P1.2 DEVELOPING A SIMPLE 2D OCEAN MODEL FOR THE EVALUATION OF THE MM5 RESULTS OVER BODEGA BAY

Adam Kochanski and Darko Koracin
Desert Research Institute, Reno, Nevada

Clive Dorman
Scripps Institution of Oceanography, San Diego, California
San Diego State University, San Diego, California

1. INTRODUCTION

The wind stress, generated by a wind over the ocean surface, and the wind stress curl are crucial to generating ocean circulations. However, the available data have serious limitations. The buoy data show only characteristics of the meteorological situation at certain locations and don't provide sufficient information about the spatial distribution of the wind speed. Therefore, a computation of the wind stress curl, which is extremely important in the generation of the upwelling, can not be performed based only on the buoy data. The satellite data, on the other hand, provide a spatial picture of the wind speed, but their sparse resolution and the lack of valid data close to the shore limits their application to the coastal ocean simulations. Because of that, the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) seems to be a good alternative data source that could be used for forcing the ocean models, if it provides accurate results in coastal areas. Hence, the main goal of this work is to examine how the MM5 model performs in the coastal area of Bodega Bay and if its results can be used for forcing ocean models.

2. MODELS SETUP

The atmospheric MM5 model examined in our study was set up for two domains: the first one with a 9km resolution, and the second one, nested, with a 1km resolution.

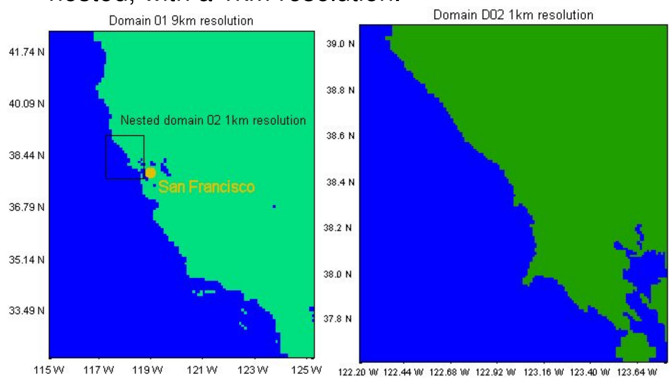

Fig. 1. The analyzed domains for the MM5 and the reduced-gravity 2D ocean models. Simulated period: 07.01.2001 through 07.31.2001 – 744 h.

The area covered by the two model domains was: first domain, 31.84-42.41 north and 114.99-126.53 west - 103x127 grid points; the second domain, 37.65-39.05 north, 122.27-123.87 west - 133x148 grid points (see Fig.1). For simulating the ocean response to modeled atmospheric forcing a reduced-gravity 2D ocean model proposed by Enriquez and Friehe (1995) was used. In order to avoid problems with data interpolation, the ocean model domains were set up in such a way that the MM5 and the 2D model grid points matched with each other.

3. BASIC VALIDATION OF THE MM5 DATA

For the simulation of the ocean response to atmospheric forcing the accuracy of the wind speed is extremely important (Charney 1955). Therefore, the first step of our study is the validation of the model-simulated winds by comparison with the data from the measurement buoy. Figure 2 shows the time series of the wind speed as simulated by MM5 and as measured by buoy 46013 for July 2001.

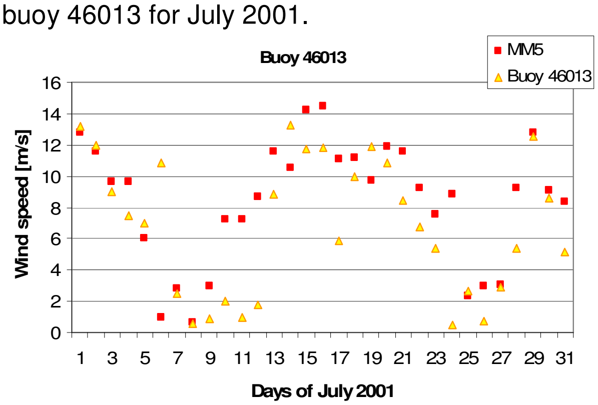

Fig. 2. The wind speed computed from MM5 model and measured by buoy 46013 (Bodega Bay).

As can be noticed, the values of the wind speed simulated by the MM5 model are very similar to those measured by the buoy. All trends of increase or decrease in the wind strength showed by the buoys are represented by the model with high accuracy. The overall correlation factor between MM5 and buoy data for the analyzed period is equal to 0.7 which suggests that the model winds and wind stress can be used as a source of data for the analyzed area.

Beside the wind stress, the wind stress curl also plays an important role in generating vertical ocean circulations in the area of Bodega Bay (Dever et al. 2006). In order to see if the MM5 model is capable of simulating the wind stress curl pattern, the model-computed curl was compared with the curl derived from set of buoys 46013, D090 and E090 (shown in Fig.3), that were deployed during the WEST experiment (Largier at al. 2006).

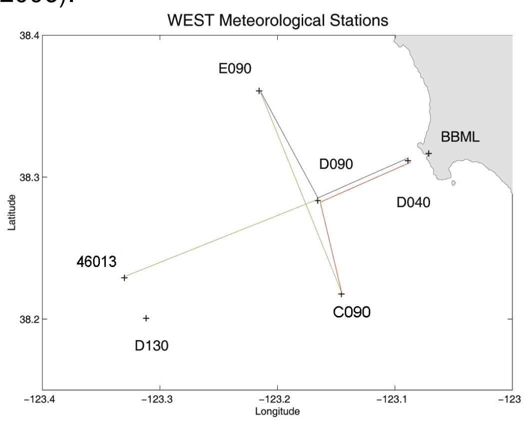

Fig. 3. Location of buoys used for wind stress curl computation (46013, D090, E090)

Figure 4 shows time series of the wind stress curl computed using data obtained from measurement buoys (schemes 2 and 3), and simulated by the meteorological mesoscale model MM5 for the locations of buoys D090 and E090. In both cases the wind stress was computed using the Large and Pond formula (Large and Pond 1980). Figure 4 shows that the model was able to predict the magnitude and the general trend of the wind stress curl; however, in some cases significant discrepancies between the measured and modeled data can be observed. During the first week of the considered period (168 hours) the model slightly underestimated the wind stress curl, whereas during the next five-day episode of relaxation (weak wind stress curl) the measured and predicted values were on a similar level. During the period from the 12 to the 16th of July (hours 288 to 384), both modeled and measured wind stress increased rapidly to the level of about 1.5 Pa/100 km; however, the peak value predicted by the model was around 15% higher than that measured by buoys. Further oscillations in the wind stress curl occurred between 17 and 21 June 2001 and were not very precisely predicted by the model. During the first part of this period the model underestimated the wind stress curl, whereas during the second part the model overestimated it. Even though there is some bias between the measured and predicted values, the amplitude of the wind stress oscillations was reproduced by the model with good accuracy. During the next period both the model and buoys show stabilization of the wind stress, approaching a value of 0.1 Pa/100km. However in this case, the amplitude of the model curl is slightly higher than that measured by buoys. The episode of last upwelling occurring between 28th and 29th of July, as well as the sudden drop and rise of the wind stress curl that occurred on 30 June, were predicted with very good accuracy.

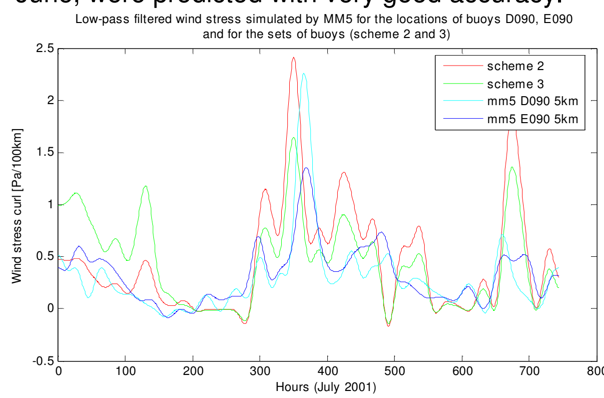

Fig. 4. 38h low-pass filtered wind stress curl computed by MM5 model and measured by the set of three buoys.

Despite some discrepancies described above, the MM5 model was able to reproduce the magnitude and general trend of the wind stress curl. The overall correlation factor between the MM5 and the buoy-computed curl (Scheme 2) was equal to 0.6, which is a good result, keeping in mind that the buoy-derived wind stress curl can not be considered as ground truth. In fact, based on the data from a set of three buoys (in our case 46013, D090 and E090) the wind stress curl can be computed in various ways that provide significantly different results. In Fig.4 we presented examples of buoy wind stress curl derived according to two different schemes. In Scheme 2 the wind stress curl was computed as follows:

Curl= $(\tau_{yD090}-\tau_{y46013})/\Delta x - (\tau_{xE090}-\tau_{xD090})/\Delta y$

In Scheme 3 the curl was computed according to the following formula:

Curl= $(\tau_{yD090}-\tau_{y46013})/\Delta x - (\tau_{xE090}-\tau_{x46013})/\Delta y$, where τ is the wind stress component, and Δx and Δy are the east-west and north-south distance between buoys. As can be seen, the difference just between two schemes used for wind stress curl computation from buoy data is significant. For the two analyzed schemes, the differences in magnitude can reach 0.75 Pa/100 km, with an overall correlation factor equal to 0.7. Because of this uncertainty the buoy-derived wind stress curl can not be used for clear verification of MM5 results and an additional analysis described in Section 4 is needed.

4. VERIFICATION OF MM5 RESULTS USING THE 2D OCEAN MODEL

The verification of the MM5 results, by comparison with the buoy-derived wind stress curl is questionable because of the uncertainties in the wind stress curl computed from buoy data (see the previous section). Therefore we decided to use an indirect method for the analysis of the applicability of MM5 data to the coastal ocean simulation. There are no spatial wind stress data of desired resolution for the analyzed area and period. However, there is the high frequency radar (CODAR) data, presenting the pattern of surface currents induced by the wind. Therefore, we force the simple 2D ocean model with the MM5 data, and then, we determine the applicability of this data based on a comparison between the simulated and measured ocean current pattern. Detailed information about the radar setup and the measurement methodology can be found in Kaplan and Largier (2006).

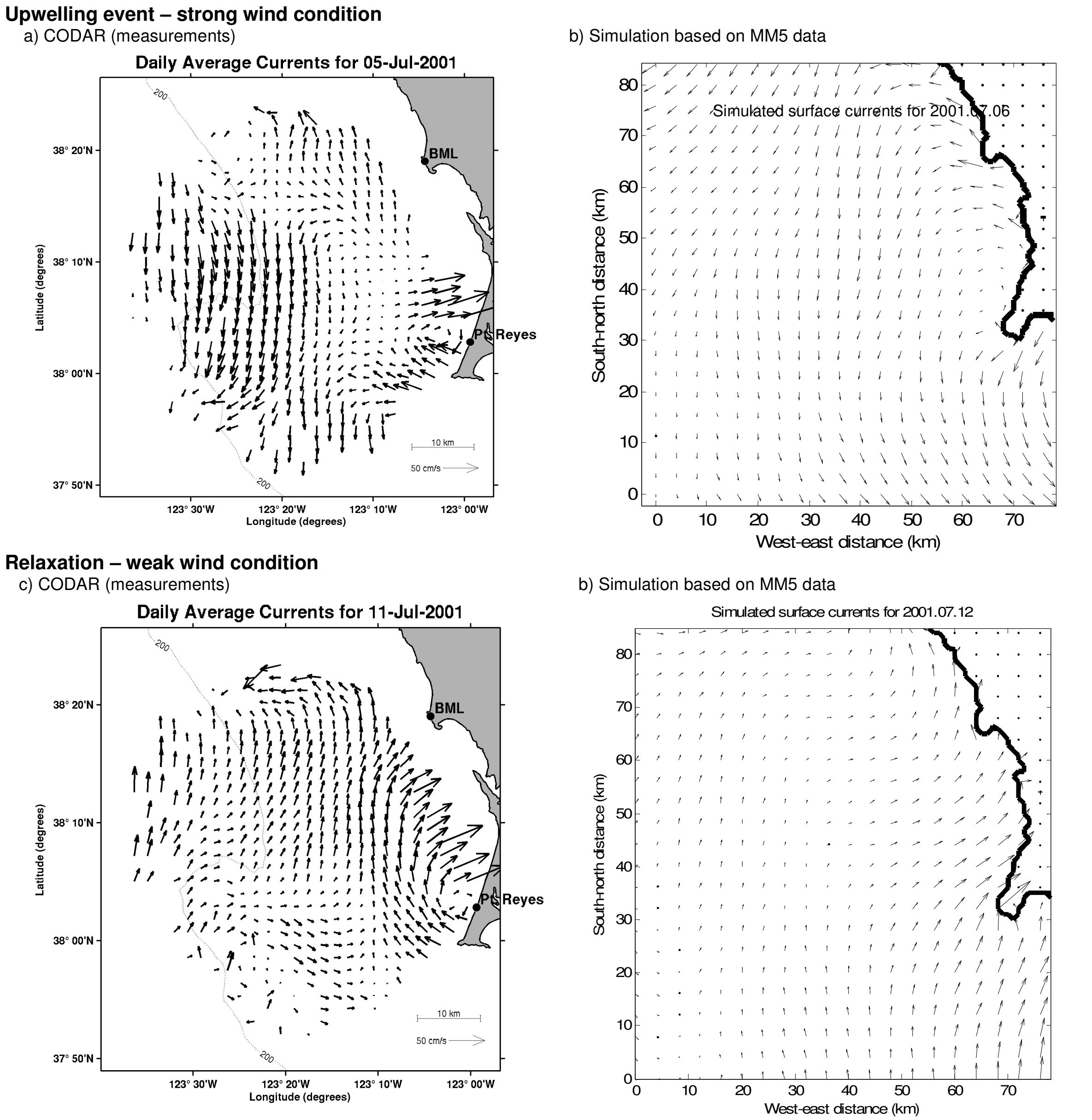

Fig.5. Comparison between the measured and simulated surface currents for the upwelling period a) and b) and relaxation period c) and d).

In order to validate the surface currents obtained from the 2D ocean model forced with MM5 data, two cases were examined: the first one for the strong wind speed conditions corresponding to upwelling (mean wind speed 15.4 m/s), and the second one for weak wind conditions during the relaxation period (mean wind speed 1.5 m/s). In both cases the simulated results were compared with the CODAR data. The comparison between the surface current simulated by the model and measured by CODAR is presented in Fig. 5.

For strong winds (Fig. 5a) the main measured current is located in the middle of the domain and transports the surface water toward the south. A similar feature can be noticed in a Fig. 5 b) showing the simulated surface currents. The direction of this current corresponds to the mean wind stress direction (along the shore) deflected to the right by Coriolis force. Also the counter-clockwise water circulation west of the Bodega Marine Laboratory (BML) evident on the CODAR picture can be noticed on the figure showing the modeled circulation. However, the location of this eddy is slightly misinterpreted by the model which predicted this feature closer to the shore. The change of the strength of the surface currents seems to be well represented by the model. The strongest currents simulated by the 2D ocean model are located close to the shore and weaken offshore in manner similar to what can be observed in the CODAR data. Also the clockwise eddy forming close to Point Rayes has its representation in the modeled pattern. However, the westward component of the current located south of this cape is not accurately represented by the model. Also, the currents in the southern part of the domain are not represented accurately. The probable reason for that may be the sudden change of the ocean depth over the south part which is not taken into account by the deployed two-dimensional simple ocean model.

The simulated and measured currents for low wind speed conditions are presented in Fig. 5 c, d. When the wind calms the relaxation occurs - the masses of water pushed by the wind toward the south and "piled up" over there move back northward. This phenomenon is apparent both in Fig. 5 c representing the measured data, as well as in Fig. 5 d showing the pattern of simulated surface currents. Also, the counter-clockwise rotation of currents in the vicinity of BML, as well as the change of direction toward the east in the vicinity of Pt. Reyes, can be noticed both in CODAR and in the modeled currents pattern. However, the location of these features is moved slightly toward the shore with respect to measurement data. The southern part of the analyzed domain (south of Pt. Reyes) corresponding to the rapid change in bathymetry seems not to be accurately simulated, probably more due to the 2D model limitations than because of the inaccuracy in MM5 data.

In general, all of the main features observed in the CODAR measurements have their representation in simulation, which confirms that using the MM5 model for forcing the ocean models is a good alternative. Of course, the performed analysis does not evaluate quantitatively the MM5 results, but it shows that in practical applications the accuracy of the MM5 data is good enough for using them as an input for ocean models in coastal areas. In the presented case, observed discrepancies between measured and simulated ocean current pattern is more the result of the simplicity of the 2D ocean model than inaccuracy of MM5 results. Further investigations, including direct wind stress measurements and more advanced ocean models, are required to provide more quantitative conclusion.

7. ACKNOWLEDGEMENT

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8. References

Charney, J. G.,1955: The generation of ocean currents by wind. *J. Mar. Res.*, **14**, 477-498

Dever, E.P., Dorman, C.E., Largier, J.L., 2006. Surface boundary layer variability off northern California, USA during upwelling, *Deep-Sea Research II*, **53** (2006) 2887–2905.

Enriquez A. G., Friehe C. A. 1995: Effects of Wind Stress and Wind Stress Curl Variability on Coastal Upwelling. *J. Phys. Ocean.,***25**, 1651-1671

Kaplan David M., John Largier 2006: HF radar-derived origin and destination of surface waters off Bodega Bay, California, *Deep-Sea Research II* **53** (2006) 2906–2930

Large, W. G., and S. Pond, 1981: Open ocean momentum flux measurements in moderate to strong winds. *J. Phys. Ocean*, **11**, 324-481.

Largier John L. and coauthors, WEST: A northern California study of the role of wind-driven transport in the productivity of coastal plankton communities, *Deep-Sea Research II* **53** (2006) 2833–2849