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Long-Island New York and its Wave Harvest Potential

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1 Introduction

The Earth's landscape is mostly dominated by water. In fact, 71 percent of all land is primarily covered by water (USGS). Yet the harvest of conventional energy in the United States is still primary centered on "non-renewable" energy sources (i.e fossil fuels). In days of rising global temperatures, prices and the need of more fossil resources, certainly we are at the verge of collapse while American corporations still retain the top-down models. Top-down energy models are in layman crafted toward the financial revenue, however often neglecting the efficiency and impact on the environment. It seems obvious that a new need for conventional technologies that utilize reusable energy sources, such as solar, are in largely a part of the energy-crisis solution. Most certainly, the ocean one day may provide solutions to a global energy crisis.

In more recent years, the potential of wave-energy harvesting has seemed to gained major popularity for the simple reason that oceanic waves are unused power potential. Especially within oceans, William G. Van Dorn mentions that about 10 per-cent of all waves will be around 5 meters (Oceanography and Seamanship). In such dynamic cases, the gravitational potential energy of each ocean wave could be stored as electric energy. Swedish corporation such as Ocean Harvesting Technologies (OHT) does exactly that, harvests the energy of oceanic waves through specially designed buoys controlled with pistons that generate electricity. The technologies found within these systems, are far more advance for the purpose of this paper, however, we mention this as a demonstration to the reader that indeed the potential of such technologies is upcoming and seems very promising.

For many reasons we turn now our attention to New York state as a strong candidate of energy wave harvesting. After all, New York state is a coastal state implying that many major storms and ocean swells from the Atlantic could be used as potential energy harvesting opportunities. In addition, considering the New York Ocean Action Plan (nyc.gov) there has been a major interest in expanding the economic growth in our oceans, and thereby technologies such as OHT would provide a major economic boost to the marine and energy sustainability.

In this research project we will analyze the potential wave energy harvest in Long-Island, Montauk, which is considered to be the tip of New York state that directly communicated with the Atlantic ocean. Using buoy data from the National Oceanic and Atmospheric Administratio (NOAA), we investigate the period and wave height parameters recorded from a single buoy, extrapolate the values, and perform preliminary calculations to estimate the potential energy harvested. In this paper, we argue that since Montauk is located at such a unique position – being affected directly by the swells originating from the Atlanic – we hypothesize that the energy harvest potential will comparable to other renewable energy sources, if not greater.

2 THEORY

2.1 LINEAR WAVE THEORY

Waves, nonetheless ocean waves are direct carriers of momentum and energy. To answer our research question, we need to quantify the energy that a typical-wave is capable of producing, more importantly the energy per unit time meaning the power each crest on average would be able to reproduce. Oceanic waves are driven by very complex and data-driven models that consider the interplay of physical parameters. However, this is not to say that to an first order approximation, we're able to estimate an average power rate of the ocean using two of the most important wave parameters such as period and wave amplitude. The simplest form of approximations could be used by the Linear Wave Theory (LWT) to evaluate the energy of waves considering only the gravitational potential as the main driver for energy.

The Linear Wave Theory (LWT) is used as an approximation only utilizing the gravitational force (g). Note that in order to utilize the boundary conditions of the LWT, we assume that the water depth, wavelength are greater than the amplitude of each wave (Leo Holthuijsen). By solving the boundary conditions of the Mass Balance and Continuity equations, one is able to describe such oceanic waves by a harmonic wave from equation (5.4.1) in Holthuijsen book:

$$\eta(x,t) = Asin(\omega t - kx) \qquad (1)$$

which is the familiar simple harmonic oscillator that we've seen throughout this course. The energy associated with equation (1) could be solved by the energy transport which results in equation:

$$E = \frac{\rho g \eta^2}{2}$$

Since we're interested in the power harvesting potential, the total power will be proportional to the group velocity, described by the following equation:

$$\bar{P} = E_{total} C_{group} = \frac{\rho_{H_2O} g^2 T \eta^2}{32\pi} \qquad (2)$$

where η is the amplitude of the wave and T the wave period and C_{group} is defined as the partial differentiation between the angular frequency and restoring coefficient:

$$C_{group} = \frac{\partial \omega}{\partial k} = \frac{g}{2\omega}$$

2.2 Ocean Power Technologies

3 Data

Long Island being a diverse marine environment, is surrounded by many wave buoys that are capable of recording weather and wave parameters at a given location. Such information is vital for many local weather forecasts, in addition is very useful information for ships that carry large cargo.

Nonetheless, for our analysis we explore the wave parameters for a single buoy located a few miles away from Montauk Long-Island, located at the peak of Long-Island where it's in direct contact with the Atlantic Ocean, as seen in Figure 4.3. The uniqueness of the buoy selected (buoy number: 44017) is that it would be most prune to swells originating from the Atlantic without the interference of major land between Montauk and the origin of swell. We expect that other buoys located on the sides of Long-Island to be affected primarily from wind-directions.

The data collected to conduct this analysis is taken from the National Oceanic and Atmospheric Administration (NOAA). Since the data collected for 2018 has not been available for our particular buoy, we choose a 4-month period between January 1, 2017 to April 30 2017. The data collected is recorded on an average hour basis, hence for each day we estimate the median period and height of the wave cycle. For each day-bin we also assume that the error correlation is homoscedastic meaning that all error bars are roughly the same, defined by the standard error of the population:

$$\sigma = \frac{\sigma_N}{\sqrt{N}}$$

For each day, we also apply a 2σ quality cut, for data points that may have had anomalous recordings. Finally once we have the data reduced, we proceed to estimate the linear-wave energy output under the following constraint:

$$P \approx Q\bar{P} \qquad (3)$$

where Q is an arbitrary and adjustable efficiency factor. We imagine that Q is determined on the efficiency of the machine to convert mechanical energy to eclectic energy. Further, based on literature, the Q-factor will also be frequency dependent, however to simplify our calculations we will assume Q to constant at roughly 0.6 which is consistent with the literature (US DOE). For each day that we estimate the energy, we also compute the average dollar per kW rate according to the EIA, is 19.28 cents per kWh, and last the total energy produced in the month is computed by the summation of all energy for a given month, described by the relationship:

$$P_{month} \approx \sum_{n=1}^{N_{day}} P_n \qquad (4)$$

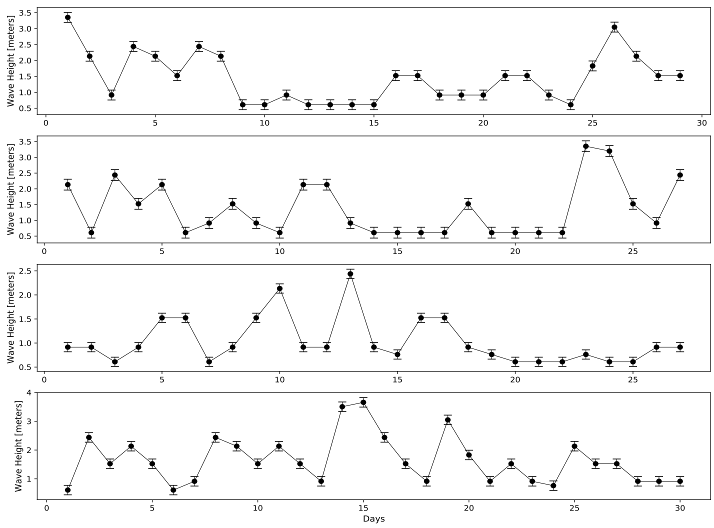

Figure 4.1: Extrapolated day median values of wave height in meters. The order of the panel is from January 2017 from the top. Each day-bin is associated with the standard error of the population.

4 DISCUSSION

After following the data-analysis procedures highlighted in section 3, we begin to explore the preliminary data extrapolated from buoy 44017. In Figure 4.1, we see the median wave height in meters for each day of the month. The error bars are the standard error statistic of the population of that chosen month. In these figures, the main point demonstrated is that throughout the month, there are natural occurring cycles of high to low wave heights. In particular, we notice the repeating pattern for the firs two months (first and second from the top) with the pattern of high low high wave heights. This indeed may be a variation caused by the new/full moon cycles that ultimately may produce the high tide.

For each day observation, we calculate the predicted energy that the associated heights per kWh, since each data point represents a cycle of 24 hours. Finally, we apply to our energy results equation (2), with an arbitrary range from 0.1 being less effective, and 0.9 being very effective. For each bin, we also compute given its associated energy, the cost per kWh rate.

As predicted, these first order estimates estimate that the energy output for each month well succeed over 10 kWh rates, which are far more efficient than the average solar panel of 300 watt. In some cases, just like March, seen in the last panel of figure 4.2, the energy harvest can corresponds to over 100 kWh with a price of approximately 150 dollars for a single day. While the numbers associated with a single energy-machine harvester may not be as impressive, we remind the reader that this would be for one machine only. More impressively, we note that in some cases, the results approach an impressive upper limit of over 120 kWh per day, which would be about half of the energy consumption of a house in New York(http://insideenergy.org). If instead we consider equation (3), where we take the summation of all days into account, in some cases a machine would be able to produce roughly 500

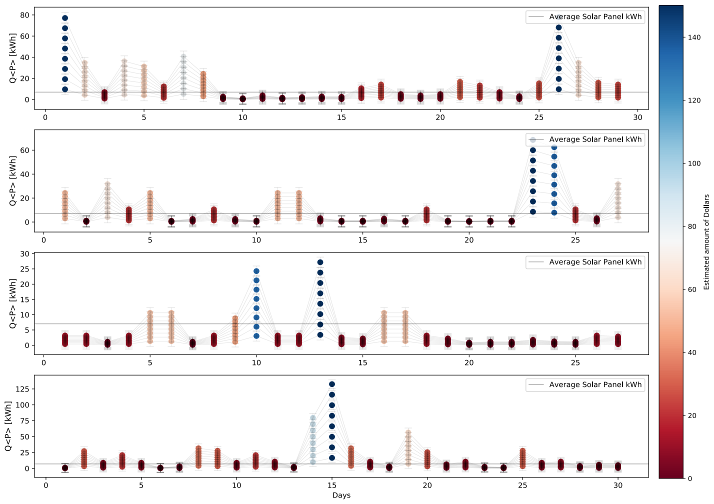

Figure 4.2: Estimated power per units of hours for each median day-bin. For a series of Q-factors (see section 3) we explore the power parameter for each given value. For each day, we also compute the estimated amount of dollars per kWh. Each day-bin is associated with the standard error of the population.

kW a month as an upper limit, and about 100 kW per month as the lower limit. In the upper limit case, this would almost come close to the average house energy consumption that would be generated by a single wave-energy generator.

The data collected for the purpose of this analysis however, is not the full story. While a single buoy with our selection criterion may able to display impressive amounts of energy harvesting potential, we recognize that our data selection method may have excluded wave heights and periods that may have been abnormal. To validate some of the extreme values, a similar analysis would have to be conducted for neighbouring buoys that would show that indeed this is a real signal instead of a improper reported value. More importantly, while the LWT gives us an first order approximation of the power harvesting potential, we note that the LWT is a simplification of oceanic waves. Instead other advanced methods that correctly predict the evolution of waves as functions of distance, topography and time are perhaps more robust and would yield to accuracy. Nonetheless, our first order approximations do seem promising, any by considering the data alone, the coasts of Montauk see enough of amplitude and period variations for future harvesting. We also acknowledge, that these wave energy harvesting machines would most likely need to be in the numbers of hundreds to cover some of the major energy consumption for parts of Long Island alone.

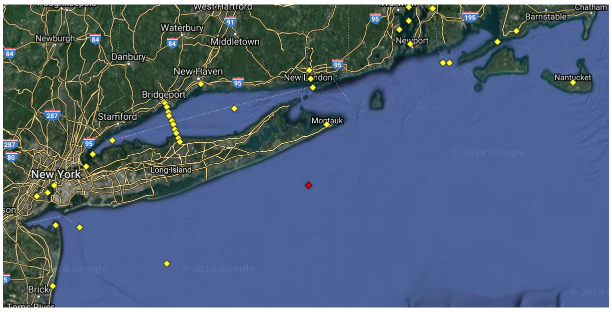

Figure 5.1: Google maps satellite image of the location buoy 44017 that was used for this analysis. The red dot represent its position in the ocean. We note its unique position with respect to Long Island as oceanic swells would propagate through the Atlantic without any landscape barriers.

5 Conclusion

In this research paper we report the median heights and periods of waves recorded by buoy 44017 by NOAA for 4 recorded months during 2017. Using the LWT, we estimate a power generation function that is directly proportional to the amplitude squared and period of the waves. We find that during those 4 months selected, that there is enough of variation in the wave height and period to drive waves up to 3 meters in height. The extrapolated power values under some energy constraints for the majority are comparable to the power harvesting of conventional solar panels. We find that the minimum and maximum power boundaries per month could be as high as 500 kWh per month and low as 100 kWh, however we speculate that these values may fluctuate in random ways from storms that are simply chaotic. However, the future work remaining on this project would be to examine the underlying cycles of wave height and periods per season. If we're able to access the total history of the buoy and also other surrounding ones, then it would be more interesting to investigate the underlying cycles and potential energy harvest.

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