An Investigation Of Terrain-Atmosphere-Ocean Interactions Along the Coastal Regions Of North America

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LONG-TERM GOALS

The long-term goal of this project is to improve our understanding of: (1) the structure, evolution, and dynamics of the interaction of extratropical fronts/cyclones with coastal orography, (2) air-sea interactions associated with coastal fronts and rapidly deepening cyclones along the East Coast, and (3) the ability of mesoscale models to simulate coastal phenomena at high resolution.

OBJECTIVES

One objective has been to obtain a better understanding of the three-dimensional structure of a landfalling falling baroclinic wave along the U.S. West coast using the Penn State/National Center for Atmospheric Research Mesoscale Model (MM5) in an idealized configuration. There have been a growing number of field case studies investigating this terrain-frontal interaction, such as Colle et al. (2002) supported by this project, but idealized simulations provide a more systematic investigation of how terrain changes the structure and dynamical balances of a landfalling front.

To investigate air-sea interactions along the East coast, the NOAA Wavewatch III (WW3) has been setup to run in real-time over the western Atlantic using surface wind forcing from the real-time MM5 and NCEP GFS models. Specific experiments have been designed to exchange surface forcing between the MM5 and WW3 in order to quantify the wave field impact on the development of nor-easters along the East Coast. This work helps determine whether a fully coupled modeling system is needed for nor-easters during the cool season over this region.

Improving mesoscale predictability in the coastal zone requires the use of mesoscale ensembles. However, it is not clear how to construct this ensemble in terms of different physics and initial conditions. This project has begun to explore this for the landfall of hurricane Floyd on 16 September 1999 along the U.S. East Coast, and an 18-member real-time ensemble system has also been constructed to better understand the use of ensembles along the East Coast.

The final goal of this past year has been to better understand some of the mesoscale weather along the East Coast, such as the sea breeze and transient evolution of convection near the coast. The sea breezes across southern New England are complicated by Long Island and the urban centers.

APPROACH

The MM5 has been employed to investigate the physical processes of frontal and cyclone

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modification along the coastal zones of North America as well as air-sea interactions. The software developed to initialize an idealized baroclinic wave follows the approach of Fritsch et al. (1980) and Nuss and Anthes (1987). This technique combines trigonometric functions and meteorological balances to construct a wave with vertical structure of that typically found in the atmosphere. The MM5 is nested down to 6-km grid spacing along the central U.S. West coast, and the work this past year has focussed on the impact of terrain geometry on the frontal interaction, ranging from a narrow ridge to a broad plateau. Preliminary simulations are also being conducted to explore the role of surface fluxes and diabatic precipitation effects on the pre-frontal flow blocking.

The surface roughness in operational models such as MM5 is parameterized using Charnock's relationship, but this does not take into account wave age and height. The WaveWatchIII (WW3) is currently being run in real-time at 1.0^{o} horizontal resolution and the results are being verified at the offshore buoys. The impact of waves are explored by rerunning select MM5 simulations using the wave-induced surface stress calculated from the wave model at 0.25^{o} resolution. This setup is used to quantify the impact of waves on the development of two nor-easter cyclones along the East Coast on 30 December 2000 and 6 February 2003.

The role on sea surface temperature (SST) structure on East coast cyclogenesis is explored by simulating two nor-easter cyclone cases using different SSTs (same day different year) and SST resolution (32-km versus 14-km). If these sensitivities are relatively small, this would suggest that having a time-evolving SST from a coupled model is not that important, since other physical processes are also active during cyclogenesis (wave-induced drag, latent heating, baroclinic instability, etc...).

In order to better understand the mesoscale predictability in the coastal zone, the work on the extratropical transition of Floyd supported by this project (Colle 2003) was expanded to look at the impact of using different physics and initial conditions on the simulations. The case was rerun at 32-km grid spacing using the 3 different PBL parameterizations (Eta, MRF, and Blackadar), 4 different convective parameterizations (CPs = Kain-Fritsch, new version of Kain-Fritsch, Grell, and Betts-Miller). A separate simulation was also completed using the NCEP GFS model for initialization.

During the summer of 2003 the real-time MM5 system at Stony Brook was setup to include an 18-member ensemble down to 12-km grid spacing over the Northeast U.S., which is the highest resolution and largest ensemble over the Northeast U.S. The MM5 system for the 0000 UTC cycle includes the 12 physics members (the 3 PBL and 4 CPs mentioned above) initialized by the Eta, as well as the GFS, and 5 Eta bred members at 2100 UTC. All MM5 forecasts are verified using all available observations in order to assess model skill versus resolution and impact of including a different number of ensembles members across coastal New England.

WORK COMPLETED

The software for the idealized baroclinic wave has been improved to include nested MM5 domains down to 6-km grid spacing using a variety of terrain configurations (real and ideal terrain). Several simulations have been closely analyzed using real coastal/inland terrain, a narrow ridge, and a plateau to investigate the role of barrier width on the coastal circulations and frontal interaction. Time series of the basic state quantities and frontogenesis calculations help reveal some of the fundamental differences between simulations. These simulations have been repeated for both a weak and strong landfalling frontal/cyclone events. Additional simulations including the effects of surface fluxes and moisture have also been completed, but not fully analyzed. This work is currently being written up for a thesis and formal publication.

The real-time wave modeling using WW3 has been improved by starting the wave model with the previous cycle's (12-h old) wave field, and the domain was expanded to cover much of the western Atlantic by including the NCEP GFS winds outside of the MM5 domain. The one-hourly wind output from the MM5 and 3-hourly GFS are being used for real-time 48-h wave forecasts from the WW3 model. Time series plots and statistics have been created for the simulated versus observed wave height at the coastal buoys. These comparisons will continue through the winter of 2003-2004.

The MM5 research on the landfall of hurricane Floyd described in the previous report has been written up for publication and it is in press to *Monthly Weather Review.* Since the operational models failed to properly simulate this event, this research was expanded to address the mesoscale predictability. Several additional simulations were completed using different model physics and initializations at 32-km grid spacing. In collaboration with a few other colleagues, these results have been submitted for publication in the *Bulletin of the American Meteorological Society.*

A new sea breeze case(10 June 2003) has been simulated using MM5 for detailed analysis as a part of an undergraduate project. This case study was selected since several unique observations were available for verification such as ferry weather observations over Long Island Sound, ACARS observations from JFK and LGA airports, and Brookhaven National Laboratory meteorological tower data.

The real-time MM5 at Stony Brook, which has been running down to 4-km grid spacing over coastal southern New England during the past four years, has been expanded to include a 18-member ensemble down to 12-km grid spacing over the Northeast U.S. Computer scripts has been written to automate the system to use 12-different physics options in the MM5 as well as interpolate the NCEP GFS, and Eta breds for different initial and boundary conditions. A new MM5 web page has been developed (http://fractus.msrc.sunysb.edu/mm5rte). This page includes ensemble means, spreads, and spaghetti plots. There are also probability plots for precipitation exceeding certain thresholds (trace, 0.01-0.10 inches, 0.10-0.25 inches, etc...). Software has been written to verify all MM5 ensemble forecasts using conventional surface and upper air observations. An automated MM5 archiving system has been developed, in which many of the full three-dimensional MM5 fields are saved.

RESULTS

A series of simulations were completed for an idealized mid-latitude cyclone approaching the West Coast that is similar in magnitude to that frequently observed during the cool season (central pressure around 995 mb). Figure 1 shows a Hovmoller diagram for the potential temperature gradient as the trailing cold front approaches the northern California coast for a simulation using real topography (control) and no terrain. The prefrontal flow blocking results in a terrain-parallel barrier jet to 20 m s^{-1} (not shown), and the temperature gradient nearly doubles in magnitude as the front gets to within 200-km of the coast. Most of this frontogenetical increase is the result of the confluence and shearing deformation terms (not shown), while tilting results in frontolysis over the windward slope. The wind and temperature differences between the control and no terrain extends about a Rossby radius (200 km). The front is also a few hours slower in the control because of upstream blocking.

Additional idealized simulations were completed using more simple terrain geometry involving either a narrow (50-km half width) ridge or a plateau to the east of the 2-km crest. The amount of blocking and the strength of the barrier jet is dependent on the barrier width. A plateau has a barrier jet that is nearly 20% stronger and 50% wider than a narrow ridge of similar terrain height. As a result, the frontal strength is nearly twice as strong for the plateau, and the plateau results are more similar to the control using real terrain. The plateau induces a larger (deeper) pressure perturbation that extends farther upstream (not shown). These results suggest that not only is the steep coastal terrain important for frontal interaction, but the broad high terrain of the western U.S. also enhances frontal blocking.

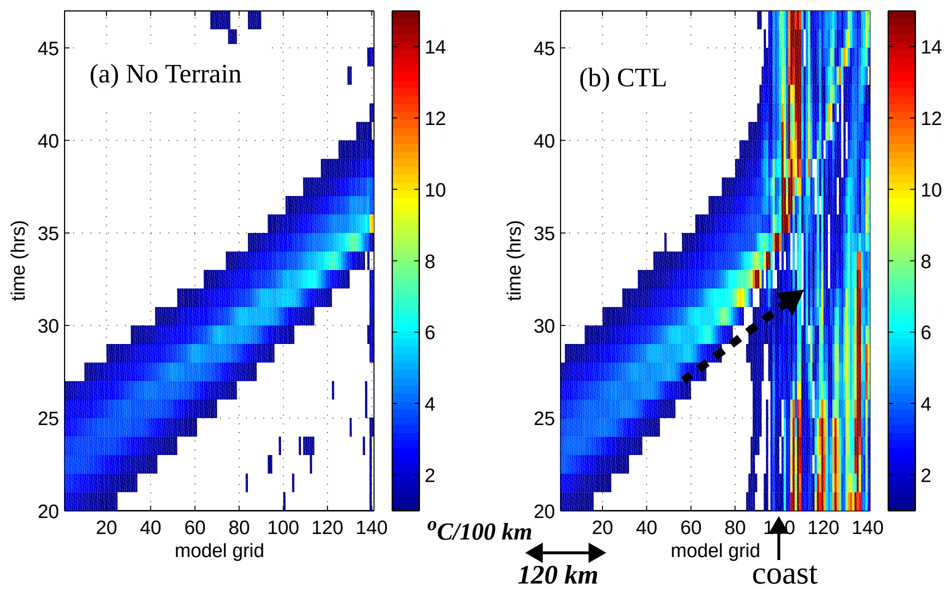

Figure 1: (a) Hovmoller diagram of potential temperature gradient (^{o}C/100 km) versus hour of the 6-km simulation for the (a) no terrain and (b) real terrain simulations. The dashed line in (b) is the orientation of the no terrain frontal speed. The terrain induces rapid frontogenesis within 200 km of the coast and retards its forward motion.

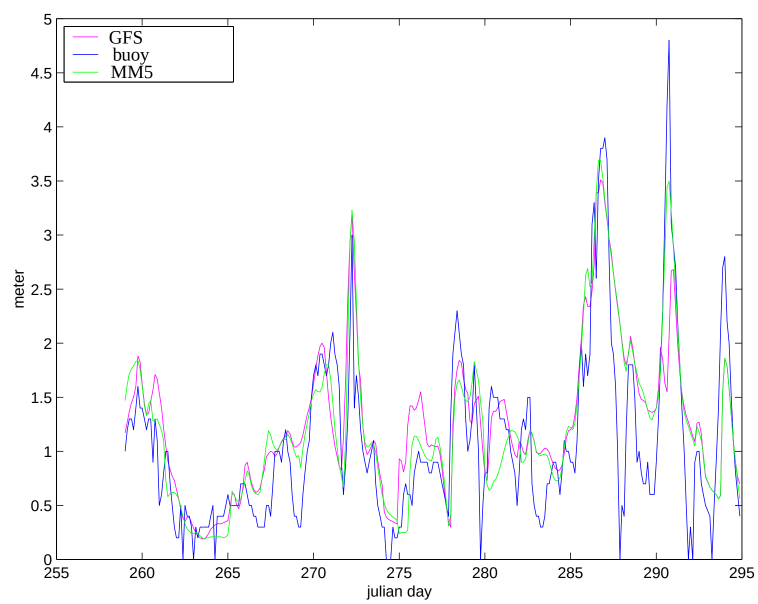

Figure 2. Comparison between the wave height at buoy 44025 (150 km south of Long Island, NY) between the observations (blue line) and the real-time WavewatchIII (WW3) simulations using the short-term (0-24 h) forecast winds from either the NCEP GFS (pink) or MM5 winds (green) from mid-September 2002 to late October 2002. The WWW3 simulations are close to observed, with some underestimation of the peaks. Using the MM5 12-km winds helped with the forecast of some of the peaks.

Figure 2 shows a time series of the short-term (0-24-h) WW3 forecasts using the NCEP GFS winds or the MM5 winds (GFS winds outside MM5 domain east of 65 ^{o}W). The WW3 is able to realistically simulate some of the peaks associated with some of the individual storm events. Using all buoys, the WW3 system has a 0.5 m mean underprediction of waves > 1.5 m, while it overpredicts wave height by 0.25 m on average for waves less than 1.0 m. Using the MM5 has improved on some of the peak wave events, likely because of its increased spatial resolution along the East coast (36 and 12-km) relative to the GFS.

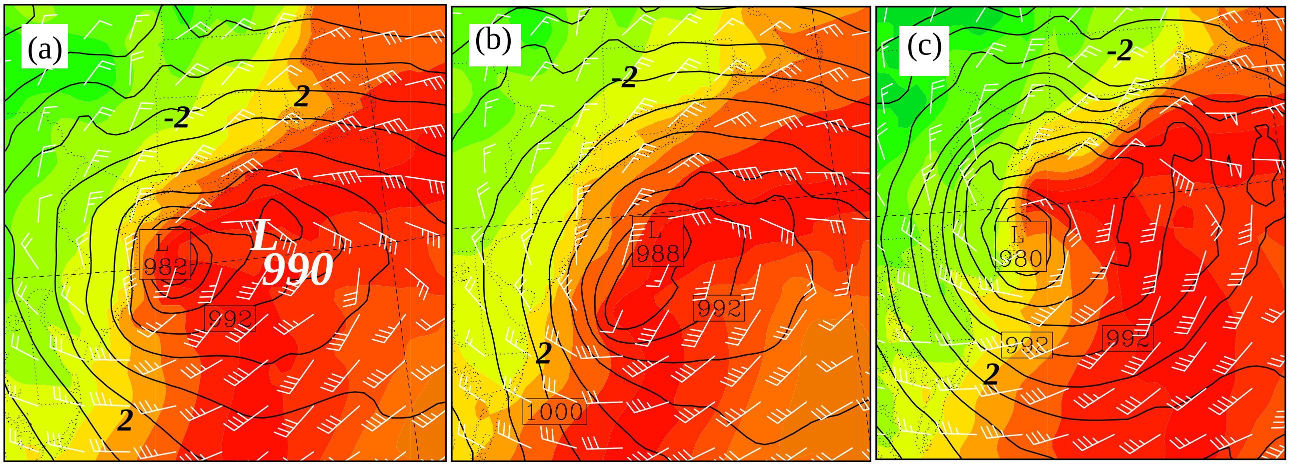

Figure 3. Sea-level pressure, surface winds (full barb = 10 kts), and surface temperature (every 2 °C) for the 33 h 12-km forecast on 2100 UTC 30 December 2000 for the (a) CTL (MRF PBL), (b) WW3-derived roughness length, and (c) Burk-Thompson PBL (no WW3). Using the wave model increased the surface roughness, which in turn reduced the strength of the cyclone by 6 mb and it is closer to the observed (white L in plot a).

The nor-easter of 30 December 2000 was tested using either the control (MRF PBL), roughness lengths as derived from running the WW3 using the control MM5 wind field, or the Burk-Thompson (B-T) PBL. Using the larger roughness lengths from WW3 results in a 6 mb weaker cyclone than the control by h 33 (Fig. 3), and the central pressure is closer to the observed. The control is too deep and close to the coast; therefore, it predicted rain for New York City, when in fact heavy snow fell. The B-T PBL uses a Charnock constant that is half that of the control, so the cyclone is 2 mb deeper and closer to the coast than the control. The wave sensitivities are 50% larger for a deep cyclone than the weaker (1000 mb) cyclone on 7 February 2003. For these deep systems the wave sensitivities are comparable to PBL sensitivities, therefore suggesting that wave modeling can be added to an ensemble for storm events. The sensitivity to using a different SST initializations was not as large as the PBL and wave experiments for the 2000 cyclone.

It was found that the predictability of the Floyd pressure fields using the 32-km MM5 was not very sensitive (1-3 mb) to the PBL and convective parameterizations used, but the precipitation amounts varied by 40-50% just inland of the coast. In particular, the Betts-Miller CP resulted in a broader and less precipitation in the areas of maximum flooding than the other CPs.

IMPACT/APPLICATION

Landfalling fronts and cyclones along the U.S. West Coast are often associated with strong winds, which are enhanced by the steep coastal topography ("barrier jet"), and heavy precipitation. This study is helping our understanding of landfalling fronts by diagnosing high resolution model simulations.

There has been limited work investigating the impact of sea surface waves and SST variations on the development and evolution of extratropical cyclones over the western Atlantic. This study has conducted several sensitivity experiments using one-way coupling of the MM5 to a wave model and using different resolution/perturbations of SST. It appears that for some major storms the effects of the sea surface are often non-negligible.

A real-time 18-member ensemble has been constructed and is being validated with the output posted on the web and sent to the surrounding NWS offices.

TRANSITIONS

The real-time MM5 ensembles are sent to the surrounding National Weather Service forecast offices around New York City for the forecasters to evaluate and use on a daily basis.

RELATED PROJECTS

1 – Our East Coast real-time MM5 verification and ensemble effort is a natural extension of Dr. Cliff Mass' real-time MM5 work along the West Coast, which is also sponsored by ONR.

2 - The real-time ensemble work with the local NWS offices is also supported by a UCAR/COMET grant entitled "Improving operational weather forecasting through real-time ensembles and verification.".

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