Benchmarking Mesoscale variability in global eddy-permitting simulation against satellite data

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@NLOA 2016
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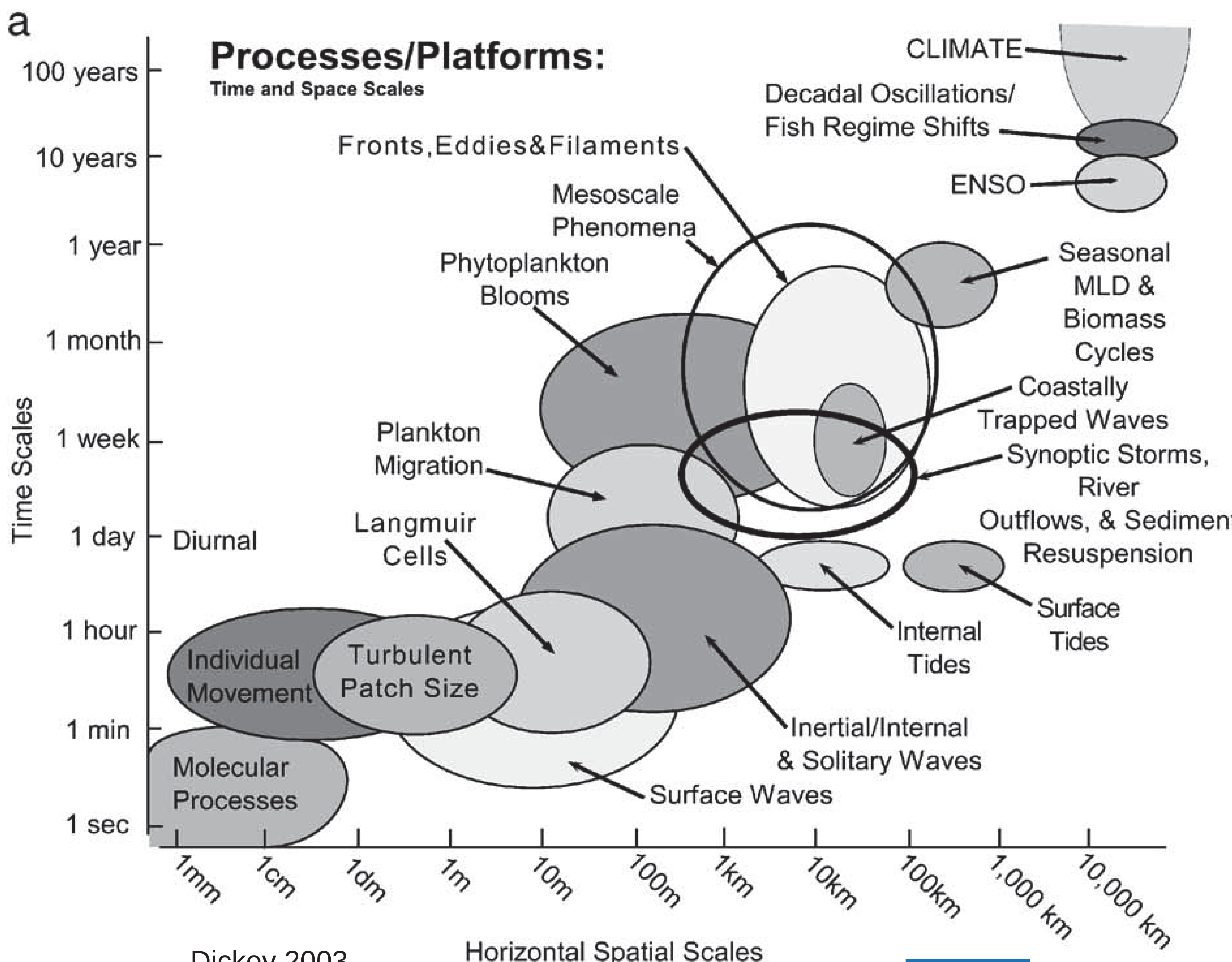
cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

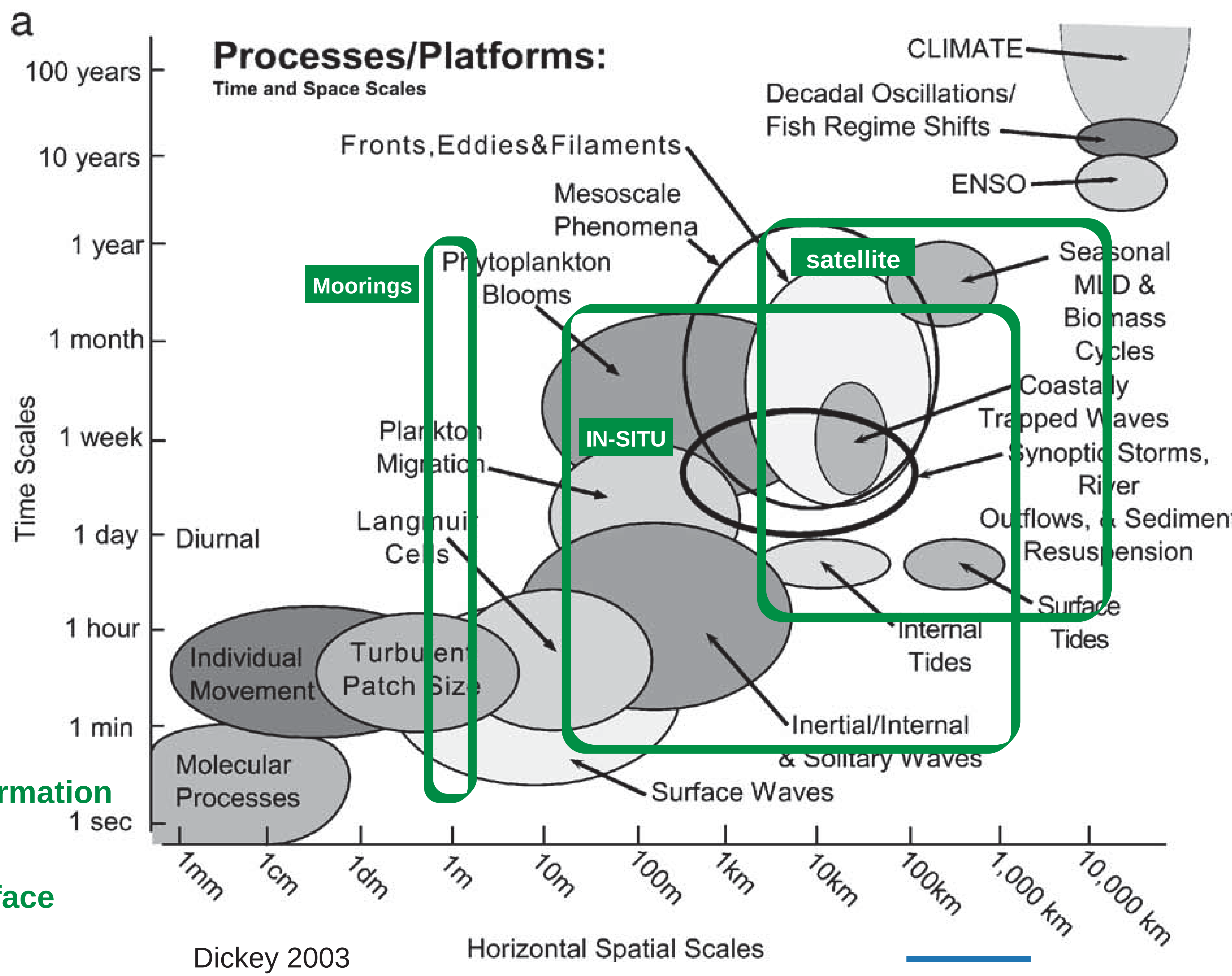
Outline



Dickey 2003

Eddy permitting models

Outline



Few and sparse information from in-situ data

satellite monitor surface physics only

Dickey 2003

Eddy permitting models

Outline

- Eddies are responsible for

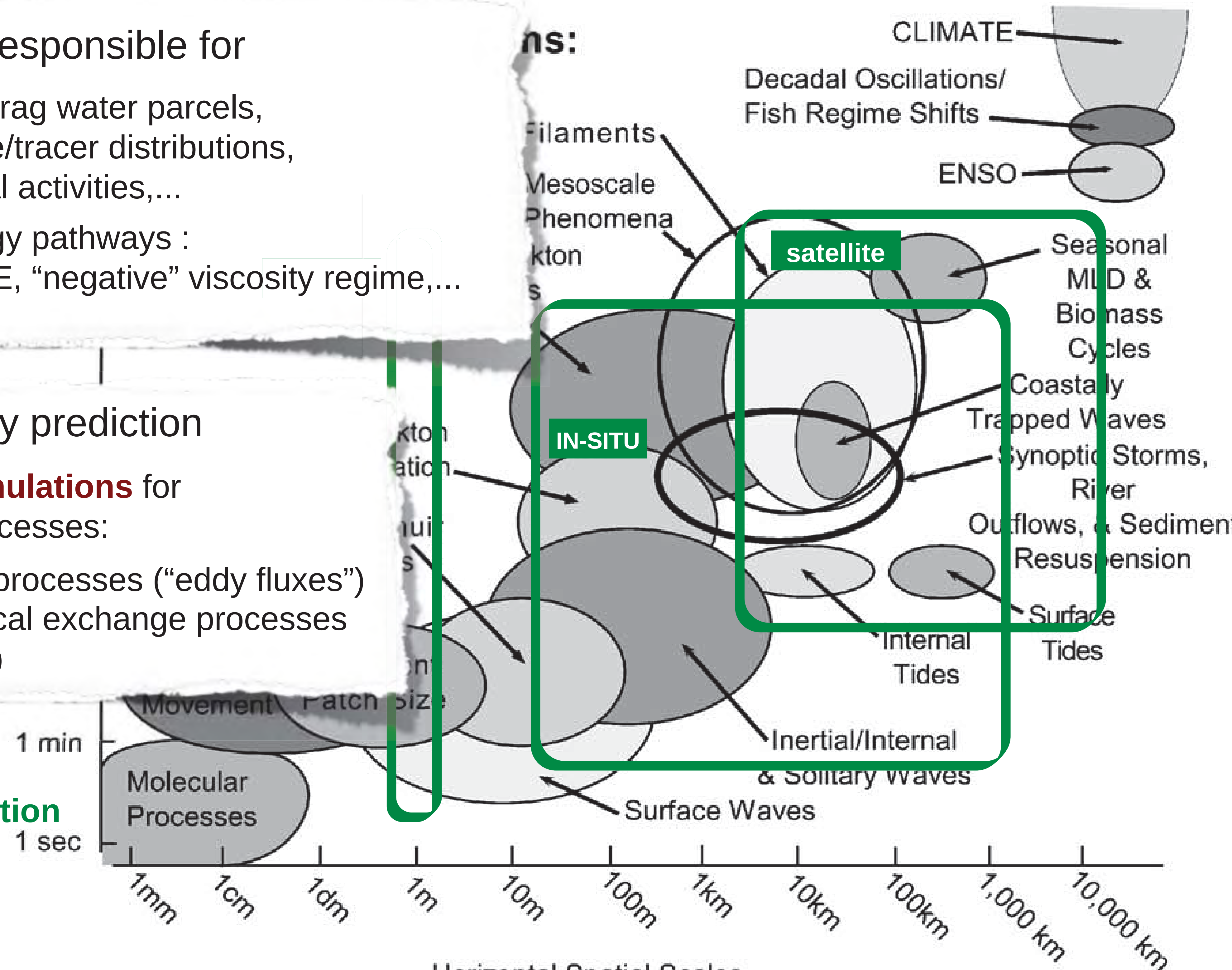
as ocean probes : drag water parcels, influencing resource/tracer distributions, enhancing biological activities,...

as preferential energy pathways : transferring PE to KE, "negative" viscosity regime,...

- Quantitatively prediction

need to rely **on simulations** for main unknown processes:

-- lateral exchange processes ("eddy fluxes")
-- upper-ocean vertical exchange processes ("vertical exchange")



Dickey 2003

Few and sparse information from in-situ data

satellite monitor surface physics only

Eddy permitting models

Outline

- Role for assimilation :
  - correct initial ocean state towards a more realistic description
  - include possible missing features caused by poor resolution

→ at any length-scale? What's its performance at mesoscale level?

Quantitative assessment of variability over three datasets

1) NEMO free simulation at 1/4
10y run 2003-2012

2) C-GLORS reanalysis of NEMO simulation at 1/4
10y 2003-2012
(Storto et al. 2014)

3) Satellite/scatterometer dataset at 1/4
10y run 2003-2012
(AVISO/OSCAR datasets)

- Global ocean basin

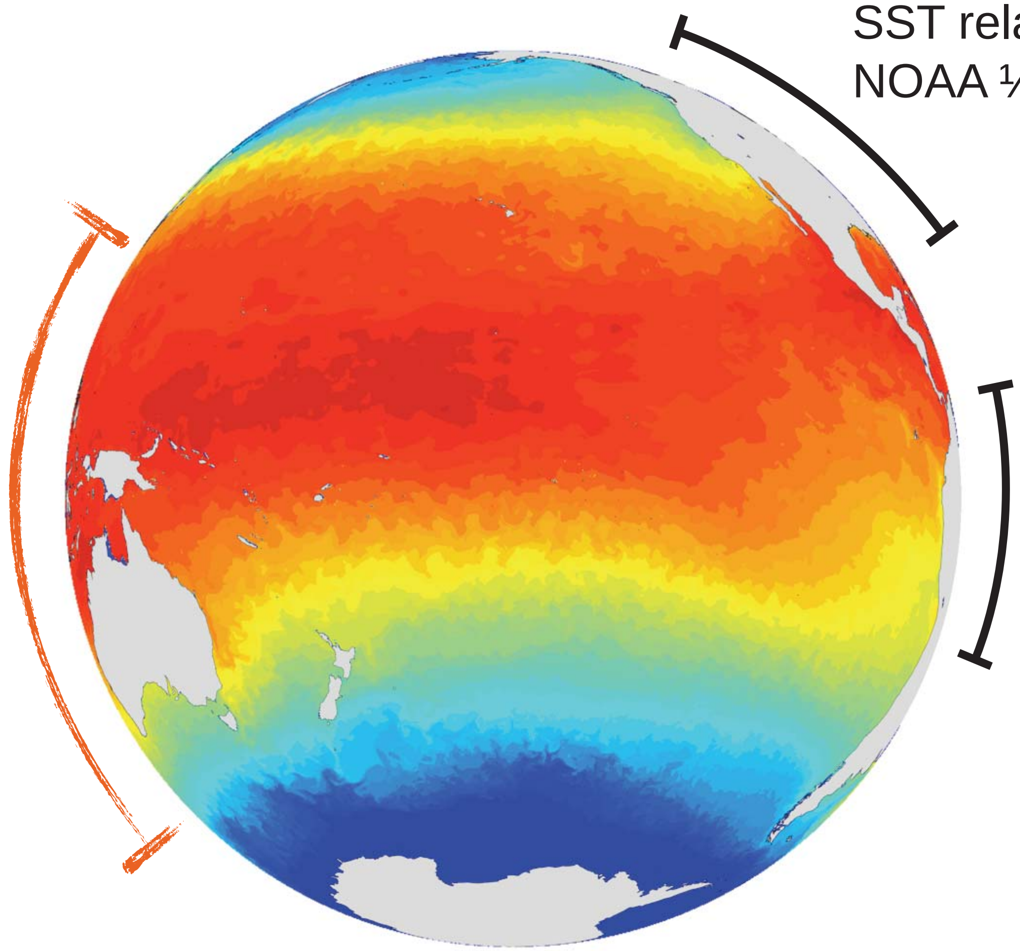
OceanVar assimilation scheme

- C-Glors exploits a 3Dvar assimilation scheme (*Storto et al. 2015*) with updates from multiple datasources.

3Dvar assimilation data :

- in-situ temperature and salinity (XBT, CTD, Argo, Moorings, etc. assembled by Ifremer)

- along-track satellite altimetry observations (Jason-2, Altika and CryoSat2 by CLS/AVISO)



SST relaxation scheme towards NOAA ¼ Analyses

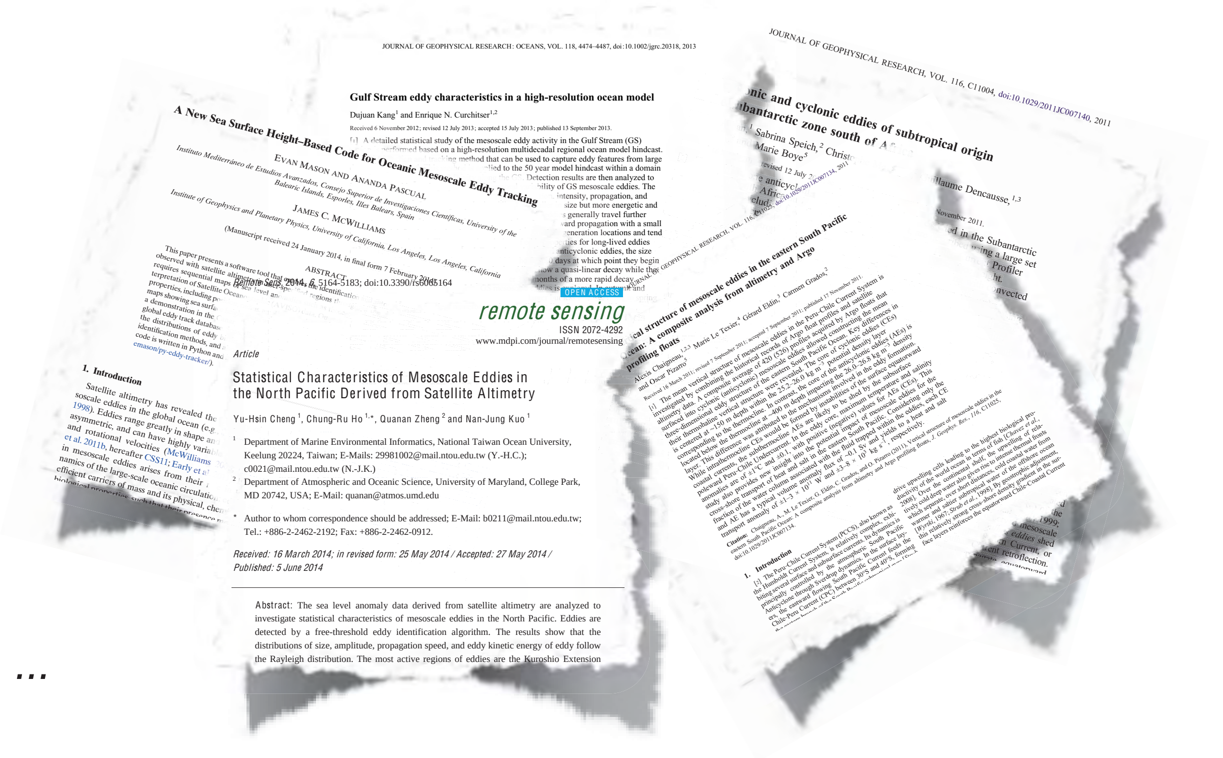
SSS relaxation scheme to monthly objective analysis of MetOffice EN4

Corrections are added to the surface/sub-surface salinity and temperature (Cooper et al. 1996)

A plethora of schemes in literature

- Regional eddy tracking

  - Okubo-Weiss Method *Weiss (1991), Isern-Fontanet et al. (2004)...*
  - 2D-Wavelet Methods *Doglioli et al. (2007), ...*
  - Winding angle Methods *Sandarjoen et al. (2000), ...*
  - Geodesic transport theory *Beron-Vera et al. (2013), ...*
  - Geometric analysis UV fields *Nencioli et al. (2010), ...*
  - ....



- Some comparison with in-situ or satellite data

  Trani et al. (2011), Chaigneau et al. (2011),Griffa et al. (2008), Shoosmith et al. (2005)...

Methods for Global Ocean

- This overall census shrinks to a bunch of methods considering the global ocean....

  - Okubo-Weiss method

    local balance between deformation and vortical flow

$$W = (v_x + u_y)^2 + (u_x - v_y)^2 - (v_x - u_y)^2 < 0$$

strains... relative vorticity

require a regional cutoff value $< \sigma(x, y)$

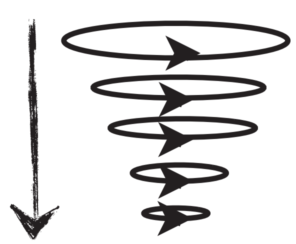
Very noisy, tendency of generating false-positive eddies

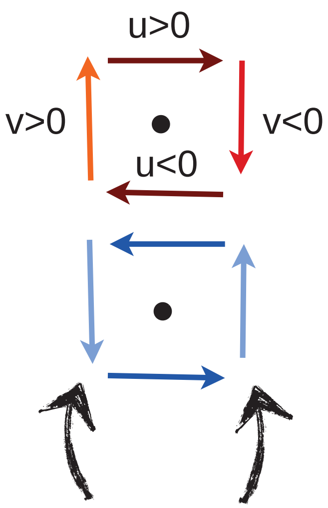
  - Our method is a modified geometry based algorithm

- detection of anomaly SSH pattern (horizontal extension)
- detection of rotation inside the eddy at least 5m deep

filter-out spurious eddy-like patterns that do not show a corresponding vortex
(close to coastline, merging AVISO SSH and OSCAR UV, ...)

Access to vertical extension of eddies!!!



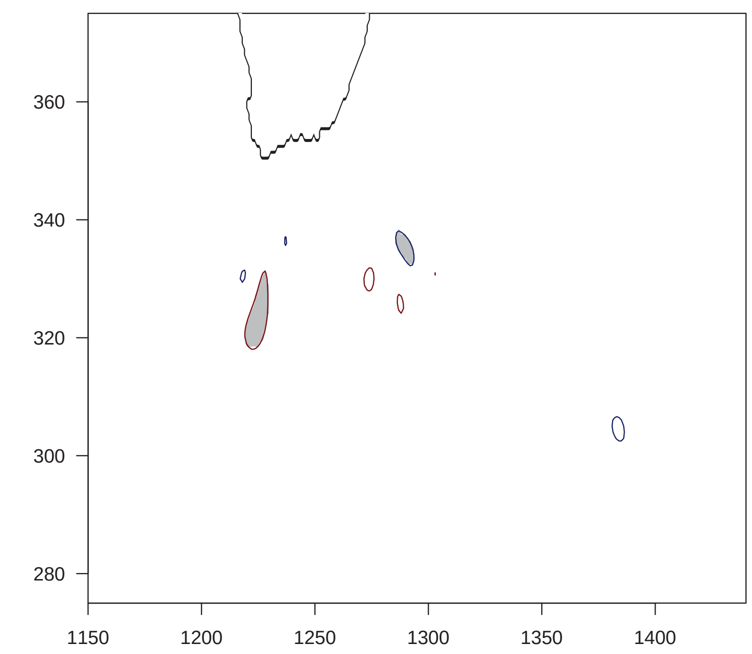


nearest points
on a square

Geometry-based method on SLA

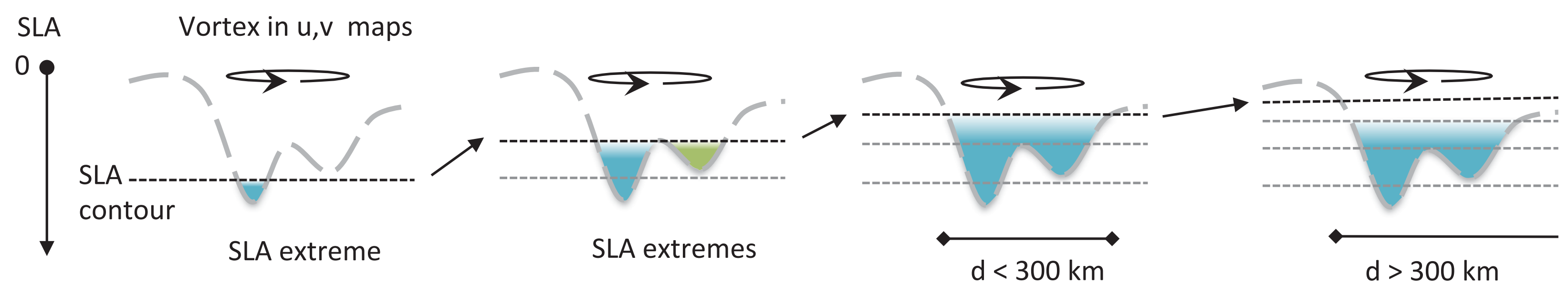
- Horizontal extension emerging from consecutive cuts of SLA contours

SLA > 50 cm

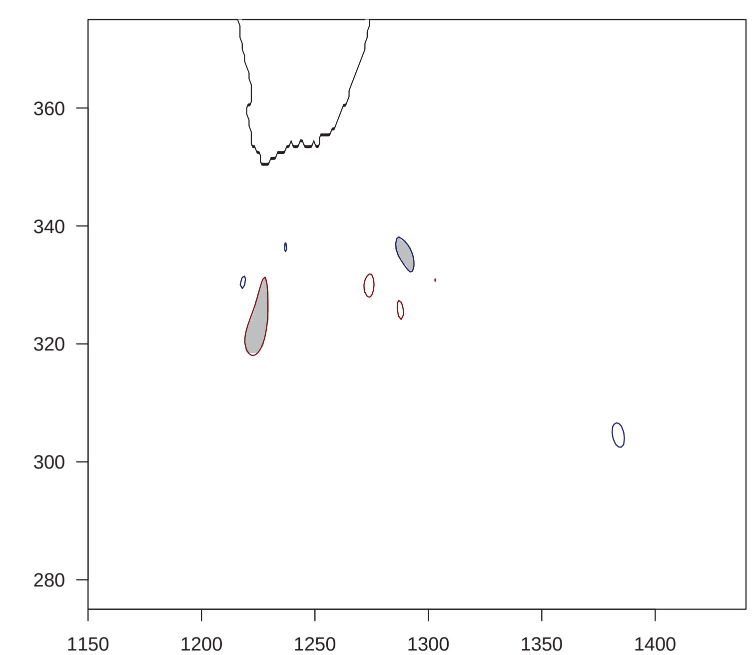


- ☑ Eddies are limited to a maximum area of *d* radius

1° method (size)

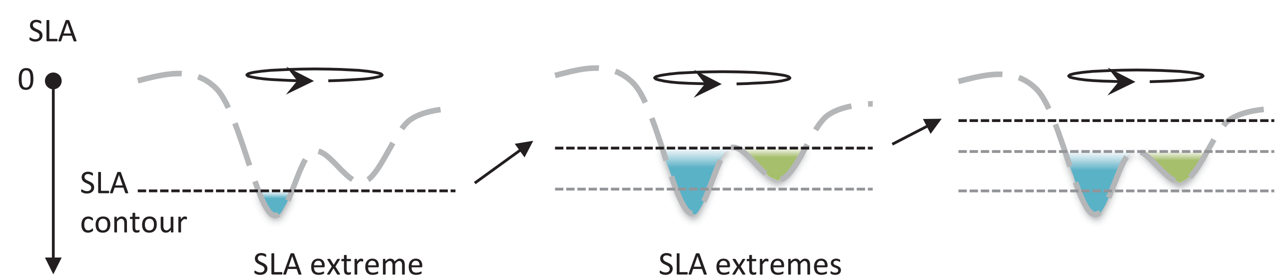


Cons: depending on a parameter *d*, weak dependency



- ☑ Any local extreme of SLA corresponds to a different eddy

2° method (single extreme)



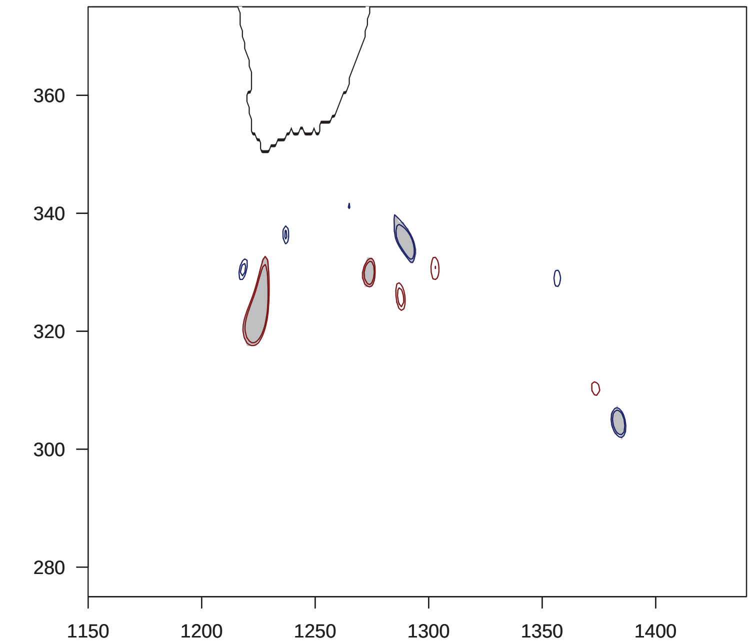
Cons: double counting "moving" eddies in maps that are averaged over several days.
underestimate of eddy size

Geometry-based method on SLA

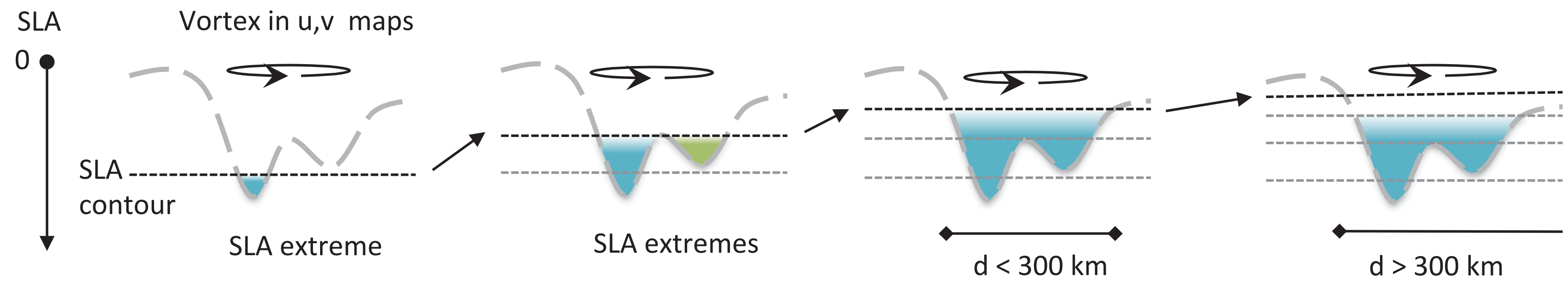
- Horizontal extension emerging from consecutive cuts of SLA contours

☑ Eddies are limited to a maximum area of *d* radius

SLA > 45 cm



1° method (size)



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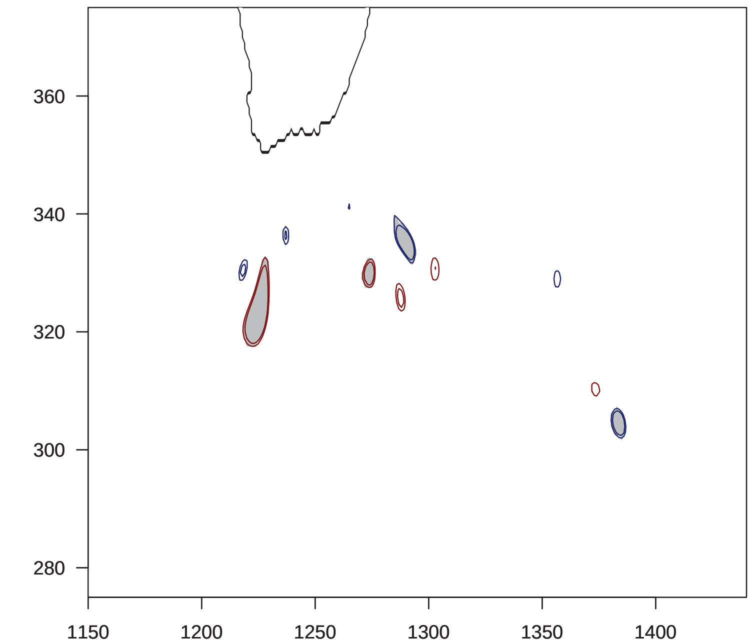

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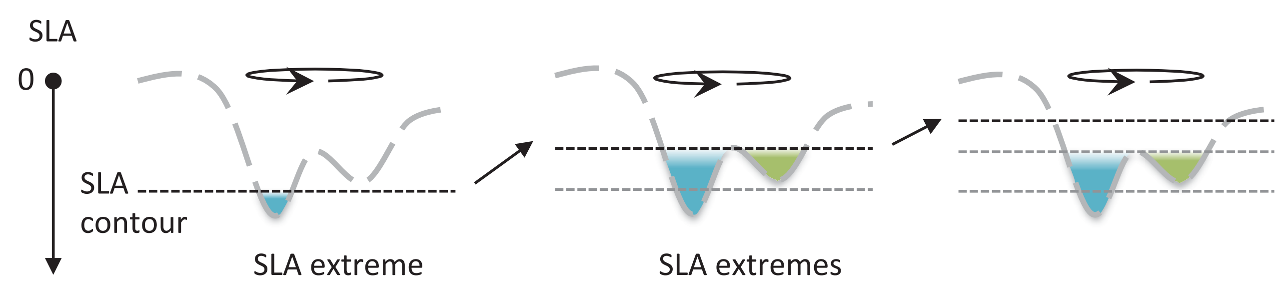

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Geometry-based method on SLA

- Horizontal extension emerging from consecutive cuts of SLA contours

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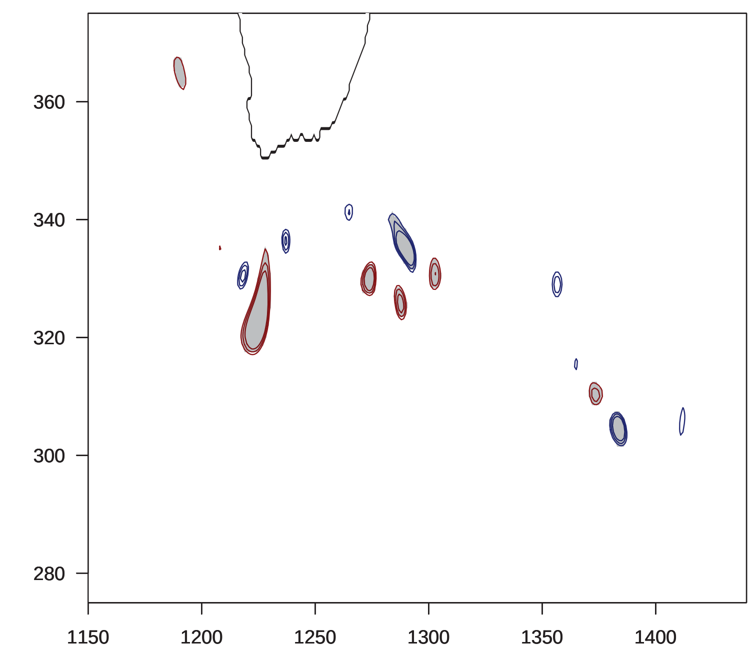

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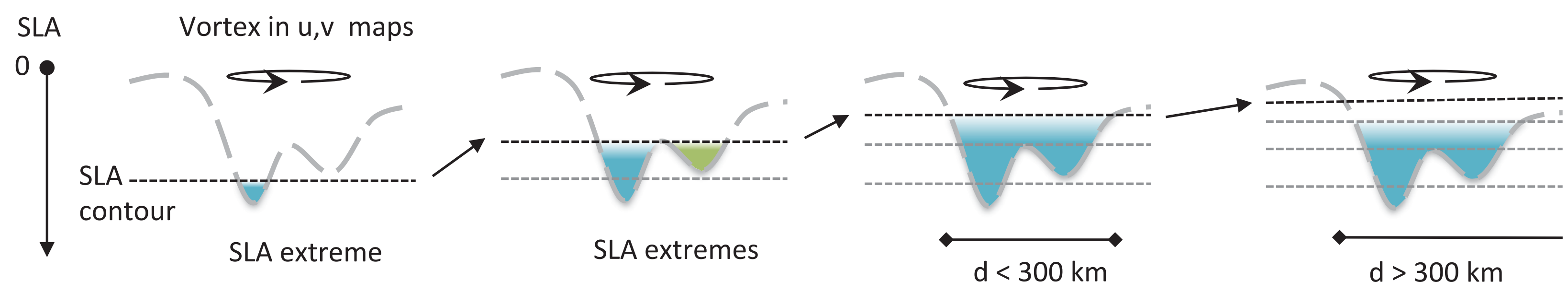

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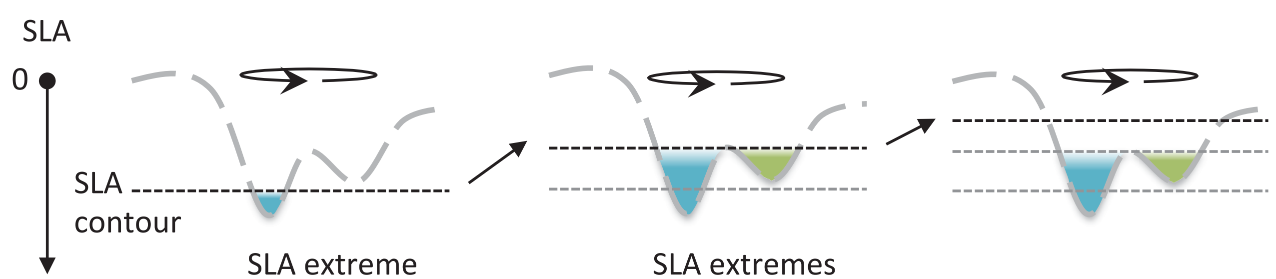

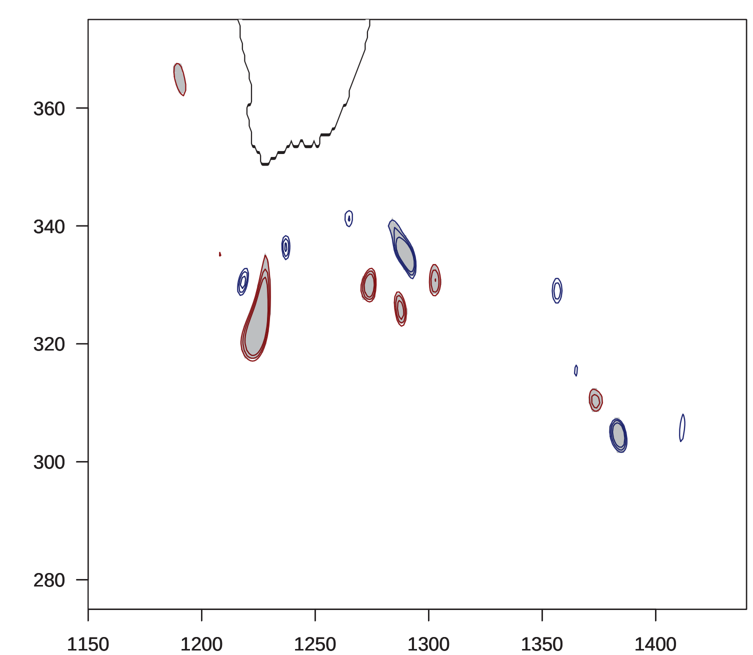

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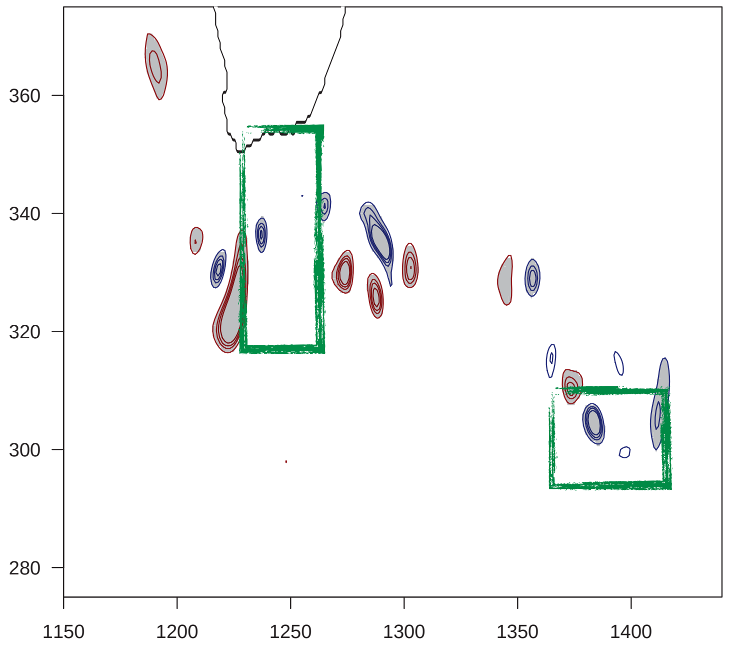
Geometry-based method on SLA

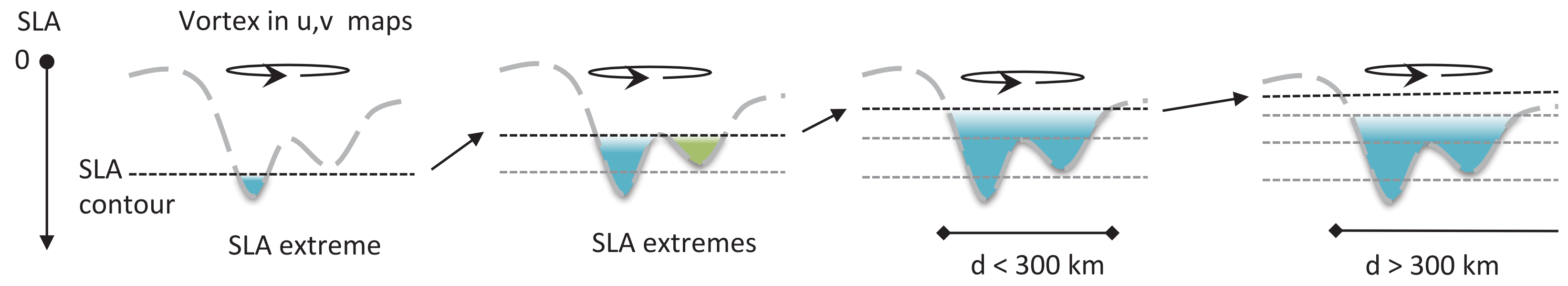
- Horizontal extension emerging from consecutive cuts of SLA contours

  - Eddies are limited to a maximum area of *d* radius

SLA > 40 cm



1° method (size)



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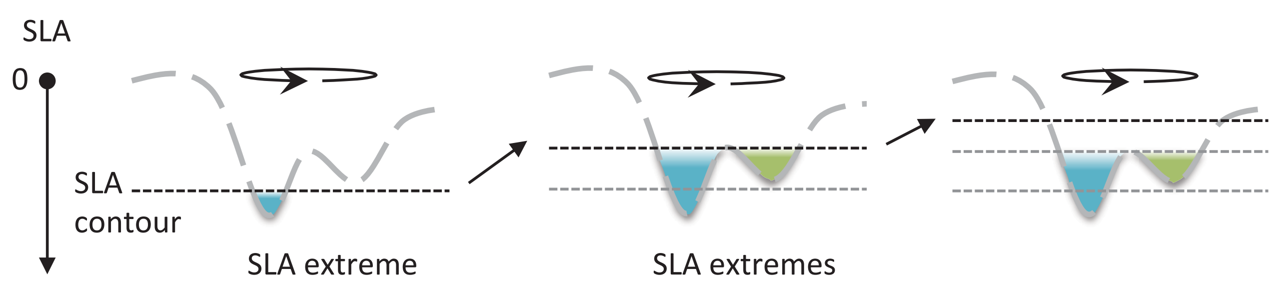
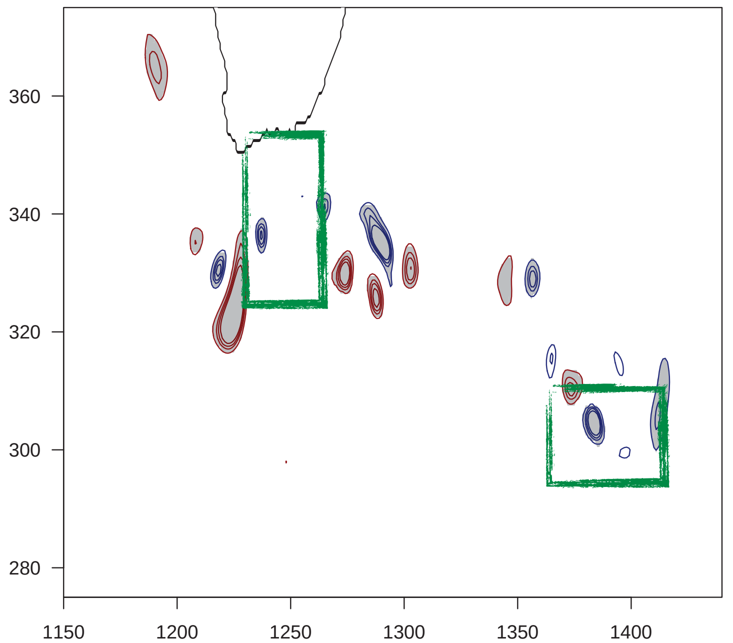
  - Any local extreme of SLA corresponds to a different eddy

2° method (single extreme)





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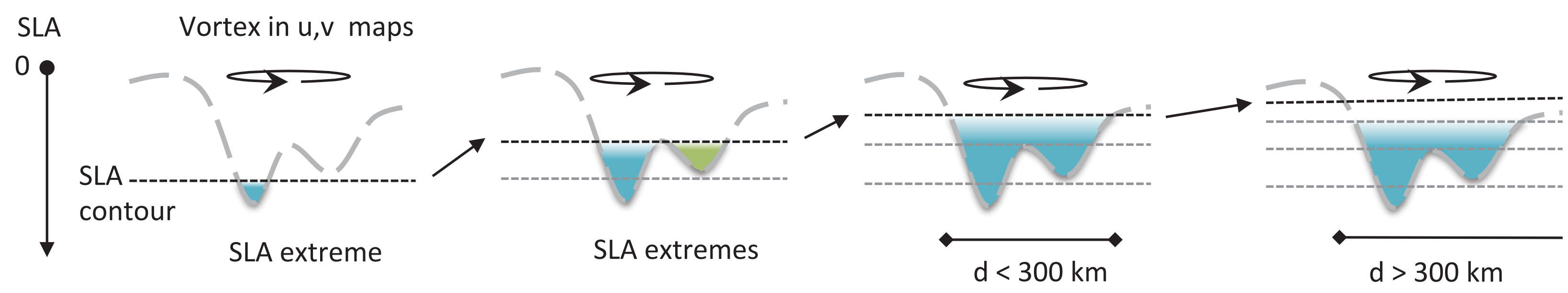
Geometry-based method on SLA

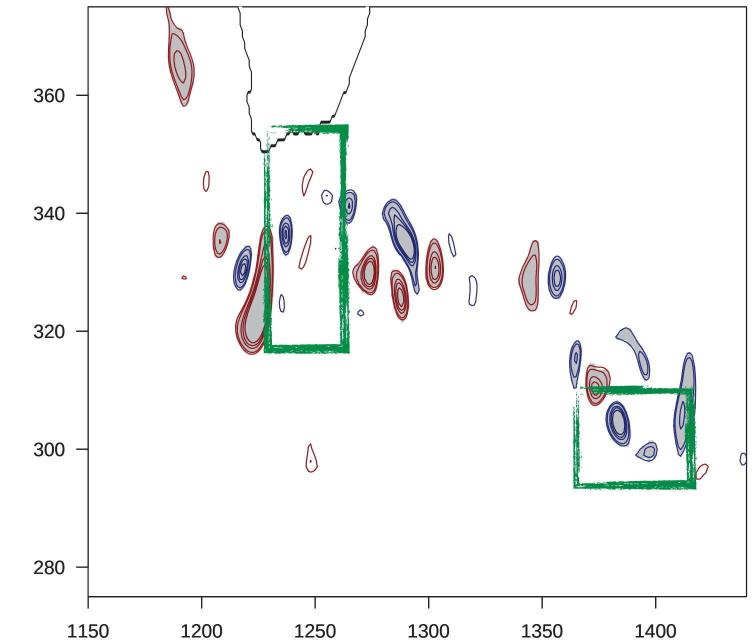
❑ Horizontal extension emerging from consecutive cuts of SLA contours

☑ Eddies are limited to a maximum area of *d* radius

SLA > 30 cm

1° method (size)





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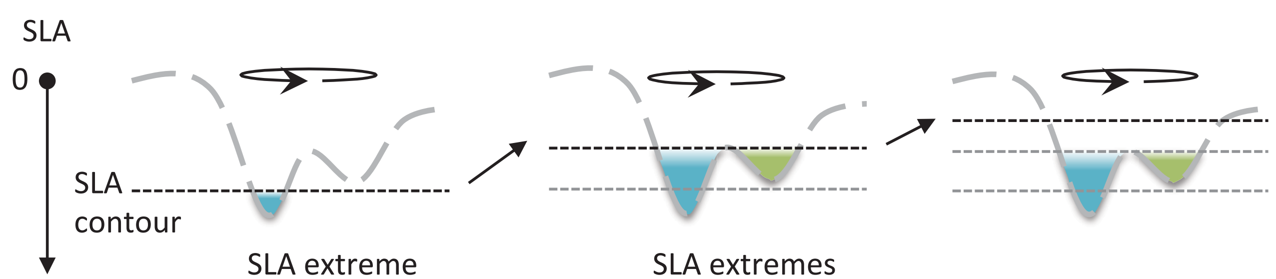
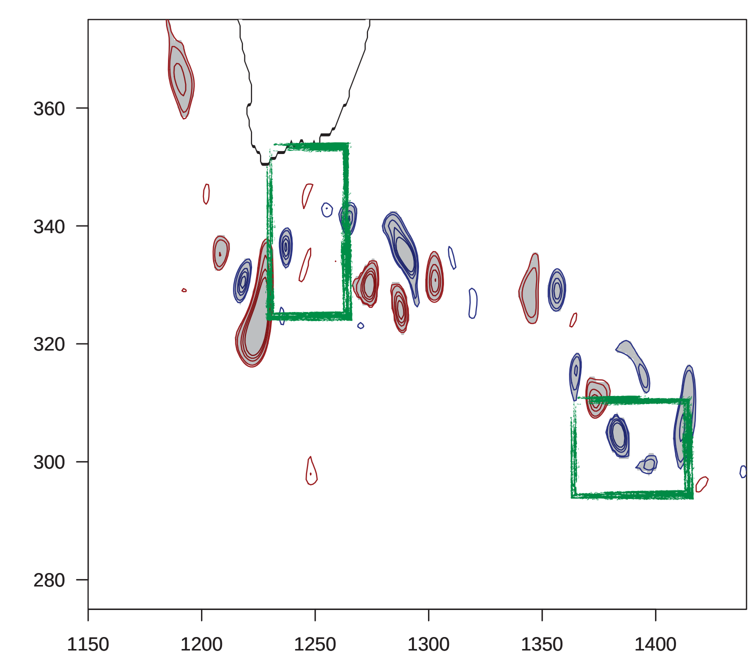
2° method (single extreme)





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Geometry-based method on SLA

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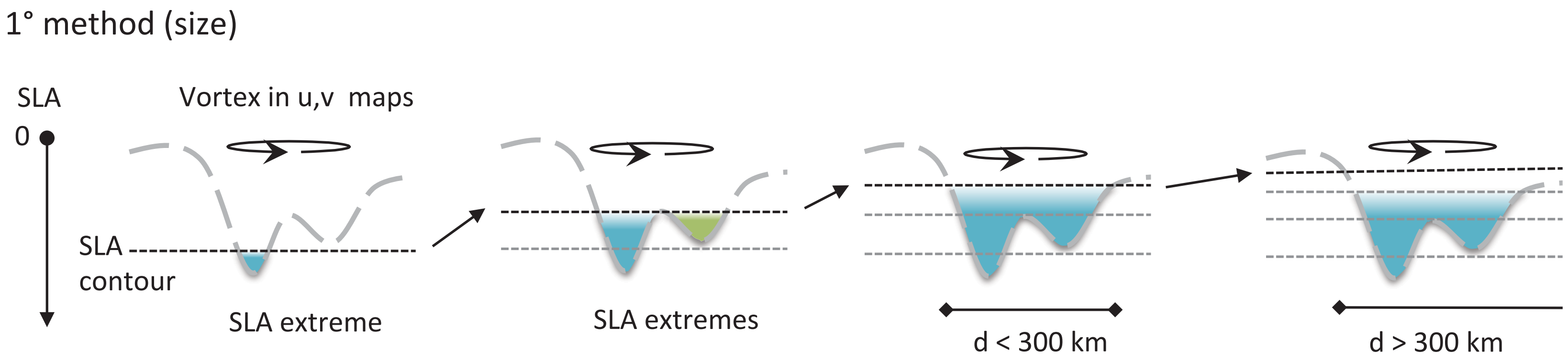

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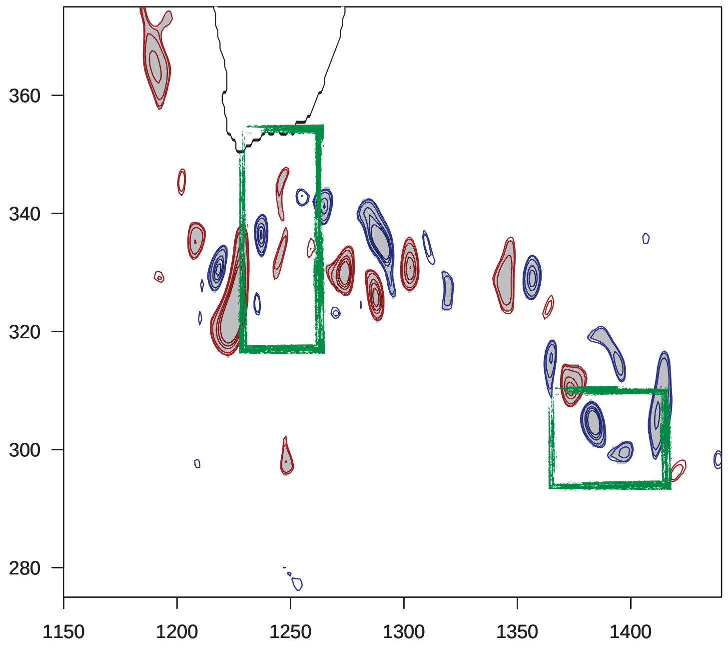
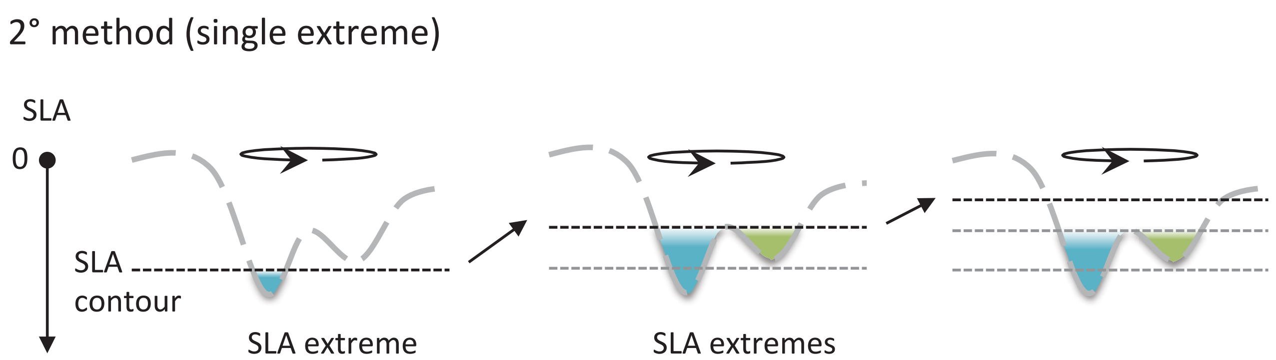
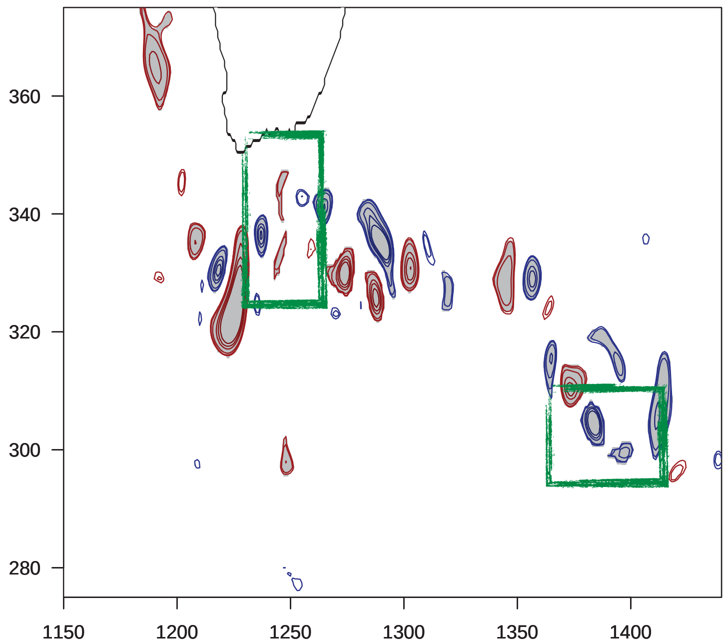
SLA > 25 cm



  - Any local extreme of SLA corresponds to a different eddy





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Geometry-based method on SLA

- Horizontal extension emerging from consecutive cuts of SLA contours

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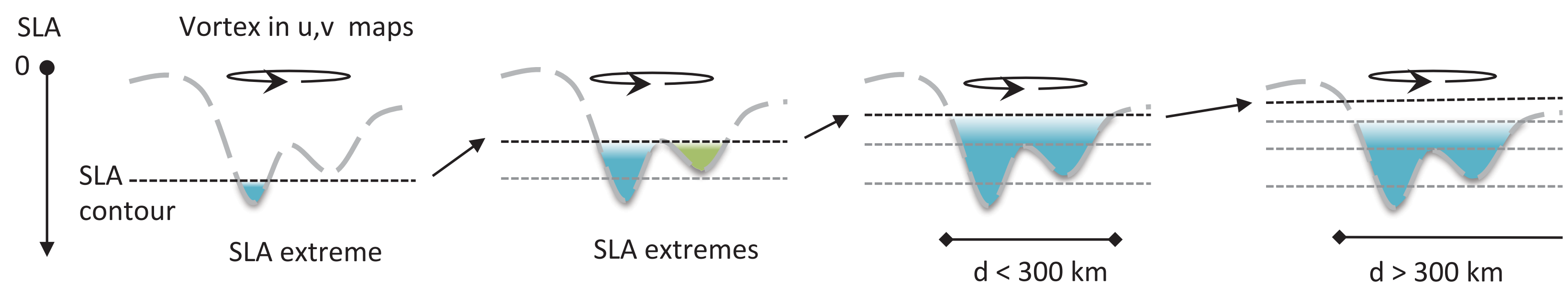
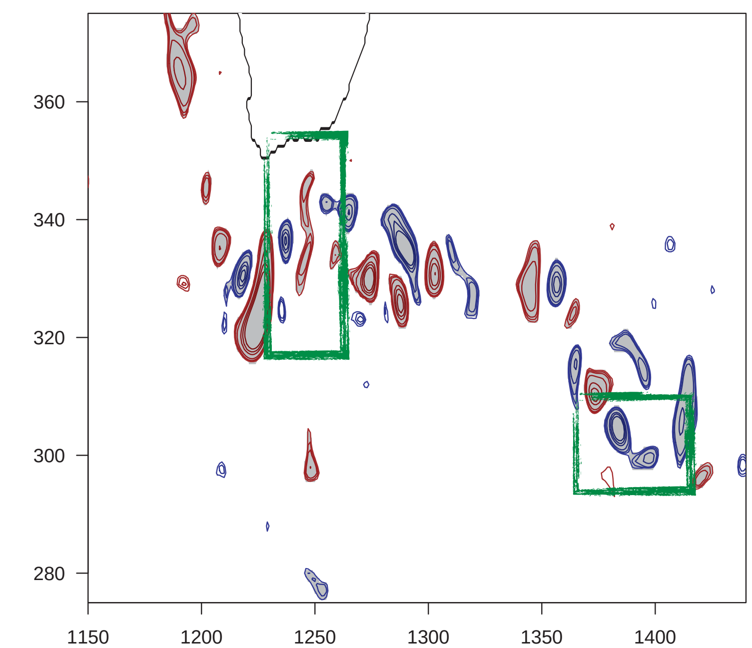
SLA > 20 cm

1° method (size)





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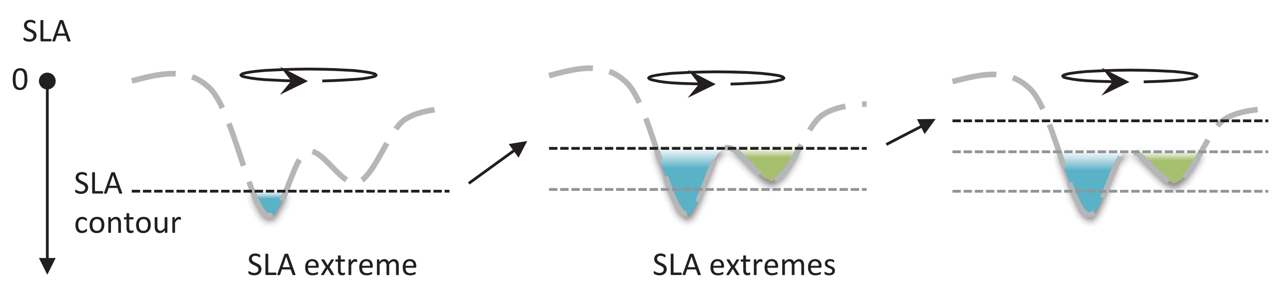
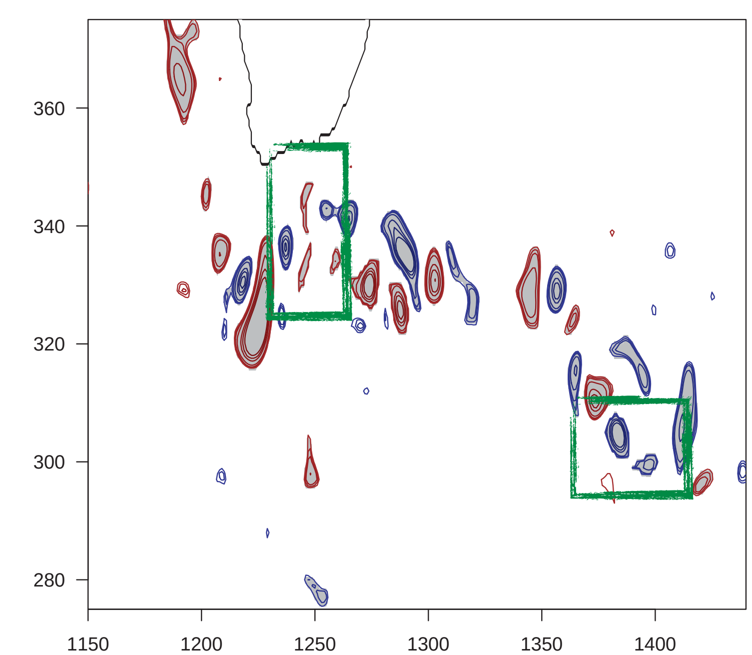
2° method (single extreme)





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Geometry-based method on SLA

❑ Horizontal extension emerging from consecutive cuts of SLA contours

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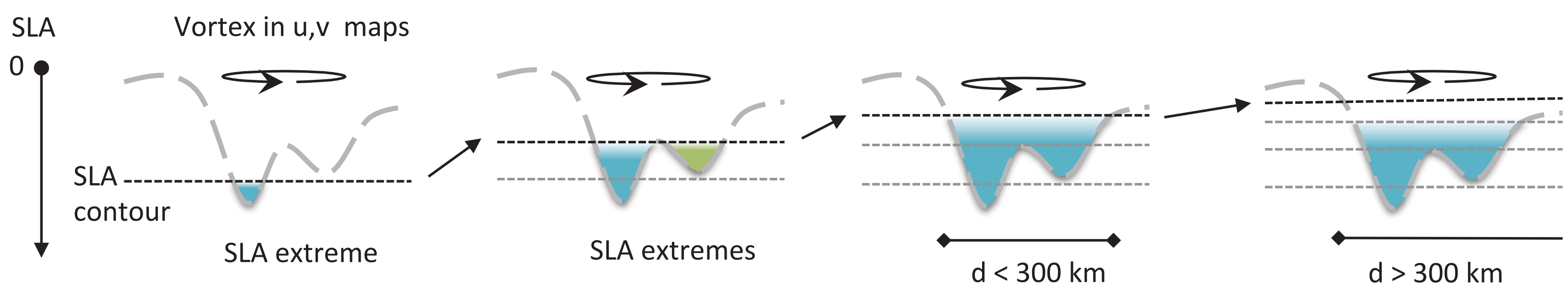
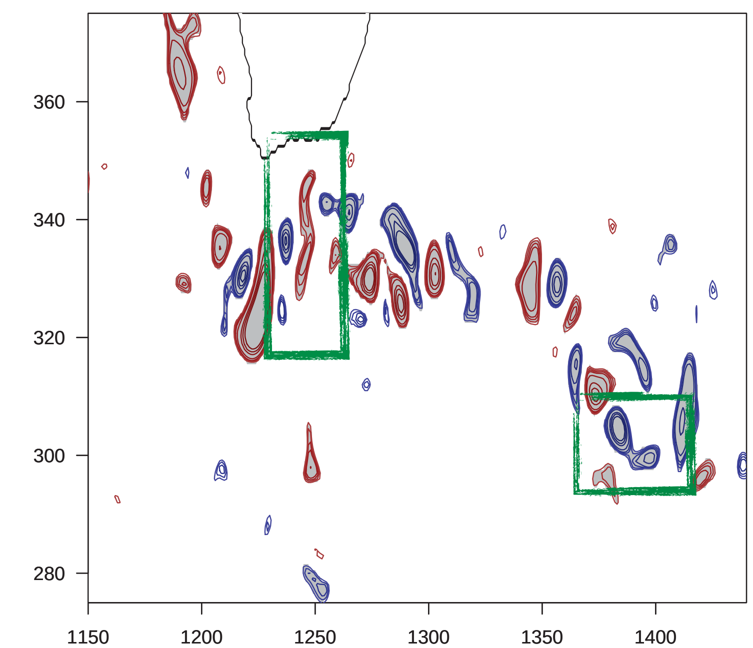
SLA > 15 cm

1° method (size)





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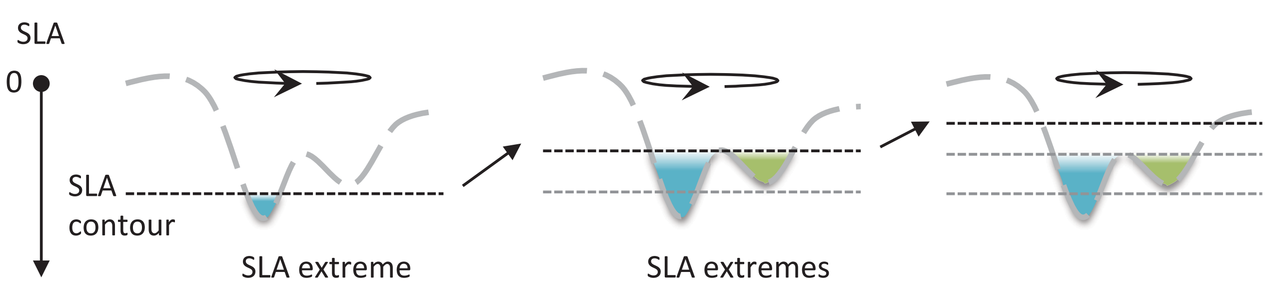
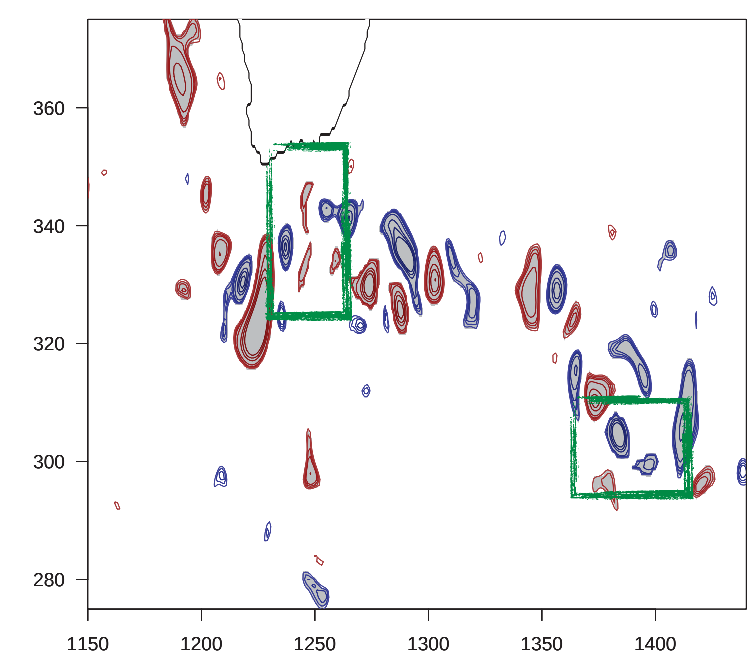
2° method (single extreme)





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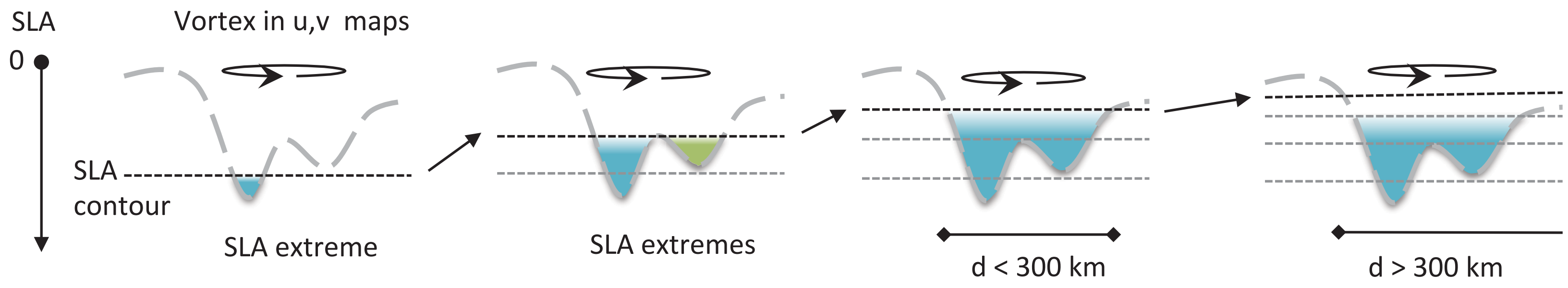
Geometry-based method on SLA

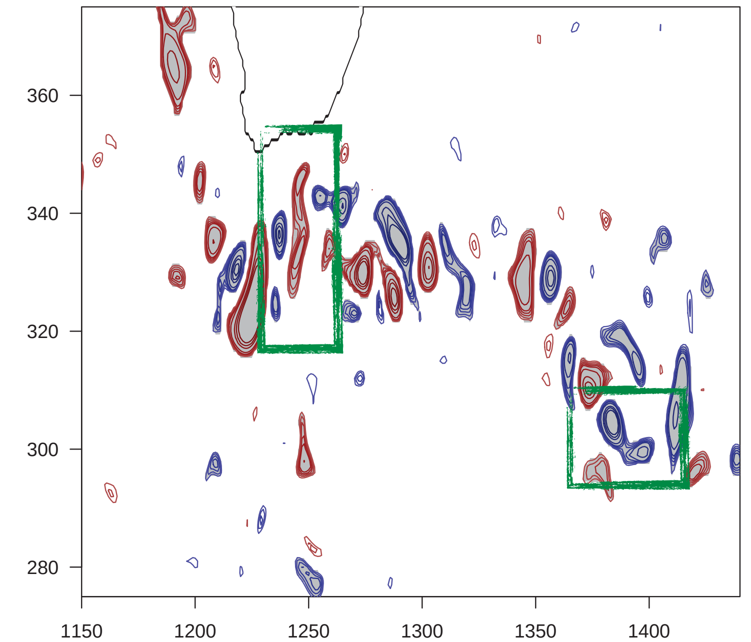
- ☐ Horizontal extension emerging from consecutive cuts of SLA contours

SLA > 14 cm

- ☑ Eddies are limited to a maximum area of *d* radius

1° method (size)





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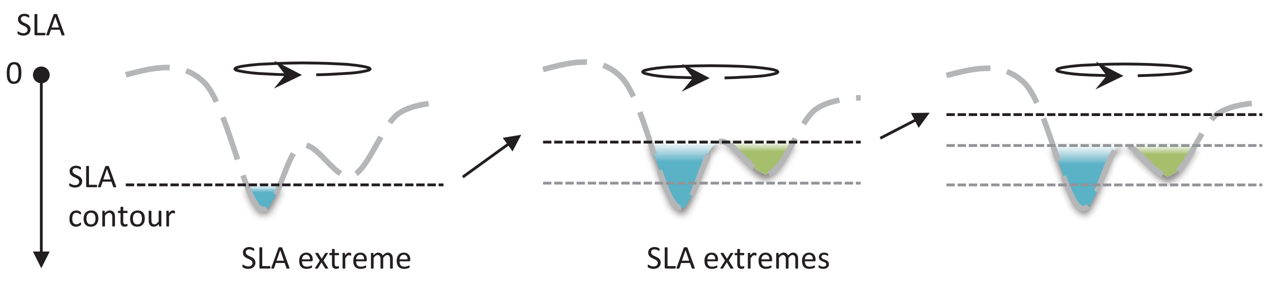
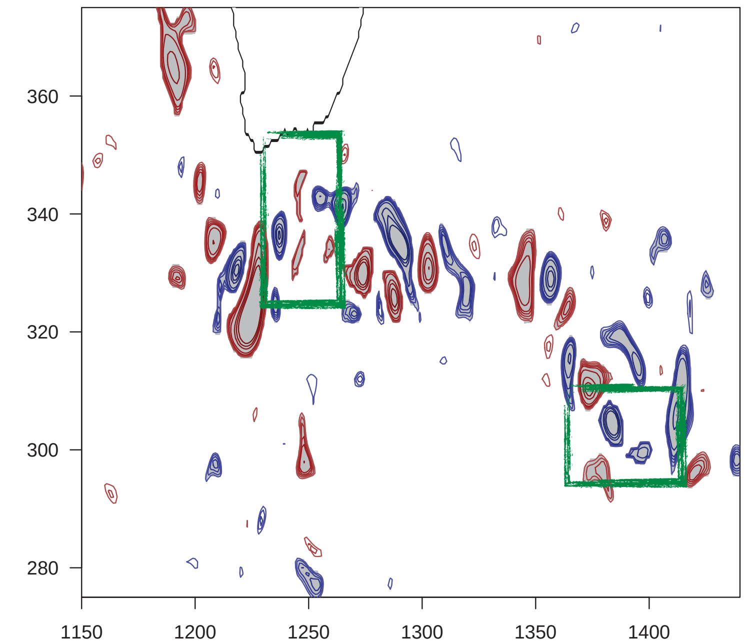
- ☑ Any local extreme of SLA corresponds to a different eddy

2° method (single extreme)





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Geometry-based method on SLA

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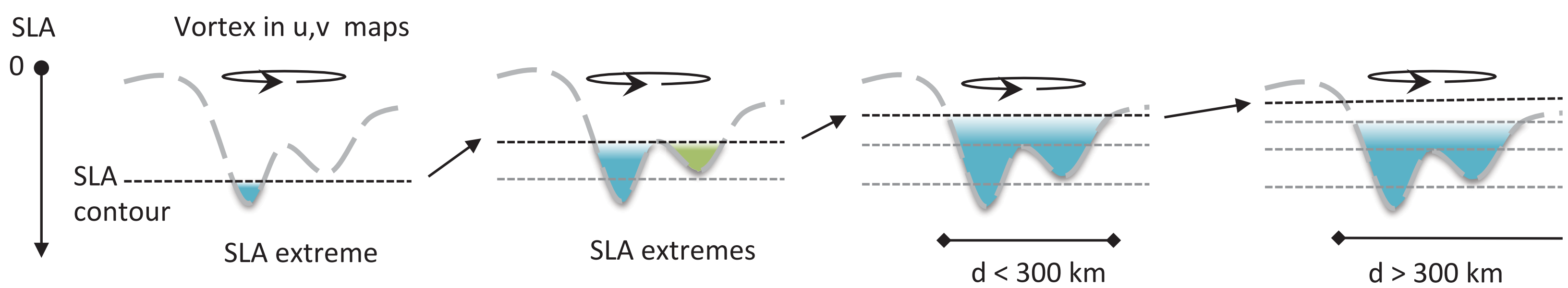
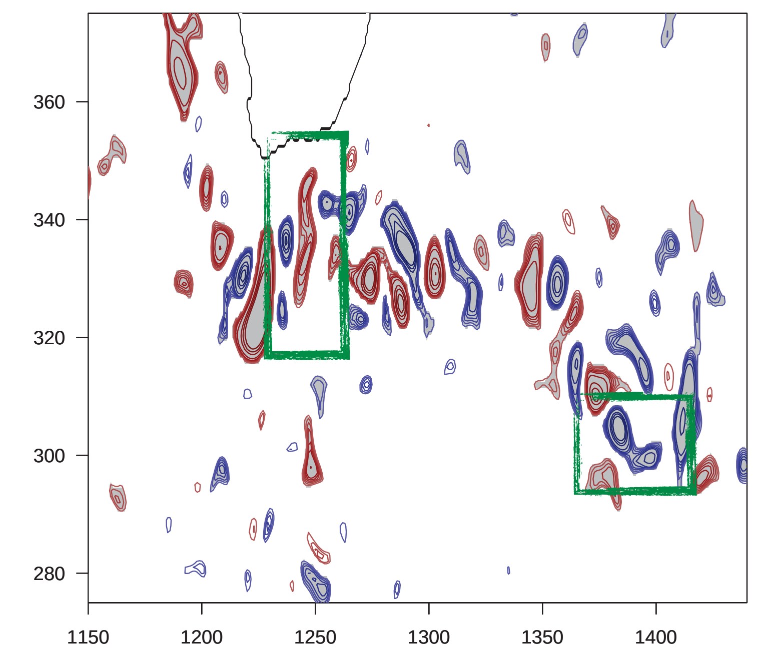
SLA > 13 cm

1° method (size)





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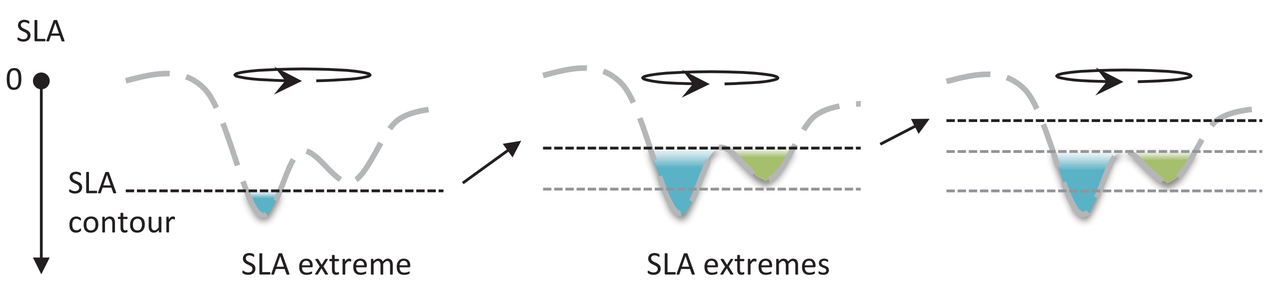
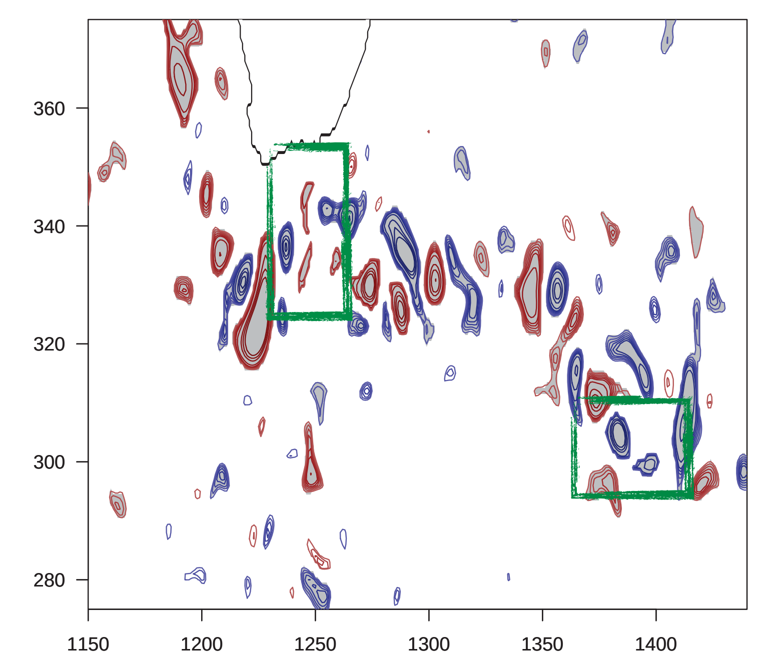
2° method (single extreme)





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Geometry-based method on SLA

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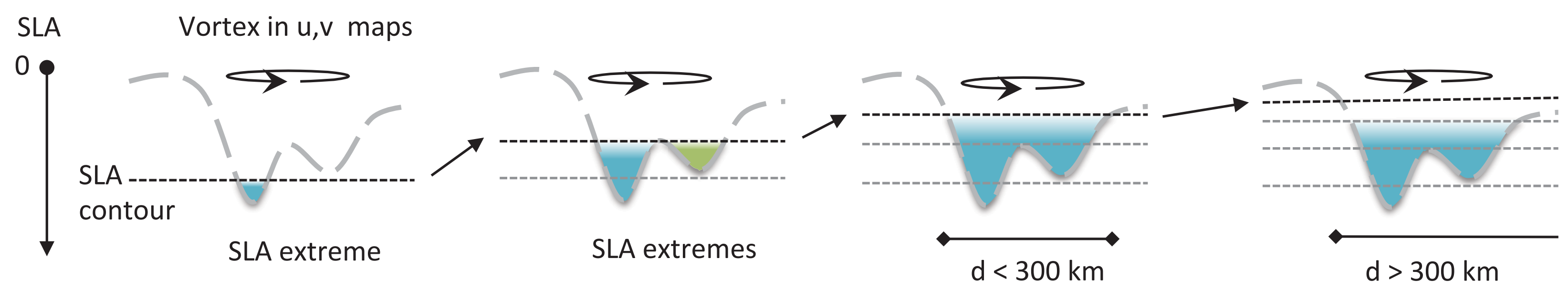
1° method (size)



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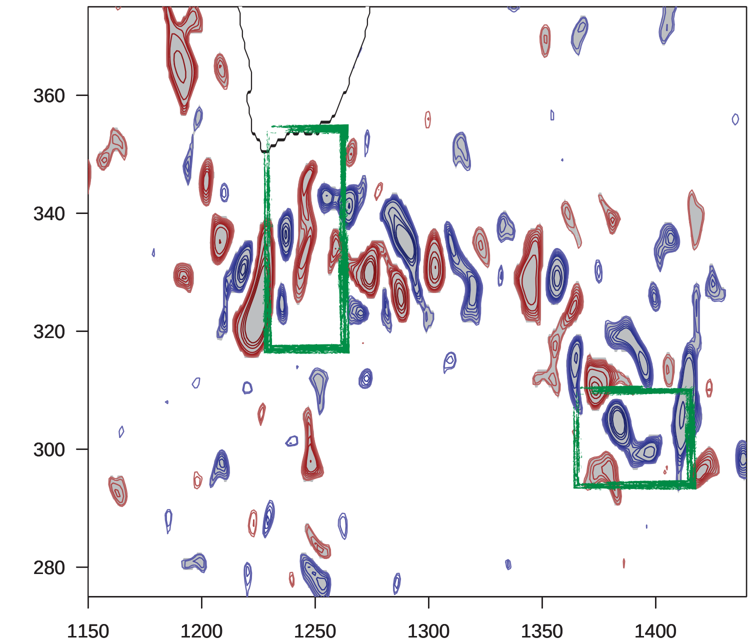
SLA > 11 cm



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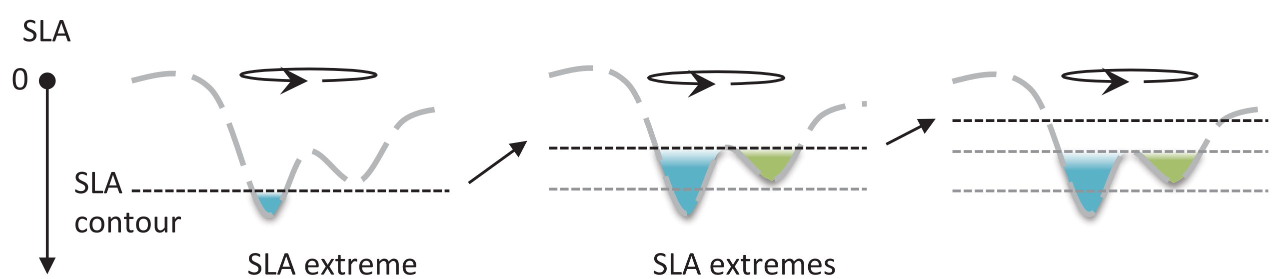
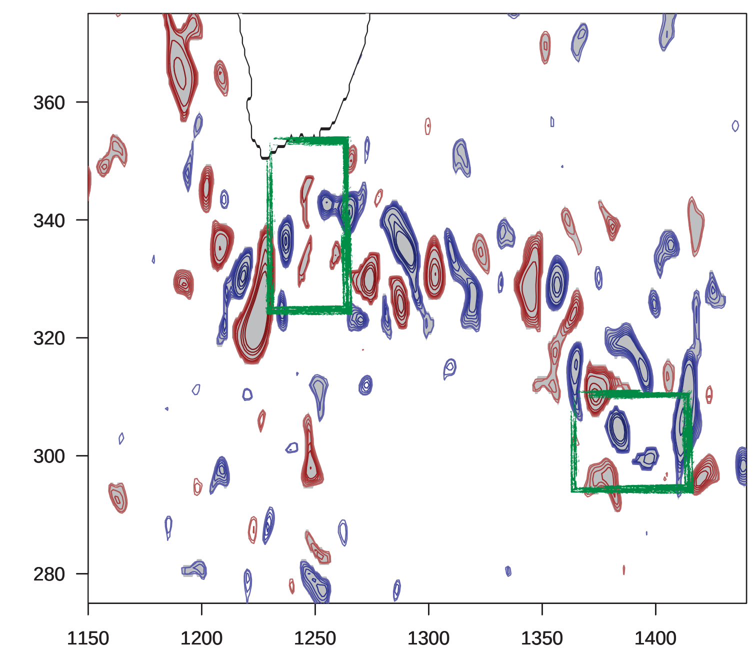
2° method (single extreme)





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Geometry-based method on SLA

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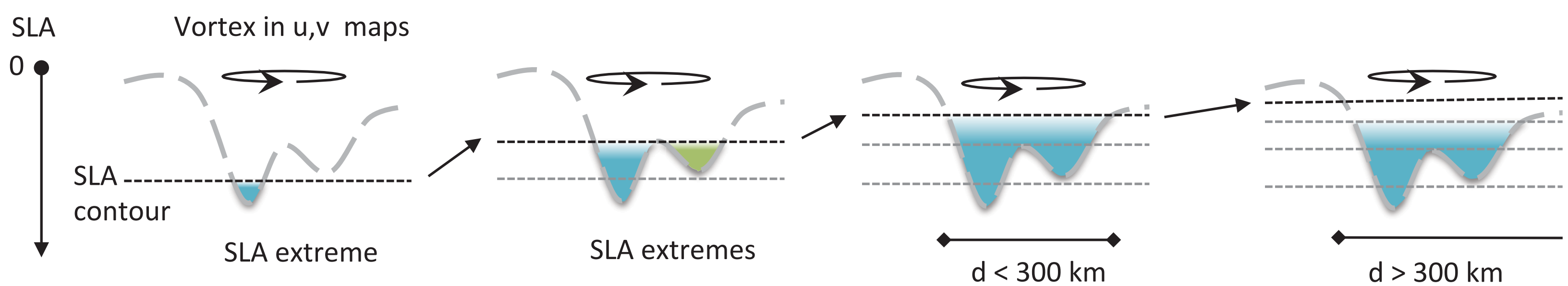
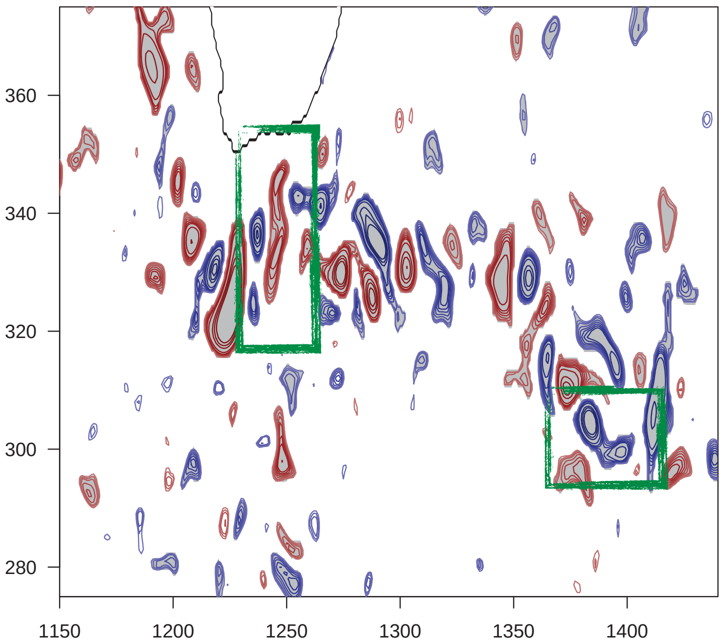
SLA > 9 cm

1° method (size)





Cons: depending on a parameter <u>*d*</u>, weak dependency

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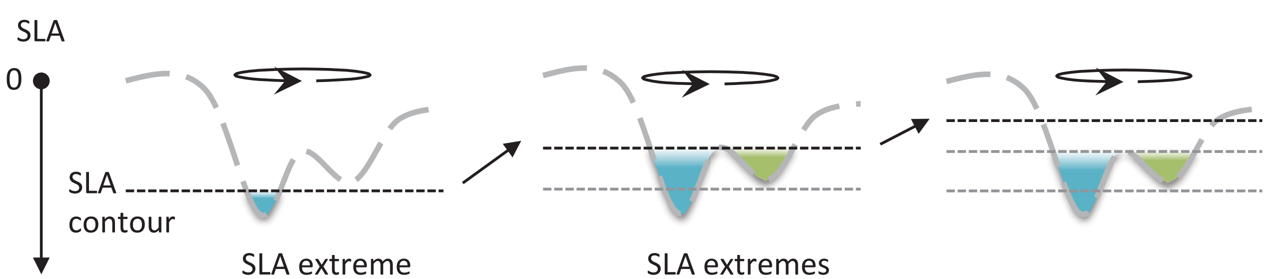
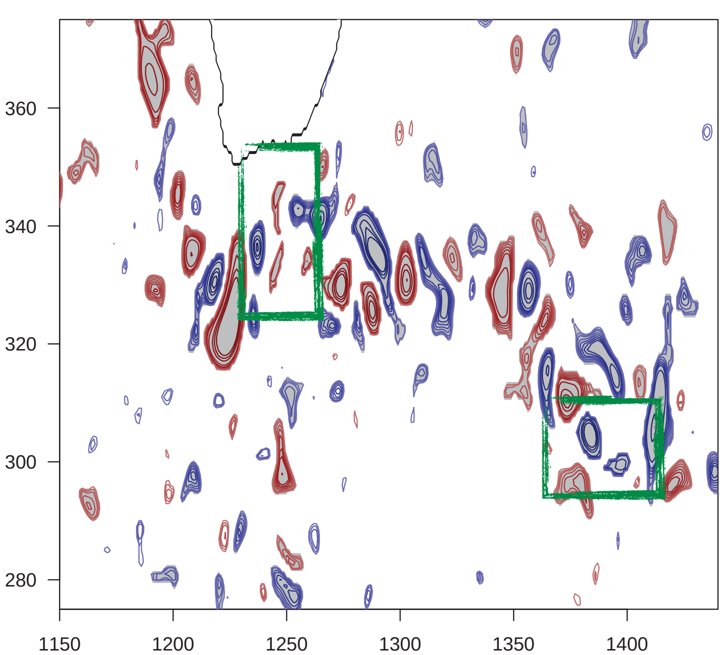
2° method (single extreme)





Cons: double counting “moving” eddies in maps that are averaged over several days.
underestimate of eddy size

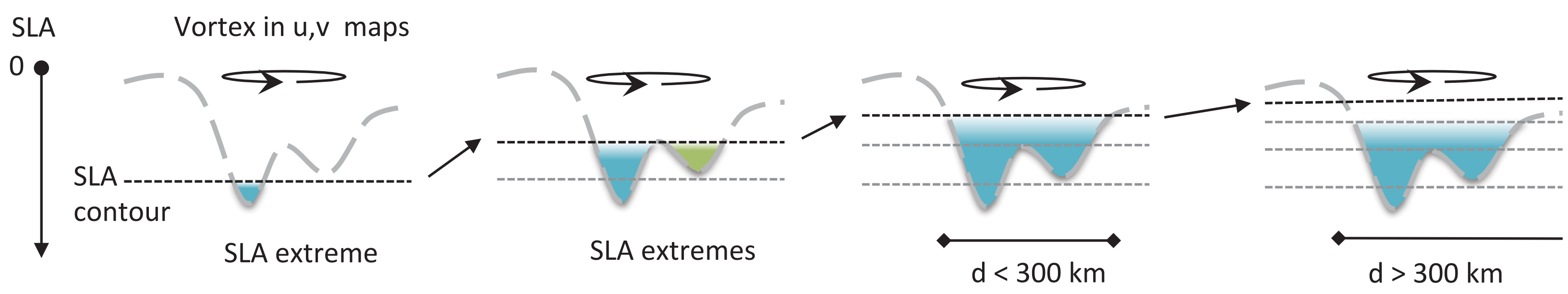
Geometry-based method on SLA

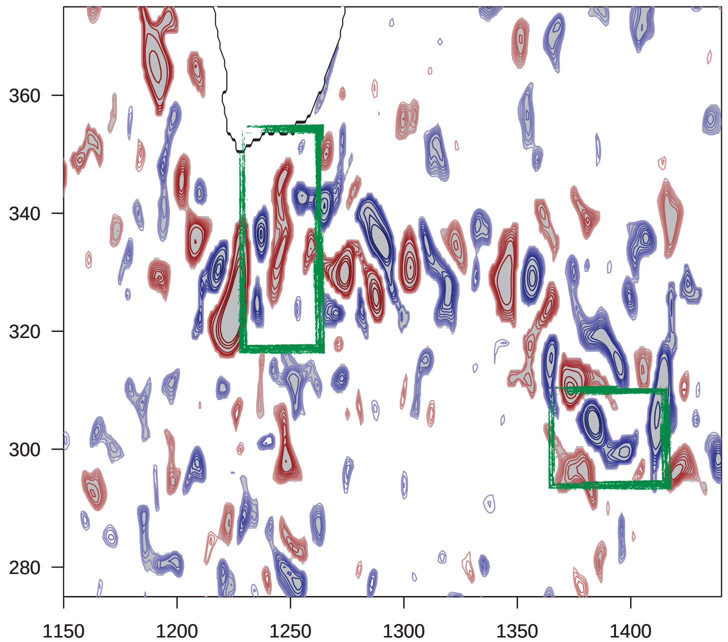
- Horizontal extension emerging from consecutive cuts of SLA contours

  - Eddies are limited to a maximum area of *d* radius

SLA > 7 cm

1° method (size)

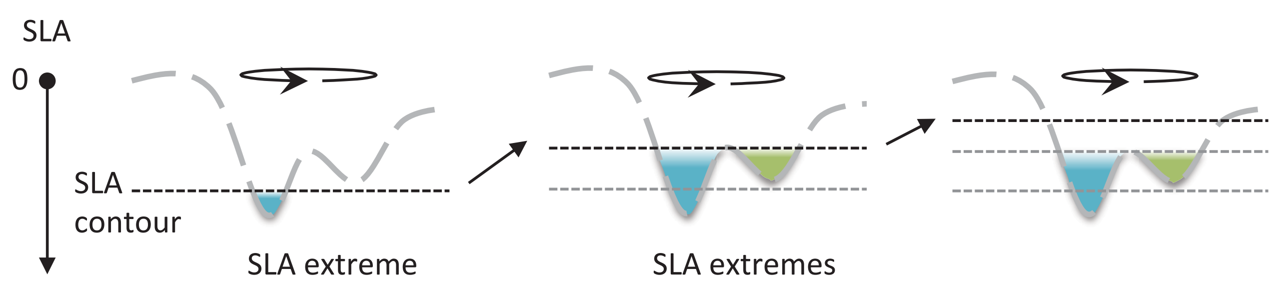


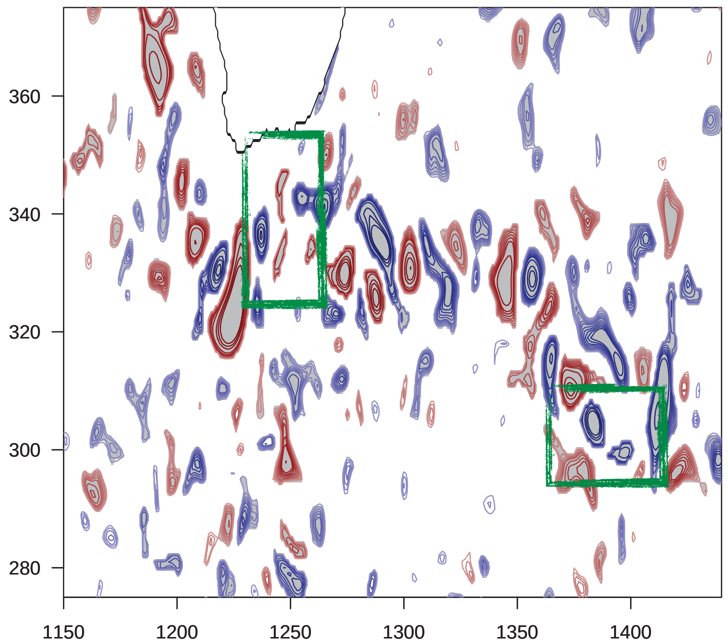


Cons: depending on a parameter *d*, weak dependency

  - Any local extreme of SLA corresponds to a different eddy

2° method (single extreme)





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underestimate of eddy size

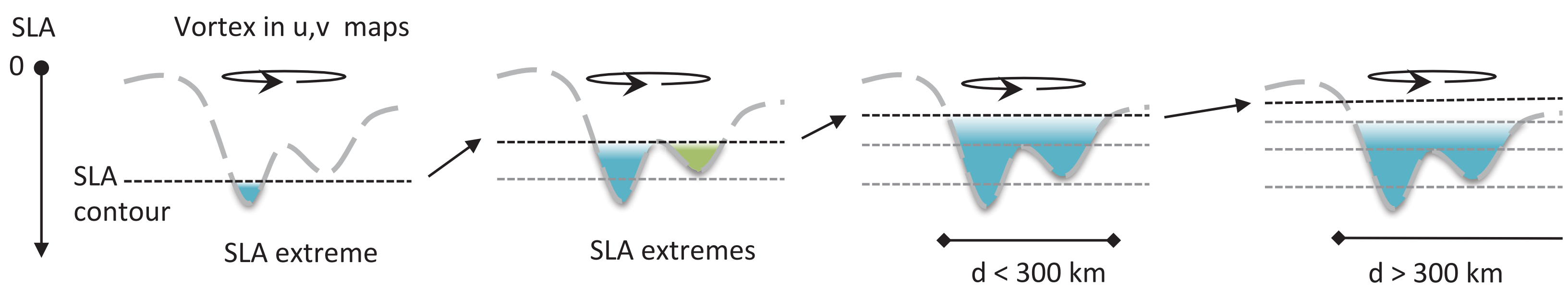
Geometry-based method on SLA

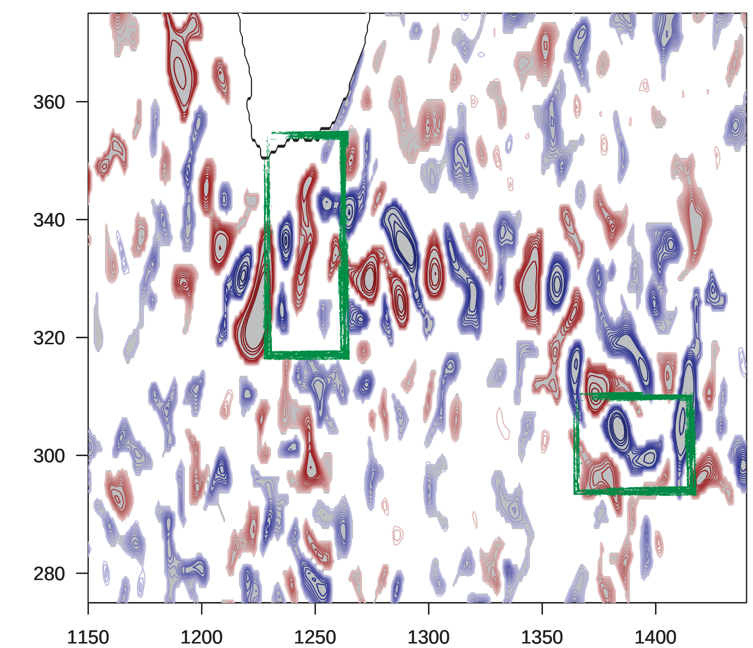
- Horizontal extension emerging from consecutive cuts of SLA contours

- ☑ Eddies are limited to a maximum area of *d* radius

SLA > 5 cm

1° method (size)





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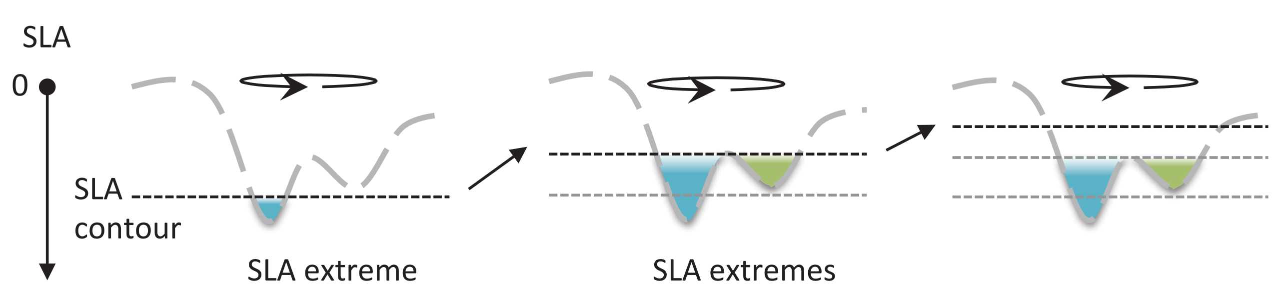

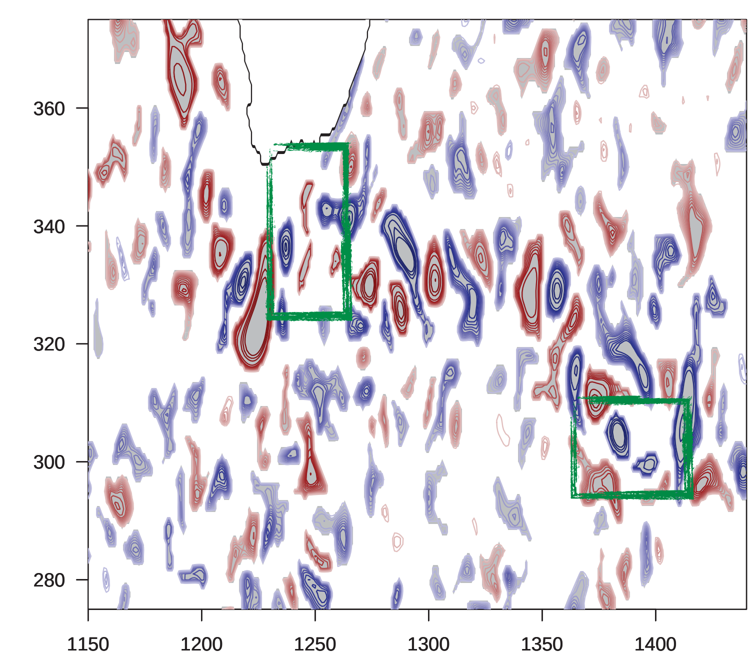

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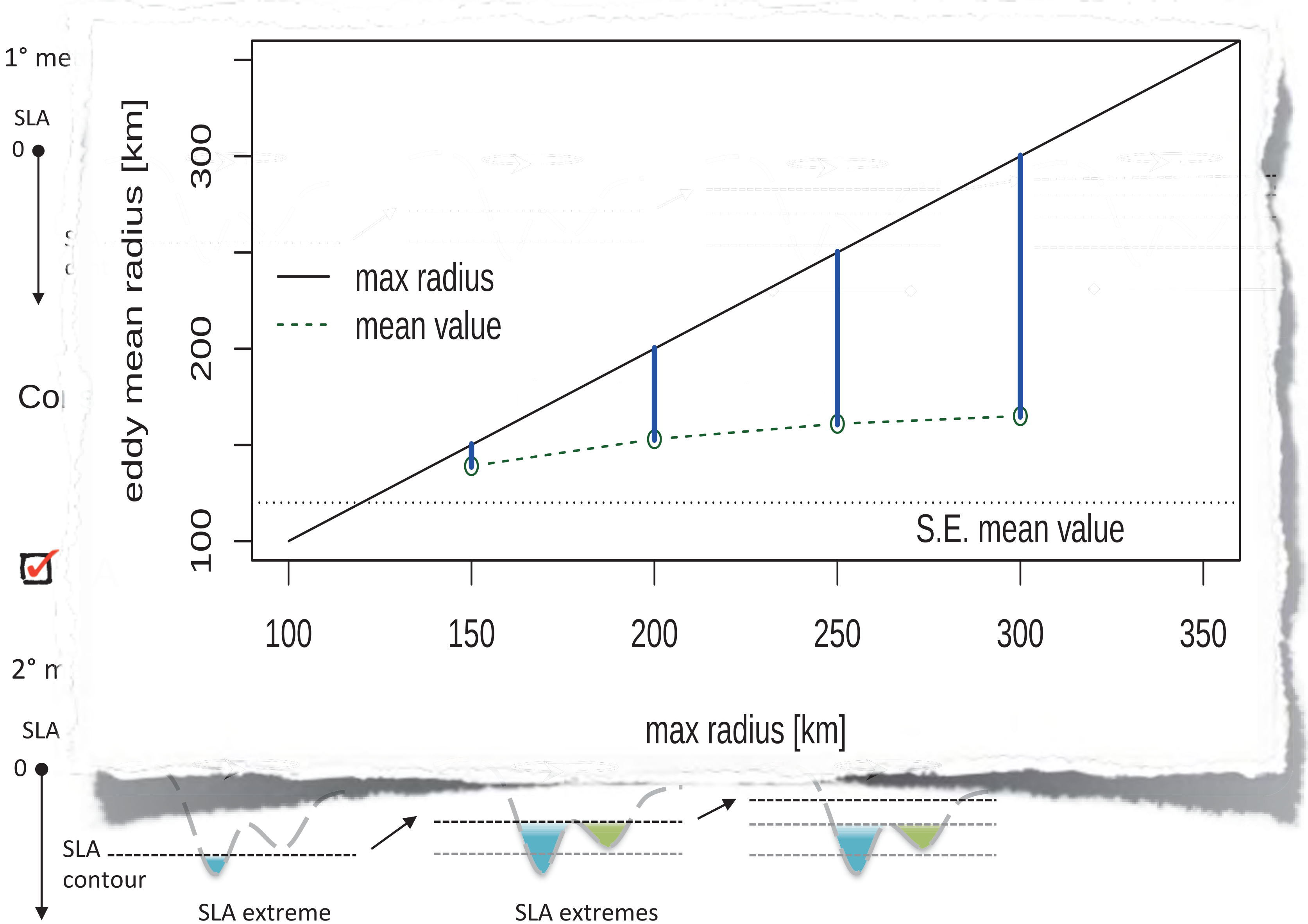
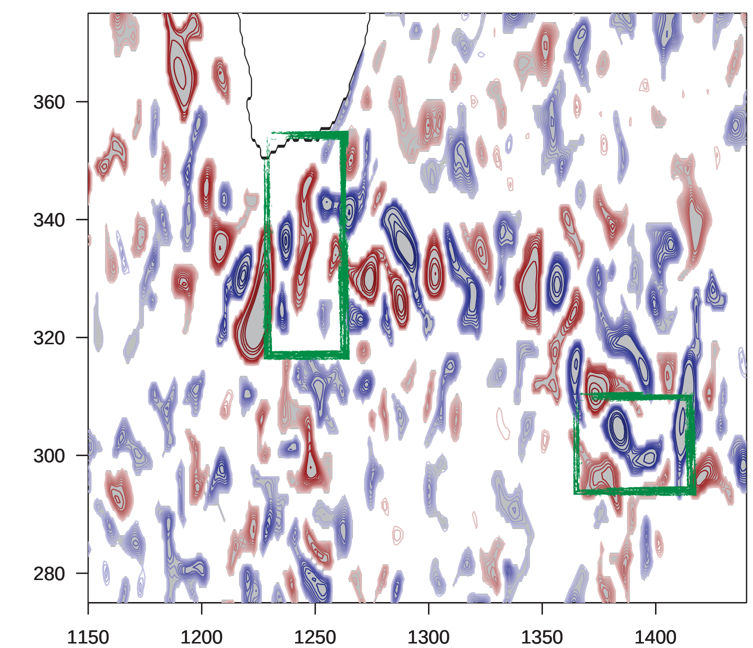
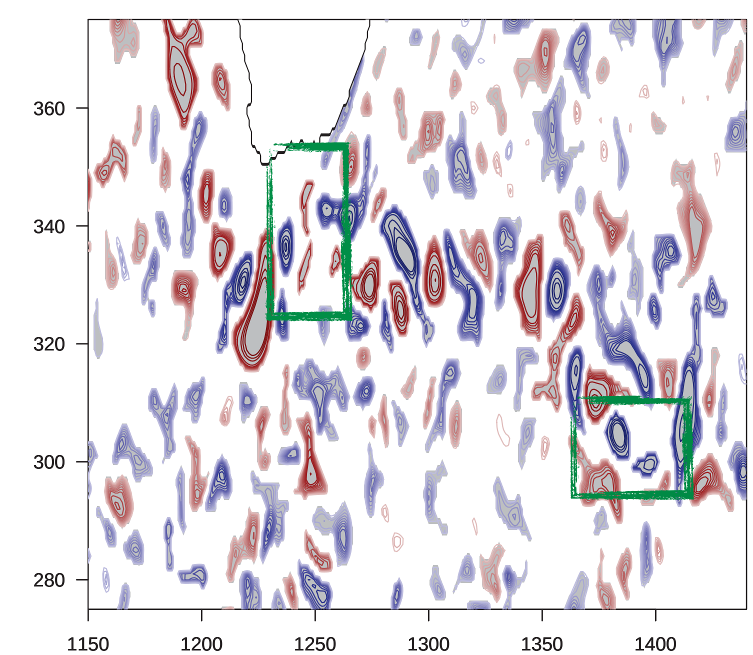






Cons: double counting “moving” eddies in maps that are averaged over several days.
underestimate of eddy size

Geometry-based method on SLA

- Tracking algorithm: nearest-neighbor method

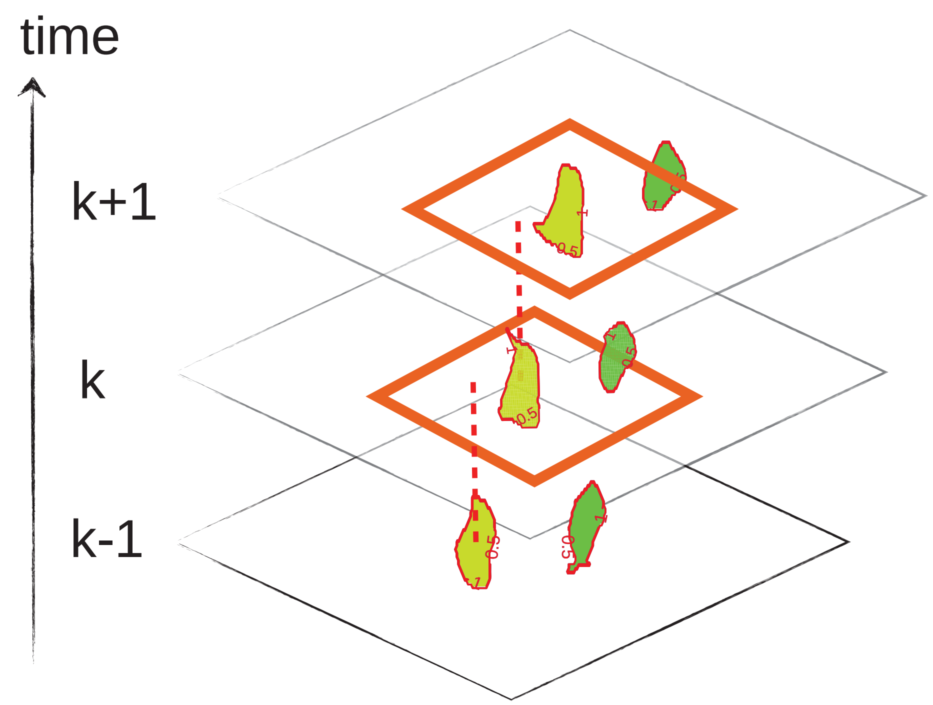
  Eddy at time k+1 are tracked to

  -- closest eddy at k
  -- best area ratio at time k if

  more than one eddy within 4 points

  size eddy ratio is 2 (or 1/2) times bigger

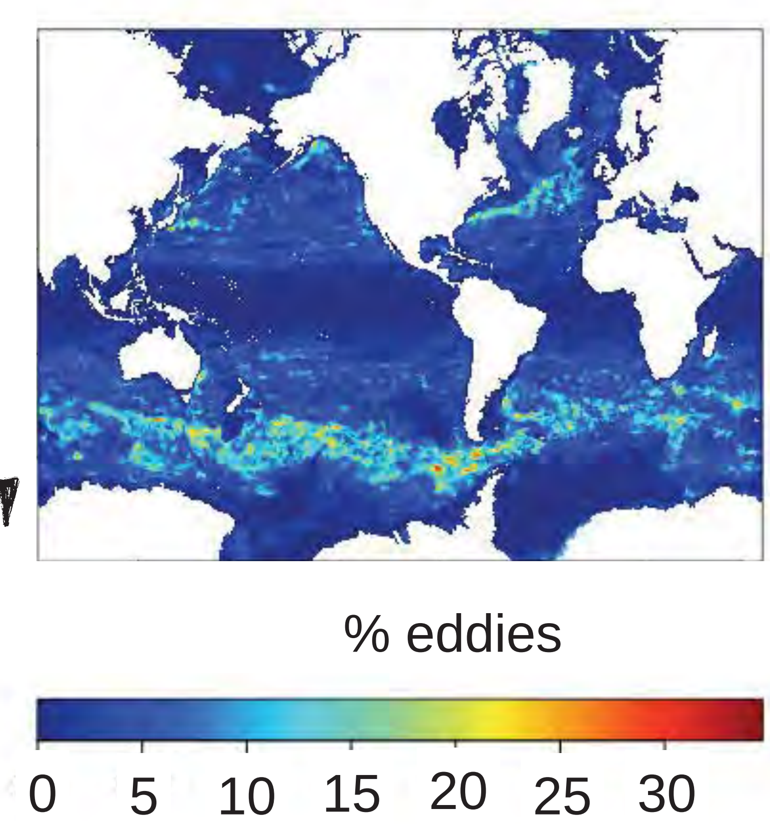
  max eddy speed : 25 cm/s
  box of 150 km radius for weekly maps



- A further tracking between k and k+2 is implemented

  ☑ Fraction of eddies that are
  lost and re-found as function of position.
  Contribution to **<u>long-lived eddies</u>**
  (> longer than 16 weeks)

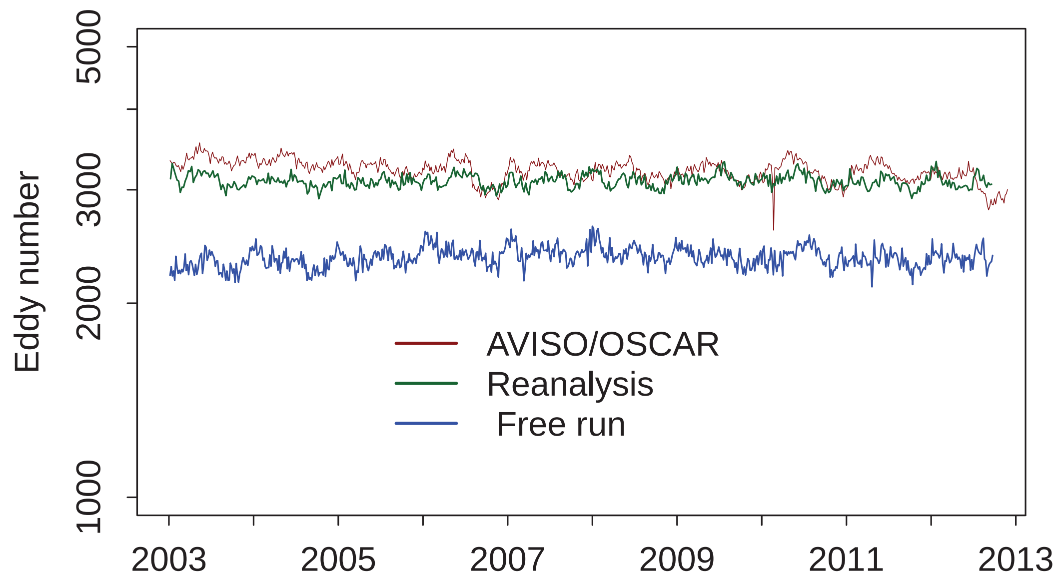
minimum eddy size imposed is > 25 km of radius



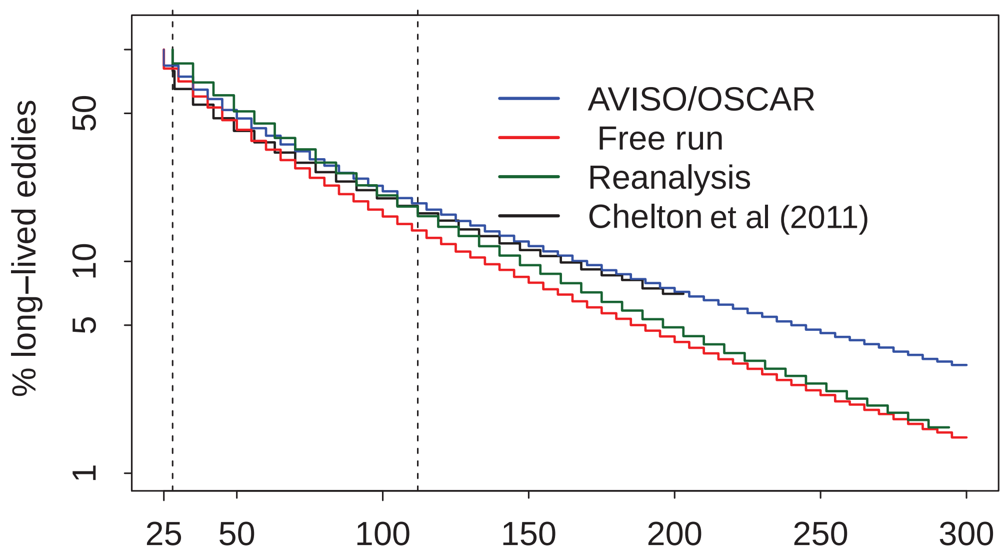
10-year statistics on Global Ocean

10 years statistics on Global ocean basin

number of eddies per record



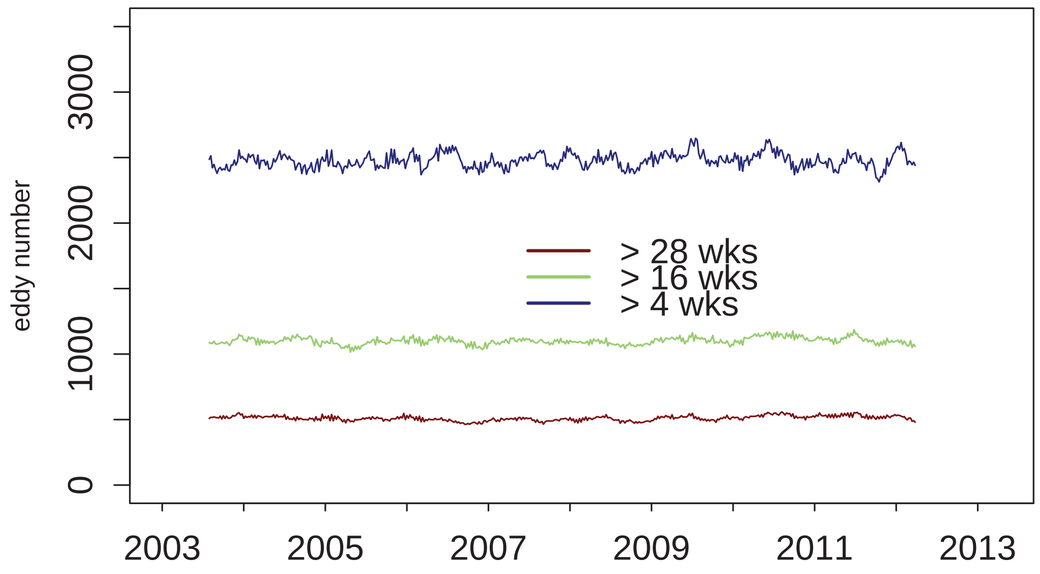
decay rate



short lived eddies

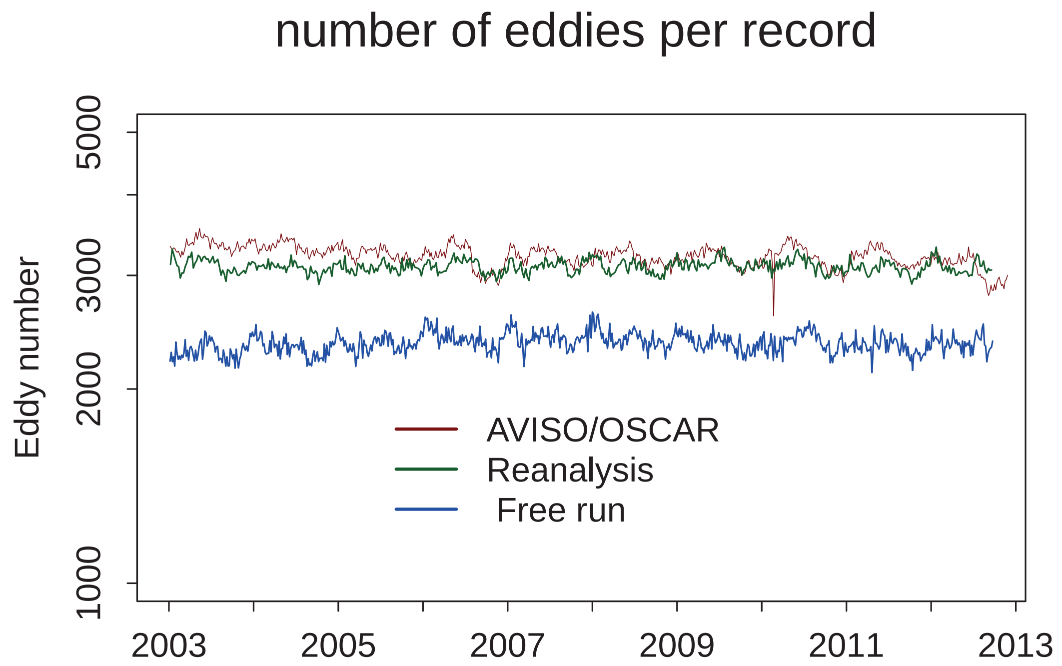
long lived eddies

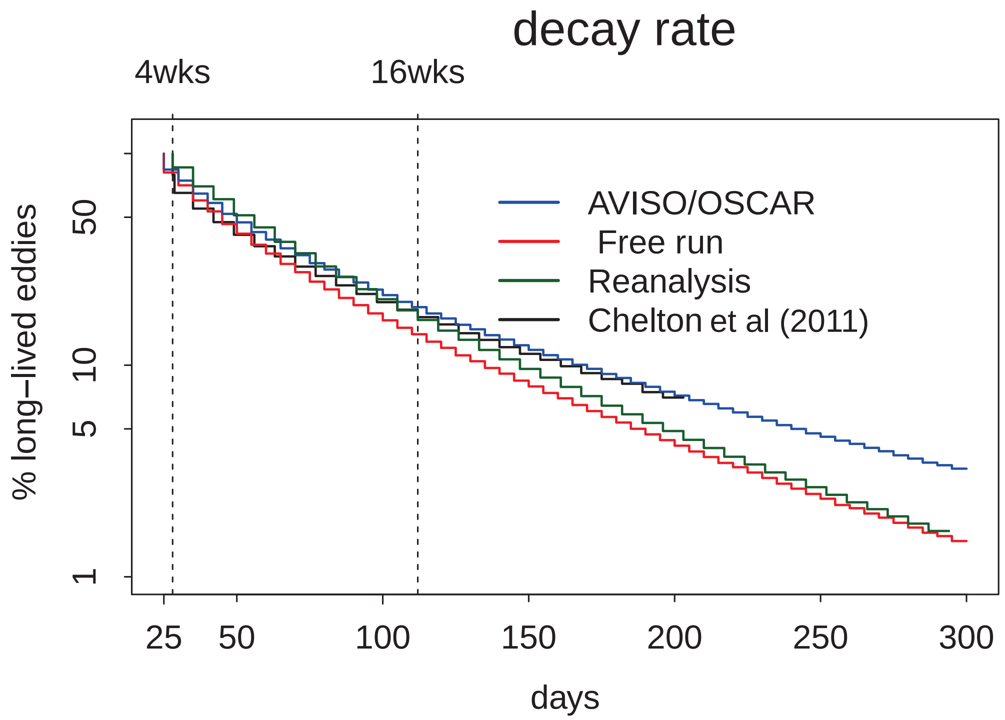
number of eddies with lifetime longer than 4,16,28 weeks



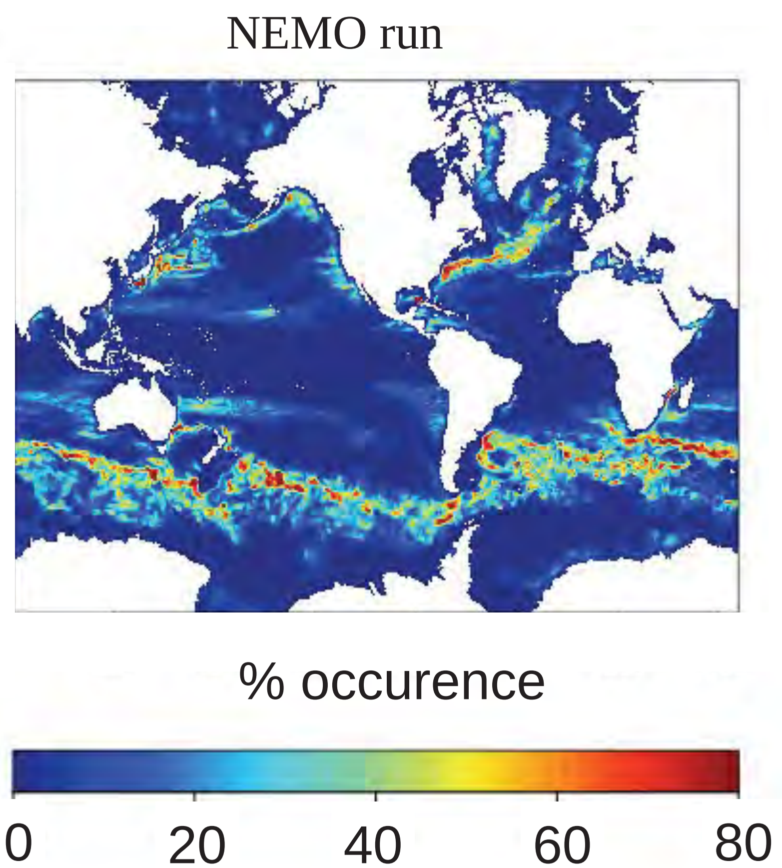
Reanalysis dataset

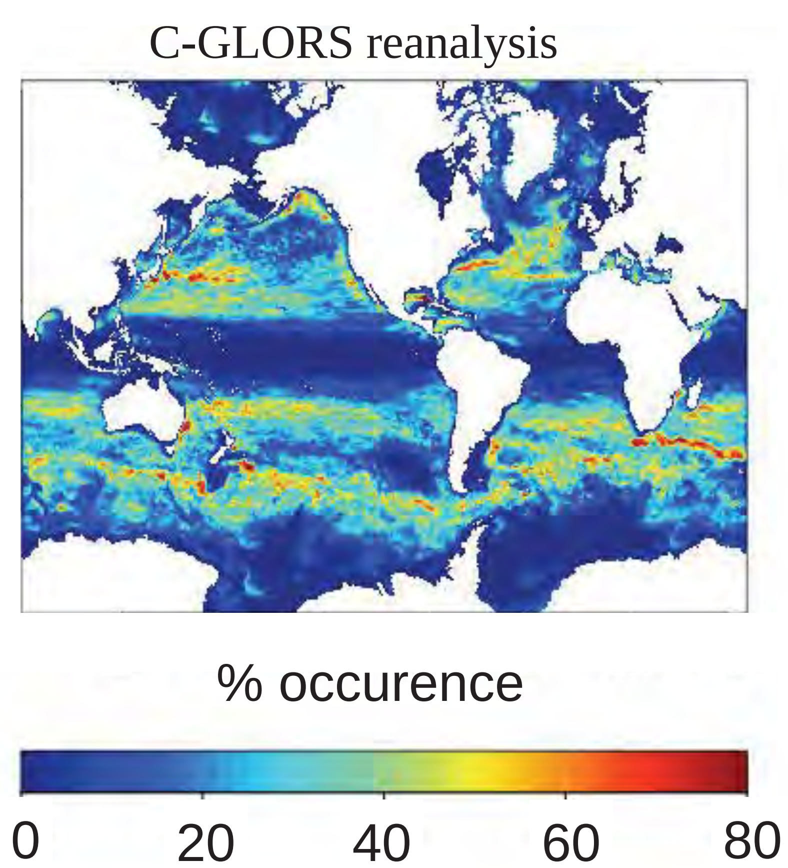
10 years statistics on Global ocean basin

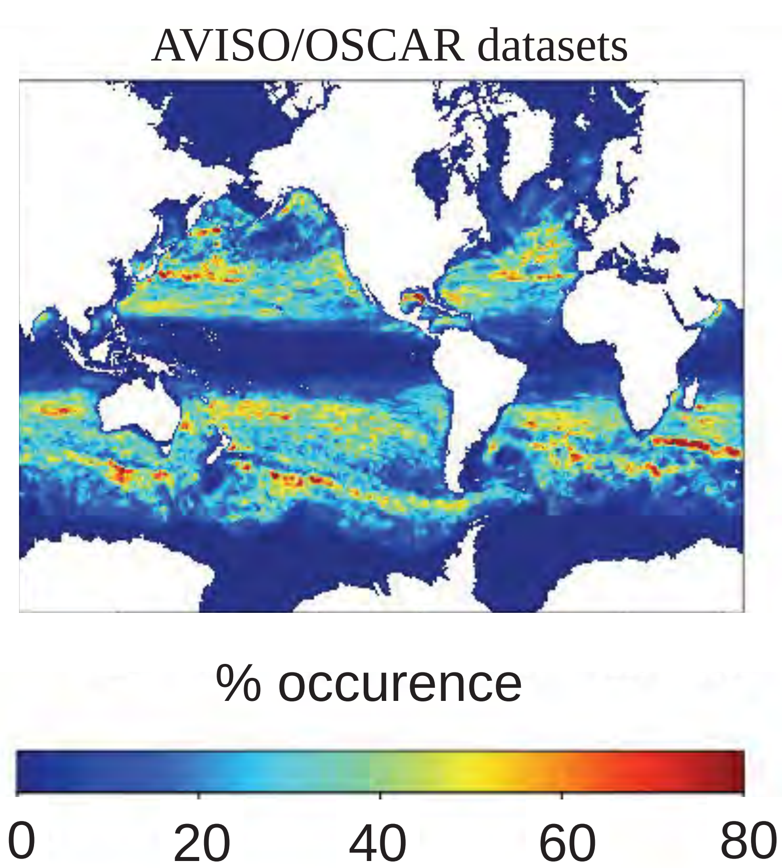




- Fraction of eddy occurrence in 10 yrs for eddies with lifetime longer than 16 weeks

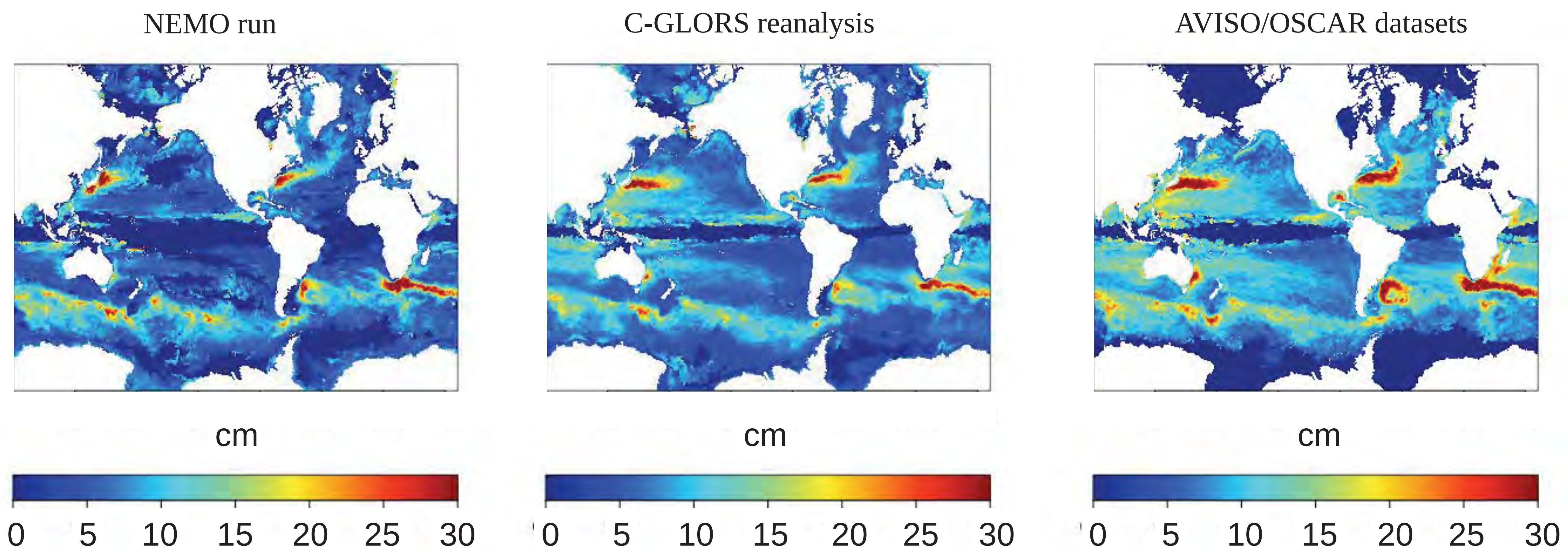






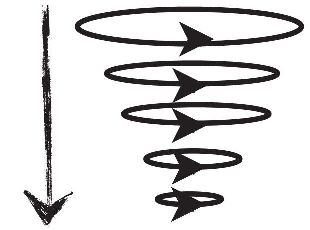
10 years statistics on Global basin

- Mean amplitude for eddies with lifetime longer than 16 weeks

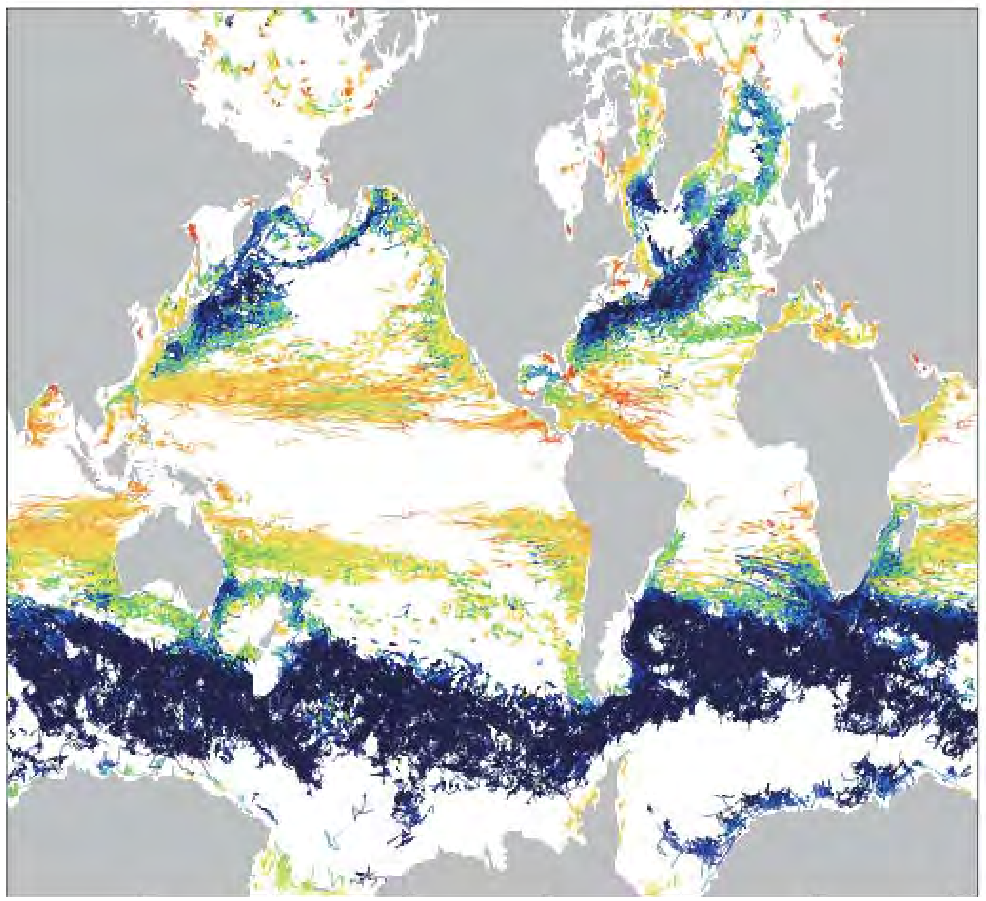


10 years statistics on Global basin

- Trajectories of eddies with lifetime longer than 16 weeks Vs depth

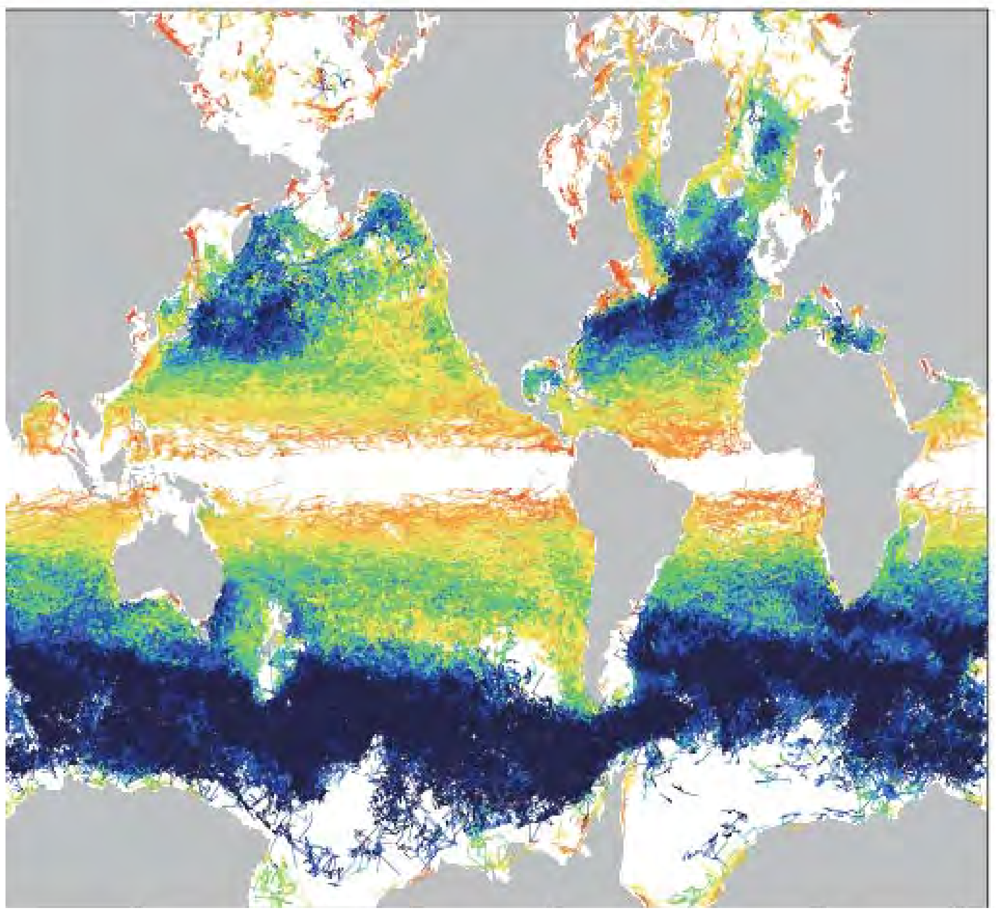


13925 westward   6436 eastward

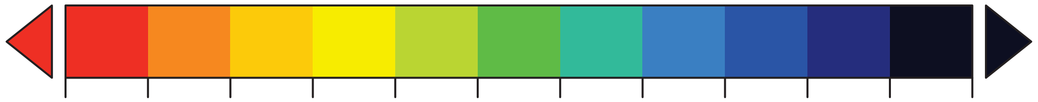


NEMO run

26961 westward   11513 eastward



C-GLORS reanalysis



Mean Depth [m]

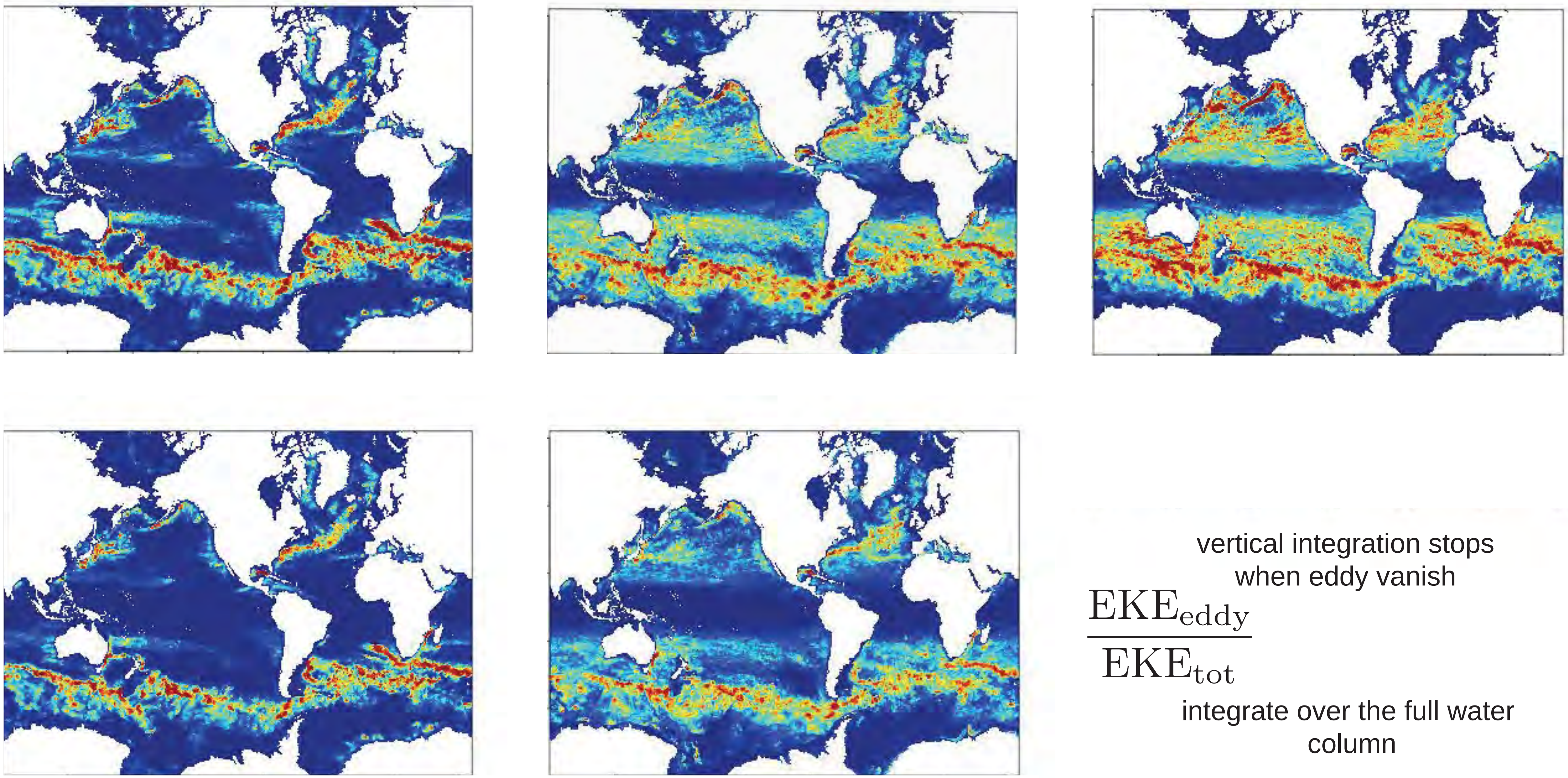
- Fraction of total EKE, transported by eddies with lifetime longer than 16 weeks

$$\frac{\mathrm{EKE}_{\mathrm{eddy}}}{\mathrm{EKE}_{\mathrm{tot}}}$$

NEMO run | C-GLORS reanalysis | AVISO/OSCAR datasets

Surface

3D



vertical integration stops when eddy vanish

$$\frac{\mathrm{EKE}_{\mathrm{eddy}}}{\mathrm{EKE}_{\mathrm{tot}}}$$

integrate over the full water column

% EKE

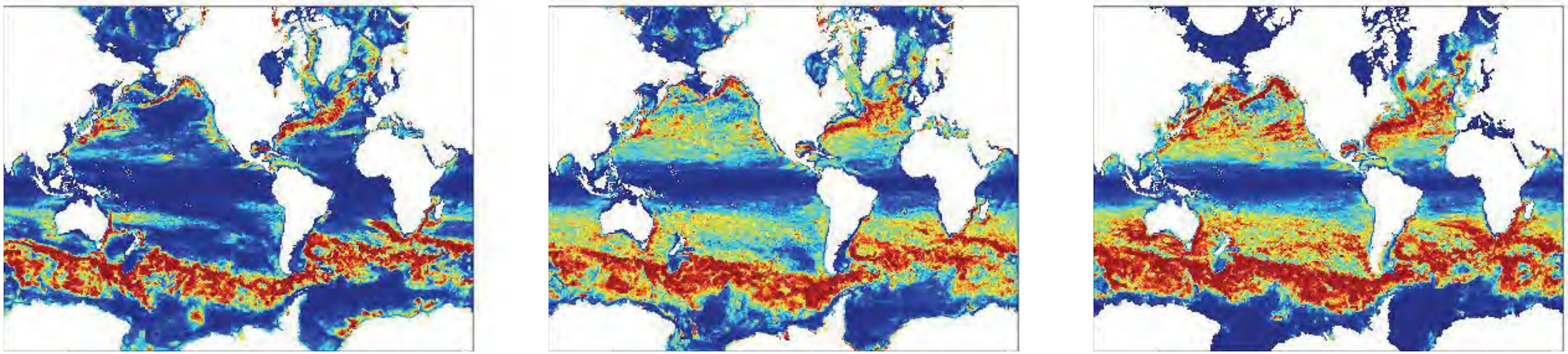
% EKE

- Fraction of total EKE, transported by eddies with lifetime longer than 4 weeks

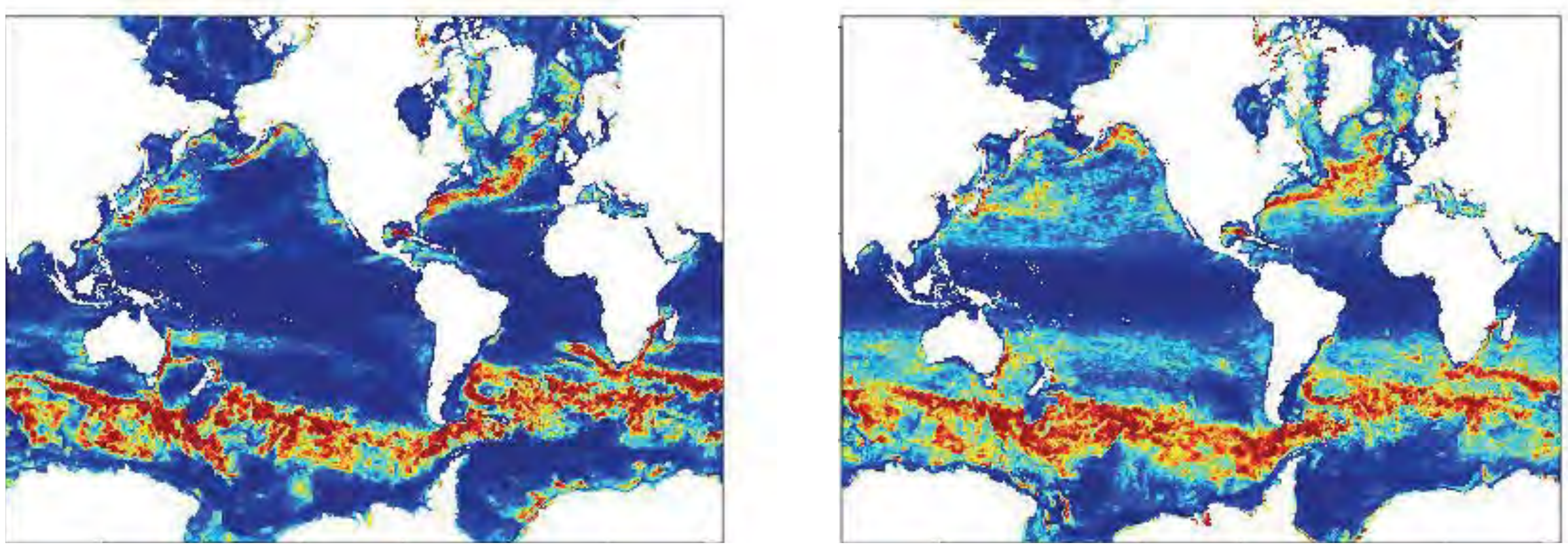
$$\frac{\mathrm{EKE}_{\mathrm{eddy}}}{\mathrm{EKE}_{\mathrm{tot}}}$$

NEMO run | C-GLORS reanalysis | AVISO/OSCAR datasets

Surface



3D



vertical integration stops when eddy vanish

$$\frac{\mathrm{EKE}_{\mathrm{eddy}}}{\mathrm{EKE}_{\mathrm{tot}}}$$

integrate over the full water column

% EKE | % EKE

Summary

- Eddies populate any corners of ocean basin, being responsible for diverse phenomenologies

- Eddy census gather three different datasets to highlight the impact of assimilation:

1) NEMO free simulation at 1/4

2) C-GLORS reanalysis at 1/4

3) observed datasets (AVISO/OSCAR) at 1/4

- Assimilation seems to

@ global level — recover most of the mesoscale variability from satellite/in-situ data and consistently generate variability in the interior

@ local level — correct the behavior of each single eddy towards a more realistic profiles

NEXT — Can we give some “trustful” estimates of heat and freshwater fluxes at global level ??

Summary

NEXT How it performs over an 1/16° eddying simulation of the global sea ice-ocean system ??

*Iovino, **AC** et al., GMDD 2016*

*Stepanov, **AC** et al., JGR:Ocean 2016*

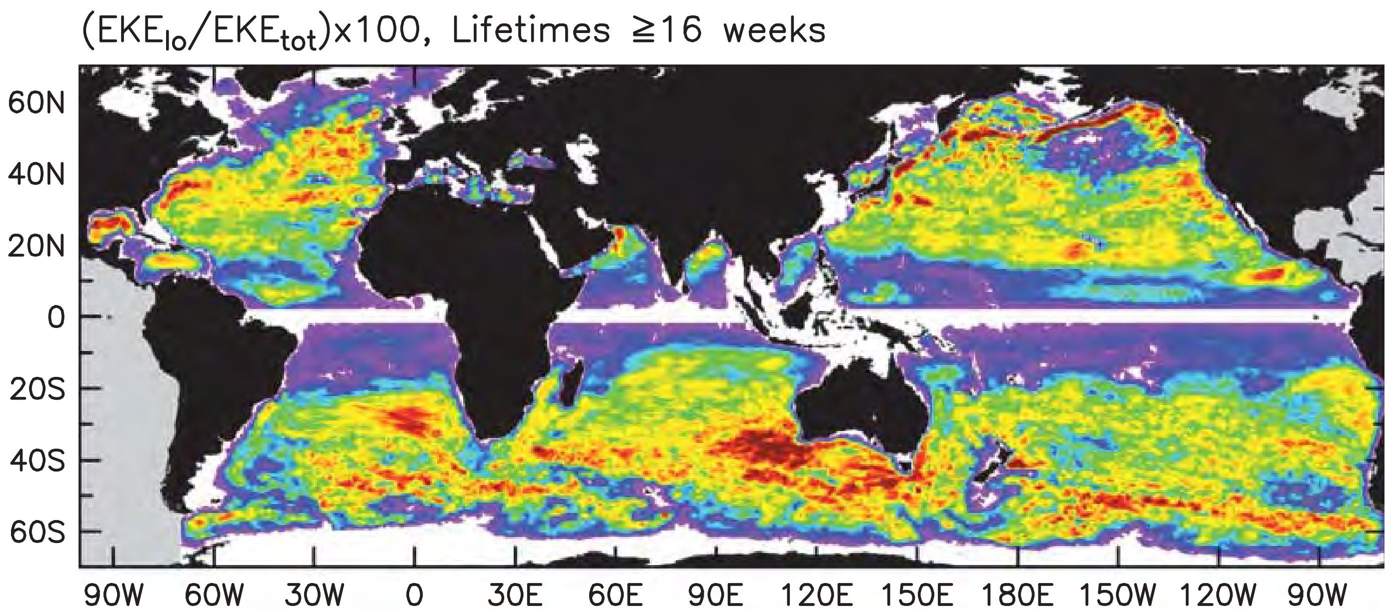
*Stepanov, **AC** et al., JGR:Ocean 2016*

Thank you!

Centro Euro-Mediterraneo sui Cambiamenti Climatici

Backup slides

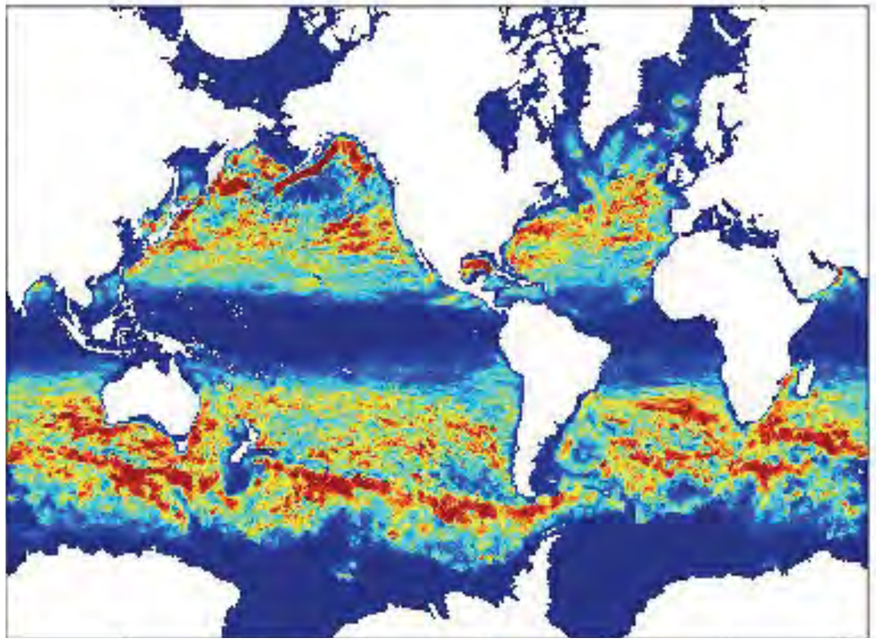
AVISO 1/3



maps averaged over boxes 1° x 1°

(Chelton et al. 2011)

AVISO 1/4 and OSCAR datasets



Regional case study:
Peru-Chile current system

Peru-Chile currents

- The role of eddies on Peru-Chile current system

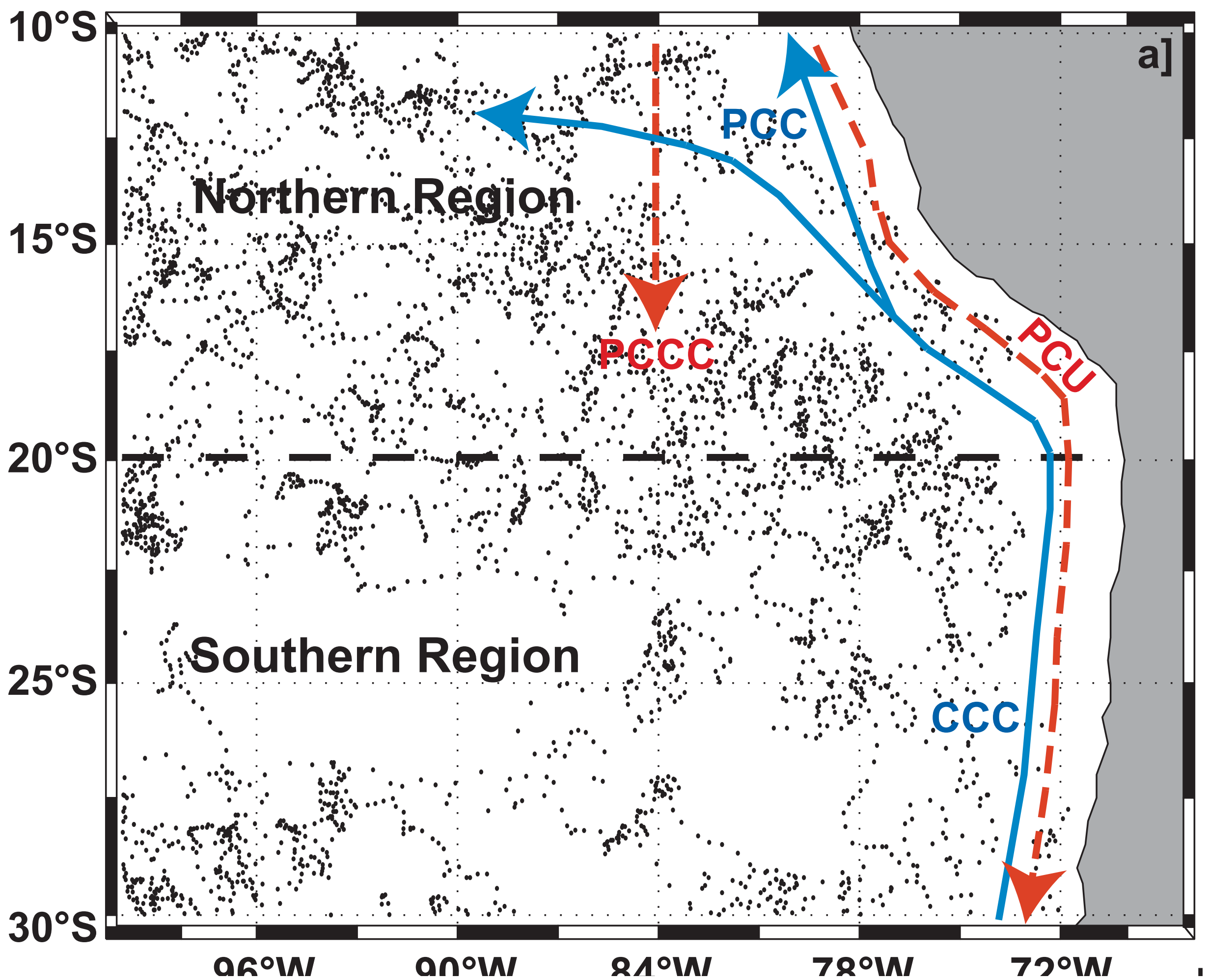
  - ☑ acquire a water mass structure typical of their formation region and propagate offshore

  - ☑ In this new environment, eddies appear as anomalous water masses with temperature and salinity anomalies

anti-cyclonic eddies generated from front instabilities of warm poleward currents

cyclonic eddies transport cold water offshore, trapping recently upwelled water

warm, salty sub-surface subtropical water from 9° S in fall (austral spring)



(Chaigneau et al. 2011)

near-costal cold upwelling region

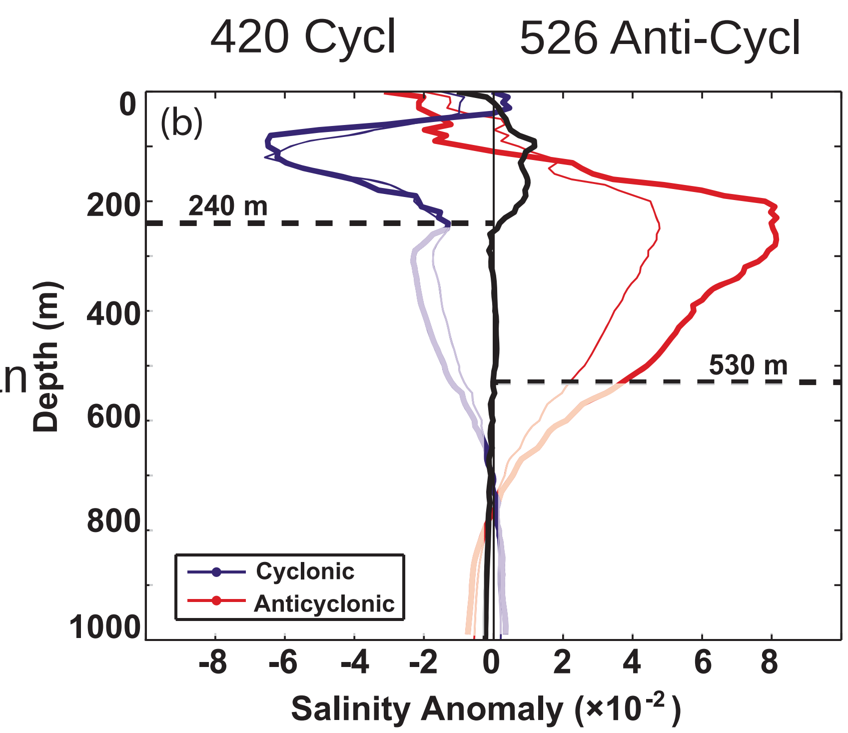
Regional case study

- ☐ Salinity anomaly trapped in the eddies

AE (red)

CE (blue)

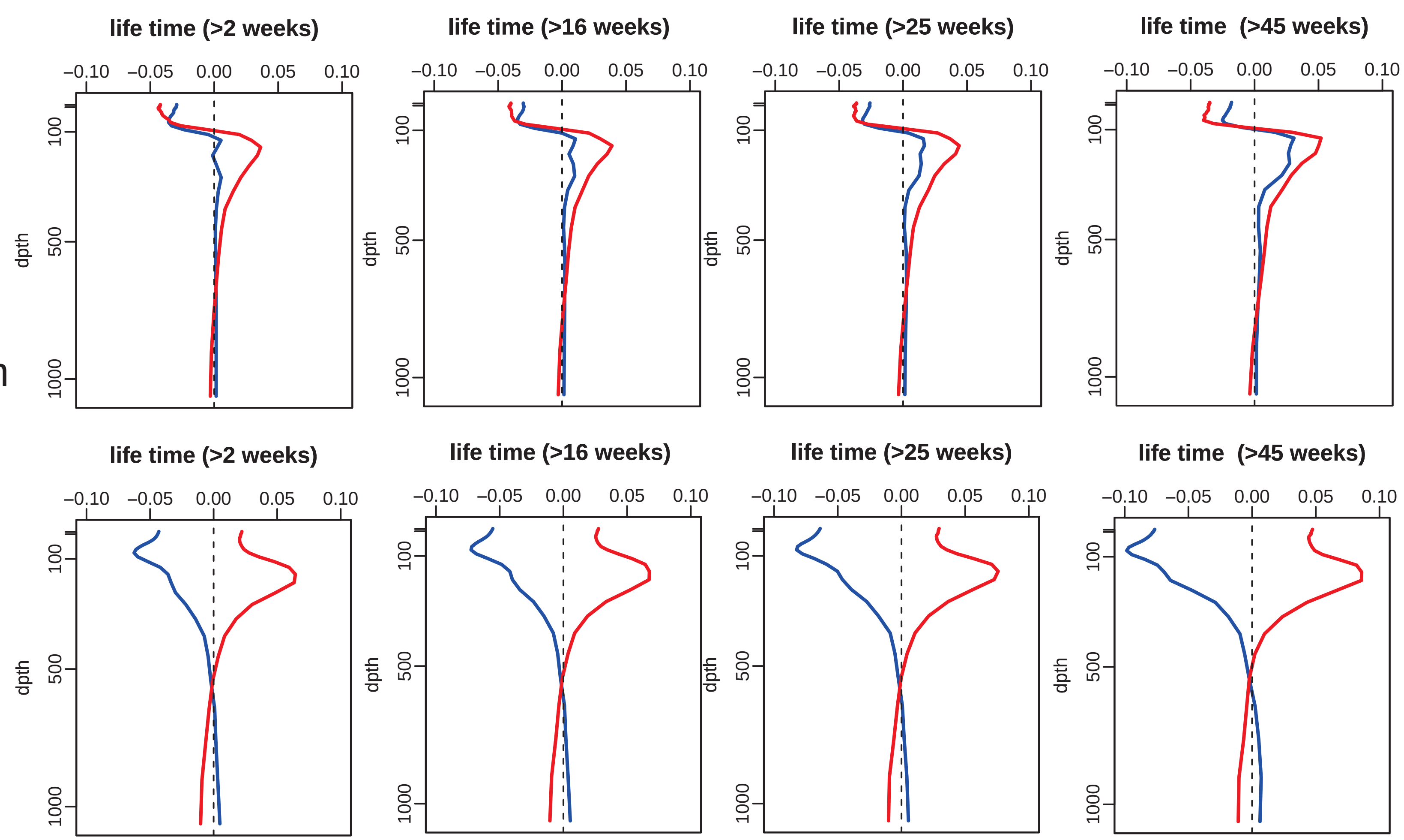
Argo profile Dec 2003-Oct 2009. Anomaly eval. vs climatological mean from CSIRO Atlas of Regional Seas (Chaigneau et al. 2011)



- ☑ Reanalysis corrects mean amount as well as profile in fall season. Anomaly eval. vs climatological mean from 10ys run

No assim

C-Glors



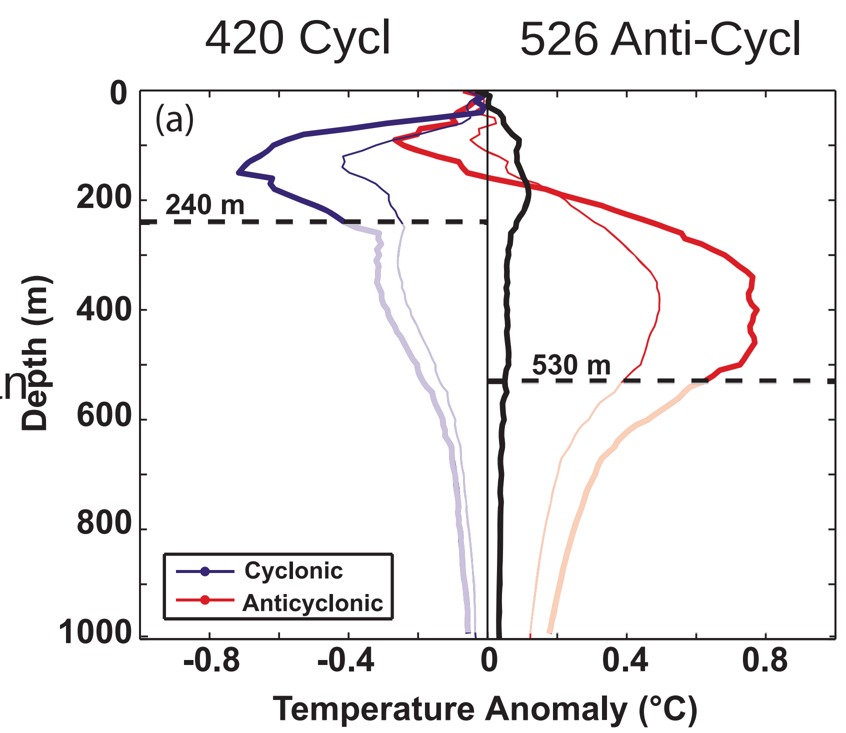
Regional case study

- Temperature anomaly trapped in the eddies

AE (red)

CE (blue)

Argo profile Dec 2003-Oct 2009.
Anomaly eval. vs climatological mean
from CSIRO Atlas of Regional Seas
(Chaigneau et al. 2011)



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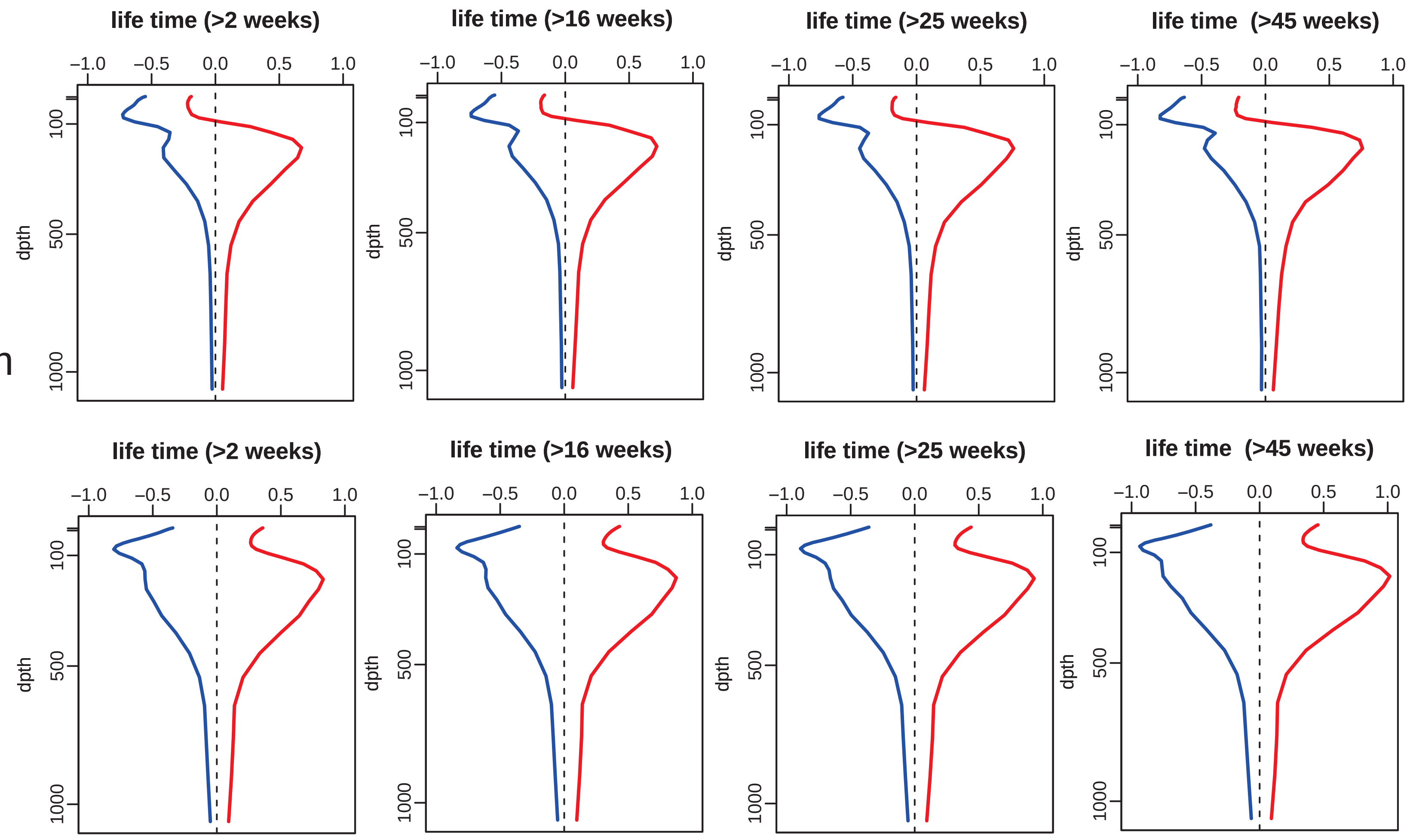

Regional case study

- Section of eddy

(Chaigneau et al. 2011)

C-GLORS