An eddy tracking algorithm from dynamical systems theory

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Third International Workshop
NONLINEAR PROCESSES IN OCEANIC AND ATMOSPHERIC FLOWS

Universitat de les Illes Balears
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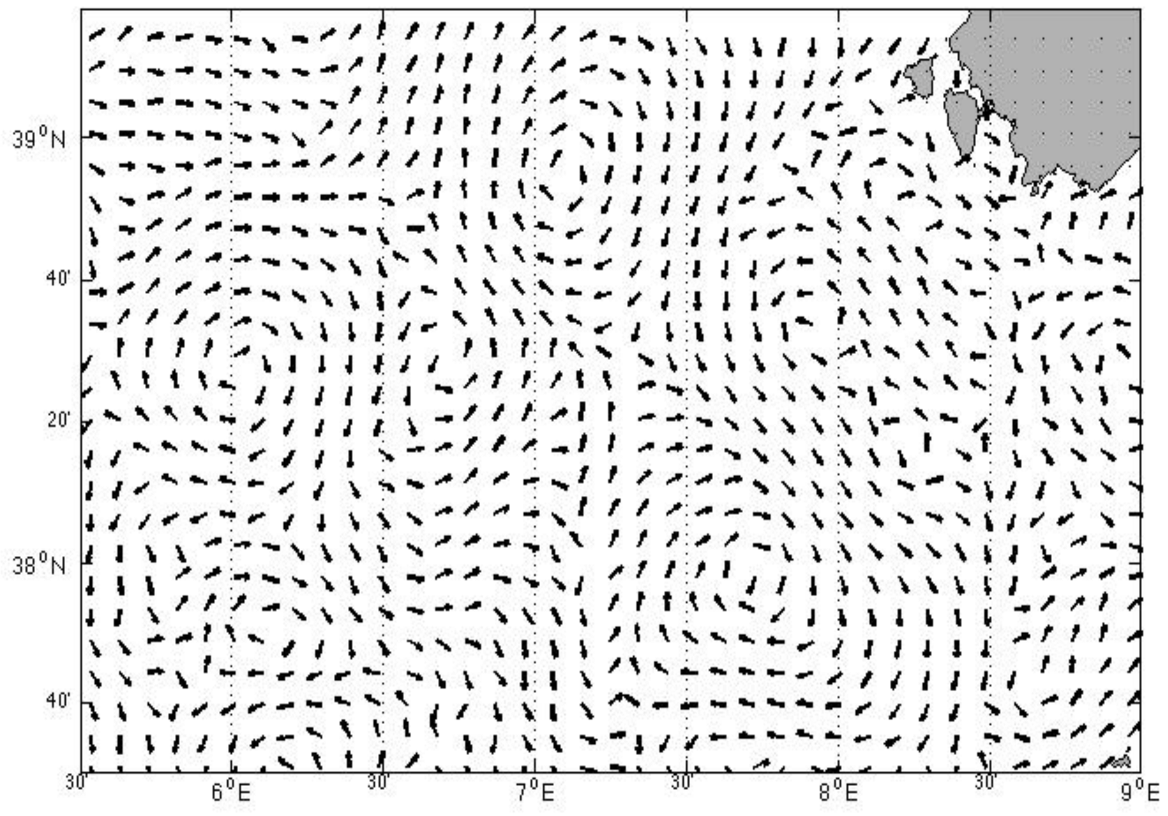
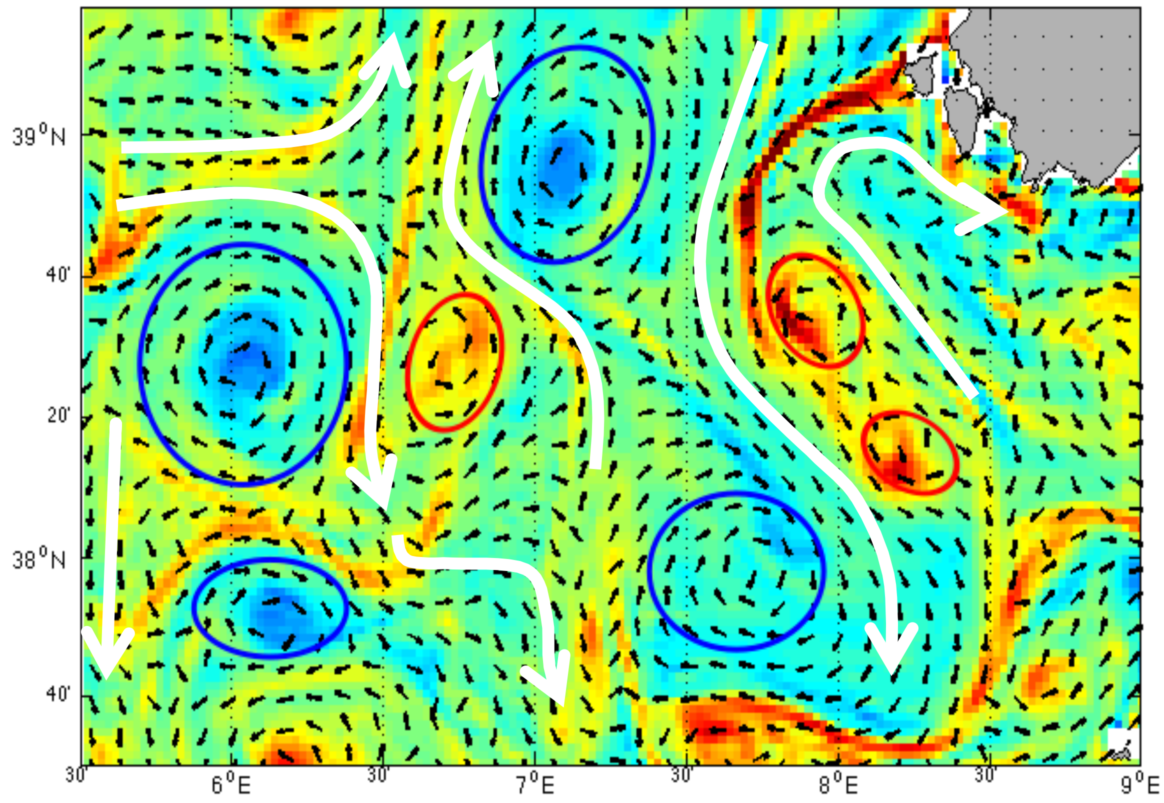
Motivation



Motivation



WHAT HAVE WE DONE?

A METHOD FOR IDENTIFYING AND TRACKING EDDIES FROM VELOCITY FIELDS

HOW?

APPLYING THE THEORY OF 2D STATIONARY DYNAMICAL SYSTEMS

Description of the Method

1. Center of the eddies
Stagnation Points and LSA

2. Size of the eddies
Surrounding SP's

3. Link different times
Tracking Algorithm

1. and 2.
At a frozen time

1. Center of Eddies

2D – steady flow

$$\frac{d\mathbf{r}}{dt} = \mathbf{v}(\mathbf{r}, \tau_0) = \mathbf{v_{st}}(\mathbf{r})$$

Stagnation Points

$$\mathbf{v_{st}}(\mathbf{r_0}) = 0$$

Near the SP's

$$\mathbf{v_{st}}(\mathbf{r_0} + \delta\mathbf{r}) = \mathcal{J}(\mathbf{r_0}) \cdot \delta\mathbf{r}$$

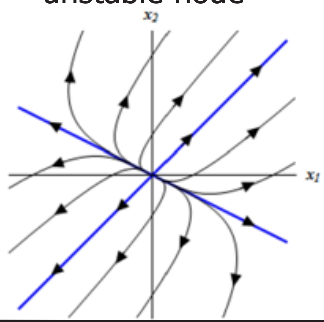
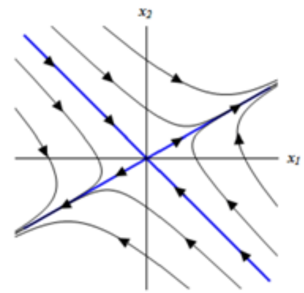
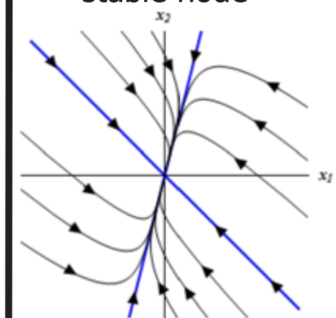
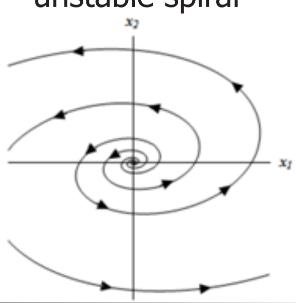
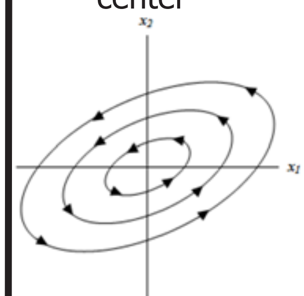
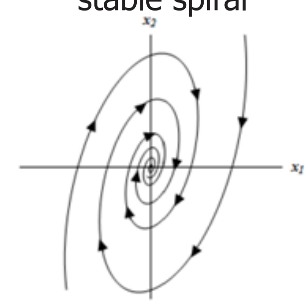
The velocity field is mainly dominated by the Jacobian Matrix

$$\mathcal{J}(\mathbf{r_0}) = \left. \begin{pmatrix} u_x & u_y \\ v_x & v_y \end{pmatrix} \right|_{\mathbf{r_0}}$$

Linear Stability Analysis

$$\lambda_{1,2} = \frac{1}{2}\left(T_{\mathcal{J}} \pm \sqrt{T_{\mathcal{J}}^2 - 4\Delta_{\mathcal{J}}}\right)$$

The eigenvectors-eigenvalues of the Jacobian matrix allow us to know the behaviour around the stagnation points

	$\mathrm{Re}(\lambda_{1,2}) > 0$	$\mathrm{Re}(\lambda_1) > 0 > \mathrm{Re}(\lambda_2)$	$\mathrm{Re}(\lambda_{1,2}) = 0$	$\mathrm{Re}(\lambda_{1,2}) < 0$
$\lambda_{1,2} \in \mathbb{R}$	unstable node 	saddle node 		stable node 
$\lambda_{1,2} \in \mathbb{C}$	unstable spiral 		center 	stable spiral 

Linear Stability Analysis

$$\lambda_{1,2} = \frac{1}{2}\left(T_{\mathcal{J}} \pm \sqrt{W}\right)$$

$$W = \underline{\sigma^2} - \underline{\omega^2}$$

W Okubo – Weiss parameter

deformation – vorticity

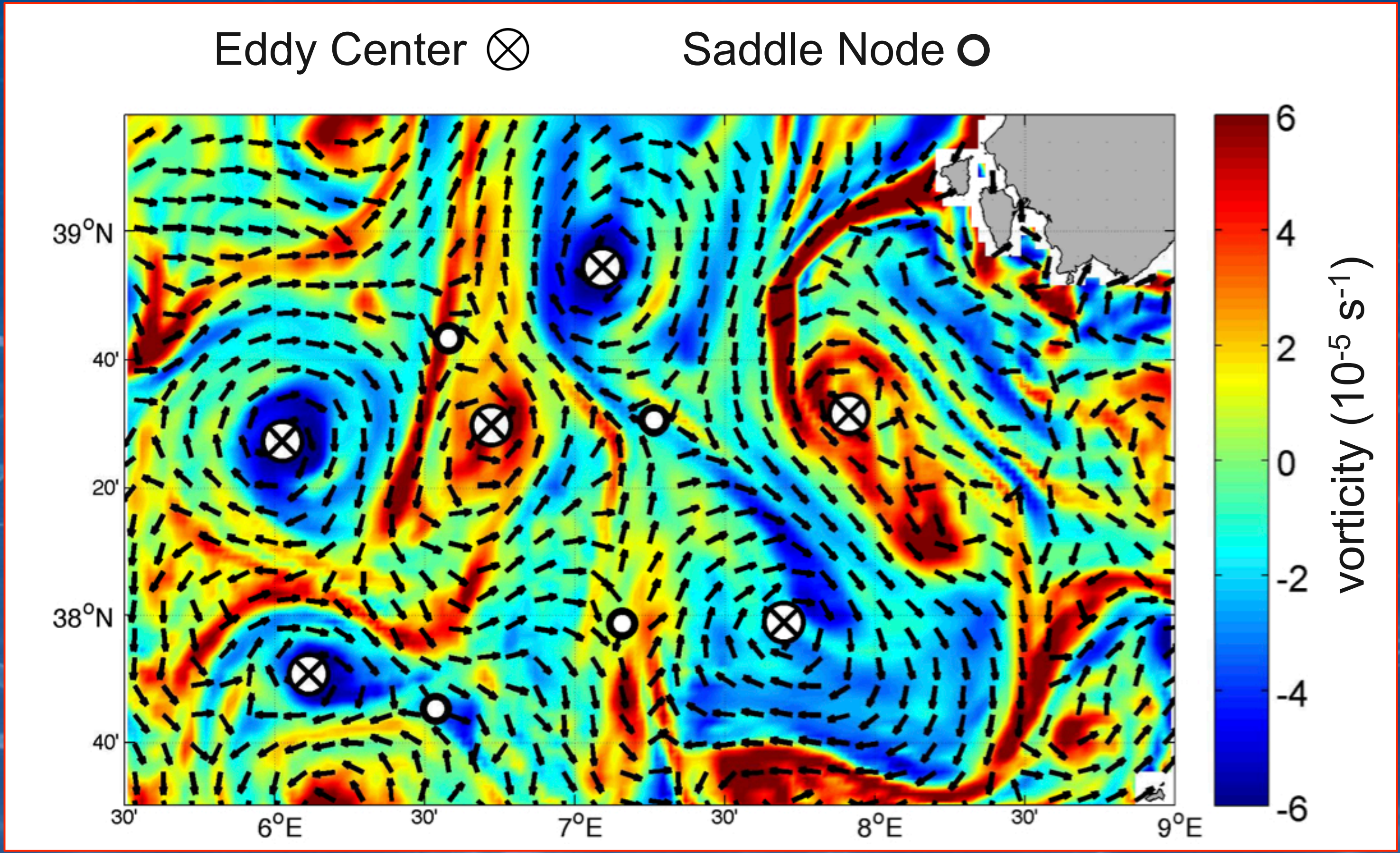
W < 0 ➔ Eddy Center

$$T_{\mathcal{J}} = u_x + v_y \equiv \nabla \cdot \mathbf{v_{st}}$$

For incompressible 2D flux

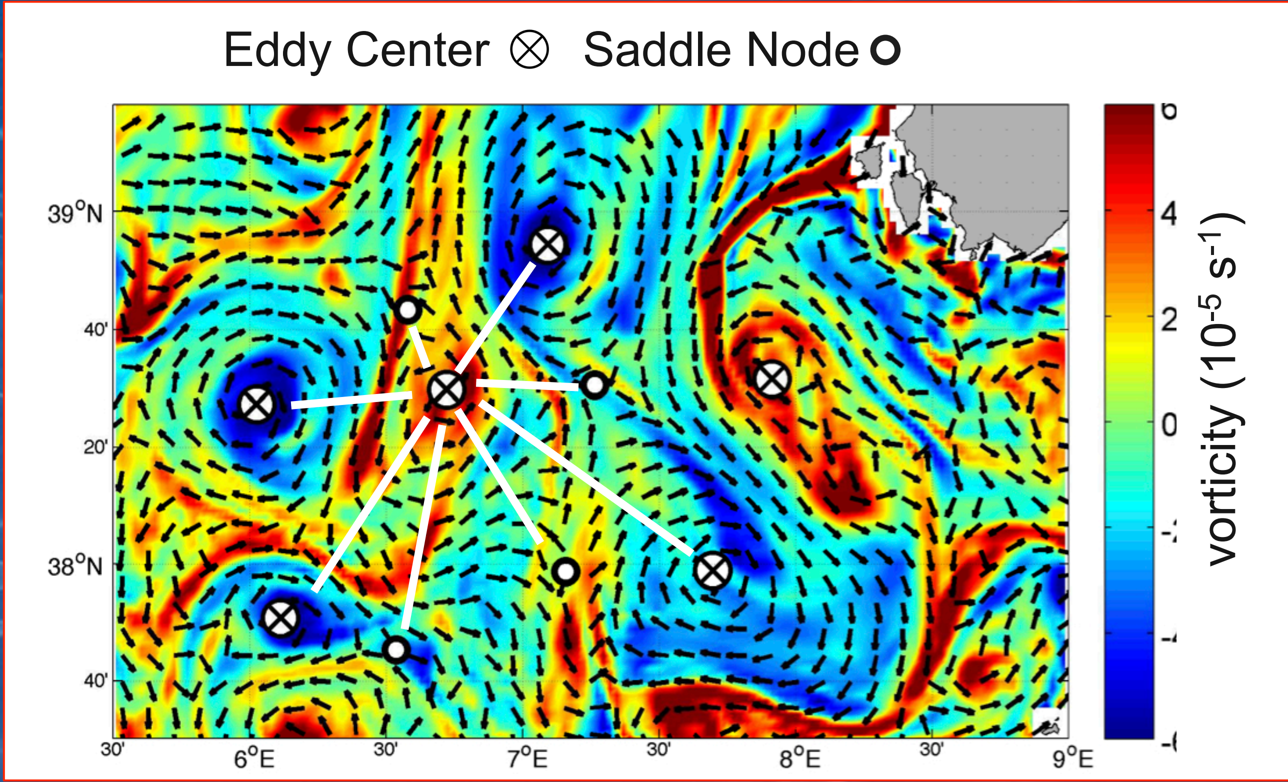
➔ Only Saddle Nodes & Centers

Example



ROMS (WMOP regional configuration)
Model Resolution ~2 km
Area: South-West of Sardinia
Date: 2015-05-02

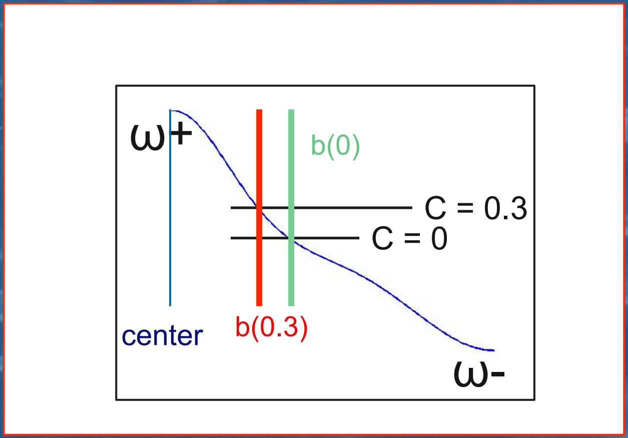
2. Size of the Eddies

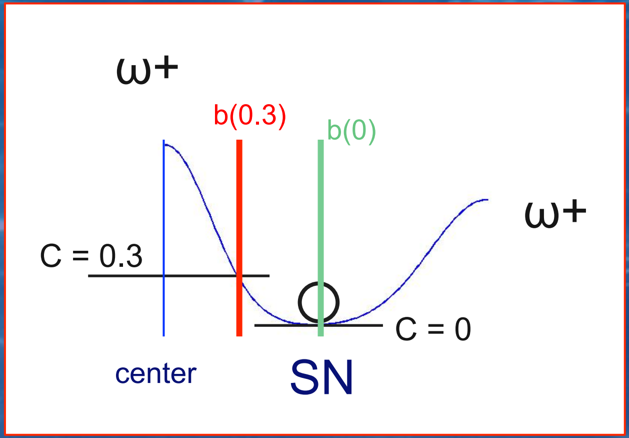


Stationary Field with eddy vortexs + saddle nodes
Eddy Boundaries are stimated evaluating the vorticity along the white lines

2. Size of the Eddies

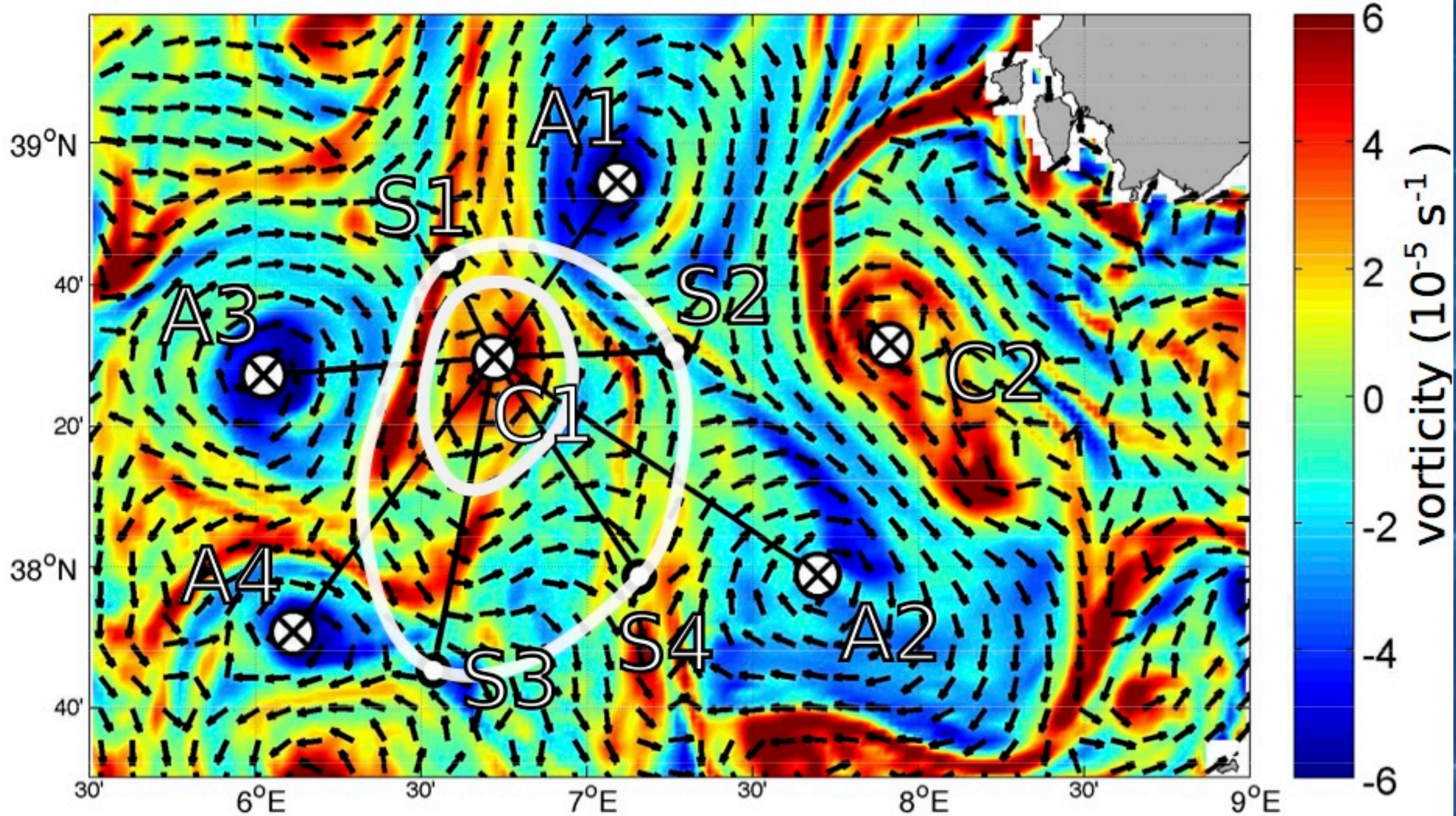
Vorcitiy profiles along the connecting lines





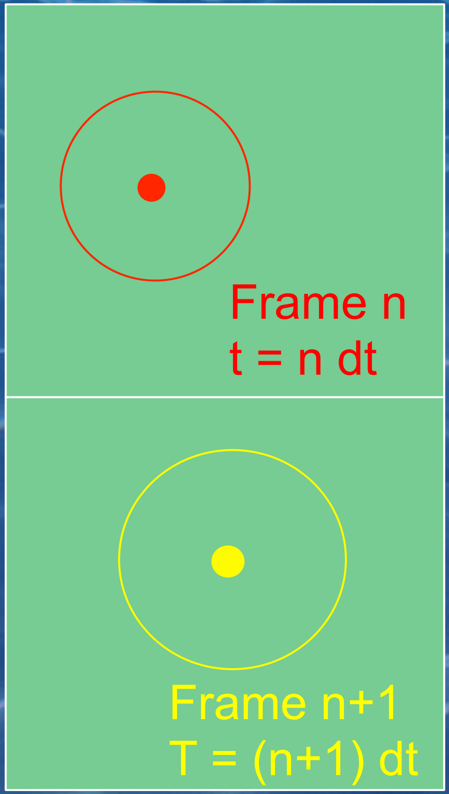
We define eddy boundary as the point in the connecting line where $\omega = c\ \omega_+$

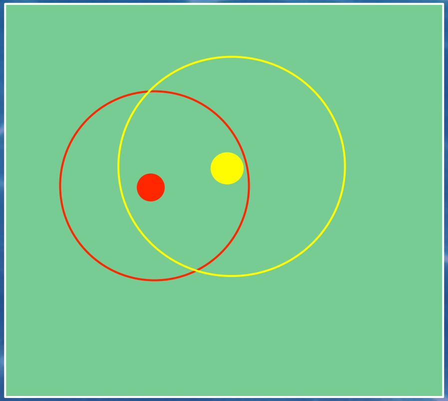
2. Size of the Eddies



3. Tracking algorithm

We have eddy data at a discrete sequence of times
Relate the eddy data in each snapshot with his previos and next snapshots
Decide the correspondence between eddies of consecutive frames

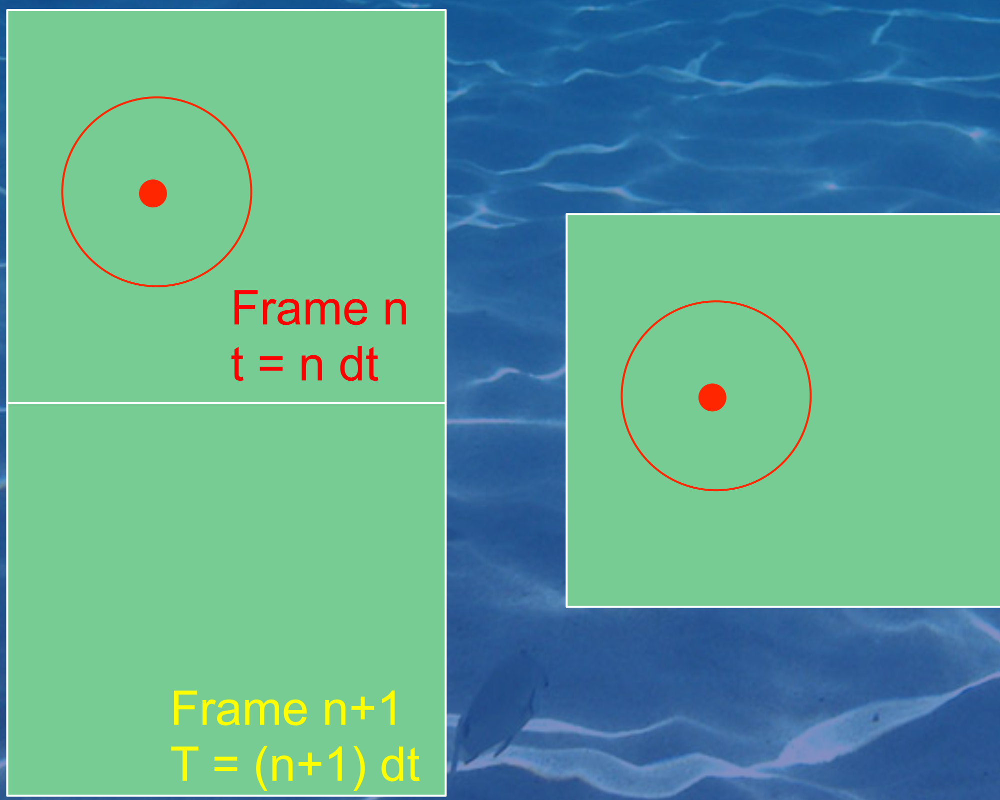




It is the same eddy
The eddy has moved
His radio has increased

3. Tracking algorithm

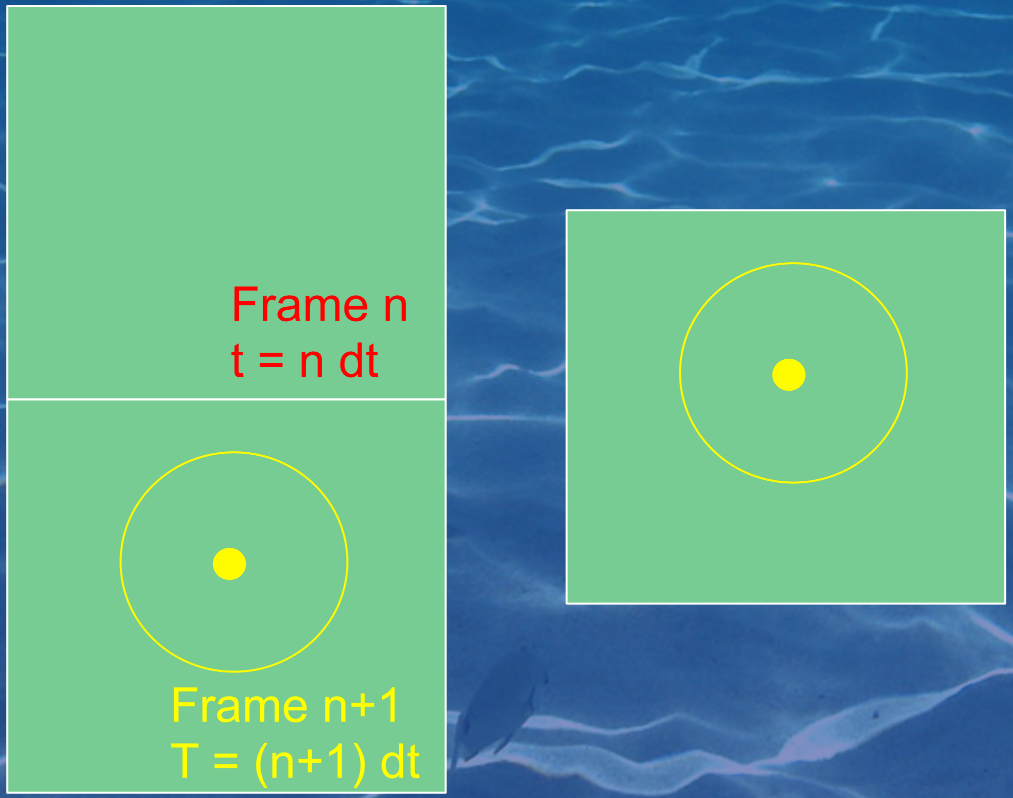
Relate the eddy data in each snapshot with his previos and next snapshots
Decide the correspondence between eddies at consecutive frames



The eddy has finished his life

3. Tracking algorithm

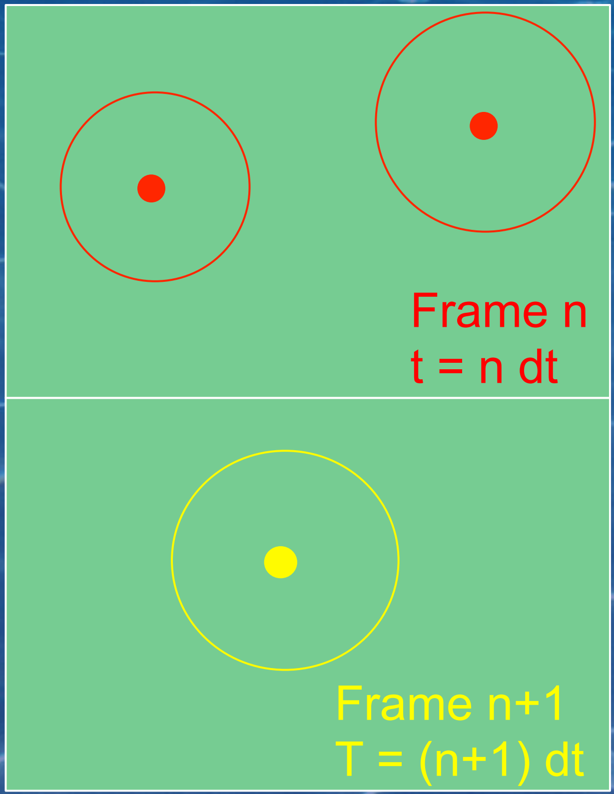
Relate the eddy data in each snapshot with his previos and next snapshots
Decide the correspondence between eddies at consecutive frames

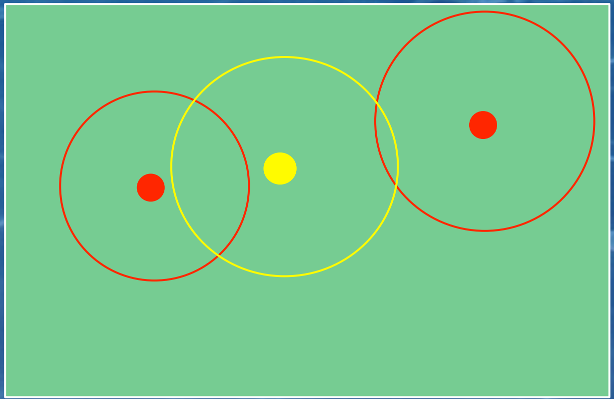


An eddy has born

3. Tracking algorithm

Relate the eddy data in each snapshot with his previos and next snapshots
Decide the correspondence between eddies at consecutive frames





???

3. Tracking algorithm

Two main problems:

a) Loosing the signature of and eddy in a single frame

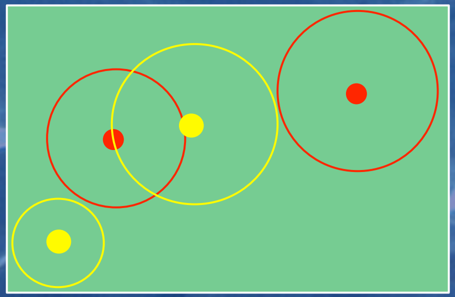
Sampling errors and/or noisy data from measurements or inhability of the method to detect eddies

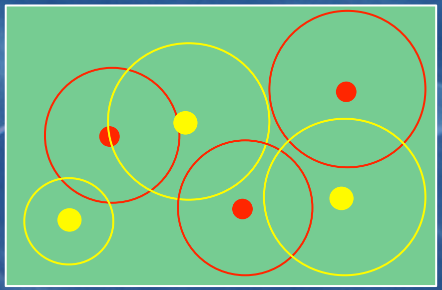
Leads to artificial dead + born of eddies

b) Missmatching connections

Wrong decision in the eddy matching between frames

Coupled configurations





3. Tracking algorithm

Two main problems:

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Sampling errors and/or noisy data from measurements

Inhability of the method to detect eddies

Leads to artificial dead + born of eddies

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Coupled configurations

Collective minimization of distances of all the possible pairments

Search for Mesoscale Eddies

Mesoscale eddies

Rotatory CS's present in all world oceans.

Important role in regulating the global climate and transport processes

Mesoscale eddies

Data

Length Scale
~ 50 – 200 km

Temporal Persistence
~ 4 weeks – several years

Search of Mesoscale Eddies

Data Used: Geostrophic velocities derived from Satellite Altimetry
Dataset of 20 years of weekly SSH data from AVISO product
http://www.aviso.altimetry.fr/

Mesoscale eddies

Data
Satellite Altimetry

Spatial domain
Global

Spatial resolution
0.25 x 0.25 º

Period of observations
1992 – 2012 (20 years)

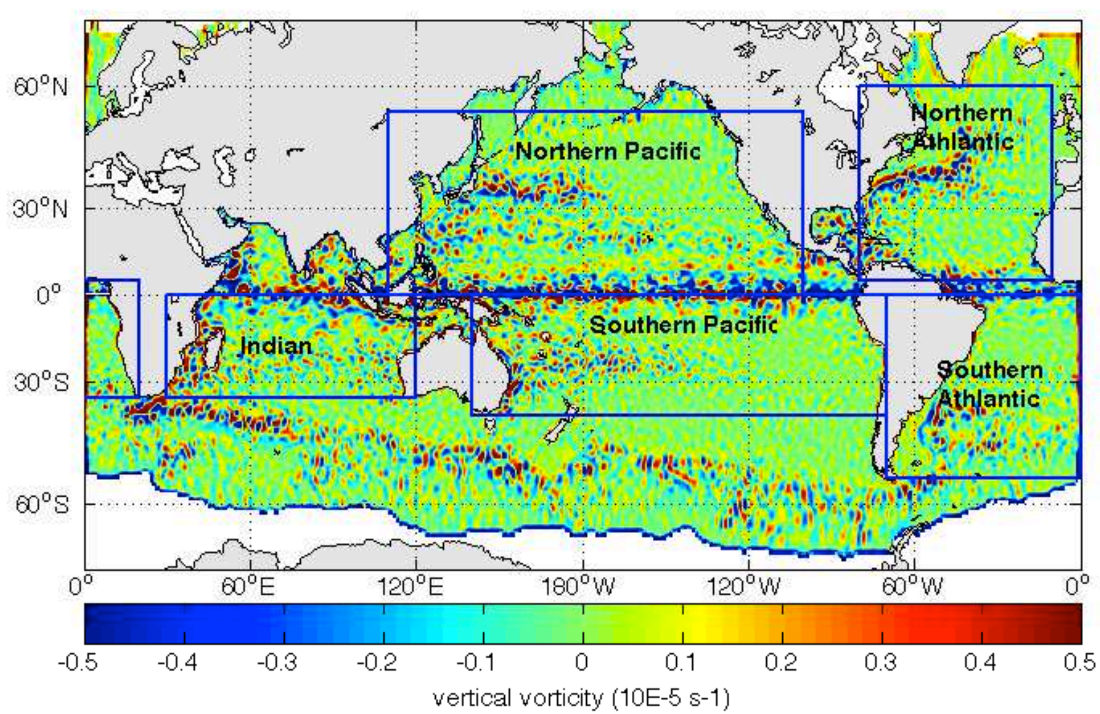
Time step
1 week

Geostrophic Balance

It is the *steady state* of a flow in the Earth Rotating System, where pressure gradients are balanced with the Coriolis force

$$u(x,y) = -\frac{g}{f}\frac{\partial H}{\partial y}$$

$$v(x,y) = \frac{g}{f}\frac{\partial H}{\partial x}$$



Snapshot of vorticity field of Geostrophic Velocities from AVISO SSH

Results(i)

www.researchgate.net

FULL TEXT

Dataset · January 2016

DOI: 10.13140/RG.2.1.1492.5682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Abstract

Dataset associated to the article 'An eddy tracking algorithm from dynamical systems theory', Ocean Dynamics, which is under revision.

eddies_19921014_20120208.nc

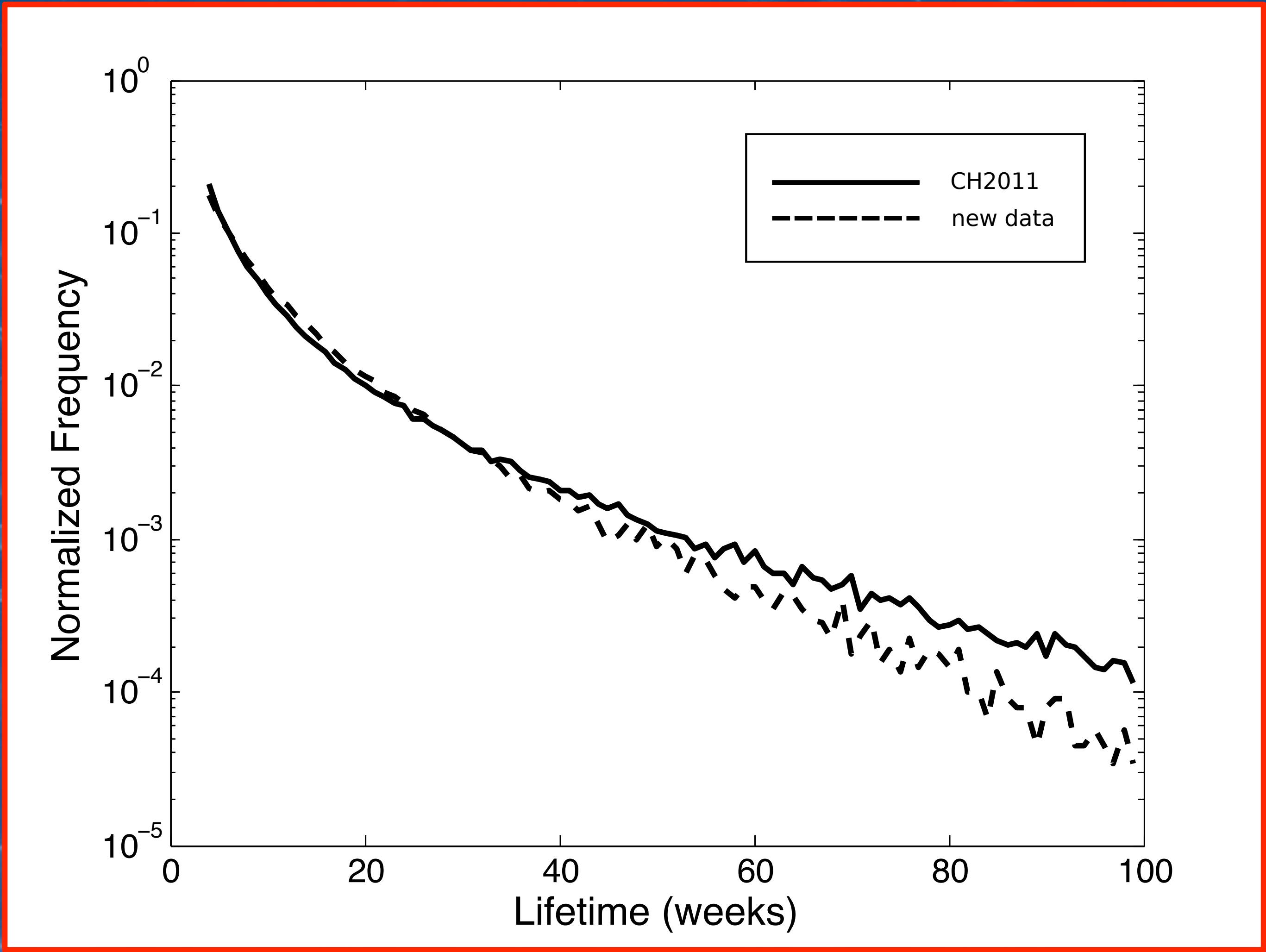
21.22 MB

Sorry, there is no online preview for this file type.

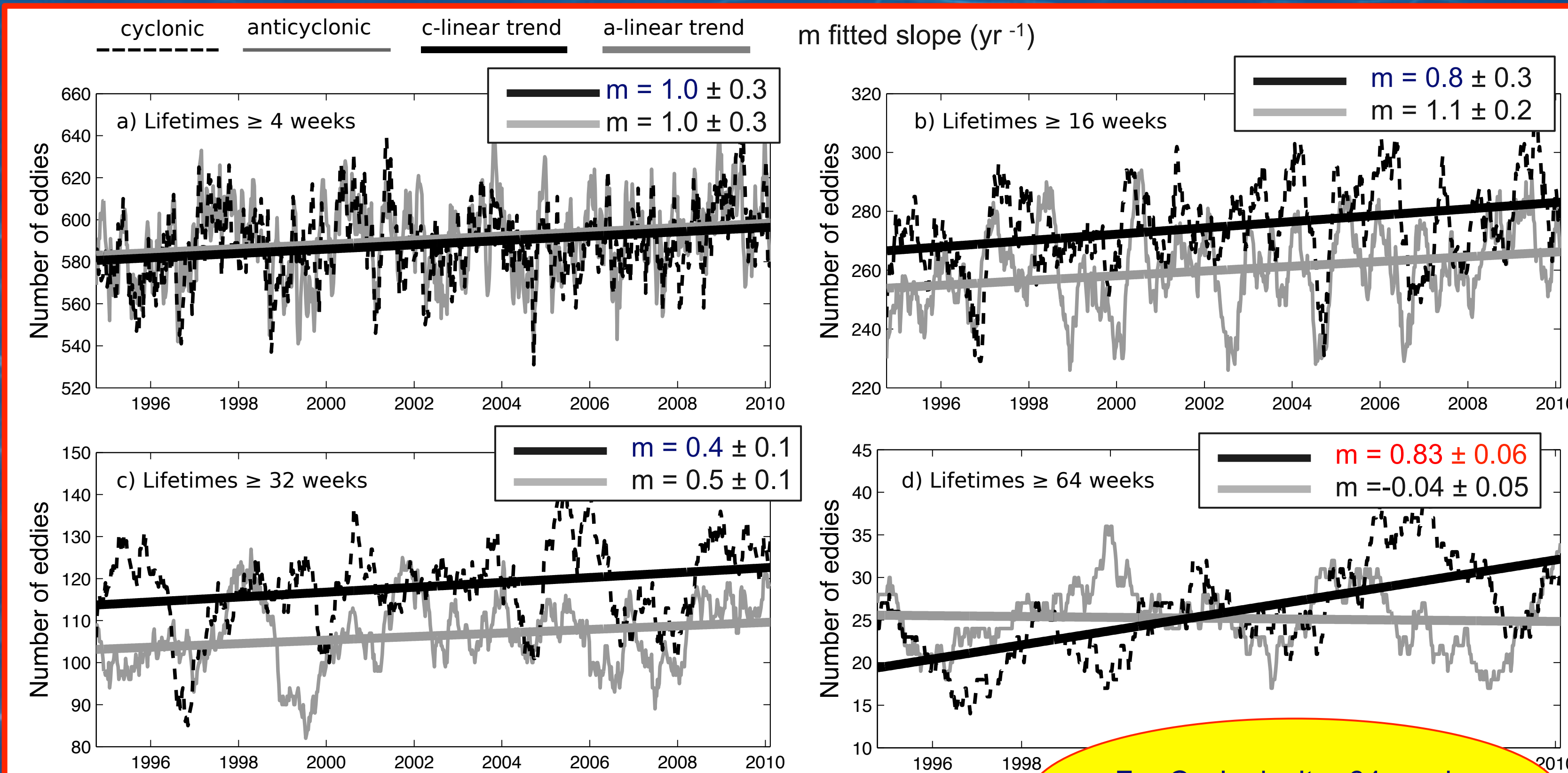
To view this dataset, please download it below.

Download

Results (ii) Lifetimes

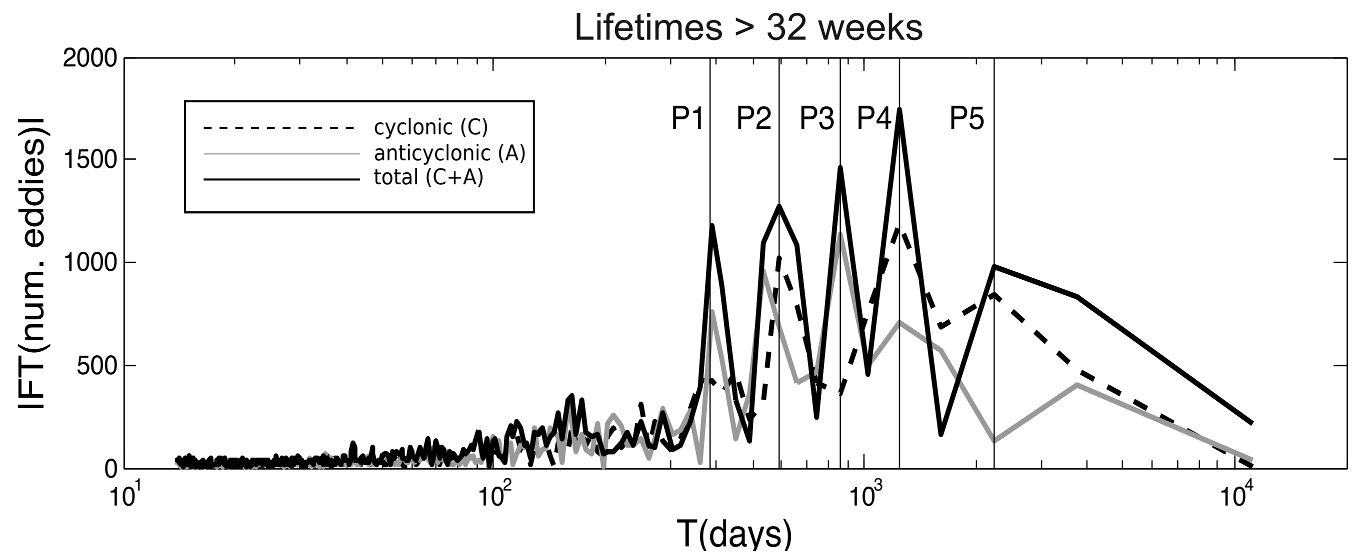


R (ii) TimeSeries



For Cyclonic, lt > 64 weeks
m/<n> = 3% yearly!

R (iii) Spectra



[P1, P2, P3, P4, P5] = [1.0, 1.6, 2.4, 3.4, 6.1] years

Summary

Method

- Eddies are detected as Eulerian structures at frozen times and then tracked
- The eddy center and size are stimated from stagnation points
- The tracking method improves the existing methods at the decision making of pairments when coupled configurations are involved

Mesoscale Eddies

- The temporal and spatial scales of mesoscale eddies allows to represent them as time-evolving Eulerian structures
- We provide database of 20 years of eddies in the global ocean
- The database compares qualitatively well against other global databases in terms of lifetimes, latitudinal distribution, density distribution

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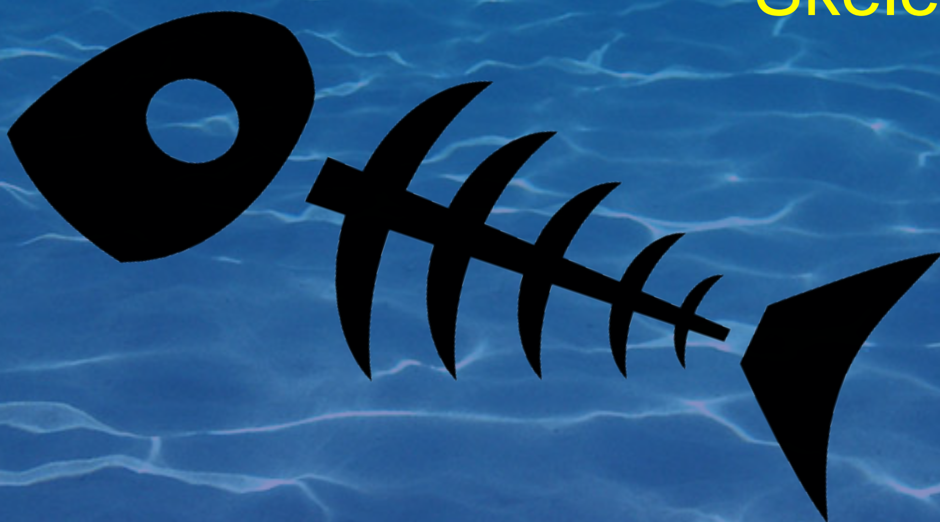
"Discovering the
Skeleton of the flow"



Thank you for your attention