

The Pre-industrial Interhemispheric Gradient of Atmospheric pCO₂

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Introduction

Results from Global Ocean Biogeochemical Models

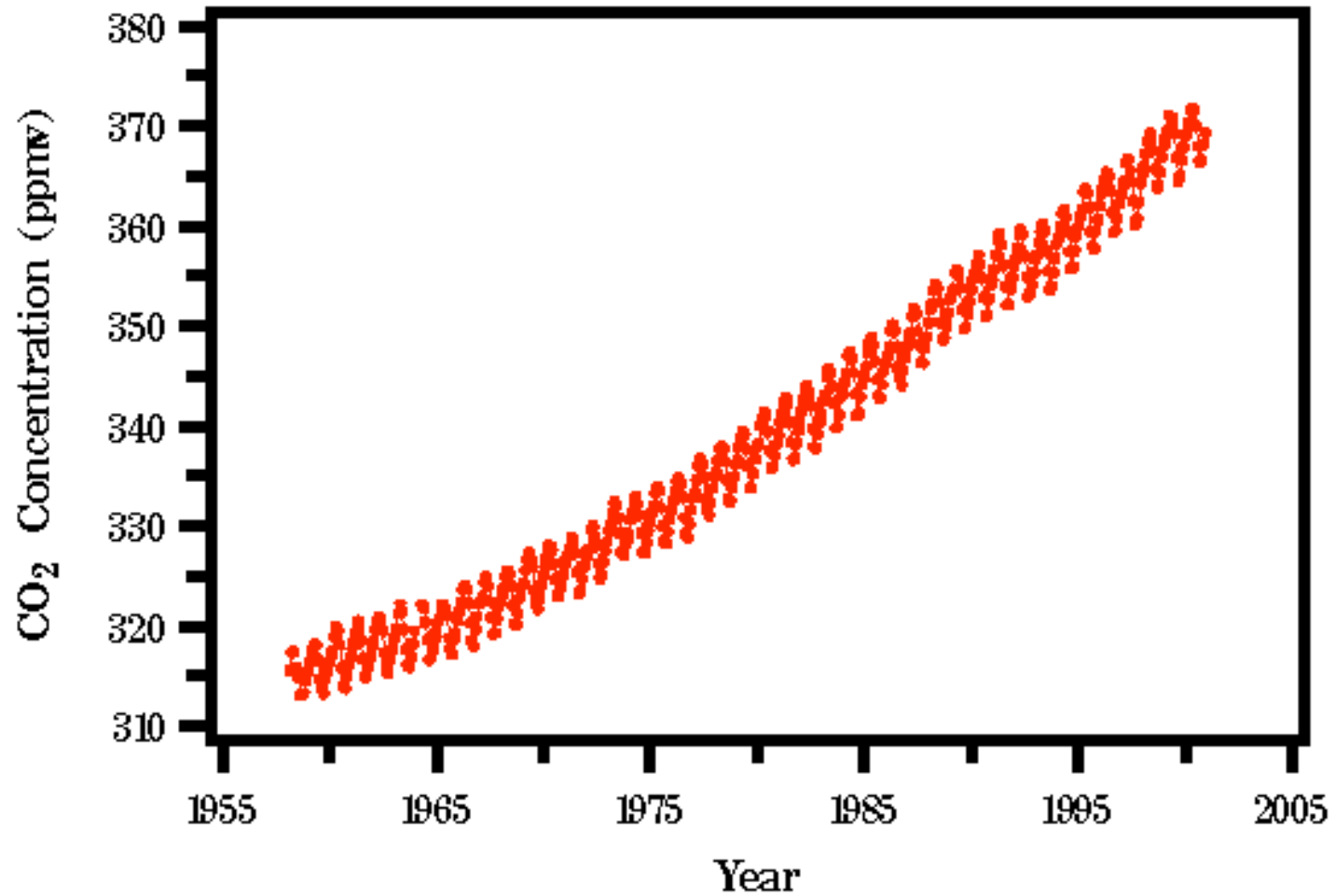
Mechanisms – River, Iron, Oceanic Transport

Thanks to : J. Orr, O. Aumont, Z. Lachkar, P. Cadule, P. Bousquet, P. Peylin

SOLAS Open Science Conference – Xiamen 2007

Introduction

Mauna Loa, Hawaii

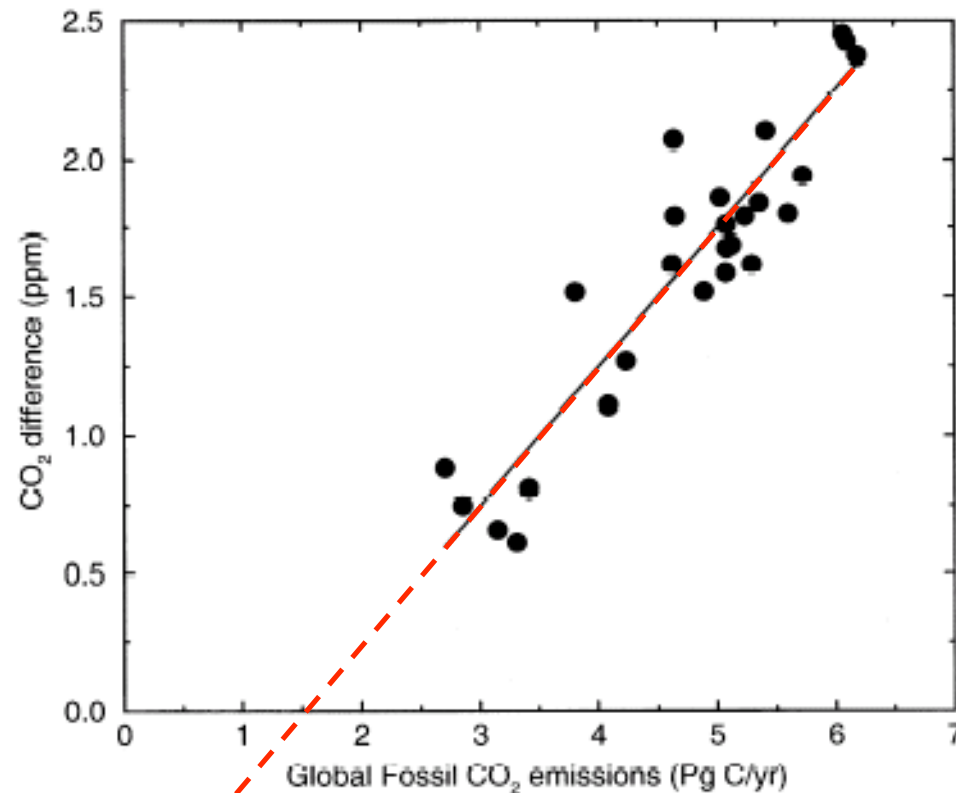


Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)

Introduction

Seminal work by Dave Keeling - 1989

Atm. pCO₂ grows faster at Mauna Loa than at South Pole.



Intercept : $\beta = -0.8$ ppm (± 0.2)

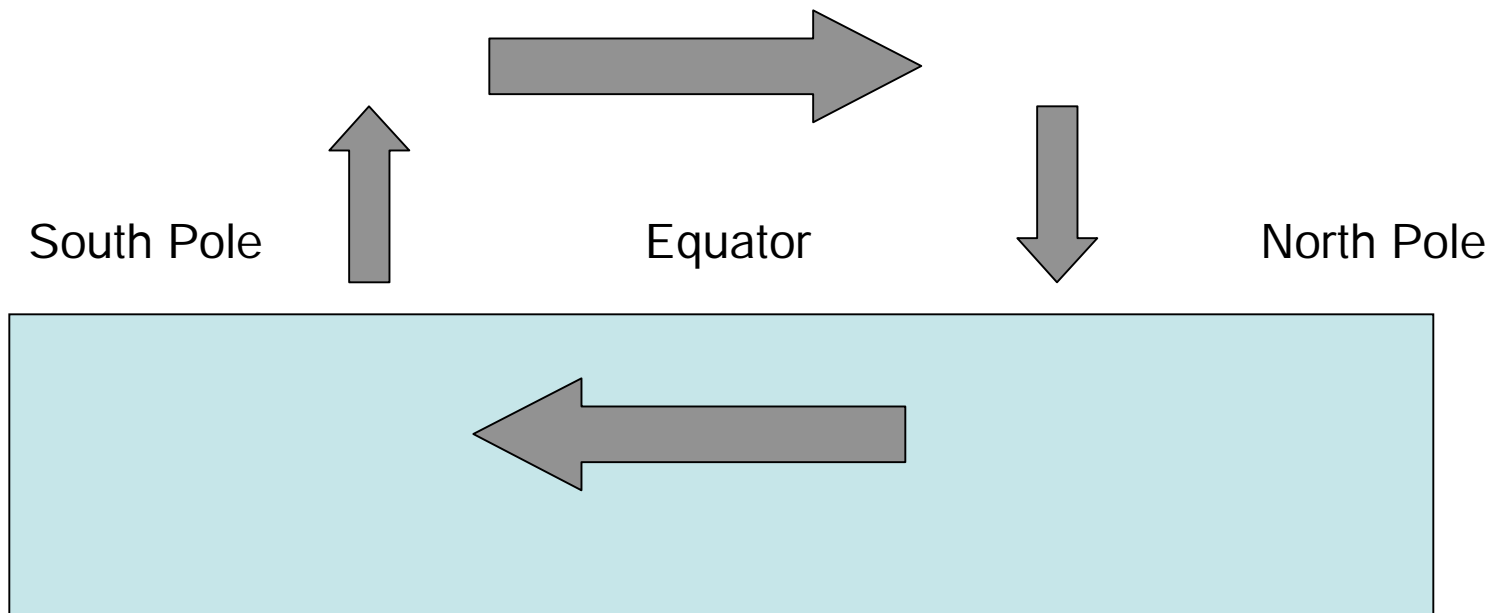
Introduction

Keeling's Hypothesis :

During Pre-industrial times,

South Pole pCO₂ was 0.8 ppm greater than at Mauna Loa.

The preindustrial ocean was transporting around 1 PgC/yr southward at the equator.

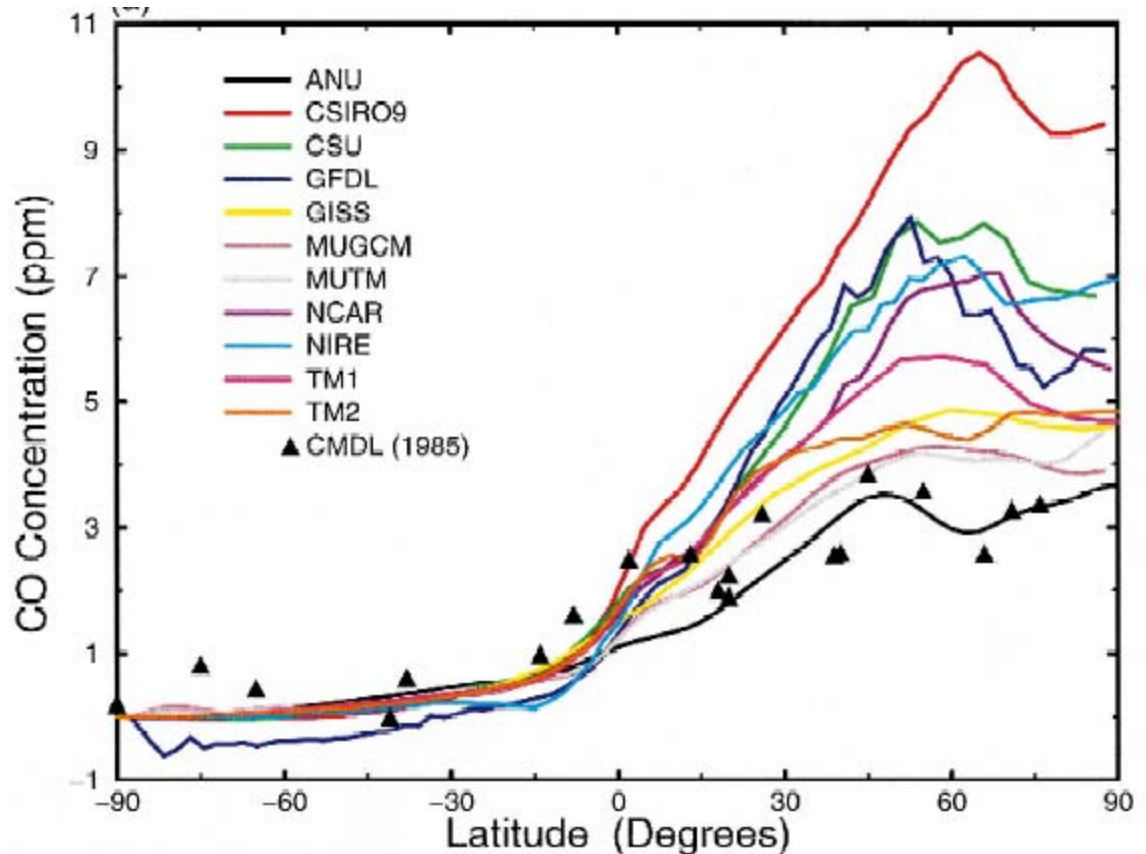


Introduction

Consequences for...

- Deriving anthropogenic sinks of carbon

(Tans et al. 1995, ...)



- Understanding / modelling the ocean carbon cycle on long time scales

(Response to future climate change / Paleo-carbon cycle)

Introduction

Previous work : OCMIP - 1

Natural Carbon Fluxes (molC/m²/yr)

red : source

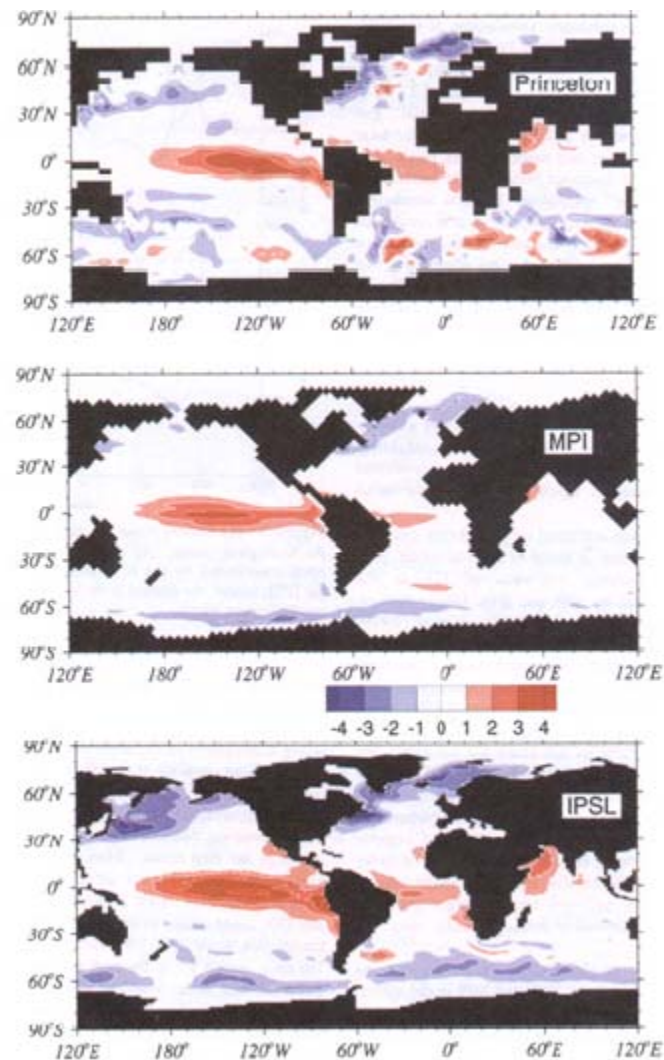
blue : sink

Almost no interhemispheric transport
of Carbon in the Ocean

Table 2. Northward Transport of Carbon at the Equator

	Princeton	IPSL	MPI
Atlantic	-0.80	-0.81	-0.75
Indo-Pacific	0.68	0.71	0.78
Global	-0.12	0.10	0.04

The transport of carbon is given in Pg C y⁻¹.



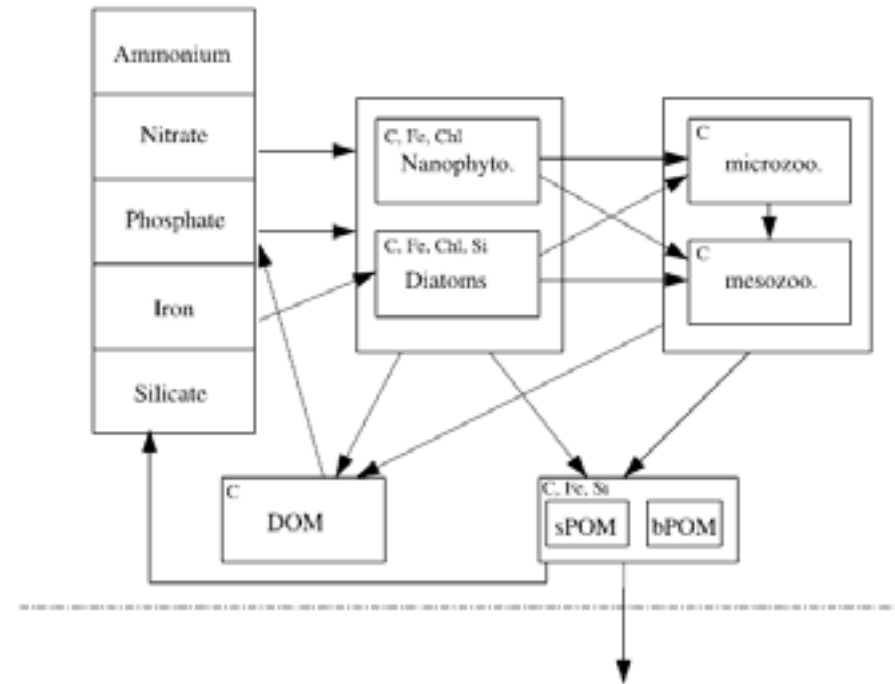
Sarmiento et al. 2000 (OCMIP-1)

New Results with PISCES

ORCA



PISCES



(Aumont and Bopp, 2006)

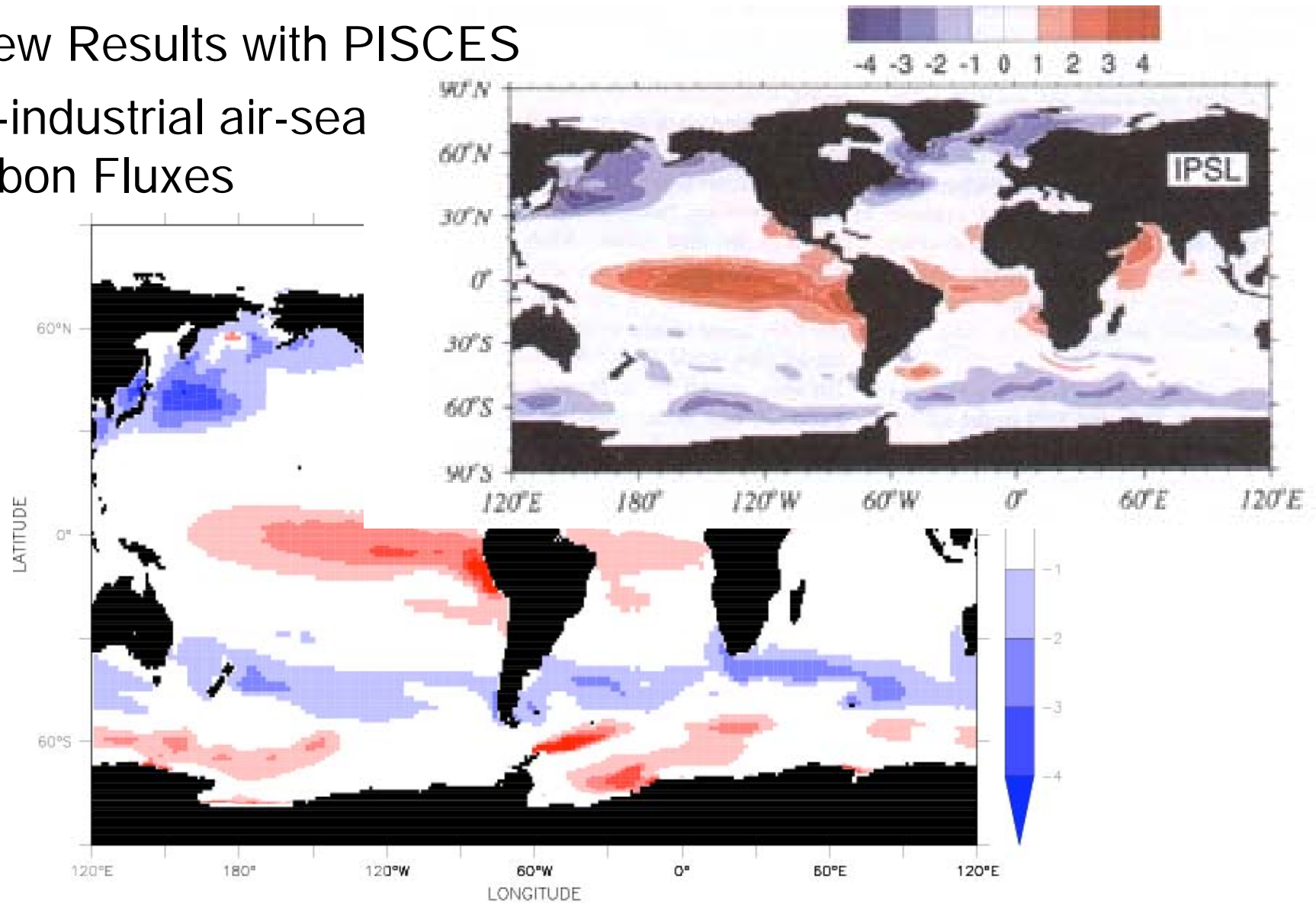
What's new? :

- Better physics
- Better biology (iron cycle)
- River input of carbon, Fe atm. deposition & sediment input....

Integration : > 3000 years , climatological forcing

New Results with PISCES

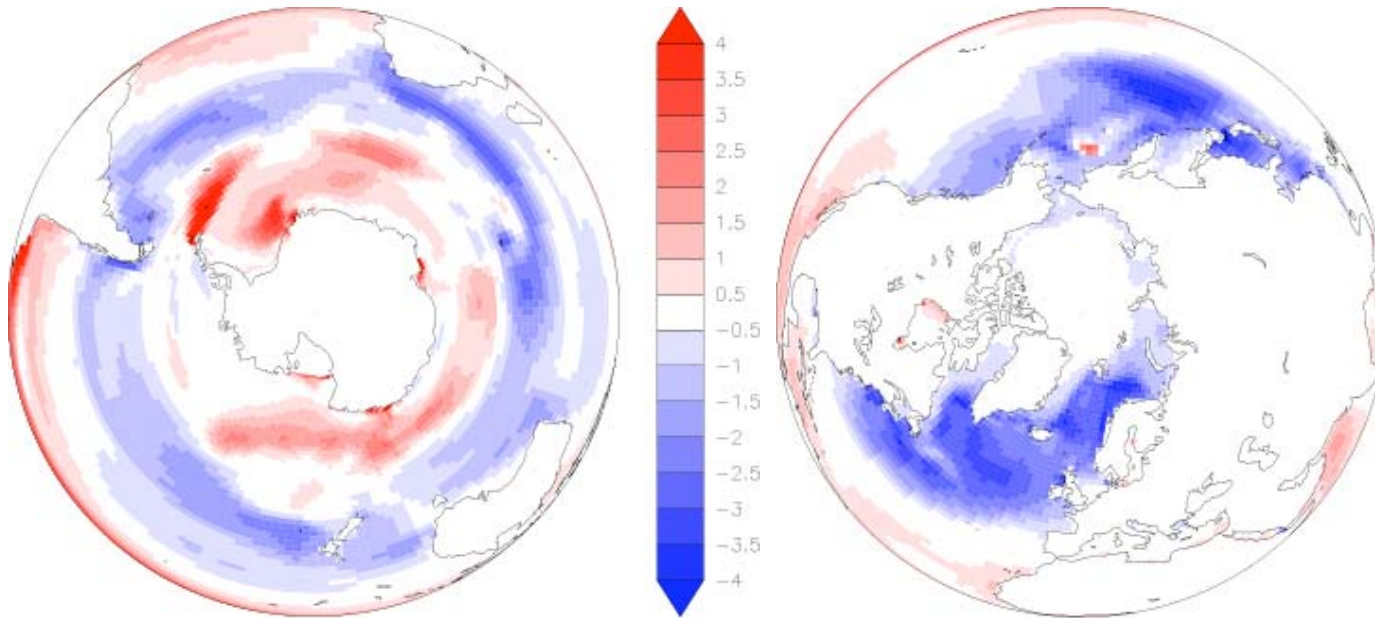
Pre-industrial air-sea
Carbon Fluxes



→ Large Efflux in the S.O.

New Results with PISCES

Pre-industrial air-sea Carbon Fluxes

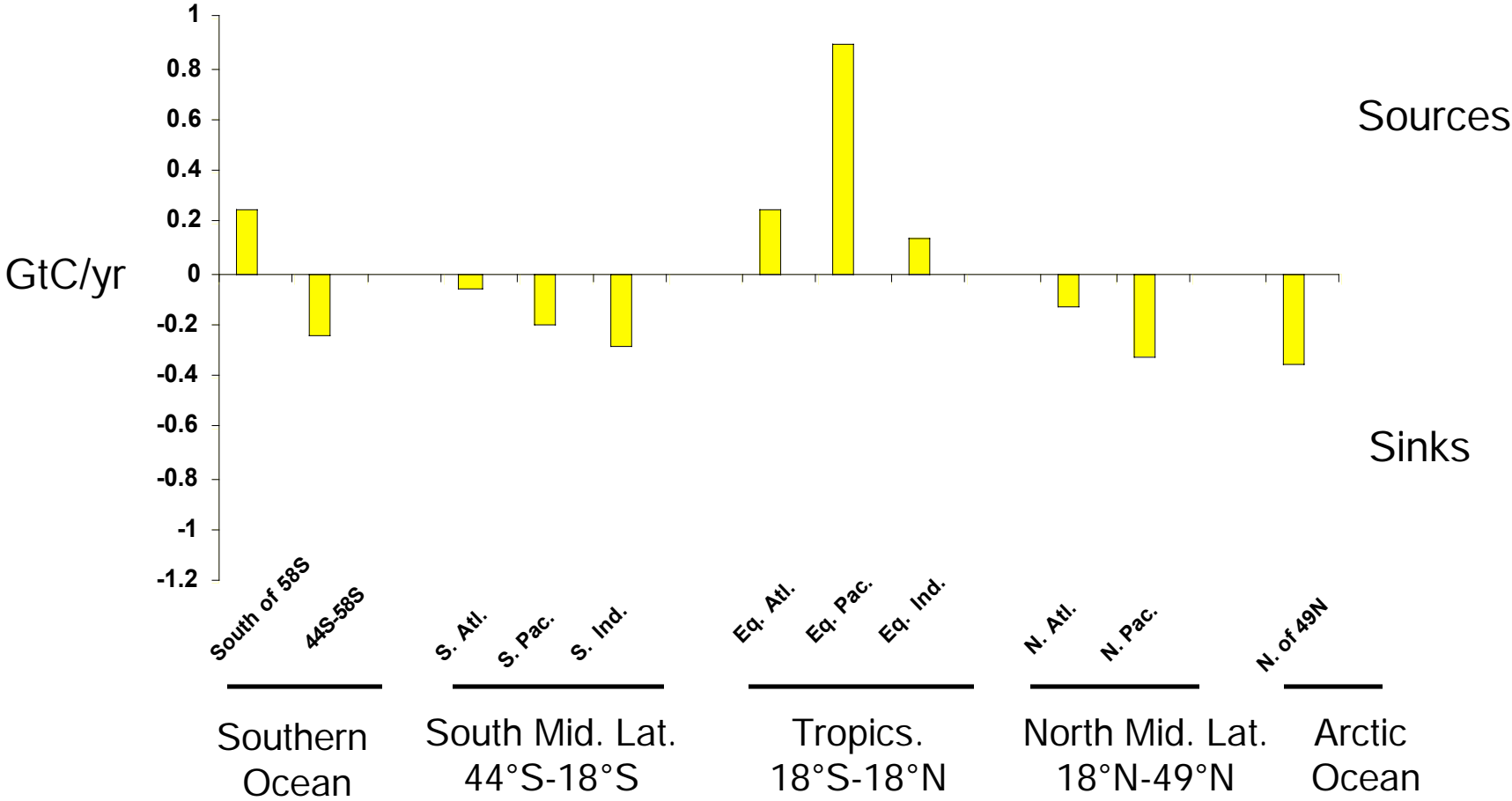


Southern
Hemisphere

Northern
Hemisphere

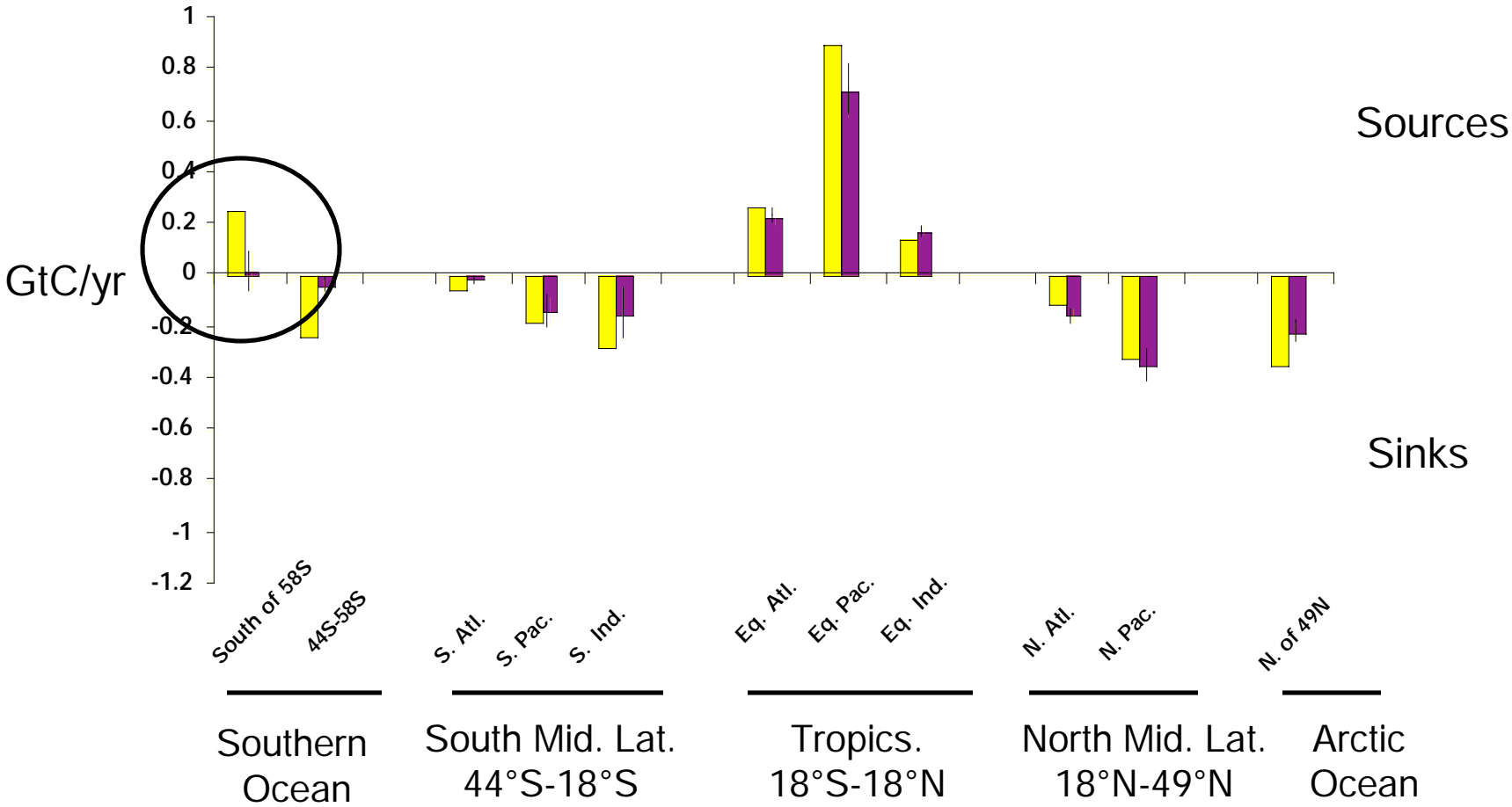
New Results with PISCES

Pre-industrial air-sea Carbon Fluxes



New Results with PISCES

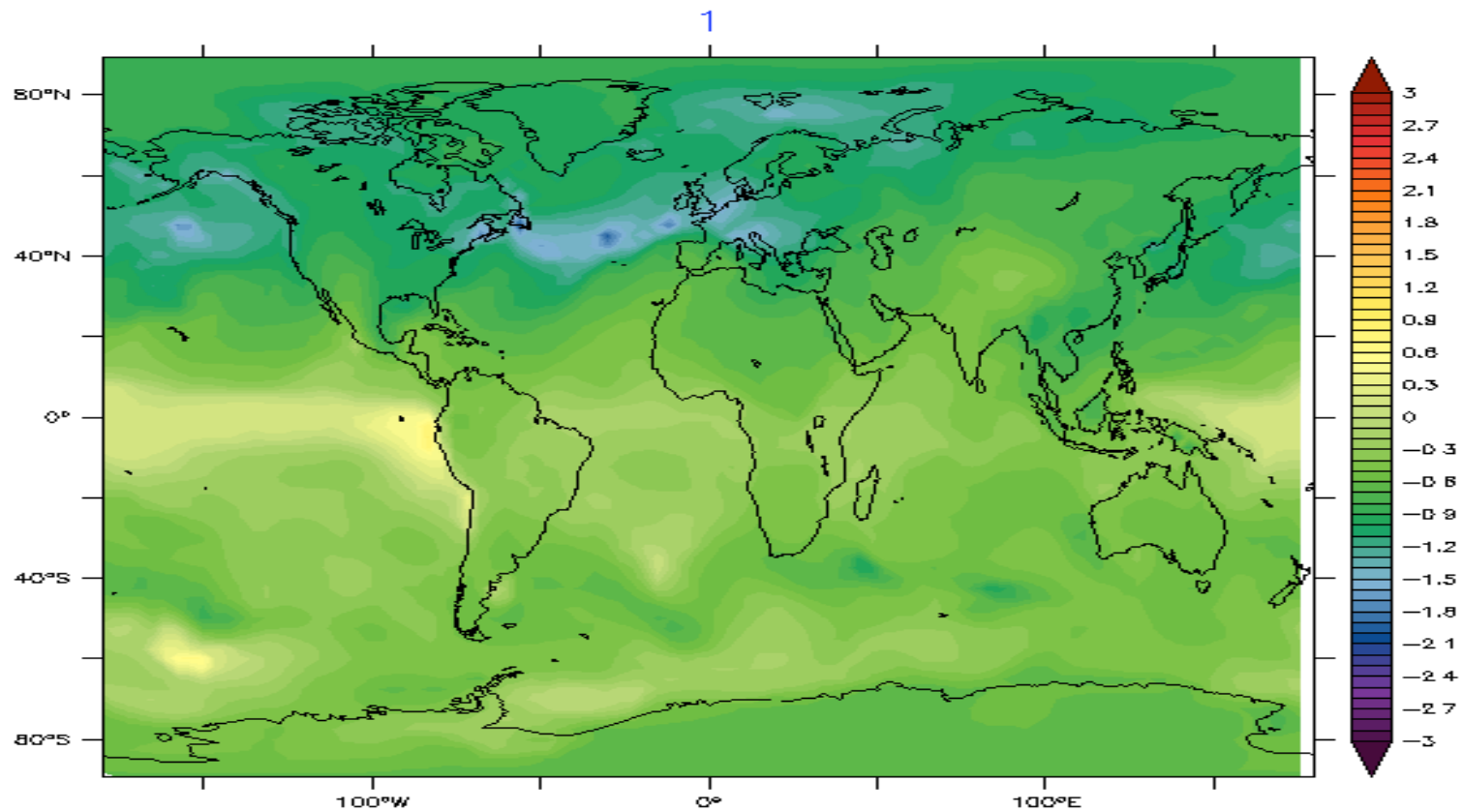
Pre-industrial air-sea Carbon Fluxes : Comparison with OCMIP-2



New Results with PISCES

Ocean Carbon Fluxes Transported by LMDZ4

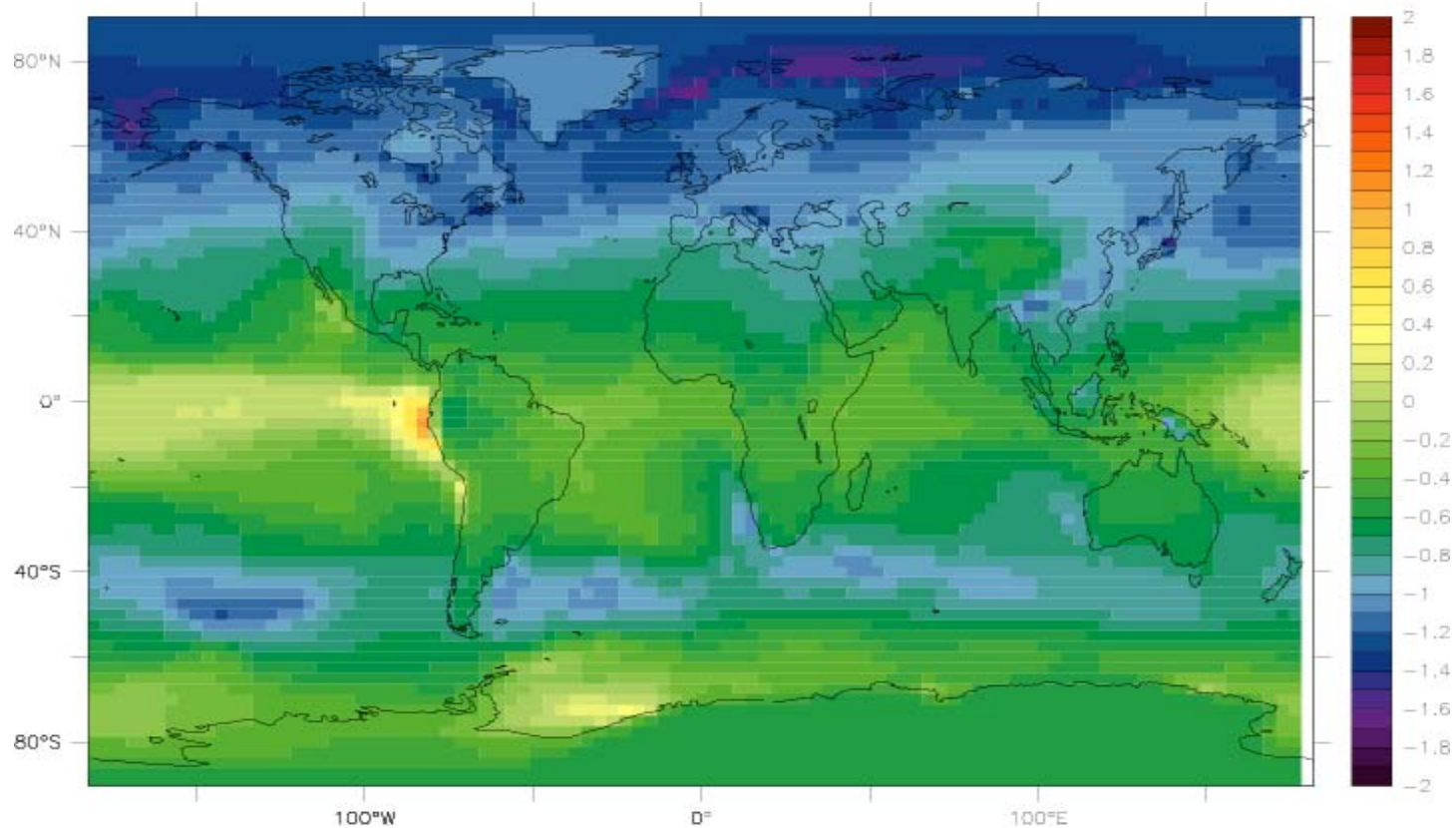
Atm. pCO₂ (ppm)



New Results with PISCES

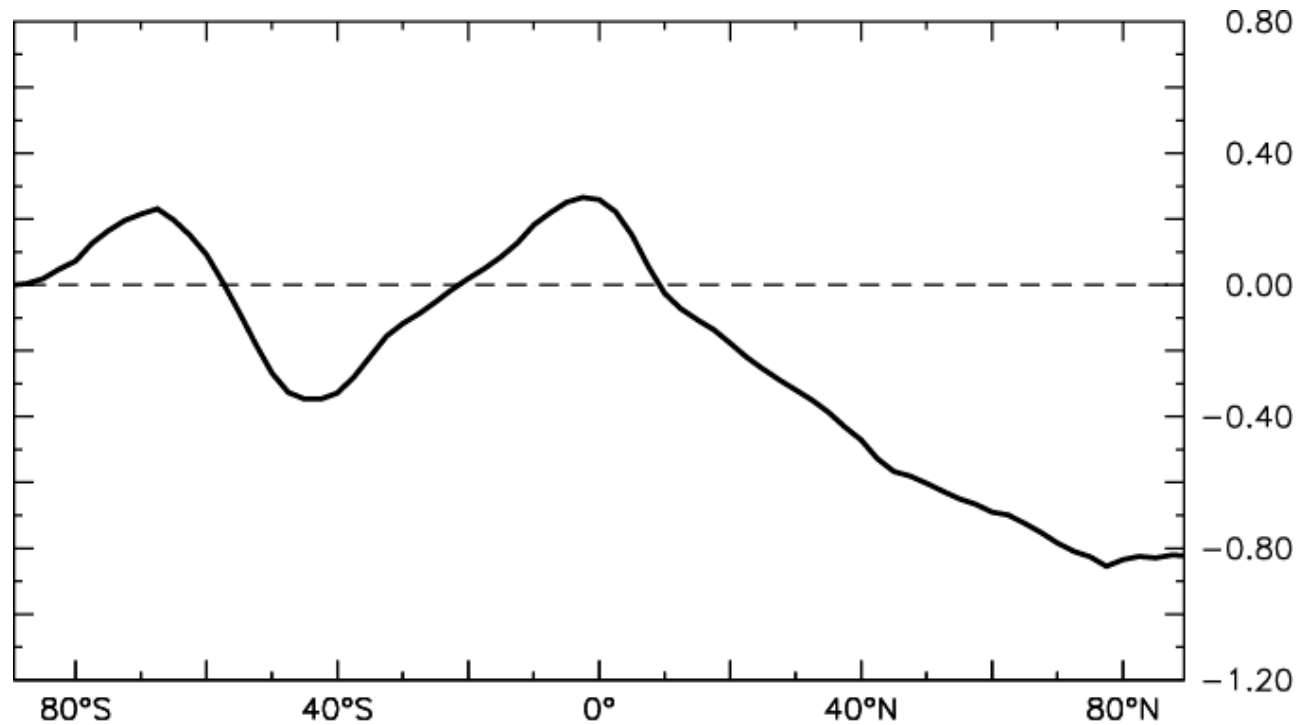
Ocean Carbon Fluxes Transported by LMDZ4

Atm. pCO₂ (ppm) : Annual Mean



New Results with PISCES

Zonal mean of Atm. pCO₂ (ppm)



MLO – SPO : -0.35 ppm (-0.8 ppm Keeling)

Cross-Equatorward Transport : 0.56 PgC/yr



Mechanisms

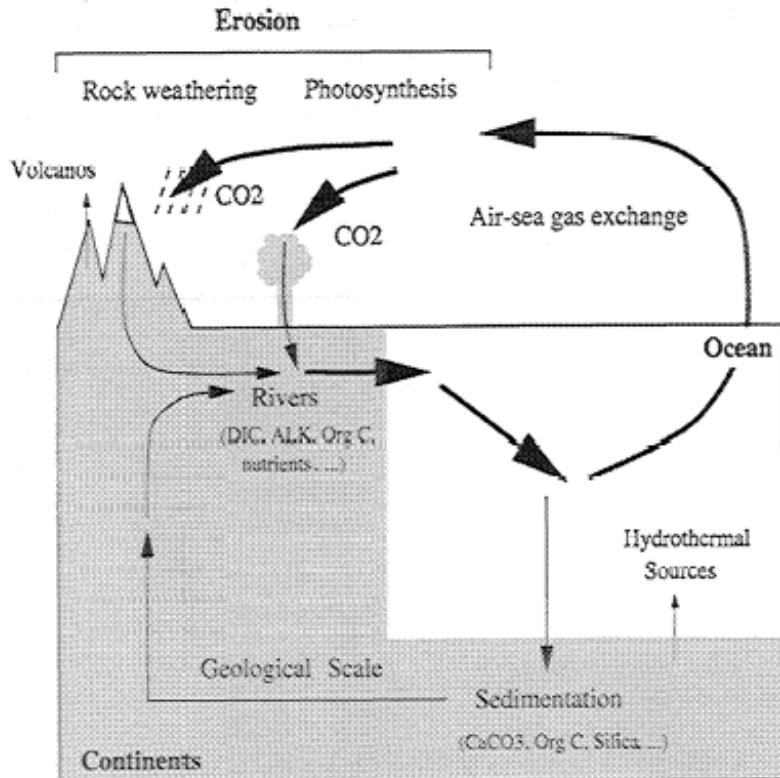
What causes the MLO-SPO gradient in the model?
Why is it insufficient?

1. River loop
2. Iron limitation in the S.O.
3. Physical transport

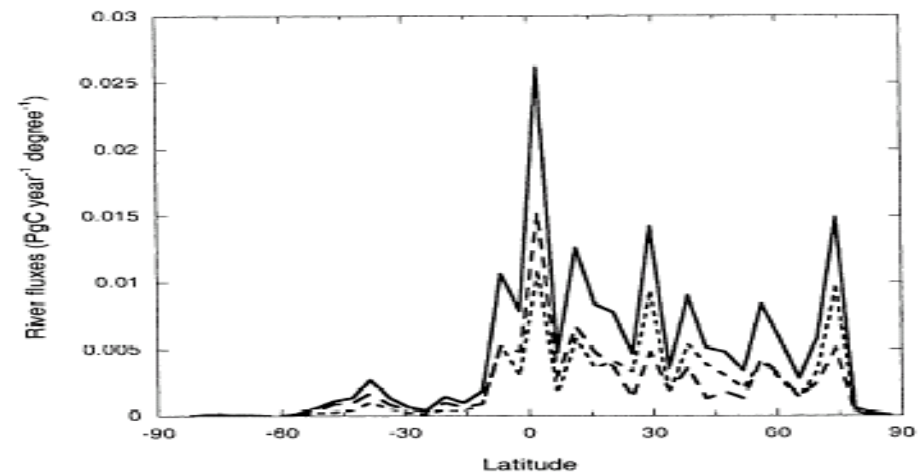
What causes the MLO-SPO gradient ?

1. River loop : Aumont et al. 2001

Hypothesis : Riverine carbon discharge is predominantly located in the N.H
Loss of riverine carbon back to the atm. is also located in the S.H.



Riverine discharge of Carbon



(Ludwig et al. 1996, ...)

What causes the MLO-SPO gradient ?

In Aumont et al. 2001

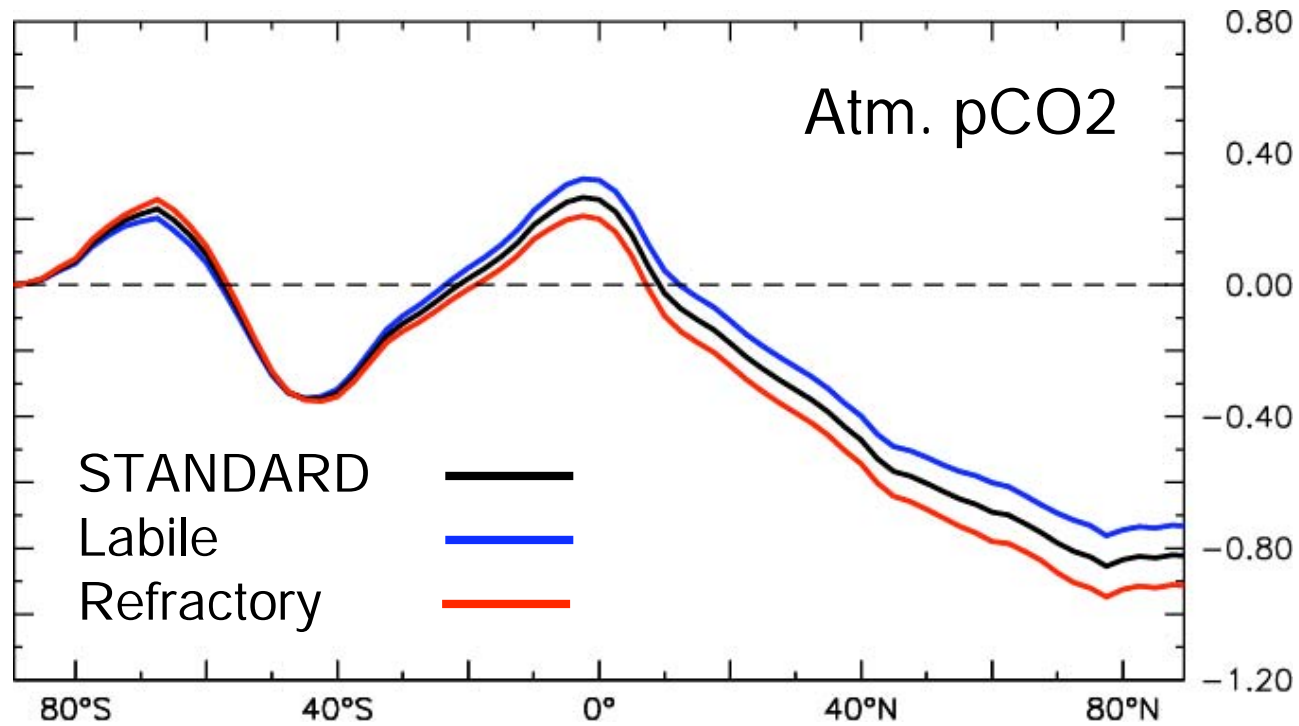
Table 1. Preindustrial Northward Transport of Carbon Within the Ocean and Resulting Gradient of Atmospheric CO₂ Between South Pole and North Pole and South Pole (SPO) and Mauna Loa (MLO) ^a

	Interhemispheric Transport, Pg C yr ⁻¹	North-South Gradient, μatm	MLO-SPO Gradient, μatm
Ocean alone	-0.10	-0.10	0.20
Standard simulation	-0.25	0.50	-0.40
Labile scenario	-0.17	-0.40	-0.30
Refractory scenario	-0.33	-0.6	-0.5
Ocean plus rivers	-0.35±0.08	-0.60±0.10	-0.20±0.10

Similar results than Aumont et al. for the river loop

- Labile scenario : Riverine C → DIC at river mouthes
- Refractory scenario : Riverine C → DIC everywhere

What causes the MLO-SPO gradient ?

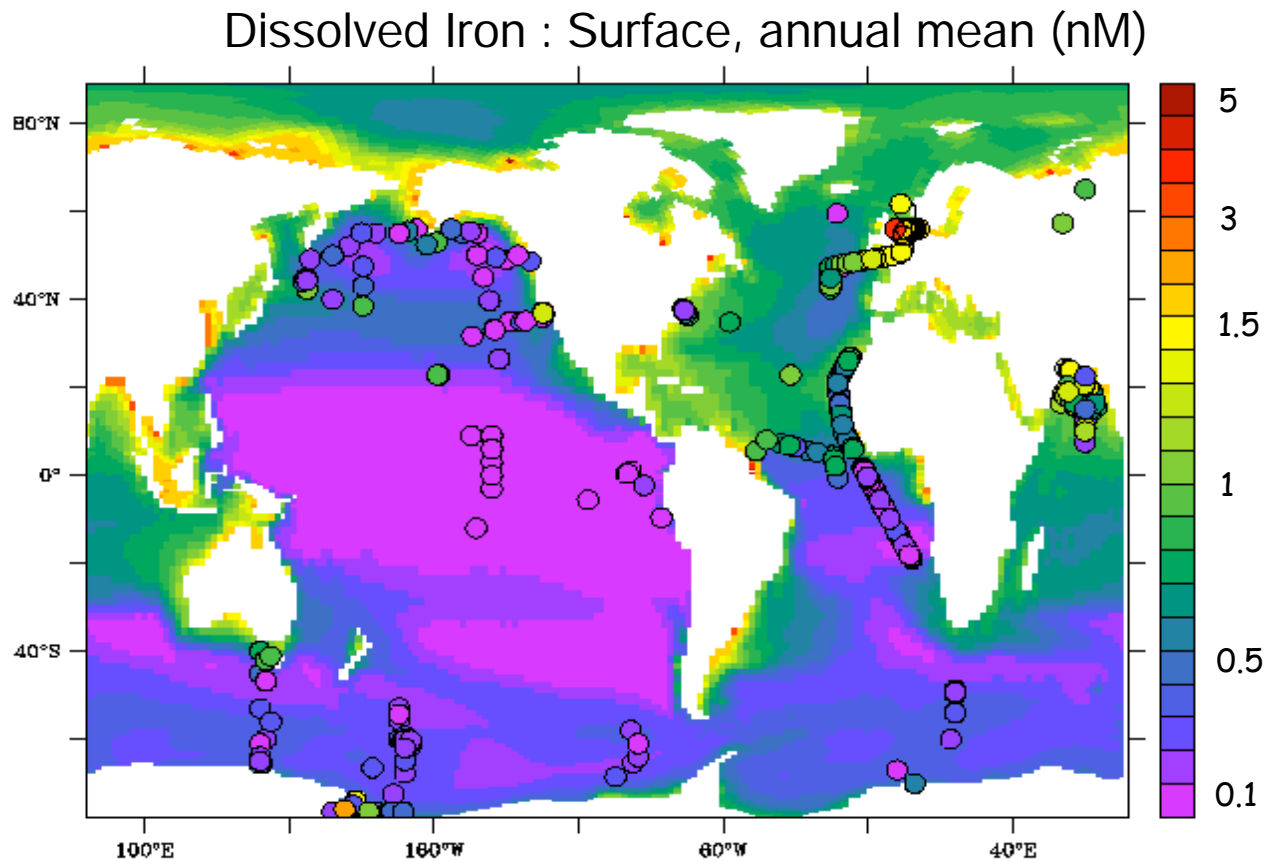


	Labile	Refractory
Cross-Equatorial Transport	0.48 PgC/yr	0.64 PgC/yr
MLO-SPO difference	-0.25 ppm	-0.45 ppm

What causes the MLO-SPO gradient ?

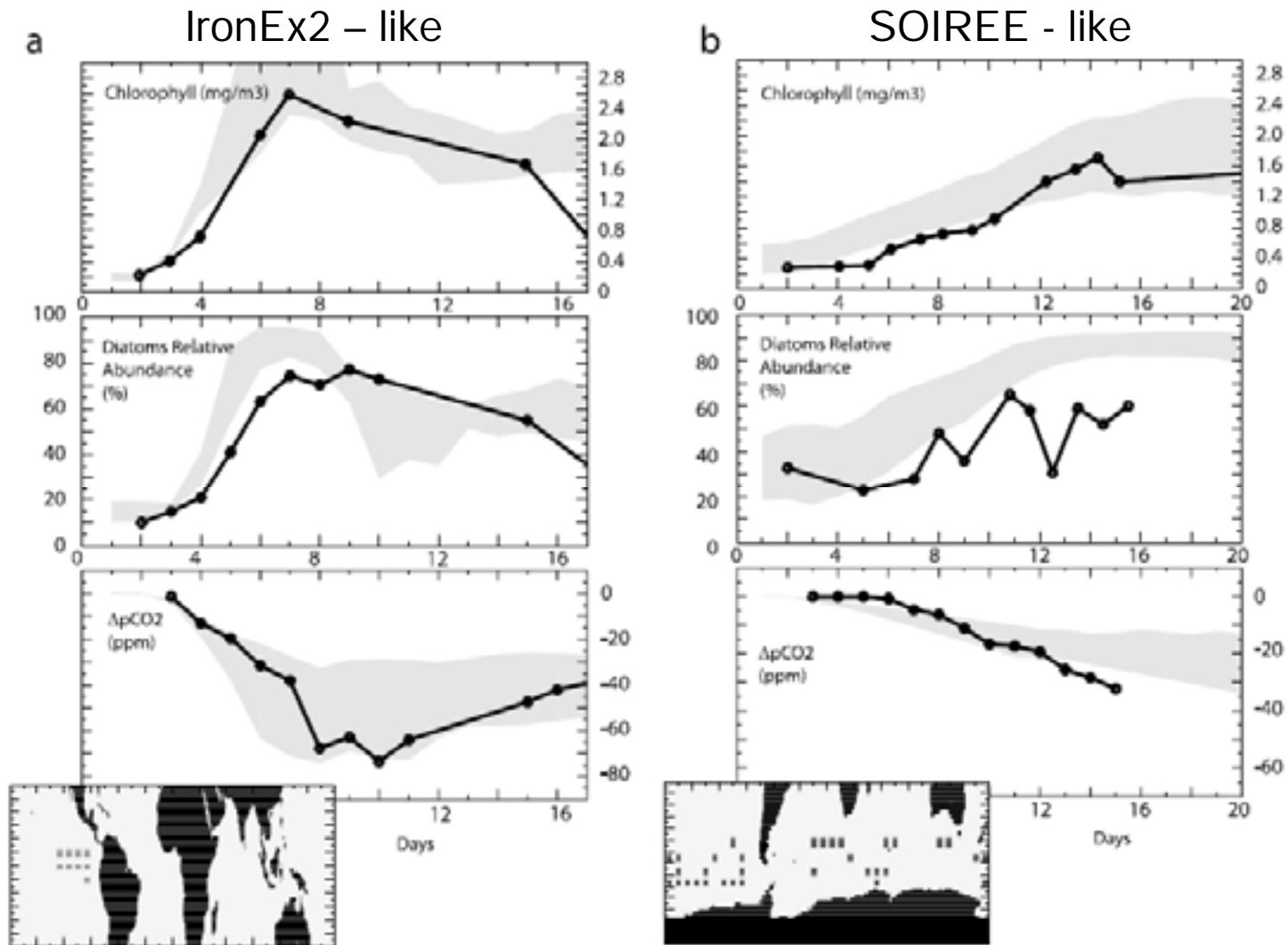
2. Iron Cycle

Hypothesis : Iron limits carbon export more in the S.H than in the N.H
Thus iron adds an assymetry in the marine carbon cycle.



What cause the MLO-SPO gradient ?

2. Iron Cycle : response to iron fertilization



What causes the MLO-SPO gradient ?

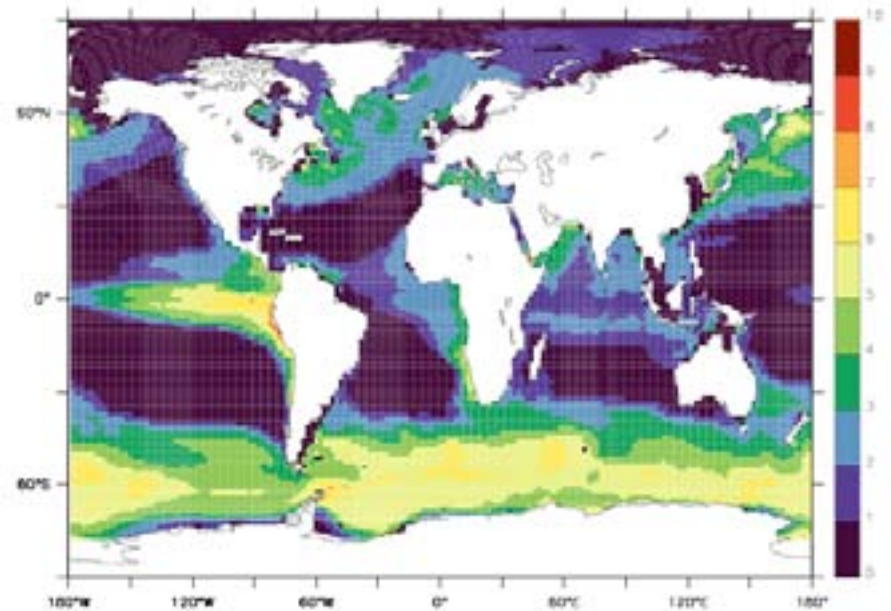
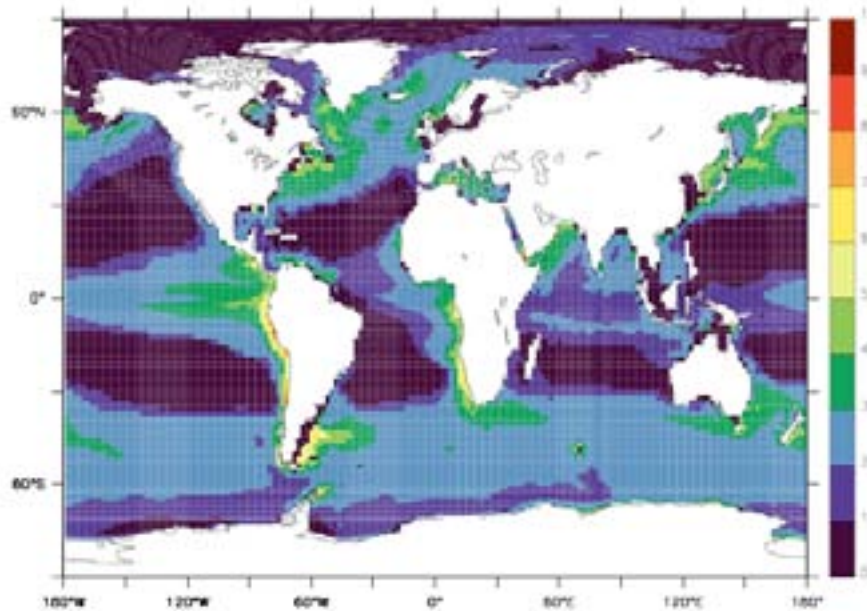
2. Iron Limitation in the S.O.

Hypothesis : Iron limits carbon export more in the S.H than in the N.H
Thus iron adds an assymetry in the marine carbon cycle.

STANDARD

Carbon Export (molC/m²/yr) at 100m

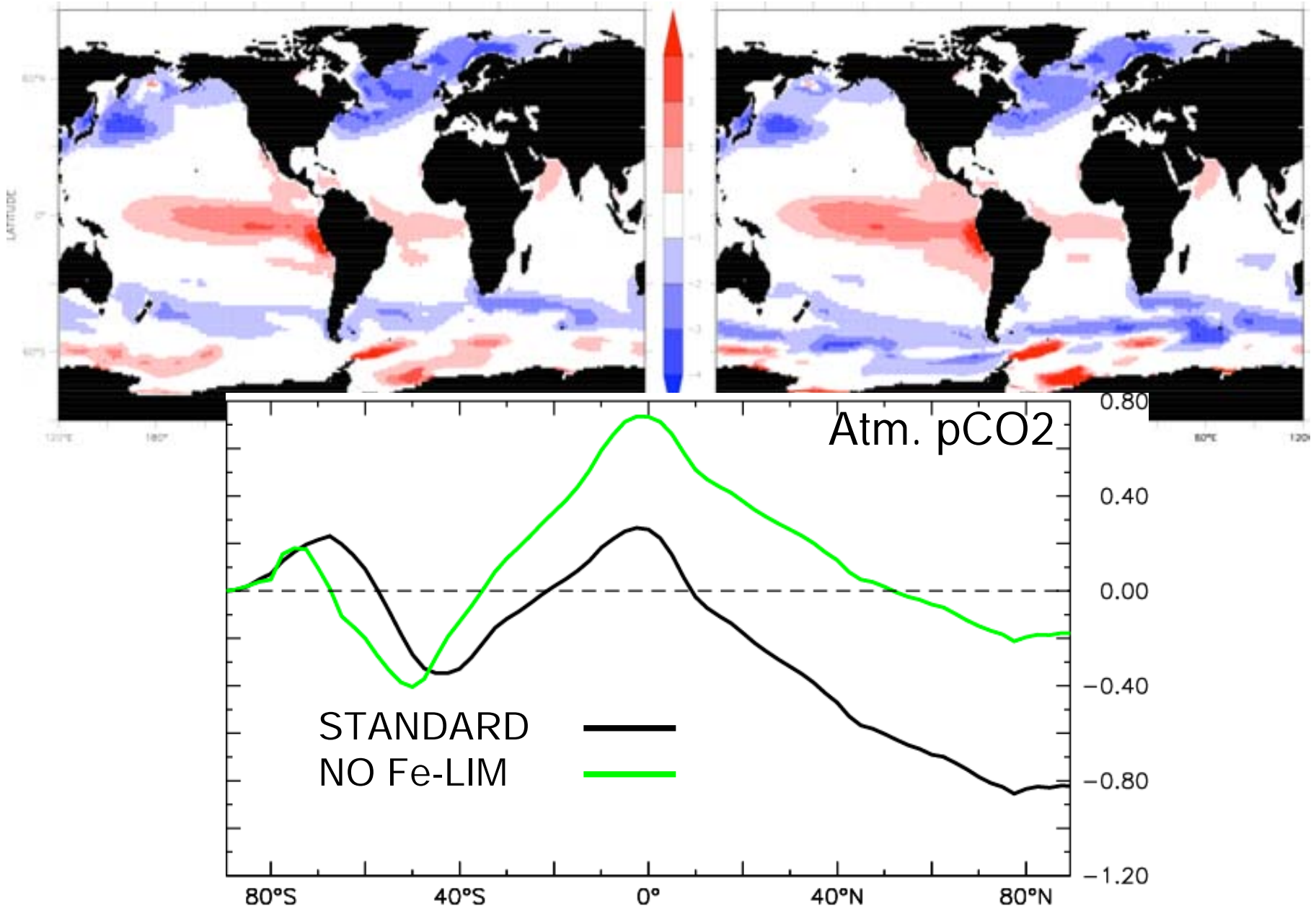
NO Fe-LIM



STANDARD

Air-Sea C Flux (molC/m²/yr)

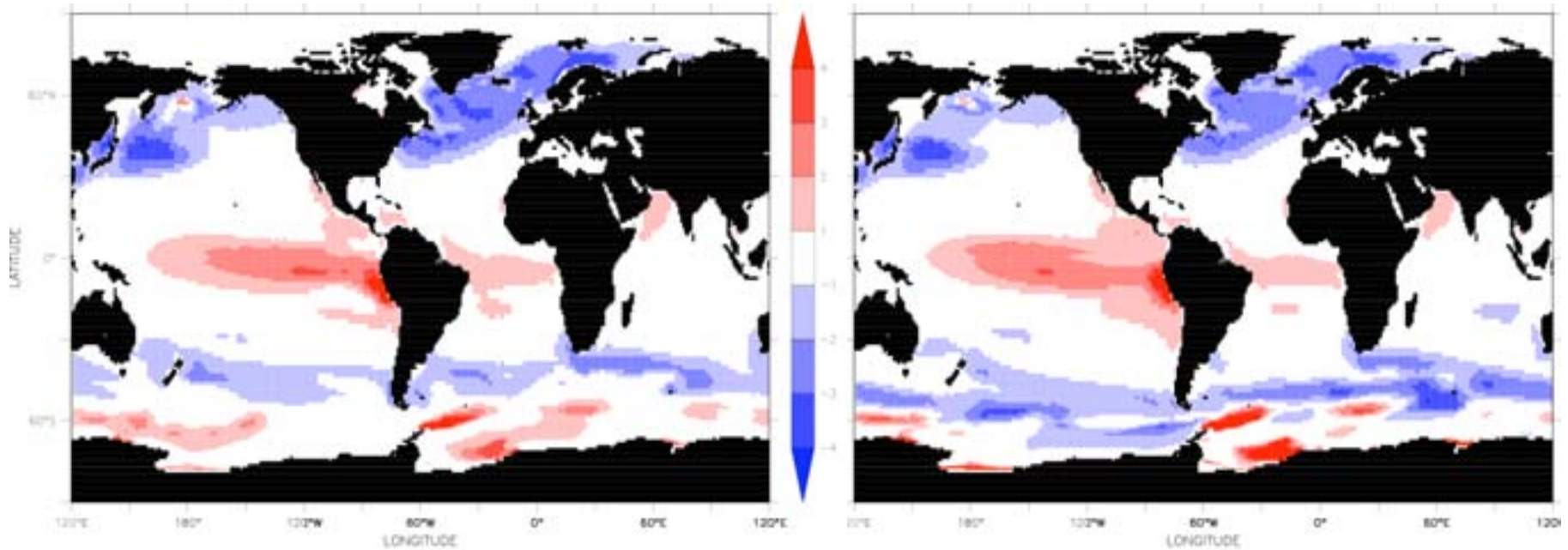
NO Fe-LIM



STANDARD

Air-Sea C Flux (molC/m²/yr)

NO Fe-LIM



STANDARD

NO Fe-LIM

Cross-Equatorial Transport

0.55 GtC/yr

0.1 GtC/yr

MLO-SPO difference

- 0.35 ppm

+ 0.4 ppm

What cause the MLO-SPO gradient ?

3. Improved Physical Transport in the ocean

- Improved Vertical Mixing
- GentMcWilliams Parametrization + Isopycnal Diffusion
- Better forcing fields
- Interactive Sea-Ice model

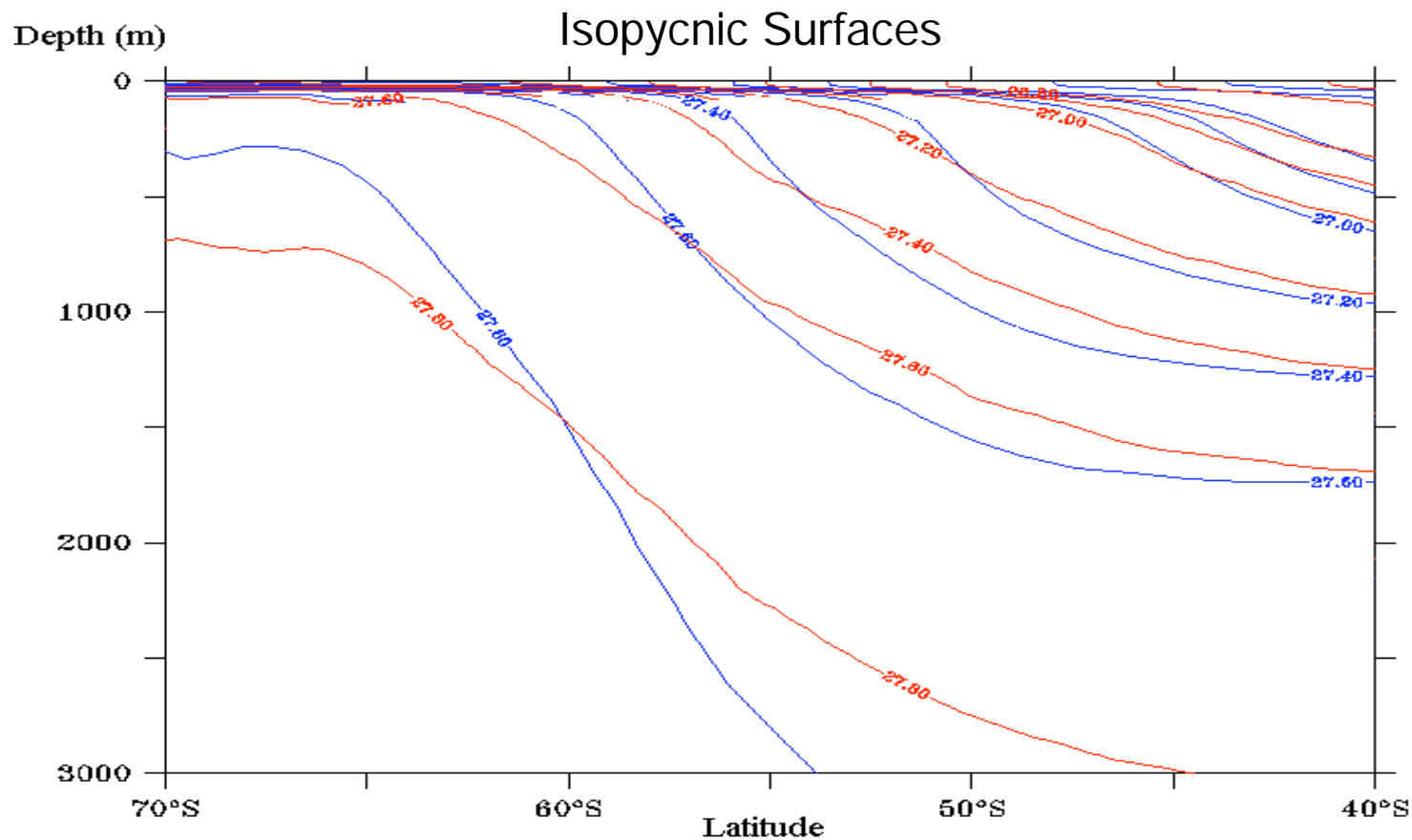
Still some defficiencies

An illustration:

Gent&McWilliams parameterization and the role of eddies

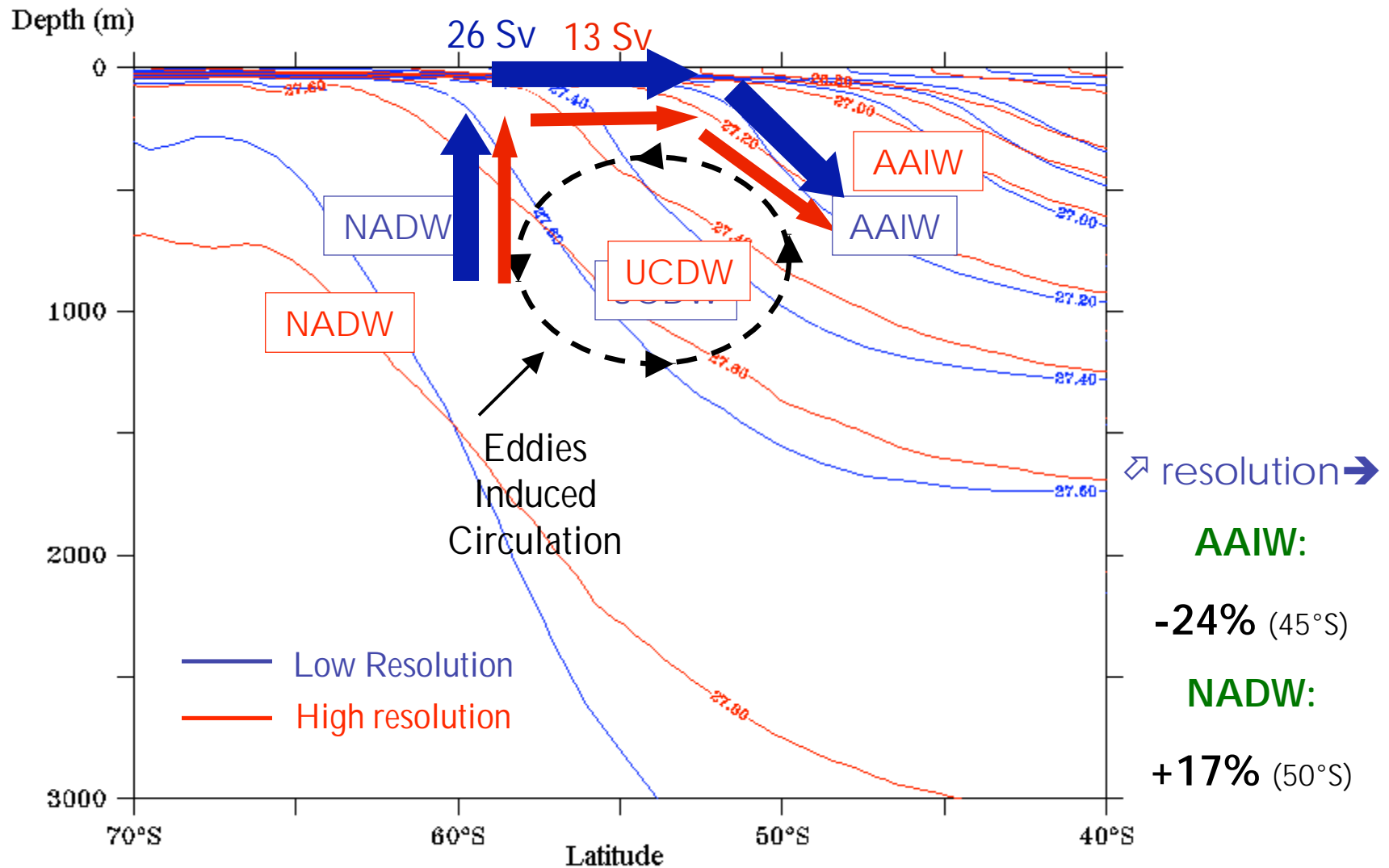
What cause the MLO-SPO gradient ?

OGCM (ORCA) Resolution 0.5° (Eddy permitting) —
OGCM (ORCA) Resolution 2° (no parameterization) —



(Z. Lachkar, PhDThesis)

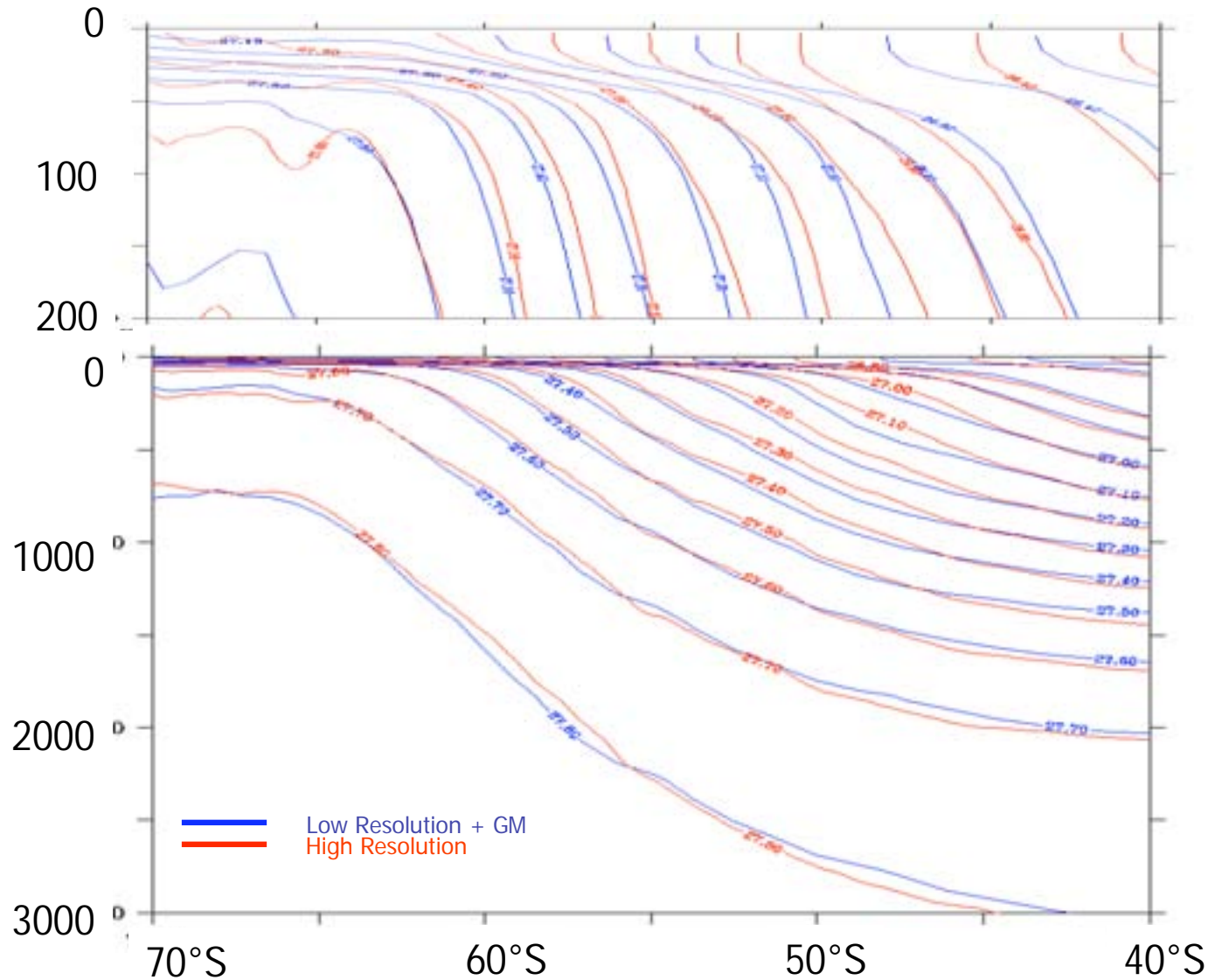
What cause the MLO-SPO gradient ?



What cause the MLO-SPO gradient ?

OGCM (ORCA) Resolution 0.5° (Eddy permitting)

OGCM (ORCA) Resolution 2° (GM parameterization)



What cause the MLO-SPO gradient ?

3. Improved Physical Transport in the ocean

- Improved Vertical Mixing
- GentMcWilliams Parametrization + Isopycnal Diffusion
- Better forcing fields
- Interactive Sea-Ice model

Still some defficiencies

An illustration:

Gent&McWilliams parameterization and the role of eddies

- OK for deep / subsurface
- unefficient for the first 100 meters

More improvements to come

Conclusions

Natural Carbon Fluxes

The river loop + iron limitation in the S.O
act to create a significant pre-industrial atm. CO₂ gradient.

- Need more improvements on the S.O. circulation
- Need to test other atmospheric transport models

This gradient should be used to validate the oceanic carbon cycle models.

Consequences on the impact of climate change on the natural carbon cycle

Anthropogenic + Natural Carbon Fluxes

Recent progress in the S.O.: Climatology (Takahashi 2007), Models, Inversions
See Poster by Metzl et al.