OVIDE

Overview of the scientific findings about the variability of natural and anthopogenic carbon in the North Atlantic

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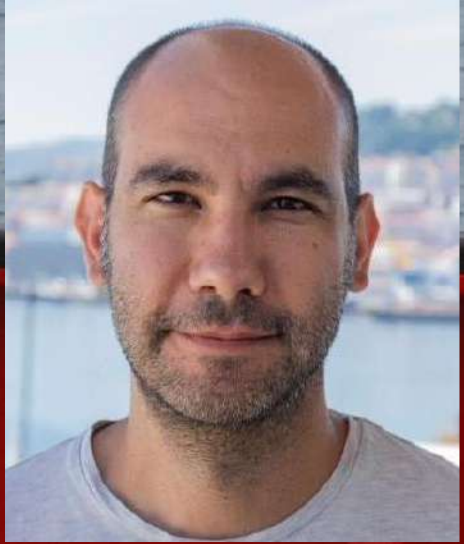
The Vigo team

Fiz F. Perez, Aida Rios, Maribel Garcia Ibañez, Marcos Fontela, Lidia Carracedo, Anton Velo, Marcos Vazquez Rodrigues and the Sarmiento crew members !

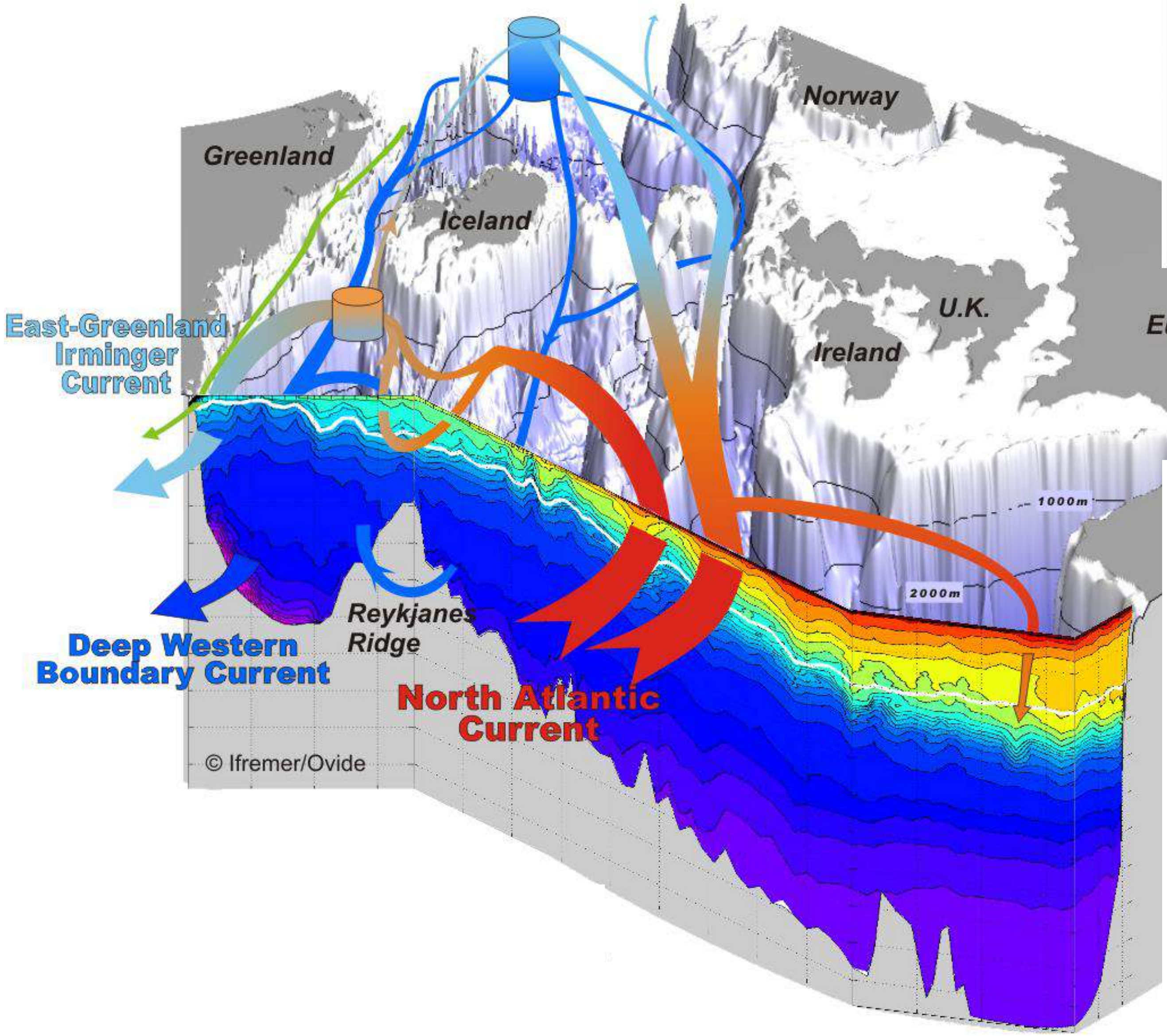


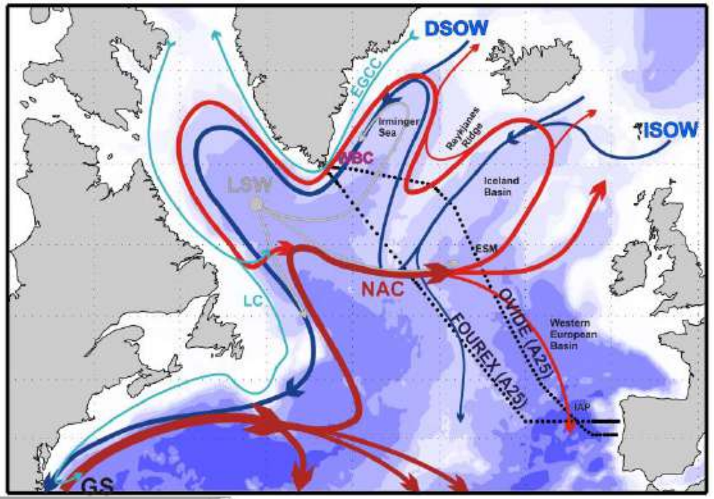



Four main scientific questions driving the OVIDE project

- ❑ **Introduction**
- ❑ Methodology
- ❑ Quantifying the variability of the Meridional Overturning Circulation (MOC) at subpolar latitudes
- ❑ Elucidating the mechanisms responsible for the storage of anthropogenic carbon dioxyde in the North Atlantic

OVIDE-A25 is one of the high frequency repeats of Go-Ship

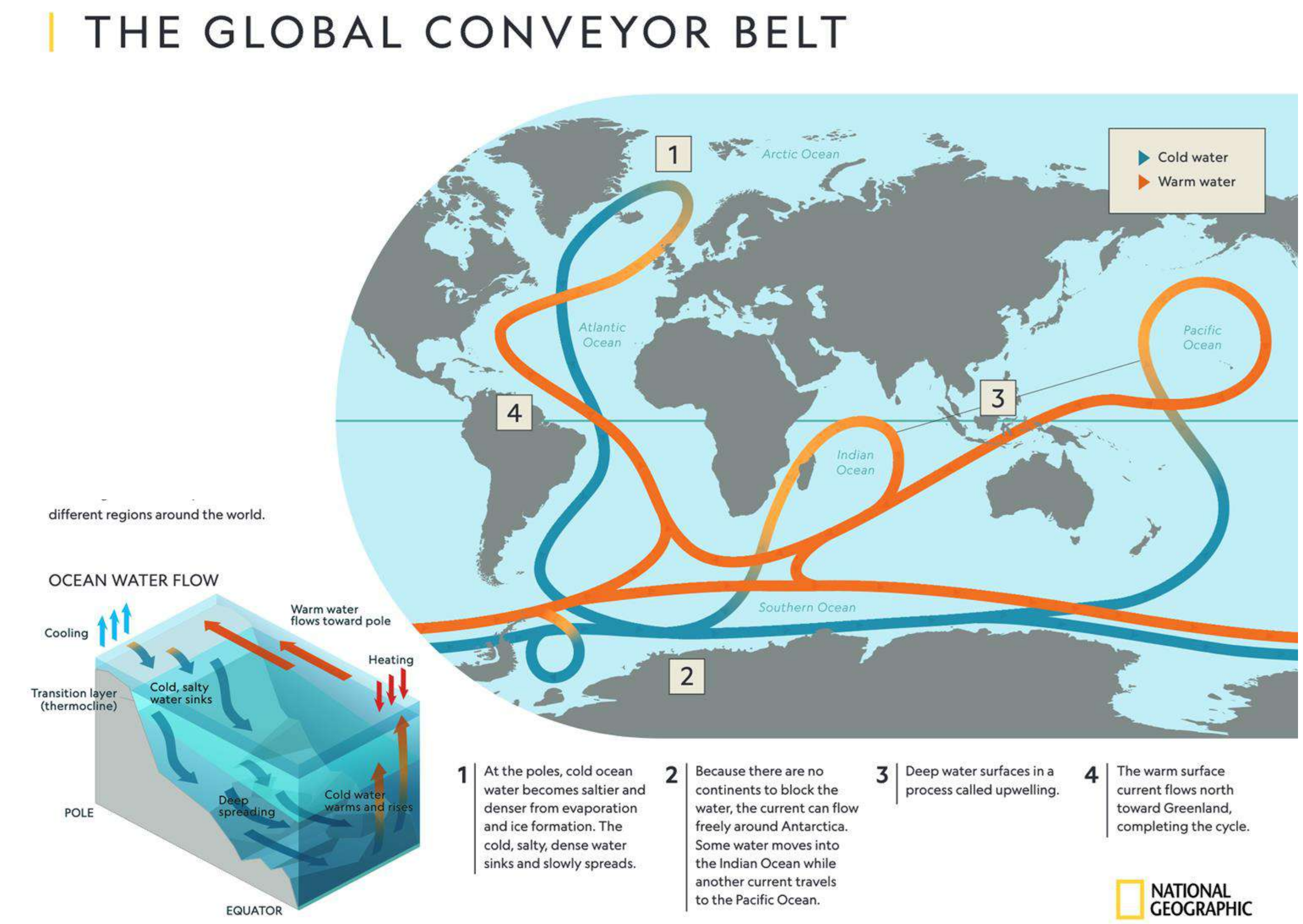




4x: August 1997
ovid02: June 2002
ovid04: June 2004
ovid06: May 2006
ovid08: June 2008
ovid10: June 2010
catarina: June 2012
geovid14: June 2014
bocats: June 2016
Ovid18: June 2018
Bocats 2: June 2021

Ocean carbon cycle: the ocean carbon pumps

What controls atmospheric CO_2 uptake and storage by the oceans?



Physical Carbon Pump (PCP):

Water mass formation and advection

Source: https://www.nationalgeographic.org/media/global-conveyor-belt/

Ocean carbon cycle: the ocean carbon pumps

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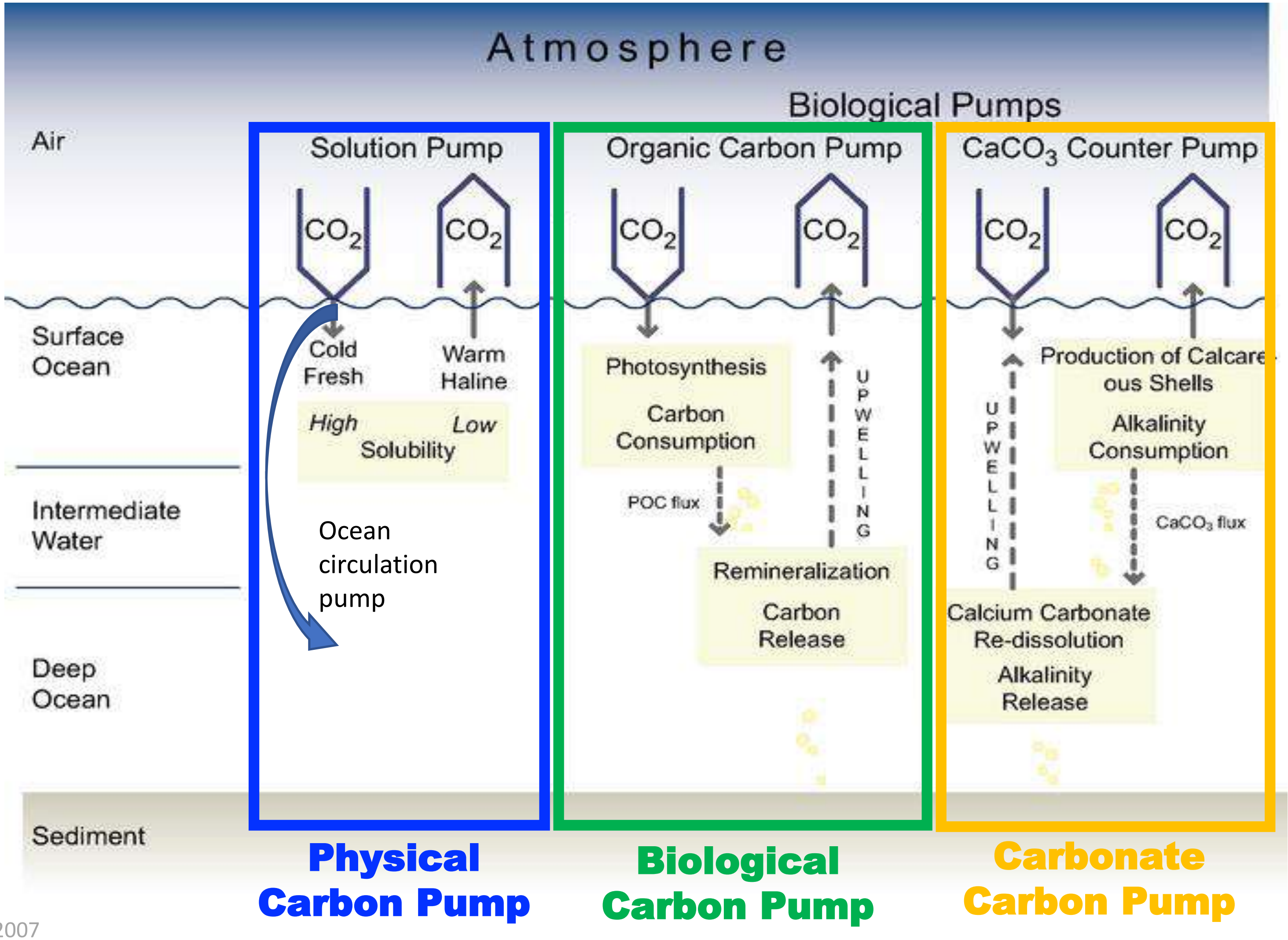
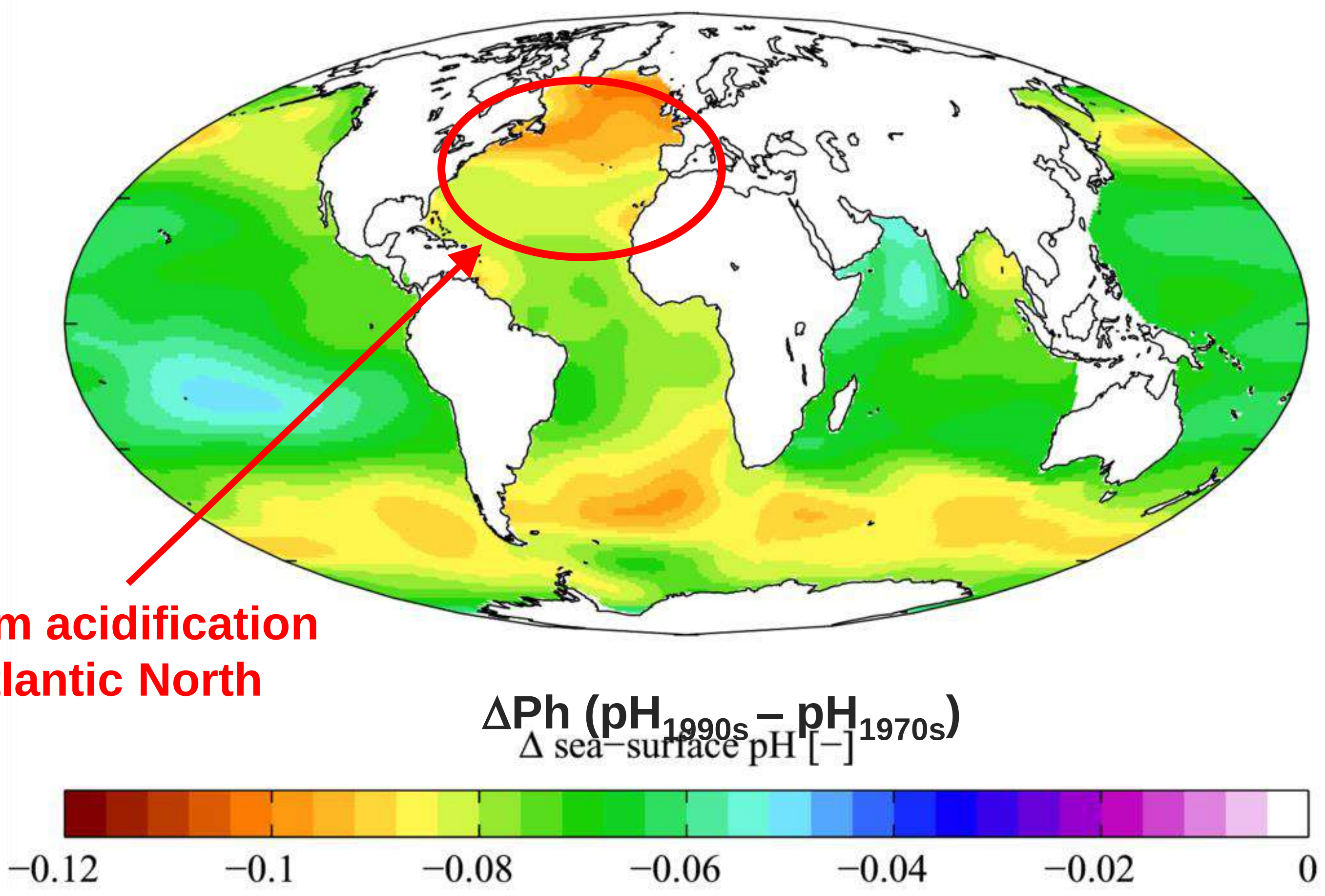


Source: IPCC AR4, 2007

The anthropogenic CO_2 : consequences

Ocean Acidification



Maximum acidification in the Atlantic North

ΔPh (pH_{1990s} – pH_{1970s})

Estimated change in annual mean sea surface pH between the pre-industrial period (1700s) and the present day (1990s). Δ pH here is in standard pH units. Calculated from fields of dissolved inorganic carbon and alkalinity from the Global Ocean Data Analysis Project (GLODAP) climatology and temperature and salinity from the World Ocean Atlas (2005) climatology using Richard Zeebe's csys package.

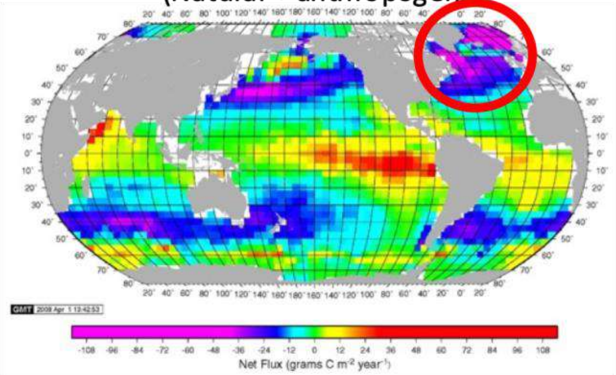
Source:
https://commons.wikimedia.org/wiki/File:WOA05_GLODAP_del_pH_AYool.png#/media/File:WOA05_GLODAP_del_pH_AYool.png

The anthropogenic CO_2 (C_{ant}): why the NA ?

North Atlantic

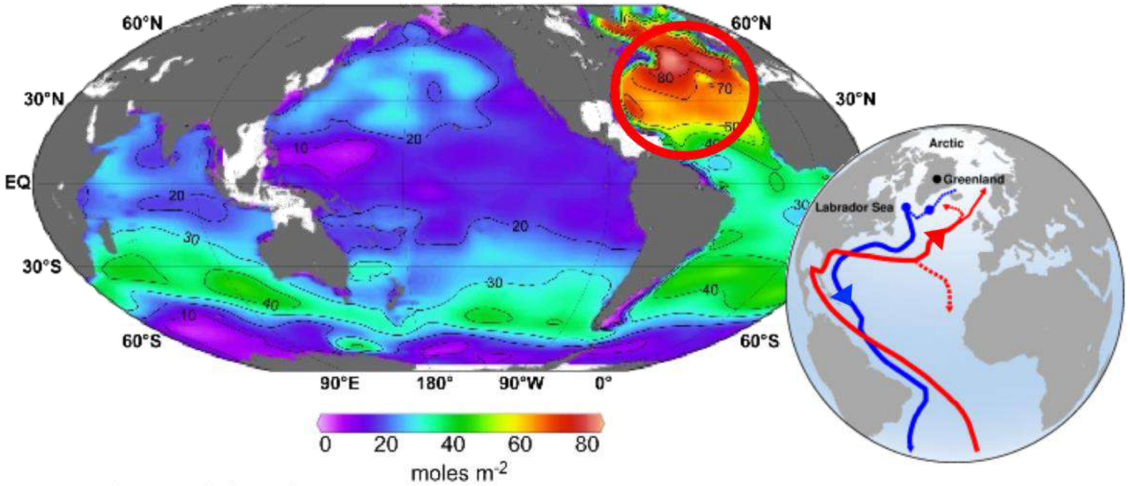
- Is a region of **large** atmospheric **CO_2 uptake** (**41%** of global ocean CO_2 flux)
  Takahashi et al. 2009
- Is the **region** of **largest accumulation of CO_2** emitted by humankind to the atmosphere (**23%** of the global oceanic Cant)
  Sabine et al. 2004

Annual mean CO_2 air-sea fluxes
(Natural + anthropogenic)



Source: Takahashi et al. (2009) DSR

Anthropogenic CO_2 inventory



Source: Sabine et al. (2004) Science

The anthropogenic CO_2 (C_{ant}): why the NA ?

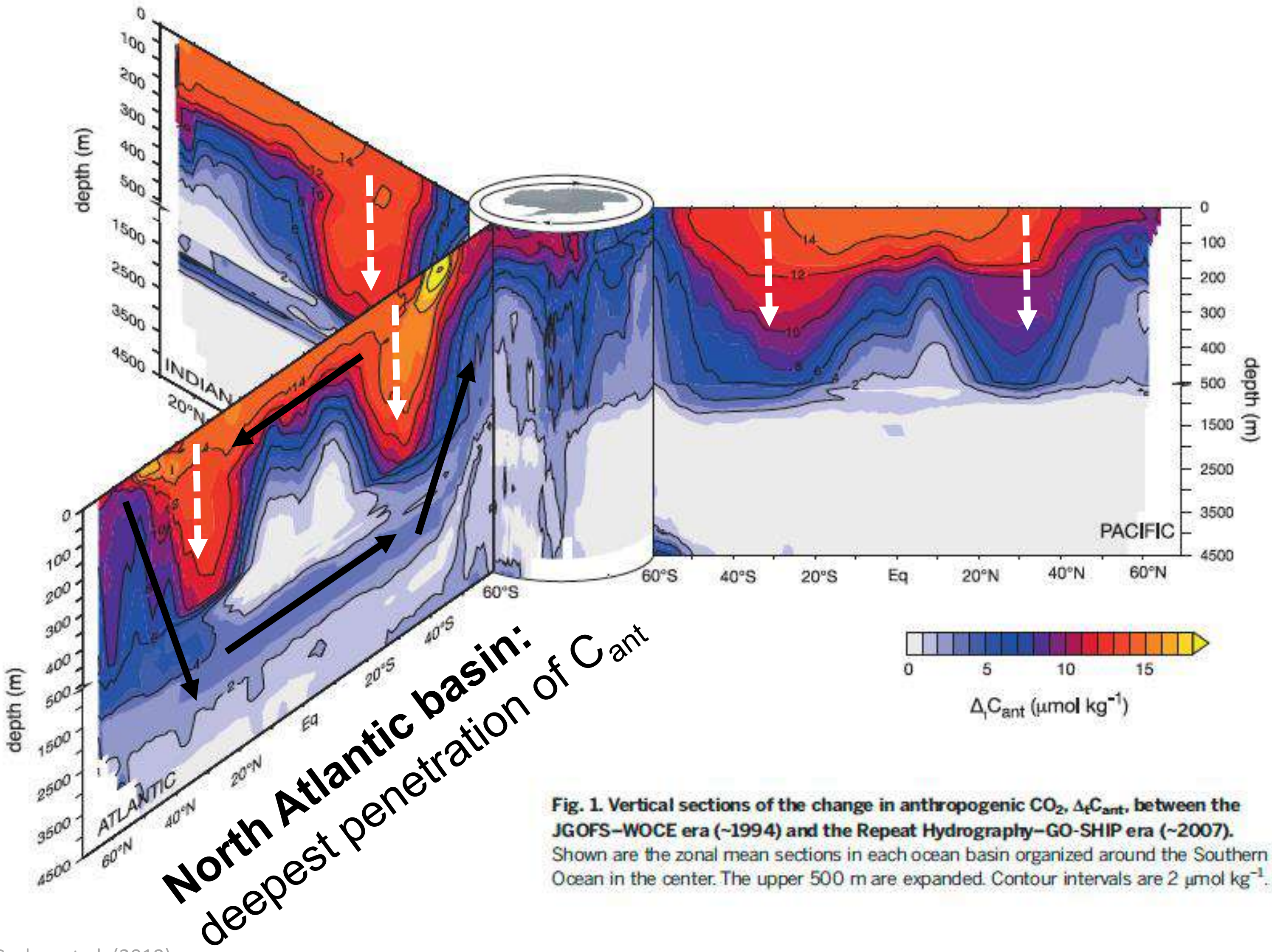


Fig. 1. Vertical sections of the change in anthropogenic CO_2, $\Delta_t C_{ant}$, between the JGOFS–WOCE era (~1994) and the Repeat Hydrography–GO-SHIP era (~2007). Shown are the zonal mean sections in each ocean basin organized around the Southern Ocean in the center. The upper 500 m are expanded. Contour intervals are 2 µmol kg^{-1}.

Source: Gruber et al. (2019)

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C_{ant} estimate methods: ocean carbon variables

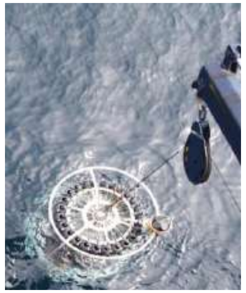
Which?

1. pH 2. A_T 3. C_T 4. pCO_2 5. CO_3^{2-}

"If you know two of these parameters you can compute all the others with a given T, S and P"

Where?

✓Cruise Chemical-CTD *in situ* data :



- pH
- A_T
- C_T
- O_2
- Salinity
- Temperature

✓World data bases:

glodap

SOCAT · SURFACE OCEAN CO_2 ATLAS ·

How?

✓ Niskin bottles' sampling :

- pH
- A_T
- C_T
- Nutrients
- ^{14}C and O^{18} isotopes
- O_2
- Salinity

✓ Analysis of the carbonate system variables

(pairs: pH/A_T, C_T/A_T)

C_{ant} estimate methods

$$DIC = DIC_{nat} + C_{ant}$$

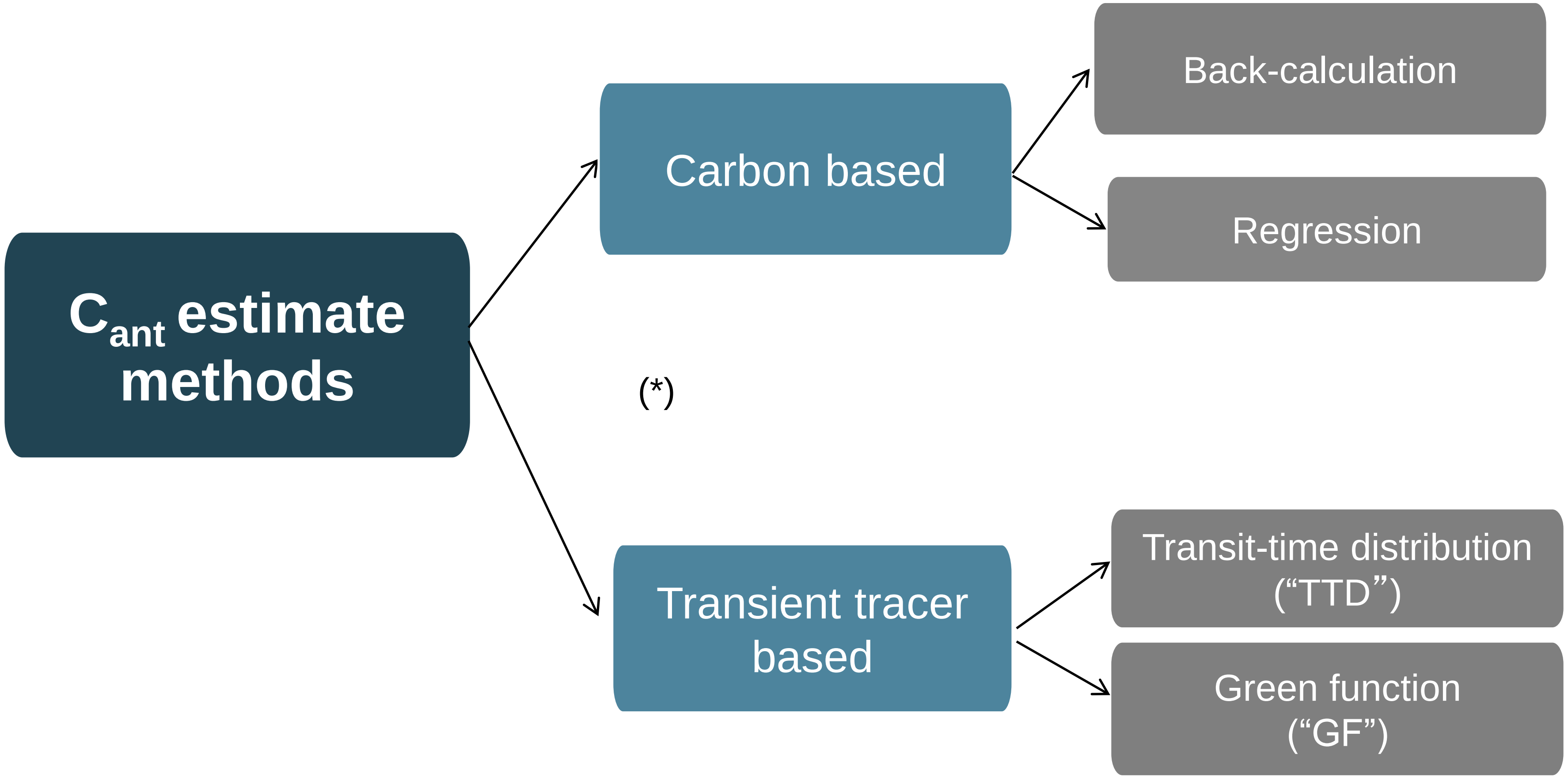
DIC_{nat}

=

C_{ant}

- C_{ant} is **not a directly measurable quantity:** it has to be estimated using indirect means.
- The anthropogenic signal in the ocean is only **a few percent (3-4%)** of DIC.
- Carbon in the ocean participates in rather **complex in situ biogeochemistry processes**.
- C_{ant} distribution in the ocean is highly **heterogeneous**.

C_{ant} estimate methods



(*) OCIM: Ocean Circulation Inverse Model (DeVries, 2014)
[a bit in-between both: inversion method with Δ14C as constraint]

C_{ant} estimate methods: back-calculation methods

Carbon based

- Indirect estimate of C_{ant} from direct measurements (A_T, C_T,..)
- Used by the first time in the 70s (Brewer, 1978; Chen y Millero,1979)
- Methods:

1/ ΔC^* (Gruber et al., 1996)

2/ C_T^0 IPSL (Lo Monaco et al., 2005)

3/ TrOCA (Touratier et al., 2007)

4/ φC_T^o (Vázquez-Rodriguez et al., 2009)

C_{ant} estimate methods: back-calculation methods

Carbon based

$$C_{ant} = C_T - \Delta C_{bio} - C_{phys}$$

$$C_{ant} = \underbrace{C_T^0}_{C_T - \Delta C_{bio}} - \underbrace{C_T^{0\pi}}_{C_T^{\pi SAT} + \Delta C_{dis}^{\pi}}$$

C_T (or DIC): measured total dissolved inorganic carbon.

ΔC_{bio}: processes of oxidation/remineralization of the organic matter and processes of dissolution of CaCO3.

$C_T^{eq,\pi}$: C_T in equilibrium in pre-industrial times.

ΔC_{dis}^{π} : disequilibrium in the interphase atm-ocean.

C_{ant} estimate methods: back-calculation methods

Carbon based

4/ φC_T^o method (Vázquez-Rodríguez et al., 2009)

- ✓ Method developed by Perez F.F. team – IIM-CSIC (Vigo)
- ✓ C_{ant} is the difference between the water mass DIC at their formation time and the DIC that it would have in preindustrial times.
- ✓ Takes into account changes in carbon concentration due organic matter remineralization and $CaCO_3$ dissolution.
- ✓ Only needs hydrographical data: carbon, oxygen and inorganic nutrients.
- ✓ Overall uncertainty: ±5.2 $\mu mol \cdot kg^{-1}$
- ✓ Reference layer: subsurface layer

C_{ant} estimate methods: back-calculation methods

Carbon based

4/ φC_T^o method (Vázquez-Rodríguez et al., 2009)

Strengths of the method:

- ✓ Proper characterization of preformed conditions.
- ✓ No need for CFC's data.
- ✓ No assumptions about Cant saturation in the water mass formation time.
- ✓ Includes corrections for warming and acidification.
- ✓ Does not need a "zero" Cant reference.
- ✓ Is based on biogeochemical and oceanographic knowledge.

Source: M. Fontela (CANAIMOC, 2021)

C_{ant} estimate methods: back-calculation methods

Carbon based

4/ φC_T^o method (Vázquez-Rodríguez et al., 2009)

Weaknesses of the method:

- ✓ Not global, only for the Atlantic Ocean.
- ✓ Depends in part on a simplified OMP.
- ✓ ΔCdis computation is based on multiple linear regressions (MLR) that are potentially improved.
- ✓ Assume constant and homogeneous stoichiometric ratios.

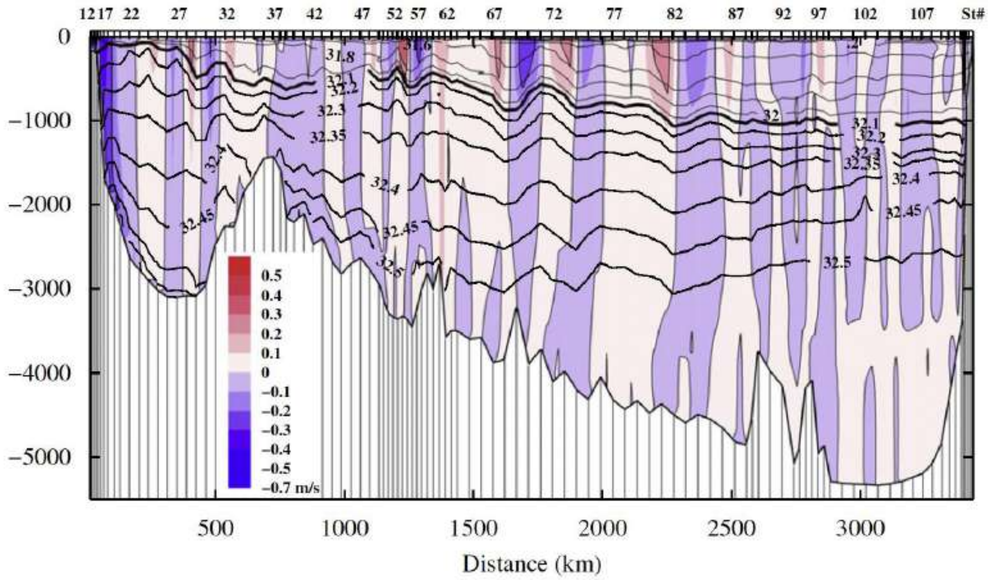
Source: M. Fontela (CANAIMOC, 2021)

Calculation of C_{ant} transports

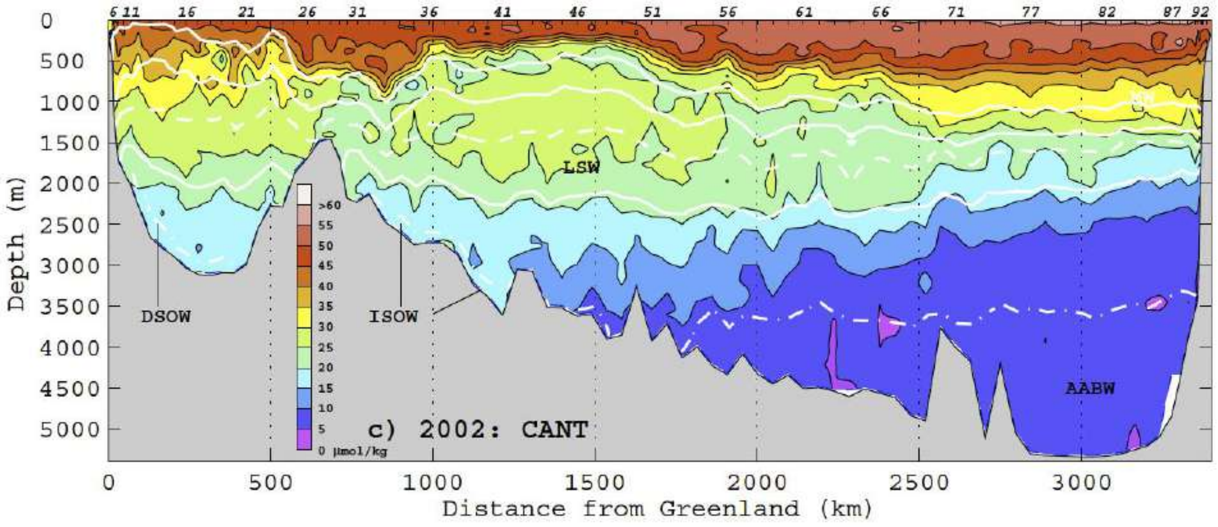
$$T_{Cant}^{section}(x,z,t) = \iint [Cant](x,z,t)\, v(x,z,t)\, \rho(x,z,t)\, dx\, dz$$

v (x,z,t)

[Cant](x,z,t)



Inverse box model



Back-calculation method

Source: Lherminier et al. (2010)

Source: Zunino et al. (2014)

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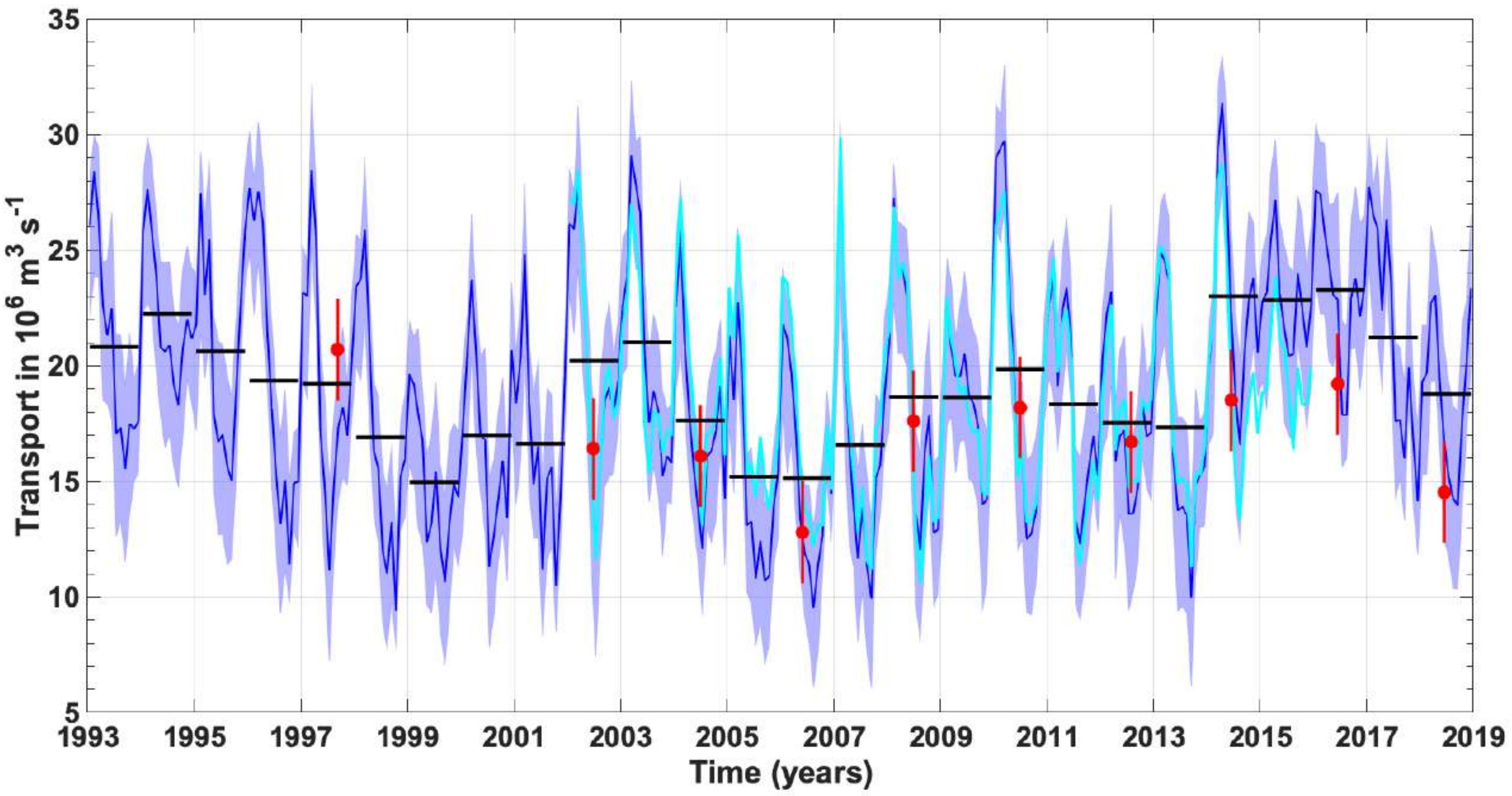
OVIDE MOC Time Series



In cyan: with all the monthly and interannual variability of the ISAS hydrography fields

In blue: with the monthly climatology of the ISAS hydrography fields

In black: annual mean

In red: MOC at the time of the cruise

The index includes 1 Sv of transport towards the Arctic and an annual mean Ekman transport of about 1 Sv southward

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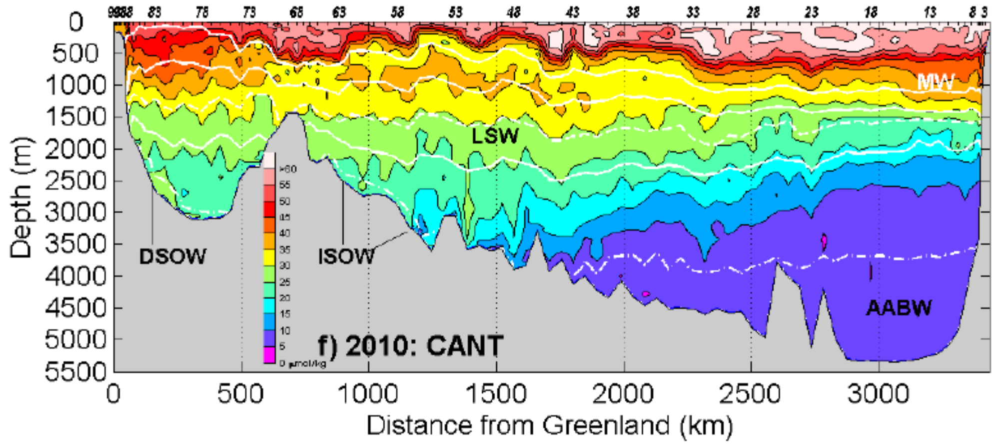
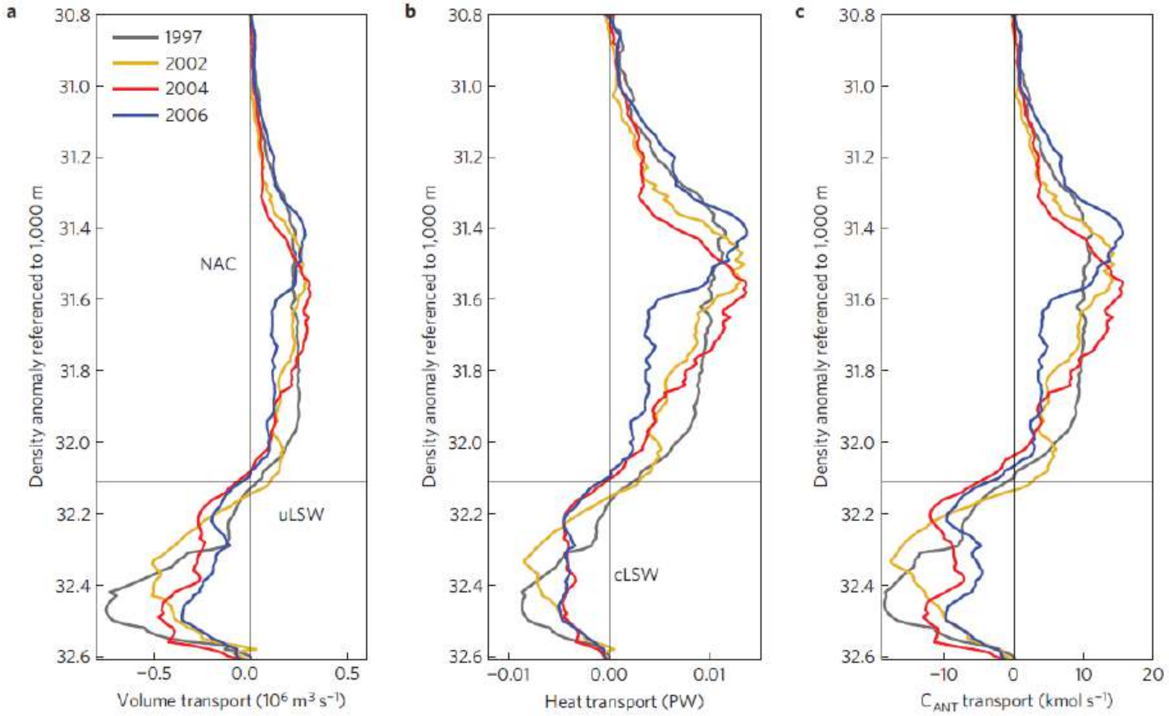
Net northward transport of Cant by the MOC



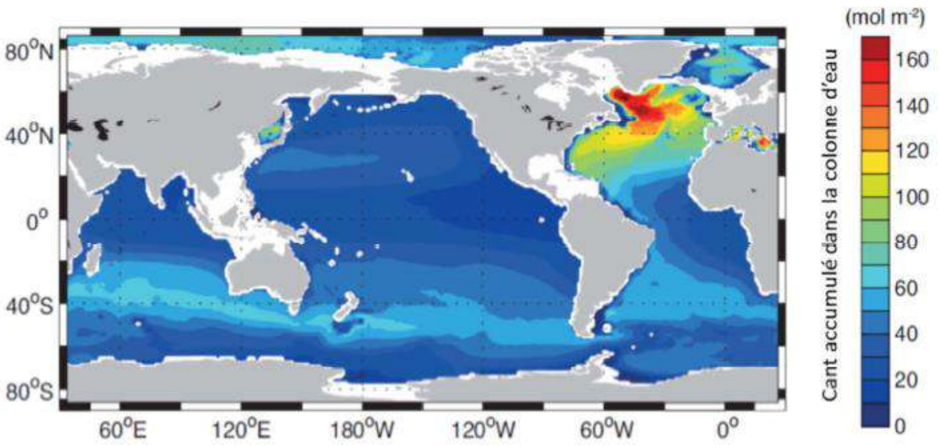
The water masses of the MOC upper (northward) limb show higher Cant than those of the MOC lower (southward) limb.

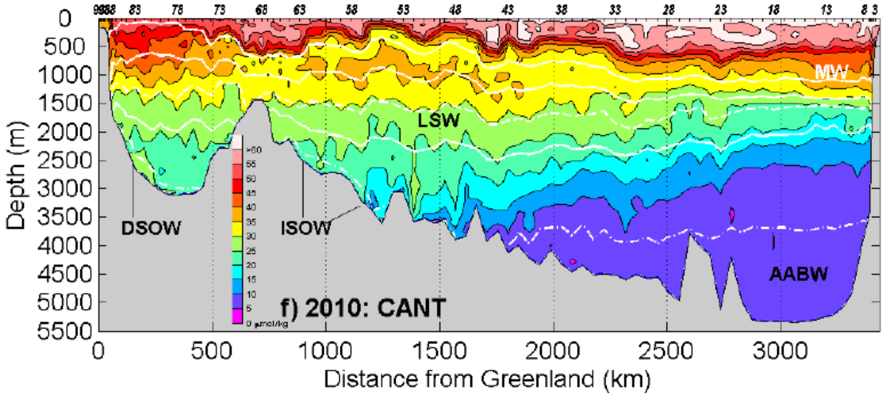


Volume transport　　Heat Transport　　Cant transport

- ❑ The net transport of Cant by the MOC is northward
- ❑ Cant accumulates in the northern North Atlantic because of this net northward transport by the MOC.
- ❑ Perez et al. (2013); Zunino et al. (2014); Perez et al. (2019)

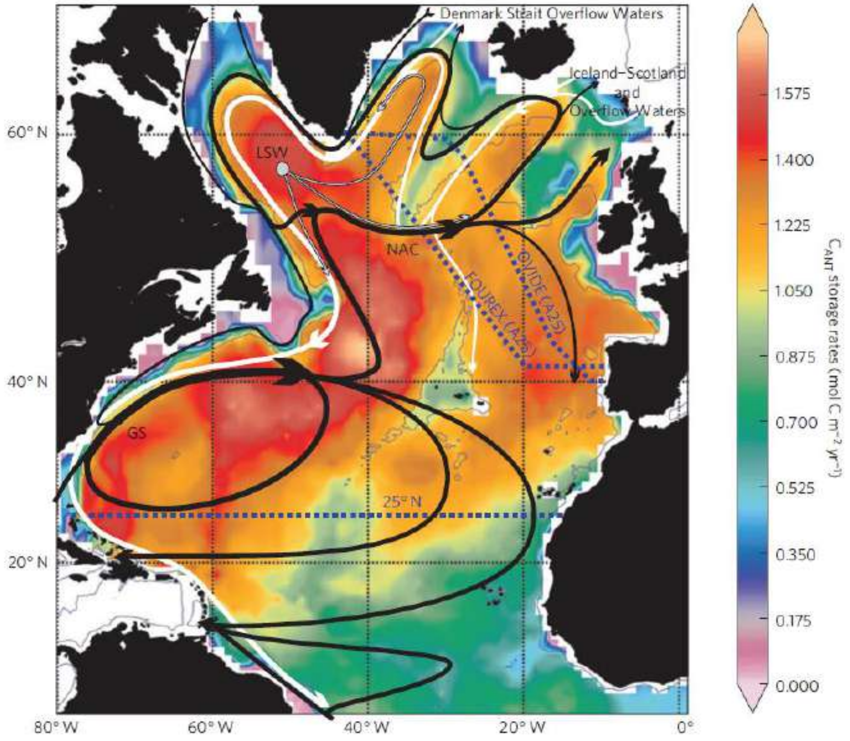
Anthropogenic CO_2 uptake, advection and storage





In the NA, Cant uptake occurs in the subtropical gyre (mostly)

C_{ant} = Anthropogenic Carbon

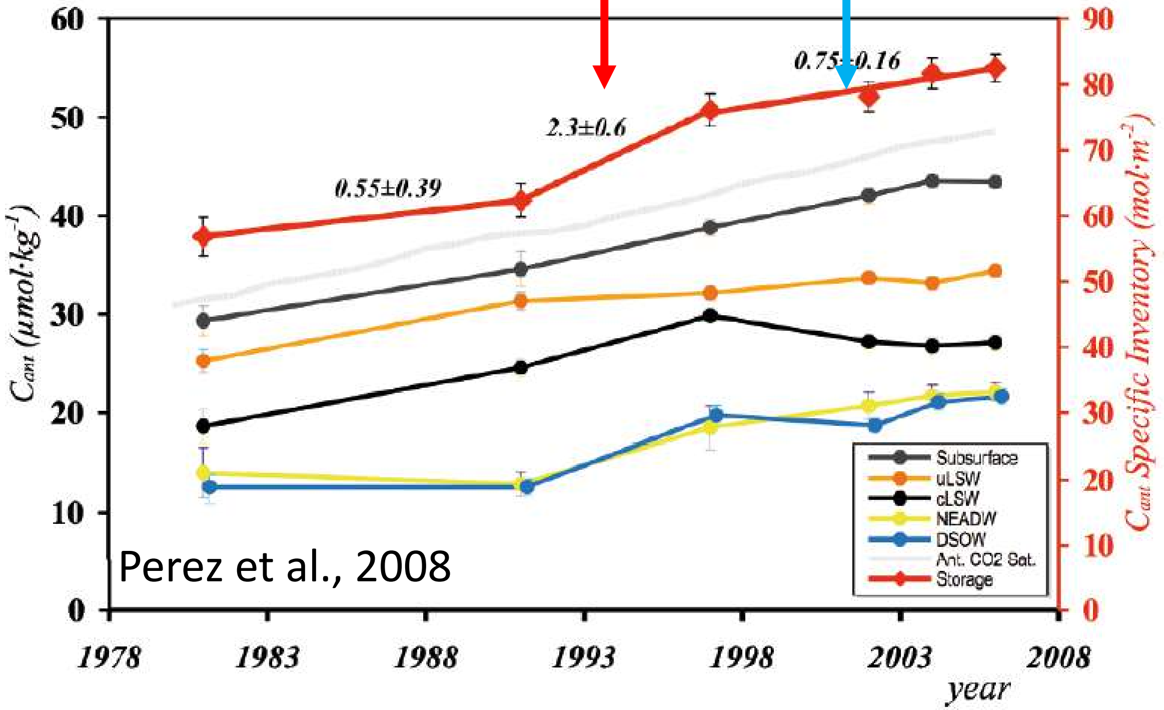


Cant storage rate in 2004 from Perez et al. (2013)

MOC variability and Cant storage rate

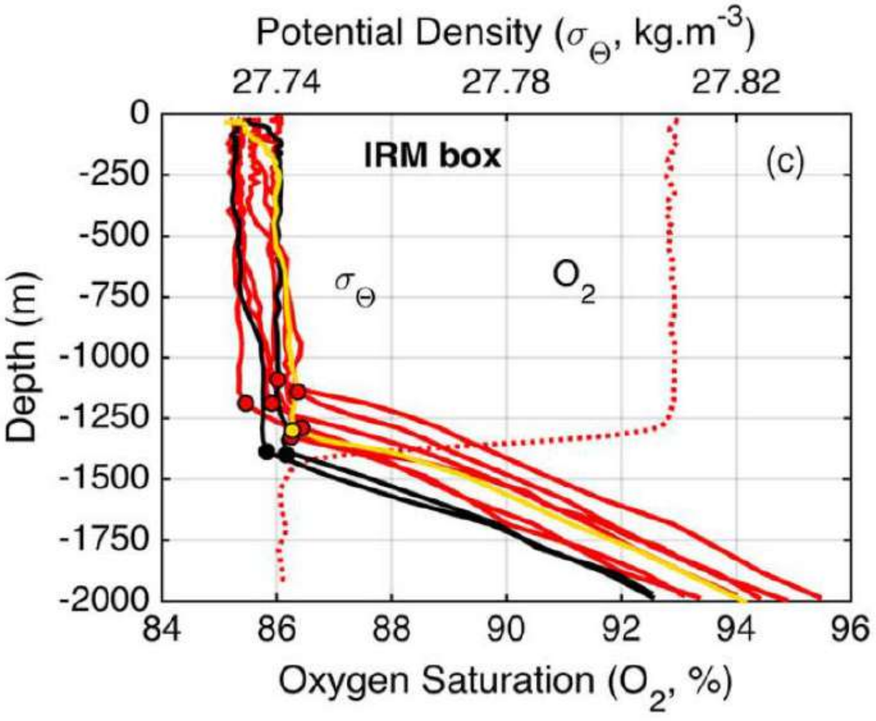
High MOC

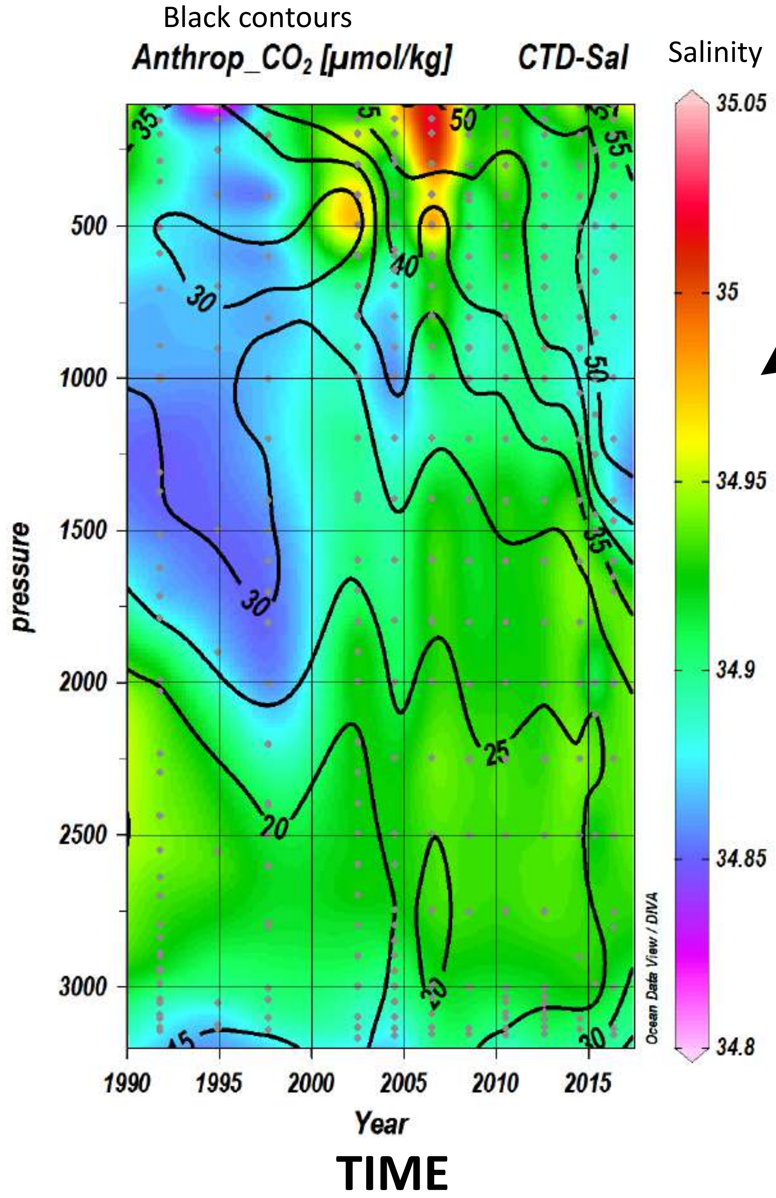
Low MOC = less northward advection of Cant = less storage

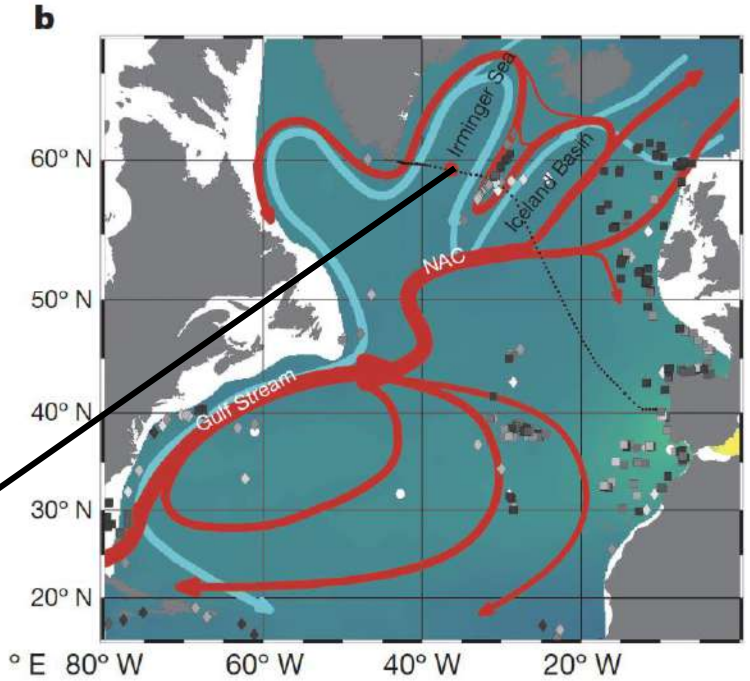


On inter-annual to decadal time scale MOC controls the storage rate of Cant in the North Atlantic subpolar gyre (see Zunino et al. 2014 for longer time scales)

Anthropogenic CO_2 cycle







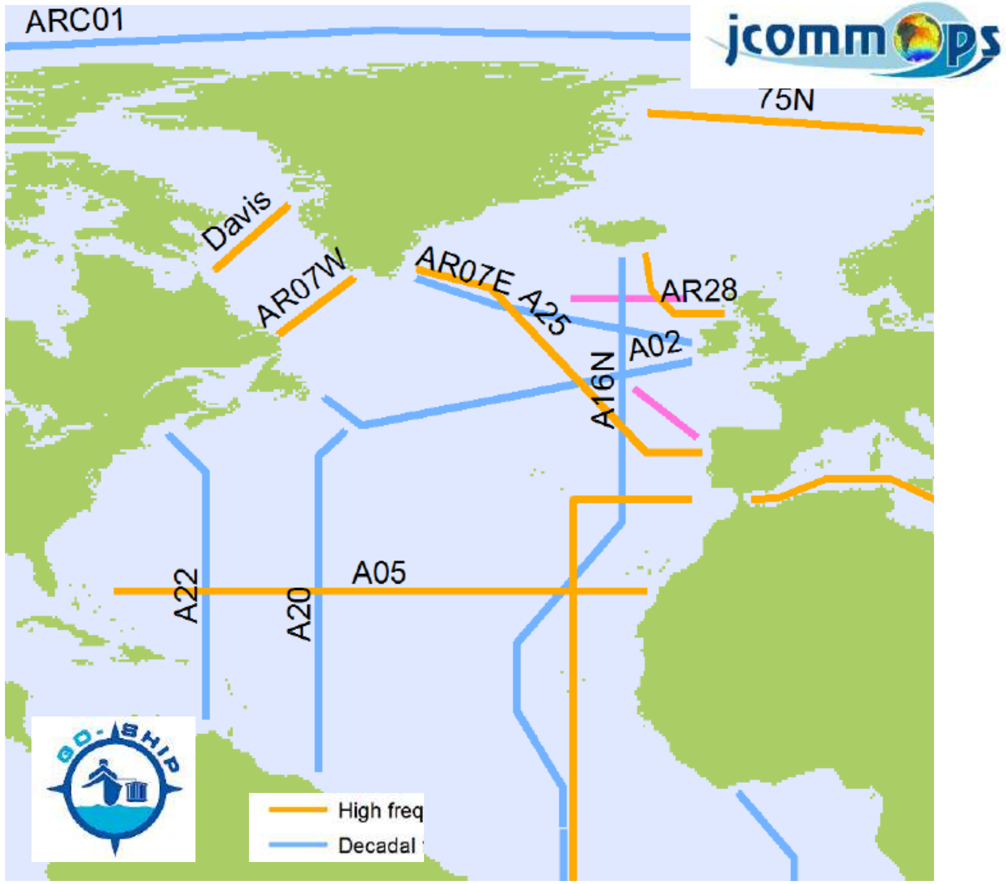
Injection of Cant into the deep ocean by deep convection events (Perez et al, Nature 2018)

Exceptionnal deep convection in the Irminger Sea during winter 2014-2015. Piron et al. (2017).

Conclusions

- The upper MOC_σ time series reveals a strong seasonal to decadal variability
- The MOC_σ variability is important to understand the interannual variability of anthropogenic CO_2 storage rate
- More deep convection in the subpolar gyre in the lastest year: Piron et al. (2017); Zunino et al. (2020).
- Data: Mercier Herle, Daniault Nathalie, Lherminier Pascale (2016). Time series of the Meridional Overturning Circulation strength at OVIDE. http://doi.org/10.17882/46445.
- Carbon related data: https://www.ncei.noaa.gov/access/ocean-carbon-data-system/oceans/RepeatSections/clivar_ovide.html
- Next occupations of the OVIDE line 2023 (Ship time already secured by Anton Velo and the Ovide group).

Go-Ship : an international context



OVIDE-A25 =

- One of the GO-SHIP high-resolution sections in the North Atlantic since 2002
- Physical and biogeochemical data
- Conducted by France (2002-2010) and Spain/France alternatively since 2012
- Contribution to CLIVAR & OSNAP