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

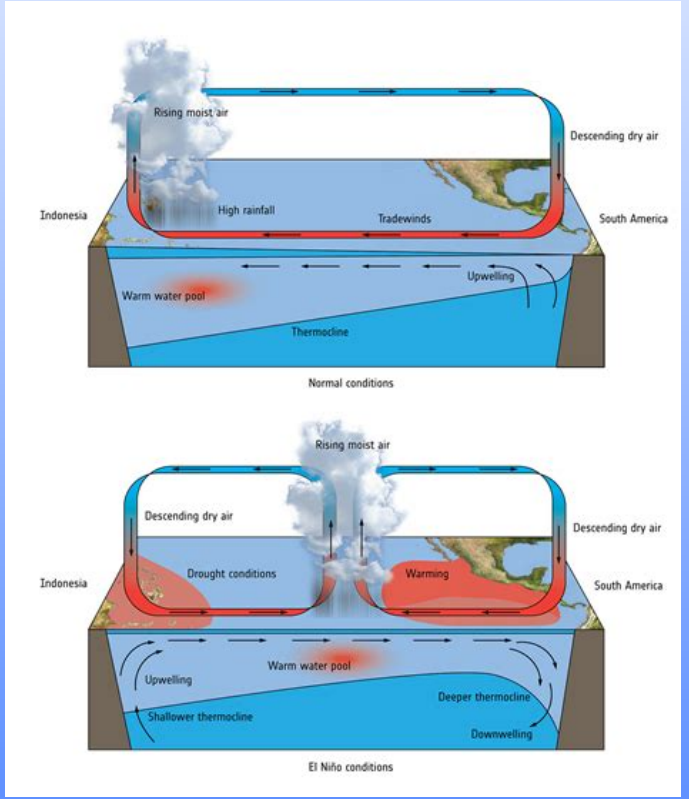

Figure 1: Changes to tropical Pacific climate during El Niño

Short-Term vs. Long-Term Change

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

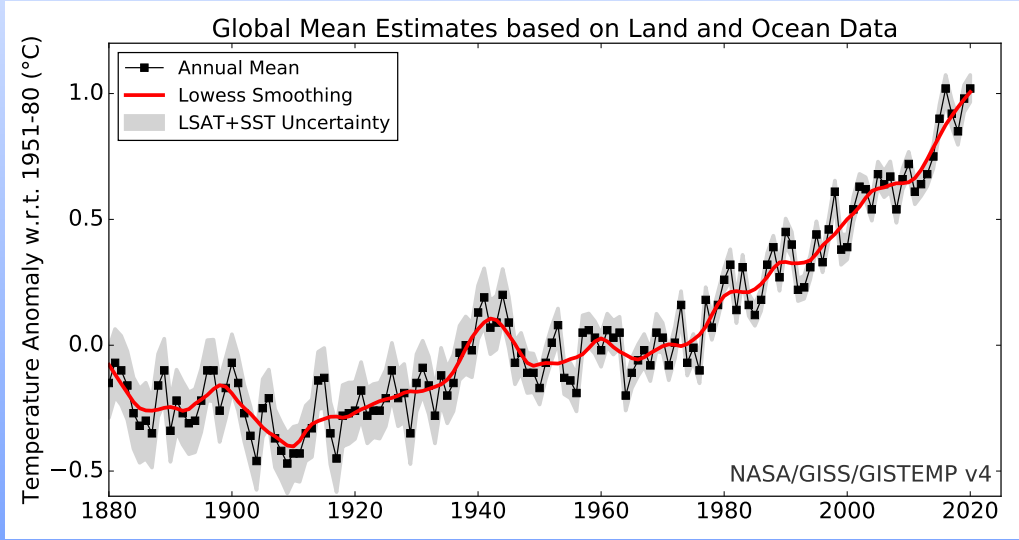

Figure 2: Global average temperature changes since 1880. Red line: smoothed average, black line: unsmoothed average

Review of Literature

Chen et. al. (2017)	Past studies disagree about whether ENSO will strengthen or weaken. This is happening because of differences in the simulation 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)	ENSO is strengthening because global warming is leading to higher stratification. Found that models agree, if you use a more flexible way of defining ENSO events.
Gap	Little research comparing the effects of greenhouse gasses vs. aerosol emissions.

Research Goals

What: Verify past research	Does the data show that ENSO will become stronger?
Why: Human impact	Figure out which human activities are causing the increase.
How: Ocean structure	Determine what changes are taking place to make ENSO stronger.

Data: the CESM1 Large Ensemble

- How do we explore hypothetical scenarios? With a computer model!
- Estimation of how the earth's climate actually works, but can receive hypothetical input of increasing greenhouse gas and aerosol levels.
- Can now find how the climate will appear in the future.
- Models may be inaccurate, so researchers use an large group of them – an ensemble.
- Control run with input as if there were no industrial emissions.

Methodology Step 1: 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

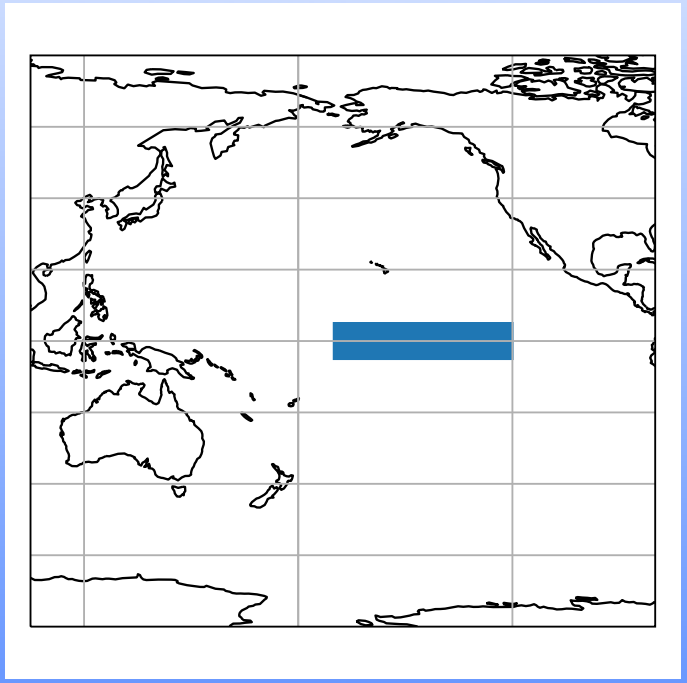

Figure 3: Niño 3.4 region is the shaded box.

Butterfly Effect: The Need for a Large Ensemble

- Small differences in initial conditions can blow up to big differences in end result: Butterfly effect!
- Each simulation by its self is inaccurate.
- Repeat simulation with slightly different initial conditions.
- Eventually, real trends may appear.

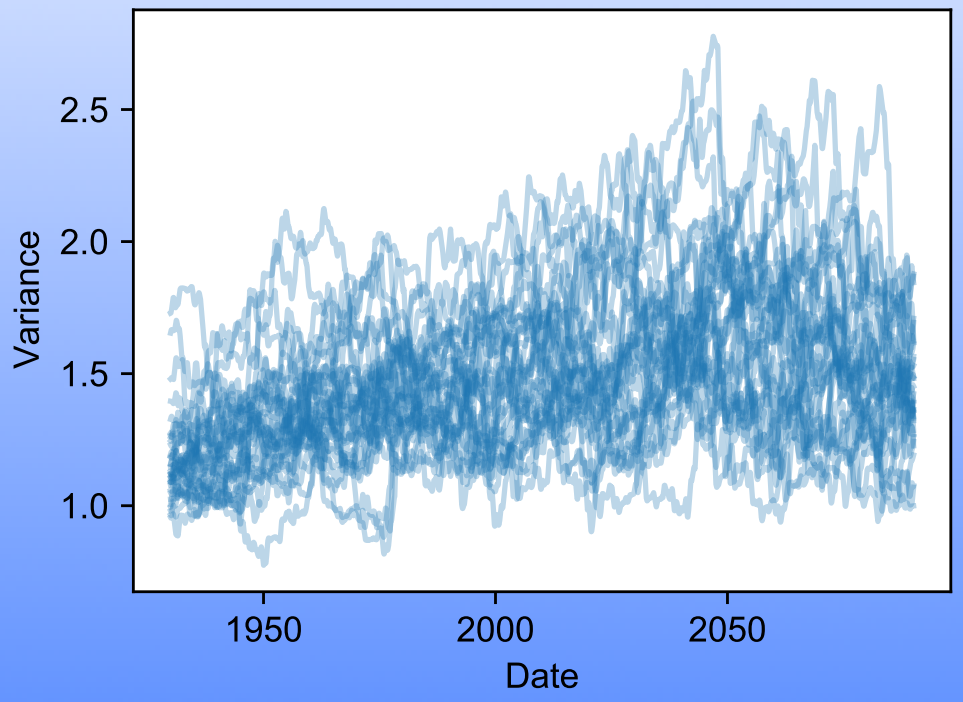

Figure 4: Niño 3.4 20-year variance for individual members in full forcing ensemble.

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.

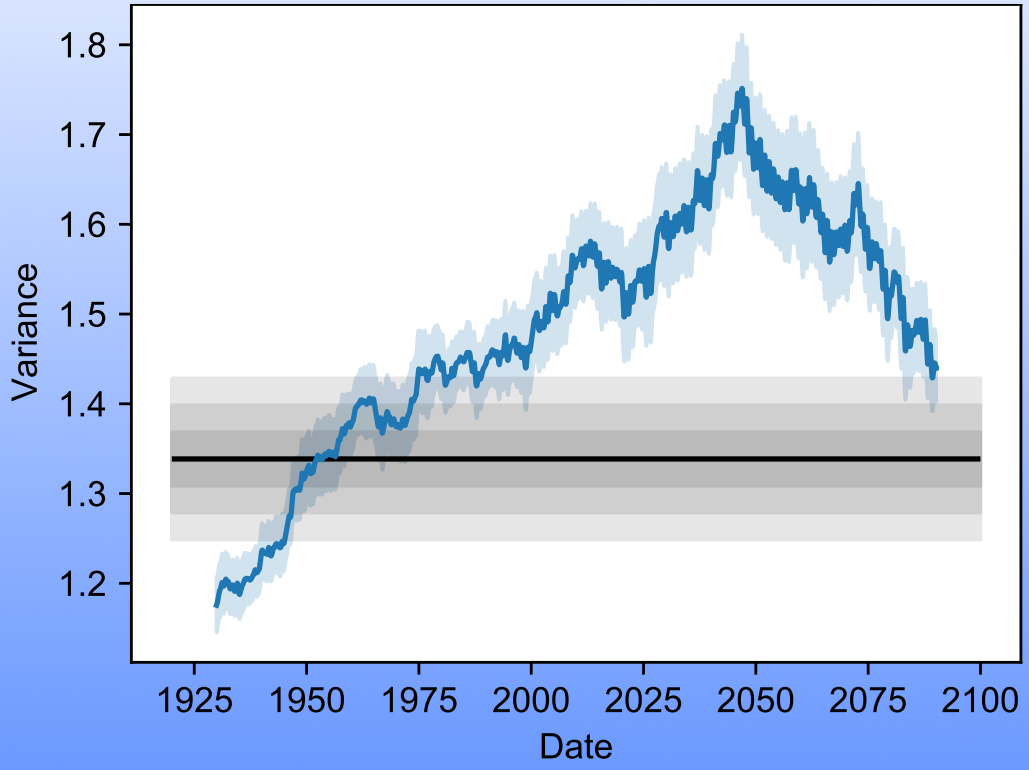

Figure 5: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and standard errors

Human Impact: 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!

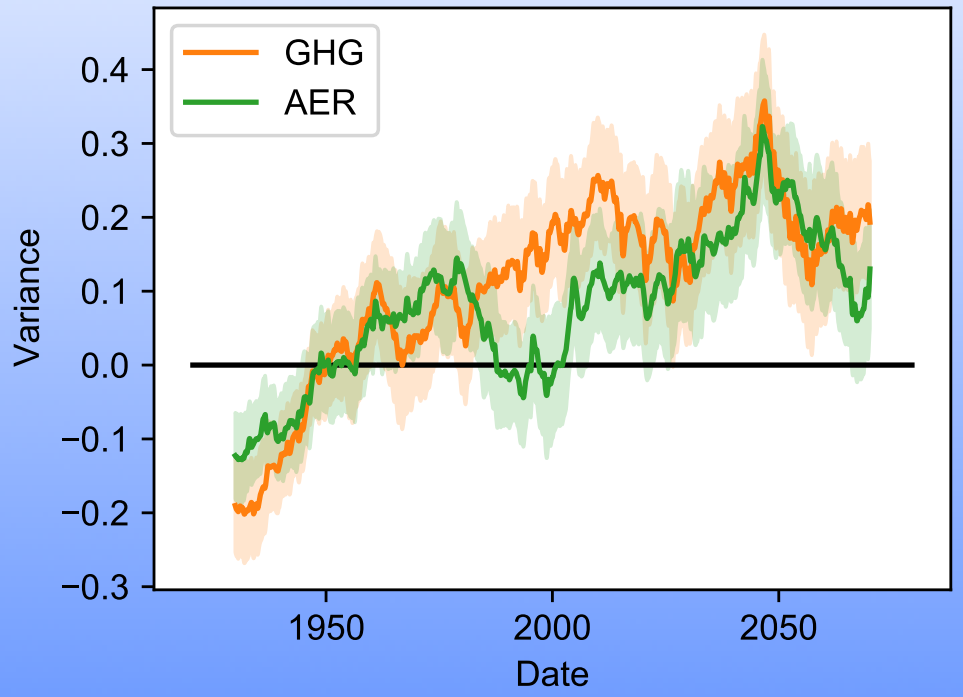

Figure 6: Influence of individual human factors. Yellow is greenhouse gasses, Green is aerosols.

How: Correlation With Changes in Ocean Temperature

- Why do greenhouse gasses and aerosols strengthen ENSO?
- Examining relationship between ocean temperature and ENSO intensity in each simulation.
- Calculate correlation coefficient between ENSO intensity and ocean temperature.
- Detrend and smooth
- Correlation coefficient at each grid-point.

Physical Mediator: Heating Difference

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

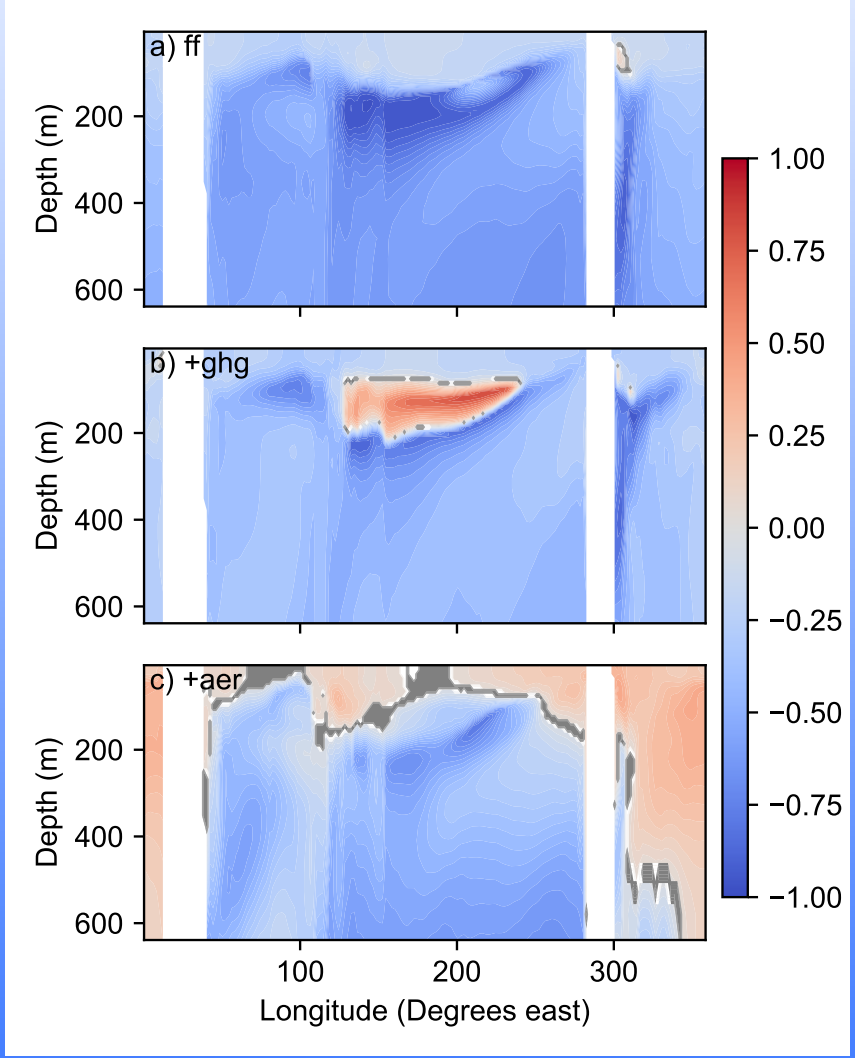

Figure 7: Correlation between ENSO intensity and ocean temperature in a) fully forced b) grenhouse and c) aersol ensembles

Conclusion

Predicted increase in variance	There is likely to be an increase in ENSO strength over the next 100 years.
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.

Discussion

- ENSO intensification is bad for human societies.
- Improve prediction ability to help people prepare.
- Reduce danger by switching to renewable energy.
- Next steps:
  - Work with other datasets, such as the new CESM2
  - Examine other variables to further analyze mediator process

Figure 8: Flooding in Peru in 2017, caused by extreme El Niño event.

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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