The Impact of Anthropogenic Forcing on ENSO Amplitude

Benjamin Goldman

What is El Niño/Southern Oscillation (ENSO)?

- Cyclical change in the temperature of the equatorial Pacific Ocean
- Driven by feedback loops involving air circulation, water movement, and heat transfer.
- Significant impact on human society: 2015-16 event
- Occurs every 2-7 years
- Intensity can be expressed as the amplitude of its cycle

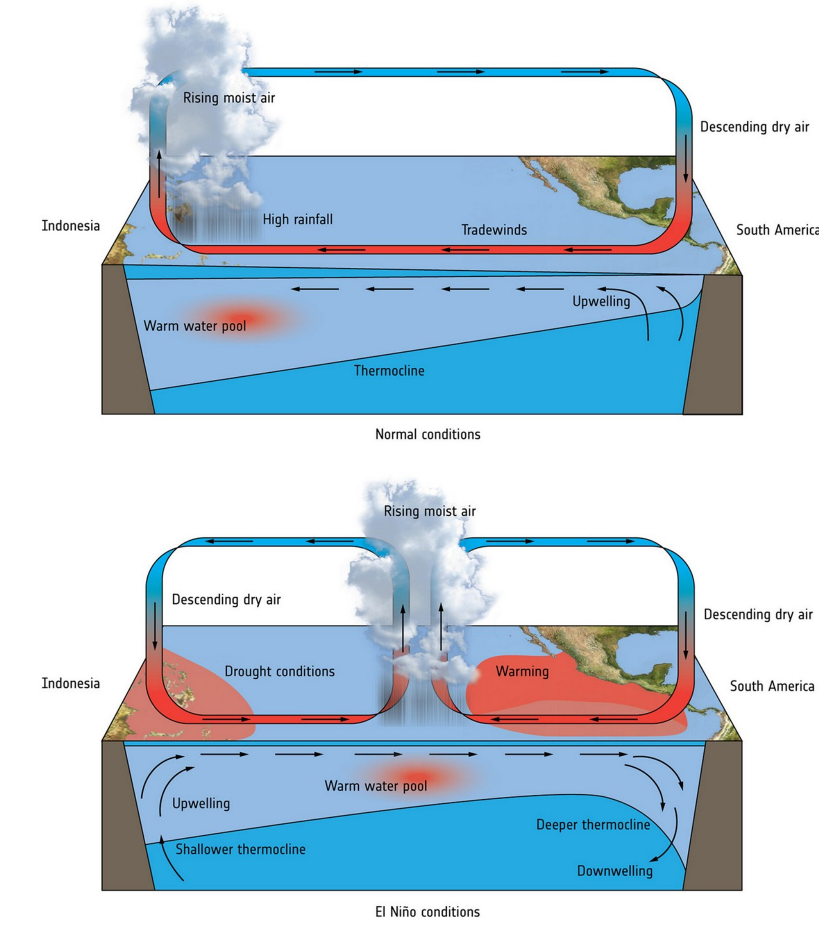


Figure 1: Changes to tropical Pacific climate during El Niño

Internal Variability vs Climate Change

Climate Variability	Climate Change
Short or medium-term changes (1-50 years)	Long-term (50+ years)
No trend/noisy	Overall trend
May have feedback loops involved	Driven by feedback loops
May be affected by forcing	Controlled by external forcing
Ex: ENSO, seasonal cycle, PDO (Pacific Decadal Oscillation)	Ex: Global warming, ice age

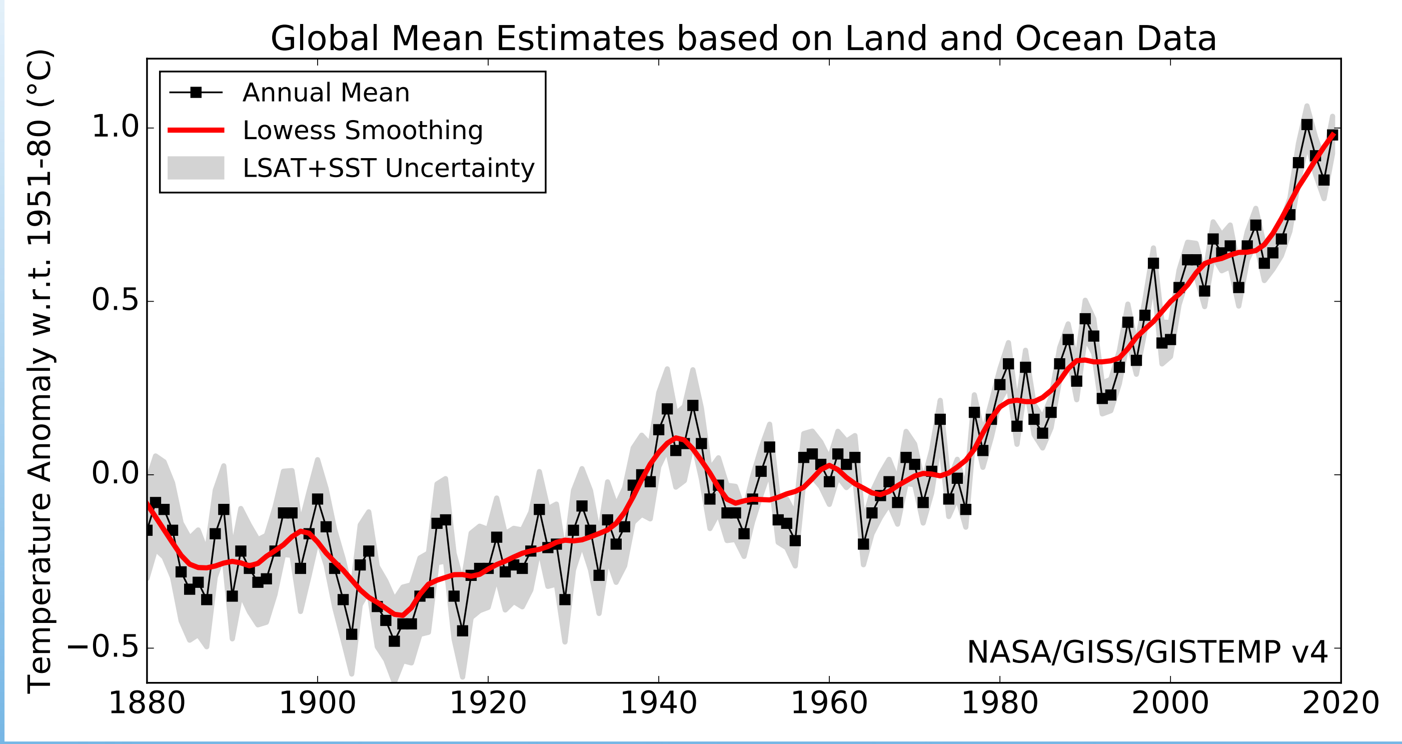


Figure 3: Global average temperature changes since 1880. Red line shows smoothed average using the LOWESS algorithm. Black line shows unsmoothed annual mean.

Review of Literature

Chen et. al. 2017	Showed that irregularities in the simulation of the air currents above the Pacific may be responsible for disagreements of future change to ENSO intensity
Maher et. al. 2018	Used an ensemble of climate models with a sample size of 40 and 100, observing increased ENSO amplitude under anthropogenic forcing, with a large amount of internal variability.
Cai et. al. 2018	Found increased variability of EP (Eastern Pacific) ENSO under global warming using EOF analysis method.
Gap	Little research on the role of individual factors on ENSO variability.

Research Goals

Problem	How large of an effect does climate change have on ENSO intensity? What factors play the largest role (greenhouse gasses vs. aerosols)?
Estimate future changes	Use a large group of climate models to estimate changes to ENSO amplitude in the future under a variety of forcing conditions.
Role of each individual factor	Compare the roles of greenhouse gasses and aerosol emissions in affecting ENSO using a bootstrap test.
Ocean structure	Analyze possible mechanism mediating forced changes to ENSO intensity

Data: the CESM LE

- Community Earth System Model Large Ensemble (CESM LE) is an ensemble of coupled model simulations.
- Coupled model: Simulation of the Earth's climate (land, ocean, atmosphere) that uses mathematical equations to predict future or past climate when input with initial conditions and prescribed forcing.
- Ensemble: a collection of model simulations that have the same physics but slightly different initial conditions.
- Control run with greenhouse gasses fixed at pre-1850 levels.

Methodology Step 1: Niño 3.4 Variance

- Calculate ENSO amplitude by taking the variance of sea surface temperature in the Niño 3.4 region for each ensemble.
- 20-year sliding windows from 1920-2100
- Sliding window: calculate variance for first 240 months centered around one date, move forward by one month, repeat

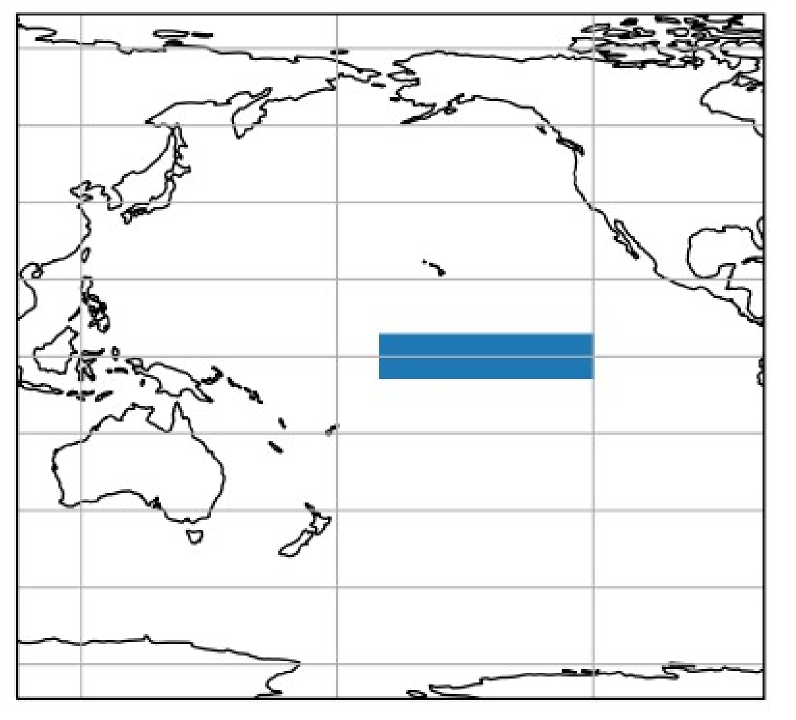


Figure 4: Niño 3.4 region is the shaded box.

Noise: the Need for a Large Ensemble

- Variability between members of the same ensemble is large
- Difficult to detect statistically significant changes with single members
- Using an ensemble allows researchers to have a larger sample size.

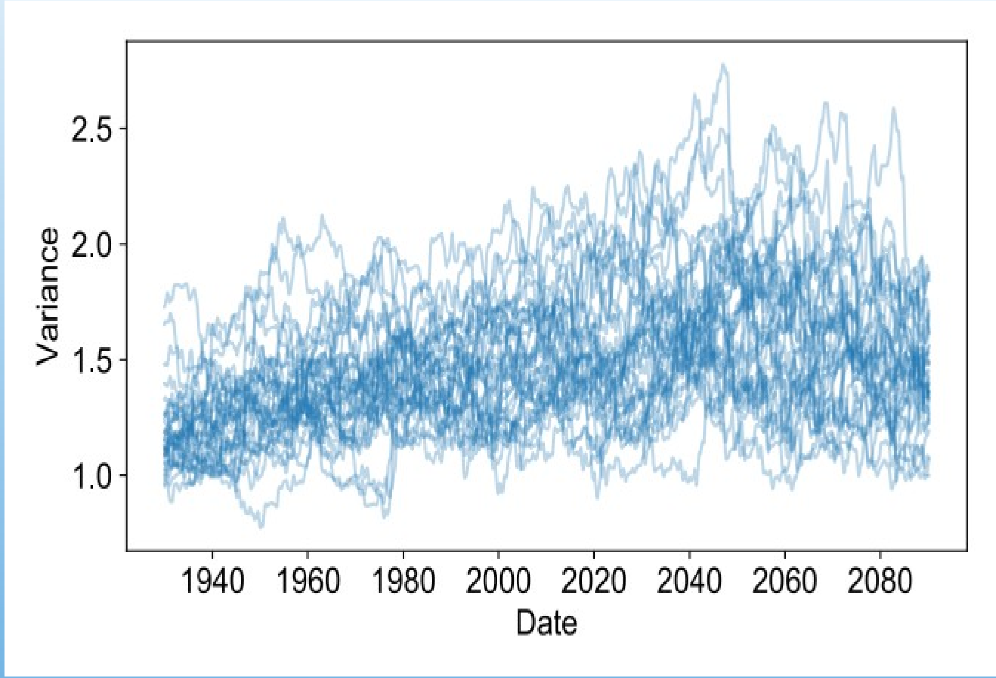


Figure 7: Niño 3.4 20-year variance for individual members in full forcing ensemble

Model Predictions for ENSO Amplitude

- Statistically significant increase in variance for fully-forced ensemble

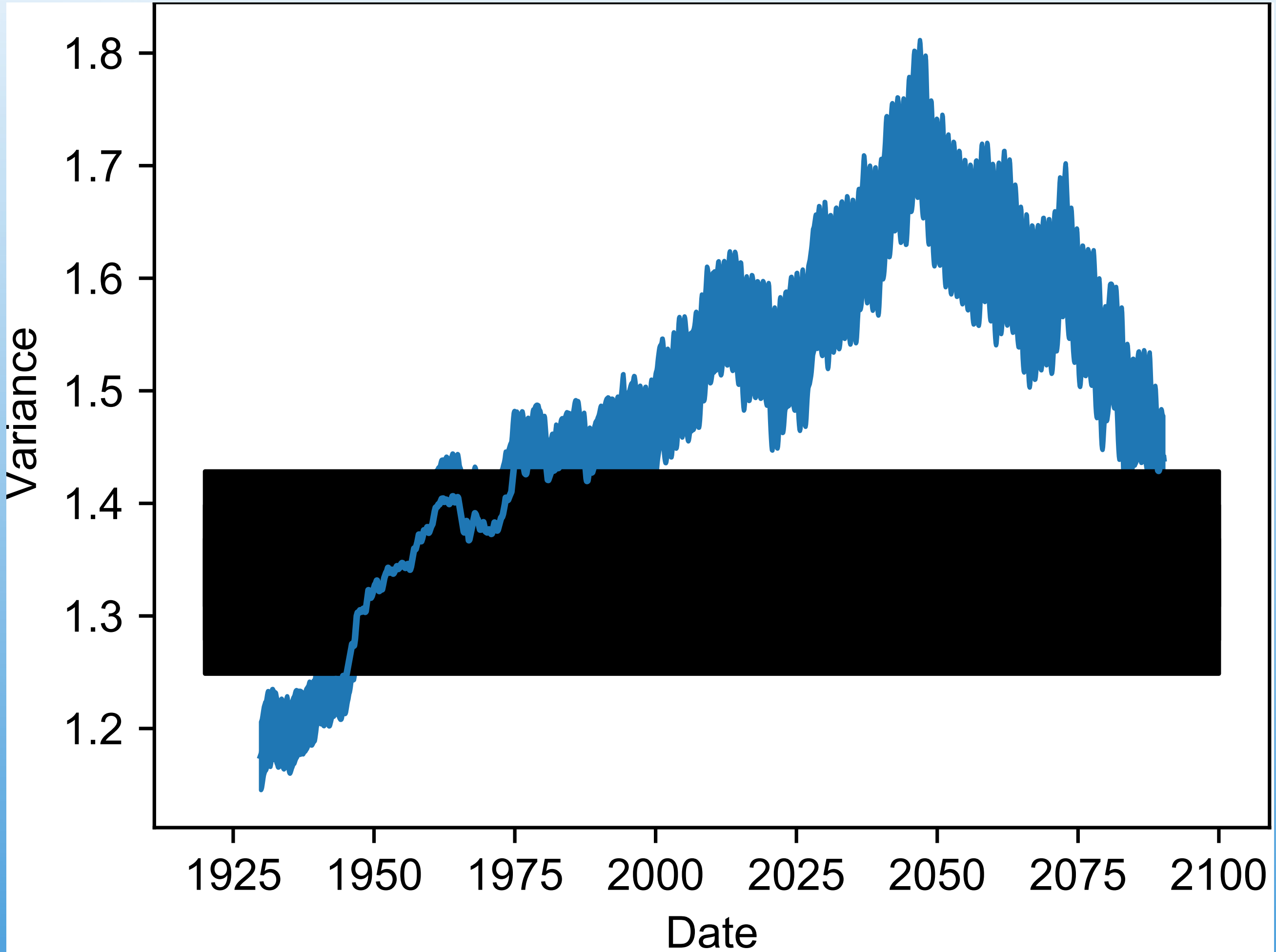


Figure 6: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and 1, 2, 3x standard error

Analysis of Individual Factors

- Single forcing ensembles are forced by all but one factor
  - Eg. xGHG ensemble is forced by aerosols, biomass burning, land use, ozone (BUT NOT GREENHOUSE GASSES)
- Subtract from fully-forced ensemble to find impact of single factor
  - +GHG ensemble captures impact of only greenhouse gasses
- Add up all single-forcing ensembles and compare to fully-forced

Role of Greenhouse and Aerosol Emissions

- Greenhouse gasses and aerosols contribute to increase in variance
- Unexplained low variance in mid-20th century
- Sum of individual factors is different from full forcing mean

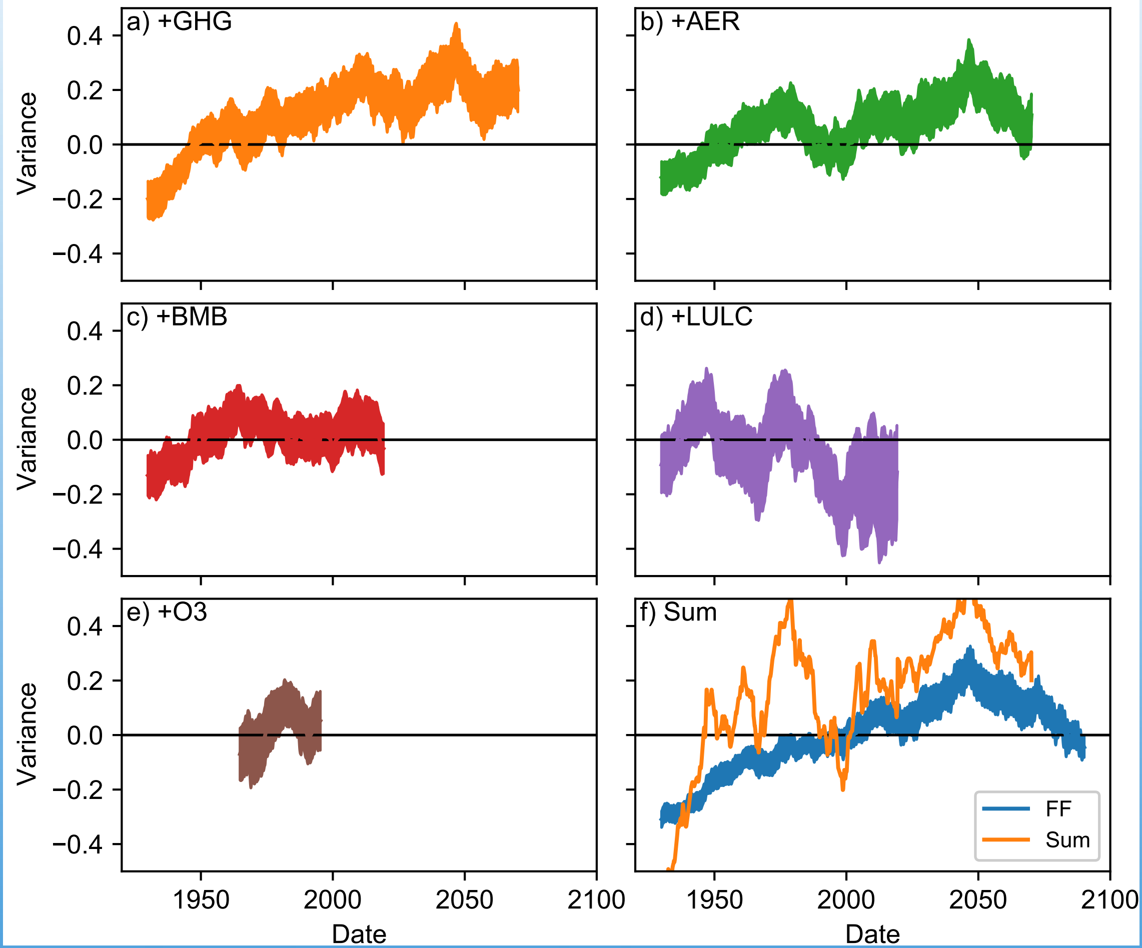
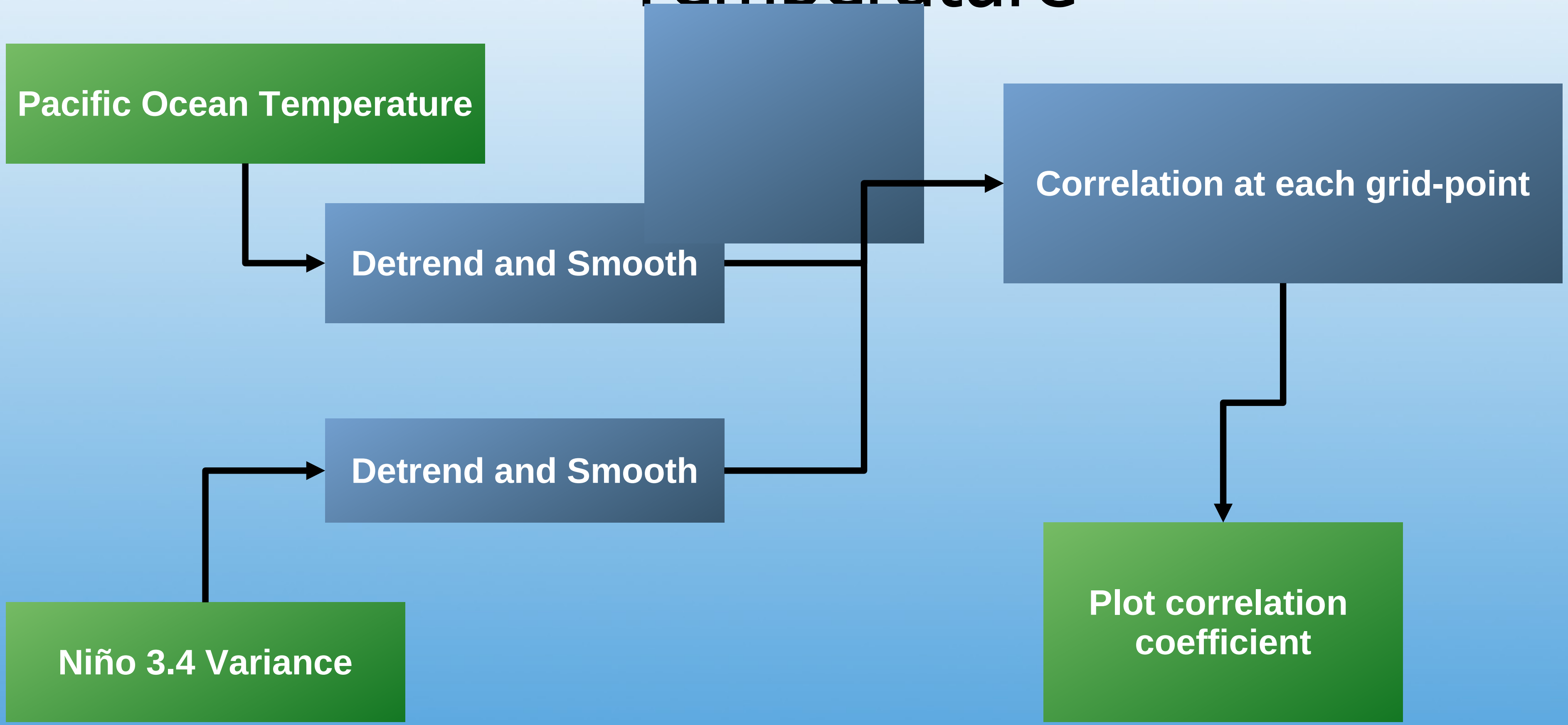
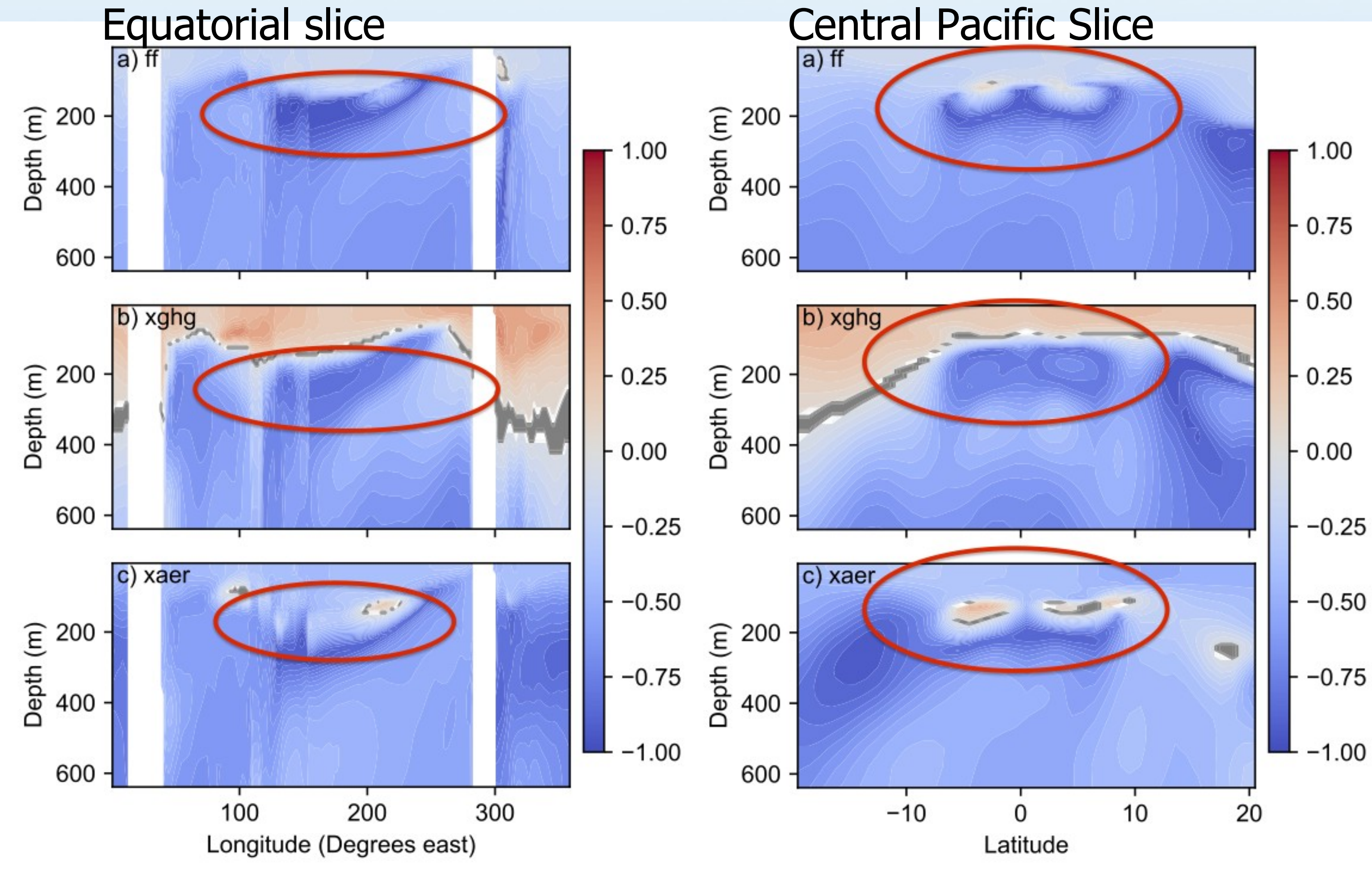


Figure 8: Difference between single-forcing and full-forcing variance for a) greenhouse gasses, b) aerosol emissions, c) biomass burning, d) land use/cover, e) ozone. f) compares sum of individual cases with fully-forced case.

Correlation With Changes to Ocean Temperature



Role of Stratification



Figures 9 and 10: correlation between detrended & smoothed Niño 3.4 20-year variance and equatorial and central pacific ocean temperature in a) fully forced b) xghg and c) xaer ensembles

Conclusions

Estimate future changes	There is likely to be an increase in ENSO strength over the next 100 years.
Analyze role of single factors	Increase is likely caused by the combined influence of greenhouse gasses and aerosols.
Physical Mechanism	Future ocean warming increases ENSO intensity by warming the upper layers of the Pacific faster than the central layers.

Application and Next Steps

- Application: to help humans prepare for future changes to the earth’s climate
- Next steps:
  - Continue analysis of association with internal variability to explain low variance from 1920-1960.
  - Compare results to analysis of CMIP6 and CESM2 ensembles.
  - Measure correlation with ocean salinity and potential density to further analyze changes to ocean structure
  - Advanced statistical analysis

Acknowledgments

- This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.
- My mentor helped me with this study

References

- Chen, L., Li, T., Yu, Y., and Behera, S. K. (2017). A possible explanation for the divergent projection of enso amplitude change under global warming. Climate Dynamics, 49(11-12):3799– 3811.
- Deser, C., Phillips, A. S., Simpson, I. R., Rosenbloom, N., Coleman, D., Lehner, F., Pendergrass, A. G., DiNezio, P., and Stevenson, S. (2020). Isolating the evolving contributions of an- thropogenic aerosols and greenhouse gases: a new cesm1 large ensemble community resource. Journal of Climate, 33(18):7835–7858.
- Kay, J. E., Deser, C., Phillips, A., Mai, A., Hannay, C., Strand, G., Arblaster, J. M., Bates, S., Danabasoglu, G., Edwards, J., et al. (2015). The community earth system model (cesm) large ensemble project: A community resource for studying climate change in the presence of internal climate variability. Bulletin of the American Meteorological Society, 96(8):1333–1349.
- Linsey, R. (2016, August 02). 2015 State of the Climate: El Niño came, saw, and conquered: NOAA Climate.gov. Retrieved December 20, 2020, from https://www.climate.gov/news-features/understanding-climate/2015-state-climate-el-ni%C3%B1o-came-saw-and-conquered
- Maher, N., Matei, D., Milinski, S., and Marotzke, J. (2018). Enso change in climate projections: Forced response or internal variability? Geophysical Research Letters, 45(20):11–390.
- Stevenson, S., Fox-Kemper, B., Jochum, M., Neale, R., Deser, C., and Meehl, G. (2012). Will there be a significant change to el nino in the twenty-first century? Journal of Climate, 25(6):2129–2145.

Image Credits

- https://www.esa.int/ESA_Multimedia/Images/2018/08/El_Nino
- https://data.giss.nasa.gov/gistemp/graphs_v4/
- http://www.cesm.ucar.edu/working_groups/

The Impact of Anthropogenic Forcing on ENSO Amplitude

Benjamin Goldman