The Ministry of Education and Science of the Russian Federation

State scientific Institution "Institute for Scientific Research of Aerospace Monitoring "AEROCOSMOS"

АЭРОКОСМОС

PARAMETERS OPTIMIZATION IN THE PROBLEM OF SEA-WAVE SPECTRA RECOVERY BY AIRSPACE IMAGES

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METHOD FOR STUDYING SEA WAVES SPECTRA

• Two-dimensional spatial spectra have a significant role in the study of spatial and time-dependent variability of the surface wave, they allow to analyze various processes occurring in the water column and to obtain information about the wind fields over the sea surface.

• Optical images are used to obtain the spatial spectra of the surface waves, allowing to capture the instantaneous field distribution of brightness on a relatively large areas with high spatial resolution.

• The proposed approach is based on using the methods of restoring characteristics of boundary atmosphere-hydrosphere based on remote sensing data, including optical images.

METHOD FOR STUDYING SEA WAVES SPECTRA

- In order to obtain spectra of the surface waves using the spatial spectra of space images must be used restoring operators, which are based on algorithms that take into account various conditions of imaging and the characteristics of the equipment.

- Using restoring operators showed its effectiveness in processing the images obtained from aircraft and space vehicles.

- The novelty of our approach is in the modification and adaptation of algorithms for space images of different spectral ranges and spatial resolution.

- This allows to carry out spectral analysis of gravity and gravity-capillary waves in a wide range of weather conditions.

THE PHYSICAL BASIS OF THE METHOD OF RESTORING SPECTRA OF SURFACE WAVES USING SPECTRA OF OPTICAL IMAGES

The brightness of radiation recorded by a remote instrument at small angles of sight

$$L(x,y) = L^{(1)} + \left[L^{(2)}(x,y) + L^{(3)}(x,y)\right]\tau_a \quad (*)$$

where $L^{(1)}$ – component of the brightness associated with scattering in the atmosphere in the direction of the receiver;

$L^{(2)}(x, y)$, $L^{(3)}(x, y)$ – components of the brightness associated with the surface reflection and the scattering in the water column;

τ_a - transmission function of the atmosphere

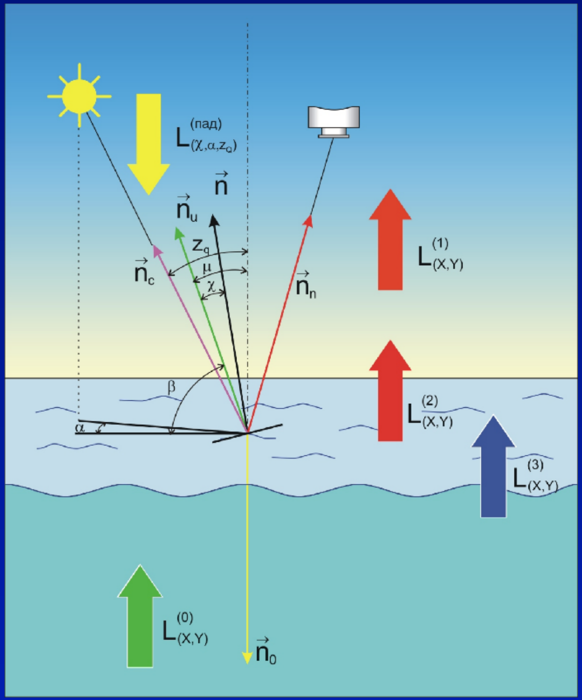


Схема формирования поля яркости излучения морской поверхности

Expanding (*) in each point of the plane (x,y) in a Taylor series by powers of the gradients (slopes) of the surface

$$\xi_x(x,y) = \frac{\partial \xi(x,y)}{\partial x}, \quad \xi_y(x,y) = \frac{\partial \xi(x,y)}{\partial y}$$

we can get:

$$L(x,y) = L^{(1)} + \left[L_0(x,y) + L_1(x,y)\xi_x(x,y) + L_2(x,y)\xi_y(x,y) + L_H(x,y)\right]\tau_a$$

where $L_0(x,y)$ - component of the brightness independent of slope;

$L_1(x,y)\xi_x(x,y)$ и $L_2(x,y)\xi_y(x,y)$ - fluctuation components;

$L_1(x,y), L_2(x,y)$ - functions depending on light conditions;

L_H - non-linear component of the brightness.

THE DEFINITION OF THE RECOVERY OPERATOR

Brightness Field Model

$$L(x,y)=C_x\xi_x(x,y)+C_y\xi_y(x,y)+N'\left(x,y,\xi_x(x,y),\xi_y(x,y)\right)$$

From the image spectra $S(k_x,k_y)$ the spectra of the gradients $\Psi_\phi(k_x,k_y)$ can be obtained

$$\Psi_\varphi(k_x,k_y)=R(k_x,k_y)S(k_x,k_y)$$

$\Psi_\varphi(k_x,k_y)$ **- two-dimensional slope spectrum;**

$R(k_x,k_y)$ **- the operator depending on conditions of light and observation, characteristics of remote equipment.**

In the linear approximation : $R(k_x,k_y)=const$

In the general case, to obtain spectra of waves is necessary to consider the non-linear effects that have a significant role in the formation of images.

The aim of the work is to find the non-linear restoring operator.

RESTORING SPECTRA OF SEA SURFACE WAVES

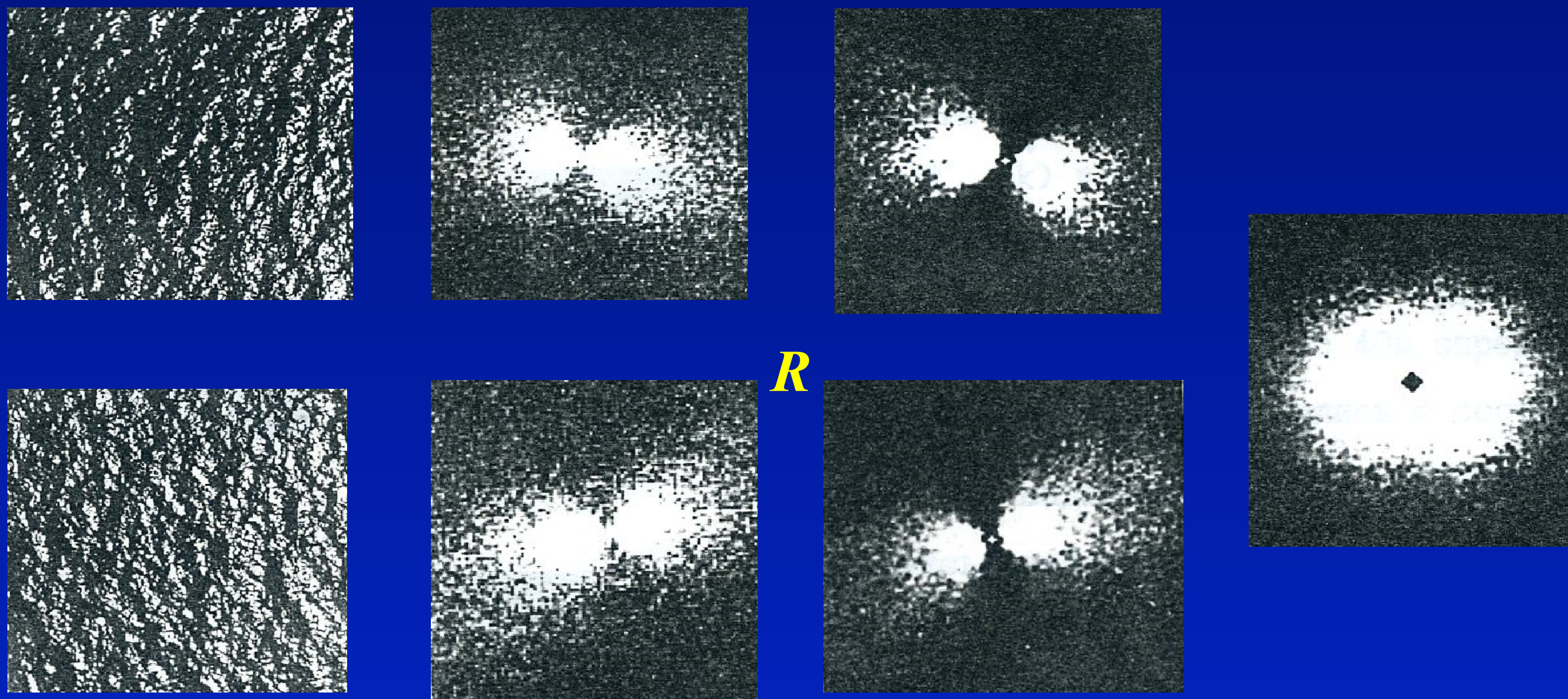


Image fragments

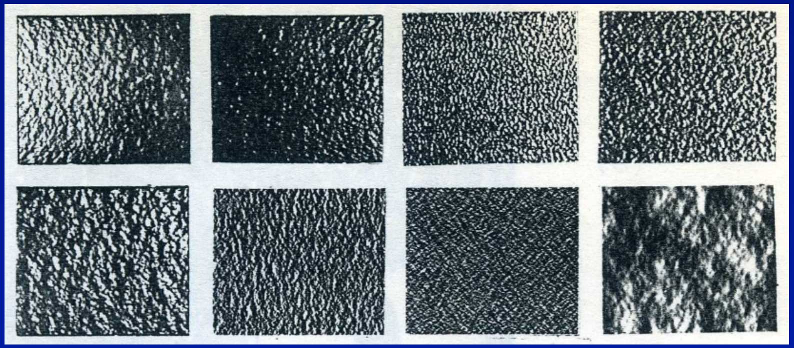
Fragments spectra

Slope spectra

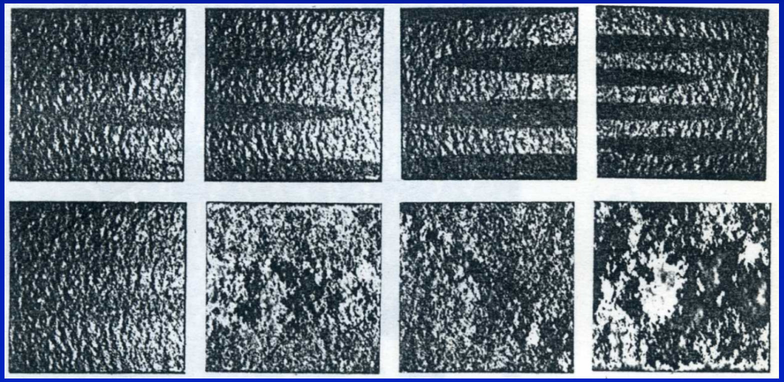
Spectrum of elevations

MODEL IMAGES OF THE SEA SURFACE

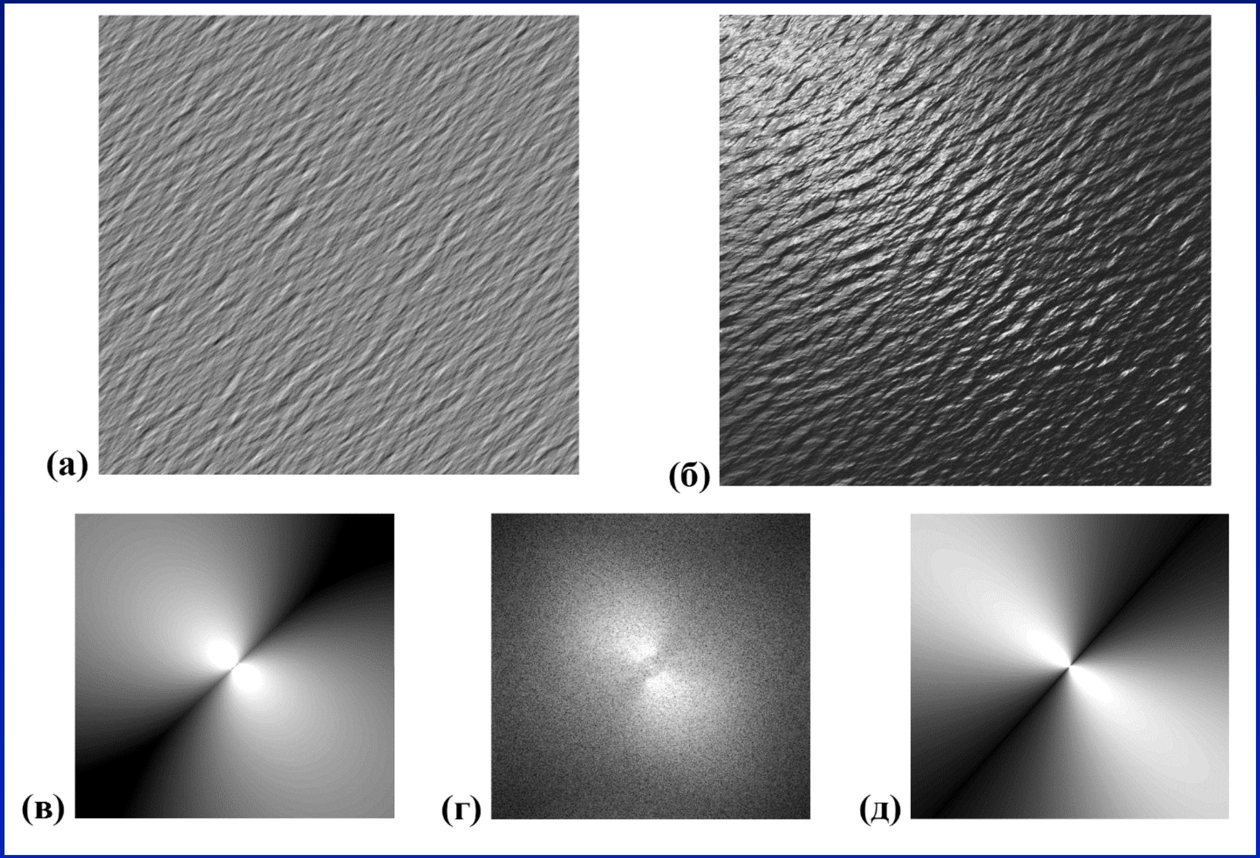
Background surface



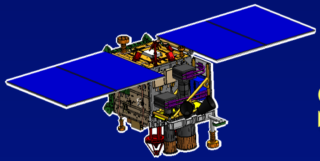
Effects on the sea surface



NUMERICAL SIMULATION FOR RECOVERY OPERATOR



Spatial frequency filter is formed by the ratio of the spectrum of sea surface slope synthesized by the numerical method, to the spectrum of model optical image obtained under specified conditions of formation of the brightness field

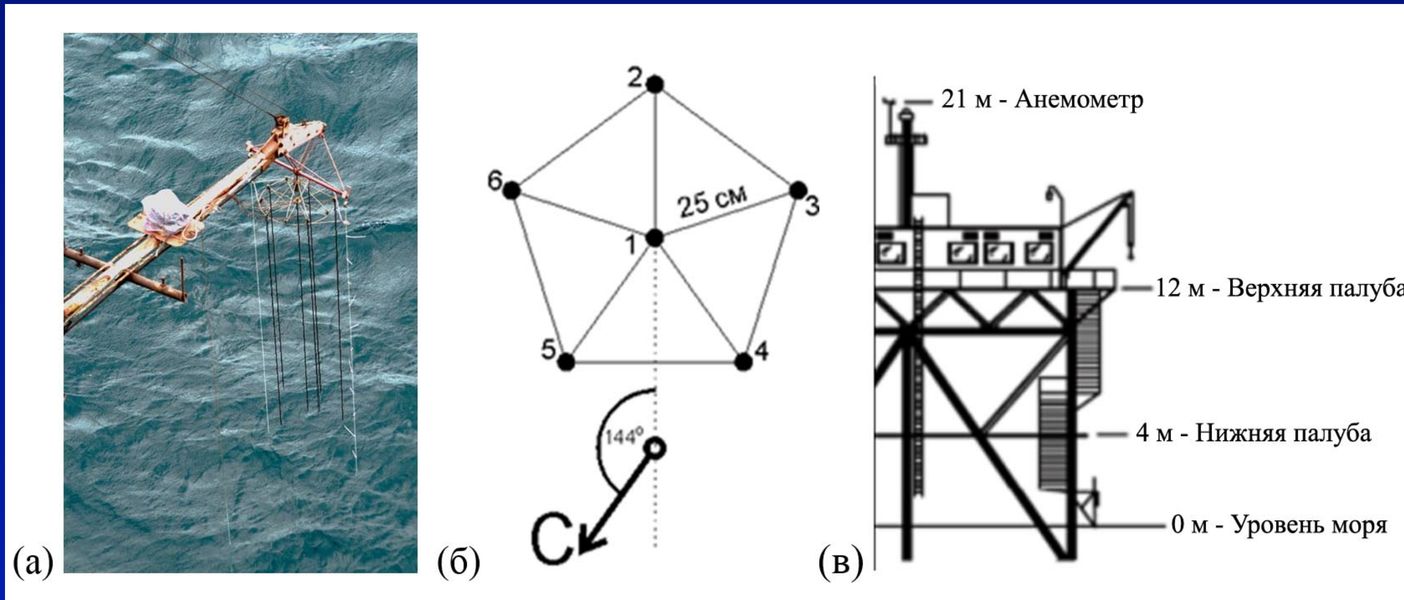


STUDY OF THE SPECTRA OF SEA WAVES BY SATELLITE AND CONTACT DATA

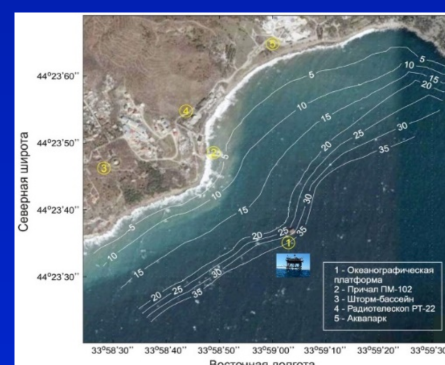
TYPES OF EXPERIMENT

- REMOTE SENSING AND SIMULTANEOUS GROUND MEASUREMENTS OF THE WAVES SPECTRA IN THE AREA OF THE STATIONARY OCEANOGRAPHIC PLATFORM
- STUDIES IN THE VISIBLE AREA OF THE WAVES SPECTRA (Λ=0.04-1.0 M) USING STRING WAVE RECORDERS, OBJECT PHOTOGRAPHY AND STEREO PHOTOGRAPHY FROM THE DECK OF AN OCEANOGRAPHIC PLATFORM
- SATELLITE IMAGERY OF RESEARCH AREA AND SIMULTANEOUS MEASUREMENTS OF THE WAVES SPECTRA WITH THE DRIFTING WAVE BUOYS
- RESEARCH IN AREAS EXPOSED TO INTENSIVE ANTHROPOGENIC INFLUENCES

GROUND MEASUREMENTS OF THE WAVES SPECTRA

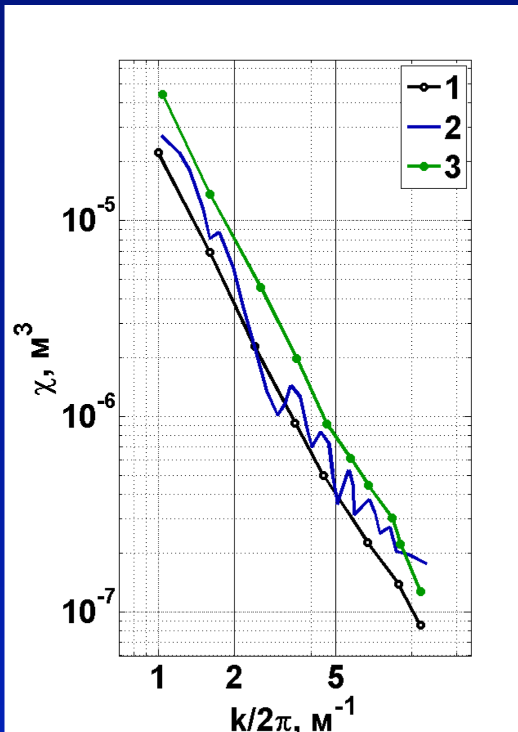


EQUIPMENT OF THE OCEANOGRAPHIC PLATFORM IN KATSIVELI



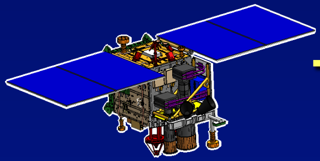
RESEARCH AREA

THE RESULTS OF EXPERIMENTAL RESEARCH



Источник информации	Характеристики пространственных спектров возвышений морской поверхности				
	среднеквадратичное отклонение σ_ξ, мм		показатель p_x		
	$\Lambda = 0.04–0.4$ м	$\Lambda = 0.1–1.0$ м	$\Lambda = 0.04–0.4$ м	$\Lambda = 0.1–1.0$ м	$\Lambda = 1.0–5.0$ м
	Комплексный эксперимент				
Нелинейное восстановление по изображениям	3.1 ± 0.7	7.8 ± 1.3	2.12 ± 0.08	2.23 ± 0.09	2.22 ± 0.08
Стереосъемка	5.4 ± 1.5	11.3 ± 2.7	2.10 ± 0.10	2.20 ± 0.17	Нет данных
Решетка струнных волнографов	3.8 ± 0.05	8.5 ± 1.7	$1.93 + 0.11$	1.98 ± 0.05	2.25 ± 0.05
	Известные аппроксимации				
Филлипс (Филлипс, 1980)	3.5	8.6	3.0	3.0	3.0
Пирсон, Московиц (Pierson Moskowitz, 1964)	2.8	7.1	3.0	3.0	3.0
Тоба (Toba, 1973)	3.7	7.3	2.5	2.5	2.5
Лейкин. Розенберг (Лейкин, Розенберг 1987)	3.3	7.0	2.6	2.6	2.6

Spectra of sea surface elevations, obtained by different methods:
1 – restoring from images using non-linear multiple method;
2 - contact measurement by string wave recorder;
3 - stereophotogrammetrical measurements;
red lines are Toba approximation



THE FORMATION OF THE MODIFIED RECOVERY OPERATOR

MODIFIED RESCOVERY OPERATOR IS REPRESENTED AS A SUPERPOSITION OF TWO OPERATORS

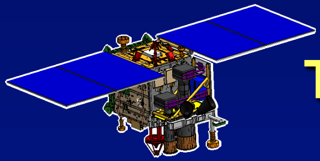
$$\mathbf{R}_{\mathrm{mod}}(\mathbf{k}) = \mathbf{R}_{\mathrm{low}}(\mathbf{k})\ \mathbf{R}_{\mathrm{high}}(\mathbf{k})$$

$\mathbf{R}_{\mathrm{high}}$ - RESCOVERY OPERATOR IN THE FIELD OF HIGH FREQUENCIES

$\mathbf{R}_{\mathrm{low}}$ - RESCOVERY OPERATOR IN THE FIELD OF LOW FREQUENCIES

$$\mathbf{R}(\mathbf{k}) = |\mathrm{C}|^{-2}\, q_4 \left(\cos(\varphi - \varphi_C)^{q_3}\ k^{-(q_1 + q_2 \cos(\varphi - \varphi_C))} \right)$$

$$\mathbf{R}_{\mathrm{low}}(\mathbf{k}) = \exp\left(-\beta k^{-\alpha}\right)$$



THE FORMATION OF THE MODIFIED RESTORING OPERATOR

COMPARISON WITH THE CONTACT DATA INCLUDES THE STEPS OF:

TRANSITION TO ONE-DIMENSIONAL SPATIAL SPECTRUM

$$\chi^{дист}(k)=C\iint\Psi(k,\varphi)kdkd\varphi$$

TRANSITION TO FREQUENCY SPECTRUM

$$\omega^2=gk$$

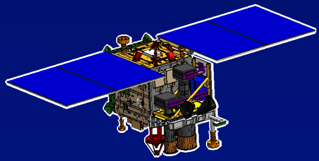
$$\psi_{low}^{дист}(\omega)=\chi_{low}^{дист}(k)\frac{2\omega}{g}.$$

CALCULATION OF THE DIFFERENCE OF SPECTRA

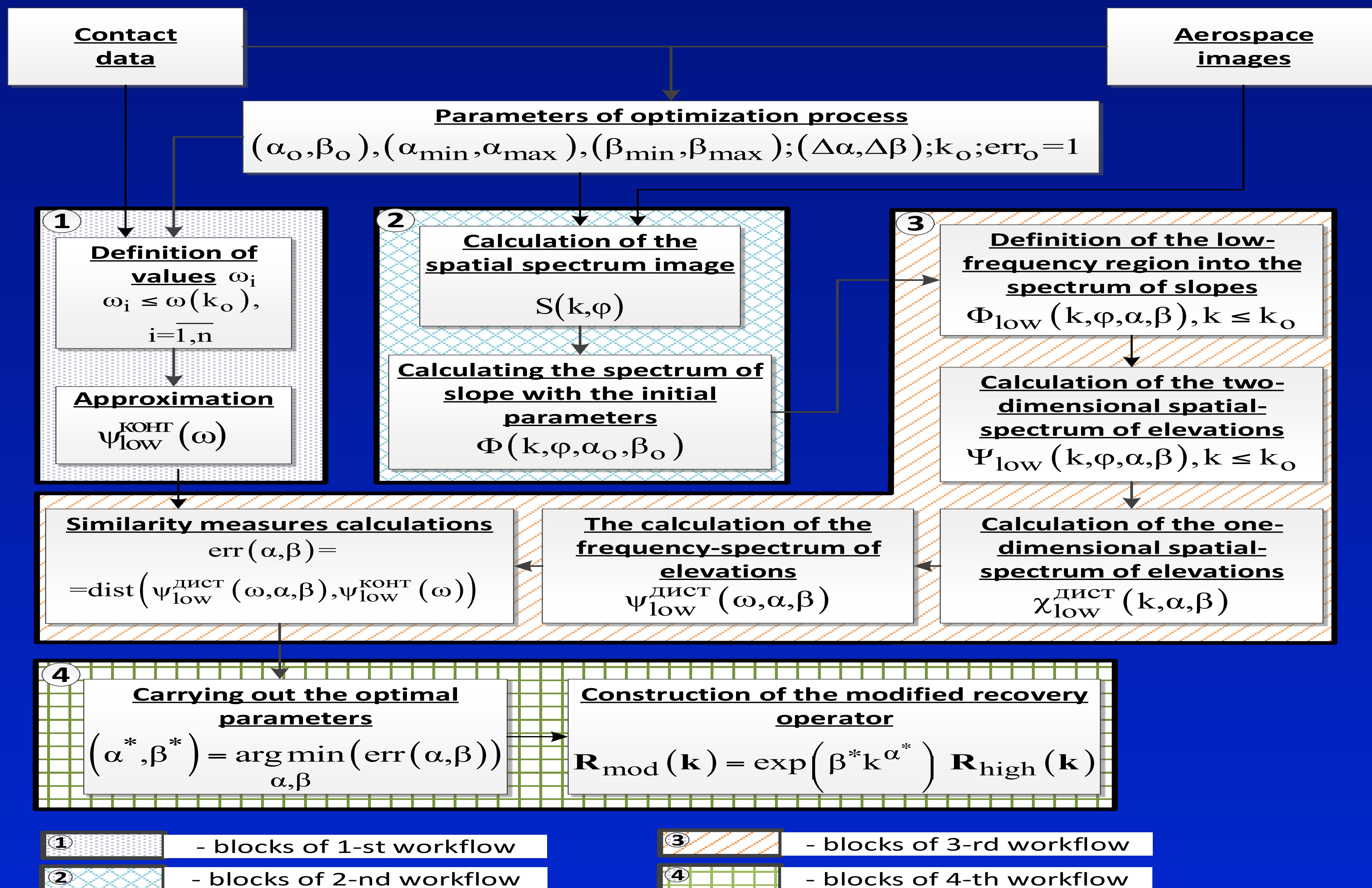
$$\mathrm{dist}\left(\psi_{low}^{дист}(\omega),\psi_{low}^{конт}(\omega)\right)=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\psi_{low}^{дист}(\omega_i)-\psi_{low}^{конт}(\omega_i)}{\psi_{low}^{конт}(\omega_i)}\right)^2}$$

FINDING OPTIMAL PARAMETER VALUES

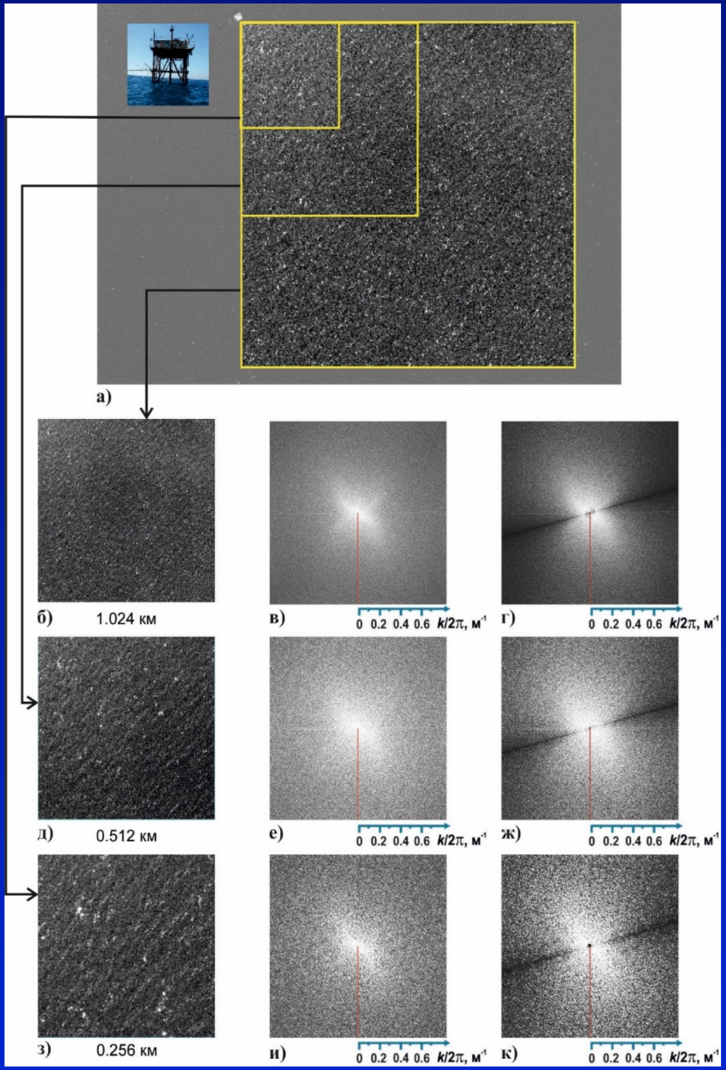
$$\left(\alpha^*,\beta^*\right)=\arg\min_{\alpha,\beta}\mathrm{dist}\left(\psi_{low}^{дист}(\omega),\psi_{low}^{конт}(\omega)\right)$$



THE BLOCK DIAGRAM OF THE FORMATION OF THE MODIFIED RESCOVERY OPERATOR

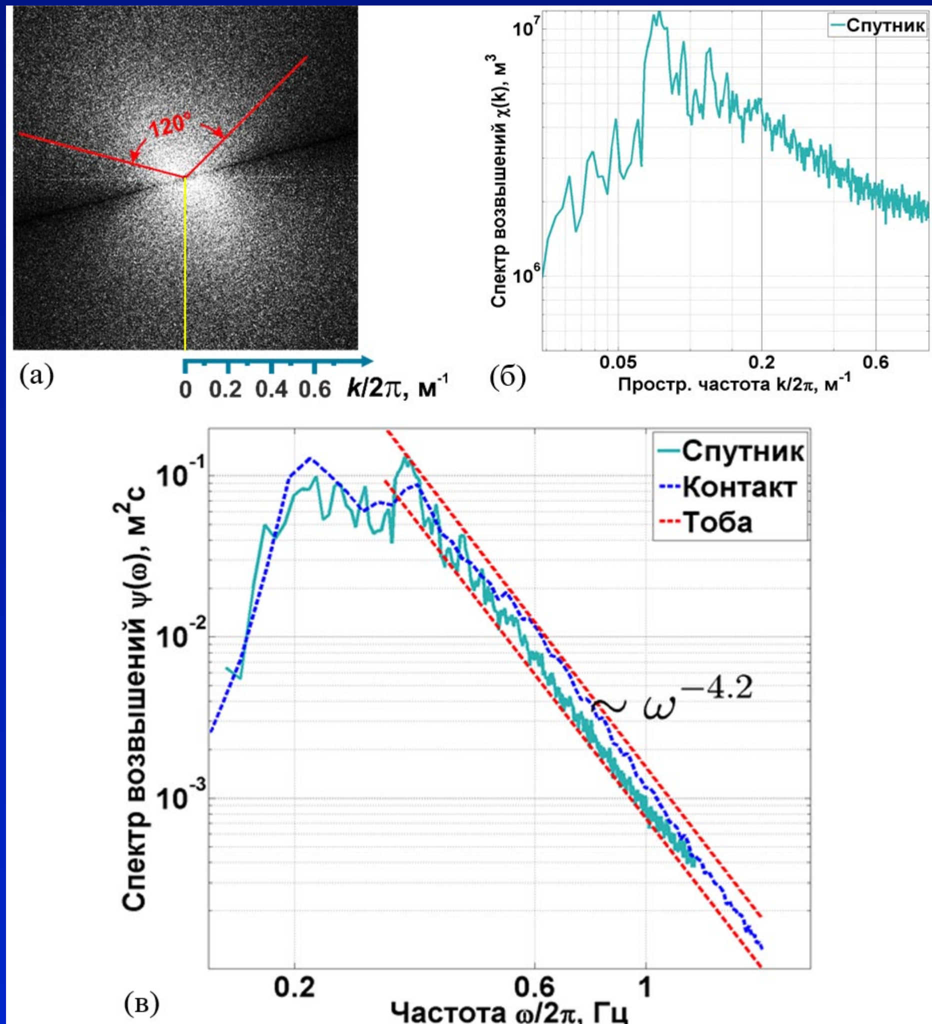


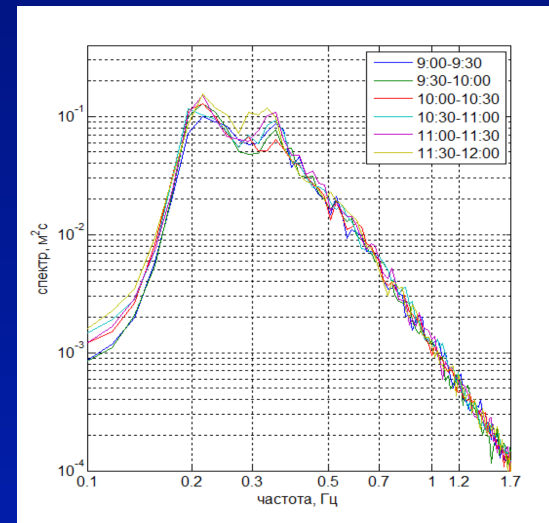
RECOVERY OF THE WAVES SPECTRA FROM SPACE IMAGES



THE RESULTS OF SPATIAL SPECTRAL PROCESSING OF THE SPACE IMAGE OBTAINED SEPTEMBER 24, 2015 FROM THE SATELLITE GEOEYE IN THE AREA OF OCEANOGRAPHIC PLATFORM

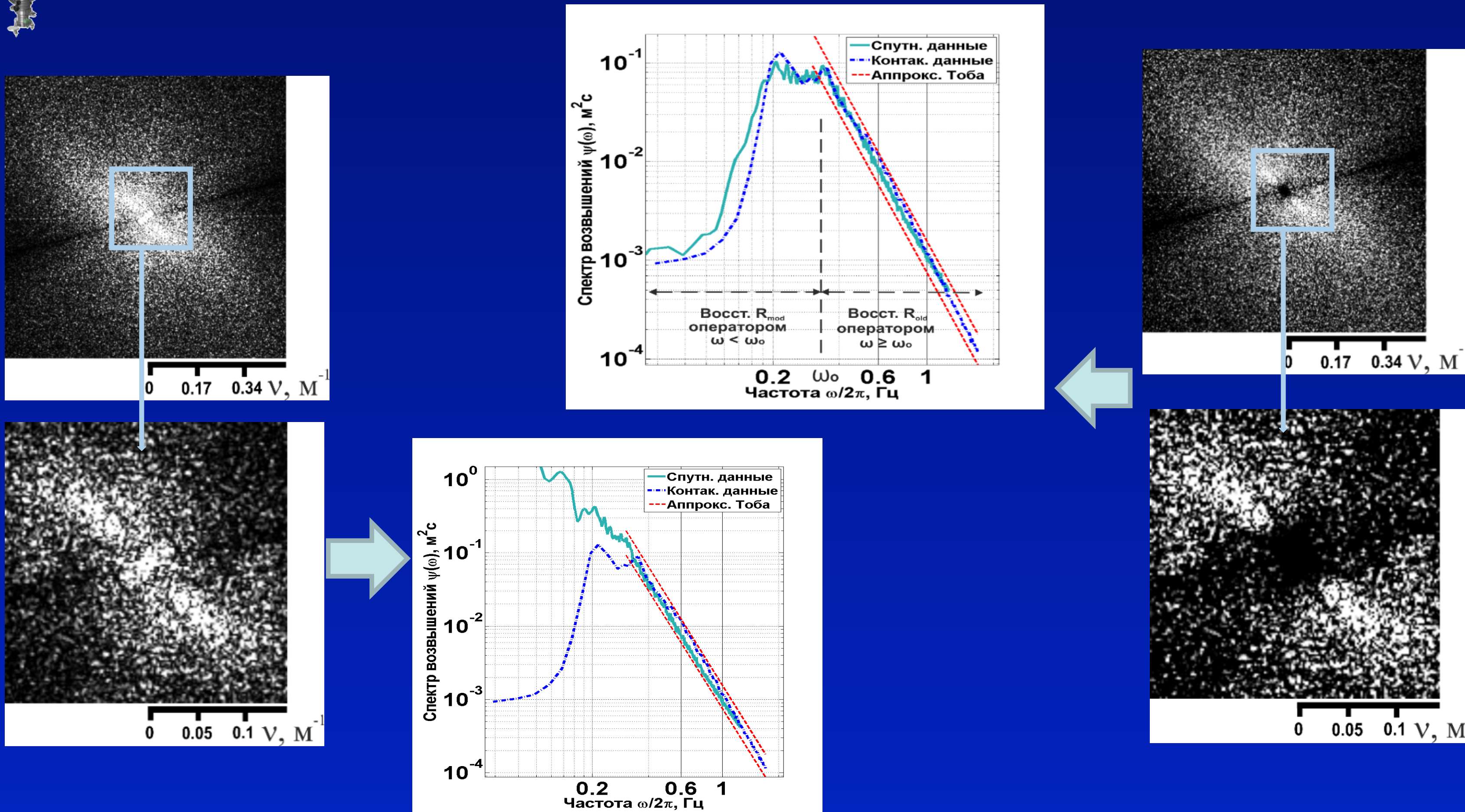
COMPARISON OF THE WAVES SPECTRA OBTAINED FROM REMOTE AND CONTACT DATA





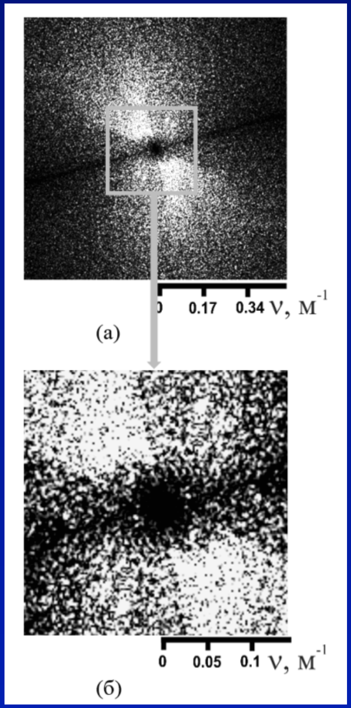
A COMPARISON OF THE WAVES SPECTRA BASED ON REMOTE AND CONTACT DATA AS WELL AS APPROXIMATION TOBA

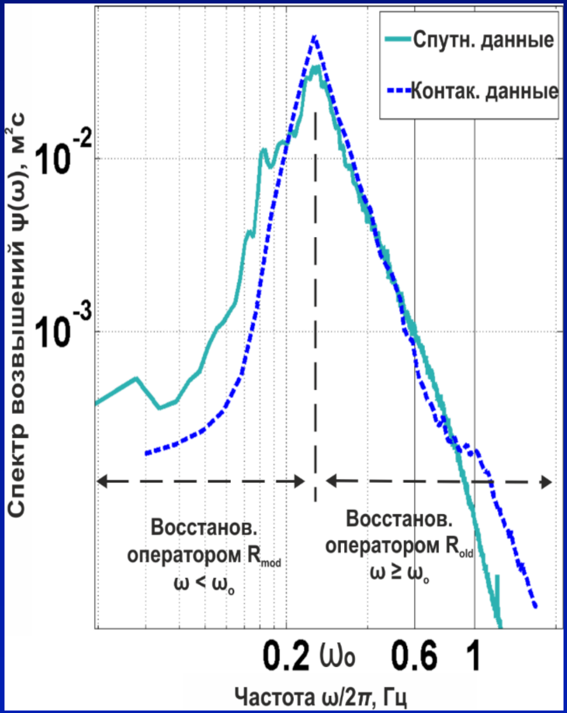
THE RESULTS OF EXPERIMENTAL RESEARCH



COMPARISON OF WIND WAVES SPECTRA OBTSAINED FROM CONTACT AND REMOTE DATA

THE RESULTS OF EXPERIMENTAL RESEARCH

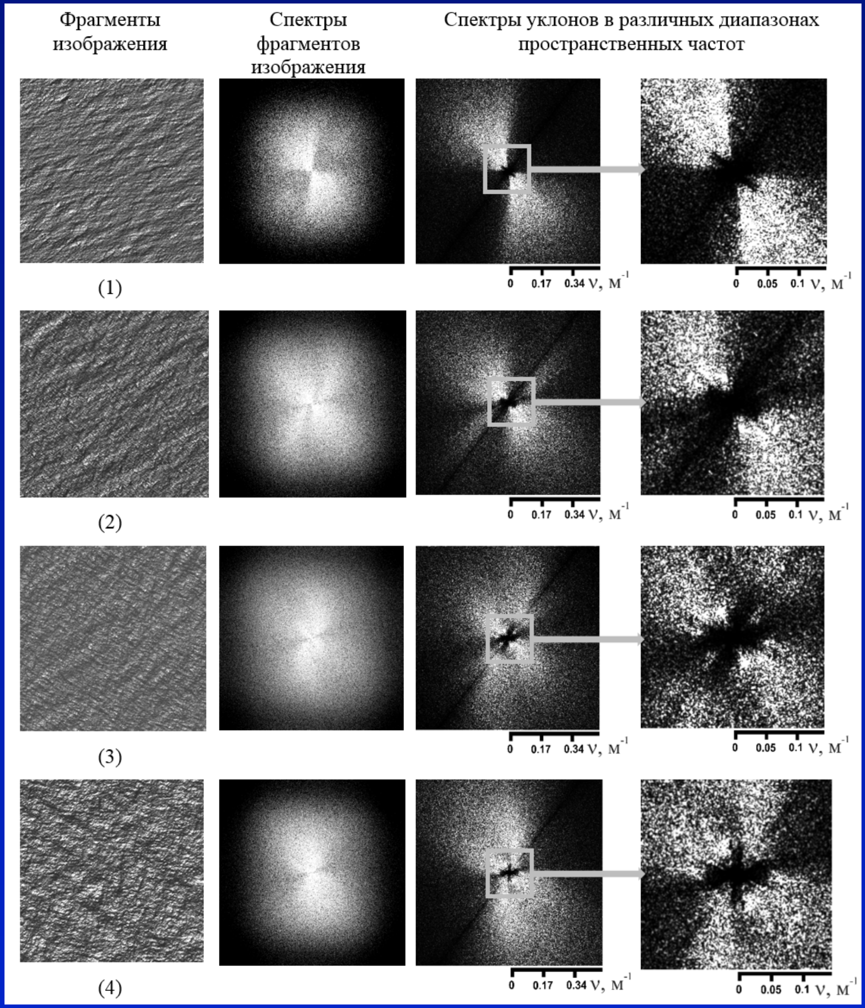




COMPARISON OF THE WIND WAVES SPECTRA IN THE PRESENCE OF SWELL WAVES , RESTORED FROM SATELLITE IMAGES BY MODIFIED OPERATOR Rmod WITH DATA OF THE STRING WAVE RECORDERS

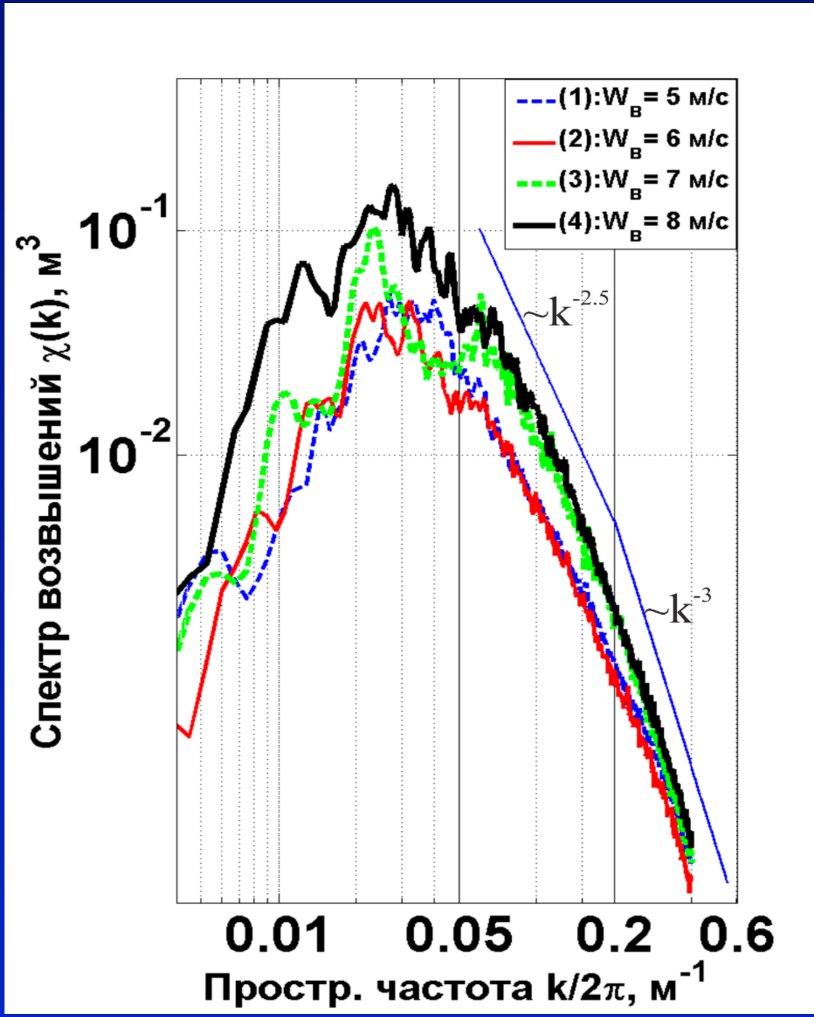
THE RESULTS OF EXPERIMENTAL RESEARCH

Fragments of space images taken at different distances from the shore in Bay Mamula area near the island Oahu. The two-dimensional spatial spectra of the fragments and restored two-dimensional spatial slope spectra in two bands of spatial frequencies



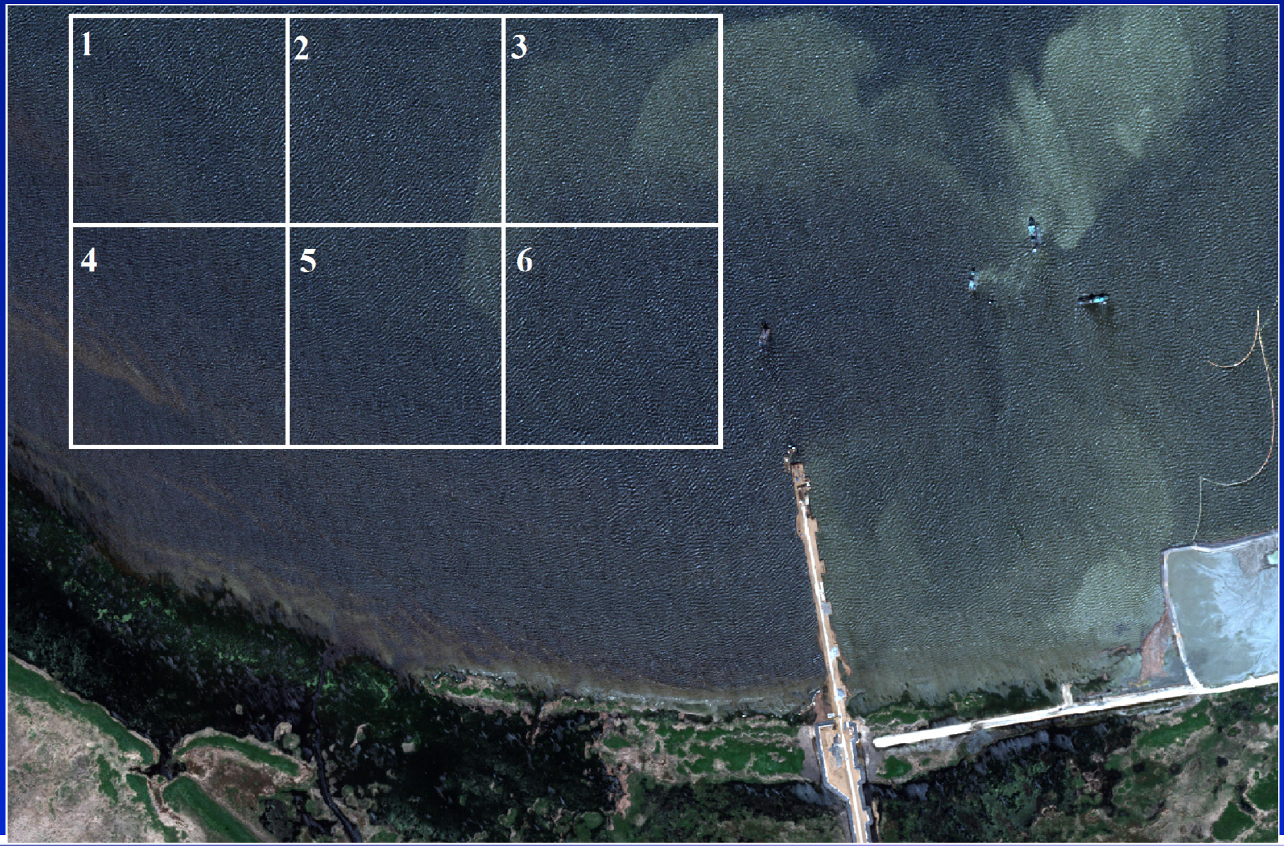
THE RESULTS OF EXPERIMENTAL RESEARCH

One-dimensional spatial spectra of the wave elevations restored from the fragments of space image taken at different distances from the shore (9.3 km, 21.3 km, 41.2 km and 52 km) with various wind speeds in Bay Mamala area near the island Oahu

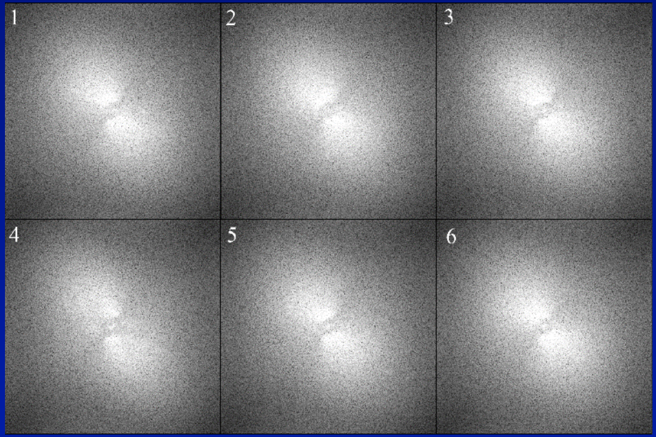


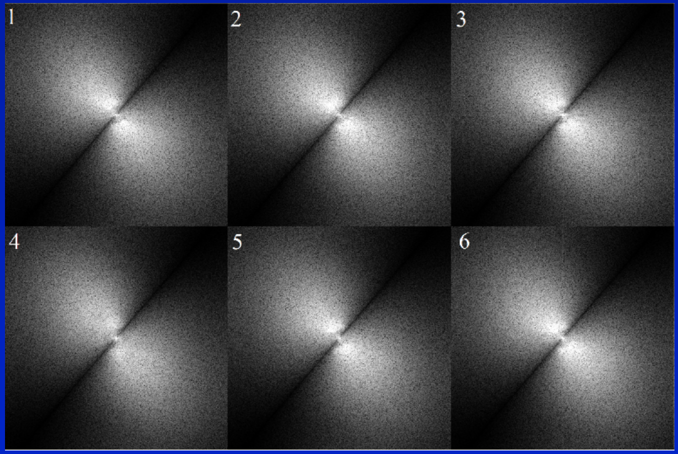
THE RESULTS OF EXPERIMENTAL RESEARCH

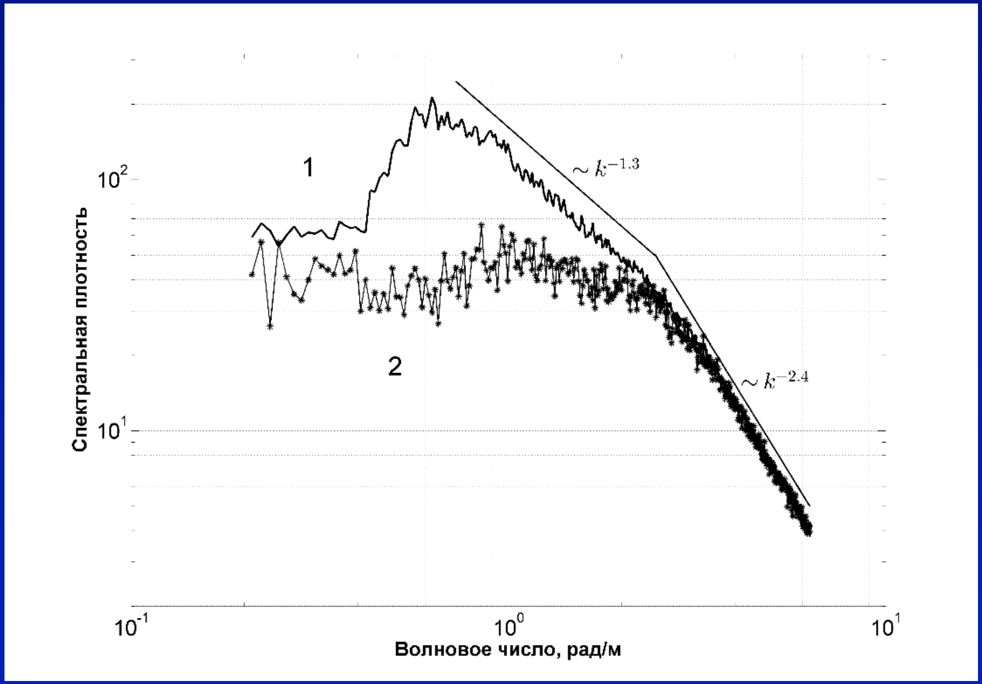
Research in areas exposed to intensive anthropogenic influences: commercial sea port of Ust-Luga in Northwest Russia, Leningrad region, Luga Bay of the Baltic sea near the settlement of Ust-Luga.



THE RESULTS OF EXPERIMENTAL RESEARCH







- Developed a method of remote measurement of the sea waves spectra using space optical images, based on the use of restoring operator in the wide range of spatial frequencies.

  The approach for tuning and validation of the developed method using data obtained by ground measurements made with a string wave recorder is proposed.

  The research of the sea waves spectra in a wide range of wavelengths is done, using the spectra of optical satellite images of high spatial resolution (0.5-1.0 m) and measurements, performed on an Oceanographic platform with a string wave recorders, stereos, as well as with the use of floating wave buoys.

  A comparison of the wave spectra was made, the spectra were restored from satellite images and images, simultaneously obtained from ground measurements.

  Analysis of the results of the comparison showed that the correlation coefficients of the assessments performed by various methods, are in average 0.8—0.9, which indicates the adequacy of the proposed methods.

  The exponential approximation coefficients of the spatial spectra are in the wavelength range of 0.04...5.0 m.

  It was shown that the waves spectra obtained experimentally using remote and contact methods are best approximated by the Toba spectrum.

  The results of applying the proposed method for waves spectra research in different water areas and under various conditions of wave generation.

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THANK YOU FOR YOUR ATTENTION

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