East Coast Upwelling Signatures in Synthetic Aperture Radar Imagery

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ABSTRACT

Seasonal coastal upwelling in the U.S. Mid-Atlantic region occurs normally during the summer months because of generally northward alongshore wind episodes. These winds force an Ekman offshore surface flow over the inner continental shelf. Colder and nutrient-rich waters from below move toward the surface replacing the offshore flowing surface waters. ERS-2 Synthetic Aperture Radar (SAR) observations before and after upwelling favorable winds along the coast of New Jersey in early summer 1996 are presented here. Upwelling conditions are confirmed from both *in-situ* and sea surface temperature satellite data. The appearance of a low backscatter region on the SAR imagery suggests the influence of the upwelling regime on the sea surface roughness. In particular, the abundance of surface slicks observed by SAR along the coast is consistent with enhanced biological activity resulting from enhanced nutrient availability in the upwelled waters.

INTRODUCTION

It is well known that seasonal coastal upwelling in the U.S. Mid-Atlantic region occurs normally during the summer months because of generally northward alongshore wind episodes [1]. Northward winds along the U.S. East Coast can produce an Ekman offshore surface flow over the inner continental shelf. A divergent surface flow is compensated by an onshore deeper flow that brings colder and nutrient-rich water to the surface. If sustained, this process can become an important mechanism for cross-shelf exchanges in the region during summertime. The Rossby radius of deformation and the horizontal gradient of the wind stress are important factors in determining the horizontal scale of the upwelling region [2]. In general, the duration of the wind events will determine the intensity and duration of the wind-driven flow.

Upwelling is commonly detected with IR spaceborne sensors, such as the NOAA Advanced Very High Resolution Radiometer (AVHRR), by observing the contrast between colder upwelled water and the surrounding warmer surface water. In Synthetic Aperture Radar (SAR) imagery, certain regions of low radar backscatter (darker areas on an image) have been at times suggested to be associated with upwelling activity, although, no direct confirmation of this is usually provided. In contrast, spaceborne SAR imaging has been

used to detect and study many other sea surface and coastal features of great interest to oceanographers. These may include surface and internal waves, ocean currents and fronts, sea ice, bathymetry, and atmospheric phenomena [3,4].

According to the Bragg model, SAR response is due to resonance of the radar microwaves with capillary and short gravity surface waves of similar wavelength [5]. The roughness of the ocean at Bragg wavelengths is setup by the local wind. As the roughness of the ocean surface increases, the amount of backscatter energy detected by the instrument increases. An increase in wind speed will thus result in an increase in backscatter. The Bragg wave spectrum is further modulated by longer waves, surface currents, and atmospheric circulation processes. This modulation is required in order for SAR to image ocean and ocean-atmosphere phenomena.

In an upwelling dominated area, temperature changes between upwelled and surrounding waters can translate into important changes in the viscous-elastic properties of the surface layer. This in turn can have an effect on the damping of Bragg waves and the backscatter amplitude observed by SAR. Changes in the air stability at the boundary layer, due to changes in the air-sea temperature difference over upwelled waters, can also have an effect on the observed backscatter. Increased stability due to lower sea surface temperatures can result in lower wind stress and a decrease in available Bragg scattering waves.

Natural and man-made surface slicks can be very effective in damping Bragg waves resulting in dark features in SAR imagery [6]. Man-made slicks are usually associated with the accidental spill or illegal dumping of petroleum products (mineral oils). Natural or biogenic slicks form because of higher concentrations of organic matter surface-active constituents of marine and terrigenous origin at the surface microlayer. These substances may include lipids, proteins, organic acids, and many other complex molecules. Observed natural slicks in SAR imagery have been associated with areas of high biological activity [7]. For example, the observation of natural slick filaments can be suggestive of enhanced biological activity in an upwelling regime [8].

It should be pointed out that low backscatter regions in SAR imagery could also be produced by low wind speed conditions. In fact, SAR imaging of the ocean surface

usually requires a minimum wind speed threshold of about 2 to 3 m/s in order to produce sufficient roughness for contrast to be observed. On the other hand, high wind speeds, usually above 10 m/s, will produce both large background clutter and increased mixing that will tend to obscure or destroy ocean surface signatures in the SAR imagery.

DATA SOURCES

The SAR data presented here include two ERS-2 SAR Precision orbits for May 29 and June 14, 1996 provided by European Space Agency (ESA). ESA's ERS-1 and ERS-2 satellites have been providing SAR C-band VV polarization images on a regular basis since mid-1991. AVHRR sea surface temperature (SST) images were available from the NOAA CoastWatch Program National Oceanographic Data Center (NODC) archive and the Rutgers University Institute of Marine and Coastal Sciences (IMCS) Remote Sensing Program. Vertical temperature profile data and current measurements were acquired at the IMCS Longterm Ecosystem Observatory (LEO-15). LEO-15 is a real-time observation network that includes an array of underwater instruments deployed off New Jersey's Little Egg Inlet and extending offshore. Ocean Surface Current Radar (OSCR) surface current vectors obtained over the shelf region off Atlantic City by IMCS were also available. OSCR uses the Doppler shift of High Frequency (HF) radio pulses (25.4 MHz) to deduce near-surface currents. Wind speed and direction were collected at the Marine Field Station located close to the Little Egg Inlet.

MAY OBSERVATIONS

Southward winds were reported during the last six days of May 1996. The vertical temperature profile for May 31 showed practically uniform SST at the surface and a deepening of isotherms toward the coast at the LEO-15 site. Available AVHRR SST for May 31 confirmed uniform surface temperature over the New Jersey coast. These observations are consistent and clearly indicate the absence of upwelling in the region during this time.

An ERS-2 SAR image of the New Jersey coast was acquired on May 29, 1996 and is shown in Fig. 1. A limited coverage of the shelf region is provided by this image. Relatively large backscatter clutter is observed over the ocean. Under closer inspection, indications of tidal exchange from inlets as well as a frontal feature along the coast can be observed.

JUNE OBSERVATIONS

Persisting northward upwelling winds were reported in the region during the second week of June 1996. The vertical temperature profile for June 12 shows colder water inshore and a shoaling of the isotherms toward the coast. AVHRR

Fig. 1. ERS-2 SAR image of the coast of New Jersey acquired on May 29, 1996.

SST data for June 12 show regions of colder temperatures along the New Jersey coast including the LEO-15 site. Strong upwelling features along the coast are observed again on June 13 AVHRR SST data with low surface SST of around 16 °C and gradients of around 0.15 °C/Km.

Additional indication of an upwelling regime during this period was provided by the OSCR daily mean observations of surface current. The data showed meandering and cyclonic circulation consistent with the upwelling region observed in the SST images at the LEO-15 site. The current meter data indicated inshore-offshore advection also consistent with active upwelling.

Fig. 2 shows an ERS-2 SAR image acquired on June 14, 1996. The surface conditions seen at this time greatly differ from those observed on the May 29 SAR image. The inner shelf region off the coast New Jersey is now dominated by a significant decrease in the radar return over the inshore side. Several regions of extreme low backscatter as well as an abundance of filament slick-like features along the coast are now observed.

Fig. 2. ERS-2 SAR image of the coast of New Jersey acquired on June 14, 1996.

DISCUSSION AND RECOMMENDATIONS

From the SAR observations presented above, it appears that the presence of low backscatter features off the New Jersey coast is associated with upwelling activity in the region. The overall level of backscatter is seen to decrease rapidly from the outer to the inner shelf region where the coldest waters are present. It should be noted that the location of the low backscatter feature off Little Egg Inlet somehow corresponds to that of an intense upwelling area observed in the SST and *in-situ* data. Closer examination of this feature at a higher spatial resolution reveals complicated patterns that may not necessarily be the direct result of the lower SST's. For example, a dense concentration of slicks and a wind speed variability-like pattern combine to form the observed feature.

To identify the significant mechanisms at play in producing these features, additional research will be required. These mechanisms will probably include a combination of changes in the air-sea stability, changes in seawater viscosity, and surface layer accretion of organic substances. A backscatter model containing parameters for air-sea stability, viscosity dependence on SST, and the presence of organic constituents at the surface needs to be developed.

As shown by the SAR data, the shelf region off New Jersey was characterized by the prevalence of filament structures of suspected natural origin during upwelling conditions. Although the observed

abundance of such filaments suggests high biological activity, further verification is still required. The presence of the slick filaments is certainly consistent with enhanced availability of organic material after sustained upwelling. Still, the need for ground truth is clear in order to conclusively identify the nature of these features.

A large low backscatter feature at the top of Fig. 2 generally coincides with a known seasonal upwelling center just south of the Hudson River Estuary. It is interesting to note that this low backscatter feature appears to be somehow "detached" from the coast. High outflow from the Hudson River was actually being reported during this time in June "unpublished"[9]. The apparent detachment of the feature from the coast may be an indication of the interaction between the coastal buoyant flow imposed by the Hudson Bay discharge and the upwelling processes over the shelf.

The seasonal recurrence of these SAR signatures will be tested during the summer of 1998. A verification experiment is being planned in coordination with an IMCS follow-up upwelling observation program scheduled for May through July. ERS-2 and RADARSAT SAR coverage of the region is being requested. In addition to the continuous LEO-15 and OSCR datasets, shipboard data which includes local wind speed and direction and sea surface microlayer constituents will be collected during multiple cruises throughout the three month period.

ACKNOWLEDGMENTS

This research is partially supported by the NOAA Satellite Ocean Remote Sensing (NSORS) Program.

REFERENCES

- [1] S.M.Glenn, M.F.Crowley, D.B.Haidvogel, and Y.T. Song, "Underwater observatory captures coastal upwelling events off New Jersey," EOS, Trans.of AGU,77(25):233-236. 1996.
- [2] G.A.Dalu and R. A. Pielke, "An analytical study of the frictional response of coastal currents and upwelling to wind stress," J. Geophys. Res., 95, 1523-153, 1990.
- [3] R.Beal, V.Kudryavtsev, D.Thompson, S.Grodsky, D.Tilley, and V.Dulov, "Large and small scale circulation signatures of the ERS-1 SAR over the Gulf Stream," Proceed. 2nd ERS-1 Symp. - Space to the Serv. of Our Environm, Hamburg, Germany, 11-14 October 1993, ESA SP-361, 547-552, 1994.
- [4] C.S.Nilsson and P.C.Tildesley, "Imaging of oceanic features by ERS 1 synthetic aperture radar", J. Geophys. Res., 100(C1):953-967, 1995.
- [5] Valenzuela, G.R., "Theories for the interaction of electromagnetic and ocean waves - A review," Boundary-Layer Meteorol., 13:61-85, 1978.
- [6] W.Alpers and H. Hühnerfuss, "The damping of ocean waves by surface films: A new look at an old problem," J. Geophys. Res., 94:6251-6265, 1989.
- [7] Gower, J.F.R, Mapping coastal currents with SAR, using naturally-occurring surface slick patterns," Proceed. 2nd ERS-1 Symp. - Space to the Serv. of Our Environm, Hamburg, Germany, 11-14 October 1993, ESA SP-361, 415-418,1994.
- [8] Alpers. W., "Measurement of mesoscale oceanic and atmospheric phenomena by ERS-1 SAR," Radio Sci. Bull., 275:14-22 (1995).
- [9] R.Chant, "personal communication", Rutgers. IMCS, 1997.