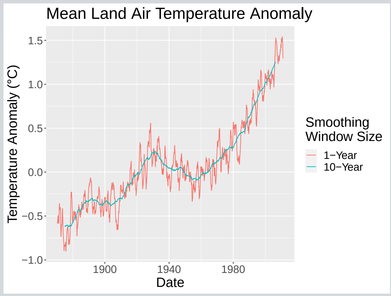
Climate Change and Variability

- 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)

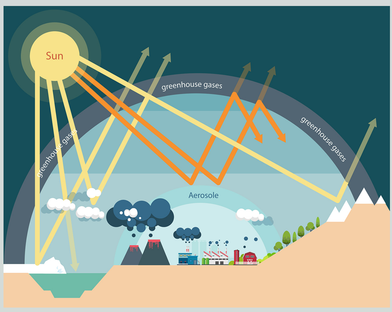
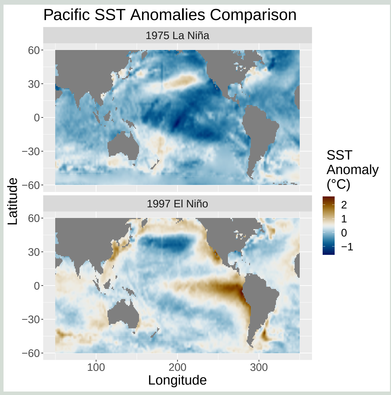


Figure 2: Factors that contribute to the greenhouse effect. `https://www.coolaustralia.org/the-greenhouse-effect-secondary`

El Niño (ENSO)

- Warming and cooling of the Pacific Ocean.
- Affects human societies through temperature and rainfall. (Ropelewski and Halpert, 1987)

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



Review of Literature

- ENSO's properties observed vary across different decades. (Lübbecke and McPhaden, 2014).
- ENSO responds to external forcing.
- Weakened ENSO during the Ice Age due to reduced CO_2 levels (Zhu et al., 2017).
- Models show possible increasing ENSO activity in the future (Zheng et al., 2017) and (Maher et al., 2018).

Gap and Questions

- 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?

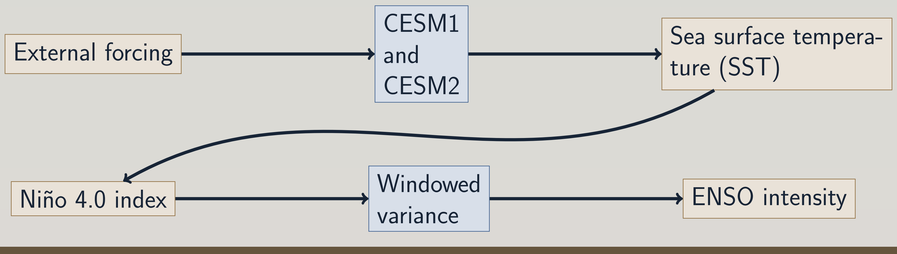
Why? Is the predicted increase (or decrease) due to human activities?

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

Model Setup (Data)

- Community Earth System Model (CESM) Versions 1 and 2 (Kay et al., 2015) (Danabasoglu et al., 2020).
- Predicts climate over 21st century with global warming.
- 40-50 simulations per ensemble.
- Control simulation with pre-1850 forcing levels.
- Single forcing ensembles that represent influence of single factor.

Measuring ENSO Intensity



References

Danabasoglu, G., Lamarque, J.-F., Bacmeister, J., Bailey, D., DuVivier, A., Edwards, J., Emmons, L., Fasullo, J., Garcia, R., Gettelman, A., et al. (2020). The community earth system model version 2 (cesm2). *Journal of Advances in Modeling Earth Systems*, 12(2).

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.

Lenssen, N. J., Schmidt, G. A., Hansen, J. E., Menne, M. J., Persin, A., Ruedy, R., and Zyss, D. (2019). Improvements in the gistemp uncertainty model. *Journal of Geophysical Research: Atmospheres*, 124(12):6307–6326.

Lübbecke, J. F. and McPhaden, M. J. (2014). Assessing the twenty-first-century shift in ENSO variability in terms of the bjerknes stability index. *Journal of Climate*, 27(7):2577–2587.

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).

Rayner, N., Parker, D. E., Horton, E., Folland, C. K., Alexander, L. V., Rowell, D., Kent, E. C., and Kaplan, A. (2003). Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *Journal of Geophysical Research: Atmospheres*, 108(D14).

Ropelewski, C. F. and Halpert, M. S. (1987). Global and regional scale precipitation patterns associated with the el niño/southern oscillation. *Monthly weather review*, 115(8):1606–1626.

Team, G. et al. (2019). Giss surface temperature analysis (gistemp), version 4. *NASA Goddard Institute for Space Studies*.

Zheng, X.-T., Hui, C., and Yeh, S.-W. (2017). Response of ENSO amplitude to global warming in CESM large ensemble: uncertainty due to internal variability. *Climate Dynamics*, 50(11-12):4019–4035.

Zhu, J., Liu, Z., Brady, E., Otto-Bliesner, B., Zhang, J., Noone, D., Tomas, R., Nusbaumer, J., Wong, T., Jahn, A., et al. (2017). Reduced enso variability at the lgm revealed by an isotope-enabled earth system model. *Geophysical Research Letters*, 44(13):6984–6992.