SURFACE MANIFESTATIONS OF NON-TIDAL INTERNAL WAVES IN THE NORTH-EASTERN BLACK SEA AS VIEWED BY SATELLITE SENSORS

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1. INTRODUCTION

It is well known that internal and surface ocean processes are strongly affected by internal waves (IW). Radar imagery is widely used for investigation of surface manifestations of internal waves. There are a great number of publications based on SAR observations of internal waves in various areas of the World Ocean [1-4]. An electronic atlas of surface manifestations of internal waves is being kept updated [5]. However, most observed internal waves are tidal by origin. They are produced by tidal currents flowing perpendicular to the local bathymetry and are regularly generated in well known locations.

Meantime, there are practically no remote sensing observations of surface manifestations of internal waves in non-tidal seas, particularly in the Black Sea, while contact measurements provide evidence of existence of rather intense IW in this area [6, 7]. The existence of short period IW occurring at unpredictable times and locations was reported. So it is of interest to investigate the IW of this kind by multisensor satellite observations.

In present paper the satellite remote sensing data (obtained by Envisat ASAR, Terra and Aqua MODIS, and NOAA AVHRR instruments) is used to study coastal dynamics of the north-eastern Black Sea. Data from multiple remote sensors are comparatively analyzed to better understand the coastal water circulation and to reveal patterns not recognizable by individual sensors. The main attention is focused on the generation and propagation of internal waves in coastal waters.

2. SURFACE MANIFESTATIONS OF NON-TIDAL INTERNAL WAVES IN SEA SURFACE RADAR IMAGERY

In 2006 – 2008, a semi-operational satellite monitoring of the north-eastern Black Sea was carried out. ASAR data from all passes of Envisat over the region of interest was obtained and analyzed. This permitted us to systematize the data and draw some statistics on surface manifestations of internal waves in coastal waters. Every ASAR image was visually analyzed in order to detect structures belonging to the class of IW packets surface manifestations. Number of internal waves in a packet, wave crests length and orientation, propagation direction, average wave length and geographical coordinates were determined for each revealed instance of the internal waves packet. All instances of IW manifestations revealed from ASAR images of north-eastern Black Sea were plotted on a map.

3. COMPARATIVE ANALYSIS OF RADAR, OPTICAL AND IR IMAGES OF SEA SURFACE

The joint analysis of data from different sensors was performed to reveal specific conditions leading to intensification of wave processes and to their manifestation in radar imagery as well as to determine possible sources of the IW generation. The basic Envisat ASAR data was therefore complemented by other satellite data. Data obtained by AVHRR on board NOAA satellites allows to retrieve SST fields for the analysis of mesoscale water dynamics. MODIS instruments aboard Terra and Aqua satellites provide SST, ocean color and other optical properties measurements. The signal received by sensors in optical range is determined by sunlight scattering at hydrosol (phytoplankton and suspended mineral particles) as well as reflection from the sea surface. Hydrosols can be viewed as passive tracers of surface currents with their frontal zones, as a rule, corresponding to flow paths. Hence, the analysis of optical images makes it possible to highlight the main meso- and small-scale water dynamics features, such as eddies, dipoles, jets, filaments and river plumes.

The main finding was that practically all cases of IW manifestations were observed in the vicinities of mesoscale sea eddy structures or hydrological fronts. We can assume that they are generated by the frontal IW generation mechanism, e.g. these IW are induced by non-stationary fronts, that is by a moving front or a front under inertial oscillations.

4. DEPENDENCE OF THE INTERNAL WAVES SURFACE MANIFESTATIONS ON THE PYCNOCLINE PROFILE

Mesoscale eddies and eddy dipoles are rather common features for the region of interest [8]. Nevertheless, as a rule the manifestation of internal waves on the sea surface generated in the vicinity of these structures can rarely be seen. It was the case in Black Sea area during tree years (2006– 2008) monitoring. But the majority of the internal wave surface manifestations in ASAR images measurements were detected in 2006.

To explain the effect the analysis of vertical profiles of sea water temperature and buoyancy frequency taken from research vessel in-situ measurements was carried out. It was found that that internal waves detected in ASAR images were generated during periods when the peak of buoyancy frequency profile was very sharp and located at a shallow depth of about 5 meters. The sharp and shallow pycnocline conditions facilitate the origination of internal solitons as well as enlarge near-surface currents associated with the internal waves. Strong near-surface currents modulate the surface wave spectrum resulting in IW manifestation in ASAR images of sea surface. So the IW manifestations on the sea surface are a result of the simultaneous combination of two effects - shallow sharp pycnocline and moving and/or oscillating non-stationary front.

5. REFERENCES

[1] Liu, A.K., J.R. Holbrook, and J.R. Apel, “Nonlinear internal wave evolution in Sulu Sea”, *J. Phys. Oceanogr*, Vol. 15, No 12, pp. 1613-1624, 1985.

[2] Alpers, W., “Theory of radar imaging of internal waves”, *Nature*, 314, pp. 245-24, 1985.

[3] Alpers, W., P. Brandt, and A. Rubino, "Internal waves generated in the Straits of Gibraltar and Messina: Observations from space", *in Remote Sensing of the European Seas*, Springer, Heidelberg, pp.319-330, 2008.

[4] Churyumov A. N., Yu. A. Kravtsov , O. Yu. Lavrova , K. Ts. Litovchenko , M. I. Mityagina , K. D. Sabinin, *“*Signatures of resonant and non-resonant scattering mechanisms on radar images of internal waves”, *Int. J. Remote Sensing*, Vol. 23, No 20, pp. 4341 – 4355, 2002.

[5] http://www.internalwaveatlas.com/Atlas_index.html

[6] Ivanov V.A., Serebryany A.N., “Short-period internal waves in the coastal zone of a non-tidal sea*”, Reports of the USSR Academy of Sciences. Physics of Atmosphere and Ocean*, Vol. 21, No 6.pp 648–656; 1985.

[7] Vlasenko V.I. , Ivanov V.A., Krasin I.G.,Lisichenok A.D., “Generation of intense short-period internal waves in the Crimean shelf zone during an event of coastal upwelling”, *Marine Hydrophysical Journal*, No 3, pp. 3–16, 1997.

[8] Lavrova, O., M. Mityagina, T. Bocharova, and M. Gade, “Multi-sensor observation of eddies and meso-scale features in coastal zones”, *Remote Sensing of the European Seas*, Springer, Heidelberg, pp. 463-474, 2008.