Predicting ocean oxygen: capabilities and potential

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Oxygen is a fundamental environmental constraint

![Graph showing oxygen concentration and its effects on water, animals, and microbes](image)

\[ N^* = NO_3^- - r_{N:P}PO_4^{3-} \]

- **Water**: Graph showing volume of water with different thresholds and regions.
- **Animals**: Graph showing the fraction of species across different oxygen concentrations.
- **Microbes**: Graph showing nitrate deficit across different oxygen concentrations.

**Nutrients & O₂**: WOA2013; Mortality data: Vaquer-Sunyer & Duarte, 2008
Warming up, turning sour, losing breath*

CMIP5 multi-model global-mean projections

Doney, Bopp, & Long, 2014

Gruber, 2011
Physical & biological controls on interior oxygen

Graphic credit: M. Long and R. Johnson (NCAR)
Timescales of natural variability in thermocline $O_2$

Variance-weighted mean period (CESM 1850-control)

$$T_x = \frac{\sum_k V(f_k, x)}{\sum_k f_k V(f_k, x)}$$
A persistent bias in Earth system models: Extensive OMZs

Thermocline (400–600 m) $O_2$ distributions

Observations

CESM
CESM Decadal Prediction Large Ensemble

Diagram:
- CORE-forcing
  - FOSI
    - Evaluation
  - Initialization
  - CPL
    - ATM
    - LND
    - OCN
    - CICE
Thermocline oxygen concentrations look to be highly predictable

Anomaly correlation coefficient: $O_2$ on $\sigma_\theta = 26.5$

courtesy of S. Yeager
Thermocline oxygen concentrations look to be highly predictable

Anomaly correlation coefficient: Salinity on $\sigma_\theta = 26.5$

courtesy of S. Yeager
North Pacific dissolved oxygen is skillfully predicted

Thermocline O_2 concentration

“Thermocline” := 200–600m mean
What mechanisms provide predictability for O$_2$?

Tracer tendency equation

\[
\frac{\partial O_2}{\partial t} + (u + u^*) \cdot \nabla O_2 = D_{iso}(O_2) + D_{dia}(O_2) + J_{bio}(O_2)
\]
What mechanisms provide predictability for $O_2$?

$O_2$ term balance: annual mean
What mechanisms provide predictability for O$_2$?

O$_2$ term balance: interannual variability (std. dev.)

- Lateral advection
- Vertical advection
- Vertical mixing (diabatic)
- Vertical mixing (adiabatic)
- Lateral mixing
- Source/sink

120°E  140°E  160°E  180°  160°W  140°W  120°W  100°W
15°N  30°N  45°N  60°N

mol m$^{-2}$ yr$^{-1}$
Timeseries observations of oxygen are sparse

Model skill in CalCOFI* region: questionable

Thermocline O$_2$

* California Cooperative Oceanic Fisheries Investigations
CalCOFI dissolved oxygen is skillfully predicted

Thermocline O₂ in CalCOFI region

Thermocline O₂ tendency

O₂ inventory 1-5 year lead

Total tendency 1-5 year lead

mol m⁻²

Year


mol m⁻² yr⁻¹

Year

What mechanisms provide predictability for $O_2$?

$O_2$ term balance: annual mean
What mechanisms provide predictability for O$_2$?

O$_2$ term balance: annual mean

[Graphs showing various mechanisms for O$_2$ term balance over the years from 1960 to 2010, including lateral advection, vertical advection (diabatic), vertical mixing (diabatic), lateral mixing, and source/sink over a 1-5 year lead time.]

DP Forecast
FOSI
What mechanisms provide predictability for $O_2$?

Mean vertical gradients

\[
O_2^{\text{heave}} = \left( \frac{\partial O_2}{\partial z} \right) \left( \frac{\partial \rho_\theta}{\partial z} \right)^{-1} \rho'_\theta
\]
East-west difference in anomaly generation mechanism

“Ventilation regime”

Correlation: $O_2$ v. $|PV|$

$\nabla \rho / \nabla z$ low
$PV$ low
$O_2$ high

Negative PV-$O_2$ correlation

$PV \approx \left( \frac{f}{\rho} \right) \frac{\partial \rho}{\partial z}$

“Heave regime”

Correlation: $O_2$ v. density

$\nabla \rho / \nabla z$ high
$PV$ high
$O_2$ high

Positive PV-$O_2$ correlation

Negative $\rho$-$O_2$ correlation

Vertical compression
Summary

• Thermocline dissolved oxygen concentrations are highly predictable on multi-annual timescales.

• Vertical displacement of isopycnals in response to basin-scale thermocline adjustment explains much of the variance in simulated CalCOFI $O_2$.

• The “heave” regime of the eastern Pacific contrasts with a “ventilation” regime of the west, indicated by differing correlations with PV.

• Model skill remains a challenge.
Questions?

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