Ocean Feature Tracking Using Sequential SAR Images

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ABSTRACT ... With repeated coverage, spaceborne SAR (Synthetic Aperture Radar) instruments provide the most efficient means to monitor and study the changes in important elements of the marine environment. Due to high-resolution of SAR data, the coverage of SAR sensor is always limited, especially for a repeat cycle. With more SAR sensors from various satellites, new data products such as ocean surface drift can be derived when two SARs' tracks overlap in a short time over coastal areas. Currently, there are two SAR sensors on different satellites with almost the exactly same path. That is, ERS-2 is following ENVISAT with a 30-minutes delay, which will be a good timing for ocean mesosclae feature tracking. For another application, a mystery ship near a big eddy with strong ship wake has been tracked between ERS-2 and ENVISAT SAR images to estimate its ship speed.

KEY WORDS: Surface Drift, Feature Tracking, Wavelet Transform, SAR

1. Introduction

Historically, ocean surface feature tracking analyses have been based on data from a single orbital sensor collected over its revisit interval of a lone, low-Earth orbital satellite. Today, ocean surface currents are being derived by performing feature tracking using data from the same type of sensors on different satellites. With all-weather, day/night imaging capability, Synthetic Aperture Radar (SAR) penetrates clouds, smoke, haze, and darkness to acquire high quality images of the Earth's surface. The ability of a SAR to provide valuable information on the type, condition, and motion of the sea-ice, ships and surface signatures of swells, wind fronts, oil slicks, and eddies has been amply demonstrated (Liu and Wu, 2001), especially for internal waves (Hsu et al., 2000). This makes SAR the frequent sensor of choice for cloudy coastal regions. Currently, there are two SAR sensors on different satellites, ERS-2 and ENVISAT, having acquisition time offset around 30 minutes with almost the exactly same path. That is, ERS-2 is following ENVISAT with a 30-minutes delay, which will be a good timing for ocean mesosclae feature tracking and new product such as ocean surface drift.

2. Wave refraction near Dong-Sha Island

A case study for wave-bathymetry interaction near Dong-Sha Island in the South China Sea has been carried out recently. Internal wave refraction by coral reef around Dong-Sha Island has been observed in this case study from sequential ERS-2 and ENVISAT SAR and MODIS images. A Taiwanese research ship OR-3 was tracking internal waves near Dong-Sha Island from April 15 – 20, 2003. A large internal wave (amplitude > 50m) passing through the ship location on April 16 was measured by a thermistor chain with pressure sensors deployed from the ship.

Figure 1(a) shows a subscene of ENVISAT ASAR image around Dong-Sha Island collected on April 16, 2003 at 2:00 am UTC, and a similar subscene of ERS-2 SAR image collected at 2:30 am UTC is shown in Figure 1(b). Fortunately, MODIS was passing through Dong-Sha Island at 3:10 am UTC with almost no cloud cover as shown in Figure 1(c). Figure 2 shows a schematic diagram combining internal waves from sequential ENVISAT ASAR, ERS-2 SAR, and MODIS images shown in Figure 1. The dashed curves are delineated from internal waves from ENVISAT image, the solid curves are from ERS-2 image, and the dotted curves are from MODIS image. This diagram shows wave refraction and reflection caused by the interactions of internal solitons with Dong-Sha Island and coral reef around it. As expected, the internal wave packets were impinged from the eastern direction on the reef, and then separated by the reef as they propagated westerly. The reflected waves can also be easily identified in the images as they propagated easterly as shown in the diagram.

Based on ship location, its horizontal distance from the Dong-Sha Island is approximately 55 km. Then, the wave traveling time can be estimated from the thermistor chain data collection time (9:00 am UTC), and the wave arriving time at the Dong-Sha Island (3:30 am UTC) from MODIS data (figure 1). Then, the internal wave speed near the Dong-Sha Island in deep water is estimated to be 2.35 m/s based on a semi-diurnal tide theory. This estimated internal wave speed is relatively larger than expected, but still is consistent with some other observations (Klymak et al., 2006).

3. Wavelet analysis of satellite images

When using multiple SAR data from different satellites to track ocean feature motion, the first step is to transform the full-resolution images to the same map projection. In this case, the ERS-2 SAR and ENVISAT ASAR subscenes used are both 512 x 512 pixels (with pixel size of 55 m approximately), and the Mexican-hat wavelet transform is applied to filter each image with several length scales. The length scale of the wavelet transform corresponds to the length scale of the Gaussian function and is based on the length scale of the feature of interest. Filtered images, acquired 28 minutes apart, are then examined to find matching features using templates, which are then readily converted to motion vectors and averaged onto a 0.88 km x 0.88 km grid. The accuracy of this technique is only limited by the persistence of the features and by the spatial resolution and navigational accuracy of satellite data. A single pixel feature displaced 55 m over 28 minutes will have a maximum velocity uncertainty of 3.3 cm/s due to sensor resolution. The geolocation uncertainty is about 25 m (sensor resolution) for ERS-2 SAR and ENVISAT narrow swath ASAR.

4. Ocean surface drift around a big eddy

Ocean surface backscattering images provided by ERS-2 SAR and ENVISAT ASAR can be used to derive ocean surface drift. SAR data from ENVISAT and ERS-2 were collected on April 27, 2005 at 01:54 and 02:22 GMT, respectively, over the southern part of Luzon Strait near Philippines. For further detailed study, a zoomed SAR subscene has been selected from each image. A case study is around the big eddy. A subscene containing the big eddy has been selected from both ERS-2 and ENVISAT images on April 27, 2005. The center of eddy from two sequential images are not coincided and shifted by a large distance due to the surface drift. Figure 3 shows the surface drift (green arrows) derived by the wavelet-based feature tracking method from these two selected subscenes of ERS-2 SAR and ENVISAT ASAR surface roughness backscattering data. The surface drift is dominated by the western current driven the wind forcing. However, a secondary cyclonic eddy motion can be detected at the northeast of the eddy center with a maximum speed of 0.7 m/s. The results are very noisy due to the low signal-noise-ratio induced by the large swell motion induced by strong eastern wind.

The wind speeds and directions for the two wind vectors from QuikSCAT in Figure 3 from left to right are listed as follows: (a) 5.44 m/s, 159.5° and (b) 3.8 m/s, 193°. The surface drift in Figure 3 is dominated by the western current driven the wind forcing from the East. The surface drift results are very noisy due the low signal-to-noise ratio induced by the large swell motion forced by strong eastern wind. However, the secondary cyclonic eddy motion can still be detected at the northeast of the eddy center. These results indicate that multiple SAR images overlapped in a short time can be used to derive ocean surface drift, and can help to identify oceanic processes such as currents and eddies.

5. Mystery ship near another big eddy

Ship and their wakes can be detected in the high-resolution SAR imagery provided by satellites. In general, ship is a very effective corner reflector, so ship can be easily observed as a bright spot in the SAR image. But, occasionally, the ship in the SAR image remains invisible, and only trailing dark turbulent wakes are seen (Liu et al., 1996). Figure 4 shows the ERS-2 60 km x 80 km SAR image obtained on April 27, 2005. Figure 5 shows ENVISAT and ERS-2 28 km x 28 km SAR subscenes from the image collected on April 27, 2005 north of Philippines in the Luzon Strait with a big eddy as shown in Figure 4. The subscenes cover the area from latitude of 20.61° to 20.86°, and longitude of 122.09° to 122.34°. The invisible ship and its wake in the boxes near the eddy can be tracked easily in these figures. Then, the ship speed is estimated from the distance between ship locations in each SAR image and SAR acquisition time interval (28 minutes) to be 5.94 m/s. Very low backscattering of the ship configuration may have hidden the invisible ship from view, or the wake could have been formed, instead, by an underwater vehicle.

In this area covered by SAR imaging, many internal tide and nonlinear internal wave packets have been observed in the SAR images (Liu et al., 1998; 2004). Based on satellite observations of internal wave distribution from the last ten years, most of internal waves in the northeast part of South China Sea are propagating westward (Hsu and Liu, 2000; Liu and Hsu, 2004). The wave crest can be as long as 200 km with amplitude of 150 m, due to strong current from the Kuroshio branching out into the South China Sea. These huge internal waves may be generated in many channels between islands in the Luzon Strait as shown in Figure 4. The surface drift pattern derived from satellites can be very useful to study the sources of internal wave generation area.

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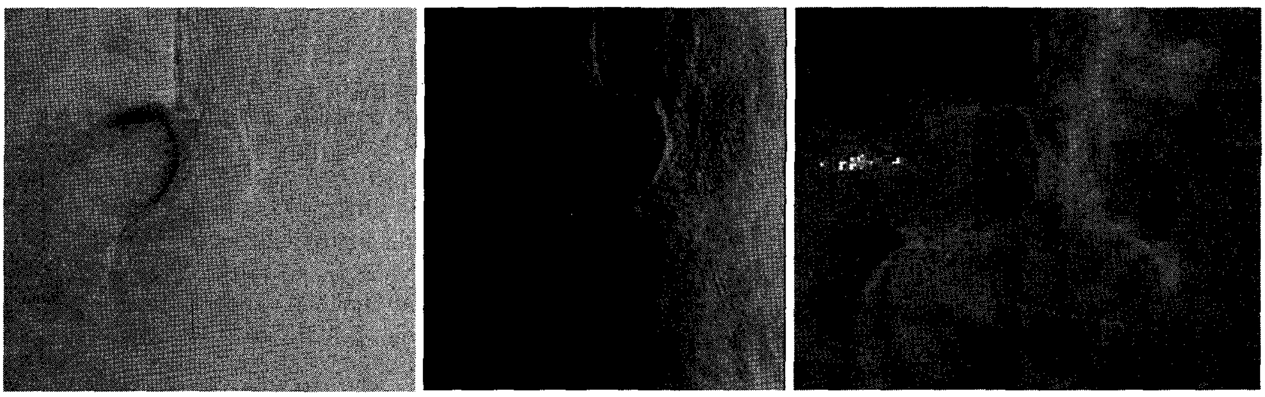
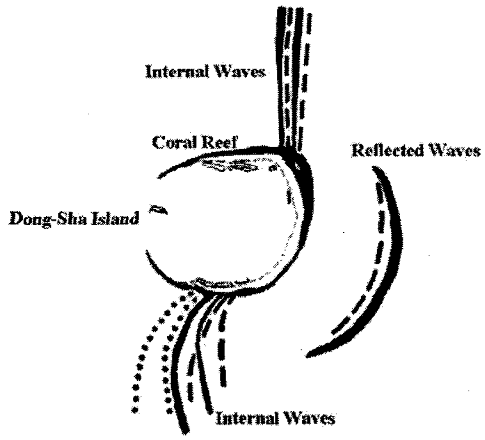


Figure 1. Subscenes of (a) ENVISAT ASAR, (b) ERS-2 SAR, and (c) MODIS image (from left to right) around Dong-Sha Island collected on April 16, 2003 at 2:00 am UTC, 2:30 am UTC, and 3:10 am UTC, respectively.



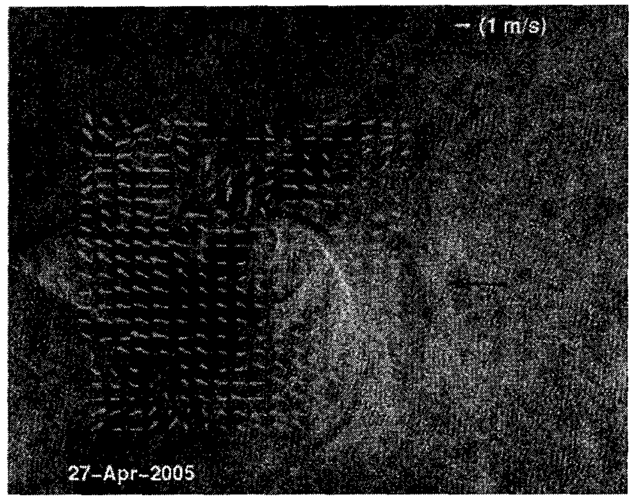


Figure 2. A schematic diagram combining internal waves from sequential ENVISAT ASAR (dashed curves), ERS-2 SAR (solid curves), and MODIS (dotted curves) images showing wave refraction around the Dong-Sha Island.

Figure 3. Ocean surface drift (green arrows) derived from ERS-2 and ENVISAT SAR data over the eddy (ENVISAT image as background). The surface drift unit of 1 m/s is indicated by a white arrow at the top. The QuikSCAT wind data are shown as red large arrows.

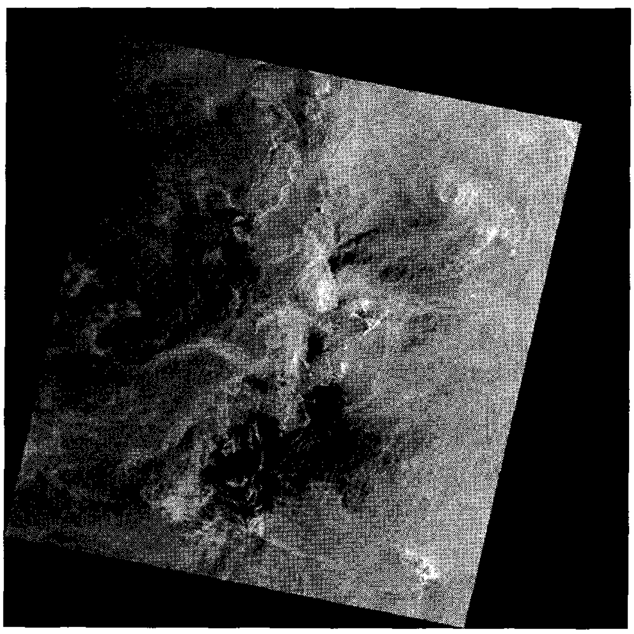


Figure 4. ERS-2 60 km x 80 km SAR image collected on April 27, 2005 in the south part of Luzon Strait (near Philippines) from the satellite descending acquisition path.

Figure 5. ENVISAT and ERS-2 28 km x 28 km SAR subscenes (copyright ESA 2005) obtained on April 27, 2005 north of Philippines in the Luzon Strait. The invisible ship and its wake near the eddy can be tracked easily as shown in the box.