Spring 5-15-2012

The Effects of Significant Rainfall Events on Surface Dissolved Oxygen Concentrations Off the Coast of Long Bay in South Carolina

Kelsey M. Couch
Coastal Carolina University

The effects of significant rainfall events on surface dissolved oxygen concentrations off the coast of Long Bay in South Carolina

By

Kelsey M. Couch

Marine Science

Submitted in Partial Fulfillment of the
Requirements for the Degree of Bachelor of Science
In the Honors Program at Coastal Carolina University

May 2012

Abstract

Long Bay in South Carolina is currently facing recurrent hypoxic conditions ("South Carolina Coastal Hypoxia"). Therefore the purpose of this study was to examine the effect of eight significant rainfall events on the surface dissolved oxygen content of the bay. Differences in theoretical values of average monthly dissolved oxygen content and actual values of average monthly dissolved oxygen were observed. When analyzed, the data from the eight-month study showed no strong correlation between significant rainfall events and changes in surface dissolved oxygen content. Phytoplankton blooms, phytoplankton productivity and seasonal stratifications could be causing these fluctuations (Lomas et al. 2009).

Introduction

Water quality, such as nutrient levels and dissolved oxygen content fluctuates seasonally throughout the year (Lomas et al. 2009). Factors such as seasonal stratification, phytoplankton productivity, nutrient import and export, or increased storm activity can affect the nutrient levels and dissolved oxygen concentrations in surface waters (Lomas et al. 2009). Storm activity, particularly larger storms associated with cold fronts, are strong enough to cause short-term reversals in current direction. These storms can also re-suspend or move sediments and discharge nutrients to the surface waters, potentially influencing the dissolved oxygen (D.O.) levels (Walker and Hammack 2000).

A study conducted by Valiela et al. (1998) on the observed effects of a large-scale storm, such as Hurricane Bob, found that the coastal watershed and coastal waters of Cape Cod, Massachusetts experienced several changes. These effects included surface to bottom mixture of the water column, circulation changes which resulted in an upwelling of nutrients that created a phytoplankton bloom, and erosion of the beach (Valiela et al. 1998). Storm activity, such as typhoons or hurricanes and winter cold fronts, created density currents and turbidity currents that caused circulation of the water column (Fan and Kao 2008). This ultimately influenced the water quality and more specifically the dissolved oxygen content in the surface and bottom waters of the observed lagoon (Fan and Kao 2008).

This study will focus on the relationship, if any exists, between storm activity and dissolved oxygen content in the waters of Long Bay, off the coast of Myrtle Beach, South Carolina. This study will focus not only on major storm events, such as hurricanes, during the hurricane season, but also on storm events before and after hurricane season. Data will be collected using the Apache Pier Real-time Water Quality and Weather Monitoring Station and using surface weather map data from the National Oceanic and Atmospheric Administration (NOAA).

This study has particular importance because of the recent and persistent hypoxic condition of Long Bay, South Carolina ("South Carolina Coastal Hypoxia"). Eutrophication and hypoxia caused by excessive nutrient loading can have negative impacts on local marine fisheries (Turner and Rabalais 2003). Eutrophication and the resulting hypoxic conditions can cause increased phytoplankton and algal blooms, as well as mortality of local fish and other organisms (Bishop et al. 2006).

Materials and Methods

The data for the study was obtained through Coastal Carolina University's Burroughs and Chapin Center for Marine and Wetland Studies Apache Pier Real-Time Water Quality and Weather Monitoring Station, located in Myrtle Beach, South Carolina (Fig. 1). The Apache Pier Real-Time Water Quality and Weather Monitoring Station collects data for 14 different parameters in the waters of Long Bay, off the coast of Myrtle Beach, South Carolina. The water quality station's sensors provide real-time

surface and bottom data for temperature (°F), salinity (ppt), and dissolved oxygen content (mg/L) and percent saturation (%); while the mounted meteorology station's sensors provide data for

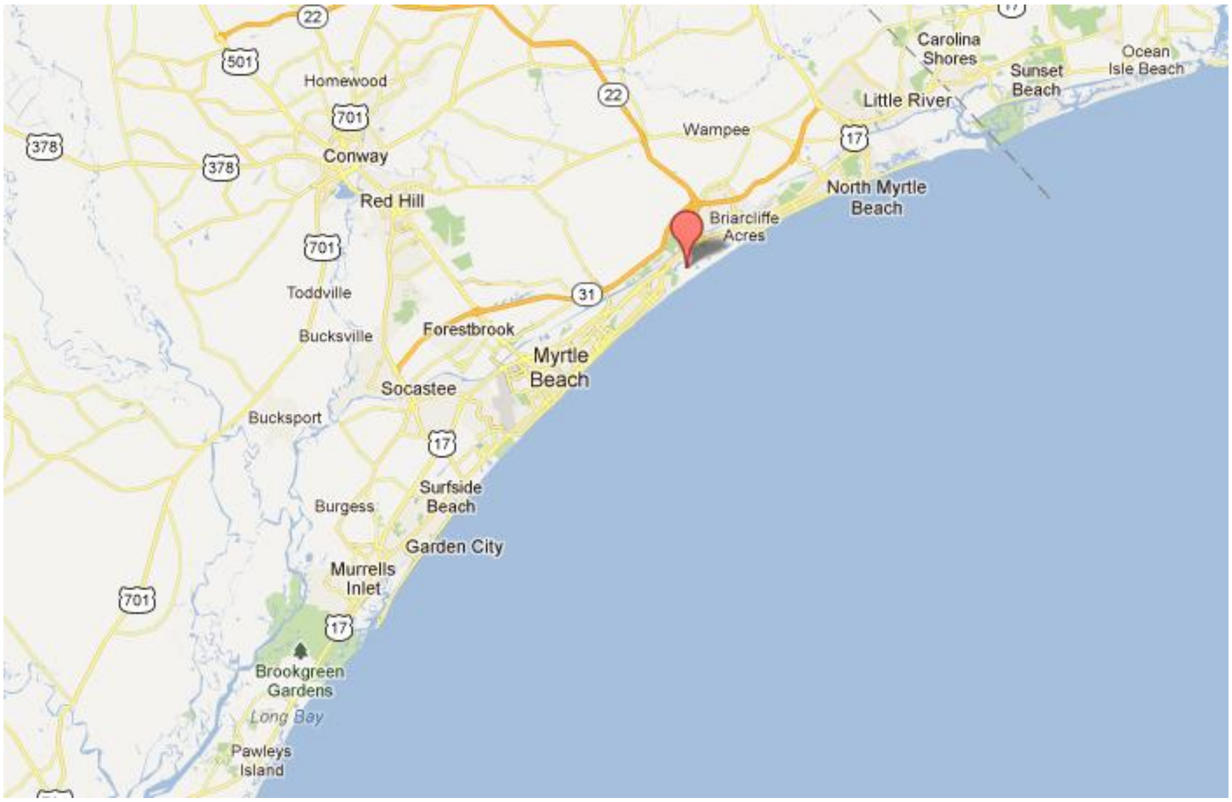

Figure 1. The location of the Apache Pier Real-Time Water Quality and Weather Monitoring Station at Apache Pier in Myrtle Beach, South Carolina.

wind speed (mph), air temperature (°F), barometric pressure (inHg), and precipitation (cm). The stations collect data every 15 minutes, 24-hours per day ("Apache Pier"), unless a malfunction occurs.

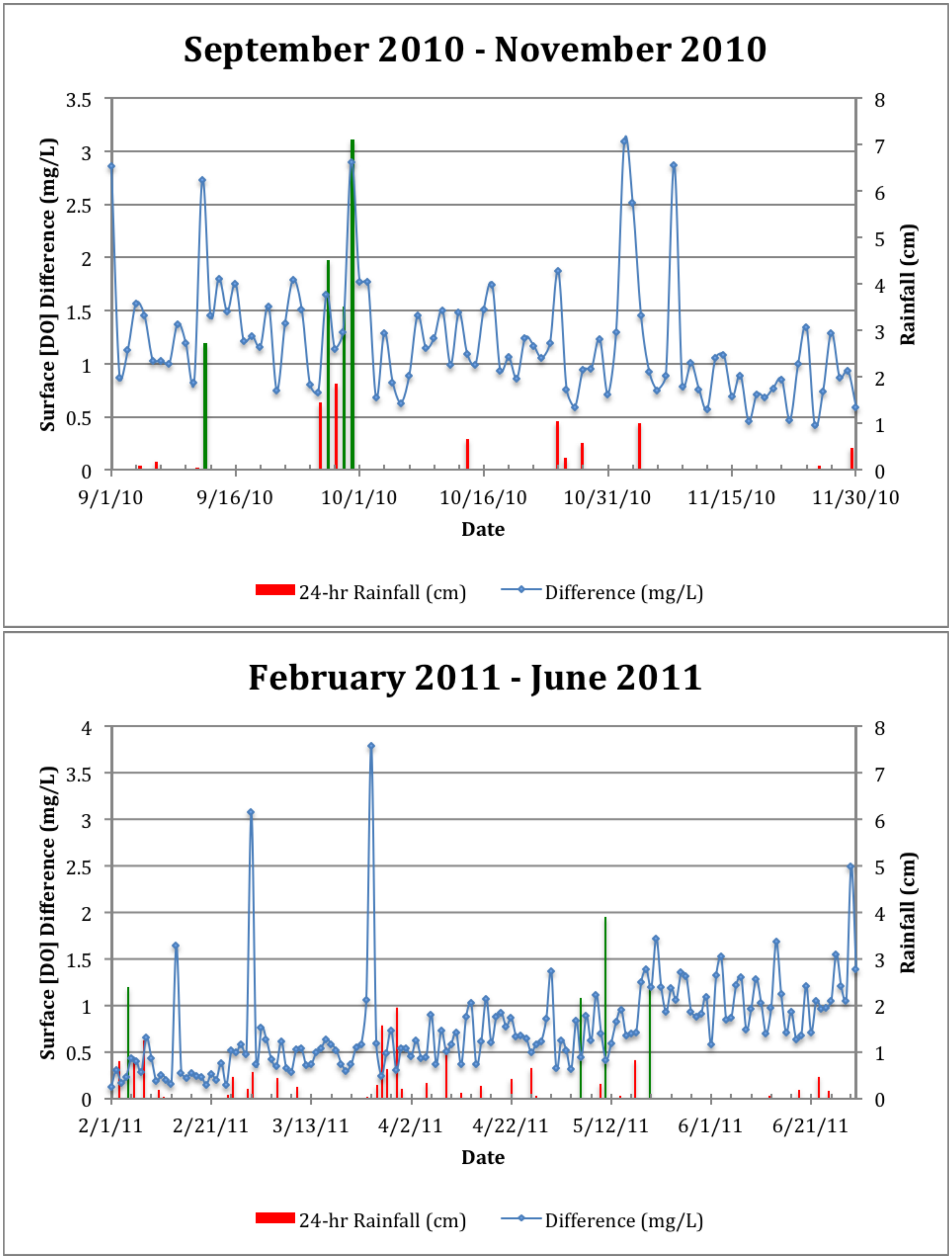

Figure 2. The average surface dissolved oxygen content difference and rainfall (12-hour increments) plotted against dates. The eight significant rainfall events that occurred over the course of the study are in green.

Data was collected for the months of September 2010 through November 2010 and February 2011 through June 2011. The exclusion of December 2010, January 2010, July 2011, August 2011, and September 2011 is due to the presence of corrupted data. According to the National Hurricane Center, the Atlantic hurricane season begins June 1^{st} and ends November 30^{th} ("National Hurricane Center"). Due to the corrupted data present in several months, data will be collected for one month at the beginning of hurricane season and the last three months at the end of hurricane season. This duration is ideal because it provides supplementary data to use for correlations as well as data outside of the typically strongest storm season.

The results of the surface dissolved oxygen (mg/L) content and the rainfall (in), obtained from the Apache Pier Real-Time Water Quality and Weather Monitoring Station, were plotted for each month. The surface dissolved oxygen content difference (between maximum surface dissolved oxygen content and minimum surface dissolved oxygen content) and rainfall (in 12-hour increments) were plotted against the corresponding days in each month. Eight significant rainfall events were then chosen from throughout the collected data, with each "significant" event defined as greater than two centimeters of rainfall in a 12-hour period (Figure 2). Surface weather maps obtained from NOAA were then used to identify any weather systems and the possible weather associated with those systems in order to account for the amount of rainfall present in each of the eight significant rainfall events (Appendix I).

Results and Discussion

During this experiment, only complete, uncorrupted data was used. Therefore the months of December 2010, January 2011, July 2011, August 2011, and September 2011 were excluded because of the presence of corrupted data. The corrupted data for these months was most likely caused by malfunctioning equipment. An linear regression line for each month's data was used to obtain the correlation coefficient (R^2). The R^2 values for each month are shown in Table 1.

Correlation								
	2010			2011				
	September	October	November	February	March	April	May	June
R^2 =	0.22678	0.03844	0.00126	0.0055	0.00173	0.0594	0.06671	0.01779

Table 1. The R^2 values for each of the collected months' data. Values above 0.7 show strong correlation.

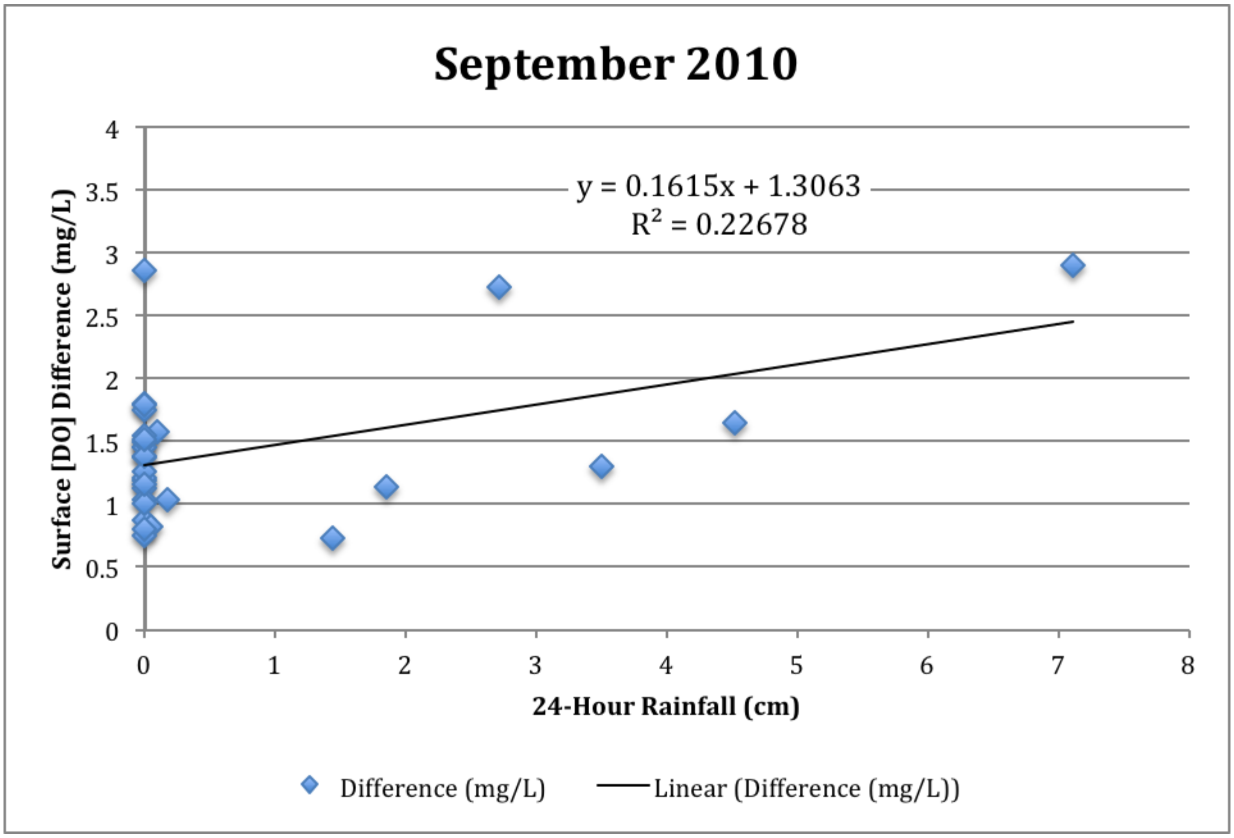

Figure 3. The linear regression line for the month of September 2010 that shows the equation as well as the R^2 value. This is an example of the regression lines obtained for all of the months in the study.

In order to show strong correlation or evidence of a statistically significant relationship between surface dissolved oxygen content differences and 12-hour rainfall, the R^2 value must be above 0.7. This indicates that at a 70% confidence level, a statistically significant relationship exists between these variables. Therefore, based on these linear regression lines and R^2 values for each of the months, no statistically significant relationship between surface dissolved oxygen content differences versus 12-hour rainfall was evident (Figure 3).

Using the basic form of Henry's law, the theoretical surface dissolved oxygen content values, as a function of atmospheric pressure, later used for comparison were obtained. The basic form of Henry's law is (Waser et al. 155), where in this study, P_A is the atmospheric pressure:

$$[A] = k_H \cdot P_A$$

(Equation 1)

Using the average density of seawater at 1.025 g/cm^3, Henry's law constant at 1.03 × 10^{-3} mol/kg atm obtained from Broecker and Peng's Table 3-1 (112), the partial pressure of O_2 in the atmosphere at 0.21 (Waser et al. 81), and the molecular weight of water at 31.998 g/mol, Equation 1 can be modified. Thus this yields the following formula:

$$[DO] = P_A \cdot 1.025 \frac{g}{cm^3} \cdot 0.21 \cdot 31.998 \frac{g}{mol} \cdot 1.03 \times 10^{-3} \frac{mol}{kg \cdot atm} \cdot 0.03342 \frac{atm}{inHg}$$

(Equation 2)

Therefore using Equation 2 and the maximum and minimum atmospheric pressure collected during the months, the theoretical maximum and minimum surface dissolved oxygen content differences were calculated. Once calculated, the average maximums and the average minimums of both the theoretical and actual surface dissolved oxygen content differences were obtained. The average percent error for both the maximum and minimum surface dissolved oxygen content differences for each month were calculated using the Equation 3:

$$\%\ error = \left| \frac{(expected - actual)}{actual} \right| \times 100\%$$

(Equation 3)

The percent errors for each month that were obtained using Equation 3 were then placed in the following table (Table 2).

Percent Error								
	2010			2011				
	September	October	November	February	March	April	May	June
Monthly Average Max DO (mg/L)	3.9126	1.7983	14.6037	33.1144	22.3537	10.2381	2.3541	2.4645
Monthly Average Min DO (mg/L)	24.0736	14.3550	0.1859	28.1374	12.7725	0.6711	10.2453	17.8591

Table 2. The calculated percent errors for the average maximum and minimum dissolved oxygen content (mg/L) for each month. Value obtained by comparing collected data to calculated Henry's law data.

Based on Table 2, in the months of September 2010, October 2010, May 2011, and June 2011, atmospheric pressure in conjunction with Henry's law appeared to be the driving force in the monthly average maximum surface dissolved oxygen content difference. This is apparent in the small monthly average maximum percent error between the theoretical values calculated using Equation 2 and the actual collected values. In the months of November 2010, February 2011, March 2011, and April 2011, atmospheric pressure in conjunction with Henry's law also appeared to be the driving force for monthly average minimum surface dissolved oxygen content differences. This is again apparent in the small percent error.

However, for the months of November 2010, February 2011, March 2011, and April 2011, the monthly average maximum surface dissolved oxygen content difference has a large percent error. The months of September 2010, October 2010, May 2011, and June 2011 also have a large percent error, but for the monthly average minimum surface dissolved oxygen content difference. These large monthly average minimum percent errors are not driven by atmospheric pressure in conjunction with Henry's law.

These large monthly average maximum surface dissolved oxygen percent errors, especially common in the months of November 2010, February 2011, March 2011, and April 2011 where colder water temperatures are present, could be attributed to coastal upwelling. It is this coastal upwelling forces cold, saline, dissolved-oxygen-depleted water up into the surface waters of the shallower continental shelf (Grantham et al. 2004). Also if large phytoplankton blooms or increased phytoplankton productivity (Lomas et al. 2009) are present, this could cause further depletion of the monthly average maximum surface dissolved oxygen content, further exacerbating the problem (Grantham et al. 2004). Anthropogenic nutrient loading into the surface waters causes eutrophication, which ultimately results in these large phytoplankton blooms (Koibuchi and Masahiko 2007).

Conclusion

The increasingly recurrent hypoxia events in Long Bay, South Carolina is particularly important. The purpose of this study was to examine the effect of significant rainfall events on surface dissolved content. However after statistical analysis, there was no strong correlation between significant rainfall events and surface dissolved oxygen content. For the months with small percent errors, atmospheric pressure in conjunction with Henry's law was the driving force for the monthly average maximum and minimum surface dissolved oxygen content. Yet for the months with colder water temperatures (November 2010, February 2011, March 2011, and April 2011) large percent errors in monthly average maximum surface dissolved oxygen content was observed. These large percent errors could be the result of the upwelling of cold, saline, dissolved-oxygen-depleted water into the surface waters of the continental shelf (Grantham et al. 2004) and increased phytoplankton blooms caused by nutrient loading and eutrophication (Koibuchi and Masahiko 2007).

Acknowledgements

I would like to thank Dr. Craig Gilman for all of his input and guidance during the course of this project. I am especially thankful for his help in obtaining the meteorological data needed for further analyses. I would also like to thank Dr. Mark Couch for his guidance on the statistical analyses conducted in this experiment.

References

"Apache Pier Real-Time Water Quality and Weather Monitoring Station." *YSI - Remote Monitoring and Control System*. YSIEcoNet, 2005. Web. 25 Apr. 2011. <http://www.ysieconet.com/public/WebUI/Default.aspx?hidCustomerID=131>.

Bishop, Melanie J., Sean P. Powers, Hugh J. Porter, and Charles H. Peterson. "Benthic Biological Effects of Seasonal Hypoxia in a Eutrophic Estuary Predate Rapid Coastal Development." *Estuarine Coastal and Shelf Science* 70 (2006): 415-422. *ScienceDirect*. Web. 25 Apr. 2011.

Broecker, Wallace S. and Tsung-Hung Peng. "The Atmospheric Imprint: The Cycles of Gas Within the Sea." *Tracers in the Sea*. Palisades: Lamont-Doherty Geological Observatory, Columbia University, 1982. 112. Print.

Buzzelli, Christopher, Olcay Akman, Tracy Buck, Eric Koepfler, James Morris, and Alan Lewitus. "Relationships among Water-Quality Parameters from the North Inlet-Winyah Bay Estuarine Research Reserve, South Carolina." *Journal of Coastal Research* 45 (2004): 59-74. *BioOne*. Web. 25 Apr. 2011.

“Daily Weather Maps.” Map. NOAA and Department of Commerce. Web. 10 Dec. 2011. <http://www.hpc.ncep.noaa.gov/dailywxmap/index_20120229.html>

D'Autilia, Roberto, Margherita Falcucci, Vincent Hull, and Luisa Parrella. "Short time dissolved oxygen dynamics in shallow water ecosystems." *Ecological Modeling* 179 (2004): 297-306. *ScienceDirect*. Web. 12 Feb. 2011.

Fan, Cheng-Wei and Shuh-Ji Kao. "Effects of climate events driven hydrodynamics on dissolved oxygen in a subtropical deep reservoir in Taiwan." *Science of the Total Environment* 393 (2008): 326-332. *ScienceDirect*. Web. 11 Feb. 2011.

Grantham, Brian A., Francis Chan, Karina J. Nielson, David S. Fox, John A. Barth, Adriana Huyer, Jane Lubchenco, and Bruce A. Menge. “Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific.” *Letters to Nature* 429 (2004): 749-754. *Academic Search Premier*. Web. 22 Feb. 2012.

Koibuchi, Yukio and Masahiko Isobe. “Phytoplankton bloom mechanism in an area affected by eutrophication: Tokyo Bay in spring 1999.” *Coastal Engineering Journal* 49.4 (2007): 461-479. *Academic Search Premier.* Web. 24 Feb. 2012.

Lomas, M. W., F. Lipschultz, D. M. Nelson, J. W. Krause, and N. R. Bates. "Biogeochemical responses to late-winter storms in the Sargasso Sea I - pulses of primary and new production." *Deep Sea Research I* 56 (2009): 843-860. *ScienceDirect*. Web. 10 Feb. 2011.

Turner, Eugene R. and Nancy N. Rabalais. "Linking Landscape and Water Quality in the Mississippi River Basin for 200 Years." *BioScience* 53.6 (2003): 563-572. *BioOne*. Web. 25 Apr. 2011.

United States. National Centers for Environmental Prediction. National Hurricane Center. *National Hurricane Center*. National Oceanic and Atmospheric Administration/National Weather Service, 14 Mar. 2011. Web. 25 Apr. 2011. <http://www.nhc.noaa.gov/index.shtml>.

United States. National Oceanic and Atmospheric Administration. NOAA in the Carolinas. *South Carolina Coastal Hypoxia*. National Oceanic and Atmospheric Administration. Web. 25 Apr. 2011.

Valiela, I., P. Peckol, C. Avanzo, J. Kremer, D. Hersh, K. Foreman, K. Lajtha, B. Seely, W. R. Geyer, T. Isaji, and R. Crawford. "Ecological effects of major storms on coastal watersheds and coastal waters: Hurricane Bob on Cape Cod." *Journal of Coastal Research* 14.1 (1998): 218-238. *JSTOR*. Web. 9 Feb. 2011.

Walker, Nan D., and Adele B. Hammack. "Impacts of winter storms on circulation and sediment transport: Atchafalaya-Vermilion Bay region, Louisiana, U.S.A." *Journal of Coastal Research* 16.4 (2000): 996-1010. *JSTOR*. Web. 2 Mar. 2011.

Waser, Jürg, Kenneth N. Trueblood, and Charles M. Knobler. "Solutions." *Chem One*. 2nd ed. New York: McGraw-Hill, 1980. 80-155. Print.

Appendix I

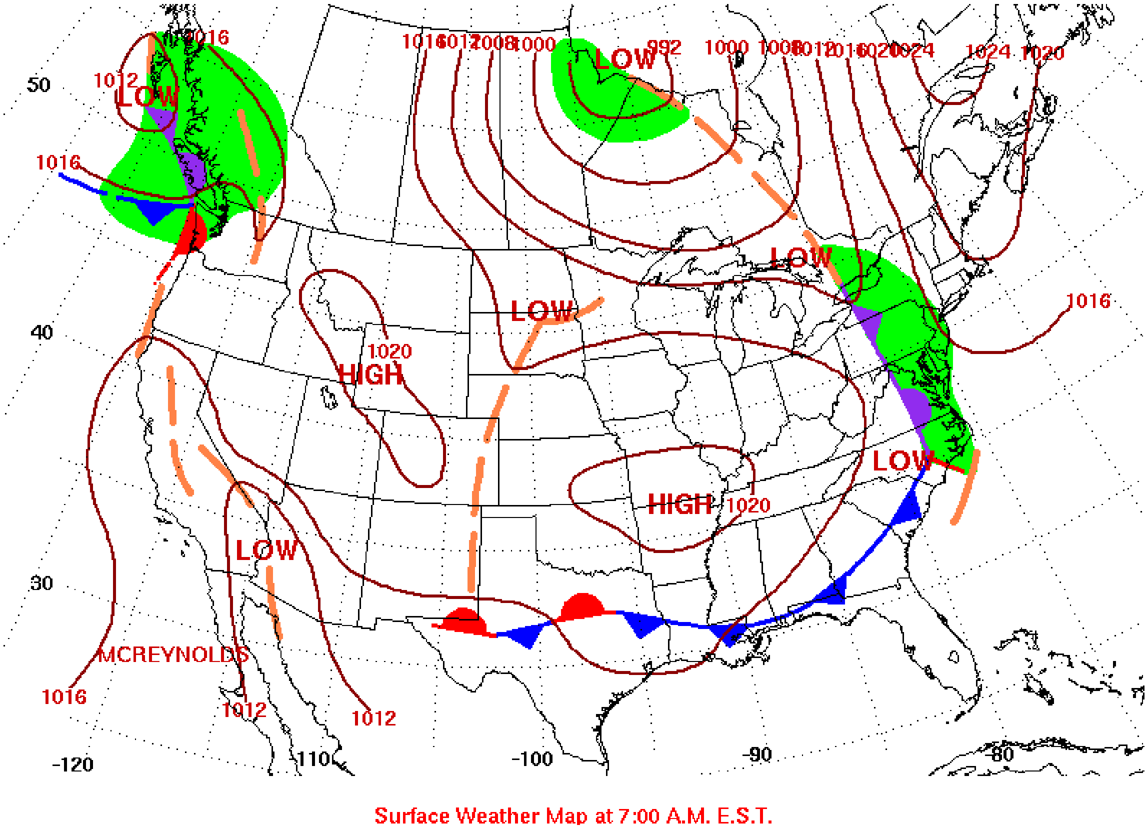

Figure 1. The surface weather map for the significant rainfall event that occurred on September 12, 2010.

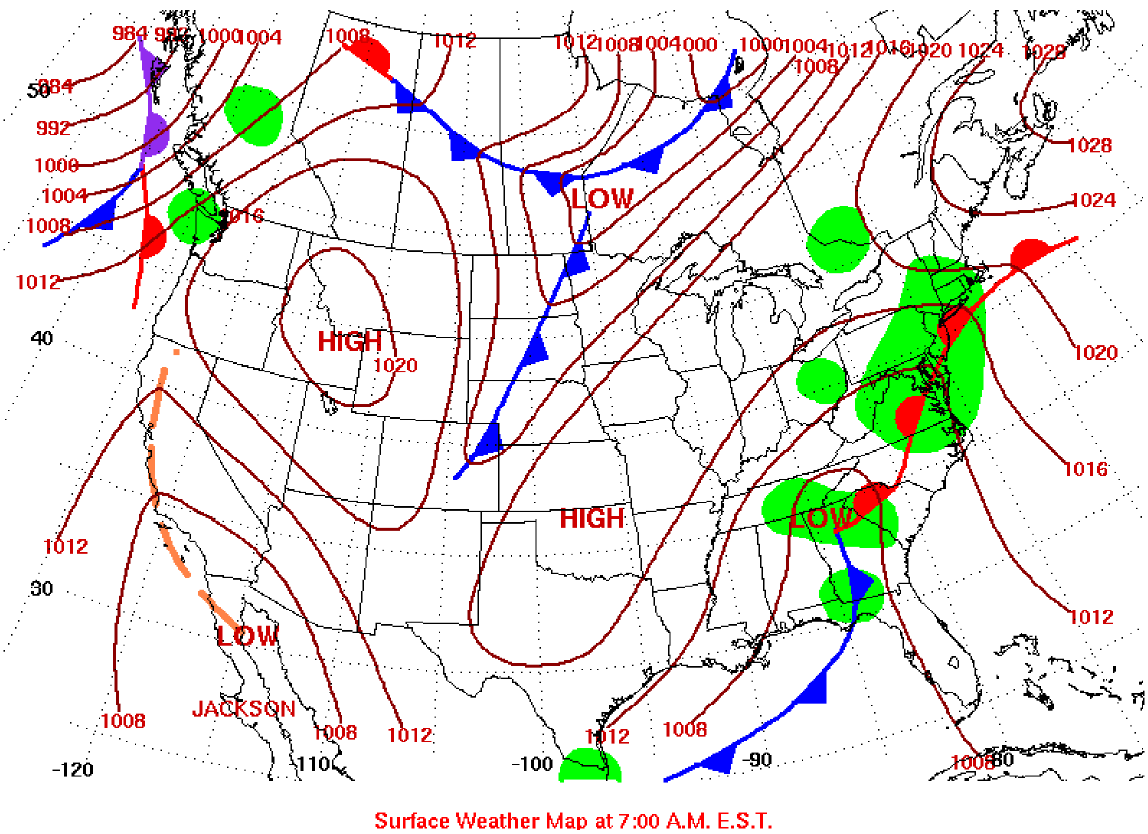

Figure 2. The surface weather map for the significant rainfall event that occurred on September 27, 2010.

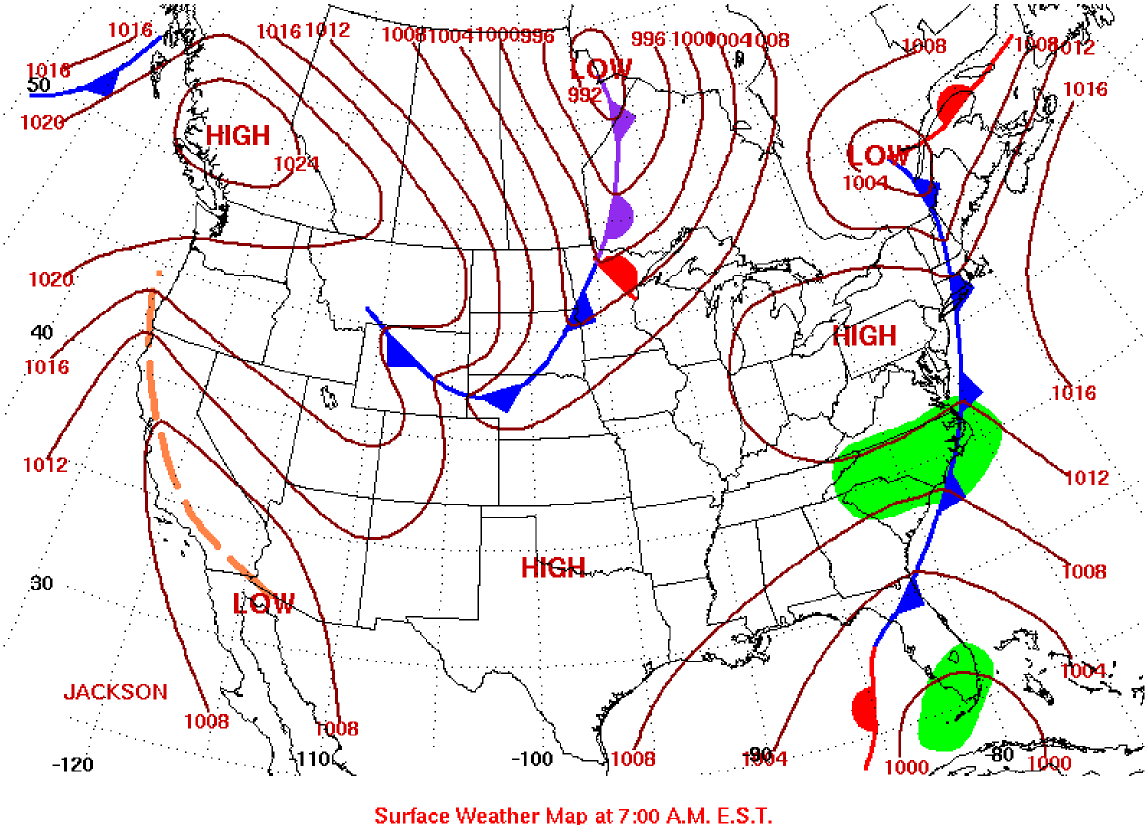

Figure 3. The surface weather map for the significant rainfall event that occurred on September 29, 2010.

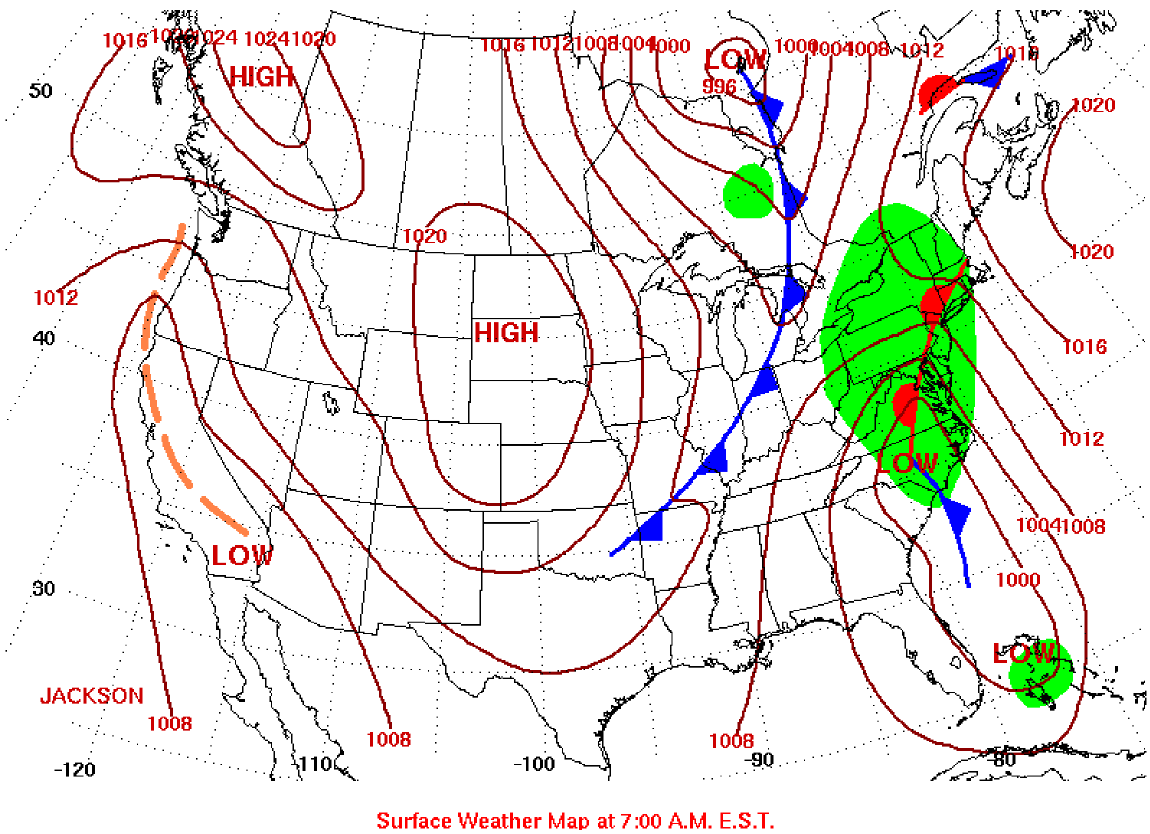

Figure 4. The surface weather map for the significant rainfall event that occurred on September 30, 2010.

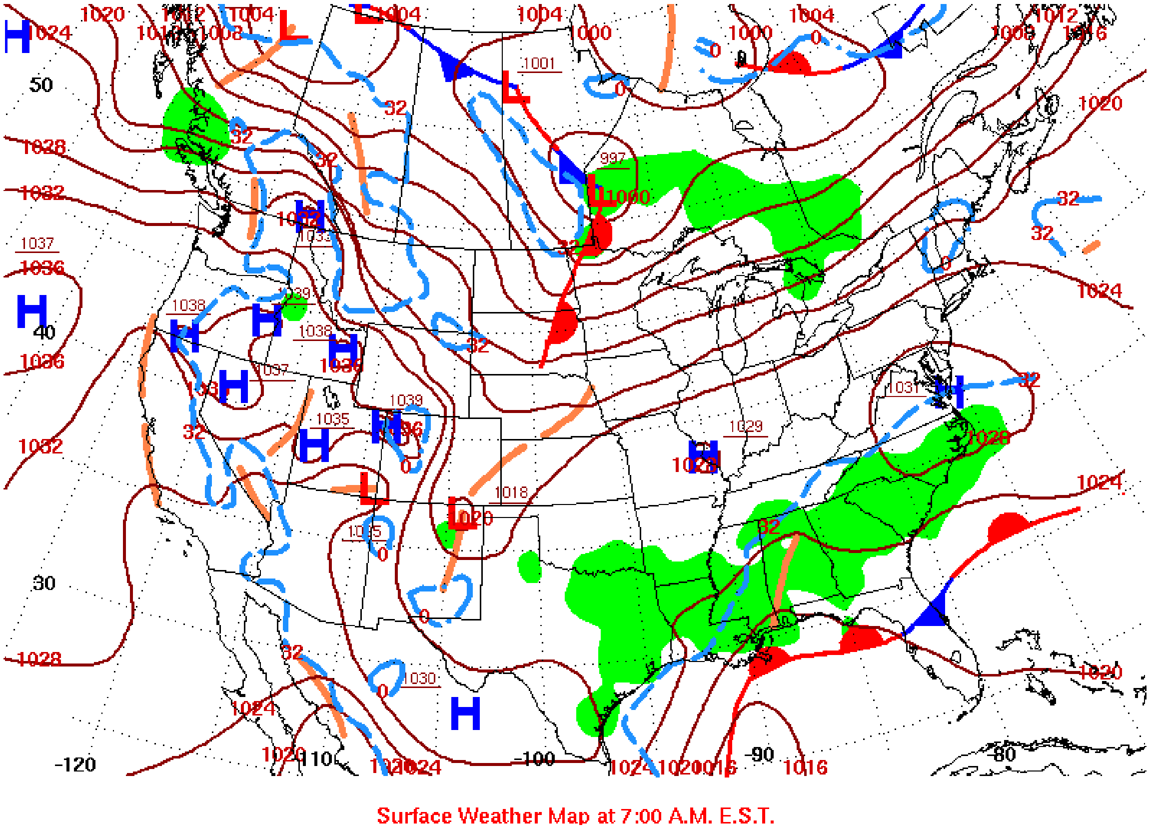

Figure 5. The surface weather map for the significant rainfall event that occurred on February 4, 2011.

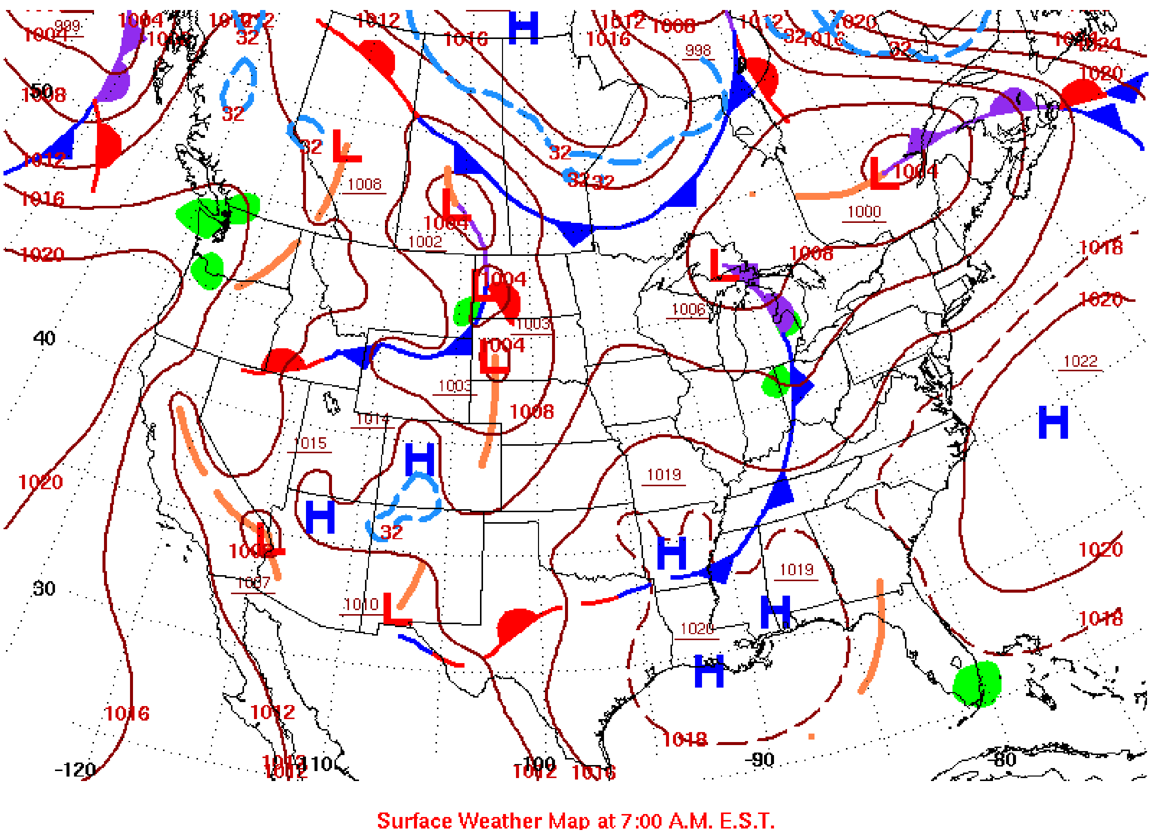

Figure 6. The surface weather map for the significant rainfall event that occurred on May 6, 2011.

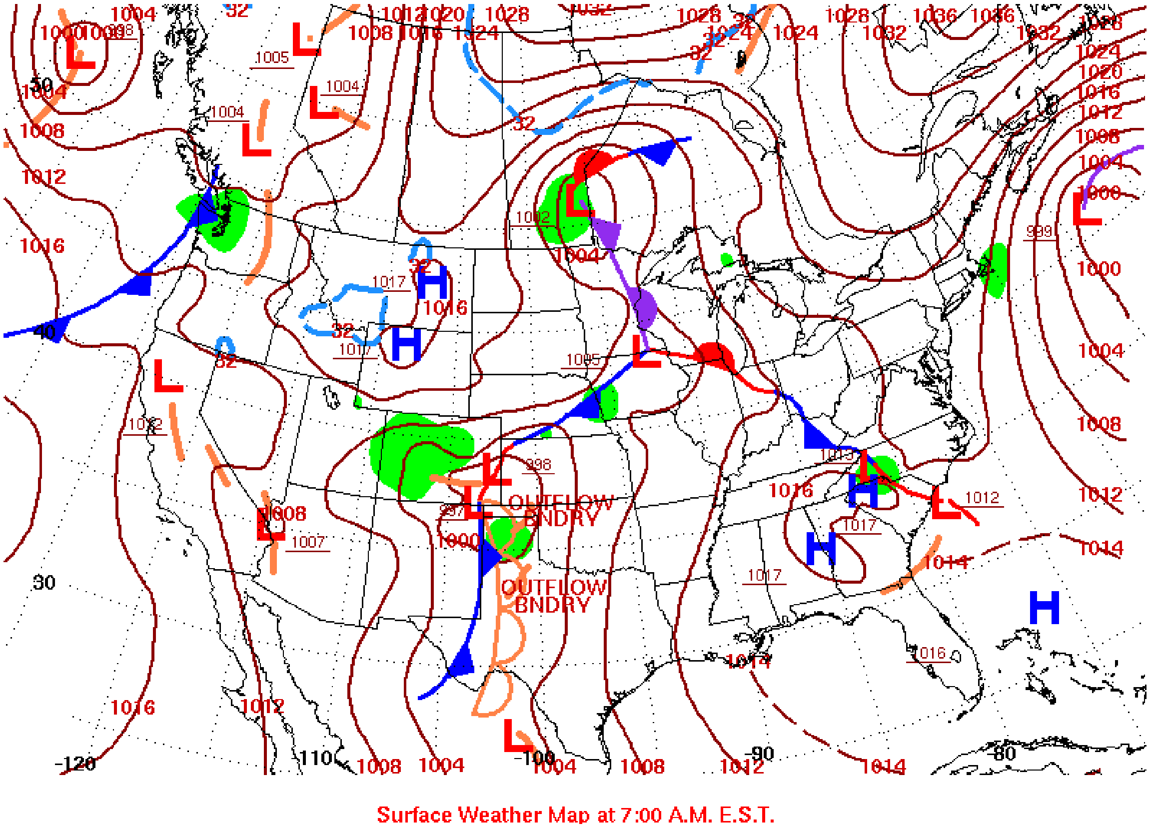

Figure 7. The surface weather map for the significant rainfall event that occurred on May 11, 2011.

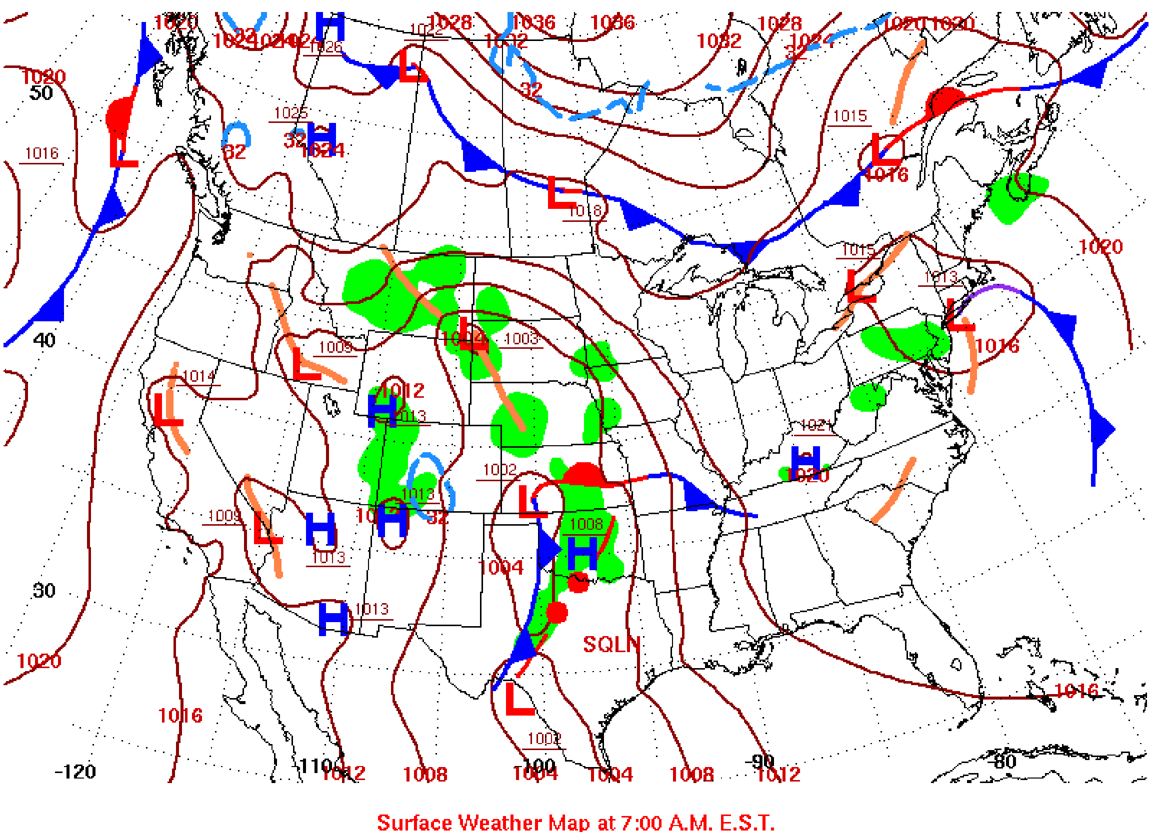

Figure 8. The surface weather map for the significant rainfall event that occurred on May 20, 2011.