Physical mechanisms driving the global ocean breathing

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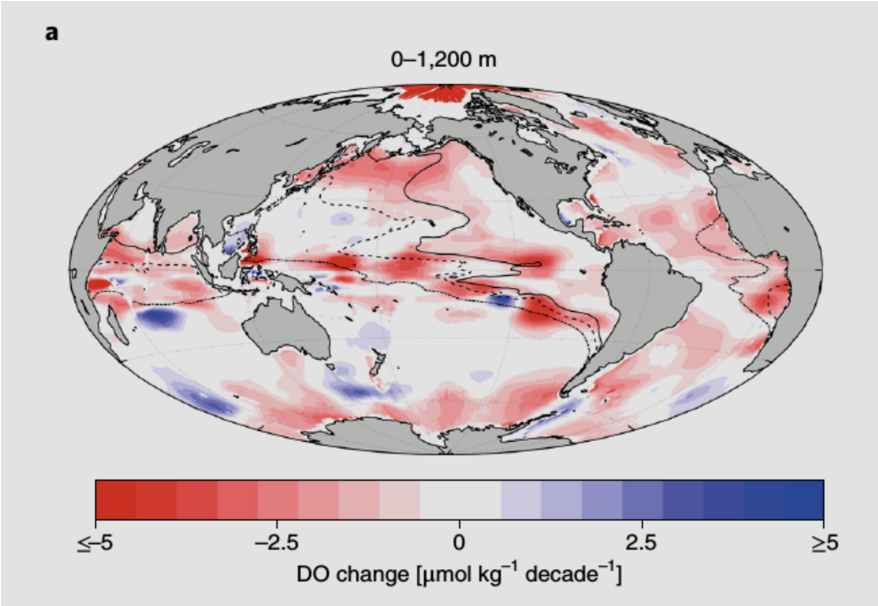
1. Introduction

- Global ocean deoxygenation has been observed over the past decades

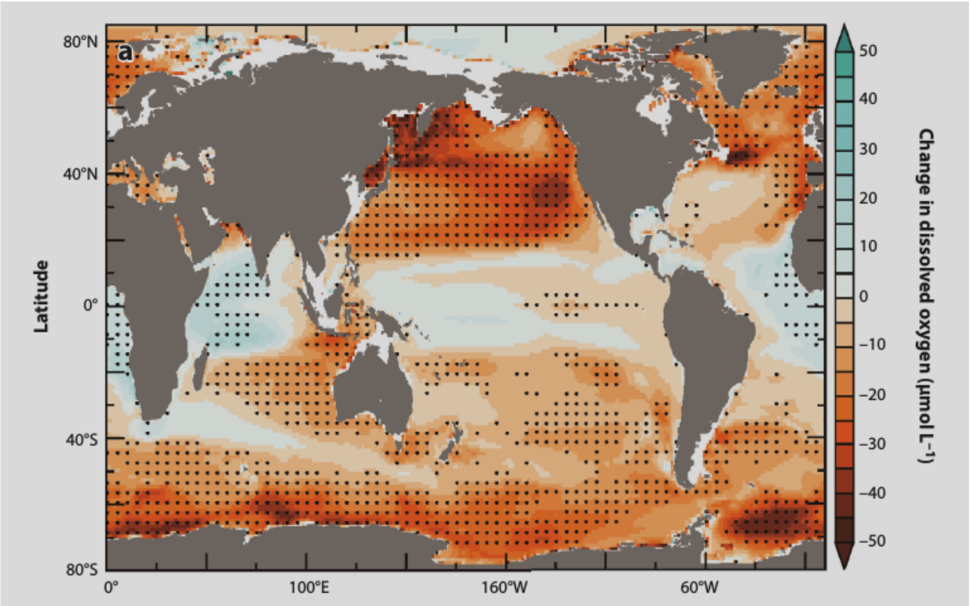
  (Schmitdko et al, 2017, Oschlies et al, 2018)



Dissolved Oxygen change between 1960-2010

- Deoxygenation is predicted by climate models to increase over the 21st century

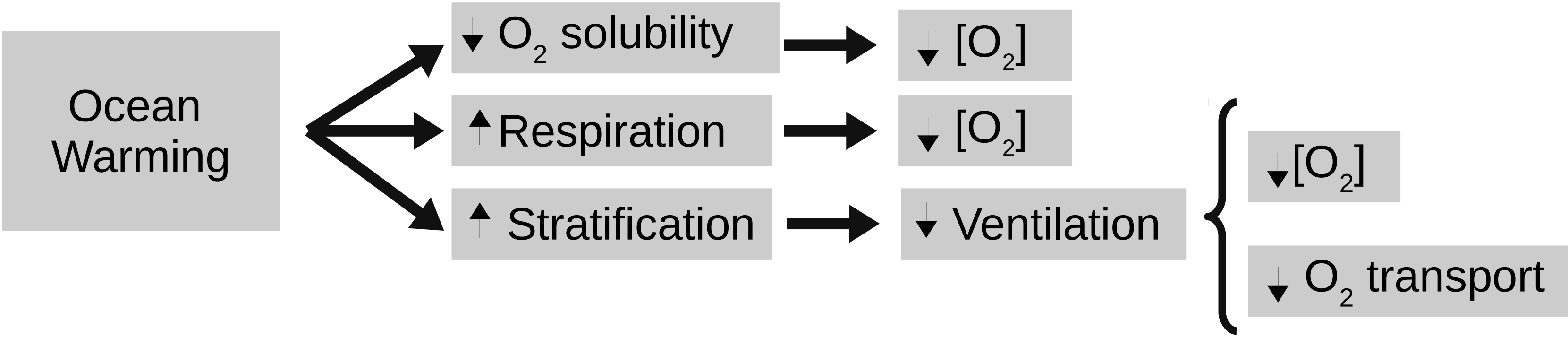
  (Bopp et al.,2013)



Dissolved Oxygen change predicted between 1990-2100

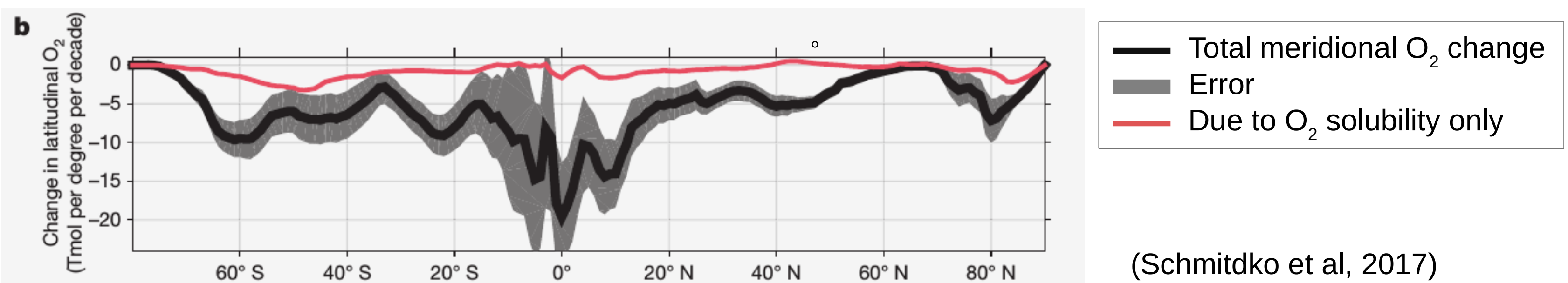
Which are the physical mechanisms driving the ongoing and future ocean deoxygenation?

1. Introduction



1. Solubility:

It is thought not to be key in the global ongoing and future ocean deoxygenation



(Schmitdko et al, 2017)

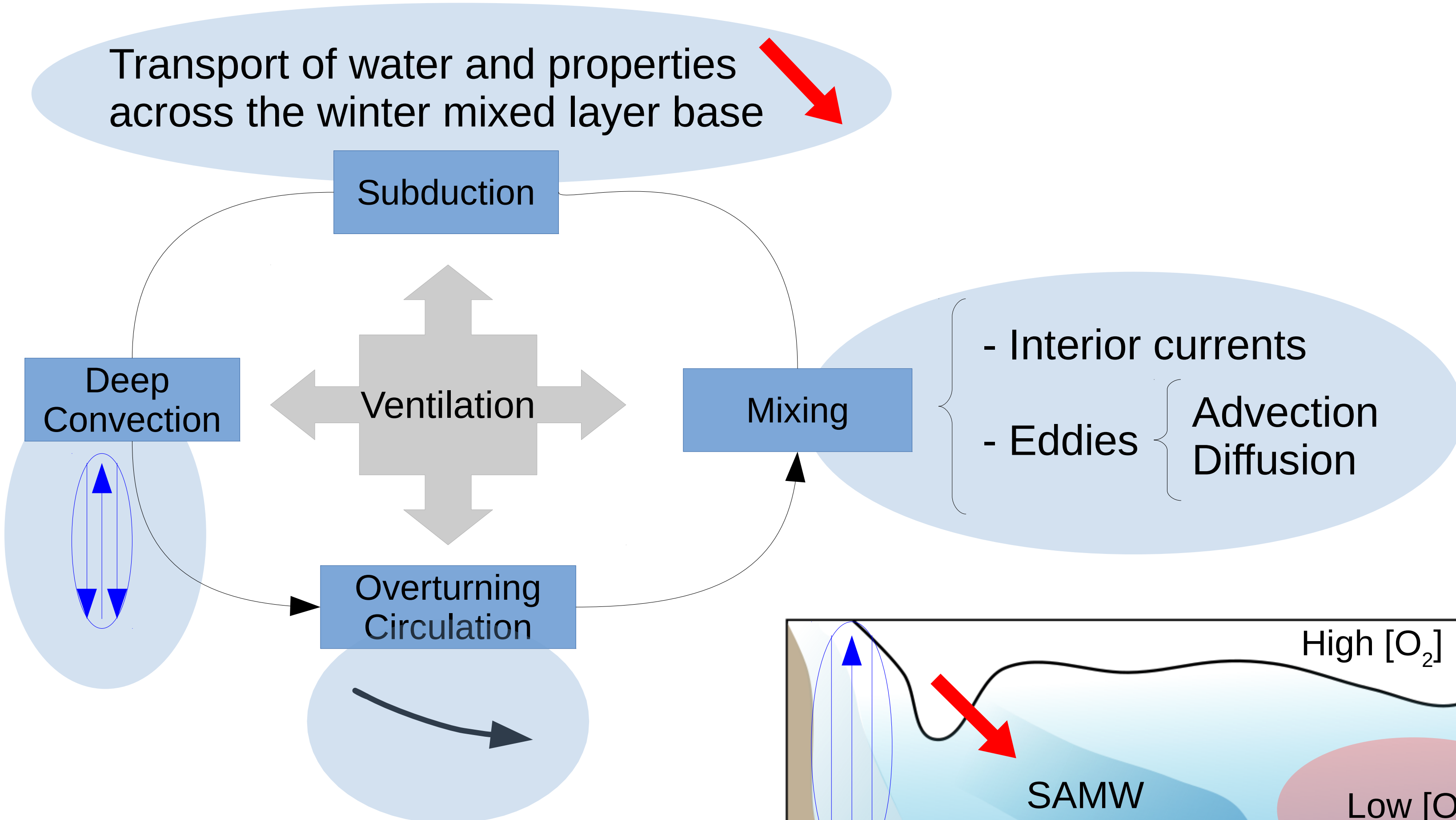
2. Respiration:

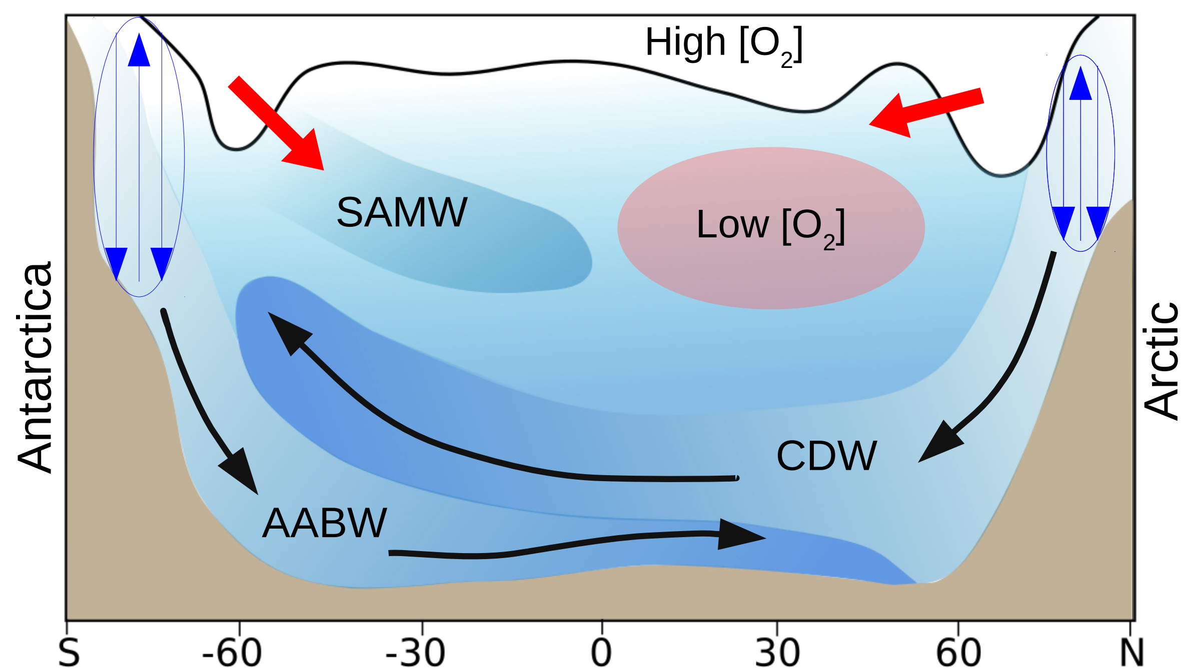
It has been suggested to be important. For example, a 5ºC rise might shift Arctic phytoplankton from net autotrophy to net heterotrophy, with resulting oxygen loss.

3. Ventilation: The focus of this study

A reduced ventilation has been suggested to be the main consequence of the increased stratification due to the global warming

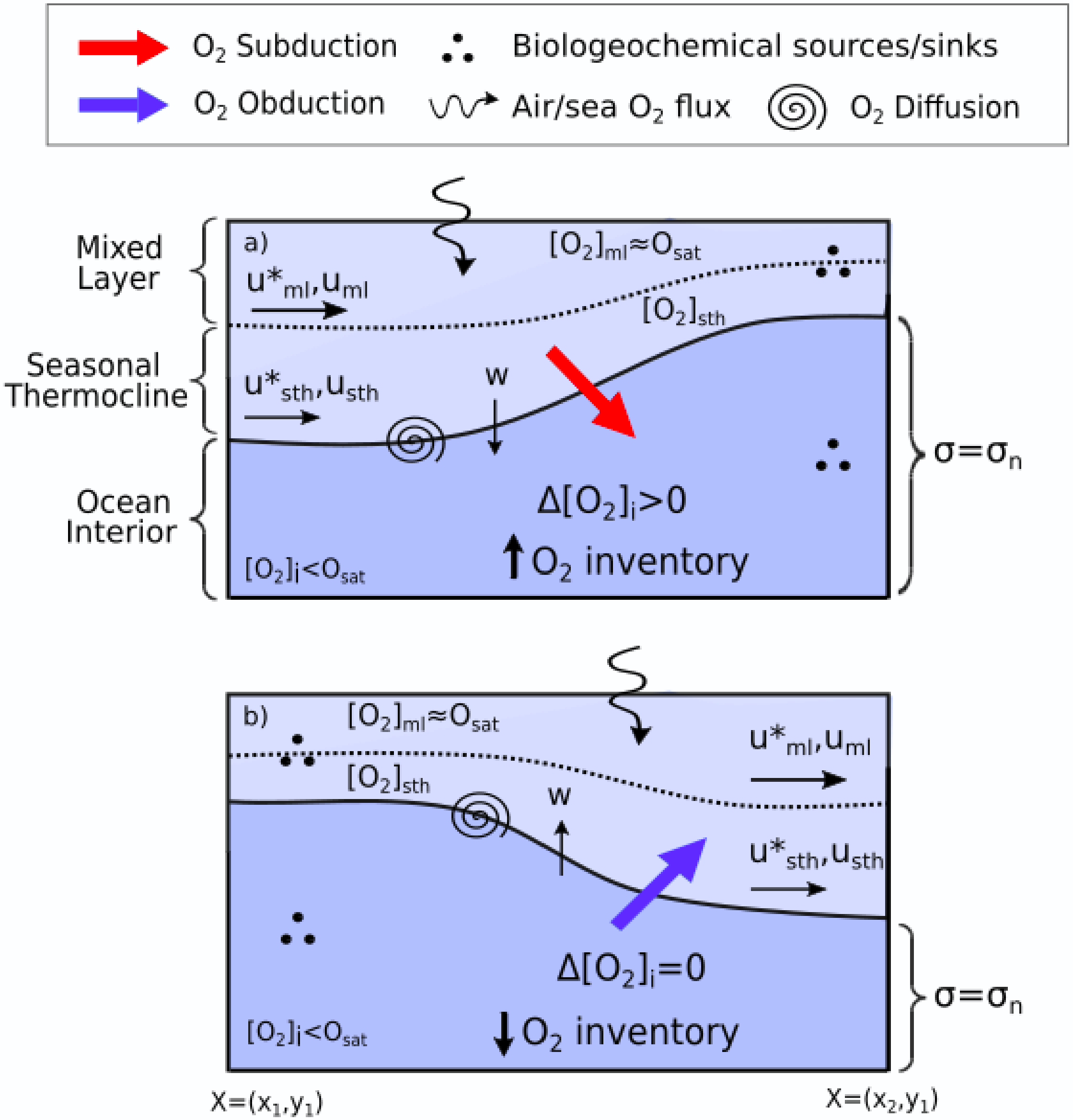
Ventilation-related mechanisms





These mechanisms play a role in the interior ocean ventilation

Oxygen Subduction



U: Geostrophic velocity
U*: Eddy (bolus) velocity
sth: seasonal thermocline
ml: mixed layer

O_2 Subduction : flux of O_2 into the permanent thermocline
- Increase the $[O_2]$
- Increase the O_2 inventory

O_2 Obduction : flux of O_2 into the mixed layer
- No change in the $[O_2]$
- Decrease the O_2 inventory

Only Subduction can change the interior $[O_2]$!

2. Methods: Computation of permanent oxygen subduction (S^{ox})

$$\underbrace{S^{Ox}(x,y)}_{O_2\,Subduction}=\underbrace{[O_2](-U_H\cdot\nabla_h H)}_{lateral\,induction}+\underbrace{[O_2](-w_H)}_{vertical\,v}+\underbrace{[O_2](-\nabla_h(U_H^*))}_{eddy-induced}+\underbrace{k_v\nabla_v[O_2]_h+k_l\nabla_l[O_2]_h\cdot\nabla_l H_{max}}_{Diffusion}$$

H: Steady winter mixed layer base
U: Horizontal velocity
U*: Horizontal bolus (eddy) velocity
K_v: Vertical diffusion coefficient (10^{-4} m^2 s^{-1})
K_l: lateral diffusion coefficient (10^2 m^2 s^{-1})

NOTE:The two extreme values for diffusion and resulting oxygen subduction were computed with the minimum and maximum diffusion coefficients (k_v=10^{-5} – 10^{-4} m^2 s^{-1} and k_l=10^2 – 10^4 m^2 s^{-1})

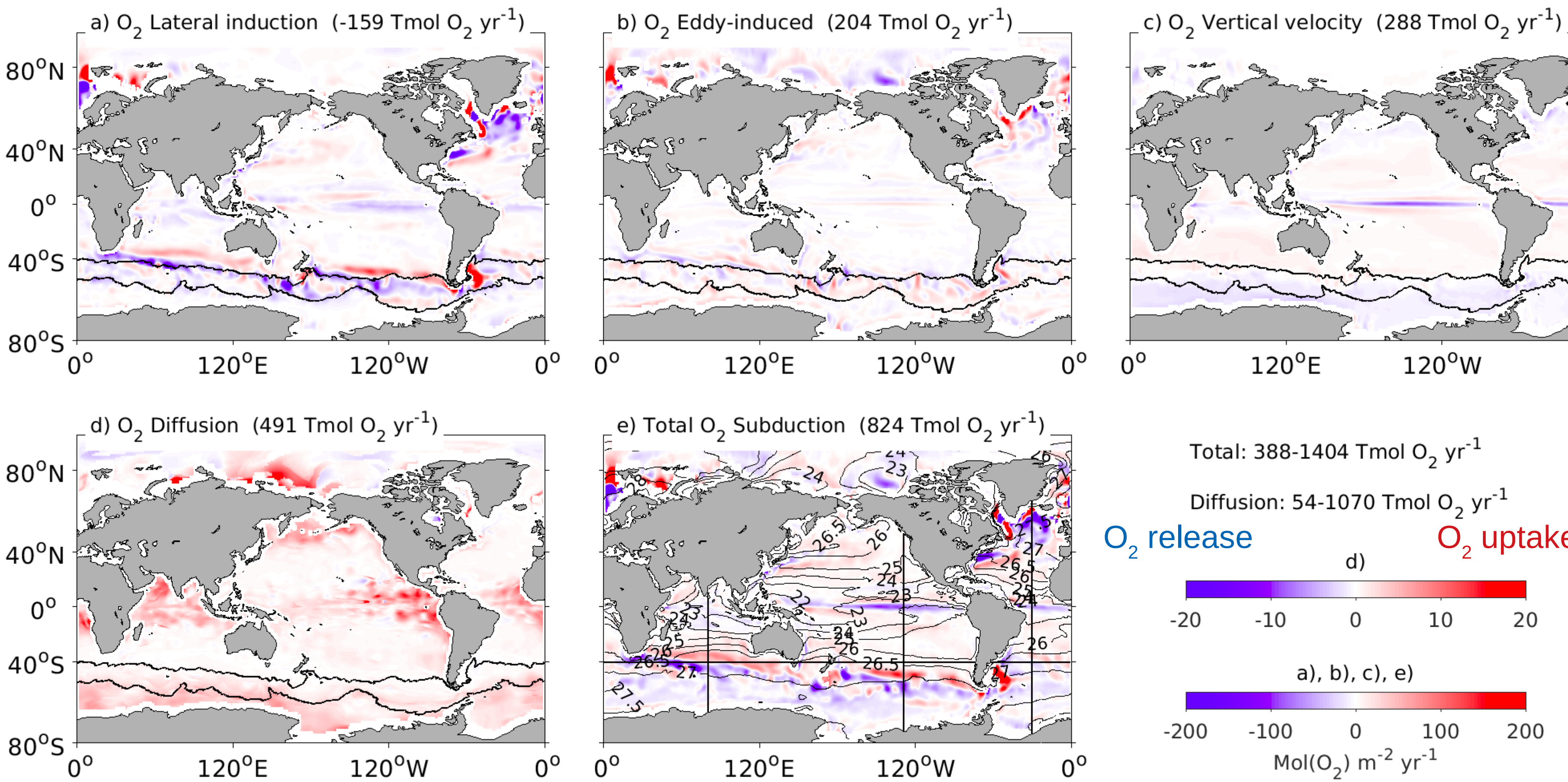
Data:

Subduction: Computed from monthly climatological fields obtained from ECCOv4r3

Oxygen: Monthly Climatological fields from WOA18

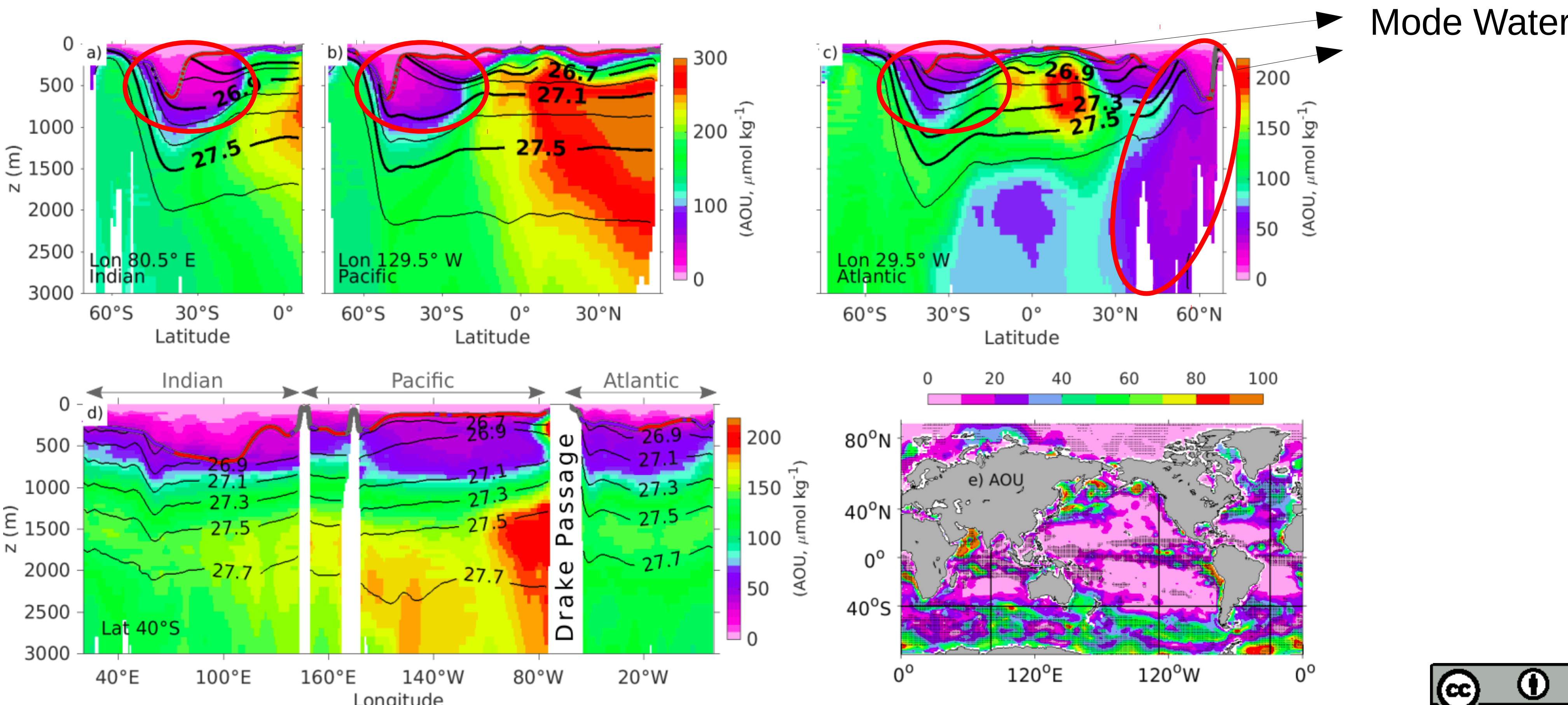
3. Results : Oxygen Subduction ans its components

- Numbers in the panel's top indicate the integrated O_2 flux due to each subduction term
- NOTE: Minimum and maximum diffusion and resulting S^{ox} are shown in the bottom right panel



Vertical sections of AOU that roughly approximates water age :

- Subductive regions (red dots on the mixed layer base) show low interior AOU.
- Obductive regions (blue dots in (a-d) and shaded in e)) correspond with older interior waters (higher AOU).
  - The ACC advection (d) causes a rapid circumpolar redistribution of oxygenated waters

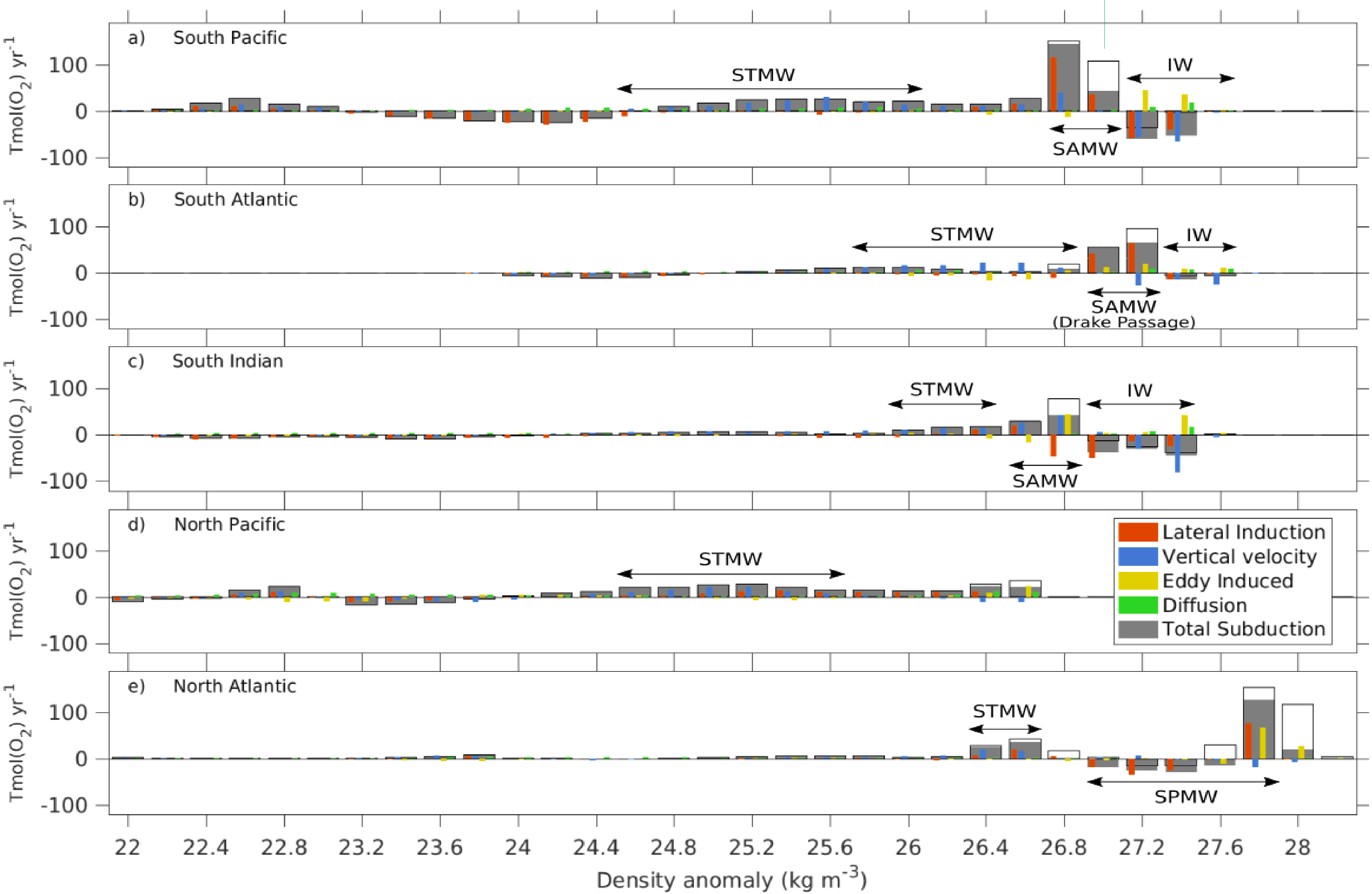


3. Results : Oxygen Subduction in density classes

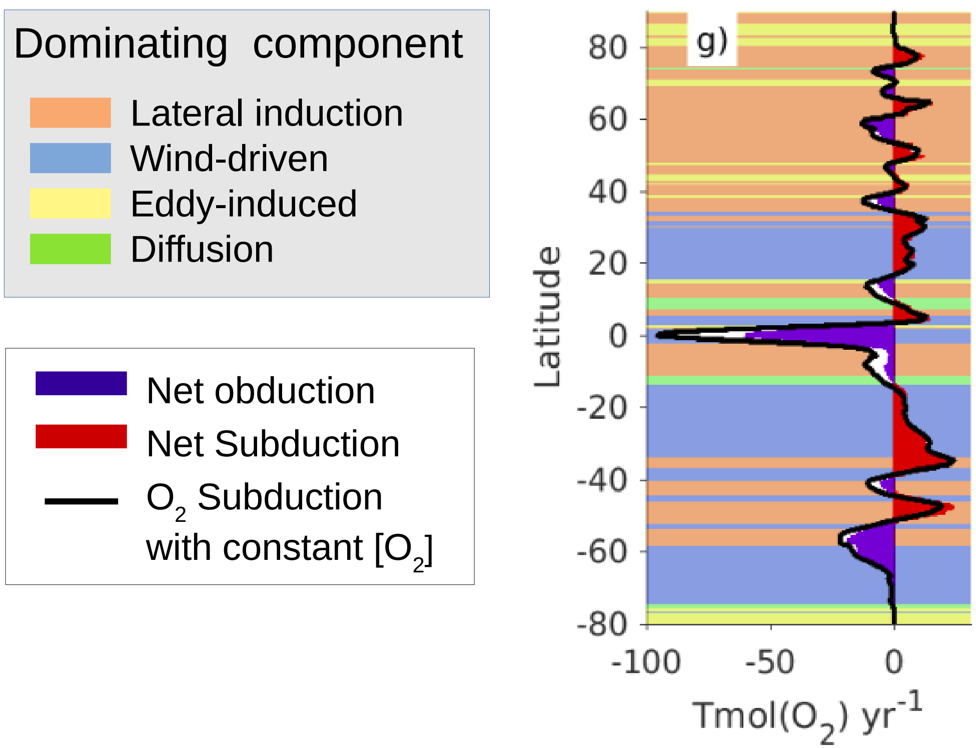
STMW: Subtropical Mode Water
SPMW: Subpolar Mode Water
IW: Intermediate Water

Total subduction with maximun diffusion

Enhanced oxygen uptake when maximum diffusion is applied

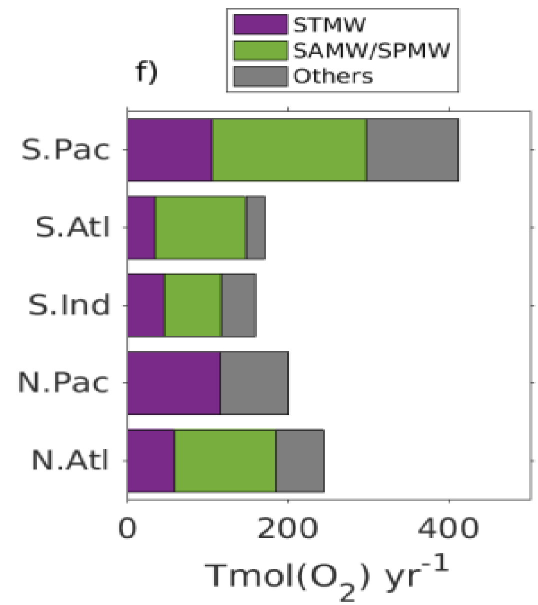


3. Results: Zonal average of oxygen subduction



- Lateral induction: dominates in the SAMW formation sites
- Wind-driven vertical velocity: relatively weak but homogeneous, dominates in the subtropical gyres where SPMW is formed.
- O_2 flux is dominated by the associated mass flux rather than by the background O_2 spatial distribution

Oxygen uptake by Mode Waters



Mode Waters outcropping surface occupies 36 % of the global ocean

But they account for ~70 % of the global oxygen uptake

4. Discussion

- **The Southern Ocean and the northern North Atlantic are the lungs of the Ocean where oxygen is provided:**
  - (i) to intermediate depths after SAMW subduction
  - (ii) to the bottom ocean during the Bottom Water formation near Antarctica
  - (iii) to deep waters (Circumpolar Deep Water) as part of the Atlantic Meridional Overturning Circulation

Mode Water density outcrops occupy only 36% of the surface of the ML base but it account for 72% of the global oxygen uptake!

- **The relative contribution of the subduction mechanisms to the oxygen uptake is linked to water-mass formation processes and varies geographically**
  - Intense lateral induction in localized hot-spots drives SAMW and SPMW formation in subtropical-subpolar regions
  - the wind-driven vertical velocity dominates the O_2 uptake by the STMW in the Subtropical Gyres

The total oxygen uptake is regulated by physical mass flux while the spatial distribution of the [O_2] has a minor role.

4. Discussion

- **Diffusion could be key for the global (de)oxygenation since it is the main contributor of O_2 subduction at global scale, but with a large range of uncertainty**.
  - Recent studies (Sallée et al., 2012, Kwon et al., 2016) have shown negligible values of diffusion even by using the maximum k_v and k_l.
  - The difference between this and the other studies seems to be the deepes ECCOv4 mixed layer which results in stronger lateral diffusion

A decrease in the diffusive subduction has been suggested to be the main driver of the future ocean deoxygenation over this century (Couespel et al. 2019)

Diffusion can change the oxygen uptake in one order of magnitude, it needs to be carefully considered