# ESTIMATE OF SHORT WAVE CURVATURE FROM ANGULAR RADIOMETRIC MEASUREMENTS

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## 1. INTRODUCTION

Short gravity and gravity-capillary waves play a very important role in ocean-atmosphere interaction, affecting the momentum exchange through wind waves generation and dissipation. At the same time, short waves affect the electromagnetic waves emission and scattering from the sea surface, and this effect is used in satellite radiometers and scatterometers for remote measurements of winds over ocean. The relations between wind, waves and emitted/scattered signal are extremely complicated and can hardly be described unambiguously by any theoretical model. Therefore experimental measurements of the ocean–atmosphere interaction parameters under various meteorological conditions are of high importance.

In an ideal case, an experiment should combine synchronous and collocated remote sensing (radiometer, radar, etc.) and in situ measurements. The oceanographic platforms are of particular importance because they provide a unique opportunity of long-term measurements of sea and atmosphere parameters in a fixed point using various kinds of sensors, both remote sensing and contact instruments.

The paper presents the results of the experiment CAPMOS'05 performed on an offshore oceanographic platform in the Black Sea in June 2005. The major goal of the experiments was to compare the results of synchronous active and passive microwave measurements of waved sea surface, focusing on the ocean wave spectrum retrieval.

The task to measure the wave parameters in the open sea is a considerable challenge, especially for short gravity-capillary waves. Traditional wave gauges are not usable for very short wave measurements because of disturbances introduced by a gauge itself. The problem may be solved by applying remote techniques, either optical or microwave radar. A number of various models of wind wave spectrum have been proposed to date by various authors; [1–3] are only some of them. It is worthy of note that most of these models agree, more or less, at the range of long waves, whereas at the range of short gravity-capillary waves the disagreement can be of an order of magnitude. This problem calls for further experimental efforts, which would allow gathering more data on the short wave parameters under a variety of environmental conditions.

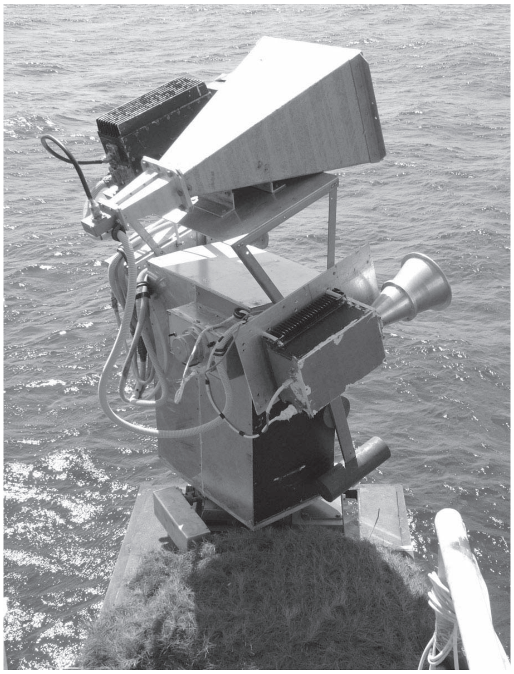

**Figure 1.** Radiometers mounted on a rotator

## 2. EXPERIMENTAL RESULTS

The experiment CAPMOS'05 was carried out on a research oceanographic platform located about 600 m to the south of Crimea coast near Katsiveli, Ukraine. The sea depth at the site is 28 to 32 m, so the deep water and long fetch conditions were ensured for prevailing winds from the south, south-east and south-west. The platform was equipped with a set of contact and remote sensing instruments. Conventional contact sensors were used for direct measurements of atmosphere and sea boundary layer parameters (wind speed and direction, air temperature, water temperature and salinity profiles, etc.) whereas microwave and IR radiometers were used for remote sensing measurements of surface temperature and wave parameters.

The list of radiometers used during the experiment included an S-band radiometer (V-pol.), a K- and Ka-band polarimeter (3 Stokes parameters), a W-band radiometer (V- and H-pol.), and a thermal infrared band (IR) radiometer. All the radiometers were mounted on an automatic rotator (Fig. 1), which permitted to change the angle of observation in both azimuth and elevation planes. The rotator with radiometers was mounted on a boom 4 m long, to reduce the reflected radiation from the platform itself as well as a wave pattern distortion. On the same boom, a mast with meteorological instruments and a wave gauge were installed.

Angular radiometric measurements were applied for surface wave spectrum retrieval starting from an idea first proposed by Trokhimovski [4]. The physical base for this approach is so-called Etkin-Kravtsov effect, which is a phenomenon of resonant thermal microwave radiation from a rough surface. The resonance conditions look as follows:

$$\rho^2 + 2\rho \sin\theta \cos\varphi - \cos^2\theta = 0, \quad \rho = n\frac{\lambda}{\Lambda} \tag{1}$$

where $\lambda = 2\pi/k$ is electromagnetic wavelength, $k$ is electromagnetic wave number, $\Lambda = 2\pi/K$ is surface wavelength, $K$ is surface wave number, $\theta$ is incidence angle, $\varphi$ is azimuth angle between surface $\boldsymbol{K}$ and electromagnetic $\boldsymbol{k}$ wave vectors, $n = \pm 1, \pm 2, \ldots$ is an order of the resonance.

It is evident that for different relations between surface and electromagnetic wave length the resonance occurs at different angles. When a waved sea surface is observed at an angle $\theta$ by a radiometer operating at the wavelength $\lambda$, a particular harmonic of continues spectrum of surface waves, which has the wavelength $\Lambda$ satisfying (1), makes an essential contribution to the microwave thermal radiation. Hence a microwave radiometer scanning over wide range of angles $\theta$ may be used for the surface waves spectroscopy. The principal consideration should be kept in mind that we are talking about surface waves with the length of the same order as an electromagnetic wave length, i.e. we consider gravity-capillary waves.

The algorithm of the spectrum parameters retrieval from angular radiometric measurements reduces an inverse problem to a direct one. First, the brightness contrast (i.e. the difference of the brightness temperatures of the waved and the smooth surface) produced by the waves with any particular (randomly defined) set of spectrum parameters is computed, and then the combination of the spectrum parameters is chosen to ensure the best fit of the computed and the measured experimentally contrasts. To solve the direct problem, a two-scale model of the sea surface is used. The brightness contrast produced by the long (relative to electromagnetic wavelength) waves is computed using Kirchhoff approximation. The brightness contrast produced by short waves was computed using the small perturbation method. A more detailed description of the algorithm may be found in [5].

Figure 2 shows an example of wave parameters retrieval from Ka-band polarimeter measurements performed on June 8-9, 2005 using the mentioned algorithm. Left panel in the Fig. 2 presents the retrieved curvature spectrum of gravity-capillary waves at mean wind speed about 4 m/s. Vertical dotted lines on the left panel indicate the range of wave numbers $0.05k < K < 2k$ where the proposed algorithm for the wave parameters retrieval was applied. The right panel in the Fig. 2 presents the results of the curvature spectrum retrieval during about 28 hours of permanent measurements. In all, 64 spectra similar to that shown on the left panel have been retrieved. The mean wind speed during this period varied from 3 to 12 m/s. The dynamics of various spectral components under non-stable wind is shown by various symbols. To keep the plot more visible, only five spectral components are shown with wave numbers, correspondingly: $K1 = 0.562$ rad/cm, $K2 = 2.415$ rad/cm, $K3 = 3.477$ rad/cm, $K4 = 5.007$ rad/cm, $K5 = 14.95$ rad/cm. The position of the chosen components in the spectrum is indicated with arrows and respective numbers on the left plot. It is evident that the spectral components close to the curvature maximum are the most sensitive to the wind speed variations.

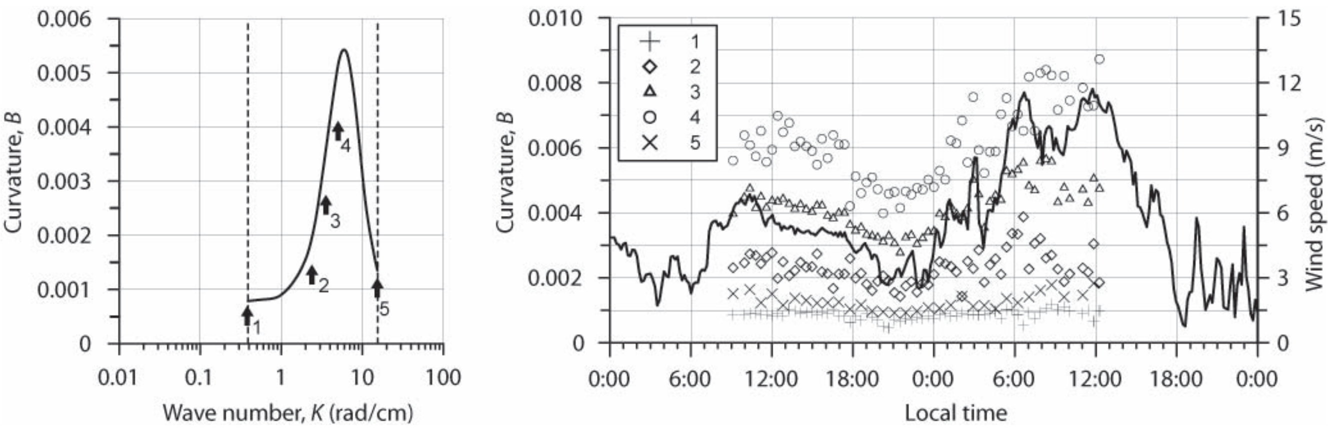

**Figure 2.** Left panel: curvature spectrum at mean wind speed 4 m/s retrieved from Ka-band polarimeter data; the numbers 1 to 5 indicate the position of various spectral components. Right panel: evolution of the spectral components with the wind speed; solid line — wind speed, symbols 1 to 5 correspond to the spectral components in the left plot

## 3. CONCLUSIONS

A novel approach for the gravity-capillary wave spectrum estimate from the angular radiometric measurements permits to trace the spectrum parameter evolution under unstable winds. The curvature spectrum as well as long wave slope variance followed the variations of surface wind. The spectral components in the vicinity of the maximum of the wave curvature (about 6 rad/cm) reveal maximal sensitivity to wind velocity variations.

## 4. REFERENCES

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