

# Comprehensive Ground-Space Monitoring of Anthropogenic Impact on Russian Black Sea Coastal Water Areas

V.G. Bondur and V.V. Zamshin

**Abstract** In this paper, we describe the developed methods and technologies, as well as the created research prototype of a ground-space regional monitoring system that was used for comprehensive experimental research of anthropogenic impact on Russian Black sea coastal water areas. Changes in significant water environment parameters (generation of additional spectral components of surface waves; changes in marine surface roughness affecting normalized radar cross-section; turbidity field anomalies affecting spectral brightness variations in various bands of electromagnetic spectrum, etc.) registered in satellite imagery of water areas under anthropogenic impact were revealed. It has been established that these effects were predominantly caused by deep wastewater discharges. Zones of anthropogenic pollution propagations, as well as pipe breakages, have been revealed. The validation of the obtained satellite imagery processing results has been conducted based on sea truth data carried out using buoys, as well as from boats and hydrophysical platform.

**Keywords** Remote sensing of the earth · Satellite monitoring  
Satellite imagery · In situ measurements · Coastal water areas · Wave spectra  
Anthropogenic impact

## Introduction

One of the most urgent problems of sustainable nature management is the prevention of environmental pollution, including sea and ocean water area pollution. Anthropogenic impact on coastal water area ecosystems is essential among such problems [2, 4, 9, 21]. The abovementioned problems are crucial for coastal water

---

V.G. Bondur (✉) · V.V. Zamshin  
State Scientific Institution “Institute for Scientific Research of Aerospace Monitoring  
“AEROCOSMOS”, Moscow, Russia  
e-mail: vgbondur@aerocosmos.info

V.V. Zamshin  
e-mail: office@aerocosmos.info

© The Author(s) 2018  
K.V. Anisimov et al. (eds.), *Proceedings of the Scientific-Practical Conference  
“Research and Development - 2016”*, [https://doi.org/10.1007/978-3-319-62870-7\\_66](https://doi.org/10.1007/978-3-319-62870-7_66)

areas of Russia, including the Black Sea shelf. This is due to intensive recreation activity, housing development, the start of hydrocarbon production on the shelf, as well as to planned construction of terminals, cross-country pipelines, and communication lines [22, 26]. One of the most efficient methods to solve these problems is the application of satellite monitoring methods and technologies combined with local sea truth measurements [1, 2, 4]. Therewith, it is necessary to perform comprehensive ground-space monitoring using various types of data, such as satellite optical and radar imagery processing results, results from in situ measurements of current velocity profiles, temperature, pollutant concentrations, hydrooptical, and hydrobiological parameters, etc., [1, 2, 4, 15, 16, 19, 24, 29].

In this effort, we present the results of experimental study of the Russian Black Sea coast using the developed methods and technologies of comprehensive ground-space monitoring of coastal water areas, as well as using the created research prototype of a regional system for collection and processing satellite and in situ data to monitor anthropogenic and natural impacts on the water environment for providing environmental safety and decreasing anthropogenic load on marine ecosystems.

The research is supported by the Ministry of Education and Science of the Russian Federation (unique project Identifier: RFMEFI57714X0110).

## **The Methods and Technologies Used, and the Monitoring System Research Prototype**

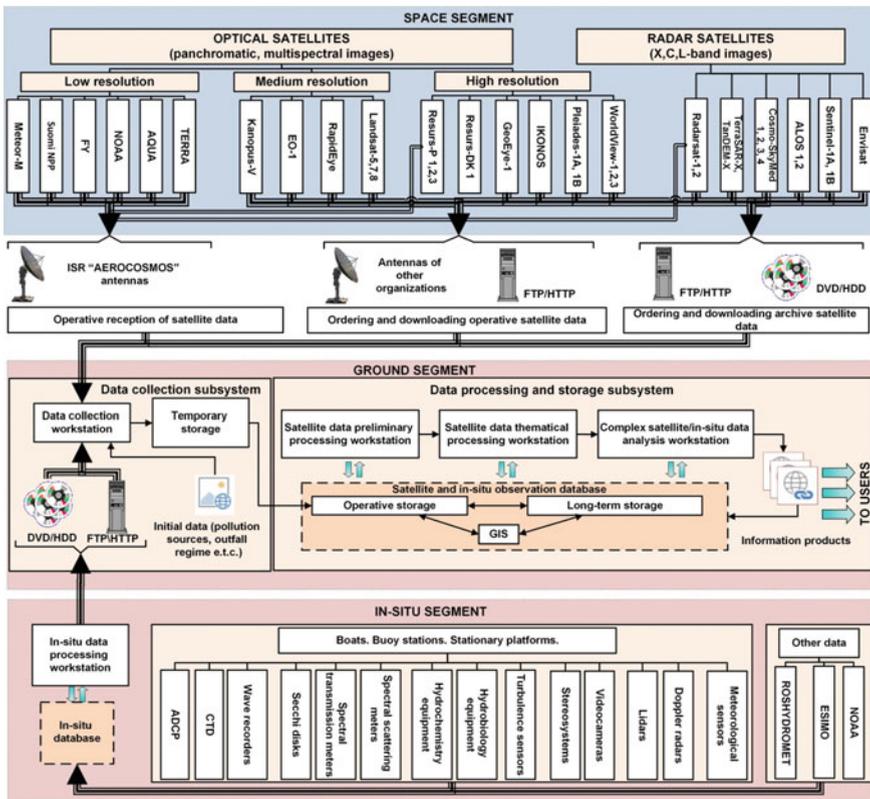
In this research, the following developed methods have been applied:

- Linear and nonlinear methods for retrieving surface wave slope and elevation spectra using satellite optical imagery, based on the synthesis of retrieving operators which are parametrized spatial frequency filters taking into account linear and nonlinear components of the function of brightness field modulation by disturbed sea surface [5, 6, 14].
- An operator building method retrieving sea wave slope and elevation spectra using satellite imagery spectra, based on the parametrization of these operators and their synthesis by means of numerical modeling using the wavenumber power function having parameters, which depend on wave azimuth [5].
- A method of direct assessment of sea wave spatial spectra using wave buoy arrays. This method is based on the wavelet transform allowing for studying nonstationary phenomena [6, 23].
- A method of sea surface multi-polarized radar imagery processing, when normalized radar cross-section (NRCS) is given as a sum of Bragg scattering-related polarized scattering and non-polarized scattering related with wave breaking [20].
- A method of comparing sea surface structure statistical characteristics obtained using in situ methods and satellite data obtained using sea wave dispersion relationship.

The developed technologies for collection and comprehensive processing of various satellites and in situ data generated during coastal water area monitoring were used during the research. These technologies provide collection and systematization of satellite and in situ data in terms of time series; thematic processing providing analysis of such data time series for determination of significant water environment parameters and for detection of anomalies of anthropogenic origin; validation and verification of determined water environment parameters registered by satellite imagery using sea truth data.

In this effort, the sea truth and its interpretation methods played a significant part, including the methods to measure wave spectra using a string wave meter array, ADCP data processing methods, methods of laser location and sea surface Doppler radiolocation from the Stationary oceanographic platform, etc., which are described in [6, 22, 26].

To realize the methods and technologies developed, the research prototype of a regional system of coastal water area ground-space monitoring (Research Prototype) has been created. The flowchart of this Research Prototype is given in Fig. 1.



**Fig. 1** The flowchart of the Ground-Space Monitoring Regional System Research Prototype developed

The system consists of:

- The Space segment, including various satellites, whose data are suitable for the monitoring system information support.
- The Ground segment, including data collection, processing, and storage subsystems serving for satellite data collection and analysis, data storage and handling, as well as for information product formation.
- The In Situ segment, including buoy stations, boats, stationary platforms, and additional ground information sources providing data on water environment conditions.

Individual system segments are interconnected by information communication, reception and transmission tools, which include antennas, FTP/HTTP channels, and DVD/HDD disks.

## Features of the Conducted Experimental Research

The comprehensive experimental research was conducted at three sites of the Black sea water areas located near the cities of Sevastopol and Gelendzhik, and Katsively settlement. The studied sites were characterized by permanent sources of anthropogenic pollution, i.e., deep wastewater discharges. There is a deep wastewater outfall near the city of Sevastopol whose diffuser extends into the sea to a distance of  $\sim 3.3$  km. This outfall discharges tens of millions of cubic meters of wastewater from a treatment plant per year. Similar anthropogenic sources are located near the city of Gelendzhik.

During the comprehensive experiments using the developed methods, technologies, and the Research Prototype, collection, systematization, processing, and analysis of satellite optical and radar imagery, as well as of various in situ data obtained using boats and buoys, and from the stationary platform (see Fig. 1) at the moments of satellite imaging were carried out. Information products with significant water environment parameters characterizing levels of anthropogenic impact on coastal water areas of the studied sites were created as a result of the obtained data processing.

Both anthropogenic pollutions escaping damaged outfall collectors near the shore, and random pollutions due to river run-offs, ship effluents, and other were investigated using satellite optical and radar imagery with the results validated by sea truth from boats, buoys, and the stationary oceanographic platform.

While implementing in situ experiments, we have considered the experience gained during comprehensive studies of water areas near the Oahu Island (Hawaii) influenced by deep wastewater discharges which were described in [2, 4, 7, 8, 11–13, 15, 17, 19, 24, 25, 29]. The most important feature of those studies was the revealed effect of generation and propagation of short-period internal waves causing surface wave modulation, which had been registered by satellite imagery [1, 9].

This was proved during the large-scale modeling in a hydrodynamic basin [10], as well as during various satellite and sea truth data processing [2, 4, 8]. In the framework of this effort, the abovementioned research has been continued and further developed, including due to the development of new methods and technologies, and application of the created research prototype of a ground-space monitoring system.

During the comprehensive monitoring of the Black sea coastal water areas near the cities of Sevastopol and Gelendzhik, and the Katsively settlement, the data were obtained using more than 20 types of equipment, including satellite optical panchromatic and multispectral systems aboard Resurs-P, WORLDVIEW; GEOEYE; Landsat 7,8, and other satellites, satellite synthesized aperture radars aboard TerraSAR-X, SENTINEL-1A, acoustic current velocity meters (ADCP), CTD, thermistor strings, turbidity gages, microstructure probes, etc.

To validate the developed remote sensing methods, the experimental research from the oceanographic platform near Katsively settlement was carried out.

## Main Comprehensive Research Results

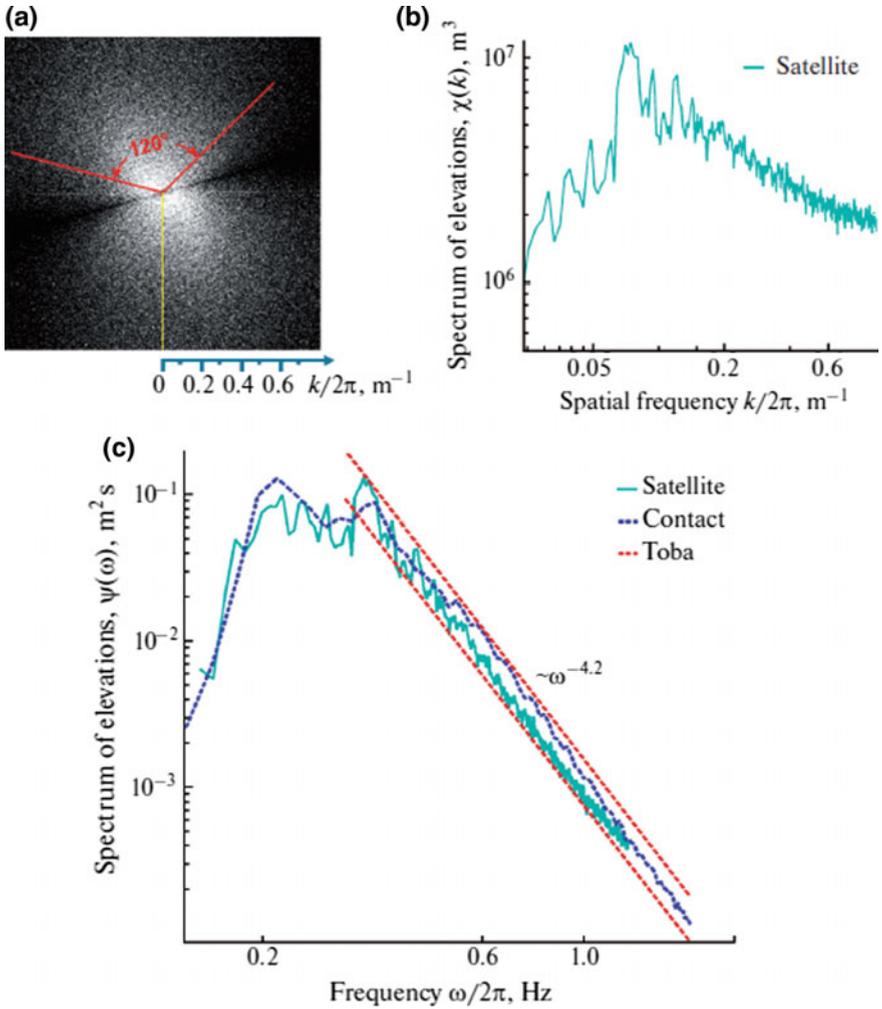
Performance assessment for the data obtained through satellite imagery processing has been carried out using sea truth data. For example, when assessing the adequacy of developed methods for wave spectra retrieval using satellite imagery spectra [5, 6, 14], sea surface slope and elevation spectra obtained through high-resolution satellite image processing were compared with wave spectra measured by a string wave meter array and through stereo photography from a hydrophysical platform [6].

Figure 2 shows the example results of comparing sea wave spectra retrieved from GEOEYE image fragment processing, obtained by a string wave meter array, and with Toba approximation [28].

As can be seen from Fig. 2,  $\Psi(\omega)$  frequency spectra obtained using the developed remote methods [5, 6, 14] and those obtained in situ agree well. The degree of coincidence between these spectra obtained using  $\Psi_{sat}(\omega)$  satellite and  $\Psi_{cont}(\omega)$  in situ data is estimated by the measure of the deviation [6].

$$\Delta = \sqrt{\frac{1}{N} \sum_{n=1}^N \left( 1 - \frac{\psi_{sat}(\omega_n)^2}{\psi_{cont}(\omega_n)^2} \right)^2}, \quad \text{which is } \Delta \approx 0.07$$

The Toba approximation is given in Fig. 2 [28]:  $\Psi(\omega) = \alpha g u_* \omega^{-4}$ , where  $\omega = 2\pi f$  is the cyclic frequency,  $u_*$  is the frictional velocity of the wind,  $\alpha$  is the coefficient for two lines equal 0.06 and 0.11. The analysis of Fig. 2 shows good correlation between the measured frequency wave spectra and Toba approximation in the gravity wave equilibrium interval.

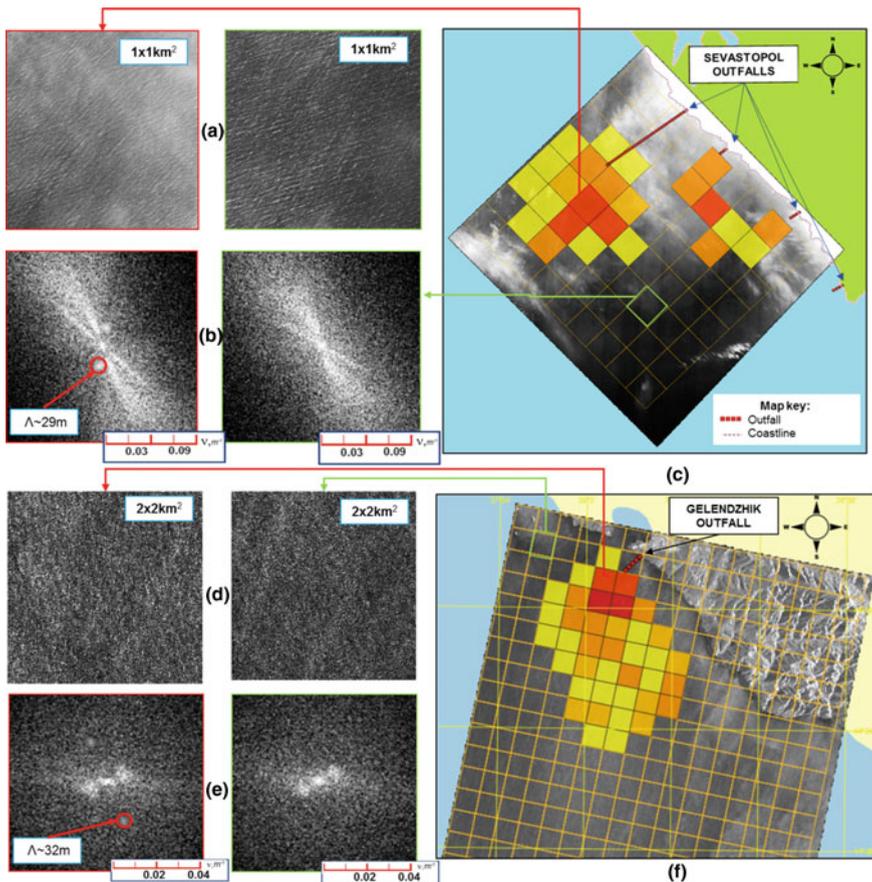


**Fig. 2** Comparison of sea wave spectra retrieved from satellite and in situ data, and with the Toba approximation: **a** 2D spatial spectrum of sea surface slopes retrieved from a satellite image; **b** 1D spatial spectrum of elevations retrieved from satellite data; **c** superposition of the frequency spectra of the sea surface retrieved from a satellite image with a string wave meter array, and from the Toba approximation [28]

To detect surface manifestations of anthropogenic pollution caused by deep wastewater discharges, spatial spectral processing of high-resolution satellite optical and radar imagery was applied. The processing was based on the remote spatial frequency spectrometry method [1]. Such processing has allowed us to reveal the coastal water areas affected by short-period internal waves generated by deep wastewater discharges [1, 2, 4].

The example spatial spectral processing result for the fragments of GEOEYE optical high-resolution (0.5 m) image taken on September 10, 2015, for the coastal water area near Sevastopol where deep wastewater outfalls are placed, is given in Fig. 3a, b, c. The example spatial spectral processing result for the fragment of TerraSAR-X high-resolution (2.0 m) radar image taken on 6 October 2013 for the coastal water area near Gelendzhik where a deep wastewater outfall is placed, is given in Fig. 3d, e, f.

Figure 3a, b show the examples of 1 x 1 km<sup>2</sup> fragments of the processed optical satellite image and relevant 2D spatial spectra (left—the zones of deep outfall



**Fig. 3** Examples of spatial spectral processing of GEOEYE optical image taken on 10 September 2015 for the coastal water area near Sevastopol (a, b, c) and TerraSAR-X radar image taken on 6 October 2013 for the coastal water area near Gelendzhik (d, e, f): **a, b, d, e**—fragments of original satellite images and correspondent 2D spatial spectra (*left*—the zones of deep outfall surface manifestation, *right*—background); **c, f**—maps showing spatial distributions of deep outfall surface manifestations. “Quasimonochromatic” spectral maxima are seen in anomalous fragment spectra (relevant spatial period,  $\Lambda \sim 30\text{ m}$ )

surface manifestation near Sevastopol, right—background). As can be seen from the analysis of Fig. 3b, narrow symmetric spectral maxima (one is circled) is distinctly seen in the spectrum of the anomalous area. These spectral maxima correspond to certain periodic structures on the sea surface caused by propagating high-frequency internal waves generated by the deep outfall [1, 2, 4]. The spatial period of such structures is  $\Lambda \sim 29$  m, and the width is  $\Delta\Lambda = 2\text{--}3$  m. Thus, the condition of “quasimonochromaticity”  $\Delta\Lambda \gg \Lambda$  is satisfied.

Figure 3d, e show the results of similar spatial spectral processing of TerraSAR-X radar image taken on 6 October 2013 for the coastal water area near Gelendzhik where an outfall is located. As for the optical satellite image, “quasimonochromatic” spectral maxima are observed in the 2D spectrum of anomalous radar satellite image  $2 \times 2$  km<sup>2</sup> fragment (in the area of a deep outfall). Such  $\Delta\Lambda = 2\text{--}3$  m spectral maxima are the evidence of a periodic spatial structure with  $\Lambda \sim 32$  m length. This is a surface manifestation of short-period internal waves generated by a wastewater jet near Gelendzhik.

Figure 3c, f show the maps of high-frequency internal wave surface manifestations in the vicinity of deep outfalls near Sevastopol and Gelendzhik. Processed fragments of optical and radar satellite images to which anomalous spectra correspond are marked with different colors depending on additional spectral harmonic intensities. Red color represents the highest level of anomaly manifestation, and light yellow represents the lowest one. The background is not painted. Red lines denote outfalls.

The analysis of Fig. 3c shows evident anthropogenic pollution caused by the main deep outfall (upper part of the figure) and by some lesser ones (lower) near Sevastopol (Herakleian Peninsula). The area of surface manifestations of the main outfall has almost round shape with  $\sim 5$  km diameter. The distance between this area and the shore is  $\sim 2.5\text{--}3$  km. The areas of surface manifestations of two lesser outfalls are merged. They have similar shapes with 1–2 km widths and are 0.5–4.5 km off shore. They can be observed within  $\sim 5$  km along the shore.

The analysis of Fig. 3f shows that the surface anomaly detected through spatial spectral processing of satellite radar image processing near Gelendzhik outfall has an elongated shape with  $14 \times 18$  km<sup>2</sup>.

The processing of 152 image fragments with spectral maxima revealed in satellite imagery obtained in various moments during outfall monitoring near Sevastopol and Gelendzhik has shown that spatial periods corresponding to surface manifestations of internal waves generated by deep outfalls vary within  $\Lambda \sim 20\text{--}80$  m ( $\bar{\Lambda} \sim 35$  m is the average). The widths of “quasimonochromatic” spectral components vary within  $\Delta\Lambda = 1.8\text{--}3.2$  m ( $\overline{\Delta\Lambda} = 2.1$  m is the average).

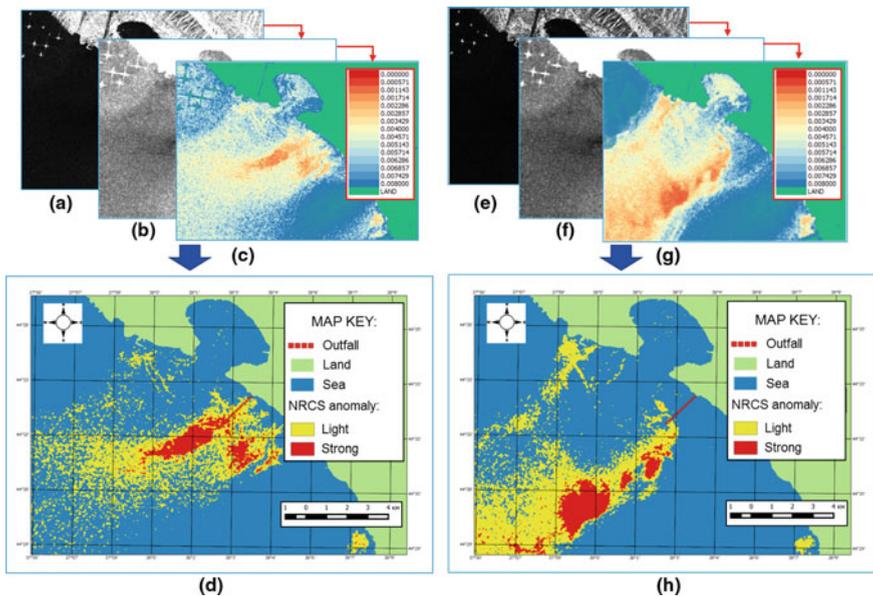
Figure 4 presents the example processing of SENTINEL-1A radar images taken on 14 September and 2 October 2016 for the Gelendzhik coastal water area near the deep outfall. This figure shows the fragments of original radar satellite images (VV polarization) subjected to georeferencing and radio calibration (a,e), as well as the results of smoothing (median filter with  $9 \times 9$ -pixel scanning window) and brightness histogram equalization (b,f). Figure 4c, g present the results of

thresholding and color-coding, and Fig. 4d, h present the maps of NRCS negative contrasts (2.5–4 dB) with pointed out outfall location near Gelendzhik.

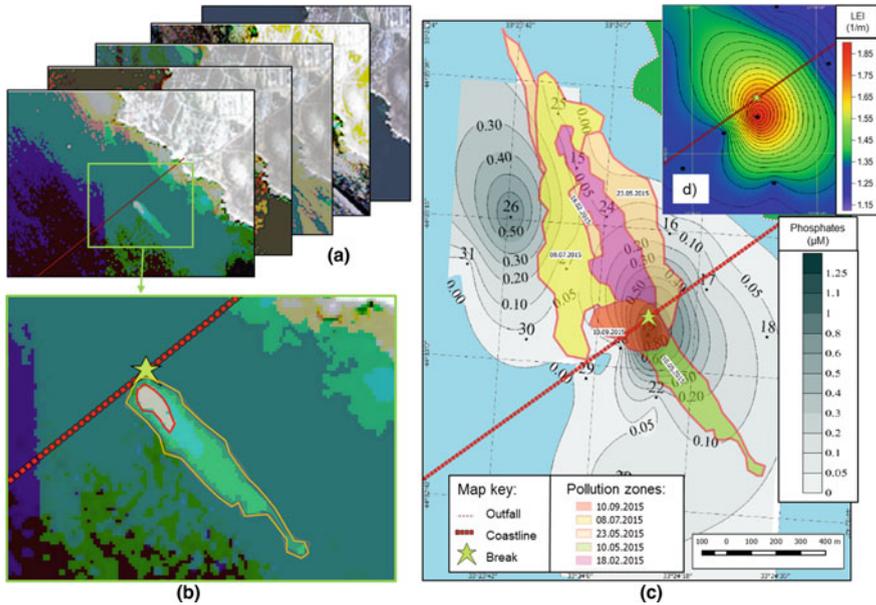
Spectral informative features were applied during the processing multispectral satellite imagery [3, 13, 16]. To detect anomalies of water environment hydrooptical characteristics attributed to outfall collector locations, spatial distributions of color index values were used [1, 3, 18]. Figure 5a shows the example fragments of time series for the processed satellite imagery obtained on 18 February, 10 and 25 May, 8 July, and 10 September 2015 by GEOEYE-1 and WorldView-2, 3 satellites for the coastal water area near Sevastopol.

Figure 5b presents an enlarged fragment of WorldView-3 (10 may 2015) processed image. There is a distinct optical anomaly adjacent from southeastward to the collector (in the area of its damage) in this image. Figure 5c shows a generalized sketch-map of all the anomalies which were registered in 2015-experiments. These anomalies were caused by wastewater escaping the damaged outfall collector. Phosphate concentration distributions measured by in situ sensors are also given in Fig. 5c. Increased phosphate concentration is observed in the near-surface water layer down to 5 m depth in the area of the collector’s damage. Figure 5d show the results of sea truth boat measurements of light extinction index (LEI) at a wavelength of 370 nm (the 9-band sensor of directional light extinction index).

As we can see from the analysis of Fig. 5c, the detected outfall collector damage (denoted with an asterisk) is located at a distance of about 800 m offshore, whereas



**Fig. 4** Example processing (a, b, c, e, f, g) of SENTINEL-1A [27] radar images of Gelendzhik coastal water areas taken on 14 September 2016 (left) and 2 October 2016 (right), as well as distribution maps for anomalous NRCS values (d, h) due to deep outfall manifestations (d, h)



**Fig. 5** Satellite optical multispectral imagery processing examples (18 February, 10 and 25 May, 8 July, and 10 September 2015, GEOEYE-1 and WorldView-2,3 satellites) for the coastal water area near Sevastopol (a, b). The map with superposed zones of anthropogenic impact due to outfall collector damage, created on the basis of sea truth hydrochemical (c) and hydrooptical (d) data

the outfall collector has the total length of 3.3 km. Phosphate concentration increase (Fig. 5c) and light extinction index increase from 1.15 to 1.9 1/m in the near-surface sea layer (Fig. 5d) are revealed in the vicinity of the damage.

Similar results were obtained by satellite and in situ observations near Gelendzhik.

## Conclusion

Using the developed methods, technologies, and the Research Prototype of the regional ground-space monitoring system, the study of the anthropogenic impact on the ecosystems of the Black sea coastal water areas near the cities of Sevastopol, Gelendzhik, and Katsively settlement was carried out. During the comprehensive monitoring, more than 20 types of equipment were used, including satellite optical multispectral systems, acoustic current velocity meters, CTD, thermistor strings, turbidity sensors, microstructure probes, etc. Thirty-four types of information products quantifying significant water environment parameters and levels of anthropogenic impacts on the coastal water area ecosystems were generated based on the processing of large volume of data collected (more than 1 TB).

The comparison of collected remote and in situ data has verified the adequacy of developed remote sensing methods and methods for processing satellite imagery in various electromagnetic wave spectrum bands. For example, the measure of the difference between wave spectra retrieved using satellite imagery and those obtained by the string wave meter array is 0.07.

Spatial spectral processing of high-resolution (0.5–2.0 m) optical and radar images has allowed us to detect surface manifestations of anthropogenic pollution caused by deep outfalls near Sevastopol and Gelendzhik and to determine their dimensions (from 5 to 18 km). These manifestations can be detected by “quasi-monochromatic” spectral maxima (width,  $\Delta\lambda = 1.8\text{--}3.2$  m ( $\overline{\Delta\lambda} = 2.1$  m is the average) indicating the presence of quasiperiodic structures with spatial periods,  $\Lambda \sim 20\text{--}80$  m ( $\overline{\Lambda} \sim 35$  m is the average) on the sea surface caused by interaction of surface waves and short-period internal waves generated by deep outfalls.

Radar satellite VV polarization-imagery processing has enabled us to establish that anomalies of NRCS with prevalent negative contrasts (2.5–4 dB) appear periodically near the outfall collectors. These anomalies were caused by surface wave field transformation related with internal wave generation, as well as with direct impact of slicks, i.e., smoothed stripes of floating-up wastewater jets.

On the basis of satellite multispectral imagery and sea truth data processing, we have detected the zones of intensive anthropogenic impacts related to deep wastewater discharges and damages of outfall collectors near Sevastopol and Gelendzhik. These deep wastewater discharges can be seen in satellite imagery in the form of anomalies having increased brightness and typical dimensions from 0.5 to 3 km, which are located at a distance of approximately 0.5 to 1.5 km from the shore. These results are confirmed by the data obtained during hydrochemical and hydrooptical measurements from aboard ships.

The analysis of the obtained results proves the efficiency of used satellite methods and technologies, as well as the efficiency of the created research prototype of a regional system of coastal water area ground-space monitoring.

**Acknowledgement** The Research is carried out with the financial support of the state represented by the Ministry of Education and Science of the Russian Federation. Agreement (contract) no. 14.577.21.0110 08. Sep 2014. Unique project Identifier: RFMEFI57714X0110.

## References

1. Bondur, V.G.: Aerospace methods in modern oceanology *New Ideas in Oceanology*, vol. 1 Physics. Chemistry. Biology, pp. 55–117 + ill. Nauka, Moscow (2004)
2. Bondur, V.G.: Complex Satellite Monitoring of Coastal Water Areas 31st International Symposium on Remote Sensing of Environment. *ISRSE*, 7 p (2005)
3. Bondur, V.G.: Modern Approaches to Processing Large Hyperspectral and Multispectral Aerospace Data Flows. *Izvestiya, Atmospheric and Oceanic Physics* **50**(9), 840–852 (2014). doi:[10.1134/S0001433814090060](https://doi.org/10.1134/S0001433814090060)

4. Bondur, V.G.: Satellite monitoring and mathematical modelling of deep runoff turbulent jets in coastal water areas. In: *Book Waste Water—Evaluation and Management*, pp. 155–180. InTech, Croatia (2011). ISBN 978-953-307-233-3
5. Bondur, V.G., Dulov, V.A., Murynin, A.B., Ignatiev, V.Yu.: Retrieving sea-wave spectra using satellite-imagery spectra in a wide range of frequencies. *Izvestia, Atmospheric and Oceanic Physics*. **52**(6), 637–648 (2016)
6. Bondur, V.G., Dulov, V.A., Murynin, A.B., Yurovsky, Yu.Yu.: A study of sea-wave spectra in a wide wavelength range from satellite and in-situ data. *Izvestia, Atmospheric and Oceanic Physics*. **52**(9), 888–903 (2016). doi:[10.1134/S0001433816090097](https://doi.org/10.1134/S0001433816090097)
7. Bondur, V.G., Filatov, N.N.: Study of physical processes in coastal zone for detecting anthropogenic impact by means of remote sensing. *Proceeding of the 7 Workshop on Physical processes in natural waters*. 2–5 July 2003. Petrozavodsk, Russia, 98–103 2003
8. Bondur, V.G., Filatov, N.N., Grebenyuk, Yu.V., Dolotov, Yu.S., Zdorovennov, R.E., Petrov, M.P., Tsidilina, M.N.: Studies of hydrophysical processes during monitoring of the anthropogenic impact on coastal basins using the example of Mamala Bay of Oahu Island in Hawaii. *Oceanology* **47**(6), 769–787 (2007)
9. Bondur, V.G., Grebenuk, Y.V.: Remote indication of anthropogenic influence on marine environment caused by depth wastewater plume: Modeling, experiments. *Issledovanie Zemli iz Kosmosa*. **6**, 49–67 (2001)
10. Bondur, V.G., Grebenyuk, Yu.V., Ezhova, E.V., Kazakov, V.I., Sergeev, D.A., Soustova, I.A., Troitskaya, YuI: Surface manifestations of internal waves investigated by a subsurface buoyant jet: 1. The Mechanism of Internal-Wave Generation. *Izvestiya, Atmospheric and Oceanic Physics* **45**(6), 779–790 (2009)
11. Bondur, V.G., Grebenyuk, Yu.V., Sabinin, K.D.: The spectral characteristics and kinematics of short-period internal waves on the Hawaiian shelf. *Izvestiya, Atmospheric and Oceanic Physics* **45**(5), 598–607 (2009)
12. Bondur, V.G., Grebenyuk, Yu.V., Sabinin, K.D.: Variability of internal tides in the coastal water area of Oahu Island (Hawaii). *Oceanology*. **48**(5), 611–621 (2008)
13. Bondur, V.G., Keeler, R.N., Starchenkov, S.A., Rybakova, N.I.: Monitoring of the pollution of the ocean coastal water areas using space multispectral high resolution imagery. *Issledovanie Zemli iz Kosmosa* **6**, 42–49 (2006)
14. Bondur, V.G., Murynin, A.B.: Methods for retrieval of sea wave spectra from aerospace image spectra. *Izvestiya, Atmospheric and Oceanic Physics* **52**(9), 877–887 (2016). doi:[10.1134/S0001433816090085](https://doi.org/10.1134/S0001433816090085)
15. Bondur, V.G., Tsidilina, M.N. “Features of Formation of Remote Sensing and Sea truth Databases for The Monitoring of Anthropogenic Impact on Ecosystems of Coastal Water Areas.” 31st International Symposium on Remote Sensing of Environment. *ISRSE*, 192–195 2005
16. Bondur, V.G., Vorobjev, V.E., Grebenjuk, Y.V., Sabinin, K.D., Serebryany, A.N.: Study of fields of currents and pollution of the coastal waters on the Gelendzhik Shelf of the Black Sea with space data. *Izvestiya, Atmospheric and Oceanic Physics* **49**(9), 886–896 (2013)
17. Bondur, V.G., Zhurbas, V.M., Grebenyuk, Yu.V.: Mathematical Modeling of Turbulent Jets of Deep-Water Sewage Discharge into Coastal Basins. *Oceanology*. **46**(6), 757–771 (2006)
18. Bondur, V.G., Zubkov, E.V. Showing up the small-scale ocean upper layer optical inhomogeneities by the multispectral space images with the high surface resolution. Part 1. The canals and channels drainage effects at the coastal zone. *Issledovanie Zemli iz Kosmosa*. **4**, 54–61 (2005)
19. Gibson, C.H., Keeler, R.N., Bondur, V.G., Leung, P.T., Prandke, H., Vithanage, D.: Submerged turbulence detection with optical satellites. In: Frouin, R.J., Lee, Z. (eds.) *Proc. of SPIE, Coastal Remote Sensing*, 1–8, Vol. 6680, 6680X, Aug. 26–27 (2007). doi:[10.1117/12.732257](https://doi.org/10.1117/12.732257)
20. Hansen, M., Kudryavtsev, V., Chapron, B., Brekke, C., Johannessen, J.: Wave breaking in slicks: impacts on C-band quad-polarized SAR measurements. *IEEE Geoscience and Remote Sensing Letters*. (2015)

21. Israel, YuA, Tsyban, A.B.: Ocean anthropogenic ecology, p. 520. Flinta Nauka, Moscow (2009)
22. Ivanov, V.A., Katunina, E.V., Soyga, E.E.: Assessment of anthropogenic impacts on the ecosystem of the waters of the Herakleian peninsula in the vicinity of deep drains. *Processes in GeoMedia* **5**(1), 62–68 (2016)
23. Leckler, F., Ardhuin, F., Benetazzo, A., Bergamasco, F., Peureux, C., Dulov, V.: Analysis and interpretation of frequency-wavenumber spectra of young wind waves. *Journal of Physical Oceanography. American Meteorological Society (United States)* **45**(10), 2484–2496 (2015)
24. Keeler, R., Bondur, V., Gibson, C. Optical satellite imagery detection of internal wave effects from a submerged turbulent outfall in the stratified ocean. *Geophysical Research Letters* **32** (L12610), 1–5 (2005). doi:[10.1029/2005GL022390](https://doi.org/10.1029/2005GL022390)
25. Keeler, R., Bondur, V., Vithanage, D.: Sea truth measurements for remote sensing of littoral water. *Sea Technology*, 53–58 April, 2004
26. Kuklev, S.B., Zatsepin, A.G., Baranov, V.I., Ocherednik, V.V., Kukleva, O.N.: The results from monitoring of Gelendzhik marine deep release outlet using Acoustic Doppler Current Profiler. *Nauchny Almanakh*. 2017 (in print)
27. Sentinels Scientific Data Hub [Electronic resource] URL: <https://scihub.copernicus.eu/> (Assessed date: 2 Aug. 2016)./(Contains modified Copernicus Sentinel data 2016)
28. Toba, J.: Local balance in the air-sea boundary process. *Oceanogr. Soc. Japan*. **29**, 209–225 (1973)
29. Vedernikov, V.I., Bondur, V.G., Vinogradov, M.E., Landry, M.R., Tsidilina, M.N.: Anthropogenic Influence on the Planktonic Community in the Basin of Mamala Bay (Oahu Island, Hawaii) Based on Field and Satellite Data. *Oceanology* **47**(2), 221–237 (2007)

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

