Temperature and Surface Pressure Analysis of Vancouver Island

Physics 411 Course Project

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1 Introduction

The purpose of this project is to analyze temperature and surface pressure data collected from the UVic School Weather Network (http://www.victoriaweather.ca). This network collects data from a number of weather stations located around lower Vancouver Island, which is on the west coast of British Columbia, Canada.

The data is collected at two different sample rates, minutely and hourly. The minute resolution is gathered from a group of 5 stations, which are the University of Victoria Science Building (UVic), Monterey (Mon), Craigflower (Craig), Shawnigan Lake (SL), and Cumberland (Cumb). The hour resolution is a group of 15 stations, which are the previous 5, Bowser (Bow), Cortes (Cor), Happy Valley (HV), James Bay (JB), Macaulay (Mac), Phoenix (Ph), Royal Victoria Yacht Club (RVYC), Rogers (Ro), Strawberry (Straw) and the Vancouver Island University (VIU). In total, there are 15 stations in which data is collected from. The total record length of the data is from January 1, 2016, to July 31, 2022, for the minute and hour resolution respectively. For this project, only the data from the year 2017-2018 is considered which is then divided into a summer and winter ranges. The summer range is from June 1$^{\text{st}}$, 2017 to September 30$^{\text{th}}$, 2017 and winter range is from November 11$^{\text{th}}$, 2017 to February 28$^{\text{th}}$, 2018.

The minute data for both temperature and pressure is analyzed first, where some plots of their respective time series, power spectral densities (PSDs), histograms of measurements and cross-correlation between the stations are shown.

For the hour data, a 2D interpolation temperature map of lower Vancouver Island is created. As well as applying Empirical Orthogonal Functions (EOFs) to the temperature data to find any spatial patterns between the stations.

2 Minute Resolution Data

There are a total of 5 stations used for this resolution, UVic, Monterey, Craigflower, Shawnigan Lake, and Cumberland, Figure 1 shows a map of these stations. For each station a check was done to see if there were any empty values within the desired ranges, all the station's data were found to be complete.

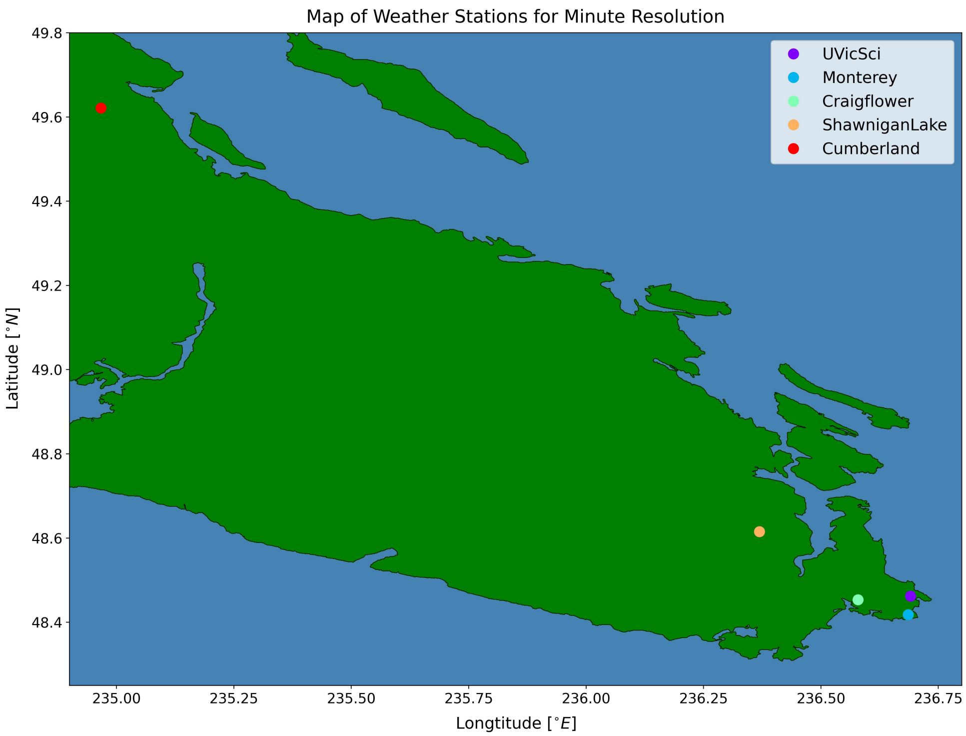

Figure 1: Map of Stations used for Minute Resolution

2.1 Time Series and Power Spectral Density

The plots for the time series and power spectral densities (PSDs) for each station are separated into two sections: temperature and pressure. The time series are recorded in the time-domain and the PSDs are calculated in the frequency-domain using the Welch method.

2.1.1 For Temperature

Temperature is recorded in units of $^{\circ}C$ and the PSDs are calculated in units of $^{\circ}C^2/cpd$, where cpd are cycles per day. As expected, the summer time series reported higher temperatures, where the winter had lower temperatures. In the summer, temperatures almost reached 35°C at Shawnigan Lake and low as 5°C. In the winter, temperatures had a high of almost 17.5°C at Monterey and a low of roughly -7°C at Cumberland.

The PSDs for both summer and winter of each station have a dominant peak at 10^{-5} cpd and some smaller ones at higher cpds, suggesting there is some weather "pattern". All of these peaks are larger in the summer than the winter, further suggesting this "pattern' is stronger in the summer.

Looking at the variance-preserving PSDs, the first peak is much greater in the summer, however, in the winter, the secondary peak is greater. Again, suggesting this "pattern" is stronger in the summer times.

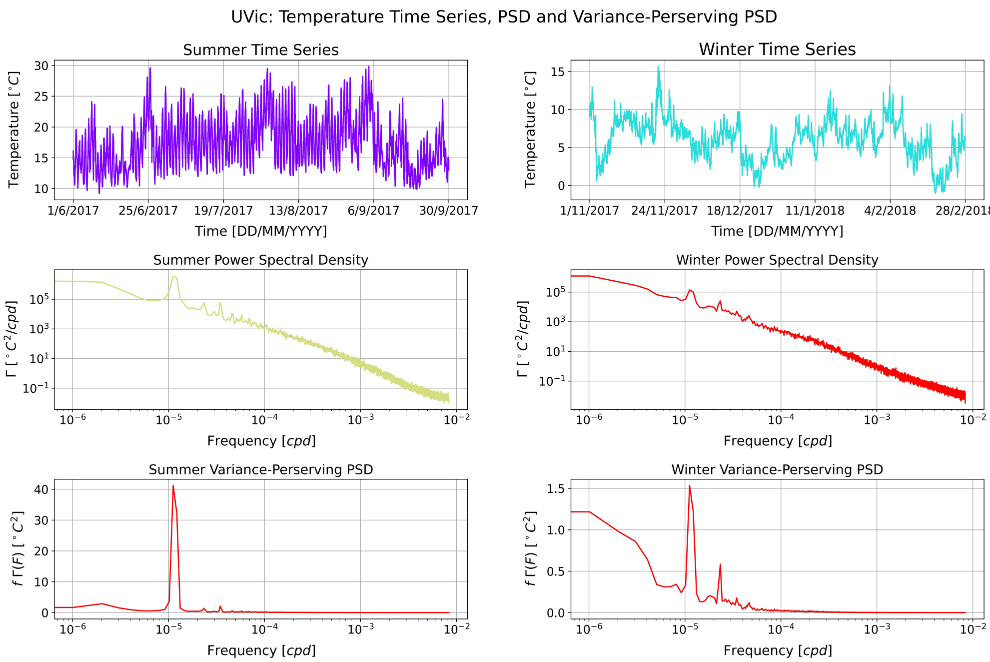

Figure 2: Time Series and Power Spectral Density for UVic

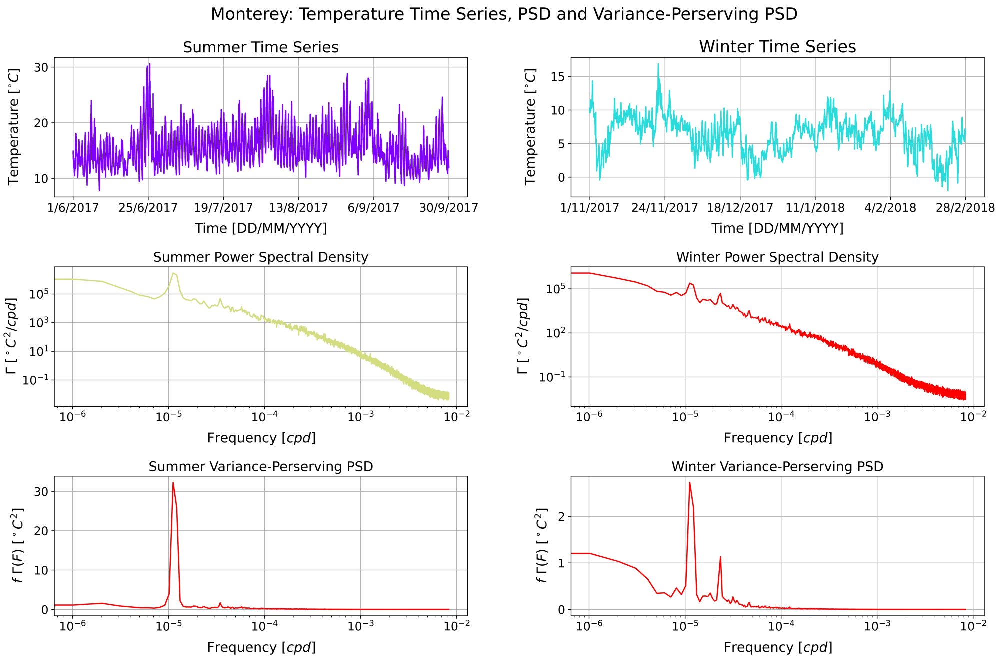

Figure 3: Time Series and Power Spectral Density for Monterey

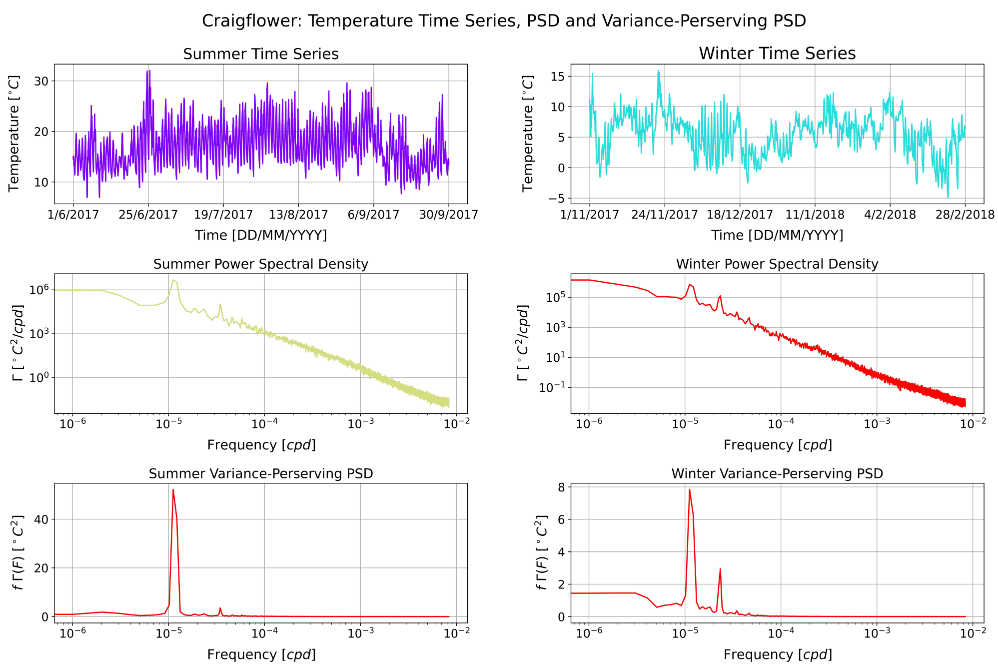

Figure 4: Time Series and Power Spectral Density for Craigflower

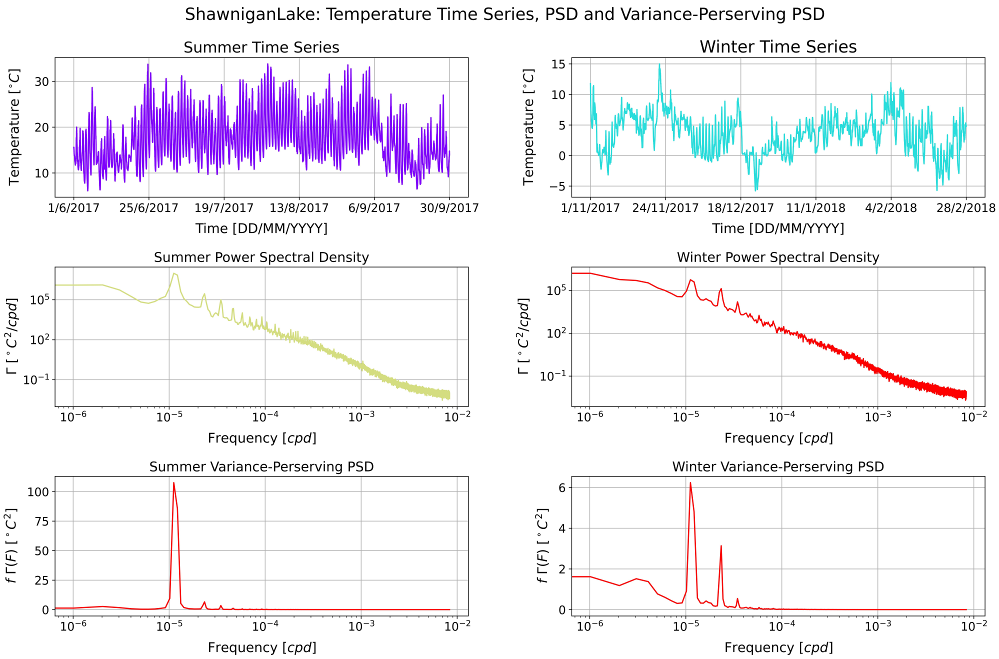

Figure 5: Time Series and Power Spectral Density for Shawnigan Lake

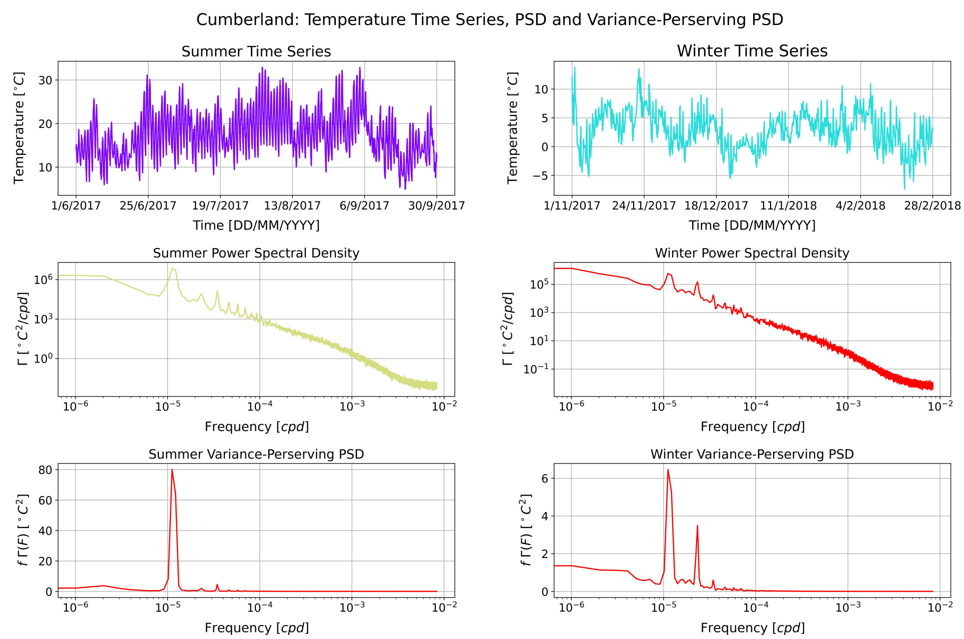

Figure 6: Time Series and Power Spectral Density for Cumberland

Station	Mean ($^{\circ}C$)	Standard Deviation ($^{\circ}C$)
UVic	17.33	4.04
Monterey	15.59	3.41
Craigflower	17.11	4.08
Shawnigan Lake	17.57	5.45
Cumberland	17.52	5.23

Table 1: Temperature Means and Standard Deviation for the Summer range

Station	Mean ($^{\circ}C$)	Standard Deviation ($^{\circ}C$)
UVic	6.04	2.61
Monterey	6.30	2.69
Craigflower	5.48	3.18
Shawnigan Lake	3.48	3.17
Cumberland	2.90	3.08

Table 2: Temperature Means and Standard Deviation for the Winter range

Looking at the above table of means and standard deviations (STDs), the variance in the STD of the winter range is lower than in the summer. This is because the winter has a higher cloud coverage, which helps keep temperatures more stable.

2.1.2 For Pressure

Pressure is recorded in units of hPa and the PSDs are calculated in units of hPa^2/cpd, again cpd are cycles per day. Each of the time series for winter and summer for each station behaved the same. Cumberland had the largest extremes for the winter ranges with values of 990 and 1040 hPa. Shawnigan Lake had the largest extremes for the summer ranges with values of roughly 1000 and 1025 hPa.

Looking at the PSDs for the summer range for each station, it can be seen that they share the same peaks as the summer range PSDs for the temperature data. However, for the winter range the PSDs for the pressure data do not match any peaks of winter temperature PSDs. This suggests that this "pattern", considered in the previous section, disappears in winter and returns in the summer. The variance-preserving form, further supports this.

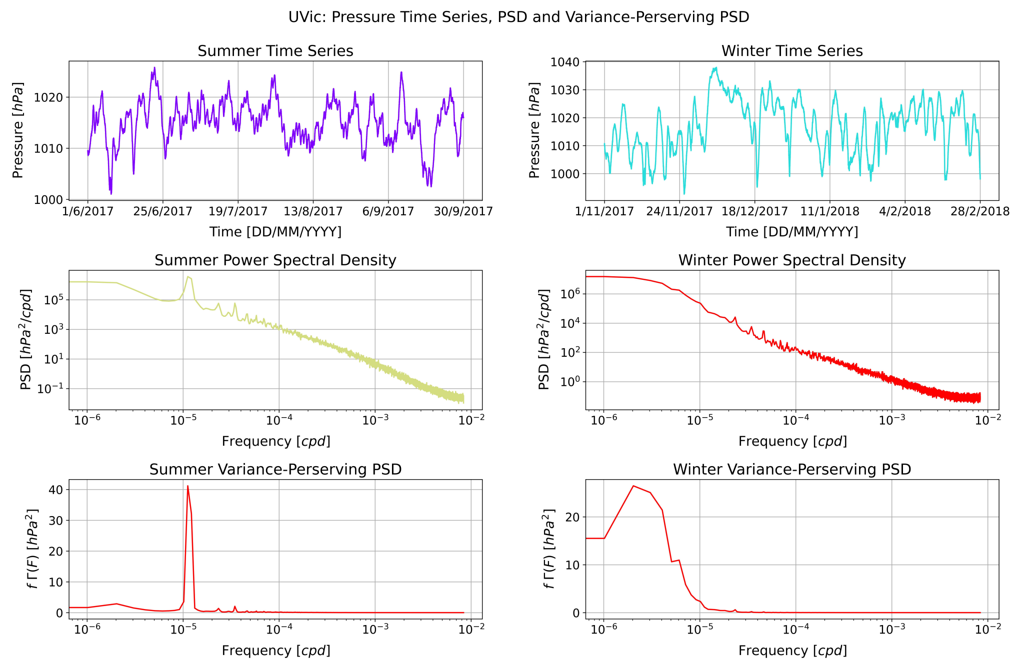

Figure 7: Time Series and Power Spectral Density for UVic

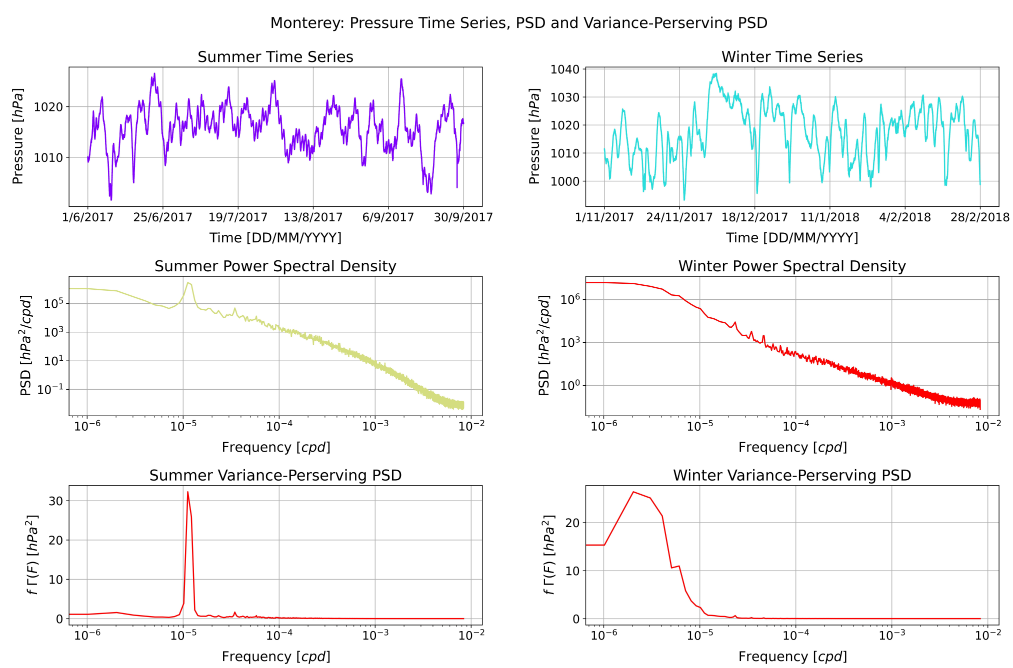

Figure 8: Time Series and Power Spectral Density for Monterey

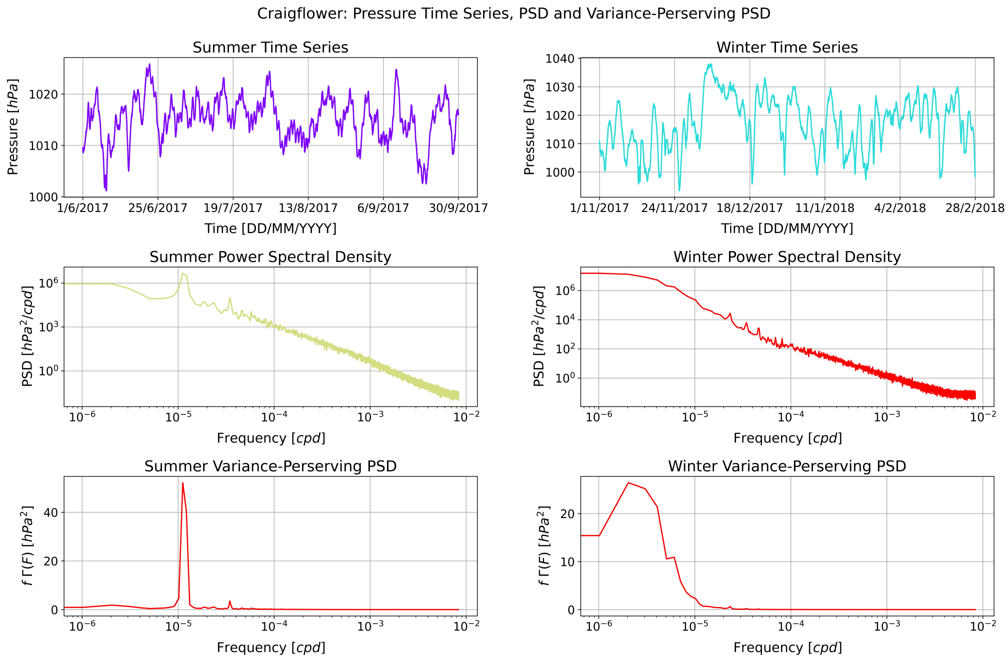

Figure 9: Time Series and Power Spectral Density for Craigflower

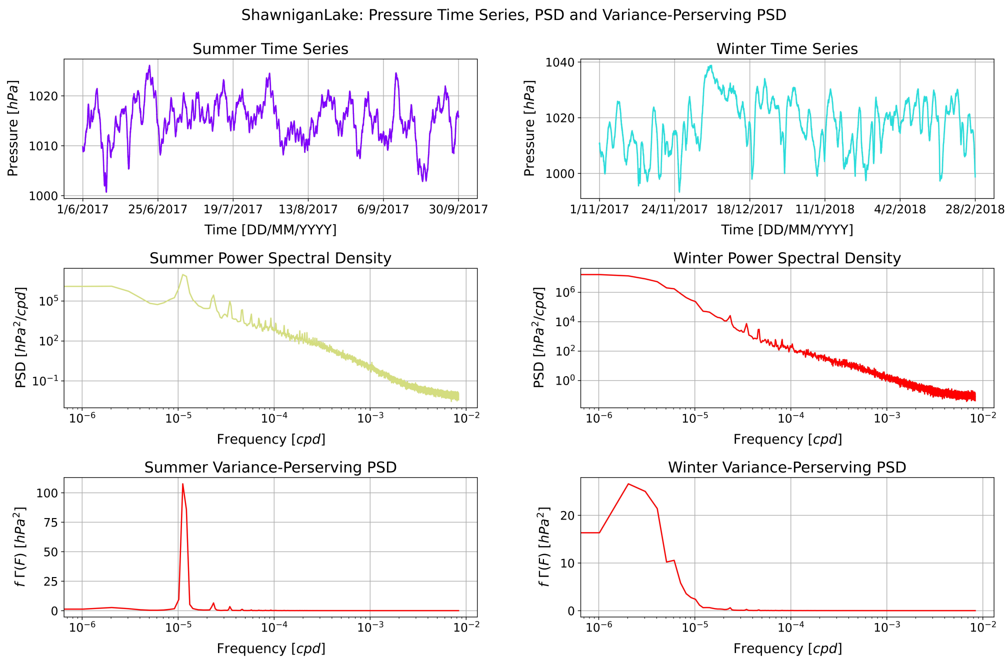

Figure 10: Time Series and Power Spectral Density for Shawnigan Lake

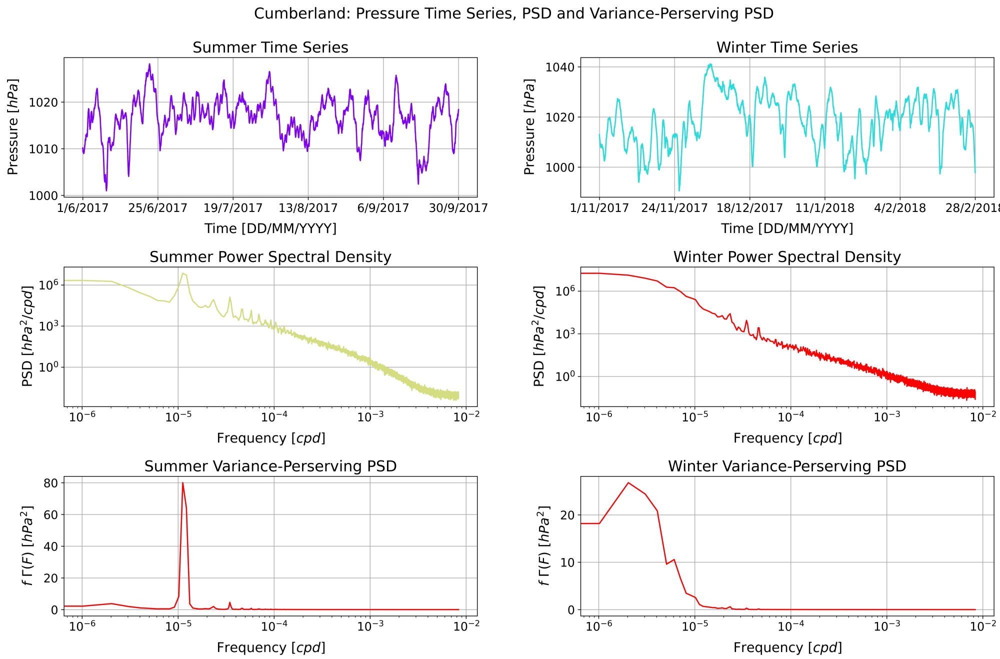

Figure 11: Time Series and Power Spectral Density for Cumberland

Station	Mean (hPa)	Standard Deviation (hPa)
UVic	1015.16	4.17
Monterey	1015.80	4.21
Craigflower	1015.16	4.20
Shawnigan Lake	1015.22	4.18
Cumberland	1016.66	4.39

Table 3: Pressure Means and Standard Deviation for the Summer range

Station	Mean (hPa)	Standard Deviation (hPa)
UVic	1016.92	9.22
Monterey	1017.46	9.19
Craigflower	1017.04	9.20
Shawnigan Lake	1017.29	9.30
Cumberland	1018.28	9.89

Table 4: Pressure Means and Standard Deviation for the Winter range

Unlike the variance in the STDs of the temperature, the variance in the STDs in the pressure is smaller. It is known that the mean surface pressure throughout an entire year does not vary much, however, this is not considering any extremes in the seasons. This suggests that winter has greater extremes than the summer.

After examining Tables 1 through 4, it can be concluded that lower Vancouver Island has a mild climate.

The summer of 2017 temperature averages around 17°C and the pressure averages around 1015 hPa. In the winter of 2017, the averages were around 4.8°C and 1017 hPa.

2.2 Histograms

The histogram for each station is plotted with their probability distribution functions (PDFs) traced over top of the data. Each histogram represents a count of temperatures and pressures in the summer and winter for each station, the y-axis is labelled 'Normalized Counts".

2.2.1 For Temperature

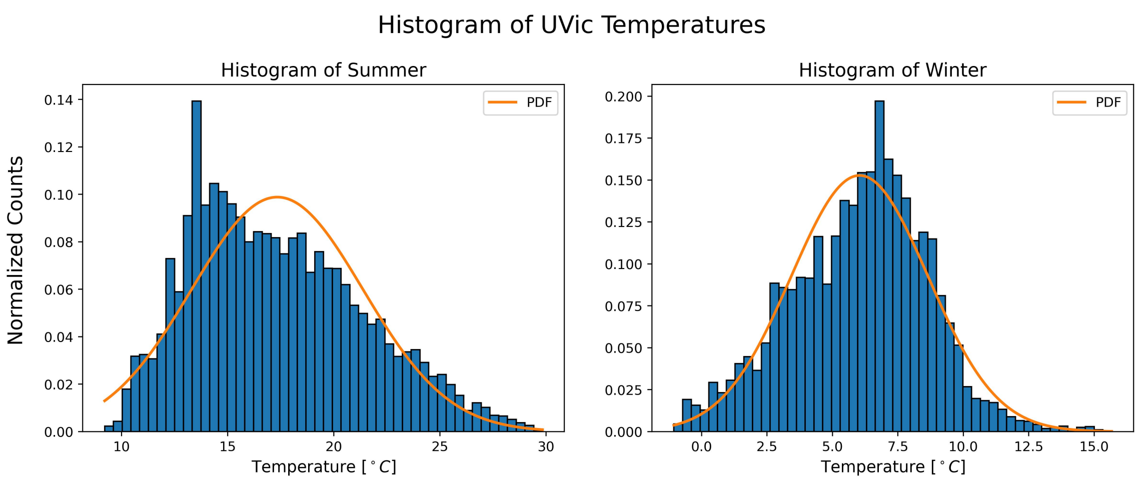

Figure 12: Temperature PDF Histogram of UVic

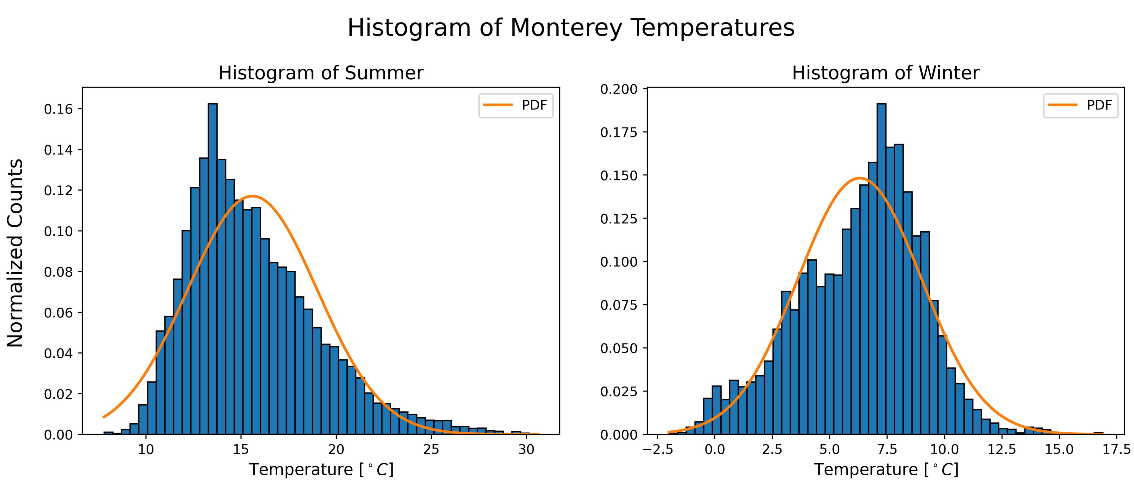

Figure 13: Temperature PDF Histogram of Monterey

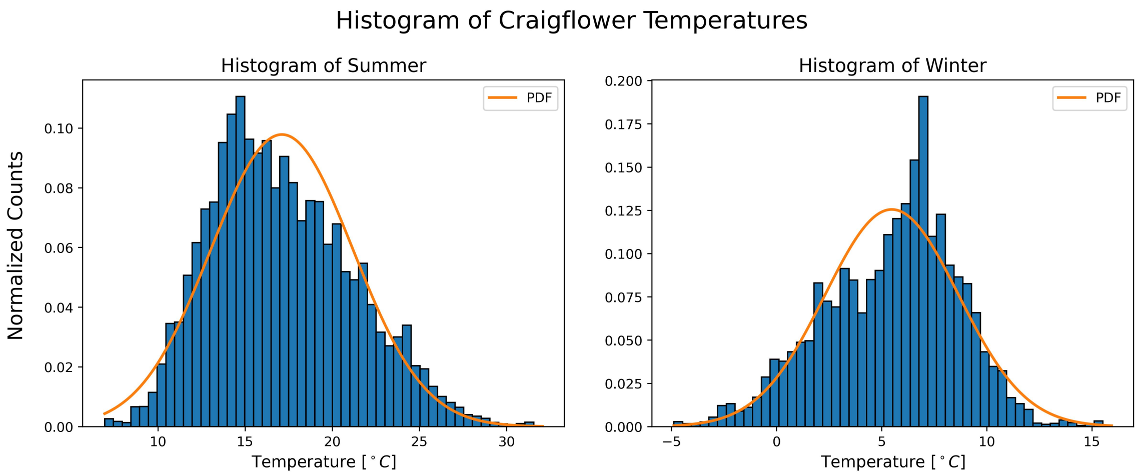

Figure 14: Temperature PDF Histogram of Craigflower

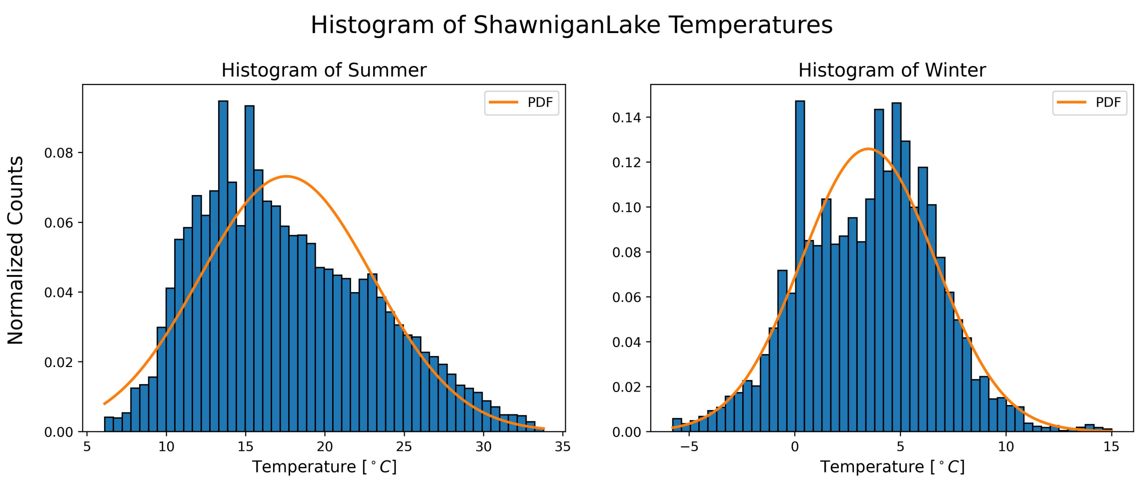

Figure 15: Temperature PDF Histogram of Shawnigan Lake

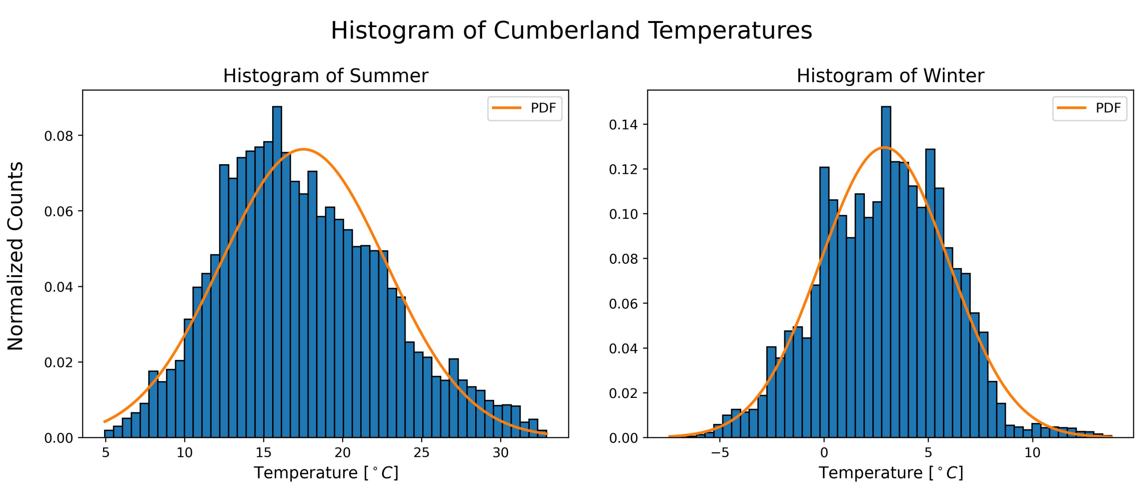

Figure 16: Temperature PDF Histogram of Cumberland

2.2.2 For Pressure

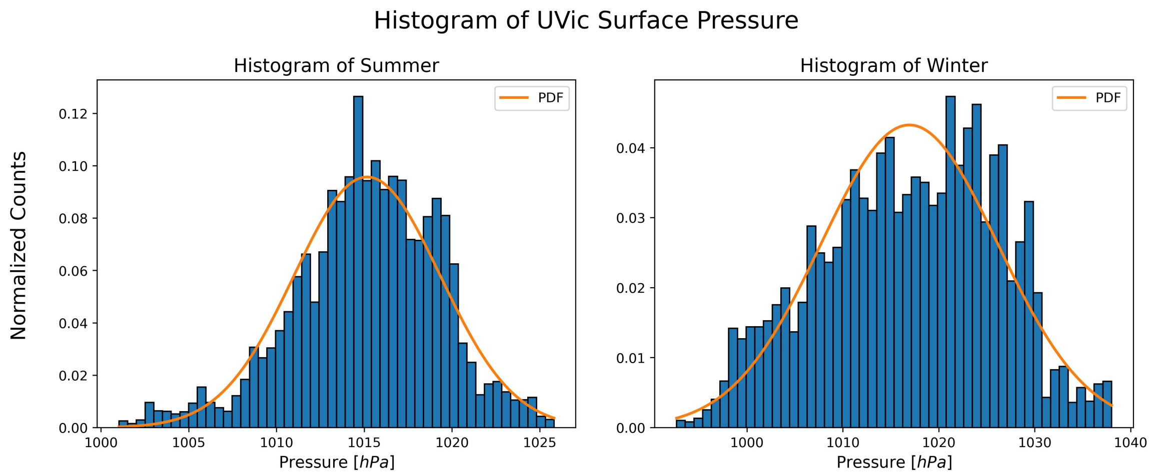

Figure 17: Pressure PDF Histogram of UVic

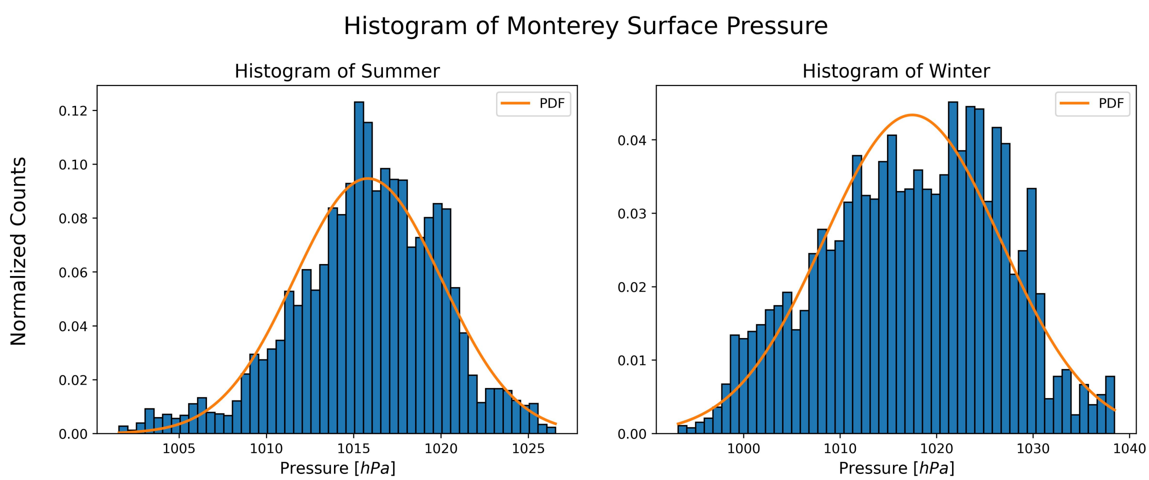

Figure 18: Pressure PDF Histogram of Monterey

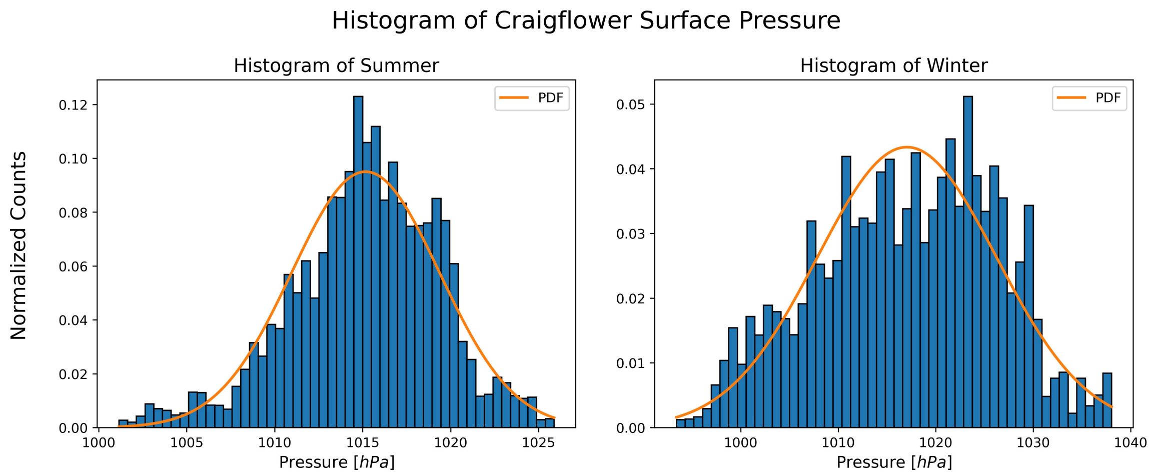

Figure 19: Pressure PDF Histogram of Craigflower

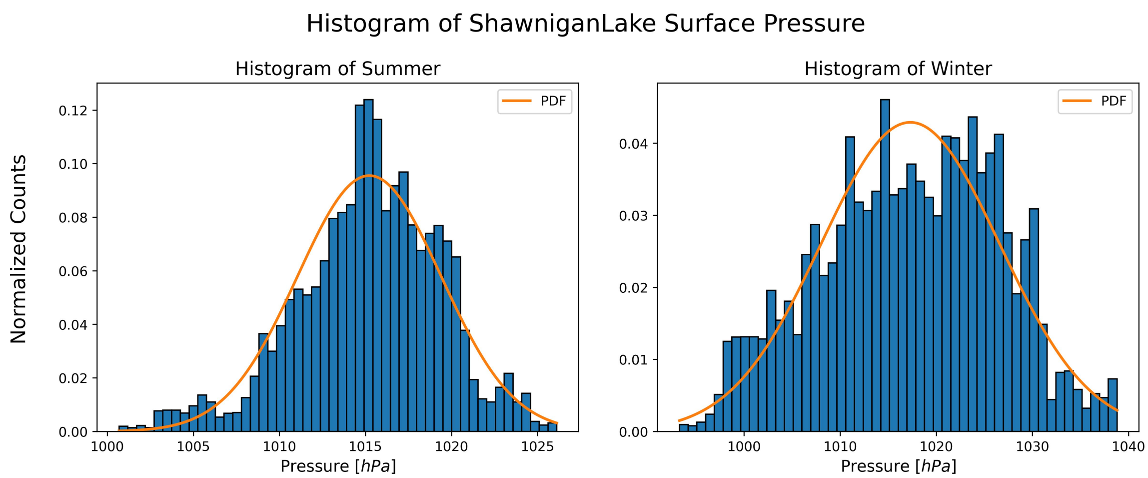

Figure 20: Pressure PDF Histogram of Shawnigan Lake

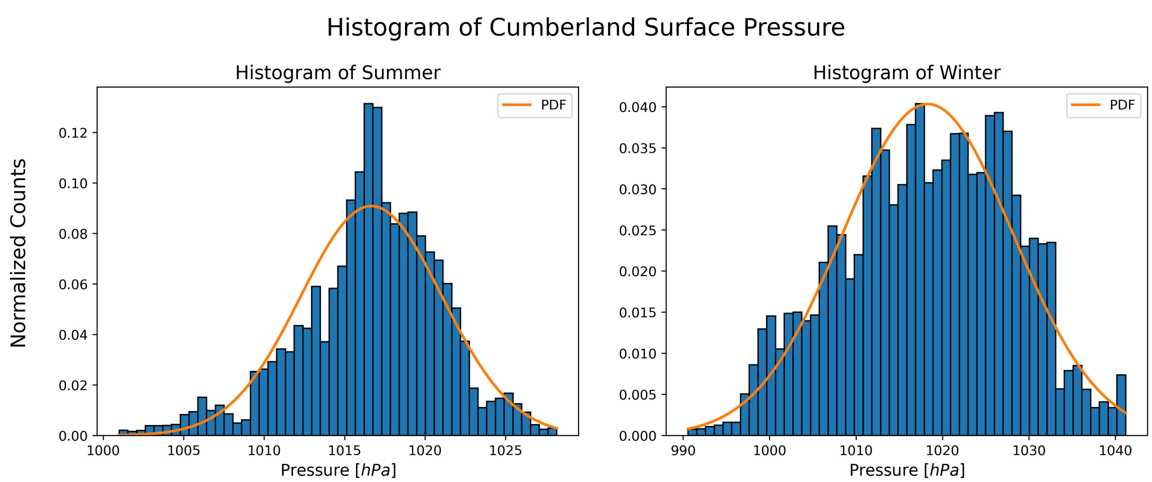

Figure 21: Pressure PDF Histogram of Cumberland

All the histograms for both temperature and pressure were found to be skewed to the right, this matches the values in Tables 1 through 4. Therefore, the mean temperature is always above $0°C$ and the mean pressure is above 1010 hPa.

2.3 Correlation between Stations

Correlation, more specifically cross-correlation, is a measure of linear similarity between different sets of data. Here it can be used to measure how well each station's data match each others'; thus giving a value, known as the cross-correlation coefficient (R_{xy}), for how accurate the overall temperature and pressure readings are.

The cross-correlation coefficient is always in the range $-1 < R_{xy} < 1$. A perfectly negative coefficient means as one system increases, the other decreases. A perfectly positive value means both systems increase. It is important to know that strong correlation values do not mean that one causes the other, it means there exists a strong linear relationship between systems.

2.3.1 For Temperature

Looking at Figure 22, all the correlation values were calculated to have strong positive values. In the summer, the lowest value is 84%, and the highest is a perfect 100%. In the winter, the lowest is 86% and the highest is again 100%. Implying there is a strong linear relationship between all the stations.

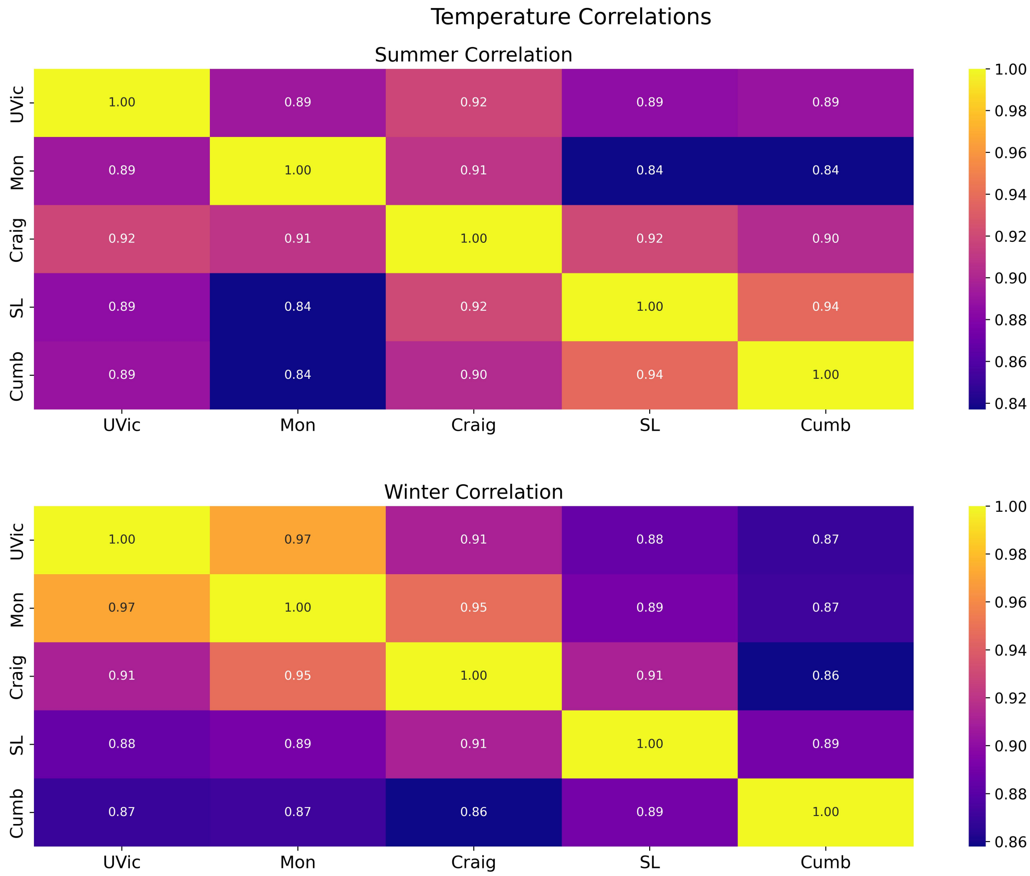

Figure 22: Temperature Correlation between the Stations

2.3.2 For Pressure

The correlation values between the stations for the pressure data were calculated to be even stronger than the temperature. For both summer and winter the values ranged from 98% to 100%. Again, Implying there is a strong linear relationship between all the stations.

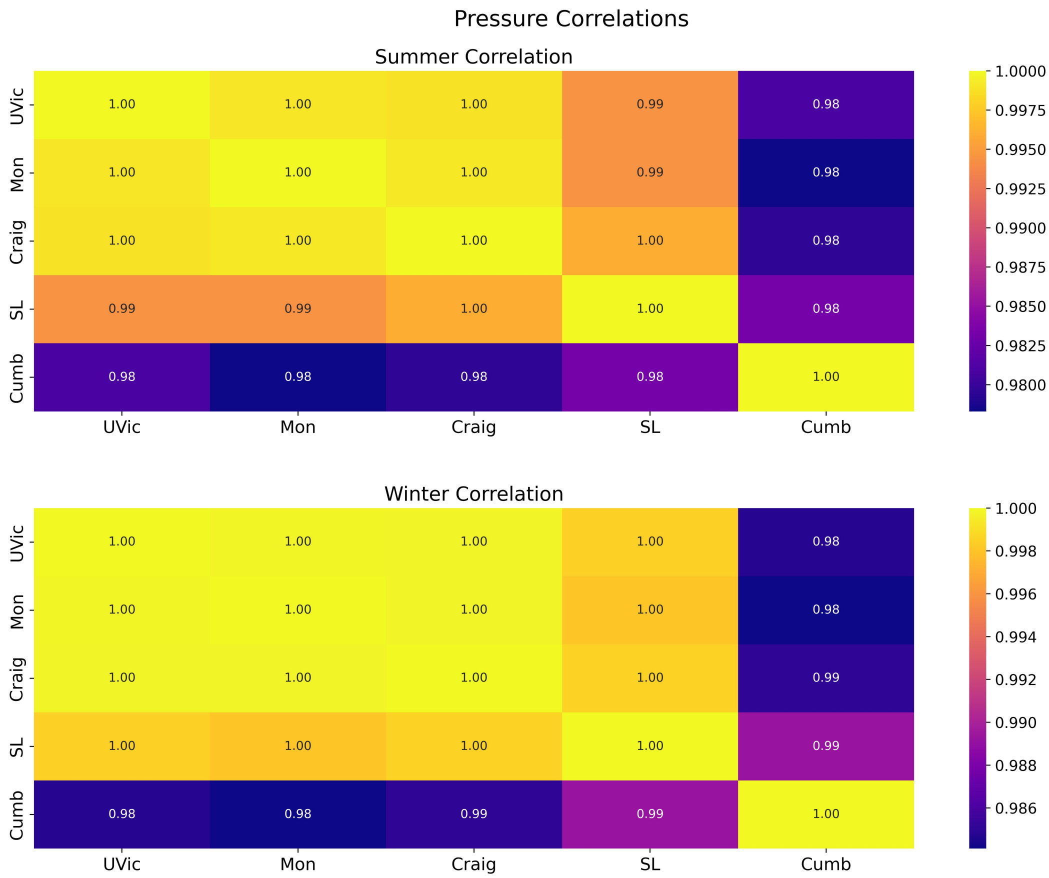

Figure 23: Pressure Correlation between the Stations

The correlation values between all the stations for the summer and winter range for both the temperature and pressure data were calculated to have a strong linear relationship. This is expected as all the stations are located roughly near each other. Another thing to notice is that the Cumberland station has the lowest correlation values among all the stations, although it still has a strong value, this is expected as it is the furthest located station in the group 5 (See Figure 1).

Since all the stations have strong positive correlations this suggests two things: that all the stations are recording the temperature and pressure successfully, and that the weather for the region is being correctly measured.

3 Hour Resolution Data

The hour resolution is a collected from a group of 15 stations: Bowser (Bow), Cortes (Cor), Craigflower (Craig), Cumberland, (Cumb), Happy Valley (HV), James Bay (JB), Macaulay (Mac), Monterey (Mon), Phoenix (Ph), Royal Victoria Yacht Club (RCYC), Rogers (Ro), Shawnigan Lake (SL), Strawberry (Straw), University of Victoria, (UVic), Vancouver Island University (VIU). Figure 24 shows a map of all these stations.

A check was done to see if there were any empty values within the desired ranges, some were found. These empty values, (Nan), occur when the station did not function properly to record the data at that time, these spots are filled in by applying a cubic interpolation scheme to data.

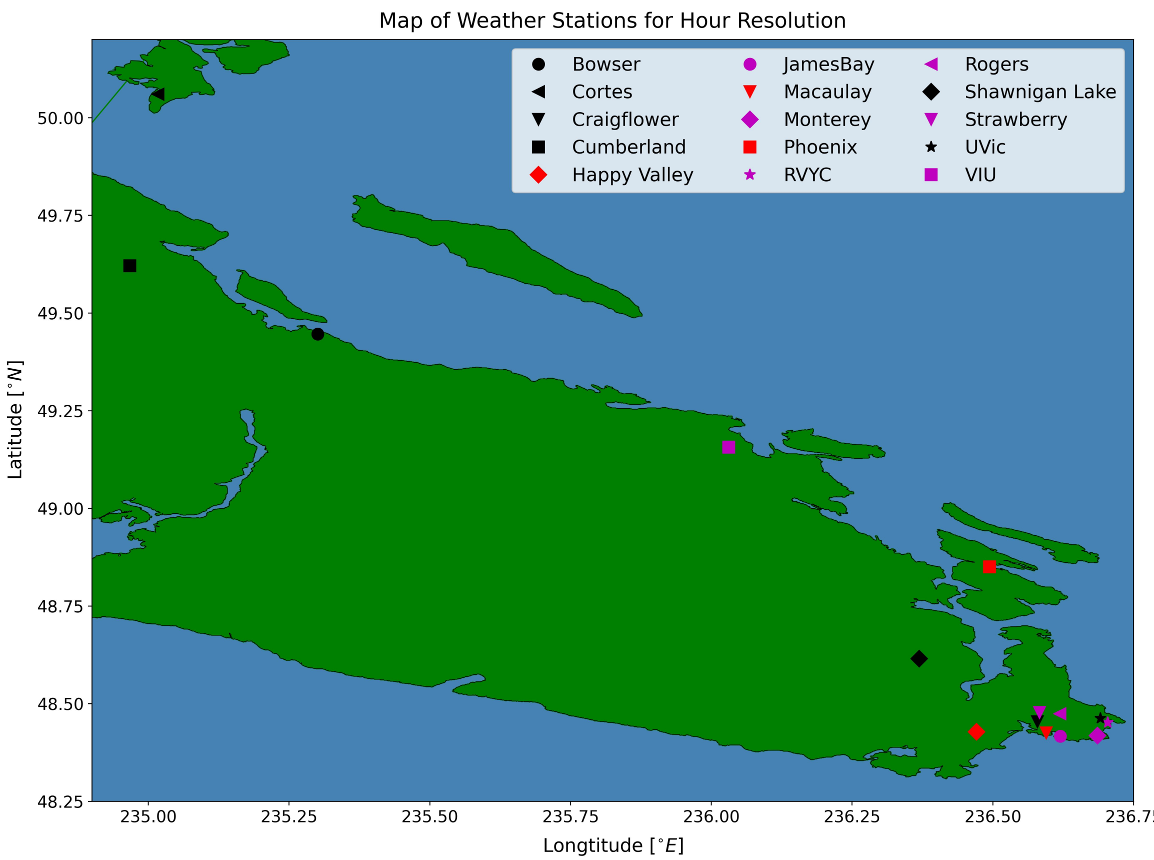

Figure 24: Map of Stations used for Hour Resolution

3.1 Temperature Heatmap of lower Vancouver Island

The following figures are temperature heatmaps. A heatmap is a data visualization technique that allows data to be shown as a colour in 2 dimensions. In this case they are being used to see a temperature map of lower Vancouver Island in the summer and winter.

Each heatmap has a colour bar which represents the temperatures (in $^\circ C$) across the region, the hottest shown in red and the coldest in blue. The map was created by interpolating the average temperature for each station and their respective locations across a 1000×1000 grid, then plotting using filled contour lines over a map of lower Van. Island.

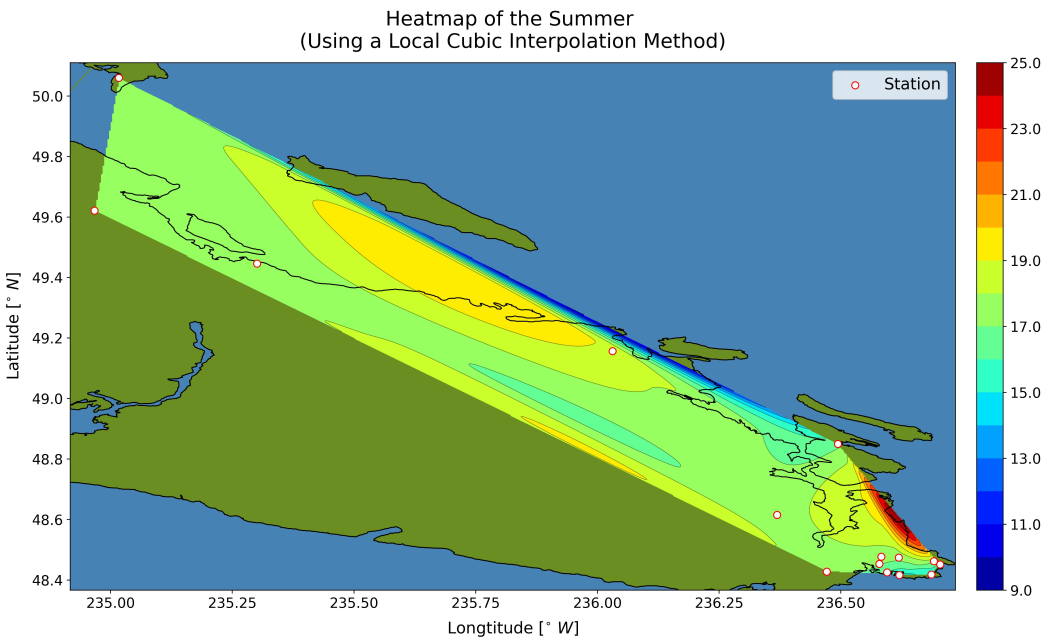

Figure 25: Temperature [$^\circ C$] Heatmap of the Summer

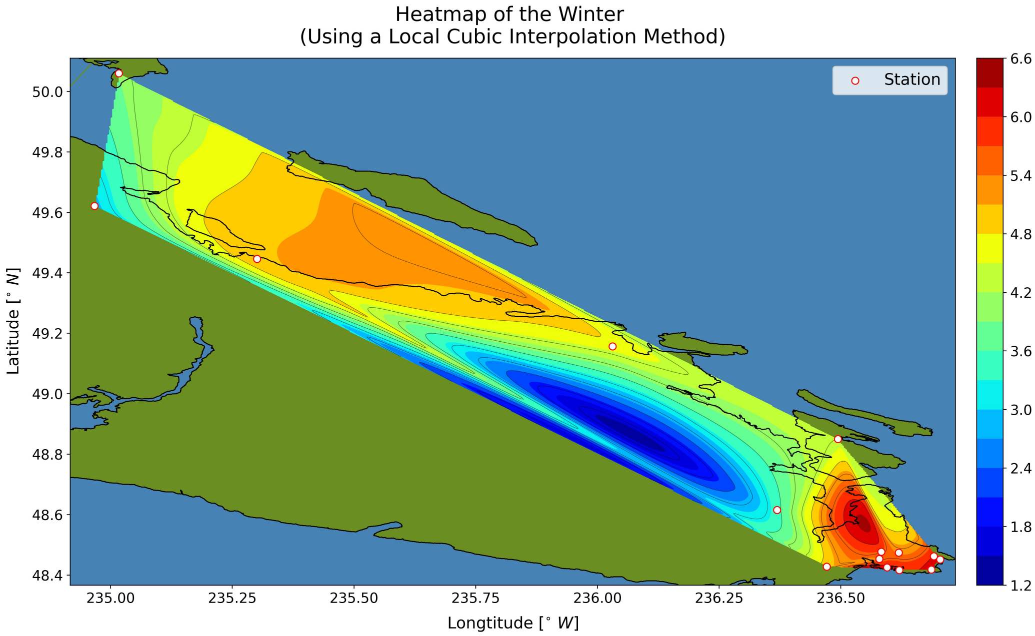

Figure 26: Temperature $[^{\circ}C]$ Heatmap of the Winter

Looking at Figure 25, it can be seen that the inland temperatures are calculated to be higher, except near the Saanich peninsula. The majority of the weather stations in which data is recorded from are located near the coast, meaning there isn't a lot of data inland to properly interpolate temperatures there. However, the higher temperatures inland are expected in the summer as it doesn't have the constant sea winds cooling these areas down.

Figure 26, the heatmap for winter, shows the reverse of the summer's. The warmer temperatures are actually near the coast, this is because the surrounding water takes a significant amount energy to cool compared to land. In other words, the inland areas are protected by warmer sea water and its wind.

- Click here to see a video of the summer temperature heatmaps.
- Click here to see a video of the winter temperature heatmaps.

3.2 Empirical Orthogonal Functions (EOFs)

The finally thing to be analyzed are the patterns (i.e spatial modes) involved in the EOFs for the summer and winter. The three most significant modes which are represented by EOF 1, EOF 2, and EOF 3 are plotted with their respective principle components time series for analysis. The EOFs were interpolated over a 100×100 grid, the grid size could not be increased due to computing power. Each EOF map shows a correlation of how well the temperatures across the region are related to each other and as well as the stations. The time series plot shows the amplitude of each principle components.

Comparing the summer and winter EOFs, there is a higher correlation in the summer temperatures. This means that the temperature variations during the summer are less significant than in the winter. Looking the principle component plots of both summer and winter, it can be seen that summer has less variation.

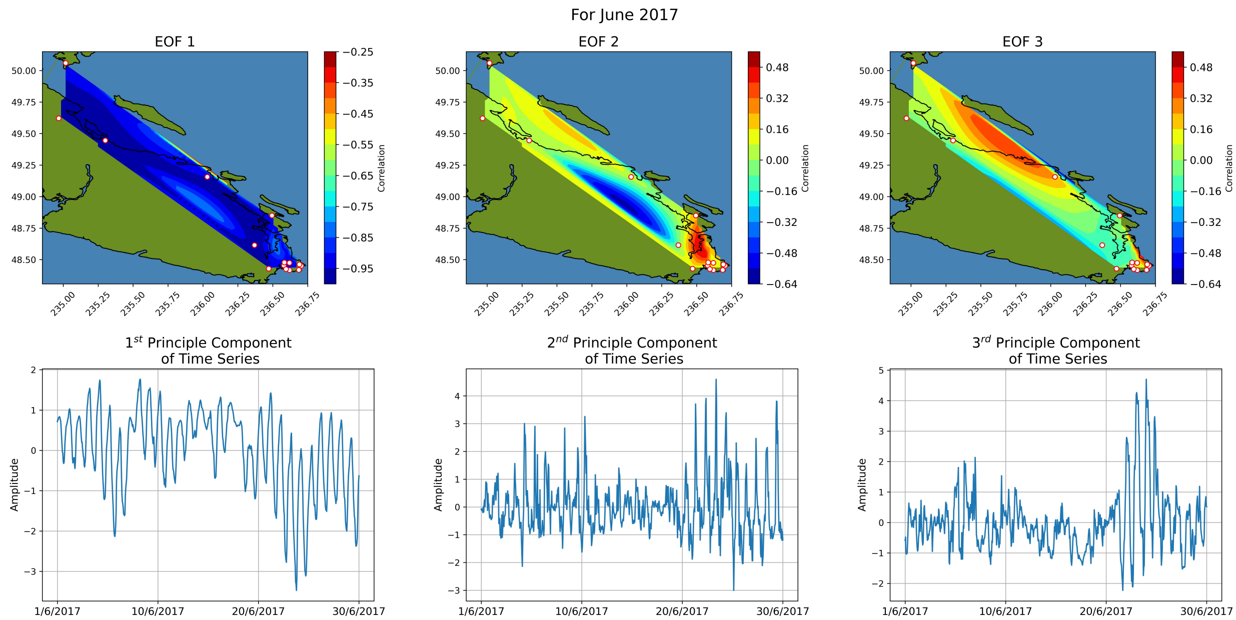

Figure 27: EOF and Principle Components for the Summer

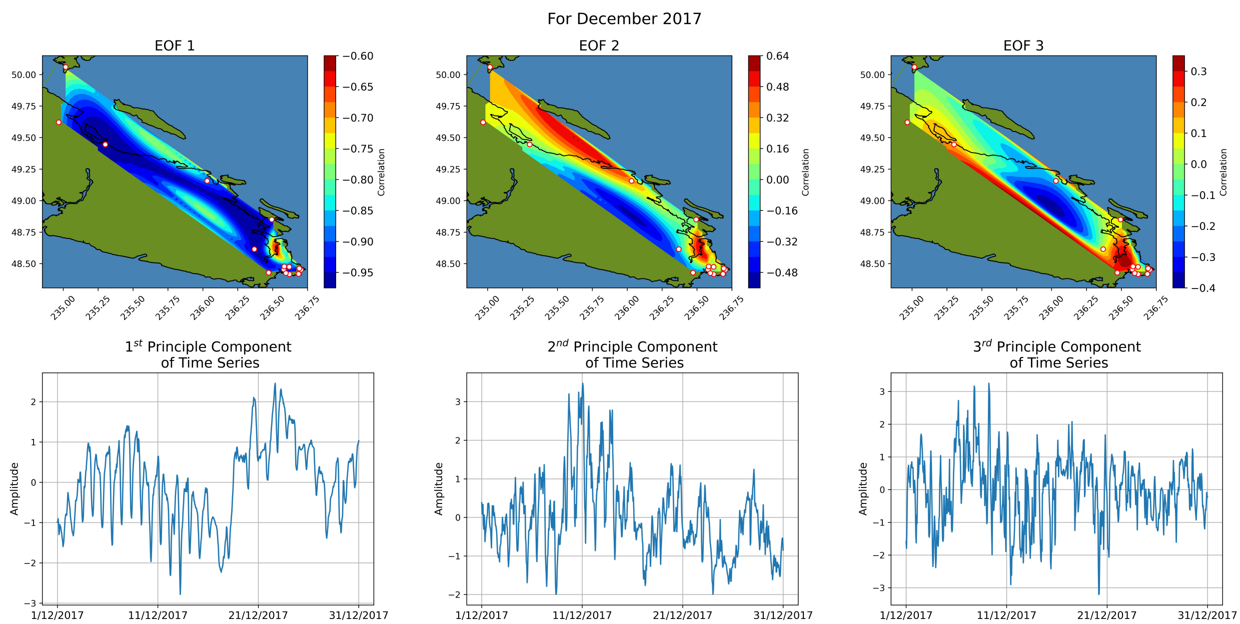

Figure 28: EOF and Prinicple Componetns for the Winter

4 Conclusion

This project focused on temperature and surface pressure analysis of lower Vancouver Island, where data was collected by the UVic School Weather Network. This data was recorded at two different rates: minutely and hourly, which was than separated into a summer and winter range from the year 2017 for better analysis.

In total there were 15 stations that data was collected by. For the minutely data, only a group of 5 were used: UVic, Monterey, Craigflower, Shawnigan Lake, and Cumberland. This data was analyzed by plotting their time series, PSDs, histograms and correlations for both summer and winter.

For the hour data, all 15 stations were used to record data. However, only the temperature for summer and winter was analyzed. A 2D interpolated heatmap of lower Vancouver Island was created to visualize the average temperatures throughout the summer and winter. As well as a video showing the evolution of temperature for each season.

As expected the temperatures were generally higher in the summer, however, the temperature variance is smaller in the winter. The correlation values between the 5 stations used for the minute data were found to be high, within the range 86% to 100%, implying there is a strong linear relationship between the stations and that they are consistent with each other.