Patterns of deoxygenation in the global ocean

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GO$_2$NE
Global Ocean Oxygen NEtwork

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SFB 754

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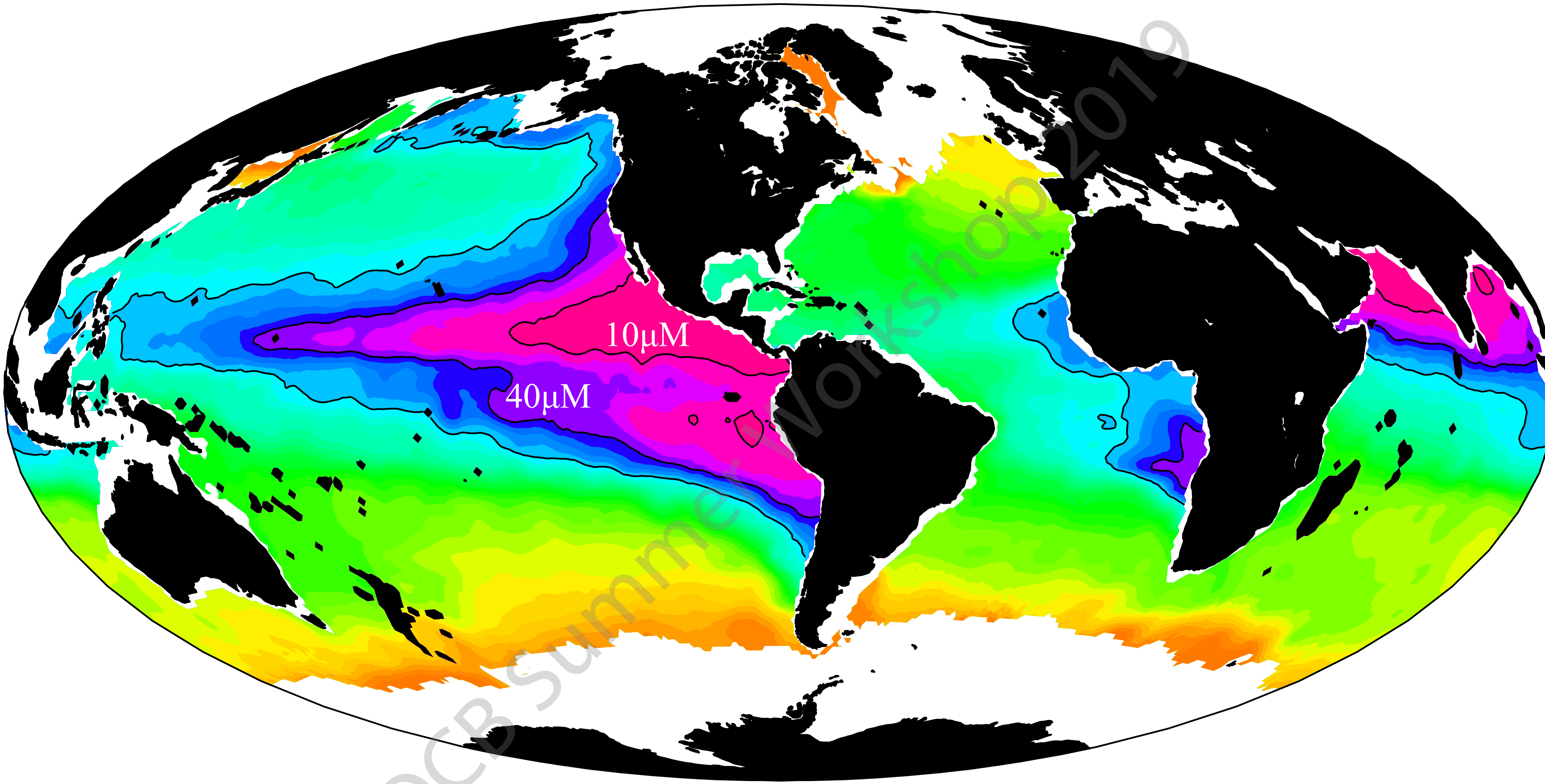
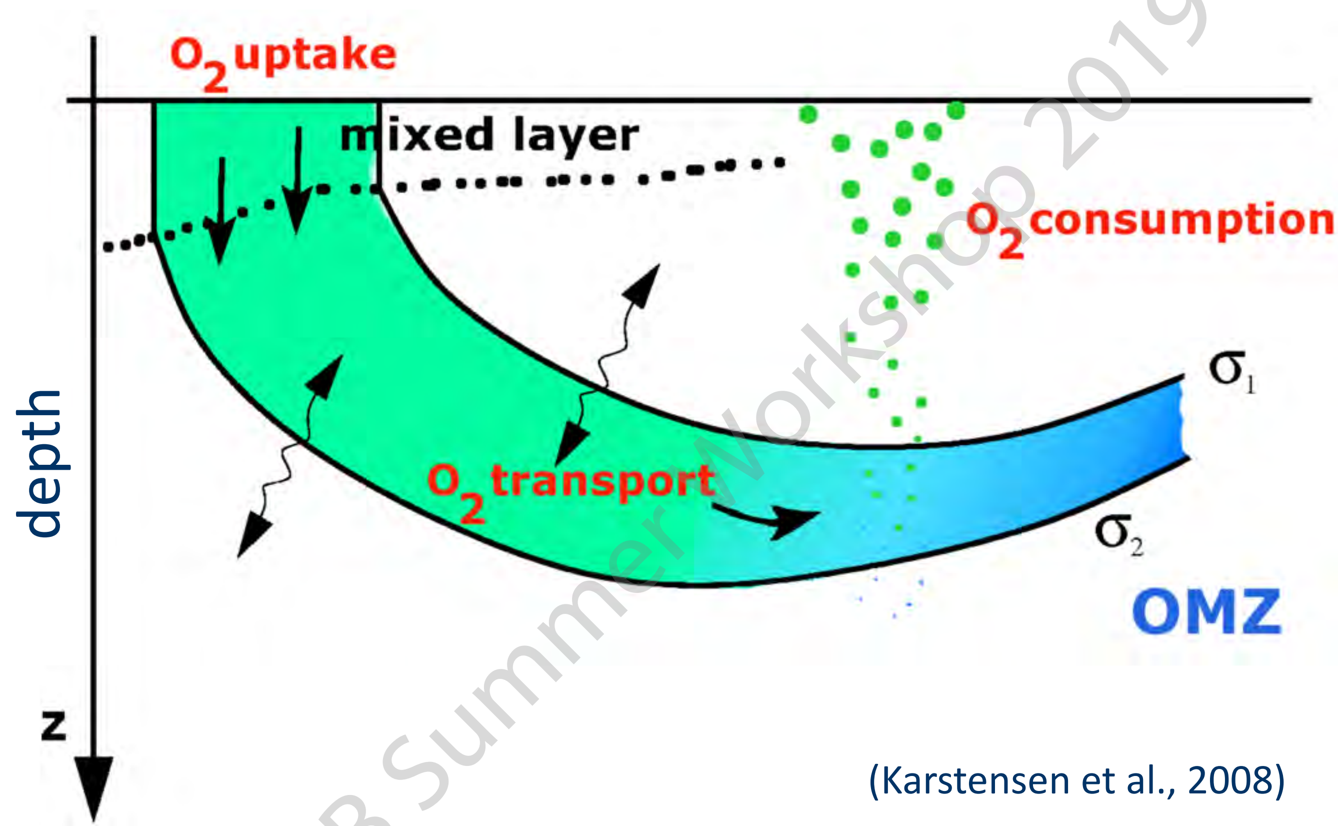
Dissolved Oxygen in the Ocean



O_2 on $\sigma=26.9$ isopycnal (upper ocean, 0-400m)

Atmospheric inventory 37.500 Pmol	2.3% "CO_2" 97.7%	Oceanic inventory 227 Pmol
	99.4% O_2 0.6%	

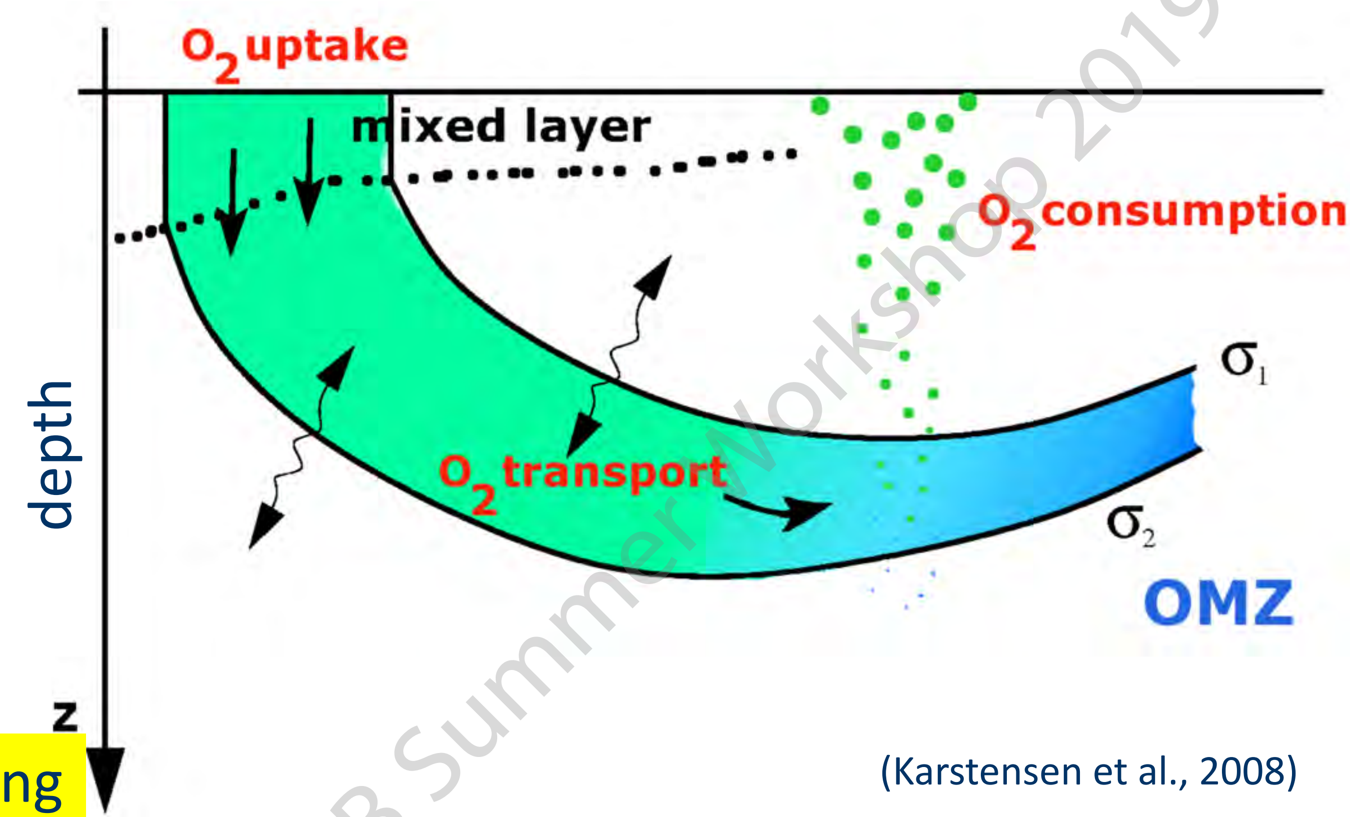
Schematic picture of O_2 cycling



(Karstensen et al., 2008)

- O_2 uptake: Gas exchange with atmosphere
- O_2 transport: supply via vertical mixing & circulation
- O_2 consumption via respiration of organic matter

Schematic picture of O_2 cycling



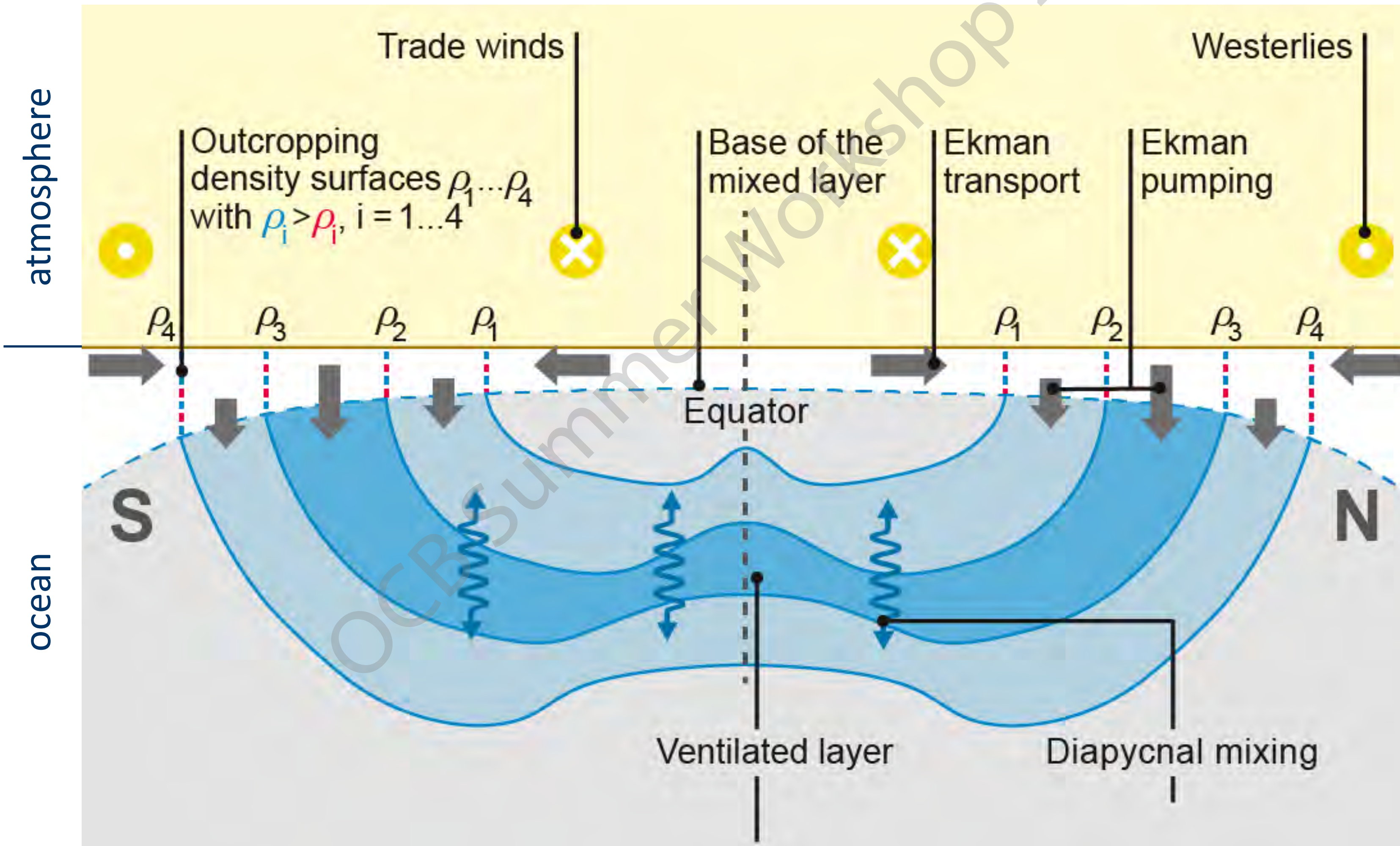
(Karstensen et al., 2008)

warming

- O_2 uptake: Gas exchange with atmosphere
- O_2 transport: supply via vertical mixing & circulation
- ? O_2 consumption via respiration of organic matter

Subtropical thermocline

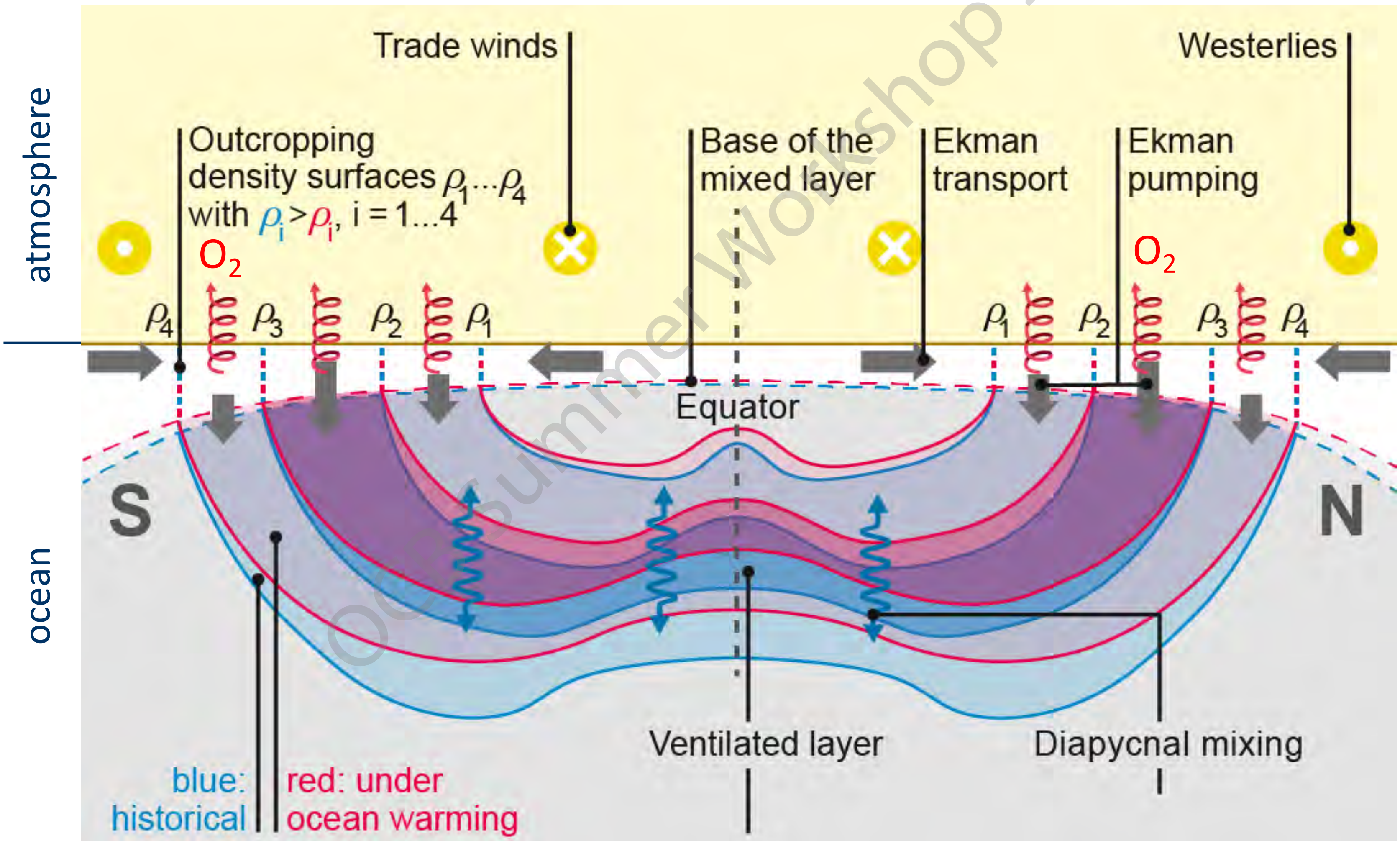
zonally averaged view of the upper ocean



(Oschlies et al., Nat.Geosci., 2018)

Effects of warming

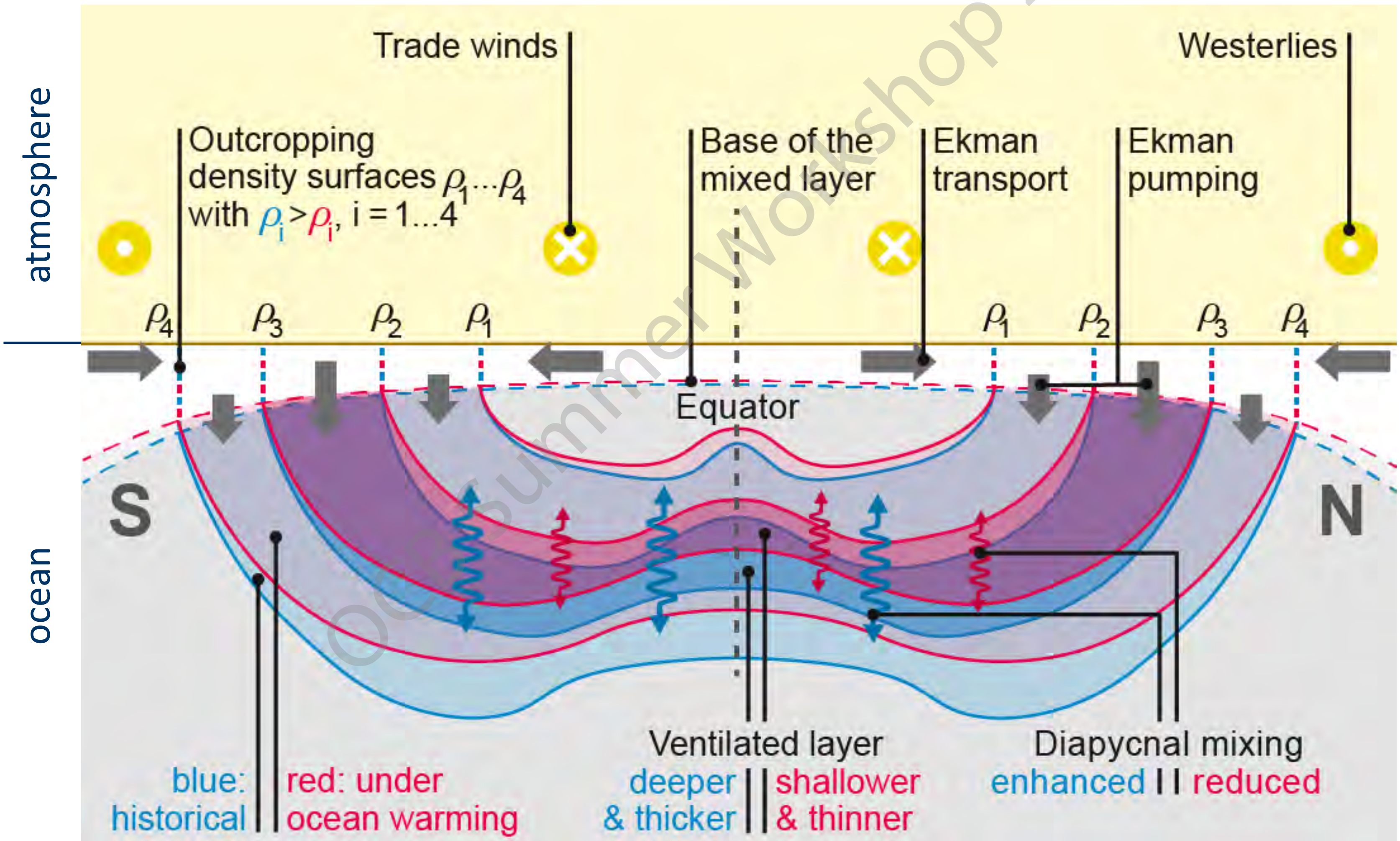
Drop in solubility, enhanced stratification



(Oschlies et al., Nat.Geosci., 2018)

Effects of warming

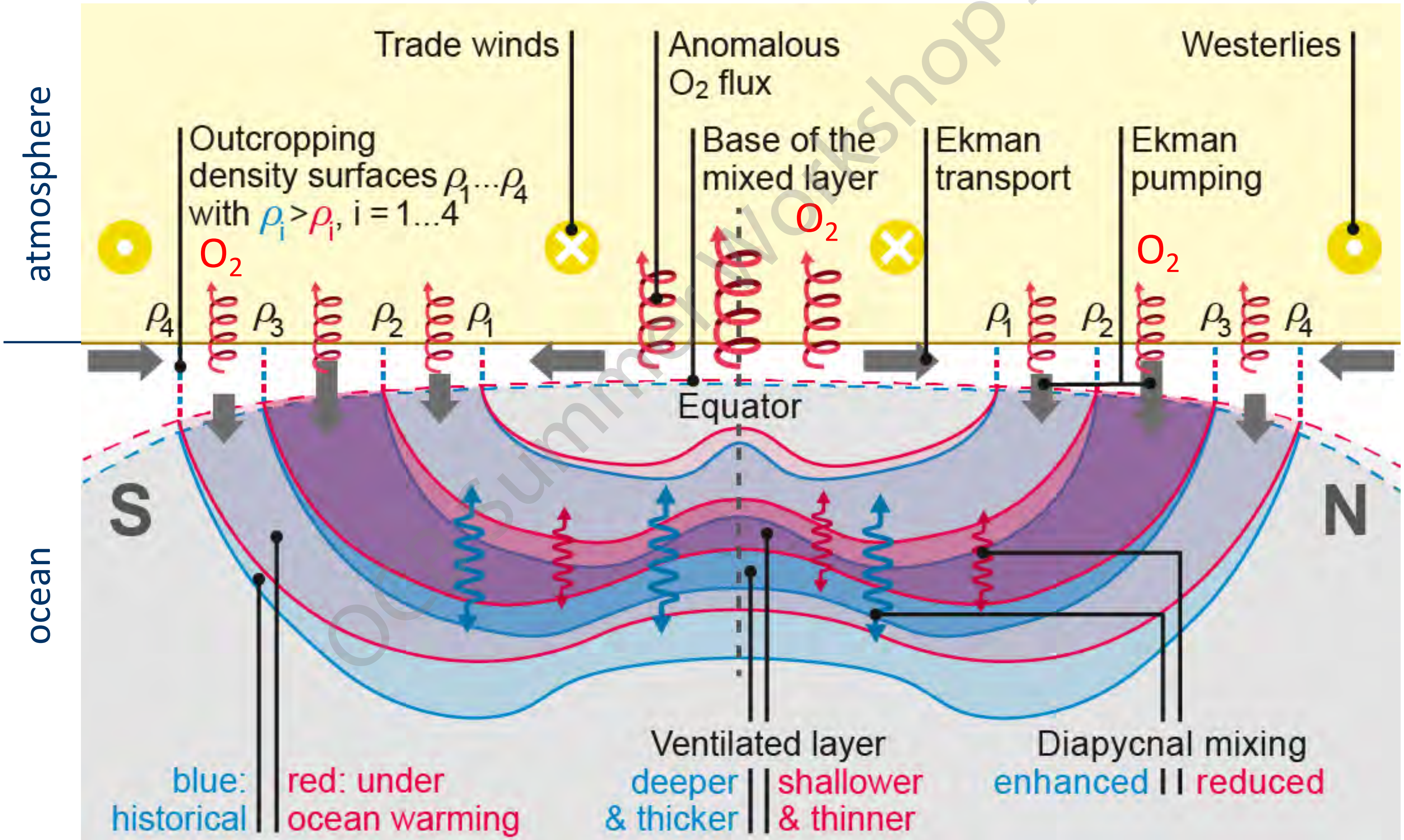
enhanced stratification, reduced mixing



(Oschlies et al., Nat.Geosci., 2018)

Effects of warming

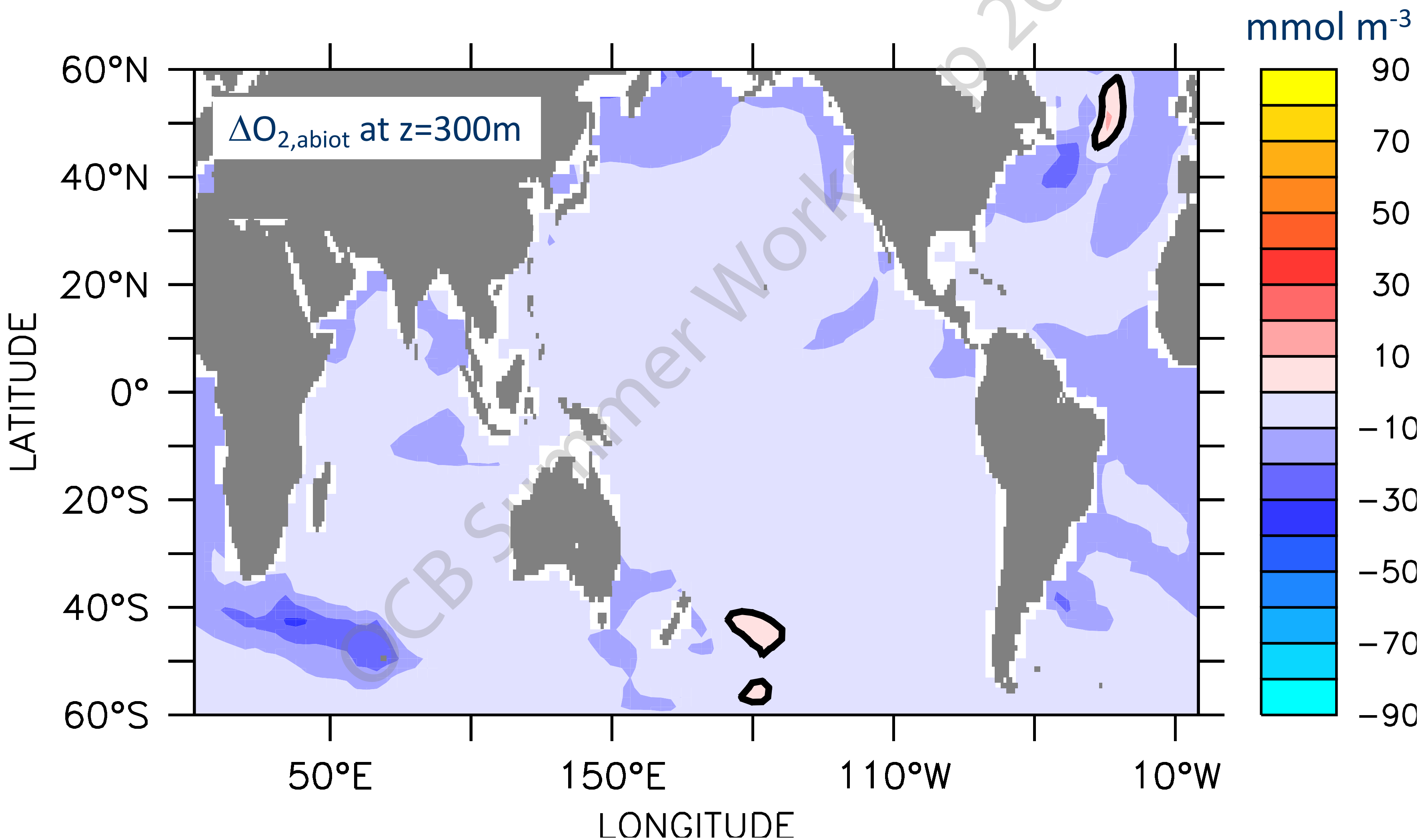
shallower thermocline → faster ventilation, less mixing, more oxygenated waters



(Oschlies et al., Nat.Geosci., 2018)

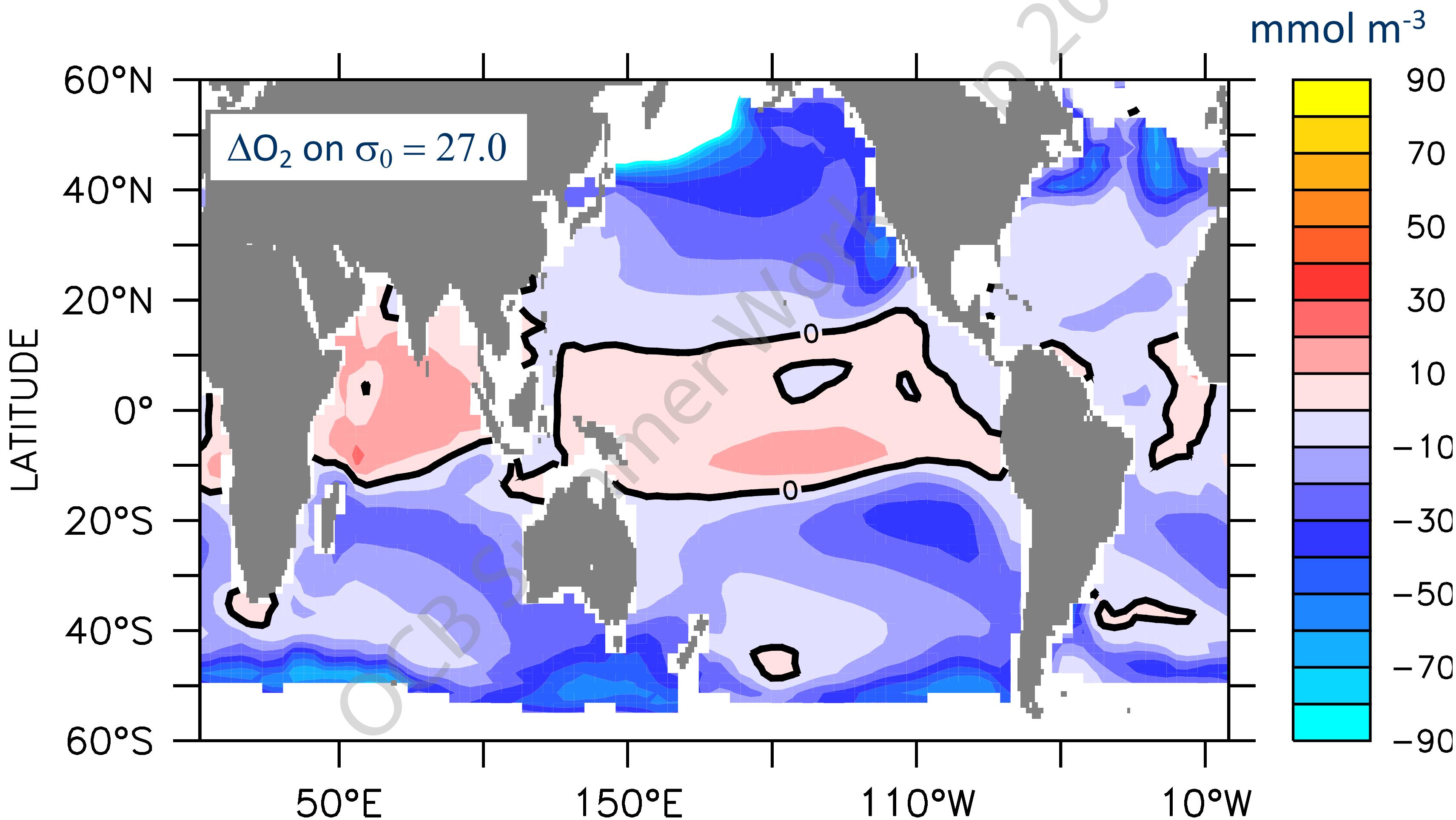
Effects of warming

“Abiotic O_2” in tropical thermocline (yr 2100 – 1990)



Effects of warming

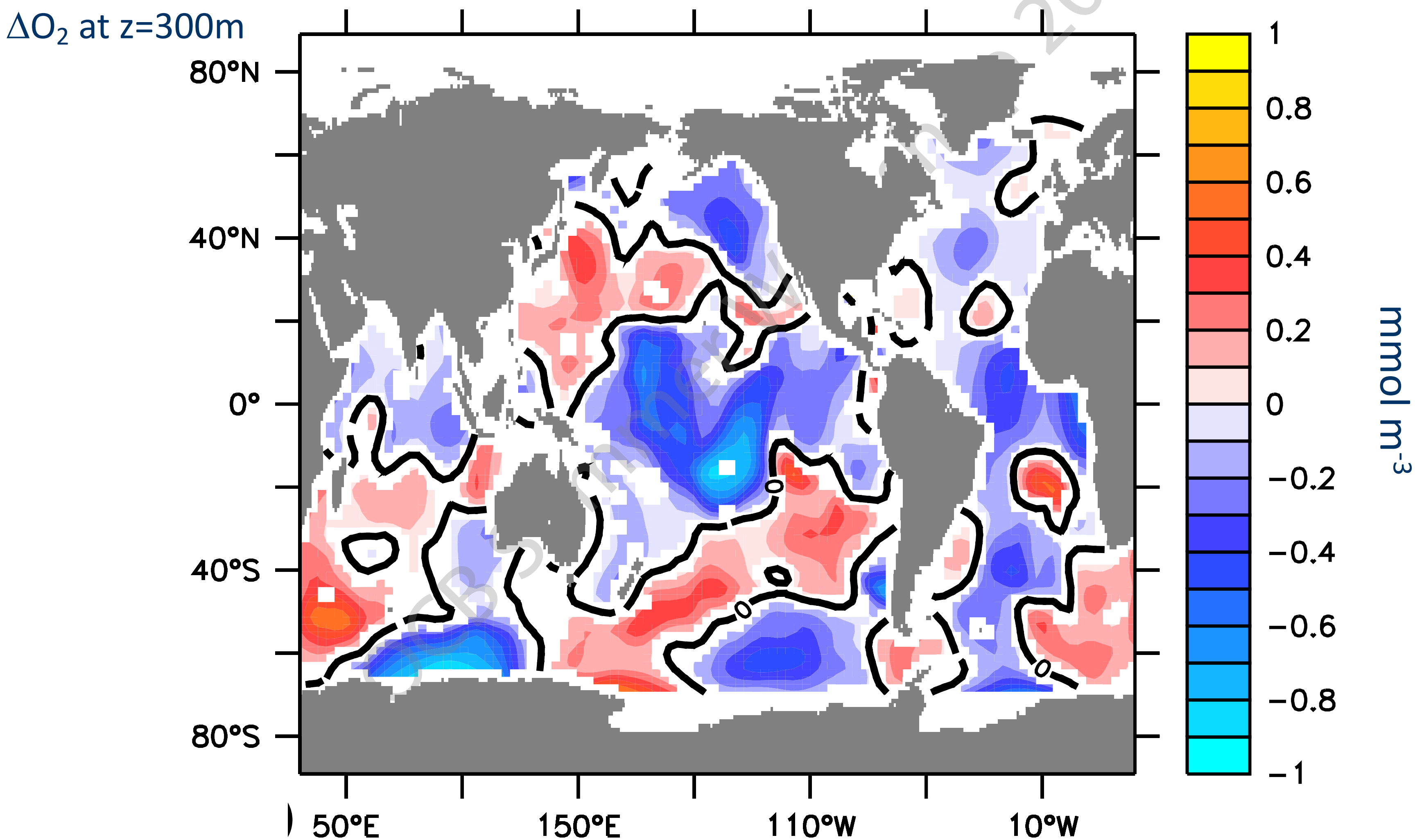
Elevated O_2 in tropical thermocline (yr 2100 – 1990)



(Oschlies et al., GBC 2008; also Takano et al., GBC 2018; less pronounced in NCAR large ensemble, Long et al., GBC 2016)

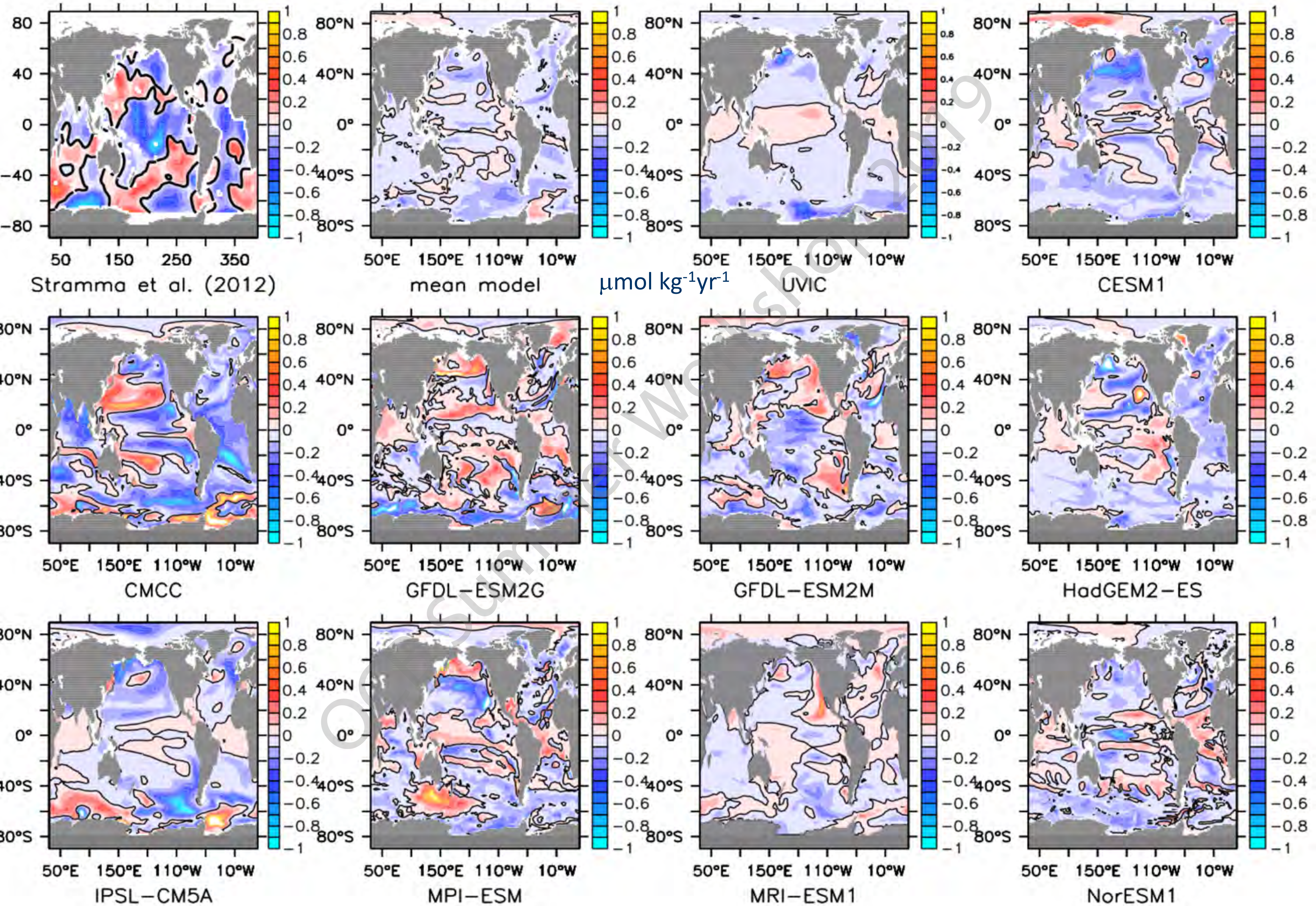
What do the data say?

Declining O_2 in tropical thermocline (yr 2010 – 1960)

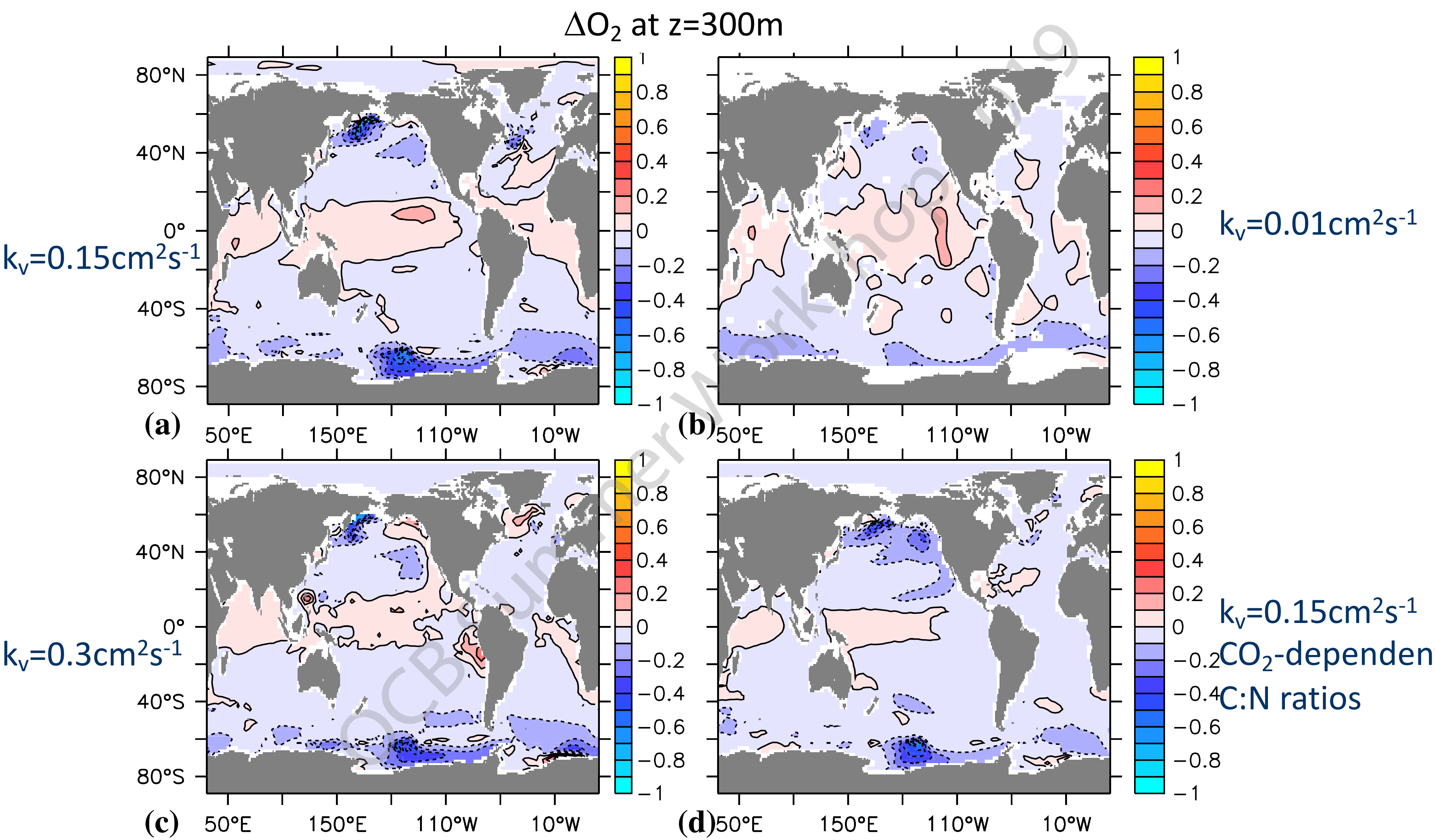


(Stramma et al., BG 2012)

Observational pattern estimate & simulated CMIP5 model patterns



Diapycnal mixing? (UVic, 1960-2010)



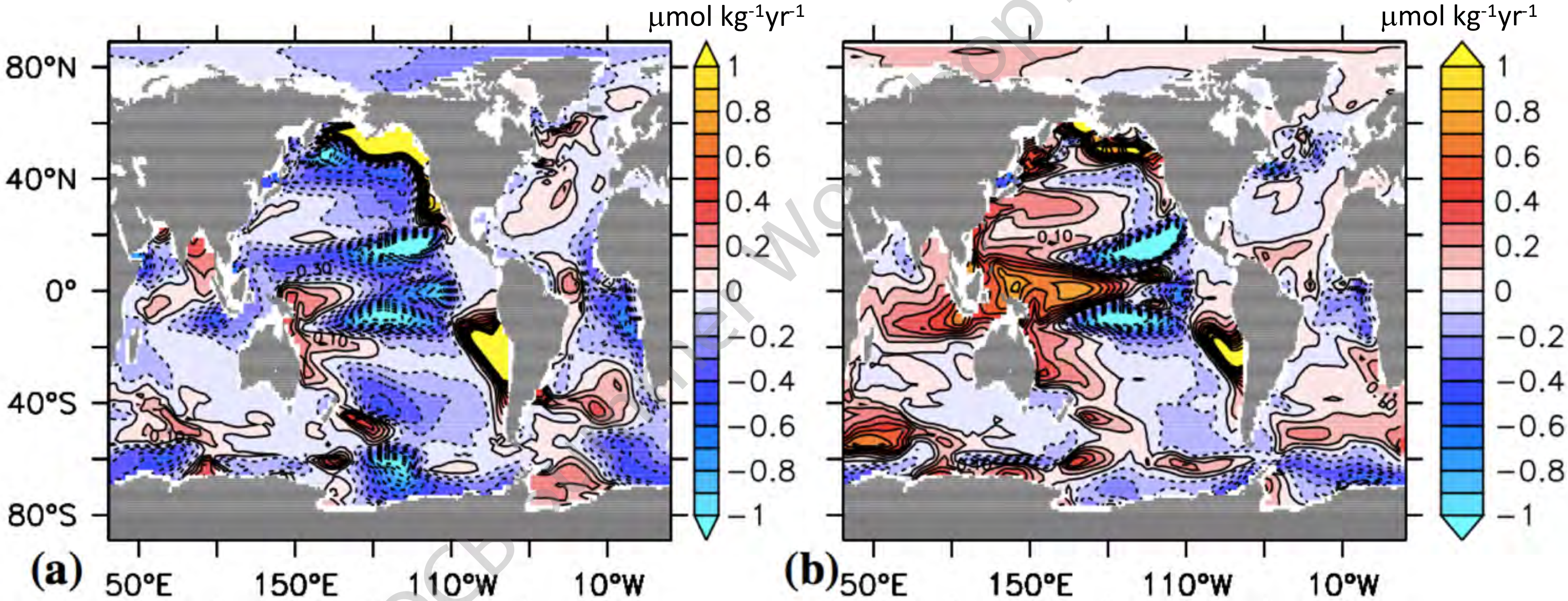
(Stramma et al., BG 2012; also: Bahl et al., GBC 2019)

All model configurations show O_2 increase in tropical thermocline!

Pronounced impact of winds!

ΔO_2 at z=300m (2010 – 1960)

Identical forcing with CORE winds **after** 1958



NCAR/NCEP climatology **prior** to 1958

CORE climatology **prior** to 1958

(Stramma et al., BG 2012)

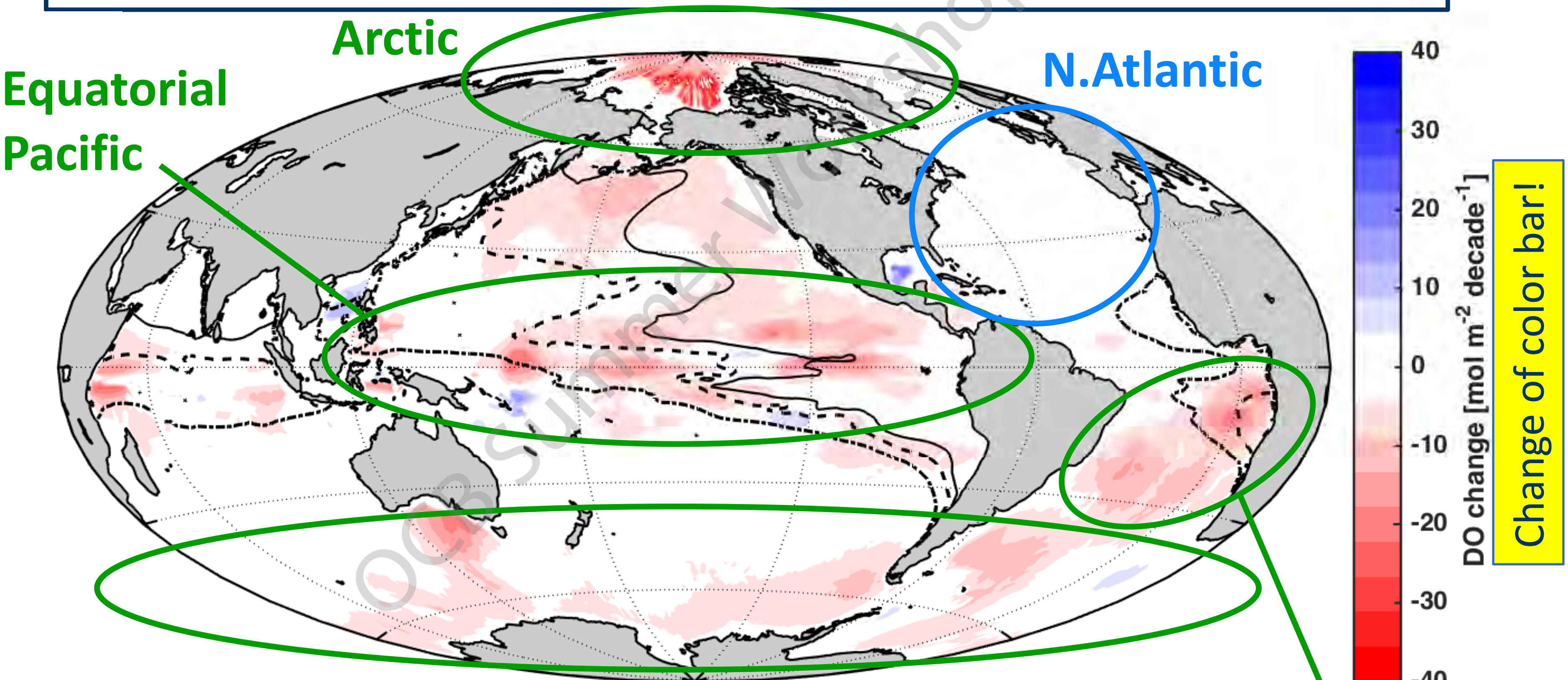
Legacy of winds prior to 1960s!

Conclusions (i)

- Observed deoxygenation in the tropical thermocline still not fully understood.
  - Likely not driven by warming (at least not directly)
  - Wind changes play dominant role
  - Natural and anthropogenically forced variability

Total oxygen change (1960-2010)

Observational estimate:
Oceanic O_2 loss: ~1 Pmol/decade
i.e. ~2 % during past 50 years.



vertically integrated O_2 change

(Schmidtko et al., Nature 2017)

Oxygen change (1960-2010)

Observational estimate:

Oceanic O_2 loss: ~1 Pmol/decade

What do the models say?

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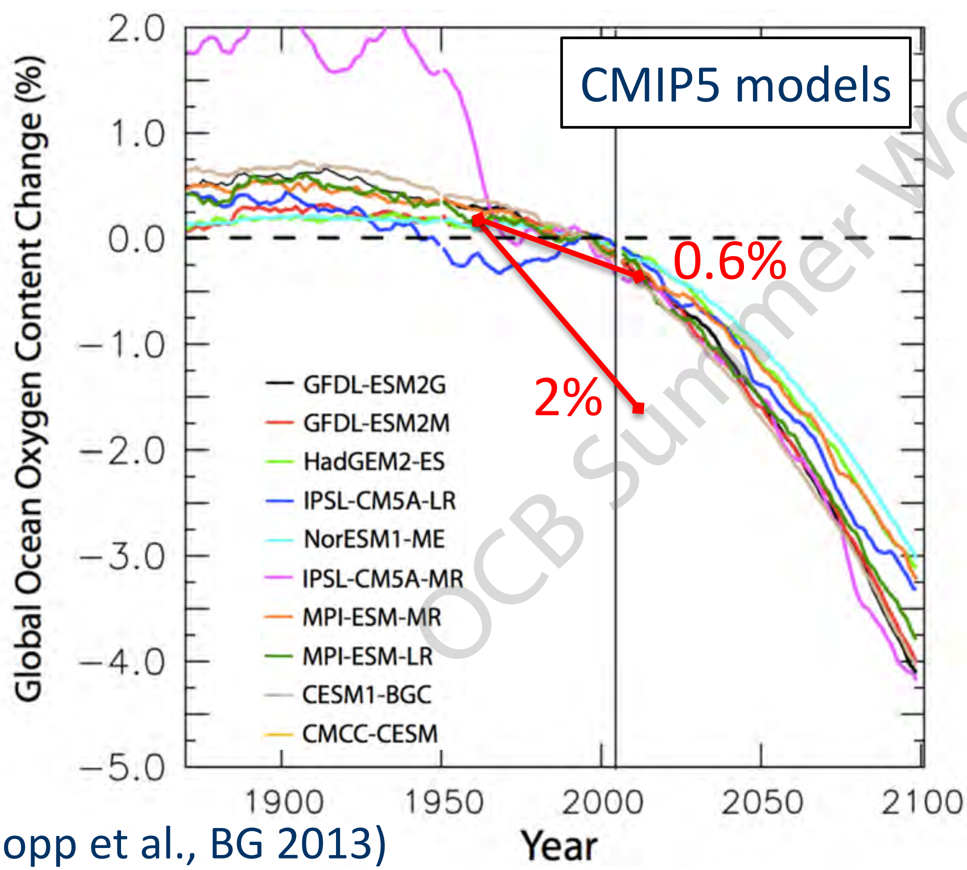
What do the models say?

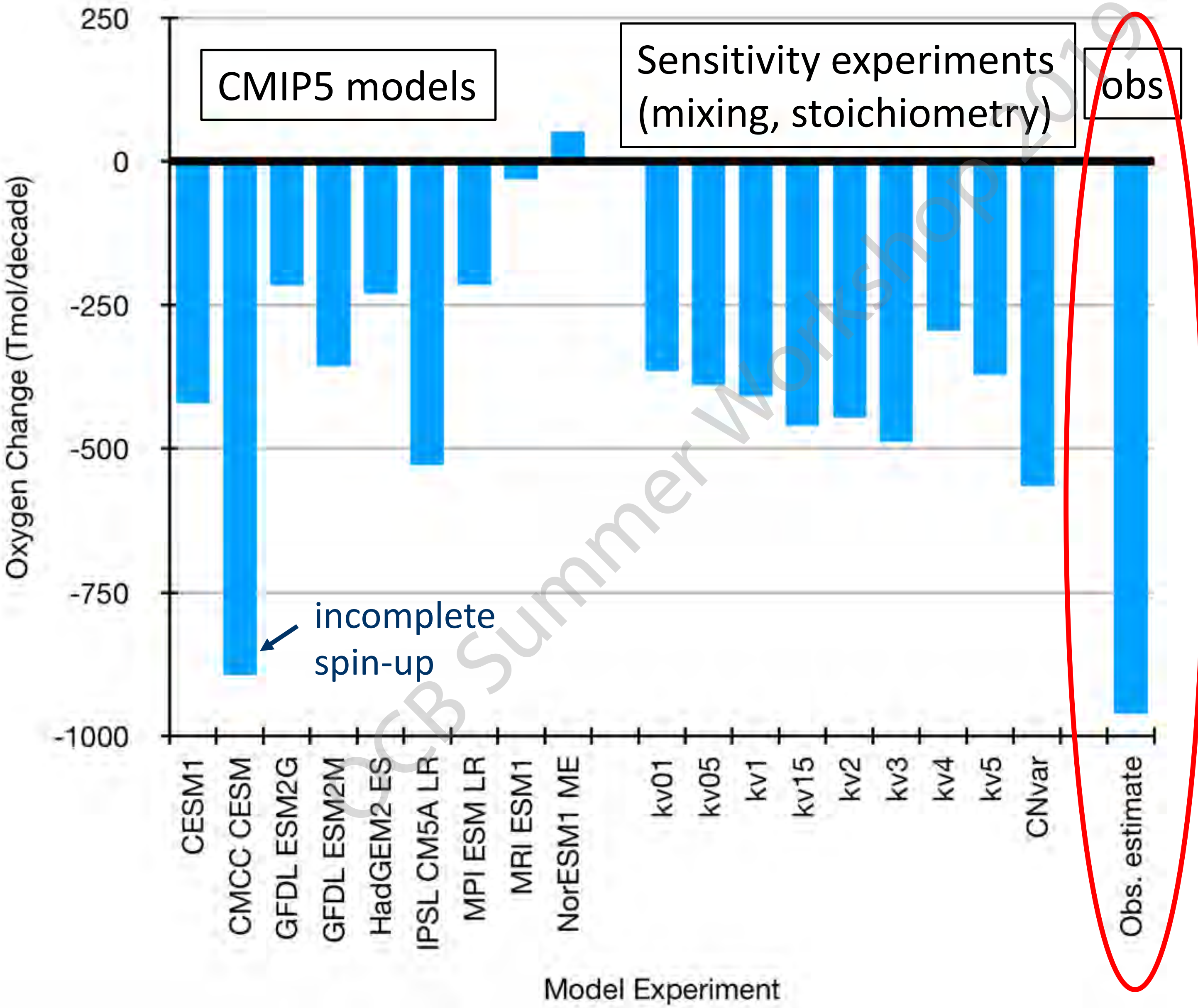


(Bopp et al., BG 2013)

O_2 loss in CMIP5 models:
~0.3 Pmol/decade.
(0.12 Pmol/decade in NCAR large ensemble)

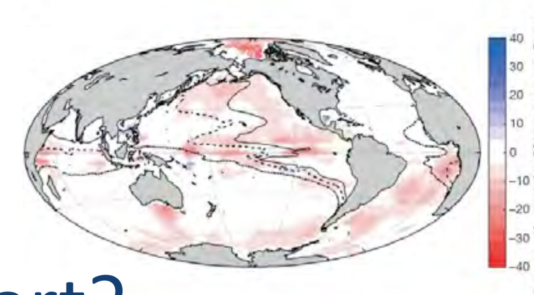
Models underestimate obs. trend estimate by factor 2-3 or more.

Oxygen change (1960-2010)



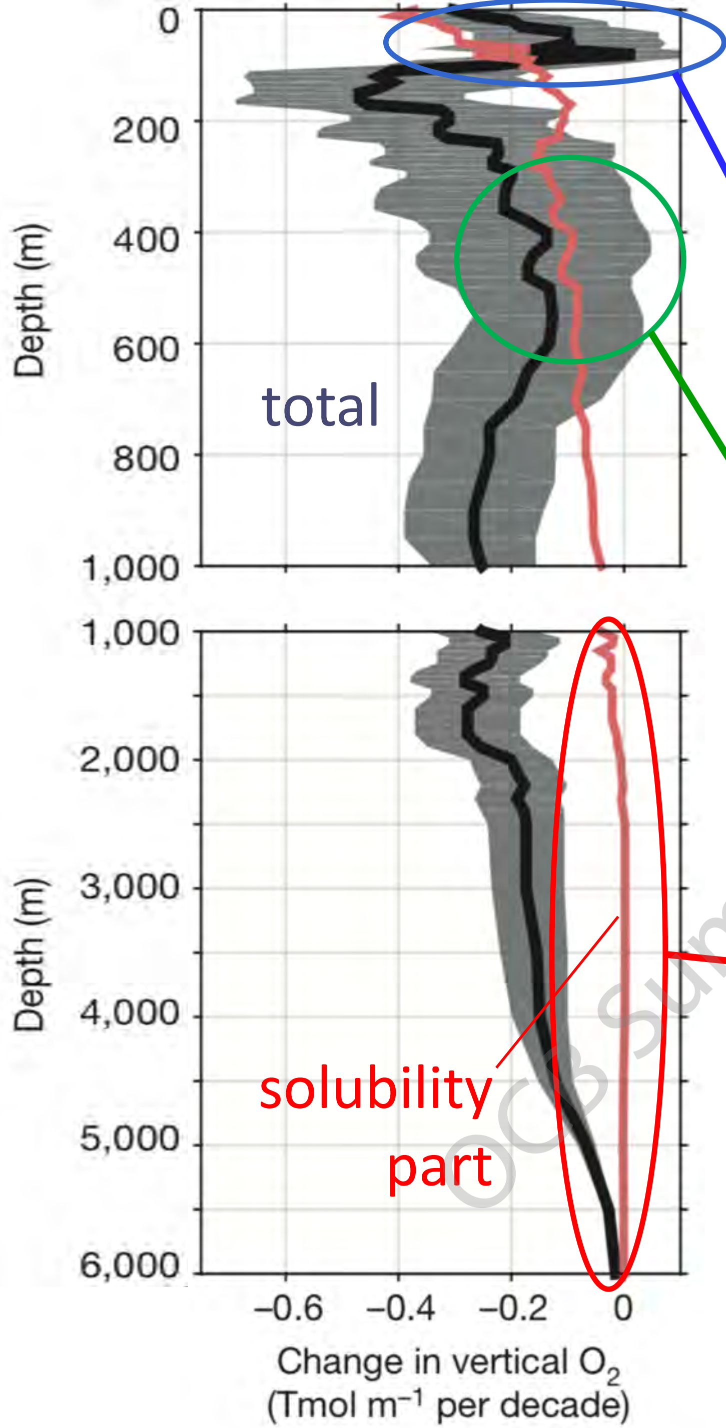
Have not yet been able to reach observed O_2 loss.

Possible causes for systematic underestimate?



- Mapping? Data treatment?
- Solubility, biotic or circulation part?
  → Solubility?

Total and solubility part of O_2 change



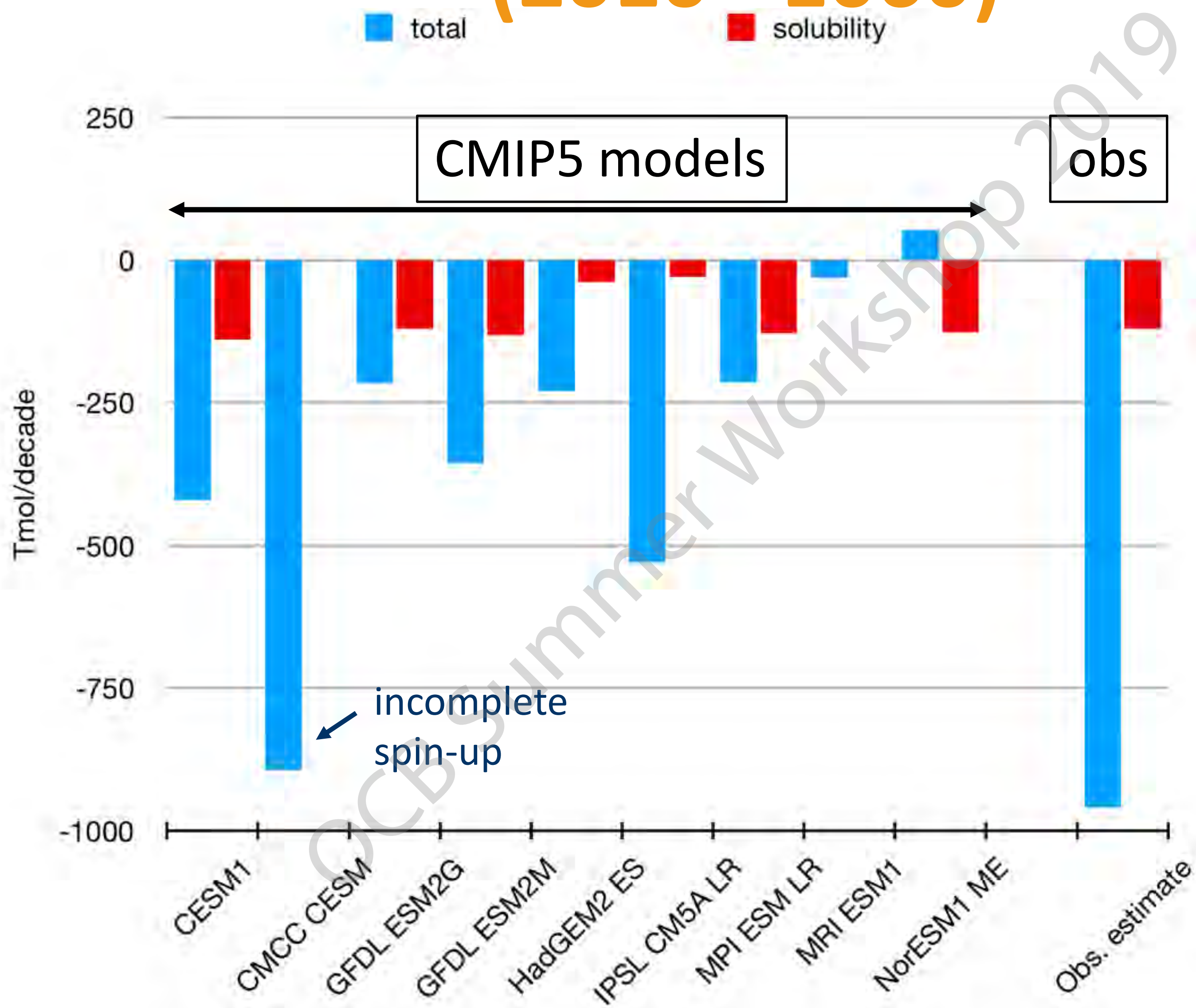
Less O_2 loss in upper water column than to be expected from warming

300-600m O_2 loss equivalent to loss expected from solubility changes

Deep ocean O_2 loss (75% of total below 1000m) not related to solubility change

(Schmidtko et al., Nature 2017)

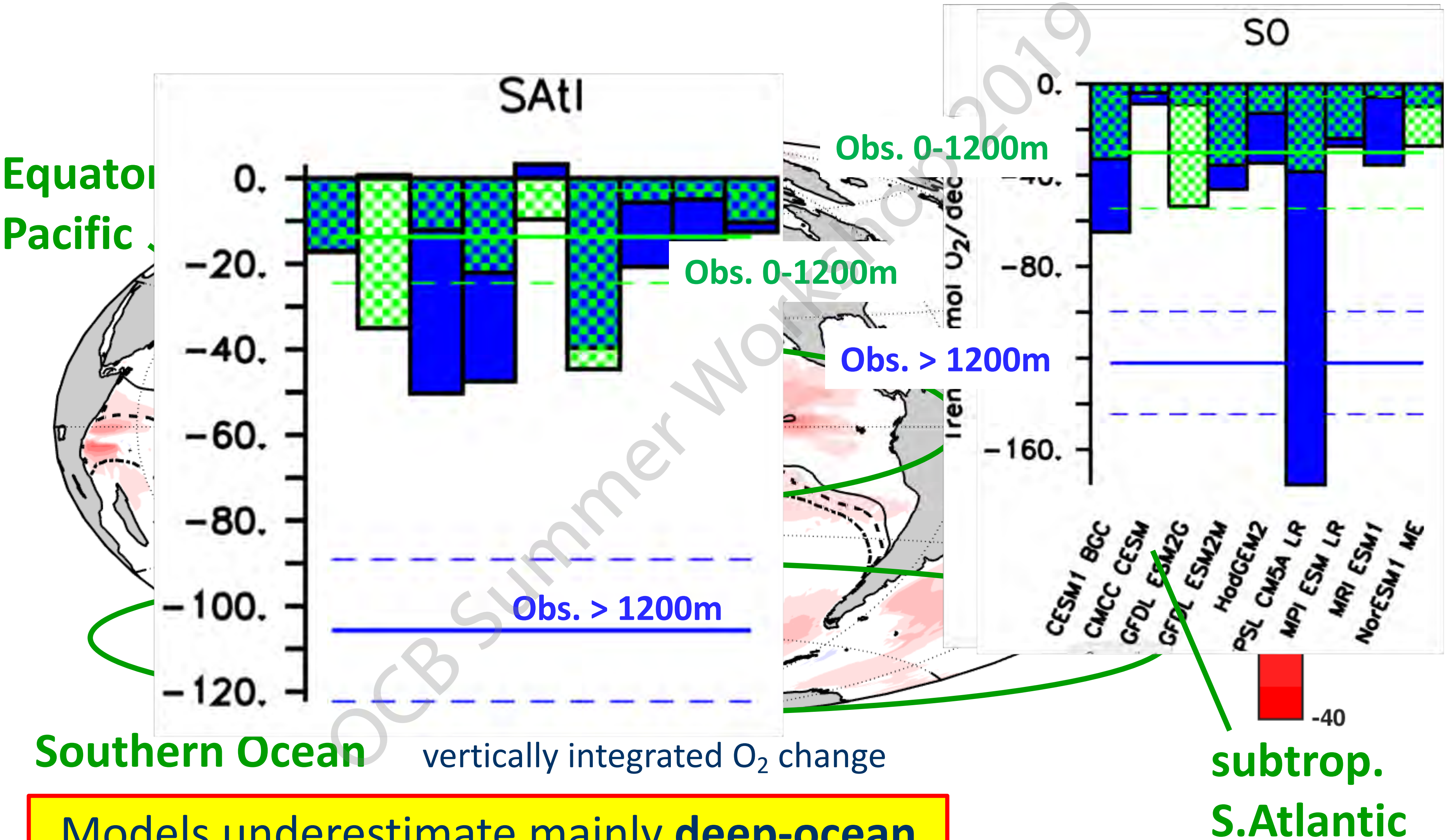
Total and solubility part of O_2 change (2010 - 1060)



Good CMIP5 model-data agreement for solubility-driven part!

→ Circulation & biology cause discrepancies

Regions of above-average O_2 decline

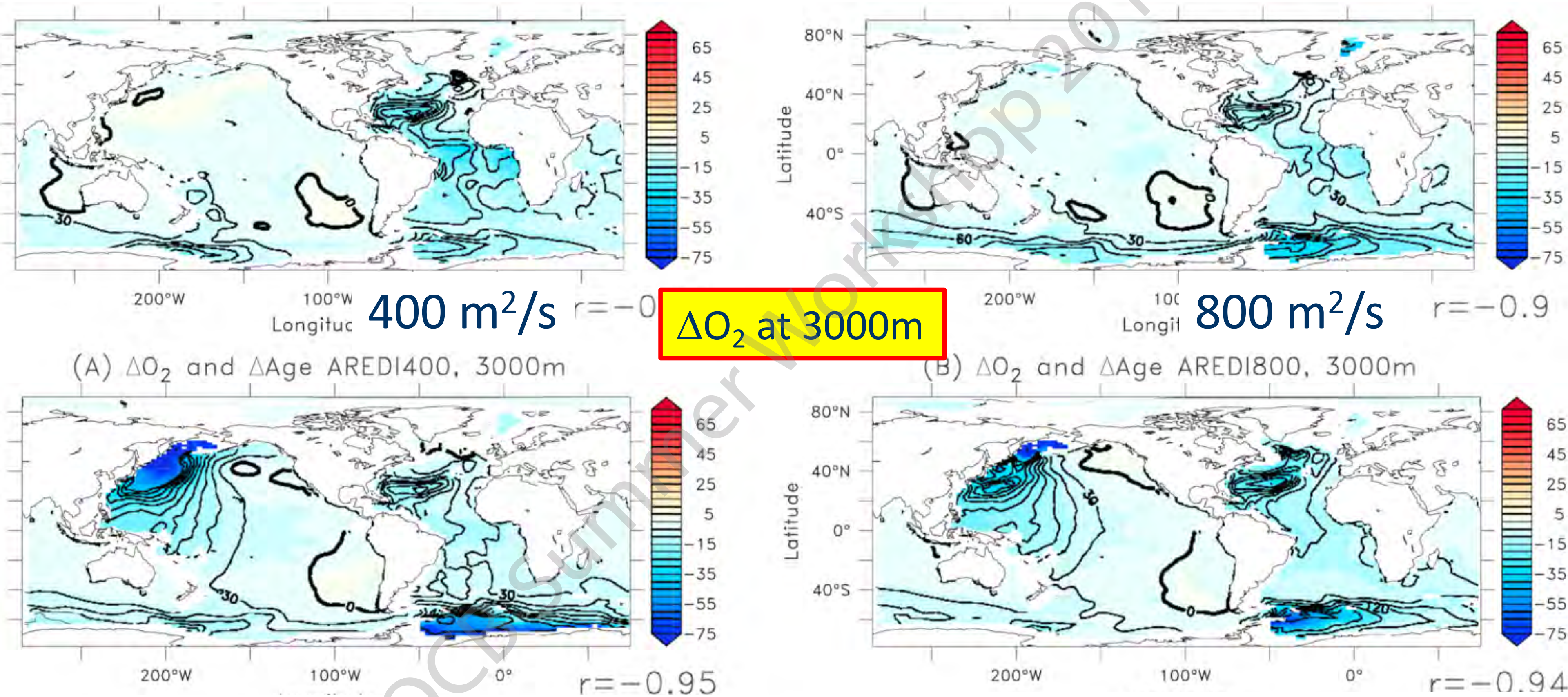


vertically integrated O_2 change

Models underestimate mainly **deep-ocean** deoxygenation (not a solubility effect!)

(Schmidtko et al., Nature 2017)

Sensitivity to isopycnal mixing upon doubling of atmospheric CO_2



Abernathey and Marshall (2013)

Abernathey and Marshall, zon.av.

- Stronger deoxygenation in deep ocean for strong mixing.

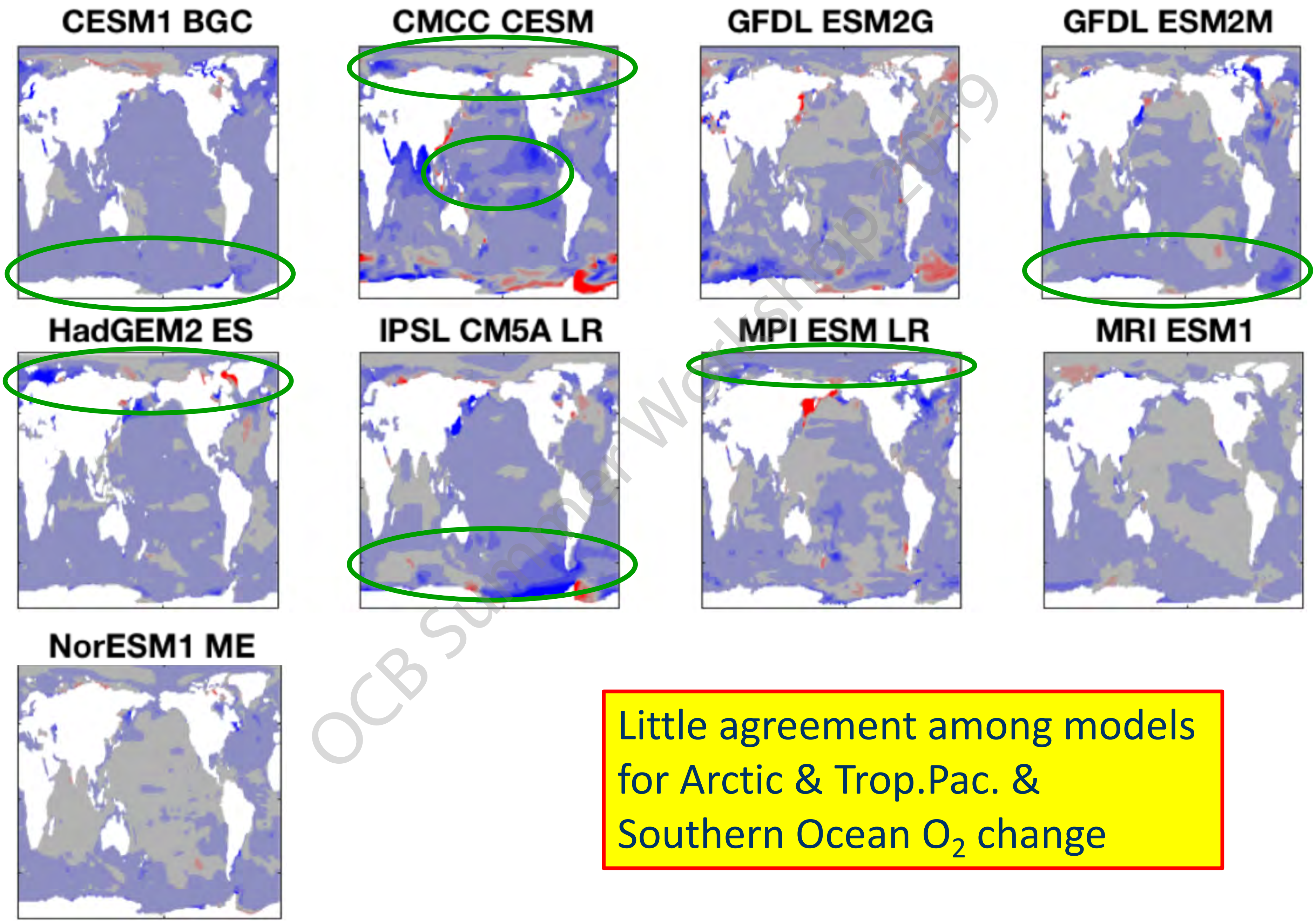
(Bahl et al., GBC 2019)

Conclusions (ii)

- Wherever we look, (global) **models underestimate O_2 trends & variability**
- Good agreement for solubility-driven part & often OK for upper ~1000m **(except trop.Pac.)**
- **Most models underestimate deep-ocean deoxygenation (not a solubility effect) (or are data-derived estimates too high???)**
- Need to understand impact of circulation changes, particularly in the deep ocean.
- Overlooked biogeochemical feedbacks?

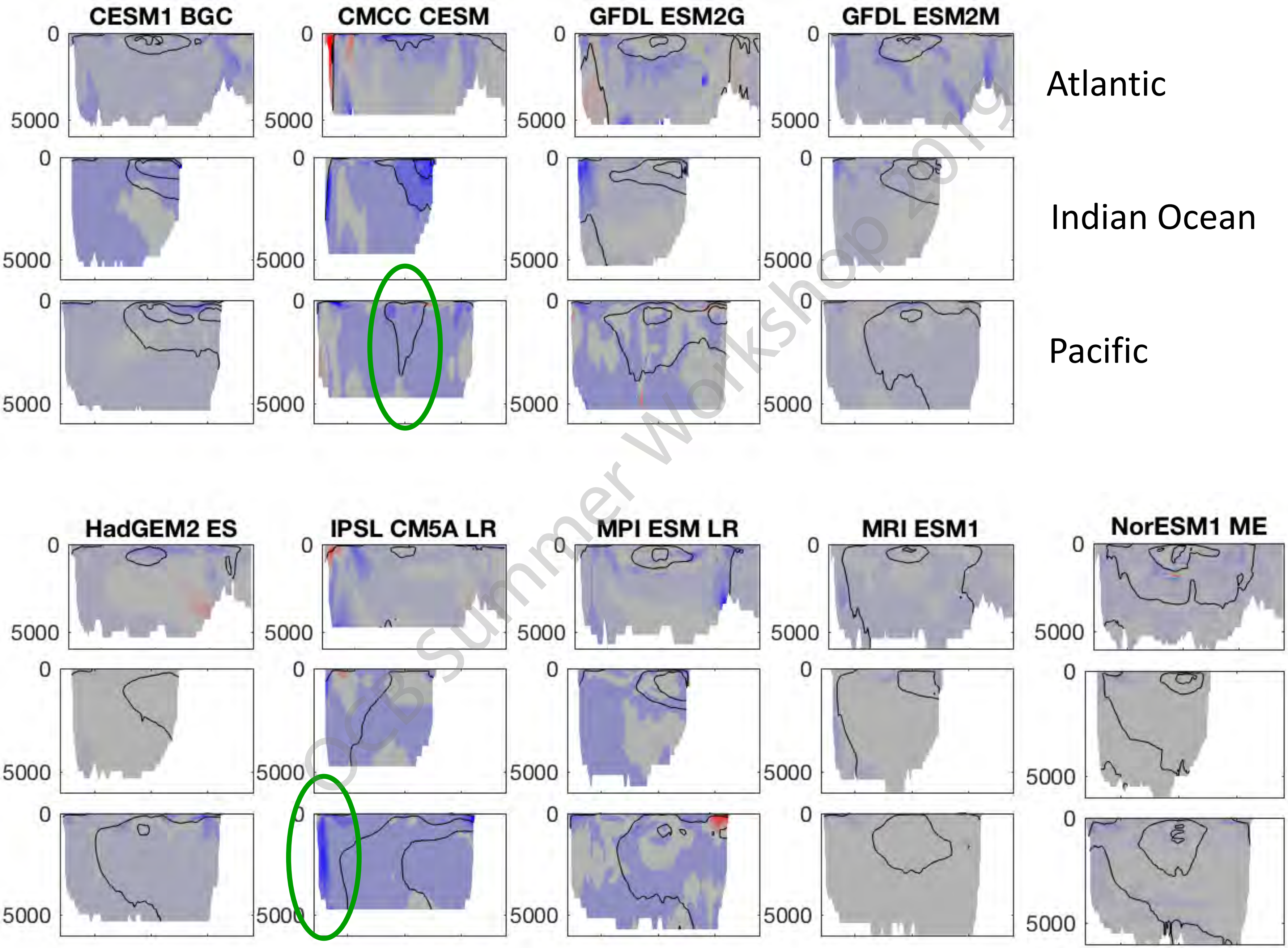
Thank you!

CMIP5 oxygen trends



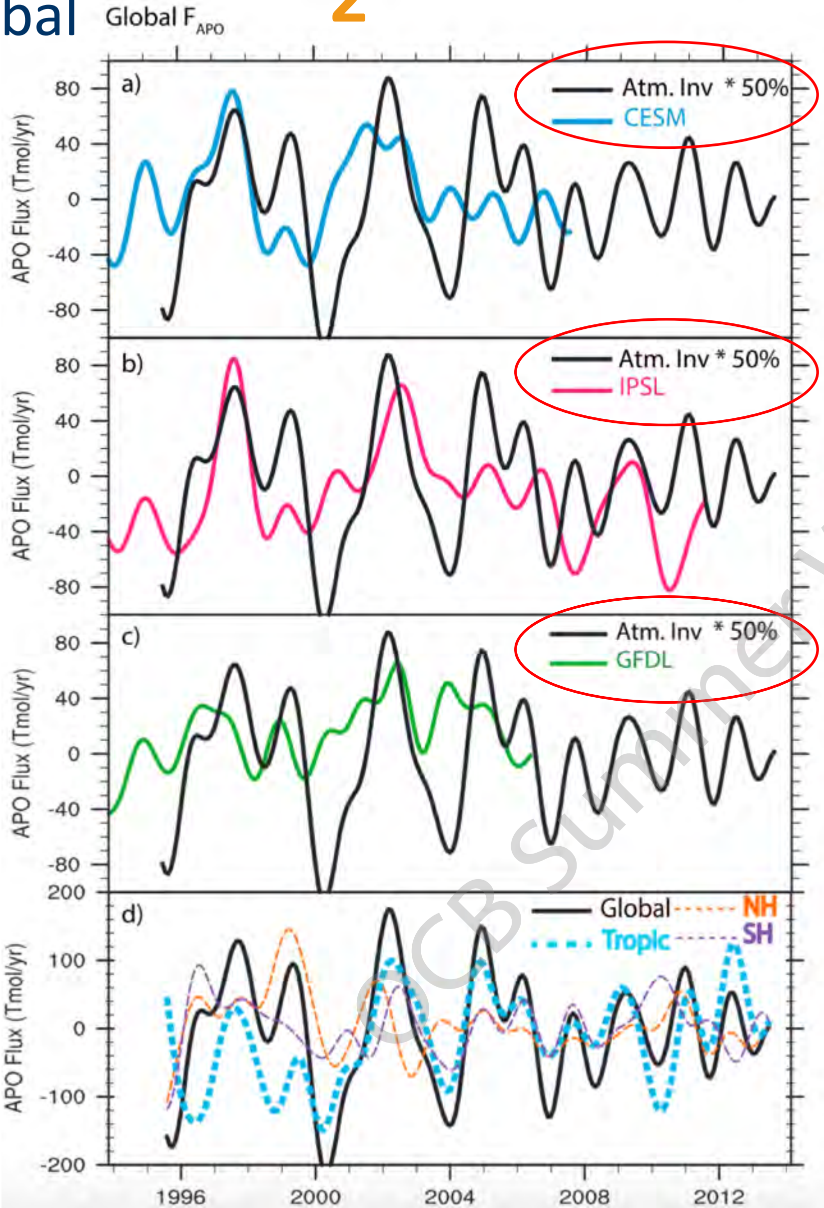
Little agreement among models for Arctic & Trop.Pac. & Southern Ocean O_2 change

CMIP5 models



O_2 air-sea flux variability

global

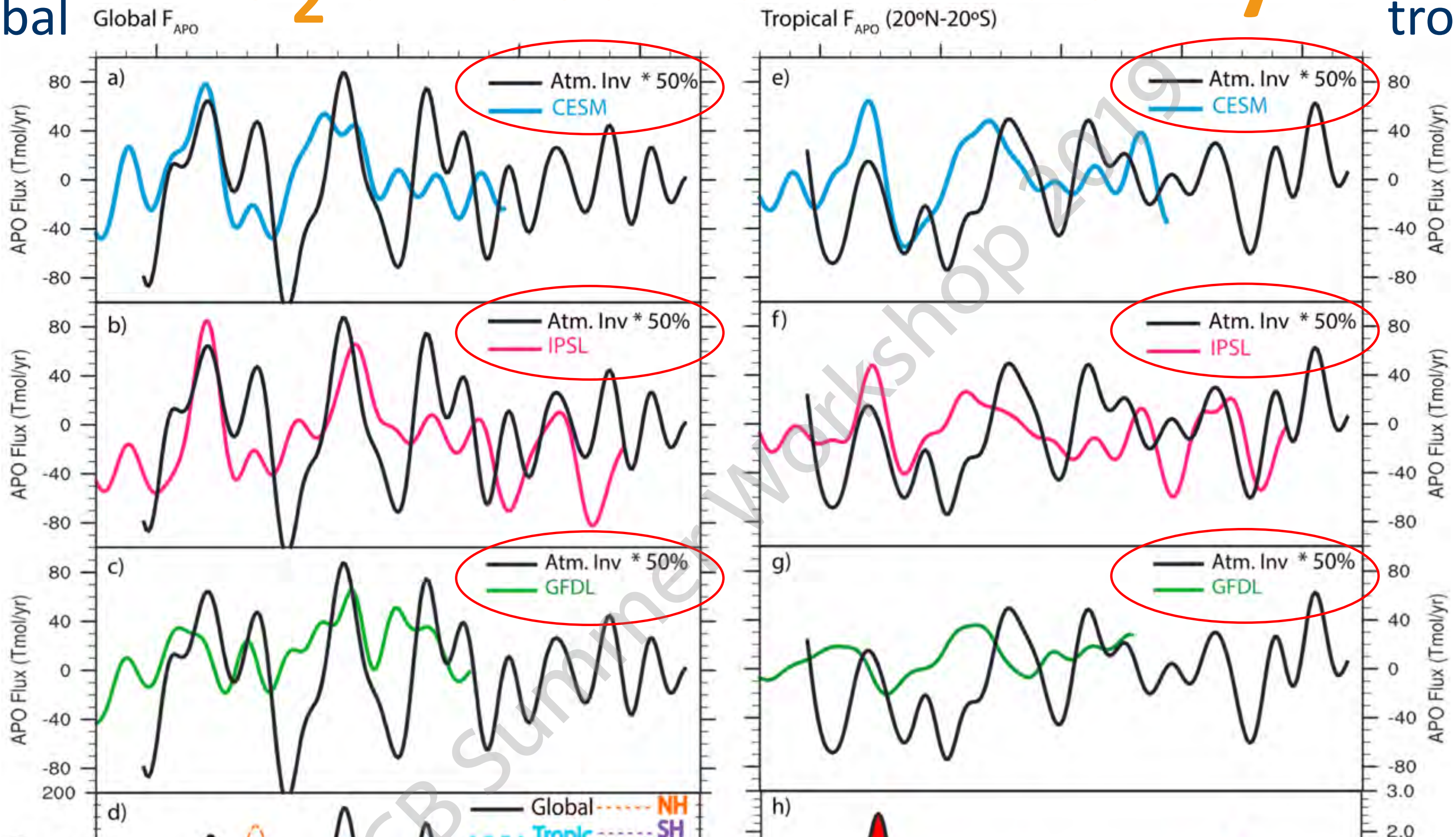


(Eddebbar et al., GBC 2017)

O_2 air-sea flux variability

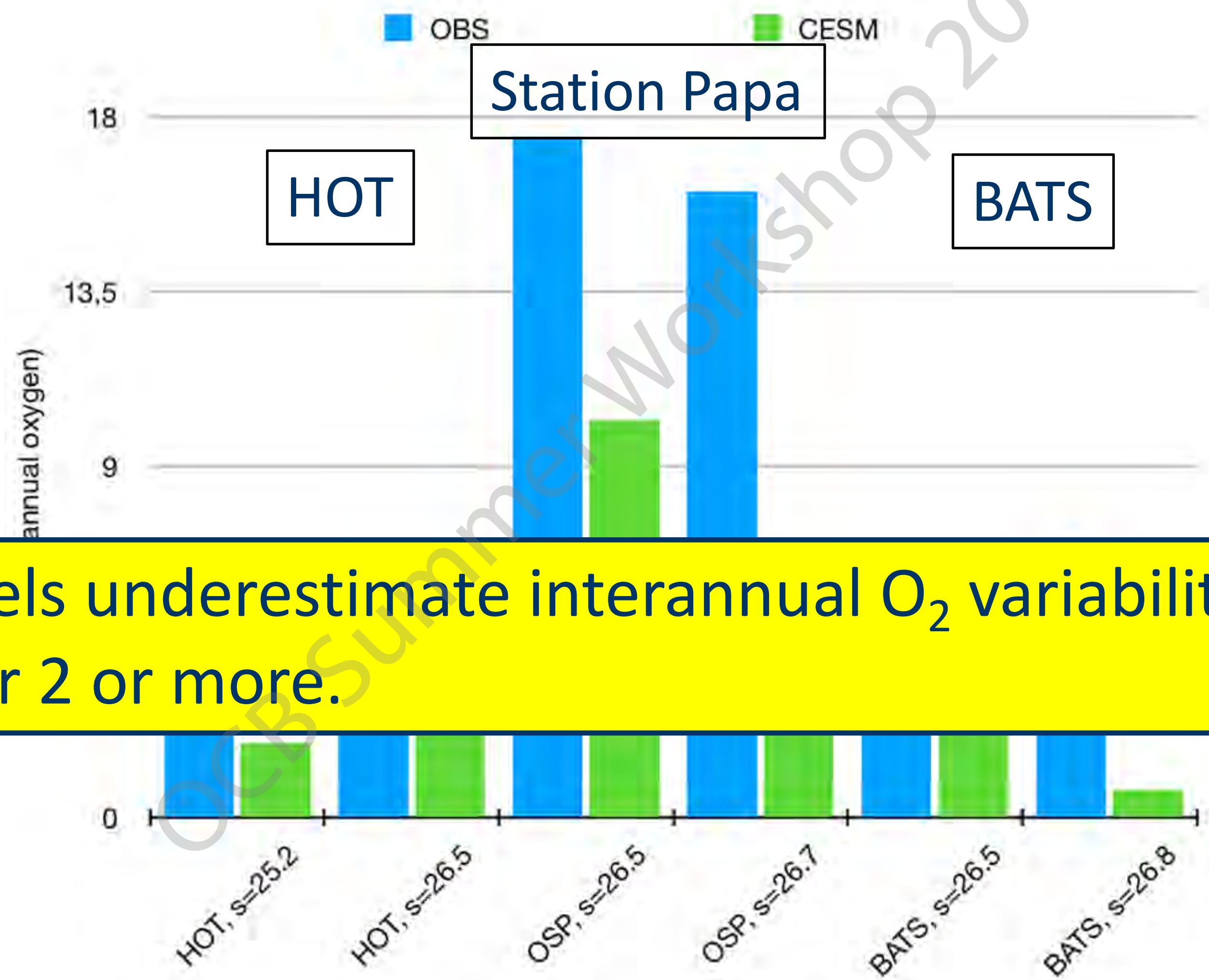
global

tropical



Models forced with realistic atmospheric forcing (CORE-2) underestimate interannual O_2 air-sea flux variability by factor 2 or more.

O_2(annual mean) variability at time-series sites

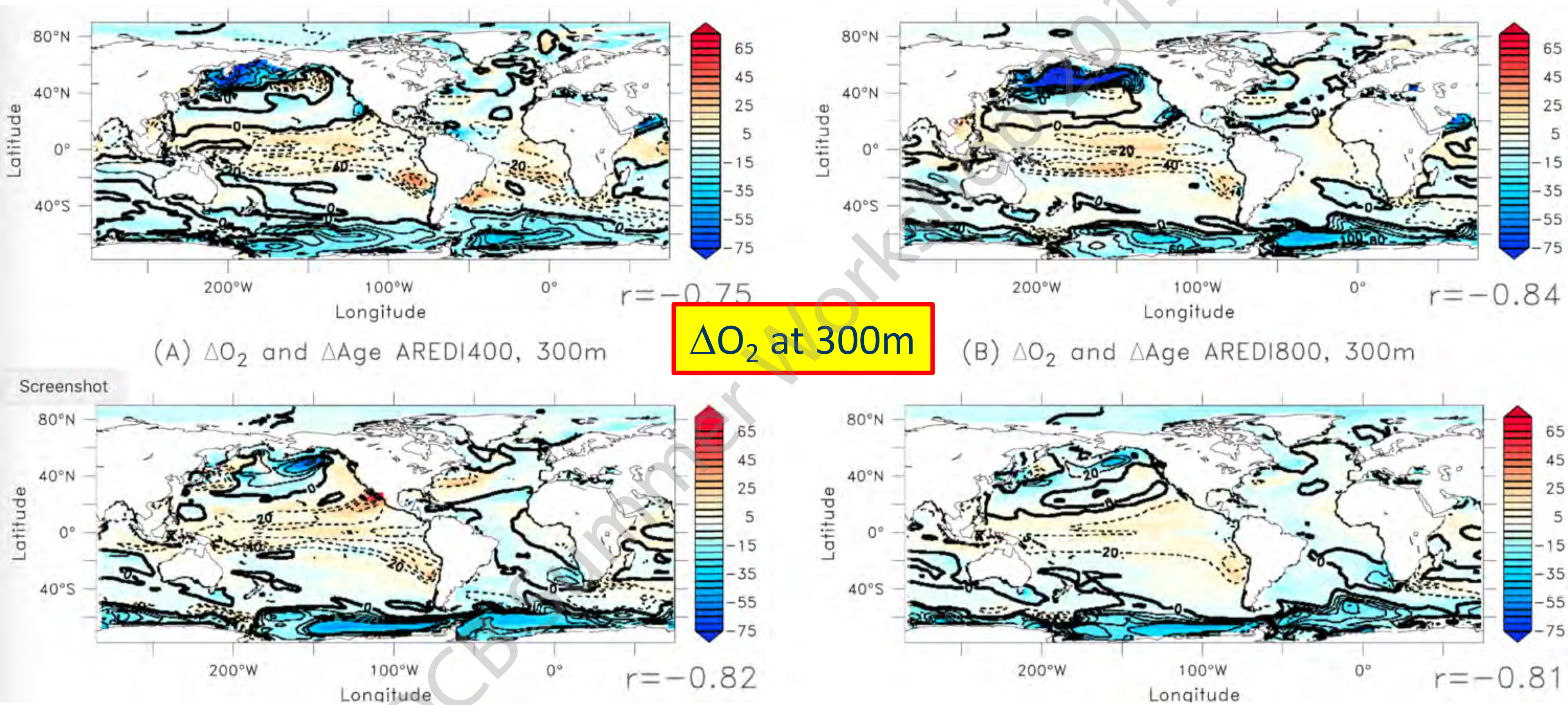


Models underestimate interannual O_2 variability by factor 2 or more.

(after Long et al., GBC 2016)

Isopycnal mixing?

GFDL (CM2Mc) @ doubling of atmospheric CO_2



- O_2 increase in tropical thermocline
- Strong deoxygenation in subpolar N.Pac. for low mixing.

(Bahl et al., GBC 2019)