Altimetry and operational wind-wave prediction - combined use to enhance both systems

D. Vandemark[1], H. Feng[1], F. Arduin[2], B. Chapron[3], N.Tran[4], H. Tolman[5], B. Beckley[6]

[1]Ocean Process Analysis Lab ,University of New Hampshire, USA;
[2]Hydrographic and Oceanographic Service, Brest, France; [3]IFREMER/Centre de Brest, France;
[4]CLS, Ramonville StAgne, France ; [5]NOAA/NCEP/EMC, Camp Springs, MD USA ; [6]SGT, Inc., Greenbelt MD USA

University of New Hampshire

I. Abstract

Marine wave forecasting offices now operationally assimilate ocean significant wave height data, derived globally from satellite altimetry, and consider these data as an important staple. Indeed their use leads to not only enhanced model performance but these data represent also a valuable model validation data source. However, there is still significant room for marine wave forecast improvement and areas where altimetry can contribute even more. This is particularly true, for instance, for constraining model prediction in regions of storms and strong currents where wave breaking and wave/current interaction processes are central to many aspects of a fully coupled atmosphere-ocean system.

During the course of this project, we will perform a series of studies on ocean surface gravity waves in order to improve their prediction. Our primary materials will be a state-of-the-art ocean surface wave model and satellite altimeter data from the Jason-1, OSTM, Topex/Poseidon, and Envisat missions. This will be supplemented by surface fields such as NWP and scatterometry winds, OGCM and altimeter-derived ocean surface currents, and by directional wave buoy measurements. Two objectives will be pursued: (1) an analysis of wind-wave processes based on twin experiments with a WAVEWATCH 3 model hindcast that does not assimilate altimeter sea state data – since the focus is on the evaluation of the model physics. The extensive NDBC and directional wave buoy network will be central to this analysis for independent validation and algorithm developments. Resulting changes to the model will be implemented as part of operational marine wind and wave prediction efforts at NCEP. (2) We will also complete the development of an alternative approach to operational correction for OSTM altimeter sea level estimate error due to unresolved variability in wind-wave conditions. This sea state bias correction works with a blend of altimeter and wave model data at each point along the satellite track. The improved sea state range correction results are expected to move OSTM altimeter accuracy towards the 2.5 cm goal. Overall, the project results are intended to strengthen growing ties between satellite altimetry and operational oceanography.

II. Objectives and Near-Term Research

Overall Framework

This research is being conducted in tandem directions with the understanding that these efforts need to merge as improvements are made in both wave modeling and sea state range bias corrections. One operational goal is use of NCEP and/or ECMWF wave model products in routine sea state bias correction for sea level estimates. As presented below, the two project tasks are:

A. Assessment and improvement of numerical wave model output through altimeter-constrained approaches

B. Refinement of empirical sea state bias algorithms for both Jason-1 and Jason-2 altimeters through use of WAVEWATCH 3 hindcast data.

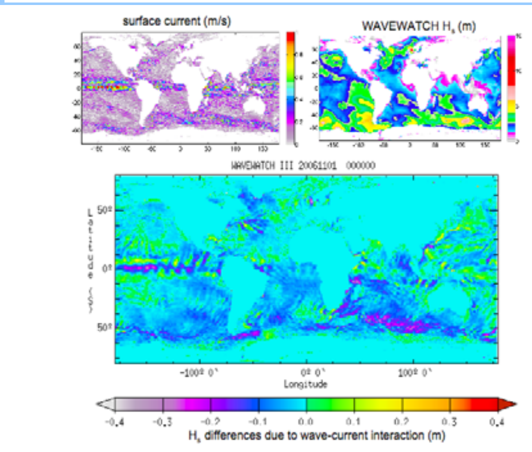
Year One Activities

A. WAVEWATCH 3 Model Investigations (Ardhuin et al.)
- Evaluate wave/current interaction impact on global wave model data
- Utilize altimeter backscatter data to constrain wave dissipation estimates within the wave model

B. Sea State Bias Modeling (Vandemark et al.)
- Implement latest version WAVEWATCH 3 code (Ver 3.04) and rebuild 2000-2009 J1 and J2 SSB algorithm support data sets for UNH and CLS
- Complete development of the first version of a global three-dimensional sea state bias model (see Tran et al. this meeting)
- Investigate alternate NP methods for sea state bias inversion to gain speed and possibly accuracy (see Feng et al. this meeting)

III. WAVEWATCH 3 Investigations

Study One - Wave/Current Interaction: At this stage, operational surface wind-wave modeling does not typically make use of surface current data to alter the predicted sea state, mostly because the velocity data do not exist at the required accuracy and resolution. However, MERCATOR and OSCAR surface current products are now maturing to the stage where the existing wave/current interaction physics within models such as WAVEWATCH 3 can be tested. Our initial evaluations (using MERCATOR currents within model runs) suggest that **wave field interactions with persistent equatorial flows are not negligible** and thus we will be using these satellite-informed surface current products to further investigate hindcast accuracy as well as the impact of these model output changes in sea state bias correction determination.



Wave/Current Interaction Demonstration

Shown at left are-

• Surface current estimates from MERCATOR

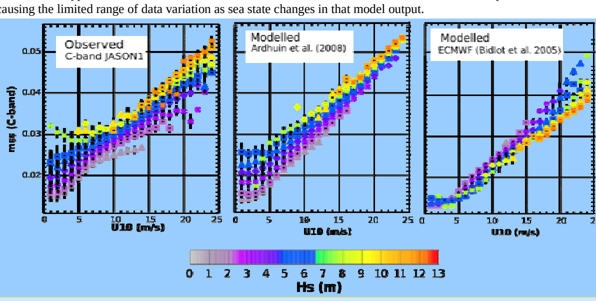
• Sea state (in m) from the wave model

• Difference in sea state (m) between a model run with and w/o surface currents as a surface boundary condition

First indications are that the physics within the model appear sound and that significant systematic changes within the 2D wave spectrum will occur and can be validated and evaluated.

Study Two - Revision of Wave Model Dissipation Formulation: The balance of wave action is driven in most wave models by wind input, nonlinear wave-wave interaction, and energy dissipation terms. Recently, Ardhuin et al. (2008) have been evaluating new methodologies for using SAR and altimetry to evaluate and modify the dissipation term of swell and shorter gravity waves within the WAM and WAVEWATCH 3 models. The standard physics used for our comparisons hails from ECMWF - Bidlot et al. (2005). **For constraint and validation of model adjustment, we are using Jason-1 and Jason-2 C-band altimeter backscatter and SWH data** (Feng et al., 2006; Gourrion et al., 2002) **to estimate the sea surface slope variance** for long to intermediate scale gravity waves and then comparing this to the revised WAVEWATCH data (Hamon, 2008; Ardhuin et al. 2008). **Shown below:**

- Three averaged estimates of the longer wave mean square slope (0.4 Hz cutoff) with the altimeter estimates similar to buoy-derived data. **Note the wave height (Hs) dependence of the data for a given wind speed (U10).**
- The Ardhuin 2008 results are showing much closer agreement to the satellite-derived slope data.
- It is hypothesized that the role of the mean wavenumber <k> within the Bidlot et al. dissipation term formulation is causing the limited range of data variation as sea state changes in that model output.



References

Ardhuin, F., N. Rascle, and K. A. Belibassakis, "Explicit wave-averaged primitive equations using a generalized Lagrangian mean," Ocean Modelling, **2008** in press. See also [http://arxiv.org/abs/physics/0702067].

Bidlot, J., S. Abdalla, and P. Janssen, "A revised formulation for ocean wave dissipation in CY25R1," Tech. Rep. Memorandum R60.9/JB/0516, Research Department, ECMWF, Reading, U. K.,**2005**.

Feng, H., D. Vandemark, Y. Quilfen, B. Chapron, and B. Beckley, "Assessment of wind-forcing impact on a global wind-wave model using the topex altimeter," Ocean Eng., vol. 33, pp. 1431–1461, **2006**.doi:10.1016/j.oceaneng.2005.10.015.

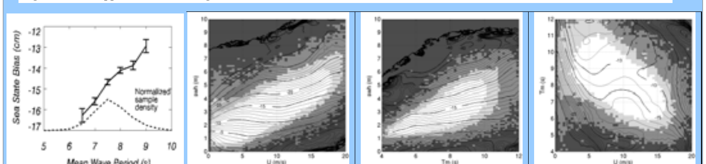
Gourrion J., D. Vandemark, S. A. Bailey, B. Chapron, Investigation of C-band altimeter cross section dependence on wind speed and sea state, Can. J. Rem. Sens., 28(3), 484-489, **2002**.

Hamon, M. Validation of sea state in terms of surface slope data, Masters Dissertation, U. de Bretagne Occ., Brest, **2008**.

IV. Beyond the Two Parameter Sea State Bias Models

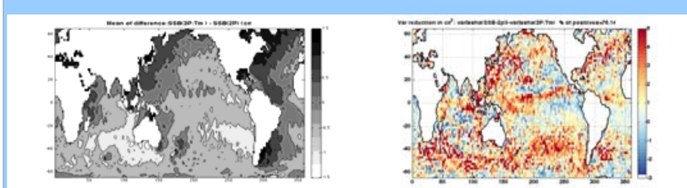
Two guiding assumptions for future work are that 1) daily wave model data are now of high enough quality to support improved altimeter range error estimation from space and, 2) SSB corrections using only the altimeter wave height and wind speed data will contain systematic error that can be improved upon.

Results from ongoing team SSB research will be shown at this meeting (see Feng et al. and Tran et al.). Here we highlight a most recent study to develop a global three dimensional SSB model built using mean wave period (T_m) estimates taken from 2D directional wave spectral output of WAVEWATCH 3 (ver 2.22) along with Jason-1 sea state and wind data. We also continue to evaluate the use of statistical clustering (Vandemark et al., 2006) as a means to devise regionally-tailored SSB algorithms for applications including coastal zone measurements.



A 3D SSB Model for Jason-1 (see Tran et al. this meeting for more details)

Shown above are nonparametric estimates of sea level error explained by the 3D combination of sea state, wind speed, and mean wave period (m_1/m_0). Results are for all Jason-1 data in 2002. The panel above left shows results for case of SWH=3.2 m and U10=9.5 m/s and indicates nearly linear dependence of range error on wave period. Note - longer period wave conditions show a lower SSB and the total range is > 3 cm ~= 1%SWH. Panels at right are slices through the SSB model (3D lookup table) built using Local Linear Kernel smoothing approach (Labroue et al., 2004). Contours represent the SSB (in cm). The fixed values of the 3rd variable in these panels are Tm=8.4 s, U10=9.5 m/s and SWH=3.2m.



Differences with the 2P Jason-1 SSB Model

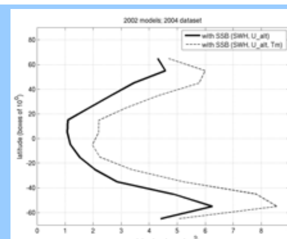
Above left - Spatial mean difference (in cm) between 2D and 3D SSB models over a one year period

Above right - Spatial variation reduction (enhancement) for the 3D vs. 2D SSB models with red being reduction (increased skill).

At right - zonal average of variance reduction for 3D and 2D models versus a 3%SWH benchmark.

1st Conclusions: Overall we are seeing the largest improvements in an SSB model since the 90s - much greater than with the fuzzy clustering or 2D approaches (Tran et al. 2006, Vandemark et al., 2006).

The cross basin mean SSB model differences illustrate the spatial pattern of wave period with its meridional variation rather than zonal as for SWH and U10.



References

Labroue, S, et al., Nonparametric estimates of the sea state bias for the Jason-1 radar altimeter, Marine Geodesy, 27: 531-481, 2004.

Tran N., D. Vandemark, H. Feng, B. Chapron, S. Labroue and B. Beckley. New models for satellite altimeter sea state bias correction developed using global wave model data, J. Geophys. Res.-Oceans, 2006.

Tran N., D. Vandemark, B. Chapron, S. Labroue., H. Feng, J. Lambin, N. Picot, H. Tolman. The sea state bias as determined by a combined use of satellite altimeter and wave model data, this meeting and in preparation, 2008.

Vandemark D., N. Tran, B. Beckley, B. Chapron, and P. Gaspar, Direct estimation of sea state impacts on radar altimeter sea level measurements, *Geophys. Res. Lett.*, 29(24), 2148.doi:10.1029/2002GL015776, 2002.

Vandemark, D., H. Feng, T. S. Moore, N. Tran, B. Chapron and B. Beckley, Use of fuzzy logic clustering analysis to assess wave impacts on altimeter range error estimation, Venice OSTST meeting, ftp://eos.sr.unh.edu/pub/outgoing/DougV, 2006.

Acknowledgments: The research is sponsored by the NASA Science Mission Directorate.

Ocean Surface Topography Science Team Meeting

Nice, France, 10-12 November, 2008