# The Impact of Anthropogenic Forcing on ENSO Amplitude

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**Key Points:**

- NCAR's CESM Large Ensemble predicts increase to Niño 3.4 variance over the $21^{st}$ century.
- Increase can mainly be attributed to greenhouse gas and aerosol emissions.
- Changes to ENSO amplitude are linked to changes to equatorial Pacific ocean stratification.

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## Abstract

The El Niño/Southern Oscillation (ENSO) is the dominant mode of interannual climate variability, with substantial associated global socio-economic impacts. Due to their significance, shifts in ENSO under climate change also have the potential to substantial impact human society and natural ecosystems. However, it is currently unclear what effect greenhouse gas (GHG) and industrial aerosol (AER) emissions will have on ENSO and even less clear what effect a combination of these factors might have when changing in tandem. This study examines transient changes to ENSO variance under a variety of forcing scenarios using the CESM1 Large and Single-Forcing Ensembles. These multi-member ensembles span the historical record (1920-2005) and much of the 21st C (2006-2080 for GHG/AER). A 2000-year pre-industrial (PI) control simulation is used to account for model drift and 20-year running variance of the Niño 3.4 SST index is used as a proxy for ENSO variance. The ensemble mean and standard error of each ensemble is calculated, while the Probability Density Function (PDF) is computed for the PI control simulation to estimate the statistical significance of simulated changes. We identify significant increases in variance under full-forcing conditions during the historical record and attribute these mainly to changes in GHG, with the potential emergence of AER-driven increases in the decades to come. We calculate the correlation coefficient between ocean temperature in the equatorial Pacific and Niño 3.4 under various forcing conditions and .


## Plain Language Summary

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## 1 Introduction

El Niño is the main mode of interanual climate variability, originating from an interaction between the atmosphere and water movement and temperature in the Pacific ocean (Bjerknes, 1969). The reasons for studying ENSO are clear, as ENSO drastically affects climate patterns worldwide, modulating rainfall and temperature in nearly every continent (Ropelewski & Halpert, 1987). For example, the recent 2015-2016 El Niño event contributed to record-breaking high temperatures and droughts in South America (Jiménez-Muñoz et al., 2016). At the same time, long-term anthropogenic greenhouse gas emissions are causing global temperatures to increase through a greenhouse effect . It remains unclear how greenhouse gasses and other factors will affect ENSO.

External forcing is defined as climate forcing caused by external factors, most notably greenhouse gasses, natural and artificial aerosol emissions, land use changes, and stratospheric ozone changes. Greenhouse gas emissions have a clear impact on the earth's climate, global warming. In contrast, internal variability is defined as changes to the earth's climate originating from natural climatic processes, such as ENSO, Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO), and others.

Research on the effect of external forcing on ENSO remains inconclusive, as results from similar studies conflict. Nowack et al. (2017) predicted an overall increase in Niño 3.4 standard deviation under a combination of 4x$CO_2$ and interactive ozone forcing using single-model simulations, showing that greenhouse gasses increase the frequency of extreme ENSO by favoring a more Niño-like in the tropical Pacific, while ozone dampens this effect. In contrast, a few studies have found that ENSO amplitude decreases under global warming in certain coupled models (Kohyama et al., 2018).

However, other studies have failed to find any statistically significant ENSO response to external forcing (Stevenson, 2012). Analysis using NCAR's CESM Large Ensemble shows an ensemble size of at least 15 models is necessary to attribute changes to Niño variance to external forcing and reject the null hypothesis that internal variability is responsible for changes to ENSO (Zheng et al., 2018). A number of modes of internal variability have been shown to modulate ENSO, including the AMO (Levine et al., 2017) and Tropical Pacific Decadal Variability (TPDV) (Zheng et al., 2018). An analysis of the Max Plank Institute's Grand Ensemble as well as NCAR's CESM Large Ensemble suggests that 80% of changes to ENSO amplitude can be attributed to internal variability, but given a large enough ensemble, significant changes due to forcing can be detected (Maher et al., 2018).

In this study, we show that NCAR's CESM predicts significant increase in ENSO amplitude in the 21st century, and that greenhouse gasses and aerosol emissions play important roles in causing this increase. As in previous studies, we examine the role of internal variability in conjunction with forcing. We hypothesize that increased stratification in the future plays a large role in causing this predicted increase.

## 2 Materials and Data

## 3 Methods

## 4 Data

## 5 Results

## 6 Conclusions and Discussion

### Acknowledgments

Enter acknowledgments, including your data availability statement, here.

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