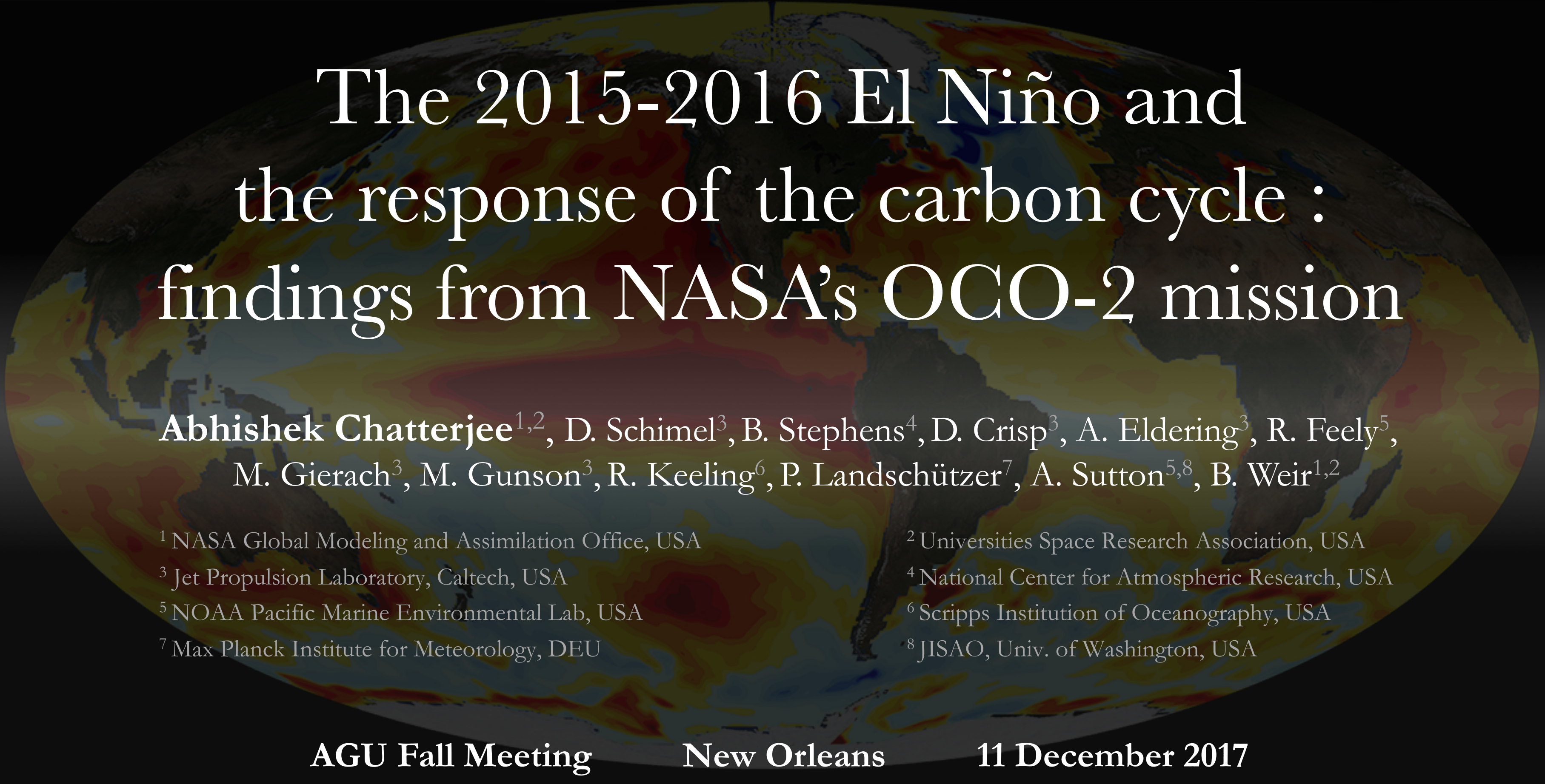


The 2015-2016 El Niño and the response of the carbon cycle : findings from NASA's OCO-2 mission

Abhishek Chatterjee[1,2], D. Schimel[3], B. Stephens[4], D. Crisp[3], A. Eldering[3], R. Feely[5], M. Gierach[3], M. Gunson[3], R. Keeling[6], P. Landschützer[7], A. Sutton[5,8], B. Weir[1,2]

[1] NASA Global Modeling and Assimilation Office, USA
[2] Universities Space Research Association, USA
[3] Jet Propulsion Laboratory, Caltech, USA
[4] National Center for Atmospheric Research, USA
[5] NOAA Pacific Marine Environmental Lab, USA
[6] Scripps Institution of Oceanography, USA
[7] Max Planck Institute for Meteorology, DEU
[8] JISAO, Univ. of Washington, USA

AGU Fall Meeting **New Orleans** **11 December 2017**

Focus of this talk

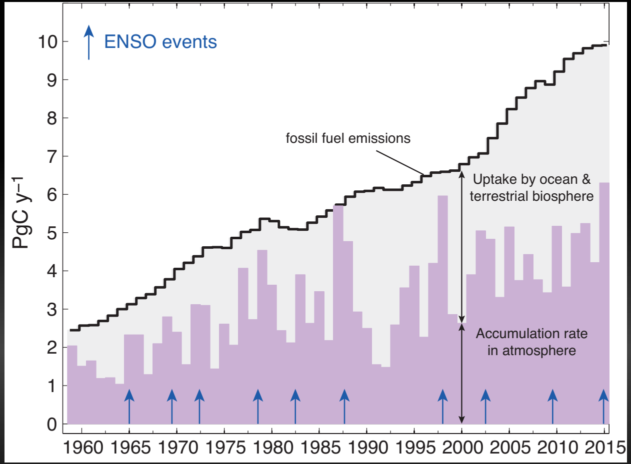
- ☐ OCO-2 provides a first-hand look at the space-time evolution of tropical atmospheric CO_2 concentrations in response to the 2015-2016 El Niño
- ☐ The tropical Pacific Ocean plays an early and important role in modulating the changes in atmospheric CO_2 concentrations during El Niño events
- ☐ Net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

The ENSO - CO_2 story …

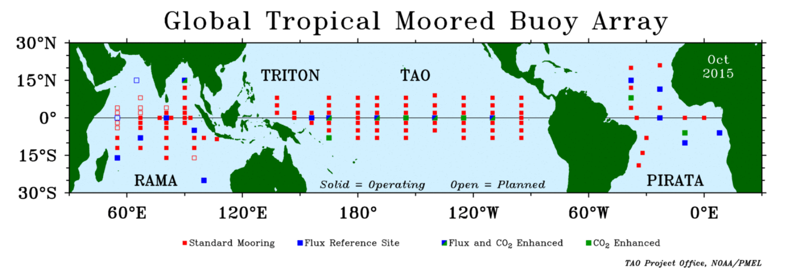
- ❑ Correlations between atmospheric CO_2 growth rate and ENSO activity have been reported since the 1970s

  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

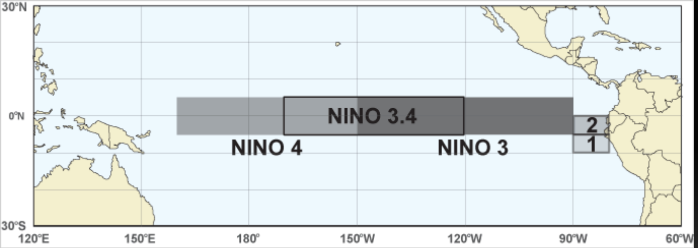


Does OCO-2 observations provide insight into the relationship between ENSO and the carbon cycle?



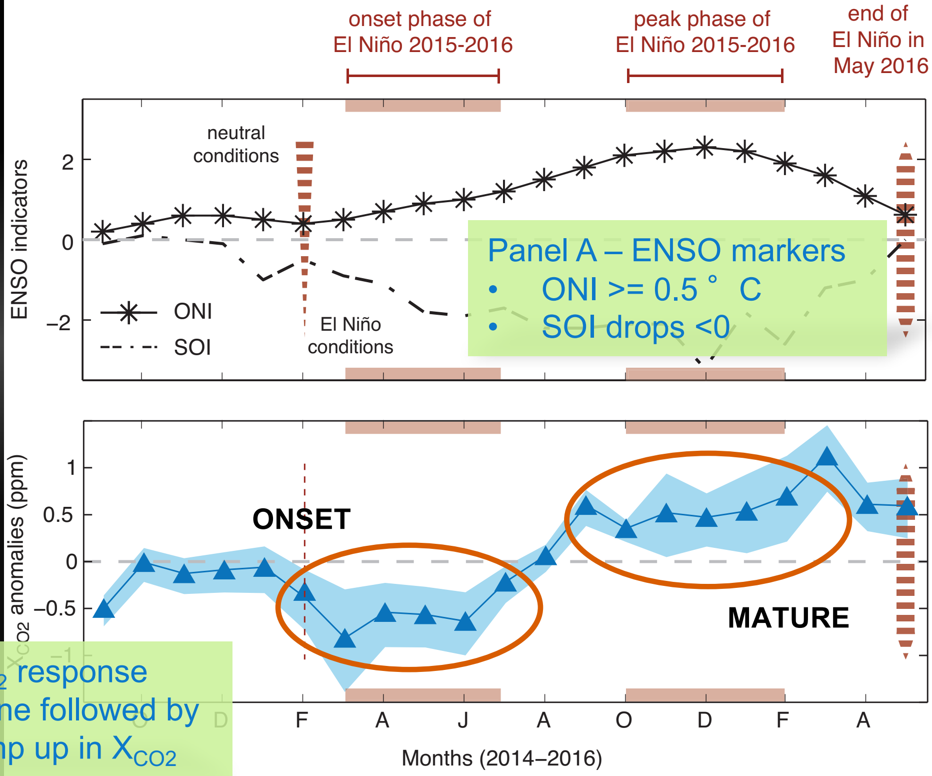
TAO Project Office, NOAA/PMEL

Observable trends in 2015-2016



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

Sep 2014 – May 2016



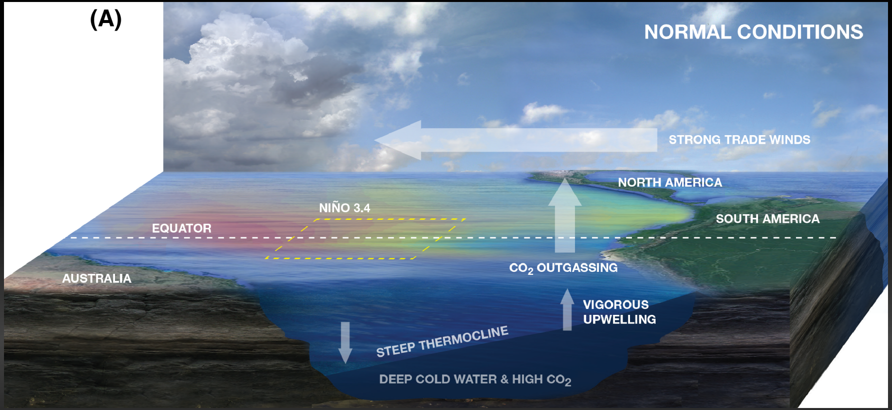
Panel A – ENSO markers

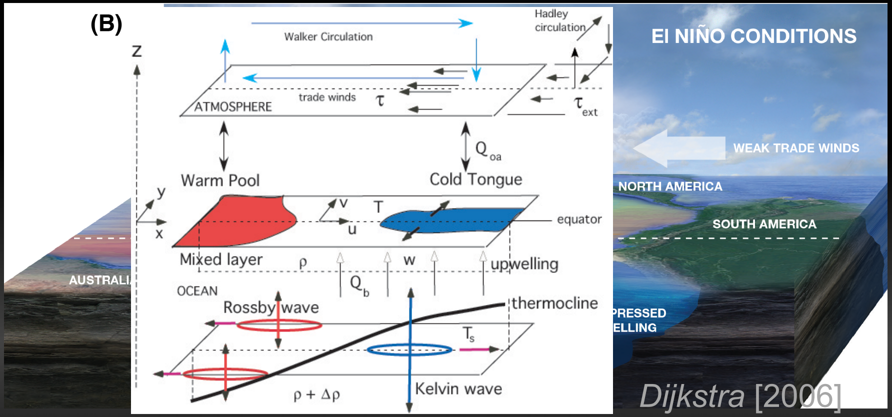
- ONI >= 0.5 ° C
- SOI drops <0

Panel B – X_{CO2} response

- initial decline followed by steady ramp up in X_{CO2}

Carbon system in the Tropical Pacific



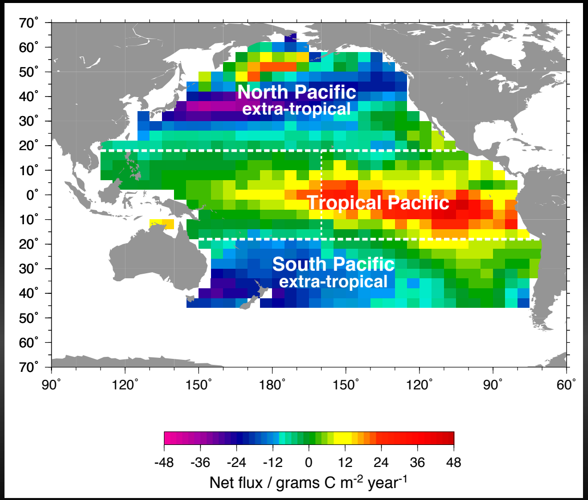


Dijkstra [2006]

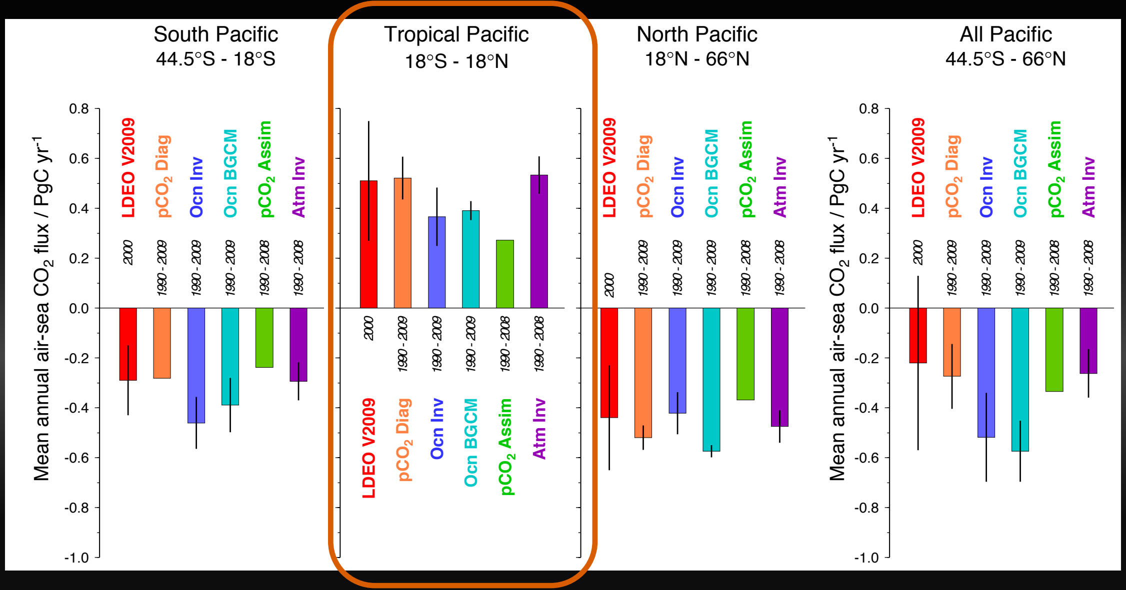
- Normal conditions: upwelling of cold subsurface waters that have high potential pCO_2 + inefficient biological pump → strong CO_2 outgassing

- 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

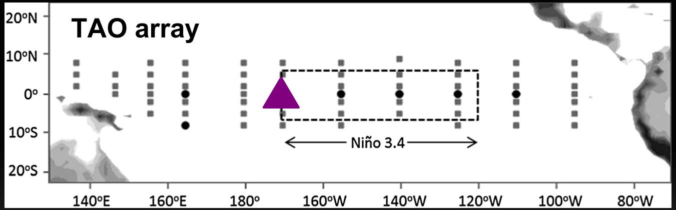


Ishii et al. [2014]



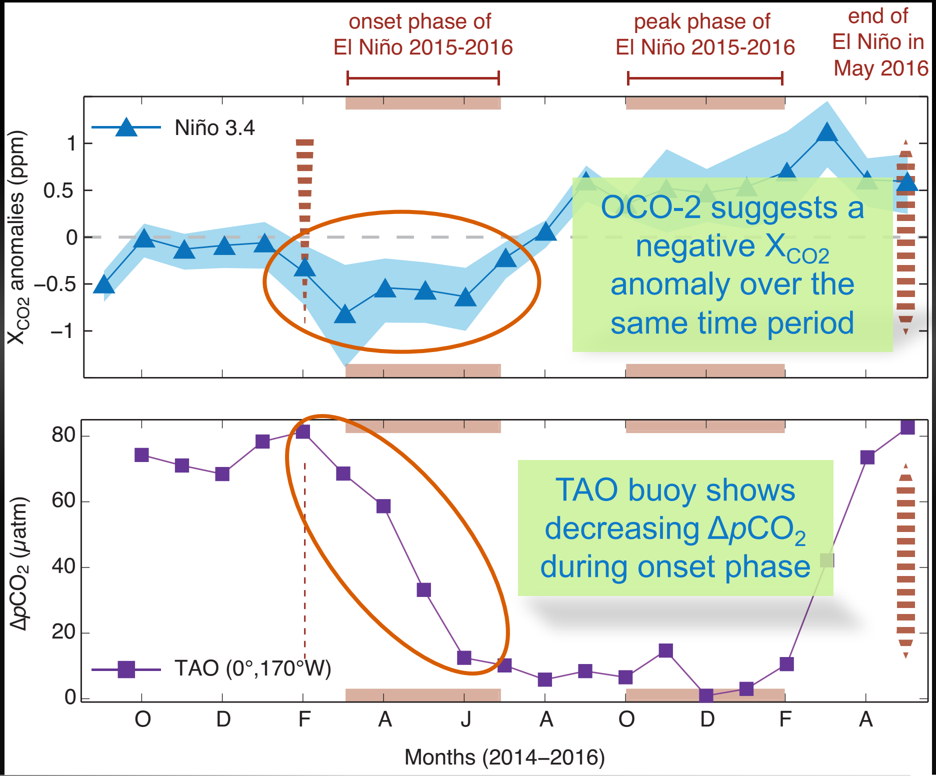
- ❑ Estimate of trop. Pacific flux: 0.4 - 0.6 PgC yr^{-1}
- ❑ Area of trop. Pacific – Ishii definition (~66 million km^2), Niño 3.4 (~6 million km^2)

Response of the ocean carbon cycle



Sutton et al. [2014]

Chatterjee et al. [2017]

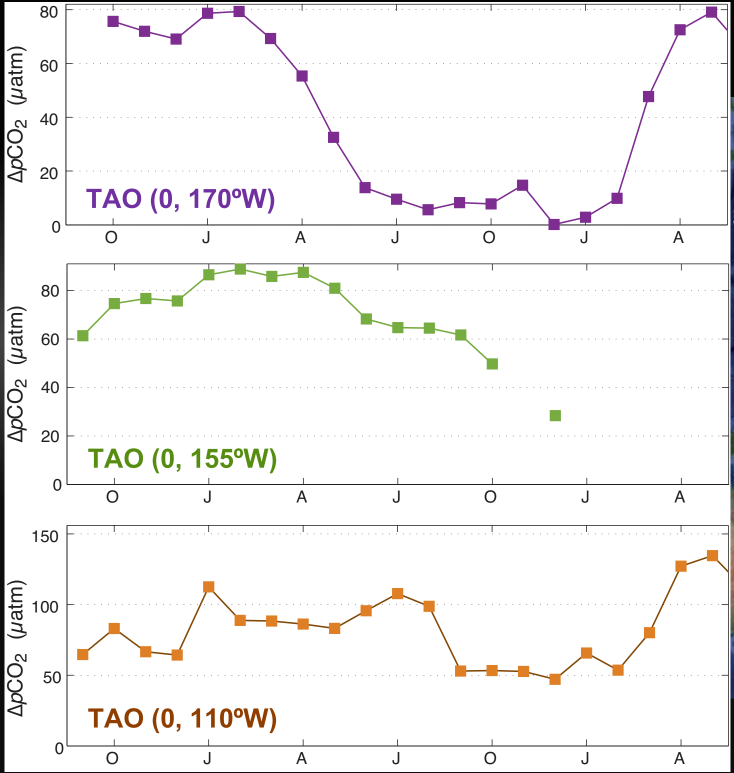


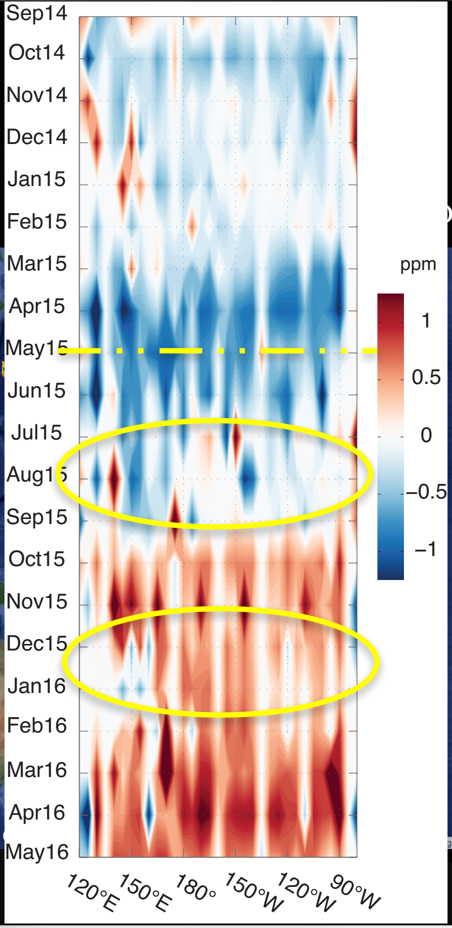
OCO-2 suggests a negative X_{CO2} anomaly over the same time period

TAO buoy shows decreasing ΔpCO_2 during onset phase

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



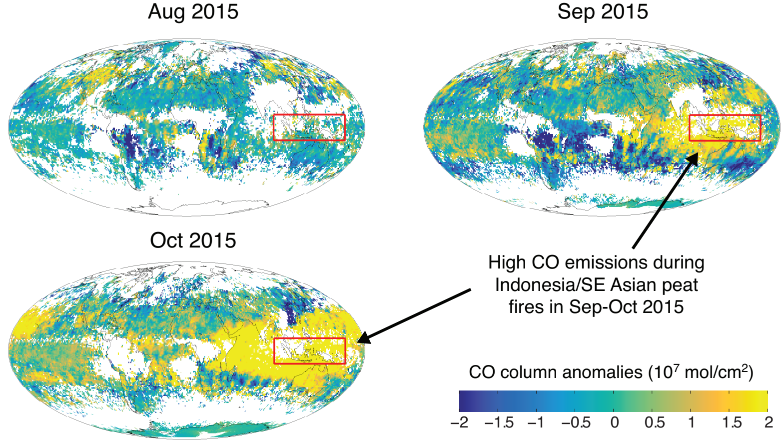


rings

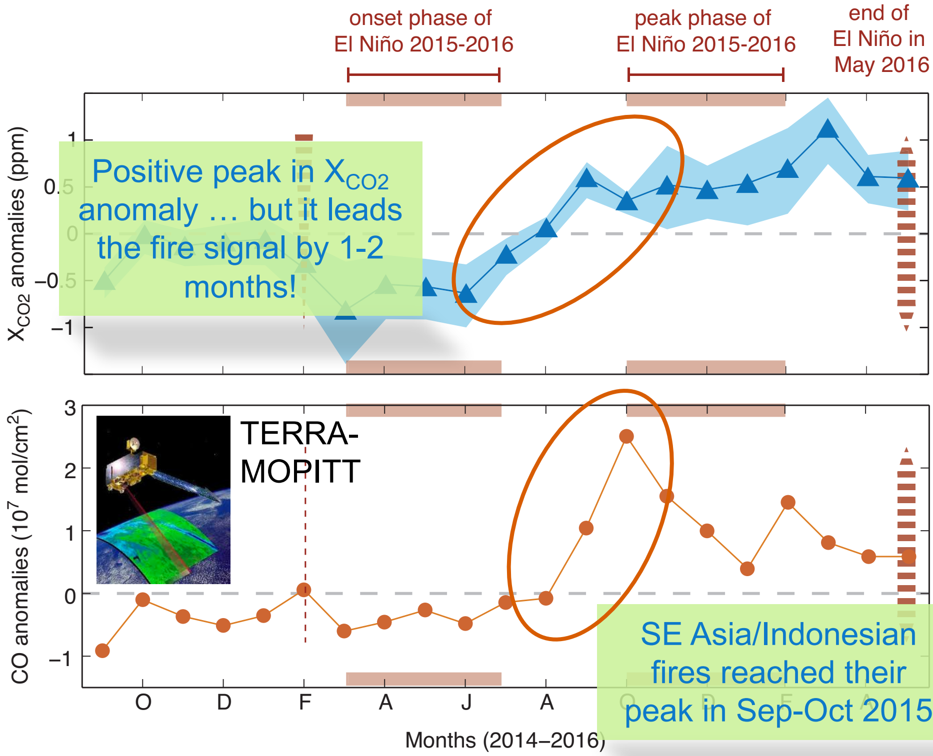
Time evolution of X_{CO2} anomalies averaged over 5ºS – 5ºN

Response of the terrestrial carbon cycle

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



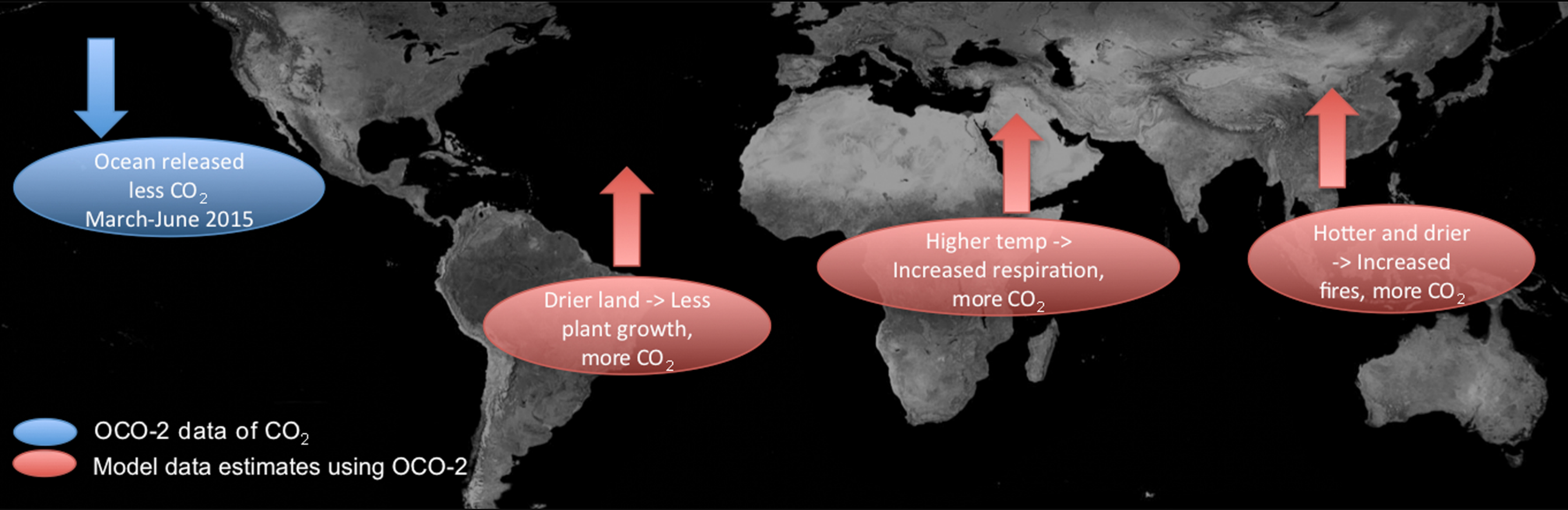
High CO emissions during Indonesia/SE Asian peat fires in Sep-Oct 2015



Positive peak in X_{CO2} anomaly … but it leads the fire signal by 1-2 months!

SE Asia/Indonesian fires reached their peak in Sep-Oct 2015

Response of the terrestrial carbon cycle



Ocean released less CO_2 March-June 2015

Drier land -> Less plant growth, more CO_2

Higher temp -> Increased respiration, more CO_2

Hotter and drier -> Increased fires, more CO_2

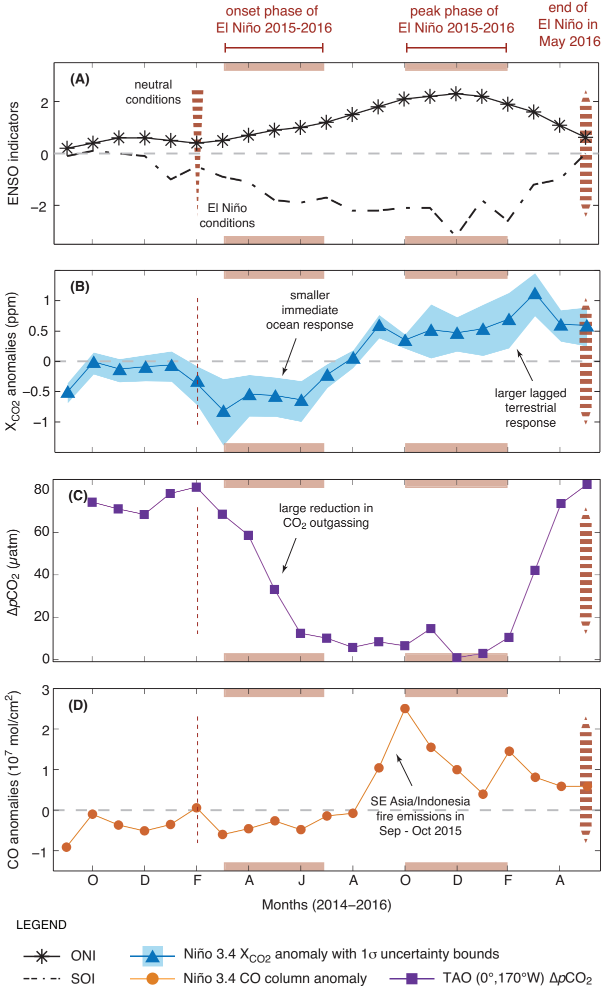
🔵 OCO-2 data of CO_2
🔴 Model data estimates using OCO-2

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

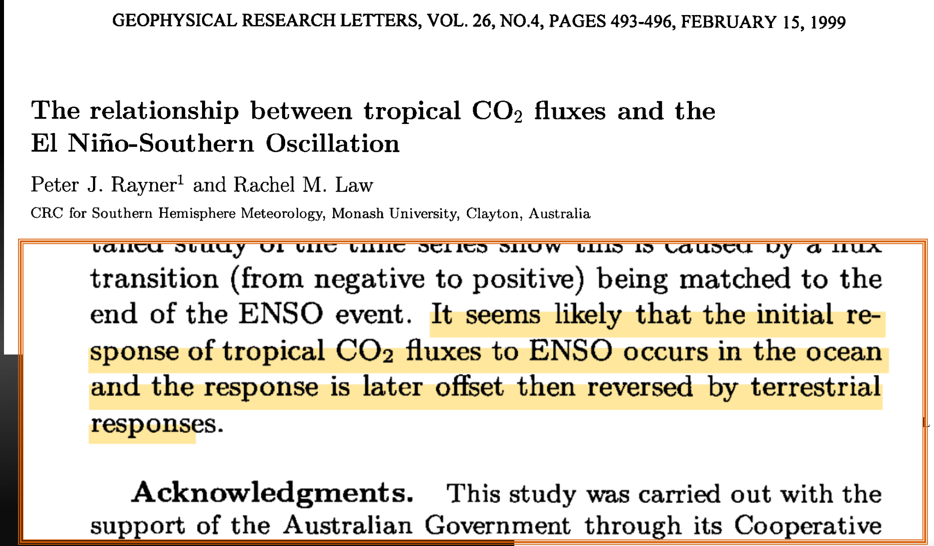
Putting it all together…

- ❑ 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

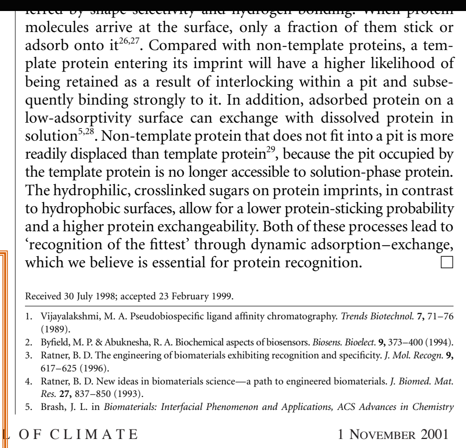
The relationship between tropical CO$_2$ fluxes and the El Niño-Southern Oscillation

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

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

tailed study of the time series show this is caused by a flux 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

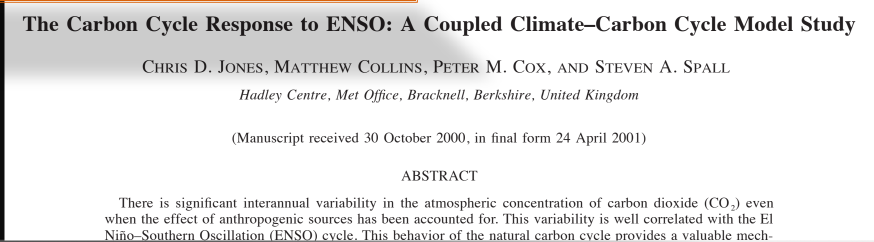


ferred by shape selectivity and hydrogen bonding. When protein molecules arrive at the surface, only a fraction of them stick or adsorb onto it[26,27]. Compared with non-template proteins, a template protein entering its imprint will have a higher likelihood of being retained as a result of interlocking 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.

1. Vijayalakshmi, M. A. Pseudobiospecific ligand affinity chromatography. *Trends Biotechnol.* **7**, 71–76 (1989).
2. Byfield, M. P. & Abuknesha, R. A. Biochemical aspects of biosensors. *Biosens. Bioelect.* **9**, 373–400 (1994).
3. Ratner, B. D. The engineering of biomaterials exhibiting recognition and specificity. *J. Mol. Recogn.* **9**, 617–625 (1996).
4. Ratner, B. D. New ideas in biomaterials science—a path to engineered biomaterials. *J. Biomed. Mat. Res.* **27**, 837–850 (1993).
5. Brash, J. L. in *Biomaterials: Interfacial Phenomenon and Applications, ACS Advances in Chemistry*

OF CLIMATE 1 NOVEMBER 2001



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

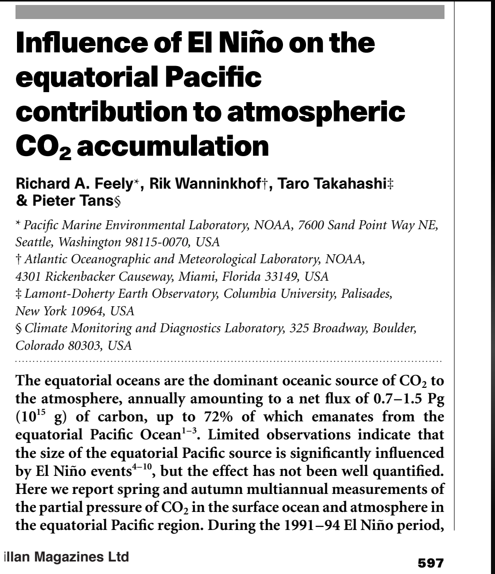
CHRIS D. JONES, MATTHEW COLLINS, PETER M. COX, AND STEVEN A. SPALL

Hadley Centre, Met Office, Bracknell, Berkshire, United Kingdom

(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-



Influence of El Niño on the equatorial Pacific contribution to atmospheric CO$_2$ accumulation

Richard A. Feely*, Rik Wanninkhof†, Taro Takahashi‡ & Pieter Tans§

* *Pacific Marine Environmental Laboratory, NOAA, 7600 Sand Point Way NE, Seattle, Washington 98115-0070, USA*
† *Atlantic Oceanographic and Meteorological Laboratory, NOAA, 4301 Rickenbacker Causeway, Miami, Florida 33149, USA*
‡ *Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York 10964, USA*
§ *Climate Monitoring and Diagnostics Laboratory, 325 Broadway, Boulder, Colorado 80303, USA*

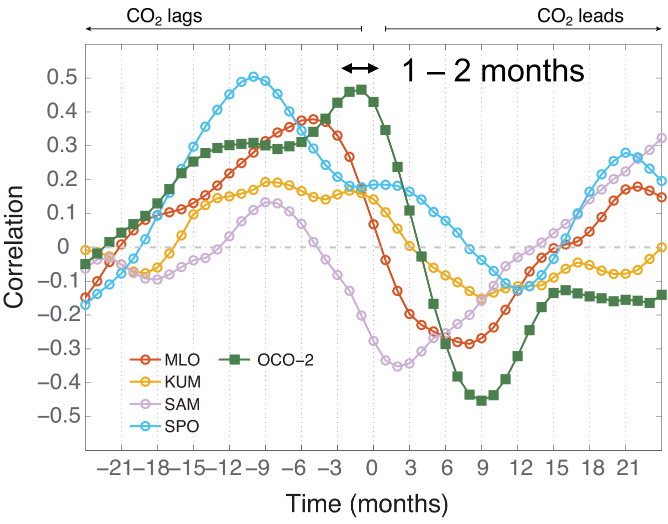
The equatorial oceans are the dominant oceanic source of CO$_2$ to the atmosphere, annually amounting to a net flux of 0.7–1.5 Pg (10^{15} g) of carbon, up to 72% of which emanate from the equatorial Pacific Ocean[1–3]. Limited observations indicate that the size of the equatorial Pacific source is significantly 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,

illan Magazines Ltd 597

Feely et al. [1999]

Jones et al. [2001]

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

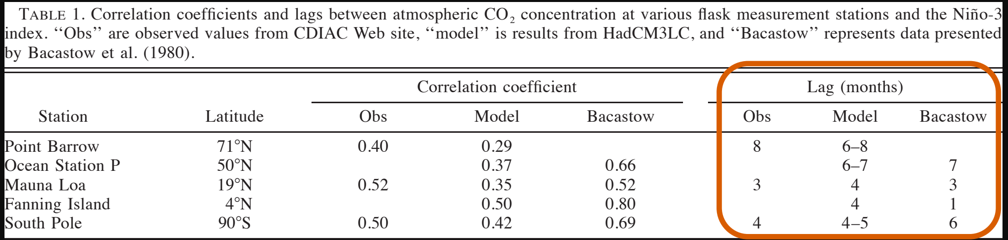


TABLE 1. Correlation coefficients and lags between atmospheric CO_2 concentration at various flask measurement stations and the Niño-3 index. “Obs” are observed values from CDIAC Web site, “model” is results from HadCM3LC, and “Bacastow” represents data presented by Bacastow et al. (1980).

		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

GMAO

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

References

Bacastow [1976], *Nature* 261, pp. 116-118
Cox et al. [2013], *Nature* 494, pp. 341-344
Feely et al. [1999], *Nature* 398, pp. 597-601
Keeling et al. [1985], *Nature* 375, pp. 666-670
Newell and Weare [1977], *GRL* 4, pp. 1-2
Sutton et al. [2014], *GBC* 28, pp. 131-145

Bacastow [1980], *Science* 210, pp. 66-68
Chatterjee et al. [2017], *Science* 358, 6360
Ishii et al. [2014], *Biogeosciences* 11, pp. 709-734
Jones et al. [2001], *J. Climate* 14, pp. 4113-41
Rayner et al. [1999], *GRL* 26, pp. 493-496
Wenzel et al. [2016], *Nature* 538, pp. 499-501

QUESTIONS?

abhishek.chatterjee@nasa.gov