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Monitoring of Anthropogenic Influence on Mamala Bay Water Area (Hawaii) Using IKONOS and QuickBird Imagery

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Abstract - Results from remote detection of anthropogenic influence on littoral water areas using high resolution IKONOS and QuickBird images and ground truth data are presented. The monitoring was carried out in 2002-2004 for the water area of Mamala Bay (Oahu Island, Hawaii). Detection of propagation zones for surface anomalies caused by anthropogenic effects related with deep outfalls was carried out using fragment-wise spatial spectrum analysis of panchromatic satellite images based on the method of remote spatial-frequency spectrometry. Apart from satellite imagery, data on meteorological, hydrophysical and hydrobiological fields of the studied water area collected by boats and stationary buoy stations was used for this monitoring. Results of the monitoring and complex analysis of remote sensing and ground-truth data enabled to develop recommendations for decreasing anthropogenic load on the littoral zone of Oahu Island (Hawaii).

Keywords: image processing, Ocean pollution, monitoring.

1. INTRODUCTION

One of important areas of application for aerospace methods and remote sensing systems is the monitoring of anthropogenic impact on littoral water areas of seas and oceans (Bondur, 2004, 2005). This paper presents some results from the use of high resolution IKONOS and QuickBird images for the monitoring of the Mamala Bay water area near Waikiki Beach (Hawaii), carried out in 2002-2004 (Bondur, 2005). The main purpose was to analyze the effect of the Sand Island deep outfall on the ecosystem of the Mamala Bay water area and to develop recommendations for nature protection measures aimed at decreasing anthropogenic pressure on the recreational zone of Oahu Island (Hawaii) (Bondur, 2005; Keeler et al., 2004).

2. BASIC CHARACTERISTICS OF THE OBJECT OF STUDY, FEATURES OF DATA COLLECTION AND PROCESSING.

The research was carried out in the Mamala Bay water area located in southern part of Oahu Island, a part of the Hawaiian archipelago. In Mamala Bay there are two collectors of wastewater. The more powerful of them is the Sand Island Outfall. This system is situated in the vicinity of Honolulu harbor and performs primary processing of sewage waters. The jet of processed sewage is routed to the ocean through the pipeline to the diffuser (~1km), located at ~4 km from the coast at a depth of about 70 m (Fischer, 1979).

As it is shown in (Bondur and Grebenuk, 2001; Keeler et al., 2005), the outfall device produces a turbulent jet (or a series of jets) of fresh water in the marine environment, the density of which differs from that of the environment at the depth of the diffuser. This buoyant jet has an effect on the density gradient layer and generates internal waves that change the structure of surface waves (Bondur, 2001; 2004; Bondur and Grebenuk, 2001). There also exist other physical mechanisms related with deep outfalls that change the character of the sea surface waves (Bondur and Grebenuk, 2001; Keeler et al., 2005). These changes can be detected in high-resolution images of oceanic surface, including those taken by satellites (Bondur, 2001, 2004).

For the monitoring of the Mamala Bay water area, high-resolution IKONOS (1 m) and QuickBird (0.6 m) images of the studied region were used. Sea and ground truth observations using boats and ground stations were also carried out. This enabled us to determine the parameters of the sea surface waves (wave buoys), current fields (ADP and drifters), vertical profiles of temperature and salinity (boats and buoy stations), microstructural characteristics, tidal conditions, wind fields, etc. (Bondur, Filatov, 2003; Keeler et al., 2004).

Processing of panchromatic satellite images was carried out using a technique based on the method of remote spatial-frequency spectrometry (Bondur, 2001, 2004). For this, the original images were divided into fragments of 1024x1024 and 2048x2048 pixels, ensuring sampling volumes sufficient to attain required statistical precision for spatial spectra evaluation and achieve the spatial resolution needed for estimating geometrical characteristics of areas affected by anthropogenic factors (Bondur, 2004). These fragments were used to evaluate 2D-spatial spectra and their cross-sections in different directions; to determine informative indicators of these spectra; to compute parameters of spectral harmonics; to carry out statistical analysis of informative indicators; to detect abnormal areas related to the deep outfall and to evaluate dimensions of these areas.

The technique described above was used for processing of IKONOS and QuickBird imagery. After this, the results obtained were compared with results from processing sea truth data. Complex analysis of collected and processed data was carried out, which enabled us to develop recommendations concerning measures to be taken for the protection of environment.

3. PROCESSING RESULTS AND THEIR ANALYSIS.

Fig. 1 presents, as examples, results from processing of several IKONOS image fragments taken on September 13, 2003. Analysis of spatial spectra of these fragments allowed revealing their distinctions. Spectra of fragments covering

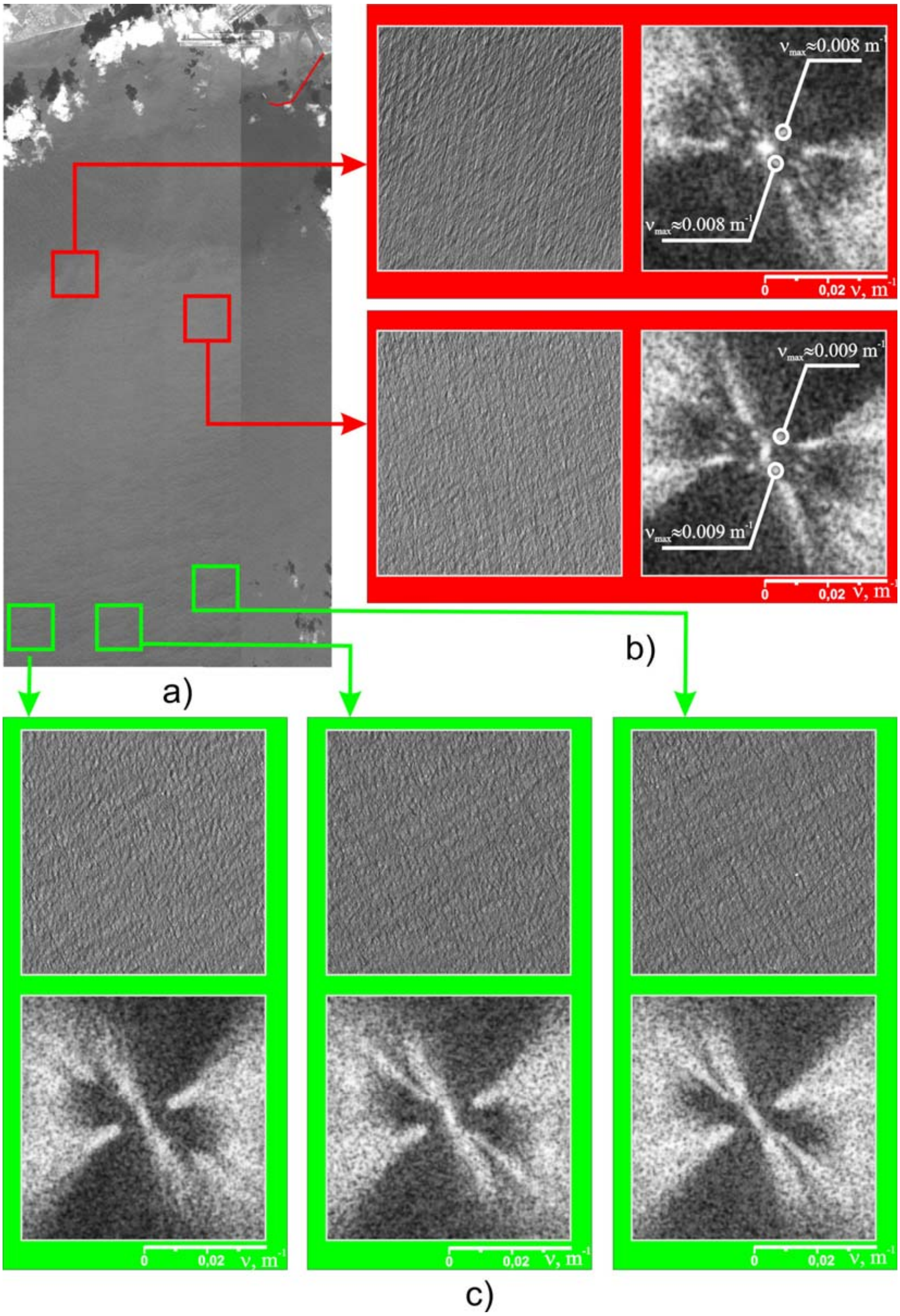

Figure 1. IKONOS image taken on September 13, 2003 (a) and spectra of its fragments for the outfall (b) and background (c) areas

areas situated nearest to the diffuser of the outfall device visibly show additional spectral harmonics not observed in background fragments. Such harmonics were identified for the first time in (Bondur 2001, 2004). The physical mechanism mainly responsible for the formation of such spectral components is internal waves generated by deep outfalls (Bondur 2001, 2004), although other mechanisms may also be possible (Bondur, Grebenuk, 2001; Keeler et al., 2005).

Based on the results of identifying imagery fragments containing additional spectral harmonics, we were able to determine propagation zones for the sea surface anomalies caused by the Sand Island deep outfall. Fig. 2a displays a panorama of surface anomaly propagation built using fragments of IKONOS images taken on September 13, 2003. The size of these fragments is about 2x2 km^2. Anomalous zones with different manifestation of additional spectral harmonics are shown in a different hue (color). We can see that the anomaly is extended in the southwestern direction. It extends up to the image edge and its width is about 7.5 km. The strongest contrast area of this anomaly (dark color) ranges to ~ 14 km from the diffuser and its azimuth is ~210°-220° to the North.

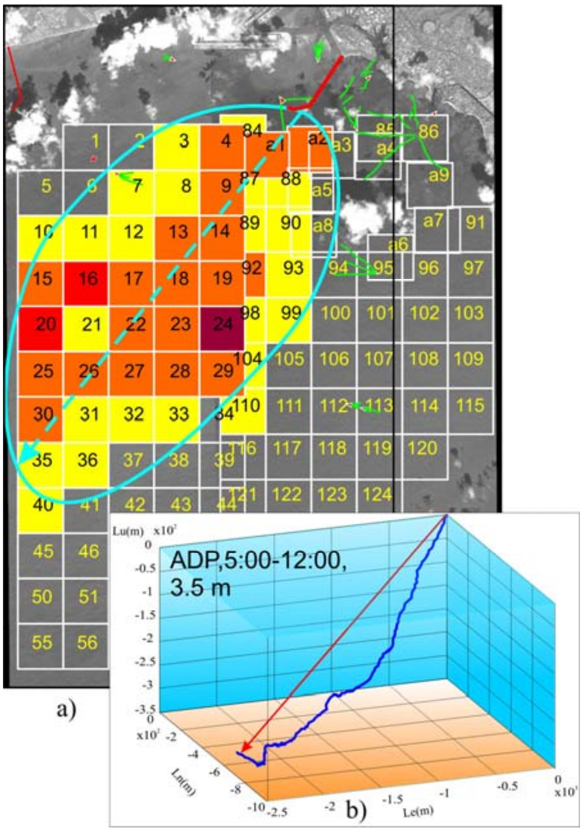

Figure 2. Area of surface anomaly propagation according to IKONOS data (September 13, 2003) – a) and progressive vector diagram of current field (ADP measurements, 5:00 – 12:00 LT, 3.5 m horizon – b)

Fig. 3a presents a similar panorama obtained from processing of a QuickBird image taken on September 14, 2003 (fragment size: ~1.33x1.33 км). We can see that the propagation zone of the anomaly has a shape composed of two lobes. The prevailing direction of the major lobe is southwestern (azimuth ~210°), and the smaller lobe is oriented to the southeast (azimuth ~155°). The length of the southwestern lobe in the image exceeds 14 km and its width is about 8 km. The Southeastern lobe is about 9 km long and 4 km wide. The greatest contrast (dark color) of this surface anomaly is observed in the proximity of the diffuser, while near the edges the contrast decreases.

An anomaly of similar shape was also detected on high-resolution satellite images taken in 2002 (Bondur, 2004, 2005).

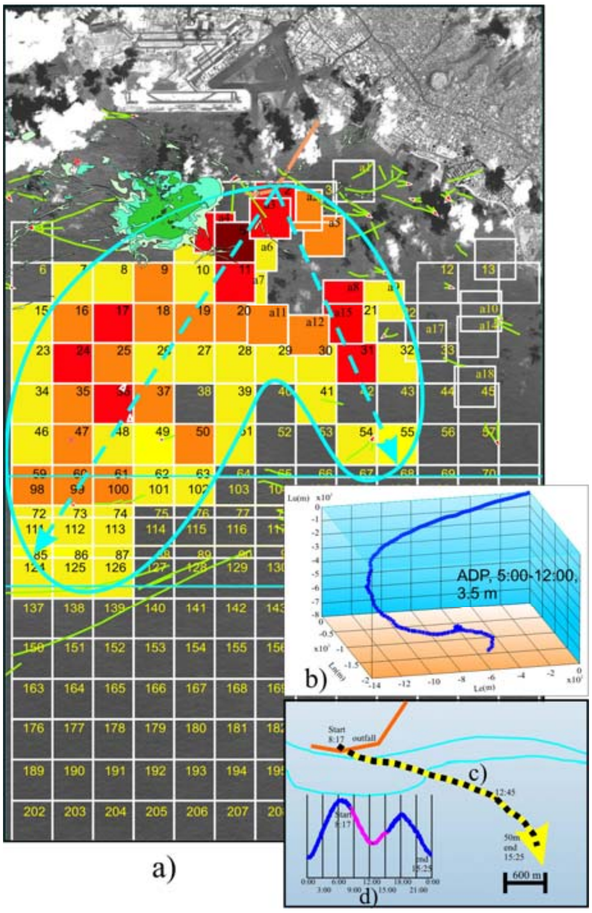

Figure 3. Area of surface anomaly propagation according to QuickBird data (September 14, 2003) – a) and progressive vector diagram of current field (ADP measurements, 5:00 – 12:00 LT, 3.5 m horizon – b), and tide graph – c)

The averaged parameters for additional spectral harmonics detected in spectra of anomalous zones on IKONOS images taken on September 13 and 14, 2003 are as follows: mean frequencies $\bar{\nu}$ ~9,5*10^{-3} m^{-1} and $\bar{\nu}$ ~ 8,7*10^{-3} m^{-1};

corresponding wavelengths $\overline{\Lambda}$ ~105 m and $\overline{\Lambda}$ ~106 m; average width of spectral maxima $\overline{\Delta\nu}$ ~2.9*10^{-3} m^{-1} and $\overline{\Delta\nu}$ ~2,8*10^{-3} m^{-1} (wavelength ranges $\overline{\Lambda}\Delta$ ~14 and $\overline{\Lambda}\Delta$ ~13.5m).

Based on spectra obtained using wave buoys located in the area affected by the deep outfall, we were also able to detect additional spectral harmonics similar to those found in satellite data, with almost the same characteristics (Bondur, 2004).

Results from processing of a series of space images taken on different days testify to the recurrence of some observable superficial effects related with the deep outfall in the Mamala Bay water area. This relates, first of all, to the southwestern lobes of abnormal areas detected. A similar stable form may result from the regular southwestern transfer of water mass in the surface layer (~220° - 235°) detected in data collected using the ADP (Acoustic Doppler Profiler) (Bondur, Filatov, 2003; Bondur, 2004; 2005). Fig. 2b presents an example of a progressive vector diagram obtained from the ADP sensor at the depth of 3.5 m on September 13, 2003. This direction is characteristic of the main trade currents in the studied region (Bondur, Filatov, 2003).

Fig. 3b shows an example of a 3D progressive vector diagram built based on data collected by the ADP2 station (the closest to the diffuser) at a depth of 3.5 m during the next day of September 14, 2003. Analysis of progressive vector diagrams of current fields near the ADP2 station in the morning enables us to conclude that the southwestern direction of water mass transfer prevailed at all depths for a long time (currents velocity was in the range of 10-20 cm/s). However, this direction has changed to the southeast near the time of space imaging. This is related with the change in tidal phase (see Fig. 3d). This resulted in the appearance of two lobes in the surface anomaly detected on QuickBird images taken in 2003, and IKONOS images taken in 2002 (Bondur, 2004, 2005). Southeastern propagation of wastewaters is also revealed in current measurements carried out using a Lagrange drifter deployed in the region of the diffuser at a depth of about 50 m on September 14, 2003 (see Fig. 3c). These measurements show that the transfer of water mass had a southeastern direction with average velocity 13 cm/s (Bondur, 2004, 2005).

On the whole, based upon the analysis of satellite imagery, as well as meteorological and physical characteristics of the environment determined by in situ measurements, we can state that the character of surface manifestation of the anthropogenic effects studied and the direction of propagation of polluted zones change with hydrometeorological conditions. This should be taken into account when developing measures for the protection of environment.

4. CONCLUSION

Analysis of results obtained using space monitoring of the Mamala Bay water area allows us to make a conclusion regarding the impact of the deep outfall on the ecological condition of the area and formulate recommendations on measures to be taken. Taking into account the significant volume of wastewater ejected into the Mamala Bay water area (about 500,000 m^3 a day), the considerable amount of harmful substances contained inside it, and the strict requirements for seawater quality in the Honolulu recreational zone, a number of measures aimed at diminishing anthropogenic impact on the ecosystem of Mamala Bay can be put forward. Such measures may include the control of outfall operations allowing for the changes in meteorological conditions, shutting off some diffuser orifices, increasing the density of wastewater, etc. (Bondur, 2005).

Thus, the efficiency of space monitoring of anthropogenic impact on littoral water areas carried out using high-resolution satellite imaging and ground truth measurements is confirmed.

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