

ARGO FLOATS

Advanced Methods in Oceanography

Lecture 4

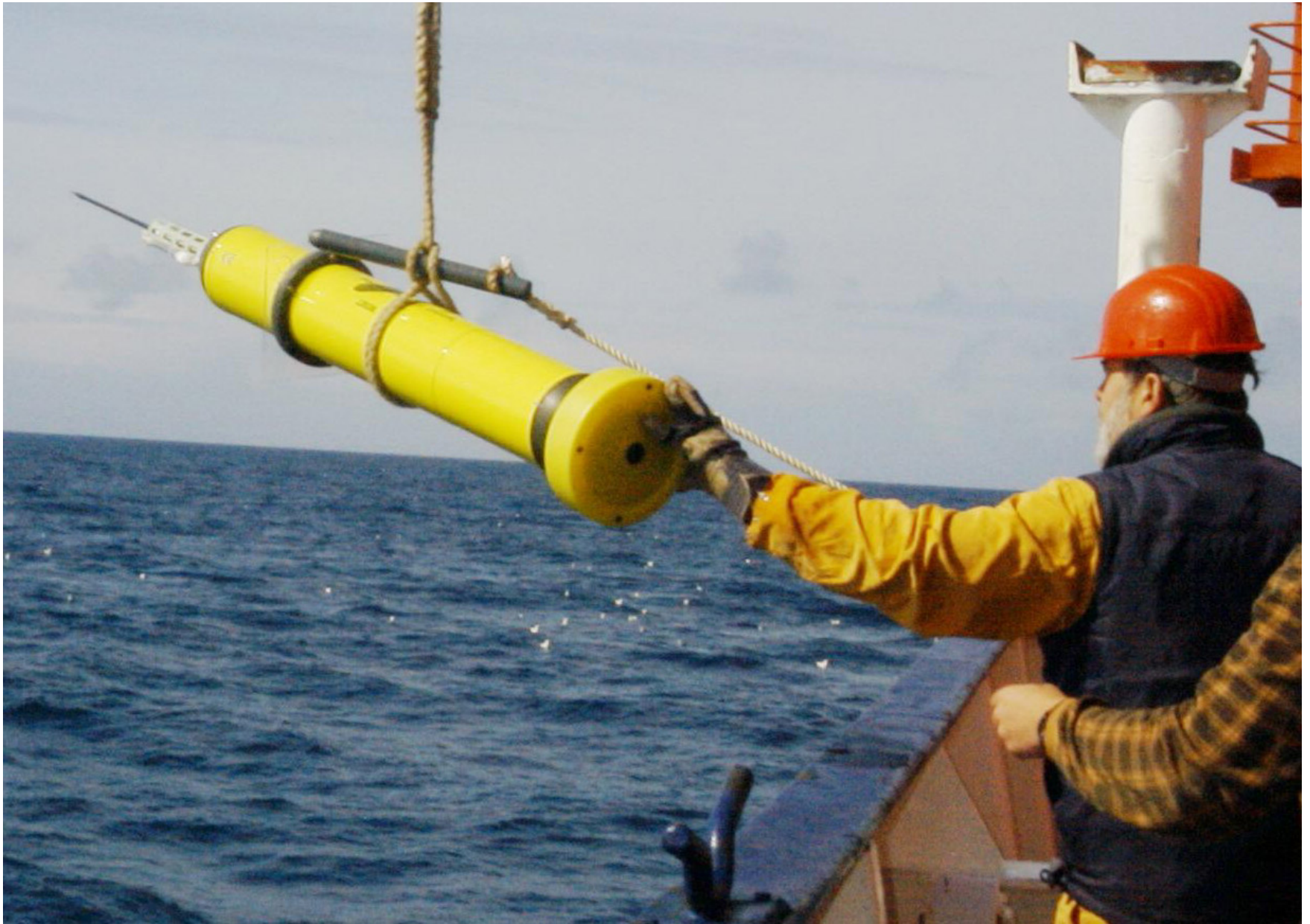
For the end of the the lectures you should be able to...

- Describe the Argo float and the Argo network
- Describe the change of heat content following the 2009/2010 AMOC slowdown
- Describe how to obtain the ocean circulation from Argo float displacements

Argo Floats

- What is an Argo float?
 - Description
 - Principle
- Two case studies
 - The heat content during 2009/10 events
 - The deep ocean circulation

Argo Float



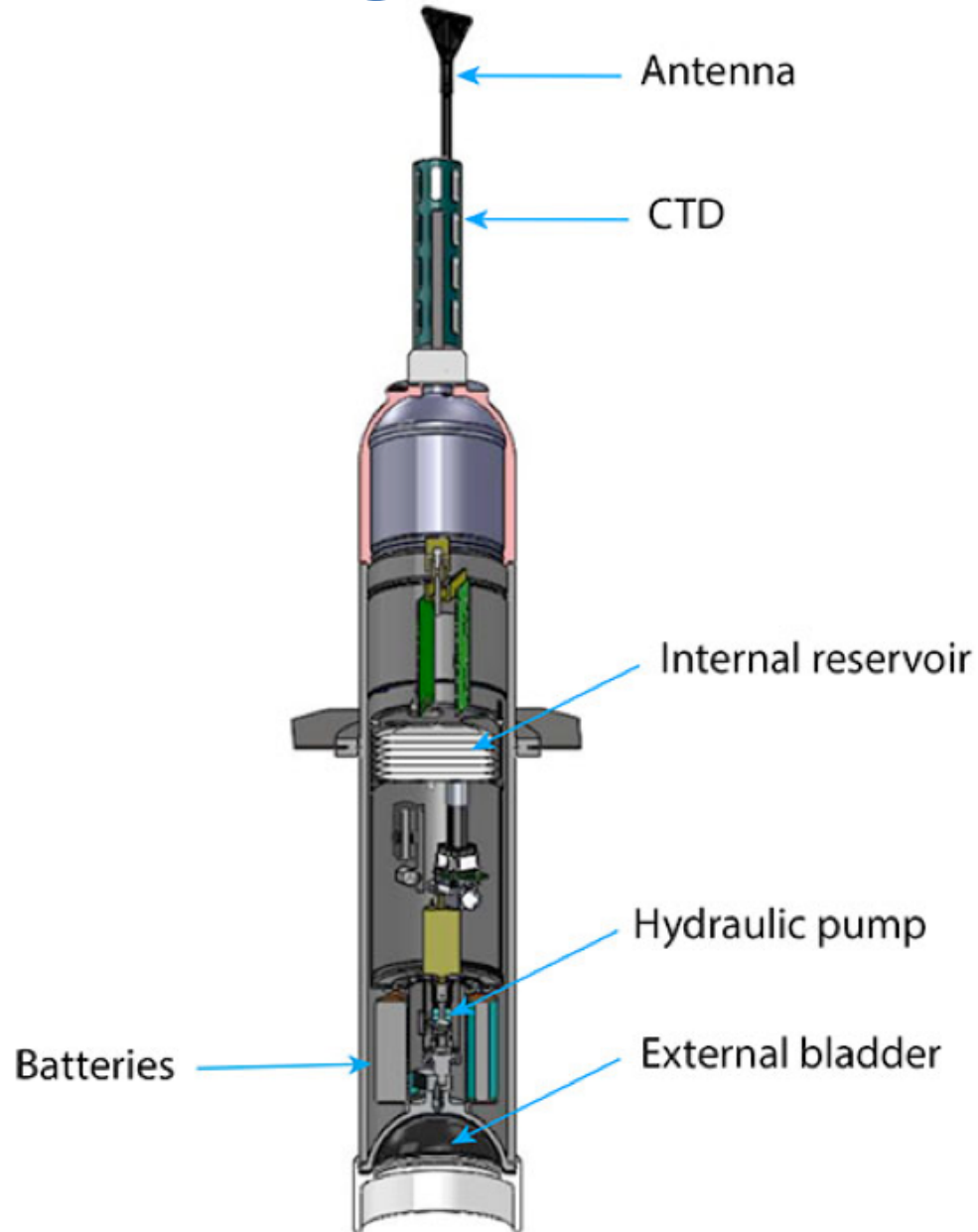
Argo Float

An Argo float is a self-contained robot platforms for ocean exploration.

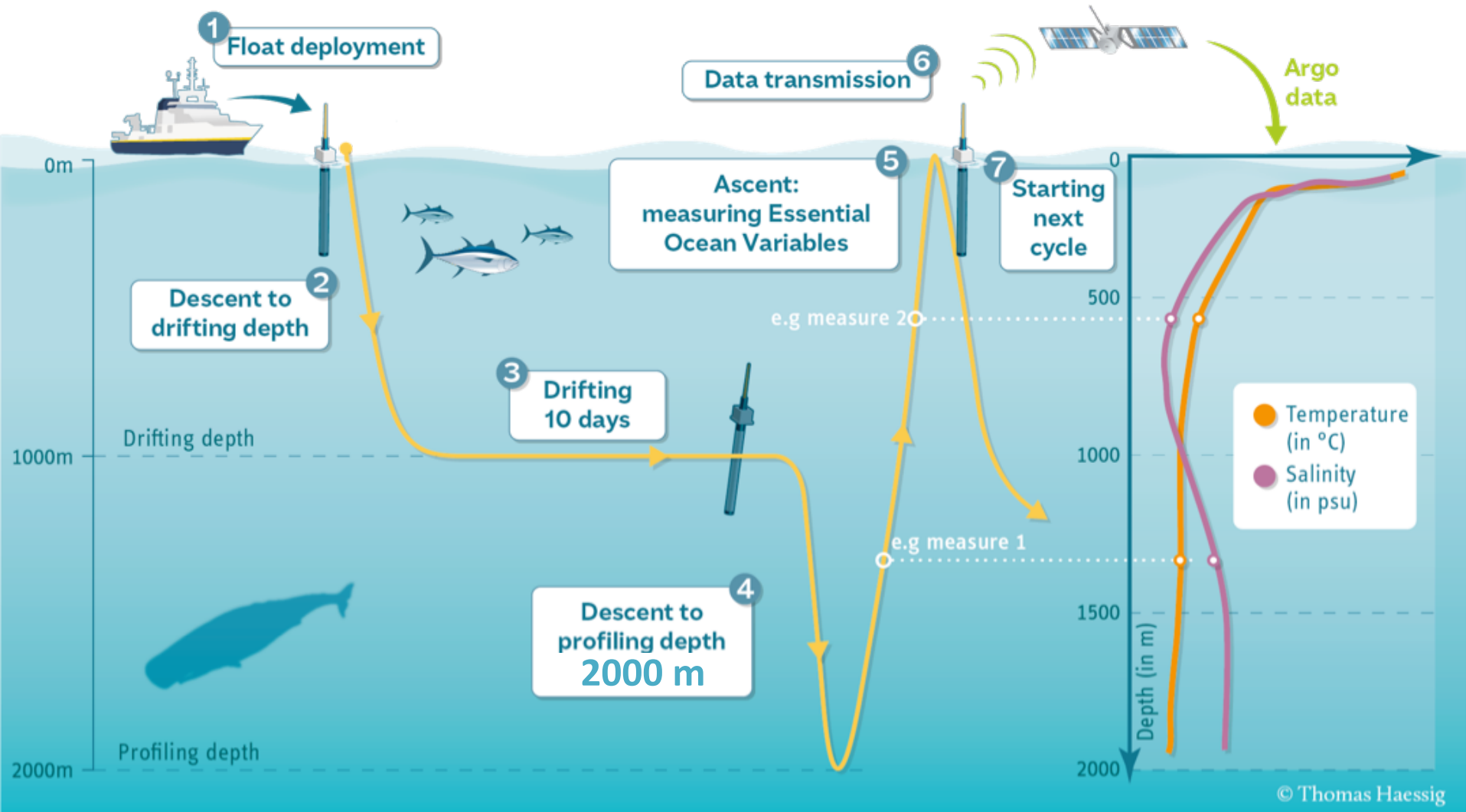
It measures:

- temperature (T),
- salinity (S), and
- ocean current (u,v).

Argo Float

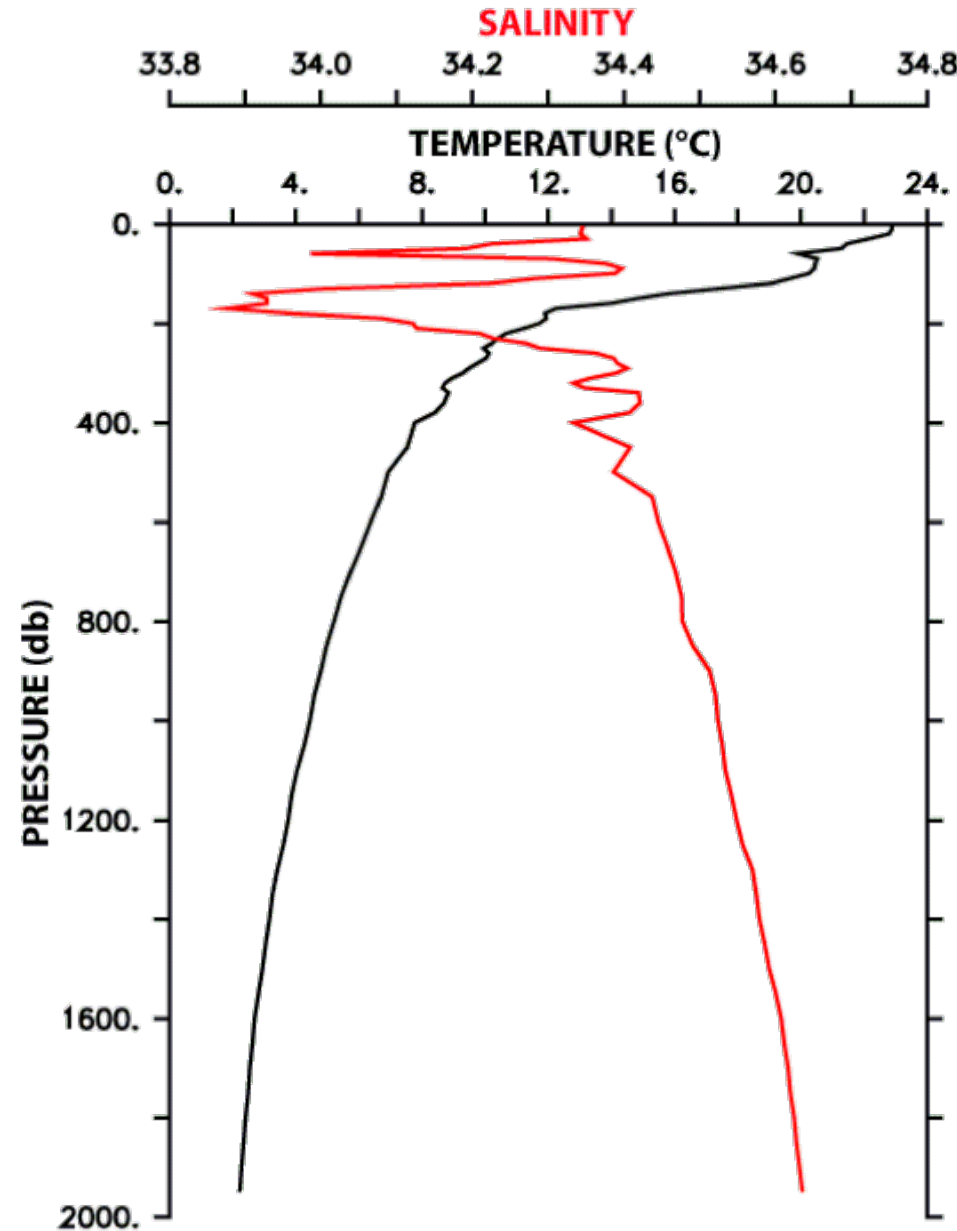


Argo Float Cycle



Argo Float

A float profile from the
North Pacific Ocean:



Argo Float

Float operating considerations:

- Must operate for 4-5 years without maintenance
- Lithium or Alkaline batteries (Lithium is more expensive but has a better energy density)
- Energy budget split equally between buoyancy changes and data telemetry)
- Sensors must remain operational throughout the float life
- Capable of data telemetry in all weather at all latitudes

Argo Float

Float operating characteristics:

- Measurements down to 2000 m with vertical spacing of 10 to 50 metres
- Average horizontal spacing of floats is 300 km
- 10-day cycle
- Measures temperature (T) and salinity (S) , sometimes oxygen; other payloads possible but constrained by energy budget
- No control over location: floats carried by ocean currents: Some remain close to deployment location, others are carried hundreds, or even thousands of kilometers



Argo Network

Argo is

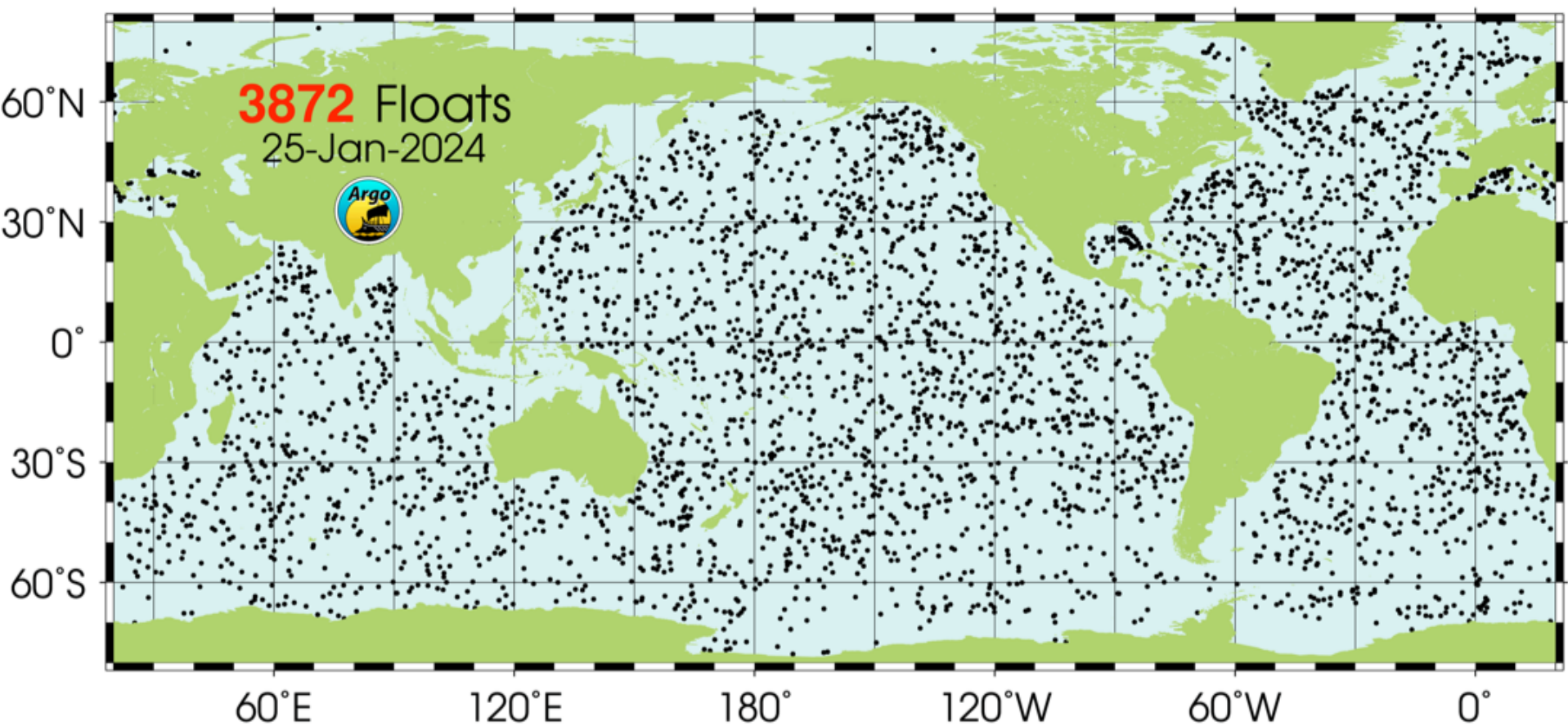
- A network of approximately 3000 floats
- Deployed since 2000
Global coverage since 2004
3000 floats reached in Nov 2007
- Achieved 1 million profiles on Nov 2012
120,000 profiles are being added each year
- 25 contributing countries (France, UK, Germany, Canada, USA, Australia, Japan, Korea, India, ...)



Argo Network

The present array

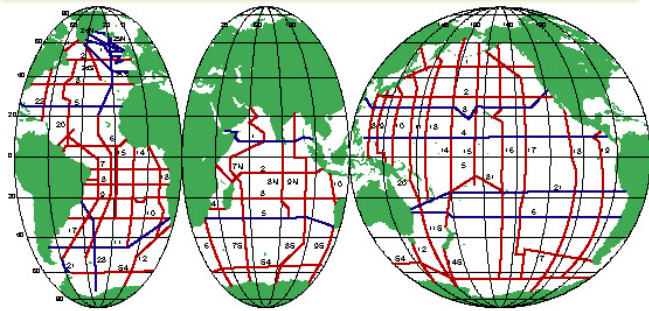
It is an automated Global Ocean Observing System!



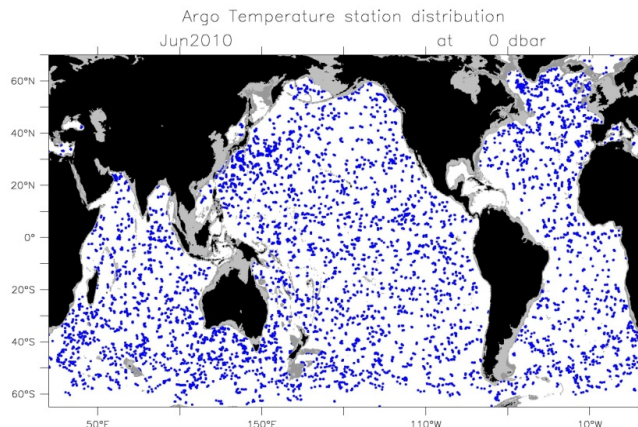


Argo Network

Argo is revolutionizing global ocean observations



- **3.5 years:** the time for HMS Challenger to complete the first survey of ocean temperature on global scale
 - 263 profiles.
- **7 years:** the time for the multi-ship World Ocean Circulation Experiment to complete the first global survey of ocean temperature and salinity.
 - 10,000 profiles , ~ 8,500 € each.
- **1 month:** the time for the Argo Program to collect a global survey
 - 9,000 ocean T,S profiles, ~ 200 € each.



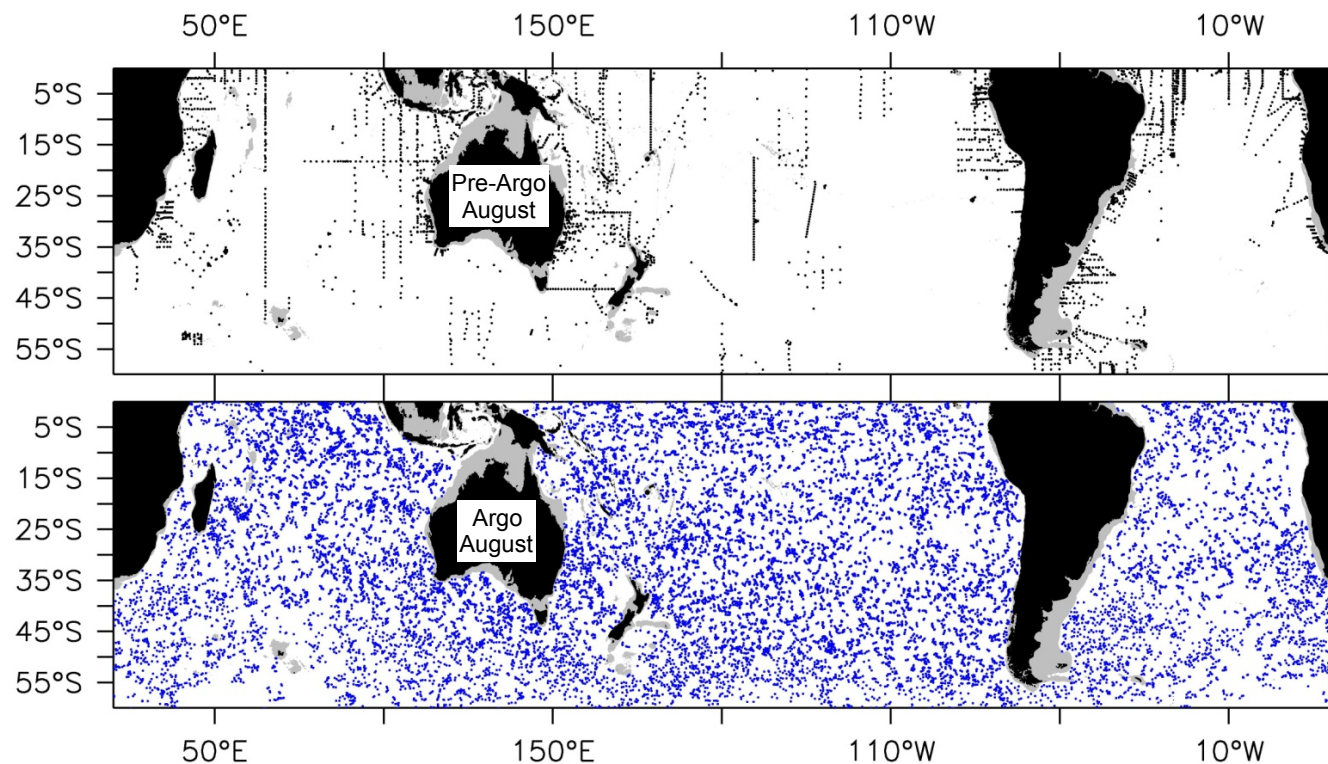


Argo Network

Argo is revolutionizing global ocean observations

Argo floats don't mind bad weather

During Pre-Argo data in the southern hemisphere were extremely sparse in winter.



1951-2000: All August
T,S profiles > 1000 m.
Source: World Ocean Database.

2004-2009: Argo August
T,S profiles > 1000 m.



Argo Network

What Argo can do best

- Systematic global coverage enables global problems to be studied (high data volume: Argo has now measured more ocean T/S profiles (~ 0.5 million than all ship-based measurements in the history of oceanography)
- Deeper penetration than high-volume measurements in the past (mainly T-only profiles to 750m)
- No seasonal bias in measurements (summer/winter) unlike ship measurements
- Can study monthly / seasonal / annual / interannual changes



Argo Network

Main uses of Argo data

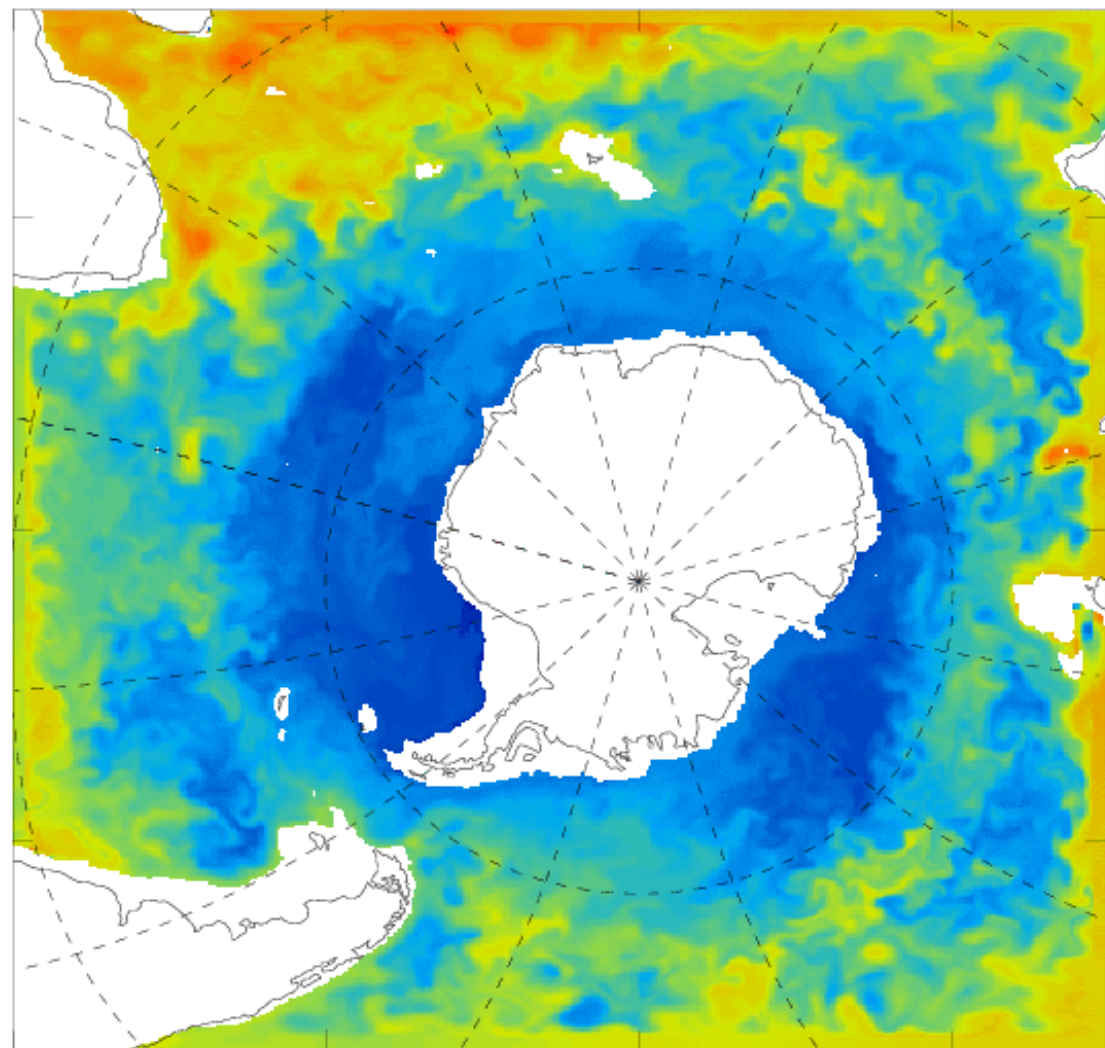
- Operational:
 - Centers in Australia, France, Japan, UK and USA routinely produce global and regional
 - Analyses of subsurface properties using Argo data.
 - Beginning to learn how to do seasonal forecasts
- Research: Climate change; global ocean heat content; sea-level rise due to thermal expansion of oceans.
- www.argo.net; follow link to 'Argo Project Office'



Argo Network

Argo application:

Potential Temperature,
1000 m, 1 Feb 2009 UK
Met Office model, using
Argo data



-1.8

0.76

2.92

5.28

7.64

10



Argo Network

What Argo can't do yet

- Small-scale vertical (< 10 m) or horizontal (< 300 km) studies
- Large or energy-hungry payloads
- Repeat measurements at a fixed location
- Deeper than 2000 metres (there exists Deep-Argo, though)
- Not good in shallow water or near boundaries



Argo Network

Comparison with other observation methods

	Depth	Vertical Resolution	Horizontal Resolution	Properties
Argo	0-2000 m	~10 m	~300 km, 2D	T, S
Satellite	Surface	N/A	~a few km to a few tens of km, 2D	SST, SSH, Colour (chl), Roughness (wind), & (SSS)
Ship transect	0-bottom	~1 m	~40 km, 1D	T,S, oxygen, nutrients,& pH, noble gasses, isotopes, Carbon, CFC, phytoplankton, zooplankton, etc...



Argo case study

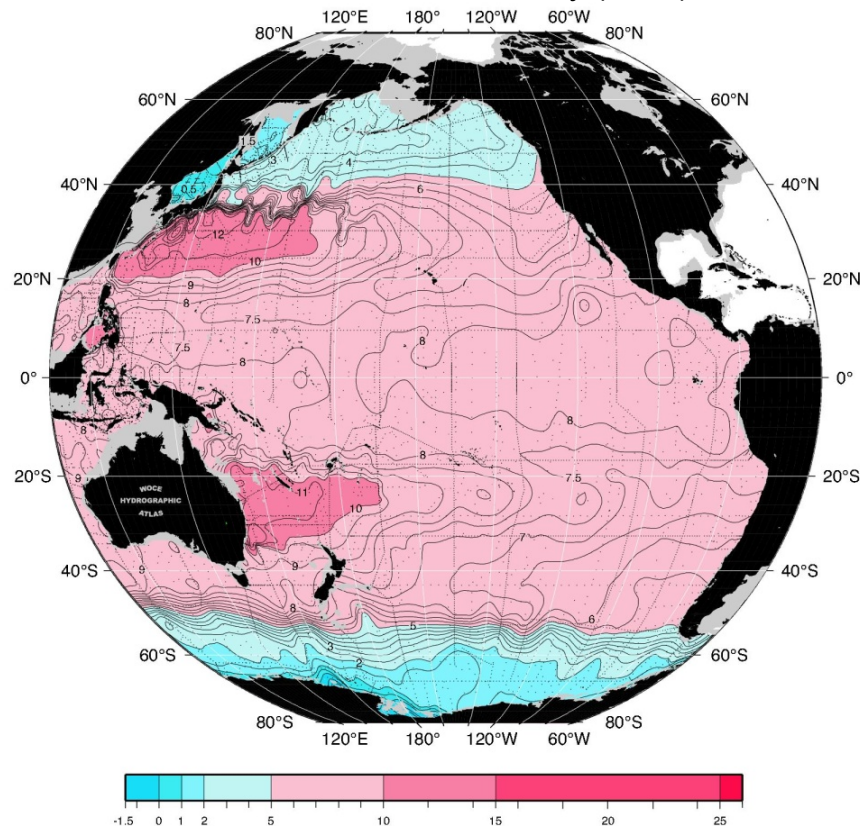
- 1. Temperature mean fields and variability**
- 2. The 2009/10 events**
- 3. The deep circulation**



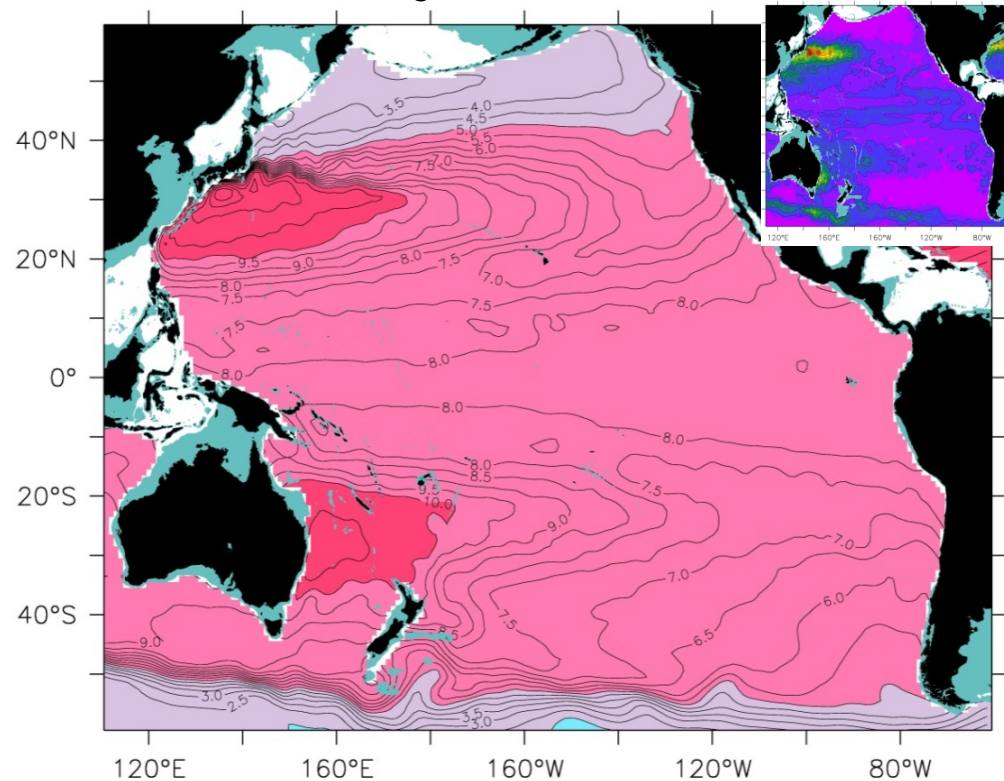
Argo case study

Argo provides mean fields with unprecedented accuracy

Potential temperature ($^{\circ}\text{C}$) 500 m
WOCE Pacific Atlas, Talley (2007)



Potential temperature ($^{\circ}\text{C}$) 500 m
Argo 2004-2009 mean



From a few thousand profiles:

WOCE produced neither a snapshot or a time mean, but rather a multi-year composite of snapshots from many transects. The sampling errors are difficult to estimate.

From a few hundred thousand profiles:

Argo provides both time means and snapshots, with realistic error estimates. (Inset plot: standard deviation of monthly temperatures)



Argo case study

The 2009/10 AMOC slowdown events?

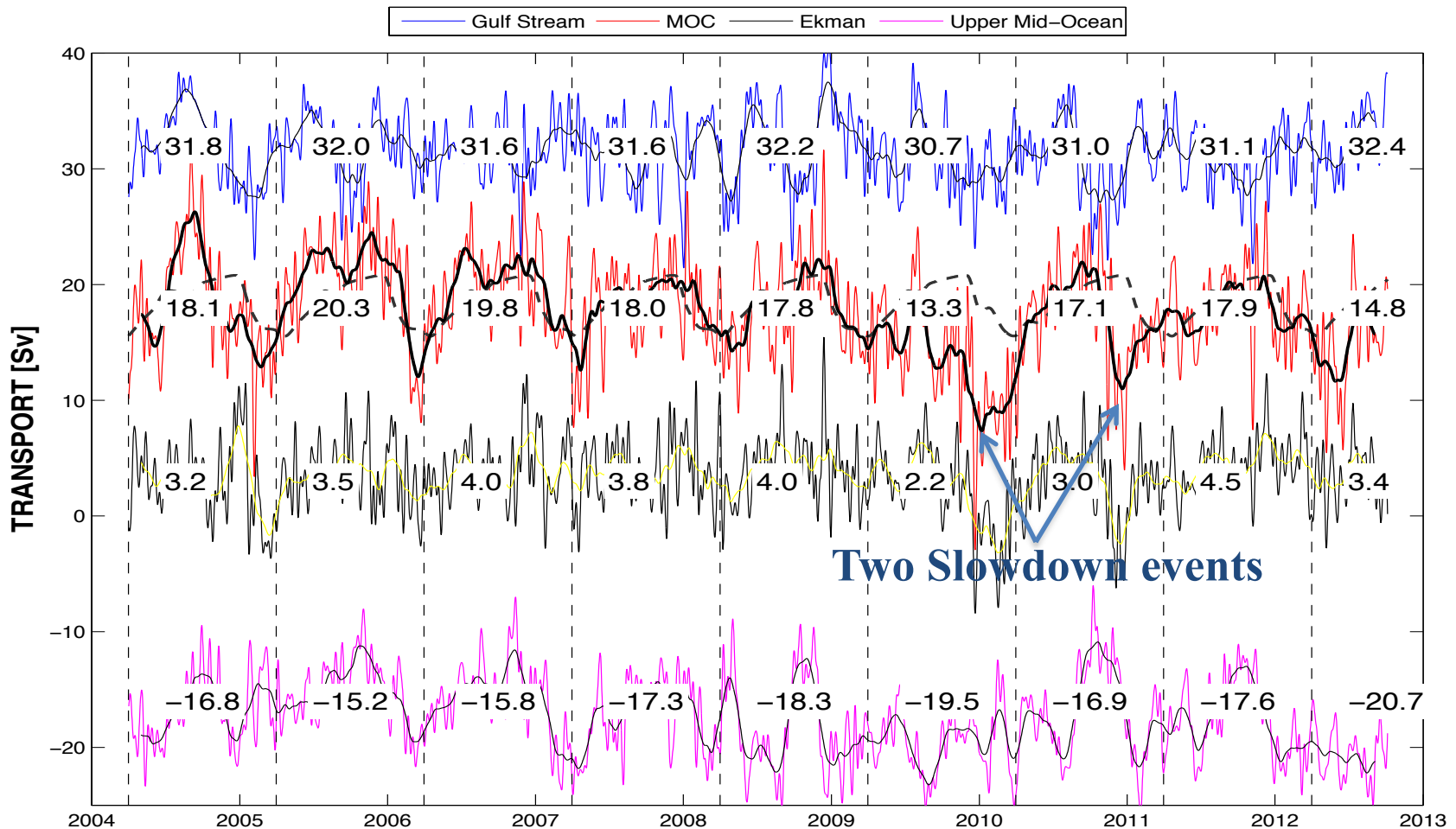
Could you remind me the events?



Argo case study

The 2009/10 AMOC slowdown events?

Could you remind me the events?



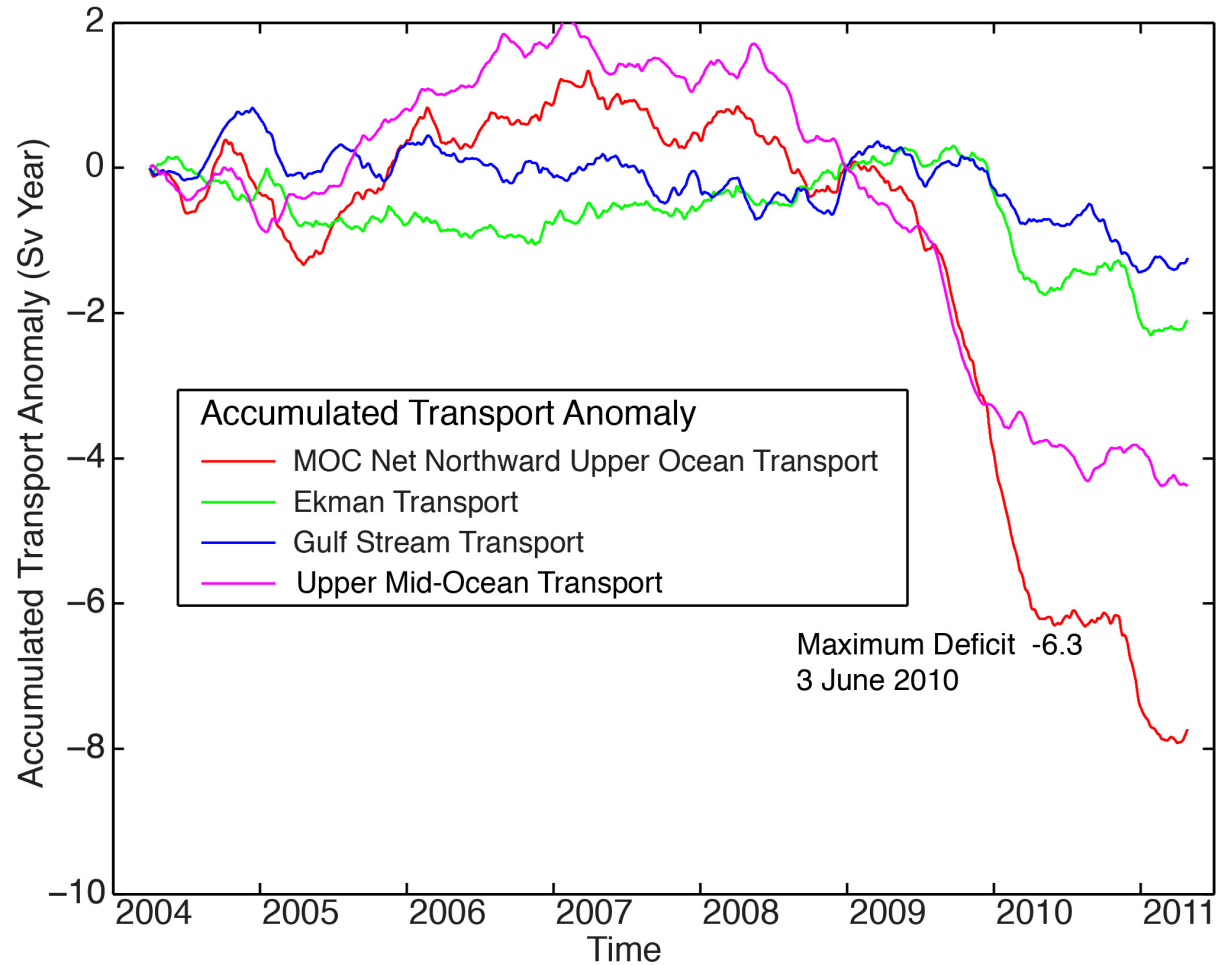


Argo case study

The 2009/10 AMOC slowdown events?

The two events leads to an anomalous in cumulative transport, i.e. a deficit of -6.3 Sv in June 2010.

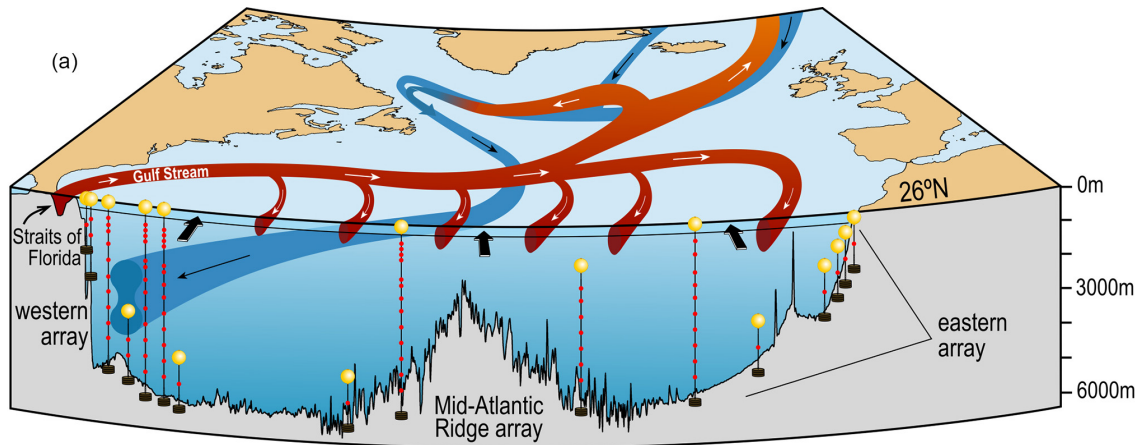
Why does a weak baroclinic cumulative transport matter for the climate?





Argo case study

The 2009/10 AMOC slowdown events?



Why does a weak baroclinic transport matter for the climate?

- Weaker northward transport of warm water the surface, and
- Weaker southward transport of cold water at depth.

Heat transport decrease -> Cooling northward of 26°N

Could we demonstrate this link?



Argo case study

The 2009/10 AMOC slowdown events?

AMOC decrease can lead to a

because of thermal stratification

Heat transport decrease, which can lead

because of reduction in heat convergence

to a cooling in the northward of 26°N

What do observations suggest?



Argo case study

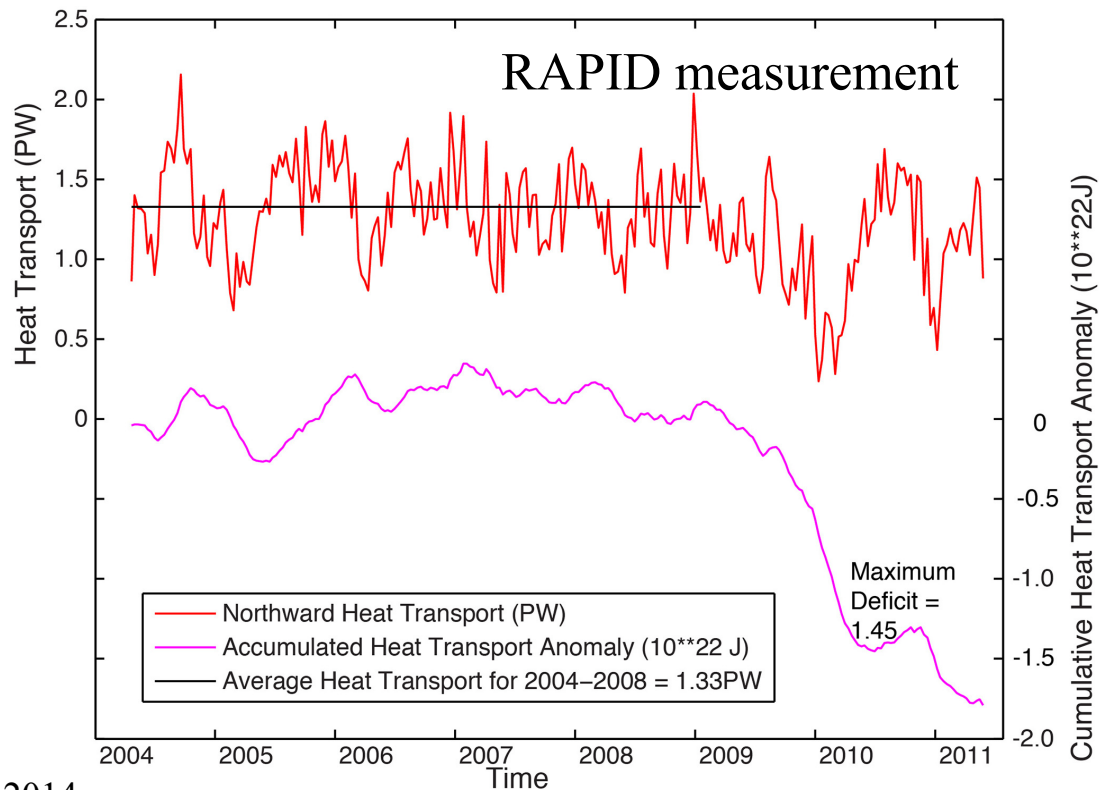
The 2009/10 AMOC slowdown events?

AMOC decrease can lead to a

because of thermal stratification

Heat transport decrease

What do observations suggest?





Heat transport decrease, which can lead

to a cooling in the northward of 26°N

What do observations suggest?

(a) ARGO Floats

Heat Content Anomaly ($\times 10^{21}$ J)

14.5 $\times 10^{21}$ J



Argo case study

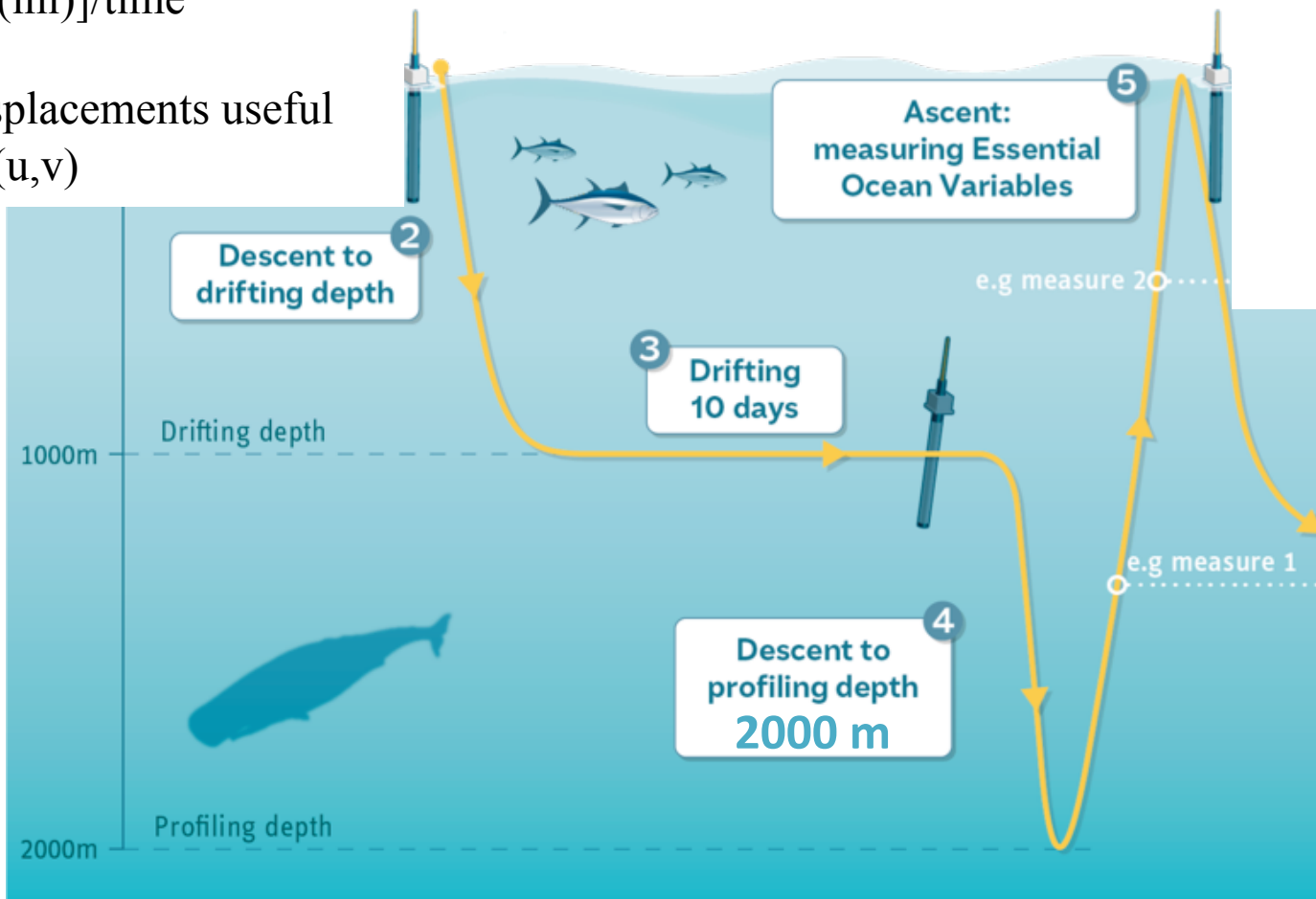
The deep circulation

Argo measure velocity at ~1,000 dbar through floater displacements

$$v = [\text{lat}(\text{fin}) - \text{lat}(\text{ini})] / \text{time}$$

$$u = [\text{lon}(\text{fin}) - \text{lon}(\text{ini})] / \text{time}$$

~1,000,000 displacements useful
for computing (u,v)

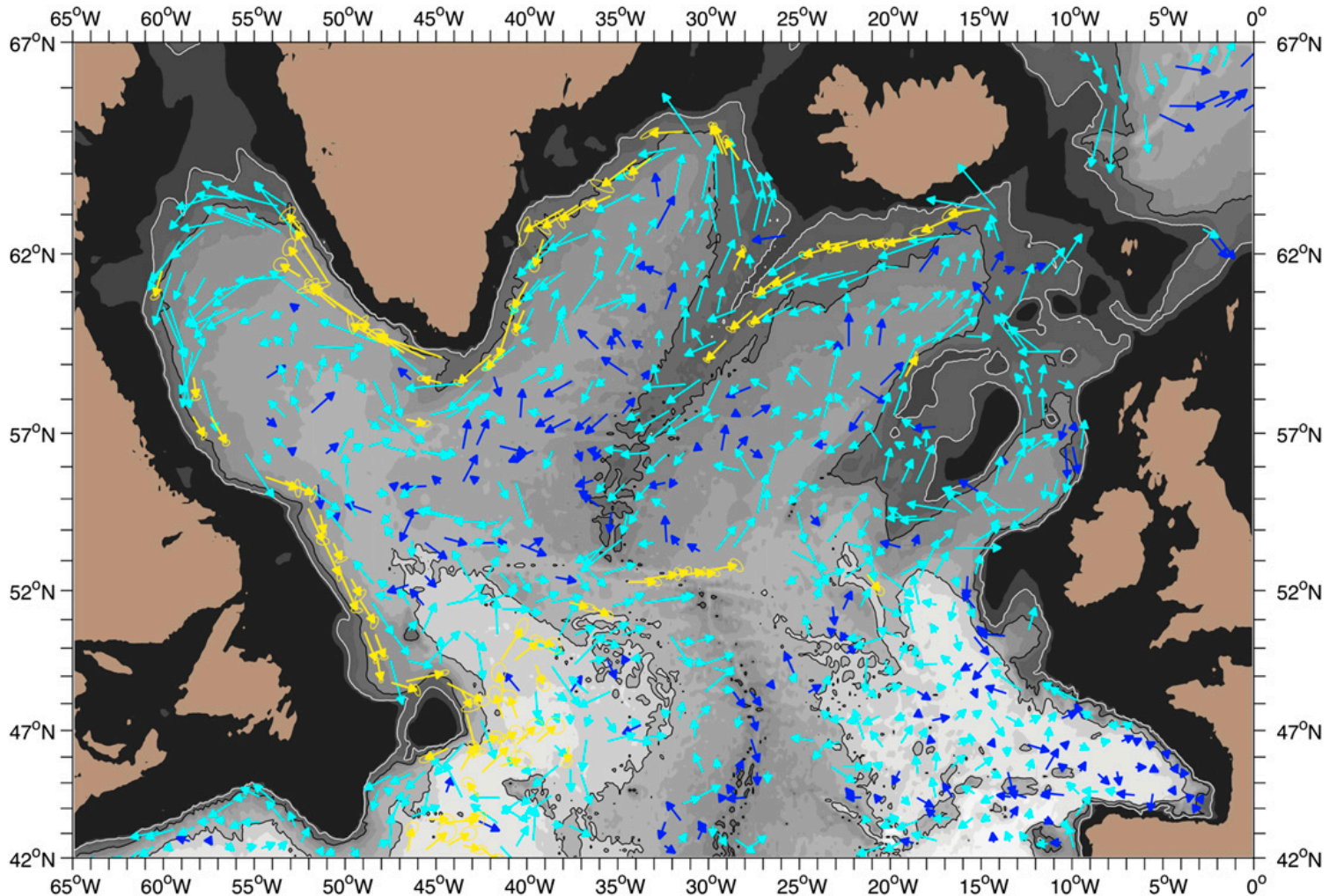




Argo case study

The deep circulation

Argo measure velocity at $\sim 1,000$ dbar through floaters displacement

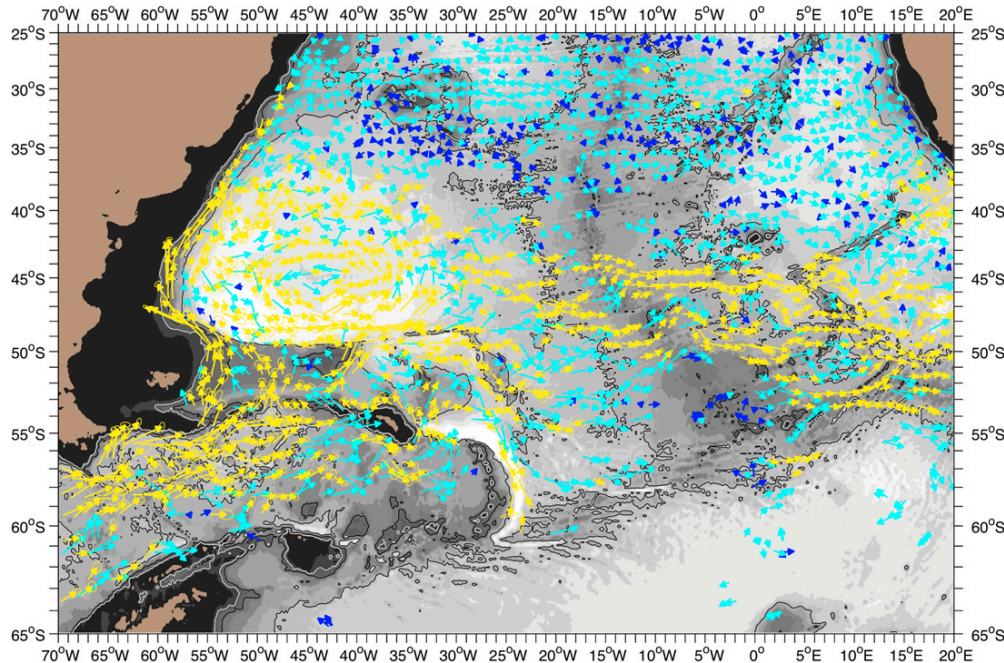




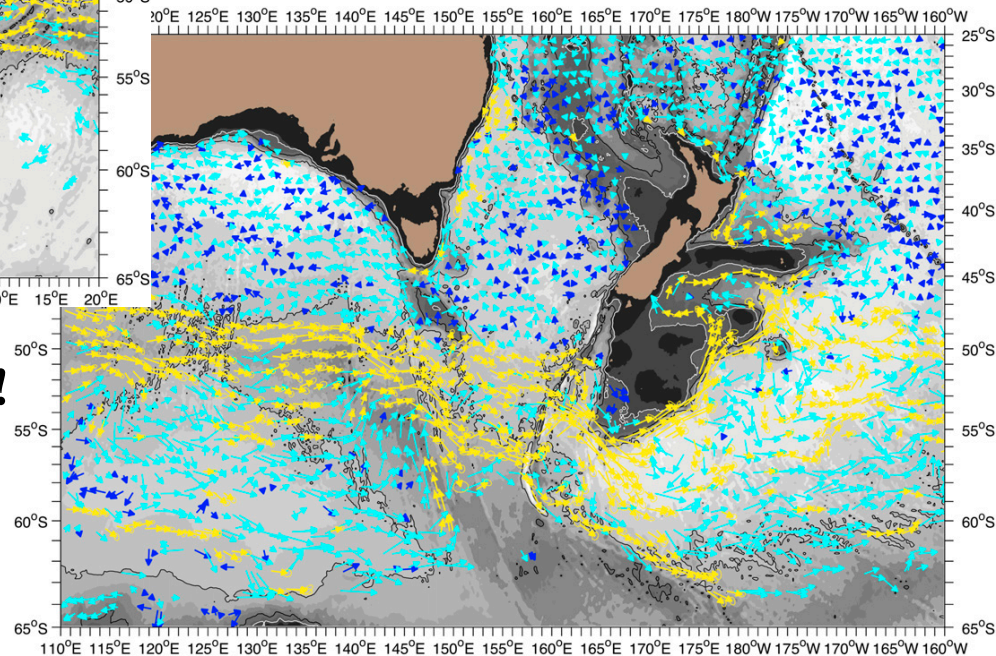
Argo case study

The deep circulation

Argo measure velocity at $\sim 1,000$ dbar through floaters displacement



Average velocities at $\sim 1,000$ dbar on a $1^\circ \times 1^\circ$ grid from the 394,035 displacements.



We have velocities for the entire ocean!
However these velocities might be unphysical... Because they are average of an inhomogeneous field, they induce an artificial horizontal divergence.



Argo case study

The deep circulation

Extracting the physical geostrophic displacement from the average Argo velocities

Geostrophic Balance on a sphere:
$$-fv = -\frac{1}{a \cos \theta} \frac{\partial \Phi}{\partial \lambda}$$

What assumption leads to that?
$$+fu = -\frac{1}{a} \frac{\partial \Phi}{\partial \theta}.$$

Where Φ is the geopotential at pressure 1,000 dbar, such as the hydrostatic reads: $\delta p = -\rho \delta \Phi$.

From geostrophy, we can obtained:
$$\frac{\partial^2 \Phi}{\partial \lambda^2} + \frac{\partial^2 \Phi}{\partial \theta^2} = a \left[\frac{\partial(fv \cos \theta)}{\partial \lambda} - \frac{\partial(fu)}{\partial \theta} \right]. \quad (*)$$

If f was constant Φ would represent a streamfunction, but here the horizontal flow is divergent, even the “physical geostrophic” one (i.e. β term).

How to solve (*)?



Argo case study

The deep circulation

Extracting the physical geostrophic displacement from the average Argo velocities

$$\frac{\partial^2 \Phi}{\partial \lambda^2} + \frac{\partial^2 \Phi}{\partial \theta^2} = a \left[\frac{\partial(fv \cos \theta)}{\partial \lambda} - \frac{\partial(fu)}{\partial \theta} \right]. \quad (*)$$

How to solve (*)?

A simple way is to rewrite (*) as $\frac{\partial \Phi}{\partial t} = \frac{\partial^2 \Phi}{\partial \lambda^2} + \frac{\partial^2 \Phi}{\partial \theta^2} - a \left[\frac{\partial(fv \cos \theta)}{\partial \lambda} - \frac{\partial(fu)}{\partial \theta} \right] \quad (**)$

Thus Φ is the asymptotic solution ($t \rightarrow \infty$) of (**) which verifies (*).

The equation (**) is nothing else than an inhomogeneous diffusion equation where the source is $a \left[\frac{\partial(fv \cos \theta)}{\partial \lambda} - \frac{\partial(fu)}{\partial \theta} \right]$, the vorticity.

So we have Φ , if we know the boundary conditions?

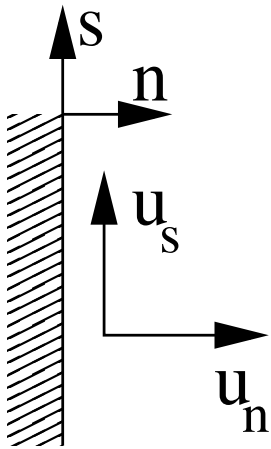
Note: If you think of (**) as a heat-diffusion equation the source of heat needs to be balanced by the loss at the boundary for equilibrium to be achieved. So that BC are crucial.



Argo case study

The deep circulation

Extracting the physical geostrophic displacement from the average Argo velocities



The Boundary conditions:

- The tangential velocities is geostrophic
- Note that assuming that the the normal velocity is geostrophic, since it need to be $u_n=0$ at to conserve mass, would leads to Φ is constant along the boundary...

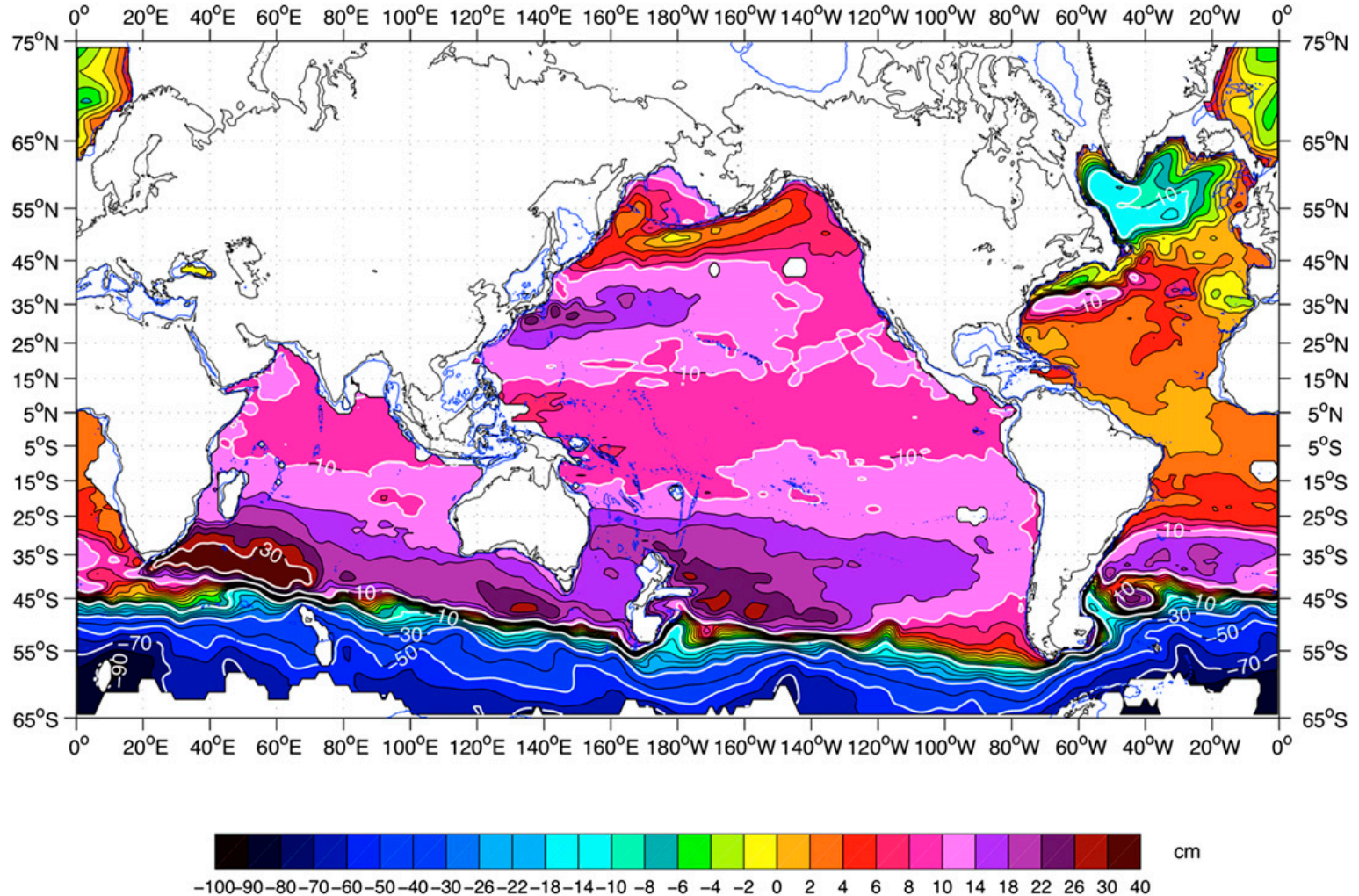
**We need to be careful with
geostrophic balance and mass conservation/boundary condition:
The solution can be trivial!**



Argo case study

The deep circulation

Global Geopotential height (Φ/g) at 1,000 dbar

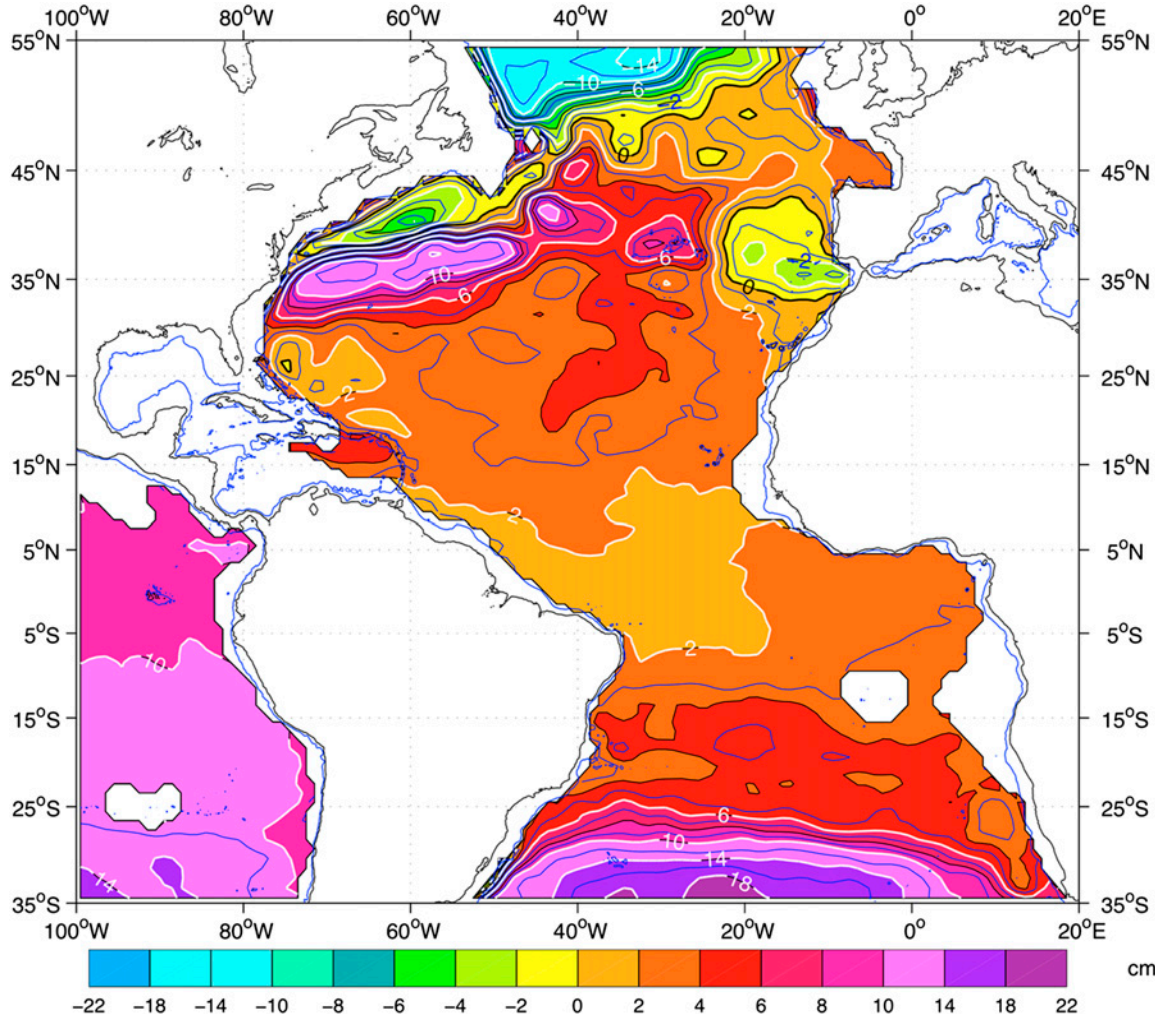




Argo case study

The deep circulation

Global Geopotential height (Φ/g) at 1,000 dbar



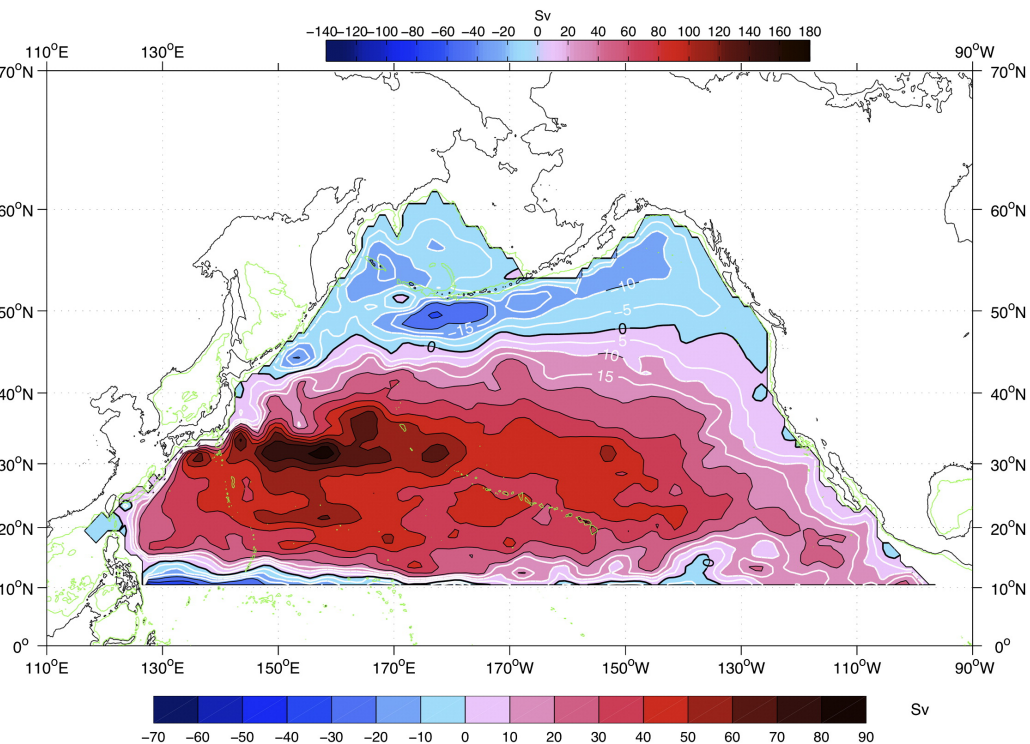
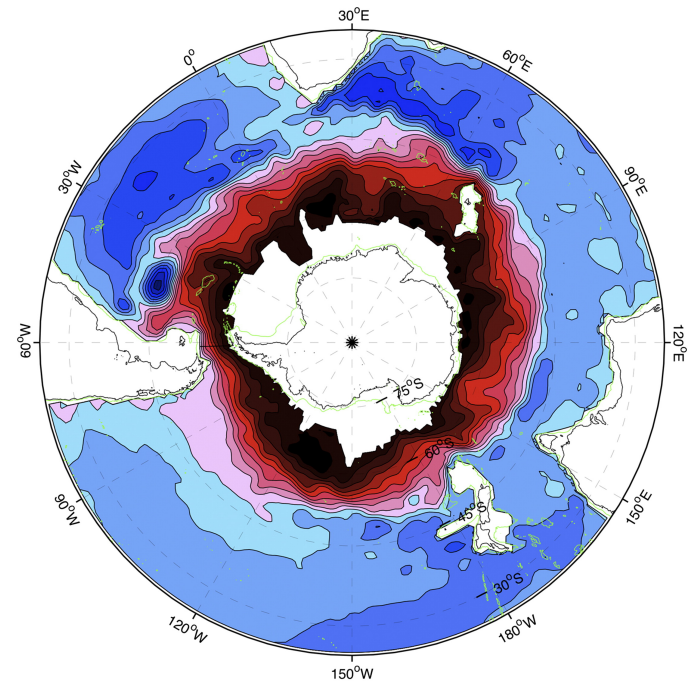
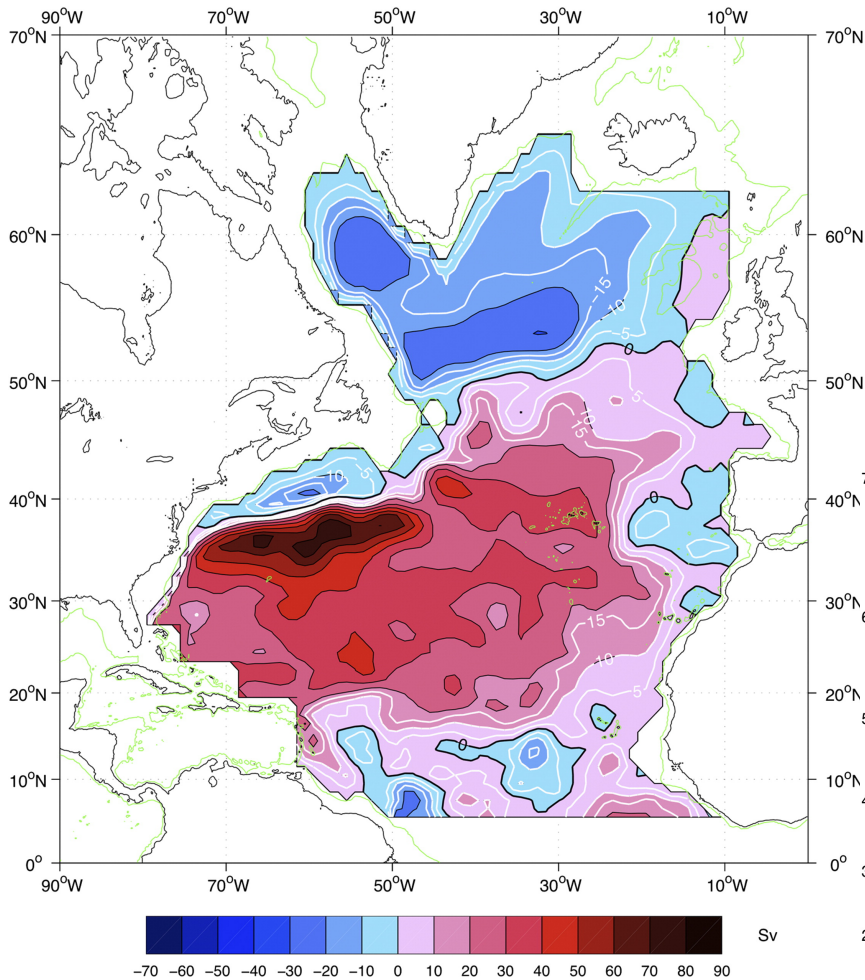
Knowing the geopotential at one given level one can find the ocean circulation for the entire ocean using the thermal wind balance.

It means that Argo floats displacements give us the reference level, whereas temperature and salinity gives us the velocities shear.



Argo case study

The barotropic circulation





Argo

Summary:

During this lecture we have

- The principle of Argo float;
- The way Argo floats network revolutionize *in situ* measurements;
- Study how Argo float measurements help us understand AMOC events;
- Demonstrate how Argo float displacements can be used to infer the deep circulation.