Rutgers University Coastal Ocean Observation Laboratory (RU-COOL) Advanced Modeling System Developed to Cost-Effectively Support Offshore Wind Energy Development and Operational Applications

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***Abstract*—Studies are underway that are evaluating the offshore wind resource along the coast of New Jersey in an effort to determine the variability of the wind resource. One major source of variability is the sea-land breeze circulation that occurs during periods of peak energy demand. The sea breeze front, driven by the thermal difference between the warm land and relatively cooler ocean during hot summer afternoons, propagates inland and under weak atmospheric boundary layer wind conditions can affect much of the state. However, little is known about the offshore component of the sea breeze circulation. A large zone of subsidence over the coastal ocean, and subsequent divergence near the surface, is known to occur in unison with the inland-propagating sea breeze front. RU-COOL's unique monitoring and modeling endeavors are focused on exploring the details of these offshore dynamics of the sea breeze circulation and its development during both coastal upwelling and non-upwelling events.**

A case study from the August 13, 2012 is analyzed in this paper; coastal upwelling resulted from persistent south to southeasterly winds for days. In addition, a sea breeze front formed in the afternoon, propagating inland and producing a zone of weak winds offshore that coincides with the targeted area of offshore wind development. Model results, using unique declouded satellite sea surface temperature data, are validated inshore against weather radar and offshore against coastal ocean radar (CODAR). Small-scale offshore wind variability is resolved and verified in the model, which will be critical for producing accurate and reliable offshore wind resource assessments and precise operational forecasts for the future.

***Index Terms*—Offshore wind, atmospheric modeling, sea breeze, upwelling, HF radar, weather radar, satellite SST, WRF, air-sea interaction, coastal processes**

I. Introduction

Offshore wind energy has the potential for alleviating high energy supply and demand issues associated with the USA's heavily populated East Coast. A primary concern with offshore wind energy development along these highly populated centers is the high cost of implementing the construction and operation of wind turbines in an offshore environment. Although construction and subsequent power production costs will remain high in the near-term, a possible solution for providing significant cost reductions relevant to offshore wind energy development can be realized with accurate wind resource assessments and representative wind forecasts. The use of high-resolution numerical weather prediction (NWP) is a cost-effective means in which to study the wind resource prior to construction and provide precise operational forecasts that will enhance operational decisions related to the energy market and integration of wind power into the energy grid system.

Studies are underway that are evaluating the offshore wind resource along the coast of New Jersey in an effort to determine the variability of the wind resource. Once this variability is determined, the "risks" associated with offshore wind development, operations, and power supply into the affected energy grid will be minimized. Rutgers Institute of Marine and Coastal Sciences (IMCS) is integrating validated remote sensing technology and site-specific in-situ data into numerical modeling routines. The incorporation of this innovative monitoring data should significantly reduce the random error and systematic biases inherent in the resource assessment and NWP analyses.

It is well known that the offshore wind resource is influenced by synoptic weather patterns. Less is known about the effects of mesoscale and local influences of the sea breeze circulation. The sea breeze that forms along the New Jersey coast is one of the primary microclimate circulations that affect the offshore environment. The sea breeze front, driven by the thermal difference between the warm land and relatively cooler ocean during hot summer afternoons, propagates inland and under weak atmospheric boundary layer wind conditions can affect much of the state. Doppler weather radar, visible/infrared (IR) satellite imagery, and coastal ocean radar (CODAR) have detected the development of the sea breeze over offshore waters, along the coastline, and within adjacent inland areas.

However, little is known about the offshore component of the sea breeze circulation. A large zone of subsidence over the coastal ocean, and subsequent divergence near the surface, has been shown through NWP to occur in unison with the inland-propagating sea breeze front. Our unique monitoring and modeling endeavors are focused on exploring the details of these offshore dynamics of the sea breeze circulation and its development during both coastal upwelling and non-upwelling events. Consequently, accurate numerical simulation of the timing and intensity of the sea breeze circulation is crucial in accurately assessing and predicting offshore wind power potential and subsequent energy production during the times of peak energy demand along coastal communities and the adjacent densely populated areas.

II. Model Setup

To enhance understanding of the physics that control the sea breeze circulation and overall dynamics of the offshore wind resource, RU-COOL has developed and is currently running a high-resolution version of the Weather Research and Forecasting (WRF) model Advanced Research Core (ARW) [1]. Data from the operational 12-km North American Mesoscale (NAM) model are used as lateral initial conditions. Nested within the North American NAM domain is our operational 3-km RU-WRF domain, a mesoscale-resolving domain that stretches from south of Cape Hatteras to north of Cape Cod, with a focus on the coastal waters of New Jersey. Lateral boundary conditions after initialization are set using the new Rapid Refresh (RAP), which replaced the Rapid Update Cycle (RUC) on May 1, 2012 as the National Oceanic and Atmospheric Administration (NOAA) next-generation hourly-updated assimilation/modeling system.

Current operational NWP models (e.g. NAM and Global Forecast System, GFS) use relatively low resolution bottom boundary conditions over the ocean (i.e. sea surface temperatures, SST). Both NAM and GFS use the Real-Time Global SST High Resolution (RTG SST HR) product. This $1/12^{th}$ degree (~9.25 km) composite incorporates the most recent 24 hours of in-situ (e.g. buoys, ships) and satellite (Advanced Very High Resolution Radiometer, AVHRR; MetOp) data.

Our RU-WRF model incorporates improved, higher resolution bottom boundary conditions that aim to more accurately represent the ocean thermal conditions (SST)—a critical driver of atmospheric winds. Because cloudy signals are usually colder than the ocean surface, warmest pixel composites of several satellite scans have frequently been used in the past to remove any data contaminated by clouds or cloudy edges. However, this technique is prone to also eliminate coastal upwelling and storm mixing, processes that produce cold SSTs. Therefore, RU-COOL "de-clouds" its satellite SST data by using various temperature and near IR thresholds which are empirically derived by season and location. Then, a 3-day *coldest* pixel composite of this de-clouded, 1-km resolution AVHRR data is performed, in order to preserve and resolve coastal upwelling and storm mixing. Finally, a coldest pixel composite is again performed with the 3-day AVHRR data and NASA's Short-term Prediction Research and Transition Center (SPoRT) SST Composite product [2] to fill in any remaining gaps due to persistent clouds. SPoRT's SST product is a 2-km, 7-day weighted blend of Moderate-Resolution Imaging Spectroradiometer (MODIS) and National Environmental Satellite, Data, and Information Service (NESDIS) data.

III. Case Study

To closely investigate the offshore dynamics and wind patterns within the sea breeze circulation, a unique case study was chosen. South to southeasterly winds over New Jersey persisted for several days prior to August 12-13, 2012, producing offshore Ekman transport at the ocean surface [3]. Cooler water from the winter's cold pool storage below upwelled to replace the departing warmer surface waters. The coastal upwelling event was not captured by the RTG SST HR product (Figure 1), but with skies beginning to clear on August 13, the RU-COOL enhanced de-clouded satellite product did (Figure 2).

Relatively quiescent synoptic conditions prevailed during the morning and afternoon of August 13. Solar daytime heating elevated land temperatures over inland NJ to 30ºC; strong terrestrial heating in conjunction with cool coastal upwelling created a land/sea temperature difference upwards of 9ºC. A sea breeze front, evident in the Doppler weather radar backscatter in clear-air mode at KDIX, began to form at about 15-16 UTC (11 am-noon local time) and dissipated at around 00 UTC the next day (8 pm local time). Figure 3 shows KDIX weather radar at time of initiation at about 16 UTC and also at a time in the middle of duration of the sea breeze front propagation inland.

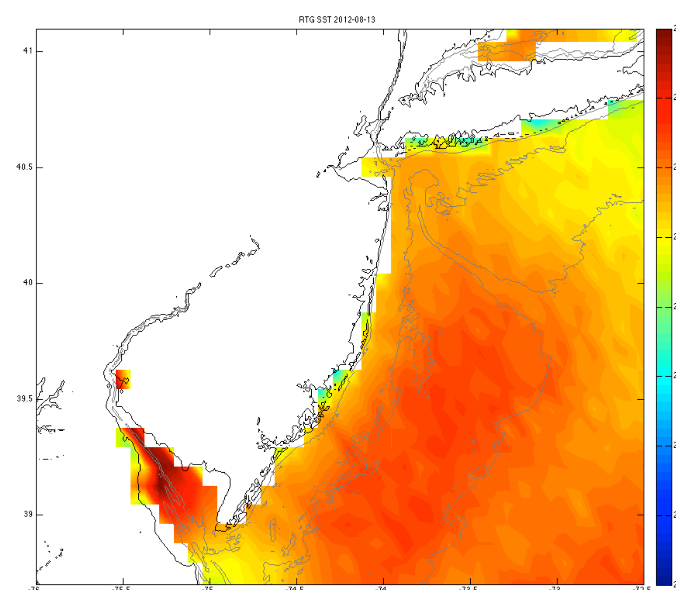

Fig. 1. RTG SST HR did not capture the coastal upwelling event on August 13, 2012. Note coastal waters of NJ are generally about 25-26ºC.

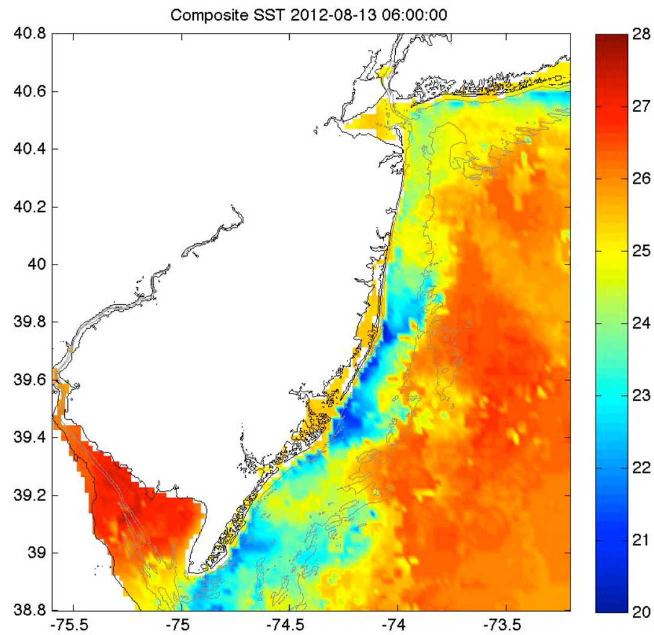

Fig. 2. RU-COOL 3-day coldest pixel composite (AVHRR + NASA SPoRT) captured the coastal upwelling (~21-23ºC) event. Upwelling temperatures were 3-4ºC cooler than surrounding coastal waters.

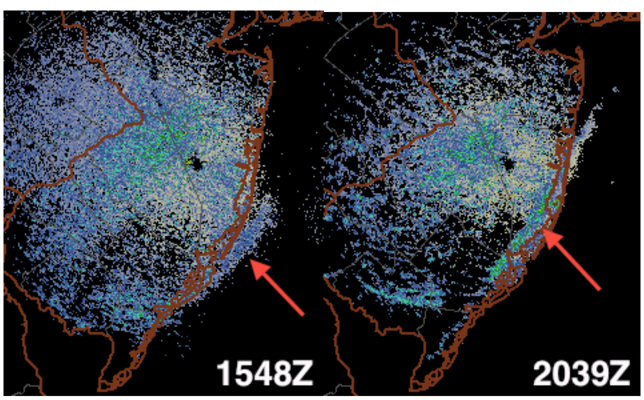

Fig. 3. KDIX weather radar in clear-air mode from 1548Z (left) and 2039Z (right). The sea breeze front is evident in the convergence of higher reflectivities at both times, indicated by the red arrows.

RU-WRF model results from that day, using the new RU-COOL composite SST product as bottom boundary conditions, are consistent with the general initiation time of the sea breeze front (~15 UTC) along the NJ coast (Figure 4). In addition, RU-WRF dissipates the sea breeze front at about 00 UTC on the 14th, which matches well with time of dissipation indicated by the KDIX weather radar. Therefore, our RU-WRF model run correctly validates inshore with the available KDIX Doppler weather radar.

Note the surface divergence of winds just offshore of the coast in Figure 4, extending from Long Beach Island south to Cape May. This general weak offshore zone of winds, common in similar sea breeze circulations, coincides with future offshore wind development areas. Thus, it is critical to validate the offshore component of this sea breeze case to ensure correct analysis of offshore wind variability.

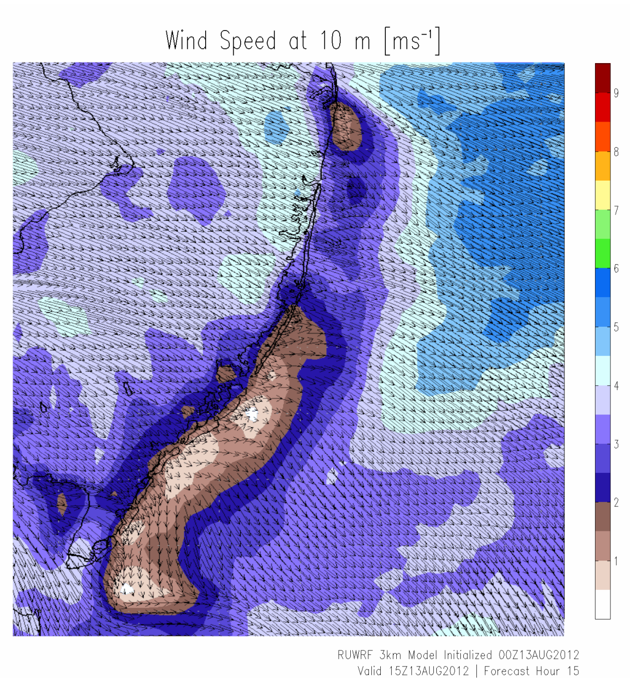

Fig. 4. RU-WRF model results from August 13, 2012 initiate the sea breeze front along the NJ coast at about 15 UTC.

To validate the model offshore for this case, high frequency (HF) coastal radar (CODAR) is used [4]. A thirteen MHZ HF radar network was installed as part of the current offshore wind assessment project for New Jersey as funded by the New Jersey Board of Public Utilities (NJBPU). This nested CODAR network provides hourly high-resolution surface current maps in near-real time. By monitoring the spatial patterns in the surface current data from the installed CODAR network, we can begin to resolve the spatial variability in surface winds offshore.

The elongated zone of surface divergence and weak winds apparent in the model just offshore, extending from southeast of Cape May north to Long Beach Island (Figure 4) is also apparent in the CODAR de-tided current velocities (Figure 5). These velocities are hourly-averaged, centered at 16 UTC. Furthermore, the area of higher wind speeds (approaching 6 m $s^{-1)}$ farther north and offshore in the model (Figure 4) can be seen in the stronger surface currents in the CODAR data south of Long Island and north of Long Beach Island (Figure 5). We can begin to validate these mesoscale details in the surface wind patterns offshore from the model against surface current data from the new CODAR system.

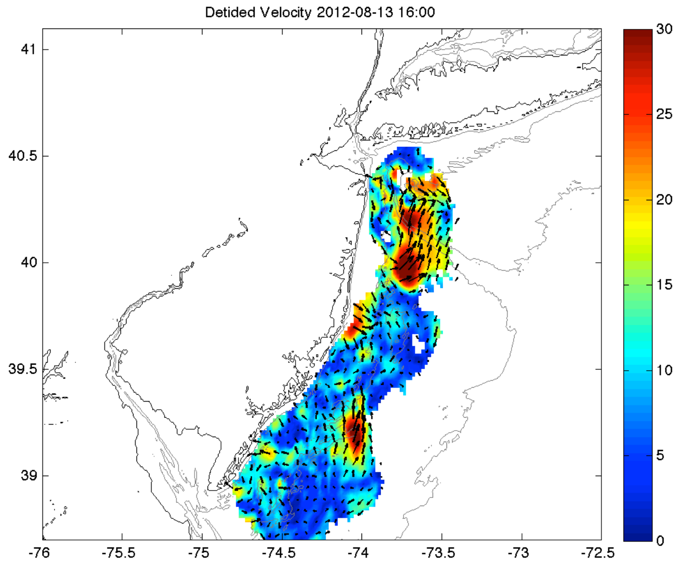

Fig. 5. CODAR hourly-averaged de-tided current velocities from August 13, 2012, centered at 16 UTC. Units contoured are cm/s.

IV. Conclusions

With a new and unique method of de-clouding and compositing SST from satellites, we can begin to preserve and resolve coastal upwelling as evidenced on August 13, 2012. Using this new satellite SST product as improved bottom boundary conditions over water for the RU-WRF atmospheric model, more reliable and accurate wind resource assessments and precise operational forecasts of winds can be achieved.

In the August 13, 2012 case study, the RU-WRF model validates inshore via the KDIX Doppler weather radar; the model's initiation timing and general propagation of the sea breeze front inland matches well with observed surface convergence of dust and other particulates along the sea breeze front apparent in the radar data. The RU-WRF model also validates for the case study offshore via CODAR surface current observations; small-scale variability in the modeled winds (surface divergence, weak wind zone) aligns well with observed de-tided current velocities from the installed CODAR system.

In this study, we have begun to resolve and understand the offshore properties of the sea breeze circulation, which are critical factors in determining accurate offshore wind resource assessments and analyses, especially during hot summer afternoons when energy demand is at its peak. Additional cases (e.g. upwelling vs. non-upwelling, RTG vs. SPoRT vs. RU-COOL SST runs, NAM and GFS vs. RU-WRF) will be analyzed and SST sensitivity runs will be conducted to further refine diagnoses and prognoses of the offshore component of the sea breeze.

Acknowledgments

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