Tropical Ecological Forecasting for ENSO Using a Global Modeling Framework

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1. Objectives

- Exploring the potential of DOE's Energy Exascale Earth System Model (E3SM) for ecosystem forecasting
- Providing consistent and highly spatiotemporal meteorology forcing data for site-level trait modeling development and comparisons
- Studying impacts of ENSO on tropical ecosystems and carbon dynamics as well as climate and biogeochemical extremes

2. Introduction

The El Niño Southern Oscillation (ENSO) is the most important inter-annual and semi-decadal mode of climate variability and has significant impacts on the global climate through shifting climate patterns and regimes, changing frequencies of climatic and weather extremes, and modulating regional and local water and energy cycles and balances. The impacts and responses of global ecosystem and biosphere to ENSO remain largely uncertain because:

- the responses are highly heterogeneous and depend on the biogeophysical and biogeochemical characteristics associated with plant functional type (PFTs),
- there are few observations and significant knowledge gaps of the impacts, and
- they are strongly influenced by large-scale teleconnections driven by oceanic variability.

In this study, we investigated the following subjects using a modeling approach.

- E3SM model performance in AMIP-style simulations for ecosystem forecasting
- PFT-level responses to ENSO events focusing on two major El Niño events (1997–1998 and 2015–2016)
- Impacts of ENSO on the inter-annual variability of the atmospheric CO_2 growth rate
- Influence of ENSO-induced extremes on tropical ecosystems
- Strength of oceanic drivers on the terrestrial carbon cycle and its extremes

3. Methodology and Models

Energy Exascale Earth System Model (E3SM) at 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), and thermodynamic sea ice (CICE)
- Data ocean reads NOAA Optimum Interpolation (OI) version 2 daily sea surface temperature (SST) as well as ice fractions
- Future SST projections provided by 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.

4. Results and Discussions

4.1 Plant Functional Type (PFT)-level responses to ENSO

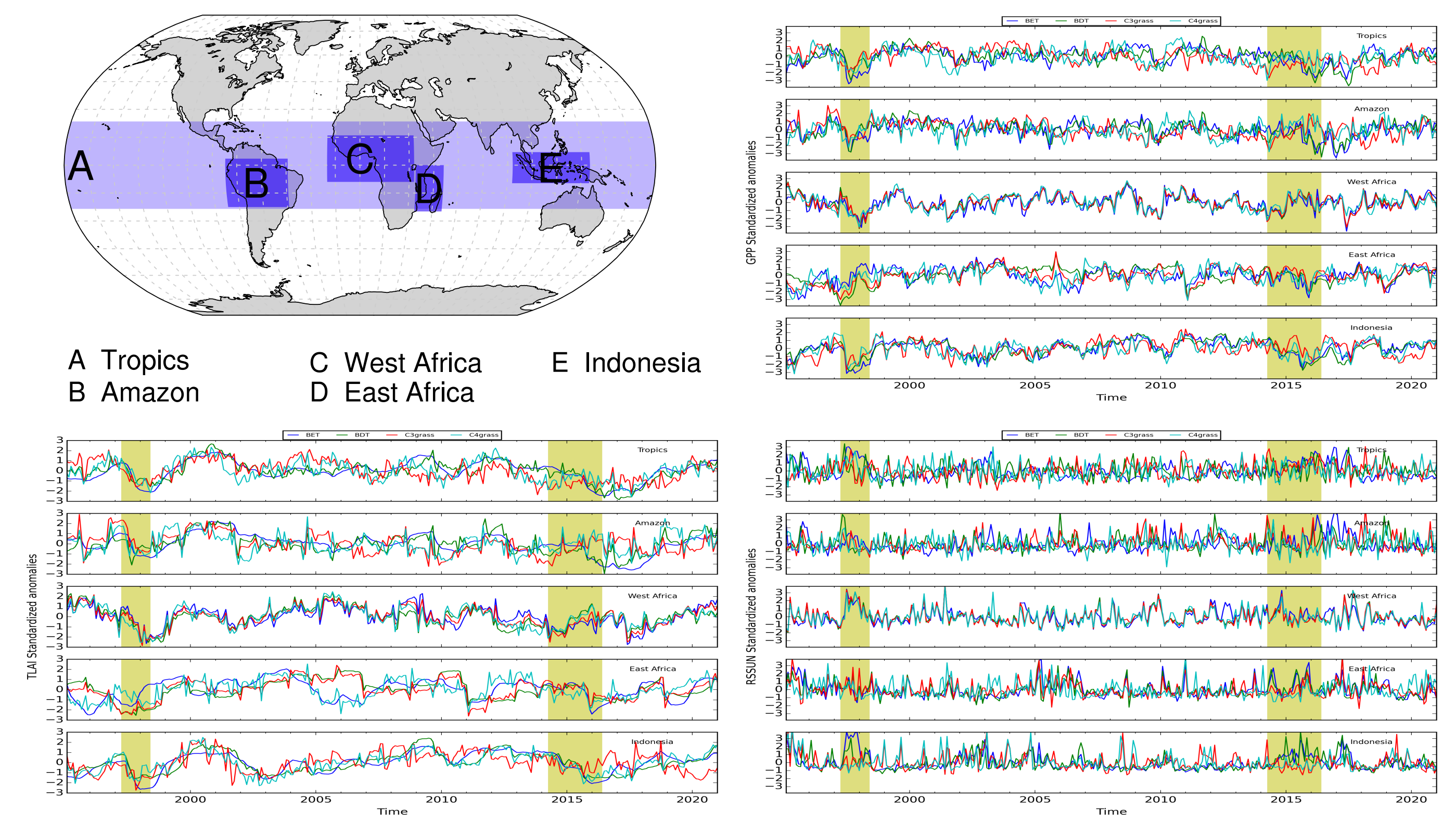

Figure 1: *Time evolution of the standardized anomalies of gross primary product (GPP), leaf area index (TLAI), and stomatal resistance on sunlit leaf (RSSUN) for four PFTs (Tropical Broadleaf Evergreen Tree (BET), Tropical Broadleaf Deciduous Tree (BDT), and C_3 and C_4 grass in five tropical regions from 1995 to 2020. The 1997–1998 and 2014–2016 El Niño events are shaded in a yellow color.*

4.2 Effects of ENSO-induced extremes on terrestrial ecosystem

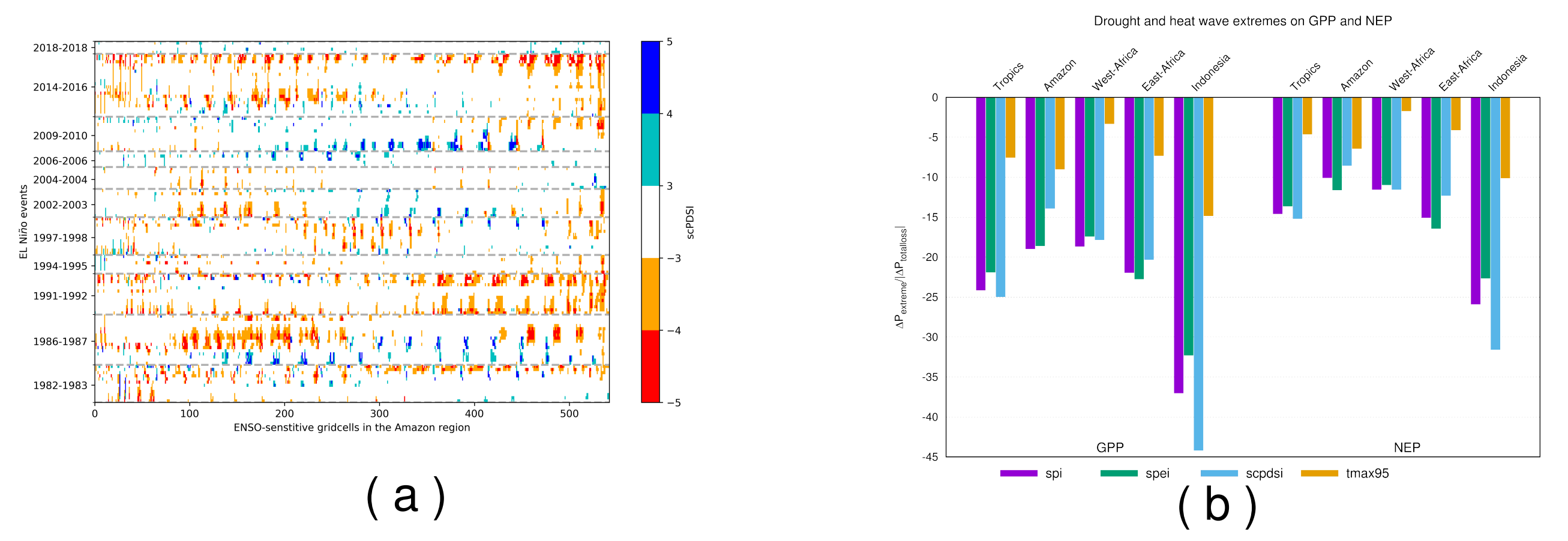

Figure 2: *(a) scPDSI distributions over the ENSO-sensitive grids of the Amazon region (X-axis) and the El Niño months from 1982-2020; (b) percentages of the GPP and NPP losses due to extremes to the absolute values of total losses.*

4.3 ENSO impacts on CO_2 seasonality and IAV

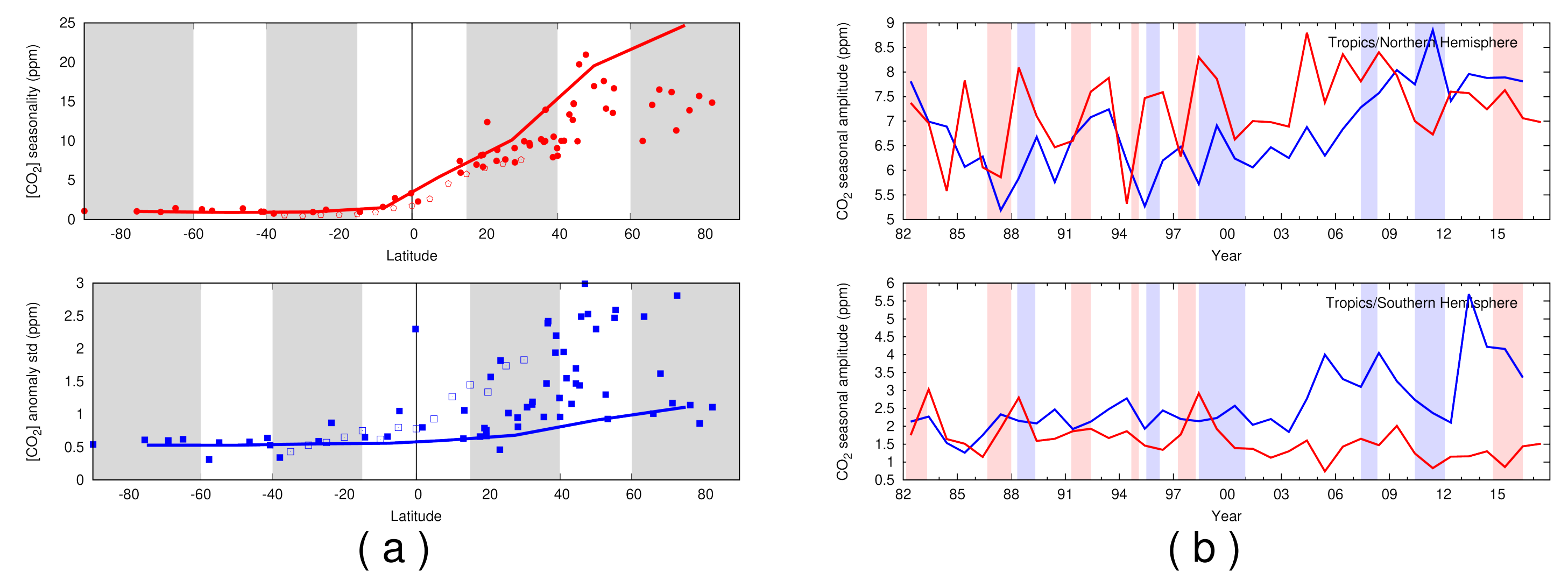

Figure 3: *(a) Observed (point) and modeled (line) latitudinal seasonality and IAV of $[CO_2]$; (b) Observed (blue) and modeled (red) CO_2 seasonality trends over the tropics from 1982 to 2016. Shaded red and blue areas show El Niño and La Niña years respectively*

4.4 Oceanic drivers

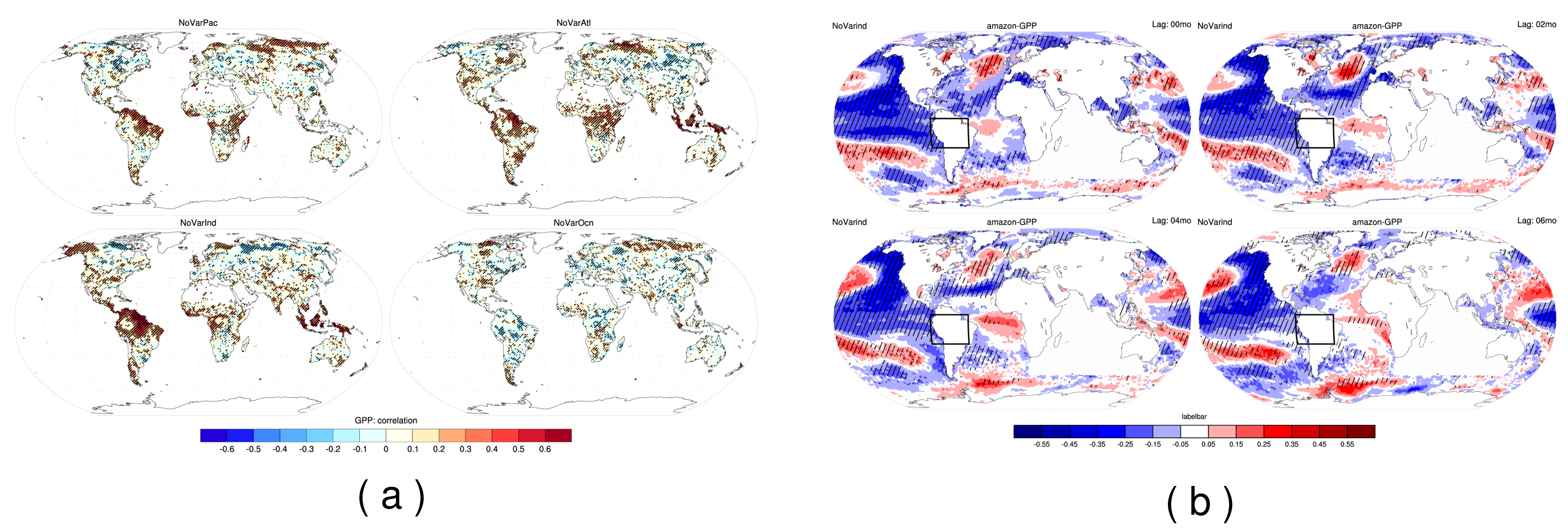

Figure 4: *(a) Correlation coefficients between GPP anomalies of four idealized and control experiments; (b) Correlations between SST and GPP anomalies in the Amazon region.*

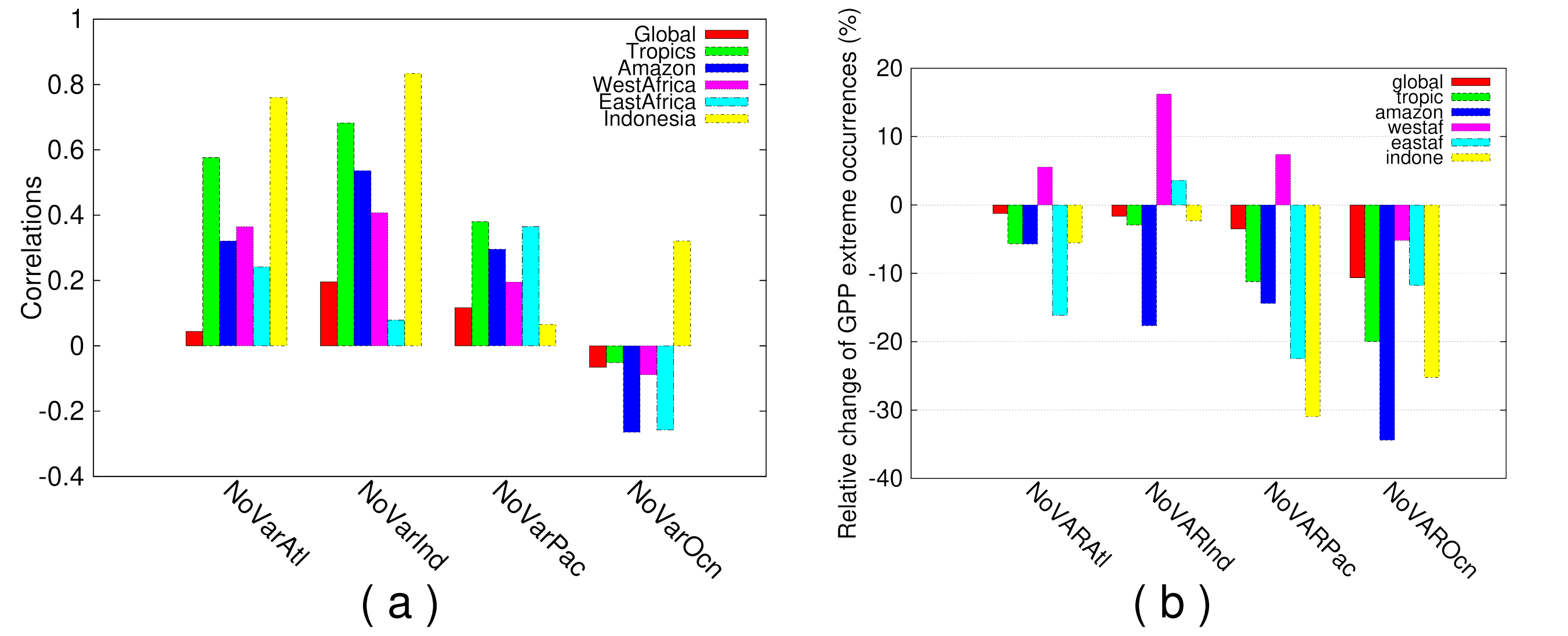

Figure 5: *(a) Correlation coefficients of GPP anomalies between four idealized and control experiments; (b) Relative changes of occurrences of BGC extremes simulated by four idealized and control experiments.*

5. Conclusions

- ENSO has large influences on tropical ecosystem productivity, and the responses of subgrid PFTs to ENSO forcing vary.
- ENSO-induced drought and heat waves strongly affect terrestrial ecosystem, and approximately 18–43% total GPP/respiration losses are caused by rare climate extremes.
- Simulated CO_2 IAV is lower and seasonality is higher than observed, particularly in the northern high latitudes. Seasonality in the tropics shows an increasing trend since 1997.
- SST IAVs from the Atlantic and Pacific Oceans are dominant factors responsible for the IAV of global carbon fluxes and play a nearly equal role in the carbon fluxes in the Amazon region.
- Without oceanic variability in certain oceans, the simulated drought and GPP extreme occurrences are reduced by 4–91% and 2–36%, respectively, in tropical regions.

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