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

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SOLAS Remote Sensing for Studying the Ocean-Atmosphere Interface  
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Focus of this talk

- OCO-2 provides a first-hand look at the space-time evolution of tropical atmospheric CO₂ 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 CO₂ concentrations during El Niño events.
- Net impact of El Niño on the global carbon cycle is an increase in atmospheric CO₂ concentrations.
El Niño 2015-2016

Courtesy: GMAO/SVS, NASA GSFC
Correlations between atmospheric CO₂ 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 CO₂ 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?
GOSAT and OCO-2 era

Monthly coverage over the Pacific

GOSAT and OCO-2

Niño 3.4
5°S - 5°N
170°W - 120°W

XCO2 concentrations (ppm)

XCO2 anomalies (ppm)

'zero' anomaly line
Niño 3.4 XCO2 anomaly

El Niño 2015-2016
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 $\geq$ 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 $\rightarrow$ strong $CO_2$ outgassing

- **El Niño conditions:** deepening of thermocline, reduction in upwelling, weakening of trade winds + more efficient biological pump $\rightarrow$ decreases $CO_2$ outgassing by 40-60%
Air-sea CO$_2$ flux in the Tropical Pacific

- 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$^2$)

Ishii et al. [2014]
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

![Image of maps showing CO emissions during August-October 2015](Image)

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 CO₂, March-June 2015
- Drier land -> Less plant growth, more CO₂
- Higher temp -> Increased respiration, more CO₂
- Hotter and drier -> Increased fires, more CO₂

OCO-2 data of CO₂
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 CO₂ outgassing over the tropical Pacific – negative CO₂ anomalies throughout but with perceptible west-east gradients

- **Mature Phase of ENSO: Fall 2015 onwards**
  - increase in CO₂ anomalies registered over the tropical Pacific – combination of reduced biospheric activity and increase in fire activity

*Chatterjee et al. [2017], Science*
The relationship between tropical CO₂ fluxes and the
El Niño-Southern Oscillation

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The relationship between tropical CO₂ fluxes and the El Niño-Southern Oscillation is examined using time series data from a coupled climate-carbon cycle model. The analysis suggests that the initial response of tropical CO₂ fluxes to the ENSO event is caused by a flux transition from negative to positive, which is followed by a delayed response in the ocean and land. This delayed response is attributed to changes in atmospheric CO₂ concentrations and land surface fluxes. The study highlights the importance of considering the interannual variability in the carbon cycle when analyzing the impact of ENSO on carbon fluxes.

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

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 (CO₂) 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-
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

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QUESTIONS?

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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
Isolating the negative anomaly to the trop. Pacific

- **Niño 3.4**
- **Trop. Atlantic**
- **N. Pacific**
- **S. Pacific**

### Specific region analyzed
- **Global**
  - $X_{\text{CO}_2}$ anomalies over the Pacific Ocean are responding to changes in terrestrial CO$_2$ concentrations
- **Tropical Atlantic**
  - $X_{\text{CO}_2}$ anomalies over the Pacific Ocean are responding to changes in global CO$_2$ concentrations
- **North Pacific**
  - $X_{\text{CO}_2}$ anomalies over the tropical Pacific Ocean are responding to changes in CO$_2$ concentrations across the entire Pacific Ocean
- **South Pacific**
  - $X_{\text{CO}_2}$ anomalies over the tropical Pacific Ocean are responding to changes in CO$_2$ concentrations across the entire Pacific Ocean

### Alternative hypothesis
- X$_{\text{CO}_2}$ anomalies over the Pacific Ocean are responding to changes in terrestrial CO$_2$ concentrations
- X$_{\text{CO}_2}$ anomalies over the Pacific Ocean are responding to changes in global CO$_2$ concentrations
- X$_{\text{CO}_2}$ anomalies over the tropical Pacific Ocean are responding to changes in CO$_2$ concentrations across the entire Pacific Ocean

### What are the signature of X$_{\text{CO}_2}$ anomalies in other ocean basins with respect to those observed over the trop. Pacific Ocean?


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

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