# ENSO-driven Variability of Air-Sea $O_2$ Fluxes: Observations and Mechanisms

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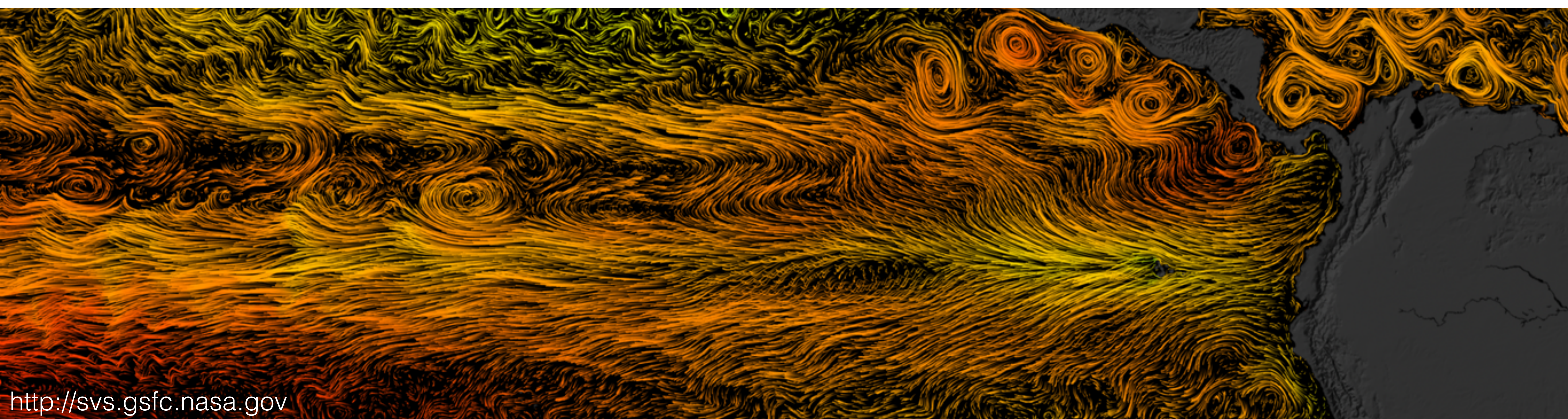
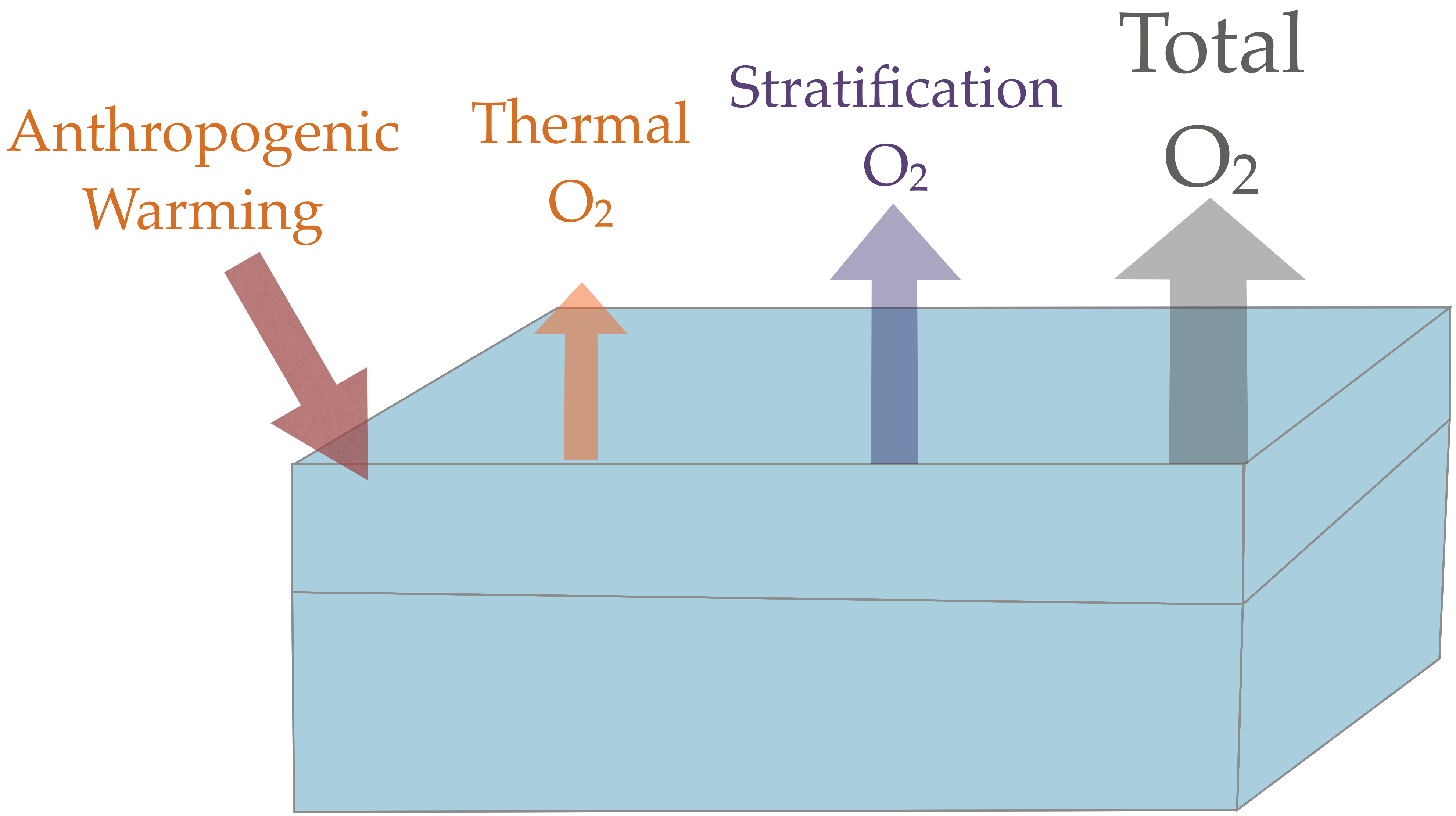
NSF GRFP
Scripps $O_2$ Program
Atmospheric Oxygen Research
Scripps $CO_2$ Program
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

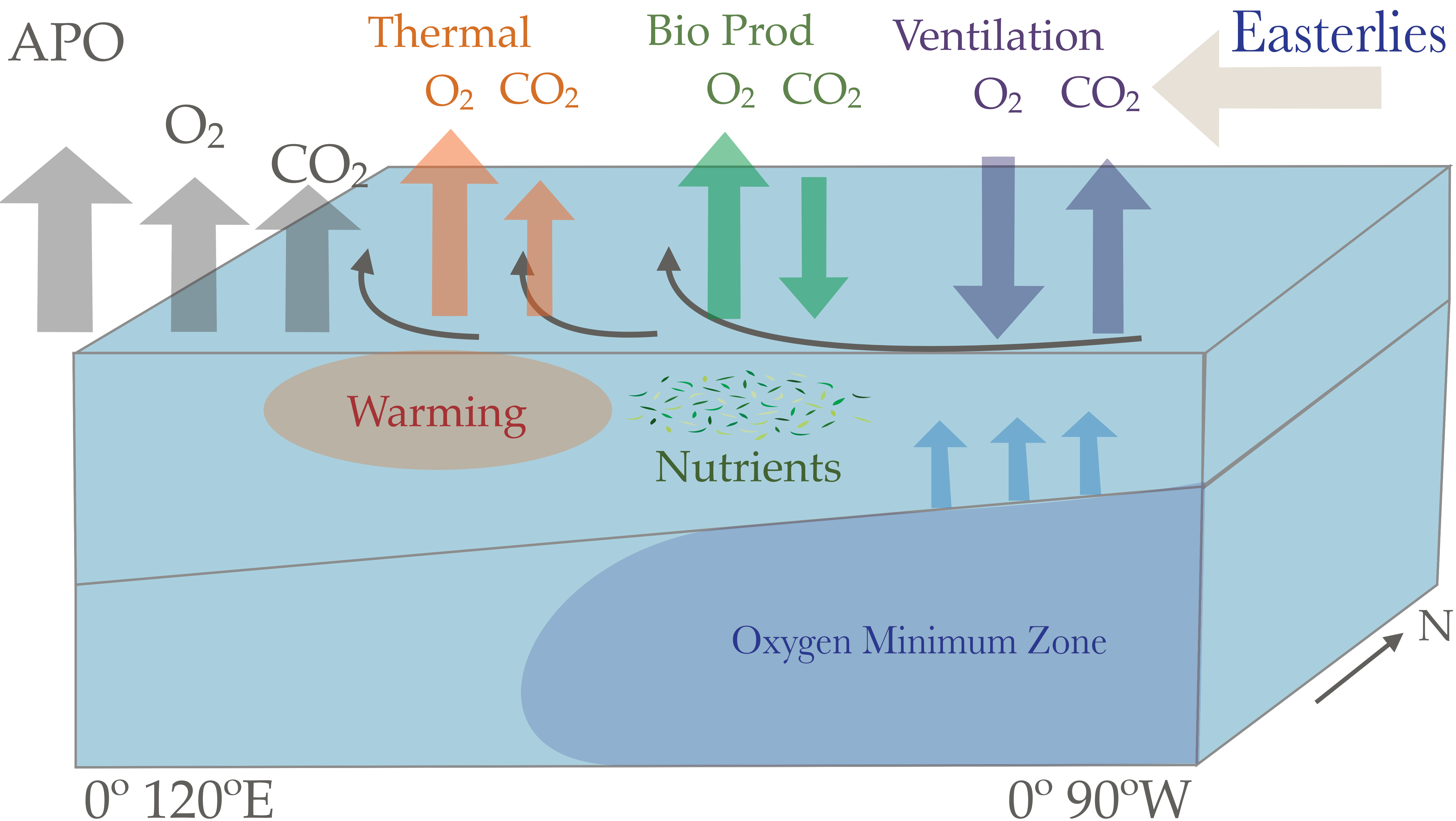


# Driving questions



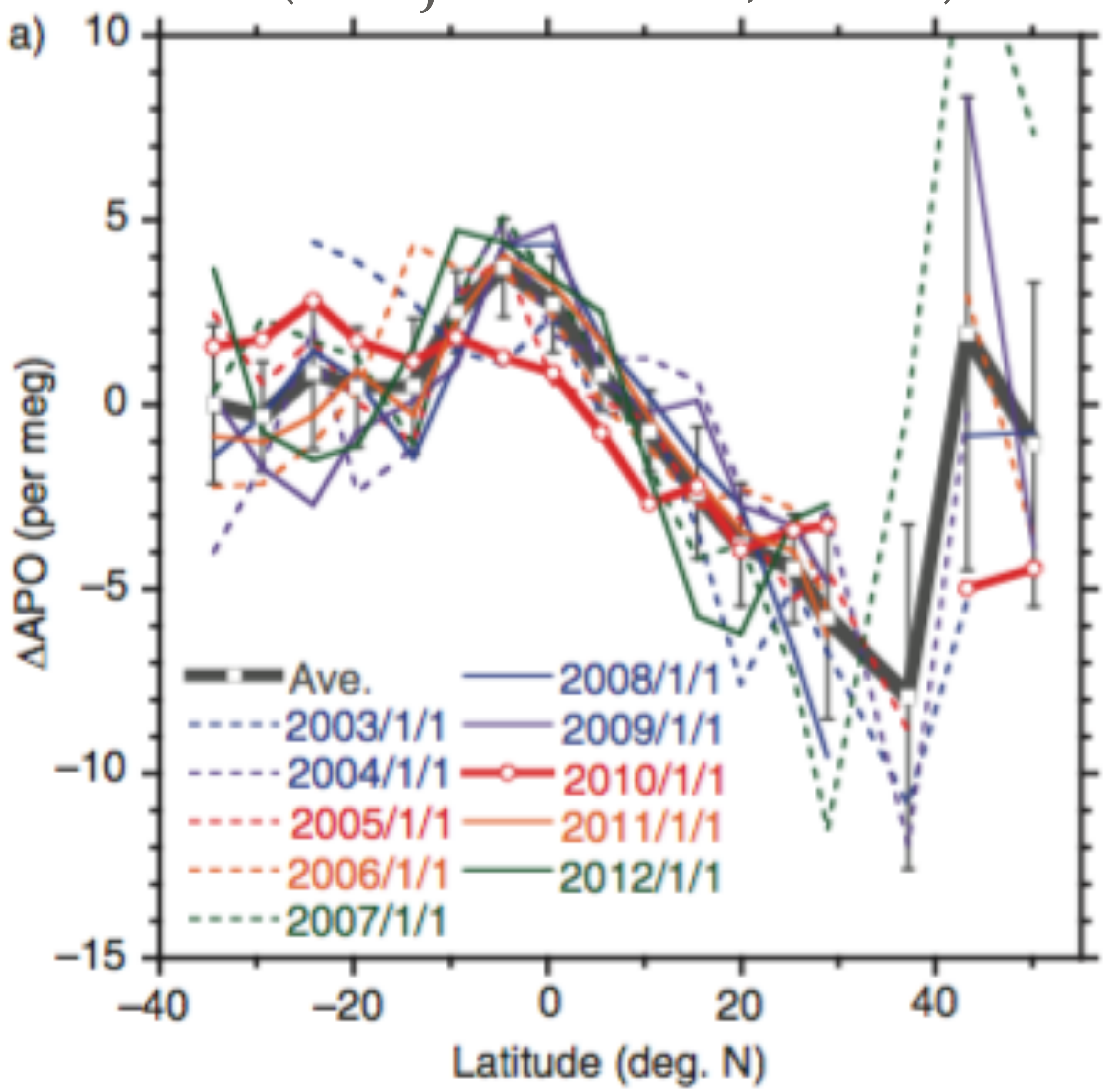

1. Observations and models point to loss of dissolved $O_2$ due to warming, but **Natural variability complicates attribution**.
2. What are ENSO impacts on air-sea flux of $O_2$?
3. Can we use ENSO response of APO to validate ocean models?

# Background


APO
$O_2$
$CO_2$
Thermal
$O_2$ $CO_2$
Bio Prod
$O_2$ $CO_2$
Ventilation
$O_2$ $CO_2$
Easterlies
Warming
Nutrients
Oxygen Minimum Zone
N
0º 120ºE
0º 90ºW

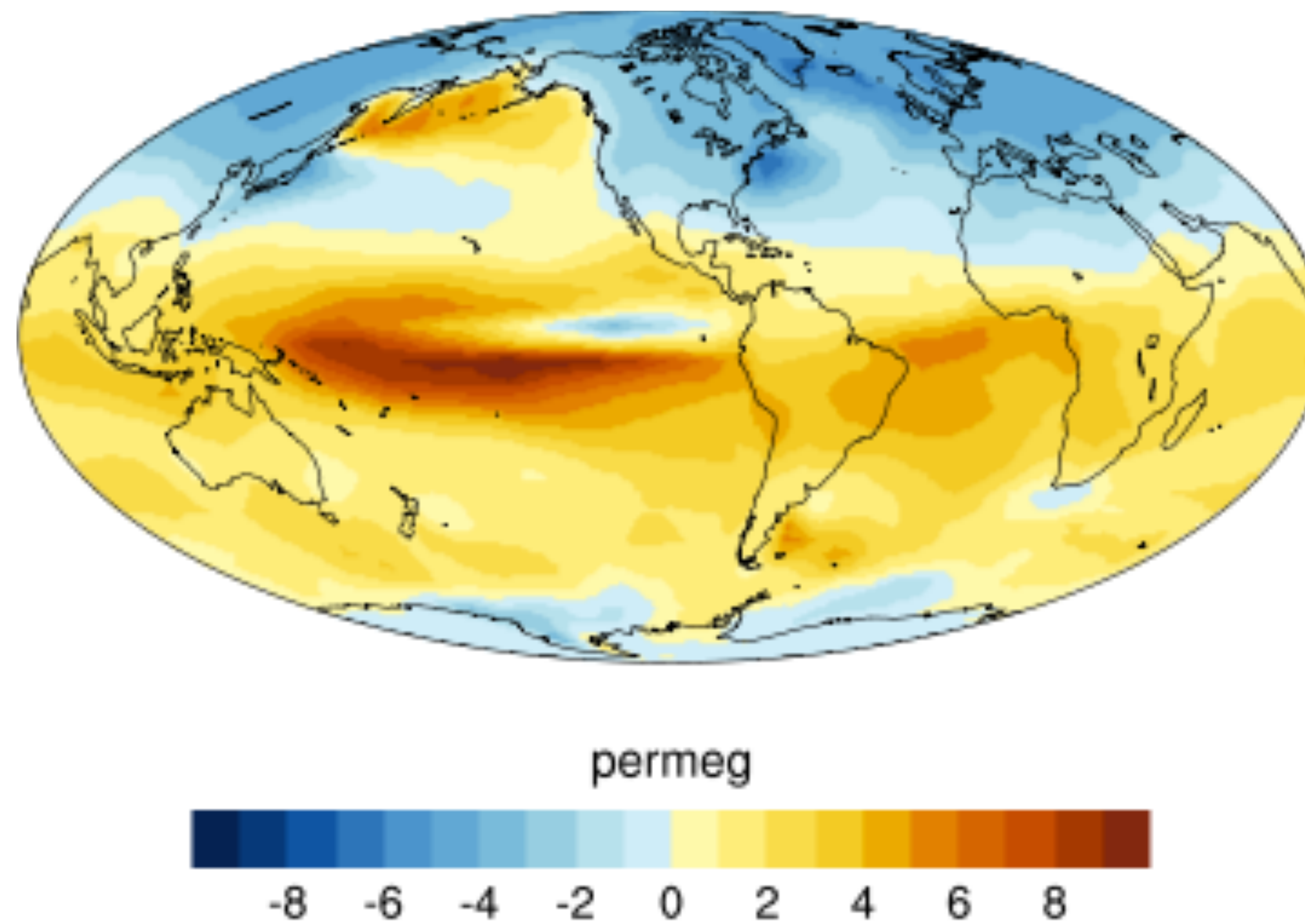
# Background

Observed Mean δAPO
(Tohjima et al., 2015)

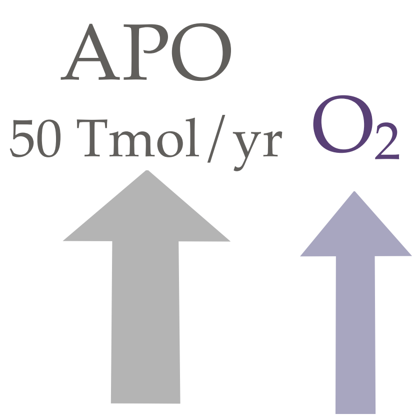


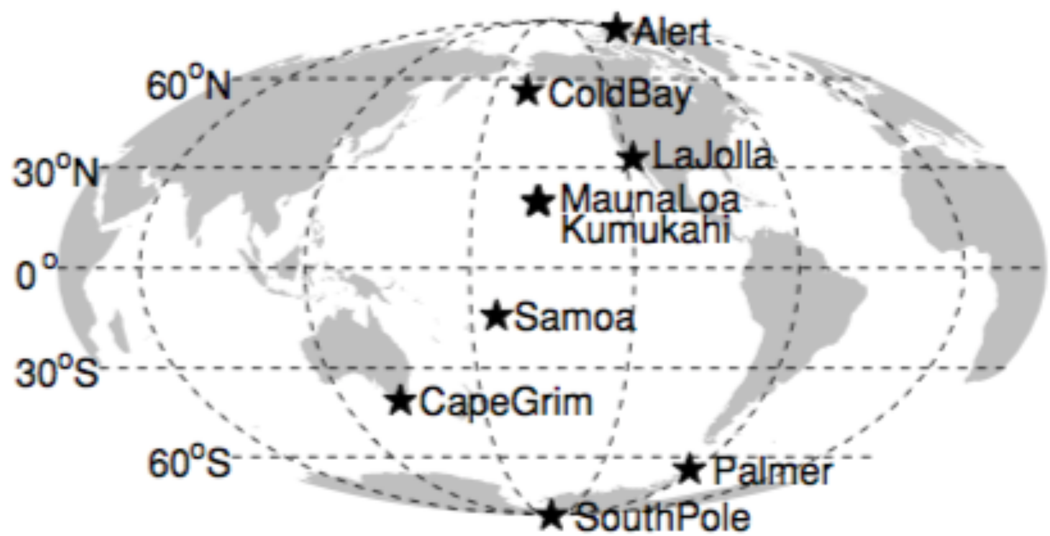

Tohjima et al., 2015

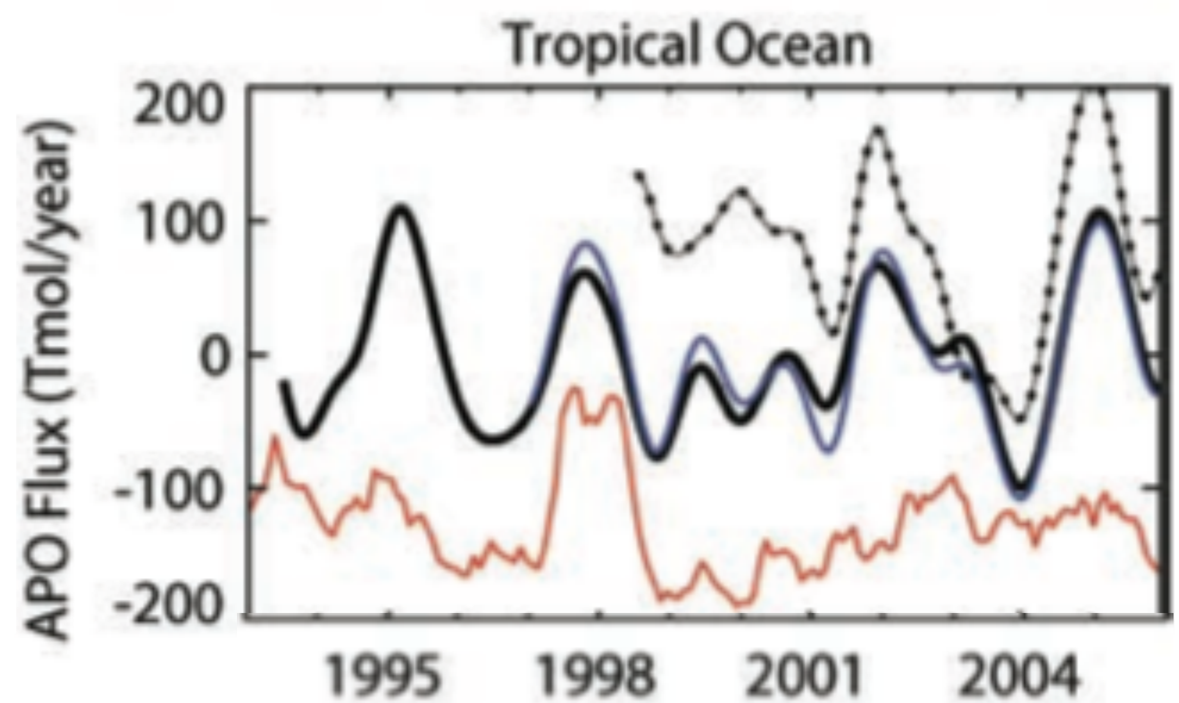
Model Mean δAPO
(TM3 / CESM)



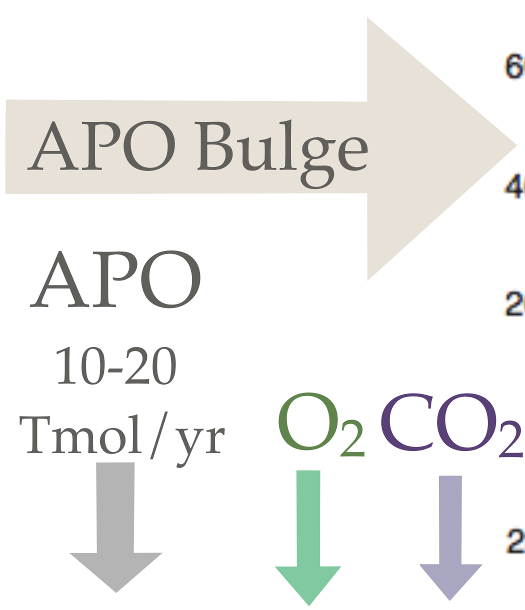
# ENSO Impacts on APO

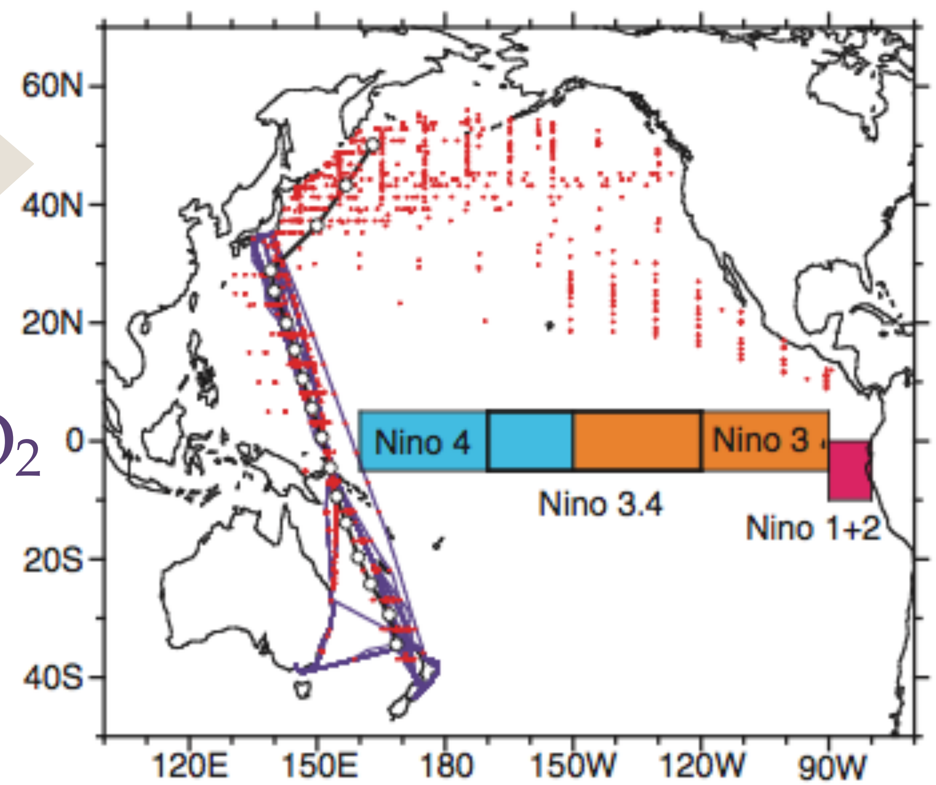


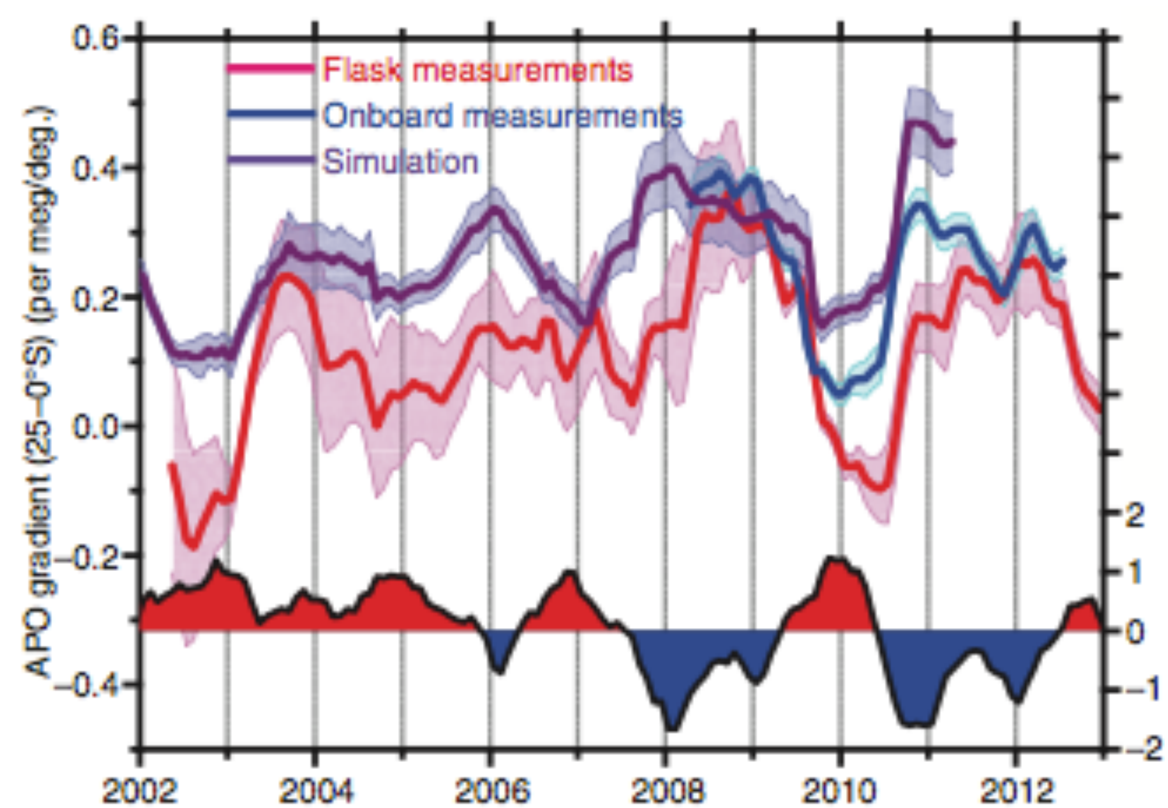




Rödenbeck et al., 2008



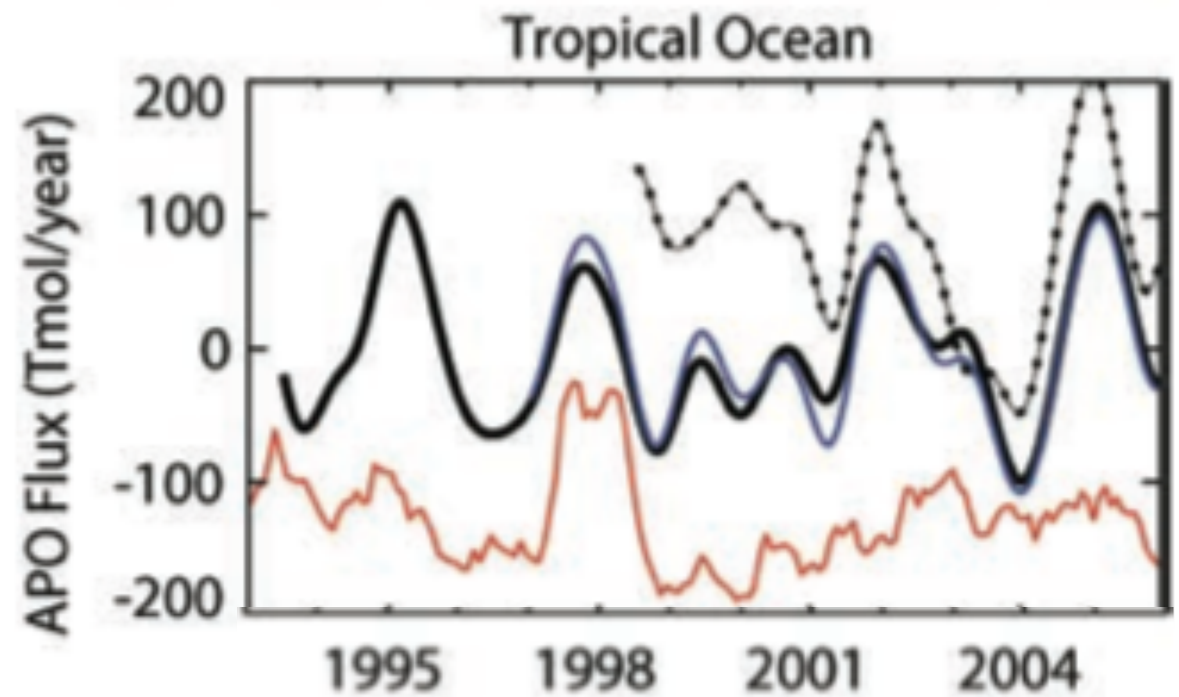



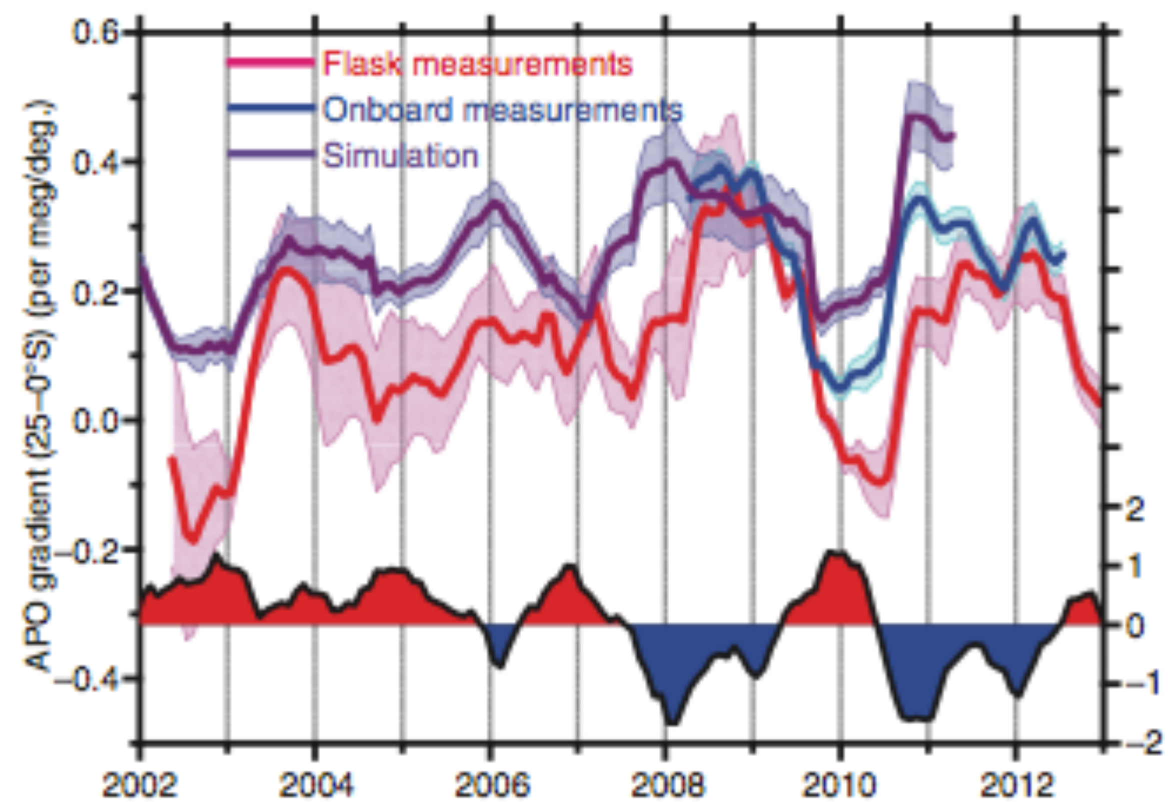

Tohjima et al., 2015

# 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?

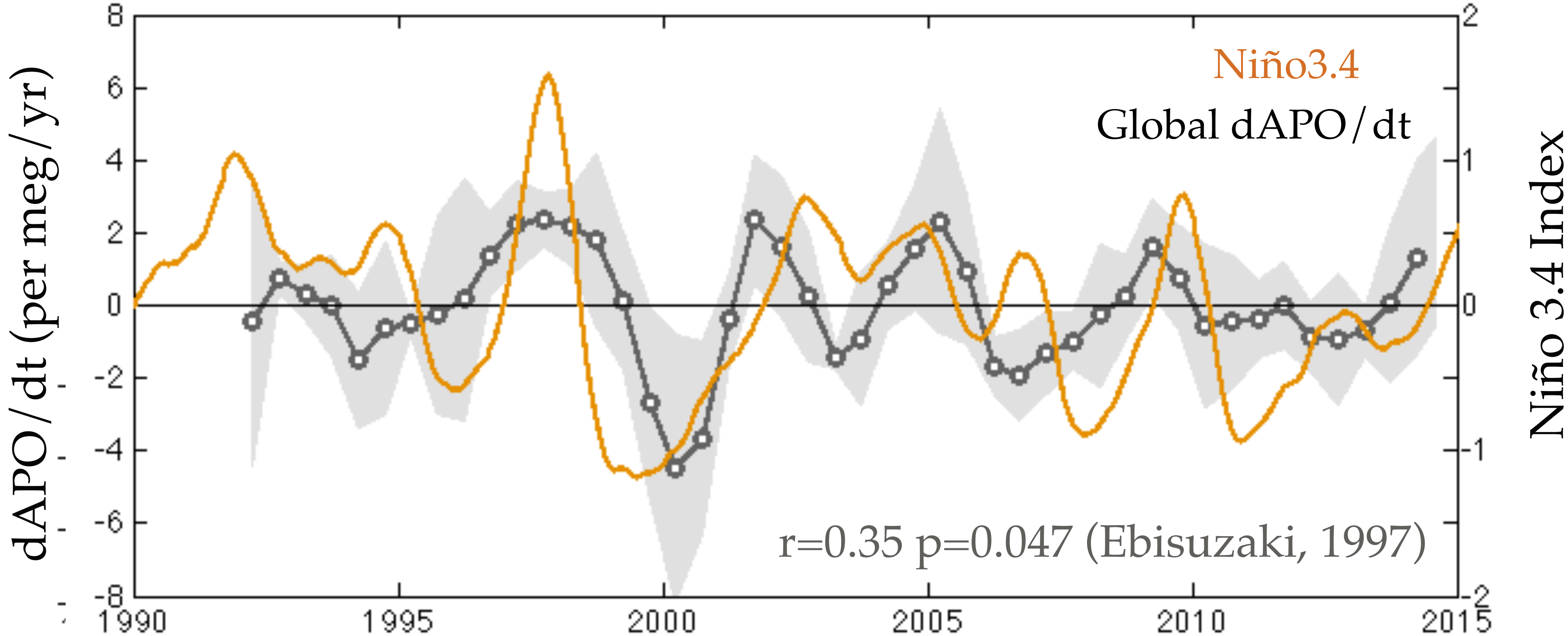


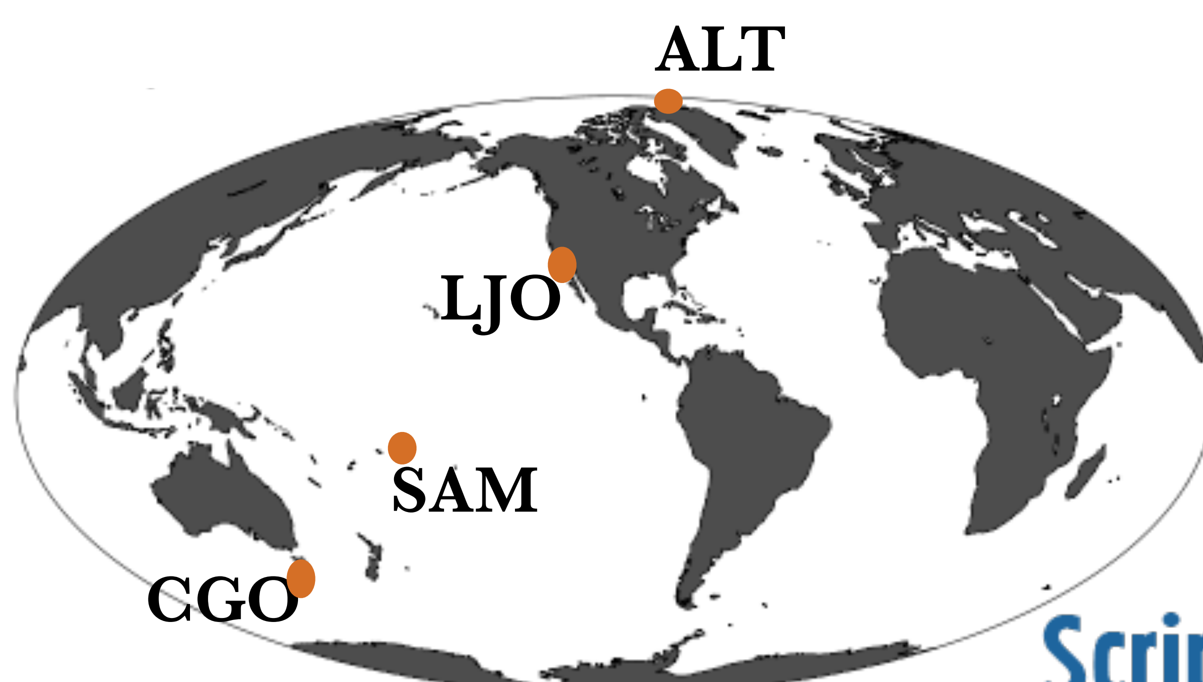

Rödenbeck et al., 2008




Tohjima et al., 2015

# Scripps $O_2$ Network Observations

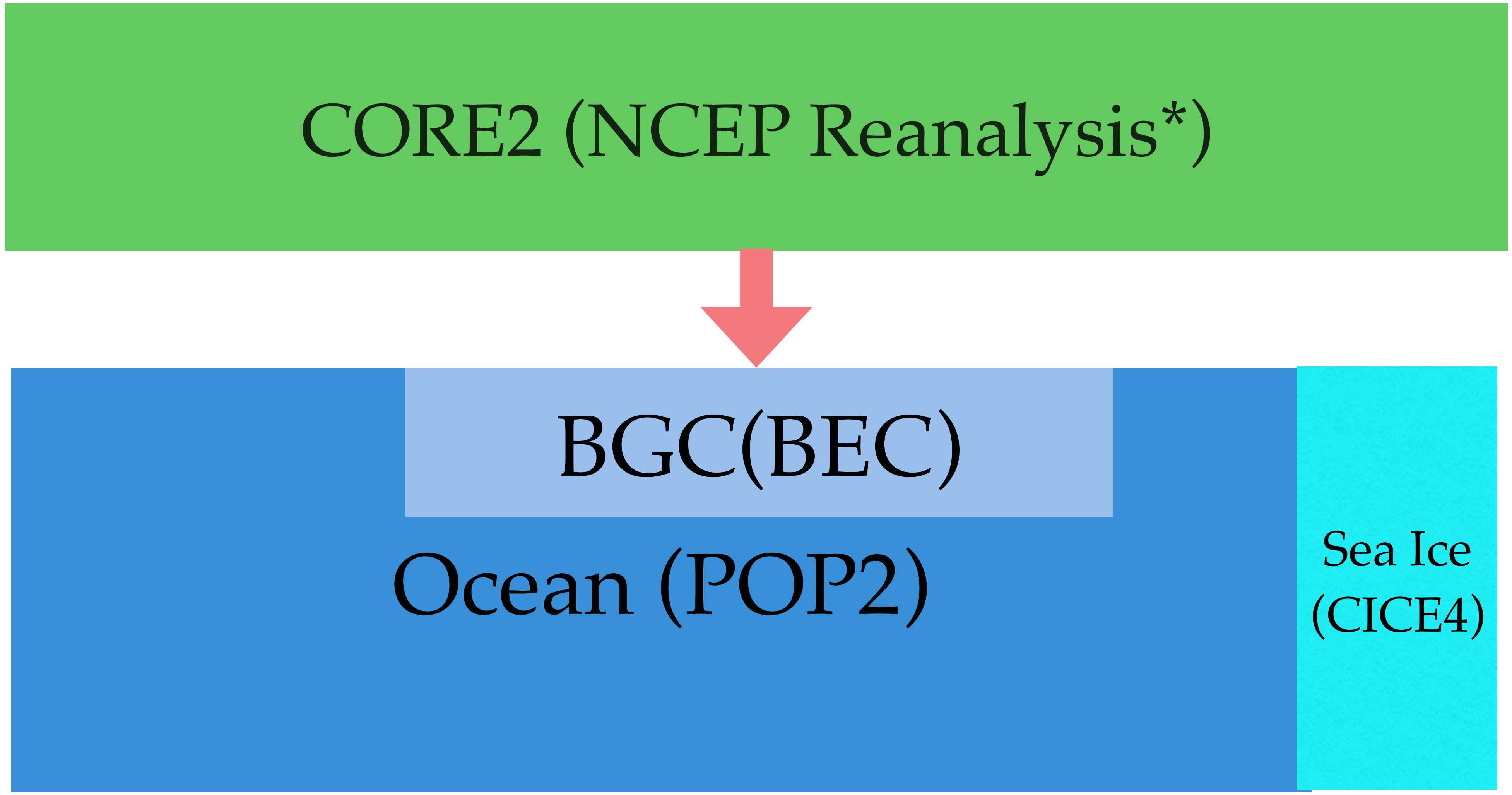


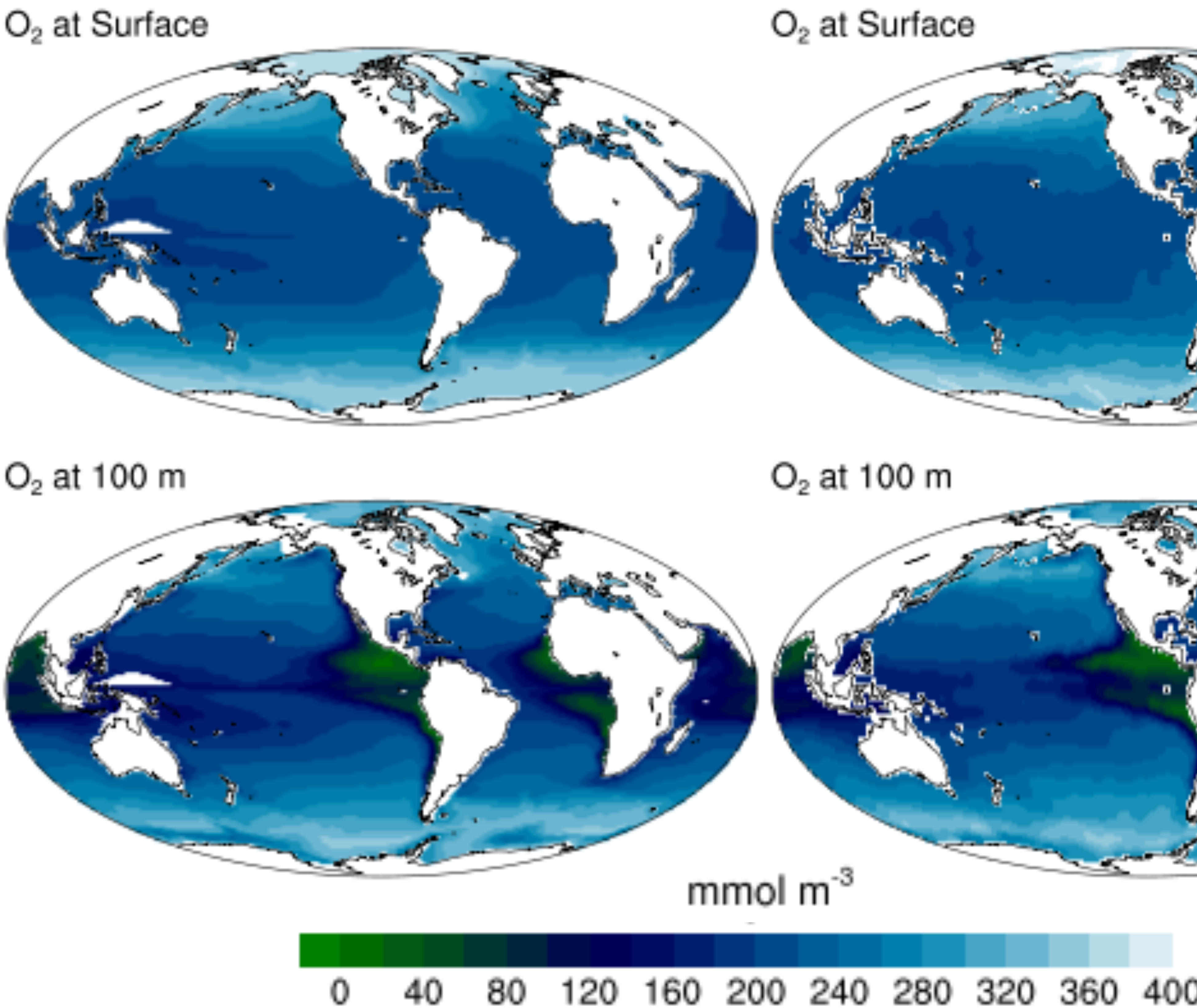

Scripps $O_2$ Program

# Models Examined

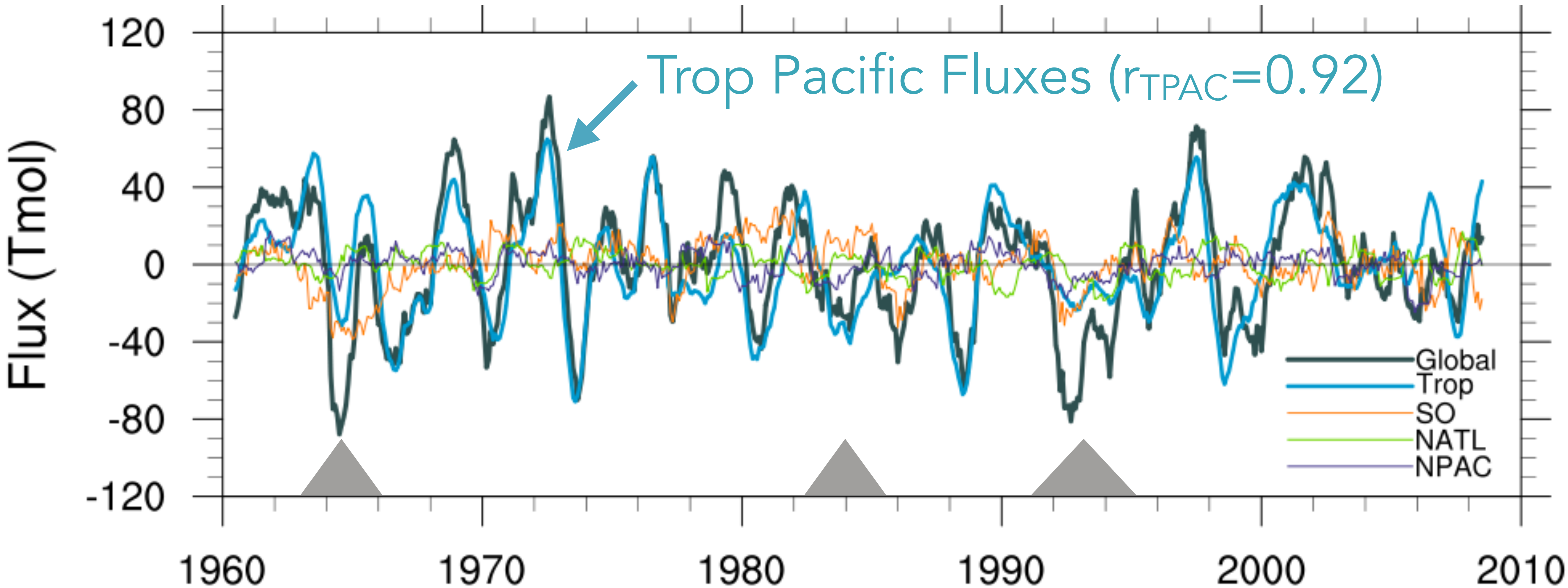
1. "Hindcast" **CESM simulation (CORE2-forced, Jan 1960- Dec 2008)**
2. Transport CESM APO Fluxes in TM3
3. Fully coupled ("1850 control") CMIP5 model intercomparison



Model Climatology (CESM-BGC) | Observations Climatology (NOAA WOA 2013)



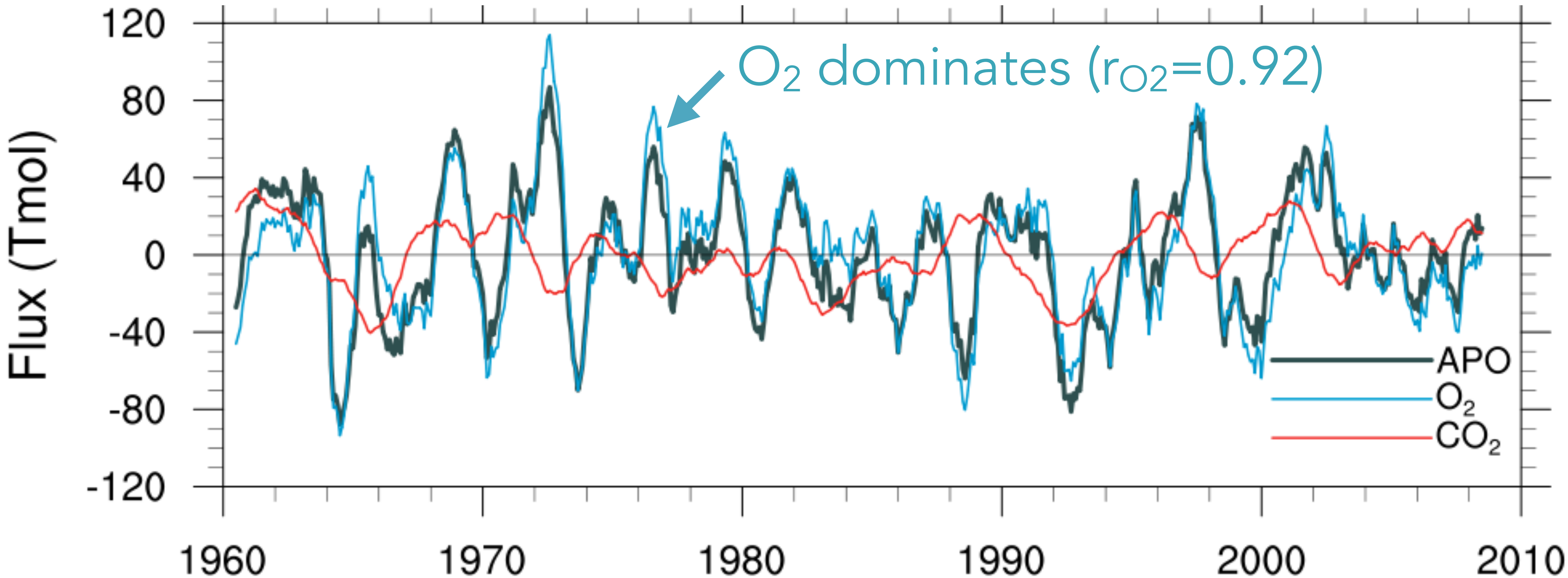
# Global APO Fluxes in CESM: Regional Contributions




*Trop Pacific 20N°-20°S

* Note drawdown in 1998-2001 is driven in CESM by tropical rather than norther basins (e.g. Hamme and Keeling, 2008)
* Volcanic eruptions show large departures in all basins (1964, 1992), see Plattner et al., (2002)

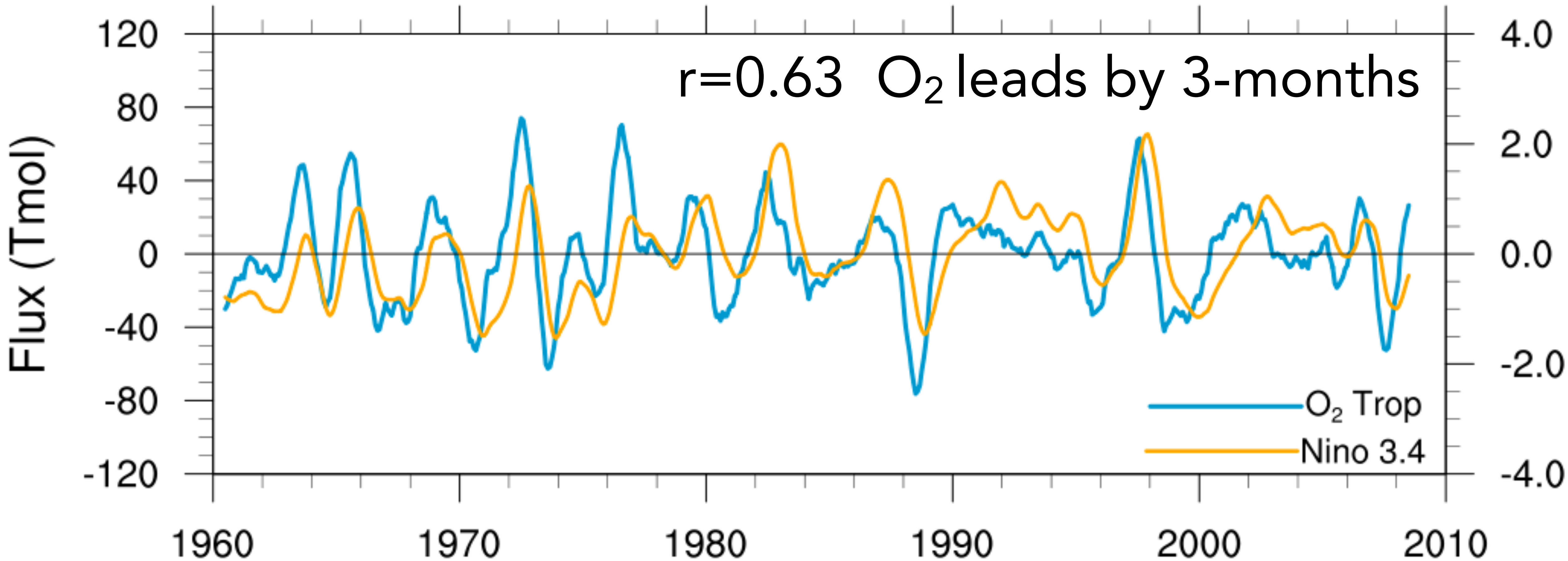
# Global APO Fluxes in CESM: $O_2$ vs. $CO_2$



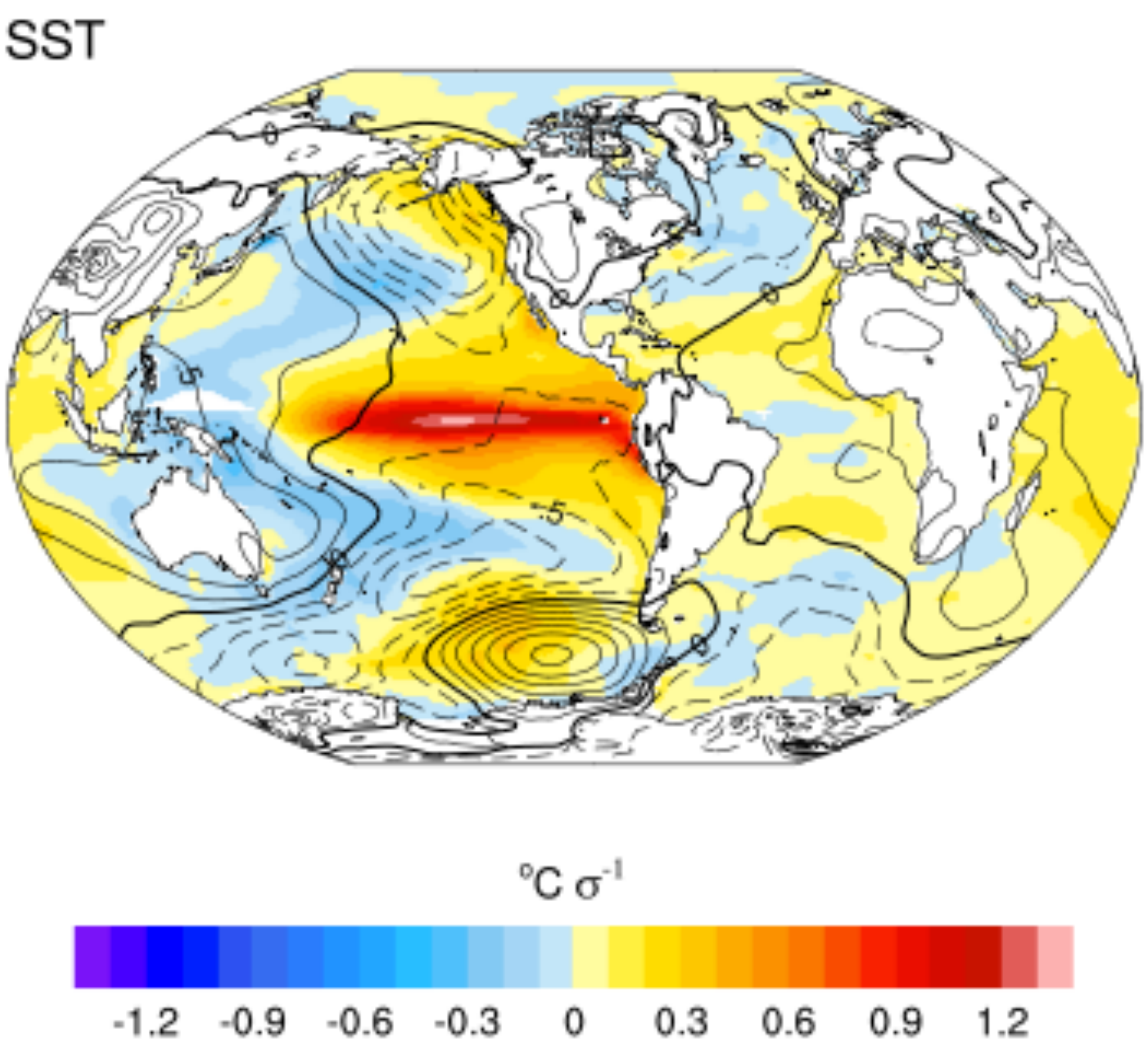

- As expected from slower $CO_2$ response timescale due to carbonate chemistry buffering (Broecker and Peng, 1974; Keeling and Severinghaus, 2000)

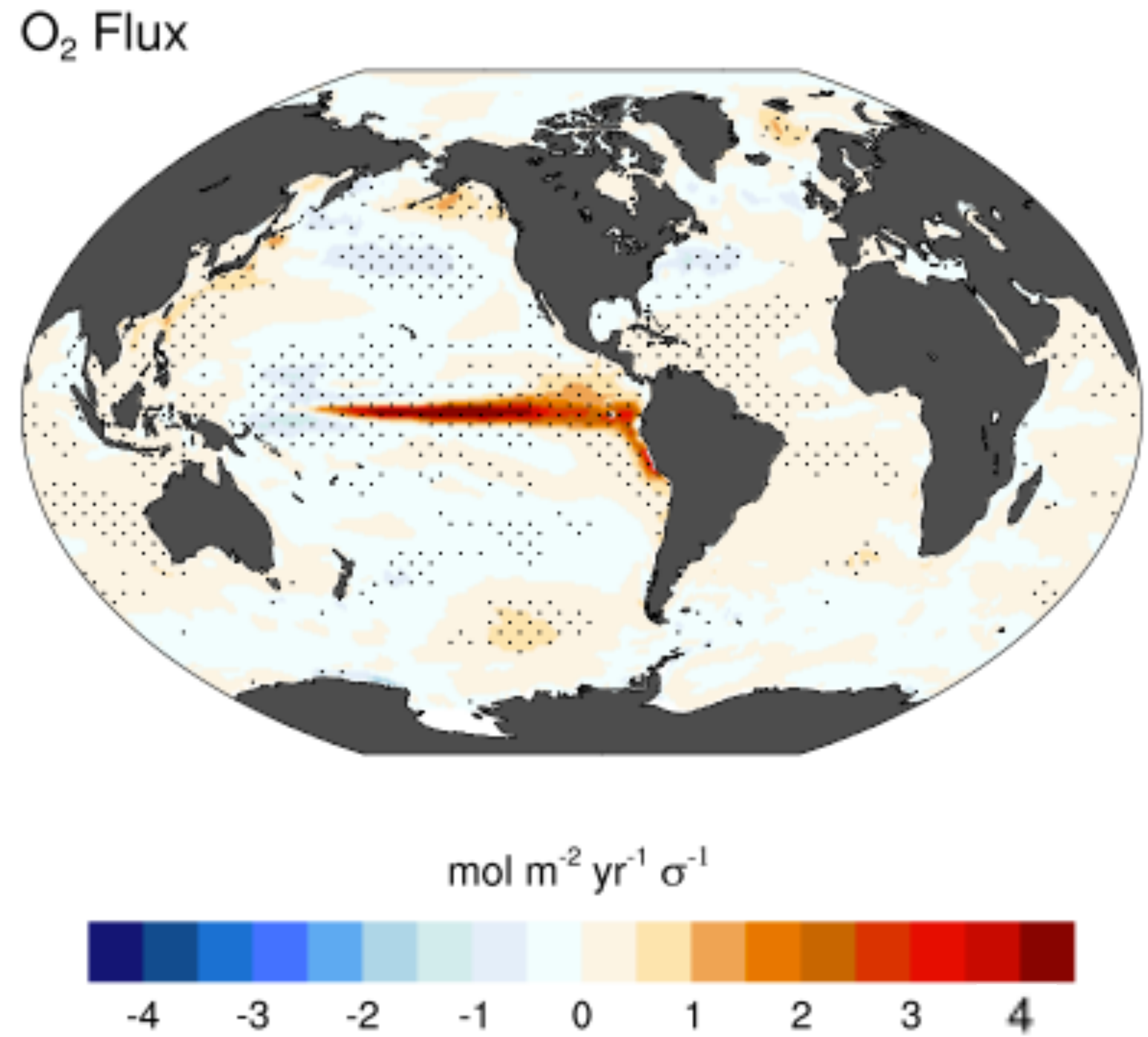
**We focus on tropical $O_2$ flux response to ENSO

# $O_2$ Flux Response to ENSO in CESM



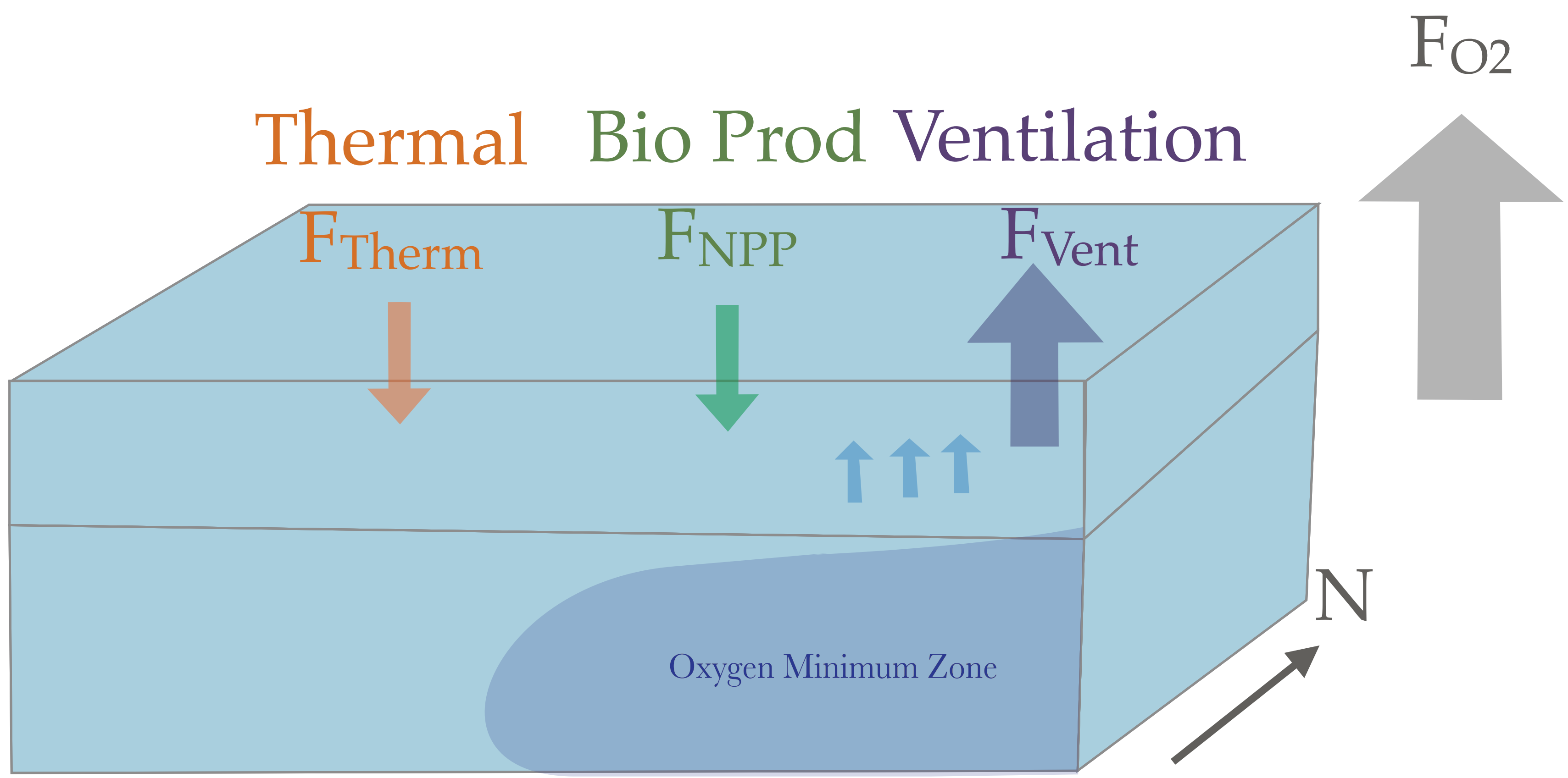
# $O_2$ Flux Response to ENSO in CESM




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

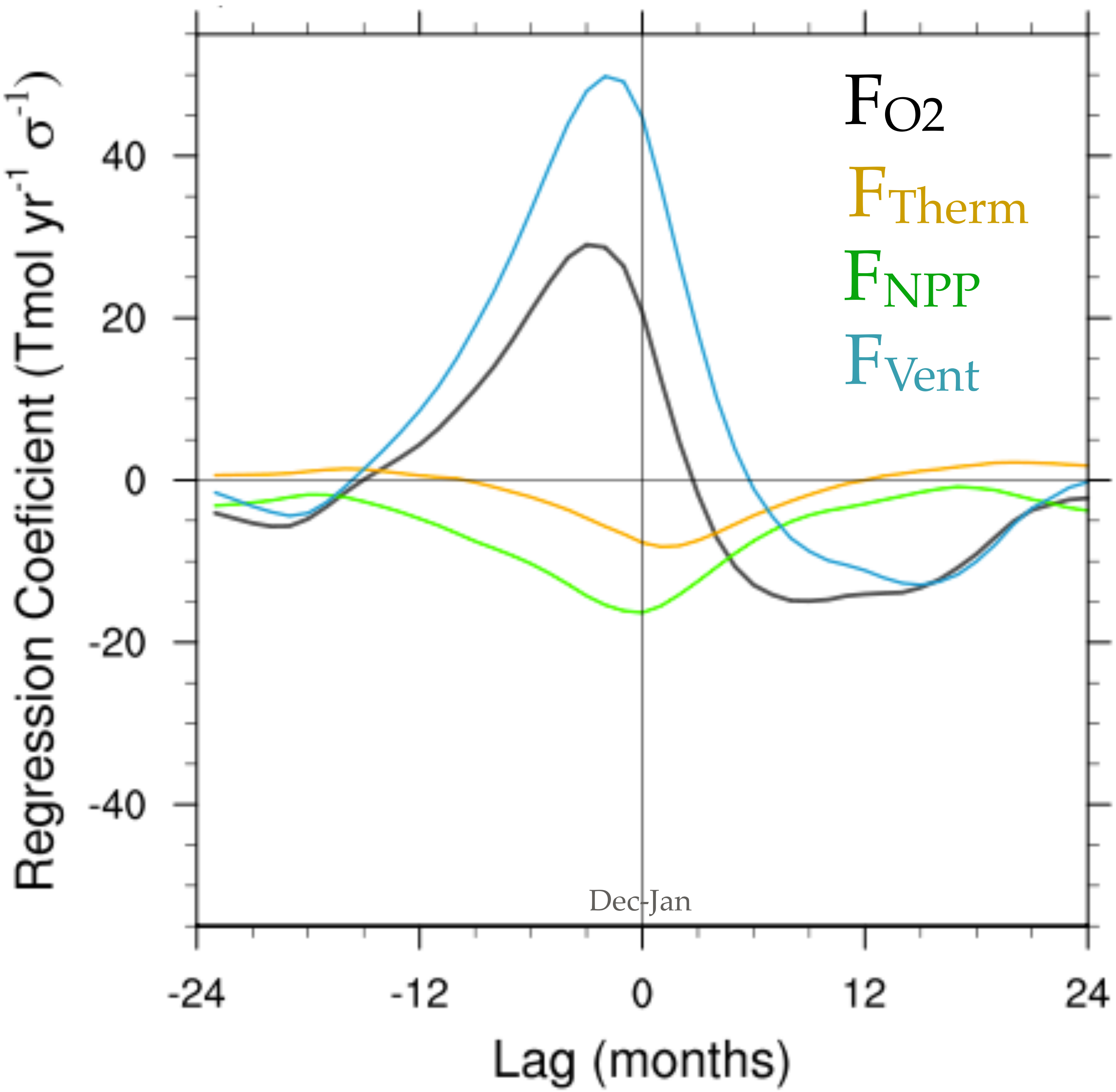



$$F_{O_2} = F_{Therm} + F_{NPP} + F_{Vent}$$

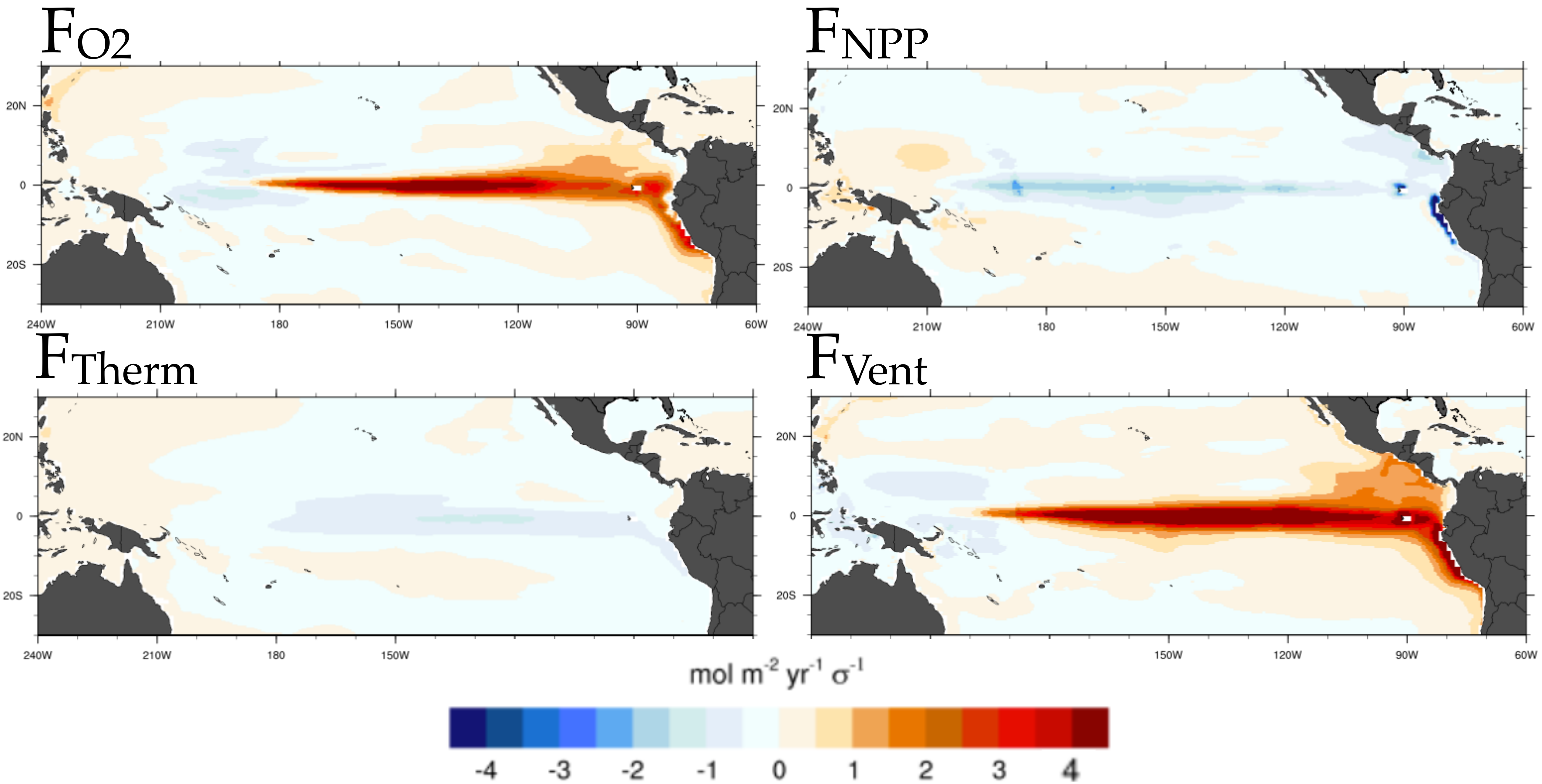
$$F_{Therm} = \frac{\partial O_2^{sol}}{\partial T}\frac{Q}{\rho C_p}$$ (Keeling et al., 1993)

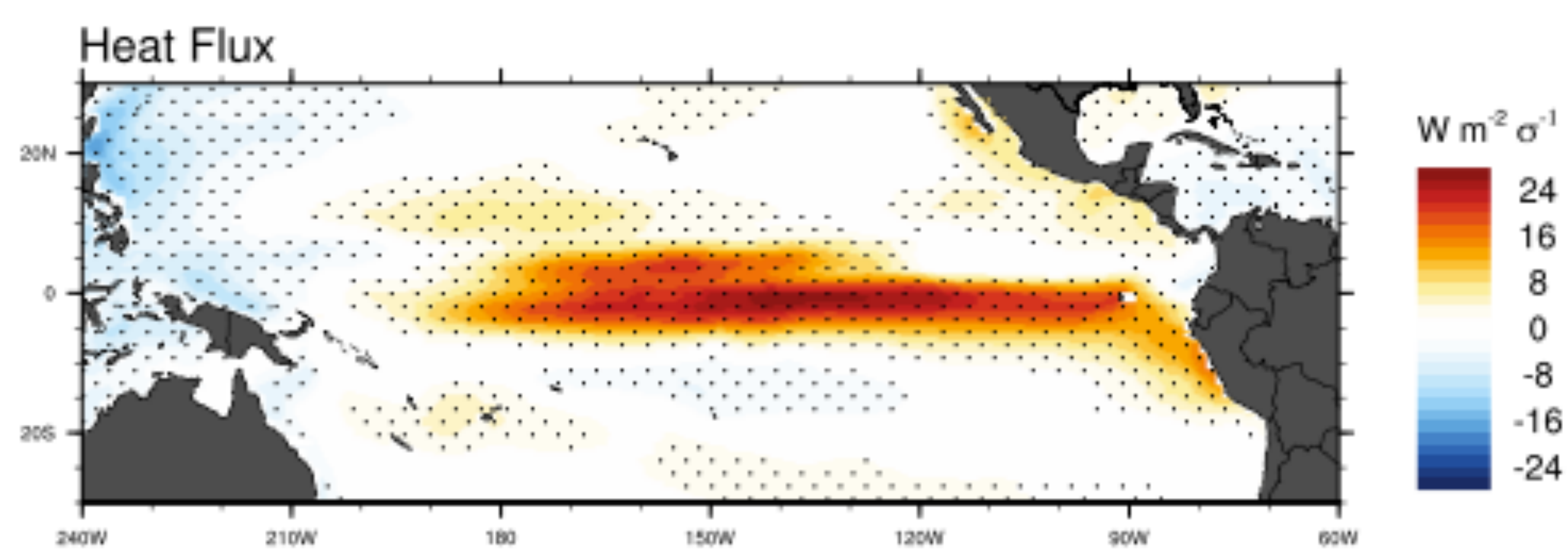
$$F_{NPP} = \int_0^{100m} Prod(O_2) - Cons(O_2) dz$$

# Tropical Pacific $O_2$ Flux Vs. Niño3.4 in CESM

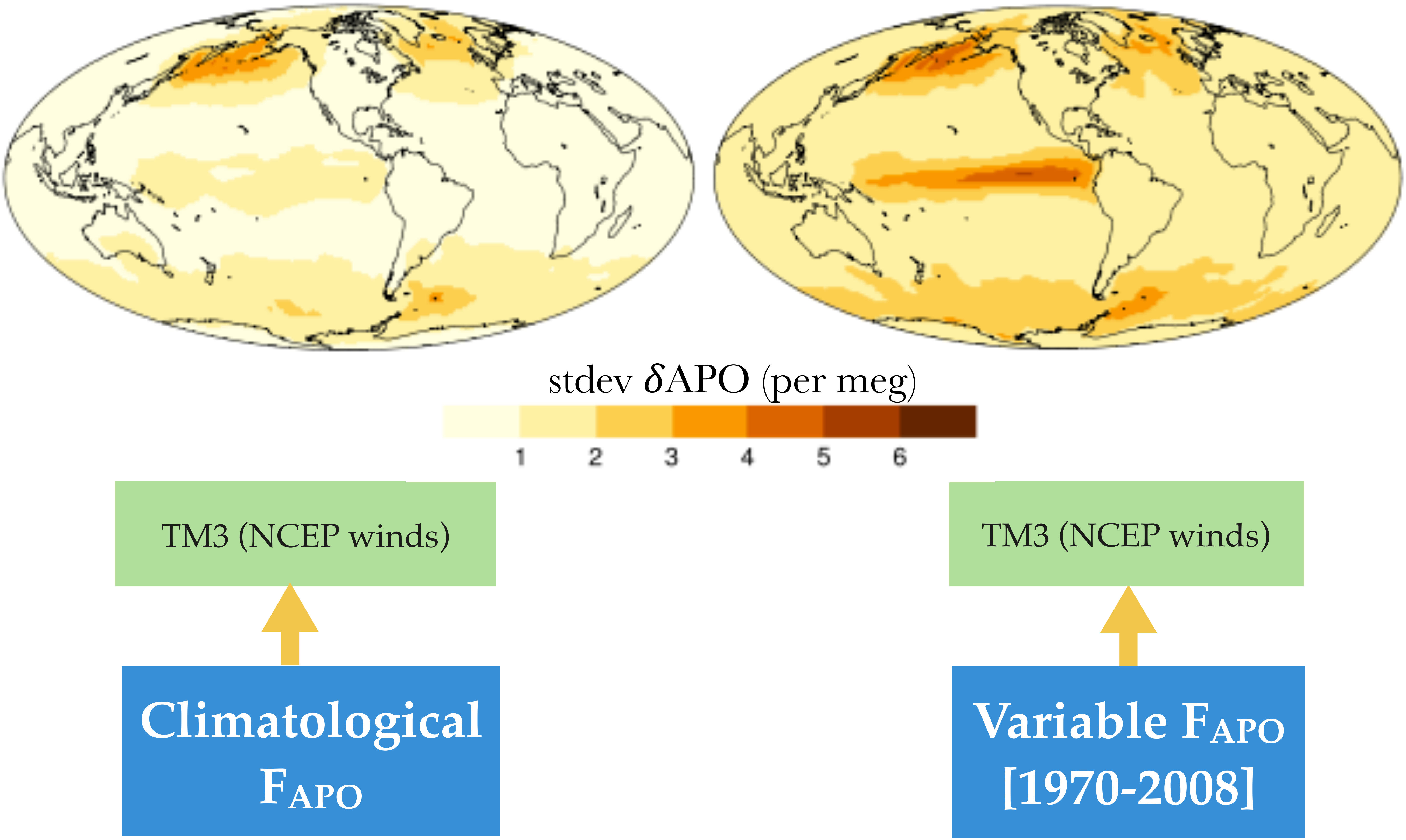


# $O_2$ Flux Response to ENSO in CESM: Mechanisms



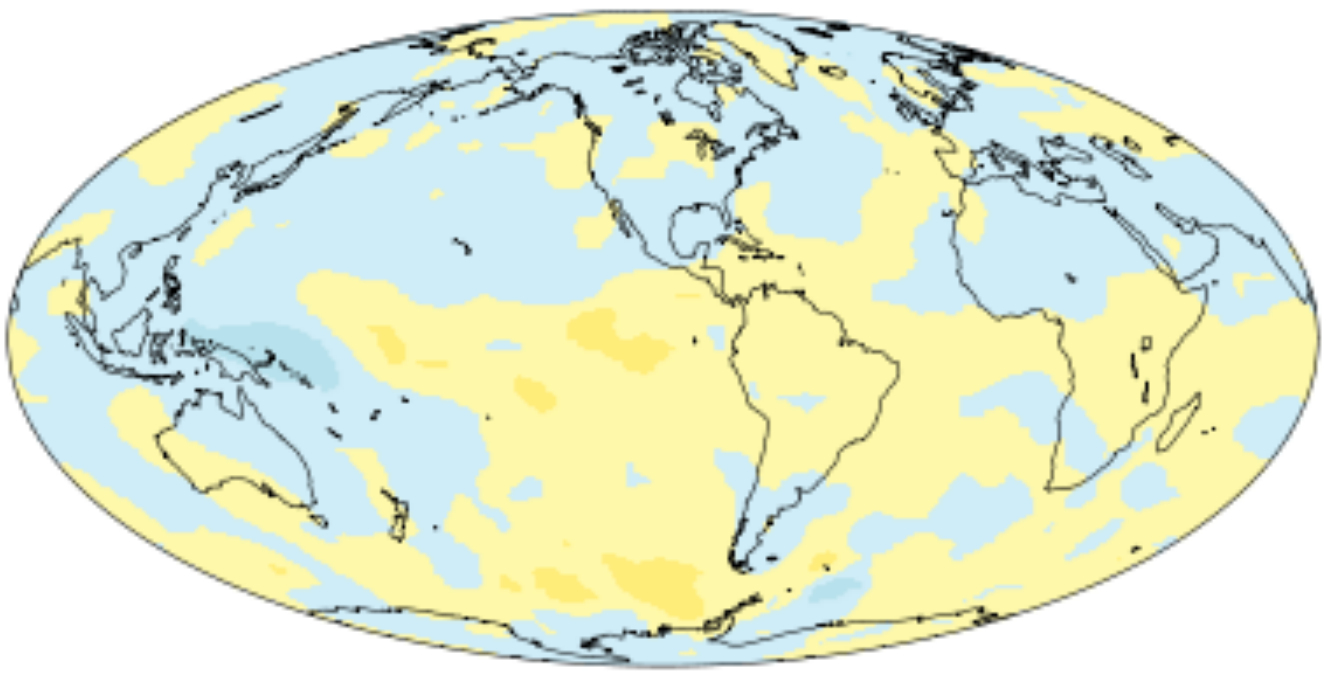



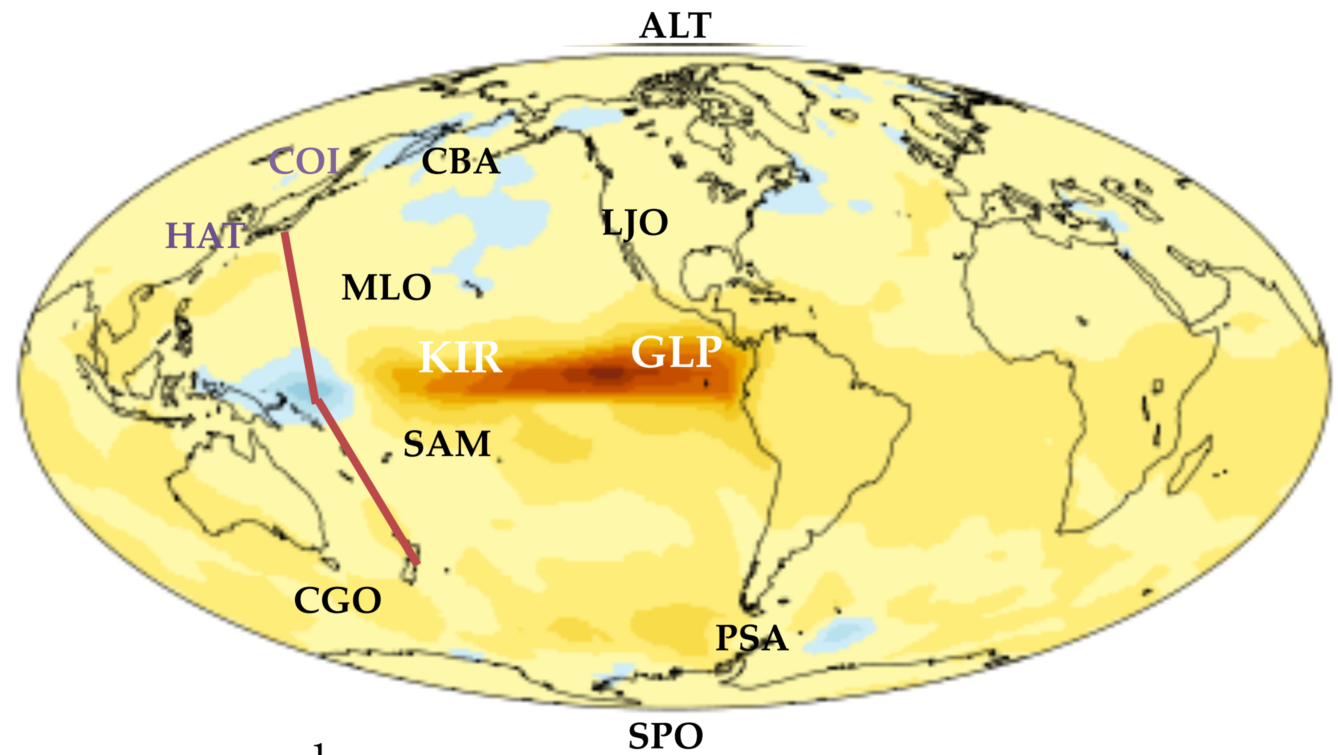
# Influence of Atmospheric Transport

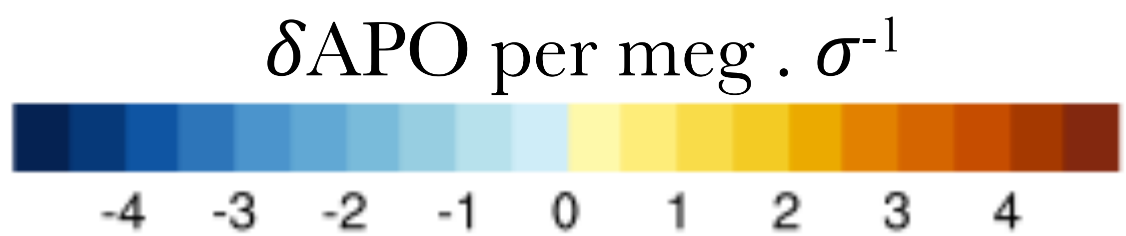


Atmospheric transport effects only

Atmospheric + Air-sea Flux variability






TM3 (NCEP winds)

↑

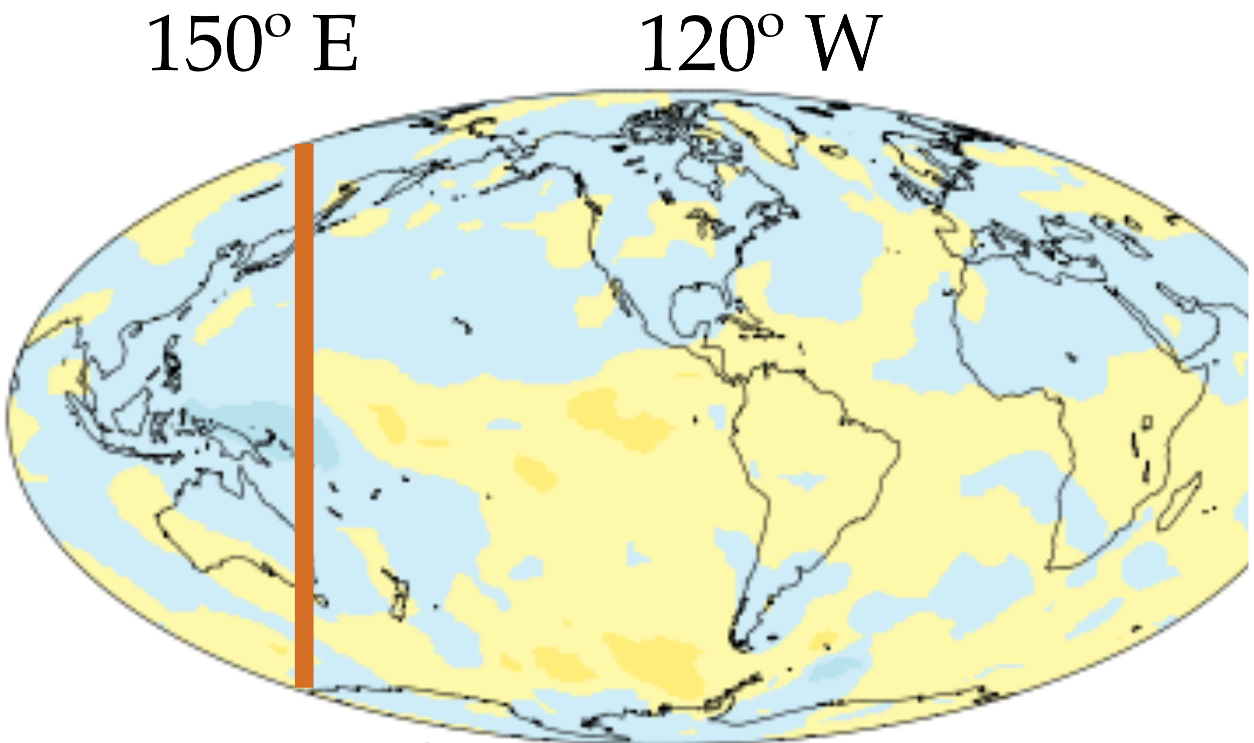
**Climatological $F_{APO}$**

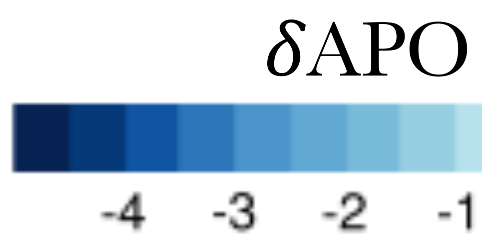
TM3 (NCEP winds)

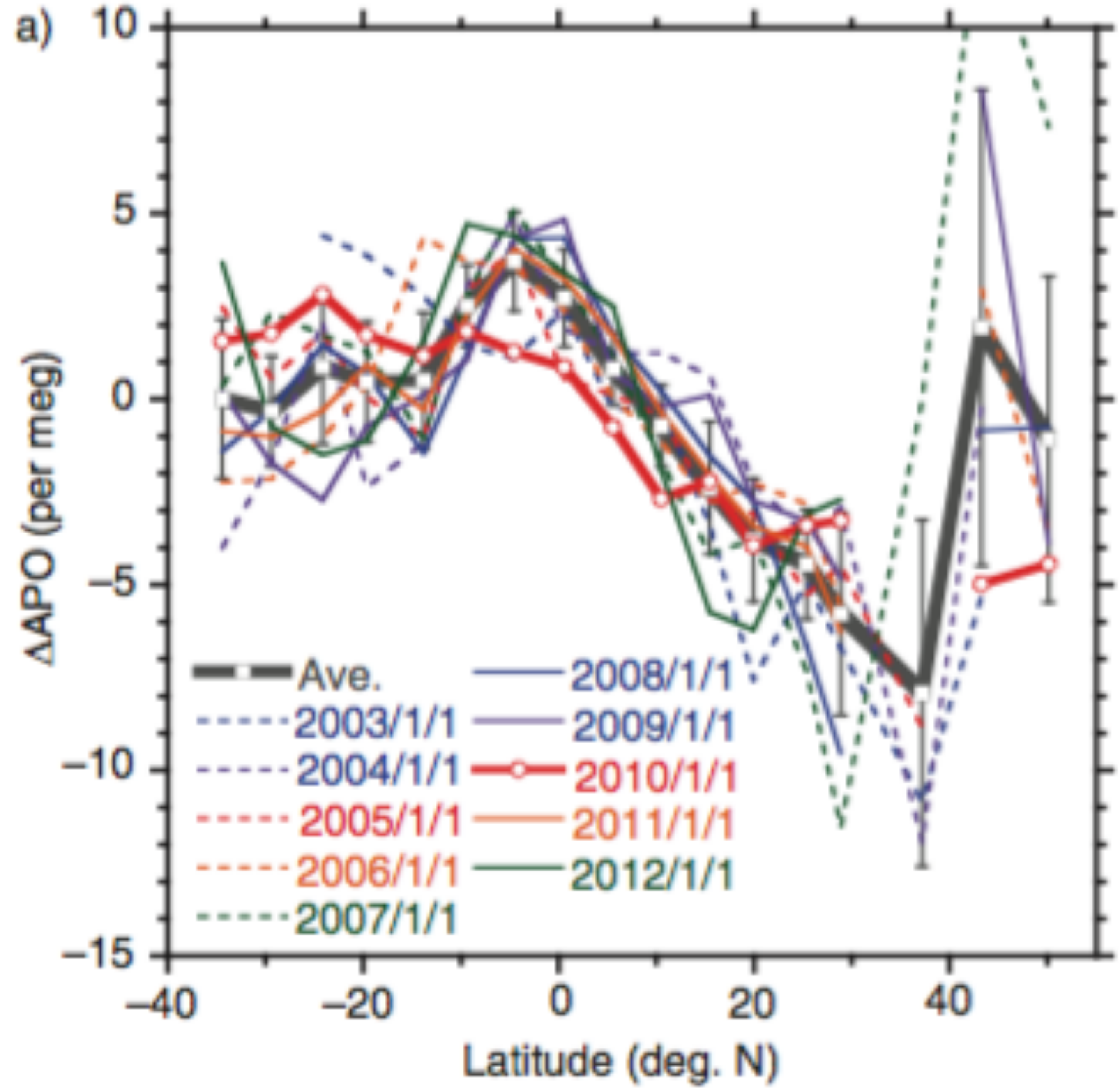
↑

**Variable $F_{APO}$ [1970-2008]**

# Atmospheric transport effects only



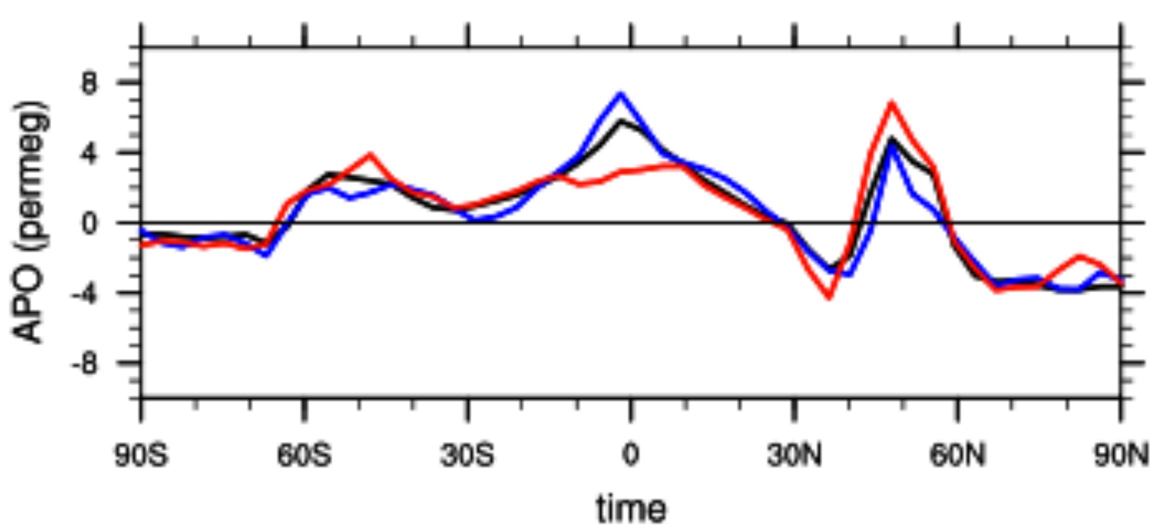



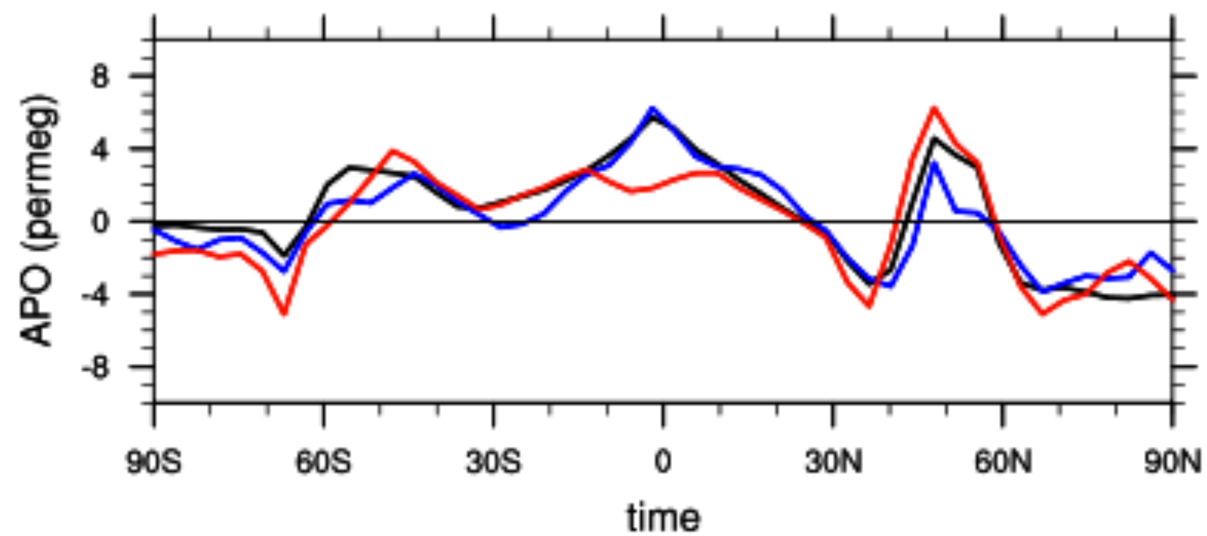

Tohjima et al., 2015

Mean δAPO

El Niño 97-98

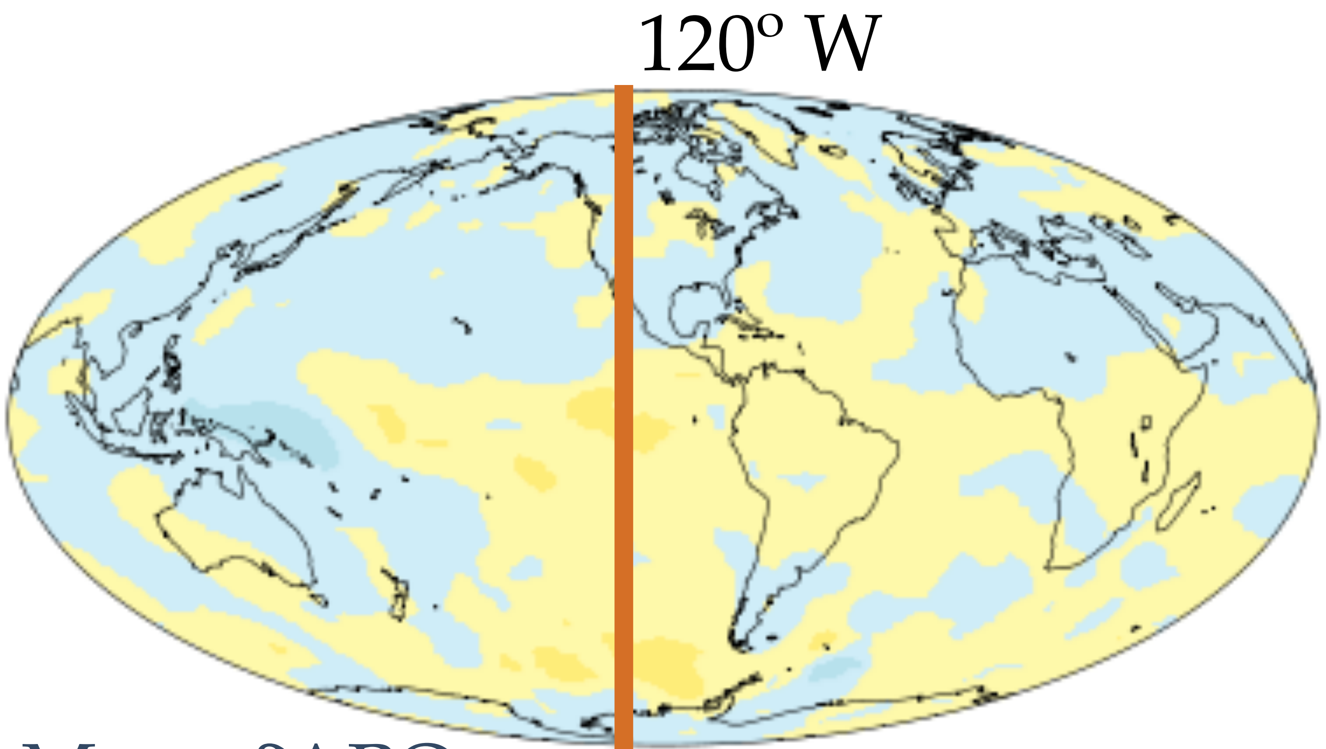
La Niña 98-99

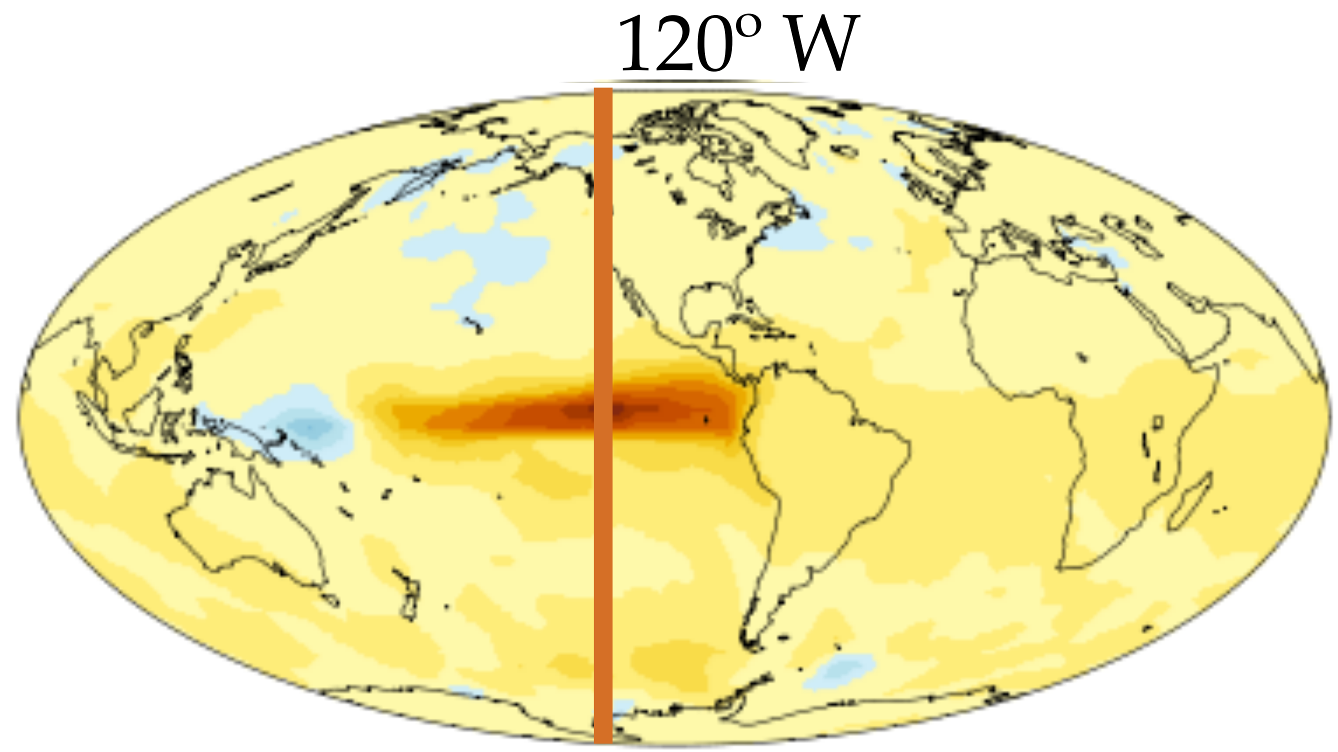


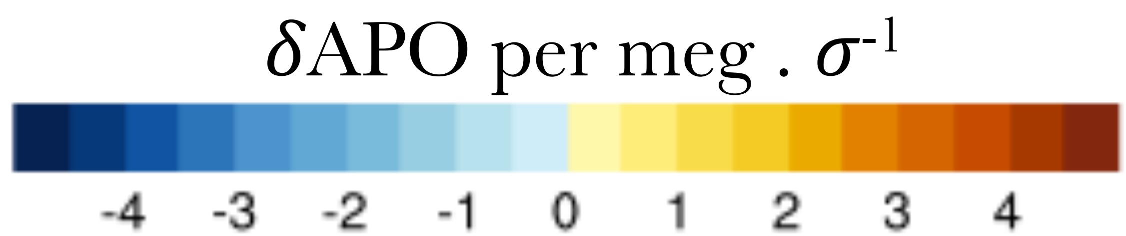
## Atmospheric transport effects only

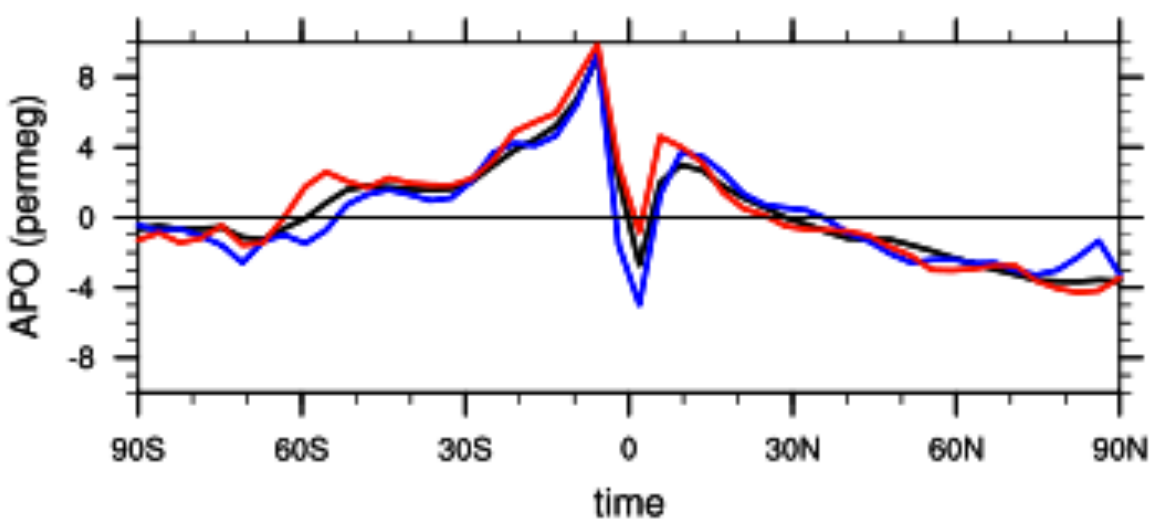
## Atmospheric + Air-sea Flux variability

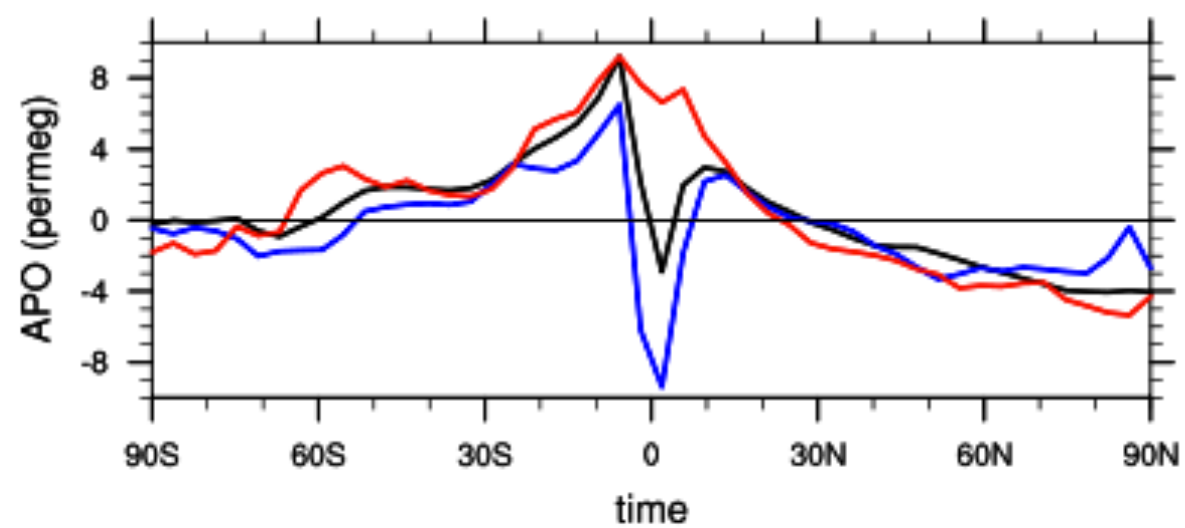



Mean $\delta$APO
El Niño 97-98
La Niña 98-99



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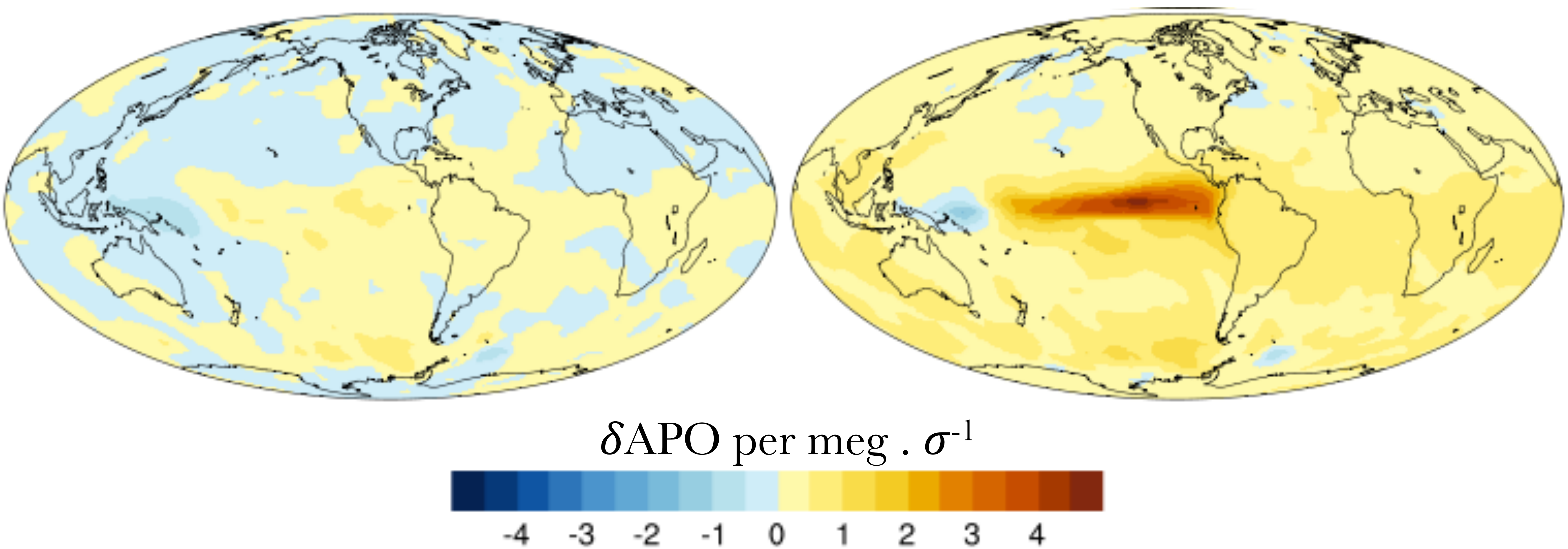
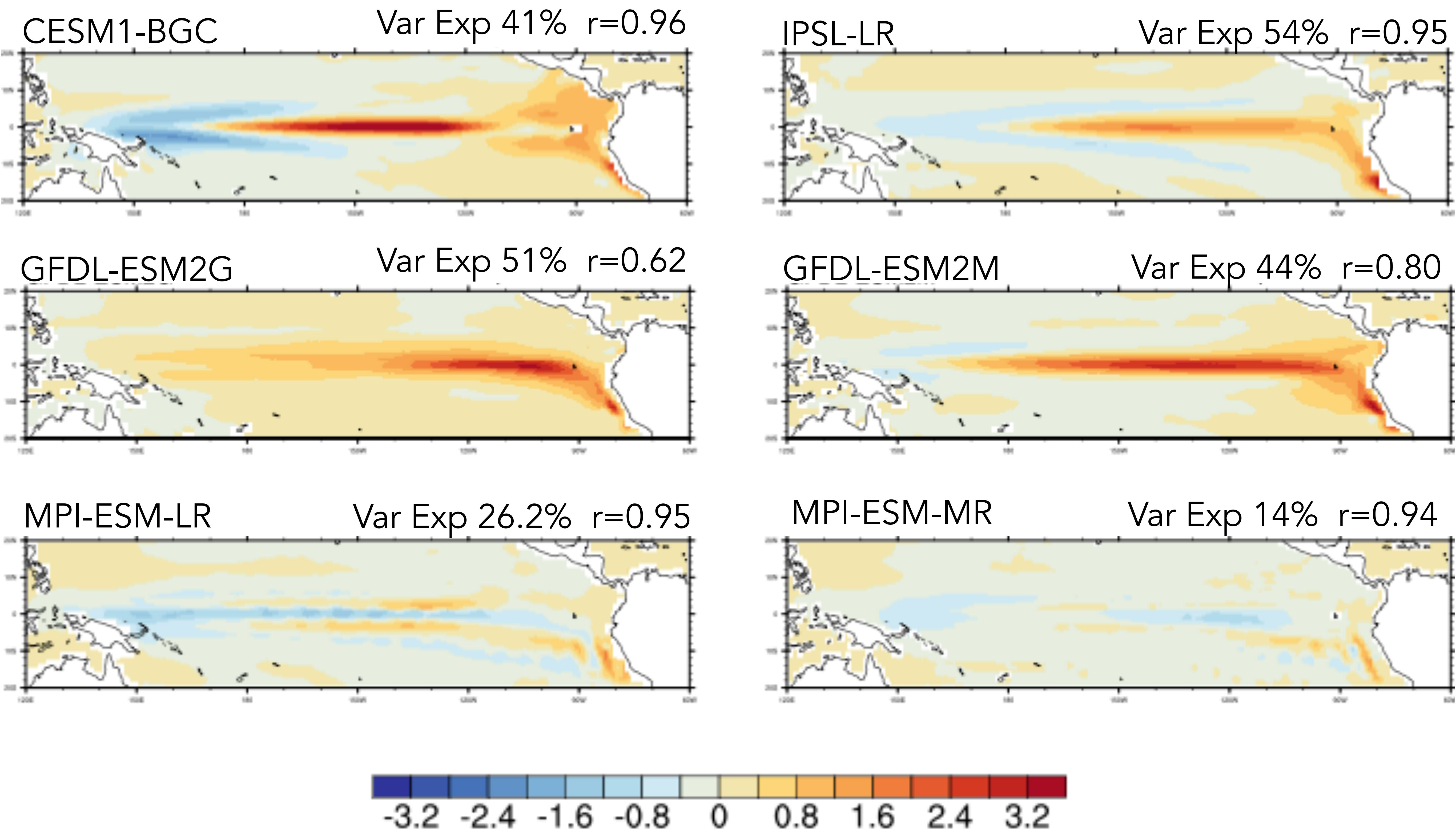


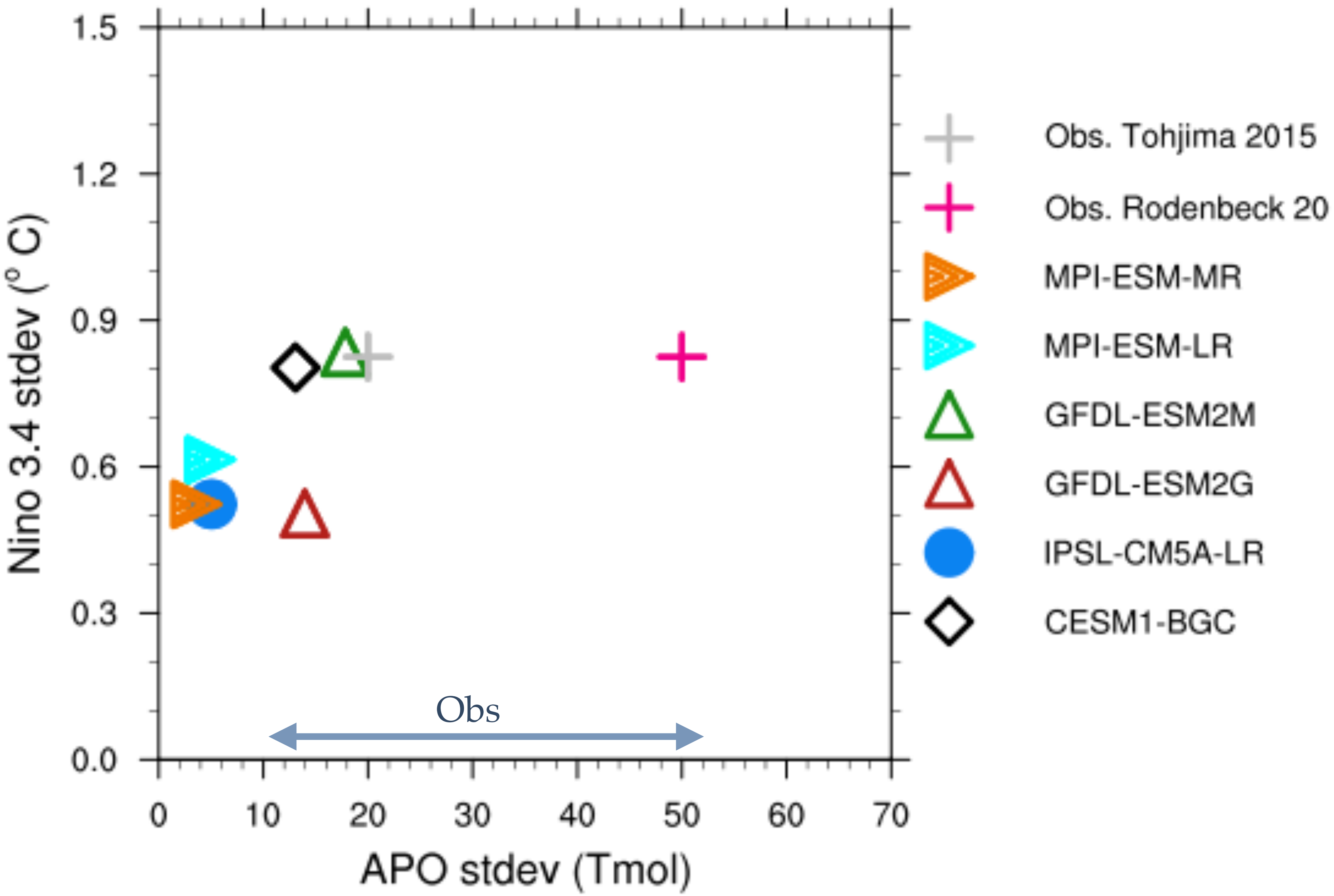

1. Atmospheric winds drive **western** tropical Pacific $\delta$APO variability, but not in the **eastern** tropical Pacific, where ventilation dominates
2. ENSO phenomenology permits both Tohjima et al., 2015 AND Rödenbeck et al., 2008 mechanisms. $O_2$ ventilation is a major driver.

# CMIP5 Models




1st EOF of $O_2$ fluxes

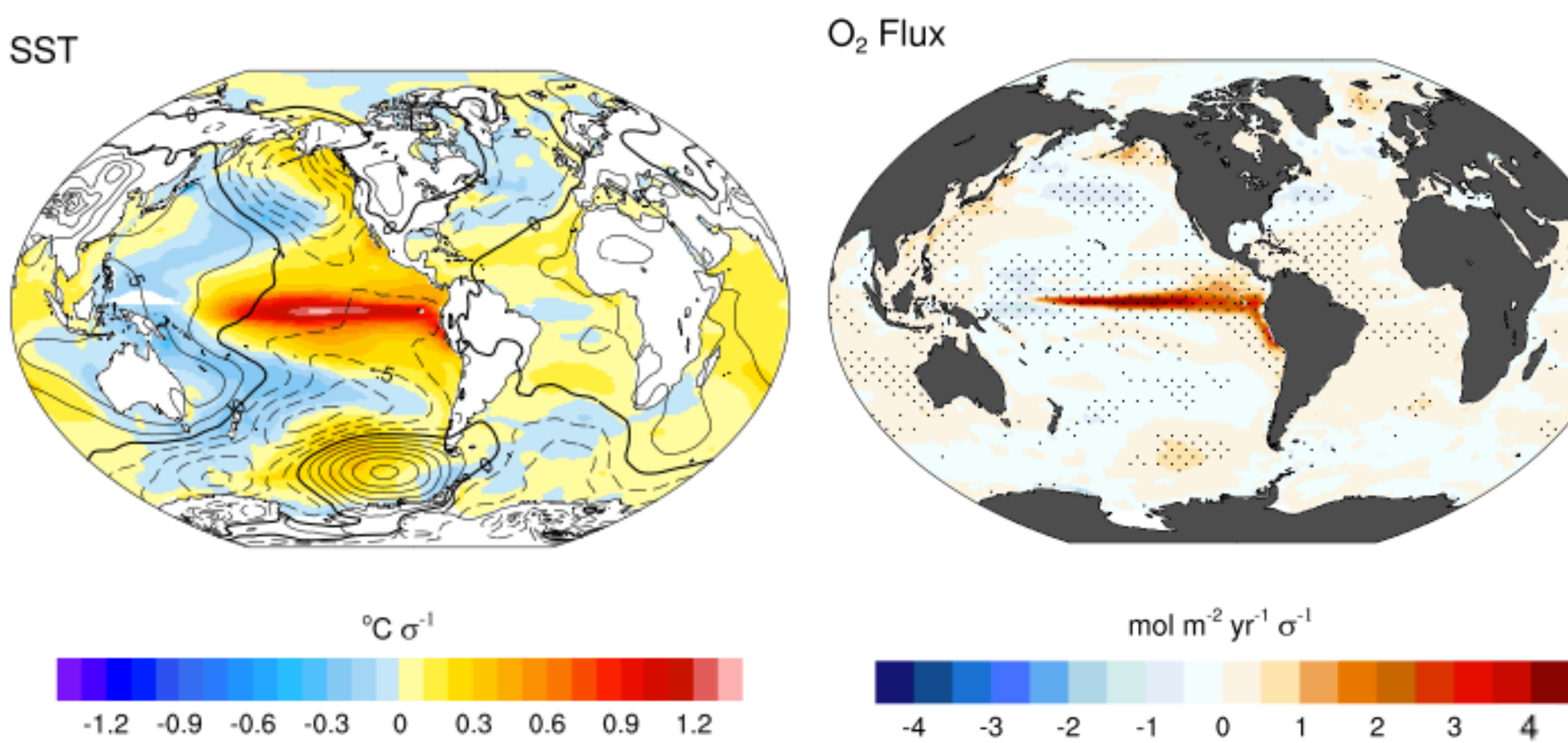
# Models Validation




Tropical Pacific 20ºN-20ºS

# 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 $\delta$APO response: Enhanced observational coverage needed for ocean models validation



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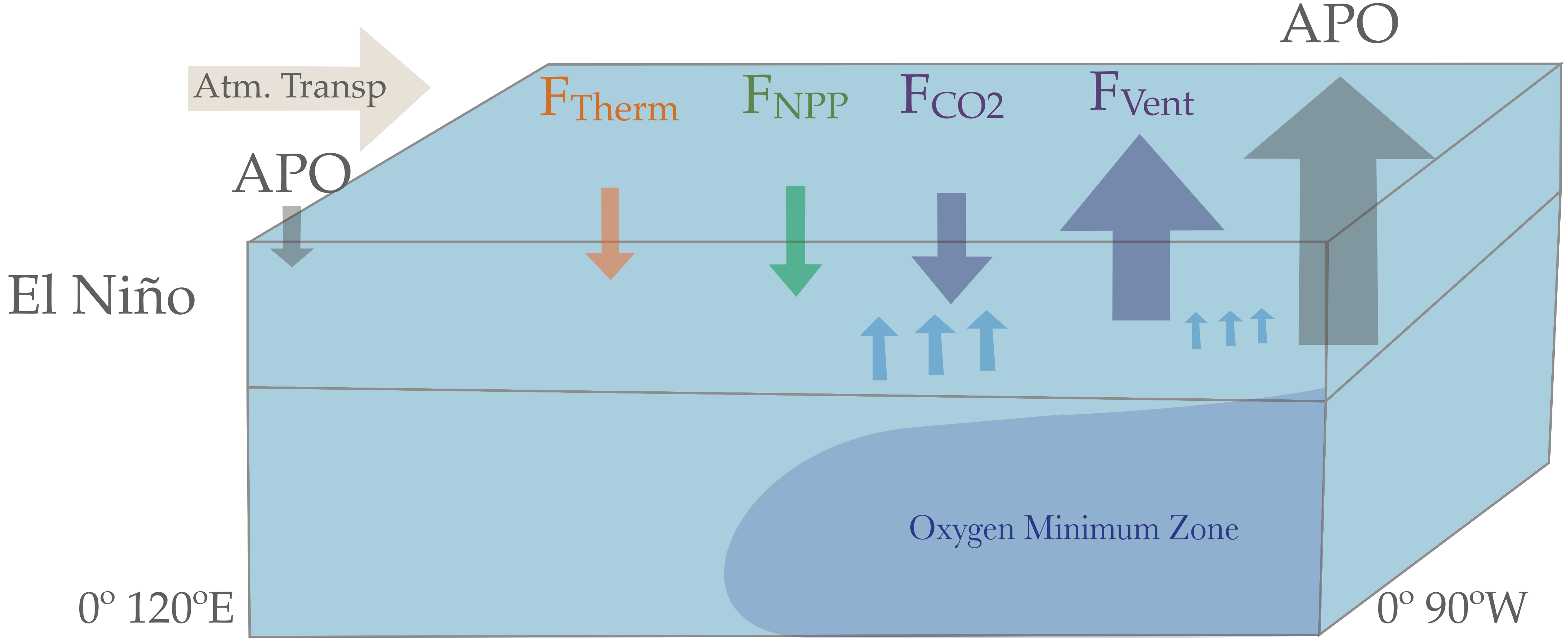

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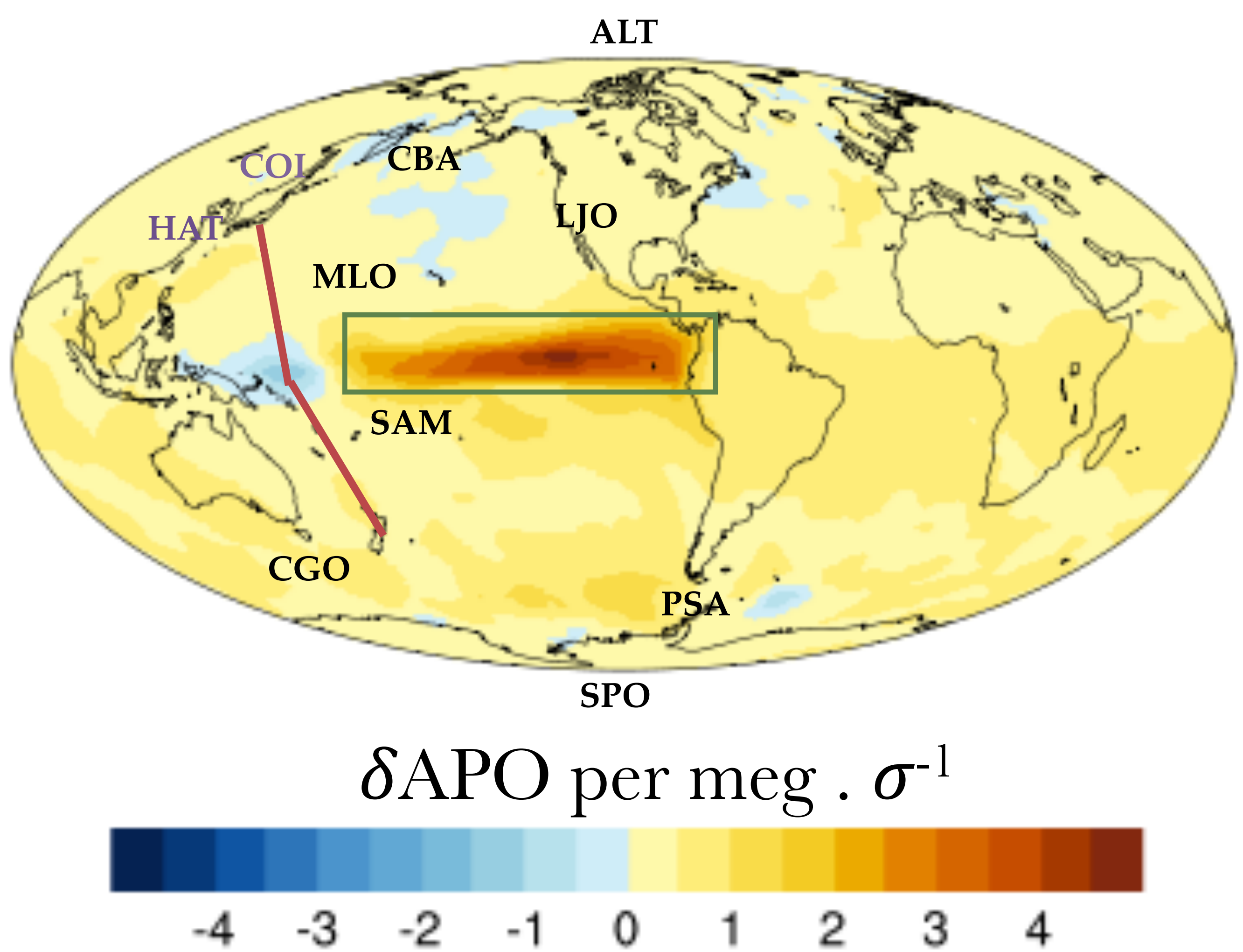
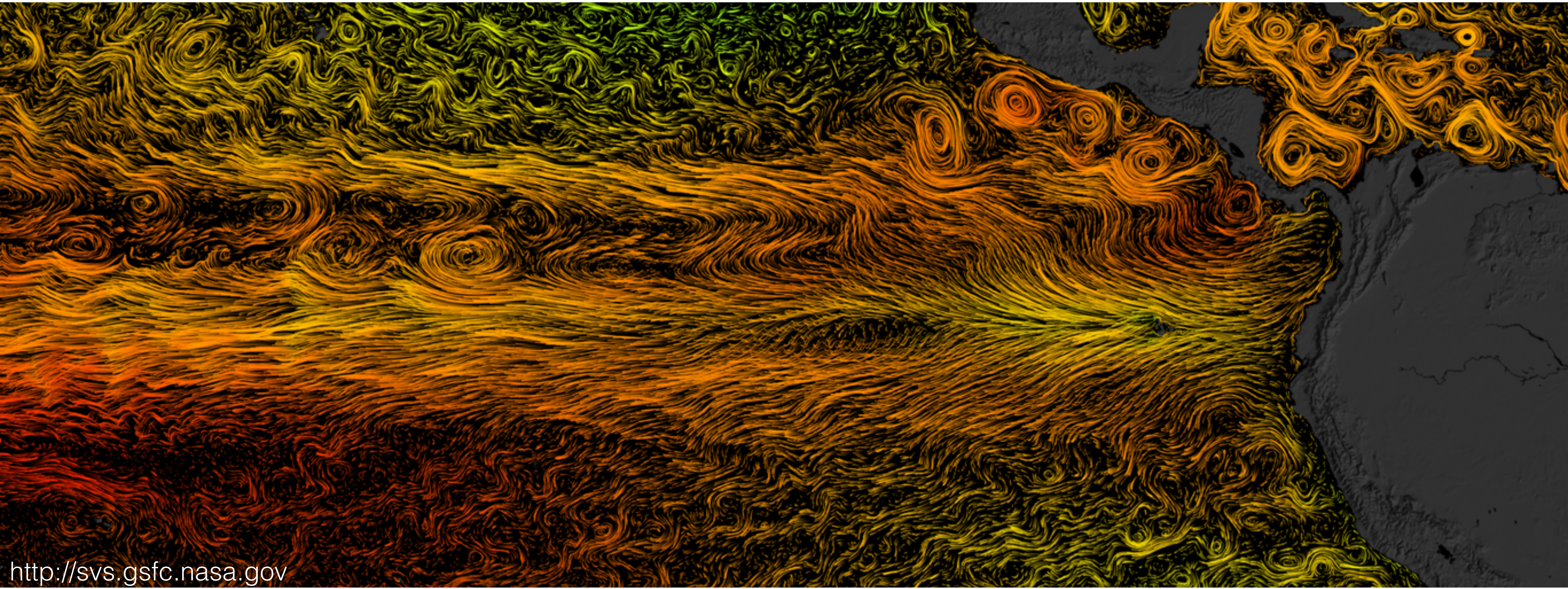
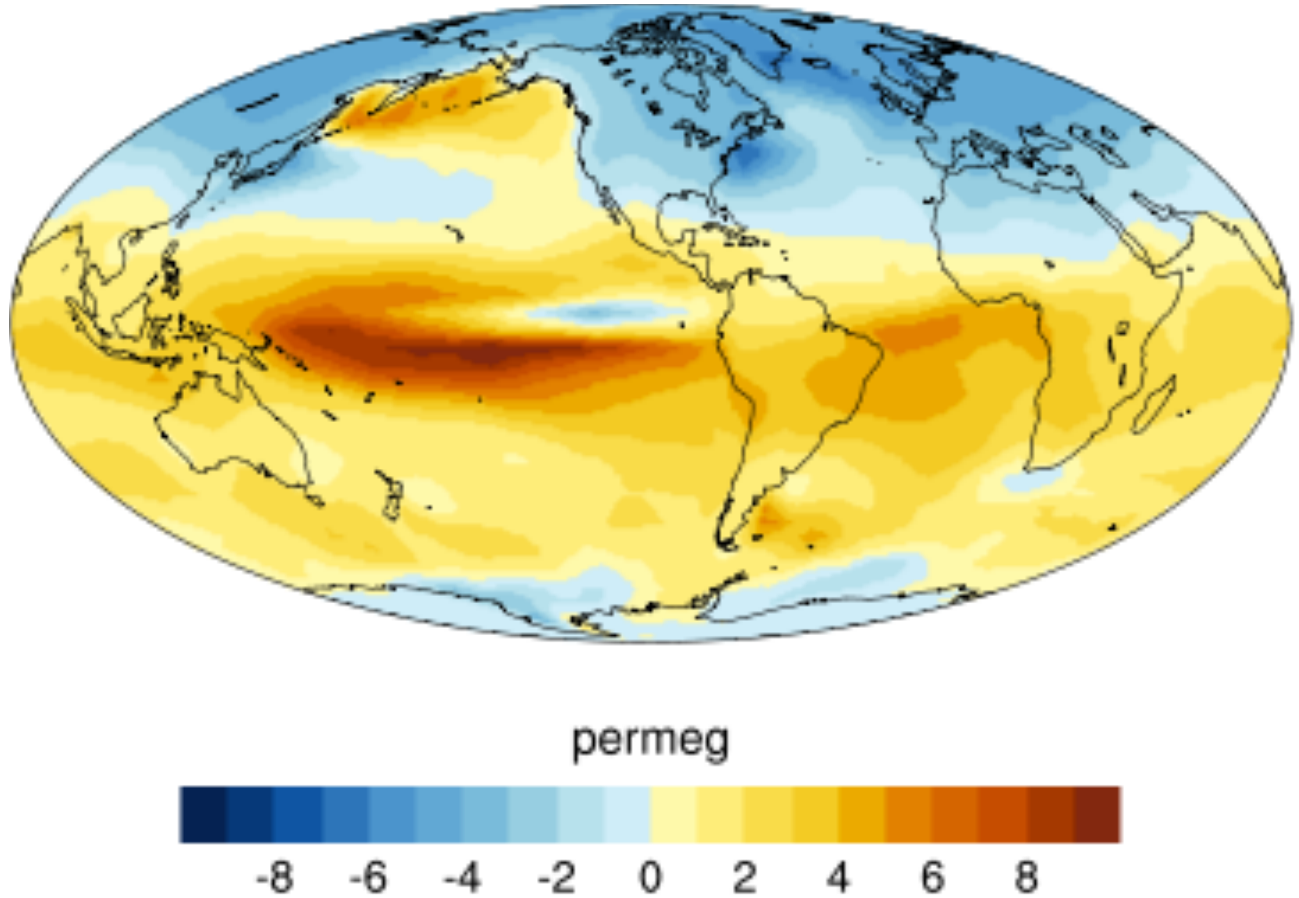


# QUESTIONS?

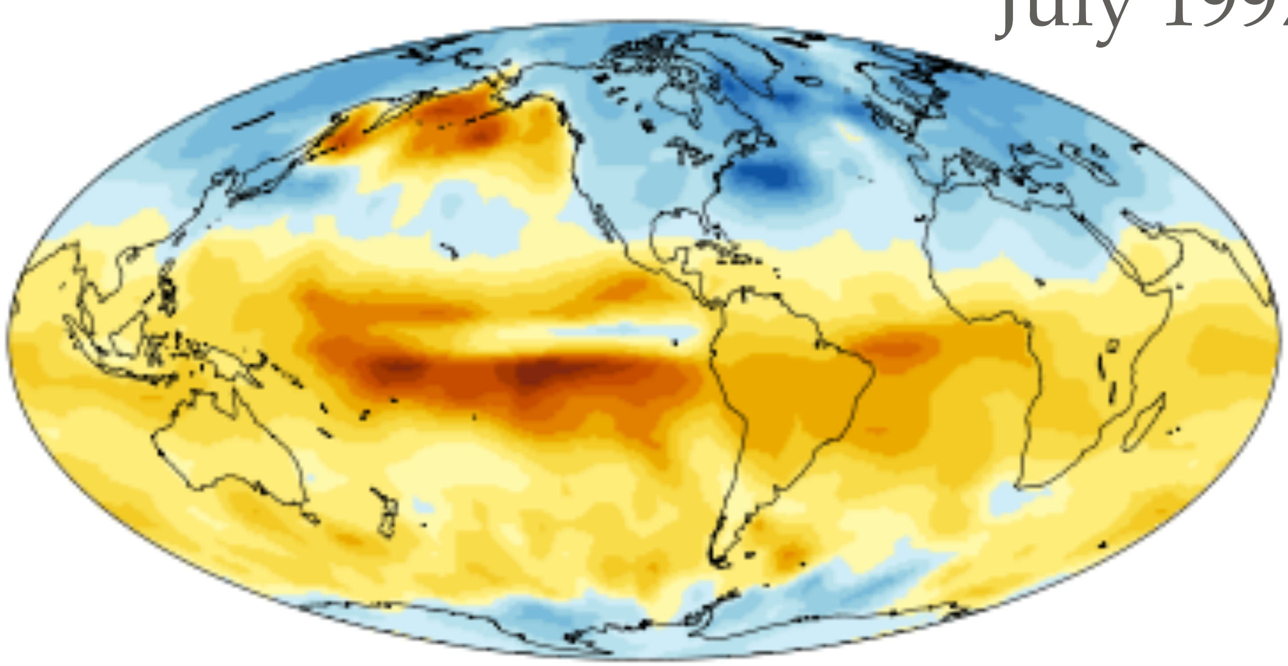


# Additional Slides

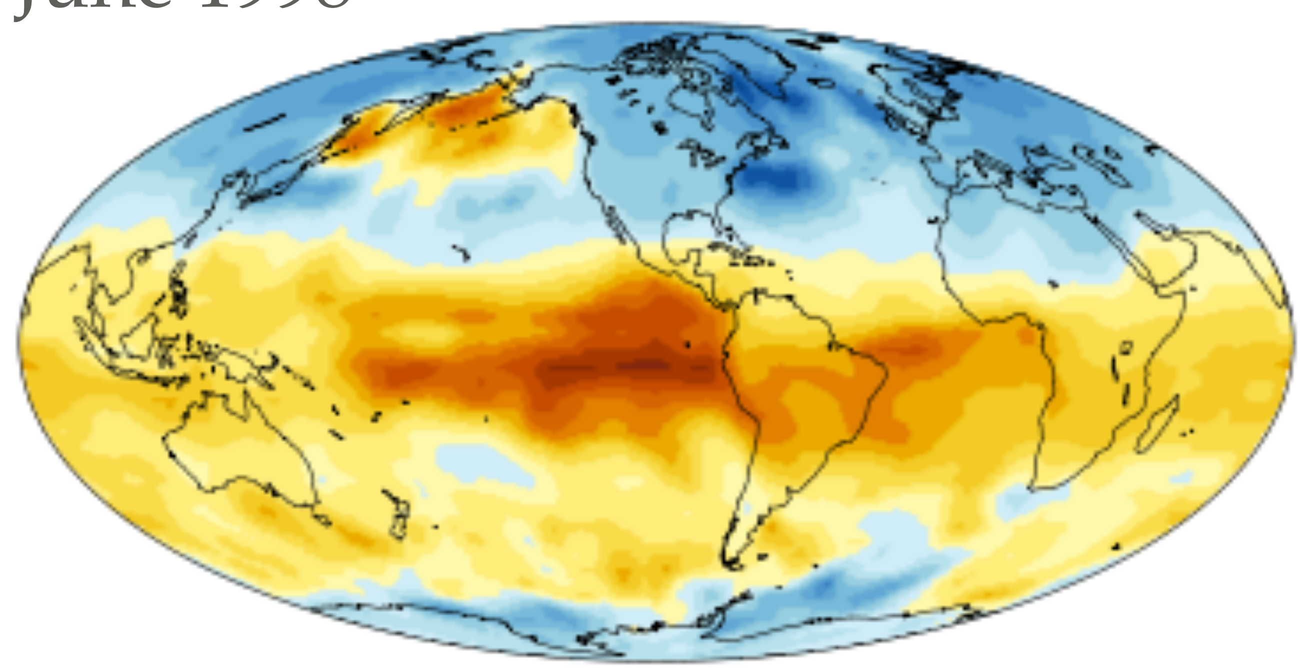
# Model Mean $\delta$APO




July 1997- June 1998

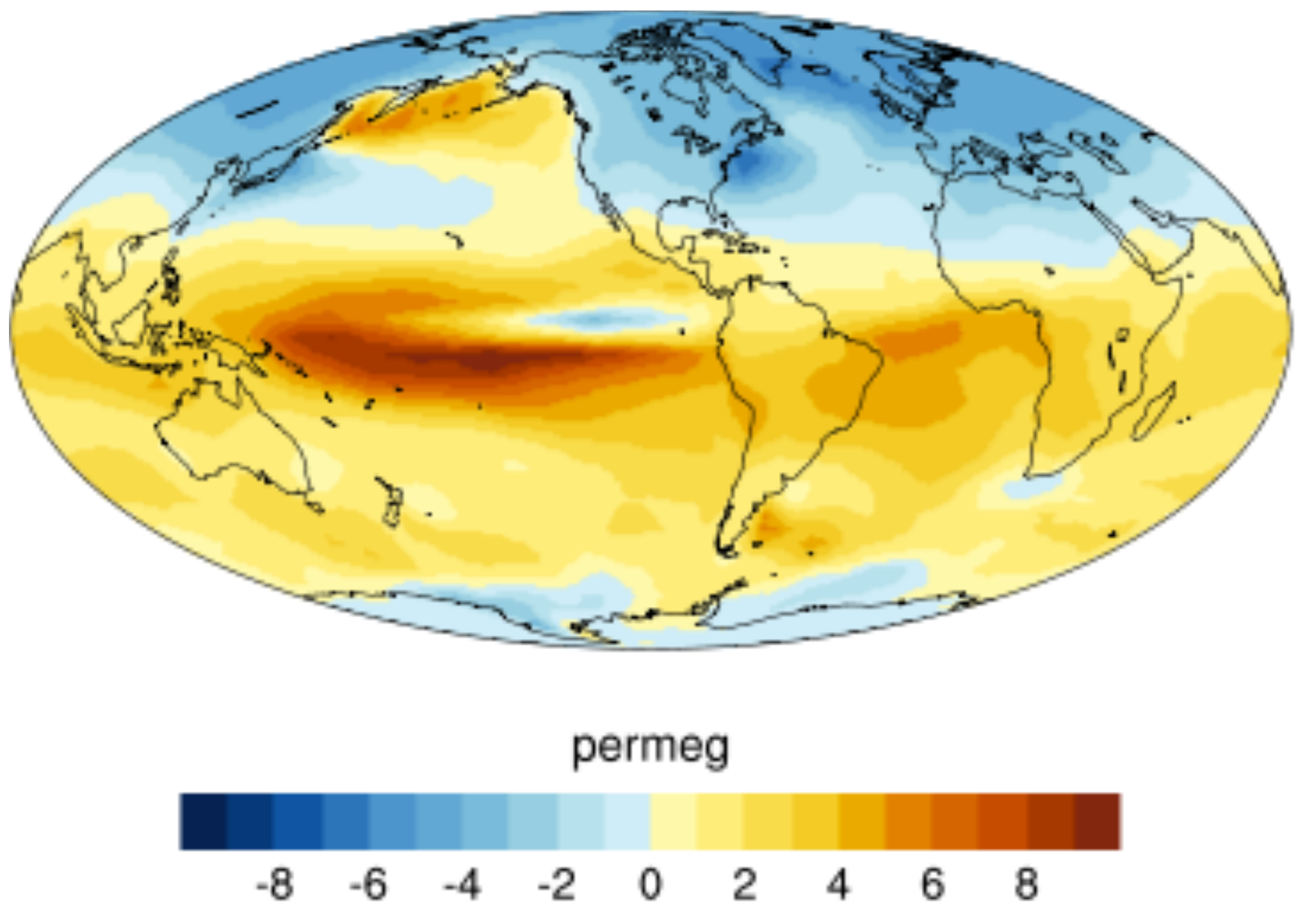


Climatological Flux +TM3

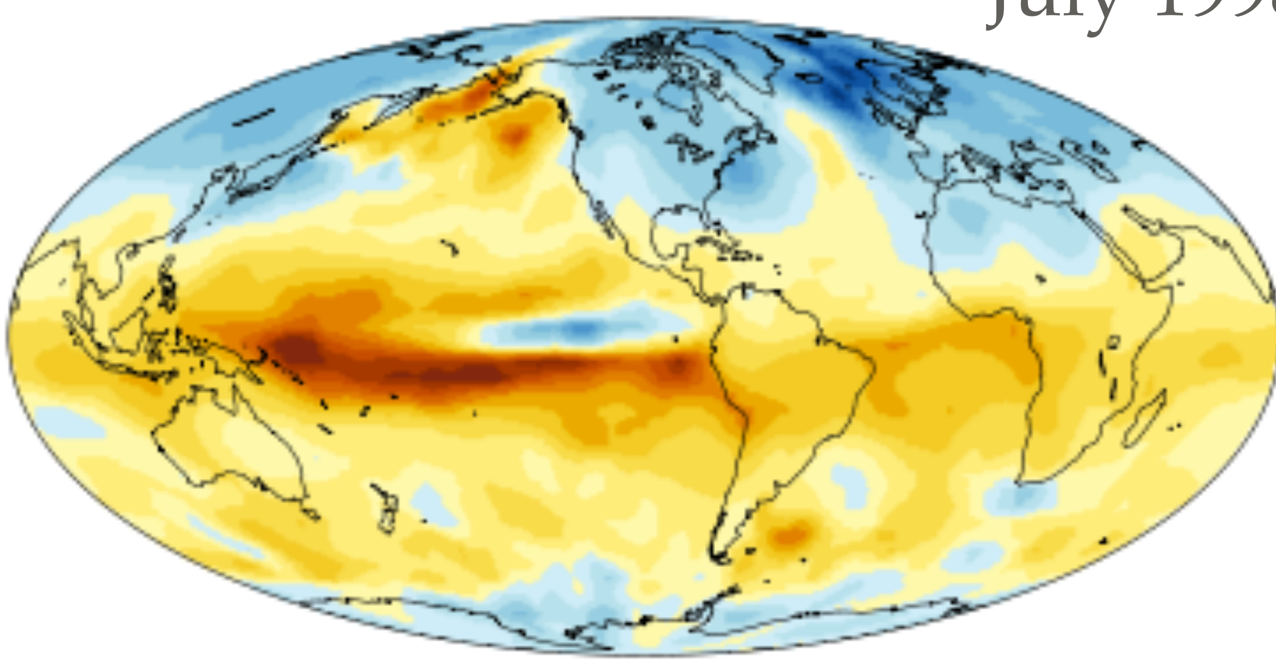


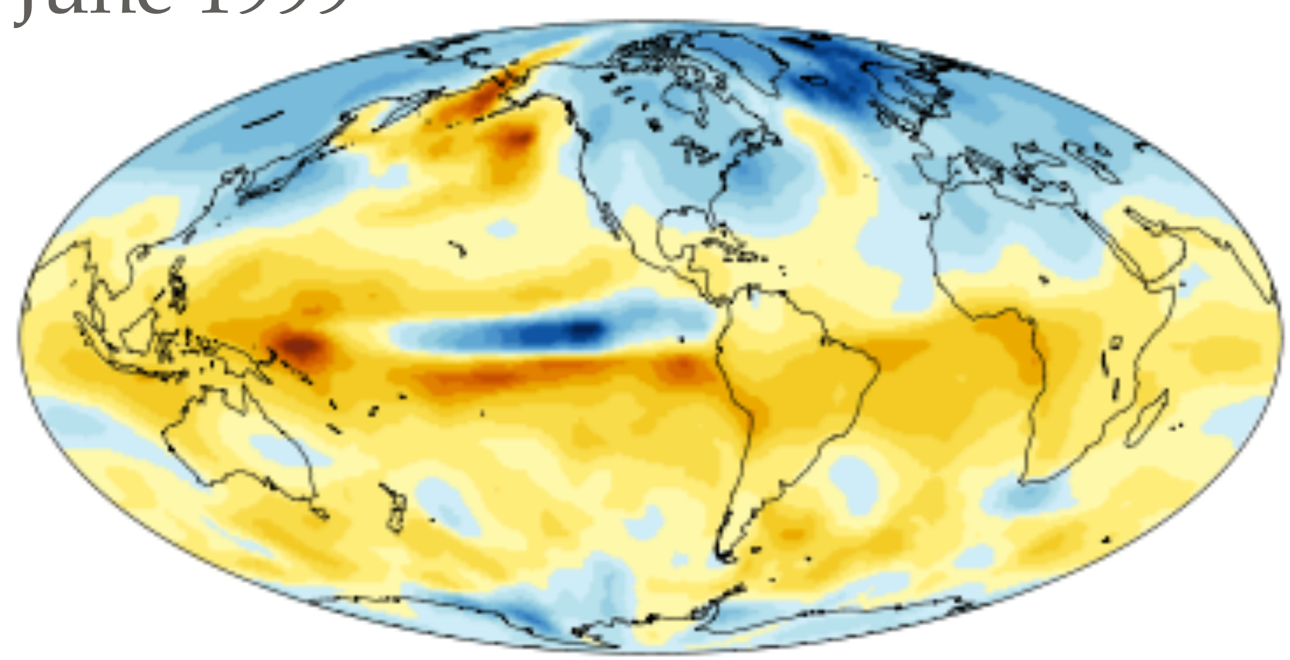
Variable Flux +TM3

Model Mean $\delta$APO




July 1998- June 1999

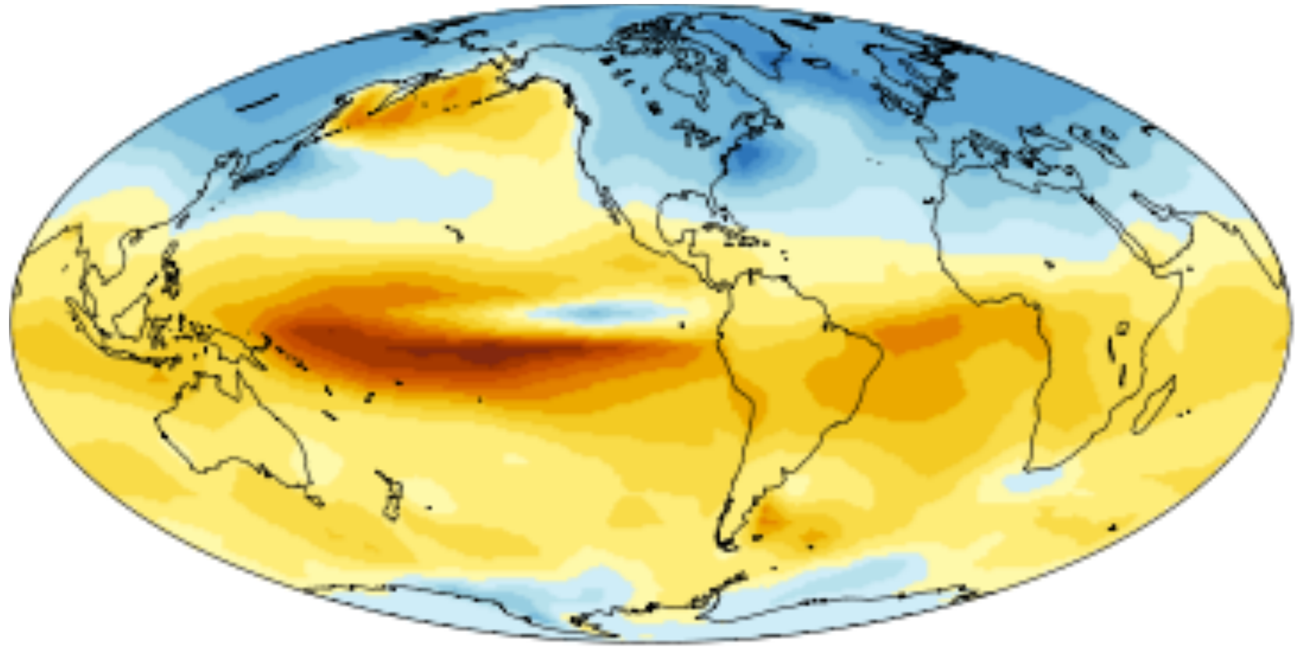


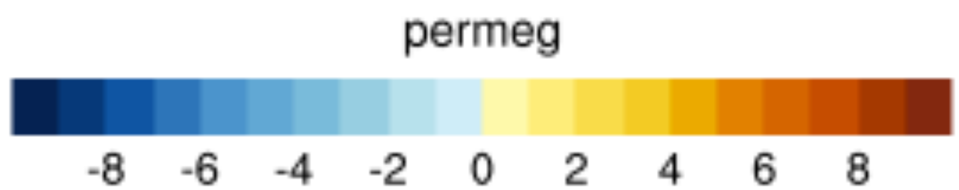


Climatological Flux +TM3

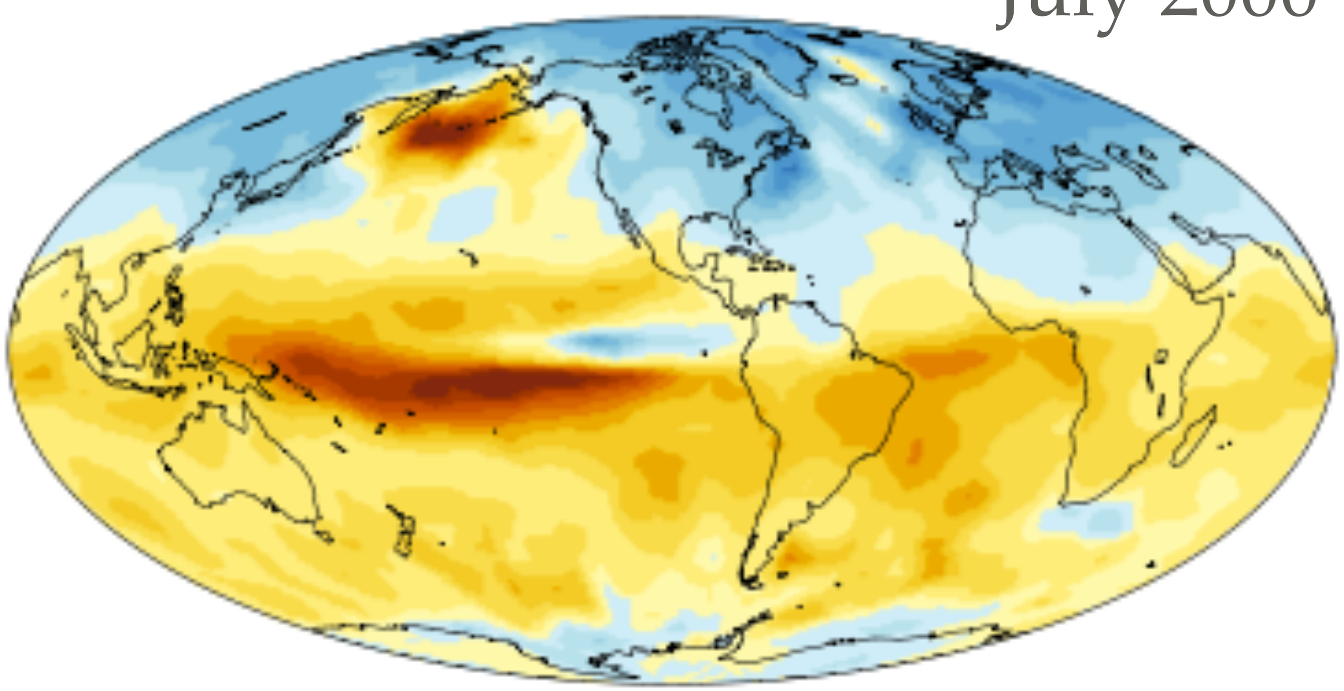
Variable Flux +TM3

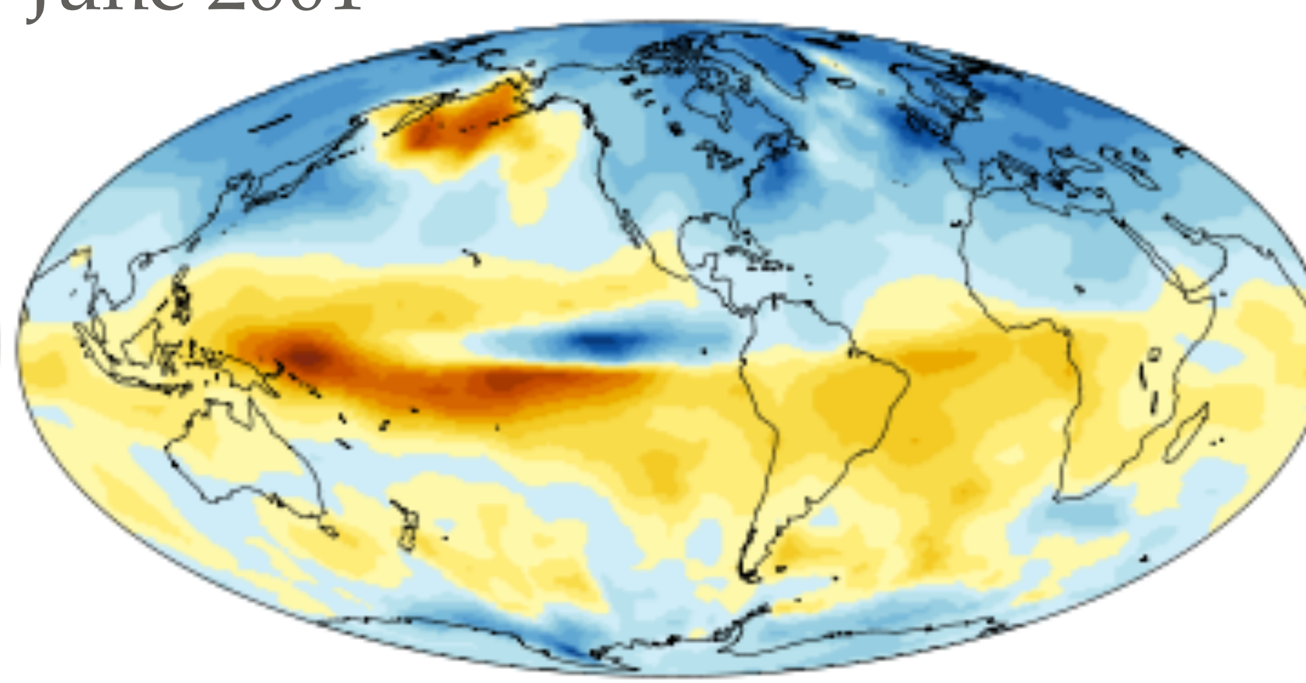
# Model Mean $\delta$APO





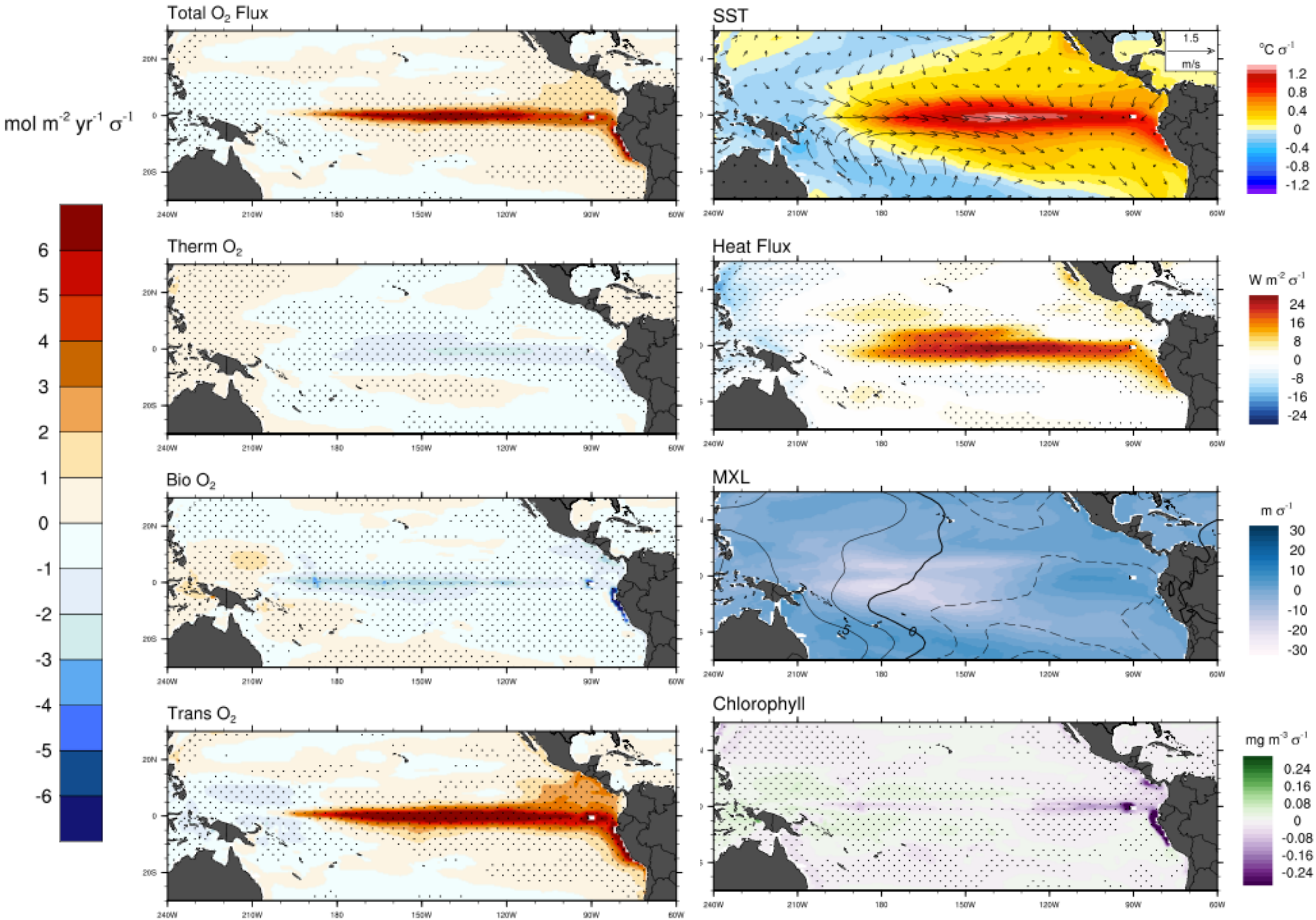

July 2000- June 2001





Climatological Flux +TM3

Variable Flux +TM3


Total O2 Flux
SST
Therm O2
Heat Flux
Bio O2
MXL
Trans O2
Chlorophyll
mol m-2 yr-1 σ-1
°C σ-1
W m-2 σ-1
m σ-1
mg m-3 σ-1
1.5 m/s
240W 210W 180 150W 120W 90W 60W
20N 0 20S