FINAL REPORT FOR COMET PARTNER'S PROJECT: THE NEW JERSEY SEA BREEZE AND ITS RELATIONSHIP TO COASTAL UPWELLING

between
RUTGERS UNIVERSITY, INSTITUTE FOR MARINE AND COASTAL SCIENCES
and
THE NATIONAL WEATHER SERVICE FORECAST OFFICE, MOUNT HOLLY, NEW JERSEY

SECTION 1: PROJECT OBJECTIVES AND ACCOMPLISHMENTS

Objectives:

1) To determine the influence of upwelling on sea surface temperatures (SSTs) and the resultant impact to the overlying atmosphere.

2) To determine the impact of SSTs on coastal climatology and sea breeze development.

3) To evaluate how a better understanding of sea breeze structure and dynamics can improve the forecast process.

4) To establish a collaborative working relationship between Rutgers and the NWS.

Introduction

Upwelling due to synoptic scale southwesterly winds can cause sea surface temperatures (SSTs) to decrease by about 5°C along the New Jersey coast (Figure 1). The decrease in surface ocean temperatures impacts the overlying atmosphere by cooling it. These cooler temperatures can be transported inland during sea breeze development, which can be felt well beyond the coast (Figure 2).

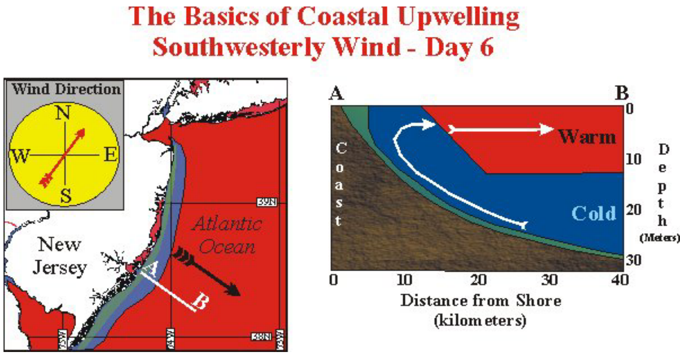

Figure 1. Schematic drawing showing upwelling along the NJ coast due to southwesterly winds (Courtesy of Mike Crowley)

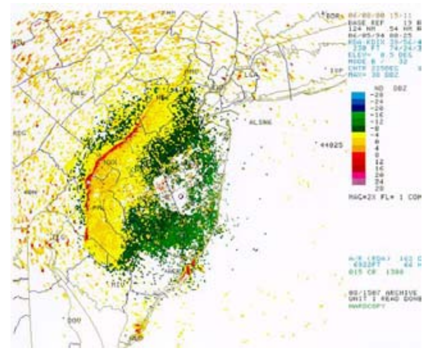

Figure 2. Radar image of sea breeze extending into Pennsylvania

Numerical simulations with the Regional Atmospheric Modeling System (RAMS) were used to examine the effect of coastal upwelling on sea breeze development along the New Jersey coast. Model runs were made using actual SSTs from AVHRR satellite imagery showing moderate to strong upwelling as well as with a representative SST map with no upwelling present. This was done to isolate the effect of SSTs on the sea breeze by keeping all other parameters constant.

Regional Atmospheric Modeling System (RAMS)

RAMS is a non-hydrostatic model constructed around a full set of primitive dynamical equations which govern atmospheric motions. It has optional parameterization for turbulent diffusion, solar and terrestrial radiation, moist processes including the formation and interaction of clouds and precipitation, sensible and latent heat exchange, soil, vegetation, and surface water.

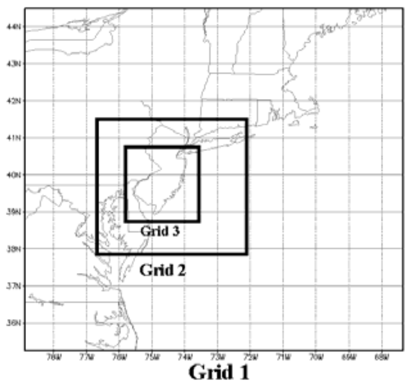

Figure 3. RAMS grid configuration for simulations

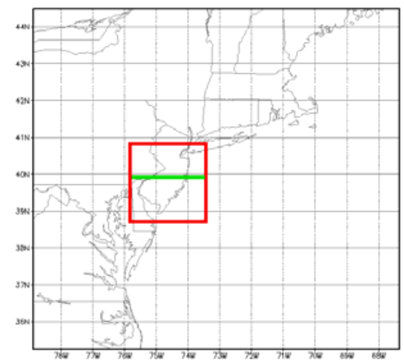

Figure 4. Study area (red rectangle) and cross section plots (green line)

Model Specifications

- Three nested grids (Figure 3 above)
- Grid 1 – 32 km resolution 34x34 points with a 40 s time step
- Grid 2 – 8 km resolution 50x50 points with a 13 s time step
- Grid 3 – 2 km resolution 90x106 points with a 4 s time step
- 45 vertical levels with almost half of them below 2 km
- 48 hour simulation
- Used both upwelling and non-upwelling SSTs (AVHRR)
- Harrington radiation scheme
- Mellor and Yamada subgrid turbulence scheme
- NCEP Reanalysis data for model initialization

To understand the impact SSTs have on coastal climate, simulations were conducted using two different oceanic states. One case had moderate to strong upwelling along the coast of New Jersey and a second which showed no signs of upwelling. All other variables were held constant so the effect of the SSTs could be examined.

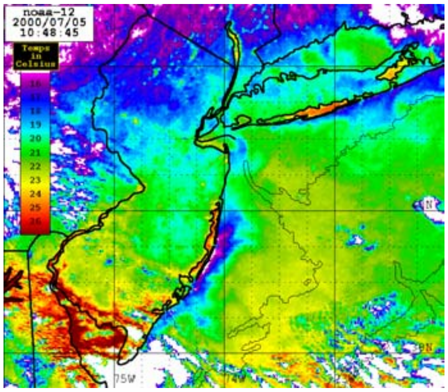

Figure 5. July 5, 2000 11Z SST image before processing

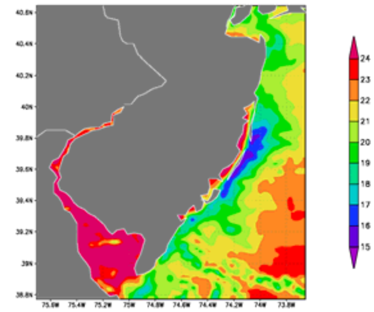

Figure 6. July 5, 2000 SSTs after processing (Upwelling)

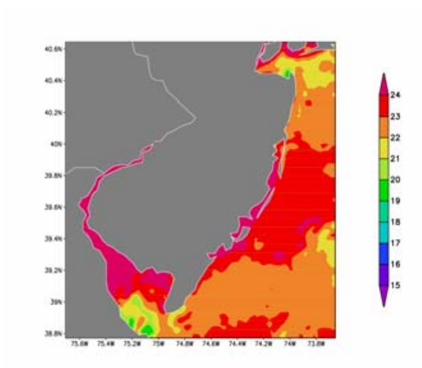

Figure 7. July 27, 2000 SSTs after processing (No Upwelling)

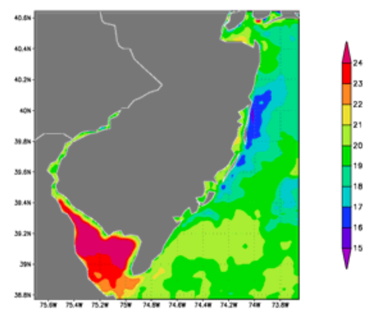

Figure 8. June 23, 2000 SSTs after processing (Upwelling)

The New Jersey Sea Breeze: Background

Figure 9 shows a typical sea breeze and its vertical wind structure. Its vertical extent is usually from between 300 and 1500 meters, while its horizontal extent can be felt solely along the shore or well into southeastern Pennsylvania.

Doppler radar reflectivity can be used to identify sea breeze formation and location. This is most visible when the radar is in clear-air mode (Figure 10). The sea breeze can be seen as the red curve along the coast of New Jersey.

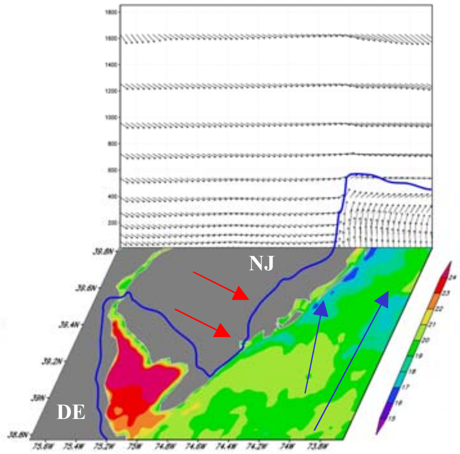

Figure 9. Sea breeze horizontal and vertical extent with SSTs (ºC)

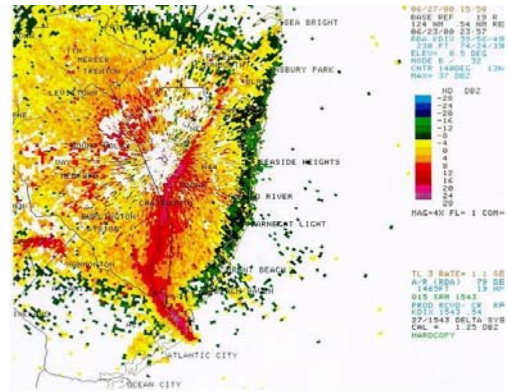

Figure 10. June 24, 2000 0Z radar reflectivity

Case Study: July 5, 2000

We examined the temperatures at 2 m to see the differences caused by different SST initializations. Figures 11 and 12 show the 2 m temperature simulated with the different SST initializations. Figures 13 and 14 show that the cooler upwelled SSTs resulted in cooler temperatures above the sea surface which were transported inland during sea breeze formation.

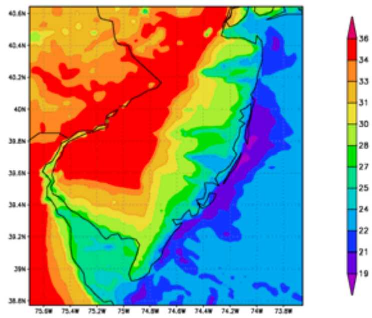

Figure 11. 2 m temperature (ºC) with upwelling SSTs

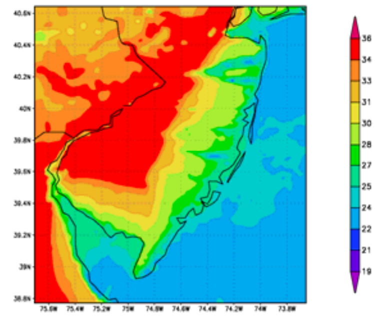

Figure 12. 2 m temperature (ºC) with non-upwelling SSTs

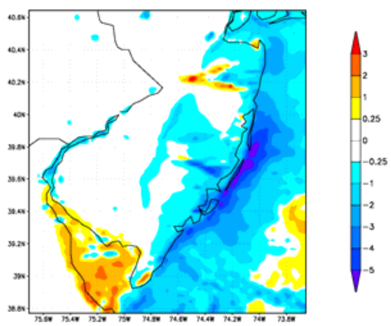

Figure 13. 2 m temperature difference (ºC) (upwelling – non-upwelling)

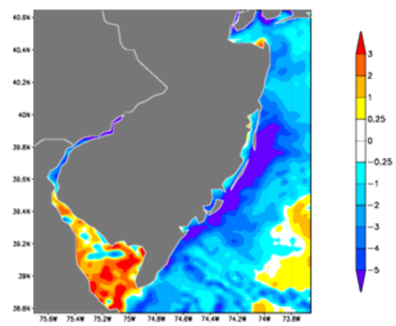

Figure 14. SST difference (ºC) (upwelling – non-upwelling

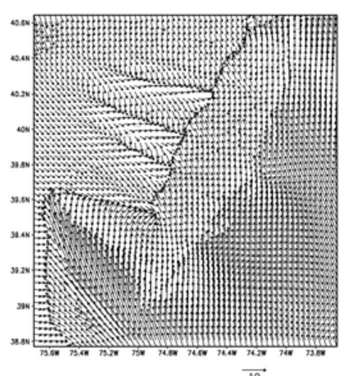

Figure 15. 10 m wind vectors with upwelling SSTs

Figure 15 shows the wind vectors at 10 m which are generally out of the southeast in the sea breeze. Figures 16 and 17 show a cross section through 39.8º N of temperatures. The effect of upwelled SSTs can be seen in the lower right hand side of figure 16 and is strongest in the lowest 100 m but can extend beyond.

Case Study: June 23, 2000

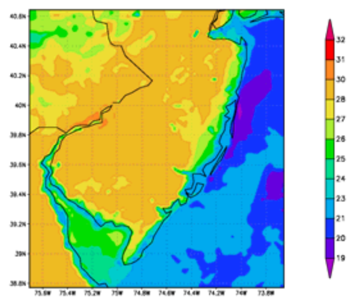

Figure 18. 2 m temperature (ºC) with upwelling SSTs

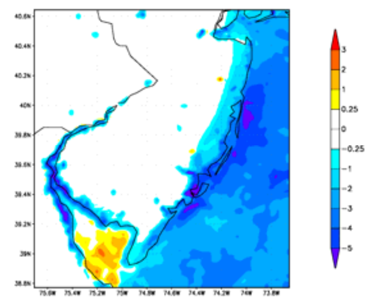

Figure 19. 2 m temperature difference (ºC) (upwelling – non-upwelling

Figures 18 and 19 shows the 2 m temperature with upwelling SSTs and the difference between the two cases. Similar results were seen although since the sea breeze did not penetrate far inland most of the temperature anomalies remained near the coast. Figures 20 and 21 show vertical velocities at 500 m and wind vectors at 10 m. The low level convergence from the sea breeze front causes upward vertical velocities which are greatest at the mid to upper portion of the sea breeze. The vertical structure of the sea breeze can be seen in Figures 22 and 23. In Figure 22 the vertical velocity cross section shows the upward/downward couplet that is typically seen in sea breeze fronts. This is especially clear when the sea breeze occurs during a west or northwest wind. The wind vectors in Figure 23 show the wind structure within the sea breeze circulation.

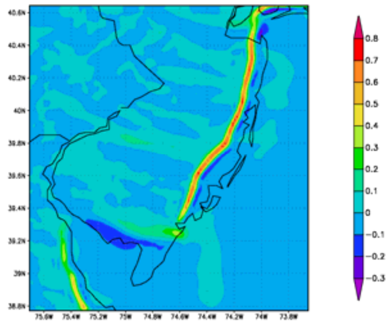

Figure 20. Vertical velocity (m/s) at 500 m with upwelling

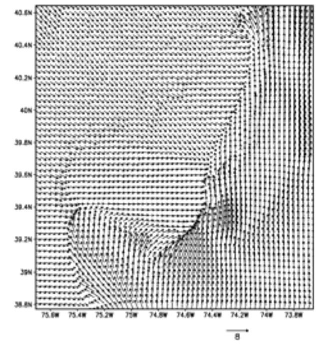

Figure 21. 10 m wind vectors with upwelling SSTs

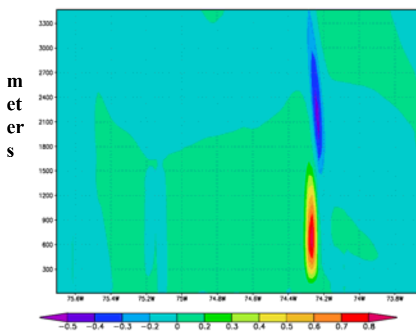

Figure 21. Vertical Velocity couplet marking the sea breeze front location 20Z

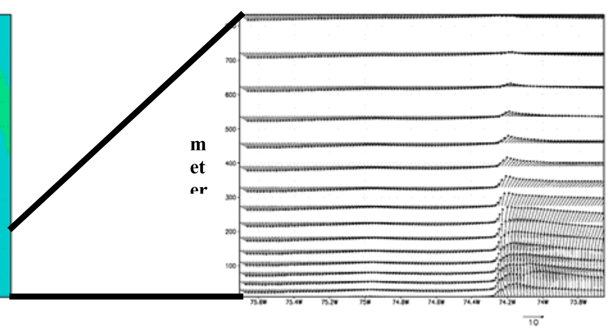

Figure 20. Vertical cross section through 39.8º N of wind

Conclusions

The main effect of the upwelling of cooler SSTs is to decrease the overlying atmospheric temperatures, which can be transported inland during a sea breeze. The difference is greatest right along the shore where temperatures can be as much as 4 to 5ºC cooler and decreases the farther you move inland. The vertical extent of temperature differences is most visible in the lowest 100 m with some differences seen up to 400 m.

SECTION 2: SUMMARY OF UNIVERSITY/NWS EXCHANGES

(1) The NWS Science and Operation Officer made regular visits to the Rutgers IMCS to meet with faculty and students, and to evaluate the progress of the research. NWS marine focal point Jim Eberwine also made occasional visits to Rutgers.

(2) Study results were posted to the IMCS web site at:

http://marine.rutgers.edu/cool/seabreeze/

and were brought to the attention of the NWS forecasters. These results included many case studies with radar loops and surface maps, as well as the selected cased with RAMS model output.

(3) Study results were presented to the NWS staff at a station seminar in October.

(4) A poster from the presentation: "Effect of Coastal Upwelling on Circulation and Climate in Coastal Regions" at the 2002 AGU meeting (co-authored by Rutgers and NWS) is on display at the NWS office.

(5) One of the participants in this project, Lou Bowers served as a Summer Volunteer Intern at the Mount Holly NWS office. Several other Rutgers students have also served as NWS volunteers.

SECTION 3: PRESENTATIONS AND PUBLICATIONS

- POSTER: <u>Effect of Coastal Upwelling on Circulation and Climate in Coastal Regions</u>
  Luke Oman, Louis Bowers, Scott Glenn, Richard Dunk, Alan Cope.
  American Geophysical Union Fall Meeting, Moscone Center, San Francisco, California. December 6 - 10, 2002

- <u>Sea Breeze Forecasting and Applications Along the New Jersey Coast</u>
  Louis Bowers, Richard Dunk, Josh Kohut, Hugh Roarty, and Scott Glenn
  AMS Fifth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, Seattle, WA. August 6 - 8, 2003

- January 2003: NJ Board of Public of Utilities (NJBPU), presentation at Rutgers IMCS, “Offshore/coastal wind/ocean monitoring and sea breeze modeling for central and southern NJ coastal areas in support of potential wind energy development.”

- April 2003: NJBPU, presentation at NJBPU Trenton Office of Clean Energy, “Offshore/coastal monitoring and sea breeze modeling for near and far shore waters associated with the NJ coast in support of wind energy development.”

- August 2003: NJBPU, presentation at the Rutgers IMCS Tuckerton Marine Field Station, “Coastal and offshore monitoring and sea breeze modeling in support of potential wind energy to be used to supplement power at the source during peak demand periods.”

- September 2003: University of Delaware - Center for Energy and the Environment, NJBPU / Office of Clean Energy, Delaware State Energy Office, National Renewable Energy Laboratory (NREL) / NWTC, Connectiv Power Utility, presentation at Distributed Energy Meeting, Conectiv Regional Office, Newark, DE, “Distributed Energy Resources for New Jersey and Delaware Coastal Areas.”

- November 2003: UMDNJ, presentation at UMDNJ, “Sea breeze modeling and coastal/inland monitoring in support of pine pollen transport, dispersion, and deposition associated with asthma cases relevant to coastal communities and adjacent inland areas.”

- December 2003: PSEG, presentation at PSEG Hdqts at Newark, “Use of sea breeze modeling and offshore wind/current remote sensing to enhance the accuracy of convective storm development and coastal storm predictions.”

- February 2004: NJBPU and Department of Energy (DOE), presentation at Rutgers IMCS, “Coastal/offshore remote/in-situ monitoring and Atlantic sea breeze/Delaware Bay breeze modeling in support of wind energy development for the entire NJ and DE coasts along with adjacent offshore waters out to 100 nautical miles.”

- March 2004: NJDEP Div. of Fish and Wildlife and NJDEP Dept. of Science and Technology, presentation at NJDEP, “Coastal/offshore wind assessment using remote sensing and sea breeze modeling to support wind energy development and associated environmental impact issues related to wildlife including migratory and shore birds.”

- April 2004: NJ Clean Air Council, UMDNJ, NJDEP, and the US Forest Service, presentation at NJ Chamber of Commerce, “Coastal and inland remote/in-situ monitoring and sea breeze modeling in support of air contaminant transport and dispersion within the sea breeze circulation; this effort will focus on the following issues: air pollution, health, counter terrorism, and forest fire propagation/intensification.”

- May 2004: University of Delaware and Delaware Energy Office, presentation at UDEL, “Coastal/offshore remote and in-situ monitoring and sea breeze/wind field modeling in support of wind energy development along and offshore of the NJ and DE coasts.”

- June 2004: NJBPU and Island Wind, Inc., presentation at the Rutgers IMCS Marine Field Station, “Coastal monitoring and sea breeze modeling in support of wind energy development at the Marine Field Station.”

SECTION 4: SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED

4.1 Benefits to the University

(1) The greatest benefit to the University of this project has been the stronger working relationship with Mount Holly NWS. Rutgers scientists and NWS scientists are now on a first name basis, and regularly discuss ongoing and new projects with each other.

(2) Rutgers gained access to historical operational Doppler Radar data to use for research purposes.

(3) This project launched a Masters thesis topic for one of the student participants.

(4) Persistent use of project results in numerous presentations by project scientists eventually led to direct state support to continue this research.

4.2 Benefits to the NWS

(1) As a result of this project, there is now a much stronger working relationship between the NWS Mount Holly office and Rutgers University, specifically the IMCS. We feel this relationship can lead to cooperative research on a larger scale, possibly a COMET Collaborative Project involving marine/coastal zone research.

(2) The NWS has access to a large amount of meteorological and oceanographic data collected by the IMCS Coastal Ocean Observation Lab (COOL). Most of this data is available through the IMCS "COOL" web site, but we hope soon to be able to ingest into AWIPS the meteorological tower data from the IMCS Tuckerton, NJ research site.

(3) As a result of numerous case studies, with and without numerical modeling, the NWS now has a better understanding of NJ sea breeze behavior under varying synoptic conditions. These case studies will be valuable for seasonal reference and for training of new forecasters.

(4) Specifically, we have seen through the modeling results that cold water upwelling along the NJ shore can locally enhance the afternoon sea breeze, resulting in farther inland penetration and somewhat cooler temperatures near the shore. This result will be increasingly important as the NWS moves into operational production of hourly high-resolution gridded forecasts of temperature and winds.