Expected changes in fine-scale (1–100 km) Lagrangian structures detected from altimetry from the SWOT mission

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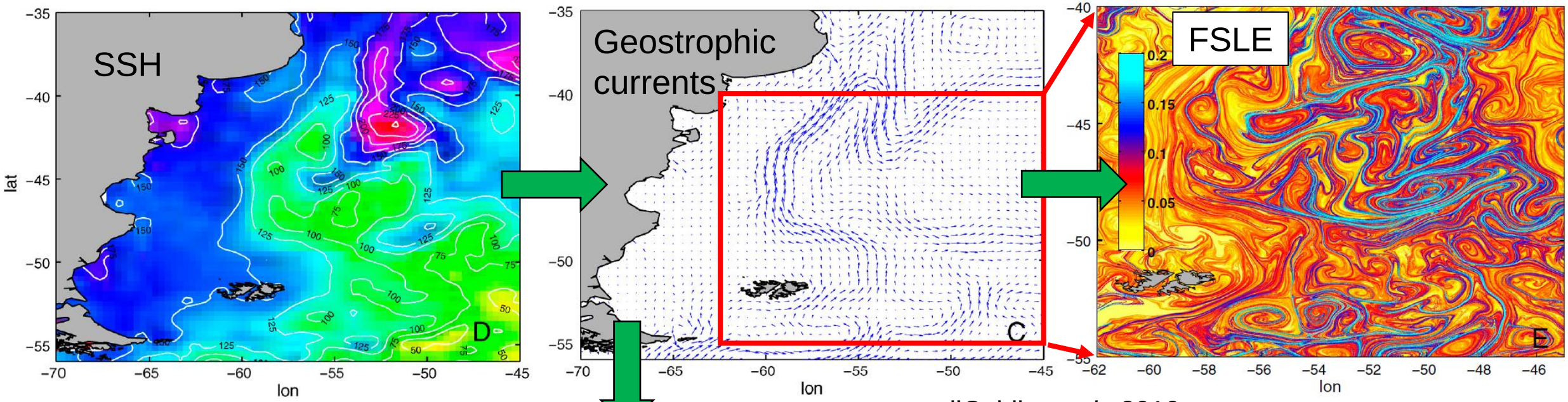
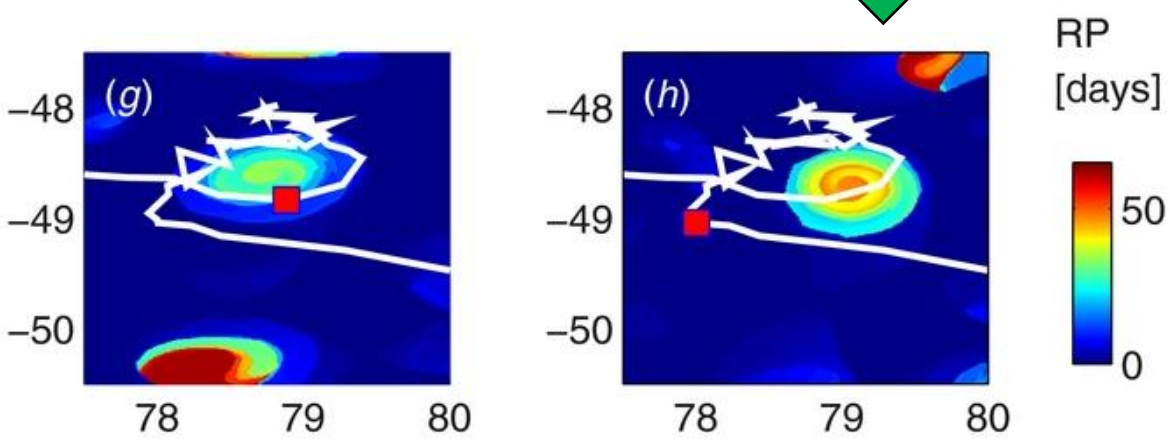
LOCEAN
Laboratoire d'Océanographie et du Climat
Expérimentations et Approches Numériques

Lagrangian structures derived from altimetry



d'Ovidio *et al*., 2010



d'Ovidio *et al*., 2013

Identification of **Lagrangian Coherent Structures**

→ Ex: Finite-Size Lyapunov Exponent (FSLE)

Identification of **retention structures**:

→ Ex: Retention Parameter (RP)

Lagrangian structures → Fish concentration

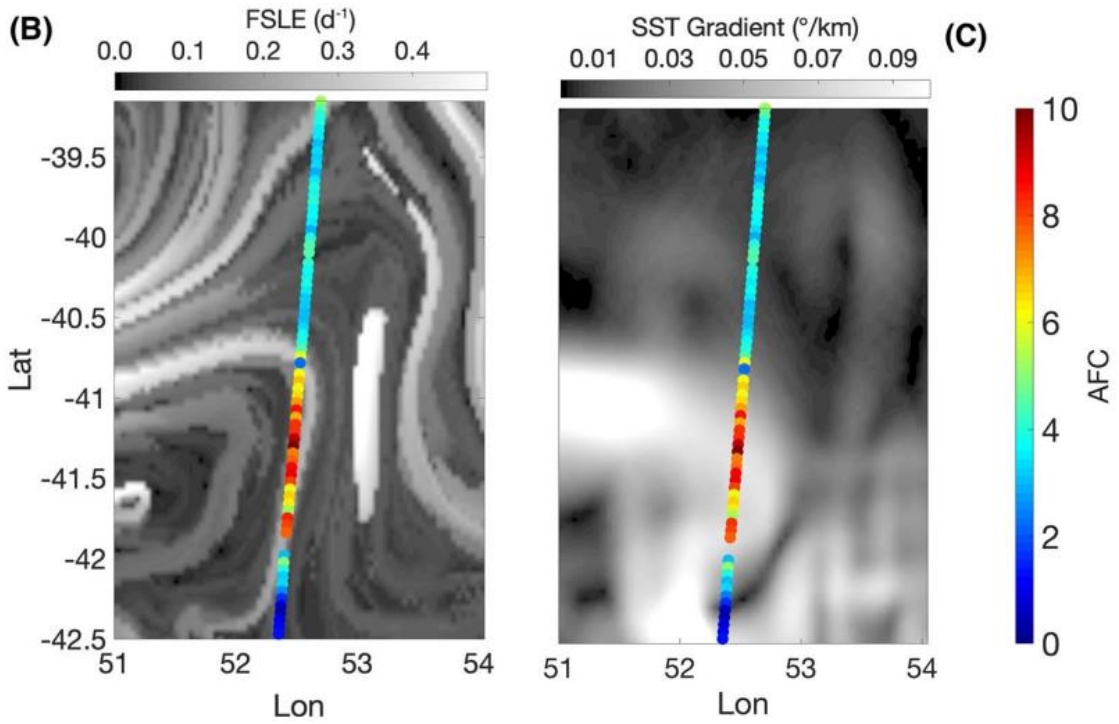
scientific reports

OPEN

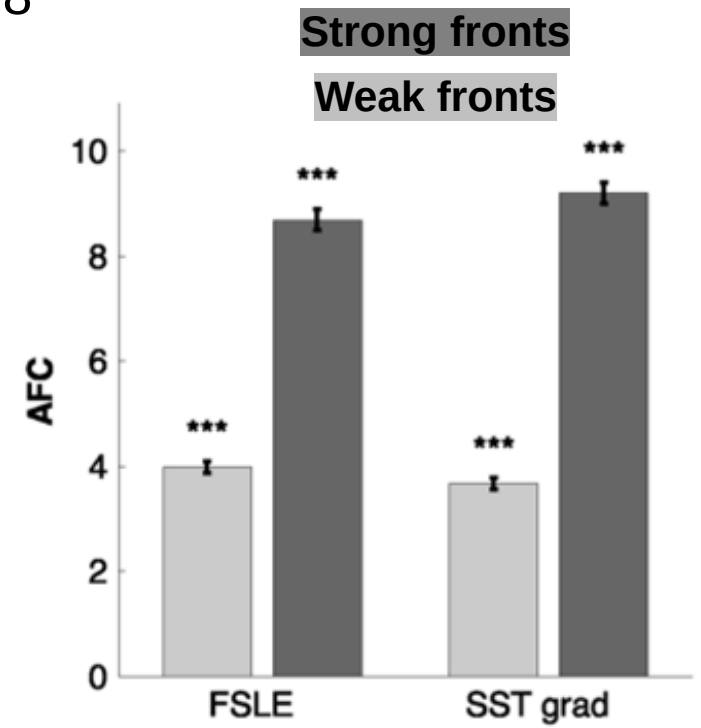
Fine-scale structures as spots of increased fish concentration in the open ocean

Alberto Baudena[1,2]✉, Enrico Ser-Giacomi[1,6], Donatella D'Onofrio[3,4], Xavier Capet[1], Cedric Cotté[1], Yves Cherel[5] & Francesco D'Ovidio[1]

2018



Acoustic **F**ish **C**oncentration



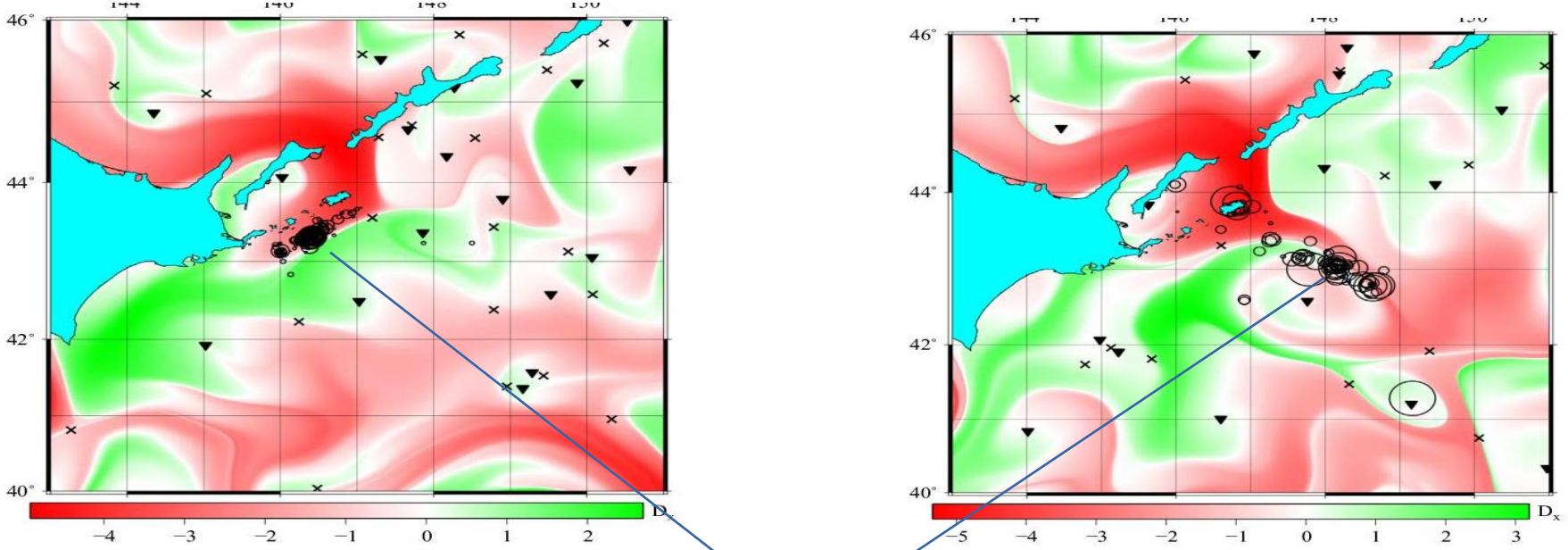
Lagrangian structures → Fisheries

Identifying Lagrangian fronts with favourable fishery conditions

S.V. Prants *, M.V. Budyansky, M.Yu. Uleysky

Pacific Oceanological Institute of the Russian Academy of Sciences, 43 Baltiiskaya st., 690041 Vladivostok, Russia

DSR, 2014



Catches

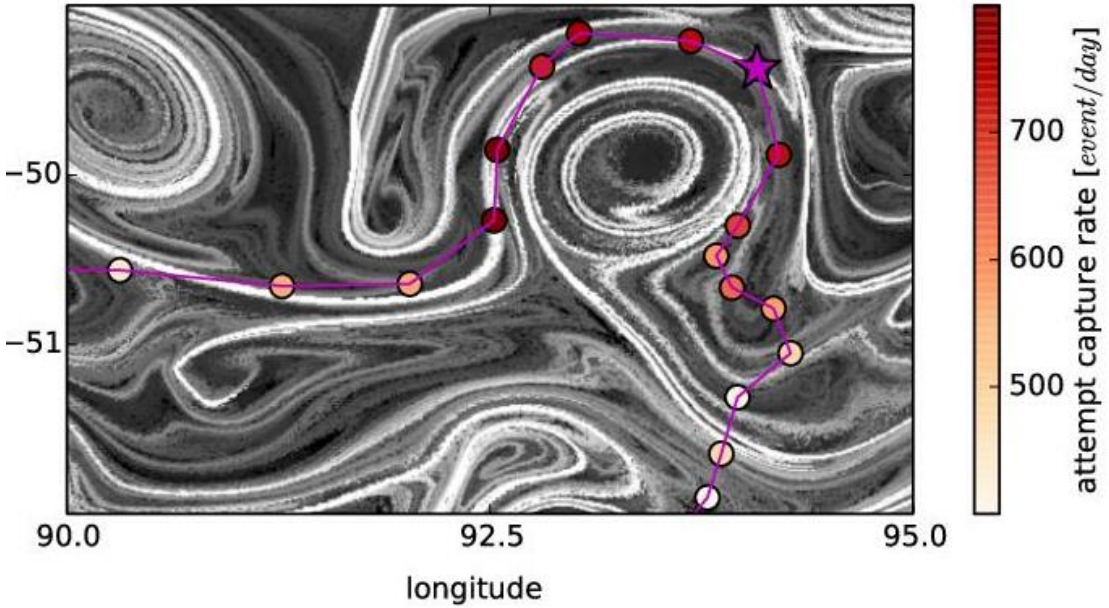
Lagrangian structures → Top predators

Quasi-planktonic behavior of foraging top marine predators

Alice Della Penna[1,2,3], Silvia De Monte[4], Elodie Kestenare[5], Christophe Guinet[6] & Francesco d'Ovidio[1]

Scientific Report, 2015

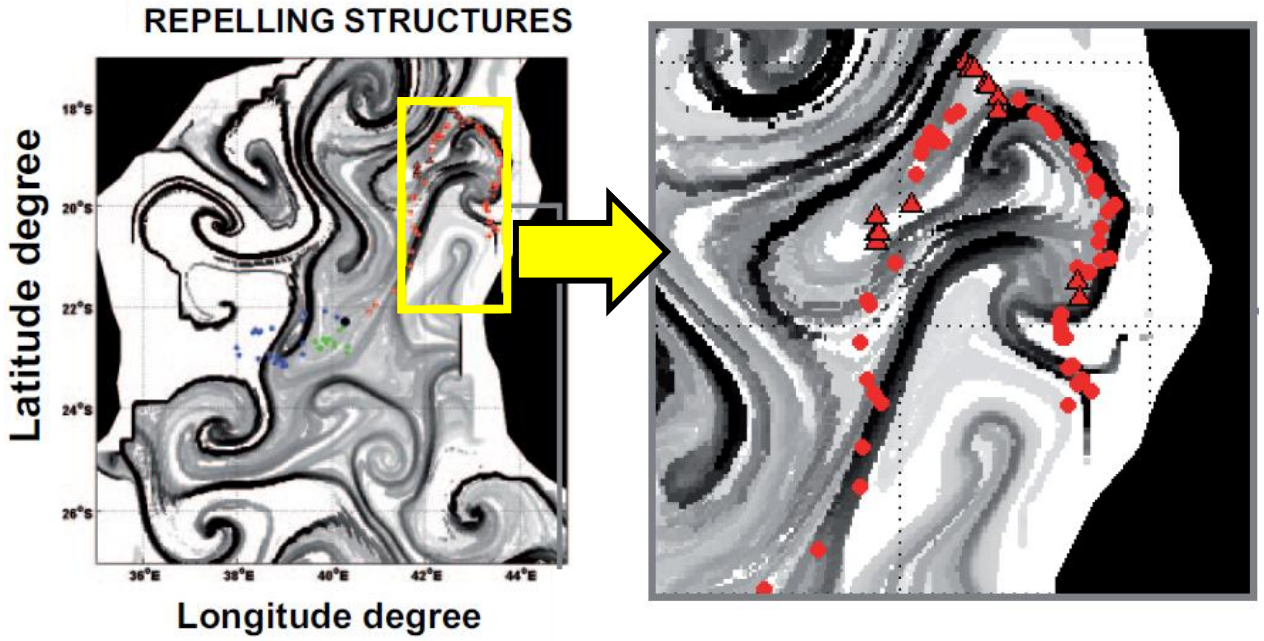
Image: © E. Pauthenet



Top marine predators track Lagrangian coherent structures

Emilie Tew Kai[a,1], Vincent Rossi[b], Joel Sudre[b], Henri Weimerskirch[c], Cristobal Lopez[d], Emilio Hernandez-Garcia[d], Francis Marsac[a], and Veronique Garçon[b]

PNAS, 2009

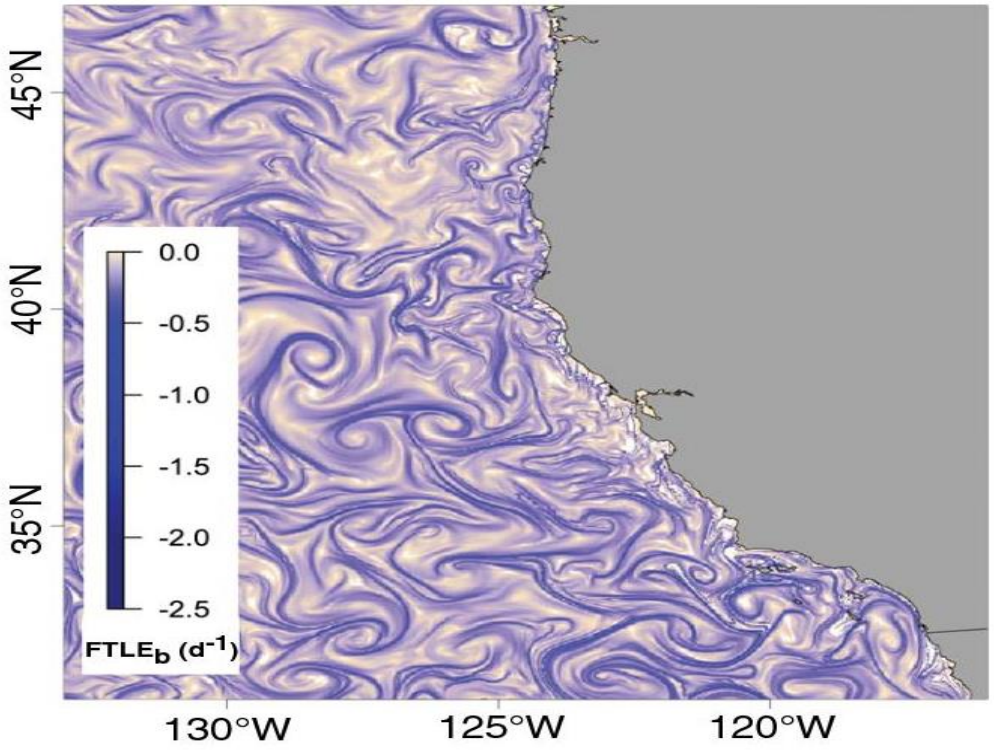


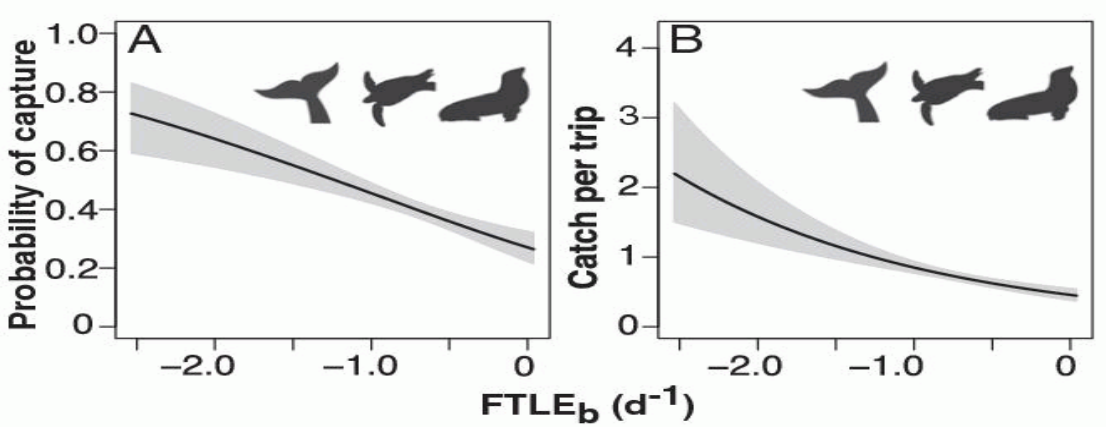
Lagrangian structures → Fishery bycatch

Fisheries bycatch risk to marine megafauna is intensified in Lagrangian coherent structures

PNAS, 2018

Kylie L. Scales[a,b,1], Elliott L. Hazen[b], Michael G. Jacox[b,c], Frederic Castruccio[d], Sara M. Maxwell[e], Rebecca L. Lewison[f], and Steven J. Bograd[b]





Limits of nadir altimetry

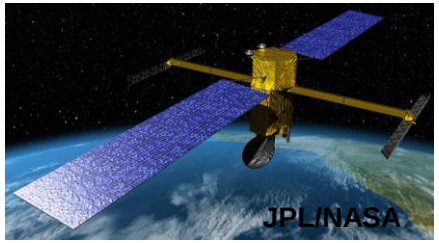
- Nadir altimetry limited to the large **mesoscale** >100–150 km in wavelength (eddy diameter >50–75 km) (Ballarotta *et al*., 2019)

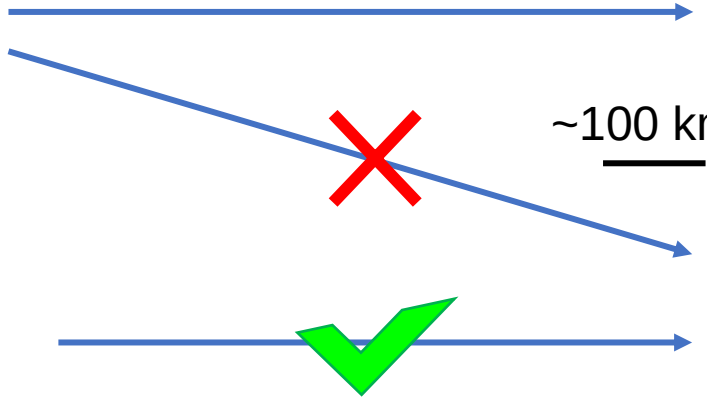
- **Fine scales** (1–100 km, hours to weeks) ~= temporal scales of **ecological processes**

- **SWOT** (Surface Water and Ocean Topography): spatial resolution 15–30 km in wavelength (Morrow *et al*., 2019) → Will see a large part of fine-scales (eddy diameter >7–15 km)

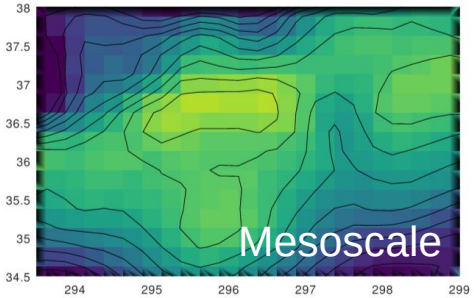
Nadir altimetry

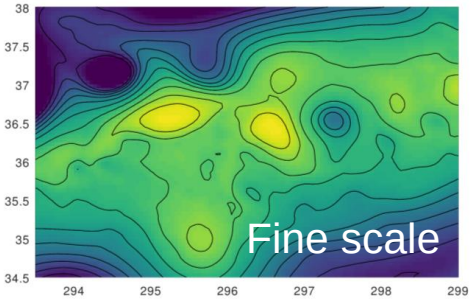
SWOT

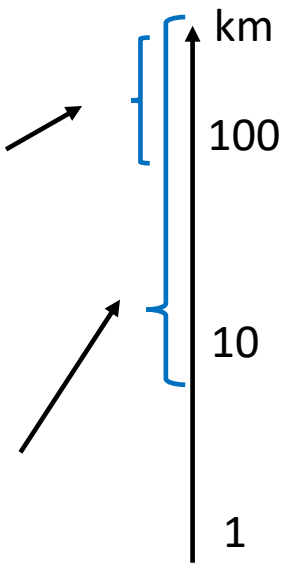




SSH







Questions

- Should we expect a breakthough in Lagrangian structures detected from altimetry with the SWOT mission?

- What are the implications for ecological studies?

→ Changes in the strength of these structures?

→ Qualitative changes: structure details? New structures?

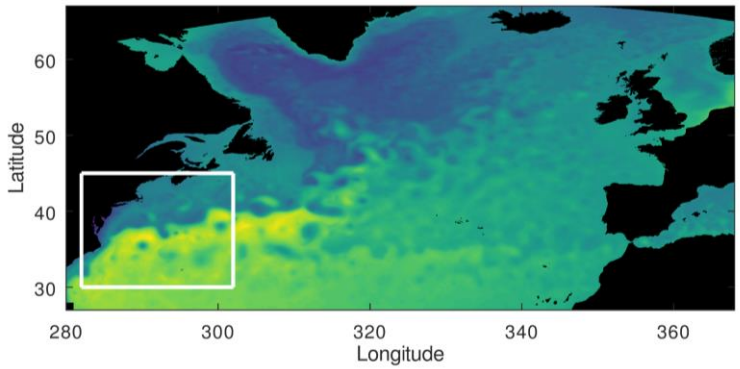
Data (CLS):

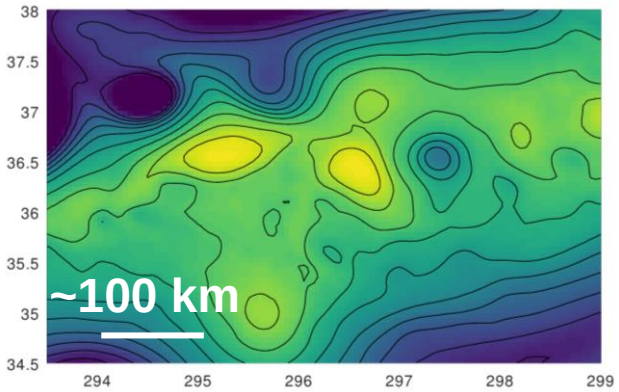
Model NEMO–NATL60
SSH (1/60°)
Hourly outputs

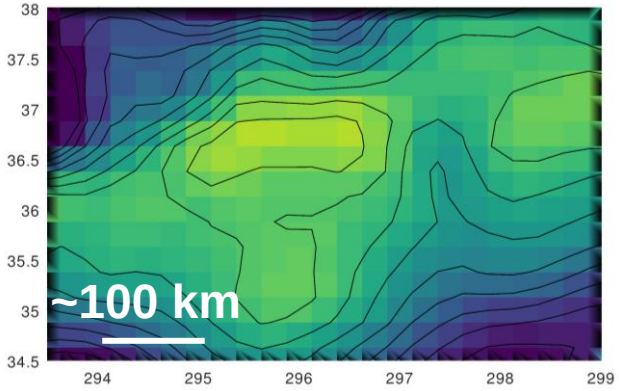
Study area: North Atlantic
+ zoom Gulf Stream

Interpolated on a 1/20° grid & daily-averaged (~**SWOT**)

DUACS reconstruction 1/4° daily (~**nadir altimetry**)







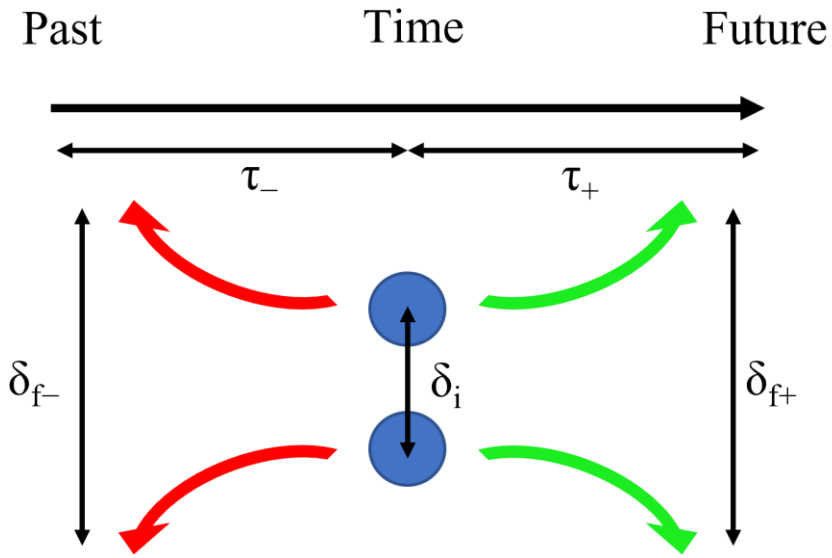
Methods:

- 01/02/2013 (**winter**, weak stratification) & 01/08/2013 (**summer**, strong stratification)
- Surface geostrophic velocities (Arbic et al., 2012)
- **Finite-Size Lyapunov Exponent** (FSLE) & **Retention Parameter** (RP)

Lagrangian diagnostics

Lyapunov exponent (FSLE)

Aurell *el al*., 1997



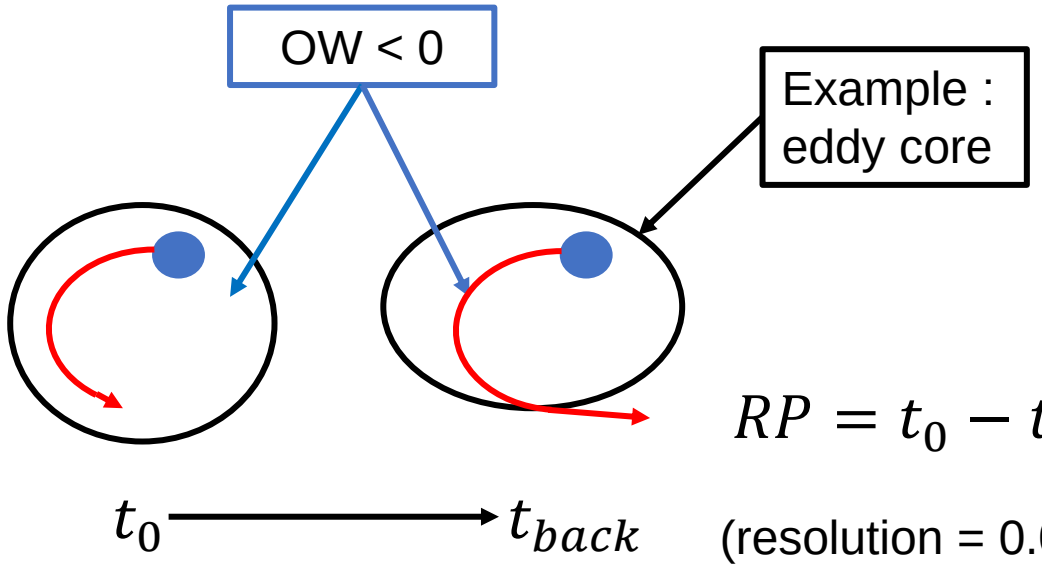
$$\lambda = \frac{1}{\tau}\ln\frac{\delta_f}{\delta_i} \cong \overline{strain\ rate}$$

δ_i = resolution = 0.01° et δ_f = 0.2°

Retention Parameter (RP)

d'Ovidio *et al*., 2013

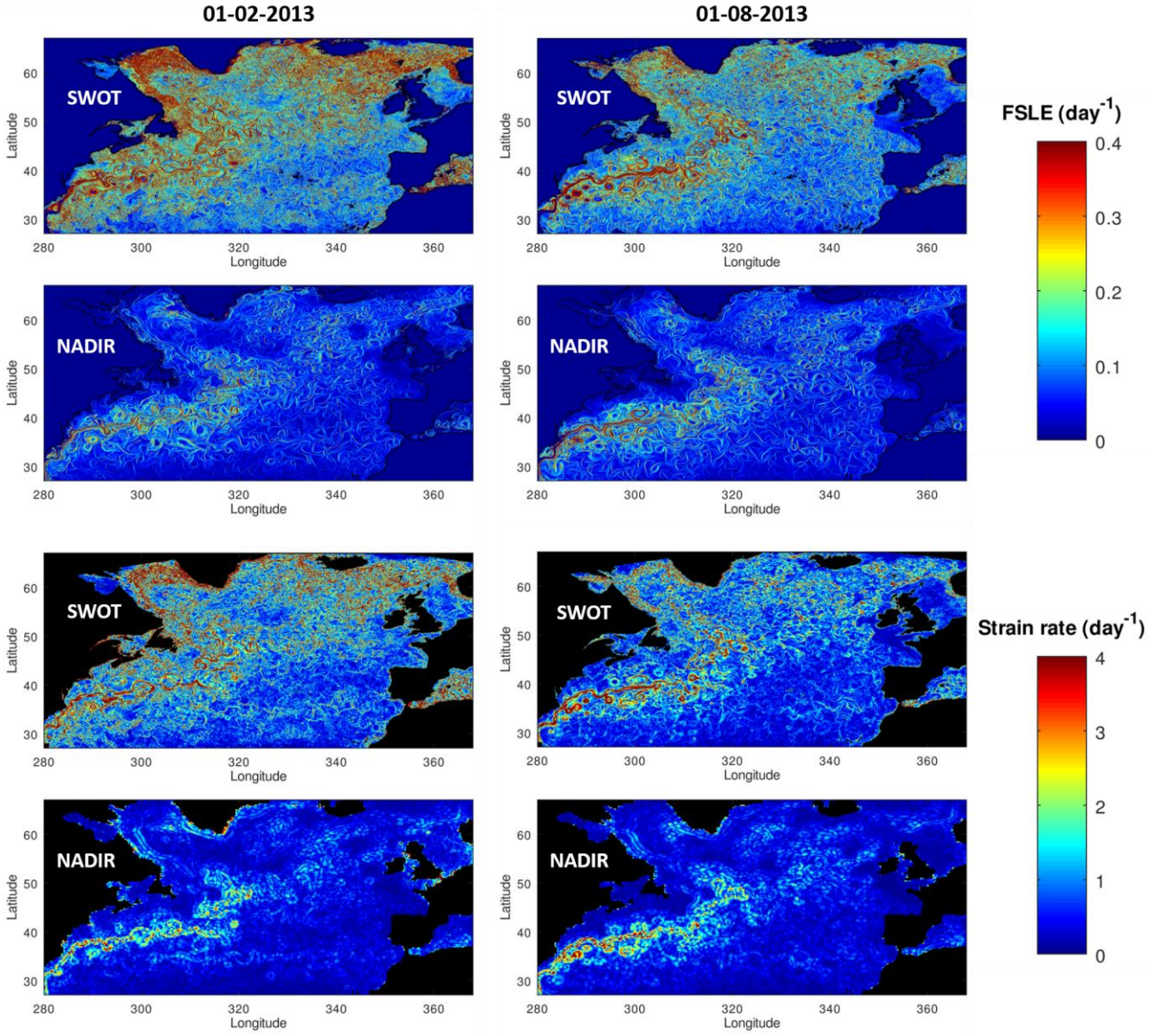
1) Compute Okubo-Weiss parameter (OW)
2) Particles initialized where OW < 0
3) Compute particle trajectories backward in time
4) RP = number of days particles remain in OW < 0



$$RP = t_0 - t_{back}$$

(resolution = 0.02°, max 121 days)

FSLE & strain rate

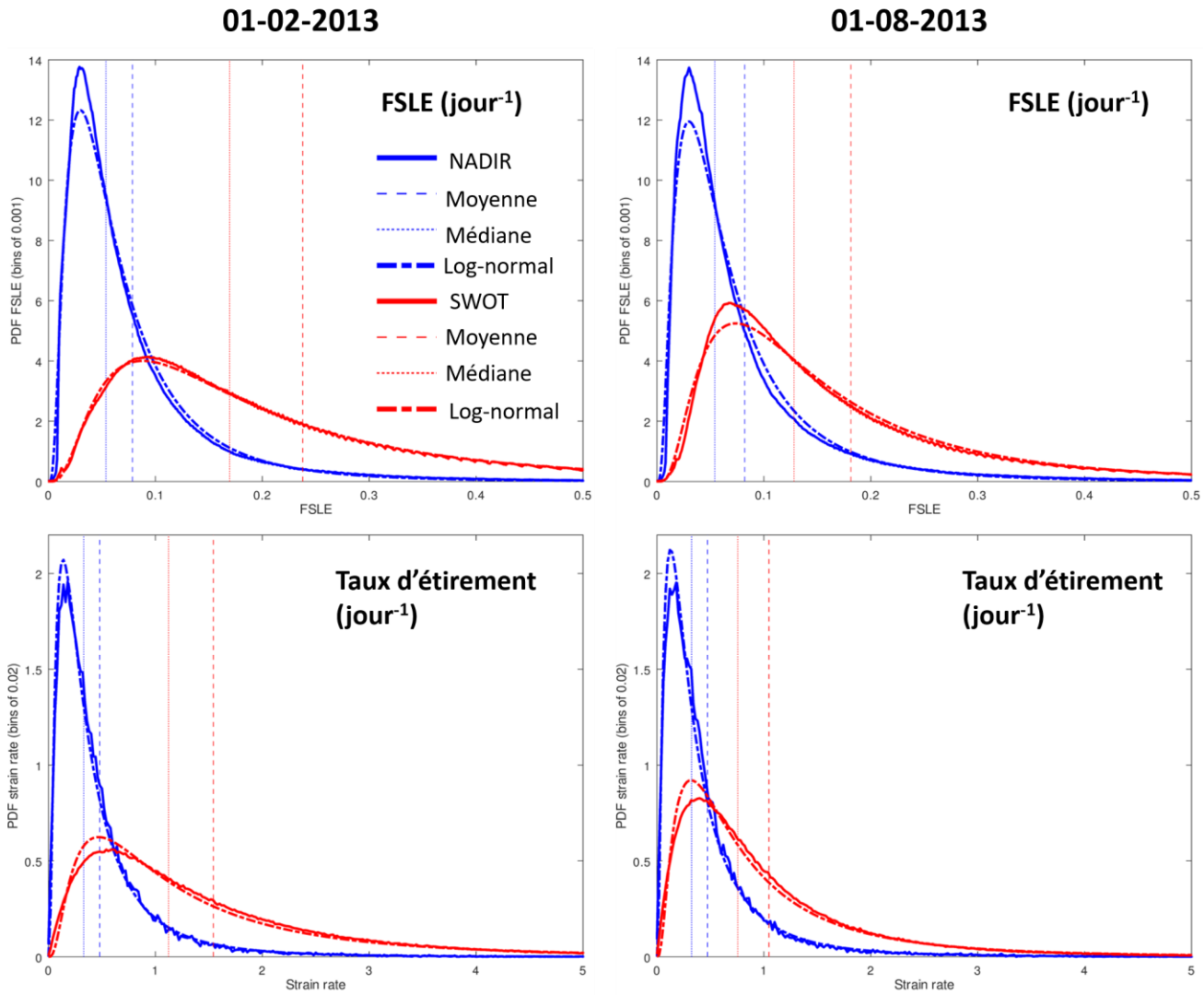


FSLE (stirring) 2 to 3 times underestimated on average by Nadir vs SWOT

- With high spatial **heterogeneity**
- And high **seasonality**

Similar results for the strain rate

FSLE & strain rate

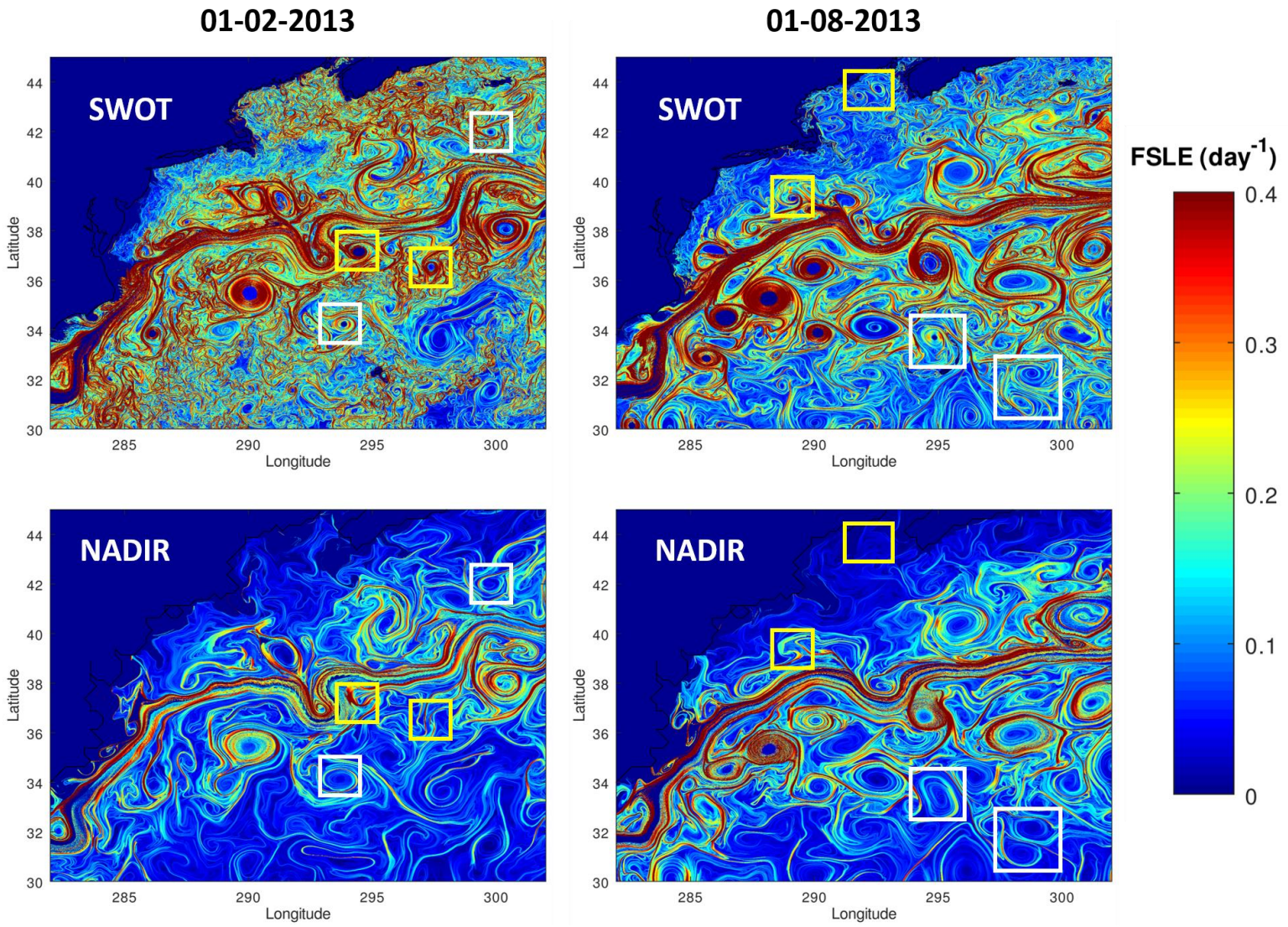


Log-normal Probability Density Function of the FSLE & the strain rate

→ The strain rate **controles** mostly FSLEs

→ Underestimation of the stirring mostly due to the **smoothing** of the SSH field by nadir altimetry

FSLE : zoom Gulf Stream



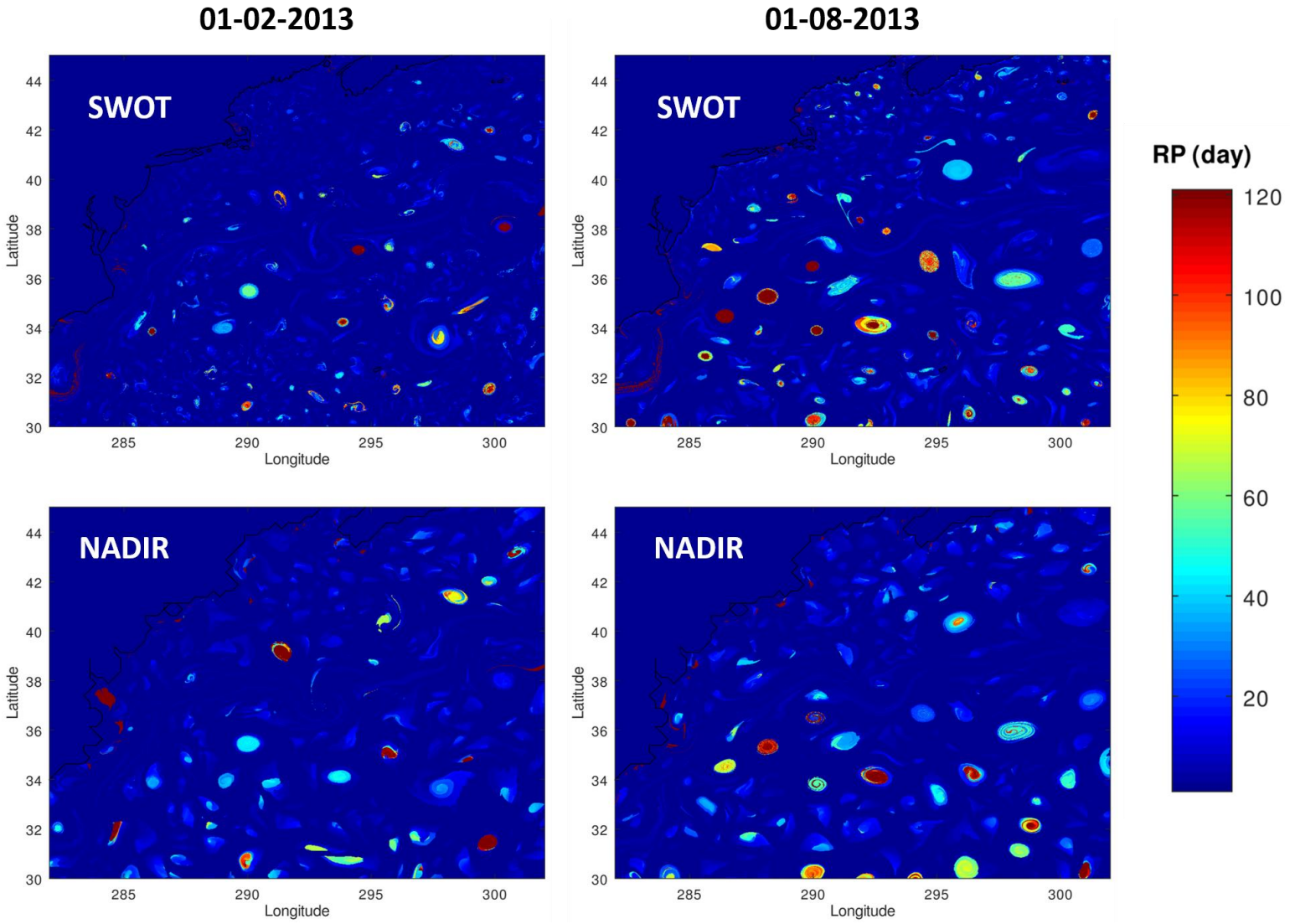
SWOT vs NADIR :

- Better eddy identification
- Clearer **separation** eddy core & boundary
- Identification of fine-scale structures

Eddy extended by NADIR

Eddy missed by NADIR

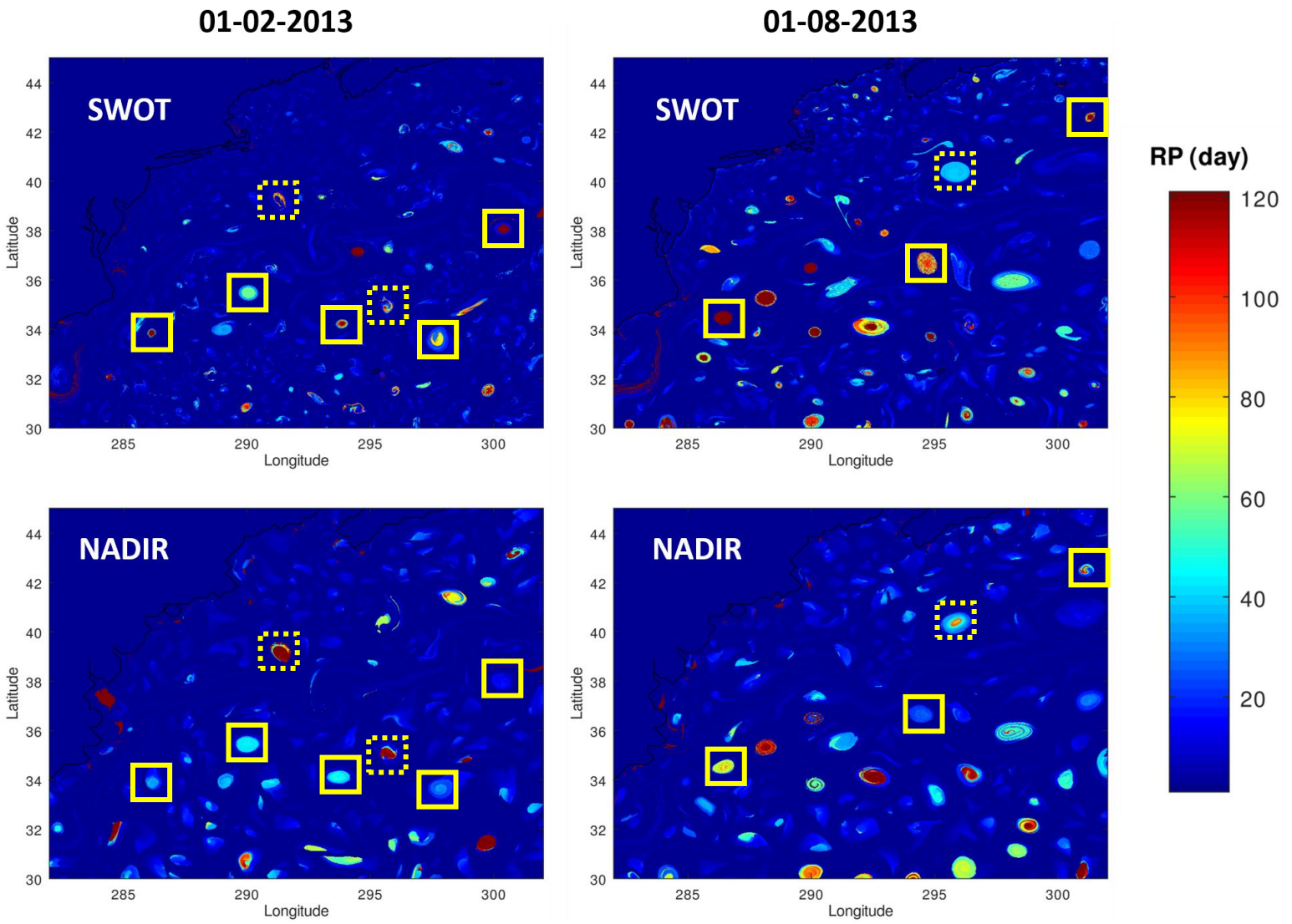
Retention Parameter : zoom on Gulf Stream



NADIR in comparaison with SWOT:

- Weakened retention
- Enhanced retention
- « Trap » → « Exchange »
- « Exchange » → « Exchange »
- « Exchange » → « Trap »
- New type of eddy

Retention Parameter : zoom on Gulf Stream



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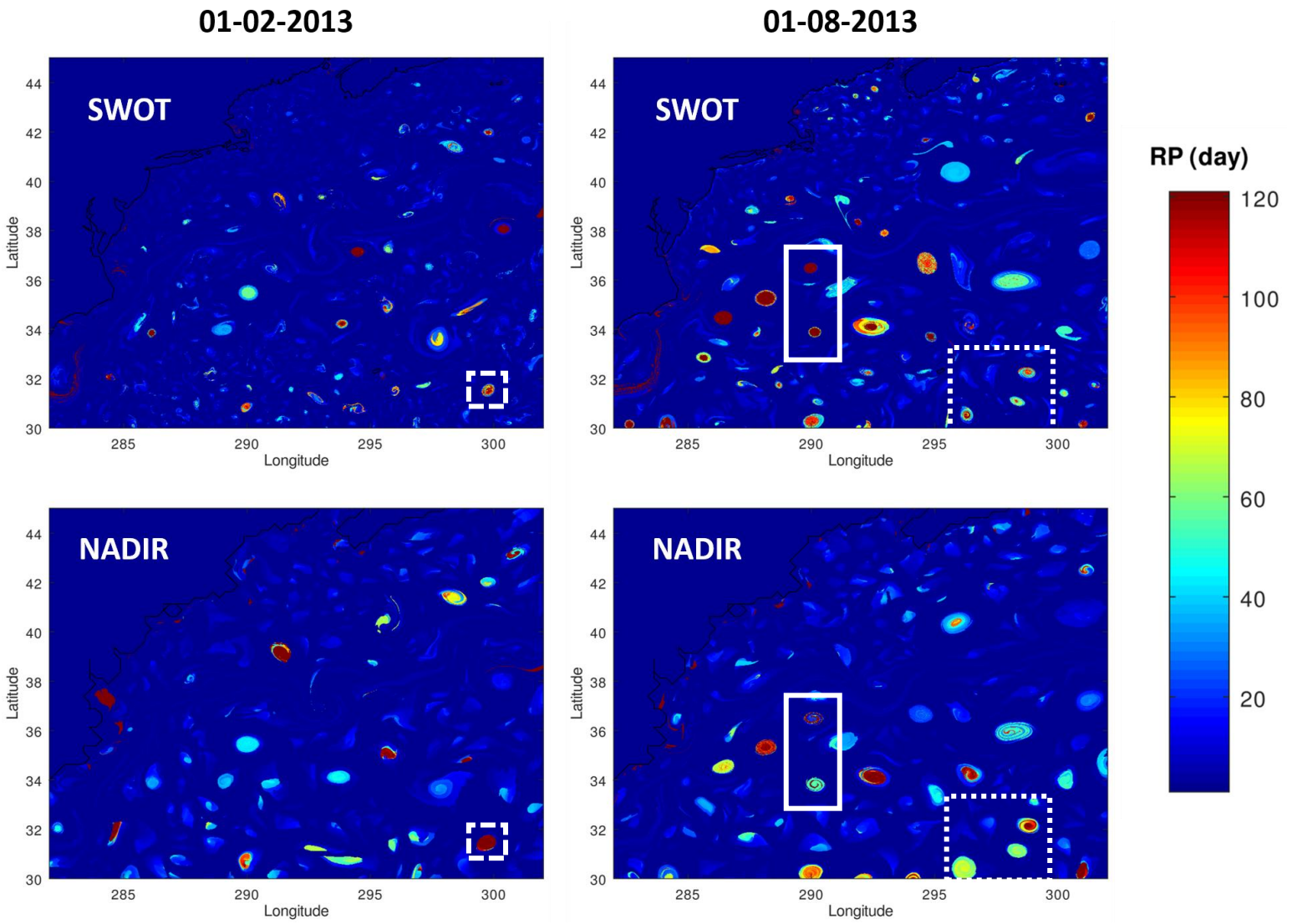

NADIR in comparaison with SWOT:

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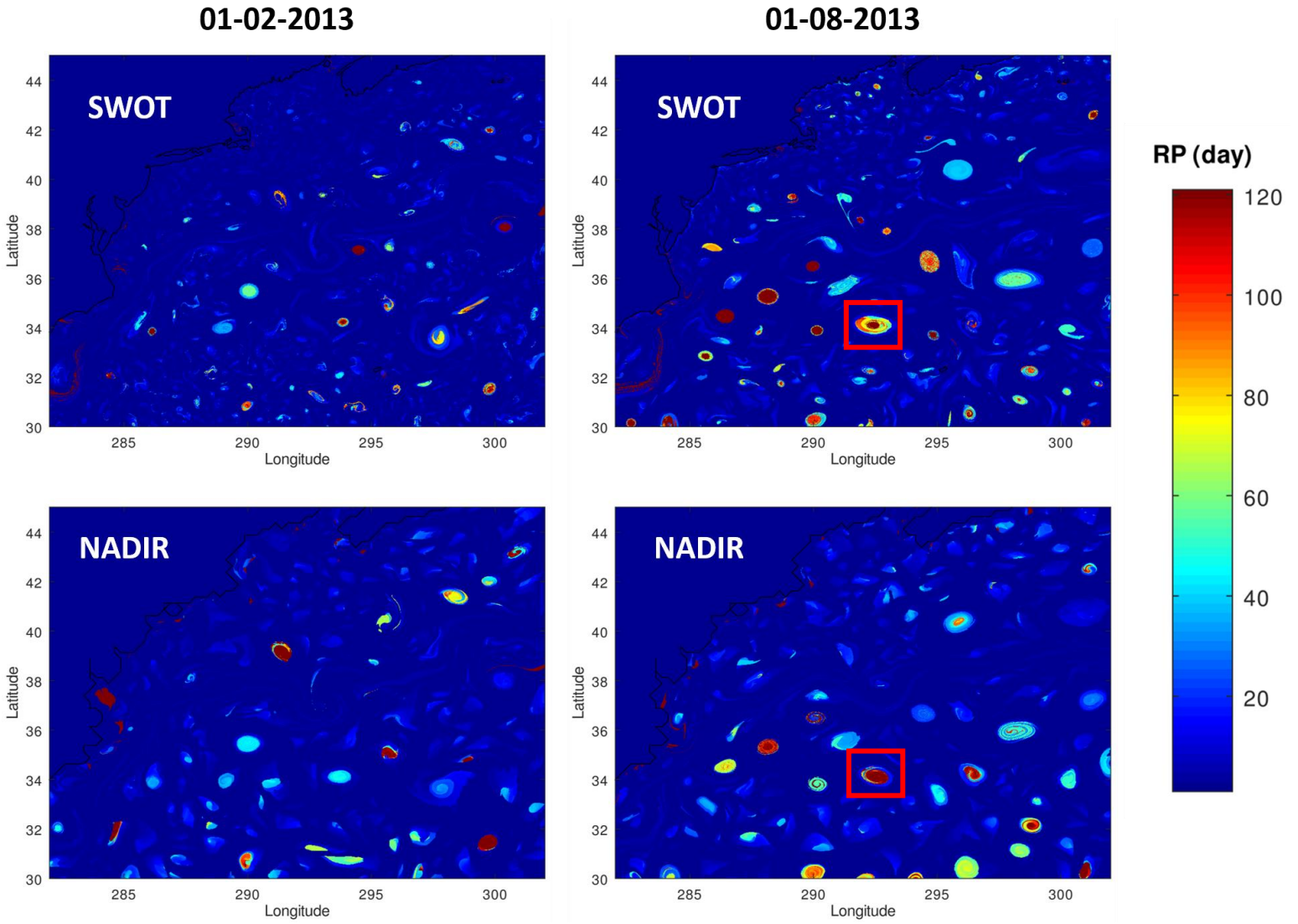
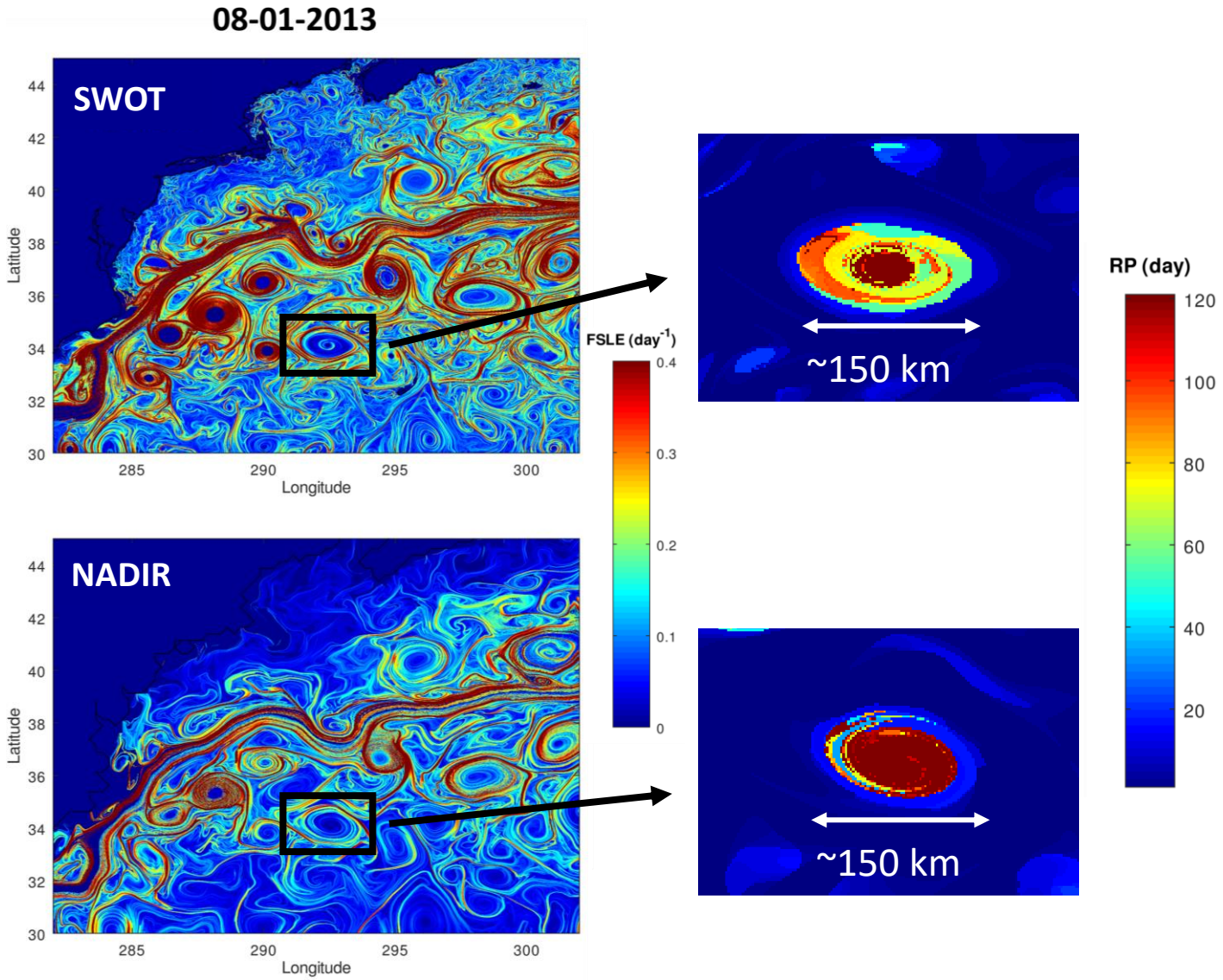


NADIR in comparaison with SWOT:

- Weakened retention
- Enhanced retention
- « trap » → « exchange »
- « exchange » → « exchange »
- « exchange » → « trap »
- New type of eddy

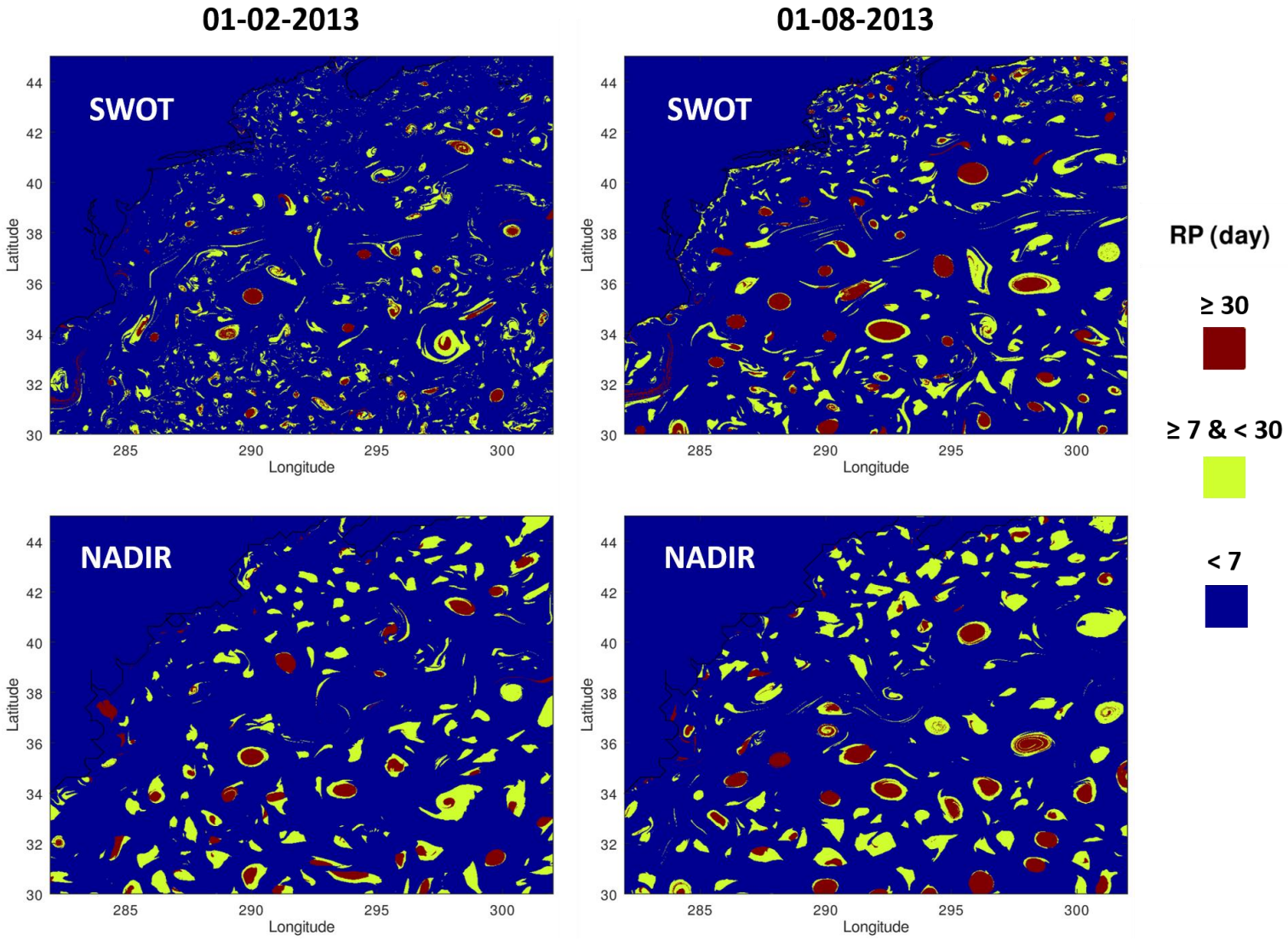
A new class of eddies?



- Identification of an « **eddy inside an eddy** »
- Permeable ring + highly retentive core

→ **Different** ecological & biogeochemical implicaions?

"Ecologically relevant retentive regions"



- 7 days: ~ temporal scale of planctonic interactions (competition, grazing)

- 30 days: ~ temporal scales of complex ecological interactions (foraging trips of top marine predators)

NADIR vs SWOT:

Total area:

→ Winter: +38% & +58%

→ Summer: +5% & −6%

→ Regions are more numerous but **fragmented** in fine-scale structures (O(1–10) km)

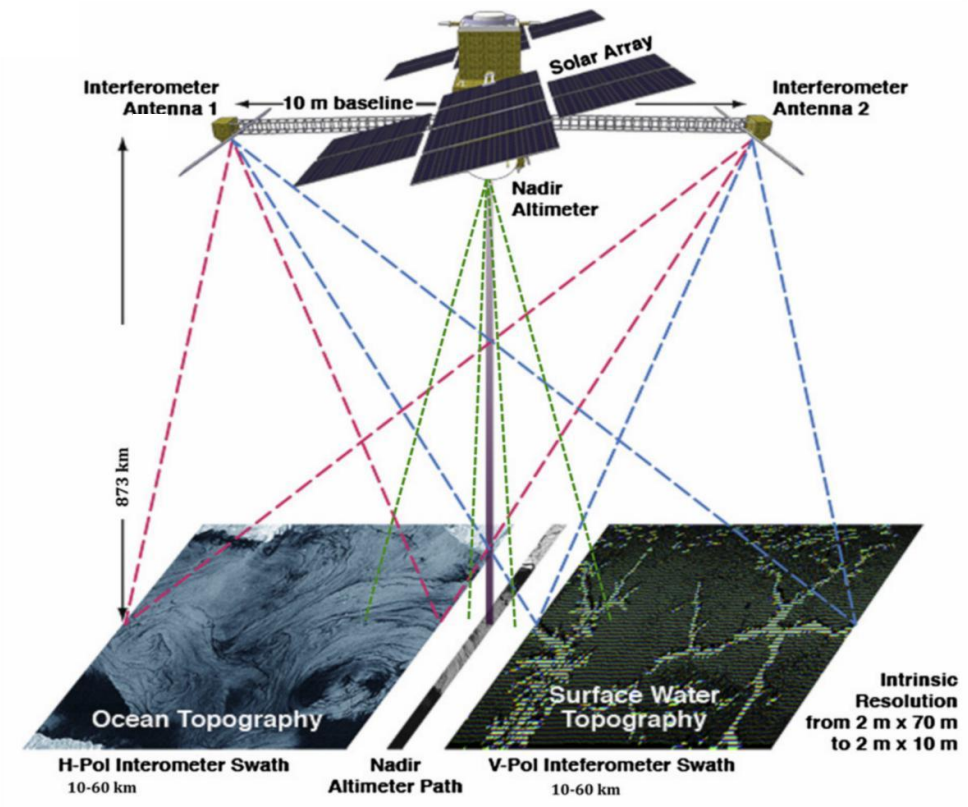
Conclusion

- We expect **major changes** in the identification of Lagrangian structures from altimetry with SWOT, especially in regions with small Rossby radius
- Large improvement of the **identification** and description of **fine-scale** structures
- SWOT data should be crucial for many **ecological, conservation & social** applications

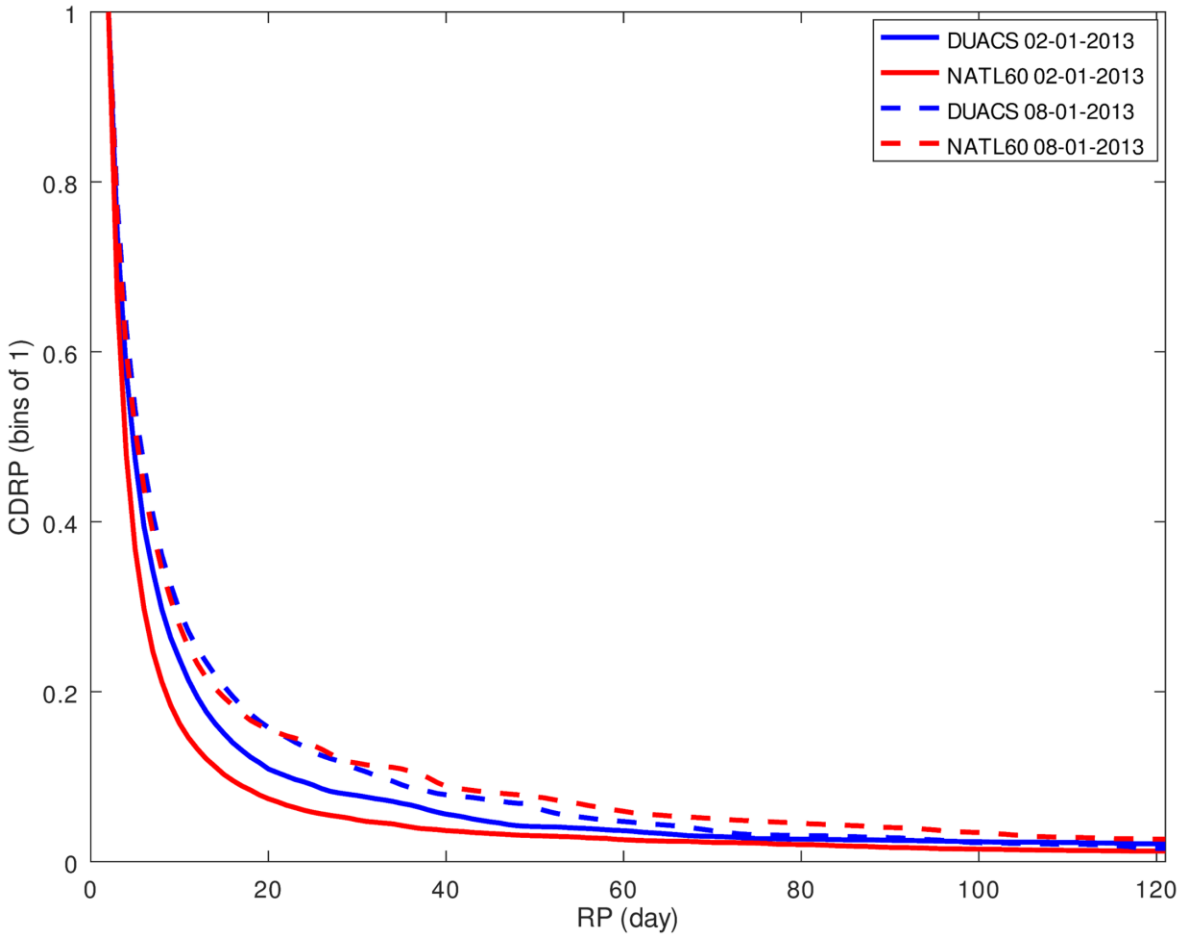
Perspectives

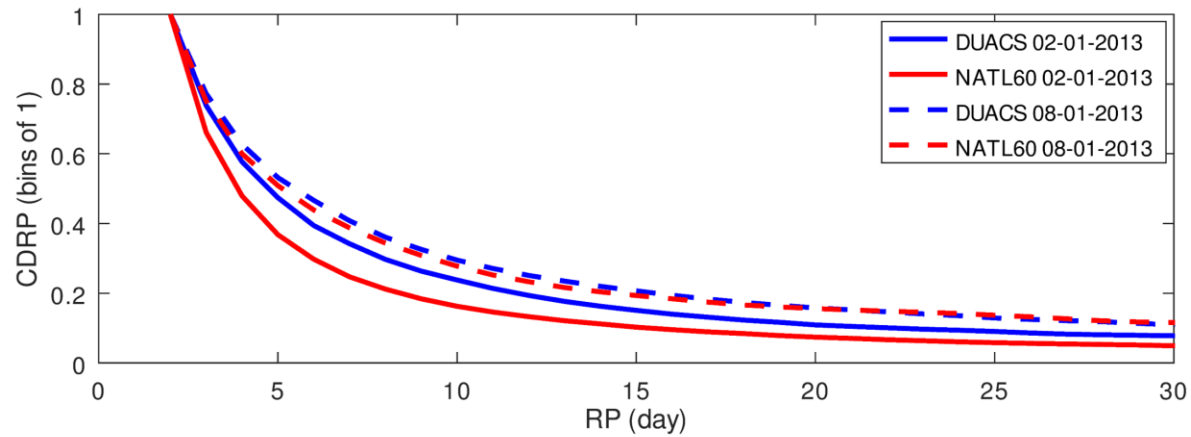
- Need of **ground truth**
- Coupling future real SWOT data with **ecological/biogeochimical data**
- Impacts of **vertical & ageostrophic** velocities?

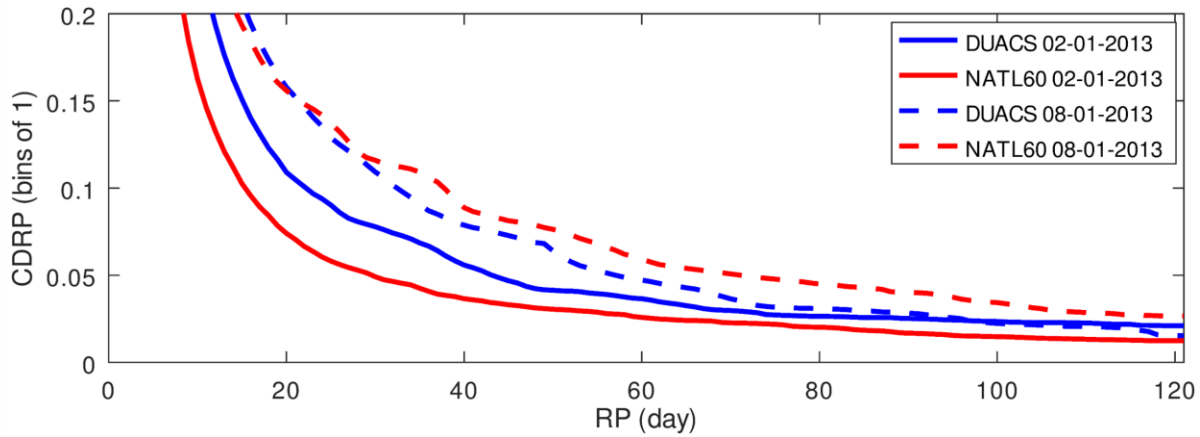
Thanks for your attention!



FSLE (jour^{-1})	01-02-2013			01-08-2013		
	NADIR	SWOT	Scale	NADIR	SWOT	Scale
Moyenne	0.078	0.238	3.03	0.082	0.181	2.21
Médiane	0.054	0.169	3.15	0.054	0.128	2.37
Écart type	0.084	0.233	2.79	0.093	0.177	1.91
Taux d'étirement (jour^{-1})	01-02-2013			01-08-2013		
	NADIR	SWOT	Scale	NADIR	SWOT	Scale
Moyenne	0.479	1.542	3.22	0.472	1.048	2.22
Médiane	0.330	1.122	3.40	0.323	0.755	2.34
Écart type	0.532	1.520	2.86	0.500	1.017	2.04


DUACS 02-01-2013
NATL60 02-01-2013
DUACS 08-01-2013
NATL60 08-01-2013
CDRP (bins of 1)
RP (day)
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100
120


DUACS 02-01-2013
NATL60 02-01-2013
DUACS 08-01-2013
NATL60 08-01-2013
CDRP (bins of 1)
RP (day)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30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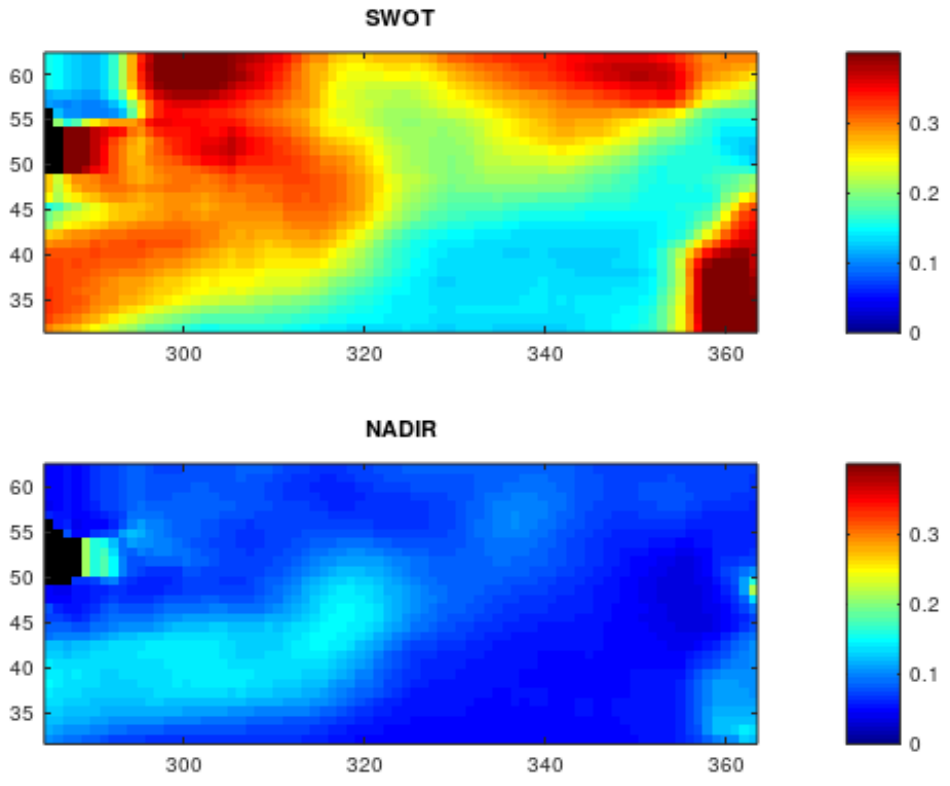
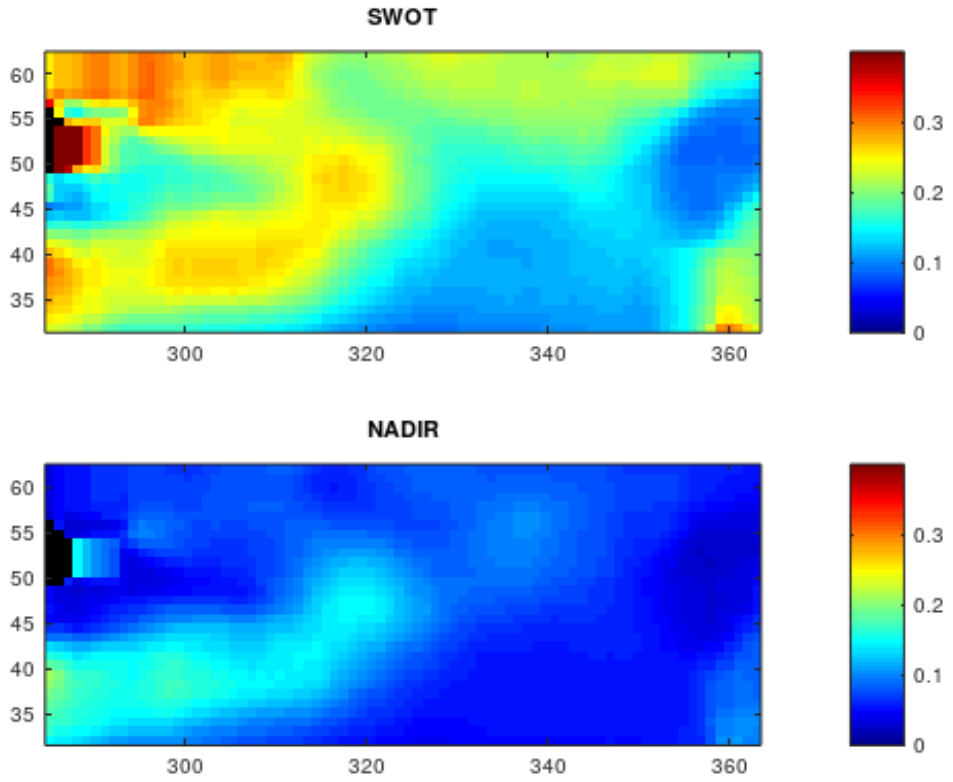
NATL60 02-01-2013
DUACS 08-01-2013
NATL60 08-01-2013
CDRP (bins of 1)
RP (day)
0
0.05
0.1
0.15
0.2
0
20
40
60
80
100
120

01-02-2013



01-08-2013



Averaged FSLE on 10° x 10° boxes, every 1°

Fine-scale processes and impacts on ecosystems

REVIEW ARTICLE

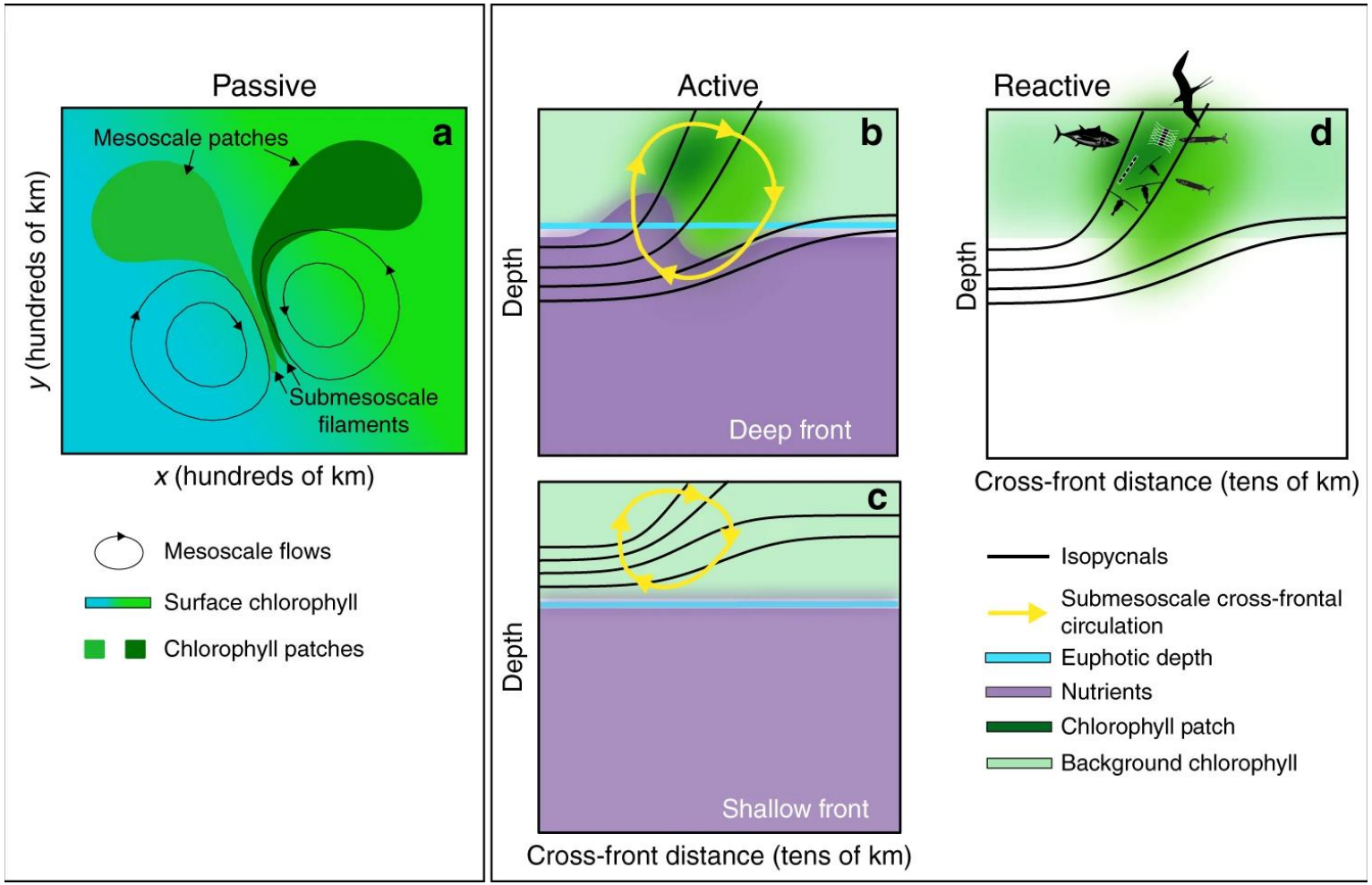
DOI: 10.1038/s41467-018-07059-3 OPEN

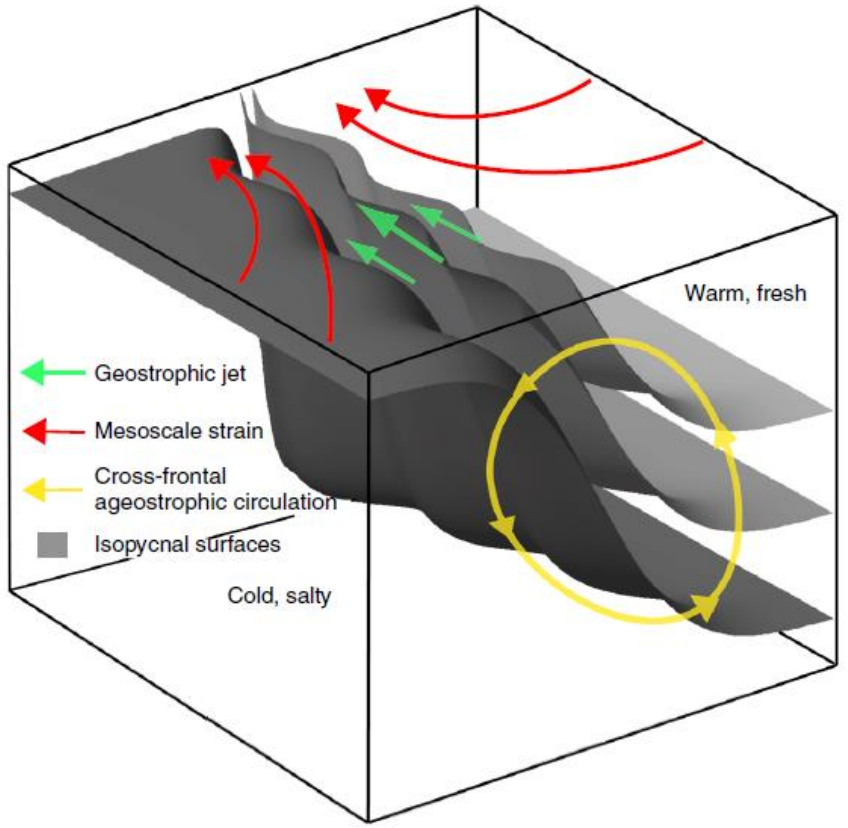
The role of submesoscale currents in structuring marine ecosystems

2018

Marina Lévy [1], Peter J.S. Franks[2] & K. Shafer Smith[3,4]

nature COMMUNICATIONS





Annual Review of Marine Science

A Satellite-Based Lagrangian View on Phytoplankton Dynamics

Yoav Lehahn,[1,2,*] Francesco d'Ovidio,[3,*] and Ilan Koren[2]