ATOC 5860 Application Lab #1

**Questions to guide your analysis of Notebook #1:**

For full credit: write answers to the questions and then upload this document to your github along with notebook #1 (including any edits that you make).

**My responses are in blue.**

1) Composite Loveland Pass, Colorado snowpack. Fill out the following table showing the April 1 SWE in all years, in El Nino years (conditioned on Nino3.4 being 1 degree C warmer than average), and in La Nina years (condition on Nino3.4 being 1 degree C cooler than average).

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Mean SWE** | **Std. Dev. SWE** | **N (# years)** |
| **All years** | **16.33** | **4.22** | **81** |
| **El Nino Years** | **15.29** | **4.0** | **16** |
| **La Nina Years** | **17.78** | **4.11** | **15** |

Sample = years that are El Nino or La Nina; Population = all years of data

2) Use hypothesis testing to assess if the differences in snowpack are statistically significant. Write the 5 steps. Test your hypothesis using bootstrapping.

Instructions for bootstrap: Say there are N years with El Nino conditions. Instead of averaging the Loveland SWE in those N years, randomly grab N Loveland SWE values and take their average. Then do this again, and again, and again 1000 times. In the end you will end up with a distribution of SWE averages in the case of random sampling, i.e., the distribution you would expect if there was no physical relationship between Nino3.4 SST anomalies and Loveland Pass SWE.

Steps:

1. State the significance level (alpha)
2. State the null hypothesis H0 and the alternative H1
3. State the statistic to be used and the assumptions required to use it
4. State the critical region
5. Evaluate the statistic and state the conclusion
6. Plot a histogram of this distribution and provide basic statistics describing this distribution( (mean, standard deviation, minimum, and maximum).

Chart, histogram

Description automatically generated

Mean: 16.34

Standard deviation: 1.02

Minimum: 12.49

Maximum: 19.69

1. Quantify the likelihood of getting your value of mean SWE by chance alone using percentiles of this bootstrapped distribution. What is the probability that differences between the El Nino composite and all years occurred by chance? What is the probability that differences between the La Nina composite and all years occurred by chance?

Follow the steps of hypothesis testing:

1. Significance level: Alpha = 5% = 0.05
2. Null Hypothesis: H0 = The difference between the El Nino composite and all years occurred by chance. In other words, there is no relationship between El Nino index and Loveland SWE.

Alternate Hypothesis: H1 = There is a relationship between El Nino index and Loveland SWE.

1. We will use the Z-statistic. We are assuming the underlying data is normally distributed.
2. The critical region is -1.96 > z , z > 1.96 or critical value of z +/- 1.96
3. Evaluate the statistic:

El Nino:

One-tailed: Z-statistic = -0.99, 16.05%

Two-tailed: Z-statistic = -0.99, 32.1%

(16.05% chance of rejecting the null hypothesis incorrectly)

La Nina:

One-tailed: Z = 1.42, 7.75%

Two-tailed: Z = 1.42, 15.51%

(Percentages would have to be less than 5% to reject null hypothesis)

We cannot reject the null hypothesis for either El Nino or La Nina, meaning it is possible that the different between El Nino/La Nina composite and all years occurred by chance.

3) Test the sensitivity of the results obtained in 2) by changing the number of bootstraps, the statistical significance level, or the definition of El Nino/La Nina (e.g., change the temperature threshold so that El Nino is defined using a 0.5 degree C temperature anomaly or a 3 degree C temperature anomaly). In other words – play and learn something about the robustness of your conclusions.

**If we change number of bootstraps, Nbs, from 1000 to 100,000 we get:**

El Nino:

One-tailed: Z-statistic = -1, 15.91% probability

Two-tailed: Z-statistic = -1, 31.81% probability

(15.91% of rejecting the null hypothesis incorrectly)

La Nina:

One-tailed: Z = 1.38, 8.41%

Two-tailed: Z = 1.38, 16.81%

We cannot reject the null hypothesis. Changing Nbs did not make a huge difference. For El Nino the percentages are slightly smaller than they were before and for La Nina the percentages are slightly larger than before.

**If we change definition interval to El Nino > 0.5, La Nina < -0.5**

El Nino:

One-tailed: Z-statistic = -0.98, 16.31% probability

Two-tailed: Z-statistic = -0.98, 32.62% probability

(16.31% of rejecting the null hypothesis incorrectly)

La Nina:

One-tailed: Z = 2.04, 2.07%

Two-tailed: Z = 2.04, 4.13%

La Nina became statistically significant, meaning we can reject the null hypothesis for La Nina with this criterion because the percentages for both the one-tailed and two-tailed tests are less than 5%.

4) Maybe you want to see if you get the same answer when you use a t-test… Maybe you want to set up the bootstrap in another way?? Another bootstrapping approach is provided by Vineel Yettella (ATOC Ph.D. 2018). Check these out and see what you find!!

In the bootstrapping done by Vineel Yettella, we see that a sample mean of zero is within the confidence interval so we fail to reject the null hypothesis that the difference in the means of the two populations that the samples came from is equal to zero. This is found by doing bootstrapping on the full data set and on the El Nino dataset and finding the difference between the means in each iteration.

In the notebook, we see that the percentages calculated using the Barnes notes and using Welch’s t-test are the same, namely 84.27%. \*I think\* this implies there is a 15.73% chance of incorrectly rejecting the null hypothesis.

**Questions to guide your analysis of Notebook #2:**

For full credit: write answers to the questions and then upload this document to your github along with notebook #1 (including any edits that you make).

**My responses are in blue.**

Chart, histogram

Description automatically generated1) 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?

For the 1850 control run:

Population mean: 287.11 (Kelvin?)

Population standard deviation: 0.1

For the standardized 1850 control run:

Population mean: 0.0

Population standard deviation: 1.0

The distribution of the standardized data is Gaussian, with a slightly longer tail on the left that the right.

2) 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?

Hypothesis testing:

1. State the significance level (alpha)
   1. We will use a confidence level of 95%, meaning alpha=0.05.
2. State the null hypothesis H0 and the alternative H1
   1. Null hypothesis (H0): The member 1 mean temperature and the 1850 control mean temperature are the same. | The warming in the first ensemble member is not significant. [Not interesting result]
   2. Alternative (H1): The member 2 mean temperature and the 1850 control mean temperature are not the same. | The warming in the first ensemble member is significant. [something interesting is happening]
3. State the statistic to be used and the assumptions required to use it
   1. We will use both the z-statistic and the t-statistic.
   2. The use of the t-statistic assumes the underlying distribution is normally distributed.
   3. We are assuming the years are independent of each other.
4. State the critical region
   1. Z-statistic: For 95% confidence level, the critical value is …(data
      1. the critical region is -1.96 <= z <= 1.96 so we will reject the null hypothesis if z is outside of this region (?) (10 degrees of freedom, 95%...)
      2. z does not care about the number of degrees of freedom
   2. T-statistic: For 95% confidence level, the critical value of t (depends on the degrees of freedom, I think we have 10 (years) -1 = 9 OR 180 years so 180-1=179)… critical value of 1.833.
5. Evaluate the statistic and state the conclusion
   1. Z-statistic = 35.36, probability = 0.0%
   2. T-statistic = 37.12, probability = 0.0%

We can reject the null hypothesis because the t- and z-statistics are well beyond the critical values.

\*Change the start and end years; when does global warming become statistically significant in first ensemble member?

Do it with 1950-2050:

z-statistic = 62.66, probability 0.0%

t-statistic = 9.5, probability 0.0%

Do it with 1920-1930:

z-statistic = -0.57, probability 71.6%

t-statistic = -1.42, probability 90.5%

Do it with 1920-1940:

z-statistic = -0.48, probability 68.38%

t-statistic = -0.61, probability 72.59%

Do it with 1920-1950:

z-statistic = 0.4, probability 34.31%

t-statistic = 0.48, probability 31.64%

Do it with 1920-1960:

z-statistic = 0.58, probability 28.03%

t-statistic = 0.61, probability 27.25%

Do it with 1920-1970:

z-statistic = -0.19, probability 57.49%

t-statistic = 0.19, probability 57.54%

Do it with 1920-1980:

z-statistic = 0.09, probability 46.23%

t-statistic = 0.1, probability 46.21%

Do it with 1920-1980:

z-statistic = 2.08, probability 1.85%

t-statistic = 1.78, probability 4.0%

So this is when it first becomes significant because Z > 1.65!

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.

T-statistic Confidence Intervals:

95%: 3.61 – 3.66 [0.05 wide]

99%: 3.6 – 3.67 [0.07 wide]

Z-statistic Confidence Intervals:

95%: 3.61 – 3.66 [0.05 wide]

99%: 3.6 – 3.66 [0.06 wide]

The confidence intervals are the same for the t- and z-statistics at the 95% confidence level and are only different by 0.01 in the 99% confidence interval.

A normal distribution is not a good approximation.

Re-do with different number of ensemble members (6, 3); how many members do you need?

6 Ensemble members: (must use t-statistic since N<30)

T-statistic Confidence Intervals:

95%: 3.5953 – 3.6819 [0.0866 wide]

99%: 3.5707 – 3.7065 [0.1358 wide]

3 Ensemble members: (must use t-statistic since N<30)

T-statistic Confidence Intervals:

95%: 3.5869 – 3.7365 [0.1496 wide]

99%: 3.4891 – 3.8343 [0.3452 wide]

It almost looks like the confidence intervals get wider as the number of ensemble members gets smaller. This makes sense because then there is more uncertainty in the interval.

You need about 6 ensemble members. The confidence intervals for 6 members and for all members are fairly similar so 6 members is sufficient.