The Use of Wind Gustiness and Air Density in Wave Modelling: Implementation at ECMWF

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The impact and the implications of using wind gustiness and quasi-realistic air density on wave modelling have been clearly demonstrated by Abdalla and Cavaleri (2002). While air density evaluation is rather straightforward, it is not the case with the wind gustiness. There are two main approaches to include the wind speed variability in wave modelling. The first approach is the use of the Monte-Carlo simulation technique by superimposing random variability over the model (mean) wind speeds; see, *e.g.*, Abdalla and Cavaleri (2002). This approach provides instantaneous impact that may not represent the actual one. For the mean impact of gustiness, one needs to carry out several tens of realisations and average their impact. This can not be implemented in an operational set-up like the one at ECMWF. The other alternative is to replace the traditional input source term in the wave model by an enhanced form that includes the mean impact of gustiness; see, *e.g.*, Janssen (1986). Although it only provides the mean impact, this approach is more convenient for operational applications.

From the wave modelling point of view, both wind gustiness and air density affect wave generation through the wind input source term that can be written generically:

$$\frac{\partial F}{\partial t} = \gamma F \qquad \text{with} \qquad \gamma = \gamma\left(\frac{\rho_{air}}{\rho_{water}}\ ,\ u_*\right)$$

where, F is the energy density of a wave component, t is the time, $\rho_{air} / \rho_{water}$ is the air-water density ratio (which is usually assumed constant in wave models), and u_* is the wind friction velocity component along wave propagation direction. Usually mean wind velocity is used. This implies an ignorance of the impact of variability at scales lower than or comparable to the atmospheric model resolution. To include this impact, an enhanced input source term with the mean impact of gustiness can be estimated as:

$$\begin{aligned}\overline{\gamma}(u_*) &= \int_{u_*=-\infty}^{\infty} \frac{1}{\sigma_* \sqrt{2\pi}} \exp\left(-\frac{\left(u_* - \overline{u_*}\right)^2}{2\,\sigma_*^{\,2}}\right) \gamma(u_*)\, du_* \\ &\cong 0.5\left[\gamma\left(\overline{u_*} - \sigma_*\right) + \gamma\left(\overline{u_*} + \sigma_*\right)\right]\end{aligned}$$

Here u_* represents the instantaneous unresolved friction velocity, σ_* is its standard deviation and the *over-bar* represents the mean value of the quantity over the whole grid-box/time-step. The second equation follows from the Gauss-Hermite quadrature. To estimate the value of σ_*, one can make use of the empirical expression of Panofsky *et al.* (1977) which requires the knowledge of the height of the lowest inversion and the Monin-Obukhov length. Abdalla (2001) explains this with some details.

Several experiments were carried out to test this implementation using low-resolution model (T159). The positive impact encouraged the application with the current ECMWF model resolution of T511/L60. The spatial resolution of the atmospheric model is about 40 km while that of the wave model is 55 km. The integration time step is 15 minutes. The two-way coupling between the atmospheric and the wave models is done at each time step. This set-up was run for the periods: 22 Nov.-14 Dec. 2000 and 1-27 Jun. 2001. The wave scores (anomaly correlation and standard deviation of error) of the significant wave height compared to those of the control run are shown in Fig. 1 for the 23 cases. Although the Northern Hemisphere (NH) scores are almost neutral for the first 6 days, remarkable positive impact can be seen for the Southern Hemisphere (SH). Verifying the model forecast wave heights against both the in-situ buoy and the ERS-2 radar altimeter observations further proved this impact. In general, the new implementation increases the average wave height, which is usually a positive impact to compensate for the general model tendency to have negative bias. This implementation will soon be tested in an e-suite at ECMWF.

References:

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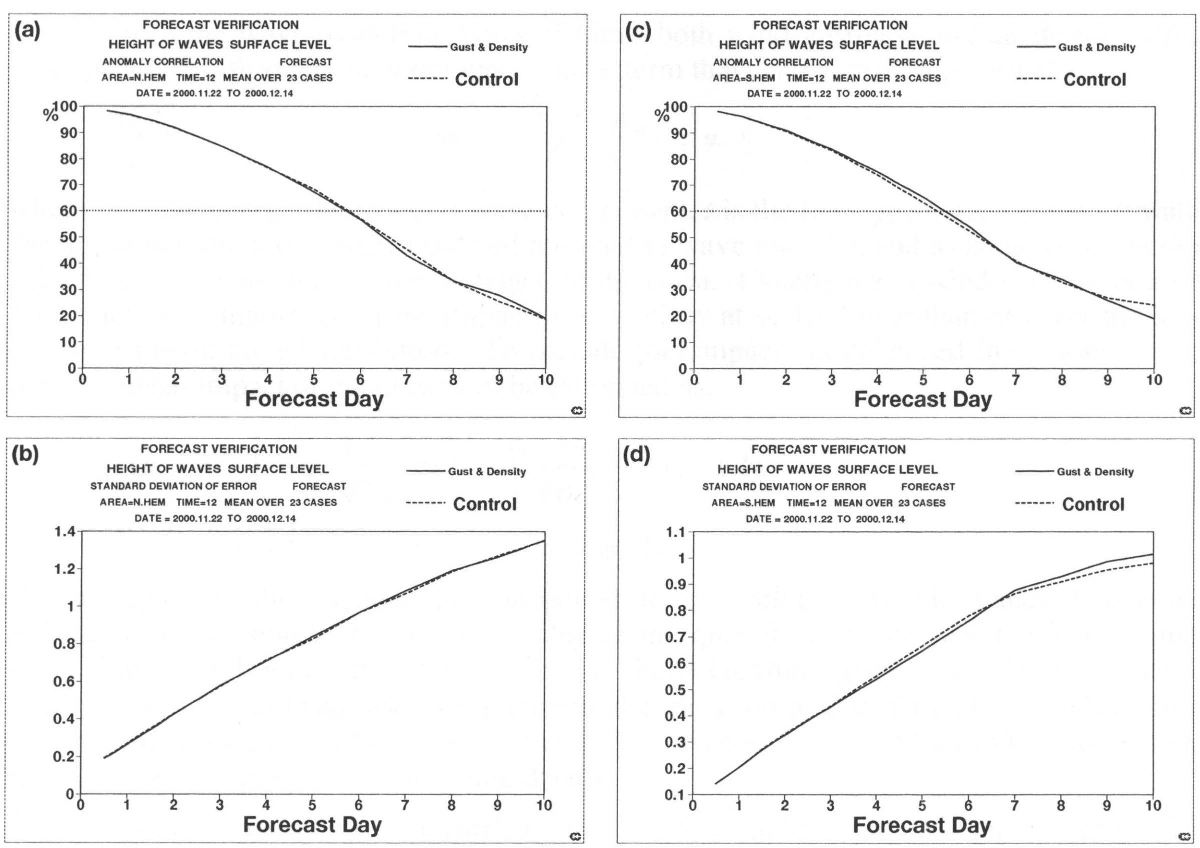

Fig. 1: Significant wave height scores (anomaly correlation and standard deviation of error) for 23 cases (22 Nov. - 14 Dec. 2000) for NH (panels a & b) and SH (panels c & d).