

EVOLUTION OF EROSION HOT SPOTS ON A BARRIER ISLAND: FIRE ISLAND, NEW YORK

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Abstract: The distribution and evolution of local, shoreline features was examined by repeated mapping of the shoreline using a sub-meter GPS to map Fire Island from June to December. One region of erosion or "hot spot" was documented to migrate to the west, in the direction of the net longshore transport, at a rate of 2.1 m/day and then to the east at a rate of 4.2 m/day. Another shoreline feature followed the progression of a theoretical advection/diffusion model created earlier by other investigators to predict the migration of longshore sandwaves. This feature migrated to the west at 0.83 m/day. Similar features on the barrier island migrated to the west up to 51.5 m/day while others migrated to the east at rates up to 93.1 m/day. No trends in migration rate with the wavelength of the hot spot could be found. Rates tended to range between 1 and 100 m/day.

INTRODUCTION

Shoreline undulations are alternating landward and seaward displacements of the shoreline. Shoreline undulations manifest themselves in many different forms. Beach cusps, longshore sandwaves, and erosion hot spots are all classes of shoreline undulations. An erosion hot spot is defined for this paper as a specific section of the shoreline, of limited extent, which has become scoured of sand while nearby stretches of beach go relatively unscathed. The main goal of this study was to address whether or not erosion hot spots consistently appear in the same locations and whether or not they migrate in the direction of net longshore transport. While mapping the ocean shoreline of a barrier island, Fire Island, we were able to study an erosional hot spot, a possible longshore sandwave and the wavelengths that compose undulating characteristics of the shoreline along the total length of Fire Island.

Study Area

Fire Island was chosen as the site for this research based on the previous works by Allen and Labash (1996), as described by Gravens (1999), and by Batten (2003). Fire Island is one of the south shore barrier beaches of Long Island, New York. It extends from Fire Island Inlet to Moriches Inlet and is approximately 50 km long and averages less than 0.5 km in width (National Park Service, 2006). Robert Moses State Park occupies its western extremity; to the east, Fire Island National Seashore encompasses most of its length and Smith Point County Park is found at its eastern terminus. Winds are primarily from the west but can vary from the southwest in summer to the northwest in winter. Waves generally approach from the south-southeast with an approximate wave height of 1 meter (Batten, 2003). Fire Island has a semi-diurnal tidal cycle (Batten, 2003). The direction of net longshore sand transport is from east to west (Gravens, 1999).

METHODS

The shoreline was mapped using an Ashtech Reliance Submeter GPS with an Ashtech BR2 Beacon Receiver and a Psion handheld controller. The technique used to map the shoreline was similar to that used by Allen and LaBash (1996), and described in Gravens (1999). The shoreline was defined as the boundary between the saturated and the unsaturated sand; this wet/dry contact is usually used in interpreting shoreline position from aerial photographs (Anders and Byrnes, 1991). Multiple surveys were conducted from June 2005 through December 2005. The surveys of individual features taken for this study were 4 hours or less in duration. Surveying the total length of Fire Island took about 4 to 5 hours to complete using four-wheeled vehicle, a Polaris Ranger.

Shoreline undulations were subjected to spectral analysis to look for dominant frequencies and changes of phase, which might indicate migration. The spectral analysis was conducted using MATLAB. The data was detrended using equal spacings of 1 meter. After the data was detrended it was run through a Fast Fourier Transform (FFT) in order to identify the dominant wavelengths. Individual wavelengths could then be processed using and inverse FFT (IFFT) in order to obtain information about changes in amplitude and shifts in phase.

RESULTS

Smith Point Hot Spot

On 12 June, 2005 a shoreline undulation or “hot spot” was first mapped approximately 5 km east of Smith Point County Park. Smith Point County Park was then surveyed seven more times during the five month interval of June through October and twice afterwards on 17 and 18 November and 1 December, 2005. The majority of the surveys were conducted during the falling tide in order to catch the high tide shoreline as well as possible. The dune line remained stationary throughout the period. Several of the surveys were conducted specifically to see the results of a variety of passing storms. Between 12 June and 22 September, 2005 the hot spot became significantly less prominent in part because of shoreline recession to the east (Figure 1).

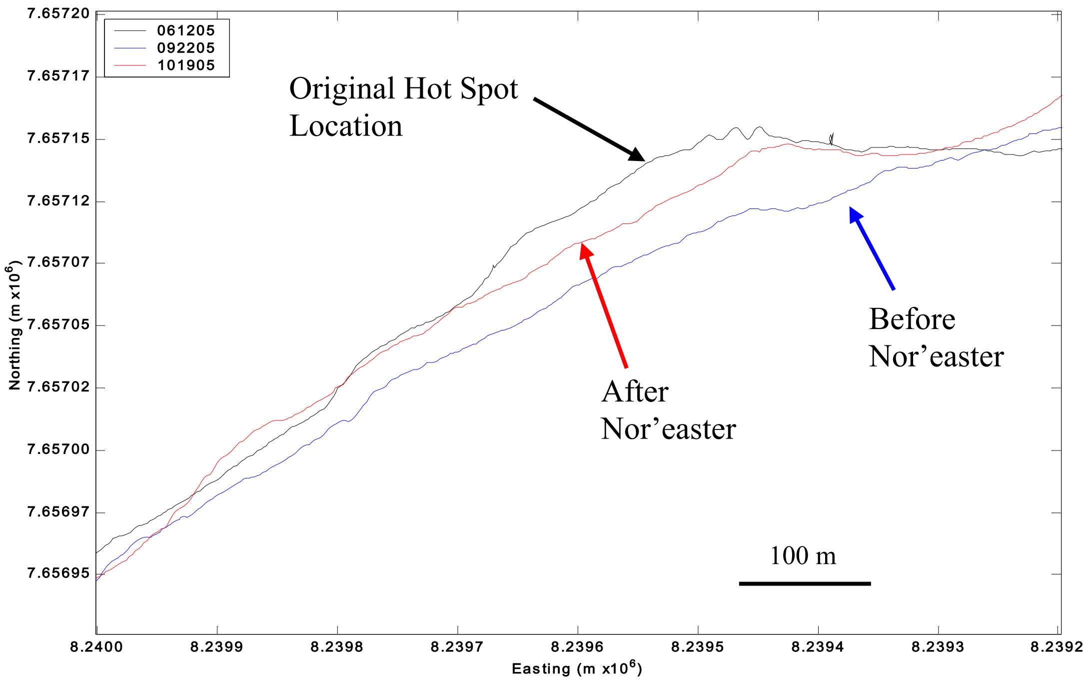

Figure 1. Condition of the Smith Point Hot Spot: original position, before and after a nor'easter in October, 2005.

In mid October, the area suffered the effects of a nor'easter that lasted for over a week. Wave heights were in excess of 5 meters and wave periods were over 14 seconds. The general direction of the storm waves were to the northwest, which would drive a westward longshore transport of sand. A survey was conducted on 19 October, 2005 after the storm had passed and the beach had experienced extensive damage. Significant change occurred between the 22 September, 2005 and 19 October, 2005. The erosional hot spot appeared to have persisted in the same location after the passage of the nor'easter (Figure 1).

To better visualize the changes in the dominant component of the Smith Point hot spot, its dominant periodicity was isolated by the IFFT as a sinusoid with a wavelength of 1000 m and an amplitude of 16.3 m (Figure 2). (In order to accurately compare the surveys the origin for each survey was chosen to be the easting value of 8239005 m.) Over time the hot spot had filled in or "healed" itself. There appeared to be no migration. This erosion hot spot healed in place reducing in amplitude at a maximum rate of about 0.1 m/day for a total reduction in amplitude to 6.5 m. By the end of the survey period (October 19, 2005), however, the amplitude had increased to

7.2 m and it seems to have migrated approximately 60 m to the west (Figure 2). This seemed to have been in response to the nor'easter of 7 October, 2005. Although the average westward migration over the 129 day period was about 0.5 m/day, almost all of the migration occurred in the last month when the westward migration rate was about 2.1 m/day over 27 days (Figure 2).

The two long surveys of Fire Island included the Smith Point hot spot and these were added to the other surveys of the Smith Point hot spot in order to see how the hot spot

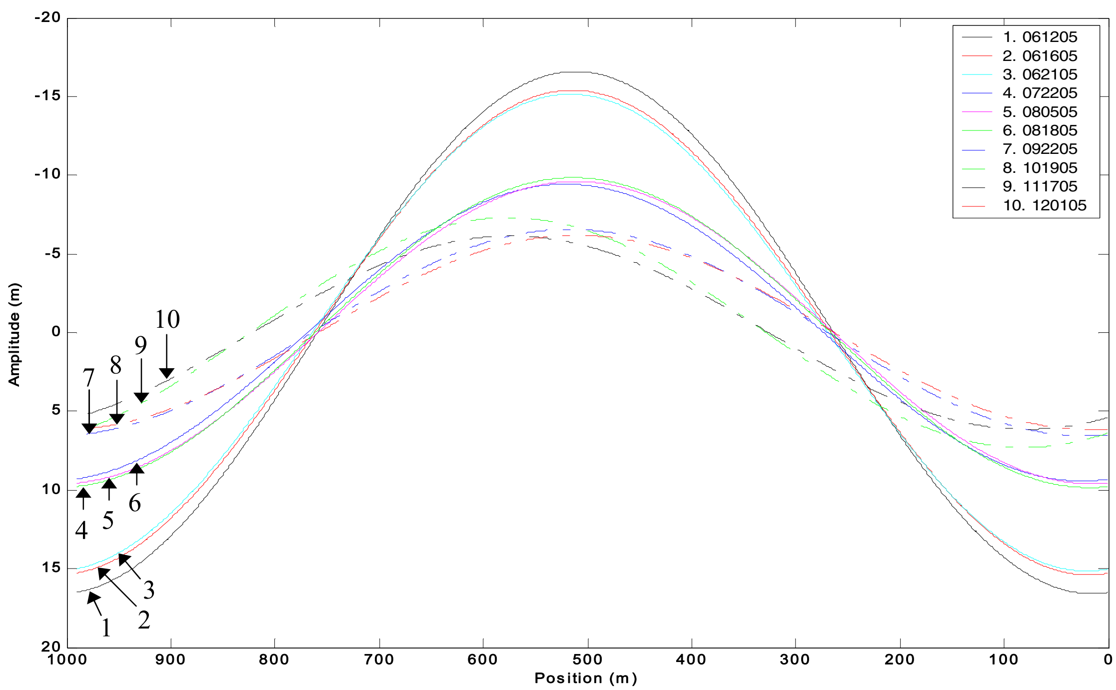

Figure 2. Principal component of Smith Point Hot Spot

had progressed after the nor'easter. The amplitude of the hot spot decreased with time to the approximate height as before the nor'easter (Figure 2). It can also be seen that the hot spot migrated back towards the east to almost its original location in between the two surveys at a rate of 4.2 m/day.

Kates Point

Another shoreline feature monitored at Smith Point was a seaward displacement of the shoreline equivalent to the sand packets or longshore sandwaves studied by Thevenot and Kraus (1995). The feature was found east of the Smith Point hot spot, and was referred to as Kates Point by local surfers. Over the period from 16 June to 19 October, 2005, Kates Point decreased in size and shifted westward in the direction of longshore transport (Figure 3). The erosional area west of Kates Point may have been caused by the point itself interrupting longshore transport and acting like a groin. Groin-like behavior of transient, natural features have been noted in other places (Jay Tanski, Sea Grant Cooperative Extension Service, 2006, personal communication). Kates Point overall migrated to the west and simultaneously decreased in amplitude. The surveys of 17 and 18 November and 1 December showed that the erosional area has decreased in size at the same time that Kates Point has decreased in size. It appeared that sediment eroded from Kates Point was filling in the erosional area to the west. The position of each of these features has shifted to

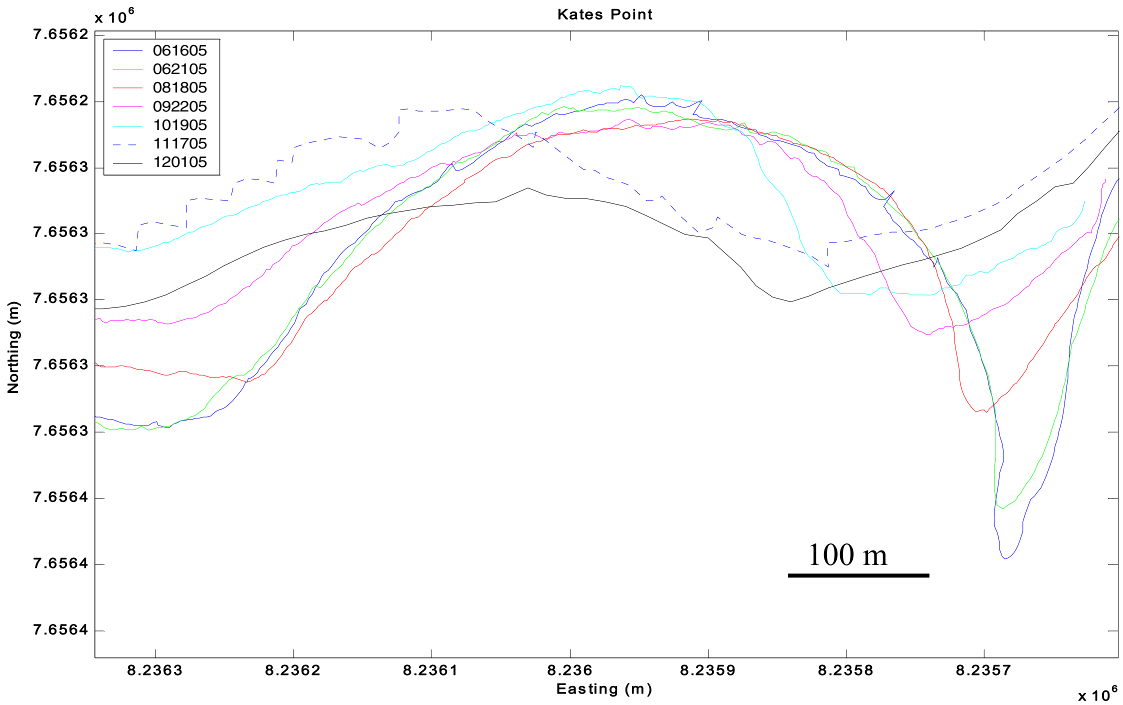

Figure 3. Surveys of Kates Point

the west. During this period the point migrated 110 m to the west at a rate of 0.88 m/day and simultaneously decreased in amplitude 80 m at a rate of 0.64 m/day (Figure 3).

Thevenot and Kraus (1995) had previously calculated a theoretical, advection-diffusion equation to model shoreline change and sand transport of longshore sand waves. Their model showed that the total sand wave body moved west and spread out with a substantial decrease in the amplitude. Although the scale of the model was much larger, the agreement in form suggests that Kates Point is, in fact, behaving according to the combination of longshore advection and diffusion processes.

Fire Island

On 17-18 November, 2005 and 1 December, 2005 surveys were conducted down the length of Fire Island over a four to five-hour period. The spectra generated for each survey were passed through a three-point running average to smooth the results. Dominant wavelengths of 1830 m and 1045 m were found by Gravens (1999) (labeled in red on Figures 4 and 5). From the survey on 17-18 November, 2005, dominant wavelengths appeared at 4779, 3186, 2811, 2276 and 1707 meters (Figure

4). From the survey on 1 December, 2005, dominant wavelengths appeared at 5973, 3186, 2515, 1911 and 1541 meters (Figure 5). The longer wavelengths emerged as the most important but we believe that was, in part, due to the large-scale trends that

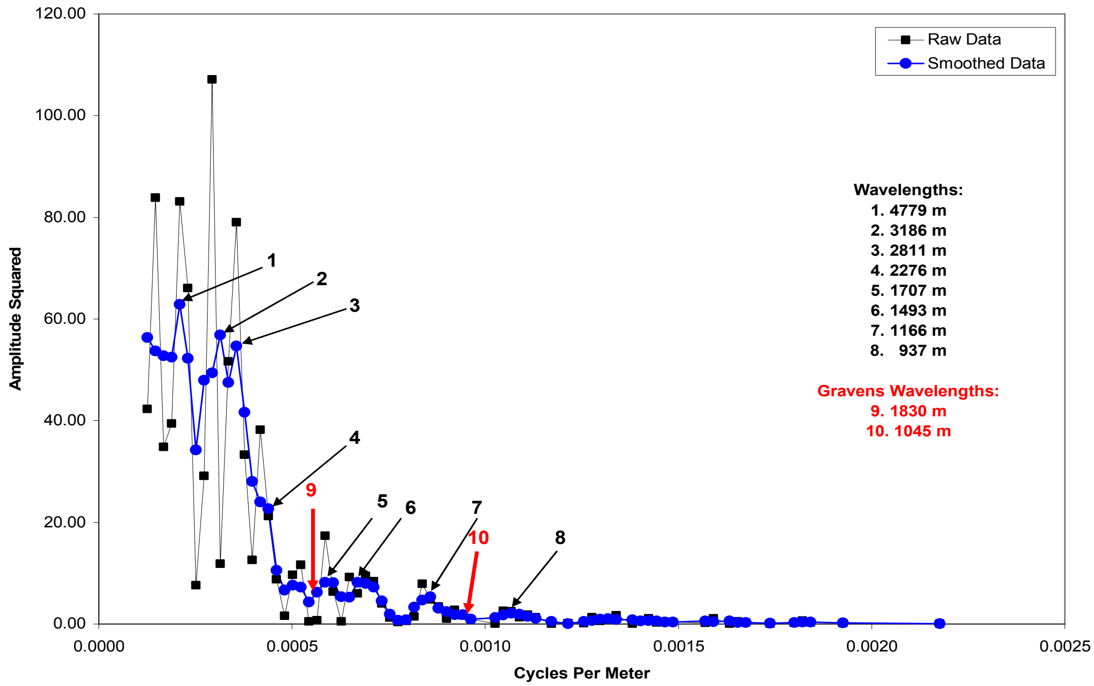

Figure 4. Fire Island Spectra of the survey on 17-18 November, 2005 smoothed with a three-point running average.

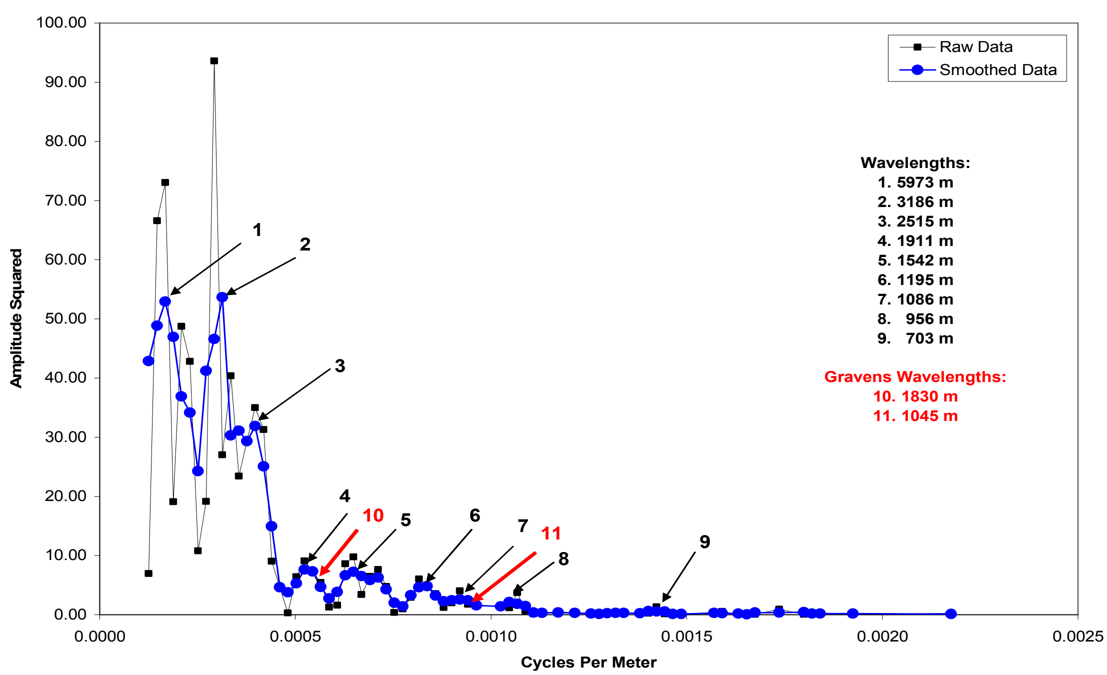

Figure 5. Fire Island Spectra of the survey of 1 December, 2005 smoothed with a three-point running average.

were not completely removed by the de-trending process. There may have been secondary peaks in the spectrum from November, 2005 at 1493 m, 1166 m and 937 m. Secondary peaks may also appear from December, 2005 at 1195 m, 1086 m, 956 m and, perhaps, even at 703 m. The component with a wavelength of 1086 m was close to that found by Gravens (1999) at 1045 m and approximately the size of the individual feature that was studied at Smith Point. The wavelength of 1911 m was also found by Gravens (1999) at 1830 m.

For any particular component, the change in phase between the November and December surveys was used to calculate the migration rate. Previous investigators had suggested that either larger wavelengths migrate faster or smaller wavelengths migrate faster, but these data cannot support either assertion. There does not seem to be a trend in migration rate. In addition, some wavelengths seemed to have migrated to the east in the same period that some migrated to the west. Waves during this period, as recorded at Buoy 44025 <www.ndbc.noaa.gov/station_history.php?station=44025>, would predominantly drive sand along shore from east to west but there were some reversals in the period. As Thevenot and Kraus (1995) remind us, local nearshore bathymetry can substantially influence the sand transport direction.

Some components for both the November and December surveys were of particular interest even though they were not dominant ones. The periodicity along the Fire Island shoreline with the largest wavelength was 24 km and appeared to move to the west at a rate of 44.1 m/day. The 15.9 km wavelength had the largest amplitude at 86.7 m. The 1291 m feature was the fastest migrating feature to the west at a rate of 51.5 m/day. The wavelength, 1493 m migrated the fastest to the east at a rate of 93.1 m/day. The wavelength, 2811 m had the greatest increase in amplitude, 0.27 m/day. It may be that components of different wavelengths respond differently to changing wave conditions but investigating such a phenomenon was beyond the scope of this work.

DISCUSSION

Migration rates of hot spots appear to be between 1 and 100 m/day. It seems, however, that there was no relationship between migration rates and wavelengths of erosional hot spots. In the specific case of the Smith Point Hot spot, the feature healed in place without migrating and migrated when storm activity caused it to grow. The sand packet referred to as Kates Point, on the other hand, migrated and dispersed according to advection-and-diffusion processes for longshore features. The undulations which are the superposition of a continuum of wavelengths had components which migrated at various rates and directions without an obvious pattern. They all were responding to the same water wave climate but that the net displacement over any particular period varied both in the direction and by the degree of the response.

Gravens (1999) suggested that shoreline undulations do not migrate from one end of Fire Island to the other but that migration within the range of the shoreline undulation is possible. Although it seems that shoreline features (e.g. Kates Point sandwave) do migrate in the direction of the long-term longshore transport over periods of weeks, two considerations are noteworthy. First, individual components of the shoreline features may respond differently to the angle of wave attack. Particular wavelengths may preferentially migrate faster under waves arriving at different angles or slightly different direction. Second, depending on the speed of the longshore currents, it may be possible that some wavelengths migrate in the direction of longshore transport while others migrate in the opposite direction in a manner similar to the migration of antidunes in a river (Freedman and Sanders, 1978).

The presence and characteristics of shoreline undulations may have important implications for beach nourishment projects. Gravens (1999) suggested that nourishment projects be designed with a "shoreline undulation buffer" so that the average width of the beach is wide enough to accommodate the erosional hot spots that naturally develop. Dolan and Stewart (2006) further suggest that renourishment projects be designed to mimic the naturally occurring undulations in order to attempt to improve the rate at which ecological recovery takes place after the disturbance.

CONCLUSION

The behavior of shoreline undulations remains elusive. One feature studied in detail seemed to heal in place with little migration, but the other evidence is consistent with migration rates up to 100 m/day. Over long stretches of shoreline, the superposition of many different wavelengths of undulations obscures individual features and would make predictions difficult.

The sandwave, a positive feature referred to as Kates Point, evolved according to the modeled advection/diffusion process of Thevenot and Kraus (1995; Equation 1), migrating in the net longshore transport direction.

The data collected for this study was close to the results gathered by Gravens (1999). Gravens (1999) had shoreline undulations with amplitudes ranging from 20 to over 30 meters. The amplitude for the shoreline undulation at Smith Point Park was 16.3 m with a wavelength of 1 km. Gravens (1999) found dominant wavelengths of 3010 m, 1045 m, 2050 m, 2135 m, 1385 m, and 1310 m. We found dominant wavelengths of 3414 m, 6826 m, and 4779 m, similar in range to what Gravens (1999) found. Based on the power spectrum the dominant wavelengths for long beach distances were found to be 23893, 15928, 11964 m. Gravens (1999) had found similar wavelengths of 2135 m, 1830 m, 1065 m and 1045m as compared to the values found in our study at wavelengths of 2172 m, 1837 m, 1062 m and 1038 m.

This data does not support the contention that longer wavelengths migrate faster than smaller wavelengths or *visa versa*.

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