Wind-induced upwelling in the Kerguelen Plateau Region

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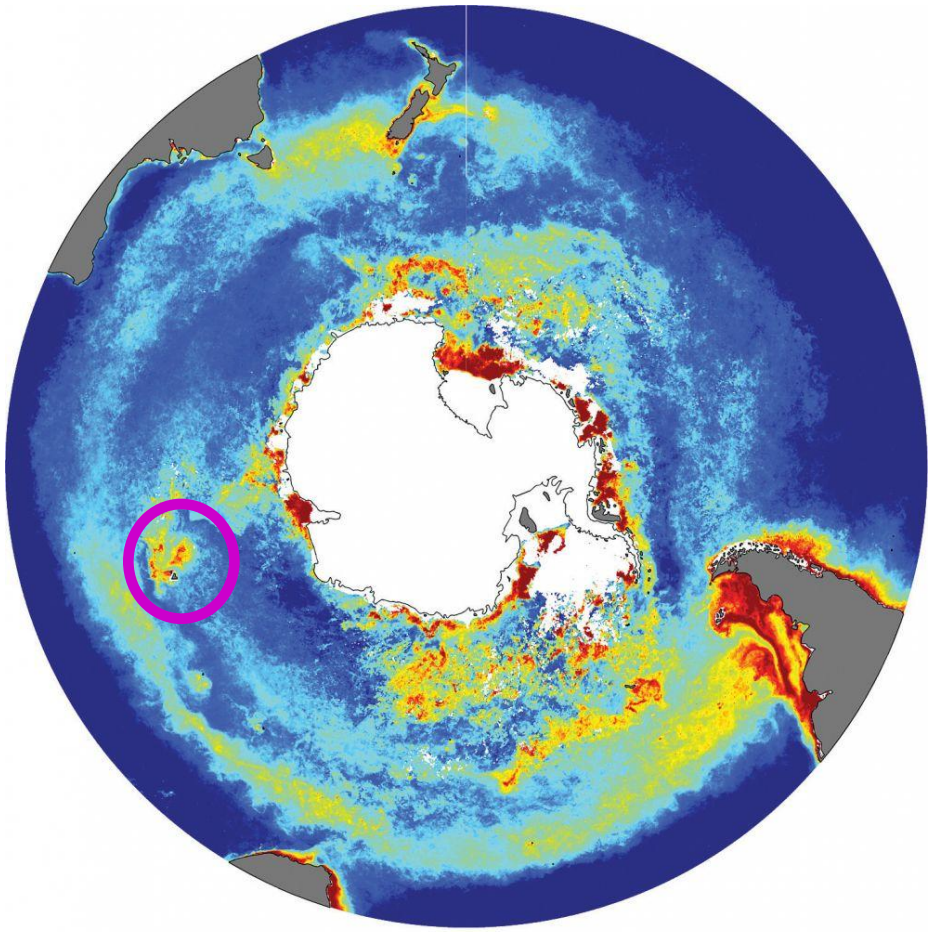
KEOPS-2 Project



S. Ocean Chl-A distribution Robert Johnson

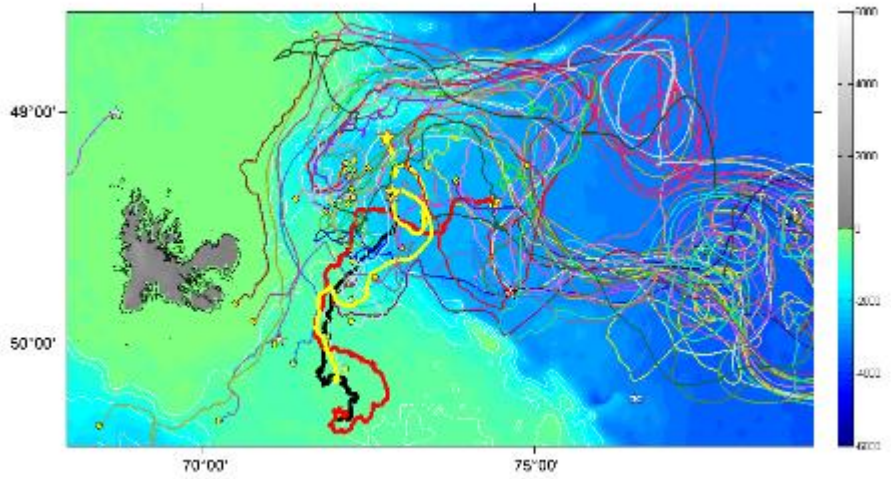
We investigated the **role of wind-forcing** over eddies and on upwelling.

Southern Ocean generally HNLC – high nutrient low chlorophyll

High chlorophyll found downstream of volcanic plateaux – like Kerguelen

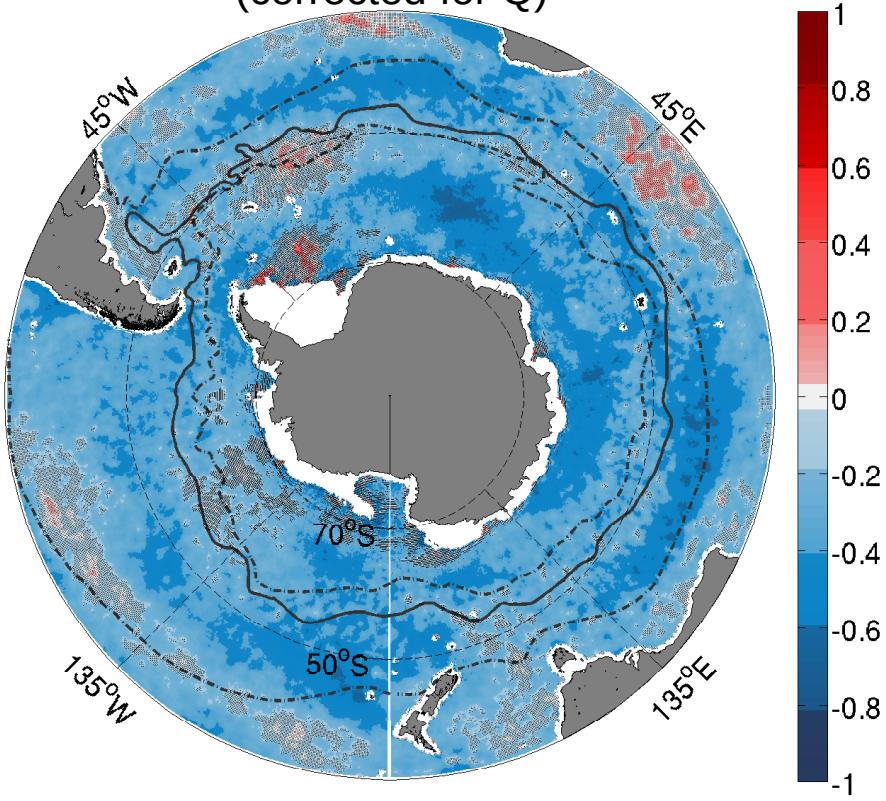
KEOPS 2 is a French project to investigate the impact of natural iron fertilization on the biogeochemical cycles downstream of Kerguelen

Large in-situ program in Oct-Nov 2011 to study physical & biogeochemical processes – lagrangian & eulerian

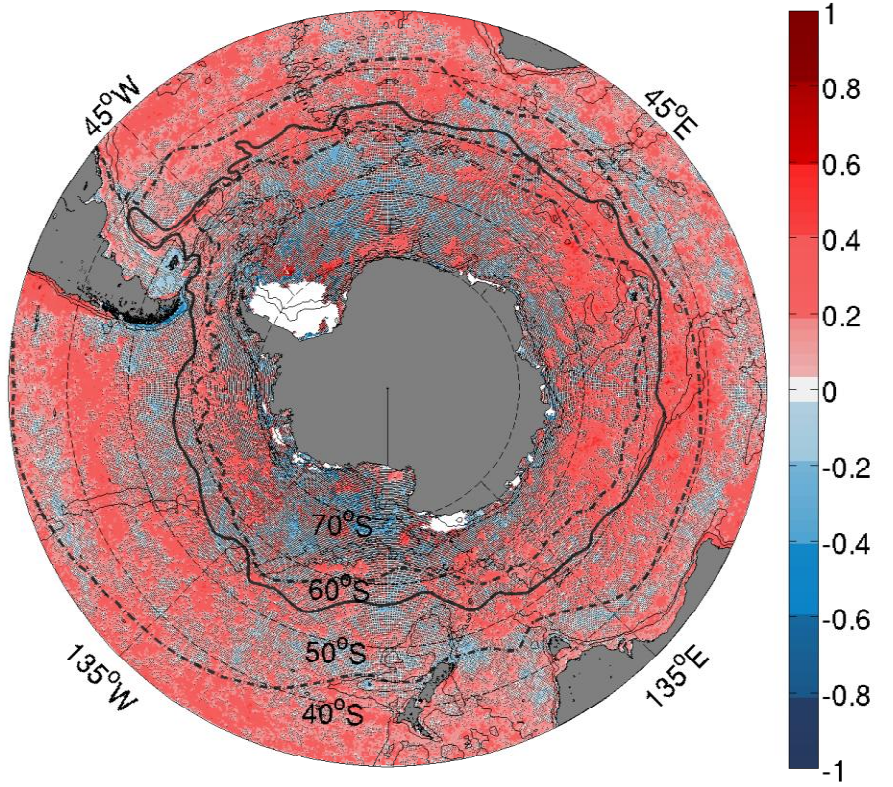


S. Ocean winds, SST & chlorophyll – large-scale processes

Partial correlation : Wind speed & SST
(corrected for Q)



Correlation : Wind speed & Chl-A



Carranza & Gille, 2014

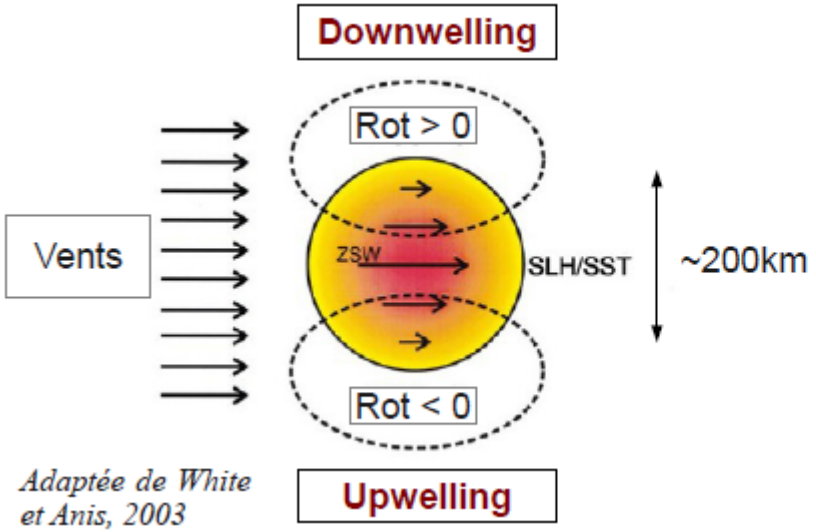
Higher winds deepen surface mixed layer – bringing cooler, nutrient-rich water to surface

=> **neg. Correlation with SST**;

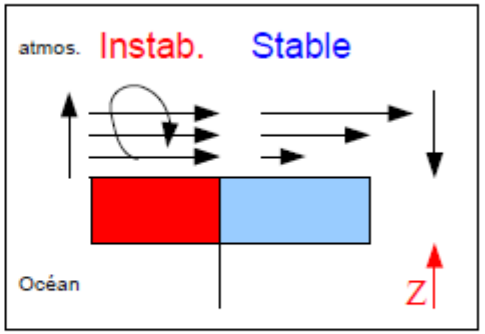
=> **pos. Correlation with Chl-A**

Coupling of wind and ocean eddies (SST gradients)

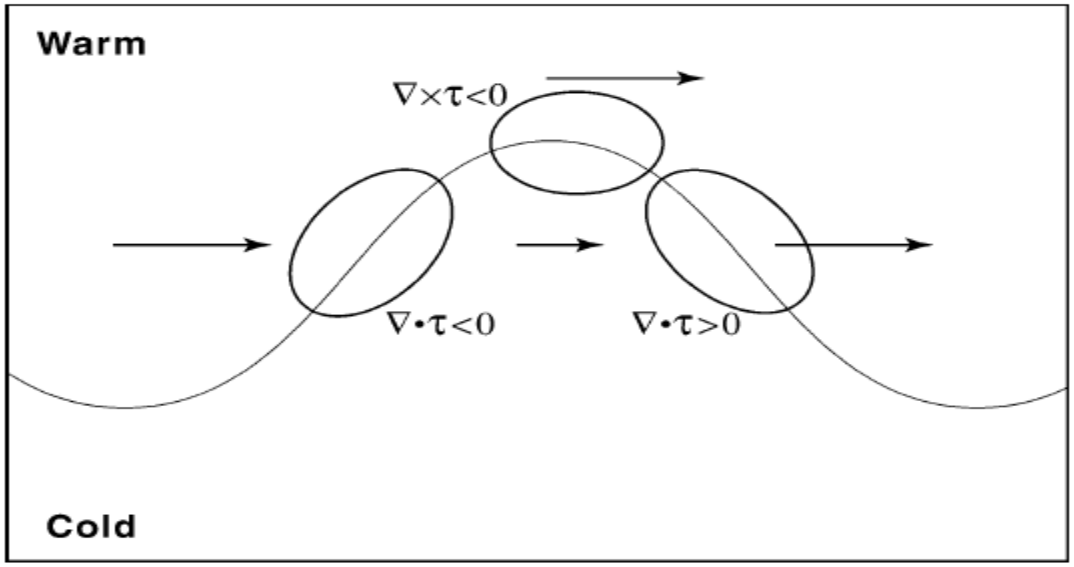
Over warm-core eddies



Adaptée de White et Anis, 2003



Over meandering fronts

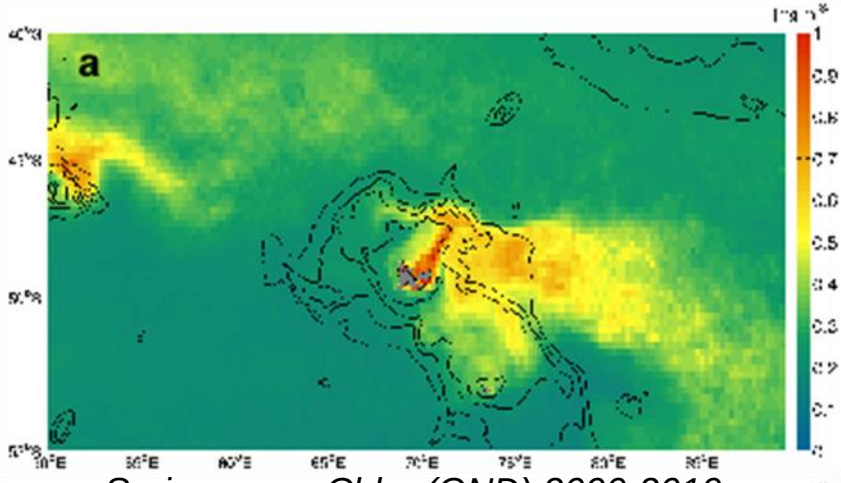


$$w = rot\left(\frac{\tau}{\rho f}\right) = \frac{1}{\rho f} rot(\tau)$$

from O'Neill et al. (2003).

How does SST and wind coupling impact on upwelling, and chlorophyll distribution?

Objectives of this study



Spring mean Chl-a (OND) 2000-2010

For the region around Kerguelen :

1) To what extent do wind stress & wind stress curl driven mechanisms control SST (and by extension, Chl-A ?)

2) What is the role of these wind-driven processes in the region of the chlorophyll bloom, downstream of Kerguelen?

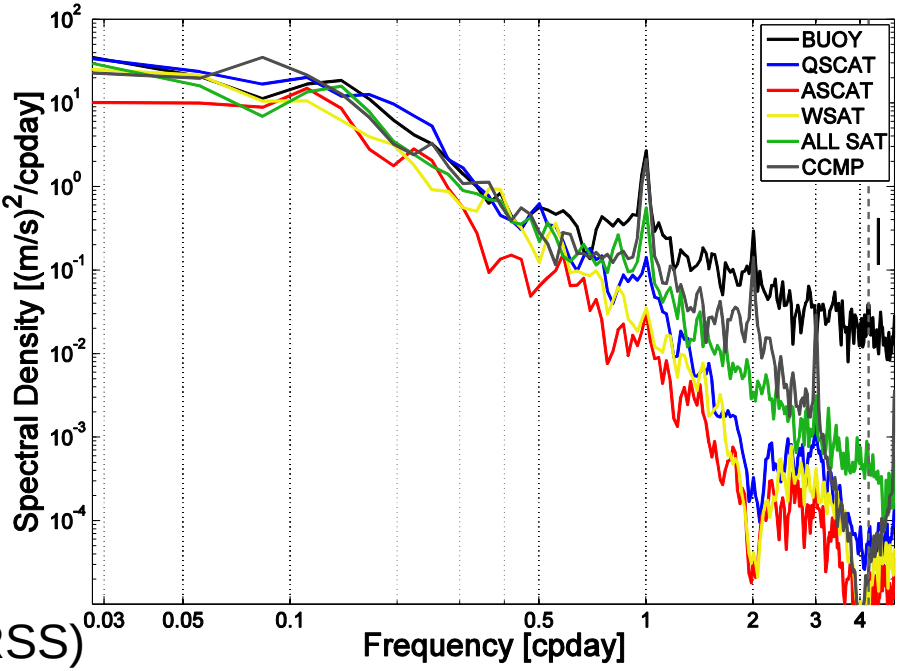
3) What is the role of the Kerguelen wind-shadow in modifying upwelling?

Data used for this study

7-yr Study period for mesoscale analysis : Nov 2002 – Oct 2009
+ 2-mth KEOPS-2 period : Oct-Nov 2011

WINDS
1999-2009 : Quikscat L4 winds from Cersat.
> 2009: CCMP winds, to capture high-frequency variability.

Figure : wind at the VOCALS mooring, with strong diurnal and semi-diurnal peaks.



SST data from AMSR-E - ¼° grid (from RSS)

Ocean colour Chl-A from ESA / Globcolour – ¼° grid

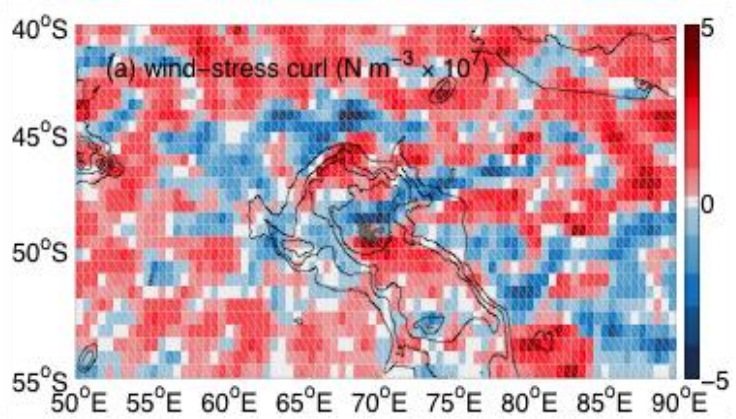
Altimetric Surface geostrophic velocities from DUACS / AVISO – ¼° grid

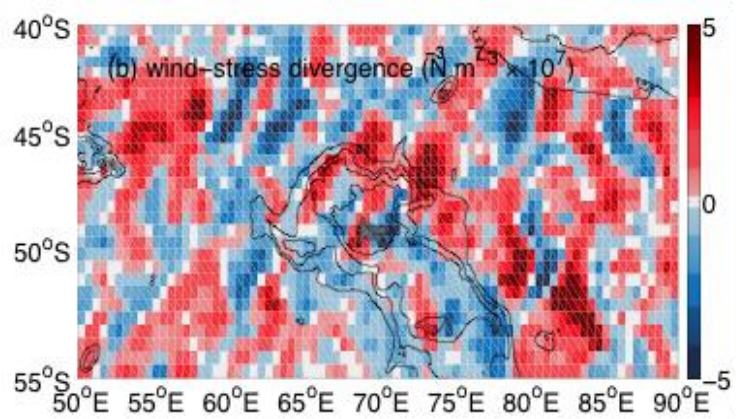
Surface heat fluxes from NCEP : CFSR

Wind coupling with SST gradients at eddy scales

December 2004 to February 2005, spatially filtered to remove large-scale signal, after O'Neill et al. 2003

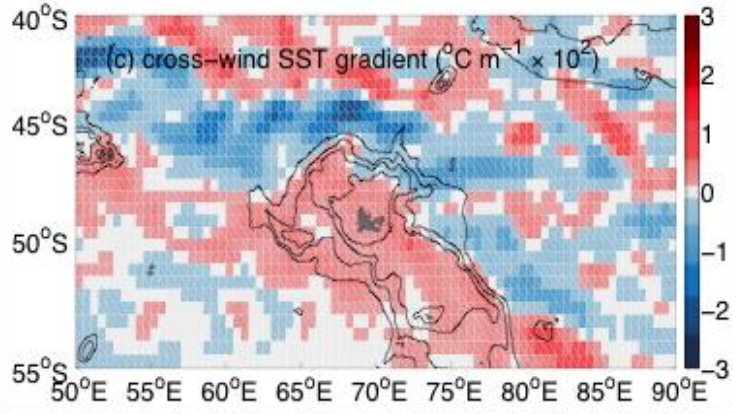
Wind stress curl

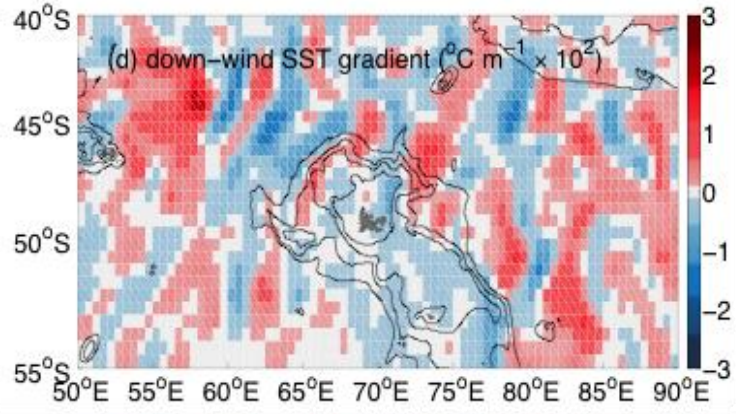




Wind stress divergence

Cross-wind SST gradient





Down-wind SST gradient

$$(\nabla T \times \hat{\tau}).\boldsymbol{k} = |\nabla T| \sin\theta$$

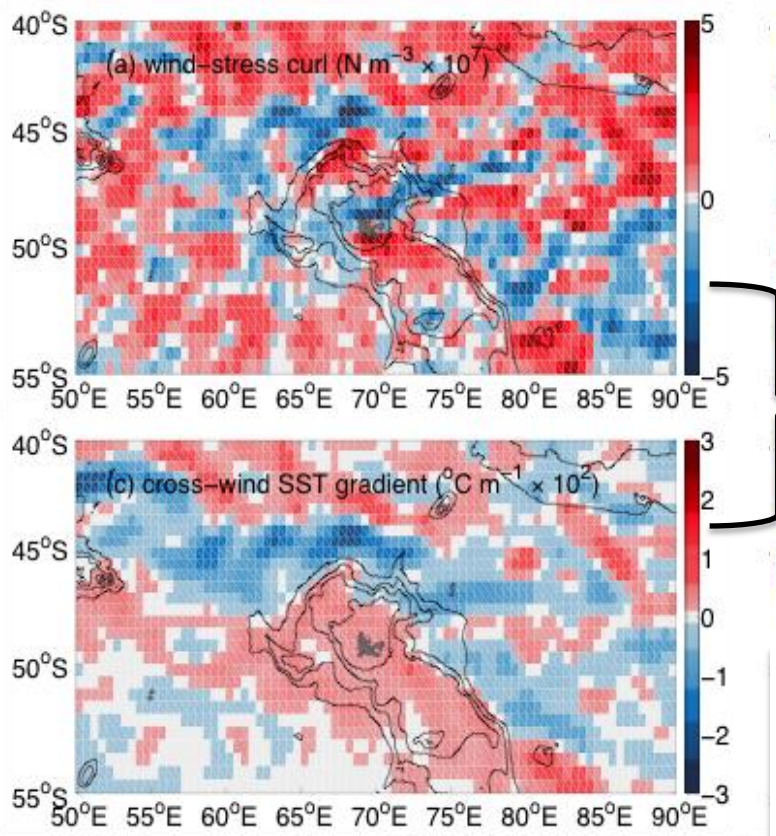
$$\nabla T.\hat{\tau} = |\nabla T| \cos\theta$$

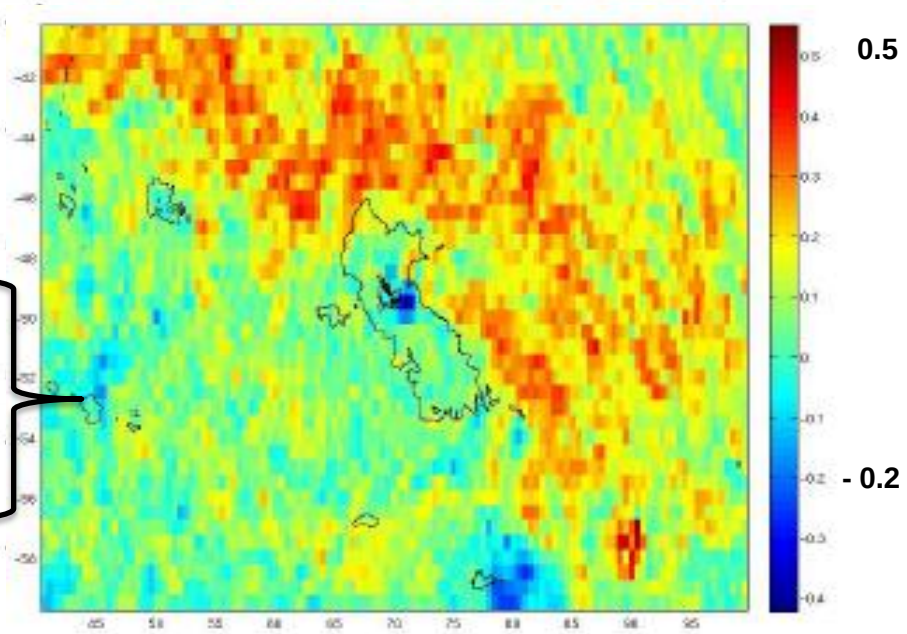
Wind coupling with SST gradients at eddy scales

Wind stress curl

Cross-wind SST gradient

Eddy energy





Correlation :

WSC & Cross-wind SST grad

$$(\nabla T \times \hat{\tau}) . \boldsymbol{k} = |\nabla T| \sin\theta$$

Impact on Chlorophylle : Ekman pumping around eddies / meanders

curl (τ) ~2.e^{-7} N.m^{-3}

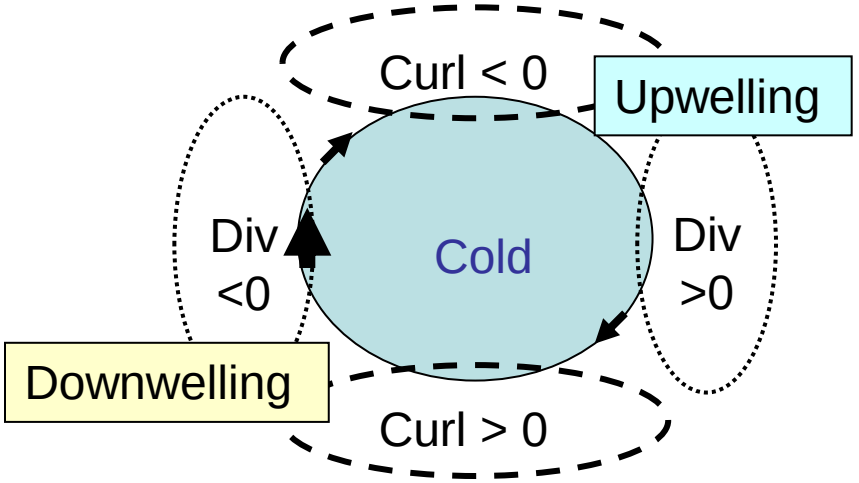
w ~ 20 cm/day

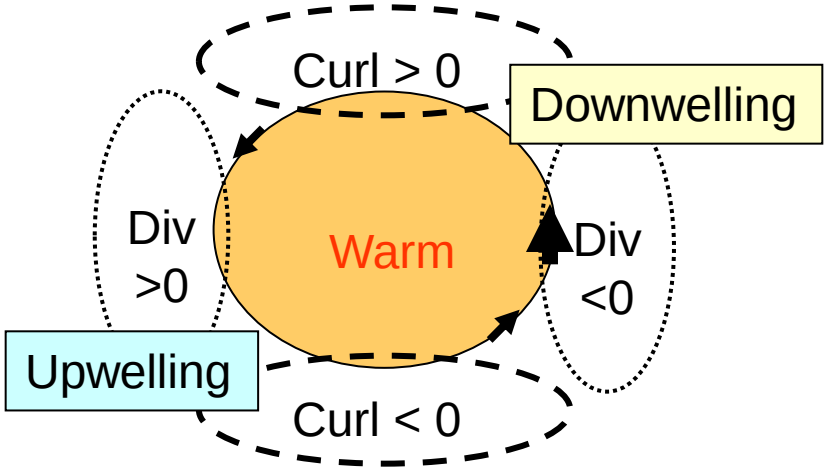
~5 m per month

Eddies / meanders are persistent (τ of 3 months)

Persistent regions of wind-driven upwelling / downwelling around large-slow eddies

Amplitude of wind-driven *w* is small (compared to stronger *w* in filaments)

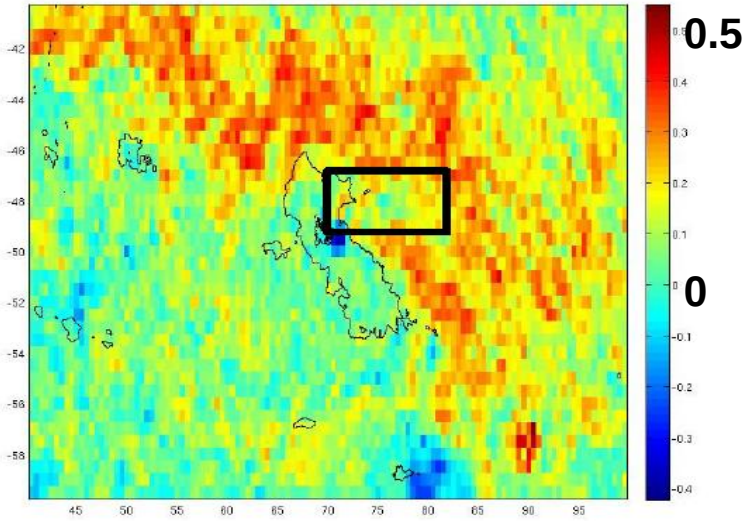




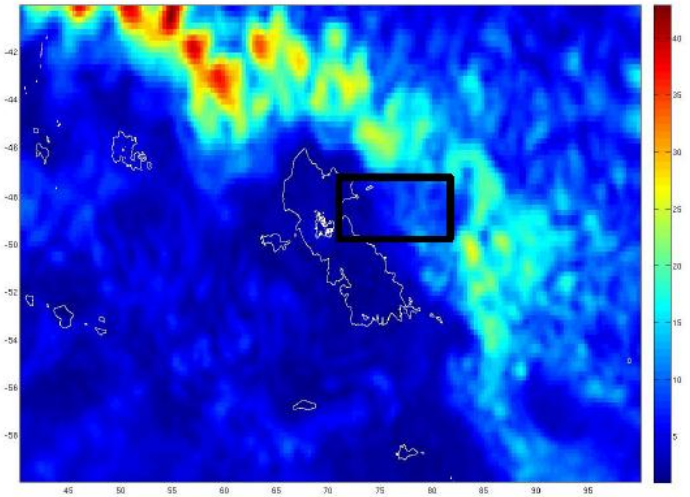
Close to Kerguelen ?

Maximum Chlorophyll blooms occur in regions where mesoscale wind-SST gradient coupling is less efficient !

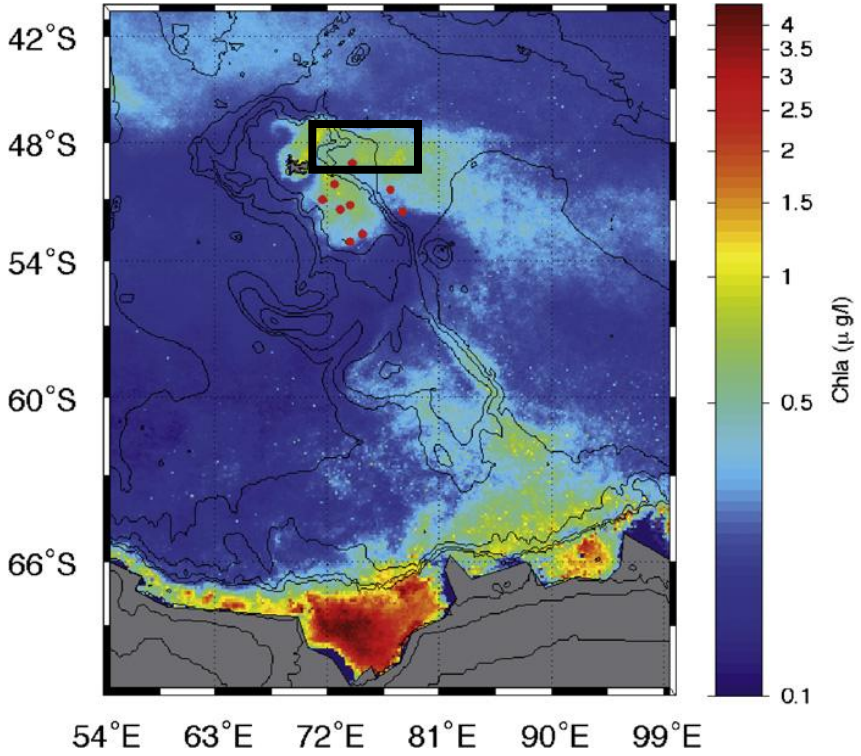
Corrélation Rotationnel/Crosswind



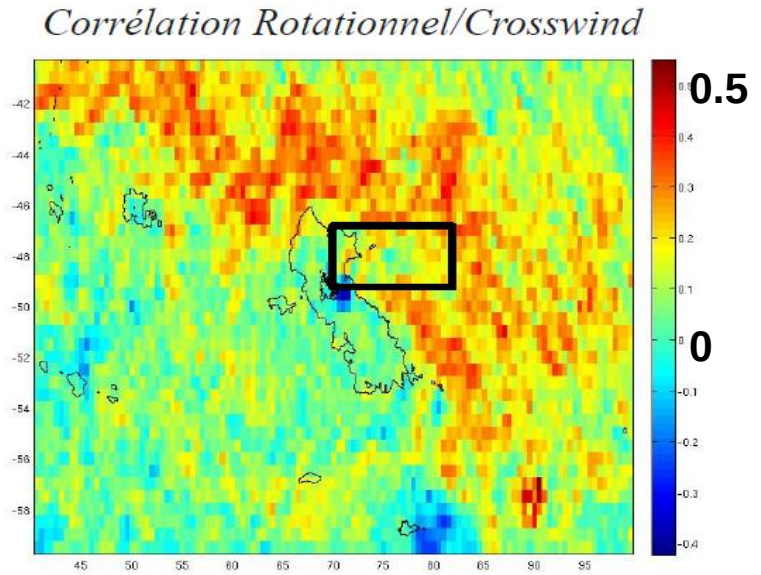
EKE : énergie cinétique tourbillonnaire



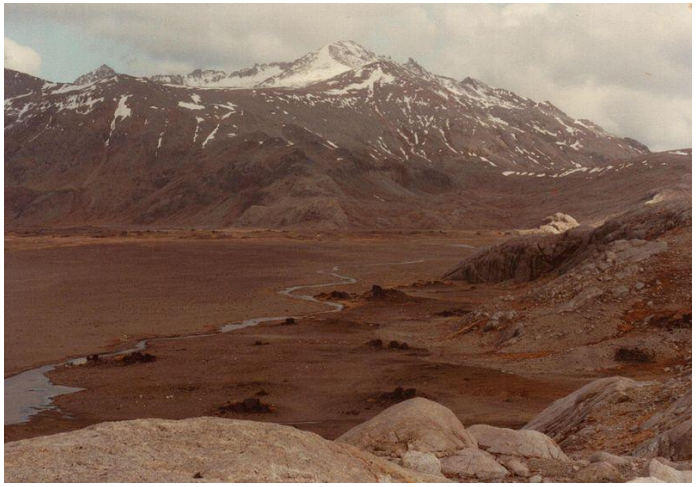
Chl-A climatology MODIS 1997-2007

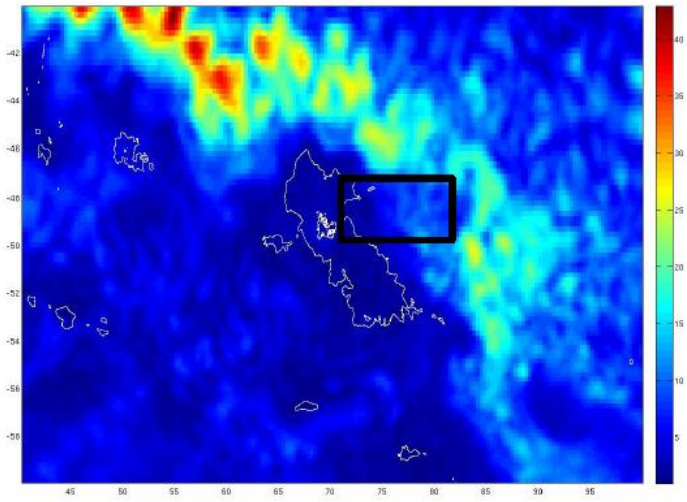


Impact of the orographie of Kerguelen (wind-shadow) on this wind-SST coupling?



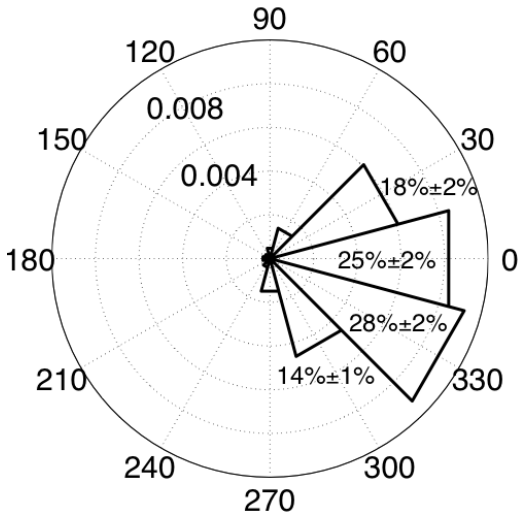
Galliéni Massif (Pic du Grand-Ross),1,850 metres





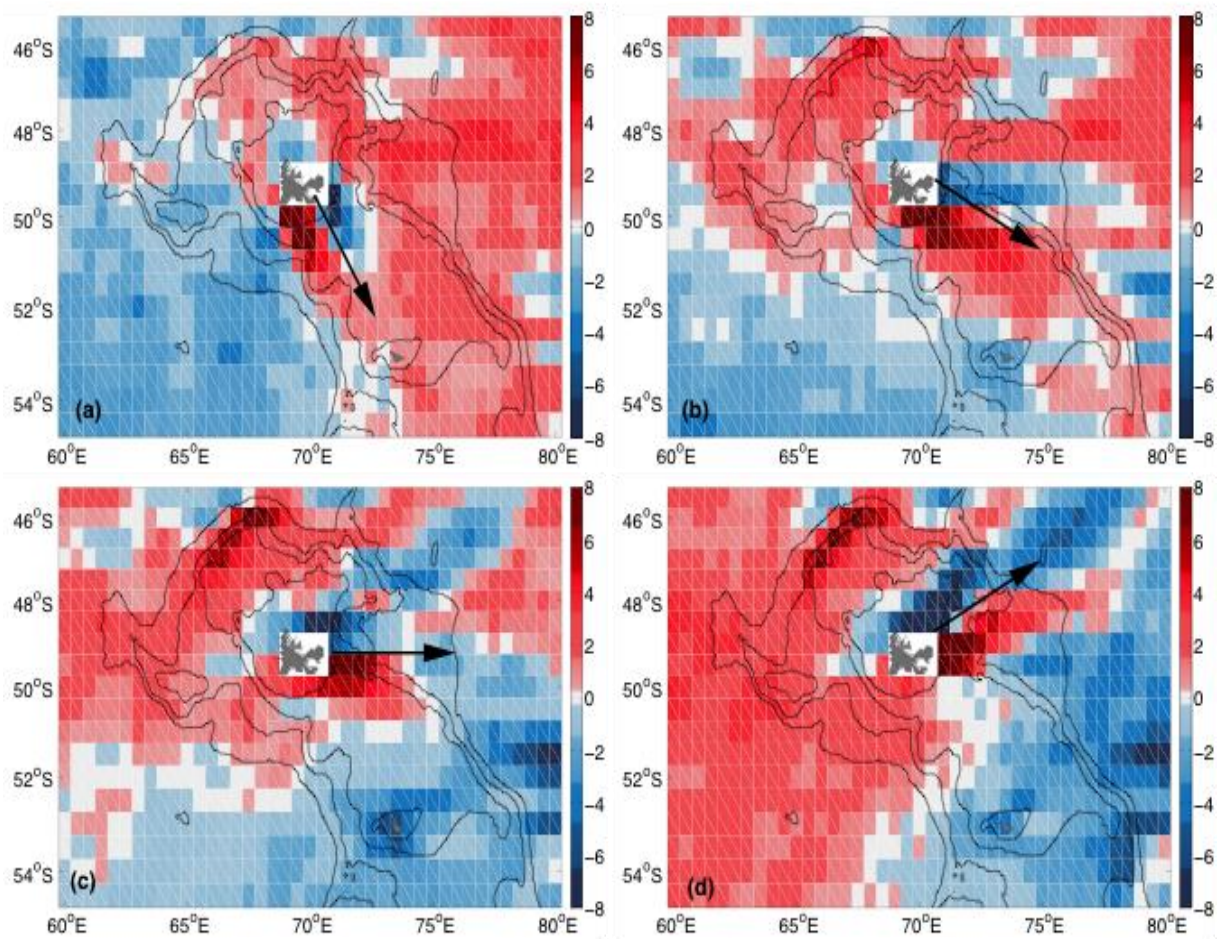
Pattern of WSC downstream of Kerguelen

As noted by Chelton et al., 2004



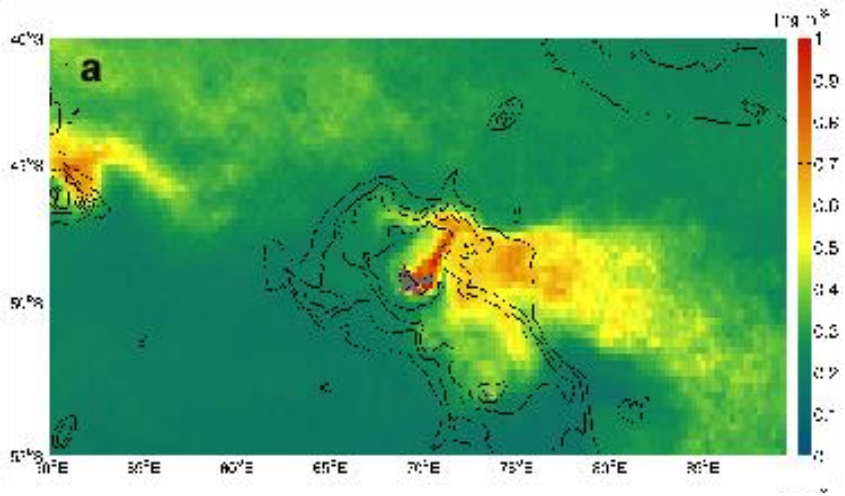
Wind rose east of Kerguelen
% days in each bin

Wind-stress curl sorted by prevailing wind direction
(in 10^{-7} N m^{-3})

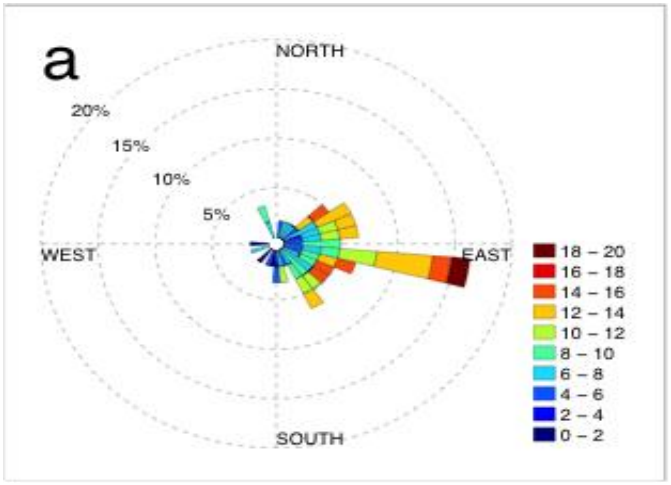


Blue – persistent upwelling favorable winds – ENE of Kerguelen

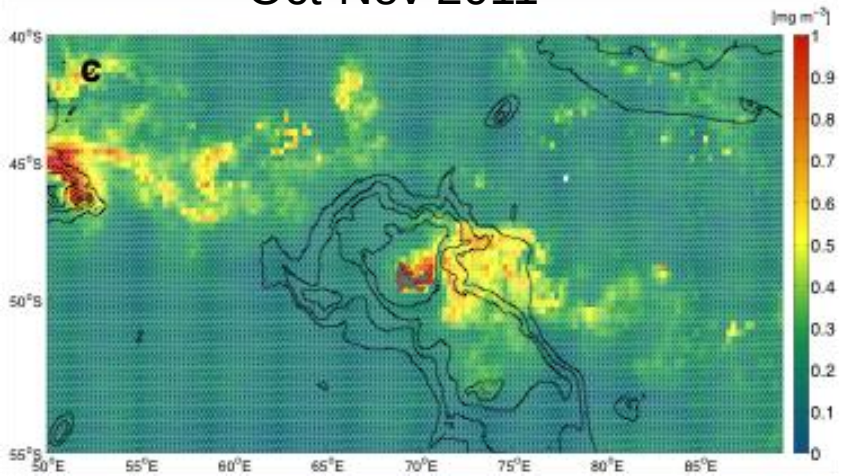
Upwelling winds and Chl-a for the KEOPS period

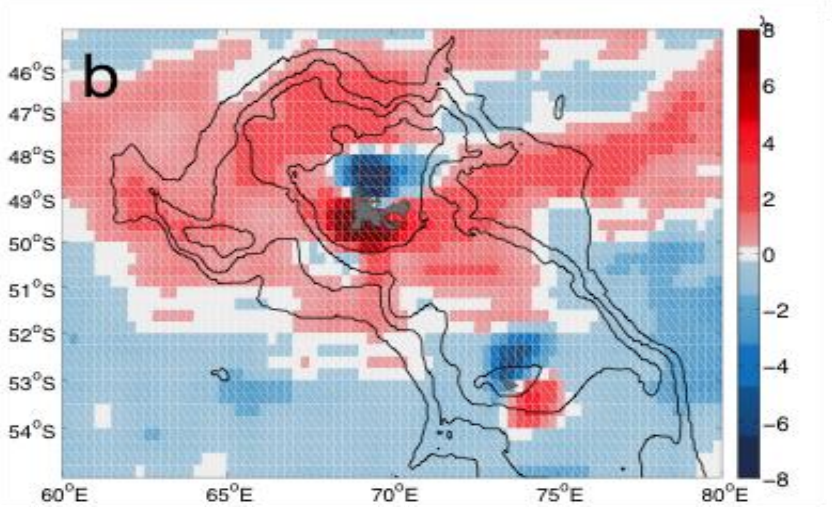


Spring mean Chl-a (OND) over 2000-2010



Mean Chl-a for KEOPS-2 : Oct-Nov 2011





Wind rose and mean WSC pattern during KEOPS-2

Wind-driven upwelling near plateau – small but persistent

Wind-stress curl : 2-5 x 10^{-7} N m^{-2}

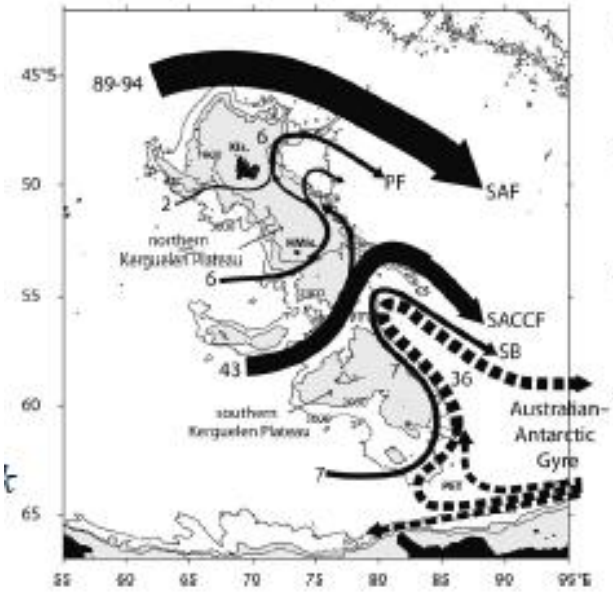
Vertical Ekman pumping upwelling : 2-4 x 10^{-6} m/s

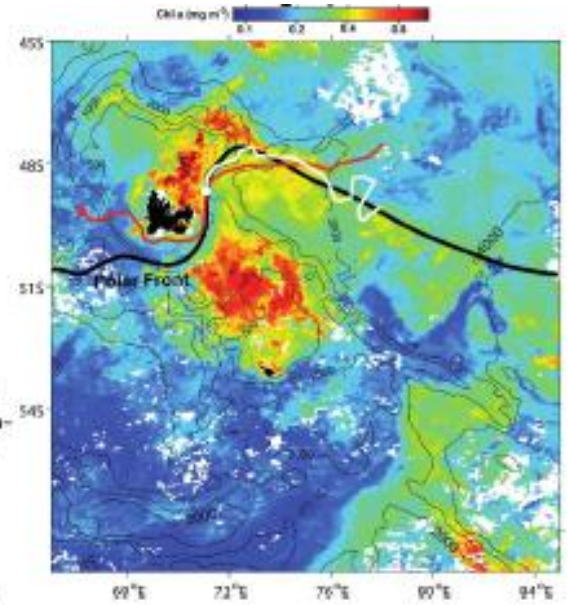
Change of thermocline depth of 5-10 m per month.

Small but persistent over the shallow NE shelf

Other processes : wind & tide-driven vertical mixing on shelf. Upwelling associated with slope current instabilities.

Branches of the ACC current





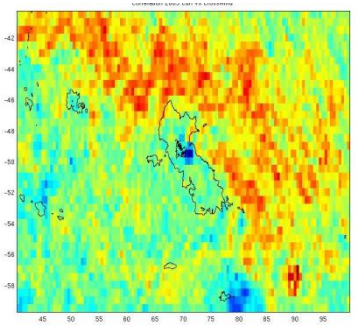
High ChL-A on plateau & downstream

Conclusions

1) In the Chl-A bloom downstream of Kerguelen :

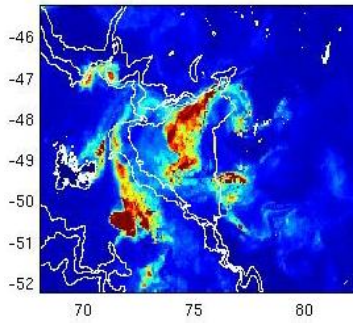
- Coupling of wind and mesoscale SST gradients => occurs downstream in moderate to high EKE regions

=> impact on upwelling/downwelling over the downstream bloom … under investigation



2) Close to the Plateau

- Impact of the orography. Positive/negative dipole in WSC. Shallow plateau to NE of Kerguelen has upwelling most of the time
- During KEOPS-2, this WSC driven upwelling is small, but could « precondition » a shallower thermocline leading to chlorophyll bloom events.



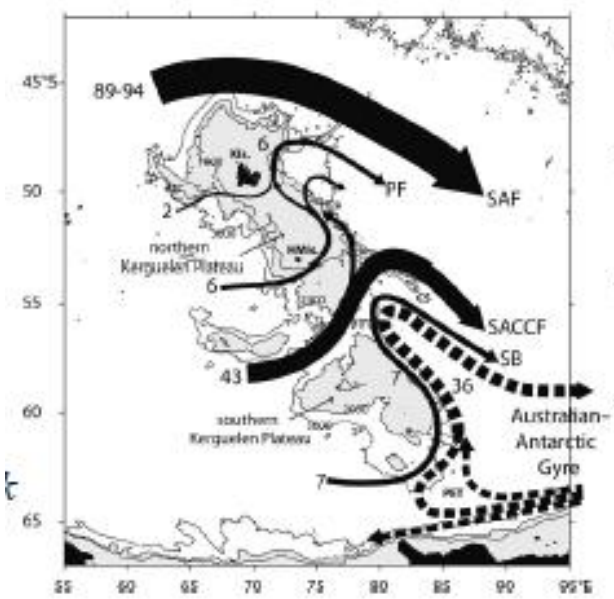
3) High-resolution wind products crucial for examining these regional processes.

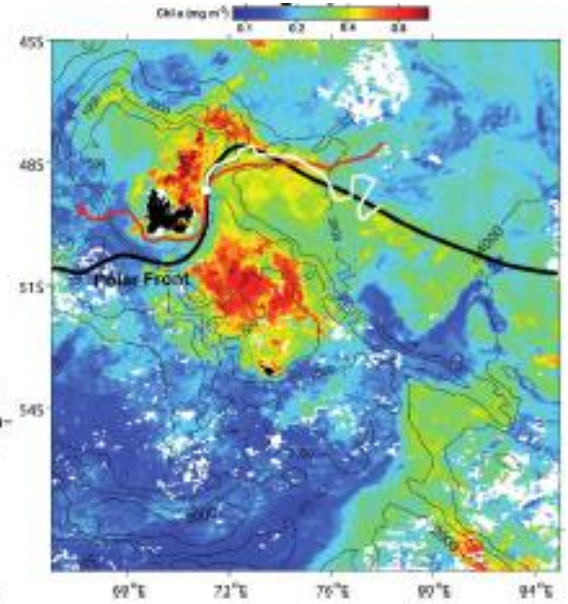
Submitted to KEOPS-2 special issue in Biogeosciences Discussion

extras

Physical mechanisms dominating the study region

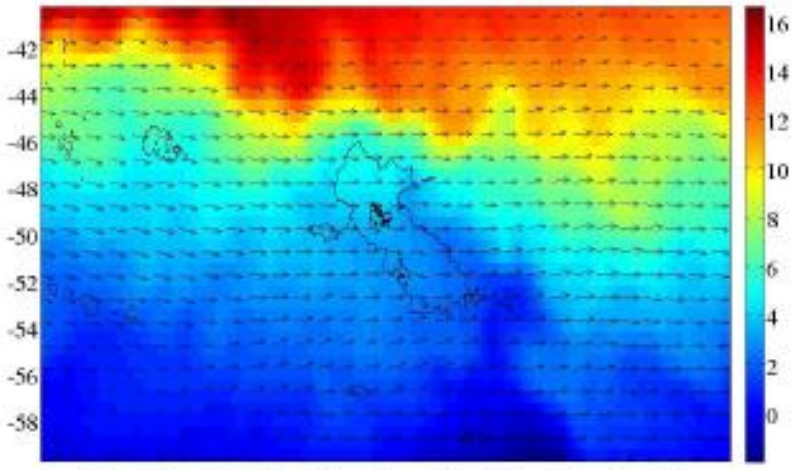
Branches of the ACC current





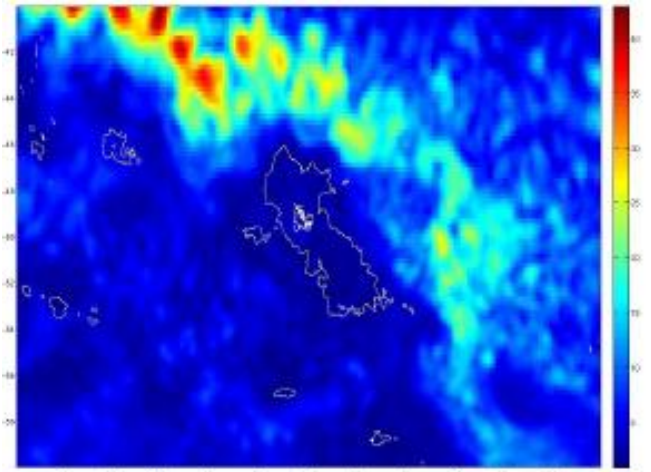
High ChL-A on plateau & downstream

Strong SST gradients and winds



SST (° C) averaged over 2009

Energetic mesoscale eddies

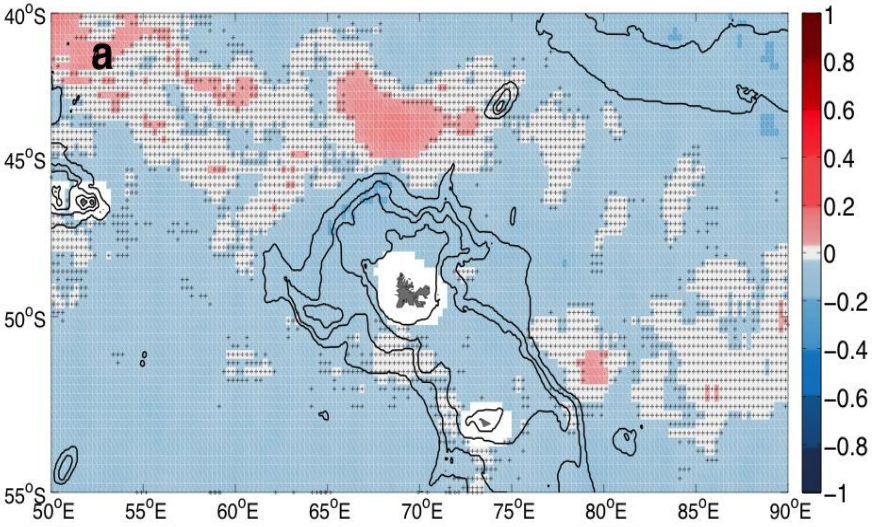


Altimetric EKE averaged over 2009

Wind-SST correlations near Kerguelen

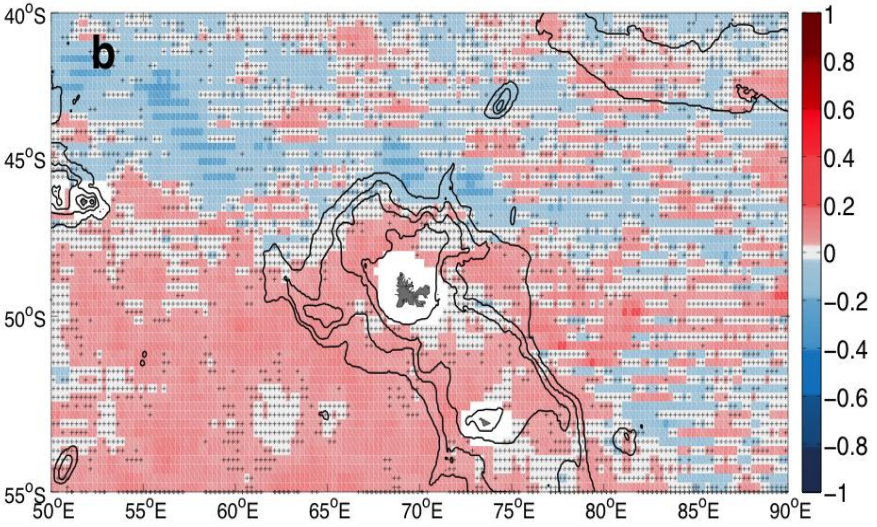
Partial correlations – controlled for heat flux – for spring-summer Sept - Feb

wind speed vs SST



Blue indicates that stronger winds deepen mixed layer bringing cooler water to surface => **neg. Correlation with SST**;

wind stress curl vs SST

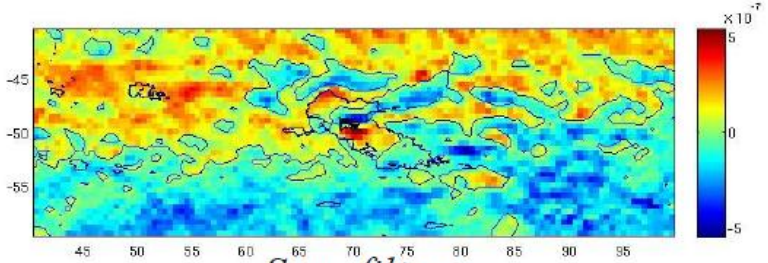


Red indicates that negative wind-stress curl (i.e. upwelling) is linked to cold SSTs

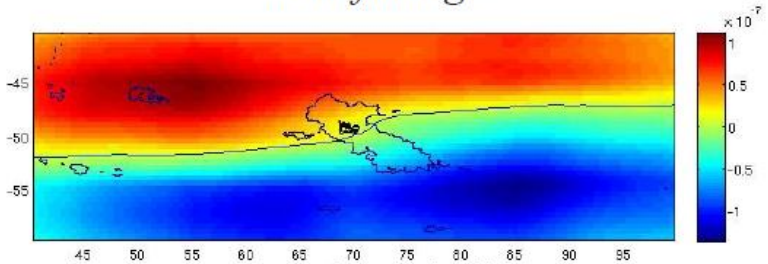
Importance du filtrage spatial et temporel

➡ Corrélations différentes suivant les échelles

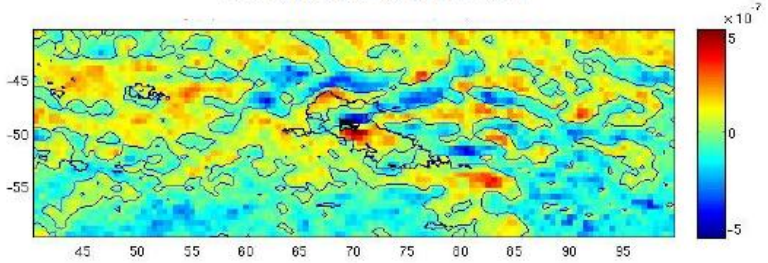
Rotationnel tension de vent moyenne 2009



Sans filtrage

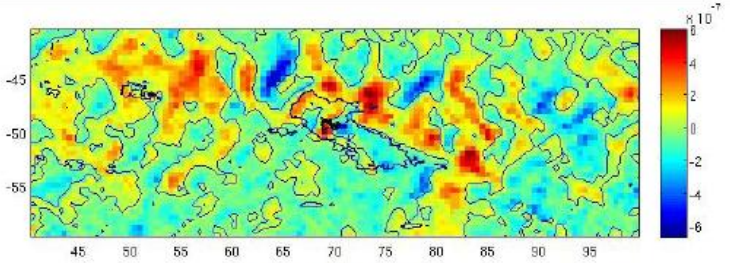


Grandes échelles

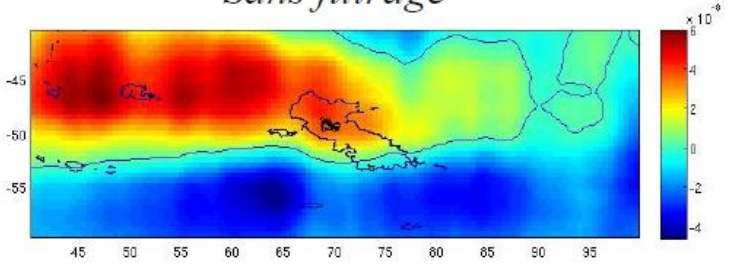


Faibles échelles < 10°x30°

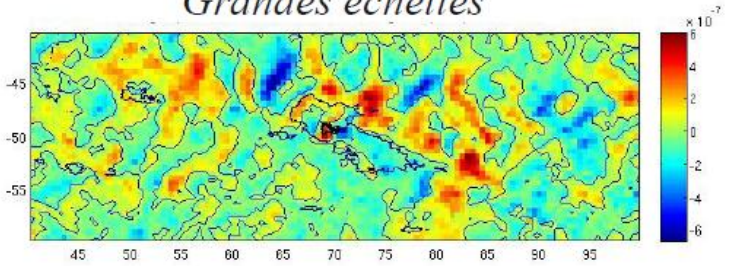
Divergence tension de vent moyenne 2009



Sans filtrage



Grandes échelles



Faibles échelles < 10°x30°

Moyenne sur 3 mois : échelle de décorrélation typique des tourbillons océaniques