The Impact of Anthropogenic Forcing on ENSO Amplitude

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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

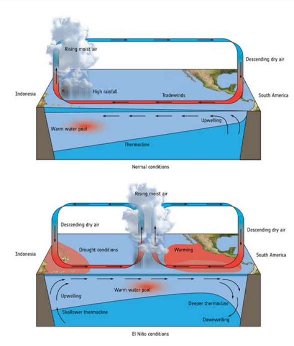

Figure 1: Changes to tropical Pacific climate during El Niño. `https://www.esa.int/ESA_Multimedia/Images/2018/08/El_Nino`

Long-Term vs Short-Term Change

- Long-term change: climate change/global warming
  - Causes: greenhouse gasses, aerosols (smoke), land use, etc.
- Short-term change: climate variability
  - ENSO, seasons, AMO (Atlantic Multidecadal Oscillation), etc.

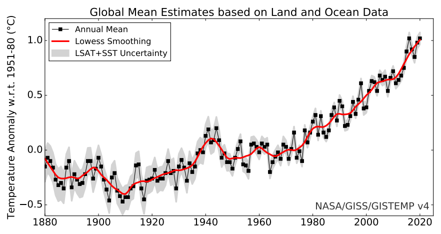

Figure 2: Global average temperature changes since 1880. Red line: smoothed average, black line: unsmoothed average. `https://data.giss.nasa.gov/gistemp/graphs_v4`

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 (Kay et al., 2015).
- 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.

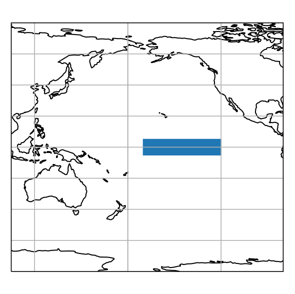

Figure 3: Ninño 3.4 region is the shaded box.

Butterfly Effect: The Need for a Large Ensemble

- Butterfly effect: Small differences in initial conditions can become big differences in end result (Lorenz, 1963).
- 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.

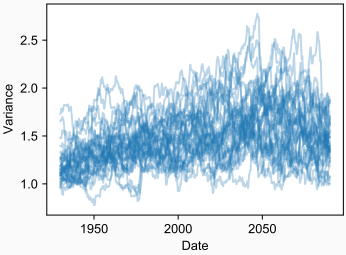

Figure 4: Ninño 3.4 20-year variance for individual members in full forcing ensemble.

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.

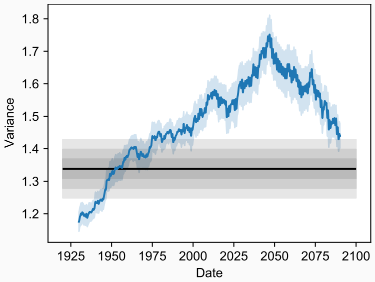

Figure 5: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and standard errors

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: disagree with previous studies (Deser et al., 2020).
- Greenhouse gasses and aerosols are both human-produced.

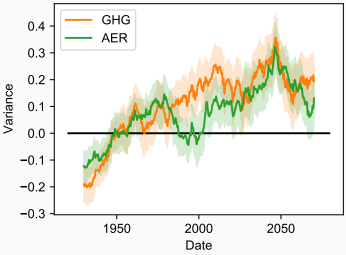

Figure 6: Influence of individual human factors. Yellow is greenhouse gasses, green is aerosols.

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.

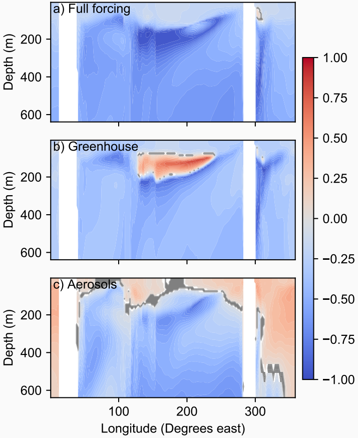

Figure 7: Correlation between ENSO intensity and ocean temperature in 3 major ensembles

Conclusion and Discussion

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

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- 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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