ENSO-driven Variability of Air-Sea O₂ Fluxes: Observations and Mechanisms

Yassir Eddebbar*, R. Keeling, M. Long, M. Manizza, L. Resplandy
1. Observations and models point to loss of dissolved O$_2$ due to warming, but **Natural variability complicates attribution**.

2. What are ENSO impacts on air-sea flux of O$_2$?

3. Can we use ENSO response of APO to validate ocean models?
Background

Nutrients

Warming

APO

Oxygen Minimum Zone

N

Easterlies

Ventilation

O_2

CO_2

Thermal

O_2

CO_2

Bio Prod

O_2

CO_2

O_2

CO_2

CO_2

O_2

0° 120°E 0° 90°W
Background

Observed Mean $\delta$APO (Tohjima et al., 2015)

Model Mean $\delta$APO (TM3/CESM)

Tohjima et al., 2015
ENSO Impacts on APO

Tohjima et al., 2015

APO Bulge

APO 50 Tmol/yr

APO 10-20 Tmol/yr

Rödenbeck et al., 2008

Tohjima et al., 2015
ENSO Impacts on APO

1. Are these results inconsistent with each other? Does ENSO allow for both scenarios?

2. What is the response in Scripps Network? In coupled ocean-BGC models? What is its spatial and temporal character? What mechanisms drive it?

3. What is the role of atmospheric transport on APO distribution?
Scripps O$_2$ Network Observations

$r=0.40$ $p=0.027$ (Ebisuzaki, 1997)

Niño3.4

SAM $dAPO/dt$

Scripps O$_2$ Network Observations

$r=0.35$ $p<0.05$ (Ebisuzaki, 1997)

Niño3.4 $dAPO/dt$

Global $dAPO/dt$

$r=0.35$ $p=0.047$ (Ebisuzaki, 1997)

Niño 3.4 Index

LJO

SAM

CGO

ALT

Scripps O$_2$ Program
Models Examined

1. “Hindcast” CESM simulation (CORE2-forced, Jan 1960- Dec 2008)
2. Transport CESM APO Fluxes in TM3
3. Fully coupled (“1850 control”) CMIP5 model intercomparison

![Diagram of Models Examined]

- CORE2 (NCEP Reanalysis*)
- BGC(BEC)
- Ocean (POP2)
- Sea Ice (CICE4)
Global APO Fluxes in CESM: Regional Contributions

* Trop Pacific Fluxes ($r_{TPAC}=0.92$)

* Note drawdown in 1998-2001 is driven in CESM by tropical rather than northern basins (e.g. Hamme and Keeling, 2008)

* Volcanic eruptions show large departures in all basins (1964, 1992), see Plattner et al., (2002)
Global APO Fluxes in CESM: $O_2$ vs. $CO_2$

* As expected from slower $CO_2$ response timescale due to carbonate chemistry buffering (Broecker and Peng, 1974; Keeling and Severinghaus, 2000)

**We focus on tropical $O_2$ flux response to ENSO
$O_2$ Flux Response to ENSO in CESM

$r=0.63$  $O_2$ leads by 3-months
1. Significant outgassing of O$_2$ along eastern-central pacific during El Niño
2. Small anomalous uptake of O$_2$ in Western pacific
3. Extratropical response: outgassing in southern ocean (Verdy et al., 2007)
$O_2$ Flux Response to ENSO in CESM: Mechanisms

$F_{O_2} = F_{Therm} + F_{NPP} + F_{Vent}$

$F_{Therm} = \frac{\partial O_2^{sol}}{\partial T} \cdot \frac{Q}{\rho C_p}$  \hspace{1cm} (Keeling et al., 1993)

$F_{NPP} = \int_{0}^{100m} Prod(O_2) - Cons(O_2) dz$
Tropical Pacific $O_2$ Flux Vs. Niño3.4 in CESM
O₂ Flux Response to ENSO in CESM: Mechanisms

\[ \text{FO₂} = \text{FTherm} + \text{FNPP} + \text{FVent} \]
Influence of Atmospheric Transport

Climatological $F_{APO}$

TM3 (NCEP winds)

Variable $F_{APO}$ [1970-2008]
Atmospheric transport effects only

Atmospheric + Air-sea Flux variability

\[ \delta \text{APO per meg} \cdot \sigma^{-1} \]

Climatological \( F_{\text{APO}} \)

Variable \( F_{\text{APO}} \) [1970-2008]
Atmospheric transport effects only

150° E 120° W

Mean δAPO
El Niño 97-98
La Niña 98-99

Tohjima et al., 2015
Atmospheric transport effects only

Atmospheric + Air-sea Flux variability

120° W

Mean $\delta$APO

El Niño 97-98

La Niña 98-99

$\delta$APO per meg . $\sigma^{-1}$

$\delta$APO (per meg) vs time

$\delta$APO (per meg) vs time
Atmospheric transport effects only

Atmospheric + Air-sea Flux variability

1. Atmospheric winds drive **western** tropical Pacific δAPO variability, but not in the **eastern** tropical Pacific, where ventilation dominates.

2. ENSO phenomenology permits both Tohjima et al., 2015 AND Rödenbeck et al., 2008 mechanisms. O₂ ventilation is a major driver.
CMIP5 Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Variance Explained</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CESM1-BGC</td>
<td>41%</td>
<td>r=0.96</td>
</tr>
<tr>
<td>IPSL-LR</td>
<td>54%</td>
<td>r=0.95</td>
</tr>
<tr>
<td>GFDL-ESM2G</td>
<td>51%</td>
<td>r=0.62</td>
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<tr>
<td>GFDL-ESM2M</td>
<td>44%</td>
<td>r=0.80</td>
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<tr>
<td>MPI-ESM-LR</td>
<td>26.2%</td>
<td>r=0.95</td>
</tr>
<tr>
<td>MPI-ESM-MR</td>
<td>14%</td>
<td>r=0.94</td>
</tr>
</tbody>
</table>

1st EOF of O₂ fluxes
Models Validation

Tropical Pacific 20°N-20°S
Summary

1. El Niño causes anomalous outgassing of APO driven by tropical $O_2$ fluxes in CESM and other models.

2. Changes in upwelling (source and rates) dominate $O_2$ response, counteracted by reduced biological productivity and thermal fluxes.

3. There is a considerable zonal complexity in atmospheric δAPO response: Enhanced observational coverage needed for ocean models validation.
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Additional Slides
Model Mean $\delta$APO

July 1997- June 1998

Climatological Flux +TM3  Variable Flux +TM3
Model Mean δAPO

July 1998- June 1999

Climatological Flux +TM3

Variable Flux +TM3
Model Mean $\delta$APO

July 2000- June 2001

Climatological Flux +TM3

Variable Flux +TM3