

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, the atmosphere, 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, wind-wave interactions, or bottom friction
- 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 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. Alvisè Benetazzo (ISMAR Venezia) is performing the calibration of the stereo system and the reconstruction of sea surface geometries, that expertise has been transferred to Ifremer with graduate student Fabien Leckler and developments at the two institutions are now allowing reliable analysis of data acquired in 2011. The spectral analysis and whitecap detection is performed 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

Wave model parameterizations for wind wave evolution The main challenge faced for the energy balance of wind seas is the non-local nature of all terms in the spectral domain. This is well known for the non-linear 4-wave interaction term (Hasselmann, 1962), but it is becoming also increasingly clear for the wind input and the dissipation terms. For the wind input, the well-known quasi-linear effect (Fabrikant, 1976; Janssen, 1991) is a positive feedback of the short waves in the spectrum on the growth of all spectral components, whereas the sheltering effect discussed by Hara and Belcher (2004), is a negative feedback term that affects the short wave growth based on the long wave growth. The combination of the two effects leads to behaviors that are not fully understood, with clear impacts on the variability of wind stress and mean square slopes.

Similarly, there is growing evidence for the generation of both longer and shorter wave components from the breaking of waves of intermediate scale (Yurovskaya et al., 2013; Tulin and Waseda, 1999; Caudal, 2012), in addition to the “cumulative” effect of short wave dissipation due to large scale breakers, already introduced in source term parameterizations (Banner and Morison, 2010; Ardhuin et al., 2010; Rogers et al., 2010). The generation of long waves by short wave modulation must also be mentioned (Garrett and Smith, 1976). On top of that, it is also expected that the breaking of waves changes the wind profile and wind-wave growth term (Reul et al., 2008), an effect introduced in the parameterization by Banner and Morison (2010).

Finally, it is well known that the DIA parameterization for non-linear interactions leads to biases in spectral shape and integrated parameters (Banner and Young, 1994; Ardhuin et al., 2007).

There are thus many effects that need to be considered, with possible strong non-linear interactions between them, and it is not clear how to transform each type of measurement into a clear constraint for the functional form and magnitude of these effects. We have begun to test the impact of short wave generation by breaking waves as an additional effect into the TEST451 parameterization Rascle and Ardhuin (2013).

Existing parametrizations, including those of Banner and Morison (2010), Rogers et al. (2010) or our own, fail to produce the proper balance at frequencies above 3 times the peak of the wind sea. While we are investigating this issue in relation to the missing processes listed above, we have thus gone back to the use of a diagnostic f^{-5} tail, allowing a reduction of the sheltering, which produces a wind stress that varies more with the wave age, and thus an enhanced wind sea growth at short fetch. Combining this with a re-adjustment of the wind-dependant part in the swell dissipation, and a parametrization for friction below the ice, resulted in a TEST471 adjustment.

The stereo video data acquired during this NOPP project is providing a very interesting constraint on

the directional distribution at frequencies up to 5 times the wind sea peak frequency, as shown in figure 1, taken from Leckler et al. (tted). In particular, no parametrization is yet able to reproduce the very

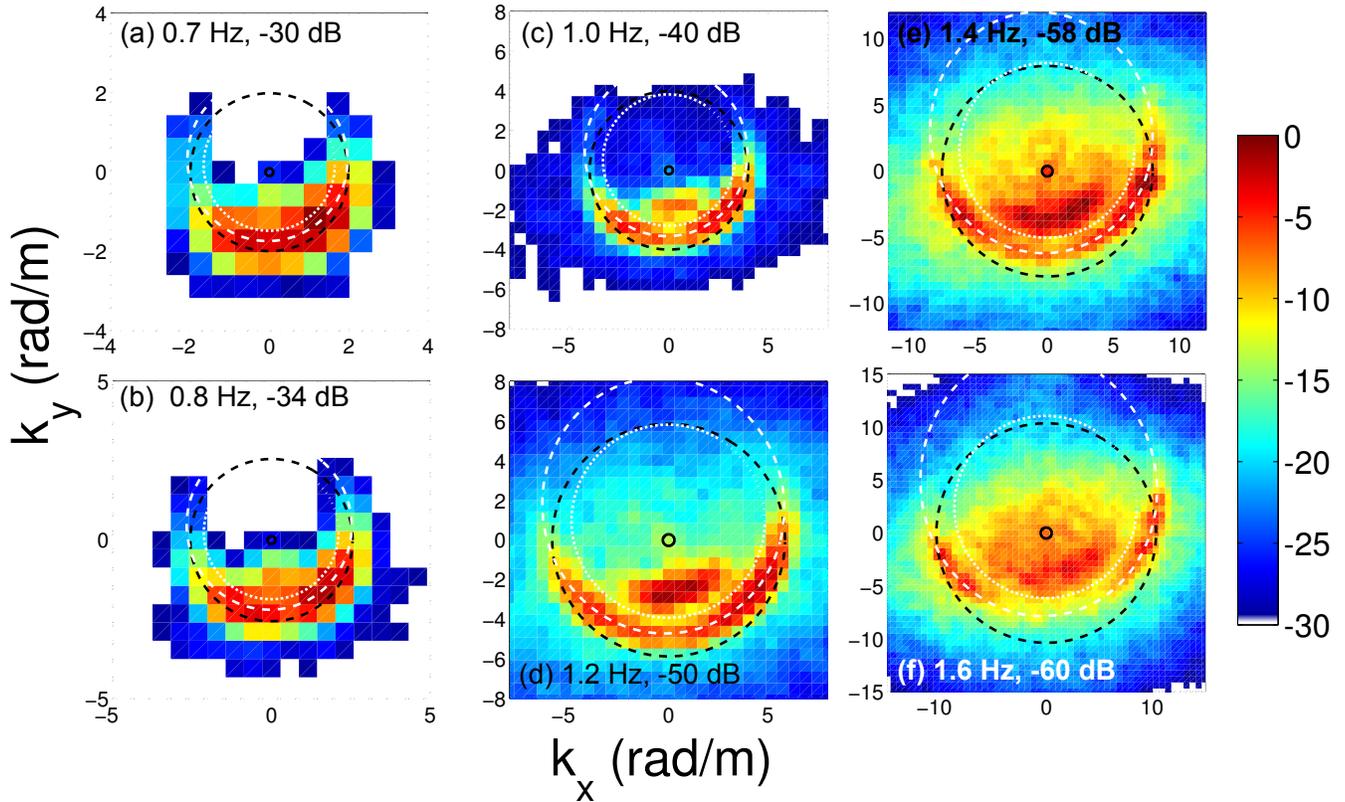


Figure 1: Slices of the double-sided spectrum for positive absolute frequencies 0.7, 0.8, 1.0, 1.2, 1.4 and 1.6 Hz. The energy appears in the direction from where it is coming. For each panel the color scale spans 30 dB with the dark red corresponding to the power indicated on the figure (e.g. -30 dB) relative to $1 \text{ m}^4/\text{Hz}$. Note that 1.4 and 1.6 Hz are twice 0.7 and 0.8 Hz, so that the first harmonic of the components in (a) and (b) appear at approximately twice the wavenumbers in panels (e) and (f). In each panel, the linear dispersion relation without current is plotted in black, in white with a uniform current $U = 0.15 \text{ m/s}$ towards the trigonometric angle 99 degrees. The white dashed line marks approximately the separation between the linear part of the spectrum and the faster non-linear components.

strong ratio of maximum energy at high oblique angle relative to the wind compared to the low energy in the wind direction, at frequencies from 3 to 5 times the peak frequency. This ratio is even stronger when one properly removes the second order harmonics from the measured signal, providing a canonically-transformed spectrum (Krasitskii, 1994). Future work will attempt to merge the detailed spectral measurements from stereo, with constraints from underwater acoustics (Ardhuin et al., 2013), and parametrizations.

Implementation in WAVEWATCH III

Several items have made their way to the trunk of the NCEP subversion server over FY2014

- a parametric source of free infragravity wave energy at the shorelines (Ardhuin et al., 2014)

- an adjustment of the ST4 parameterization to correct short fetch low biases and high biases in the high frequency tail energy level (TEST471).
- an under-the-ice friction parametrization that generalizes to turbulent boundary layers the viscous theory used by Liu et al. (1991).

RESULTS

The wave model validation this year has been balanced between global scale applications, and coastal applications (Delpy et al., 2014; Roland and Ardhuin, 2014). This is illustrated here by the impact on wave heights of the new adjustment to the tail, wind input, and swell dissipation in figure 2

MSE difference for Hs: MULTI-T451-2012 - MULTI-T471-2012 (percentage points)

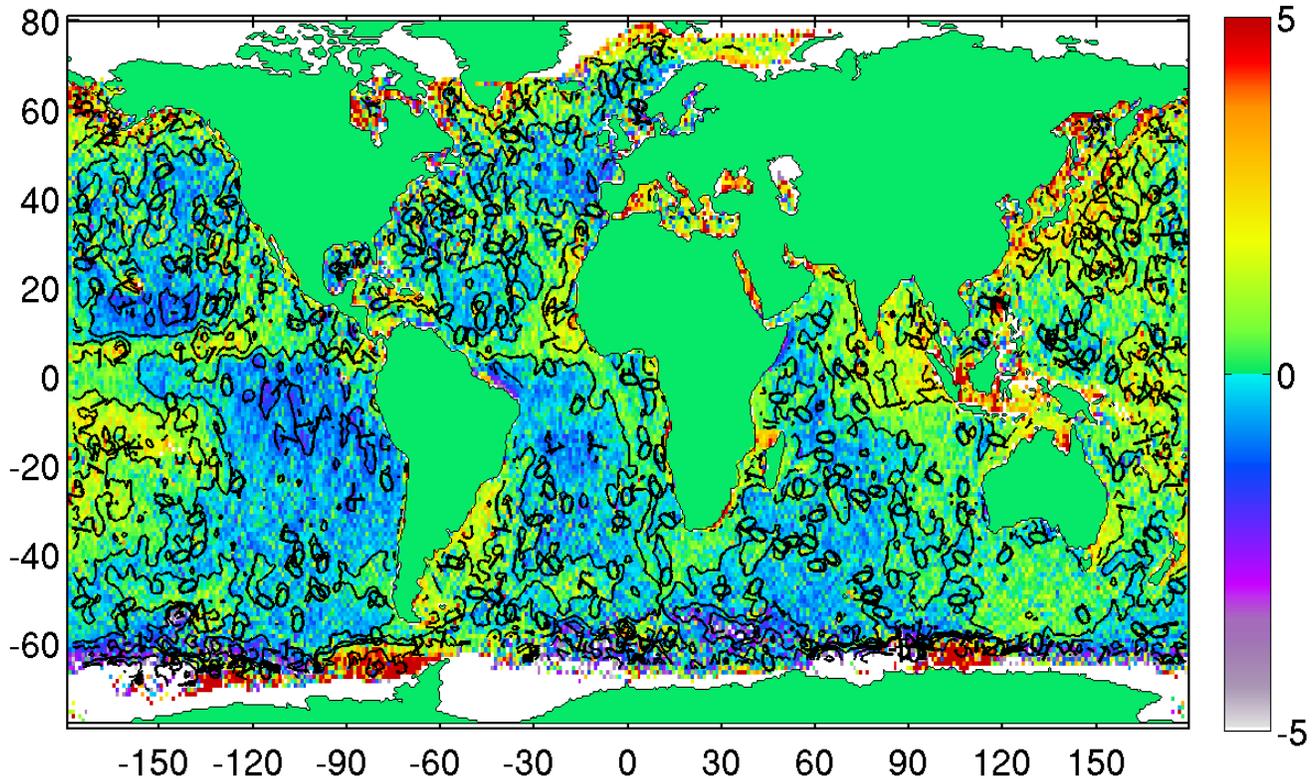


Figure 2: Change in normalized root mean square error against altimeter data, when TEST471 is replaced by TEST451. The reds and yellows correspond to regions where errors have been reduced with the new TEST471 parametrization, blues are regions with larger errors.

IMPACT AND APPLICATIONS

The combined use of underwater acoustic data, numerical wave models, and remote sensing offers new opportunities for investigating the directional wave spectrum, up to very high frequencies. A collaboration with W. Farrell has started on this topic with the visit of a master student in the summer 2014. This work should be important for resolving the poorly known variability of wind stress and wind-wave growth for young seas (short fetch or high wind speeds).

National Security Improving wave forecasts are relevant to a variety of defence applications. The most dramatic improvement brought in the operational models by the present 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 Delpy et al. (2014). The capability and understanding of this driving process in three dimensions will certainly lead to improved water quality models.

TRANSITIONS

Operational wave models at NOAA/NCEP have been switched from the parameterization by Tolman and Chalikov (1996) to the TEST451, only 3 months after the parameterization had been adjusted. This shows the amazing capability brought about by the new way of developing model frameworks at NCEP using outside contributions on the same subversion server. This happened during FY2012. Since that time, many adjustments and bug corrections have been disseminated, using the same tools, and have made their way into the version 4.18 of the WAVEWATCH III code, now publically available on request from NCEP. We will continue helping NOAA/NCEP and others in testing and implementing these parameterizations. We are also committed to support outside users, with two training courses in Brest in FY14 (November 2013 and March 2014).

A 19-year reanalysis database has been made available to the public (<http://www.tinyurl.com/iowagaftp>).

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 was focused on the development of stereo-video techniques and numerical wave modeling, IOWAGA allowed 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 also benefitted from the GLOBWAVE project, funded by the European Space Agency and the French Space Agency to facilitate the use of satellite remote sensing data of ocean waves.

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