# Diagnostics of the Agulhas Eddies Propagation in Ocean Reanalyses, OGCMs and Satellite Altimetry

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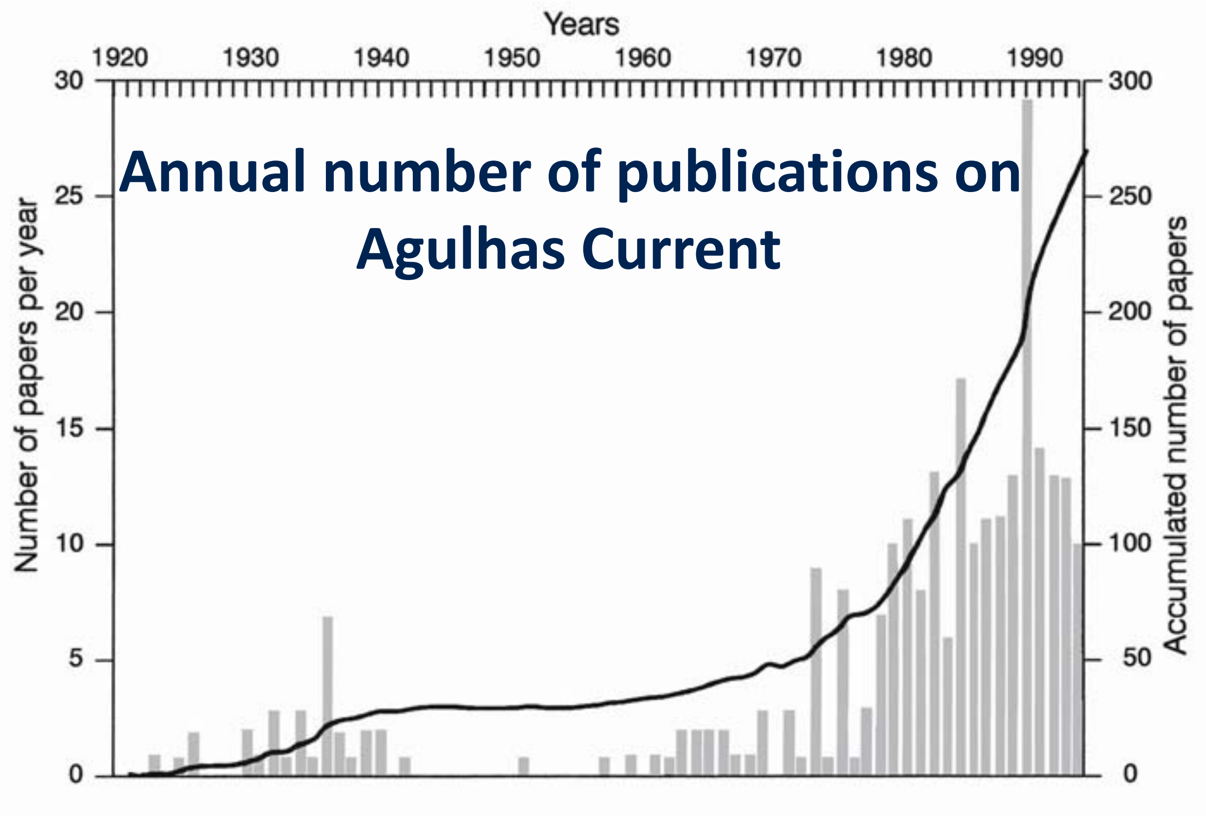
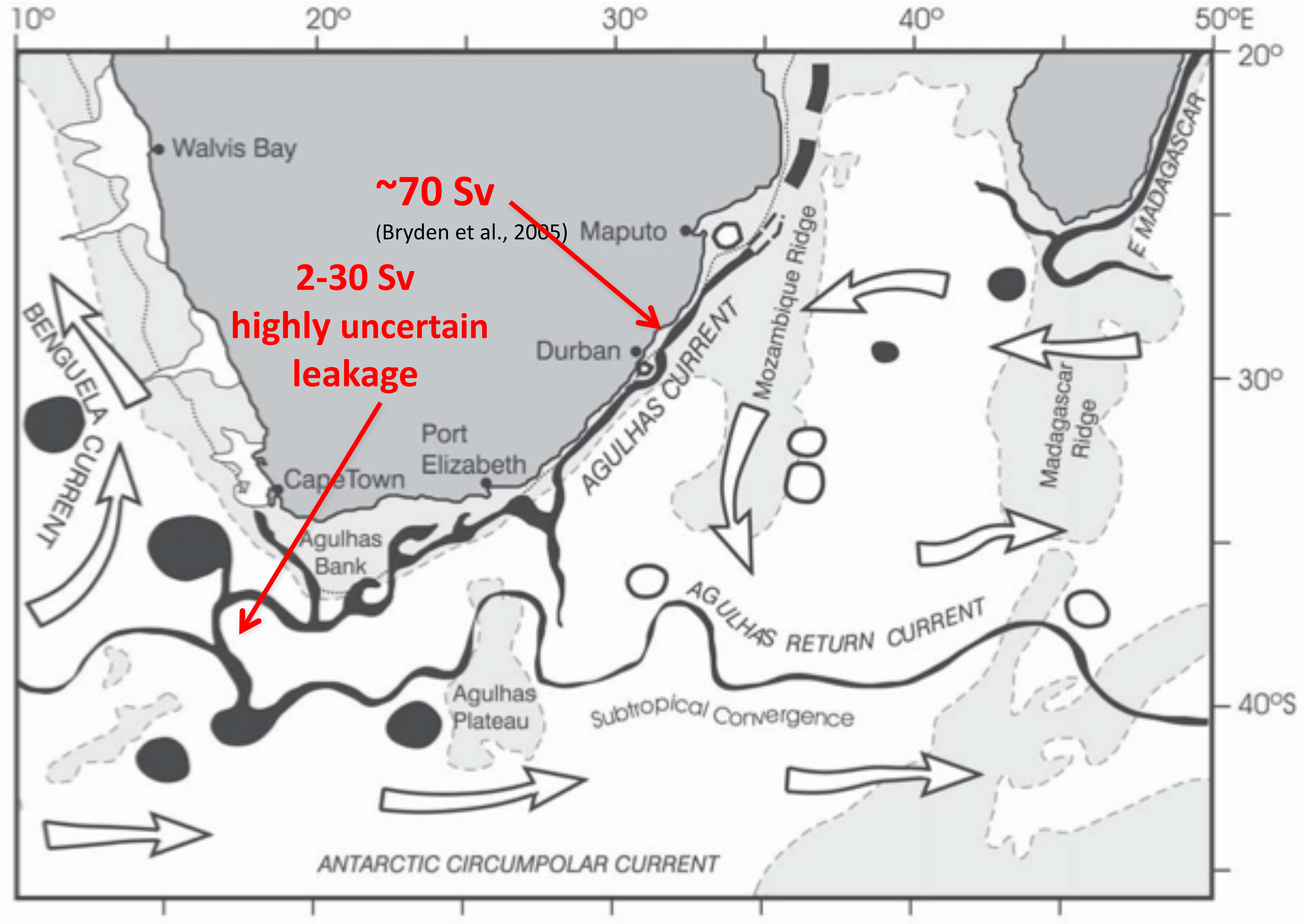
Sources and Sinks of Ocean Mesoscale Eddy Energy, 13/03/2019

# Motivation

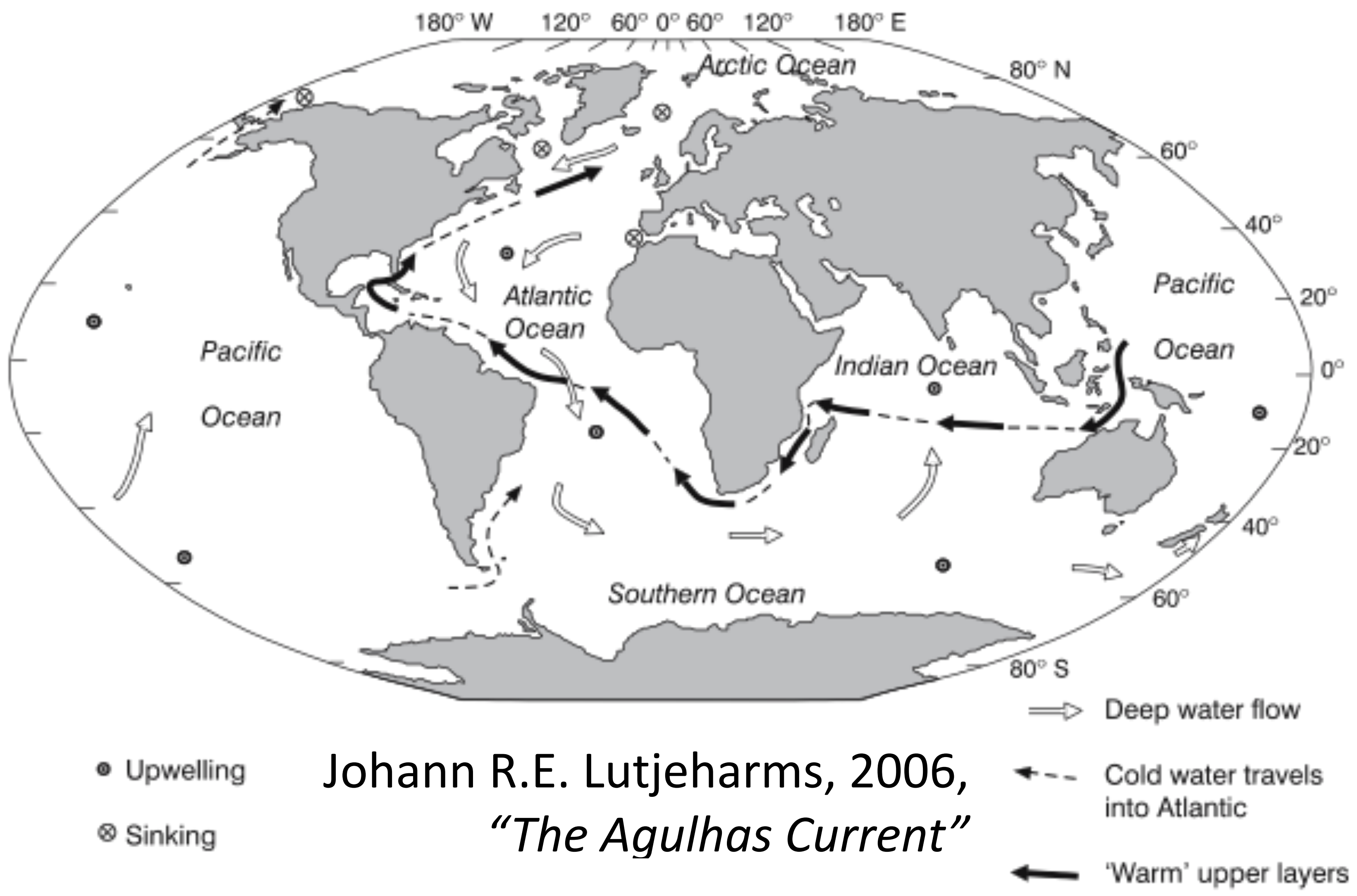
- **Agulhas Current** is a classic **western boundary current**
- It is also know as a **“Sea of Eddies”**
- **Agulhas** position is controlled by the bottom topography - continental shelf and Agulhas Plateau
- **Surface** velocities in the core **are up to 100 cm/s (6km/h), with the peaks up to 245 cm/s**




Johann R.E. Lutjeharms, 2006, *“The Agulhas Current”*

# Motivation




Johann R.E. Lutjeharms, 2006, *“The Agulhas Current”*

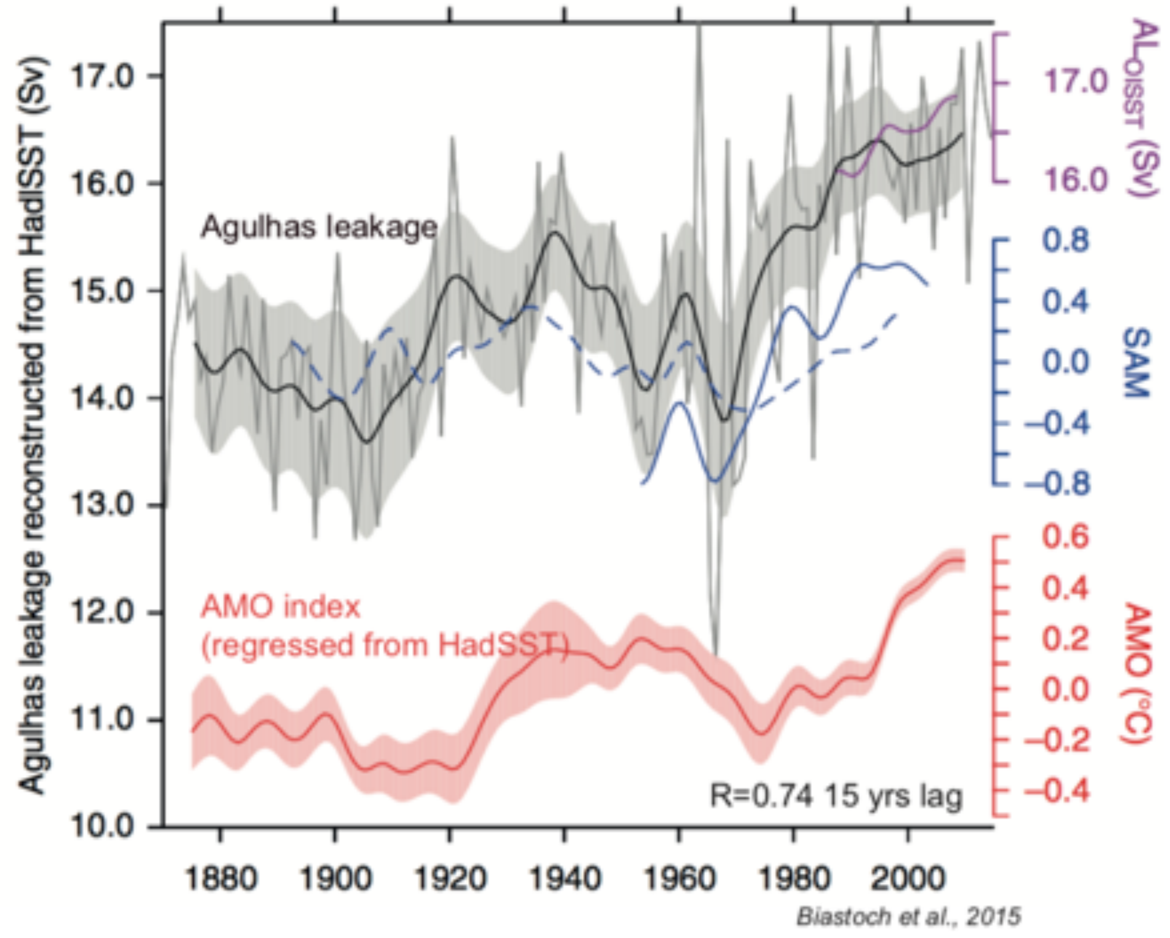
- Agulhas Current plays a **key role** in the global conveyor belt being the strongest WBC:

  *at 32N and S latitude*

  Agulhas **70 Sv**

  Gulf Stream **34 Sv**

  Kuroshio **42 Sv**




*Biastoch et al., 2015*

- Model drifters and **40%** of the Agulhas leakage volume transport reach the North Atlantic within 12 years supporting the dynamics of AMOC circulation

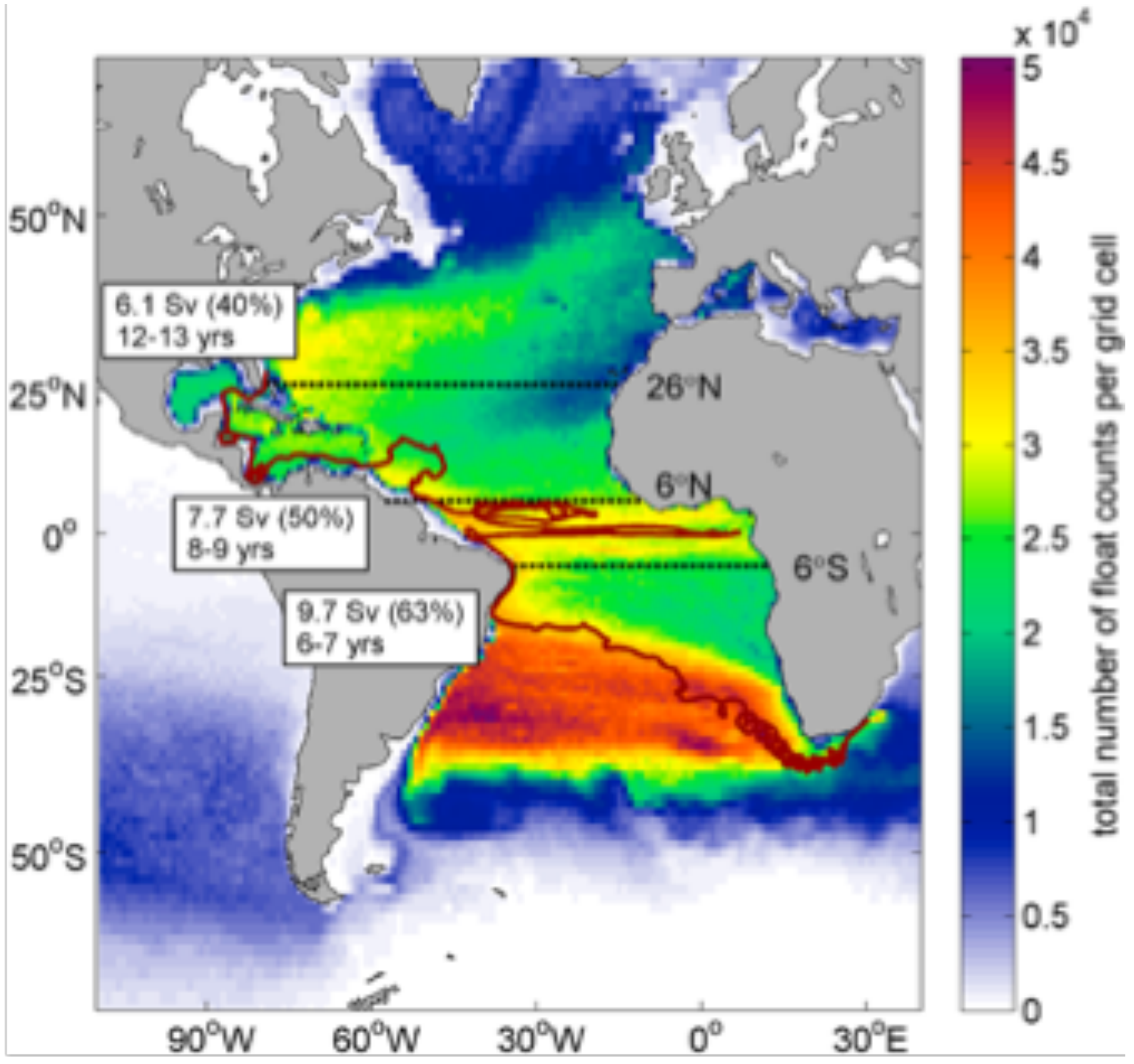
*Ruhs et al., 2015 - NEMO based study*

- Agulhas leakage responds to changes in the position and intensity of the westerly winds band in the SH

*Durgadoo et al., 2013 - NEMO based study*

- It affects decadal variability of the Atlantic Overturning Circulation (r=**0.74** - 15 yrs lag)

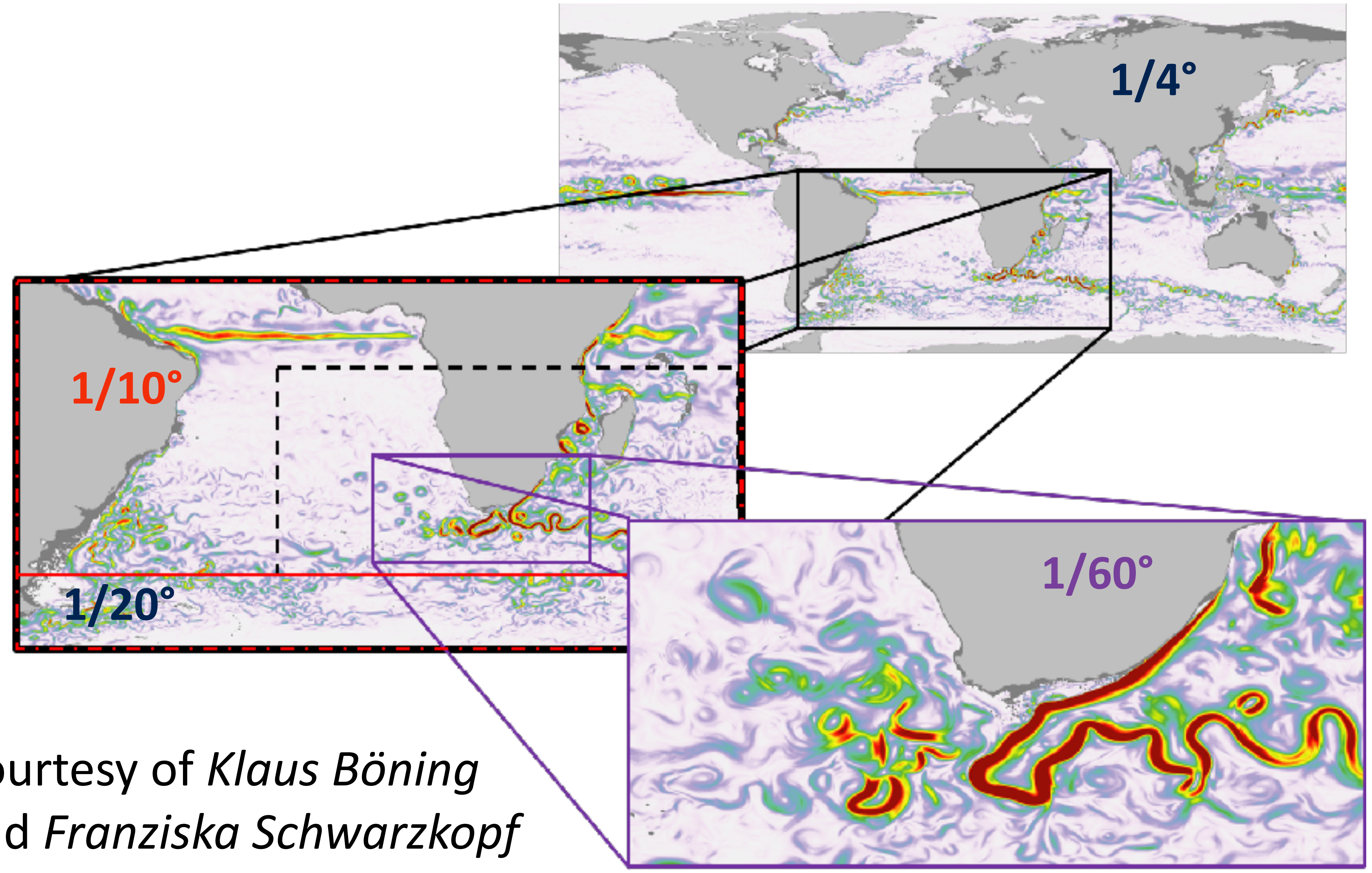
*Biastoch et al., 2008; Biastoch et al., 2015; Kelly et al., 2016*




Ruhs et al., 2015 - NEMO based study

# Model experiments design - hindcast 1958-2009

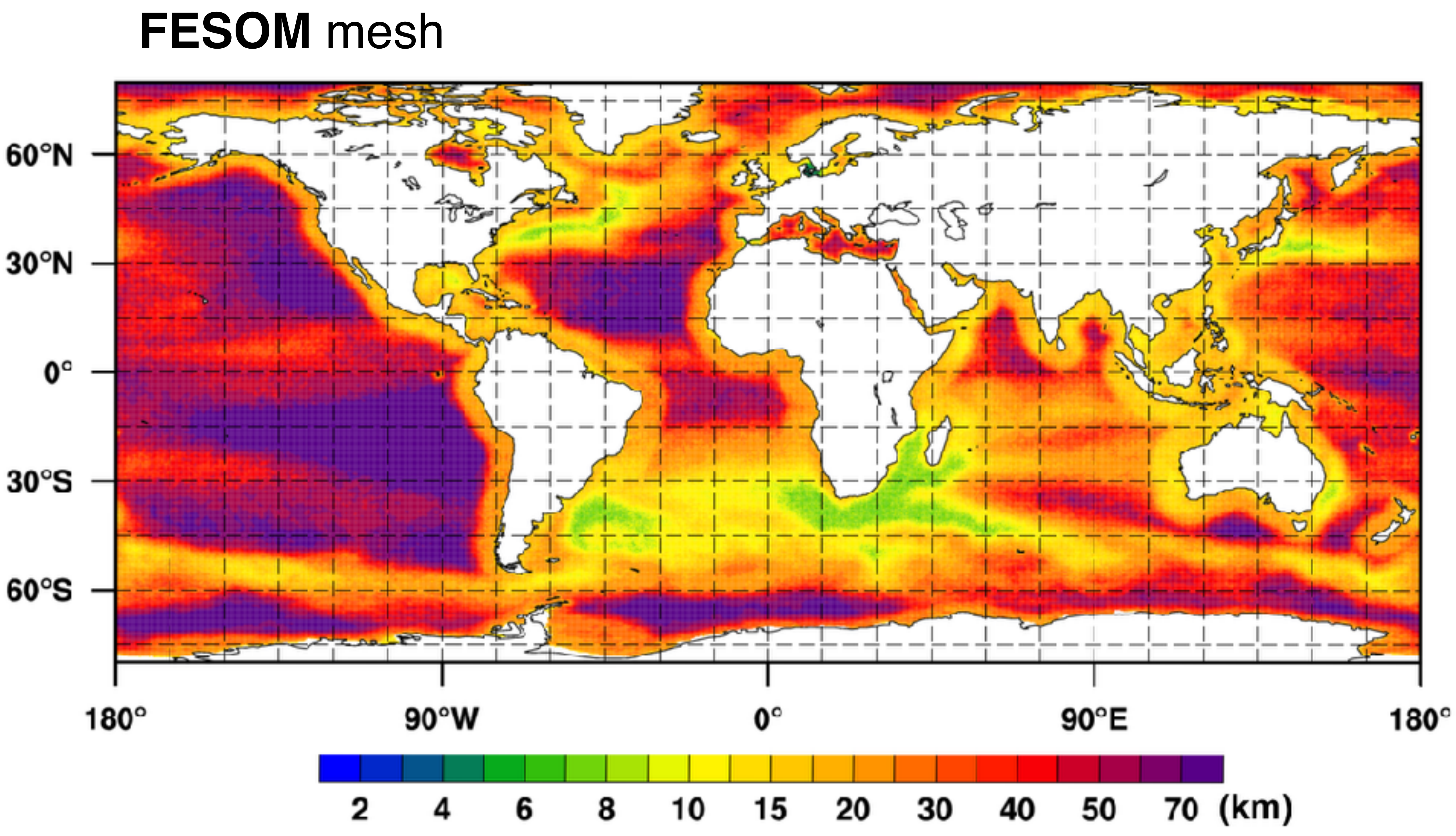
## NEMO INALT
(Indian Ocean Atlantic Nest)




Courtesy of *Klaus Böning* and *Franziska Schwarzkopf*

- LIM2 sea ice (elastic-viscous rheology)
- Tripolar ORCA grid
- Total Grid Points:

## FESOM
(Finite Element Sea-Ice Ocean Model)




- NCEP CORE2 Forcing
- 47 vertical levels

Courtesy of *Dmitry Sein*

(i) The time scales of SSH variability across the Agulhas regions
(ii) Comparison of the SSH variability across the model experiments, ocean reanalyses and satellite altimetry

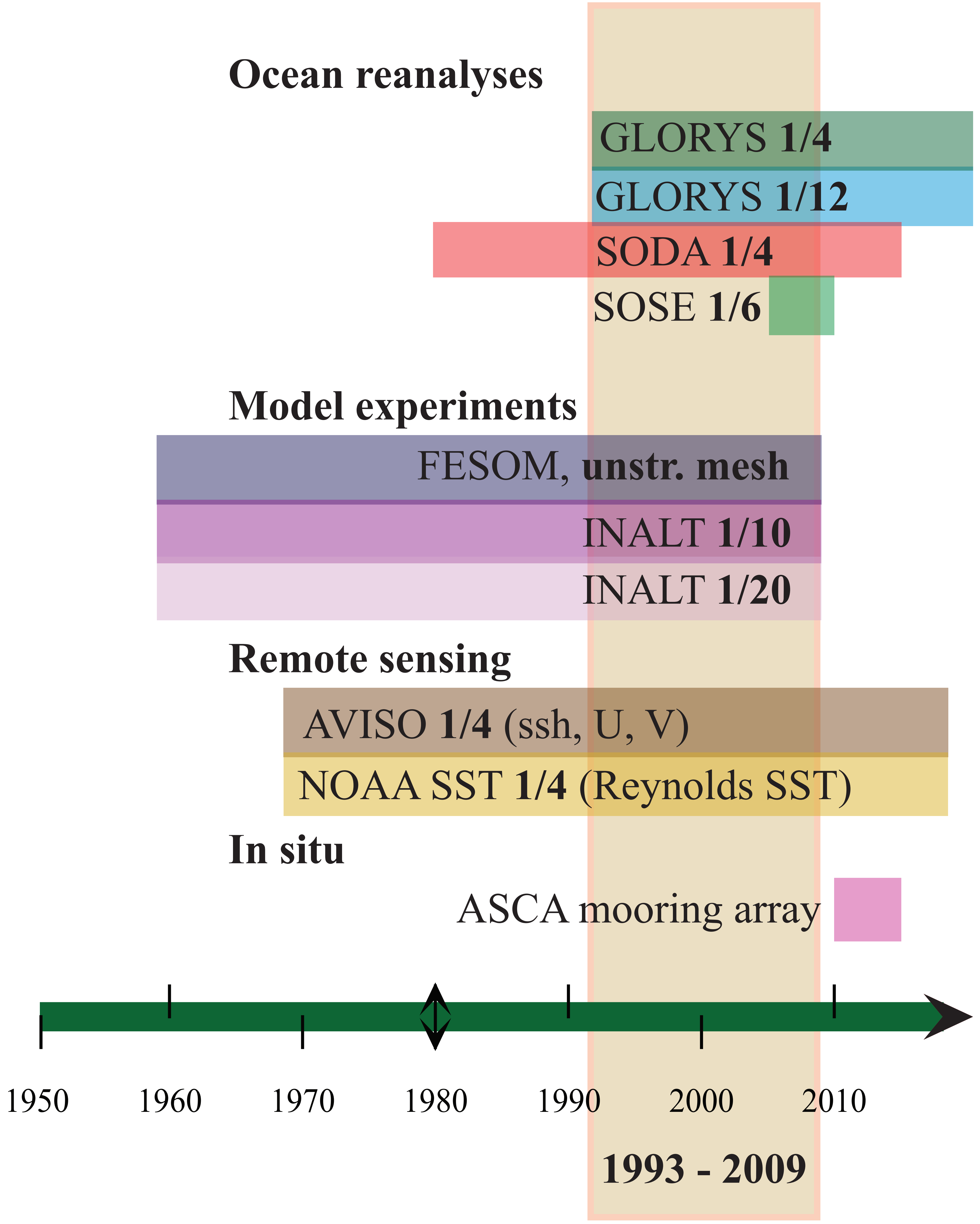
# Datasets

## Ocean reanalyses

| | | | | |
|---|---|---|---|---|
| Global Ocean Reanalysis (**GLORYS 040**) | 1/4° | daily mean | NEMO (MERCATOR) | 1993 - pr. |
| Global Ocean Reanalysis (**GLORYS 012**) | 1/12° | daily mean | NEMO (MERCATOR) | 1993 - pr. |
| **SODA** (Simple Ocean Data Assimilation) ocean/sea ice reanalysis ) | 1/4° | daily mean | MOM5 (University of Maryland) | 1980 - 2015 |
| **SOSE** (Southern Ocean State Estimate) | 1/6° regional SO | daily mean | MIT GCM | 2005 - 2010 |

## Model experiments

| | | | | |
|---|---|---|---|---|
| **FESOM** | unst.m. (1/10° highest) | 5-daily mean | FESOM (AWI) | 1958 - 2009 |
| **NEMO** | 1/4° global | | NEMO (GEOMAR) | |
| INALT10 | 1/10° nest | 5-daily mean | | 1958 - 2009 |
| INALT20 | 1/20° nest | 5-daily mean | | 1958 - 2009 |
| INALT60 | 1/60° nest | 5-daily mean | | separate years |



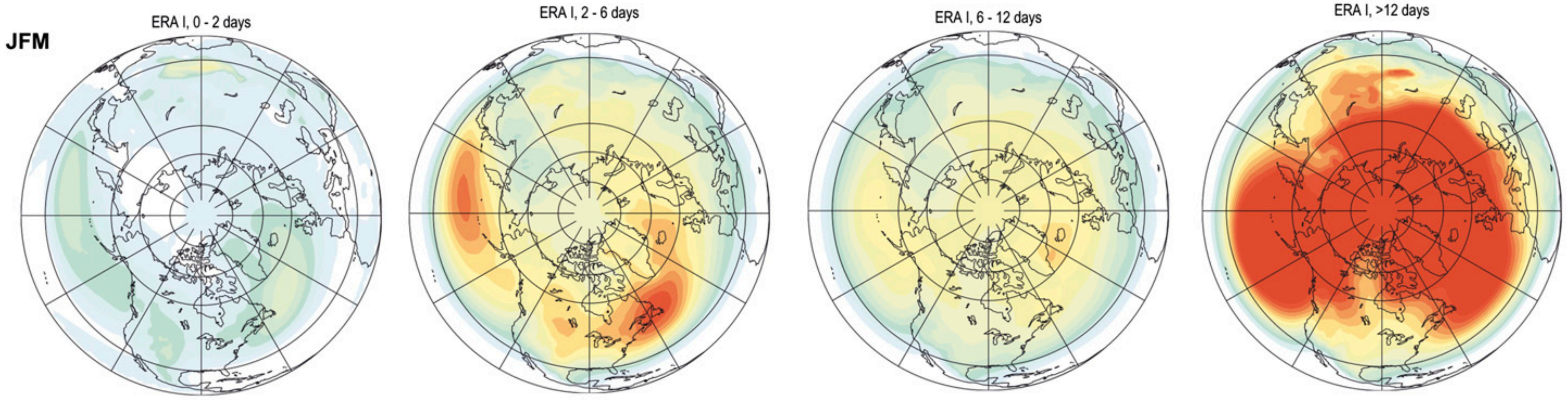
# Bandpassing

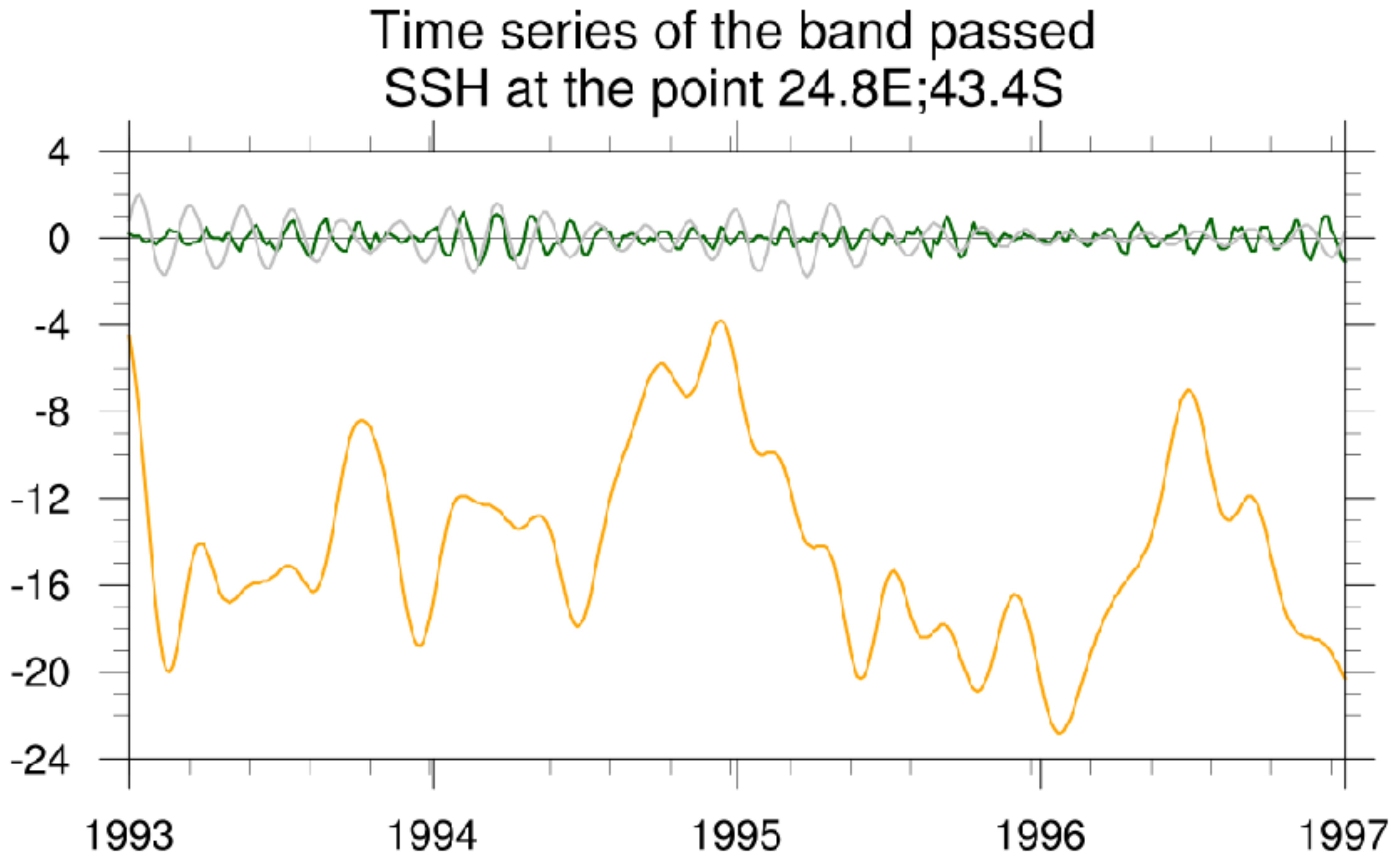
Adaptation of the methodology, widely used in diagnostics of the atmospheric dynamics:

$$f\ (x,y,t) = f_l(x,y,t) + f_s(x,y,t) + f_h(x,y,t)$$

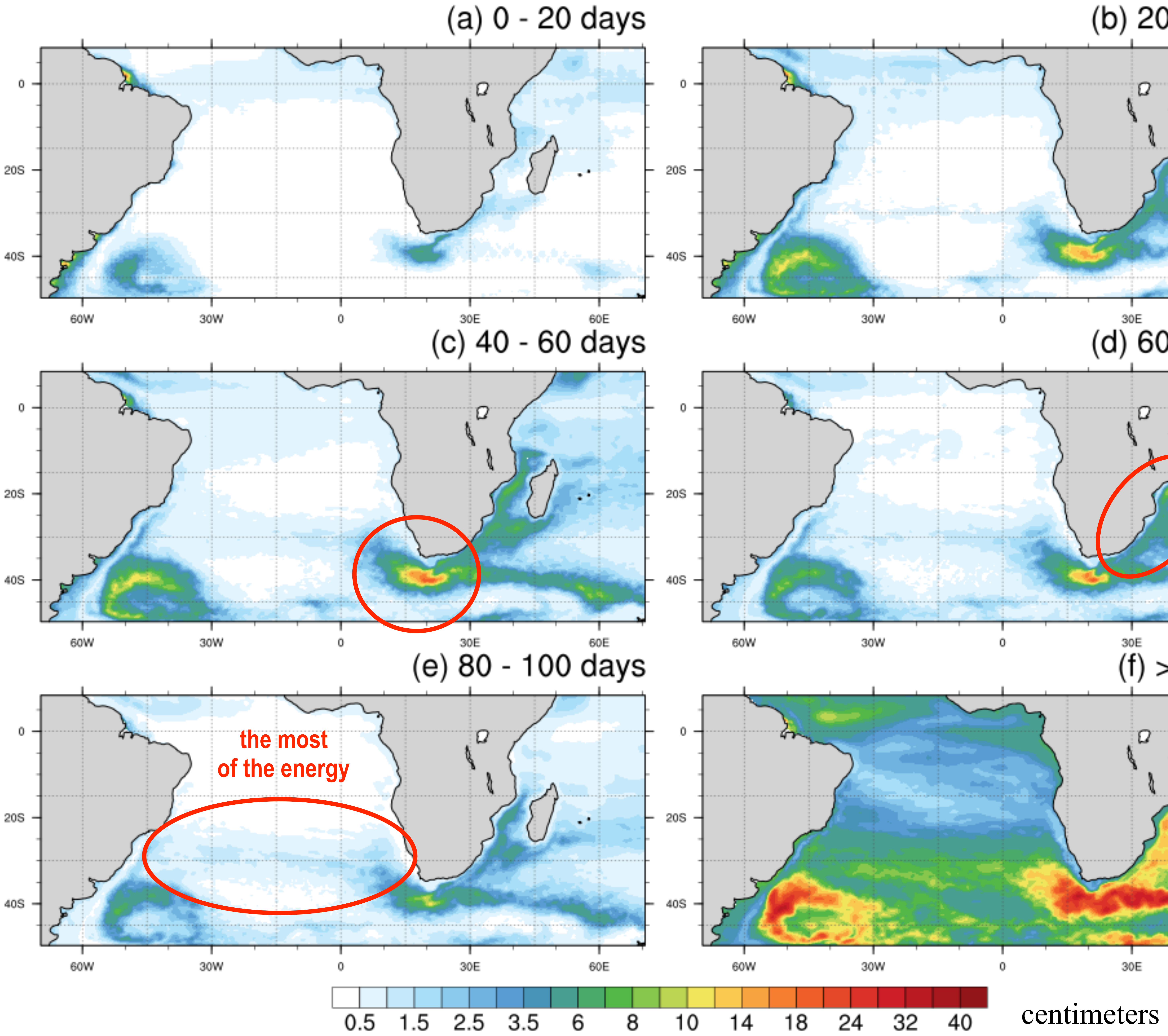
Jones and Simmonds 1993
Zolina and Gulev, 2003
Gulev et al., 2002
Kravtsov et al., 2016
among many others

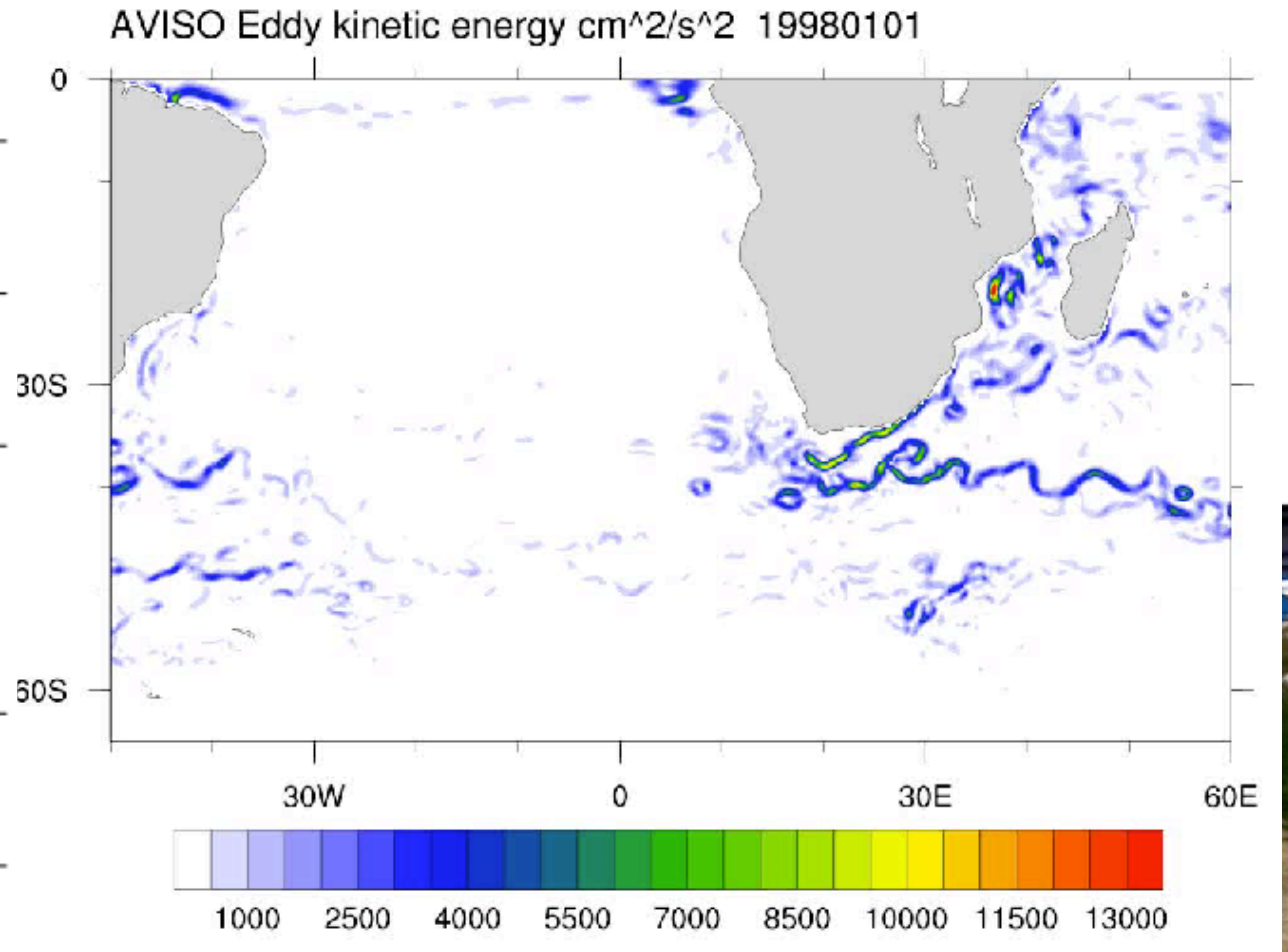
Example for Sea Level Pressure (Kravtsov et al.,



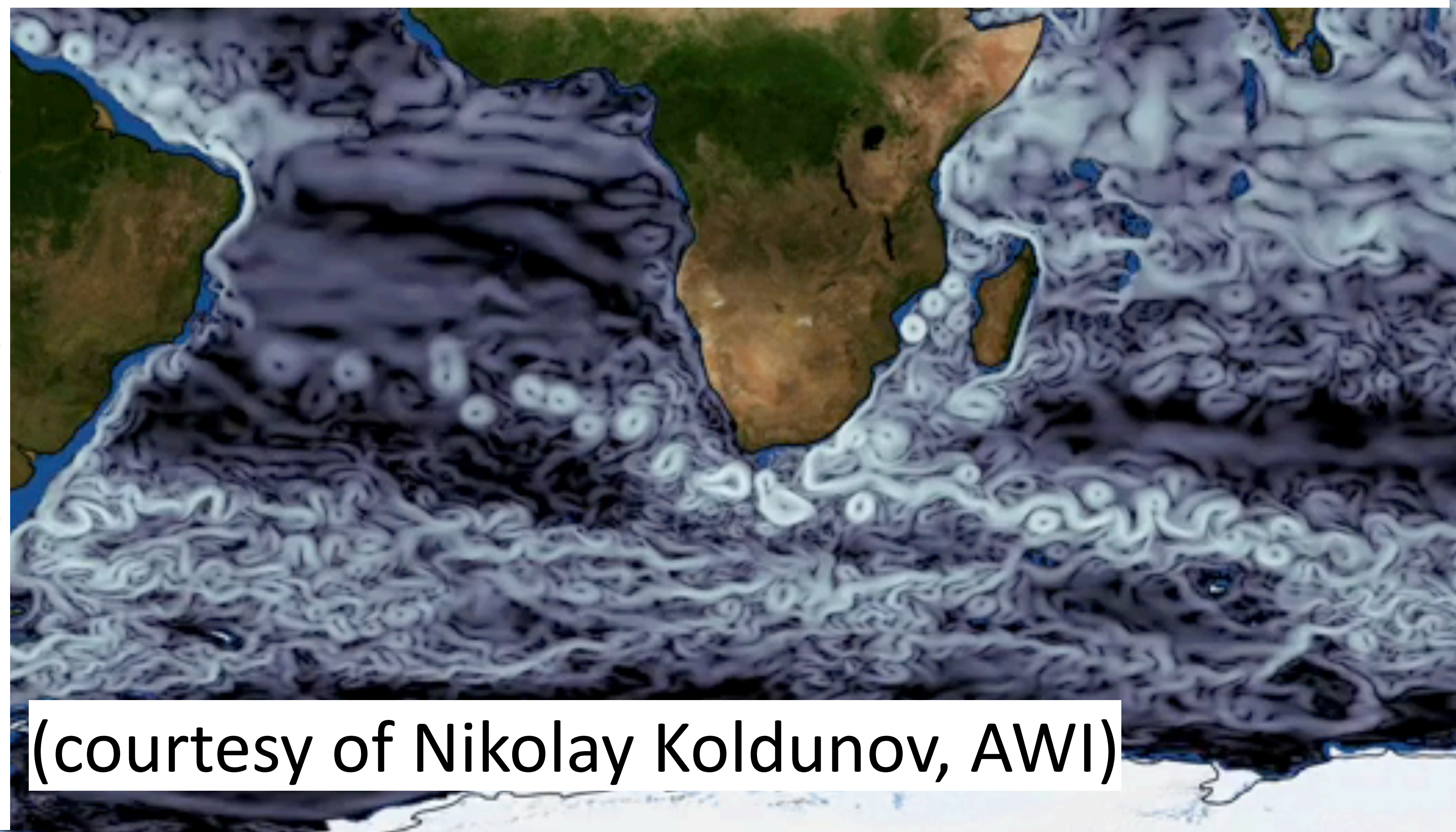



# Bandpassed SSH in different time ranges, AVISO, 1993-2009



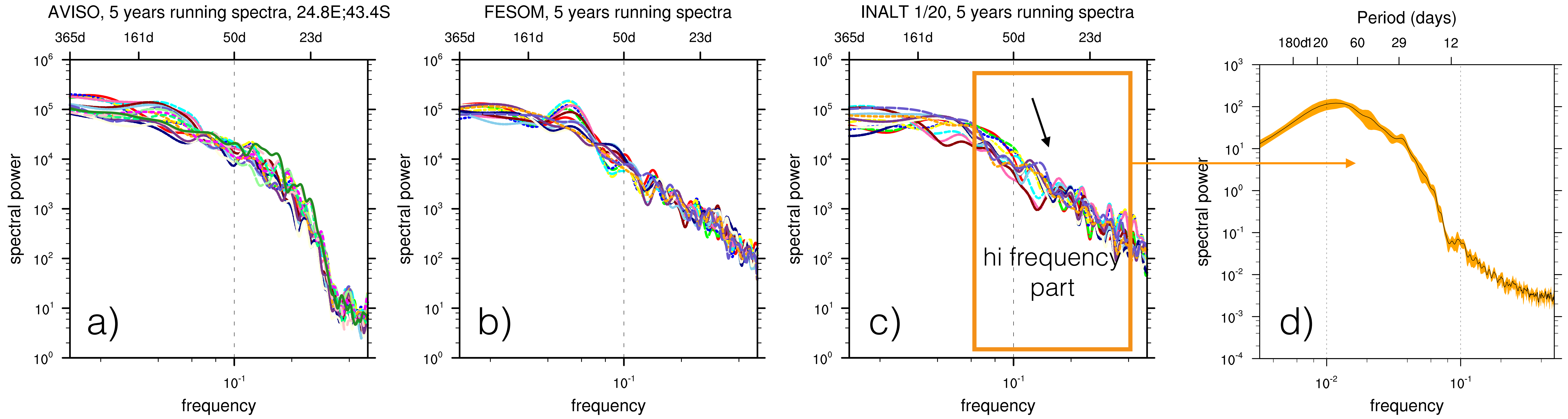




100 m currents, FESOM



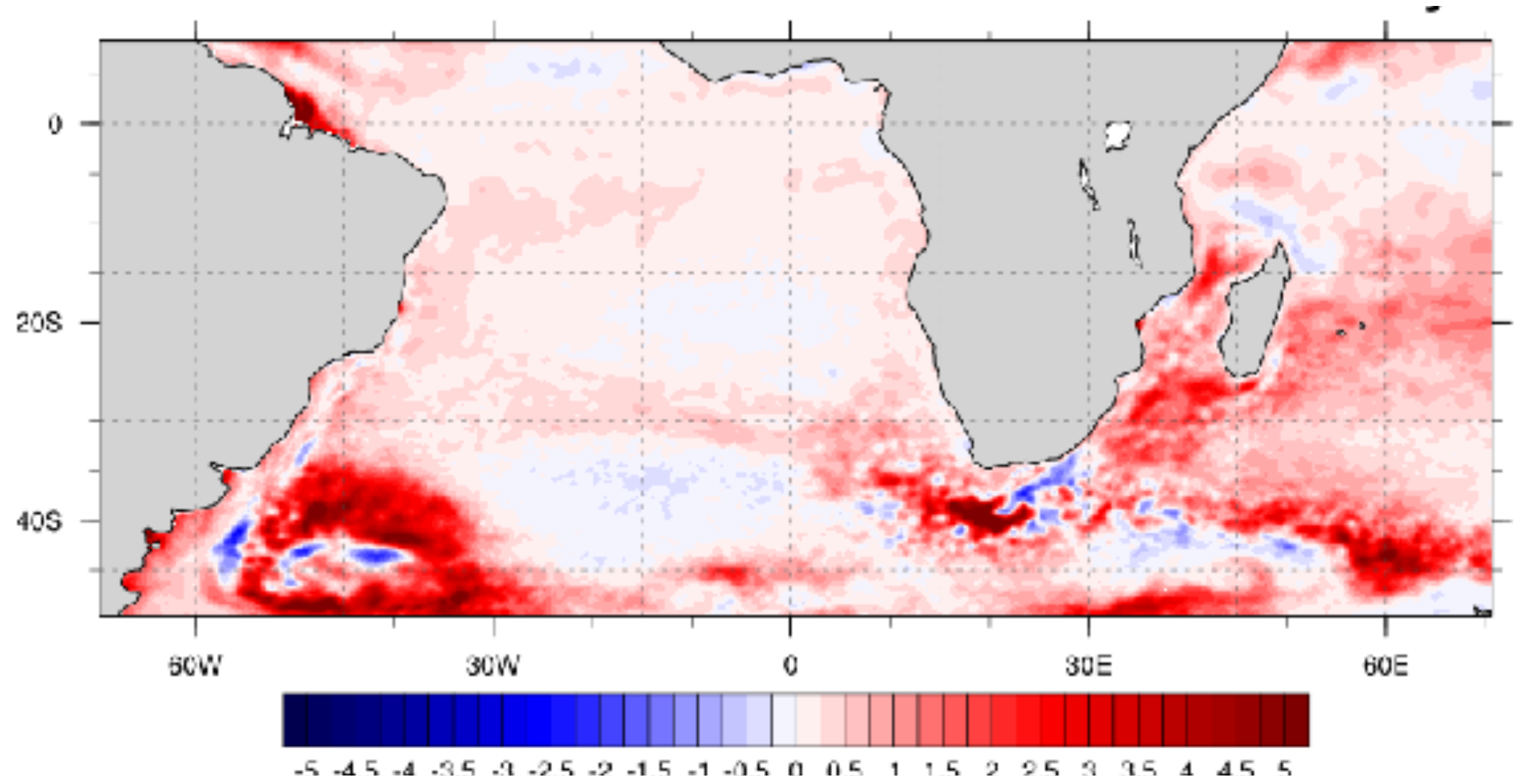
(courtesy of Nikolay Koldunov, AWI)

# Leading frequency in temporal spectra, AVISO, 1993-2009

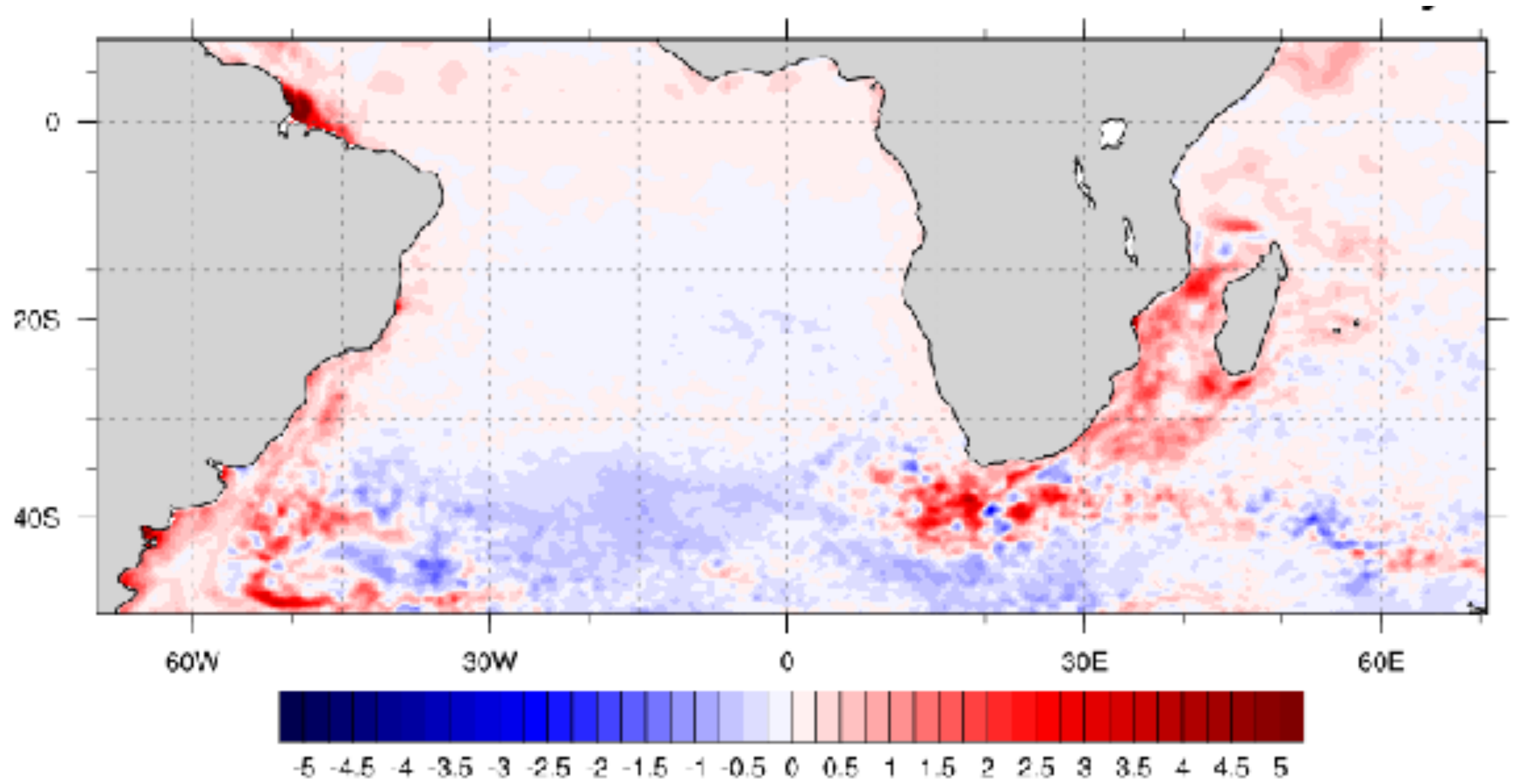



# 40-60 days, 1993-2009, focus on Agulhas retroflection

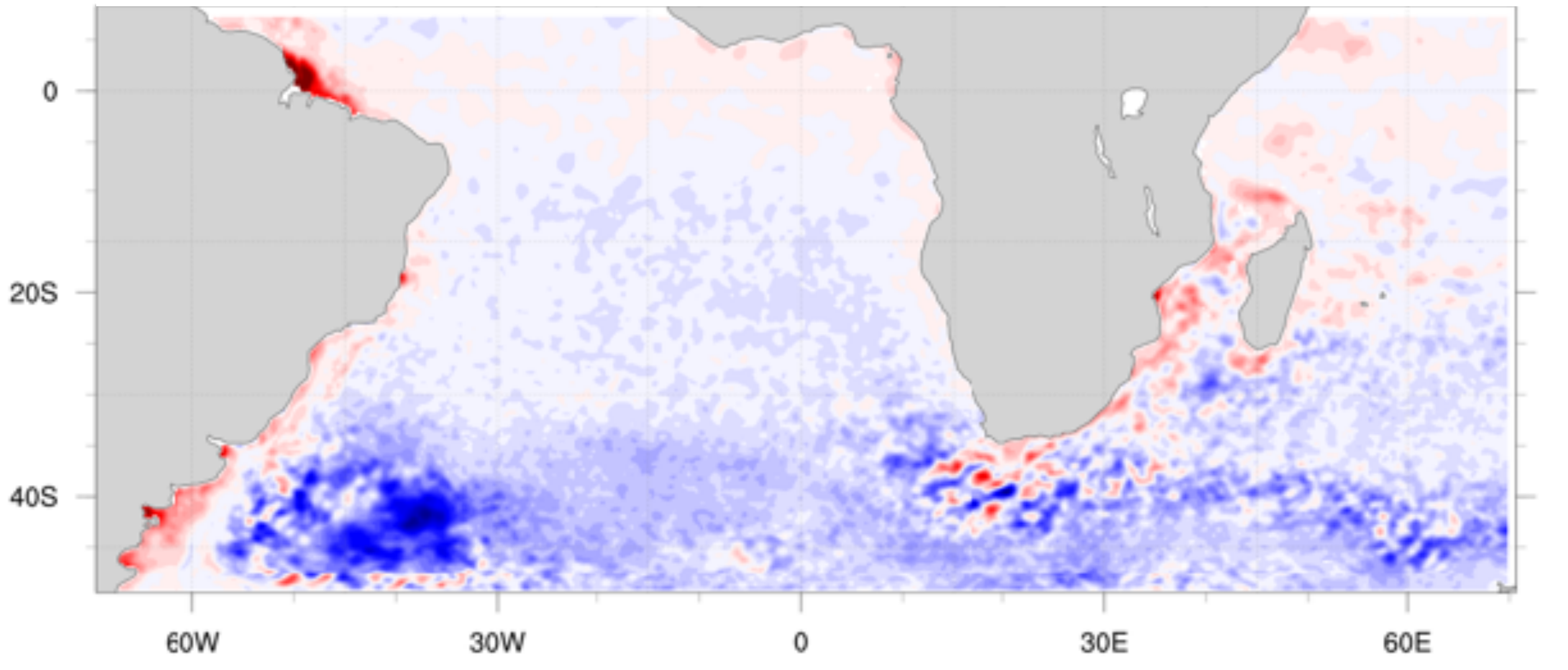
## AVISO - INALT 1/10



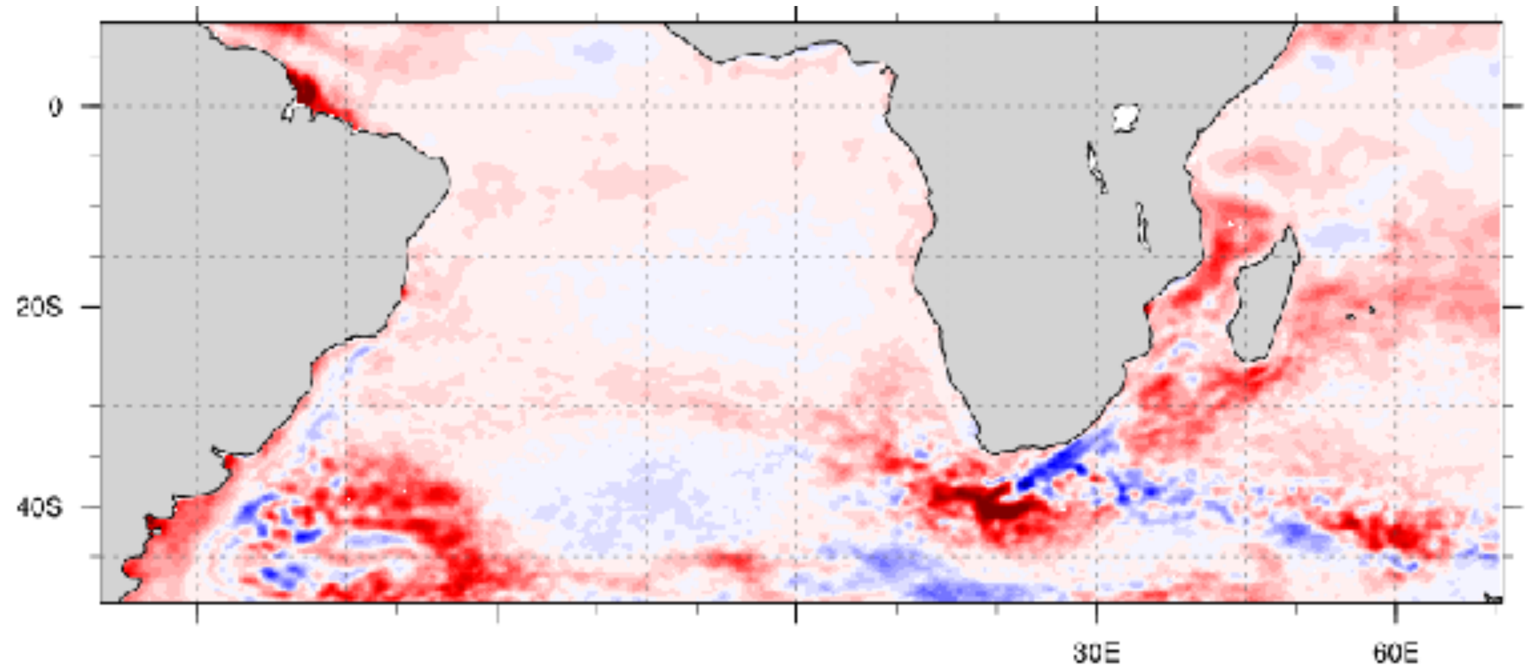

## AVISO - GLORYS2V4_1/4



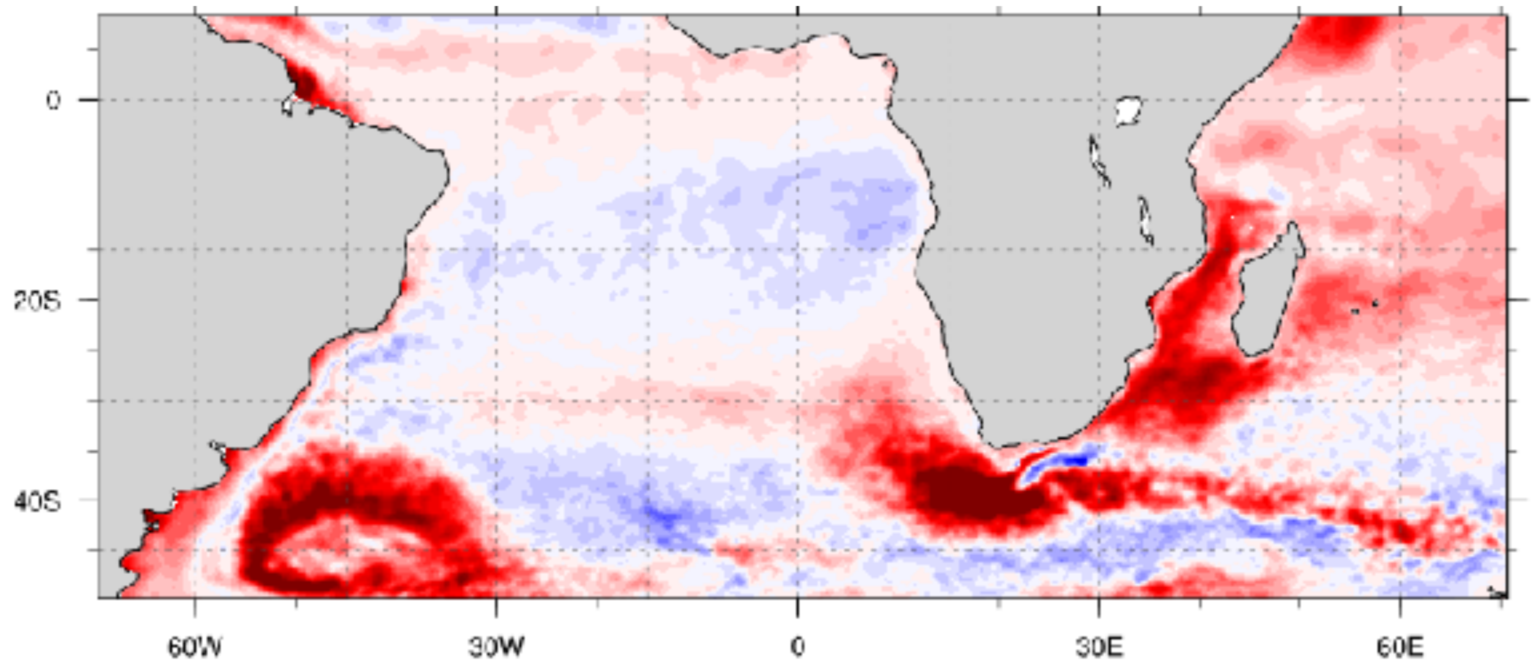

## AVISO - GLORYS012V1_1/12



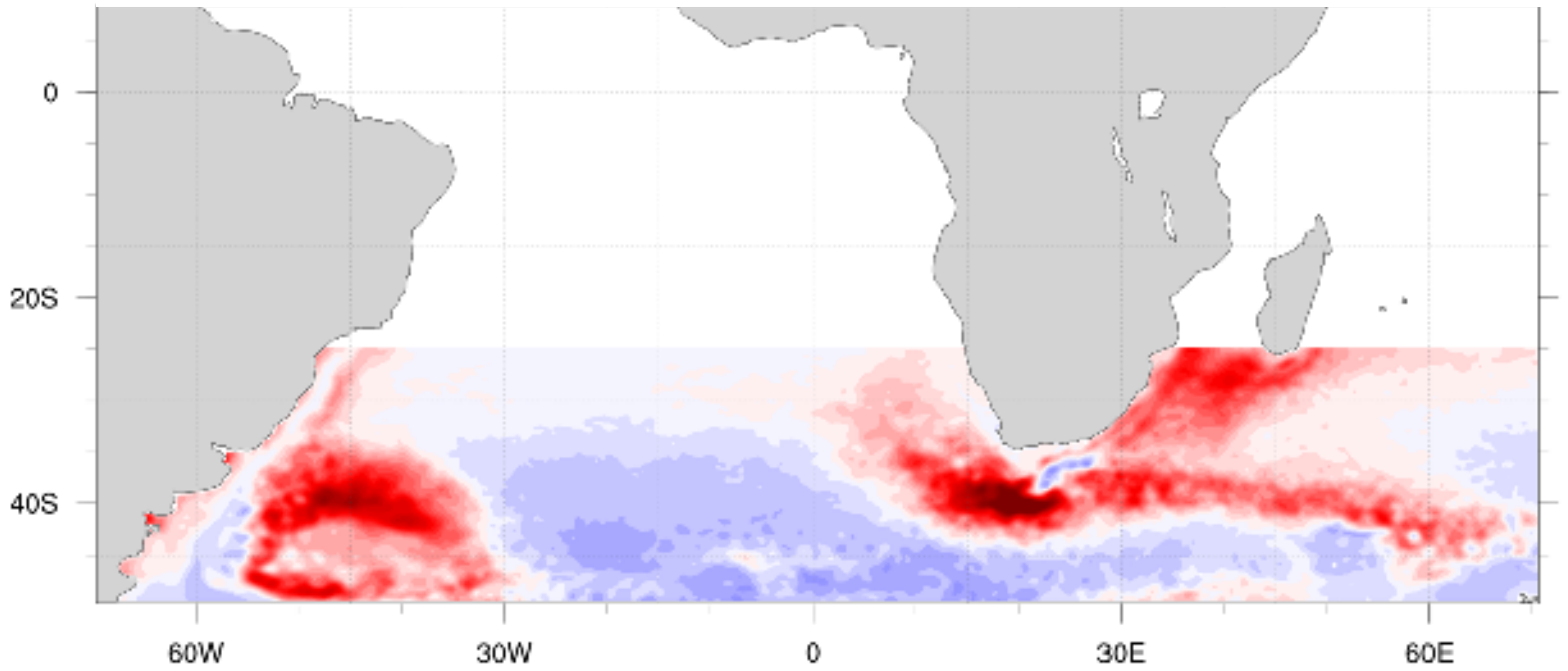

## AVISO - INALT 1/20



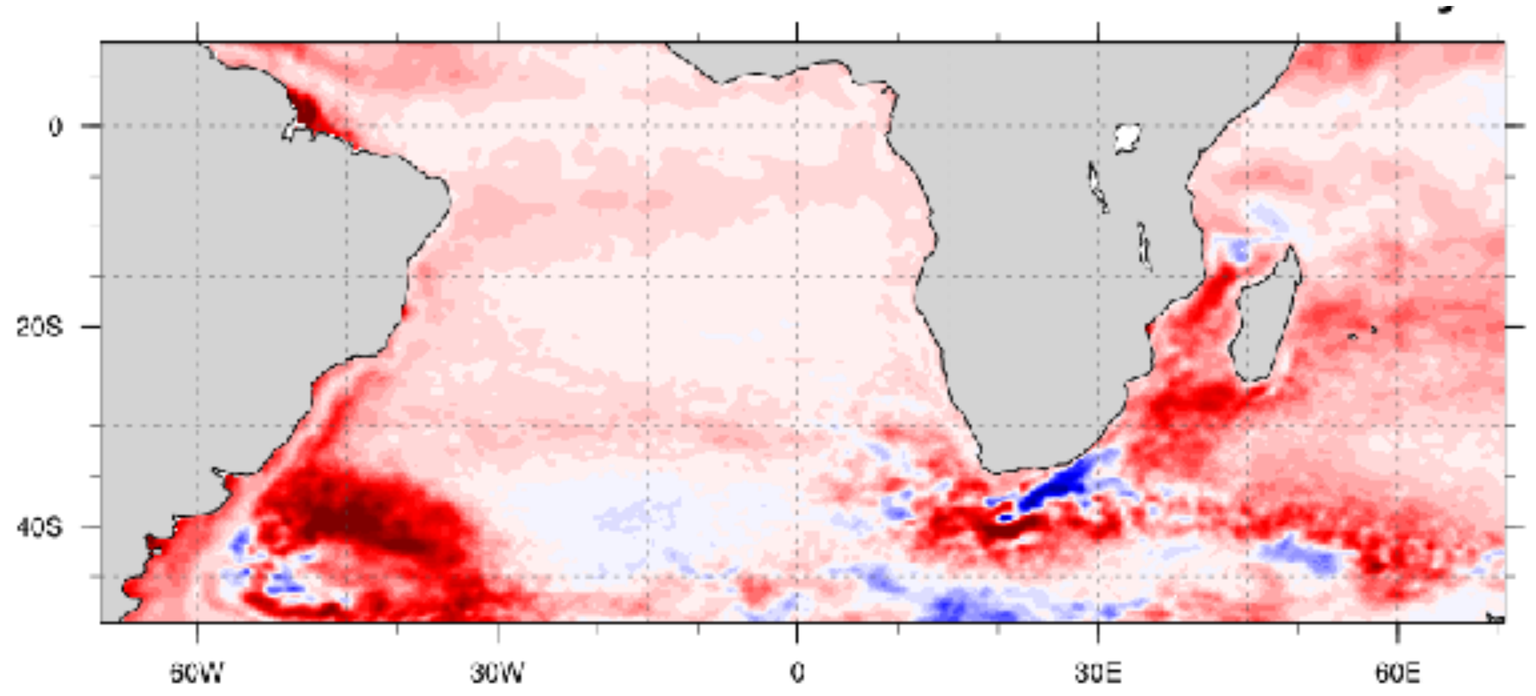

## AVISO - SODA_1/4



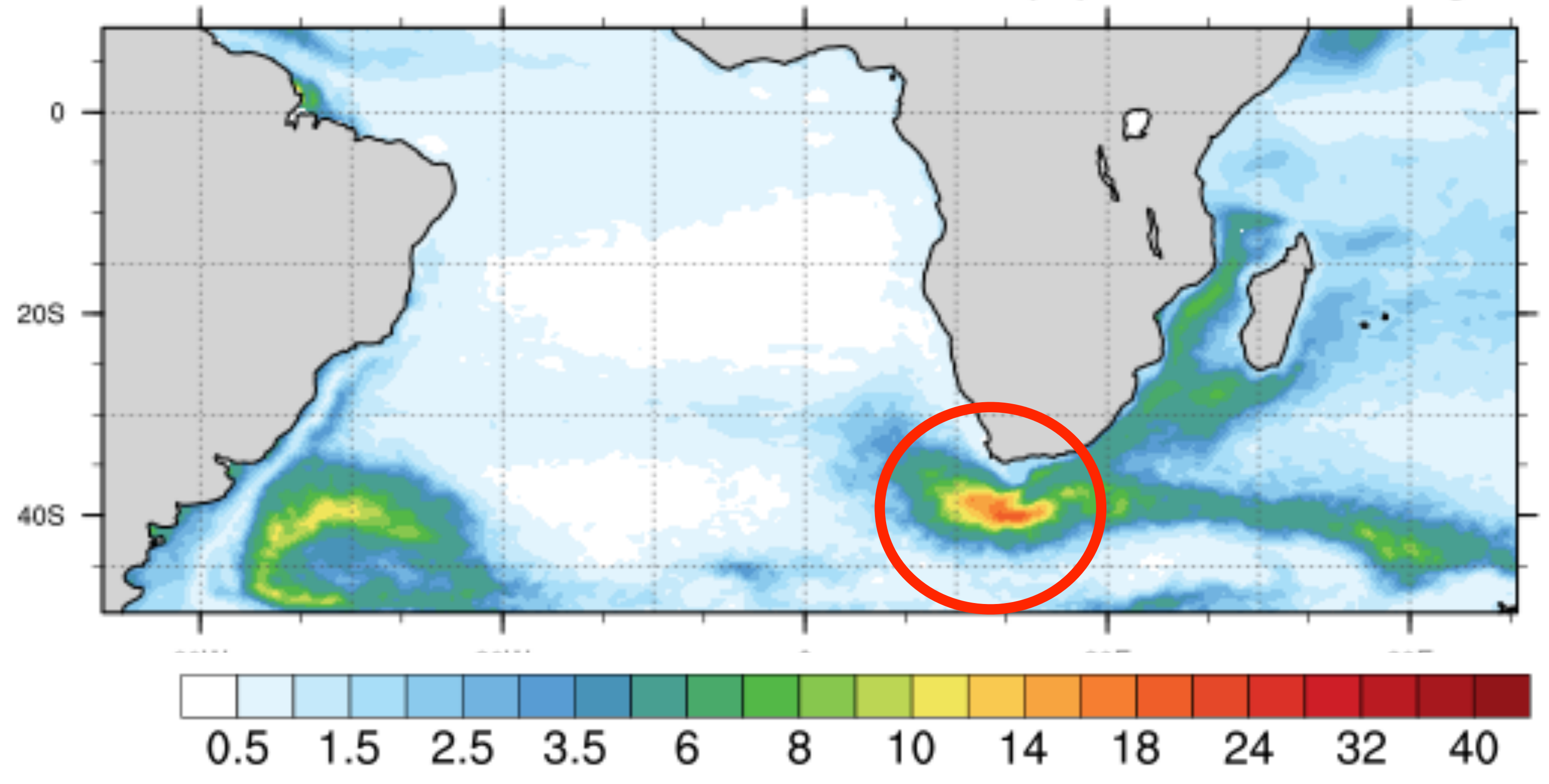

## AVISO - SOSE 1/6




## AVISO - FESOM

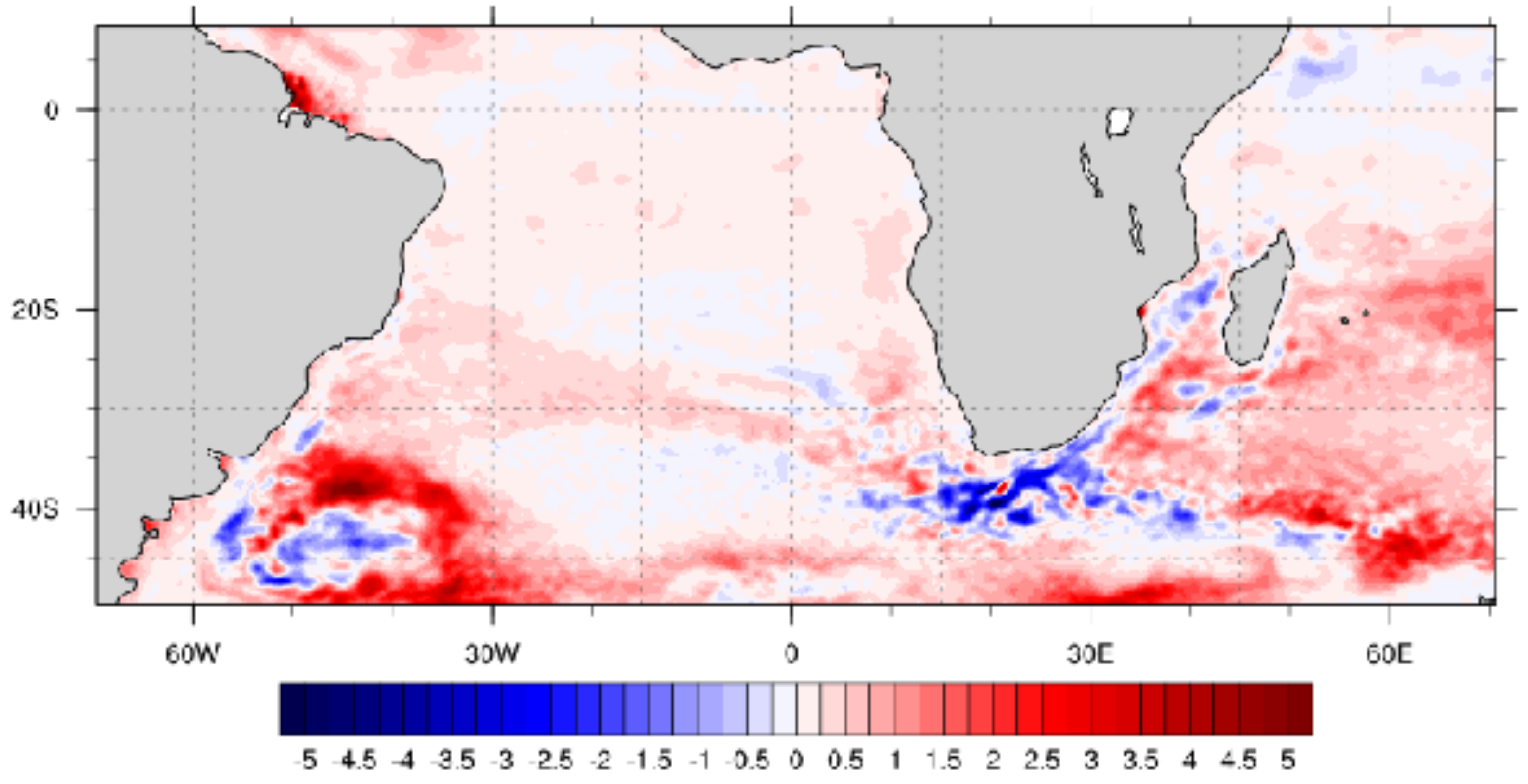



(c) 40 - 60 days

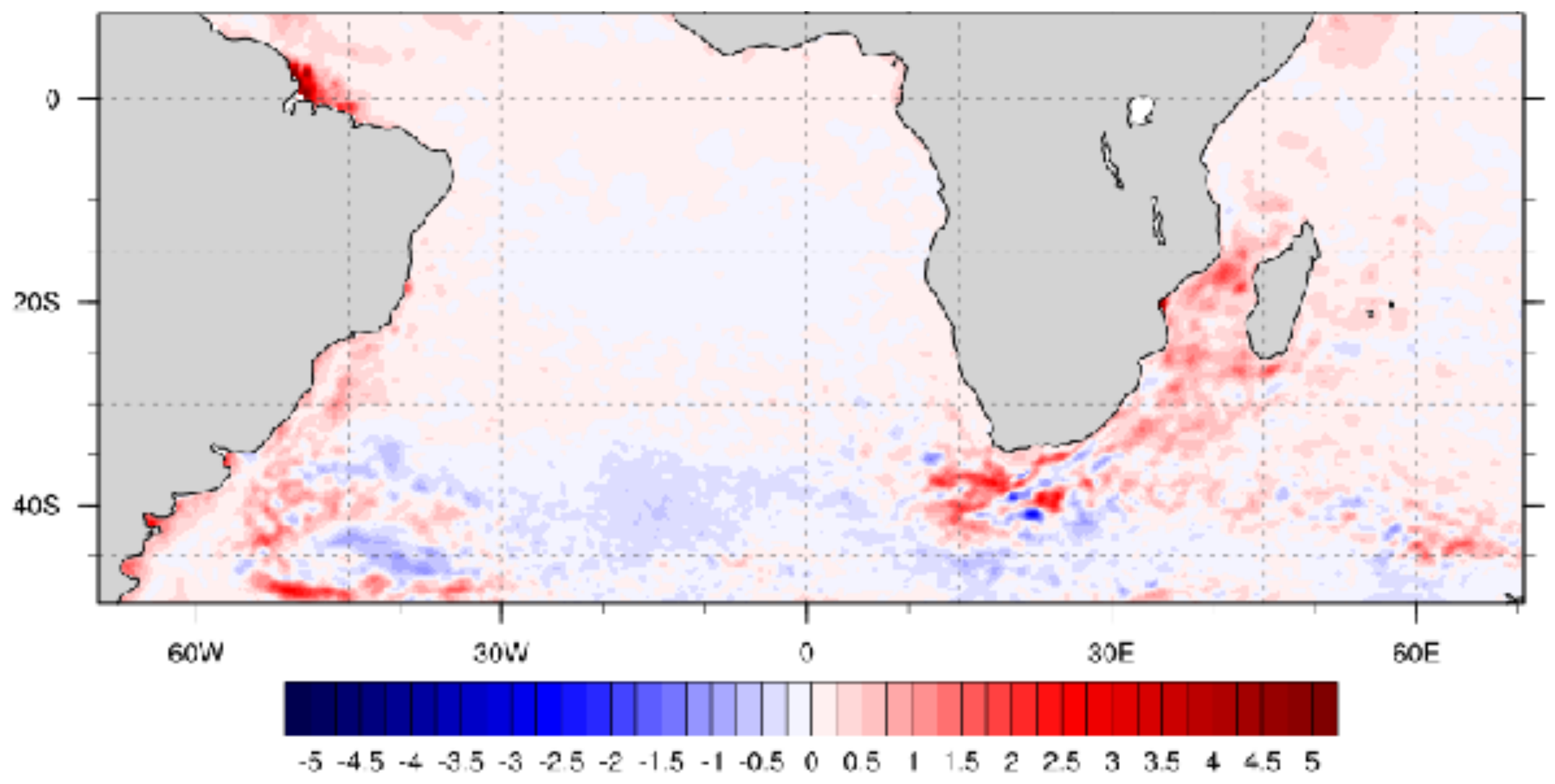


# 60-80 days, 1993-2009, focus on Mozambique channel

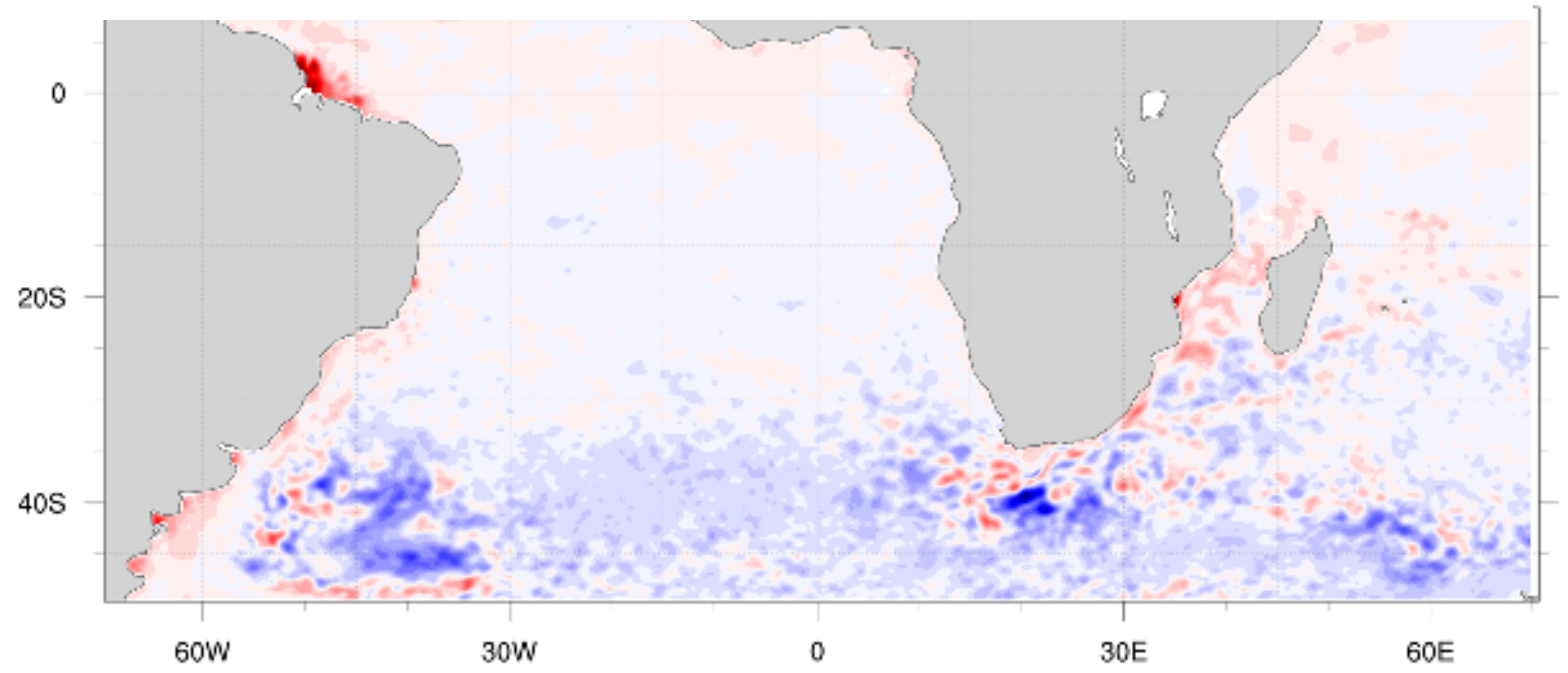
## AVISO - INALT 1/10



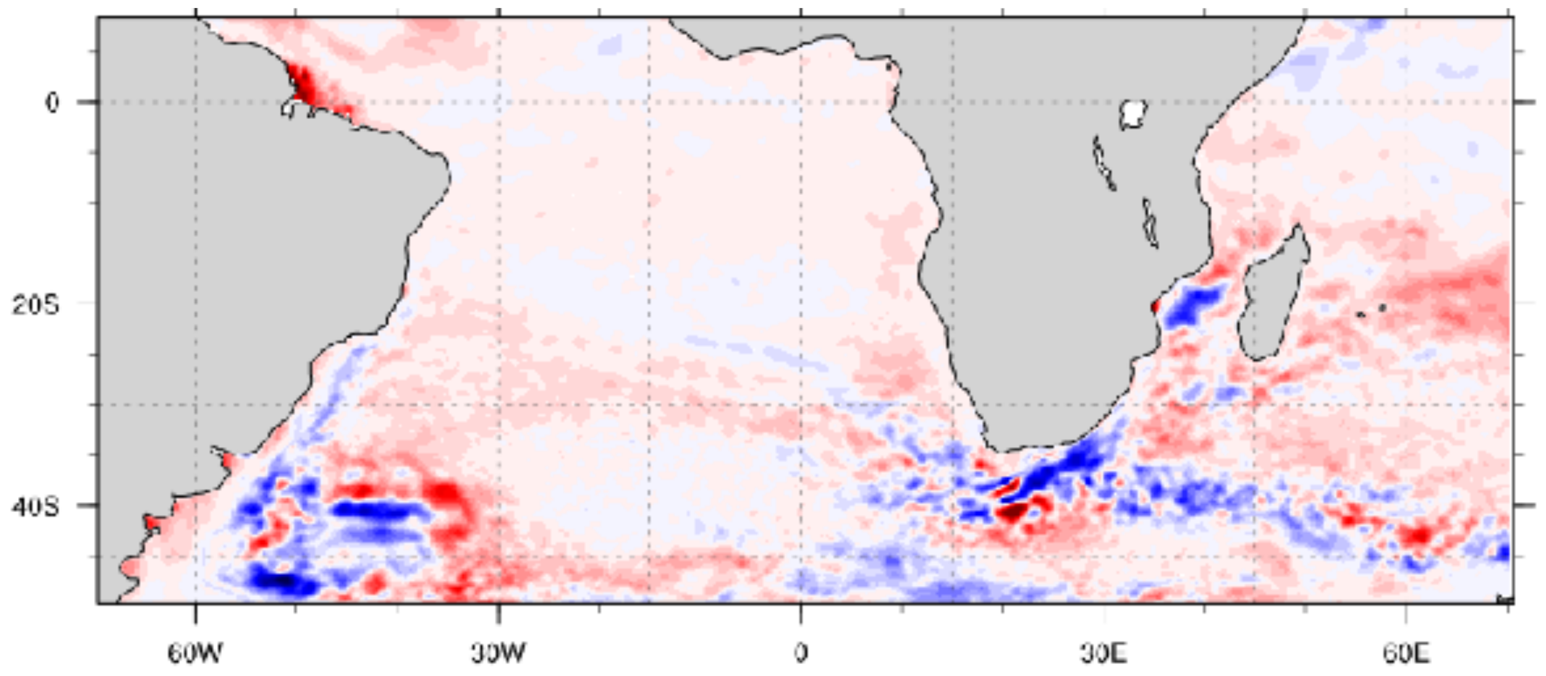

## AVISO - GLORYS2V4_1/4



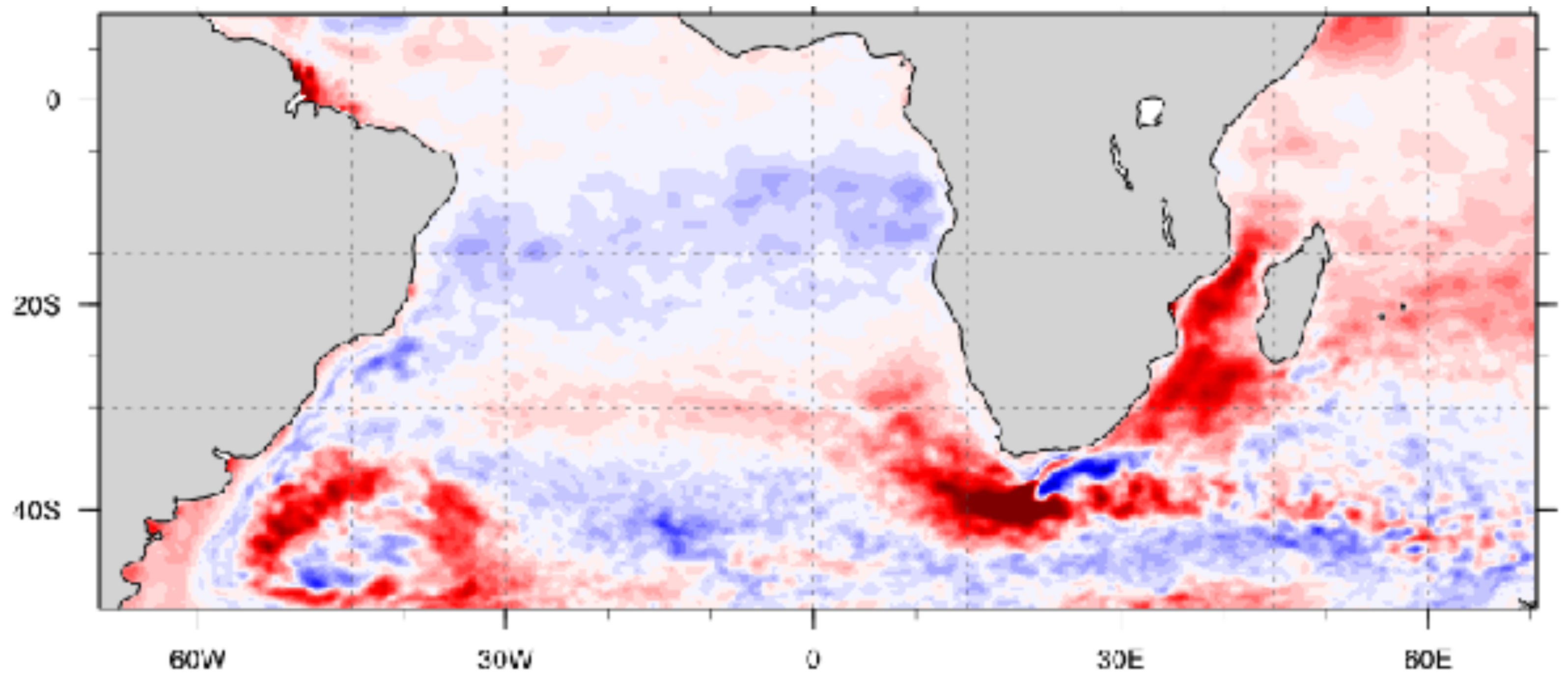

## AVISO - GLORYS012V1_1/12



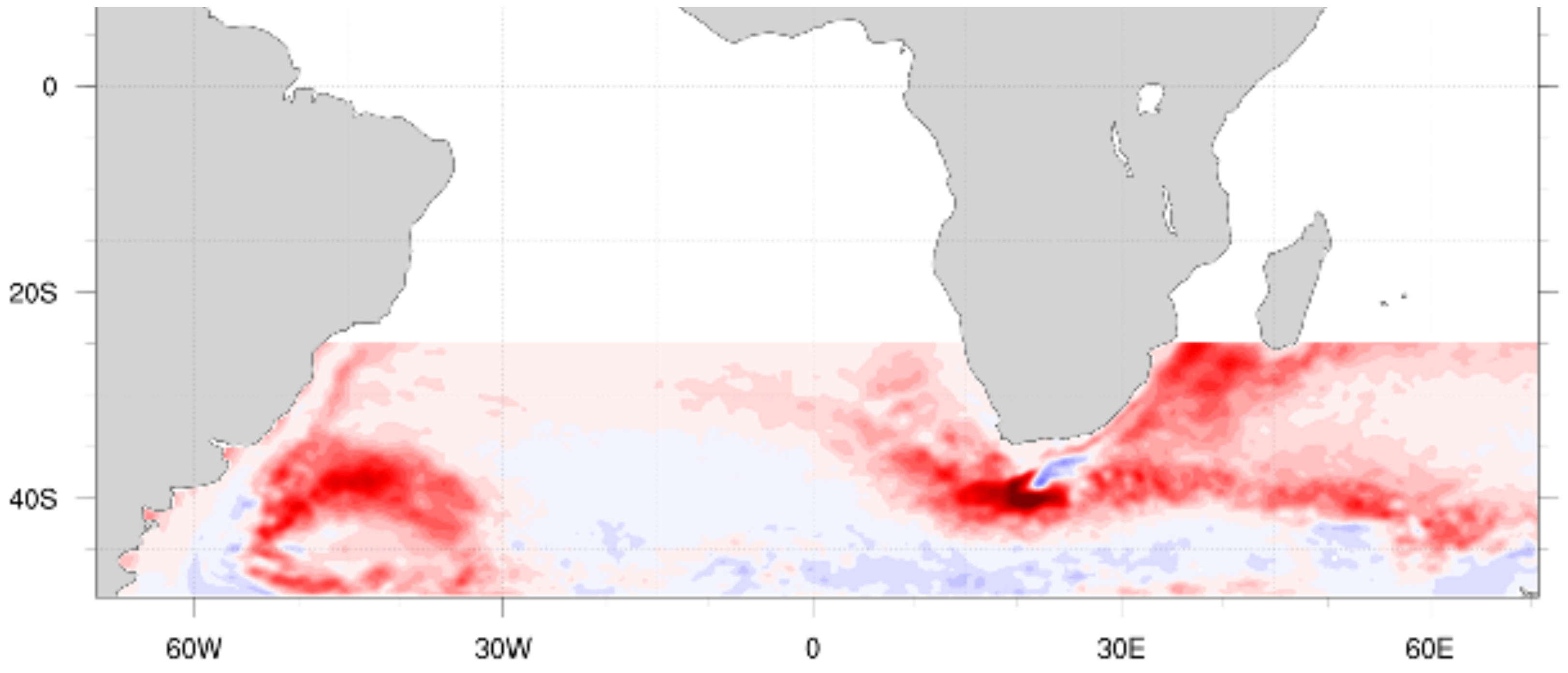

## AVISO - INALT 1/20



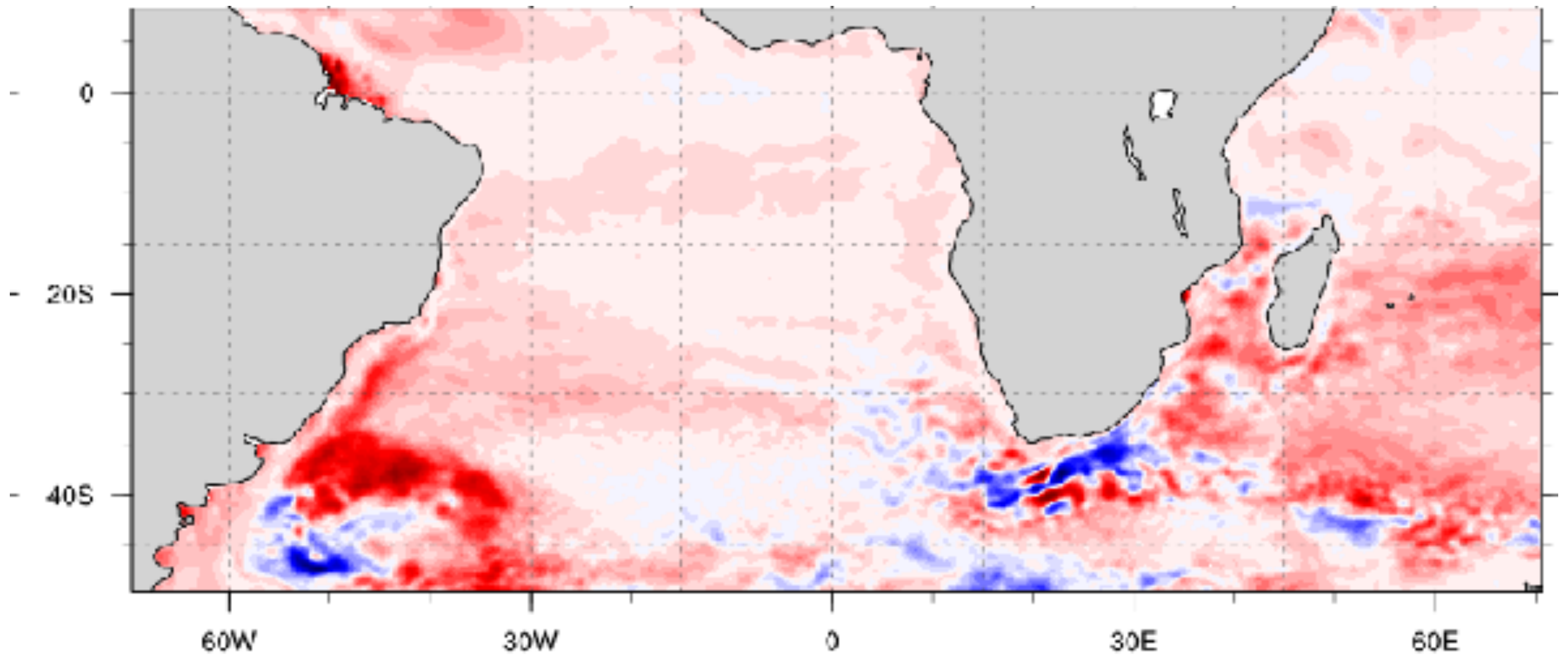

## AVISO - SODA_1/4



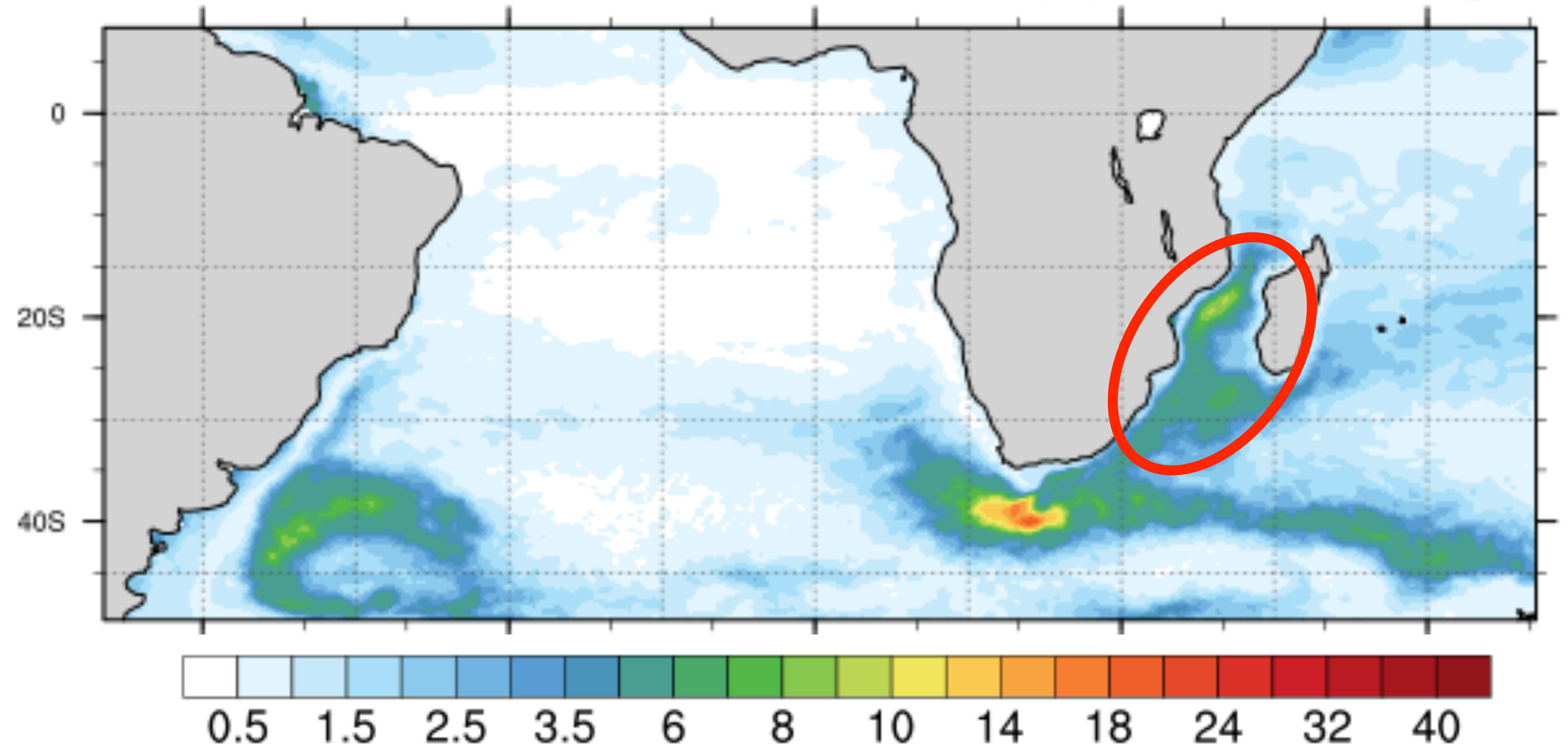

## AVISO - SOSE 1/6




## AVISO - FESOM

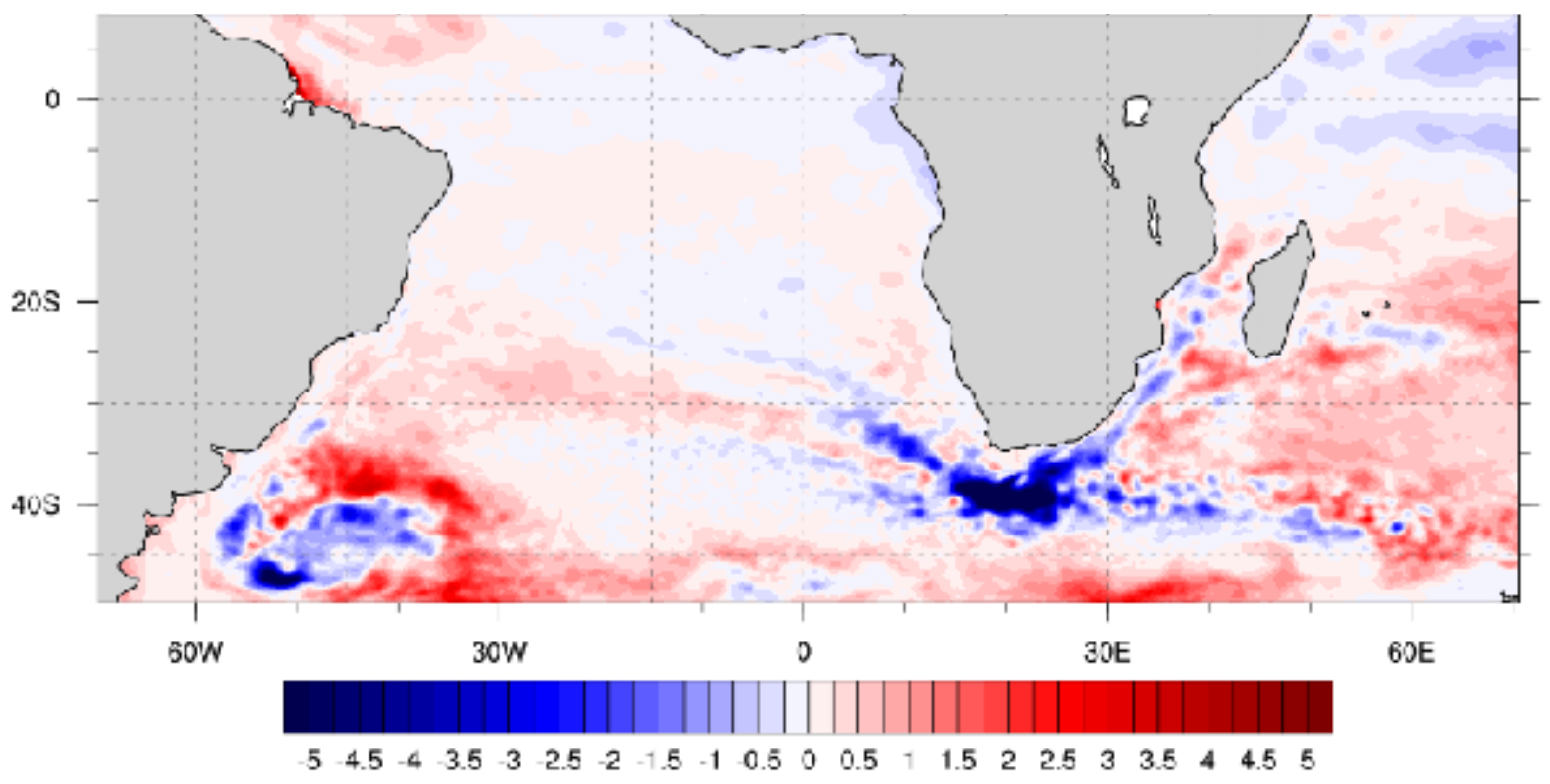



(d) 60 - 80 days

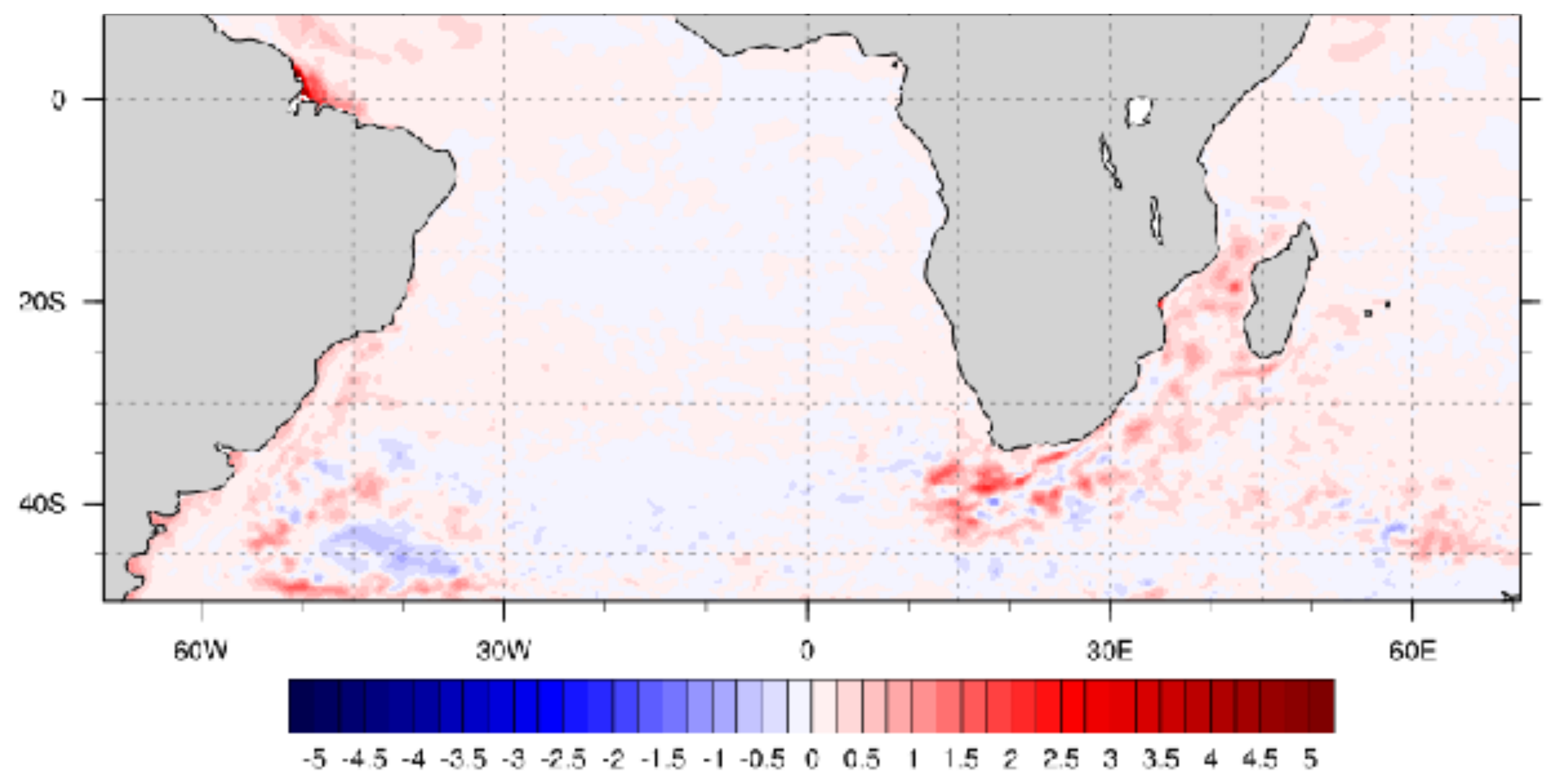


# 80-100 days, 1993-2009, focus on Central South Atlantic

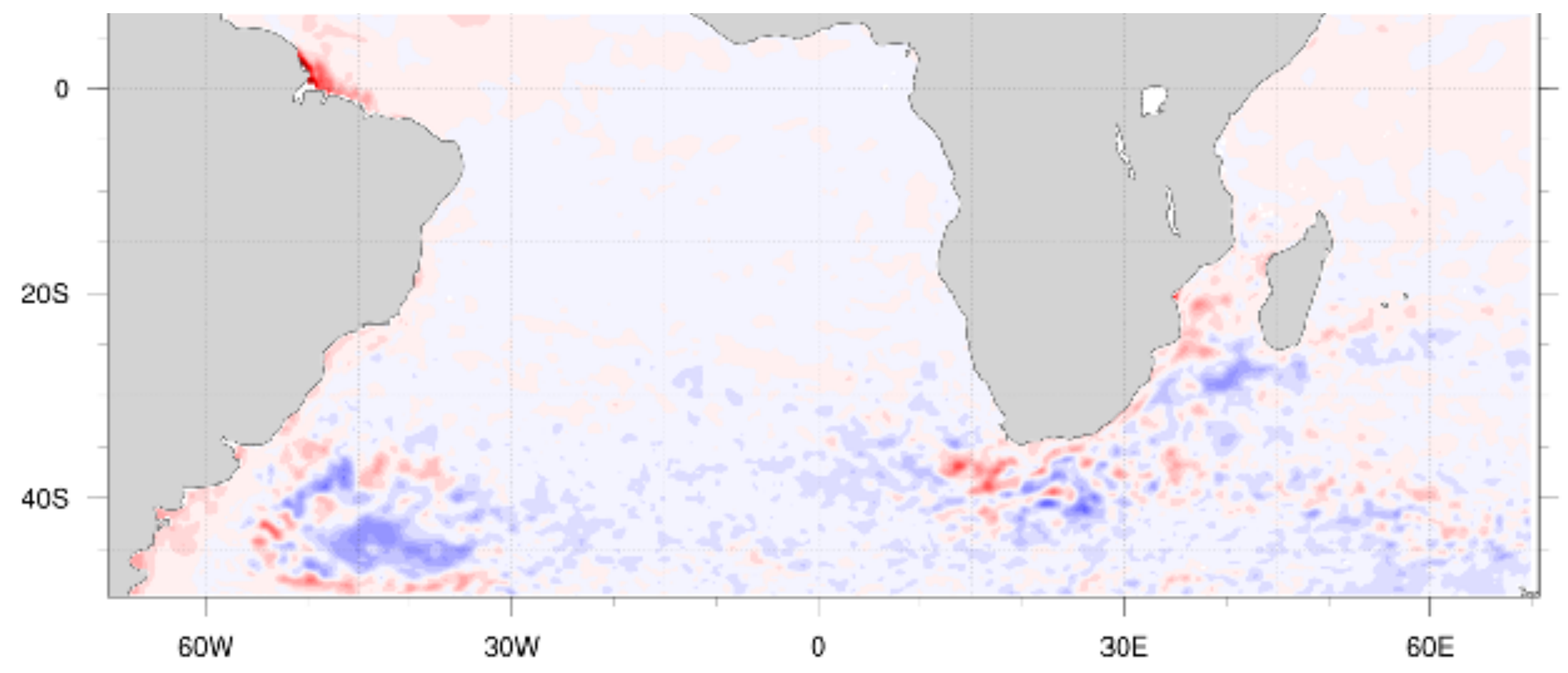
## AVISO - INALT 1/10



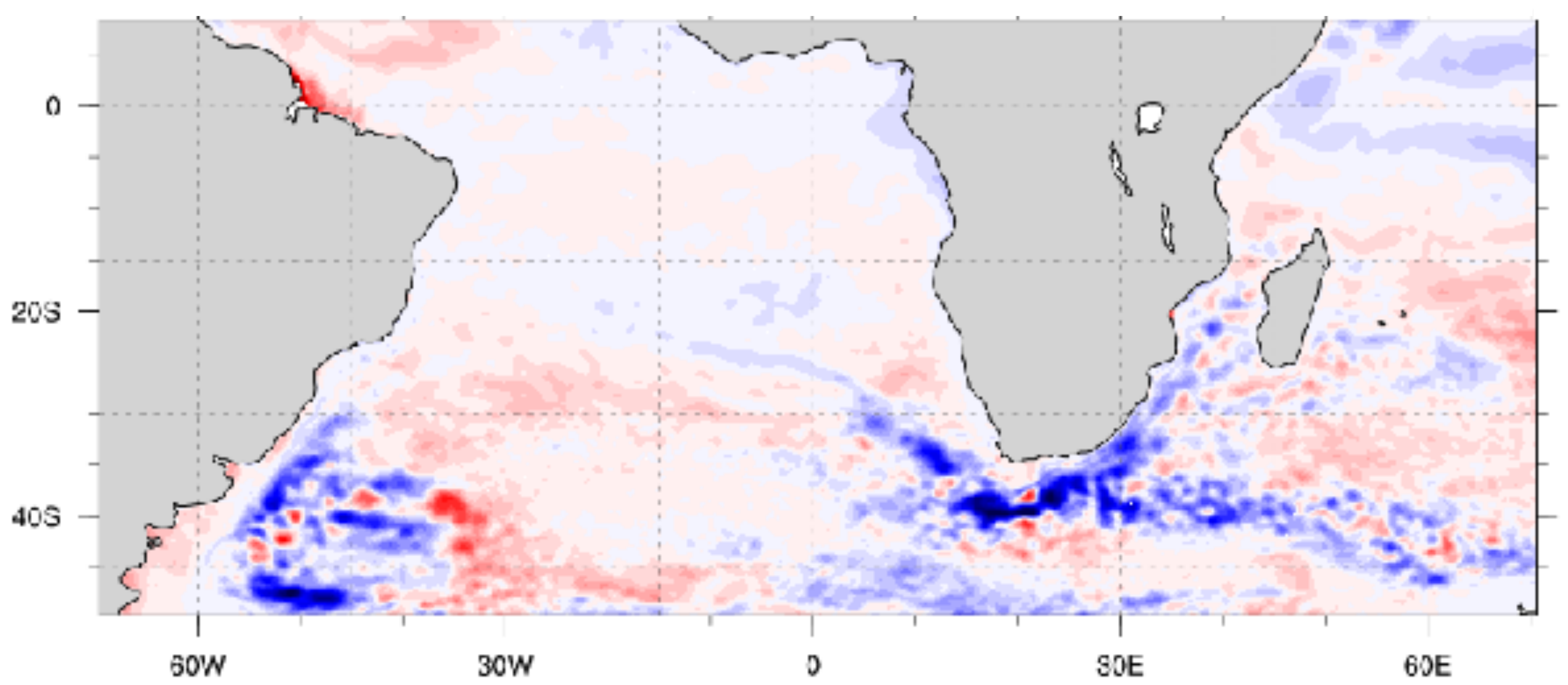

## AVISO - GLORYS2V4_1/4



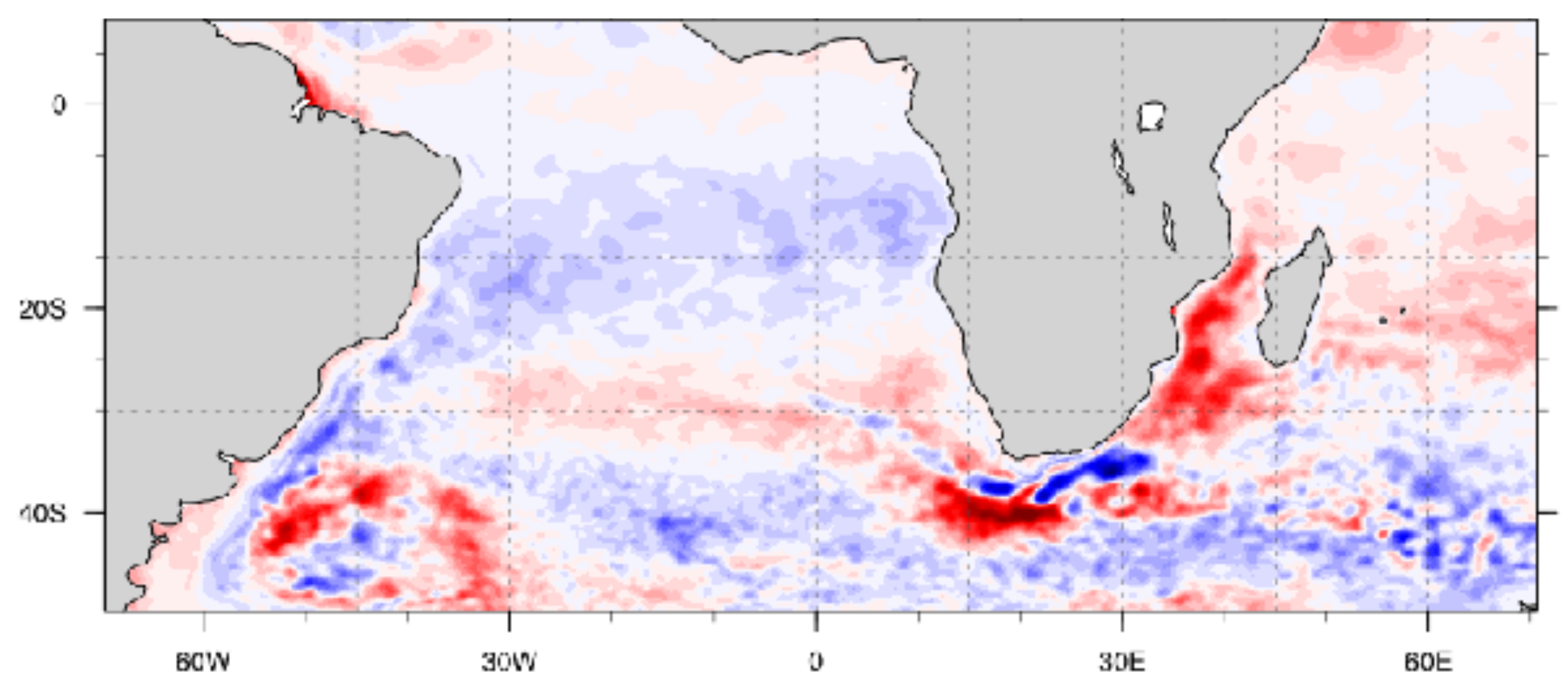

## AVISO - GLORYS012V1_1/12



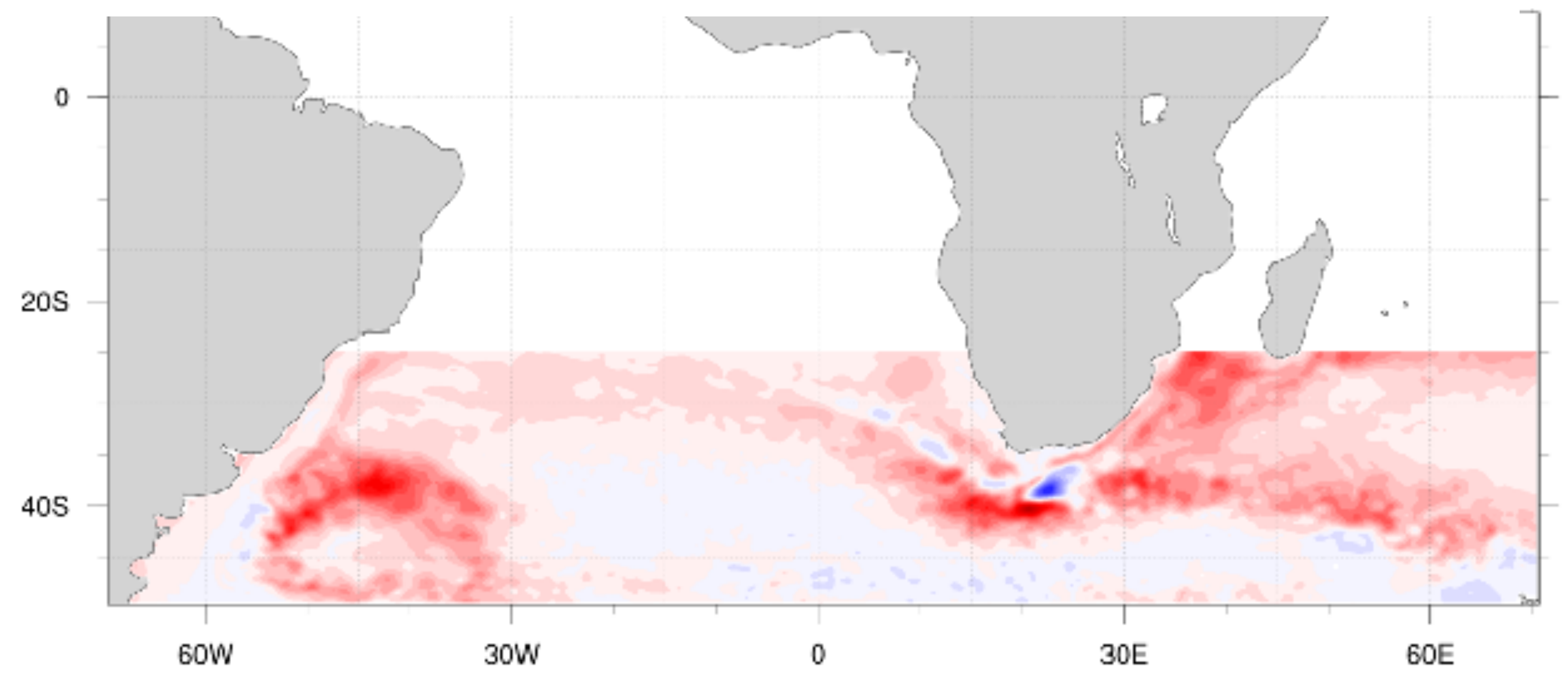

## AVISO - INALT 1/20



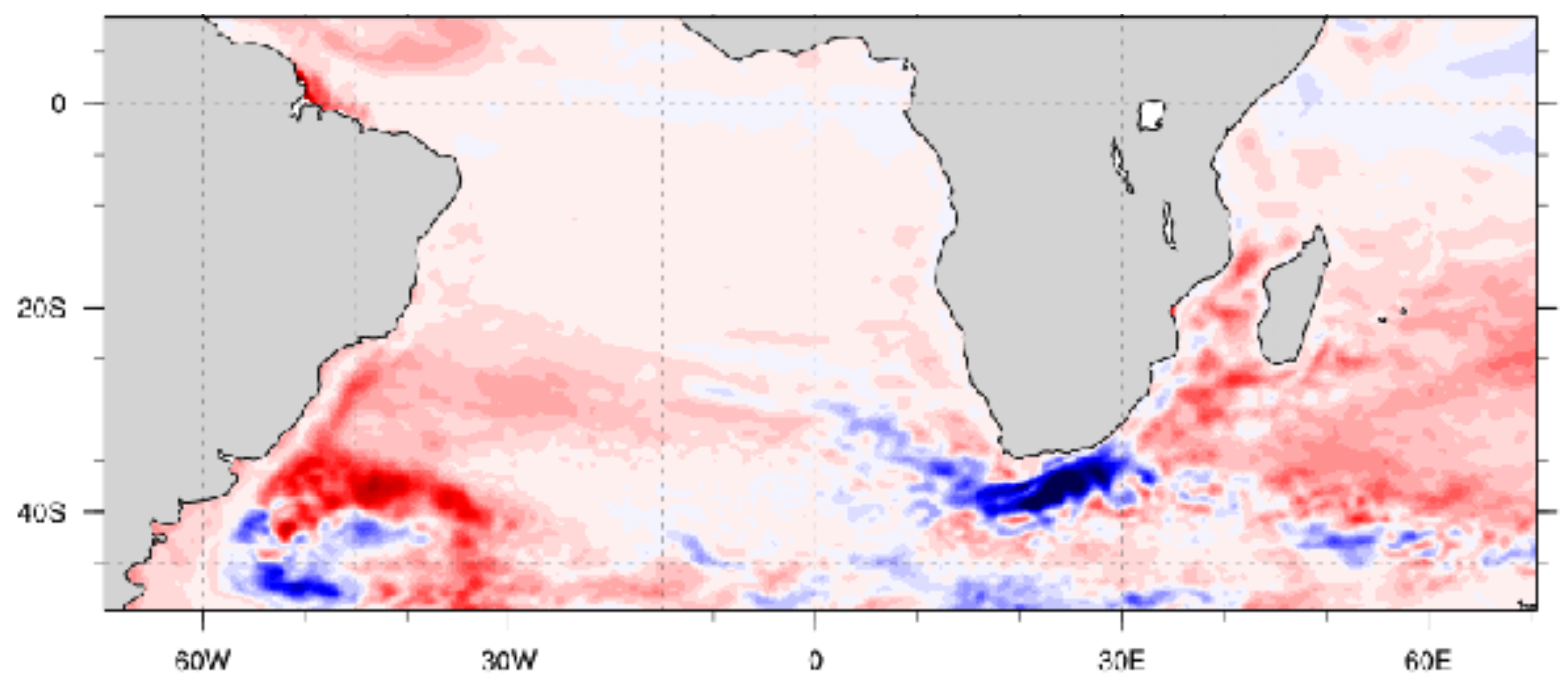

## AVISO - SODA_1/4

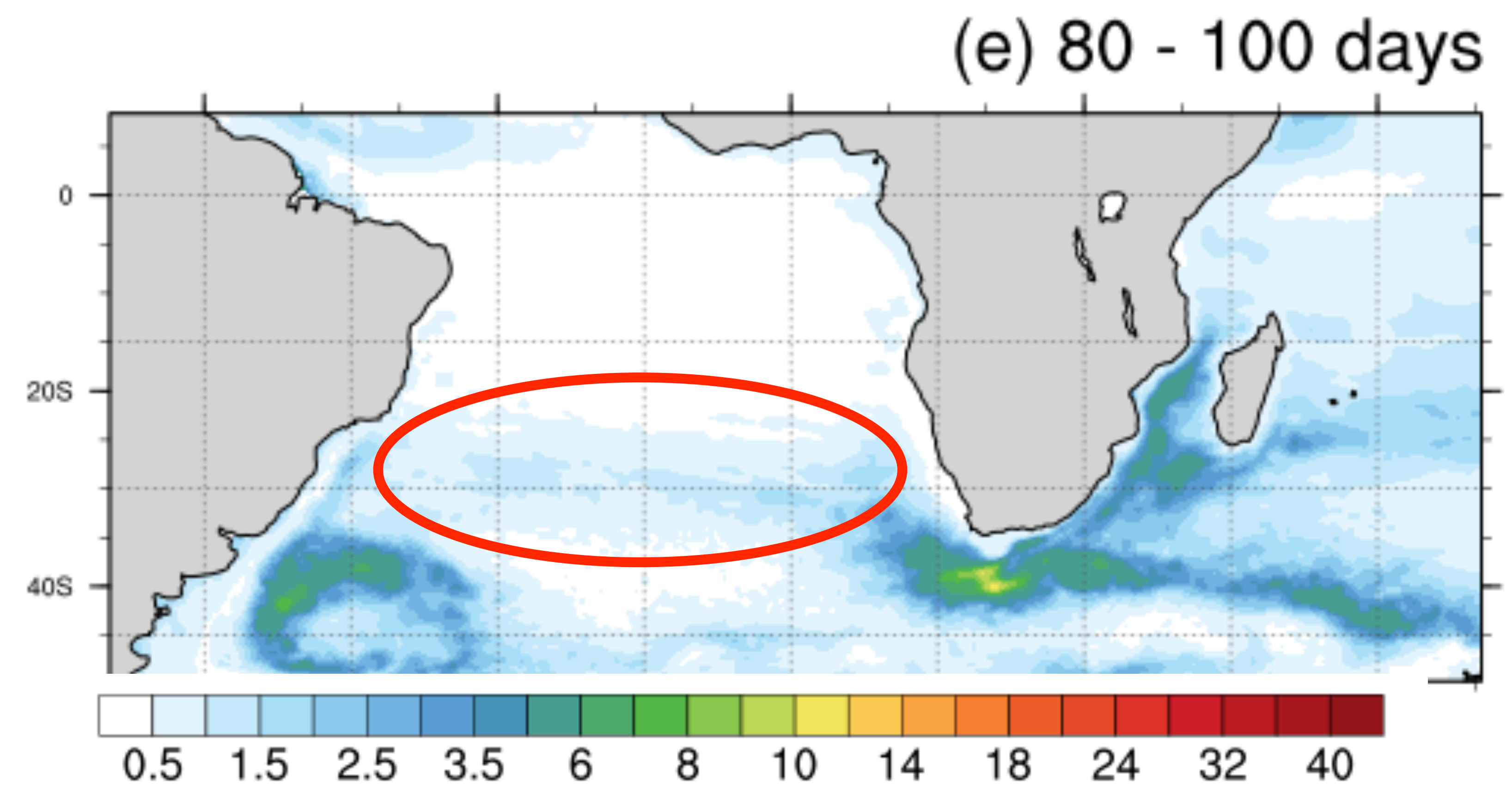



## AVISO - SOSE 1/6



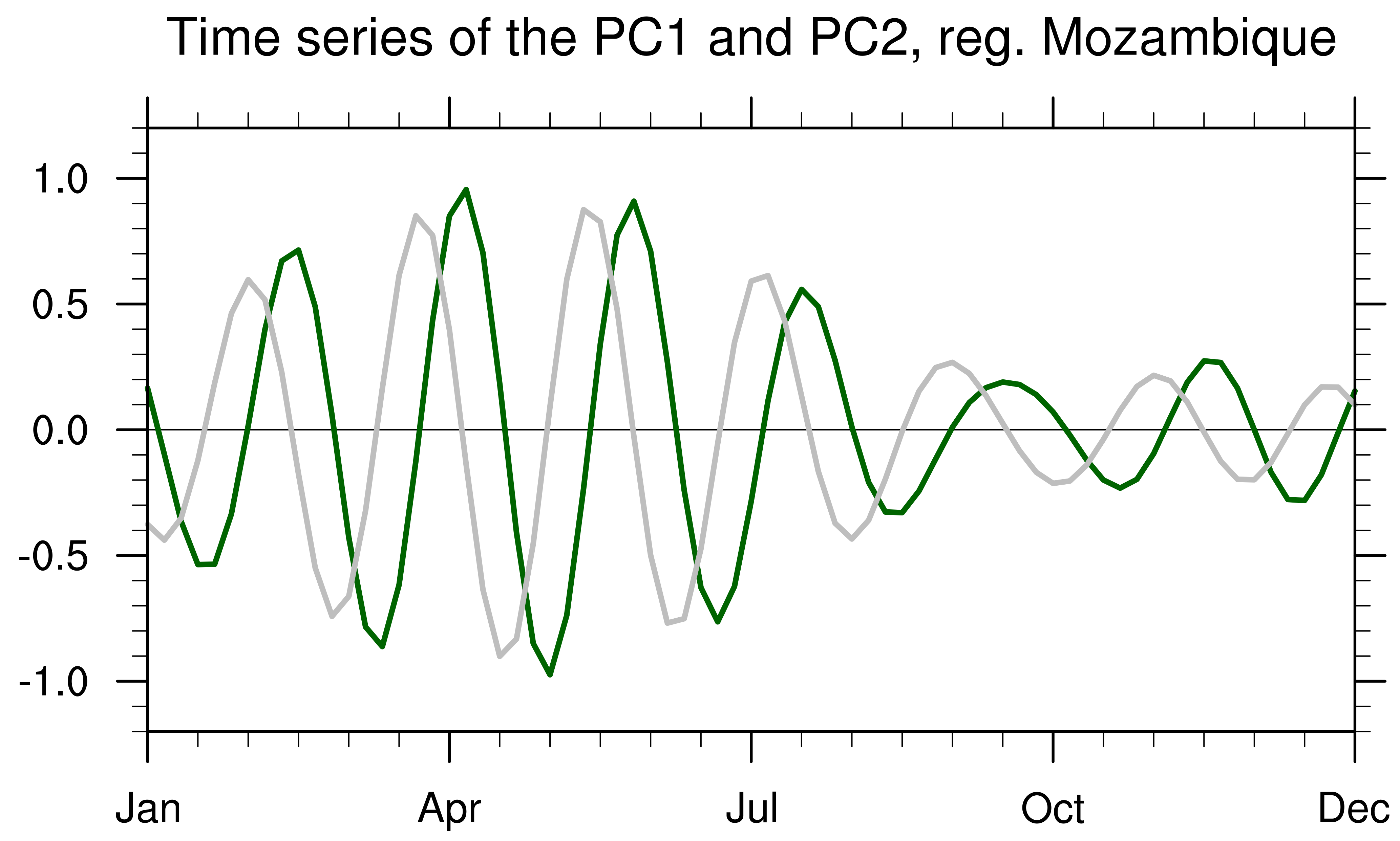

## AVISO - FESOM

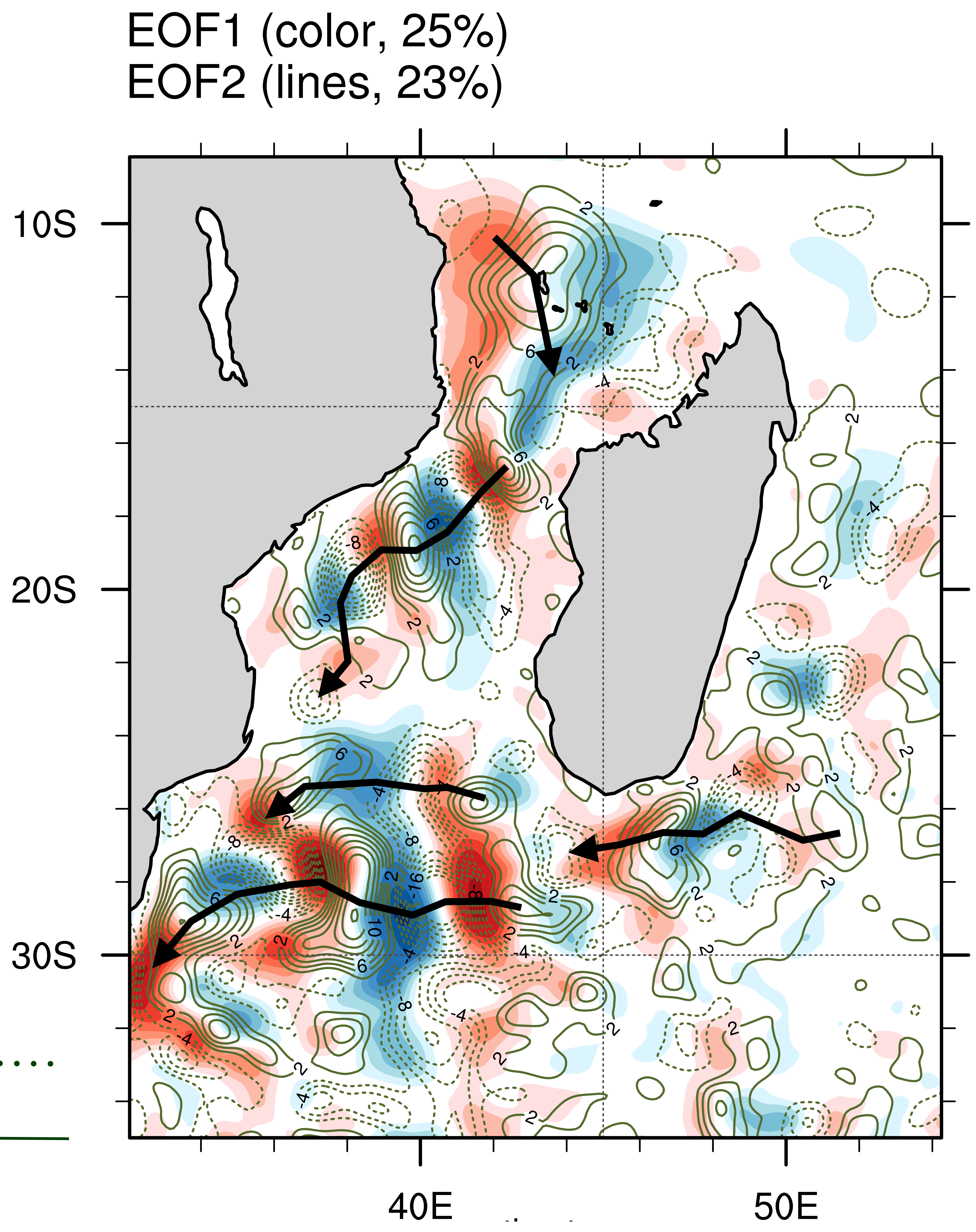


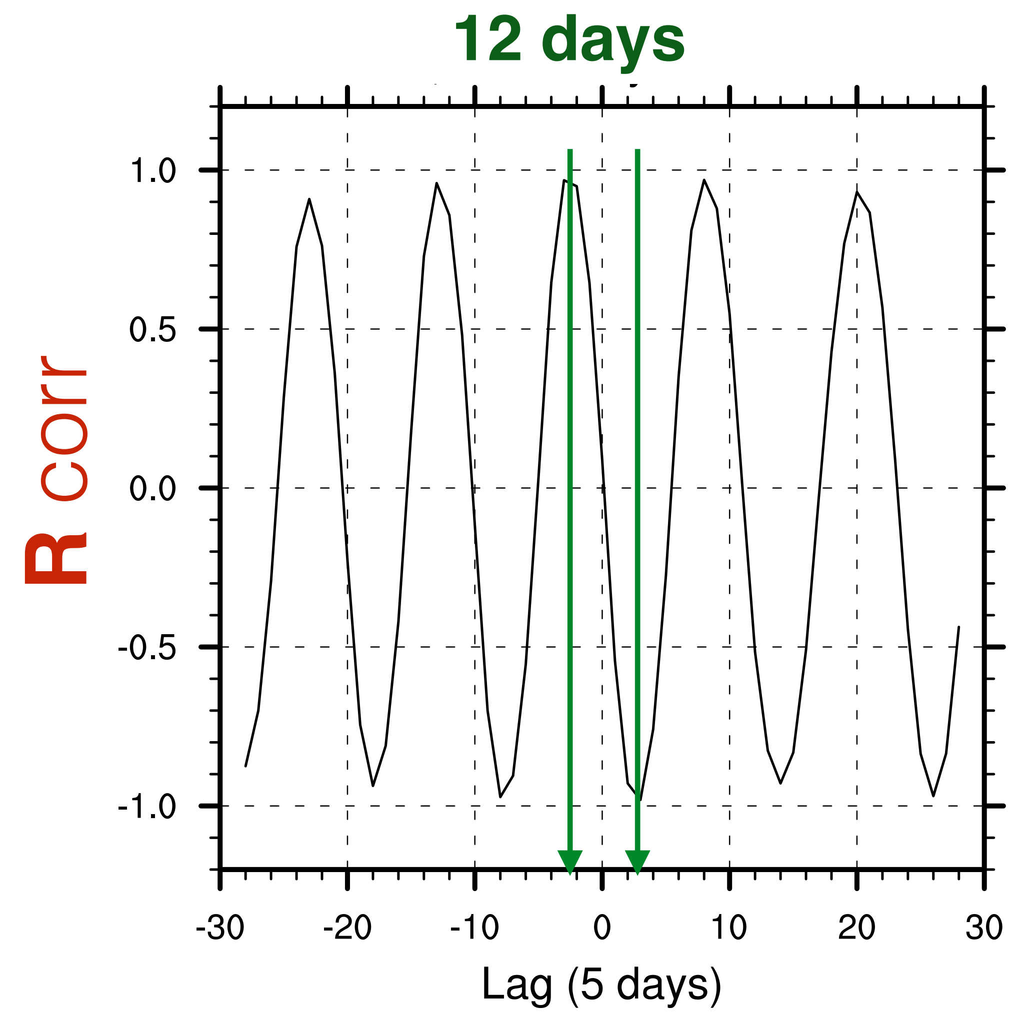



# Diagnostics of the propagating patterns, 60 - 80 days, yr. 2000

Principal components analysis




**12 days - 120 km**
**1 day - 10 km**
**0.4 km/h**

EOF 1 negative values

EOF 1 positive values

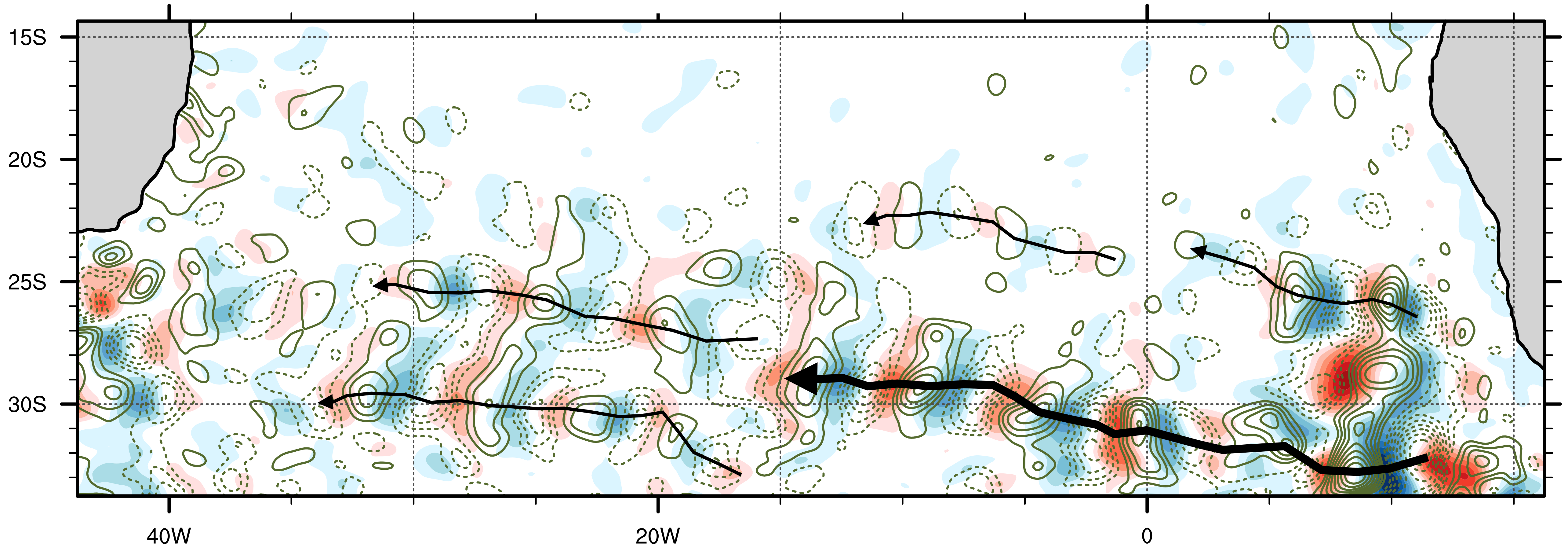
EOF 2 negative values

EOF 2 positive values

# 2000-2001, 80-100d

## AVISO

EOF1 (color, 21%)
EOF2 (lines, 20%)

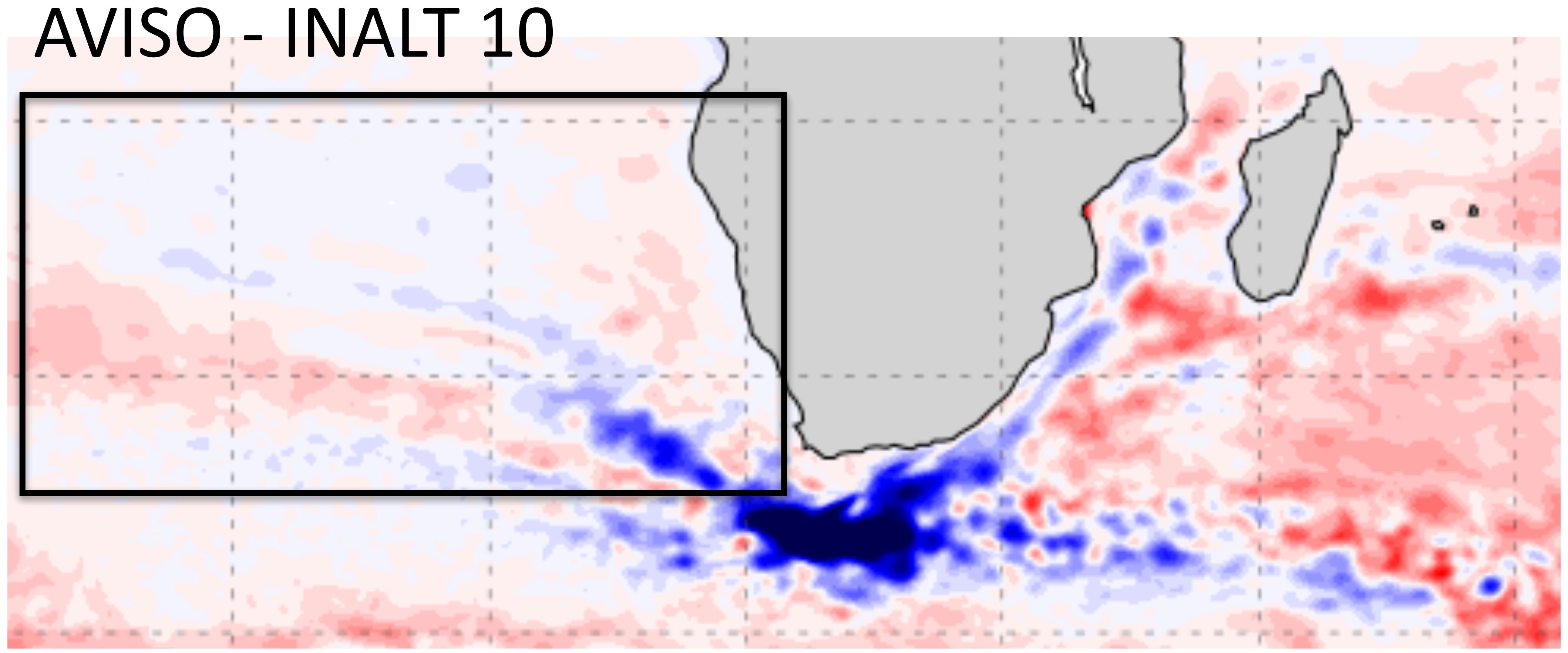


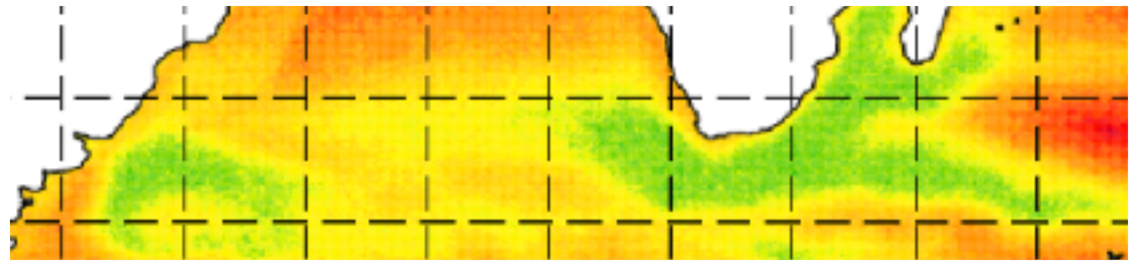

EOF 1 negative values

EOF 1 positive values

EOF 2 negative values

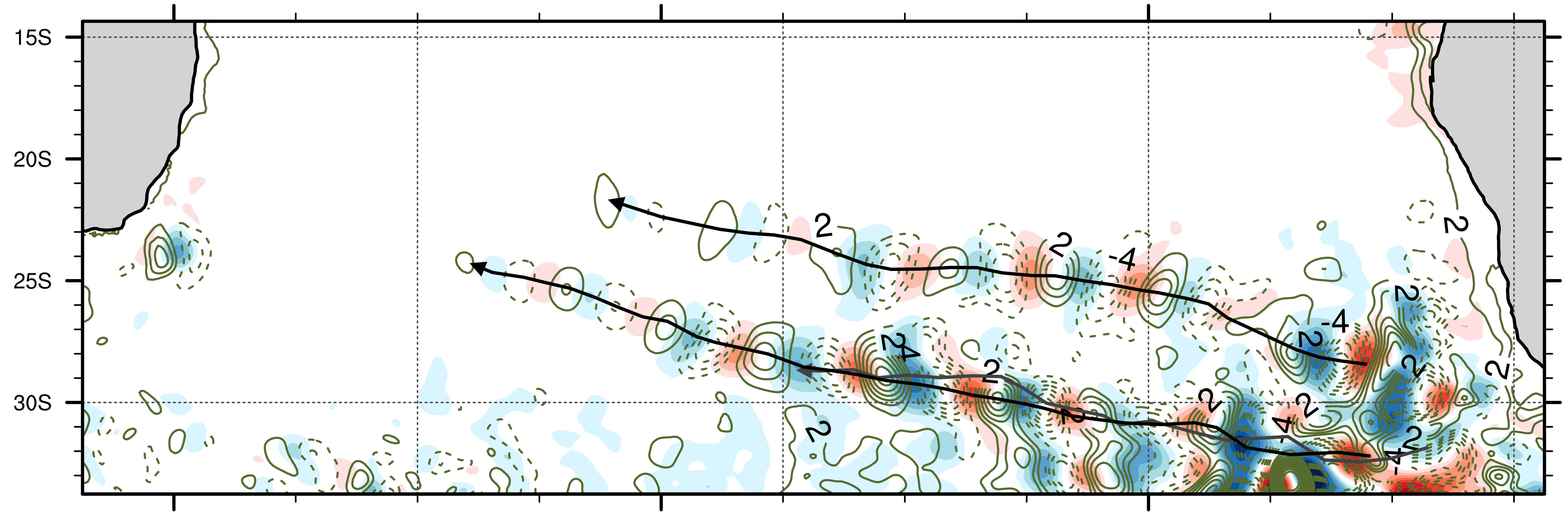
EOF 2 positive values



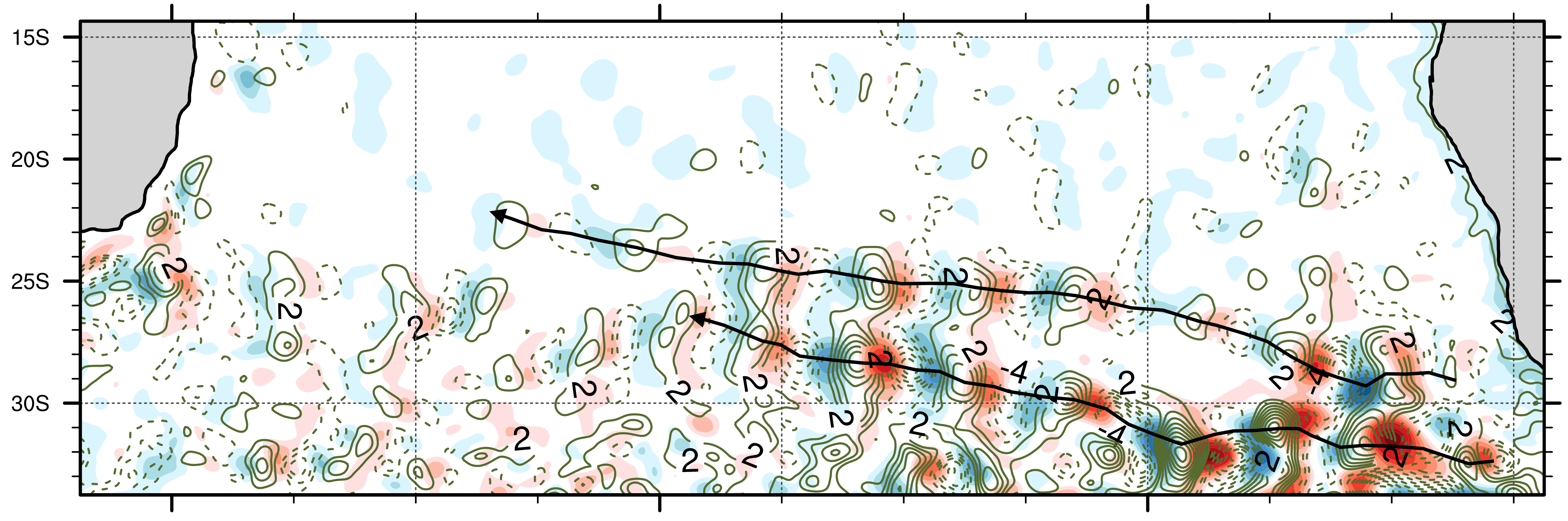
## FESOM

EOF1 (color, 37%)
EOF2 (lines,32%)



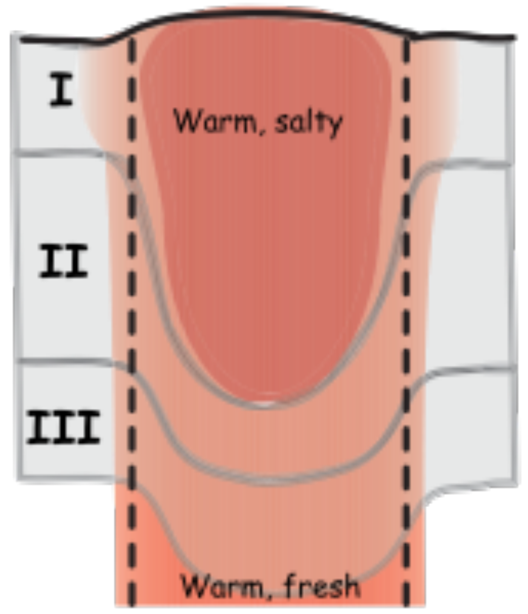

## INALT 10

EOF1 (color, 43%)
EOF2 (lines, 41%)

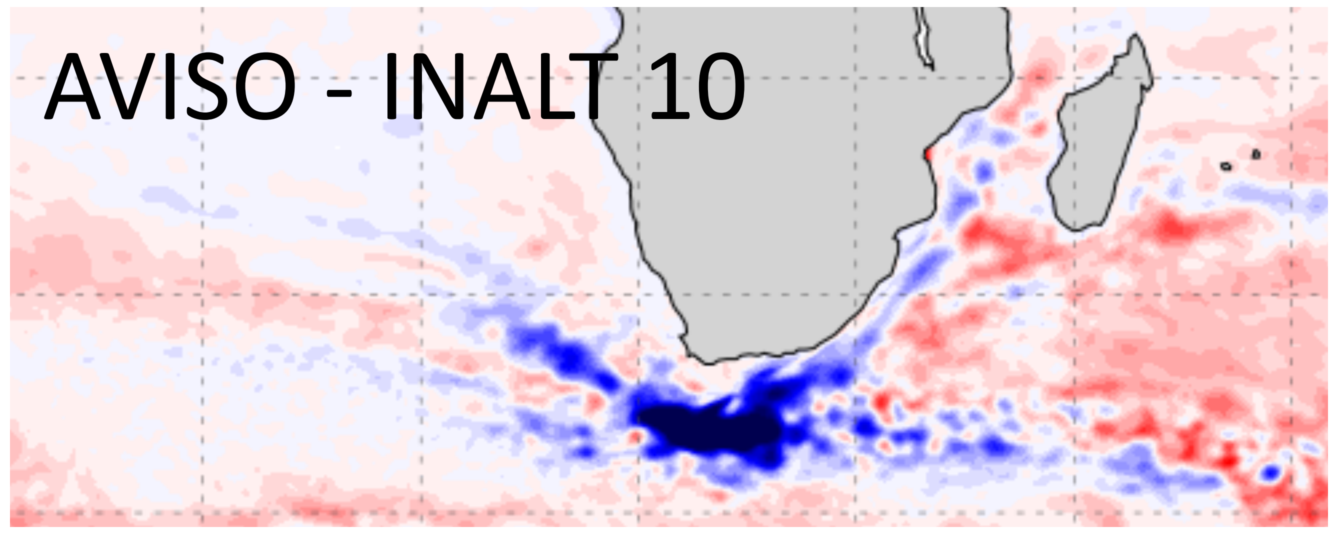


# 2000-2001, 80-100d

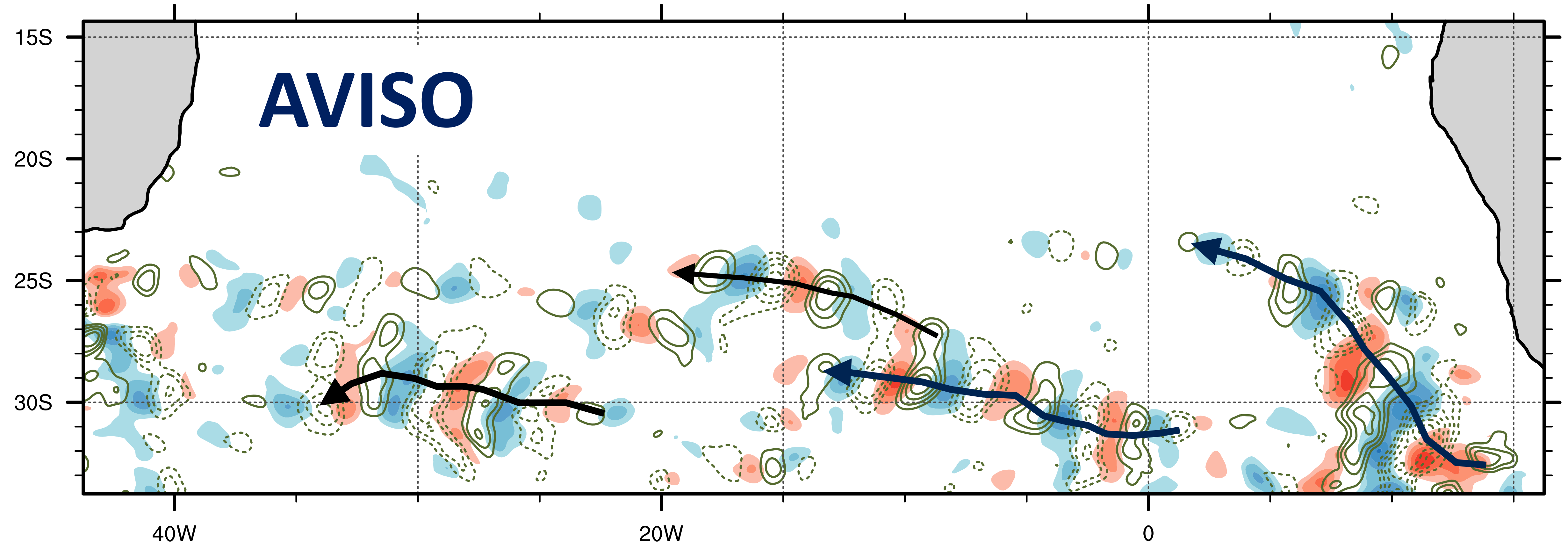
# 2000-2001, 80-100d, anticyclonic eddies only

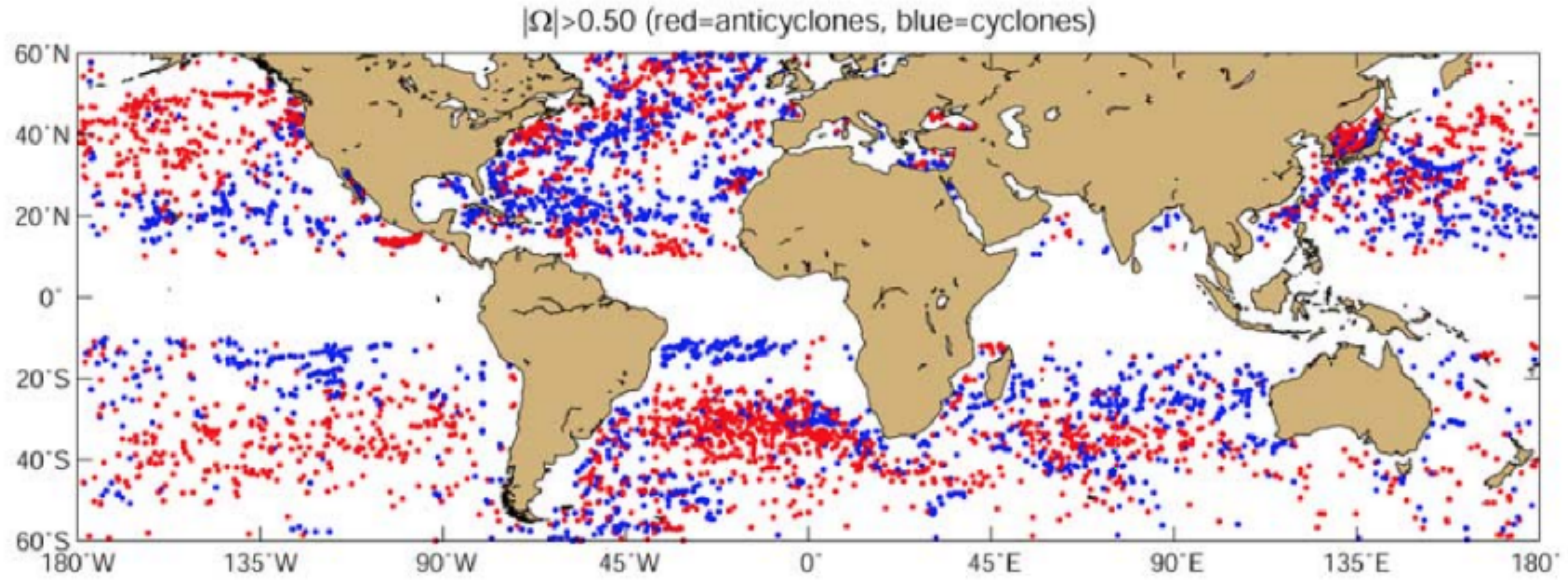



*Frenger et al., 2015*



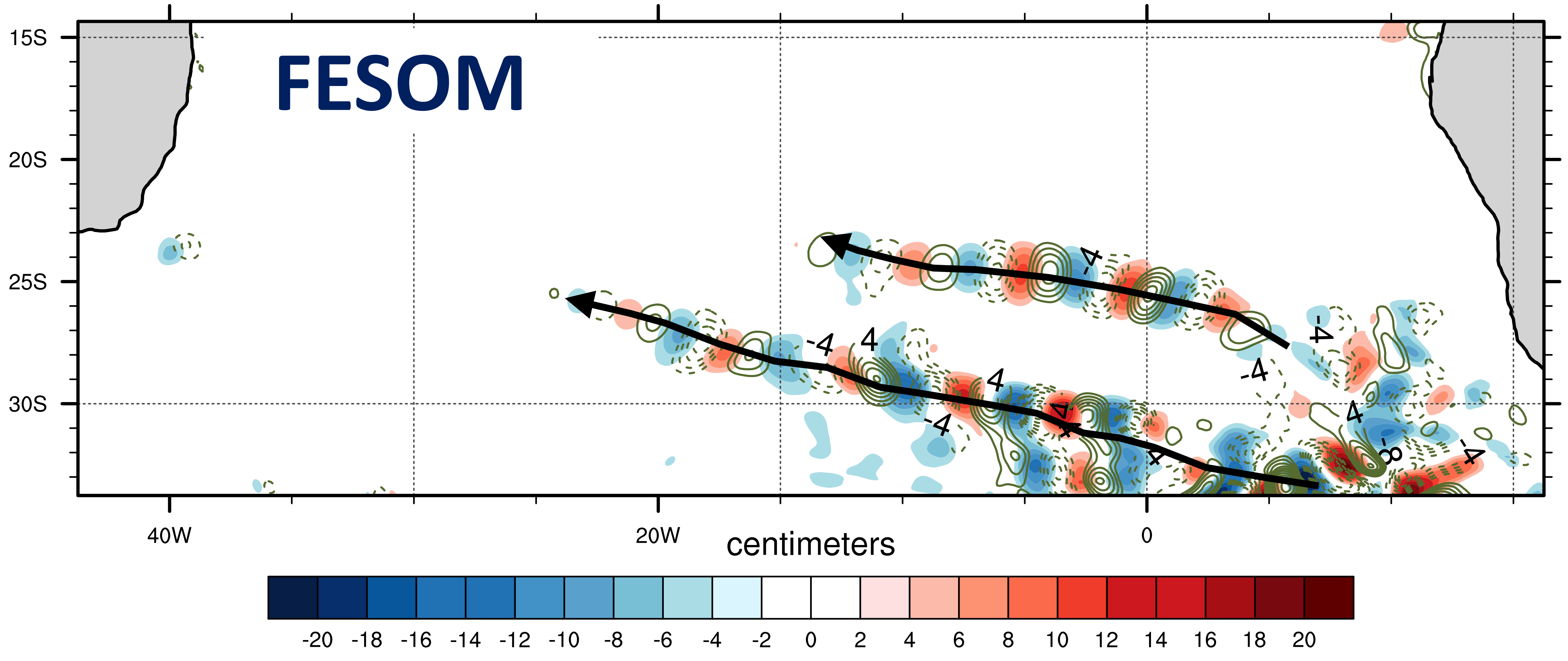

EOF1 (color, 20%)
EOF2 (lines, 19%)



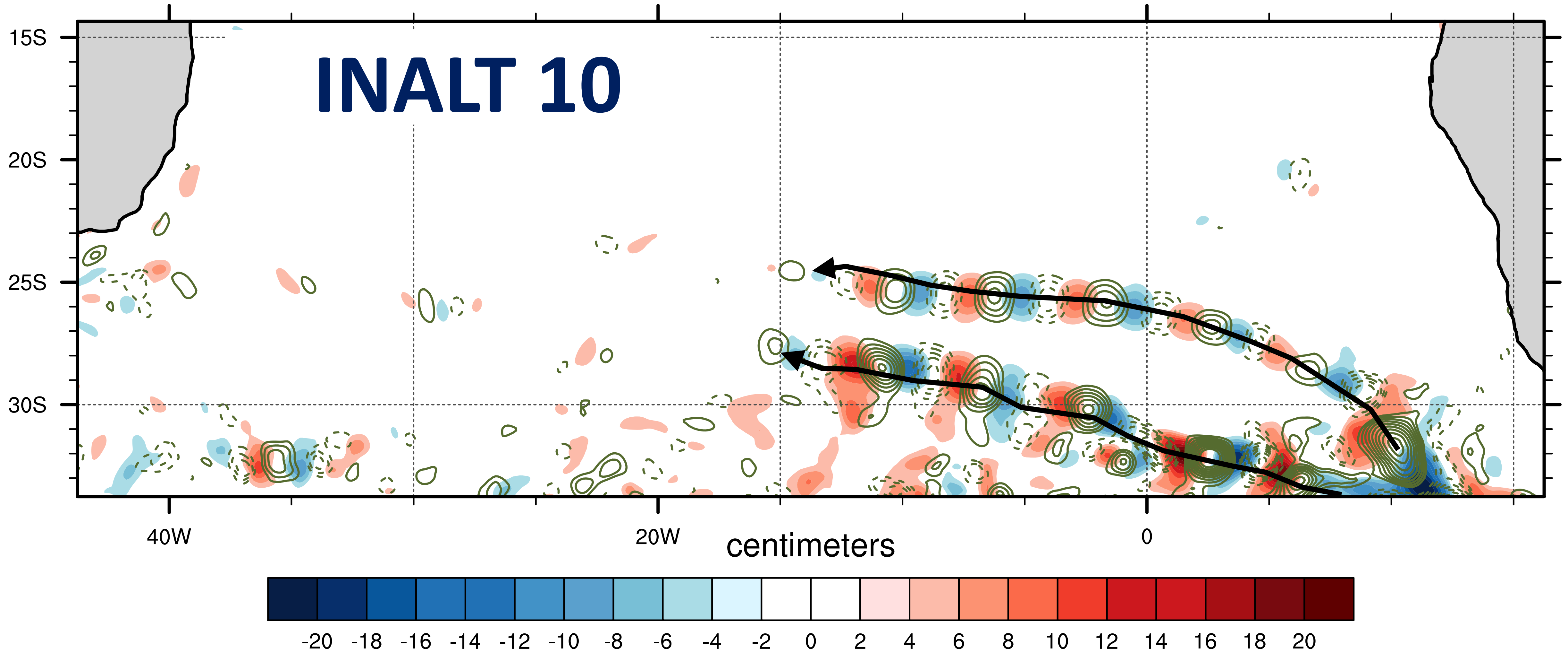




*Griffa et al. 2008*

EOF1 (color, 37%)
EOF2 (lines,36%)

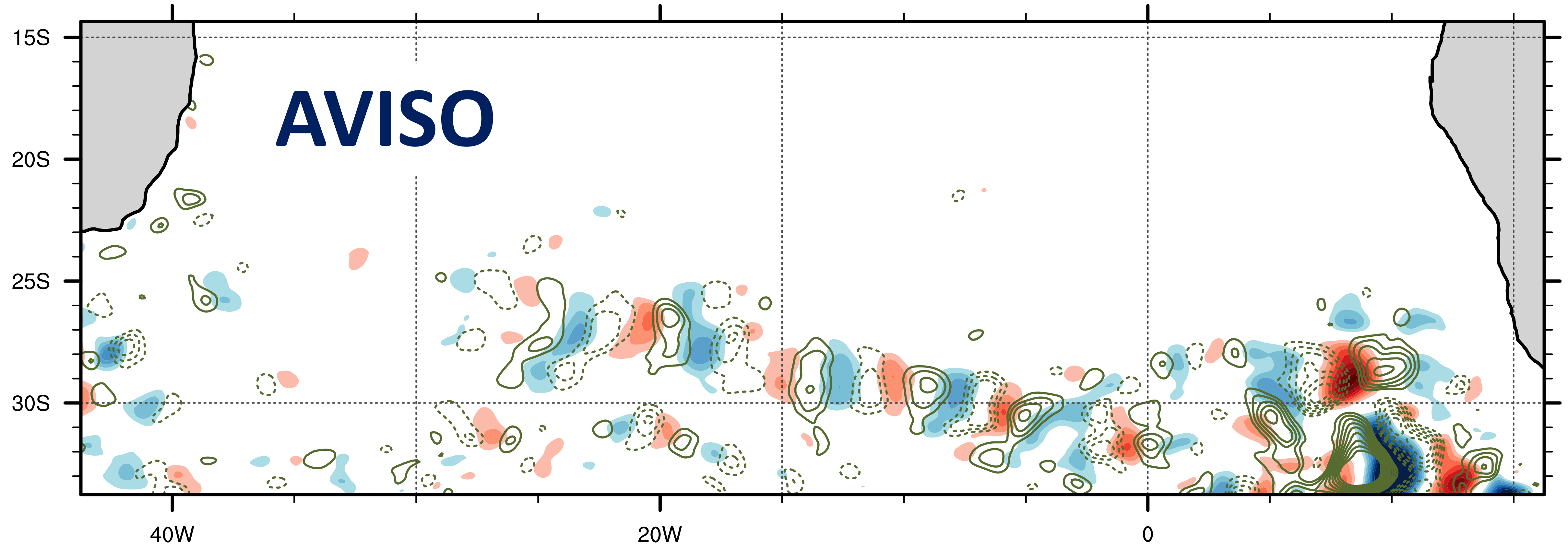



EOF1 (color, 44%)
EOF2 (lines, 41%)

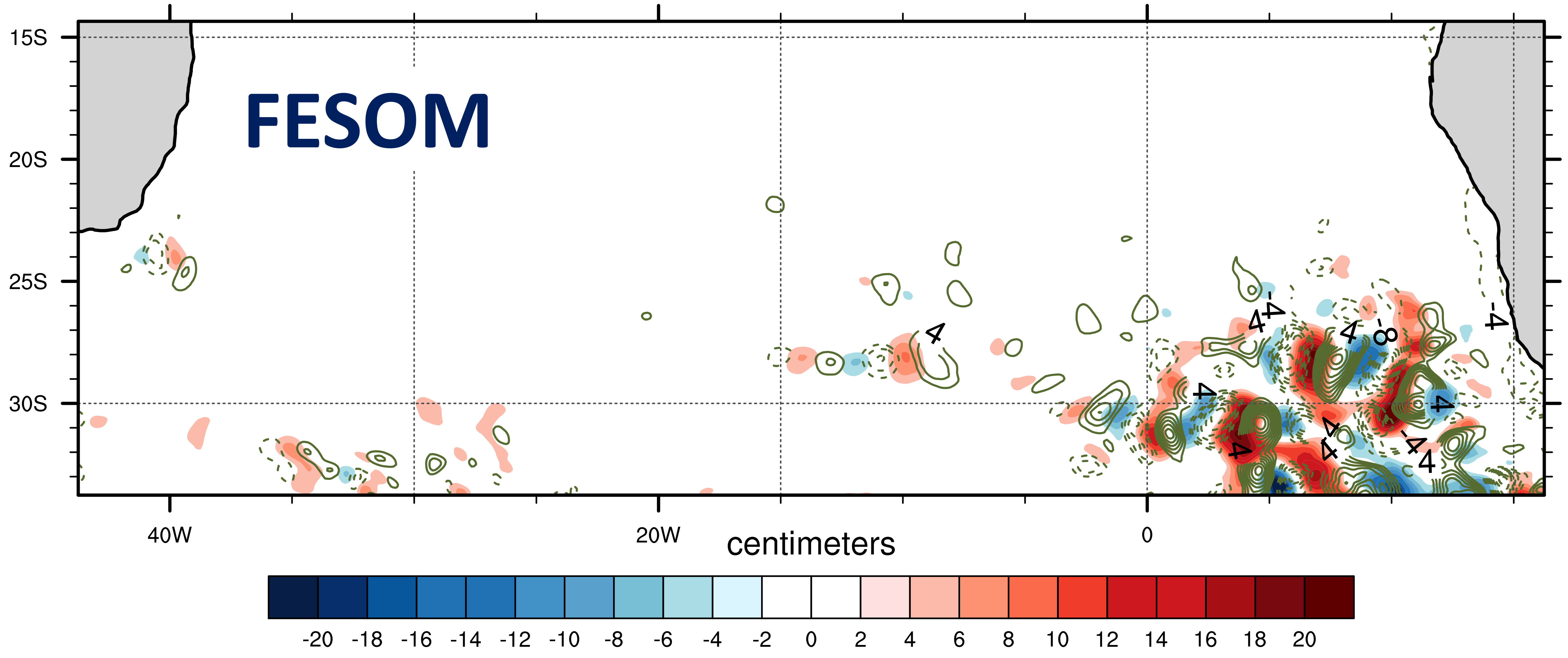


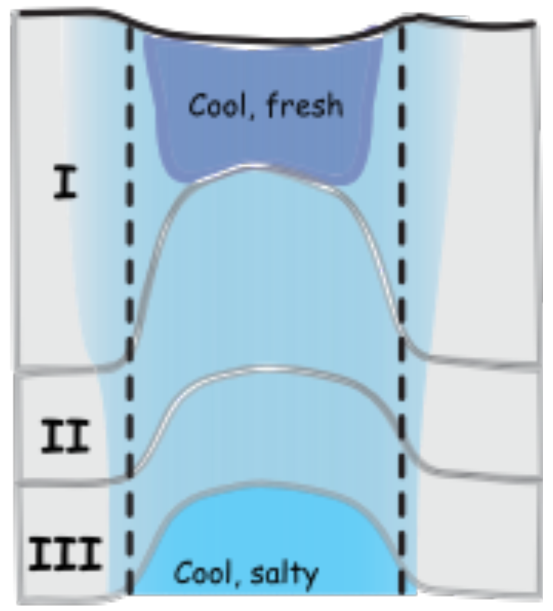
# 2000-2001, 80-100d, cyclonic eddies only

EOF1 (color, 21%)
EOF2 (lines, 20%)

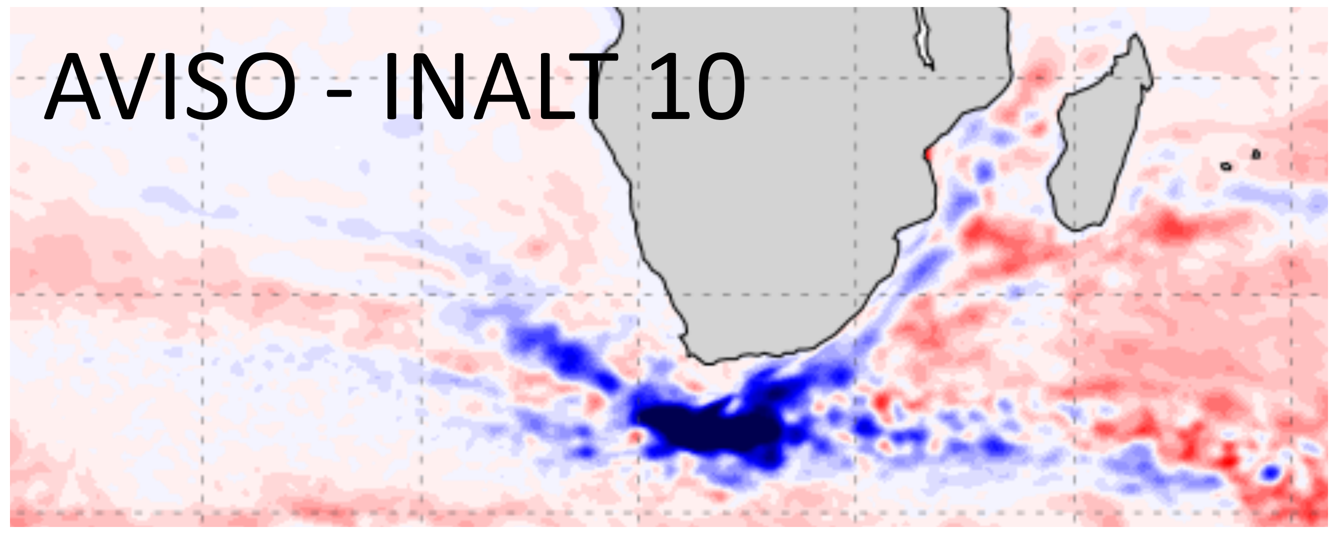


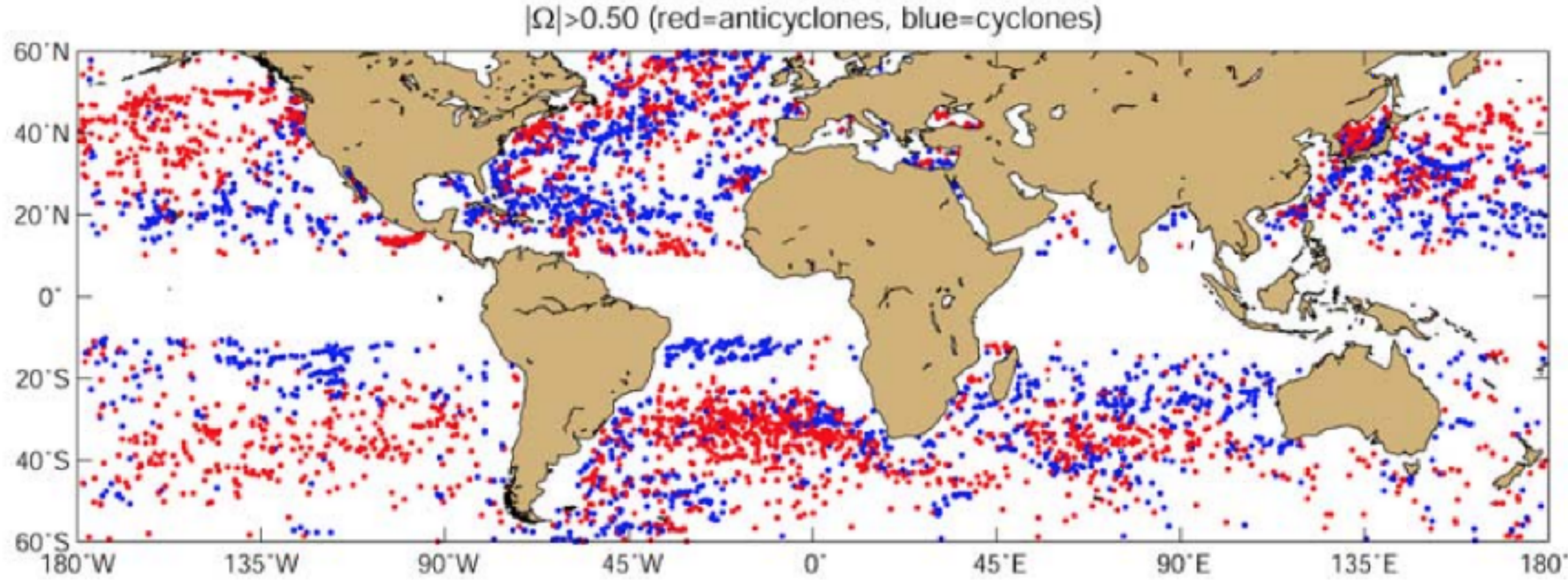

EOF1 (color, 35%)
EOF2 (lines,31%)



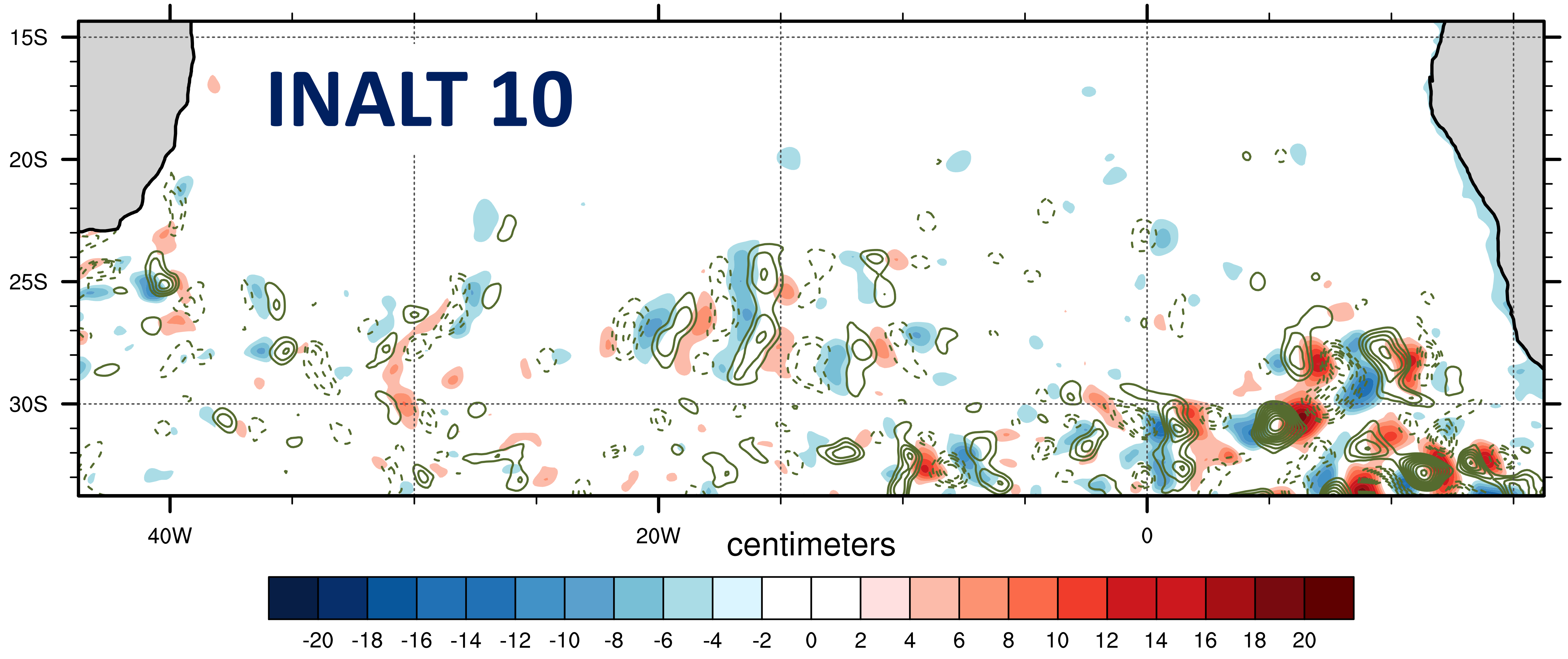

*Frenger et al., 2015*



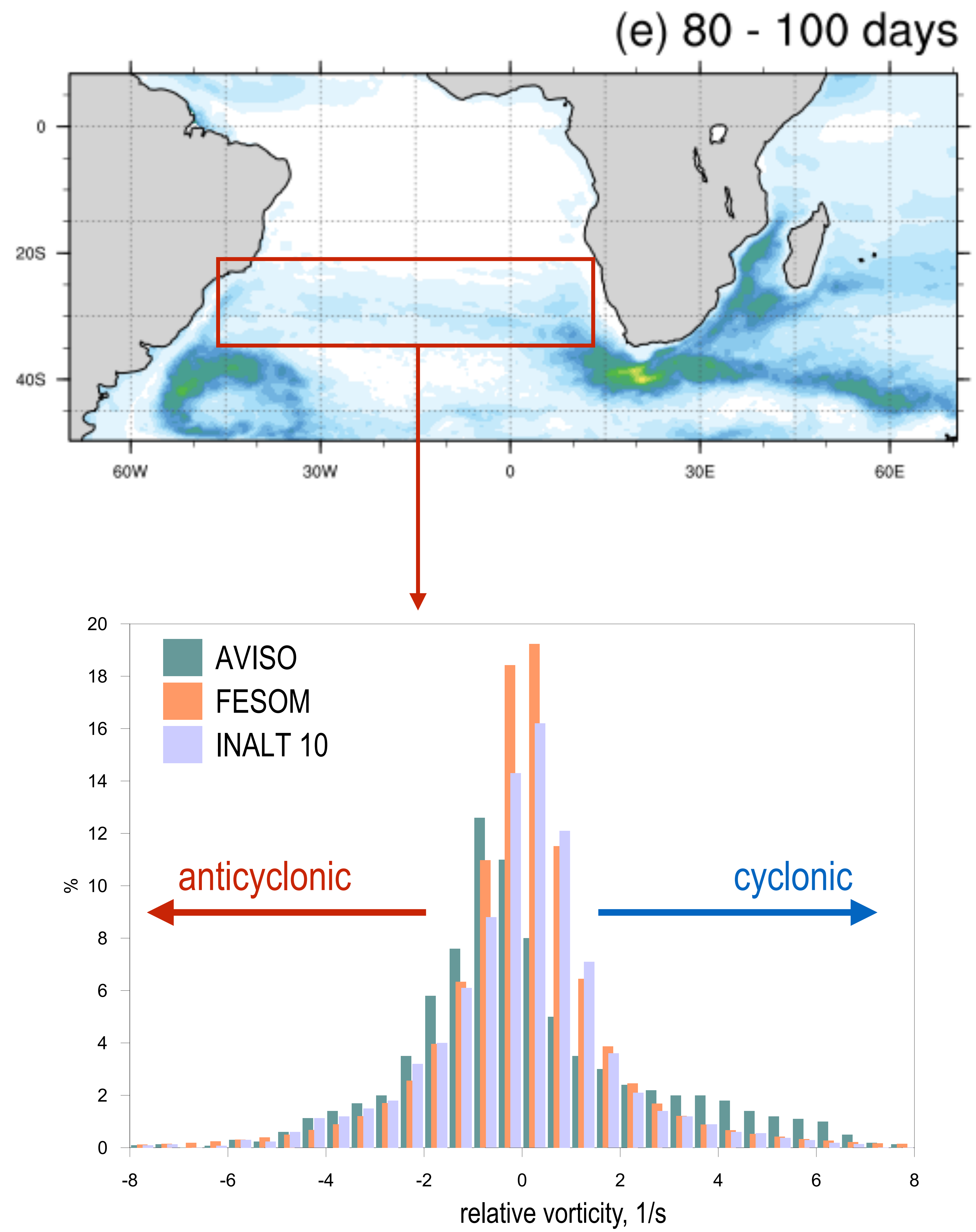




*Griffa et al. 2008*

EOF1 (color, 43%)
EOF2 (lines, 39%)



# 2000-2001, regional probability distribution of relative vorticity






Pilo et al.,2015

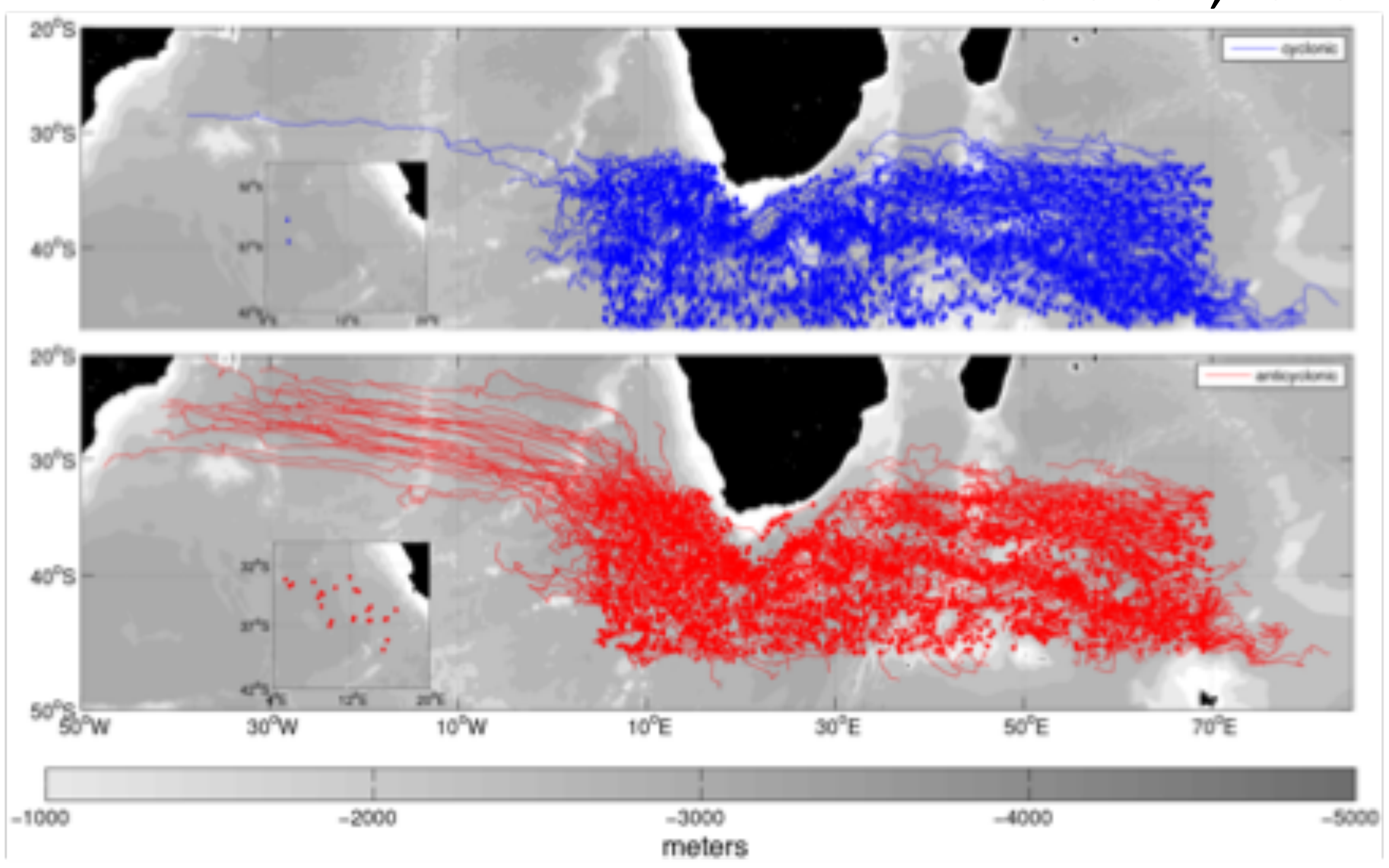



**Figure 5.** Trajectories of **(a)** cyclonic, and **(b)** anticyclonic eddies first identified in the AC system between October 1992 and April 2012. Insets in **(a)** and **(b)** show the South Atlantic crossing eddies' first locations.

# Summary

**(i) We present a methodology for the fast Eulerian OCMs diagnostics**

**(ii) After the time scales of 80 days agreement in SSH variability between datasets is better comparing to the higher frequencies**

**(iii) FESOM and INALT models generally agree in size, speed and the shape of propagating mesoscale eddies over the Agulhas Current with AVISO data**

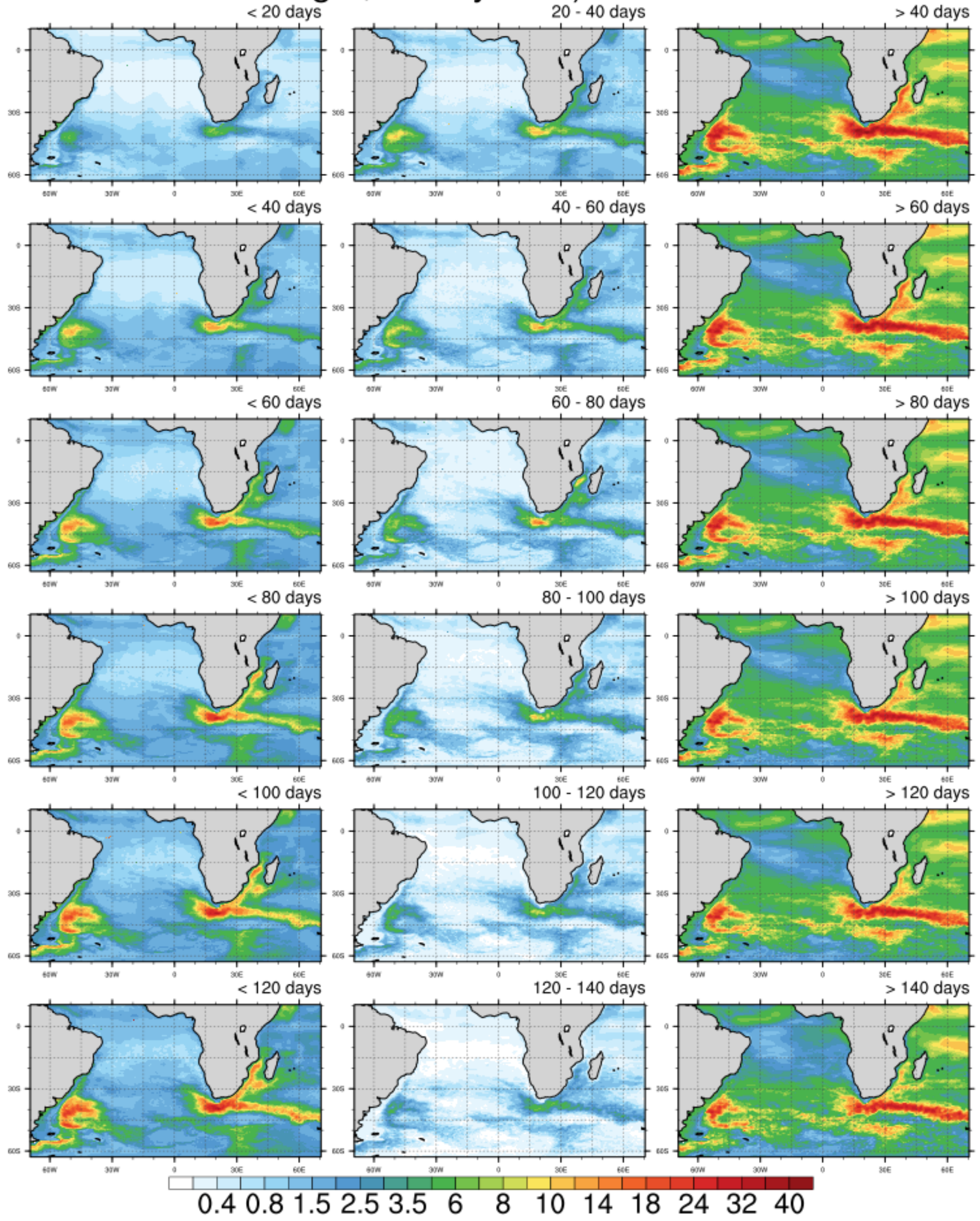
**(iv) Two independent OGCMs provide the same deflection of the anticyclonic eddies path in the Central South Atlantic from both AVISO and ORS (assimilating AVISO)**

(i) AVISO gridded dataset might not be resolving eddies equatorward from the certain latitude
(ii) Common bias for OGCMs (vorticity balance?)
(iii) How important is this bias for the global Agulhas influence

**To do**

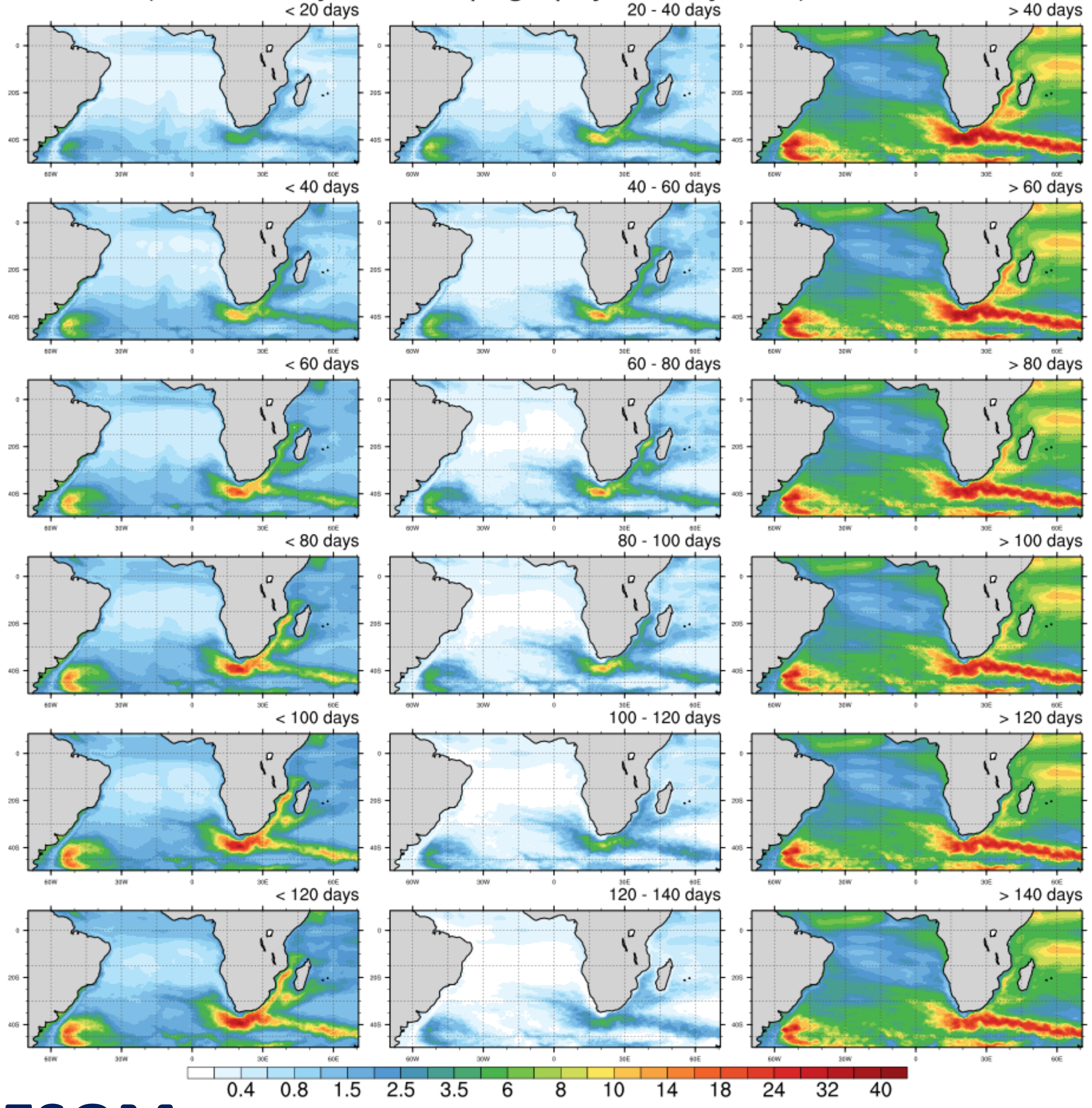
(i) Check this with along track data

Standart deviations (cm) of the band-pass filtered SSH
Sea Surface Height, 5-daily data)



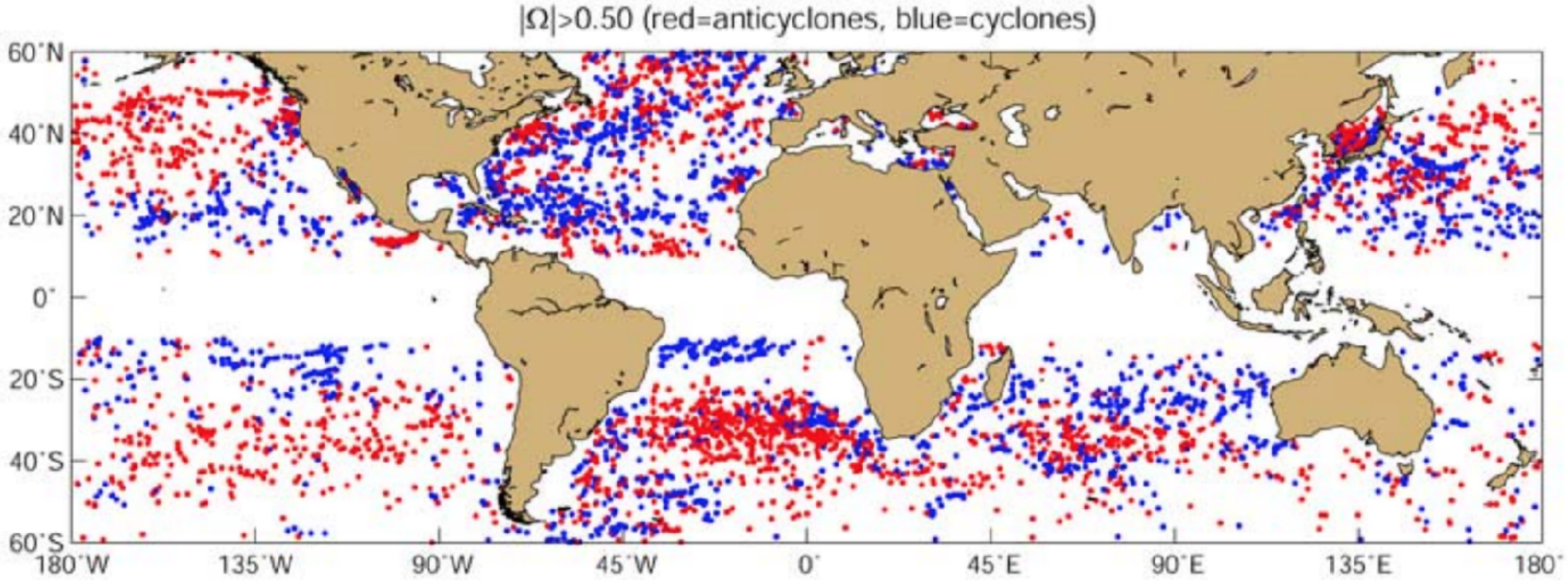

**INALT 20**

Standart deviations (cm) of the band-pass filtered SSH
(Absolute Dynamic Topography, 5-daily data)



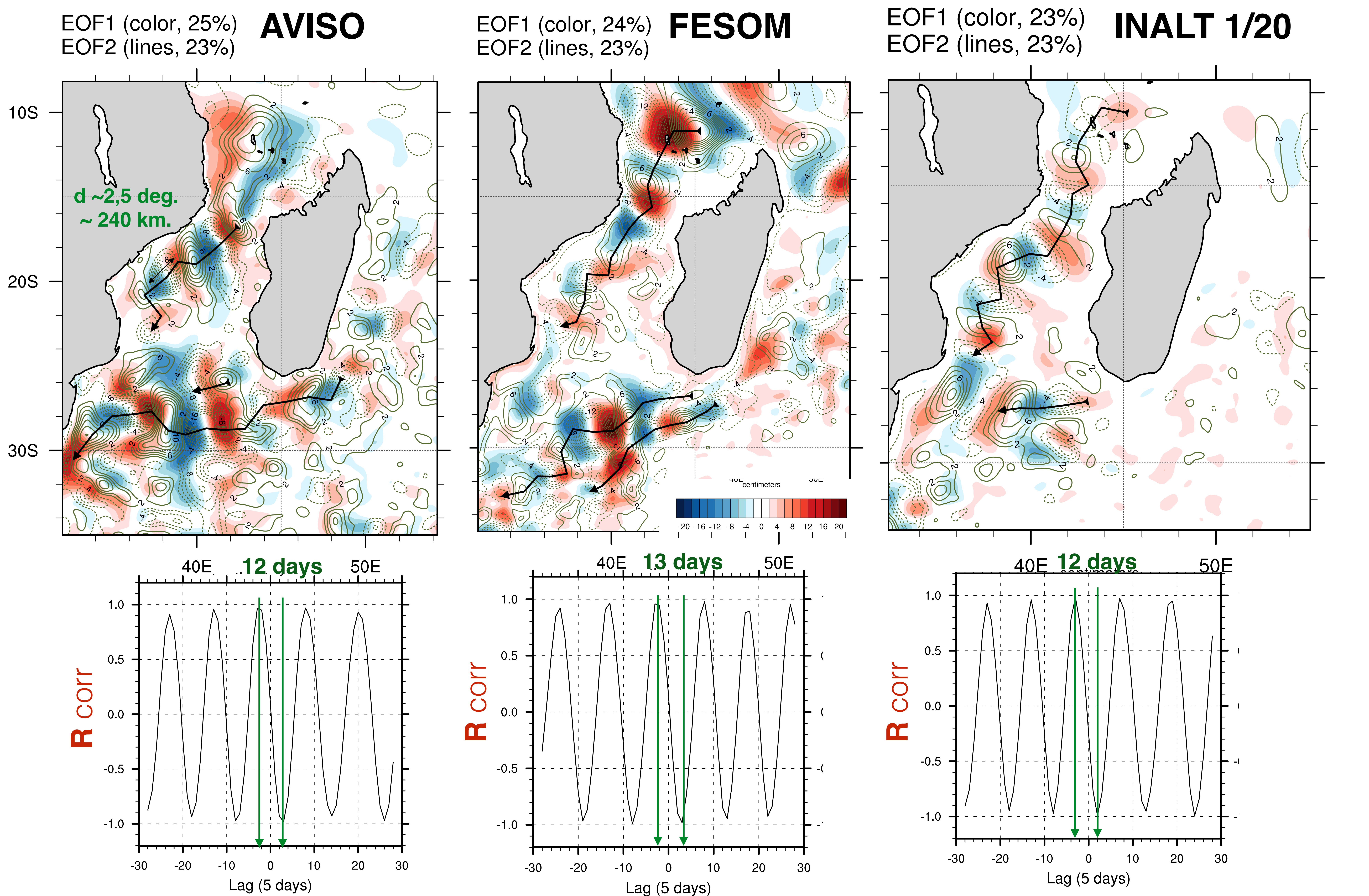

**FESOM**

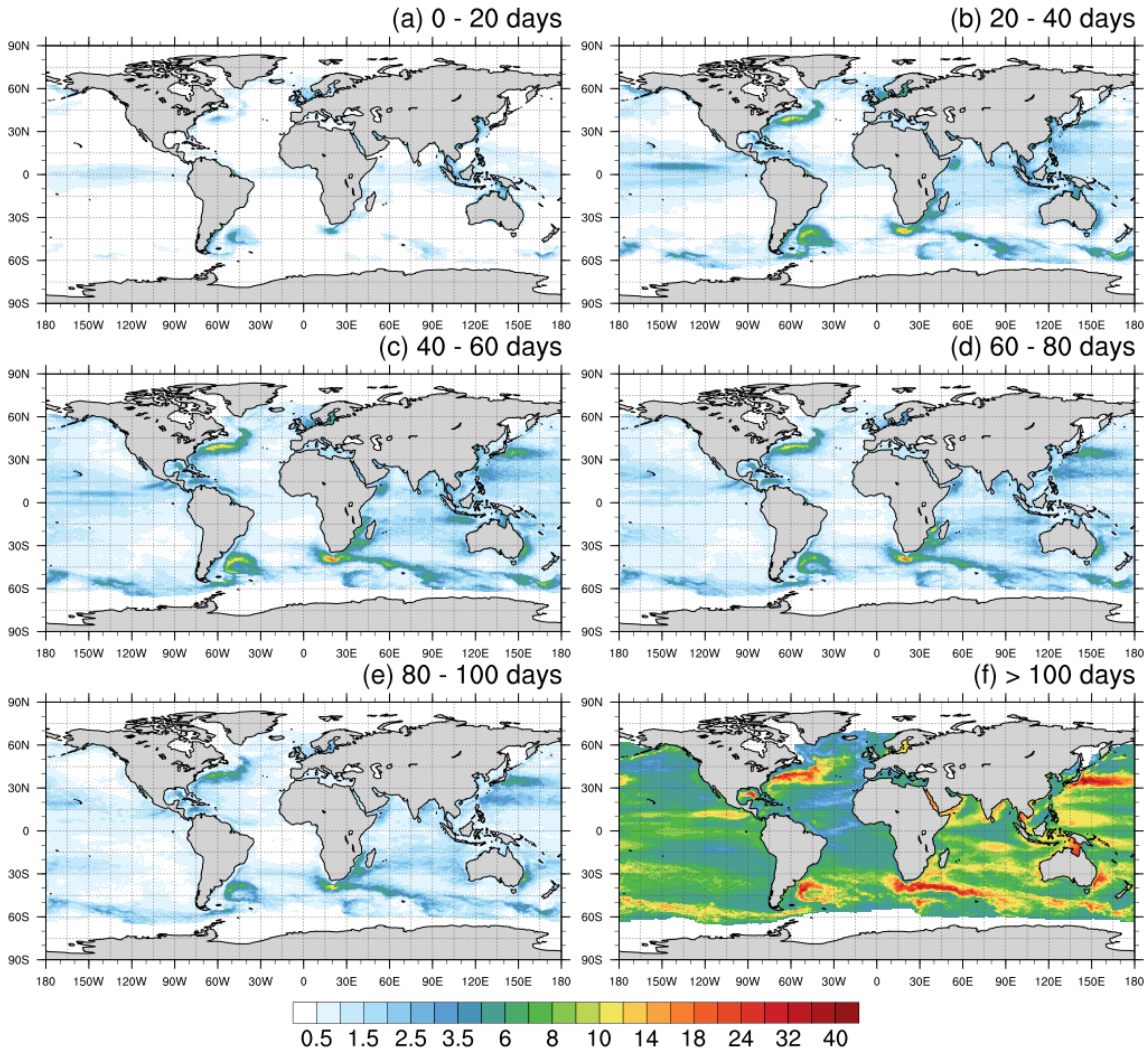
Natalia Tilinina@AWI BHV




Griffa et al. 2008

# Diagnostics of the propagating patterns, 60-80 days, yr. 2000





(a) 0 - 20 days
(b) 20 - 40 days
(c) 40 - 60 days
(d) 60 - 80 days
(e) 80 - 100 days
(f) > 100 days
90N 60N 30N 0 30S 60S 90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0.5 1.5 2.5 3.5 6 8 10 14 18 24 32 40

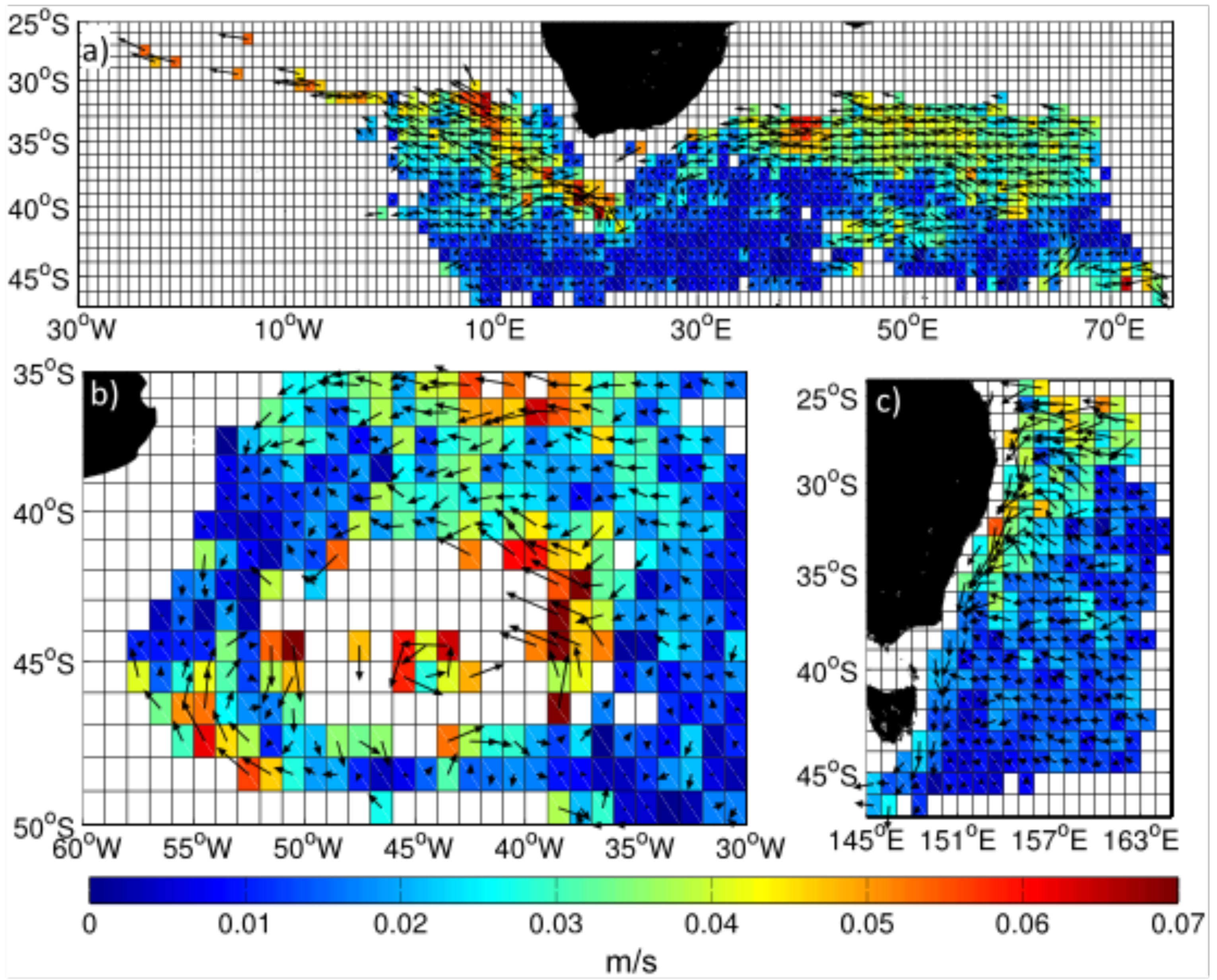
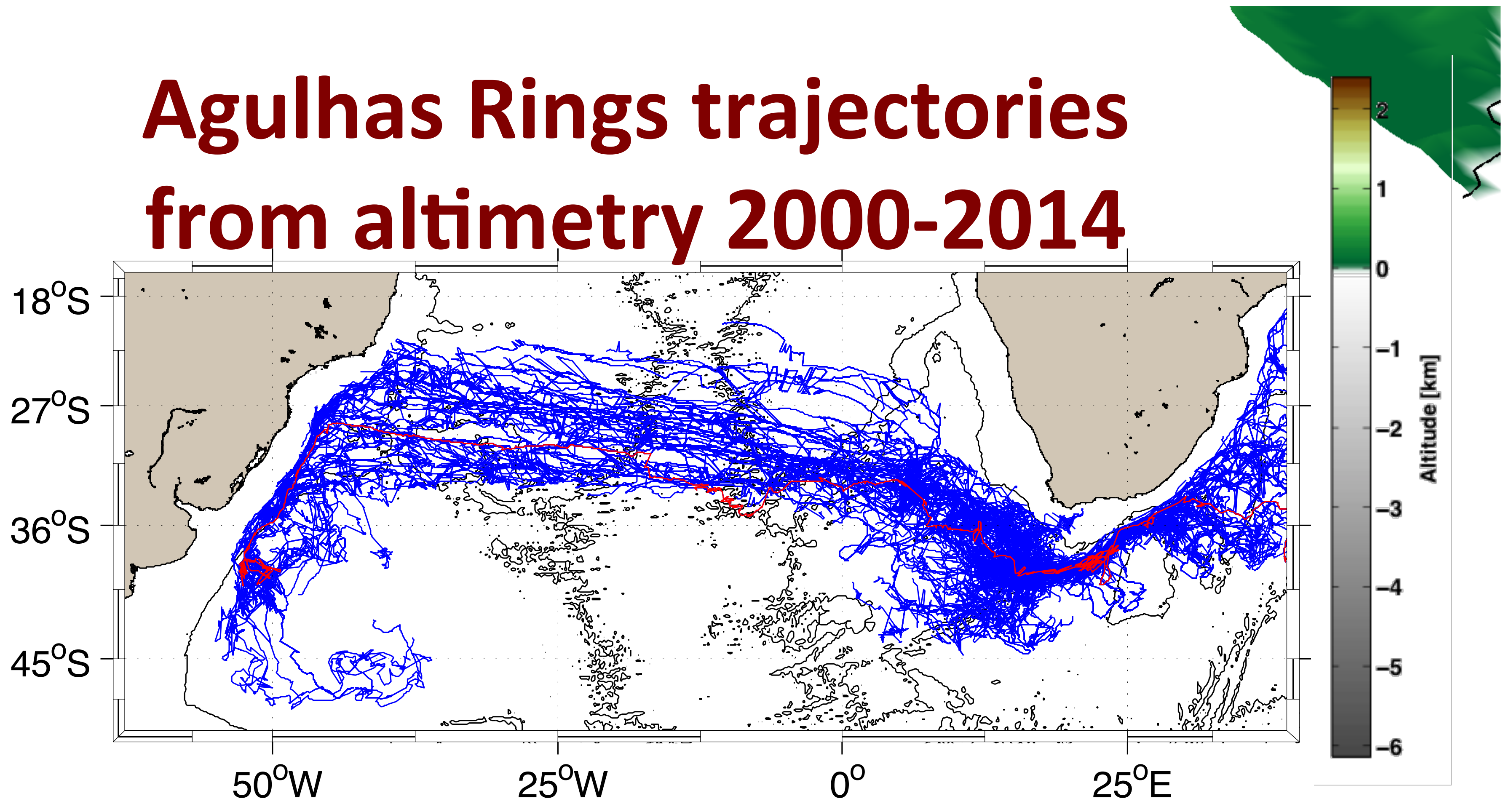



**Figure 8.** Eddy mean propagation speeds (colours) and directions (arrows) for 1° × 1° cells containing more than 20 eddies in the **(a)** AC, **(b)** BC, and **(c)** EAC systems.

## Agulhas Rings trajectories from altimetry 2000-2014




*Master2 Thesis of Rémi Laxenaire*, 2015

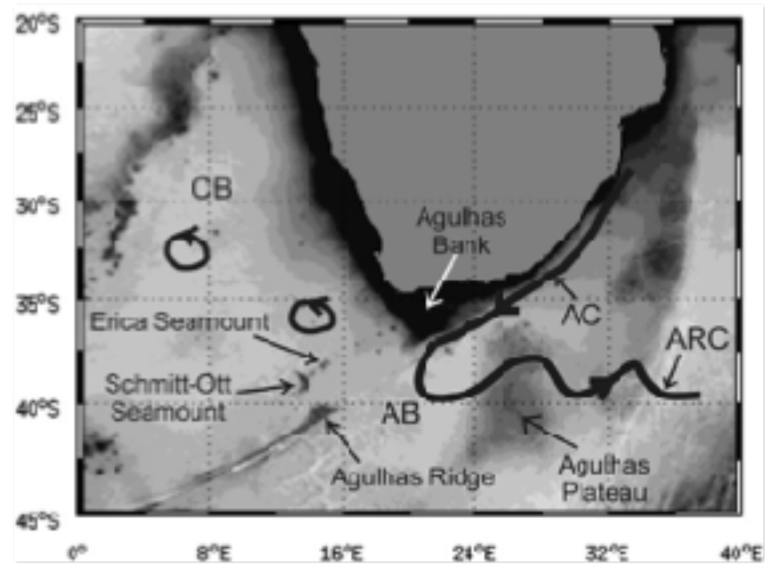



**Fig. 1.** Bathymetric map of the area of study, with the locations of the Cape Basin (CB) and Agulhas Basin (AB), and topographic features cited in the text. The solid lines show the schematic track of the Agulhas Current (AC), Agulhas Return Current (ARC), and a few Agulhas rings.

Dencausse et al., 2010

634 G. S. Pilo et al.: Eddies in Southern Hemisphere western boundary currents

Pilo et al.,2015

Fu et al.,2009

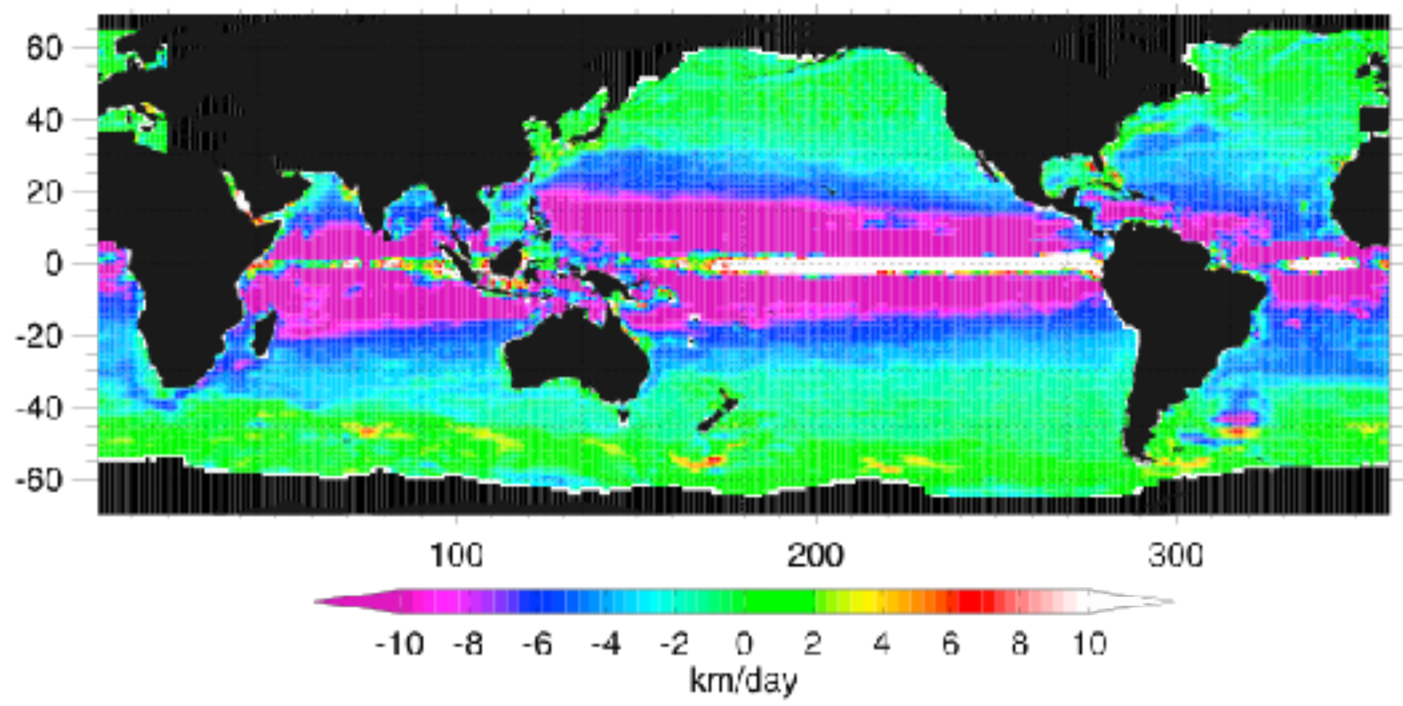



Figure 1. The zonal velocity of eddy propagation.

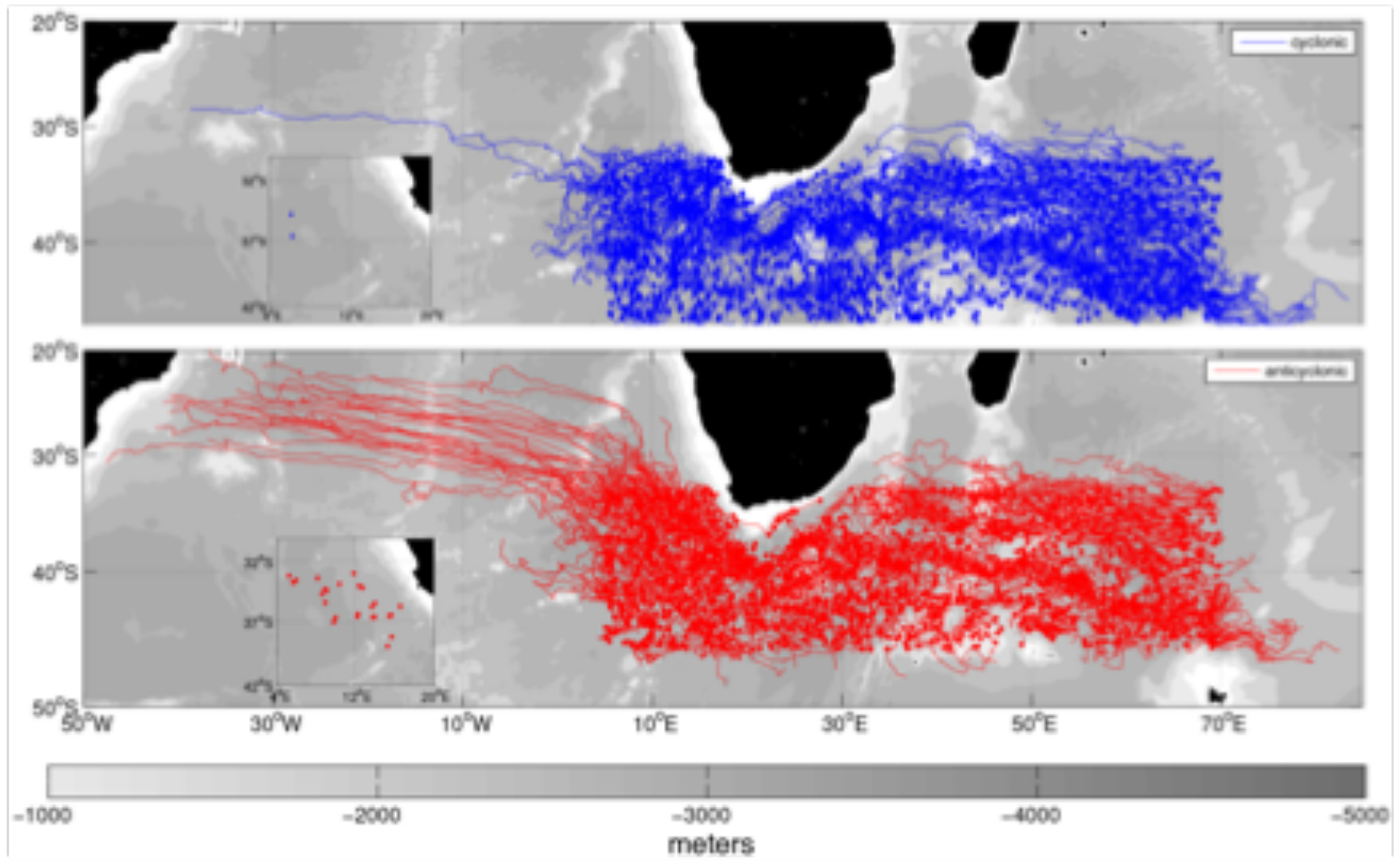



**Figure 5.** Trajectories of **(a)** cyclonic, and **(b)** anticyclonic eddies first identified in the AC system between October 1992 and April 2012. Insets in **(a)** and **(b)** show the South Atlantic crossing eddies' first locations.