A Forecasting Strategy for Tropical Ecosystems Using ACME

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Abstract

A record-setting El Niño appeared to be setting up for a late fall or early winter peak in 2015–2016, portending hot and dry conditions for the island nations of the western Pacific. To study the responses and feedbacks of drought effects induced by ENSO events, we are conducting a series of global Earth system model simulations using the Accelerated Climate Model for Energy (ACME) v0.3 model. These simulations will draw upon the ensemble of NOAA ENSO forecast sea surface temperature (SST) predictions that extend 9 months into the future. The experimental design consists of a carbon cycle spin up simulation using repeated 1982–1994 SST forcing from reanalysis, 5-y ENSO simulations for the 1997 (1996–2000) and the 2015 (2014–2018) events, and one or more non-ENSO control simulations. A combined set of historical and NOAA forecast SSTs are being used for the 2015 ENSO simulations. Analysis of ecosystem impacts, investigating anomalies in soil moisture, GPP, and stomatal conductance, will be performed across both events. ACME coupler output from the atmosphere will be saved at 3-h frequency for use as offline forcing for new model parameterization development and testing within the NGEE Tropics project.

Rationale

- To study responses and feedbacks of tropical drought effects induced by 1997–1998 and 2015–2016 El Niño events in the existing ACME land model (baseline model)
- To study the 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 CAM5-SE for use in process model development and testing
- To test the utility of the ACME framework for tropical carbon cycle forecasting (complementing effort of Yiqi Luo and Dan Ricciuto for SPRUCE)

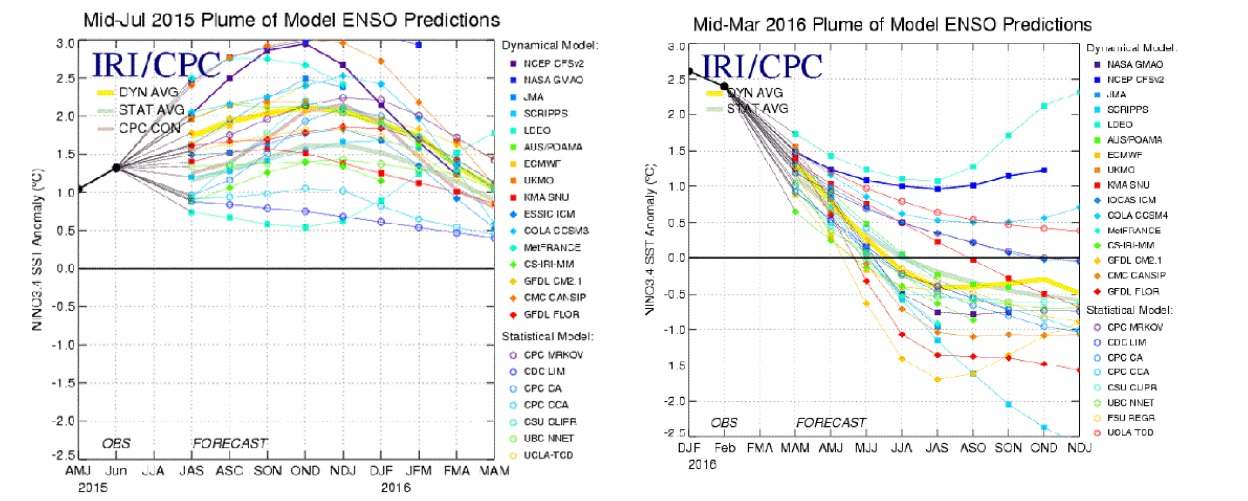

Figure 1: *Shown are examples of modeled sea surface temperature (SST) projections prior to the peak SST for the current event (left) and after the peak (right).*

Experimental Design

Model Configuration

- DOE Accelerated Climate Modeling for Energy (ACME) model version 0.3
- 1-degree (ne30np4) F-compset configuration: Active atmosphere (CAM5-SE) and land (ALM) 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 estimated 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

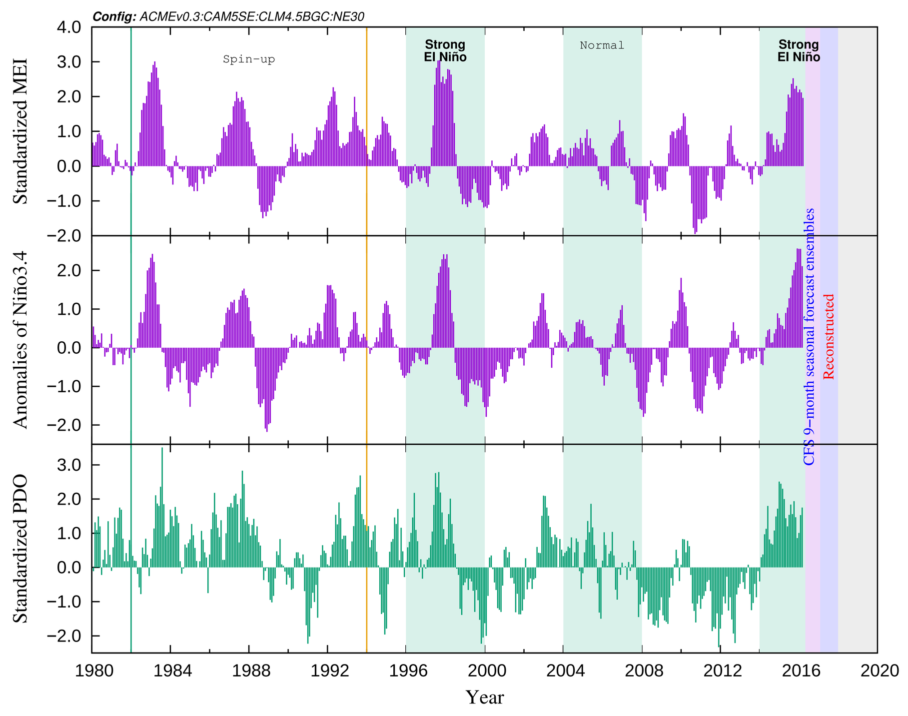

Figure 2: *Spin up and simulation experiments are shown with respect to the standardized Multivariate ENSO Index (MEI), temperature anomalies of the Niño3.4 region, and the standardized Pacific Decadal Oscillation index.*

Preliminary Results

- The ACME v0.3 model was built and tested on Titan (OLCF), Cori and Edison (NERSC).
- The F-compset configuration was tested and performance optimized at both ne30 ($\sim 1^\circ$) and ne120 ($\sim \frac{1}{4}^\circ$) resolutions. Given the queue wait times for moderately sized jobs and limited performance, we decided that ne120 was computationally prohibitive.
- The 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 simulation cycled 13 times (169 years), yielding a 10-y average NEE of ~ 0 Pg C y^{-1} and an absolute value of NEE of ~ 2 Pg C y^{-1}
- A 25 year transient simulation through 2020 was performed and is analyzed below

Carbon Cycle Equilibrium

As shown in Figure 3, the global and tropical average net ecosystem exchange (NEE) is approaching zero, indicating that the terrestrial carbon pools are adjusting toward an equilibrium state.

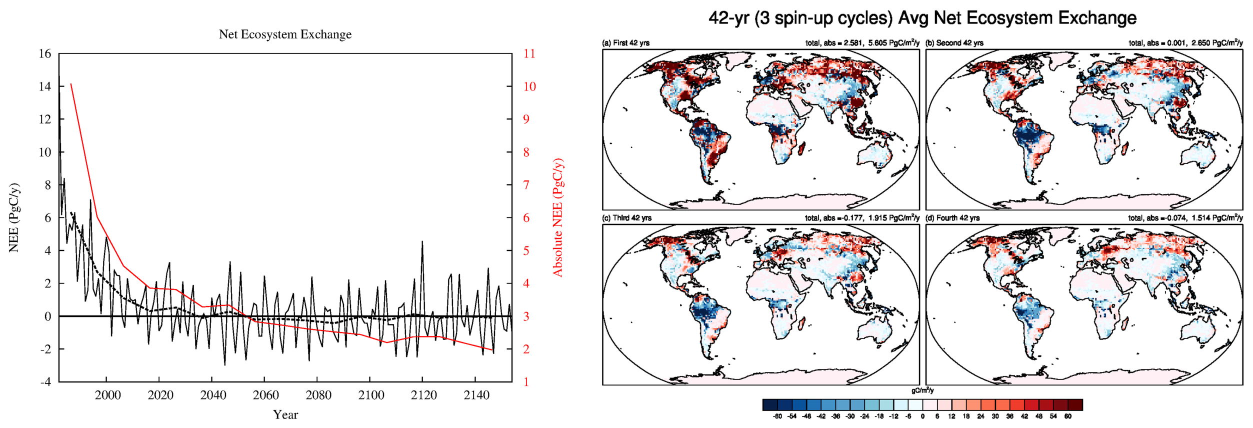

Figure 3: *The plot (left) shows the net ecosystem exchange (NEE) (solid black), the 5-y running mean of NEE (dashed black), and the absolute value of NGEE (solid red) globally from cycling the 1982–1994 OISSTv2 forcing. The years shown on the x-axis are just accumulated during the cycling. The maps (right) show four 42-y mean NEE distributions from the spin up simulation.*

Model Patterns for the 1997–1998 El Niño Event

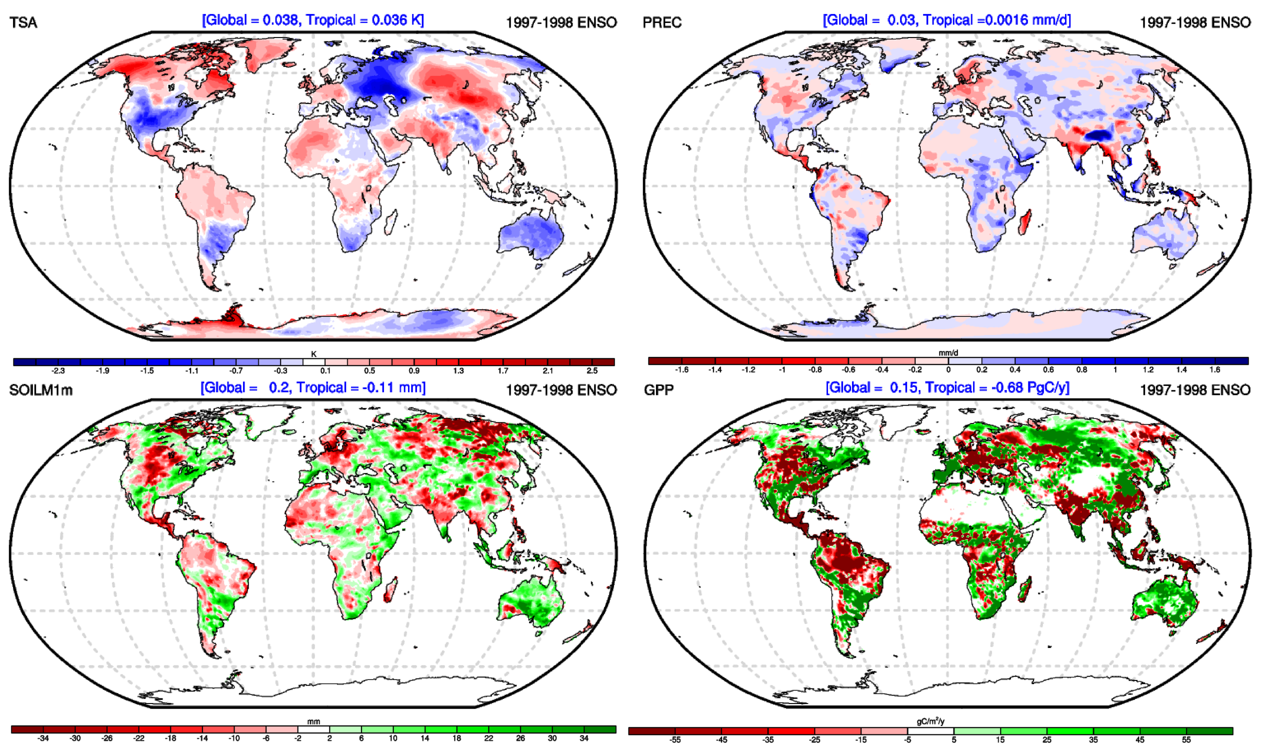

Figure 4: *Anomaly maps for the 1997–1998 ENSO for the 2-m air temperature (TSA), precipitation (PREC), soil moisture to 1 m (SOILM1m), and gross primary production (GPP) are calculated by subtracting the 1982–2015 mean (climatology) variable from the 1997–1998 mean variable. While the model exhibited global increases in soil moisture and GPP, in the tropics it projected a mean decrease in soil moisture of 0.11 mm and a mean reduction in GPP of 0.68 Pg C y^{-1}.*

Model Patterns for the 2014–2016 El Niño Event

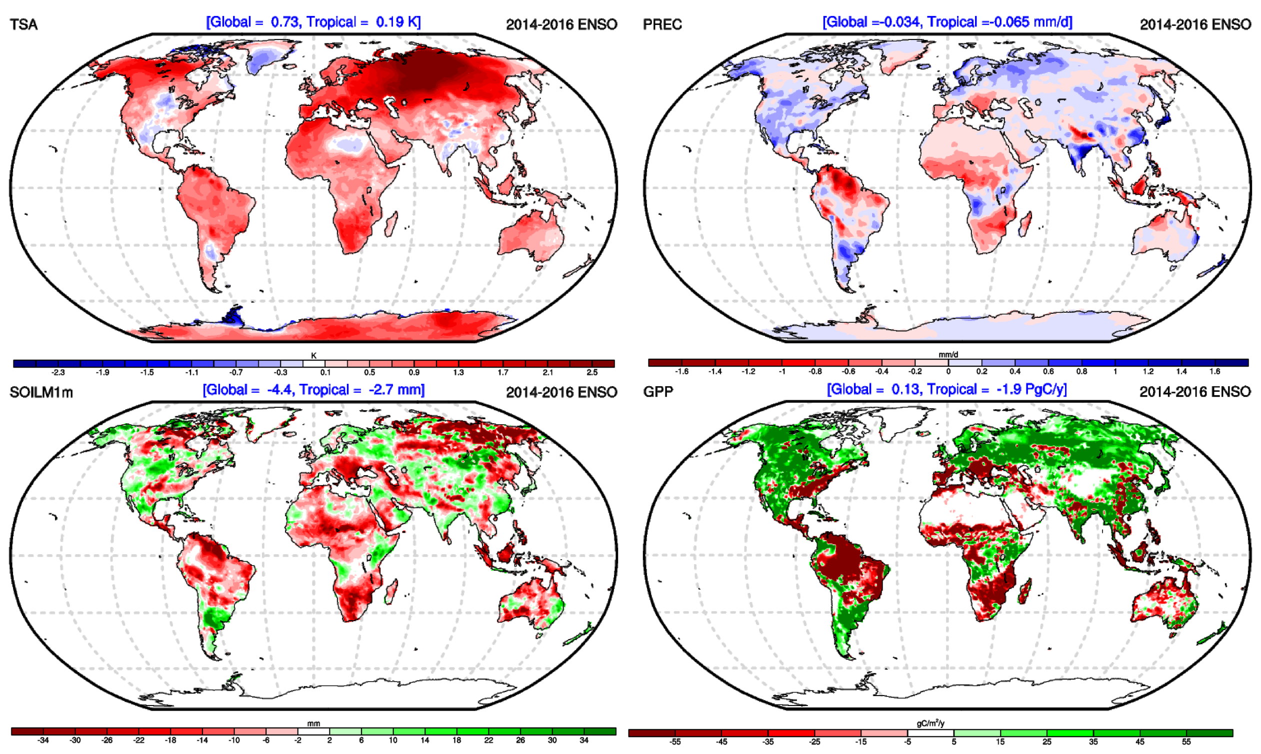

Figure 5: *Anomaly maps for the 2014–2016 ENSO for the 2-m air temperature (TSA), precipitation (PREC), soil moisture to 1 m (SOILM1m), and gross primary production (GPP) are calculated by subtracting the 1982–2015 mean (climatology) variable from the 2014–2016 mean variable. The model exhibited large scale increases in global 2-m air temperature over land of 0.73°C and reduced precipitation globally (-0.034 mm/d) and in the tropics (-0.065 mm/d). Tropical soil moisture was projected to decrease by 2.7 mm and tropical GPP was reduced by 1.9 Pg C y^{-1}.*

Model Patterns for the 2005 Amazon Drought

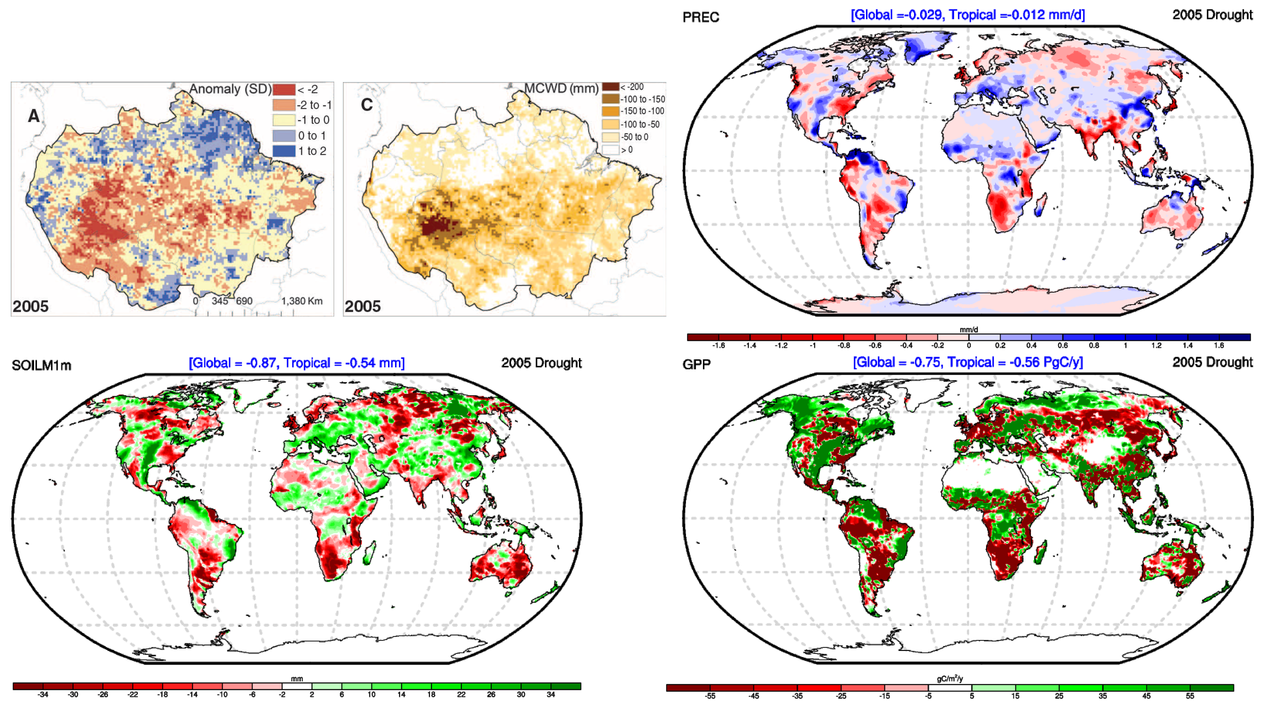

Figure 6: *The model appears to capture the overall pattern of drought in the Amazon during 2005. The upper left figures are (A) the satellite-derived standardized anomalies for dry-season rainfall and (C) the difference in the 12-month (October to September) maximum climatological water deficit (MCWD) from the decadal mean (excluding 2005 and 2010) for the Amazon basin from Simon et al. (2010). The soil moisture anomaly from the model correlates well with (A) and the GPP anomaly correlates well with (C).*

Model Patterns for the 2010 Amazon Drought

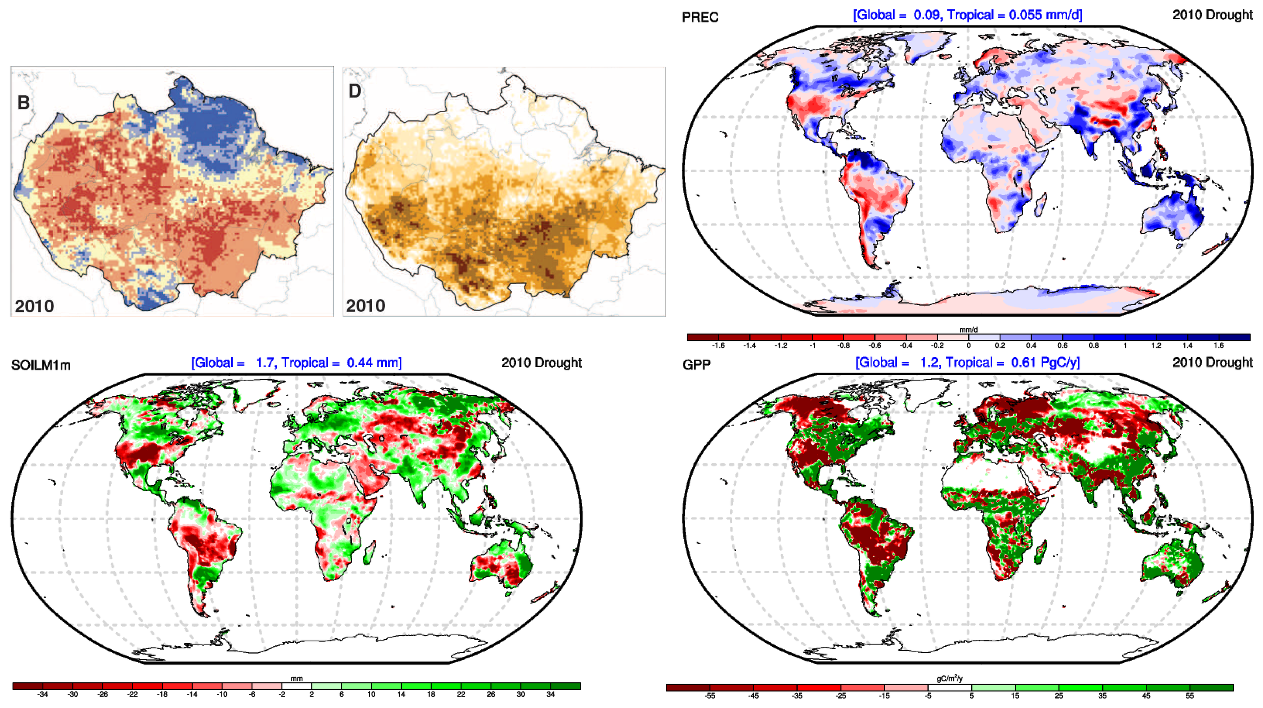

Figure 7: *The model appears to capture the overall pattern of drought in the Amazon during 2010. The upper left figures are (B) the satellite-derived standardized anomalies for dry-season rainfall and (D) the difference in the 12-month (October to September) maximum climatological water deficit (MCWD) from the decadal mean (excluding 2005 and 2010) for the Amazon basin from Simon et al. (2010). The soil moisture anomaly from the model correlates well with (B) and the GPP anomaly correlates well with (D).*

Summary and Next Steps

- Analysis of spin up simulation indicated that land carbon pools approached equilibrium when driven by OISSTv2 sea surface temperatures.
- 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.
- The first run through the transient simulation showed expected anomalies in outgoing longwave radiation (not shown) and precipitation, with expected ecosystem responses in leaf area index (not shown), stomatal conductance (not shown), and GPP.
- Daily mean quantities were saved from simulations, including PFT-level output for many of the variables for detailed analysis.
- In a second run through the transient simulation, we will save 3-hourly coupler history for use with future offline (I-compset) simulations for model development and testing.
- Analysis of the spatial patterns of soil moisture and GPP for ENSO events will be compared with observations. Those for the 2005 and 2010 Amazon droughts are consistent with data reported by Simon et al. (2011).

References

Lewis, Simon L., Paulo M. Brando, Oliver L. Phillips, Geertje M. F. van der Heijden and Daniel Nepstad (2011), The 2010 Amazon drought, *Science*, 331(6017):554, doi:10.1126/science.1200807.

Acknowledgments

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