Natural and Anthropogenic Carbon Changes in the South Indian Ocean

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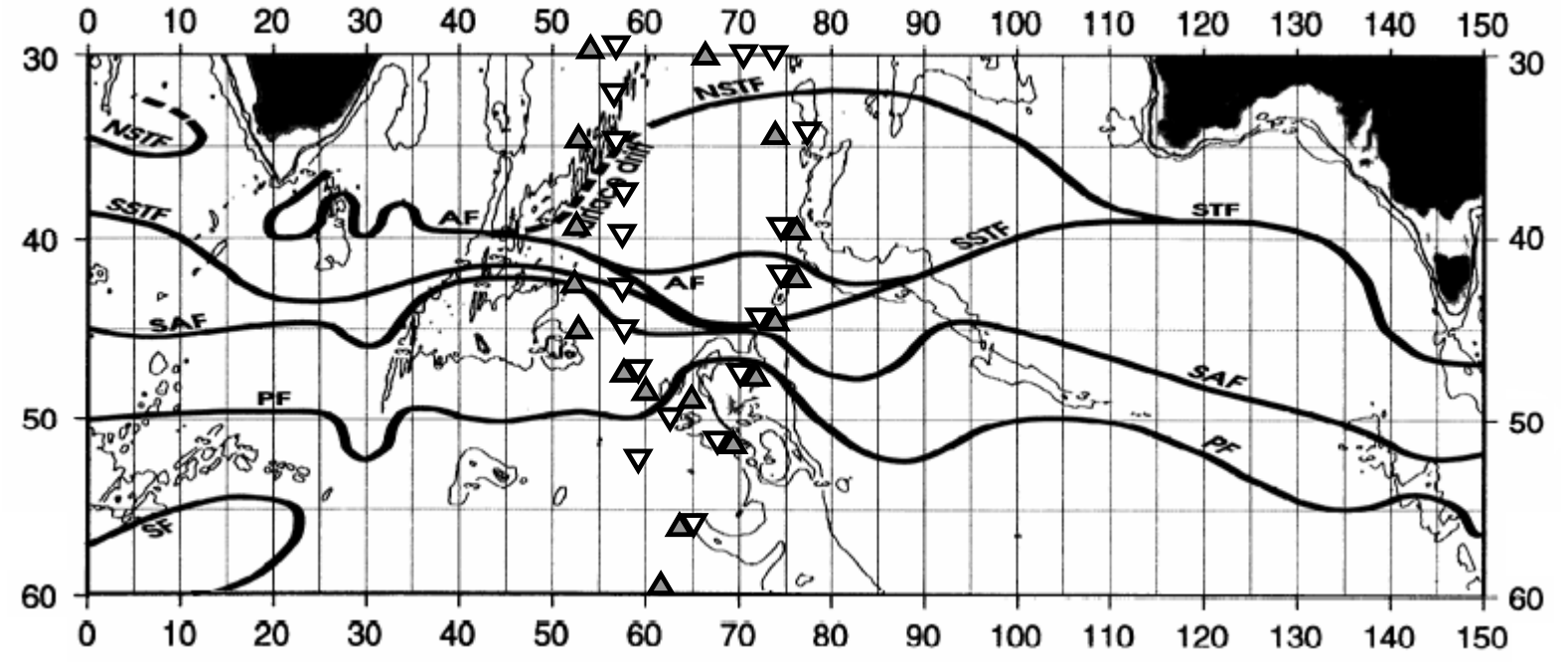
N.O. Marion-Dufresne, original painting by Christophe Verdier, January 2004

Hydrological fronts and water masses in the South Indian Ocean



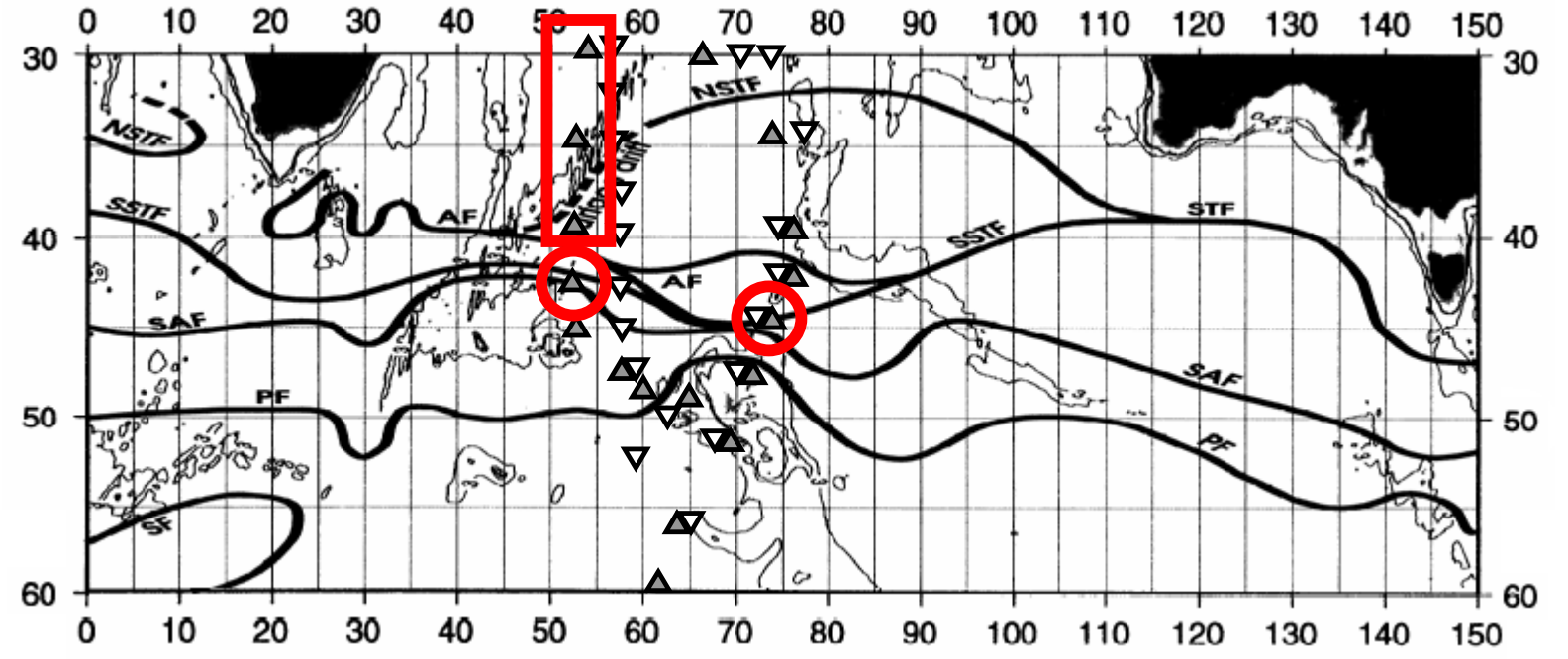
Mean position of hydrological fronts (Belkin and Gordon, 1996)

Observations :

▽ **INDIGO :** 1 cruise conducted in 1985

▲ **OISO :** 6 cruises conducted between 1998 and 2001
→ interannual variability

Hydrological fronts and water masses in the South Indian Ocean



Mean position of hydrological fronts (Belkin and Gordon, 1996)

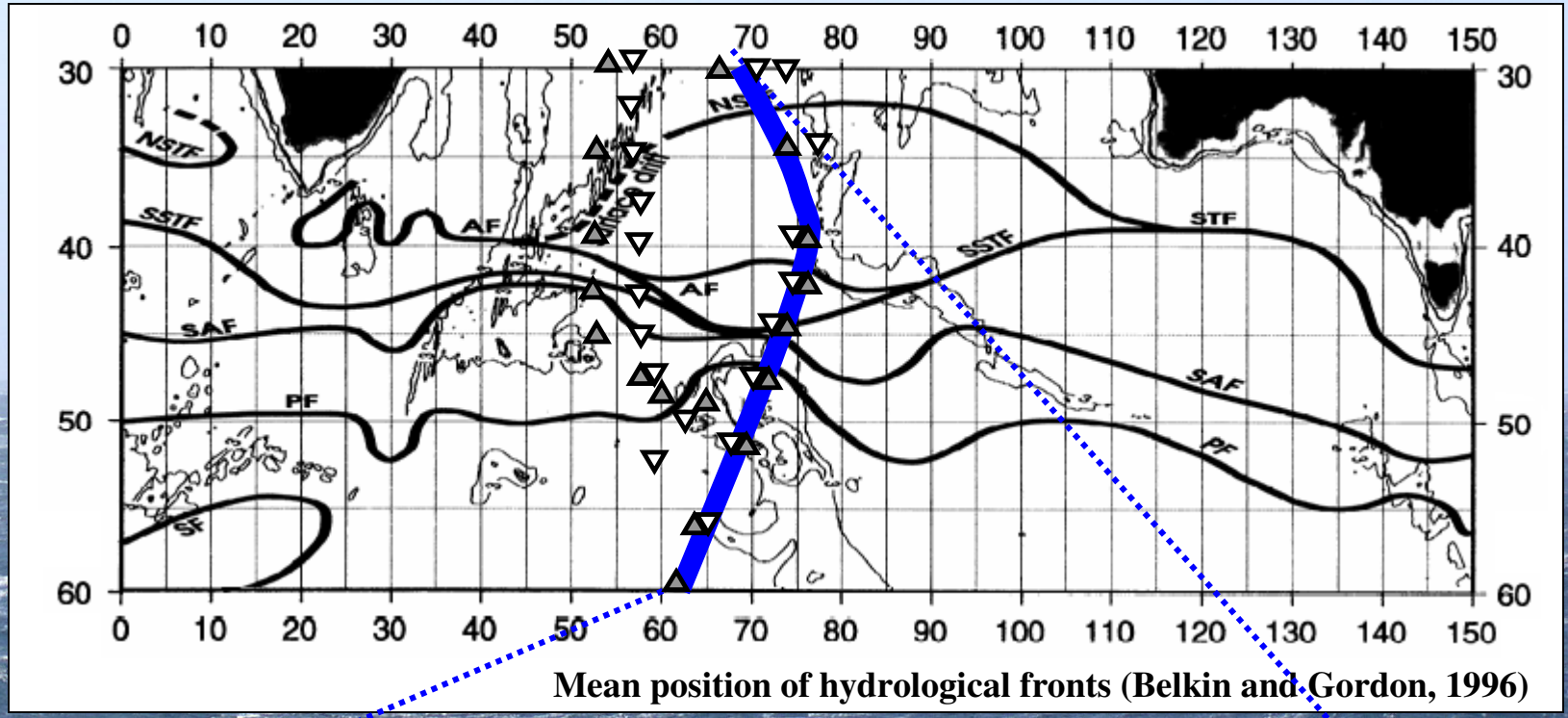
Large interannual variability

○ associated with the SAF (movement of the front) and

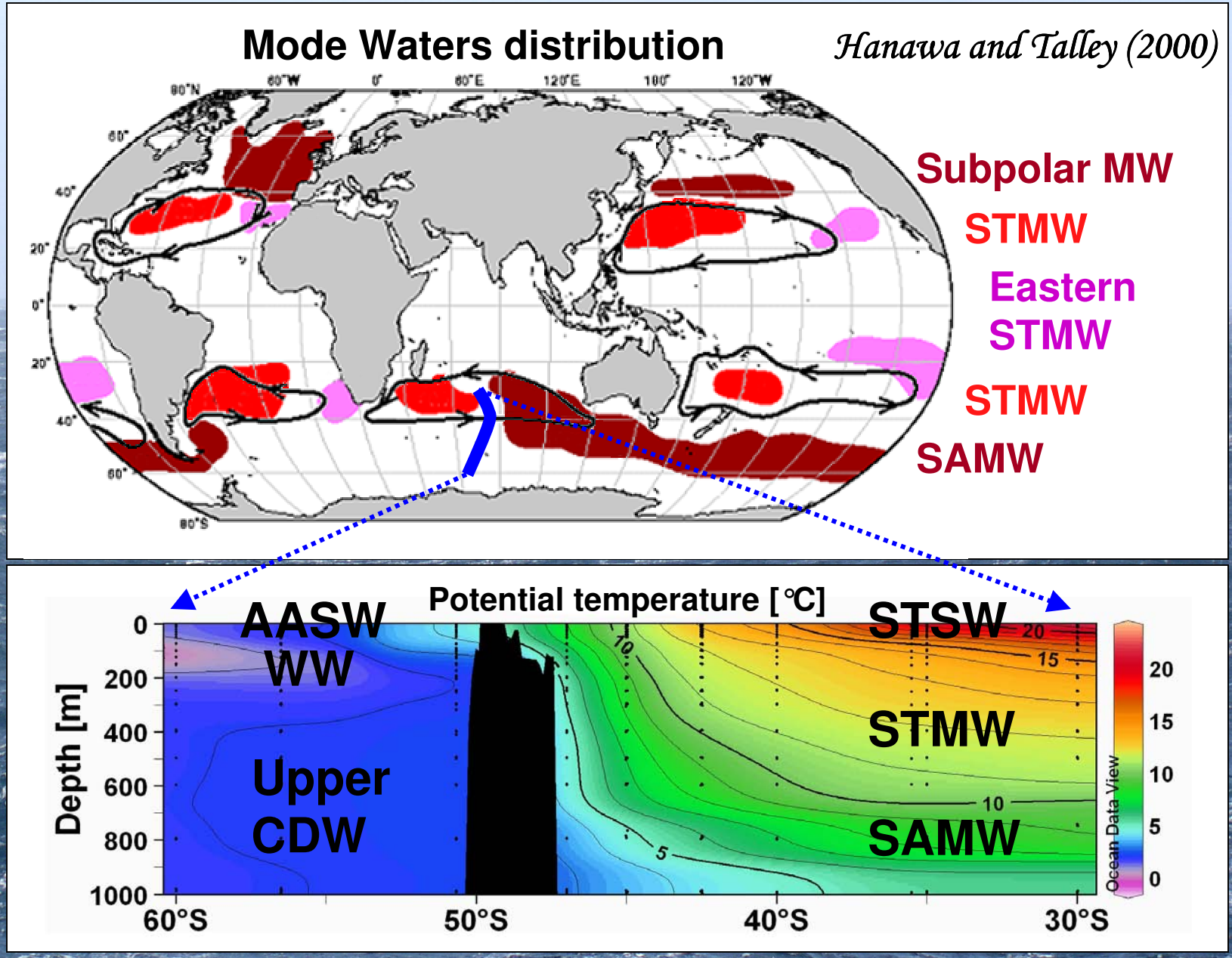
▯ north of the SAF in the western Indian Ocean (mesoscale feature created by the Madagascar Current and the Agulhas Return Current)

Rodgers et al. (in prep.)

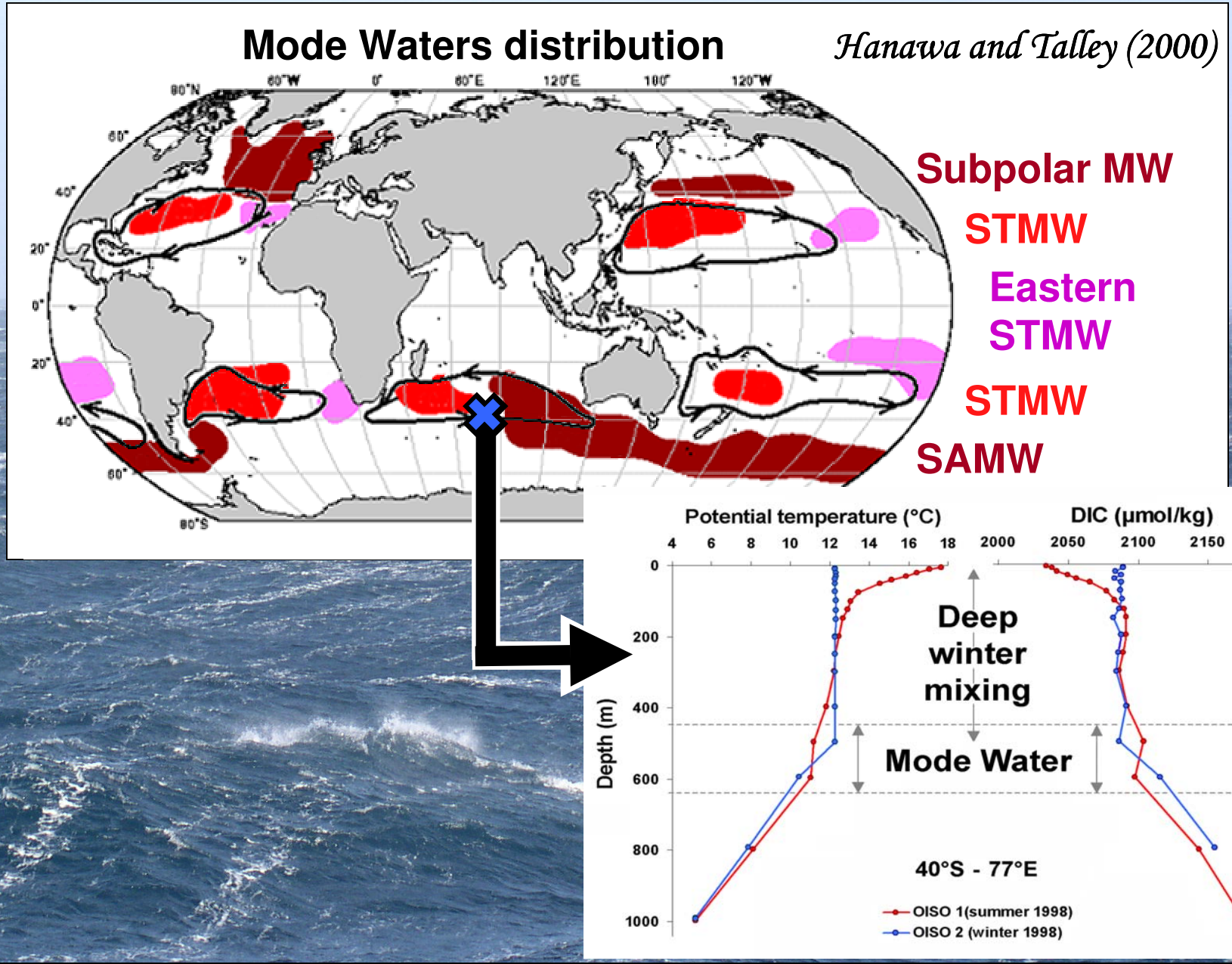
Hydrological fronts and water masses in the South Indian Ocean



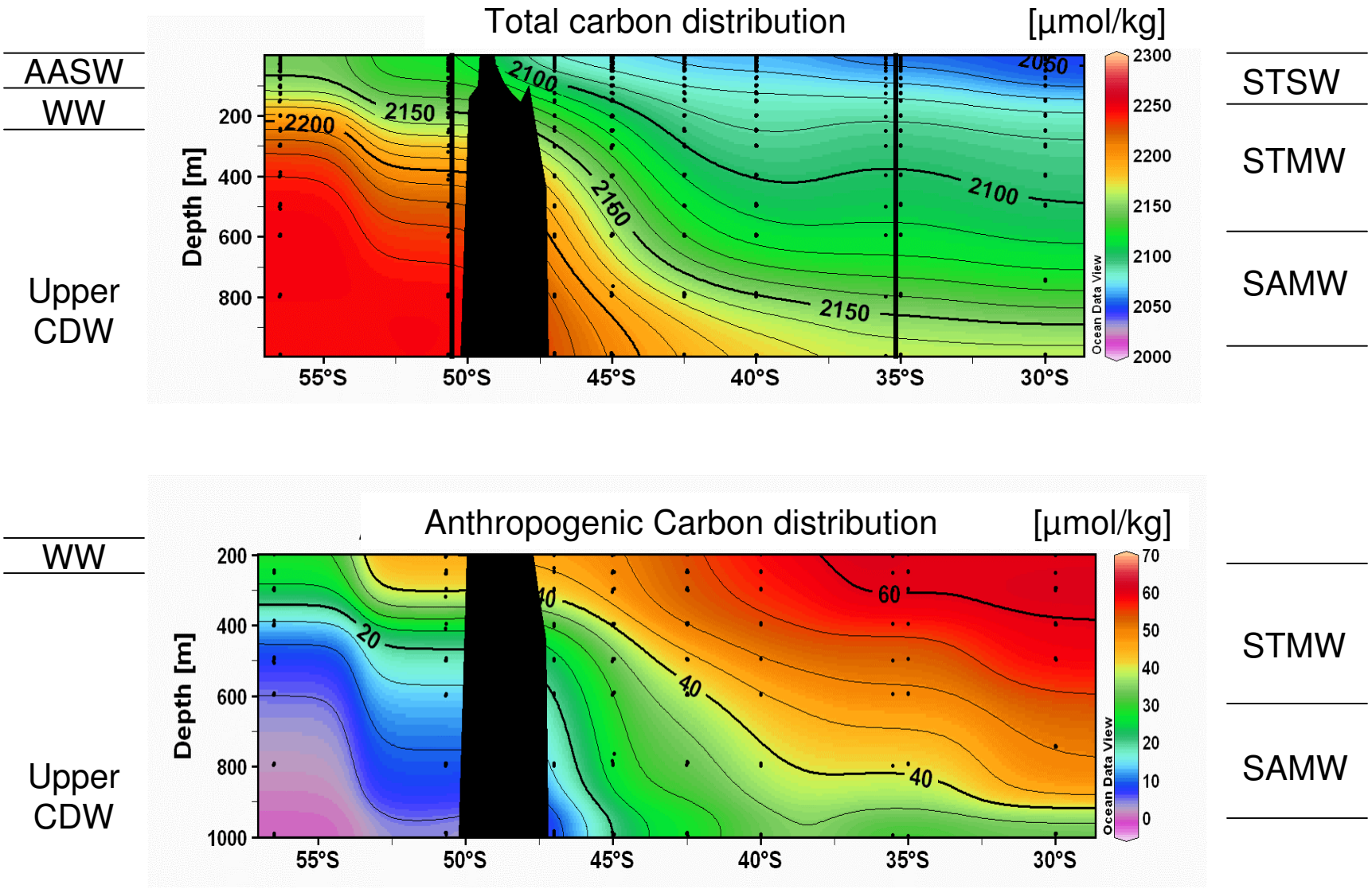
Hydrological fronts and water masses in the South Indian Ocean



Mode Waters

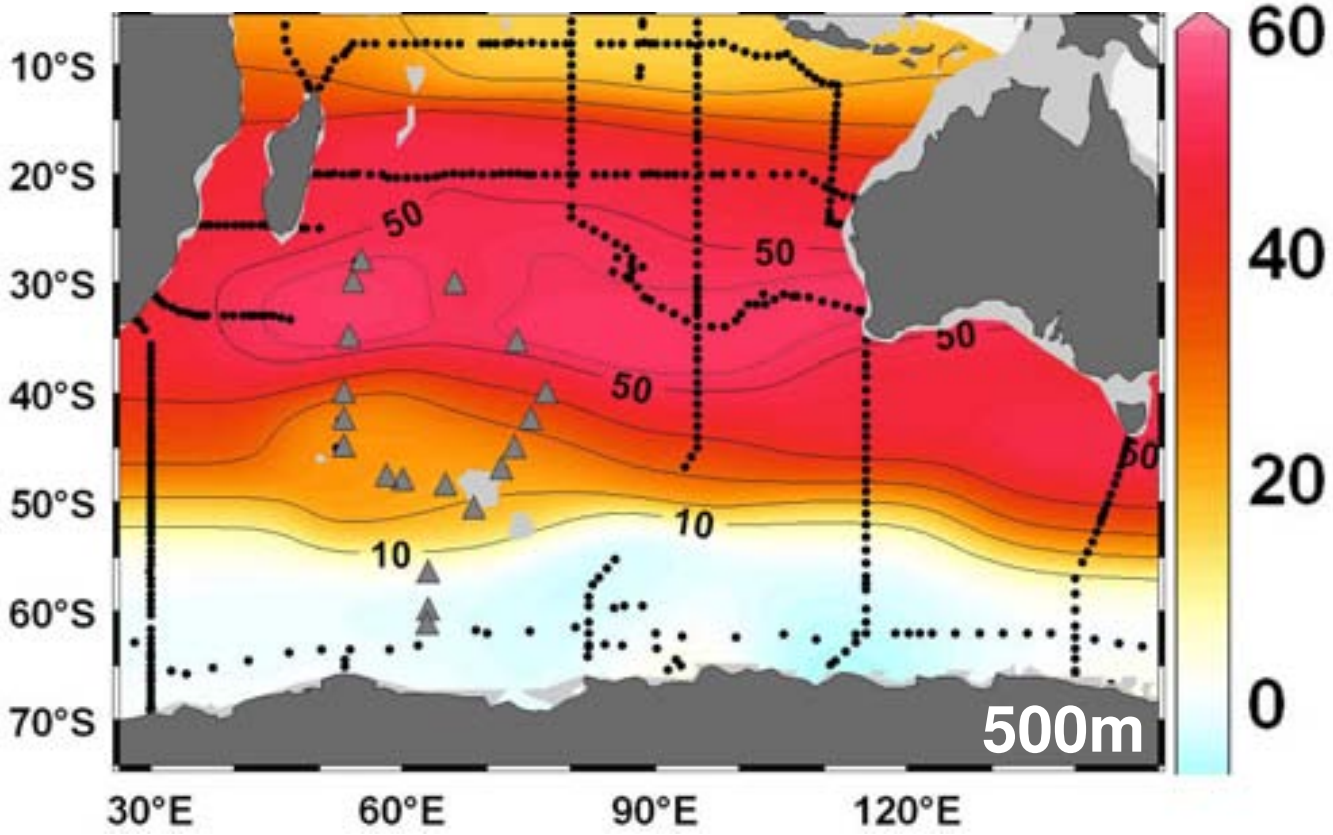

Mode Waters distribution
Hanawa and Talley (2000)
Subpolar MW
STMW
Eastern STMW
STMW
SAMW
Potential temperature (°C)
DIC (µmol/kg)
Deep winter mixing
Mode Water
Depth (m)
40°S - 77°E
OISO 1(summer 1998)
OISO 2 (winter 1998)

Total Carbon and Anthropogenic Carbon distributions



Anthropogenic Carbon in Mode Waters

Anthropogenic carbon distribution at 500m in the late 1990's [µmol/kg]



Anthropogenic carbon calculated from observations (TCO_2, TA, O_2 and conservative tracers)

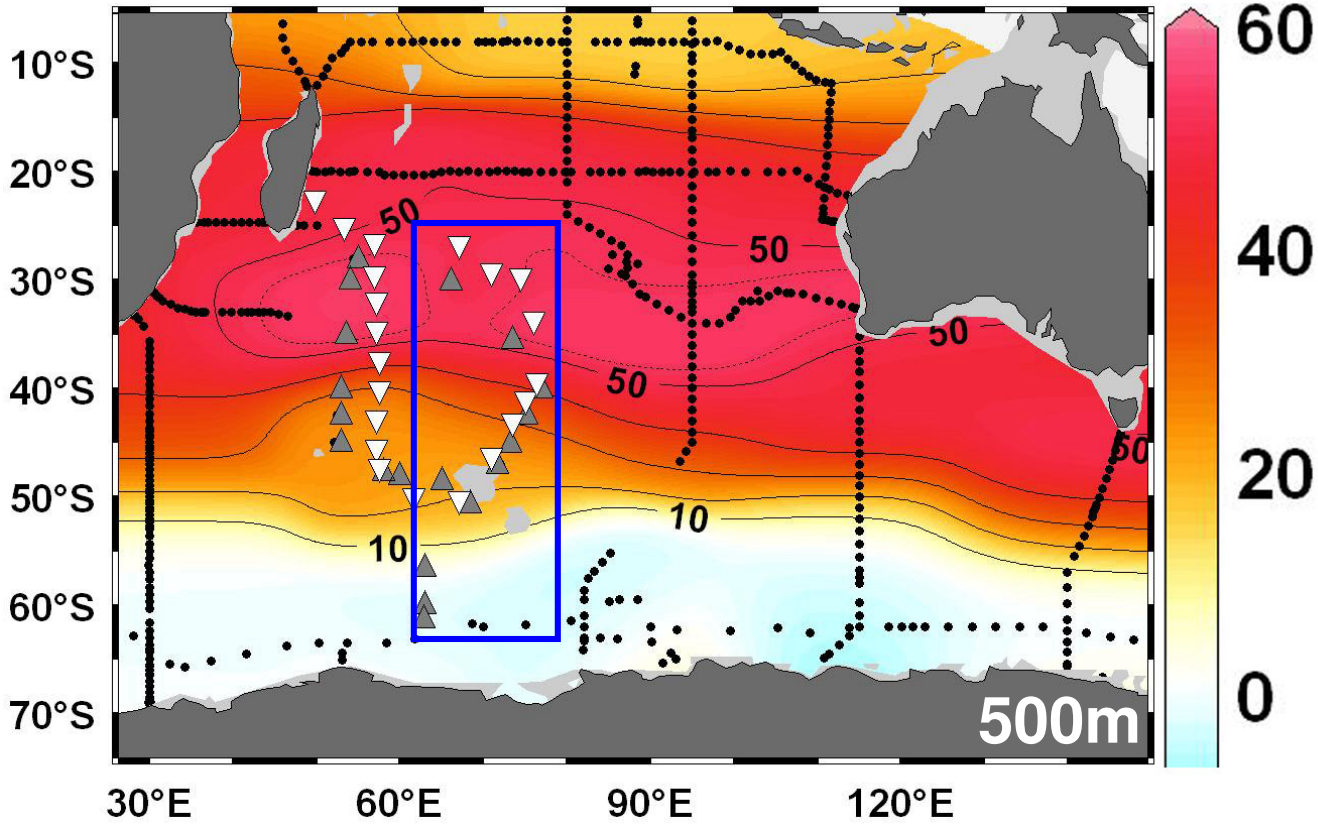
Observations :

- **WOCE (1995-1996)**
- **OISO 1 to 3 (1998)**

Large accumulation of anthropogenic carbon at mid-latitudes (20-40°S) in recently formed Mode Waters

Anthropogenic Carbon in Mode Waters

Anthropogenic carbon distribution at 500m in the late 1990's



Anthropogenic carbon calculated from observations (TCO_2, TA, O_2 and conservative tracers)

Observations :

- ▽ INDIGO 1 (1985)
- • WOCE (1995-1996)
- △ OISO 1 to 3 (1998)

Comparison of recent observations (1998-2001) with historical measurements (1985) to evaluate the decadal change in ocean carbon

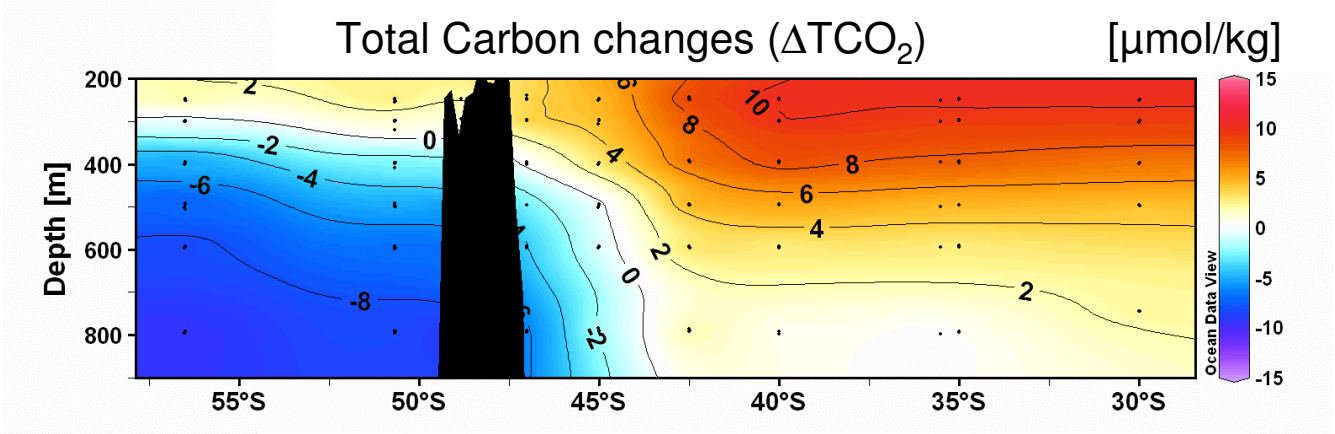
Total Carbon changes

Multi-Linear Regression (MLR) technique

<u>method 1 (only conservative tracers)</u> : TCO_2 = MRL (S, T, NO)

WW

Upper CDW



STMW

SAMW

Multi-Linear Regressions with observations from the first cruise :

<u>INDIGO (1985)</u> : Total Carbon = 31.86*S - 26.49*T - 0.551*NO + 1477.7

applied to S, T and NO from the second cruise

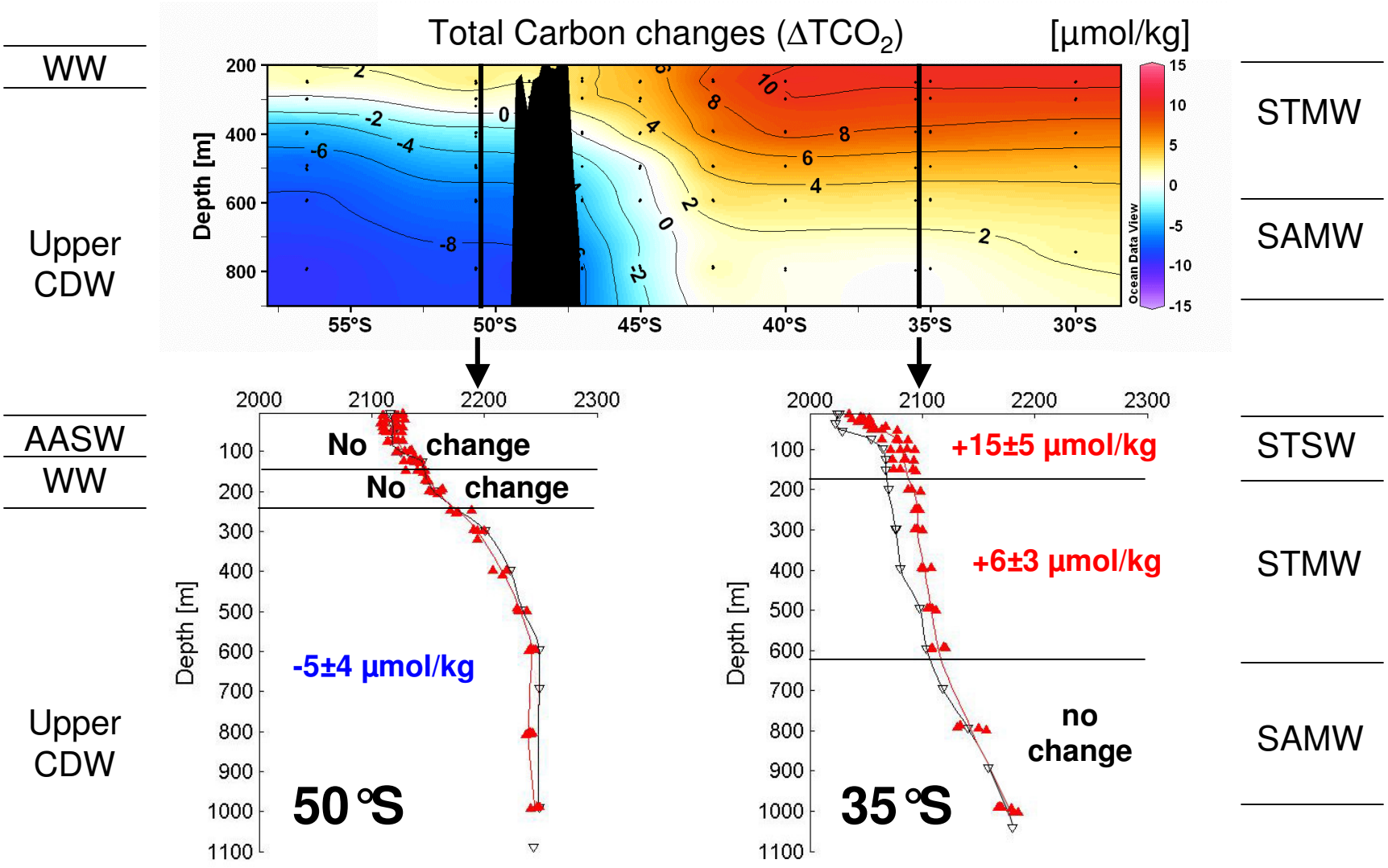
→ <u>Total Carbon in 1985 interpolated on S, T, NO observed in 1998-2001</u>

Total Carbon change = difference from Total Carbon observed in 1998-2001

Total Carbon changes

Multi-Linear Regression (MLR) technique

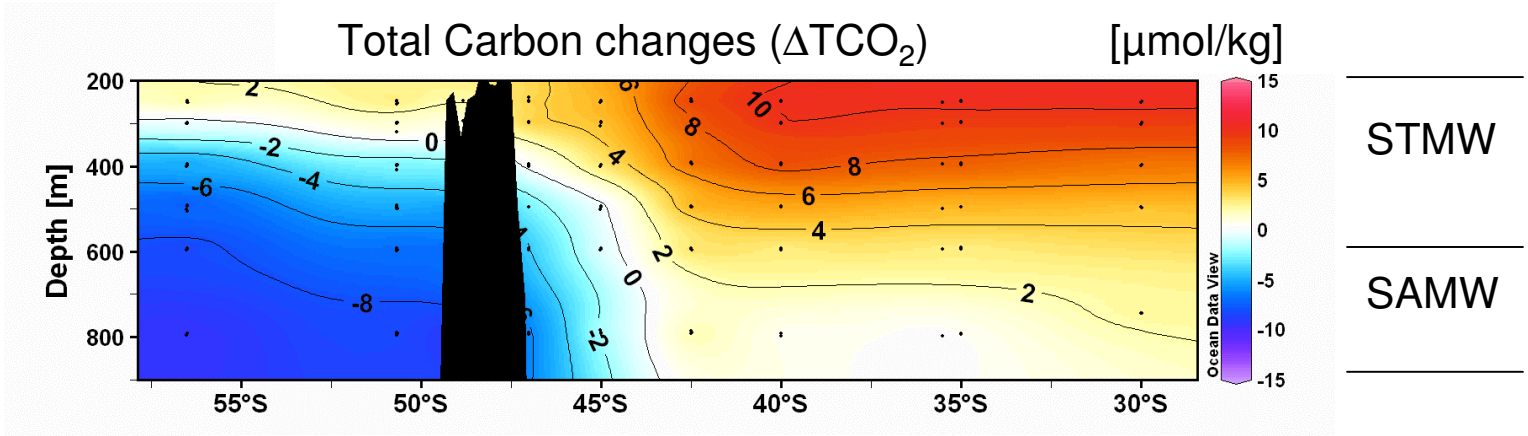
<u>method 1 (only conservative tracers)</u> : TCO_2 = MRL (S, T, NO)



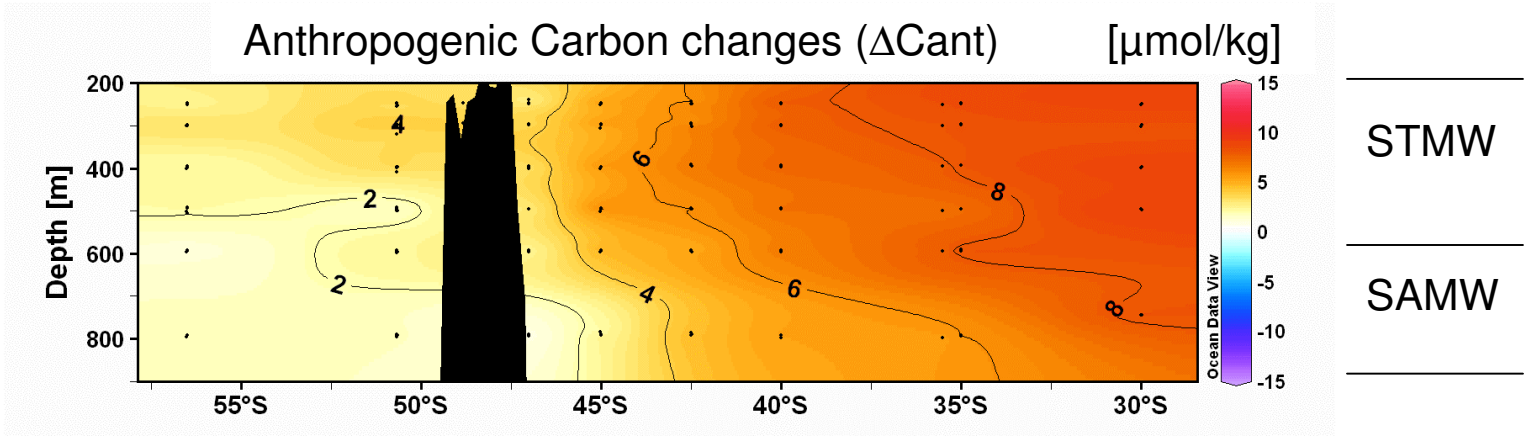
Total and Anthropogenic Carbon changes

Multi-Linear Regression (MLR) technique

method 1 (only conservative tracers) : TCO_2 = MRL (S, T, NO)



method 2 (physical and BGC tracers) : TCO2 = MRL (S, T, O_2, Nut, Alk)



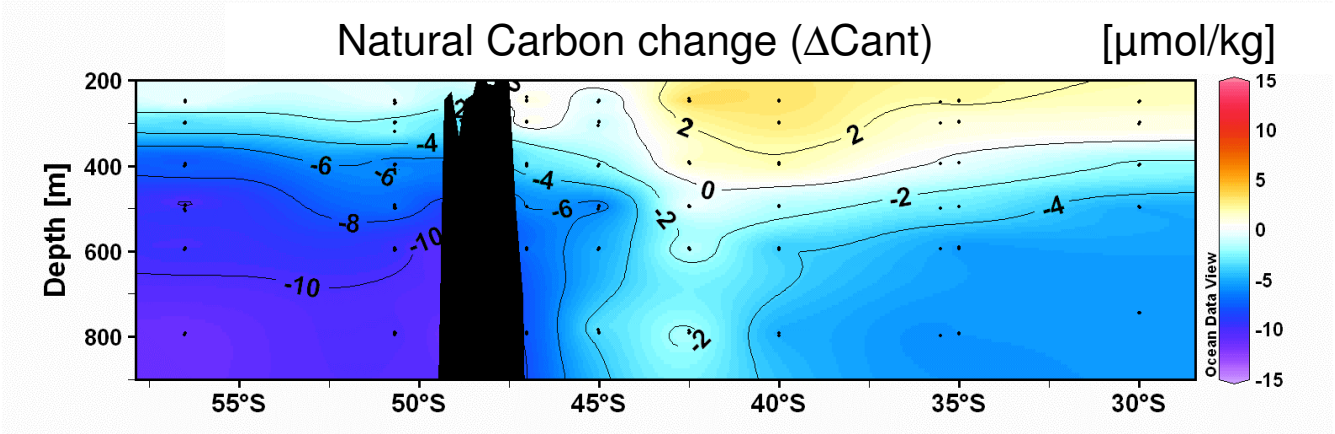
‘Natural’ Carbon changes

Multi-Linear Regression (MLR) technique

<u>Difference between MLR methods 1 and 2</u> : ΔTCO2 - ΔCant

WW

Upper CDW



STMW

SAMW

When the anthropogenic signal is removed from the total carbon change, the remaining pattern shows

- large decrease in Upper Circumpolar Deep Water (6-12 µmol/kg)

- small decrease in Subantarctic Mode Waters (4-6 µmol/kg)

- no change in subsurface waters and STMW (small increase in newly formed STMW?)

Summary / Perspectives

NORTH OF THE POLAR FRONT

Mode Waters transport anthropogenic CO_2 from the surface to mid-depths (down to approx. 1000m).

- **In STMW:** The invasion of anthropogenic CO_2 explains most of (all) the TCO_2 increase (TCO_2 increased by 8 (± 3) µmol/kg)
- **In SAMW:** The invasion of anthropogenic CO_2 is compensated for by an equal decrease in ocean carbon → No change in TCO_2.

SOUTH OF THE POLAR FRONT

No significant change in anthropogenic carbon

- **In WW (200m):** TCO_2 increased by 5 (± 3) µmol/kg
- **In the upper CDW:** TCO_2 decreased by 9 (± 6) µmol/kg

Causes and consequences ?

What are the mechanisms driving the change in natural carbon

Are these changes representative of the South Indian Ocean?

What will be the evolution in the next decades ?

Ocean Carbon Model NEMO2

Components: Ocean Model OPA9 (GM90 and TKE mixed layer scheme),
Biogeochemical Model PISCES (NPZD model),
Ice Model LIM2

Resolution: 2°x 2° resolution (enhanced at the equator)
31 non -regular vertical levels (19 levels in the upper 500 meters)

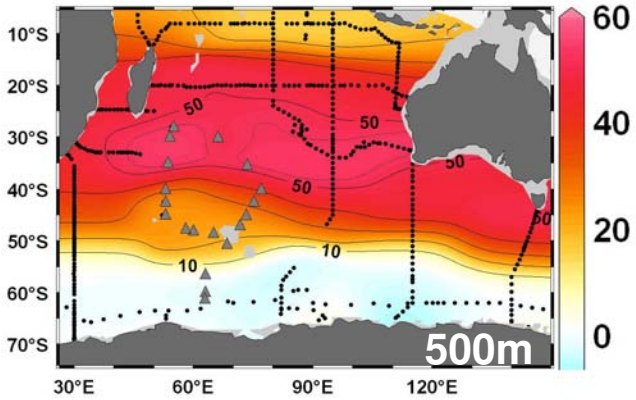
Forgings: ERA40 heat fluxes and winds
CORE freshwater fluxes

(SST and SSS restored to Reynolds SST and Levitus SSS using bulk formulas)

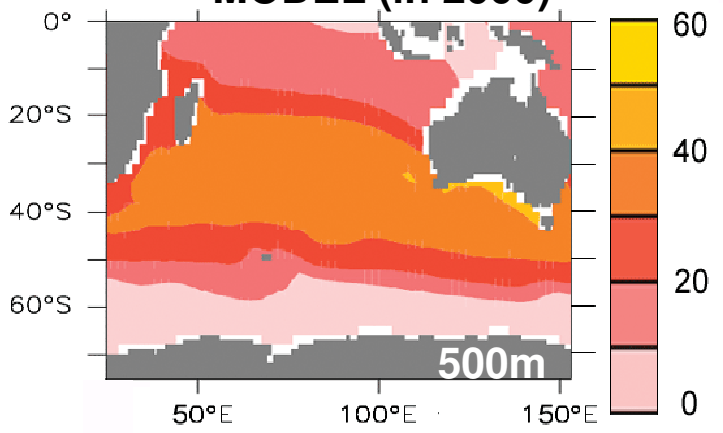
CO_2 scenario: Pre-industrial run keeping atmospheric CO2 constant at 278 ppm
Anthropogenic run using the observed atmospheric CO2 values

ANTHROPOGENIC CARBON at 500m (µmol/kg)

DATA (late 1990's)

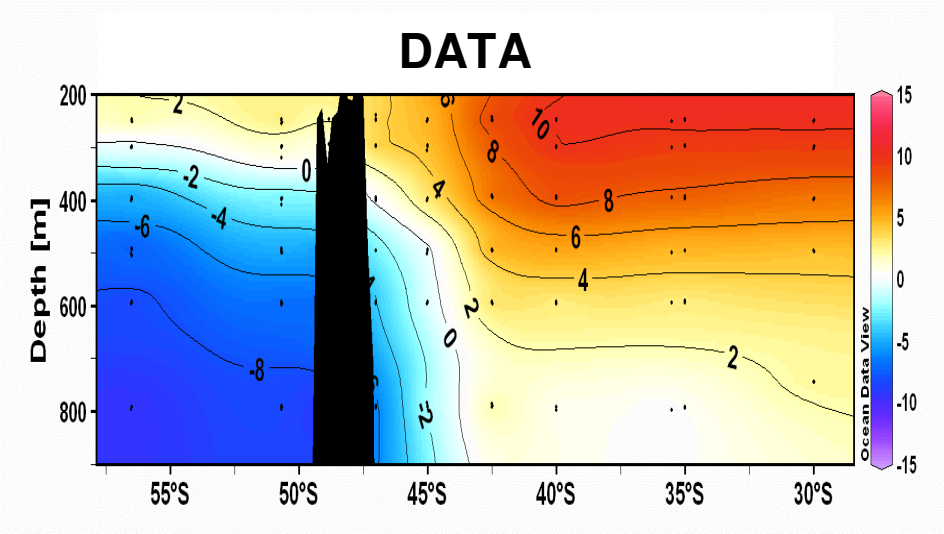


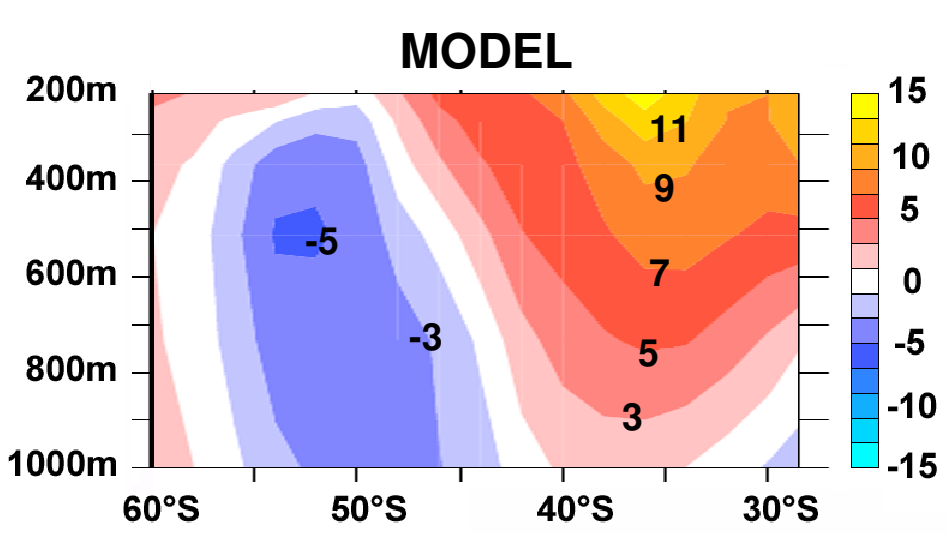
MODEL (in 2000)



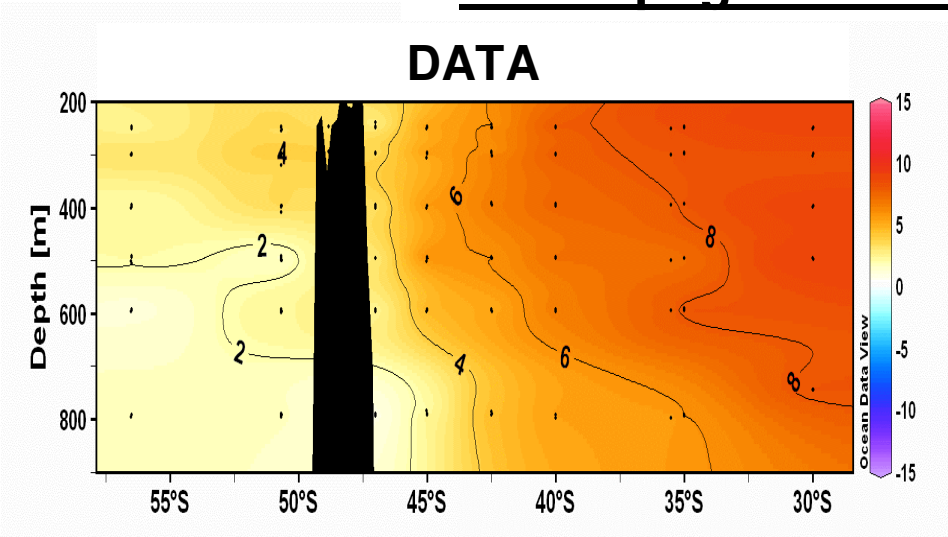
DATA / MODEL : Total and Anthropogenic Carbon changes

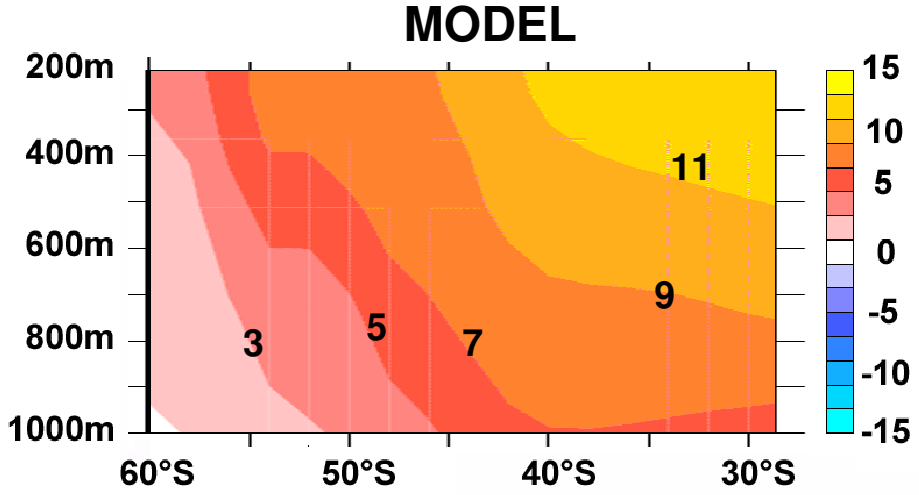
Total Carbon change (µmol/kg)





Anthropogenic Carbon change (µmol/kg)

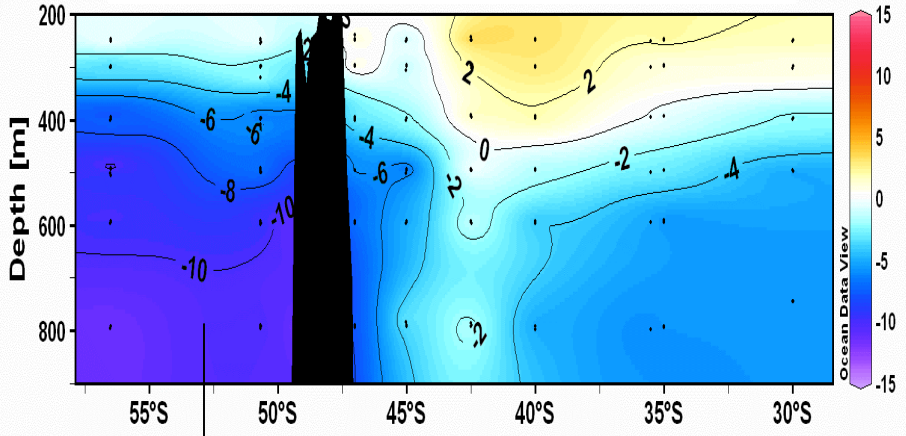




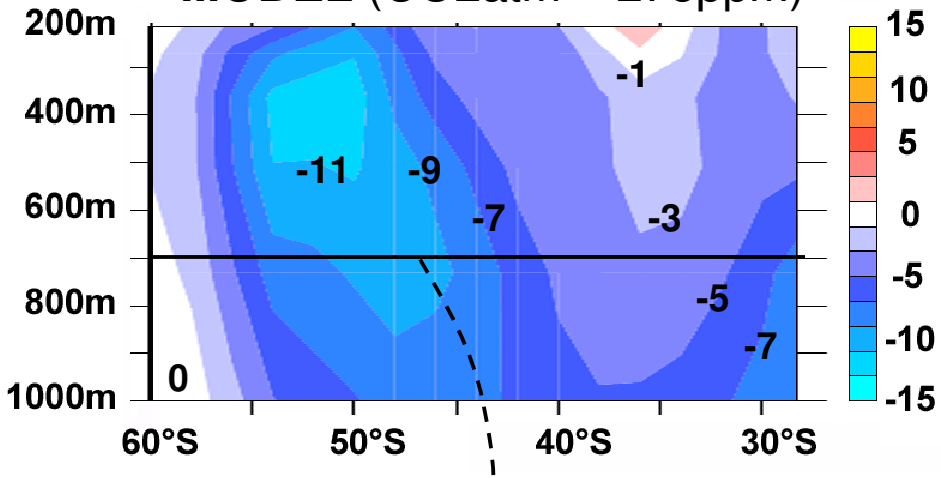
DATA / MODEL : 'Natural' Carbon changes

Natural Carbon change (µmol/kg)

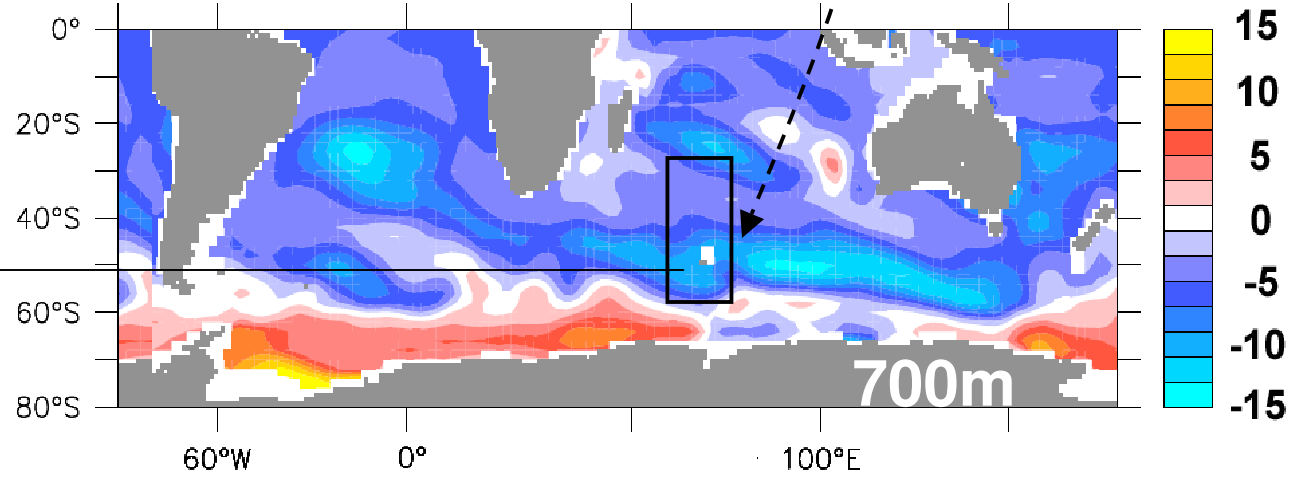
DATA (ΔTCO_2-$\Delta Cant$)



MODEL (CO2atm = 278ppm)



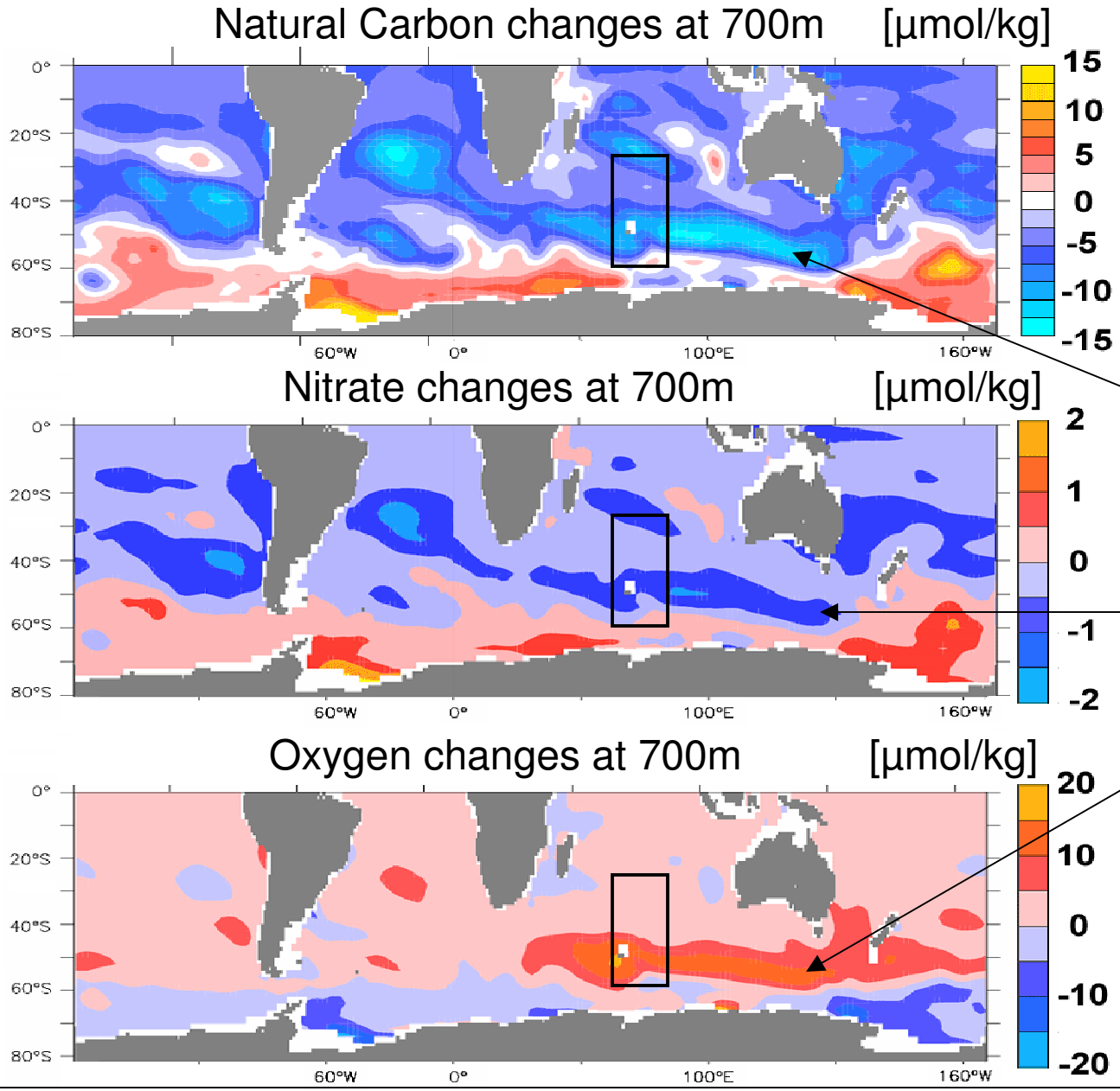
MODEL: Natural Carbon changes at 700m [µmol/kg]



Carbon decrease associated with

- **Warming**
- **Oxygen increase**
- **Nutrients decrease**

MODEL : Large scale changes



Carbon decrease associated with

Nutrients decrease

Oxygen increase

To be continued…