OBSERVATIONS OF SEA SURFACE WAVES IN WIDE WAVELENGTH RANGE WITH OPTICAL SYSTEM

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This paper is concerned with the real-time observation system of optical devices for recording of sea waves characteristics in wide range of wavelength from centimeters to hundreds meter.
The energy spectra of short waves are obtained in real time by spectral analysis of sea surface image [1] with spectral analyzer operating under no coherent light. The spectral-kinematics characteristics of long energy waves are determined from optical RTI images (range-time-intensity images) constructed from optical profiles of sea surface recorded from carrier to horizon. The possibility of implementing of such system for infrared light is discussed.
The real-time observation system was used from shore, ship and helicopter for monitoring of sea surface roughness in real time. The results of sea waves transformations caused by subsurface processed (such as internal waves), bottom topography, wind front, oil slicks and so on are presented.

Spectral analysis of sea wave image

The new approach to the evaluation of the sea wave spectra is developed using twoscale model of sea roughness [2]. Elevations of sea surface are presented as sum of elevations of long and short waves: $z(x,y) = z_l + z_s$ and the vector of surface slope – as sum of vectors for long $\mathbf{q}_l$ and short $\mathbf{q}_s$ waves/
We shell limits by the case when intensity of sea surface I depends on the slopes of short waves in one direction q_1 (for grazing angles it is direction of observation) and represents I as Tailor expansion in local point on the long wave.
The informative expression for spectra of sea wave's image will be

$$G_I \approx I'^2 (1 + \frac{I''^2}{I'^2} \langle q_{l1}{}^2 \rangle) k_1{}^2 G_s(\vec{k}) . \qquad (1)$$

Where $\langle q_{l1}{}^2 \rangle$ is dispersion of long surface wave slope. The optical contrast of short waves is modulated by the long wave slopes and because the coefficient before wave spectra is changed. It was shown that relative spectral measurements such as spectral contrasts, frequency and angle characteristics of sea wave spectra have better accuracy than absolute measurements.

Measurements of sea wave spectra

The no coherent optical spectrum analyzer of sea surface image in real time based on modulation of image by the transparent with harmonic coefficient of transparency was developed in IAP RAS [3]. The two-dimensional spectra with size 200 spatial frequencies on 33 directions of waves in angle diapason 100^0 ($\pm 50^0$ from direction of observation of spectrum analyzer) with angle resolution about $3{,}2^0$ is derived during one sec. The spatial frequency diapason depends on focal distance of lens, height and angle of observation of spectrum analyzer.

For example, the spectra of sea waves derived with optical spectrum analyzer are presented on fig. 1.This experiments were conducted on the pier in city Theodosia, Black sea 29.06.2008. Height and angle of observation of spectrum analyzer were 8 m and 25^0 accordingly. For this geometry of observation the optical spectrum analyzer recorded wave spectra for waves with wavelength from 84.3cm to 2.2cm. The angle between wind and direction of observation was about 50^0. Conditions of illumination - overcast sky.

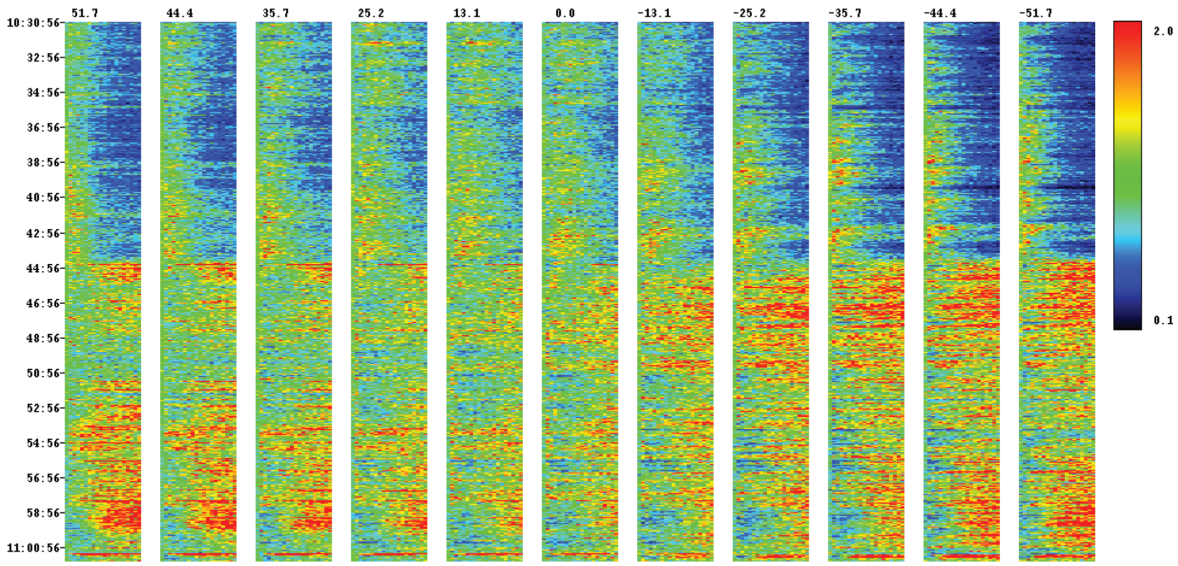

Fig.1 Spectra of sea waves in color temperature scale (right) in conventional units. Vertical axes – time from 10:30:56, duration of recording equals to 0:30:52.

Each column on fig. 1 represents spectra averaged over some wave's directions near direction pointed on the top of column. Angle of the wave traveling counted off direction of observation of spectrum analyzer. Wind direction corresponds to angle -50^0. The spatial frequency of spectra increases from the left to the right (from min to max values) in each column. The value of spectra is presented in color temperature scale in conventional units. Each column is normalized by its mean value by whole time.

In 10:44:56 one can see sharp increasing of centimeter wave's spectra caused by the wind front followed with increasing wind speed from 5 m/s to 8 m/s. The direction of wind was not changed. Note that intensity of decimeter waves does not change.

2D image of space-time wave slopes

Kinematics characteristics of long surface waves are determined from 2D image of space-time wave slopes (RTI images of sea surface in coordinates range – time – intensity of surface), constructed by optical profiles of sea surface [4-6]. This RTI images are the optical analog of radar images derived from side-looking radars and other devices with analogous principles of images formation but having some flexibility depending of needed spatial resolution: it is possible to form RTI images with various range from tens meters to kilometers. The optical device for creating of 2D optical images of space-time wave slopes based on linear array of CCD photodiodes placed in focal plane of the lens was developed. This device after installing on the ship (the shore or sea platform) registers the optical profiles of sea surface ranging from some tens meters away of place of installing to horizon and part of the sky.

Two such devices are installed on the ship in order to record two optical RTI images for various directions of observation. Two this images permit to receive whole information about kinematics characteristics of sea surface waves regardless the dispersion relation and on the other hand to display all systems of waves with various directions of traveling having on the sea surface, because optical contrast of surface waves decreasing with increasing of the angle between directions of observation and wave traveling (1).

For removing of RTI image distortion caused by the ship tossing it is proposed to count beginning of the RTI image from the image of horizon line. The position of the horizon point is determined by the jump of intensity on the horizon.

The method for determination of kinematics characteristics of long surface waves from two RTI images without using dispersion relation is proposed.

Fig. 2 show two RTI images for various directions of observations derived from two optical devices installed on the pier in the Theodosia city, Black sea. The swell with period 2,34 sec traveling from sea to shore is represented on this images as stripes.

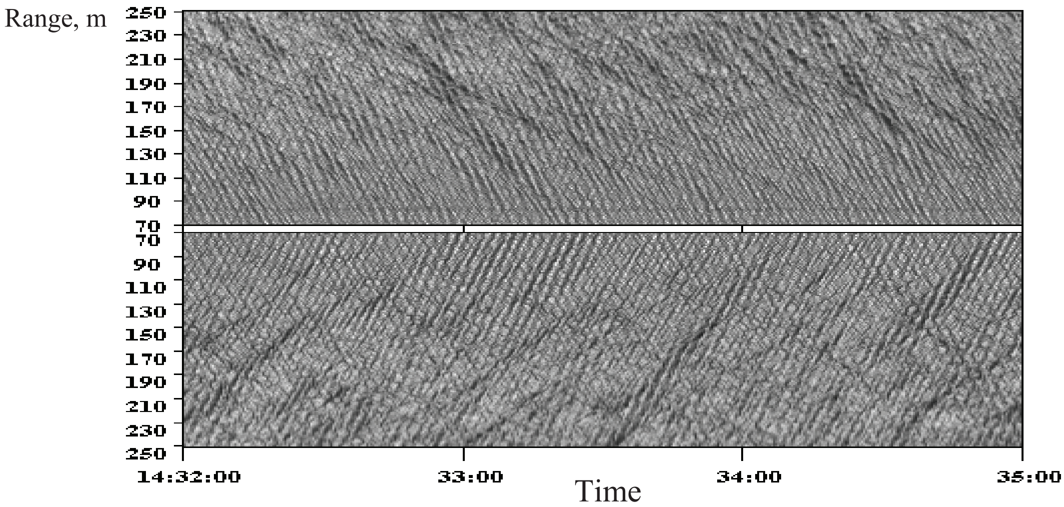

Fig.2 Optical RTI images for two directions of observation with angle between directions equals to 40^0. The intensity of sea surface is represented in gray scale in conventional units. Images are joined by its origins. h = 15m.

Besides long wave images on fig.2 there are black stripes with optical contrast increasing to horizon. The analysis of sea surface intensity under grazing angles taking into account shadowing of waves was shown that this stripes are determined by increasing of sea roughness. Velocity of these stripes determined from images fig. 2 equals to group velocity of long surface wave also appearing on this figure. These stripes are caused by group structure of long waves.

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