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Automatic identification of oceanic eddies in infrared satellite images

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ABSTRACT

Oceanic eddies have a large impact on climate and human activities; consequently, it is worthwhile to characterise them. One of their main features is size; however, it is a difficult task to obtain user-independent estimates of this feature from brightness temperature maps for eddies near the Iberian Peninsula. The reason is that the current methods in the scientific literature are unable to handle the variability in the shape and size of these eddies as well as the weak temperature gradients associated with them, especially those found off Iberia or those methods employ user-defined values that influence the estimate of the eddies' sizes. Our new method solves these problems using orientation fields and clustering methods. Its outcome is an ellipse that characterizes the size of the eddies with good precision.

1. Introduction

Oceanic eddies, which are mesoscale water structures exhibiting rotating flow patterns (Paillet, 1999), have an impact on the global climate (Garabato et al., 2007), on air–sea fluxes of heat and gases (Vecchi et al., 2004), on acoustic wave propagation (Jian et al., 2009), on surfactant slick spread (Schuler et al., 2004), on plankton dynamics (Smith et al., 1996), and even on oil rig tow, owing to water drag (Horizon Marine Inc., 2009). Therefore, the study of this phenomenon is very important. Recently, it has been shown that satellite images, namely brightness temperature maps, are a good tool for studying mesoscale eddies due to their spatial and time resolution (Oliveira et al., 2000). Satellites from the National Oceanographic and Atmospheric Agency (NOAA) equipped with an Advanced Very High Resolution Radiometer (AVHRR) are able to provide brightness temperature maps from approximately the same geographic zone every 6 h, when the cloud coverage allows it. These brightness temperature maps contain important information regarding the mesoscale phenomena and are known to be less noisy than sea surface temperature maps (Oliveira et al., 2000; Torres et al., 2003). For this reason, we use brightness temperature maps in the present study.

The quantitative characterization of mesoscale eddies by human analysts should be avoided because it is not reproducible owing to the subjective interpretation of the images. Consequently, the aim of this paper is to present a new method that allows us to determine algorithmically the size of eddies. The method is able to calculate an optimal value for the radius of a circle that surrounds the eddy. Consequently, the value for this radius is adjusted to each eddy, which is important in our case because eddies have a large range of sizes. When we tried to use the same initial estimate of the radius value for all eddies, setting the value equal to the eddies' maximum expected radius, the final radius values calculated for eddies of different sizes tended to be similar and to have values close to the one we set initially. This finding explains why we cannot use methods published in the scientific literature where the user chooses values for the maximum sizes of the eddies. Previous works where this value is not set by a user are available (Thonet et al., 1995; Yang et al., 2001; Chaudhuri et al., 2004), but they cannot be employed in our case because they cannot handle the weak temperature gradients and the structure variability of the eddies off the Iberian Peninsula.

Our method defines the optimum radius of the eddies and finds its core by applying clustering algorithms in an innovative way. Then it determines an ellipse that accurately fits the eddies' borders, by fitting the points within the optimum radius whose flow orientations are closest to those of an elliptical flow. Various works in the scientific literature are capable of determining an outline for eddies, but they are incapable of finding the optimal

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value of the radius of the eddies (Peckinpaugh and Holyer, 1994; Ji et al., 1999; Alexanin and Alexanina, 2000; Jin et al., 2008).

2. Related work

Works such as those of Fernandes (2009) and Castellani (2006) are focused on the automatic detection of eddies, i.e., the separation of regions presenting rotating flow patterns from those that do not exhibit these patterns. For a review of this topic, consult Fernandes (2009). The focus of the present work is the automatic definition of the size of the eddies. When analyzing works related to the present one, we will separate the methods that use orientation or velocity fields (Thonet et al., 1995; Alexanin and Alexanina, 2000; Yang et al., 2001) from those that do not (Peckinpaugh and Holyer, 1994; Ji et al., 1999; Chaudhuri et al., 2004; Jin et al., 2008); the reason is that our method employs an orientation field, which is a simplified version of a velocity field where the water flow sense is unknown. We will first analyze the methods employing orientation or velocity fields. In the work of Alexanin and Alexanina (2000), an ellipse that surrounds the eddy is calculated using points from the orientation field within a zone whose size is defined by the system user, something that we are able to avoid with our method. In addition, the orientation field is given by the dominant flow orientation inside a window, namely the orientation with the minimal difference in angle from the orientation orthogonal to the temperature gradient summed over all pixels inside the window. In our case, the dominant orientation in each window is close to random because the temperature gradients are weak. Consequently, the water flow orientation is not defined correctly, as depicted in Fig. 1b. The weak temperature gradients present in our brightness temperature maps also prevent the application of the work of Thonet et al. (1995) and Yang et al. (2001). The former authors obtain the orientation field from the average value of image gradients, an average which is too variable in our case to allow the identification of the eddies, as shown in Fig. 1c. If we combine the orientation field determined by the method described in the present paper with the method of Thonet et al., we are still unable to determine a size for the eddy. The reason is that the radius of the circular edges of eddies cannot be calculated with the method of Thonet et al. because it is impossible to define the position of the critical point (the center of water rotation) of the phase portrait that characterizes the eddy. In fact, the critical points are not concentrated in the center of the water rotation, as may be seen in Fig. 1d. Regarding the work of Yang et al. (2001), the optical flow method employed does not allow the determination of the direction of the water flow in our case because of the variability of the velocity field, as depicted in Fig. 1e. In addition, the application of their Jordan curve index, which mainly consists of summing the variations of the orientations over a closed curve, to our orientation field does not

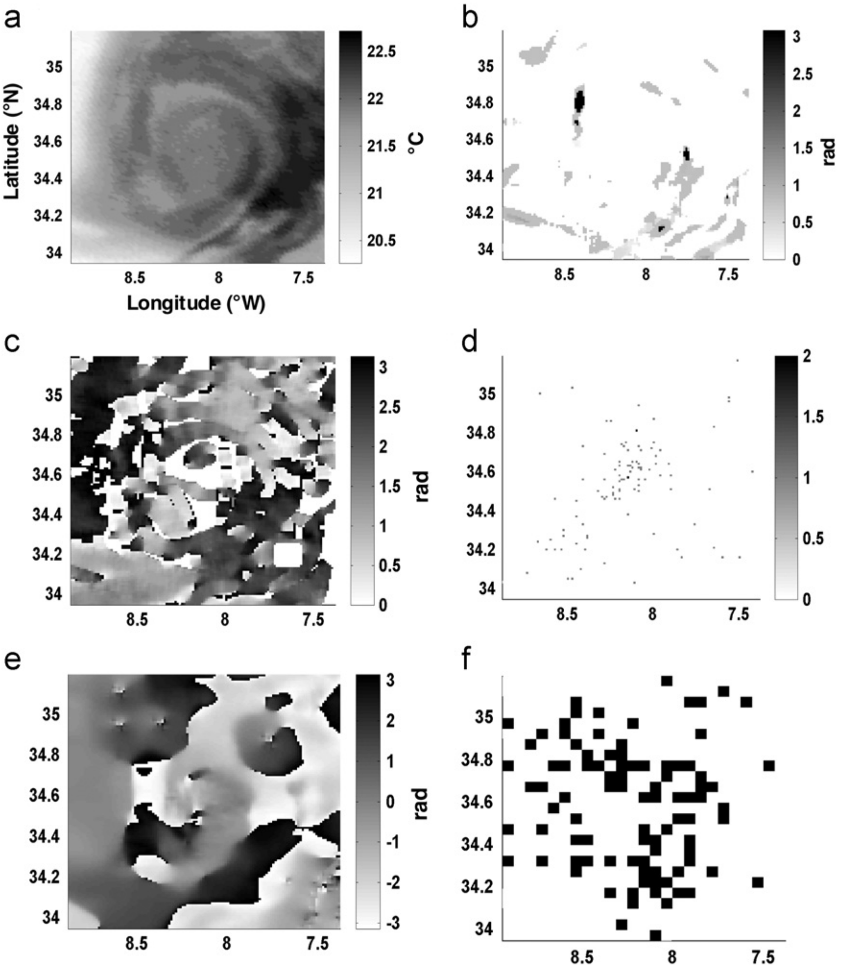

Fig. 1. (a) Brightness temperature of an eddy. The studies shown in (b)–(f) are relative to this eddy. Orientation fields from: (b) Alexanin and Alexanina (2000), and (c) Thonet et al. (1995). (d) Histogram of the position of critical points for Thonet et al. (1995) phase portraits. (e) Velocity directions from Yang et al. (2001). (f) Possible water rotation centers determined with Jordan curve index from Yang et al. (2001).