TOWARDS A TRACKING OF SMALL SCALE EDDIES USING HIGH-RESOLUTION RADARSAT-2 AND TERRASAR-X IMAGERY

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ABSTRACT

In previous work 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 or both in conjunction (1). In the frame of this effort, we will discuss the developed algorithms by means of a changing domain: from mesoscale to small-scale. Although we achieved promising results in the mesoscale domain, the extension of the approaches to the study the variability of small-scale eddies is highly challenging.

High-resolution radar data provides valuable information on the position of fronts, their origin, peaking, transition and destruction. They will be used to receive statistical and other information about their variability, to observe the formation of meanders along the fronts and their departure with the formation of vortices. Therefore, computer vision algorithms will be developed or adapted to yield results in the field of small-scale high-resolution SAR imagery, based on the approaches presented in (1). We distinguish between type, form and dynamic characteristics of the phenomena stipulated by a front and observed in its immediate proximity. Thus, jets, spiral eddies, vortical dipoles, internal waves etc. will be analyzed.

The tracking task is only one part of the project "Detection and Tracking of Small Scale Eddies Using High-Resolution RADARSAT-2 and TerraSAR-X Imagery" (DTeddie). The other task is the detection of natural surface films by means of high-resolution SAR image interpretation and complementary in-situ measurement, which will be presented in another EARSeL 2012 contribution by O. Lavrova (Russian Space Research Centre (IKI), Moscow). Inside the DTeddie project, special attention will be paid to dynamics of small-scale fronts in the Black Sea and Baltic Sea. The input of frontal instabilities in the structure formation process will be highlighted.

The DTeddie project is supported by the Canadian Space Agency CSA and the German Space Agency DLR by means of the announcement CSA-DLR-2010, project OCE0995.

INTRODUCTION

In this work, we will give a summary of the recent research in the field of current estimation by means of tracking sea surface films in SAR image sequences. Beginning at the mesoscale we put our emphasis on the challenges that become evident when using high-resolution SAR images namely from RADARSAT-2 and TerraSAR-X for the tracking of sub-mesoscale tracking.

The satellite data, which we use for tracking of signatures of sea surface films, is provided by means of the DTeddie project. The name DTeddie stands for "Detection and Tracking of Small Scale Eddies Using High-Resolution RADARSAT-2 and TerraSAR-X Imagery" and is supported by the Canadian Space Agency CSA and the German Space Agency DLR by means of the announcement CSA-DLR-2010, project OCE0995. Due to the inter-disciplinarily aim, it is a collaborative project between the University of Hamburg (Dept. of Informatics and Institute of Oceanography) and the remote sensing research group at the IKI (Russian Space Research Institute). In this work we focus on the tracking part, which is developed at the University of Hamburg.

In previous work 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). We will highlight the challenges, which occur when we extend our promising results to high resolution SAR imagery and the tracking of sub-mesoscale surface films. The region of interest is the area around Gelendzhik (Black Sea). Due to legal requirements we are only allowed to acquire RADARSAT-2 images over Russian territory, where vortical structures of surface films have been detected during past research (2).

Because of high variability in space and time, the spontaneity of their appearance, the instability and their short lifetimes, small-scale eddies are extremely difficult to study by remote sensors. Two consecutive images should e.g. have a time difference of only a few hours at most. This is far below the revisit rate of a single sensor and thus requires the use more than one satellite. Additionally, we have a need for a high geographic quality of the image data. With the high resolution data provided by RADARSAT-2 and TerraSAR-X it will be possible even to study small scale eddies with sizes of less than 1 km. Using data from both satellites we will benefit from the high spatial resolution, the multiple modes of polarization (more robust feature detection and classification) and the higher temporal resolution. Having characteristic sizes less than the Rossby deformation radius (about 18 km for the Black Sea) these vortical structures are not seen in optical or IR imagery due to the absence of thermal and optical contrasts as well as due to limited spatial resolution. Closely interrelated with the investigation of the small-scale dynamics on the sea shelf is the study of fine spatial structure of currents involved in vortical motion.

In this work we assume that there are surface films visible as linear structures of lower radar backscatter (3) and that the movement of these signatures is caused by the local sea surface current. Thus the tracking of these surface film signatures corresponds to an estimation of the local sea surface current. In (1) we have shown, that this can be used in conjunction with medium resolution images of both optical and SAR-sensors to detect mesoscale current properties. The development of the corresponding algorithms is insofar challenging, as nearly all motion detection algorithms have their origin in the research area of computer vision or video analysis. Mesoscale SAR image sequences differ from video image sequences in various manners:

- They have been acquired using different sensors.
- There is a larger temporal distance between the SAR images.
- The spatial distance between image items is larger for SAR image sequences.
- The geometric size of SAR images is larger.
- SAR images require advanced preprocessing before the tracking process.

Additionally the visibility of surface films depends on other environmental conditions like the wind speed (5) and the surface films are of a high morpho-dynamic are temporal unstable.

To cope the challenges at the mesoscale we have built a framework, which supports the decomposition of large motion into a global motion model and small motion deviations from that model and introduced a fast normalized cross-correlation technique into the field of sea surface film tracking (1). We also adapted differential methods, like e.g. the approach of Horn & Schunck (4) into the framework and achieved promising results at the measurement of mesoscale currents.

METHODS

The step from medium resolution to high-resolution SAR images for tracking signatures at the sea surface requires a re-investigation of the previously developed tracking algorithms. In order to perform the task of tracking objects on the sea surface successfully, we need to preprocess the images of the image series. We therefore developed a semi-automatic preprocessing chain, which is based on the Python programming language (5) and the GDAL-python interface (6). Both are open source and can be used collaboratively by the project partners (see Figure 1).

Beginning with the satellite raw data (Level-1 products), the sensor normalization to beta- and sigma-naught values of the normalized Radar cross-section (NRCS) is performed. If needed, advanced speckle-filters can be applied to the images. For this work, we have chosen the Gamma-MAP (maximum a posteriori) Filter for speckle suppression (5). After filtering and sensor normalization the orthorectification is done automatically, and the images have to be manually co-registered, because of the geometric error of the high-resolution images. If the error is about 10m per scene, which is quite a high accuracy, the displacement of a pixel at a resolution of 1m can be up to 10 pixels. This has to be corrected from scene to scene by hand. On the other hand, the manual registration of images using already orthorectified images does not take too much time for a few control points, which seems to be a good compromise between speed and accuracy.

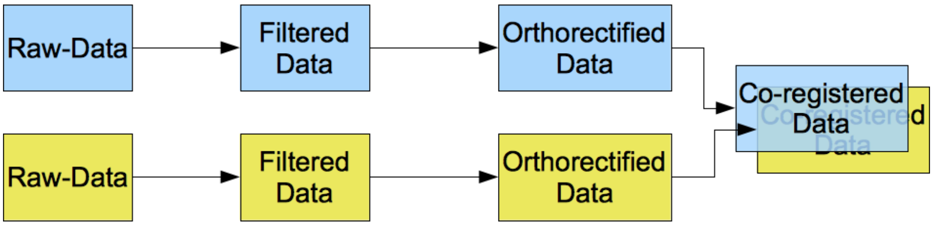

Figure 1: The developed generic pre-processing chain: According to different sensors, an individual filtering (sensor normalization) is done. Using the geometry metadata the images are automatically orthorectified. The last step, the co-registration has to be done manually. Previews are automatically generated at each step of the process chain.

When using high-resolution images, new challenges arise below the mesoscale as these kinds of images have different spatial but nearly the same temporal resolution. It is also mainly unknown, if the different imaging properties of high resolution SAR results in different signatures of sea surface films. As the RADARSAT-2 uses the C-Band and the TerraSAR-X uses the X-Band, we also might expect different general imaging properties as well. Another challenge is the successful data acquisition for strongly requested platforms like TerraSAR-X and RADARSAT-2. Figure 2 shows a plot of the differences between video analysis, mesoscale and sub-mesoscale motion estimation by means of spatial coverage and temporal distances.

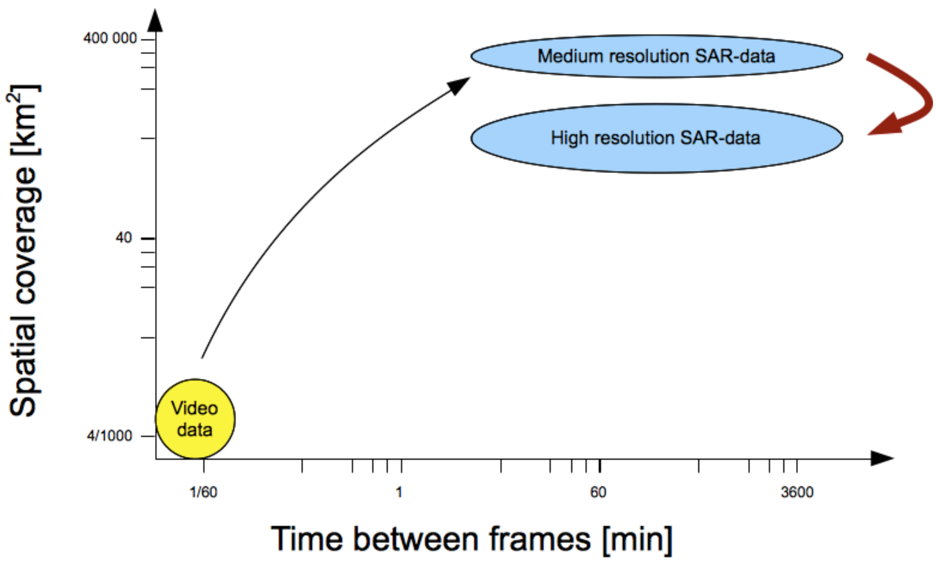

Figure 2: The challenge of tracking as presented in this work. Although the transfer of the algorithms from video analysis to medium resolution imagery is highly challenging, the use of high-resolution SAR-data still requires a huge amount of additional research.

As a first approach to determine the sea surface currents from high-resolution SAR images, we apply the fast normalized cross-correlation technique (NCC) to match patches around equally distributed features of the first image with signatures inside the second image of the series. The NCC of an image I with a mask m is defined as

$$\gamma(u,v) = \frac{\sum_{x,y}(I(x,y) - \overline{I_{u,v}})(m(x-u,y-v) - \overline{m})}{\sqrt{\sum_{x,y}(I(x,y) - \overline{I_{u,v}})^2}\sqrt{\sum_{x,y}(m(x-u,y-v) - \overline{m})^2}}$$

where $\overline{I_{u,v}}$ denotes the mean intensity of image area under the mask at position (u,v) and $\overline{m}$ is the mean intensity of the mask. The nominator of this term, the un-normalized cross-correlation can be computed much faster when performed in Fourier-space using the correlation theorem:

$$\sum_{x,y}(I(x,y) - \overline{I_{u,v}})(m(x-u,y-v) - \overline{m}) = FT^{-1}\left(FT(I') \cdot conj\left(FT(m')\right)\right)$$

Replacing the (inverse) Fourier Transform by a discrete (inverse) Fast Fourier Transform (FFT), we achieve much shorter computation time. The right part of the denominator is constant, as it only takes the mask into account and can thus be pre-computed. To speed up the computation of the left part of the denominator, Lewis proposes the use of sum tables for both $\overline{I_{u,v}}$ and $\overline{I_{u,v}}^2$ (6). These tables have to be set up once, but allow constant random access in the latter computation of the NCC.

A fast comparison algorithm is essential for the large distances between imaged signatures in high-resolution SAR imagery. Both the time difference increases and the high-resolution of the images yield to larger search spaces. Figure 3 shows a comparison of the NCC and the fast NCC algorithms, when using the FFTW library to perform the discrete FFT (7).

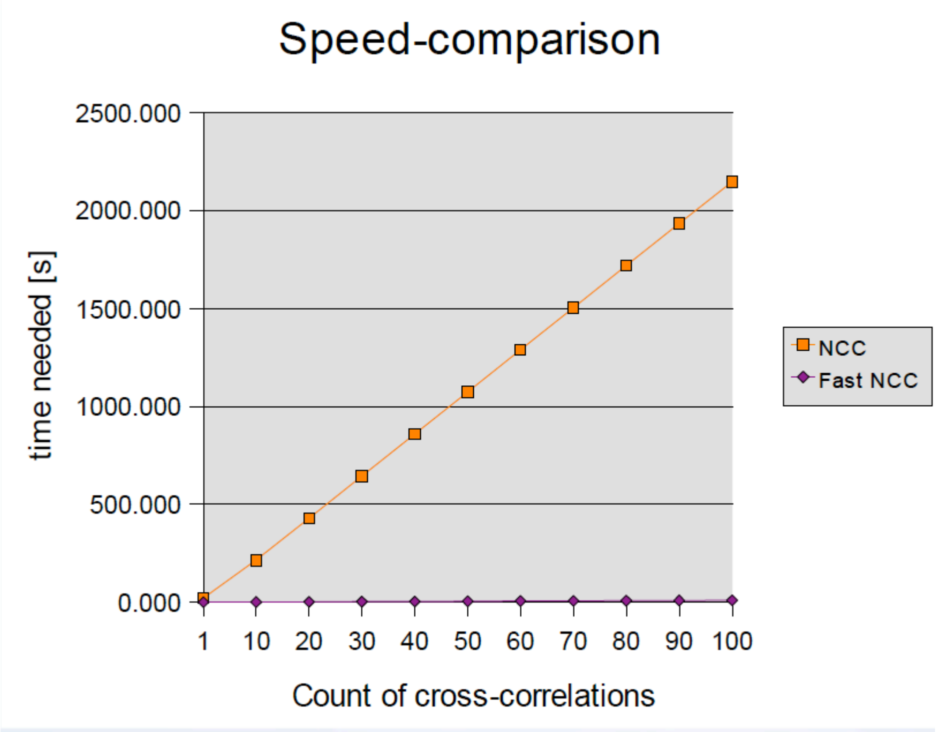

Figure 3: Runtime measurements of the Fast NCC and the NCC algorithm. The image size is 200x200 pixels, the mask size is 61x61 pixels. The results have been computed on a standard

single core desktop computer with a 2.5GHz processor. Using the fast NCC, it took about 10 seconds for 100 different cross-correlation compared to over 2000 seconds for the basic approach.

RESULTS

For the tracking presented herein, we use a pair of RADARSAT-2 and TerraSAR-X images, which have been acquired in October 2011 at the area of Gelendzhik (Black Sea). Further information can be found in table 1.

Table 1: Overview of the image characteristics of the high-resolution SAR scene acquisitions used in this study.

Satellite	Date & Time	Image Mode	Polarization	Resolution [m]
RADARSAT-2	2011-10-11 03:37 UTC	Single Look Complex	VV	3
TerraSAR-X	2011-10-11 03:44 UTC	Strip Map Mode	HH	3

Unfortunately, the images do not show any eddy-like signatures but some linear structures located near the bay of Gelendzhik. These signatures remain stable during the 7-minute time offset between both acquisitions. As an example, the RADARSAT-2 scene is shown in figure 4.

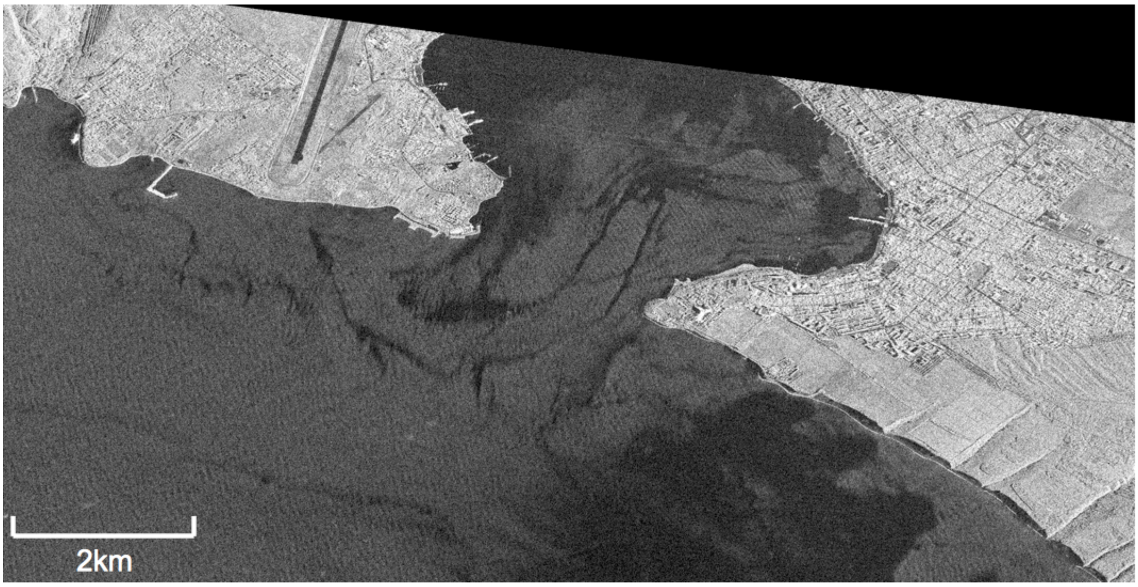

Figure 4: A subset of the ortho-rectified and co-registered RADARSAT-2 scene. There are some surface films near the bay of Gelendzhik at the scene center and some wastewater plume signatures located in the lower right area.

After the orthorectification and following manual co-registration, we applied a Gamma-MAP filter to both images with a filter size of 11x11 pixels. These filter size was large enough to suppress most of the speckle without eliminating important features of the sea surface film signatures. After the pre-processing, we mask the land areas out before 200x100 features are equally distributed on the first image. Each feature is described by its surrounding 61x61 pixels (30 in either direction).

Each feature is matched using the fast NCC in the second image with respect to a maximal distance of 100 pixels. Thus, 20,000 fast NCCs have to be performed. After the NCC, we have selected the value of maximum correlation. In figure 5 all corresponding matches with a correlation coefficient above 0.6 are shown. It is remarkable that only correlations near or beside surface films remain visible above the chosen threshold of correlation coefficient. There are however some drawbacks, as the borderline of a waste plume is also yielding highly correlated vectors, which do not depend on the sea surface current.

During the SAR acquisition, the research team at IKI has performed an in-situ measurement of the currents at the area of Gelendzhik using a Doppler-based instrument (ADCP) on a research vessel. Although the results of this measurement not yet available at a high resolution for this work, it seems, that they show quite a good agreement with the computed sea surface currents.

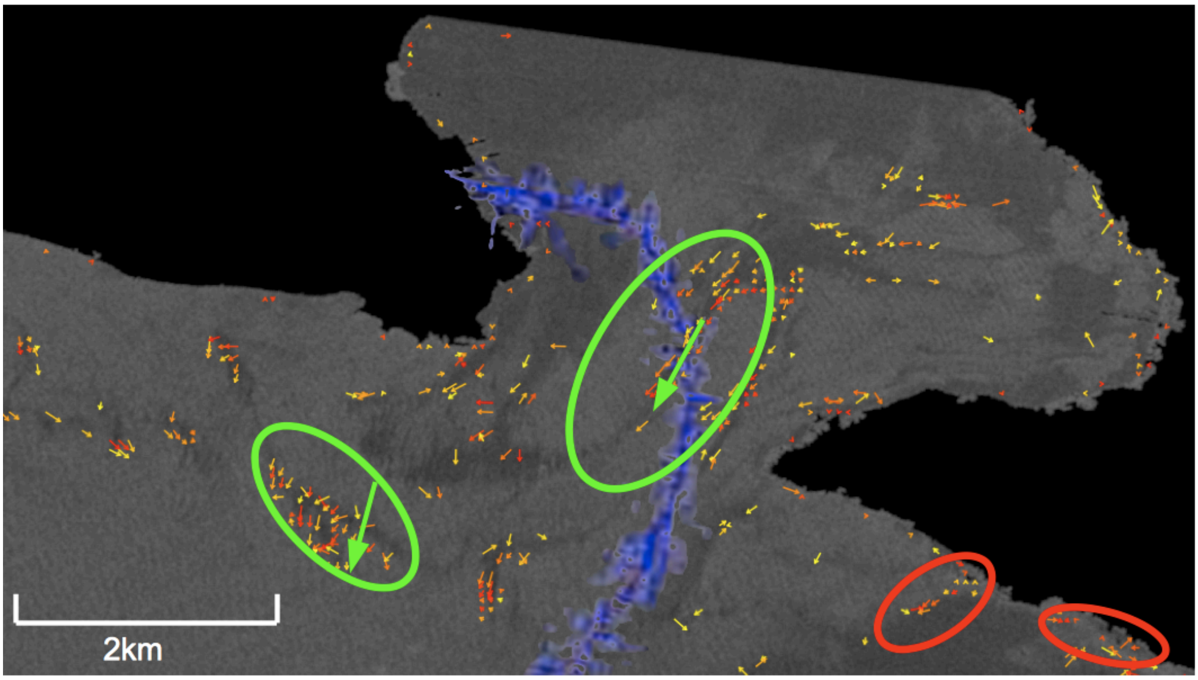

Figure 5: A subset of the ortho-rectified and co-registered RADARSAT-2 scene with overlays. Color coded arrows of the correlation coefficient (yellow: 0.5 to red: 1.0) denote matching results of the fast NCC, blue arrows represent the in-situ measurement of the sea surface current carried out by researchers of IKI.

CONCLUSIONS

The quality of the first derived measurements on sea surface currents by means of high-resolution SAR data is promising, but not competitive compared with the results we achieved at the mesoscale (1). However, the existence of homogeneous flow pattern and the good correspondence to the in-situ measurements shows, that we are on the right way towards sub-mesoscale tracking. For the future, we are planning to adapt the feature-based approaches as well as the differential approach of motion measurement to the study of sub-mesoscale sea surface current measurement.

One important contribution to reach a level of higher tracking quality is also part of the DTeddie project although it is not part of this work: The detection of eddies and surface film signatures in general based on high-resolution SAR imagery. Progress in this research filed may eliminate outliers with high correlation values, like the signatures of surface films, which are caused by wastewater plumes.

Another mentionable aspect is that we have yet not been able to acquire high-resolution SAR data of the Black Sea ROI showing signatures of eddies. But we are looking forward to June and September 2012, where we have planned the next data acquisitions in conjunction with collaborative in-situ measurements.

ACKNOWLEDGEMENTS

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