The Impact of Industrial Emissions on El Niño Intensity

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What is El Niño/Southern Oscillation (ENSO)?

- Drives extreme weather around the world
- Oscillation between warm and cold temperature in the Pacific Ocean
- Some events are more strong than others
- Significant effect on people: 2015-2016 event
- Major issue is prediction

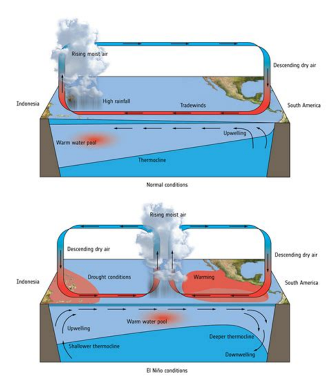

Figure 1: Changes to tropical Pacific climate during El Niño

Long-Term vs. Short-Term Change

- Long-term change: climate change/global warming
    - Causes: greenhouse gases, aerosols (smoke), land use, etc.
- Short-term change: ”climate variability”
    - ENSO

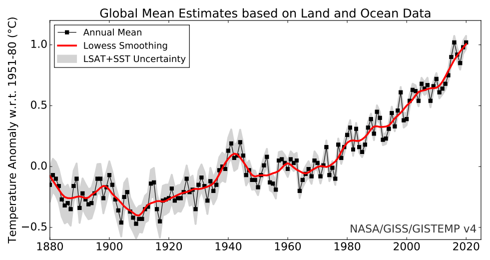

Figure 2: Global average temperature changes since 1880. Red line: smoothed average, black line: unsmoothed average

Review of Literature

- Chen et. al. (2017)
    - Past studies disagree about whether ENSO will strengthen or weaken.
    - Simulation discrepancy caused by modeling of ENSO mechanics
- Maher et. al. (2018)
    - Used a large dataset of climate predictions.
    - ENSO may become stronger in the future.
- Cai et. al. (2018)
    - Found that models agree by using a more flexible way of defining ENSO events.
    - ENSO is strengthening because global warming is leading to higher stratification.

Research Goals

Overall changes to ENSO amplitude	Estimate future changes to ENSO amplitude using the CESM1 dataset.
Role of individual factors	Compare contributions of greenhouse gasses, aerosols, land use, biomass burning, and ozone to ENSO intensity.
Changes to ocean structure	Examine changes to correlation coefficient between ENSO intensity and ocean temperature for each simulation.

Data: the CESM1 Large Ensemble

- Explore hypothetical scenarios with a computer model.
- Estimation of how the earth's climate actually works.
- Experimental group: Receives input of rising greenhouse gas and/or aerosol levels.
- Control group: Emissions fixed at levels before industrial revolution.

Niño 3.4 Variance

- How to calculate ENSO intensity in the model output?
- Step 1: Calculate sea temperature in Niño 3.4 region of tropical Pacific Ocean.
- Step 2: Convert temperature dataset to dataset representing change in temperature variation over time.
- Calculate variance around one point, move point forward slightly, repeat

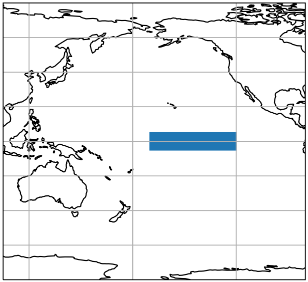

Figure 3: Niño 3.4 region is the shaded box.

Butterfly Effect: The Need for a Large Ensemble

- Butterfly effect: Small differences in initial conditions can become big differences in end result.
- Each simulation by itself is inaccurate.
- Repeat simulation with slightly different initial conditions.
- Due to larger sample size, noise can be filtered out by calculating the mean.

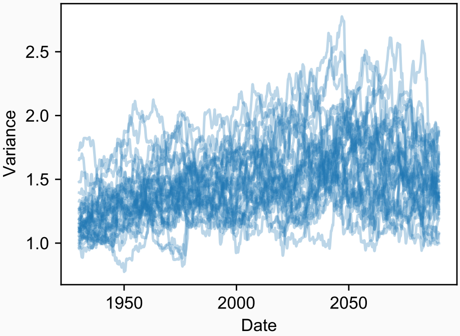

Figure 4: Niño 3.4 20-year variance for individual members in full forcing ensemble.

Model Predictions: ENSO in the Future

- Calculate mean and standard error of ENSO intensity in ensemble and control.
- ENSO is predicted to intensify in the 21st century!
- Statistically significant: exceeds 2 standard errors.
- Decreasing variance after 2060: still under investigation.

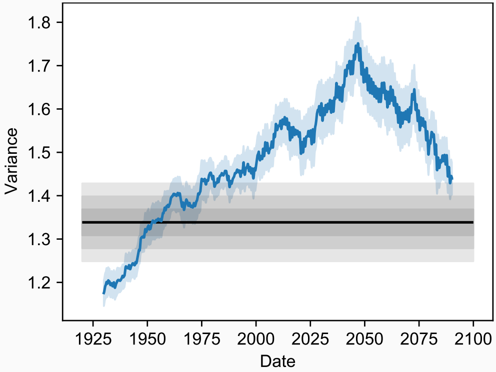

Figure 5: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and standard errors

Analysis of Individual Factors

- Why is ENSO predicted to intensify? What human impacts play the largest role?
  - Factors include: Greenhouse gasses, aerosols, natural factors.
- Separate out individual influences in model output.
- Single forcing ensembles: forced by all factors except for 1.
- Subtract "all-but-one" ensembles from original "full-forcing" ensemble.
- Resulting data represents influence of only one factor.

Role of Greenhouse and Aerosol Emissions

- Greenhouse gasses and aerosols contribute to increase in variance.
- Aerosols and greenhouse gasses have same sign: disagrees with previous studies (Deser et. al. 2020).
- Greenhouse gasses and aerosols are both human-produced.

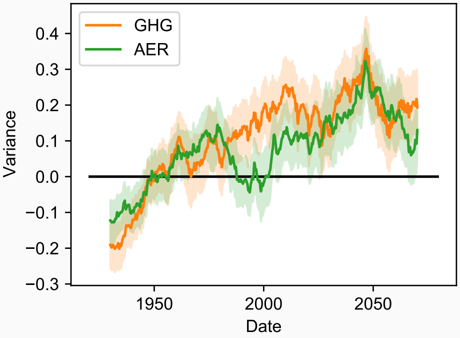

Figure 6: Influence of individual human factors. Yellow is greenhouse gasses, green is aerosols.

Correlation With Changes in Ocean Temperature

- Examine relationship between ocean temperature and ENSO intensity in each simulation.
- Calculate correlation coefficient between ENSO intensity and ocean temperature.
- Find correlation coefficient at each grid-point.

Physical Mediator: Heating Difference

- Strong negative correlation in fully forced ensemble below surface.
- Positive correlation in greenhouse ensemble and weak/zero correlation in aerosols ensemble
- Rising temperatures heat different layers of ocean at different rates, modifying heat transfer.

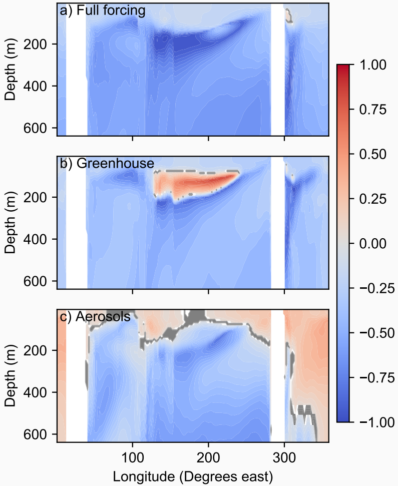

Figure 7: Correlation between ENSO intensity and ocean temperature in 3 major ensembles

Conclusion and Discussion

Predicted increase in variance	There is likely to be an increase in ENSO strength over the next 100 years. (Cai et. al. 2018)
Greenhouse gasses and aerosols	Increase is likely caused by the combined influence of greenhouse gasses and aerosols.
Heat transfer	Global warming increases ENSO intensity by warming upper layers of the Pacific faster than central layers.
Notable disagreement	Greenhouse gasses and aerosols both increase ENSO amplitude, in contrast to Deser et. al. (2020).

Applications, Next Steps, Limitations

- Improve prediction ability to help people prepare for increased likelihood of extreme weather.
- Reduce danger by switching to renewable energy.
- Limitations:
    - Only used one climate model.
    - Niño 3.4 index may not be fully accurate for various models (Cai et. al. 2018).
- Next steps:
    - Work with other datasets, such as the new CESM2.
    - Examine other variables to further analyze mediator process.

Acknowledgements

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- Thank you to my teacher, my family, and my mentor!
- Role of mentor:
    - Provide raw data from his facility
    - Suggest methods and interpretations
    - Provide feedback on results
    - Make similar calculations to check student's results

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Image Sources

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