Spatio-Temporal Sensing Data Causality Analytics

An analysis of ENSO’s global impacts

TEAM 4:
Hua Song (UMBC), Jing Tian (Towson University), Jingfeng Huang (NOAA)

Advisors:
Dr. Jianwu Wang (UMBC) and Dr. Zhibo Zhang (UMBC)

NSF CyberTraining Interdisciplinary Program in High Performance Computing, Atmospheric Physics & Big Data
University of Maryland, Baltimore County, hpcf.umbc.edu

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OUTLINE

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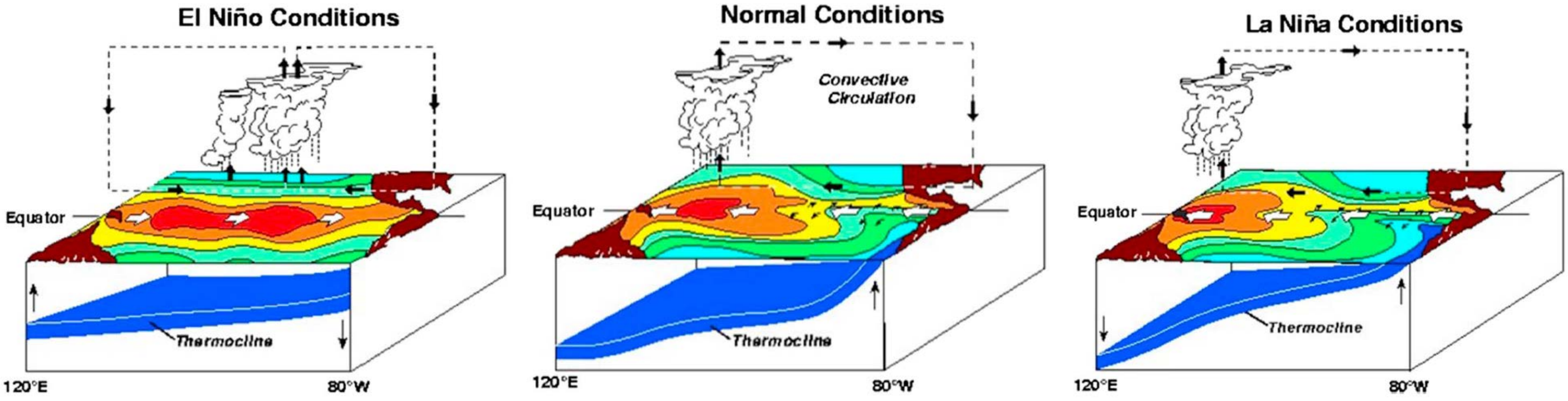
2. PART II: Observational & Reanalysis Datasets
3. PART III: Community Atmospheric Model
4. PART IV: Granger Causality Model
5. PART V: Methodology
6. PART VI: Results
7. PART VII: Conclusions
8. PART VIII: Future Work

PART I: Background & Hypothesis

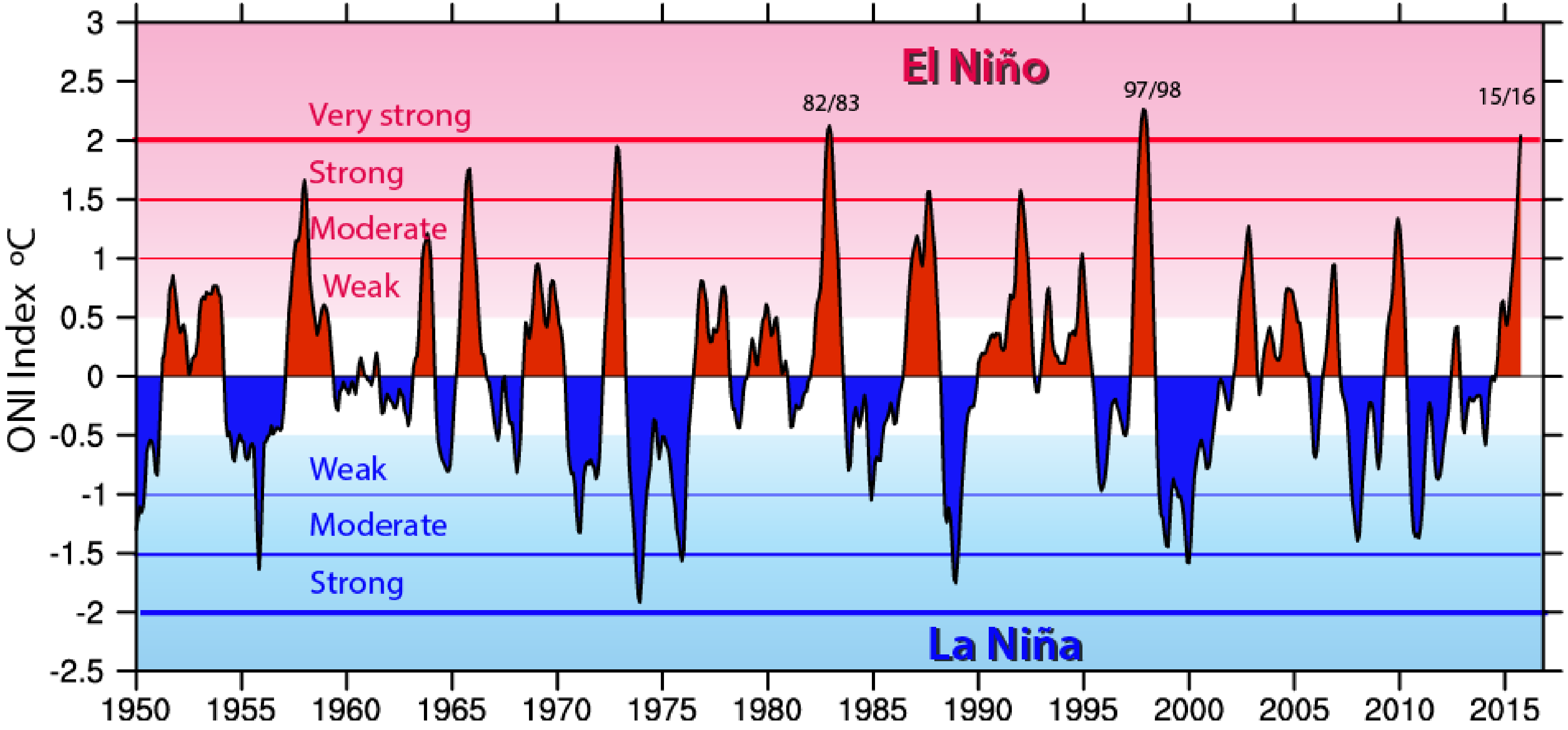
What is ENSO? --- Essentially Equatorial Pacific SST Anomaly



Schematic diagrams showing the tropical weather and oceanic condition across the equator during canonical El Niño (left) and canonical La Niña (right)..

In Yeh et al. (2017, Reviews of Geophysics) with Figure courtesy of the NOAA PMEL.

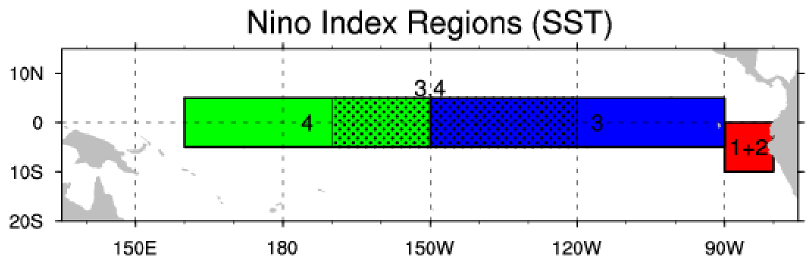
ENSO Index and El Nino Years



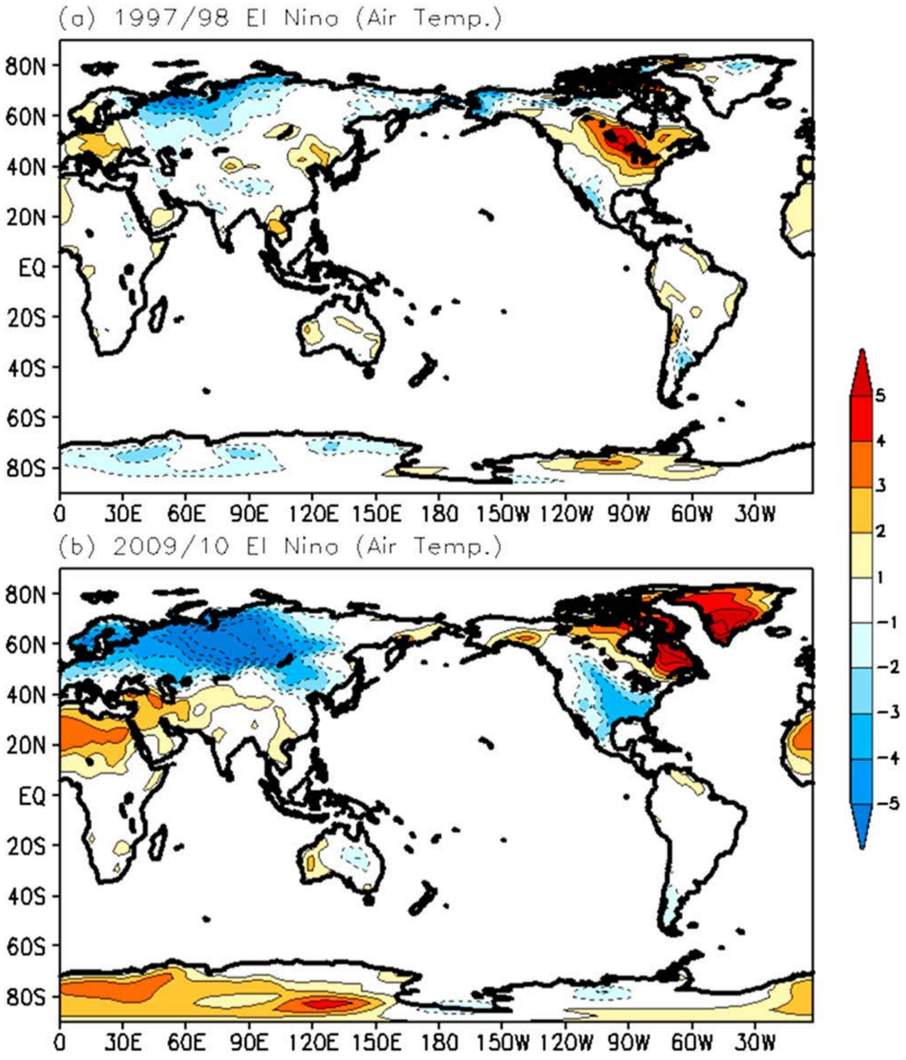
ONI (5N-5S, 170W-120W): The ONI uses the same region as the Niño 3.4 index. The ONI uses a 3-month running mean, and to be classified as a full-fledged El Niño or La Niña, the anomalies must exceed +0.5C or -0.5C for at least five consecutive months. This is the operational definition used by NOAA.

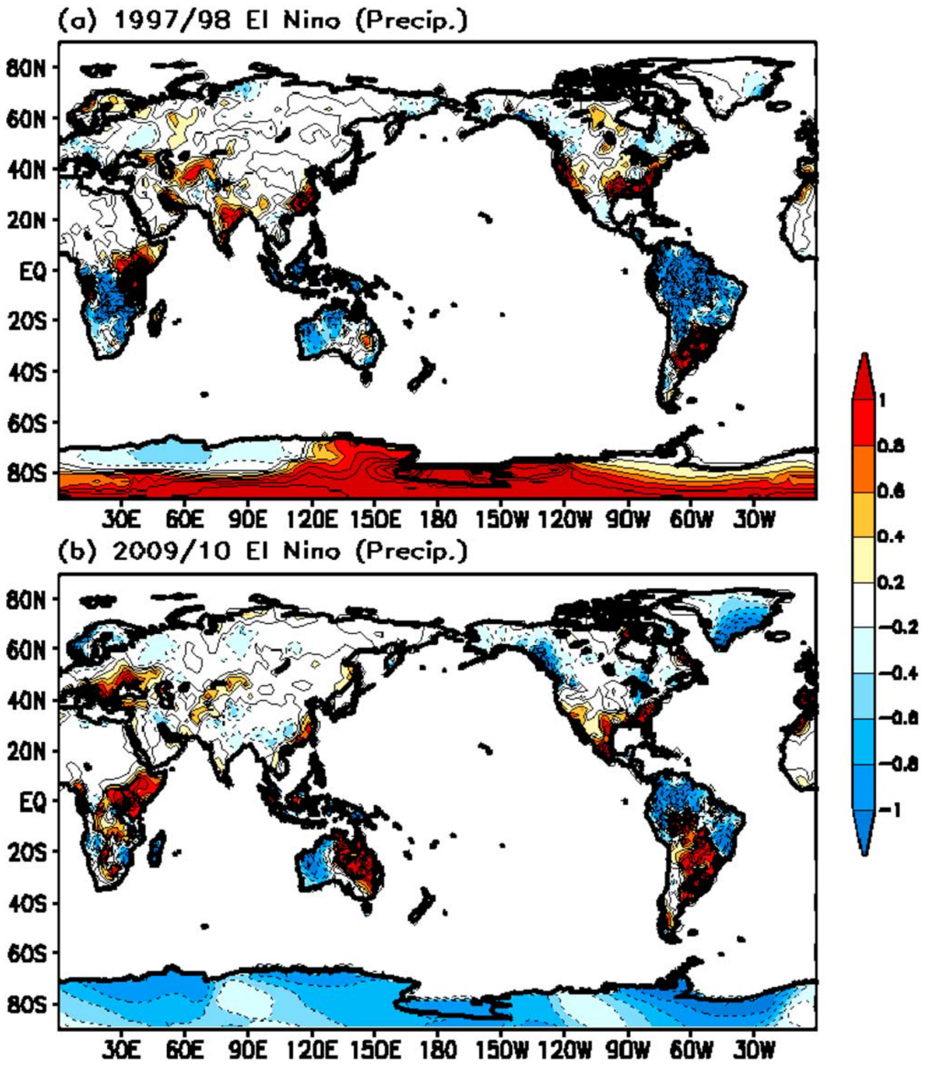
The Oceanic Niño Index (ONI) shows warm (red) and cold (blue) phases of abnormal sea surface temperatures in the tropical Pacific Ocean

Citation: Trenberth, Kevin & National Center for Atmospheric Research Staff (Eds). Last modified 02 Feb 2016. **"The Climate Data Guide: Nino SST Indices (Nino 1+2, 3, 3.4, 4; ONI and TNI)."** Retrieved from https://climatedataguide.ucar.edu/climate-data/nino-sst-indices-nino-12-3-34-4-oni-and-tni.



ENSO and the rest of the world

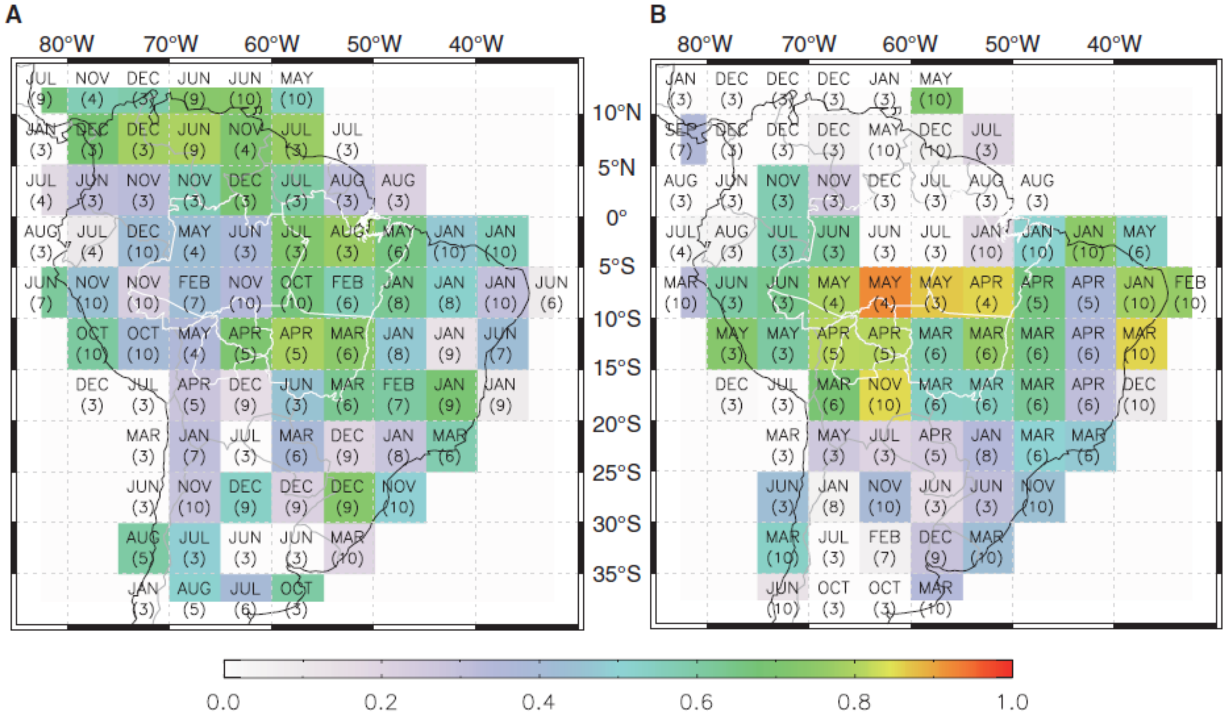




Yeh et al. (2017, Reviews of Geophysics)

ENSO and the rest of the world

(A) Maximum positive correlation between Oceanic Niño Index (ONI) and fire season severity (FSS) derived from 2001–2009 MODIS active fire data. (B) Maximum positive correlation between Atlantic Multidecadal Oscillation index (AMO) and FSS for the same period.

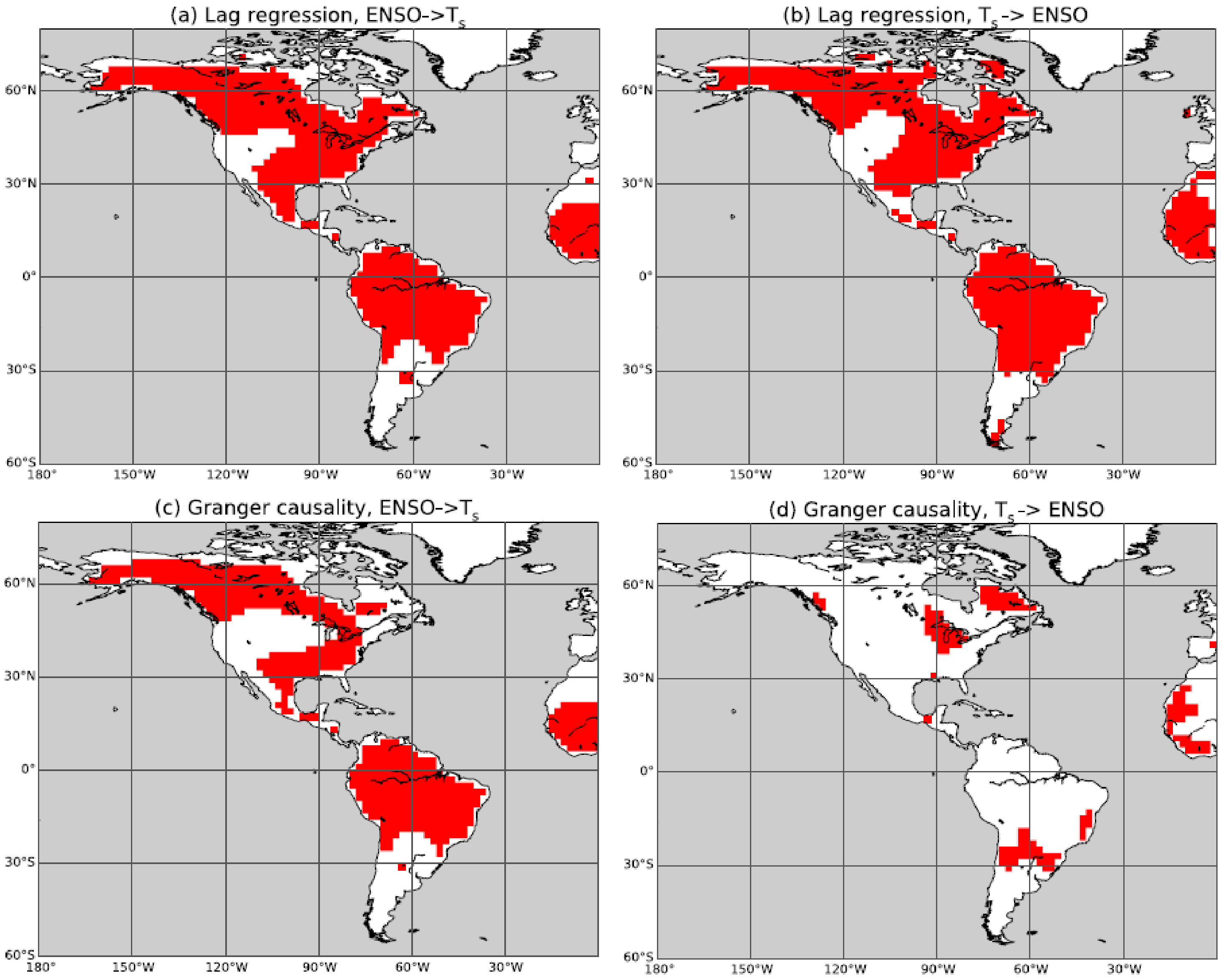


Chen et al. (2011), Science, Forecasting Fire Season Severity in South America Using Sea Surface Temperature Anomalies

Hypothesis:

We can use statistical model and CAM to confirm ENSO as one of the modulating factors that cause severe weather/climate events over remote regions through teleconnection with lagged temporal variability.

Causality vs. Regression: Who is Cause? Who is Effect?



McGraw and Barnes (2018) Journal of Climate, Memory Matters: A Case for Granger Causality in Climate Variability Studies

PART II: Observational and Reanalysis Datasets

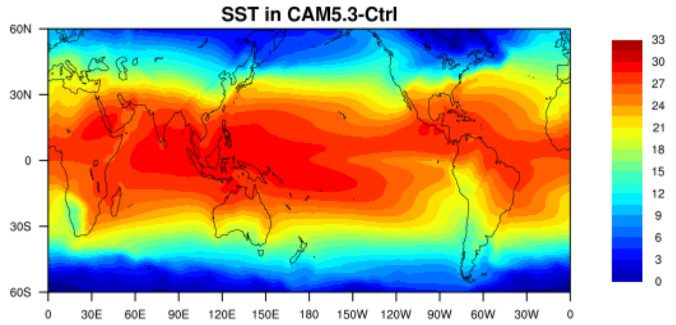
1). HadISST: Hadley Centre Sea Ice and Sea Surface Temperature data
1870-present, 1° x 1° latitude-longitude resolution (Rayner et al., 2003)

2). GPCP v2.3: Global Precipitation Climate Project Precipitation data
1979-present, 2.5° x 2.5° latitude-longitude resolution (Adler et al., 2016)

3). NCEP/NCAR Reanalysis I: using data assimilation with observations
1948-present, 2.5° x 2.5° lat-lon resolution, 17 levels (Kalnay et al., 1996)

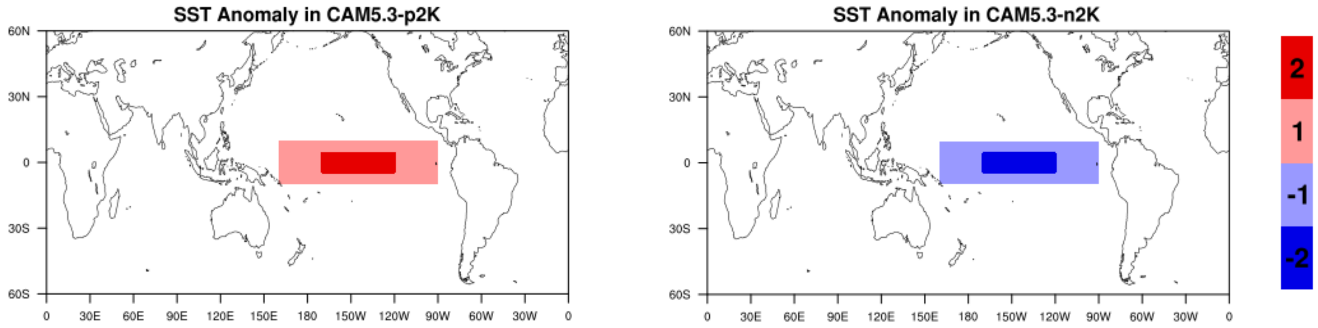
PART III: Community Atmospheric Model (CAM)

- Community Atmospheric Model (version 5.3, CAM5.3) with the CAM5 standard parameterization schemes (Neale et al. 2010).
- The CAM5.3 uses the finite volume dynamical core at 1.9° latitude × 2.5° longitude resolution with 30 vertical levels and 20-min time step.
- Three simulations: CAM5.3-Ctrl, CAM5.3-p2K, and CAM5.3-n2K. In Maya server We use 32 cores to MPI run each 3-yr simulations.



SST forcing used in CAM5.3 control run [°C]

CAM5.3-p2K



CAM5.3-n2K

PART IV: Granger Causality Model

- Lagged linear regression is frequently used to infer causality.

$$y_t \approx \sum_{i=1}^{L} a_i x_{t-i} + \epsilon. \tag{1}$$

- Lagged regression has weaknesses when one or more of the variables has autocorrelation.
- Granger causality: a time series $\mathbf{x}$ is said to "Granger cause" another time series $\mathbf{y}$, if regressing for $\mathbf{y}$ in terms of both past values of $\mathbf{y}$ and past values of $\mathbf{x}$ is statically significantly better than that of regressing in terms of past values of $\mathbf{y}$ only.
- Let $\{x_t\}_{t=1}^{T}$ and $\{y_t\}_{t=1}^{T}$ be the two time series. We perform two regressions:

$$y_t \approx \sum_{i=1}^{L} b_i y_{t-i} + \sum_{i=1}^{L} c_i x_{t-i} + \epsilon, \tag{2}$$

$$y_t \approx \sum_{i=1}^{L} d_i y_{t-i} + \epsilon. \tag{3}$$

PART V: Methodology

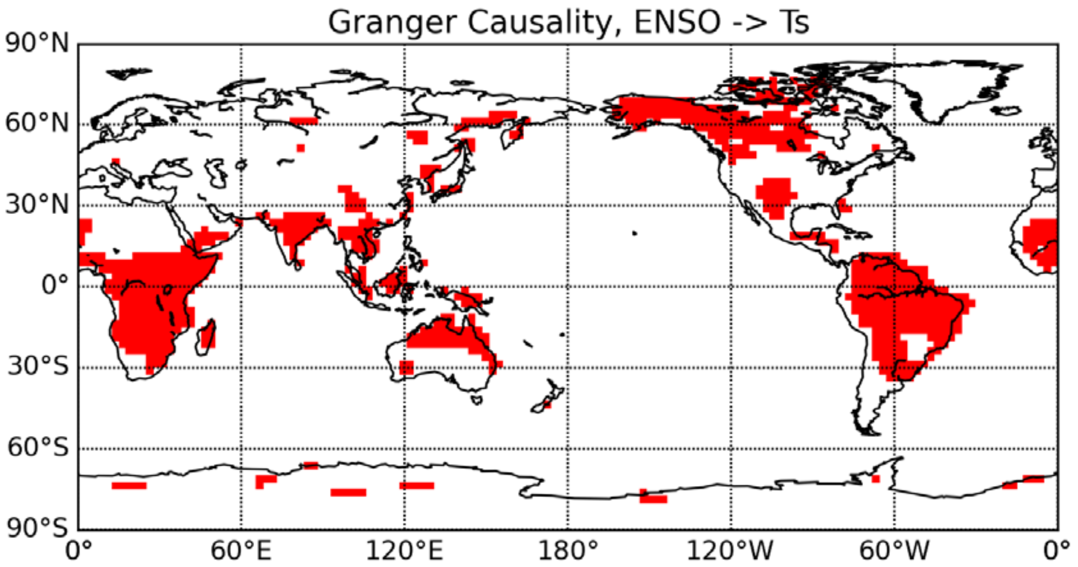
1. Granger causality determines which variable is cause, which variable is effect

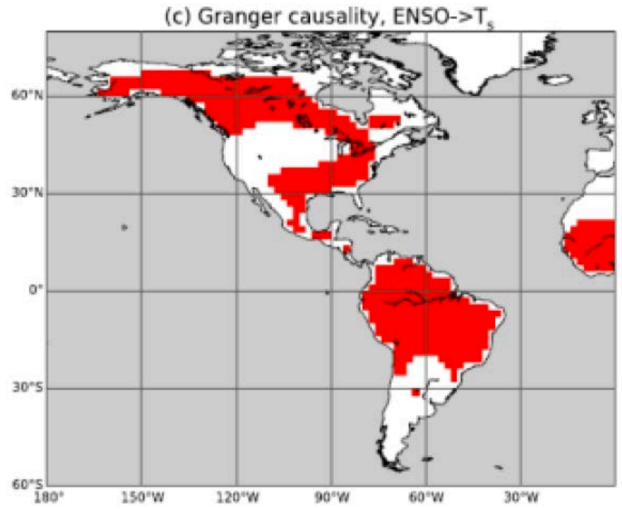
2. Granger and lag correlation are used synergistically to show the positive/negative impacts of ENSO over the regions ENSO is identified having significant impacts in Granger analysis

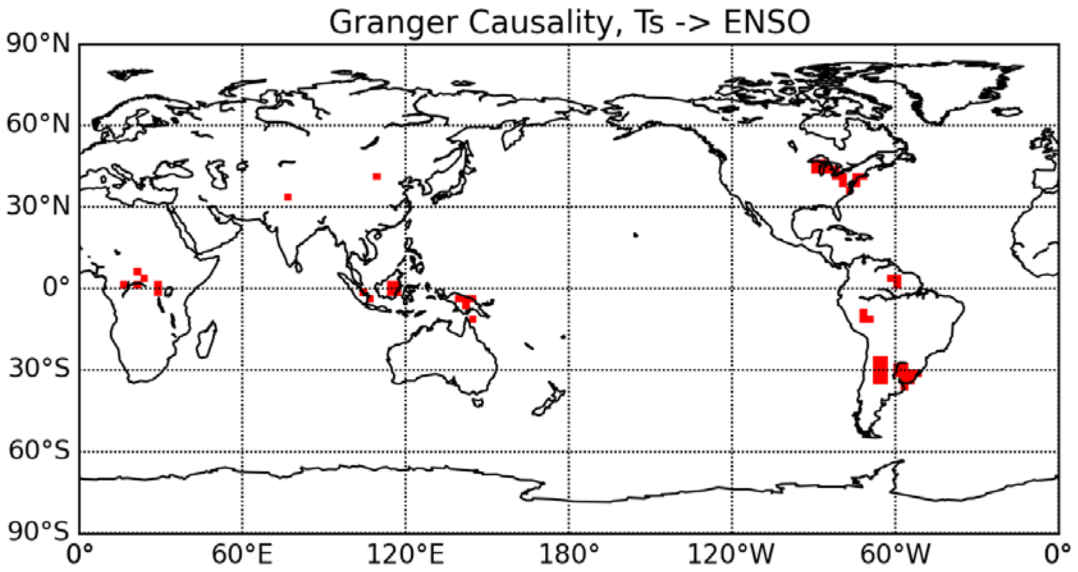
3. CAM simulation shows SST anomalies have remote global impacts

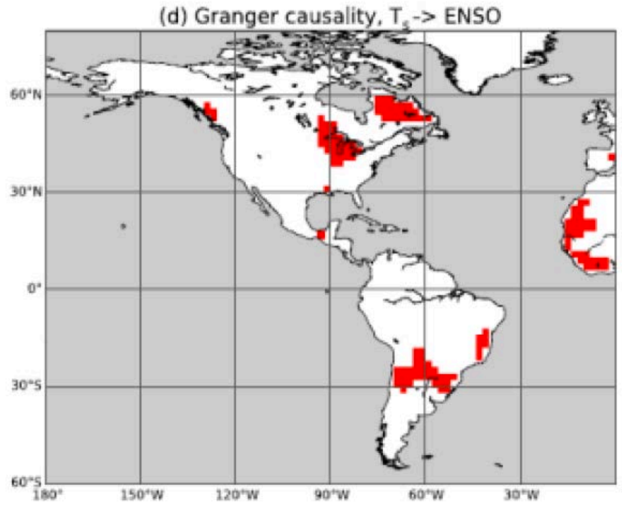
4. Spatio-temporal patterns of ENSO's global impacts as evaluated from observations and simulations match each other

Granger Causality to Determine Cause-And-Effect





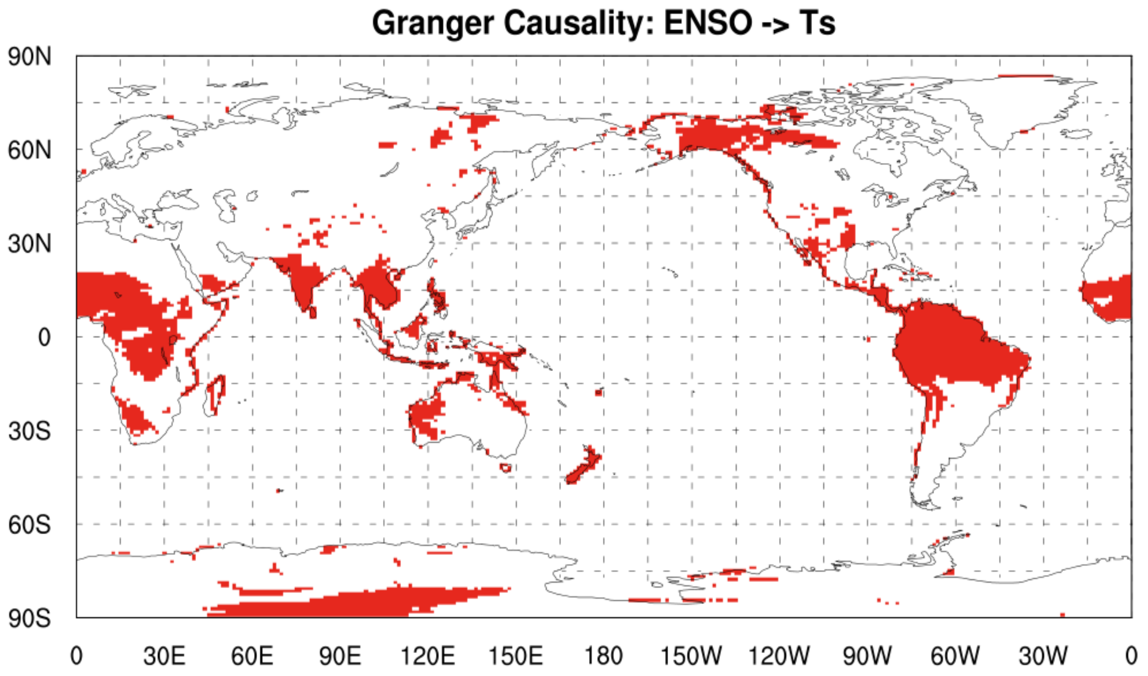


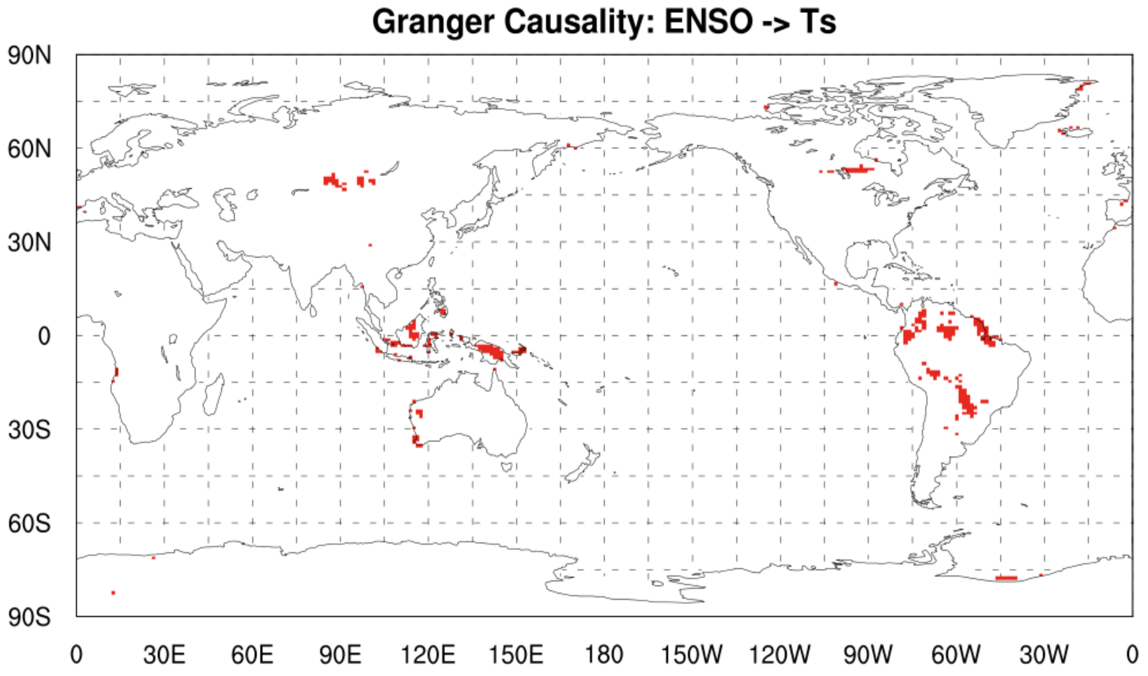


Figs 4c and 4d
McGraw and Barnes (2018)

Longer CAM5 AMIP simulation data (1979-2006):

https://www.earthsystemgrid.org/search.html?freeText=cam5.1_amip_1d





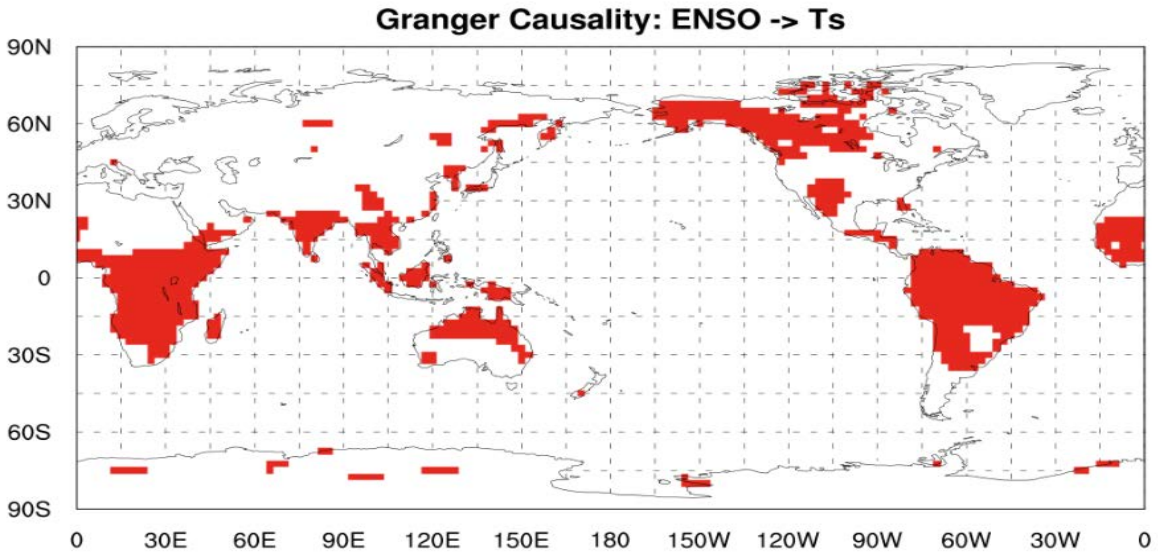
The CAM5 simulation reproduces the similar causality relationship between ENSO and Ts as in the observations.

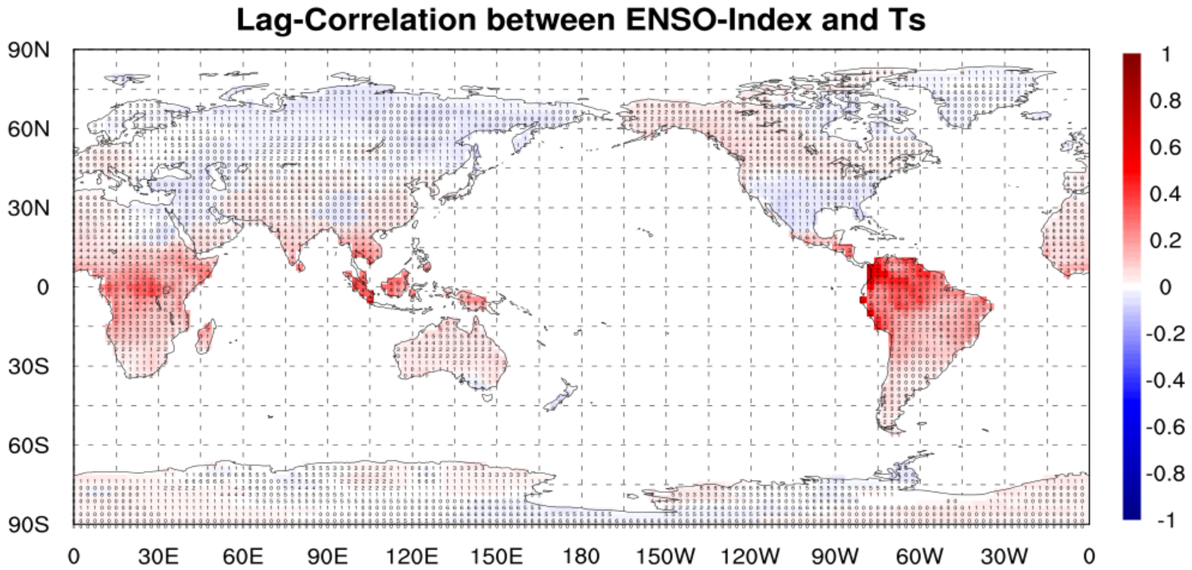
PART VI: RESULTS

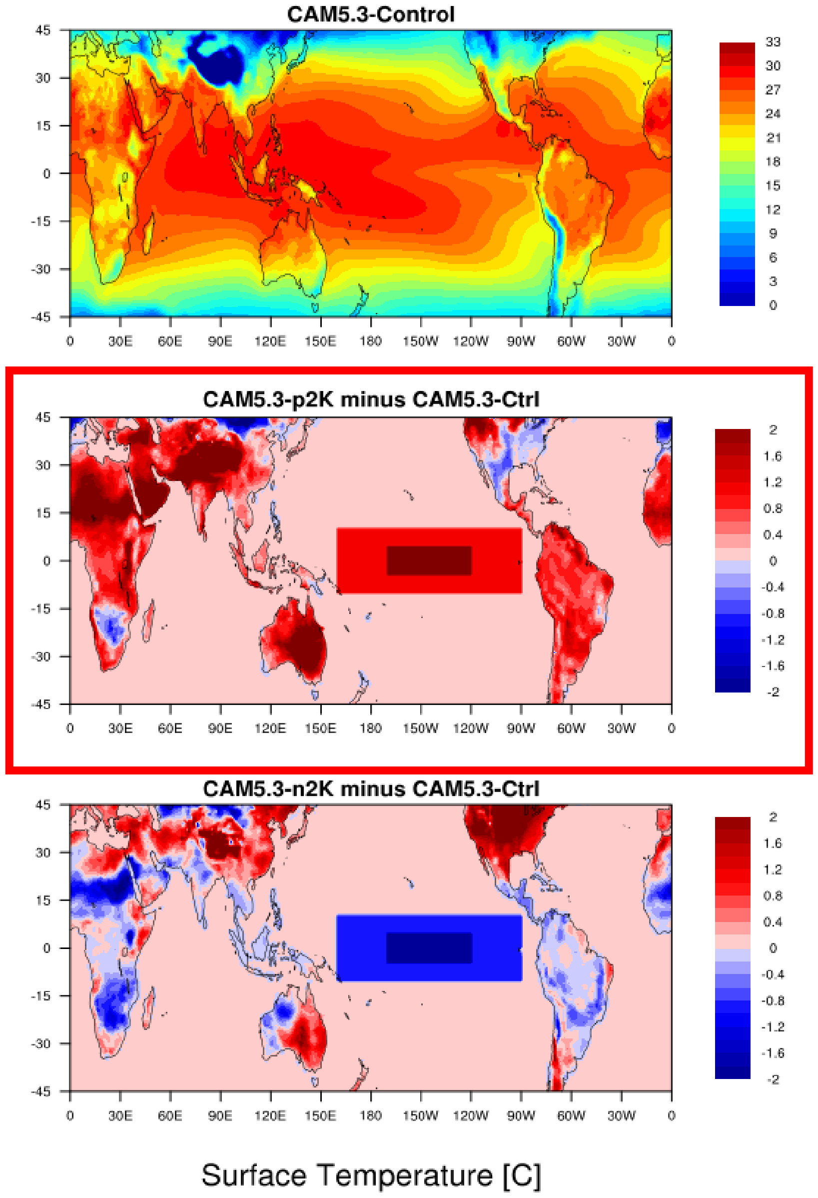
Combine our results using three methods:

1. Granger Causality Method
2. Maximum Lag-Correlation
3. Sensitivity Climate Model Simulations (CAM5.3)

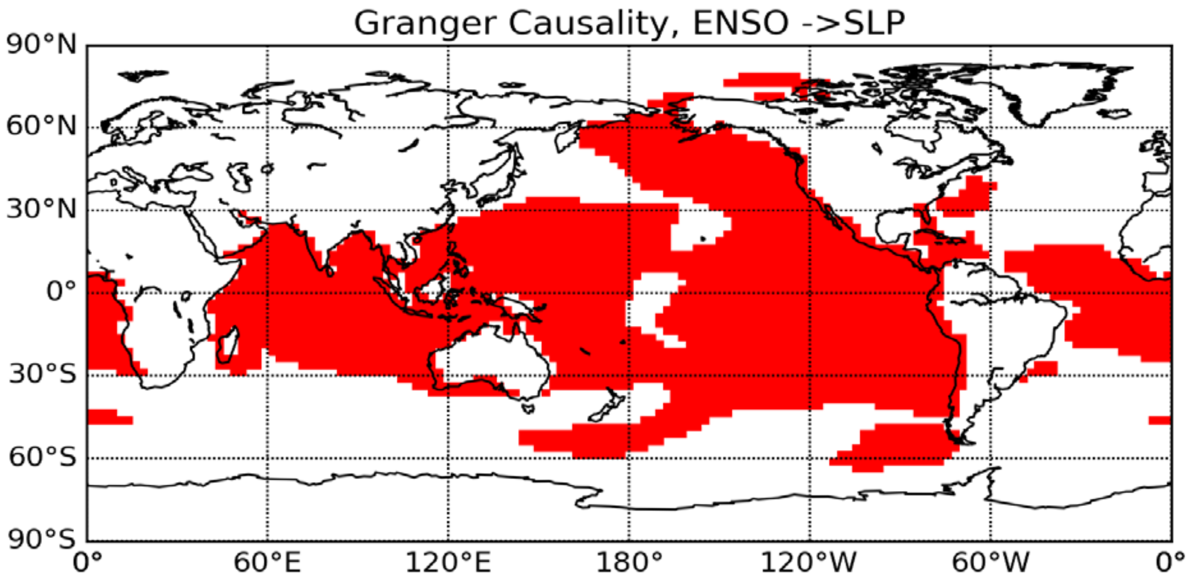
ENSO vs. Ts

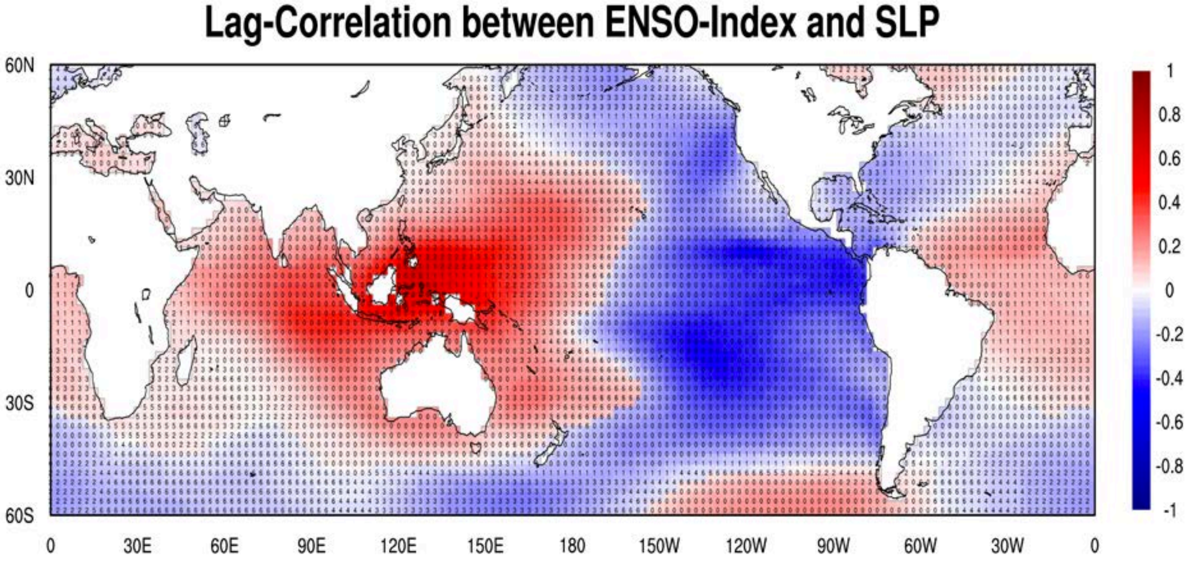

Granger Causality: ENSO -> Ts
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0

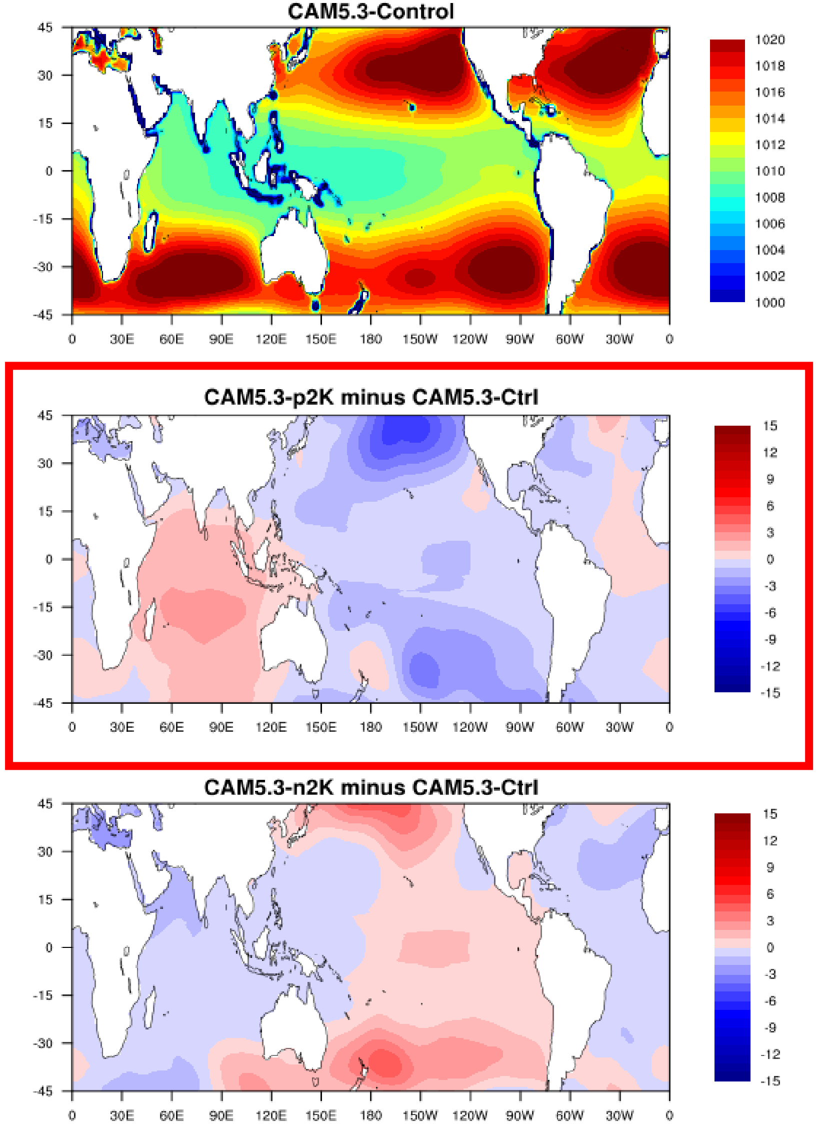

Lag-Correlation between ENSO-Index and Ts
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1


CAM5.3-Control
CAM5.3-p2K minus CAM5.3-Ctrl
CAM5.3-n2K minus CAM5.3-Ctrl
Surface Temperature [C]

ENSO vs. Surface Pressure

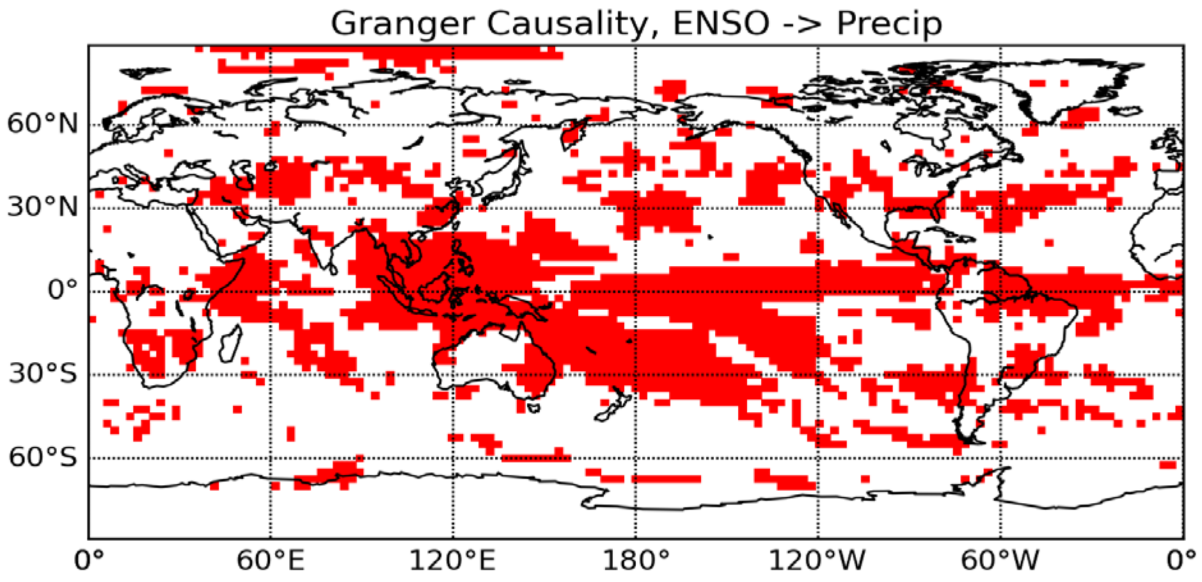


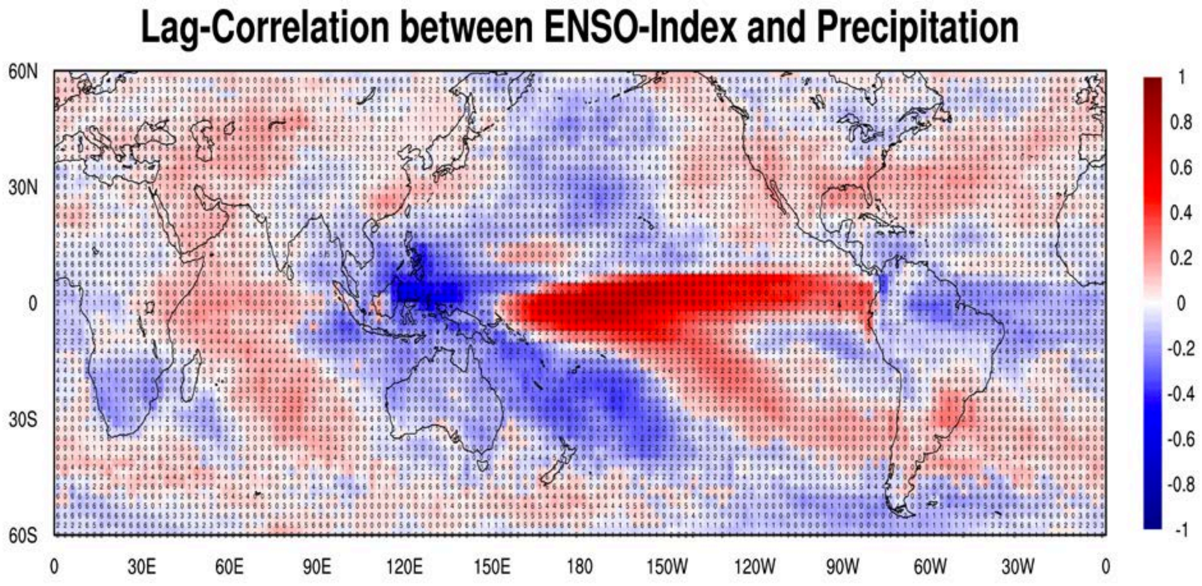


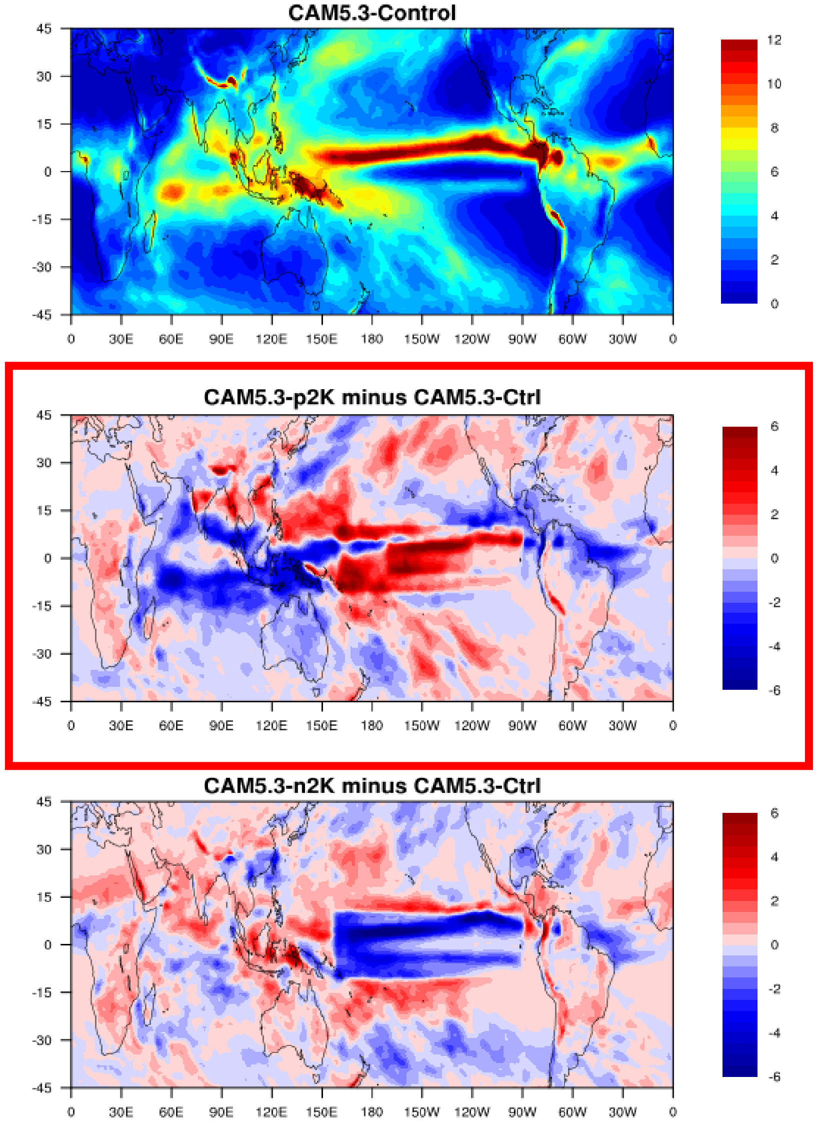


Surface Pressure [hPa]

ENSO vs. Precipitation

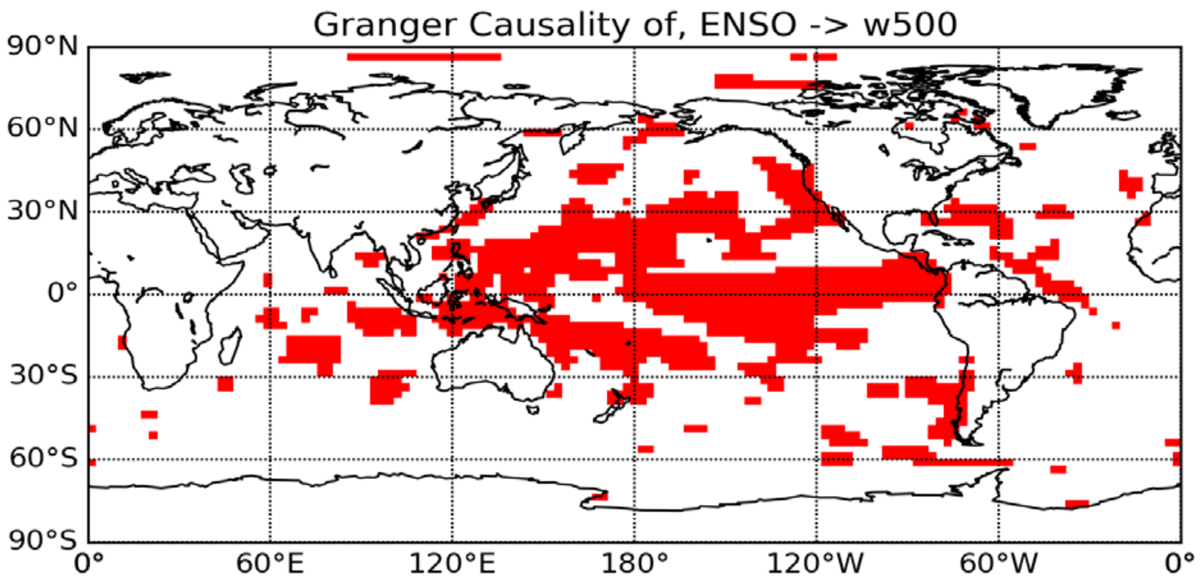


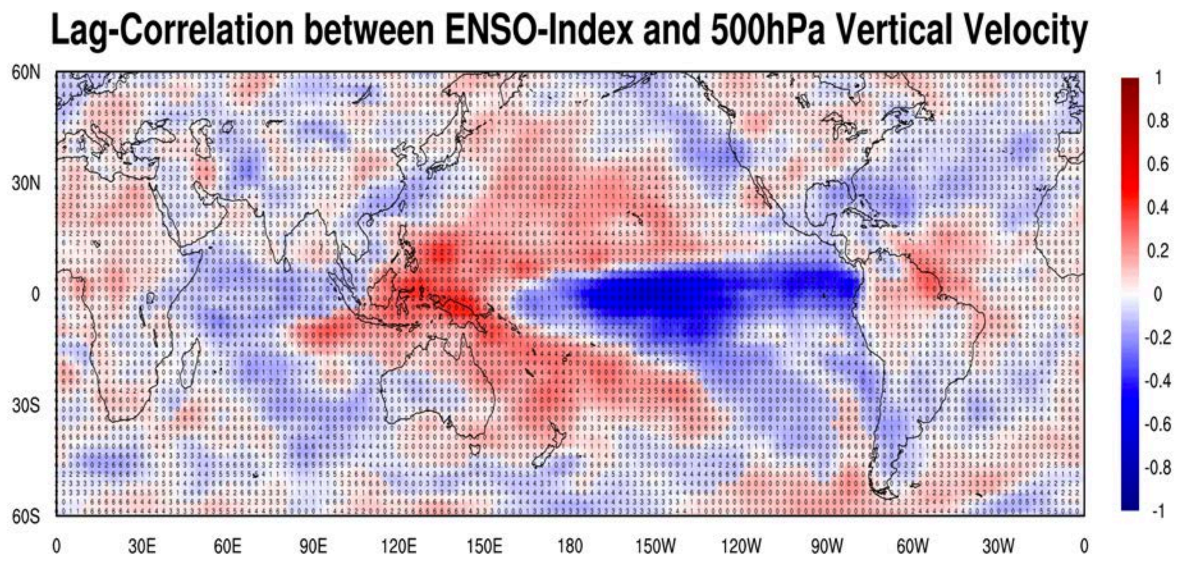


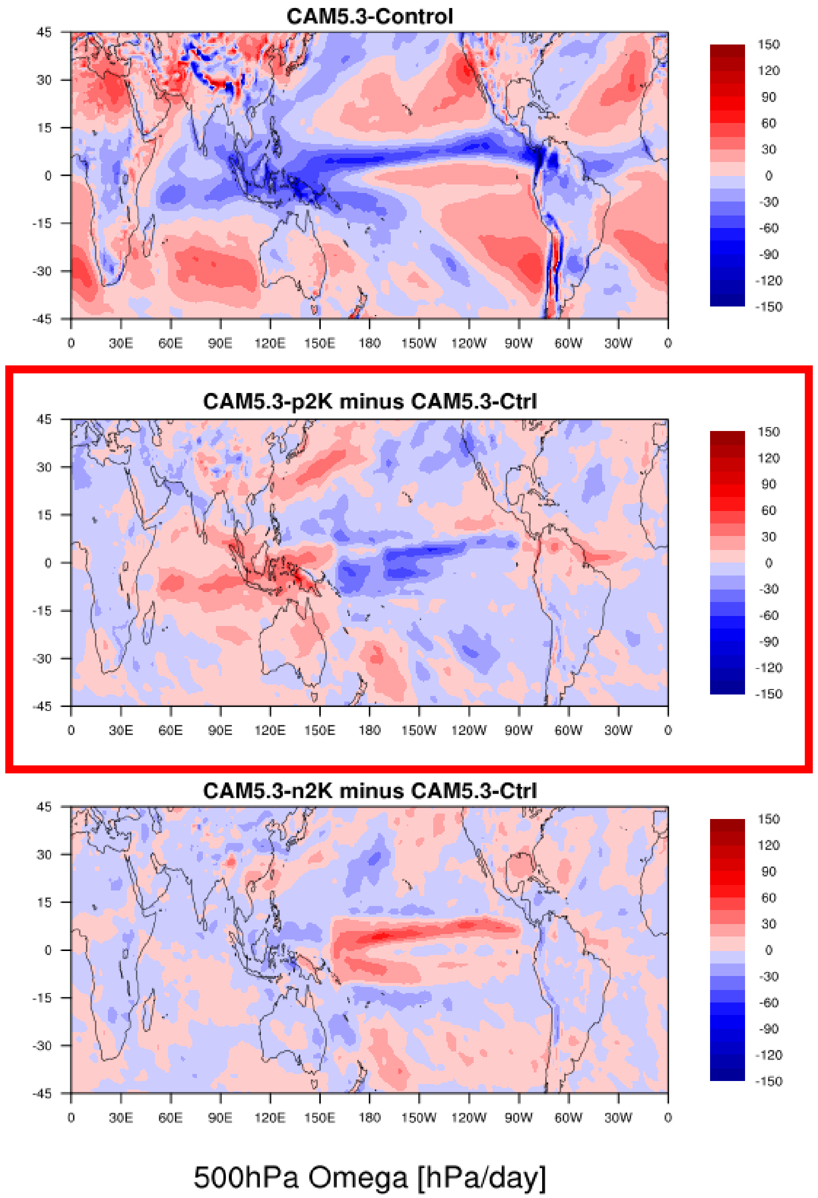


Precipitation [mm/day]

ENSO vs. Vertical Wind (500 hPa)







Part VII: Conclusions

- In contrast to Lag Correlation, Granger causality analysis was able to clearly show ENSO as the modulating cause to precipitation, land surface temperature, surface pressure, vertical wind etc.
- CAM successfully simulated ENSO's remote impacts on other weather variables as well
- The spatio-temporal patterns of ENSO's remote impacts on other variables are similar to the model simulated patterns to some extents

Hypothesis IS CONFIRMED:

We can use statistical model and CAM to confirm ENSO as one of the modulating factors that cause severe weather/climate events over remote regions through teleconnection with lagged temporal variability.

Part VIII: Future Work

- Compare causality on multiple variables and test parallel computing (if possible)
- Summarize our results and draft our report
- Analyze the impact of ENSO on clouds and aerosol
- Analyze the impact of ENSO on other interesting economic factors, such as crop yield and wheat stock price etc.

Thank you !

Questions?