Characterizing Surface Transport Barriers in the South China Sea

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Award Number: N00014-12-1-0665 http://web.mit.ed/endlab

LONG-TERM GOALS

The long term goal of this project is to advance the state of the art in mathematical methods for detecting key Lagrangian transport structures in velocity field data sets for spatially complex, time-dependent, ocean surface flows. Such transport structures are typically not inherently obvious in snapshots of the Eulerian velocity field and require analysis methods with foundations in Lagrangian flow transport. Several such methods are currently being developed, and we seek to assess the utility of several of the leading methods.

OBJECTIVES

The scientific objective is to test and develop novel methods, with a focus of the approach of Lagrangian Coherent Structures (LCSs). We seek to demonstrate the utility and robustness of the method through application to ocean data sets, and to assess the challenges when using noisy, real-world data sets, such as those generated by HF radar.

APPROACH

The approach involves using MATLAB and C++ based software to perform processing of the data sets. The code has been developed by a graduate student (Allshouse) and a postdoc (Leclair). Data sets for analysis are provided by other members of the DRI, such as John Wilkin, and HF radar data from the Taiwanese TORI network.

WORK COMPLETED

In the past year, we have focused on testing the most popular and simple method based on FTLE analysis as a robust, quick-and-somewhat dirty approach that can be readily applied to real world data sets. This is in contrast to some of the more mathematically intricate methods that are likely to break down without high-resolution numerical data. In addtion, we have investigated the utility of several other new methods through application to canonical flows, a promising example being the Fuzzy Clustering Methods (FCM). In addtion, we refined our calculations in which we apply the LCS method to a coral reef system flow, rigorously identifying hyperbolic and elliptic flow structures.

RESULTS

The FTLE approach was found to be quite robust in the face of noise and discretization, lending more weight to it being potentially widely applicable to the interpretation of HF Radar data. We did find however, that characterization of FTLE ridges in terms of their influence on Lagrangian shear, normal repulsion and in-line stretching is fraught with challenges (Allshouse & Peacock 2015a; Figure 1).

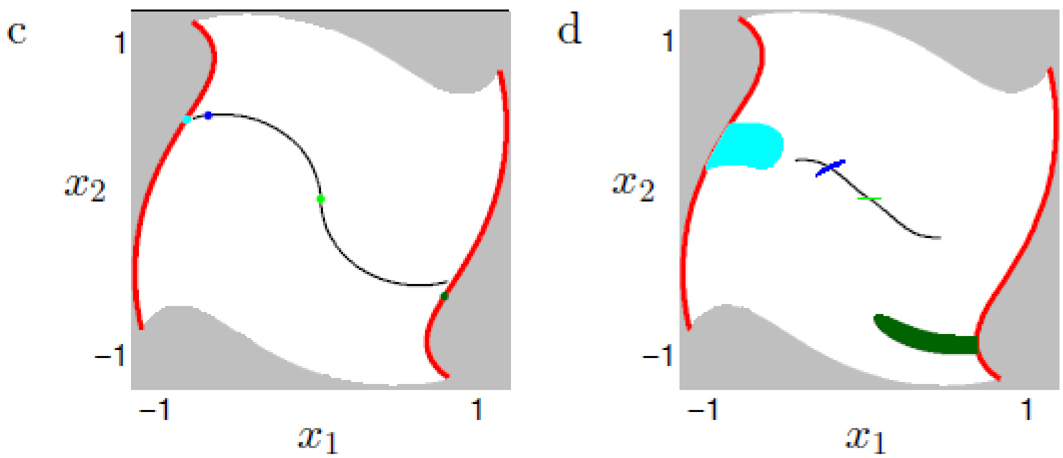

Figure 1: For an analytical flow field, advection of passive tracers initally placed next to FTLE ridges with different properties reveals the different natures types of streching that can occur. Light blue and dark green experience normal stretching, whereas dark blue and light green experience Lagrangian shear.

The pros and cons of several different methods was investigate through application to the canonical double-gyre flow. Out of all the new methods, the Fuzzy Clustering Method (FCM) appears to be a straightforward, computationally efficient and numerically robust method for identifying Lagrangian flow structures. The details of our studies were presented in a substantial review article (Allshouse & Peacock 2015b) and a shorter review (Peacock, Froyland & Haller 2015).

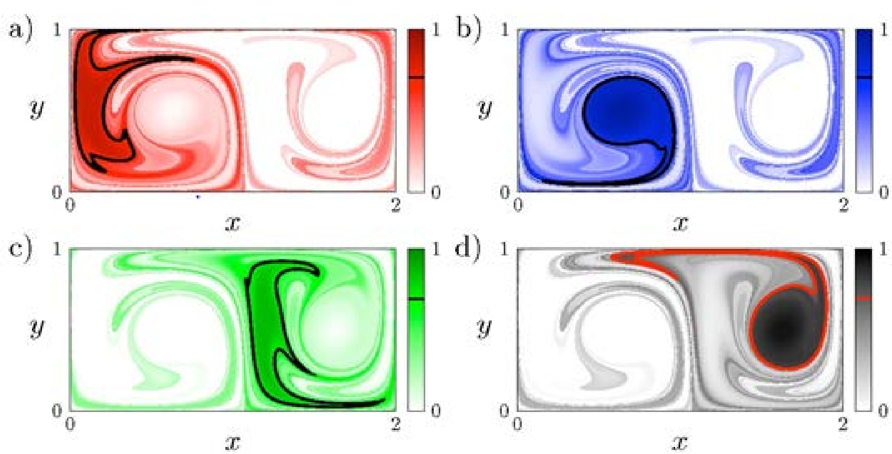

Figure 2: The Fuzzy Clustering Method (FCM) efficiently and robustly detects four coherent sets within the canonical double-gyre flow.

We have also advanced the applicability of LCS methods to real world studies of ocean surface transport via the inclusion of windage factors in the transport model. Our study showed that windage is a highly important factor that has substantial impact of the results of Lagrangian calculations, and it is imperative that it be included in real world applications (Allshouse *et al.* 2015).

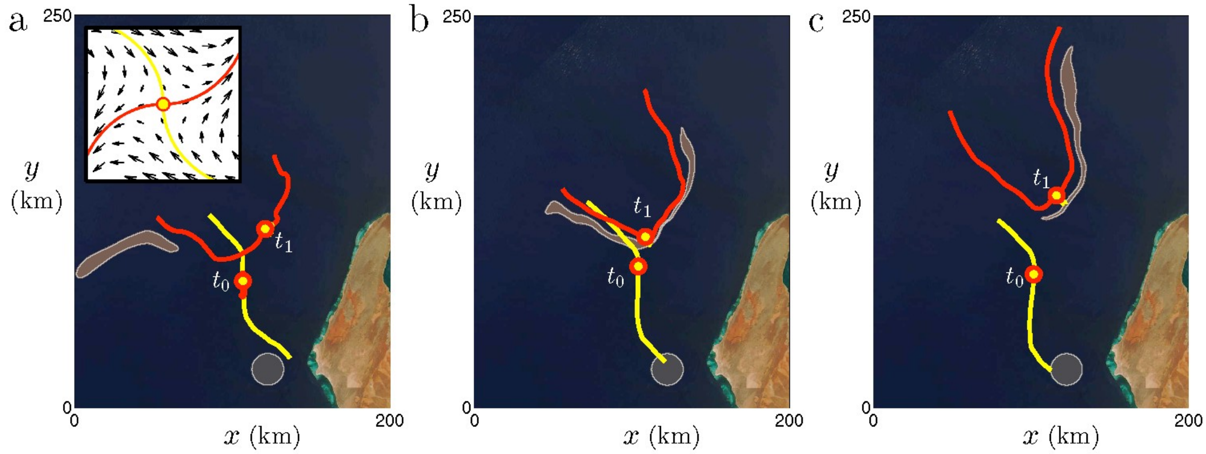

Figure 3: The impact of windage on a hypothetical tracer release event of Ningaloo Reef in Western Australia between 0:00 11th December and 0:00 18th December 2009. (a) In the absence of windage, the initially circular tracer patch (gray patch) and the dominant hyperbolic saddle-point (red/yellow circle) are advected from time t_0 to time t_1 (11 to 18 December 2009). In its final state, the tracer patch (brown patch) is only modestly stretched by the saddle-point because it lies somewhat beyond its domain of influence. The inset in (a) presents the local velocity field in the frame of reference of the moving saddle-point, revealing the saddle-point like velocity field. The inclusion of windage factors (b) C_w = 0.0075 and (c) C_w = 0.015 relocates the saddle-point, the shrinkline position relative to the initial tracer patch, and the final patch position.

IMPACT/APPLICATIONS

This work continues to advance the state-of-the-art regarding the application of Lagrangian data analysis methods to real-world ocean transport problems. A reasonable expectation over the next five-to-ten years is that some aspects these methods will become adopted by and implemented into decision-making systems.

PUBLICATIONS

Allshouse, M.R. and Peacock, T., "Refining finite-time Lyapunov exponent ridges and the challenges of classifying them," *CHAOS*, 25, 087410 (2015a). [published]

Allshouse, M.R. and Peacock, T., "Lagrangian based methods for coherent structure detection," *CHAOS*, 25, 097617, (2015b). [published]

Allshouse, M.R., Ivey, G.N., Lowe, R.J., Jones, N.L., Beegle-Krause, C.J., Xu., J., and Peacock, T., "Revealing the impact of windage on ocean surface Lagrangian coherent structures," 2015. [submitted]

Peacock, T., G. Froyland and G. Haller, "Introduction to focus issue: objective detection of coherent structures," CHAOS (2015). [in press]