### Answers

### Question 1

First - Use the 2600-year long 1850 control run to calculate population statistics with constant forcing

(in the absence of climate change). Find the population mean and population standard deviation for CESM1

global annual mean surface temperature. Standardize the data and again find the population mean and population

standard deviation. Plot a histogram of the standardized data. Is the distribution Gaussian?

- The distribution is mainly gaussian, with a bit of a negative skew (a shift to negative values). I believe that it's gaussian enough to use.

### Question 2

Next, calculate global warming in the first ensemble member over a given time period defined by the startyear and endyear variables. Compare the warming in this first ensemble member with the 1850 control run statistics and assess if the warming is statistically significant. Use hypothesis testing and state the 5 steps. What is your null hypothesis? Try using a z-statistic (appropriate for N>30) and a t-statistic (appropriate for N<30). What is the probability that the warming in the first ensemble member occurred by chance? Change the startyear and endyear variables – When does global warming become statistically significant in the first ensemble member?

General hypothesis: global warming has a statistically signficant warming signal in the CESM model as time increases.

Five hypothesis steps:

1) For this case, I used the standard confidence level of alpha=.05.

2) Null hypothesis H0: The CESM control run mean temperature = CESM warming ensemble mean temps

Alternative hypothesis H1: CESM control run mean temps != CESM warming ensemble mean temps

3) Assume that standardized temperatures are normally distributed. When N >=30, we can use either z or t tests with confidence. But, when N < 30, the population is too small and a t test must be used.

4) For this experiment, I used N=50, making the z test a reasonable statistic. For a confidence level of .05, we must yield a z = 1.96.

5) Using the code above, and using years 1980 to 2030 (N=50), z=41.46, which is way larger than 1.96, meaning that we can reject the null hypothesis! The probability of this warming occuring by chance is 0%

Start and end years also seem to affect the z and t results. Using the year range 1940 to 1970 yields a t=.13 value, which is not statistically significant. But, using years 1990 to 2020, we find that t=10.82, which is statistically significant. So, looking at temperature data later in the ensemble record (which has more warming) leads to a higher confidence in our general hypothesis!

### Question 3

Many climate modeling centers run only a handful of ensemble members for climate change projections. Given that the CESM Large Ensemble has lots of members, you can calculate the warming over the 21st century and place confidence intervals in that warming by assessing the spread across ensemble members. Calculate confidence intervals using both a z-statistic and a t-statistic. How different are they? Plot a histogram of global warming in the ensemble members – Is a normal distribution a good approximation? Re-do your confidence interval analysis by assuming that you only had 6 ensemble members or 3 ensemble members. How many members do you need? Look at the difference between a 95% confidence interval and a 99% confidence interval.

- Using a high N value (around 60) yields a relatively scattered but normal distribution. For the case of 6 ensemble members, the distribution is even more fragmented, but

### Question 4

When is global warming statistically significant? What are the statistical tests you used? How important is the ensemble size?

- For this activity, we first loaded and plotted CESM data to get a sense of our dataset. We then standardized the data and ran z / t tests, finding that global warming is statistically significant using both metrics.

- Looking at ensemble size, using 2 and 3 member runs generally increases the spread in confidence values. But, a 4 member ensemble yields:

- 95% confidence limits - t-statistic: 3.62 < X < 3.7

- 99% confidence limits - z-statistic: 3.58 < X < 3.73

- This result seems more reasonable to me! Adding additional ensembles doesn't seem to significantly improve these confidence limits.