Physical processes and linkages to carbon uptake

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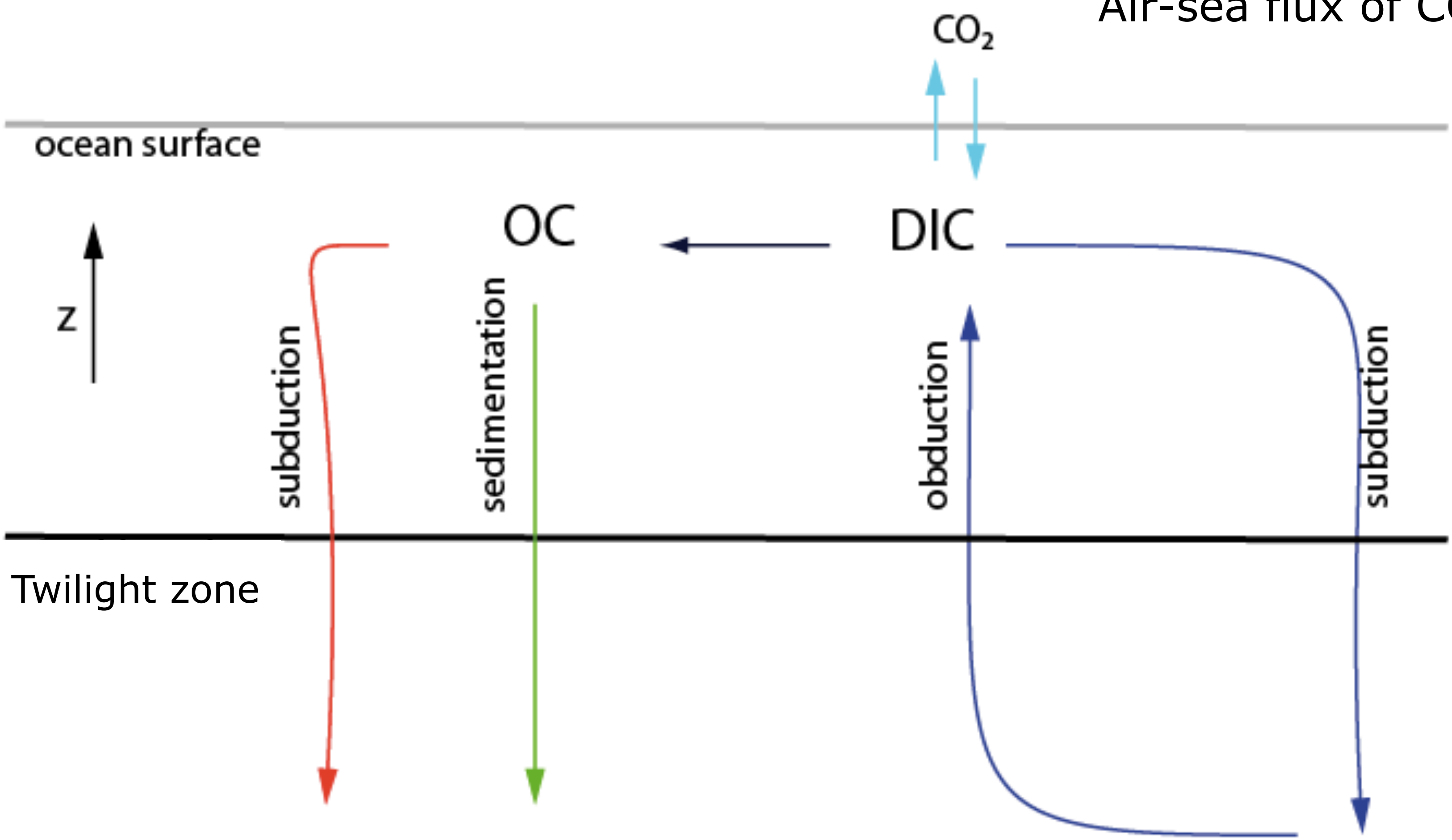
Carbon fluxes into the ocean

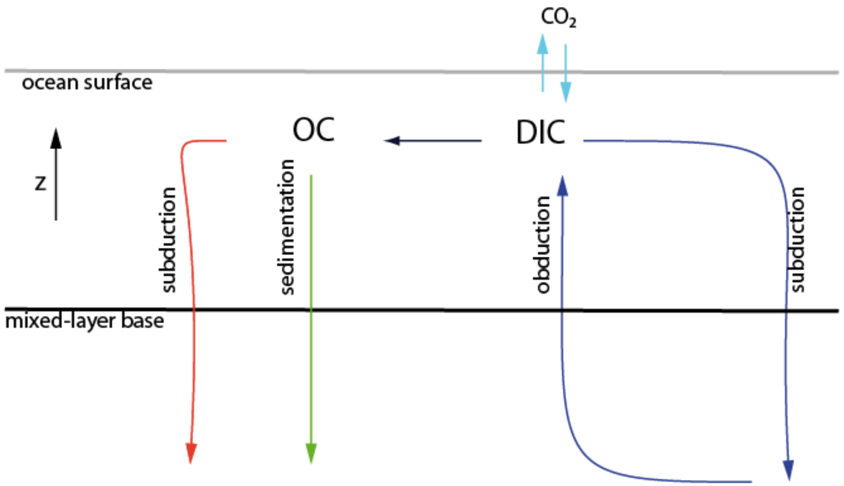
Air-sea flux of CO_2



Biological pump
of organic material

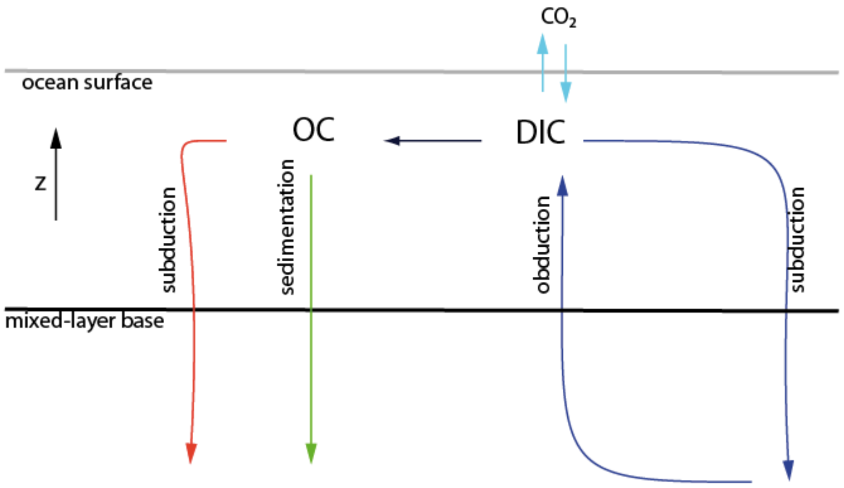
Physical fluxes
of inorganic carbon

Preindustrial ocean



Equilibrium :
Net physical fluxes of DIC = biological pump
Net air-sea flux is close to zero

Preindustrial ocean



Equilibrium :
Net physical fluxes of DIC = biological pump
Net air-sea flux is close to zero

Are the gross fluxes of DIC much larger than the biological pump ?

How large is subduction of OC compared to sedimentation ?

What are the regional distribution of these carbon fluxes ?

Contemporary ocean

CO_2 concentrations in the atmosphere have increased due to anthropogenic emissions

Ocean has absorbed between 1/3 and 1/4 of this excess carbon emissions

Ocean uptake is saturating

Ocean circulation and productivity have not drastically changed

Oceanic uptake of anthropogenic CO2 is achieved by physical fluxes: subduction of DIC

Contemporary ocean

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Oceanic uptake of anthropogenic CO2 is achieved by physical fluxes: subduction of DIC

How and where is subduction operating ?

What is the contribution of meso/submesoscale features ?

What will be the effect of a change in circulation ?

What will be the effect of a change in physiology / ecosystem / C:N ratio ?

Uptake of anthropogenic carbon

1) Change of CO_2 in atmosphere

Unperturbed circulation, unperturbed biological pump

2) Change in ocean circulation

-> change in N supply

-> change in biological pump

Unperturbed circulation, perturbed biological pump

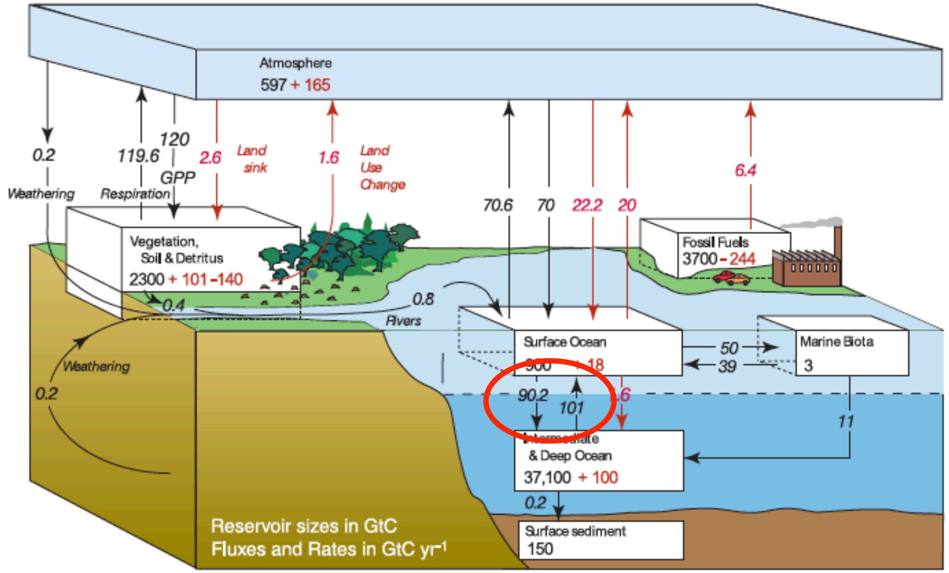
3) Change in physiology, ecosystem structure, C/N ratio

-> change in biological pump

Perturbed circulation, perturbed biological pump

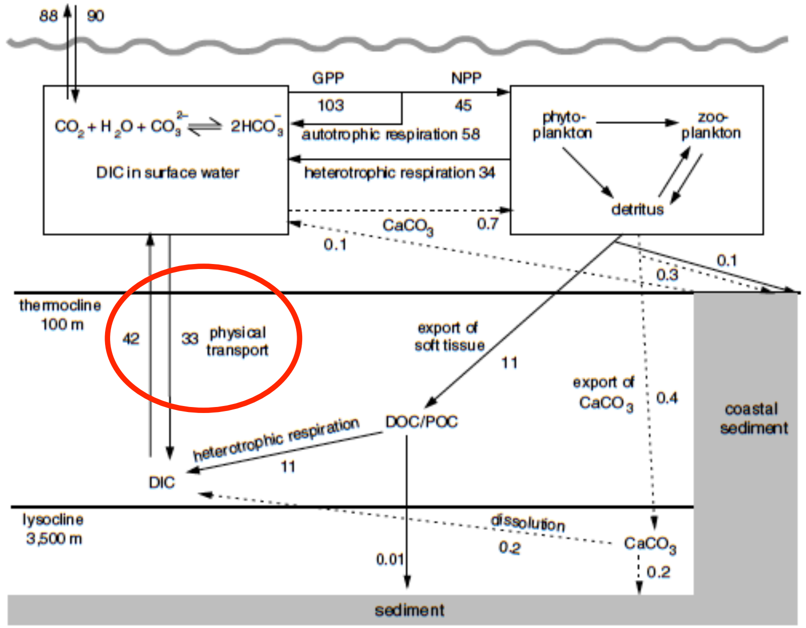
How will these different changes modify the uptake in the future ?

Pre-industrial ocean

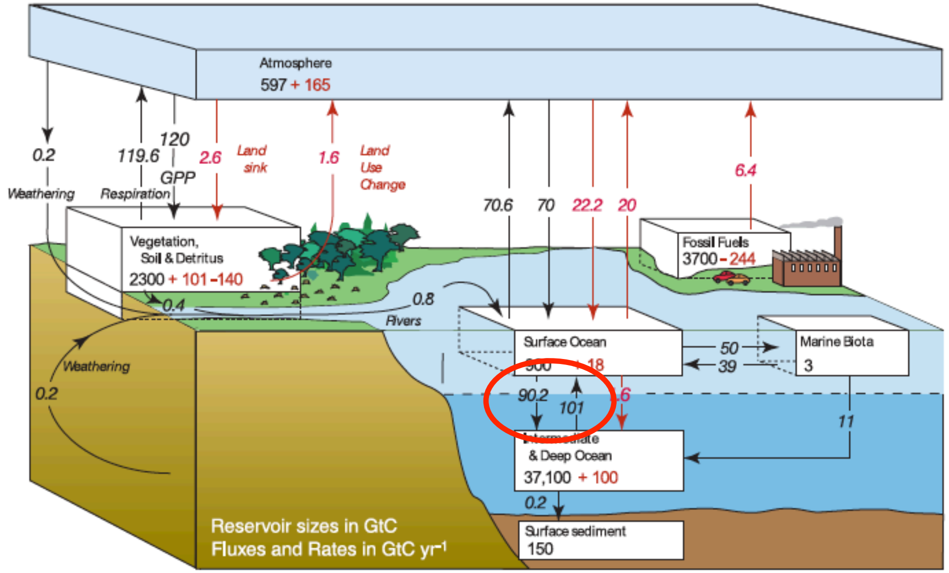


IPCC, 2007, 2013

Carbon cycling in the ocean



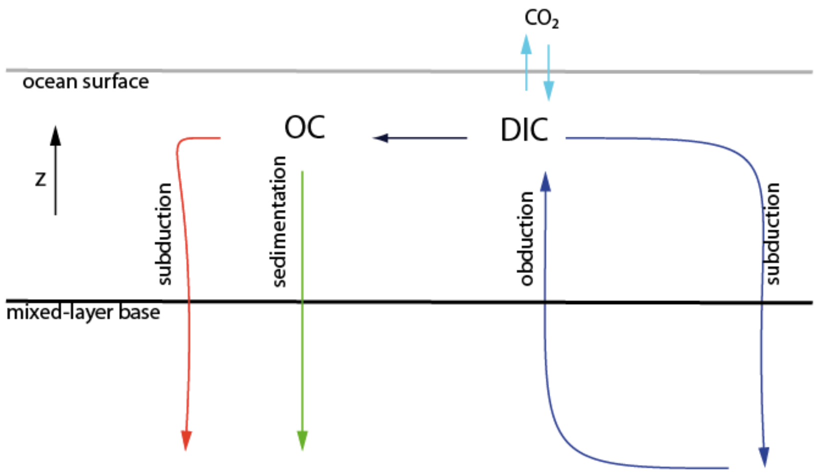
IPCC, 2001, 2011



IPCC, 2007, 2013

Besides for a few regional studies, very little is know on

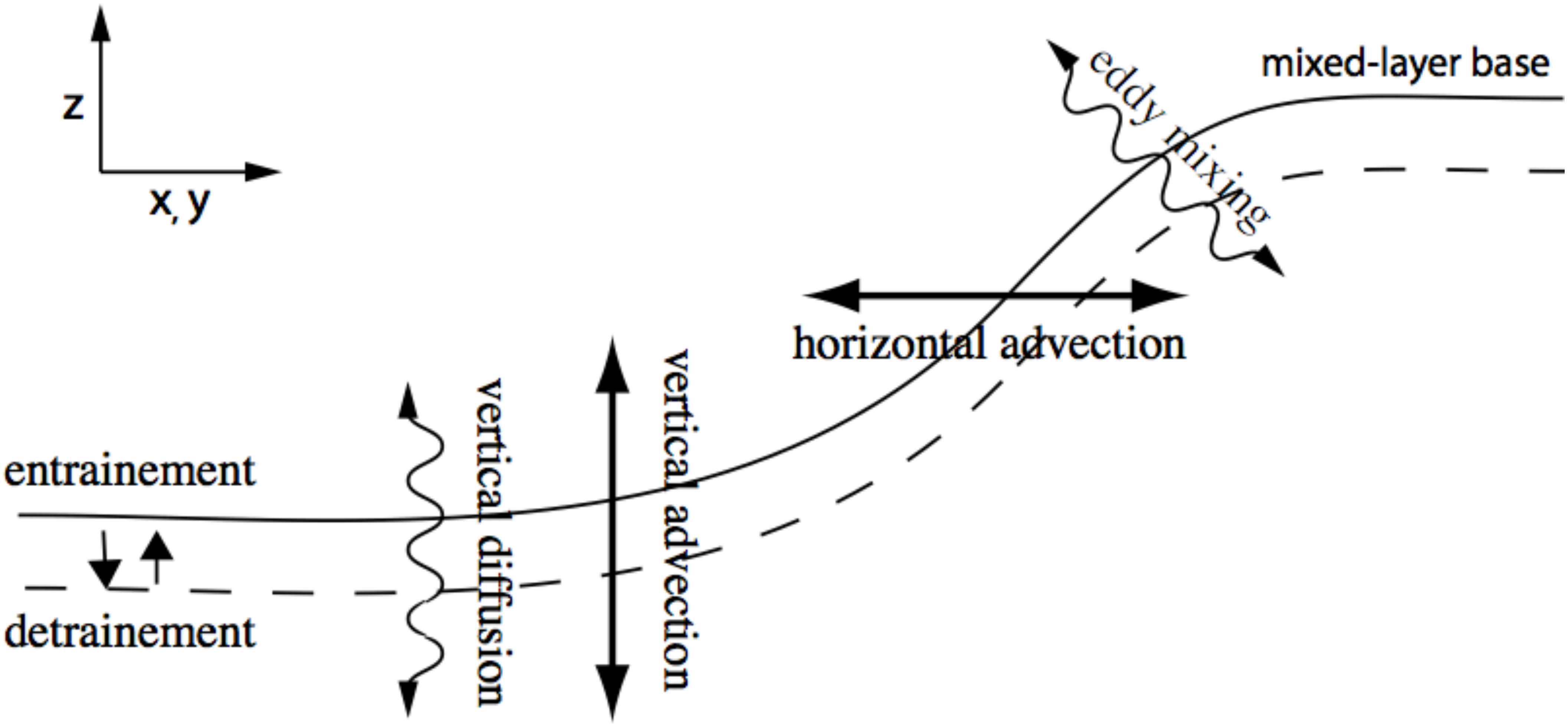
the physical transport between surface and deep ocean



Meaningful boundary for biological pump: euphotic depth

Meaningful boundary for physical fluxes: surface boundary layer
Or mixed-layer depth

Subduction/obduction : mechanisms



Subduction/obduction estimates

Instantaneous flux across
the time varying mixed-layer depth

$$S_{\text{ann}}^{\text{TR}} = \int_0^{365} \left(-c_h \cdot w_h - c_h \cdot \vec{u}_h \vec{\nabla} h - c_h \cdot \frac{\partial h}{\partial t} - A_z^h \cdot \frac{\partial c_h}{\partial z} \right) dt,$$

Annual Subduction / Obduction rate

Subduction/obduction estimates

Instantaneous flux across
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Annual Subduction / Obduction rate

Extremely difficult to estimate from observations

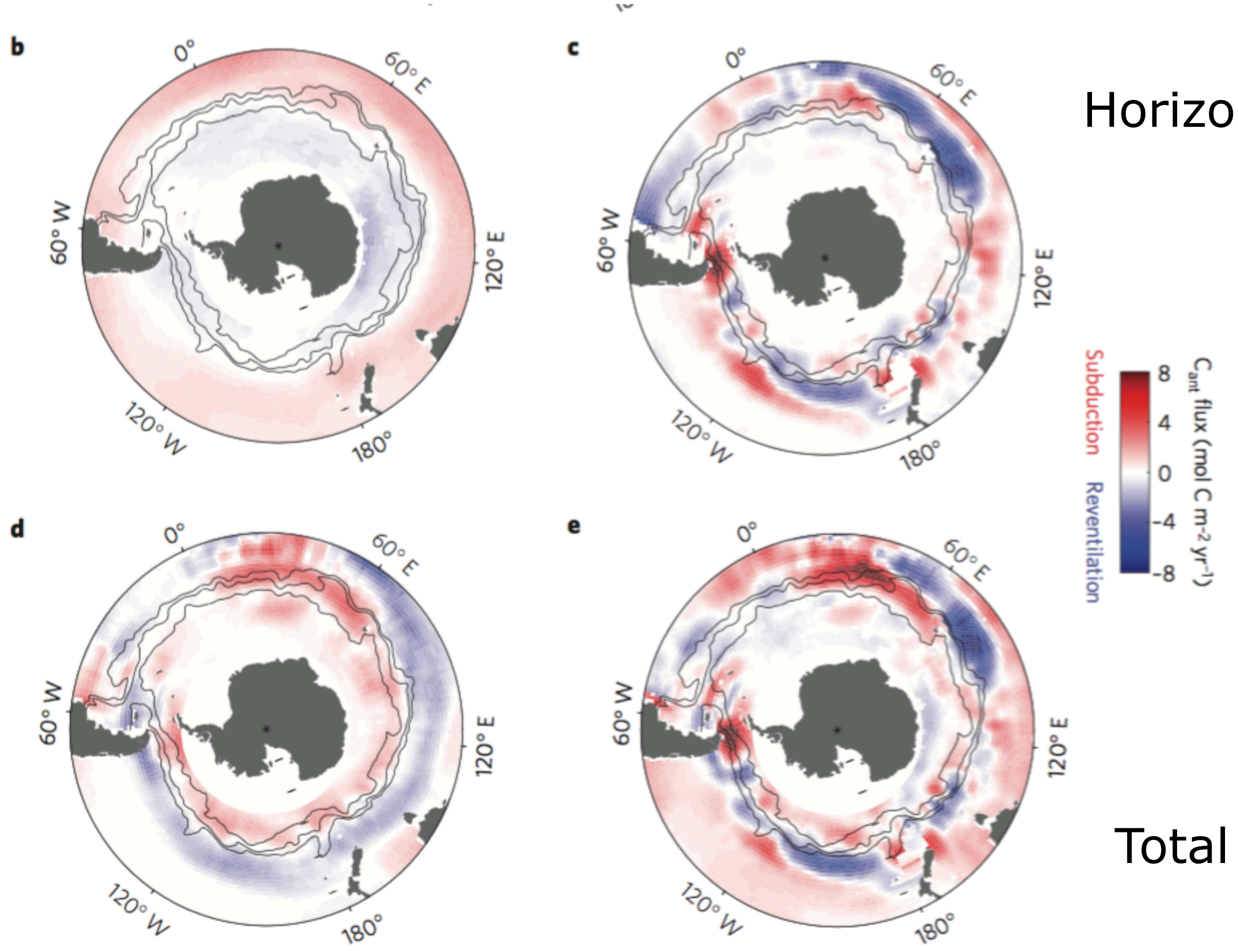
Models offer a framework where all the fields are consistent
and the fluxes can be estimated

Subduction/obduction estimates

Flux across the winter mixed-layer depth: estimates based on observations

Vertical

Horizontal



Eddy

Total

Sallée et al, 2012

Outline

1. Pre-industrial carbon transfers in the global ocean (Levy et al., GBC, 2013)
2. Antropogenic carbon penetration in the global ocean (Bopp et al., GRL, 2015)
3. Role of (sub-)mesoscales in the North East Atlantic (Karleskind et al., JGR 2011a, Oce. Mod. 2011b)

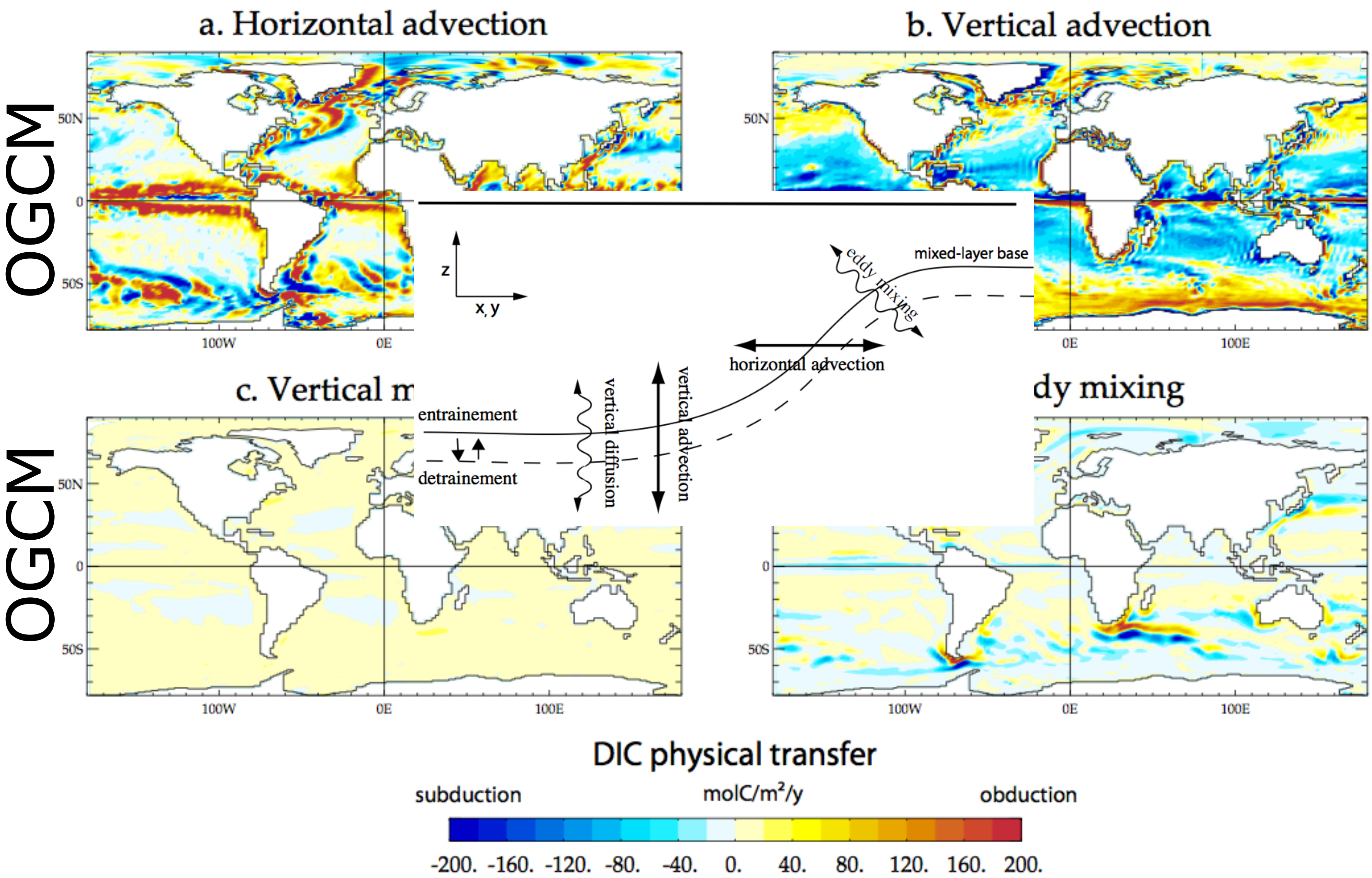
1. OGCM: ORCA2-PISCES

climatological simulation for the pre-industrial ocean

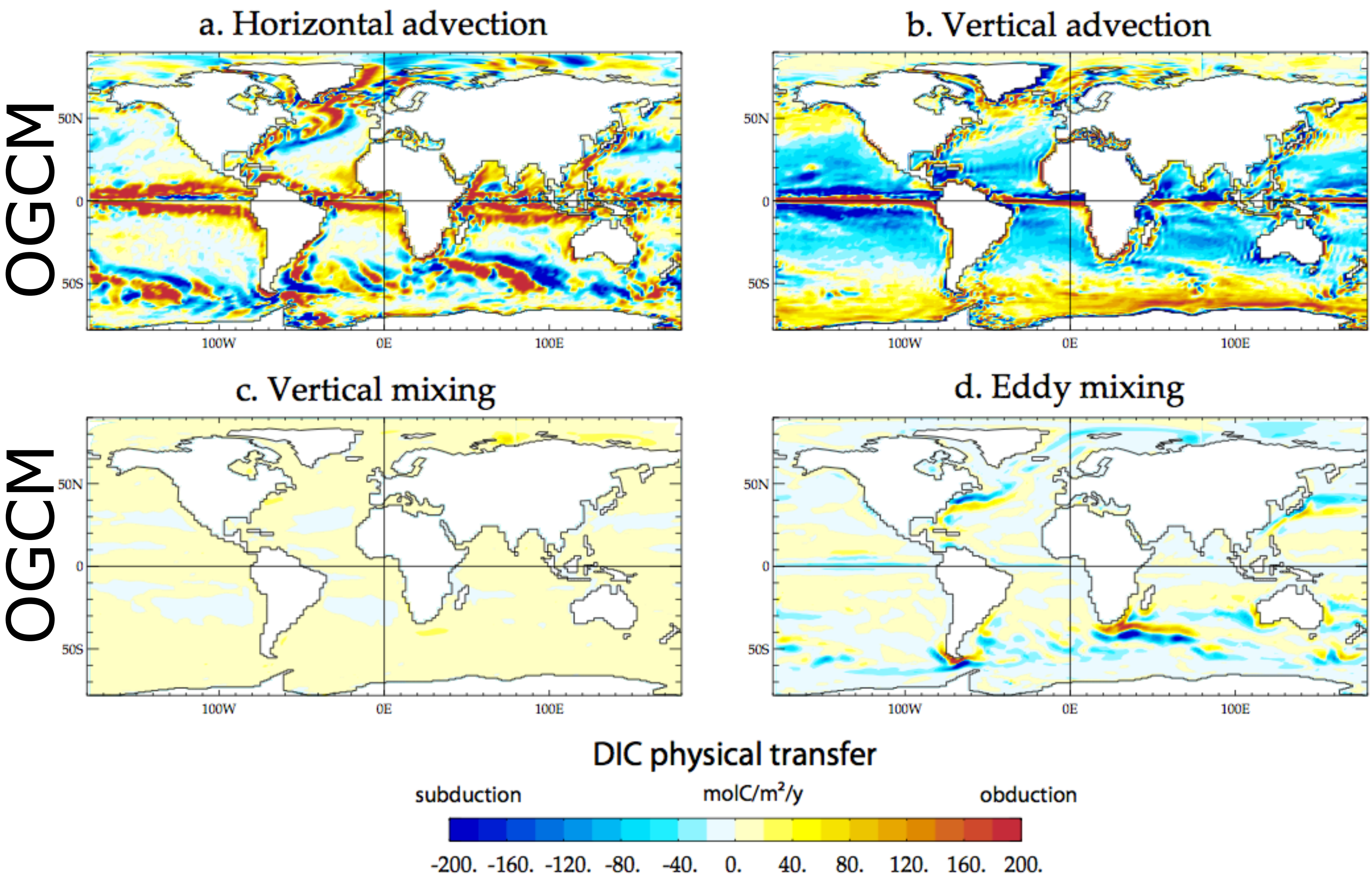
2. Global climatological data

DIC (GLODAP), Wind (CORE2), U (AVISO), MLD (De Boyer Montegut)

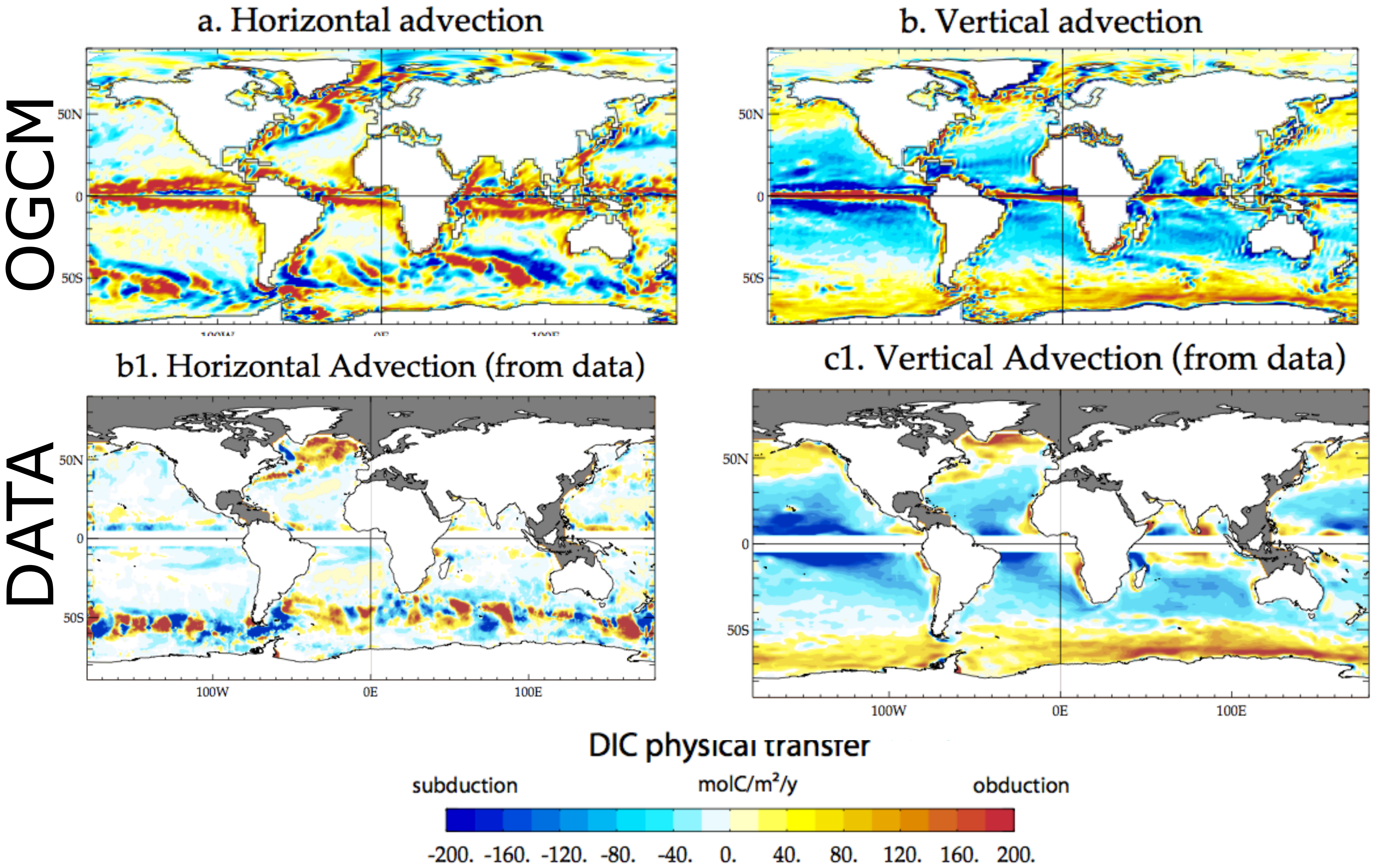
Subduction and obduction of DIC



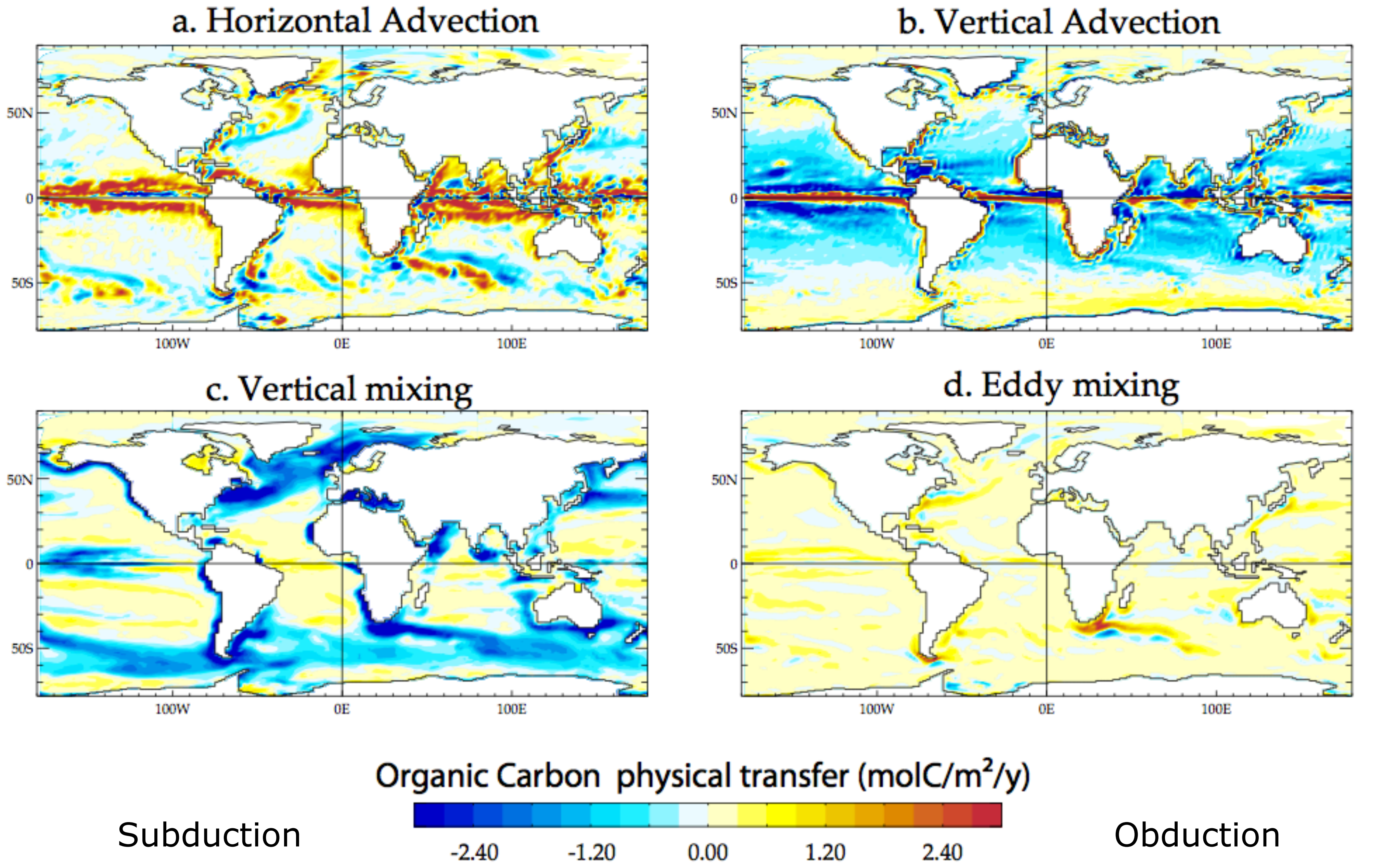
Subduction and obduction of DIC



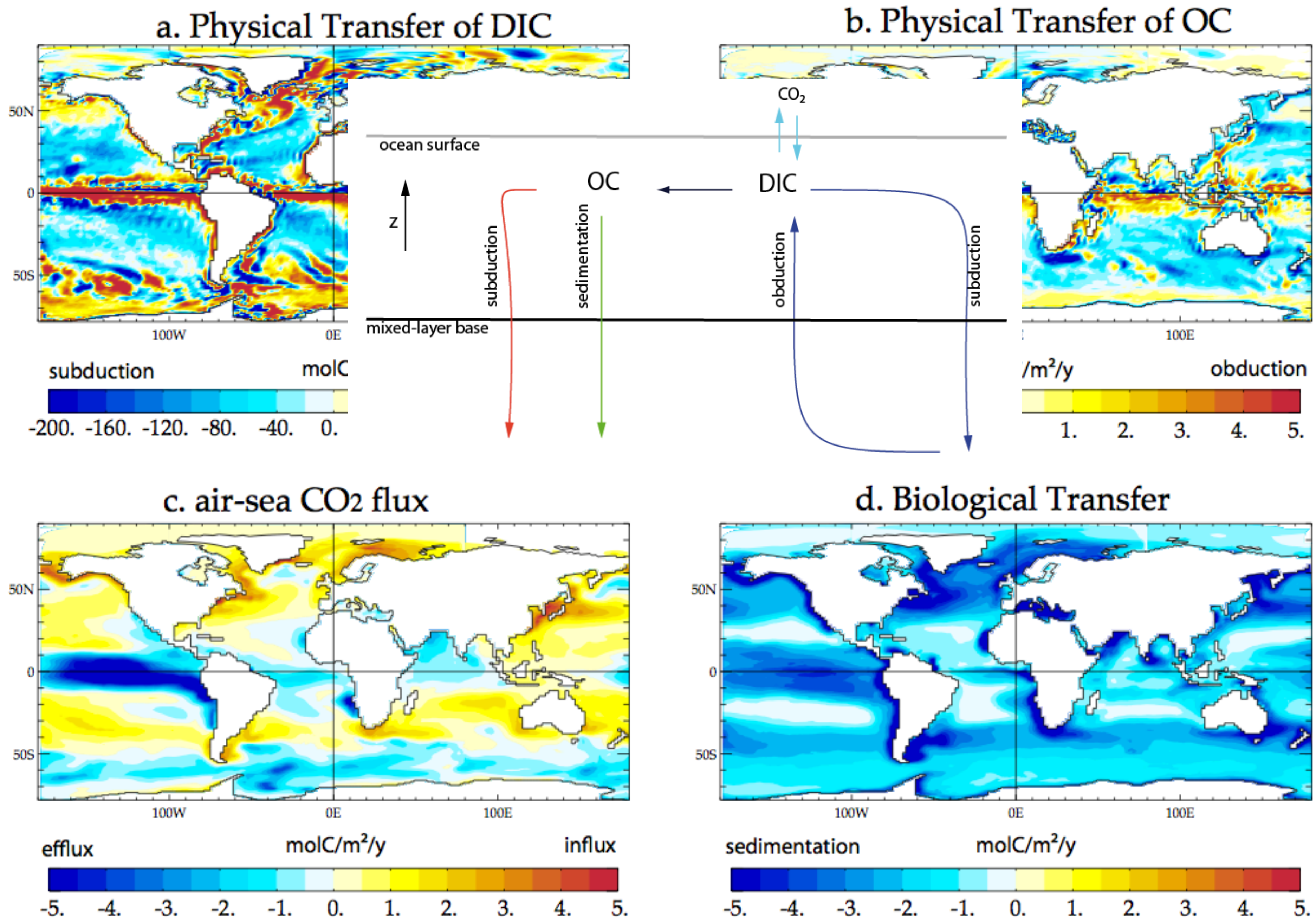
Subduction and obduction of DIC



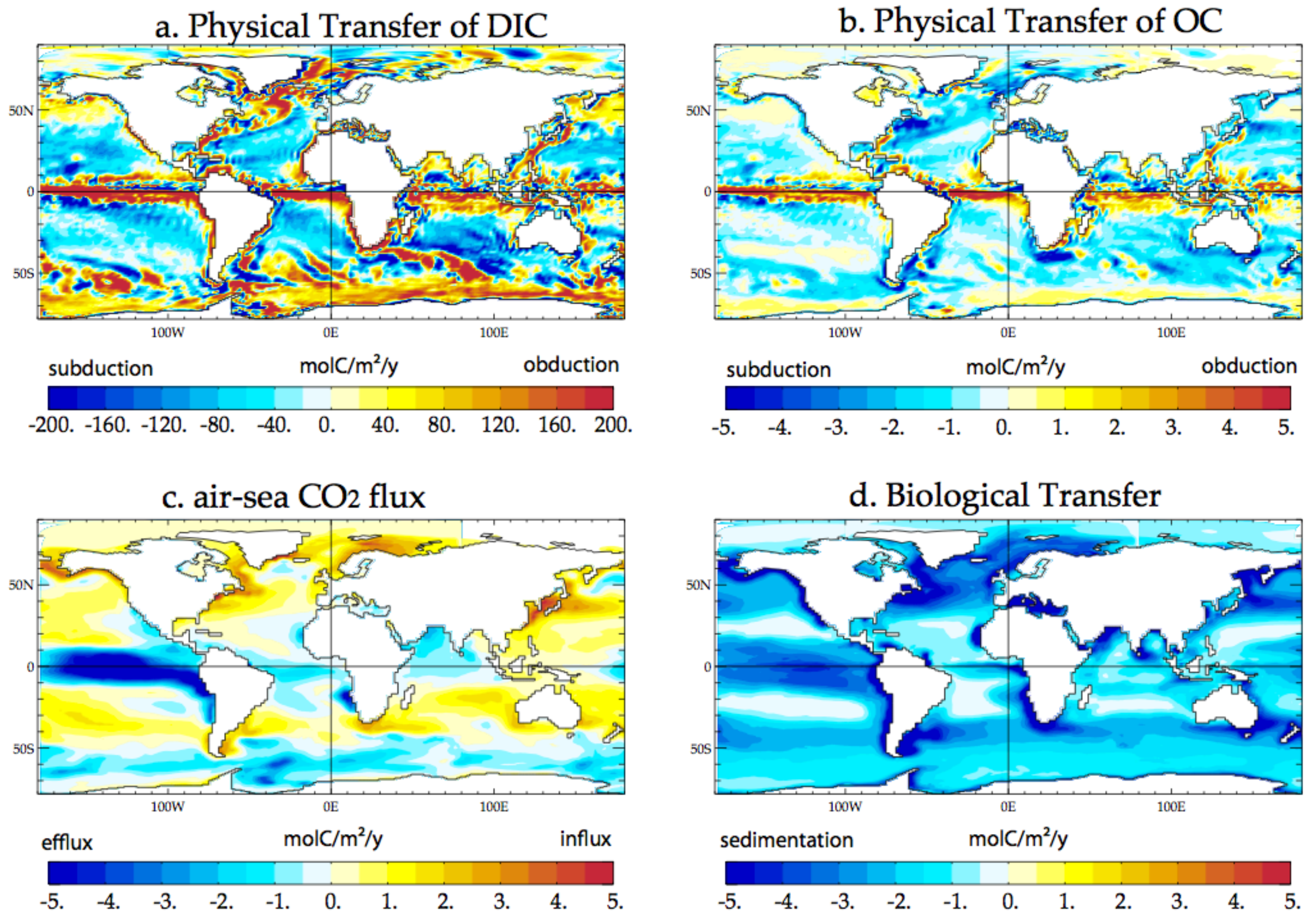
Subduction and obduction of OC



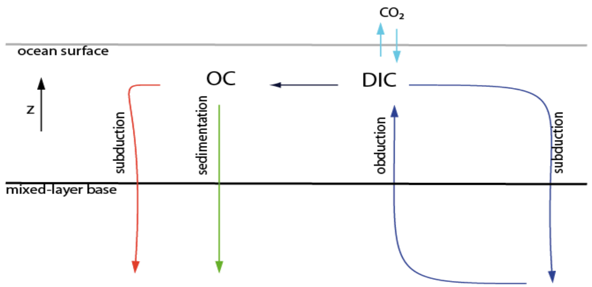
Carbon fluxes through the ML

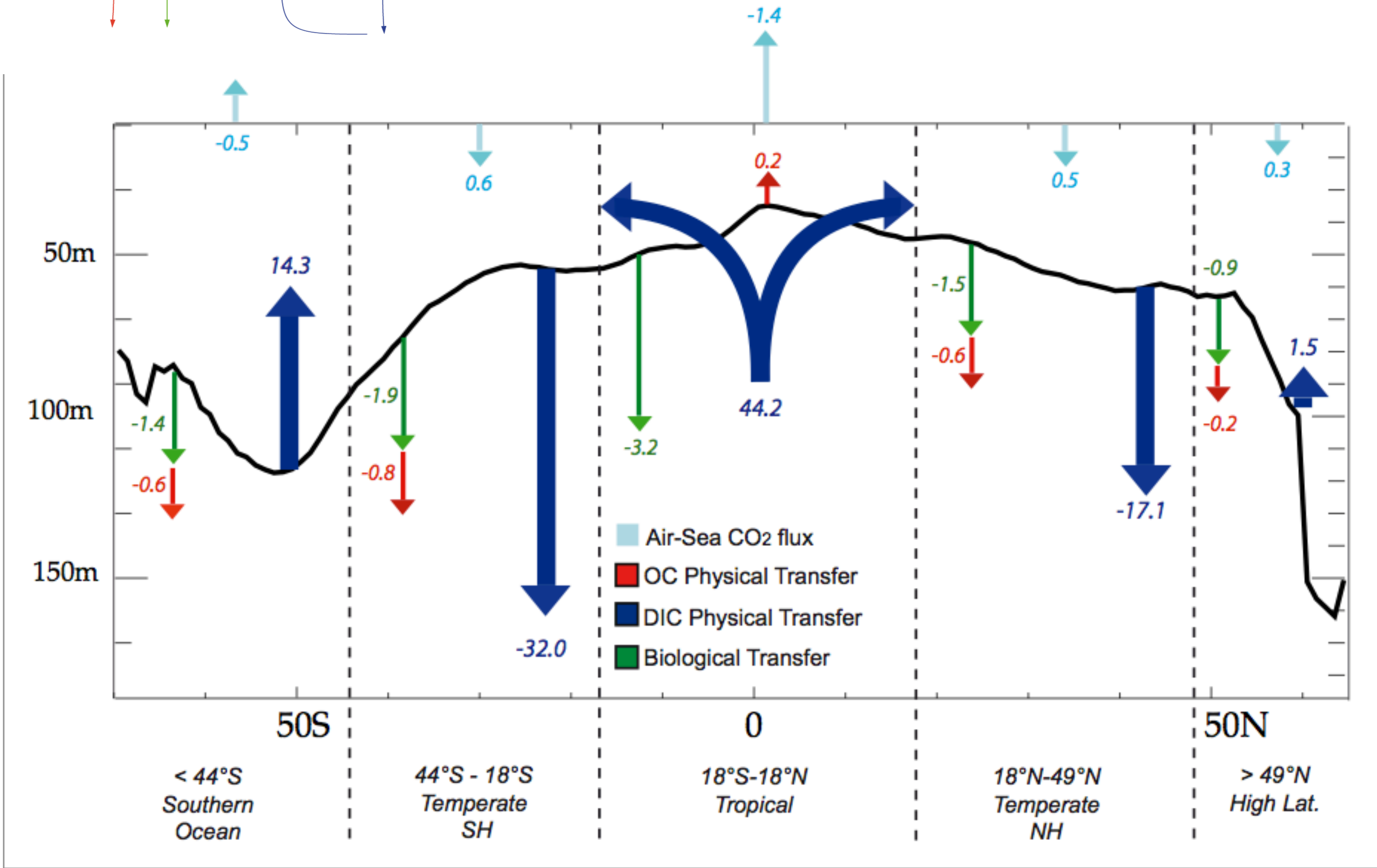


Carbon fluxes through the ML

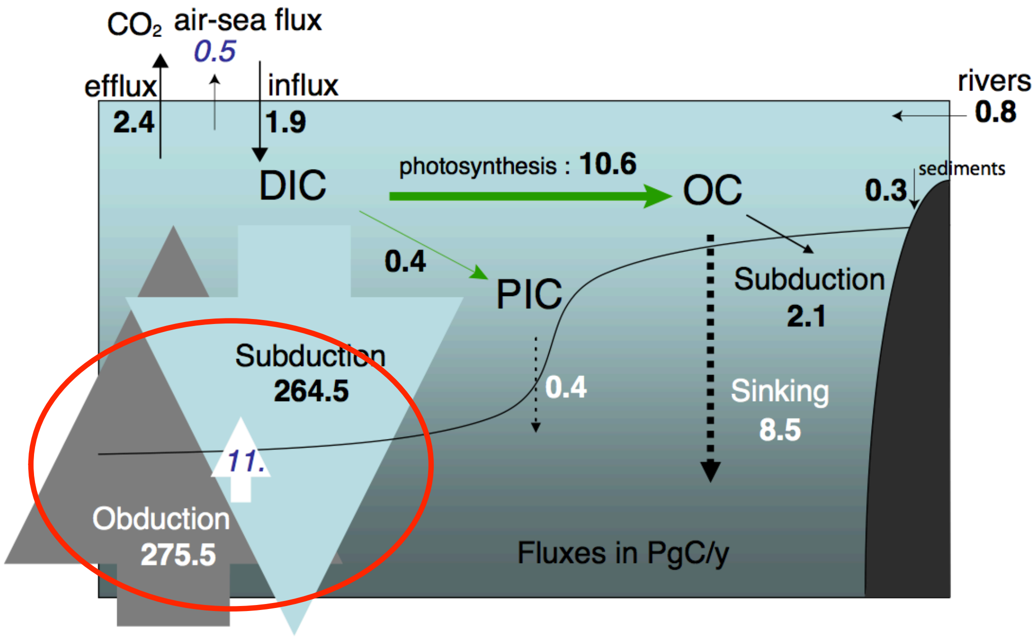


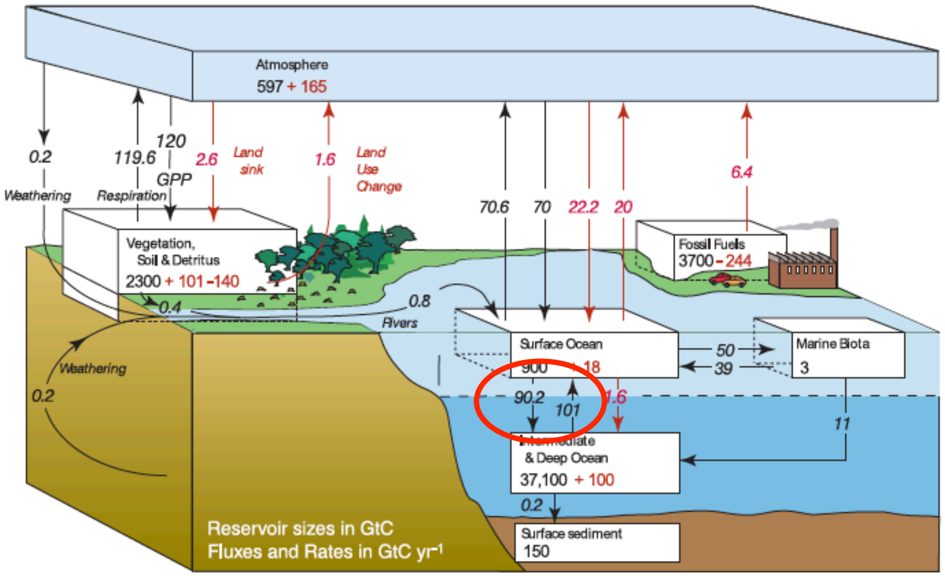
Carbon fluxes through the ML





Revised pre-industrial carbon budget for the ML





AR4, 2007

For antropogenic carbon flux estimates

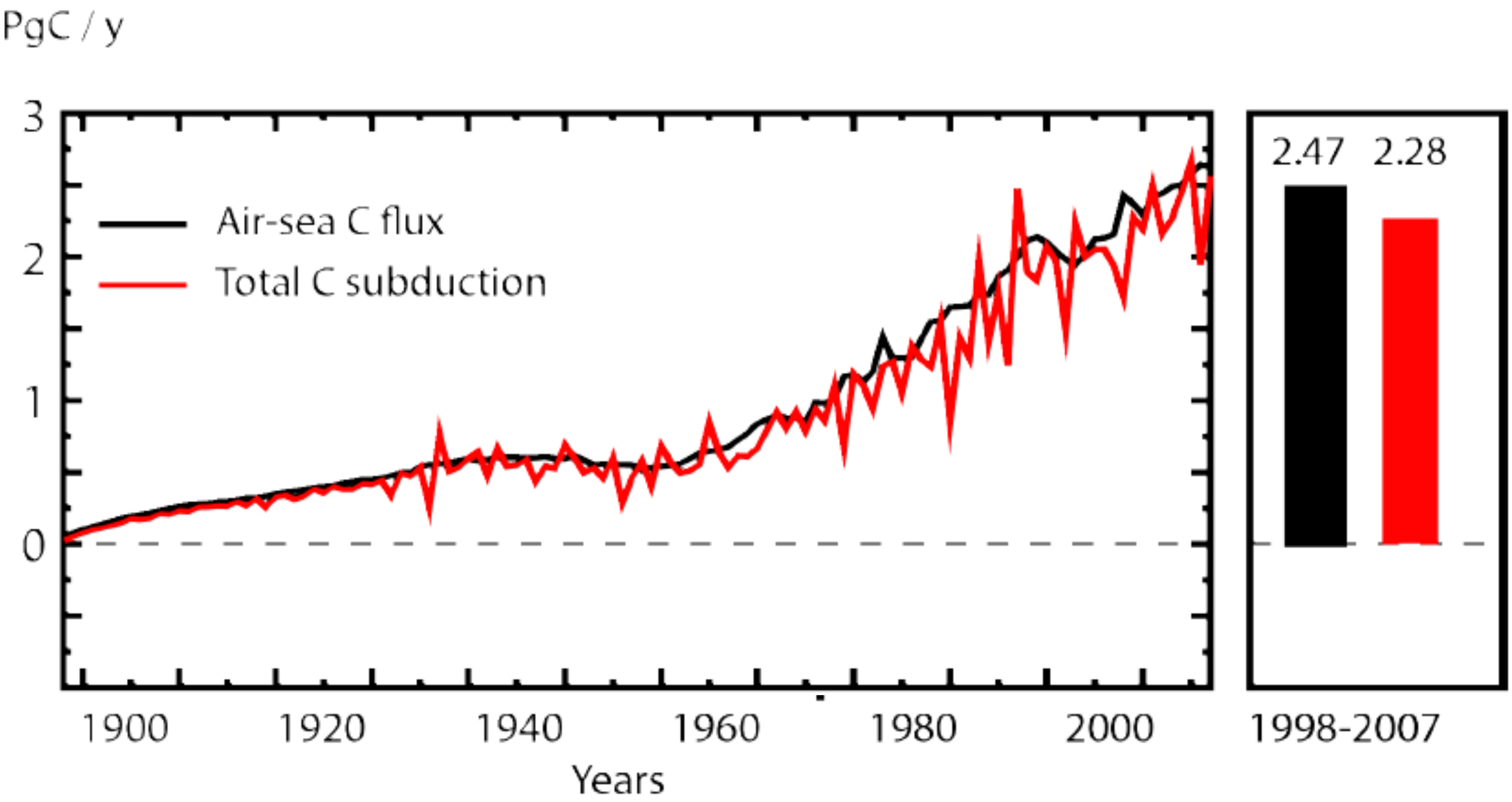
OGCM: ORCA2-PISCES

Historical simulation (1890-2007) with / without trend in atm pCO2

The circulation and biological pump are identical in the two simulations

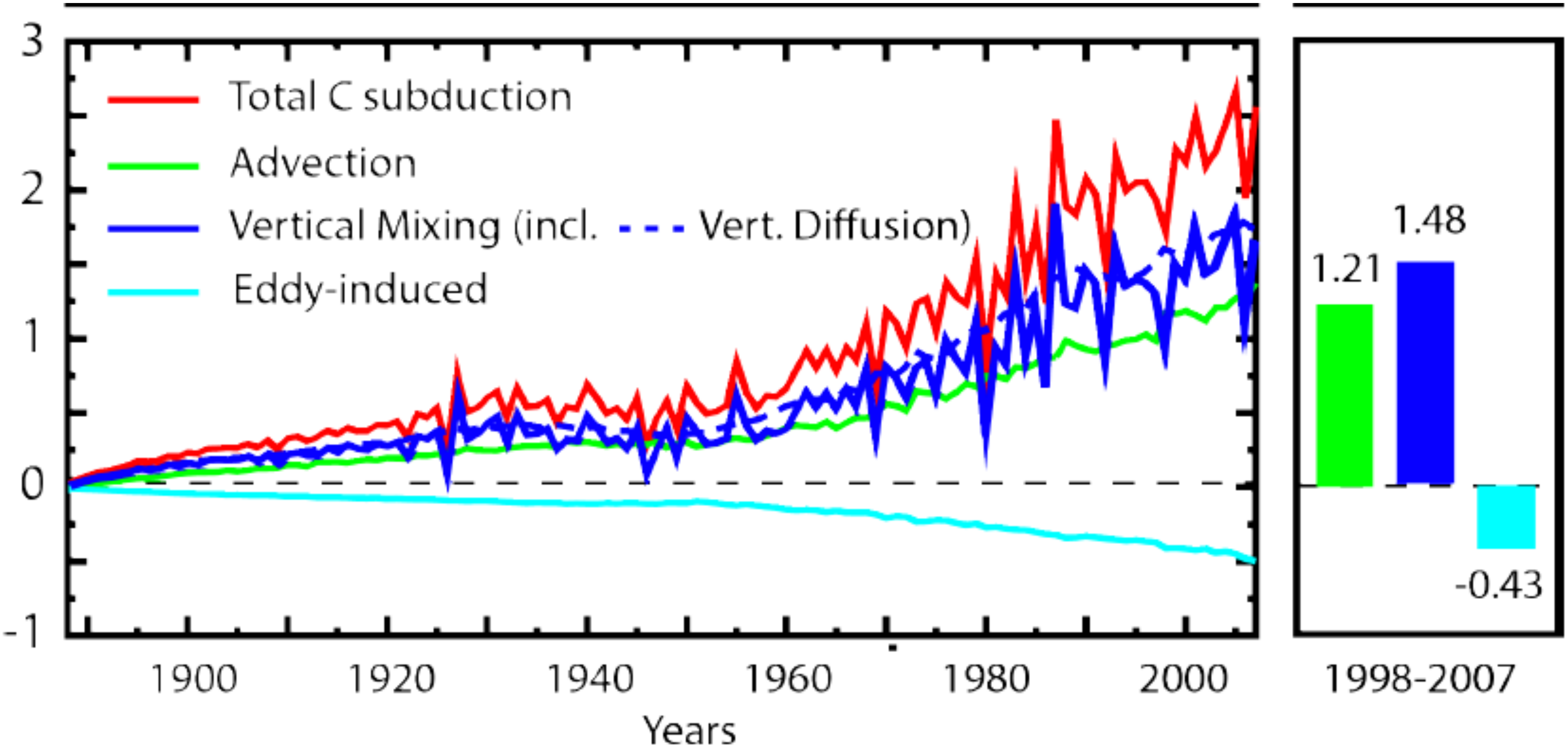
We look at the difference between the two to access anthropogenic carbon

Antropogenic fluxes

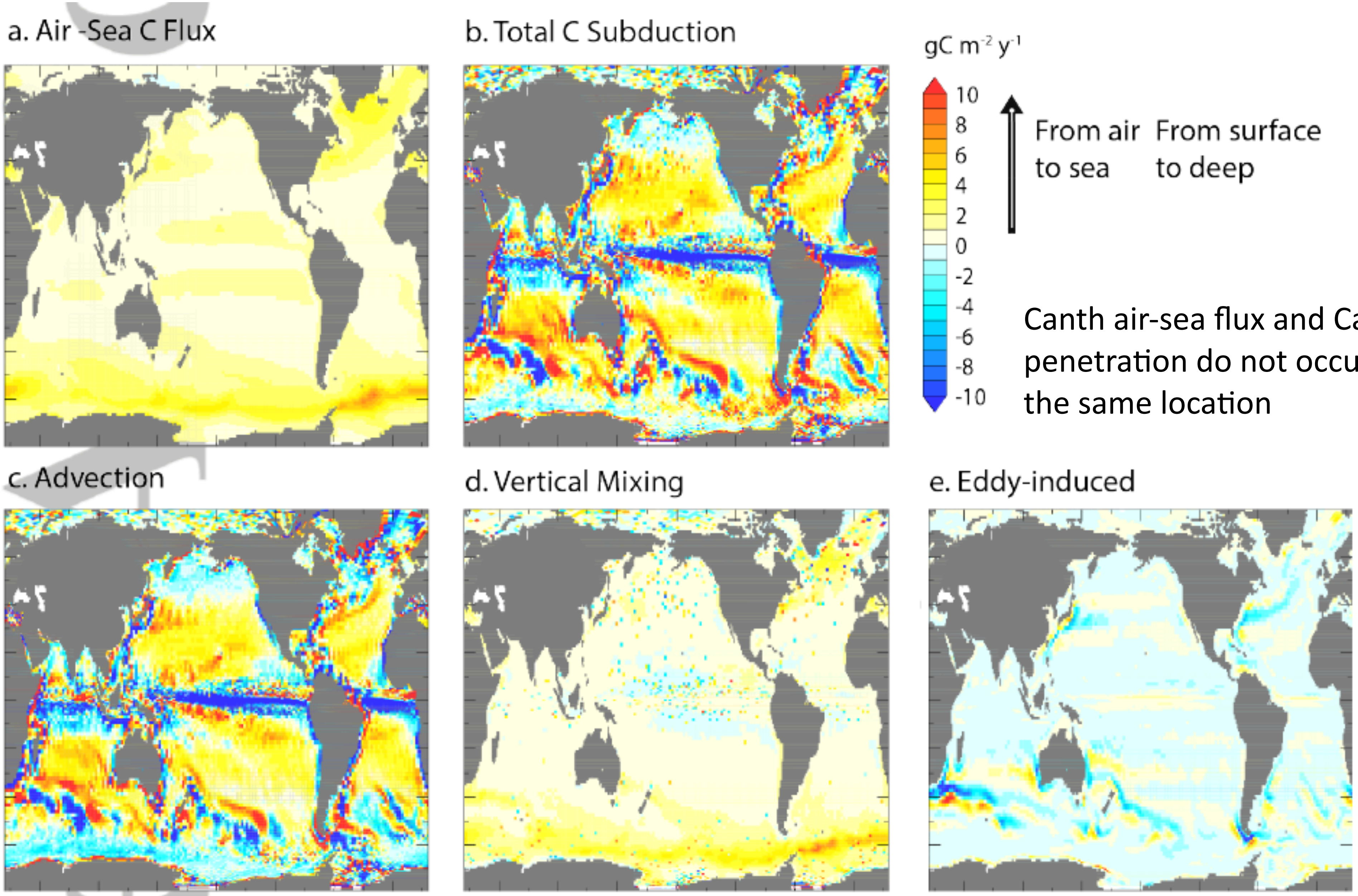


larger interannual variability in carbon subduction than in air-sea carbon flux

Antropogenic fluxes



Antropogenic fluxes



Canth air-sea flux and Canth penetration do not occur at the same location

For antropogenic carbon flux estimates

OGCM: ORCA2-PISCES

Historical simulation (1890-2007) with trend in atm pCO2

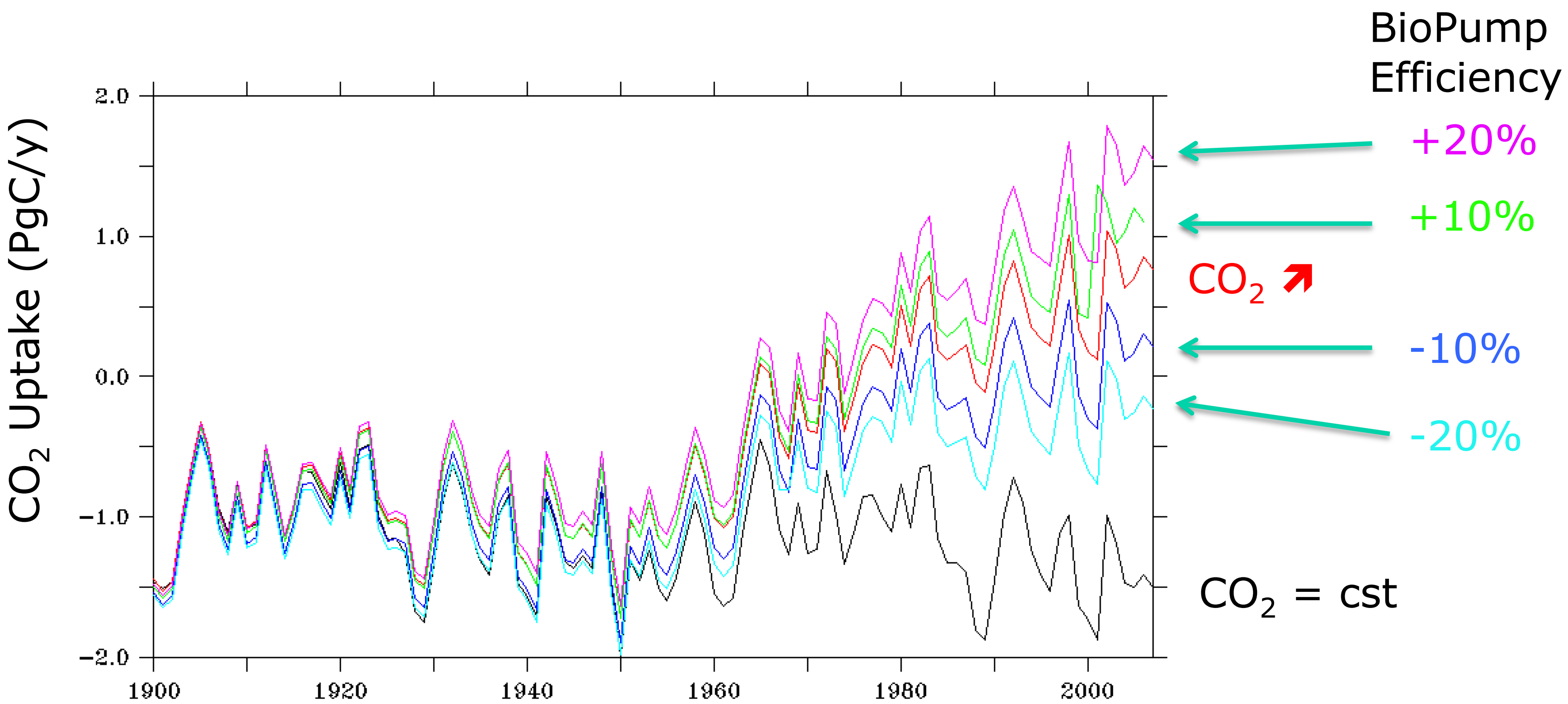
Efficiency of the biological pump is controlled by changing the C:N ratio of PP

$$C/N = 7.625\ (\ 1 + x.\ (CO_2^{t} - CO_2^{1888})\ /\ (CO_2^{2007} - CO_2^{1888})$$

With x = 0.2, 0.1, -0.1, -0.2

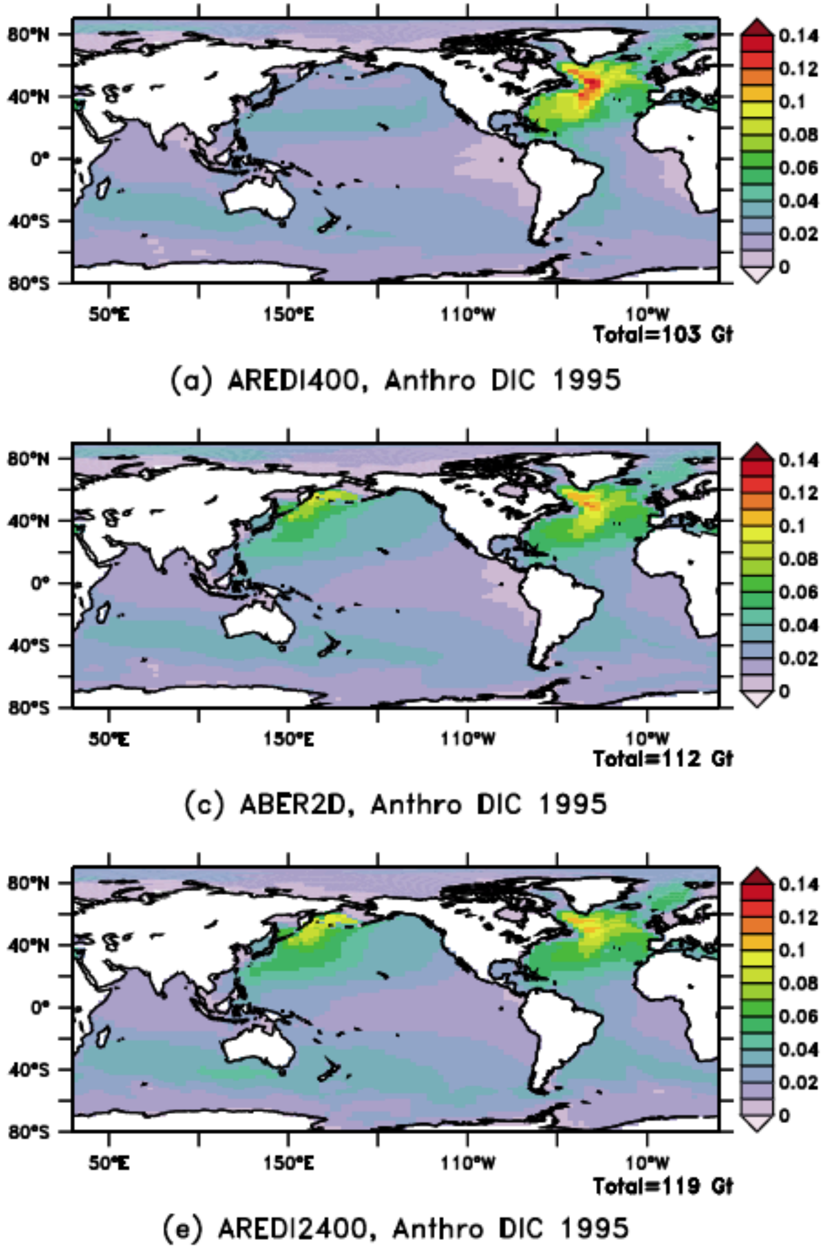
Circulation is the same for all experiments

Impact of biological pump efficiency



Bopp et al., work in progress

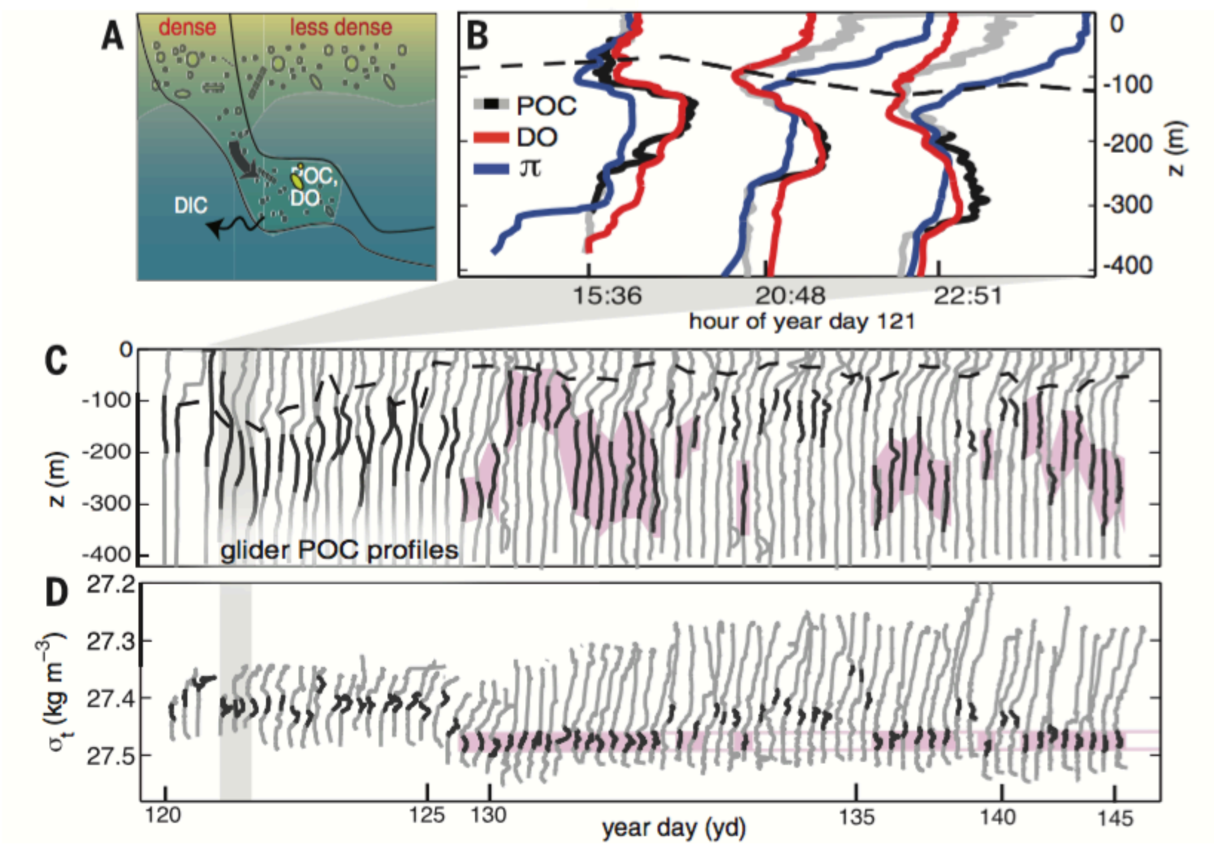
Eddy flux



Sensitivity of Canth upatke to lateral eddy mixing

Gnanadesikan et al., 2015

Submesoscale contribution

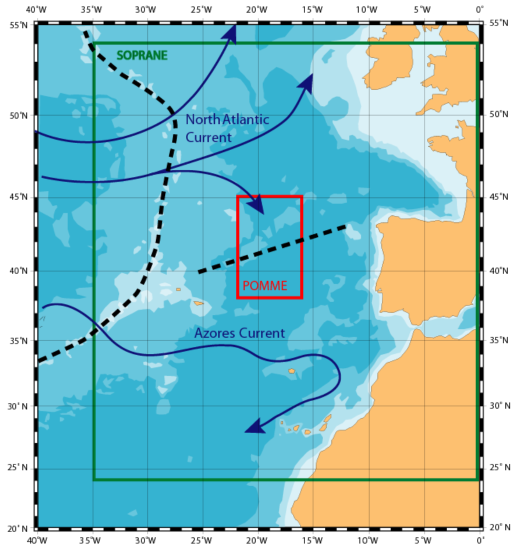


Subduction of POC and DOC

Omand et al., 2015

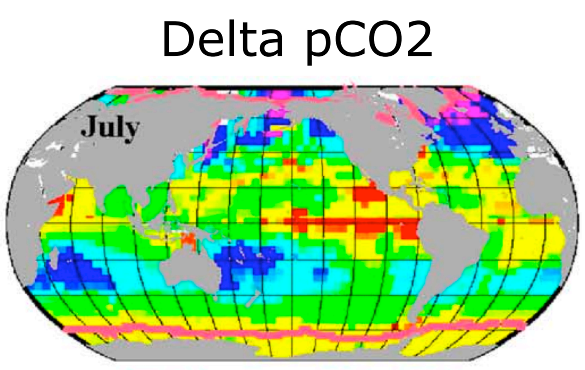
Program Ocean Multidisciplinary MEsoscale

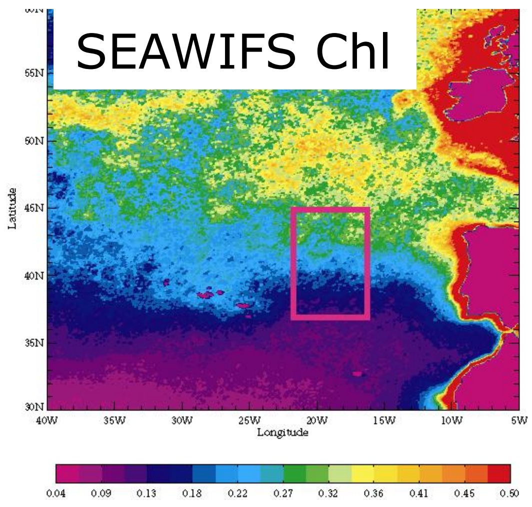
Objective : Role of eddies on subduction of NEAMW and on their biogeochemical properties

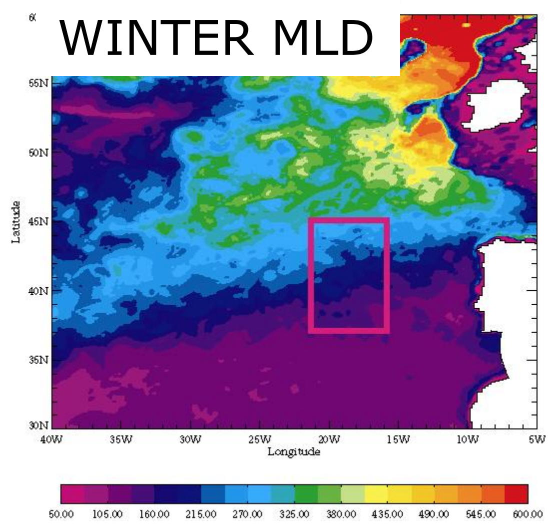


Pomme area

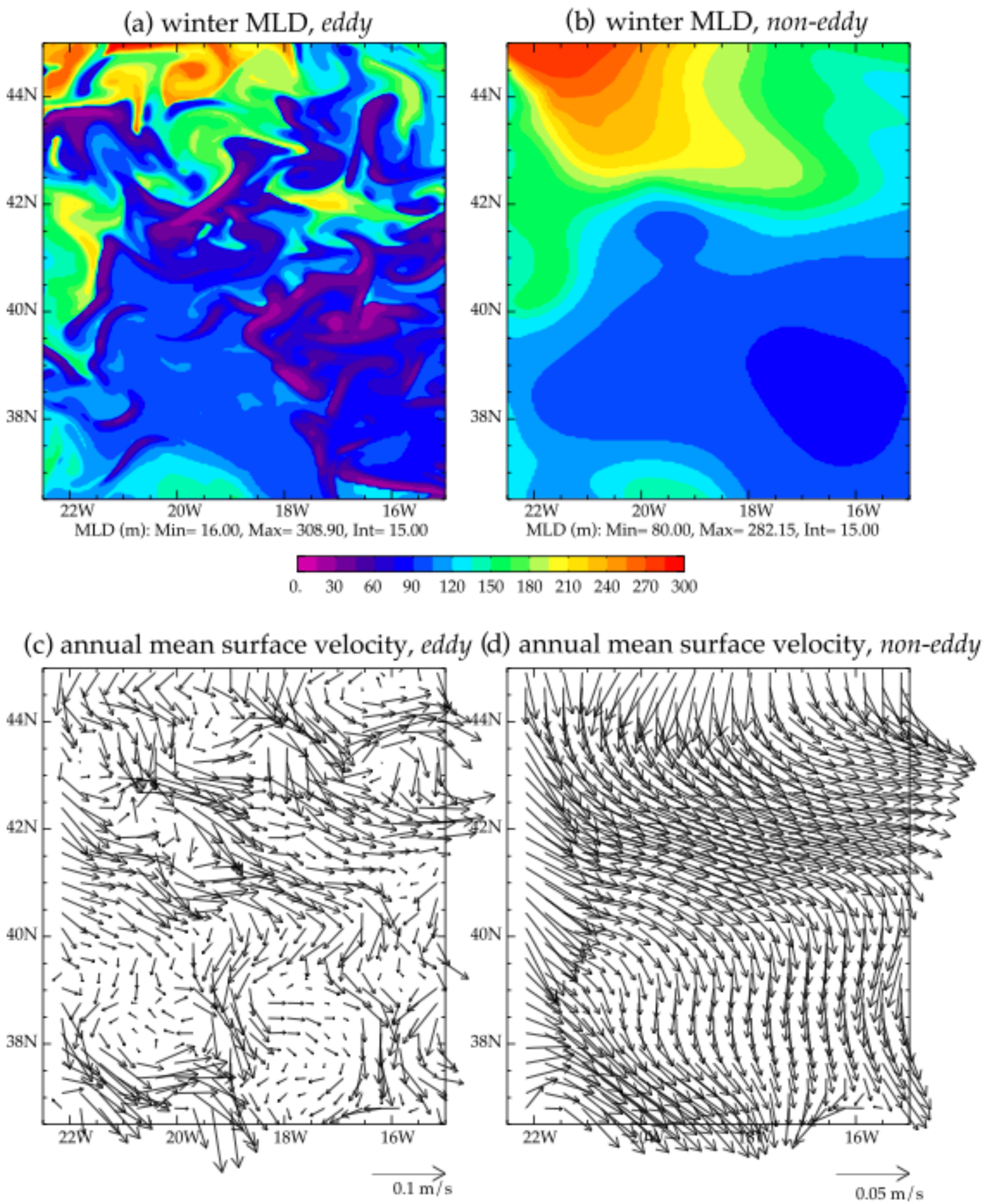
- Strong CO_2 sink
- Mixed-layer depth gradient
- Spring phytoplankton bloom







Regional eddy-resolving model

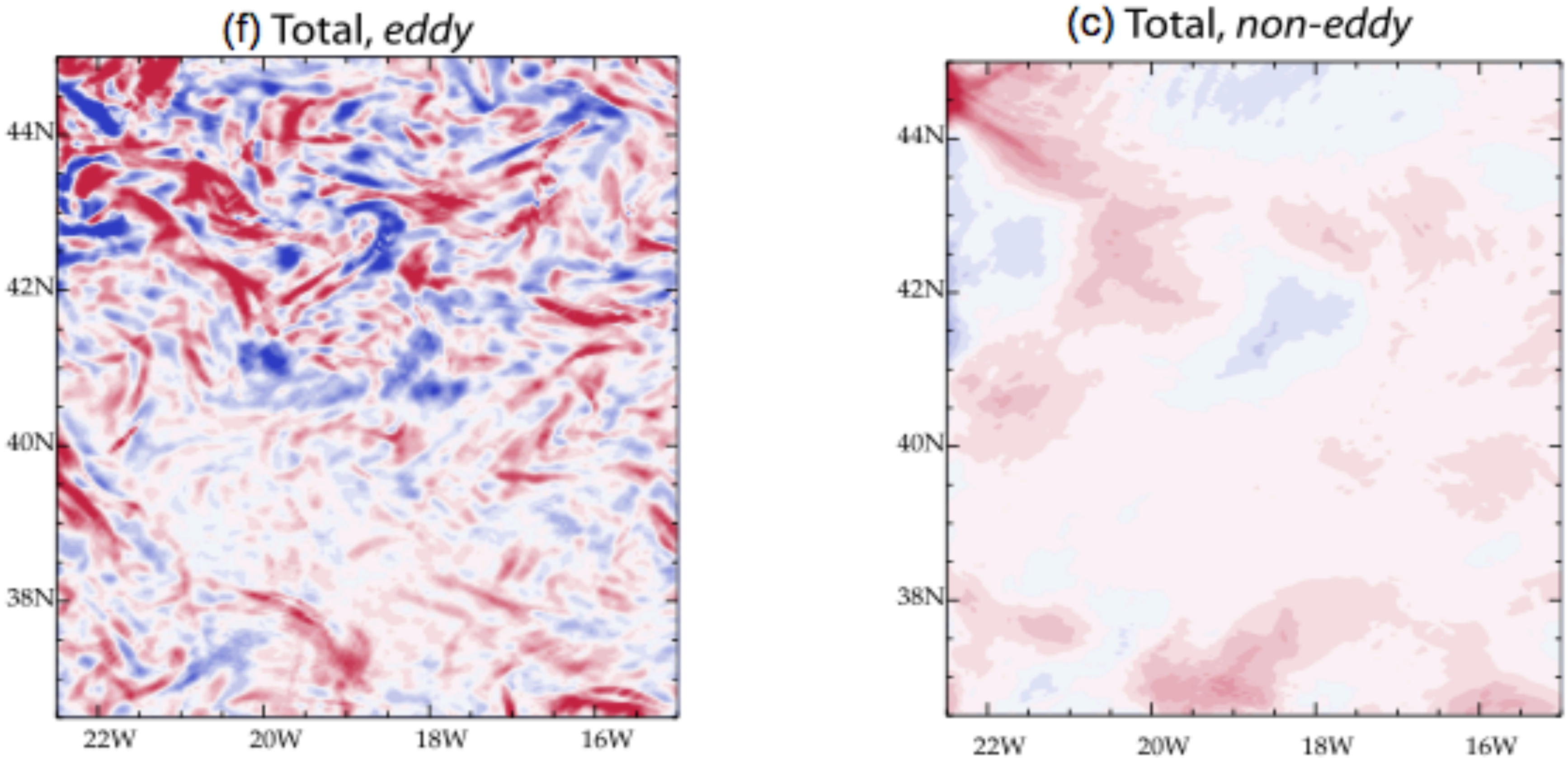


2 simulations

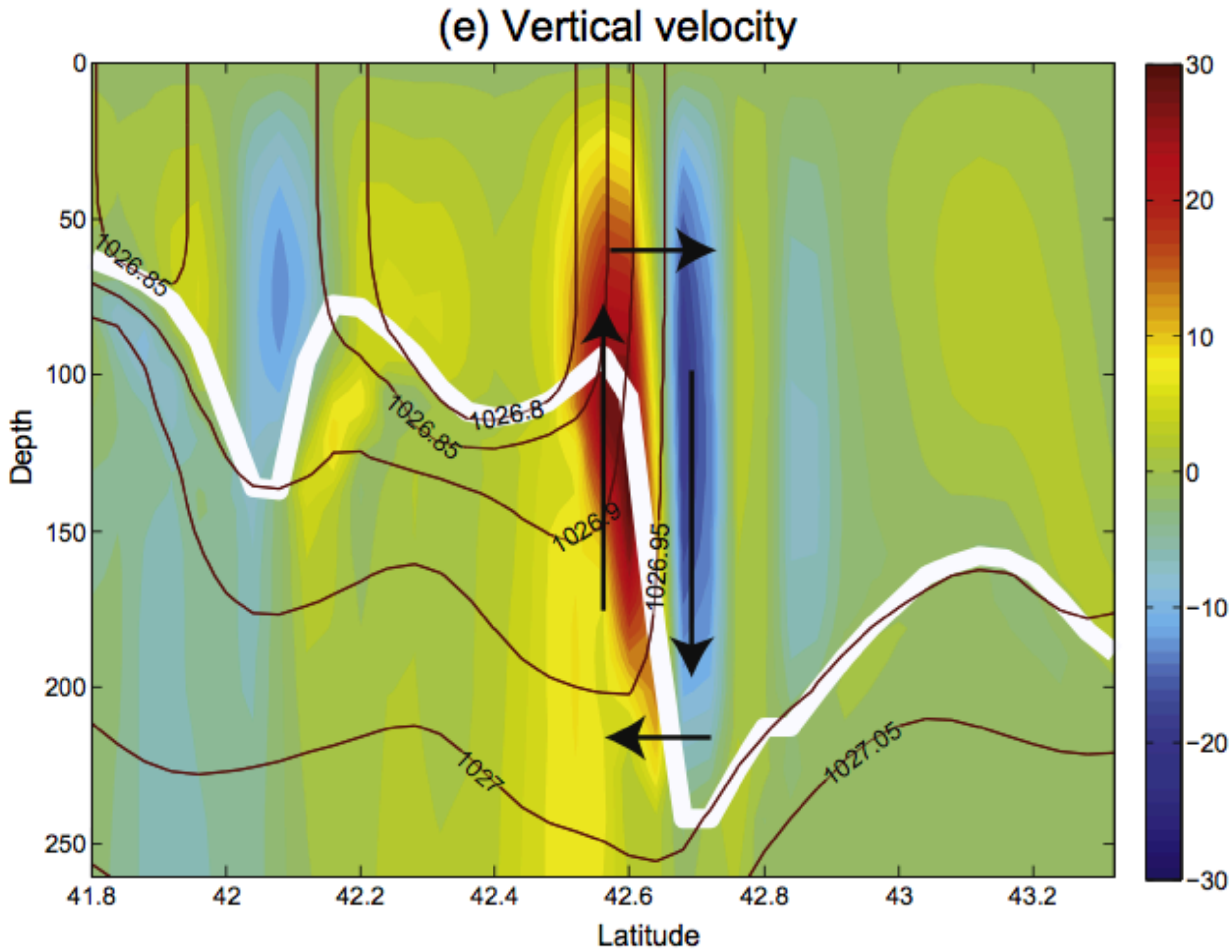
Eddy

Non-eddy

Karleskind et al, 2011

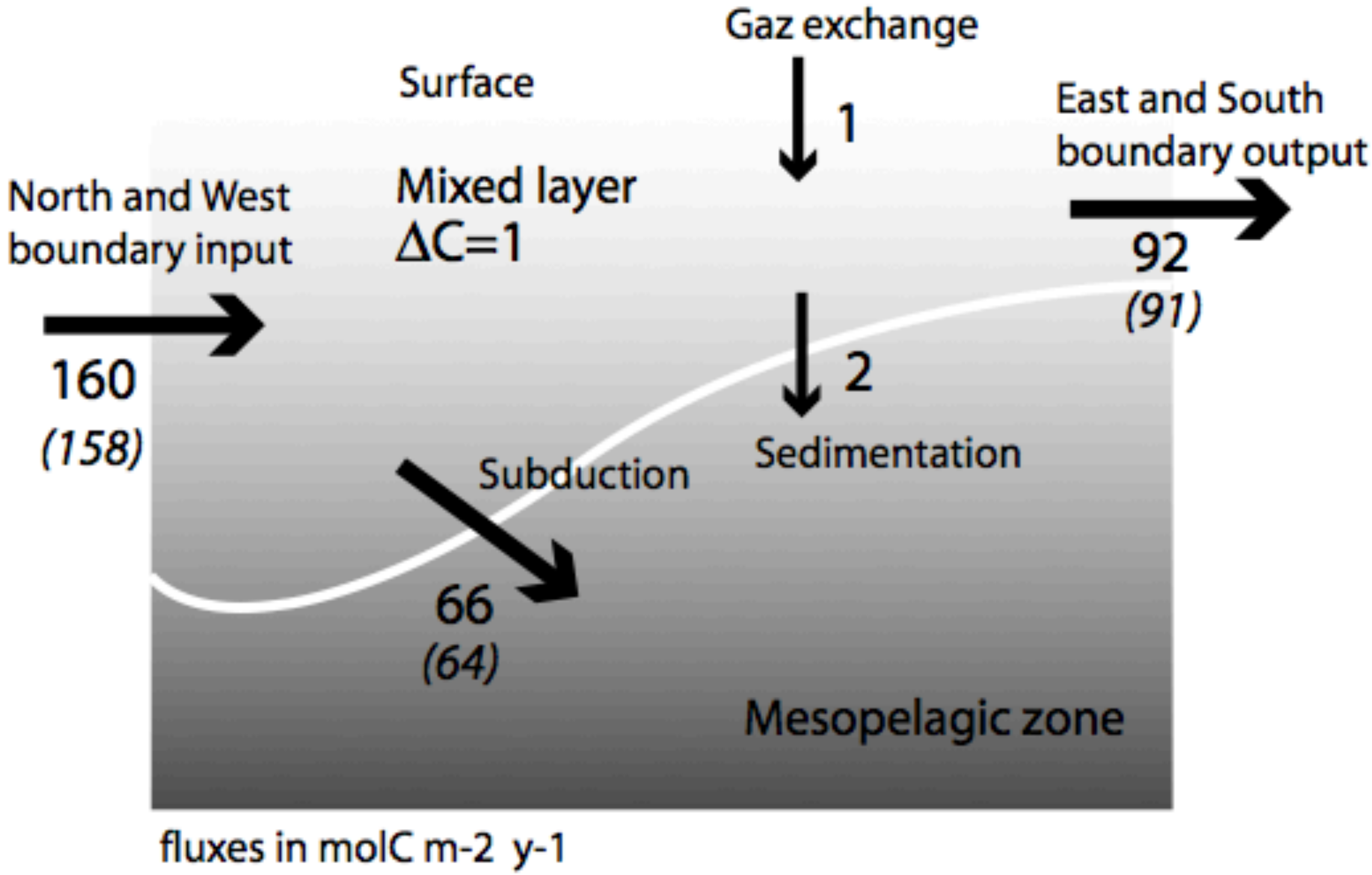


Subduction rate



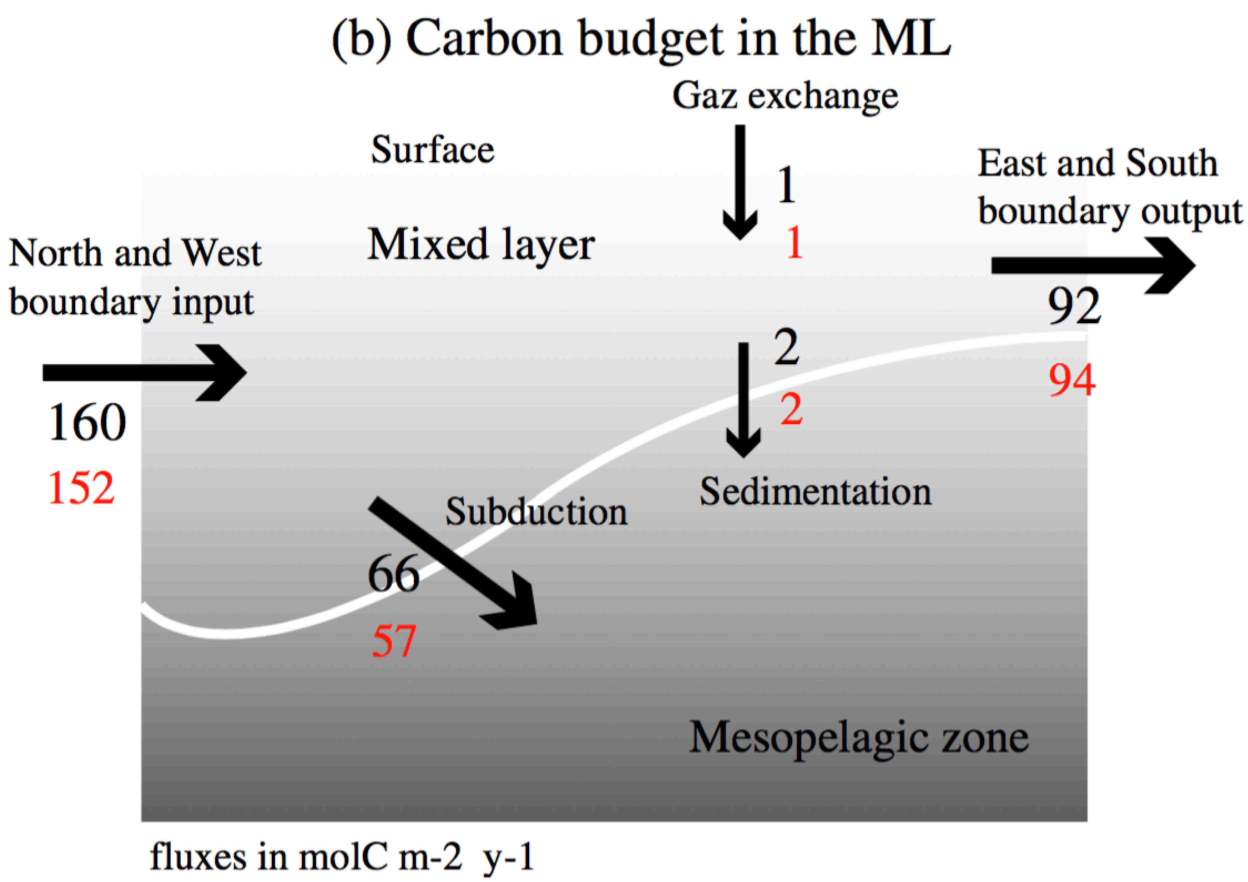
(e) Vertical velocity
Depth
Latitude
0
50
100
150
200
250
41.8
42
42.2
42.4
42.6
42.8
43
43.2
1026.85
1026.8
1026.85
1026.9
1026.95
1027
1027.05
30
20
10
0
−10
−20
−30

Carbon flux estimates from the model



Carbon penetration in the eddy simulation:
96 % subduction of DIC
2 % subduction of Organic carbon
2 % sedimentation of Organic carbon

Carbon flux estimates from the model



Carbon penetration in the non-eddy simulation (red):
10 % less subduction of DIC
10 % less subduction of Organic carbon
No change sedimentation of Organic carbon

CONCLUSIONS

- At temperate latitudes, more than 90% of the carbon flux to the deep ocean due to subduction of DIC, the rest by sedimentation
- 1/3 organic carbon export is through subduction, 2/3 by sedimentation (without contribution of submesoscales)
- Canth air-sea flux and Canth penetration are close in magnitude but do not occur at the same location

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- At temperate latitudes, more than 90% of the carbon flux to the deep ocean due to subduction of DIC, the rest by sedimentation
- 1/3 organic carbon export is through subduction, 2/3 by sedimentation (without contribution of submesoscales)
- Canth air-sea flux and Canth penetration are close in magnitude but do not occur at the same location
- Contribution of submesoscales to the export of DIC, DOC, POC and Canth ?
- Vertical structure of the physical export ?
- Interplay between the changes in physical fluxes and of the biological pump efficiency ?