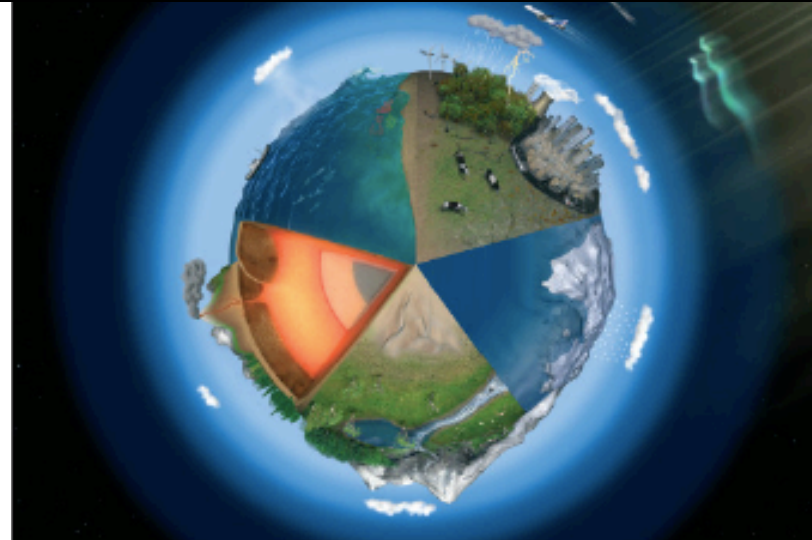


# Summer School Alpbach 2010

ADVANCES IN STUDIES OF OCEAN CIRCULATION FROM  
SATELLITE OBSERVATIONS



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Nansen Environmental and Remote Sensing Center  
Bergen, Norway



## GLOBAL OCEAN CIRCULATION

Ocean currents, together with the atmospheric wind field, are fundamental drivers of the integrated Earth system.

Through air-sea interaction and mutually feedbacks they modify the local heat conditions and transport heat from low to high latitudes.

Currents are playing an essential role in shaping the weather, the marine environment and the climate.

The currents transport and redistribute pollutant material such as oil spills etc.

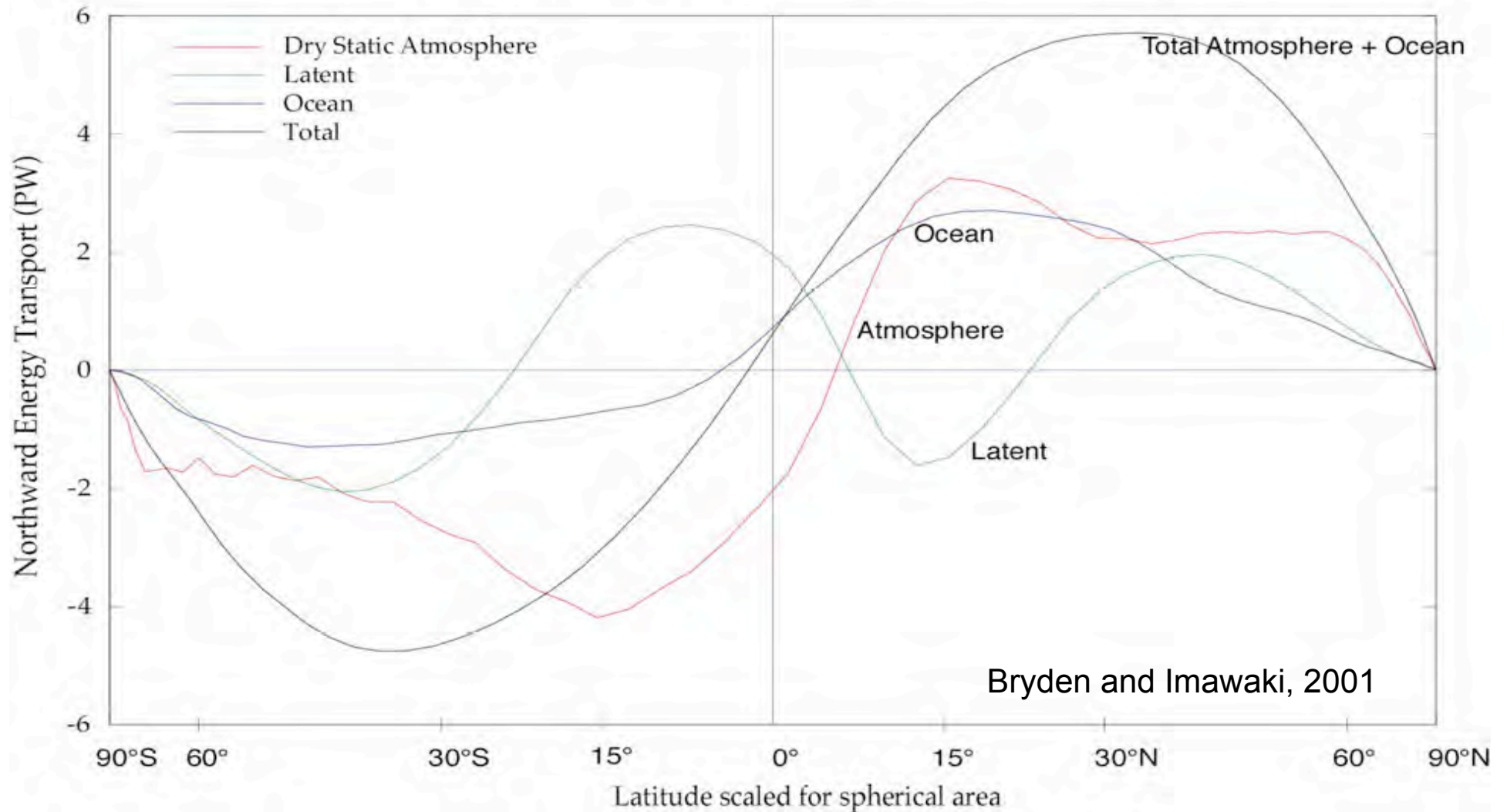
Currents act as servants of nutrients for the fish stocks and mammals.

Accurate quantitative knowledge of the ocean currents remain incomplete both with respect to the mean and the temporal variability.



Summer School Alpbach, Austria, 27 July - 5 August 2010

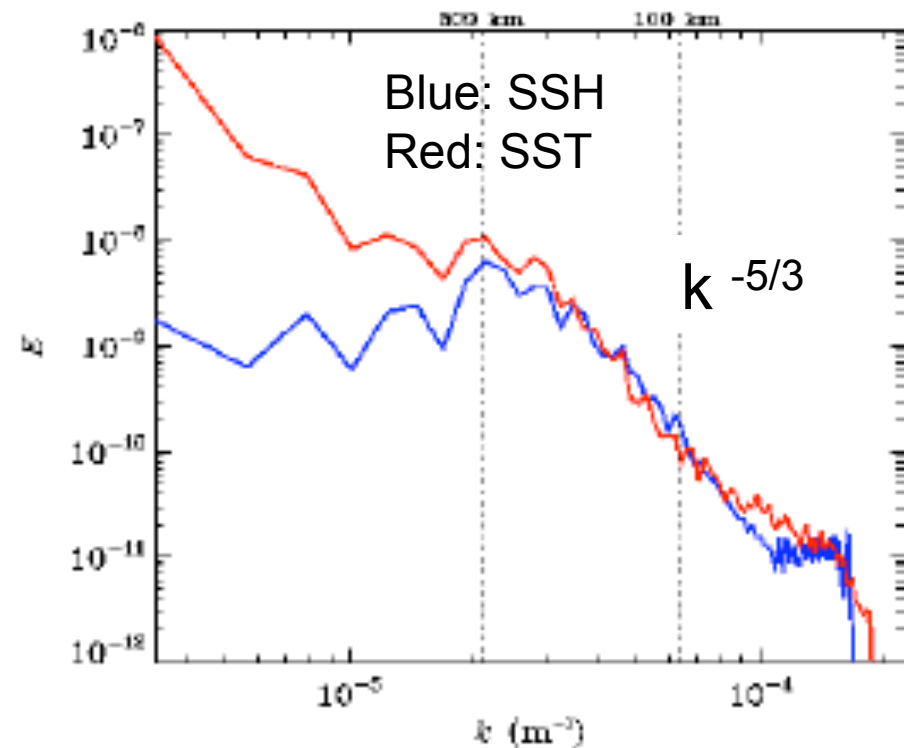
### Components of Global Energy Balance



## GLOBAL OCEAN CIRCULATION

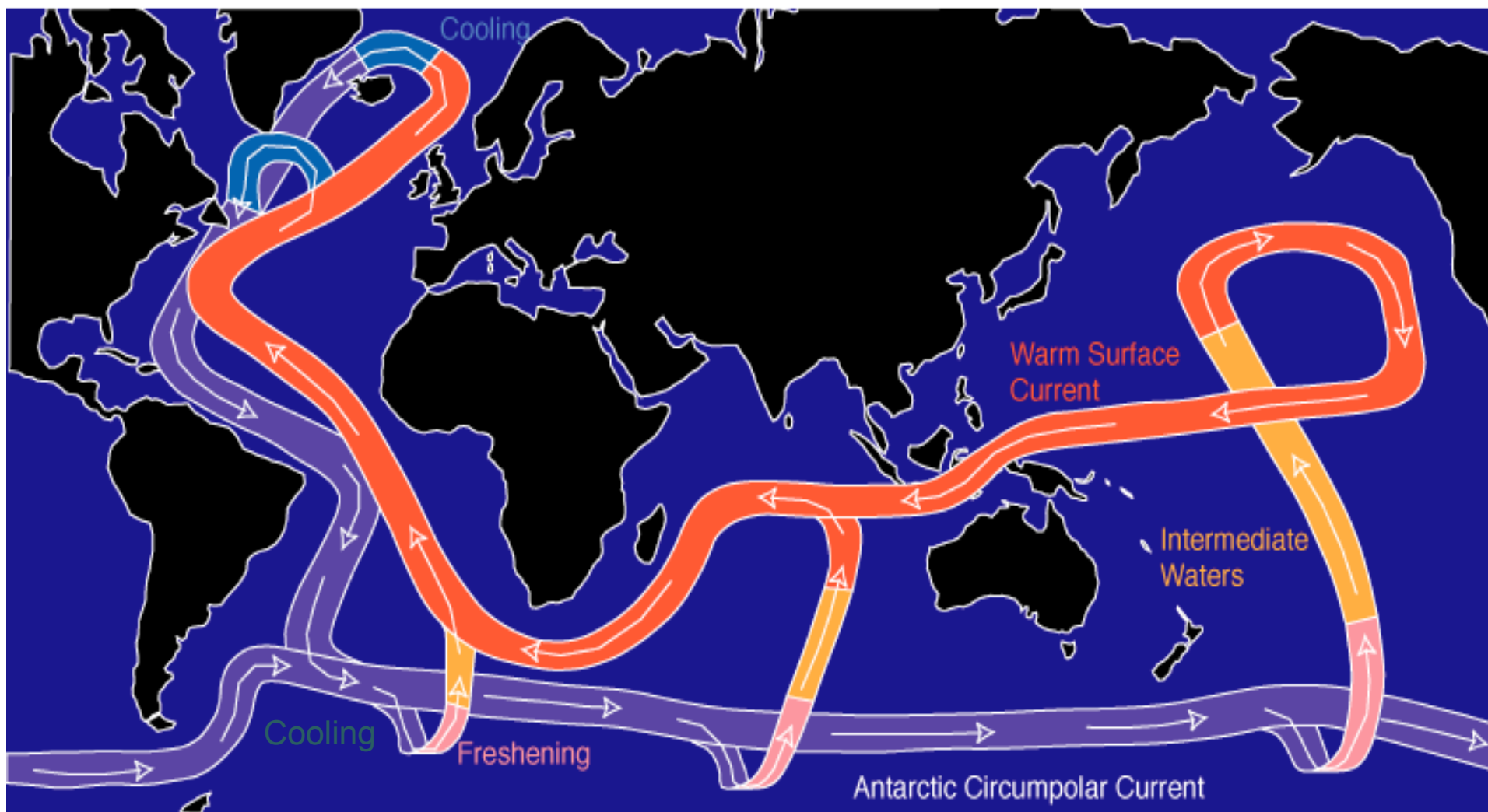
Ocean circulation can be classified according to spectral characteristics:

- the slowly varying global and basin scale mean circulation at spatial scales from 300 - 1000 km.
- the more dynamic mesoscale currents (e.g. ocean eddies that acts as the weather in the ocean) centered at scales of 50 - 200 km.
- the sub-mesoscale currents at scales from 1-10 km where non-linear processes become more and more dominating.

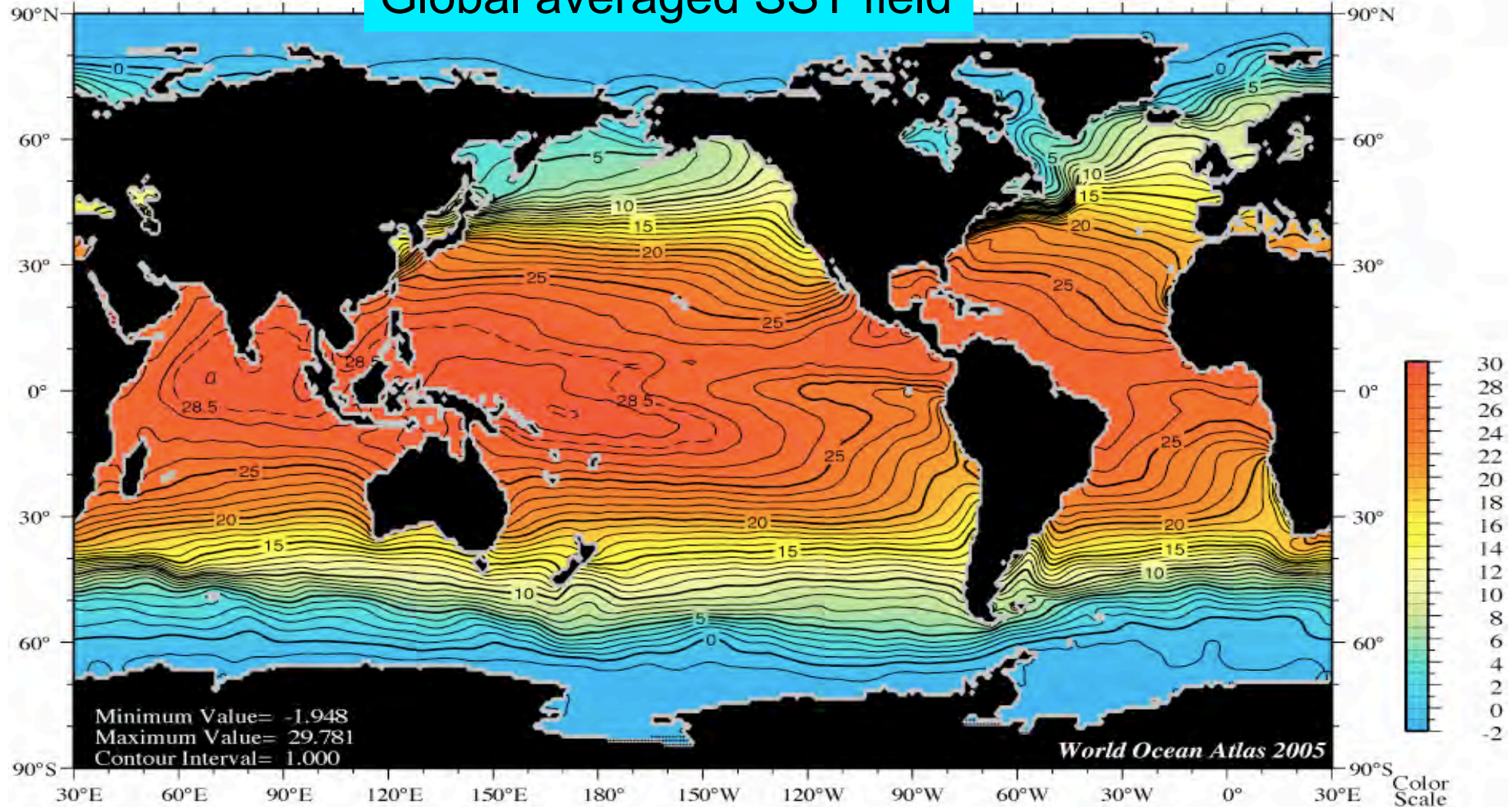


Isern-Fontanet et al., GRL 2006

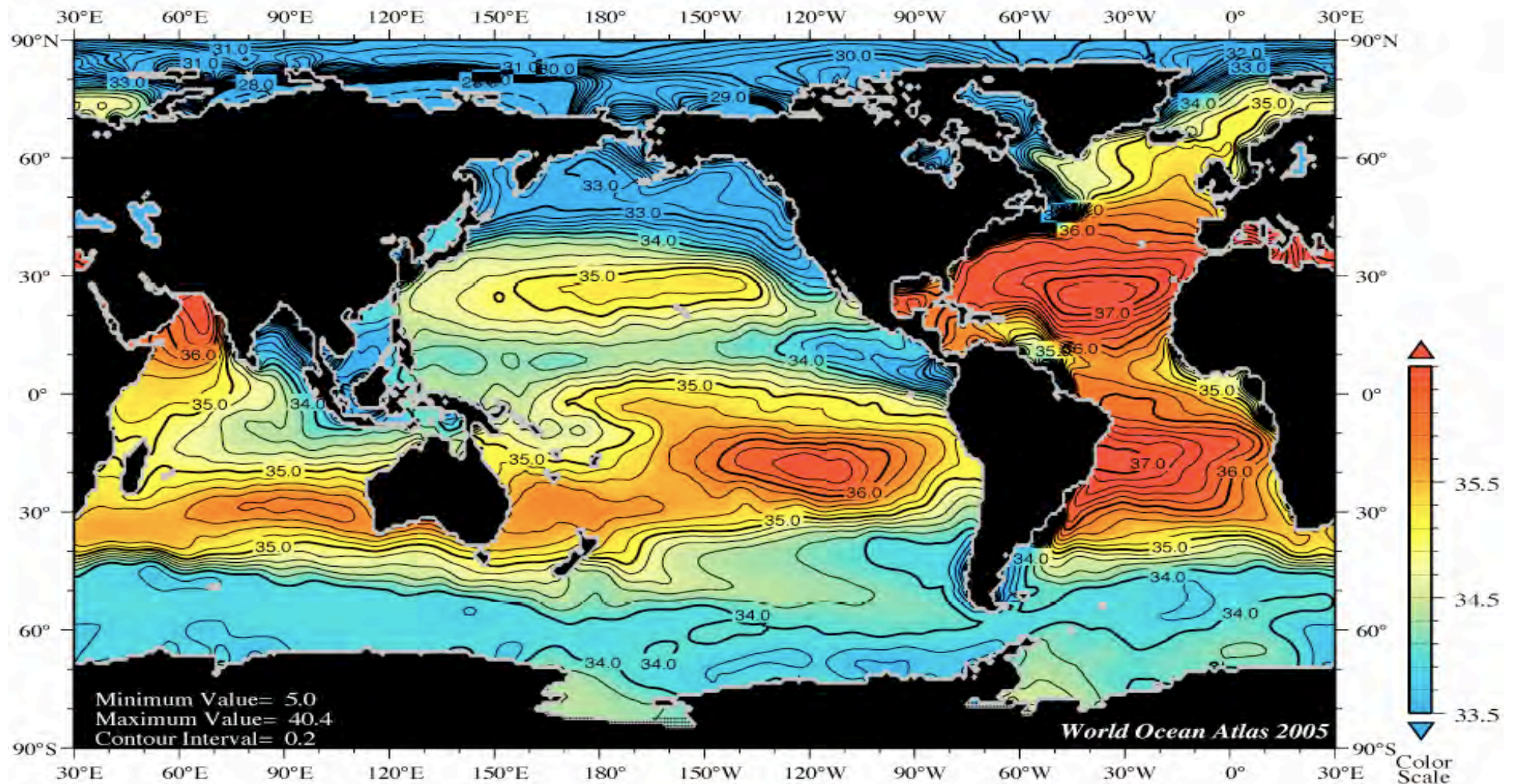
## GLOBAL OCEAN CIRCULATION – THE CONVEYOR BELT



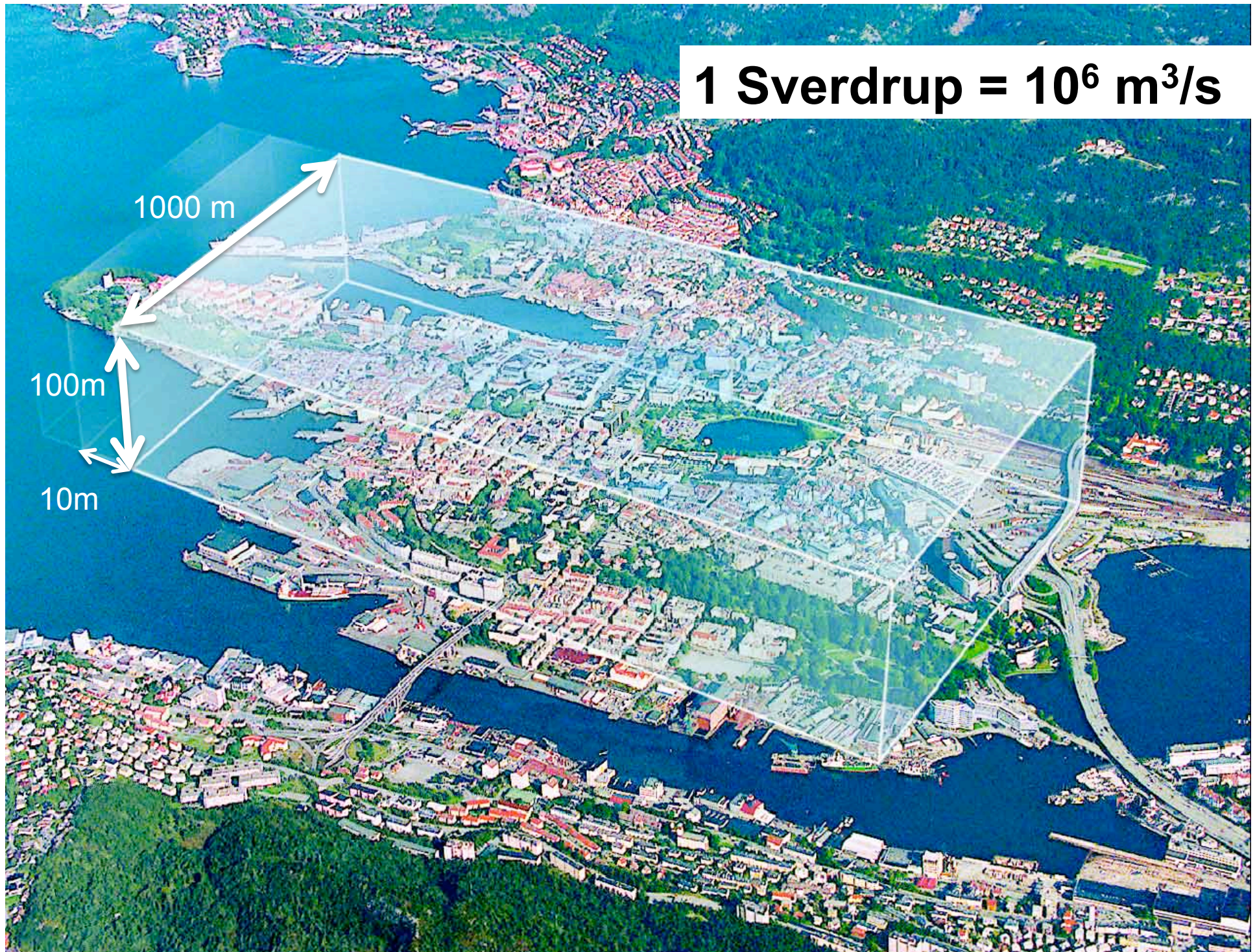
## Global averaged SST field



## Global averaged Surface salinity field



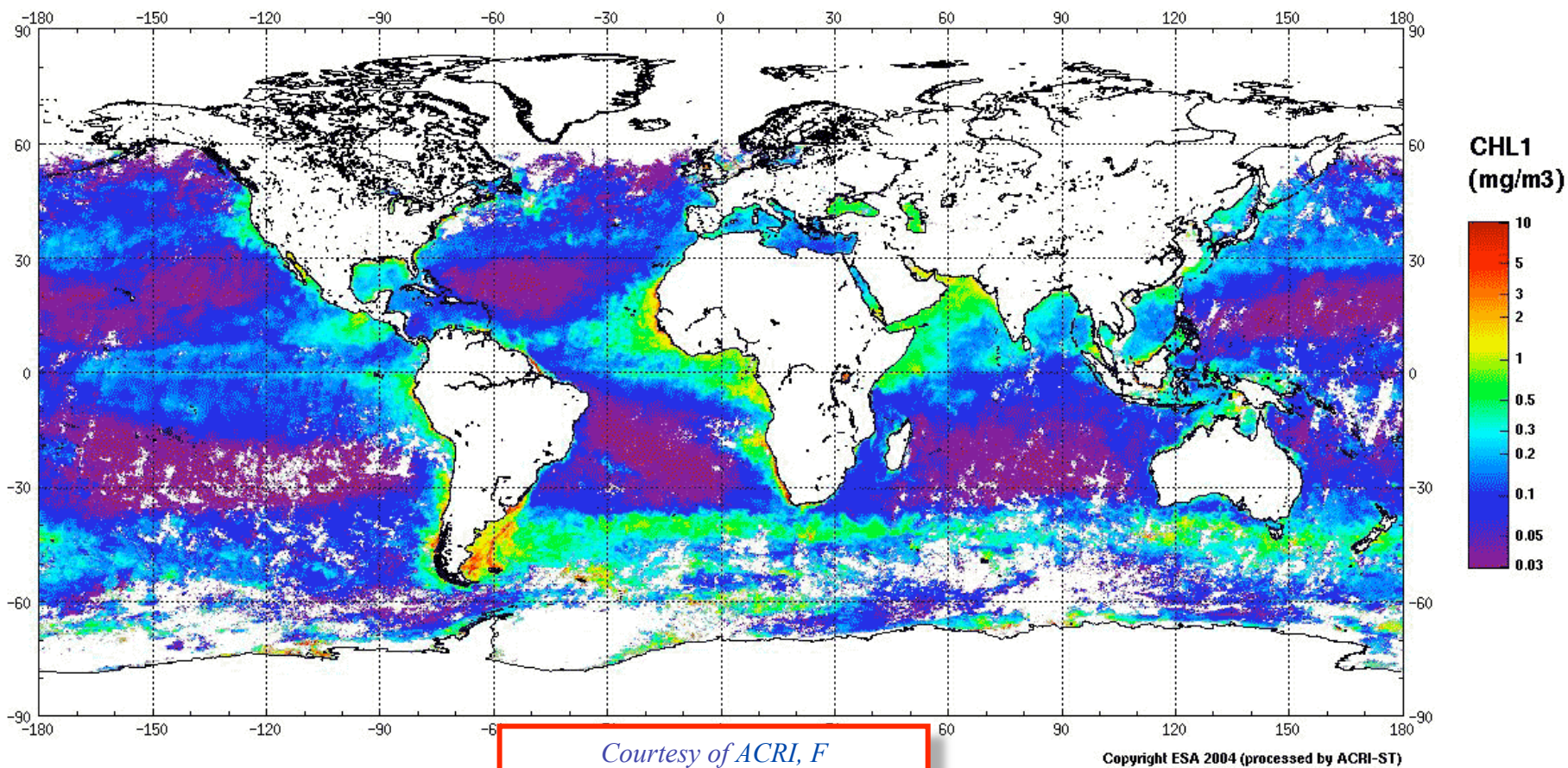
**1 Sverdrup =  $10^6 \text{ m}^3/\text{s}$**



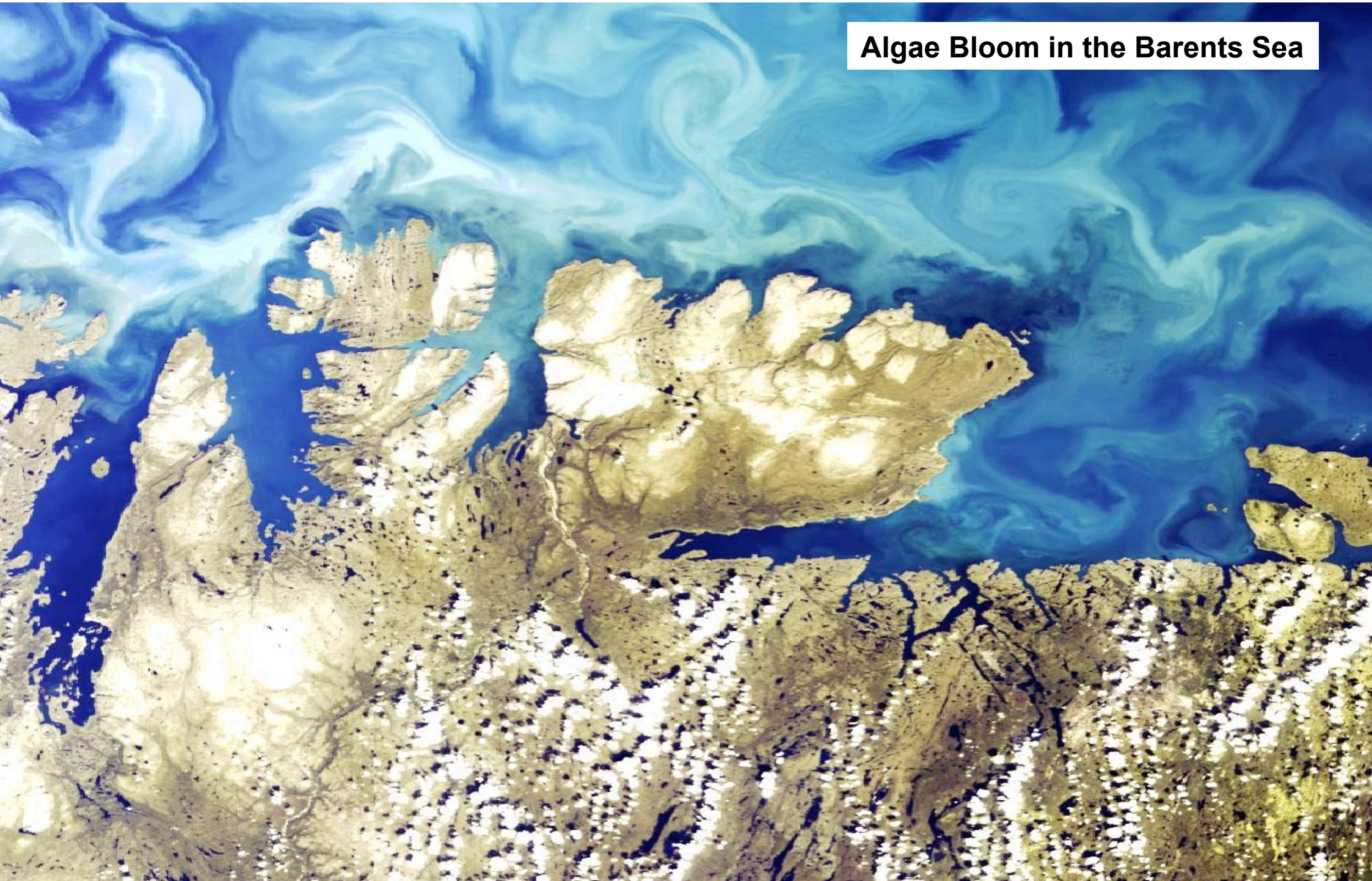
## MONITORING GLOBAL OCEAN CIRCULATION FROM SATELLITES

Satellites	Sensor Type	Observed Quantity	Derived higher level information
Envisat Aqua SeaWiFS	Imaging spectrometers	Water leaving radiances	Distribution of phytoplankton that is partly a result of advection by ocean currents
Envisat Aqua Metop AVHRR	Infrared Radiometers	Sea surface temperature	Frontal zones and filaments that is consistent with 3D ocean currents.
Envisat Jason 2	Altimetry	Sea surface height	Surface geostrophic current, global ocean circulation, mesoscale eddy variability
CHAMP GRACE GOCE	Accelerometer Gradiometer	Gravity Mass changes and geoid height	Reconstruction of bottom pressure and mean dynamic topography
Envisat TerraSAR	SAR InSAR	Doppler centroid shift	Retrieval of surface current
SMOS (Aquarius)	Passive microwaves	Surface salinity	Salinity fronts, freshwater sources, rain pools

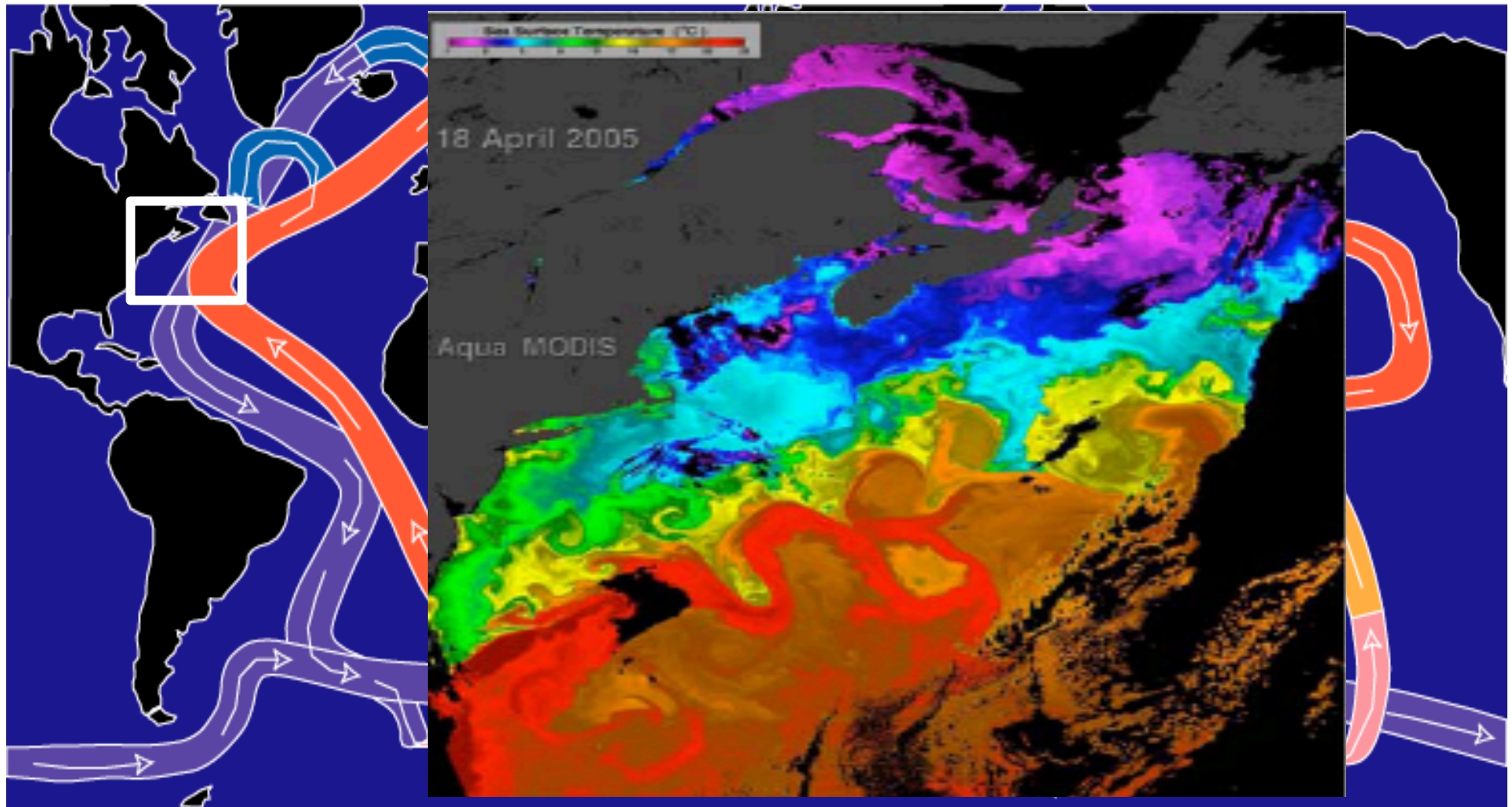
## 2003: Monthly mean ocean chlorophyll



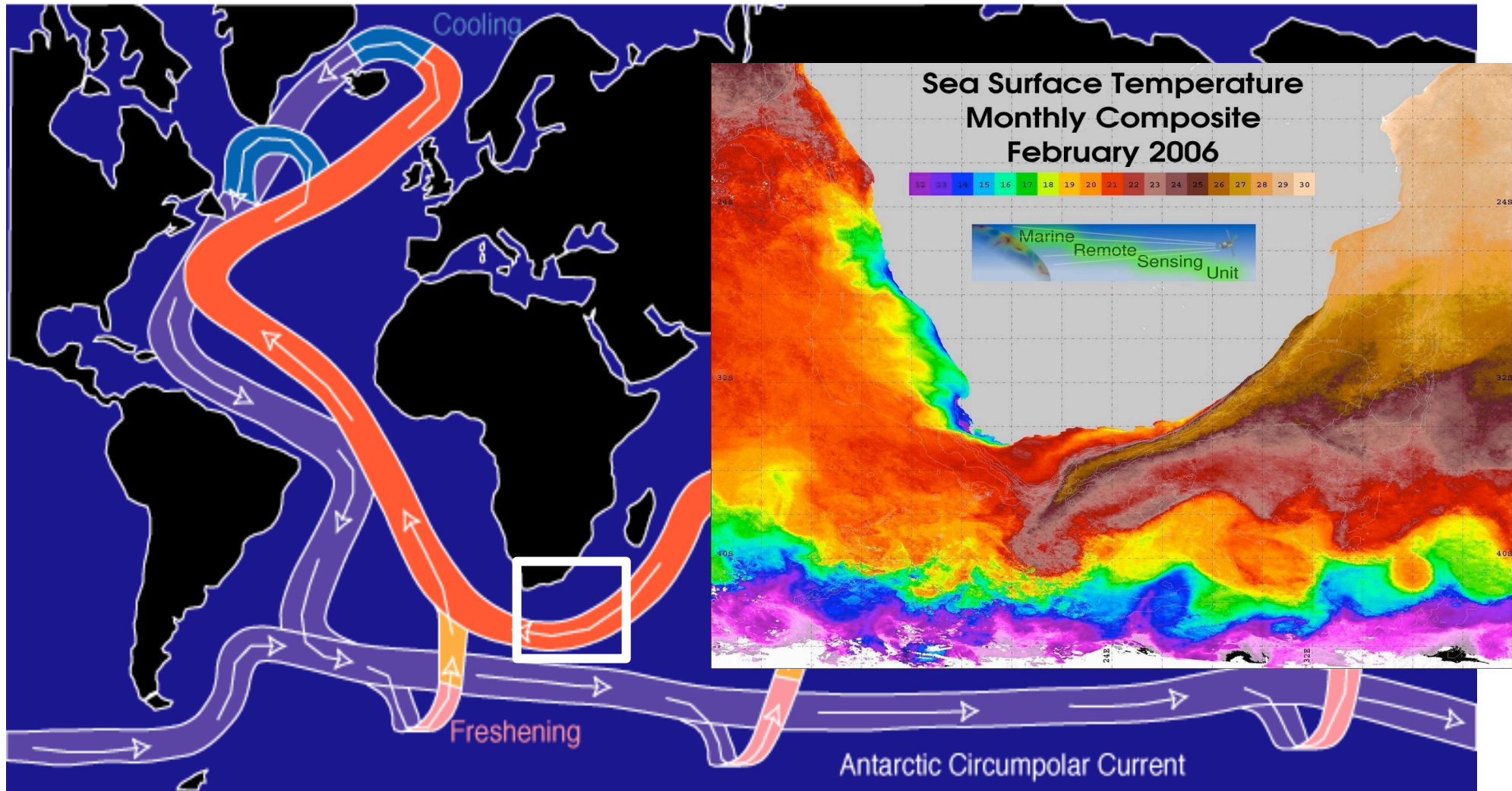
**Algae Bloom in the Barents Sea**



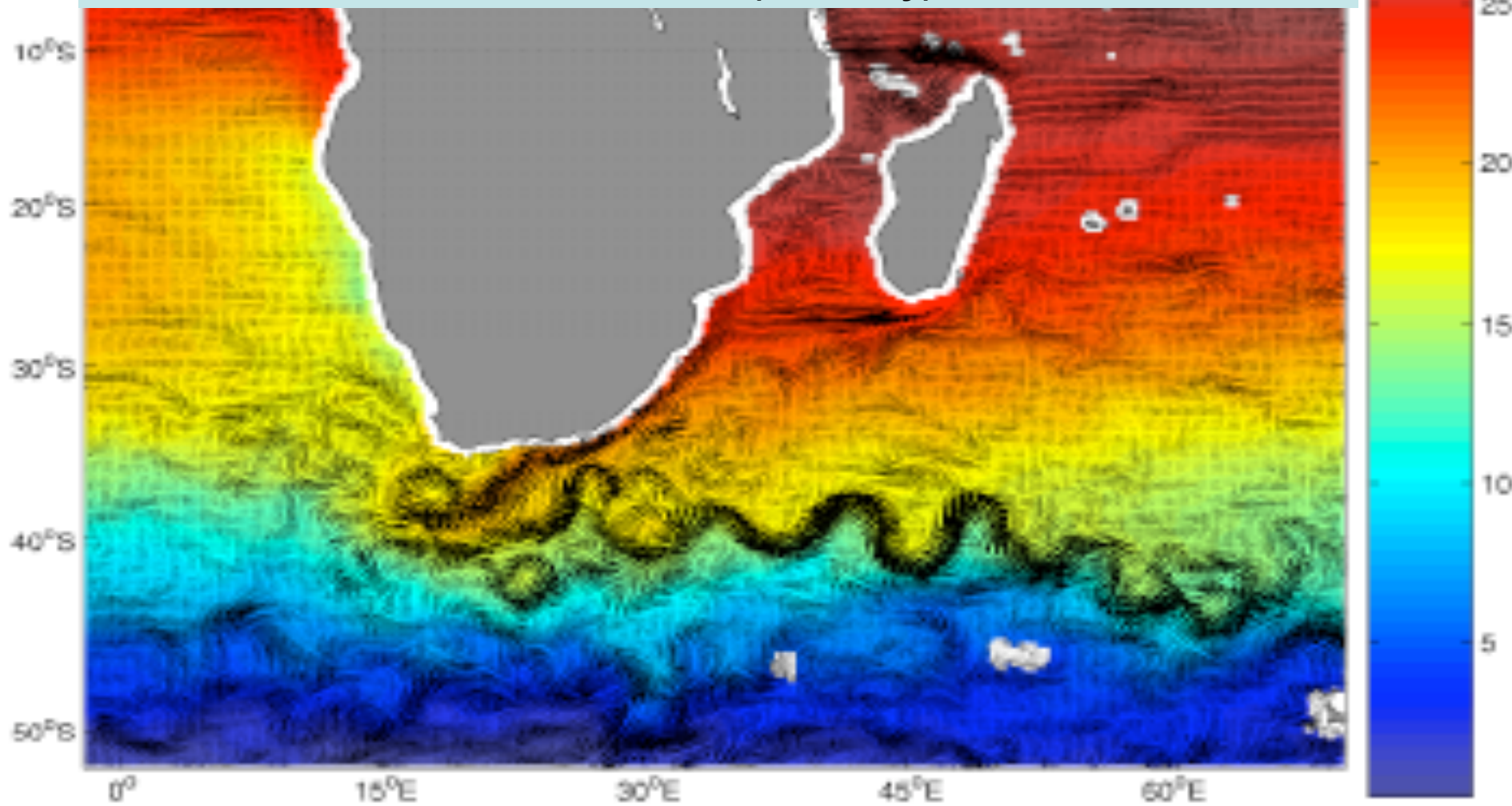
## GLOBAL OCEAN CIRCULATION – THE GULF STREAM



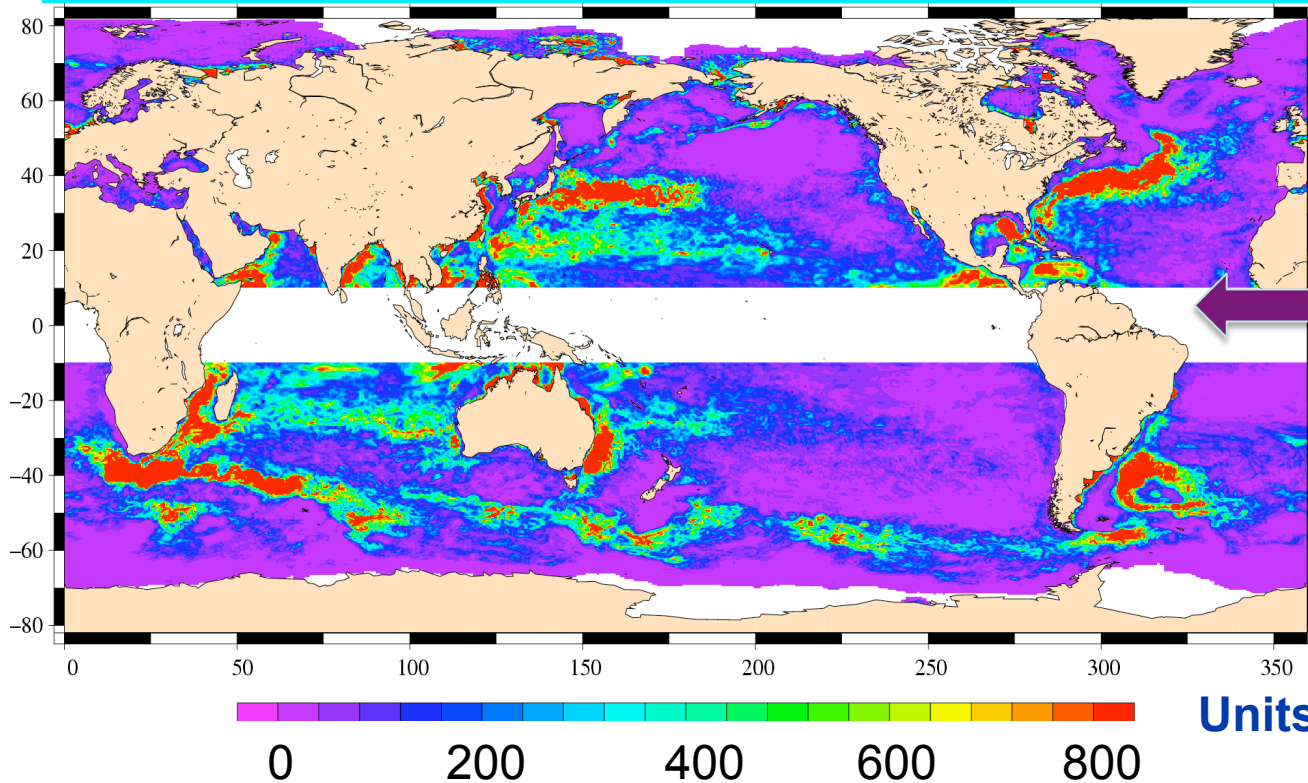
# GLOBAL OCEAN CIRCULATION – THE GREATER AGULHAS CURRENT



### SST FROM TMI-AMSR<sub>E</sub> with SLA (altimetry) + MDT from AVISO



# Monitoring the dominating ocean current regimes from Altimetry

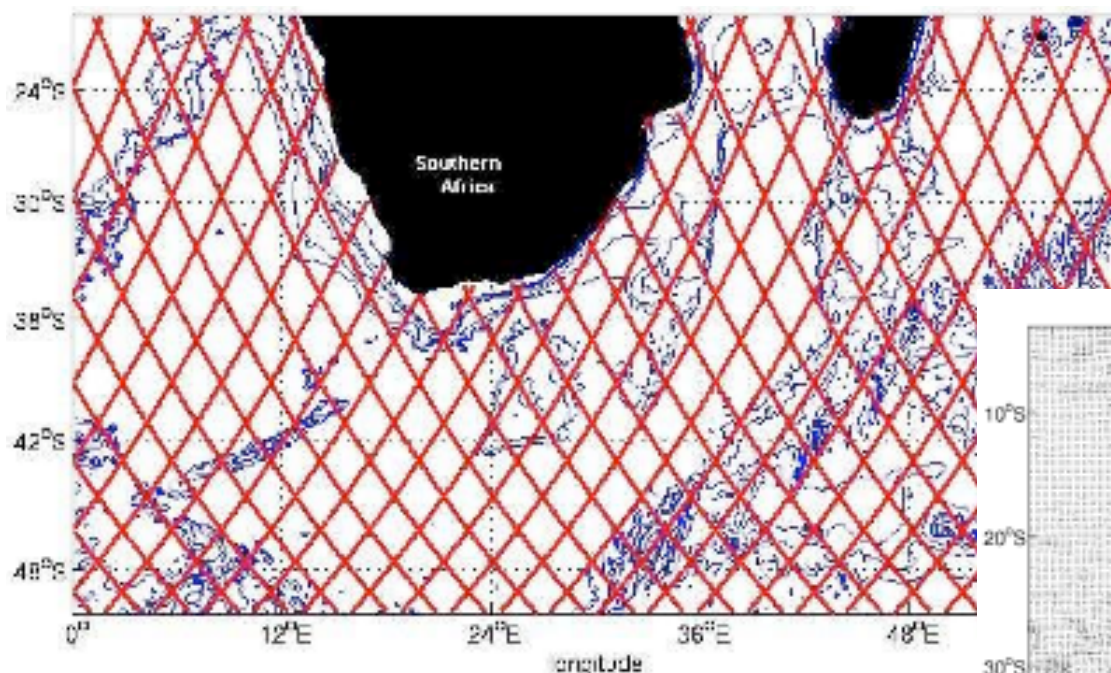


EDDY KINETIC ENERGY  
estimated with 4 satellite  
altimeters

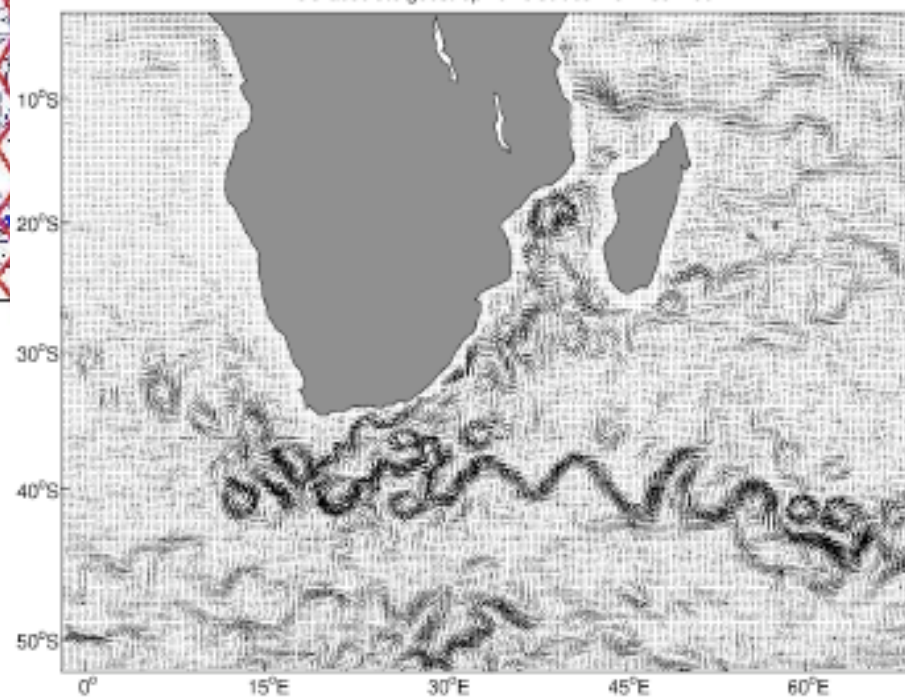
courtesy CLS

Currents redistribute and transport heat and volume.  
The Gulf Stream transport is about  $40 \text{ m}^3/\text{s}$ .

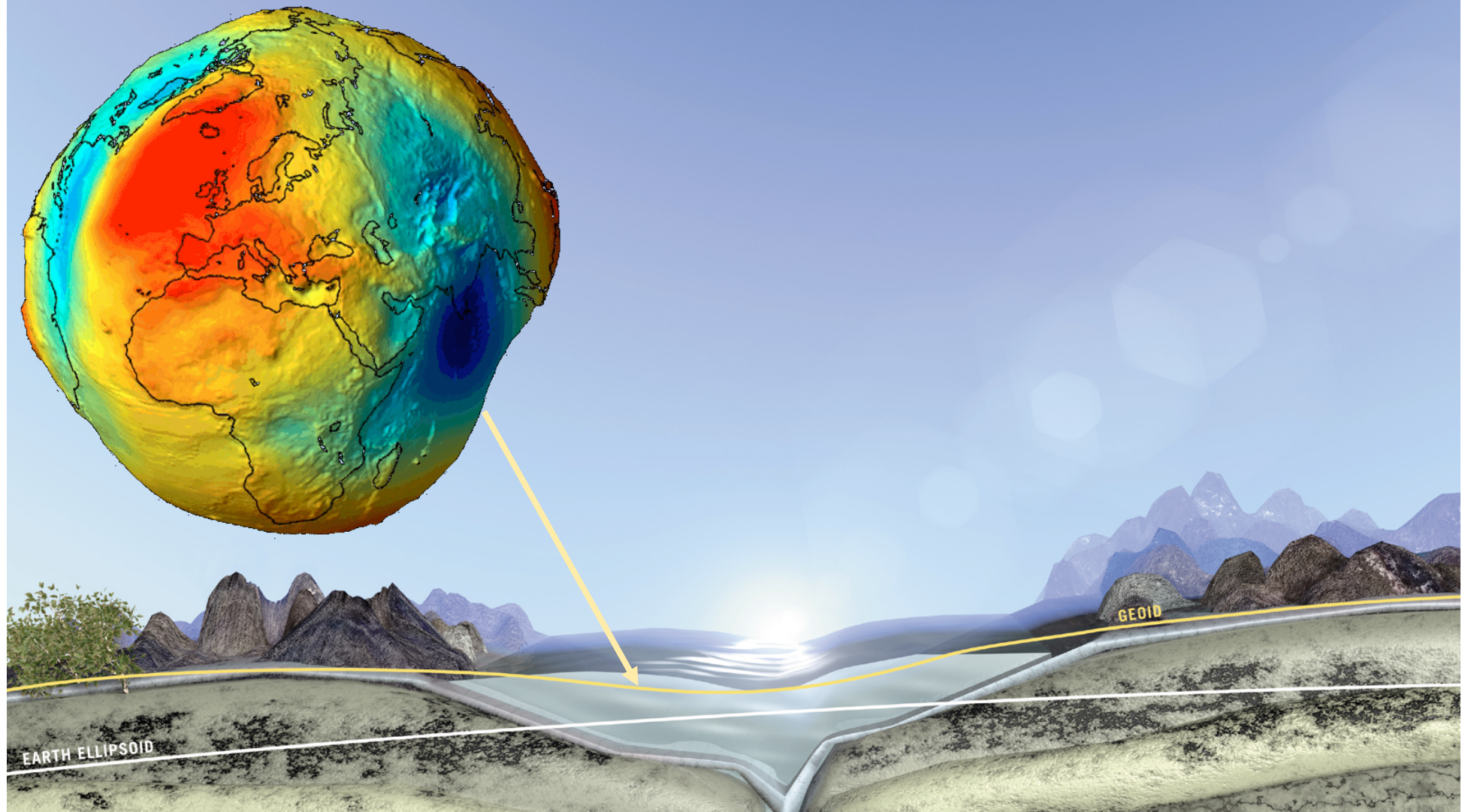
## WEEKLY SURFACE GEOSTROPHIC CURRENT FROM AVISO



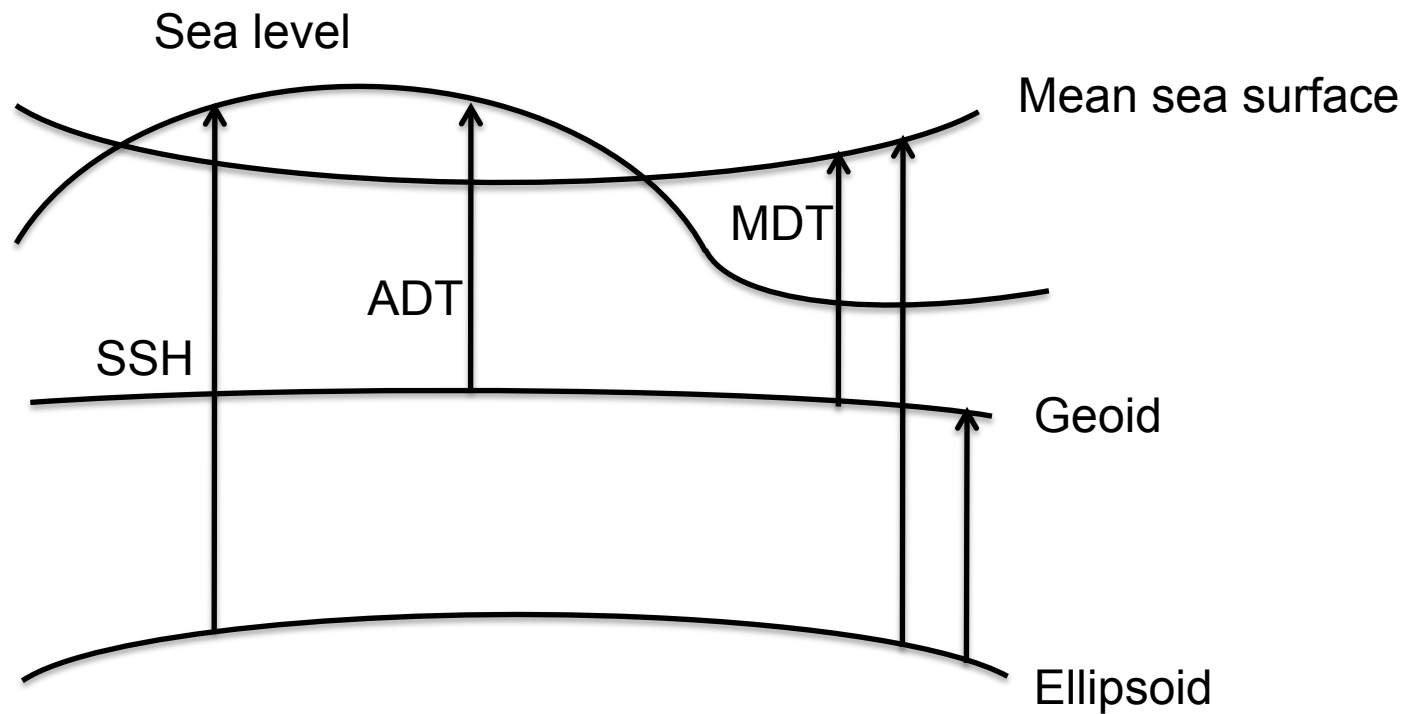
AVISO absolute geostrophic velocities: 25-Dec-2002



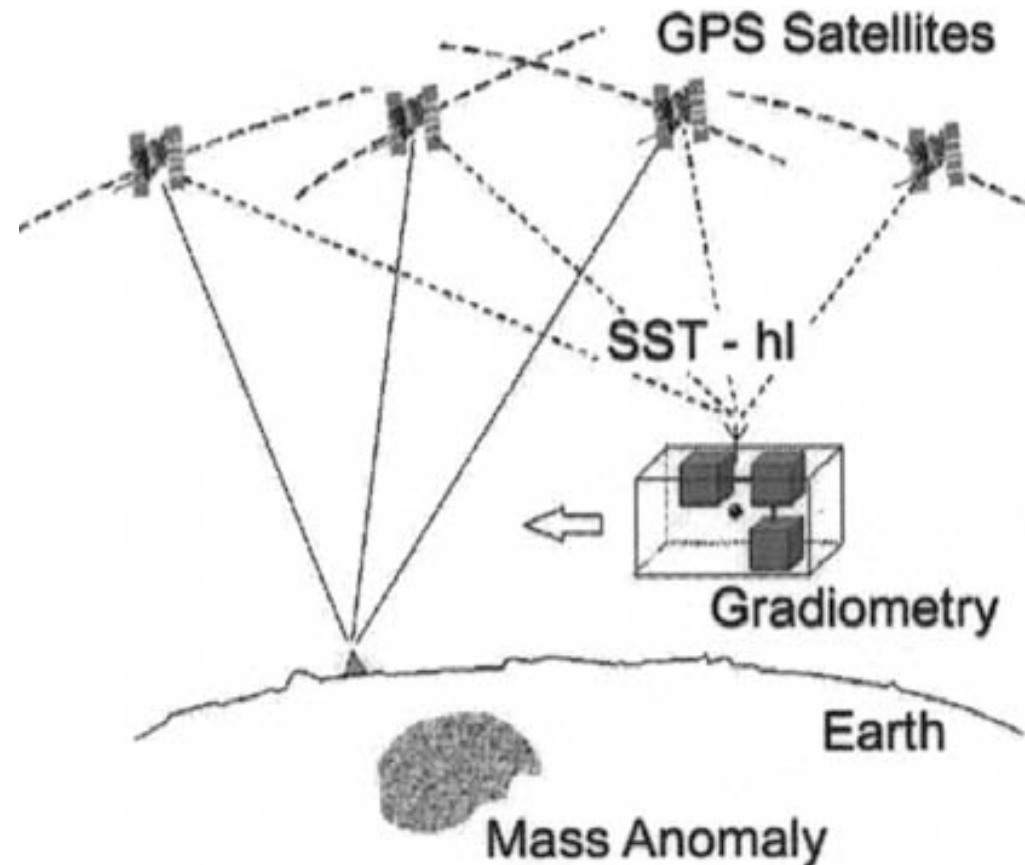
# The Earth Geoid



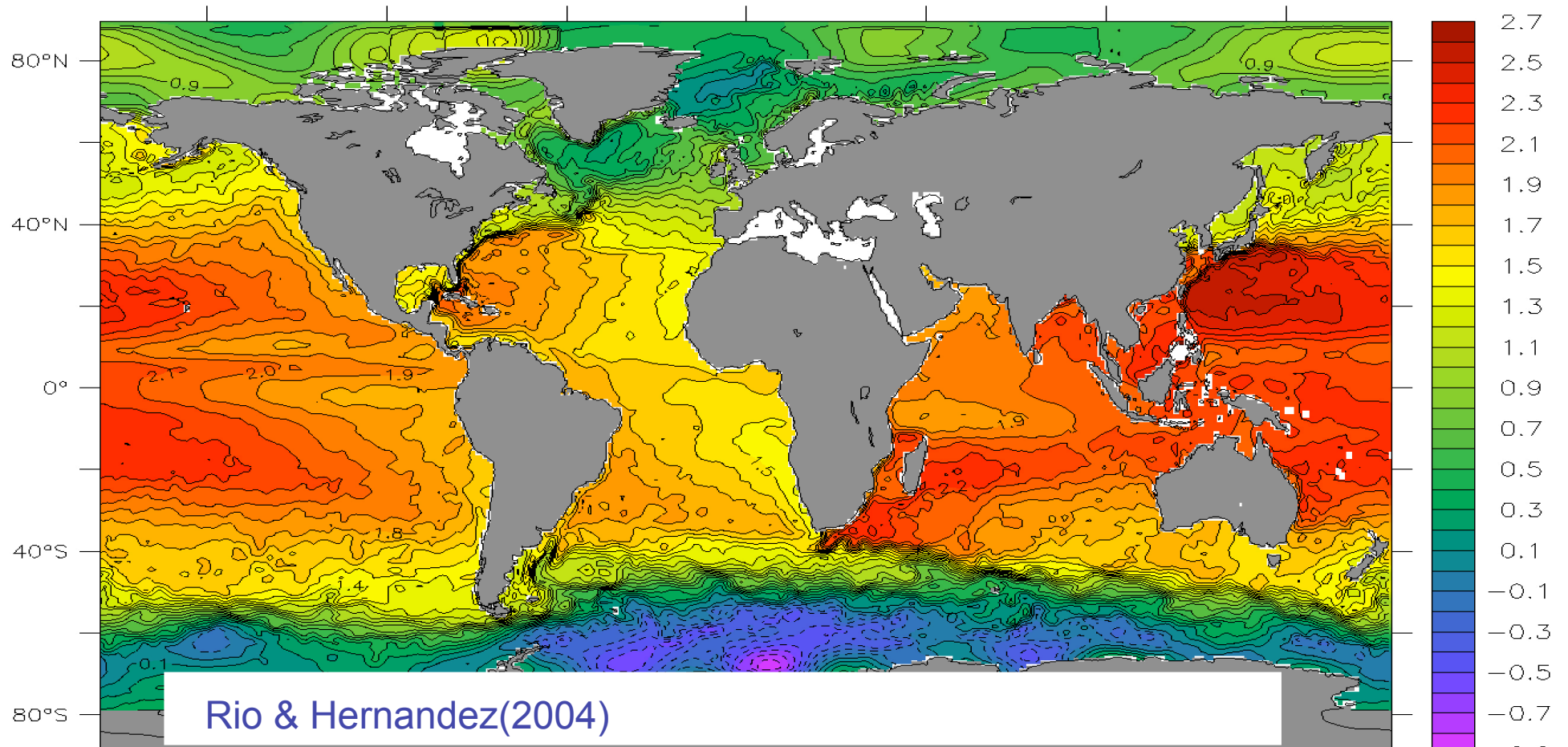
# Altimetry and gravity



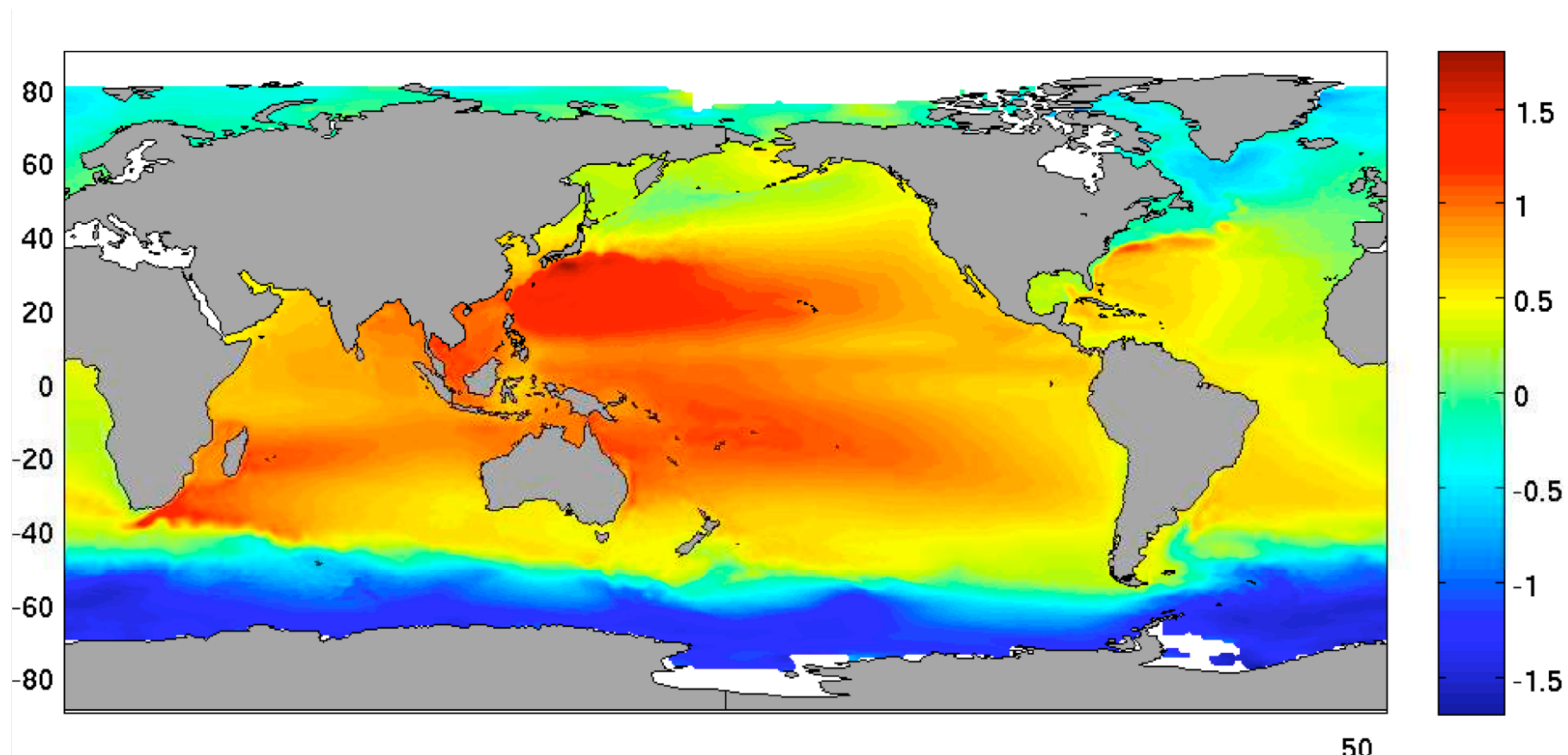
# GPS and Gradiometry – The GOCE concept



## Sea Surface Height a good proxy for near surface circulation

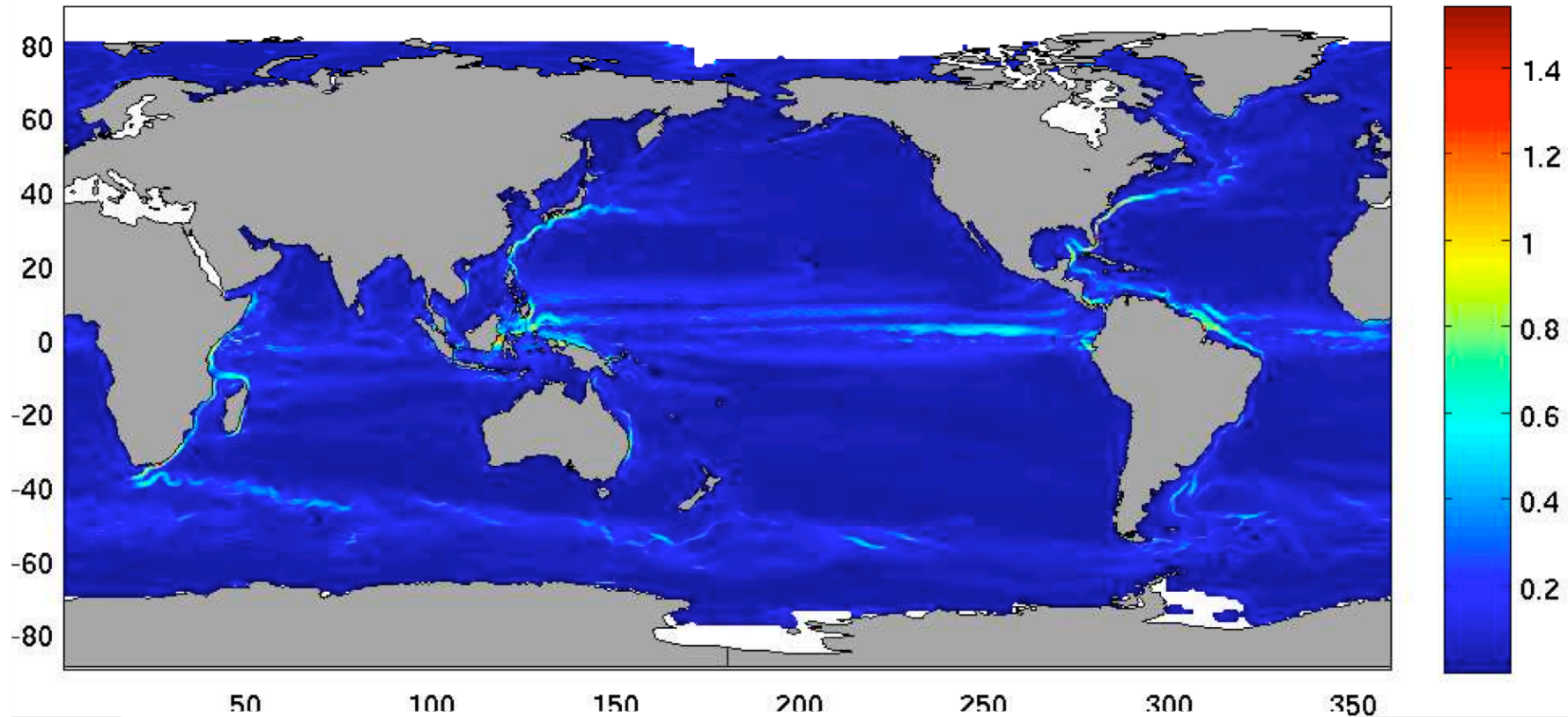


Sea Surface Height (m) a good proxy for near surface circulation



Rio et al (2009) , AVISO 2009

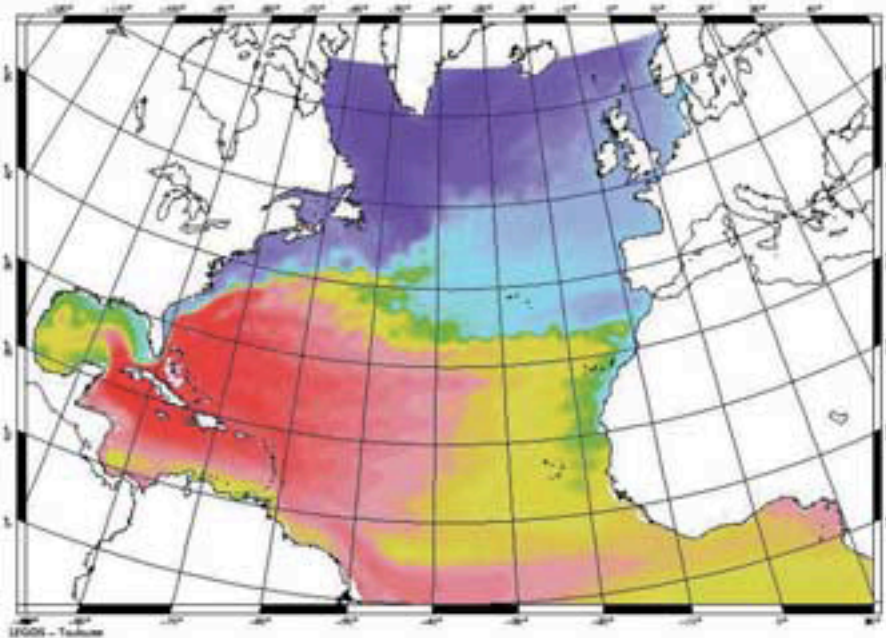
## Surface Geostrophic Current (m/s)



Rio et al (2009) , AVISO 2009

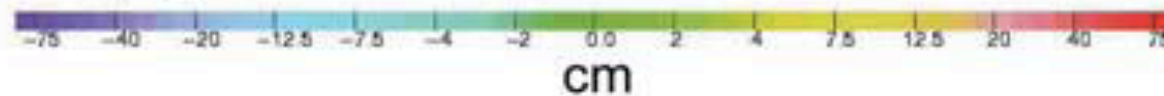
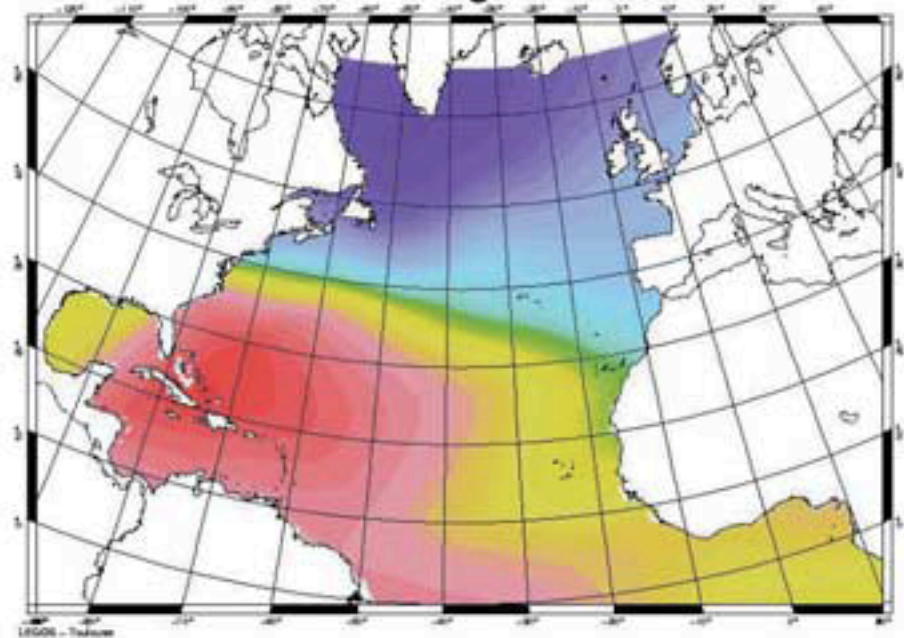
Mean dynamic topography (cm)

(a) MICOM Simulation ( $1/12^\circ$ ) - Year 14

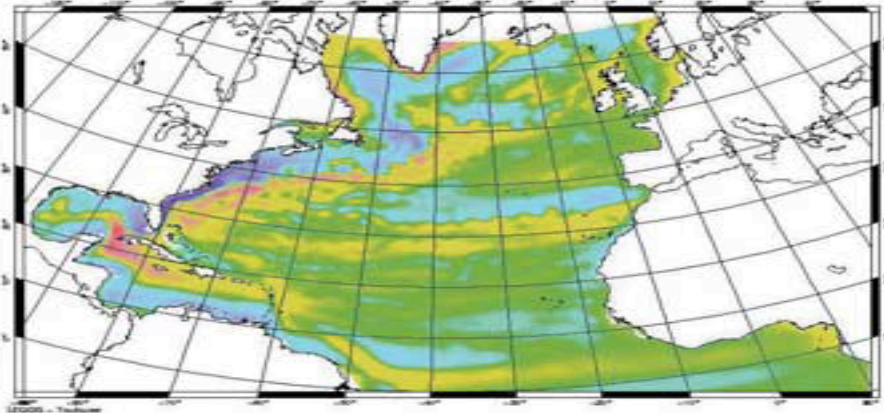


Mean dynamic topography (cm)

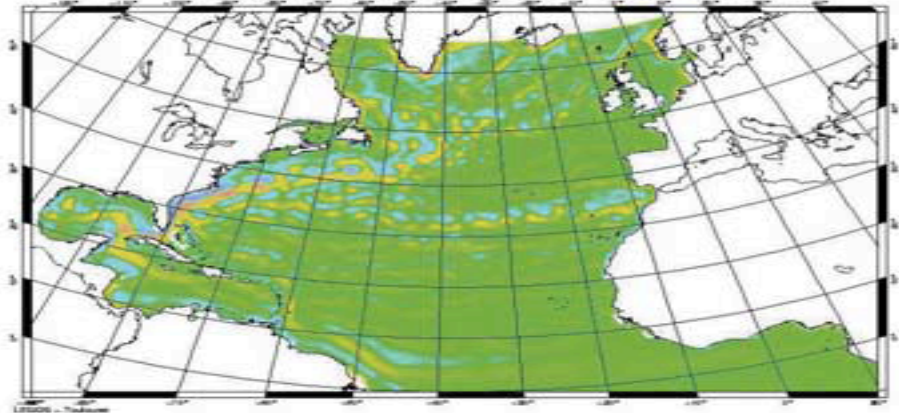
(b) MICOM Simulation ( $1/12^\circ$ ) - Year 14  
Half-wavelength > 1000 km



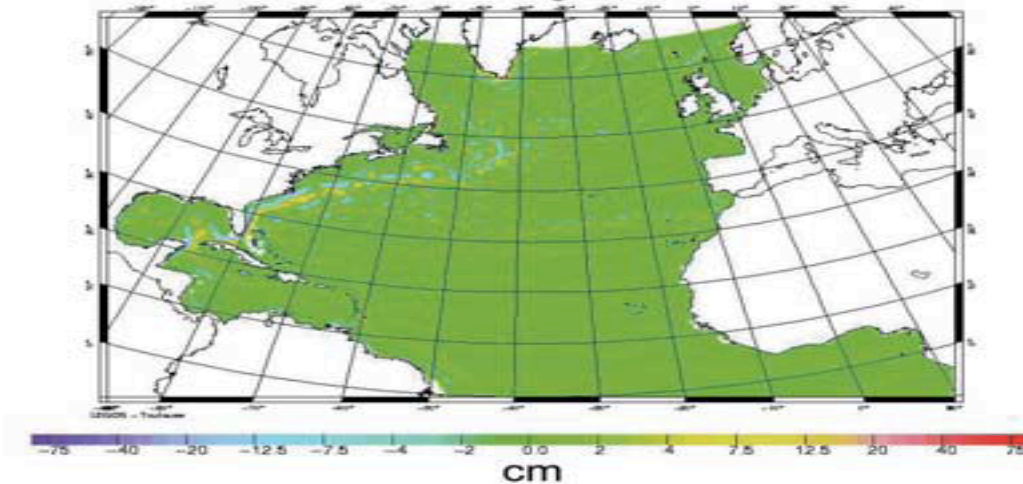
Mean dynamic topography (cm)  
(c) MICOM Simulation ( $1/12^\circ$ ) - Year 14  
Half-wavelength < 1000 km



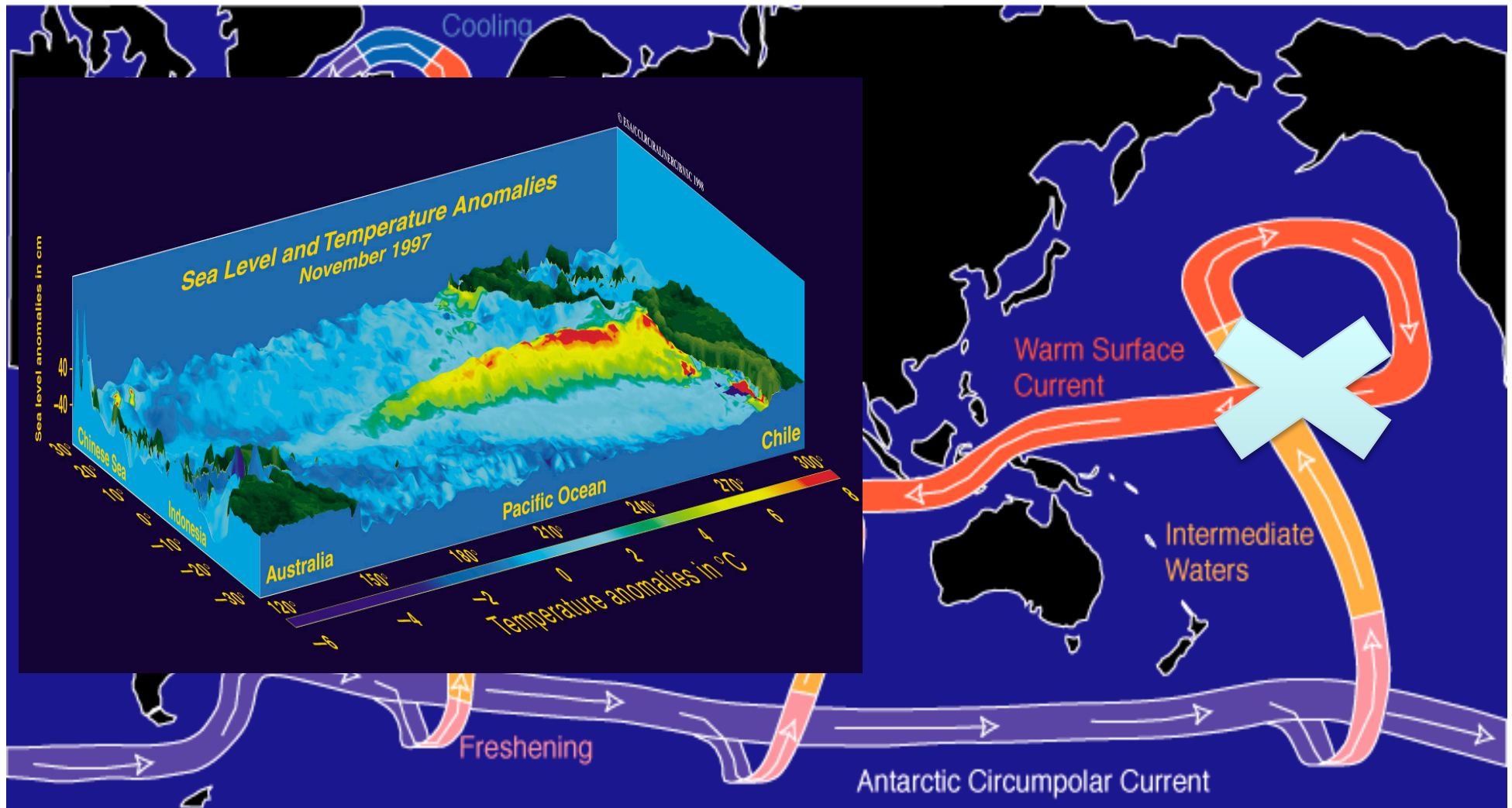
Mean dynamic topography (cm)  
(d) MICOM Simulation ( $1/12^\circ$ ) - Year 14  
Half-wavelength < 250 km



Mean dynamic topography (cm)  
(e) MICOM Simulation ( $1/12^\circ$ ) - Year 14  
Half-wavelength < 100 km



# GLOBAL OCEAN CIRCULATION – THE EL NINO CONDITION



## What is causing sea level change

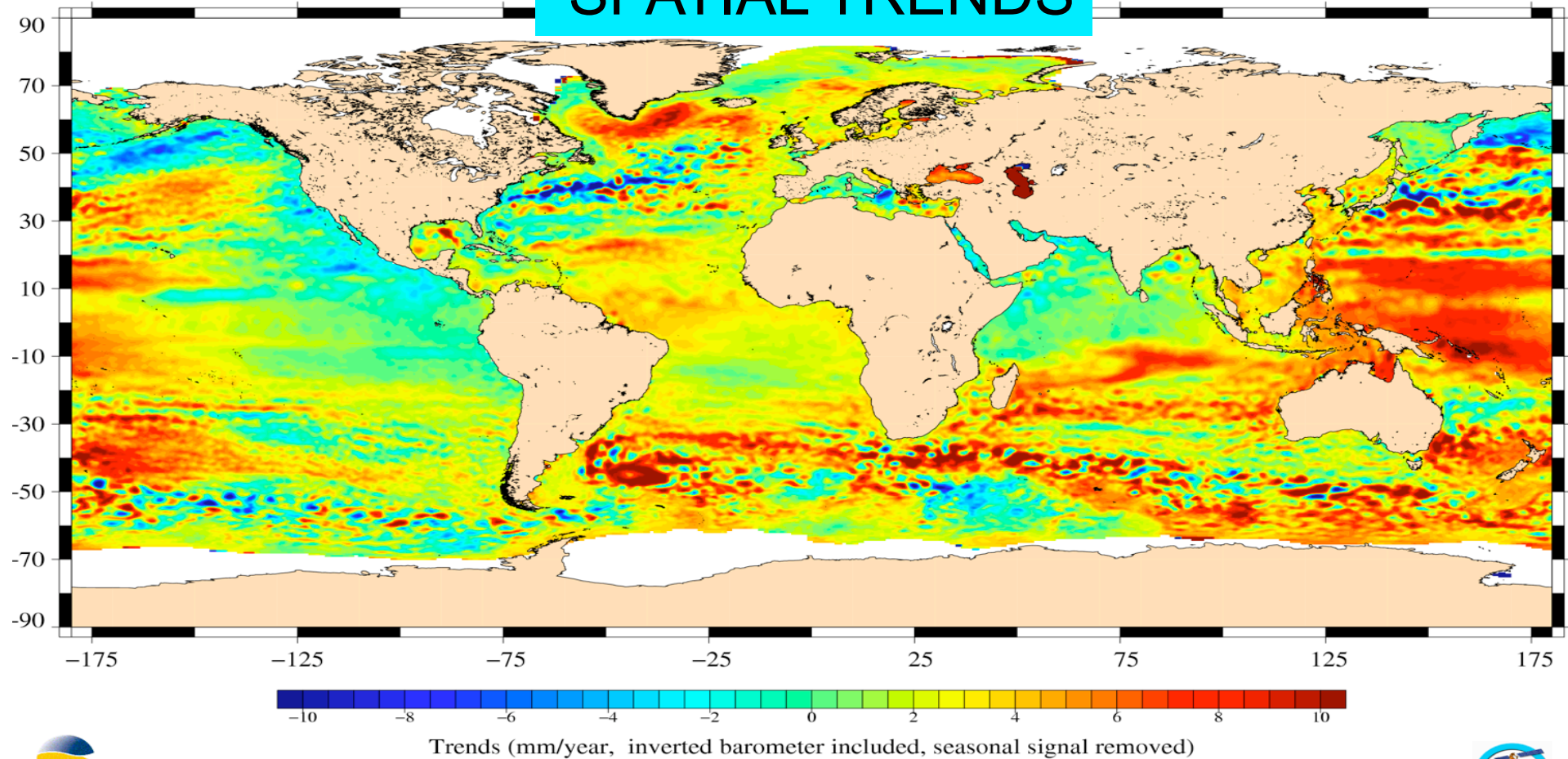
- **Change in** sea water density and ocean current

Temperature Salinity

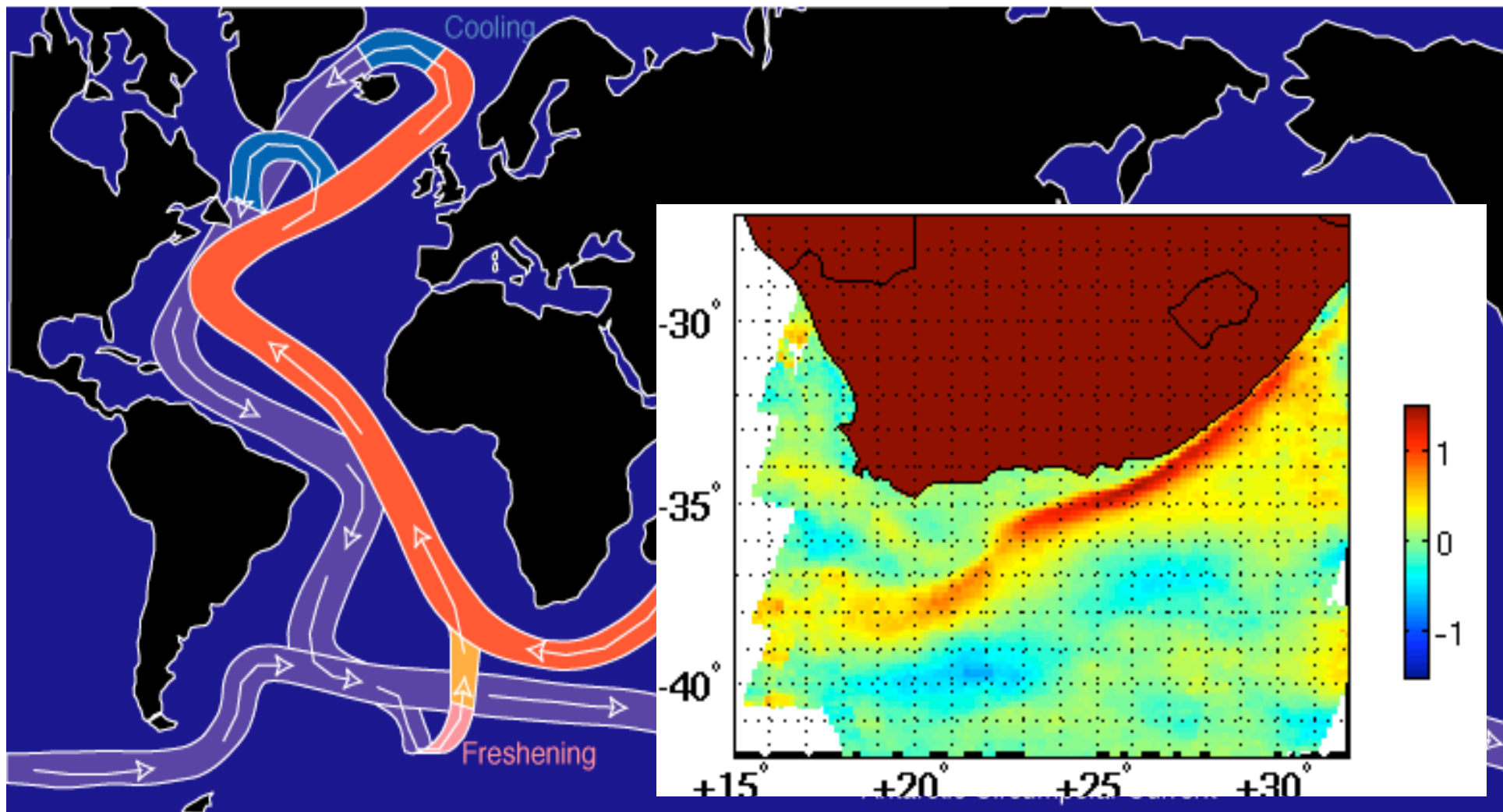
- **Change in** ocean mass

Water mass exchange with terrestrial reservoirs, mountain glaciers and ice sheets

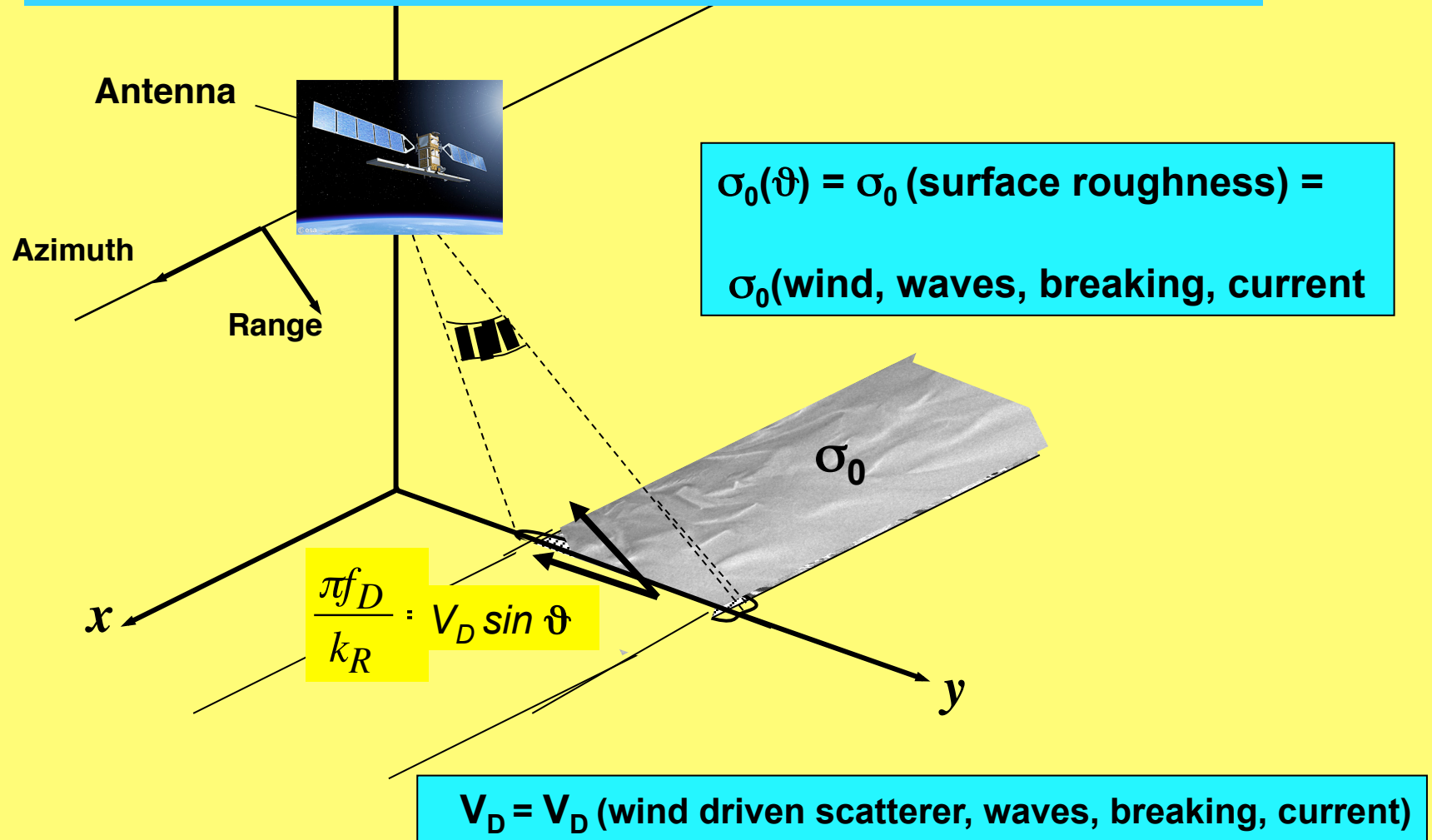
# SPATIAL TRENDS



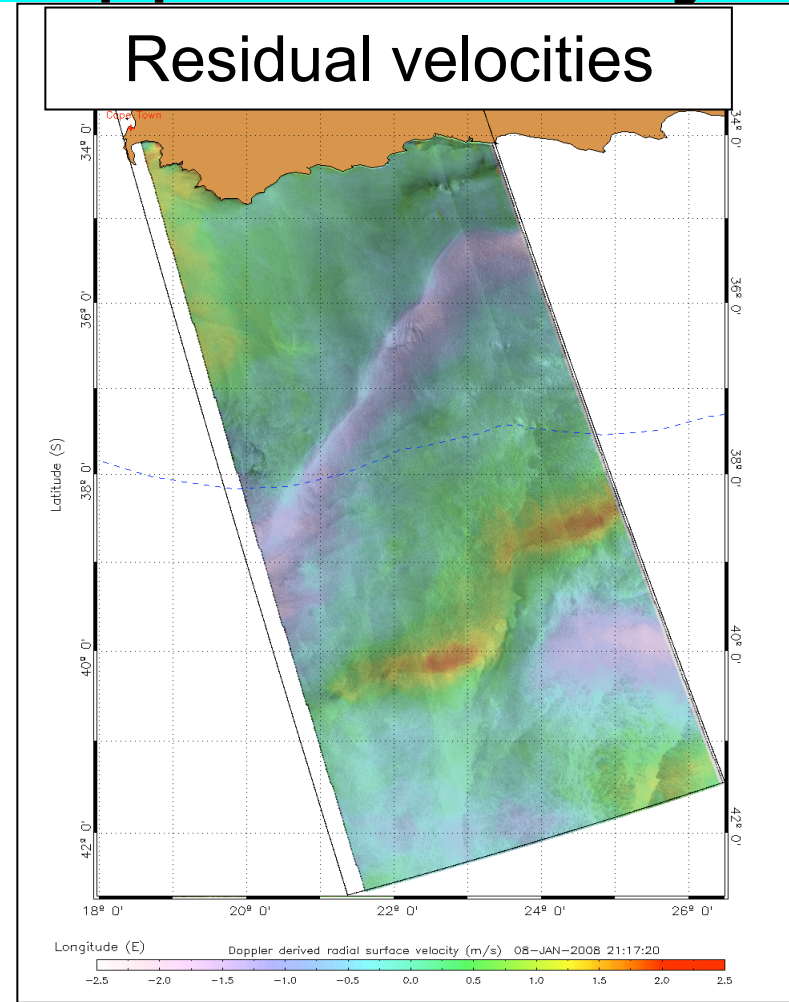
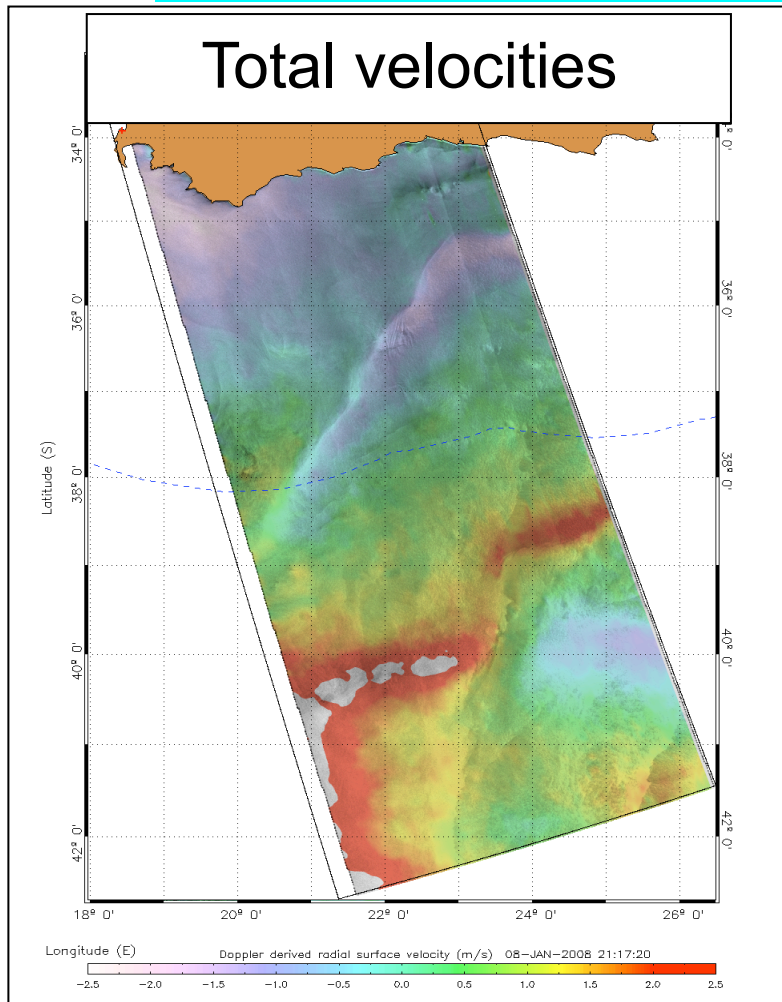
## GLOBAL OCEAN CIRCULATION – THE GREATER AGULHAS CURRENT



## APPROACH: SAR Imaging of Roughness and Doppler Shift

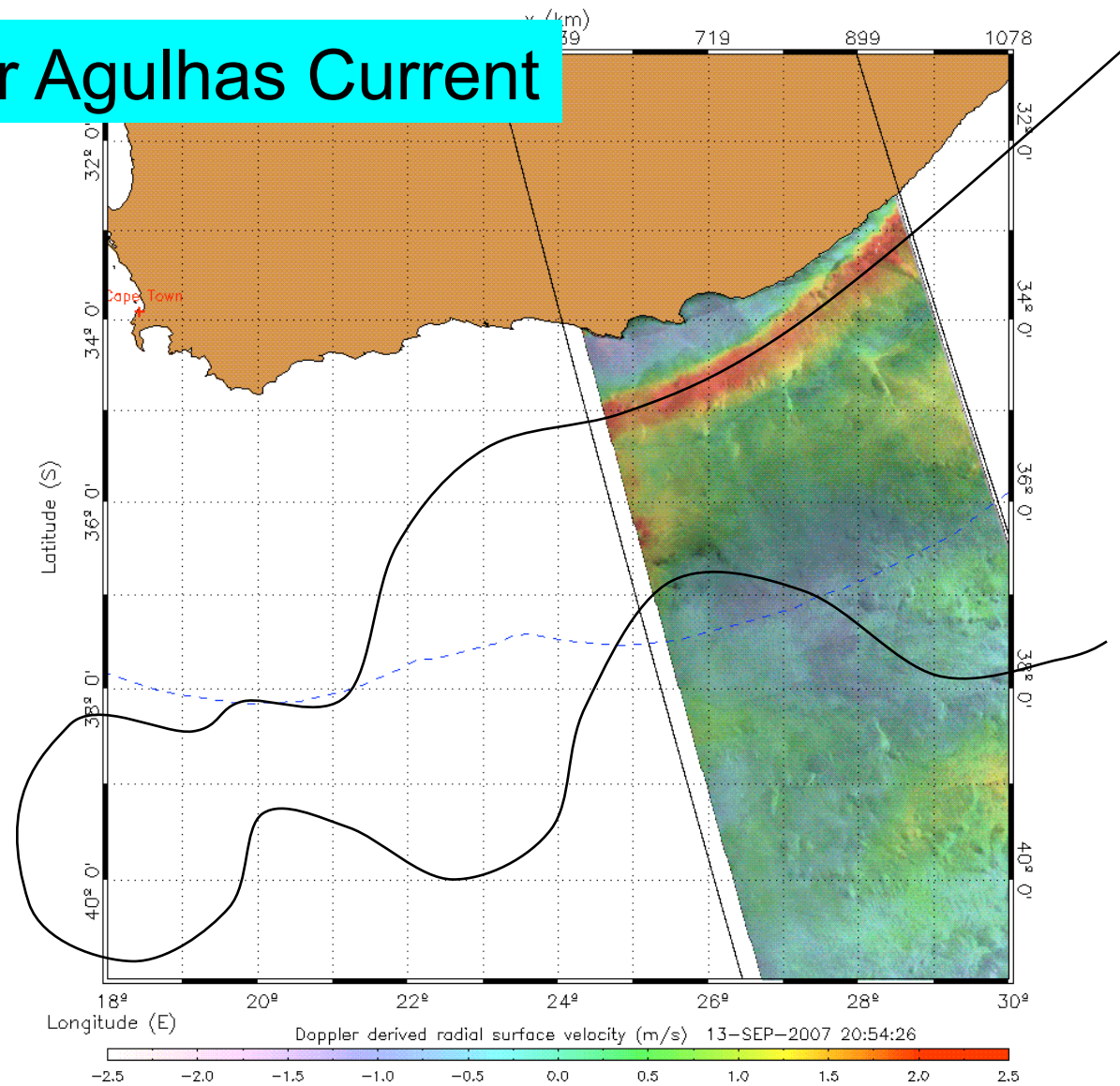


# Wind corrected Doppler velocity



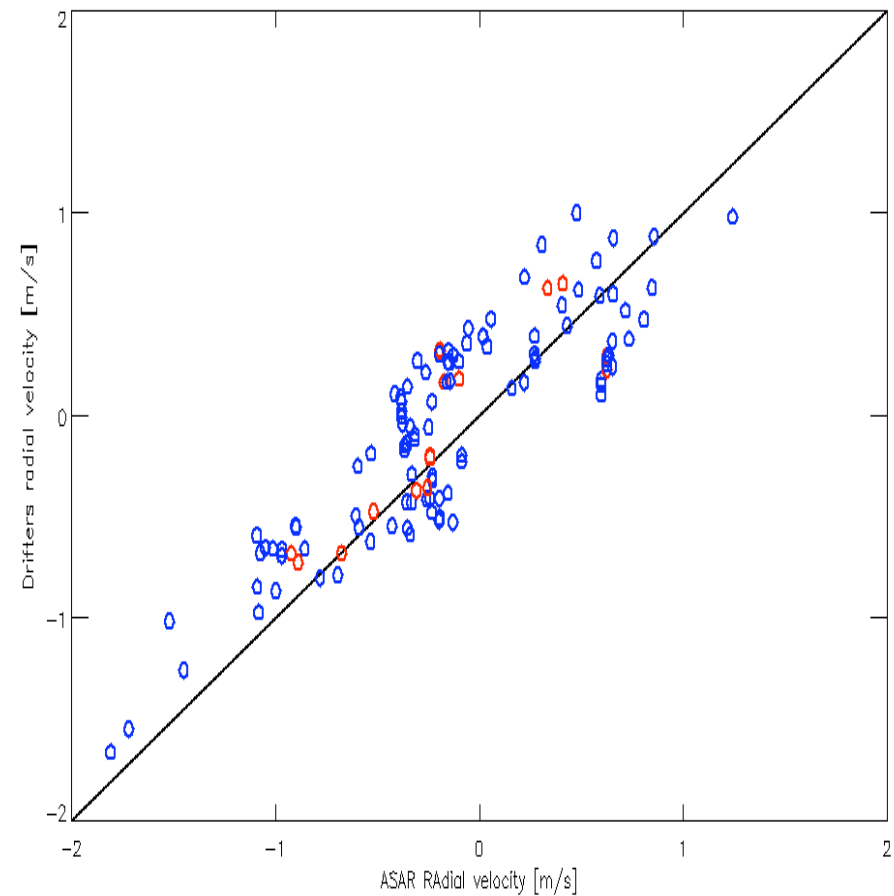
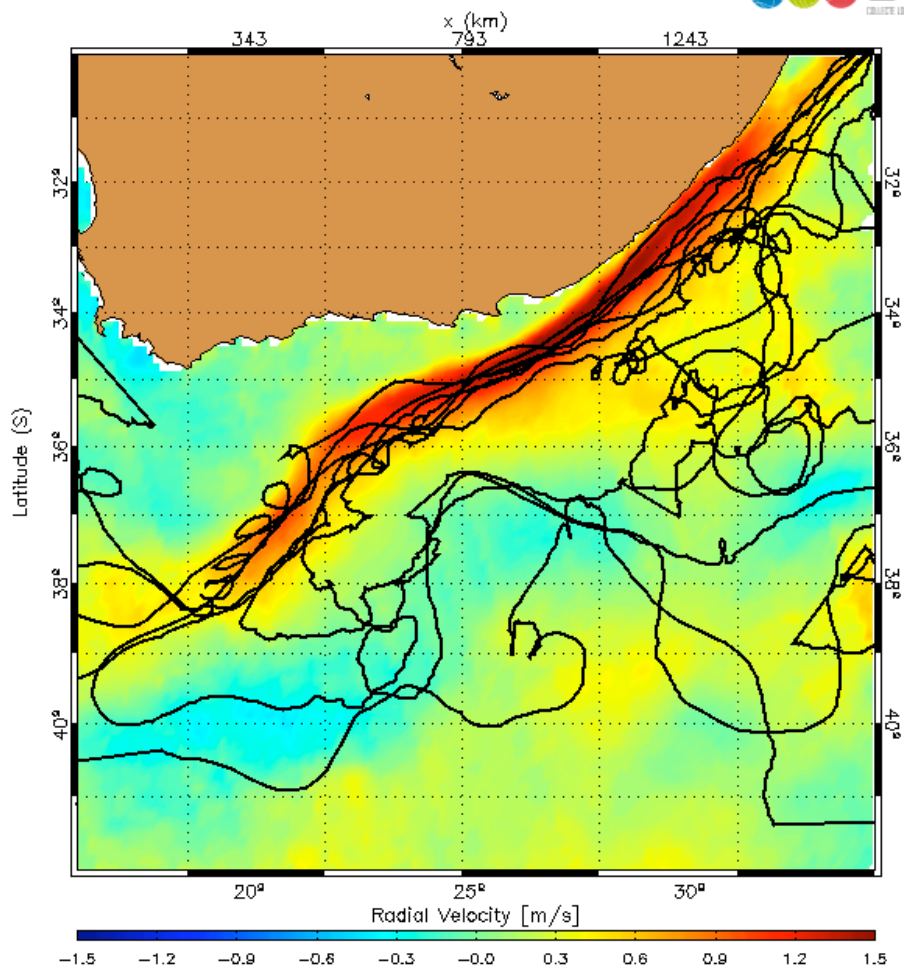
# The greater Agulhas Current

Direct measurements of surface flow of the Greater Agulhas Current as obtained from ASAR Wide Swath Mode on 13, 16, 19 and 22 September 2007. The radial surface velocity is marked in the colour bar in metres per second.

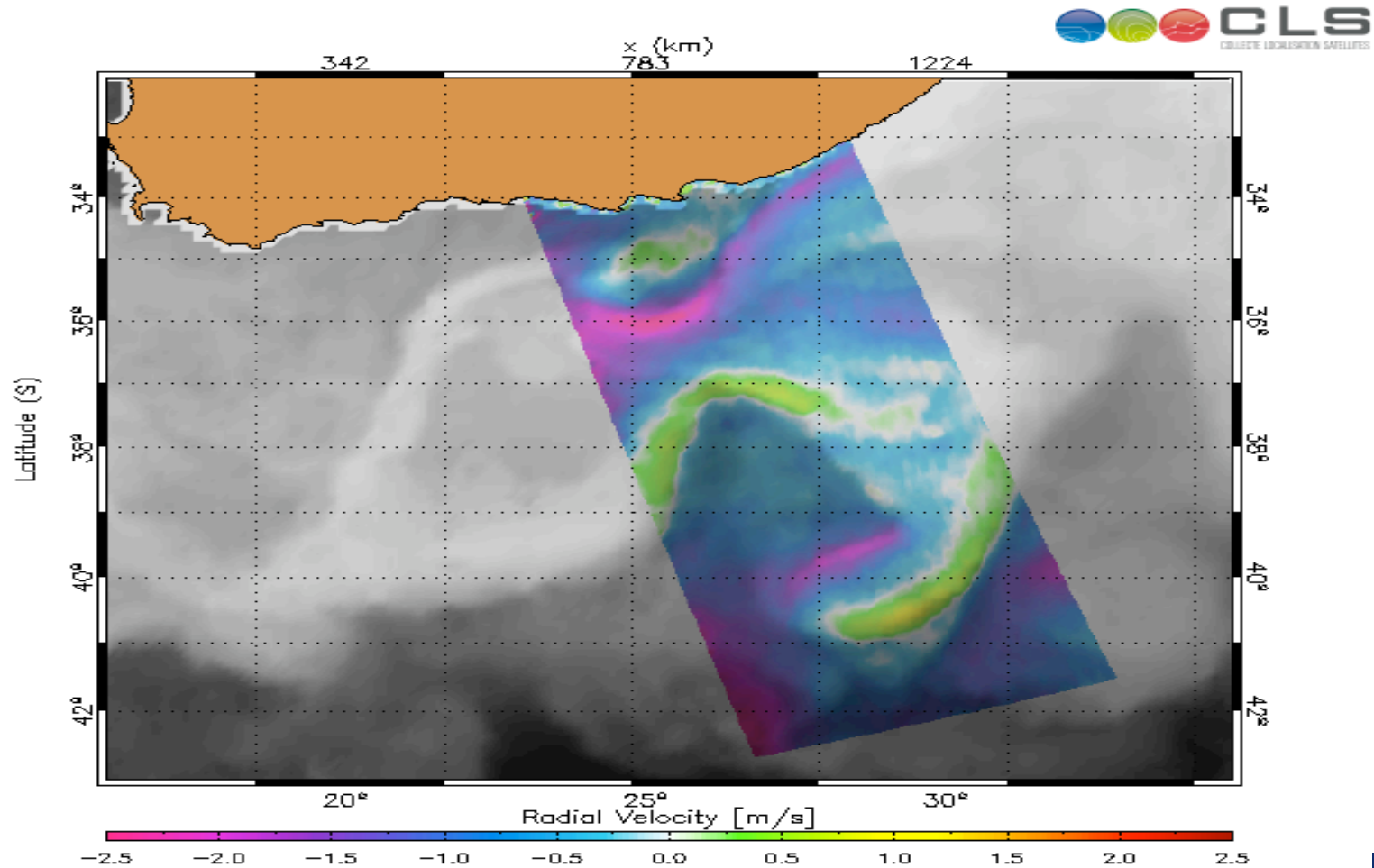


Johannessen et al., 2008

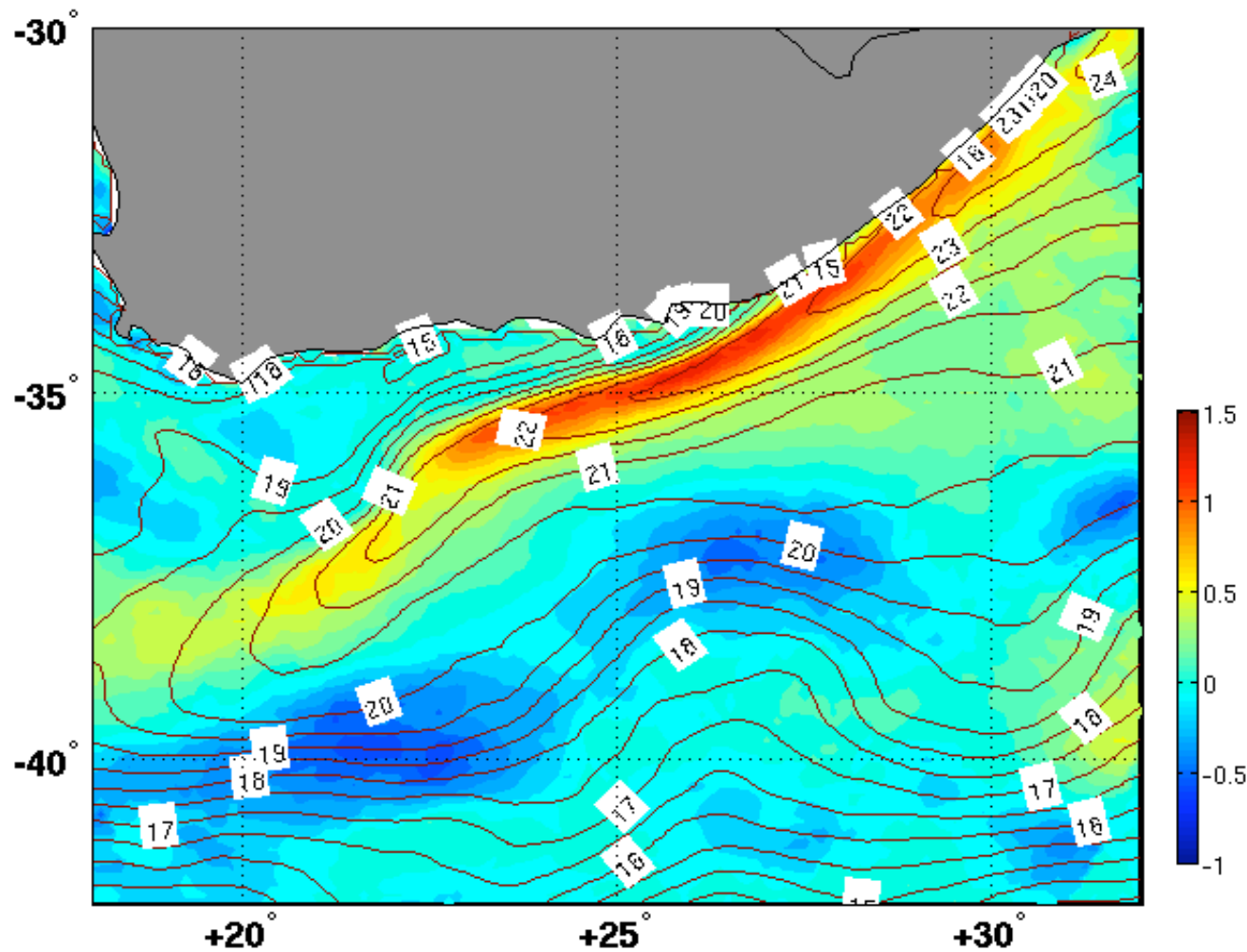
# Surface drifter trajectory and ASAR range Doppler velocity



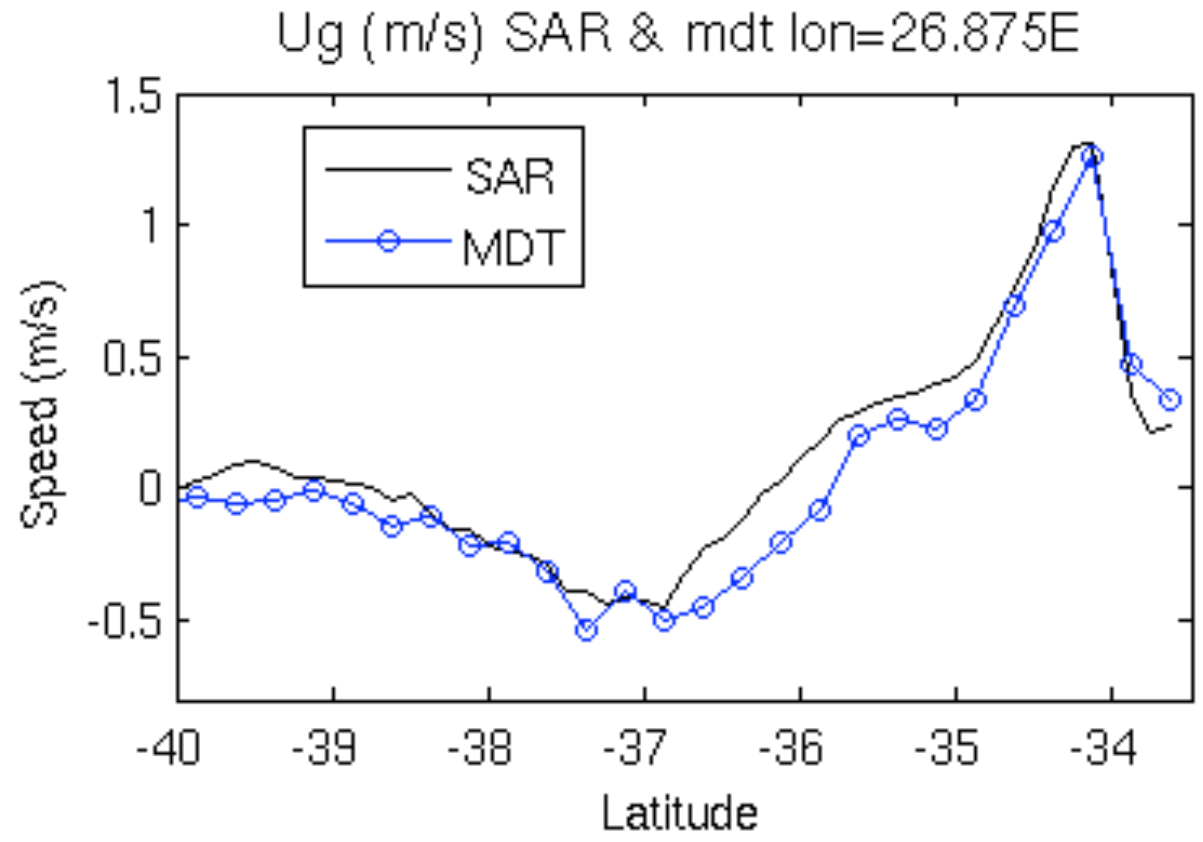
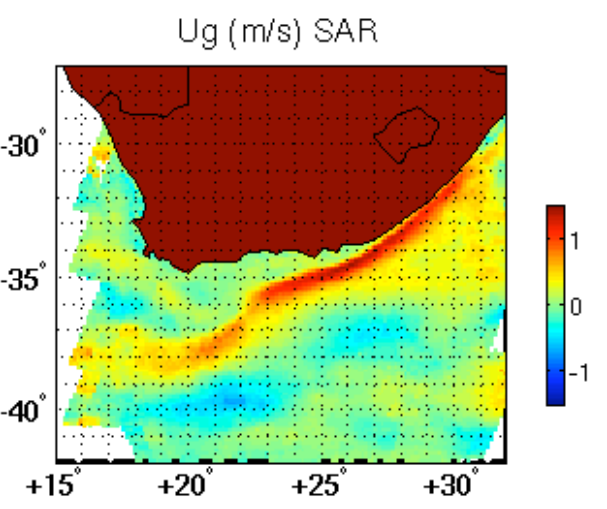
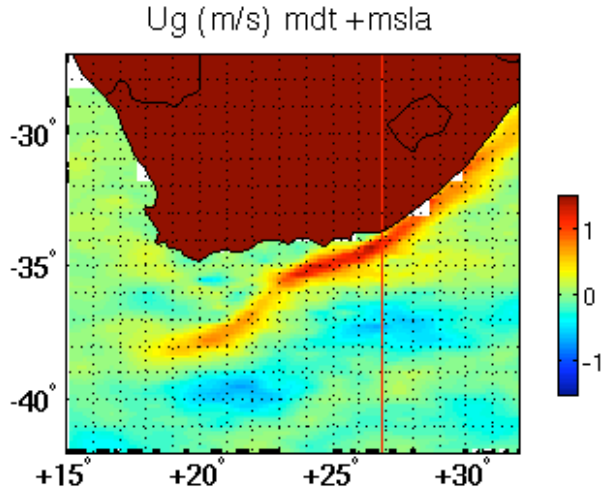
# SST and range Doppler velocity overlay – 14 April 2009

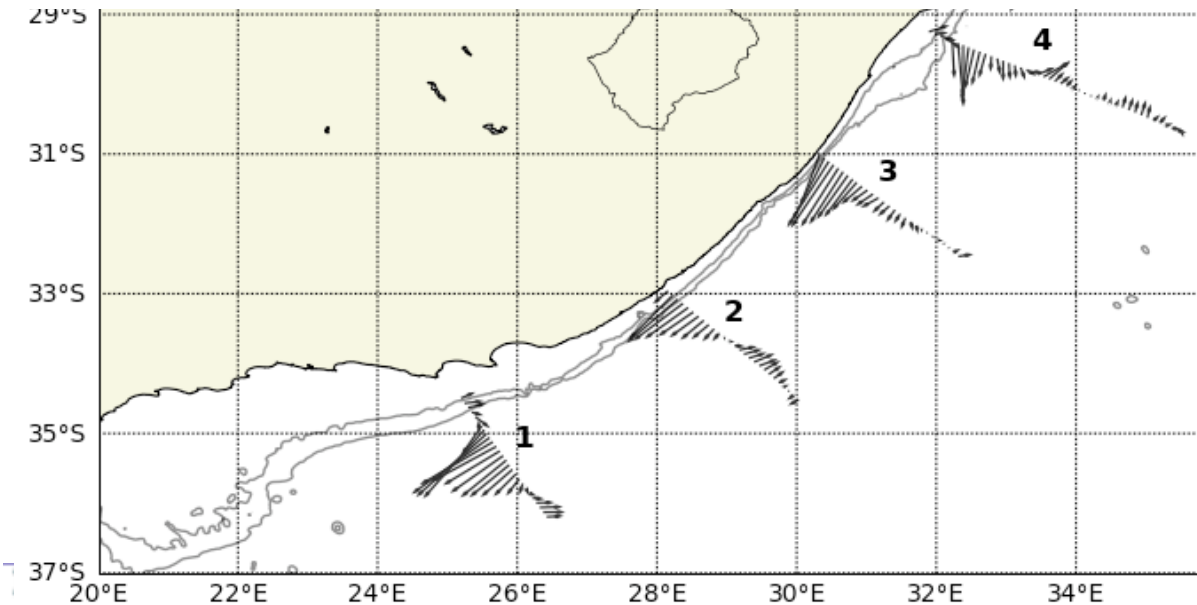
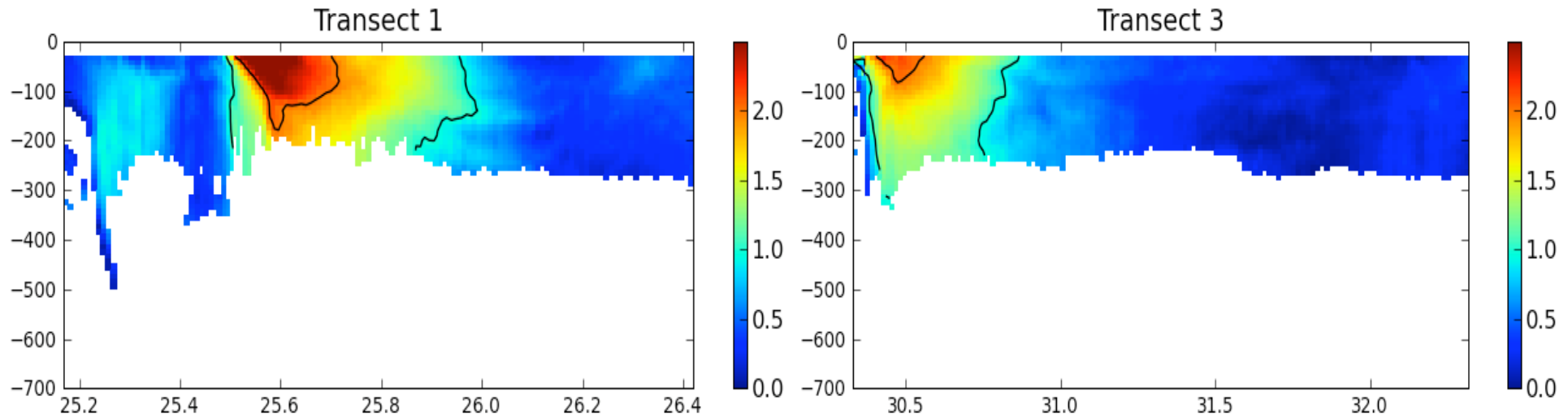


# Climatology: Range Doppler velocity & Sea Surface Temperature



# Doppler zonal velocity and MDT Geos. Current

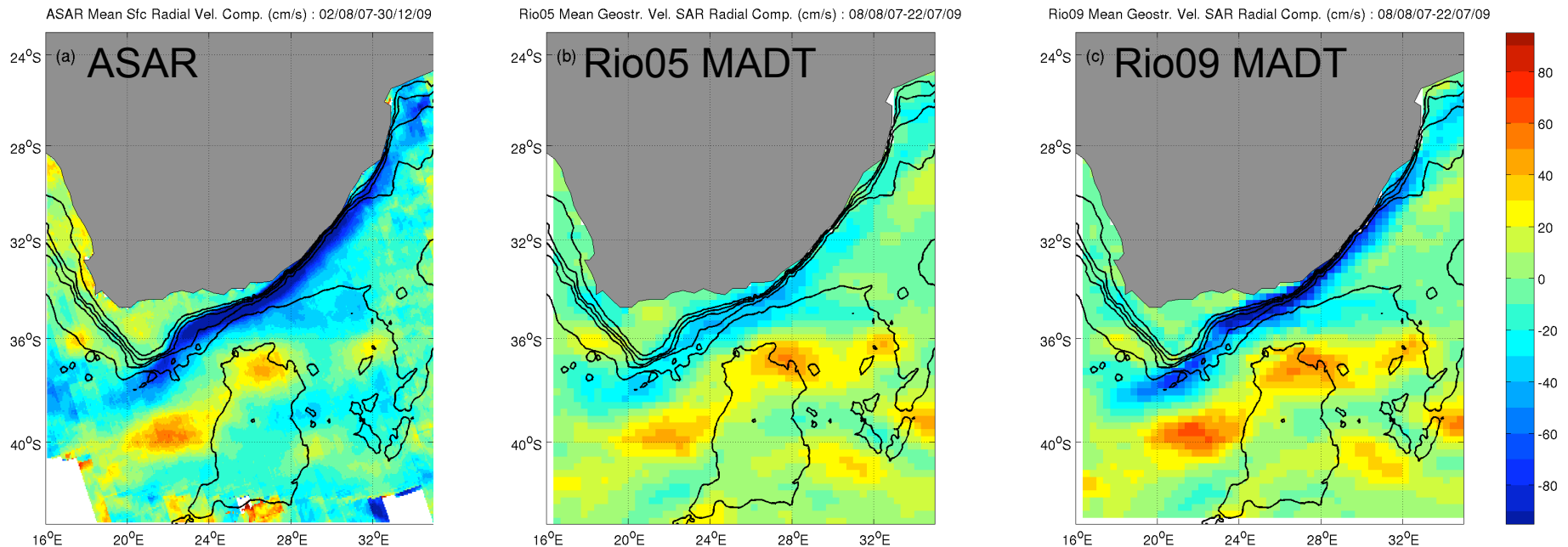




Courtesy Beal from AUCE campaign

## Rio05 / Rio09 MADT and SAR velocity comparison

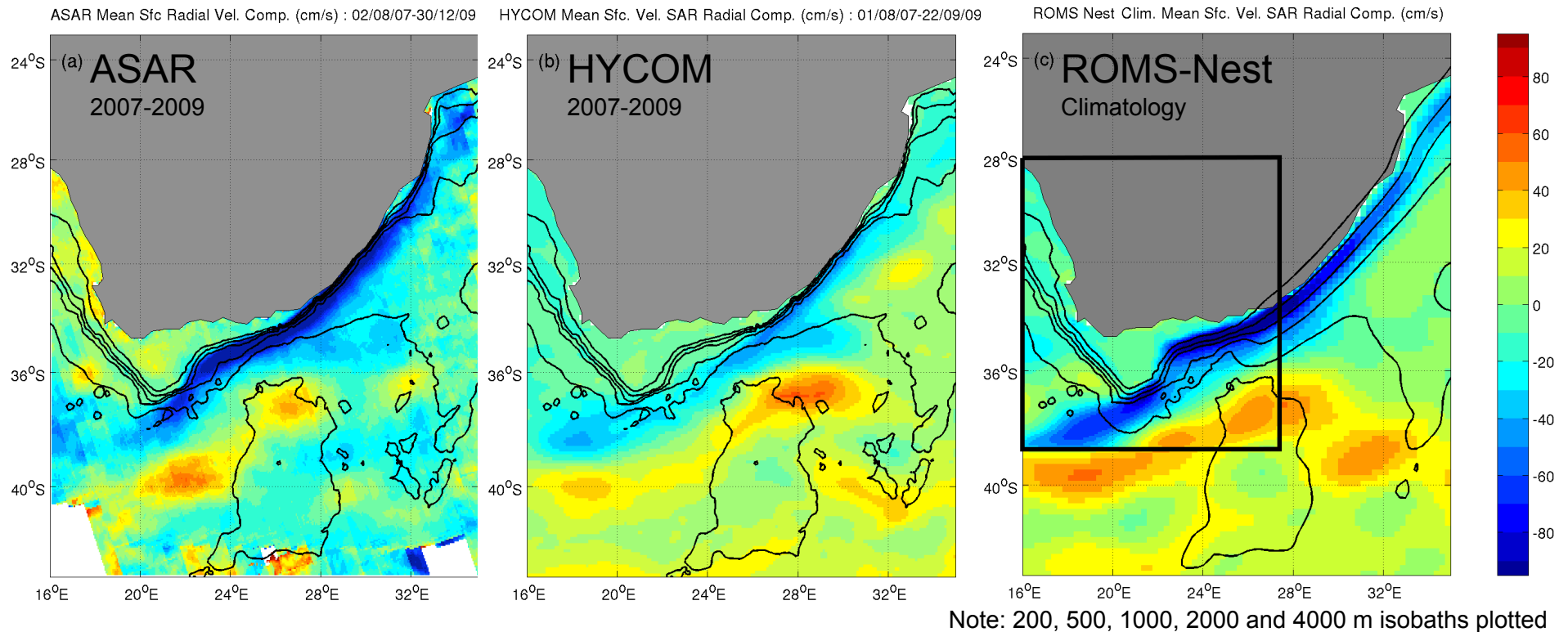
### Mean Radial Velocity Component for 2007-2009



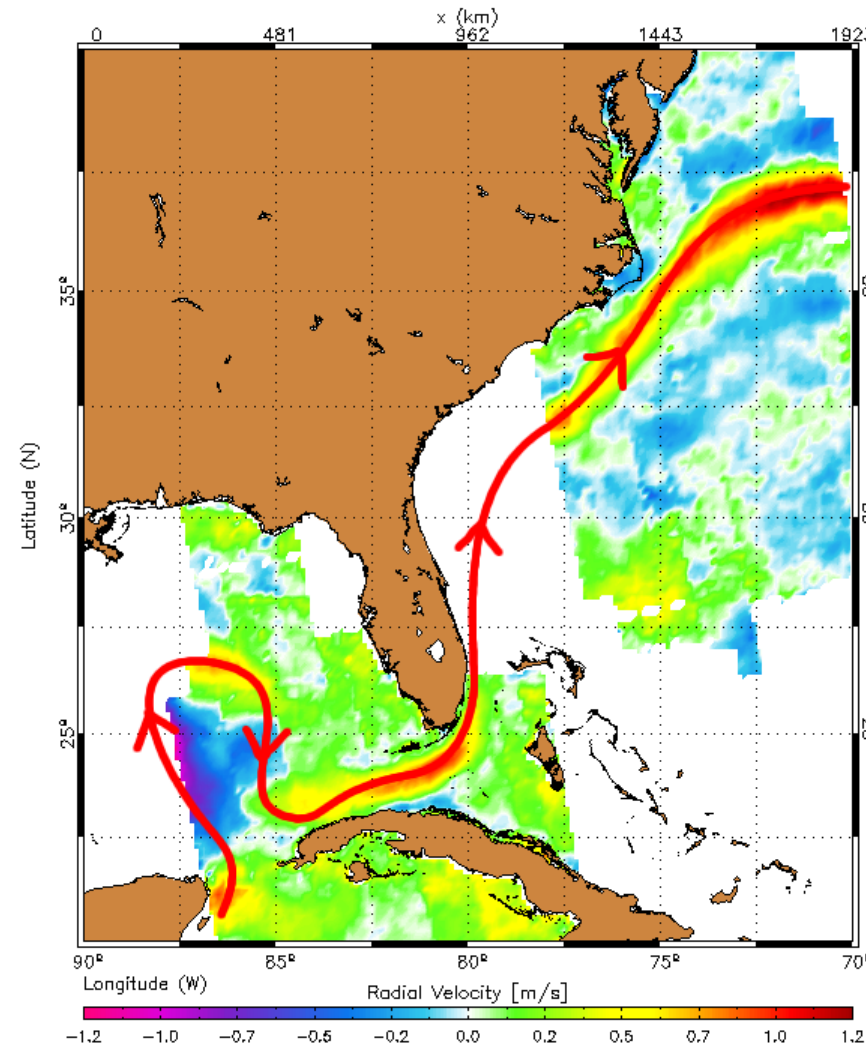
Note: 200, 500, 1000, 2000 and 4000 m isobaths plotted

- Agulhas Current radial velocities in Rio05 MADT significantly weaker than ASAR observations.
- Rio09 MADT better qualitative comparison to ASAR observations – stronger Agulhas Current core.

## Model-SAR surface radial velocity comparison

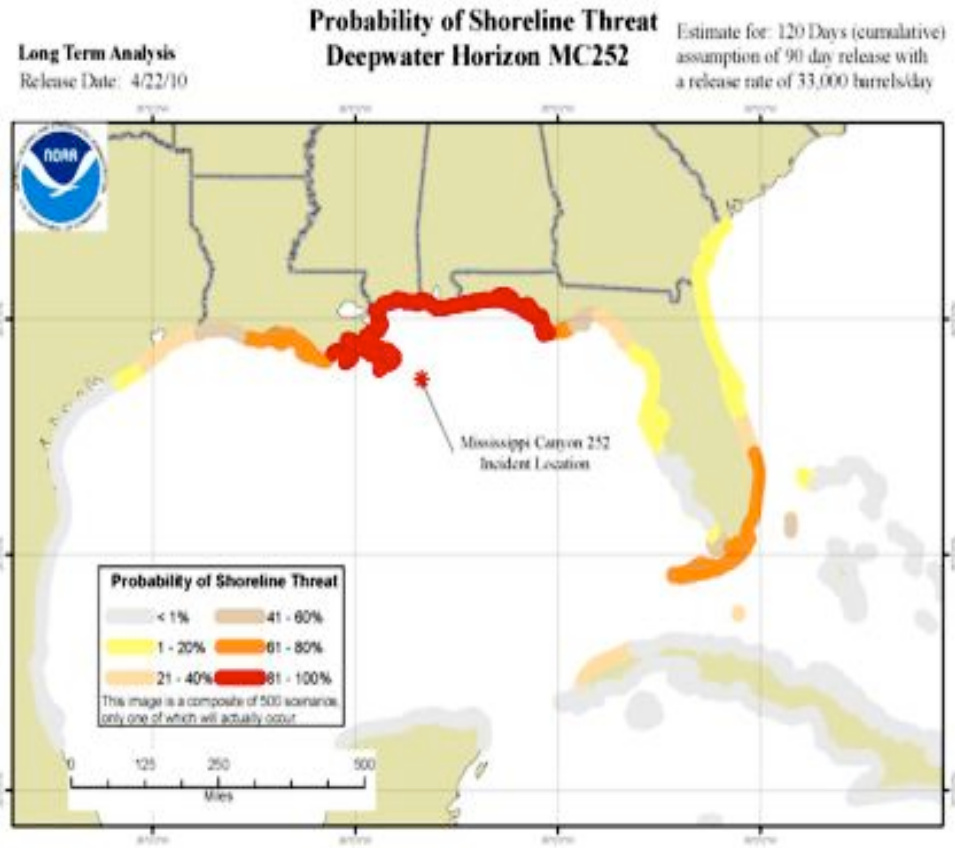


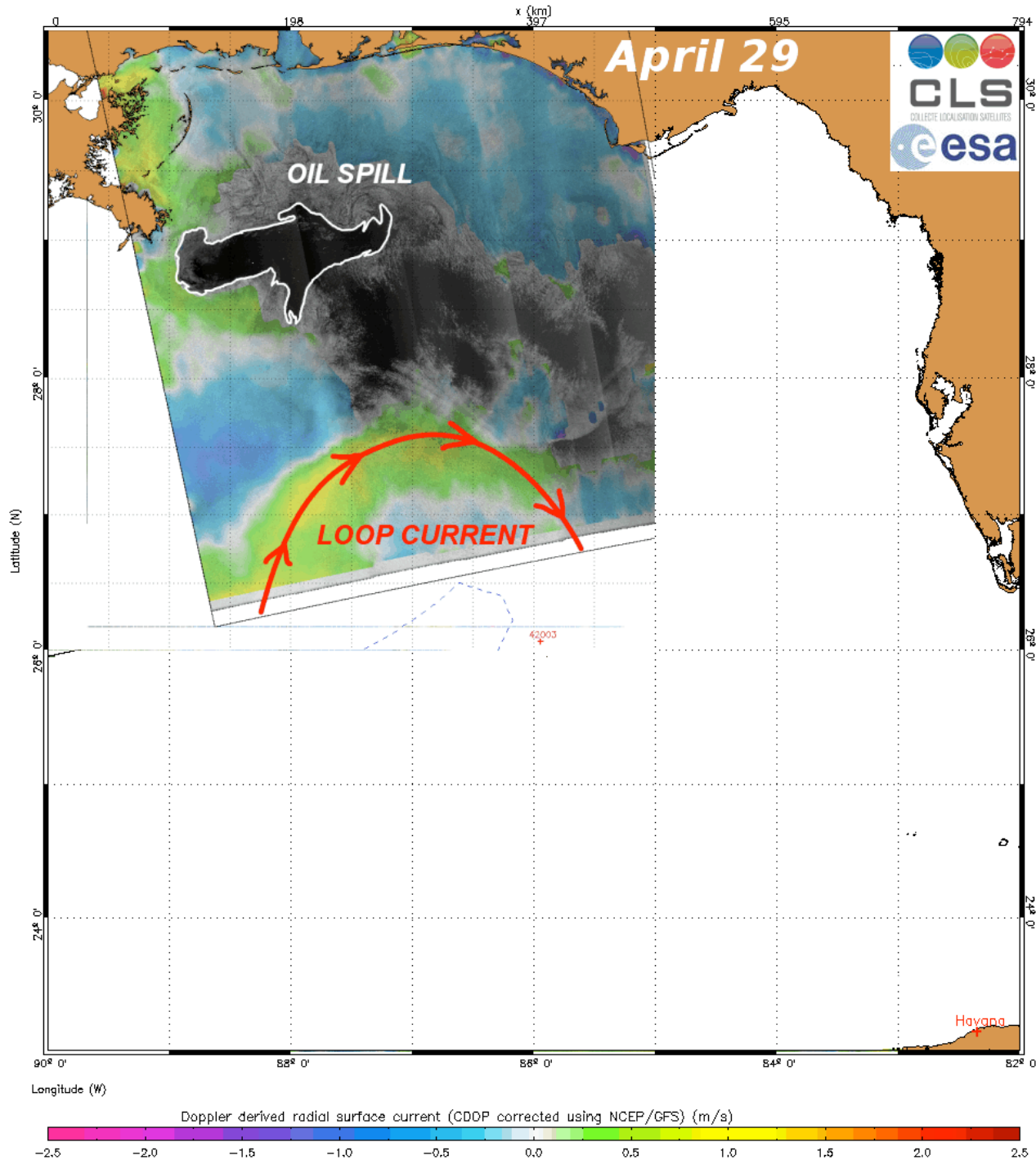
- High resolution nest (~9 km) of ROMS over Agulhas Bank has more realistic bathymetry.
- Demonstrates superior topographic steering of sigma-coordinate regime in Agulhas region (?)



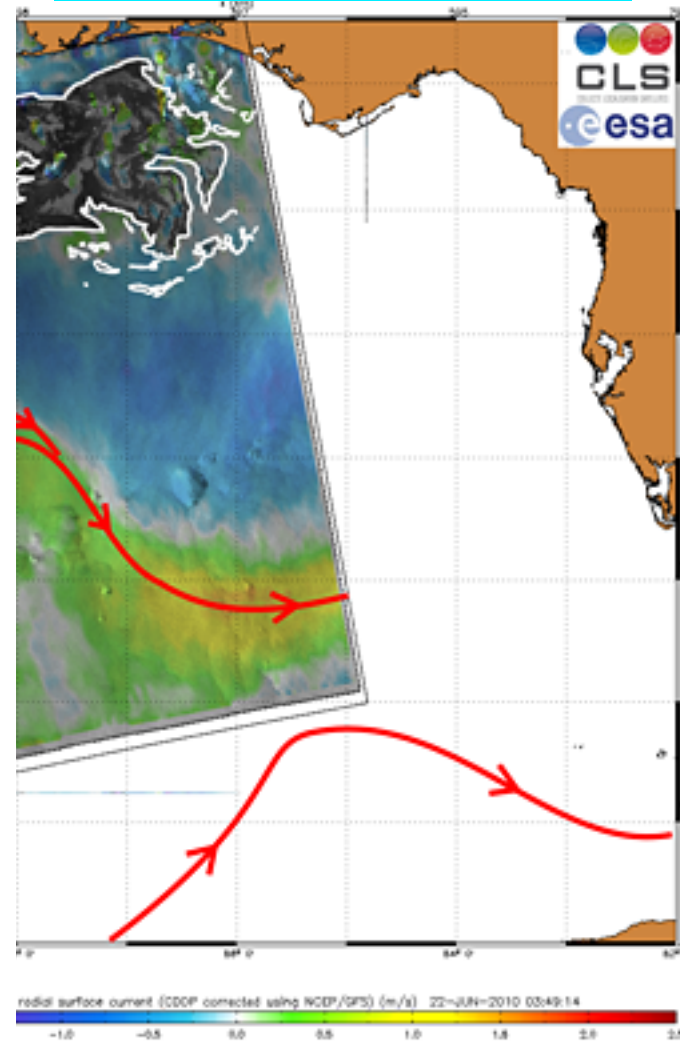
The loop current and Start of the Gulf Stream

# Oil spill in the Gulf of Mexico





**Oil Spill 22 June 2010**



**istria, 27 July - 5 August 2010**



## Summary

New advanced scheme for determination of the absolute ocean current at scales of 100-200 km and longer from combined use of altimetry and gravity measurements is now gradually emerging .

Doppler velocity retrievals from SAR is now also shown to be feasible. Wind removal is very important. Work with incidence angles  $> 30$

The relationship of the Doppler velocity to MDT in areas of steep topographic slopes is very good at finer scales down to 20-30 km.

Dynamic framework for quantitative interpretation of high resolution satellite synergy (SST, SSH, Doppler) has emerged with promising capabilities to advance estimation of ocean currents both at the mesoscale and submesoscale wavelengths.

SMOS ocean salinity estimations can be importantly adding to this concept.

Wide swath altimetry is also considered an important future concept for mesoscale and coastal current determinations.

