Wave dissipation and balance - NOPP wave project

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LONG-TERM GOALS

Wind-generated waves play a prominent role at the interfaces of the ocean with the atmosphere, land and solid Earth. Waves also define in many ways the appearance of the ocean seen by remote-sensing instruments. Beyond these geophysical aspects, waves also affect human activities at sea and on the coast. The long-term goals of this research are to obtain a better understanding of the physical processes that affect ocean surface waves and their interactions with ocean currents and turbulence, seismic waves, sediments and remote sensing systems, and to improve our forecasting and hindcasting capacity of these phenomena from the global ocean to the nearshore scale.

OBJECTIVES

- Observe and parameterize the dissipation of ocean waves due to breaking or wind-wave interactions
- Advance spectral wave modeling at all (global to beach) scales in a unified framework, in terms of parameterization and numerical developments
- Help the application of wave models to new problems (upper ocean mixing and surface drift, use

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of seismic noise data, air-sea gas exchange ...) and use these applications for feedback on the wave model quality

APPROACH

By combining theoretical advances with numerical models, remote sensing and field observations, we investigate the physical processes that affect wind-generated ocean gravity waves. The various dissipative processes that contribute to the spectral wave evolution are isolated by considering geophysical situations in which they are dominant: the long-distance swell propagation in the case of air-sea friction, the evolution of swells on shallow continent shelves in the case of bottom friction, the energy level in the spectral tail in the case of cumulative breaking effects, and the breaking statistics of waves. These require the acquisition of new data using stereo-video techniques, for the spectral levels of waves of 1 to 10 m wavelength, and the statistics of whitecaps. The full model is then confronted to a wide range of observations starting from global altimeter, SAR and buoy data. Alvise Benetazzo is performing the calibration of the stereo system and the reconstruction of sea surface geometries. The determination of the water velocities from the video data is performed by Francesco Fedele and students at Georgia Tech., and the spectral analysis and whitecap detection is performed by students at Ifremer, under the supervision of Fabrice Ardhuin. All the wave modeling effort at Ifremer (theory, parameterization and calibration) is performed by Fabrice Ardhuin and Fabien Leckler.

WORK COMPLETED

This year has seen a lot of consolidation of previous efforts, with, in particular the integration of all the Ifremer developments in the NOAA/NCEP subversion server. This has included a reformulation of the TEST441 (Ardhuin et al., 2010) and TEST500 (Filipot et al., 2010) parameterizations with a common core. This consolidation was also the occasion for improving the computer performance of the TEST441 input and disspation parameterizations. These remain relatively expensive, about two times the cost of the DIA. On a typical global scale configuration with a 3rd order advection scheme this means a 40% higher CPU cost compared to the full model using Tolman and Chalikov (1996).

Several items have been added to the code, some of which are still under testing

- the SHOWEX bottom friction parameterization (Ardhuin et al., 2003)
- a revised boundary condition for unstructured grids
- a limiter for *k*-propagation
- many output parameters (including maximum CFLs for spatial and spectral propagation, including all fields relevant for 3D wave-current coupling as discussed by Bennis et al. (2011) and Bennis et al. (in press)
- a reformulation of the attenuation induced by sea ice

The main parameterization developments and testing have consisted in

- re-writing the dissipation terms TEST441 and TEST500 with a common structure, and now estimating the “cumulative term” with the breaking probabilities used for the main dissipation term. This has led to a new variant, TEST558 (Leckler et al., 2011).

- running a 2-month hindcast of the North Atlantic with the nonlinear calculation computed using the Webb-Resio-Tracy algorithm (Webb, 1978; van Vledder, 2006).
- Producing a 20-year hindcast with CFSR winds (Saha et al., 2010)
- many output parameters (including maximum CFLs for spatial and spectral propagation, all fields relevant for 3D wave-current coupling as discussed by Bennis et al. (2011) and Bennis et al. (in press) ...)
- a reformulation of the attenuation induced by sea ice

RESULTS

A comprehensive analysis of currents effects on waves has shown that WAVEWATCH III is capable of reproducing refraction effects very accurately, and suggests that current-induced breaking may be well captured by the new parameterizations, but that will require the analysis of more detailed measurement campaigns Ardhuin et al. (2011b). These result have required some numerical modifications to all a stable integration of the wave action balance in very shallow water, namely the addition of a limiter for the frequency shift induced by currents. This kind of coastal application of the model with tidal currents and water levels has been used for the investigation of geomorphological changes Suanez et al. (2011).

The wave model has now been tested extensively with a 1991-2011 hindcast using the recent NCEP-NCAR reanalysis, the Climate Forcast System Reanalysis (Saha et al., 2010). After 1993 these winds yield stable biases for the wave heights, consistent with recent NCEP operational analyses. Interestingly the high winds are much higher than in the ECMWF operational analysis, providing a much more flat bias as a function of wave height (figure 1). A detailed case study of the February 2011 storm Quirin, in the North Atlantic, has shown that once the wind biases are corrected the parameterizations by Ardhuin et al. (2010) are capable of reproducing significant wave heights up to 20 m, as observed (Hanafin et al., 2011), and also the very large peak periods recorded by buoys and seismometers (figure 2).

Work on the seismic noise modeling is now providing interesting insights into the representativeness of seismic stations, with some stations picking up noise generated over thousands of kilometers away, such as the Hawaii stations, while others are recording noise which is mostly generated within a few hundreds of kilometers, as appears to be the case off central California (Ardhuin et al., 2011c,a; Stutzmann et al., 2011; Schimmel et al., 2011). At the lowest frequencies, the noise sources are mostly related to coastal reflection and provide a unique observation of forerunners and long swell arrivals. A 1994-2011 global hindcast of seismic sources has been performed and is freely available (Ardhuin et al., 2011). It should provide a good basis for investigating the patterns of recorded noise. Due to the uncertainties on shoreline reflection and its parameterization, this hindcast involves two runs, one with coastal reflections, and a very crude constant reflection coefficient, and the other without.

The analysis data obtained with Wave Acquisition Stereo System (WASS) has progressed and the effects of smoothing in the processing of the three-dimensional surface using the method by Benetazzo (2006) is now better understood (Ardhuin et al., 2010). The data acquired in the Black Sea in the 2011 experiment contains conditions with relatively high breaking rates and will be useful for estimating modulation effects and a possible directional dependence of breaking probabilities.

Finally, work on the nearshore flows driven by three-dimensional radiation stresses is slowly moving

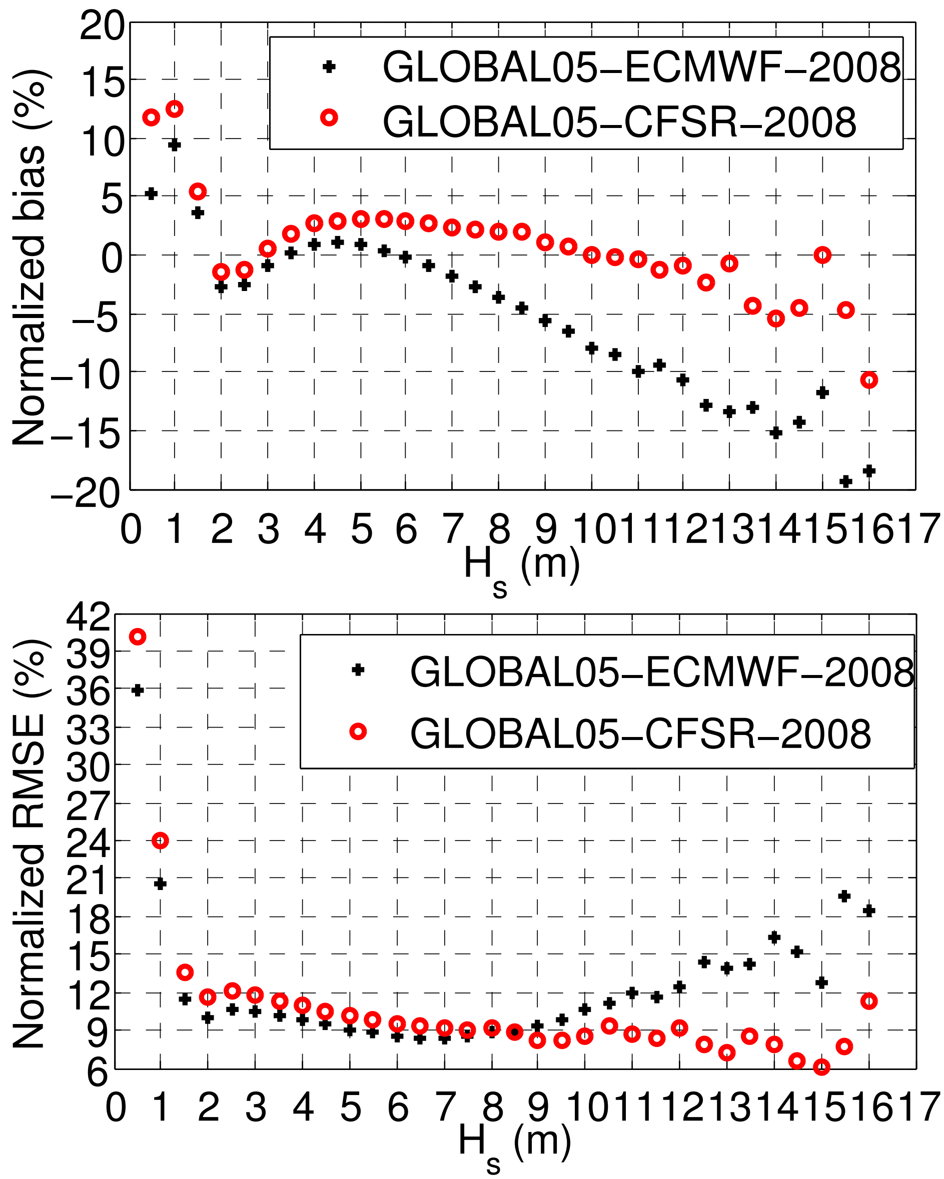

Figure 1: Normalized bias and normalized RMSE for H_s in 2008 against altimeter data, as a function of H_s.

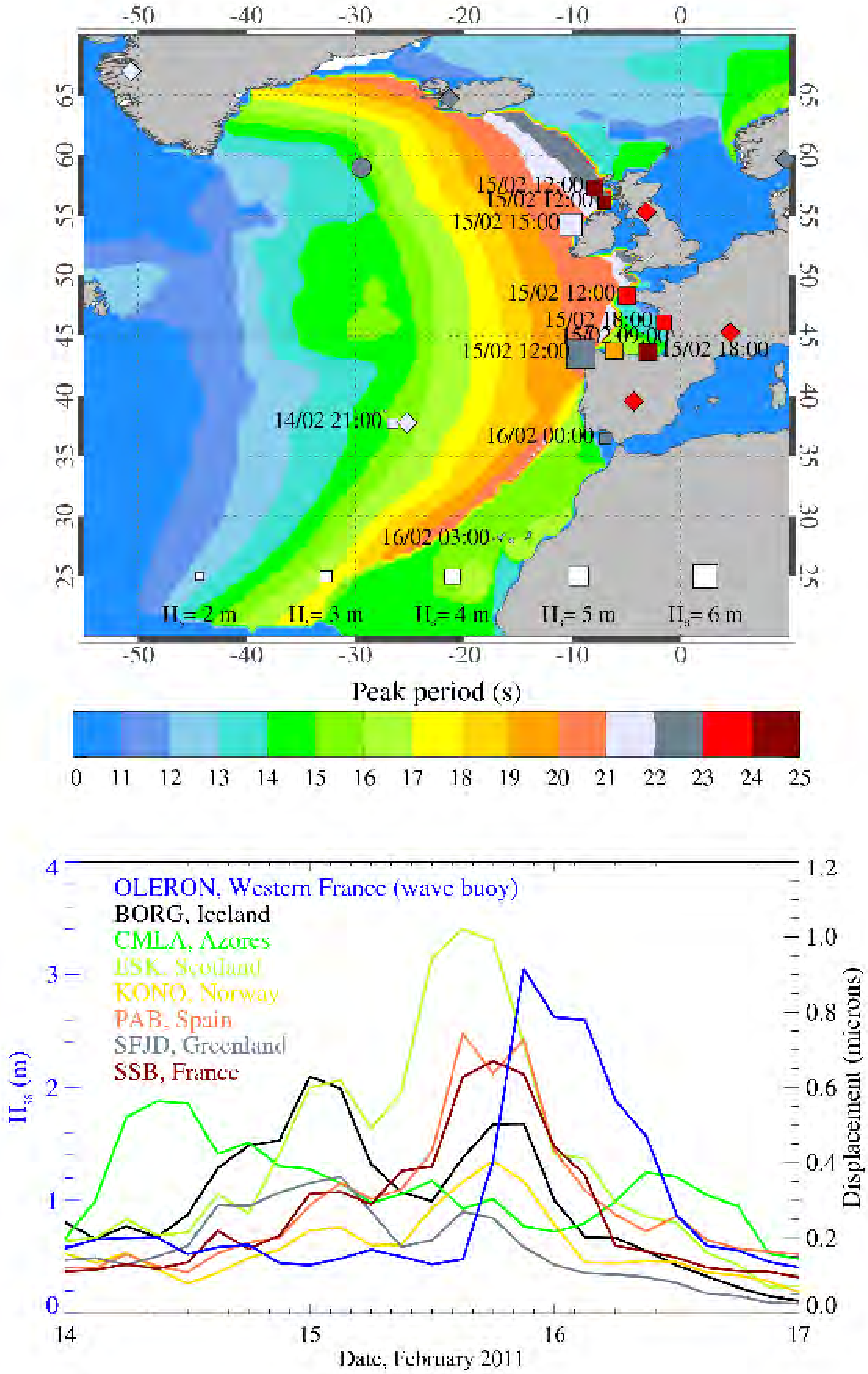

Figure 2: Peak periods as calculated with WAVEWATCH III(R), from Envisat's ASAR (circle), wave buoys (squares) data seismic stations (diamonds). The background shows the output from the model at 12:00 on the 15th, as the longest swells were encroaching on the west coast of Scotland. The size of the symbol signifying the Hs at the time of the maximum peak period observed, which is written on the figure. The colors signify the values of the peak period at that same time.

from adiabatic conditions and academic cases (Bennis et al., 2011, in press) to realistic conditions in which the flow is very sensitive to the bottom friction parameterization. Our main result in this area is the provision of a “reality check” for wave-current coupling equations, based on simple adiabatic cases, and the theoretical link between various theories (Ardhuin et al., 2008; Bennis et al., in press).

IMPACT AND APPLICATIONS

The combined use of seismic data and numerical wave models offers new opportunities for investigating the Earth structure (tomography) and observing the swell climate in regions where no buoys are deployed. Our recent work suggests that the low frequency content of the seismic records may be a good proxy for storm intensity.

National Security Improving wave forecasts are relevant to a variety of denfence applications. The most dramatic improvement brought in the operational models by the preasent work is an improved representation of swells which are most relevant for amphibious operations.

Quality of Life The transport of contaminants in the nearshore ocean is largely driven by waves. The capability and understanding of this driving process in three dimensions will certainly lead to improved water quality models.

TRANSITIONS

As mentionned above, an important part of the work was the integration of the Ifremer development branch back to the trunk of the NOAA/NCEP subversion server. This has made possible the fix of several bugs and manual errors reported by NOAA/NCEP and the ongoing discussion about the CPU performance of the code using new parameterizations. The model with these new parameterizations based on Ardhuin et al. (2010) has produced very good results in terms of accuracy in the tests performed by NCEP. We will continue helping NOAA/NCEP and others in testing and implementing these parameterizations.

At present a 18-year reanalysis database has been made available to the public (http://www.tinyurl.com/yetsofy). NCEP appears likely to use the new parameterizations for operational forecasting by 2012.

RELATED PROJECTS

The present “Ocean Waves Dissipation and spectral Balance” (WAVE-DB) shares many of the objectives of the the Integrated Ocean Waves for Geophysical and other Applications (IOWAGA) project, funded by the European Research Council. As a result, results from both projects are reported on the same web pages, where the contribution from each is clearly identified. Whereas WAVE-DB is focused on the development of stereo-video techniques and numerical wave modeling, IOWAGA allows allows a broader perspective with work on remote sensing and seismic noise, which allow a more informed calibration of the numerical wave model. Finally, the WAVE-DB activity is also benefiting from the GLOBWAVE project.

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