Title slide: Hello, my name is Benjamin Goldman, and I am presenting an in-progress study titled “The Impact of Anthropogenic Forcing on ENSO Amplitude” Have you ever experienced an especially rainy winter, or weirdly hot summer? This phenomenon is most likely caused by El Nino.

This study is on the impact of climate change on El Nino. Research on this subject is important because El Nino has a drastic effect on human society, by controlling rainfall and drought patterns all over the world. El Nino Southern Oscillation, or ENSO, is a cyclical change in the temperature of the equatorial Pacific Ocean. ENSO is one of the most influential elements of the climate system, and yet it is one of the most complex. It is driven by feedback loops where sea temperature modifies air currents, which then affect water movement, increasing changes in sea temperature, with a cycle lasting 2-7 years. These mechanics are illustrated in tho diagram, which depicts changes to Pacific climate during an ENSO event.

There are 2 major ways in which the earth’s climate can vary, Internal Variability and Climate Change. Internal variability is short-term changes to climate, lasting from 1 to around 50 years. It is usually cyclical or repetitive, with oscillation between positive and negative phases, and it is driven by feedback loops. Some examples of internal variability are ENSO, the yearly cycle of seasons, and the Pacific Decadal Oscillation, or PDO. The PDO’s recorded index is shown on figure 2. In contrast, climate change is an overall trend, but like internal variability, it can involve feedback. While internal variability may or may not be affected by external forcing such as greenhouse gasses and volcanic eruptions, climate change is often driven by external forcing. The most recent form of climate change is of course, global warming, which is shown in figure 3, but climate change also includes things like ice ages.

Internal variability is cyclical or repetitive, and it is usually controlled by feedback loops. One example of climate variability is the PDO, or Pacific Decadal Oscillation, who’s recorded index is shown in figure 2, showing it’s repetitive pattern. On the other hand, Climate Change is an overall trend in the earth’s climate, the most famous form of which is global warming, which is shown in figure 3. The factors causing climate change are known as forcing.

There has been considerable progression in research on the role of climate change in ENSO. In 2012, Stevenson et. al did not see any statistically significant difference in ENSO amplitude between the 20th century and projections of the 21st century. Some studies predicted that ENSO intensity would increase, while others predicted a decrease. In 2017, Chen et. al addressed this disagreement, finding that differences in the modelling of the air currents above the Pacific may be responsible. Finally, in 2018, Maher et. al studied ENSO intensity predictions in a large group of climate models, and found that ENSO amplitude increases under global warming, with internal variability contributing greatly to noise. Past research on ENSO and climate change is inconclusive. My study does not aim to end this ambiguity, but help to clarify things. Also, there is little research on the effect of individual forcing factors, such as greenhouse gasses, on ENSO.

It is still unknown how large of an impact humans have on El Nino. The first goal of my study is to estimate future changes to ENSO amplitude. I aimed to do this for a number of forcing environments. Additionally, a goal of this study is to determine the statistical significance of these changes. Next, this study analyzes the role of individual factors, the most important of which are greenhouse emissions and aerosol emissions, as well as a few natural factors. Also, this study aims to examine the physical mechanism responsible for any observed chnges.

My main source of data is NCAR Climate Lab's Community Earth System Model Large Ensemble, or CESM1 LE, which is a group of copuled model simulations. A coupled model uses an input of climate forcing records and predictions, and uses equations to simulate the interaction between Earth's atmosphere and ocean, and outputs the earth's climate state each month. An ensemble is a collection of model simulations with the same forcing input, the same physics simulation, but different initial conditions. This setup allows researchers to determine which changes to the Earth's climate are caused by climate forcing, and which are caused by internal variability. The Large ensemble also contains a control simulation with all forcing fixed at its levels in 1850.

The first step in my methodology was to measure ENSO intensity in each simulation. To do this, I used a common procedure of measuring ENSO amplitude, to take the variance of the sea surface temperature in the Nino 3.4 region of the Pacific ocean, which is depicted in the map. I calculated the variance using a process called windowing, where you calculate the variance for the 240 months, or 20 years, centered around a point, and then move that point forward by one month and repeat the process. I then calculated the mean and standard error for each ensemble, and the mean and standard error for the control run.

ENSO is a very noisy, or chaotic phenomenon, with slight differences in initial conditions leading to very different results. This noise is clearly shown in the graph, showing the wide range of ENSO amplitude between different members. This chaotic property is why ensembles are necessary, as when you combine all of these data points, long-term trends can be detected, although they may be faint.

The results of the previous calculation are shown on the graph. Each colored line represents a different forcing scenario, and the grey line represents the control. The colored envelopes surrounding the lines shows the standard error, which is dependent on the size of the ensemble. As you can see in the first plot, there is an increase in variance in the fully forced ensemble, which exceeds two standard errors. The other graphs contain records from single forcing simulations, which will be addressed next.

The next stage in the methodology is to determine how large of a role individual factors play in ENSO intensity. To do this, I took advantage of the CESM1 Single Forcing Ensemble. The single forcing ensemble contains simulations forced with all factors except one of them, so for example, the greenhouse gas ensemble is forced by aerosol emissions, biomass burning, land use, and ozone. To determine the role of individual factors, I randomly selected members from each single forcing ensemble and subtracted it from a random member of the full forcing ensemble, and repeated this process 1000 times for each group. This process of repeated random selection is known as the Bootstrap process.

The results of this process are shown on the graph. According to the data, greenhouse gasses and aerosol emissions likely increase ENSO intensity. However, the relationship between the single factors and the full forcing scenario is not additive, meaning that the sum of all of the results from the single factors is not similar to the fully-forced scenario, as shown in plot F. This means that the individual factors behave differently together compared to separately. This question merits further research.

The most recent stage of my methodology and results is an analysis of the physical processes through which climate change affects ENSO intensity. To do this, I calculated the correlation coefficient between the ENSO strength calculated in previous steps and ocean temperature, at a range of depths. To improve the statistical reliability of the data, I detrended and smoothed both timeseries. The next slide has the results of this computation.

Shown here is the correlation coefficient between ENSO amplitude and ocean temperature across the equatorial pacific. The left is a slice stretching across the equator, while the right is a slice through the central pacific. A reference for these locations is shown on the map. These graphs show that ENSO intensity is correlated with the difference between the upper and central layers of the tropical pacific, also known as stratification. Additional calculations are necessary to further validate this result, as well as further analysis and discussion of these figures.

Although this study is still in progress, a number of conclusions can be drawn which address the research goals of the study. First, there is likely to be an increase in ENSO intensity during the coming century. It is unknown how probable or great this increase will be. The major contributors to this predicted increase is a combination of human greenhouse gas and aerosol emissions. Also, it is clear that stratification plays an important role in the impact of global warming on ENSO.

My mentor and I need to do a deeper analysis of the role of internal variability in ENSO. We will also measure correlation between ENSO intensity and other ocean qualities, such as potential density and salinity, as well as a deeper analysis of the role of stratification. Deeper statistical analysis also will be done to further quantify the extent and likelihood of changes to ENSO under global warming. Finally, we need to compare these results with similar analyses of other models. The application of this project and others like it is to help humans to prepare for future changes to the earth's climate.

Acknowledgements: The data used in this study was created at NCAR's computer laboratories. My mentor, Dr. John Fasullo provided crucial help in this study, and

his colleague, Peter Gent, helped analyze the results in context of oceanography.

References

Image credits

Thank you for listening!