Oceanic drivers for tropical terrestrial carbon cycle and extreme

Min Xu [1] Forrest M. Hoffman [1] Salil Mahajan [1] Jiafu Mao [1]
Paul Levine [2]

[1]Oak Ridge National Laboratory, Oak Ridge

[2]University of California, Irvine, California

January 25 2019

Outlines

- Introduction and motivation
- Model and data
- Results and discussions
- Conclusions
- Future work

Introduction and motivation

Oceanic variability and modes play very important roles in global climate and ecosystems:

- *Regulate* global climate and climate variability through oceanic and atmospheric teleconnections
- *Shift* weather patterns and climate regimes
- *Change* intensity and frequency of climate extremes
- *Modify* regional and local water and energy cycles
- *Interplay* with each other with significant feedback to local and global climate

Eventually they strongly affect the terrestrial carbon cycles, especially over the tropics in which lands are surrounded by a large area of ocean water.

Introduction and Motivation (cont'd)

There are three important oceanic modes originating from the Pacific, Atlantic and Indian oceans respectively and are generally represented by interannual and decadal variability of sea surface temperature (SST):

- El Niño-Southern Oscillation (ENSO) measured by Niño3.4 index
- Atlantic Multidecadal Oscillation (AMO) measured by AMO index
- Indian Ocean Dipole (IOD) measured by Dipole Mode Index (DMI)

Many studies of impacts of oceanic modes on global climate have been done, however due to the complex interactions between them, which in turn can affect their variability and feedback to climate, there are still large uncertainties in their impacts on tropical climate and terrestrial ecosystems.

ENSO impacts on GPP

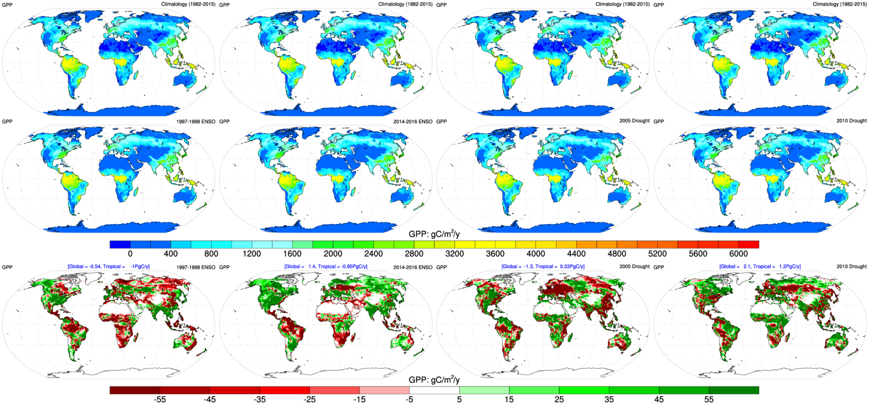

Figure: Model simulated GPP anomalies in two El Niño events and 2005 and 2010 amazon drought.

ENSO impacts on drought

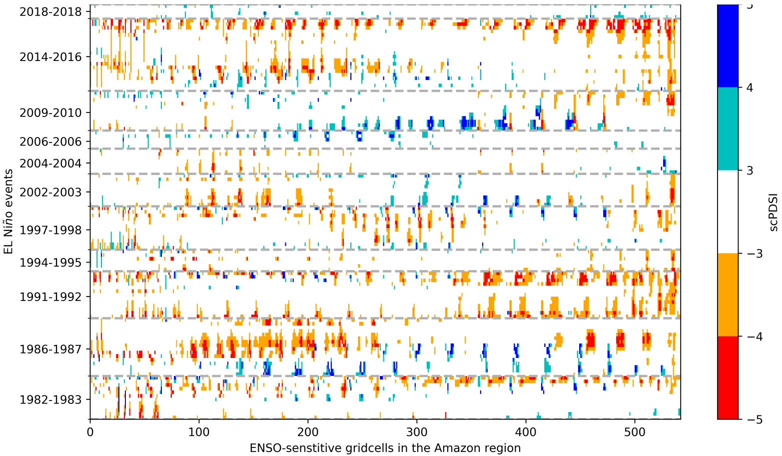

Figure: The scPDSI distributions over the ENSO-sensitive grid cells of the Amazon region (X axis) and the El Niño months from 1982 to 2020.

ENSO and Walker circulation

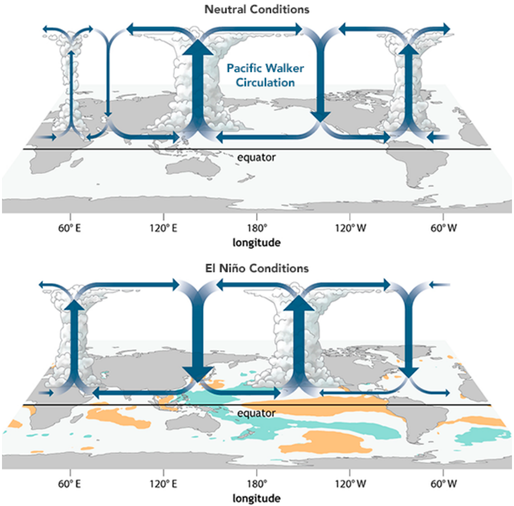

Figure: Walker circulation under neutral and El Niño conditions (Courtesy of NOAA/Climate.gov, obtained from `https://earthobservatory.nasa.gov/features/ElNino`)

Global Ocean Basins

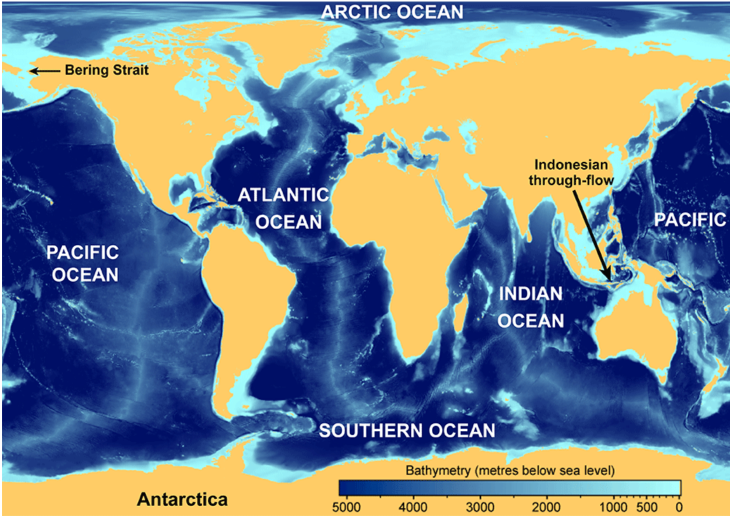

Figure: Global ocean basins (Obtained from `http://www.euroargo-edu.org/explore/argoeu_4.php`)

Objectives

We focus our study on understanding the roles of interannual variability (IAV) of sea surface temperatures of different oceans on the IAVs of land climate and terrestrial carbon cycles. In this study, we want to:

- **Decompose the influences of SST IAVs on climate and climatic extremes**
- **Estimate their attributions to the variability of terrestrial carbon fluxes in the tropics**

Model and data

- Energy Exascale Earth System Model version 0.3
  - 1-degree (ne30np4) F-compset configuration simulation:
    - active atmosphere model with spectral element dynamic core (CAM5-SE)
    - **active land model with the biogeochemical model turned on**
    - data ocean (DOCN)
    - thermodynamic sea ice (CICE)
  - Data ocean reads NOAA Optimum Interpolation (OI) version 2 **daily** sea surface temperature (SST)
  - Ice fractions are also provided by the OISST v2 product
  - Future SST projections come from 9-month seasonal forecasts of the NOAA Climate Forecast System (CFSv2)
  - Beyond CFS seasonal forecast period, SSTs and ice fractions are estimated from historical OISSTv2 data till 2020

Spin-up and experiments

We first spinned up the model by forcing it with recycled OISST data from 1982 to 1995 for **840** model years. After it reached its equilibrium status, a control run (named **CONTROL**) was simulated and forced by OISST data from year 1996 to 2020. Beside the control simulation, we also conducted four idealized experiments from year 1996 to 2020 to study the effects of different oceanic modes on climate and terrestrial carbon cycle:

- **NoVarOcn**: Same as CONTROL, except using a climatology daily SST averaged from 1982-2016
- **NoVarAtl**: Same as CONTROL, except SSTs in the Atlantic Ocean from the above climatology daily SSTs
- **NoVarInd**: Same as CONTROL, except SSTs in the Indian Ocean from the above climatology daily SSTs
- **NoVarPac**: Same as CONTROL, except SSTs in the Pacific Ocean from the above climatology daily SSTs

Regions

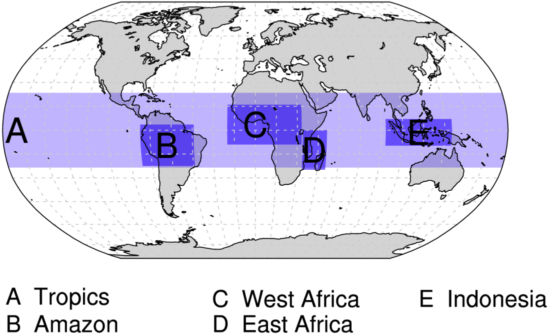

Figure: The four regions over the tropics for calculations of regional anomalies

Oceanic Modes in the forcing SST data

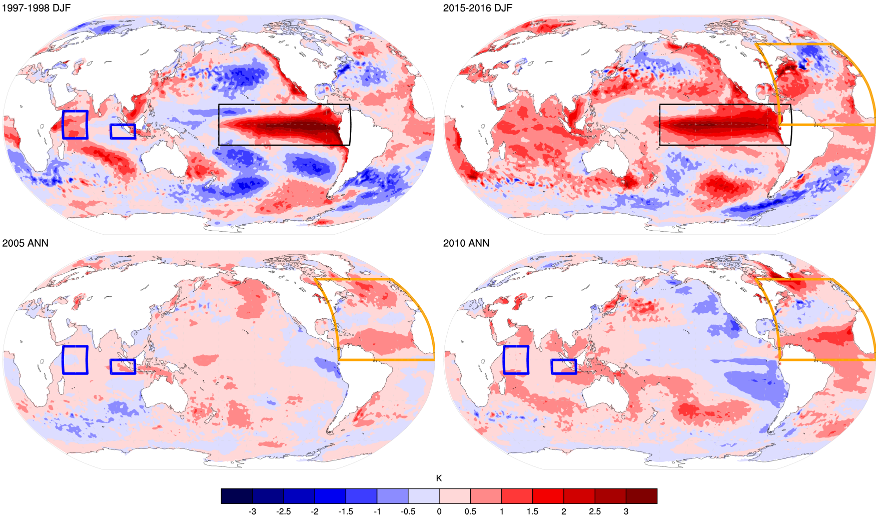

Figure: Boreal wintertime SST anomalies during 1997-1998 and 2015-2016 (upper panel) and annual SST anomalies in 2005 and 2010 (bottom panel).

Oceanic modes from three largest oceans

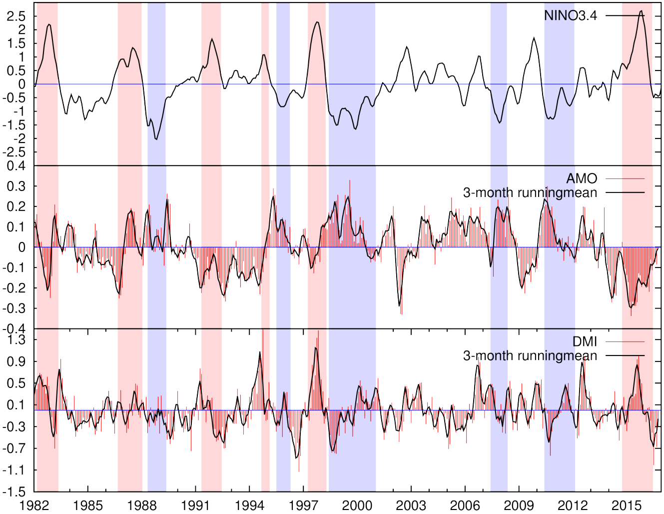

Figure: Niño3.4, AMO and DMI time evolution during 1982 to 2016.

GPP anomalies - Amazon

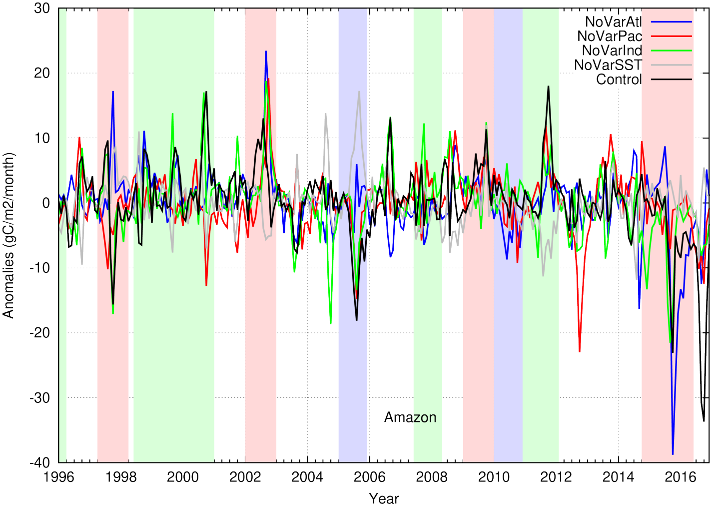

Figure: GPP anomalies averaged over the amazon region.

GPP anomalies - Tropics

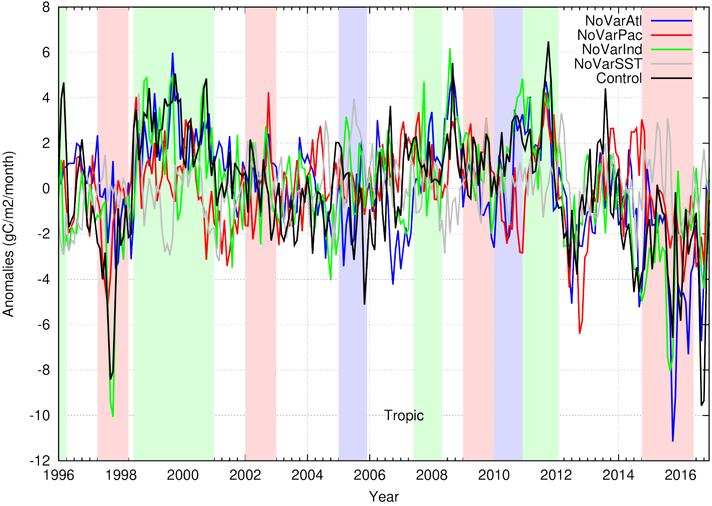

Figure: GPP anomalies averaged over the entire tropics.

Effects of oceanic modes on GPP IAVs

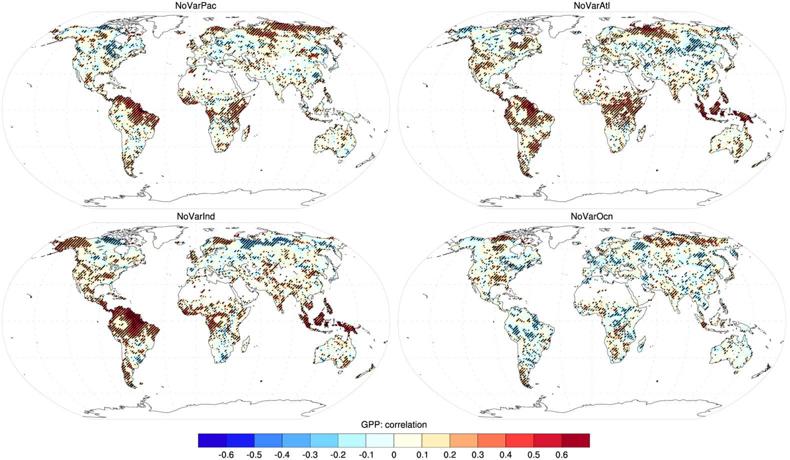

Figure: Geographic distributions of correlation coefficients of monthly GPP anomalies of four idealized experiments with that of the CONTROL (Stippled areas denote that they are significant at a 95% confidence level).

Correlations of regional GPP anomalies

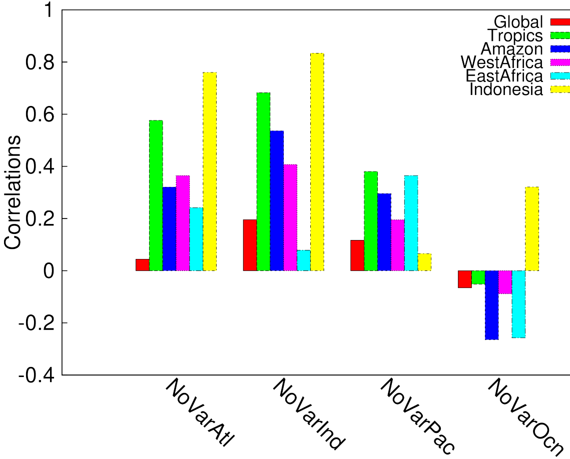

Figure: Correlation coefficients of monthly GPP anomalies of four idealized experiments with that of the CONTROL over the globe and 5 regions (Values larger than 0.16 indicate significant correlations at a 95% confidence level).

Effects on climate extremes

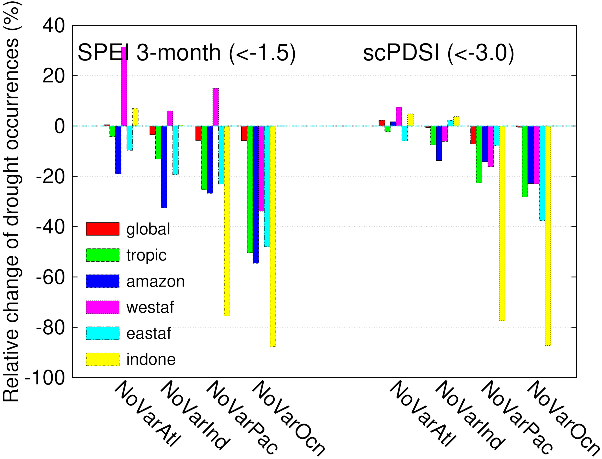

Figure: Relative changes of occurrences of extreme drought events simulated by the four idealized experiments compared with those by the CONTROL experiment over the globe and five regions.

Effects on BGC extremes

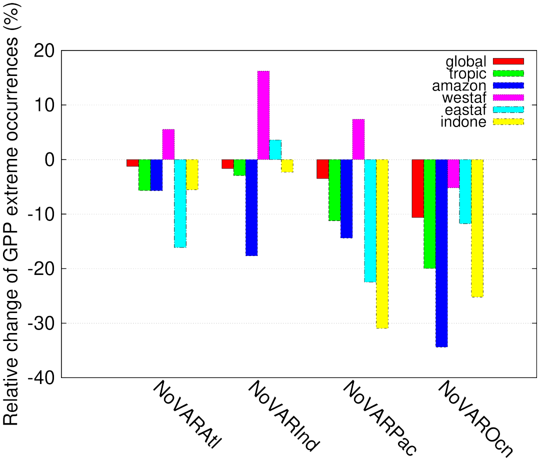

Figure: Same as the above slide, except for GPP negative anomalies.

Correlation between SST and amazon GPP anomalies (NoVarAtl)

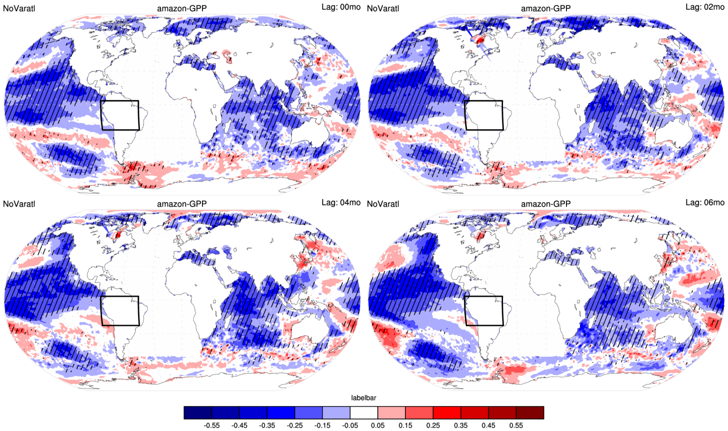

Figure: Correlations between SST and GPP anomalies in the amazon region for NoVarAtl (Stippled areas denote that they are significant at a 95% confidence level).

Correlation between SST and amazon GPP anomalies (NoVarPac)

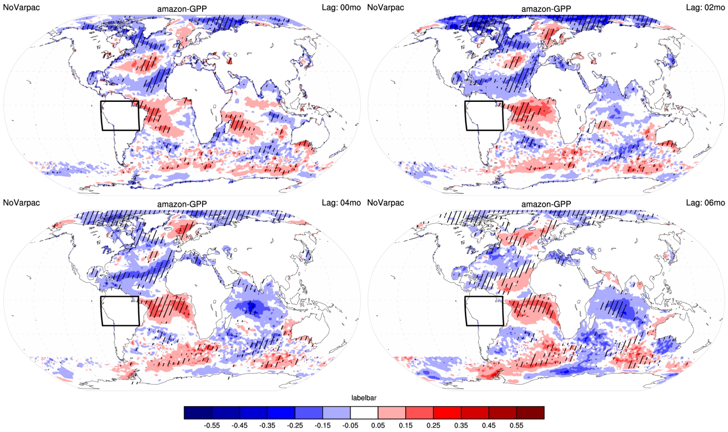

Figure: Same as above except for NoVarPac.

Correlation between SST and amazon GPP anomalies (NoVarInd)

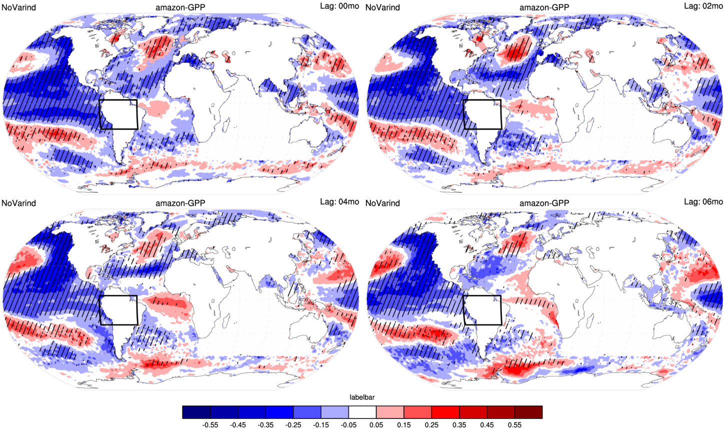

Figure: Same as above except for NoVarInd.

scPDSI (NoVarAtl)

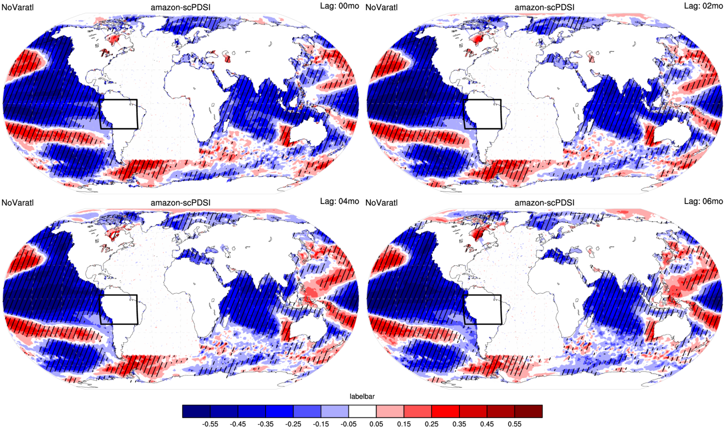

Figure: Correlations between SST and scPDSI anomalies in the amazon region for NoVarAtl (Stippled areas denote that they are significant at a 95% confidence level).

scPDSI (NoVarPac)

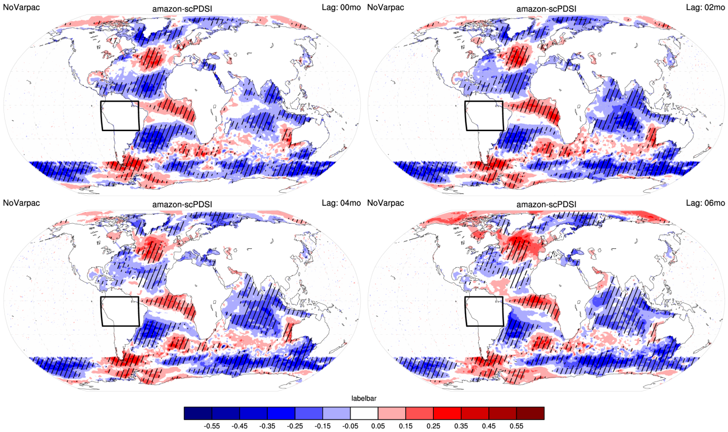

Figure: Same as above except for NoVarPac.

scPDSI (NoVarInd)

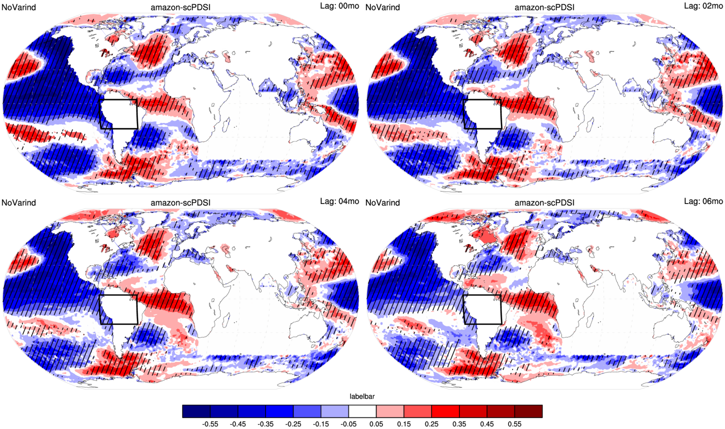

Figure: Same as above except for NoVarInd.

Conclusions I

- SST IAVs from the Atlantic and Pacific Oceans are dominant factors responsible for the IAVs of global carbon fluxes and play a nearly equal role on the carbon fluxes in the amazon region
- SST IAVs from the Indian Ocean determines the GPP IAVs in eastern Africa, while SST IAVS from the Pacific Ocean explain most variations of GPP in the Indonesia region
- the experiment without SST IAVs over global oceans (NoVarOcn) even wrongly simulated the GPP anomaly variations nearly in all regions, and the variations are expected from the internal variability from land, atmosphere and their interactions

Conclusions II

- the oceanic variability also highly impacts the occurrences of both short-term (SPEI) and long-term (scPDSI) droughts. Without oceanic variability in a certain ocean, the simulated drought occurrences are reduced by 4-91% depending on regions and oceans, except for western Africa, the number of extremes surprisingly rise. This may be due to the climate in western Africa resulting from the interactions between three oceans
- the changes of GPP extreme occurrences show similar results as those of climate extreme occurrences, but the reductions are much less and range from 2 to 36% varying with regions and oceans
- the large reductions in the amazon region both for climate and BGC extremes in the NoVarInd experiment indicate that the Indian Ocean plays an important role in extreme events in the amazon region through atmospheric bridges and teleconnections

Future work

We plan to continue our research on the following aspects:

- conduct ensemble simulations to evaluate uncertainties
- study the effects of SST warming on global climate and ecosystems
- conduct fully coupled simulations using E3SM v1 and analyze the oceanic modes in regulating terrestrial carbon cycles and dynamics

Acknowledgment

This research was supported through as part of the **Next Generation Ecosystem Experiments-Tropics** and the **Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation** Scientific Focus Area (RUBISCO SFA), which are sponsored by the Climate and Environmental Sciences Division (CESD) of the Biological and Environmental Research (BER) Program in the U.S. Department of Energy Office of Science.

This research used resources of the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility and the Oak Ridge Leadership Computing Facility at the Oak Ridge National Laboratory, which are supported by the Office of Science of the U.S. Department of Energy under Contract No. **DE-AC02-05CH11231** and **DE-AC05-00OR22725** respectively.

Next Generation Ecosystem Experiments-Tropics
Ecosystem Processes
Modeling, Prediction
Systems Understanding

RUBISCO
REDUCING UNCERTAINTIES IN BIOGEOCHEMICAL INTERACTIONS THROUGH SYNTHESIS AND COMPUTATION

Questions?