Oceanic dynamic phenomena and sea ice study in the Northwest Pacific Ocean

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Abstract
Analysis of ERS-2 SAR and Envisat ASAR images of the Northwest Pacific Ocean was carried out to reveal the areas of the surface manifestations of dynamic oceanic and atmospheric phenomena such as currents, fronts, upwellings, eddies, internal waves, sea ice, polar lows, cold air outbreaks, etc. Interpretation of radar signatures was confirmed by visible and infrared images, QuikSCAT winds, ship observations and other relevant data. The Kuroshio-Oyashio confluence zone, Soya Warm Current, Okhotsk Sea shelf, the Kuril Straits area, Pacific Ocean east of Kamchatka, Peter the Great and Toyama Bays, Taiwan Strait and several areas in the East-China and South-China Seas were selected for detailed study with ALOS PALSAR and AVNIR-2 data.

Keywords: Envisat ASAR, ERS-2 SAR, ALOS PALSAR, radar signatures, oceanic and atmospheric dynamic phenomena.

1. INTRODUCTION

The Asian marginal seas and the Northwest Pacific Ocean east of Kamchatka, Kuril Islands and Japan Islands are characterized by the increased characterized by monsoon climate with the significant seasonal variations of oceanic and atmospheric parameters. Intended coastal line of Japan and Kuril Islands, bordering on deep Pacific Ocean trench, straits connecting the Pacific Ocean with the Okhotsk and Japan Seas, sharp slope of Primorye shelf rising from the Japan Basin at 2500-3000 m up to 50 m just 20-50 km off the coast in a combination with canyons crossing the shelf are responsible for complicated water dynamics. Interaction of the cold Oyashio Current with the warm Kuroshio Current and interaction of strong tidal flows with islands and underwater relief also generates the vortex formations and fronts. Cyclone's passing and river's discharge caused by heavy rains influence on water structure too. Sharp thermal and ocean color contrasts are usually associated with the warm and cold currents and the wind induced upwellings. Sea surface temperature varies from 22-27°C in August to -1.8°C in February. Sea ice originates in the Okhotsk Sea, around Sakhalin, near Hokkaido, in the Tatarsky Strait and in Peter the Great Bay. The difference between water and air temperatures reaches in winter 10-15°C. Convective rolls and cells are formed in the marine boundary layer during cold air outbreaks.

Main aim of the first stage of the project was selection the areas for detailed study the surface manifestations of the oceanic and atmospheric phenomena with the usage of ALOS PALSAR all weather data. This aim was achieved by analysis of ERS-1 and ERS-2 SAR and Envisat ASAR images together with ancillary information collected in the frames of several ongoing ESA projects. SAR and ASAR images cover the studied areas nonuniformly. Thus a list of selected areas can by corrected in the future. Below we will present several examples showing the imprints of the currents, eddies, internal waves, organized mesoscale convection in the marine boundary layer of the atmosphere, etc. revealed on C-band SAR. Application of L-band polarization SAR images should improve understanding of radar signatures.

2. OCEANIC PHENOMENA

The south-western Okhotsk Sea is very dynamic area where the various oceanic phenomena such as Soya Warm Current, eddies, internal waves, sea ice etc. can be detected on SAR images and compared with theoretical models and experimental data collected by research vessels, moored buoys and ground radars both Japanese and Russian scientists [1-4]. Fig. 1 shows Soya Current boundary and eddy-like formations on ERS-1 quick-look SAR images. Shape and radar contrast of the boundary against the background depend on environmental conditions and changes from season to season.

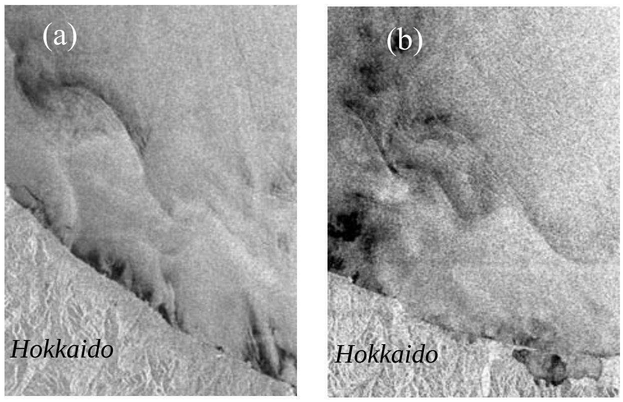

Figure 1. ERS-1 SAR QL images taken on 17 October at 01:17 UTC (a) and on 28 September 1995 at 01:14 UTC (b) showing the eddy streets and waves in the Soya Warm Current area.

C-band radar contrasts correlate strongly with thermal gradients that illustrates Fig. 2. The narrow bright lines on ERS-2 SAR image result from the increased wave breaking at the current boundary and the dark features are due to damping of centimeter-scale surface wind waves by natural slicks. Very likely that L-band radar contrasts caused by above-mentioned reasons will be different that calls to further study using PALSAR data.

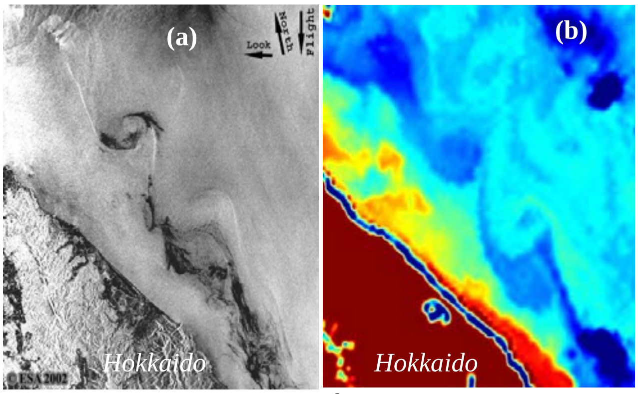

Figure 2. ERS-2 SAR image for 13 May 2002, at 01:18 UTC (a) and NOAA AVHRR infrared image at 03:46 UTC (b) showing eddies in the area of the Soya Warm Current.

PALSAR image covering the Soya Current area (Fig. 3) was acquired in spring when current velocity and thermal contrast of the Soya waters against the background were small compare to summer time. However the fronts associated with the current are detected. The thawing sea ice possesses by high contrast and the fine details of ice distribution are clearly seen. The sea ice serves as a tracer of surface circulation at other areas too.

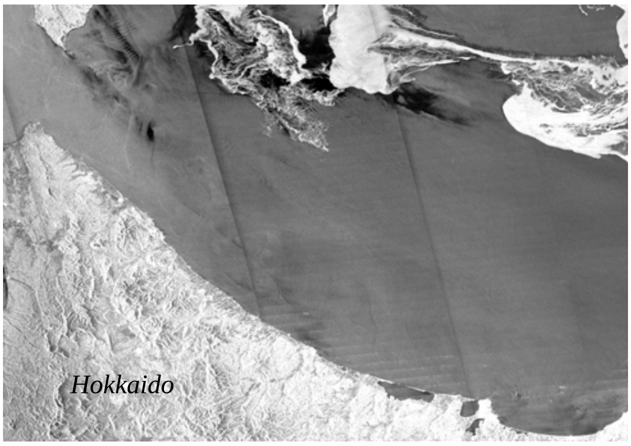

Figure 3. ALOS PALSAR image taken on 18 April 2007 at 12:40 UTC showing the low-contrast features associated with the Soya Warm Current and thawing sea ice.

The Kuroshio-Oyashio frontal zone is characterized by the complicated circulation, the presence of synoptic eddies and narrow jets, sharp thermal gradients ad intensive air-sea interaction. High probability of cloudiness in this area hinders to get the regular information on the sea surface using satellite infrared and visible sensors such as AVHRR and MODIS as opposite to SAR images. Fig. 4aб show the sharp boundaries dividing the Kuroshio warm waters 1 with temperature t = 16ºC and the Oyashio cold waters 2 with t = 6ºC and eddy structures 3 of various scales and other features of surface circulation.

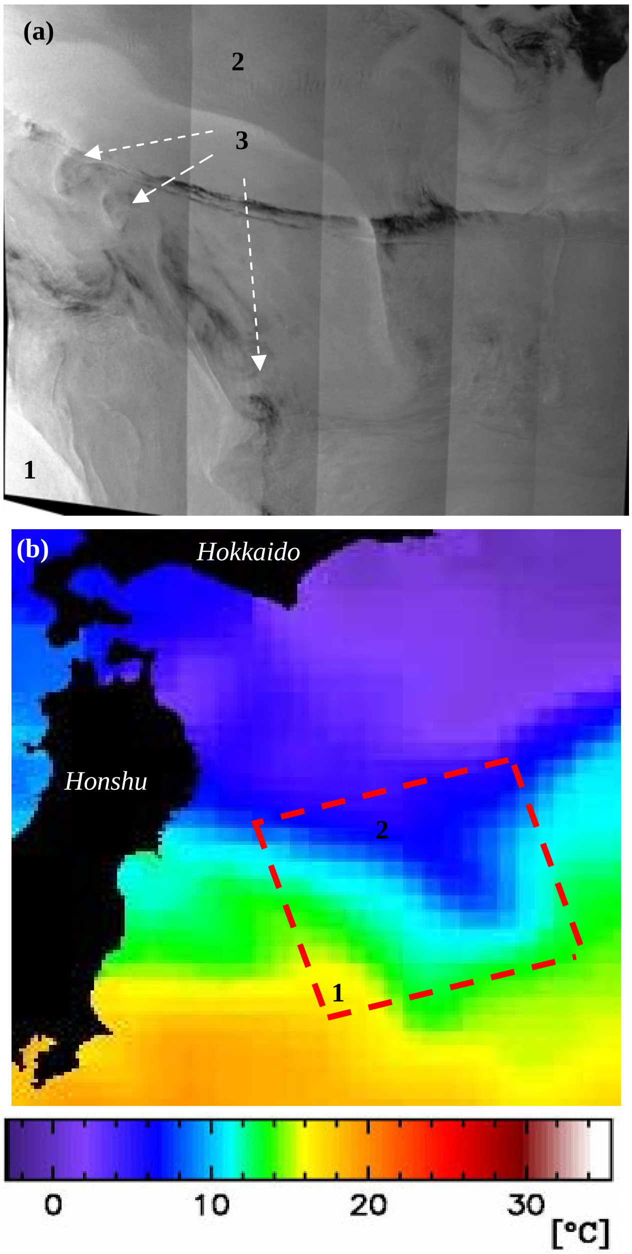

Figure 4. (a) ALOS PALSAR image acquired on 18 April 2006 and (b) New Generation Sea Surface Temperature map produced at the same day by the Tohoku University http://www.ocean.caos.tohoku.ac.jp/~merge/sstbinary/ showing correlation between radar and thermal contrasts.

Important application of SAR data is study of the surface manifestations of oceanic internal waves to determine the sources and mechanisms of their generation and to retrieve the hydrological structure of waters in which they propagated [5-7]. Several packets of nonlinear internal waves generated by successive tidal flows to the west of Tsugaru Strait are distinguished in Fig. 5. The decrease of wavelength and intensity of individual waves from front to rear of wave packets are clearly seen.

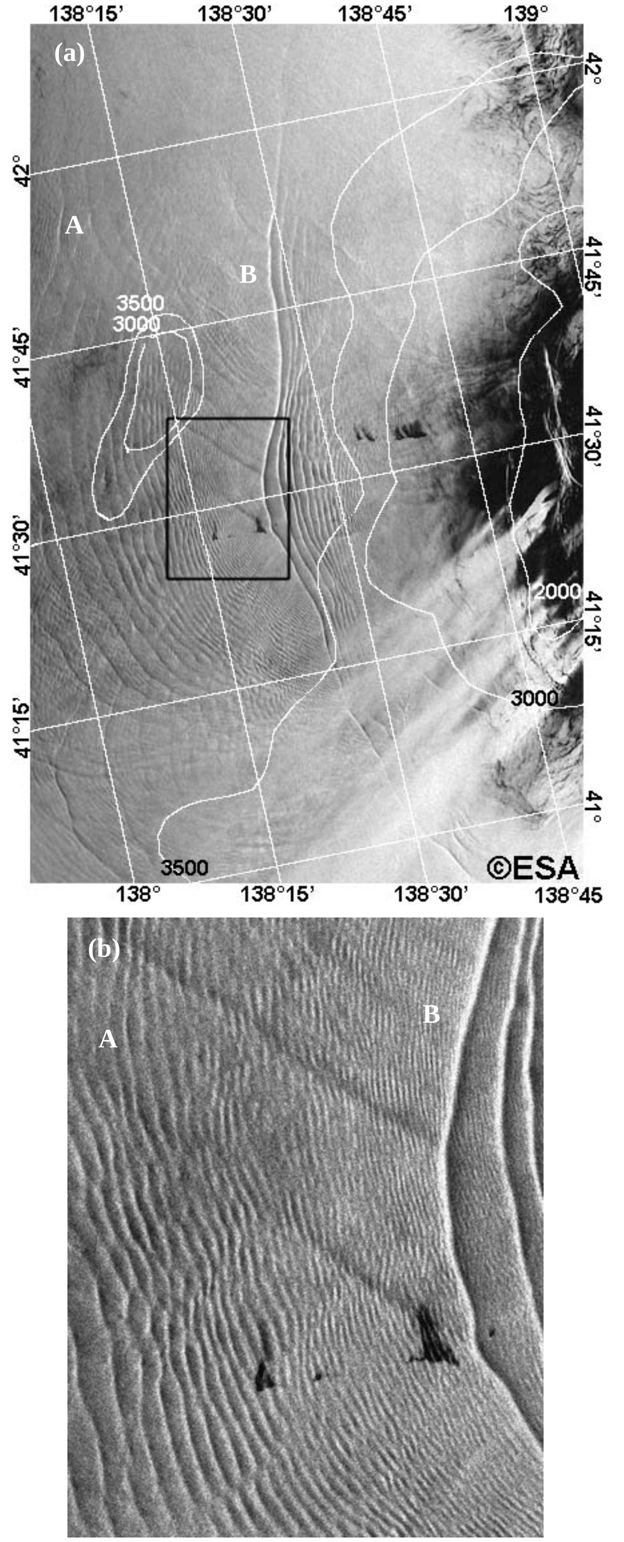

Figure 5. (a) ERS-2 SAR image of the Japan Sea taken on 7 September 1997 at 01:30 UTC with superimposed isobaths (white lines, depths in meters). A rectangle marks the boundaries of the fragment (b) the size of 18 x 25 km showing the first three westward-propagating waves of packet B incident packet A tail. Dark patches are oil spills.

3. SEA ICE

Monitoring the formation, development, melting, concentration, thickness, movement and other parameters of ice as well as winter mesoscale cyclones (MCs), which are frequently observed in the Bering, Okhotsk and Japan Seas, is vital importance to physical oceanographers to study regional climate changes, air/sea/ice interaction, and formation of ocean water properties. The main sources of quantitative spatial information to examine sea ice and winter storms are satellite data and fields of geophysical parameters retrieved from measurements of various satellite sensors. SAR signatures of various types of sea ice, their geographical and seasonal variations were studied by joint analysis of satellite images obtained by passive and active sensors operating at the visible, infrared and microwave ranges, weather maps and coastal stations reports [8].

Fig. 6 shows variability of brightness contrasts of sea ice in Peter the Great Bay measured by Envisat ASAR and Terra MODIS. They are due to the differences of environmental conditions during ice formation, the presence and properties of snow cover and other factors influencing on radar backscatter and albedo [7, 8] and emphasized the usefulness of multisensor techniques for sea ice classification.

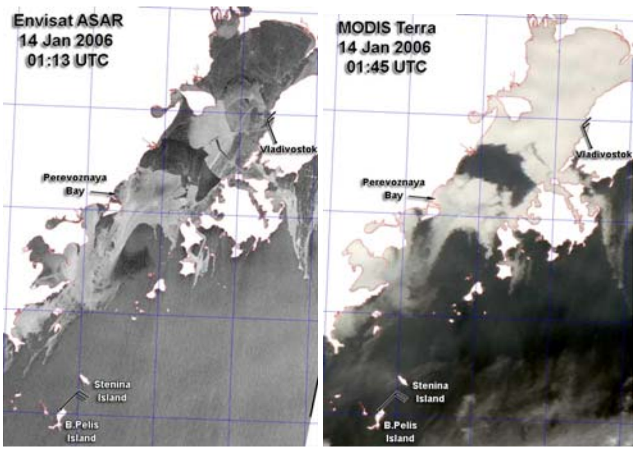

Figure 6. Envisat ASAR (left) and Terra MODIS (right) images of sea ice in Peter the Great Bay acquired on 14 January 2006 at 01:13 (left) and at 01:45 UTC (right)

A wide swath Envisat Advanced Synthetic Aperture Radar (ASAR) is an important tool for the study of mesoscale cyclones over the ocean since it can contribute the high-resolution near-surface wind field. Promising sources of regularly available remotely sensed data (as opposite to occasional ASAR images) are the Aqua Advanced Microwave Scanning Radiometers (AMSR-E), the QuikSCAT Seawinds scatterometer and Terra and Aqua MORIS spectroradiometer. All these sensors are characterized by a wide swath and possess improved spatial resolution and/or have additional spectral channels compare to such sensors as the SSM/I, AMSU, AVHRR, etc. [9].

Envisat ASAR image of mesoscale cyclone near ice edge in the northern Okhotsk Sea is depicted in Fig. 7a. The values of total water vapor content and total cloud liquid water content in the cyclone area estimated from Aqua AMSR-E brightness temperatures at 23.8 and 36.6 GHz are equal to 6-8 kg/m^2 and 0.05-0.08 kg/m^2, correspondingly. The cyclone cloud band is characterized by the brightness temperature of 190-200 K at 89.0 GHz with horizontal polarization (Fig. 7b). Atmospheric front with the wave-like features divides the zones of strong and weak winds (Fig. 7a). Bands of alternating brightness mark wind direction in the area of strong winds located to the north of the front. Further north, the giant ice fields surrounded by the dark bands are clearly distinguished. Their brightness is higher then that of the open sea near the ice edge. At the bottom left, where wind speed increases, radar contrast of the marginal ice zone against the open water becomes negative.

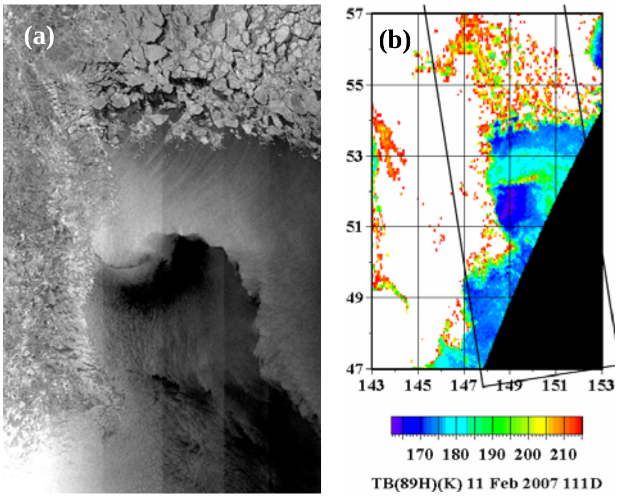

Figure 7. Mesoscale cyclone and sea ice in the Northern Okhotsk Sea on 11 February 2007: (a) Envisat ASAR image and (b) brightness temperature at 89.0 GHz, horizontal polarization.

4. CONCLUSION

Several areas in the Northwest Pacific Ocean were chosen as the study sites by analysis of several hundreds of ERS-1 and ERS-2 SAR and Envisat ASAR images and taking into account the amount of both remotely sensed and in-situ ancillary data available at these sites. They include the Kuroshio-Oyashio confluence zone, Soya Warm Current area, Okhotsk Sea shelf, the Kuril Straits area, Pacific Ocean east of Kamchatka, Peter the Great and Toyama Bays, Taiwan Strait and several areas in the East-China and South-China Seas. Examples presented in a paper show the advantages of multisensor analysis, which gives a new insight in understanding of physical factors determining radar signatures and improves their interpretation. This approach will be applied to analysis of ALOS PALSAR images of the chosen sea areas.

ACKNOWLEDGMENT

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