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AN OBJECTIVE CLIMATOLOGY OF CAROLINA COASTAL FRONTS

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1. INTRODUCTION AND BACKGROUND

The coastal front is a mesoscale feature that forms in geographically favored areas, such as off the New England and southeast coasts of the United States, as well as in the Gulf of Mexico off the Texas coast. The area along the southeast coast is a prime location for the formation of coastal fronts due to the presence of the Appalachian Mountains to the west and the Gulf Stream located just off the coast. The Gulf Stream provides a source of warm, moist air while the mountains allow cold air to funnel equator-ward creating a natural baroclinic zone.

Coastal fronts generally form during the winter months and are typically associated with cold air damming (CAD). They have characteristics of an eastward moving warm front, with temperature contrasts that can reach more than 10°C over a very short distance. Coastal fronts are of major importance in the coastal zone and inland areas. They are often associated with enhanced precipitation, can mark the transition zone between frozen and liquid precipitation, and can act as a focus for cyclogenesis. Therefore, an accurate understanding of the coastal front and its behavior is vital to local forecasters. This study is part of the Collaborative Scientific, Technology, Applied Research (CSTAR) program, which is an effort between researchers and forecasters to improve primarily wintertime forecasting in the southeast United States. Studies of CAD and the effects of split fronts on CAD are also part of this CSTAR program.

Early work involving coastal fronts began in 1941 with a study by J. M. Austin about the need to forecast cyclogenesis, and hence frontogenesis. Carson (1950) investigated the formation of stratus associated with the coastal front, which he termed the Gulf Stream front. Bosart et al. (1975) studied New England coastal frontogenesis and discovered a mesoscale boundary-layer frontal phenomenon that they called a coastal front, since the effects of the orography, land-sea temperature difference, coastal configuration, and friction played roles in the development of these fronts. Bosart (1979) described the role of the coastal front in the development of the Presidents' Day Snowstorm of 18-19 February 1979. The coastal front was particularly important in that case since it acted to destabilize the atmosphere and as the initiation point for cyclogenesis. Using objective criteria based on the frontogenesis equation, Anderson (1991) performed a climatology of coastal fronts that developed along the Carolina coast.

2. DATA AND METHODOLOGY

The intent of the climatology is to create a historical database of coastal fronts and examine the characteristics of fronts that show similar behavior to better understand the synoptic conditions that influence coastal fronts and their movement. In order to perform the desired coastal front climatology, offshore and onshore data were required. Offshore data, specifically data from moored buoys, were obtained from the National Data Buoy Center website (http://www.ndbc.noaa.gov), which archives data for United States offshore platforms, including buoys. Hourly observational data were used. It was also necessary that the data include air temperature, wind direction, and wind speed. Buoy 41001, located 150 NM east of Cape Hatteras, North Carolina, and buoy 41002, located 250 NM east of Charleston, South Carolina were used as the offshore stations for the climatology.

Data for the onshore stations were obtained from the National Climatic Data Center compact disks, Solar and Meteorological Surface Observation Network for 1961-1990 and Hourly United States Weather Observations for 1991-1995. The disks contain hourly standard meteorological data for various observing stations in the United States. Cape Hatteras and Wilmington North Carolina were used as the onshore stations for the climatology.

To perform the climatology, an objective method was developed to identify coastal fronts off the Carolina coast. Two pairs of stations were established, each consisting of an offshore station (buoy) and an onshore station. In our case the pairs were buoy 41001 and Cape Hatteras, and buoy 41002 and Wilmington. Based on a similar method developed by Anderson, criteria for identifying and tracking offshore coastal fronts were developed. In order to be classified a coastal front between Cape Hatteras and buoy 41001, all the following criteria must be met for at least four consecutive hours:

1.) Wind direction at 41001 must be between 20° and 160° inclusive.

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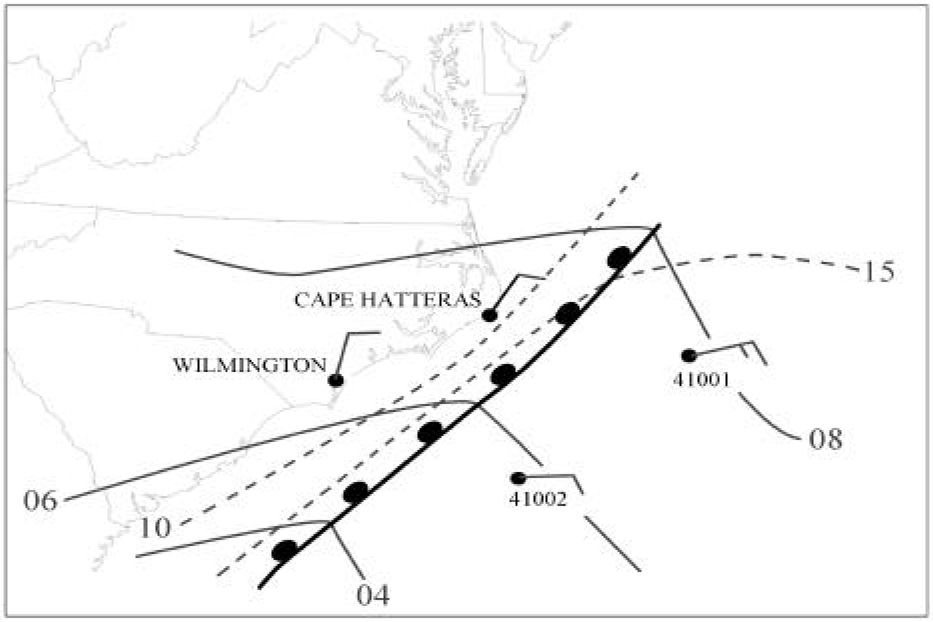

Figure 1. Locations of the stations used in the offshore coastal front detection algorithm. Also shown is the typical structure of a coastal front. Isotherms (dashed) are in degrees Celsius, Isobars (solid) are in hPA and winds are in knots.

2.) Wind direction at Cape Hatteras must be greater than 330° and must also be 20° counter-clockwise of the wind direction at 41001.
3.) Wind speed at 41001 must be at least 4.1m/s (8kts).
4.) Air temperature at 41001 must be at least 3°C greater than that at Cape Hatteras.

Similarly, in order to be classified a coastal front between Wilmington and buoy 41002, all the following criteria must be met for a least four consecutive hours:

1.) Wind direction at 41002 must be between 50° and 160° inclusive.
2.) Wind direction at Wilmington must be greater than 330° and must also be 20° counterclockwise of wind at 41002.
3.) Wind speed at 41002 must be at least 4.1m/s (8kts).
4.) Air temperature at 41002 must be at least 3°C greater than the Wilmington air temperature.

A coastal front was considered a single case as long as the preceding criteria were met. If there was a gap between cases of six hours or less, then those cases were combined into a single case. If there were more than six hours between cases, then those were considered as two separate cases.

The preceding criteria for coastal front identification are based on the surface structure of a coastal front observed during the Genesis of Atlantic Lows Experiment (GALE), which represents the typical structure of a coastal front. Since the offshore detection algorithm described above does not identify coastal fronts that make landfall, it was necessary to develop a detection algorithm for land-falling fronts. Using data from National Climatic Data Center compact disks, an objective algorithm for identifying land-falling coastal fronts was developed.

The following algorithm was applied during and several hours after an offshore coastal front was detected using the method described in the previous section. Again, two pairs of stations were created, one pair consisting of Raleigh and Cape Hatteras, North Carolina, the other consisting of Raleigh and Wilmington. In order for a coastal front to be identified as making landfall, all the following criteria must have been met:

1.) A Clockwise wind shift of at least 20° at Cape Hatteras/Wilmington over the period of one hour (between two consecutive readings).
2.) An increase in air temperature of at least 2°C at Cape Hatteras/Wilmington during the same hour as clockwise wind shift occurred.
3.) Wind direction at Cape Hatteras/ Wilmington must be between 30° and 180° after wind shift has occurred.
4.) Air temperature at Cape Hatteras (or Wilmington) must be at least 2°C greater than air temperature at Raleigh at the hour after wind shift is observed.

The results of the detection criteria were compared to three hourly NMC surface maps to test the accuracy of the method. After several revisions based on the NMC maps, the criteria above were determined to effectively detect coastal fronts that move onshore. The same applies for the offshore detection criteria.

3. RESULTS

Using the method described in the previous section, a seven-year climatology was performed. Years 1988 through 1994 were used in the climatology. Years before 1988 were not used, since hourly buoy data for those years is not available. Another factor limiting the climatology was the absence data from one or both buoys at times. During times in which both buoys were missing, no coastal front would be detected even if one were present.

A total of 358 offshore coastal fronts were detected during the seven-year climatology. Of these 358 cases, 191 occurred between 15 October and 15 April. The majority of the coastal fronts were found to have an offshore duration of sixteen hours or less. Fronts occurred during all months, with longer duration fronts favoring the cold season months (October through March).

The large number of coastal front cases that were detected between mid April and mid October are mainly the result of the objective algorithm detecting what appears to be a nocturnal boundary-layer phenomenon, similar to a land/sea breeze circulation. These events develop during the evening hours, when winds over the land are generally calm and winds over the water have an easterly component. The fronts disappear during the morning hours when solar heating occurs and the temperature contrast between the land and buoy is lost. These fronts are referred to as "diurnal fronts" since they do not persist during the daytime hours, are short lived, and typically have weak temperature gradients. The occurrence of these fronts is not limited to the warm season, but the majority are warm season events. The cold season fronts tend to be longer in duration, show a much larger land/sea temperature contrast, and persist during the daytime hours. These cases represent the more classical definition of coastal fronts, since they are the fronts that have a noticeable impact on sensible weather and aid in cyclogenesis.

From the 358 offshore cases, 148 were found to have moved onshore based on the onshore detection algorithm described in the previous section. Of those 148 onshore cases, 80 were found to be associated with the diurnal fronts described above. The remaining 68 onshore cases represented fronts that showed consistent frontal characteristics and could not be classified as diurnal fronts. The strength of the front is based on comparisons of temperature differences between stations, duration of the front, and magnitude of the frontogenesis term. The onshore cases are extremely important, since they not only influence conditions near the coast, but also areas well inland. The movement of these onshore fronts is often difficult to predict, and therefore is a prime focus of this research. Preliminary examination shows that once the coastal front makes landfall, coastal areas continue to warm several hours after landfall. We are also examining the temperature difference trend between coastal stations and inland stations in order to assess the time required for inland stations to warm following the coastal front passage. Early work shows that warming is slow for inland stations, and may require up to a day for areas well in land, such as Raleigh, to fully feel the effects of the warm air behind the coastal front.

Preliminary classification of coastal fronts began by separating cases based on several different characteristics. This includes fronts that remained entirely offshore to those that moved onshore, fronts

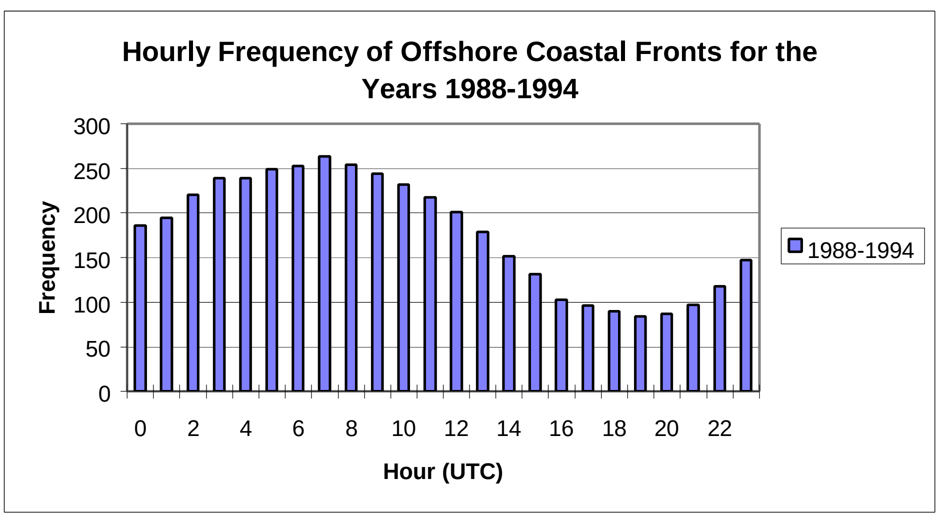

Figure 2. Frequency distribution of coastal front occurrence based on the time of day. The large frequency of fronts occurring between 03Z and 13Z represent "diurnal" fronts, caused by nighttime cooling and confluent flow offshore.

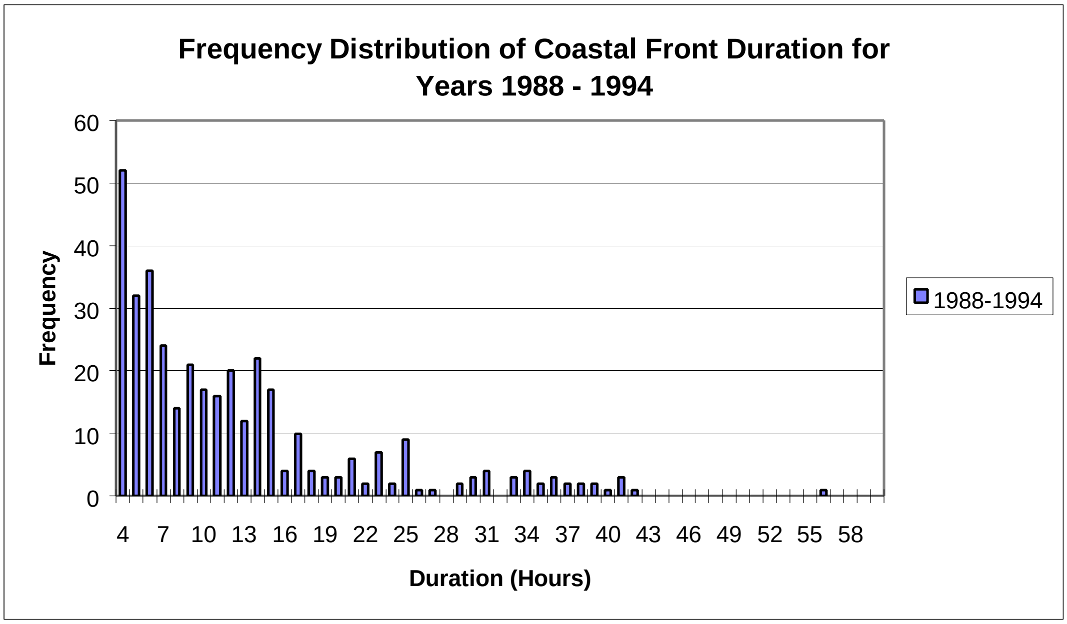

Figure 3. Frequency Distribution of the duration of coastal fronts for years 1988-1994. The majority of cases have a duration of 16 hours or less.

associated with CAD events versus those that were not, short versus long duration fronts, and fronts with large temperature gradients versus those with small temperature gradients. Once a suitable set of classifications is made, a composite of each set will be made, and statistically significant features noted.

4. ONGOING RESEARCH

Currently, a comprehensive objective method is being developed that will track the onshore movement of the coastal front, as well as accurately mark its frontolysis. The development of this method is necessary since it will help determine the duration of onshore fronts, and because the onshore movement of coastal fronts is a prime interest to local forecasters. Ultimately, the goal of this research is to have a comprehensive climatology of coastal fronts completed, along with composites of sets of coastal fronts that have similar characteristics. From these composites, synoptic features that are statistically significant will be identified and passed on to forecasters as a method for improving coastal front forecasting in Virginia and the Carolinas.

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