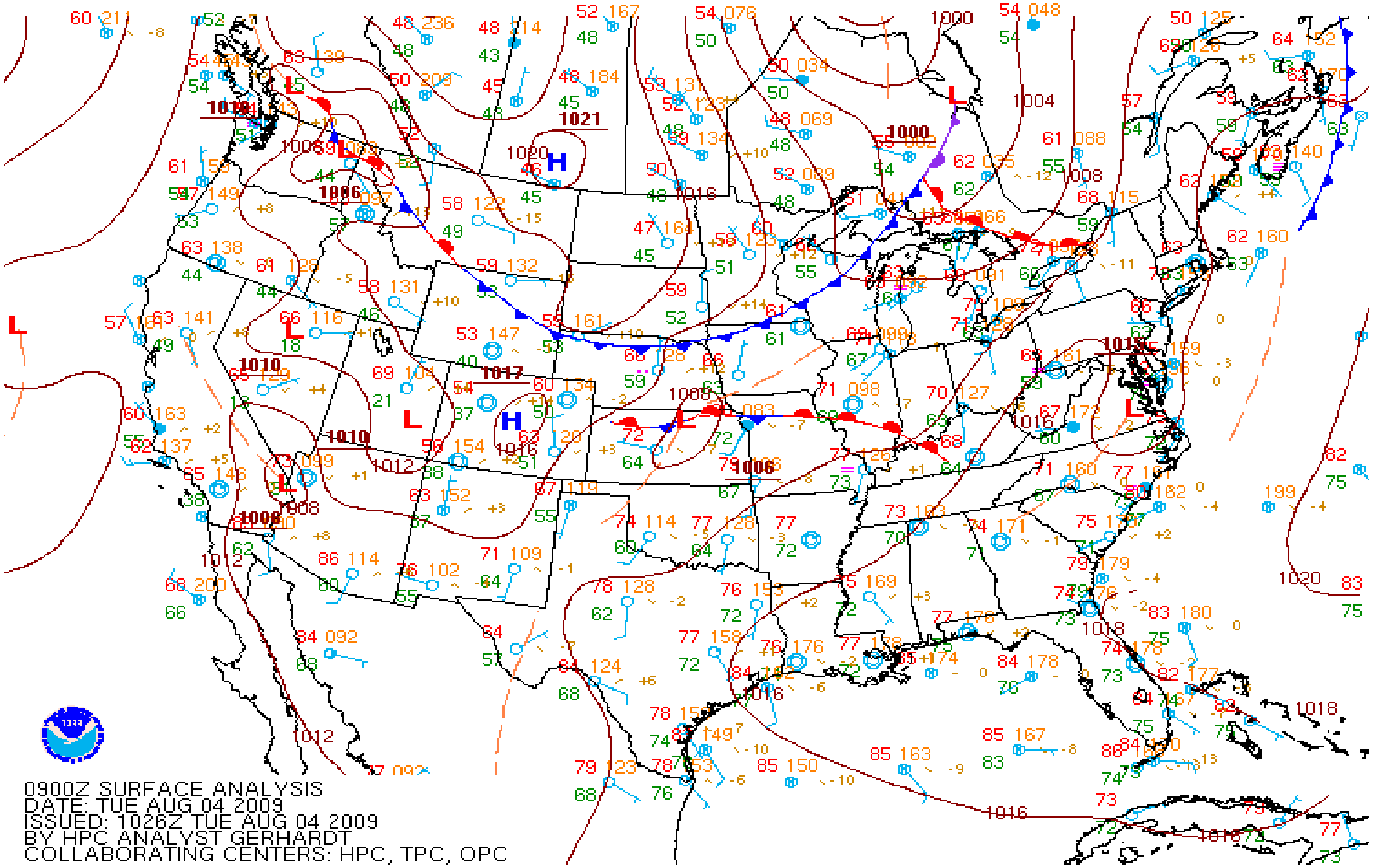


Figure 14. HPC 0900 UTC 4 August 2009 surface analysis.
Note high pressure centered well east of the mid Atlantic coast.

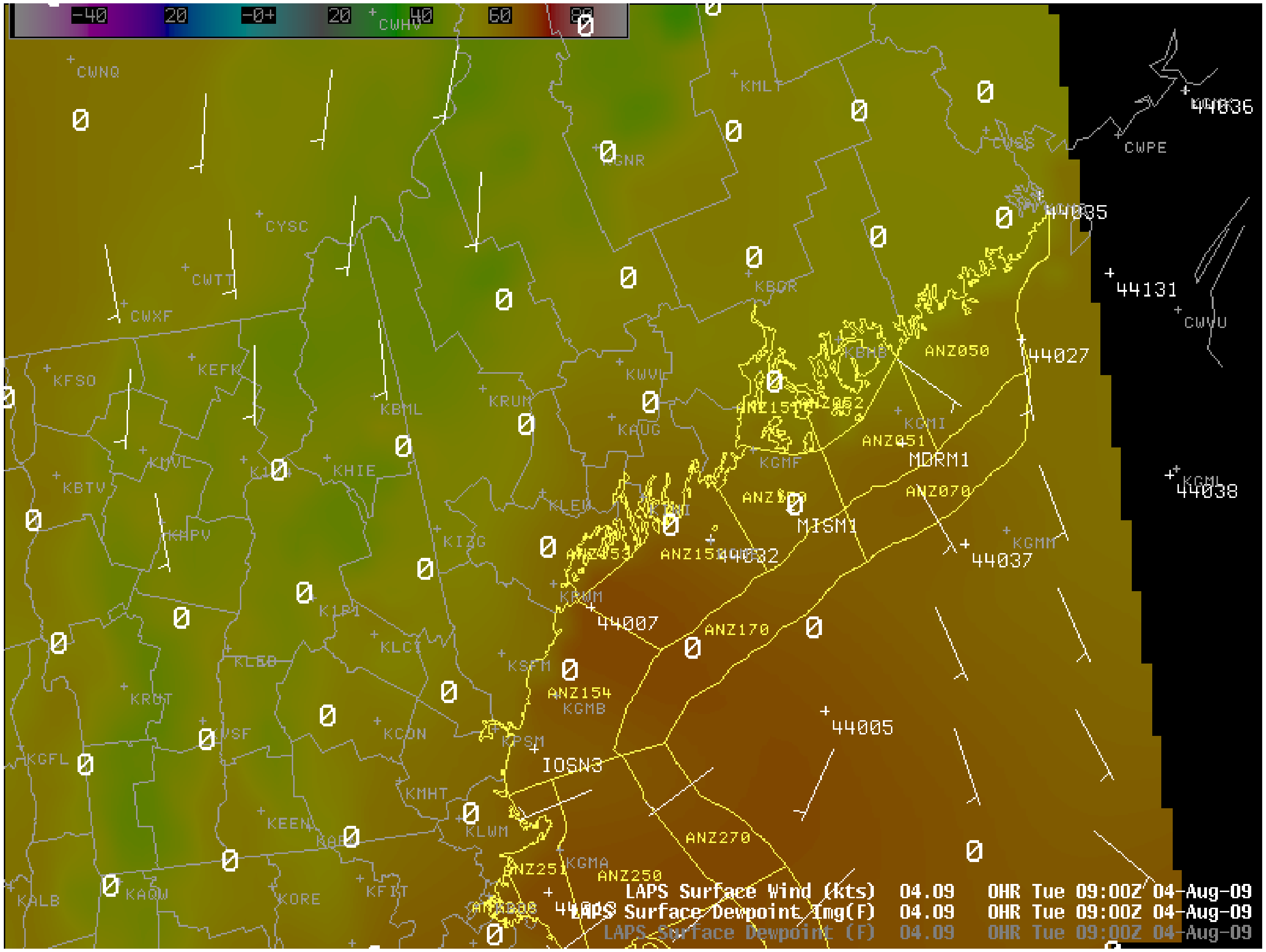


Figure 15. LAPS 0900 UTC 4 August 2009 dew point and surface winds. Dew points over the coastal waters were near 18° C.

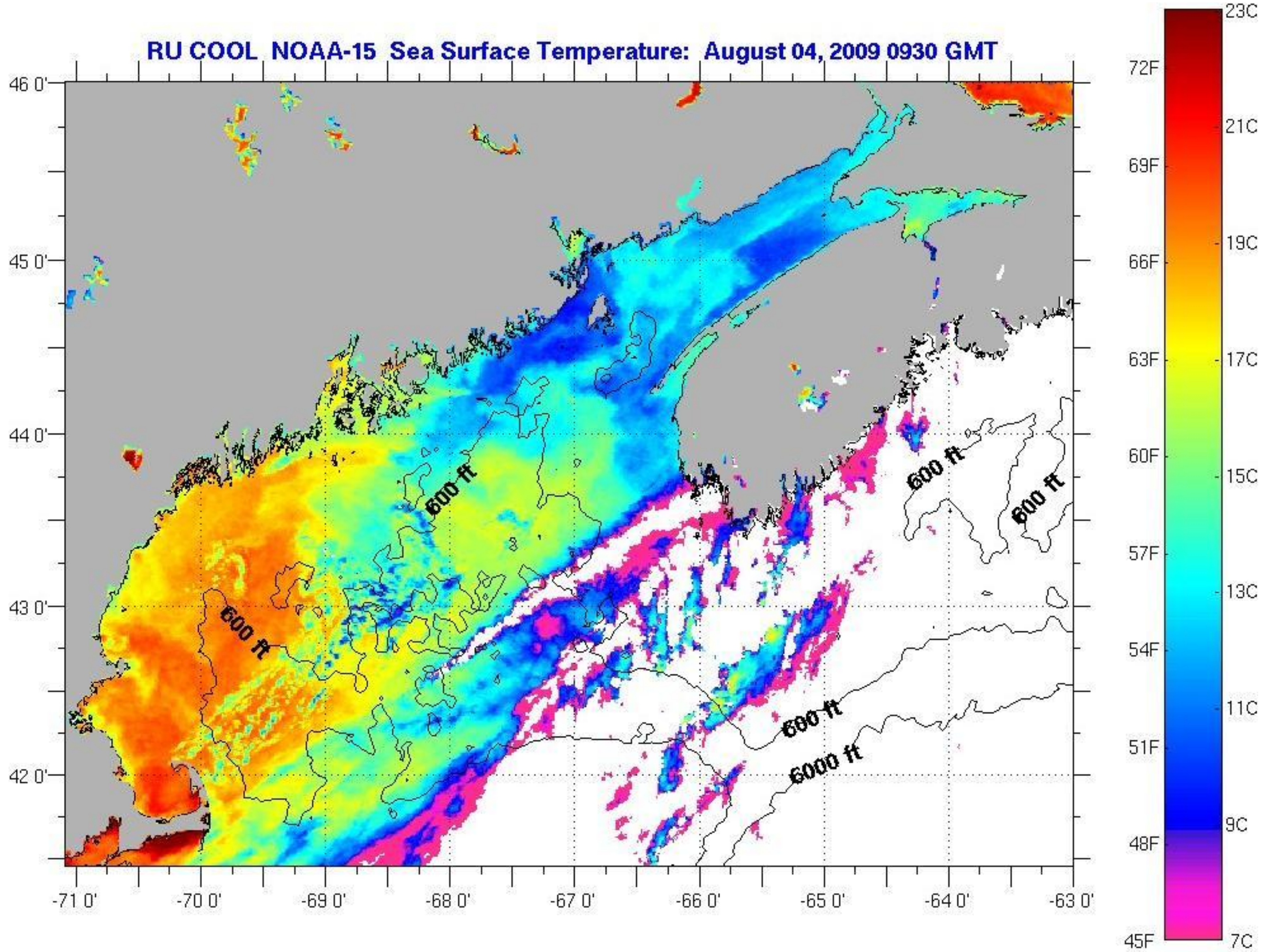


Figure 16. NOAA-15 SST analysis valid 0900 UTC 4 August (degrees C). This image was created from 1 km resolution NOAA-15 images for the valid time at the Coastal Ocean Observing Lab at Rutgers University.

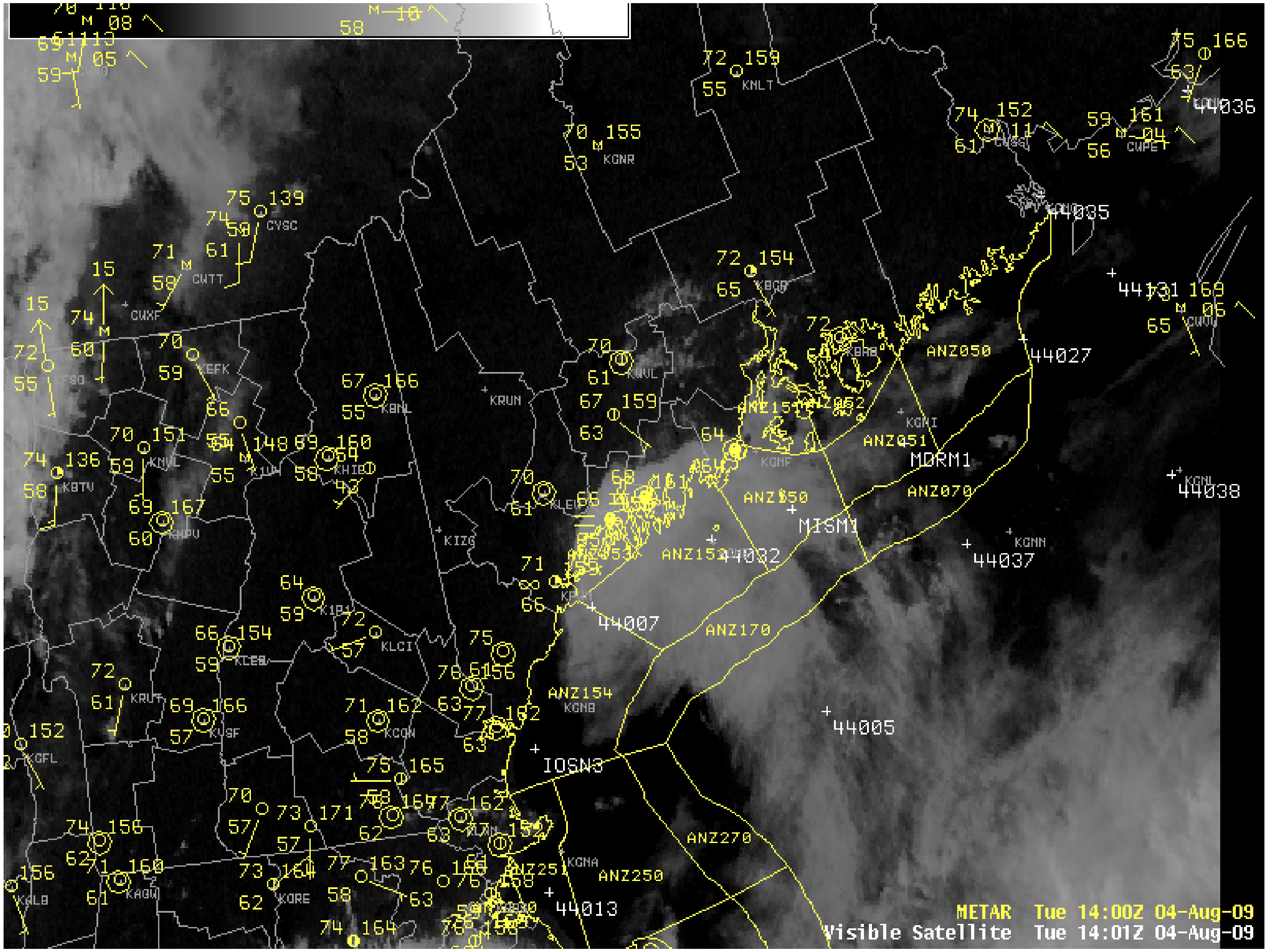


Figure 17. Visible satellite image valid 1401 UTC 4 August 2009.

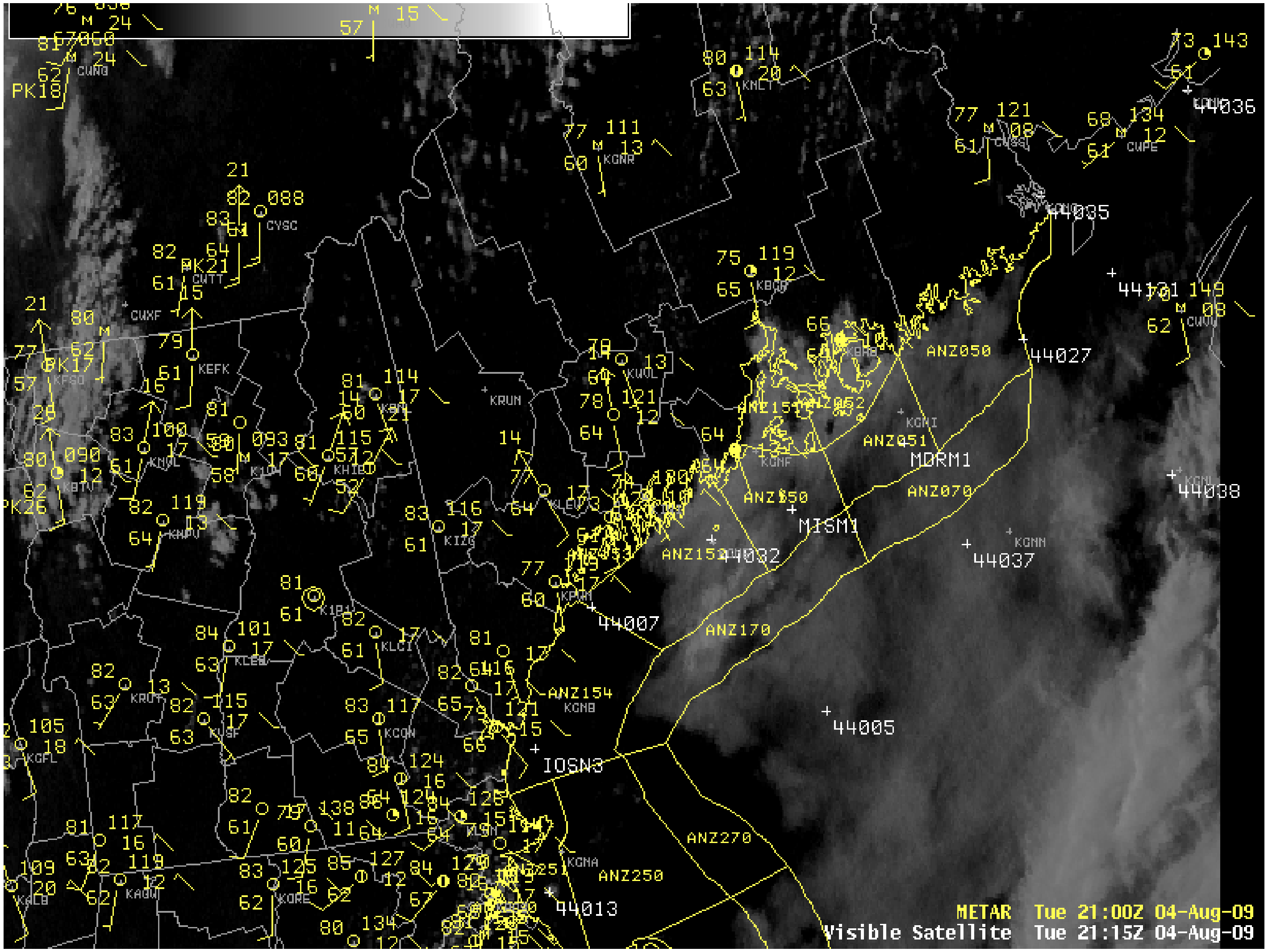


Figure 18. Visible satellite image valid 2115 UTC 4 August 2009.