The Effect of Sea Surface Temperature on New Jersey Sea Breeze Dynamics

Louis A. Bowers

Advisor:
Scott Glenn

Committee:
Richard Dunk
Rutgers University

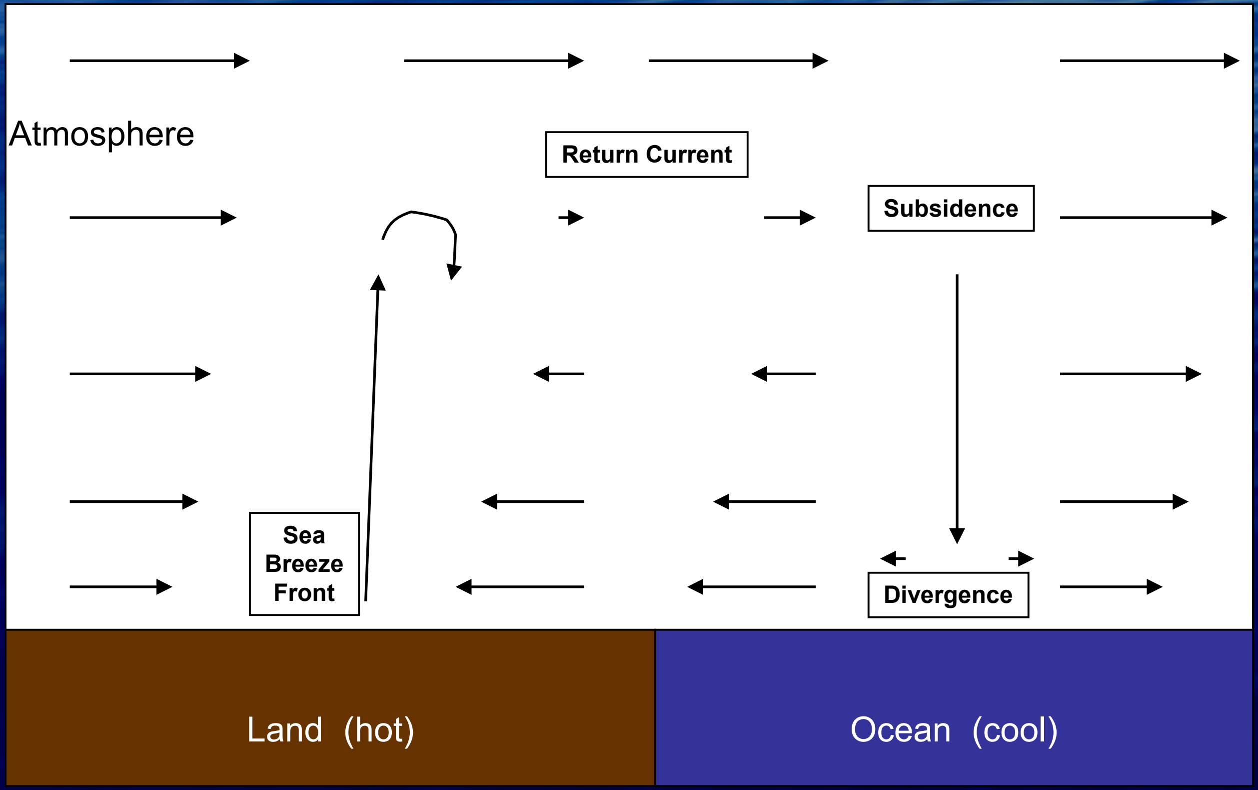
James Eberwine
National Weather Service
Mount Holly, NJ

Coastal Ocean Observation Lab
Institute of Marine and Coastal Sciences
Rutgers University

Thesis Outline

- Introduction
- Weather Research Forecast (WRF) model
- Characteristics of the New Jersey sea breeze – coastal upwelling relationship
- Sensitivity Study
- Case Studies
  - June 6, 2004
  - June 5, 2004
- Conclusions and Future Work

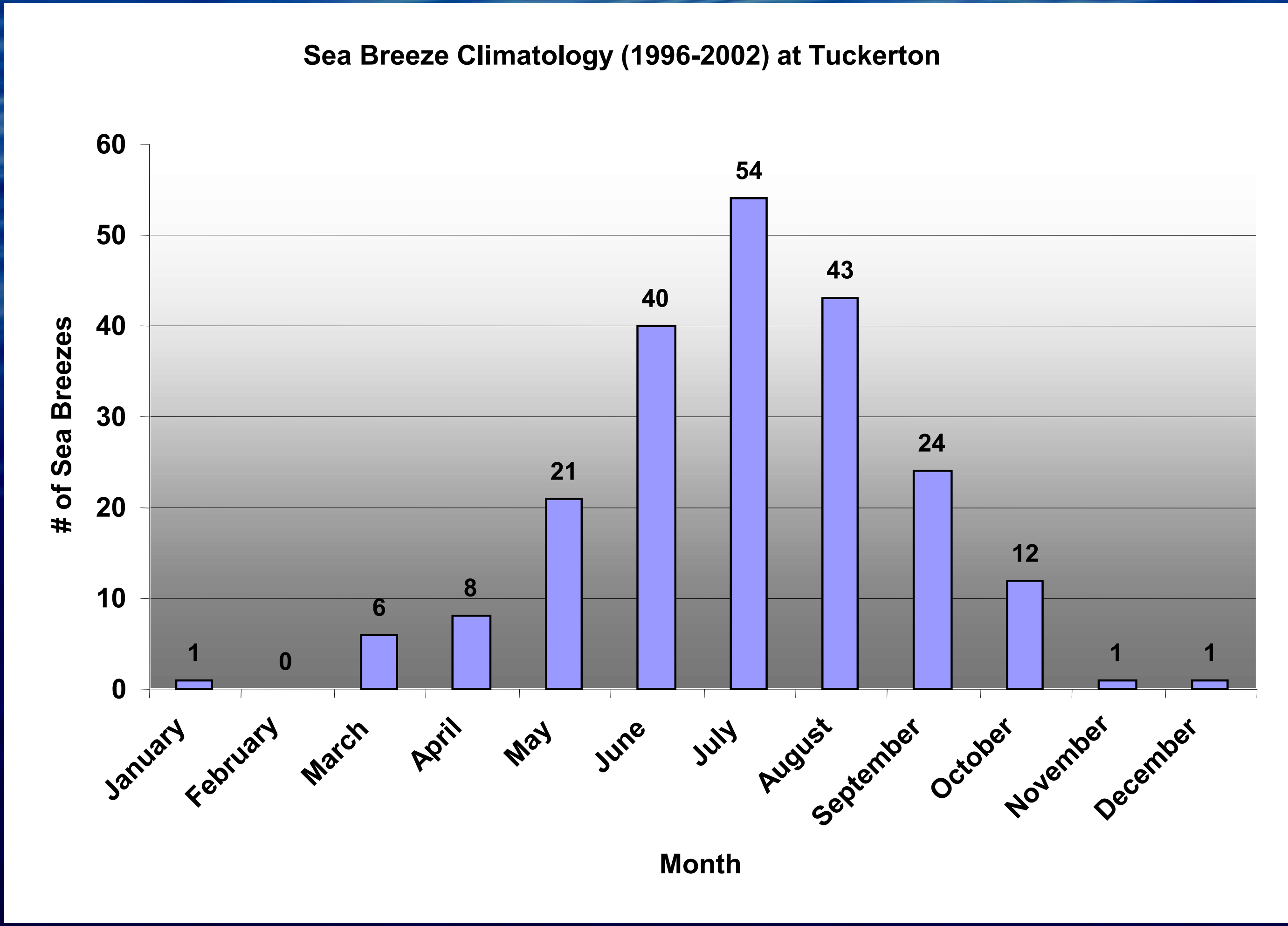
What is a sea breeze?



- Develops as a result of the land/sea temperature gradient

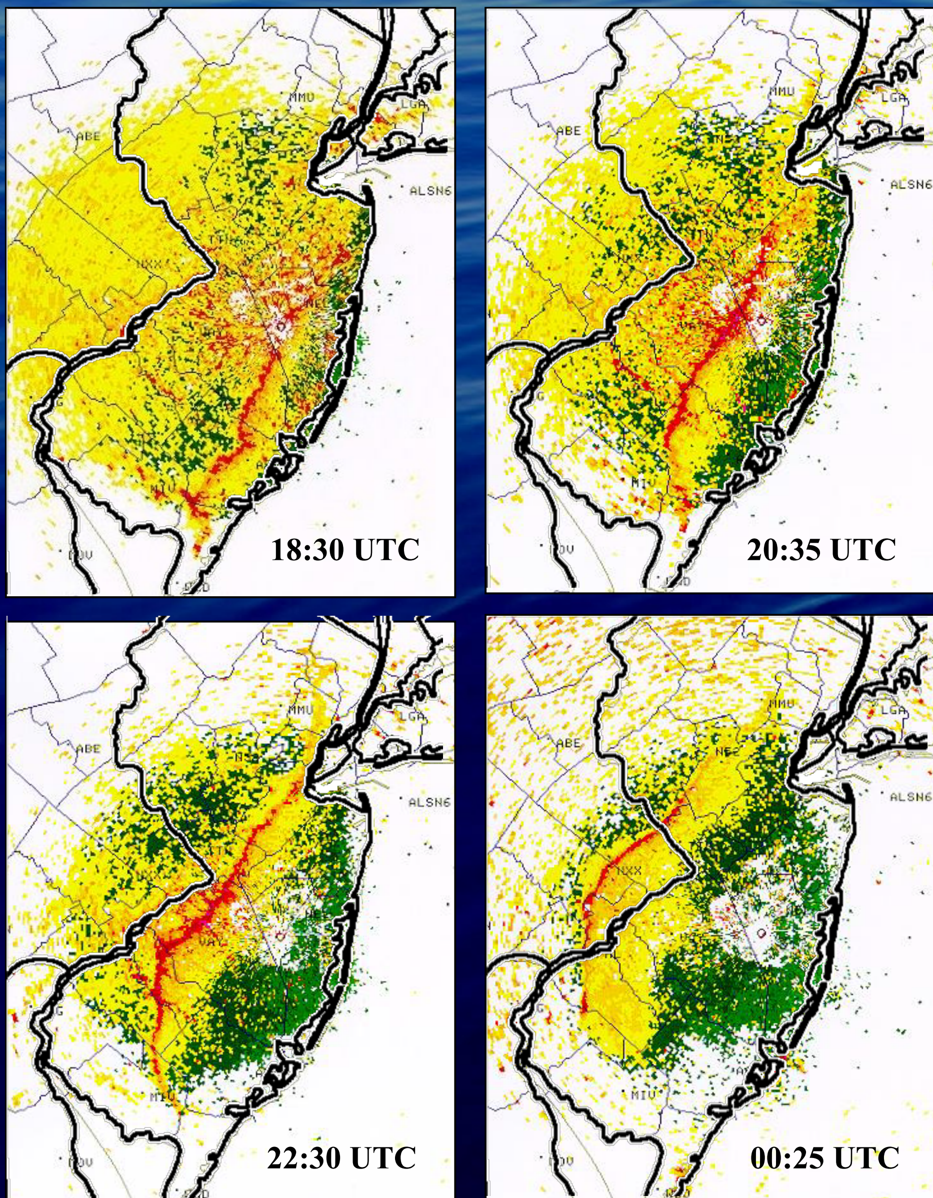
When and how often does the sea breeze occur?

- Develops as a result of the land/sea temperature gradient
- Can occur during almost any month of the year



Who does the sea breeze affect?

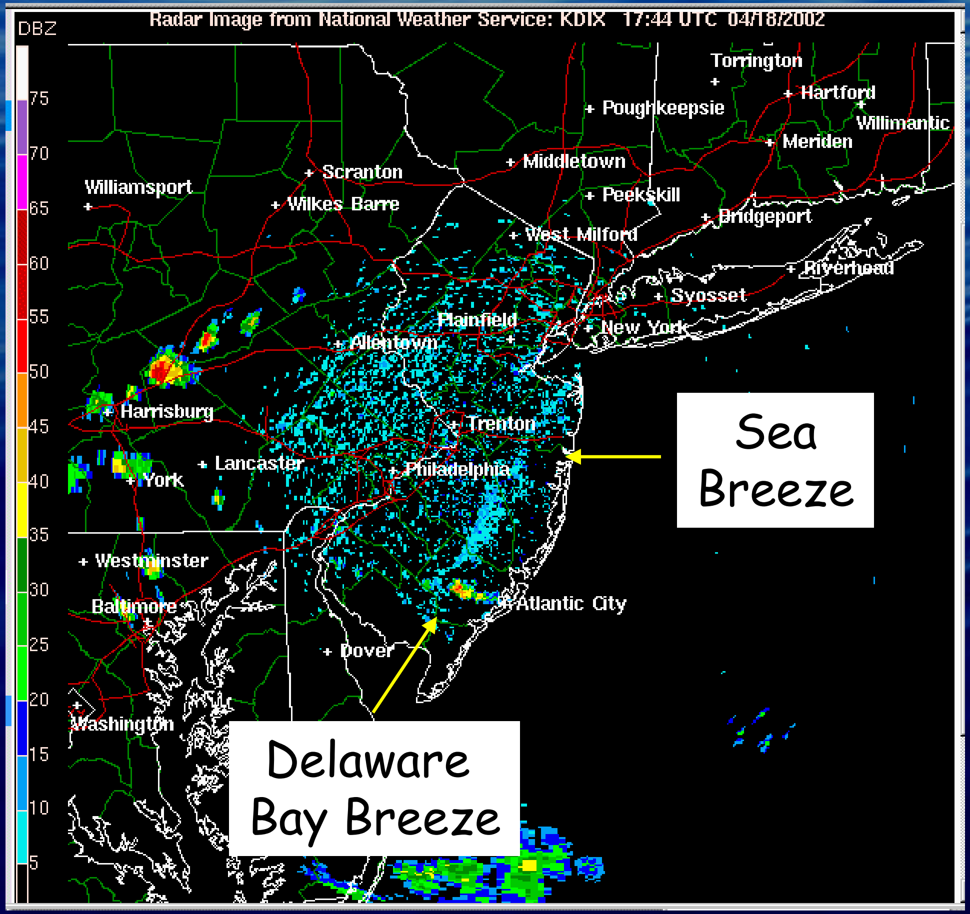
Radar Reflectivity from Doppler radar



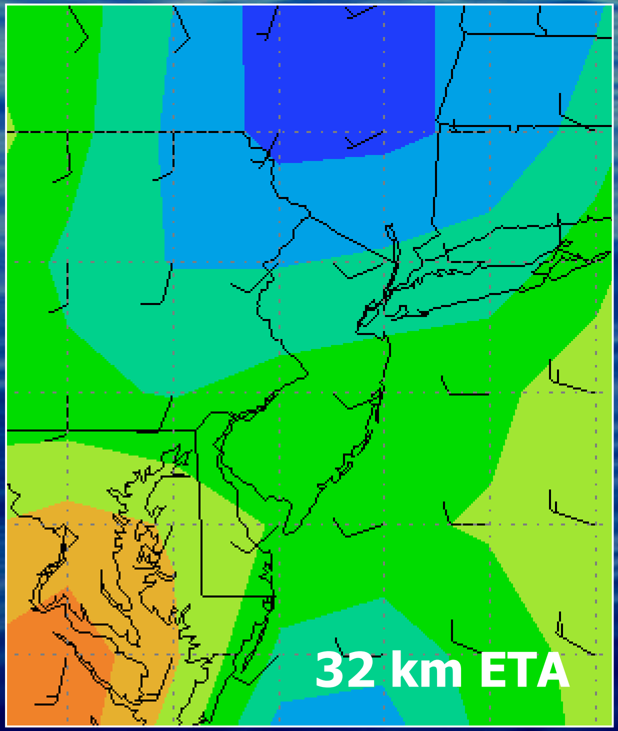
- Develops as a result of the land/sea temperature gradient
- Can occur during almost any month of the year
- Can affect almost all of New Jersey and into SE Pennsylvania

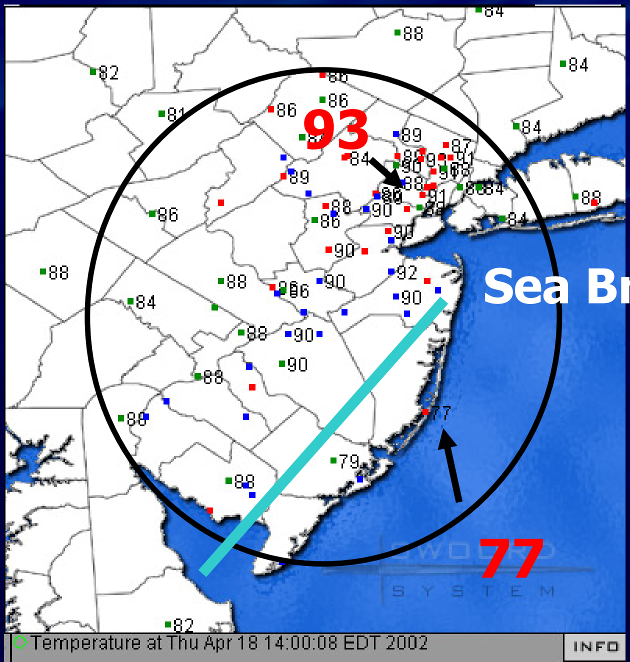
Why is the sea breeze important?

Radar Reflectivity loop from Doppler radar



- Develops as a result of the land/sea temperature gradient
- Can occur during any month of the year
- Can affect almost all of New Jersey and into SE Pennsylvania
- Focus for occasional thunderstorm development

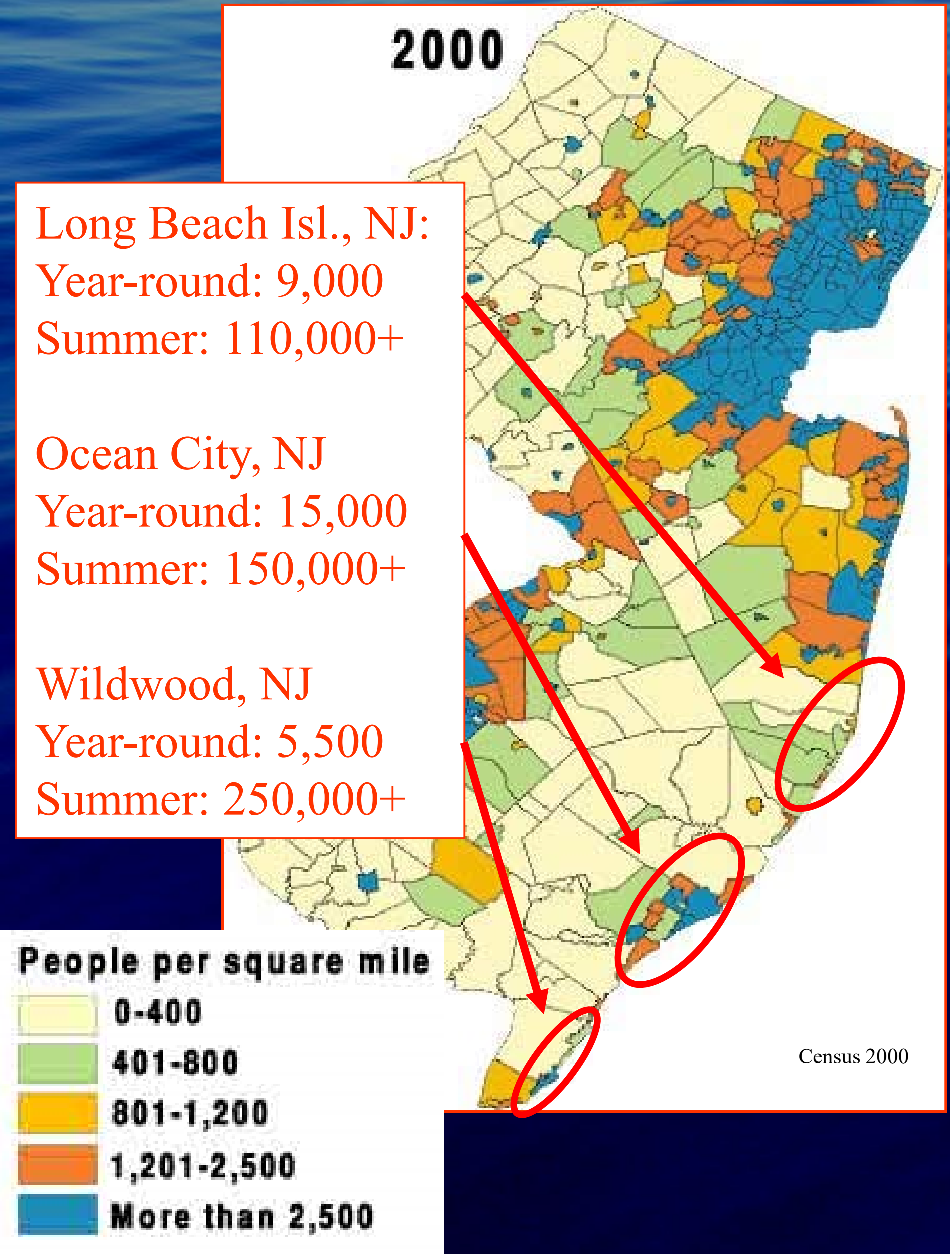




Why is the sea breeze important scientifically?

- Develops as a result of the land/sea temperature gradient
- Can occur during any month of the year
- Can affect almost all of New Jersey and into SE Pennsylvania
- Focus for occasional severe thunderstorm development
- Current models unable to fully resolve sea breeze

Why is the sea breeze important for the public?

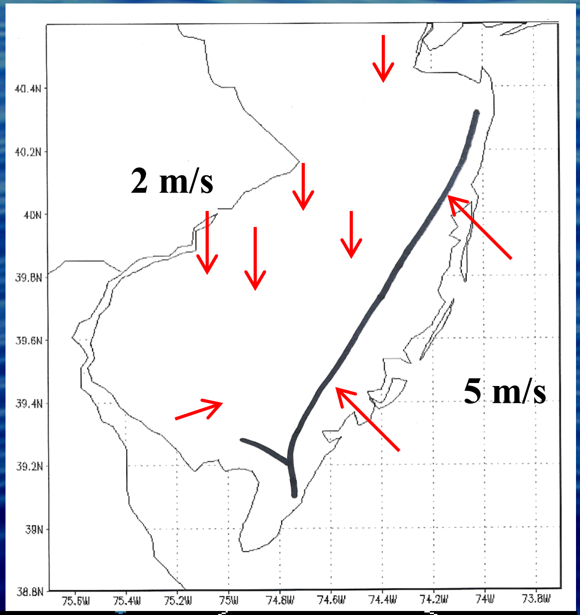


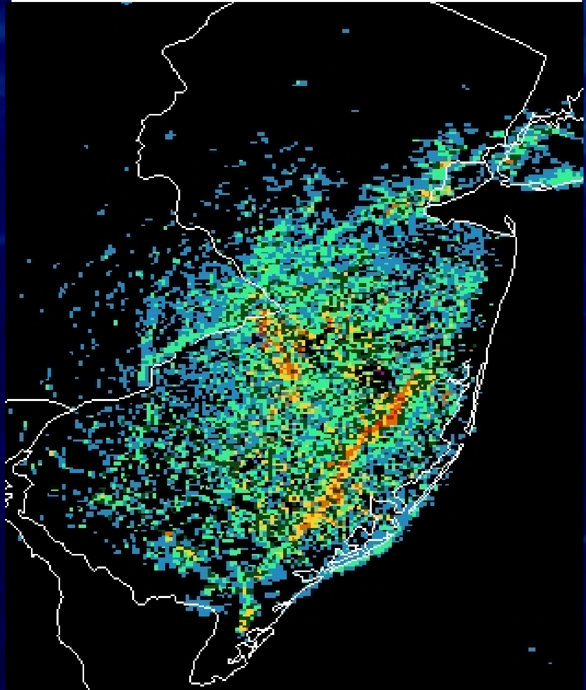
- Develops as a result of the land/sea temperature gradient
- Can occur during any month of the year
- Can affect almost all of New Jersey and into SE Pennsylvania
- Focus for occasional severe thunderstorm development
- Current models unable to resolve sea breeze
- Tourism and Energy

How is the sea breeze detected?

Sea breeze identification

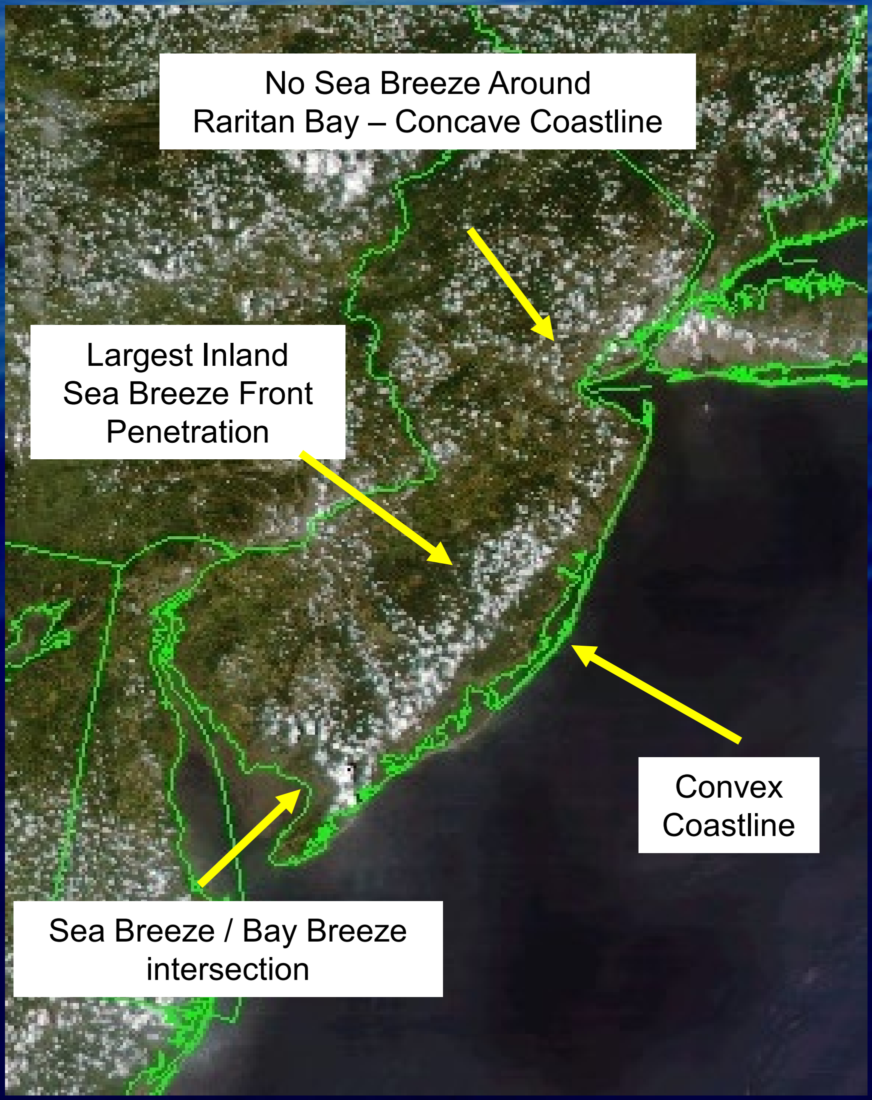
- Surface Observations
  - Wind speed increases with an onshore component
  - Relative Humidity increases
- Doppler Radar
  - Detected as a thin-line of higher reflectivity
- Visible Satellite imagery
  - AVHRR
  - MODIS





Characteristics of the sea breeze

MODIS Visible Satellite Image



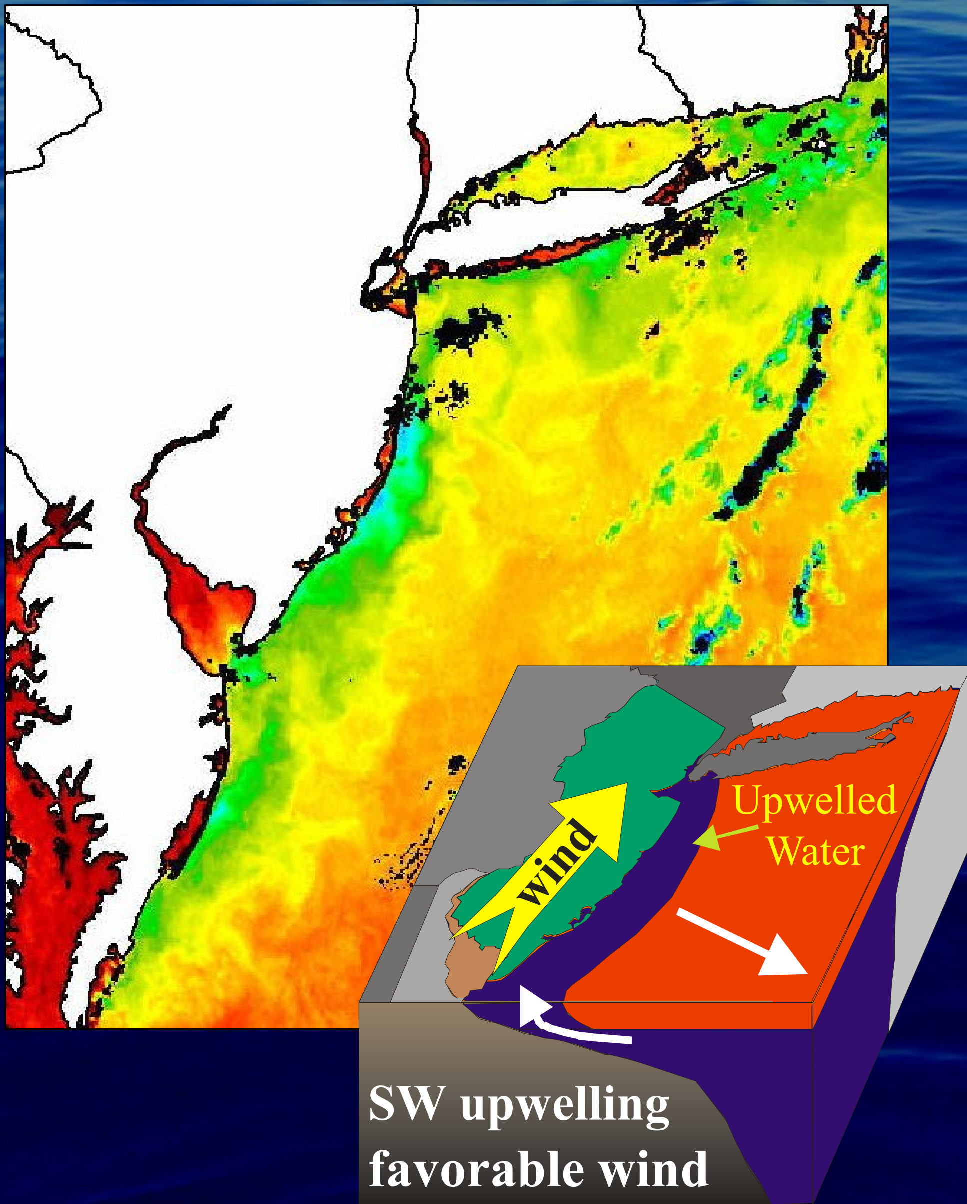
Factors necessary for sea breeze development and inland penetration

- Land-sea temperature gradient
- Synoptic Flow Aloft
  - Offshore 850 mb flow > 11 m/s will disrupt development and restrict inland penetration (Kwiatkowski, 1999)
- Coastline configuration
  - Convex coast is sea breeze favorable (McPherson, 1970)

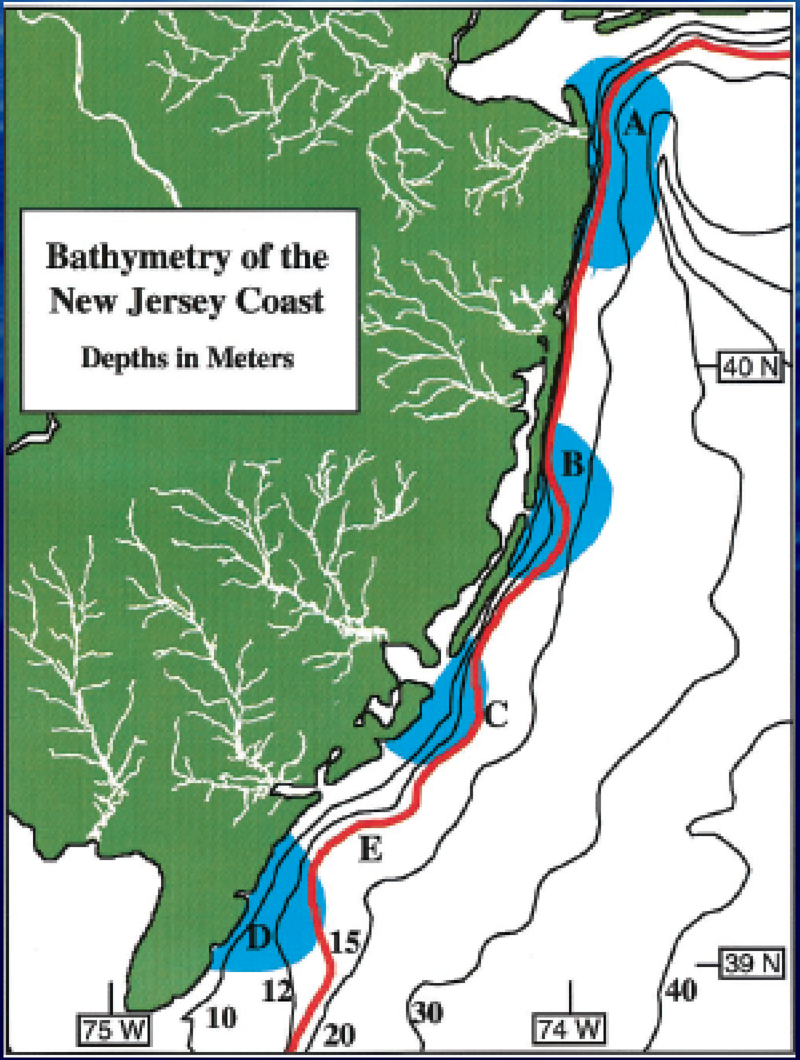
What is coastal upwelling?

- Driven by summertime winds
- Persistent slow southwesterly or southerly wind pushes surface water offshore
- Surface water is replaced by colder bottom water
- Large ocean temperature gradient over a thin band of water in the nearshore ocean
- Over 10 C SST decreases have been noted

AVHRR SST



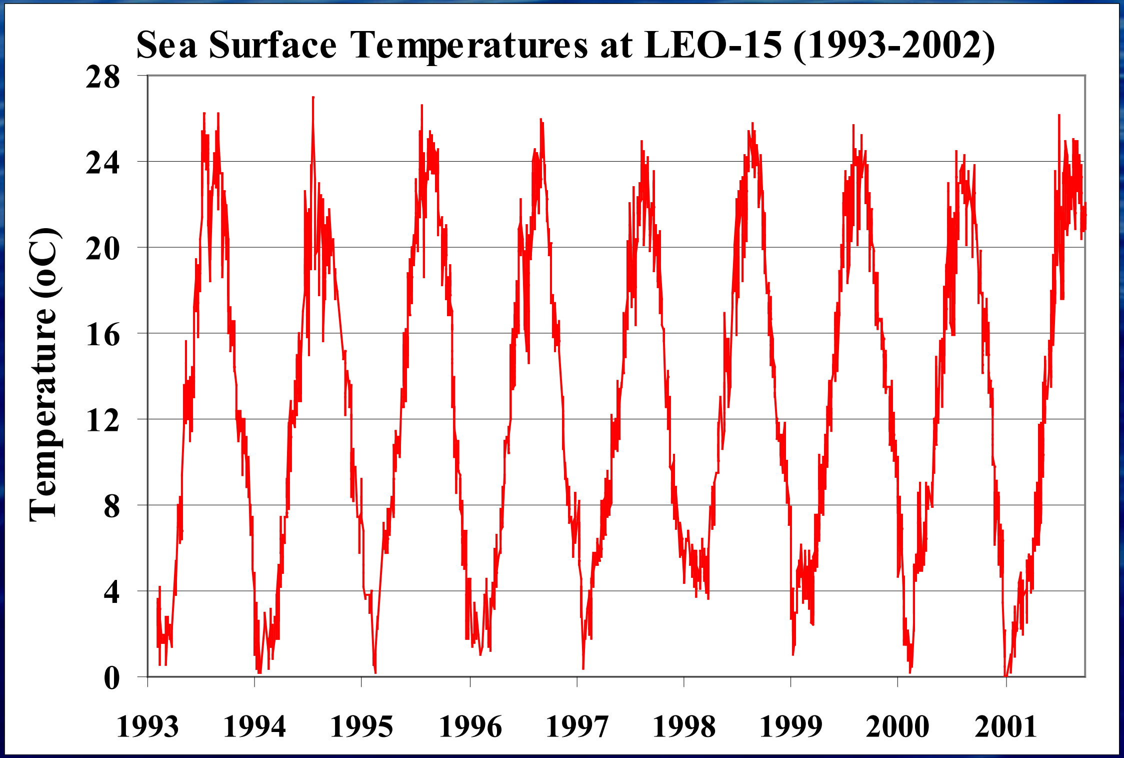
What is coastal upwelling?



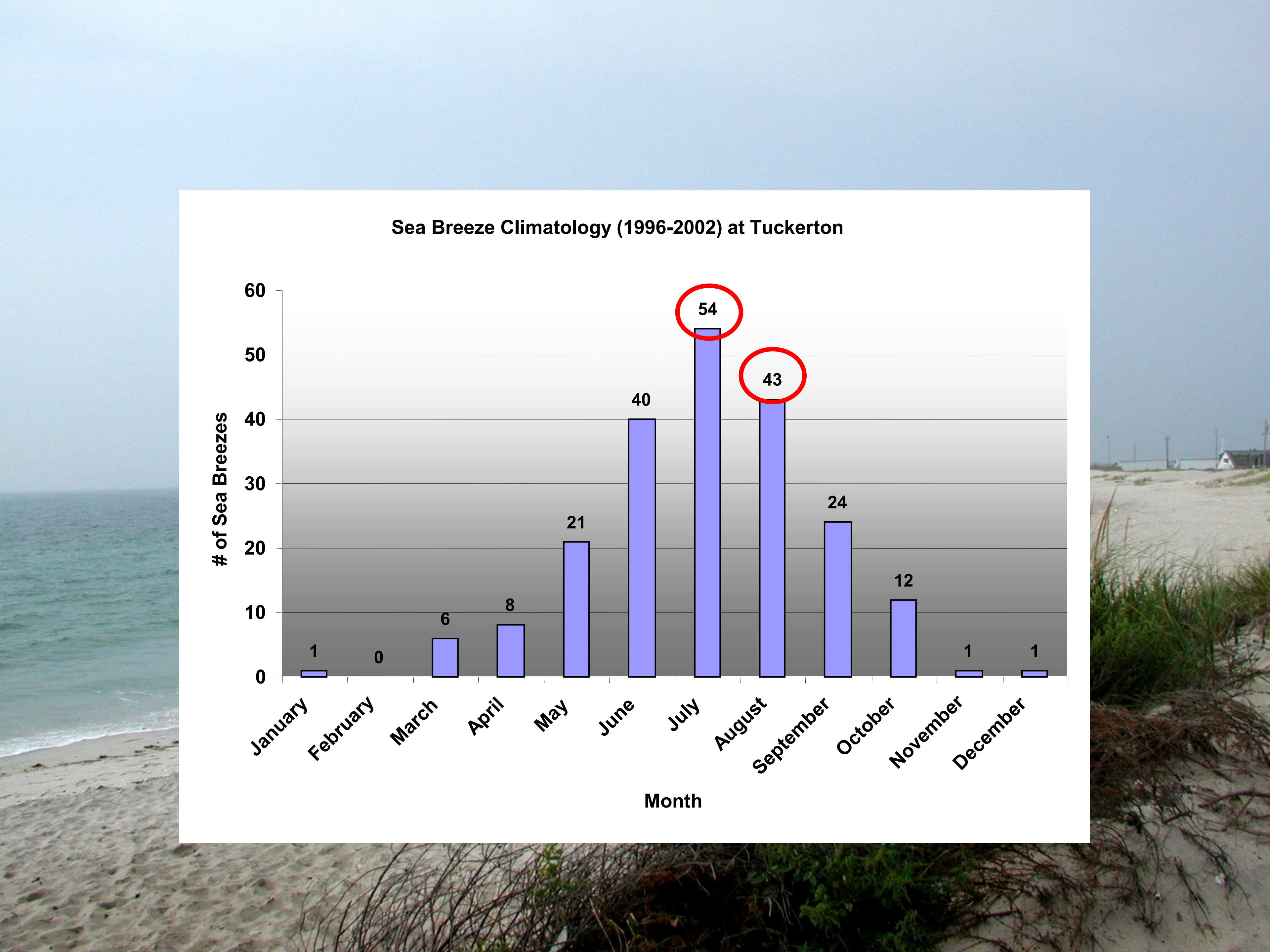
- Upwelling frequently occurs at four distinct upwelling centers along the NJ coast
- Upwelling centers occur near topographic highs in the bathymetry (Glenn et. al., 1996; Song et. al., 2001)
- Coastal ocean research, including the coastal upwelling phenomenon have taken place at LEO-15 offshore Tuckerton, NJ

Annual Variation of SST

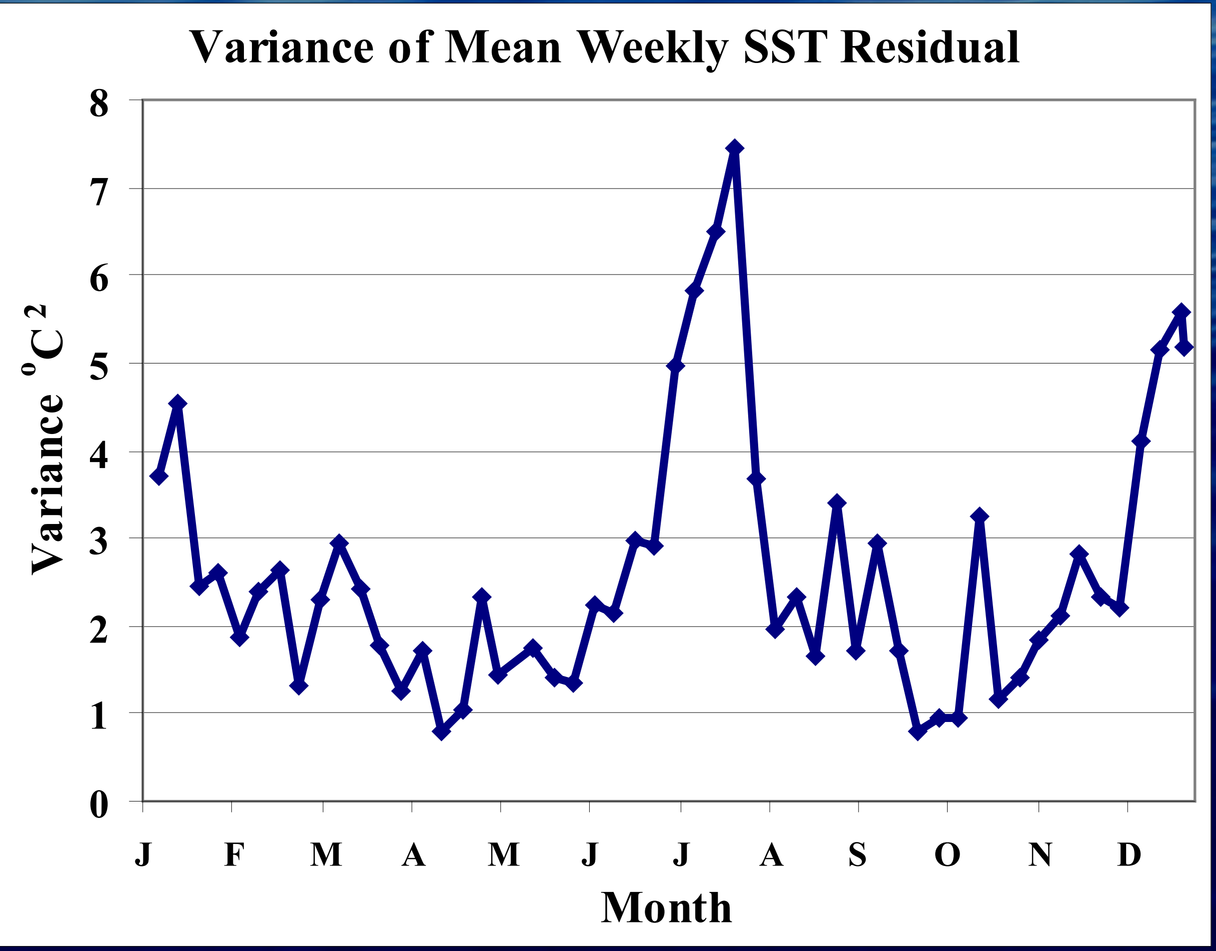
- Variation of SSTs at LEO-15 occur primarily due to seasonality
- SST can and does vary annually due to atmospheric conditions; harsh winters (1994, 2001), El Nino (1998) and heavy rainfall (2000)
- Maximum SST detected at LEO-15 is between 27 and 28 C



Courtesy of Mike Crowley


Sea Breeze Climatology (1996-2002) at Tuckerton
# of Sea Breezes
60
50
40
30
20
10
0
1
0
6
8
21
40
54
43
24
12
1
1
January
February
March
April
May
June
July
August
September
October
November
December
Month

What is coastal upwelling?



Courtesy of Mike Crowley

- Secondary variation in summer SST at LEO-15 is upwelling (Glenn et al., 2004)
- The most variation in summer SST due to upwelling occurs during July and August (Inghram and Eberwine, 1984; Glenn et al., 2004)
- Upwelling and the sea breeze match up climatologically, but is there a relationship?

Hypothesis

1. The New Jersey sea breeze can be "turned on and off" depending on the state of the nearshore coastal ocean.

2. The structure within the sea breeze circulation can vary between upwelling and non-upwelling regimes.

3. The shape of the sea breeze front can be influenced by the presence of upwelling.

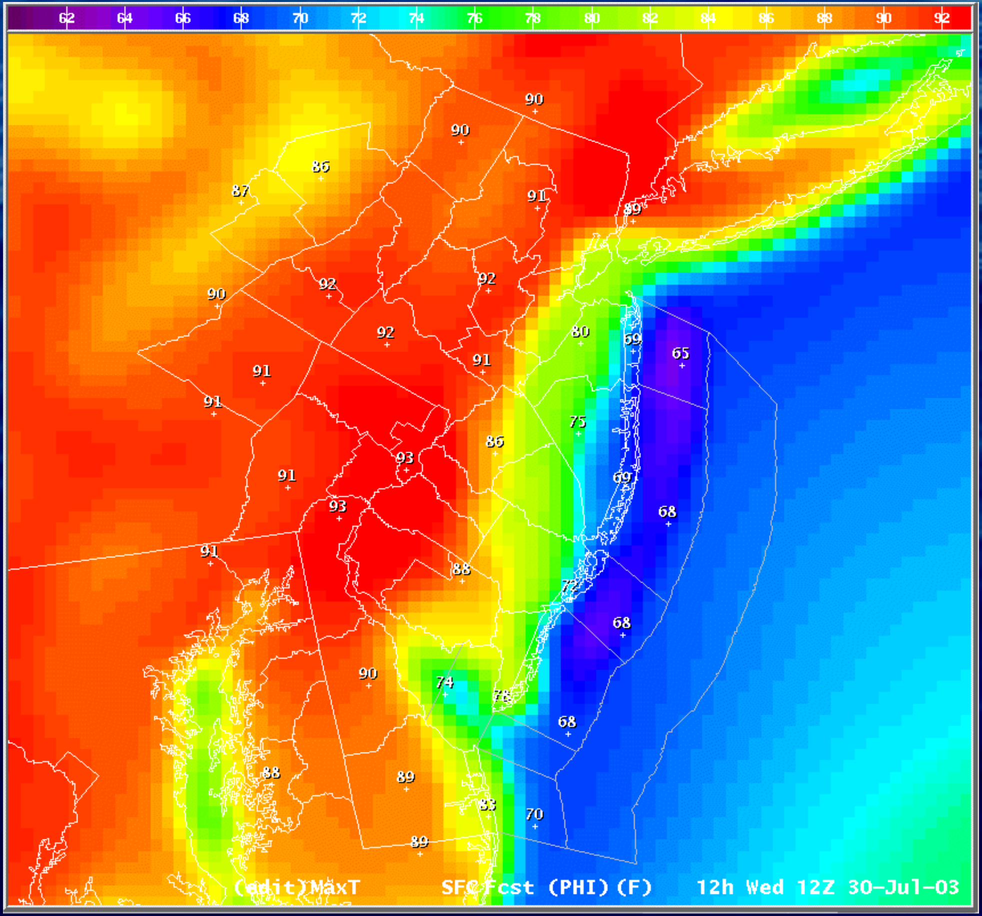
Why is the sea breeze important?

- Meteorological forecasting
  - Air temperature
  - Wind speed and direction
  - Thunderstorms
  - Marine
  - Aviation

- Public Utilities
  - Load forecast

- Public Health
  - Pollution
  - Pollen

- Homeland Security
  - Circulation of released chemical or biological agents



Thesis Outline

- Introduction
- Weather Research Forecast (WRF) model
- Characteristics of the New Jersey sea breeze – coastal upwelling relationship
- Sensitivity Study
- Case Studies
  - June 6, 2004
  - June 5, 2004
- Conclusions and Future Work

Weather Research Forecast Model

- Developed by NCAR/MMM and NOAA/FSL
- Released as community research model (2000)
- Developed for research and operational purposes
- Operational-test phase NWS model late 2004
- Intended full operational use by 2007

- Arakawa C-grid
- 3rd order Runge-Kutta Technique
- Mass-based terrain following coordinate

- Output as netcdf
- Model graphics displayed using the Grid Analysis and Display System (GrADS)

Weather Research Forecast Model

- WRF (2 km resolution)
  - ETA Boundary Conditions (22 km resolution)
    - Observational Data
    - RTG_SST (0.5 degree resolution)
      - GOES SST
      - Climatology
  - NASA PO.DAAC SST (4 km resolution)
    - AVHRR SST (1.1 km resolution)

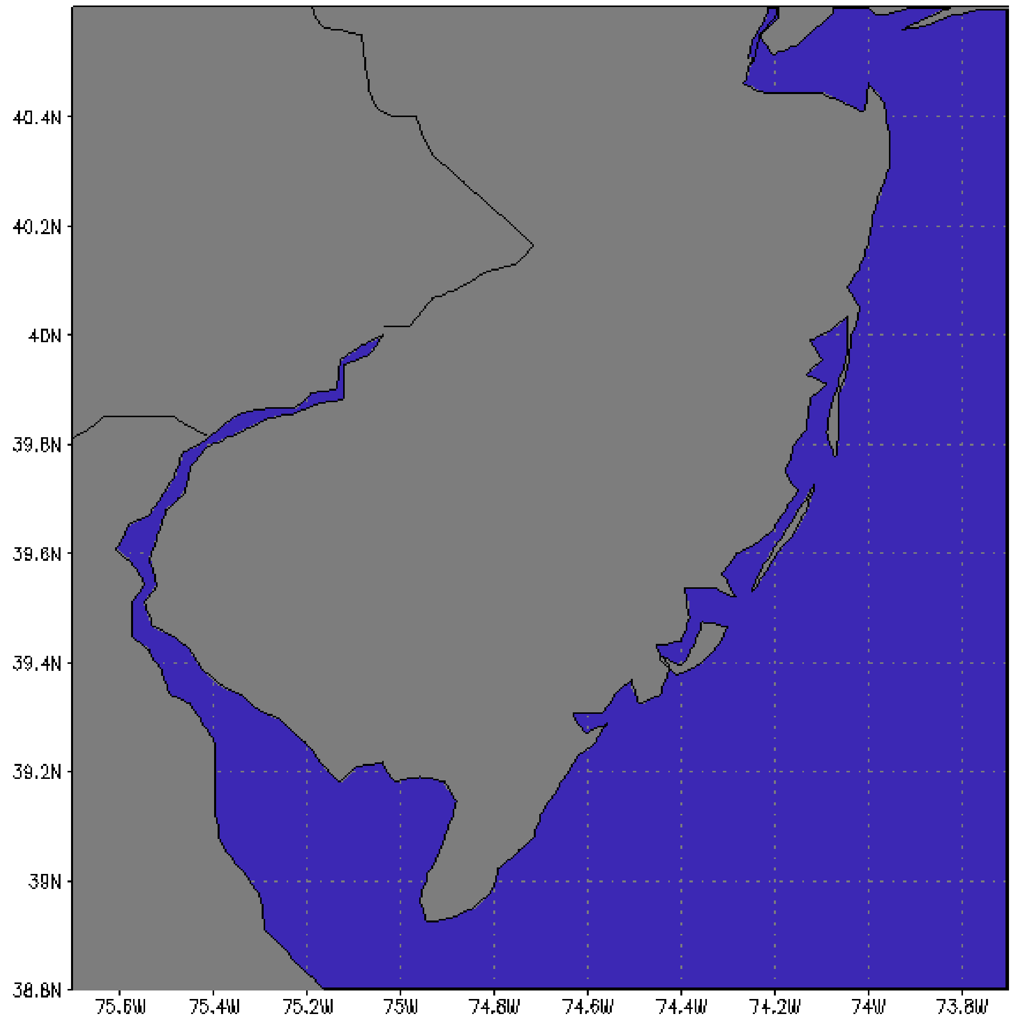
Weather Research Forecast Model

- 2 km spatial resolution
- 12 s time step
- 24 hour simulation

- ETA Model BCs
- AVHRR (4 km) derived SST

- Built on linux platform
- Run locally at IMCS
- Tested operationally with positive results during LaTTE

Model Domain



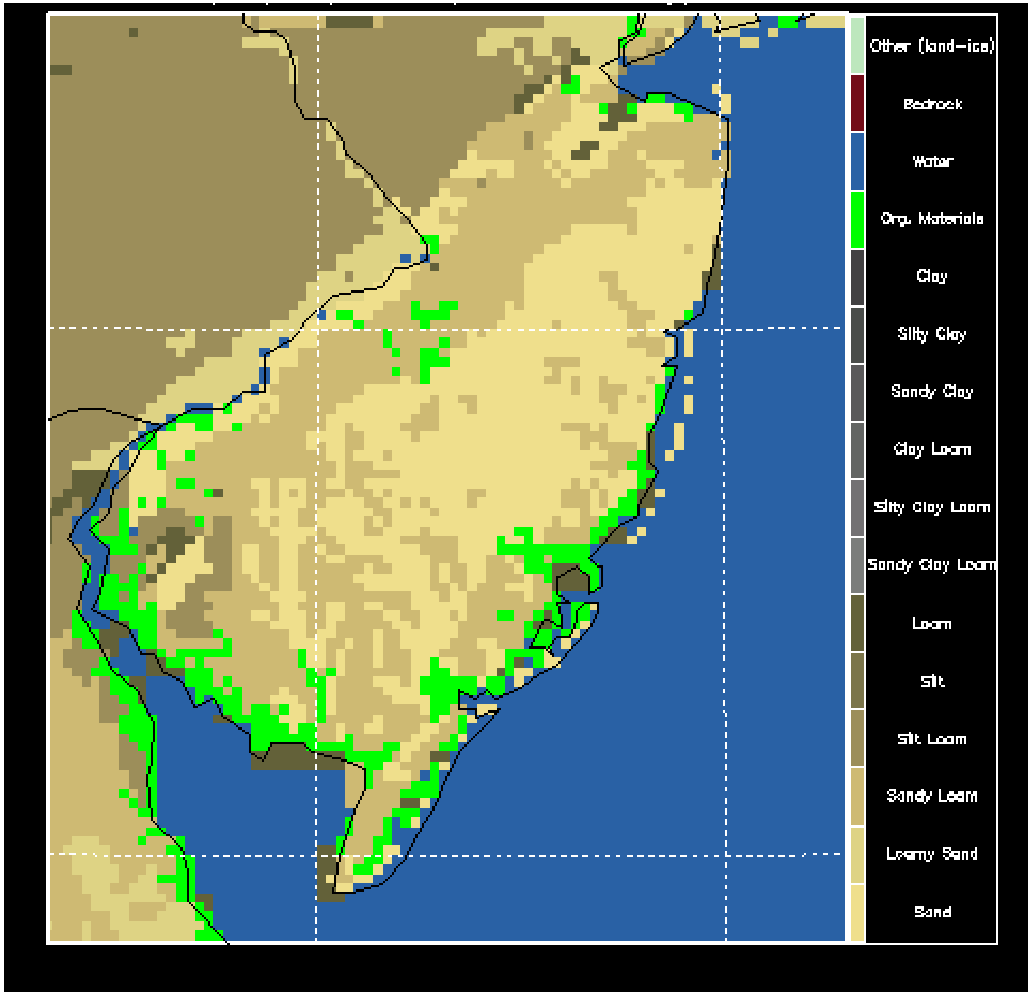
Weather Research Forecast Model

- 2 km spatial resolution
- 12 s time step
- 24 hour simulation

- ETA Model BCs
- AVHRR (4 km) derived SST

- Built on linux platform
- Run locally at IMCS
- Tested operationally with positive results during LaTTE

Coastline and Soil Use



Weather Research Forecast Model

- 2 km spatial resolution
- 12 s time step
- 24 hour simulation

- ETA Model BCs
- AVHRR (4 km) derived SST

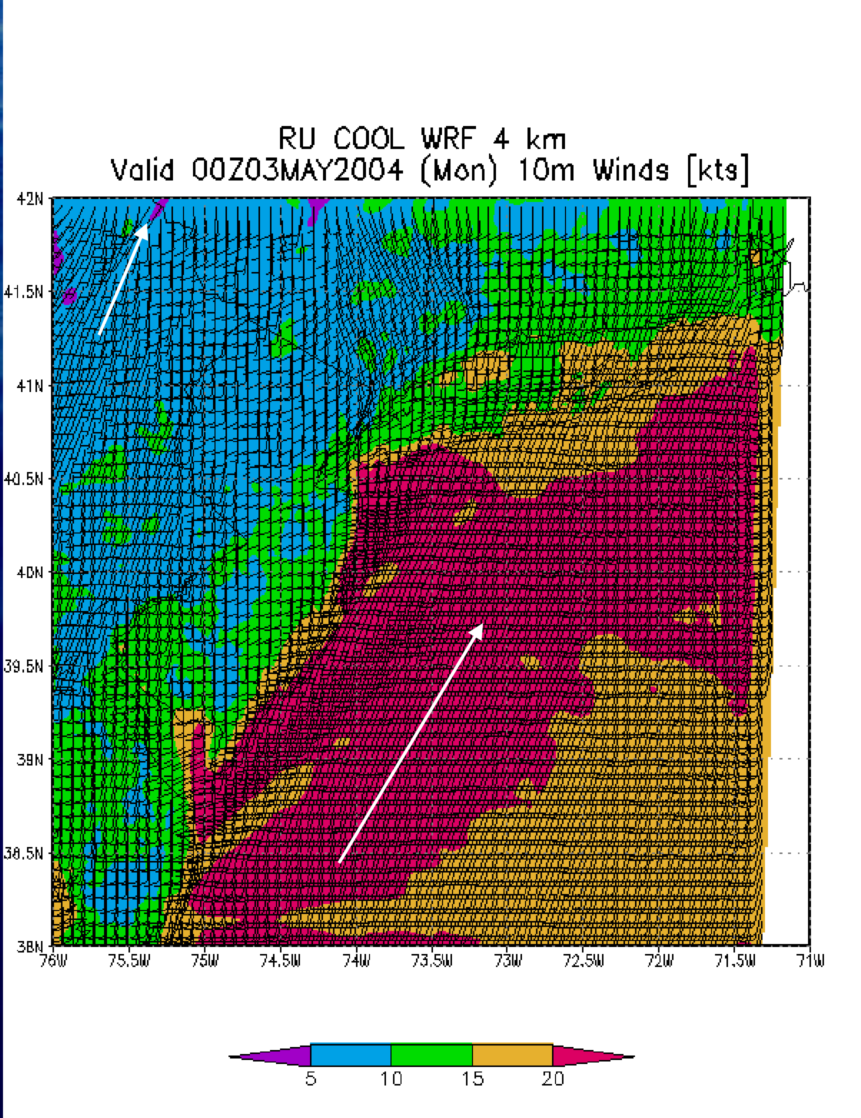
Introduction to the WRF Modeling System

- Built on linux platform
- Run locally at IMCS
- Tested operationally with positive results during LaTTE

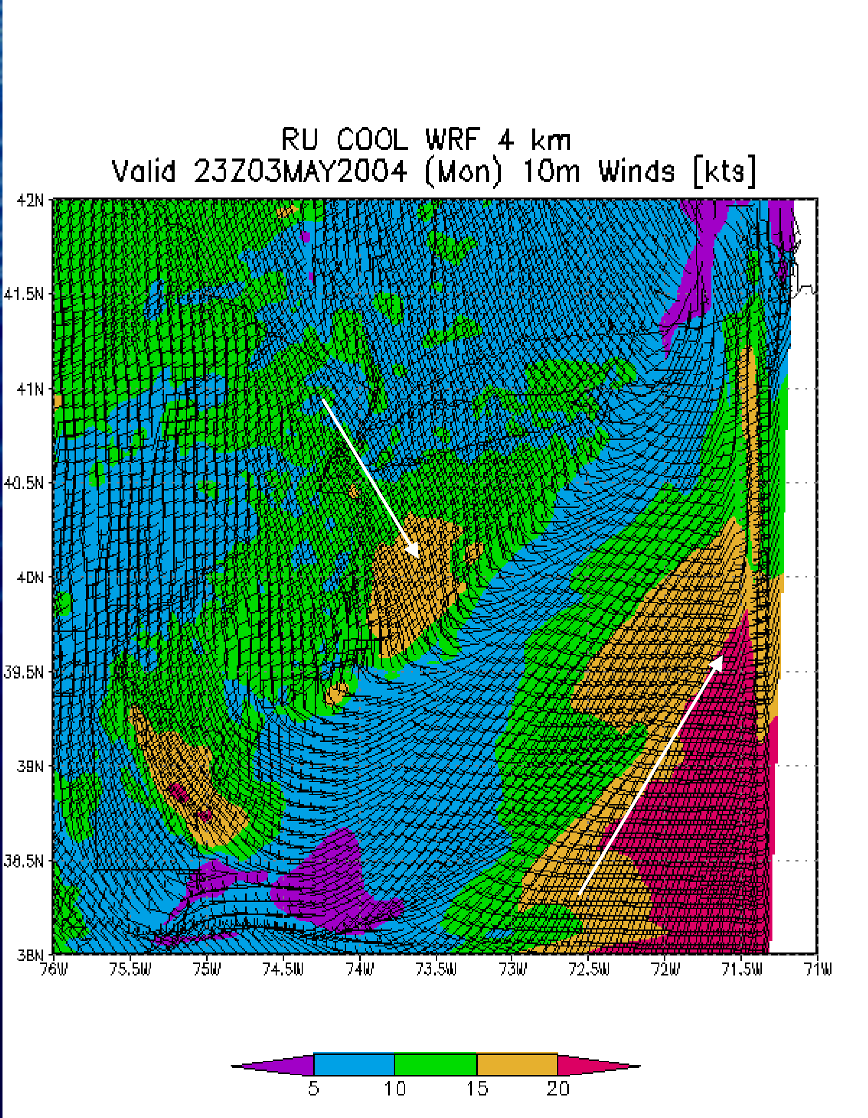
Wei Wang
NCAR/MMM

LaTTE Cold Frontal Passage: May 3rd, 2004 – 4 km resolution

Upwelling



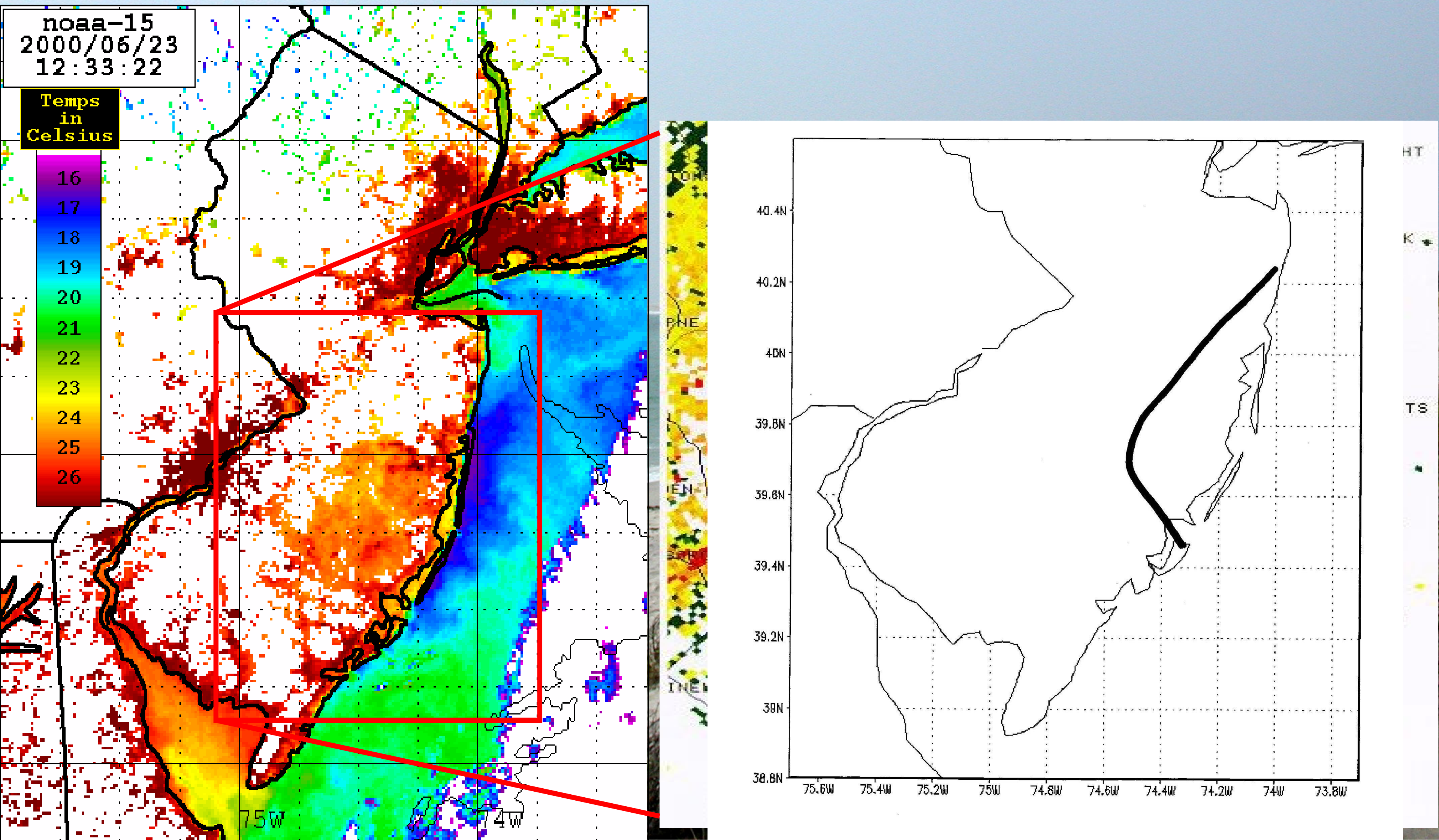
Downwelling



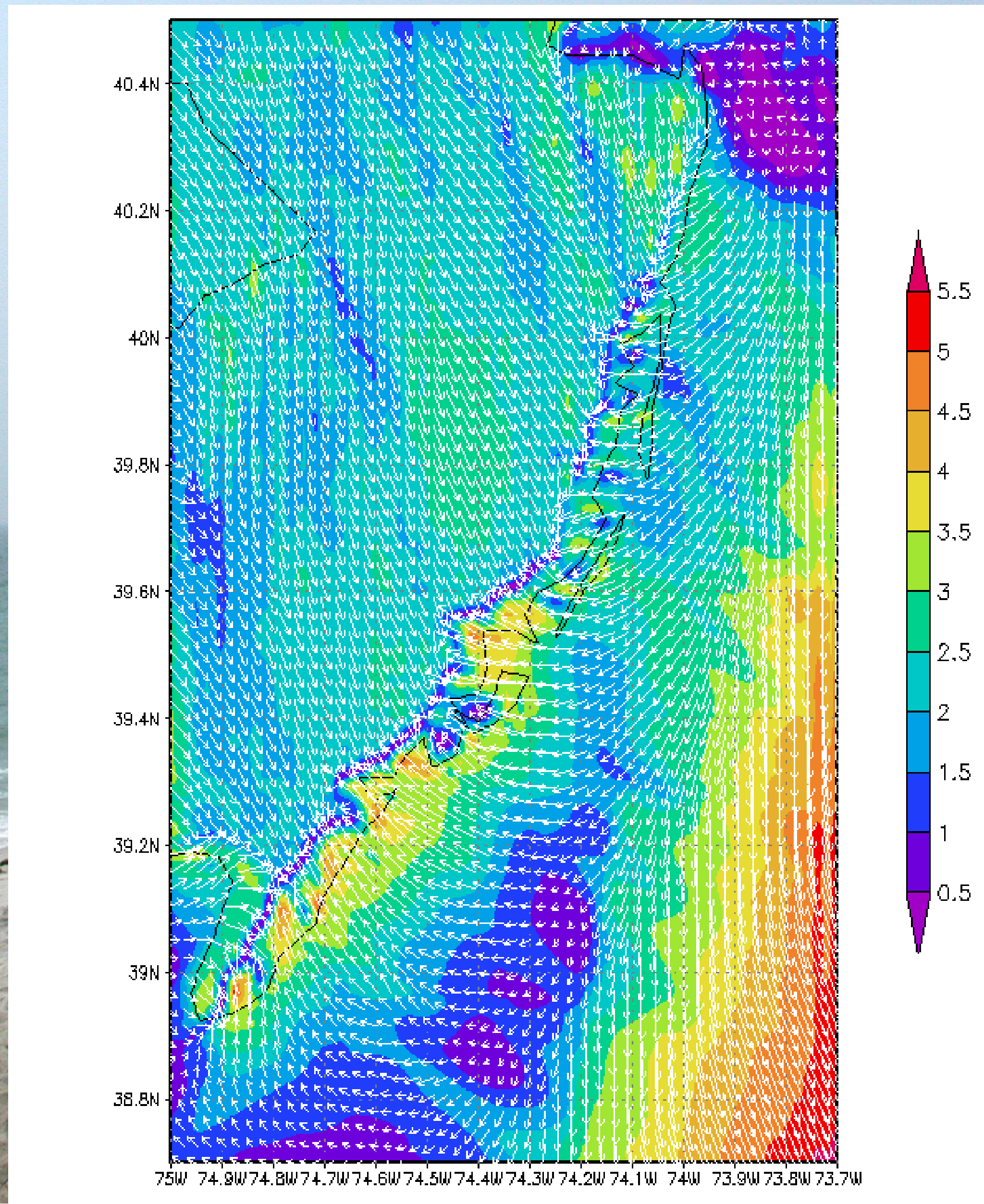
Thesis Outline

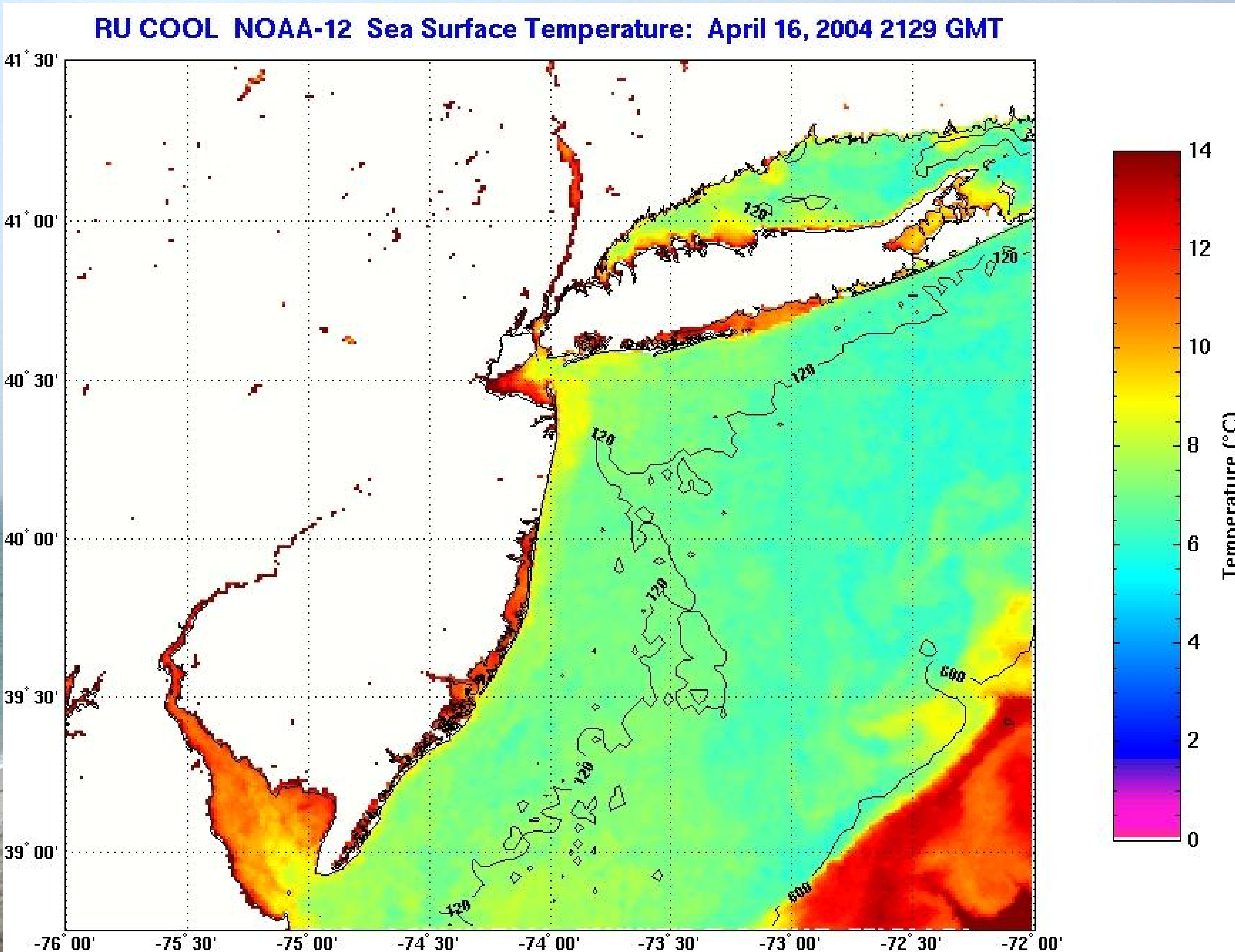
- Introduction
- Weather Research Forecast (WRF) model
- Characteristics of the New Jersey sea breeze – coastal upwelling relationship
- Sensitivity Study
- Case Studies
  - June 6, 2004
  - June 5, 2004
- Conclusions and Future Work

Variations in the Shape of the Sea Breeze Front
June 23, 2000: SST and Radar Reflectivity



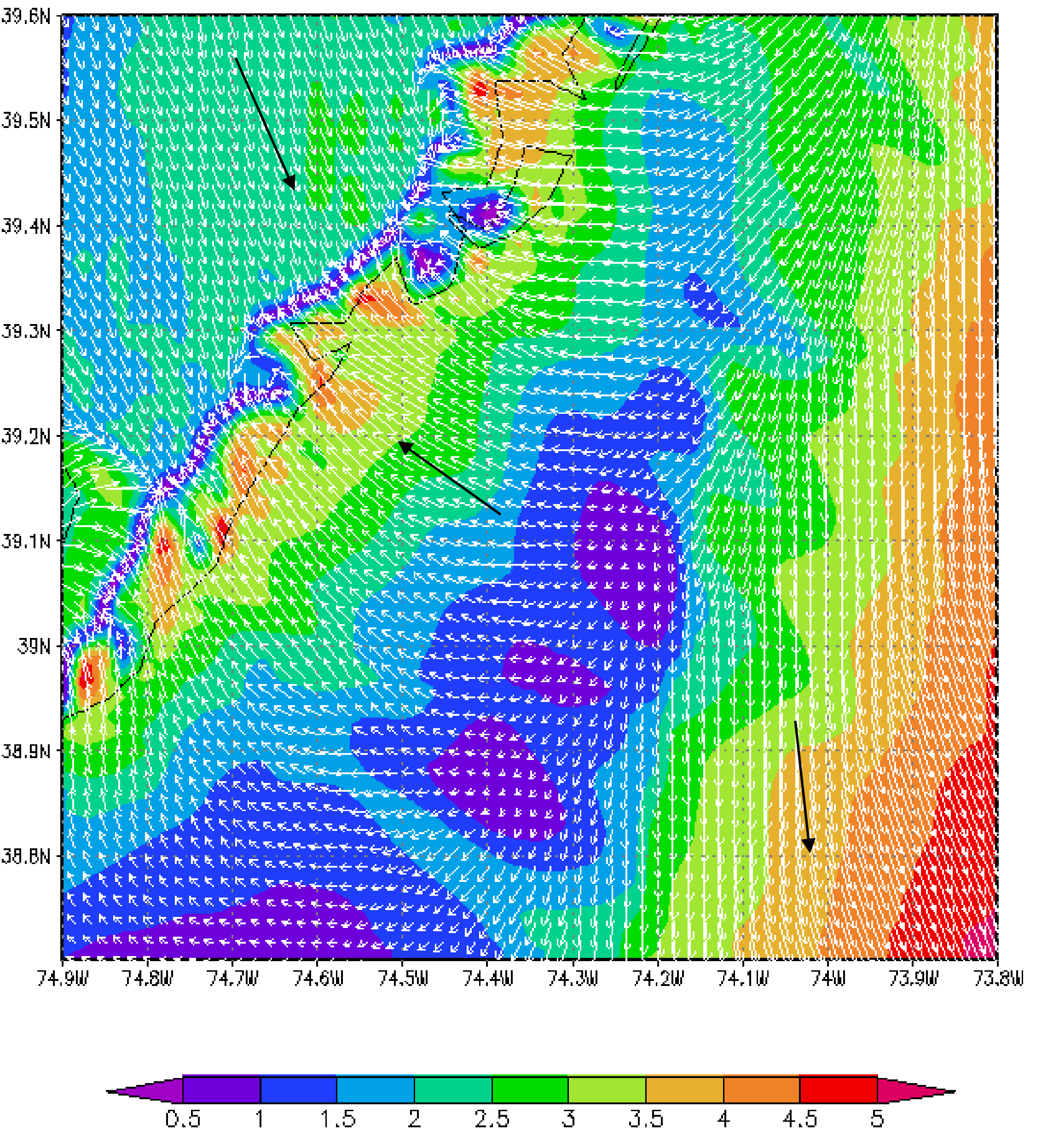
Variations in the Shape of the Sea Breeze Front
April 16, 2004 WRF Case Study: Wind Speed (m/s, shaded) and Wind Vector (arrows)




RU COOL NOAA-12 Sea Surface Temperature: April 16, 2004 2129 GMT
41° 30'
41° 00'
40° 30'
40° 00'
39° 30'
39° 00'
-76° 00'
-75° 30'
-75° 00'
-74° 30'
-74° 00'
-73° 30'
-73° 00'
-72° 30'
-72° 00'
120
600
Temperature (°C)
14
12
10
8
6
4
2
0

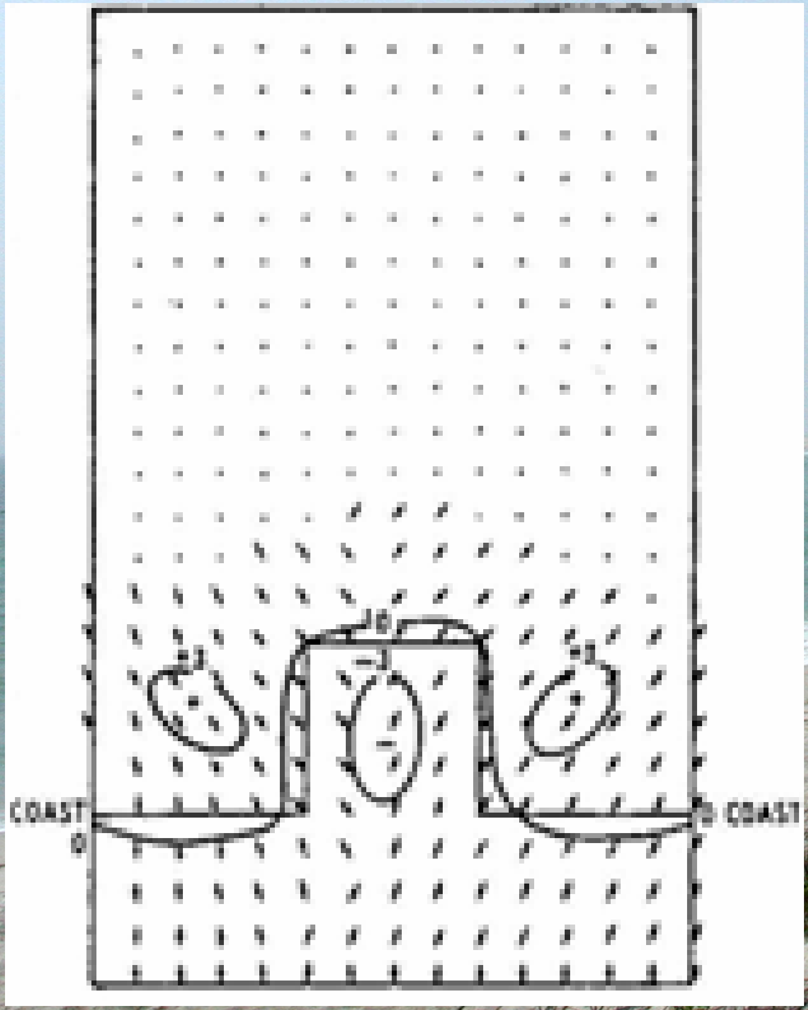
Variations in the Shape of the Sea Breeze Front

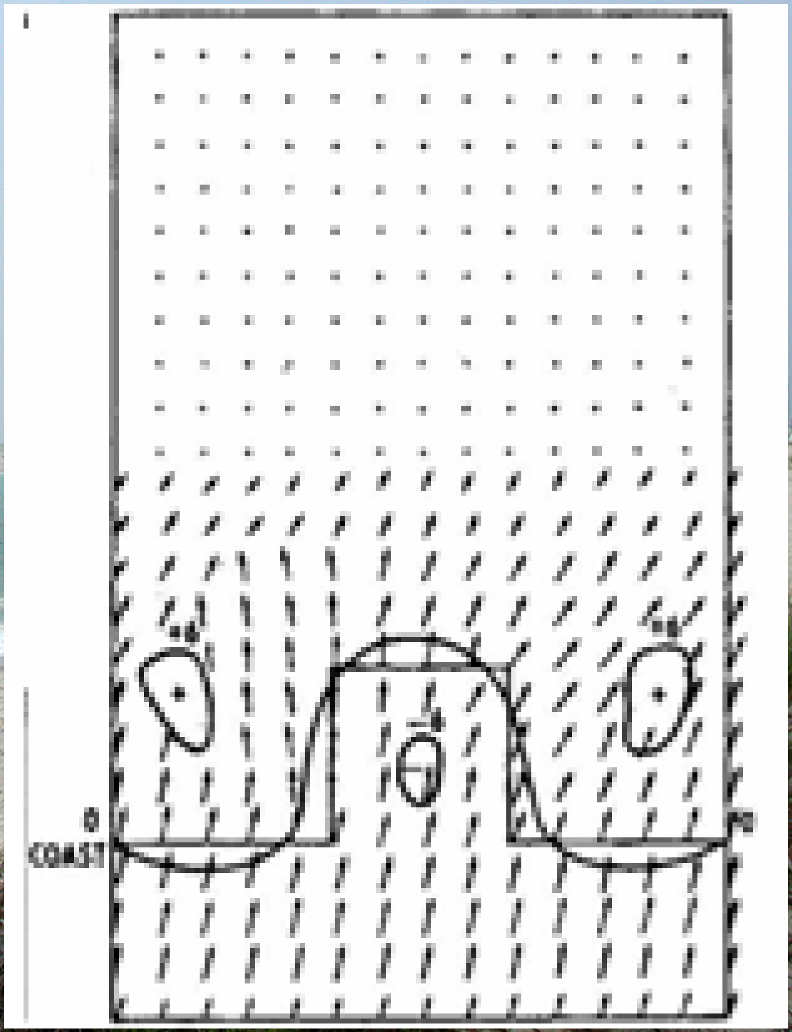
April 16, 2004 WRF Case Study: Wind Speed (m/s, shaded) and Wind Vector (arrows)



- Small-scale variation in the sea breeze front occurs near bays and estuaries
- Strongest wind speeds occur along the sides of the bay due to wind divergence in the center
- We will come back to the area of calm winds offshore in a few moments

Variations in the Shape of the Sea Breeze Front
Idealized Model (McPherson, 1970):
Vertical Velocity (cm/s, contours) and Wind Vector (arrows)



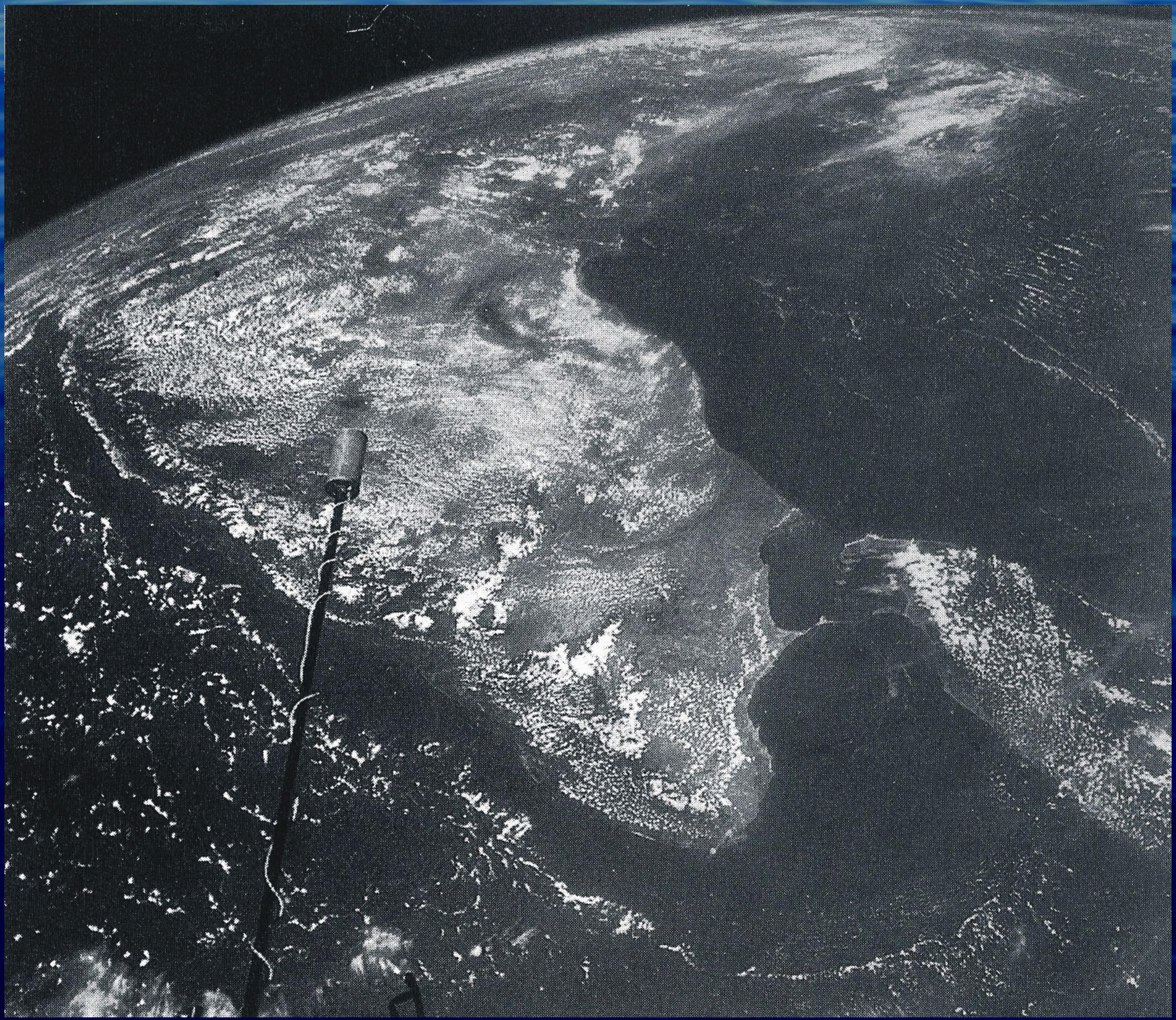


(McPherson, 1970)

Offshore Extention of the Sea Breeze

- Picture of India taken by Gemini XI in 1966
- Cloudless area offshore has stable, sinking air due to the sea breeze circulation
- Offshore extent of the sea breeze is 2-3 times the inland penetration of the sea breeze front

(Simpson, 1994; and many others)

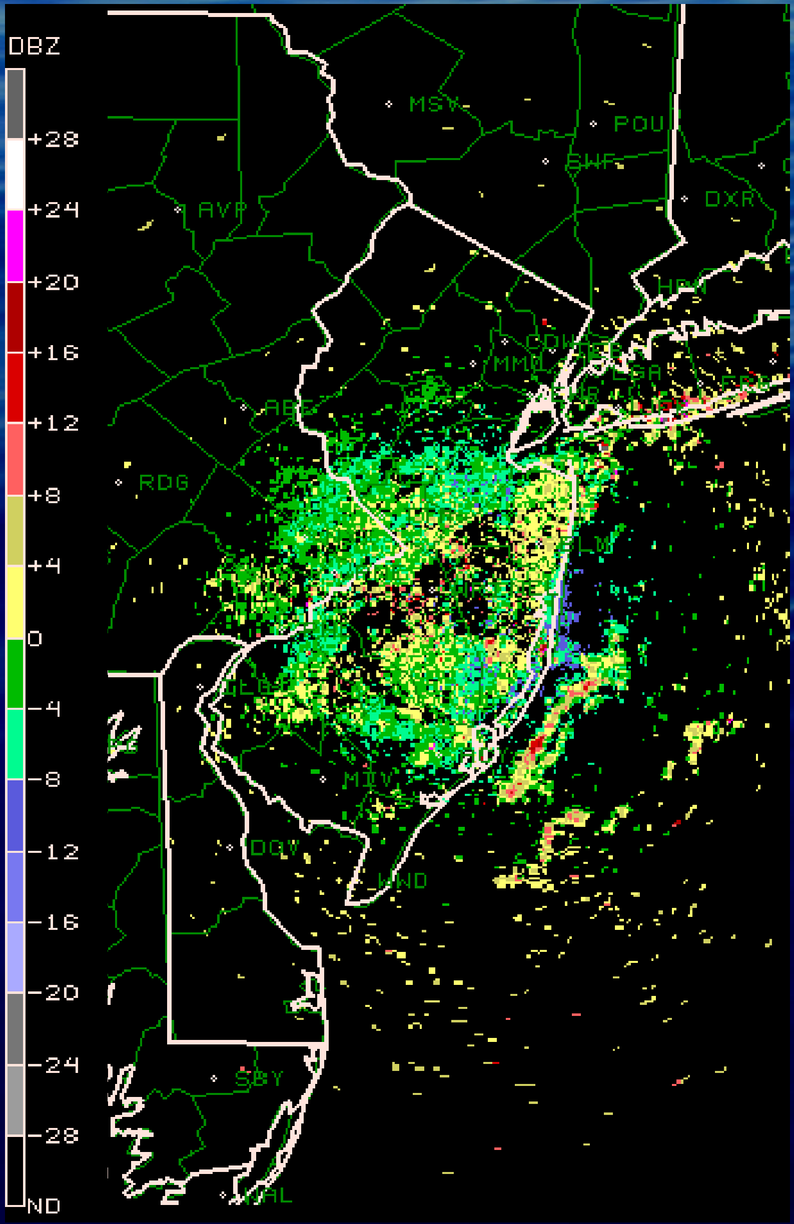


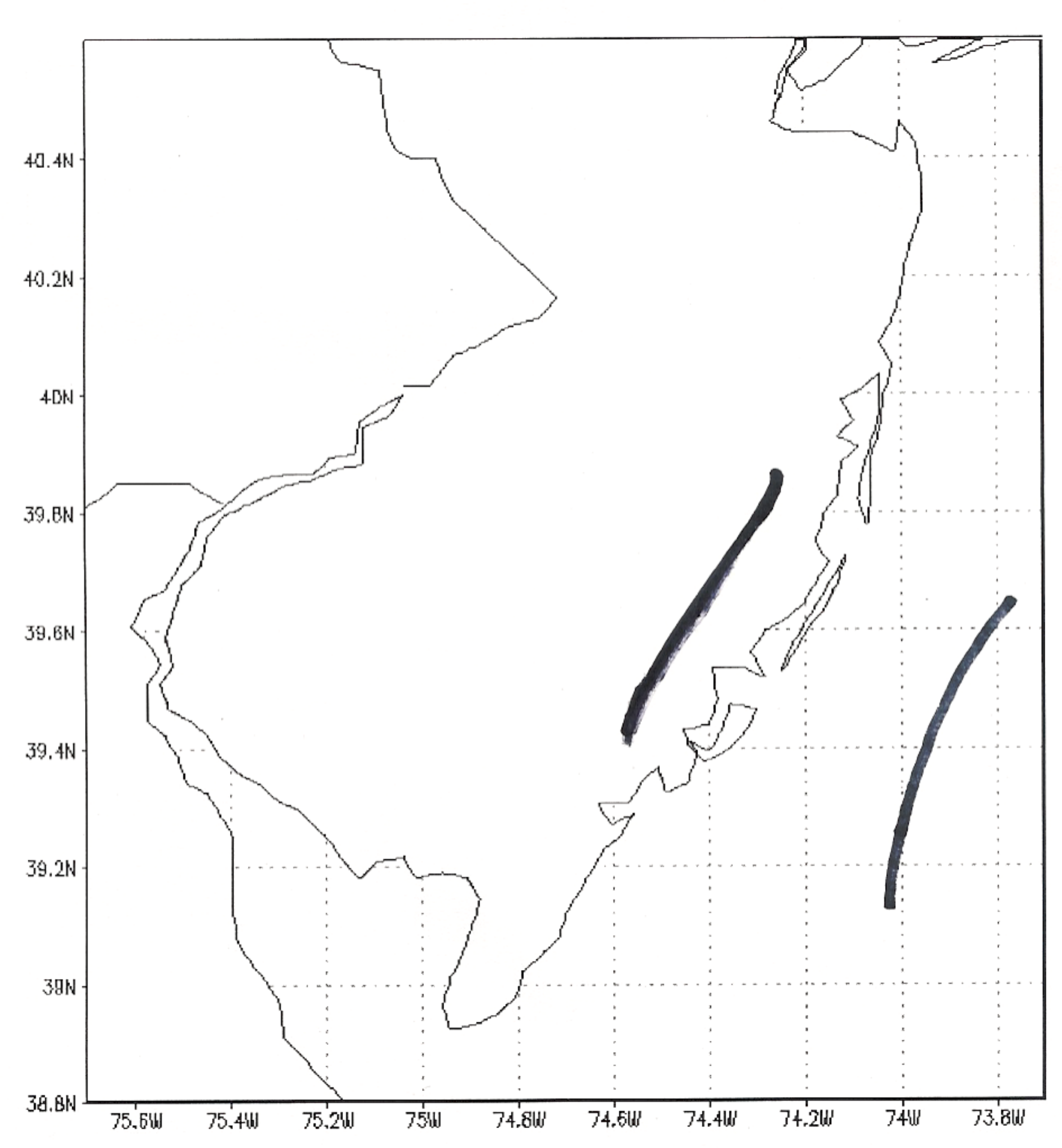
Offshore Extention of the Sea Breeze

- Picture of Florida taken by Gemini XII in 1966
- Sea breezes are occurring along both the east and west Florida coast
- Lack of sunglint off of the calm ocean surface is seen in a dark strip off the west coast as the smooth ocean surface scatters less reflected light
- The smooth surface is indicative of calm winds and divergent winds with little wave activity at the offshore edge of the sea breeze

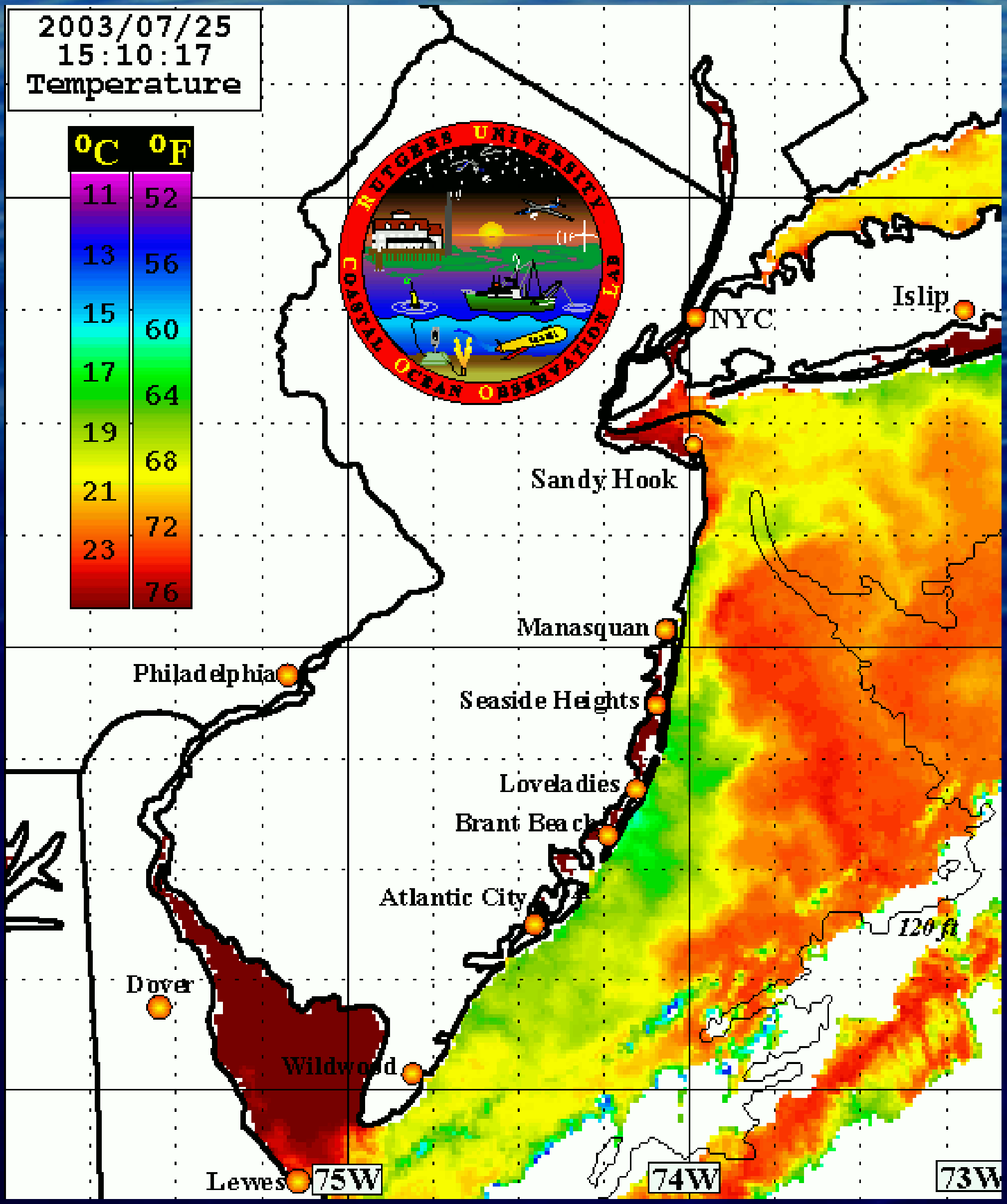
(Fett and Tag, 1984)

Offshore Extention of the Sea Breeze
Offshore Sea Breeze Front July 26, 2003



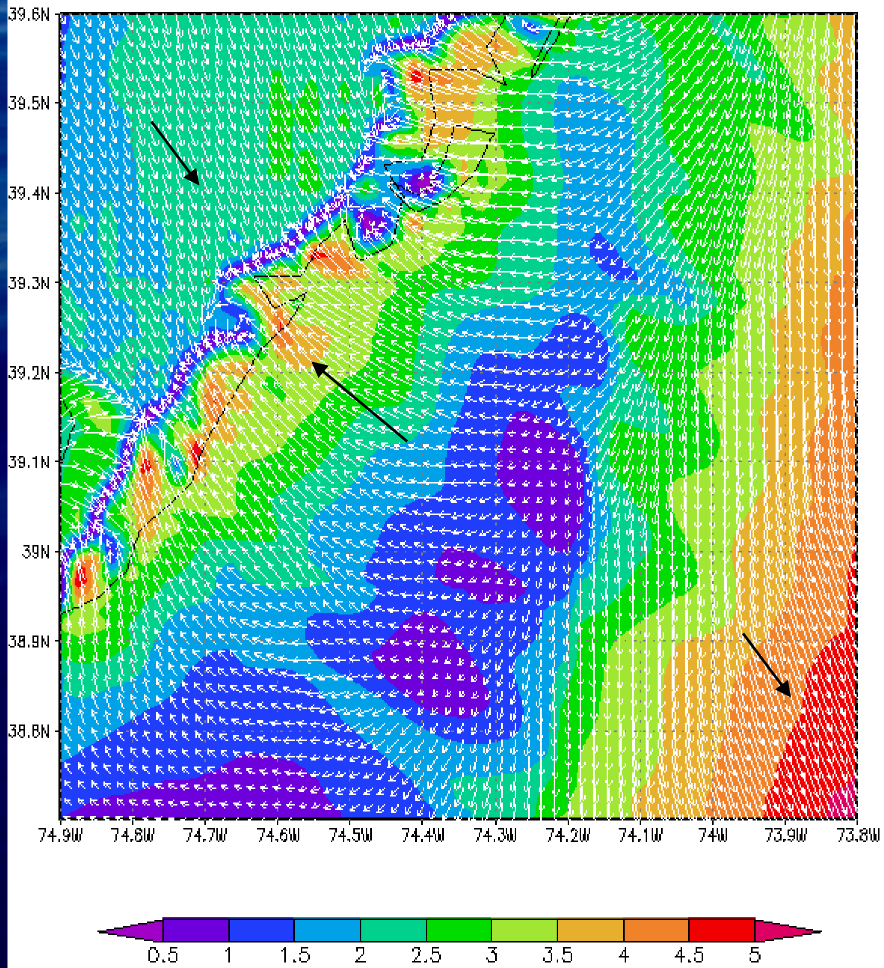


Offshore Extention of the Sea Breeze
Offshore Sea Breeze Front July 26, 2003

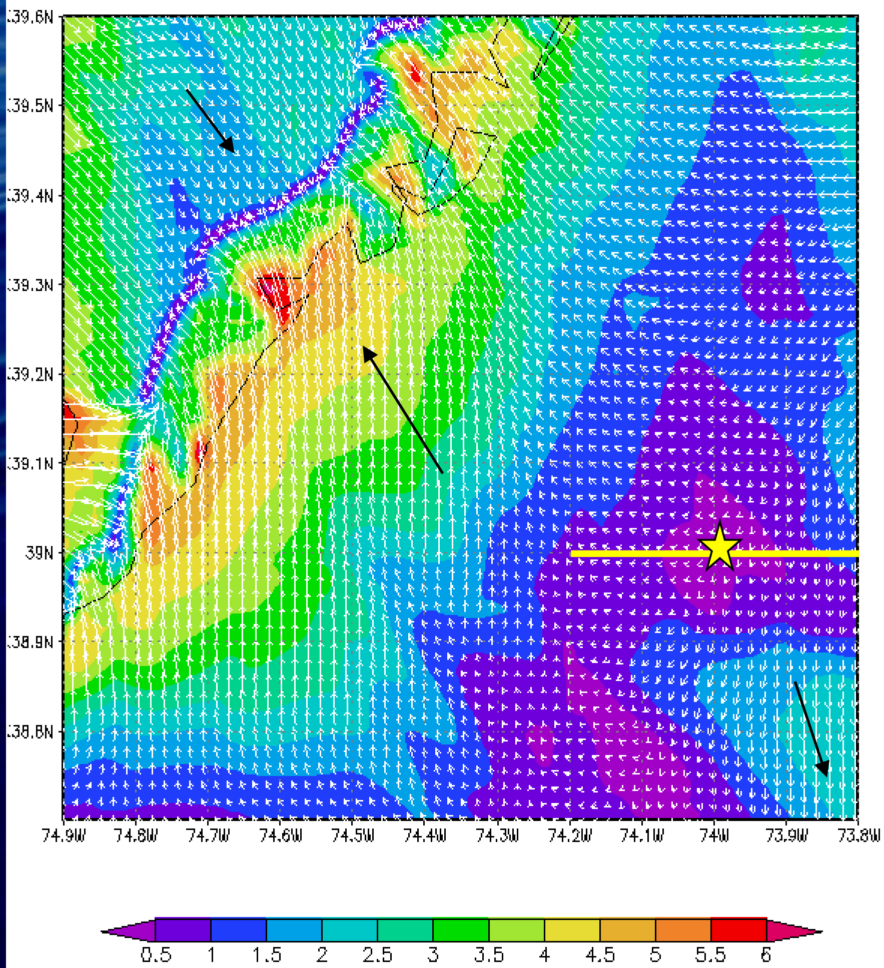


Offshore Extention of the Sea Breeze
Offshore Divergence Zone WRF Case: April 16, 2004 Winds (m/s, shaded)

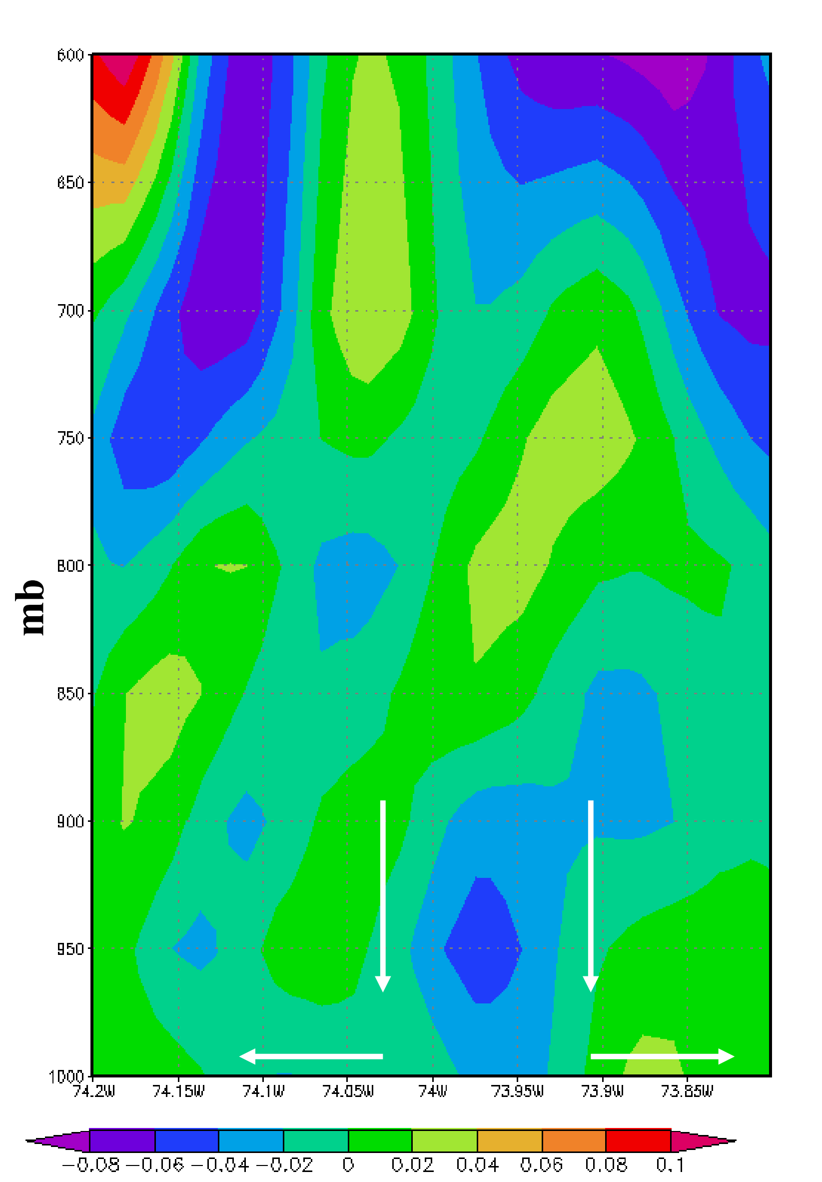
April 16, 2004 1800 GMT



April 16, 2004 2000 GMT



April 16, 2004 2000 GMT
Vertical Velocity (m/s)



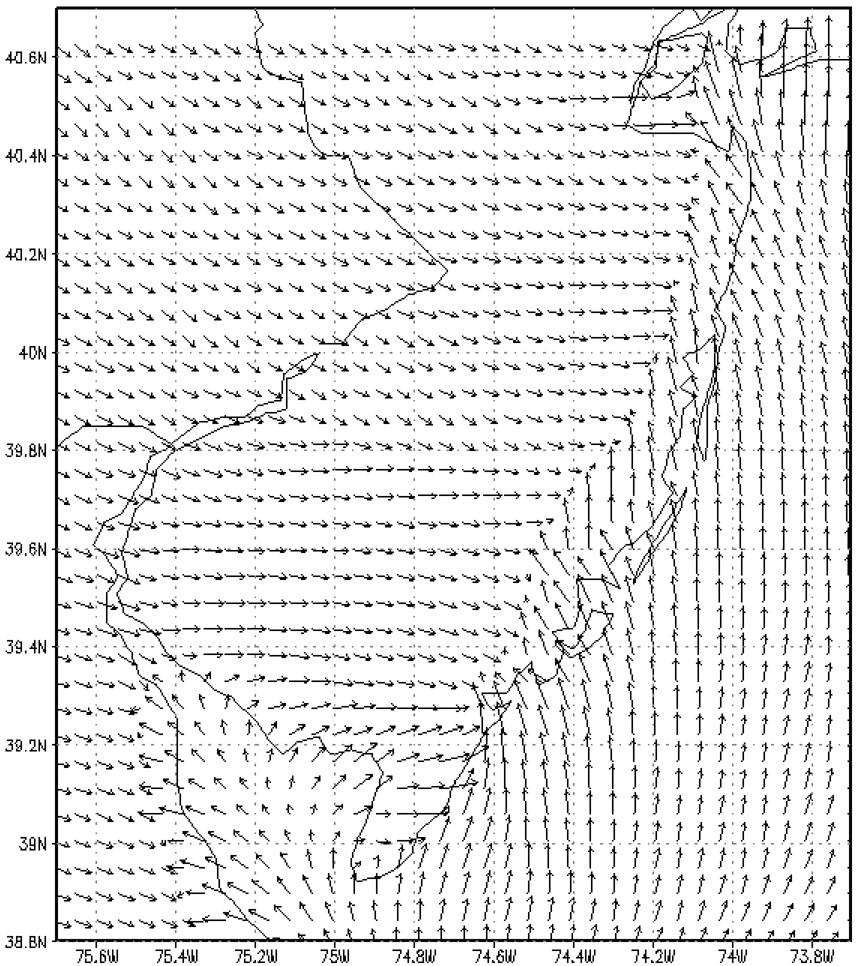
Thesis Outline

- Introduction
- Weather Research Forecast (WRF) model
- Characteristics of the New Jersey sea breeze – coastal upwelling relationship
- Sensitivity Study
- Case Studies
  - June 6, 2004
  - June 5, 2004
- Conclusions and Future Work

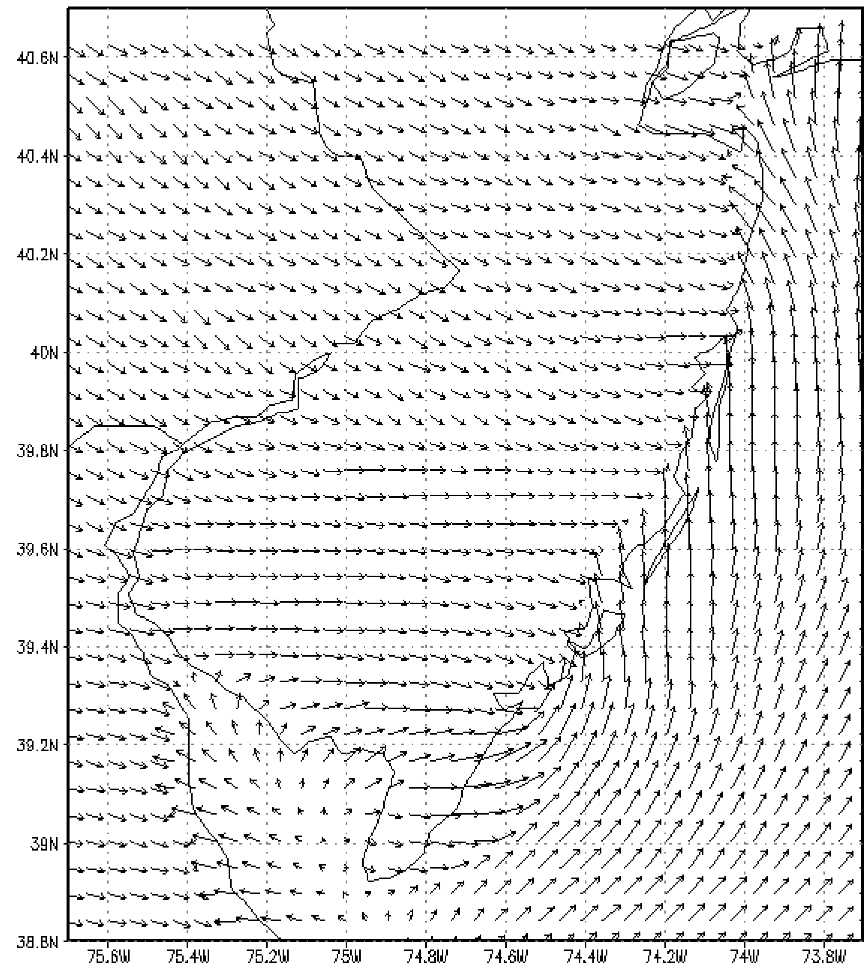
Sensitivity Test

- A) 15 C SST
- B) 17 C SST

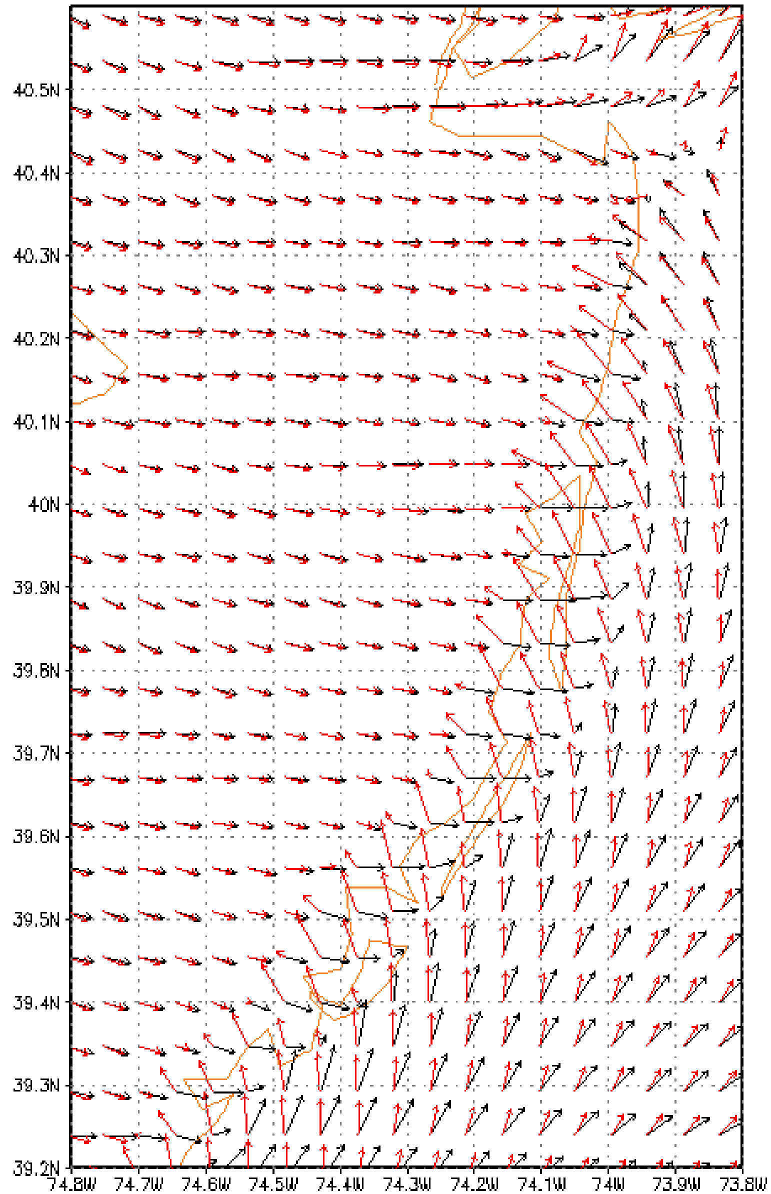
15 C Case



17 C Case

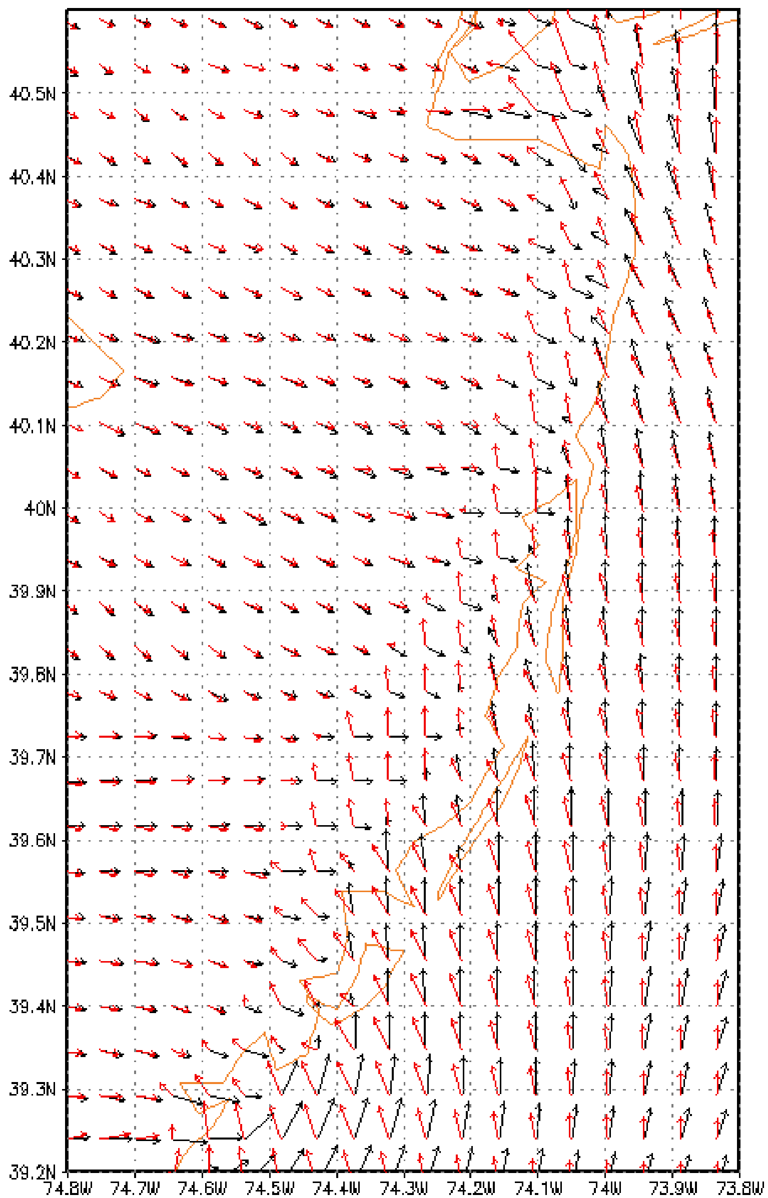


Wind Vector Difference at 1800 GMT



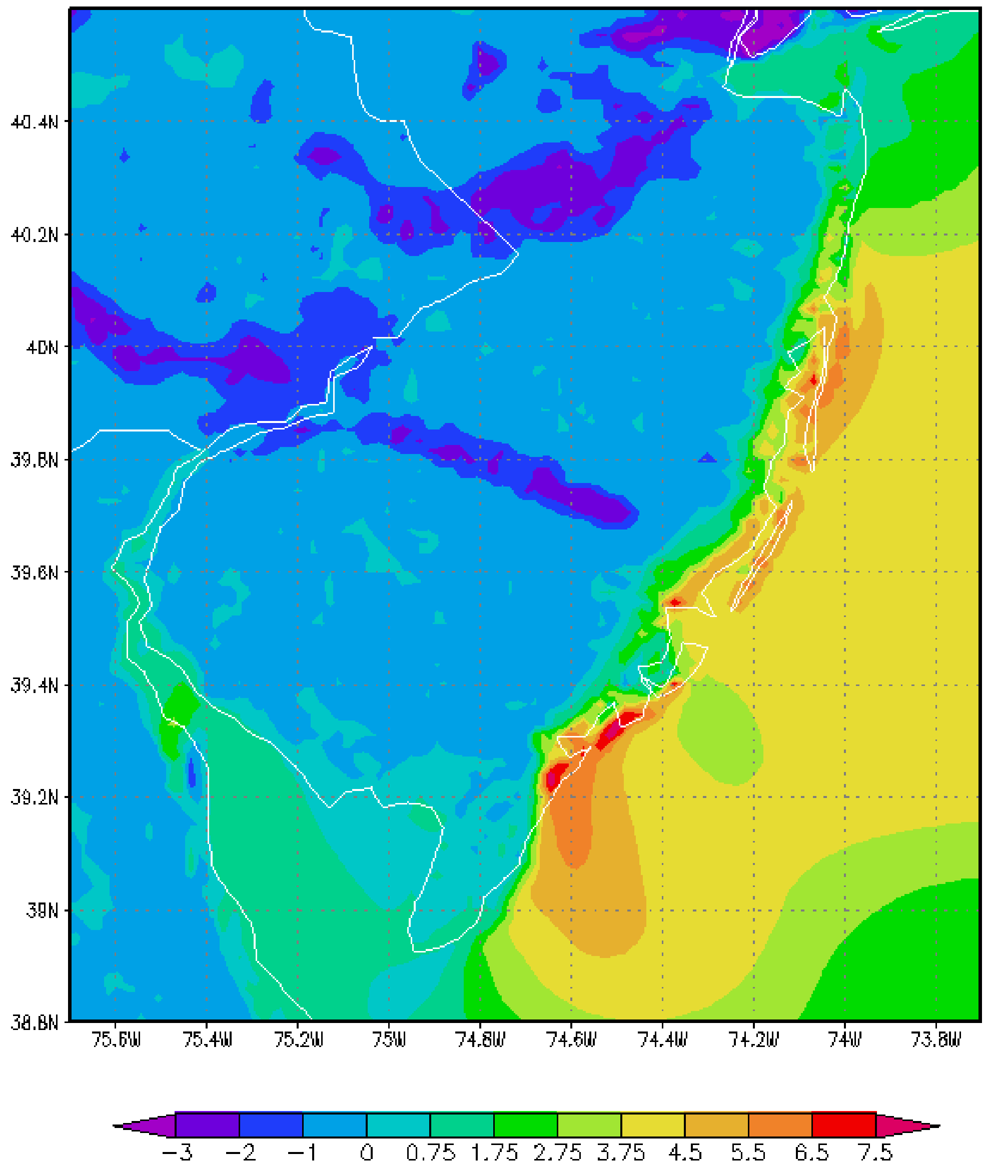
15 C SST 17 C SST

Wind Vector Difference at 2200 GMT

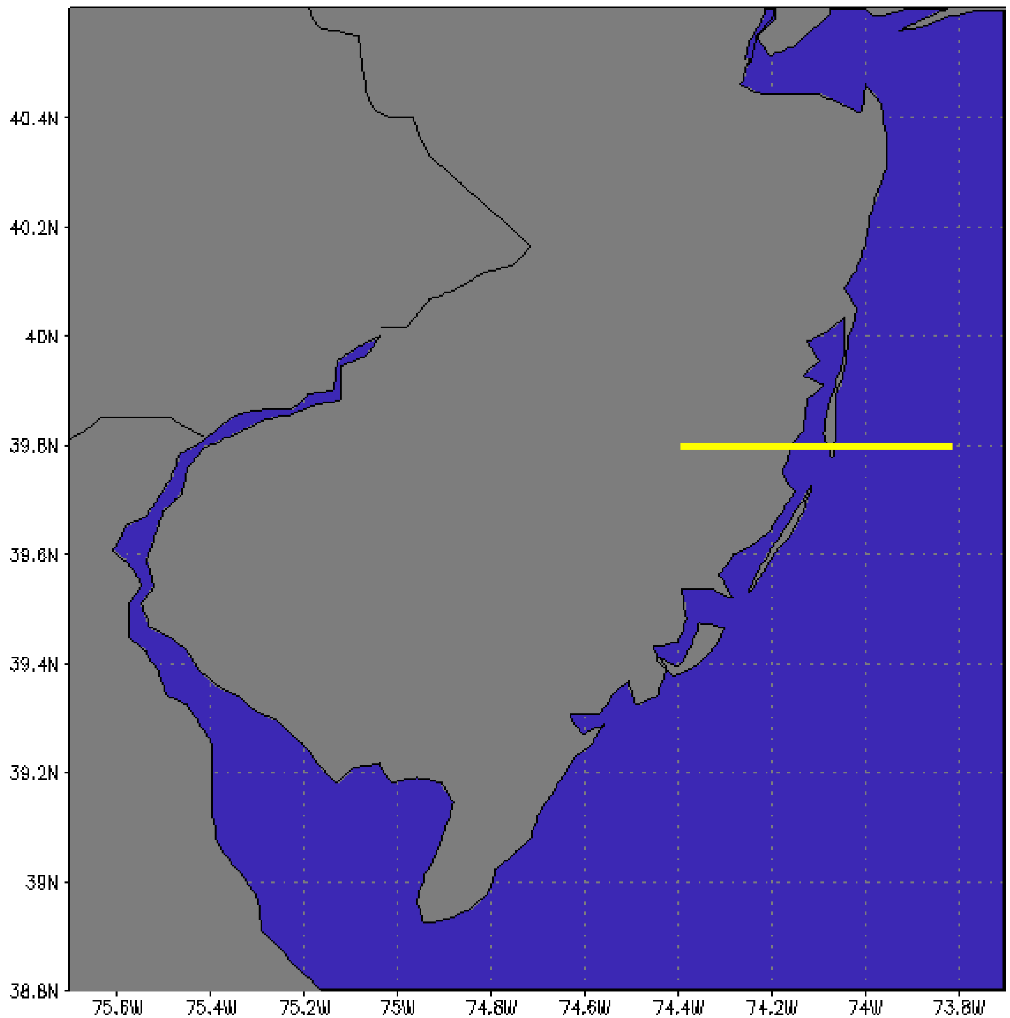


15 C SST 17 C SST

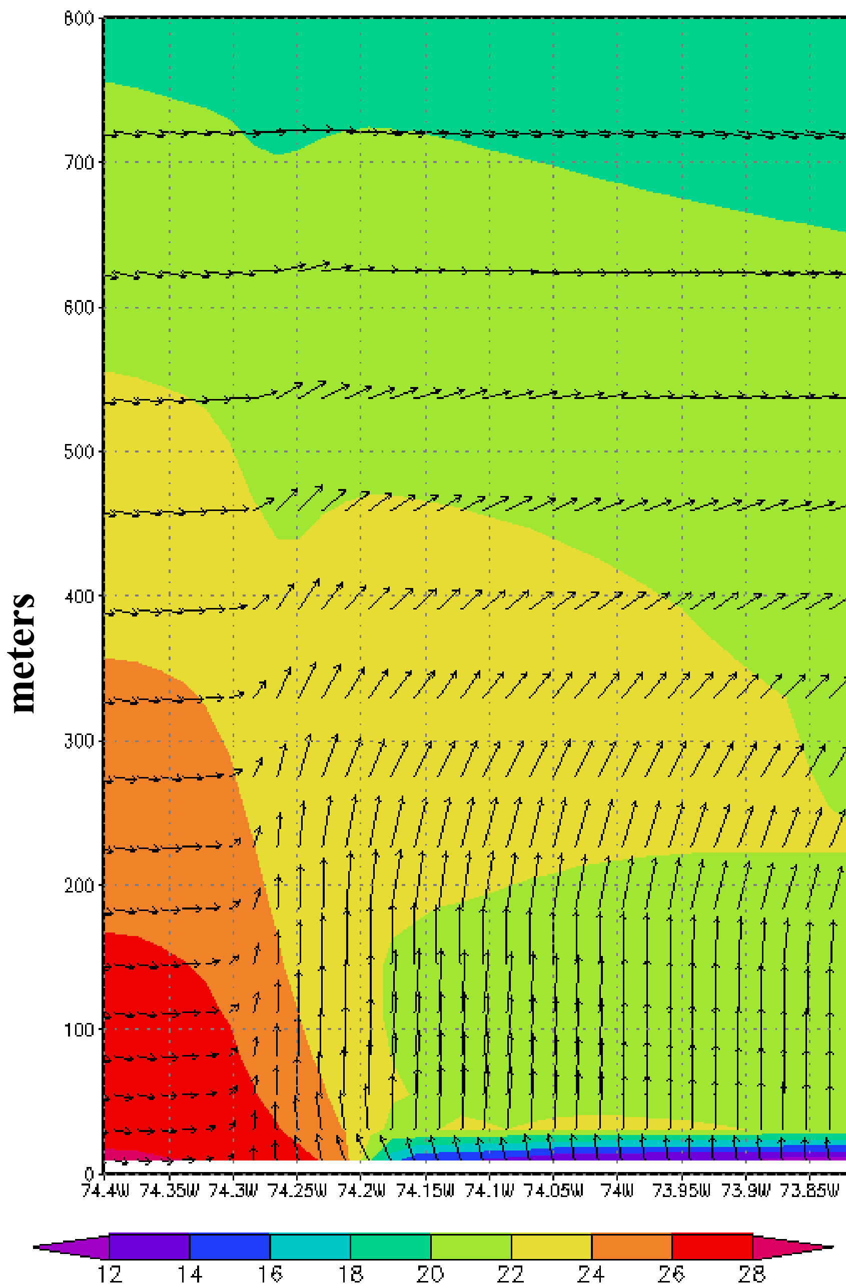
Air Temperature Difference at 2000 GMT



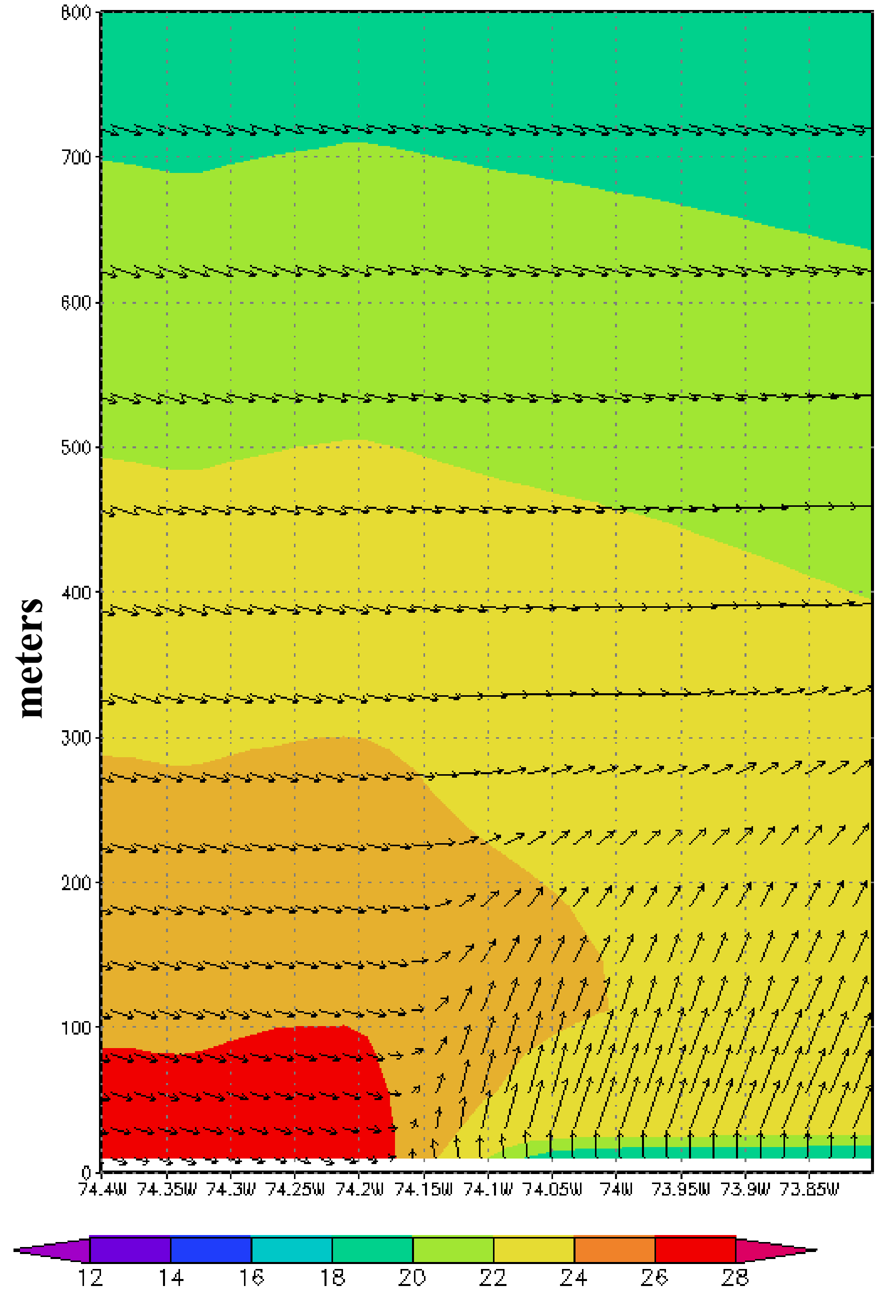
Positive values indicate
17 C SST
simulation was warmer



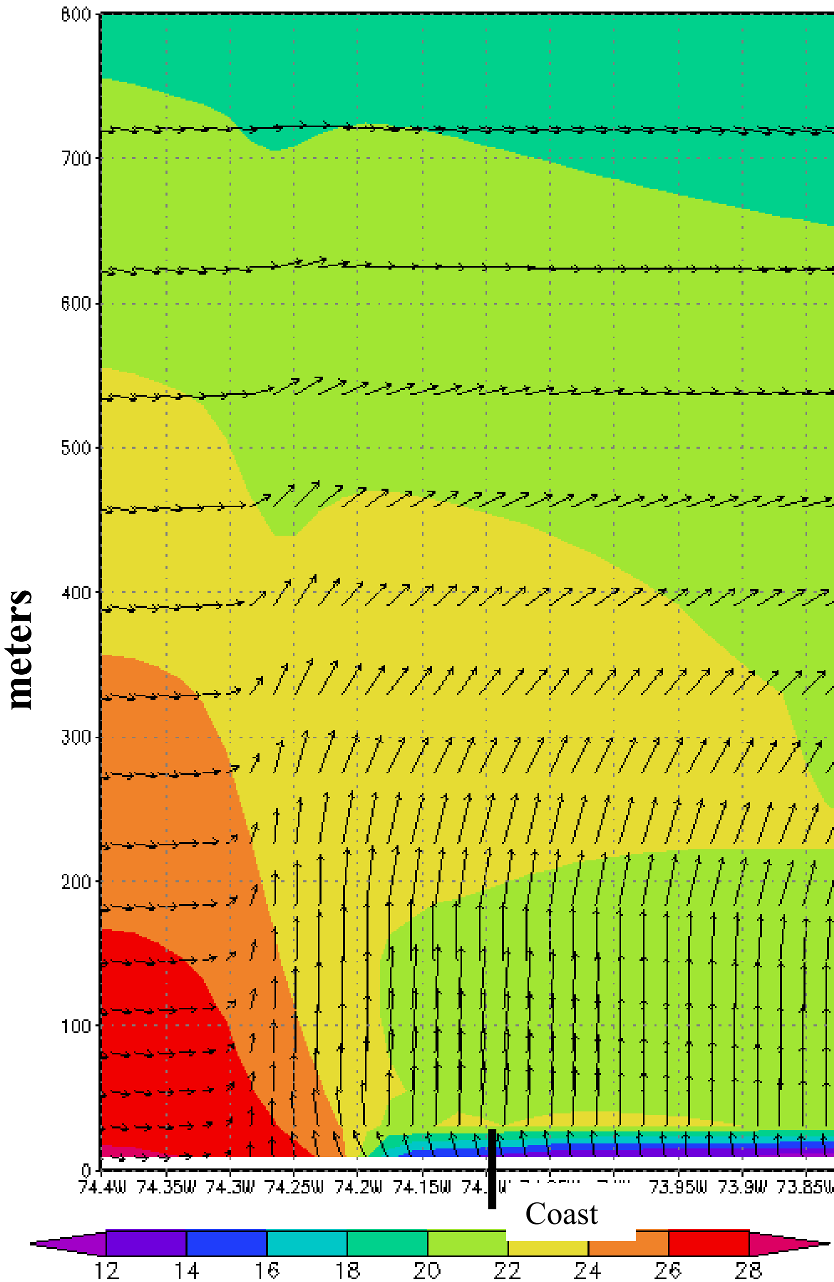
40.4N
40.2N
40N
39.8N
39.6N
39.4N
39.2N
39N
38.8N
75.6W
75.4W
75.2W
75W
74.8W
74.6W
74.4W
74.2W
74W
73.8W



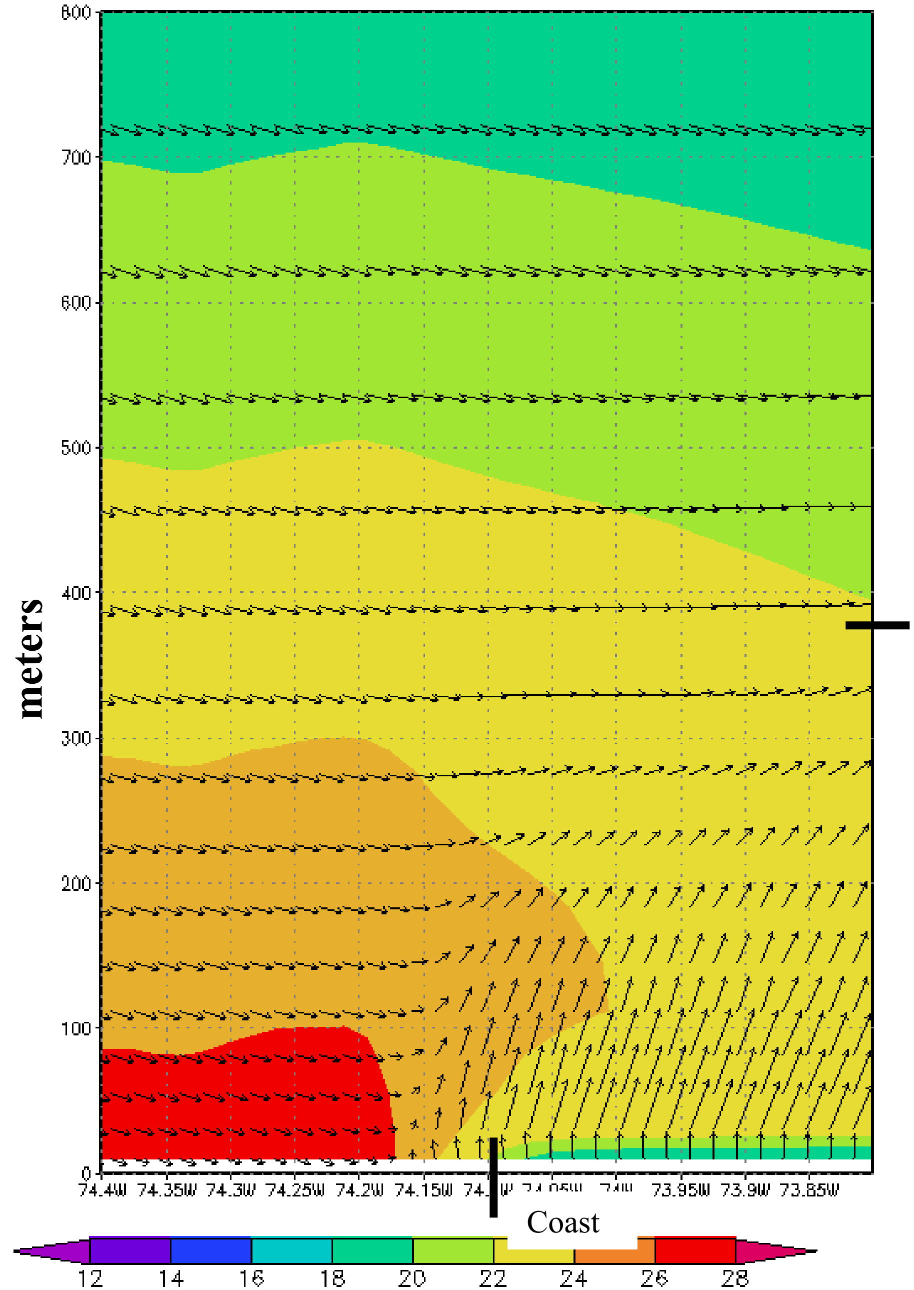
800
700
600
500
400
300
200
100
0
meters
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W 74.1W 74.05W 74W 73.95W 73.9W 73.85W
12 14 16 18 20 22 24 26 28



800
700
600
500
400
300
200
100
0
meters
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W 74.1W 74.05W 74W 73.95W 73.9W 73.85W
12 14 16 18 20 22 24 26 28



meters
800
700
600
500
400
300
200
100
0
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W
73.95W 73.9W 73.85W
Coast
12 14 16 18 20 22 24 26 28



meters
800
700
600
500
400
300
200
100
0
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W
73.95W 73.9W 73.85W
Coast
12 14 16 18 20 22 24 26 28

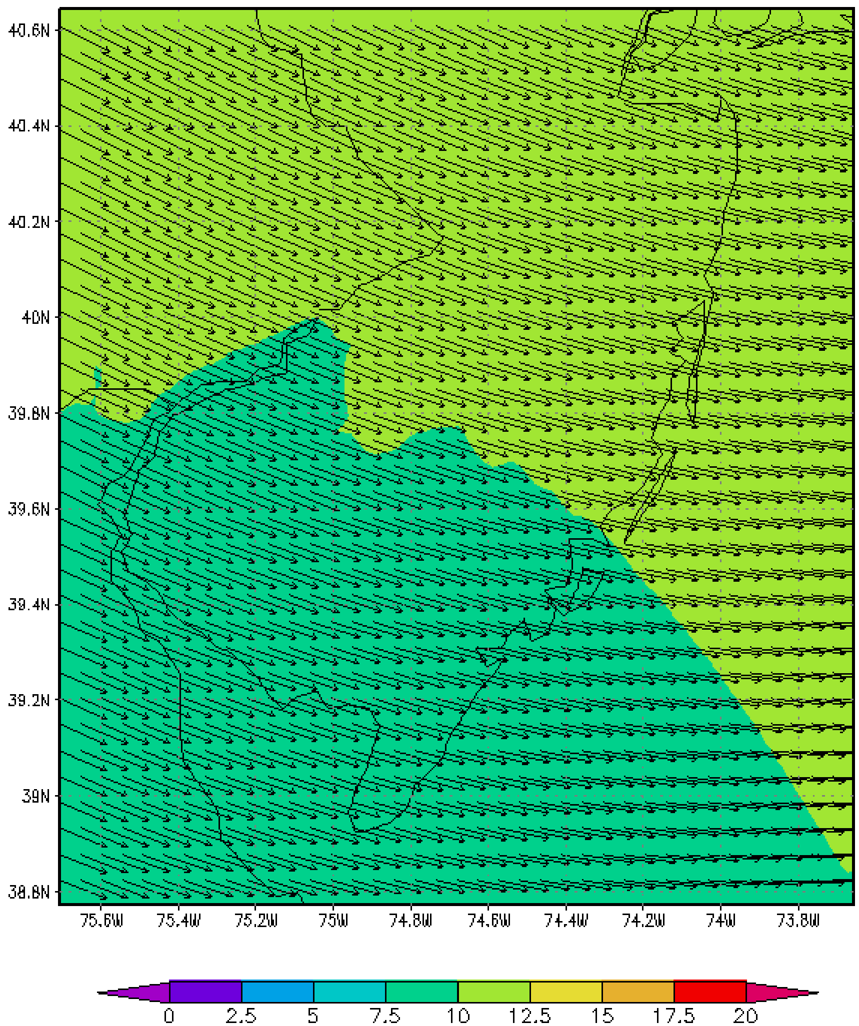
Thesis Outline

- Introduction
- Weather Research Forecast (WRF) model
- Characteristics of the New Jersey sea breeze – coastal upwelling relationship
- Sensitivity Study
- Case Studies
  - June 6, 2004
  - June 5, 2004
- Conclusions and Future Work

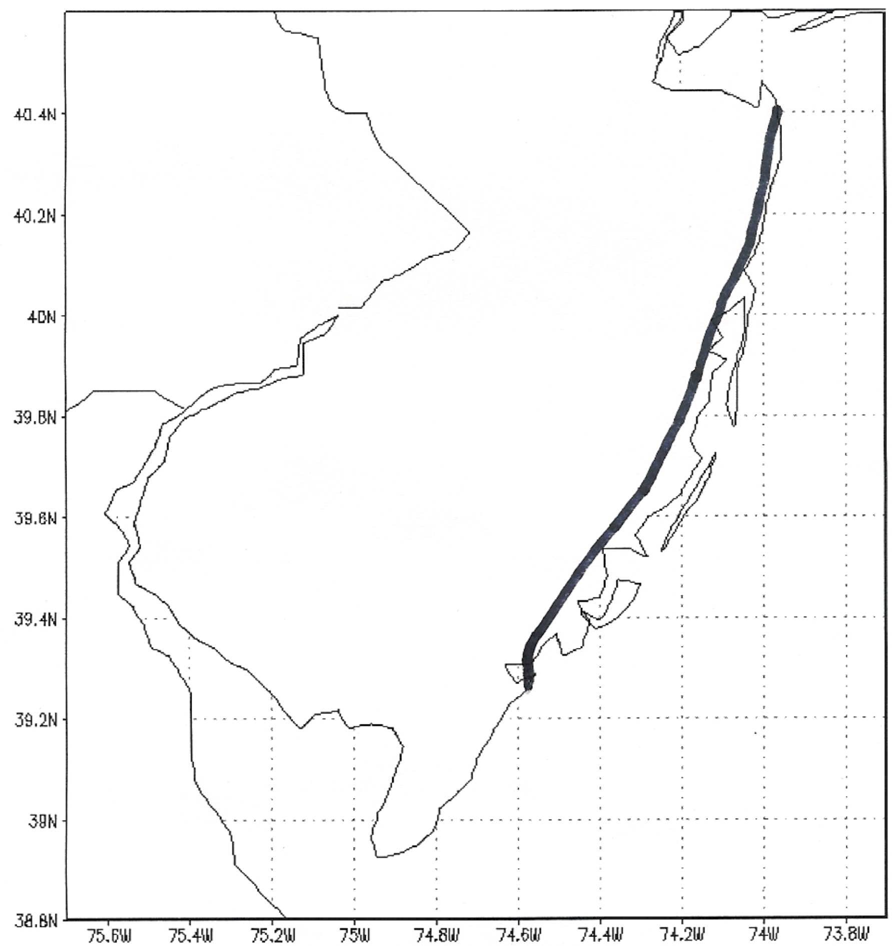
July 6, 2004 Sea Breeze Event

- C) July 6, 2004 SST – with upwelling
- D) July 16, 2004 SST – no upwelling (~ +6 C)

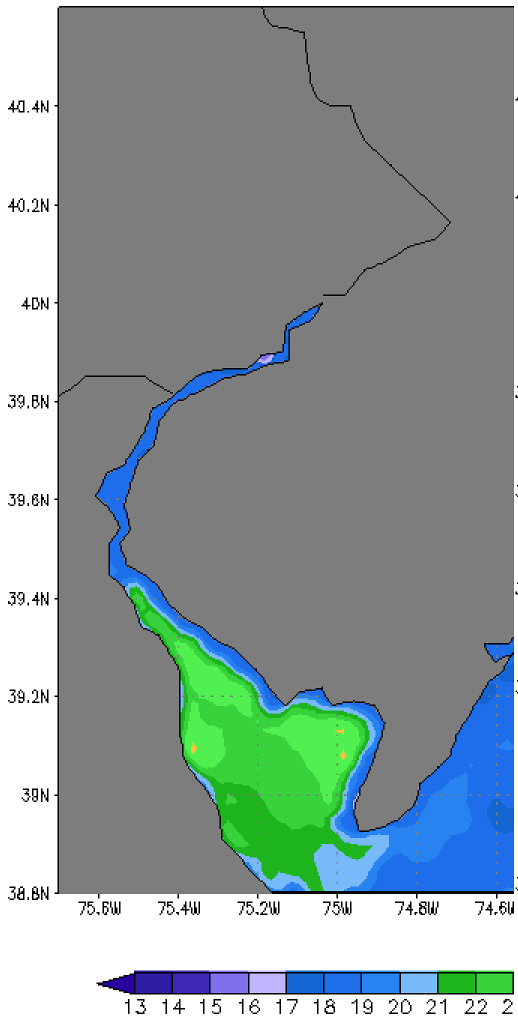
850 mb flow



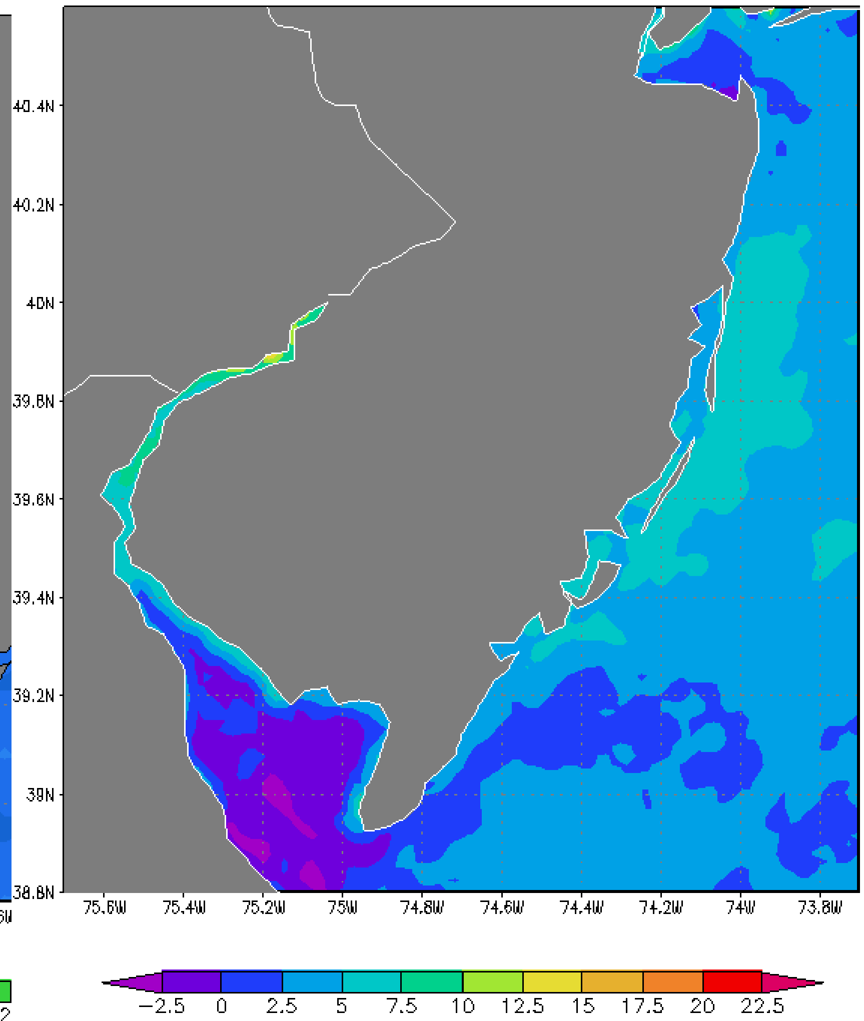
Radar detected sea breeze front



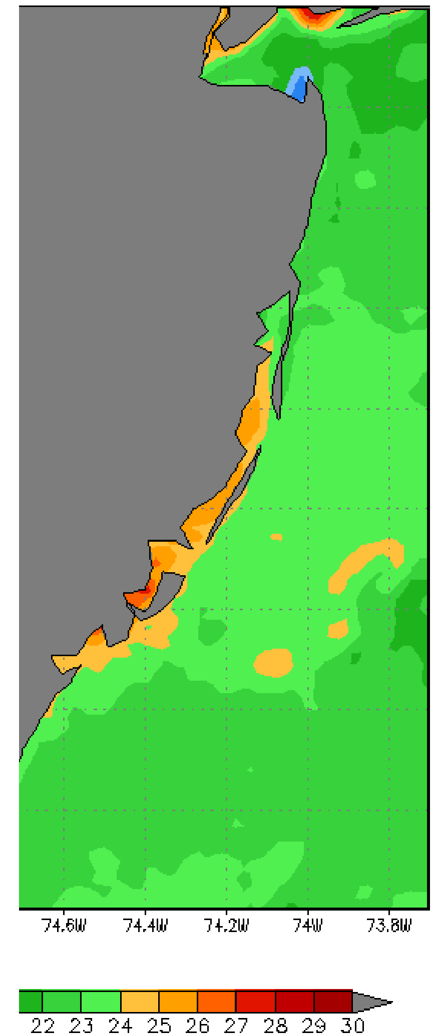
July 6



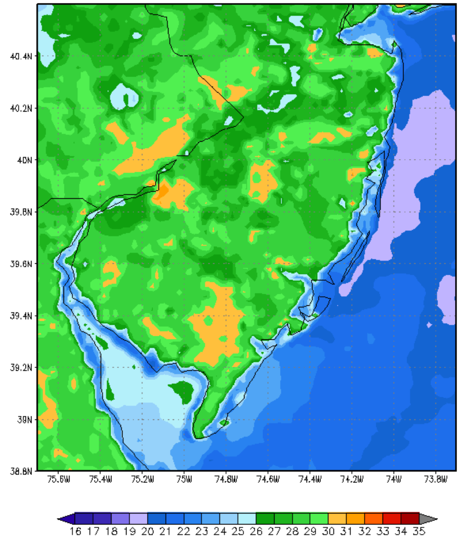
SST Difference

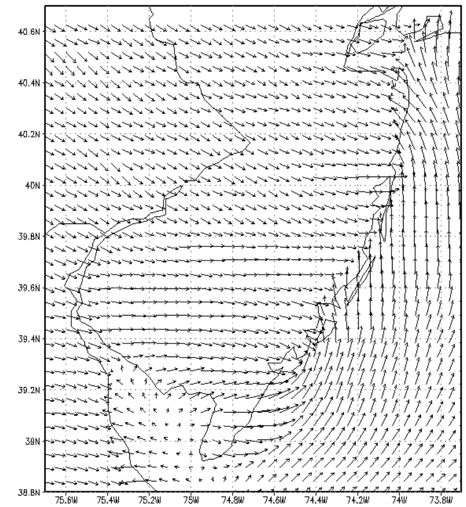


6 SST

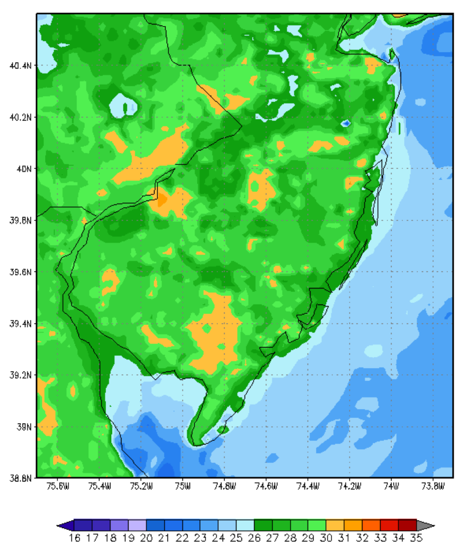


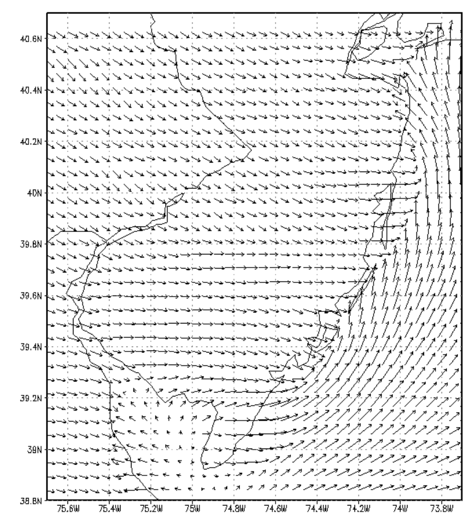
July 6 SST



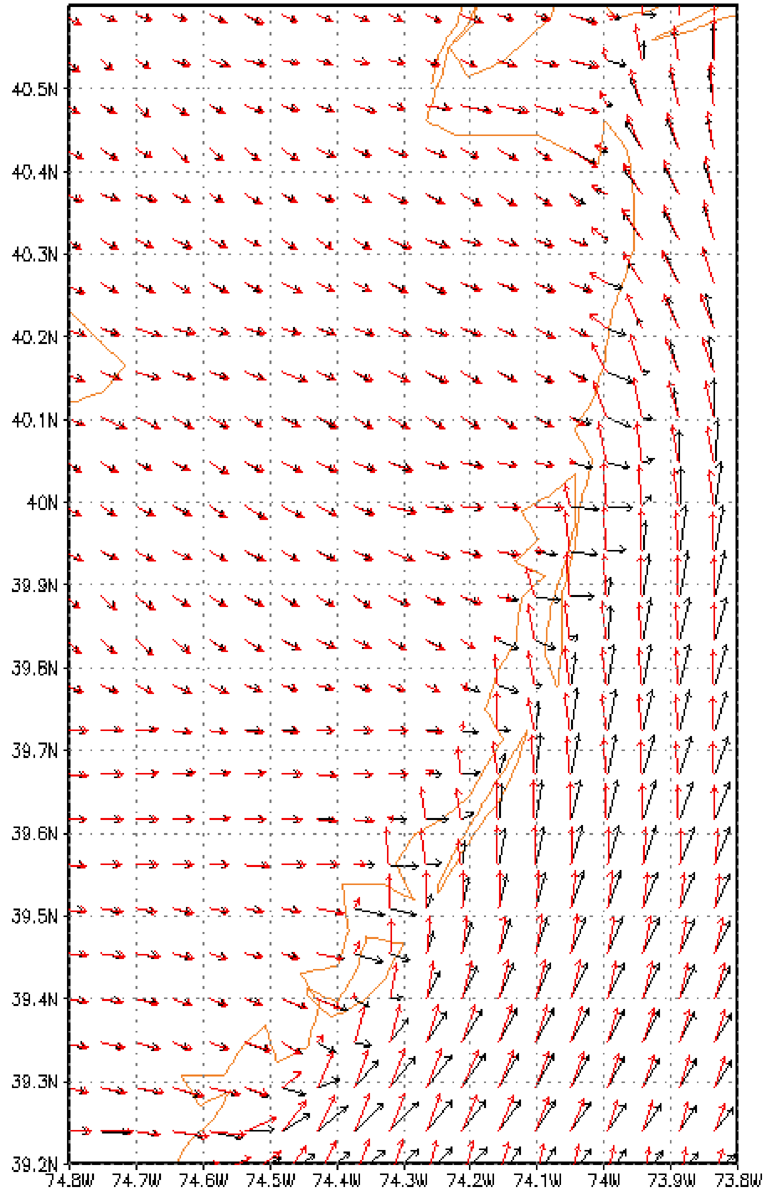


July 16 SST

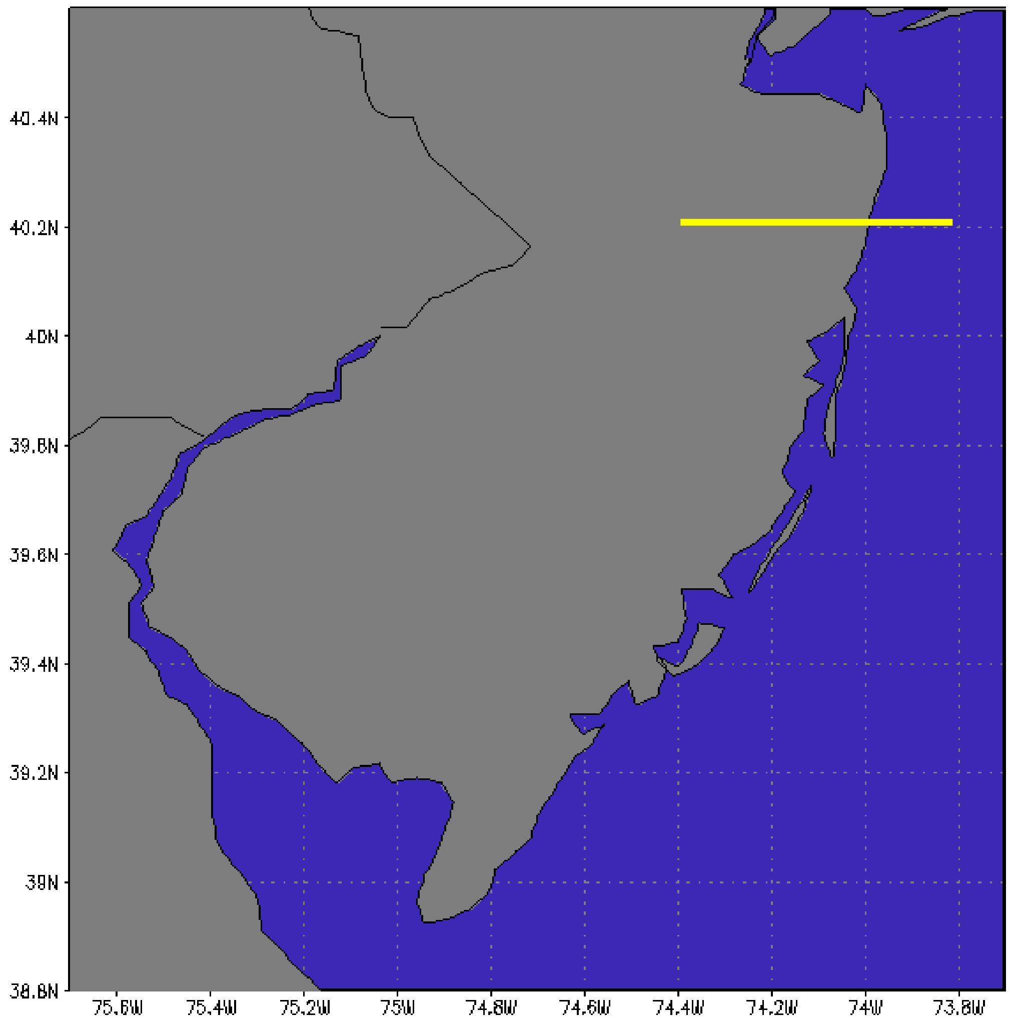




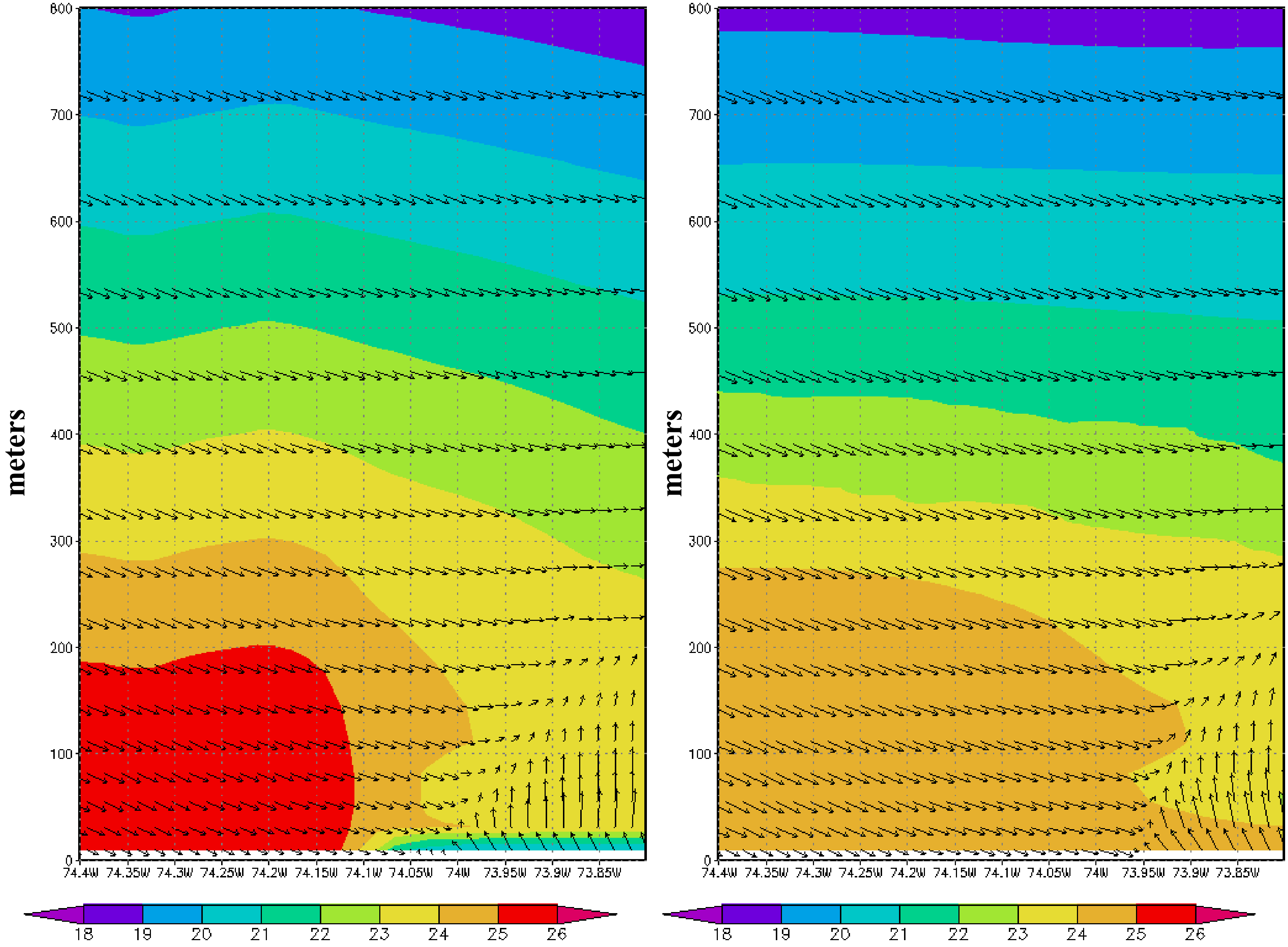
Wind Vector Difference at 2200 GMT



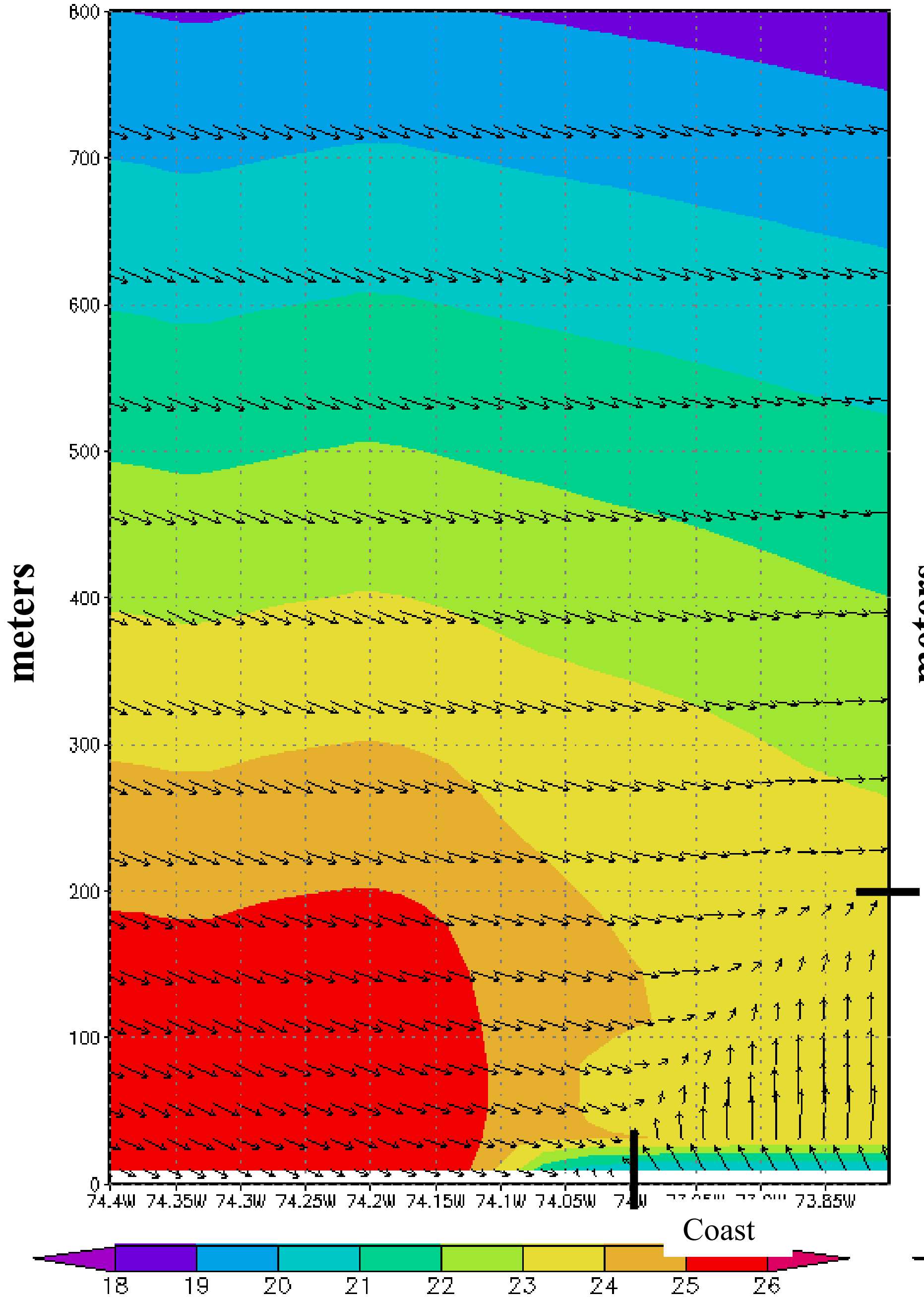
July 6 SST July 16 SST



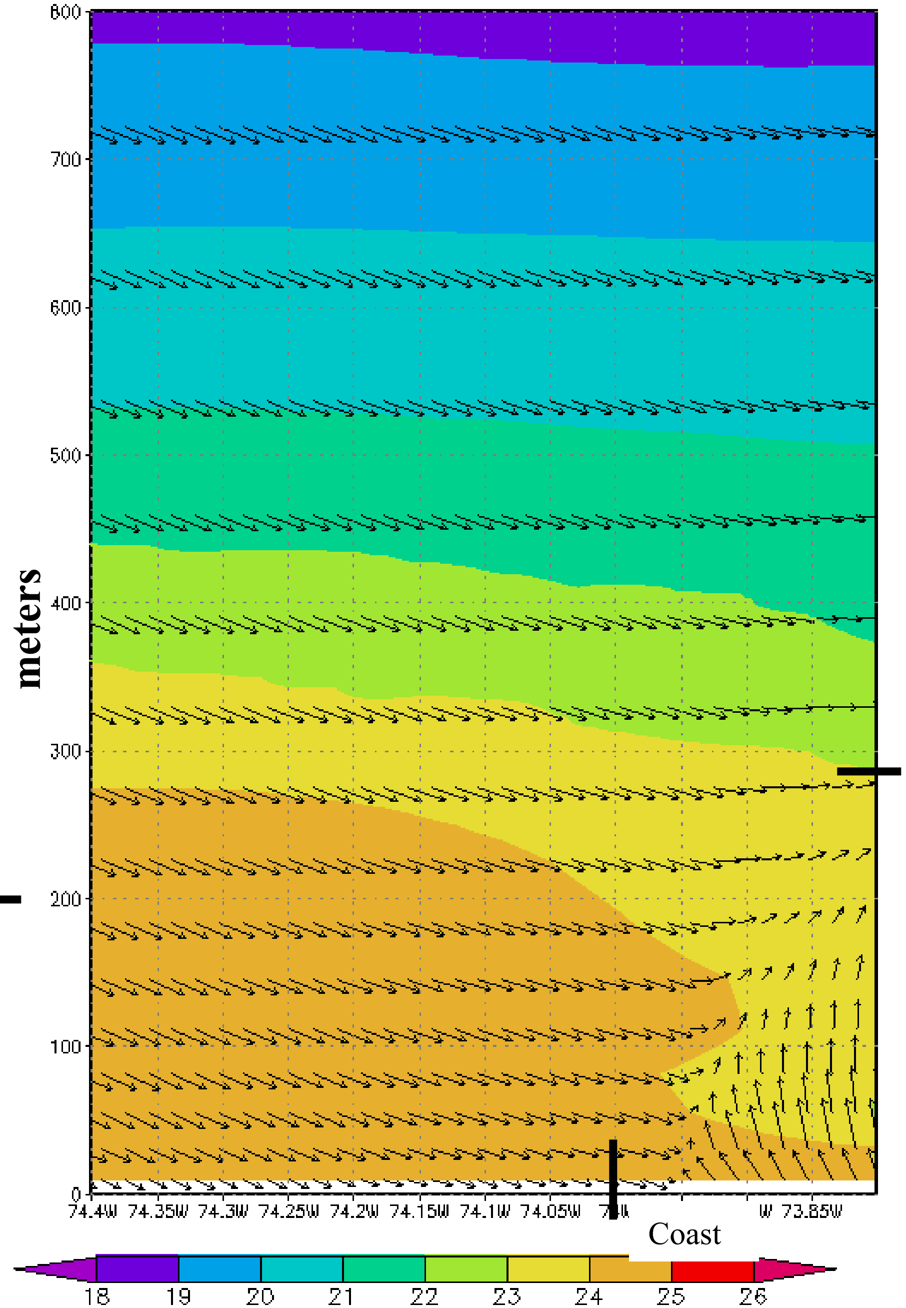
40.4N
40.2N
40N
39.8N
39.6N
39.4N
39.2N
39N
38.8N
75.6W
75.4W
75.2W
75W
74.8W
74.6W
74.4W
74.2W
74W
73.8W



meters
800
700
600
500
400
300
200
100
0
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W 74.1W 74.05W 74W 73.95W 73.9W 73.85W
18 19 20 21 22 23 24 25 26



meters
800
700
600
500
400
300
200
100
0
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W 74.1W 74.05W 74W 73.85W
Coast
18 19 20 21 22 23 24 25 26

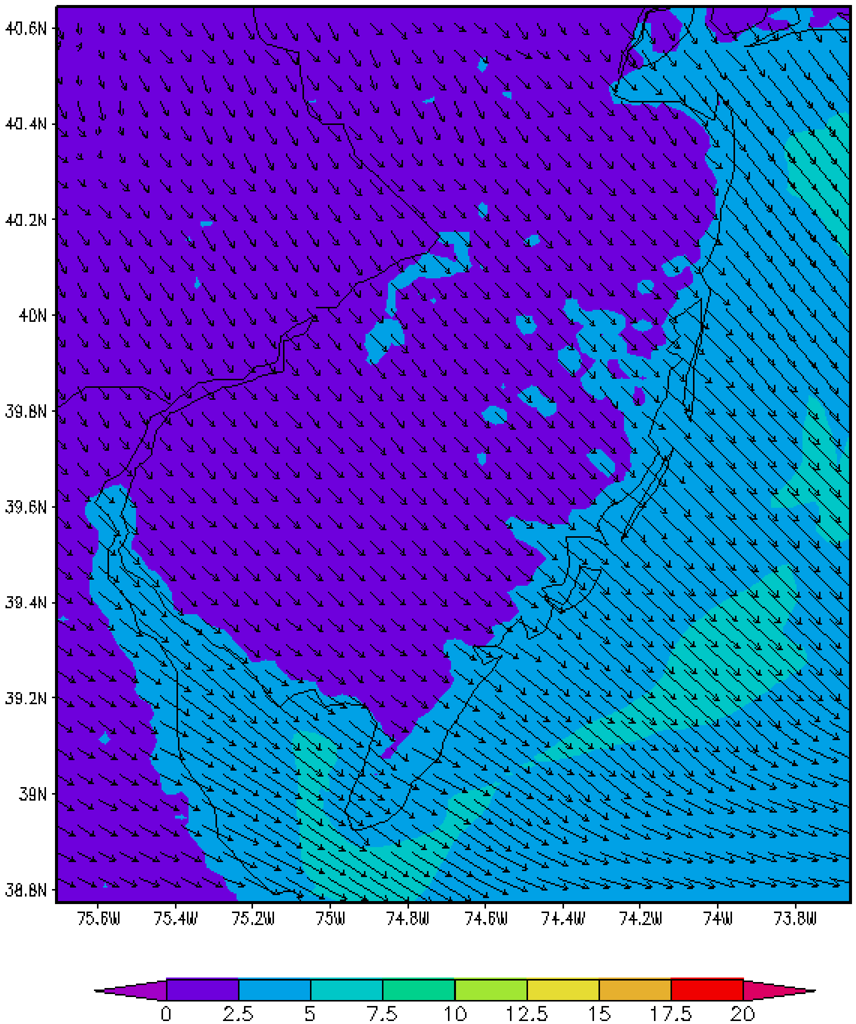


meters
800
700
600
500
400
300
200
100
0
74.4W 74.35W 74.3W 74.25W 74.2W 74.15W 74.1W 74.05W W 73.85W
Coast
18 19 20 21 22 23 24 25 26

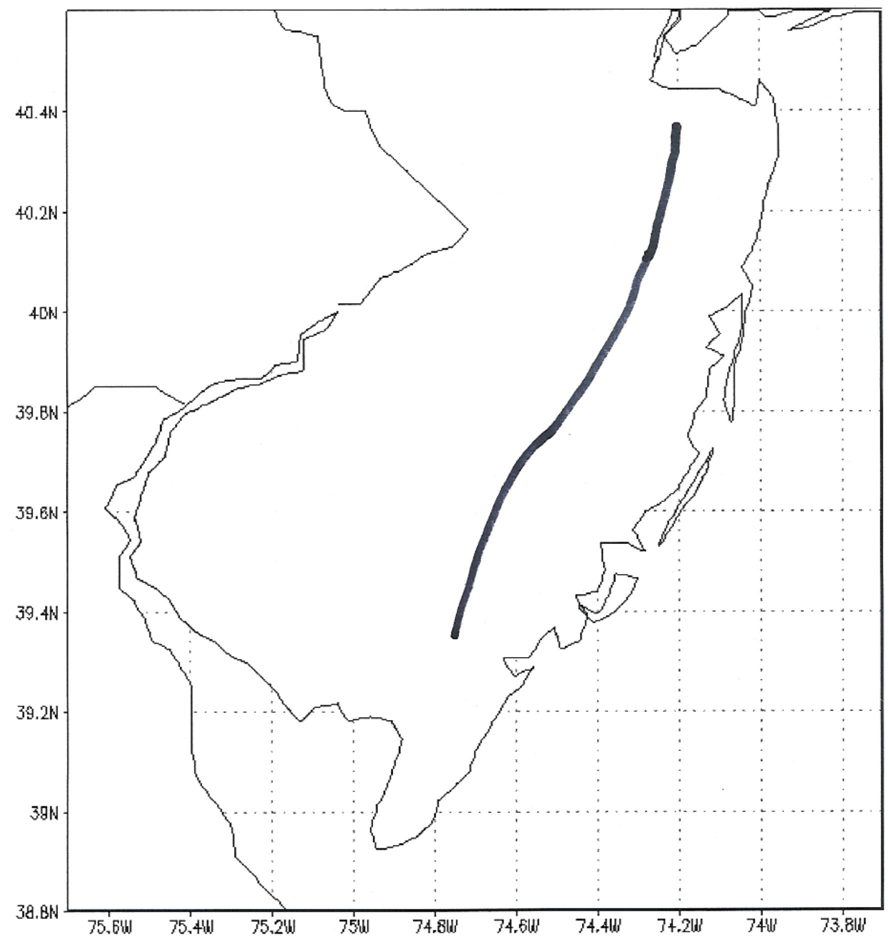
July 5, 2004

- E) July 5, 2004 SST – with upwelling
- F) July 16, 2004 SST – no upwelling (~ +8 C)
- G) Climatological Maximum SST (~ +12 C)

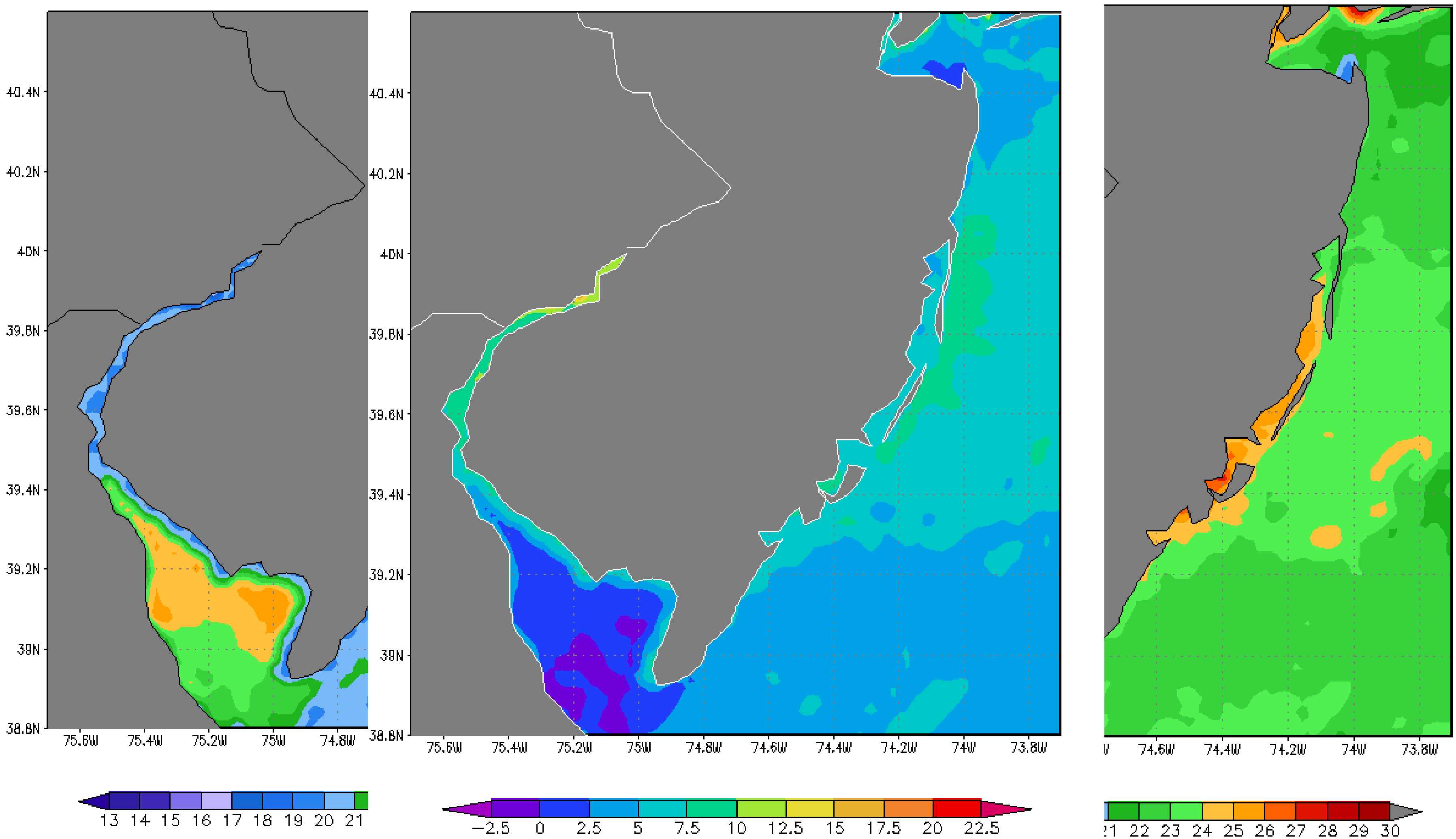
850 mb flow



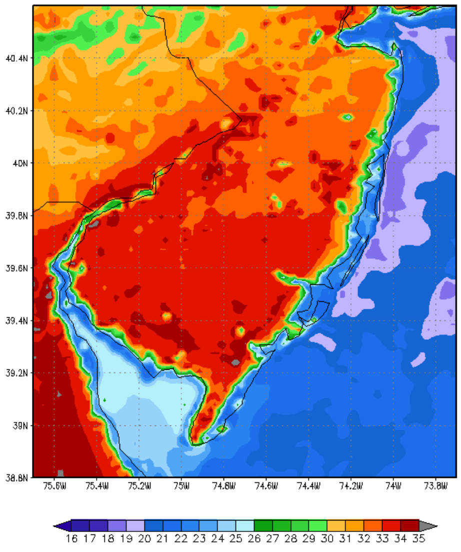
Radar detected sea breeze front

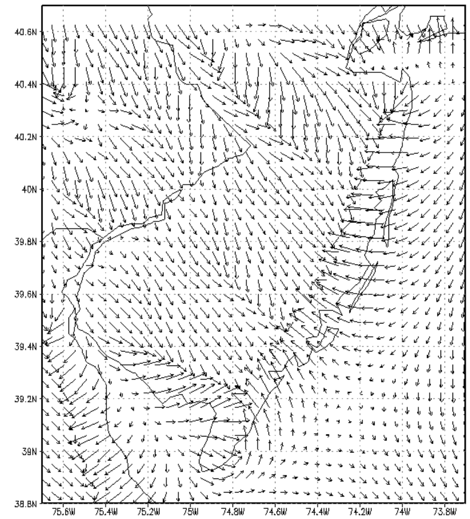


July SST Difference 16 SST

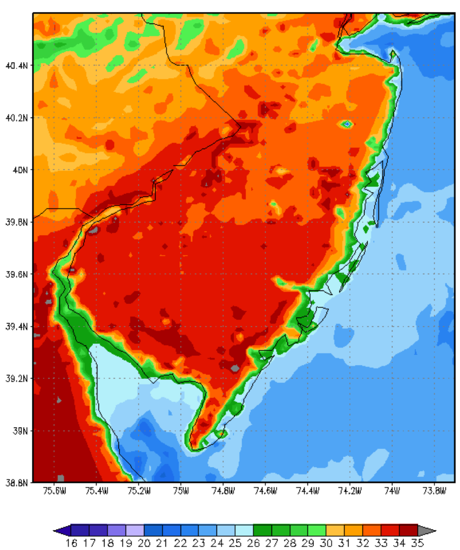


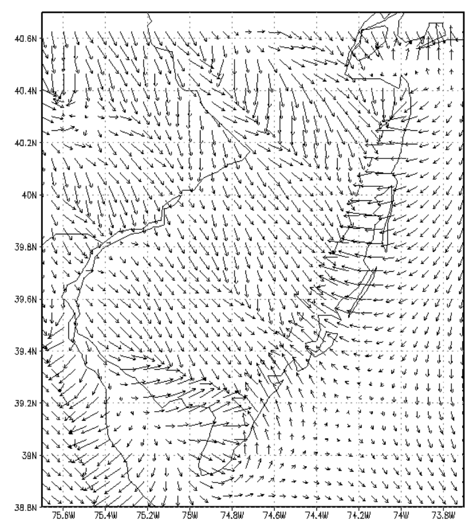
July 5 SST



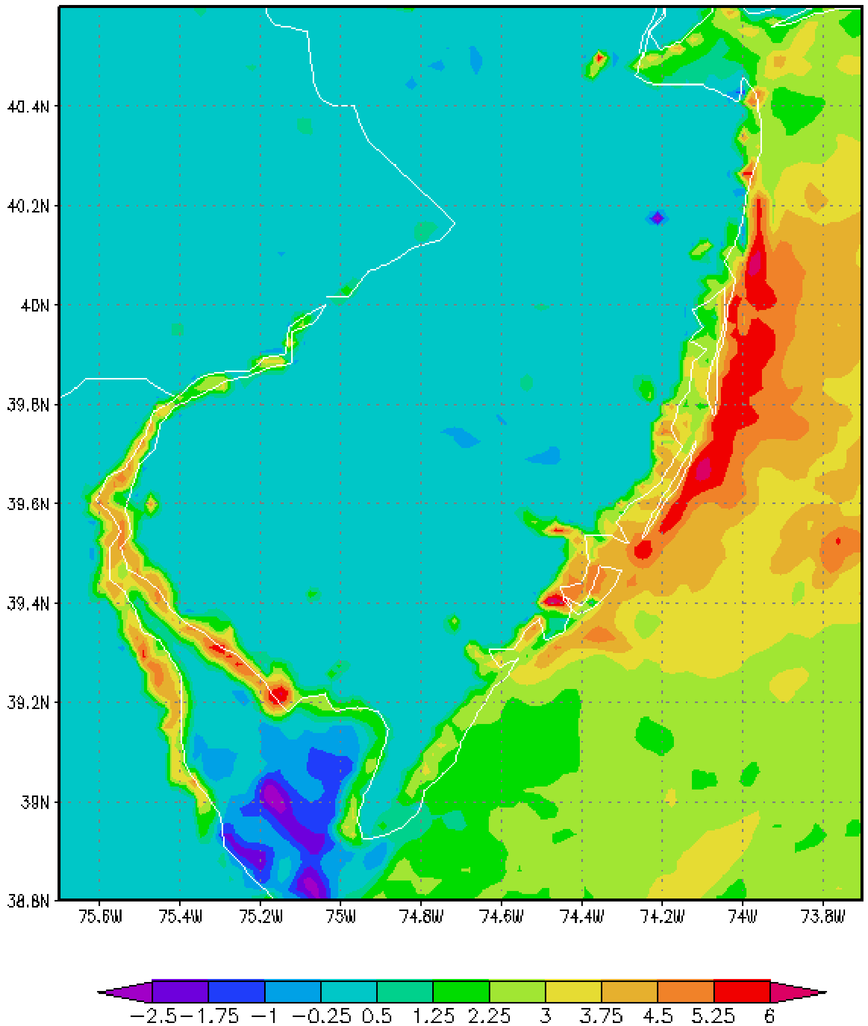


July 16 SST



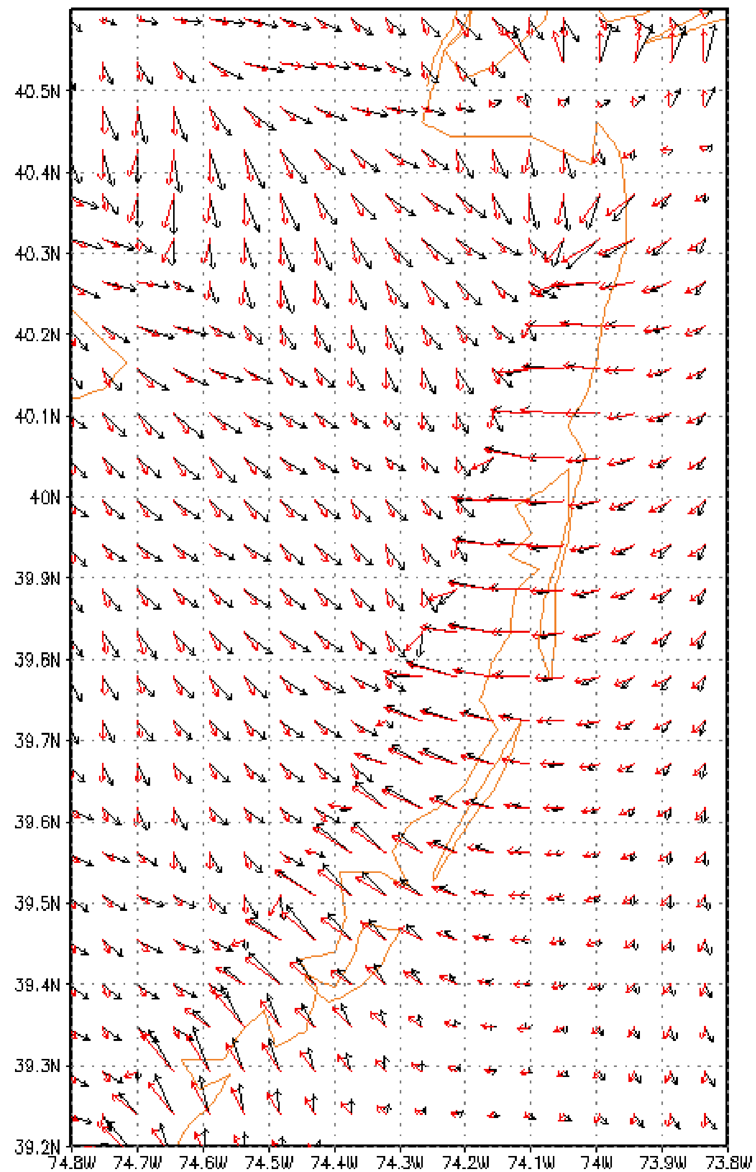


Air Temperature difference at 2000 GMT



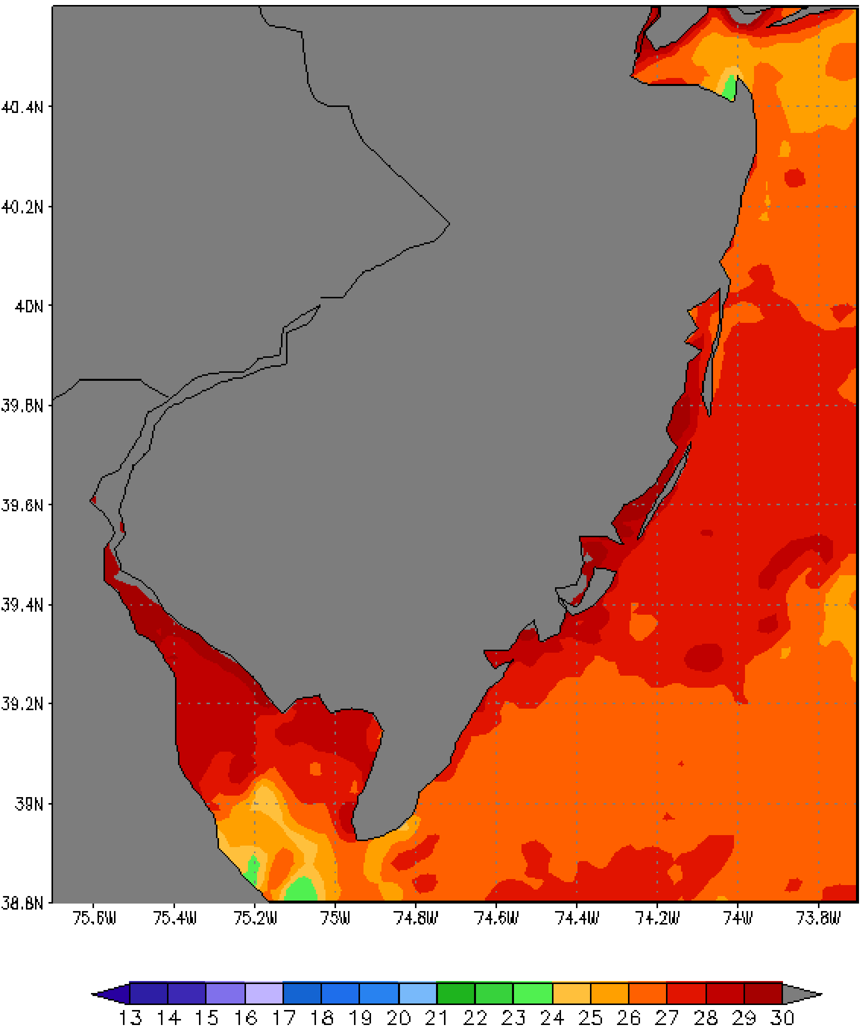
Positive values indicate July 16 SST simulation was warmer

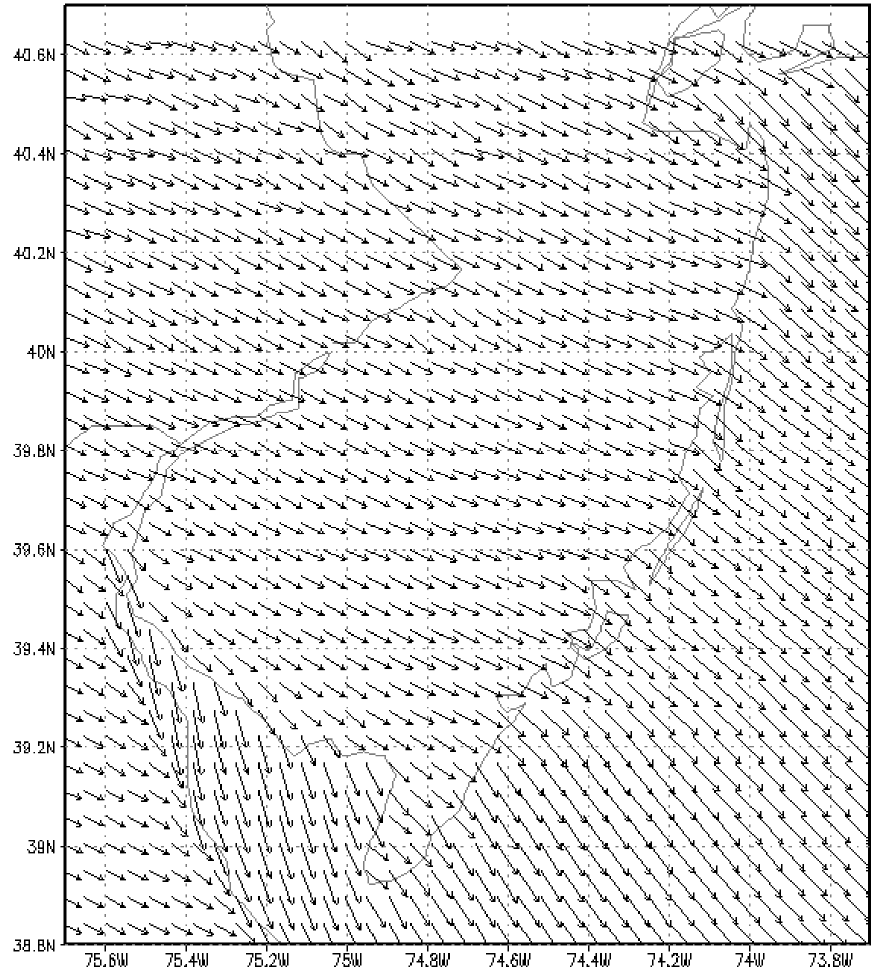
Wind Vector Difference at 2200 GMT



July 5 SST **July 16 SST**

Climatological Max SST





Thesis Outline

- Introduction
- Weather Research Forecast (WRF) model
- Characteristics of the New Jersey sea breeze – coastal upwelling relationship
- Sensitivity Study
- Case Studies
  - June 6, 2004
  - June 5, 2004
- Conclusions and Future Work

Conclusions

1. The New Jersey sea breeze has been shown to be "turned on and off" using a mesoscale model with variations in nearshore SST.

2. The extent of inland penetration of the sea breeze front and the vertical depth of the sea breeze does vary depending on the ocean temperature offshore.

3. The shape of the sea breeze front may be influenced by the presence of upwelling, however the coastline configuration is important as well.

Future Work

1. Additional model simulations
   - Larger number of case study days
   - Wider array of synoptic flow conditions
   - Wider array of SST variations

2. Very high resolution modeling study of New Jersey bays and inlets to determine what effect they have on the overall shape of the sea breeze front.

3. Use of a coupled ocean – atmosphere model to examine what feedbacks exist between coastal upwelling and the sea breeze.

Acknowledgements

Advisor:

Scott Glenn

Committee:

Richard Dunk

James Eberwine

Acknowledgements

IMCS

Faculty and Staff

Computing Services

Graduate Students

RU COOL

National Weather Service Mount Holly

Acknowledgements

My always supportive family and friends

And especially for the loving support
and understanding of my fiancé

Suzanne