ERS SAR observations of the Korean coastal waters

Leonid M. Mitnik [1], Hong-Joo Yoon[2], Vyacheslav A. Dubina[1], Sang-Woo Kim[2] and Young-Seup Kim[2]

[1] V.I. Il'ichev Pacific Oceanological Institute FEB RAS, 43 Baltiyskaya St., Vladivostok 690041, Russia
Phone: 7-4232-312-854; fax: 7-4232-312-573; e-mail: mitnik@poi.dvo.ru; dubina@poi.dvo.ru

[2] Pukyong National University 599-1, Daeyeon3-Dong, Nam-Gu, Busan, 608-737 Korea
Phone: +82-51-620-6271; fax: +82-51-625-2529; e-mail: yoonhj@pknu.ac.kr; kimys@pknu.ac.kr; skim@pknu.ac.kr

Abstract: The processes of regional scales in the East Korean coastal waters were investigated by analysis of the Synthetic Aperture Radar (SAR) images taken by the European Research Satellites ERS-1, ERS-2 and Envisat. More than 500 quick look frames taken in 1991-2003 were examined to detect the frames with clearly surface expressions of oceanic phenomena. 26 ERS-1/2 SAR and 11 Envisat wide swath Advanced SAR (ASAR) frames were selected and obtained from the European Space Agency in a form of the precision high-resolution images. The following oceanic phenomena and processes were evident in the radar imagery through the Korean costal waters: fronts, currents, eddies, internal waves, island and ship wakes, oil pollution, etc. They manifested themselves in the field of sea surface roughness, their scale ranged from several tens meters to about 100 km. The most common morphology of these phenomena was a series of contrast dark or light curvilinear lines and bands. The joint analysis of the discussed SAR images with other satellite and *in situ* data supported and enhanced our interpretation of SAR signatures.

Keywords: ERS SAR, EKWC, eddies, internal waves

1. Introduction

The circulation of the Japan/East Sea (JES) is characterized by significant temporal and spatial variability due to such factors as seasonal fluctuations in the warm inflow through Tsushima Strait, branching of the Tsushima Warm Current (TWC), and the formation of mesoscale eddies along these branches. Thermal contrasts are usually associated with the warm and cold currents, eddies and upwelling. Indented coastal line and sharp slope of shelf rising from the Ulleung Basin at 1000-2000 m up to 50 m just 20-50 km off the coast are also contribute to complicated water dynamics. Interaction of currents with underwater relief and islands generates fronts, vortices and internal waves. Although the main features of the JES circulation are reasonably well known, a detailed description of even dominant currents like the Tsushima Warm Current (TWC), East Korean Warm Current (EKWC), etc. still eludes oceanographers. They are constantly changing and must be measured repeatedly to estimate their mean flux.

While the sampling capabilities of visible and infrared (IR) satellite sensors are well adapted for monitoring the ocean variability, the frequent cloud cover prohibits the regular observations of the sea surface. Microwaves can penetrate the clouds. However resolution and accuracy of microwave radiometers are insufficient to monitor variability at scales < 100 km as opposite to imaging radars. 25 years of experience with the analysis of satellite radar ocean images has shown their capacity to detect a variety of small-scale oceanic features. SAR appears to be the most effective way to reveal submesoscale and fine scale variability in the ocean.

Patterns of radar backscatter in a SAR image are created by the modulation of small-scale surface waves, resulted from a variety of atmospheric and oceanic processes. The oceanic processes include those that possess thermal signatures (fronts, currents, upwellings, eddies, etc.) and do not possess them (spiral eddies, ship wakes, internal waves, etc.). Difficulties in interpretation can arise when radar signatures caused by oceanic dynamic are observed against the background variations caused by the surface wind variability and/or rain cells.

The main aim of this ongoing research is to investigate in details the oceanic phenomena in the East Korean Coastal waters to increase their understanding by joint analysis of the SAR images and supplementary data.

2. SAR data

Most of the images of the East Korean Coastal Waters (EKCW) were obtained from ERS-1/2 with C-band SAR with vertical (VV) polarization. The size of an image is about 100 x 100 km and a spatial resolution is 25 x 25 m. More than 900 images were taken in 1991-2003.

The size of an Envisat ASAR image in wide swath regime is about 400 x 400 km and a resolution is 150 x 150 m. 25 ASAR images with horizontal polarization were taken from September 2002 till September 2003.

All the images were downloaded from the web sites of the European Space Agency (ESA) and ground stations. They represent the quick look (QL) images having the reduced spatial and radiometric resolution. A total of 26 ERS-1/2 precision high- resolution product images were obtained from the ESA as a result of selection of the QL frames with the clearly surface imprints of the oceanic phenomena.

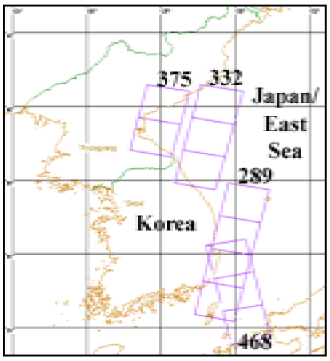


Fig. 1. The rectangles indicate the area covered by the ERS-1/2 SAR images taken on various tracks.

3. Examples of results

The visual identification of oceanic dynamic phenomena in the EKCW area was guided by numerous assessments of SAR signatures [1-5]. Most current fronts, eddies, spiral eddies, IWs and ship wakes were primarily identified through the characteristics assemblage of contrast (dark and/or light), narrow, curvilinear bands. The AVHRR data generally supported and enhanced our interpretation of SAR signatures.

A direct comparison between SAR and altimeter data is difficult because the temporal and spatial coverage and resolution of the two systems are quite different. By combining the altimeter sea level heights from several tracks over a time interval of at least 10 days, it is possible to establish geostrophic velocity anomaly maps resolving current features with scales of a few tens of kilometers. Thus the altimeter may not capture many of short-lived mesoscale features observed by SAR.

Joint analysis of SAR and ocean color images helped to identify the physical and biological processes controlling the main backscatter features found on the SAR images.

Surface weather maps provided data on the surface wind and sea state observed during SAR sensing.

East Korean Warm Current and eddies

The EKWC, one of the TWC branch, flows to the north along the eastern coast of Korea. The EKWC is separated from the coast at 38-40°N and flows to the northeast where it meets the North Korean Cold Current and forms a subpolar front. NOAA AVHRR IR images revealed the currents, mesoscale eddies, streamers and other features of surface circulation. These features were reliably detected on IR images taken in cold season.

Two fragments of ERS-2 SAR images (track 289) depicted in Fig.2 show clearly the EKWC front and other oceanic phenomena. Increment of the Normalized Radar Cross Section of the front relative to the background along section AA (Fig.2a) is ≈ 3.5-4.0 dB and a width of the current shift zone is ≈ 0.5 km.

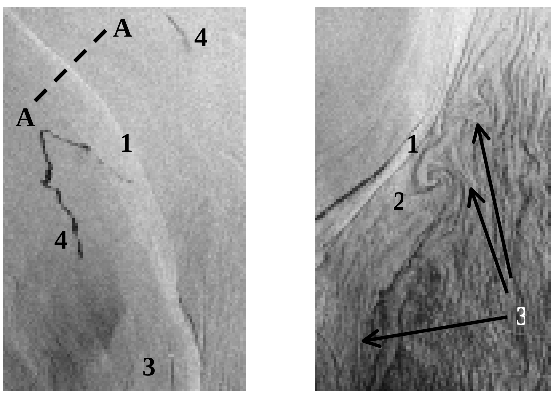


Fig. 2. Fragments of ERS-2 SAR image (25x 40 km) for 27 September 1999 at 02:02 UTC, track 289 showing the EKWC front (1), spiral eddies (2), ships (bright dots), ship wakes (3), filamentary slicks and oil slicks (4).

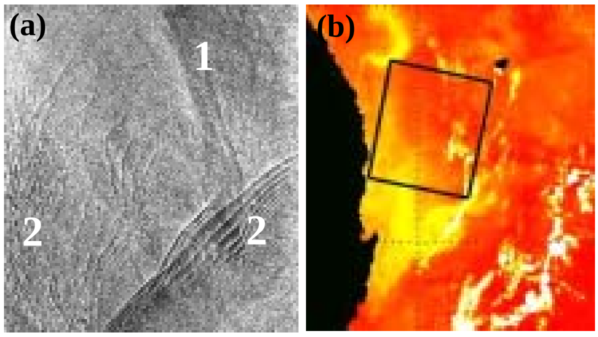


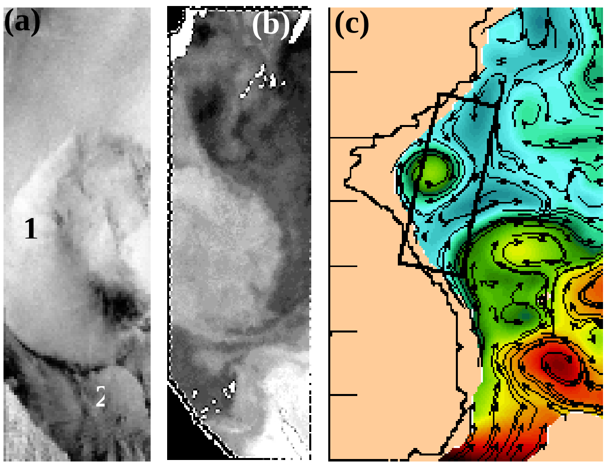
Fig.3. (a) ERS-2 SAR image (track 289) at 02:02 UTC showing the imprints of the EKWC front (1) and the IWs (2) and (b) AVHRR-derived SST at 04:37 UTC for 2 September 1996.

ERS-2 SAR sensing on 2 September 1996 (track 289) was taken at wind speed varied between 2 and 5 m/s that is favorable for detection of oceanic phenomena. A light contrast curve band (1) the width of about 1.5-2.5 km in the upper middle part of the image (Fig.3a) is very likely the EKWC front. It is seen due to current shift. Examination of the AVHRR-derived SST for 1 September at 23:08UTC and for 2 September at 04:37 UTC (Fig.3b) did not reveal thermal contrast of the front. An anticyclonic (AC) eddy in the East Korean Bay (EKB) at about 39-40°N, 129-130°E exists most of the time.

The SAR image (Fig.4a) shows this eddy at the end of September when its thermal contrast is less than in winter (Fig.4b). TOPEX/Poseidon data confirms AC circulation in this area (Fig.4b).

The oceanic processes in the EKB have not been adequately investigated in particular due to difficulties in hydrological data acquisition. SAR imagery provides important information on the dynamic oceanic phenomena in the area. Fig.5 shows plentiful filamentary slicks in the western part of the EKB. Their shape suggests that AC circulation and a possible convergence towards the eddy center were observed.

Fig. 4. ERS-2 SAR image for 25 September 1997 at 02:06



UTC, track 332 showing the synoptic warm eddy (1) and spiral eddy (2) to the south of it (a); AVHRR-derived SST for 23 September 1997 at 21:53 UTC (b) and surface currents retrieved from TOPEX/Poseidon data (c).

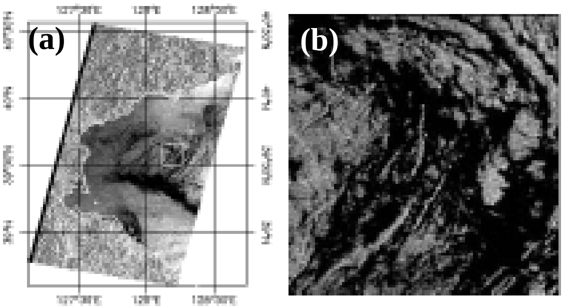


Fig.5. ERS-2 SAR image for 18 August 2002 at 02:11 UTC, track 375 showing (a) an eddy in the EKB visible due to natural filamentary slicks and (b) expressions of intensive fishery in the area marked by a white rectangle in (a). Ships (bright dots) and ship wakes behind them are well defined.

Chlorophyll-*a* (chl-*a*) (surface films) content in the dark areas of the EKB was high enough to damp the small-scale surface roughness, contrasting with the rather light image background. Eddies in the EKB and in the subpolar front were also detected on Envisat ASAR images taken on 7 and 11 April and on 13 September 2003.

Internal waves

There are few direct observations of IWs east of the Korea coast. As follows from the analysis of the ERS SAR images, significant internal wave activity is observed in the EKCW due to the combination of high tidal range and the complicated bottom topography. Fig.3a shows one of the many examples of SAR images where there are expressed several IW packets. They appear to propagate in at least three different directions. Some of these IW packets are oriented approximately parallel to the depth contours that run more or less parallel to the Korea coastline. Two packets of nonlinear internal solitary waves propagate northwestward. The packets contain about 10 rank-ordered solitons with monotonically decreasing distance between them (from about 4 km to about 0.5 km). It is also interesting to note some interaction among packets propagating in different directions.

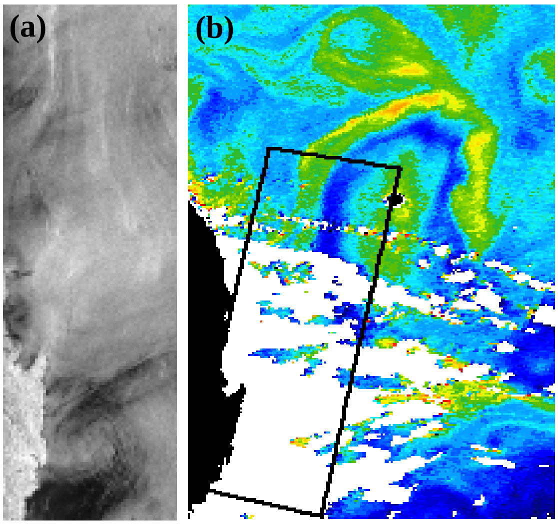


Fig. 6. (a) ERS-2 SAR image, track 289 at 02:02 UTC and (b) SeaWiFs-derived chl-*a* content at 04:08 UTC on 29 May 2000 showing a cyclonic eddy east off Busan and correlation between reduced surface roughness and increased chl-*a*.

Surface manifestations of the IWs were also detected on Envisat ASAR image for 13 September 2003.

Discussion and conclusion

This paper has selected a few of the more interesting features from the satellite SAR scenes of the EKCW. The SAR has capability to map location, size and other characteristics of eddies, fronts, IWs, etc. provided that the wind conditions are moderate (< 10-12ms^{-1}). Further work is in progress to analyze these quantitatively. SAR images, integrated with the reduced number of *in situ* observations, can provide valuable, and new information about some of the oceanographic and meteorological processes occurring in the EKCW, even when cloud cover, or the land contamination, prevents the use of other remote sensors such as the visible/infrared radiometer or altimeter. Preliminary comparisons between the SAR and altimeter results indicate that that there is qualitative agreement.

The use of visible (SeaWiFS), infrared (AVHRR) and SAR satellites data allowed the identification of the physical and biological processes controlling the main backscatter features detected on the SAR image. These processes included current fronts, eddy formation, internal waves, etc., as well as natural films associated with high biologic productivity.

Acknowledgements

This study was carried out within ESA ERS project AO3-401 and ESA Envisat project AO-ID-391. The work was supported by grant No R01-2002-000-00369-0 for The Basic Research Program of Korea Science &Engineering Foundation and grant on Technological Marine Meteorological and Climatological Data Utilization for Korean Meteorological Administration. This work is partially sponsored by a grant 03-01-0-07-006 from Far Eastern Branch of the Russian Academy of Sciences.

References

[1] Alpers, W., 1995. Measurement of mesoscale oceanic and atmospheric phenomena by ERS-1 SAR. *Radio Sci. Bull.*, 275: 14-22.
[2] **URL**: Alpers, W., L. Mitnik, L. Hock and K.S. Chen, 2002. *The Tropical and Subtropical ocean viewed by ERS-SAR.* Available at: http://earth.esa.int/application/ERS-SARTropical
[3] Da Silva, J.C.B., S.A. Ermakov, I.S. Robinson, D.R.G. Jeans and S.V. Kijashko, 1998. Role of surface films in ERS SAR signatures of internal waves on the shelf. I. Short-period internal waves, *J. Geophys. Res*., 103(C4): 8009-8031.
[4] Johannessen J.A., R.A. Shuchman, G. Digranes, D.R. Lyzenga, C. Wackerman, O.M. Johannessen and P.W. Vachon, 1996. Coastal ocean fronts and eddies imaged with ERS-1 synthetic aperture radar, *J. Geophys Res.*, 101(C3): 6651-6668.
[5] Nilsson C.S. and P.C. Tildesley, 1995. Imaging of oceanic features by ERS 1 synthetic aperture radar, *J. Geophys. Res.*, 100(C1): 953-967.