

The Impact of Anthropogenic Forcing on ENSO Amplitude

Benjamin Goldman

July 7, 2021

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

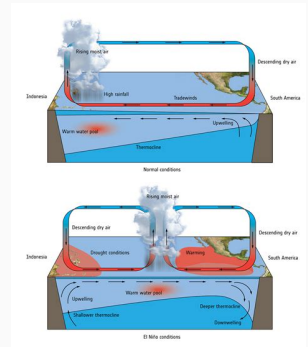


Figure 1: Changes to tropical Pacific climate during El Niño.

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.

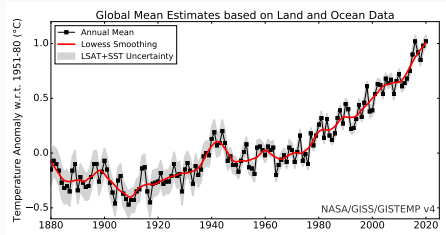


Figure 2: Global average temperature changes since 1880. Red line: smoothed average, black line: unsmoothed average. https://data.giss.nasa.gov/gistemp/graphs_v4

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.

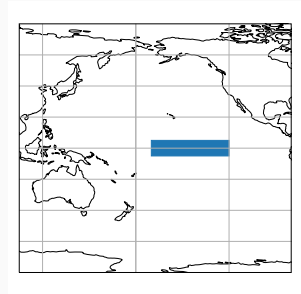


Figure 3: Niño 3.4 region is the shaded box.

Butterfly Effect: The Need for a Large Ensemble

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

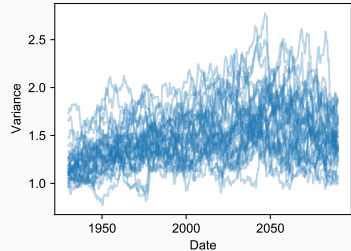


Figure 4: Niño 3.4 20-year variance for individual members in full forcing ensemble.

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.

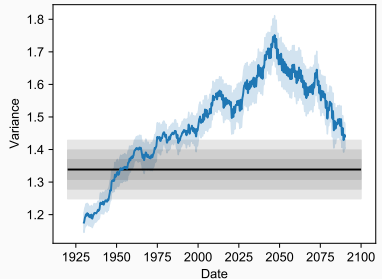


Figure 5: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and standard errors

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

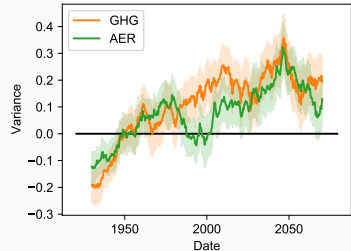


Figure 6: Influence of individual human factors. Yellow is greenhouse gasses, green is aerosols.

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.

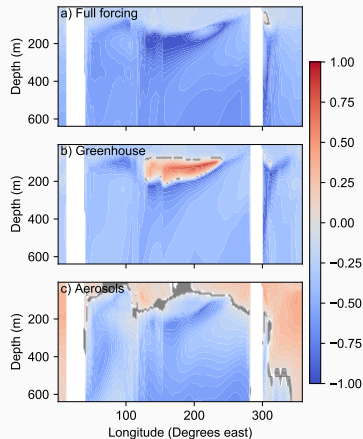


Figure 7: Correlation between ENSO intensity and ocean temperature in 3 major ensembles₁₂

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.

Acknowledgements

- 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.
- 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

References

- Cai, W., Wang, G., Dewitte, B., Wu, L., Santoso, A., Takahashi, K., Yang, Y., Carréric, A., and McPhaden, M. J. (2018). Increased variability of eastern pacific el niño under greenhouse warming. *Nature*, 564(7735):201–206.
- 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 anthropogenic 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. C., Danabasoglu, G., Edwards, J., Holland, M., Kushner, P., Lamarque, J.-F., Lawrence, D., Lindsay, K., Middleton, A., Munoz, E., Neale, R., Oleson, K., Polvani, L., and Vertenstein, M. (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.
- Lorenz, E. N. (1963). Deterministic nonperiodic flow. *Journal of atmospheric sciences*, 20(2):130–141.
- 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).