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Significance of laboratory observations for modeling wind-driven seas

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In what sense can the laboratory wind-wave observations help in investigating and modeling wave growth in wind-driven seas? This old outstanding question is addressed by an extensive laboratory study in the large IRPHE wind-wave tank (Caulliez, 2009). We show that for a wide range of parameters the fetch-limited wind wave growth observed in the facility follows fairly well the wind-wave growth law predicted by weak turbulence model (Badulin et al., 2007). The wind speeds were ranging from 3.5 to 16 m/s and wave ages c_p/U_{10} were smaller than 0.15 (c_p being the phase speed of spectral peak waves, and U_{10} the equivalent 10 m level wind speed).

The recent model of wind wave evolution proposed by Badulin et al. (2007) assumes the dominance of nonlinear four-wave resonant interactions over the direct wave input from wind and wave dissipation. The model predicts that the total wave energy is rigidly linked to the total wave energy flux (i.e. the energy growth rate dE/dt) by the relationship:

$$\frac{E\,\omega_p^4}{g^2} = \alpha \left(\frac{\omega_p^3\, dE/dt}{g^2} \right)^{1/3} \tag{1}$$

where the wave energy E is defined in a “wind-wave study sense” as the water surface elevation variance density $\langle \eta^2 \rangle$, ω_p is the wave spectral peak frequency, and α is a self-similarity parameter. Experimental data reveal that the spectral peak wave energy observed in the wind-wave tank at large fetches evolves in accordance with the asymptotic weakly turbulent theory in a wide range of wind speeds. Furthermore, the found value of the self-similarity parameter α ($\alpha \simeq 0.5$) matches very well the estimates from more than 20 data set collected over the last 50 years of wind-wave studies at sea.

It is then shown that the characteristic parameters of the laboratory wave field development follow remarkably well the $3/2$ Toba’s law $H \sim T^{3/2}$, H and T being the significant wave height and period. In a definite range of fetches and wind speeds, its dependency on friction velocity u_* is also described by an expression similar to those proposed by Toba (1972) on local energy balance and dimensional considerations, i.e.

$$H = B(g u_*)^{1/2} T^{3/2} \tag{2}$$

g being the gravity acceleration and B a constant. From a physical viewpoint, this heuristic law in u_* infers not only the total wave energy flux dE/dt in Eq.(1) to be constant as pointed out by Badulin et al. (2007), but also the ratio of the form drag due to dominant waves to the total surface drag to be constant.

Finally, the validity of the key assumption of the model, i.e. the dominance of nonlinear transfer over the net wave energy flux, is analyzed and domain of its applicability for laboratory observations is delimited. The weak turbulence model thus finds a new corroboration in wind-wave tank experiments and may bring a new vision for data analysis in the near future.

References

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