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 Pacific Ocean temperature
- Occurs every 2-7 years
- Some years are more intense than others
- Major issue is prediction

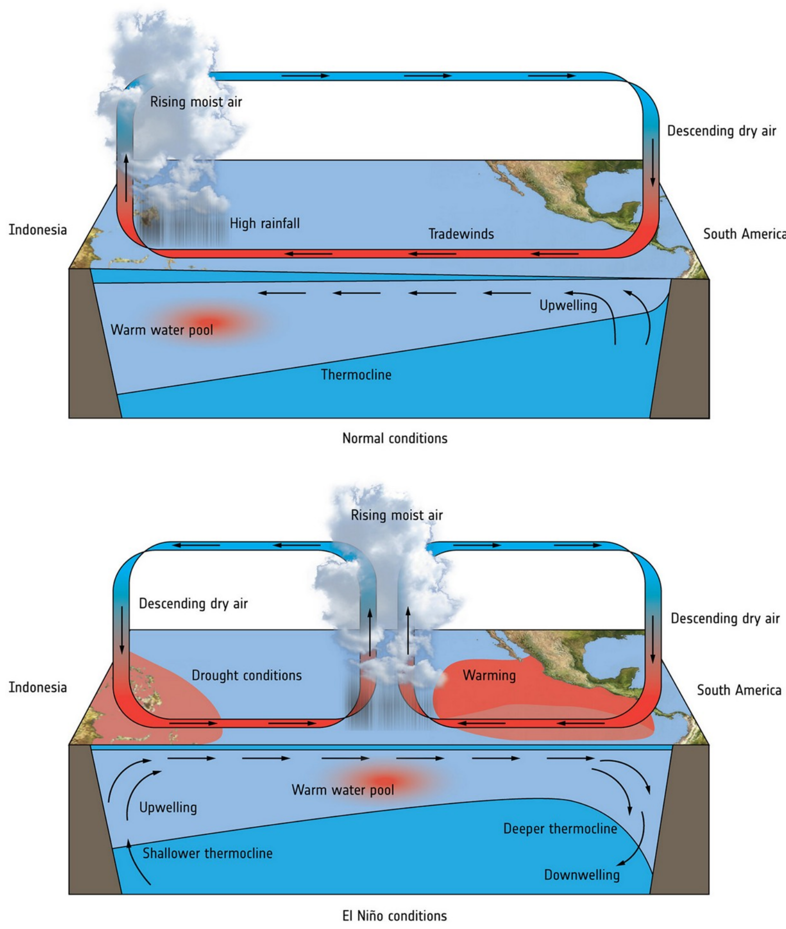


Figure 1: Changes to tropical Pacific climate during El Niño

Short vs. Long Term Change

- Weather is not climate!
- Climate varies on short term and long term
- Short term changes: ENSO and more
- Long term changes: Global warming

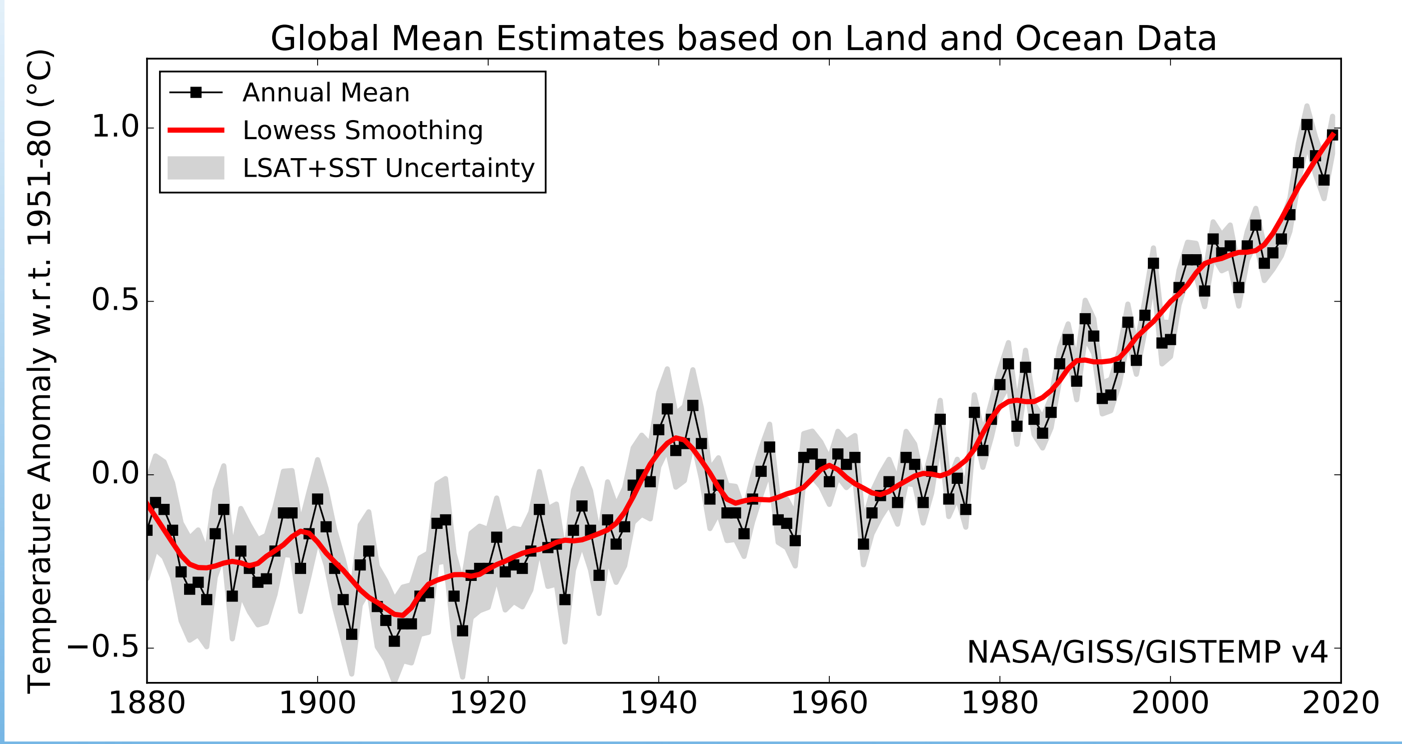


Figure 3: Global average temperature changes since 1880. Red line shows smoothed average using the LOWESS algorithm. Black line shows unsmoothed annual mean.

Review of Literature

Chen et. al. 2017	Why are the results of climate studies disagreeing about whether ENSO will intensify or weaken?
Maher et. al. 2018	Used a large dataset to estimate changes to ENSO intensity. They found that it may increase.
Cai et. al. 2018	Used a more advanced method of measuring ENSO strength and found that the data generally agrees that ENSO will intensify.
Gap	How and why are humans increasing ENSO intensity?

Research Goals

Problem	ENSO is serious, so we need to predict it.
Verify past research	Does the data show that ENSO will become stronger?
Why: Greenhouse gasses vs aerosols?	Figure out which human activities are causing the increase
How: Ocean structure	Determine what changes are taking place to make ENSO stronger

Data: the CESM LE

- 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 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

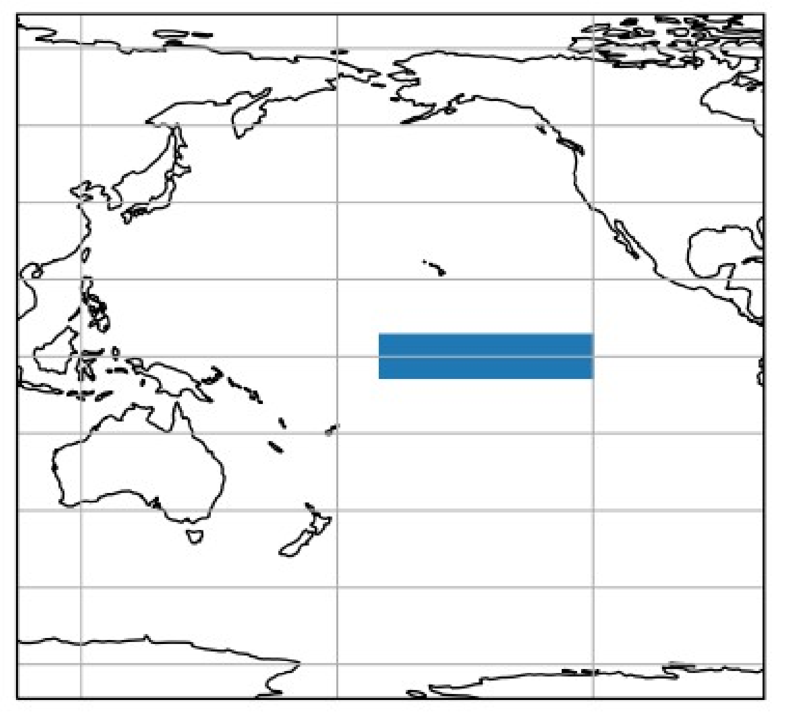


Figure 4: Niño 3.4 region is the shaded box.

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

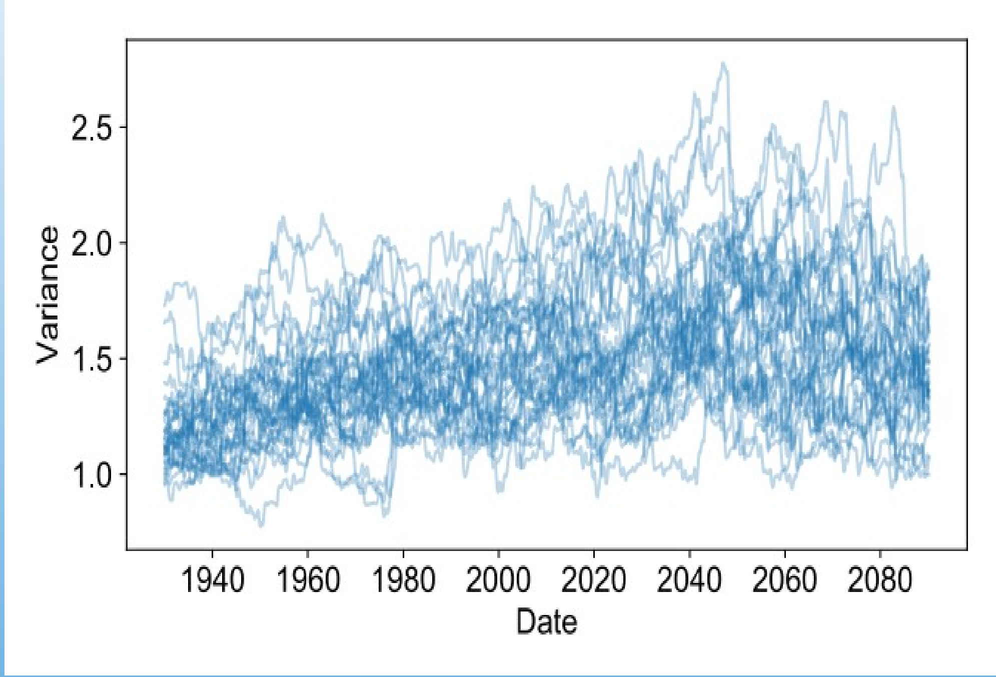


Figure 7: Niño 3.4 20-year variance for individual members in full forcing ensemble

Model Predictions: ENSO in the Future

- Calculate mean and standard error for ENSO intensity in ensemble and control
- ENSO is predicted to intensify in the 21st century!
- This means more extreme weather!

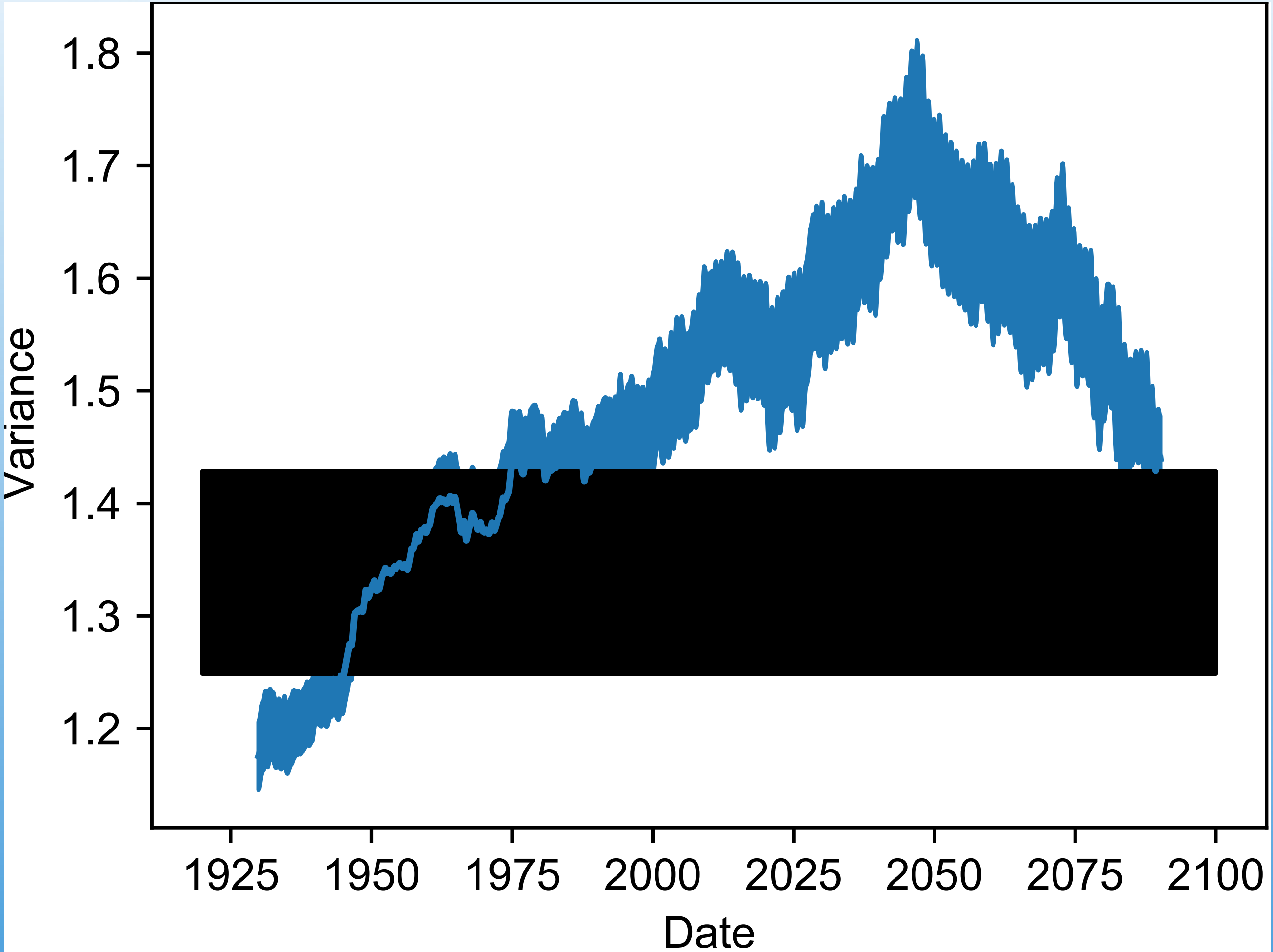


Figure 6: 20-year variance of Niño 3.4 index for fully-forced ensemble. Grey bar shows control mean and 1, 2, 3x standard error

Analysis of Individual Factors

- Why is ENSO predicted to intensify? What human impacts play the largest role?
  - 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
- Sum of individual factors is different from full forcing mean
- Greenhouse gasses and aerosols are both human-produced!

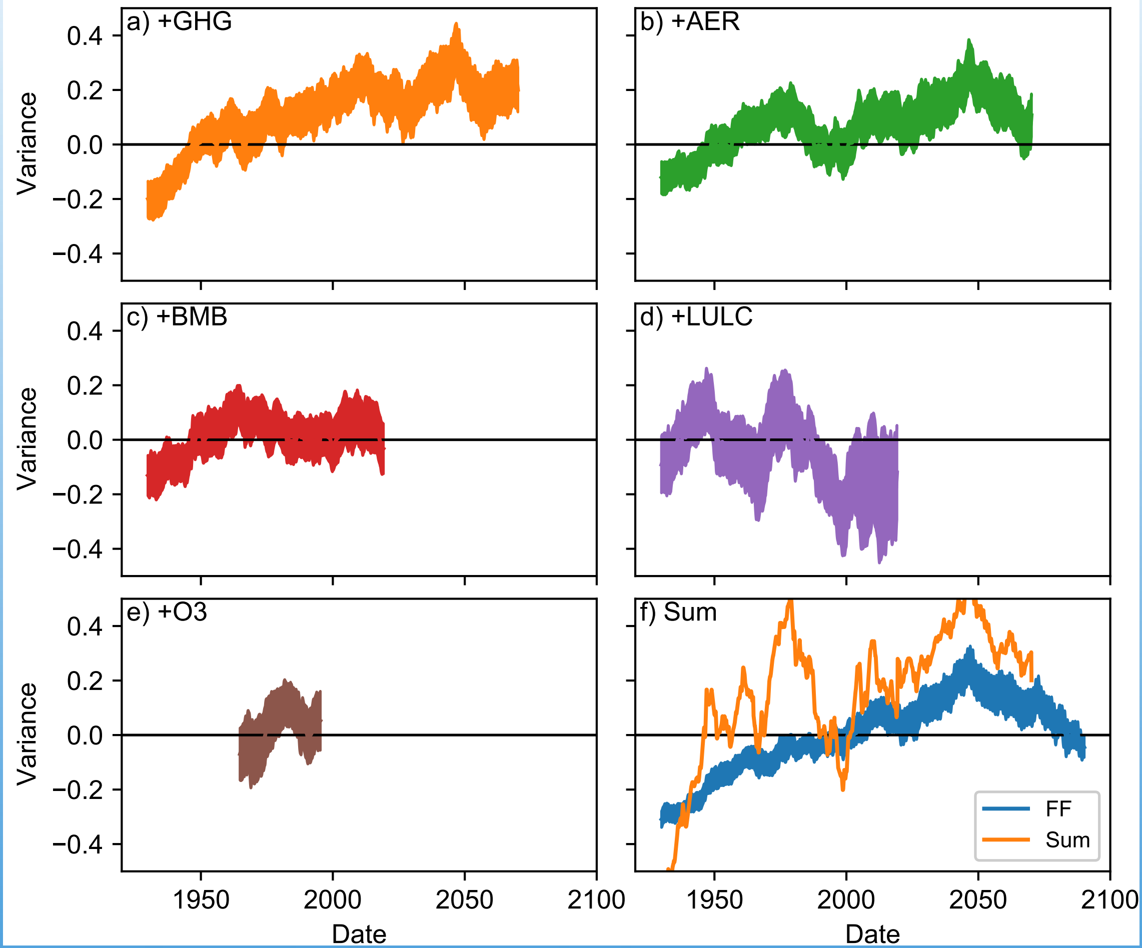
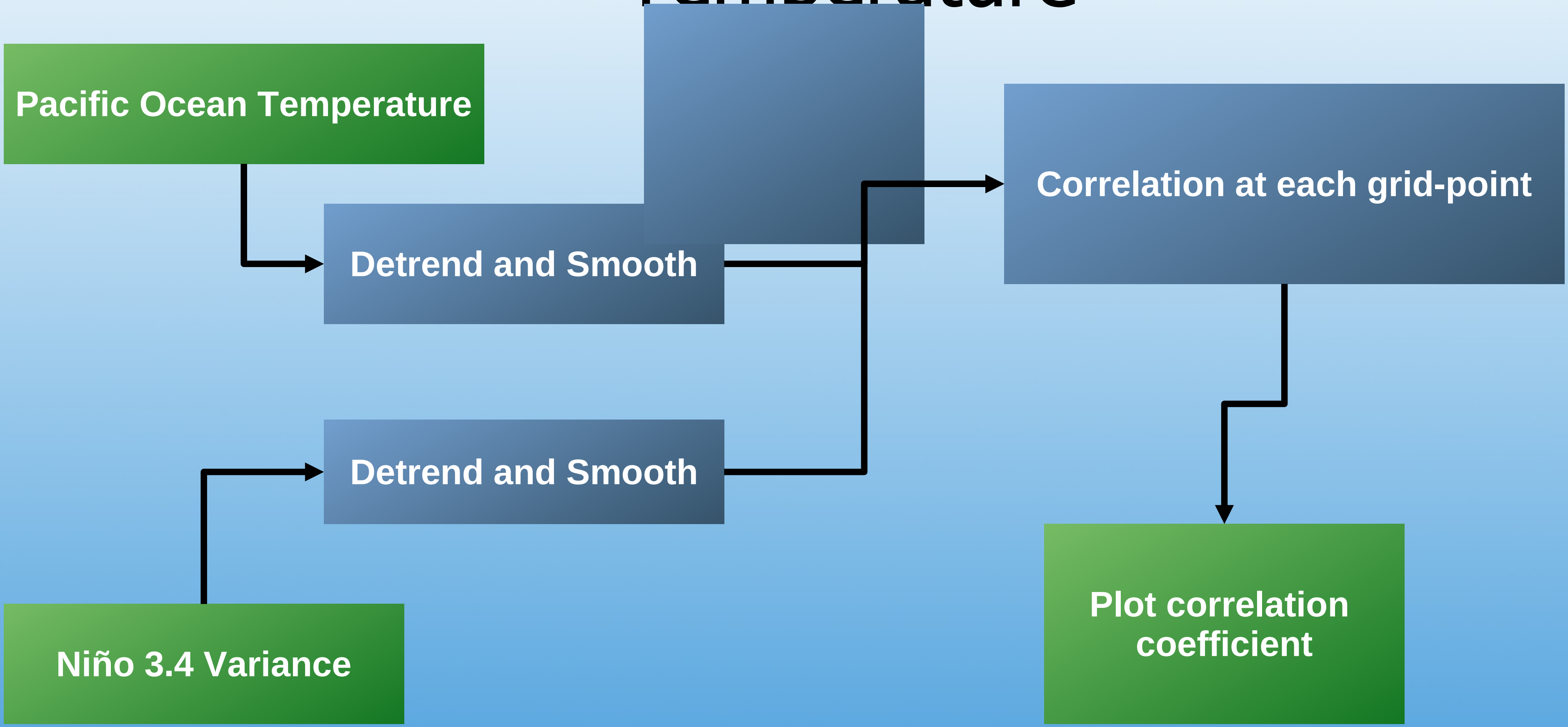


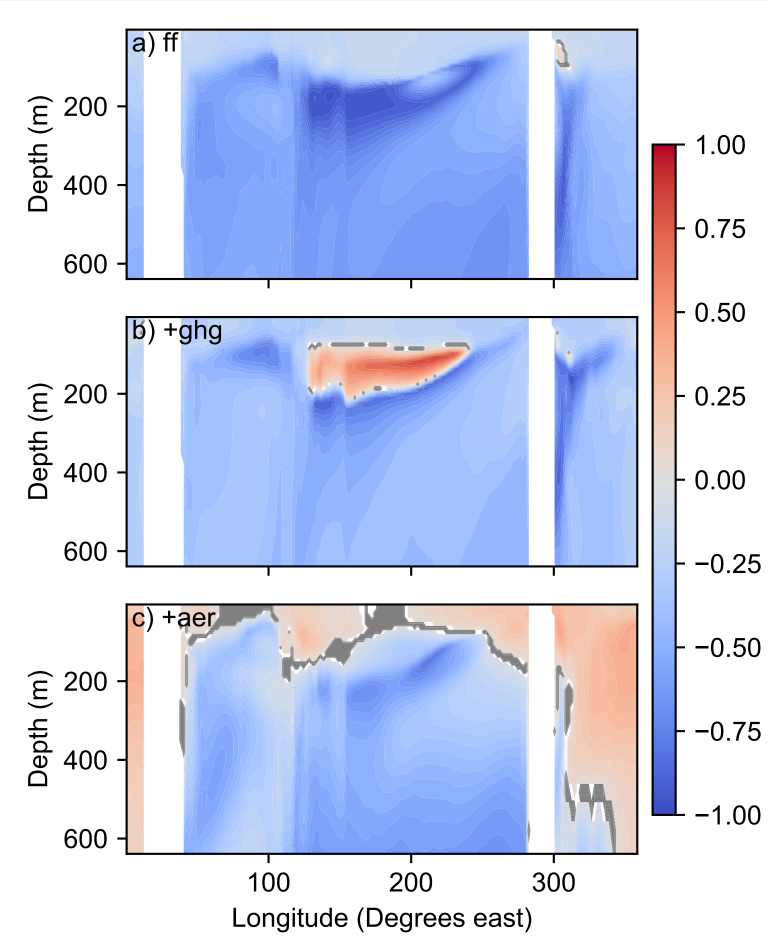
Figure 8: Difference between single-forcing and full-forcing variance for a) greenhouse gasses, b) aerosol emissions, c) biomass burning, d) land use/cover, e) ozone. f) compares sum of individual cases with fully-forced case.

Correlation With Changes to Ocean Temperature



Role of Stratification

Figure 9 correlation between detrended & smoothed Niño 3.4 20-year variance and equatoriall pacific ocean temperature in a) fully forced b) ghg and c) aer ensembles



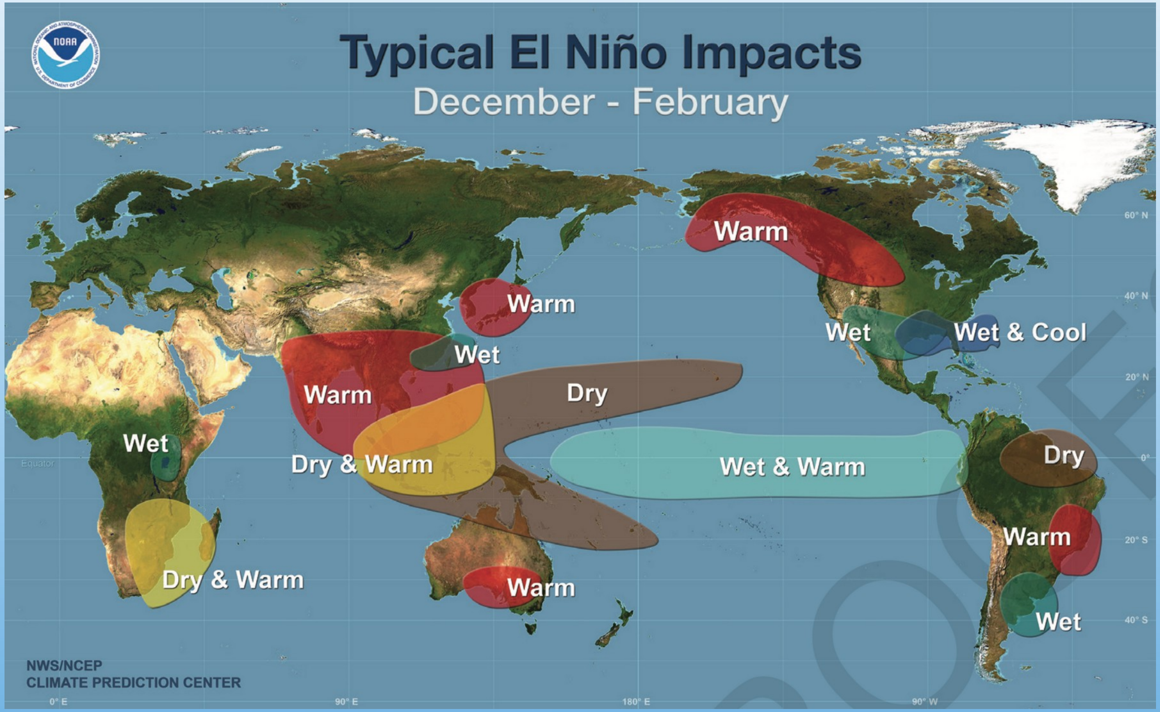
- Strong negative correlation in fully forced ensemble below surface
- Positive correlation in ghg ensemble
- Weak/zero correlation in aer ensemble
- Rising temperatures will heat different layers of ocean at different rates

Summary

Estimate future changes	There is likely to be an increase in ENSO strength over the next 100 years.
Analyze role of single factors	Increase is likely caused by the combined influence of greenhouse gasses and aerosols.
Physical Mechanism	Future ocean warming increases ENSO intensity by warming the upper layers of the Pacific faster than the central layers.

Discussion

- ENSO intensification means more extreme weather
- Predict it to help those affected
- Reduce greenhouse emissions



Application and Next Steps

- Application: to help humans prepare for future changes to the earth’s climate
- Next steps:
  - Continue analysis of association with internal variability to explain low variance from 1920-1960.
  - Compare results to analysis of CMIP6 and CESM2 ensembles.
  - Measure correlation with ocean salinity and potential density to further analyze changes to ocean structure
  - Advanced statistical analysis

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The Impact of Anthropogenic Forcing on ENSO Amplitude

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