DETECTING AND TRACKING SMALL SCALE EDDIES IN THE BLACK SEA AND THE BALTIC SEA USING HIGH-RESOLUTION RADARSAT-2 AND TERRASAR-X IMAGERY (DTEDDIE)

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ABSTRACT

High-resolution Synthetic Aperture radar (SAR) images of coastal and off-coastal areas provide a nearly weather independent monitoring of small-scale oceanographic features. In this paper, we describe the advances, which have been achieved within the DTeddie project. Therefore, we present the application of formerly developed algorithms to high-resolution SAR data to estimate the sea surface current at sub-mesoscale. Inside the derived current sea surface current fields, vortical structures, e.g. eddies, will be detected by means of local current anomalies. Another approach uses the alignment of anchored ships as an indicator of the sea surface current. To infer dependent information for each ship, we present an automatic registration method between coastal photographs and the SAR images. Both approaches have proven to yield valuable results with respect to the detection of vortical current flows at sub-mesoscale.

***Index Terms*—** SAR, coastal remote sensing, eddies, multi-modal registration

1. INTRODUCTION

The aim of the DTEddie[1] project is to develop algorithms to detect, track and measure small scale eddies using high-resolution SAR images from both RADARSAT-2 and TerraSAR-X. The principle areas of interest are the northeastern Black Sea and the central Baltic Sea [1][2].

The project participants have experience in the development of algorithms to extract oceanic features from SAR imagery, in their interpretation, and in oceanographic field campaigns. For the detection of sub-mesoscale eddies in high-resolution SAR images we present two different approaches:

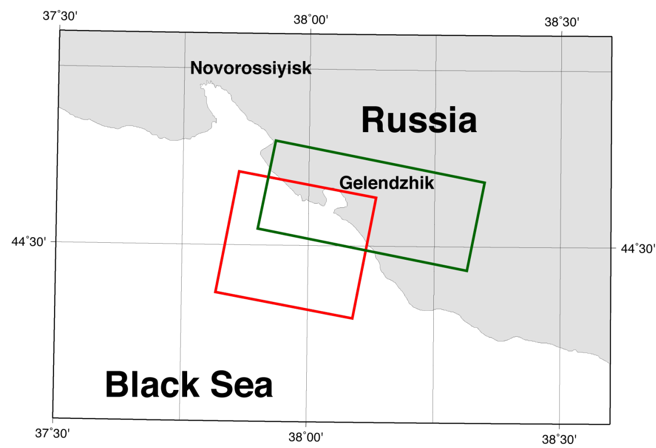

Figure 1: Map of the coastal area off Gelendzhik indicating the location of the satellite images used for the tracking approach: RADARSAT-2 (green) and TerraSAR-X (red).

- The detection of turbulent signatures in single SAR images and
- The tracking of marine surface films` signatures in temporally close pairs of SAR images.

We have already shown that mesoscale surface currents in the Baltic Sea may be detected and measured by tracking natural surface films using SAR images or optical images [1]. For the detection task of turbulent signatures on high-resolution SAR images, two different approaches have been developed. In this paper we present the results of sea surface current estimation from SAR imagery. We will further interpret the resulting vector fields with respect to eddies as local current anomalies.

2. SATELLITE DATA

For the sea surface current estimation task, two high-resolution SAR satellite sensors, namely the TerraSAR-X and the RADARSAT-2, acquired the images used herein. Both images were taken on Oct. 11, 2011 and show the

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coastal area located close to the Bay of Gelendzhik where vortical structures of surface films have been detected during past research [8]. A map of the region is shown in Fig. 1. The RADARSAT-2 image was acquired at 03:37:02 UTC, the acquisition time of the TerraSAR-X image was 03:44:07 UTC. Both images have been co-registered to a common resolution of 3×3 m^2 per pixel. Due to legal requirements, we are only allowed to acquire RADARSAT-2 images over Russian territory.

For the second task, the estimation of the orientation of anchored ships based on ships' properties, another SAR image is used. The image is a RADARSAT-2 multi-look-fine image, which has been acquired at September 10, 2012 at 15:25:53 UTC. The photograph was taken at same date and time by means of the joint field experiments from a high vantage point near Gelendzhik.

3. METHODS

3.1. Tracking signatures of sea surface films

The tracking of sea surface films is based on image series analysis approaches, like e.g. pattern matching and Optical Flow algorithms. As a preliminary of each approach, signatures (tracers) need to be visible on each image, which correspond to objects drifting with the sea surface current. Since we are using SAR imagery in this paper, we select the signatures of sea surface films as tracers. These anthropogenic or biogenic surface films cause a local damping of the radar backscatter and may thus be detected by image processing techniques.

In [6] we presented a unified motion estimation framework, which uses a combination of maximum-cross-correlation (MCC) and optical flow (OF) techniques embedded in a model-based multi-scale processing scheme.

For this paper, we use the developed framework to detect and track the sea surface films' signatures using an MCC approach. We further determine a global motion model for the resulting vector field and use the deviation of each vector with respect to that global motion model to determine a local current component (or: anomaly). This approach has been presented in [7] and is applied for high-resolution SAR imagery for the first time herein.

3.2. Estimating ships' properties and orientation

Another developed method for the detection and validation of sea surface currents from a single SAR image is based on the orientation of anchored ships. Those ships tend to orient along the local surface current and the near-surface wind, whose direction can therefore be determined from the ships' orientation [8].
To investigate the effect of different ship properties with respect to the orientation and the surface currents, we used an approach developed in [9]. Using this approach, it is possible to semi-automatically map geo-located photographs of the ships to the corresponding SAR signatures.

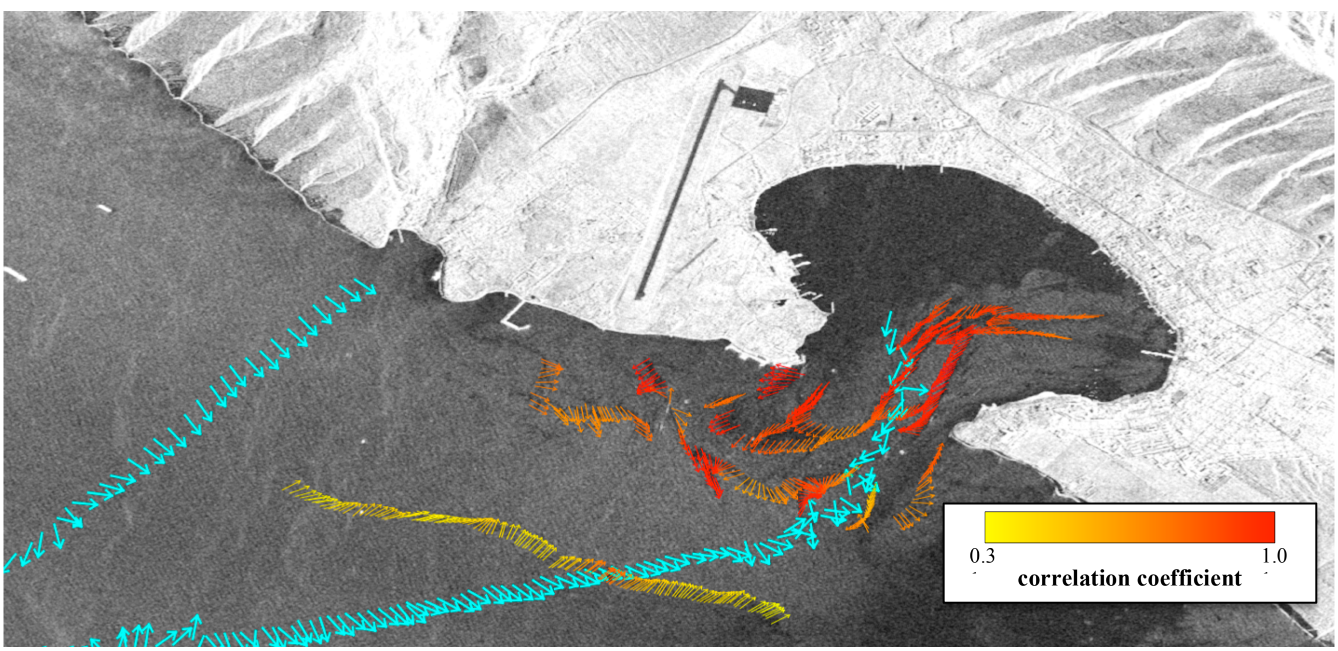

Figure 2: Comparison of the derived sea surface currents (yellow, red) with the corresponding ADCP currents (cyan) for the Bay of Gelendzhik (Black Sea) on October 11, 2011. A fast normalized cross-correlation with a smooth decision function has been used for assignment. In the background: TerraSAR-X-image (© DLR).

4. RESULTS

4.1. Sub-mesoscale tracking results

The developed tracking framework uses a combination of maximum-cross-correlation (MCC) and optical flow (OF) techniques embedded in a model-based multi-scale processing scheme. Here we present the sub-mesoscale tracking results for the Black Sea region (see Figure 1 and [4][5]). To validate the derived sea surface currents field, campaigns have been regularly carried out at the Bay of Gelendzhik. Additionally a joint field experiment has been performed in autumn 2012. During planned SAR acquisitions in that period, a yacht with an Acoustic Doppler Current Profiler (ADCP) collected reference data of surface and subsurface currents (Fig. 2).

The results in Figure 2 show a general matching between the ADCP currents and the currents derived from a pair of RADARSAT-2 and TerraSAR-X images on Oct. 11, 2011. The RADARSAT-2 image was acquired at 03:37:02 UTC, the acquisition time of the TerraSAR-X image was 03:44:07 UTC. Both images have been co-registered with a common resolution of 3×3 m^2 per pixel. The mean shift of the tracers is about 50 m, which corresponds to a mean current velocity of about 12 cm/s. Figure 2 also shows that the matching of signatures of surface films yields higher correlation coefficients in the Bay area than further offshore. The reason is that the linear surface film signature offshore has a lower contrast to the surrounding water surface.

Studies in other regions of interest have shown the existence of an eddy-like circulation as part of the tracers' local motion component [6][7]. Thus, we present the extraction of the local component for the Gelendzhik bay area, too. After unreliable results were filtered out an affine global motion model was determined by means of a least square registration approach. The local component of this motion can then be extracted by eliminating the global motion from the tracking results. Figure 3 shows a detailed view of the results of this area (left) and the extracted and over-emphasized local motion component (right). Note that, unlike the studies presented in [6] and [7], the extracted local motion component is comparably small and diffuse. However, evidence for two eddy-like turbulent features can be found, too (Fig. 3, right).

4.2. Ship co-registration

Using the approach developed in [9], it is possible to semi-automatically map geo-located photographs of the ships to the corresponding SAR signatures (Figure 4). The SAR image is a RADARSAT-2 multi-look-fine image, which has been acquired at September 10, 2012 at 15:25:53 UTC. The photograph was taken at same date and time by means of the joint field experiments from a high vantage point near Gelendzhik.

5. CONCLUSIONS

We have presented the preliminary results for the DTEddie projects by means of sub-mesoscale sea surface current derivation from SAR images and the interpretation of the results with respect to eddy detection. In addition, we presented a registration approach, which allows for a registration between photographs and SAR images of anchored ships, which may also be used as an indicator of the local sea surface current.

The developed approaches presented herein yielded valuable results for high-resolution SAR images. As a conclusion, these algorithms allow an insight into sub-mesoscale phenomena of the sea surface currents using SAR imagery for the first time.

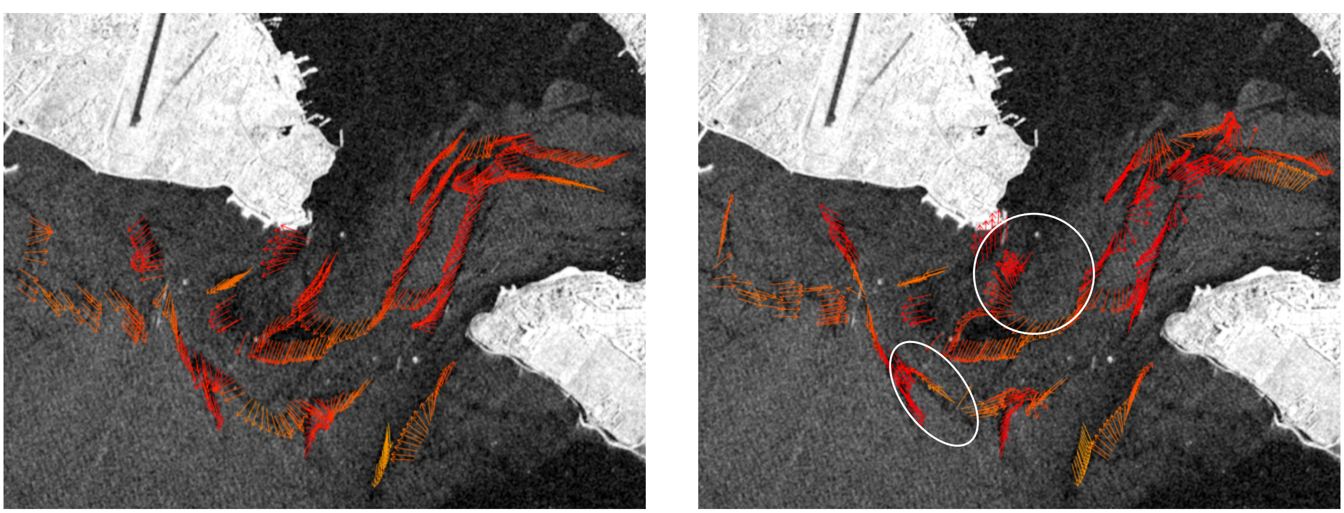

Figure 3: Analysis of the derived sea surface currents from Figure 1 for the bay area. Left: Detailed Results for the bay area. Right: Overemphasized local current component w.r.t an affine global motion model. White circles denote partial local eddy-like turbulences. In the background: TerraSAR-X-image (© DLR).

To allow for a deeper understanding and interpretation of the signatures inside the high-resolution SAR images, other collocated satellite images have been acquired and analyzed. Although those SAR images did not show eddy-like signatures, the ADCP measurements clearly revealed a large number of anti-cyclonic and cyclonic small-scale eddies [10][11]. Joint analyses of radar and ADCP data allowed detecting six internal wave packets encountered in the study region during the measurements. Their amplitudes ranged from 8 m to 12 m and the characteristic wavelength was between 90 m and 100 m. It is the use of satellite radar data of spatial resolutions as high as 3 m that made it possible to reveal surface manifestations of internal waves of such small scales [12].

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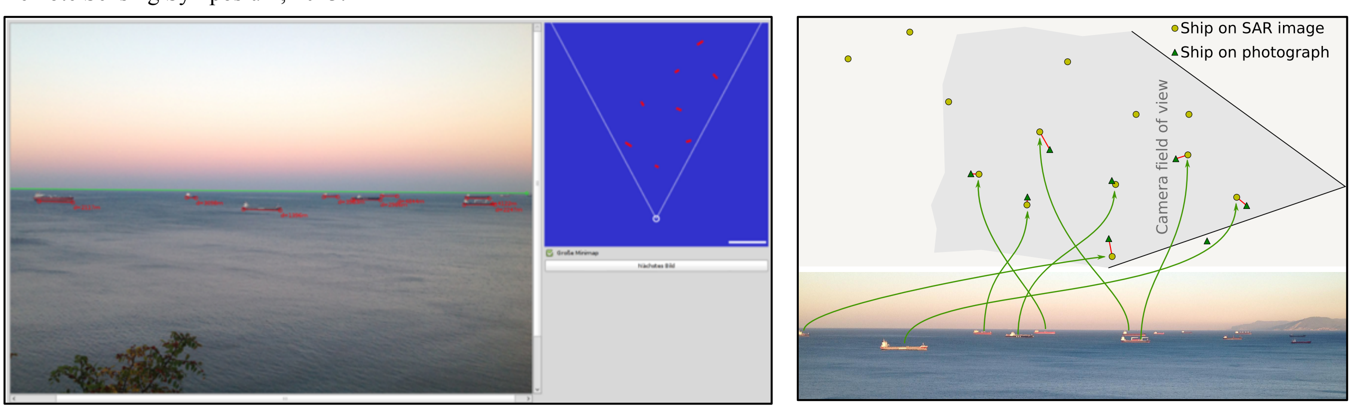

Figure 4: Left: Screenshot of the developed ship detection and semi-automatically assignment software. Right: Mapping between ships on photographs and the corresponding signatures in SAR images, which have been acquired at the same time. The result of the automatic matching is marked with red edges.