Directional short wind wave spectra derived from the sea surface photography

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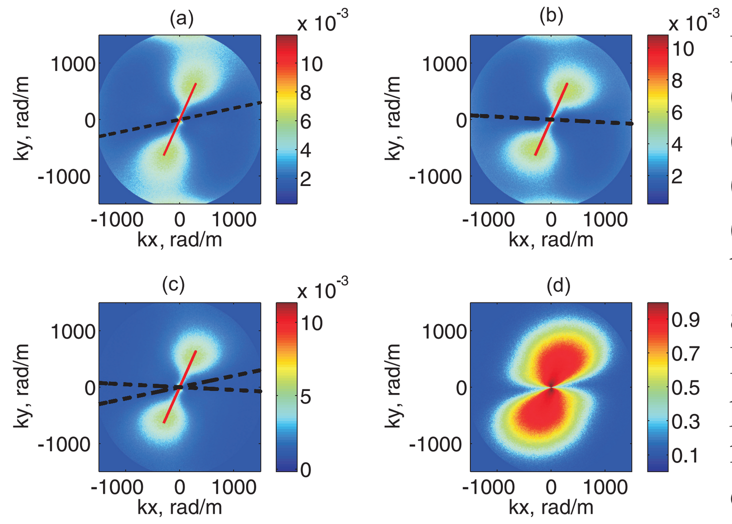
Method

- The measurements were carried out during the autumn 2009−2012 in the Black Sea coastal zone using the Marine Hydrophysical Institute's research platform located 500 m offshore at 30 m depth.

- The measurement method combines stereophotography and image brightness contrast processing. The approach is based on evaluating a linear relationship between the sea surface slopes and the sea surface brightness variations. Kosnik and Dulov [2011] found a high correlation between stereoderived surface elevation and the surface brightness variations in the range of wave numbers from 10 to 50 rad/m. Accepting that the brightness is linearly related to the surface slope, it is naturally to expand the transfer function between slope and image brightness to higher wavenumbers.

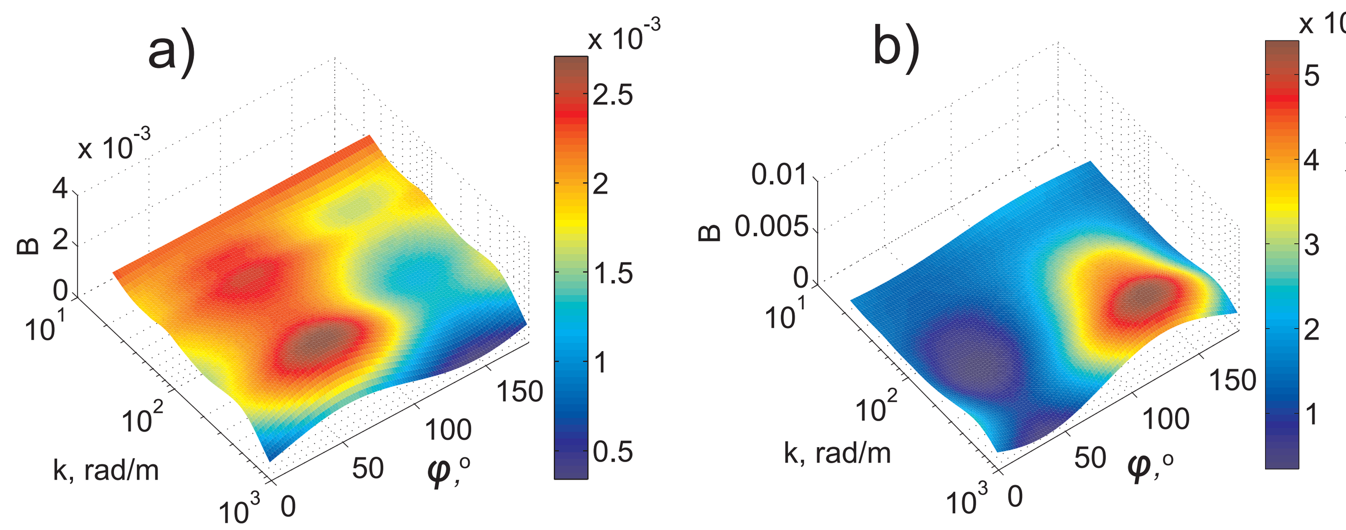
- The method strongly builds on the brightness cross-spectral analysis to reduce the noise within this short wave gravity and capillary range.



Brightness spectrum of
(a) left images
(b) right images,
(c) the real part of cross spectrum,
(d) square of coherence function between the brightness fields from left and right cameras.
Dash lines indicate directions perpendicular to the direction of the mean brightness gradient. Red lines denote the wind direction.

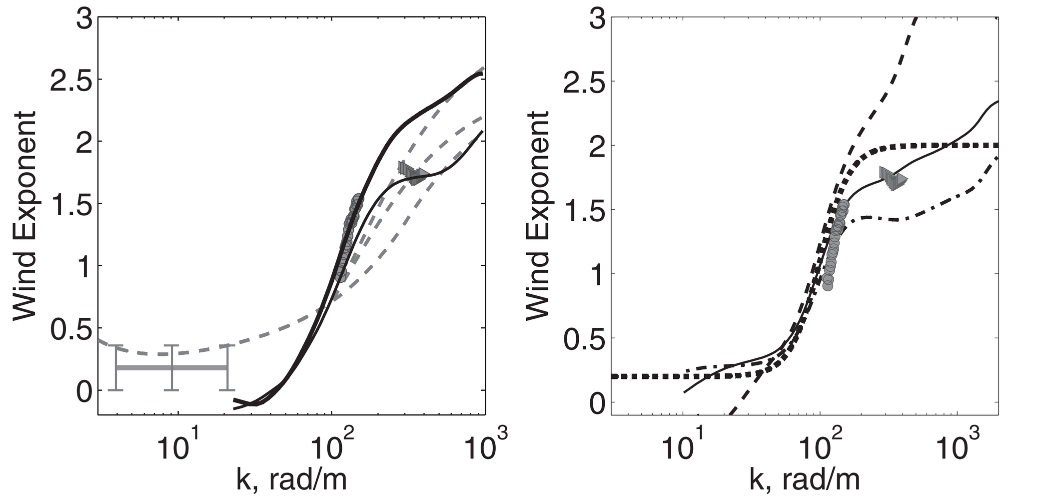
Results. Spectrum Properties.

- All the retrieved spectra demonstrate well-pronounced directionality with spectral maximum aligned with the measured wind direction. A secondary capillary peak is well visible at lower windspeeds and visually disappears at higher windspeeds.

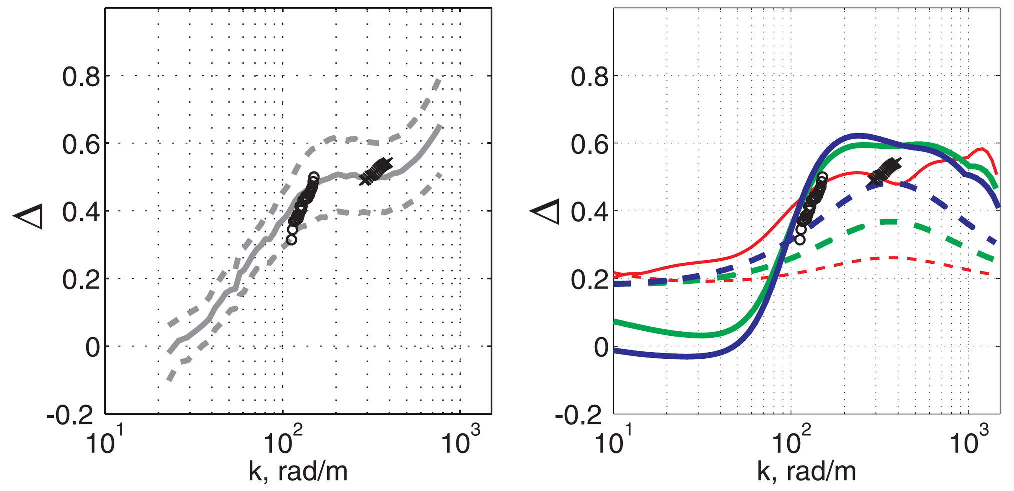


Directional curvature spectra in the coordinate system fixed to the stereo base. (a) Wind speed 9 m/s ; (b) Wind speed 12 m/s.

- As found, the folded spectra of decimeter waves are very weakly dependent on the wind speed and its direction. Wind speed and direction sensitivity only starts to appear in the short wavelength range, more precisely in the vicinity of the wave number 100 rad/m, where the wind exponent (the exponent in $B \sim U^{\alpha}$) grows from 0.5 to 1.5–2.5 at 800 rad/m, and angular anisotropy parameter introduced by [Elfouhaily et al., 1997] amounts the value of 0.5. These aspects are consistent with other previously reported optical and radar data. For the latter, we solely extracted the polarization sensitivity to best isolate the contribution associated to the wave saturation spectrum around the Bragg resonant wave number. For the former, mean-squared slope statistics were used to assess the integrated shortscale directional spectral properties.

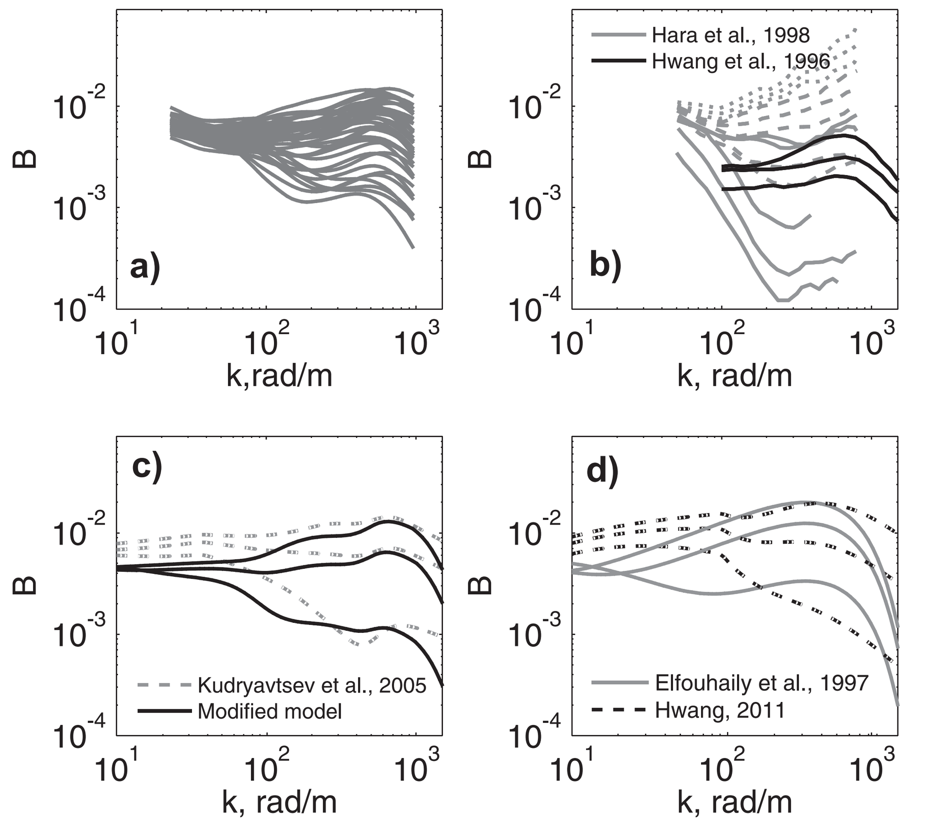


(left) Wind exponent for all runs (bottom solid line) and for winds lower 10 m/s (top solid line). Dash lines show wind exponent from Hwang [2011] model. Gray solid line with confidential intervals demonstrates Banner et al. [1989] result.
(right) Revised model wind exponent. The model wind exponents correspond to U=5 m/s (dash), U=10 m/s (solid), and U=15 m/s (dash-dotted). Dotted line in right plot shows parameter $2/n$. Symbols in both plots show wind exponent for Bragg scattering derived from C-band (circles) and Ku-band (triangles) data averaged around the wind speed 10 m/s.



(left) Parameter of the angular anisotropy derived from spectral measurements, (solid line with confident intervals shown by dash lines), and from C-band and Ku-band radar measurements (open circles and crosses correspondingly).
(right) The same parameter following (dash lines) Elfouhaily et al. [1997] model and (solid lines) the revised model at wind speeds 5 m/s (red), 10 m/s (green), 15 m/s (blue). Symbols are the same as in the left plot.

- Comparisons with other measurements and semiempirical models of short wind wave spectra show the spectra consistence, however, some remarkable differences in the shape of omnidirectional spectrum, angular spreading and spectral wind sensitivity apparently exist.



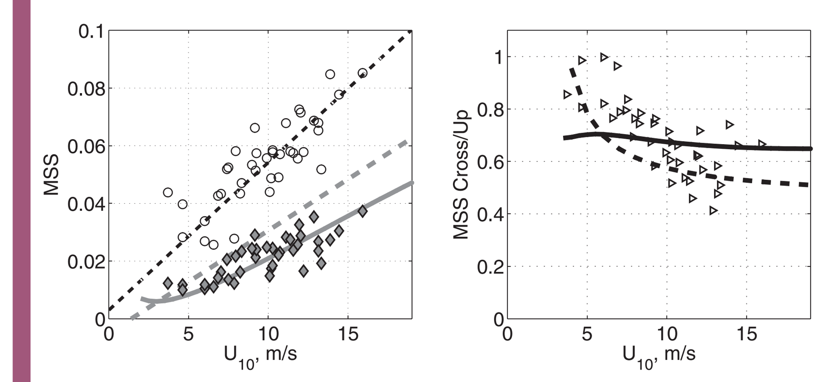
Omnidirectional wave number saturation spectra.
(a) Present measurements; (b) field measurements by Hwang et al. [1996] (wind speeds are 2.1, 3.5, and 5.7 m/s) and by Hara et al. [1998], u = 0.1, 0.2, and 0.3 m/s; (c) the revised model and model by Kudryavtsev et al. [2003] at windspeeds 5, 10, and 15 m/s; (d) model by Elfouhaily et al. [1997] and Hwang [2011].

Revised Semiempirical Spectral Model

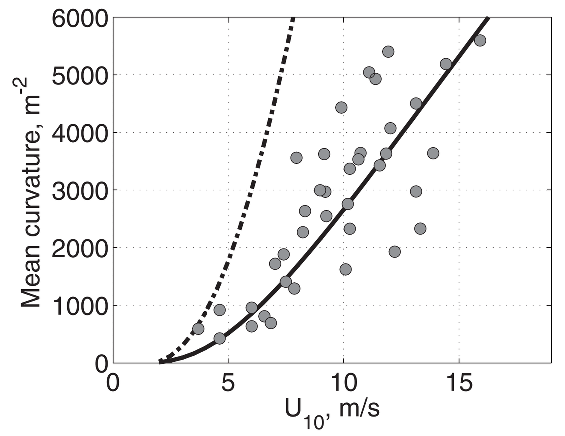
- Field measurements of wind wave spectra are still rare, and the reported data thus provide valuable information to bring new evidences on the 2-D spectral distribution of short wind waves in the wavelength range from decimeters to millimeters. On the basis of the new in situ measurements, we then propose to revise the semiempirical analytical model of short wind wave spectra developed by [Kudryavtsev et al.,2003, 2005].

- The key parameter of the model is exponent n governing the nonlinear dissipation rate: $D \sim B^{n+1}$, where B is saturation spectrum. New additional constraints are used to refine the dependence of n on dimensionless wave number to match the inferred wind exponent data.

- The mean saturation spectrum is further adjusted to be consistent with the robust Cox and Munk [1954] dependence of mean-square slope on wind speed.



(a) Mean-square slopes of short waves (gray diamonds) and waves in the whole wave number region (circles). Dash black line is Cox and Munk relation, dash gray line is Cox and Munk relation for the short waves, solid line corresponds to model calculations. (b) Ratio of the MSS in cross-wind to the MSS in the up-wind direction for the short wind waves; dash lines - Cox and Munk data, symbols are the ratio estimated from measured spectra, solid line is the model.



Mean curvature of the short waves: symbols are the data, solid and dash lines are the model mean curvature in the wave number range 20 rad/m < k <1000 rad/m, k>20 rad/m, correspondingly.

- As developed, the proposed two-dimensional wave number spectrum is valid over the ultragravity and capillary large wave numbers, and is analytically amenable to different usage (radar scattering, air-sea interaction issues, etc.).