Estimation of instantaneous stream-functions in the ocean from SST images

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Abstract

We present a new method for the estimation of surface currents from satellite images. This method is based on the multifractal singularity extraction technique, the Maximum Singular Stream-function Method (MSSM), which provides an approximation to the stream-function from experimental data in 2D turbulent systems. The essence of MSSM relies on statistical and geometrical properties associated to the energy cascade in flows; due to that association, the method provides an instantaneous velocity field and thus it does not require a sequence of images to evaluate velocities. The technique can be applied to images of different tracers; as an application, we show the results on AVHRR SST images.

Keywords: singularity analysis, surface velocities, sea surface temperature.

1. Introduction

A key problem in operational oceanography is to have a good estimation of the velocity field in real time. In situ data are often sparse and not synoptic which makes the use of oceanographic satellites almost essential. However, the estimation of surface velocities from satellite data is far from been trivial. In principle, the simplest way is to apply the geostrophic approximation to altimetric measurements. Unfortunately, these measurements only allow to estimate one of the velocity components. To retrieve the complete 2D field some kind of interpolation is required (Le Traon et al. 1998). An attractive alternative is to try to estimate surface velocities from Sea Surface Temperature (SST) images. In the past years some techniques, such as the maximum cross-correlation method (MCC) have been developed with this objectives (e.g. Bowen et al. 2002). However, this method has three main drawbacks, the final resolution of the velocity field is lower than the original, it needs a sequence of images and a very fine tuning. An alternative method that potentially can overcome these problems is the Maximum Singularity Stream Function Method (MSSM) that has been succesfuly applied to low (9 km) and median (4 km) spatial resolution SST images (Turiel et al. 2005 and Isern-Fontanet et al. 2005). In this paper we show the results of the method when applied to high resolution (1 km) SST images.

2. The Maximum Singularity Stream-Function Method

This method can be decomposed into three steps (Turiel et al. 2005):

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Step 1 Singularity analysis: Let *s(**x**)* be a multifractal signal in a planar flow(AVHRR SST in our case). It will be assumed that *s(**x**)* is mainly advected by the flow, but not necessarily conserved (even more, difussive and/or reactive effects may be important). What is characteristic to multifractal signals is local power-law scaling. Such scaling is assessed using wavelet projections of | *s(**x**)*| over an appropriate wavelet function , at each location ***x*** and variable scales *r* (what will be denoted by *T (**x**,r)*). Then, the signal *s* will be multifractal if and only if

$$T\,(\mathbf{x},r) \quad r^{h(x)}$$

Then, at each point ***x*** is assigned a singularity exponent *h(**x**).*

Step 2 Main streamlines identification: Once every point ***x*** is assigned a singularity exponent *h(**x**)*, it is possible to decompose the signal into different patterns (the fractal components). Then, we assume that the Most Singular Manifold (MSM), given by

$$h \quad \{h(\mathbf{x}) \mid h(x) < h_0\},$$

where h_0 is a given threshold value (h_0=0), represents streamlines. Thus we impose that velocities over this set (v) have to be parallel to the MSM. *As a first guess* we take the modulus equal to 1 and the same sign as *s(**x**).*

Step 3 Stream-function reconstruction: The Most Singular Stream-function is reconstructed using only the velocities over the MSM (v') through the convolution

$$= \boldsymbol{g}*(\boldsymbol{e}_z \; v'), \qquad T_F(\boldsymbol{g})=i\boldsymbol{k}/k^2$$

Where $T_F(\boldsymbol{g})$ is the Fourier expression of the vectorial kernel ***g***. This algorithm has been experimentally validated in different instances as image-processing (Turiel et al. 2002) and analysis of meteorological images (Grazzini et al. 2002), exhibiting a high performance.

3. Results and discussion

Figure 1 shows the original AVHRR SST image captured directly from the NOAA satellites, the MSM and the resulting stream-function (the MSS) for two images of an Algerian eddy. First it is important to notice that although in this figure we show a sequence, the MSS is computed from a single image. On the other hand, it is also important to realize that the final resolution is the same as the original image and in principle only one parameter has to be selected (h_0). As it is evident from the figure, the MSM outlines some of the streamlines of the flow. However, due to sensor limitations and numerical errors these streamlines may brake into pieces (Turiel et al. 2005). Another aspect of the MSM is that they are relatively thick lines. In theory, the MSM should have been obtained as the set with a singularity exponent equal to the most singular exponent instead of applying a threshold value to get it but inhomogeneities of the flow makes necessary the definition here used.

The stream-function has been constructed using only the information contained on the MSM and using the non-dimensional velocity defined previously (v'). Previous studies (Turiel et al. 2005 and Isern-Fontanet et al. 2005) have demonstrated that when compared with altimetry the MSM provides a better estimation of the stream-function than the SST. Unfortunately, since it is a geometrical method it is only able to identify some streamlines but not the sense and intensity of the velocities over these stream-lines. This produces an indetermination in the stream-function that has to be solved using independent data such as altimetric measurements (Isern-Fontanet et al. 2005).

Although some limitations, the problem of the estimation of velocity modulus and sense this method has proven to be very robust and with an enormous potential for operational oceanography. In previous studies it has been shown that for global-scale velocity fields a good choice for solving the indetermination of the method is using altimetry. On the other hand, for coastal and regional observing systems two strategies are possible. First, since the region is constrained, empirical models could be developed for the estimation of the velocity. Second, it could be combined with in situ measurements such as moored currentmeters.

Figure 1: From top to bottom: SST image of an Algerian eddy (western Mediterranean sea), spatial distribution of the Most Singular Manifold (h, *MSM*) and the Maximum Singular Stream-function (, MSS). These images corresponds to August 4 2003 (NOAA-16 satellite) and August 7 2003 (NOAA-15 satellite).

Acknowledgements

This work is a contribution to the EU MERSEA project (AIP3-CT-2003-502885) and has also been partially supported by the MCyT project ESEOO (VEM2003-20577). A. Turiel is funded by a Ramon y Cajal fellowship from the Spanish Ministry of Education. The AVHRR SST images have been downloaded from http://ers.cmima.csic.es/saidin/ using the SAIDIN utility built with fundings from the EU MAMA project (EVR1-CT-2001-20010).

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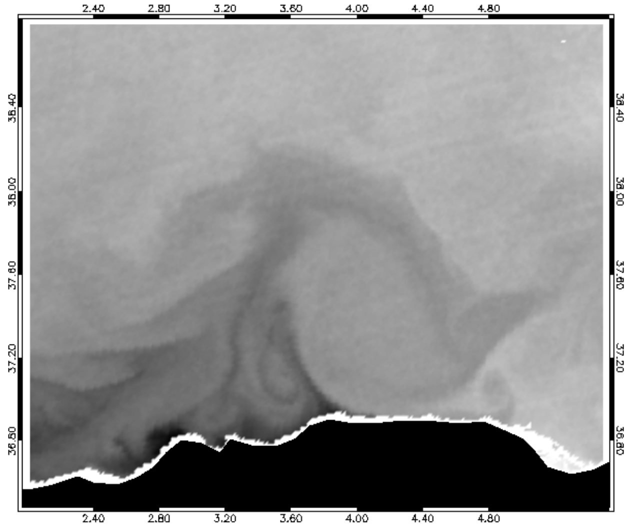
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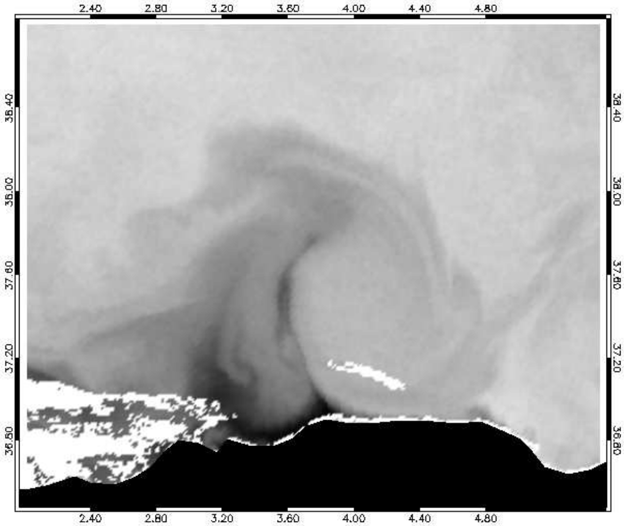
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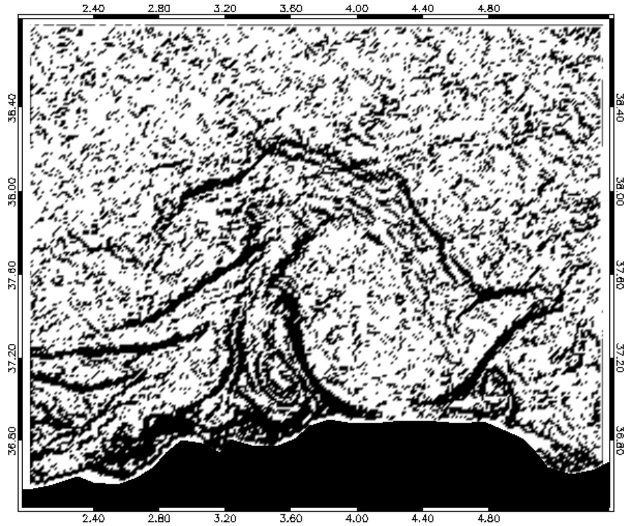
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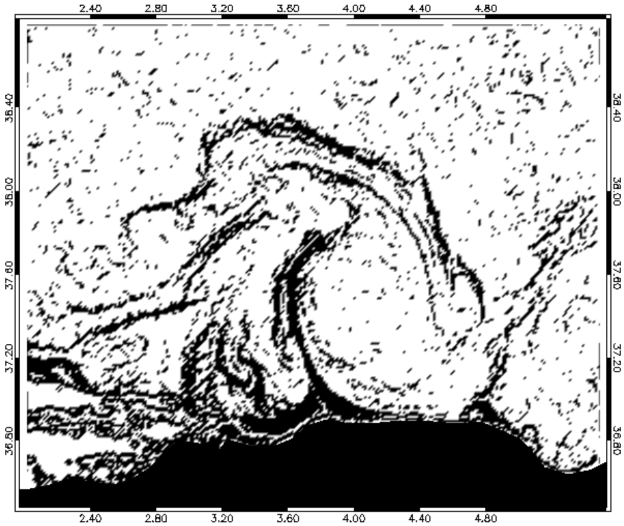
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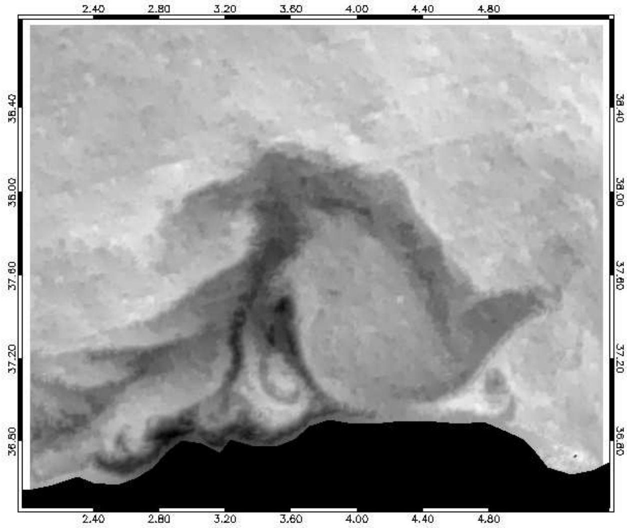
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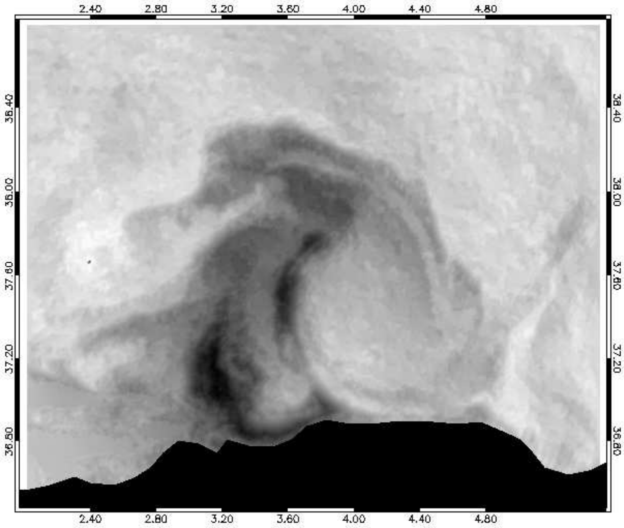
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