

The Impact of Anthropogenic Forcing on ENSO Amplitude

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Climate Change and Variability

- Global warming
- Long-term trends vs short-term randomness

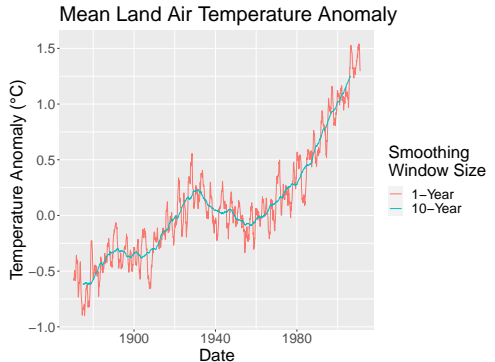


Figure 1: Global mean land air temperature in GISSTEMP 4 dataset. (Team et al., 2019) and (Lenssen et al., 2019)

Climate forcing

- **Forcing**: any external factor that affects climate.

GHG Greenhouse gasses

AER Aerosols (natural:
volcanic ash, artificial:
smoke)

BMB Biomass burning

LULC Land use/cover
(deforestation,
desertification)

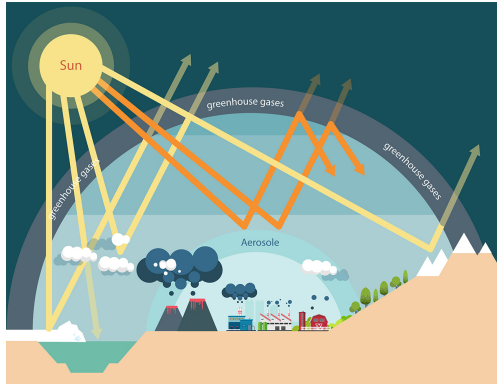
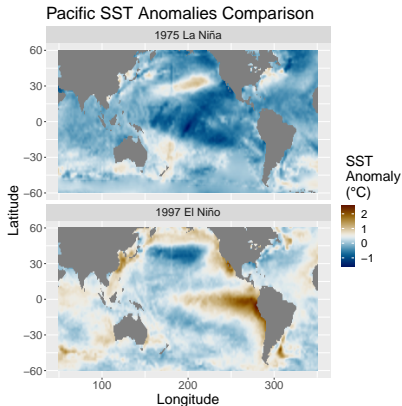


Figure 2: Factors that contribute to the greenhouse effect. <https://www.coolaustralia.org/the-greenhouse-effect-secondary>

El Niño (ENSO)

- Warming and cooling of the Pacific Ocean.
- Affects human societies through temperature and rainfall. (Ropelewski and Halpert, 1987)
- May be affected by climate change.

Figure 3: Comparison of SST anomaly between 1975 La Niña event and 1997 El Niño event in HadISST 1 dataset. (Rayner et al., 2003)



- ENSO's properties observed vary across different decades. (Lübbecke and McPhaden, 2014).
- ENSO responds to external forcing.
 - Correlation between ENSO strength and sunspot activity (Emile-Geay et al., 2007).
 - Weakened ENSO during the Ice Age due to reduced CO₂ levels (Zhu et al., 2017).
- Models show possible increasing ENSO activity in the future (Zheng et al., 2017) and (Maher et al., 2018).
- Factors other than CO₂ can affect ENSO.
 - Ozone emissions reduce ENSO activity (Nowack et al., 2017).
 - Aerosol emissions modify ENSO geographical center (Stevenson et al., 2017).

- Little research using a large ensemble to examine the effect of individual factors on ENSO.
- Considerable disagreement between studies on whether ENSO will strengthen or weaken due to global warming

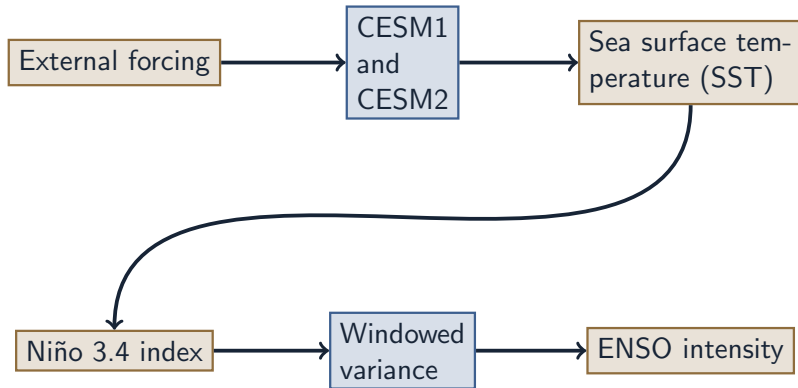
What? Do the CESM1 and CESM2 predict increased or decreased ENSO intensity in the future?

Why? Is the predicted increase (or decrease) due to human activities?

How? What processes are causing greenhouse gasses and aerosols to affect ENSO?

- CESM1 (Kay et al., 2015) and CESM2 (Danabasoglu et al., 2020)
- Observed forcing levels from 1850-2005
- Predicted forcing levels from 2005-2100
- Ensembles have 40 and 50 simulations respectively
- Control simulation with pre-1850 forcing levels
- Single forcing ensembles that represent influence of single factor

Measuring ENSO Intensity



ENSO is Becoming Stronger

- Increase in ENSO intensity in both ensembles.
- Increase slows down in CESM1 and decreases in CESM2 after around 2050.

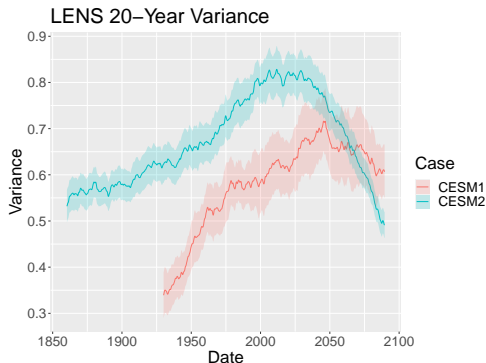


Figure 4: ENSO intensity ensemble mean and standard error for CESM1 and CESM2

Influence of Aerosols and Greenhouse Gasses

- Influence of each factor on ENSO amplitude.
- Increased variance due to greenhouse gas emissions.
- Somewhat increased variance from aerosol emissions, but not linear.

Takeaway: Human activities are triggering predicted strengthening of ENSO.

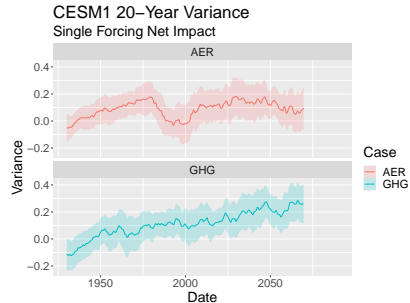


Figure 5: Influence of GHG, AER, and BMB forcing on ENSO amplitude in CESM1

Correlation With Ocean Temperature

- Correlation coefficient between ocean temperature and ENSO amplitude.
- Negative coefficient in subsurface layer.
- Positive coefficient in surface layer.
- Suggests that ocean stratification may be mediating global warming influence on ENSO.
- Difference in heating modifies mechanics of ENSO cycle.

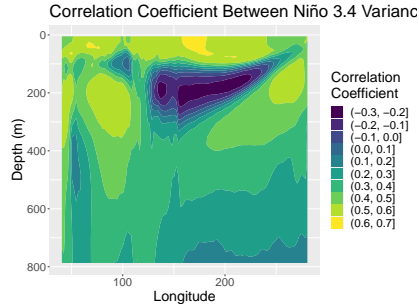


Figure 6: Correlation coefficient between ENSO amplitude and ocean temperature in equatorial cross-section in the fully-forced CESM1 ensemble

Wavelet Analysis

- Separate ENSO record into changes in period over time.
- Increase in power in late 21st century agrees with previous results.
- In CESM1, increase in ENSO intensity is mainly strengthening of longer-period cycle.
- In CESM2, longer-period ENSO weakens after 2025.

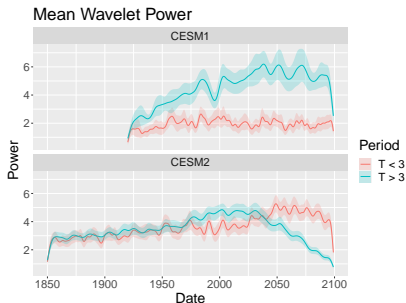


Figure 7: Wavelet power spectrum for the Niño 3.4 index in the fully-forced CESM1 and CESM2 ensembles

- Rising greenhouse gas levels increase Pacific Ocean stratification, strengthening ENSO cycle.
- Aerosol influence is nonlinear because aerosol levels are not purely increasing.
- Stronger ENSO may lead to greater temperature variability and extreme weather.
- CESM1 and CESM2 conflict in their prediction of the changes to ENSO's frequency.

Limitations:

- Niño 3.4 index shown to be inaccurate for some models (Cai et al., 2018).
- CESM may contain biases.

Application: to improve our ability to predict ENSO and help people prepare for increased likelihood of extreme weather.

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