Deriving Mesoscale Surface Current Fields from Multi-Sensor Satellite Data

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Abstract – Sequential multi-sensor satellite images from Envisat ASAR and WiFS are used for the computation of mesoscale surface currents in the Northern and Southern Baltic Proper. Different marine surface films and accumulated algae at the water surface are imaged by the sensors working in the optical, infrared, and microwave part of the electromagnetic spectrum and can thus be used as tracers for the local motion of the sea surface. Taking advantage of the sufficiently short time lags between the multiple image acquisitions (from less than one hour to one day) and of the high spatial coverage we calculated surface motion fields by enhancing and combining image-processing techniques. In some cases, data from sensors working at different electromagnetic bands (e.g., Landsat TM and SAR) can be used to apply high-speed feature-matching (cross-correlation) techniques for motion detection. Our computed two-dimensional surface current fields are compared with, and they complement, existing data from numerical models.

Keywords: multi-sensor, surface currents, optical flow.

1. INTRODUCTION

Remote sensing data from satellite-borne sensors working at the same or different electromagnetic frequencies can be used to derive ocean current fields, if the same features are visible in the different data sets and if the data were acquired within a certain time period, which depends on the lifetime of the observed features, on the current speed, and on the sensors' spatial resolution. These features may be driven by the local surface motion, and the correlation of the two-dimensional data sets may therefore allow for the calculation of mesoscale ocean current fields.

While several studies have been performed on the use of single sensor types (i.e. either optical or radar) for the calculation of surface motion, the combined use of those sensors for sea surface current estimates has not sufficiently been demonstrated so far. Marine surface films are well suited for such kind of data analyses, because they may change both the sea surface roughness and its emissivity of electromagnetic waves (Gade *et al.* 2003, and literature cited therein), and may thus be visible on both optical and radar imagery.

Depending on the sensors' imaging characteristics and of the amount of available data we have applied different methods: a fast normalized cross-correlation analysis was performed with single-channel data from different sensors (working at different electromagnetic frequencies). A differential method based on the Gradient (or Optical Flow) Constraint Equation (Horn and Schunck, 1981) was used for series of multi-channel data acquired at the same electromagnetic bands and within a short period of time. In this paper, we present examples for each of the methods.

2. RESULTS

Series of satellite images showing imprints of singular sea surface features may be used to derive local surface currents through a maximum cross correlation (MCC) analysis. We have used a pair of ENVISAT ASAR Wide Swath-Mode images acquired on May 15, 2005 over the south-eastern Baltic Sea (Fig. 1) at 09:00 UTC and 20:25 UTC. The white rectangle inserted into Fig. 1 denotes the 82.5 km × 60 km area, where two oil spills have been detected in both images as dark irregular patches.

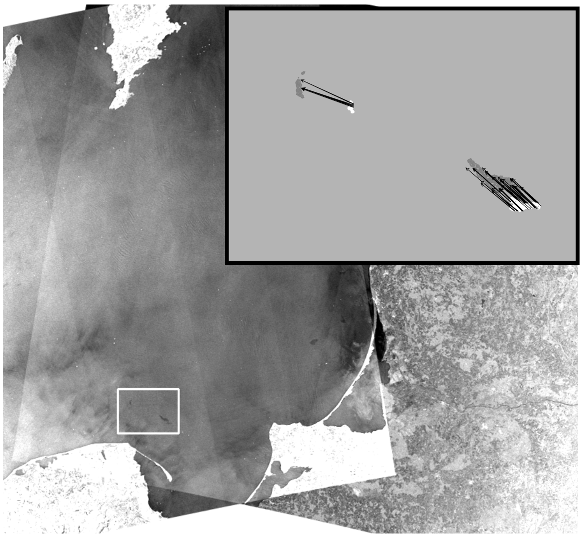

Figure 1. Composite of two ASAR images of the southeastern Baltic Sea acquired on May 15, 2005. The white square north of the Bay of Gdansk denotes the (82.5 km × 60 km) part of the images used for the correlation analysis, whose results are inserted on the upper right.

After the feature detection in the first SAR image we calculated the two-dimensional cross-correlation of the surrounding 50 pixels × 50 pixels area of each detected feature point and the corresponding, but larger (230 pixels × 230 pixels) part of the second SAR image. The local maximum of this correlation was used to determine the surface motion vectors. Our results are inserted in Fig. 1. The white patches in the background origin from the ASAR image acquired at 09:00 UTC, whereas the dark grey patches origin from ASAR image acquired at 20:25 UTC. The arrows are mostly parallel and denote a mean surface speed between 17 cm/s and 28 cm/s.

Our results are in good agreement with modeled currents obtained with the HIROMB model run at SMHI (Fig. 2). In both cases a drift towards north-west was derived. Moreover, according to HIROMB the drift of the north-western spill should be (slightly) larger, which was confirmed by our analysis.

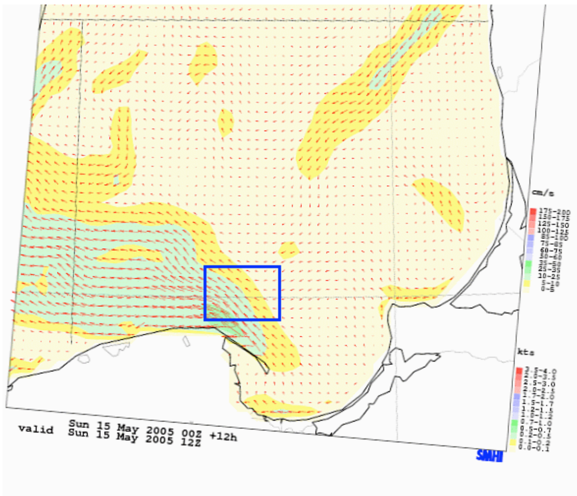

Figure 2. Modeled sea surface currents on May 15, 2005, in the Southern Baltic Proper. Results were obtained with the HIROMB model run at SMHI. The blue square denotes the areas, in which the oil spills were detected (Fig. 1).

The composite of the two WiFS images acquired on July 30, 1999, at 10:03 UTC and 10:39 UTC, and showing imprints of cyanobacteria surface accumulations, is shown in Fig. 3. From both acquisitions band 1 was used for our analyses, whose results are inserted on the upper right of Fig. 3. In the shaded areas (where the algae caused pronounced signatures) we calculated realistic surface currents of about 25 cm/s - 35 cm/s.

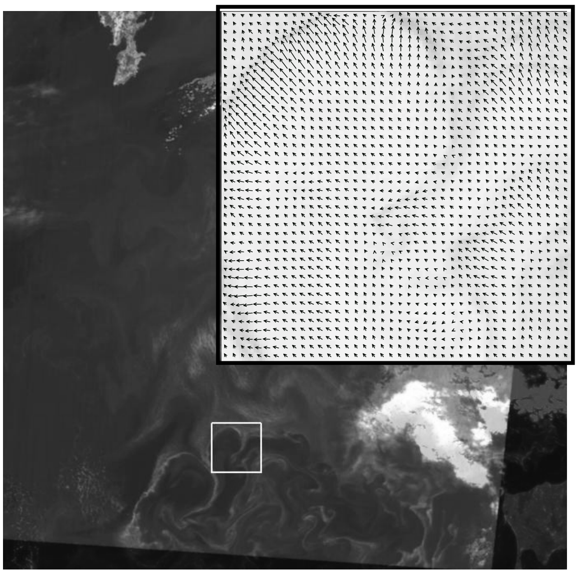

Figure 3. Composite of two WiFS images of the Southern Baltic Proper from July 30, 1999. Gotland's southern tip is visible in the upper left part. The white square denotes the (22.5 km × 22.5 km) subsection used for the differential analysis, whose results are inserted on the upper right.

The corresponding model results from the BSHcmod are shown in Fig. 4. Whereas our results show a general surface motion towards north (note that Fig. 3 is not georeferenced), the BSHcmod predicted a mean current of the uppermost 8 m layer towards south-east. At the time of image acquisitions a moderate wind of 5 m/s from the south was measured on Hel Peninsula (Poland), which apparently forced a northbound surface motion in the area of interest. Apparently this motion can be detected using sequential satellite imagery, whereas it may not be strong enough to influence the mean current in the uppermost sea layer.

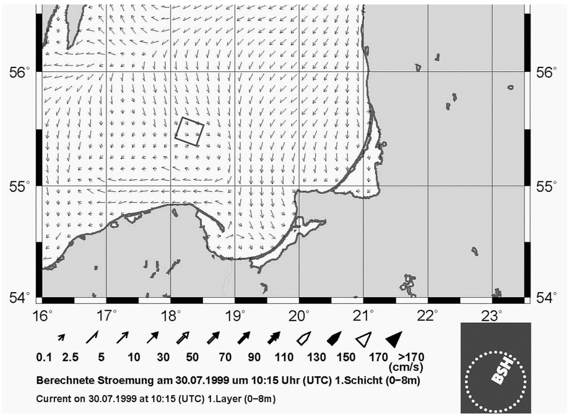

Figure 4. Modeled sea surface currents on July 30, 1999, in the Southern Baltic Proper. Results were obtained with the BSH current model. The inserted square denotes the location of the area, for which surface motions were calculated from satellite images (Fig. 3).

3. CONCLUSIONS

We have demonstrated that multi-sensor satellite data can be used to compute small-scale pixel motions, if accumulated algae or oil spills are present on the water surface. The two methods applied for this study are a cross-correlation analysis and a differential method based on the Optical Flow algorithm of Horn and Schunck (1981). Because of the different sensor characteristics, the first method was applied using high-resolution imagery (30 m pixel size), whereas the latter was applied using lower resolution imagery (188 m and 1.1 km pixel sizes). Both methods, however, are not restricted to certain pixel sizes.

Resulting surface current fields, like those presented in this paper, may complement model results provided by local hydrographic agencies, particularly since their results were calculated for a mean water depth of some meters and on a much coarser grid (e.g., 4 m depth and a 5’ × 6’ grid, respectively, see the available data from the SMHI). The use of satellite data, as shown herein, may therefore be a valuable addition to the existing model data.

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