THE USE OF SPATIAL CONSTRAINTS IN THE DERIVATION OF MESOSCALE SEA SURFACE CURRENT FIELDS FROM MULTI-SENSOR SATELLITE DATA

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INTRODUCTION

Mesoscale dynamic sea surface features, such as eddies, fronts, or dipoles, are of key importance for our understanding of local dynamics of the marine coastal environment. However, they are often not fully resolved by numerical models currently in use. Series of satellite images (with resolutions ranging from a few meters to hundreds of meters), acquired within a short time period (from less than an hour to a day), can be used to close this gap, if the spatial and temporal extent of those dynamic surface features fits to the spatial and temporal resolution of the sensors and of the data acquisitions, respectively. Moreover, current tracers that are detectable by all applied sensors, need to be present during the whole time of image acquisitions.

In this paper, we present the use of spatial constraints in algorithms for the derivation of mesoscale sea surface currents using multi-sensor / multi-channel satellite images. In order to show example results of the methods we have selected satellite data from different sensors imaging the Baltic Sea and the North Sea. In addition, we compare our results quantitatively with the sea surface currents that have been derived from numerical models.

SATELLITE DATA

The images were acquired by the Thematic Mapper (TM), the ERS-2 Synthetic Aperture Radar (SAR) and the Sea Viewing Wide Field-of-view Sensor (SeaWiFS) during extensive summer algae (cyanobacterial) blooms in July 1997 (Northern Baltic Proper), in August 1999 (Southern Baltic Proper), after an oil spillage in May 2005 by the Envisat Advanced SAR (north of the Bay of Gdansk), and during an algae bloom in May 2008 in the North Sea. Both natural and man-made surface films affect the sea surface and thus are visible on satellite imagery [4,5,12]

IMAGE ANALYSIS USING SPATIAL CONSTRAINTS

In [13] we have already shown that data from sensors working at different electromagnetic frequency bands (e.g., TM and SAR) can be used to apply high-speed feature-matching (cross-correlation) techniques for motion detection [8]. The drawback of these locally applied feature-matching algorithms, however, is that they do not take into account the smoothness of motion within some spatial neighborhood. In order to overcome this drawback we have embedded this constraint into the results of the feature-matching methods through the application of relaxation techniques after the computation of sea surface currents by local methods [2, 11].

The application of this technique leads to a maximization of the 'global' (i.e., underlying) smoothness inside a given neighborhood. Therefore, alterative motion targets have to be estimated a priori. This approach is very different from general vector field smoothing operations (e.g., the replacement of each motion vector by the average motion vectors in some spatial neighborhood), since only the relaxation techniques provide valid alternative motion targets for each vector. After the application of the relaxation our results are compared with the numerical model results of the sea surface currents provided by local agencies [3,7]. It has to be mentioned that this vector field comparison is not trivial, because of the different spatio-temporal and (water-) depth resolution of the derived and the model currents [10,14].

Moreover, in other cases, best results are obtained through the calculation of the Optical Flow between subsequent images acquired by the same sensor (e.g. SeaWiFS) [13]. These Optical Flow algorithms are implicitly based on the assumption that the Optical Flow (motion) is smooth within a certain spatial neighborhood [6]. However, several approaches exist that are based on different models for spatial smoothness. We show that the Lucas-Kanade algorithm [1,9] can be transformed into the Structure Tensor approach by changing the neighborhood smoothness constraint. Again, we compare the results of these two algorithms with the numerical model results provided by local agencies.

CONCLUSIONS

We demonstrate that the addition, or the change, of spatial constraints in the presented algorithms lead to promising results of the derivation of sea surface currents from satellite data. A great improvement results from the use of relaxation techniques as a post-processing step after the derivation of currents using feature-matching methods. As an example, Figure 1 shows sea surface currents (yellow arrows) derived using a pair of ERS SAR and Landsat TM images. Regions of main improvement are highlighted by blue circles: in those areas calculation errors such as crossing vectors (arrows) in the left Panel are corrected in the relaxed vector field in the right Panel. Our results (left Panel) represent the local smoothness much better, without reducing the correlation factor for each (local) motion.

Finally, the Structure Tensor approach leads to more realistic results than the Lucas-Kanade method, when applied for the derivation of sea surface currents. This is caused by the different spatial relationship model, which is used by the Structure Tensor approach.

Our results clearly show that satellite images may be used to derive mesoscale sea surface currents, but also that special attention has to be paid to the very kind of algorithm used. We also note that sea surface features visible on the used satellite imagery must be present, in order to allow for successful surface current derivation. Any kind (i.e., biogenic or anthropogenic) sea surface films are well suited in this respect.

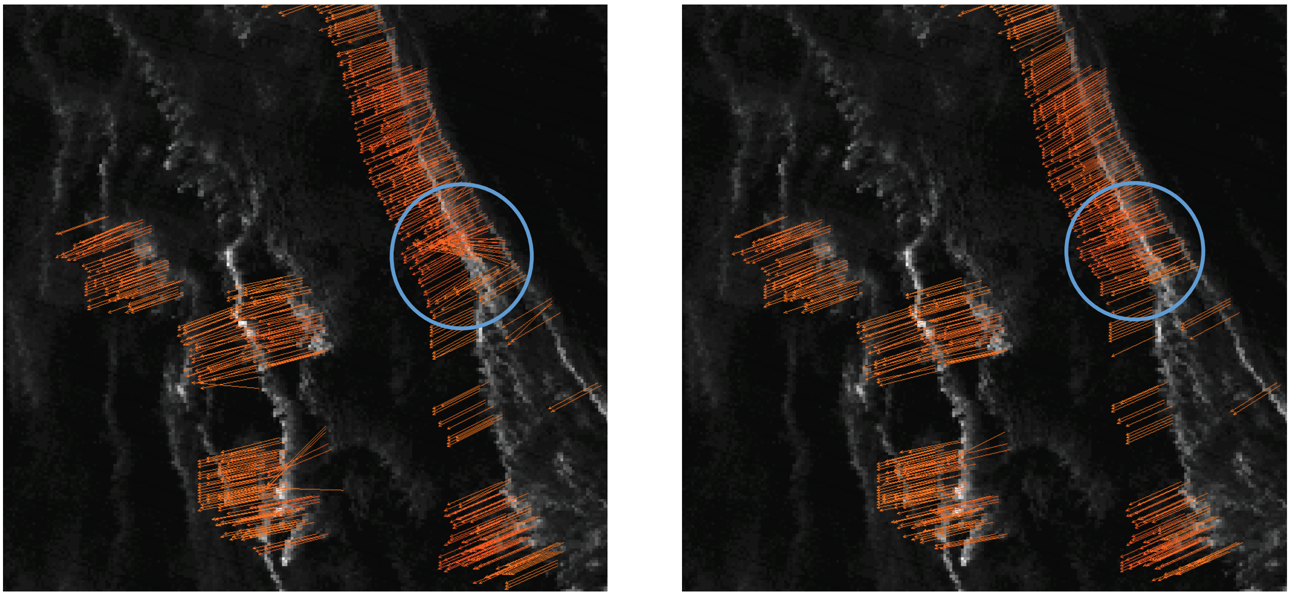

Figure 1: The application of a relaxation algorithm on sea surface currents derived using a correlation approach on a Thematic Mapper (TM) (background image) and a Synthetic Aperture Radar (SAR) image. Left: The result of the normalized maximum cross correlation (MCC) feature-matching method. Right: The same result, but after the application of a relaxation algorithm. Motion vectors with a cross correlation lower than 0.60 are not displayed.

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