2.1 THE BEST WINDS FOR OCEAN MODELS?

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1. INTRODUCTION

Shallow seas and wide continental shelves respond dramatically to local energetic episodic wind forcing, such as atmospheric fronts and tropical storms. High-resolution ocean models show great promise in simulating the ocean environment at these regional scales, but are often limited by the availability of gridded wind fields for surface fluxes that have high enough spatial and temporal resolution to adequately capture these strong events. Numerical weather prediction products are typically too coarse and the fields can be too smooth to adequately resolve these energetic systems. Winds measured by the Seawinds scatterometer aboard the Quikscat satellite have admirable quality and spatial resolution, but the bandlike sampling can lead to large temporal gaps at some locations, which complicate the representation of moving weather systems. In this study, comparisons are made between results of a numerical model of the Gulf of Mexico (GoM) forced by objectively gridded satellite scatterometer winds, Eta-29 atmospheric model forecast data, and a hybrid of the satellite and numerical weather prediction products. Validation of the model results with in-situ observations shows the strengths and weaknesses of using the different gridded winds for modeling the region. Particular attention is paid to episodic weather events, such as tropical systems and atmospheric fronts. The West Florida Shelf (WFS) region is chosen for the focus of this study as a testbed for examining how best to use satellite derived winds to force regional-scale ocean models.

2 THE MODEL

This study evaluates the solution from simulations of the GoM using the Navy Coastal Ocean Model (NCOM). The NCOM is a three-dimensional primitive equation hydrostatic ocean model developed at the Navy Research Laboratory (see *Martin* [2000]). The model's hybrid sigma (terrain following) and z (geopotential) level vertical coordinate is useful for simulating upper ocean processes in domains encompassing both deep ocean basins and very shallow shelves. The NCOM is set up to simulate the

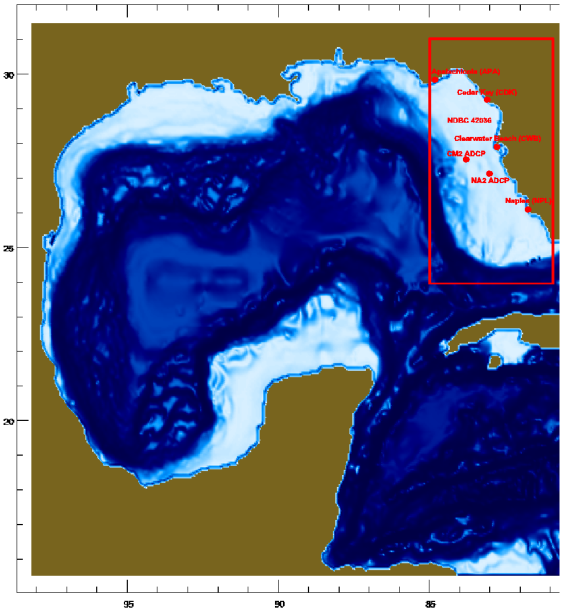

Fig. 1. NCOM simulation domain and topography. The locations of the data sources used in this study are shown: Sea level data from four coastal stations, and horizontal vector velocity data from ADCPs. The ADCP data were collected as part of the Coastal Ocean Monitoring and Prediction System at the University of South Florida.

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entire GoM and Caribbean north of Honduras (15° 30' N) to 80° 36' W with 1/20° between like variables on the C-grid, 20 sigma levels above 100 m and 20 z-levels below 100 m to a maximum depth of 4000 m (Figure 1). The model is forced by discharge from 30 rivers, transport through the open boundary (with monthly climatology temperature and salinity) yielding a mean transport through the Yucatan Strait of approximately 30 Sv, monthly climatology surface heat flux, and twelve-hourly winds. A surface salinity flux has the effect of uniformly evaporating an amount of water at a rate equal to the sum of the annual average discharge rates of the 30 rivers. The model is spun up from rest using DaSilva monthly climatology wind stress for approximately five and one-half years before the twelve-hourly wind stresses are applied.

$$\boldsymbol{\tau} = \rho \quad C_{DN} U_{10EN} \mathbf{U}_{10EN}, \tag{1}$$

The background is calculated as a weighted average of the scatterometer observations. The Gaussian weighting function has spatial standard deviation of 50 km, and a temporal standard deviation of 12 hours. Spatial and temporal displacements of greater that three standard deviations are not considered in the averages.

3 THE WIND FIELDS

Three gridded wind products are used to force the ocean model: the 29 km resolution Eta-29 model 10 m winds, winds derived from the SeaWinds scatterometer aboard the QuikSCAT satellite objectively mapped to a 1/2° grid using winds from the same scatterometer data to create a background field, and another mapping of the QuikSCAT winds using the Eta-29 winds as the background field (these three wind fields will be termed ETA, QSCAT, and QSCAT/ETA, respectively, for convenience). Wind stress fields are prepared to force the ocean model from July 21, 1999 through the end of 2000. The starting date corresponds to the beginning of the QuikSCAT observations.

To form the two gridded scatterometer wind products, the pseudostress is objectively gridded using the variational method described by *Pegion et al.* [2000]. The functional

$$\begin{aligned} f = \sum_{i,j}^{I,J} \Big\{ & \beta_a \sigma_{P_o}^{-2} \left[\left(P_x - P_{x_o} \right)^2 - \left(P_y - P_{y_o} \right)^2 \right] + \\ & \beta_d L^4 \left[\nabla^2 \left(P_x - P_{x_{bg}} \right) \right]^2 + \\ & \beta_d L^4 \left[\nabla^2 \left(P_y - P_{y_{bg}} \right) \right]^2 + \\ & \beta_e L^2 \left[k \cdot \nabla \times \left(\vec{P} - \vec{P}_{bg} \right) \right]^2 \Big\} \end{aligned} \tag{2}$$

is minimized for the solution pseudostress (P_x, P_y). Here, the terms with the small 'o' subscripts are the observations from the satellite, and the terms with the small 'bg' subscripts are the background field. The betas are weights, sigma is the uncertainty of the observational average within a grid cell, and *L* is a grid-spacing dependent dimensionless length scale. The first term represents the misfits to the scatterometer observations, the second and third terms comprise a penalty function to smooth with respect to the background field, and the last term is the misfit to the vorticity of the background field.

For the QSCAT gridded wind product, the background field is constructed from 3-day binned QuikSCAT wind data, Gaussian smoothed with a 2° and 6 hour standard deviations. For the QSCAT/ETA product, the background field is the Eta-29 wind field.

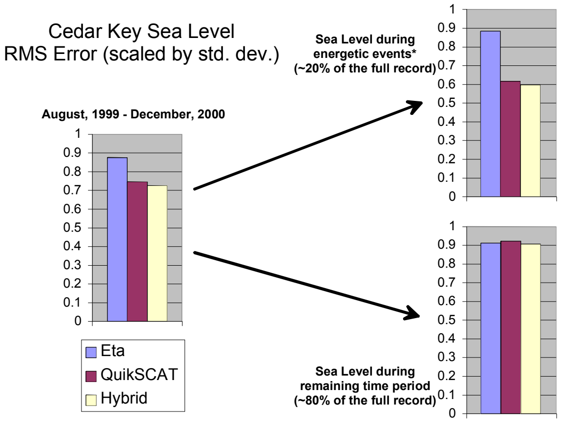
Observations collected within a twelve-hour window centered on 0:00Z or 12:00Z are treated as the observations at the middle of the time window. Therefore, twelve hourly gridded wind pseudostress fields are produced. For consistency, the Eta-29 wind fields from the same twice-daily times are selected for the model experiments. The wind stress is computed from the bulk formula with the drag coefficients computed using a quadratic function of the wind speed. The resultant wind stress is interpolated to the ocean model grid using bicubic splines.

4 RESULTS

The ocean model solutions are compared to data collected over the WFS. The WFS is chosen as a test-bed for evaluating the impact of the different wind stress fields as forcing for coastal and regional scale ocean models because it has been shown that the circulation on the inner and middle WFS is primarily driven by local winds (See Weisberg, et al. [2001]). The region is also subject to episodic energetic forcing from tropical and extratropical storms. It is useful to study the response of the ocean model forced by the various wind products during these periods of energetic forcing. Data are collected from coastal sea level (SL) stations and from a moored acoustic doppler current profiler deployed as part of the Coastal Ocean Monitoring and Prediction program at the University of South Florida. Only the SL comparisons will be discussed here.

SL time series from the NCOM experiments are compared to in situ data at four stations along the WFS: Naples, Clearwater Beach, Cedar Key, and Apalachicola (Figure 1). The observational and model data are filtered to form sets of daily SL values. SL root mean square error (RMSE) scaled by the standard deviation (of the observational data computed over same time record used for computing RMSE) is used as one metric for evaluating the model performance. SL can be thought of as a function of the wind stress (alongshore) integrated along the characteristics of the coastally trapped waves, propagating counterclockwise around the GoM. The Florida Keys to the south of the shelf act to approximate an insulating boundary.

The results are similar for all stations studied; Cedar Key is used as an example here. The standard deviation of the observations is 13.1 cm for the full time record studied at this location. The scaled RMSEs are 0.88, 0.75, and 0.73 for the simulations forced by ETA, QSCAT, and QSCAT/ETA, respectively (Fig. 2). To study the different behavior of the ocean model response to energetic wind forcing versus the more typical conditions, the time record is decomposed into two parts. The first consists of all data within a 7-day window centered around any day with observed SL fluctuations greater than two standard deviations (26.2 cm, in this case) of the mean. This record comprises approximately 20% of the data. Most of this subset of data is from the late fall through early spring months when there are frequent passages of cold fronts through the region, with occasional tropical cyclones (three passed during this period) during the summer and early fall months. The second part of the decomposed record consists of the remaining data, and contains more moderate or weak SL fluctuations. The results show that during weak or moderate events the simulations perform similarly with scaled (now by a standard deviation of 9.5 cm) RMSEs of 0.91, 0.92, and 0.91 corresponding to the ETA, QSCAT, and QSCAT/ETA forced simulations, respectively (Fig. 2). However, during the part of the record corresponding to energetic SL fluctuations (and, thus, more energetic forcing), the simulations forced by the scatterometer derived gridded wind products perform much better. Scaled (by a standard deviation of 20.2 cm) RMSEs are 0.88, 0.62, and 0.60 for the simulations as ordered above. That is, using this metric, the model solution shows significant improvement when the QSCAT and QSCAT/ETA gridded wind stress fields are used during periods of energetic wind forcing, however, the model performance is similar under all conditions when forced by the ETA wind stress fields.



* "Energetic events" defined as |observed sea level| > 2 standard deviations with 7 - day window

Figure 2. Cedar Key's RMS sea level, scaled by it's standard deviation. Partitioning energetic and non-energetic events highlights shortcomings of the Eta winds for energetic events.

5 DISCUSSION

The large errors in the model solution when forced by the ETA wind stress fields are primarily due to the fact that the ETA wind fields are smooth and weak (Fig. 3), a trait often found in numerical weather prediction products. The scatterometer observations are better able to represent the intensity and spatial patterns of energetic weather systems. Comparisons of the wind stress from the gridded products to the wind stress computed from National Data Buoy Center measurements show that the average ETA wind stress is approximately 50% of the magnitude of the observations, whereas the scatterometer derived wind stress fields have quite similar magnitudes to the observations in this region. It is not clear, however, whether simply multiplying the ETA wind stress vectors by a scalar is an appropriate solution, as the spatial structure of QSCAT and QSCAT/ETA fields is often quite different from the ETA fields. An example from each of the three fields during the passage of Tropical Storm Harvey illustrates this fact (Fig. 4).

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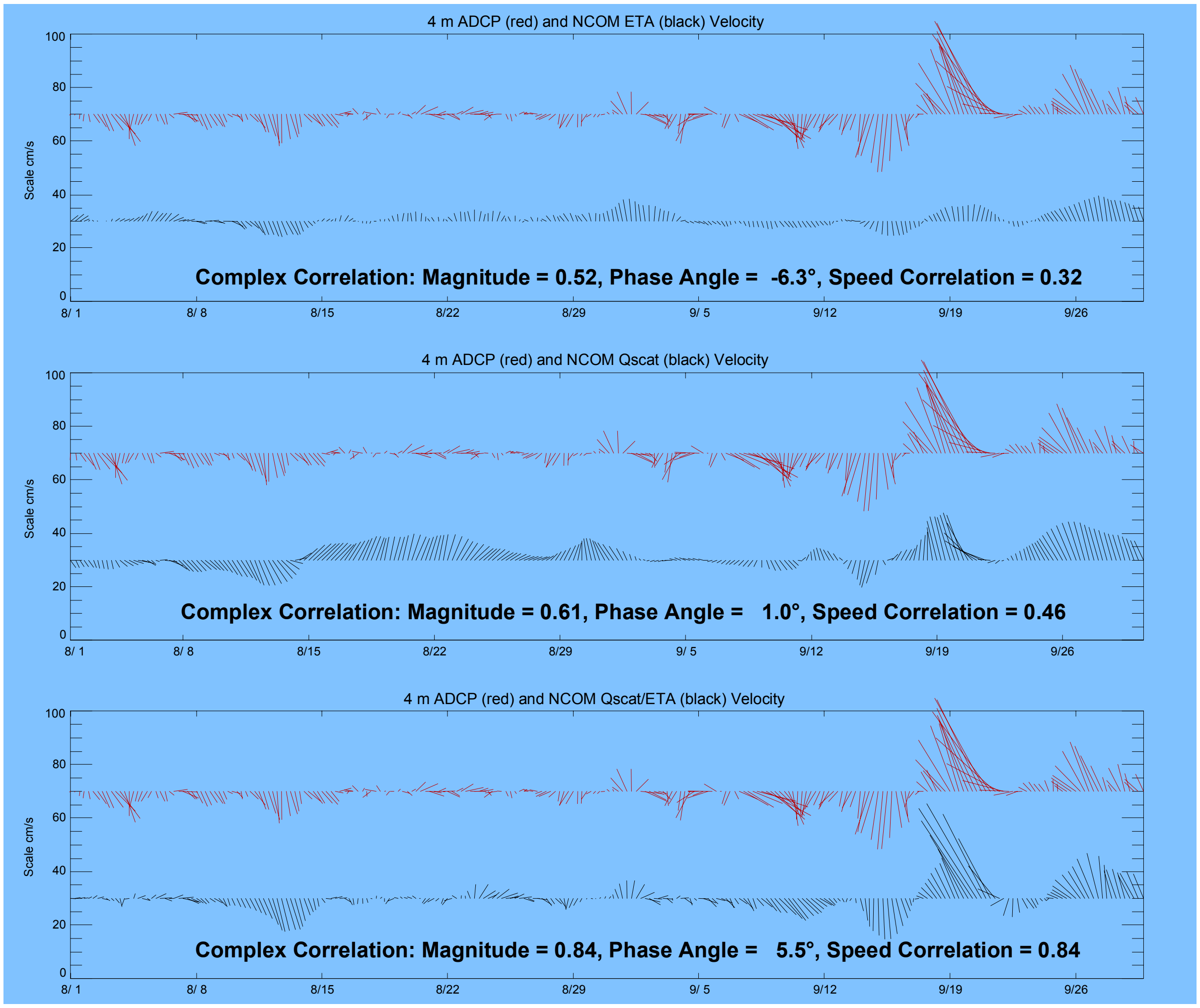

Figure3. Vector time series for modeled 4m currents (black), compared to ADCP observations (red), for model runs forced with each gridded product (top: Eta; middle: QSCAT; and bottom: QSCAT/Eta hybrid).

ADCP data. Simulations were performed on the IBM SPs at Florida State University and the Naval Oceanographic Office. Computer time was provided by the DoD High Performance Computing Modernization Office. This project was sponsored by funding provided by the DoD Distributed Marine Environment Forecast System, by the Office of Naval Research Secretary of the Navy grant awarded to Dr. James J. O'Brien, by a NASA Office of Earth Science grant to the COAPS authors and through NASA funding for the Ocean Vector wind Science Team. Frank Wentz at Remote Sensing Systems produced the scatterometer data.

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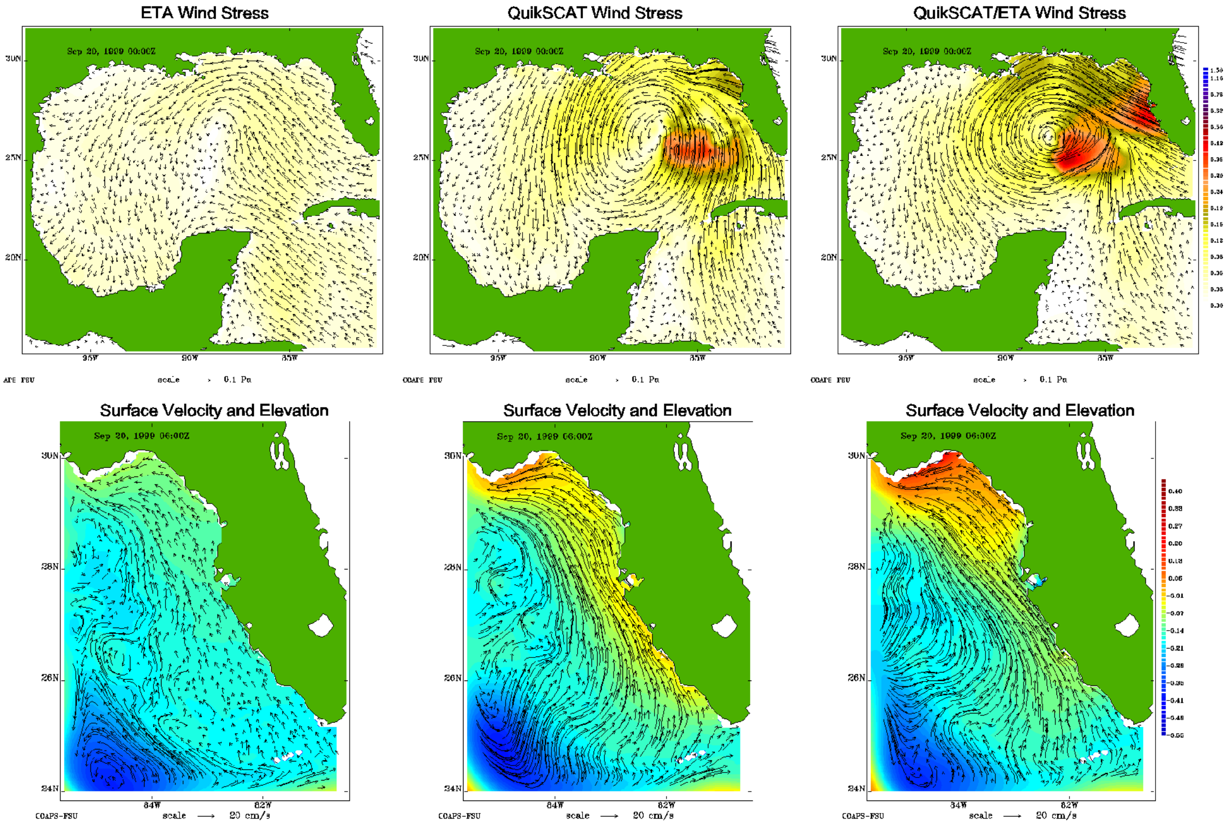

Figure 4: Top: wind stress (Nm^{-2}) fields from the gridded ETA (left), QSCAT (middle) and QSCAT/ETA (right) wind stress fields on September 20, 1999, just prior to T.S. Harvey passing eastward over the WFS. Bottom: surface velocity (vectors) and surface height change (colors) associated with the above wind stresses products.