The Impact of Anthropogenic Forcing on ENSO Amplitude

Ben Goldman

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Introduction

Climate Change and Variability

- Global warming
- Long-term trends vs short-term randomness

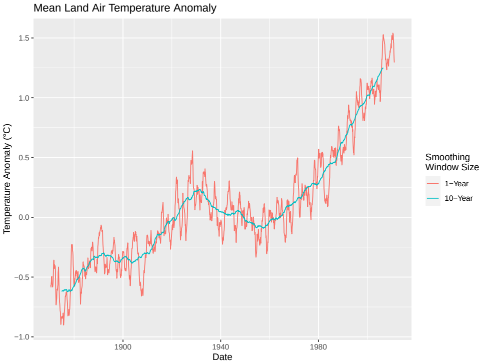


Figure 1: Global mean land air temperature in GISSTEMP 4 dataset. (Team et al., 2019) and (Lenssen et al., 2019)

Climate forcing

- Forcing: any external factor that affects climate.

GHG Greenhouse gasses

AER Aerosols (natural: volcanic ash, artificial: smoke)

BMB Biomass burning

LULC Land use/cover (deforestation, desertification)

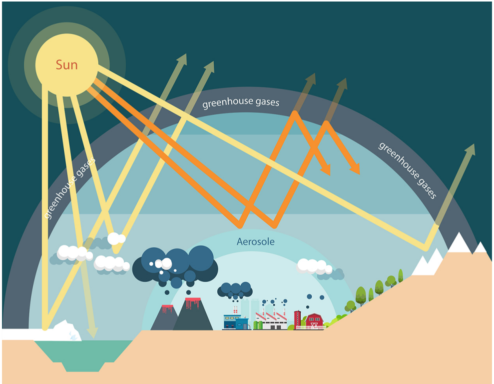


Figure 2: Factors that contribute to the greenhouse effect.

El Niño (ENSO)

- Warming and cooling of the Pacific Ocean.
- Affects human societies through temperature and rainfall. (Ropelewski and Halpert, 1987)
- May be affected by climate change.

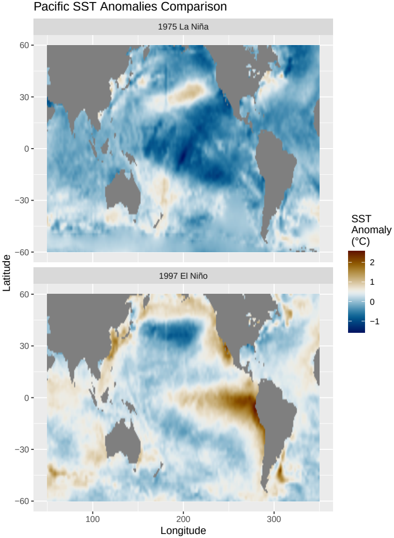
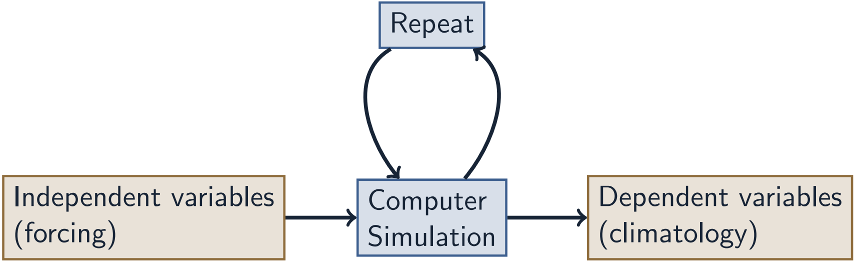


Figure 3: Comparison of SST anomaly between 1975 La Niña event and 1997 El Niño event in HadISST 1 dataset. (Rayner et al., 2003)

Method: Climate Simulation

- Run climate simulation with predicted forcing levels as input.
- Ensemble: set of repeated simulations of the same model.



Review of Literature

- ENSO changes over time (Lübbecke and McPhaden, 2014).
- ENSO responds to external forcing.
  - Correlation between ENSO strength and sunspot activity (Emile-Geay et al., 2007).
  - Weakened ENSO during the Ice Age due to reduced CO_2 levels (Zhu et al., 2017).
- Models show possible increasing ENSO activity in the future (Zheng et al., 2017) and (Maher et al., 2018).
- Factors other than CO_2 can affect ENSO.
  - Ozone emission may reduce ENSO activity (Nowack et al., 2017)
  - Aerosol emission may reduce ENSO activity (Stevenson et al., 2017)

Gap

- Little research using a large ensemble to examine the effect of individual factors on ENSO.
- Considerable disagreement between studies on whether ENSO will strengthen or weaken due to global warming

Questions

What? Do the CESM1 and CESM2 predict increased or decreased ENSO intensity in the future?

Why? Is the predicted increase (or decrease) due to human activities?

How? What processes are causing greenhouse gasses and aerosols to affect ENSO?

Data, Methods, and Results

Methods Overview

- Precollected predictions of sea surface temperature from climate models.
- Calculate ENSO intensity in model output.
- Use single forcing ensembles to estimate contributions each forcing item.
- Plot correlation between ENSO intensity and ocean temperature to examine relationship between heat transfer, forcing, and ENSO.
- Use wavelet analysis to analyze changes to ENSO at different frequencies.

Role of Mentor and Student

Student:

- Analyze raw data on computer
- Produce graphics for analysis and publication
- Write documentation
- Identify key features of results

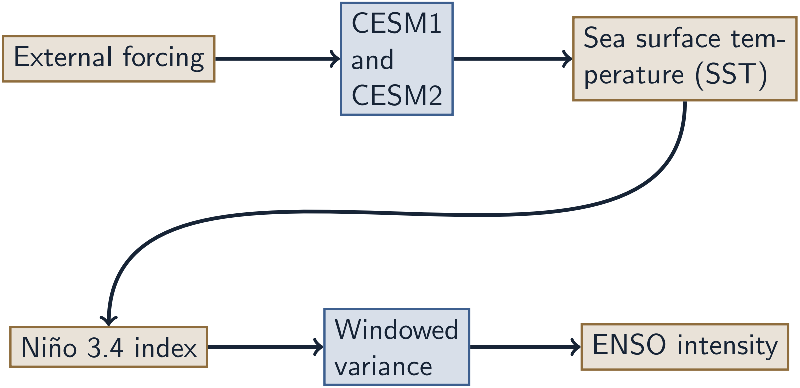
Mentor:

- Review student writing
- Interpret results in the context of climatology
- Conduct parallel analysis
- Provide raw data from facility

Model Setup

- CESM1 (Kay et al., 2015) and CESM2 (Danabasoglu et al., 2020)
- Observed forcing levels from 1850-2005
- Predicted forcing levels from 2005-2100
- Ensembles have 40 and 50 simulations respectively
- Control simulation with pre-1850 forcing levels

Measuring ENSO Intensity



ENSO is Becoming Stronger

- Increase in ENSO intensity in both ensembles.
- Increase slows down in CESM1 and decreases in CESM2 after around 2050.
  - May be caused by aerosol emissions.

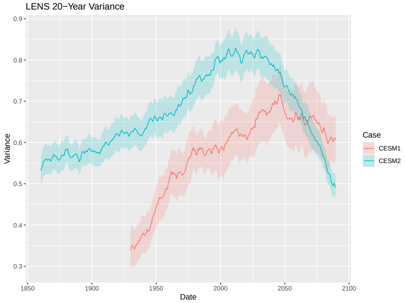


Figure 4: ENSO intensity ensemble mean and standard error for CESM1 and CESM2

Influence of Aerosols and Greenhouse Gasses

- Influence of each factor on ENSO amplitude.
- Increased variance due to greenhouse gas emissions.
- Somewhat increased variance from aerosol emissions, but not linear.
- Inconclusive results from biomass burning and land use forcing

Takeaway: Human activities are triggering predicted strengthening of ENSO.

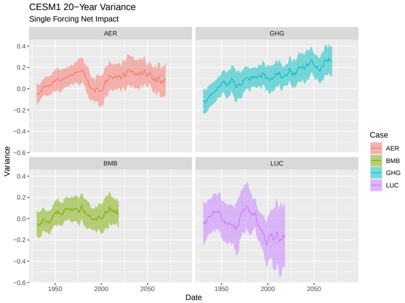


Figure 5: Influence of GHG, AER, and BMB forcing on ENSO amplitude in CESM1

Correlation With Ocean Temperature

- Correlation coefficient between ocean temperature and ENSO amplitude.
- Negative coefficient in subsurface layer.
- Positive coefficient in surface layer.
- Suggests that ocean stratification may be mediating global warming influence on ENSO.
- Difference in heating modifies mechanics of ENSO cycle.

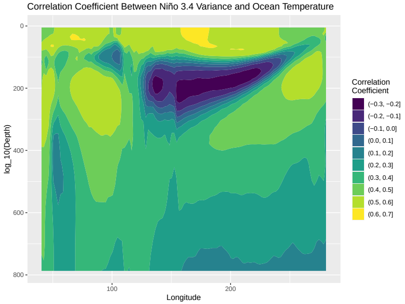


Figure 6: Correlation coefficient between ENSO amplitude and ocean temperature in equatorial cross-section in the fully-forced CESM1 ensemble

Wavelet Analysis

- Separate ENSO record into frequency over time.
- Increase in power in late 21st century agrees with previous results.
- CESM2 shows a slight “speeding up” of ENSO as period decreases in late 21st century.

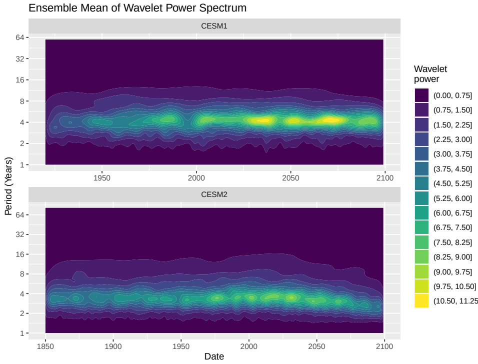


Figure 7: Wavelet power spectrum for the Niño 3.4 index in the fully-forced CESM1 and CESM2 ensembles

Conclusion

Conclusions and Discussion

- There is likely to be an increase in ENSO strength over the next 100 years. Agrees with Cai et al. (2018).
- Variance increase is likely caused by the combined influence of greenhouse gasses and aerosols.
- Global warming increases ENSO intensity by warming upper layers of the Pacific faster than central layers.

Application, Limitation, and Next Steps

Application Improve prediction ability to help people prepare for increased likelihood of extreme weather.

Limitation Niño 3.4 index may not be fully accurate for various models (Cai et al., 2018). Also, CESM may contain biases and is not completely accurate.

Next steps Examine other variables to further analyze mediator process, continue wavelet analysis methods to focus on individual frequency bands.

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