# Dynamical Systems Analysis of IAS-ROMS Near-surface Velocity field

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## Abstract

Dynamical systems techniques are used to analyze the near-surface velocity (30 m depth) of Intra-Americas (Caribbean and gulf of Mexico) ROMS model and understand the transport and mixing of particles in the system. Finite Size Lyapunov exponents (FSLE) and double time slice method are used to identify stable and unstable manifolds of the flow field. Lobes arising from intersection of the manifolds at vortex edges indicating regions of exchange in and out of the vortices, whereas barriers to transport are identified by their tangency. A particular condition consisting of two interacting vortices near the Yucatan channel is investigated in detail. Time-averaged FSLE maps and of the Okubo-Weiss invariant are used to identify areas of strong and weak mixing in the region

## Fixed Points in the Caribbean and Eastern of Gulf of Mexico

- A near-surface flow pattern that tends to occur with some regularity in several numerical models is shown in Fig. 1. It depicts the anticyclonic circulation associated with the Loop-Current and another anticyclone which is about to squeeze through Yucatan Channel. Here, one month of near-surface velocity (30 m) obtained from the Intra-Americas Sea ROMS model (Moore, Di Lorenzo, Arango, Miliff, Sheinbaum) are used to determine the fixed points and stream lines, with special interest in the hyperbolic point located between the two anticyclones.

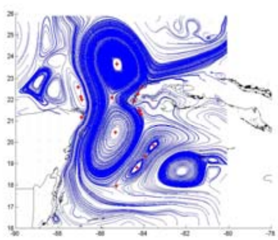


FIG. 1

## Stable and unstable manifolds

Once a hyperbolic point is identified, a cloud of neutral particles is placed in its vicinity. Forward time integration (from t-dt → t) of the lagrangian velocity equations permits identification of the unstable manifold, (blue), whereas backward integration (t+dt →t), yields the stable manifold (red)

- In the Yucatan Channel, both manifolds symptotically converge to the hyperbolic point, which suggests the existence of a hyperbolic trajectory.

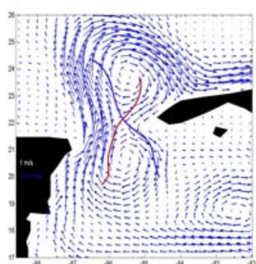
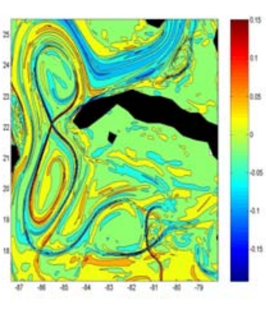


FIG. 2

## Finite Size Lyapunov Exponents (FSLE)

- Finite Size Lyapunov Exponents (FSLE) are also used to compute stable and unstable manifolds. Such exponents are inversely proportional to the time a particle pair takes to separate a predetermined distance δ when they were initially separated by δ(0). When integration is carried out forward (t→t+δt), minimal time separation defines the stable manifold (repelling material lines). Similarly, Integration backward in time from (t→t-δt) determines the unstable manifold (attracting material lines) from the minimal time separation. Regions of strong mixing appear as a tangle of stretching and compressing lines that organize the flow since particles cannot cross these lines.



$$\lambda(t,\delta(t),\delta(o)) = \frac{1}{t}\ln\left(\frac{\delta(t)}{\delta(0)}\right)$$

*and*

$$\delta(t) = \sqrt{(x_1(t)-x_2(t))^2 + (y_1(t)-y_2(t))^2}$$

## Introduction

The Western Caribbean is a region of great tourist and economic development which requires proper management . Here lies the Meso-American Barrier Reef System (MBRS), the second largest reef-system of the world.

•The reefs are fragile marine ecosystems with great biodiversity. Connectivity between different reef areas is affected by the ocean circulation as well as human activities and is basic for its survival.

• Understanding connectivity in the MBRS is complicated due to high eddy activity and the presence of strong jet-like currents.

•Dynamical Systems Theory provides a clear framework to understand why, where and when exchanges of particles between different flow regimes may occur.

## Objectives

•Identify typical patterns of the flow: Even though the region is highly variable, there are circulation patterns that appear with some regularity

•Find stagnation points and stream-lines associated to these patterns and their “geometric” characteristics. This is complicated by the time-dependence of the flow.

•Investigate how these "geometric elements" evolve and what information can provide for understanding the exchange of particles between regions.

## Mean Okubo-Weiss as a guide to identify hyperbolic trajectories

Mean Okubo-Weiss parameter for the whole simulation period (one month). Regions that remain negative on average are vorticity dominated whereas positive values indicate strain dominated flow. Maximum positive value in Yucatan Channel center identifies the hyperbolic point.

$Q=||S||^2 - ||\Omega||^2$
$S$=strain
$\Omega$=vorticity

- When Q is positive (negative), the flow is strain-dominated (vorticity dominated) .

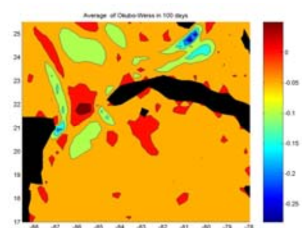
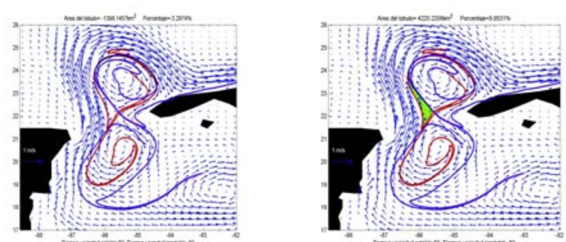
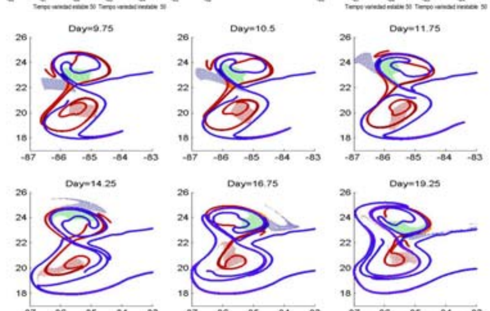


FIG. 3

- When the stable and unstable manifolds converge to the hyperbolic point, the flow changes its speed and direction continuously and possibly intersect, forming regions known as lobes. These lobes indicate the areas where particle-exchange occurs between the eddies and the exterior. The manifolds themselves represent barriers to transport.






Time-evolution of blobs of particles showing their behavior on regions defined by the geometric features of the flow.

## SUMMARY

- **The Okubo-Weiss criteria was used to help determine the presence of hyperbolic trajectories in the region.**
- **A case-study of one month allowed identification of a hyperbolic trajectory in the Yucatan Channel and regions where exchange between eddies and the external flow field occurs (Lobes). The double time-slice method and FSLE technique gave similar results.**
- **Finite Size Lyapunov Exponents gave similar results without the need to specify a-priori the saddle points of the flow. These are preliminary results from a M. Sc. Project lyzed, with the purpose of detecting and visualizing lagrangean structures in the whole IAS region.**