An estimate of the global dissolved oxygen trend for the last 50 years

Open ocean and coastal deoxygenation: assessing variability and trends

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2022 53rd Ocean Liege Colloquium

Background:

- Global upper ocean lost **approximately 2%** of O_2 inventory in the last 50 years (Schmidtko et al., 2017; Ito et al., 2017)

- Earth System Models struggle to reproduce this trend both in magnitude and spatial pattern (Stramma et al., 2012; Bopp et al., 2013; Long et al., 2017; 2019; Oschlies et al., 2018)

- Both observations and models are incomplete – but they are complementary

Outline:

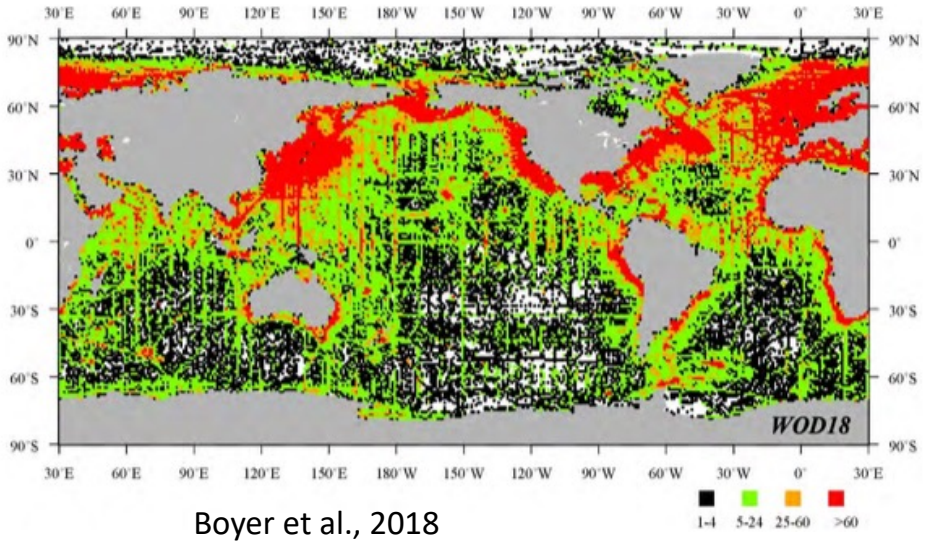
- **Estimate the global O_2 inventory trend** from the World Ocean Database (WOD, Boyer et al., 2018)
  - Optimal interpolation

- **Compare CMIP6 models and observations**
  - **Subsample model O_2 field according to WOD sampling pattern**
  - **Assess sampling bias by comparing subsampled and full model**
  - Climatology
  - Deoxygenation trends
  - Representation of regional trends

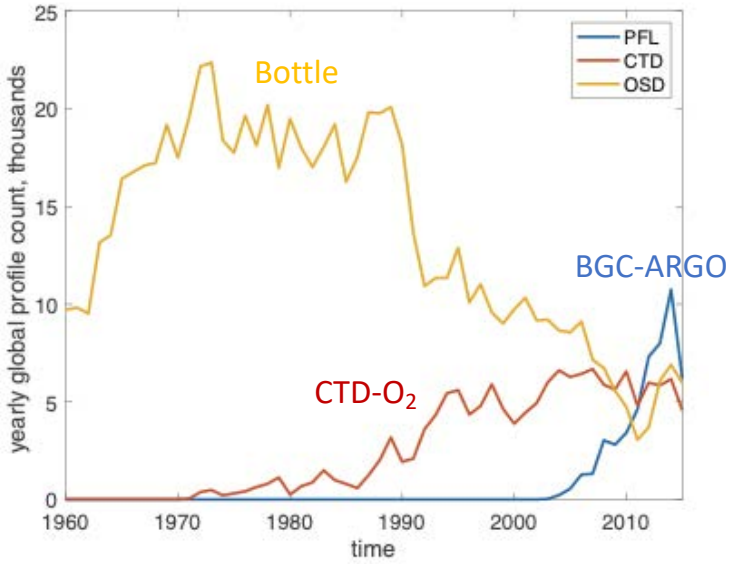
Method:

- Data Source: WOD select
- Observational pattern, sampling density and measurement technique evolve over time

Number and distribution of bottle data from WOD 2018

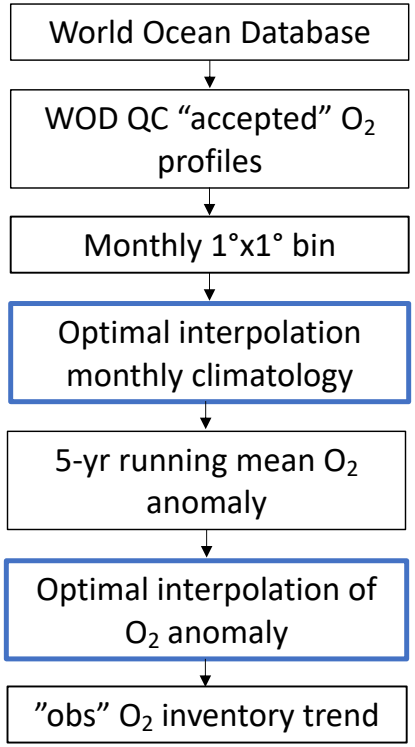


Boyer et al., 2018



Method: objective mapping of historical O_2 data

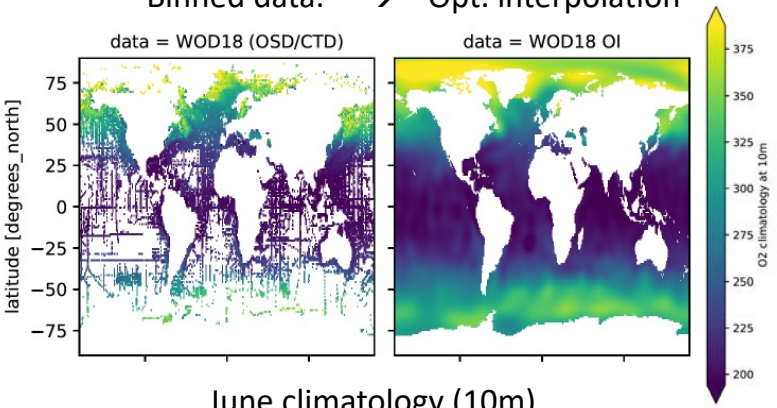
- **Bottle (1965-)** and **CTD (1987-)**
- **Optimal Interpolation (OI)** from discrete to grid
- **Monthly climatology** (gridded)
- **O_2 anomaly:** OI of the 5-year running mean of anomaly field



Optimal interpolation (Bretherton et al., 1976; Davis, 1985; Daley 1991; Wunsch 1996)

Gaussian covariance function is assumed

Binned data. → Opt. interpolation



June climatology (10m)

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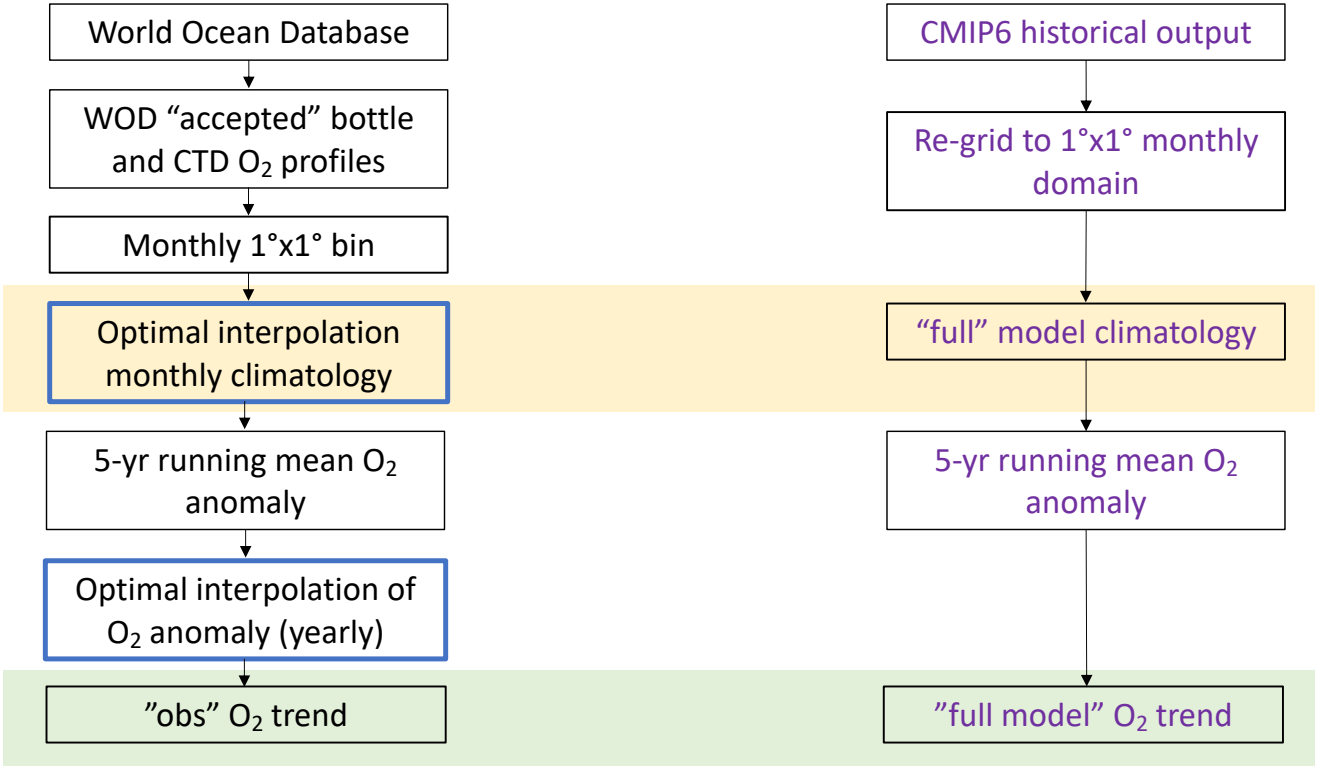

Method: objective mapping of historical O_2 data

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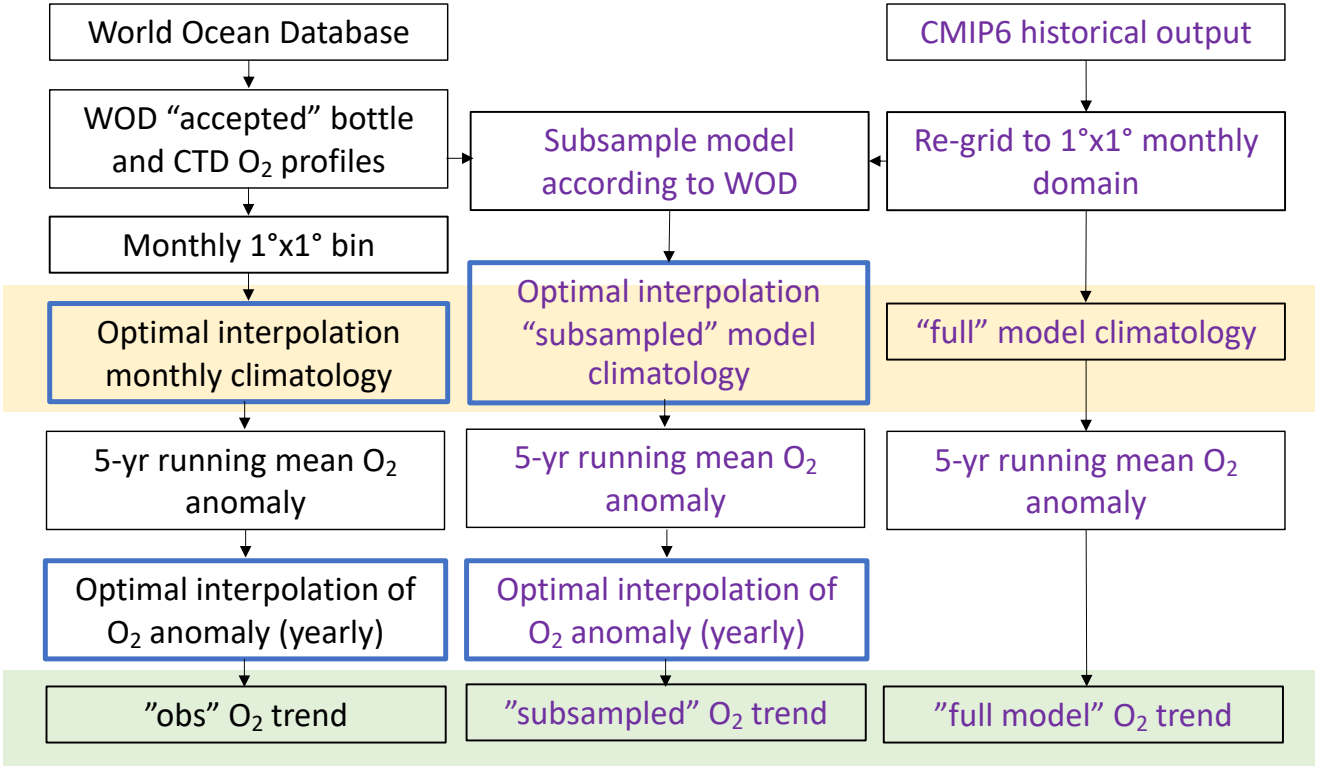
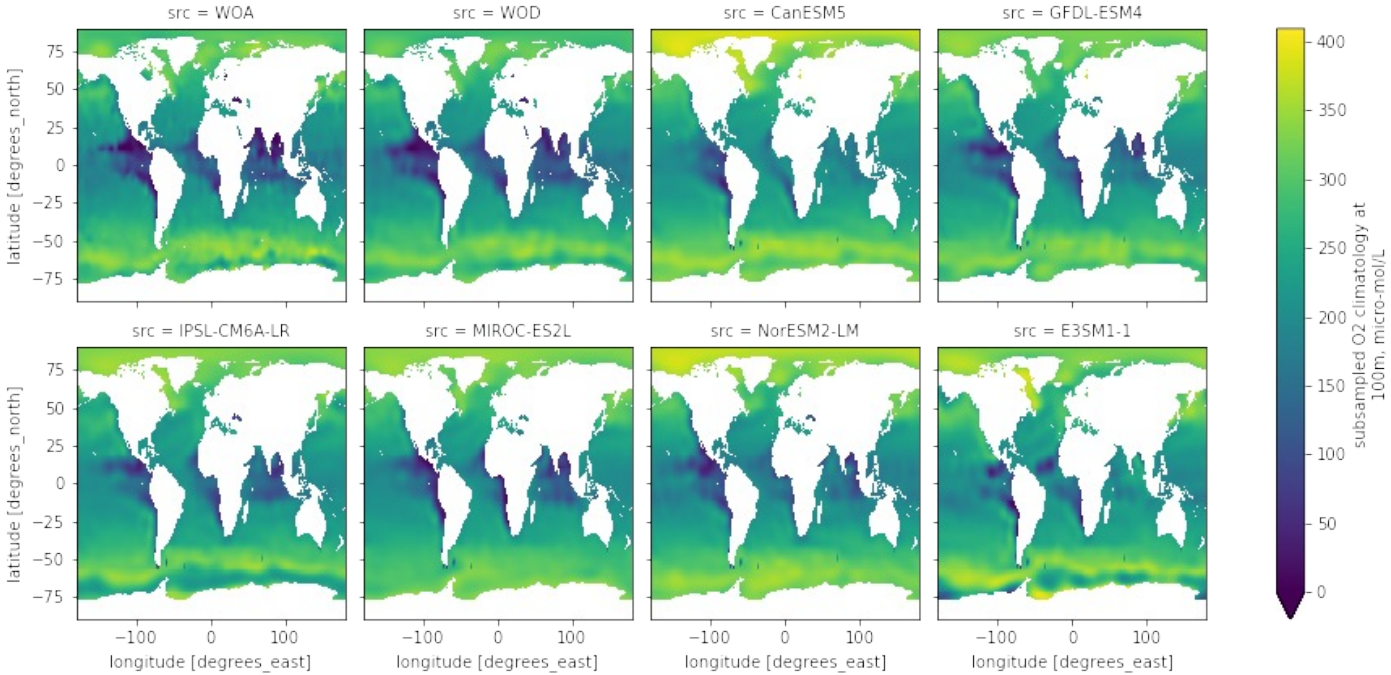


Result: CMIP6 models' climatology

- CanESM5
- GFDL-ESM4
- IPSL-CM6A-LR
- MIROC-ES2L
- NorESM2-LM
- E3SM1-1

December climatology at 100m depth : subsampled and gap-filled



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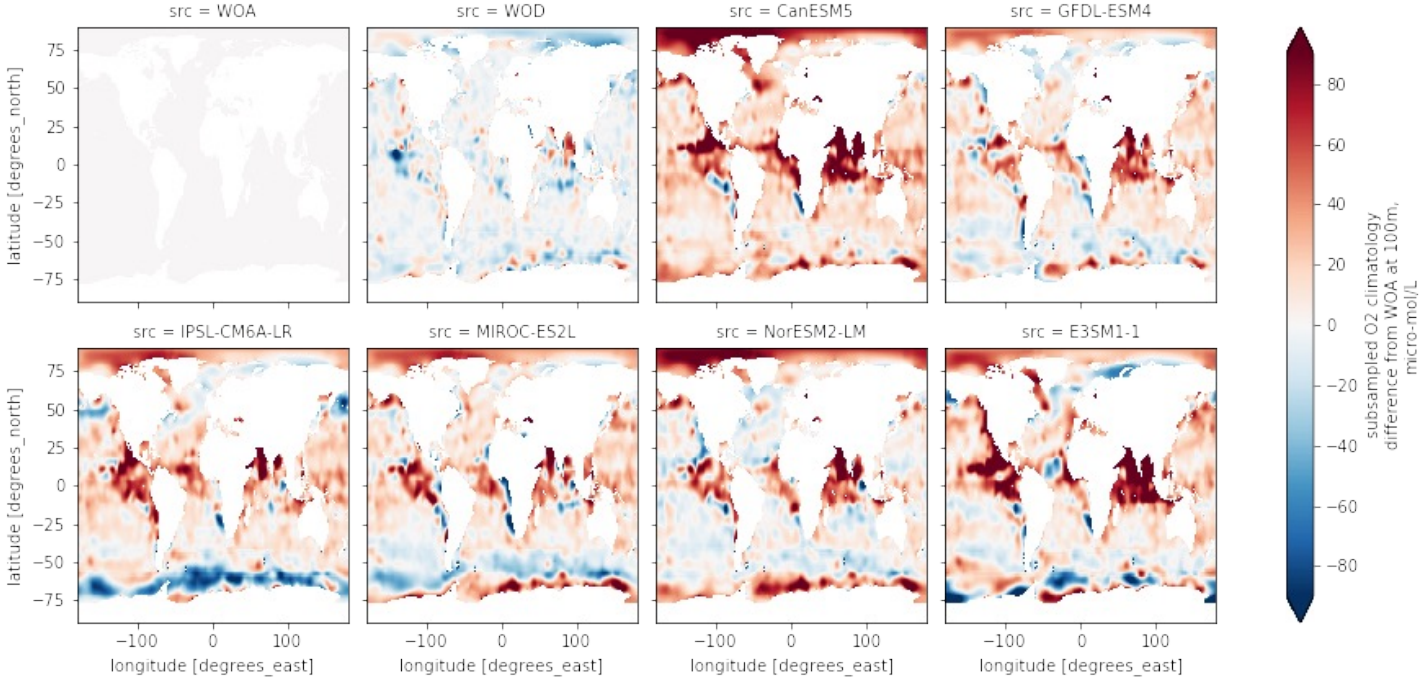
December climatology at 100m depth : subsampled and gap-filled, difference from WOA



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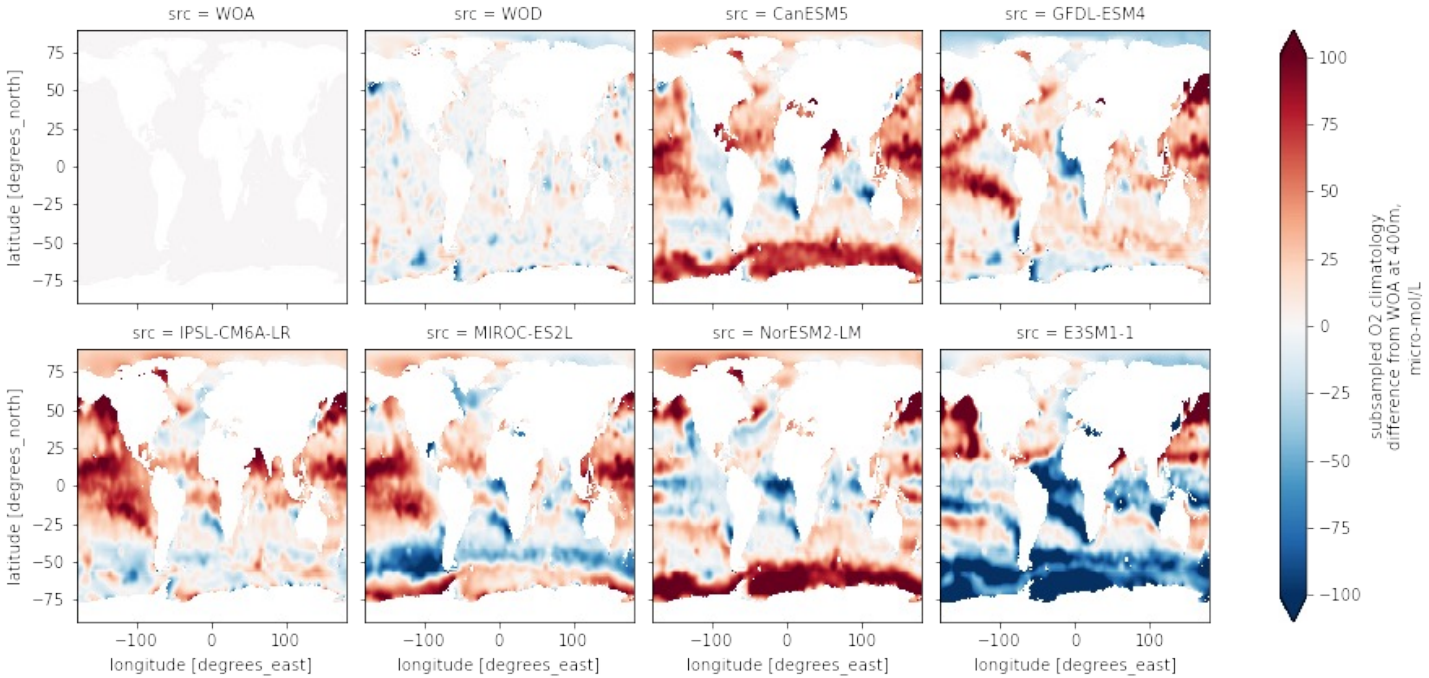
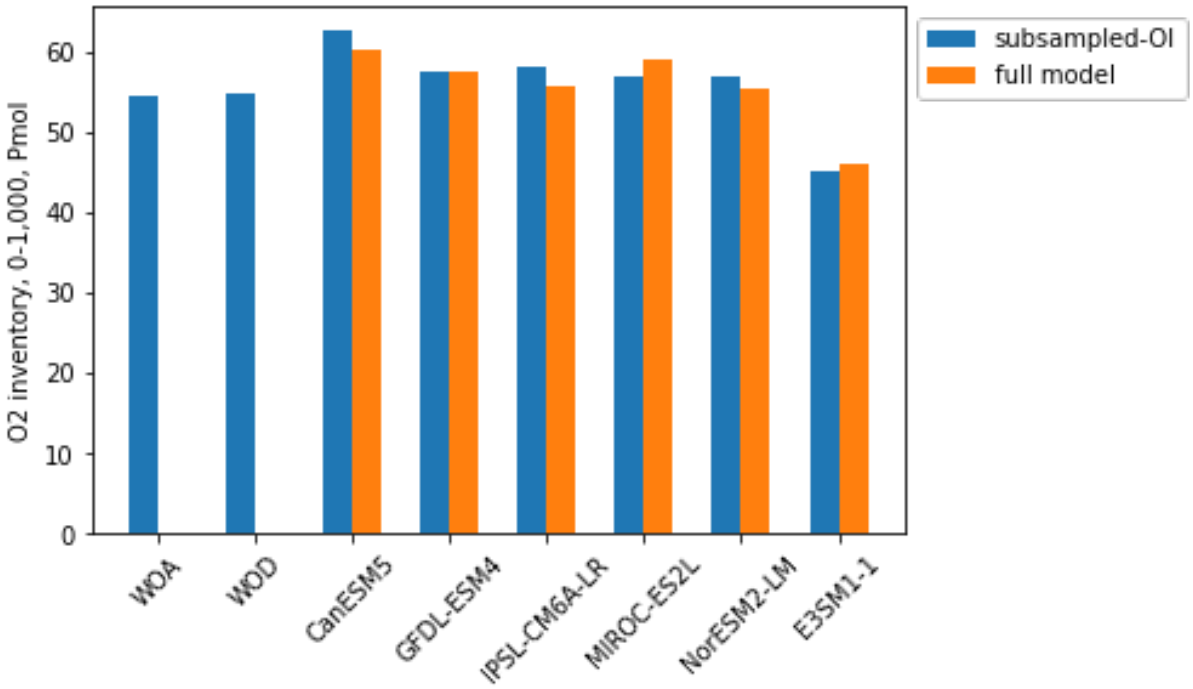
December climatology at 400m depth : subsampled and gap-filled, difference from WOA



Result: Climatological global O_2 inventory

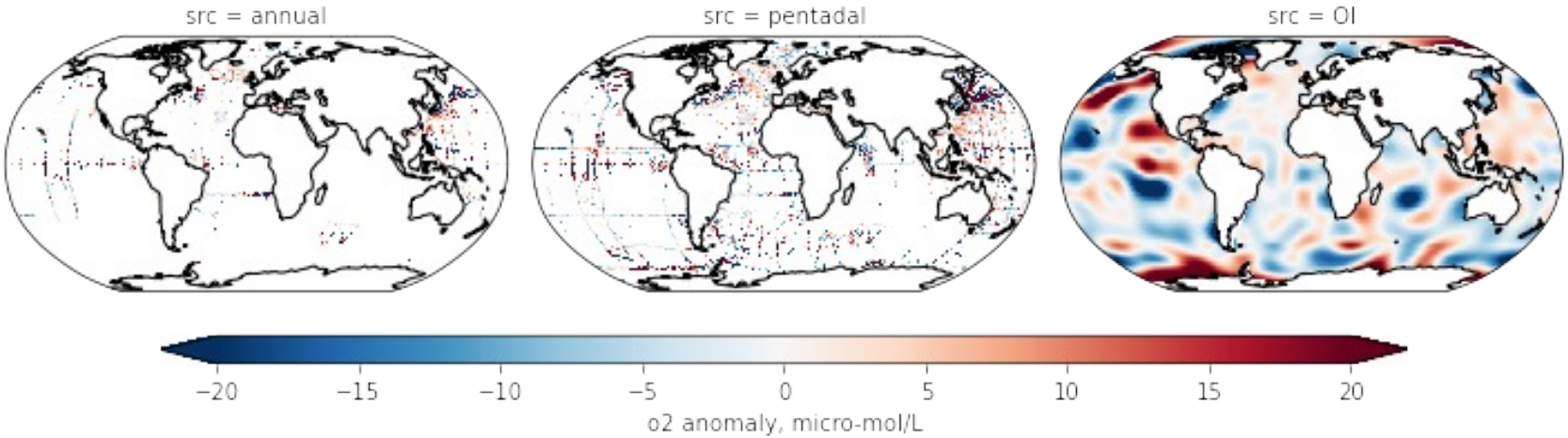
- WOA climatological inventory ~ 55Pmol
- Model estimates range ~ 46 - 60Pmol
- *Subsampled model O_2 inventories are within 4% of the full model value*

0-1,000m O_2 inventory (annual mean climatology)



Result: gap-fill by running mean and optimal interpolation

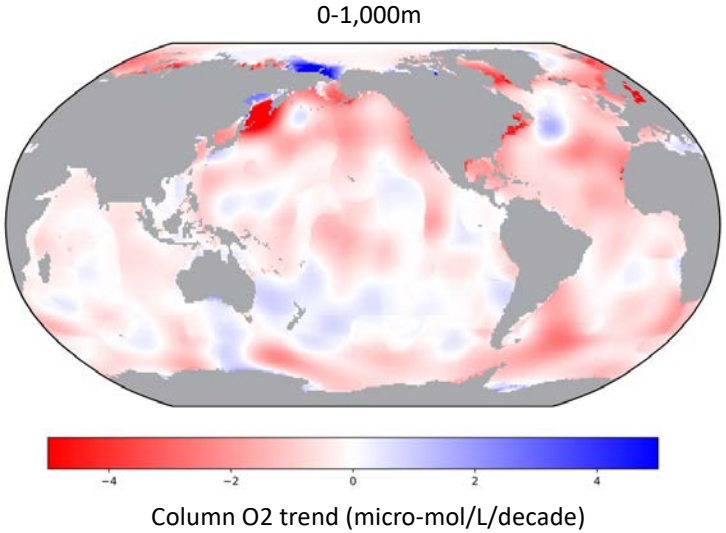
Binned O_2 anomaly from Year 1991 → 5-year running mean of the O_2 anomaly → Gap-filled O_2 anomaly field by optimal interpolation



Year 1991

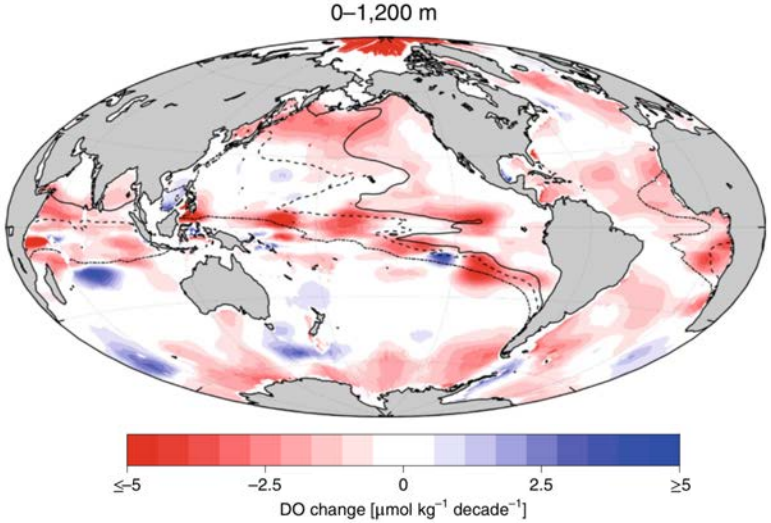
Result: Global O_2 trend map

This study



-162 ± 40 Tmol/decade,
approx. **1.5% loss** over 50 years

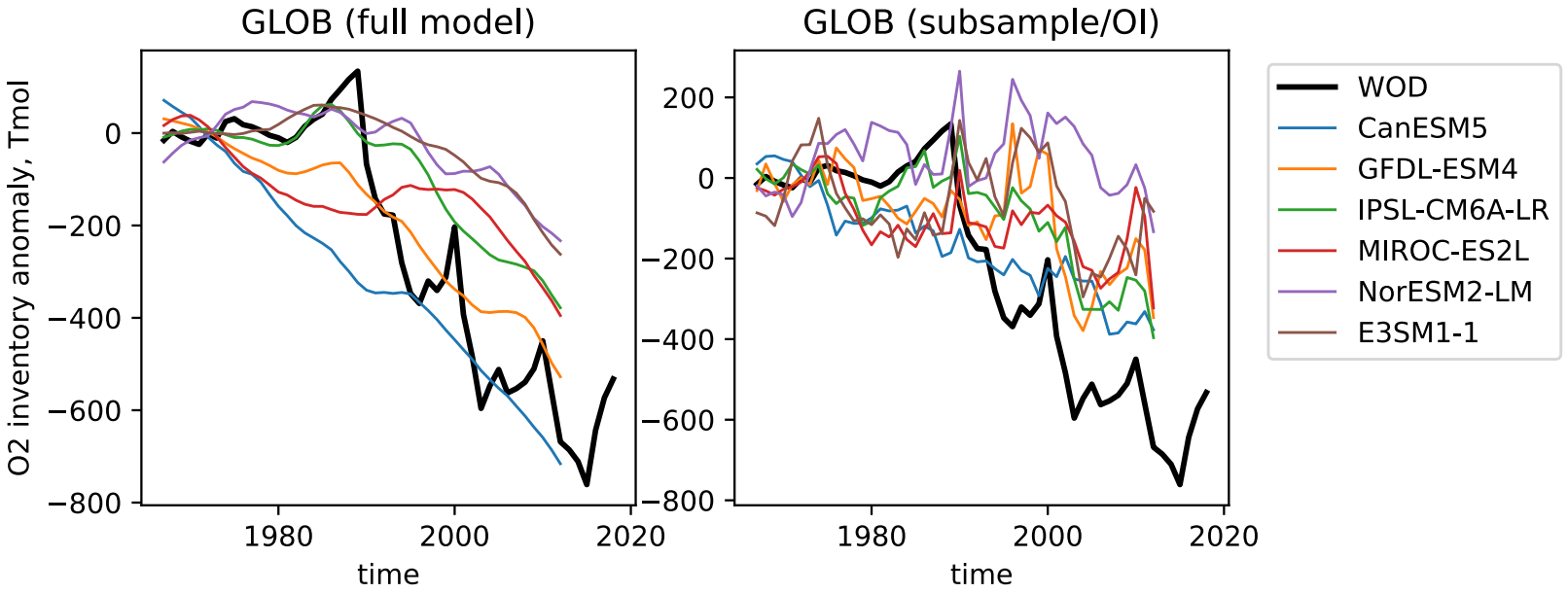
Schmidtko et al., 2017



-258 ± 18.5 Tmol/decade,
approx. **2% loss** over 50 year

Result: Global O_2 inventory time series

5-year running mean, 0-1,000m global O_2 inventory trend

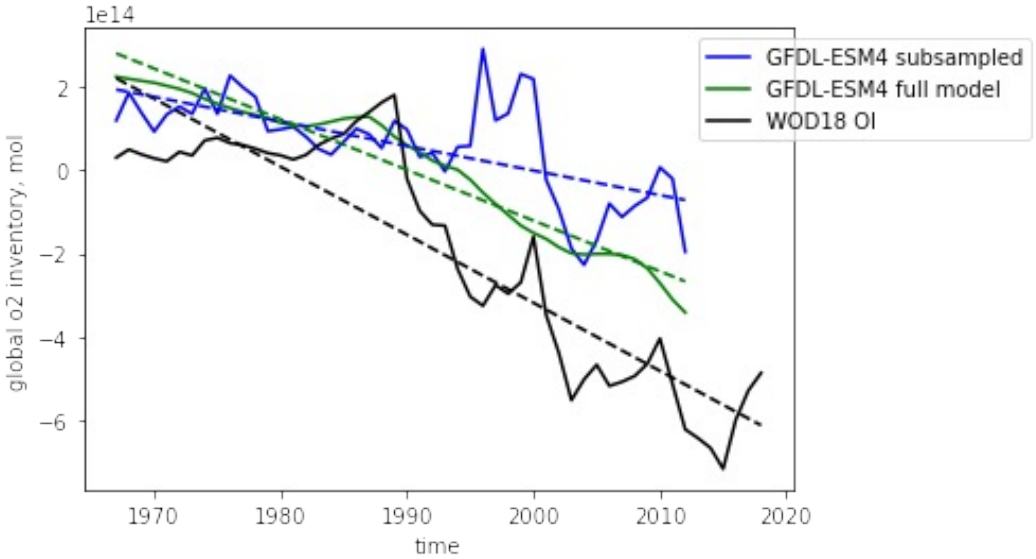


- Some models show comparable trend to observations (full model)
- Subsampled model trend shows comparable interannual ”noise”

Result: Global O_2 inventory time series

5-year running mean, 0-1,000m global O_2 inventory trend

In GFDL-ESM4, subsampled model output shows spurious peaks in late 1990s and late 2000s that is not present in the full model



- Some models show comparable trend to observations (full model)
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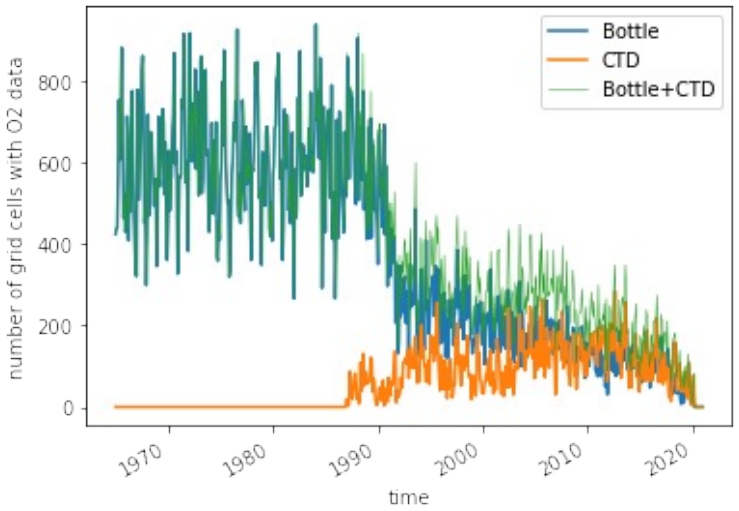
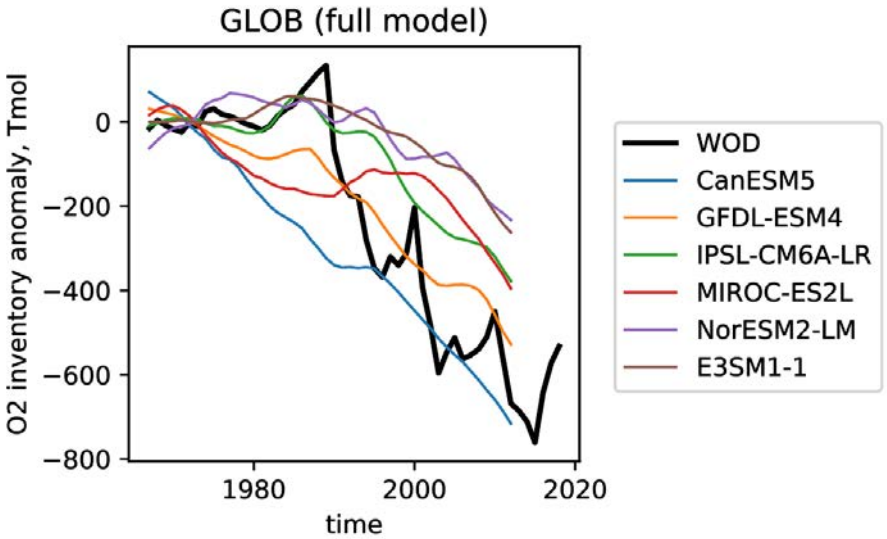
Result: sensitivity experiment with normalized data count

- Monthly profile count shows sharp decline after 1990
- This coincides with the start of strong deoxygenation





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- Monthly profile count shows sharp decline after 1990
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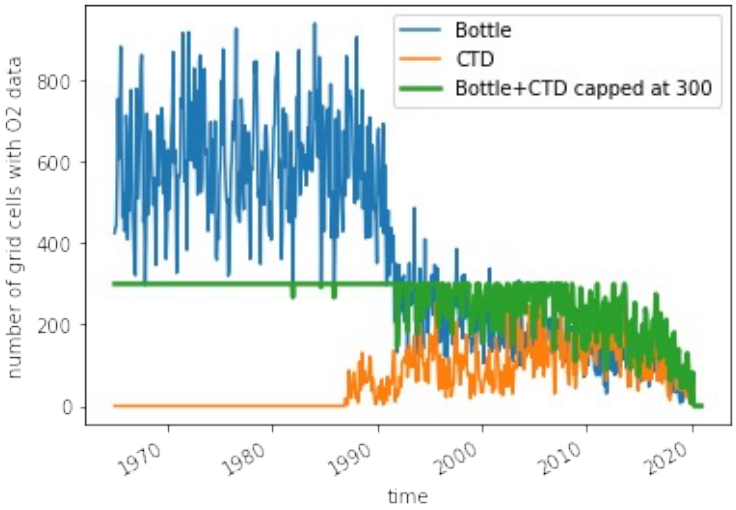
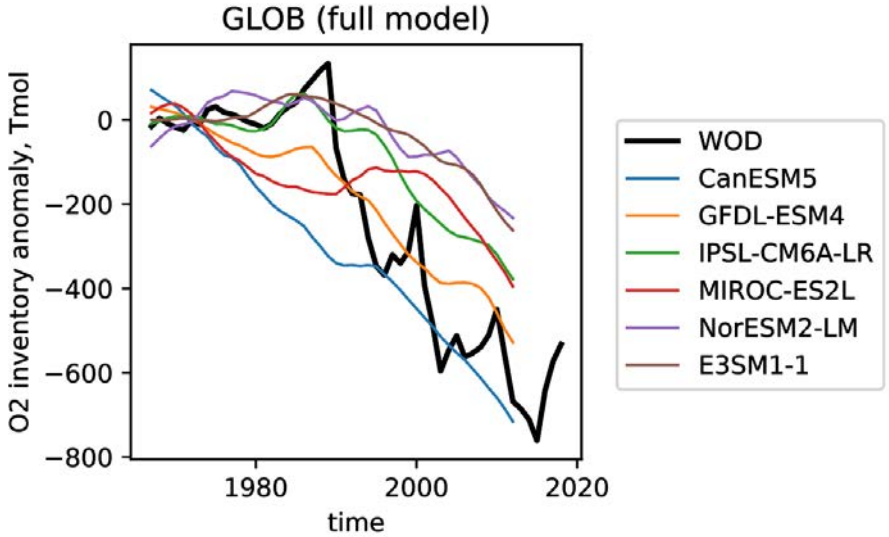
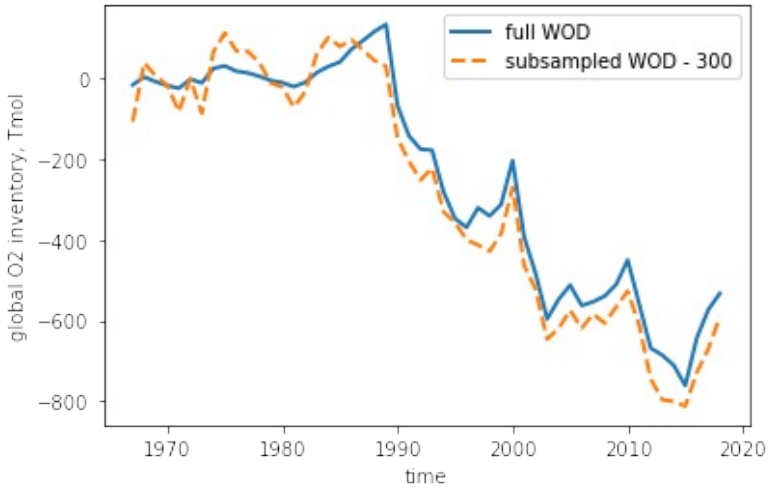
- *Randomly drop observed profiles to normalize the data count*

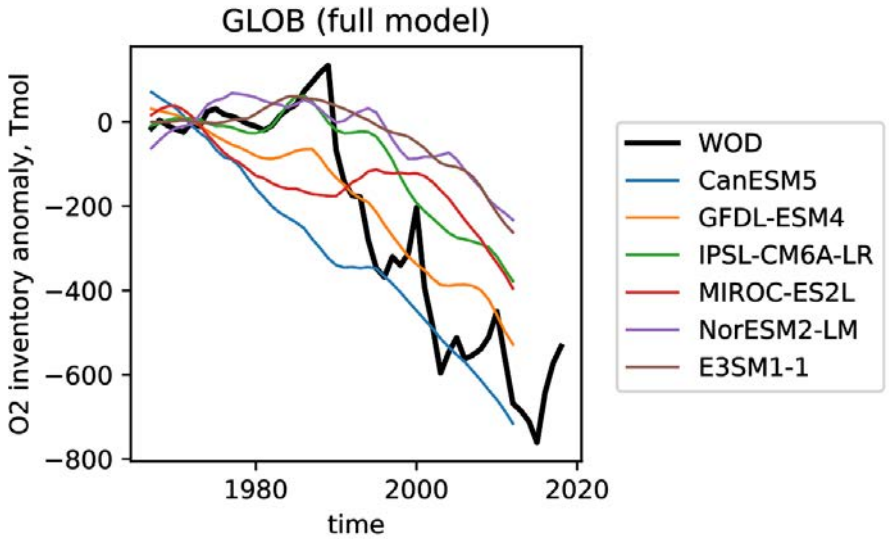




Result: sensitivity experiment with normalized data count

- Monthly profile count shows sharp decline after 1990
- This coincides with the start of strong deoxygenation
- *Randomly drop observed profiles to normalize the data count*
- ***Similar deoxygenation trend***

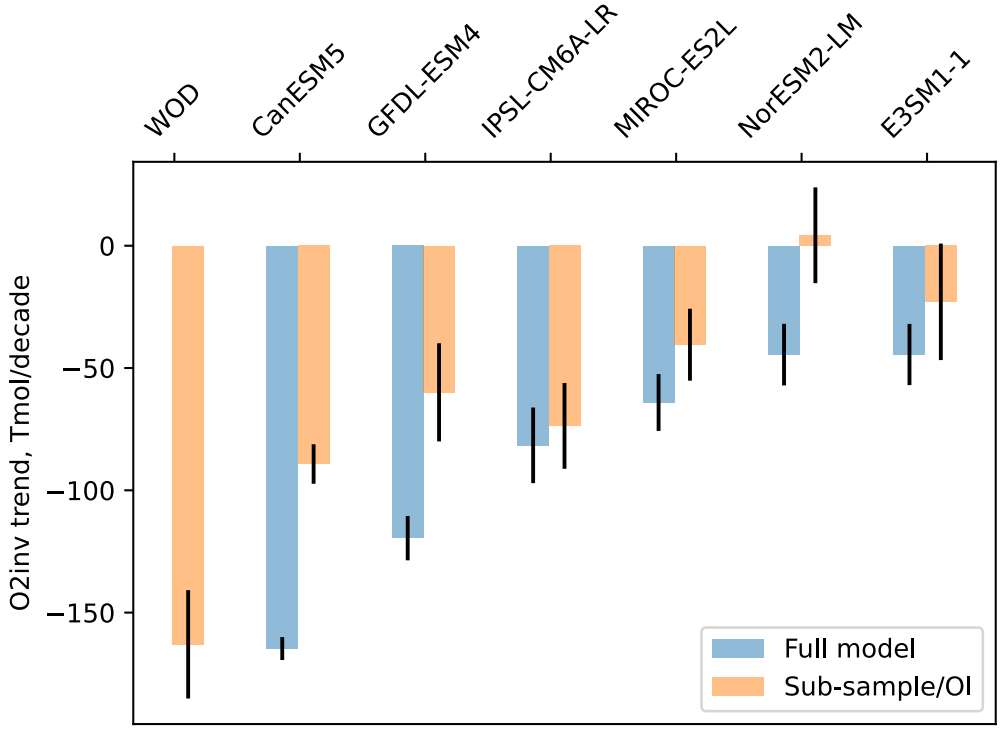




Result: Global O_2 inventory time series

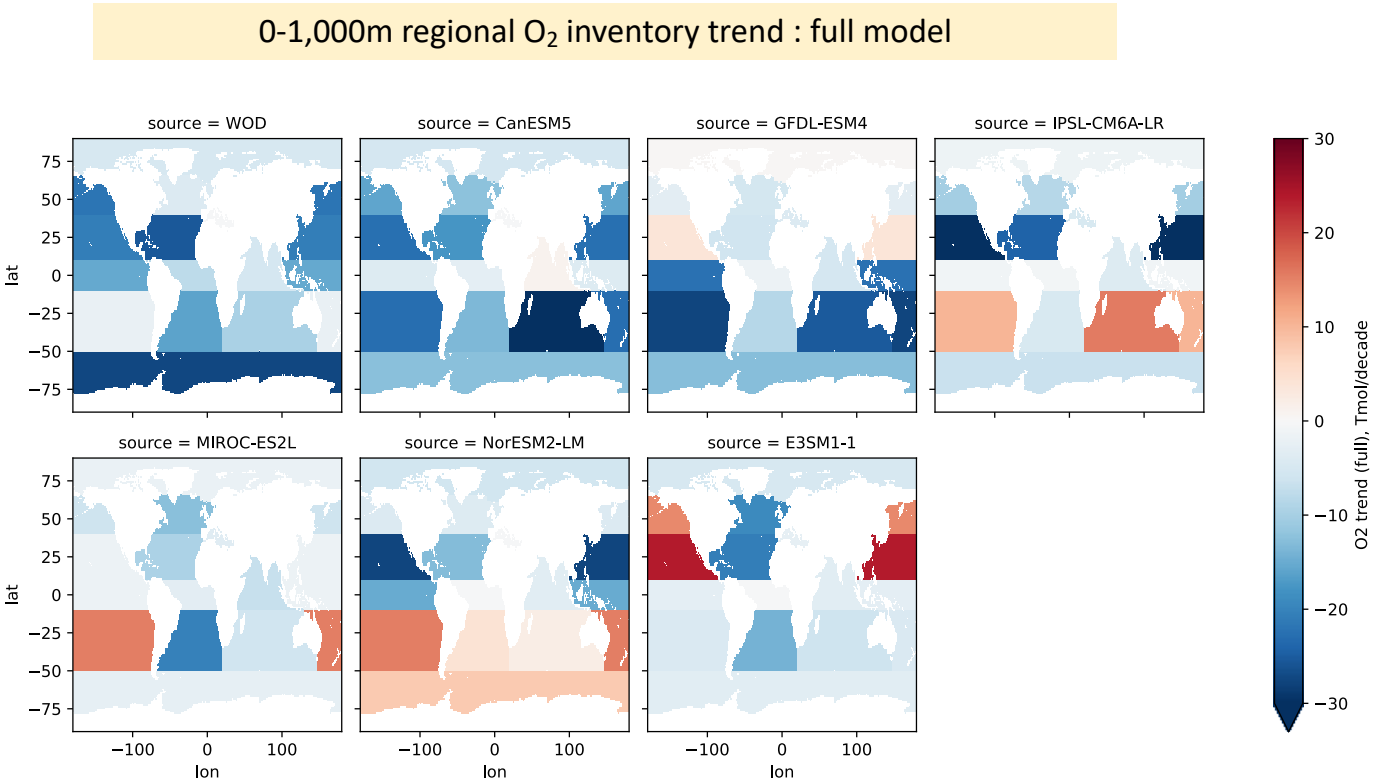
0-1,000m global O_2 inventory linear trend (1967-2012)

- Subsampled models significantly *underestimate* observed deoxygenation trend
- Subsampled trend also underestimate full model trend
- **Where is the disagreement coming from?**



Result: Patterns of O_2 inventory trend

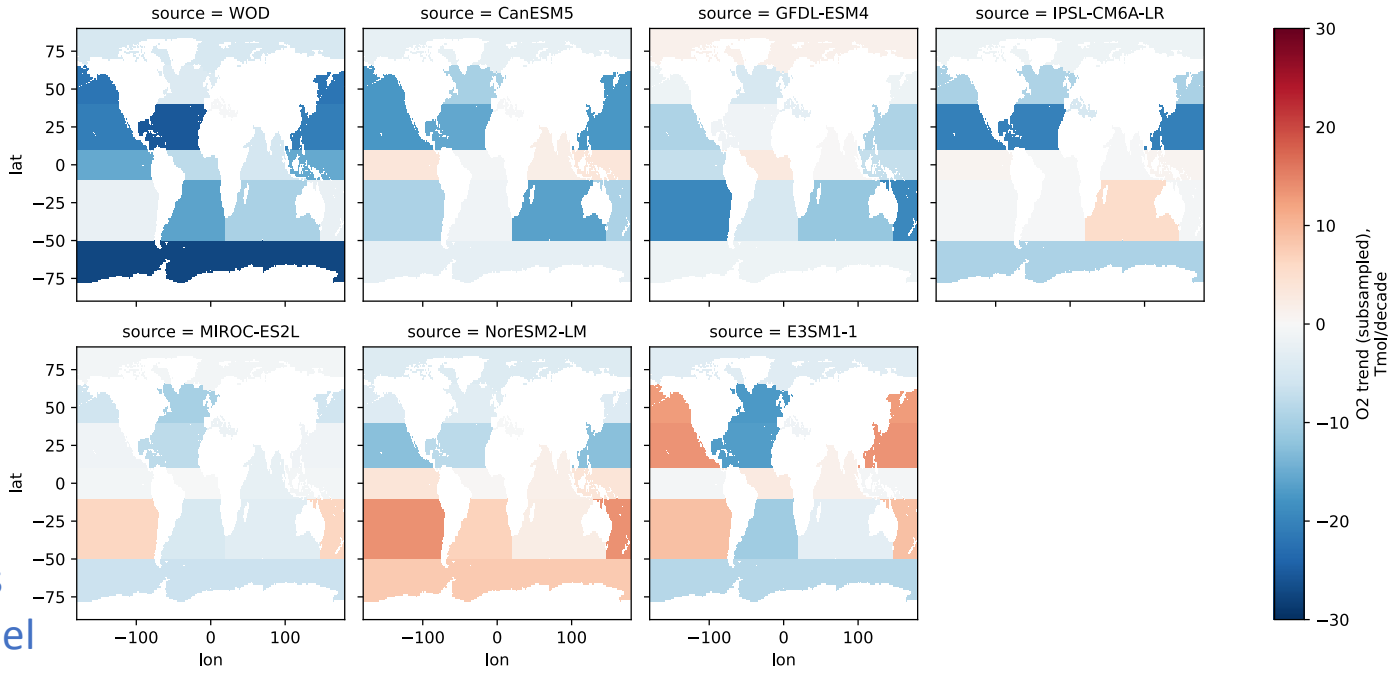
- 11 regional inventory trends in color scale
- Consistent in the North Atlantic
- Disagreements in the SH



Result: Patterns of O_2 inventory trend

- 11 regional inventory trends in color scale
- Consistent in the North Atlantic
- Disagreements in the SH
- Subsampled model generally preserves the sign of full model trend

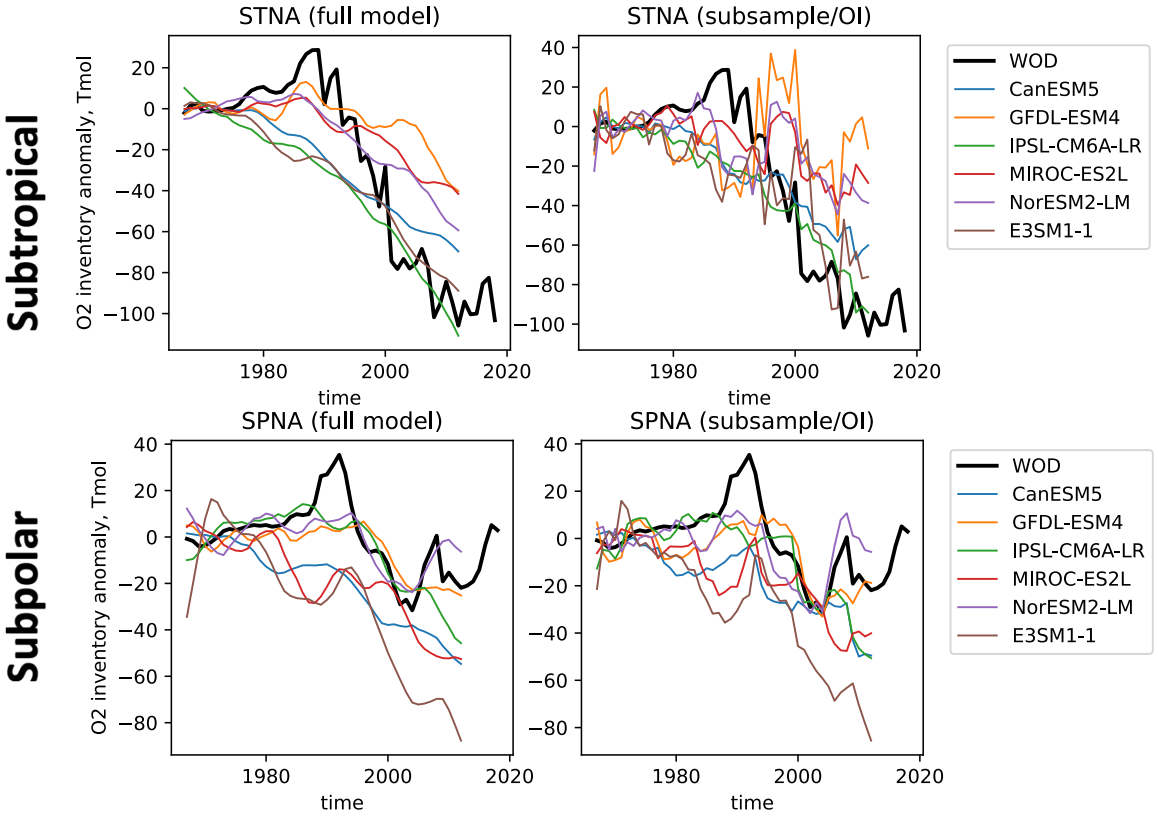
0-1,000m regional O_2 inventory trend : subsampled model



Result: Regional O_2 inventory time series

- North Atlantic is relatively data-rich
- Subsampled model generally capture the full model trend
- Some subsampled models show spurious peaks

STNA = Subtropical North Atlantic; **SPNA** = Subpolar North Atlantic



Result: Regional O_2 inventory trend

- North Atlantic is relatively data-rich
- Subsampled model generally capture the full model trend
- Some subsampled models show spurious peaks
- Models are overlapping/ bracketing the observed values

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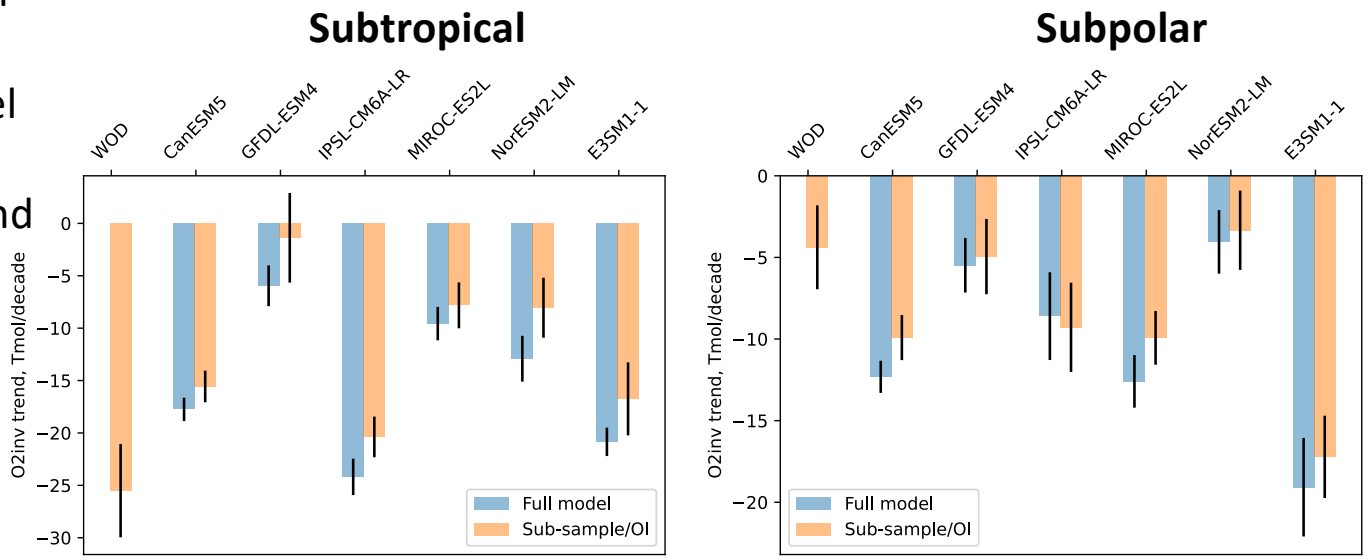
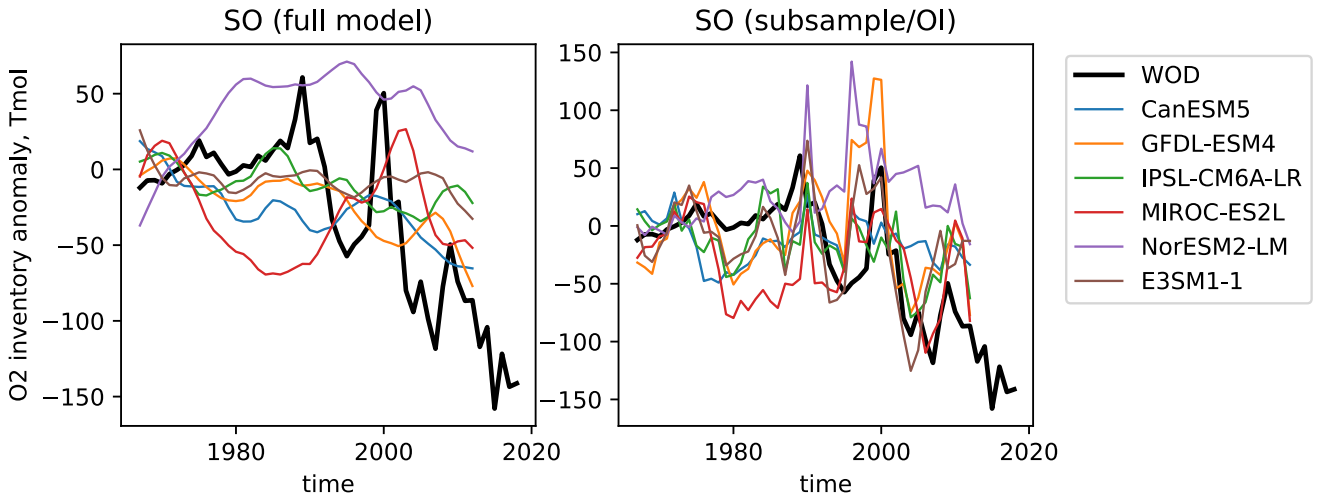


Result: Regional O_2 inventory trend

SO = Southern Ocean

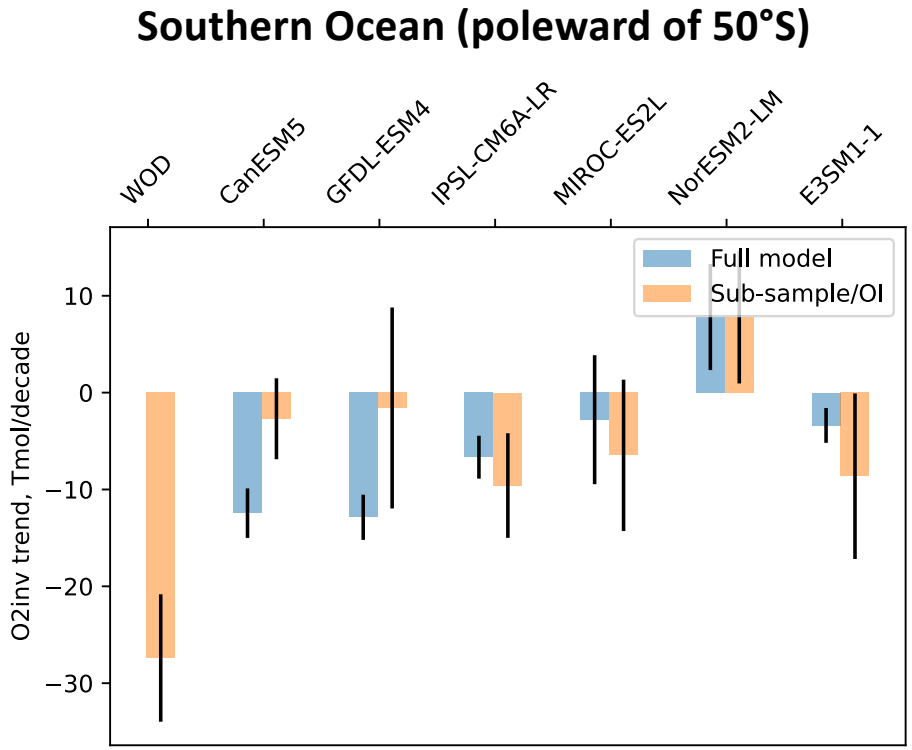
- Southern Ocean is relatively data-poor
- Major sampling noises are visible in the subsampled model data



Result: Regional O_2 inventory trend

SO = Southern Ocean

- Southern Ocean is relatively data-poor
- Major sampling noises are visible in the subsampled model data
- OI is not doing a good job in the SO!!!



Summary: an estimate of the global deoxygenation trend

- **1.5 ± 0.4% loss of O_2 over the last 50 years**
  - Less tropical deoxygenation in comparison to Schmidtko et al (2017)

- **CMIP6 models are closer to observations than previous generations** but still underestimates the global trend
  - Models bracket the observation in the North Atlantic

- **Models are not perfect but useful for understanding observations**
  - Subsampled models can illustrate the noisy global/regional time series caused by the sampling biases (e.g. Southern Ocean)

Moving forward

- Observational intercomparison
  - Standardized comparison of different gap-fill approaches
  - Coastal and regional assessments

- Integration of new observations: BGC-Argo

- Reproducibility & open access
  - Data source: **WOD select**
  - Scripts: **github.com/takaito1/optint_wod_o2**

Thank you!

Result: Climatology

- CanESM5
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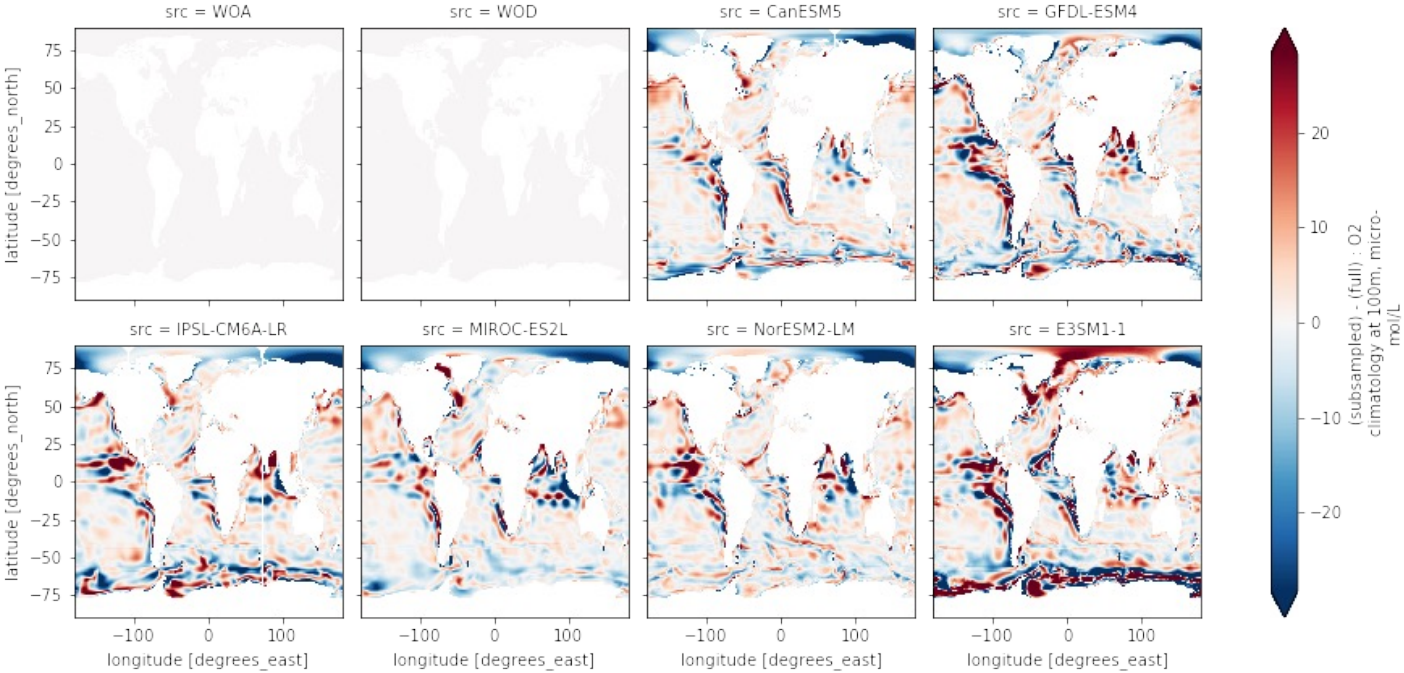
December climatology at 100m depth : subsampled and gap-filled, difference from full model



Result: Global O_2 inventory time series

0-1,000m global O_2 inventory linear trend (1967-2012)

- NH trend (~90Tmol/decade) and SH (~70Tmol/decade)
- Comparing NH vs SH trends, subsampled models better capture the full model trend in the NH. Major discrepancies in the SH