A Tropical Ecological Forecasting Strategy for ENSO Based on a Global Modeling Framework

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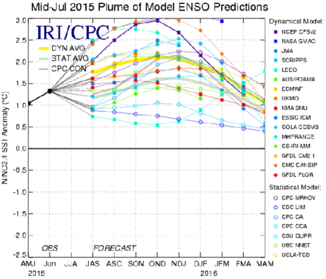
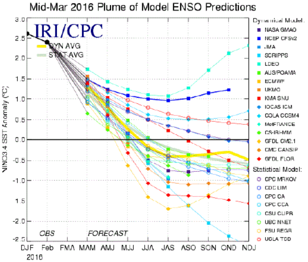
Rationale

- To study responses and feedbacks of tropical droughts induced by 1997–1998 and 2015–2016 El Niño events in the Energy Exascale Earth System Model (E3SM, formerly called ACME) land model
- To study model responses of the 2005 and 2010 Amazon droughts, which were a consequence of Atlantic Ocean conditions
- To construct a set of meteorological forcing data, including strong tropical land–atmosphere interactions, from the atmosphere model for use in process model development and testing
- To test the utility of the E3SM framework for tropical carbon cycle forecasting

Model Configuration

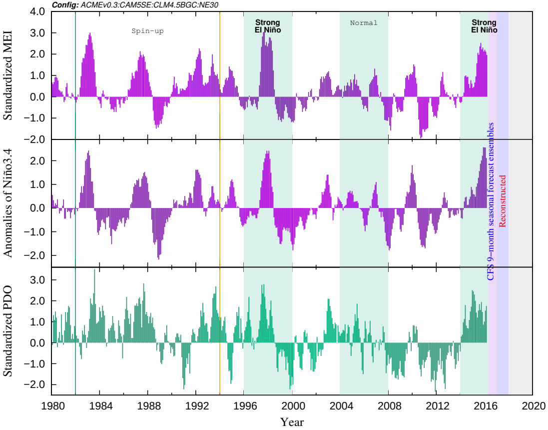
- **Energy Exascale Earth System Model (E3SM) v0.3**
- **1-degree (ne30np4) AMIP-style (F-compset) configuration**: Active atmosphere (CAM5-SE) and land (ELM) with data ocean (DOCN) and thermodynamic sea ice (CICE)
  - Data ocean reads NOAA Optimum Interpolation (OI) version 2 daily sea surface temperature (SST) (September 1981–present)
  - Ice fractions are also provided in the OISSTv2 data set
  - Future SST projections come from 9-month seasonal forecasts of the NOAA Climate Forecasting System (CFSv2)
  - Beyond 9 months from present, SSTs and ice fractions are drawn from historical OISSTv2 data to complete 5-y simulations





Simulation Protocol

- Spin up strategy: Start with CESM/CLM4.5-BGC year 2000 initial state and cycle 1982–1994 OISSTv2 data
- Simulate entire 1997–2018 period, saving 3-h coupler history for atmosphere fields needed for subsequent offline land model forcing
- Non-ENSO control simulation from (a) 5-y window between 1997 and 2014 ENSOs or (b) climatology of selected weak El Niño/La Niña years

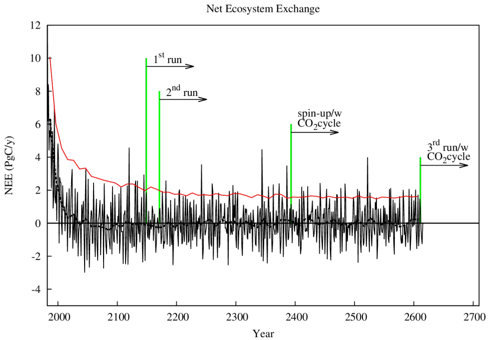


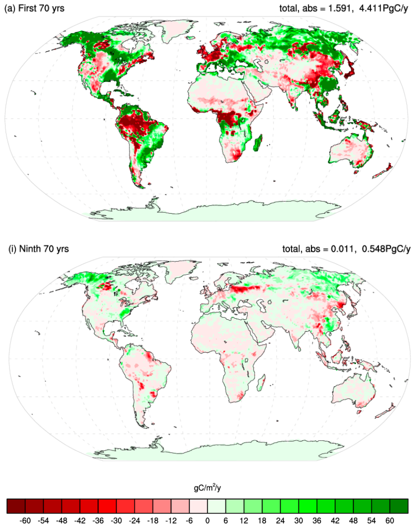
Spin up and simulation experiments are shown with respect to the standardized Multivariate ENSO Index (MEI), temperature anomalies of the Niño3.4 region, and the standardized Pacific Decadal Oscillation index.

Modeling Status

- E3SM v0.3 model was built and tested on Titan (OLCF), Cori and Edison (NERSC).
- F-compset configuration was tested and performance optimized at both ne30 ($\sim 1^\circ$) and ne120 ($\sim \frac{1}{4}^\circ$) resolutions. Given queue wait times for moderately sized jobs and limited performance, we decided ne120 was computationally prohibitive.
- OISSTv2 data were remapped to the target ne30 grid to reduce the computational cost of remapping by the data ocean model at run time.
- The spin up cycled 13 times (169 years) before initial simulation, and it continues for additional ensemble members.
- Four 25-year simulations, starting with different initial conditions, through 2020 were performed.
- Land model results were evaluated using the International Land Model Benchmarking (ILAMB) package.

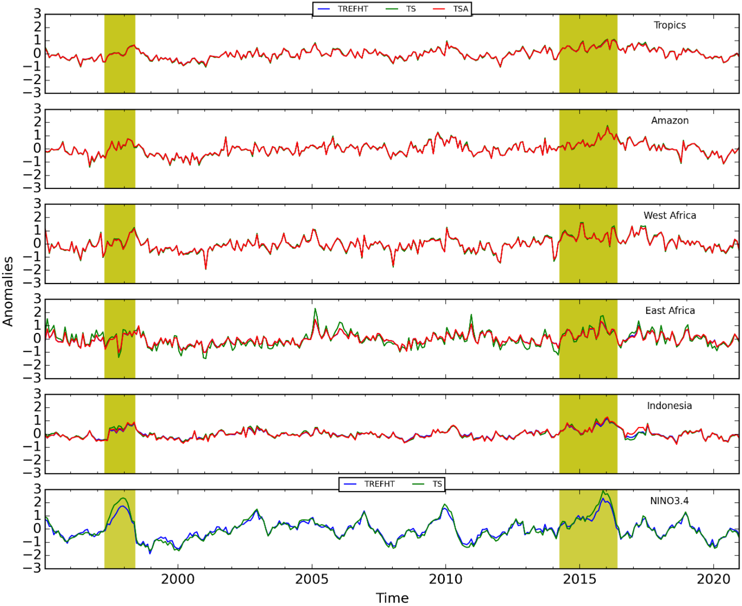
Carbon Cycle Equilibrium



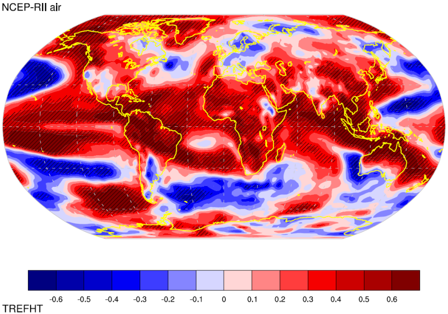


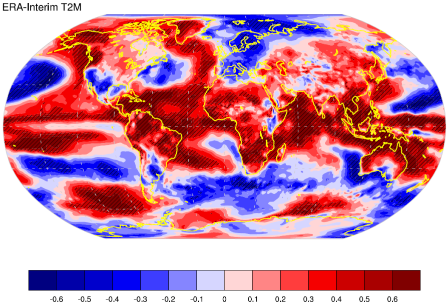
The plot (above) shows the net ecosystem exchange (NEE) (solid black), the 5-y running mean of NEE (dashed black), and the absolute value of NEE (solid red) globally from cycling the 1982–1994 OISSTv2 forcing. The years shown on the *x*-axis are simply accumulated during the cycling. The maps (right) show the first and last 70-yr mean NEE distributions from the spin up simulation.

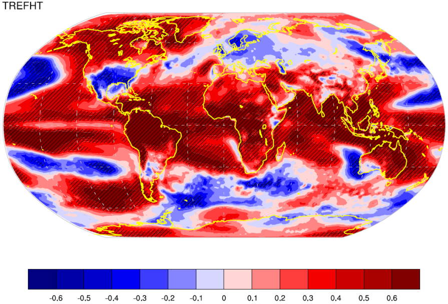
Regional surface and 2 m air temperature anomalies



Global 2-m air temperature

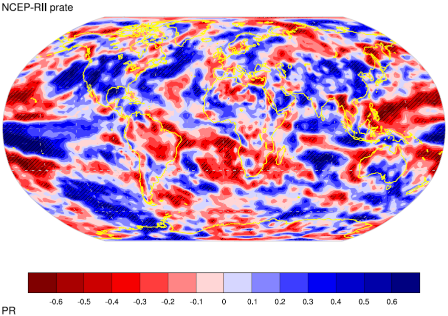


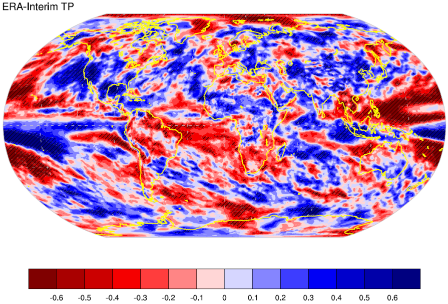


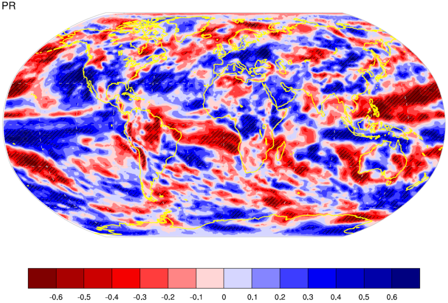


Correlation of annual mean 2-m air temperature with sea surface temperatures over the Niño 3.4 region (November–February) during 1995–2016. The hatching indicates locations where the correlation is at a 90% confidence level or higher.

Global precipitation

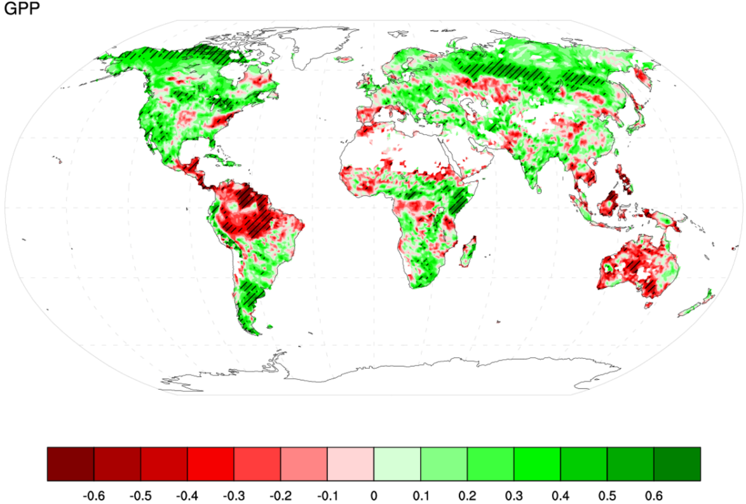






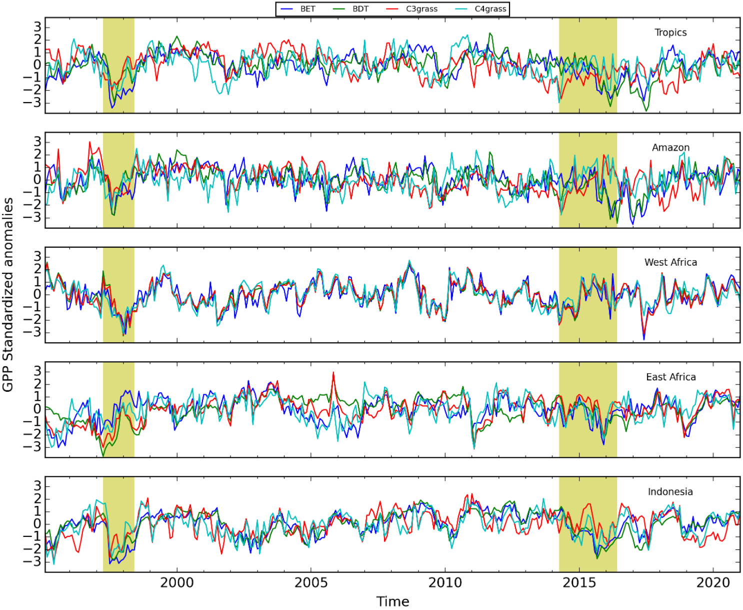
Correlation of annual total precipitation with sea surface temperatures over the Niño 3.4 region (November–February) during 1995–2016. The hatching indicates locations where the correlation is at a 90% confidence level or higher.

Global gross primary production (GPP)

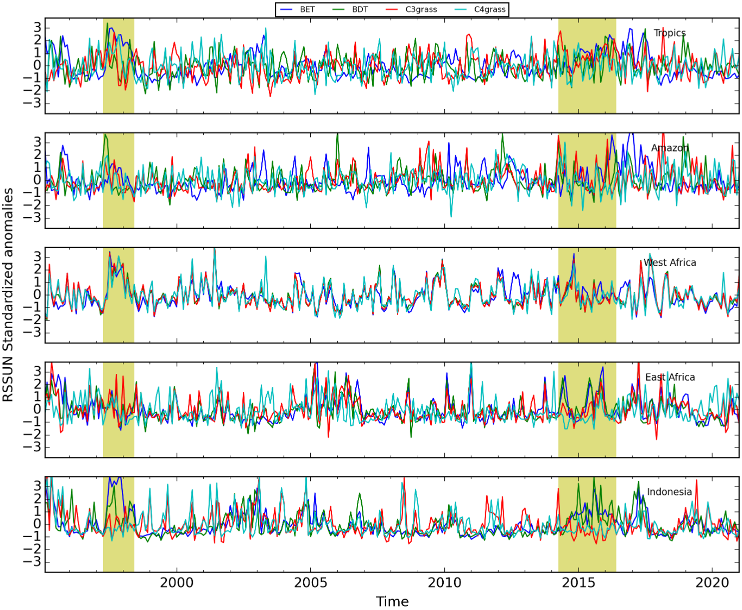


Correlation of annual gross primary production with 5-month averages of sea surface temperatures over the Niño 3.4 region (November–February) during 1995–2016. The hatching indicates locations where the correlation is at a 90% confidence level or higher.

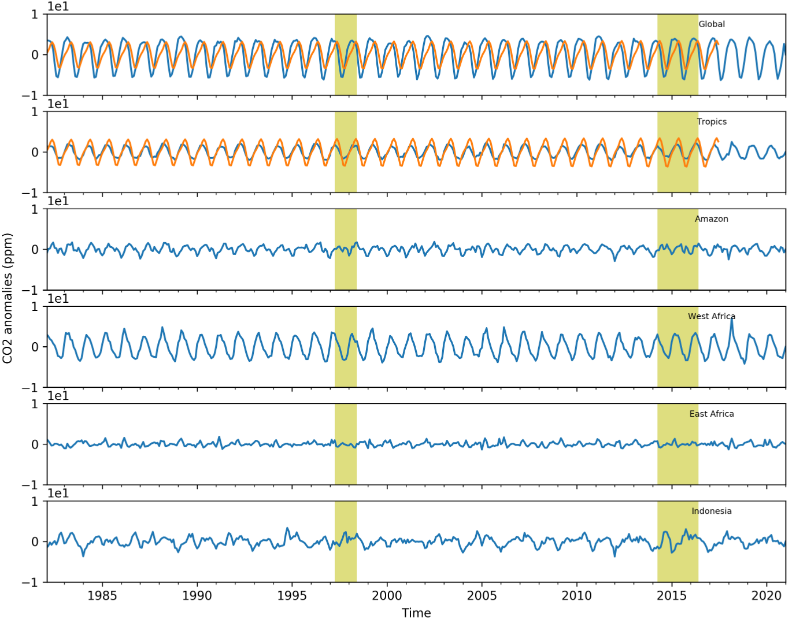
Regional PFT-level gross primary production anomalies



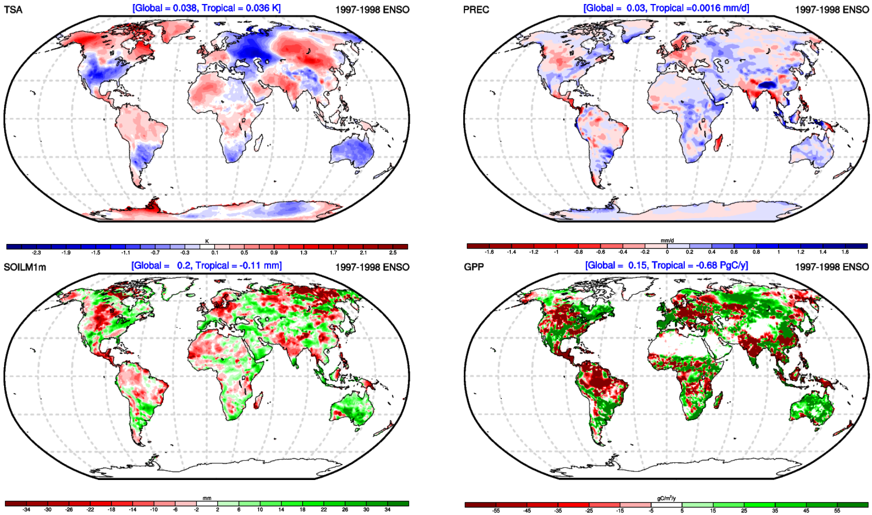
Regional PFT-level stomatal resistance anomalies



Regional atmospheric CO_2 mole fraction anomalies

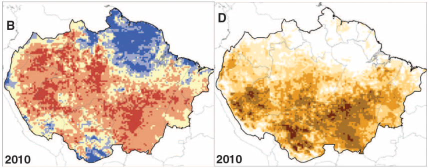


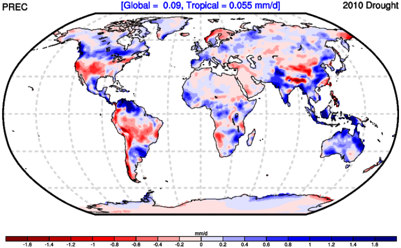
Model Patterns for the 1997–1998 El Niño Event

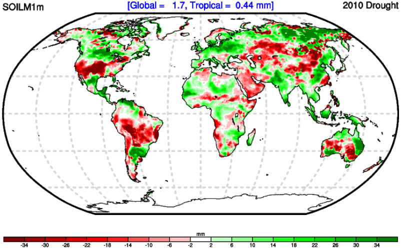


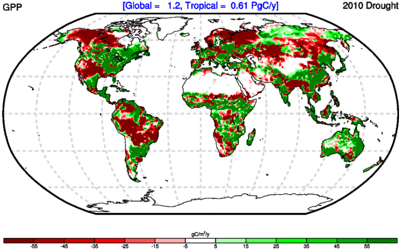
Anomaly maps for the 1997–1998 ENSO for the 2-m air temperature (TSA), precipitation (PREC), soil moisture to 1 m (SOILM1m), and gross primary production (GPP) are calculated by subtracting the 1982–2015 mean (climatology) variable from the 1997–1998 mean variable. While the model exhibited global increases in soil moisture and GPP, it projected a mean decrease in soil moisture of 0.11 mm and a mean reduction in GPP of 0.68 $\mathrm{Pg\,C\,y^{-1}}$ in the tropics.

Model Patterns for the 2010 Amazon Drought



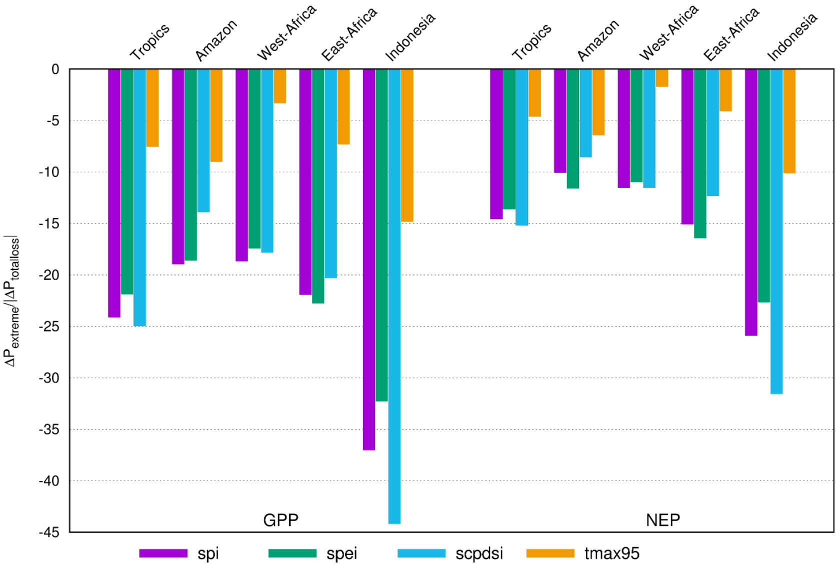






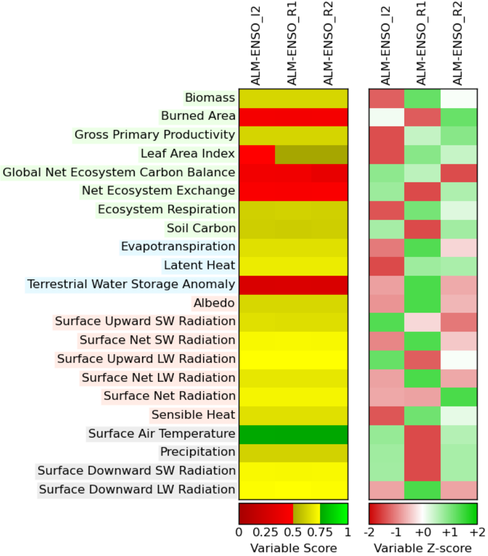
The model appears to capture the overall pattern of drought in the Amazon during 2010. The upper left figures are (B) the satellite-derived standardized anomalies for dry-season rainfall and (D) the difference in the 12-month (October to September) maximum climatological water deficit (MCWD) from the decadal mean (excluding 2005 and 2010) for the Amazon basin from Lewis et al. (2011). The soil moisture anomaly from the model correlates well with (B) and the GPP anomaly correlates well with (D).

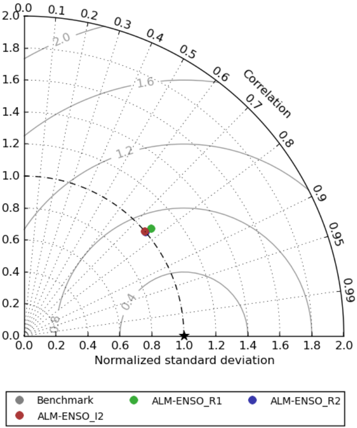
Rare Climate Extremes Account for 25–45% of GPP Losses



SPI = Standardized Precipitation Index; SPEI = Standardized Precipitation-Evapotranspiration Index; scPDSI = Self-calibrating Palmer Drought Index; Tmax95 = Temperature exceeding the 95th percentile

ILAMB Assessment





Global spatial variance of GPP compared with the FLUXNET-MTE benchmark (1995–2009)

The mean state of the two AMIP-style ensemble members is equivalent, as is the offline ALM simulation performed using the coupler forcing from the second ensemble member.

Summary and Next Steps

- Analysis of spin up simulation indicated that land carbon pools approached equilibrium when driven by OISSTv2 (1982–1994).
- ILAMB climate evaluation of the spin up run showed a +0.5 K bias in mean surface air temperature over land and a positive bias in mean precipitation at high elevations.
- Patterns of 2-m air temperature and precipitation correlations with Niño 3.4 SSTs were consistent with NCEP and ERA-Interim reanalyses.
- Patterns of GPP correlations with Niño 3.4 SSTs were consistent with expectations, especially GPP reductions in the Amazon and Indonesia.
- Patterns of precipitation and soil moisture for the 2010 Amazon drought were consistent with data reported by Lewis et al. (2011).
- Next steps:
  - decompose carbon fluxes (growth, respiration, fire), compare atmospheric CO_2 variability with observations, and compare with site plant-scale measurements.
  - upgrade to E3SM v1 model and use methodology to investigate energy, water, and biogeochemical extremes.

Acknowledgments

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References

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