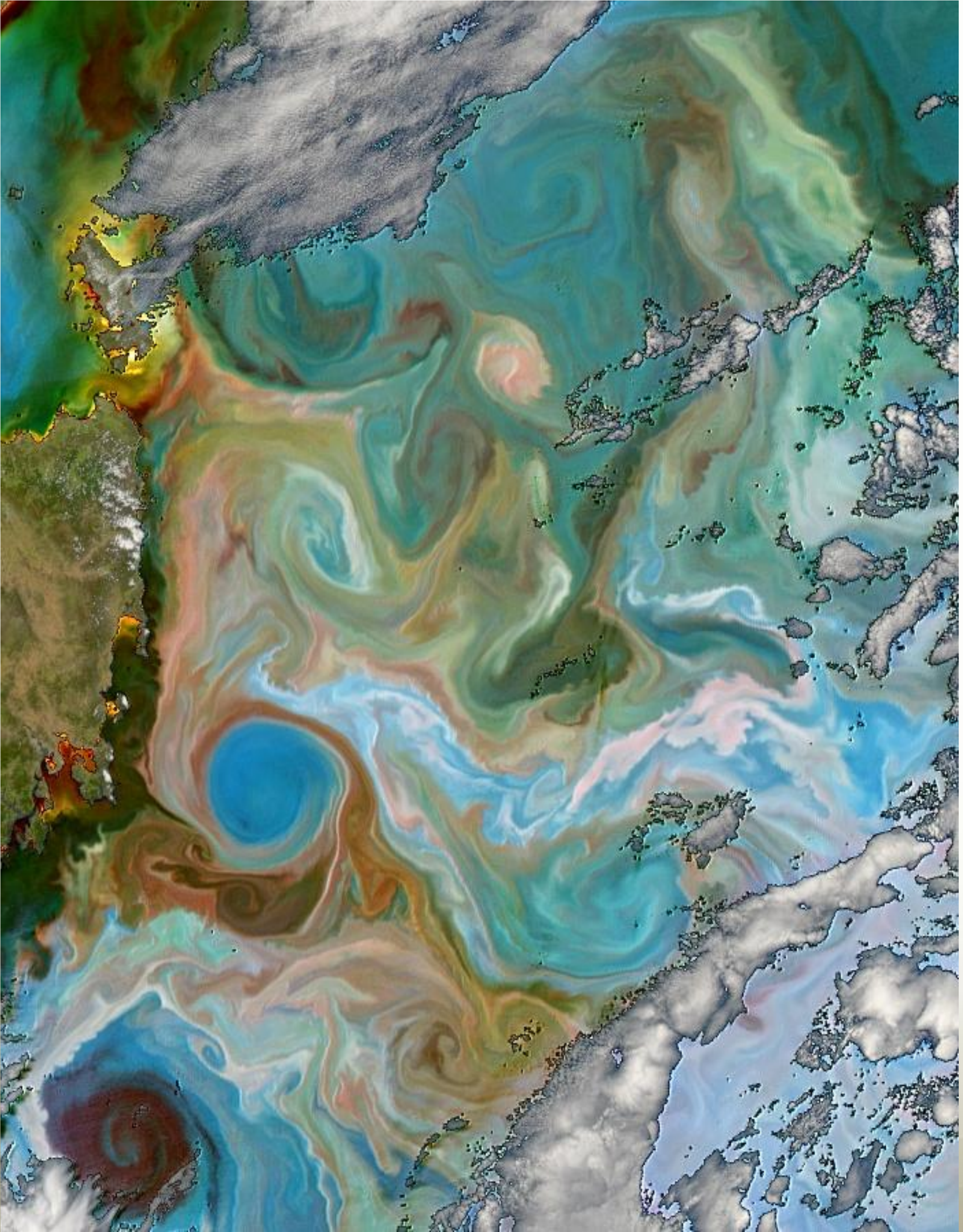

Assimilation of submesoscale observations into ocean models

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Ingredients of the talk …

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Motivations:

An extended range of scales (including submesoscales) are becoming accesssible to observations

- Ocean color satellites: SeaWifs, MODIS, MERIS …
- HR altimetric satellites: SWOT, (SARAL/AltiKa)

An opportunity/a need to think about Data Assimilation accordingly

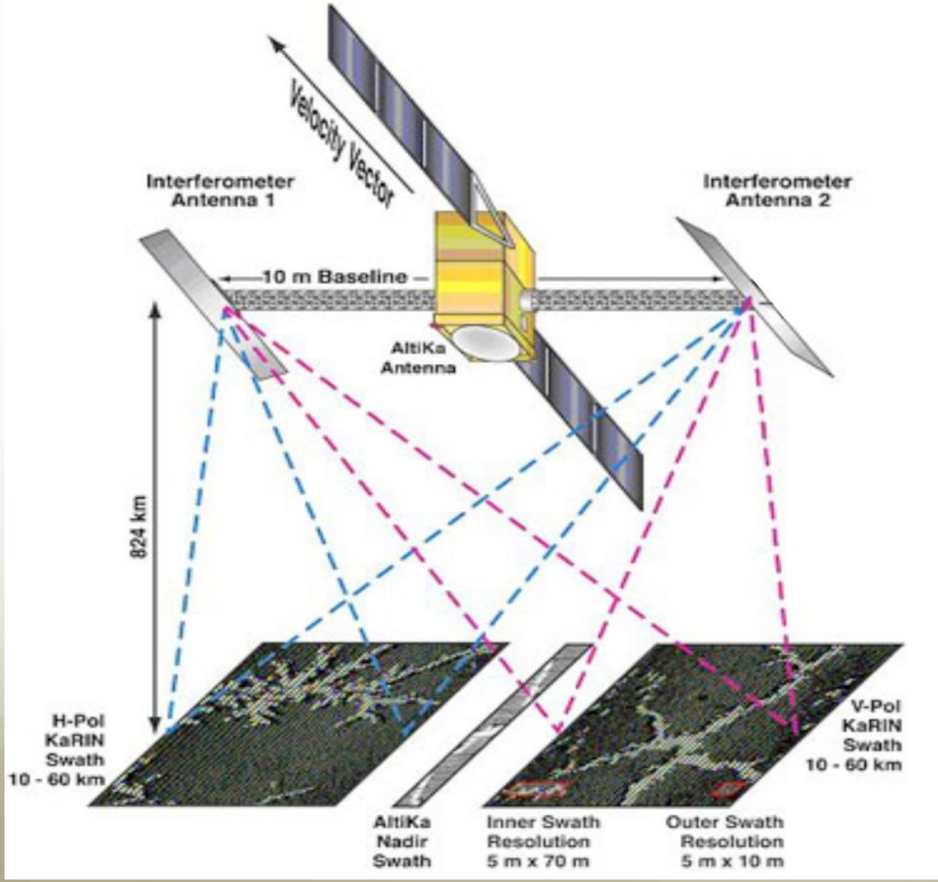
Perhaps need to look at actual data differently (data proxy, data image, etc…)

1. Data assimilation and the submesoscale observations
   - The general problem, new challenges
2. An exploratory/preliminary study
   - Submesoscale observations treated as image informations

1. Data assimilation (DA) and submesoscale observations

- **Assumption**
  - Submesoscales are a "useful" part of the ocean dynamics spectrum (Klein, Ferrari, etc…)
- **Questions:**
  - What will we do with submesoscale observations when we have them from SWOT for example ?
  - Are we doing well to use submesocale observations of SST or ocean color satellite data ?
  - How this influence our way of thinking DA ?
- **First order answer:**
  - DA efficiency is dependent of the numerical model quality, which in turn, depends strongly on the resolution

The SWOT case



- O(1km) resolution data
- In 2020, global models should reach O(1km) resolution but not solve well 1 km processes
- But, in 2020, plenty of regional models will do it
- Will the OGCMs be able to represent the actual submesoscale physics (probably not) ? Will SWOT data be "observables" in OGCMs ?

DA new challenges

- **DA will have to deal with**
  - New practical complexities
    - Size of data sets and of model state vectors
    - More nested model systems
  - Growing theoretical complexities
    - Increase of non-linear effects
    - Non-Gaussian statistics
- **New avenues for DA may be:**
  - Building better parameterizations, DA not necessarily for state estimation (Wirth & Verron, 2010)
  - Multiscale DA
  - Image DA (as a complement, not alone): Information from tracers, biology, "movies"
  - …

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2. An exploratory/preliminary study of submesoscale DA

- **Objectives:**
  - Assimilation of submesoscale observations into ocean models for the control of larger scales:
    - Is it feasible ? Can we use data proxies ? Image data ?
      - Are Lyapunov exponents a reliable proxy/image ?
    - Can we make the link between altimetry and ocean color ? between physics and biogeochemistry ?

- **An exploratory study:**

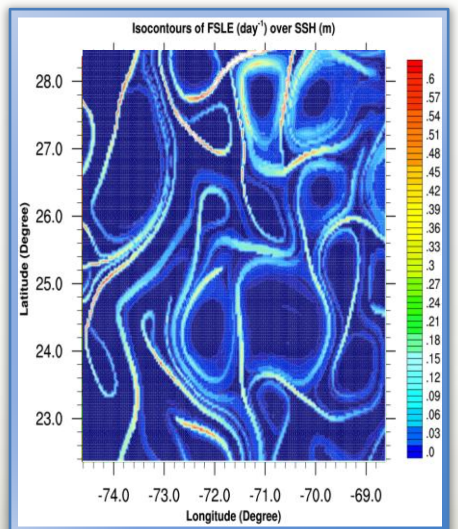
  (Inspired by D'Ovidio et al. 2004, 2009 and Lehan et al. 2007 works on the characterization of submesoscales by Lyapunov exponents)

  - Twin experiment approach:
    - Truth assumed to be known
  - Step 1:
    - Are Lyapunov exponents invertibles to larger scale ocean circulation ?
  - Step 2:
    - Are submesoscale ocean color images invertibles to larger scale ocean circulation ?

Step 1:

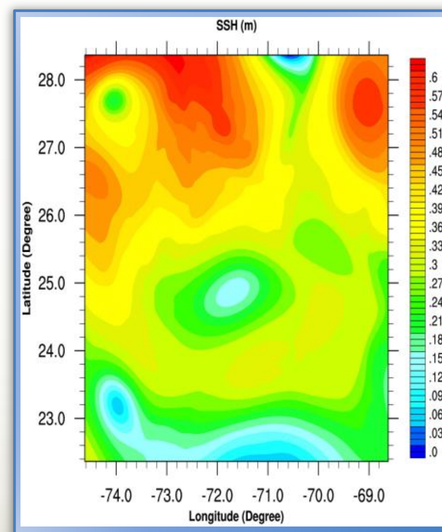
Are Lyapunov exponents invertibles to larger scale ocean circulation ?

?



Submesoscales

At this stage characterized by Lyapunov exponents



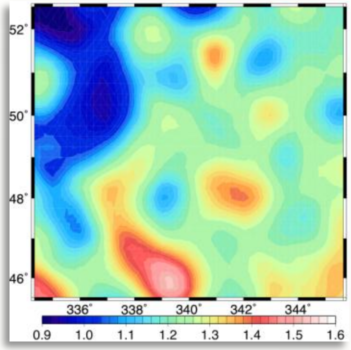
Mesoscales

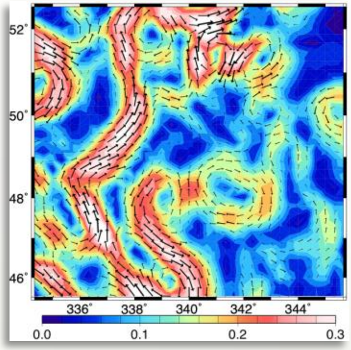
For example velocity fields

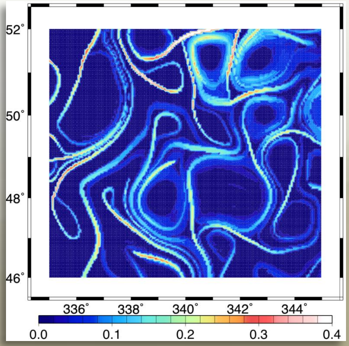
Methodological approach

- **Data:**
  - A North East Atlantic dataset (POMME region)
  - AVISO altimeter data (Topex/Poseidon, ERS1/2, Jason, ENVISAT satellites)
  - 1992-2008 period: 16 years
  - 1/3 resolution
  - Weekly anomalies + Mean sea surface: 798 weekly mesoscale velocity maps
  - Lyapunov exponents (FSLE) computed from those velocity fields at 1/18 resolution

- **Reference**
  - One specific day taken as truth







classical — pseudo-observations — image

$$J = J_C + J_P + J_I$$

$$J = \| y - Hx \| + \| y^p - H^p x \| + \| I_D - I_M \|$$

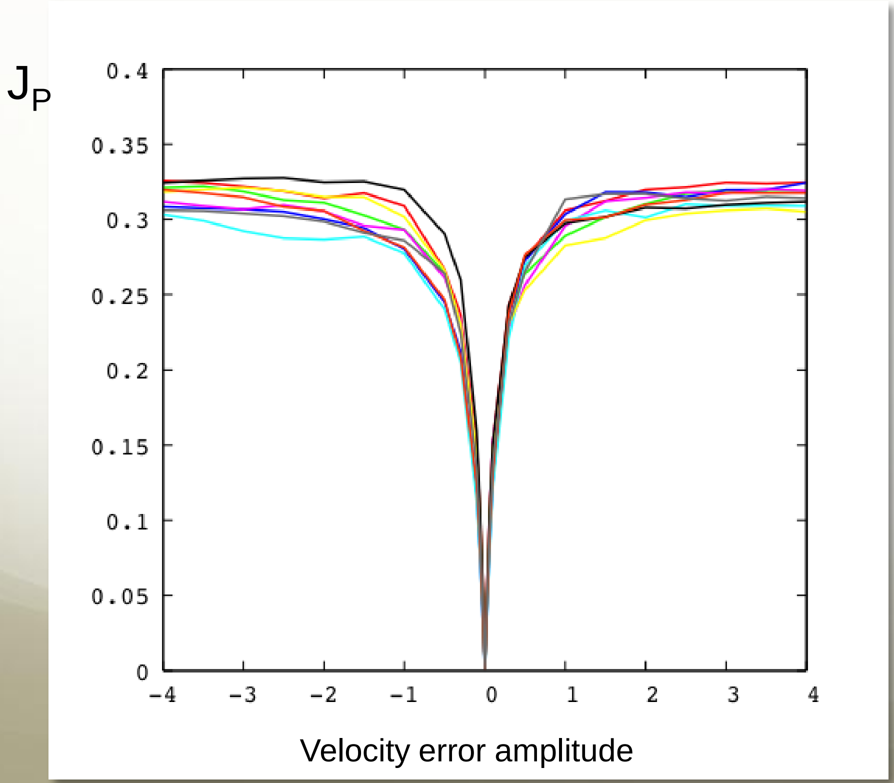
- **Definition of a cost-function**
  - **Classical data:** data and model variable linked by observation operator
  - **Proxy data:** data and model variable linked by proxy observation operator
  - **Image data:** both data and model variables are converted into images, only the images "speak" together, not the actual variables

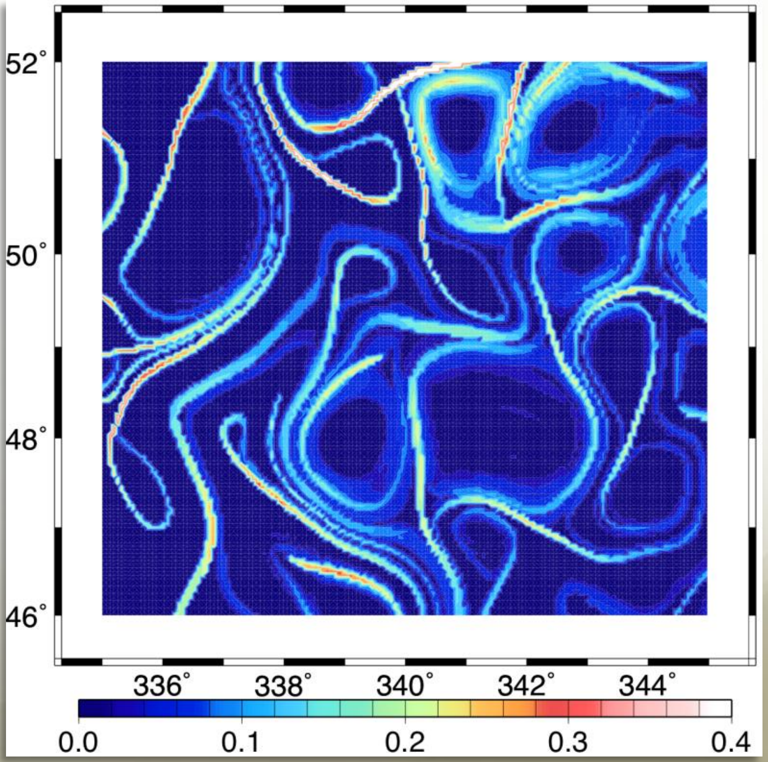
- **Solving the inverse problem: there is a cost function minimum which can be identified**
  - Sensitivity studies
    - Studying the variations of the cost function (FSLE misfits) as a function of velocity errors
    - Exploring the error space proposed by the AVISO datasets
  - Inversion:
    - Actually minimizing the cost function and identify the minimum
    - Simulated annealing algorithm

The FSLE as proxy data

- Minimize

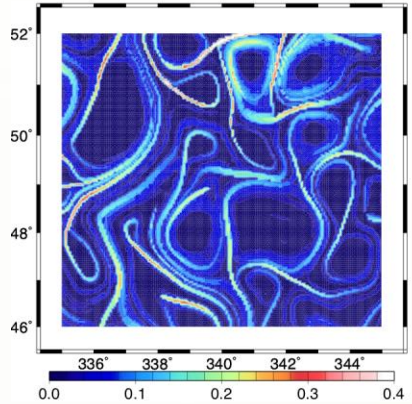
$$J = J_P = || y^p - H^p x ||$$



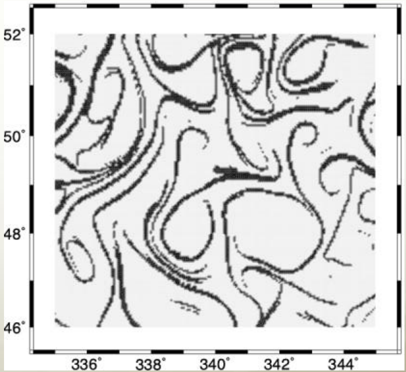


Transform the Lyapunov exponents into (very simple) images

- Observed image structures are extracted using a binarization of the gradient norm
- Y= 1 if || δY || > σ otherwise Y=0
- The threshold σ is chosen such a given percentage of pixels are kept (80%)
- 1/18 resolution for FSLE, FSLE image, velocity control at AVISO scale (1/3)



|| δFSLE ||

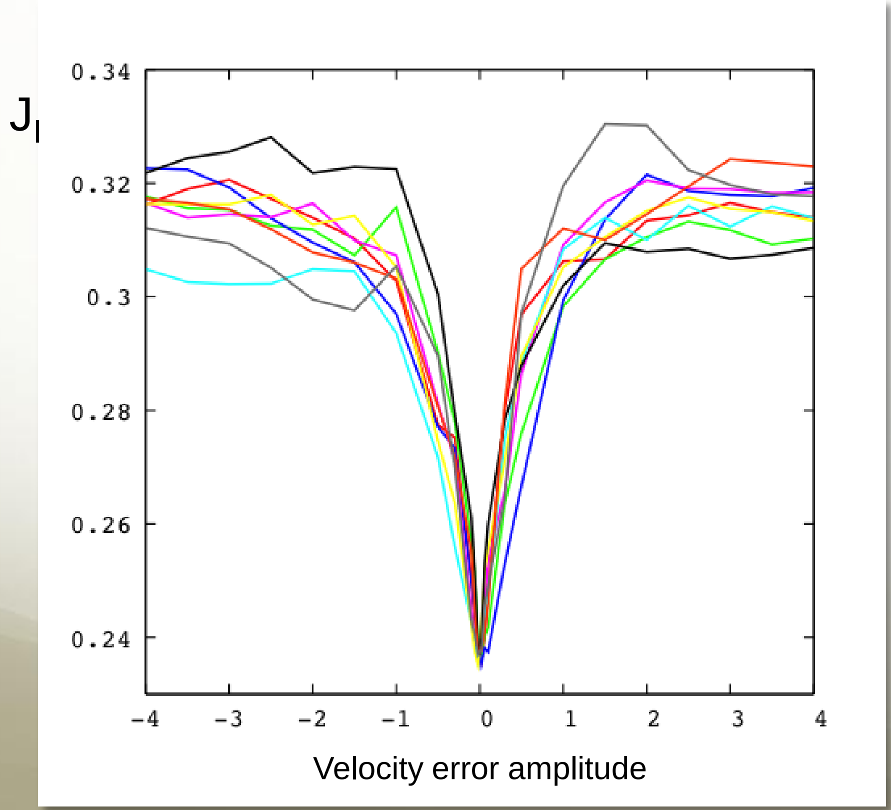


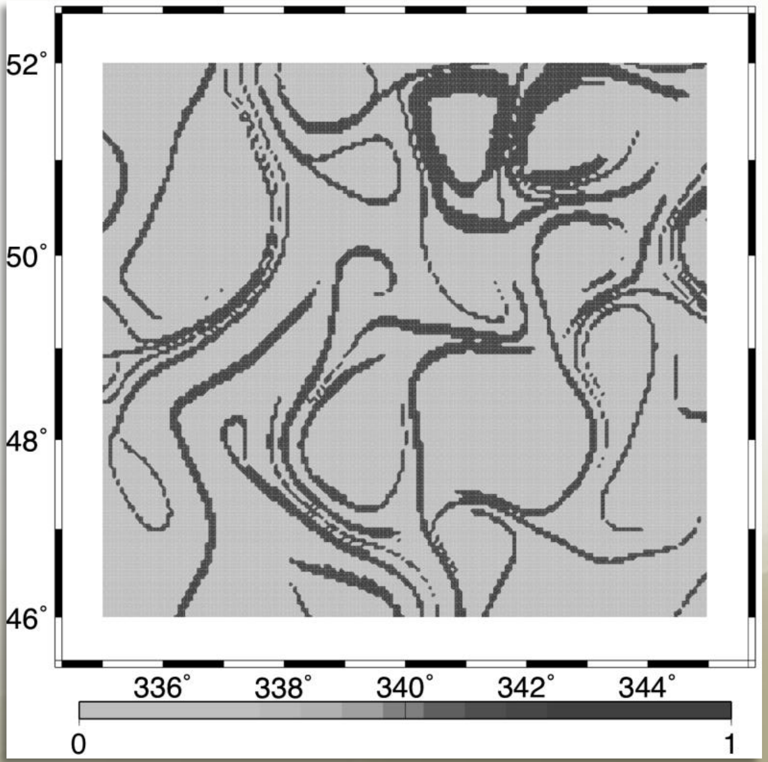
Skeleton image

The FSLE as image data

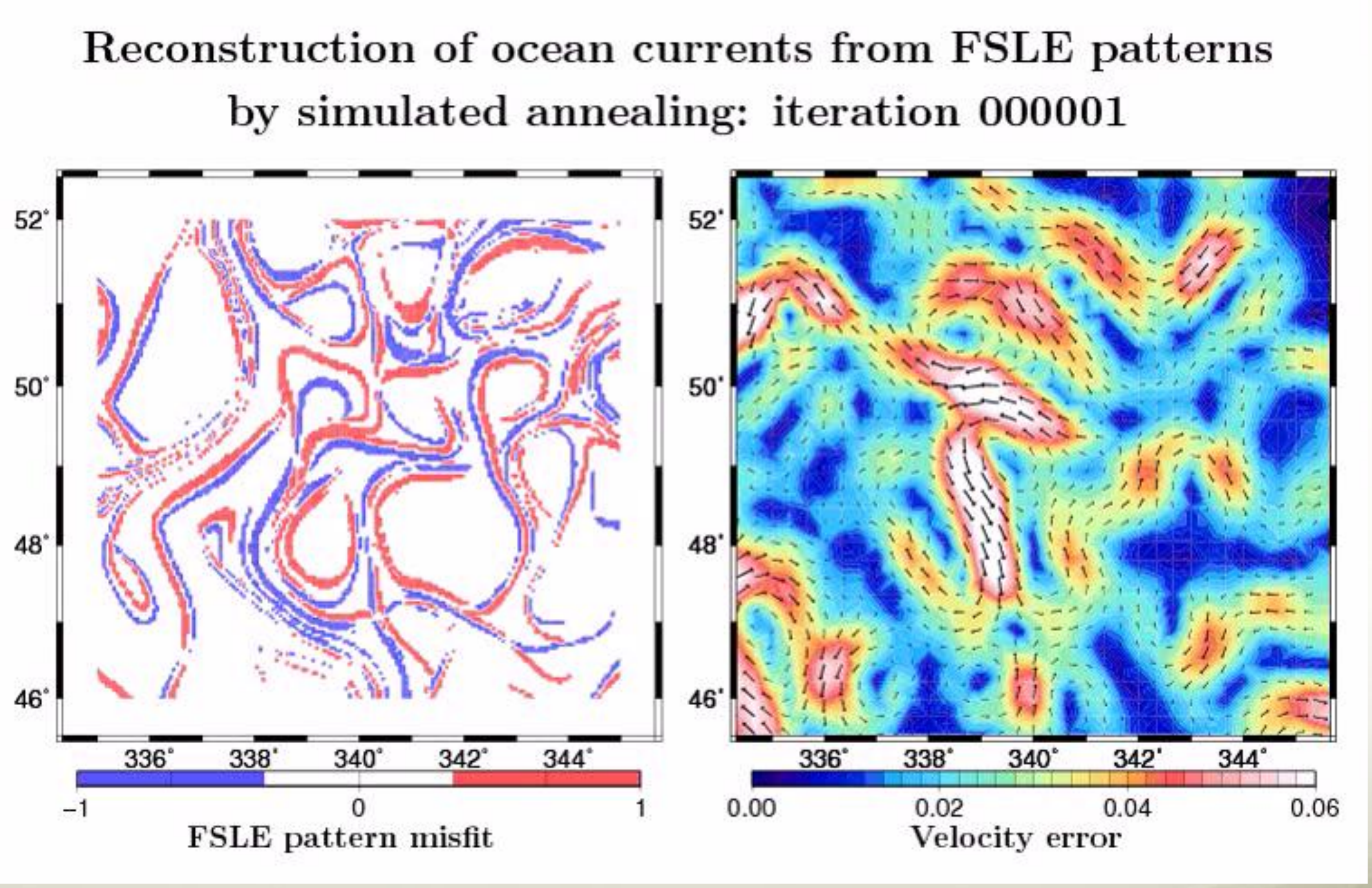
- Minimize

$$J = J_I = || I_D - I_M ||$$





The FSLE as image data (2)

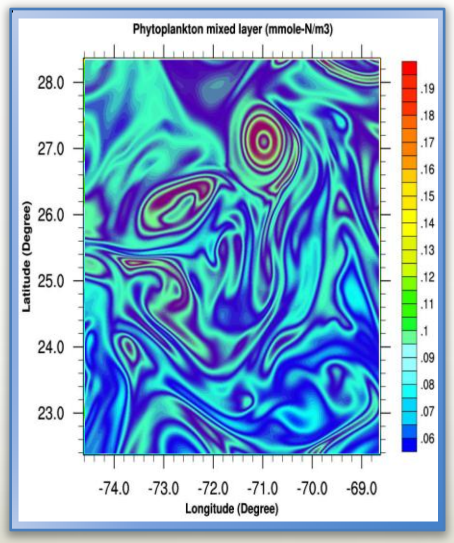


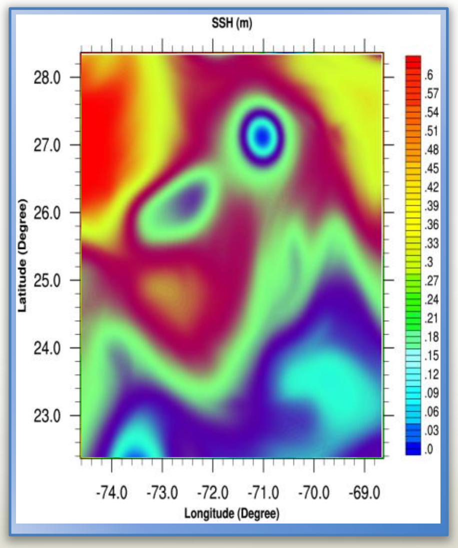
Step 2:

Are submesoscale ocean color images invertibles to larger scale ocean circulation ?

Phytoplancton

SSH



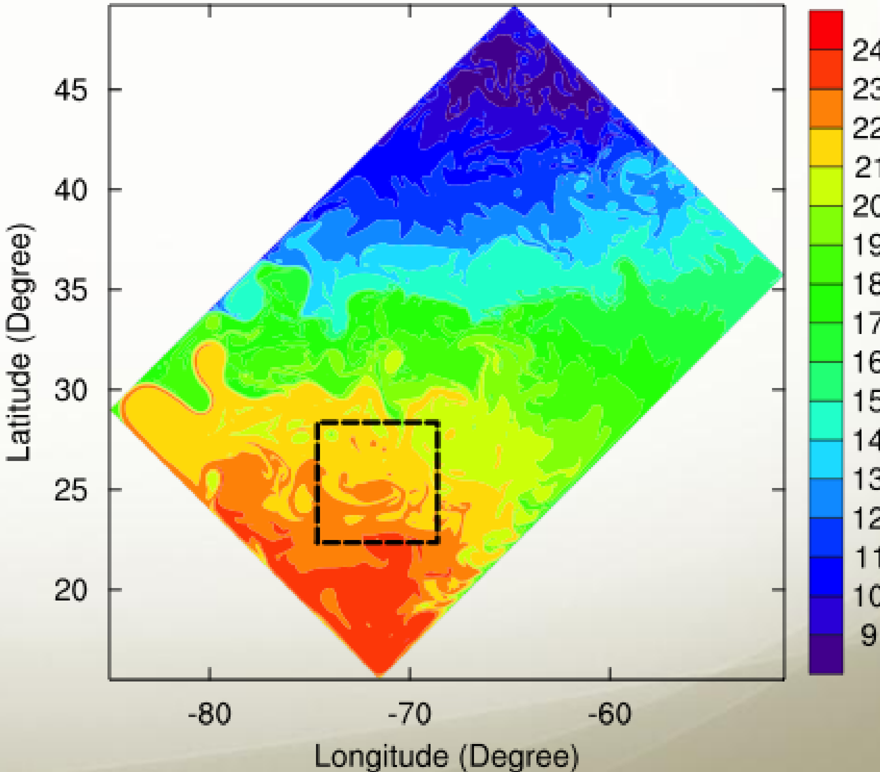


Submesoscales

Mesoscales

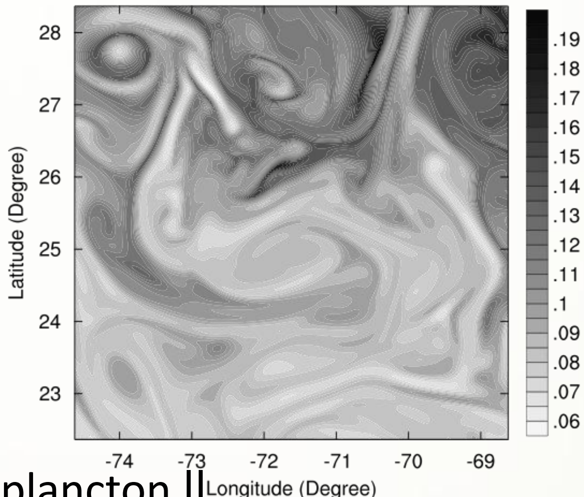
Methodological approach

- Data extraction from the GYRE numerical experiment database (Lévy et al., 2009)
- Double-gyre Gulf Stream-like experiment
- Coupled physico-biogeochemical model (NEMO-LOBSTER)
- 1/54 resolution
- 6 by 6 box extracted from the full domain

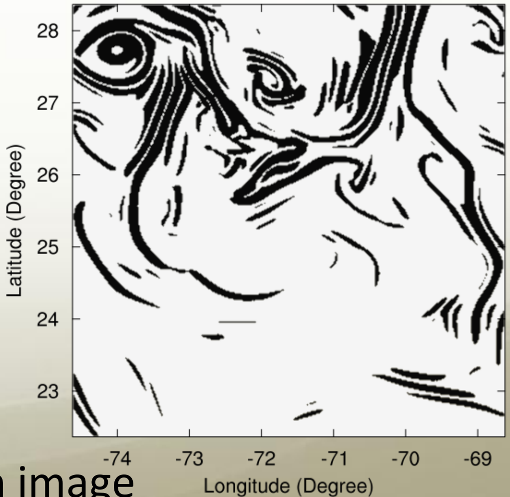


Generation of phytoplancton (or SST) images

- Observed image structures are extracted using a binarization of the gradient norm
- $Y = 1$ if $\| \delta Y \| > \sigma$ otherwise $Y = 0$
- The threshold σ is chosen such a given percentage of pixels are kept (e. g. 80%)
- Computed on 1/54 resolution (velocity field at 1/4)



|| δPhytoplancton ||

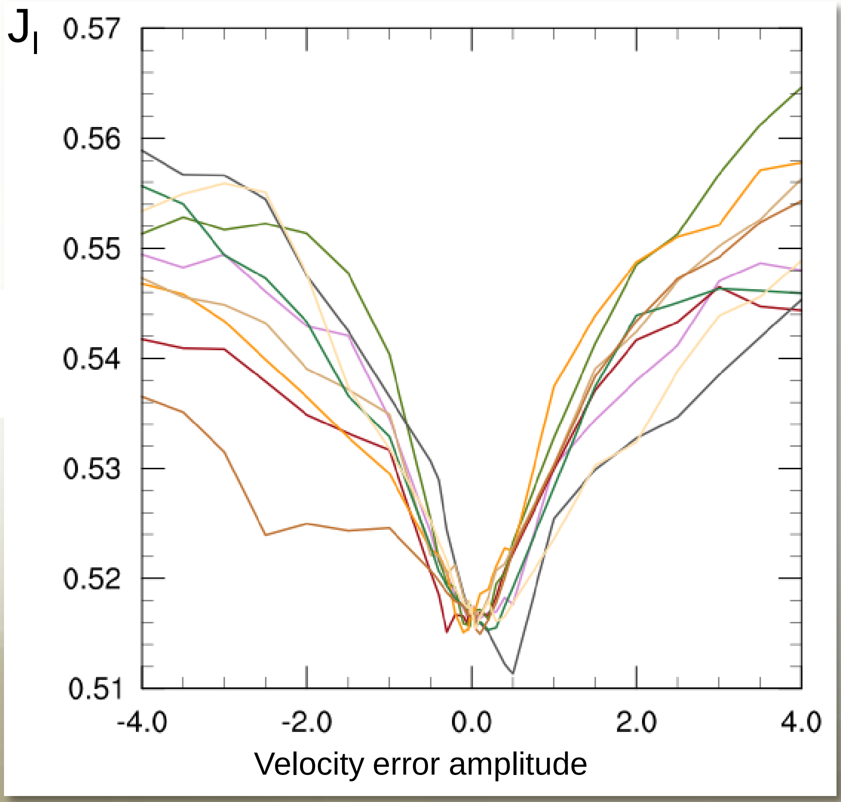


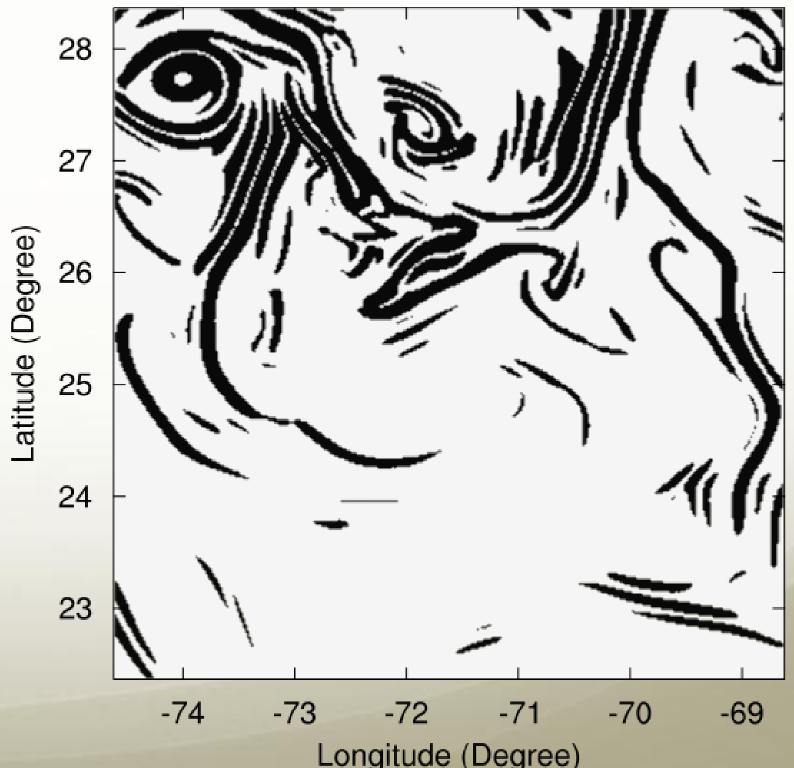
Skeleton image

Phytoplanction as image data

- Minimize

$$J = J_I = \| I_D - I_M \|$$

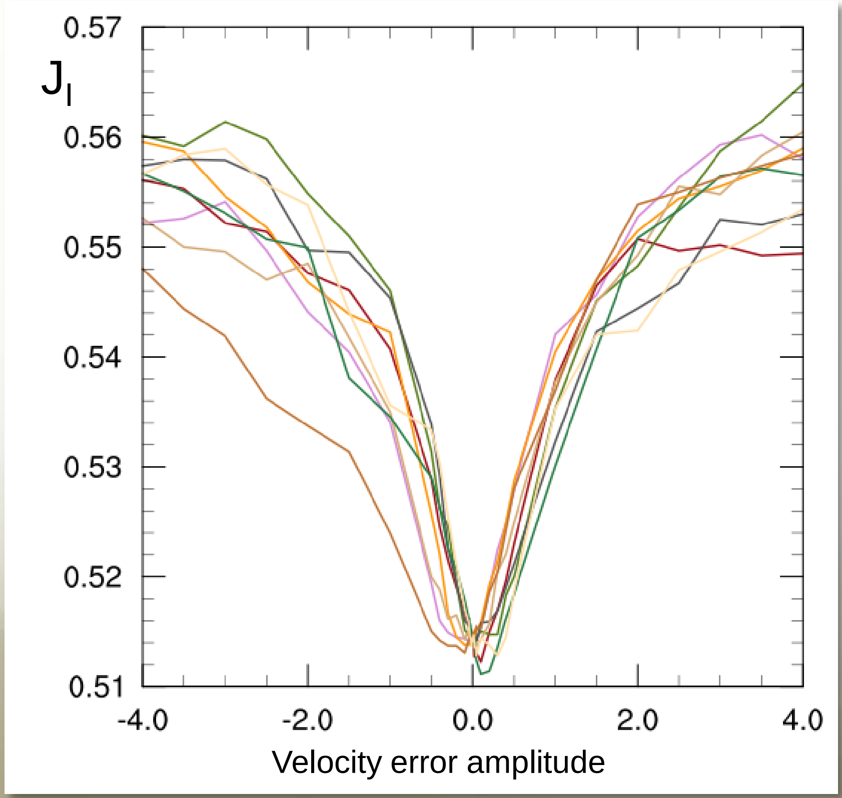


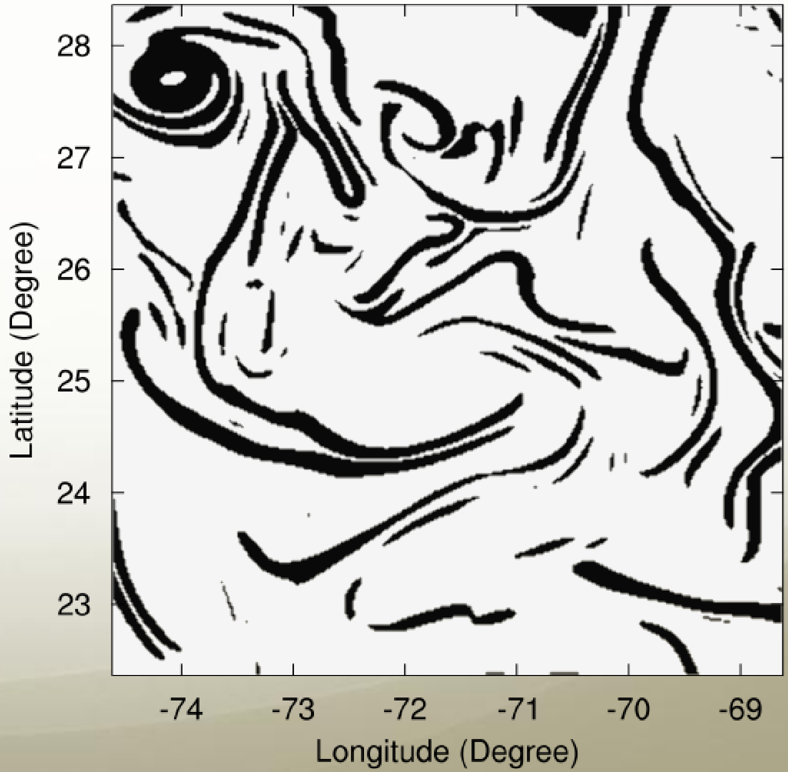


SST as image data

- Minimize

$$J = J_I = || I_D - I_M ||$$





Conclusions

- Lyapunov exponents (FSLE) can be inverted to larger scales
  - Submesoscales must be used to (partly) control mesoscales and larger scales
    - Other data such as altimetry certainly necessary (complexify the cost function, provide first guess, …)
  - A way to parameterize submesoscale effects in eddy-resolving only models ?
    - Here: 1/18 into 1/3
    - Range of validity of strain effects ?
  - Sensitivity study and inversion performed, full DA to be done
- Phytoplanction (or other tracers such as SST) invertible to larger scales
  - Feasibility of the phytoplanction/SST inversion
  - Resolution factor: 1/54 into 1/4
  - Sensitivity study performed (more required), full inversion and DA to be done

Conclusions (2)

- Ocean dynamics and ocean biogeochemistry "talking together" through image structures
  - Ocean Color data might be used to control ocean physics
- Limits:
  - Twin experiment context
  - Limits of Lyapunov exponent image and physical representations
  - Limited effort dedicated on image generation (binarization)…
  - Data assimilation specific (minimization, non-linearity, …)
  - Etc…
- Next
  - Setting up the full submesoscale DA system in a coupled physico-biogeochemical model