THE USE OF PRE-STORM BOUNDARY-LAYER BAROCLINICITY IN DETERMINING AND OPERATIONALLY IMPLEMENTING THE ATLANTIC SURFACE CYCLONE INTENSIFICATION INDEX

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Abstract. The lateral motion of the Gulf Stream off the eastern seaboard of the United States during the winter season can act to dramatically enhance the low-level baroclinicity within the coastal zone during periods of offshore cold advection. The ralative close proximity of the Gulf Stream current off the mid-Atlantic coast can result in the rapid and intense destabilization of the marine atmospheric boundary layer directly above and shoreward of the Gulf Stream within this region. This airmass modification period often precedes either wintertime coastal cyclogenesis or the cyclonic re-development of existing mid-latitude cyclones. A climatological study investigating the relationship between the severity of the pre-storm, cold advection period and subsequent cyclogenic intensification was undertaken by Cione et al. in 1993. Findings from this study illustrate that the thermal structure of the continental airmass as well as the position of the Gulf Stream front relative to land during the pre-storm period (i.e., 24–48 h prior to the initial cyclonic intensification) are linked to the observed rate of surface cyclonic deepening for storms that either advected into or initially developed within the Carolina-southeast Virginia offshore coastal zone. It is a major objective of this research to test the potential operational utility of this pre-storm low level baroclinic linkage to subsequent cyclogenesis in an actual National Weather Service (NWS) coastal winter storm forecast setting.

The ability to produce coastal surface cyclone intensity forecasts recently became available to North Carolina State University researchers and NWS forecasters. This statistical forecast guidance utilizes regression relationships derived from a nine-season (January 1982–April 1990), 116-storm study conducted previously. During the period between February 1994 and February 1996, the Atlantic Surface Cyclone Intensification Index (ASCII) was successfully implemented in an operational setting by the NWS at the Raleigh-Durham (RAH) forecast office for 10 winter storms. Analysis of these ASCII forecasts will be presented.

Keywords: Cyclogenesis, Rapid deepening, Gulf Stream, Baroclinicity, Cold air advection.

1. Introduction

During the late fall through early spring strong low-level horizontal baroclinicity often exists within the U.S. mid-Atlantic coastal zone during episodes of offshore

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cold air advection. This condition arises due to the unique and very close juxtaposition of the Gulf Stream current relative to land within this region. Often, the average horizontal distance to the Gulf Stream from Cape Hatteras, North Carolina (NC) is less than 60 km offshore and nearly 200 km offshore Wilmington, NC. In both locations wintertime Gulf Stream Front (GSF) sea surface temperatures (SSTs) typically range between 22 °C and 25 °C. During the initial onset of offshore cold advection, continental-in-origin surface air temperatures can range between -20 °C and 10 °C, and in some cases remain at or below 0 °C for 24 to 48 h. As this cold, dry air encounters the much warmer SSTs near the western boundary of the GSF, large differences between the 10-m surface air temperature (T_A) and the SST close to the GSF result. Similarly, significant differences between the specific humidity of the relatively dry 10-m surface continental air (q_A) and (assumed to be saturated) specific humidity of the air immediately above the sea surface (q_{SST}) can also occur. Since surface fluxes of heat and moisture are proportional to temperature and humidity differences between the sea, surface and air, large values of sensible and latent heat fluxes often in excess of 1500 W m^{-2} can result near the GSF during periods of intense offshore cold advection (Wayland and Raman, 1989; Riordan, 1990; Vukovich, 1991). Even under moderate cold air outbreak (CAO) conditions, the degree of vertical heat and moisture transport that occurs within the lower troposphere is often enough to radically de-stabilize the low level offshore Gulf Stream environment.

Fantini (1990) has shown that this pre-storm de-stabilization may act to significantly increase the likelihood for subsequent rapid cyclogenesis and or re-intensification. The apparent importance of the pre-storm period on future cyclonic intensification prompted an investigation of the effects of pre-storm baroclinicity on coastal cyclogenesis that frequently occurs during winter months within the mid-Atlantic U.S. offshore region (Frederiksen, 1979; Sanders and Gyakum, 1980; Roebber, 1984; Sanders, 1986; Rogers and Bosart, 1986; Dirks et al., 1988). Results from a climatological study by Cione et al. (1993) have shown that the degree of low-level baroclinicity observed near the Gulf Stream during the pre-storm period is correlated with future cyclonic intensification of winter storms off the U.S. mid-Atlantic coast. It is the primary objective of the current study to test the potential usefulness of the Cione et al. (1993)-derived Atlantic Surface Cyclone Intensification Index (ASCII) in an actual National Weather Service (NWS) operational winter storm forecast setting. A description of how ASCII was originally established and operationally utilized will be presented. Preliminary results from the February 1994–February 1996 implementation of ASCII as well as other significant operational uses of the Cione et al. (1993) pre-storm baroclinic regression relationship will also be discussed.

2. Pre-Storm Link to Cyclonic Intensification

A recent climatological study conducted by Cione et al. (1993) investigated cold season (November–April) coastal cyclonic episodes from the period 1982 through 1990. The major goal of this research was to investigate the potential effects Gulf Stream-induced low-level baroclinicity had on subsequent cyclonic intensification within the US mid-Atlantic coastal zone. To determine the effects of marine boundary-layer baroclinicity directly associated with the presence of the Gulf Stream off the Carolinas and Virginia, the region between 38° N and 32° N and 79° W and 72° W was chosen as the storm domain for the Cione et al. (1993) study (see Figure 1). The region highlighted in Figure 1 was selected so that storms entering this region would be subjected to the highly variable baroclinic zone associated with the lateral meanders of the Gulf Stream (Pietrafesa and Janowitz, 1980). It should be noted that all cyclonically oriented, surface low pressure systems analyzed with a closed isobar entirely contained within the study domain were considered 'storm events'. All east coast winter storms between 1982 and 1990 that remained within this region for a period exceeding 6 h were analyzed. Past storm track information was retrieved from the National Centers for Environmental Prediction (NCEP) North American surface weather maps via the National Climatic Data Center (NCDC). A 13 year, digitized (1978 through 1990) once-to-twice weekly data set was used to depict regional SST conditions within the study domain. Since detailed SSTs were only available in nine of these thirteen years dating back to January 1982, only storms occurring after 1982 were included in this study.

In order to accomplish the research objective linking pre-storm low-level baroclinicity with cyclogenic intensification, low-level baroclinic indicators were established. These indicators were devised as a means to ascertain quantitatively the average near-surface thermal contrasts present between the SSTs near the GSF and the cold continental air advecting off the NC coastline during the wintertime pre-storm period. A measure of the low-level pre-storm baroclinicity was obtained using the near-surface air temperatures at coastal locations and the corresponding SST of the GSF. Cape Hatteras and Wilmington, NC were the coastal observation sites used in the Cione et al. (1993) study. Near-surface air temperatures were obtained at hourly intervals at both locations. The air temperatures were averaged during the offshore cold advective period. After combining the averaged surface air temperatures with the SST at the western boundary of the GSF, the average pre-storm air-sea temperature contrast was calculated. In addition to the average pre-storm air-sea temperature contrast, an average low-level pre-storm thermal gradient was calculated by using the distance between the GSF and the coastal stations of Cape Hatteras and Wilmington, NC. The gradient was included so as to incorporate the potential relative impact GSF position has on the low-level thermodynamic modification of the offshore advecting airmass. It should be noted that SSTs were assumed to be constant throughout the period over which coastal

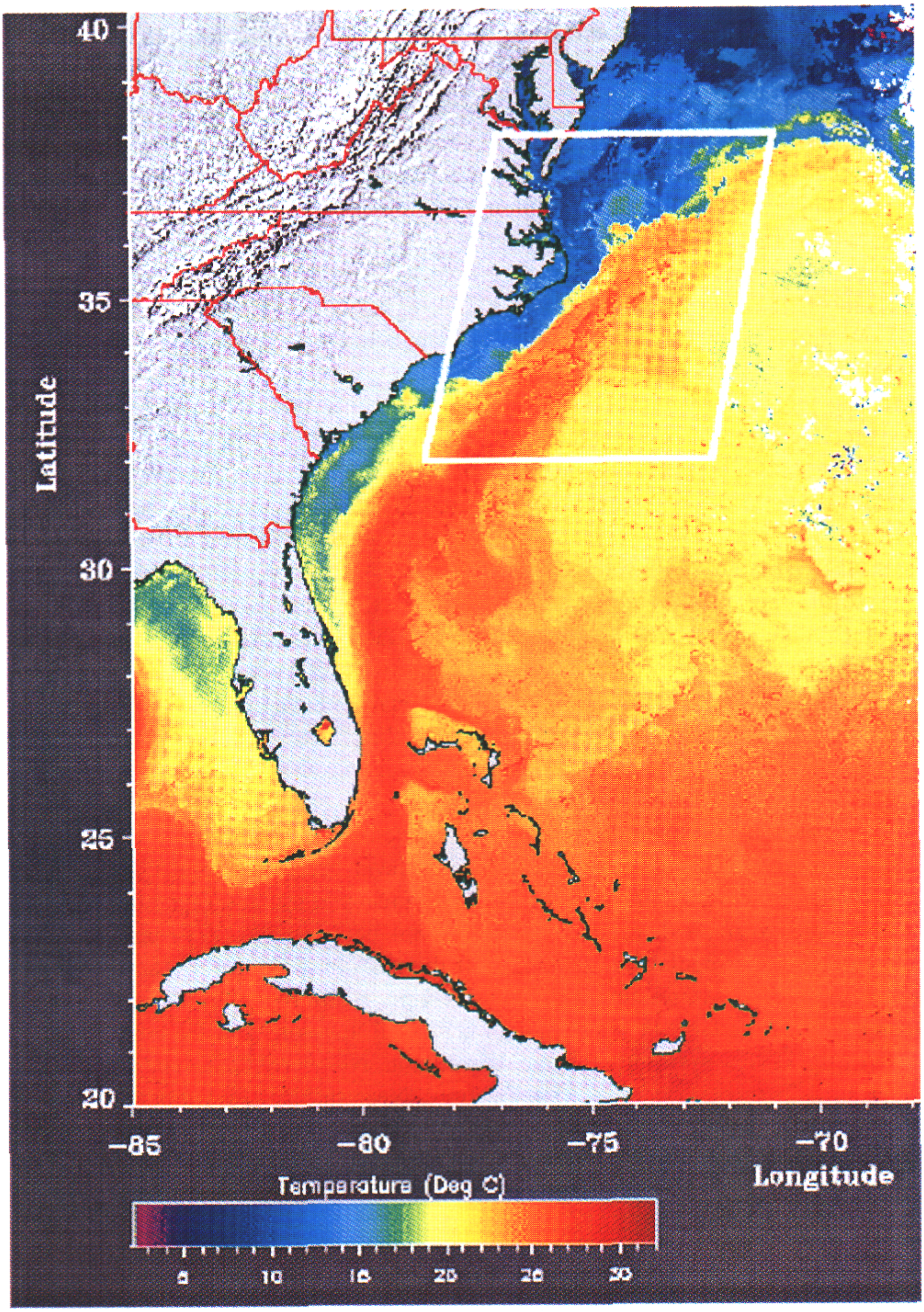

Figure 1. A 4 km AVHRR SST image depicting the offshore region of the eastern United States. The image is a 3-day composite ending 3 March 1998. Also illustrated is the outlined cyclonic study domain used in both the ASCII and Cione et al. (1993) studies. The SST legend (measured in °C) at the bottom of the figure illustrates the dramatic horizontal SST contrasts. Maximum SST gradients at this time are shown to approach 15 °C $(10\ \text{km})^{-1}$ off the North Carolina coast.

surface air temperatures were averaged. Storm intensification was taken to be the observed surface central pressure decrease experienced by a cyclone located in the study area. The normalized units for storm intensification are taken to be mb $12\ \mathrm{h}^{-1}$.

Results from this winter storm climatology revealed that the pre-storm baroclinic nature of the coastal mid-Atlantic region was strongly linked to the subsequent development of regional coastal cyclones. Figure 2 illustrates a linear regression of the total pressure change of the surface cyclone dependent (normalized to a 12 h period) on the pre-storm baroclinic index (PSBI). The results from this 116 storm study illustrate a statistically significant geometric mean of the regression coefficients (r) of 0.562 (at the 0.01% level) between the pre-storm baroclinicity and future (i.e., 24–48 h) storm development that explains 31.6% of the total variance. Much of the scatter, or unexplained variance (i.e., $1 - r^2$) observed in Figure 2, is a result of other important contributing cyclogenic processes that were not included in this research.

Also evident in Figure 2 is a solid relationship between the PSBI and $\mathrm{d}p/\mathrm{d}t$ for weaker intensifying cyclonic events (i.e., <12 mb $(12\ \mathrm{h})^{-1}$). In fact, stratification of storms exhibiting surface intensification rates less than 12 mb $(12\ \mathrm{h})^{-1}$ illustrates a statistically significant r value of .698 (at the 0.01% level) between the PSBI and $\mathrm{d}p/\mathrm{d}t$, accounting for 48.7% of the total variance (not shown). In addition, it can be shown from Figure 2 that for the 38 storms that experienced average PSBI values less than $\sim 1.0\,^{\circ}\mathrm{C}\ (10\ \mathrm{km})^{-1}$ *only one* (i.e., 2.6%) was observed to rapidly intensify (i.e., $\mathrm{d}p/\mathrm{d}t$ at least 12 mb $(12\ \mathrm{h})^{-1}$). Of the remaining 37 cyclones, 36 exhibited rates of cyclonic intensification no greater than 8 mb $(12\ \mathrm{h})^{-1}$. From these results, it appears that the likelihood for rapid cyclonic intensification (i.e., 'bombs') when the PSBI is less than approximately $1\ ^{\circ}\mathrm{C}\ (10\ \mathrm{km})^{-1}$ (or more conservatively $0.9\ ^{\circ}\mathrm{C}\ (10\ \mathrm{km})^{-1}$) is highly unlikely even when other contributing factors potentially impacting upon surface cyclonic intensification are not explicitly taken into account. Also from Figure 2 we see that for a PSBI greater than $1.7\ ^{\circ}\mathrm{C}\ (10\ \mathrm{km})^{-1}$, 12 of the 16 storms (75%) were observed to 'bomb' (i.e., $\mathrm{d}p/\mathrm{d}t$ at least 12 mb $(12\ \mathrm{h})^{-1}$).

3. ASCII Technique Development and Operational Methodology

3.1. DATA ENHANCEMENT

In January 1993, AVHRR SST data obtained from the National Oceanic and Atmospheric Administration (NOAA) polar orbiting series became available to the North Carolina State University (NCSU) research group on a twice daily basis via direct reception of satellite data using an in-situ antenna based receiving station and a dedicated computer workstation-based processing facility at NCSU. The dramatic increase in both spatial and temporal resolution (i.e., twice daily 1.1 km resolution SST data, in real time versus composite NOAA analyses received once

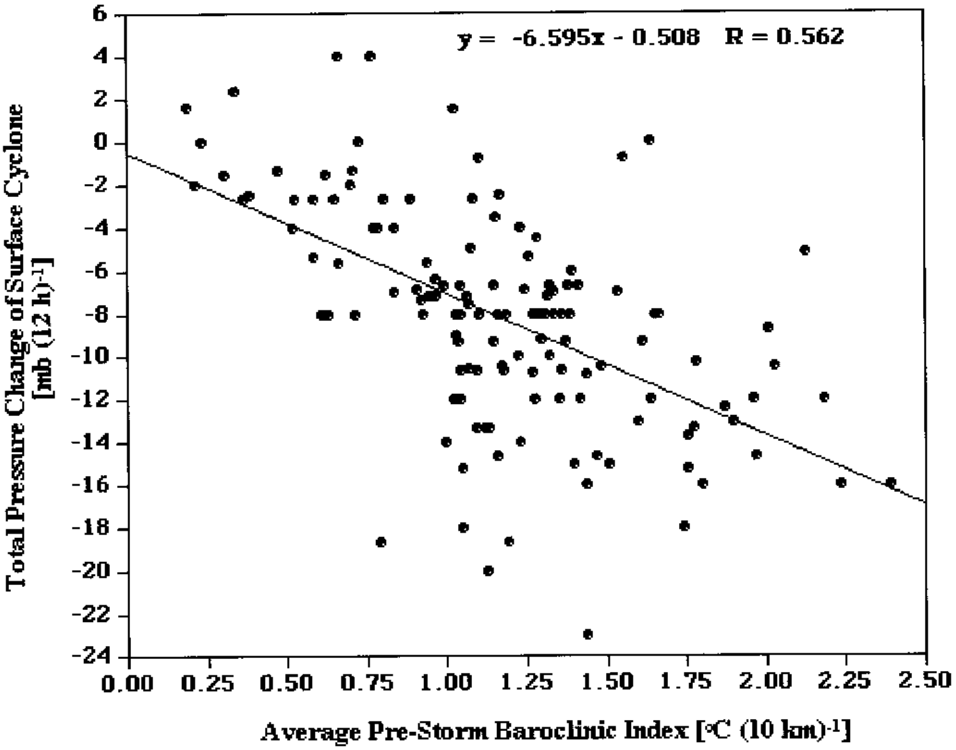

Figure 2. A linear regression of the (dependent) observed surface cyclone central pressure decrease for the 116 cyclonic events that occurred during the 1982–1990 Cione et al. (1993) climatology on the (independent) average Pre-Storm Baroclinic Index (PSBI). The PSBI, measured in °C $(10\ \text{km})^{-1}$, is the average 24 h cold air outbreak air temperature at Cape Hatteras and Wilmington minus the SST of the GSF divided by the GSF offshore distance. The units of cyclonic intensification are normalized to mb $(12\ \text{h})^{-1}$. The regression equation of the total pressure change of the surface cyclone on the PSBI, and the statistically significant (at the 0.01% level) geometric mean of the regression coefficients (r), are also illustrated.

or twice weekly) made it possible to obtain highly accurate representations of SST conditions present off the Carolina-southeast Virginia coastline on a routine basis. While clouds act as a contaminant, the AVHRR digital data can be composited to create ‘relatively clear’ images. In addition, it should be noted that during the onset of offshore cold advection, regional sky conditions are typically clear. During the January–March and November–December period of 1993, each mid-Atlantic CAO event that occurred was documented. During these offshore cold advective periods (which typically persisted for 24–48 h), regional SST data and surface air temperatures at both Cape Hatteras and Wilmington were recorded. Using these near-real-time data in conjunction with the Cione et al. (1993) regression equation (illustrated in Figure 2), it was possible to arrive at a predictive index for surface cyclogenesis/re-intensification within the mid-Atlantic coastal zone. During the 1993 winter periods this predictive index, or ASCII, was consistently produced well before (i.e., 24 h or more) any signs of offshore cyclogenesis or redevelopment were evident. This rather large 'lead-time' made ASCII a potentially useful tool to RAH forecasters, who are responsible for making area forecasts and marine advisory statements during periods of coastal cyclogenesis.

3.2. NWS RAH OPERATIONAL TECHNIQUE

The operational implementation of the ASCII forecast technique began on February 1, 1994. The testing and logistical development of ASCII, however, was developed prior to this date. During the 1993 winter storm season, NCSU researchers worked closely with NWS RAH journeyman forecaster, Rick Neuherz and Science and Operations Officer (SOO), Kermit Keeter to devise an operationally-viable technique designed to assess the (pre-storm, surface-induced) likelihood of wintertime cyclonic intensification within the Carolina–Virginia coastal zone. The following section outlines the methodology of how ASCII is determined by the NWS/NCSU collaborative forecast team.

3.2.1. *Determination of ASCII*

Since winter storms were of interest, the first step was to define the chronological parameters of the 'winter season'. For the purposes of this study, the winter storm season is defined as the period between November 1st and March 31st. A second time period, which had to be defined, was the pre-storm offshore cold advective period, or CAO period. The onset of a CAO is established when offshore flow conditions (with a northerly component) are reported at the NC surface coastal stations of Cape Hatteras and Wilmington. The CAO period continues until the low-level wind direction at Cape Hatteras and Wilmington deviates outside the range of 270° and 360° for a period greater than 3 h. An additional constraining factor of the pre-storm, cold advective period is that it must last a minimum of 12 h. Throughout the period of cold advection, hourly surface air temperatures at the NC coastal stations are recorded. These temperatures are averaged once the CAO period finishes.

During the CAO (which typically lasts between 24–48 h), 1.1 km AVHRR SST data are downloaded from polar orbiting satellites twice daily. If at all possible, a single relatively cloud-free image that closely corresponds to the CAO chronological mid-point is used to establish the pre-storm position and the SST of GSF directly offshore (i.e., normal to) the coastal locations of Cape Hatteras and Wilmington, NC. If cloudy conditions partially obscure the SST distribution during the CAO, two consecutive images 12 h apart are composited in order to establish the GSF SST and location. It should also be noted that GSF positions off Cape Hatteras and Wilmington typically vary between 15–25 km per week (Cione et al., 1993). However, over the 24–72 h time frame in which ASCII is utilized, typical GSF horizontal 'meandering' is on the order of 2–10 km.

From the AVHRR imagery, the location of the GSF is often readily apparent by an abrupt increase in SST with increasing horizontal distance offshore. Typical GSF SST gradients range between 6–12 °C over 2–8 km. The actual horizontal point at which the rapid SST increase ceases to increase off Cape Hatteras becomes the location of the GSF for Cape Hatteras. A similar procedure is conducted to determine the GSF location offshore of Wilmington. Using this high temporal and spatial resolution GSF position and SST data, in conjunction with the averaged coastal Hatteras and Wilmington CAO air temperatures, a PSBI of the low level coastal region is computed (by dividing the combined average Cape Hatteras/Wilmington air temperature value by the combined average Cape Hatteras/Wilmington GSF horizontal distance). While there is a degree of subjectivity in determining the GSF and the associated GSF SST, the horizontal SST increase is many times clearly evident (i.e., SST increase of 6 °C or more) and occurs over a very short horizontal distance (i.e., often <5 km). Since typical average GSF distances are in excess of 110 km, 'GSF location errors' on the order of 5 km are not expected to impact significantly on the results illustrated in this research.

Using the PSBI with the existing regression equation derived from the Cione et al. 1993 climatological study (see Figure 2), an ASCII forecast (given in mb $(12\ \text{h})^{-1}$) can then be obtained for any given PSBI often well before (i.e., about 24 h prior to) the initiation of coastal cyclonic re-development. As such, ASCII provides an indication of the degree of cyclonic intensification that is due to the contribution of low-level pre-storm baroclinicity. It should be noted, however, that ASCII is a cyclonic intensification index and *not* a cyclogenesis forecast and, as such, ASCII does not assess the likelihood of cyclone formation. The actual onset of occurrence, as well as the duration of the cyclonic system within the forecast domain highlighted in Figure 1, are important issues which cannot be addressed by the current ASCII predictive technique and therefore must be addressed independently by traditional and/or other forecast methodologies. An additional constraint is that ASCII can only be extended out to a maximum 24 h beyond the initial time of cyclonic intensification. Since ASCII generates a 12 h cyclonic intensification forecast, this translates into a linear extension of the original 12 h ASCII forecast value.

3.3. INITIAL IMPLEMENTATION OF ASCII

Over the February 1994–January 1996 testing period, ten winter storms met the pre-storm and domain-limited criteria necessary for ASCII operational implementation. In order to capture the potential 'added value' of the ASCII forecast technique *over existing operational model forecast guidance*, a comparison between ASCII and the NCEP Nested Grid Model (NGM) forecasts of surface cyclonic intensification for these ten events was made. (It should be noted that comparisons with NCEP's Eta model were not possible since archived Eta model forecast fields do not fully extend back to January 1994.) In order to make the comparison between ASCII and NGM forecasts, a 'benchmark' observed rate of intensification experienced by the ten storms had to be established. In this study, NCEP gridded three-hourly analysis data obtained from the NCDC were used as 'ground truth' and served as cyclonic intensification verification for both ASCII and NGM forecasts. The area outlined in Figure 1 encompasses the cyclonic study domain used in the study. Since the NCDC-archived NGM dataset contained forecast fields every 2 h up to a maximum of 12 h after each NGM 0000Z and 1200Z model run, NGM forecast values used in this study were *always* within 12 h of the initial NCEP analysis. This point is made, since ASCII forecast values used were generated at least 24 h prior to the time of initial cyclonic intensification and, unlike the 12 h NGM forecasts, *were not updated* throughout the period of cyclonic intensification period. Despite this 'forecast handicap', results illustrated in Table I show that, overall, ASCII-predicted rates of cyclonic intensification for the ten events documented in our study are closer to NCEP 'observed' rates of intensification when compared with NGM predicted values.

Results illustrated in Table I show that the root mean square (RMS) forecast error is lower for ASCII forecasts (relative to NGM forecasts) for these ten storms. All forecast errors illustrated in Table I have been normalized and have the units mb $(12 \text{ h})^{-1}$. The ASCII 2.25 mb $(12 \text{ h})^{-1}$ RMS forecast error represents a 28.6% improvement over the NGM 3.15 mb $(12 \text{ h})^{-1}$ RMS forecast error. This ASCII 'added forecast value' is also visually apparent in Figure 3, which depicts the NGM predicted intensification (open triangles) and the ASCII predicted intensification (solid triangles) relative to the NCEP analyses 'observed' cyclonic intensification. The dashed line in Figure 3 represents a perfect 'one-to-one' correlation between the predicted and observed surface cyclonic intensification for the ten winter storms listed in Table I. Relative to the observed surface pressure decrease, the difference between the predicted values and the dashed line is the forecast error. Events which were under (over)-forecasted are illustrated left and above (right and below) the dashed line in Figure 3. From Figure 3 and Table I we see a 'negative bias' for both ASCII and NGM forecast values. That is, both illustrate a tendency to *under*-forecast the actual rate of cyclonic intensification. However, for these 10 events, the ASCII mean forecast error (i.e., bias) of -1.30 mb $(12 \text{ h})^{-1}$ represents a 0.5 mb $(12 \text{ h})^{-1}$ improvement over the NGM mean forecast error of -1.81 mb $(12 \text{ h})^{-1}$.

While these findings suggest that the use of the ASCII forecast technique can provide 'added value' over NGM-only numerical forecasts of coastal cyclonic intensification, the *greatest degree* of 'added value' is obtained from ASCII when it is specifically utilized during forecasted instances of relatively weak-to-moderate cyclonic intensification. In fact, for five of the seven cases that exhibited intensification rates less than 11 mb $(12 \text{ h})^{-1}$, ASCII forecasts were closer to the observed rate of intensification when compared to NGM forecasts (see Figure 3 and Table I). In addition, and unlike previously illustrated results, ASCII did not depict an under-intensification forecast trend for these seven weaker events (see Table I). The ASCII mean forecast error, or bias, for these storms was $+0.14$ mb $(12 \text{ h})^{-1}$. In

TABLE I

ASCII and NGM verification. All values are given in normalized units of mb $(12\ h)^{-1}$.

Date of storm	NCEP 'observed' dp/dt	NGM predicted dp/dt	ASCII predicted dp/dt	NGM forecast error	ASCII forecast error	**Forecast error (FE) statistics**	NGM	ASCII
2/2/94	8.80	3.20	5.90	−5.60	−2.90	**Min FE**	−5.60	−5.30
14/3/94	11.10	8.30	7.30	−2.80	−3.80	**Max FE**	3.50	2.40
14/10/95	2.10	2.30	2.70	0.20	0.60	**Range FE**	9.10	7.70
22/12/95	9.00	8.00	9.60	−1.00	0.60	**Mean FE**	−1.81	−1.31
23/12/95	2.00	5.50	3.00	3.50	1.00	**RMS FE**	3.15	2.25
23/1/95	9.00	12.00	9.10	3.00	0.10	**Count**	10.00	10.00
30/1/95	10.20	5.50	9.30	−4.70	−0.90			
14/11/95	14.00	8.70	9.00	−5.30	−5.00	***Mean FE (wk)****	*−0.89*	*0.14*
7/1/96	17.30	13.50	12.00	−3.80	−5.30	***RMS FE (wk)****	*2.80*	*1.21*
16/2/96	8.60	6.90	11.00	−1.70	2.40	***Count (wk)****	*7.00*	*7.00*

* Indicates statistics for 'weak' events that exhibited intensification rates <11 mb $(12\ h)^{-1}$.

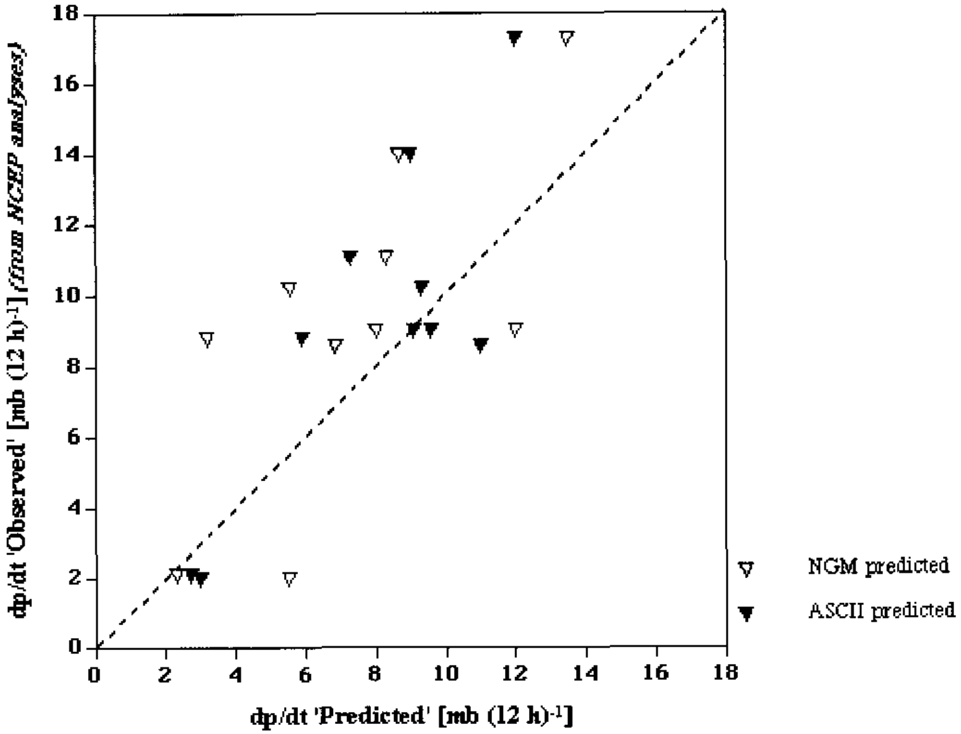

Figure 3. The ASCII and NGM predicted cyclonic intensification relative to the NCEP analysis 'observed' rate of surface cyclonic intensification for the ten storms operationally forecast by the NWS RAH forecast office during the February 1994–February 1996 winter periods. In addition, a dashed line depicting a 'perfect' correlation between the predicted and observed rate of cyclonic intensification is shown. The surface cyclonic intensification has units of mb $(12\ \mathrm{h})^{-1}$.

comparison, NGM forecasts did show an under-intensification trend with a mean forecast error of -0.89 mb $(12\ \mathrm{h})^{-1}$. It should also be noted that for these seven cases, the RMS forecast errors for NGM and ASCII were 2.80 mb $(12\ \mathrm{h})^{-1}$ and 1.21 mb $(12\ \mathrm{h})^{-1}$, respectively. This ASCII value represents a 56.8% reduction in the RMS forecast error over the NGM.

It should be noted that the ASCII forecast technique may also be useful in determining the likelihood for the occurrence of cyclonic 'bombs' (i.e., storms exhibiting $\mathrm{d}p/\mathrm{d}t$ of at least 12 mb $(12\ \mathrm{h})^{-1}$). This guidance can be determined by first obtaining the ASCII predicted intensification rate from the PSBI (see Section 3.2.1). From Figure 2, it can be seen that the ASCII values of -7 mb $(12\ \mathrm{h})^{-1}$ and -11.5 mb $(12\ \mathrm{h})^{-1}$ equate to the PSBIs of $\sim$1.0 °C $(10\ \mathrm{km})^{-1}$ and 1.7 °C $(10\ \mathrm{km})^{-1}$, respectively. As previously mentioned, and evidenced in Figure 2, it appears that these PSBI values may represent 'threshold values' for which rapid intensification is: (a) likely (i.e., ASCII forecast values ≤ -11.5 mb $(12\ \mathrm{h})^{-1}$); or (b) highly unlikely (i.e., ASCII forecast values ≥ -7.0 mb $(12\ \mathrm{h})^{-1}$). Note that of the ten events in Figure 3, three were forecast by ASCII to be 'very unlikely to bomb' while one was forecast to be 'very likely to bomb'. In all four cases the 'ASCII bomb likelihood forecast' was verified.

4. Discussion

ASCII has been developed and found to be useful as a diagnostic tool for NWS forecasters to employ as a potential gauge for extratropical surface cyclone development within the U.S. mid-Atlantic coastal zone. This 'gauge', while statistically generated, is firmly physically based. The premise is that during periods of offshore cold advection, large gradients in SST just off the U.S. Carolina and southeast Virginia coastline translate into large surface fluxes of heat and moisture near the western boundary of the GSF. These pronounced and often long-lived (i.e., 24–48 h) surface heat flux patterns can act to radically destabilize the marine atmospheric boundary layer through the vertical transport of heat and moisture. It is herein postulated that if this airmass modification process is sufficiently robust, it can act to 'prime' or 'set the stage' for deep convection and significant surface cyclonic intensification within this offshore region. This argument assumes that a pre-existing cyclonic disturbance enters the destabilized regime, and also that other contributing factors such as upper level forcing conditions remain favorable for cyclonic development.

The successful utilization of the ASCII forecast guidance technique at the NWS RAH forecast office in Raleigh, NC, over the February 1994–January 1996 period has been very encouraging. While additional storms are needed to verify the initial findings illustrated in this study, it is nevertheless evident from the results presented here that the ASCII statistical forecast technique can contribute 'added value' over 'numerical-only' NGM forecasts of wintertime surface cyclonic intensification within the U.S. Carolina-southeast Virginia coastal zone. Preliminary findings suggest that ASCII's 'added value' may be most significant in cases where weak-to-moderate cyclonic intensification is anticipated. For storms that intensified by 11 mb $(12\ \mathrm{h})^{-1}$ or less, the RMS forecast error and forecast bias were considerably lower for ASCII forecasts of surface cyclonic intensification when compared to similar NGM forecasts.

In an operational setting, RAH forecasters utilize the ASCII technique to gauge the potential for cyclonic intensification due to forcing associated with the low level horizontal baroclinic environment during the pre-storm period. In a flow pattern where upper level forcing is weak and the potential for surface-induced forcing to dominate exists, RAH forecasters have invoked the ASCII technique as a means of recognising the potential for, what at times in the past, has been the not well-anticipated and often surprising and sudden intensification of cyclones in the coastal waters of the Carolinas and southeast Virginia. In addition, when the numeric value of ASCII is less than (exceeds) -11.5 mb $(12\ \mathrm{h})^{-1}$ (-7.0 mb

$(12\ \mathrm{h})^{-1}$) the likelihood for a coastal cyclonic 'bomb' (i.e., cyclonic intensification in excess of 12 mb over a 12 h period dramatically increases (decreases). This information could be of direct use to operational meteorologists in a coastal cyclogenesis forecast setting, especially when presented with ambiguous and/or conflicting numerical guidance. Under such conditions, an NWS forecaster would have the opportunity to include information on the PSBI, in conjunction with other available guidance, prior to issuing a forecast on regional cyclonic development. It is this type of 'added value' forecast guidance that can prove to be invaluable to operational meteorologists responsible for making accurate and timely forecasts of winter storm development within the U.S. mid-Atlantic coastal zone.

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