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Monitoring of Anthropogenic Influence on Water Areas of Hawaiian Islands Using RADARSAT and ENVISAT Radar Imagery

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Abstract - This paper discusses results from satellite monitoring of anthropogenic influence on coastal water areas caused by a deep outfall in Mamala Bay (Oahu Island, Hawaii) using RADARSAT and ENVISAT data. The propagation area of anomaly surface manifestations caused by this anthropogenic impact was detected by considering informative features of radar images using method of the statistically significant sliding window.
Sea truth data on hydrophysical field and wind field characteristics for the studied area in 2003 – 2004 was also used during monitoring. Recommendations on how to decrease the anthropogenic pressure on the Mamala Bay water area (Oahu Island, Hawaii) are developed based on the satellite monitoring results.

Keywords: Radar image processing, ocean pollution, monitoring, RADARSAT, ENVISAT

1. INTRODUCTION

Radar methods are widely used for solving a wide range of problems related to the study of the upper ocean layer and ocean–atmosphere interaction processes. Application of radar imaging is very effective for monitoring of anthropogenic influence on sea and ocean water areas and coastal areas (Bondur, 2004; 2005; Bulatov et al., 2003).
The application of radar methods for marine water area monitoring is very promising due to its all-weather survey capabilities, capability of round-the-clock operation. These methods develop intensively and in near future will give a possibility to have satellite radar images of 1 m spatial resolution.
The problem of monitoring anthropogenic impact on marine water areas using radar data can be solved by application of special processing methods, combining classic algorithms of digital image analysis with specialized methods for recognition and classification (Bondur, 2004; Bondur, Starchenkov, 2001).
Results from applying RADARSAT and ENVISAT images toward the monitoring of anthropogenic impact on Mamala Bay (Oahu Island, Hawaii) water area are discussed in this paper.

2. FEATURES OF THE SUBJECT OF STUDY, MONITORING ORGANIZATION AND DATA PROCESSING

Wastewater discharge into the ocean through deep collectors is the main source of anthropogenic pollution both for water areas of Hawaiian Islands and for most coastal water areas. The Wastewater Treatment Plant (WWTP) located on Sand Island (Honolulu) has a daily discharge rate more than 300000 m^3/day (Fisher, 1979). The length of the outfall pipe is about 4.0 km. Treated sewage enters the Mamala Bay water area through a 3-sectioned diffuser (length is about 1 km), at a depth of 70 meters. The Honouliuli WWTP is located on the western coast of the Bay (more than 190000 m^3/day discharge rate). Thus, the total rate of sewage discharge in Mamala Bay reaches 500000 m^3/day being significant anthropogenic load on the bay water area (Fisher, 1979).

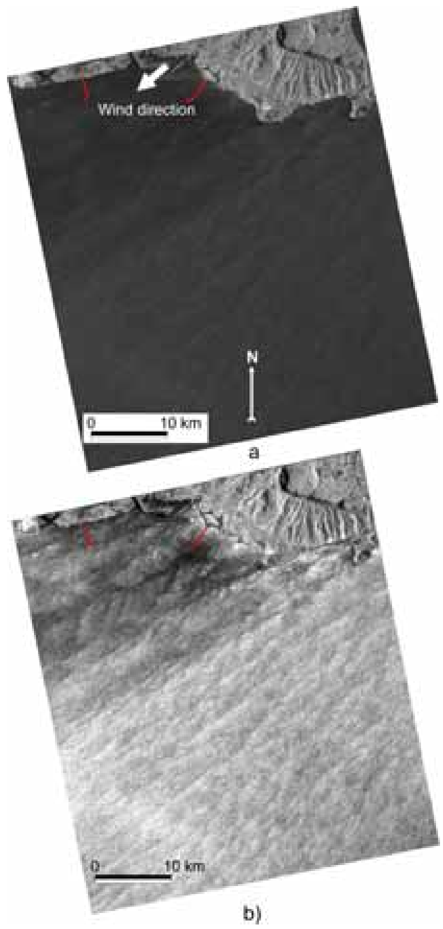

Figure 1. Original (a) and pre-processed (b) radar images of Mamala Bay, RADARSAT, September 5, 2003

Radar imaging using the RADARSAT (5.6 cm sensing wavelength, HH-polarization) and ENVISAT (ASAR, 5.6 cm wavelength, HH-, HV-, VH- and VV-polarizations) satellites was carried out during the monitoring of anthropogenic influence caused by the deep outfall in the Mamala Bay water area in 2003 - 2004 (Bondur 2004, 2005). Fine Beam and Standard Beam modes were used for RADARSAT imaging (RADARSAT Data Product Specifications, 2000), Image Mode and Alternating Polarization Mode (HH- and VV-polarization) were used for ENVISAT imaging (ENVISAT ASAR Product Handbook, 2004). To analyze synoptic conditions and ocean surface temperature (SST), multispectral images taken by the MODIS camera (AQUA and TERRA satellites) at the times closest to radar imaging time were used (Bondur, 2005).

The processing of radar images was carried out in automated mode using specially created software described in (Bondur, Starchenkov, 2001). The phases of preliminary and thematic processing were realized during the analysis of radar imagery. Pre-processing consists of calibration (σ^0 (sigma nought) calculation), speckle-noise elimination, geo-coding and formation of improved images by applying equalization procedures. Thematic processing included the following main stages: scanning of pre-processed imagery by a statistically significant sliding window, and calculation of informative attributes in each window, as well as statistical analysis, choice of optimal informative attributes and automated classification.

Considering the important influence of wind conditions on radar image formation (Mityagina et al., 2004), data on wind fields obtained by ships and ground stations were used for the analysis. To verify the results of radar image processing, in situ hydrophysical and hydrobiological data were also used (Bondur, 2004; 2005). Use of additional information allowed us to decrease error probability during classification of radar imagery down to 0.04-0.06 using the Neyman-Pearson criterion.

3. PROCESSING RESULTS AND THEIR ANALYSIS

Fig. 1 and 2 present examples from a series of radar images taken during the monitoring of the studied water area by RADARSAT and ENVISAT satellites (Bondur, 2004; 2005). Fig. 1a gives the original radar image of Mamala Bay taken on September 5, 2003 (18:40:26 Hawaiian Local Time - HLT) by RADARSAT, and Fig. 1b gives the pre-processed image. A fragment of the original ENVISAT (ASAR) radar image taken on September 13, 2003 (10:26:12 HLT) is given in Fig. 2a, and the improved image is given in Fig. 2b.

Wind contribution to radar imagery formation was already mentioned above. This is most important for coastal water areas where air flows interacting with coastal landscape features undergo various changes that can be registered in radar imagery as various signatures (Mityagina et al., 2004). A digital elevation model of Oahu Island (30 meters per pixel resolution) was used to register wind effects while detecting anomalies caused by wastewater outfalls. A model fragment with the radar image from Fig. 1b is given in Fig. 3. Using such model allowed us to obtain information on the orographic features of Oahu Island coast. In addition, analysis of the radar image in 3D mode allows us to detect anomalous signatures more precisely, in order to make an evaluation of wind influence on radar signal formation. As we can see in Fig. 3, the orographic features of the Koolau Range, namely the Kalihi and Nuuanu end-to-end valleys, allow north-eastern trade winds to enter Mamala Bay through them.

Detection of areas related to the deep outfall and anomalies caused by the dynamic influence of wind was carried out using automated classification procedures based on various types of informative attributes (Bondur, Starchenkov, 2001). The presence of disturbed ocean surface revealing in the variations of Bragg component of reflected radio waves (Bondur, 2004) made possible the detection of the deep outfall in Mamala Bay

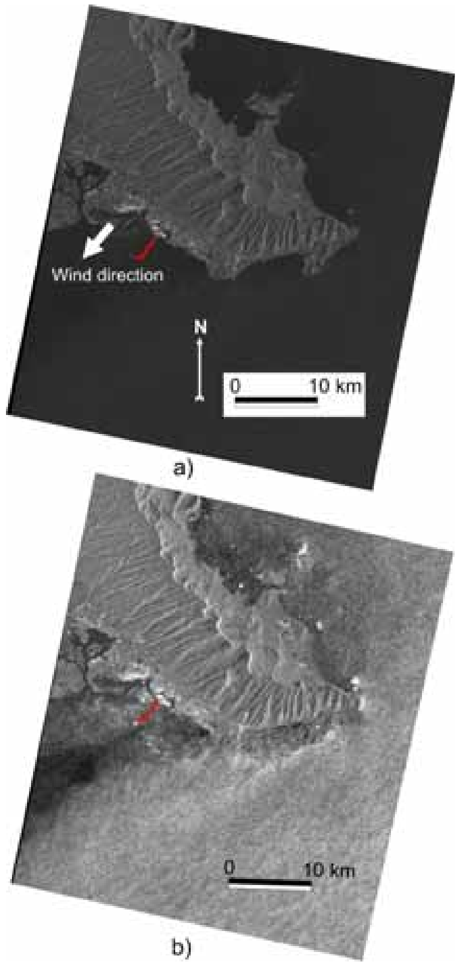

Figure 2. Original (a) and pre-processed (b) radar images of Mamala Bay, ENVISAT, September 13, 2003

water area against the anomalies caused by wind flows from Nuuanu Valley and Manoa Valley. The results of anomaly detection induced by Sand Island Outfall are given in Fig. 4.

We succeeded in detecting an anomaly caused by the this deep outfall as a result of classifying an image fragment showing the end of the collector (see Fig. 4). The maximum size of the anomaly caused by the Sand Island Outfall was 18.5 km and direction was 232°.

The detection result for the anomaly caused by wastewater discharge through Sand Island Outfall according the ENVISAT radar image taken on September 13, 2003 is shown in Fig. 5. The maximum size of the anomaly detected as a result of automated classification was 13.6 km, and direction was 237°.

As the analysis of sea truth hydrophysical measurement results has shown, at the time of imaging on September 13, 2003 in Mamala Bay, isothermy was observed to the depth of 65 – 75 m and the seasonal thermocline was at the depth of about 80 – 90 m. Such a situation provided favorable conditions for the rising of wastewater to near-surface ocean layers and facilitated manifestation of surface anomalies. South- western transfer of water mass in the vicinity of the diffuser using ADP (Acoustic Doppler Profiler) was detected as a result of

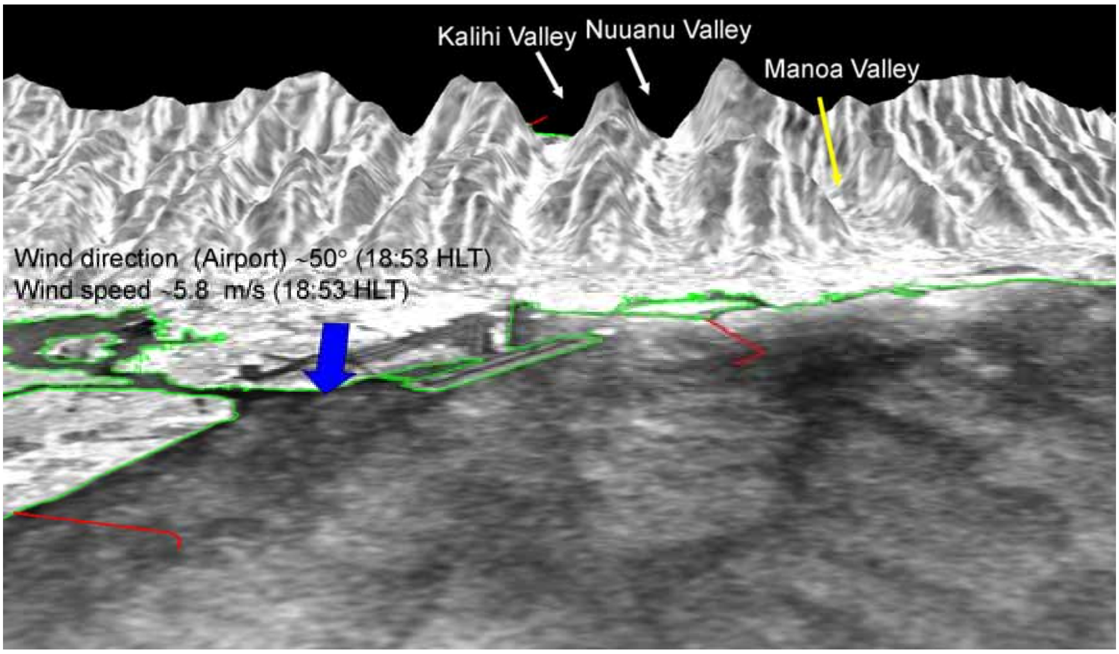

Figure 3. 3D representation of radar image of September 5, 2003 (RADARSAT) showing orographic features of Koolau Range

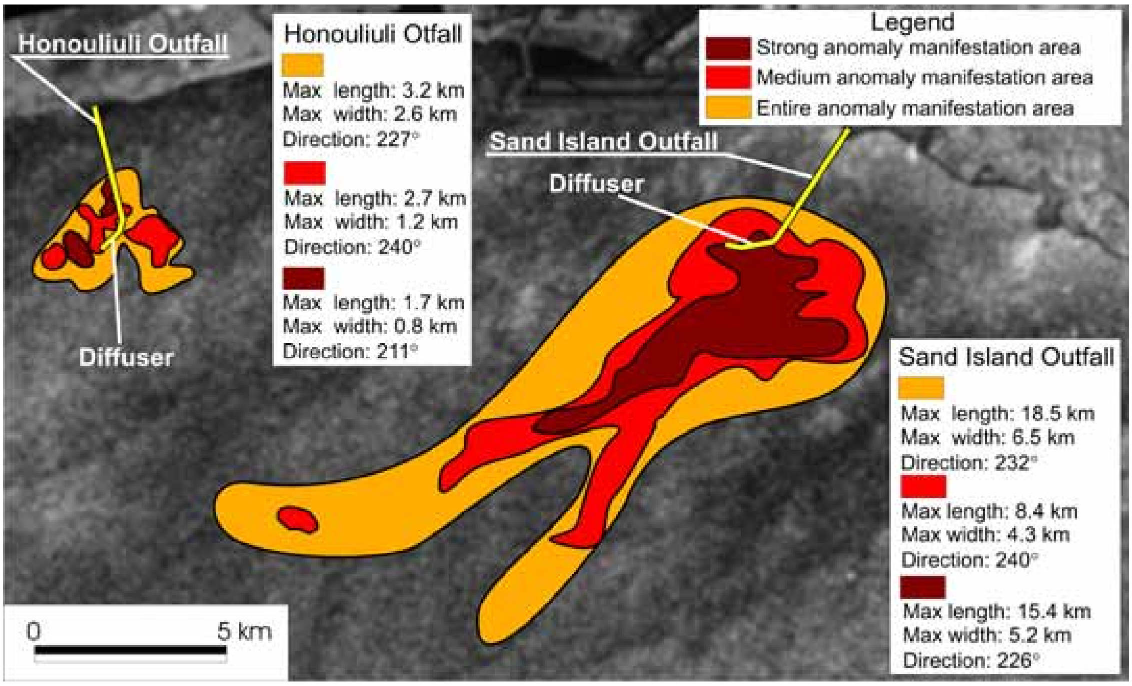

Figure 4. Detection of anomalies caused by deep outfalls in Mamala Bay using radar image taken by RADARSAT on September 5, 2003 and anomaly geometric characteristics

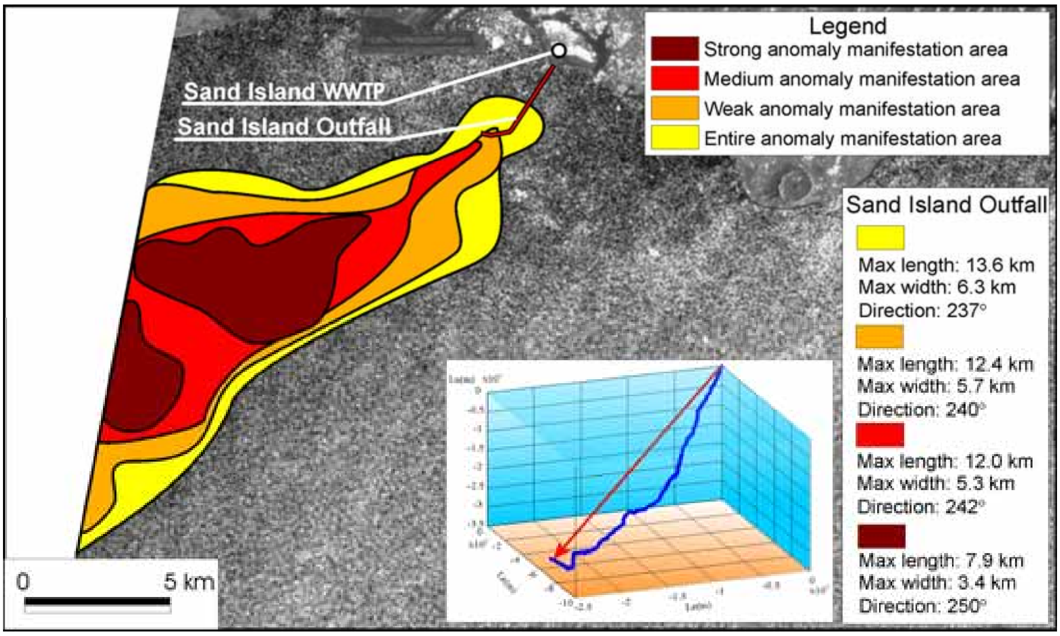

Figure 5. Detection of anomaly caused by deep outfall in Mamala Bay using radar image taken by ENVISAT (ASAR) on September 13, 2003 and anomaly geometric characteristics. A progressive vector diagram is in the bottom

current field analysis for September 13, 2003, 5:00-12:00 (HLT). This fact shows a tight correlation with the direction of the anomaly detected in the radar image (see Fig. 5).

As a result of hydrobiological measurements on September 13, 2003, increased content of heterotrophic cells (Hbact) and cyanobacteria (Syn) in seawater down to ~ 70 m depth was registered to the southwest of the Sand Island Outfall diffuser. A high concentration of heterotrophic cells Hbact is a biological indicator of water pollution. The fact that higher value of the TOTBact = Hbact + Syn parameter was observed in the south-west direction from the diffuser (70 m depth) is the evidence of jets rising to the surface and south-west water mass transfer.

Processing and analysis procedures similar to those described above were applied to each radar image acquired during the monitoring of Oahu Island coastal water area. This allowed us to understand processes in water areas exposed to anthropogenic influence under various hydrometeorological conditions. Thus, it was detected that the direction of buoyant wastewater jet transfer was in the range of 180-250° (Fig. 4 and 5). This fact is confirmed by hydrophysical sea truth measurements of current fields using ADP (Fig. 5). Anomaly extension determined using radar images can exceed 20 km in this direction, which is evidence of the wide propagation of the surface manifestation area for such anthropogenic effects.

4. CONCLUSION

Complex analysis of satellite radar imagery and data from hydrophysical and hydrobiological measurements of water environment parameters in Mamala Bay water area are in good agreement. This confirms the efficiency of radar methods for coastal water area monitoring, as well as the efficiency of the proposed methods of digital processing and classification of radar images, allowing operative detection and analysis of propagation area for anomalies caused by deep outfalls. Automation of classification processes significantly reduces time needed for radar image processing and increases the reliability of the obtained results.

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