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”

1: El Nino Southern Oscillation, or ENSO, is a cyclical change in the temperature of the equatorial Pacific Ocean. It is driven by feedback loops where sea temperature modifies air currents, which then modify water movement, which increases changes in sea temperature. It has a cycle lasting 2-7 years, and it is the second most important form of climate variability, with only the seasonal cycle having a greater impact. It affects weather patterns around the world and has a great impact on human society. Figure 1 shows a record of the observed Nino index since 1950, with positive values representing higher temperature. Figure 2 shows ENSO’s variability pattern.

2: There are 2 major ways in which the earth’s climate can vary, Internal Variability and Climate Change. Internal variability is cyclical or repetitive, and it is usually controlled by feedback loops. One example of climate variability is the AMO, or Atlantic Multidecadal Oscillation, who’s recorded index is shown in figure 3, showing it’s wave-like pattern with a frequency of around 50 years. 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 4.

3: There has been considerable progression in research on the role of climate change in ENSO. In 2012, Samantha Stevenson did not detect any statistically significant difference in ENSO amplitude between the 20th century and projections of the 21st century. In 2018, Zheng et. al. used a large group of climate simulations to determine changes to ENSO amplitude under global warming. They found that most variability in ENSO amplitude can be attributed to climate variability, and a group of at least 30 simulations is necessary to detect statistically significant forced changes. Finally, in 2018, Maher et. al. used 2 groups of climate models, containing 40 and 100 simulations, and found that ENSO amplitude increases under global warming, with a large amount of ENSO variability caused by internal variability, but forced changes were significant under strong forcing.

4: My main source of data is NCAR’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 LE has a sub-ensemble forced by the combination of all forcing factors, ensembles forced by all but one factor, and a control run with all factors fixed at their state in 1850.

5: This is an overview of the steps of my methodology, which I will go into detail into next. First, I identify changes to ENSO amplitude under global warming by calculating variance on 20-year sliding windows. Next, I look at the separate contributions of individual factors, such as greenhouse emissions, in comparison with the simulations including all the factors. Finally, I look at the correlation between ENSO variance and ocean temperature to determine what physical processes cause climate change to affect ENSO amplitude.

6: 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 20 years centered around a central 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. The results of this calculation are shown on the graph. As you can see, there is a slight increase in variance in the fully forced ensemble, and even smaller changes in the greenhouse gas and aerosol ensembles. The land use/cover ensemble had a much smaller sample size, so even though there appears to be a large change over time, that conclusion is not robust.

7: 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.

8: The next stage in the methodology is to determine how large of a role various 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 dentermine the role of individual factors, I subtracted each ensemble from the fully forced ensemble, leaving behind the influence of only the factor in question. 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.

9: 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 reduce the chance of receiving a “false positive”, I detrended and smoothed both timeseries. The next slide has the results of this computation.

10: 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.

11: Although this study is still in progress, a number of conclusions can be drawn. 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. This project still has a long way to go. 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, using the CMIP6, or Coupled Model Intercomparison Project Phase 6 dataset to see if our conclusions hold true in other simulations.