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 \hspace{1cm} 14 March 2018
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

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 operate — 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

Figure:
- Graph showing XCO2 concentrations (ppm) from 2009 to 2016.
- Map indicating Niño 3.4 (5°S - 5°N, 170°W - 120°W) and El Niño 2015-2016 anomaly line.

Graph Details:
- XCO2 concentrations range from 386 to 402 ppm.
- Niño 3.4 anomaly line marked with 'zero' anomaly line.
- El Niño 2015-2016 highlighted with specific months (Jul09 to May16).
Observable trends in 2015-2016

Time-series showing the temporal evolution of $X_{CO_2}$ anomalies over Niño 3.4

Sep 2014 – May 2016

Panel A – ENSO markers
- ONI $\geq$ 0.5 °C
- SOI drops <0

Panel B – $X_{CO_2}$ response
- initial decline followed by steady ramp up in $X_{CO_2}$
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$^2$)
Continued investigation into the interannual, decadal, and multidecadal dynamics that impact the equatorial El Niño events to anthropogenic climate change. Orbital inversions are able to capture the interannual variability of sea-air CO cycle and its interaction with other modes of large-scale climate variability in this region and around the globe. Orr et al. provides real-time, in situ meteorological and oceanographic measurements such as wind velocity, ocean temperature, and salinity from the TAO/TRITON array of moored buoys established between 1984 and 1994, which were widely used to study the ENSO events and during the transitions between events. Laboratory (PMEL) Carbon Group to deploy autonomous CO instruments over the past two decades have allowed NOAA to sustain observations in the equatorial Pacific. Climate change predictions in the equatorial Pacific are key to understanding how ENSO and CO systems may change in the future. Natural and anthropogenic forcing at interannual and decadal scales may interact to affect seawater chemistry and the ocean uptake of CO. Carbon cycle and pH in this important region. In addition to interannual and decadal-scale controls on ocean carbon, the global oceans are also important of different physical processes that give rise to them, which also in turn affect the carbon cycle. The ENSO observing system in the equatorial Pacific has become key to understanding ENSO warming and cooling events and their impacts on the ocean carbon cycle. The role of physical forcing on ocean carbon is as critical as the contribution from biological production. The role of the ocean in the rising atmospheric CO concentration is expected to reduce calcium precipitation with respect to calcium carbonate minerals (CaCO3). Calcium precipitation is a process known as ocean acidification. Calcium precipitation rates in a variety of organisms, including tropical corals, are likely to be affected by ocean acidification. The importance of different physical processes that give rise to them, which also in turn affect the carbon cycle, is key to understanding how ENSO and CO systems may change in the future. Natural and anthropogenic forcing at interannual and decadal scales may interact to affect seawater chemistry and the ocean uptake of CO.
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 CO₂ flux
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 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 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*
The relationship between tropical CO₂ fluxes and the El Niño-Southern Oscillation
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The observational record is described further in section 2. The correlation between these anomalous changes in CO₂ concentrations in the atmosphere and the oceans during the 1991–94 El Niño event is shown in Figure 1. The correlation coefficient is 0.5–0.7, indicating that the initial response of tropical CO₂ fluxes to ENSO occurs in the ocean and the response is later offset as a result of increased terrestrial exchange of CO₂.

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

**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
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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

What are the signature of X_{CO2} 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

<table>
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<th>Station</th>
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<th>Correlation coefficient</th>
<th>Lag (months)</th>
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<td>Model</td>
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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).