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Section 1 - Analyzing Data to Extract Model Parameters

For the analysis, our group analyzed weather data from the Government of Canada's historical data at Prince Rupert station in 2020 [1]. To come to this conclusion our group wanted to find the month that had the least amount of noise, which meant a month with a low or possibly least amount of storms that directly adds noise to tidal data. Factors to determine how stormy a month included Total Precipitation, Extreme Precipitation, Extreme Speed of Max Gust, Mean Monthly Shine Hours, and Percent Possible Sunshine. These factors allow the group to determine which month had the least noise. Total precipitation indicates how much rain or snow could have affected the tidal data for any given month, reducing this would be ideal. Extreme Total Precipitation and Speed of Max Gust gives a good indicator of whether a storm had happened that month and if there were any outliers affecting the total data which should also be minimized. Mean Monthly Sunshine Hours and Percent Possible Sunshine are additional information that also indicated how many storms could have happened in a month, with more sunshine meaning a lower chance of many storms. It can be seen below that May had the least total precipitation (53.5 mm), least extreme total precipitation (10.4 mm) and least extreme max gust speed(48 km/hr). It was also the month that had the most mean monthly sunshine hours (171.1 hours) and second most percent possible sunshine (34.5%) of all the months. Because of this our group chose the month of May for our 30-day analysis.

Table 1: Weather Data of Prince Rupert Station in 2020 [1] [2]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sum - Total Precipitation (mm)	270.4	187.2	194.4	111.1	53.5	130.3	204.1	419.8	149.3	262.4	432.4	297.5
Extreme - Total Precipitation (mm)	40.8	27.4	28.8	28.8	10.4	30.1	64.4	70.9	36.3	41.7	51	38.7
Extreme - Speed of Max Gust (km/hr)	94	76	80	72	48	55	48	54	80	63	81	87
Mean monthly sunshine hours	40.1	65.2	103.0	145.8	171.1	154.5	149.7	149.7	115.7	72.4	43.0	32.1
Percent possible sunshine	16.2	23.8	28.1	34.6	34.5	30.1	29.1	32.4	30.2	22.1	16.7	13.9

We translated the FFT code provided on LEARN (written by Professor Borland) into Python code to be able to utilize Python's libraries to make things easier. NumPy and Pandas were used to make dynamic arrays that provide flexibility in managing collections of data. SciPy was used for its Fast Fourier Transform functions. Finally, graphical libraries like matplotlib were used to generate clean looking plots of data. Firstly, changing water levels with respect to time was plotted to grasp a visual on what the results should look like.

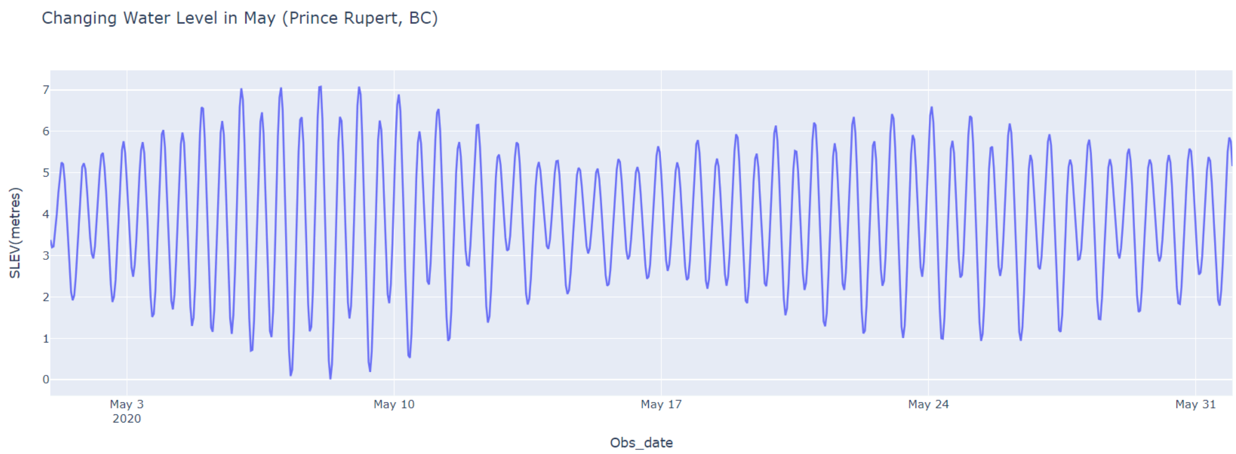


Figure 1: Changing Water Levels in May, 2020 (Prince Rupert, BC)

Our code manages to transform time data into frequency domain data, extract the 10 most significant waves that are characteristic of the original data, and translate it back into time domain to be plotted and compared with our original database. The wave generated digitally via code would then be used in later sections of this report to predict future tide data.

First, the code applies FFT and calculates the magnitude of the fourier coefficients and stores them in an array. The 10 largest magnitude coefficients are identified and their index values in the fourier coefficients array and are stored for later. Results were normalized automatically by SciPy's FFT function. Now, knowing the indices of the 10 largest coefficients, we sequentially extract phase and amplitude values from each.

The code calculates the amplitudes for the Fourier coefficients by taking the absolute value of the coefficients, dividing the first coefficient by the sample size, and dividing the rest of the coefficients by two times the sample size. This logic is reversing the scaling done by SciPy's FFT functions such that when we later transform back into time domain, the amplitude will be correctly scaled. Finally, amplitude values are appended into a NumPy array. Next, phase was calculated using NumPy's angle() function, and was subsequently divided by sample size to normalize it.

Frequency had to be computed differently. From reviewing Professor Borland's code, we developed a methodology and were able to find a function in SciPy that does it for us. Professor Borland generated frequency bins that correspond to the FFT output and SciPy's fftfreq() function does that. fftfreq() returns the Discrete Fourier Transform sample frequencies and considers the number of data points in the original wave data. The function is particularly useful when analyzing the frequency content of signals using FFT.

The next page covers a multitude of plots validating our methodology, showing accurate re-modelling of the original tide data using its 10 largest magnitude fourier coefficients following the methodology above.

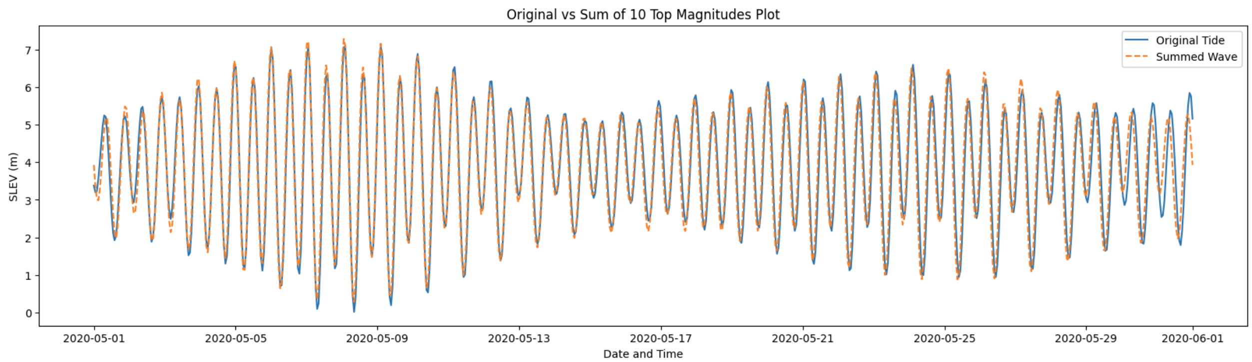


Figure 2: Actual wave data compared to wave generated by 10 largest magnitude fourier coefficients

A comparison of the model and the actual data for the month of May, reveals that model has high accuracy. The magnitude of the graph is mostly accurate with slight under prediction from May 7th to May 10th. The model has the correct frequency and phase for the most part, but there is out of phase predictions for the last two days of May (May 30th, 31st)

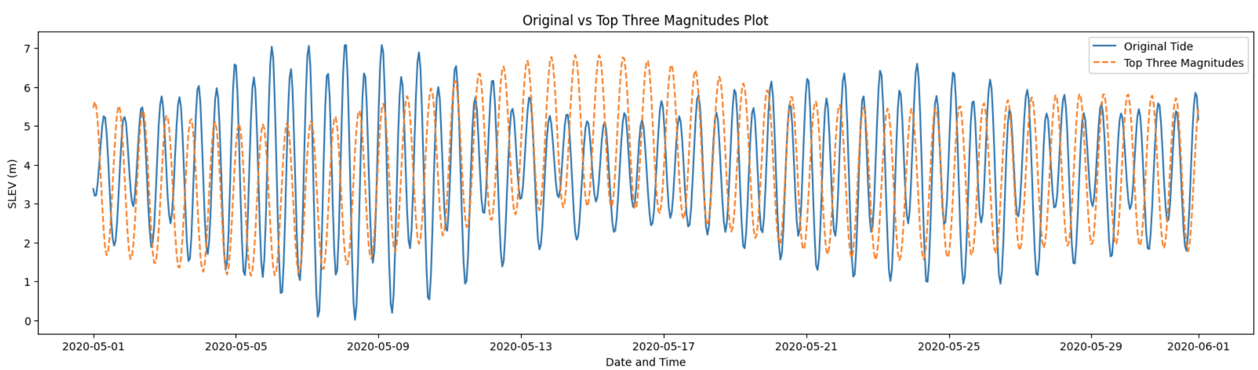


Figure 3: Actual wave data compared to wave generated by 3 largest magnitude fourier coefficients (excluding zero frequency term)

As expected the 3 component model is visually less accurate. Although the overall shape is accurate. (Small dip at beginning followed by gradual rise and fall followed by steady state. The phase is very out of sync and the model is not able to capture the predictions of extrema very well.

Section 2 - Predicting Tides with the Analog Computer

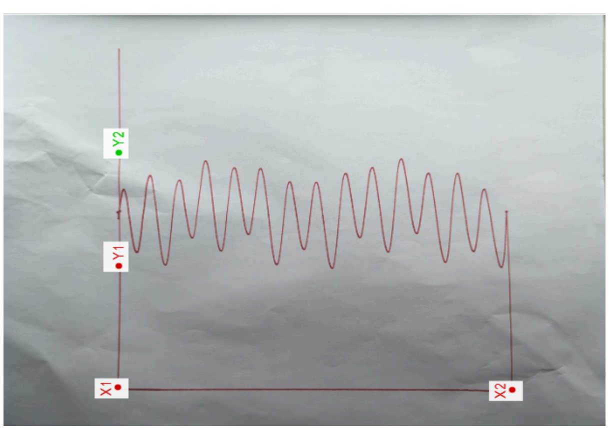
The analog wave machine was capable of combining three individual waves using amplitude, frequency and phase values from each wave. From the digital analysis in Section 1, data from the 3 largest wave components were used (excluding zero frequency component) to input into the wave machine.

Amplitude was in meters and ranged from -2.5 meters and 2.5 meters. Based on our calculations, we had waves with amplitudes greater than 2.5 meters in our top 3, thus, resorted to scaling the amplitudes of all the waves down and then have the scaling factor re-applied for results analysis.

Frequency represents how many tide cycles occur in a day. The frequency settings of the machine were limited to 0 to 5 cycles per day. Since we wished to plot wave machine results for a week, and we knew that there were approximately two cycles per day, we knew that there should be roughly 14 cycles/7 days.

Finally, the phase was in π radians and ranged from 0 to 2π radians. To validate results, waves were plotted into the Desmos graphing calculator to have a visual for comparison against the analog computer and to validate our results.

Machine operation was approached with supervision of a teaching assistant to ensure correct and safe operation. Instructions were closely followed, wires were visually checked to be plugged in, and the reset button on the machine was clicked to reset the pane to its starting location. Next, using the knobs provided, a test run was conducted of a sinusoidal wave with an amplitude of 1 and phase of 0 to determine a reference for how the data should be scaled to account for 7 days in a single run of the machine. We ran 2 different tests of the wave machine. The wave values for the first test were later proven to be incorrect. After viewing test results, they were adjusted to meet a correct scaling and phase shift based on the wave machine's constraints. With the second test, the group ensured correct values were input into the wave machine and the results were visually validated against the wave generated earlier via the graphing calculator.



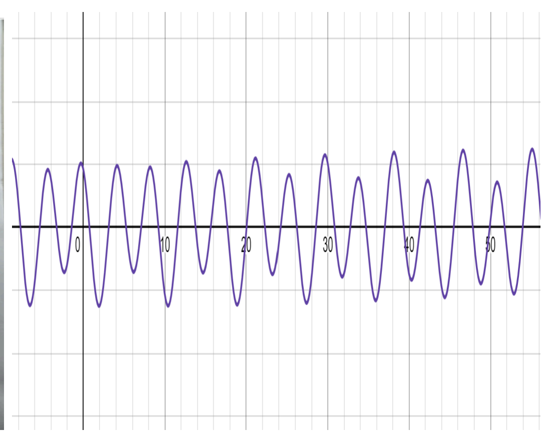
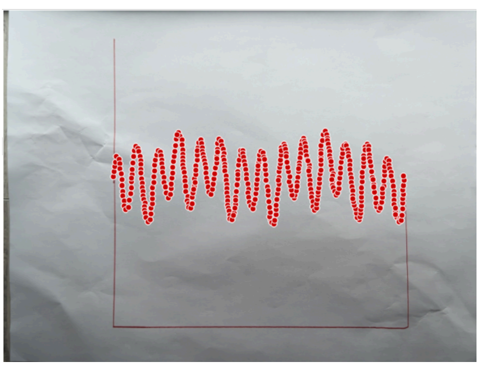


Figure 4: Wave generated via analog machine (left) and Figure 5: wave generated via graphing calculator with the same input frequency, amplitude and phase data(right)

After collection of our data,, We researched websites or software applications that could be used for the transcription. We tested the “Grabit” package in matlab, along with “WebPlotDigitizer“ and “GraphReader” [3][4][5]. We chose “Grabit” because of its intuitive software interface (good design principles) and because it has less steps to generate a transcription compared to other programs. After taking a picture of the results of the wave machine on a phone, we were able to upload the image to the computer and feed it into Grabit.

As a preliminary, we used sample predictions when running the machine for the first time. Sample values include an amplitude of 1 m, a frequency of 1 cycle/day and a phase of 0 pi radians. This preliminary step allowed us to identify the correct horizontal scaling factor needed for the machine to sketch an equivalent of 7 days of tidal data. This process showed that our graph's raw results would exceed the raw limits of the machine, hence horizontal scaling had to occur and a scaling factor of 2.889 was chosen.

We then had to mark the extrema points to scale the axes of the graph in Grabit. For the x-axis, we placed a pin of 0 for the beginning of the graph and a pin value of 7 for the end of the graph. Similarly, for the y-axis we selected a minimum value of 2 and a maximum value of 6, attained from prediction simulations in Section 3. Finally, after setting up the axis values, the graph was traced by placing data points as closely as possible in the software via manually input through mouse clicks. After points were placed, the software was able to generate a CSV of plot data that would followingly be processed in Python.



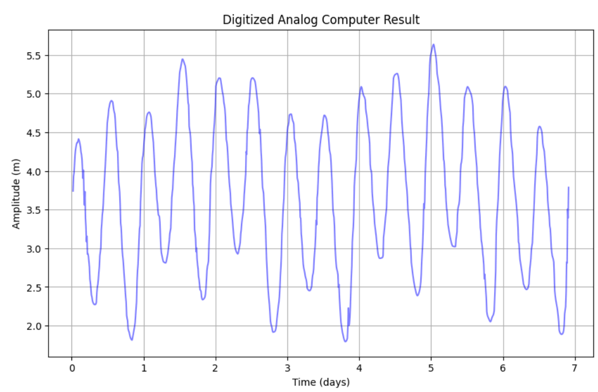


Figure 5 and 6: Digital point interpolation of points (Left), and digital transcription of digital point transcription.

In the digital representation of the analog computer results, there were some inconsistancies (at approximately between days 3 and 4). This is attributed due to human error from plotting with the software. Our transcription contained 1000 points, however for comparison of these results to the actual data in section 4 we needed it to contain the same amount of elements as the actual data (168). The results from the analog computer were then downsampled to 168 terms for compatibility. Downsampling is the subsampling of a discrete signal [6]. A qualitative check was done to verify that the downsampled example retained the shape of the wave created by the analog computer.

Finally we inputted this information as a spreadsheet document, which was loaded into the python language code which was able to create a graph.

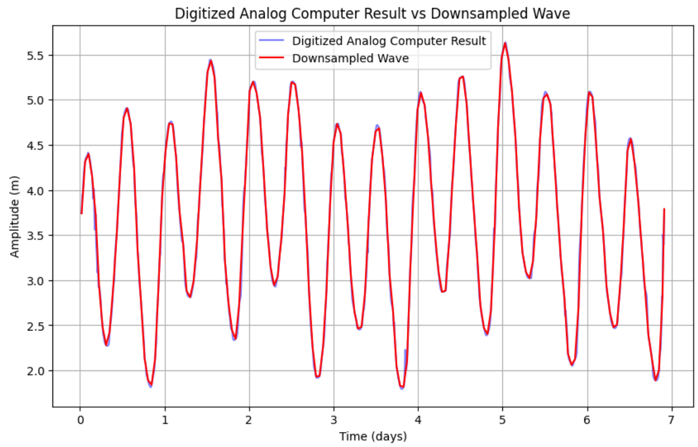


Figure 7 : Final results for predictions.

We were able to qualitatively compare the results with actual data (please section appendix 3,), Overall finding that some of the transcriptions were accurate. Quantitative analysis of these predictions will be discussed in part 4 of the report.

Section 3 - Predicting Tides Digitally

We generated the results for 9 fourier components plus the zero frequency component (total of 10 components) from day 30 to day 37. The zero frequency simply adds a reference point for vertical translation of the function. To create this plot, we had to do additional processing of data after extracting the amplitude, frequency and phase term from the fast fourier transform in section 1. We had to do a vertical translation of the terms inside the cosine as we converted from hour to days (we had to multiply by 24 to the inside of cosine terms). Thus our initial model was of the form:

$$wave\,prediction = \Sigma(\,Amplitude_i * cos(24(2\pi * frequency_i * time + phase_i * \pi)))$$

where $i \epsilon Z$ (integers) and represents i cosine terms and $time$ is measure in days

We continued use of this model, extrapolating it through the first 7 days of June (June 1 to June 8). Once we extrapolated it, we had a set of hourly data points with the magnitude of predicted tide values in meters. A picture of the 9 terms is provided below (note that for all graph comparisons, the zero frequency component term was added).

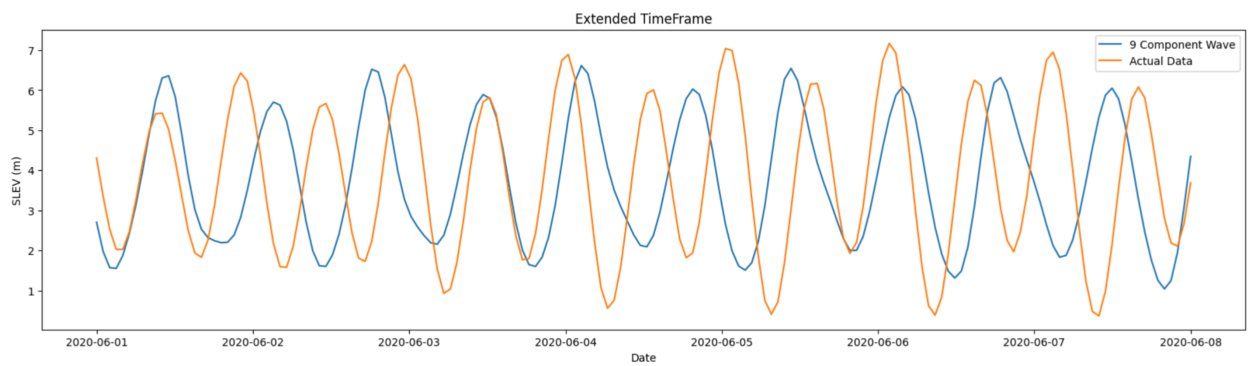


Figure 8: Actual Tide Data for June compared to 9 component prediction

To verify the basic performance we used a qualitative check by plotting our predicted data and the actual hourly date. Our results indicated that the shape of the predictions was indeed sinusoidal. Due to the non-constant peak and trough values for the tides, we could indeed tell that the tidal predictions were a sum of several sinusoidal terms. Additionally the peak and trough values for the predicted tide values closely matched that of the actual data. Although the convexities of the predicted results closely matched with the actual results, there is a noticeable phase shift between the sets of data. In addition, for the predictions at the start of their period (from June 1 to June 2), the magnitude of the prediction is far less than the magnitude of the actual data. Though the phase shift and magnitude inaccuracies are rather small, we surmise that it would show poor values in accuracy in Section 4. Quantitative metrics for assessing performance of these predictions will be discussed in section 4.

Different iterations of tidal prediction were done with varying numbers of tidal components from 0 1, 3, 5, 7, and 9. See Appendix for all iterations (5 was excluded in analysis below). For each result we obtained an array of the final results that had a timestep of 1 hour between variables, exactly like the actual wave data. and graphed them with the actual data in that time period. Sample graphs are provided below:

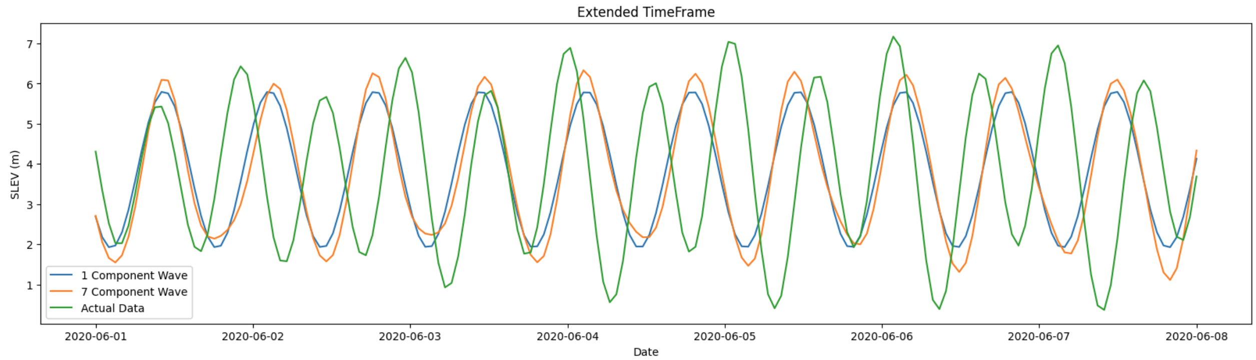


Figure 9 : Actual Data vs. Curves for 7 and 1 component

As observed, the results for the 7 component predictions have more accurate amplitudes when compared to the 1 component waves. The 1 component wave is a basic cosine wave that is scaled by amplitude and frequency to meet tidal data. However, both the 1 and 7 component predictions are out of phase compared with the actual data, and their peaks do not reach the same magnitude of the actual data, compared to the 9 component wave.

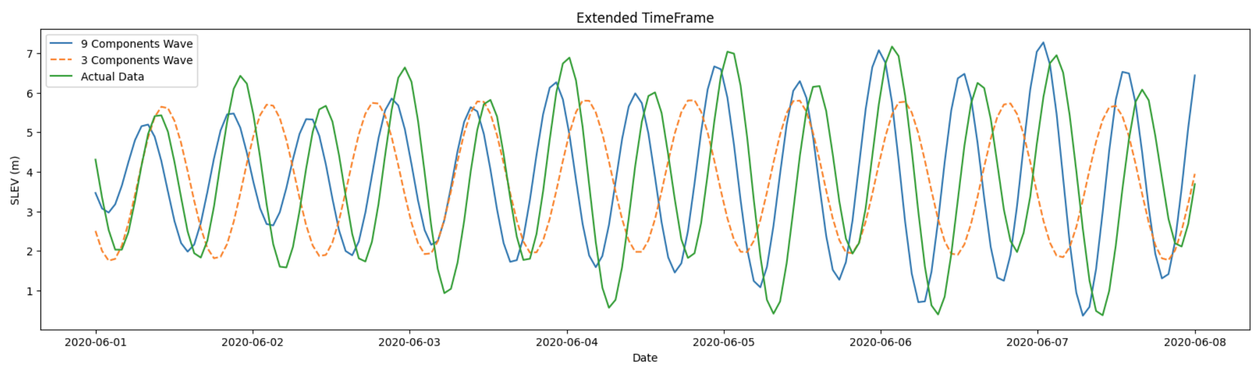


Figure 10: Actual Data vs. Curves for 9 and 3 components

Similarly, the response for the 9 component waves have more accurate amplitudes when compared to the 3 component waves. The results, while not perfectly aligned, match the phase of the actual data better. Individual Graphs for all 0, 1, 3, 5, 7, and 9 component predictions compared with the actual prediction data are found in the appendix. We increased the order of predictions by 2 ascendingly to observe these responses. As previously mentioned we found that as we add more cosine terms to our model, the overall predicted results tend to approach the actual data with better amplitude, frequency and phase responses of predictions. More cosine terms generates a signal that is more characteristic of the original wave. This is consistent with what we may expect from such a Fourier analysis as further validated by an academic article from the University of British Columbia that states: "As we add more and more terms the graphs start looking more and more like f(t), expect with minor discontinuities" [7] (where f(t) is the original function that is modeled).

Section 4 - Comparisons of Predictions to Actual Data

<u>Root Mean Square Error:</u>
Root mean square error tells us how far from a line if from another line it is being compared to. In this case we perform root mean square error calculations to compare the digital prediction to the actual data and the analog prediction to the analog data. The root mean square error tells the average difference in magnitude between any two points at a specific time for two waves. Each amplitude of the tide is stored in an array of 168 elements, representing one value for every hour in the 7-day period. We can calculate the residuals by subtracting each term of the array and squaring them. Those values are then average and square rooted to get our root mean square error [8]. These calculations result in the following:

$$RMSE_{Digital} = 1.9067$$

$$RMSE_{Analog} = 1.5591$$

These results imply that on average the analog prediction is closer to the actual data than the digital prediction. Upon closer inspection it can be observed that both results are larger than we would like. A root mean square error value of 0 means that both lines are exactly the same but both obtained values are greater than one. This implies that on average our digital prediction is 1.91m away from the actual data and that our analog prediction is 1.56m away. For future results, it should be noted that predictions should be iterated on to minimize the root mean square error as much as possible.

<u>Cross Correlation (Time Domain):</u>
For our time domain metric, we chose to use cross correlation to indicate if our predictions have the correct phase shift when compared to the actual data [9]. The x-axis of cross correlation plots shows how similar plots are to one another after applying lag between the prediction and the actual data. Positive x-values indicate how much the actual data is phase shifted to the right while negative x-value indicate how much the actual data is phase shifted. The y-value is a unitless value that shows how similar the two graphs are at any given amount of phase shift of the actual data and not amplitude of the wave in meters. Plotting the correlation found in Python through the numpy library against the lag results in the following plots [10]:

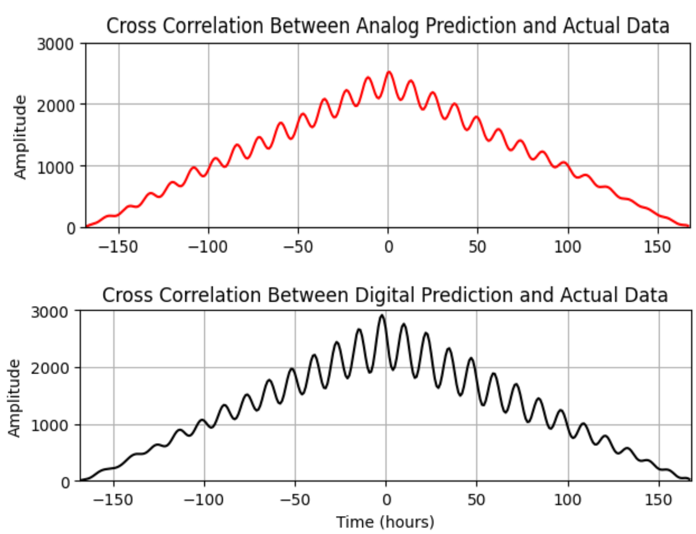
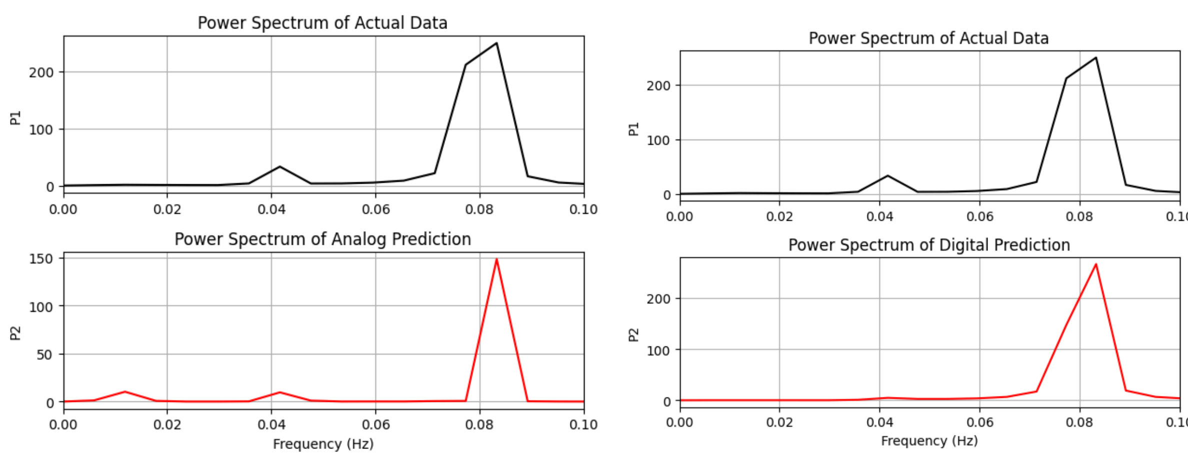


Figure 11: Cross Correlation Plots Between Predictions and Actual Data

From the plots it can be observed that the peak occurs close to 0. This indicates that our predictions are most accurate when the actual data is phase shifted by a value around 0. The exact value can be calculated by determining the maximum value and where it occurs. The maximum value for the analog prediction plot is 2521.71 at 1 hour while the maximum value for the digital prediction plot is 2915.42 at -2 hours. This means that our analog prediction is most similar to the actual data after it has been phase shifted 1 hour forward while the digital prediction is most similar to the actual data after it has been phase shifted 2 hours backwards. Another key point to note from the data is the average cross correlation of the two plots which are calculated to be 1172.98 for the analog prediction plot and 1232.79 for the digital plot. This shows that at different values of lag the digital prediction is on average more similar to the actual data than the analog prediction. The plot's x-axis also ranges from -168 to 168 hours showing that the actual data holds some resemblance to both the digital and analog prediction after being phase shifted 168 hours in either direction.

<u>Power Spectrum and Coherence (Frequency Domain):</u>

The last metric used to compare the predictions to the actual data is power spectrum and coherence to compare the similarity of two signals in the frequency domain [11]. The first step of doing this comparison is to convert our existing waves into the time domain which can be done by calculating the periodogram of each wave. In the code the periodogram function was used with the scaling parameter 'density' resulting in the unit of the y-axis being W/Hz. These can then be plotted as the power spectrum over a provided frequency shown below:



Figures 12 and 13: Power Spectrum Comparison of Analog and Digital Prediction to Actual Data

The Coherence estimation shows at what frequencies both signals peak at. In the above figure it can be calculated that all plots have a peak at 0.0833 Hz. In the coherence estimation it would show a large peak at 0.0833 Hz when the actual data is compared to both the analog and digital prediction. This result tells us that there are shared components of all the signals at that frequency. The difference however is the magnitude of those peaks. At 0.0833 Hz the power spectral density is 248.90 W/Hz for the actual data, 148.32 W/Hz for the analog prediction, and 265.45 for the digital prediction. The magnitude of the power spectral density of the digital prediction is closer to that of the actual data than the analog prediction implying that there are more similarities between the frequency of the digital prediction and the actual data.

Section 5 - Reflection

Engineers shoulder significant responsibility, as their designs, execution, and innovation shape the tools and services that society uses every day. The topic of tides is becoming increasingly important as climate change continues to trend toward rising sea levels and changes in tidal patterns. Consequently, it becomes ever more important that engineers design with consideration of tides and how things should be designed to be sustainable when tides rise even more. Concerning tides, engineers must follow certain codes to address them as a consideration when constructing features in coastal or flood-prone areas. These considerations need to be made throughout the entire process of infrastructure development, including planning, measuring, constructing, and post-construction phases.

Engineers play a crucial role in the protection of society with respect to tides. They are responsible for designing infrastructure that is resilient to the effects of rising tides and will positively benefit society. They need to consider the following three factors when designing new infrastructure.

1. **Risk Assessment:** Engineers need to assess and manage risks related to tidal effects. They need to evaluate the potential risks, whether the safety is compromised, and what measures they need to implement to mitigate these risks. In relation to tides, considerations include coastal or structural erosion, flooding, and navigation to ensure maritime travel. An example of a case where risk assessment was not sufficient was the New Orleans Levee system which was designed to protect the city from flooding [12]. Levees were breached in more than 50 locations during Hurricane Katrina in 2005 [12]. The hurricane coincided with the high tide which significantly increased water levels in the area, with the storm surge in Plaquemines reaching as much as 6.1m above sea level [12]. This forced 400,000 to flee from the city and caused a death toll of at least 1,118 [12].
2. **Measurement:** Engineers are also responsible for making sure they have the right data and measurements to make their designs safe. Even after constructing the infrastructure, they also need to monitor its performance to make sure it is in proper, safe conditions, and changes can be made if needed. For example, Foster City, California, kicked off a project to increase the height of its levees to meet the National Flood Insurance Program’s (NFIP) requirements for levee accreditation [13][14].
3. **Environment Management:** They need to consider the impact on the environment and assess whether the construction will contribute to a change in tidal patterns, disrupting ecosystems. For example, constructing artificial islands can alter the flow of water, affecting tidal currents and patterns in surrounding areas. One example of this is the artificial islands and reefs in Jinmeng Bay that hinder tidal currents and weaken tidal actions which led to the accretion of COD and NO_3^- [15].

To accomplish these objectives, some guiding principles are the compliance, regulations and standards that engineers must uphold in the design and implementation of their projects.

An example of this is the development of the “Levee Improvements Project” in Foster City, California. Foster City is a planned community, with an organized development plan that currently has a population of over 30,000 [14]. Foster City was built throughout the 1960s, but sea levels continue to rise, and an 8-mile-long levee stands in the way of preventing the city from being underwater; just one foot of sea level rise would leave much of the city below sea level [16]. In 2014, the U.S. Federal Emergency Management Agency (FEMA), completed the Central Coastal Analysis and Mapping Project (CCAMP) that analyzes hazards associated with tides and waves and found that Foster City's levees did not meet the required elevation for accreditation per Title 44 of Code of Federal Regulations Section 65.10 [13]. Unless the city's levees were increased from the 13-foot height, homeowners would have to pay a minimum of $2,000 to $3,000 annually for flood insurance [16]. As a result, more than 80 percent of the city's residents voted for a $90 million bond to raise the levee by eight feet in 2018 [16]. The Levee Improvements Project reached completion in February 2024 [17].

The development of this project is guided by principles and codes that ensure standardization across risk assessment, measurement, and environmental management, ensuring the safety and reliability of infrastructure. For the Foster City levee system, some of the codes include:

1. **Risk assessment:** To assess the risk of the city, the city had to adhere to FEMA codes. After the 2014 CCAMP studies conducted in the city, Foster City was at risk of losing its Zone X (protected by levee) status if it didn't make changes [13]. With the Levee Improvement Project kicked off, the new levees should be expected to function at least through to the 22nd century [13]. With that, they had to coincide with Sea-Level Rise (SLR) projections for the Year 2100. However, due to the uncertainty of sea level projections, levee improvements were to be designed at the least to protect against Year 2050 SLR which could be adaptable without substantial foundation rework to meet SLR for Year 2100.
2. **Measurement:** To measure SLR, they used projections from the National Research Council (NRC). This was to be consistent with planning efforts for other projects as these sea level rise projections from the 2012 NRC report, have been adopted by the City and County of San Francisco and other Bay Area Organizations for infrastructure planning as the basis of design analysis for adaptive sea level rise measures [13].
3. **Environmental management:** The DEIR provides an evaluation of the potential environmental impacts of the proposed project and recommends mitigation measures to reduce impacts to a less-than-significant level [18]. The implementation of the project would have no significant impacts except the following:
    a. Aesthetics and Shade and Shadow: The increased elevation of the levee may adversely impact scenic vistas [18].
    b. Noise and vibration: The construction of the project would expose residences, schools, hospitals, and retirement homes to temporary noise levels that would conflict with the City of Foster City Municipal Code regulations [w].

To illustrate the relationship between professional engineers, engineering codes, the protection of the public, and tides, a stock and flow diagram depicts the construction of the new levees in Foster City in Figure 14.

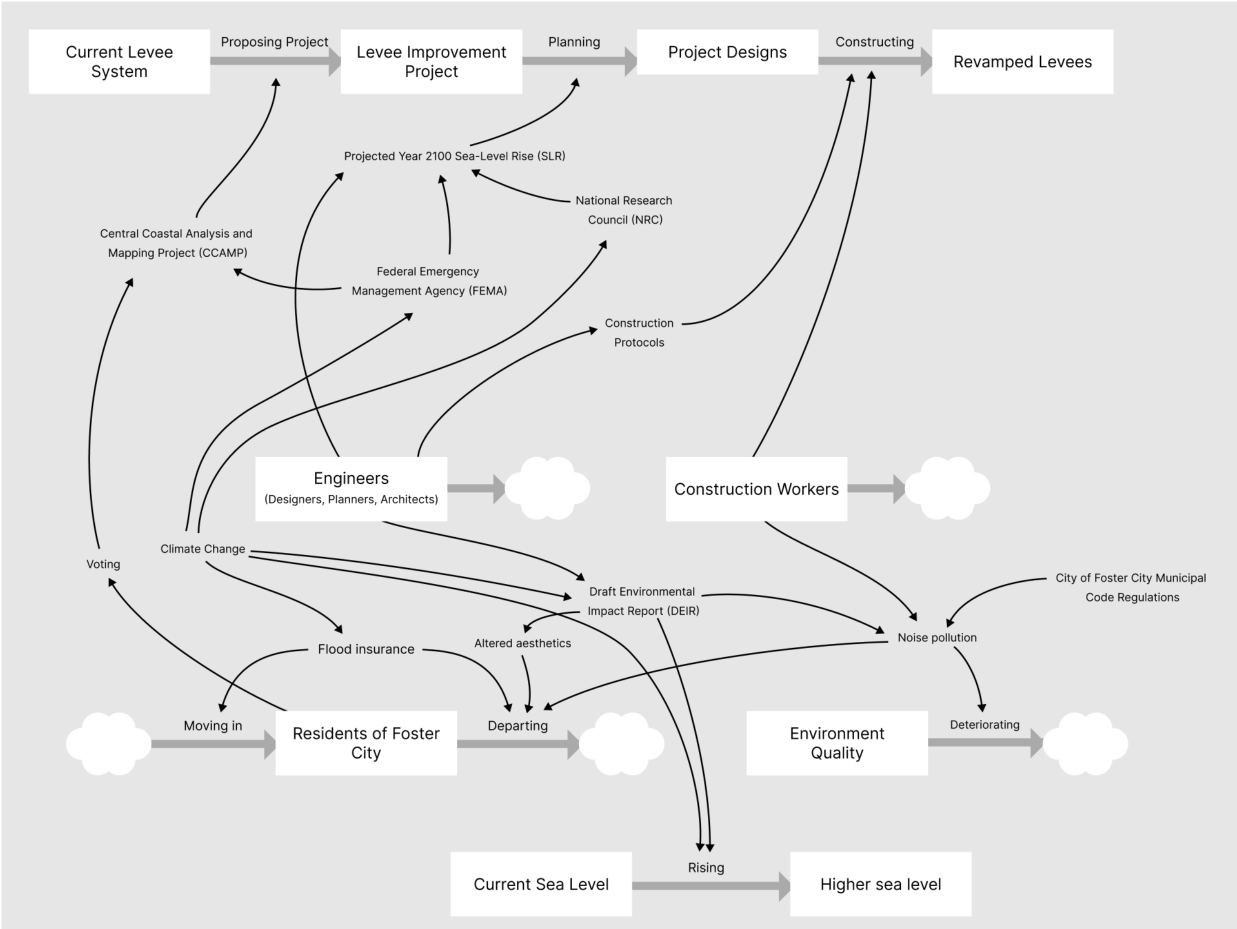
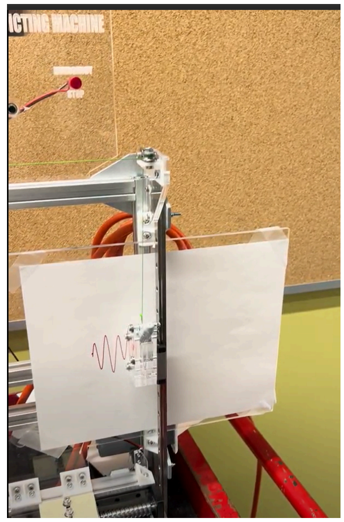


Figure 14 Stock and Flow diagram of Levee Improvement System in Foster City

This flow diagram shows how engineers integrate consideration for tides within the framework of codes and regulations to benefit society. Engineers adhered to standards across the whole journey of project proposal, planning, and construction. The Levee System Project was initiated and proposed due to the CCAMP deeming the city did not meet elevation for accreditation with rising sea levels due to climate change. As a result, engineers had to plan a new project to meet these standards provided by the FEMA. In determining the best way to implement these new levees and the right height to elevate them to, they considered the projected Year 2100 SLR provided by the NRC. Engineers are also responsible for delivering protocols to construction workers ensuring that the implementation matches the designs and is done in a safe manner. These new implementations increase the sense of security of residents of Foster City and alleviate the need for flood insurance which may influence residents to remain in the city. It also attracts potential new residents who may have been hesitant due to safety concerns.

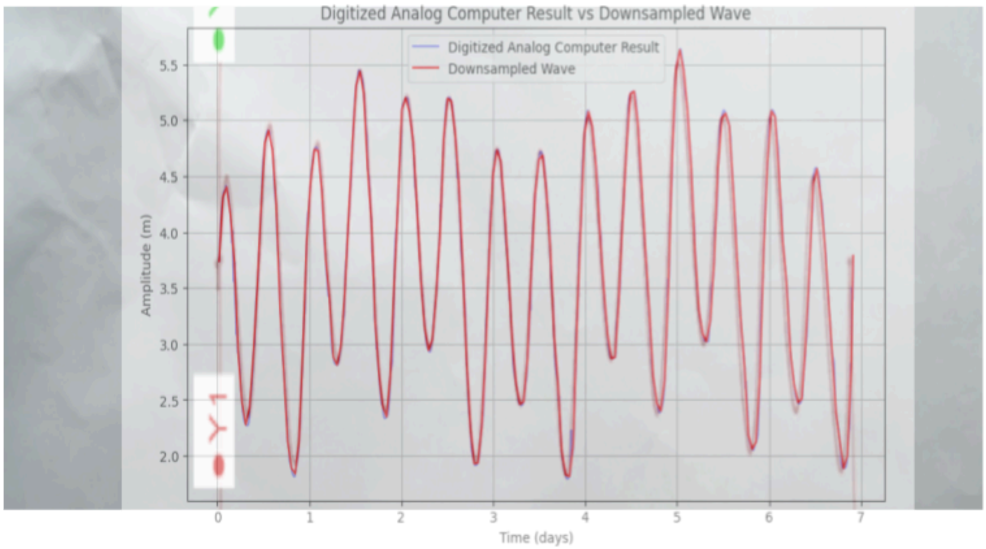
Appendix:

Section 3:

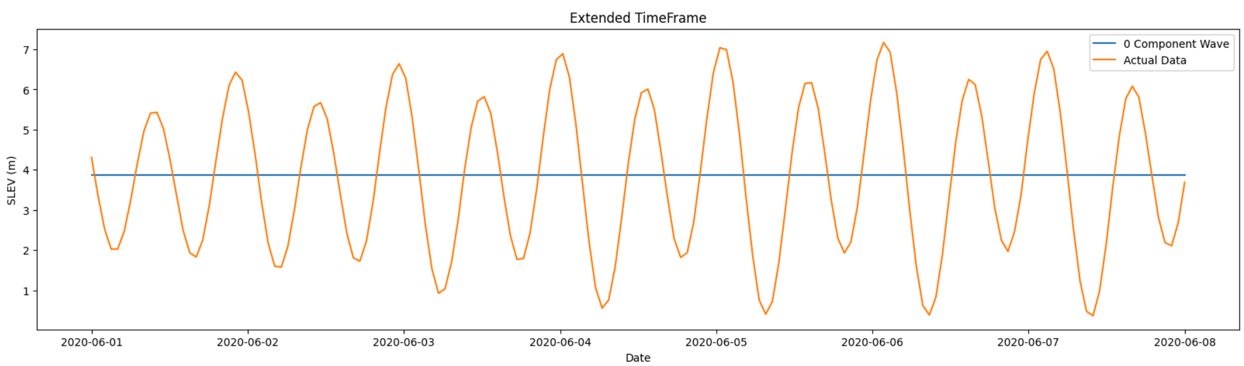


Appendix Figure 1: Still from video capture of wave machine results(provided in submission).

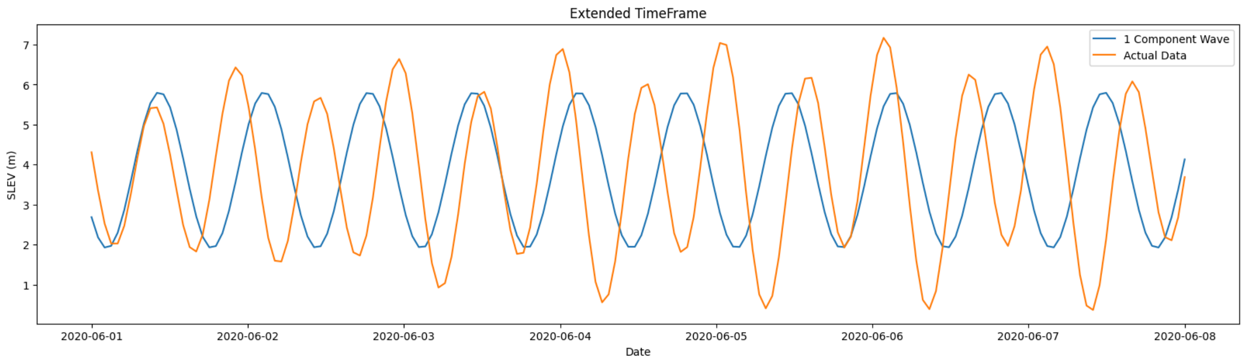
Section 4:



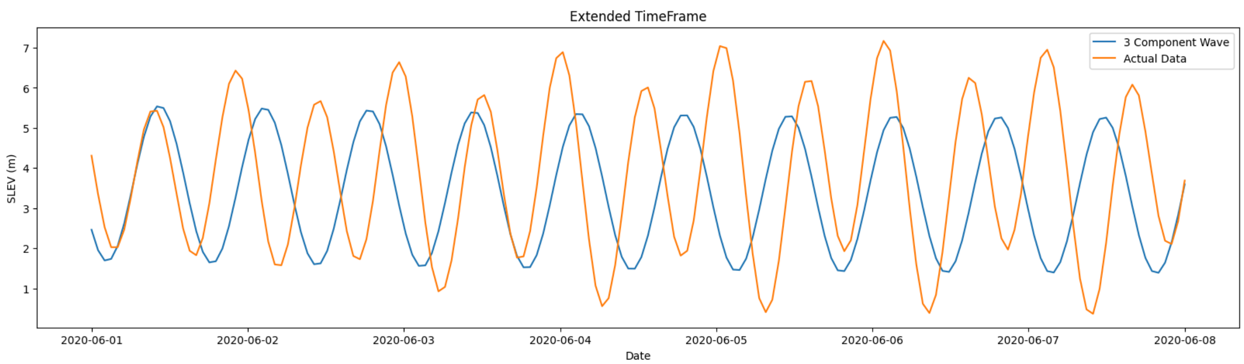
Appendix Figure 2 : Final Downsampled results overlaid with raw predictions revealing high accuracy of transcription



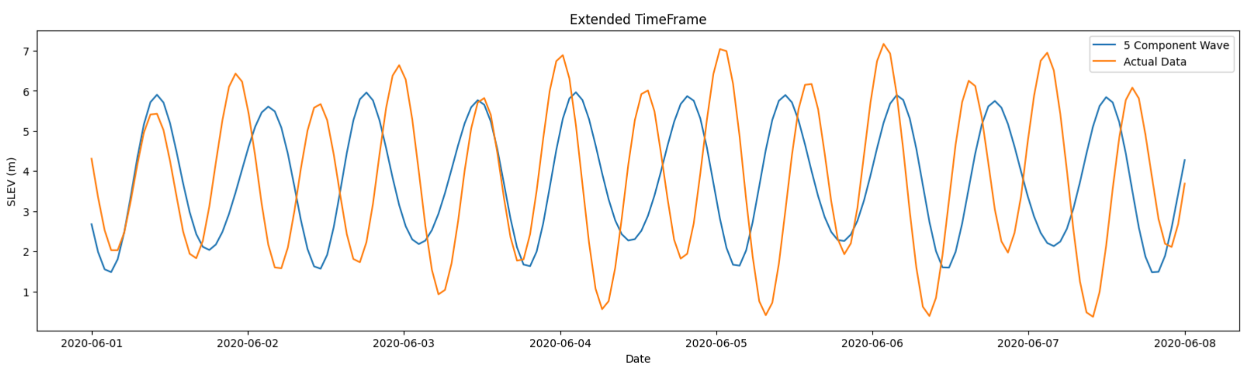
Appendix Figure 3 : 0 competent wave



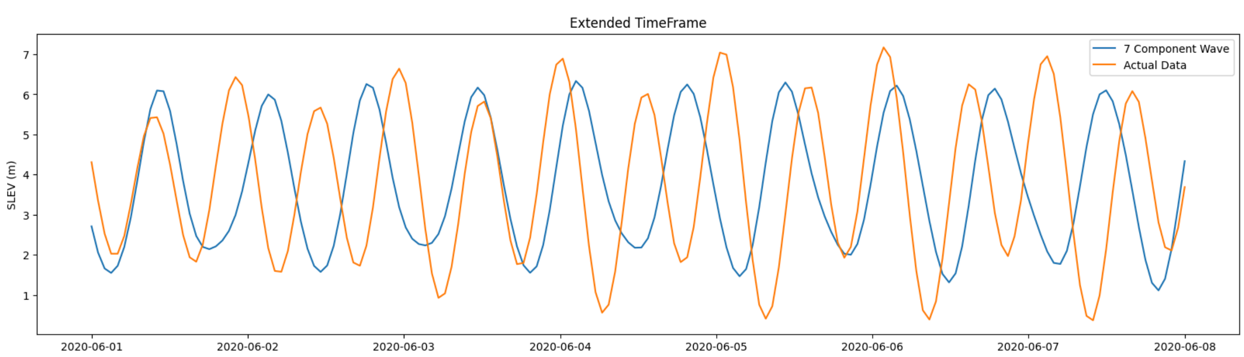
Appendix Figure 4 : 1 competent wave



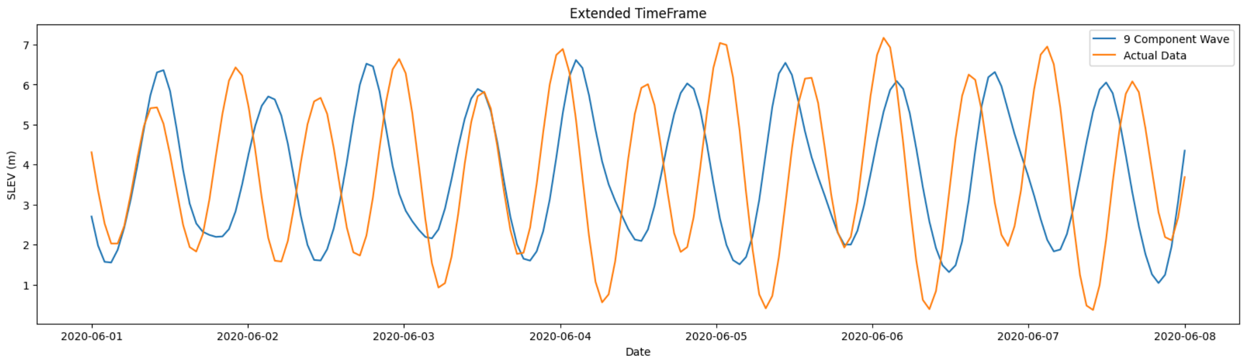
Appendix Figure 5 : 3 competent wave



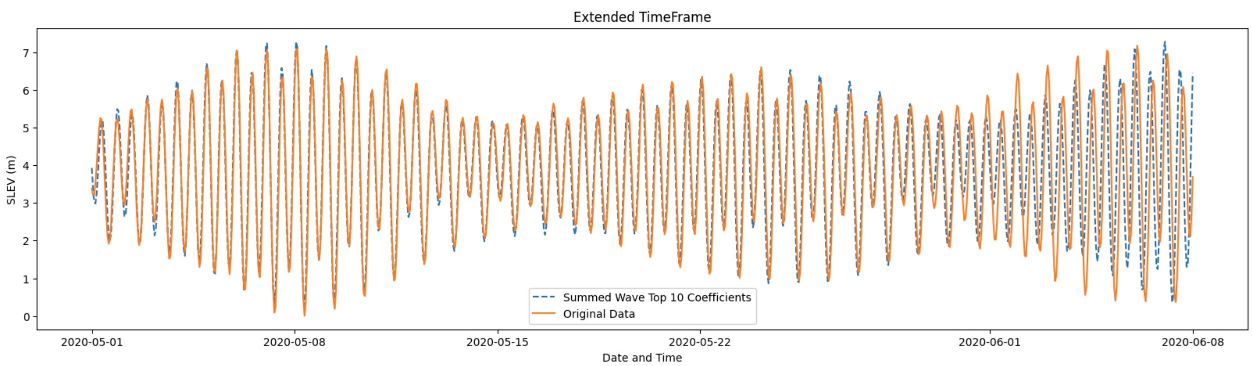
Appendix Figure 6 : 5 competent wave



Appendix Figure 7 : 7 competent wave



Appendix Figure 8 : 9 competent wave



Appendix Figure 9 : Actual wave data compared to waves generated from 9 fourier components in addition to zero frequency for testing and training data.

References

[1] “Government of Canada.” Climate, / Gouvernement du Canada, 30 Jan. 2024, climate.weather.gc.ca/climate_data/daily_data_e.html?hlyRange=2010-06-03%7C2024-03-23&dlyRange=2010-06-03%7C2024-03-22&mlyRange=%7C&StationID=48693&Prov=BC&urlExtension=_e.html&searchType=stnName&optLimit=yearRange&StartYear=1840&EndYear=2024&selRowPerPage=100&Line=1&searchMethod=contains&txtStationName=pRINCE%2BRupert&timeframe=2&Day=1&Year=2020&Month=1#.

[2] “Government of Canada.” *Climate*, / Gouvernement du Canada, 30 Jan. 2024, climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=prince%2Brupert%2Ba&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=422&dispBack=1.

[3]“GRABIT,” *www.mathworks.com*. https://www.mathworks.com/matlabcentral/fileexchange/7173-grabit (accessed Mar. 19, 2023).

[4]“automeris.io,” *automeris.io*. https://automeris.io/WebPlotDigitizer.html

[5] “graphreader.com - Online tool for reading graph image values and save as CSV / JSON,” *www.graphreader.com*. https://www.graphreader.com/

[6] “Sampling Signals Overview.” Accessed: Apr. 05, 2024. [Online]. Available: https://www.cs.toronto.edu/~jepson/csc320/notes/slidesSampling.pdf

[7]“Fourier Series,” 2007. Available: https://personal.math.ubc.ca/~feldman/m267/fs.pdf

[8] S. Glen, “RMSE: Root Mean Square Error,” *Statistics How To*, 2022. https://www.statisticshowto.com/probability-and-statistics/regression-analysis/rmse-root-mean-square-error

[9] “Cross-Correlation,” *Investopedia*, 2019. https://www.investopedia.com/terms/c/crosscorrelation.asp

[10] “Measure Signal Similarities - MATLAB & Simulink Example,” *www.mathworks.com*. https://www.mathworks.com/help/signal/ug/measuring-signal-similarities.html

[11] “Compare the Frequency Content of Two Signals - MATLAB & Simulink,” *www.mathworks.com*. https://www.mathworks.com/help/signal/ug/compare-the-frequency-content-of-two-signals.html

[12] “New Orleans Hurricane Katrina Levee Failures,” Failure Case Studies, https://eng-resources.charlotte.edu/failurecasestudies/dam-failure-cases/new-orleans-hurricane-katrina-levee-failures/ (accessed Mar. 22, 2024).

[13] “Basis of Design Overview.” Schaaf & Wheeler Consulting Civil Engineers, City of Foster City, Oct. 2016

[14] “History of Foster City,” History of Foster City | Foster City California, https://www.fostercity.org/community/page/history-foster-city (accessed Mar. 22, 2024).

[15] J. Fan *et al.*, “Impact of artificial islands and reefs on water quality in Jinmeng Bay, China,” *Water*, vol. 15, no. 5, p. 959, Mar. 2023. doi:10.3390/w15050959

[16] “A city rose on the marshes. will the Bay Take It Back?,” & the West, Stanford University, https://andthewest.stanford.edu/2018/a-city-rose-on-the-marshes-will-the-bay-take-it-back/ (accessed Mar. 22, 2024).

[17] “Foster City Levee Project,” Foster City Levee Project | Protecting the Community, https://fostercitylevee.org/ (accessed Mar. 22, 2024).

[18] “Foster City Levee Protection Planning and Improvements Project.” Urban Planning Partners Inc., Foster City, Nov. 2016