Final Scientific Progress Report on

Improving Forecasts of Topographically-Forced Weather Systems in the Carolinas and Virginia

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Overall Summary of Progress

This report summarizes the major accomplishments under CSTAR grant NA07WA0206 for the period of funding beginning on 1 May 2000 and ending on 31 August 2003. Accomplishments include progress in scientific understanding of the physical processes governing Cold-Air Damming (CAD) erosion and Coastal Front (CF) movement. However, they also include applications of findings in the collaborative development of diagnostic methods and forecast guidelines. A timeline of major milestones during this project can be found on last page of this report.

Major accomplishments include:

- Development of simple objective methods for identifying CAD and CF events.
- Development of methods of differentiating major CAD/CF types based on physical processes
- Development of a representative climatology of CAD and CF events
- Establishment of a documented archive of recent case studies of CAD/CF events
- Discovery that dynamically consistent synoptic-scale features are linked to major CAD and CF types
- Characterization of sensible weather associated with CAD events and CF passage
- Identification of key physical processes that govern CAD erosion and onshore CF movement
- Identification of limitations in model physics that may account for forecasts of premature CAD erosion
- Development and testing of an objective method for predicting onshore CF movement
- Development of AWIPS procedures and WES case studies to illustrate key findings.
- Training of graduate and undergraduate students in the area of applied research

All of the scientific findings have been shared with forecasters at participating NWS sites in the Carolinas and Virginia through:

- Virtual Co-Lab presentations
- Site Visits
- Workshops and Training Sessions
- A collaborative web site
- Posters and laminated reference materials
- Conference preprints and presentations

Three journal articles have been published based on the results of this project and two others have been accepted for publication and are undergoing revision. Two future publications based on the CAD erosion research of Wendy Stanton are currently in preparation for submission in 2004.

The Climatology of CAD and CF

A chief initial goal of CSTAR was to develop a representative climatology of CAD and CF events to improve our understanding of the important physical processes that govern their behavior. To this end, simple methods were devised and tested to identify and quantify the strength of CAD and CF events. The methods were based on hourly surface observations at key fixed locations and were tested against analyzed surface charts.

The CAD Identification Algorithm

The identification of CAD events is based on the Laplacian of hourly sea-level pressure and surface potential temperature at 10 surface observing stations in the southeastern U.S.. Details can be found in Bailey et al. (2003). The algorithm was applied to historical surface data from 1984 through 1995 to identify a sufficiently large number of cases to permit inclusion of a full spectrum of event types. Objective criteria were then developed to differentiate major types of CAD events. Once this differentiation was completed, composite maps of various atmospheric fields were constructed for each event type. NCEP re-analysis gridded data formed the basis of the composites. With a horizontal grid spacing of 2.5˚ x 2.5˚ and a temporal frequency of 6h, these fields represented the synoptic-scale environment over the U S and eastern Canada. Composite fields were constructed representing average conditions at the surface and aloft at 6-h intervals for a 96-h period centered at CAD onset.

Results

In the 12-year period, 353 CAD events were identified. Classification of these events resulted in a spectrum of types based on intensity and the relative contribution of evaporative cooling. These types include:

- i.) Dry Classical (favorable parent high, no precipitation at onset),
- ii.) Diabatically Enhanced Classical (favorable parent high, precipitation at onset),
- iii.) Weak Classical (less favorable parent high, no precipitation at onset),
- iv.) Hybrid (less favorable parent high, precipitation at onset),
- v.) In-Situ (little or no synoptic forcing, precipitation at onset

Based on the results of the composites, the main findings include the following:

- CAD frequency peaks in September, with a secondary peak in March.

- Most of the stronger events occur in winter, whereas the warm season events are typically weaker and shorter lived. For example, figure 1 below shows that the strongest events are most frequent in late fall and late winter with a systematic weakening in summer.

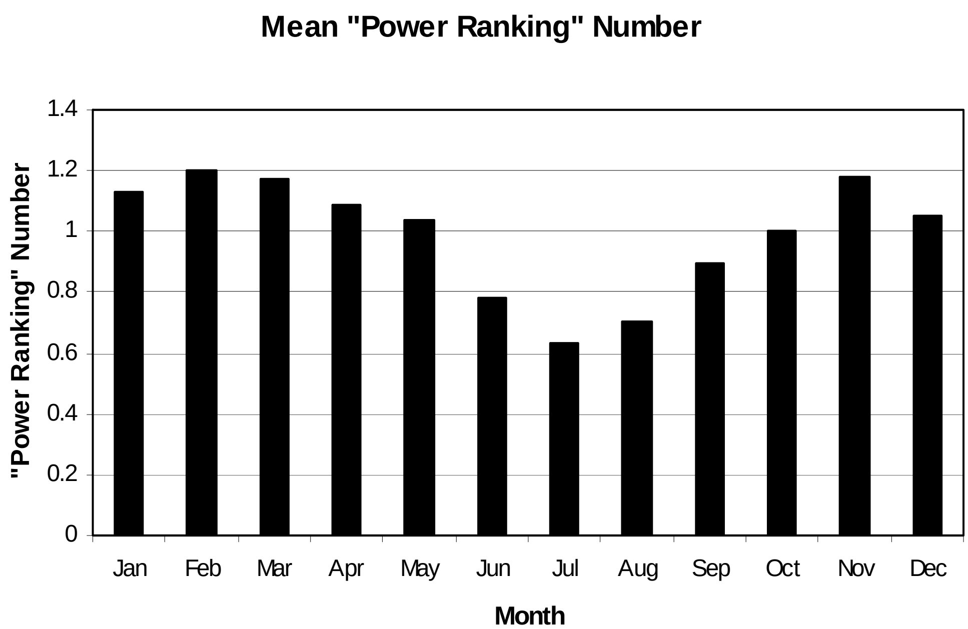

Figure 1. Average strength of CAD events detected by the objective algorithm from 1984 to 1995. The "power ranking" is an objective measure of CAD event strength based on event duration and the strength of Laplacians of pressure and potential temperature as described in Bailey et al.

- Many CAD events occur without precipitation, although these have not been historically emphasized in the scientific literature.

- Strong anticyclonic vorticity at 500 hPa is evident above the parent high during the development of Dry Classical CAD. A weak upper-level jet seems to play a secondary role in the maintenance of the surface high.

- In contrast, strong jet dynamics are evident aloft over the parent high for Diabatically Enhanced Classical cases as the jet streak moves eastward with the surface high.

- Weak Onset and Hybrid types exhibit characteristics similar to the above cases, but the parent high is more progressive and the 500-hPa short wave ridge is weaker.

- A cold front precedes the parent high by at least 24 hours for Dry Onset sub-types resulting in the depositing of cooler air over the eastern U.S. prior to onset. For Wet Onset sub-types, the cold front precedes the parent high by less than 24 hours before damming.

- Low-level southeasterly flow and southwesterly flow at 850 hPa precede the onset of damming for Wet Onset sub-types as low pressure is prominent over the Gulf of Mexico. For Dry Onset events, southeasterly flow develops much later.

- At the demise of CAD, there is downslope flow and cold advection over the cold dome at 850 hPa. A pressure-gradient force reversal and/or a cold frontal passage accompany demise.

- The classification scheme originally proposed by NWS forecasters (Hartfield et al.) appears consistent with statistically significant differences between event sub-types. This significance is confirmed not only with spatial patterns of sea-level pressure, temperature, and geopotential height, but also in terms of sensible weather differences at surface observing stations. For example, the average departure from average maximum temperature during classical CAD sub-types is more than double that during other types of CAD event.

- The case studies undertaken by Mike Brennan during his M.S. research shed light on the contribution of diabatic processes to CAD erosion. In contrast to earlier thinking, this research has demonstrated that the effect of precipitation in cases where the CAD cold dome is saturated prior to the passage of a rainband can accelerate the demise of the cold dome. The demise is brought about by the advective movement of the lateral cold dome boundary by isallobaric flow in response to latent heat release aloft above the cold dome.

- The erosion of strong classical CAD types can be classified by synoptic setting. In all, 89 cases in the period 1984-1995 were thus sorted yielding four dominant scenarios: Northwestern Low, Cold Front Passage, Coastal Low, and Residual Cold Pool. A fifth category, the Southwestern Low, was only found to occur infrequently. When forecast model errors were compared for each subgroup, results indicate that the Northwestern Low scenario is associated with the largest model errors. In this situation, the model will often mix out the shallow CAD cold dome and produce warm temperatures and southerly flow, when in fact the weather will be cloudy and calm. The Cold-Frontal Passage scenario, on the other hand, is relatively well predicted by models, although in the model atmosphere some of these events may appear to be Northwestern Low events because the model has a tendency to erode the cold dome prematurely.

The CF Identification Algorithm

The methods employed in developing the CF climatology were similar to those of CAD. They included isolation of a large data sample that incorporates all CF events, stratification of the sample into useful types, and development of composite sequences for each. Identification was based on surface hourly data from two land-sea station pairs: Cape Hatteras, North Carolina (HAT) and buoy 41001 and Wilmington, North Carolina (ILM) and buoy 41002. Objective criteria for frontal identification included minimum thresholds for land/sea thermal contrast, confluence with wind directions consistent with a coast-parallel inverted surface trough, and adiabatic frontogenesis.

Candidate cases meeting the above criteria were identified from an 11-year period of 1984-1994. These cases were then partitioned into three categories based on a second objective algorithm to detect frontal passage. The type categories include:

- Offshore fronts - those that remain offshore throughout their life history
- Onshore fronts - those that move west of HAT or ILM at some point during their lifetime
- Diurnal fronts - offshore fronts that disappear by 1800 UTC.

Composites were constructed for the three types using the same methods as described earlier.

Results

In the 11-year period, 379 coastal fronts were identified. These were sorted into three groups:

1. Onshore fronts. These systems that eventually move ashore comprise a sample of 70 cases. Of these:
    - Nearly all (in 97% of the cases) occurred during the cold season (October 15 to April 15).
    - Over 60% were associated with CAD events, and the majority of these with the dry classical type of CAD.

2. Offshore fronts. Remaining east of the coastline, these comprise a sample of 112 cases.
    - Most occurred during the cold season
    - Approximately half of the offshore fronts were associated with CAD events and mostly with the dry classical CAD.

3. Diurnal fronts. By far the majority, these cases totaled 197. Many of these phenomena may not be true fronts in the sense that they are not associated with contrasting air masses. Instead, these appear to have characteristics similar to nocturnal-boundary layer or land-breeze phenomena. By definition, diurnal types are short lived, typically lasting between 9 and 15 hours. They frequently form on several successive nights. In contrast with the onshore and offshore types, the diurnal systems were roughly equally distributed throughout the year. Only about one quarter of these events were associated with CAD, the majority of which were dry classical type CAD.

Based on analysis of the composites for each of the above types, we have found significant synoptic-scale differences that differentiate onshore and offshore types. Moreover, these differences are dynamically consistent with expected frontal behavior. For example, for cold-season CF's:

- The composite of onshore coastal fronts shows a statistically significant surface low-pressure anomaly present over eastern Texas 12 hours prior to frontogenesis. In conjunction with a sharp upper-level trough, this low-pressure anomaly tracks along the gulf coast of the United States and eventually across central North Carolina. At the time of frontogenesis for this composite, the surface geostrophic wind is directed onshore and strong warm advection at and below 925 mb is apparent along the Carolina coast. The localized warm advection, approaching relatively sharp 500 mb trough, and strong jet entrance region over the northeast are all consistent with onshore frontal movement.

- The composite of offshore fronts shows no low-pressure anomaly present at any time near Texas or the Gulf of Mexico. At the time of CF onset, surface geostrophic winds are directed from the northeast and along-shore of the Carolina coast. There is no coastal warm advection, the upper-level trough is reduced in amplitude, and jet dynamics are weaker for this composite. All of these features are dynamically consistent with the front remaining offshore.

- The diurnal-type composite is dominated by a weak but sprawling semi-stationary anticyclone centered over or just offshore of the mid-Atlantic coast. The surface geostrophic wind is directed onshore, but is weak as are upper-level dynamics. The weak fields are consistent with the formation of a nocturnal land-breeze circulation. The semi-stationary nature of the surface anticyclone is consistent with the observed tendency for this type of CF to form on several successive nights.

- Onshore fronts are influenced by diurnal and regional effects. Fronts tend to make landfall during the first 6 hours after sunrise.

Sensible Weather

To aid in surface analysis and forecasting for offshore and coastal locations, we investigated changes in sensible weather that accompany CF passage. The times of frontal passage for all coastal fronts at HAT and ILM were noted from the objective algorithm and all cases were normalized to the time of frontal passage. Winds, temperatures and precipitation were averaged for each hour beginning 6h prior to passage and ending 6h afterwards.

Results show temperature and wind signatures that resemble classic warm-front passage in that the temperature increases prior to the wind shift. However, especially at ILM but somewhat at both sites, temperatures continue to rise after the wind shift. Furthermore, at ILM the wind speed increases significantly at frontal passage.

At ILM precipitation of 0.10" or more usually occurs within 6h of frontal passage, and this most often falls prior to the front's arrival. Interestingly, at HAT only 18% of coastal fronts brought precipitation. The cause of the observed differences in winds, temperatures, and precipitation at the two coastal sites is open to conjecture. It is possible that differences in the nature of the surface environment lead to contrasting static stability or that the difference in general location are associated with moisture availability.

At most offshore sites, CF passage is preceded by increasing temperatures and accompanied by a significant wind shift. Wind speeds show no significant trend.

To aid in forecasting changes in sensible weather, we computed averages, ranges, and standard deviations of temperatures and winds for the 6h period centered on frontal passage for several sites including:

Cape Henry Light Tower
Duck Pier
Diamond Shoals Light Tower
Cape Lookout
Frying Pan Shoals Light Tower
Folly Beach
NWS Charleston, SC.

These data are now available to interested NWS participants and may serve as a useful basis for the development of SmartTools.

Physics of CAD Erosion and CF Movement

The CAD and CF climatology provided the context for detailed case studies. These were chosen for their resemblance or contrast with important composite groups. Careful hand analysis emphasized the evolution of near-surface features and provided a comparison with routine NWP forecast fields to evaluate forecast performance. Furthermore, MM5 simulations and sensitivity tests for some selected cases allowed inferences to be made about physical processes important in CAD erosion.

Case studies included:

- A split-front case of 14 February 2000. A north-south aligned split front moved east across and above the cold dome east of the Appalachians. It was hypothesized that abundant deep convection and consequent latent heat release above the cold dome would hasten CAD erosion.

- The onshore CF case of 17-18 February 2000. This front was forecast to jump ashore quickly. It was a Northwest Low case and was associated with Eta 2-m temperature errors of over 10˚F and predicted rapid premature CAD erosion.

- The onshore CF case of 15-16 December 2000. This case was suggested by NWS staff because it presented forecast difficulties. The front moved ashore more slowly than the Eta model had forecast, it resembled cases for which the Eta model had an early erosion bias, but it did not resemble the onshore composite.

- The 23-25 November 2001 CAD erosion case. This event was representative of the Northwestern Low erosion setting, and was characterized by premature erosion of the cold dome in model forecasts. The case also featured onshore CF movement.

- The 10-14 December 2001 CAD erosion case. This case was chosen because its major synoptic setting with a surface cyclone passing north of the region was found to be linked climatologically with a large NWP forecast bias of premature CAD erosion.

- The onshore CF case of 7 February 2002. This front moved to locations just onshore before being swept out by an approaching surface cyclone. It resembled the onshore composite.

- The 29-31 October 2002 CAD erosion case. This case involved coastal cyclogenesis. It also showed a large discrepancy between observations and model forecasts.

Similarities among case studies is not coincidental: Onshore fronts accompany CAD erosion, so investigation of all of the above cases will involve both processes and both are often difficult to capture in NWP forecasts.

Key results

For the above cases, differential advection, surface divergence, diabatic heating, PBL mixing, and the details of nearshore oceanic thermal fields all were found to influence the CAD erosion process and onshore motion of the coastal front. Simulation and forecasting of several of these processes, namely diabatic heating, cloud-radiation interactions, PBL mixing, and details in the sea-surface temperature (SST) field were implicated as causes of Eta forecast problems.

Differential advection, that is, cold advection near the surface countered by warm advection above the cold dome, was found to be an excellent indicator of CAD persistence. When this process was reduced or reversed, the CAD inversion weakened.

For the 17-18 February 2000, December 2000, December 2001, and October 2002 cases, surface divergence in the cold dome was apparent as the CAD erosion proceeded. Interestingly in all cases, the bulk Richardson number computed across the top of the cold dome was too large to suggest turbulent mixing. Rather, for most cases, divergence was produced in the cold air due to an increased pressure gradient to the north of the region with a cyclone passage across the Great Lakes or Ohio Valley. Similarly, for the October case, the coastal cyclone produced divergence along the southern coastal plain. This process reduces the depth of the cold dome and may contribute to drying of the inversion layer through subsidence.

Diabatic heating was demonstrated to be important in the split front case of February 2000. In this case, latent heating occurred above the cold dome resulting in southeasterly isallobaric winds near the surface that were linked to rapid northward retreat of the coastal front. Model simulations demonstrated this effect and suggest that while cloudiness and precipitation within the cold dome reinforce CAD, if deep convection occurs above a saturated dome, CAD erosion may ensue.

Also in this connection, it was discovered that the Eta forecast model allows too much solar radiation to reach the surface during overcast conditions. The large errors for several cases (October 2002, and December 2001) were linked to this limitation. This limitation was not, however, found to be the sole source of error in all cases, even during daylight hours. In model forecasts of this and other cases, there was a tendency for daytime erosion of events that in reality persisted into the nighttime hours.

Cold near-shore shelf waters contribute to retardation of the initial onshore CF movement. In the cases for 17-18 February 2000, 15-16 December 2000, and February 2002, cold pools near shore prevented detection of CF passage at the coastline. Instead, the front appeared to jump ashore to the coastal plain leaving an offshore thermal boundary in its wake. For the December case, accurate SST fields of spatial resolution of at least 1/8˚ latitude were necessary to produce a realistic nearshore frontal simulation.

Finally, for two of the cases (15-16 December 2000 and 10-14 December 2001) sensitivity tests of MM5 showed that the Blackadar PBL scheme produced superior results as compared to the MRF scheme during CAD erosion. In both cases, the 2-m thermal field and sea-level pressure features were better simulated with the Blackadar scheme. The other method resulted in more rapid CAD erosion and CF movement. This result suggests that simulation of vertical mixing during stable conditions within the cold dome may be a source of error. Evidently the operational Eta model is allowing excessive turbulent mixing in the PBL.

Other Investigations

Based on the differences discovered in composite fields between offshore and onshore CF types, as simple objective method was developed to predict onshore movement of the coastal front. The method was based on the presence or absence of key synoptic features at the time of offshore frontogenesis.

Three key features were initially tested as predictors, namely:

(a) a 500 mb trough of specified amplitude centered in the Great Plains,
(b) northeast winds along the Carolina coast from Cape Hatteras to Charleston, and
(c) low sea-level pressure along the Texas coast.

Model testing produced simplifications and led to encouraging results. For example, it was found that the 500 mb feature added no significant skill to the model, and this criterion was subsequently dropped. To test the model, all independent cases of cold-season fronts in the 1984-1994 period in the NCEP reanalysis data were chosen. In all, these included 28 onshore and 75 offshore cases. A front was assumed to remain offshore unless both criteria (b) and (c) were met at the time of offshore frontogenesis. Results were encouraging and yielded a Probability of Detection (POD) of 0.82, a False Alarm Rate (FAR) of 0.34, and a Critical Success Index (CSI) of 0.57.

Earlier research by several investigators has shown that while offshore, CF motion can be replicated by application of simple density-current theory. The application requires characterization of the thermal contrast between the cold and warm air, the depth of the cold air, and the front-normal wind component in the warm air. Once these are specified, a buoyancy-type formula predicts the speed and direction of frontal motion.

The application incorporated surface and upper-air data and involved testing with known CF cases in the 11-year dataset. Hourly observations from HAT and buoy 41001 were used for thermal and wind parameters and the depth of the cold air was determined from HAT soundings. As first step, the orientation of the CF and cold-air depth were assumed constant. In developing the model, 172 cases of onshore and offshore fronts were used.

It was found that for fronts that passed HAT, a critical threshold value of predicted frontal motion was attained prior to frontal passage. Using this threshold resulted in a POD of 0.76, an FAR of 0.53, and a CSI of 0.41.

Both the composite-based and density-current prediction schemes yield encouraging results, but both need more development. The former should be tested on more recent cases with NWP fields used as input. The frontal motion predicted by the density current method should be tested against observed motion. Subject to availability of student and NWS staff resources, it is hoped that this work will continue as part of CSTAR II.

Development of Forecast-Guidance Tools

The scientific results of this project have been shared with participating NWS forecasters through several avenues including virtual co-laboratory sessions, site visits, workshops, laminated reference materials, conference preprints and presentations, journal articles, and a collaborative Web page. In addition, AWIPS procedures have been developed to aid forecasters in real-time analysis of CAD and CF.

AWIPS Procedures

Collaboration with NWS staff at Raleigh has resulted in the incorporation of key scientific results toward the development of AWIPS procedures that are now available to the NWS community. Initial procedures were developed in the last few months of the project and it is anticipated that development will continue to be supported by CSTAR II as new cases arise. Currently two cases are available on the Weather Event Simulator (WES) and procedures can be viewed at any time for these cases.

CAD Analysis and Prediction Procedures

Research results indicate that in many CAD-erosion scenarios, cold advection aloft is a dominant process in weakening the inversion atop the cold dome and the ultimate demise of the CAD event. It is also widely recognized that during the initial stages of a CAD event, warm advection aloft with shallow cold advection beneath can act to strengthen the inversion layer and enhance CAD. Therefore, an AWIPS procedure that toggles between thermal advection near the surface and at the 850-mb level was developed in order to help forecasters recognize the role of differential thermal advection in CAD evolution. In addition to the horizontal plan projection, station profiles of thermal advection and cross-section views of thermal advection have been developed.

Other AWIPS procedures have been designed to monitor the strength of the CAD inversion (Cold-Dome Stability), the extent of cloud cover within the cold dome (CAD-layer RH), and the strength of CAD-layer divergence, which is a factor dictating the depth of the cold dome in some situations.

CF Analysis and Prediction Procedures
Nearshore CF analytical tool
Model intercomparison for CF analysis
Cross-sectional

Collaborative Contributions of NWS

i. Website development

The RAH NWSFO has developed a web site summarizing the multi-faceted NCSU-NWS collaboration efforts in Raleigh. These efforts extend well beyond the CSTAR project alone, but the CSTAR work is highlighted on this page. The page includes animated loops of CAD composites, powerpoint presentations, and other training materials resulting from CSTAR: http://www4.ncsu.edu:8030/~nwsfo/.

ii. NWS staff Case-study archival with discussions

Another element of the aforementioned web page is an ongoing case study library. Some of the CSTAR cases are included on this page as a means to facilitate exchange among offices and ultimately as a means of sharing collaborative best practices for some weather elements.

iii. NWS contribution to CAD testing and characterization

Several individuals at the RAH NWSFO, including Kermit Keeter, Scott Sharp, Gail Hartfield, and Doug Schneider were instrumental in helping us to develop and test CAD detection algorithms.

iv. Forecast discussions (both AFD's and shift briefings?)

For a time during early 2001, Drs. Riordan and Lackmann attended the RAH NWSFO shift-change briefings. This exercise proved valuable for case identification and collection of forecaster insights following a CSTAR event.

Communications

Co-Labs

A Virtual Co-Laboratory was established with support of this grant. It proved a valuable asset in sharing results directly with area forecasters. After some initial experimentation, sessions evolved to a general format. They were generally about 45 minutes in duration and were scheduled near the time of afternoon shift change at NWS sites. Typically Co-Labs involved 5 or more sites including the NWS CSTAR participants. A conference call supported voice communication among sites and visual presentations, typically in Power-Point format, were viewed via Netmeeting software. The visual presentation was also posted on the website and downloaded to participants prior to the session.

Sessions were scheduled weeks in advance to permit maximum NWS participation. The following is a list of Co-Labs together with title and presenter:

- 14 December 2000: Winter Weather NWP was presented by Lackmann.

- 11 May 2001: Overview of Progress on the Coastal Front Climatology to Date was presented by Appel and Riordan.

- 26 June 2001: Split Fronts and Their Effect on Cold-Air Damming was presented by Mike Brennan

- 20 July 2001: A Summary of CAD Types, Their Characteristics, and Classification was presented by Gary Lackmann

- 19 October 2001: Case studies of Land-Falling Coastal Fronts and Their Sensible Weather was presented by Riordan and Appel

- 2 November 2001: Recent Results: Winter-Weather NWP Characteristics was presented by Lackmann

- 2 October 2002: An Onshore Prediction Algorithm for Carolina Coastal Fronts was presented by Contre and Riordan, and Characteristics of Coastal Front Passage at Nearshore Marine Platforms was presented by Holley and Riordan

- 11 October 2002: Physical Processes and Synoptic Patterns Accompanying Cold-Air Damming Erosion presented by Lackmann and Stanton

- 15 October 2002: A repeat of Physical Processes and Synoptic Patterns Accompanying Cold-Air Damming Erosion presented by Lackmann and Stanton

- 24 October 2002: A repeat of An Onshore Prediction Algorithm for Carolina Coastal Fronts was presented by Contre and Riordan

- 21 November 2002: Cold-Air Damming Erosion: Physical Processes and Synoptic Settings, was presented by Lackmann, Stanton, and Brennan

- 6 December 2002: Physical Processes, Precipitation Type, and Numerical Weather Prediction, was presented by Lackmann

Workshops

- Summary of Findings and Shared Experience in CSTAR: NWS Headquarters; All CSTAR participants, 9–10 July 2003.

- Mid-Atlantic Marine and Coastal Meteorology Seminar: NWS Office at Newport, NC; Xie, Brennan, Appel, Contre, and Riordan, 14 May 2002.

Training Sessions

"Do operational forecast models represent freezing and melting? How to anticipate model-dependent biases." Presented to NWS Raleigh; Lackmann, 15 August 2000

"Split fronts in the cold-air damming region." Presented to NWS Raleigh, Brennan, 14 November 2000

Repeat of "Split fronts in the cold-air damming region." Presented to NWS Raleigh, Brennan, 15 December 2000

"Winter weather NWP": Invited lecture at the COMET/MSC course in Boulder, Colorado; Lackmann, February 2002.

NWS Site Visits

- Greer, SC NWSFO (17 August 2000) Lackmann
- Wilmington, NC NWSFO and Newport, NC NWSFO (24 August 2001) Riordan, Appel, and Contre
- Wakefield, VA NWSFO (16 November 2001) Lackmann, Riordan, Appel, and Contre
- Blacksburg, VA NWSFO (17 December 2001) Lackmann and Brennan

Student Contributions

This grant has supported both graduate and undergraduate students who have advanced the research and have benefited from close collaboration with NWS staff.

Graduate Participants

Chris Bailey Development of composite software; Development and testing of CAD identification algorithm, Identification of CAD types, Sensible weather and CAD. Chris is now working for the NWS at the Hydrometeorological Prediction Center (HPC).

Wyat Appel – Development and testing of CF identification algorithm, Identification of CF types, Sensible weather and CF's. Wyat is now working for the North Carolina Department of Air Quality as an air quality forecaster.

Michael Brennan – Analysis and modeling of split-front case; Installation of MM5 model. Michael is continuing on as a Ph.D. student at NCSU.

Wendy Stanton – Identification of CAD erosion types, Case studies and MM5 simulations for 10-14 December 2001 and 29-31 October 2002 cases. Wendy is now working for the NWS in the forecast office in Monterey, CA.

Keith Contre – Development and testing of CF predictor model; Analysis and MM5 modeling of 15-16 December 2000 case.

Undergraduate Participants

Timothy Holley – Analysis of 17-18 February case; sensible weather with CF passage at offshore and nearshore sites. Tim will graduate with a B.S. in Meteorology from NCSU in December, 2003.

Paul Suffern – Application of density current theory to CF movement. Paul will graduate with a B.S. in Meteorology in May, 2004.

Theses Completed
Appel, Wyat K., 2001: An Objective Climatology and Investigation of Carolina Coastal Fronts. M. S. Thesis. Marine, Earth and Atmospheric Sciences Department, North Carolina State University.

Bailey, Christopher M., 2001: A Comprehensive Climatology of Appalachian Cold Air Damming. M. S. Thesis. Marine, Earth and Atmospheric Sciences Department, North Carolina State University.

Brennan, Michael, 2001: The Impact of Split-Front Rainbands on Appalachian Cold Air Damming. M. S. Thesis. Marine, Earth and Atmospheric Sciences Department, North Carolina State University.

Stanton, Wendy, 2002: An Analysis of the Physical Processes and Model Representation of Cold Air Damming Erosion. M.S. Thesis Marine, Earth and Atmospheric Sciences Department, North Carolina State University.

Conference Proceedings
Appel, W. K., and A. J. Riordan, 2001: An objective climatology of Carolina coastal fronts. *Proceedings: 18th Conference on Weather Analysis and Forecasting.* 30 July-2 August 2001, Ft Lauderdale, FL. Amer. Meteor. Soc.

Bailey, C. M., G. M. Lackmann, G. Hartfield, and K. Keeter, 2001: A comprehensive climatology of Appalachian cold air damming. *Proceedings: 18th Conference on Weather Analysis and Forecasting.* 30 July-2 August 2001, Ft Lauderdale, FL. Amer. Meteor. Soc.

Brennan, M. J., S. E. Koch, and G. M. Lackmann, 2001: Detection and evaluation of the effects of split fronts on the evolution of Appalachian cold air damming *Proceedings: 18th Conference on Weather Analysis and Forecasting.* 30 July-2 August 2001, Ft Lauderdale, FL. Amer. Meteor. Soc.

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Lackmann, G. M., K. Keeter, L. G. Lee, and M. B. Ek, 2002: Eta model representation of freezing and melting precipitation: Implications for winter weather forecasting. *Wea. Forecasting*, **17,** 1016–1033.

Bailey, C. M., G. Hartfield, G. M. Lackmann, K. Keeter, and S. Sharp, 2003: An objective climatology, classification scheme, and assessment of sensible weather impacts for Appalachian cold-air damming. *Wea. Forecasting*, **18,** 641-661.

Brennan, M. J., G. M. Lackmann, and S. E. Koch, 2003: An analysis of the impact of a split-front rainband on Appalachian cold-air damming. *Wea. Forecasting,* **18,** 712–731.

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Brennan, M. J., G. M. Lackmann, and S. E. Koch, 2003: The impact of a split-front rainband on Appalachian cold-air damming erosion. *Bull. Amer. Meteor. Soc*., conditionally accepted, in revision.