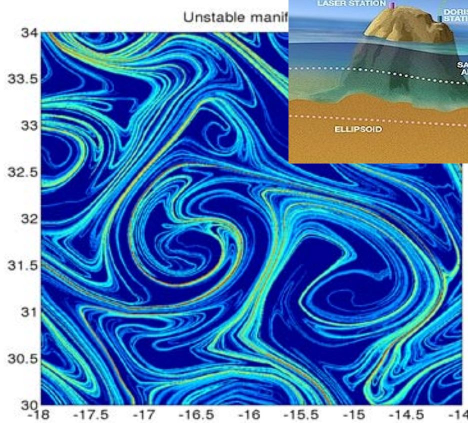
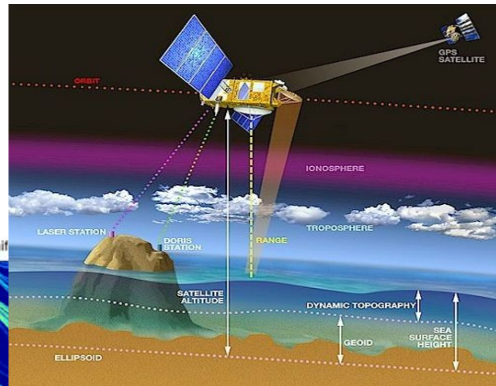
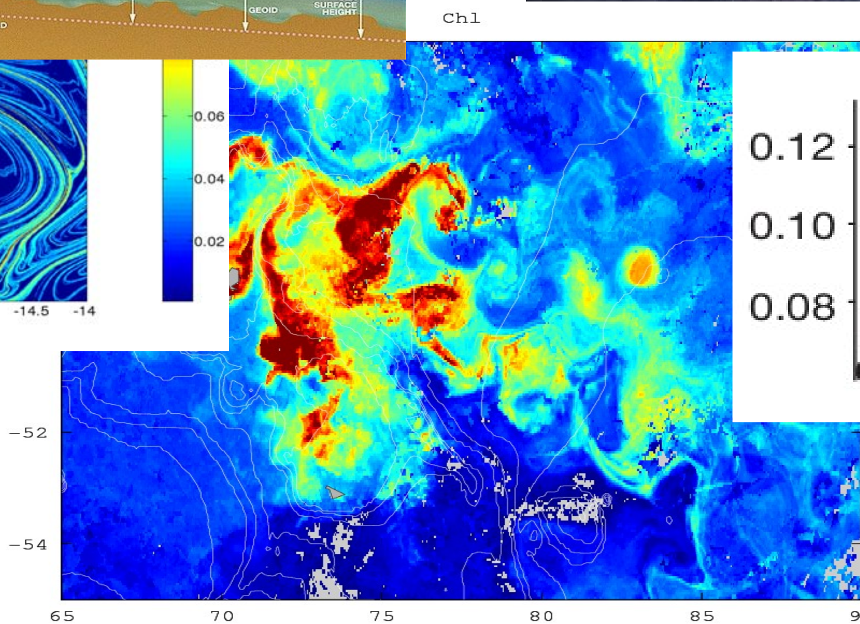
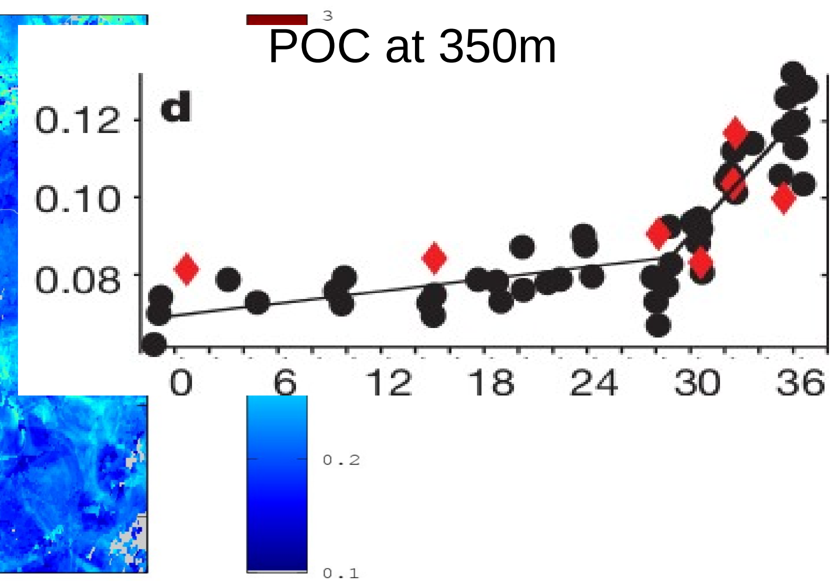
Fron carbon export to the foraging of top predators in the Kerguelen region

F. d'Ovidio CNRS, LOCEAN-IPSL, Paris







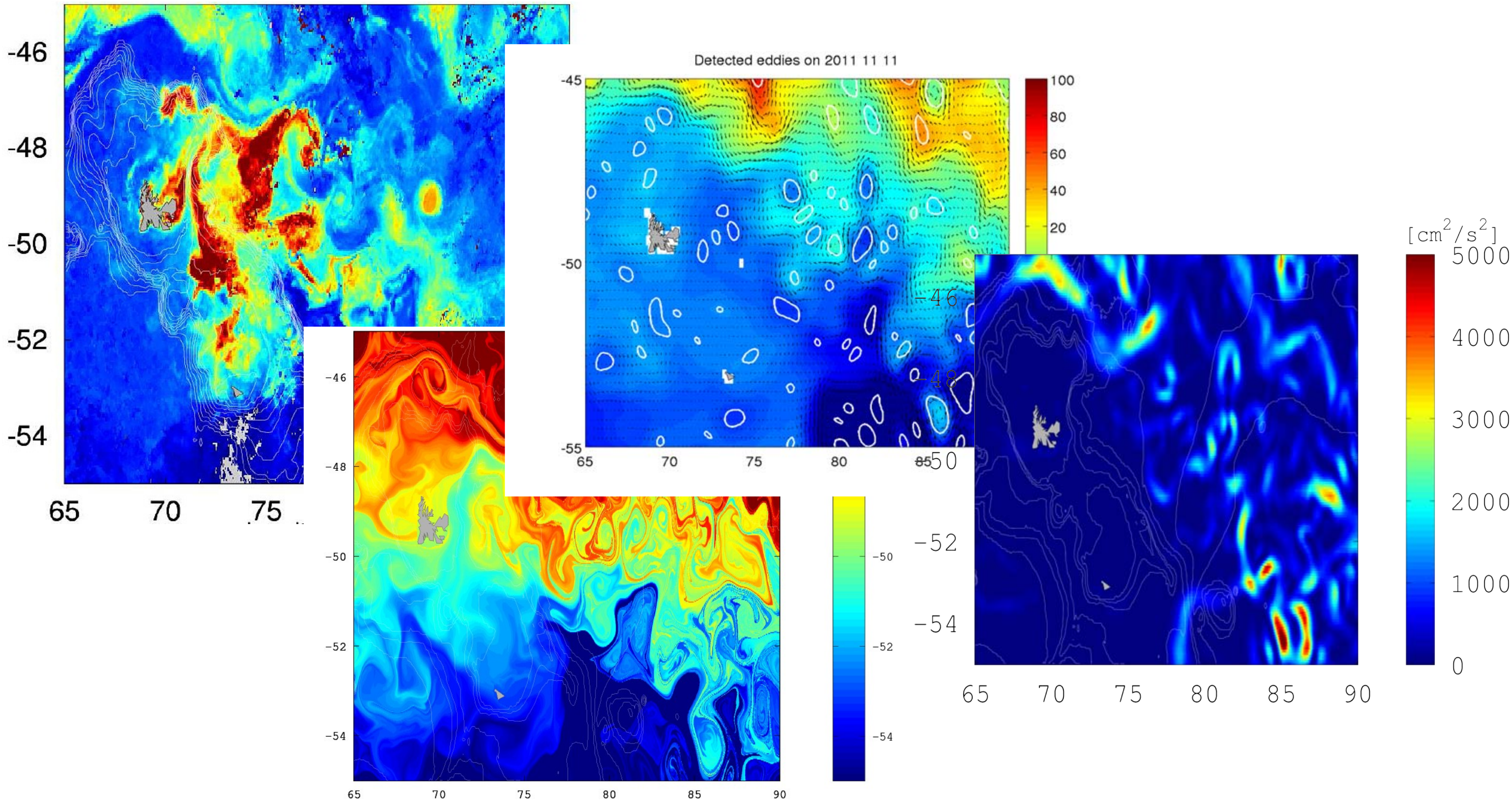


Works in collaboration with: <u>**C. Cotté,**</u> C. Guinet, Y. Cherel, M. Lévy, S. Blain, B. Quiguener, F. Nencioli, S. De Monte, S. Alvain, A. Della Penna, Y.H. Park, V. Smetacek

Thanks to CNES and CLS (altimetry and ocean color data)

As terrestrial organisms, we recognise immediately physical features like mountains and valleys, the presence of primary producers and their main limiting factor – water. We expect to find different upper trophic levels in different environments.

However, to us the open ocean looks just a seemingly homogeneous extension of salty water



Instruments unveil for us strong contrasts in water masses properties. Unlike continental environments, the ocean landscape evolves dramatically on the time scale of marine ecology and ethology (<u>days to weeks</u>)

- **demography of primary producers** (phytoplankton division time, bloom duration)
- **behavioral switches of marine predators**

Remarkably, this days-weeks temporal domain – the (sub)mesoscale - contains <u>lot of energy</u>.

Physics

Outline

Primary production

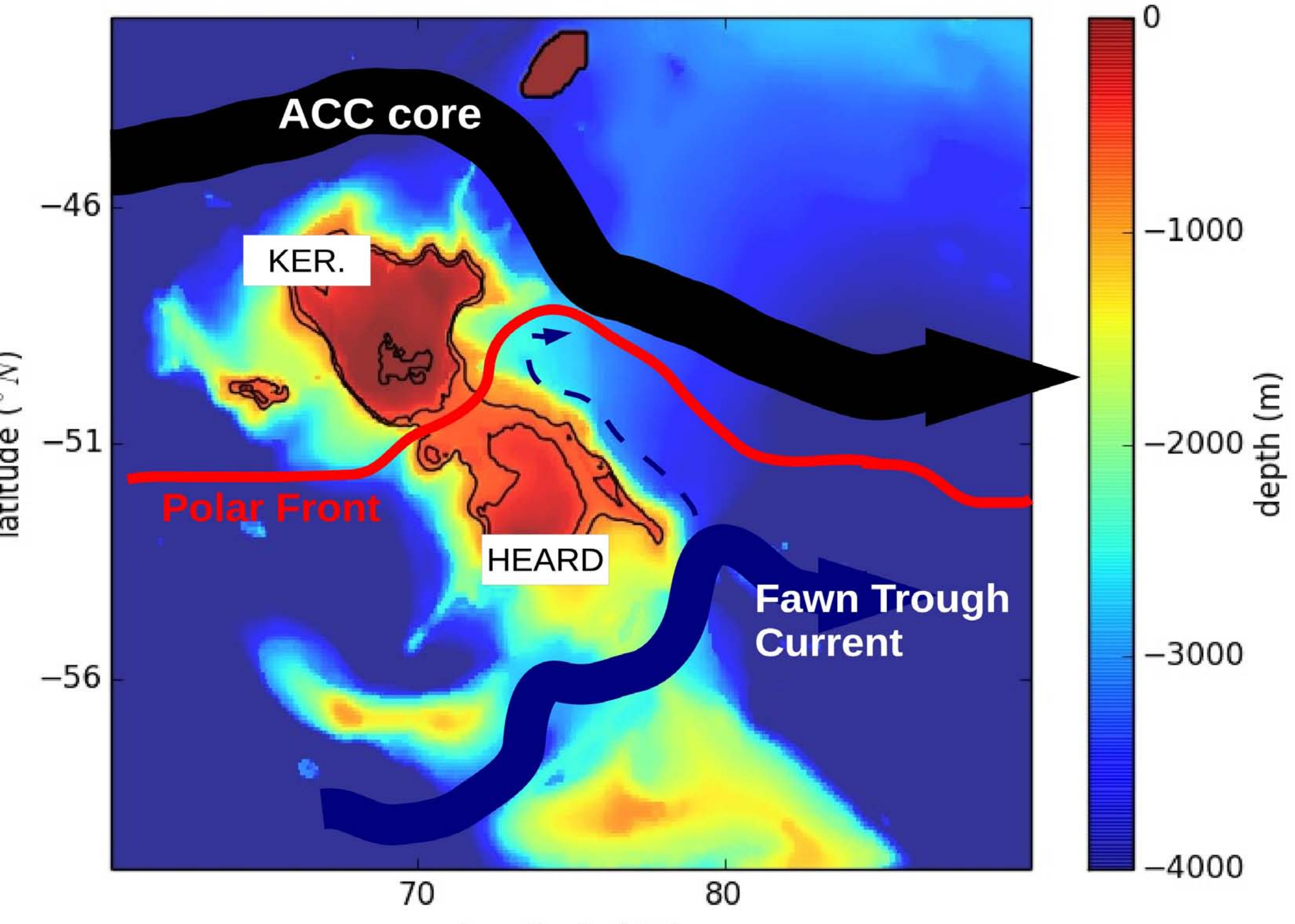
Interm. trophic levels

Top predators

1. Lateral stirring and iron delivery (KEOPS2 cruise)

2. (Sub)mesoscale dynamics and foraging of elephant seals (IPSOS-SEAL biologging)

3. Myctophids' distribution (MYCTO cruise)



ACC core
KER.
HEARD
Polar Front
Fawn Trough
Current
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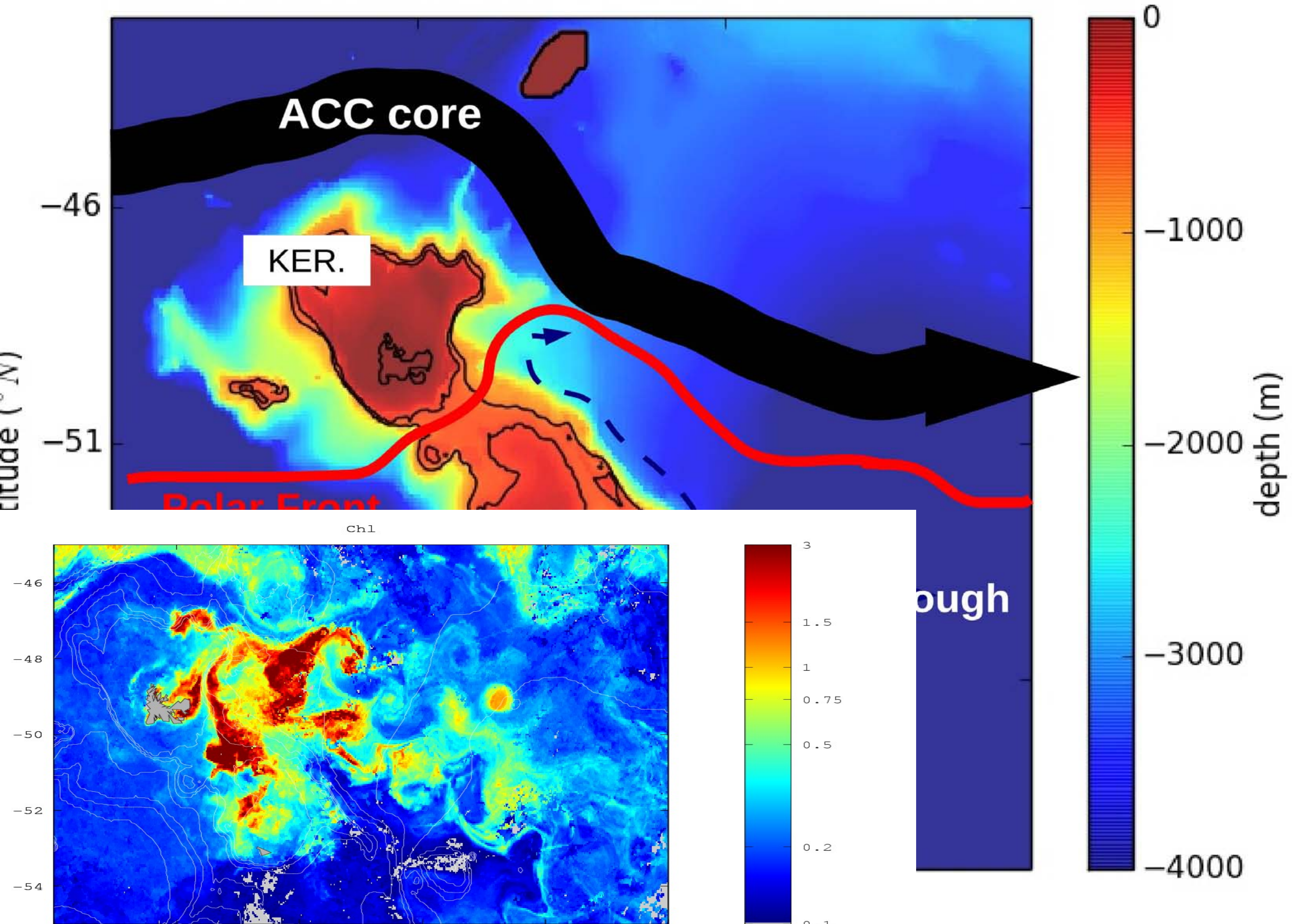
−51
−56
70
80
latitude (° N)
0
−1000
−2000
−3000
−4000
depth (m)



ACC core
KER.
−46
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0
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−2000
−3000
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depth (m)
Chl
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−52
−54
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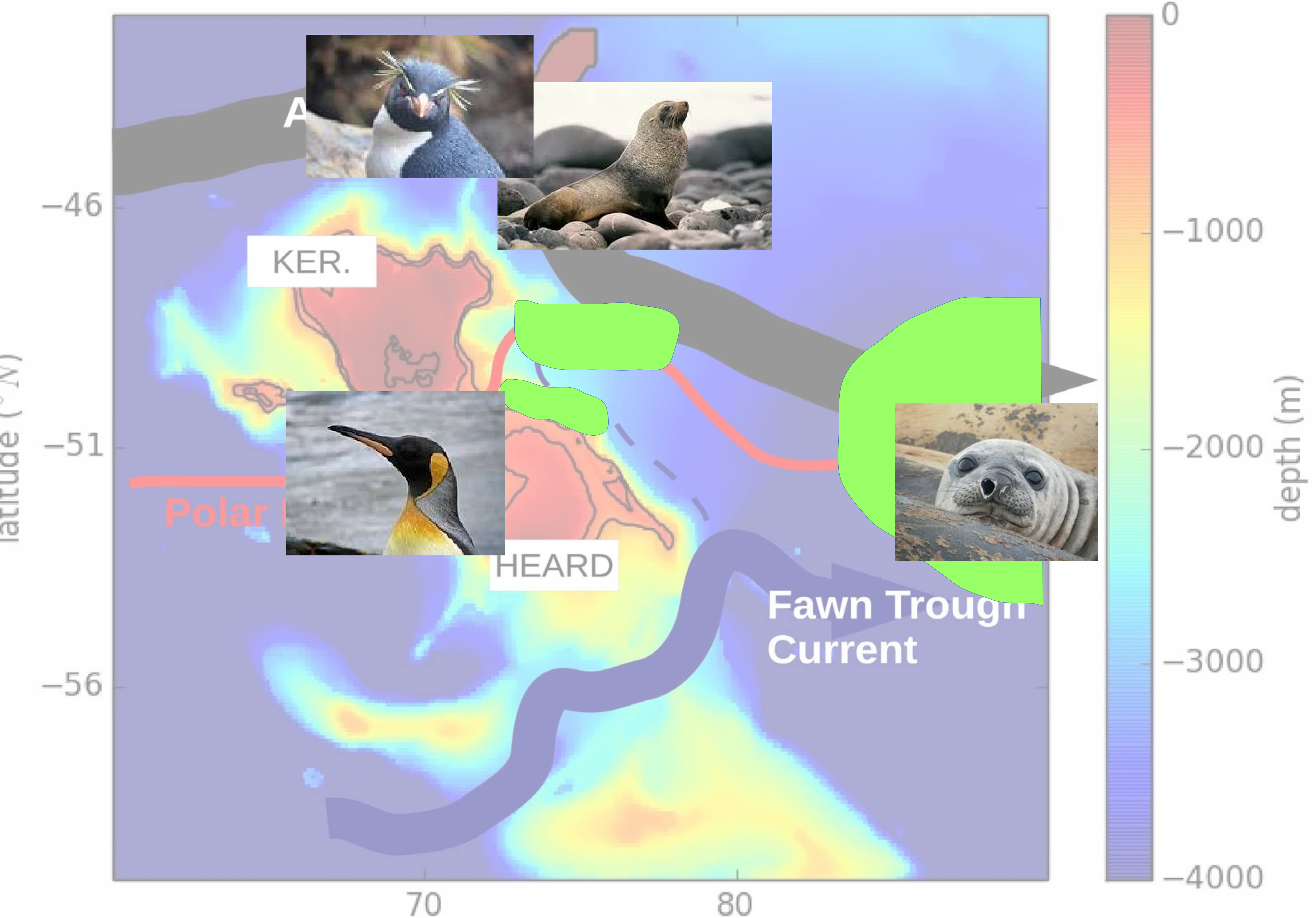
1.5
1
0.75
0.5
0.2



A
KER.
HEARD
Polar
Fawn Trough
Current
−46
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−56
70
80
latitude (° N)
0
−1000
−2000
−3000
−4000
depth (m)

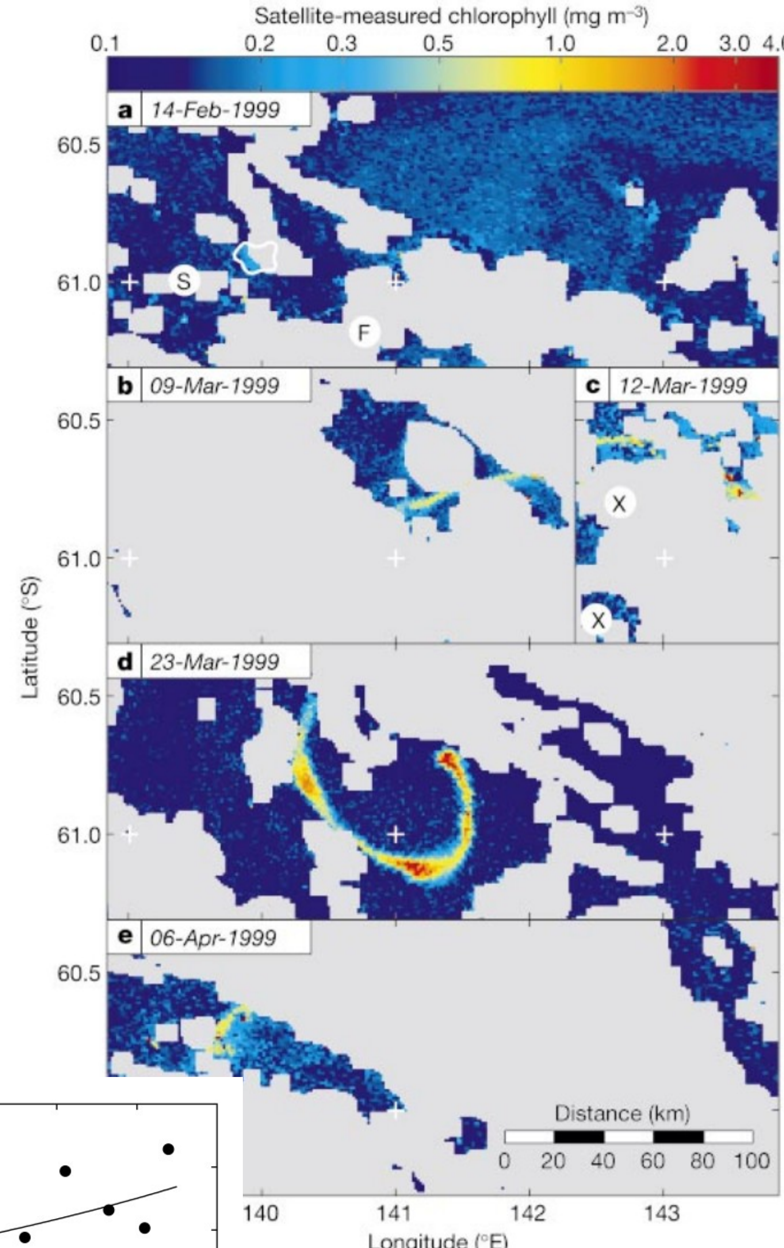
1. Lateral stirring and iron delivery in high nutrient, low chl. waters

On land, both the environment and the plants are static on ecological times, and production mainly limited by water.
On the open ocean, the environment moves, photosynthetic organisms drift and are limited by nutrients like iron

The SOIREE experiment (1999)

Importance of stirring in the development of an iron-fertilized phytoplankton bloom

Edward R. Abraham*, Cliff S. Law†, Philip W. Boyd‡, Samantha J. Lavender†§, Maria T. Maldonado‖§ & Andrew R. Bowie#†



Iron was released in nutrient-rich, low-Chlorophyll waters:

Main results

- Adding iron stimulated a planktonic bloom

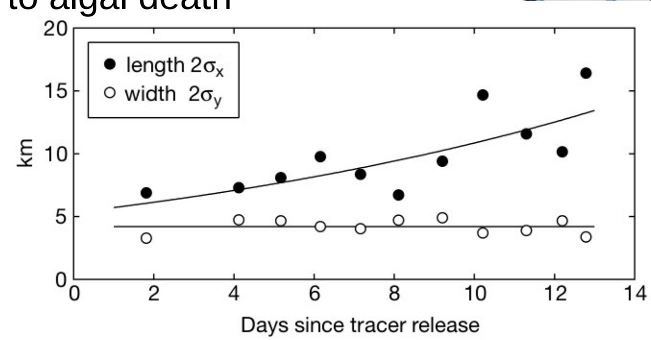
- The bloom was strongly affected by stirring

Open question:

- Does the bloom result in carbon export?

→ follow the phytoplanktonic patch from bloom to algal death

→ Estimate stirring contribution



Abraham et al., Nature, 2000

The EIFEX experiment (February 2004)

ARTICLE

doi:10.1038/nature11229

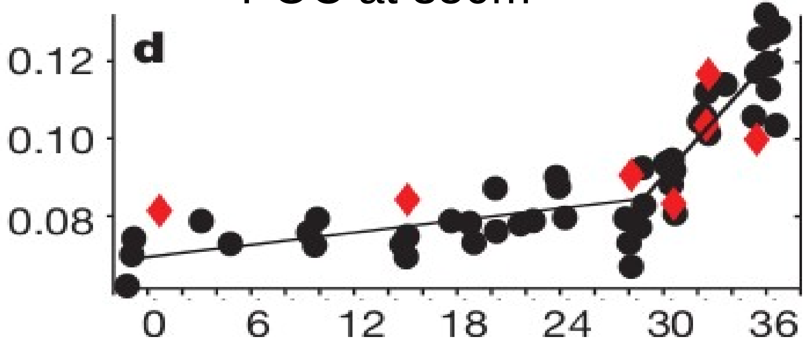
Deep carbon export from a Southern Ocean iron-fertilized diatom bloom

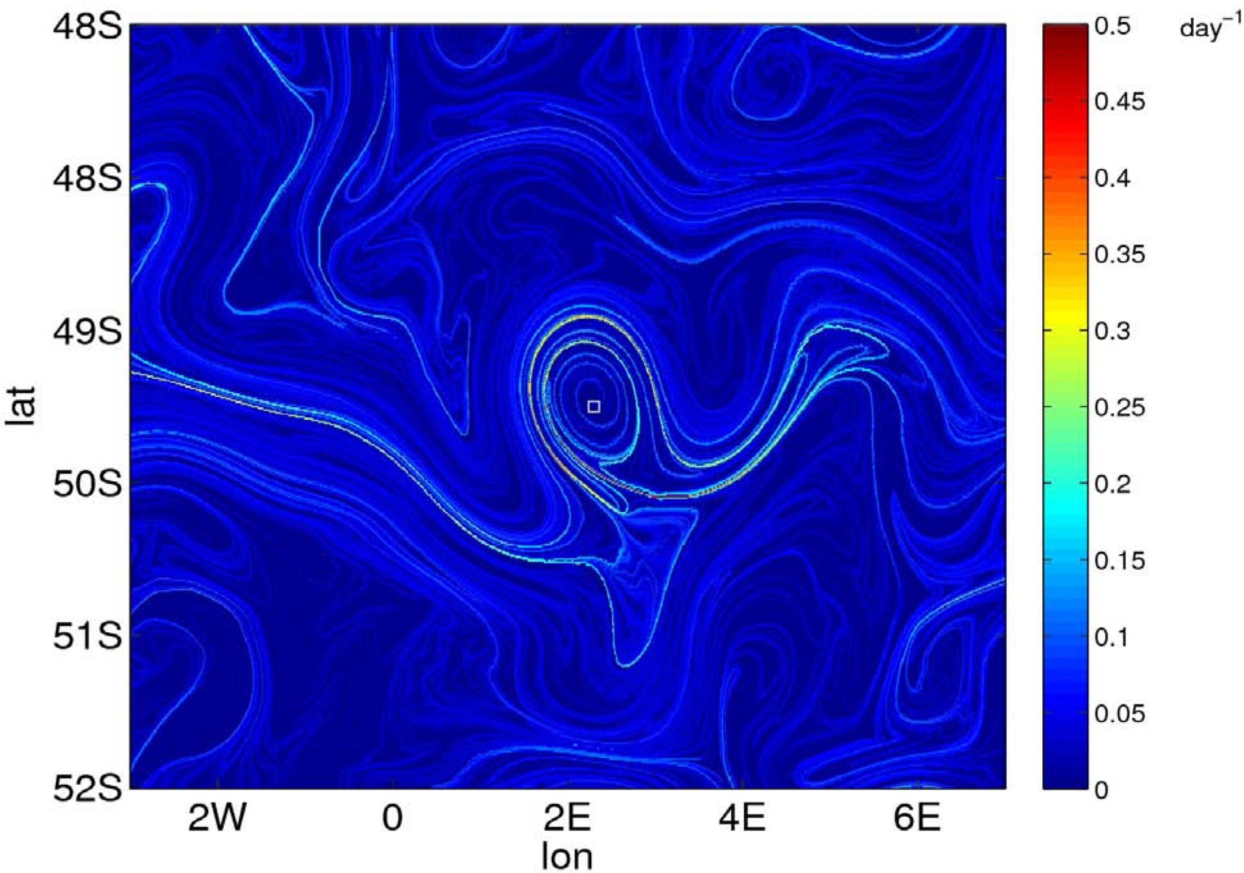
Victor Smetacek[1,2]*, Christine Klaas[1]*, Volker H. Strass[1], Philipp Assmy[1,3], Marina Montresor[4], Boris Cisewski[1,5], Nicolas Savoye[6,7], Adrian Webb[8], Francesco d'Ovidio[9], Jesús M. Arrieta[10,11], Ulrich Bathmann[1,12], Richard Bellerby[13,14], Gry Mine Berg[15], Peter Croot[16,17], Santiago Gonzalez[10], Joachim Henjes[1,18], Gerhard J. Herndl[10,19], Linn J. Hoffmann[16], Harry Leach[20], Martin Losch[1]

→ follow the phytoplanktonic patch from bloom to algal death: **40-day experiment**

→ Estimate stirring contribution: **relied on altimetry-derived diagnostics**

POC at 350m





Smetacek et al., Nature 2012

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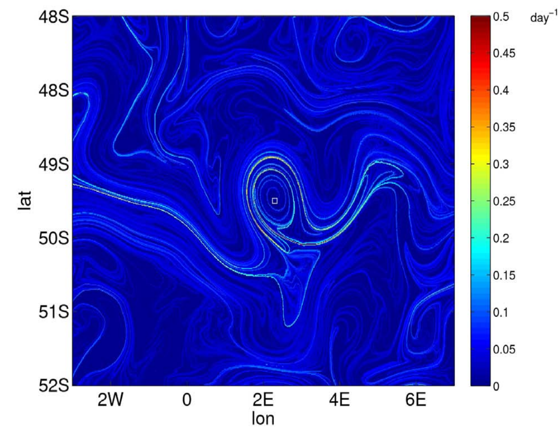
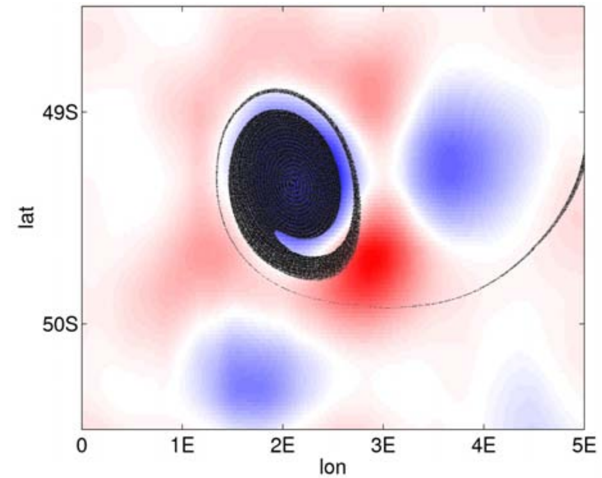
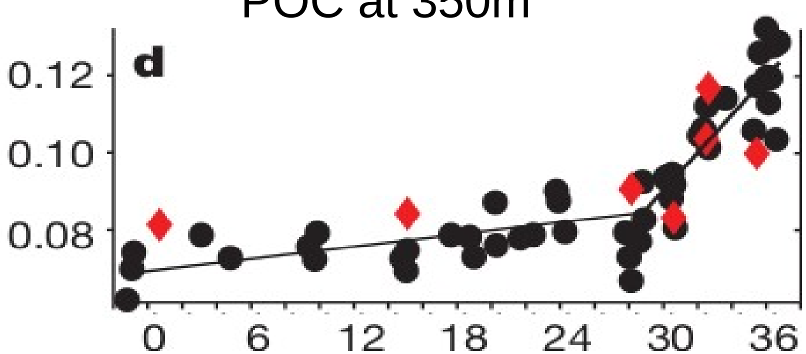
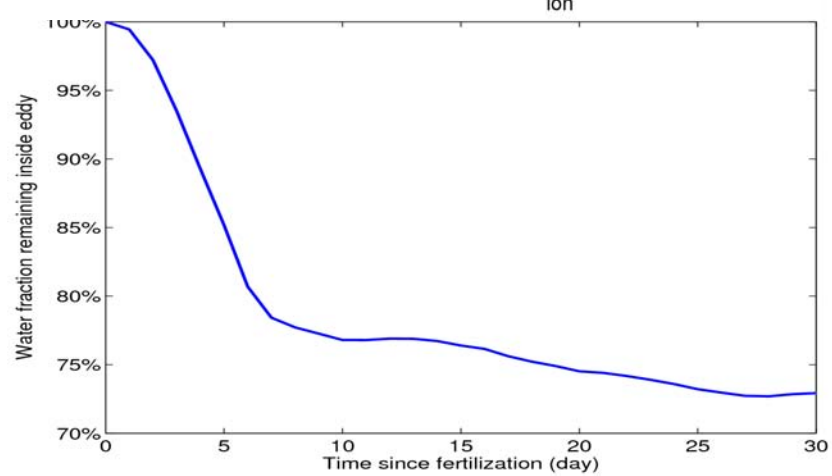




POC at 350m





Smetacek et al., Nature 2012

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ARTICLE

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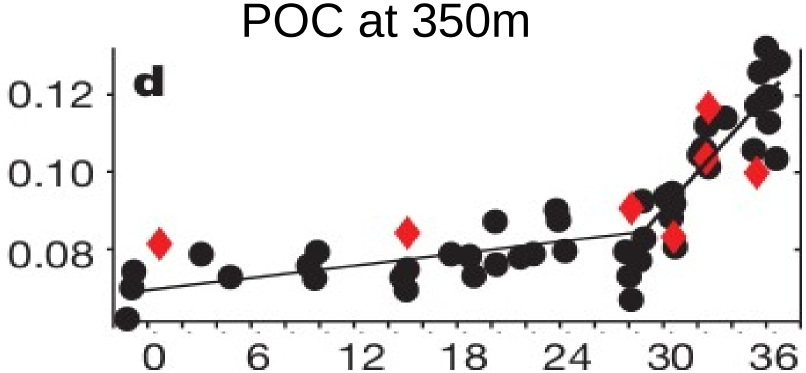
→ follow the phytoplanktonic patch from bloom to algal death: **40-day experiment**

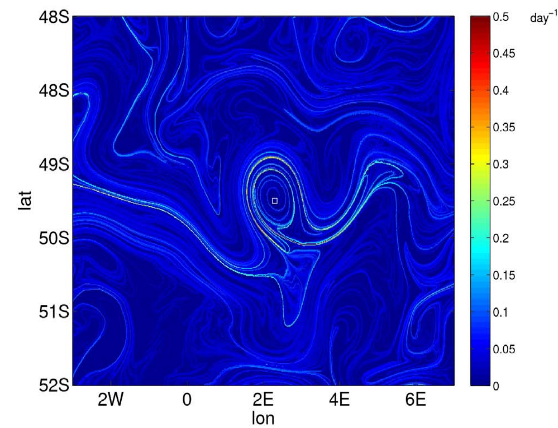
→ Estimate stirring contribution: **relied on altimetry-derived diagnostics**

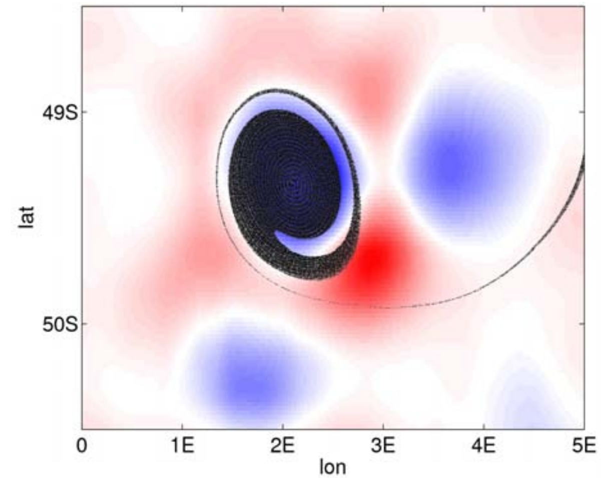
Open question:

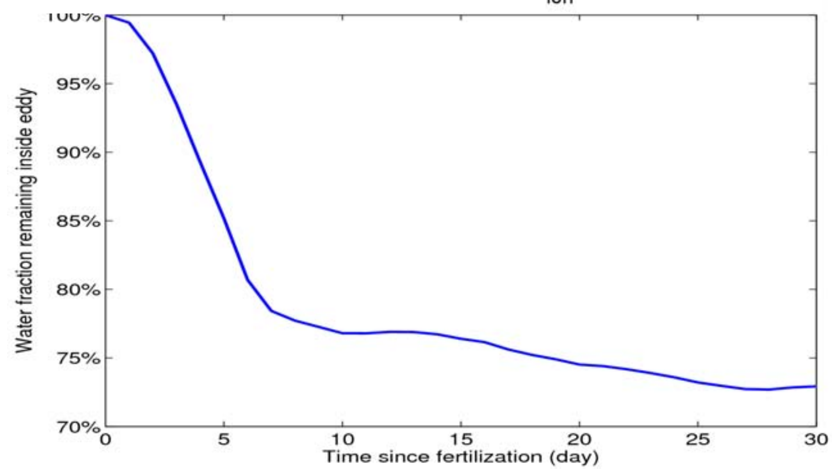
What happens in natural fertilization?

POC at 350m







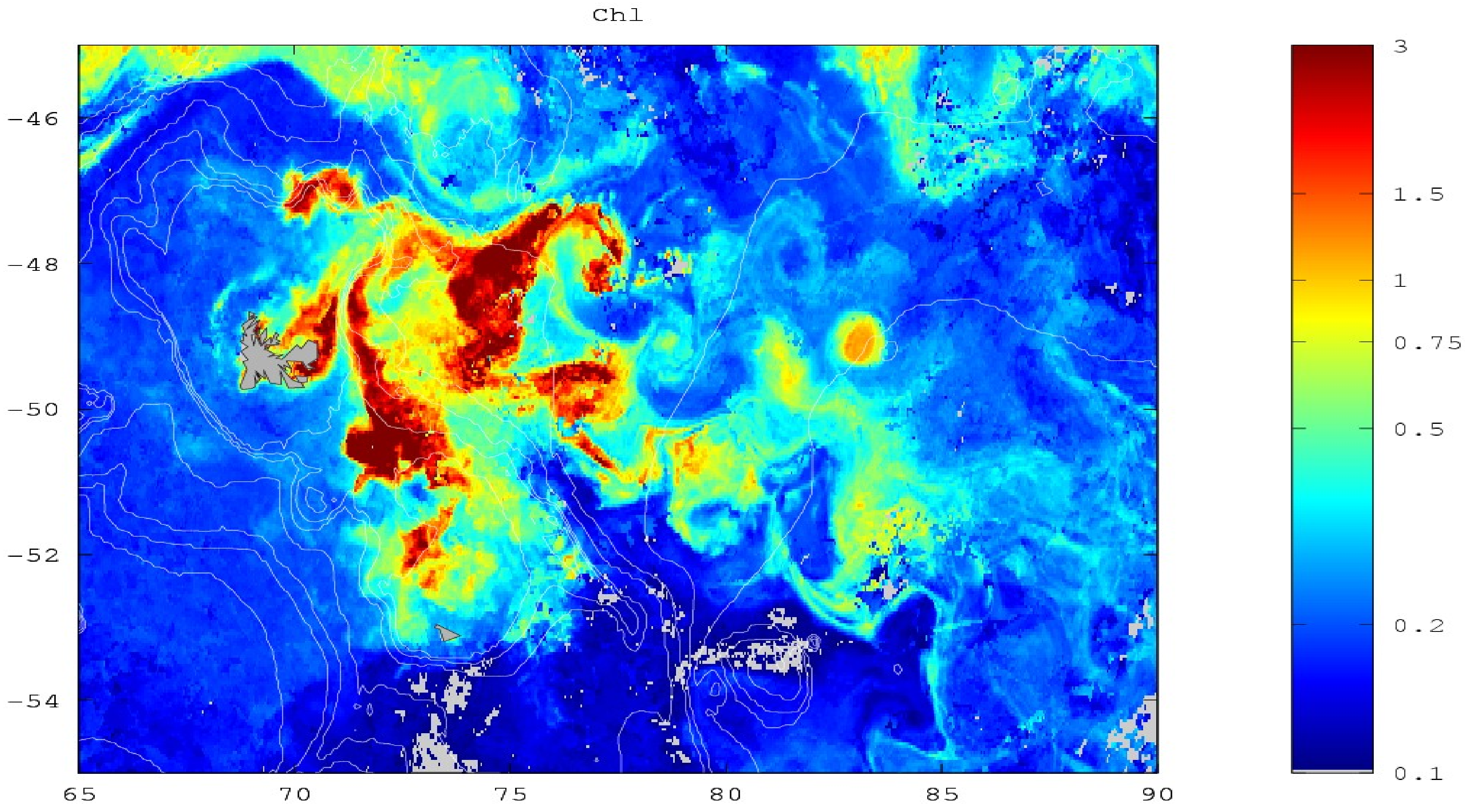


Smetacek et al., Nature 2012

The KEOPS2 experiment (end 2011)

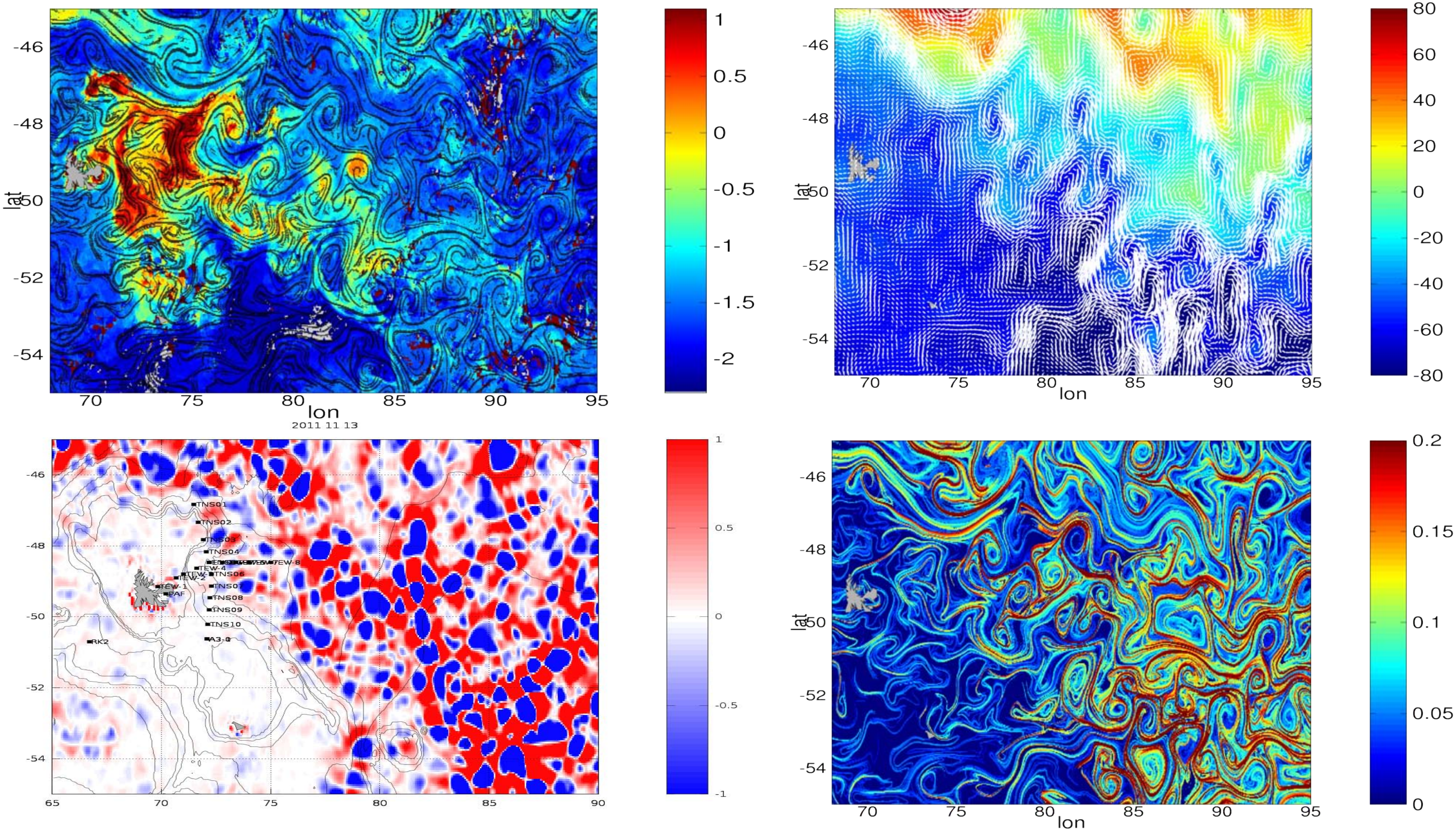
→ follow a naturally fertilized patch

→ Estimate stirring contribution and sources of iron



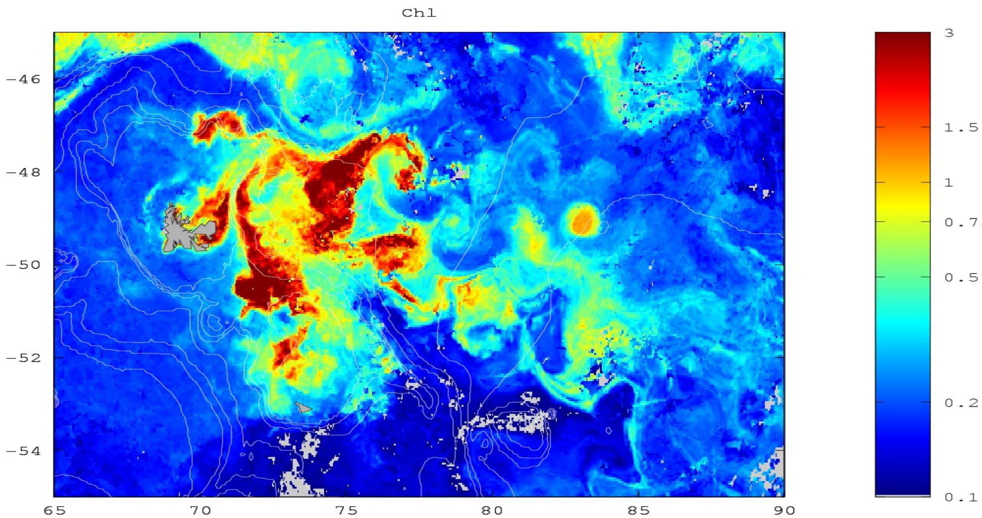
The KEOPS2 experiment (end 2011)

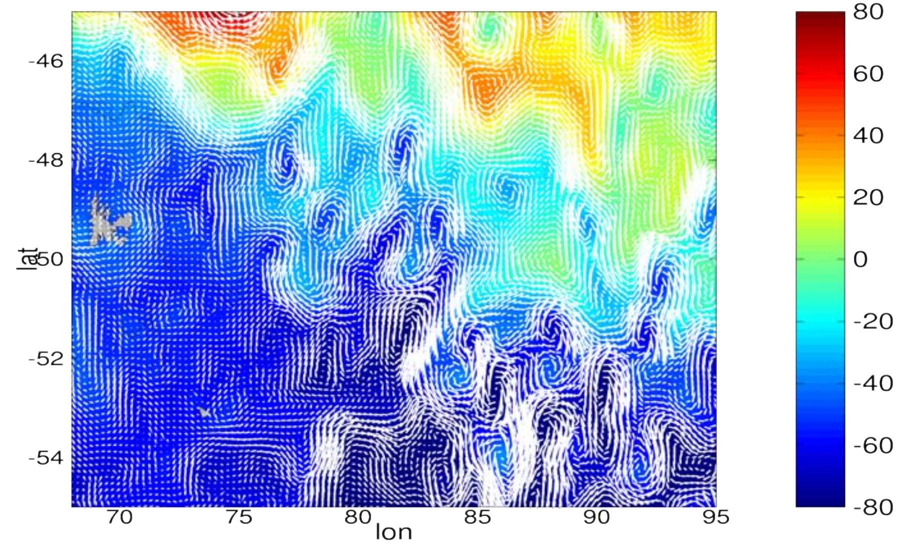
Disentangling iron sources and circulation patterns with altimetry

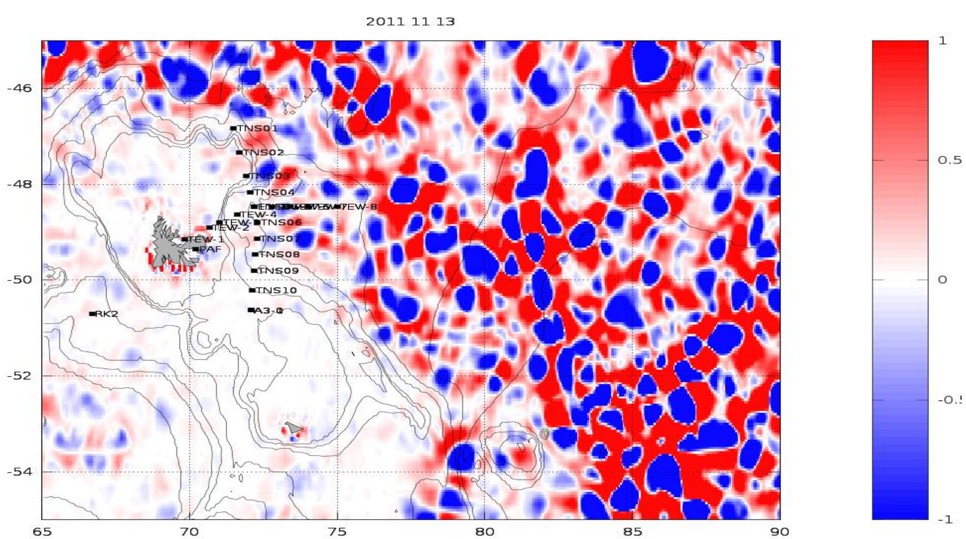


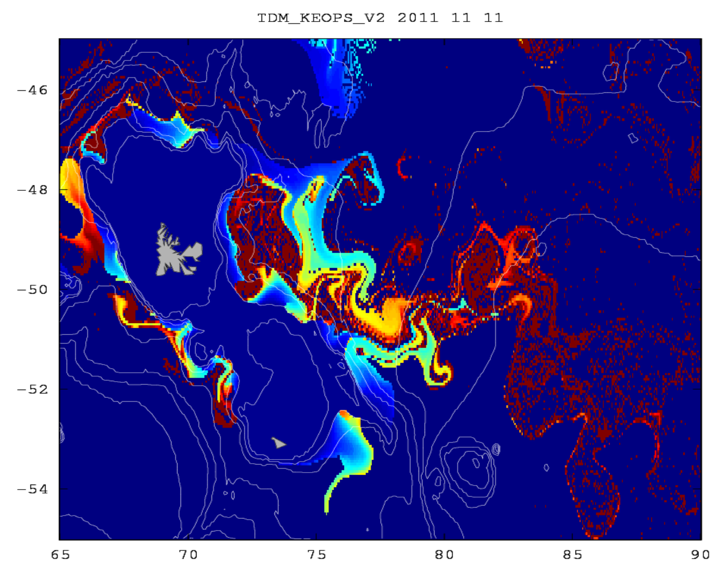
The KEOPS2 experiment (end 2011)

Disentangling iron sources and circulation patterns with altimetry

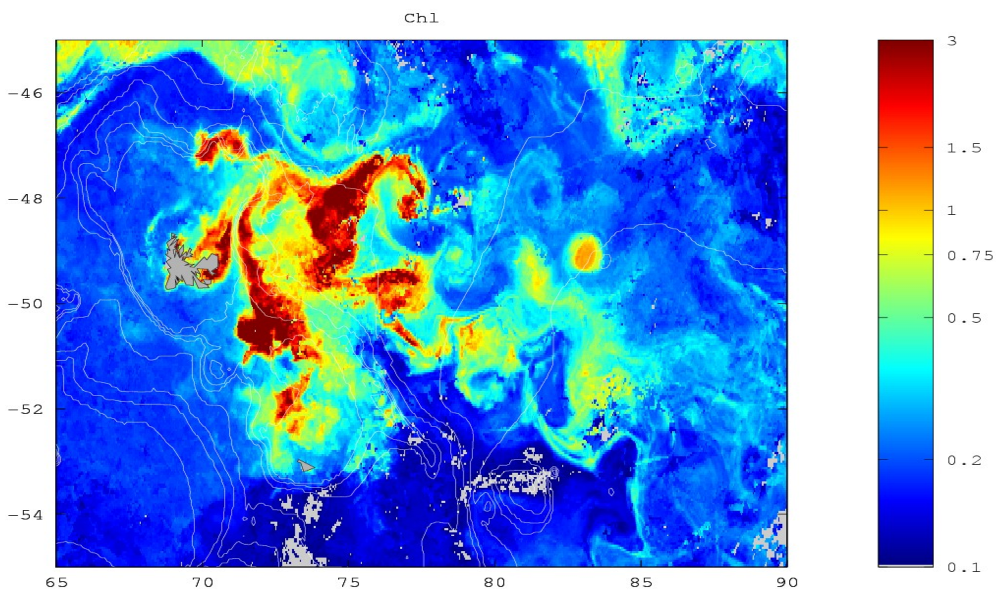






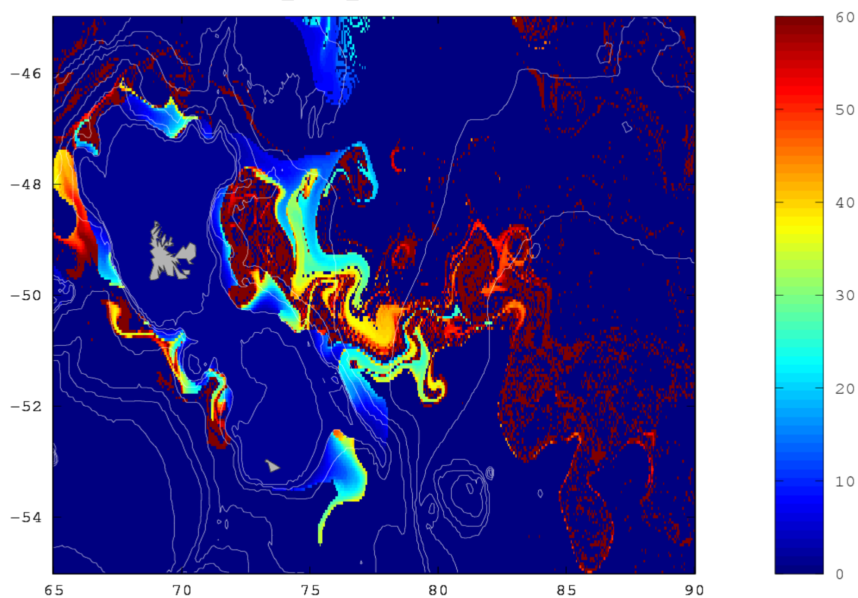


Iron concentration from altimetry data



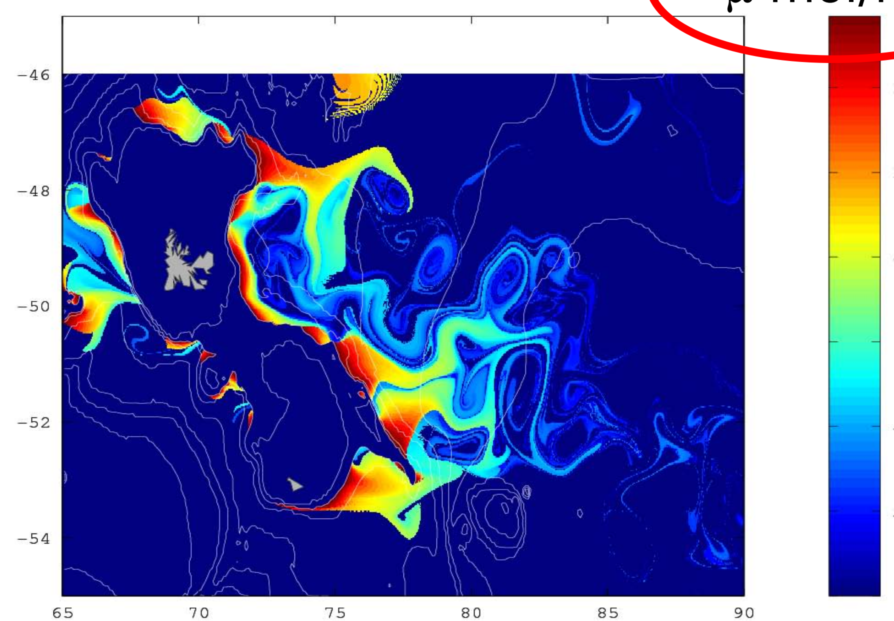
The age of water parcels can be converted in iron concentration by assuming a constant iron concentration over the plateau, an exponential scavenging dynamics and geostrophic dynamics for the mixed layer. KEOPS2 iron measurements are coherent with this approach.

Age from the plateau (days)



Iron concentration

μ mol/m²



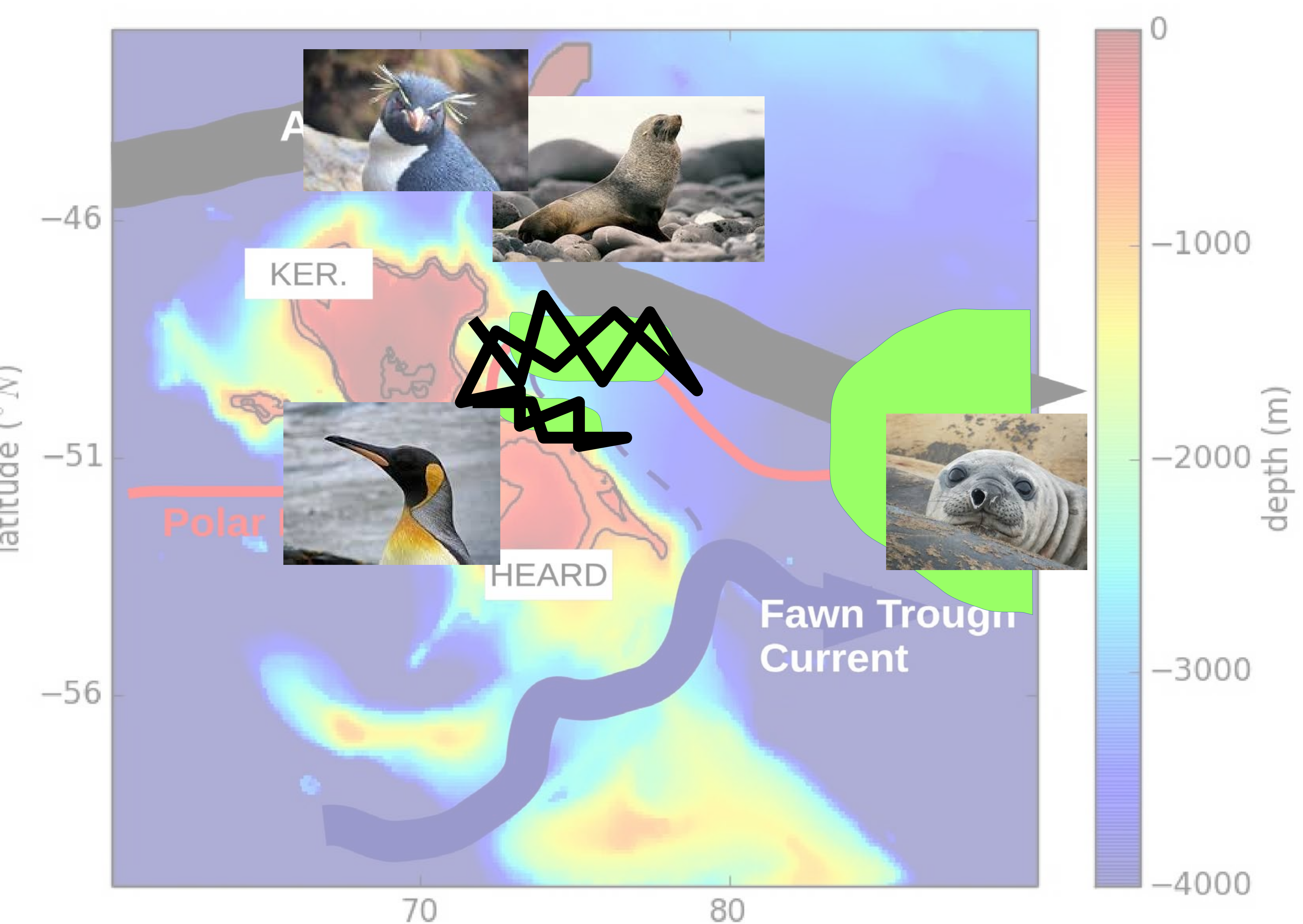
1. Conclusions (Structuring role of stirring on primary producers)

- Lateral stirring creates a “dynamical forest” in HNLC waters, by driving a stream of iron

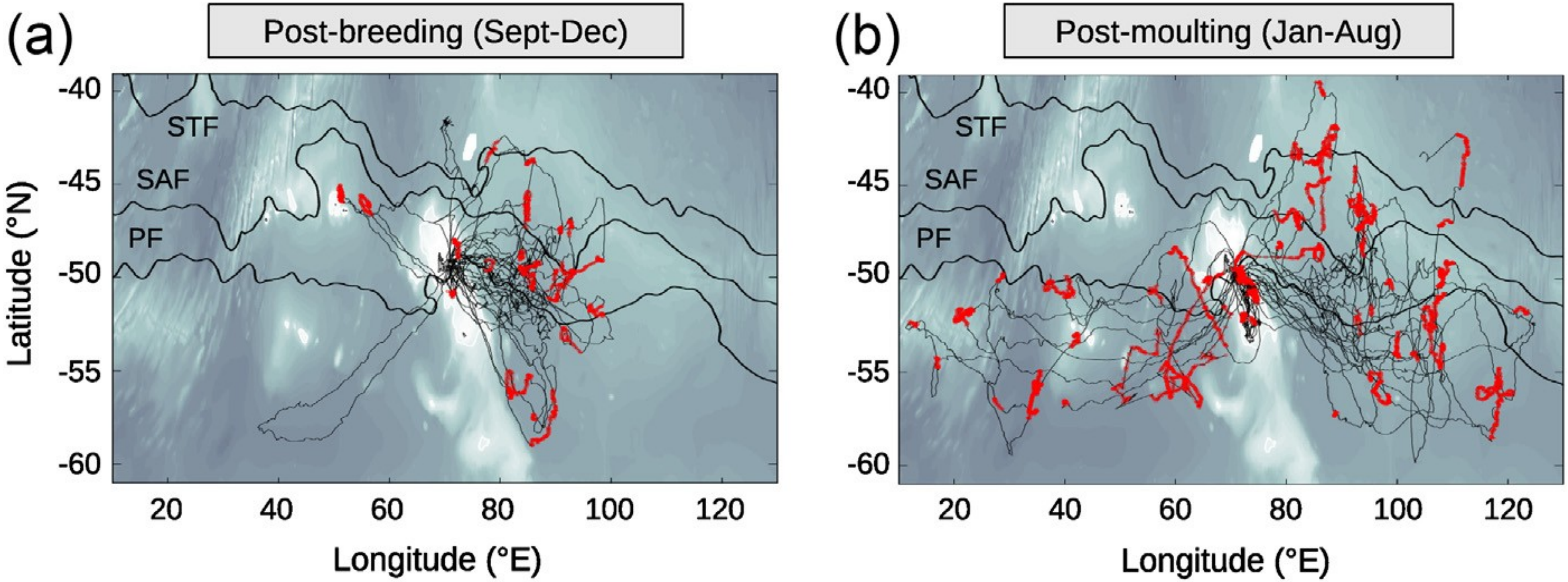
- Stirring patterns can be reconstructed accurately from altimetry and merged with in situ data (iron measurements)

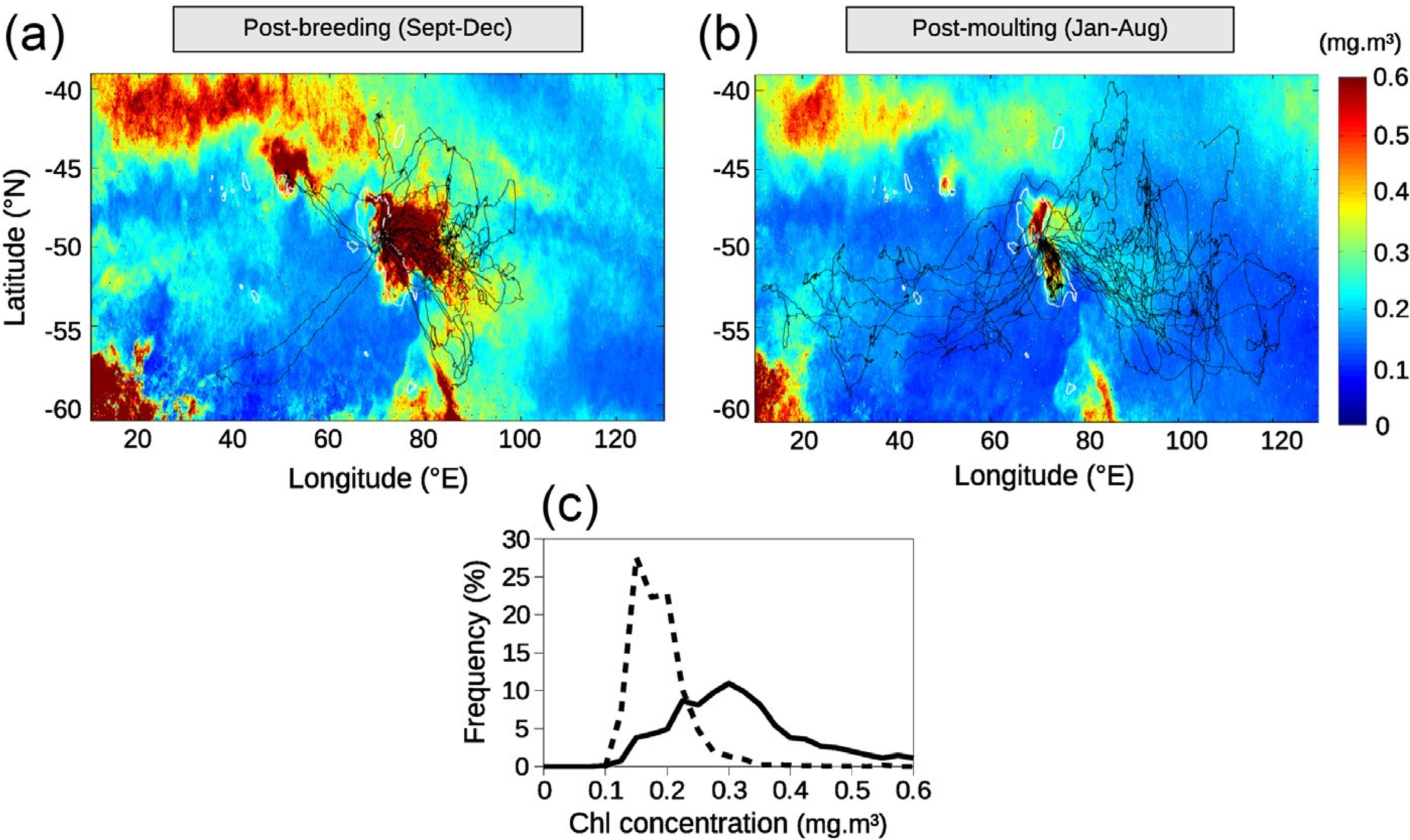
- How does the trophic chain respond to the biological active waters?

2. (Sub)mesoscale dynamics and foraging of elephant seals (IPSOS-SEAL biologging)


KER.
HEARD
Polar
Fawn Trough
Current
−46
−51
−56
70
80
latitude (° N)
0
−1000
−2000
−3000
−4000
depth (m)

Trajectories of elephant seals (black) and feeding regions (red)

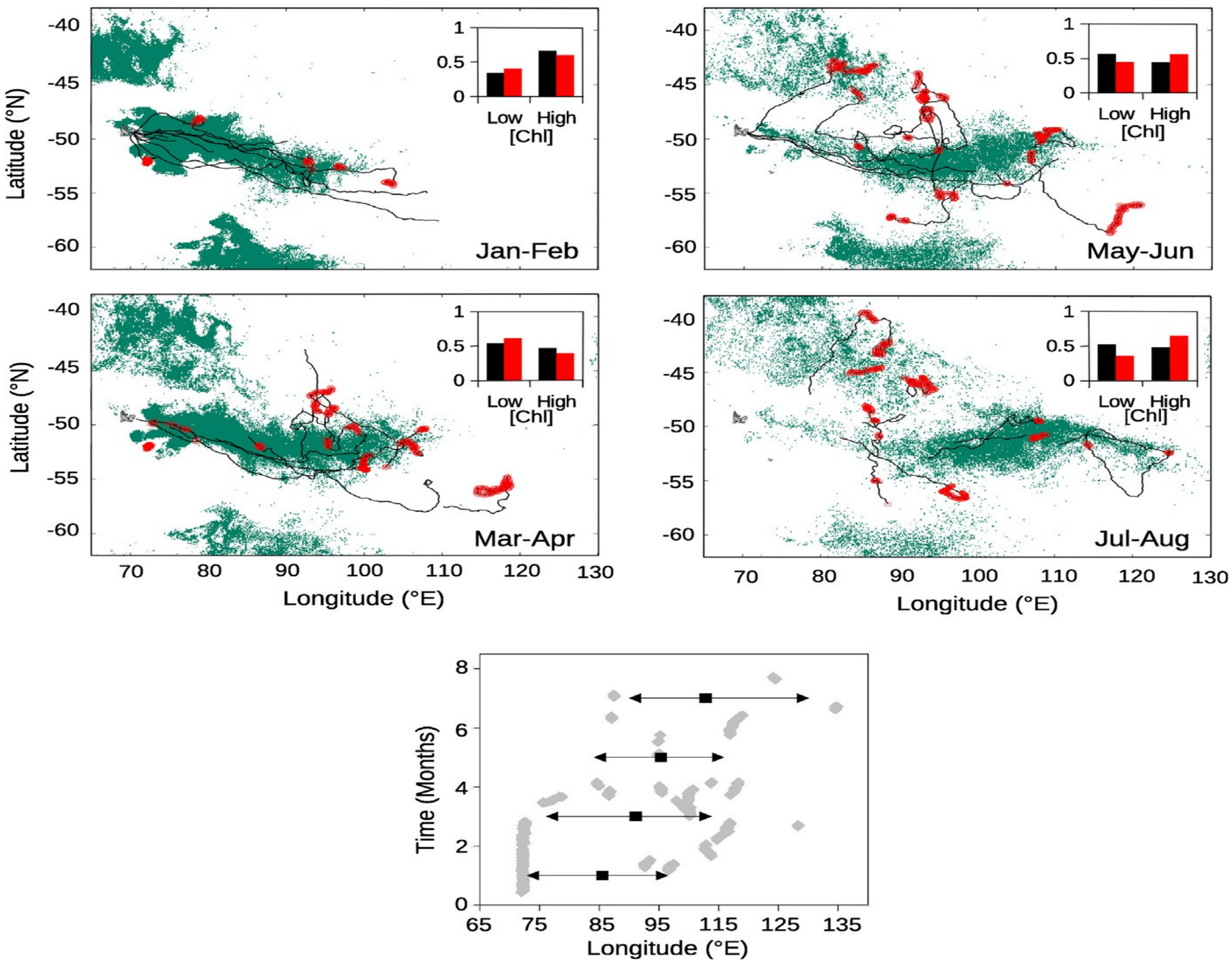




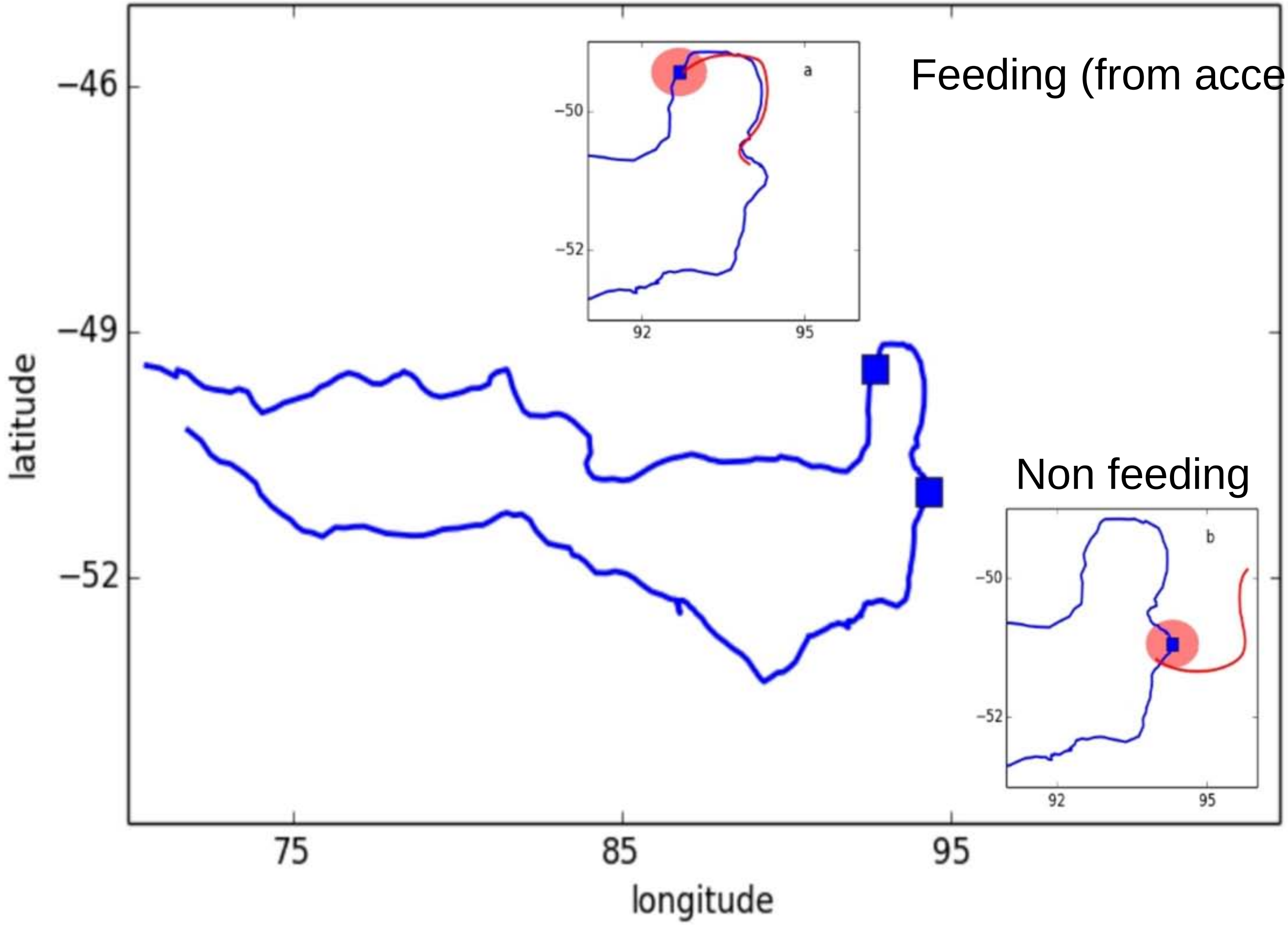
(a)
Post-breeding (Sept-Dec)
(b)
Post-moulting (Jan-Aug)
(mg.m³)
0.6
0.5
0.4
0.3
0.2
0.1
0
Latitude (°N)
-40
-45
-50
-55
-60
Longitude (°E)
20
40
60
80
100
120
(c)
Frequency (%)
30
25
20
15
10
5
0
Chl concentration (mg.m³)
0
0.1
0.2
0.3
0.4
0.5
0.6

Stirring still structures the environment during the post-bloom season, advecting eastward the water mass which previously supported high primary production.

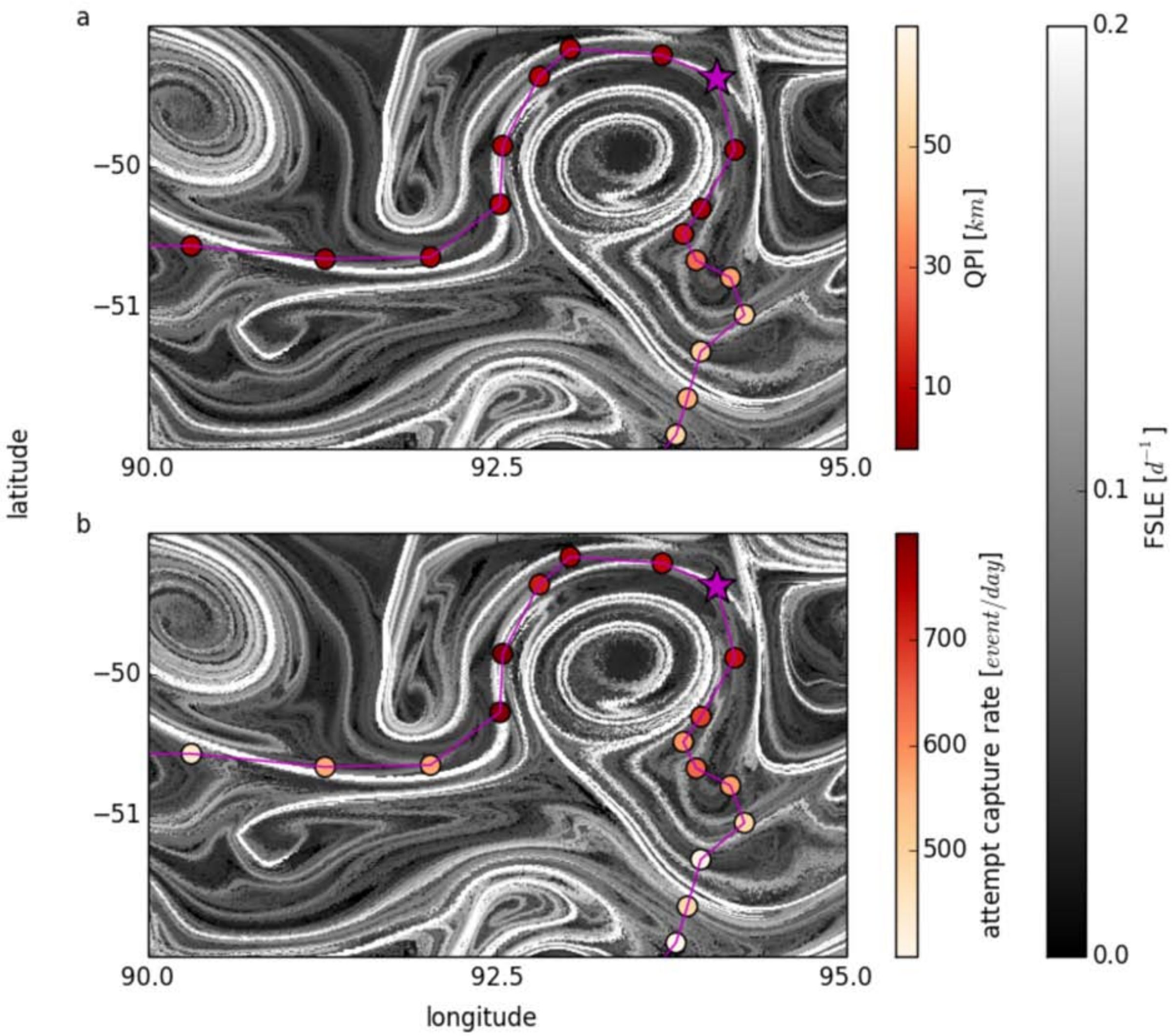
This “drifting forest” is tracked by elephant seals



At smaller scale, the ocean dynamics directly affects seals' trajectories, which becomes equivalent to “planktonic ones” when the animals feed



Blue: Seal's trajectory
Red: Lagrangian trajectories from altimetry


a
b
latitude
longitude
−50
−51
90.0
92.5
95.0
QPI [km]
50
30
10
attempt capture rate [$event/day$]
700
600
500
FSLE [d^{-1}]
0.2
0.1
0.0

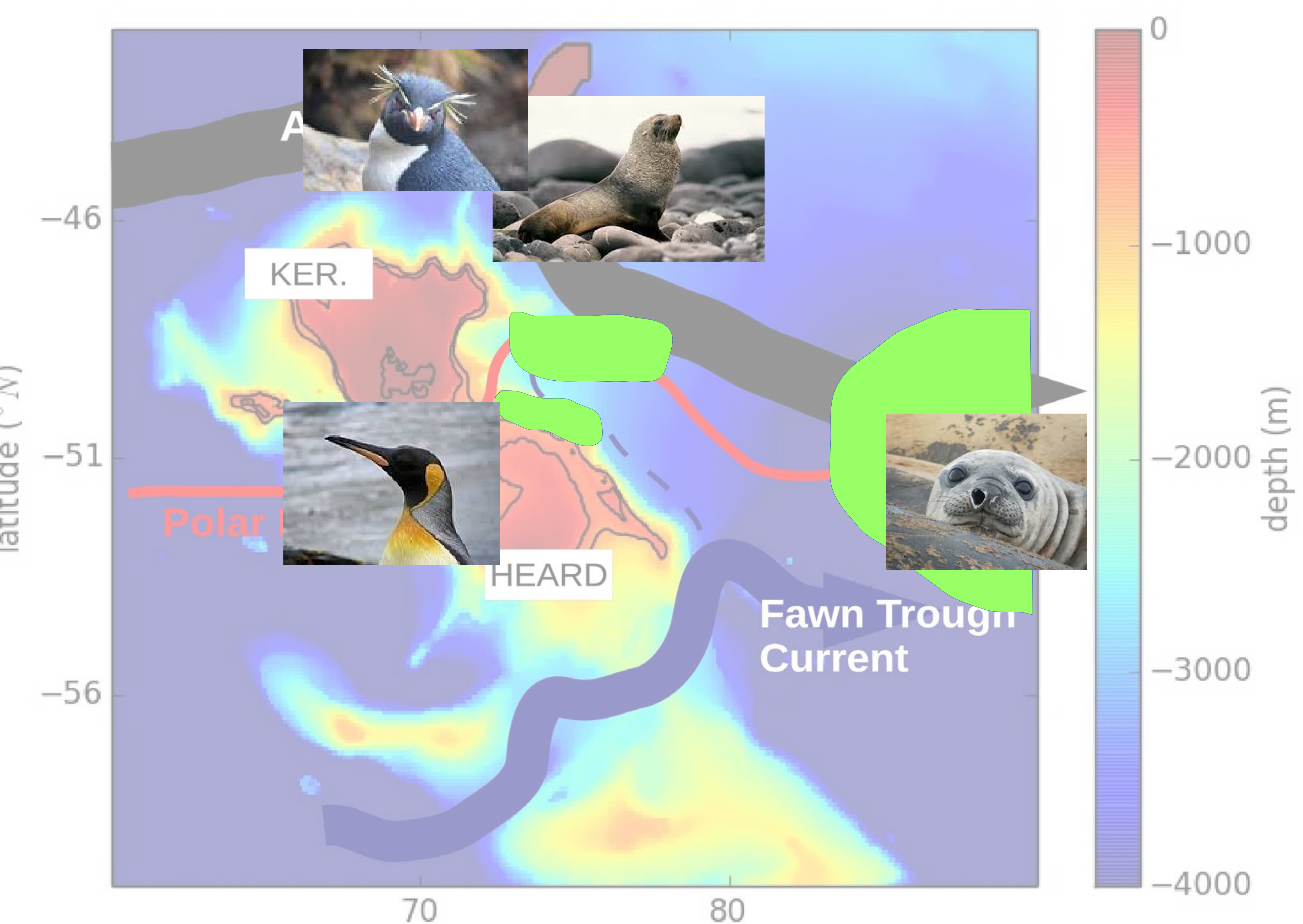
2. Conclusions (Ocean dynamics and seals' trajectories)

- At the large scales, seals track the drifting water masses that has previously supported the bloom

- At the mesoscale, seals become horizontally passive when feeding, and hence are also advected by horizontal stirring

- Where are the intermediate trophic levels distributed?

3. Myctophids' distribution (MYCTO cruise)


A
KER.
HEARD
Polar
Fawn Trough
Current
latitude (° N)
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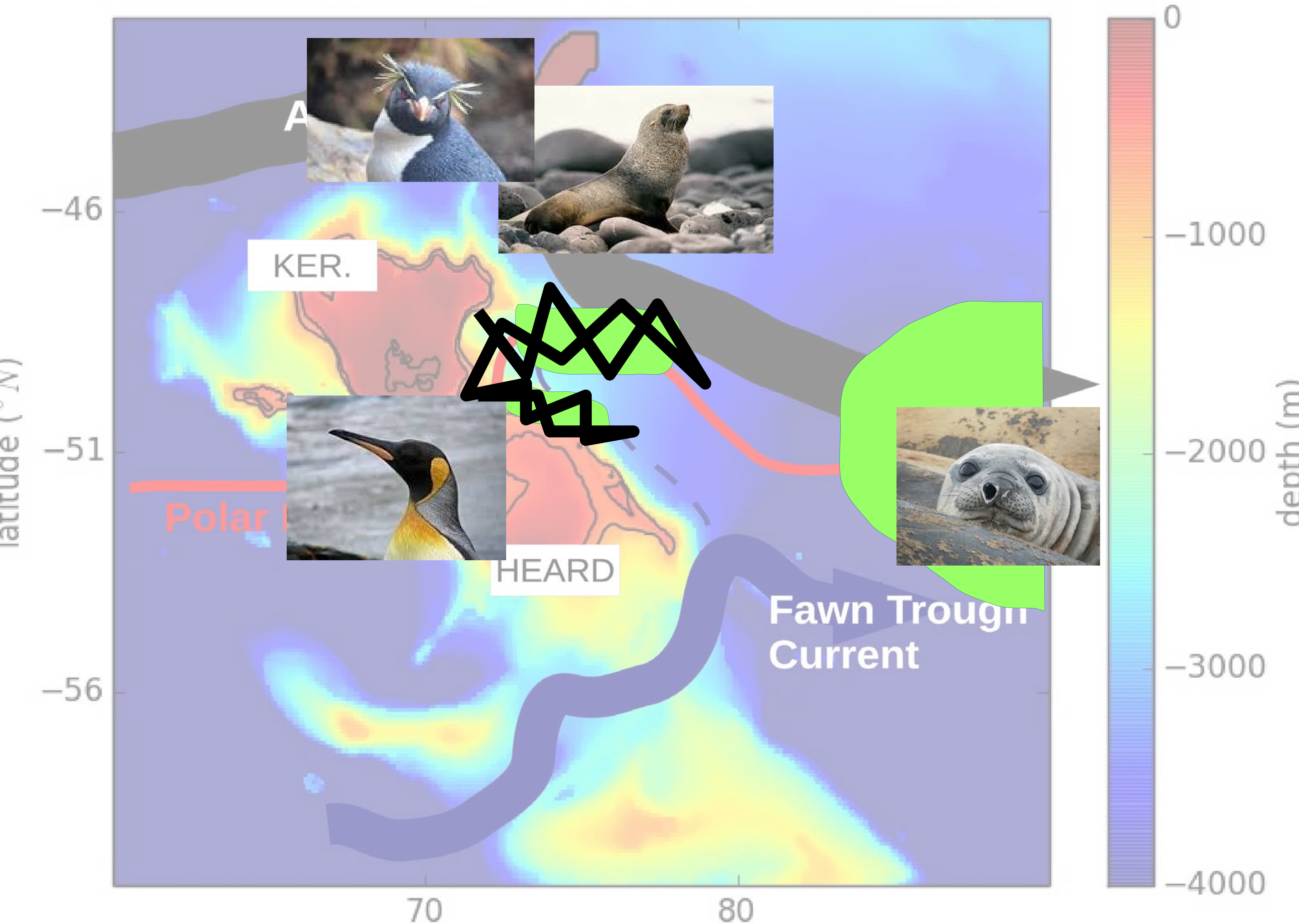
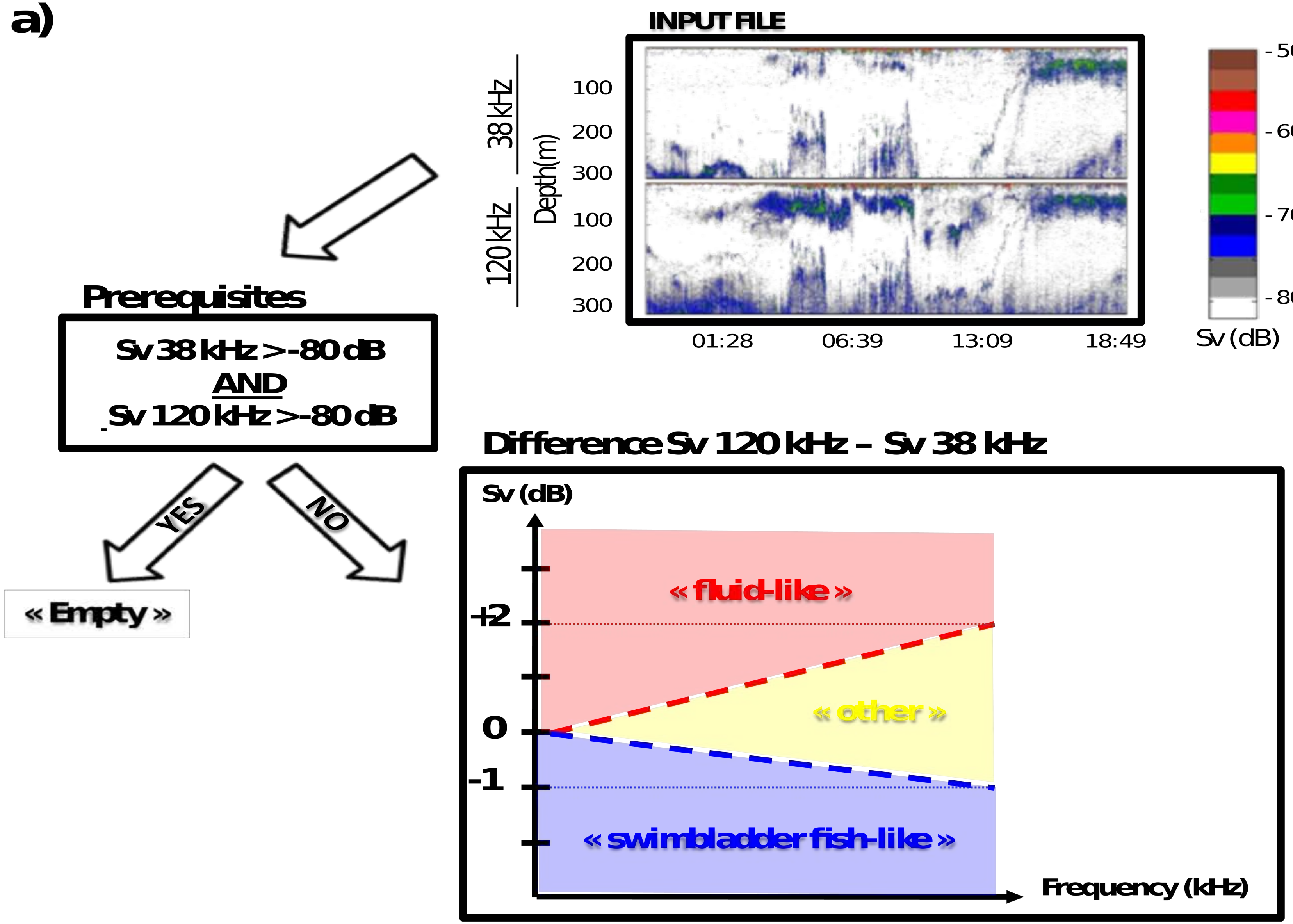
−56
70
80
depth (m)
0
−1000
−2000
−3000
−4000



KER.
HEARD
Polar
Fawn Trough
Current
−46
−51
−56
70
80
latitude (° N)
0
−1000
−2000
−3000
−4000
depth (m)

a)


INPUT FILE
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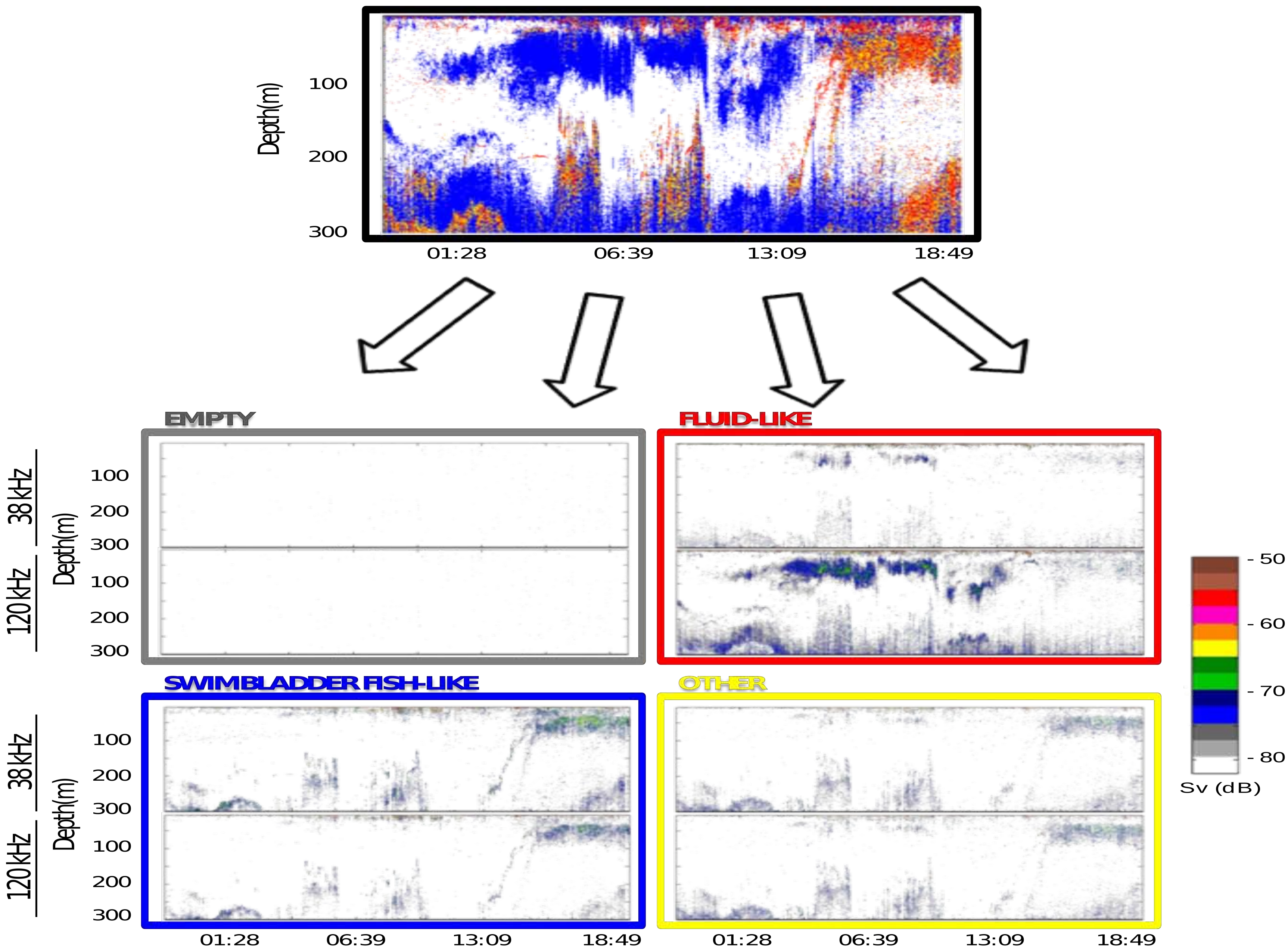
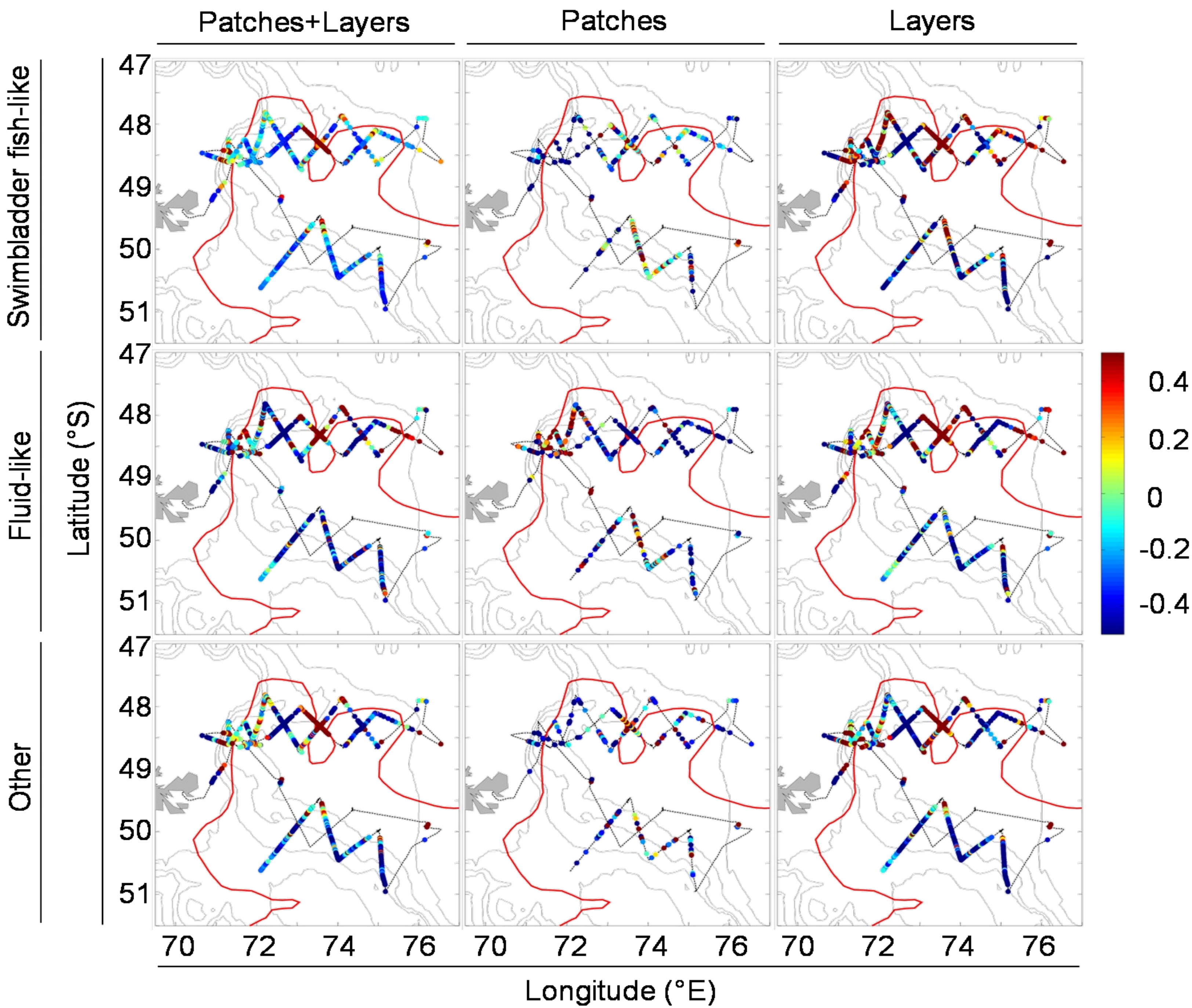
120 kHz
Depth(m)
100
200
300
100
200
300
01:28
06:39
13:09
18:49
-50
-60
-70
-80
Sv (dB)
Prerequisites
Sv 38 kHz > -80 dB
AND
Sv 120 kHz > -80 dB
YES
NO
« Empty »
Difference Sv 120 kHz – Sv 38 kHz
Sv (dB)
+2
0
-1
« fluid-like »
« other »
« swimbladder fish-like »
Frequency (kHz)

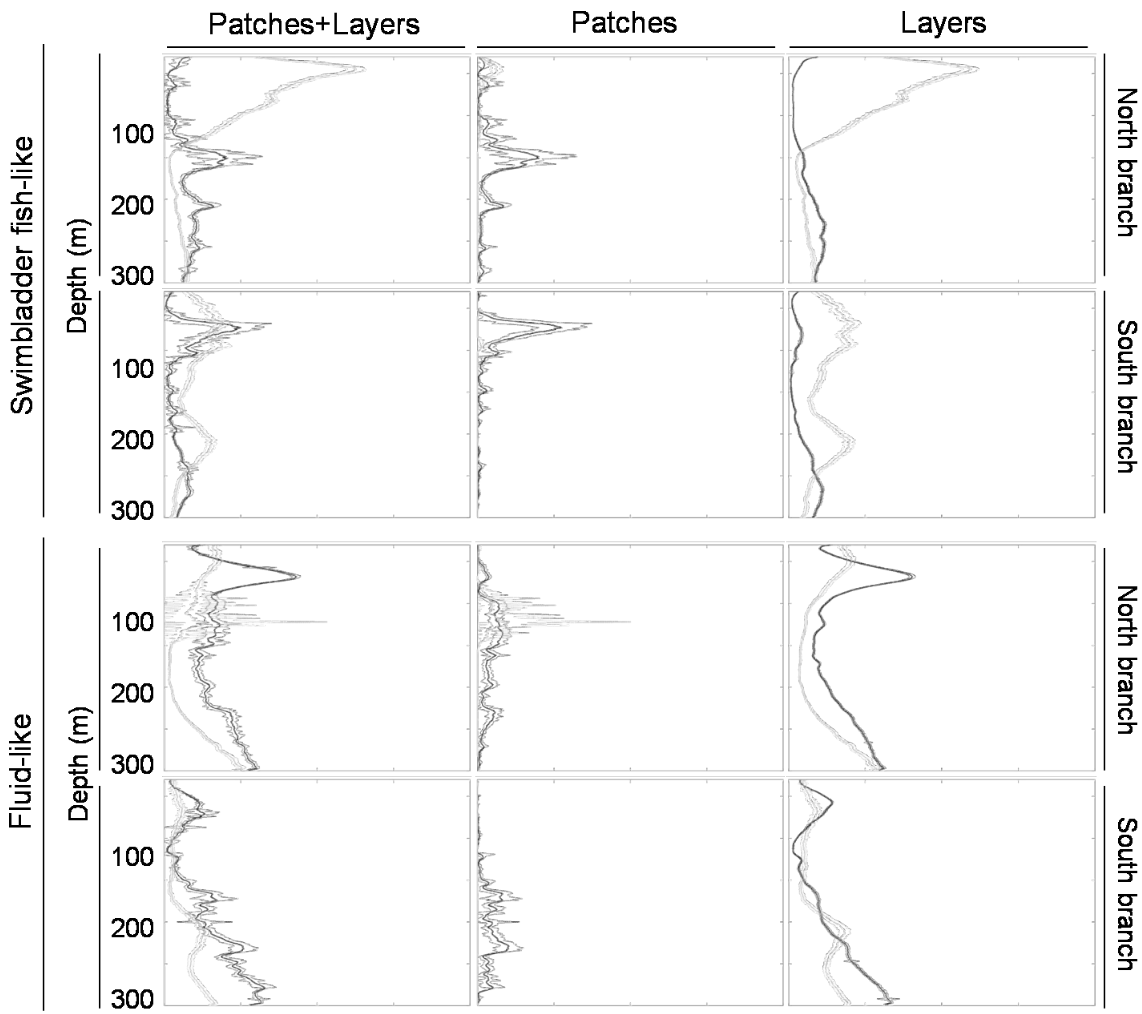


Depth(m)
100
200
300
01:28
06:39
13:09
18:49
EMPTY
FLUID-LIKE
SWIMBLADDER FISH-LIKE
OTHER
38 kHz
120 kHz
-50
-60
-70
-80
Sv (dB)

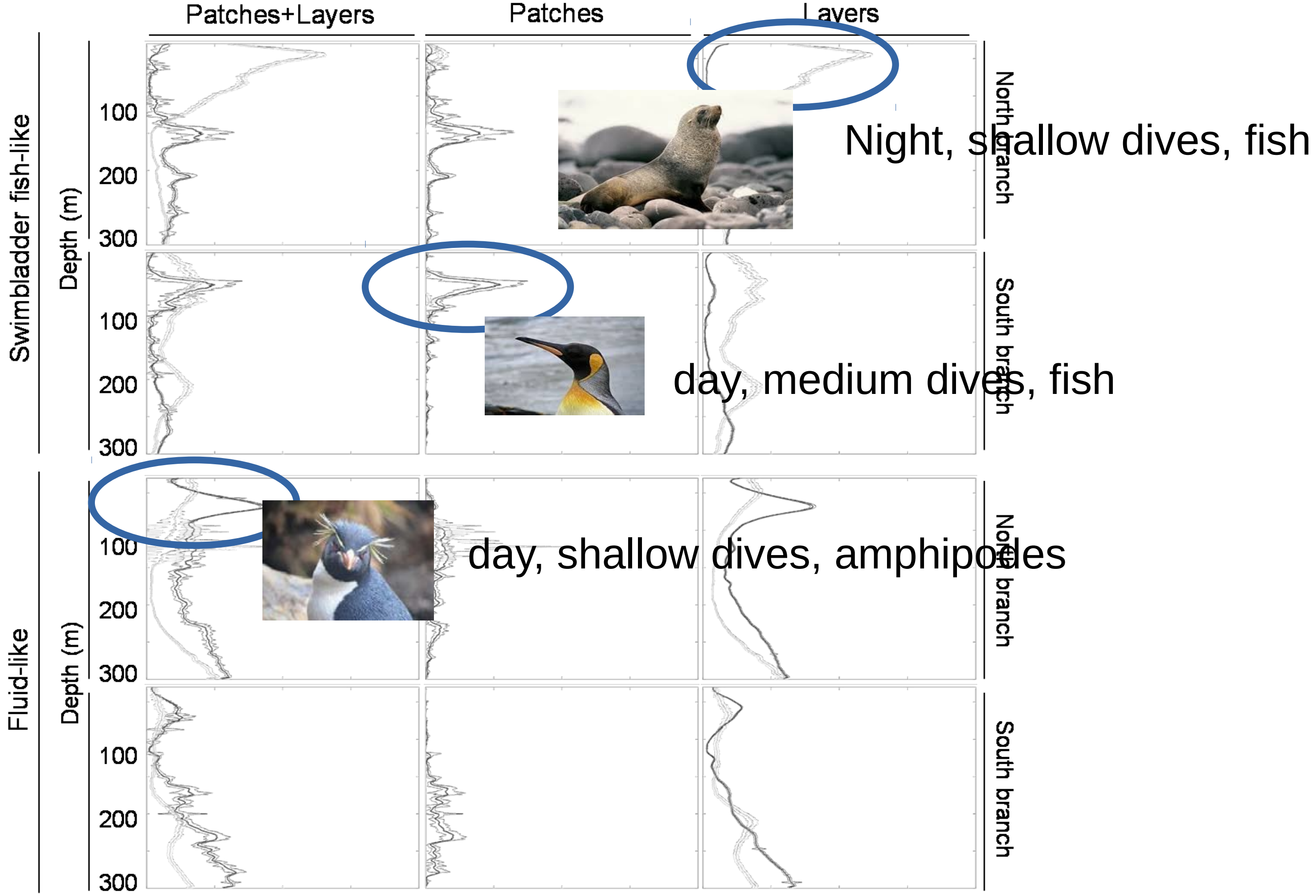
Horizontal distribution of zooplankton and nekton very difficult to interpret, even filtering out the nictemeral cycle...



.. but vertical distribution (prey item accessibility) very consistent with
The physiology of each predators!



.. but vertical distribution (prey item accessibility) very consistent with the physiology of each predators!



Conclusions

In contrast with continental ecosystems, the environment in the open ocean evolves fast, and overlaps with the ecological and ethological timescales of marine biota

On the horizontal, lateral stirring redistributes nutrients, setting the boundaries for the region with strong primary production, and then advecting further these water masses, while the biomass is transferred along the trophic chain

Intermediate trophic levels are the most difficult to characterize. At the mesoscale, the role of the physics seems more related to their vertical distribution (and hence their accessibility by predators) than on the horizontal aggregation