The Impact of Anthropogenic Forcing on ENSO Amplitude

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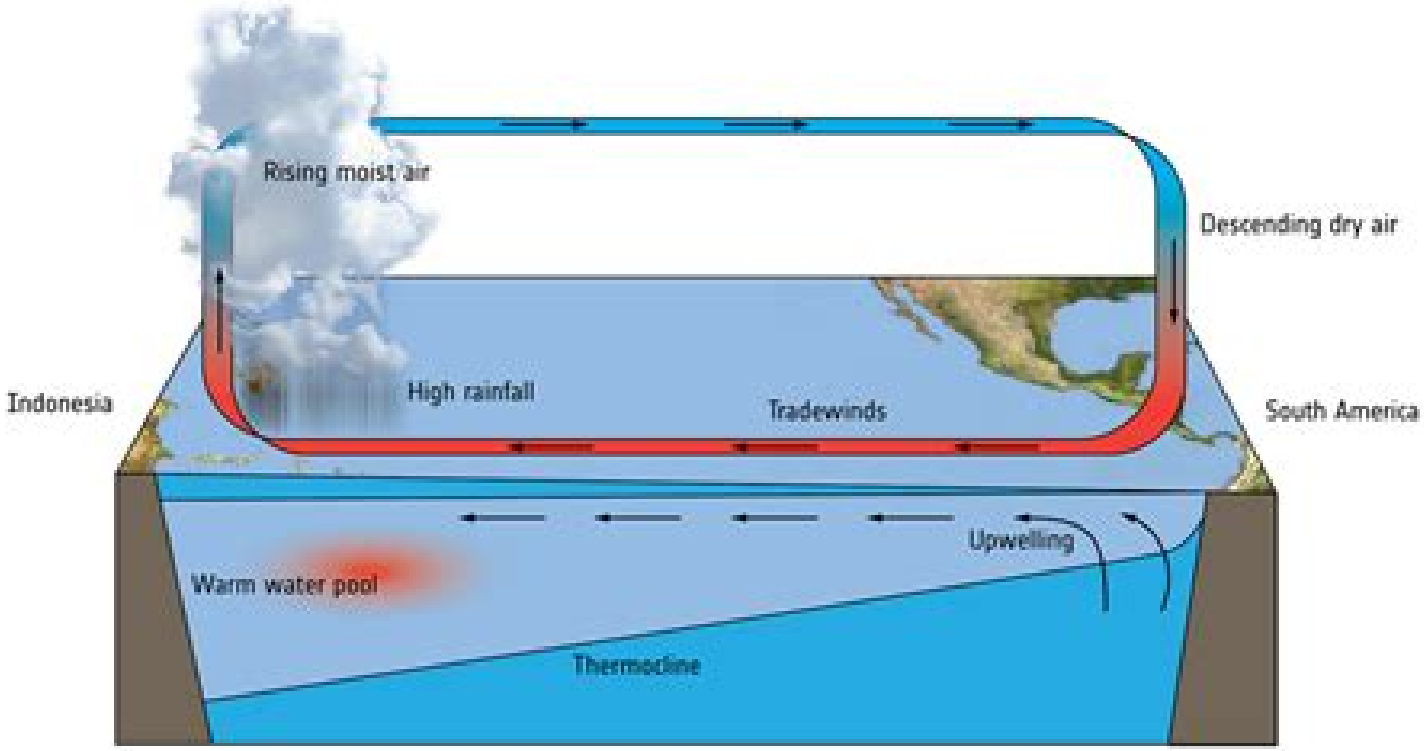
- Drives extreme weather around the world
- Oscillation between warm and cold temperature in the Pacific Ocean
- Some events are more strong than others
- Significant effect on people: 2015-2016 event
- Major issue is prediction



Normal conditions

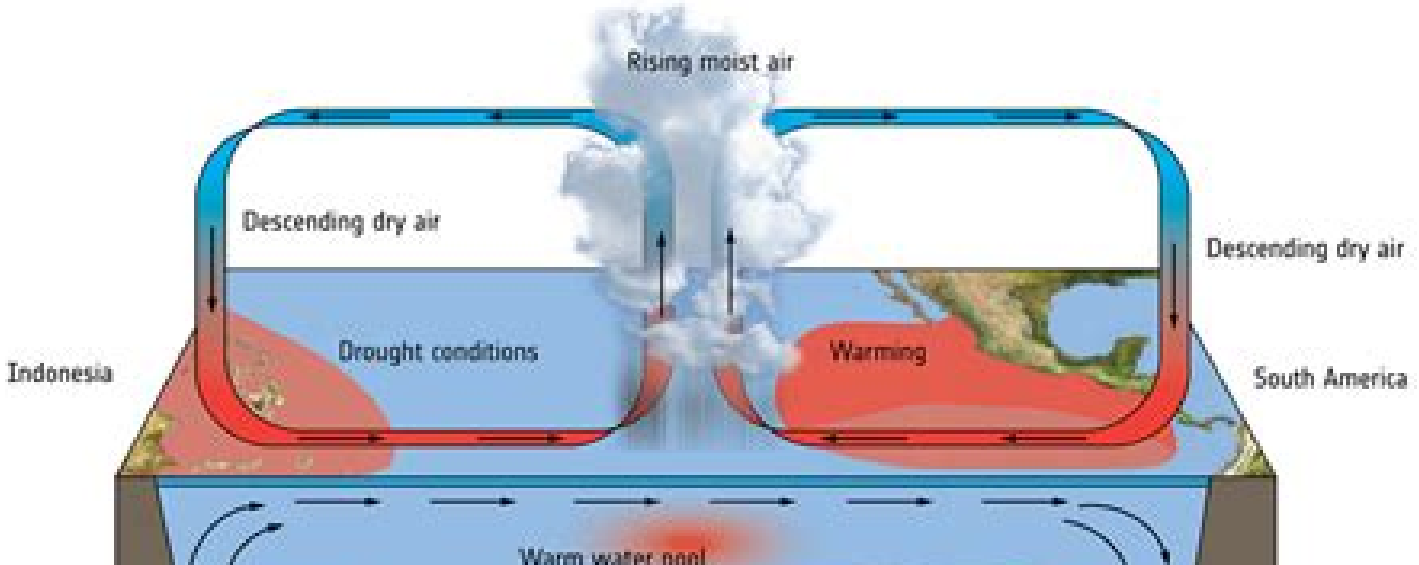


Figure: Changes to tropical Pacific climate during El Niño.
`https://www.esa.int/ESA_Multimedia/Images/2018/08/El_Nino`

- 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.

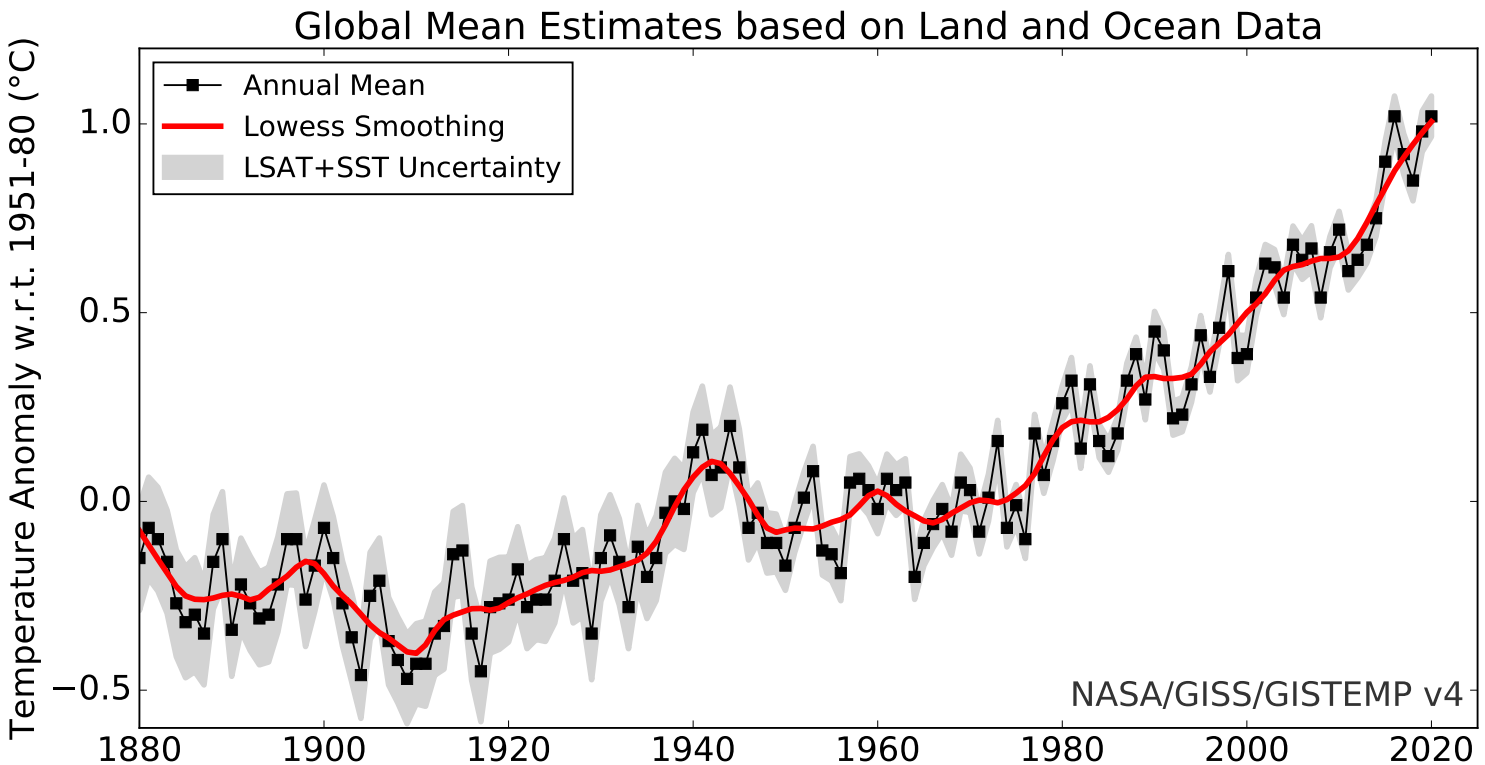
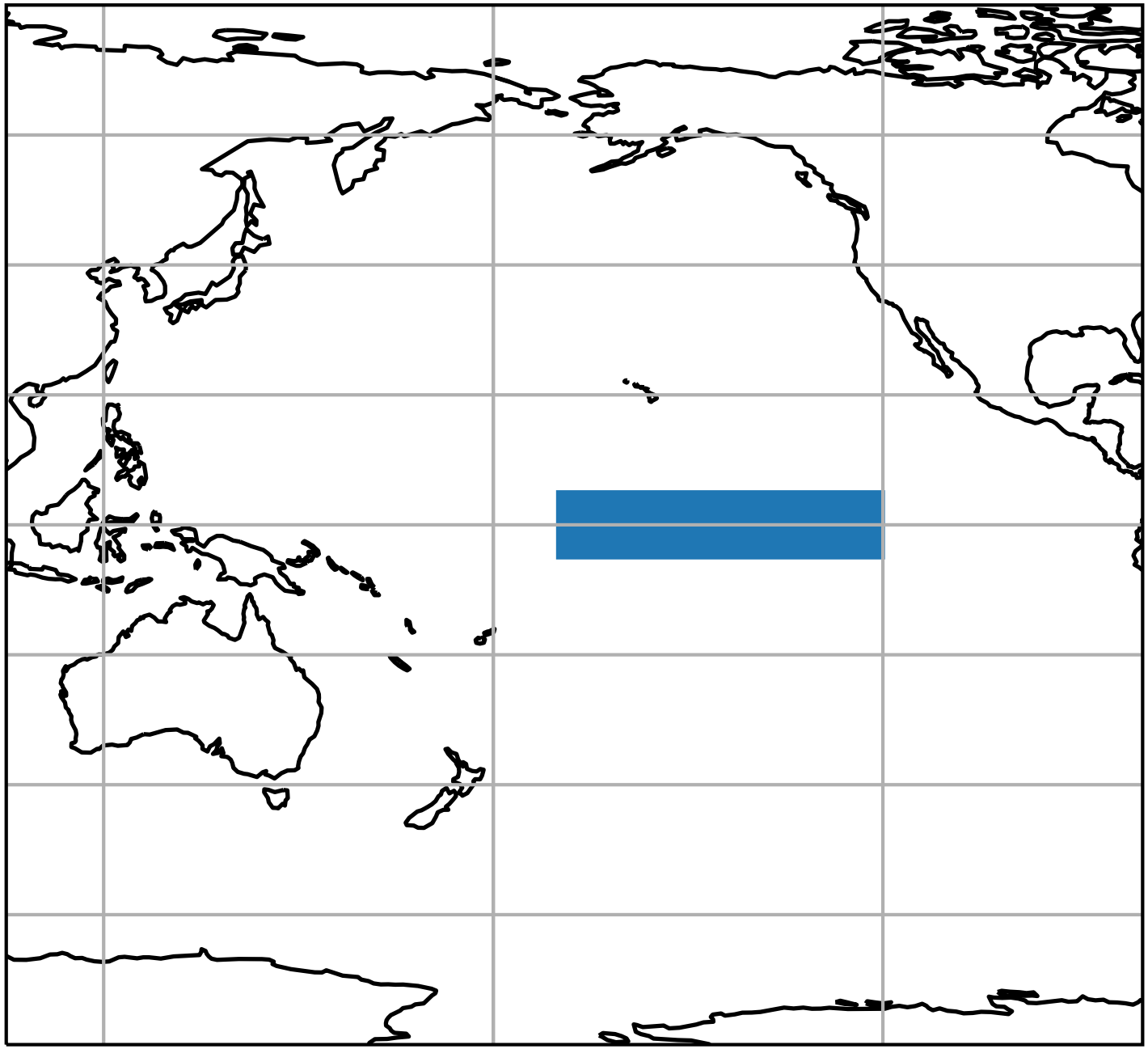


Figure: Global average temperature changes since 1880. Red line: smoothed average, black line: unsmoothed average.
https://data.giss.nasa.gov/gistemp/graphs_v4

- ?
  - Past studies disagree about whether ENSO will strengthen or weaken.
  - Simulation discrepancy caused by modeling of ENSO mechanics.
- ?
  - Used a large dataset of climate predictions.
  - ENSO may become stronger in the future.
- ?
  - 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.
- 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.
- 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.
- 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.



- 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.

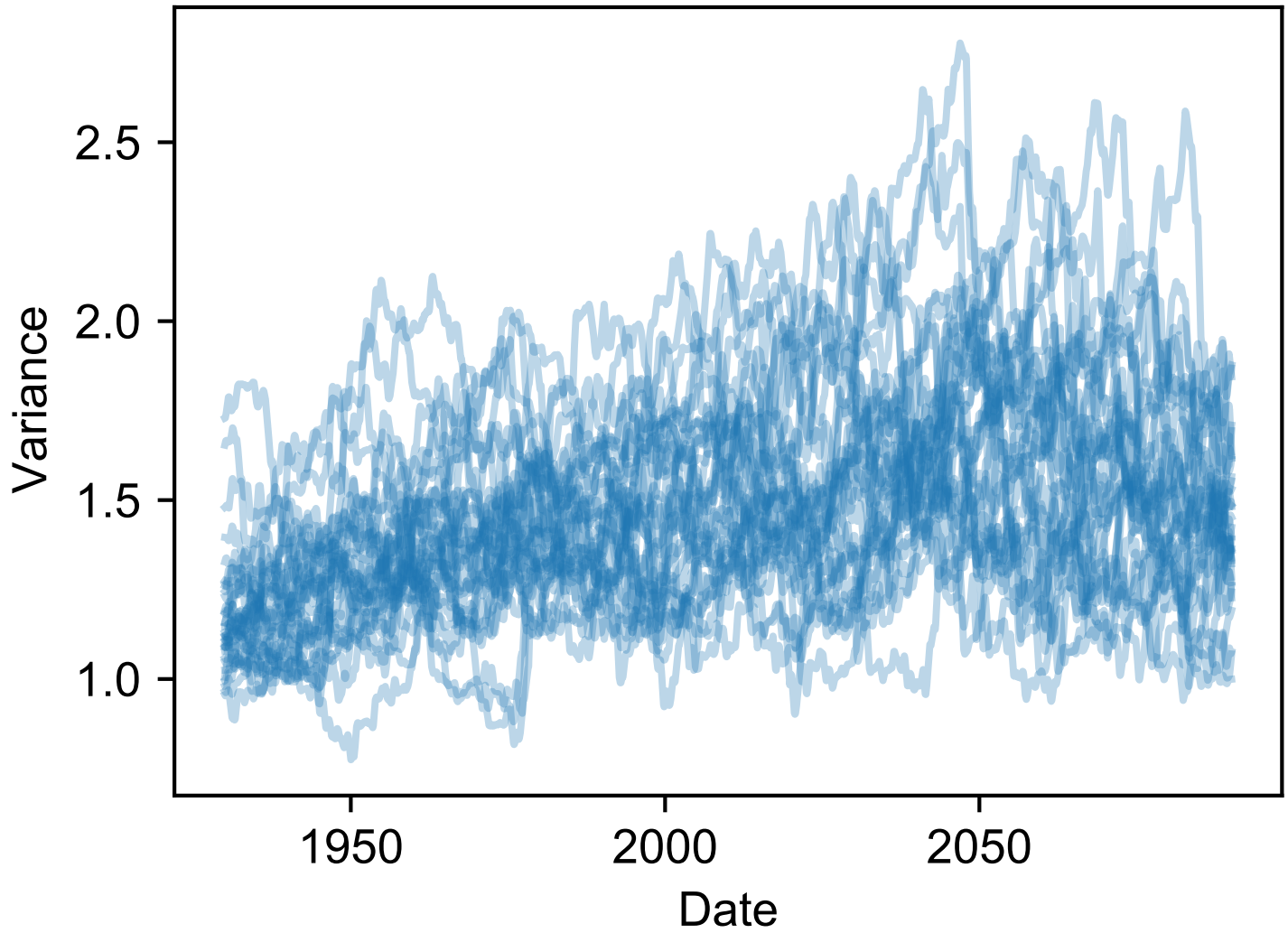


Figure: Ninño 3.4 20-year variance for individual members in full forcing ensemble.

- 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.

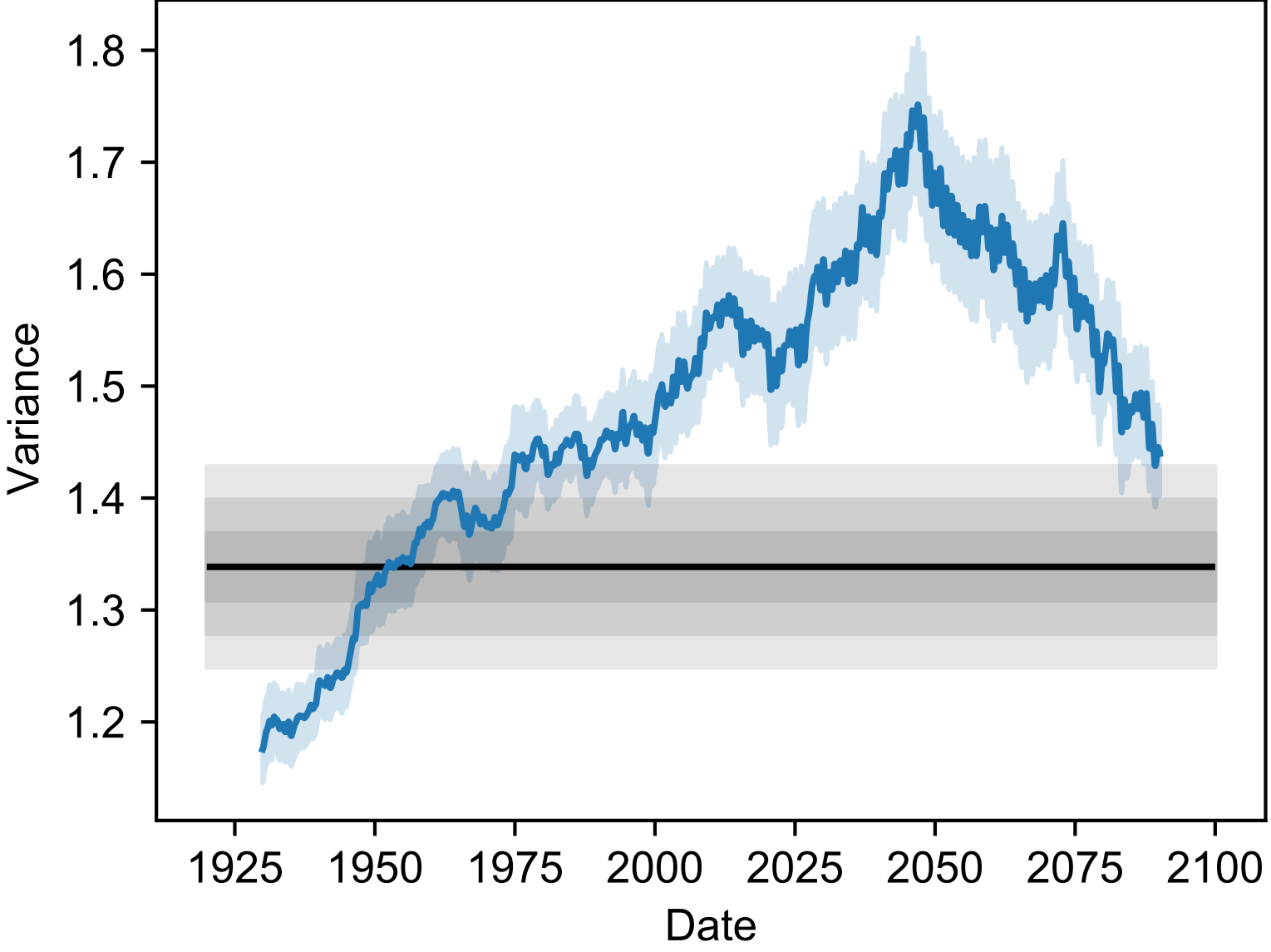


Figure: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and standard errors

- 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.

- Greenhouse gasses and aerosols contribute to increase in variance.
- Aerosols and greenhouse gasses have same sign: disagree with previous studies (?).
- Greenhouse gasses and aerosols are both human-produced.

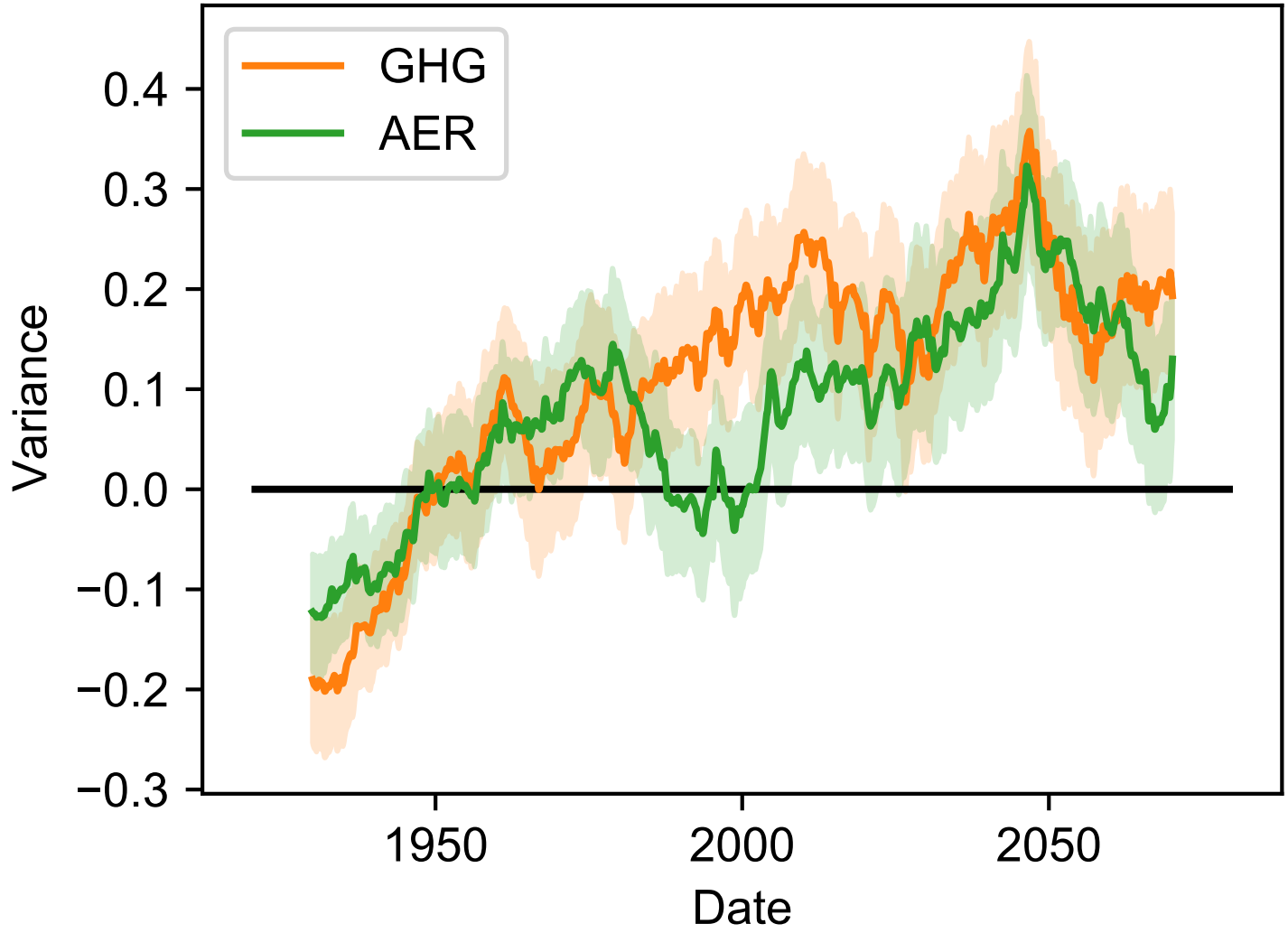


Figure: Influence of individual human factors. Yellow is greenhouse gasses, green is aerosols.

- 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.
- 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.

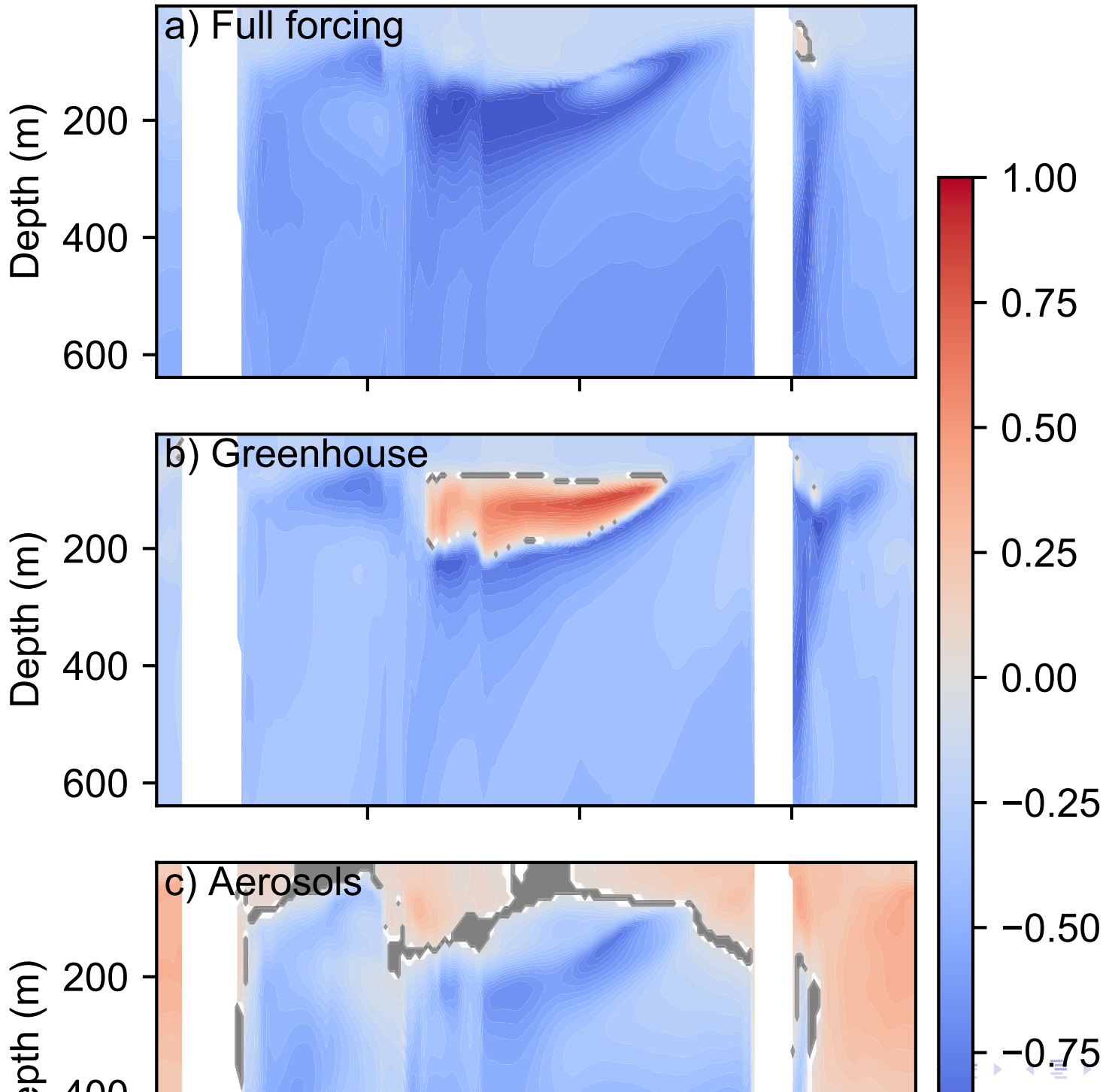

a) Full forcing
b) Greenhouse
c) Aerosols
Depth (m)
200
400
600
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75

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

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

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., Danabasoglu, G., Edwards, J., et al. (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 the 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):11–390.