Remote SST Forcing and Local Land-Atmosphere Moisture Coupling as Drivers of Amazon Temperature and Carbon Cycle Variability

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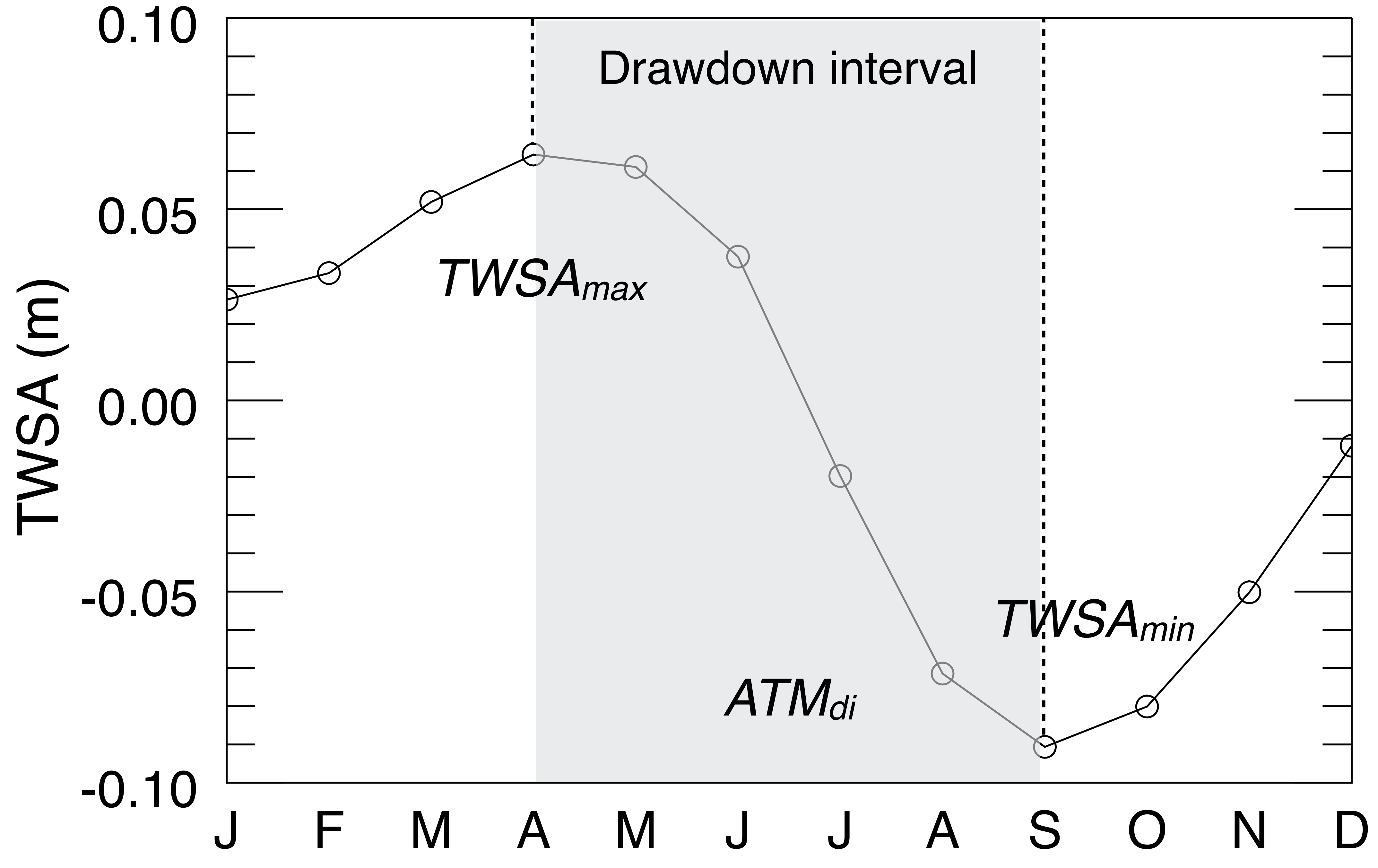
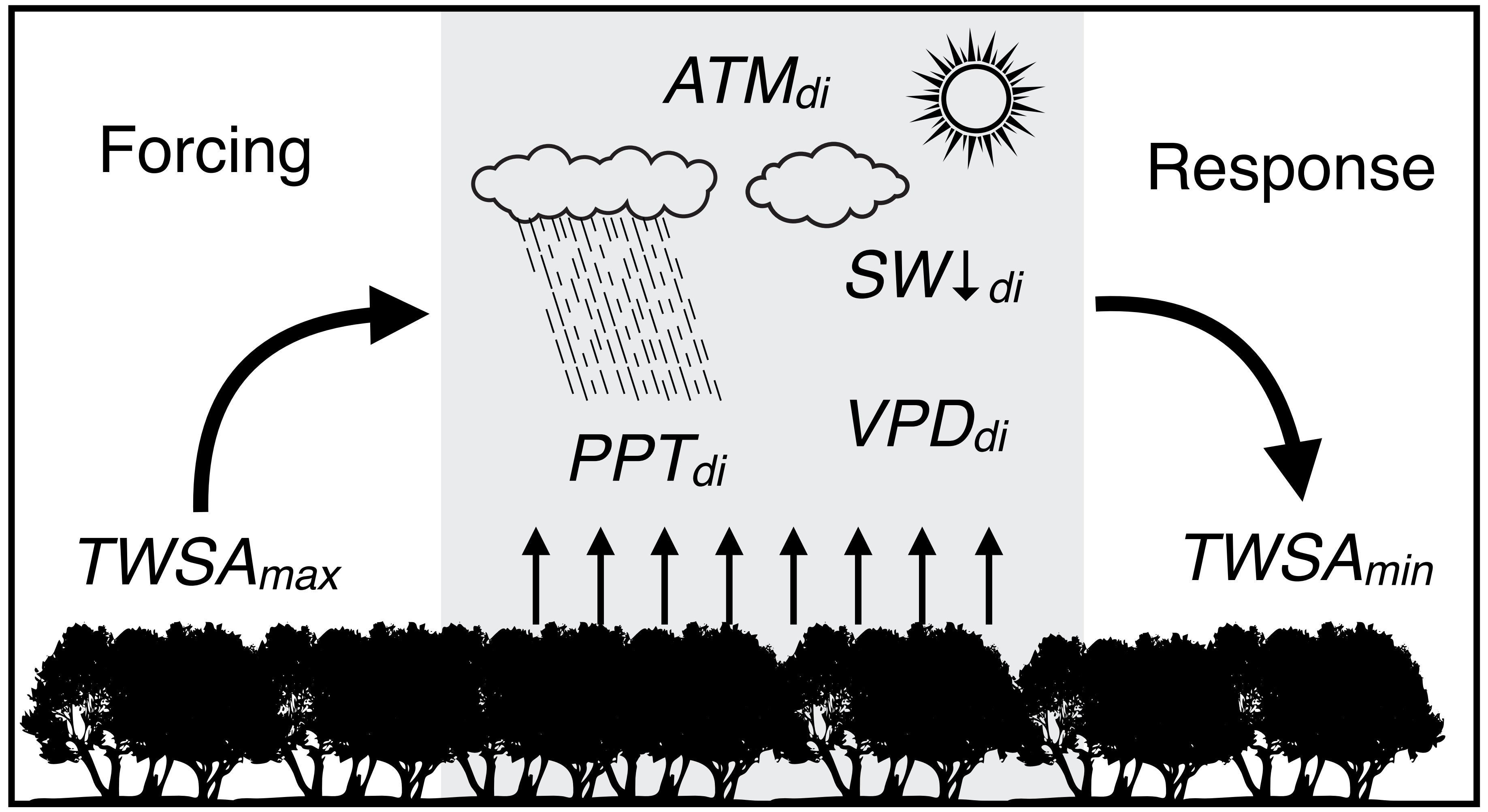
March 23, 2017

Motivation: Remote SST forcing or local land–atmosphere coupling?

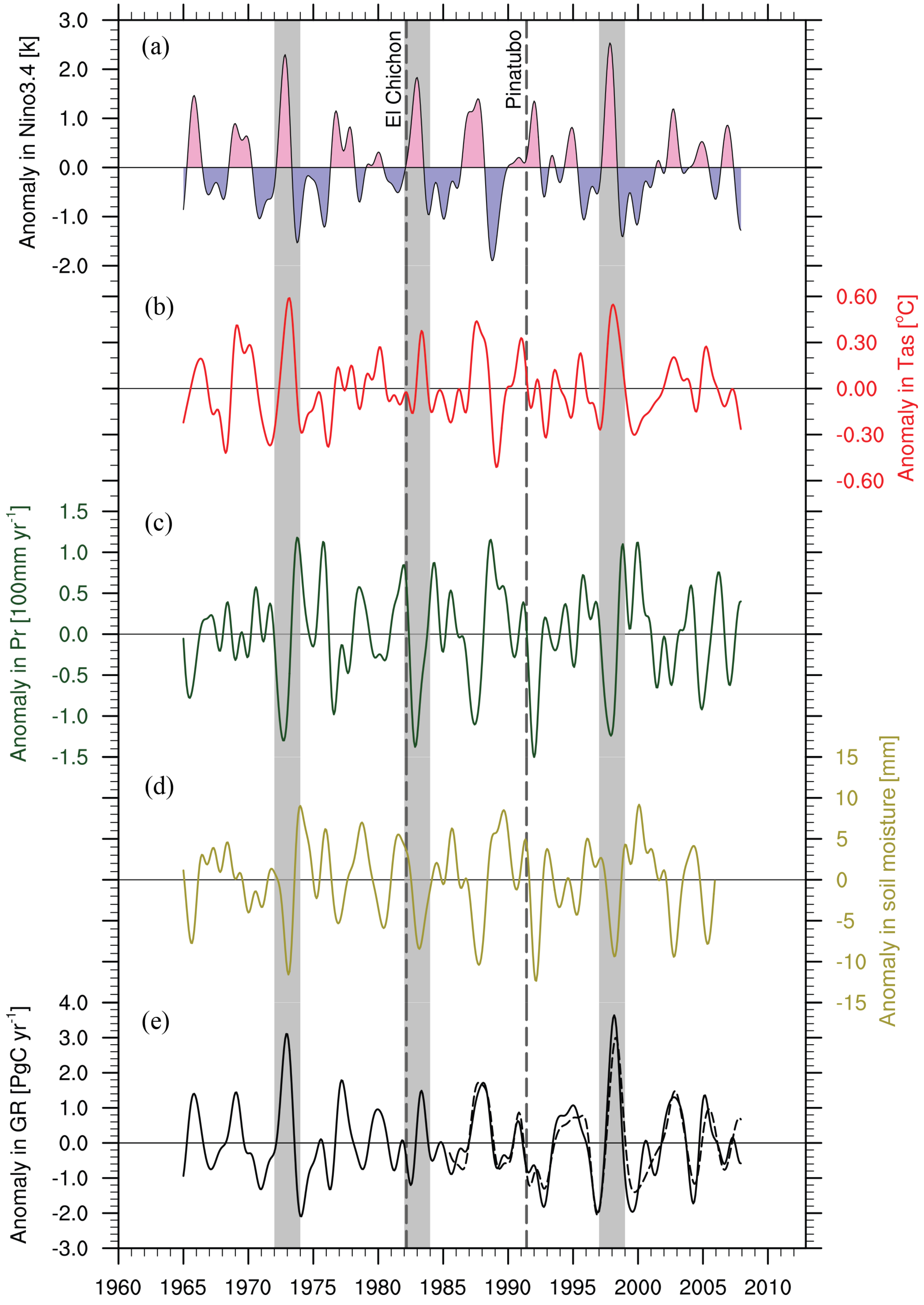




- How much are atmospheric conditions influenced by antecedent terrestrial water storage anomalies (TWSAs), and how much do they influence subsequent TWSAs?
- Benchmark land—atmosphere coupling strength in Earth system models using satellite observations
- Metrics designed for monthly TWSA observations from GRACE and atmospheric observations from other satellite platforms
- Correlation coefficients detect direct influence of land-atmosphere interactions combined with covariability due to remote SST forcing

Levine, P.A., J.T. Randerson, S.C. Swenson, and D.M. Lawrence, **2016** Evaluating the strength of the land--atmosphere moisture feedback in Earth system models using satellite observation. *Hydrology and Earth System Sciences* 20, 4837-4856 doi:10.5194/hess-2016-206

Background: ENSO effects on Amazon land surface climate



Wang *et al.*, 2016
Biogeosciences

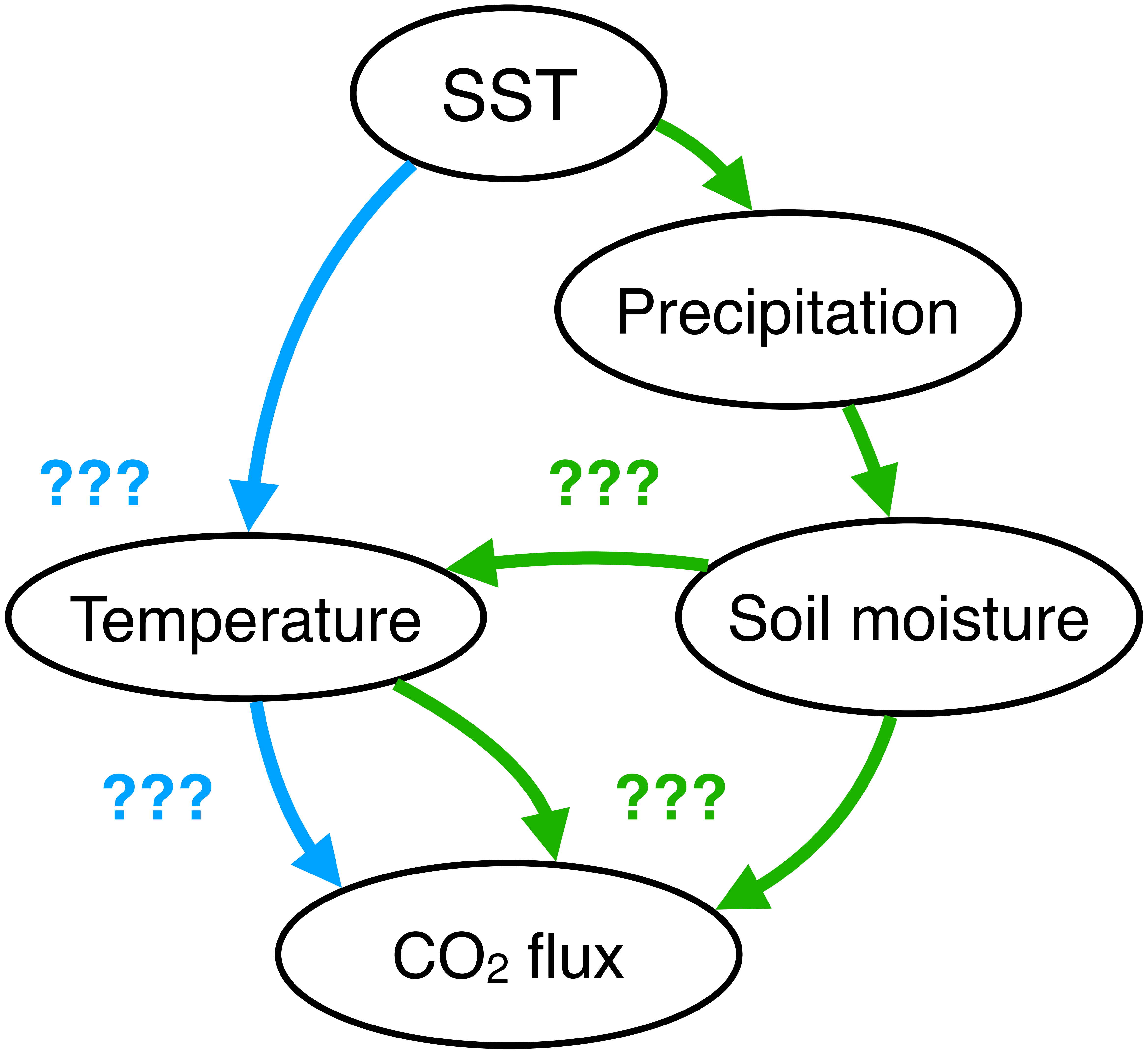
- El Niño-Southern Oscillation (ENSO) dominates interannual climate variability of the tropical land surface

	SST (Nino3.4)	Surf. air temperature	Precipitation and SM	CO_2 sink
El Niño	↑	↑	↓	↓
La Niña	↓	↓	↑	↑

- Some studies attribute CO_2 anomalies primarily to temperature variation [Cox *et al*, 2013; Piao *et al*, 2013; Wang *et al*, 2013; Wang *et al*, 2014]
- Other studies attribute CO_2 anomalies primarily to precipitation [Qian *et al*, 2011; Keppel-Aleks *et al*, 2014; Wang *et al*, 2016]
- Amazon is known as a “hot spot” of land–atmosphere coupling [Lee *et al*, 2011; Ma *et al*, 2011; Sun and Wang, 2013]

Hypothesis: Land–atmosphere coupling as a driver of Amazon ENSO variability

- SST anomalies directly affect temperature anomalies in the Amazon
- SST anomalies also affect soil moisture in the Amazon via precipitation anomalies
- SST indirectly affects Amazon temperature via land–atmosphere coupling
- Land–atmosphere coupling temperature signal contributes to CO_2 fluxes
- Soil moisture contribution strongest during the dry season

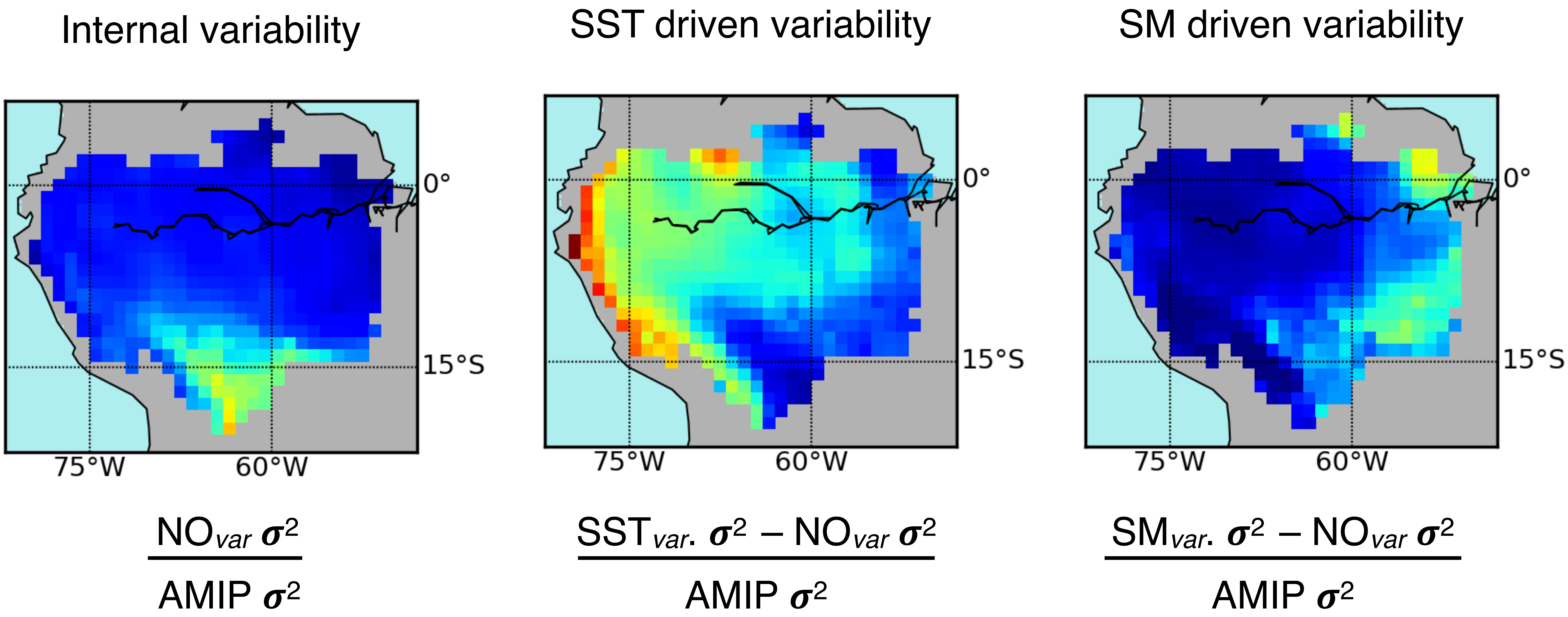


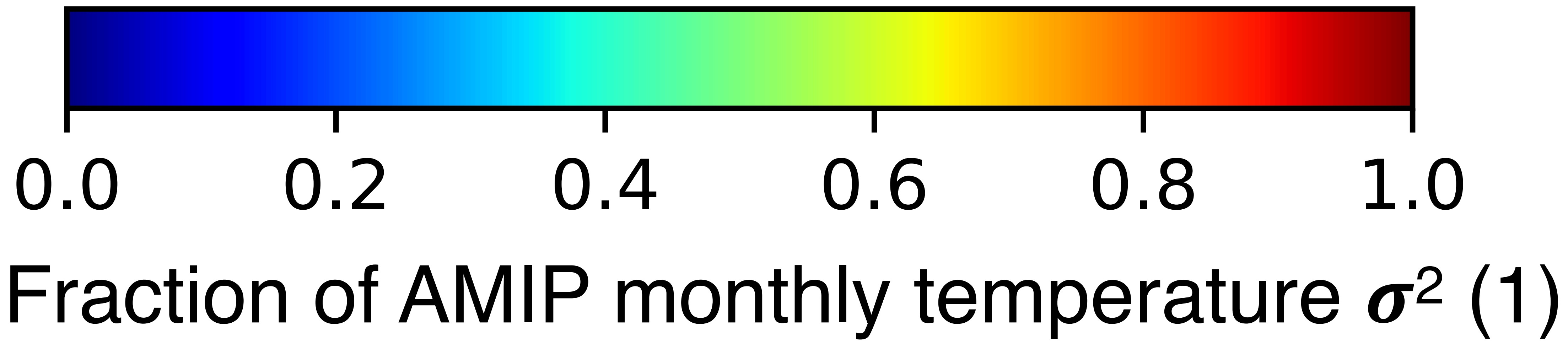
Methods: A mechanism denial experiment with an Earth System Model

- Energy Exascale Earth System Model (E3SM), v0.3 with CAM5-SE and CLM4.5-BGC
- Prescribed SST from **1982–2016** from NOAA Optimum Interpolation (OISST) v2
- Modified CLM to optionally read and write soil moisture at each time step
- Separate the direct influence of SST forcing from the indirect influence of SST-forced soil moisture variability

	SST	SM	Purpose
AMIP	Prescribed from OISST	Interactive from CLM	Control run; SM recorded at each time step
SST*var*	Prescribed from OISST	Climatology from AMIP	SST variability absent any SM variability
SM*var*	Climatology from OISST	Prescribed from AMIP	SM variability absent any SST variability
NO*var*	Climatology from OISST	Climatology from AMIP	Internal variability absent any SM and SST variability

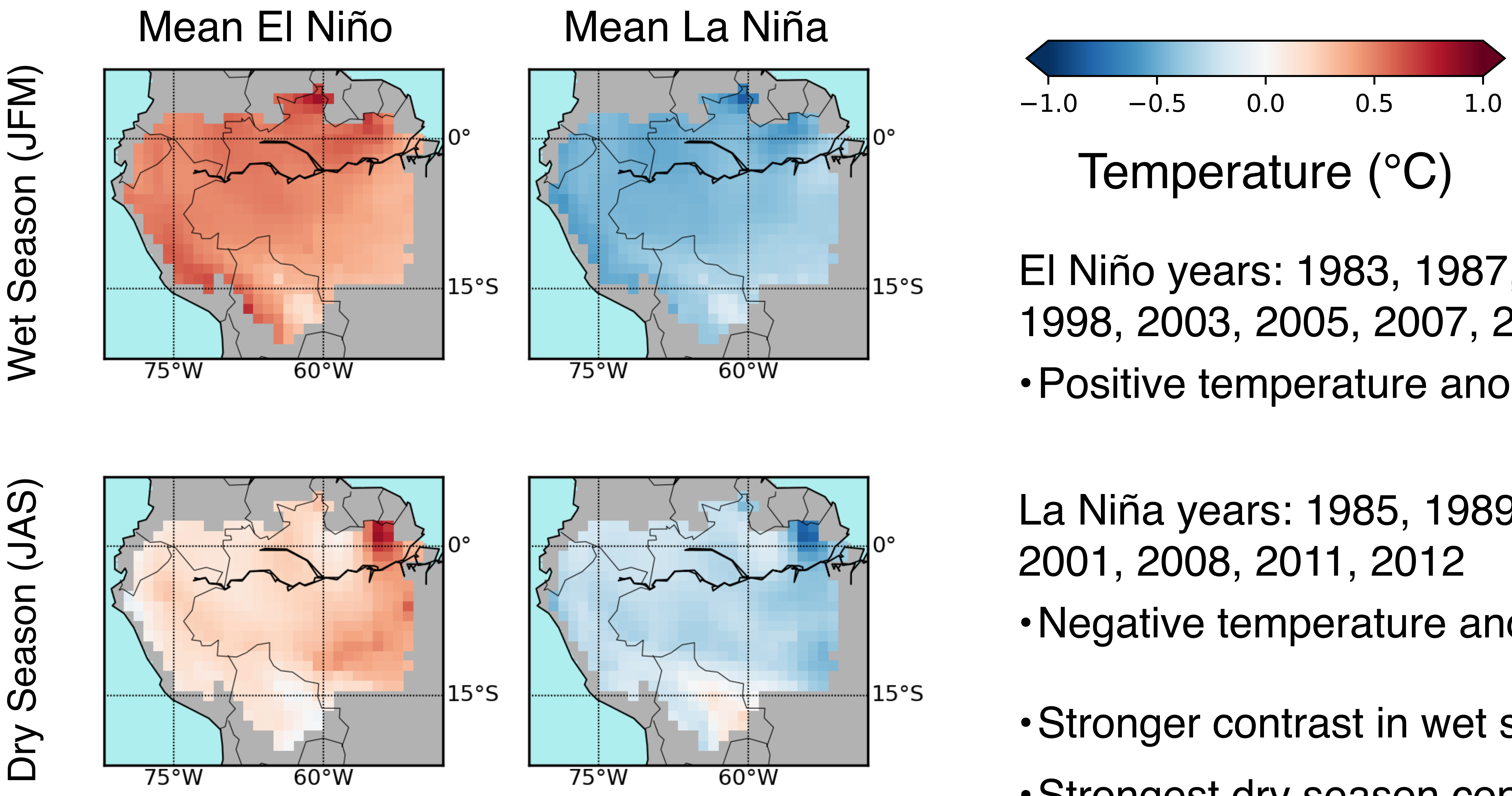
Drivers of interannual temperature variability in E3SM





- Internal variability in the south
- SM driven variability in the east

El Niño and La Niña Amazon surface air temperature anomalies



El Niño years: 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2005, 2007, 2010, 2015, 2016

- Positive temperature anomaly

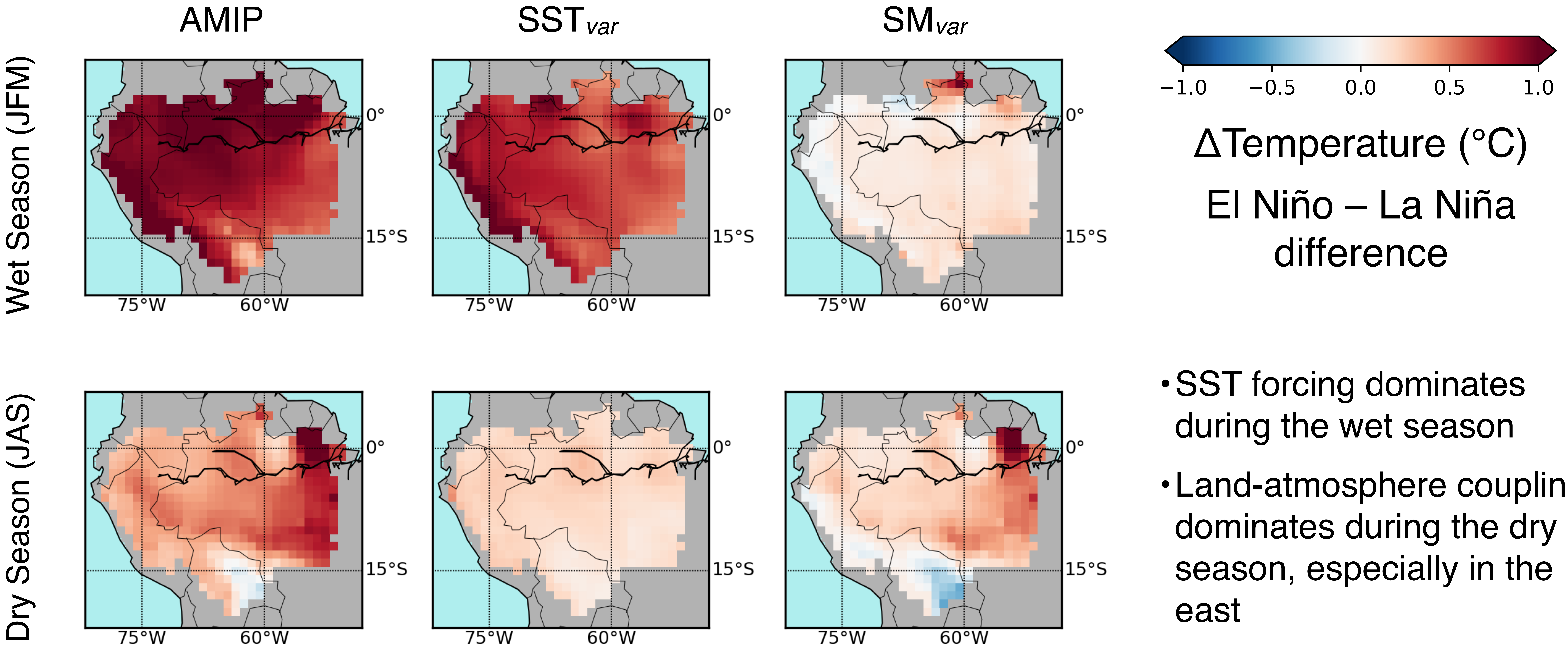
La Niña years: 1985, 1989, 1996, 1999, 2000, 2001, 2008, 2011, 2012

- Negative temperature anomaly

- Stronger contrast in wet season

- Strongest dry season contrast in the east

Difference between El Niño and La Niña Amazon surface air temperature anomalies

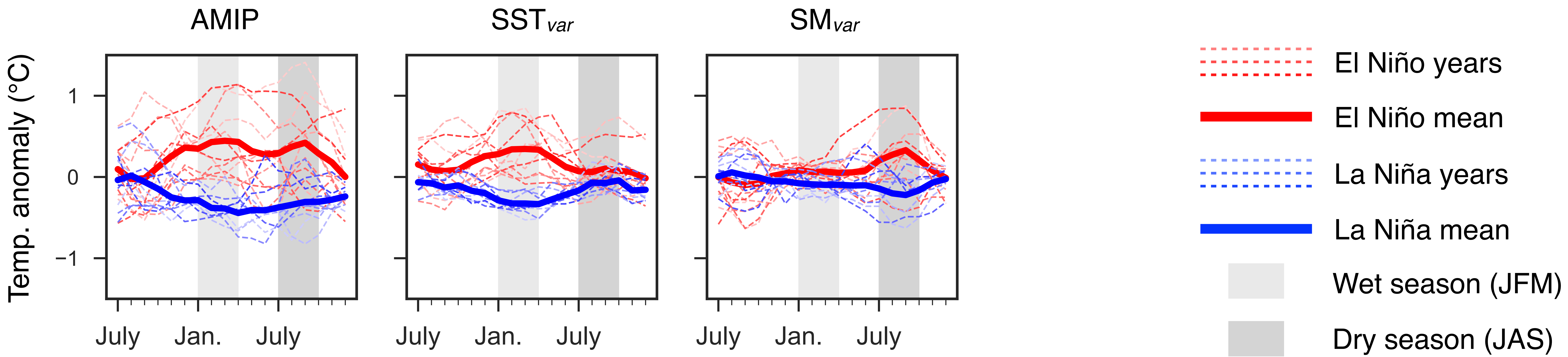


ΔTemperature (°C)

El Niño – La Niña difference

- SST forcing dominates during the wet season
- Land-atmosphere coupling dominates during the dry season, especially in the east

El Niño and La Niña temperature anomalies for the Amazon Basin, East of 60°W

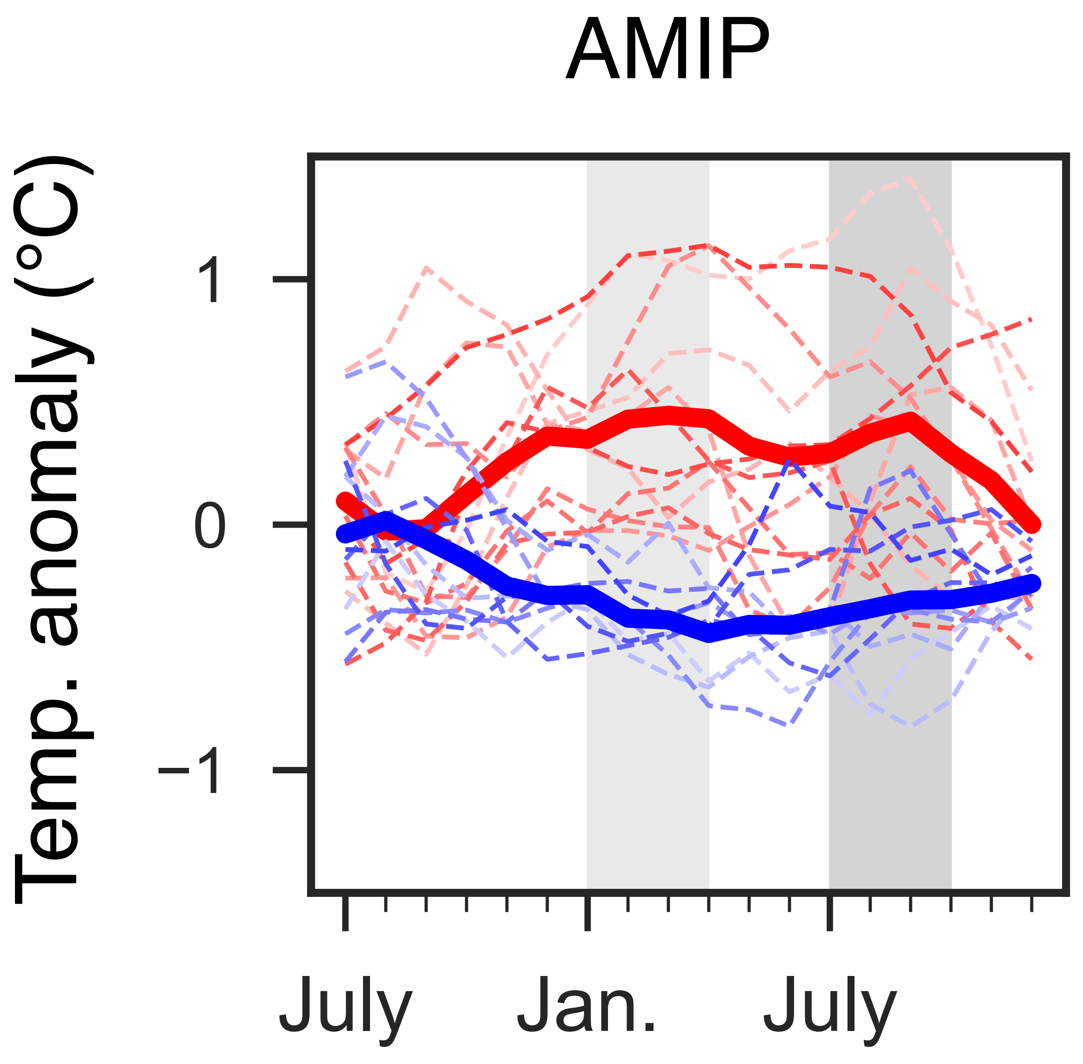


El Niño – La Niña difference

	AMIP	SST$_{var}$	(% of AMIP)	SM$_{var}$	(% of AMIP)
Wet seas (JFM)	0.81	0.67	(83%)	0.15	(19%)
Dry seas (JAS)	0.71	0.13	(18%)	0.47	(66%)

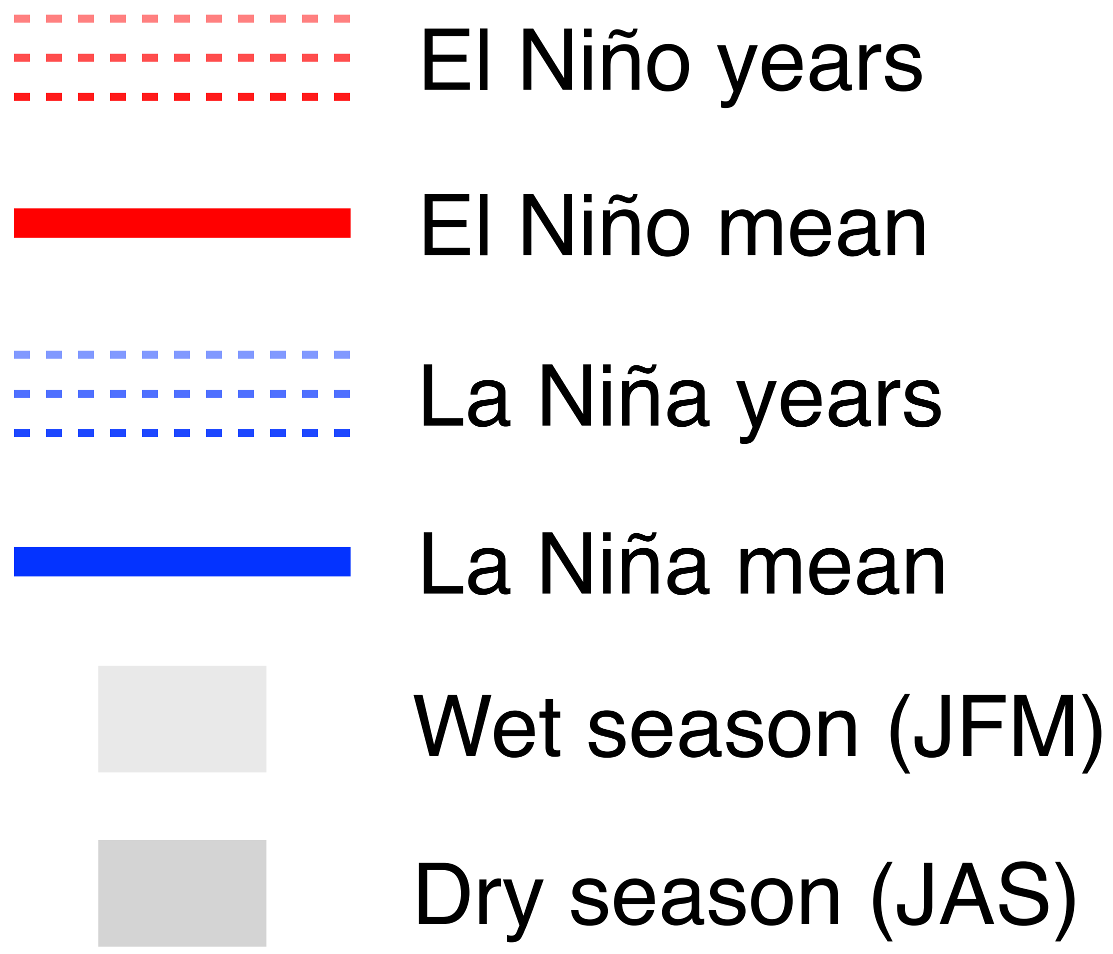
- SST forcing dominates during wet season
- Land-atmosphere coupling dominates during dry season

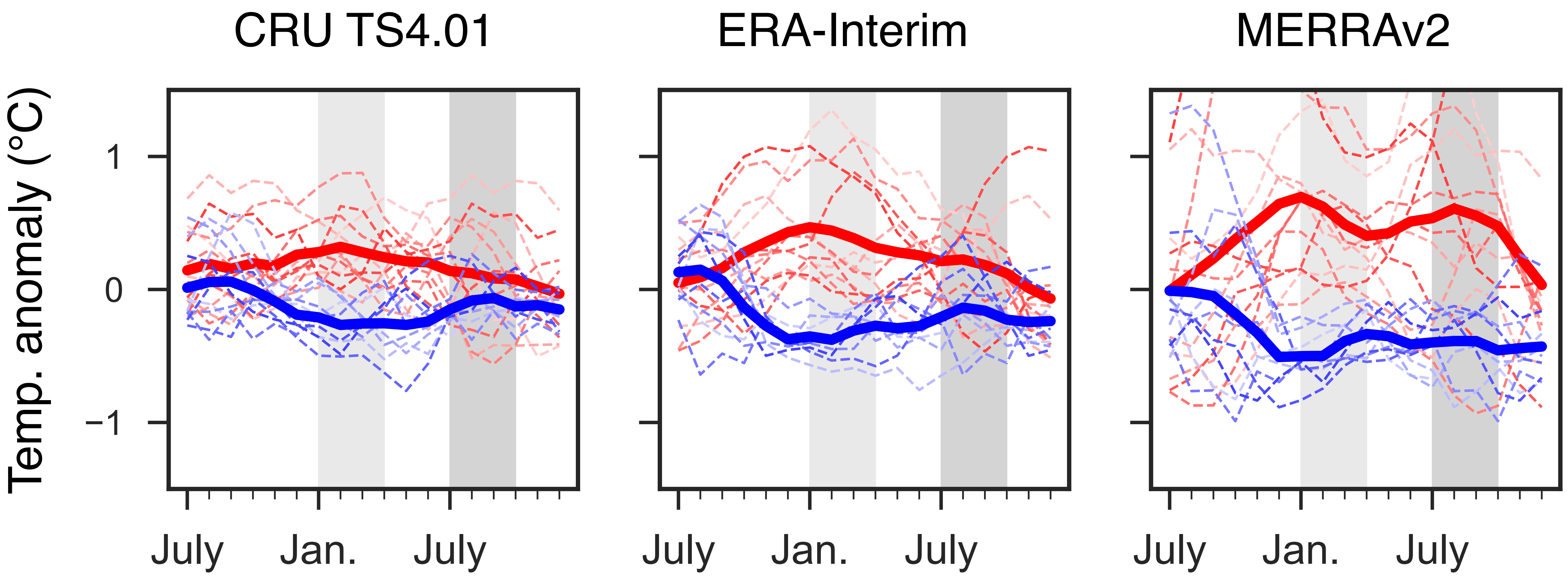
Benchmark E3SM temperature anomalies with observations and reanalysis



El Niño – La Niña difference

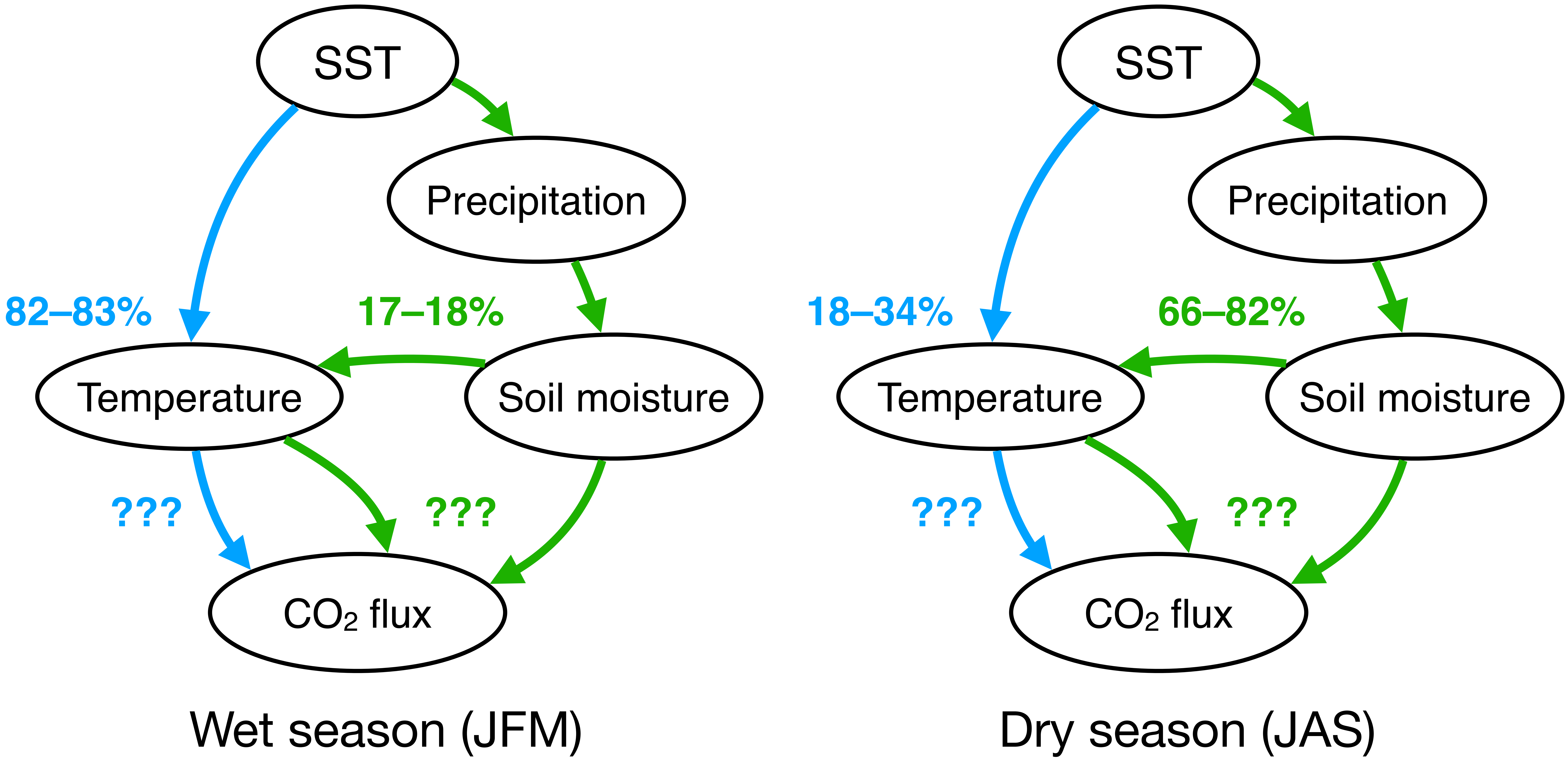
	AMIP	CRU	ERA	MERRA
Wet (JFM)	0.81	0.59	0.82	1.12
Dry (JAS)	0.71	0.20	0.37	1.00
Dry / Wet	0.88	0.34	0.45	0.89





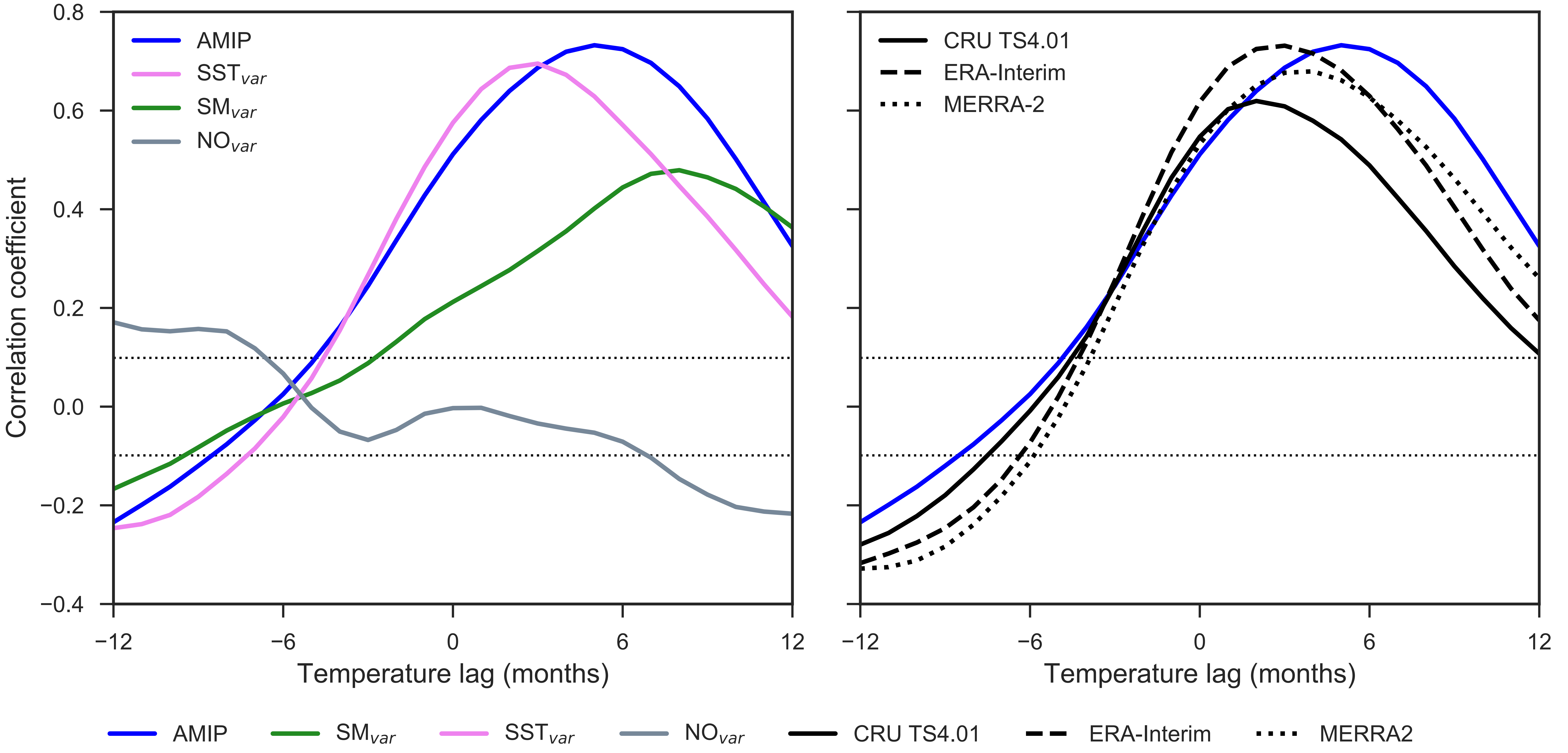
- E3SM may overestimate land surface response to ENSO
- E3SM precursors (CCSM/CAM) overestimate land–atmosphere coupling strength [Zeng *et al*, 2010; Mei and Wang, 2012]

ENSO driven temperature variability in eastern Amazon

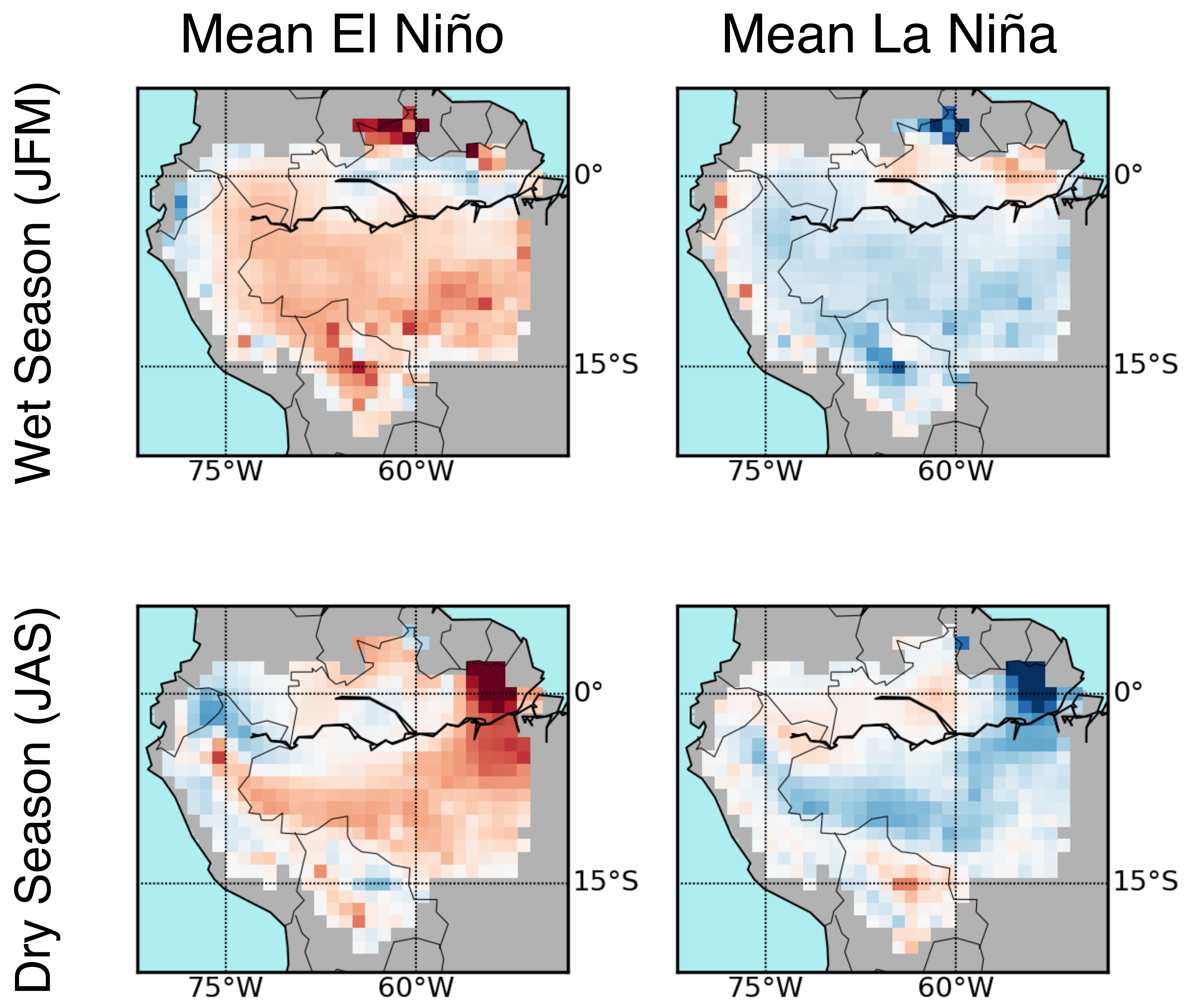


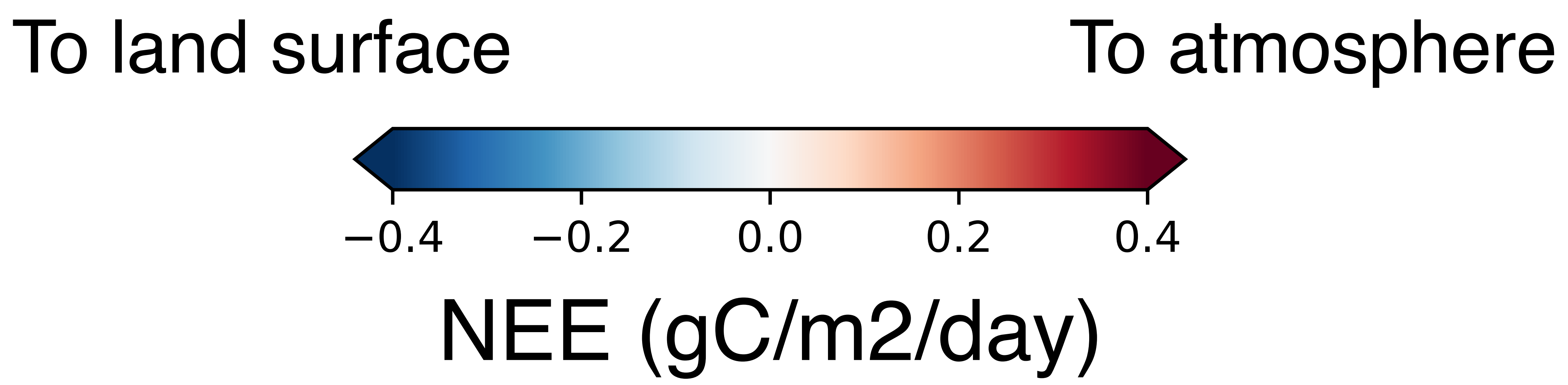
Soil moisture delays and intensifies the effect of SST on temperature

…but observations and reanalysis suggests this may be overestimated in E3SM



El Niño and La Niña net ecosystem exchange (NEE) anomalies





El Niño years: 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2005, 2007, 2010, 2015, 2016

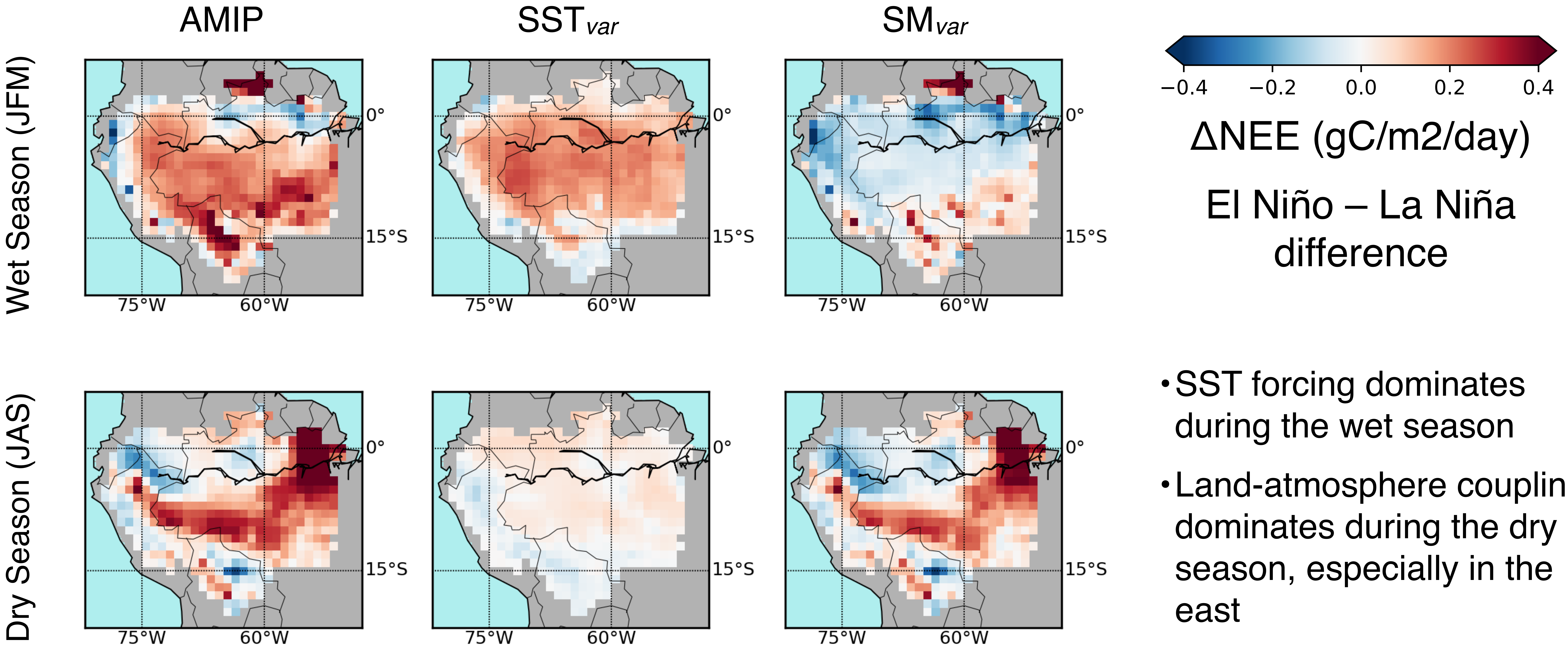
- Source of carbon to atmosphere

La Niña years: 1985, 1989, 1996, 1999, 2000, 2001, 2008, 2011, 2012

- Sink of carbon to land surface

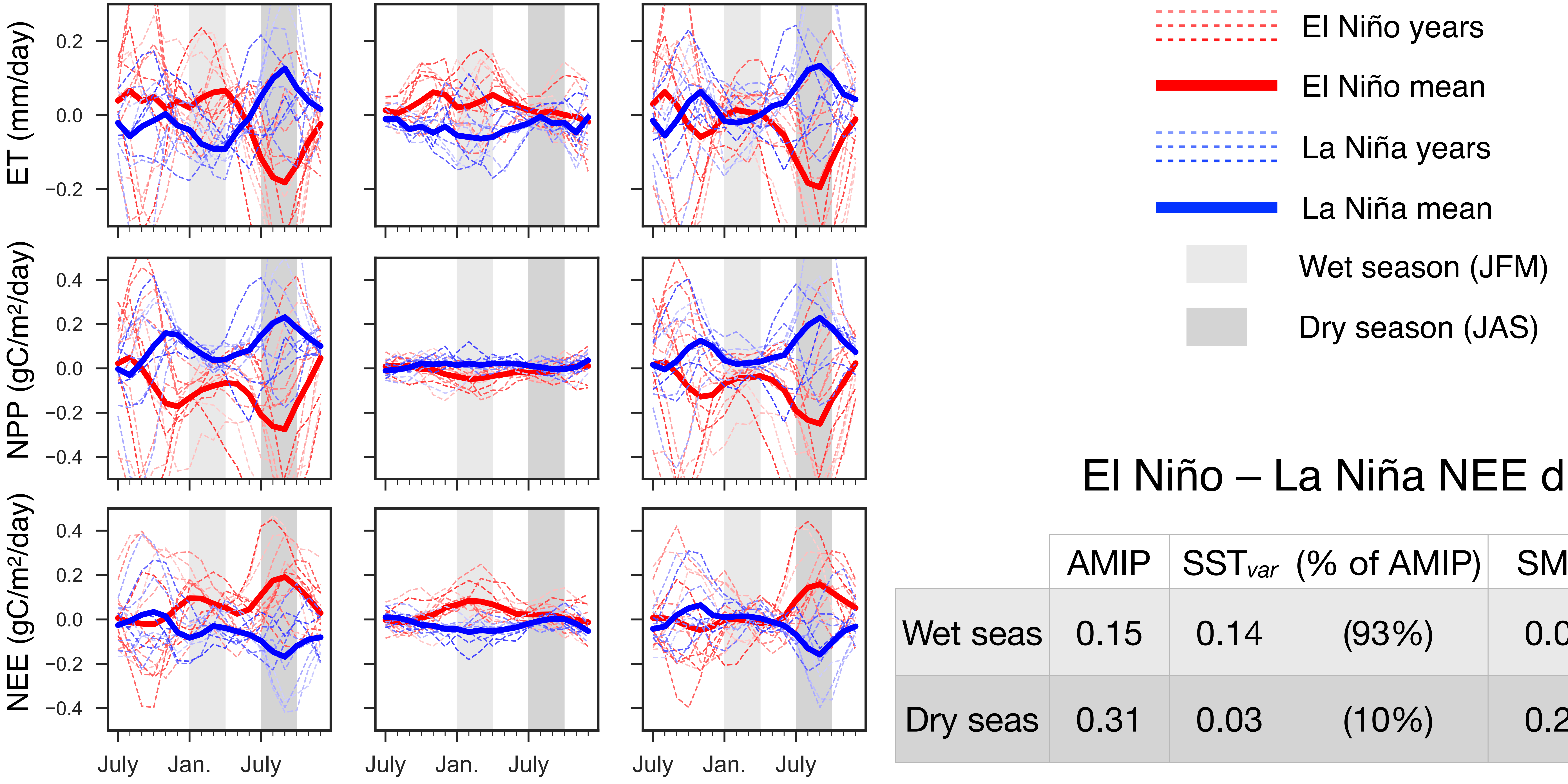
- Strongest contrast in eastern Amazon dry season

Difference between El Niño and La Niña NEE anomalies



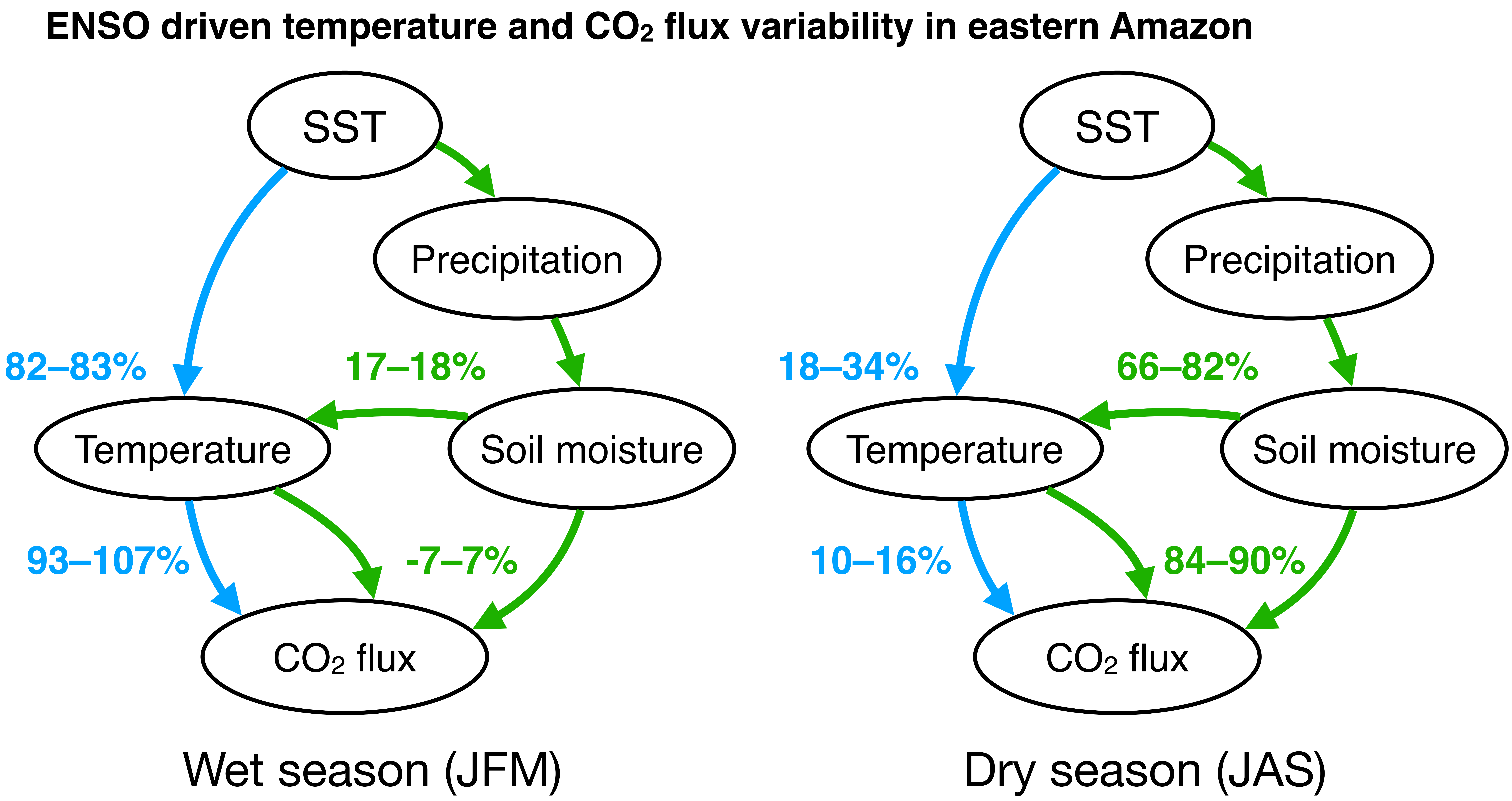
- SST forcing dominates during the wet season
- Land-atmosphere coupling dominates during the dry season, especially in the east

El Niño and La Niña NEE anomalies for the Amazon Basin, East of 60°W



El Niño – La Niña NEE difference

	AMIP	SST_{var}	(% of AMIP)	SM_{var}	(% of AMIP)
Wet seas	0.15	0.14	(93%)	0.01	(-7%)
Dry seas	0.31	0.03	(10%)	0.26	(84%)


ENSO driven temperature and CO_2 flux variability in eastern Amazon
SST
Precipitation
82–83%
17–18%
Temperature
Soil moisture
93–107%
-7–7%
CO_2 flux
Wet season (JFM)
SST
Precipitation
18–34%
66–82%
Temperature
Soil moisture
10–16%
84–90%
CO_2 flux
Dry season (JAS)

Conclusions

- Land–atmosphere coupling intensifies and extends the Amazon temperature response to ENSO in E3SM, particularly in the east
- E3SM may overestimate land–atmosphere moisture coupling in this region, but observations and reanalyses are poorly constrained
- Land–atmosphere moisture coupling likely amplifies ENSO driven NEE variations during dry season
- Partitioning studies separating temperature and hydrologic controls on NEE should consider effects of hydrology on temperature

Funding support from NASA ESS Fellowship NNX16AO38H and the Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computing (RUBISCO) Scientific Focus Area in the US DOE Office of Science

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