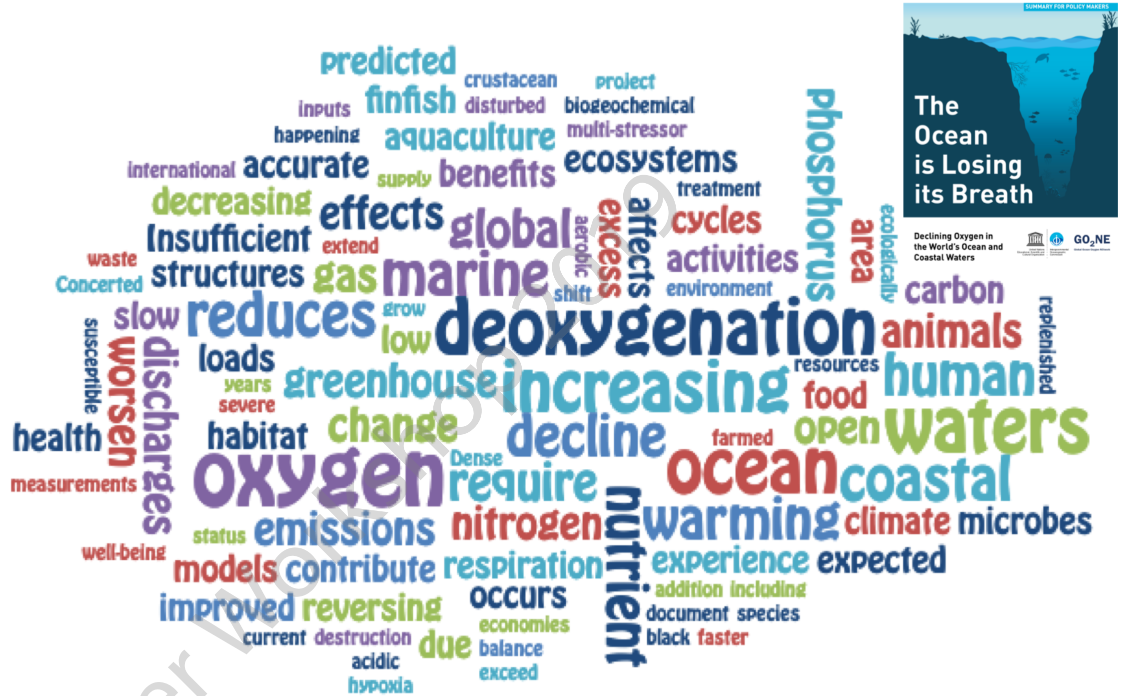
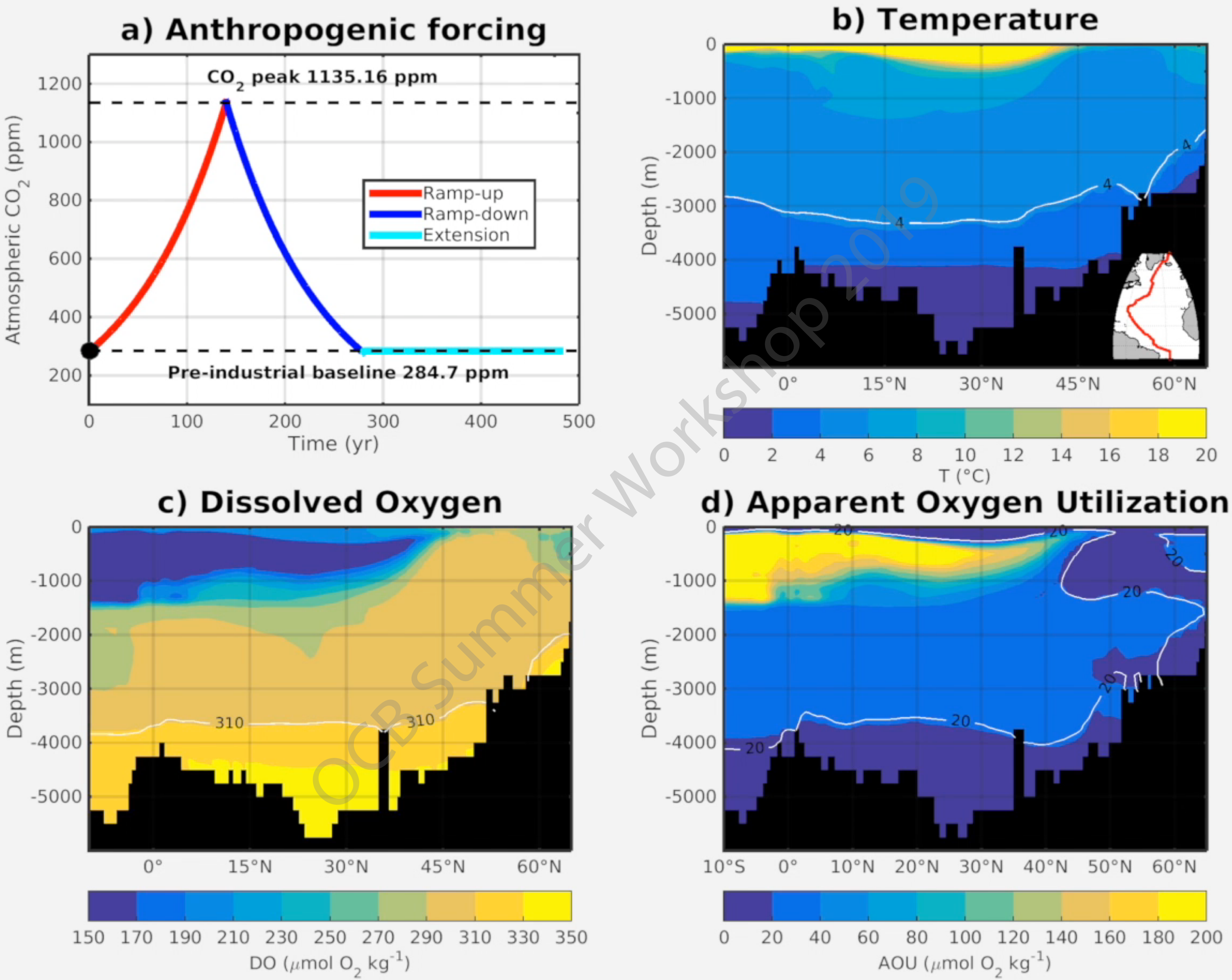
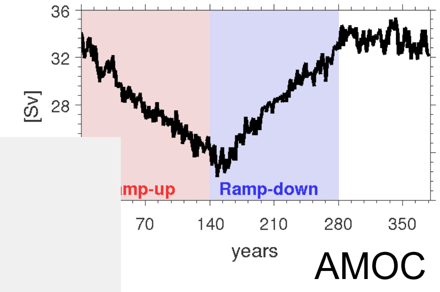


OCB-WORKSHOP 2019

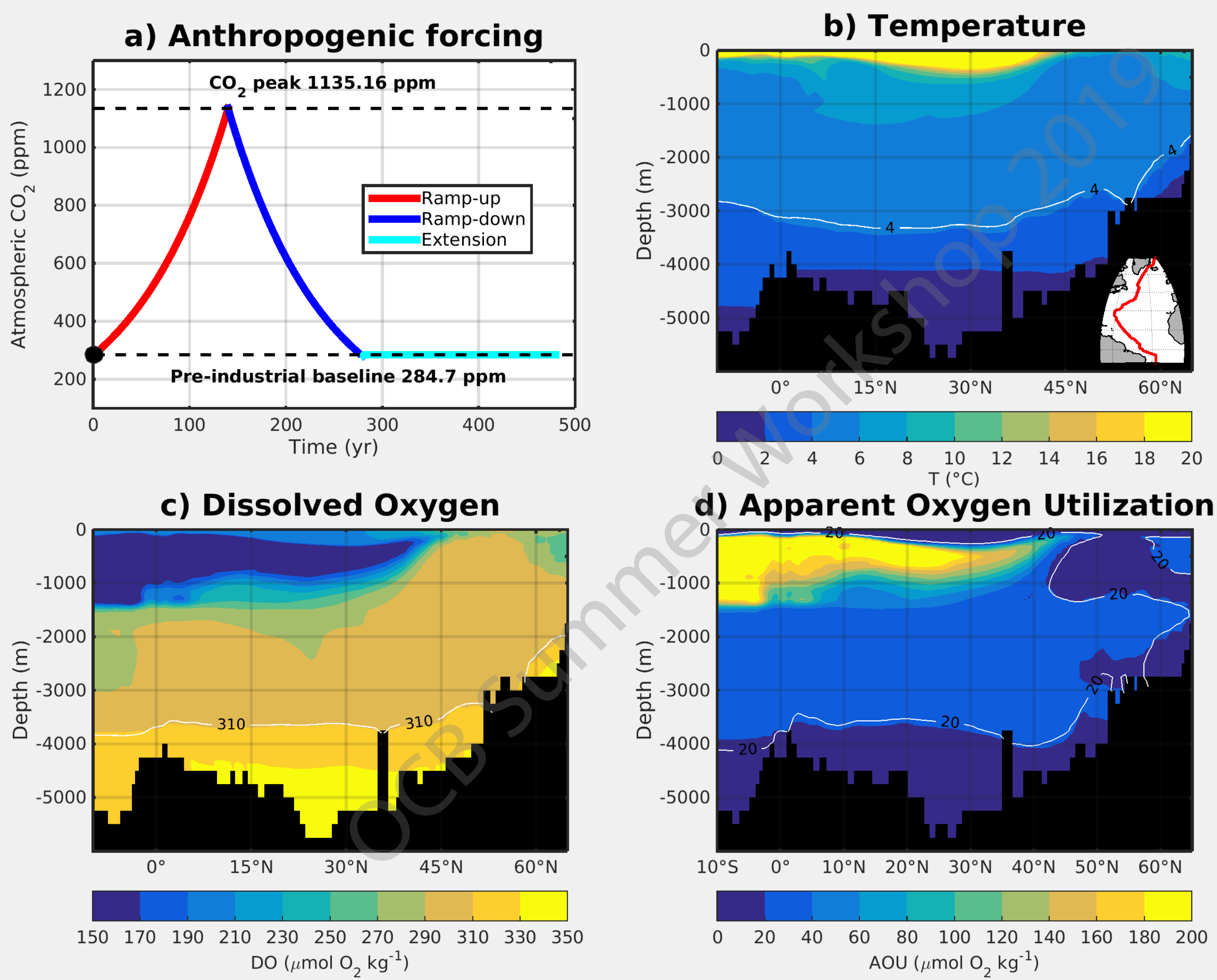
Oxygen as a proxy for circulation and ventilation variability

Jerry Tjiputra,
w/ contributions from L. Bertini, A. Olsen, S. Lauvset, J. Schwinger, N. Goris, R. Steinfeldt, C. Heinze
NORCE Norwegian Research Centre
Bjerknes Centre for Climate Research, Bergen, Norway


a) Anthropogenic forcing
CO2 peak 1135.16 ppm
Pre-industrial baseline 284.7 ppm
Ramp-up
Ramp-down
Extension
Atmospheric CO2 (ppm)
Time (yr)
b) Temperature
Depth (m)
T (°C)
c) Dissolved Oxygen
Depth (m)
DO (μmol O2 kg-1)
d) Apparent Oxygen Utilization
Depth (m)
AOU (μmol O2 kg-1)
10°S 0° 10°N 20°N 30°N 40°N 50°N 60°N

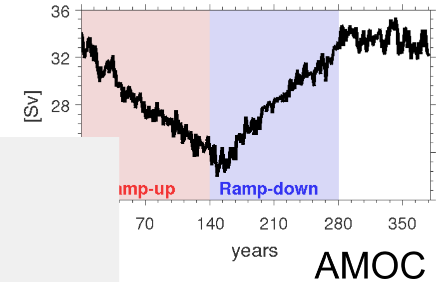


AMOC

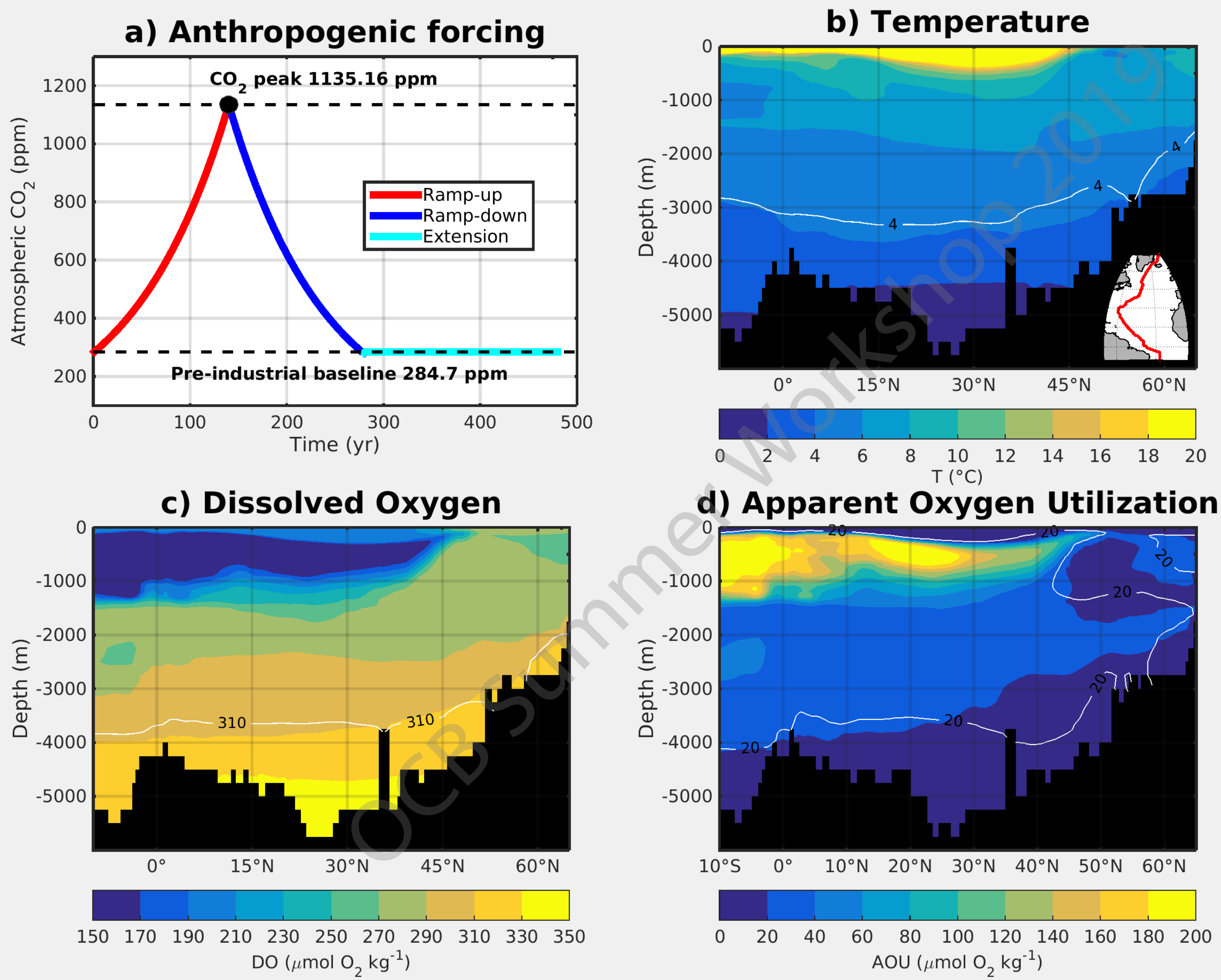


Bertini and Tjiputra (in prep.)

Bjerknes Centre for Climate Research

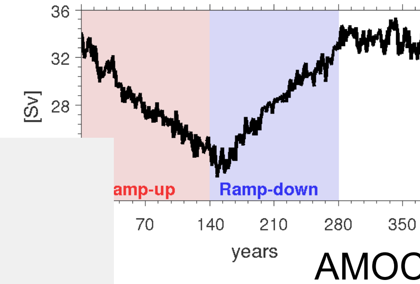


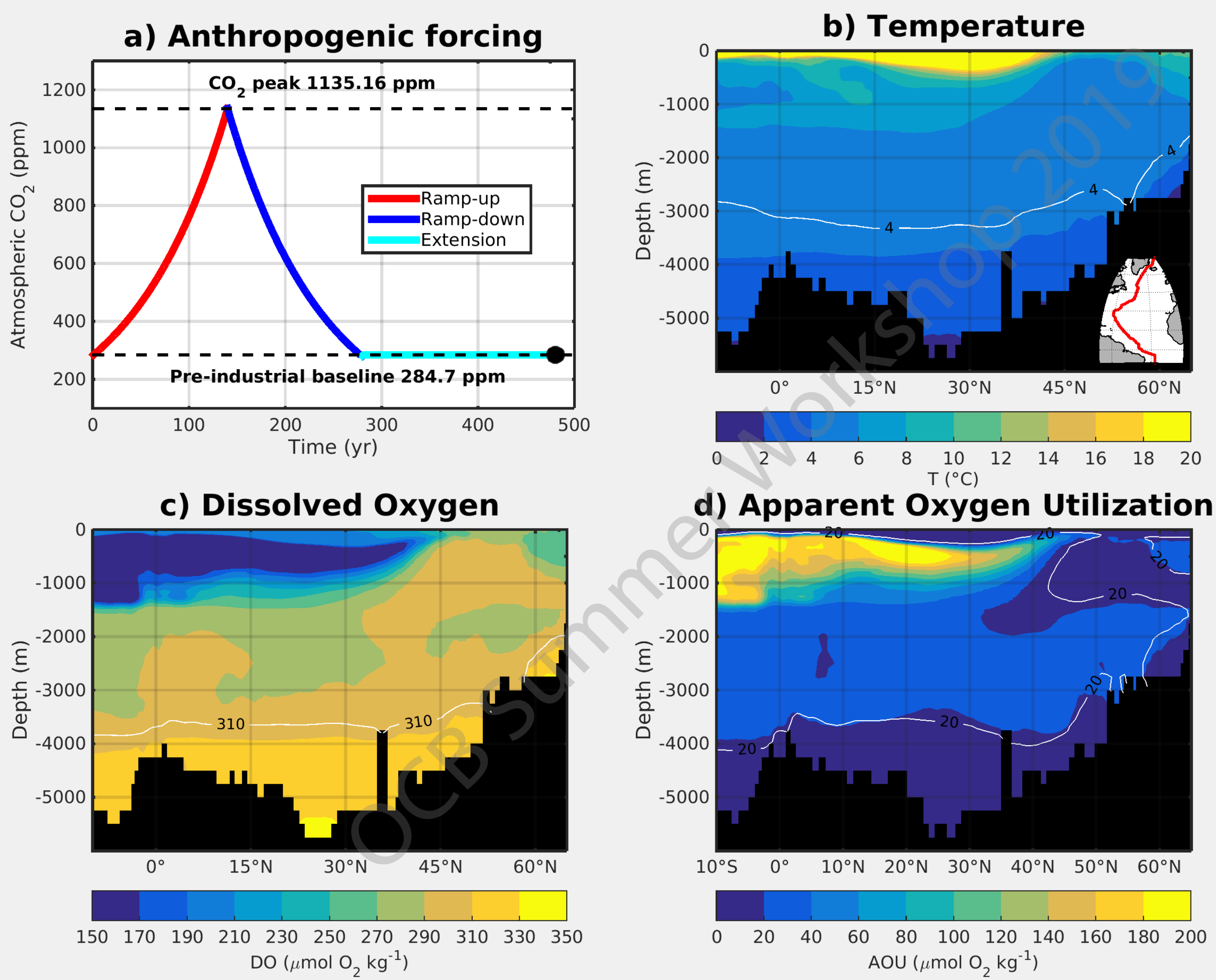
AMOC



Bertini and Tjiputra (in prep.)

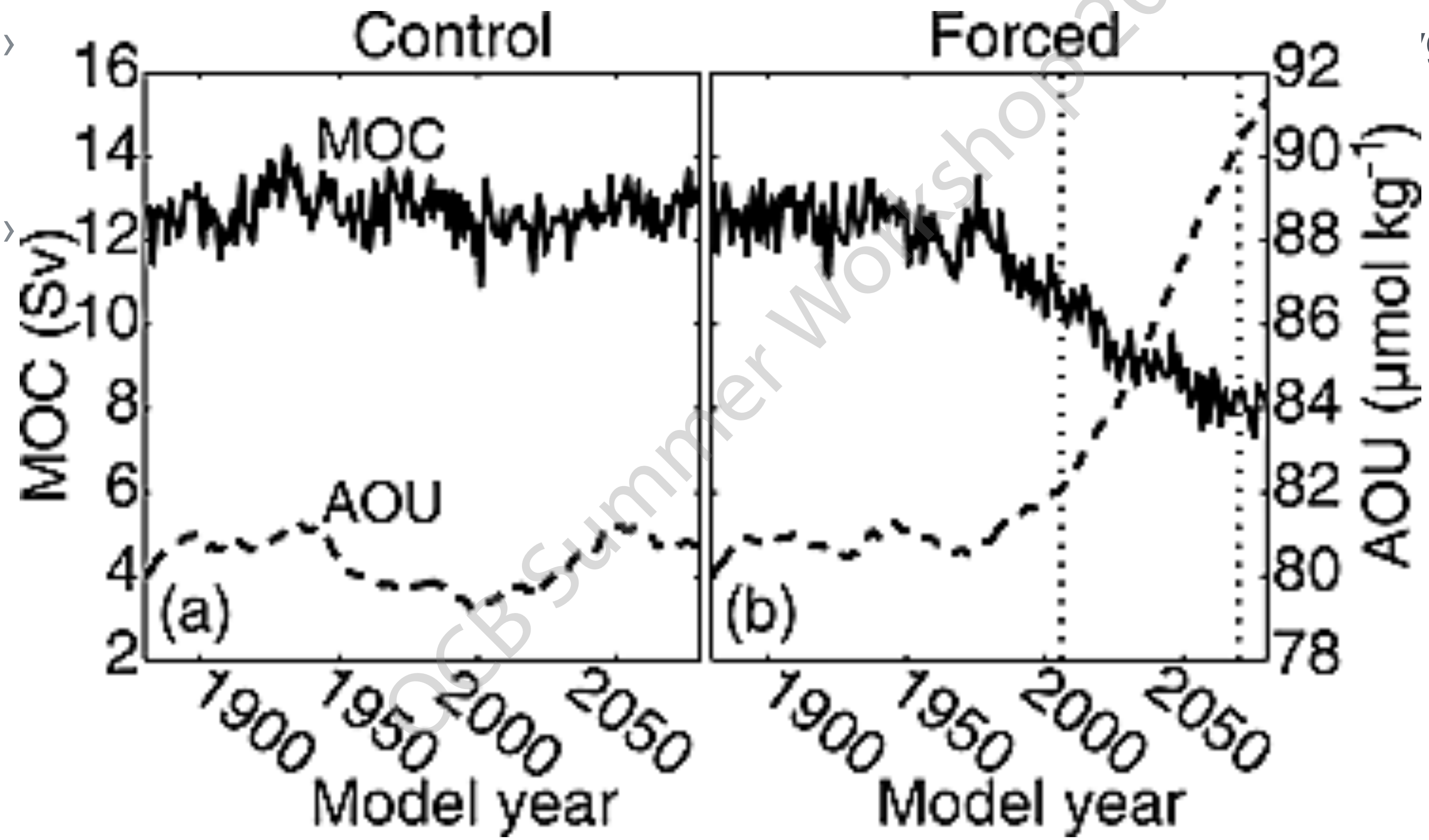
UNIVERSITY OF BERGEN | uni Research | NERSC Nansen Center, Bergen | HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH





Bertini and Tjiputra (in prep.)

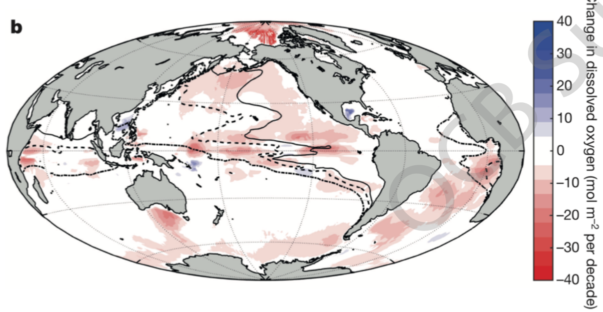
Previous studies

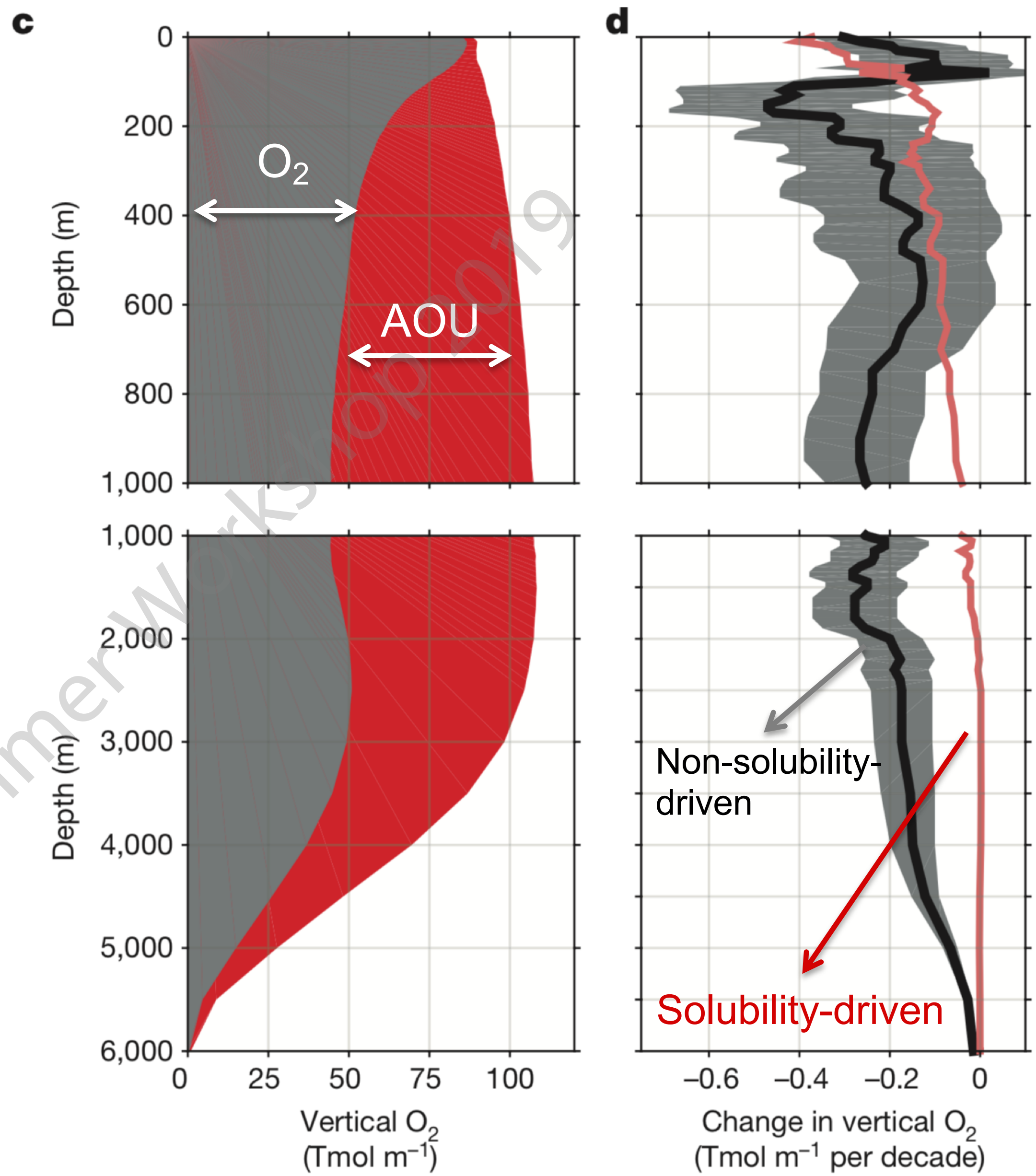


26N (2000-4500m)

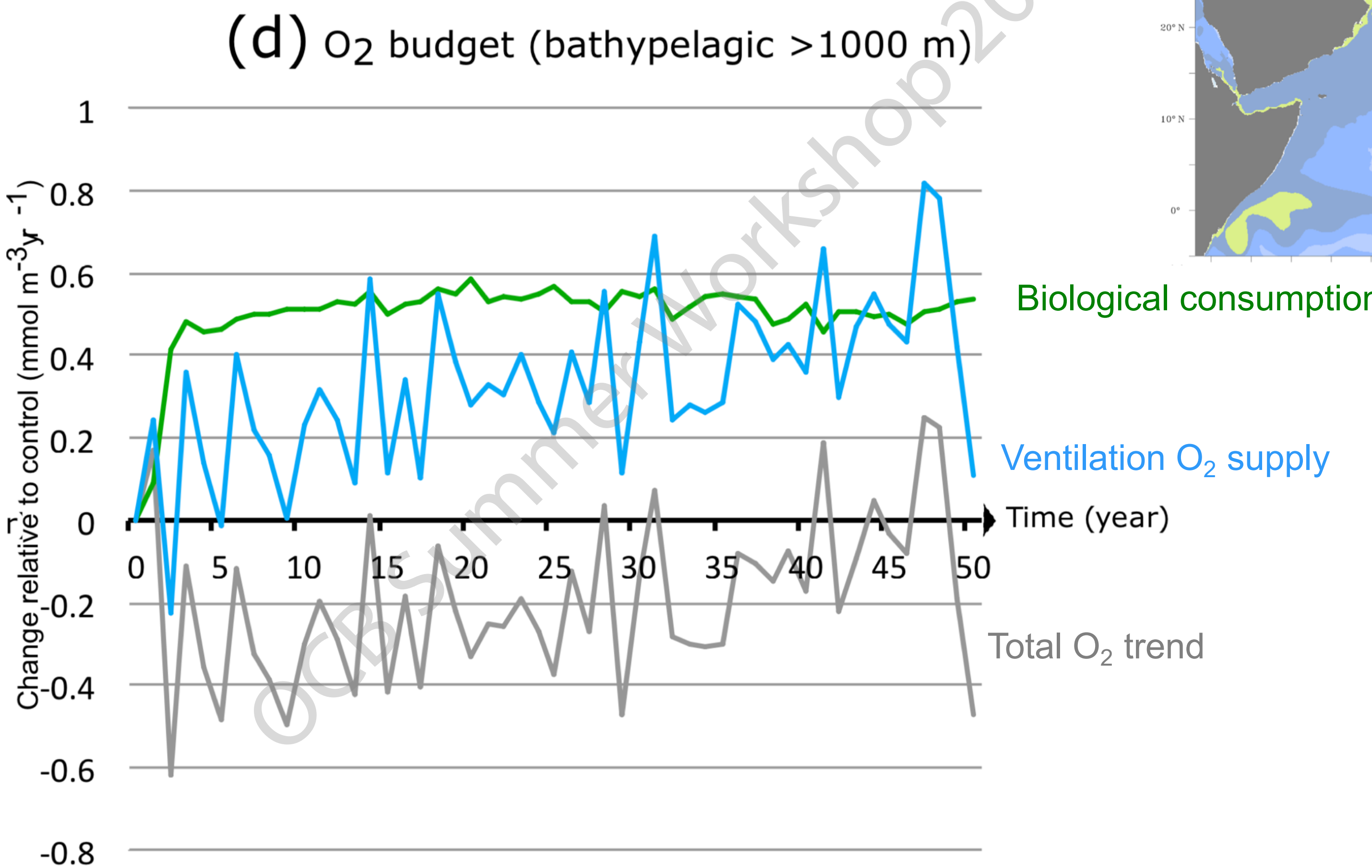
Brennan et al. (2008)

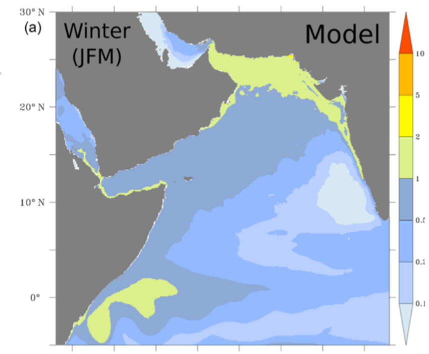
“The oxygen loss in the deep oceans can (be originated from) … a slowdown of meridional overturning circulation.” -- Schmidtko et al. (2017).





“ … hypoxic volume is driven by the variability of the transport of oxygen to the OMZ.” – Lachkar et al. (2018).



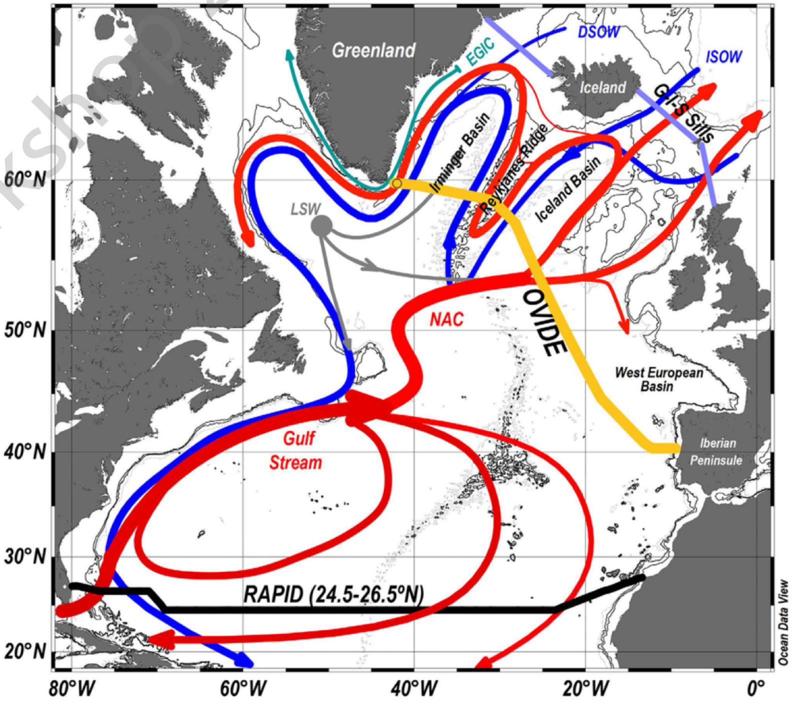


Can we use oxygen to provide early warning for (interior) circulation changes?

How soon can the projected future circulation changes be detectable?

North Atlantic Subpolar gyre (NASPG)

- Key gateway to the ocean's interior
- Sensitive to climate change
- Relatively well observed
- Regions with good predictability skill



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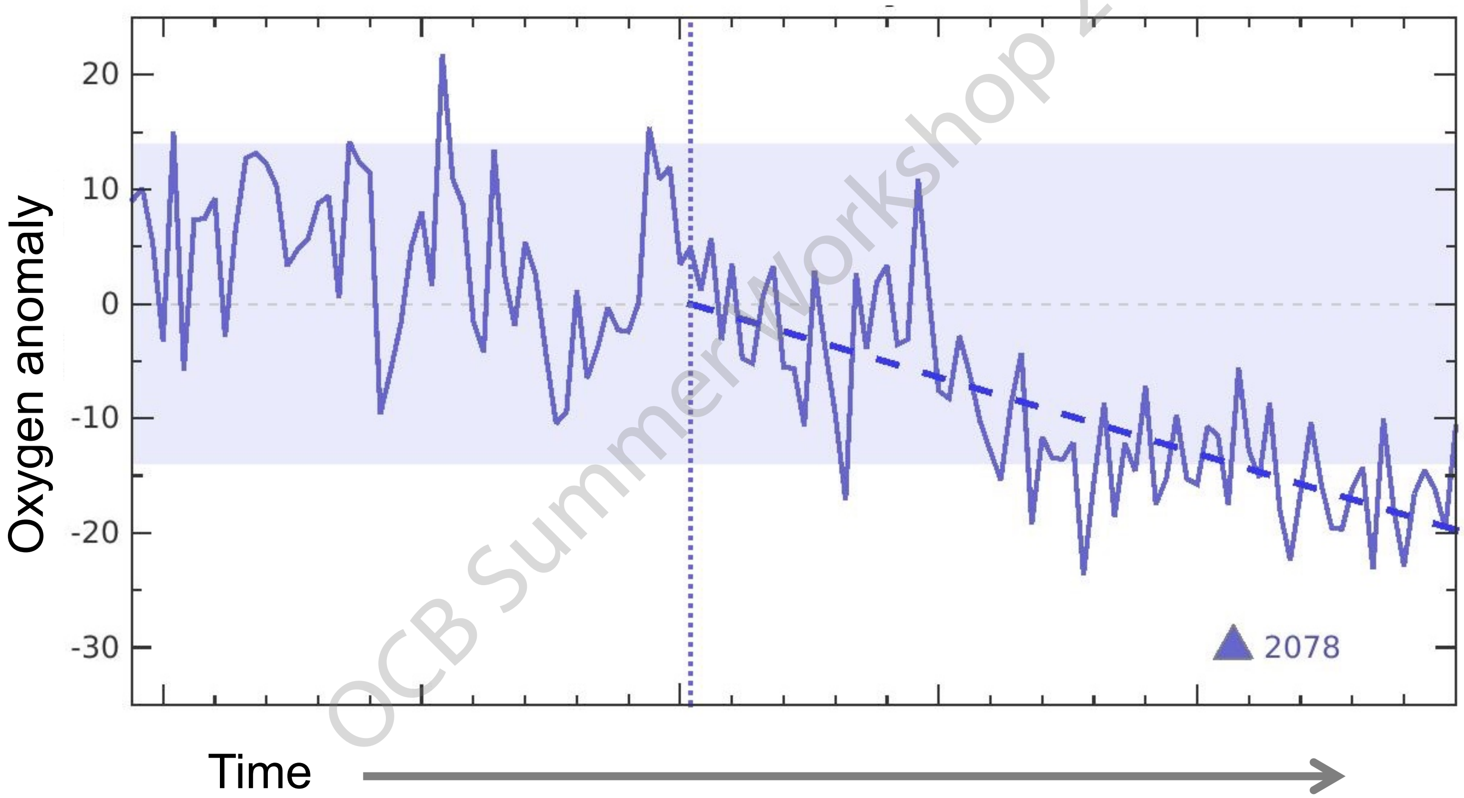
Time of Emergence (ToE = trend / 2σ)



Time of Emergence (ToE)

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1002/2015GB005310

Key Points:
- Natural variability drives strong fluctuations in dissolved oxygen within the ocean interior
- Natural variability challenges detection of forced trends in dissolved oxygen
- Time of emergence of forced trends is quantified based on state, trends, and spatial patterns

Finding forced trends in oceanic oxygen

Matthew C. Long[1], Curtis Deutsch[2], and Taka Ito[3]

Biogeosciences, 12, 3301–3320, 2015
www.biogeosciences.net/12/3301/2015/
doi:10.5194/bg-12-3301-2015

Biogeosciences
Open Access

Emergence of multiple oc
suite with an Earth systen

K. B. Rodgers[1], J. Lin[2], and T. L. Frölicher[3]
[1]Program in Atmospheric and Oceanic Science
[2]Dept. of Computer Science, Princeton Univers
[3]Environmental Physics, Institute of Biogeoche

nature COMMUNICATIONS

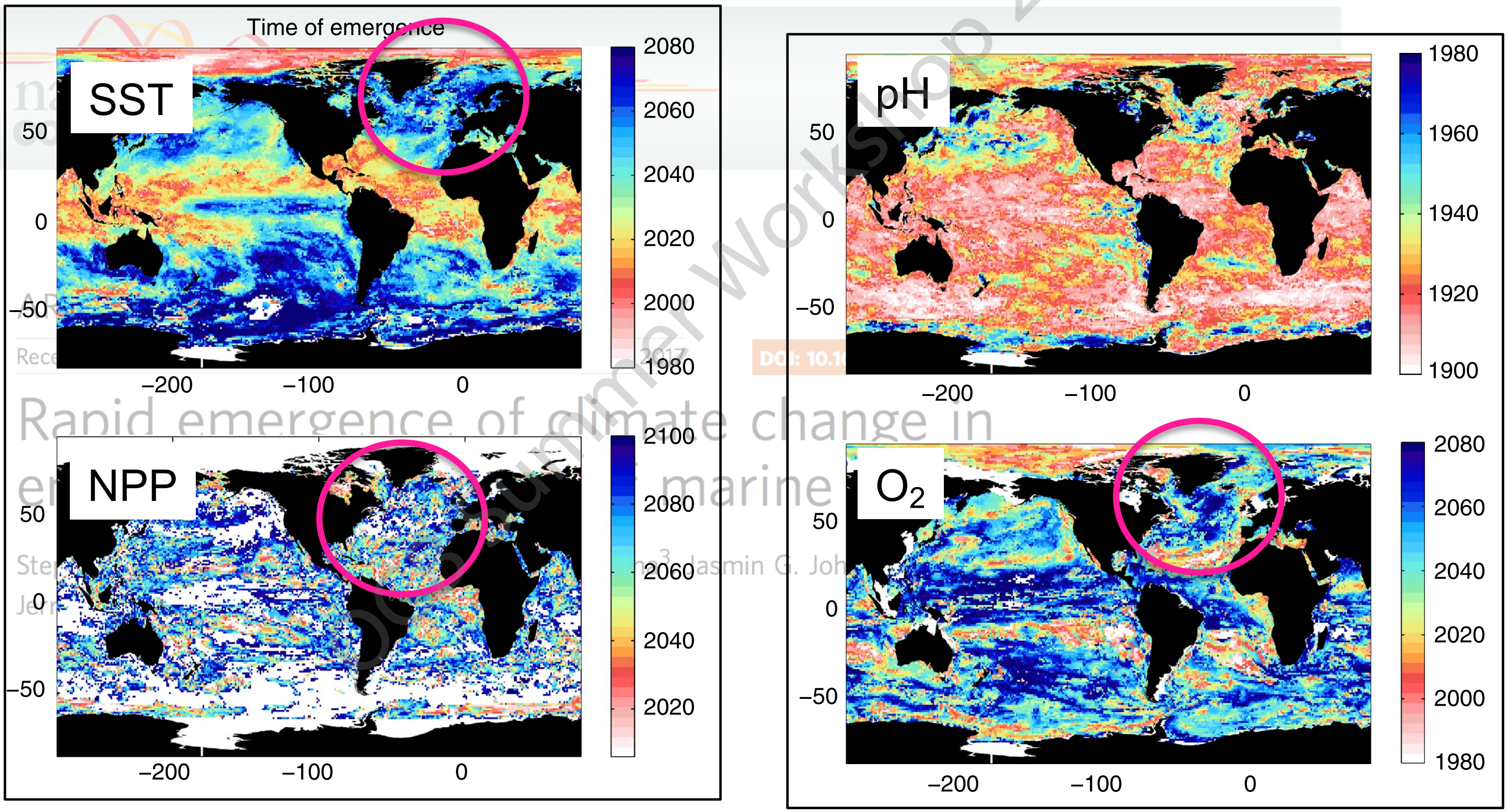
ARTICLE

Received 15 Jul 2016 | Accepted 20 Jan 2017 | Published 7 Mar 2017 DOI: 10.1038/ncomms14682 OPEN

Rapid emergence of climate change in environmental drivers of marine ecosystems

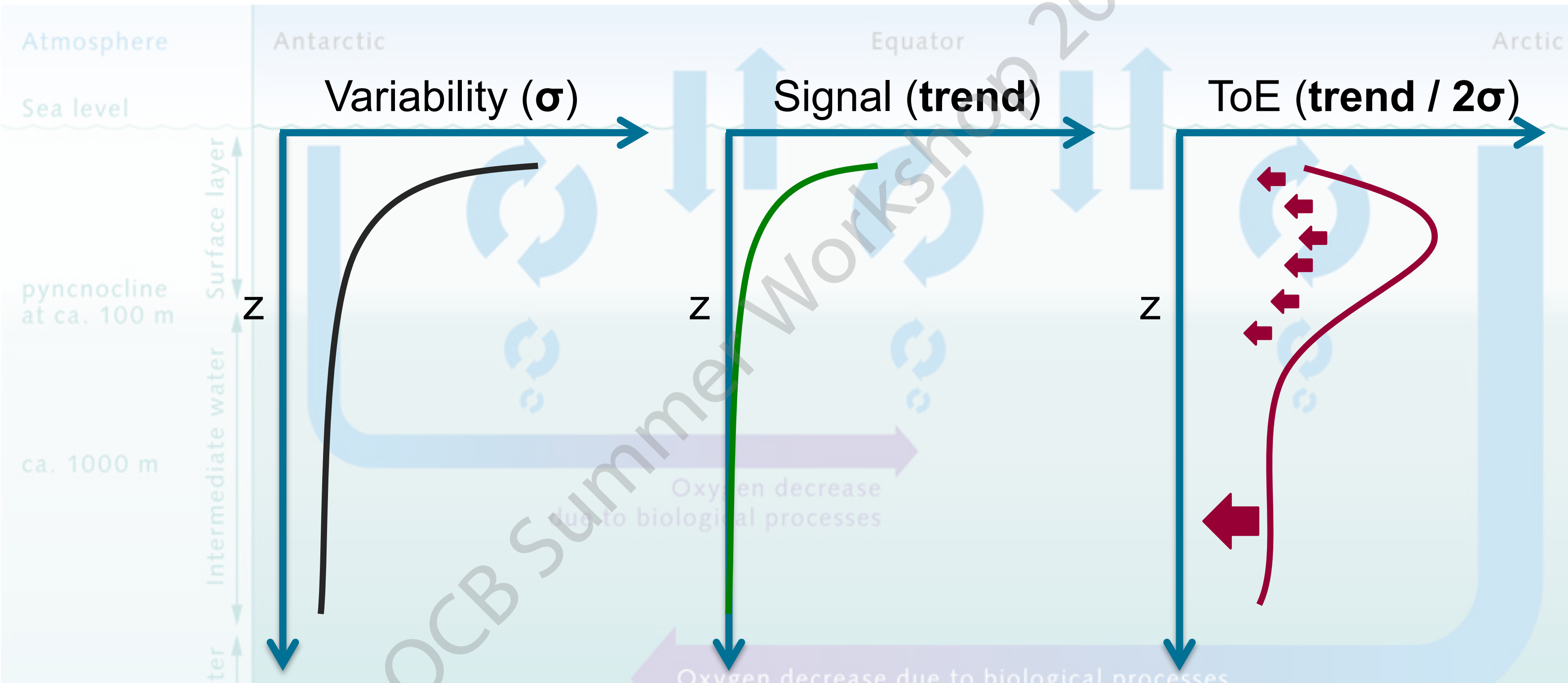
Stephanie A. Henson[1], Claudie Beaulieu[2], Tatiana Ilyina[3], Jasmin G. John[4], Matthew Long[5], Roland Séférian[6], Jerry Tjiputra[7] & Jorge L. Sarmiento[8]

Time of Emergence (ToE)



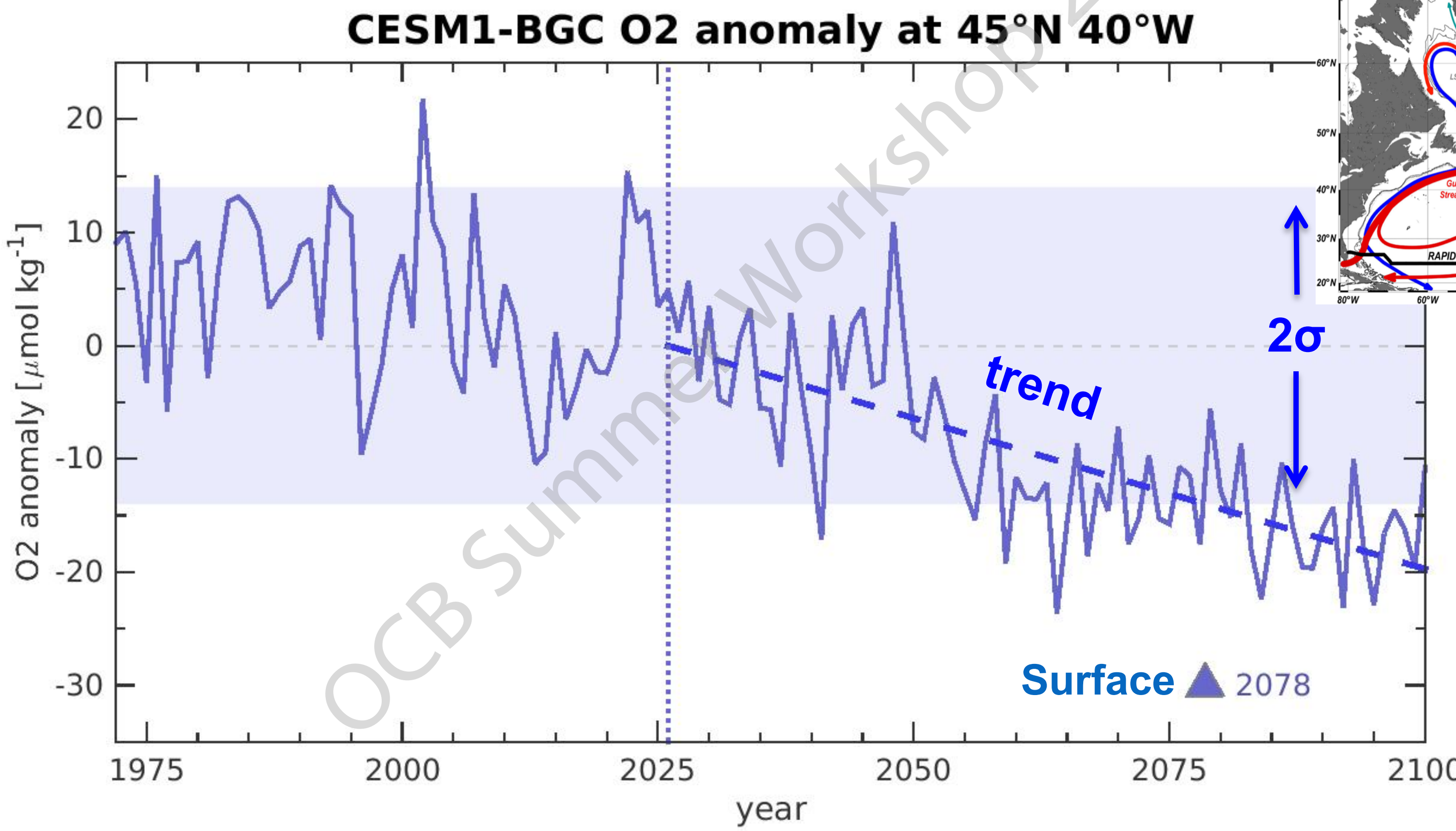
Henson et al. (2017)

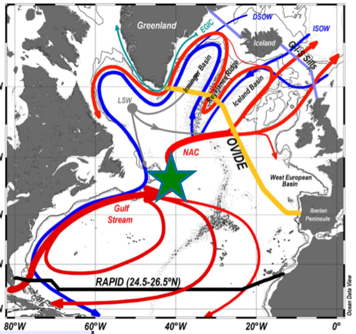
Surface and interior



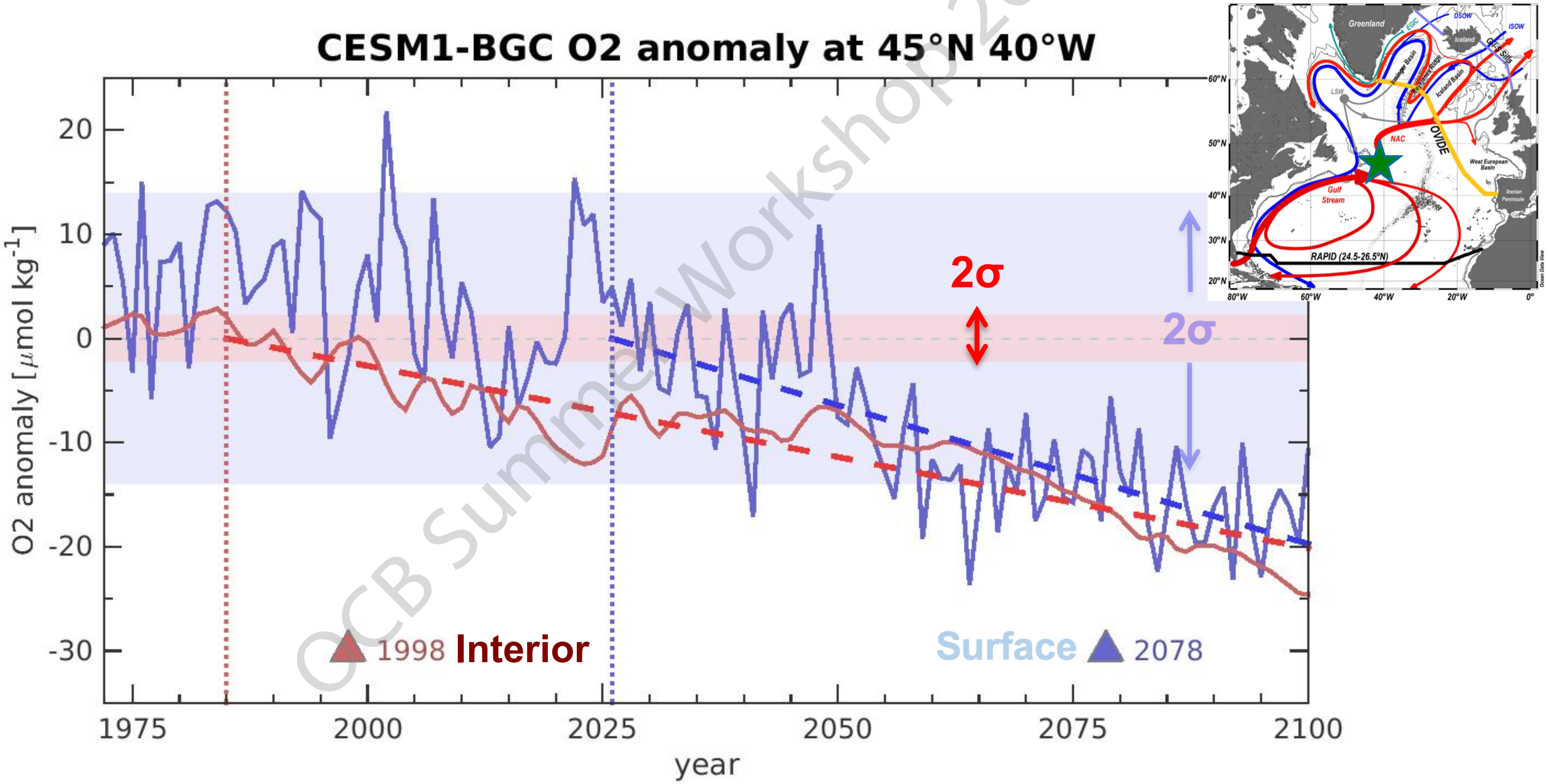
Surface (larger) variability hinders anthropogenic signals
Stable interior would be more sensitive to future changes

Time of Emergence (ToE = trend / 2σ)





Time of Emergence (ToE = trend / 2σ)

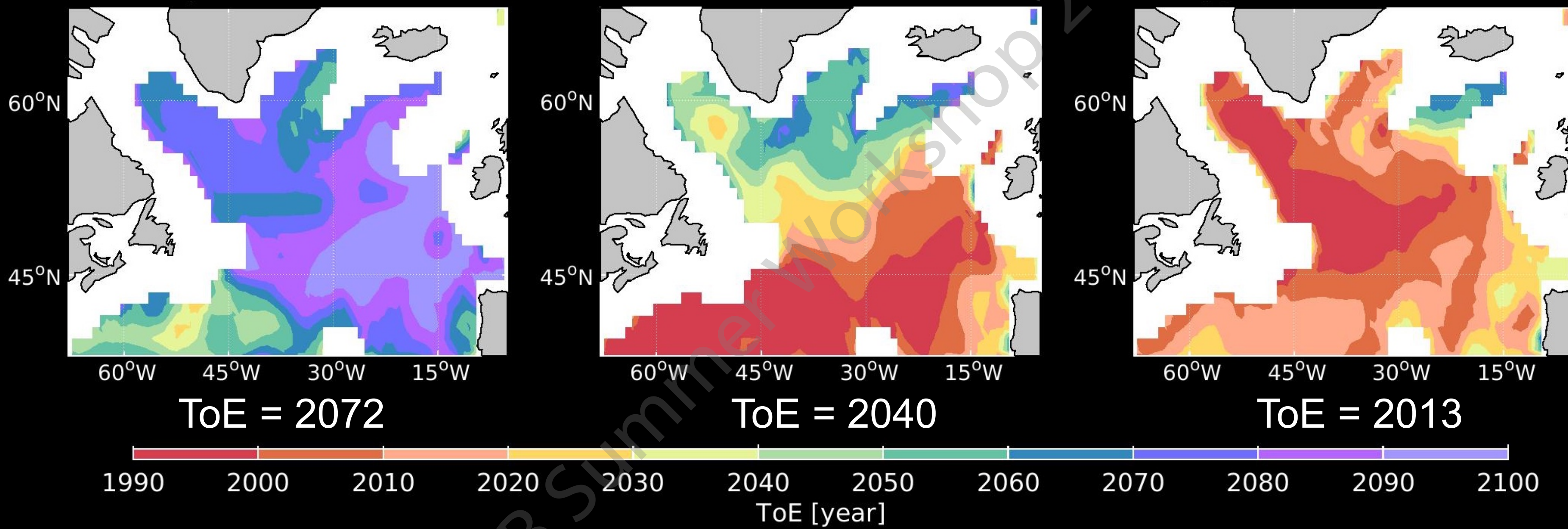


Temperature

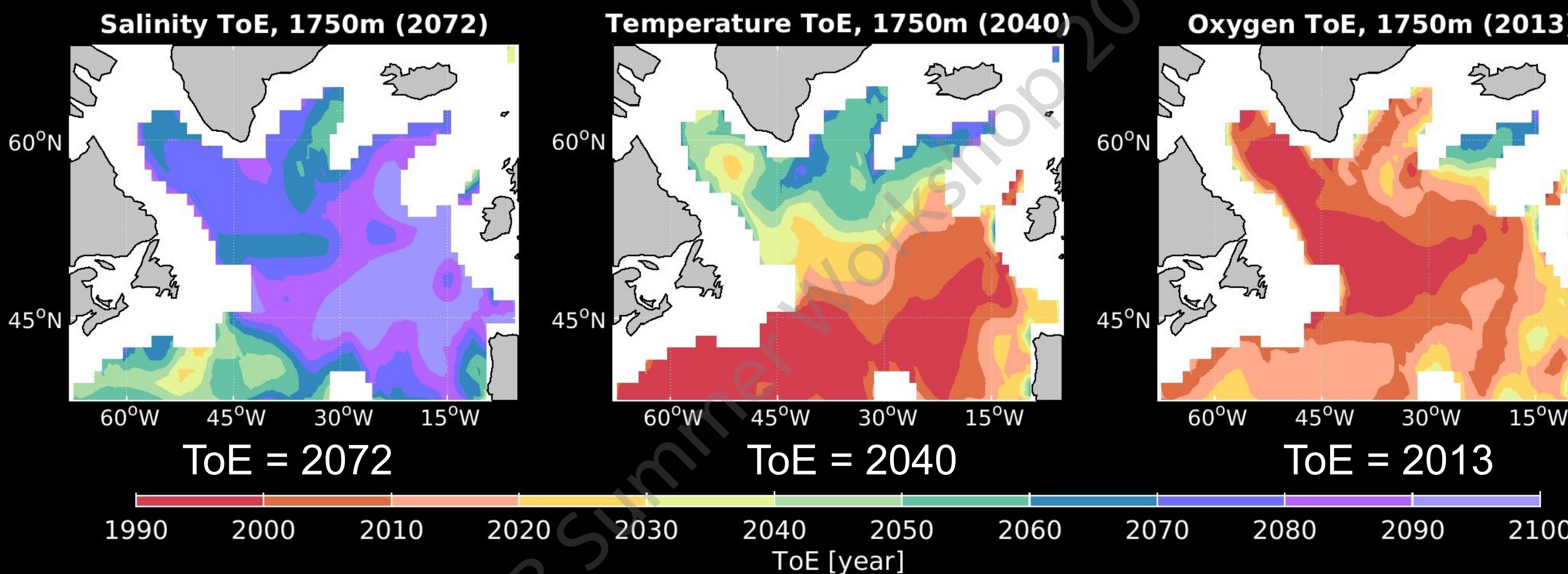
Salinity

Oxygen

ToE (1750m)



ToE (1750m)



Forced changes	Salinity	Temperature	Oxygen
Warming		✓	✓
Circulation structure	✓	✓	✓
Ventilation rate			✓

Mechanisms identification

Observations (oxygen, temperature, salinity)

› GLODAPv2 (Lauvset et al., 2017)

› WOD (World Ocean Database)

› More recent NASPG data (Rhein et al. 2017)

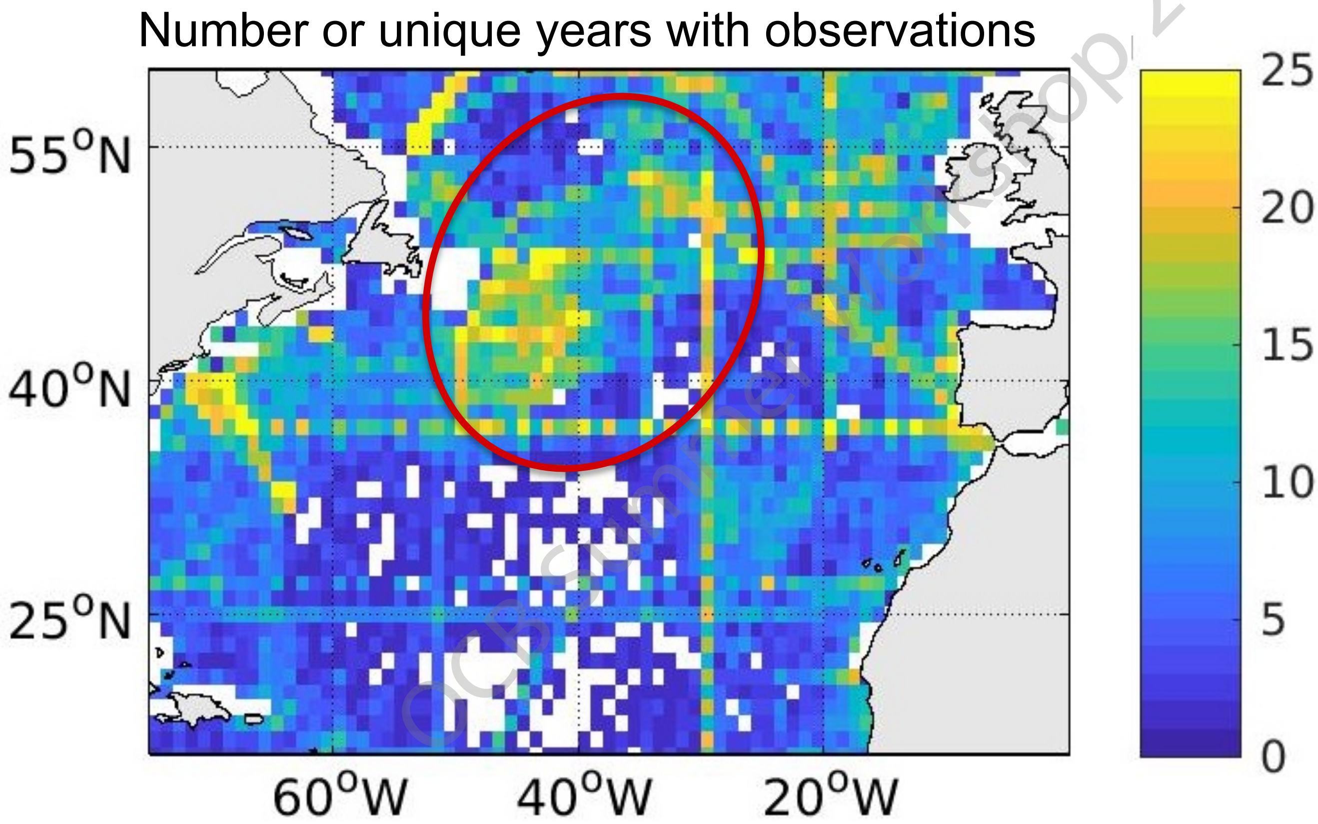
Models

› Offline, forced Ocean Bigeochemical Physical model (diagnose mechanisms)

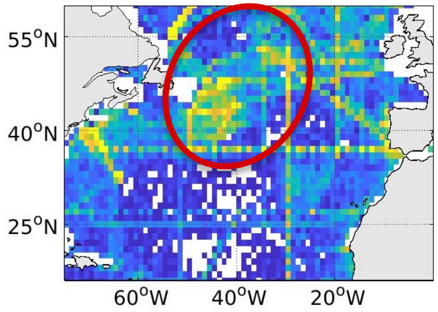
› CMIP5 ESM models (Projections, Historical-RCP8.5, 1971-2100)

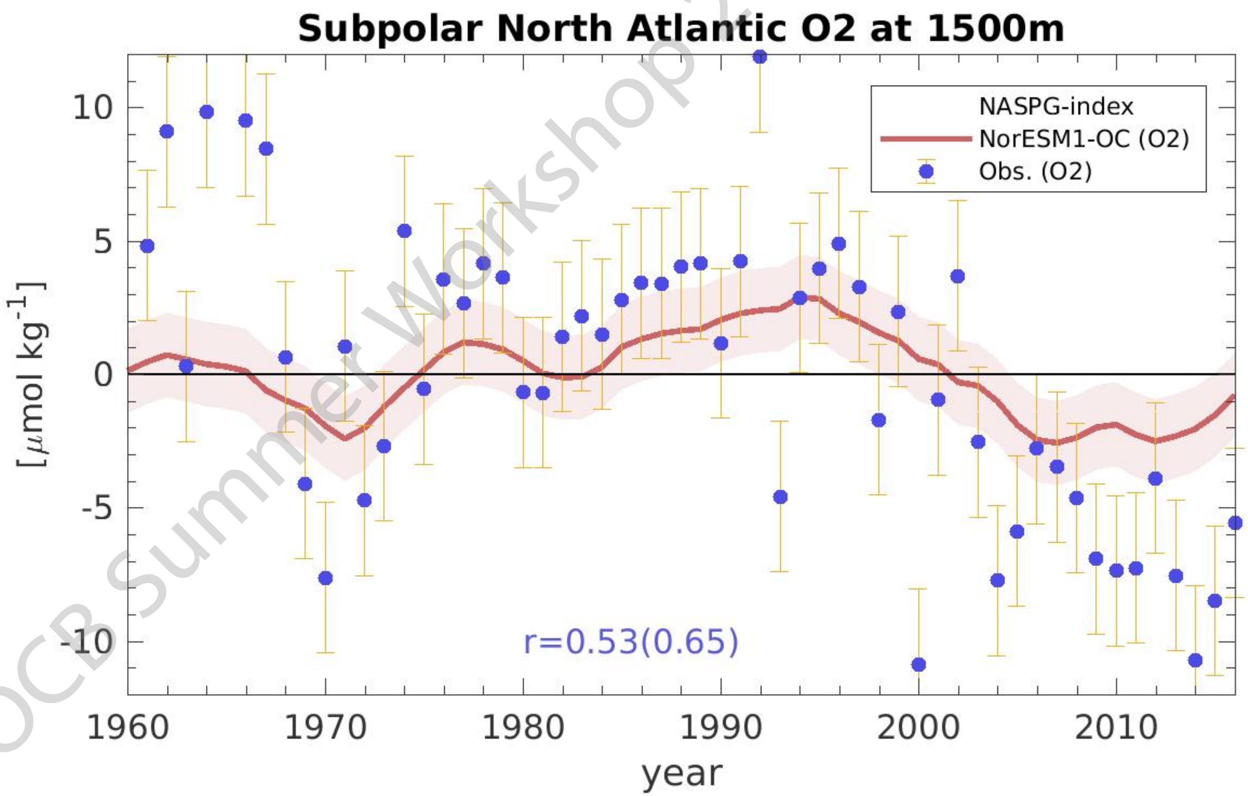
- CESM1-BGC
- GFDL-ESM2G
- GFDL-ESM2M
- HadGEM2-CC
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- MPI-ESM-LR
- NorESM1-ME

Observational coverage (1961-2016)



Temporal variability of interior (1500m) NASPG oxygen





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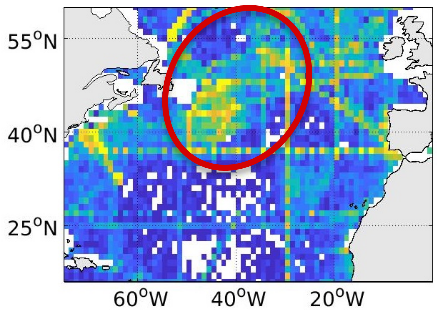
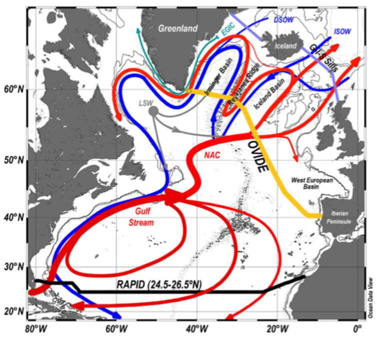
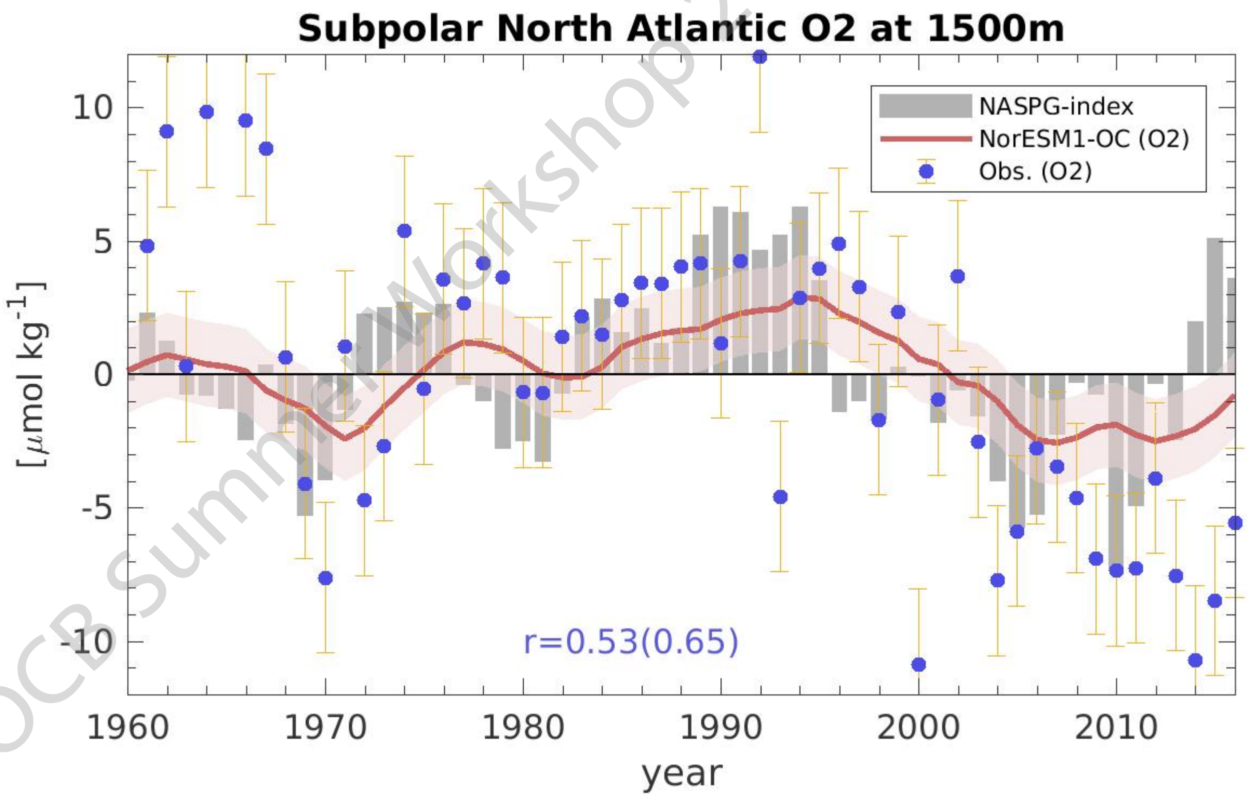
Temporal variability of interior (1500m) NASPG oxygen

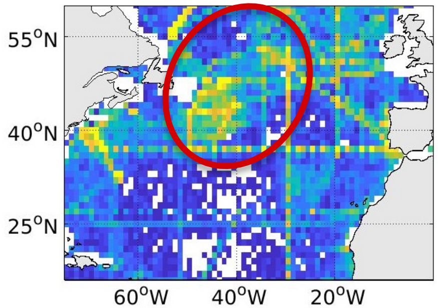


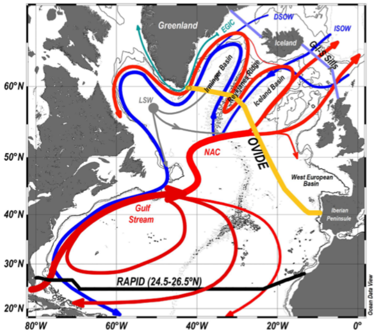


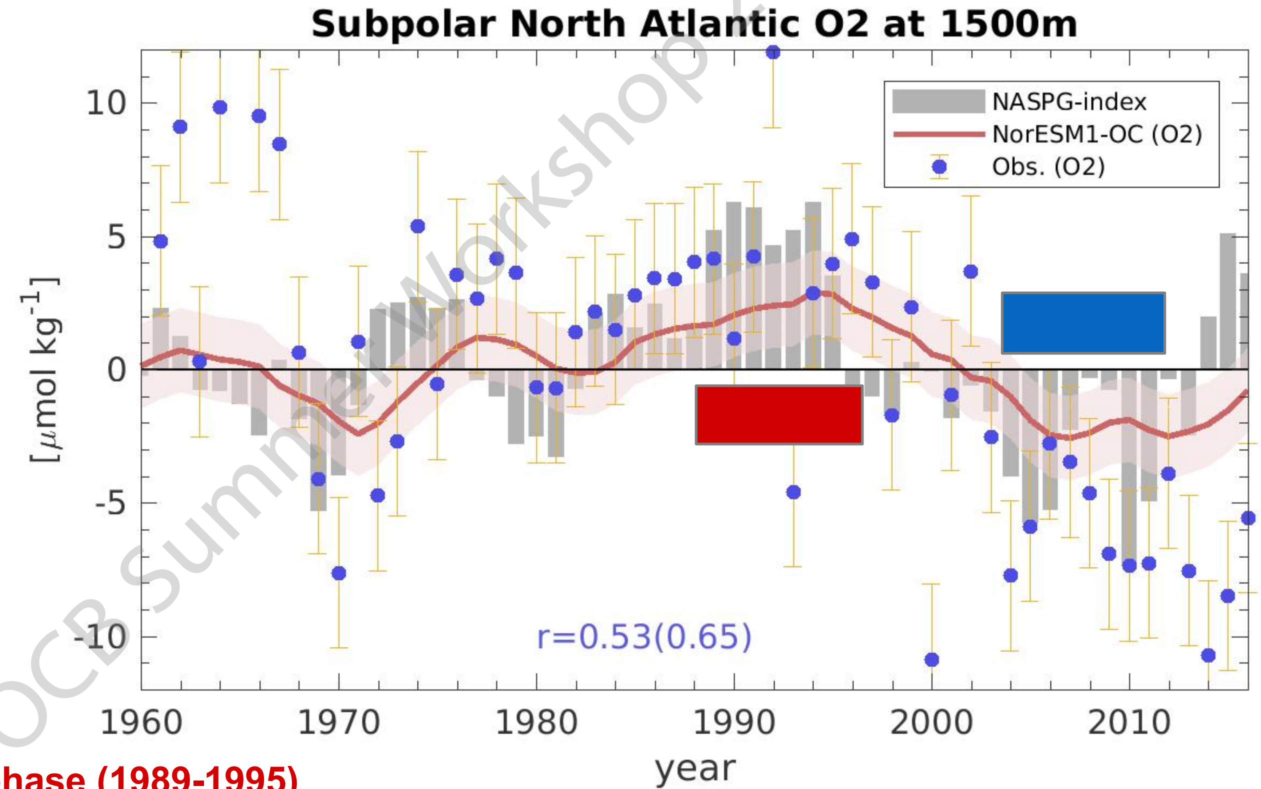


UNIVERSITY OF BERGEN uni Research NERSC Nansen Center, Bergen HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH

Temporal variability of interior (1500m) NASPG oxygen



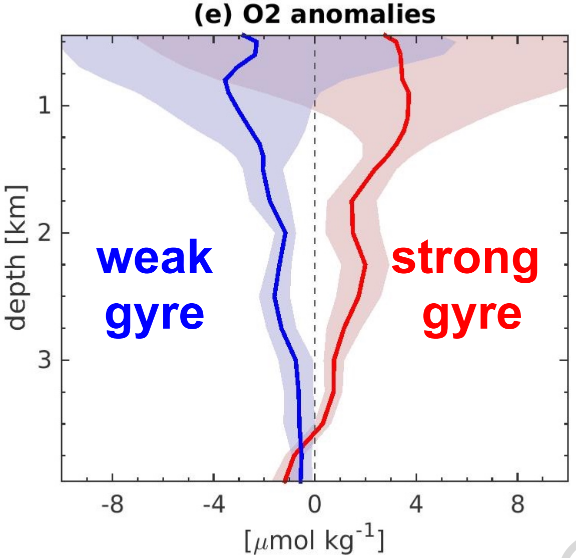


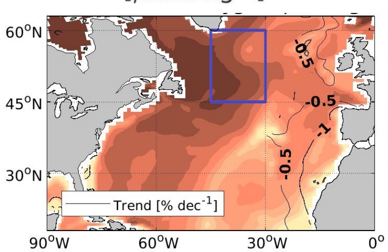


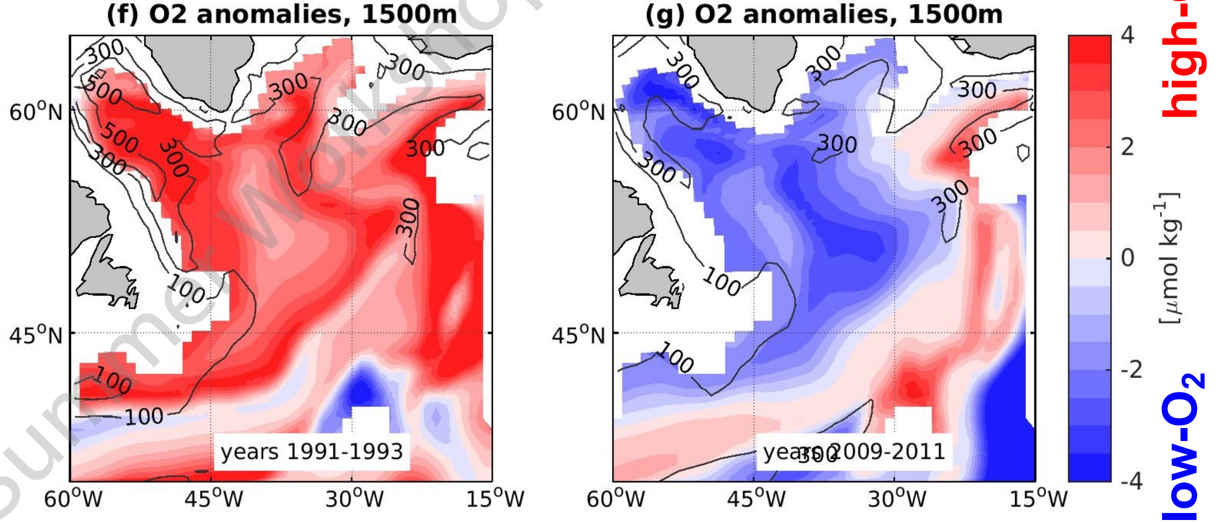
Positive NASPGi phase (1989-1995)

Negative NASPGi phase (2004-2011)

Mechanistic understanding contrasting NASPG regimes







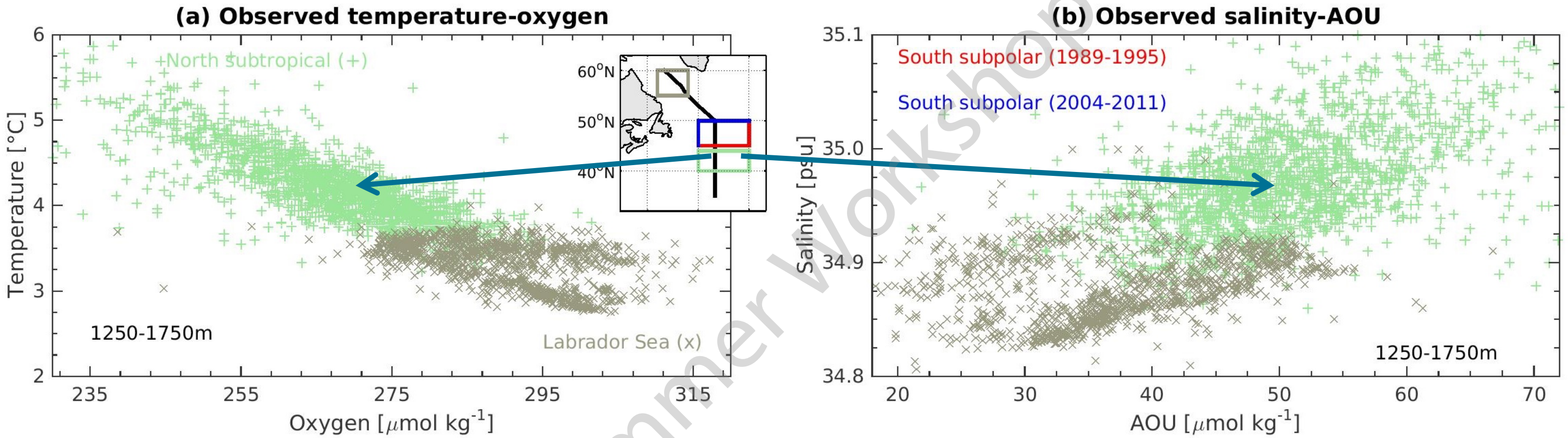
Positive NASPGi phase (1989-1995)

Negative NASPGi phase (2004-2011)

Black-contours = Mixed layer depth

Water mass properties for contrasting NASPG regimes

Observations



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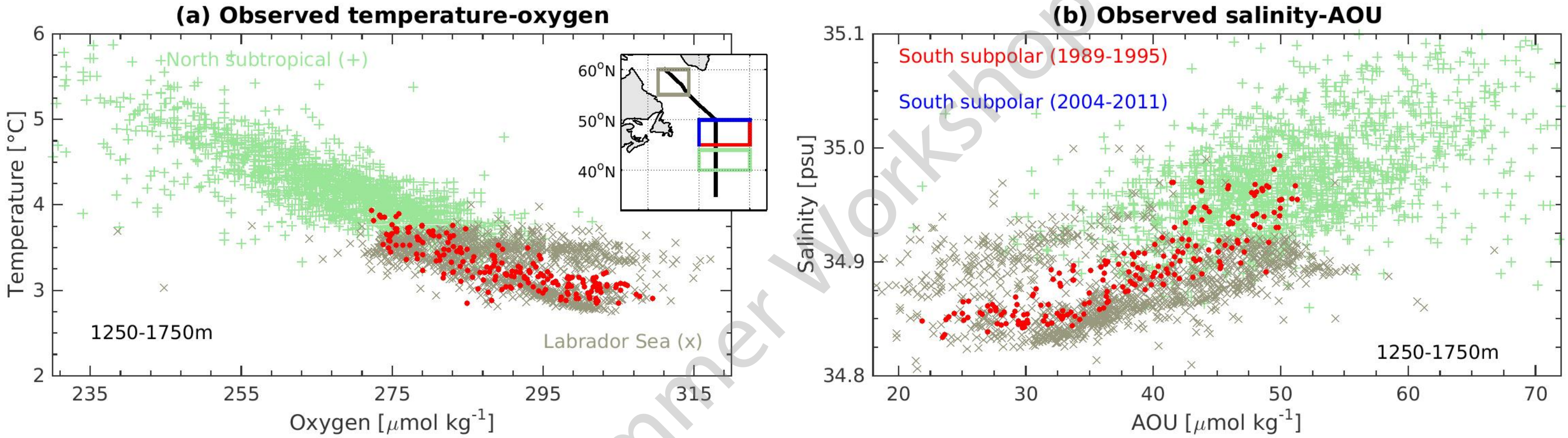
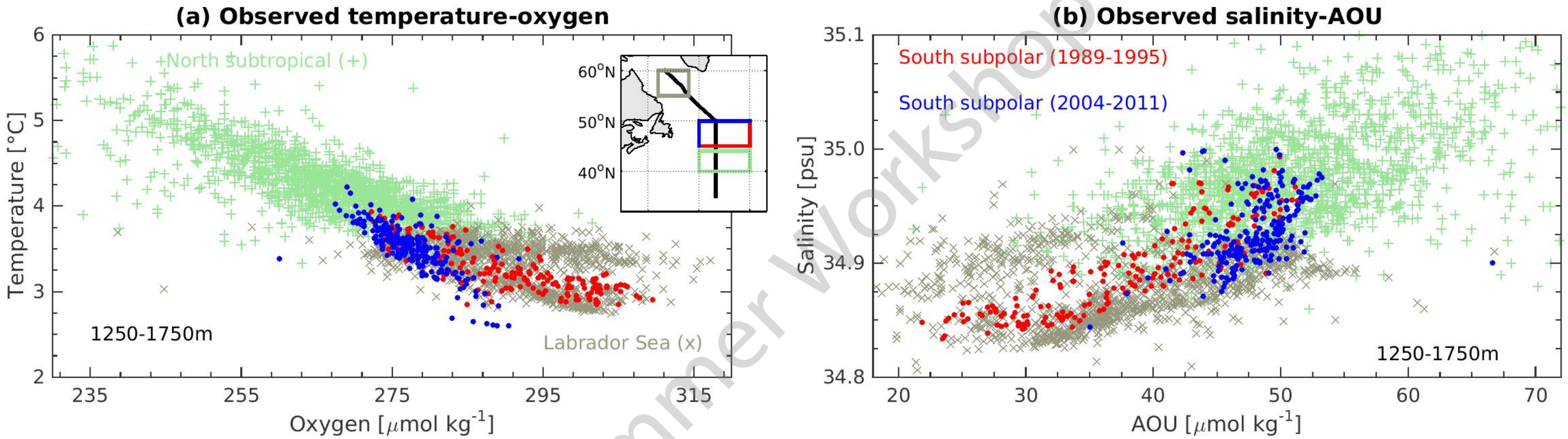
Water mass properties for contrasting NASPG regimes

Observations

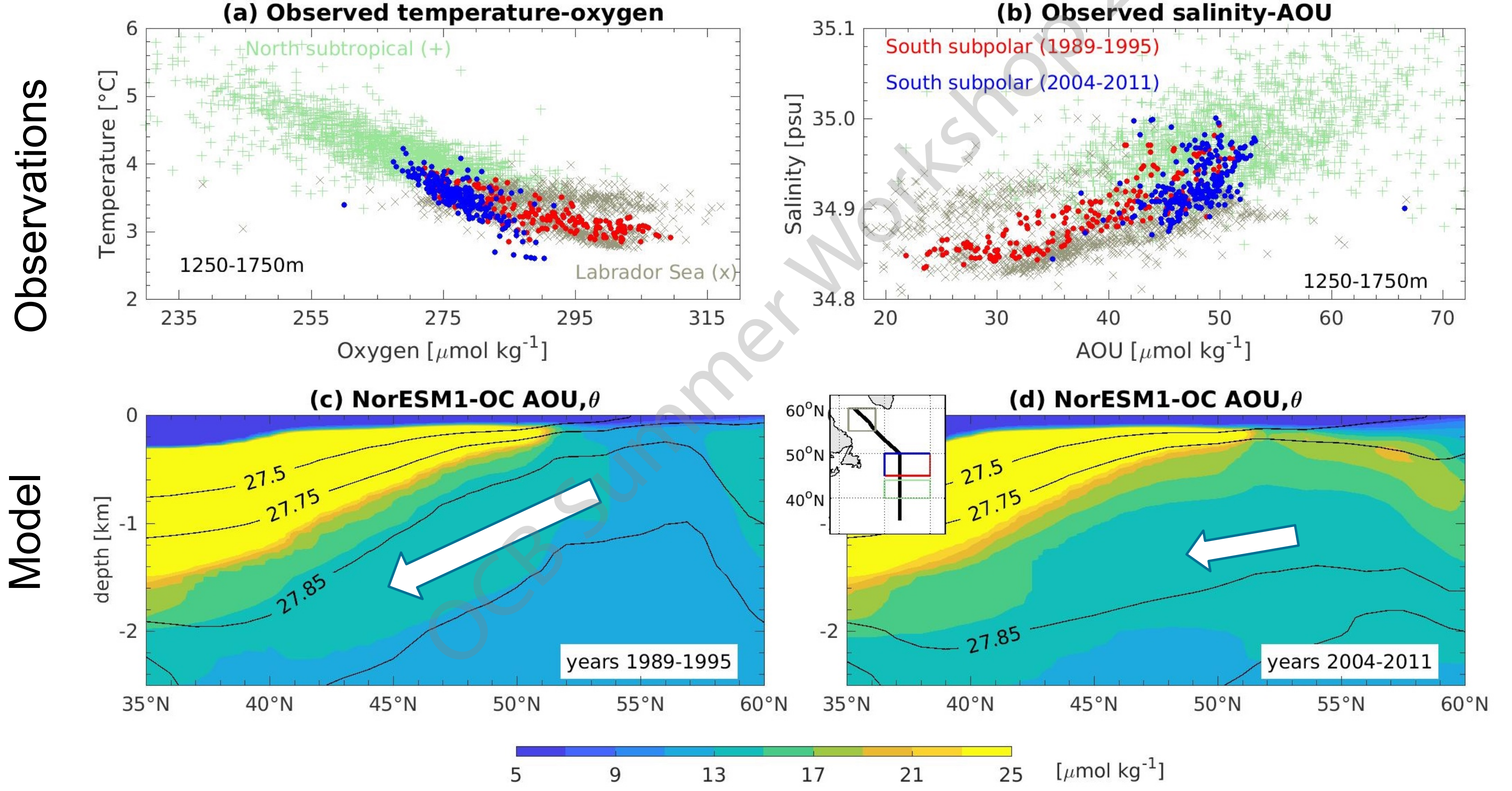


Water mass properties for contrasting NASPG regimes

Observations



Water mass properties for contrasting NASPG regimes

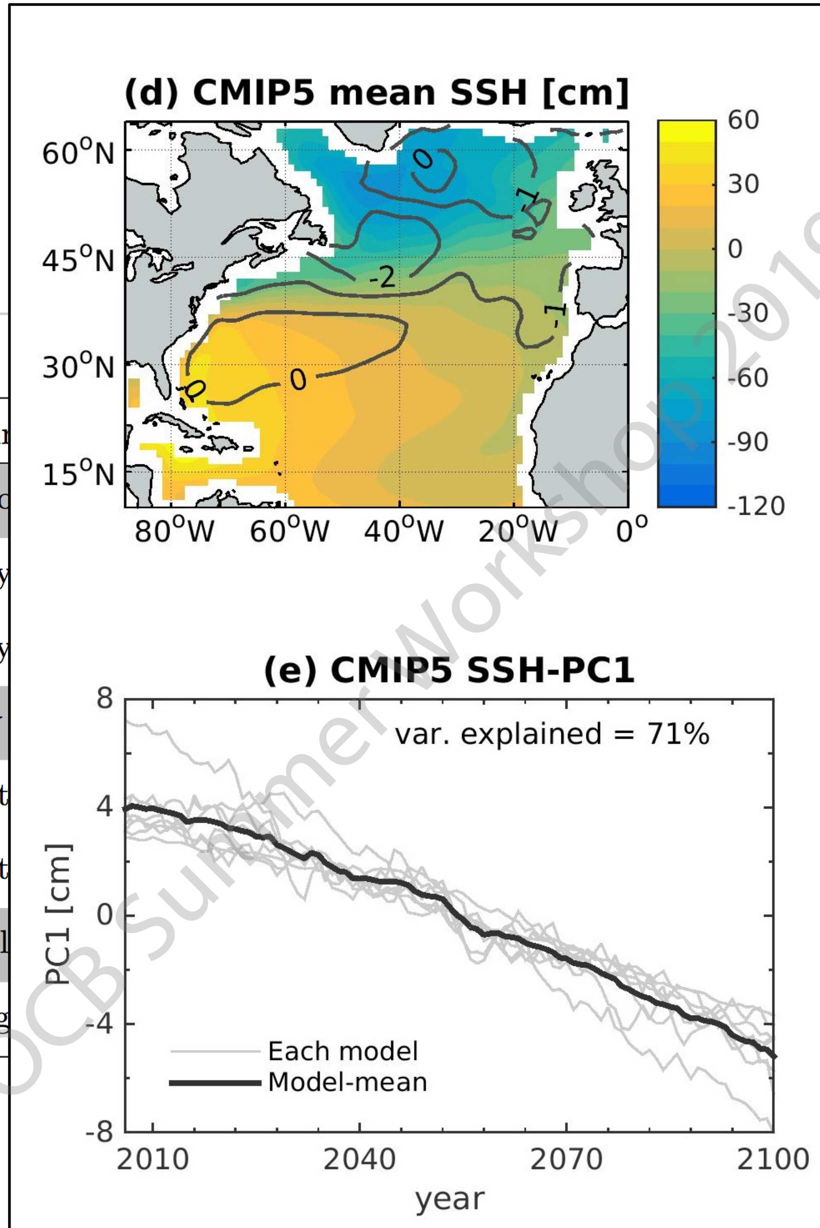


Interior NASPG oxygen multi-decadal variability

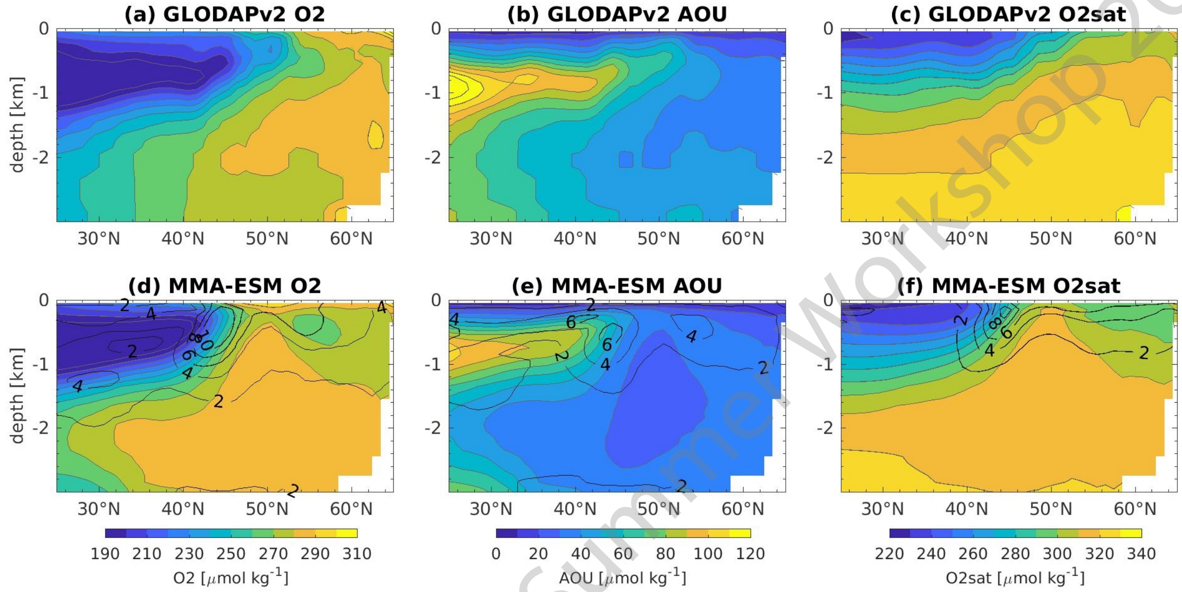
Strong gyre strength (+)	Deep Labrador Sea mixing	(+) advection of colder / newly ventilated	Higher saturation and Low AOU
Weak gyre strength (-)	Stratified Labrador Sea	(-) advection of colder / (+) old water mass	Mixed of low/high saturation and High AOU

Projections

ESM name	Modelin		References
CESM1-BGC	Dept. c	SA	*Lindsay et al.* (2014)
GFDL-ESM2G	Geophy		*Dunne et al.* (2013)
GFDL-ESM2M	Geophy		*Dunne et al.* (2013)
HadGEM2-CC	Hadley		*Collins et al.* (2011)
IPSL-CM5A-LR	L'Instit		*Séférian et al.* (2013)
IPSL-CM5A-MR	L'Instit		*Dufresne et al.* (2013)
MPI-ESM-LR	Max Pl		*Ilyina et al.* (2013)
NorESM1-ME	Norweg		*Tjiputra et al.* (2013)

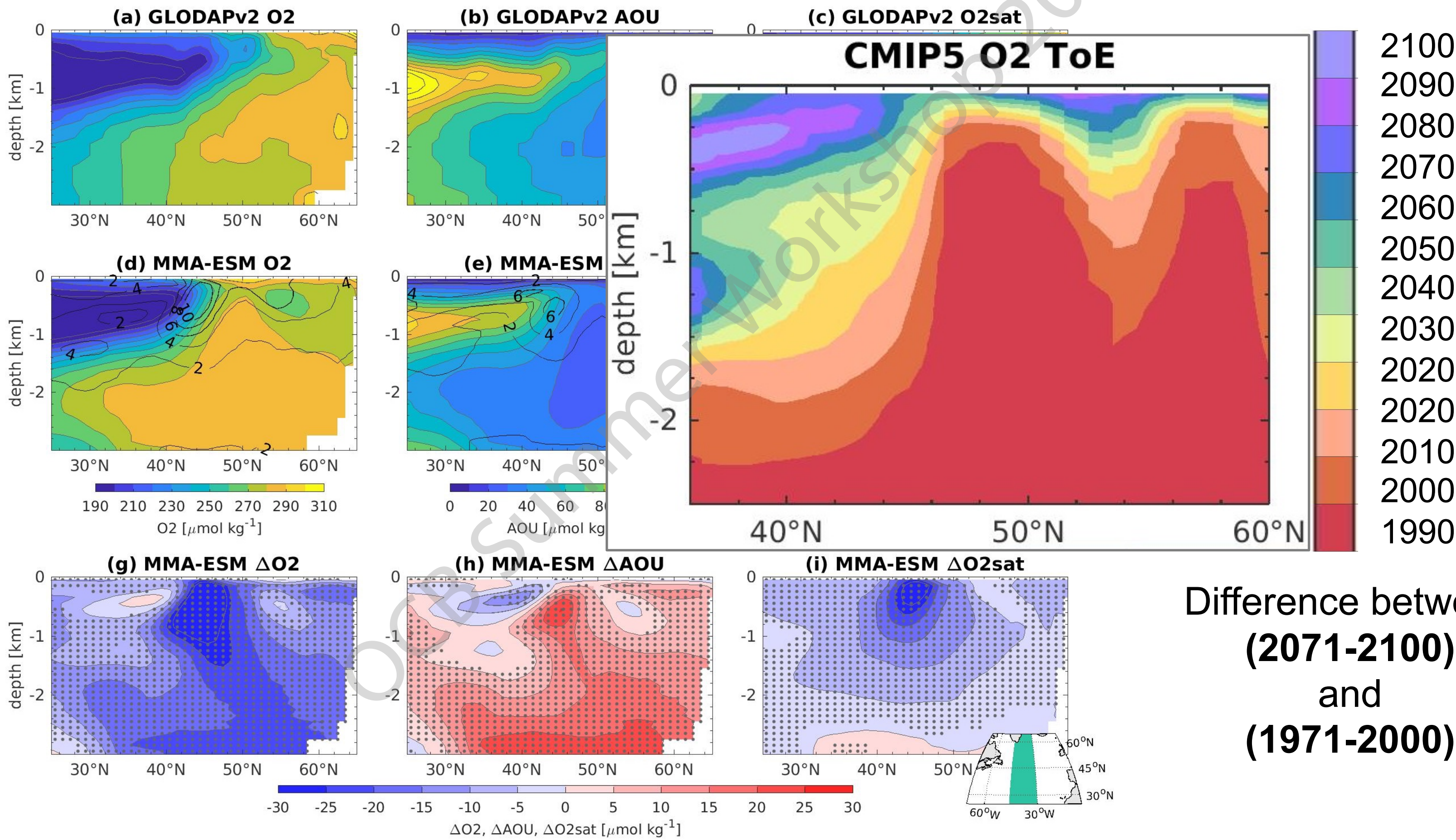


Projections (CMIP5 models)



MMA-ESM = CMIP5 models

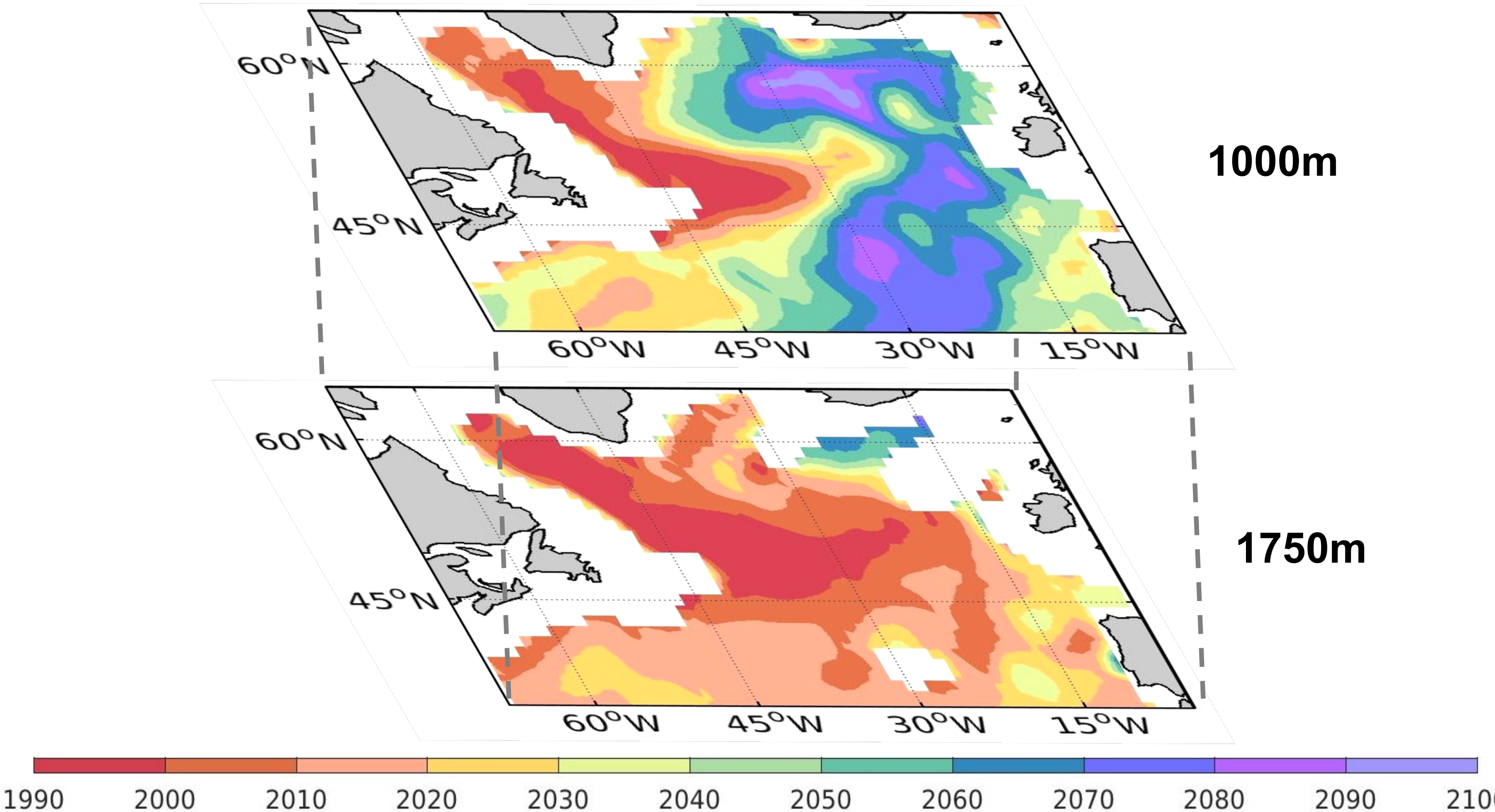
Projections (CMIP5 models)



Difference between
(2071-2100)
and
(1971-2000)

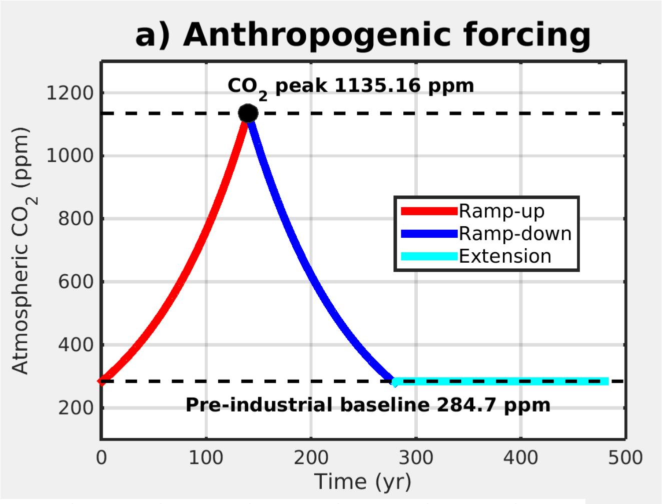
Tjiputra et al. (2018)

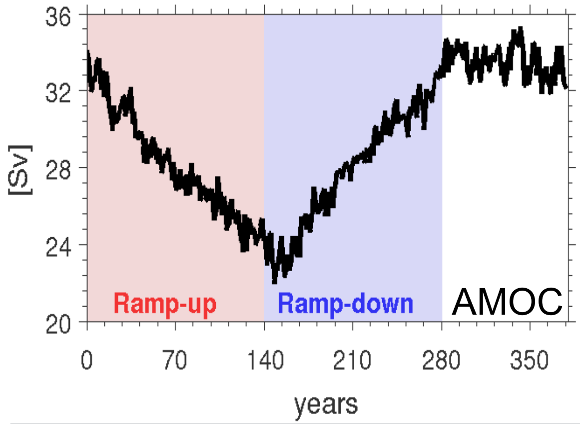
Time of Emergence (ToE)

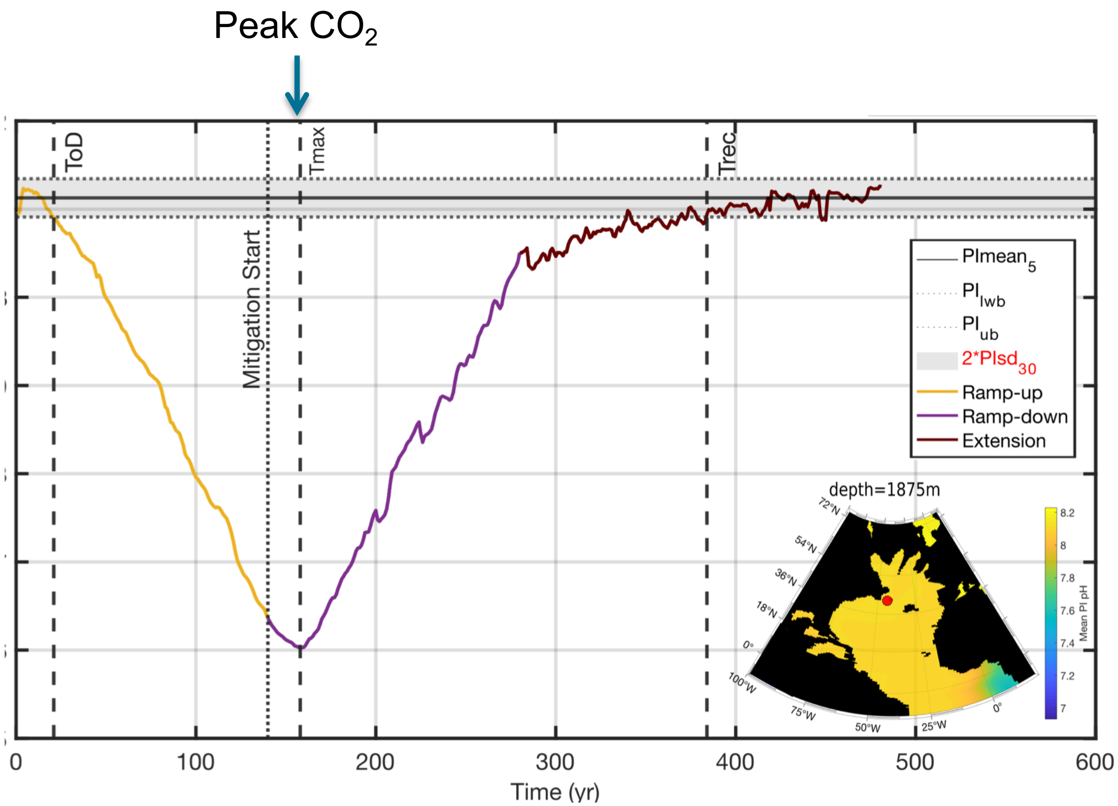


Tjiputra et al. (2018)

Detectability of circulation recovery





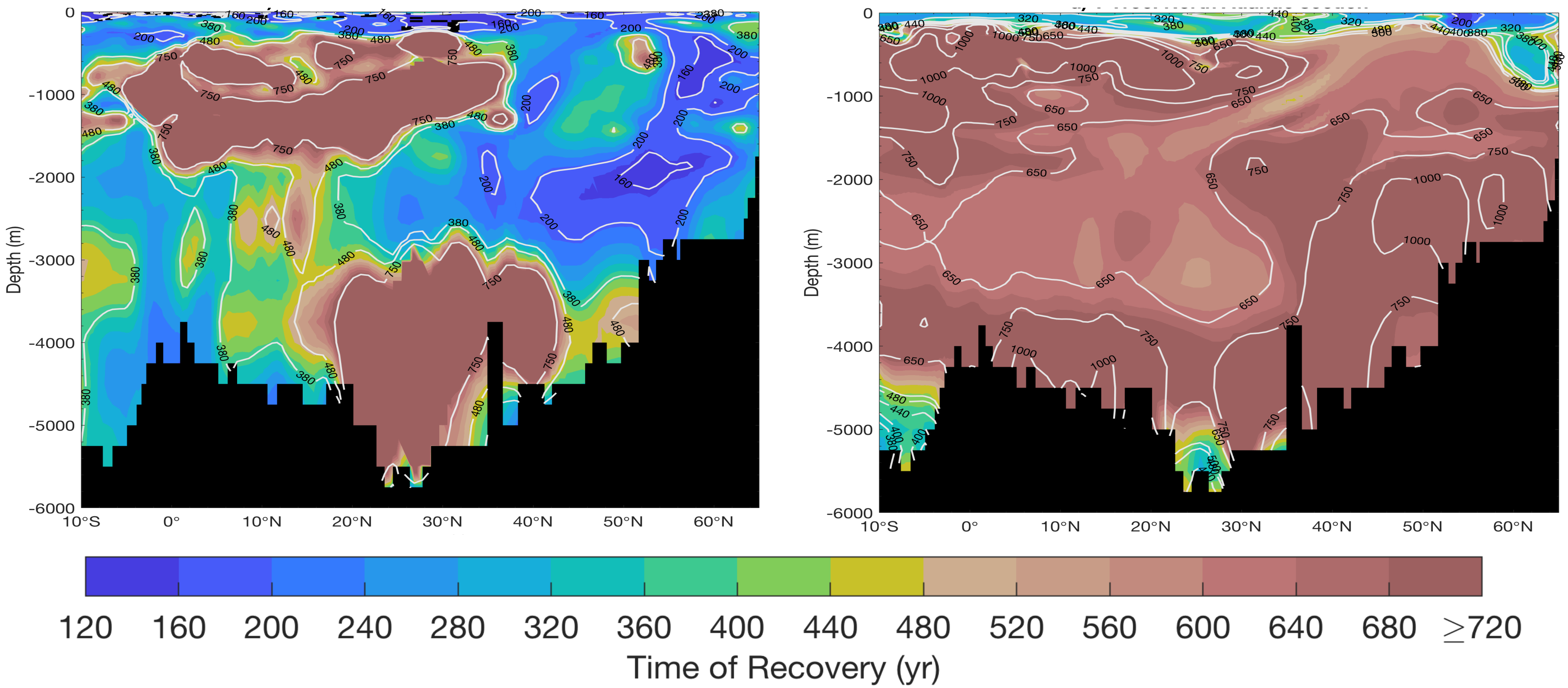


Bertini and Tjiputra (in prep.)

Detectability of circulation recovery (ToR = Time of Recovery)

AOU-ToR North Atlantic section

Temperature-ToR North Atlantic section



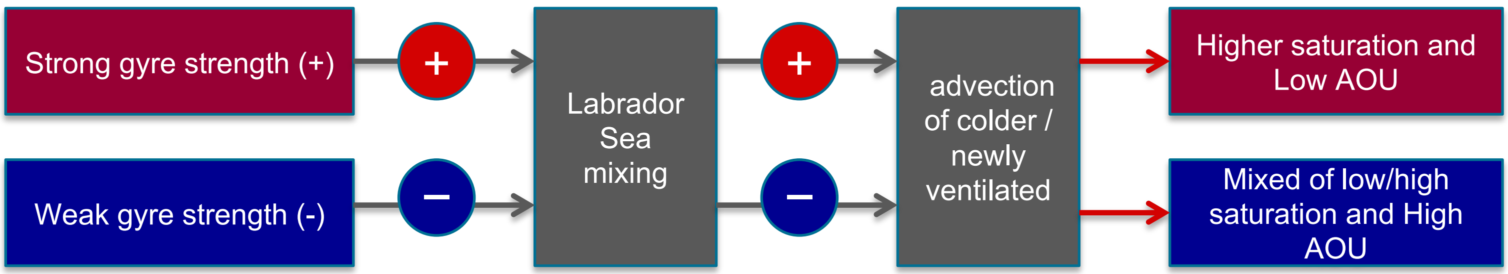
Bertini and Tjiputra (in prep.)

Can we use oxygen to provide early warning for (interior) circulation changes?

How soon can the projected future circulation changes be detectable?

Summary

› On multidecadal timescales, subpolar gyre strength drives the interior NASPG oxygen.



› Future projections:

- Steady slows down in NASPG strength over the 21st century
- This leads to deoxygenation in the interior subpolar North Atlantic, twice of the global mean
- Time of emergence of O_2 signal is in early 21st century, earlier than T and S
- Interior oxygen can be used to detect anthropogenic-induced circulation change and recovery

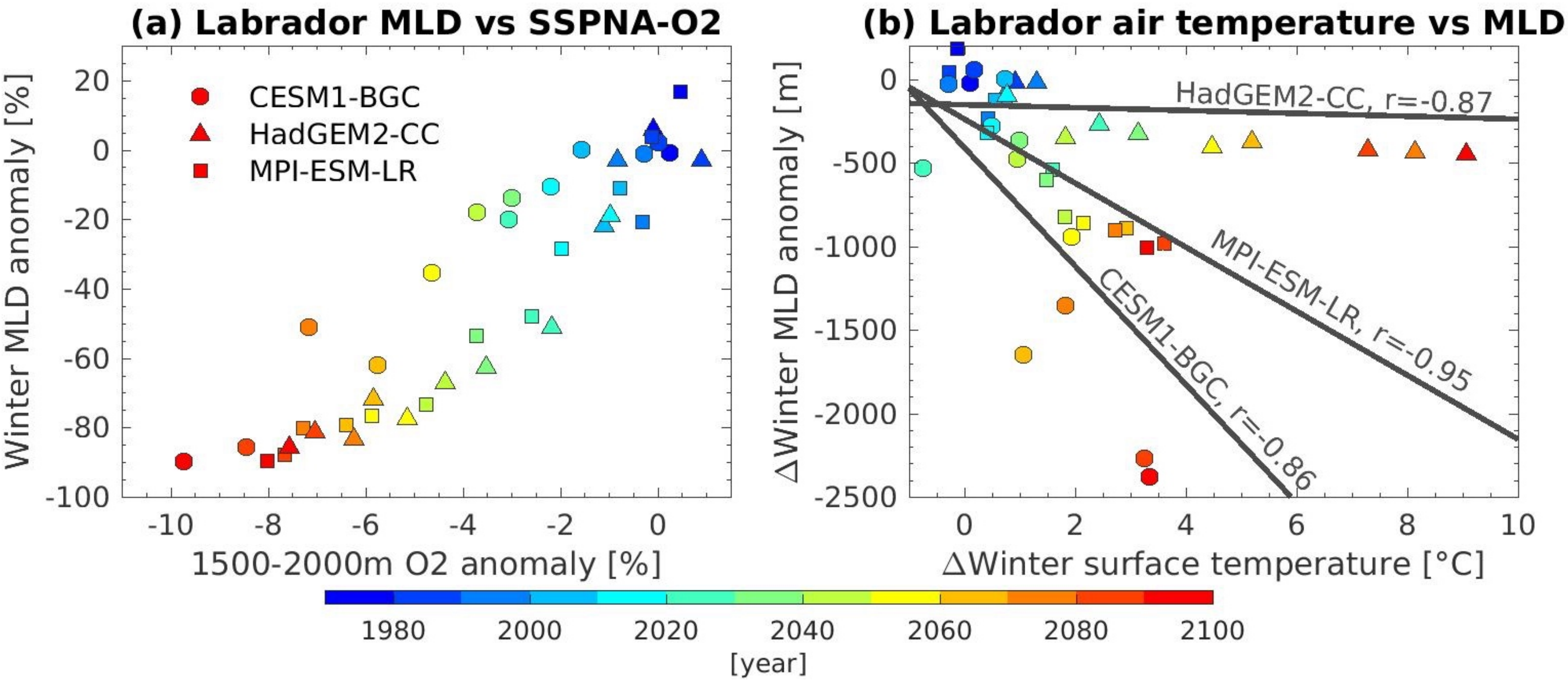
Tjiputra et al. (2018), Mechanisms and early detections of multidecadal oxygen changes in the interior subpolar North Atlantic, *Geophysical Research Letters*, 45, doi:10.1029/2018/GL077096.

Discussion points

- Our confidence in oxygen as proxy for circulation strongly depends on the assumption that Redfield ratio holds today and into the future. Is this reasonable?

- With our advanced understanding in oxygen-physical relationship, should modellers guide the observational community or be more involved in designing future ocean monitoring strategy?

Labrador MLD and NASPG oxygen relationships



Projections (best-performing ESMs)