# The 2015-2016 El Niño and the response of the carbon cycle : findings from NASA's OCO-2 mission

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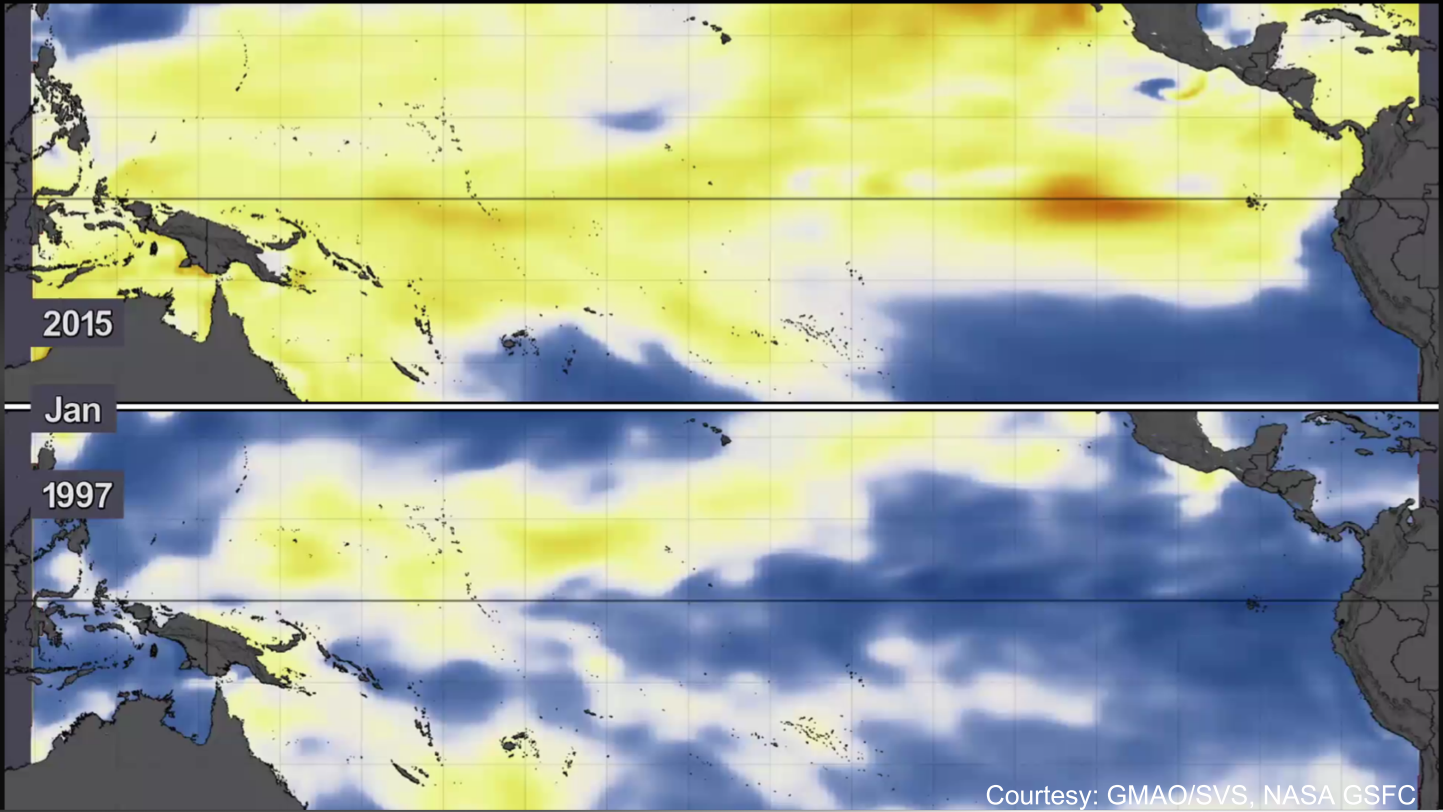
# Focus of this talk

- OCO-2 provides a first-hand look at the space-time evolution of tropical atmospheric $CO_2$ concentrations in response to the 2015-2016 El Niño
- The tropical Pacific Ocean plays an early and important role in modulating the changes in atmospheric $CO_2$ concentrations during El Niño events
- Net impact of El Niño on the global carbon cycle is an increase in atmospheric $CO_2$ concentrations

# El Niño 2015-2016

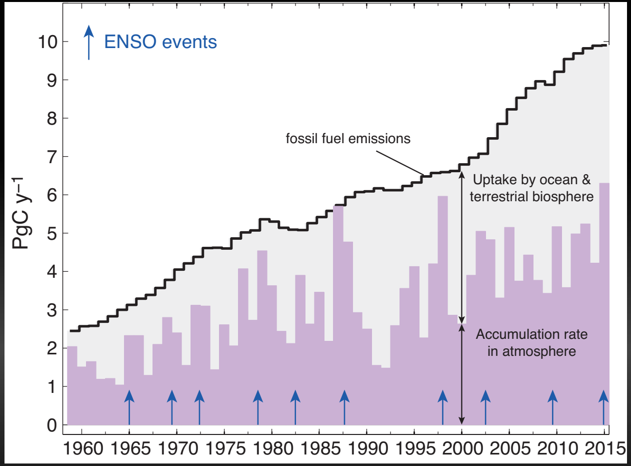


# The ENSO - $CO_2$ story …

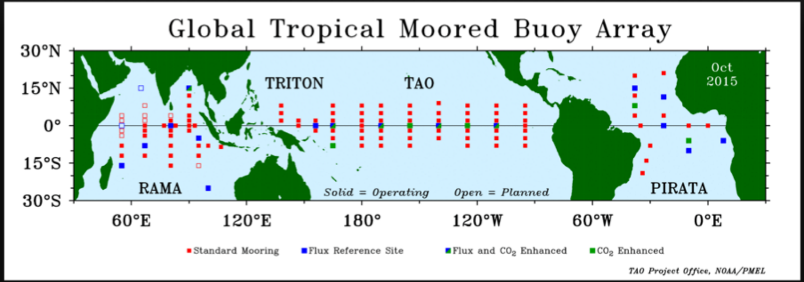
- Correlations between atmospheric $CO_2$ growth rate and ENSO activity have been reported since the 1970s

  *Bacastow* [1976], [1980]; *Newell and Weare* [1977]; *Keeling et al.* [1985]

- Studying the response of $CO_2$ to ENSO → how feedbacks between the physical climate system and global carbon cycle operates

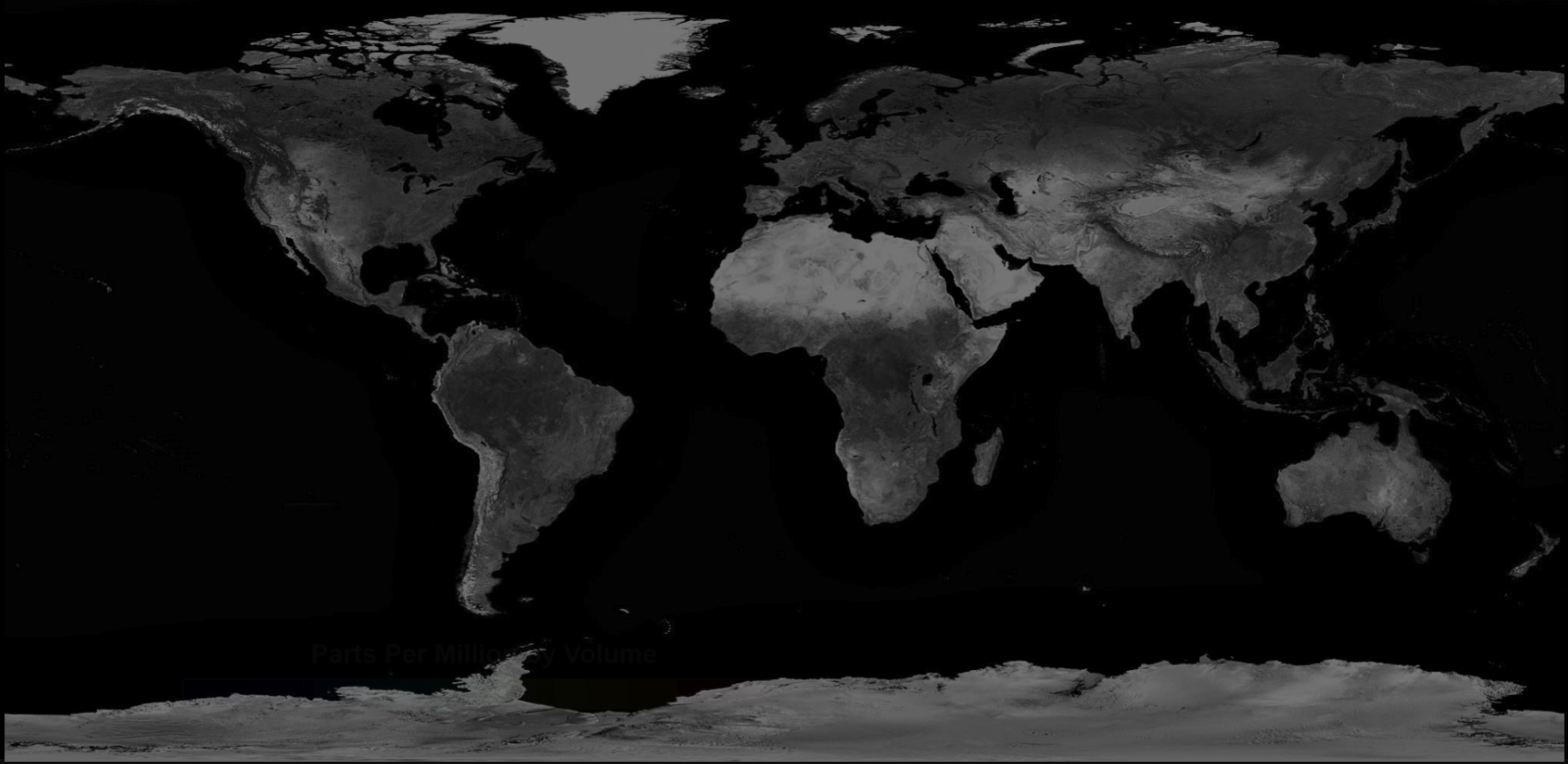



Does OCO-2 observations provide insight into the relationship between ENSO and the carbon cycle?



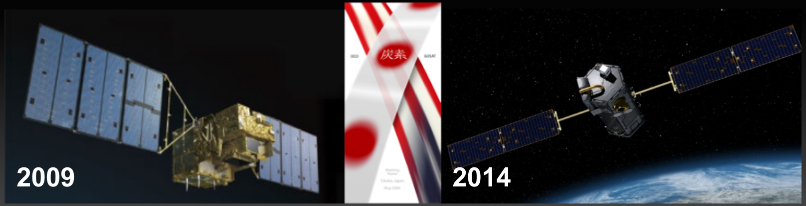
# Orbiting Carbon Observatory - 2

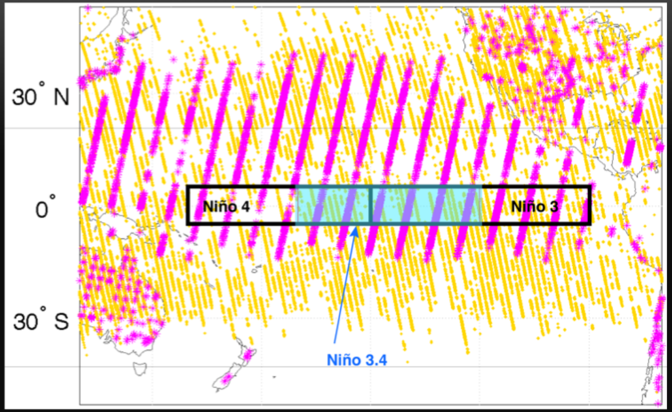
## Atmospheric Carbon Dioxide Concentration (09/06/14 - 03/31/2017)

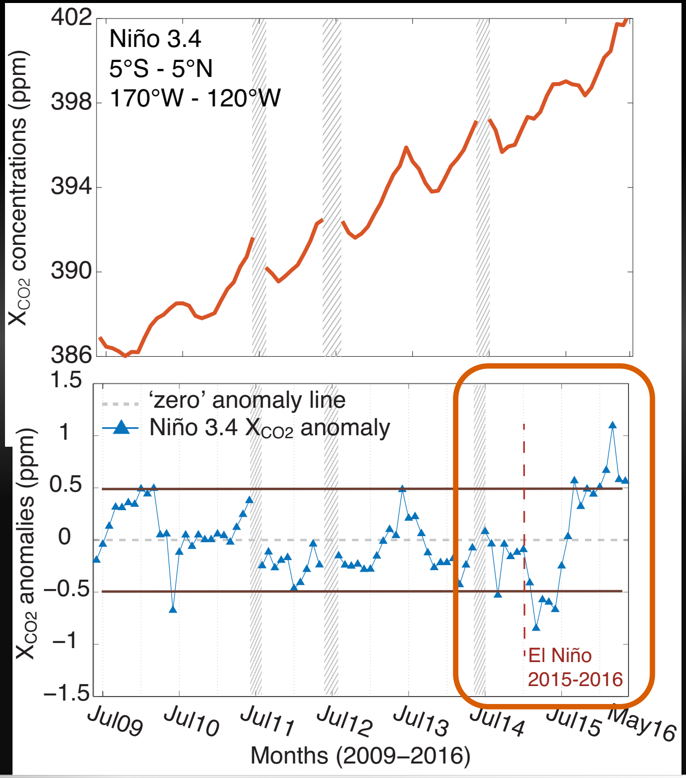


# GOSAT and OCO-2 era

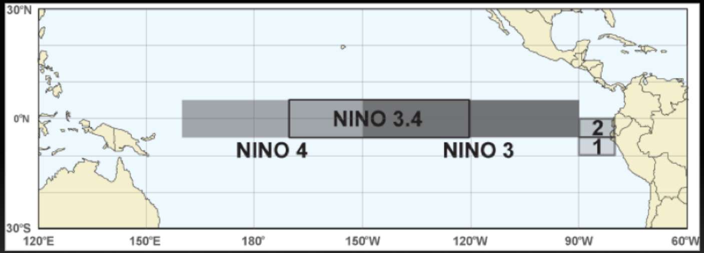
Monthly coverage over the Pacific
GOSAT and OCO-2



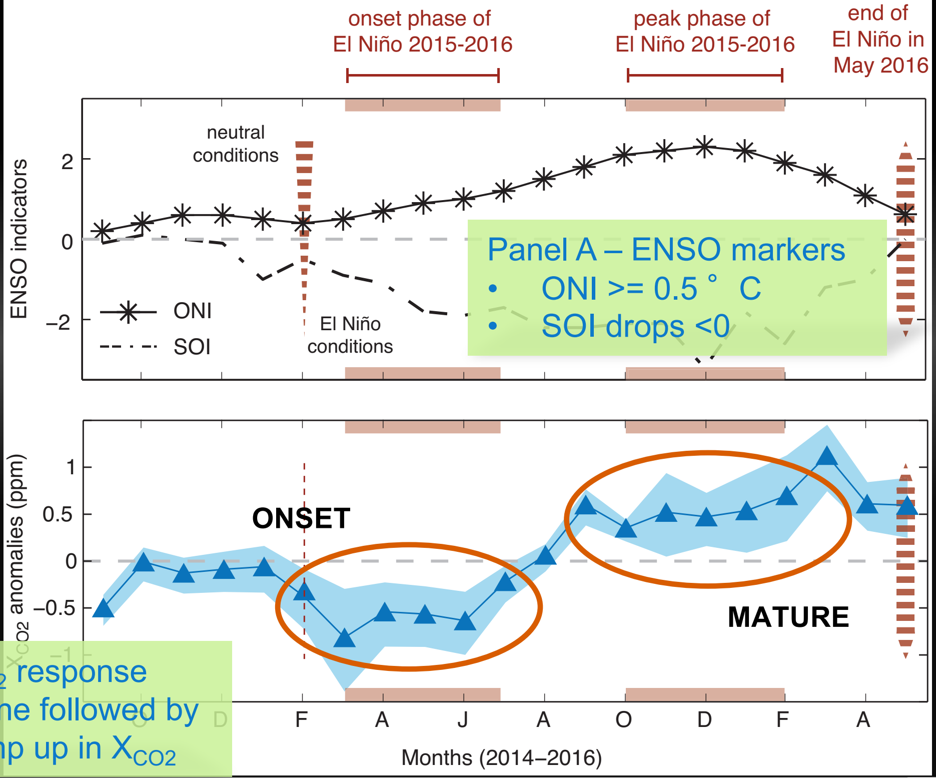



# Observable trends in 2015-2016




Time-series showing the temporal evolution of $X_{CO2}$ anomalies over Niño 3.4

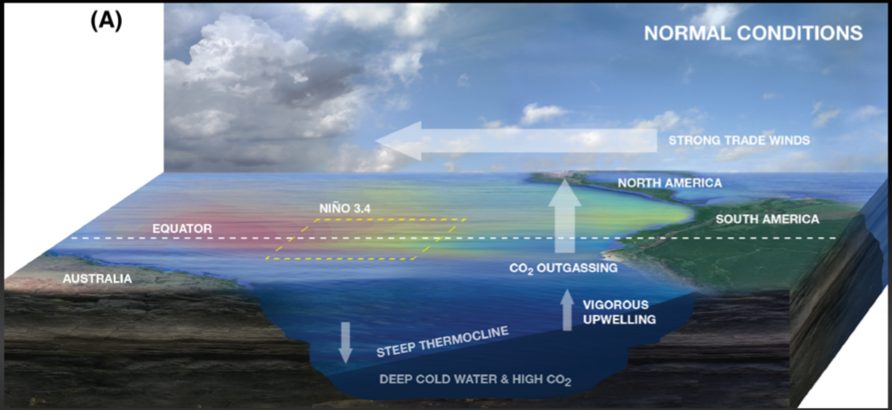
Sep 2014 – May 2016

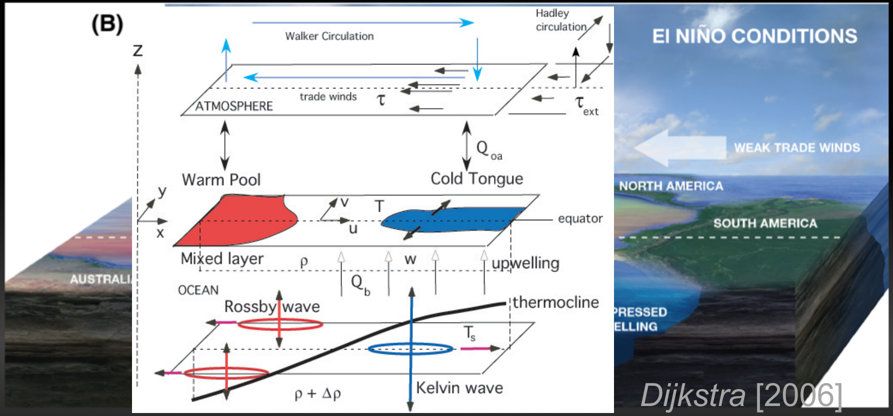



Panel A – ENSO markers
- ONI >= 0.5 ° C
- SOI drops <0

Panel B – $X_{CO2}$ response
- initial decline followed by steady ramp up in $X_{CO2}$

# Carbon system in the Tropical Pacific

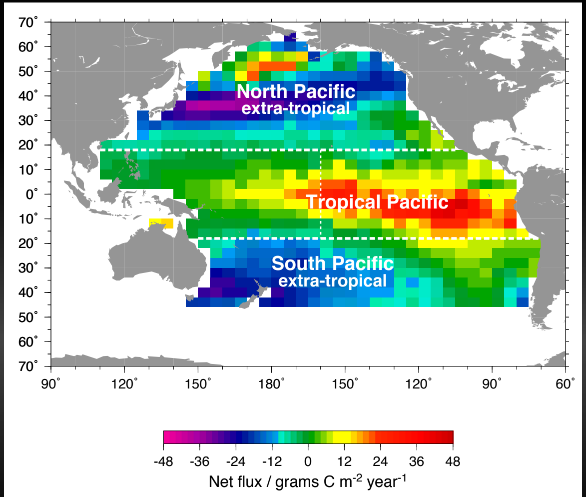


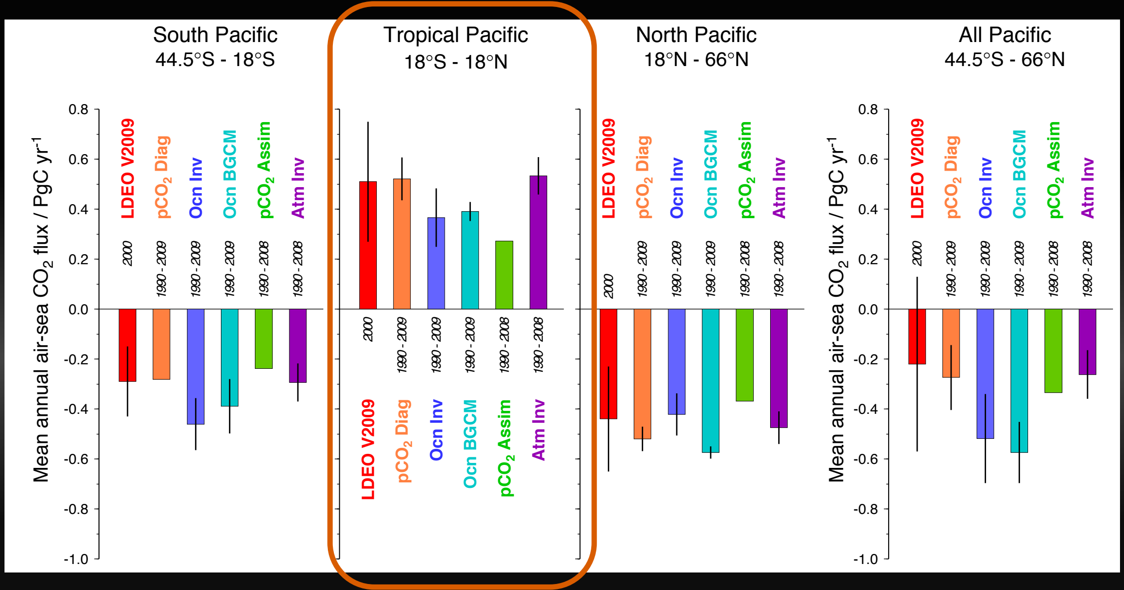

- Normal conditions: upwelling of cold subsurface waters that have high potential $pCO_2$ + inefficient biological pump → strong $CO_2$ outgassing

- El Niño conditions: deepening of thermocline, reduction in upwelling, weakening of trade winds + more efficient biological pump → decreases $CO_2$ outgassing by 40-60%

# Air-sea $CO_2$ flux in the Tropical Pacific

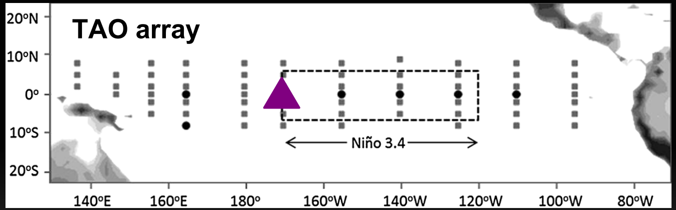



*Ishii et al.* [2014]



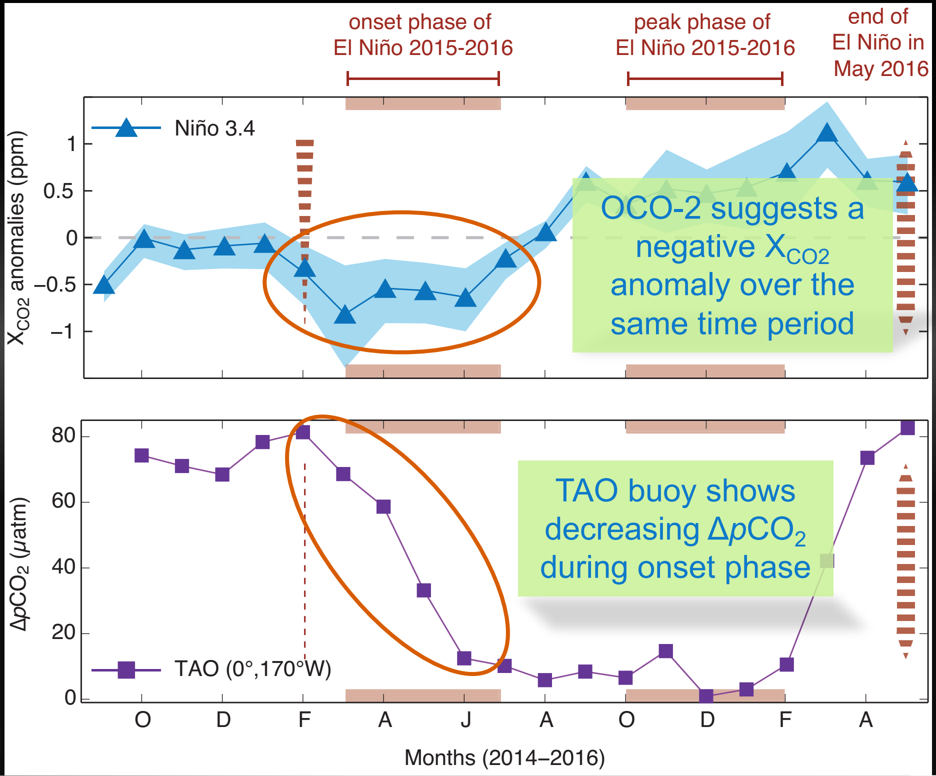

- Estimate of trop. Pacific flux: 0.4 - 0.6 PgC $yr^{-1}$
- Area of trop. Pacific – Ishii definition (~66 million $km^2$), Niño 3.4 (~6 million $km^2$)

# Response of the ocean carbon cycle



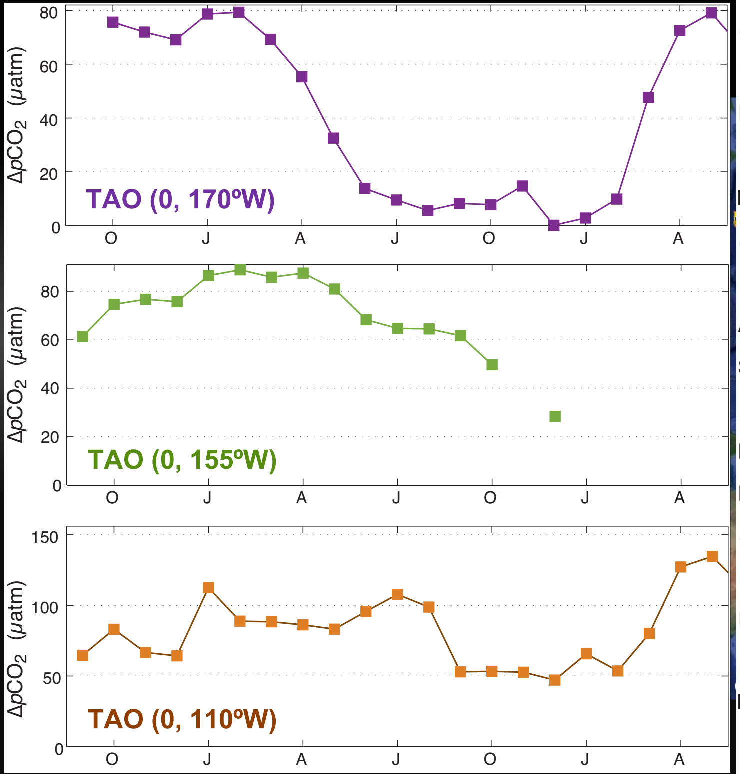

*Sutton et al.* [2014]

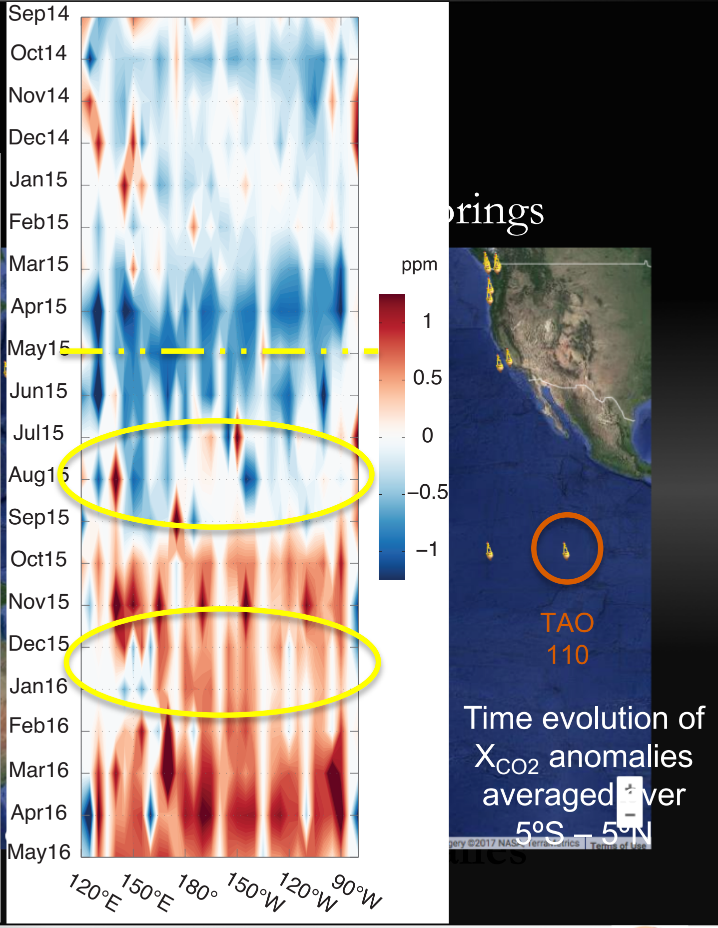

*Chatterjee et al.* [2017]



# Gradients in the ocean response

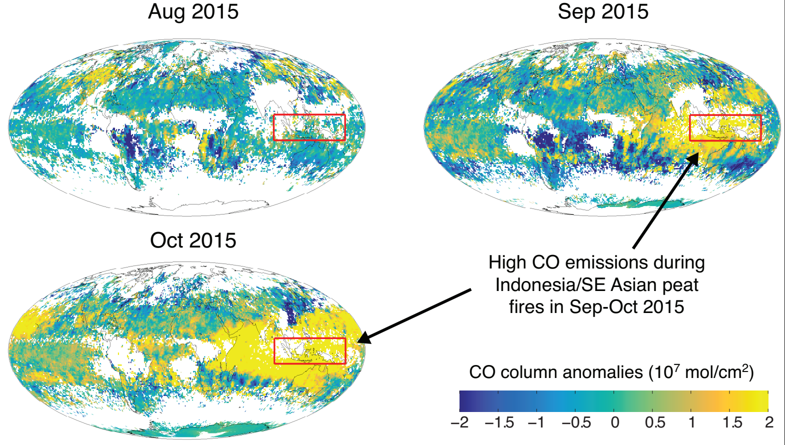
- 2015-2016 event was a “hybrid” CP/EP El Niño
- warm pool did not get all the way across the Pacific
- west-east gradients in $CO_2$ flux

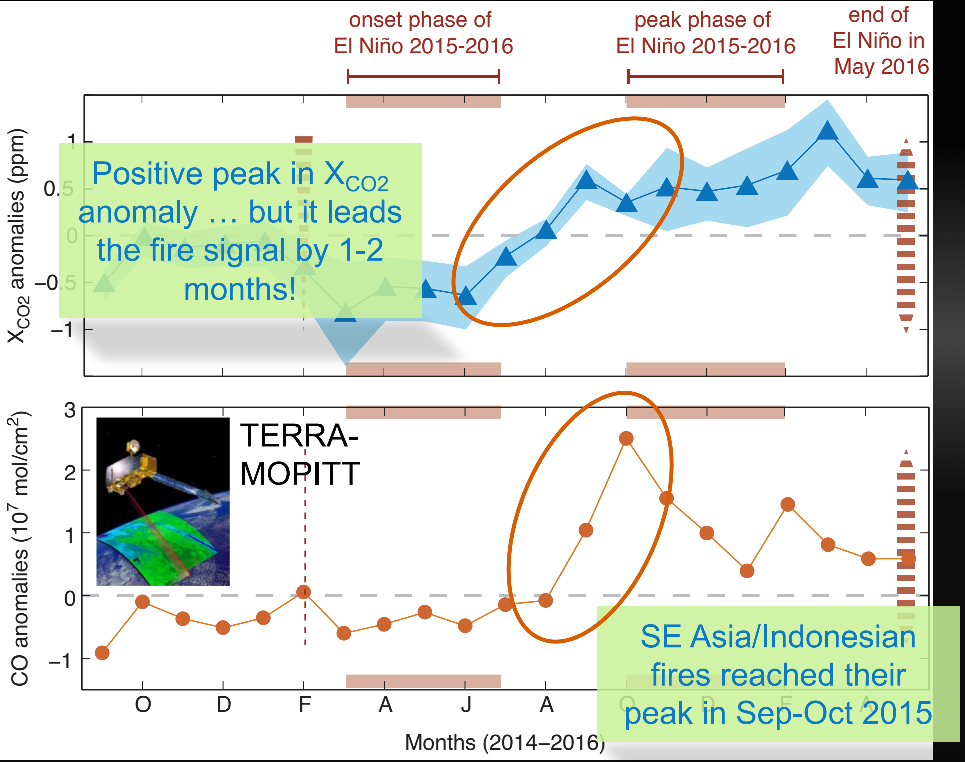


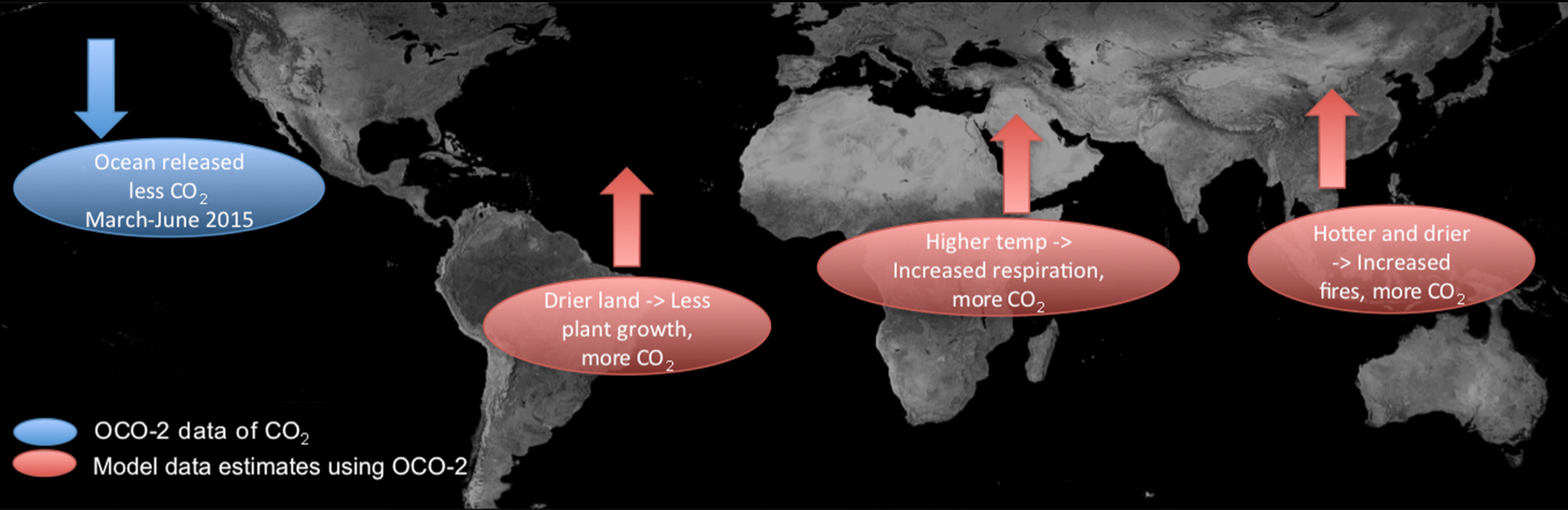
# Response of the terrestrial carbon cycle

- ❑ increase in emissions from biomass burning
- ❑ warmer and drier climate – overall reduction in biospheric activity



# Response of the terrestrial carbon cycle

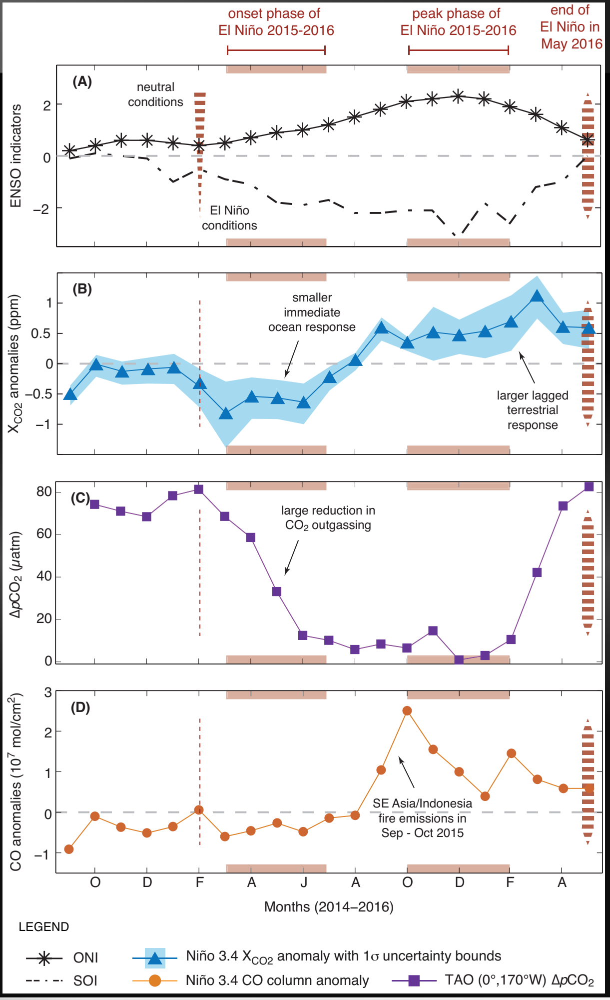



Courtesy: Annmarie Eldering, Junjie Liu and Karen Yuan (JPL)

# Putting it all together…

- Onset Phase of ENSO: Spring-Summer 2015
  - reduction in $CO_2$ outgassing over the tropical Pacific – negative $CO_2$ anomalies throughout but with perceptible west-east gradients
- Mature Phase of ENSO: Fall 2015 onwards
  - increase in $CO_2$ anomalies registered over the tropical Pacific –combination of reduced biospheric activity and increase in fire activity

*Chatterjee et al.* [2017], Science



# Ocean vs. Land contribution during ENSO

GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO.4, PAGES 493-496, FEBRUARY 15, 1999

## The relationship between tropical $CO_2$ fluxes and the El Niño-Southern Oscillation

Peter J. Rayner[1] and Rachel M. Law

CRC for Southern Hemisphere Meteorology, Monash University, Clayton, Australia

transition (from negative to positive) being matched to the end of the ENSO event. It seems likely that the initial response of tropical $CO_2$ fluxes to ENSO occurs in the ocean and the response is later offset then reversed by terrestrial responses.

**Acknowledgments.** This study was carried out with the support of the Australian Government through its Cooperative

molecules arrive at the surface, only a fraction of them stick or adsorb onto it[26,27]. Compared with non-template proteins, a template protein entering its imprint will have a higher likelihood of being retained as a result of interlocking within a pit and subsequently binding strongly to it. In addition, adsorbed protein on a low-adsorptivity surface can exchange with dissolved protein in solution[5,28]. Non-template protein that does not fit into a pit is more readily displaced than template protein[29], because the pit occupied by the template protein is no longer accessible to solution-phase protein. The hydrophilic, crosslinked sugars on protein imprints, in contrast to hydrophobic surfaces, allow for a lower protein-sticking probability and a higher protein exchangeability. Both of these processes lead to 'recognition of the fittest' through dynamic adsorption–exchange, which we believe is essential for protein recognition. □

Received 30 July 1998; accepted 23 February 1999.

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## Influence of El Niño on the equatorial Pacific contribution to atmospheric $CO_2$ accumulation

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**The equatorial oceans are the dominant oceanic source of $CO_2$ to the atmosphere, annually amounting to a net flux of 0.7–1.5 Pg ($10^{15}$ g) of carbon, up to 72% of which emanate from the equatorial Pacific Ocean[1–3]. Limited observations indicate that the size of the equatorial Pacific source is significantly influenced by El Niño events[4–10], but the effect has not been well quantified. Here we report spring and autumn multiannual measurements of the partial pressure of $CO_2$ in the surface ocean and atmosphere in the equatorial Pacific region. During the 1991–94 El Niño period,**



Feely *et al.* [1999]

OF CLIMATE 1 November 2001

## The Carbon Cycle Response to ENSO: A Coupled Climate–Carbon Cycle Model Study

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(Manuscript received 30 October 2000, in final form 24 April 2001)

ABSTRACT

There is significant interannual variability in the atmospheric concentration of carbon dioxide ($CO_2$) even when the effect of anthropogenic sources has been accounted for. This variability is well correlated with the El Niño–Southern Oscillation (ENSO) cycle. This behavior of the natural carbon cycle provides a valuable mech-

Jones *et al.* [2001]

# Key messages

- OCO-2, with its unprecedented coverage over the tropical Pacific Ocean, provides a first-hand look at the space-time evolution of atmospheric $CO_2$ concentrations during the 2015-2016 El Niño

- Oceans do contribute to the ENSO $CO_2$ effect
  - suppressed outgassing from the oceans happen early, followed by a larger (and lagged) response from the terrestrial component

- Net impact on the global carbon cycle is an increase in atmospheric $CO_2$ concentrations
  - would be even larger if it weren't for the reduction in $CO_2$ outgassing

# Acknowledgements


- GOSAT Project, ACOS and OCO-2 teams, National Data Buoy Center, Scripps and NOAA data
- C. O'Dell (CSU), P. Wennberg (Caltech), K. Trenberth (NCAR), G. McKinley (LDEO/Columbia Univ.), H. Worden (NCAR), P. Patra (JAMSTEC), J. Miller (NOAA), D. Morton (GSFC), C. Cosca (PMEL), Y. -K. Lim (GMAO), R. Kovach (GMAO), among others


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# QUESTIONS?

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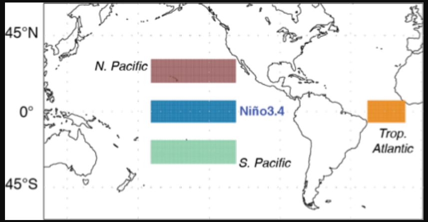
BACKUP

# How robust are these findings?

## Sources of error

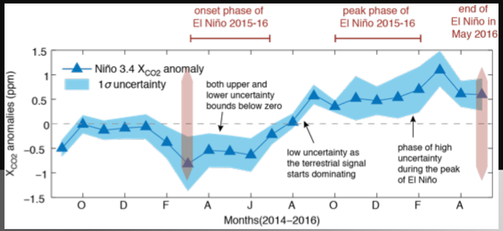
### "representativeness" of $X_{CO2}$ anomalies

- ✓ can we isolate the ocean signal to the trop. Pacific Ocean?



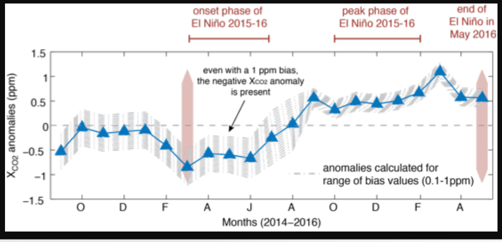

### methodological biases anomaly calculation

- ✓ stitching together GOSAT and OCO-2 records
- ✓ biases due to curve-fitting procedure



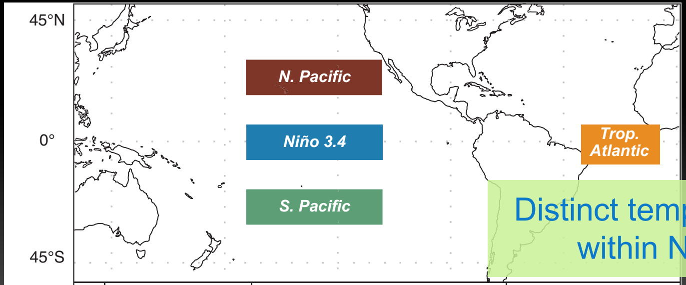

### residual "biases" in retrievals

- ✓ ocean glint retrievals are biased low (say 0.1-1.0 ppm) over the Tropics



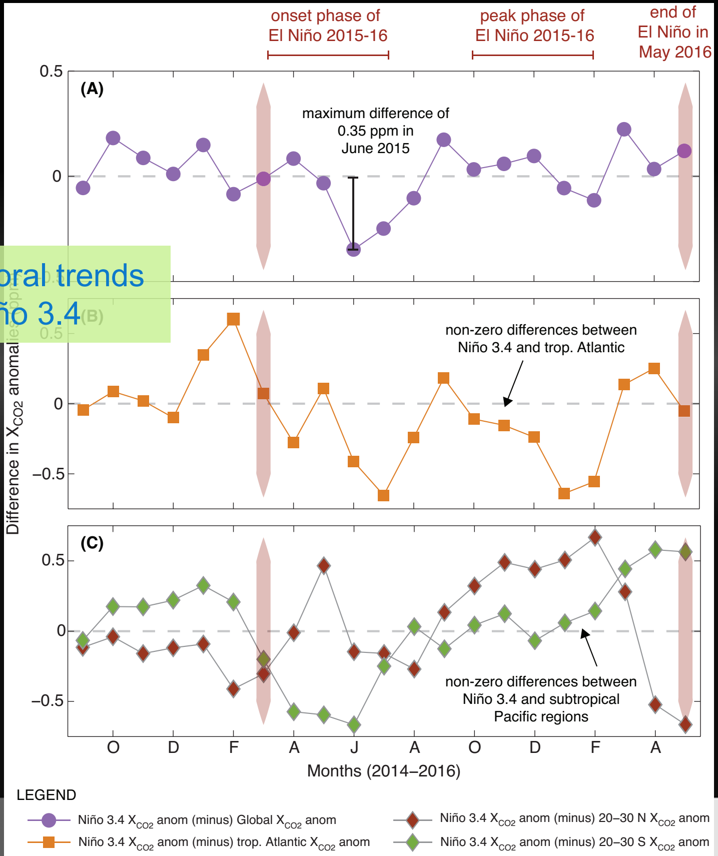
**BACKUP**

# Isolating the negative anomaly to the trop. Pacific




| | Specific region analyzed | Alternative hypothesis | Figure showing difference between analyzed region and Niño 3.4 |
|---|---|---|---|
| | Global (90°N -90°S, 0°-360°E) | $X_{CO_2}$ anomalies over the Pacific Ocean are responding to changes in terrestrial $CO_2$ concentrations | Fig. 4A |
| | Tropical Atlantic (5°N -5°S, 5°-35°W) | $X_{CO_2}$ anomalies over the Pacific Ocean are responding to changes in global $CO_2$ concentrations | Fig. 4B |
| | North Pacific (20°-30°N, 120°-170°W) | $X_{CO_2}$ anomalies over the tropical Pacific Ocean are responding to changes in $CO_2$ concentrations across the entire Pacific Ocean | Fig. 4C |
| | South Pacific (20°-30°S, 120°-170°W) | $X_{CO_2}$ anomalies over the tropical Pacific Ocean are responding to changes in $CO_2$ concentrations across the entire Pacific Ocean | Fig. 4C |

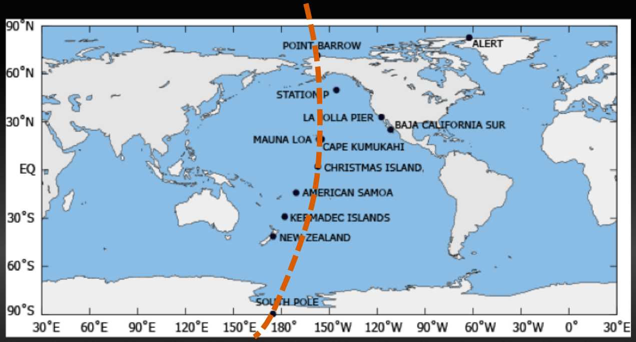
Distinct temporal trends within Niño 3.4

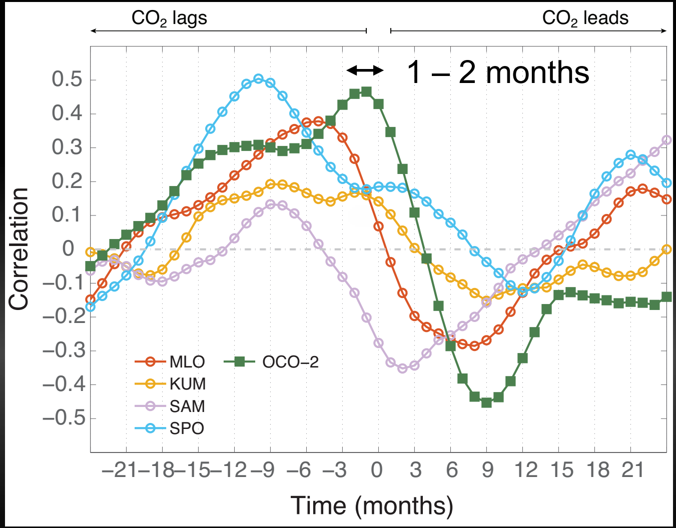



What are the signature of $X_{CO_2}$ anomalies in other ocean basins with respect to those observed over the trop. Pacific Ocean?

BACKUP

# Time lag in the observed atmospheric $CO_2$ signal




- "far-away" surface sites observe with a 3-6 month lag
- ocean signal gets diluted by the land signal
- OCO-2 observes directly over the region of action

Jones et al. [2001]

$CO_2$ lags with Niño-3 SST

TABLE 1. Correlation coefficients and lags between atmospheric $CO_2$ concentration at various flask measurement stations and the Niño-3 index. "Obs" are observed values from CDIAC Web site, "model" is results from HadCM3LC, and "Bacastow" represents data presented by Bacastow et al. (1980).

| | | Correlation coefficient | | | Lag (months) | | |
|---|---|---|---|---|---|---|---|
| Station | Latitude | Obs | Model | Bacastow | Obs | Model | Bacastow |
| Point Barrow | 71°N | 0.40 | 0.29 | | 8 | 6–8 | |
| Ocean Station P | 50°N | | 0.37 | 0.66 | | 6–7 | 7 |
| Mauna Loa | 19°N | 0.52 | 0.35 | 0.52 | 3 | 4 | 3 |
| Fanning Island | 4°N | | 0.50 | 0.80 | | 4 | 1 |
| South Pole | 90°S | 0.50 | 0.42 | 0.69 | 4 | 4–5 | 6 |