Seasonal and Yearly Profile Changes of Delaware Beaches

by

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ABSTRACT

The continuous threat of erosion on Delaware beaches has prompted state officials to initiate a 50-year shore protection plan comprising beach nourishment projects with an overall estimated cost of $170 million. The attempts of previous studies to model the evolution of Delaware beaches based on standard longshore sediment transport formulas have not provided satisfying results due to inherent limitations of one-line models and lack of high quality data.

In this study measured data from densely spaced semi-yearly profile surveys of the beaches at North Shore, Rehoboth, Dewey and Bethany is analyzed and processed to yield seasonal and yearly erosion and accretion patterns. The correlations between profile change parameters are used to highlight the shortcomings of simple one-line models in predicting Delaware beach evolution.

A two-line model using a profile length scale ratio as a parameter is introduced to estimate the rates of longshore and cross-shore sediment transport as the inversion of the measured profile data. Both cross-shore and longshore rates are found to be of the same order of magnitude giving them equal importance for sediment transport modeling. They are correlated with wave and tide forcing mechanisms as well as local nourishment activity to gain a better understanding of their interaction. Results point out a strong seasonal dependency of the cross-shore sediment movement related to seasonal changes in the local wave climate and water surface elevation. In addition, the computed average rate of longshore transport is shown to compare favorably with known values of sediment transport rates along the Delaware Atlantic coast.

Chapter 1

INTRODUCTION

Coastal communities worldwide face the problem of receding shorelines. Urbanization of coastal areas and a growing beach tourism industry require stable and continuous sandy beaches along the coastline to ensure safety of property as well as continued revenues. Beaches attract home owners, tourists and investors and provide a large variety of jobs. Their increased commercial use, however, stands in harsh contrast to inherent natural littoral processes and fluctuations which tend to reshape coastlines by means of erosion and accretion of sediment. Beaches respond and adapt to their surrounding conditions, for example, by landward migration due to long-term sea level rise or by increased erosion as a result of an extreme storm event. This response happens on various time scales depending on the main forcing mechanism causing it. Seasonal beach changes are often related to the difference in wave energy reaching the shoreline under relatively calm conditions during the summer months in comparison to the more energetic waves during the winter months, mostly due to increased storm activity. The causes for long-term erosional or accretional trends tend to be harder to interpret since occasional severe storm events and limited amount of available data restrict the analysis.

Even though constant sea level rise and increased storm intensity and frequency are processes beyond human control, their effects on coastlines and beachfront property can be mitigated, or at least postponed, by human interaction. Possible human responses to the threat of beachfront property loss can be categorized as follows. Besides the options of taking no action at all or relocating whole communities, there are two main alternatives which have been utilized in coastal engineering practice to fight the recession of shorelines: hard structures and soft structures. Groins, breakwaters and revetments are considered hard structures, whereas nourished beaches or artificial fills are considered soft structures. In recent years, beach nourishment as a means of local erosion intervention has become increasingly popular, partially due to growing public concern about the environmental impact of hard structures on recreational beaches. Beach nourishment is simply the process of placing large amounts of sediment on a beach to compensate for erosion losses. The extra volume of sand acts as protection against wave action and also increases the recreational value of a specific location by widening the subaerial beach. However, it does not eliminate the ongoing process of background erosion which results in the need of periodic renourishments.

The state of Delaware has a total of 24.5 miles (40 km) of beaches, 12 of which are incorporated into state parks. They are visited by 6 million people each year creating estimated revenues amounting to \$ 850 million. (Cape Gazette article "Coastal Erosion: A Tale of Two Towers", 10/18/06 issue). Delaware beaches are continuously eroding naturally and show seasonal shoreline variations of up to 100 feet (30 meters) or more between summer and winter. In an effort to preserve their present state and protect valuable property, periodic artificial nourishment is used as a means of intervention.

The first fill was placed at Fenwick beach in 1988 followed by numerous projects on most urbanized beaches along the Delaware coastline with renourishments occurring every two to four years. Dates and fill volumes for several selected beaches are presented in Table 1.1 for the year 1998. The most recent nourishment started on February 4, 2005 covering a distance of 2.6 miles (4.2 km) from south of Dewey to north of Rehoboth. It used 1.7 million cubic yards (1.3 million cubic meters) of sand and the initial cost is estimated at \$ 10 million. The project is part of a 50-year shore protection plan for the Delaware coast with an overall projected cost of \$ 170 million and a total volume of 7 million cubic yards of placed sand.

Table 1.1: Selected Delaware Nourishment Projects in 1998

Location	Start Date	End Date	Volume		Length		Volume / m
	[mo/day]	[mo/day]	[yd^3]	[m^3]	[ft]	[m]	[m^2]
North Shore	8/13	8/16	188,000	143,820	2,265	691	208
Rehoboth	7/25	8/12	274,300	209,840	2,750	839	250
Dewey	7/12	7/23	453,500	346,978	6,095	1,859	187
Bethany[1]	9/09	9/28	490,600	375,310	8,538	2,604	144

Considering the enormous investment it is desirable to be able to predict the expected lifetime of a specific beach fill. This requires thorough understanding of longshore and cross-shore sediment transport processes at the location of interest. However, the difficulty in predicting sediment transport quantities is embedded in our poor understanding of transport processes combined with the lack of available high quality data sets and the unpredictable nature of high intensity storm events.

Garriga and Dalrymple (2002) presented several standard computations for Delaware beaches employing the longshore sediment transport formula (or "CERC formula") first introduced by Inman and Bagnold (1963). It relates the longshore sediment transport rate Q_ℓ to the alongshore energy flux P_ℓ created by obliquely incident breaking waves. The formula also includes parameter K which Komar and Inman (1970) found to have a constant value of 0.77. Garriga and Dalrymple (2002) estimated the net littoral drift along the Delaware coastline to be approximately $2 - 3$ million cubic yards ($1.5 - 2.3$ million cubic meters). In comparison, the volume of bypassed sand at Indian River Inlet has been measured to be on the order

[1] including South Bethany

of $100,000$ cubic yards ($76,500$ cubic meters) per year which means that their model overpredicts the actual value by a factor of 20 to 30 if the standard value of $K = 0.77$ is adopted. The Pelnard-Consideré (1956) diffusion model has also been used in combination with the "CERC formula" to estimate sediment losses encountered by a rectangular beach fill over time. In accordance to actual nourishment projects in Delaware, they chose the plan view dimensions of the modeled rectangular fill to be 3 miles (4.8 km) in the longshore direction and 55 ft (17 m) in the cross-shore direction. The model predicts a cumulative loss of only 15 % of the original fill volume for the rectangular planform after 5 years and 10 % loss for the same planform with additional tapered ends. This obvious overprediction of longevity may be contributed to model limitations and the disregard of extreme storm events which are known to have a major impact on actual beach fills.

Garriga and Dalrymple (2002) encountered the same problem of overpredicted longevity when employing the U.S. Army Corps GENESIS model (Hanson, 1989) to predict the beach fill evolution. The model calibration using historic data on Delaware shoreline changes required the parameter K to be set to values between 0.04 and 0.1 which corresponds to a reduction of the value proposed by Komar and Inman (1970) by a factor of 10 to 20. Hence, the study by Garriga and Dalrymple (2002) shows that simple one-line models based on the "CERC formula" do not yield satisfying results for longshore sediment transport rates on Delaware beaches. Furthermore, it needs to be noted that profile changes on any time scale have been neglected since the one-line model GENESIS assumes an equilibrium profile. These obvious shortcomings of simple one-line models require new approaches in quantifying sediment transport rates on beaches. The cross-shore profile evolution should not be excluded from the considerations since seasonal changes in the shape of beach profiles can account for large volume changes.

In the study presented herein, more refined profile survey data following the

1998 nourishment activities listed in Table 1.1 is presented along with corresponding water level, wave and bathymetry information. The available measured data is utilized to quantify seasonal and yearly profile changes for the Delaware beaches at North Shore, Rehoboth, Dewey and Bethany including shoreline variation and cross-shore volumetric changes. A simple two-line model is used to estimate the cross-shore and longshore sediment transport rates from the measured beach profile changes following the approach described by Kobayashi and Han (1988) for the estimation of erosion at the bend of a gravel causeway. The present application of a two-line model can be interpreted as the inversion of the measured profile data to estimate the sediment transport rates. It is noted that a summary of this report will be published by Figlus and Kobayashi (2007).

Chapter 2

AVAILABLE DATA

In this chapter available data from recent beach profile surveys of Delaware beaches are presented along with the surrounding large scale bathymetry. Furthermore, available measurements of water surface elevations and important wave parameters are discussed.

2.1 Beach Profiles

The basis for this investigation is a data set provided by the Delaware Department of Natural Resources and Environmental Control (DNREC) comprising measured coordinates from several consecutive beach profile surveys at four beaches along the Delaware coastline: North Shore (NS); Rehoboth (RE); Dewey (DE); and Bethany (BE) beaches. Surveys were conducted mostly twice a year at the end of the winter and summer seasons, allowing for comparison between "summer" and "winter" profiles. An overview of locations and survey dates included herein is given in Table 2.1 along with the number of profiles measured at each beach location. These densely spaced profile surveys were initiated after the beach nourishment at the end of the summer of 1998 (see Table 1.1) starting with a survey at Dewey beach in November 1998. The surveys are part of a monitoring program investigating the performance of the placed beach fills over time and their effectiveness in sustaining protective beaches in front of urbanized coastal areas. The last available survey data was collected at Bethany beach in December 2005. The Philadelphia branch of the U.S. Army Corps of Engineers has been conducting profile surveys on Delaware

Table 2.1: Number and Date of Profile Surveys at Four Beaches

North Shore (NS) 5 Profile Lines		Rehoboth (RE) 10 Profile Lines		Dewey (DE) 18 Profile Lines		Bethany (BE) 32 Profile Lines	
Year	Month	Year	Month	Year	Month	Year	Month
				1998	11		
1999	4, 10	1999	4, 10	1999	4, 10	1999	5, 7, 10
2000	4, 11	2000	4, 11	2000	4, 11	2000	4, 10
2001	5	2001	5	2001	4	2001	6
2002	5, 10	2002	5, 10	2002	5, 10	2002	9
2003	5, 10	2003	5, 10	2003	5, 10	2003	4, 10
						2004	9
						2005	12

beaches for many years (Garriga and Dalrymple, 2002) but the spacing between adjacent profile lines, on average, is up to six times larger compared to the present data set.

The Delaware State Plane Coordinate System (Zone 0700) is used to display the x-coordinates (i.e. easting) and y-coordinates (i.e. northing) of the data points. Similarly, surface elevation is expressed using local Mean Sea Level (MSL) as the vertical reference datum (this will be explained further in section 2.3). A plan view of all profile lines is presented in Figures 2.1 and 2.2 where each beach location is denoted by a different color for easier distinction. The profile number is listed next to the respective profile survey line where the profile number at each beach increases northward with increasing values on the y-axis (northing) of the Delaware State Plane coordinate system. Depending on the location, profiles are spaced between 150 m and 350 m in the longshore direction (see Tables 2.2 and 2.3) and extend from the dune line to a water depth of about 11 m below MSL which corresponds to a cross-shore distance of roughly 700 m.

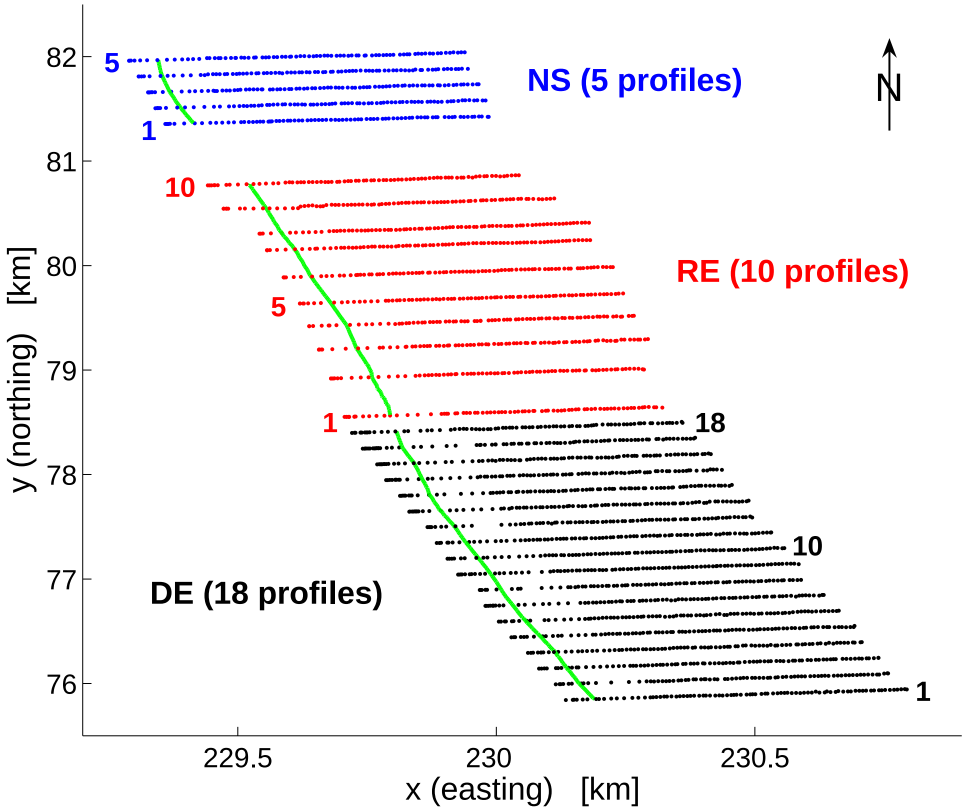


Figure 2.1: Plan view of surveyed profile lines (dots) and shoreline at MSL (line) for North Shore (NS), Rehoboth (RE) and Dewey (DE). This particular survey was conducted in October 1999.

Table 2.2: Alongshore Spacing of Profile Lines for North Shore (NS), Rehoboth (RE) and Dewey (DE) Beaches Starting from the South.

Starting Prof. #	Ending Prof. #	Distance [m]
DE 1	DE 2	152
DE 2	DE 3	153
DE 3	DE 4	153
DE 4	DE 5	152
DE 5	DE 6	153
DE 6	DE 7	152
DE 7	DE 8	152
DE 8	DE 9	152
DE 9	DE 10	152
DE 10	DE 11	154
DE 11	DE 12	153
DE 12	DE 13	153
DE 13	DE 14	153
DE 14	DE 15	153
DE 15	DE 16	153
DE 16	DE 17	154
DE 17	DE 18	153
DE 18	RE 1	152
RE 1	RE 2	368
RE 2	RE 3	277
RE 3	RE 4	227
RE 4	RE 5	216
RE 5	RE 6	253
RE 6	RE 7	263
RE 7	RE 8	160
RE 8	RE 9	241
RE 9	RE 10	231
RE 10	NS 1	612
NS 1	NS 2	153
NS 2	NS 3	153
NS 3	NS 4	153
NS 4	NS 5	155

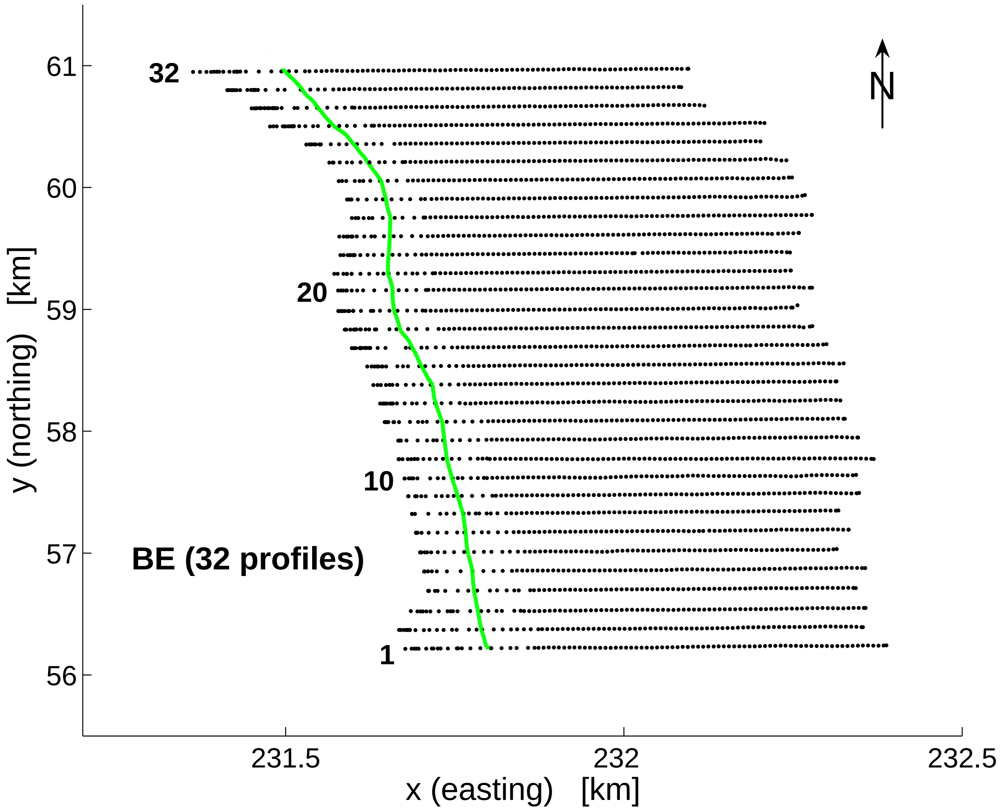


Figure 2.2: Plan view of surveyed profile lines (dots) and shoreline at MSL (line) for Bethany. This particular survey was conducted in October 2003.

Table 2.3: Alongshore Spacing of Profile Lines for Bethany (BE) Beach Starting from the South.

Starting Prof. #	Ending Prof. #	Distance [m]
BE 1	BE 2	153
BE 2	BE 3	152
BE 3	BE 4	168
BE 4	BE 5	160
BE 5	BE 6	158
BE 6	BE 7	160
BE 7	BE 8	155
BE 8	BE 9	145
BE 9	BE 10	146
BE 10	BE 11	158
BE 11	BE 12	153
BE 12	BE 13	153
BE 13	BE 14	152
BE 14	BE 15	153
BE 15	BE 16	153
BE 16	BE 17	152
BE 17	BE 18	153
BE 18	BE 19	152
BE 19	BE 20	169
BE 20	BE 21	137
BE 21	BE 22	153
BE 22	BE 23	152
BE 23	BE 24	152
BE 24	BE 25	153
BE 25	BE 26	152
BE 26	BE 27	152
BE 27	BE 28	151
BE 28	BE 29	153
BE 29	BE 30	151
BE 30	BE 31	153
BE 31	BE 32	152

Each profile includes between 80 and 100 data points which have been collected through both land-based and water-based GPS surveying techniques where GPS gives the three-dimensional location on the land and water surface. The accuracy of the depth sounding from a boat on the water surface is inferior to that of the land-based GPS due to errors associated with the depth sounding and the motion of the survey vessel on the water. An example display of one complete set of profile surveys for a particular location is presented in Figure 2.3. The 10 profiles shown in this figure have been collected at Rehoboth in April of 1999.

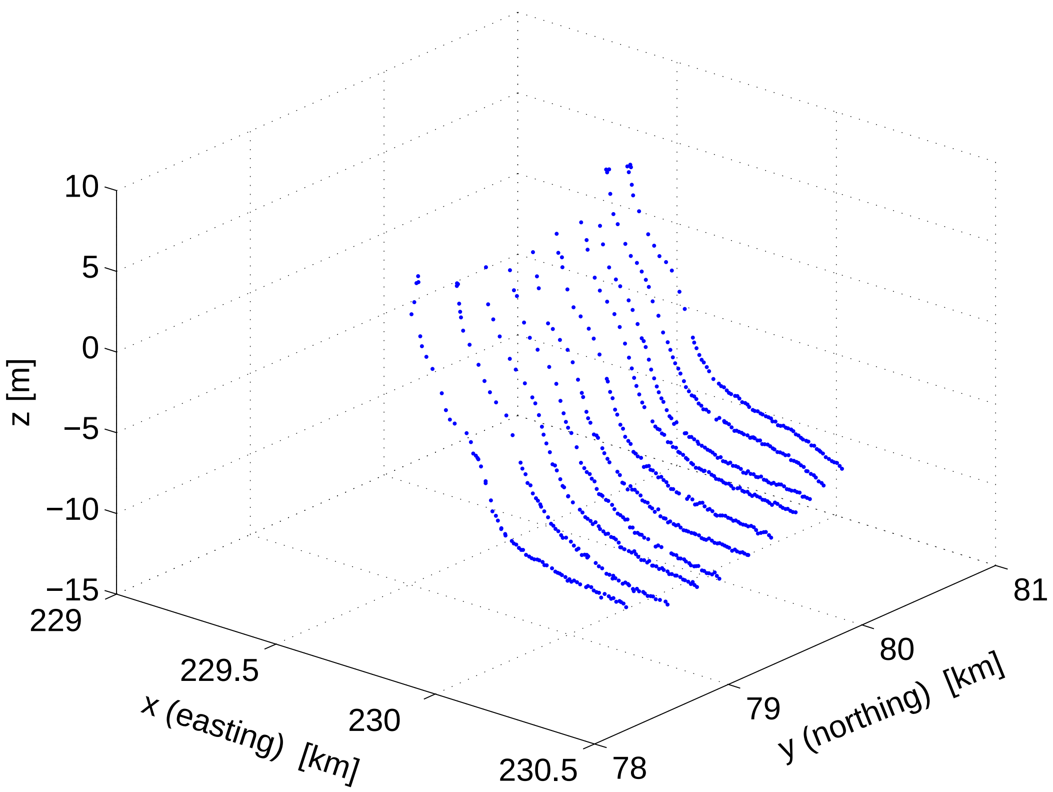


Figure 2.3: 3-D display of surveyed data points for the 10 profiles at Rehoboth collected in April of 1999.

Subsequent surveys have been done at the same profile locations over several years as listed in Table 2.1, allowing for an investigation of the evolution over time for each individual profile (see Chapter 3) in order to gain a better understanding of the sediment transport processes involved in eroding these beaches. Ramsey (1999) analyzed natural beach sand textures along the entire Atlantic Coast of Delaware. Data from ten previous studies covering a period of 55 years (1929 to 1984) were compiled to identify suitable material for beach nourishment. On average the native sand on Delaware beaches was found to be fairly well sorted with a median diameter of approximately $0.4\,mm$.

2.2 Large Scale Bathymetry

Coastal processes are affected by the bathymetry of the surrounding area. For a sound understanding of local profile evolution it is necessary to investigate the large scale bathymetric and topographic features in proximity of the specific project site under investigation. In order to merge surveyed field data of beach profiles and the bathymetry of the continental shelf, it is important to understand the respective coordinate systems used for each data set. In the following, a brief introduction on coordinate systems is given and the coordinate system used in this study is explained.

2.2.1 Coordinate Systems

Throughout history, several coordinate systems have been used to find exact locations of features on the earth's surface. In order to understand the concept of how survey points are mapped and related to each other, the definitions for geoid, ellipsoid and orthometric height have to be explained. The following explanations are summaries of material found in Schwarz (1989) and Torge (1991).

The geoid is an equipotential surface on which the potential of the earth's gravity is constant and the vector sum of the force of gravity and centrifugal force due to the earth's rotation is normal to the surface at every point. It is not visible in terms of topographic features but it is a continuous closed surface. Due to variations in the mass of the earth's land and sea masses the geoid undulates over a geographic area. This means that if a plumb line was held above the earth's surface it would not point directly towards the center of mass of the earth but rather perpendicular to the geoid. Since there are an infinite number of surfaces that might be used as geoid, the one that has been chosen coincides, on average, with the surface of the oceans or mean sea level (MSL). Because the mean sea level varies over time, and because of refined and added measurements, the present geoid model will, eventually, also have to be modified, as it has happened in the past. It is only important to know which model has been used for a specific data set. To model the geoid in space, a reference system must be established from which to take measurements. Due to the apparent shape of the earth an ellipsoid reference system is used for this purpose. The ellipsoid serves as a mathematical model for locating the earth's features geographically. From the earth's surface, geographic features can be mapped onto the ellipsoid before they are geometrically projected onto a map. The orthometric height of a point on the earth is the height above the geoid. The ellipsoidal or geodetic height is the height above the ellipsoid which can be accurately measured using Global Positioning Systems (GPS). To determine the elevation of a point on the earth, the difference between the ellipsoidal height and geoid height, or geoidal separation, has to be evaluated. This is done via interpolation using a world wide network of points with known geoidal separation (Torge, 1991).

Different geodetic datums are in use to map locations on the earth's surface. A geodetic datum is defined by the production of an ellipsoid and its corresponding geocentric and geodetic coordinate systems. The use of different datums does not implement a higher accuracy but merely a shift in location of a specific point on the map. Two geodetic datums commonly used in the United States are the North American Datum of 1927 (NAD 27) and the North American Datum of 1983 (NAD 83). Every datum is associated with a certain ellipsoid model and of course the geoid, the latest version of which is the Geoid99 with a data root-mean-square error of 4.2 cm. The NAD 27 is associated with the Clarke Spheroid of 1866 which has its origin at the survey station Meades Ranch in Kansas where the geoidal height is assumed to be zero. The NAD 83 is associated with the Geodetic Reference System of 1980 (GRS 80) and has a geocentric origin (Schwarz, 1991). It has been created using 250,000 points including 600 satellite Doppler stations and is more convenient for the use with modern survey techniques like GPS. In fact, the use of differential GPS has propelled the creation of High Accuracy Reference Networks

(HARN) throughout the U.S. to establish a modified NAD 83. In the process of datum transformation coordinates are converted from one datum to another. The accuracy is not improved by switching to a datum with an ellipsoid that more accurately models the geoid since only the reference system from which the geodetic or geocentric coordinates are measured is changed.

Elevation measurements need to be referenced to a vertical datum for comparison. In North America two vertical datums are commonly used. The National Geodetic Vertical Datum of 1929 (NGVD 29), also known as the North American Vertical Datum of 1929 (NAVD 29) and the North American Vertical Datum of 1988 (NAVD 88). Vertical datums are created independently from horizontal datums through a network of benchmarks whose orthometric heights have been measured and adjusted simultaneously relative to mean sea level (the geoid). The NGVD 29 is a vertical control datum established from mean sea levels at 26 tide gauges and fixed bench marks. It is not the actual mean sea level, the geoid or any other equipotential surface. The NAVD 88 has been created using the fixed heights of the primary tidal benchmarks referenced to the International Great Lakes Datum of 1985 and the local mean sea level height at Father Point / Rimouski, Quebec, Canada. Since the mean sea level is not the same equipotential surface at all tidal bench marks no other bench mark elevation has been used. In Section 2.3 the relation between the used vertical datum and local mean sea level (MSL) is explained in more detail.

2.2.2 Delaware Atlantic Coast Bathymetry

As pointed out in Section 2.1, the beaches under investigation are located along the Delaware coastline of the Atlantic Ocean. The plan view presented in the upper panel of Figure 2.4 shows this section of the continental shelf ranging from Cape Henlopen at the southern end of the Delaware Bay to the location of NOAA buoy 44009 at the southeast corner of the map. The bottom panel of Figure 2.4 displays the same region as a 3-D image.

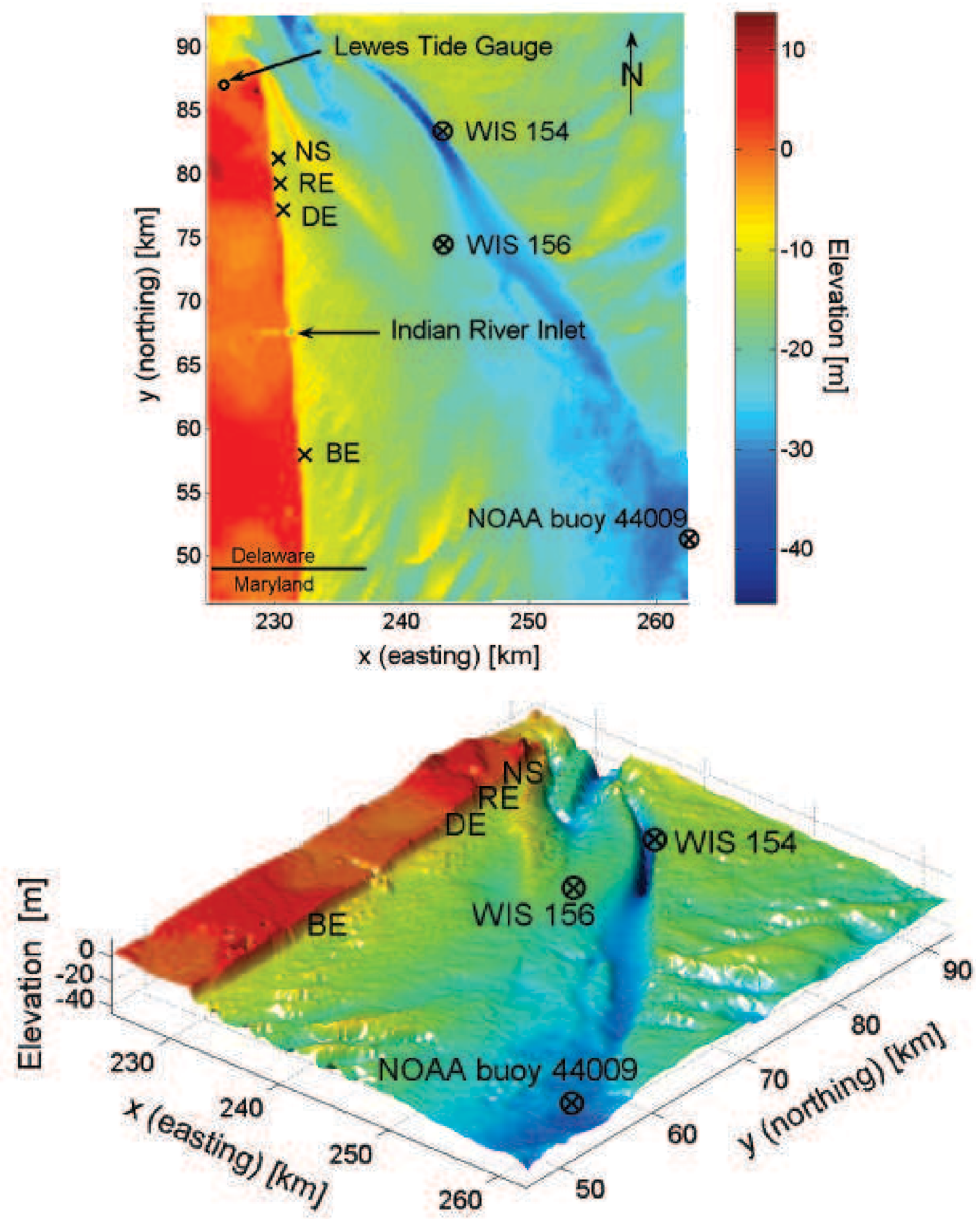


Figure 2.4: Plan view (top panel) and 3-D image (bottom panel) of the local bathymetry for the Delaware coastline. Horizontal coordinates are given in Delaware State Plane format.

The presented bathymetry data has been downloaded from NOAA's National Geophysical Data Center (NGDC) at `http://www.ngdc.noaa.gov/mgg/coastal/coastal.html`. This so called Coastal Relief Model has a maximum spatial density of 3 arc-seconds ($\sim 90m$) and an elevation resolution down to the tenth of a meter. In both panels of Figure 2.4 the horizontal coordinates are displayed in Delaware State Plane format which translates to a range in latitude from $38^\circ\ 50'\ N$ at the northern boundary to $38^\circ\ 25'\ N$ at the southern boundary. Likewise, the longitudinal range from the eastern to the western edge of the two panels is $74^\circ 42' W$ to $75^\circ 08' W$. This yields an enclosed area of $39 \times 45\, km^2$. The beaches of North Shore (NS), Rehoboth (RE) and Dewey (DE) are located adjacent to one another, whereas Bethany (BE) is situated further south along the coastline. Apparent bathymetric features like the Hen and Chicken Shoal and nearby navigation channel at the northwest corner in the map are made visible in the bottom panel of Figure 2.4 where the aspect ratio between horizontal and vertical length scale has been set to 1/100 to visually emphasize such features. In addition, the locations of the two WIS (Wave Information Study) hindcast stations 154 and 156 are displayed along with the locations of the Lewes tide gauge, Indian River Inlet and the border between the states of Delaware and Maryland. Available water level and wave information are explained and presented in Sections 2.3 and 2.4, respectively. A visual impression of the area of the beach profile measurements in comparison with the local topography is given in Figures 2.5 and 2.6 where satellite images of the project sites are overlaid by the survey lines. The survey lines are located in the areas of beach fills placed along the beaches of urbanized areas. These nourishments are used to widen the urbanized beaches and DNREC is conducting profile surveys to monitor the performance of the projects.

Figure 2.5: GoogleEarth™ image with overlay of surveyed profile lines for North Shore, Rehoboth and Dewey.

Figure 2.6: GoogleEarth^{TM} image with overlay of surveyed profile lines for Bethany.

2.3 Water Surface Elevation

Erosion and accretion at beaches often relate to relatively slow water level changes contributed to tides, storm surges and wave setup. Measured water surface elevations are available at numerous locations along the Atlantic coast. For this study, data obtained from the tide gauge at Lewes, DE (see Figure 2.4) has been used due to its close proximity to the beach locations under investigation. The exact gauge location is given as $38^\circ\ 46.9'\ N$ latitude and $75^\circ\ 7.2'\ W$ longitude ($226\ km$ easting; $87\ km$ northing). The tidal datum at this station is based on the 19-year time series data collected during the tidal epoch between 1983 and 2001. For all figures and plots presented herein, the datum ($z = 0$) has been chosen to correspond to the Mean Sea Level (MSL) determined at this tide gauge. The elevation difference between NAVD88 and MSL is $\Delta z = 0.121\ m$ (i.e. NAVD88 lies $0.121\ m$ above the specified MSL). This information can easily be accessed on the world wide web at `http://tidesandcurrents.noaa.gov`.

The information on water surface elevation from the Lewes tide gauge records has been extracted as hourly "predicted" and corresponding "measured" data. Here, the term "predicted" stands for the estimation of the water surface elevation using only tidal constituents. The tide at Lewes is semidiurnal and the mean tidal range is $1.24\ m$. The actual elevation at a given location and time also depends on the prevailing storm and wave conditions leading to storm surge and wave setup. These actual measured elevations are recorded and compared to the estimated ones. By taking the difference between the two time series the non-tidal contribution to the water surface elevation is obtained. Appendix A includes plots comparing hourly tidal and non-tidal components between the years 1998 and 2006. A compilation of this data is presented in Figure 2.7 in terms of monthly averages to show possible seasonal variations. The tidal and non-tidal contributions to the water surface elevation are denoted as η_{tide} and η_{surge}, respectively. They are related to the measured

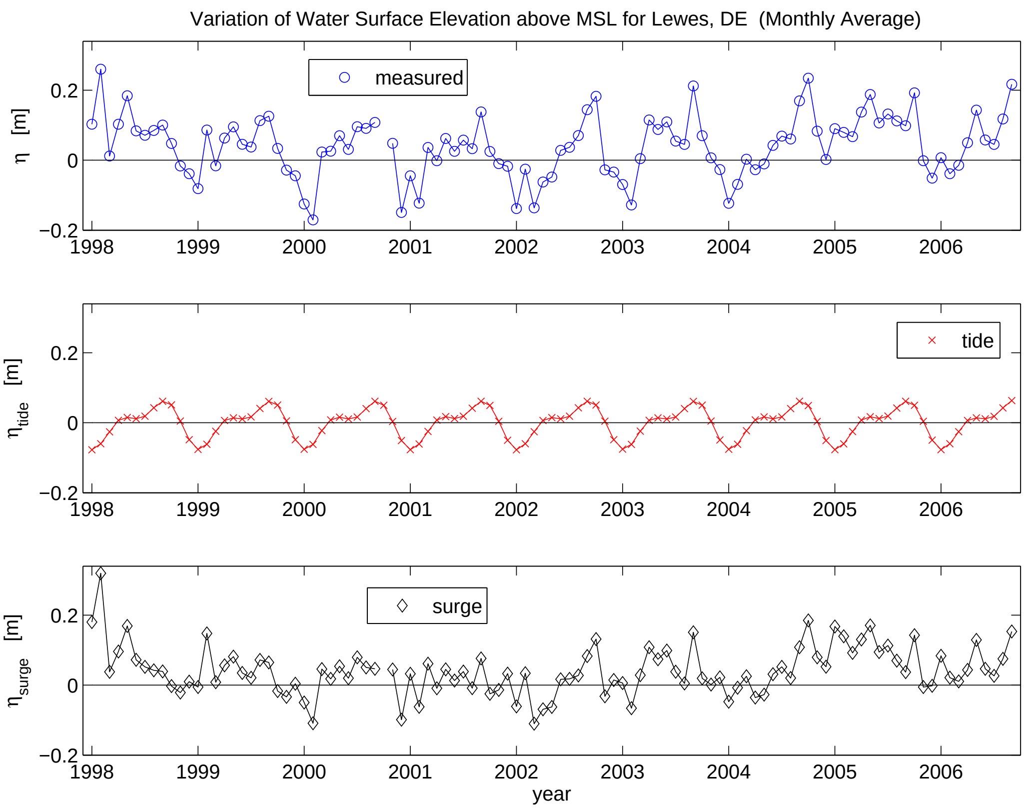


Figure 2.7: Monthly averages of water surface elevation above MSL at Lewes, DE from 1998 to 2006. The top panel displays the measured elevation η and the middle panel shows its estimated tidal contribution η_{tide}. The difference between the two is shown in the bottom panel denoted by η_{surge}.

water surface elevation η by the following equation:

$$\eta = \eta_{tide} + \eta_{surge} \tag{2.1}$$

It can be seen that the monthly average of the tidal contribution to the water surface elevation η_{tide} displays a yearly oscillation with a crest towards the end of each calendar year followed by a trough at the beginning of the new year. This results in a change in tide levels during the winter months from a higher than average value to a lower than average value. Possible effects of this regular oscillation can be seen in the cross-shore sediment transport patterns described in Chapter 4. The water level contribution denoted as η_{surge} varies more irregularly and is related to storm and wave activity resulting in storm surge and wave setup at the beach. From Figure 2.7 it can be seen that the peak value of the monthly averages of the measured water surface elevation η generally lies about $0.2\,m$ above MSL. These extreme values always occur during the winter months for the presented time frame. The monthly variability of η_{tide} and η_{surge} is on the order of $0.1\,m$.

2.4 Wave Information

Several sources of wave data relevant to the project site have been identified. The two offshore NOAA buoys 44009 and 44012 are the closest to the Delaware coastline providing historic data sets for a large variety of ocean related measurements including wave height and period. Standard meteorological data including significant wave height and spectral peak period from buoy 44009 date back as far as 1984 and new data has been stored in a fairly consistent manner up to this day. Buoy 44012 has only supplied useful data between the years 1984 and 1992 making it less valuable for this study. In addition, a shallow water measurement station exists at Lewis, DE with measurements starting in 2004 which yields only a relatively short duration of available data. All the information listed above is accessible to the public at NOAA's National Data Buoy Center website `http://www.ndbc.noaa.gov`.

Another source of wave information is hindcasted data, for example from the Wave Information Study (WIS) initiated by the U.S. Army Corps of Engineers (Coastal and Hydraulics Laboratory). The process of wave hindcasting is used for many coastal engineering applications if long-term wave data is needed at a location where no actual measurements are available. WIS data at numerous locations along U.S. coastlines is generated by numerical simulation of past wind and wave conditions from many different sources combined with large-scale bathymetry information. The hindcasted hourly WIS data at various stations along the U.S. coasts can be accessed at `http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html` and is available for the years 1980 through 1999. The WIS stations closest to the region of interest are 154 in a water depth of 16 m and 156 in a water depth of 20 m just off the coast of Delaware. The uninterrupted time series of wave related parameters is a key advantage compared to actual buoy data which can have gaps during periods of malfunction or maintenance.

The Engineer Research and Development Center (ERDC) of the U.S. Army

Corps of Engineers also lists measurements from a few wave gauges along the Delaware coast including stations at the beaches of Dewey and Bethany (`http://sandbar.wes.army.mil/public_html/pmab2web/htdocs/NorthEast.html`). Unfortunately, these data are only available for limited time periods which are not relevant for the present investigation.

Hence, the only wave data source providing measurements for the time of the conducted beach profile surveys is NOAA buoy 44009 located 26 nautical miles (48 km) southeast of Cape May, NJ, in the nominal depth of 28 m. In Appendix B hourly wave data (i.e. H_s and T_p) obtained from this buoy are displayed by means of quarterly time series plots. The data is presented for the years between 1998 and 2005. H_s equals $H_{1/3}$ denoting the significant wave height obtained as the average of the highest one-third of all measured wave heights during the 20-minute sampling period of each hour. The data sampling rate is 1 Hz. T_p is the spectral peak period of the waves during the same sampling interval. The buoy time series information is converted from the temporal domain into the frequency domain by means of a Fast Fourier Transform (FFT) allowing for the derivation of non-directional spectral wave measurements (i.e. wave energy densities with their associated frequencies). Hence, T_p is derived from the obtained spectrum as the inverse of the frequency with the maximum wave energy density. To show the seasonal variation inherent in these data, Figure 2.8 displays monthly averages of H_s and T_p for the same duration. The mean values of H_s and T_p for the entire duration between 1998 and 2005 were 1.26 m and 7.51 s, respectively. The wave height tends to be larger in winter than in summer which is contributed to high energy storm events generally occurring during the winter months. This trend can be observed in Figure 2.8 where values of the monthly averaged significant wave height H_s exceed the mean value by up to 2 m in February 1998, for example. The displayed values for the spectral peak period T_p do not show a distinct pattern of variation but show fluctuations on the order of 5 s

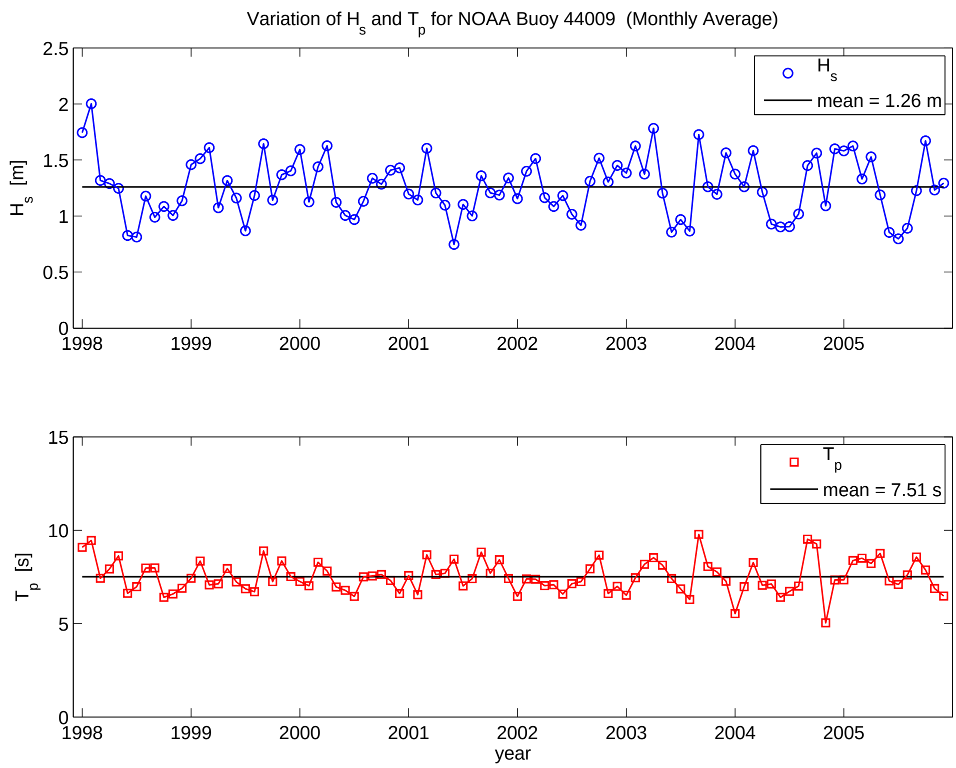


Figure 2.8: Monthly averages of H_s (circles in top panel) and T_p (squares in bottom panel) from NOAA buoy 44009 during the years 1998 to 2005. The horizontal line in both panels denotes the mean of all monthly averages over the displayed period of time.

around the mean. Unfortunately, wave direction information for this NOAA buoy is only available for the years 1997 and 1998.

Offshore wave data collected in deep water can be transformed to a shallow water location using the laws of refraction, diffraction and shoaling if the local bathymetry and the wave direction are known. 1998 is the only year in which directional wave data from both NOAA buoy and WIS hindcast coexist. Hence, to show the differences and similarities in wave data between the locations of NOAA buoy 44009 in a water depth of $28\,m$ and WIS stations 154 and 156 in water depths of $16\,m$ and $20\,m$, respectively, the monthly wave statistics for 1998 at these three locations are displayed in Figures 2.9 to 2.11. Each figure includes three panels denoted to H_s or H_{mo}, T_p, and wave direction, respectively. The top two panels display the monthly averages of the respective quantity as solid squares for the months between January and December of 1998. The standard deviation for every month is denoted by a thick bar around the average value. Maximum and minimum values are identified by solid triangles. The corresponding legends show the mean values of the presented monthly averages. For NOAA buoy 44009, the wave height H_s is the average of the highest one-third measured wave heights as explained earlier in this section. The significant wave height obtained from the WIS data is labeled H_{mo} and is derived from the energy density spectrum by integration over all frequencies. Wave direction information is made visible using wave roses. The directions of origin of the incoming waves are grouped into $22.5°$ bins and displayed as percentages of all incoming waves in a wave rose plot. Waves coming from the North have an assigned angle of $0°$ and the direction for waves coming from the East is $90°$. The mean value for the whole year is shown next to the rose plots.

The wave statistics for all three locations show similar seasonal trends. The maximum monthly averages for both significant wave height and peak period occur during the months of January and February with H_s reaching a maximum value of

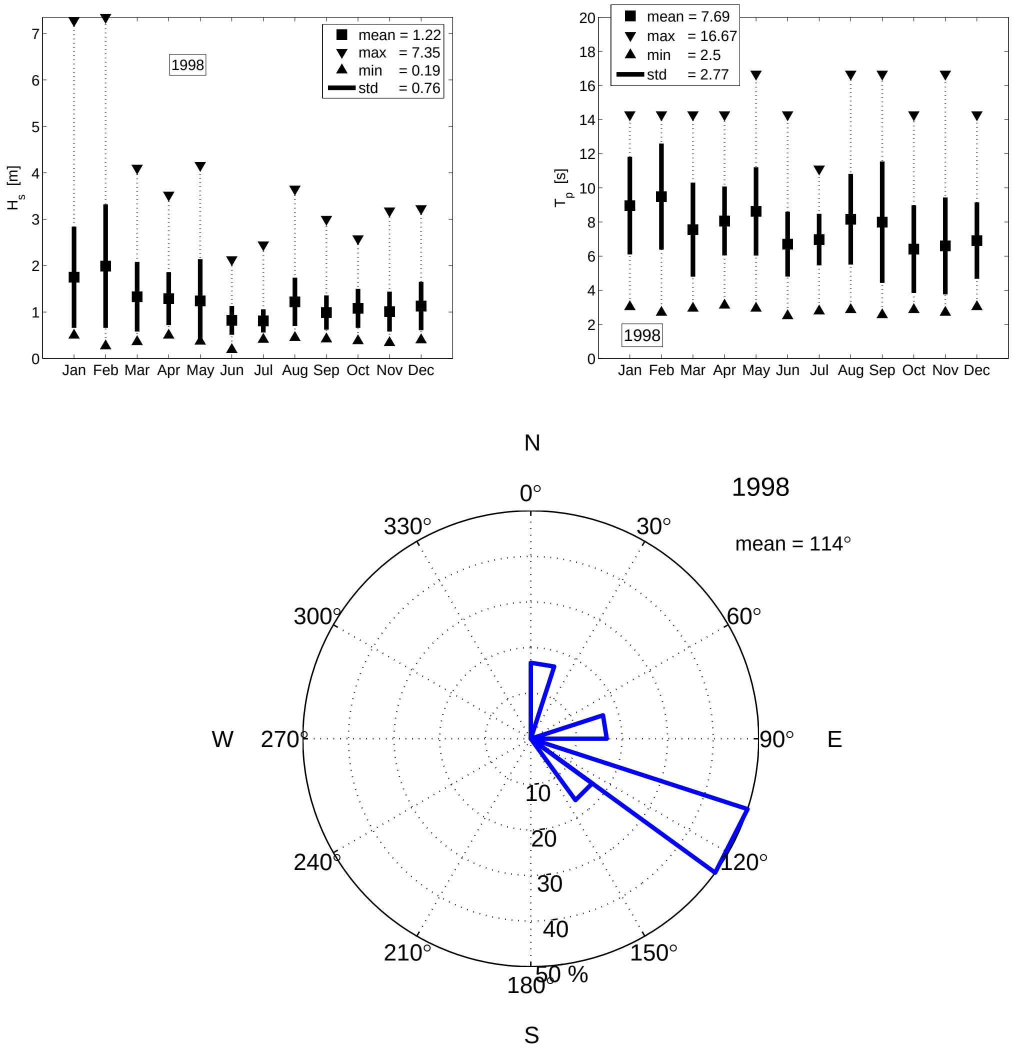


Figure 2.9: NOAA buoy 44009 data in 1998. The two top panels display the monthly statistics for the significant wave height H_s (left) and the spectral peak period T_p (right). Wave direction information is displayed as a wave rose (bottom panel) denoting the direction of origin of the incoming waves in degrees from true North as percentages of all incoming waves. The buoy is situated in a nominal water depth of $28\,m$.

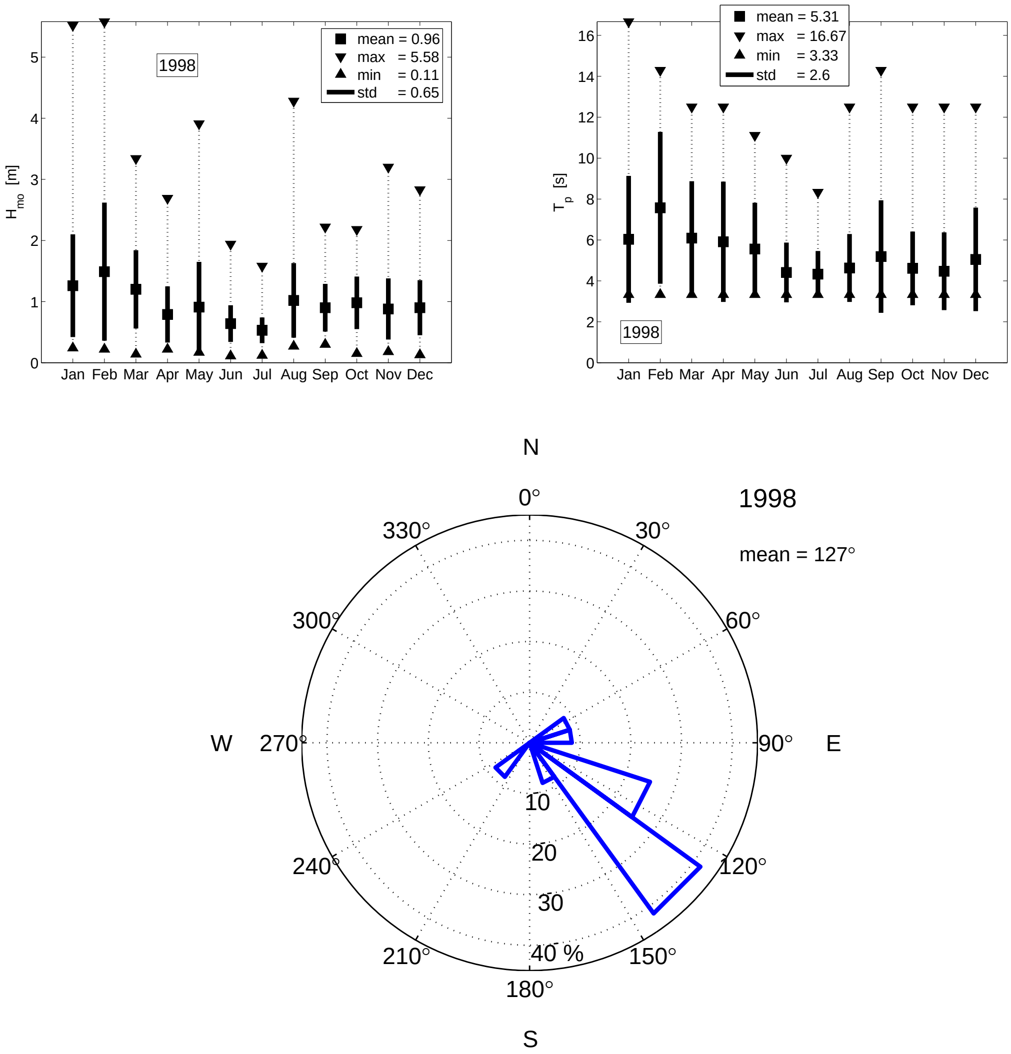


Figure 2.10: WIS hindcast station 154 data in 1998. The two top panels display the monthly statistics for the spectral significant wave height H_{mo} (left) and the spectral peak period T_p (right). Wave direction information is displayed as a wave rose (bottom panel) denoting the direction of origin of the incoming waves in degrees from true North as percentages of all incoming waves. WIS station 154 is situated in a nominal water depth of $16\,m$.

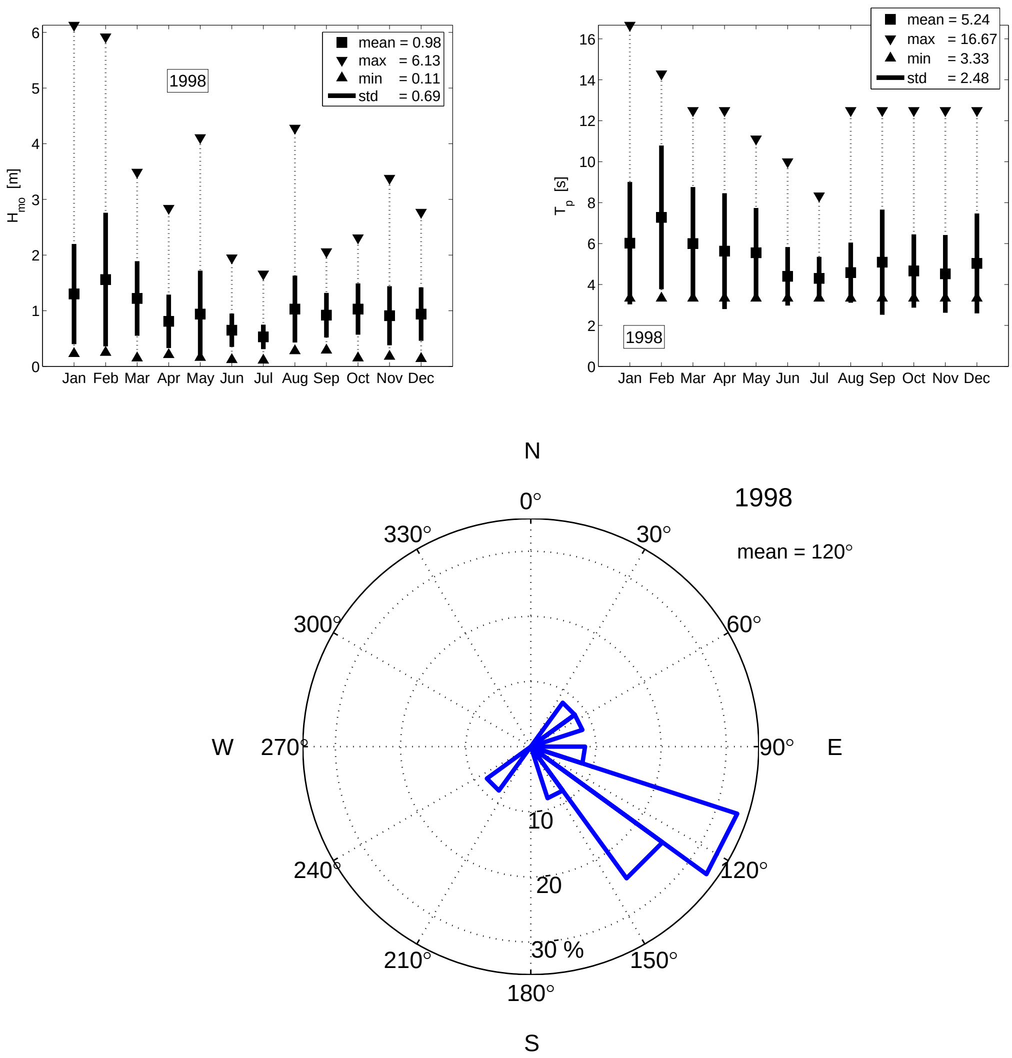


Figure 2.11: WIS hindcast station 156 data in 1998. The two top panels display the monthly statistics for the spectral significant wave height H_{mo} (left) and the spectral peak period T_p (right). Wave direction information is displayed as a wave rose (bottom panel) denoting the direction of origin of the incoming waves in degrees from true North as percentages of all incoming waves. WIS station 156 is situated in a nominal water depth of $20\,m$.

$7.35\,m$ measured by NOAA buoy 44009. The months of June and July have monthly average significant wave heights of only $1\,m$. As expected, the wave transformation process reduces the wave height and period as the waves progress into shallower water. This is made evident by comparing the respective monthly averages of Figure 2.9 to the ones in Figures 2.10 and 2.11 since the WIS stations are located in shallower water.

The overall mean wave direction is east-south-east but effects of the local bathymetry can be noted when comparing the angles of the incoming waves at different locations. In general, wave angles become more parallel to the shoreline as the waves approach shallower water. The mean wave direction determined from the buoy measurements is 114° but at the location of WIS station 154 the mean direction has actually increased to a value of 127° which can be contributed to the depth change from shallower to deeper water associated with the local navigation channel (see Figure 2.4) and inherent differences in the measured and hindcast wave directions.

The problem with the wave data presented above is the limited availability. The WIS stations 154 and 156 are in close proximity to the beaches at North Shore, Rehoboth, Dewey and Bethany but data is not available after 1999 and can thus not be used directly to interpret the beach changes obtained from the profile surveys. Only the data from offshore buoy 44009 are available for the whole time period of the investigation. Due to the minor differences between Figures 2.9, 2.10 and 2.11 it can be assumed however, that the observed beach profile changes can be qualitatively related to the data obtained from NOAA buoy 44009. The major drawback of unavailable directional information remains but is not of concern for the present study. If wave direction is required for subsequent studies, it may have to be computed from wind direction or barometric data. Depending on the application, another possibility could be the use of historic WIS data with similar statistical properties.

Chapter 3

PROFILE EVOLUTION ANALYSIS

This chapter describes the procedure for analyzing and condensing the survey data in detail. An explanation of chosen landward and seaward profile limits is given. This will be the basis for subsequent estimations on cross-shore and longshore sediment transport rates as well as erosion and accretion patterns using a two-line model.

3.1 Landward and Seaward Profile Limits

In order to perform the analysis presented hereafter it is essential to limit the cross-shore range for each measured profile to a region of interest for sediment movement. For this investigation landward and seaward limits have been chosen for each profile using the following procedure. A Cartesian x-z-coordinate system has been adapted where x denotes cross-shore distance (positive offshore) and z denotes profile elevation above MSL (positive upward). Every surveyed profile line was assigned a fixed reference location ($x = 0$) beyond its most landward data point. In a 2-D plane view sense, the reference point is aligned along the straight line of the profile and denotes the origin for the cross-shore distance of each measured profile point. It is desirable to choose landward and seaward profile limits which do not change much over time in light of the uncertainty of the survey accuracy especially in the offshore region.

The landward limit x_L has been chosen to correspond to the cross-shore location of the maximum elevation above MSL (i.e. berm or dune height). Visual investigation of profile evolution data revealed that the actual value of x_L varies only slightly over time for each consecutive survey of the same profile line. Thus, the average of all x_L values for one specific profile line is used hereafter. The sediment transport in the region landward of this average x_L may hence be assumed to be negligible.

The determination of a seaward limit for each profile line beyond which no significant sediment movement occurs is more difficult because of the survey error in deeper water. The seaward limit x_S has been chosen to coincide with the fixed cross-shore location of measured profiles beyond which rapid fluctuations in elevation can mainly be contributed to measurement errors. Figure 3.1 shows an example plot for the measured profiles of a specific profile line and the corresponding locations of x_L and x_S for this particular profile line. For the available time frame all the surveys for this profile line have been plotted together to show the degree of the profile changes. The vertical dashed lines mark the landward and seaward limits x_L and x_S, respectively. The dash-dotted line above MSL shows the standard deviation σ_z of the elevation change for each cross-shore location. Since the same scale for z and σ_z is used, an amplification factor of 2 is applied to the σ_z values to amplify the cross-shore variation of σ_z. The seaward limit x_S corresponds approximately to the location beyond which negligible profile changes with random survey errors are assumed.

For each profile line the measured profiles have been examined in the same manner as in Figure 3.1. These figures are displayed in Appendix C. Both x_L and x_S are fixed for each profile line. The corresponding profile elevations at the landward and seaward limits are denoted as z_L and z_S, respectively, and can be interpreted as the berm or dune height and the depth of closure of each measured profile. In Tables 3.1 to 3.4 the range of these elevations are shown for each profile line where "max", "mean" and "min" denote the maximum, average and minimum elevation

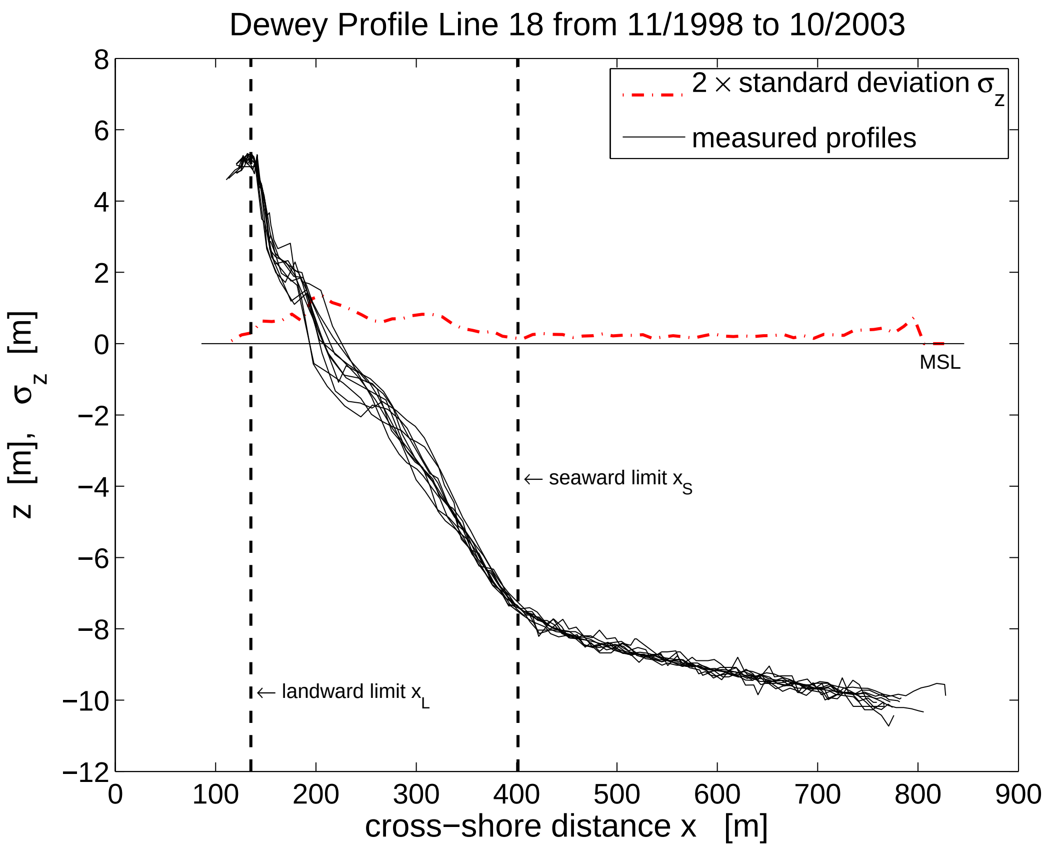


Figure 3.1: Measured profiles of Dewey beach profile line 18 between 11/1998 and 10/2003.

at the fixed cross-shore locations x_L and x_S, respectively. The variability of z_L and z_S is small relative to the mean value. Additionally, the distance $(x_S - x_L)$ between the landward and seaward limits is listed for each profile line. At the end of each table the mean values of $(x_S - x_L)$, z_L and z_S for all the profile lines are displayed for the beaches of North Shore, Rehoboth, Dewey and Bethany. The overall average values for the four beaches are roughly 220 m, 4 m and -7 m, respectively, which compares favorably with the values used by Garriga and Dalrymple (2002) for the same beaches.

Table 3.1: North Shore Profile Elevations z_L and z_S ($z = 0$ at MSL)

Profile	$x_S - x_L$ $[m]$	z_L $[m]$			z_S $[m]$		
	fixed	max	mean	min	max	mean	min
1	245	4.54	4.52	4.45	-6.67	-6.90	-7.01
2	224	4.38	4.35	3.48	-6.66	-6.80	-7.05
3	252	4.77	4.66	2.62	-7.10	-7.30	-7.41
4	209	4.62	4.56	4.27	-6.18	-6.30	-6.48
5	204	4.30	4.28	4.21	-5.66	-5.80	-6.08
Avg.:	227		4.48			-6.62	

Table 3.2: Rehoboth Profile Elevations z_L and z_S ($z = 0$ at MSL)

Profile	$x_S - x_L$ $[m]$	z_L $[m]$			z_S $[m]$		
	fixed	max	mean	min	max	mean	min
1	249	7.60	7.42	6.93	-6.38	-6.50	-6.71
2	277	5.42	5.32	5.18	-7.78	-7.90	-8.18
3	268	5.06	5.03	3.61	-7.88	-8.10	-8.24
4	238	3.93	3.92	3.77	-7.41	-7.50	-7.90
5	212	4.13	4.10	3.98	-6.75	-7.00	-7.24
6	212	4.15	4.14	4.07	-7.03	-7.20	-7.48
7	238	3.72	3.69	3.37	-7.77	-7.90	-8.19
8	209	3.80	3.72	1.71	-7.35	-7.50	-7.76
9	227	5.44	5.35	4.85	-6.51	-6.70	-7.00
10	241	4.85	4.79	3.93	-7.02	-7.20	-7.39
Avg.:	237		4.75			-7.35	

Table 3.3: Dewey Profile Elevations z_L and z_S ($z = 0$ at MSL)

Profile	$x_S - x_L$ $[m]$	z_L $[m]$			z_S $[m]$		
	fixed	max	mean	min	max	mean	min
1	259	6.41	6.23	6.15	-6.39	-6.50	-6.63
2	191	5.60	5.44	5.24	-4.79	-5.00	-5.11
3	244	4.30	4.17	4.04	-6.84	-7.00	-7.33
4	283	3.98	3.97	3.88	-7.31	-7.60	-7.78
5	238	5.48	5.21	4.73	-6.87	-7.00	-7.12
6	215	4.53	4.49	4.17	-6.29	-6.40	-6.62
7	211	4.92	4.87	4.36	-6.22	-6.40	-6.58
8	188	3.93	3.62	2.04	-5.90	-6.00	-6.09
9	215	3.96	3.44	2.49	-6.46	-6.60	-6.72
10	243	4.04	3.97	3.42	-7.09	-7.20	-7.35
11	220	4.17	4.05	3.19	-6.68	-6.90	-6.99
12	223	4.50	4.42	4.33	-6.51	-7.00	-7.23
13	238	5.54	5.42	4.79	-7.07	-7.30	-7.41
14	227	4.64	4.58	4.39	-6.69	-6.80	-6.96
15	212	5.55	5.48	5.18	-5.85	-6.00	-6.19
16	255	5.14	5.04	4.75	-7.75	-8.00	-8.25
17	243	5.46	5.37	5.15	-6.82	-7.00	-7.25
18	266	5.30	5.25	4.94	-7.26	-7.40	-7.52
Avg.:	232		4.72			-6.78	

Table 3.4: Bethany Profile Elevations z_L and z_S ($z = 0$ at MSL)

	$x_S - x_L$ $[m]$	z_L $[m]$			z_S $[m]$		
Profile	fixed	max	mean	min	max	mean	min
1	223	5.76	5.07	3.52	-5.39	-5.70	-6.00
2	231	3.31	3.19	2.32	-6.12	-6.20	-6.31
3	201	3.93	3.74	3.17	-5.26	-5.50	-5.97
4	200	3.31	3.26	2.67	-6.13	-6.30	-6.57
5	181	3.83	3.51	0.68	-6.02	-6.20	-6.37
6	179	3.56	3.47	3.32	-5.44	-5.60	-5.91
7	192	4.01	3.79	3.65	-5.43	-5.60	-5.85
8	212	3.72	3.55	3.12	-5.82	-6.20	-6.37
9	156	3.61	3.40	2.70	-4.85	-5.10	-5.45
10	181	3.93	3.80	3.04	-5.61	-5.80	-6.04
11	211	4.82	4.60	4.21	-5.63	-5.80	-6.08
12	170	4.72	4.46	3.82	-5.21	-5.60	-5.84
13	202	5.47	5.31	5.06	-5.97	-6.10	-6.17
14	205	6.06	5.99	5.72	-6.02	-6.30	-6.86
15	217	5.93	5.92	5.76	-6.97	-7.10	-7.28
16	177	5.82	5.69	5.18	-5.02	-5.30	-5.76
17	223	5.68	5.51	5.28	-6.80	-7.00	-7.27
18	186	5.76	5.74	5.41	-5.69	-5.90	-6.14
19	173	4.78	4.87	4.53	-5.02	-5.30	-5.59
20	173	4.57	4.38	3.50	-5.93	-6.20	-6.39
21	186	4.50	4.34	3.13	-6.69	-6.90	-7.13
22	195	4.58	4.45	3.43	-6.78	-6.90	-7.05
23	207	4.89	4.55	3.14	-6.83	-7.00	-7.10
24	191	3.60	3.05	2.18	-6.76	-7.00	-7.22
25	221	3.98	3.66	2.37	-7.12	-7.30	-7.44

Table 3.4: Bethany Profile Elevations z_L and z_S ($z = 0$ at MSL)

Profile	$x_S - x_L$ $[m]$	z_L $[m]$			z_S $[m]$		
	fixed	max	mean	min	max	mean	min
26	193	3.63	3.14	2.12	-6.12	-6.30	-6.51
27	182	3.87	2.95	1.89	-5.78	-6.00	-6.34
28	213	4.64	4.67	4.13	-6.83	-7.00	-7.33
29	187	5.30	5.18	3.92	-5.74	-5.90	-6.37
30	189	4.51	4.40	3.98	-5.65	-5.80	-6.12
31	224	4.65	4.49	4.10	-6.29	-6.50	-6.60
32	308	4.81	4.40	3.94	-7.70	-7.90	-8.05
Avg.:	200		4.33			-6.23	

3.2 Erosion and Accretion Patterns

Investigation of successive profile changes for the whole data set has shown distinctive trends for bar (winter) and berm (summer) profiles for all beaches included in this study. Figure 3.2 shows a typical transition from a berm profile z_1 at time t_1 to a bar profile z_2 at time t_2 for one particular profile line between the landward limit x_L and the seaward limit x_S. The following analysis attempts to describe the profile changes in concise manners and facilitate their physical interpretation.

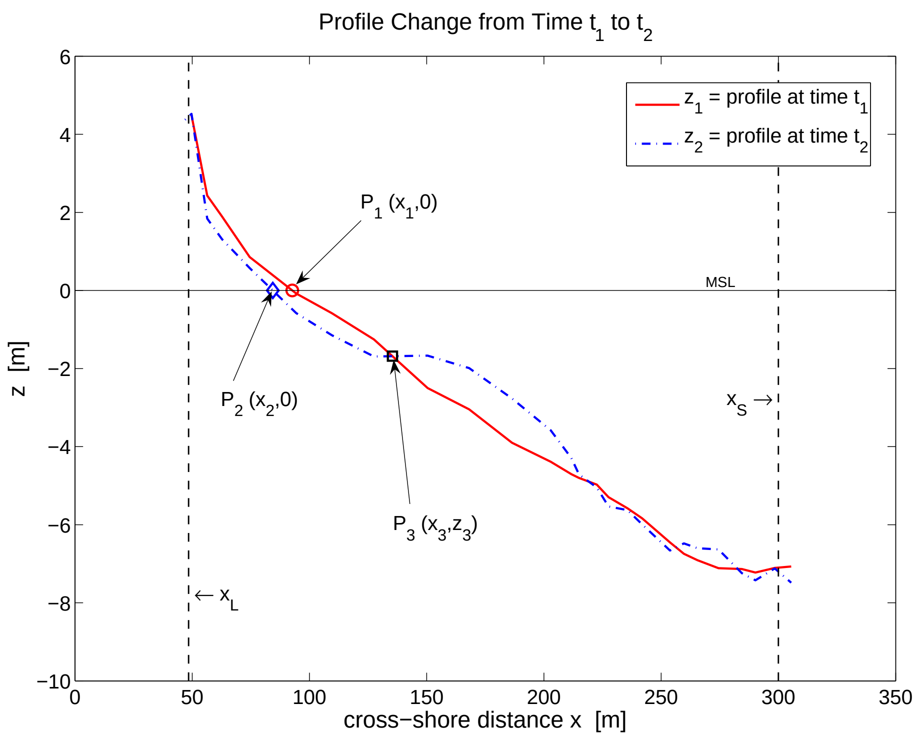


Figure 3.2: Example of profile change between two successive surveys at one particular profile line.

The points $P_1(x_1, 0)$, $P_2(x_2, 0)$ and $P_3(x_3, z_3)$ in Figure 3.2 mark important locations for further computations of erosional and accretional trends. Both P_1 and P_2 denote the zero-crossing points of the two successive profile surveys with MSL.

Hence, the horizontal shoreline change Δx at MSL from time t_1 to time t_2 can be evaluated from

$$\Delta x = x_2 - x_1 \tag{3.1}$$

where Δx is positive for shoreline advancement and negative for shoreline retreat. In order to quantify the observed seasonal change from one time level to the next, the intersection point P_3 of the two successive profiles has been determined as the location of the clear intersection between the two profile surveys. The cross-shore distance x_3 and elevation z_3 are used to identify the point P_3. Successive profile surveys were measured mostly after half a year, leading to an unambiguous intersection point when plotted together as in Figure 3.2. For some of the two successive profiles, especially the ones spaced one year apart, the intersection point P_3 was somewhat ambiguous but the profile changes were relatively small for these ambiguous cases. This can be contributed to the fact that half-yearly profile surveys correspond to characteristic bar and berm profiles whereas yearly surveys cannot resolve seasonal profile changes. The value of z_3 is negative in most cases due to an intersection point P_3 below MSL. However, it is possible for P_3 to be situated above MSL, resulting in a positive z_3 value. This is merely due to the arbitrarily chosen zero elevation at MSL. The difference in profile elevations z_1 and z_2 is taken to be Δz with

$$\Delta z = z_2 - z_1 \tag{3.2}$$

The value of Δz at a given cross-shore location is negative for erosion and positive for accretion from time t_1 to time t_2.

Two distinctive areas A_L and A_S on the landward and seaward zones can now be computed by integrating Δz from the landward limit x_L to x_3 and from x_3

to the seaward limit x_S, respectively.

$$A_L = \int\limits_{x_L}^{x_3} (\Delta z)\, dx \qquad (for\, the\, landward\, zone) \tag{3.3}$$

$$A_S = \int\limits_{x_3}^{x_S} (\Delta z)\, dx \qquad (for\, the\, seaward\, zone) \tag{3.4}$$

The areas A_L and A_S denote the change in sediment volume per unit alongshore length for the specific profile line and have units of m^2. Their values are positive for sediment gain and negative for sediment loss. The sum of A_L and A_S gives the overall value of volume change per unit length between the fixed cross-shore locations x_L and x_S.

$$(A_L + A_S) = \int\limits_{x_L}^{x_S} (\Delta z)\, dx \tag{3.5}$$

The above described computations have been made for all the successive profiles measured at each profile line. The results for all North Shore profiles are shown in Table 3.5 as an example. The corresponding tables for the beaches at Rehoboth, Dewey and Bethany can be found in Appendix D. Along with the profile line number, the two successive time levels of the profile surveys are listed as t_1 and t_2. Furthermore, the time step Δt between these surveys is shown. Displayed values for each line include Δx, z_3, A_L, A_S and $(A_L + A_S)$.

It has to be noted that although the values for the different lines on each beach presented in Table 3.5 and in Appendix D are similar, they do not always correlate well. This means that profiles measured on two adjacent profile lines at the same time level may exhibit opposing erosional and accretional trends. This spatial variability is of importance when considering longshore sediment transport rates and will be discussed in more detail in Chapter 4.

As an example for one particular profile line, Figure 3.3 shows the values of Table 3.5 corresponding to profile line 2 visualized as time series plots of Δx, z_3, A_L

Table 3.5: Erosion and Accretion of Each Profile Line at North Shore

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
1	4/1999	10/1999	6	1.7	-3.3	-31.0	24.6	-6.4
1	10/1999	4/2000	6	-13.1	-0.6	-21.5	26.3	4.8
1	4/2000	11/2000	7	-0.3	-1.5	6.1	-19.5	-13.4
1	11/2000	5/2001	6	-7.5	-2.1	-6.7	-3.9	-10.6
1	5/2001	5/2002	12	11.4	-0.6	23.9	-41.4	-17.5
1	5/2002	10/2002	5	-0.1	-1.3	-8.5	9.0	0.5
1	10/2002	5/2003	7	-26.5	-2.5	-64.4	24.4	-39.9
1	5/2003	10/2003	5	-10.9	-1.2	-45.5	23.6	-21.9
2	4/1999	10/1999	6	12.5	-1.6	23.2	-21.4	1.8
2	10/1999	4/2000	6	-20.8	-1.1	-41.5	40.6	-0.9
2	4/2000	11/2000	7	11.8	-1.8	35.1	-30.2	4.9
2	11/2000	5/2001	6	-12.6	-0.9	-16.1	-9.8	-25.9
2	5/2001	5/2002	12	18.5	-0.6	26.0	-52.0	-26.0
2	5/2002	10/2002	5	-13.3	-0.8	-13.3	15.2	1.9
2	10/2002	5/2003	7	-4.9	-2.0	-32.8	44.9	12.1
2	5/2003	10/2003	5	-13.8	-2.6	-53.4	-29.3	-82.6

and A_S. The dash-dotted trend line in the top panel shows the tendency of a receding shoreline at this particular location over the displayed period of time. Accordingly, the negative slope of the trend line in the bottom panel indicates sediment volume loss over the survey duration underlying the obvious seasonal fluctuations in A_L and A_S. The negative values of the sums of A_L and A_S at this profile line indicate that both the landward and the seaward profile areas are losing sediment over time even though seasonal variations seem to dominate.

Figure 3.4 shows the shoreline change Δx at each survey line of NS, RE, DE, and BE beach. The respective line numbers for each beach are indicated on

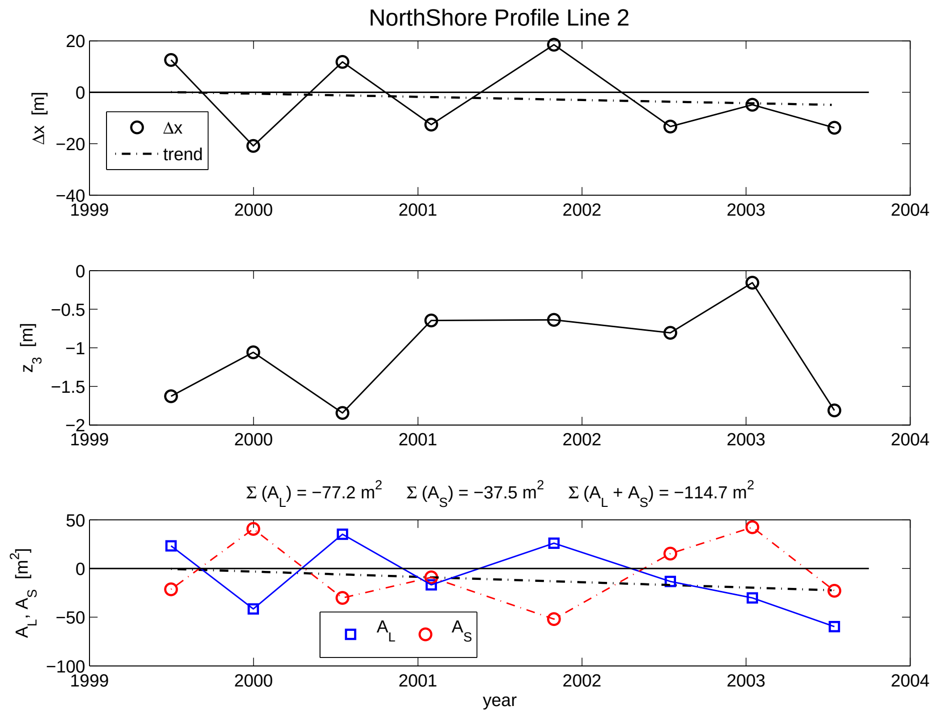


Figure 3.3: Evolution plot of Δx (top panel), z_3 (middle panel), A_L and A_S (both bottom panel) for North Shore profile line 2.

the x-axis of the top and bottom panel. The displacement of the shoreline at MSL during each survey interval is indicated by circles connected by dashed lines whereas the cumulative displacement between the first and the last available survey of each beach is shown as squares connected by solid lines. The corresponding survey dates are listed in Table 2.1. It has to be noted that for Rehoboth survey line 1 the cumulative value has been omitted because the data for the last two time intervals are not available for this survey line as indicated in the corresponding table of Appendix D on page 169.

The cumulative shoreline displacement is negative for almost every survey line on the four beaches indicating overall shoreline recession between the initial and

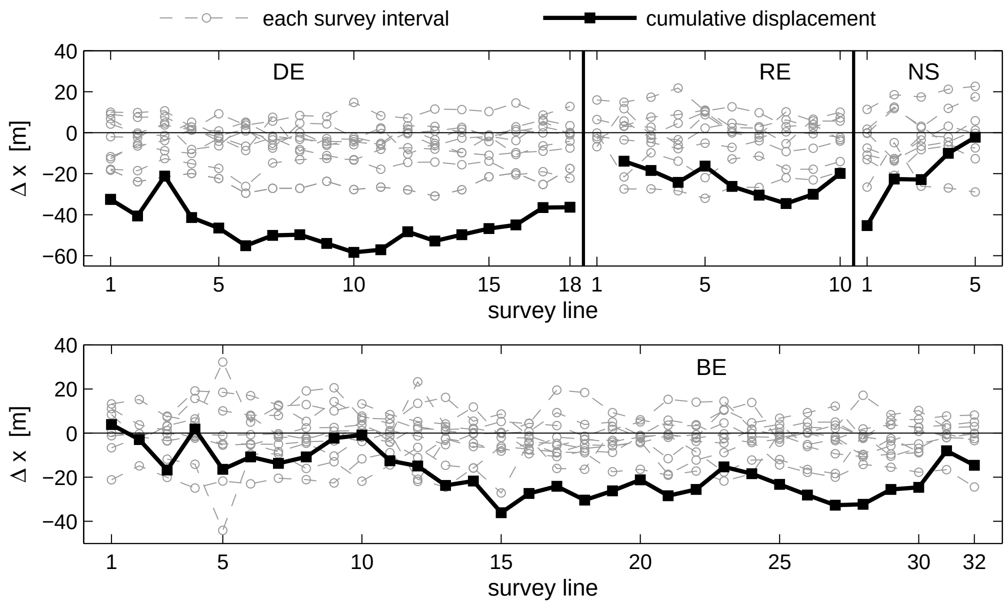


Figure 3.4: Shoreline change Δx at MSL during each survey interval together with cumulative shoreline change between initial and final profile surveys for NS, RE, and DE beaches (top) and BE beach (bottom).

final surveys on each beach. However, the spatial and temporal variations of Δx do not indicate the longshore spreading of the fill material placed on these beaches during the 1998 nourishment projects as assumed in standard one-line models to estimate the evolution of the nourished beach. In the following this observation is investigated further by means of a regression analysis.

Table 3.5: Erosion and Accretion of Each Profile Line at North Shore (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
3	4/1999	10/1999	6	2.5	-1.0	7.8	-42.4	-34.6
3	10/1999	4/2000	6	-8.3	-1.7	-37.2	65.9	28.7
3	4/2000	11/2000	7	3.2	-1.7	28.0	-25.8	2.1
3	11/2000	5/2001	6	-3.6	-1.0	-3.6	18.2	14.5
3	5/2001	5/2002	12	17.4	-0.9	33.6	-36.1	-2.5
3	5/2002	10/2002	5	-6.6	-3.8	-5.8	-4.4	-10.2
3	10/2002	5/2003	7	-26.1	-1.4	-79.5	100.1	20.5
3	5/2003	10/2003	5	-1.4	-1.7	5.8	-30.7	-24.9
4	4/1999	10/1999	6	11.9	-0.8	30.4	-3.8	26.5
4	10/1999	4/2000	6	-6.4	-1.5	-40.5	24.4	-16.1
4	4/2000	11/2000	7	-6.4	-1.7	29.1	-4.6	24.5
4	11/2000	5/2001	6	3.2	-0.5	5.0	-9.5	-4.5
4	5/2001	5/2002	12	21.2	-1.0	56.4	-43.1	13.4
4	5/2002	10/2002	5	-4.5	-4.8	-38.7	0.5	-38.2
4	10/2002	5/2003	7	-27.0	-1.2	-54.7	90.7	36.0
4	5/2003	10/2003	5	-2.1	-1.9	-33.9	-12.0	-45.9
5	4/1999	10/1999	6	17.5	-1.2	43.7	-1.4	42.3
5	10/1999	4/2000	6	-12.7	-2.2	-53.9	21.1	-32.8
5	4/2000	11/2000	7	-7.4	-2.0	15.2	-31.0	-15.8
5	11/2000	5/2001	6	-0.3	-0.8	-5.1	58.7	53.6
5	5/2001	5/2002	12	22.6	-0.8	43.4	-53.3	-9.8
5	5/2002	10/2002	5	1.2	-1.0	1.0	-4.7	-3.7
5	10/2002	5/2003	7	-28.9	-1.2	-65.7	57.9	-7.8
5	5/2003	10/2003	5	5.8	-0.6	9.0	-3.0	6.0

A linear regression analysis is performed to correlate the measured shoreline displacement Δx and the landward and seaward areas of profile change A_L and A_S. The shoreline displacement Δx and the landward area of profile change A_L are parameters related to the foreshore portion of the beach profile which includes the surf zone under normal conditions whereas the seaward area of profile change A_S is related to the offshore portion of the profile outside the influence of the surf zone. The regression analysis is done to identify the relationships between these three parameters. The data points used in this analysis are all included in Table 3.5 and Appendix D. For each of the four beaches the correlation between A_S and A_L, A_L and Δx, A_S and Δx, and $(A_L + A_S)$ and Δx is computed. The correlation coefficient R is used as a means of quantifying the degree of correlation of the respective data points where $R = 1$ denotes perfect correlation and $R = 0$ denotes no correlation at all. In addition, the equation of the best fit straight line through the origin in a least squared sense is determined for each set of parameters under comparison. The equation takes on the form of $y = m \cdot x$. Figures 3.5 through 3.8 display the obtained results graphically. For each beach four panels show the correlation of the above mentioned combinations of parameters. Data points are visually separated using filled and unfilled circles where filled ones denote corresponding time steps of $\Delta t = 1$ year between surveys and unfilled ones denote corresponding time steps of $\Delta t = 1/2$ year or less.

The regression analysis shows similar trends for all four beaches. The landward and seaward areas of erosion A_L and A_S are correlated in panel a. Relatively fair negative correlation is obtained with values of R ranging from -0.67 for Rehoboth to -0.85 for Dewey. This correlation is related to seasonal profile changes with sediment being moved from the foreshore portion of the profile to the offshore portion and vice versa. However, the slope m of the regression line with the equation $A_S = m \cdot A_L$ takes on non-dimensional values between -0.4 for Rehoboth and -0.9

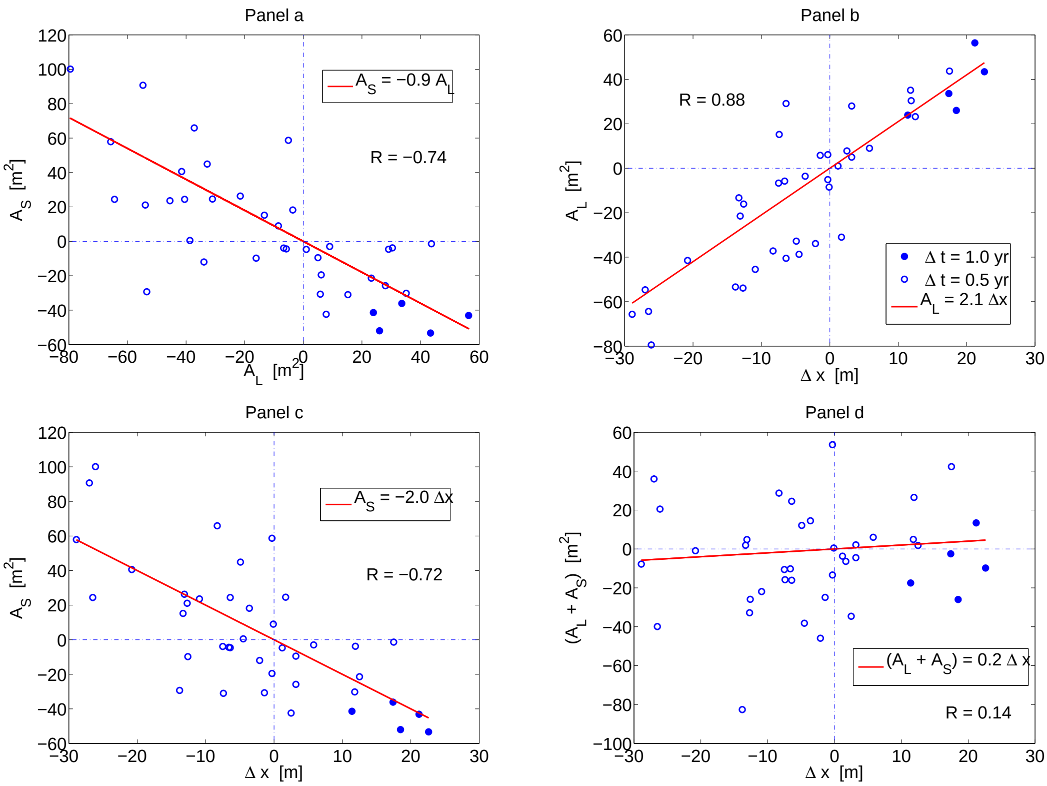


Figure 3.5: Linear regression analysis for North Shore erosion/accretion data points.

for North Shore indicating alongshore loss of sediment near the shoreline of up to 60 % of A_L. A slope of $m = -1$ in this case would indicate cross-shore changes only, with no alongshore losses.

Panel b in each of the four plots correlates the area of foreshore profile change A_L to the shoreline displacement Δx yielding a correlation coefficient R between the limits of $0.84 < R < 0.91$ which is considered a relatively good positive correlation. This makes sense in light of the fact that both quantities are related to the foreshore region of the profile. The equation $A_L = m \cdot \Delta x$ exhibits dimensional values for the slope m between $2.1\,m < m < 3.4\,m$ where the lower limit is found for the data of North Shore and the upper bound corresponds to data from Dewey. Furthermore,

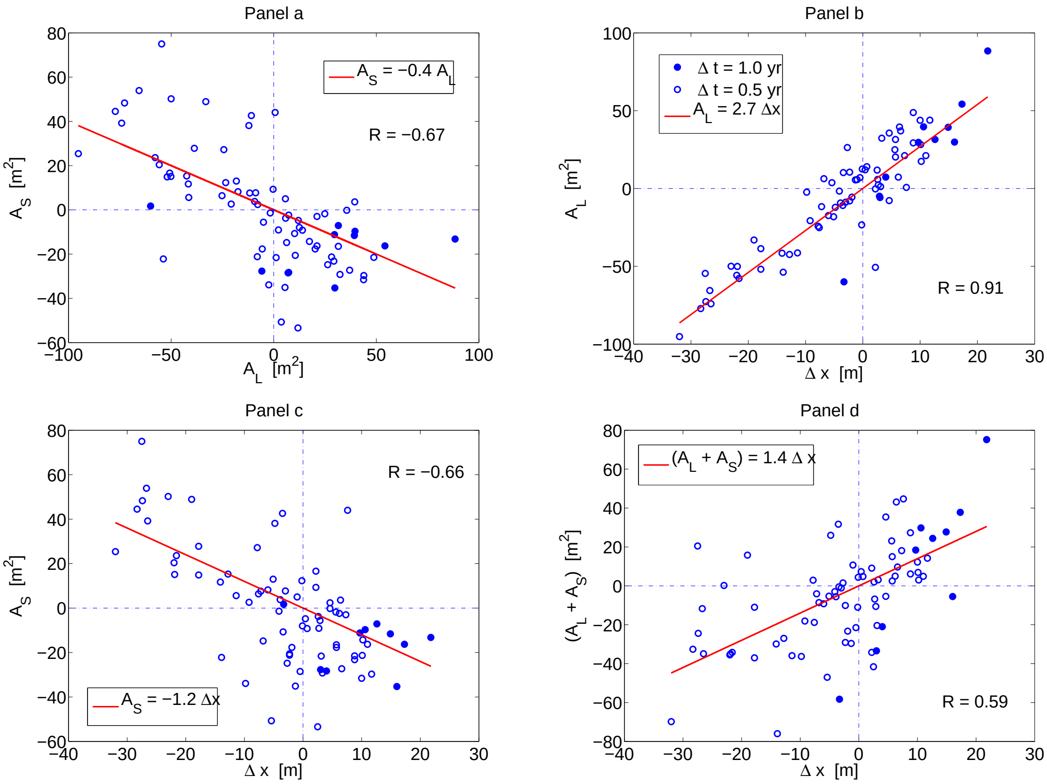


Figure 3.6: Linear regression analysis for Rehoboth erosion/accretion data points.

it has to be noted that the values of m are less than the average berm or dune height $\overline{z_L}$ of each beach (compare to Tables 3.1 through 3.4). This shows that the measured sediment loss or gain per unit width in the foreshore region is less than that due to the landward or seaward translation of the foreshore profile.

The regression analysis in panel c of Figures 3.5 through 3.8 relates the offshore quantity A_S to the foreshore quantity Δx. In this case, R takes on values ranging from -0.54 for Bethany to -0.80 for Dewey which is still considered a relatively fair correlation but clearly less than that for panel b. This indicates that the offshore profile change A_S is less correlated to the shoreline change Δx than the foreshore profile change A_L. In addition, the absolute values of the dimensional

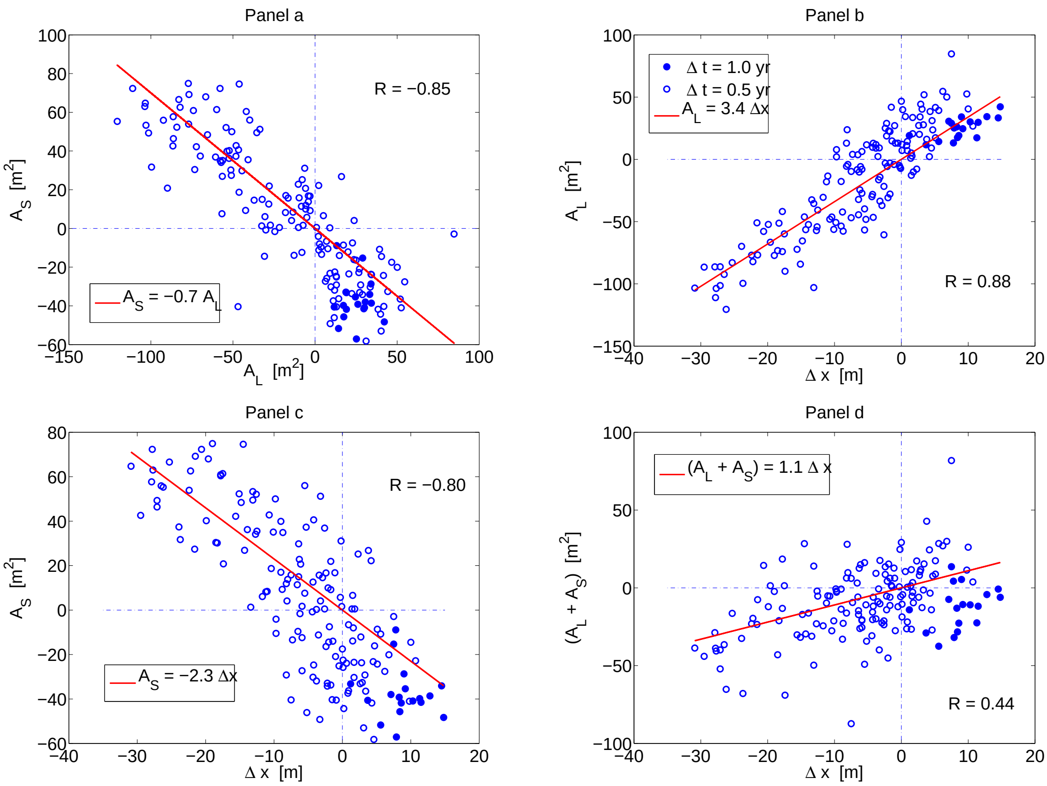


Figure 3.7: Linear regression analysis for Dewey erosion/accretion data points.

slope m are also smaller than the absolute values of the average depth of closure $\overline{z_S}$ for each beach.

Finally, panel d compares the total area of sediment loss or gain $(A_L + A_S)$ to the shoreline displacement Δx. Relatively poor correlation is obtained with values of R between 0.14 and 0.59 for the beaches at North Shore and Dewey, respectively. The dimensional values of m are in the range of $0.2\,m < m < 1.4\,m$ which is much smaller than the vertical extend of the profiles $(\overline{z_S} - \overline{z_L})$ from the top of the dune or berm to the profile depth of closure. One-line models for beach evolution using the Bruun rule (in Dean and Dalrymple, 2002) assume good correlation of these two parameters. The profile is assumed to keep its original shape or equilibrium profile,

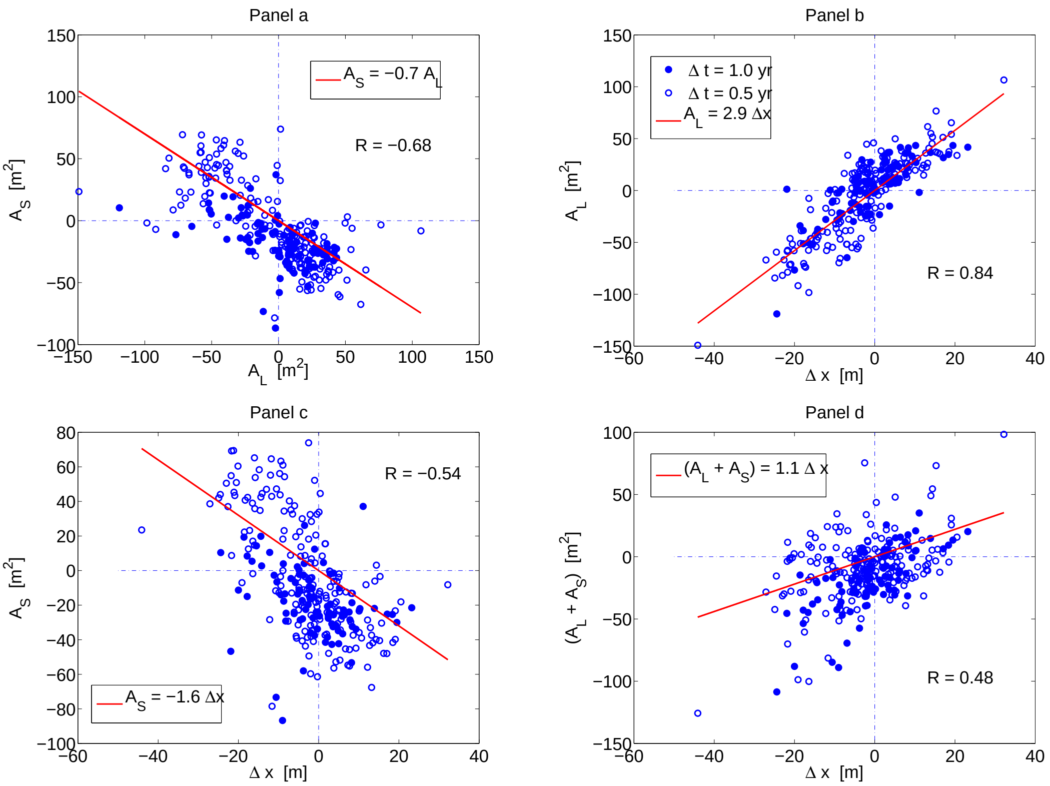


Figure 3.8: Linear regression analysis for Bethany erosion/accretion data points.

merely shifting in cross-shore location and elevation as a response to wave action and water level changes. The presented analysis clearly shows that this one-line approach cannot be used to express profile changes at Delaware beaches since the values of m in panel d of all four figures are on the order of 1 m compared to the values of $(\overline{z_S} - \overline{z_L})$ which are on the order of 10 m.

In Table 3.6 a summary of the regression analysis for the beaches at North Shore (NS), Rehoboth (RE), Dewey (DE) and Bethany (BE) is displayed for easy comparison. The lines of the table correspond to the different panels in Figures 3.5 through 3.8. The values of the best fit slope m and the correlation coefficient R are listed to indicate their variability along the Delaware coast.

Table 3.6: Summary of Regression Analysis for Four Beaches

Regression	NS		RE		DE		BE	
	m	R	m	R	m	R	m	R
$A_S = m \cdot A_L$	-0.9	-0.74	-0.4	-0.67	-0.7	-0.85	-0.7	-0.68
$A_L = m \cdot \Delta x$	2.1	0.88	2.7	0.91	3.4	0.88	2.9	0.84
$A_S = m \cdot \Delta x$	-2.0	-0.72	-1.2	-0.66	-2.3	-0.80	-1.6	-0.54
$(A_L + A_S) = m \cdot \Delta x$	0.2	0.14	1.4	0.59	1.1	0.44	1.1	0.48

Chapter 4

SEASONAL AND YEARLY CHANGES

In this chapter the data from individual profile lines is averaged for each beach and compared for the four beaches. Furthermore, a two-line model to estimate the longshore sediment transport gradient and the cross-shore sediment transport rate is presented.

4.1 Profile Changes on Four Beaches

The landward and seaward areas of profile change, A_L and A_S, the shoreline displacement Δx and the depth at the intersection point between two successive profile surveys z_3 have been evaluated for each profile line and each time step for all four beaches. These data have been presented in Table 3.5 for the beach at North Shore and in the tables in Appendix D for the beaches at Rehoboth, Dewey and Bethany. Figures 4.1 through 4.4 based on the data in these tables show each of these parameters plotted in the middle of the two survey dates. The values of the five parameters for all individual profile lines are displayed as filled circles connected by thin dashed lines to show the variability among the profile lines on each beach.

The subaerial width of the beach is an important indicator for nearshore erosion and accretion and can be observed visually. The values of Δx for each profile line show shoreline displacements between summer and winter in the range of $-20\ m$ to $20\ m$, slightly skewed towards the negative values indicating overall shoreline retreat. The most obvious retreat for all profile lines took place between the surveys in October 2002 and May 2003 which can be correlated with highly energetic

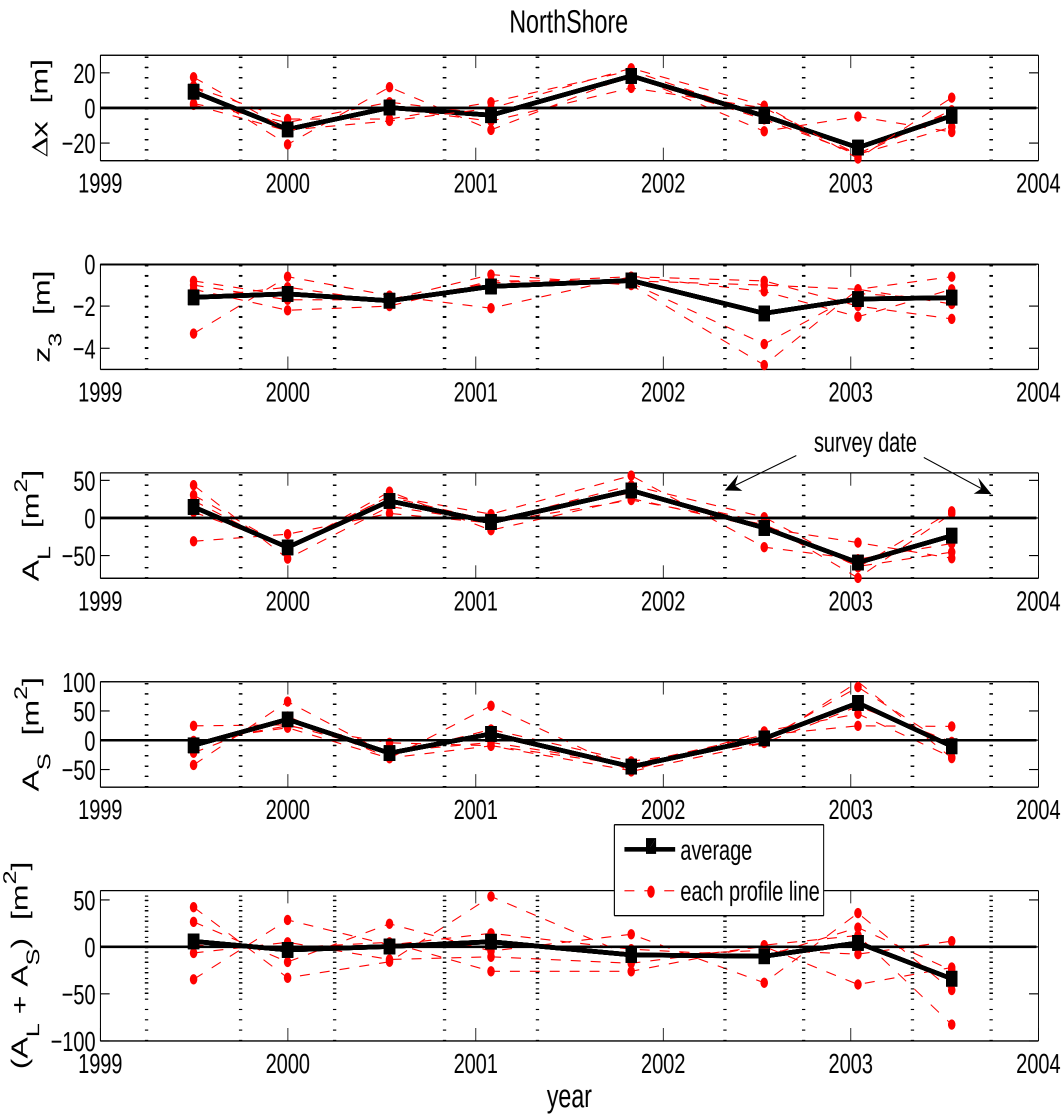


Figure 4.1: Seasonal variation of Δx (panel 1), z_3 (panel 2), A_L (panel 3), A_S (panel 4) and $A_L + A_S$ (panel 5) for North Shore beach. The values for each profile line are shown as filled circles connected by dashed lines and the average over all $N = 5$ profile lines is denoted by filled squares and connecting thick solid line. Survey dates are marked by dotted vertical lines.

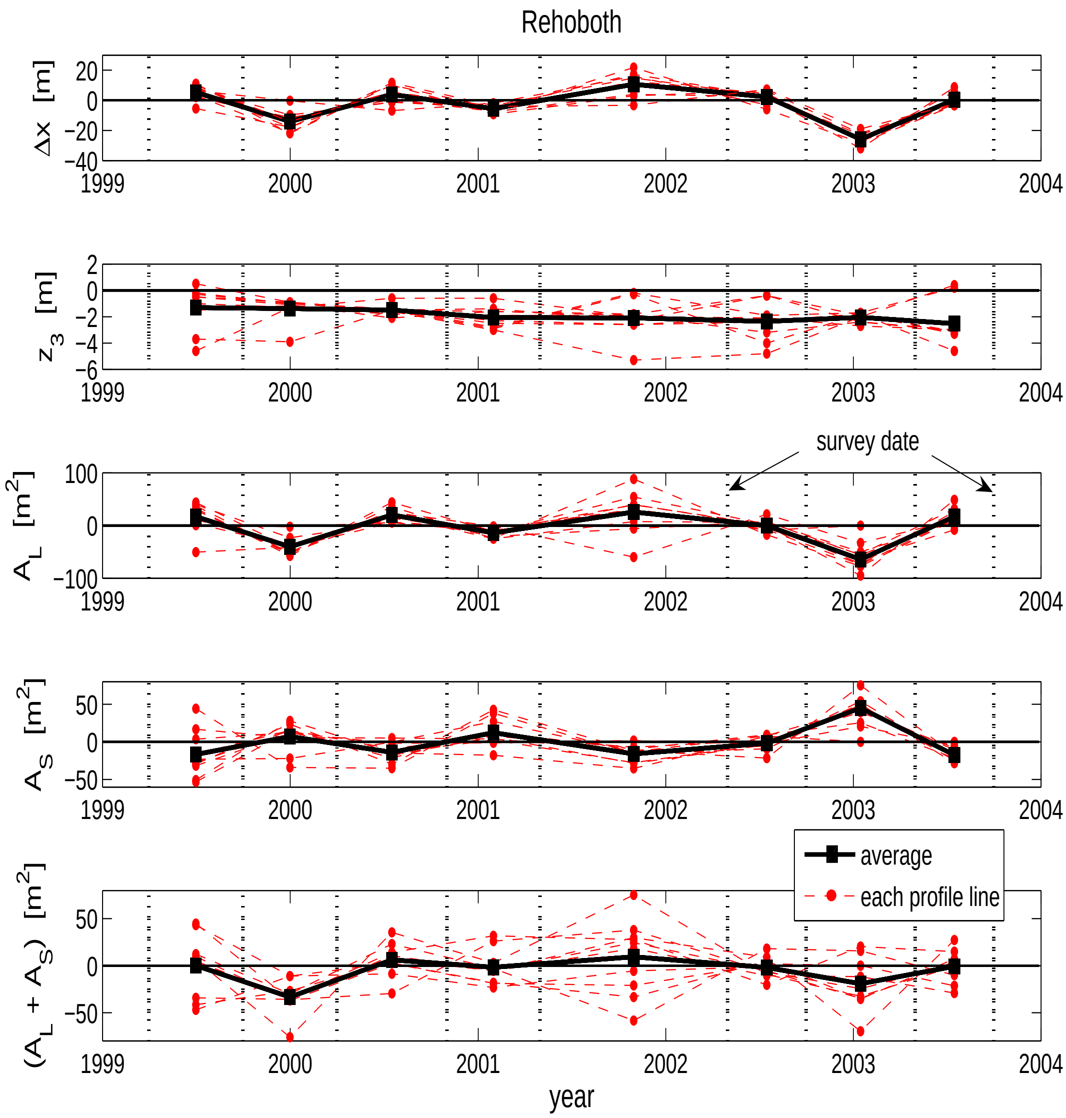


Figure 4.2: Seasonal variation of Δx (panel 1), z_3 (panel 2), A_L (panel 3), A_S (panel 4) and $(A_L + A_S)$ (panel 5) for Rehoboth beach. The values for each profile line are shown as filled circles connected by dashed lines and the average over all $N = 10$ profile lines is denoted by filled squares and connecting thick solid line. Survey dates are marked by dotted vertical lines.

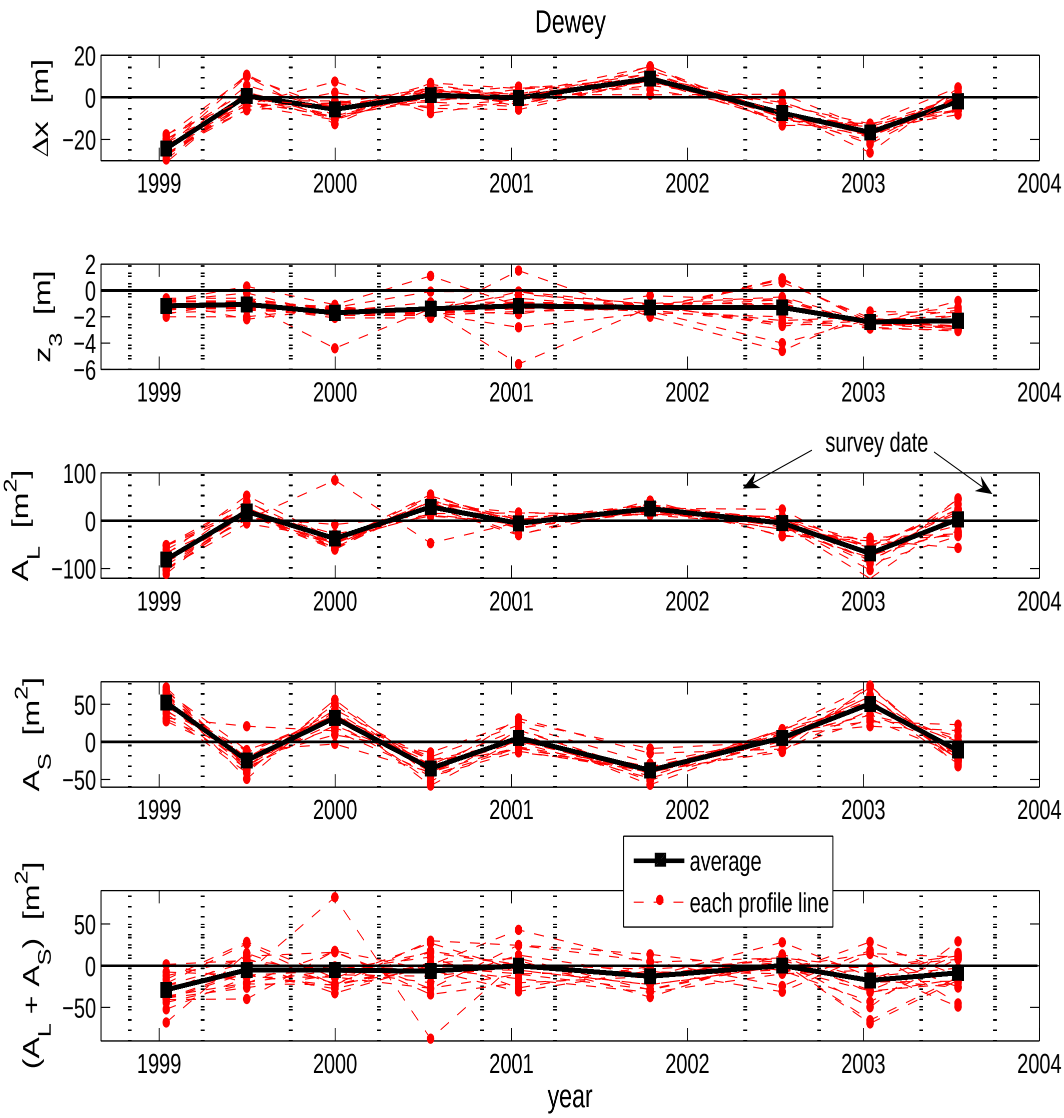


Figure 4.3: Seasonal variation of Δx (panel 1), z_3 (panel 2), A_L (panel 3), A_S (panel 4) and $(A_L + A_S)$ (panel 5) for Dewey beach. The values for each profile line are shown as filled circles connected by dashed lines and the average over all $N = 18$ profile lines is denoted by filled squares and connecting thick solid line. Survey dates are marked by dotted vertical lines.

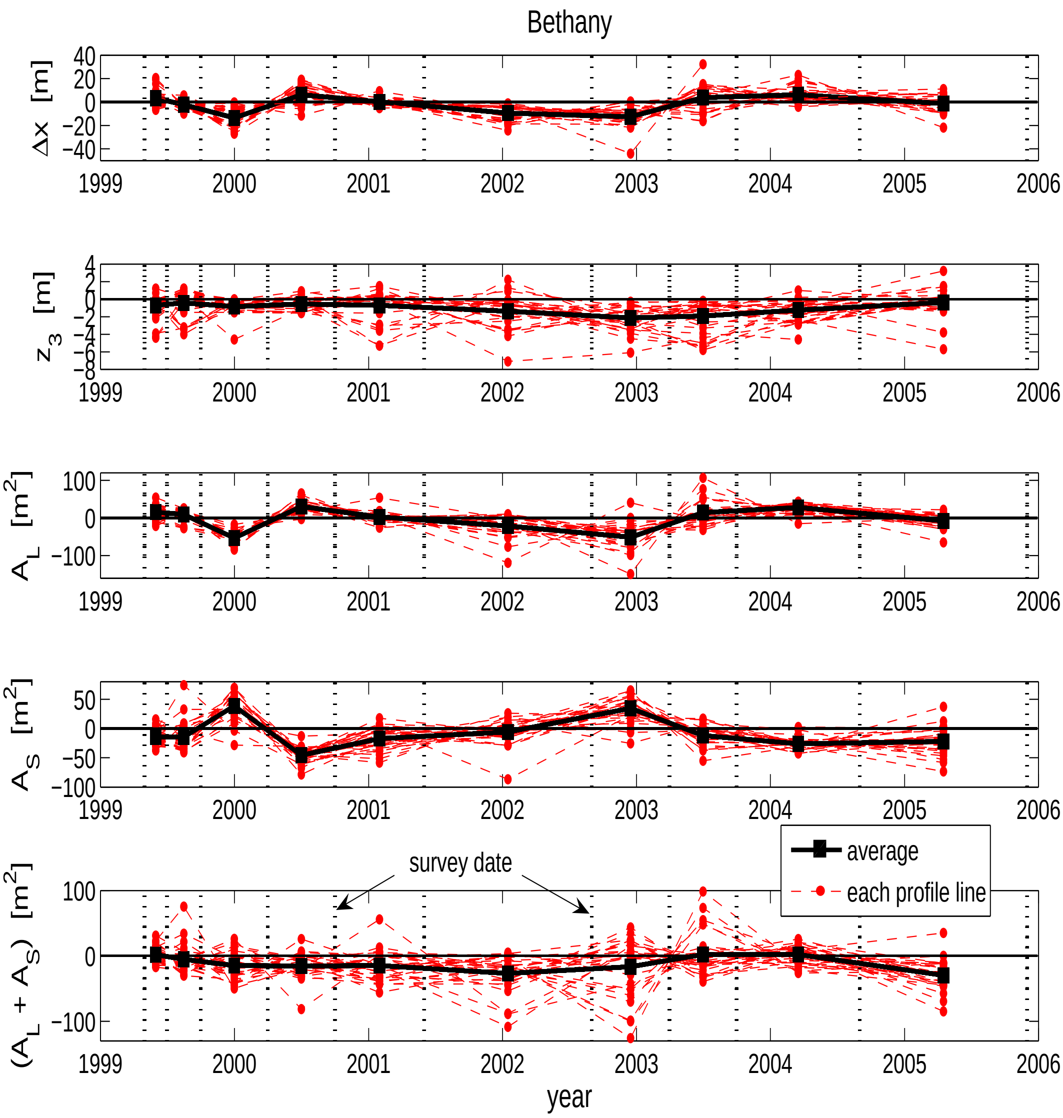


Figure 4.4: Seasonal variation of Δx (panel 1), z_3 (panel 2), A_L (panel 3), A_S (panel 4) and $(A_L + A_S)$ (panel 5) for Bethany beach. The values for each profile line are shown as filled circles connected by dashed lines and the average over all $N = 32$ profile lines is denoted by filled squares and connecting thick solid line. Survey dates are marked by dotted vertical lines.

wave conditions. Six consecutive monthly averages of the measured significant wave height H_s were up to half a meter above the mean value shown in Figure 2.8 during that fall and winter. This includes a major storm in February 2003 where hourly significant wave heights exceeded $4\,m$ for a duration of 5 days reaching a peak of about $8\,m$ (Appendix B, p.127). During this storm hourly spectral peak periods T_p stayed above $10\,s$ compared to the 3-month mean of $7.37\,s$. Only data for Dewey (Figure 4.3) comparing the two measurements in November 1998 and April 1999 show larger shoreline retreat. Even though fairly energetic wave conditions existed that winter, this can partly be contributed to the profile adjustment immediately after the beach nourishment in July 1998 (Table 1.1).

The values of z_3 range from $-7.1\,m$ to $3.2\,m$. For most individual profiles, however, they are negative and on the order of $-1\,m$ due to an intersection point between two successive profile measurements below MSL. A_L and A_S show strong seasonal trends with relatively large variations of up to $100\,m^2$ among individual profile lines. On average, these variations are on the order of $10\,m^2$ but are reduced for the time step of one year. The trends for A_L and A_S are opposite as has been pointed out by the negative slope of the regression lines in panel a of Figures 3.5 through 3.8. The sum of A_L and A_S shows the largest scatter indicating large spatial variability of erosion and accretion areas for individual profile lines.

In an effort to compare the four beaches all the parameters have been averaged for the profile lines on the beaches at North Shore, Rehoboth, Dewey and Bethany. The averaged results are listed in Tables 4.1 to 4.4. Even though the information on the variability among individual profile lines is lost, the averaged values can be used to compare the behaviors of the four nourished beaches. A visual impression of these averaged values and their evolution over time is given in Figures 4.1 through 4.4 in order to illustrate average seasonal variations for each beach. The filled squares connected by the thick solid line denote the average for each beach and are plotted together with the data points for the individual profile lines in each panel.

In addition to the average values of Δx, z_3, A_L, A_S and $(A_L + A_S)$ for each time step, the two bottom lines in Tables 4.1 to 4.4 show the cumulative shoreline displacement, the cumulative landward and seaward areas of profile change, the cumulative net eroded area and the average elevation of the intersection point between two successive profile surveys for the whole duration of available data.

Table 4.1: Average Erosion and Accretion for All $N = 5$ Profile Lines of North Shore

t_1 [mo/yr]	t_2 [mo/yr]	Δt [mo]	Δx [m]	z_3 [m]	A_L [m^2]	A_S [m^2]	$A_L + A_S$ [m^2]
4/1999	10/1999	6	9.2	-1.6	14.8	-8.9	5.9
10/1999	4/2000	6	-12.3	-1.4	-38.9	35.7	-3.3
4/2000	11/2000	7	0.2	-1.7	22.7	-22.2	0.5
11/2000	5/2001	6	-4.2	-1.1	-5.3	10.7	5.4
5/2001	5/2002	12	18.2	-0.8	36.7	-45.2	-8.5
5/2002	10/2002	5	-4.7	-2.3	-13.1	3.1	-9.9
10/2002	5/2003	7	-22.7	-1.7	-59.4	63.6	4.2
5/2003	10/2003	5	-4.5	-1.6	-23.6	-10.3	-33.9
		Cumulative Sum:	-20.6	×	-66.1	26.6	-39.6
		Average:	×	-1.5	×	×	×

For the discussion of the cumulative parameters it has to be noted that the values depend on the duration and number of surveys for each beach. The data for North Shore and Rehoboth includes 8 surveys, Dewey beach has been surveyed 9 times and Bethany data includes 10 surveys. The total shoreline displacement $\Sigma\Delta x$ at North Shore and Rehoboth is about $-22m$ between April 1999 and October 2003. At North Shore $\Sigma A_L = -66.1\, m^2$ indicates net erosion in the foreshore area of the profiles due to both offshore and alongshore sediment losses. The positive value of $\Sigma A_S = 26.6\, m^2$ yields overall accretion in the offshore area of the profiles but less

Table 4.2: Average Erosion and Accretion for All $N = 10$ Profile Lines of Rehoboth

t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
4/1999	10/1999	6	5.3	-1.3	16.9	-16.8	0.1
10/1999	4/2000	6	-14.1	-1.4	-40.3	7.0	-33.3
4/2000	11/2000	7	4.0	-1.5	20.2	-13.9	6.2
11/2000	5/2001	6	-5.5	-2.1	-14.0	12.2	-1.8
5/2001	5/2002	12	10.7	-2.1	25.4	-15.9	9.5
5/2002	10/2002	5	2.3	-2.4	-0.2	-1.8	-1.9
10/2002	5/2003	7	-25.8	-2.1	-64.3	45.1	-19.2
5/2003	10/2003	5	0.4	-2.5	16.8	-17.4	-0.6
Cumulative Sum:			-22.9	×	-39.6	-1.4	-41.0
Average:			×	-1.9	×	×	×

than erosion in the foreshore area. In view of the sum of the two parameters, $\Sigma(A_L + A_S) = -39.6\,m^2$, it can be concluded that the magnitude of the net alongshore loss is similar to that of the offshore loss. In comparison, the beach fill volume per meter alongshore distance of the 1998 nourishment at North Shore is $208\,m^2$ (Table 1.1) which has been surpassed by an increased value of $311\,m^2$ for the 2005 nourishment discussed in relation to Table 1.1. Assuming somewhat continuous net losses in 2004 and 2005 on the same order of magnitude it can be concluded that the placed beach fills exceed the actual amount of sediment lost since 1999 by a factor of 3 or more. The overall average of z_3 is $-1.5\,m$ which has the same magnitude as the offshore mean significant wave height H_s. This is the case for all four beaches.

For the beach at Rehoboth the results are similar to those obtained for North Shore except for the value of $\Sigma A_S = -1.4\,m^2$ which shows negligible overall loss of sediment in the offshore area of the profiles. Hence, the observed cumulative area change of $-39.6m^2$ for ΣA_L is assumed to be mostly related to longshore losses. The

Table 4.3: Average Erosion and Accretion for All $N = 18$ Profile Lines of Dewey

t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
11/1998	4/1999	5	-24.3	-1.2	-81.0	52.1	-28.9
4/1999	10/1999	6	0.6	-1.1	19.4	-24.5	-5.2
10/1999	4/2000	6	-5.7	-1.7	-37.4	32.0	-5.5
4/2000	11/2000	7	1.0	-1.4	28.7	-35.3	-6.6
11/2000	4/2001	5	-0.2	-1.2	-5.5	5.4	-0.2
4/2001	5/2002	13	8.9	-1.3	25.1	-37.7	-12.7
5/2002	10/2002	5	-7.5	-1.3	-5.2	5.2	0.0
10/2002	5/2003	7	-16.6	-2.4	-68.2	50.5	-17.7
5/2003	10/2003	5	-1.9	-2.3	3.1	-11.6	-8.5
		Cumulative Sum:	-45.7	×	-121.1	36.0	-85.1
		Average:	×	-1.5	×	×	×

average overall loss of sediment of the Rehoboth beach profiles explains the need for beach nourishment. However, the magnitude of the projected losses between the nourishments in 1998 and 2005 is about one third of the placed volume per unit alongshore length, which may indicate overly excessive placement of artificial beach fill. The same conclusion can be drawn from the averaged data for Dewey beach. Even though the cumulative values are larger than the ones for North Shore and Rehoboth, the additional survey in November 1998 must be accounted for because it was conducted immediately after the 1998 nourishment, yielding larger than normal quantities for Δx, A_L and A_S as shown in Table 4.3. The cumulative area changes $\Sigma A_L = -121.1\,m^2$, $\Sigma A_S = 36.0\,m^2$ and $\Sigma(A_L + A_S) = -85.1\,m^2$ indicate accretion in the offshore area of the profiles and erosion in the foreshore region due to offshore and alongshore losses, the latter being larger in magnitude.

The data for Bethany has to be interpreted differently compared to the other beaches since the duration of the surveys is longer with the last one in December

Table 4.4: Average Erosion and Accretion for All $N = 32$ Profile Lines of Bethany

t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
5 / 1999	7 / 1999	2	3.2	-0.7	15.9	-14.2	1.7
7 / 1999	10 / 1999	3	-2.2	-0.4	9.3	-14.4	-5.1
10 / 1999	4 / 2000	6	-13.5	-0.9	-53.2	38.4	-14.8
4 / 2000	10 / 2000	6	6.1	-0.5	30.3	-45.7	-15.4
10 / 2000	6 / 2001	8	0.2	-0.7	2.4	-17.3	-14.9
6 / 2001	9 / 2002	15	-9.4	-1.4	-21.1	-5.8	-26.9
9 / 2002	4 / 2003	7	-12.7	-2.1	-51.1	34.5	-16.6
4 / 2003	10 / 2003	6	3.7	-1.9	14.5	-12.2	2.2
10 / 2003	9 / 2004	11	6.2	-1.2	27.9	-26.0	1.9
9 / 2004	12 / 2005	15	-1.3	-0.4	-7.7	-22.1	-29.8
		Cumulative Sum:	-19.7	×	-32.6	-85.0	-117.6
		Average:	×	-1.3	×	×	×

2005. However, the more recent data has been collected yearly rather than semi-yearly as shown in Table 4.4. In addition, it has to be noted that the funding for the planned replenishment in 2005 was not ratified and no beach nourishment was placed at Bethany during that year. Nevertheless, the cumulative values for the shoreline displacement $\Sigma\Delta x = -19.7m$ and the profile area change $\Sigma A_L = -32.6m^2$ are comparable to the ones for the previously discussed beaches. The overall area change $\Sigma A_S = -85.0\,m^2$ in the offshore region of the profiles indicates more offshore erosion yielding a total sediment loss of $\Sigma(A_L + A_S) = -117.6\,m^2$ from 1999 until the end of 2005 attributed to longshore losses. This value corresponds closely to the amount of sediment per unit alongshore distance used for the Bethany nourishment in 1998 which was $144\,m^2$. Hence, the need for renourishment in the near future is apparent.

4.2 Two-Line Model

Previous applications of a longshore sediment transport formula and a one-line model indicate that the standard formula and one-line model may not be applicable to Delaware beaches (Garriga and Dalrymple, 2002) as pointed out in Chapter 1. In the following, a simple two-line model is used to estimate the longshore gradient of the alongshore sediment transport rate and the cross-shore sediment transport rate from the measured beach profile changes. Kobayashi and Han (1988) developed a two-line model to predict erosion at the bend of a gravel causeway. Accretion was not considered in their model. In this study, a two-line model is used for the inversion of the profile data to estimate the sediment transport rates.

It is assumed that cross-shore sediment transport is limited to the region between the landward profile limit x_L and the seaward profile limit x_S. Hence, a control volume of unit alongshore length is considered in the following. Figure 4.5 shows a schematic of the control volume used in the model. To account for the

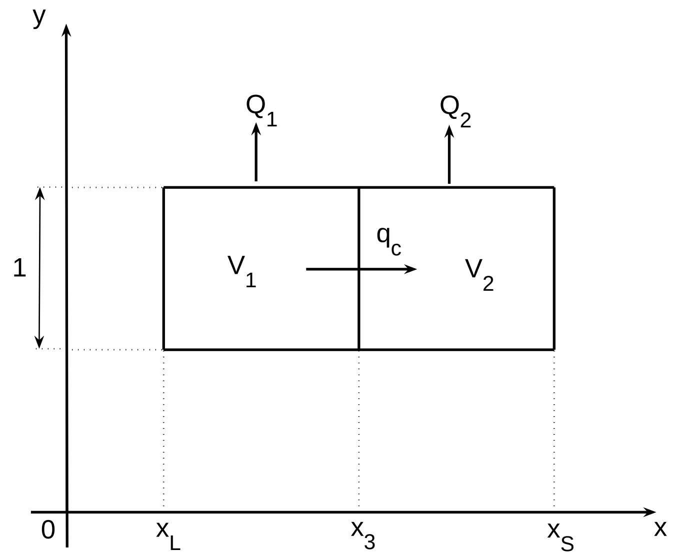


Figure 4.5: Schematic of the 2-line model control volume.

seasonal cross-shore sediment transport, the control volume is divided in two zones. Zone 1 includes the foreshore profile from x_L to the profile intersection point at x_3 in the landward region including the surf zone under normal conditions. Zone 2 spanning from the intersection location x_3 all the way to the seaward profile limit x_S comprises the seaward region of sediment transport.

The total longshore sediment transport rate Q integrated from x_L to x_S can now be separated into Q_1 and Q_2 in the zones 1 and 2, respectively.

$$Q = Q_1 + Q_2 \tag{4.1}$$

where the volumetric void fraction is included in the volumetric sediment transport rates. Thus, the sediment volume per unit longshore length in zone 1 and 2 is denoted as V_1 and V_2, respectively. The sediment transport rate between the two zones across the point x_3 is denoted by q_c which is positive offshore. The continuity equations for zones 1 and 2 are expressed as

$$\frac{\partial V_1}{\partial t} = -\frac{\partial Q_1}{\partial y} - q_c \tag{4.2}$$

$$\frac{\partial V_2}{\partial t} = -\frac{\partial Q_2}{\partial y} + q_c \tag{4.3}$$

The measured values of A_L and A_S correspond to the volume changes in zone 1 and zone 2 between the two subsequent surveys at times t_1 and t_2, respectively. To find the three unknowns Q_1, Q_2 and q_c using the above two equations, Q_1 and Q_2 are assumed to be given by

$$Q_1 = a \cdot Q \tag{4.4}$$

$$Q_2 = (1 - a) \cdot Q \tag{4.5}$$

in which the empirical parameter a is assumed constant during t_1 to t_2 and in the range of $0 < a < 1$. The gradient of the alongshore sediment transport rate Q is now written as

$$q_\ell = \frac{\partial Q}{\partial y} \tag{4.6}$$

where q_ℓ is positive or negative for the alongshore sediment loss or gain in view of Equations (4.2) and (4.3). Substitution of Equation (4.6) into Equations (4.2) and (4.3) yields

$$\frac{\partial V_1}{\partial t} = -a \cdot q_\ell - q_c \tag{4.7}$$

$$\frac{\partial V_2}{\partial t} = -(1-a) \cdot q_\ell + q_c \tag{4.8}$$

Integrating Equations (4.7) and (4.8) from time t_1 to time t_2 gives

$$\int_{t_1}^{t_2} \frac{\partial V_1}{\partial t}\, dt = -a \int_{t_1}^{t_2} q_\ell \, dt - \int_{t_1}^{t_2} q_c \, dt \tag{4.9}$$

$$\int_{t_1}^{t_2} \frac{\partial V_2}{\partial t}\, dt = -(1-a) \int_{t_1}^{t_2} q_\ell \, dt - \int_{t_1}^{t_2} q_c \, dt \tag{4.10}$$

Using A_L and A_S for the left hand sides of Equations (4.9) and (4.10) as the volume changes, time-averaging over the duration between two consecutive surveys yields

$$\frac{A_L}{t_2 - t_1} = -a \cdot \overline{q_\ell} - \overline{q_c} \tag{4.11}$$

$$\frac{A_S}{t_2 - t_1} = -(1-a) \cdot \overline{q_\ell} + \overline{q_c} \tag{4.12}$$

in which time averaged quantities are denoted with overbars.

The net longshore sediment transport rate $\overline{q_\ell}$ and the cross-shore sediment transport rate $\overline{q_c}$, both defined by Equations (4.11) and (4.12) can now be written as

$$\overline{q_\ell} = -\frac{A_L + A_S}{t_2 - t_1} \tag{4.13}$$

$$\overline{q_c} = \frac{a \cdot A_S - (1-a) \cdot A_L}{t_2 - t_1} \tag{4.14}$$

Note that Equation (4.13) is independent of the parameter a and can be determined exactly from the measured quantities A_L, A_S and $(t_2 - t_1)$. The cross-shore sediment transport gradient $\overline{q_c}$ in Equation (4.14) can be estimated if the parameter a is known.

The parameter a is assumed to be related to a profile length scale ratio. Following the results presented in Section 3.2, the cross-shore distance and elevation at point P_3 (see Figure 3.2) and at the landward and seaward limits of each profile are listed in Tables 4.5 to 4.8. The listed value for each profile line is the average of all the measured values. The bottom line of each table is the average value for all the profile lines on a beach. Note that the average value of the profile depth below MSL at the intersection point between two consecutive profile surveys, $-z_3$, is on the order of the mean offshore significant wave height $H_s = 1.26\,m$ (Figure 2.8) for all four beaches.

Table 4.5: North Shore Width Ratio w_r and Height Ratio h_r

Prof.	x_L	z_L	x_3	z_3	x_S	z_S	w_r	h_r
#	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	[-]	[-]
1	37.82	4.52	146.20	-1.64	283.23	-6.90	0.44	0.54
2	44.74	4.35	134.74	-1.43	267.11	-6.80	0.40	0.52
3	48.92	4.66	137.38	-1.65	299.82	-7.30	0.35	0.53
4	48.27	4.56	135.98	-1.68	256.76	-6.30	0.42	0.57
5	50.45	4.28	136.33	-1.22	253.09	-5.80	0.42	0.55
Avg.	46.04	4.48	138.13	-1.52	272.00	-6.62	0.41	0.54

Table 4.6: Rehoboth Width Ratio w_r and Height Ratio h_r

Prof.	x_L	z_L	x_3	z_3	x_S	z_S	w_r	h_r
#	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	[-]	[-]
1	62.58	7.42	183.86	-1.35	303.23	-6.50	0.50	0.63
2	55.27	5.32	175.35	-1.64	331.83	-7.90	0.43	0.53
3	57.55	5.03	190.24	-2.30	324.88	-8.10	0.50	0.56
4	62.74	3.92	170.59	-1.83	300.36	-7.50	0.45	0.50
5	63.10	4.10	166.63	-1.94	275.67	-7.00	0.49	0.54
6	69.46	4.14	169.90	-1.94	281.54	-7.20	0.47	0.54
7	56.83	3.69	164.26	-2.51	294.63	-7.90	0.45	0.54
8	64.35	3.72	146.89	-1.94	274.27	-7.50	0.39	0.50
9	51.89	5.35	153.43	-1.12	278.01	-6.70	0.45	0.54
10	48.28	4.79	169.22	-2.33	288.98	-7.20	0.50	0.59
Avg.	59.21	4.75	169.04	-1.89	295.34	-7.35	0.46	0.55

Two length scale ratios have been chosen for further investigation. The height ratio h_r and the width ratio w_r for each profile line in Tables 4.5 to 4.8 are defined as

$$h_r = \frac{z_L - z_3}{z_L - z_S} \; ; \qquad w_r = \frac{x_3 - x_L}{x_S - x_L} \tag{4.15}$$

where the use of the landward limit (x_L, z_L) accounts for longshore sediment transport above MSL during storms. Both h_r and w_r are about 0.5 but h_r is slightly larger than w_r because the beach profiles are concave upward. The width ratio w_r takes on values in the range of $0.30 < w_r < 0.55$ with an average for all beaches of 0.43 whereas h_r values are between 0.33 and 0.64 with an overall average of 0.53. The width ratio w_r varies less and is thus chosen to express the parameter a. It is noted that the computed results are found to be similar for h_r.

Since the longshore sediment transport rate may not be distributed uniformly

Table 4.7: Dewey Width Ratio w_r and Height Ratio h_r

Prof.	x_L	z_L	x_3	z_3	x_S	z_S	w_r	h_r
#	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	[-]	[-]
1	141.60	6.23	246.06	-1.52	400.15	-6.50	0.40	0.61
2	122.37	5.44	219.87	-1.29	313.68	-5.00	0.51	0.64
3	96.94	4.17	192.96	-1.34	341.01	-7.00	0.39	0.49
4	116.35	3.97	226.98	-2.07	399.59	-7.60	0.39	0.52
5	135.88	5.21	248.35	-1.81	373.58	-7.00	0.47	0.57
6	108.19	4.49	204.01	-1.52	322.98	-6.40	0.45	0.55
7	97.35	4.87	185.07	-1.48	307.79	-6.40	0.42	0.56
8	122.17	3.62	213.53	-1.59	310.14	-6.00	0.49	0.54
9	95.53	3.44	193.80	-1.53	310.56	-6.60	0.46	0.50
10	110.37	3.97	218.65	-1.89	354.39	-7.20	0.44	0.52
11	99.19	4.05	194.53	-1.30	319.39	-6.90	0.43	0.49
12	125.70	4.42	230.80	-1.42	348.54	-7.00	0.47	0.51
13	95.91	5.42	195.73	-1.30	333.26	-7.30	0.42	0.53
14	114.64	4.58	213.78	-1.36	341.84	-6.80	0.44	0.52
15	101.90	5.48	216.96	-1.66	312.91	-6.00	0.55	0.62
16	125.54	5.04	237.42	-1.33	380.31	-8.00	0.44	0.49
17	117.30	5.37	243.94	-1.74	358.99	-7.00	0.52	0.58
18	136.04	5.25	253.81	-1.54	401.30	-7.40	0.44	0.54
Avg.	114.61	4.72	218.68	-1.54	346.13	-6.78	0.45	0.54

in the cross-shore direction, the following empirical expression is adopted:

$$a = (w_r)^{\beta} \tag{4.16}$$

The shape parameter β is used to adjust the longshore sediment transport distribution. Equations (4.4) and (4.5) with the parameter a given by Equation (4.16) imply that the longshore sediment transport distribution is uniform if $\beta = 1$ and larger near the shoreline if $\beta < 1$. The computed values of $\overline{q_\ell}$ and $\overline{q_c}$ using Equations (4.13) and (4.14) turn out to be insensitive to the value of β as was the case with the gravel causeway erosion investigated by Kobayashi and Han (1988). Computed values for the longshore sediment transport gradient and the cross-shore transport rate on Delaware beaches using the described two-line model are presented in the following section.

Table 4.8: Bethany Width Ratio w_r and Height Ratio h_r

Prof.	x_L	z_L	x_3	z_3	x_S	z_S	w_r	h_r
#	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	$[m]$	[-]	[-]
1	72.63	5.07	166.05	-0.40	281.37	-5.70	0.45	0.51
2	74.81	3.19	149.10	0.06	291.46	-6.20	0.34	0.33
3	64.06	3.74	157.52	-0.67	267.60	-5.50	0.46	0.48
4	80.34	3.26	148.62	-0.94	283.03	-6.30	0.34	0.44
5	84.43	3.51	180.13	-2.07	274.87	-6.20	0.50	0.57
6	86.35	3.47	160.31	-0.87	265.94	-5.60	0.41	0.48
7	105.22	3.79	187.14	-0.96	298.65	-5.60	0.42	0.51
8	94.32	3.55	167.59	-0.41	307.36	-6.20	0.34	0.41
9	115.53	3.40	189.87	-1.03	272.59	-5.10	0.47	0.52
10	103.92	3.80	164.24	-0.20	285.81	-5.80	0.33	0.42
11	110.50	4.60	183.17	-0.39	321.72	-5.80	0.34	0.48
12	111.11	4.46	188.63	-1.08	282.69	-5.60	0.45	0.55
13	113.69	5.31	208.47	-1.24	315.93	-6.10	0.47	0.57
14	109.94	5.99	199.30	-1.19	316.89	-6.30	0.43	0.58
15	117.91	5.92	218.51	-1.70	334.78	-7.10	0.46	0.59
16	108.47	5.69	188.60	-0.76	285.77	-5.30	0.45	0.59
17	113.07	5.51	201.02	-1.12	336.88	-7.00	0.39	0.53
18	102.05	5.74	178.23	-0.72	290.52	-6.00	0.40	0.55
19	102.85	4.87	192.45	-0.98	277.32	-5.30	0.51	0.58
20	138.84	4.38	215.04	-1.40	312.56	-6.20	0.44	0.55
21	146.41	4.34	212.84	-0.97	332.19	-6.90	0.36	0.47
22	136.62	4.45	208.74	-1.12	331.57	-6.90	0.37	0.49
23	154.51	4.55	241.57	-1.72	361.96	-7.00	0.42	0.54
24	193.35	3.05	264.35	-1.58	382.97	-7.00	0.37	0.46
25	176.93	3.66	248.74	-1.28	398.71	-7.30	0.32	0.45
26	190.08	3.14	247.15	-0.74	383.47	-6.30	0.30	0.41
27	171.36	2.95	235.26	-0.92	354.01	-6.00	0.35	0.43
28	164.53	4.67	230.35	-0.57	378.06	-7.00	0.31	0.45
29	143.15	5.18	210.51	-0.53	331.94	-5.90	0.36	0.52
30	107.91	4.40	211.51	-1.57	298.52	-5.80	0.54	0.59
31	95.43	4.49	204.79	-1.41	318.16	-6.50	0.49	0.54
32	71.76	4.40	205.00	-2.83	380.71	-7.90	0.43	0.59
Avg.	117.57	4.33	198.90	-1.04	317.38	-6.23	0.41	0.50

4.3 Longshore and Cross-Shore Sediment Transport Rates

Since only time-averaged quantities between two successive profile surveys are considered, the overbars denoting time averages are omitted in the following. The time-averaged net longshore sediment transport rate q_ℓ is estimated using Equation (4.13) for each profile line. The tables in this section use t_i as notation for the time level at which a specific profile survey was conducted. The integer index i stands for the sequential time level where $i = 1, 2, ...n$ with $n =$ number of surveys. The month and year of each survey can be found in Table 2.1 in Section 2.1. For North Shore and Rehoboth there are $n = 9$ survey dates (4/1999, 10/1999, 4/2000, 11/2000, 5/2001, 5/2002, 10/2002, 5/2003, 10/2003). Dewey includes $n = 10$ surveys (11/1998, 4/1999, 10/1999, 4/2000, 11/2000, 4/2001, 5/2002, 10/2002, 5/2003, 10/2003) and for Bethany data from $n = 11$ surveys exists (5/1999, 7/1999, 10/1999, 4/2000, 10/2000, 6/2001, 9/2002, 4/2003, 10/2003, 9/2004, 12/2005).

The results for the computed q_ℓ are presented in Tables 4.9, 4.10, 4.11, and 4.12 and corresponding Figures 4.6, 4.7, 4.8, and 4.9 for all four beaches, respectively. In the tables the data for all individual profile lines are listed along with the spatial averages for every beach and time step. In the corresponding plots the data for each profile line are denoted by small solid circles connected by thin dashed lines to show the temporal evolution. The average values are shown as solid squares connected by a solid line for each beach. Survey dates are marked by vertical dotted lines in every plot with data points located at the mid-point between surveys. Alongshore sediment loss and gain are indicated by positive and negative q_ℓ values, respectively.

The computed data for North Shore (Table 4.9 and Figure 4.6) exhibit relatively small alongshore transport gradients on the order of $\pm 1 \ \frac{m^2}{month}$ except for the last time step between May 2003 and October 2003 where an increased average alongshore loss of $6.77 \ \frac{m^2}{month}$ is noted. Profile line 2 is the main contributor to this

Table 4.9: North Shore Net Longshore Transport Rate q_ℓ ($\frac{m^2}{month}$)

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$
1	1.07	-0.80	1.91	1.77	1.46	-0.10	5.70	4.38
2	-0.30	0.15	-0.70	4.32	2.17	-0.38	-1.73	16.52
3	5.77	-4.78	-0.30	-2.42	0.21	2.04	-2.93	4.98
4	-4.42	2.68	-3.50	0.75	-1.12	7.64	-5.14	9.18
5	-7.05	5.47	2.26	-8.93	0.82	0.74	1.11	-1.20
Avg.	-0.99	0.54	-0.07	-0.90	0.71	1.99	-0.60	6.77

large value and this result needs to be interpreted with care since no other profile line on the other beaches shows such a large value for this time step. In general, the data for North Shore displays a large variability among individual profile lines where alongshore losses do not occur continuously but rather intermittently.

For Rehoboth (Table 4.10 and Figure 4.7) the computed values for q_ℓ indicate alongshore transport rates on the same order of magnitude as for North Shore with obvious variability among profile lines. However, larger than average alongshore losses occur during different time steps denoted by positive peaks in Figure 4.7. For this beach, the intermittent character of the alongshore losses is evident as well, with maxima occurring during the winter of 2000 and 2003, both of which include several months with monthly average significant wave heights H_s extensively higher than the overall mean.

The longshore transport rate q_ℓ estimated for Dewey shows the same large variability between the separate profile lines but the alongshore sediment loss is more continuous with an average constantly greater than zero. More extreme values are experienced during the winters of 1999 and 2003, the latter of which is of the same order of magnitude as the value for Rehoboth beach which has been caused by the storm activity as described above. The larger than average alongshore transport rate in 1999 may be due to the nourishment at the end of the summer of 1998 and

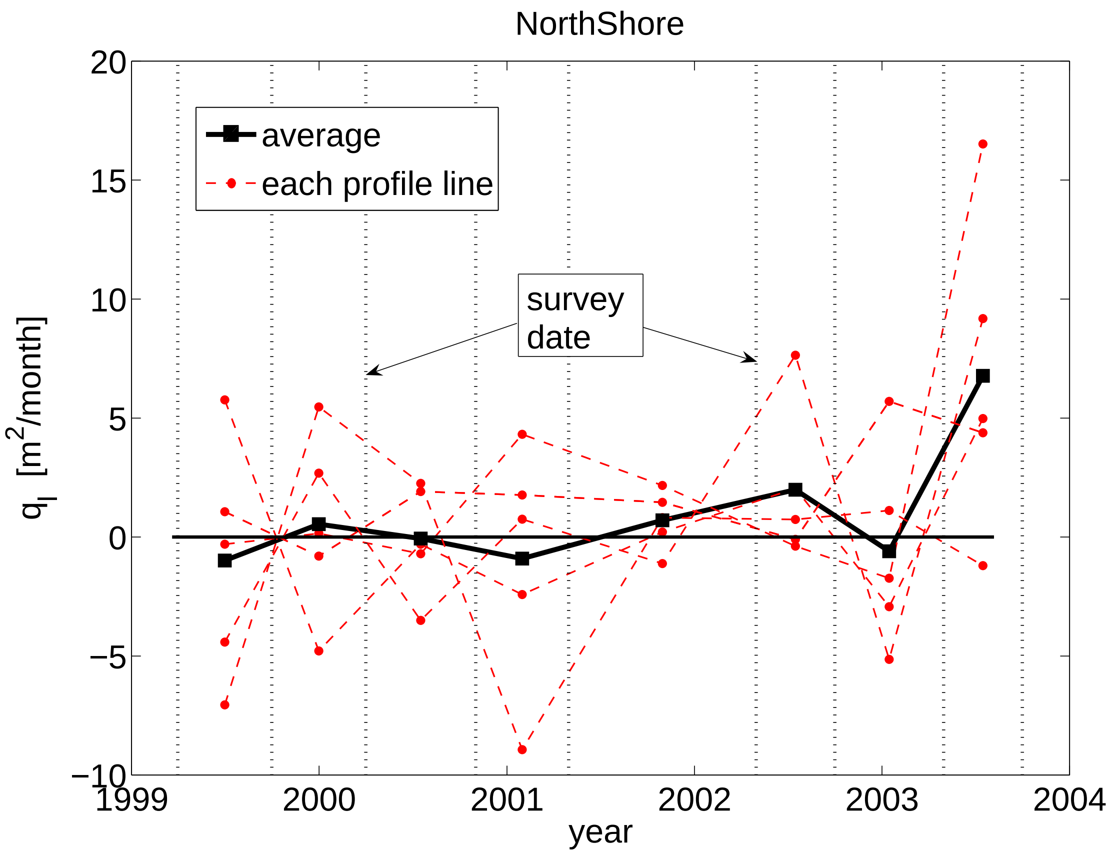


Figure 4.6: Temporal variation of q_ℓ ($\frac{m^2}{month}$) for North Shore.

is experienced for all individual profile lines.

In comparison to the other beaches, Bethany shows fairly continuous alongshore sediment loss on the order of 1 to 2 $\frac{m^2}{month}$ on the average. Individual profile line computations show the same large variability as pointed out earlier.

It can be concluded that both temporal and spatial variabilities in the longshore sediment transport rate q_ℓ exist on Delaware beaches with an overall average on the order of 1 $\frac{m^2}{month}$ denoting alongshore losses to the system. Before beach nourishment was adapted as the accepted strategy for erosion mitigation, several groin fields with a combined number of 14 groins on the beaches of North Shore, Rehoboth

Table 4.10: Rehoboth Net Longshore Transport Rate q_ℓ ($\frac{m^2}{month}$)

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$
1	-7.18	1.83	1.23	3.88	0.46	0.22	N/A	N/A
2	-0.52	5.70	-2.03	-5.28	-2.31	4.08	-2.93	-3.00
3	-7.45	6.05	4.23	-4.33	-3.15	1.36	3.49	-0.30
4	-1.02	12.67	-5.06	-0.48	-6.27	1.84	4.66	0.10
5	-0.82	5.83	-0.99	0.88	-2.48	-1.82	9.97	-5.46
6	6.93	4.50	-0.69	0.68	-2.03	1.08	4.99	-0.88
7	5.70	5.98	-1.53	0.93	-1.53	2.12	1.67	5.82
8	7.83	1.83	-0.43	3.02	2.78	-1.00	5.07	-1.46
9	-1.62	6.17	-0.36	3.13	1.75	-0.40	-0.03	4.30
10	-2.03	4.98	-3.30	0.50	4.86	-3.62	-2.26	2.02
Avg.	-0.02	5.56	-0.89	0.29	-0.79	0.39	2.74	0.13

and Dewey and a total of nine groins on the beach of Bethany had been constructed to prevent erosion. Even though they are now considered to have little to no effect on the overall littoral drift in these areas (Garriga and Dalrymple, 2002), they may still contribute to the large spatial variability encountered among individual profile lines.

The location on a shoreline where the average positive and negative longshore transport rates have the same magnitude is called a nodal point since the net littoral drift at that location is zero. Mann and Dalrymple (1986) analyzed the nodal point of the Delaware coastline and reported its average position to be located approximately 11 km south of Indian River Inlet. The sediment volume of sand bypassing at Indian River Inlet is on the order of $100,000\, yd^3$ ($76,500\, m^3$) of pumped sand per year (Garriga and Dalrymple, 2002). Assuming that the northward longshore sediment transport starts near the estimated nodal point, the order of magnitude of the gradient of the longshore sediment transport rate is 7 $\frac{m^2}{year}$, that is, 0.6 $\frac{m^2}{month}$, which is consistent with q_ℓ on the order of 1 $\frac{m^2}{month}$ at Bethany beach located south

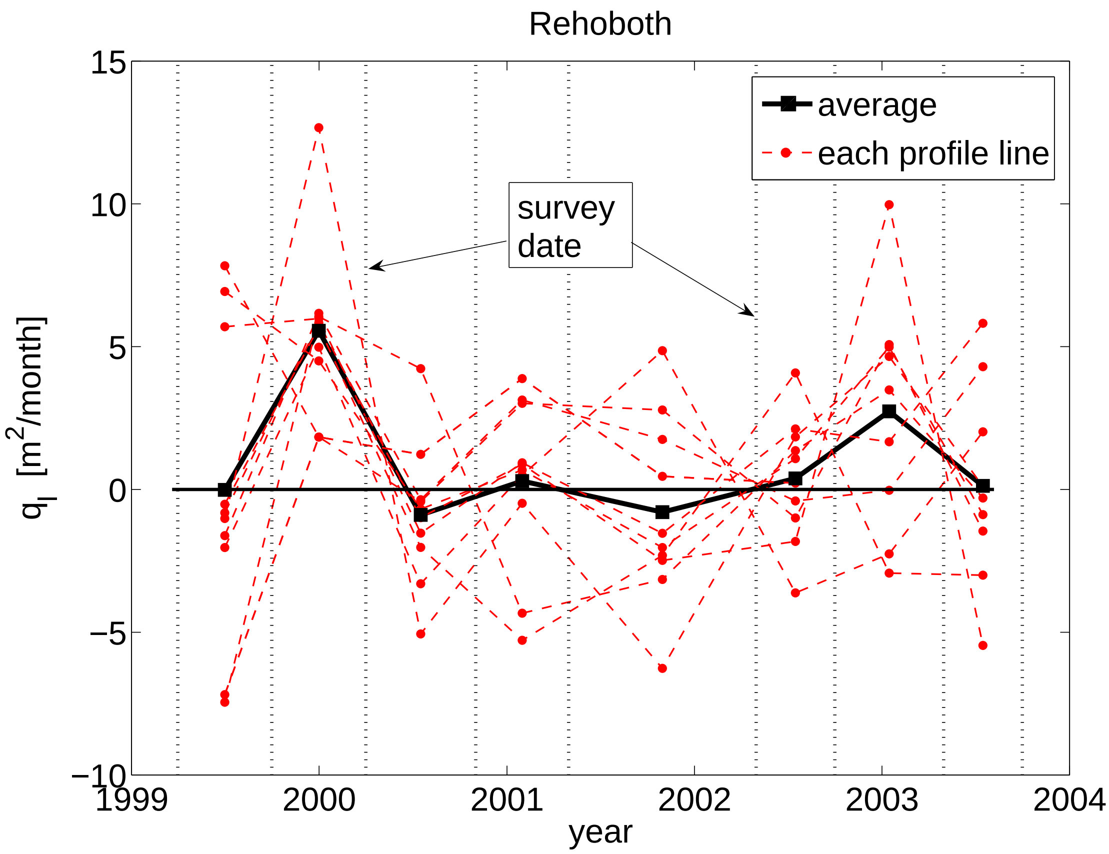


Figure 4.7: Temporal variation of q_ℓ $(\frac{m^2}{month})$ for Rehoboth.

of Indian River Inlet.

Table 4.11: Dewey Net Longshore Transport Rate q_ℓ ($\frac{m^2}{month}$)

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$	$t_9 - t_{10}$
1	4.22	-4.35	3.85	-4.27	-4.88	-0.42	4.88	-2.64	9.02
2	6.50	-1.90	-2.70	3.93	-4.94	-1.05	1.18	6.14	-1.72
3	4.70	-0.63	5.50	-0.11	-8.56	-0.33	-1.86	0.30	-1.52
4	2.42	-1.33	3.53	-2.49	-0.26	1.08	-2.34	4.54	3.24
5	4.62	1.97	3.95	-0.23	-0.08	0.82	-0.86	9.86	3.44
6	8.80	3.65	3.80	-0.49	-1.76	2.23	-0.62	9.31	2.82
7	7.98	1.48	-13.63	12.47	-1.24	2.88	-2.70	2.44	5.22
8	10.42	2.35	2.28	3.87	2.04	2.18	-1.26	7.10	-5.84
9	13.58	-2.48	3.75	0.49	3.12	2.45	1.96	0.76	9.82
10	8.12	6.65	-2.93	0.76	6.16	0.47	6.22	-2.00	5.08
11	7.30	3.50	-2.88	4.90	4.10	1.01	-5.60	1.89	0.56
12	5.76	1.75	4.60	0.20	1.92	0.57	1.88	-4.06	2.42
13	7.74	4.38	1.82	1.81	0.14	0.91	-1.96	4.23	-2.52
14	7.76	1.00	0.12	0.63	1.06	1.73	0.56	4.31	4.24
15	1.52	1.88	1.00	2.91	-2.54	0.84	1.02	2.31	-3.06
16	-0.28	3.32	0.88	-1.49	5.32	0.06	0.42	-2.06	-2.10
17	3.28	-4.75	2.45	-3.86	1.14	1.75	0.16	0.33	-2.34
18	-0.28	-1.03	1.00	-2.20	-0.14	0.33	-1.22	2.80	3.74
Avg.	5.79	0.86	0.91	0.94	0.03	0.97	-0.01	2.53	1.69

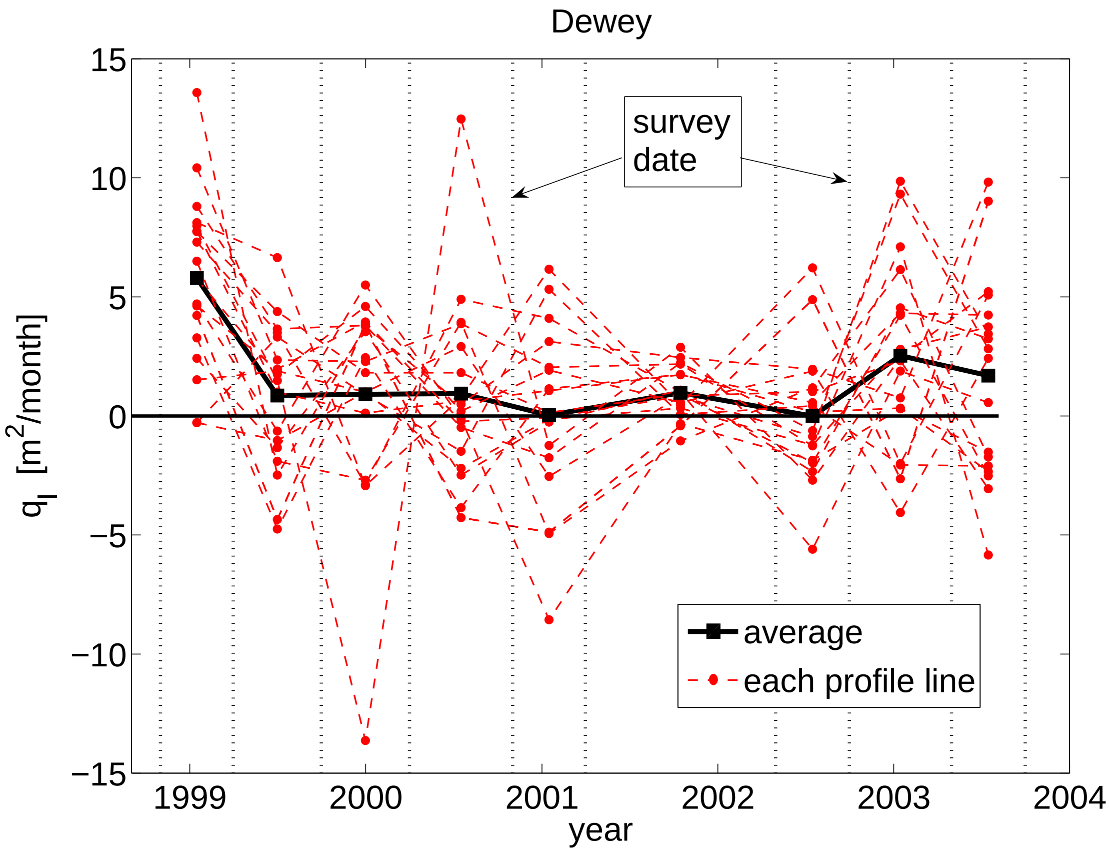


Figure 4.8: Temporal variation of q_ℓ $(\frac{m^2}{month})$ for Dewey.

Table 4.12: Bethany Net Longshore Transport Rate q_ℓ ($\frac{m^2}{month}$)

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$	$t_9 - t_{10}$	$t_{10} - t_{11}$
1	-10.45	3.90	0.40	1.00	3.00	N/A	N/A	N/A	-0.79	-2.34
2	-6.55	6.30	-2.55	0.57	-0.64	N/A	N/A	N/A	-0.65	1.11
3	-4.10	3.13	-0.40	3.85	0.53	-0.23	-3.46	6.55	-0.53	1.25
4	-3.00	5.83	7.07	-4.27	1.79	0.47	0.04	2.60	-1.43	2.63
5	-2.30	9.57	-1.93	0.72	2.91	0.13	17.96	-16.38	1.13	N/A
6	-6.50	1.90	5.23	-0.53	1.84	0.08	-1.04	1.25	-1.07	1.85
7	8.65	7.47	0.13	1.22	-0.89	2.43	-4.93	2.30	0.92	2.61
8	-15.45	-2.20	0.17	4.65	1.57	1.90	-2.67	1.77	-0.54	2.12
9	-7.85	0.67	4.98	-0.88	0.17	1.11	-1.10	2.70	-0.28	0.69
10	-4.25	1.43	1.72	3.20	-0.74	0.96	0.53	1.85	-1.02	3.83
11	-0.25	1.53	-3.33	5.12	-0.17	1.37	0.74	-0.90	1.61	1.73
12	2.15	-7.23	4.62	0.18	2.01	0.15	-0.71	0.03	-1.84	3.03
13	-0.40	-1.30	2.58	2.08	3.89	-0.22	2.79	-0.05	0.67	0.73
14	-0.55	1.67	-1.25	1.42	4.15	0.53	2.31	-2.22	1.96	2.95
15	-3.10	0.63	4.73	2.20	0.62	1.87	0.14	3.67	-1.38	4.63
16	-1.05	4.30	4.03	3.40	1.71	1.02	-0.21	4.82	0.81	2.83
17	7.00	5.40	4.87	3.60	-6.99	5.93	6.06	0.63	-1.22	5.65
18	0.85	5.10	7.15	-1.12	-0.01	1.71	7.36	-1.57	-0.85	3.13
19	-2.05	10.07	5.92	3.67	-1.61	1.28	8.64	-2.45	0.06	2.62
20	1.90	5.67	7.10	1.65	4.92	1.23	14.31	-7.98	1.22	1.71
21	7.95	1.90	-4.35	13.57	-0.21	0.98	14.11	-12.20	2.39	1.59
22	7.55	3.13	2.08	3.47	2.10	1.16	7.26	-8.17	2.08	0.77
23	6.55	-1.73	4.68	1.35	4.76	1.51	10.01	-9.08	-0.45	1.90
24	-0.10	-4.00	7.60	3.47	4.41	-0.34	4.11	0.70	-1.34	1.77
25	3.00	7.57	0.45	1.20	7.01	1.39	-2.41	2.12	0.33	2.02
26	5.25	5.07	3.12	2.88	5.40	2.86	-6.23	4.70	1.45	1.79
27	4.90	5.83	-0.30	5.25	1.93	5.87	-0.76	1.88	0.84	2.05
28	4.25	3.97	1.35	5.32	5.47	2.31	-3.40	5.50	-0.58	1.99
29	-0.80	5.73	1.27	5.78	4.10	2.53	0.37	2.28	-1.60	1.26
30	-0.30	-0.63	2.80	2.90	0.45	3.57	-3.44	5.30	-1.89	0.76
31	-6.60	-11.27	0.62	2.53	3.46	2.99	-3.37	1.48	-0.00	0.90
32	-11.45	-25.13	8.30	2.58	2.51	7.24	-2.17	-0.32	-2.33	2.10
Avg.	-0.85	1.70	2.46	2.56	1.86	1.79	2.03	-0.31	-0.13	1.99

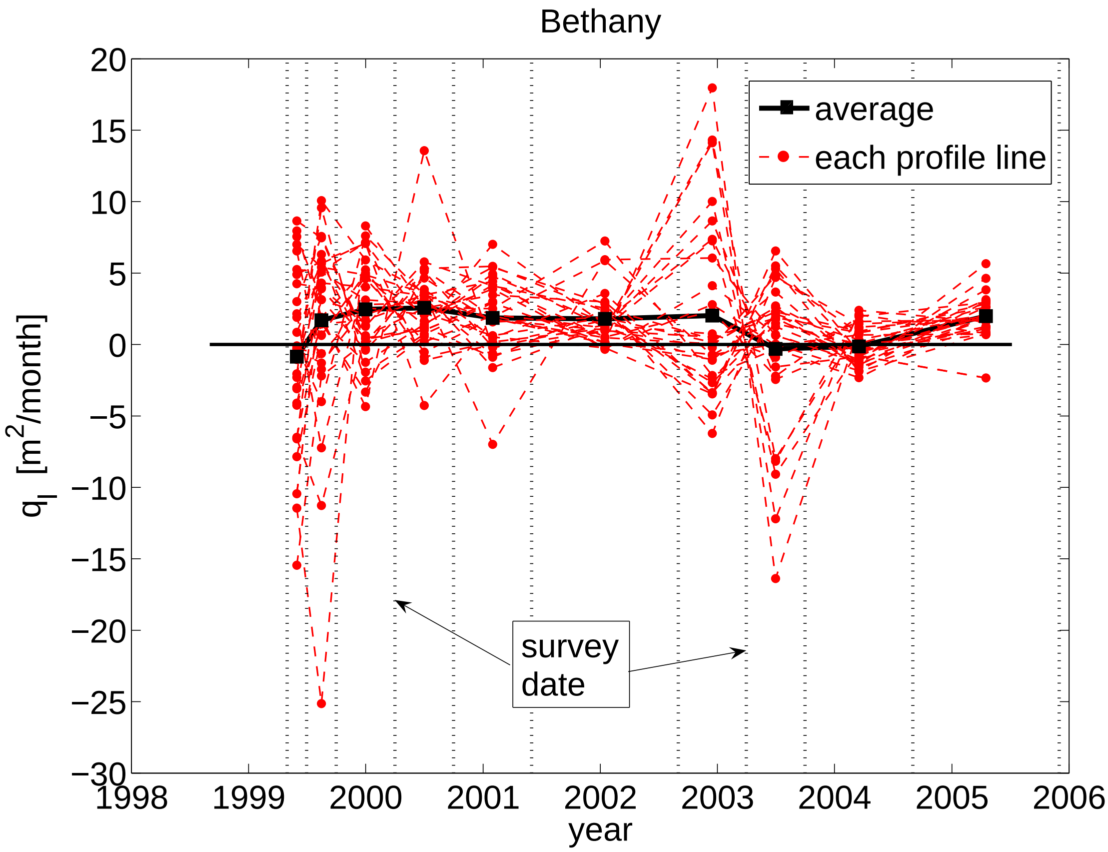


Figure 4.9: Temporal variation of q_ℓ ($\frac{m^2}{month}$) for Bethany.

The net cross-shore transport rates q_c computed using Equation (4.14) are presented in Tables 4.13 through 4.20 and Figures 4.10 through 4.13 in the same manner as for q_ℓ. The parameter a in Equation (4.14) is estimated by Equation (4.16) using the computed width ratios w_r and two different values for the shape parameter β. For every beach the values of q_c using $\beta = 0.5$ and $\beta = 1.0$ are compared. The comparison indicates that the influence of the shape parameter β on the results is negligible which is in accordance with the findings of Kobayashi and Han (1988).

Table 4.13: North Shore Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{0.5}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$
1	4.46	4.11	-2.14	-0.06	-2.96	1.77	5.40	6.19
2	-3.68	6.82	-4.57	-0.06	-3.55	2.90	5.79	0.16
3	-4.72	9.04	-3.81	2.04	-2.92	-0.05	13.10	-4.12
4	-2.19	5.01	-1.89	-1.32	-3.98	2.78	11.15	0.83
5	-2.69	5.42	-3.64	6.67	-4.15	-0.68	8.66	-1.02
Avg.	-1.77	6.08	-3.21	1.45	-3.51	1.34	8.82	0.41

Table 4.14: North Shore Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{1.0}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$
1	4.70	3.94	-1.72	0.34	-2.64	1.74	6.68	7.17
2	-3.75	6.86	-4.73	0.94	-3.04	2.81	5.39	3.99
3	-3.33	7.89	-3.89	1.46	-2.87	0.44	12.39	-2.92
4	-3.20	5.62	-2.68	-1.15	-4.23	4.53	9.98	2.92
5	-4.30	6.67	-3.13	4.64	-3.97	-0.51	8.91	-1.29
Avg.	-1.98	6.19	-3.23	1.24	-3.35	1.80	8.67	1.97

As shown in Figure 4.5, positive values for q_c denote offshore transport from zone 1 to zone 2 and negative values denote onshore transport from zone 2 to zone

Table 4.15: Rehoboth Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{0.5}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$
1	-1.48	2.59	-1.76	-1.82	-2.81	1.60	N/A	N/A
2	-5.04	5.88	-4.93	5.30	-1.75	-2.93	9.72	-4.32
3	5.13	-3.86	-3.76	5.07	-2.29	-1.42	7.93	-5.05
4	-4.20	0.43	-1.68	4.38	-3.14	2.24	7.88	-2.11
5	-2.96	4.28	-3.34	2.43	-1.56	1.32	6.64	-5.95
6	-6.74	3.96	-1.53	1.48	-1.23	0.82	7.15	-1.88
7	4.63	2.89	0.21	0.93	-1.44	-0.42	8.25	-2.33
8	-5.53	5.31	-2.21	1.56	-1.27	-0.85	4.80	-1.50
9	-5.08	4.52	-2.65	2.10	-1.78	-0.89	7.16	-4.28
10	-5.86	3.40	-1.22	-0.08	1.56	-1.65	6.33	-3.53
Avg.	-2.71	2.94	-2.29	2.13	-1.57	-0.22	7.32	-3.44

1. Similar trends for the cross-shore sediment transport rate q_c are experienced on all four beaches. Most noticeably, q_c shows apparent seasonal variations with much less variability among individual profile lines than observed for q_ℓ. The seasonal variation is on the order of 10 $\frac{m^2}{month}$. A general trend for offshore transport in winter and onshore transport in summer is noted for the whole data set. However, this seasonal variation is not completely symmetric since on average, the offshore transport rate surpasses the onshore transport rate leading to net offshore losses.

For the beach at North Shore two extremes for the average offshore transport rate can be seen in the winter of 2000 and 2003 with values of 6 $\frac{m^2}{month}$ and 9 $\frac{m^2}{month}$, respectively. These are again indicators of increased storm activity as pointed out in relation to Figure 4.7. In fact, the response of the cross-shore transport rates to periods of relatively calm wave conditions and highly energetic wave conditions is much clearer than for the longshore rates.

The tables and figures related to the Rehoboth cross-shore rates indicate very similar patterns of erosion and accretion, both in magnitude and direction,

Table 4.16: Rehoboth Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{1.0}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$
1	-2.96	2.97	-1.51	-1.02	-2.71	1.65	N/A	N/A
2	-5.16	7.16	-5.39	4.11	-2.27	-2.01	9.07	-5.00
3	3.58	-2.60	-2.88	4.17	-2.95	-1.14	8.66	-5.11
4	-4.42	3.22	-2.79	4.27	-4.52	2.64	8.91	-2.09
5	-3.13	5.51	-3.55	2.61	-2.09	0.94	8.74	-7.10
6	-5.25	4.93	-1.68	1.63	-1.66	1.05	8.22	-2.07
7	5.88	4.20	-0.12	1.14	-1.77	0.04	8.62	-1.04
8	-3.70	5.74	-2.31	2.26	-0.61	-1.07	5.98	-1.83
9	-5.44	5.88	-2.73	2.79	-1.39	-0.98	7.16	-3.33
10	-6.28	4.43	-1.90	0.02	2.56	-2.40	5.86	-3.11
Avg.	-2.69	4.14	-2.49	2.20	-1.74	-0.13	7.91	-3.41

compared to the data for the neighboring North Shore beach. Extremely large offshore transport rates are computed for the beach at Dewey immediately after the 1998 nourishment, which indicates nature's tendency to smooth out artificially created disturbances on coastlines and restore the natural equilibrium. The magnitude of q_c between the first and second survey at Dewey is between 7 $\frac{m^2}{month}$ and 19 $\frac{m^2}{month}$ for all individual profiles but in the subsequent time step the onshore transport rate for these profiles is only on the order of -5 $\frac{m^2}{month}$, which means that less than a half of the lost sediment in the foreshore zone returned following the seasonal cycle between summer and winter.

The portion of the Bethany data coinciding with the survey dates for the other three beaches follows similar cross-shore transport patterns indicating large offshore losses during the winters of 2000 and 2003 with values typically between 5 $\frac{m^2}{month}$ and 10 $\frac{m^2}{month}$. The additional data for 2004 and 2005 shows mainly onshore transport for all profile lines between the surveys in October 2003 and December 2005 which is a clear indication that no nourishment was placed at Bethany beach

Table 4.17: Dewey Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{0.5}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$	$t_9 - t_{10}$
1	7.58	-4.00	7.09	-4.43	2.66	-2.36	3.00	7.67	0.41
2	9.34	-7.38	8.56	-4.66	4.80	-1.48	-1.58	6.10	-3.77
3	7.24	-4.04	3.60	-2.04	2.16	-0.81	-0.63	7.55	-3.79
4	8.95	-2.52	7.18	-4.40	-0.01	-2.15	0.44	9.18	-4.62
5	12.22	-3.50	7.38	-5.83	-1.34	-2.46	1.73	6.05	4.07
6	11.44	-4.84	7.08	-4.49	-2.30	-2.38	2.07	10.99	-3.70
7	12.11	-1.34	-5.31	-1.35	1.40	-2.96	2.38	7.78	1.53
8	13.02	-4.77	7.34	-7.14	1.44	-2.86	2.00	9.76	-5.27
9	10.74	2.65	3.65	-5.81	3.53	-3.60	2.28	5.32	4.70
10	15.32	-5.97	7.55	-4.63	1.90	-3.56	2.34	6.40	2.04
11	13.68	-3.35	3.21	-4.91	-1.08	-2.67	-1.09	9.34	-4.50
12	13.34	-3.20	4.56	-4.11	0.70	-2.74	-2.09	9.39	-4.26
13	15.66	-4.69	6.86	-6.93	3.19	-2.87	2.08	5.33	3.67
14	17.09	-5.18	8.37	-6.12	-1.24	-2.47	-1.92	7.49	1.54
15	14.24	-5.12	3.91	-3.55	2.70	-2.93	1.94	5.78	-2.30
16	13.51	-4.19	7.43	-3.89	-0.98	-2.60	-0.68	9.63	-5.49
17	14.23	-3.11	5.64	-5.01	0.63	-2.73	3.44	10.79	-7.17
18	12.18	-3.83	7.10	-5.95	1.09	-2.86	2.75	9.88	-3.91
Avg.	12.33	-3.80	5.62	-4.74	1.07	-2.58	1.03	8.02	-1.71

in 2005.

Overall, the computed values of q_ℓ and q_c are found to be on the same order of magnitude for all the beaches investigated. Hence, this study of Delaware beaches shows that alongshore and cross-shore rates of sediment transport must be considered in the modeling of volumetric beach changes. The ability of the present 2-line model to resolve the important seasonal variations inherent to beach profile changes clearly justifies its use instead of standard one-line models by giving improved insight into the physical processes shaping our beaches.

Table 4.18: Dewey Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{1.0}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$	$t_9 - t_{10}$
1	8.56	-5.00	7.98	-5.43	1.53	-2.46	4.13	7.05	2.51
2	10.67	-7.77	8.01	-3.86	3.79	-1.69	-1.34	7.35	-4.12
3	8.34	-4.19	4.89	-2.07	0.16	-0.89	-1.07	7.62	-4.14
4	9.51	-2.83	8.00	-4.99	-0.07	-1.89	-0.11	10.25	-3.87
5	13.21	-3.08	8.23	-5.88	-1.36	-2.29	1.55	8.17	4.81
6	13.39	-4.03	7.92	-4.59	-2.68	-1.89	1.94	13.06	-3.08
7	13.93	-1.00	-8.43	1.50	1.12	-2.30	1.75	8.34	2.72
8	15.22	-4.28	7.82	-6.32	1.87	-2.40	1.73	11.26	-6.50
9	13.71	2.10	4.47	-5.71	4.21	-3.06	2.70	5.48	6.85
10	17.13	-4.49	6.90	-4.46	3.27	-3.45	3.73	5.96	3.18
11	15.32	-2.57	2.56	-3.80	-0.17	-2.44	-2.34	9.77	-4.37
12	14.57	-2.83	5.55	-4.07	1.11	-2.62	-1.69	8.51	-3.74
13	17.42	-3.69	7.27	-6.52	3.22	-2.67	1.64	6.29	3.10
14	18.83	-4.96	8.40	-5.97	-1.00	-2.09	-1.80	8.45	2.49
15	14.53	-4.76	4.10	-2.98	2.20	-2.77	2.13	6.22	-2.89
16	13.44	-3.45	7.63	-4.22	0.21	-2.59	-0.58	9.17	-5.96
17	14.88	-4.06	6.13	-5.78	0.86	-2.38	3.48	10.86	-7.63
18	12.11	-4.06	7.32	-6.44	1.06	-2.79	2.48	10.50	-3.08
Avg.	13.60	-3.61	5.82	-4.53	1.07	-2.37	1.02	8.57	-1.32

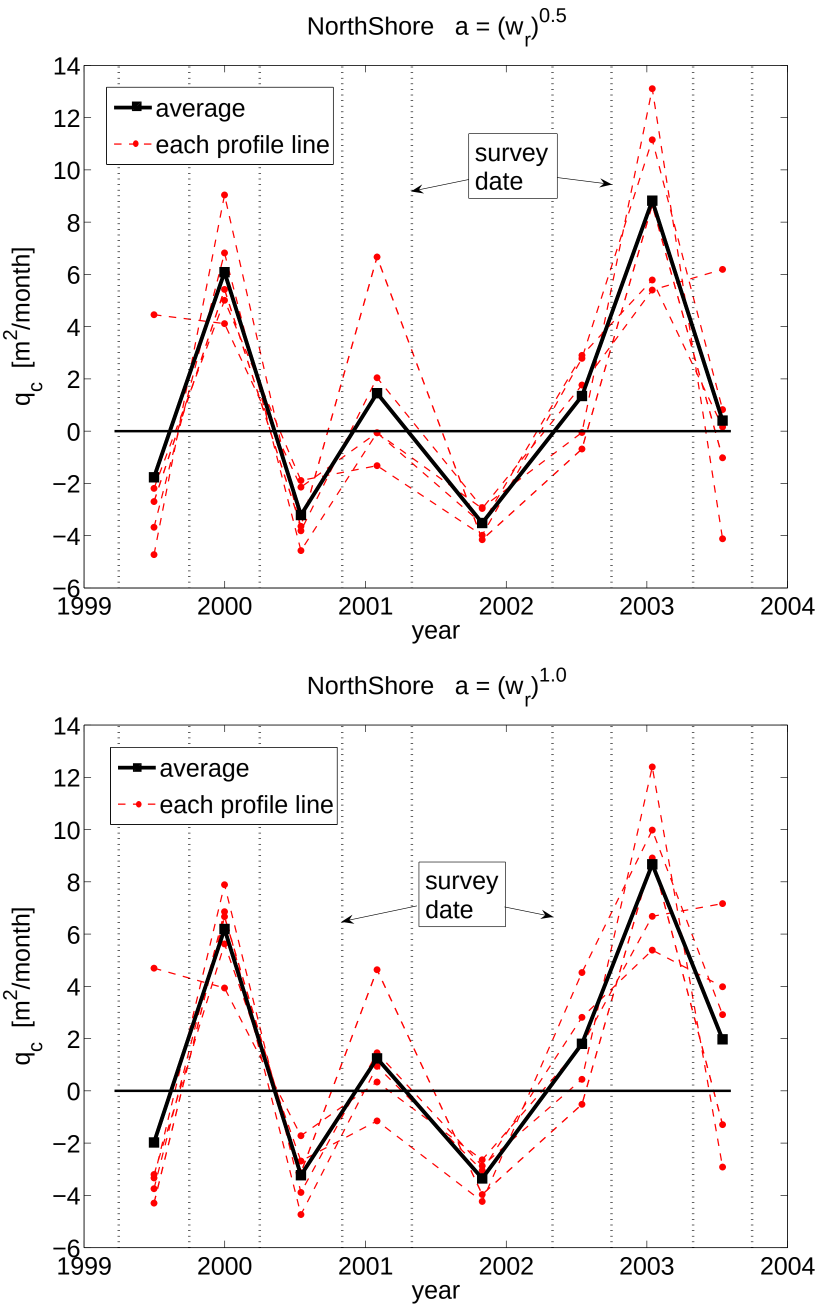


Figure 4.10: Temporal variation of q_c $(\frac{m^2}{month})$ for North Shore as estimated by the 2-line model using the width ratio w_r. The shape parameter β is 0.5 in the top panel and 1.0 in the bottom panel.

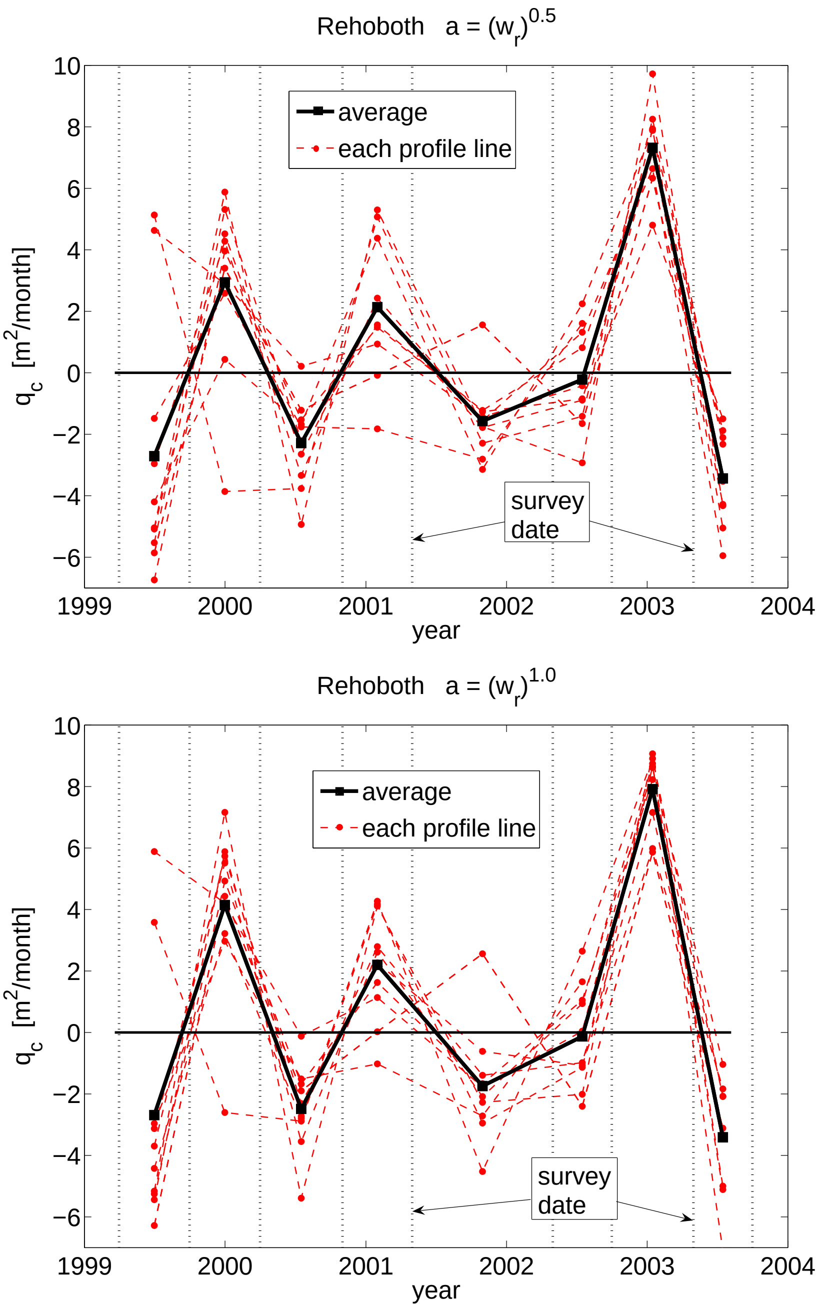


Figure 4.11: Temporal variation of q_c ($\frac{m^2}{month}$) for Rehoboth as estimated by the 2-line model using the width ratio w_r. The shape parameter β is 0.5 in the top panel and 1.0 in the bottom panel.

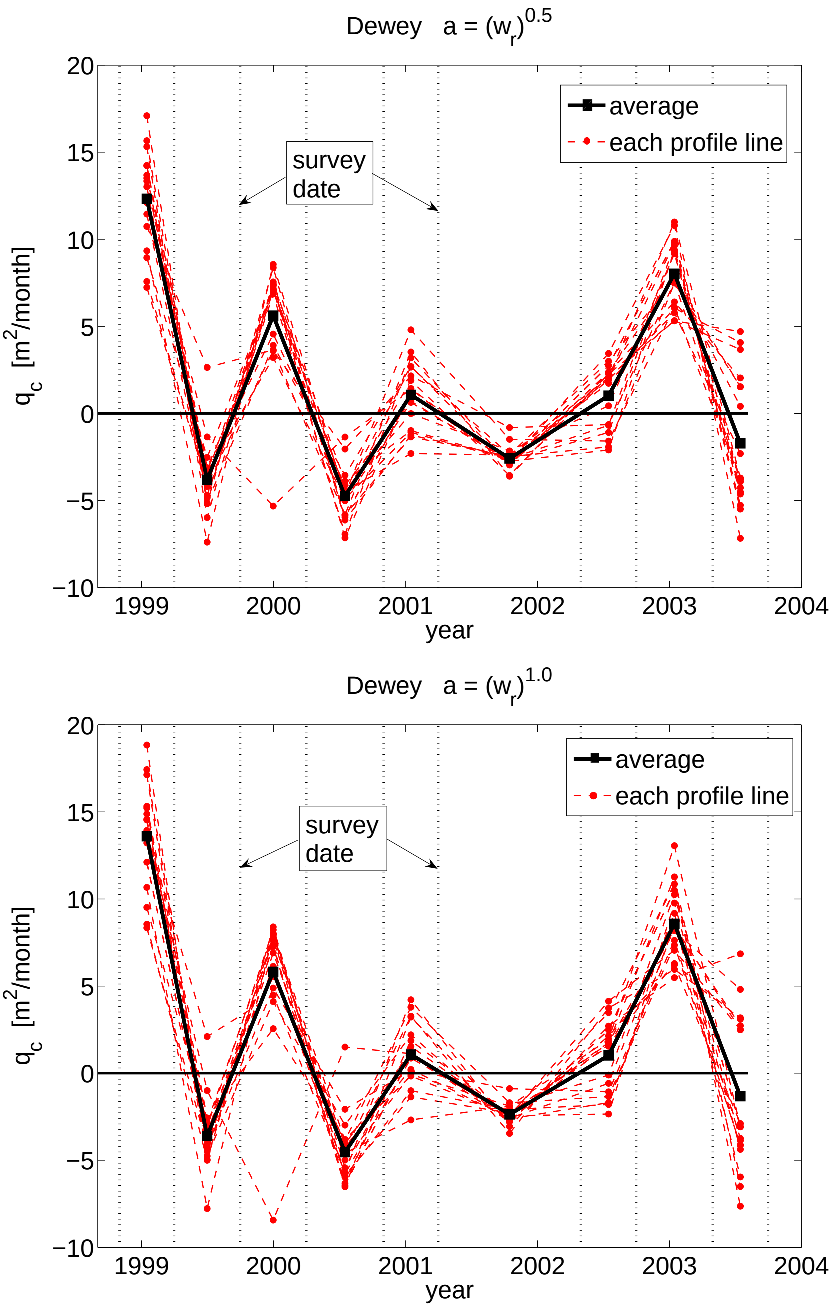


Figure 4.12: Temporal variation of q_c ($\frac{m^2}{month}$) for Dewey as estimated by the 2-line model using the width ratio w_r. The shape parameter β is 0.5 in the top panel and 1.0 in the bottom panel.

Table 4.19: Bethany Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{0.5}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$	$t_9 - t_{10}$	$t_{10} - t_{11}$
1	-9.96	-8.11	11.70	-10.93	0.86	N/A	N/A	N/A	-3.21	1.70
2	-9.56	-8.97	8.66	-6.52	0.66	N/A	N/A	N/A	-2.31	0.36
3	-12.76	-10.69	9.94	-7.88	-1.12	0.20	8.11	-7.09	-2.97	0.71
4	-16.46	-9.10	9.97	-8.42	0.82	-0.83	6.39	-2.68	-2.94	0.10
5	-12.37	-10.25	10.97	-6.73	1.15	0.07	8.58	-6.14	0.57	N/A
6	-8.88	-6.91	10.29	-8.19	-1.35	-0.72	5.88	-3.45	-2.57	0.81
7	-11.85	-7.85	8.53	-6.79	-0.52	-0.05	7.32	-3.96	-3.09	-0.12
8	-18.04	-7.08	7.62	-6.71	-0.76	-1.12	8.21	-4.78	-2.73	-0.22
9	-11.50	-6.85	7.72	-6.93	-0.68	-0.09	6.37	-5.12	-2.49	1.04
10	-7.98	-8.76	7.88	-6.26	0.39	-0.26	8.07	-5.45	-2.76	-2.24
11	-12.75	-6.19	8.79	-6.68	-0.36	-1.29	6.37	-2.57	-1.82	-1.04
12	-17.68	-2.56	8.75	-6.91	-0.39	-0.13	4.44	-2.04	-2.56	-2.12
13	-18.83	2.39	8.15	-7.33	-1.69	-0.43	5.85	-2.21	-1.55	-1.08
14	-12.27	-4.86	8.54	-5.23	-2.11	-0.61	5.91	-2.13	-3.10	-0.65
15	-7.69	-3.81	7.94	-5.54	-0.48	-1.35	5.40	0.41	-1.36	1.17
16	-9.39	-8.36	6.32	-5.72	N/A	0.19	5.69	0.85	-2.62	-0.00
17	-8.44	4.29	5.57	-4.97	-2.34	-3.57	5.56	2.69	-3.18	-2.78
18	-3.82	-11.01	4.09	-2.61	-1.07	-0.29	5.28	2.26	-2.62	-0.51
19	-5.28	-10.71	4.94	-6.24	1.74	-0.10	4.23	1.89	-3.06	-0.44
20	-5.61	-8.39	4.68	-4.74	-1.90	0.24	4.58	-3.01	-2.91	-0.11
21	-7.20	-7.82	6.95	-7.63	-2.10	1.68	4.67	-5.47	-1.99	-0.96
22	-2.59	-4.91	6.56	-4.99	-2.93	1.15	6.16	-4.21	-3.07	-0.31
23	6.46	-2.69	8.70	-6.03	-3.91	0.79	4.77	-2.69	-2.16	-1.58
24	7.73	-2.92	-1.78	-3.77	-2.93	1.61	4.78	-2.13	-2.51	-0.91
25	3.47	4.76	9.39	-7.03	-4.27	1.92	3.79	-2.27	-1.43	-1.70
26	0.37	-3.49	7.92	-6.17	-3.97	1.87	3.53	-1.87	-1.56	-1.50
27	-3.40	5.28	6.66	-7.17	-3.40	1.64	3.74	-0.70	-1.54	-1.98
28	-6.06	-2.50	4.02	-5.87	-2.36	1.21	6.50	0.50	-2.55	-1.52
29	-3.42	-4.19	8.38	-7.06	-3.22	1.97	2.75	0.34	-2.34	-1.26
30	-0.23	-3.43	6.59	-7.22	-2.62	-0.06	6.85	1.39	-2.55	-1.32
31	-3.73	7.44	5.62	-9.20	-2.34	1.26	3.43	0.15	-2.38	-1.63
32	-5.88	16.01	2.26	-9.35	-2.50	3.18	-4.39	1.27	-0.98	-2.83
Avg.	-7.36	-4.13	7.26	-6.65	-1.47	0.27	5.29	-1.94	-2.32	-0.74

Table 4.20: Bethany Net Cross-Shore Transport Rate q_c ($\frac{m^2}{month}$) for $a = (w_r)^{1.0}$

Prof.	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$	$t_4 - t_5$	$t_5 - t_6$	$t_6 - t_7$	$t_7 - t_8$	$t_8 - t_9$	$t_9 - t_{10}$	$t_{10} - t_{11}$
1	-12.27	-7.25	11.79	-10.70	1.53	N/A	N/A	N/A	-3.38	1.18
2	-11.15	-7.45	8.04	-6.38	0.51	N/A	N/A	N/A	-2.47	0.63
3	-13.64	-10.01	9.85	-7.04	-1.00	0.15	7.36	-5.66	-3.09	0.98
4	-17.19	-7.69	11.69	-9.45	1.26	-0.71	6.40	-2.04	-3.29	0.75
5	-12.84	-8.27	10.57	-6.59	1.75	0.09	12.29	-9.52	0.81	N/A
6	-10.37	-6.46	11.49	-8.31	-0.93	-0.70	5.64	-3.16	-2.81	1.23
7	-9.89	-6.14	8.56	-6.52	-0.72	0.50	6.20	-3.44	-2.87	0.47
8	-21.79	-7.61	7.66	-5.58	-0.38	-0.66	7.56	-4.35	-2.86	0.29
9	-13.18	-6.70	8.79	-7.12	-0.65	0.15	6.13	-4.54	-2.55	1.19
10	-9.01	-8.41	8.30	-5.48	0.21	-0.02	8.20	-5.00	-3.01	-1.31
11	-12.81	-5.81	7.98	-5.44	-0.40	-0.96	6.55	-2.79	-1.43	-0.63
12	-17.19	-4.15	9.76	-6.87	0.06	-0.10	4.28	-2.03	-2.96	-1.45
13	-18.91	2.11	8.71	-6.88	-0.85	-0.48	6.45	-2.22	-1.41	-0.93
14	-12.38	-4.49	8.26	-4.90	-1.18	-0.49	6.43	-2.63	-2.66	0.01
15	-8.36	-3.68	8.97	-5.06	-0.34	-0.95	5.43	1.21	-1.66	2.17
16	-9.63	-7.41	7.21	-4.97	N/A	0.42	5.64	1.91	-2.44	0.62
17	-6.80	5.56	6.70	-4.13	-3.97	-2.18	6.98	2.83	-3.47	-1.46
18	-3.61	-9.83	5.74	-2.87	-1.07	0.11	6.98	1.90	-2.81	0.22
19	-5.70	-8.67	6.14	-5.50	1.42	0.17	5.99	1.39	-3.05	0.09
20	-5.18	-7.12	6.27	-4.37	-0.79	0.52	7.78	-4.80	-2.64	0.27
21	-5.29	-7.36	5.91	-4.37	-2.15	1.92	8.07	-8.40	-1.42	-0.58
22	-0.79	-4.16	7.06	-4.17	-2.43	1.43	7.89	-6.15	-2.57	-0.13
23	7.95	-3.09	9.77	-5.73	-2.83	1.14	7.05	-4.76	-2.26	-1.15
24	7.72	-3.87	0.02	-2.95	-1.88	1.53	5.75	-1.96	-2.83	-0.49
25	4.19	6.62	9.50	-6.74	-2.55	2.26	3.20	-1.75	-1.35	-1.20
26	1.69	-2.23	8.70	-5.45	-2.63	2.58	1.98	-0.70	-1.20	-1.06
27	-2.21	6.69	6.59	-5.90	-2.94	3.06	3.56	-0.24	-1.34	-1.49
28	-5.01	-1.52	4.35	-4.56	-1.00	1.78	5.66	1.85	-2.69	-1.03
29	-3.61	-2.81	8.68	-5.67	-2.23	2.58	2.84	0.89	-2.72	-0.95
30	-0.29	-3.56	7.13	-6.66	-2.53	0.63	6.19	2.42	-2.92	-1.17
31	-5.11	5.08	5.75	-8.67	-1.61	1.88	2.73	0.46	-2.38	-1.44
32	-8.46	10.34	4.13	-8.76	-1.93	4.81	-4.88	1.20	-1.51	-2.36
Avg.	-7.54	-3.73	7.81	-6.06	-1.04	0.68	5.74	-2.00	-2.35	-0.28

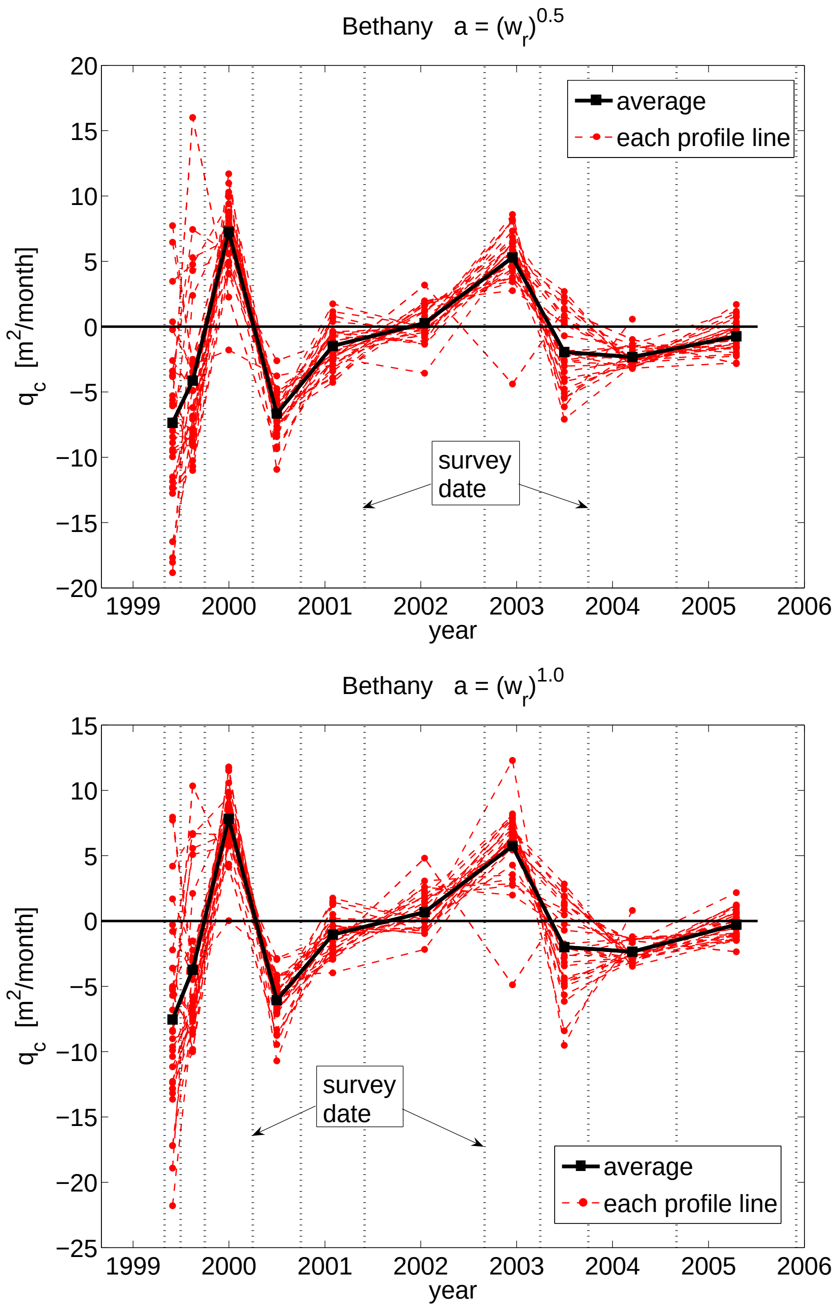


Figure 4.13: Temporal variation of q_c $(\frac{m^2}{month})$ for Bethany as estimated by the 2-line model using the width ratio w_r. The shape parameter β is 0.5 in the top panel and 1.0 in the bottom panel.

Chapter 5

SUMMARY AND CONCLUSION

The Delaware shoreline is eroding on the order of 1 m per year. In order to preserve beach front property and prevent the decline of tourist related revenues, the state government chose beach nourishment as the favorable option to conserve the present state of the shoreline of Delaware's coastal communities. This costly intervention to counteract the ongoing erosion calls for the capability to accurately predict local sediment transport quantities. In a previous study Garriga and Dalrymple (2002) showed that the one-line models based on the "CERC formula" for longshore sediment transport cannot be used to predict the shoreline evolution of the Delaware beaches accurately. The shortcomings of these one-line models can be attributed to their inherent limitations and the fact that cross-shore sediment transport has been neglected.

In the present study a different approach has been chosen to estimate the longshore and cross-shore sediment transport rates for the Delaware beaches at North Shore, Rehoboth, Dewey and Bethany. The Delaware Department of Natural Resources and Environmental Control (DNREC) has provided data from semi-yearly beach profile surveys collected after placement of the 1998 nourishments on these beaches. For North Shore, Rehoboth and Dewey the last available survey was conducted in October 2003 which was followed by a nourishment project in February 2005. The data for Bethany includes two additional surveys in September 2004 and December 2005. It has to be noted that for Bethany beach there was no nourishment project on record in 2005, which explains these continued survey efforts. Most of the surveys are spaced half a year apart in an effort to capture characteristic "summer" and "winter" profiles. The alongshore spacing of the measured profile lines is about 150 m but may reach up to 350 m for some rare cases. The measured data points cover a cross-shore distance of about 700 m on average, extending form the dune line to a water depth of roughly 11 m below mean sea level (MSL). The surrounding large scale bathymetry is presented along with water surface elevation measurements comprising tidal constituents as well as contributions of storm surges and wave setup. Together with measured wave data from NOAA buoy 44009 this information is used to interpret seasonal and yearly profile changes extracted from the measured survey data. These water level and wave data are analyzed for the duration of 1998 to 2006.

The profile evolution has been analyzed by extracting the portion of each profile line between the landward and seaward limits beyond which no significant movement of sediment is assumed. The water depth below MSL at the seaward limit is about 7 m. This allows for the separation of the active profile into two zones divided at the intersection point between two successive profile measurements. For the most part, this comparison of profiles surveyed at two consecutive time levels yields a clearly defined intersection point alleviating the determination of the respective landward and seaward areas of significant profile change. The more problematic cases occurred when no clear intersection point was evident. However, these cases are associated with very little profile change and negligible cross-shore transport.

The presented erosion and accretion patterns show distinct seasonal variations with a general increase in sediment volume in the landward zone during the spring and summer months accompanied by losses in the seaward zone. The reverse process is noted between most time levels during the fall and winter months which is related to the changing wave conditions and water surface elevations. In addition, the influence of nourishment activity is noticeable in view of increased cross-shore sediment losses in the landward zone following the nourishment in 1998.

A linear regression analysis correlating the measured shoreline displacement Δx and the areas of profile change, A_L and A_S, in the landward and seaward zone between successive time levels shows similar trends for all four beaches. A_L and Δx are quantities associated with the foreshore region of the profile which includes the surf zone whereas A_S is related to the offshore part outside the surf zone under normal conditions. The correlation coefficient R and a best fit regression line of the form $y = m \cdot x$ have been computed for several combinations of the three parameters.

A_S and A_L show a fair negative correlation ($-0.85 < R < -0.67$) which reflects onshore - offshore seasonal profile changes. However, m takes on values between -0.9 and -0.4 indicating longshore losses of sediment of up to 60 %. The correlation between A_L and Δx yields the highest values for R ($0.84 - 0.91$) because these two foreshore quantities strongly depend on each other. The slope of the corresponding linear regression line takes on dimensional values between 2.1 m and 3.4 m which are similar to the water depth $|z_3|$ at the intersection point between the landward and seaward zones. A_S and Δx also show a fair negative correlation ($-0.80 < R < -0.54$) but the degree of correlation is less, indicating that offshore profile change is less related to shoreline change.

Poor correlation is obtained between the corresponding values of $(A_L + A_S)$ and Δx ($0.14 < R < 0.59$). Furthermore, the slope m of the regression line exhibits dimensional values between 0.2 m and 1.4 m. The application of one-line models for beach evolution assumes that the total change in sediment volume per unit alongshore length is equal to the vertical extent $(z_L - z_S)$ of the profile from the dune crest to the depth of closure multiplied by the horizontal shoreline change [i.e. $(A_L + A_S) = (z_L - z_S) \cdot \Delta x$]. The measured values of $(z_L - z_S)$ are on the order of 10 m which is much larger than the values for m which are on the order of 1 m. This clearly shows that for this data a one-line model cannot be used to predict sediment transport rates accurately due to the dominant effect of seasonal variations.

Hence, a simple two-line model is employed to estimate the longshore and cross-shore sediment transport rates q_ℓ and q_c from the measured beach profile changes. In a study by Kobayashi and Han (1988) this method has proven successful in predicting erosion at the bend of a gravel causeway. The present work shows the application of a two-line model to estimate sediment transport rates as the inversion of the erosional and accretional areas obtained from measured profile changes.

The computed longshore transport rate q_ℓ is related to alongshore sediment loss ($q_\ell > 0$) or gain ($q_\ell < 0$). A large variability among individual profile lines is noted ranging between positive and negative values of 10 $\frac{m^2}{month}$ and -10 $\frac{m^2}{month}$. Large alongshore losses do not occur continuously but rather intermittently and not necessarily during the same time intervals for all beaches. This shows that both temporal and spatial variability in the longshore sediment transport rate is experienced on Delaware beaches. Longshore transport rates averaged over all profile lines are on the order of 1 $\frac{m^2}{month}$. This magnitude is consistent with the measured yearly sand bypassing volume recorded at Indian River Inlet and the length scale of the Delaware coastline south of Indian River Inlet.

Larger than average values can be related to measured wave data, local water surface elevation and nourishment projects introducing additional material for transport into the system. However, it may be hard to quantify the magnitude of each influence. For example, the rate of longshore sediment loss at Dewey beach immediately after the nourishment in the fall of 1998 exceeds the average by a factor of six. While this can be directly related to the loss of material from the new beach fill it must be noted that in the winter of 1999 three consecutive months with average significant wave heights H_s above the 7-year mean value have been recorded along with an extreme average surge elevation η_{surge} in February 1999 during lower than average tidal elevations. The combination of all these factors may have led to the extremely high longshore sediment transport rate. Another example is the extreme value of q_ℓ in the winter of 2003 where Rehoboth, Dewey and Bethany all experienced three times larger than average longshore sediment loss rates. No nourishment had taken place the year before but wave conditions have been fairly energetic with six consecutive monthly averages of the significant wave height H_s well above the 7-year mean including the second highest monthly average in March 2003.

In general, over the entire time period under investigation, longshore sediment loss is greater than longshore gain for all the beaches, consistent with the ongoing erosion of the Delaware coastline.

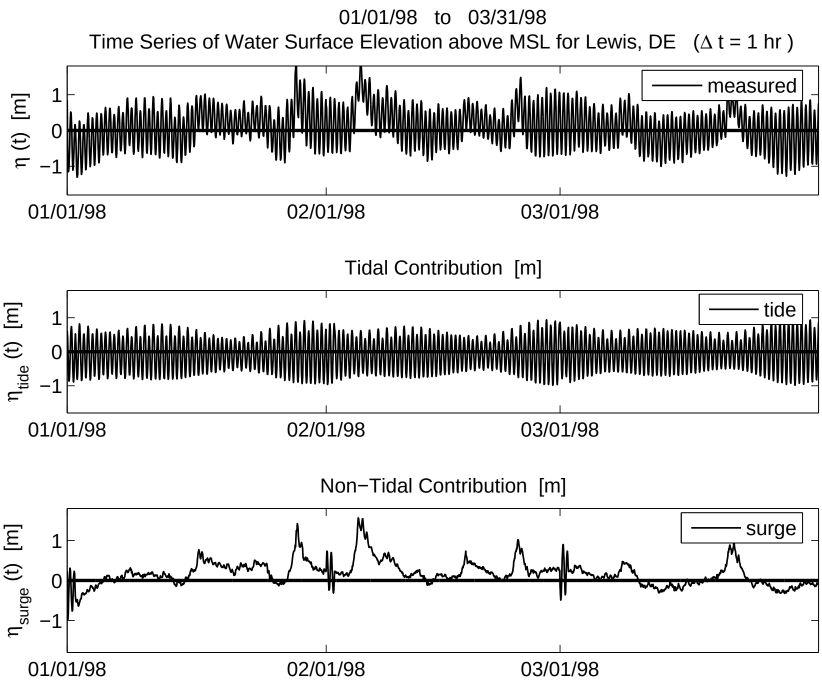
In contrast to q_ℓ, the rate of cross-shore sediment transport q_c estimated by the two-line model is more related to seasonal profile changes with $q_c > 0$ denoting offshore transport and $q_c < 0$ denoting onshore transport. The variability of q_c among individual profile lines is also much less. Seasonal variations in q_c range from values of $-10\ \frac{m^2}{month}$ to $10\ \frac{m^2}{month}$ with a general trend for offshore transport during winter and onshore transport during summer. However, seasonal variations in q_c are asymmetric, meaning that offshore transport rates in winter are not necessarily balanced by onshore transport rates in summer. This leads to a net loss of sediment offshore (and then alongshore in this two-line model) adding to the erosional trend of Delaware's Atlantic coastline. The magnitude and direction of the cross-shore transport rate can also be related to wave activity, water level elevation and preceding nourishment projects. The increased values of the longshore transport loss presented in the two examples above, are accompanied by extreme positive cross-shore transport rates denoting offshore loss of sediment during the same time intervals.

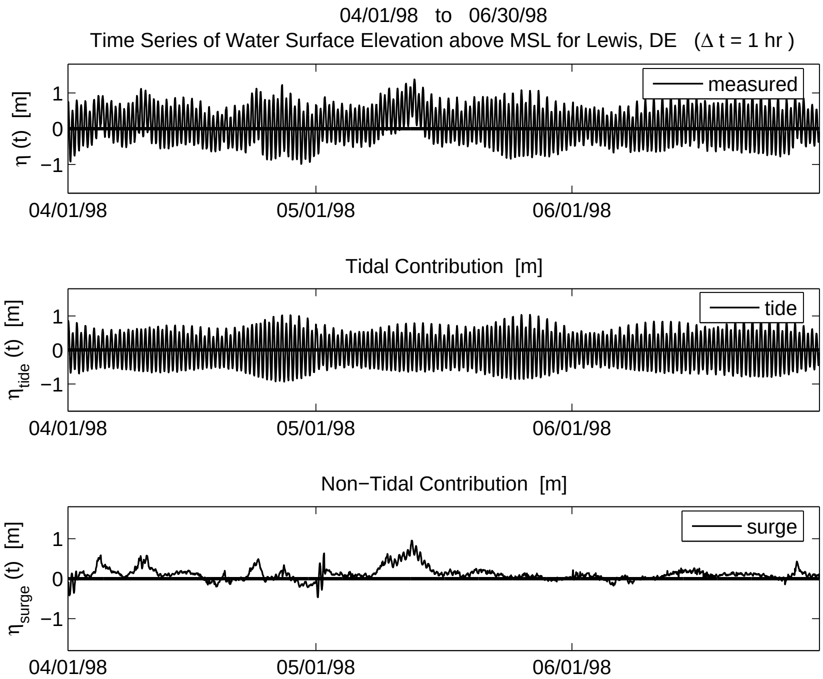
Since q_ℓ and q_c have been determined to be of the same order of magnitude, it can be concluded that both longshore and cross-shore sediment transport are important and should not be neglected when modeling volumetric beach changes. The application of a two-line model to invert measured profile data has proven to yield additional physical insight into longshore and cross-shore sediment transport processes on Delaware beaches.

Future work may comprise an extension of this investigation using survey data covering a longer period of time. The data and results presented herein will be used in a subsequent study to create and calibrate a two-dimensional numerical sediment transport model based on the existing cross-shore model CSHORE (Kobayashi et al., 2005).

Appendix A

HOURLY TIDE DATA

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04/01/98
05/01/98
06/01/98
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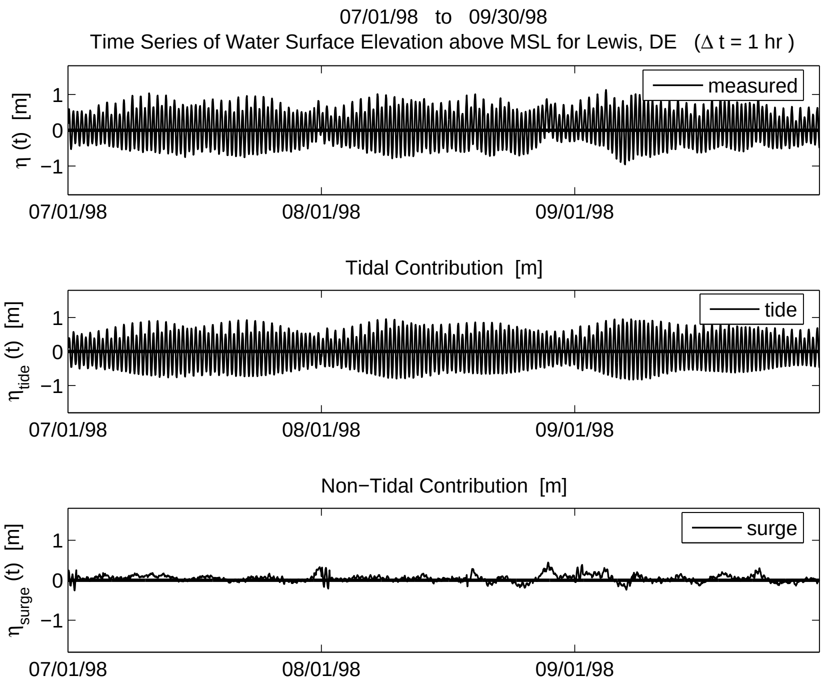
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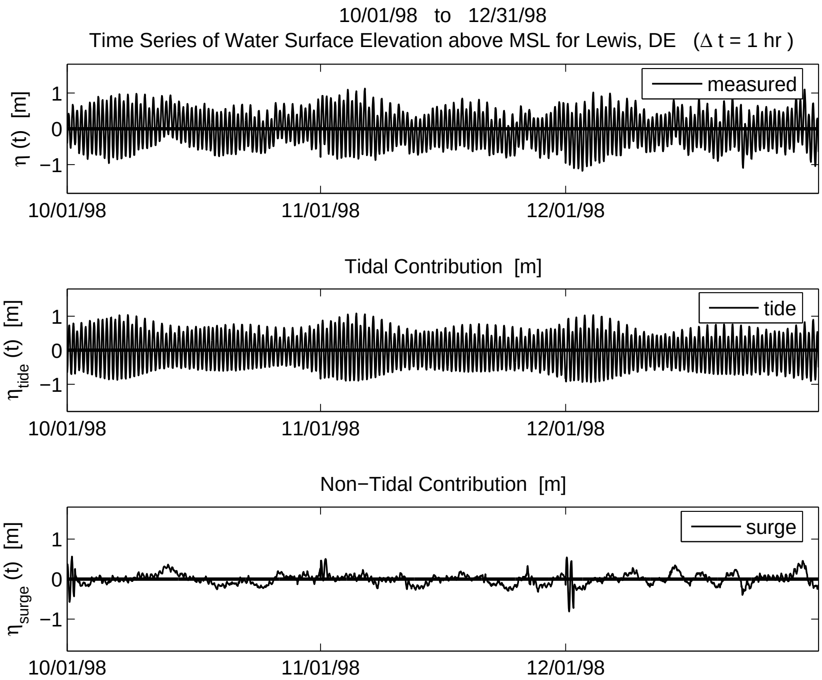
09/01/98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tide
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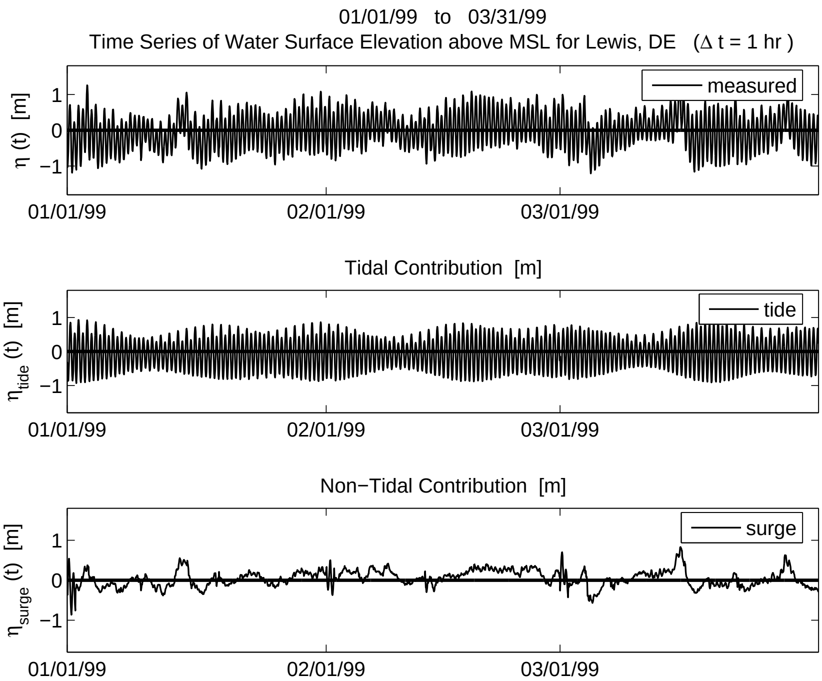
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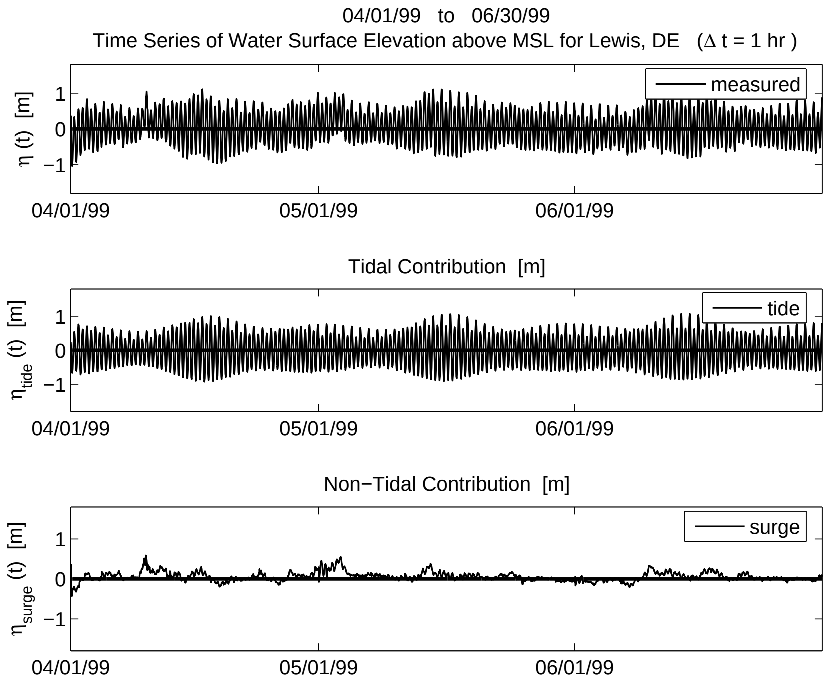
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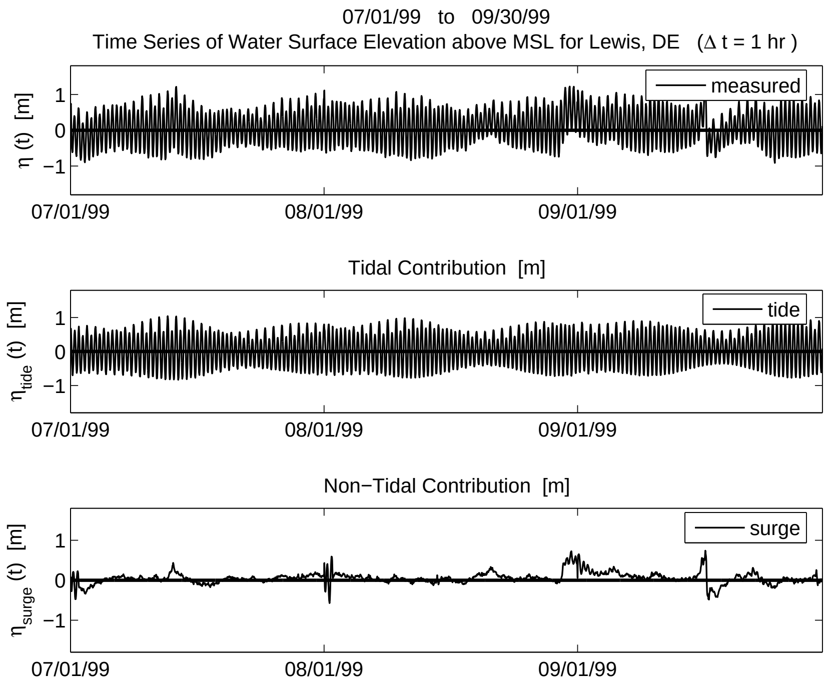
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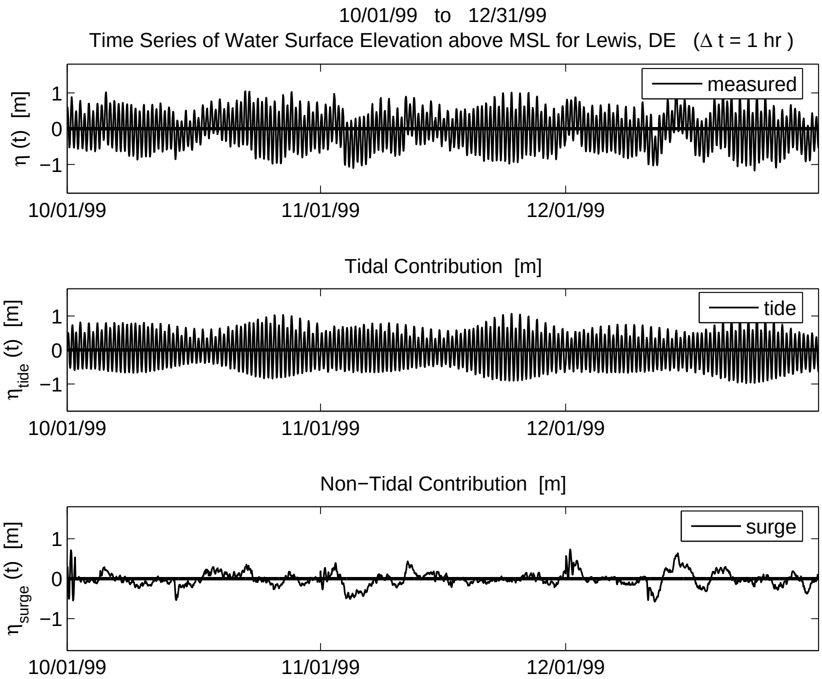
surge
η_surge (t) [m]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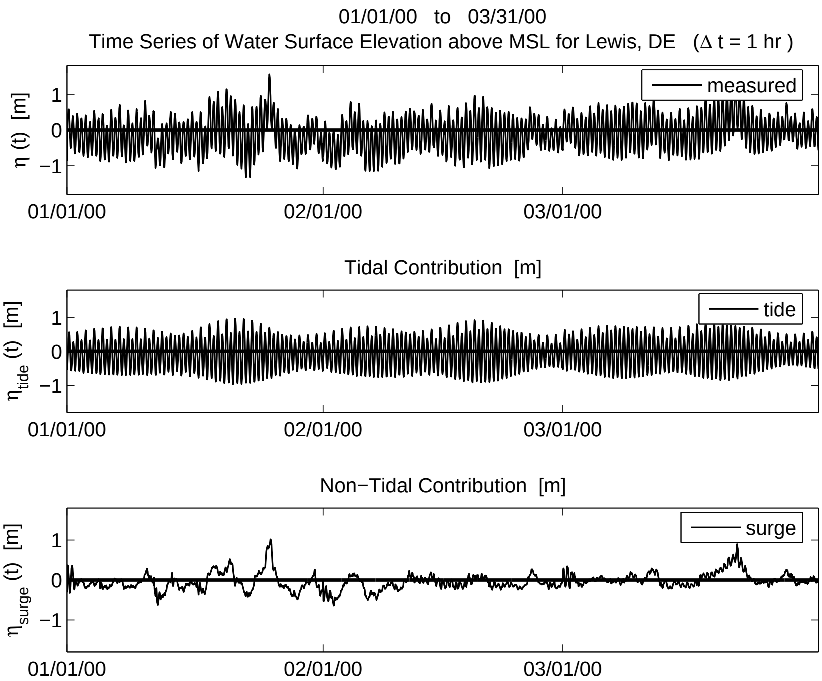
η_surge (t) [m]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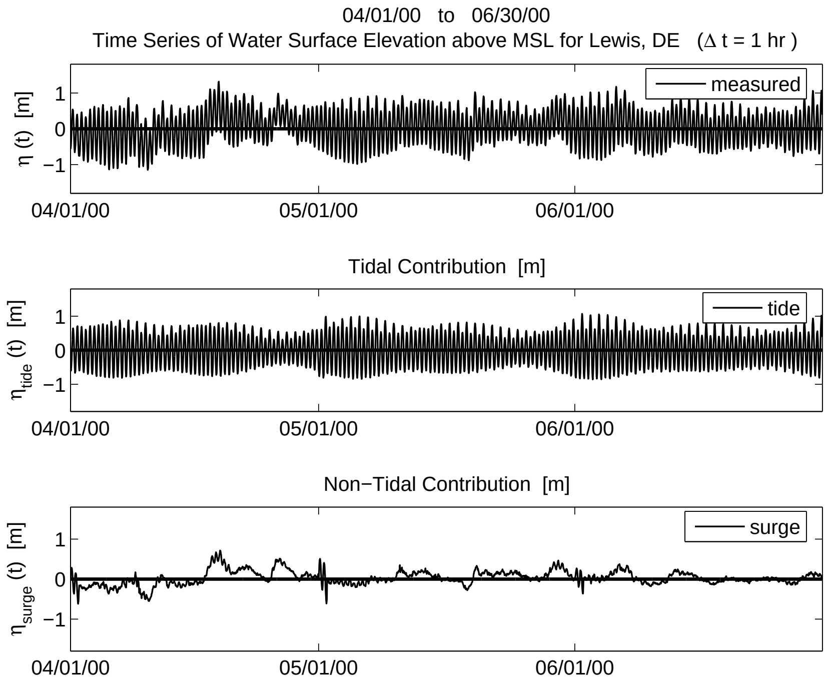
surge
η_surge (t) [m]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04/01/00
05/01/00
06/01/00
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η_tide (t) [m]
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04/01/00
05/01/00
06/01/00
Non−Tidal Contribution [m]
surge
η_surge (t) [m]
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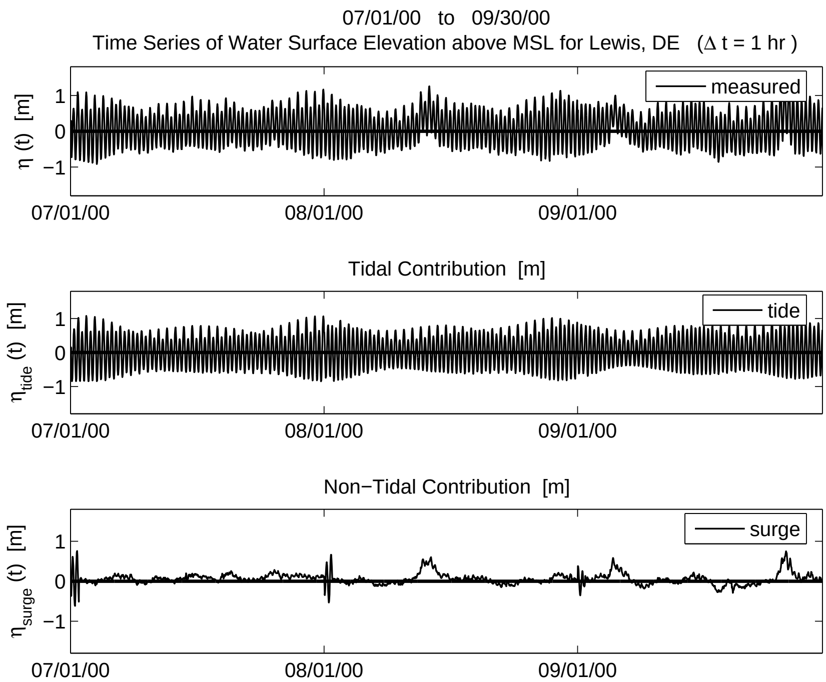
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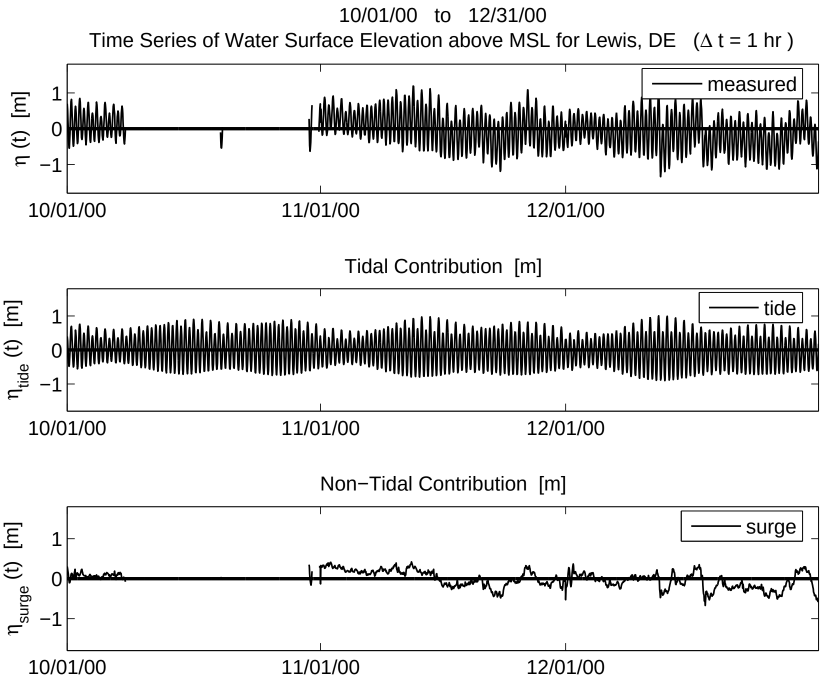
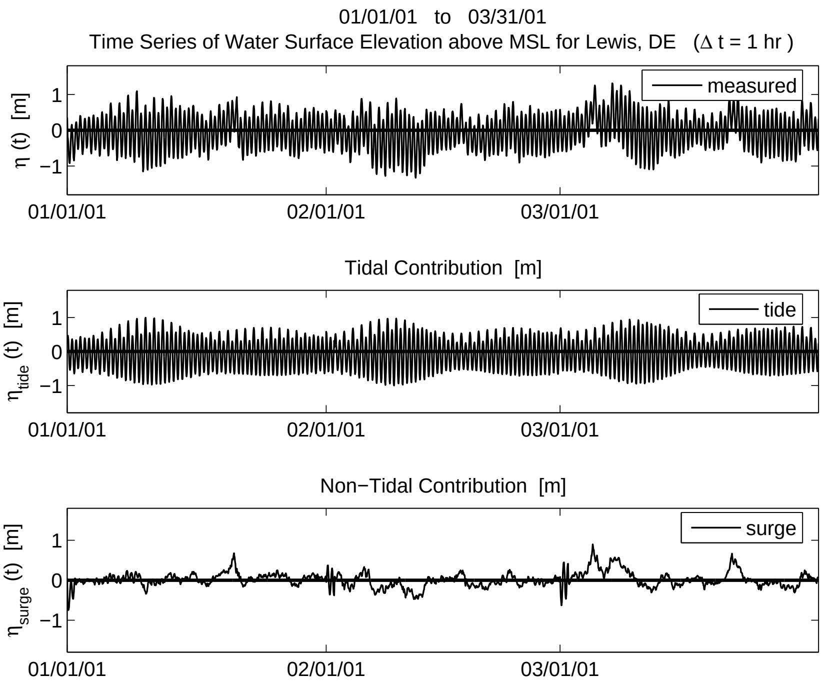
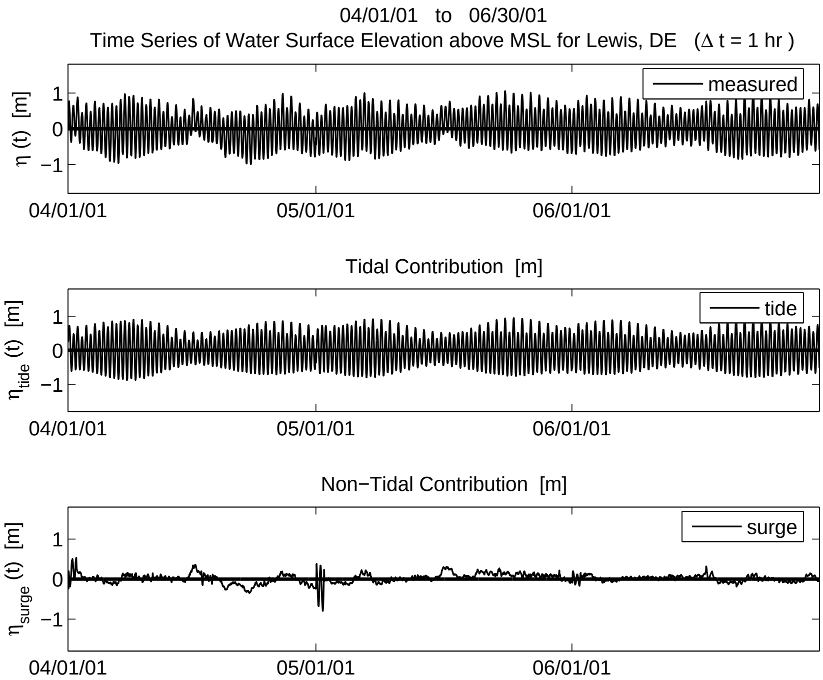
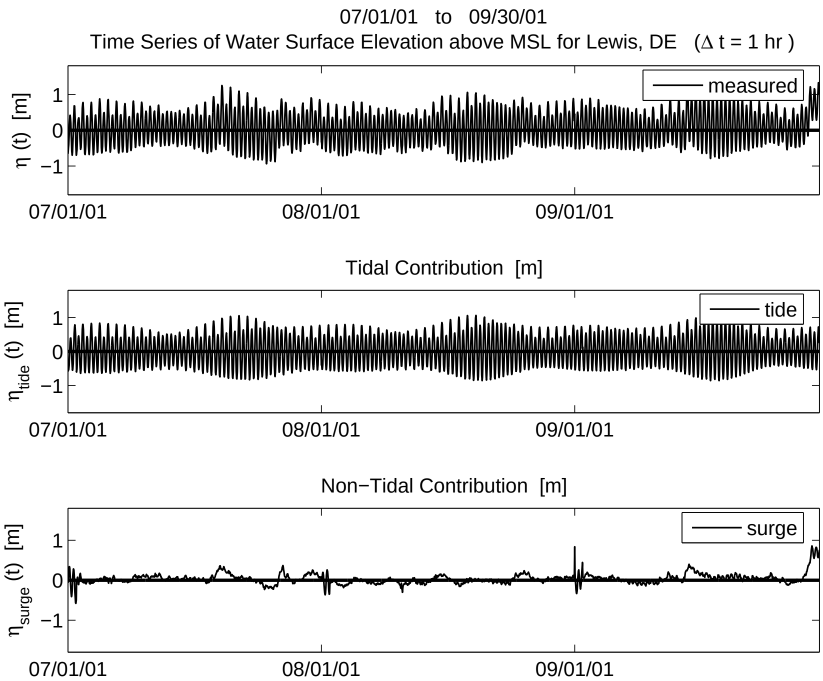
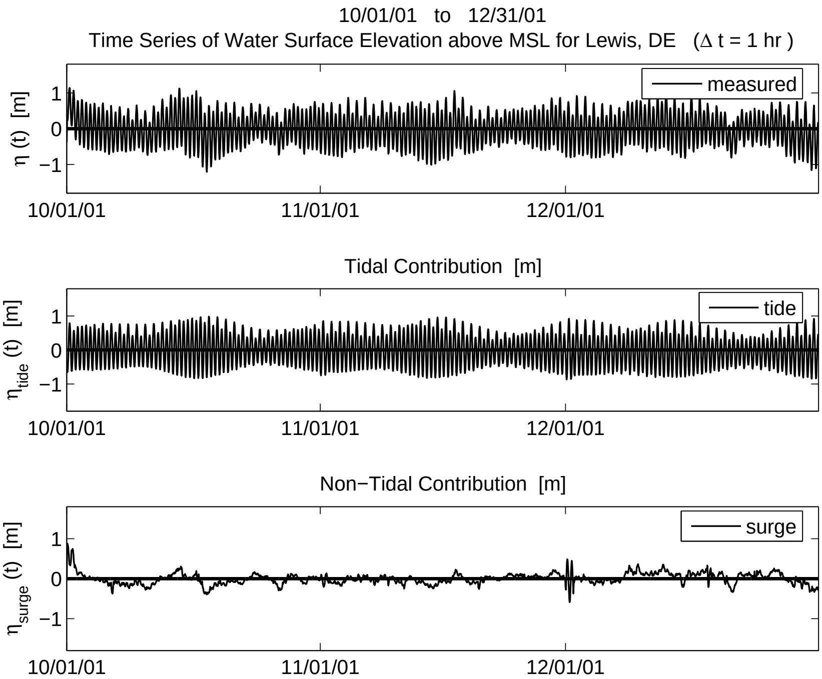
08/01/00
09/01/00

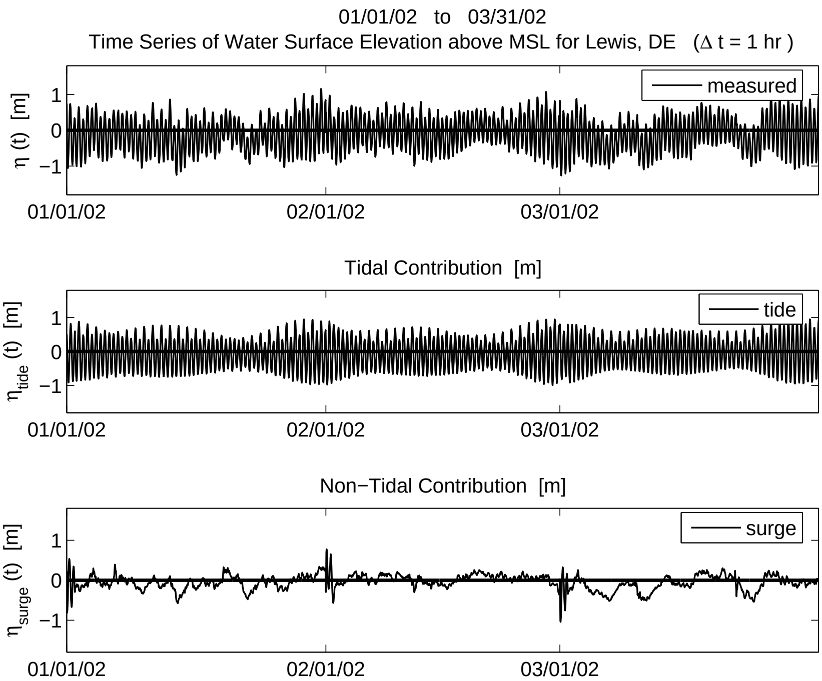

10/01/00 to 12/31/00
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
Tidal Contribution [m]
η_tide (t) [m]
tide
Non−Tidal Contribution [m]
η_surge (t) [m]
surge
1
0
−1
10/01/00
11/01/00
12/01/00

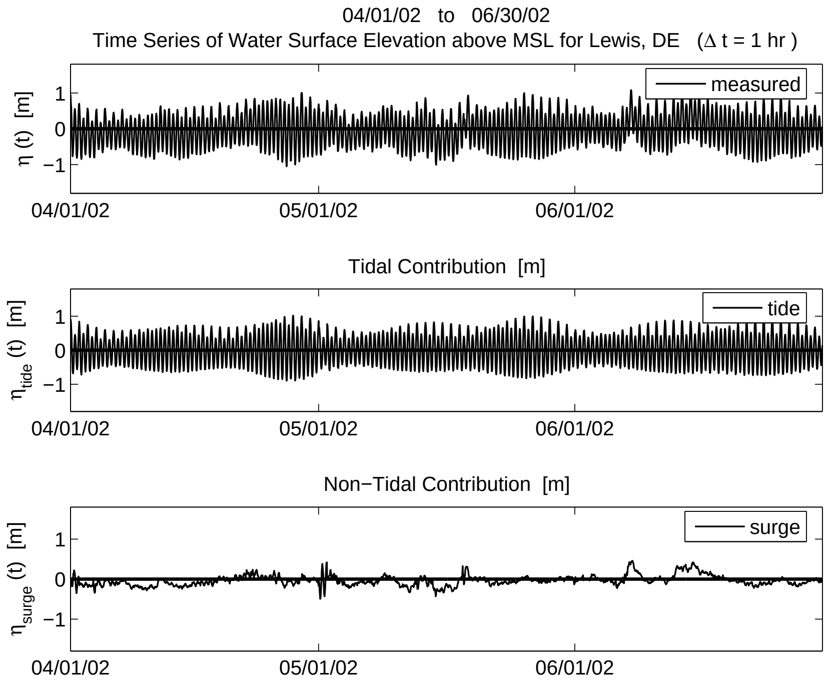

01/01/01 to 03/31/01
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
Tidal Contribution [m]
η_tide (t) [m]
tide
Non−Tidal Contribution [m]
η_surge (t) [m]
surge
1
0
−1
01/01/01
02/01/01
03/01/01

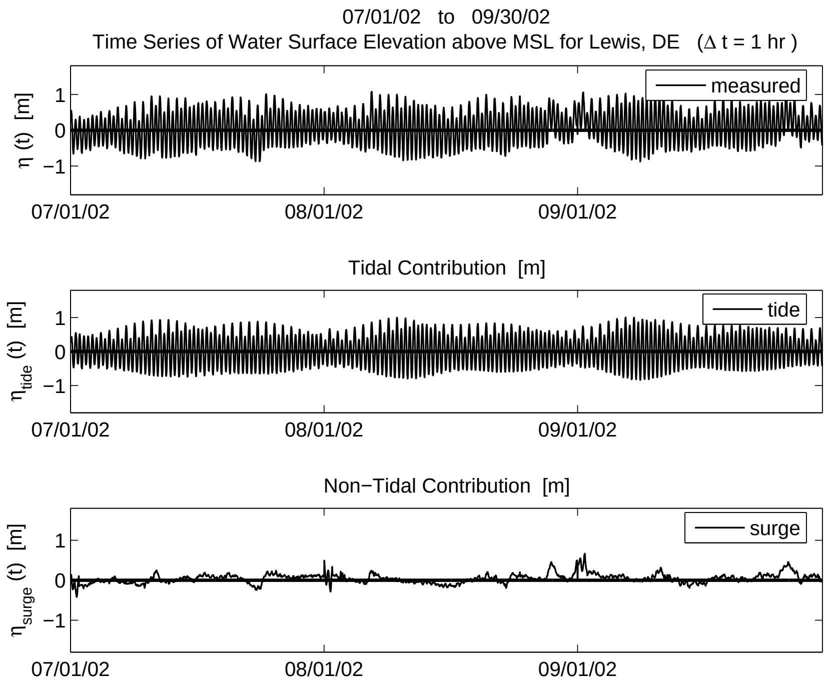

04/01/01 to 06/30/01
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
04/01/01
05/01/01
06/01/01
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

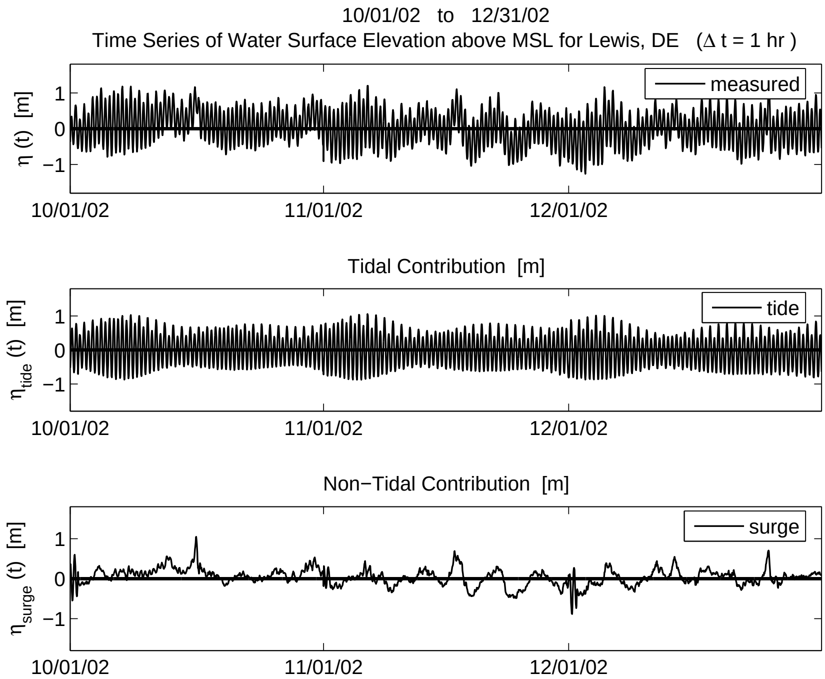

07/01/01 to 09/30/01
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
07/01/01
08/01/01
09/01/01
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

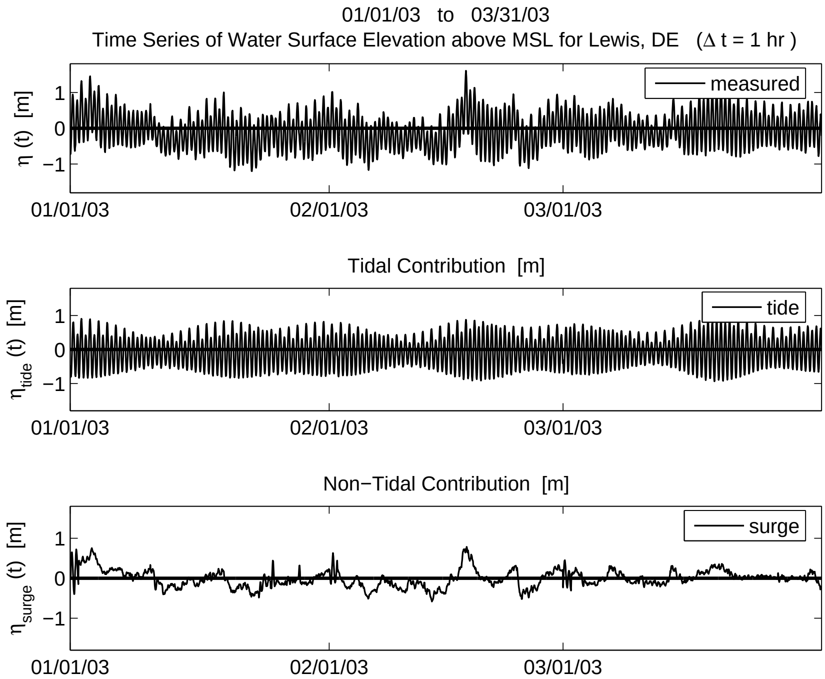

10/01/01 to 12/31/01
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
10/01/01
11/01/01
12/01/01
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

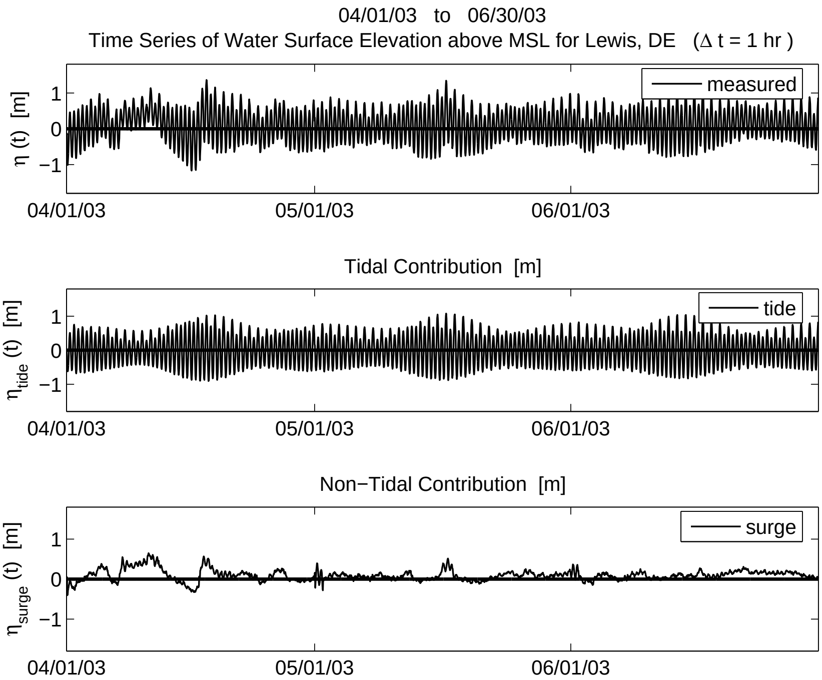

01/01/02 to 03/31/02
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
01/01/02
02/01/02
03/01/02
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

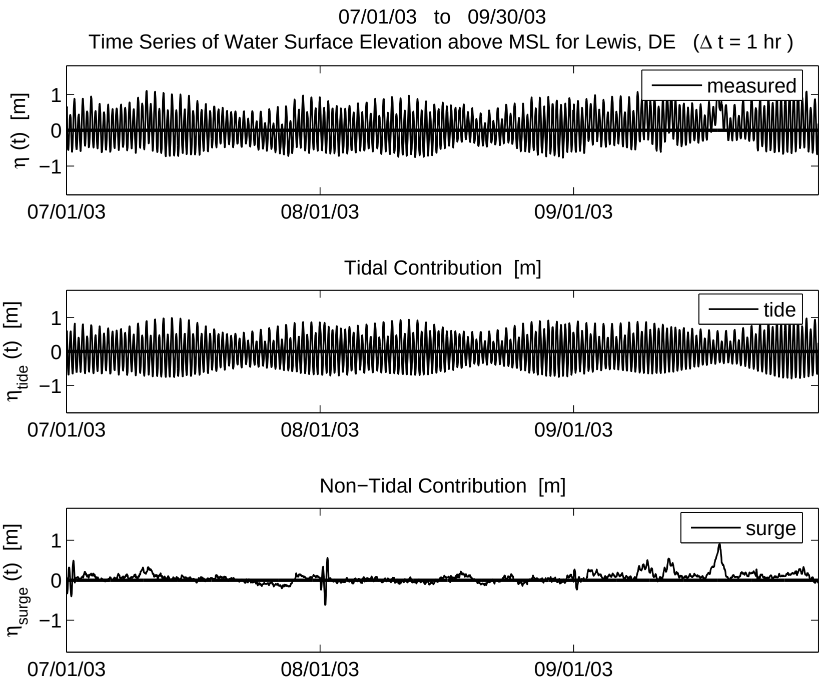

04/01/02 to 06/30/02
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
04/01/02
05/01/02
06/01/02
Tidal Contribution [m]
tide
η_tide (t) [m]
1
0
−1
04/01/02
05/01/02
06/01/02
Non−Tidal Contribution [m]
surge
η_surge (t) [m]
1
0
−1
04/01/02
05/01/02
06/01/02

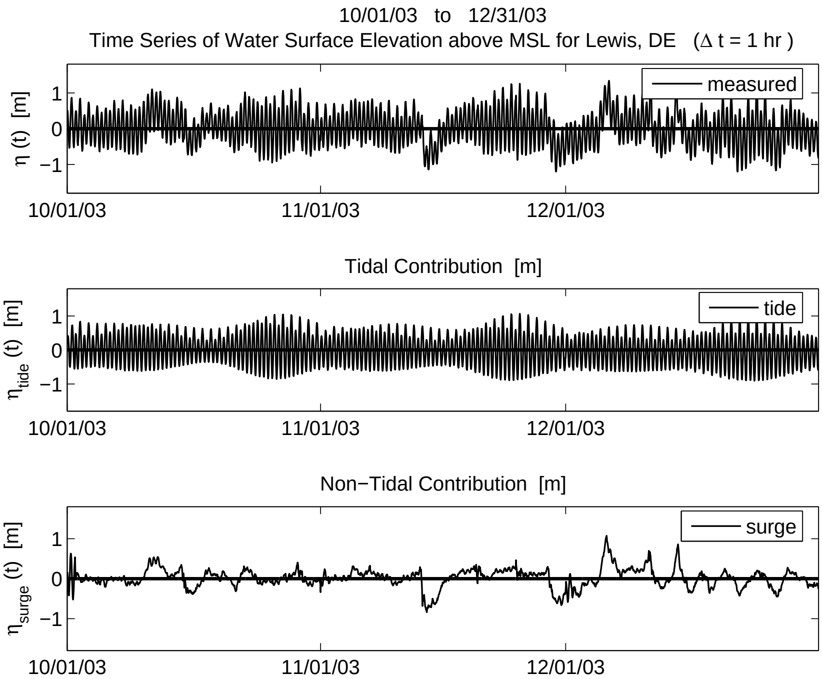

07/01/02 to 09/30/02
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
07/01/02
08/01/02
09/01/02
Tidal Contribution [m]
tide
η_tide (t) [m]
1
0
−1
07/01/02
08/01/02
09/01/02
Non−Tidal Contribution [m]
surge
η_surge (t) [m]
1
0
−1
07/01/02
08/01/02
09/01/02

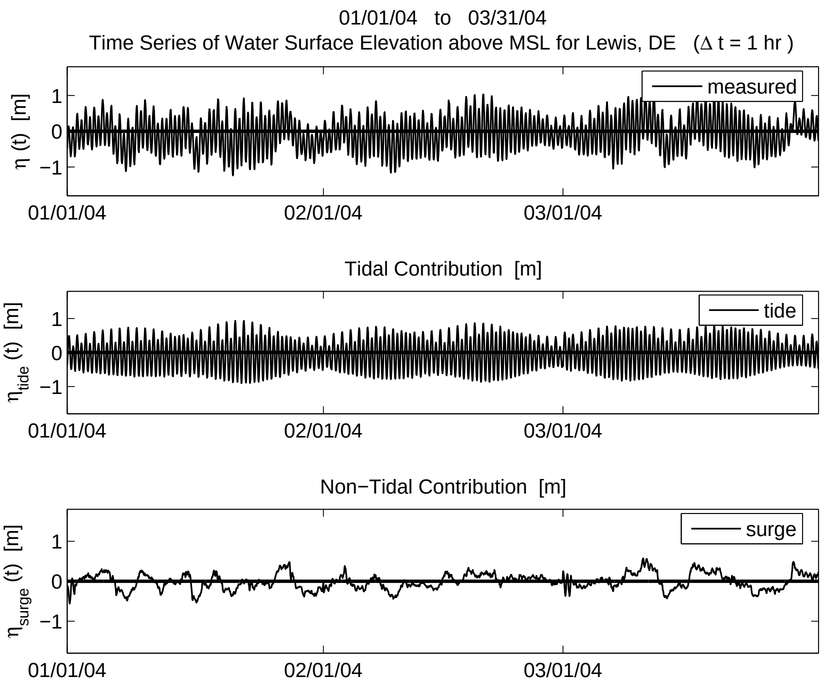

10/01/02 to 12/31/02
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
Tidal Contribution [m]
η_tide (t) [m]
tide
Non−Tidal Contribution [m]
η_surge (t) [m]
surge
10/01/02
11/01/02
12/01/02
1
0
−1

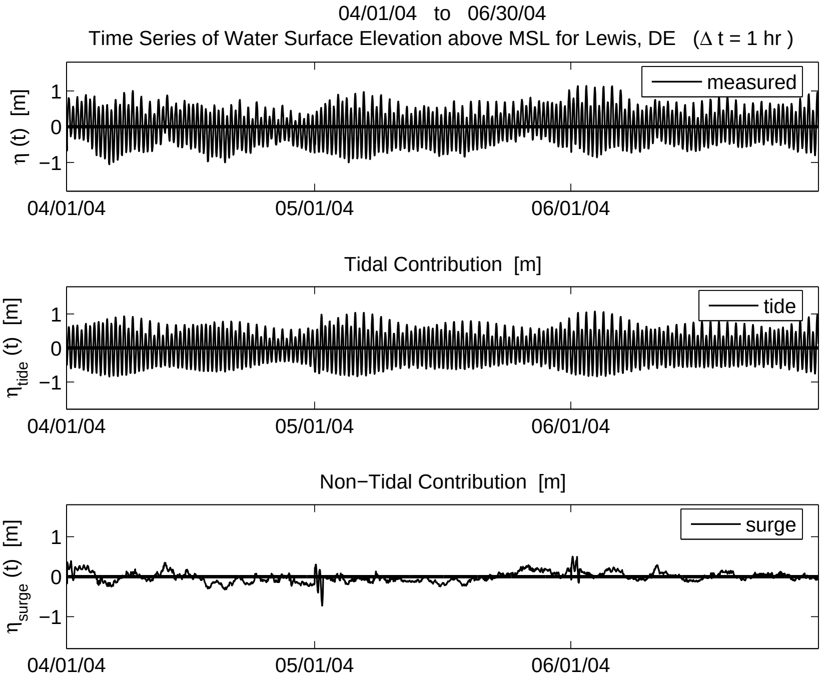

01/01/03 to 03/31/03
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
Tidal Contribution [m]
η_tide (t) [m]
tide
Non−Tidal Contribution [m]
η_surge (t) [m]
surge
01/01/03
02/01/03
03/01/03
1
0
−1

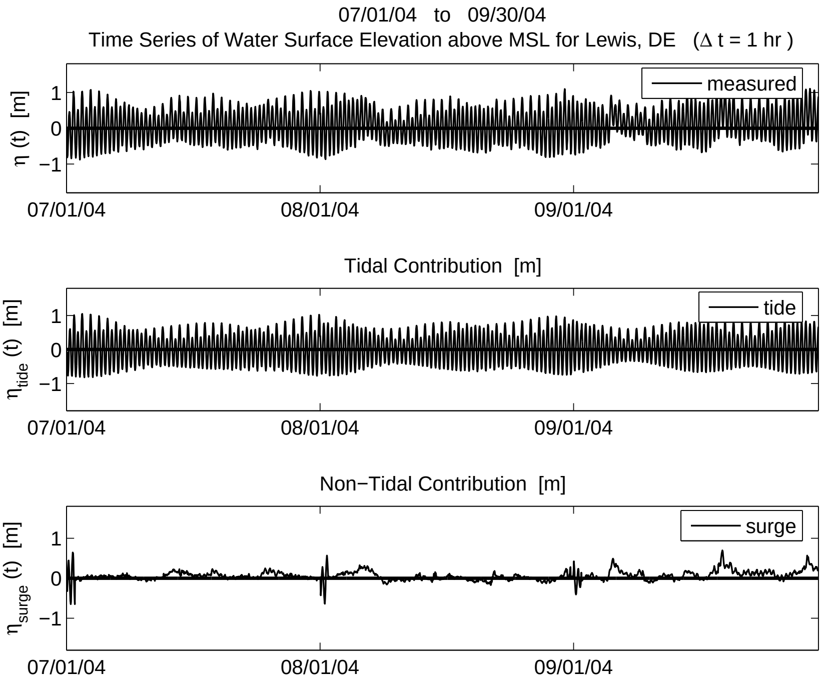

04/01/03 to 06/30/03
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
04/01/03
05/01/03
06/01/03
Tidal Contribution [m]
tide
η_tide (t) [m]
1
0
−1
04/01/03
05/01/03
06/01/03
Non−Tidal Contribution [m]
surge
η_surge (t) [m]
1
0
−1
04/01/03
05/01/03
06/01/03

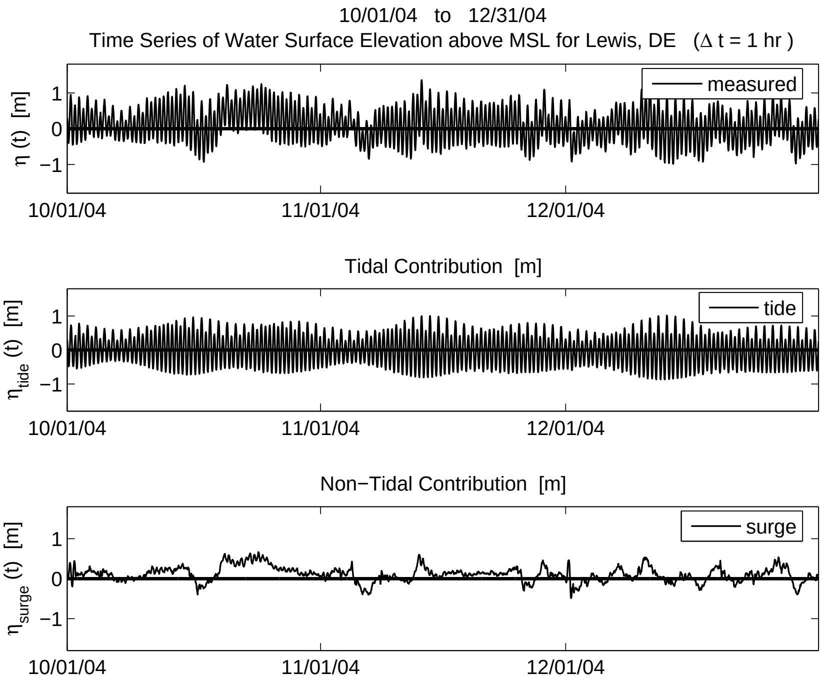

07/01/03 to 09/30/03
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
07/01/03
08/01/03
09/01/03
Tidal Contribution [m]
tide
η_tide (t) [m]
1
0
−1
07/01/03
08/01/03
09/01/03
Non−Tidal Contribution [m]
surge
η_surge (t) [m]
1
0
−1
07/01/03
08/01/03
09/01/03

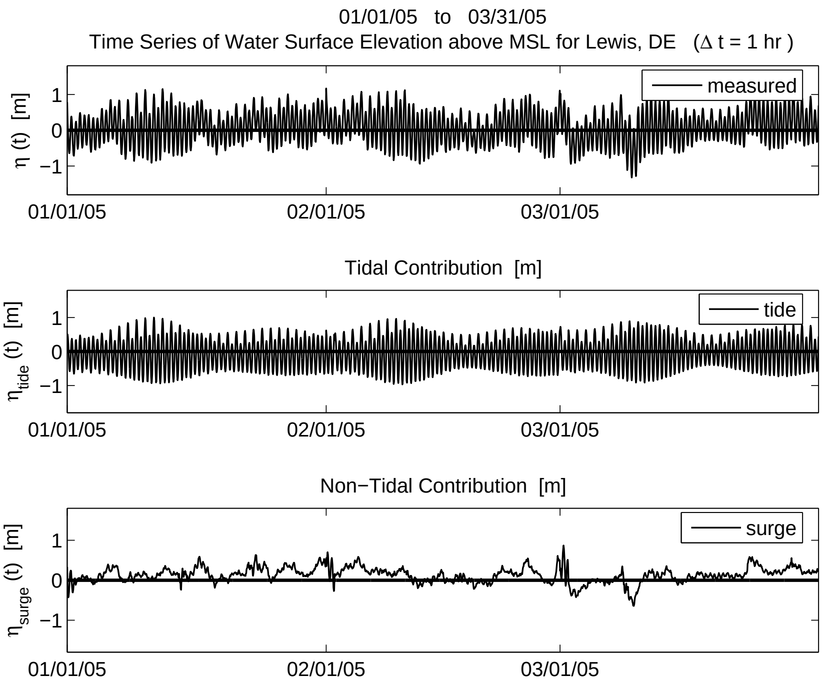

10/01/03 to 12/31/03
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
10/01/03
11/01/03
12/01/03
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

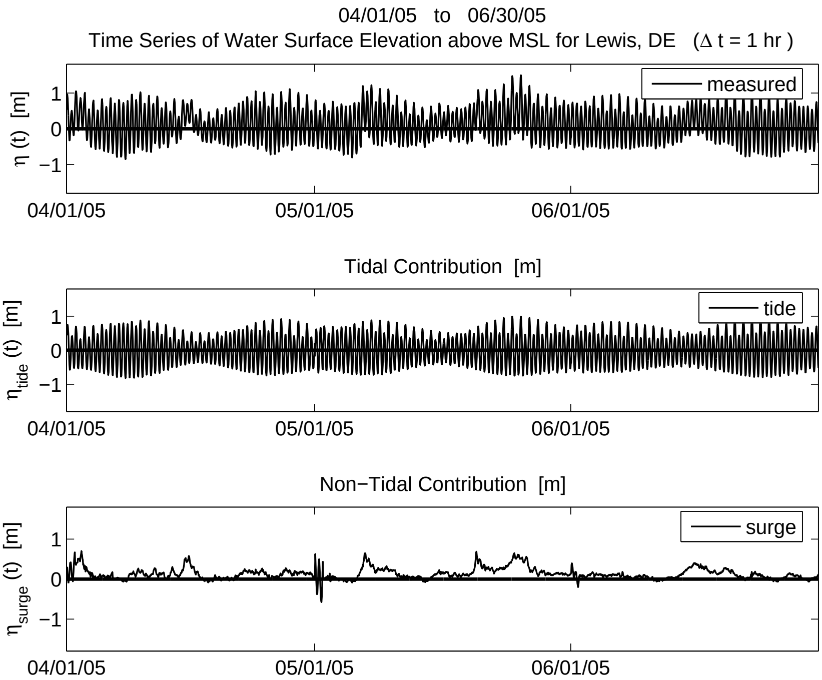

01/01/04 to 03/31/04
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
1
0
−1
01/01/04
02/01/04
03/01/04
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

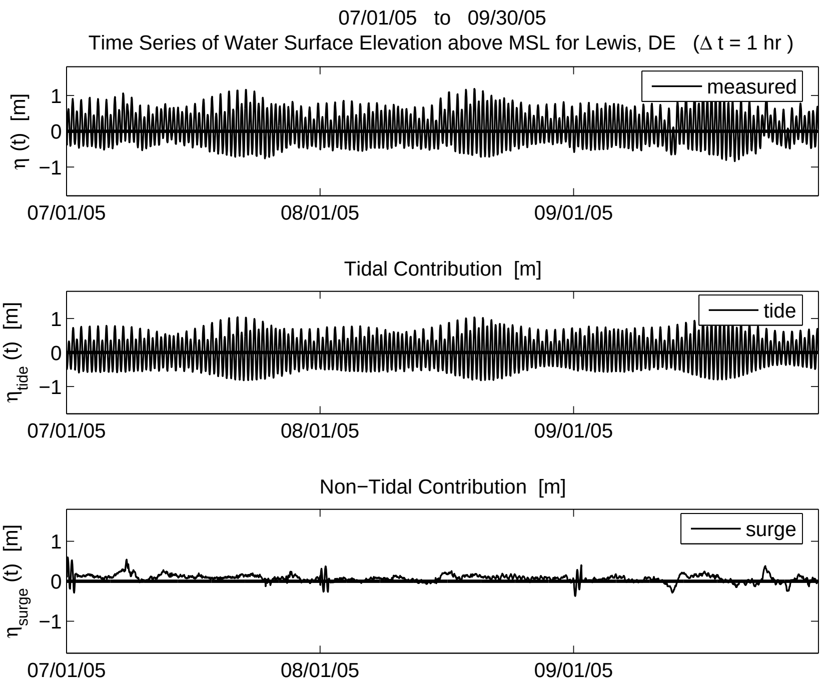

04/01/04 to 06/30/04
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
04/01/04
05/01/04
06/01/04
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

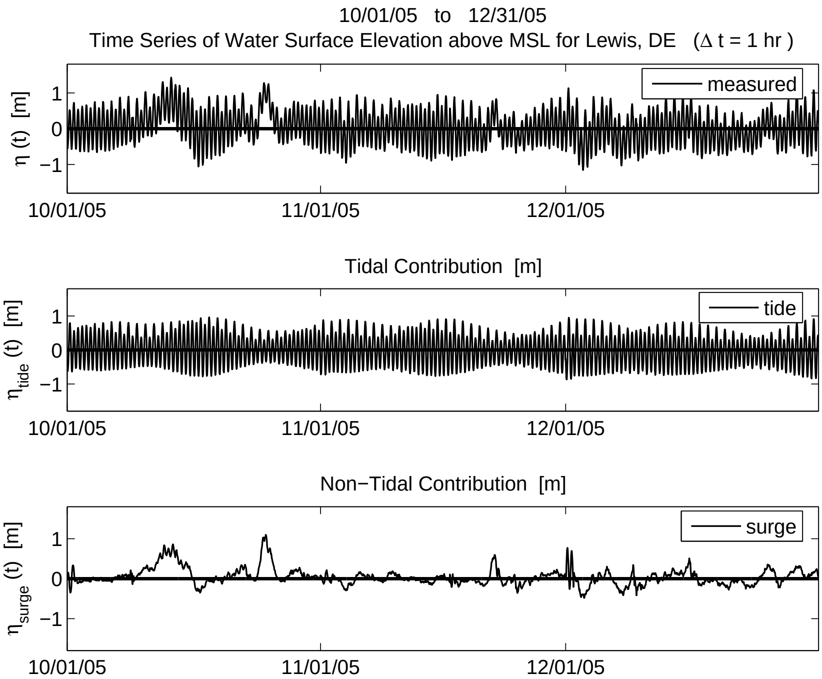

07/01/04 to 09/30/04
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
07/01/04
08/01/04
09/01/04
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

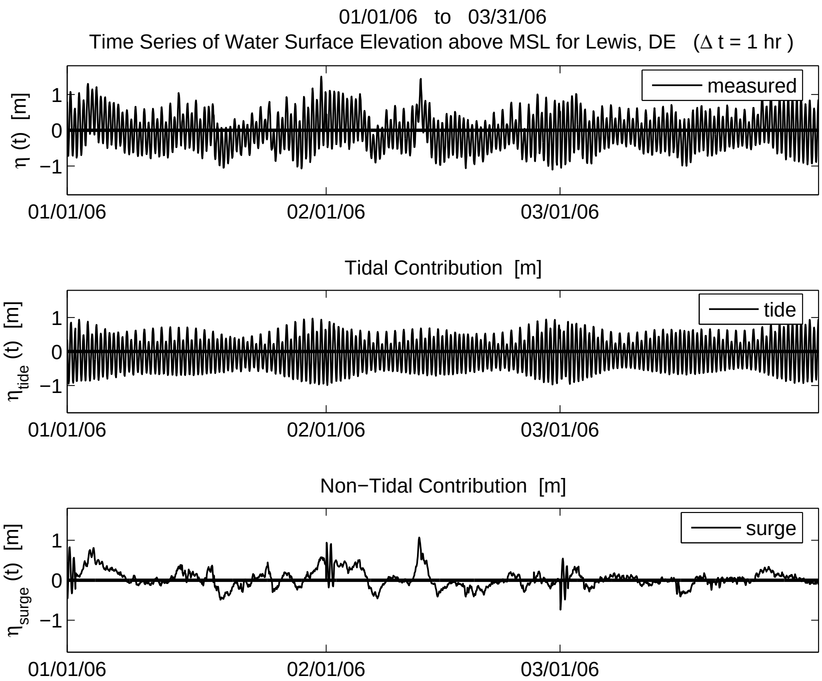

10/01/04 to 12/31/04
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
1
0
−1
10/01/04
11/01/04
12/01/04
Tidal Contribution [m]
η_tide (t) [m]
tide
1
0
−1
10/01/04
11/01/04
12/01/04
Non−Tidal Contribution [m]
η_surge (t) [m]
surge
1
0
−1
10/01/04
11/01/04
12/01/04

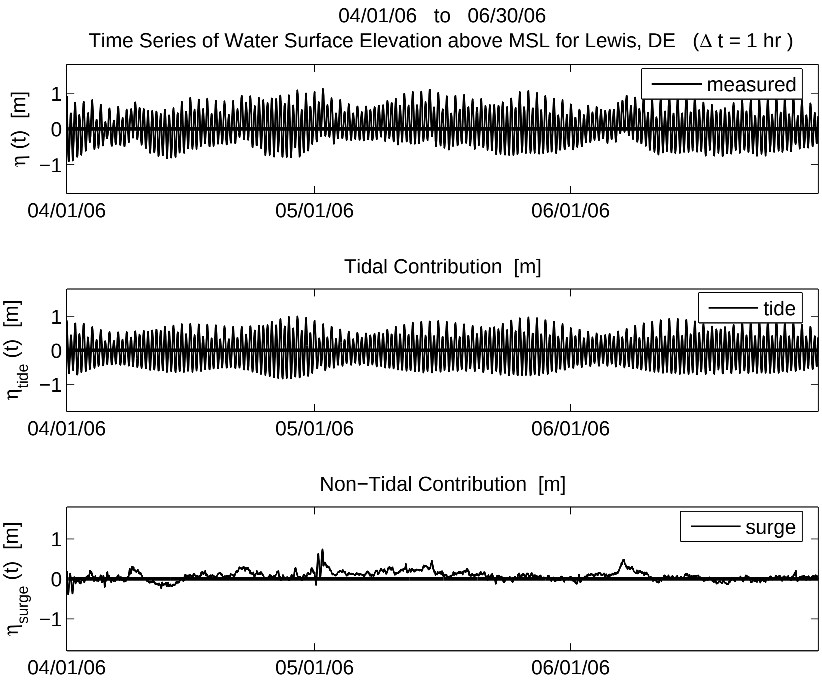

01/01/05 to 03/31/05
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
1
0
−1
01/01/05
02/01/05
03/01/05
Tidal Contribution [m]
η_tide (t) [m]
tide
1
0
−1
01/01/05
02/01/05
03/01/05
Non−Tidal Contribution [m]
η_surge (t) [m]
surge
1
0
−1
01/01/05
02/01/05
03/01/05

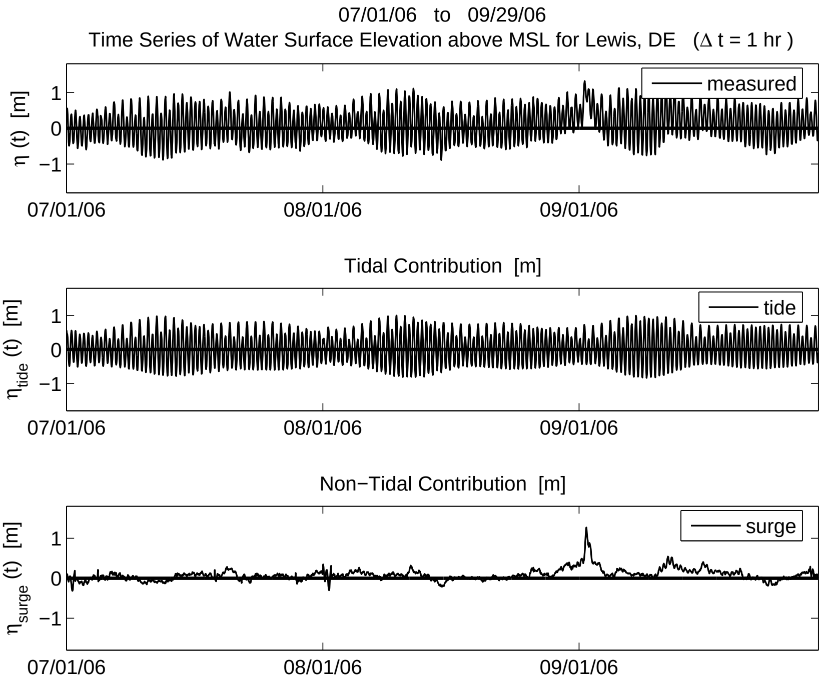

04/01/05 to 06/30/05
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
04/01/05
05/01/05
06/01/05
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]


07/01/05 to 09/30/05
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
07/01/05
08/01/05
09/01/05
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]


10/01/05 to 12/31/05
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
10/01/05
11/01/05
12/01/05
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

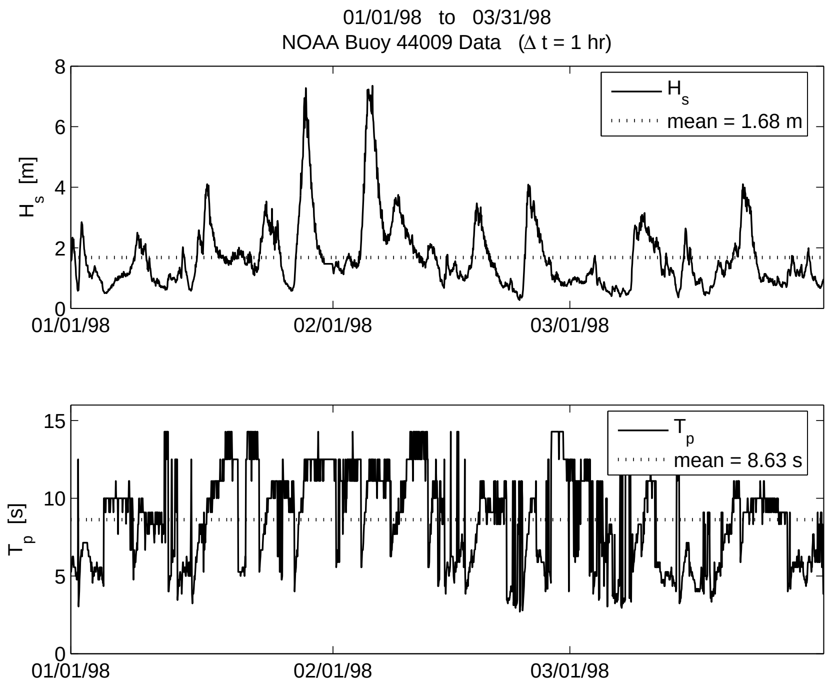

01/01/06 to 03/31/06
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
measured
η (t) [m]
01/01/06
02/01/06
03/01/06
Tidal Contribution [m]
tide
η_tide (t) [m]
Non−Tidal Contribution [m]
surge
η_surge (t) [m]

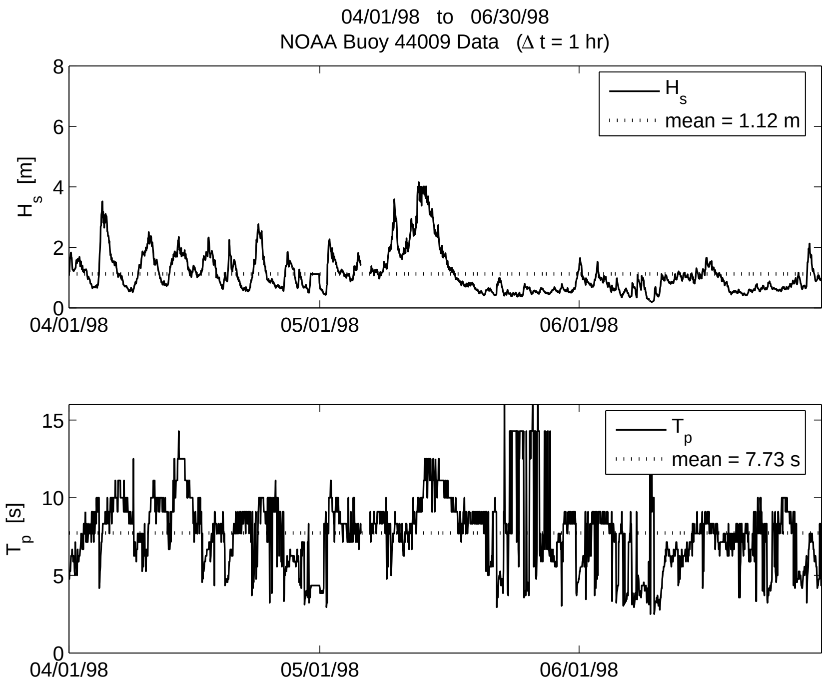

04/01/06 to 06/30/06
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
04/01/06
05/01/06
06/01/06
Tidal Contribution [m]
η_tide (t) [m]
tide
Non−Tidal Contribution [m]
η_surge (t) [m]
surge

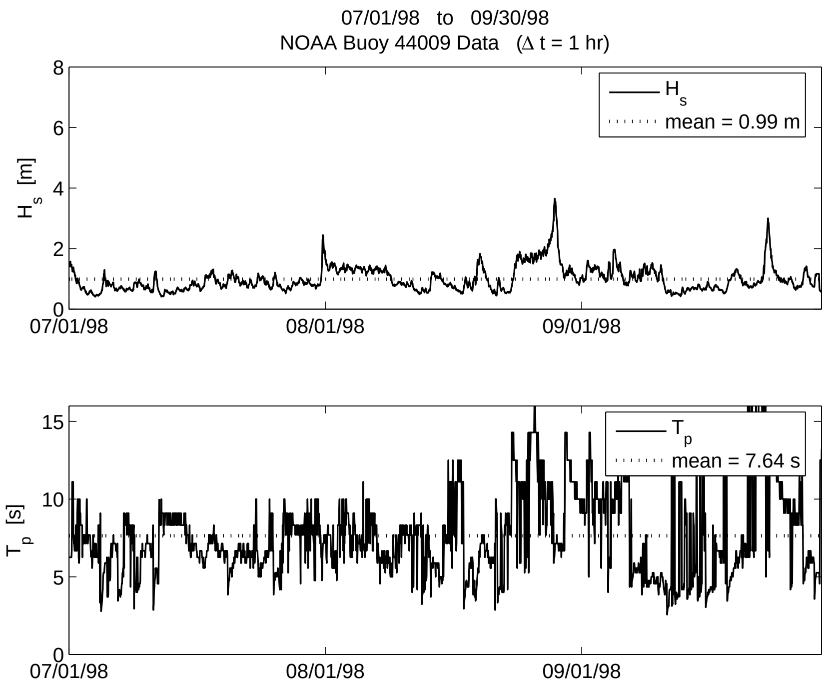

07/01/06 to 09/29/06
Time Series of Water Surface Elevation above MSL for Lewis, DE (Δ t = 1 hr)
η (t) [m]
measured
07/01/06
08/01/06
09/01/06
Tidal Contribution [m]
η_tide (t) [m]
tide
Non−Tidal Contribution [m]
η_surge (t) [m]
surge

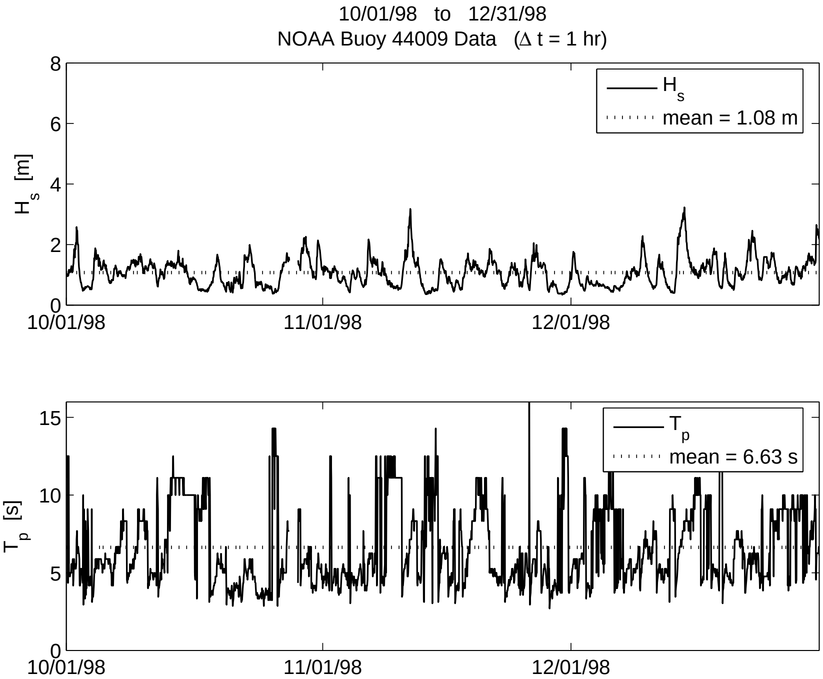
Appendix B

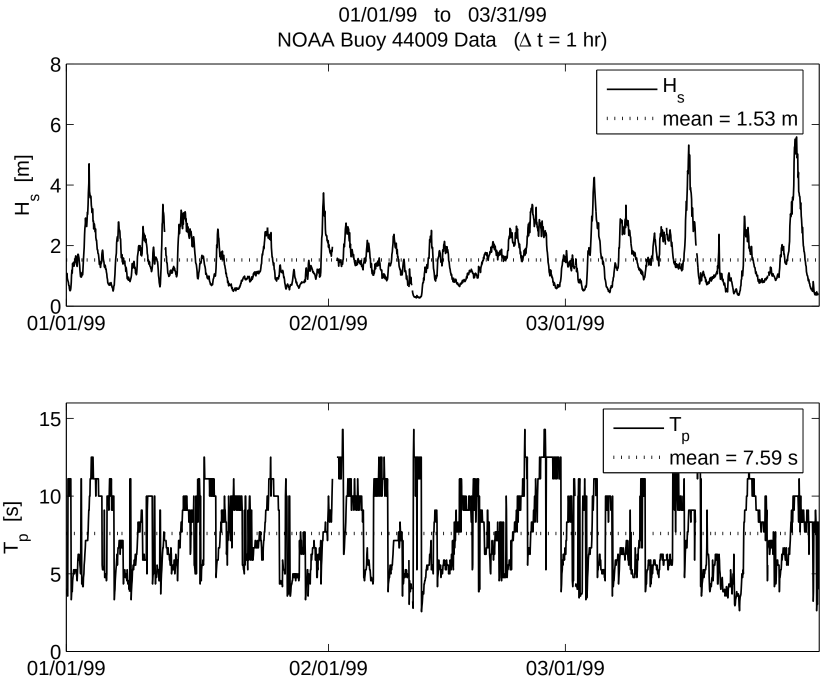
HOURLY WAVE DATA

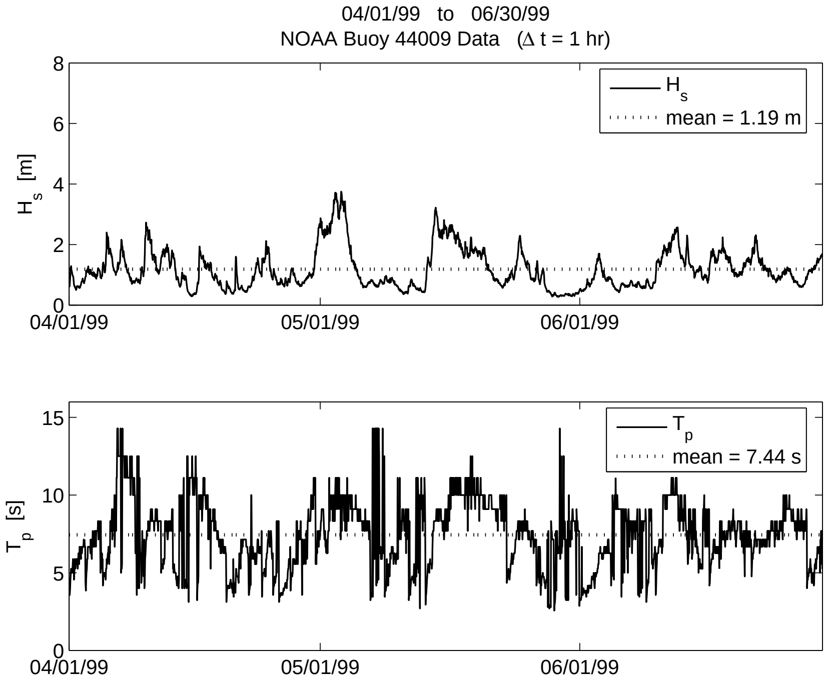


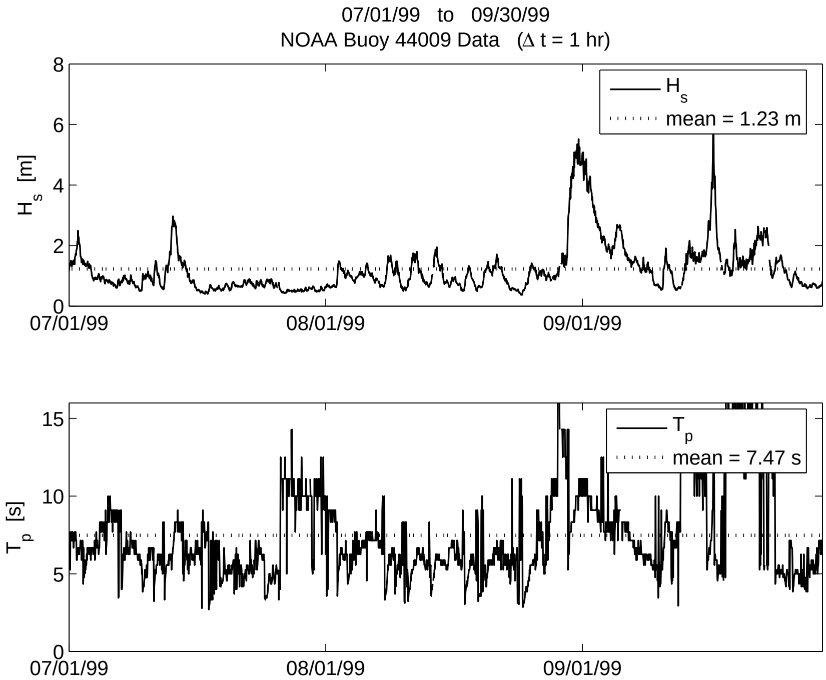

04/01/98 to 06/30/98
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s
mean = 1.12 m
H_s [m]
T_p
mean = 7.73 s
T_p [s]
04/01/98
05/01/98
06/01/98

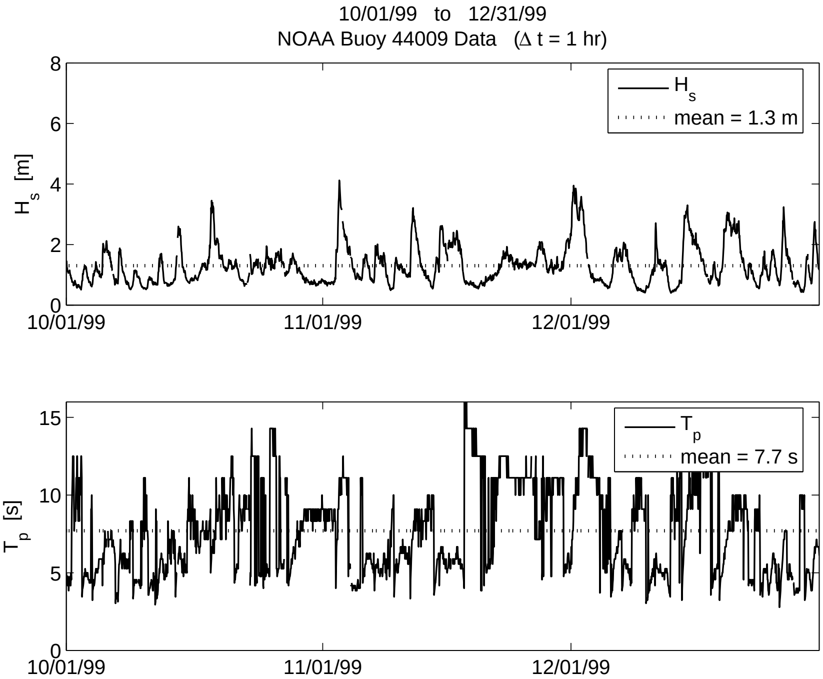

07/01/98 to 09/30/98
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s
mean = 0.99 m
H_s [m]
T_p
mean = 7.64 s
T_p [s]
07/01/98
08/01/98
09/01/98

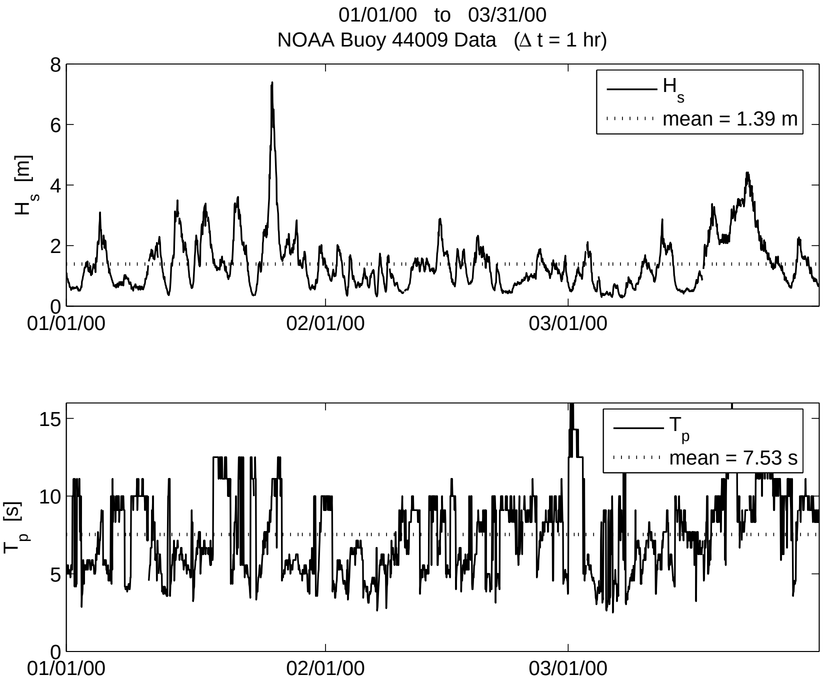

10/01/98 to 12/31/98
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.08 m
10/01/98
11/01/98
12/01/98
T_p [s]
T_p
mean = 6.63 s

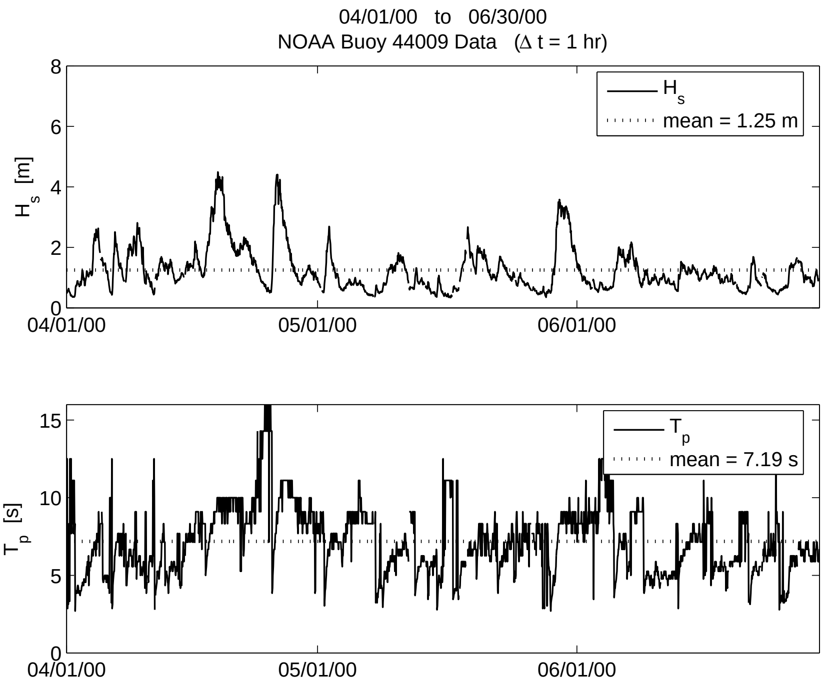

01/01/99 to 03/31/99
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.53 m
01/01/99
02/01/99
03/01/99
T_p [s]
T_p
mean = 7.59 s

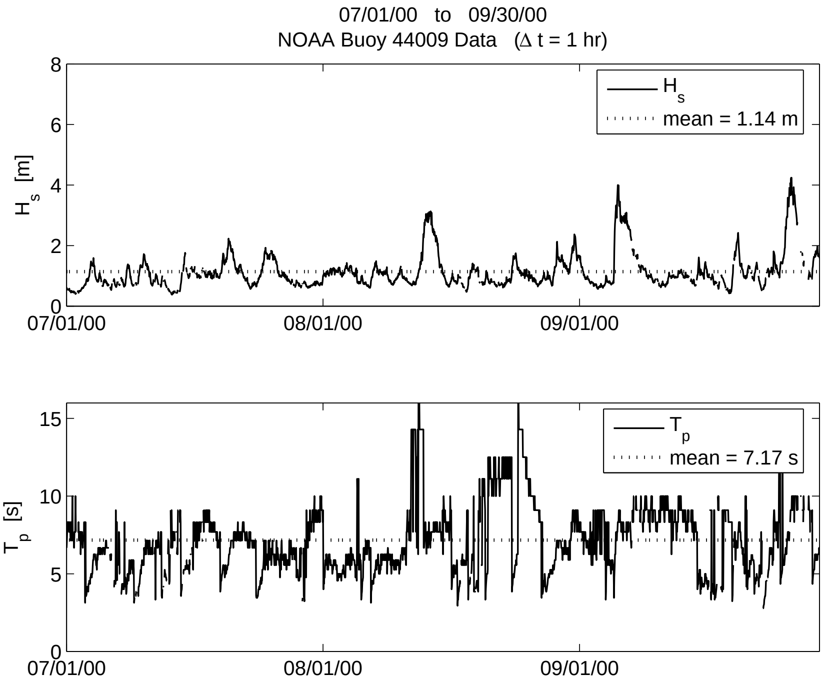

04/01/99 to 06/30/99
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.19 m
04/01/99
05/01/99
06/01/99
T_p [s]
T_p
mean = 7.44 s
04/01/99
05/01/99
06/01/99

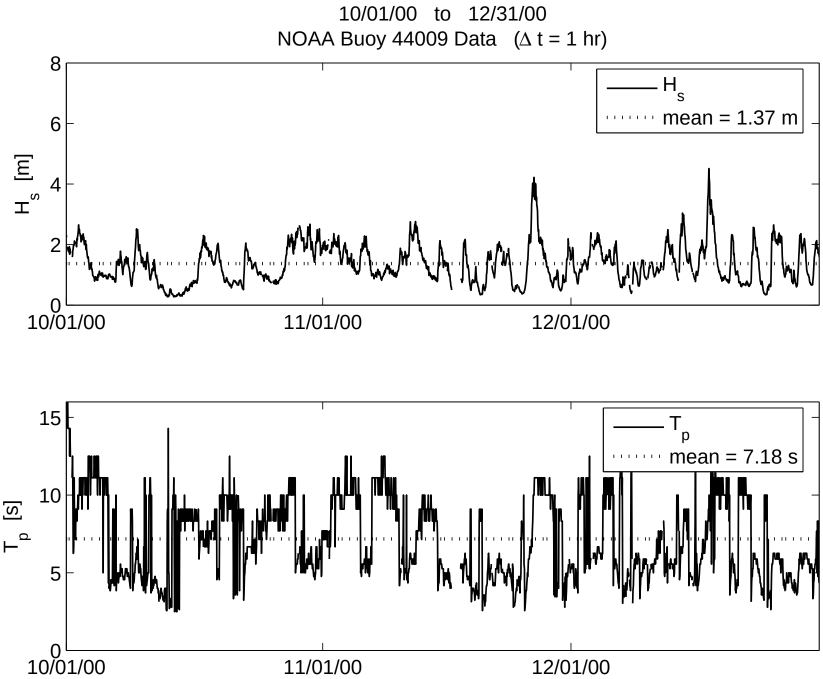

07/01/99 to 09/30/99
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.23 m
07/01/99
08/01/99
09/01/99
T_p [s]
T_p
mean = 7.47 s
07/01/99
08/01/99
09/01/99

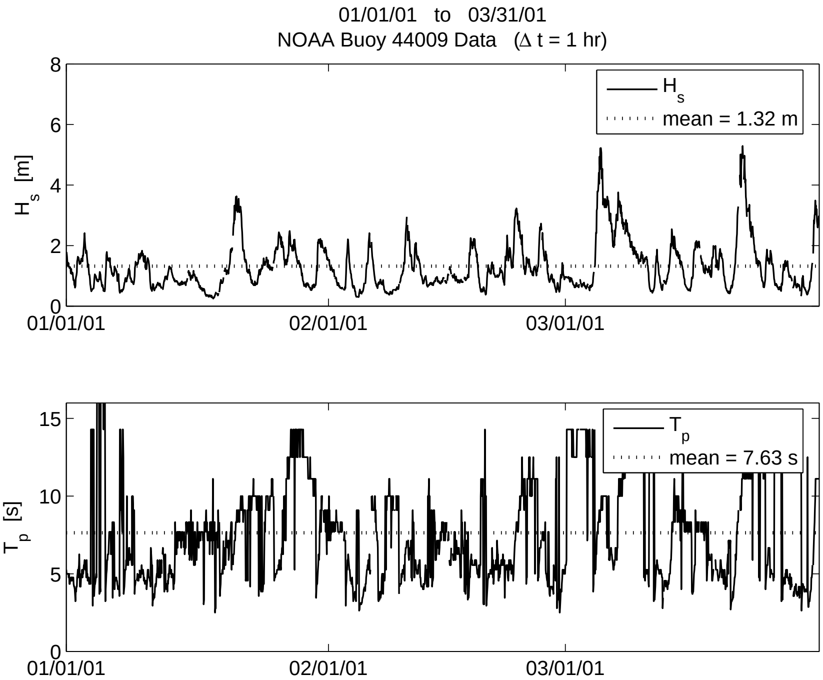

10/01/99 to 12/31/99
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.3 m
10/01/99
11/01/99
12/01/99
T_p [s]
T_p
mean = 7.7 s
10/01/99
11/01/99
12/01/99

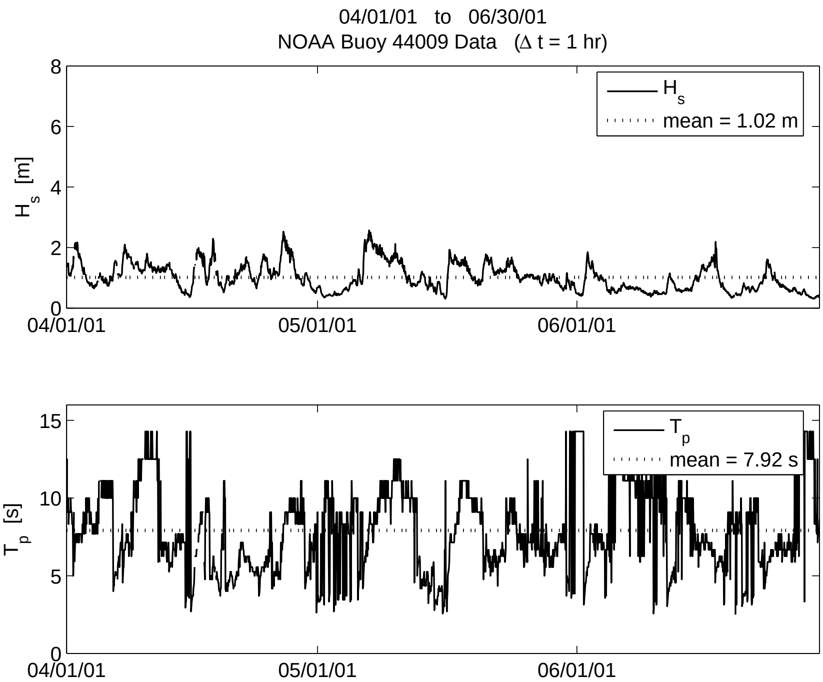

01/01/00 to 03/31/00
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.39 m
01/01/00
02/01/00
03/01/00
T_p [s]
T_p
mean = 7.53 s
01/01/00
02/01/00
03/01/00

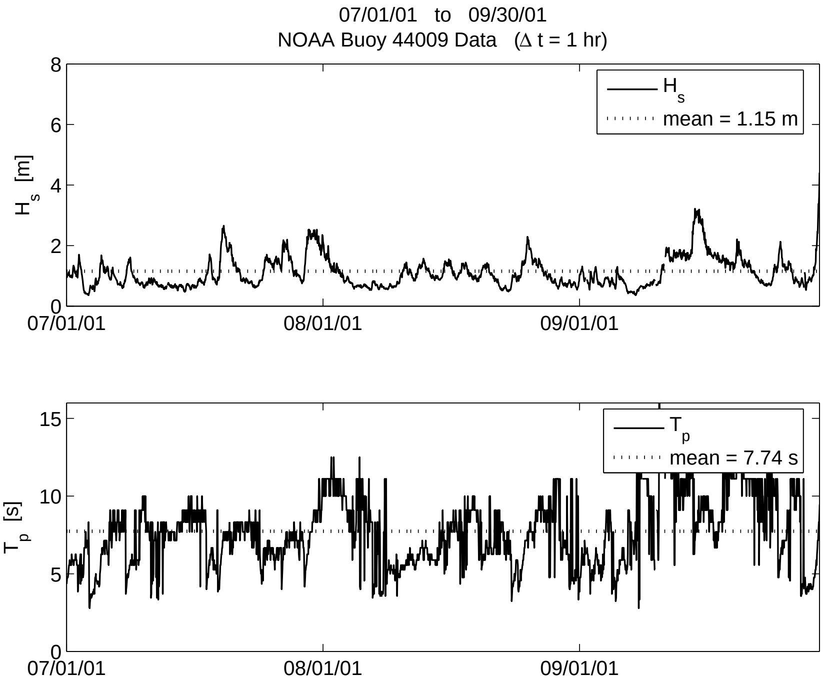

04/01/00 to 06/30/00
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.25 m
04/01/00
05/01/00
06/01/00
T_p [s]
T_p
mean = 7.19 s
04/01/00
05/01/00
06/01/00

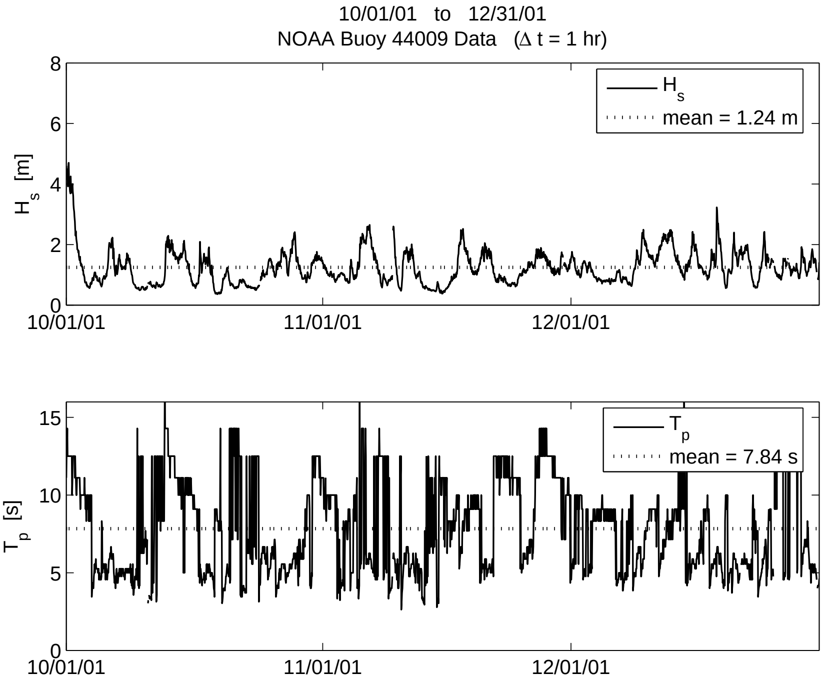

07/01/00 to 09/30/00
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.14 m
07/01/00
08/01/00
09/01/00
T_p [s]
T_p
mean = 7.17 s
07/01/00
08/01/00
09/01/00

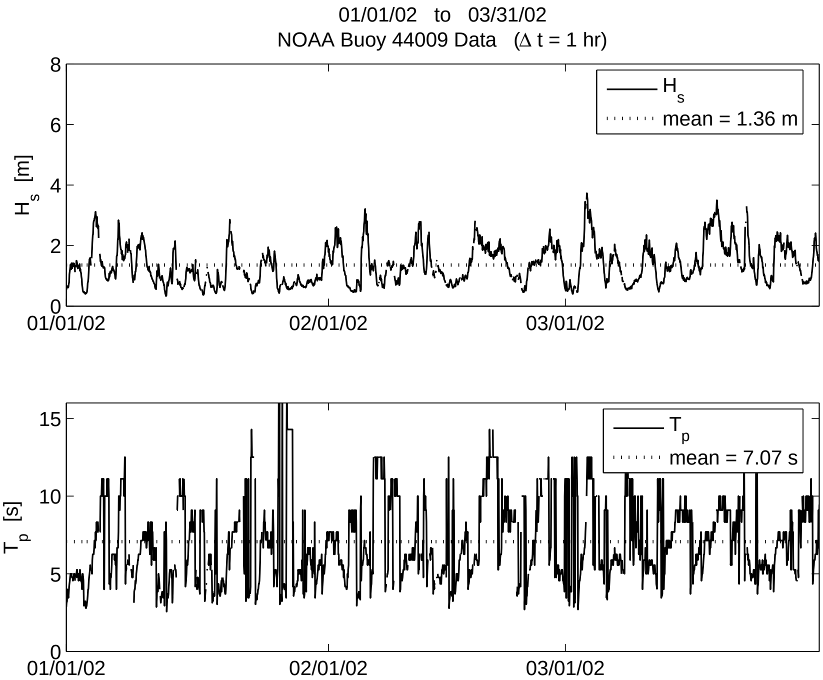

10/01/00 to 12/31/00
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.37 m
T_p [s]
T_p
mean = 7.18 s
10/01/00
11/01/00
12/01/00

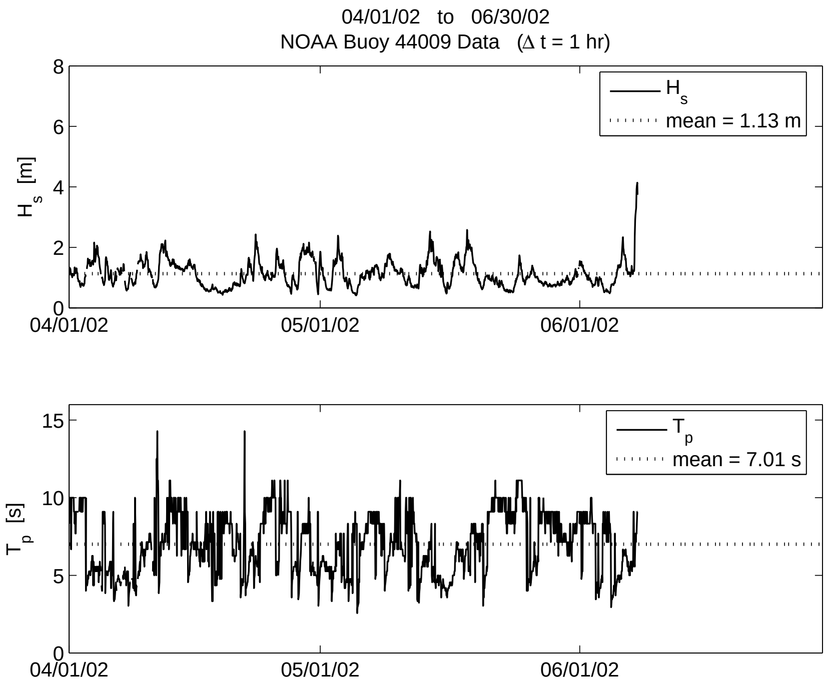

01/01/01 to 03/31/01
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.32 m
T_p [s]
T_p
mean = 7.63 s
01/01/01
02/01/01
03/01/01

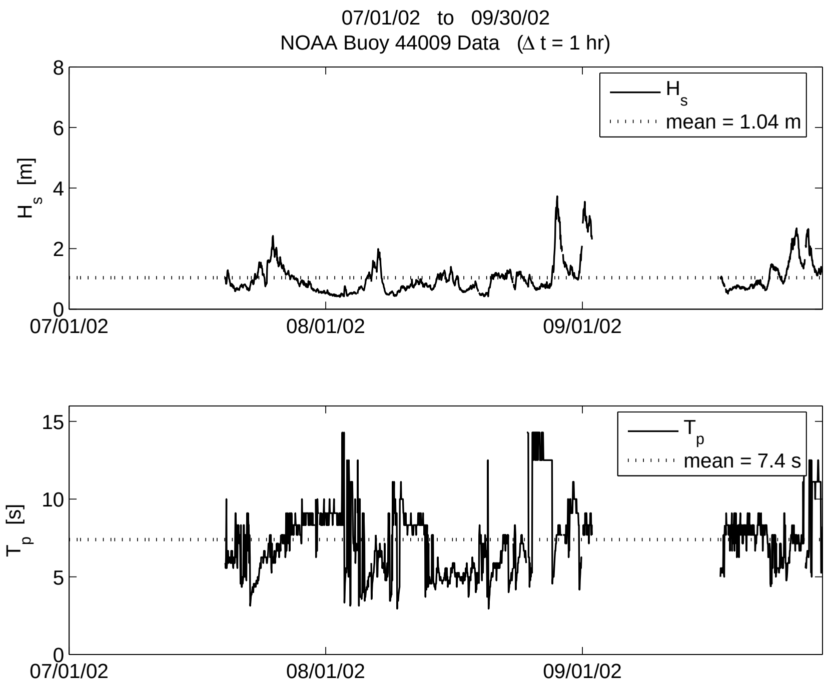

04/01/01 to 06/30/01
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.02 m
04/01/01
05/01/01
06/01/01
T_p [s]
T_p
mean = 7.92 s

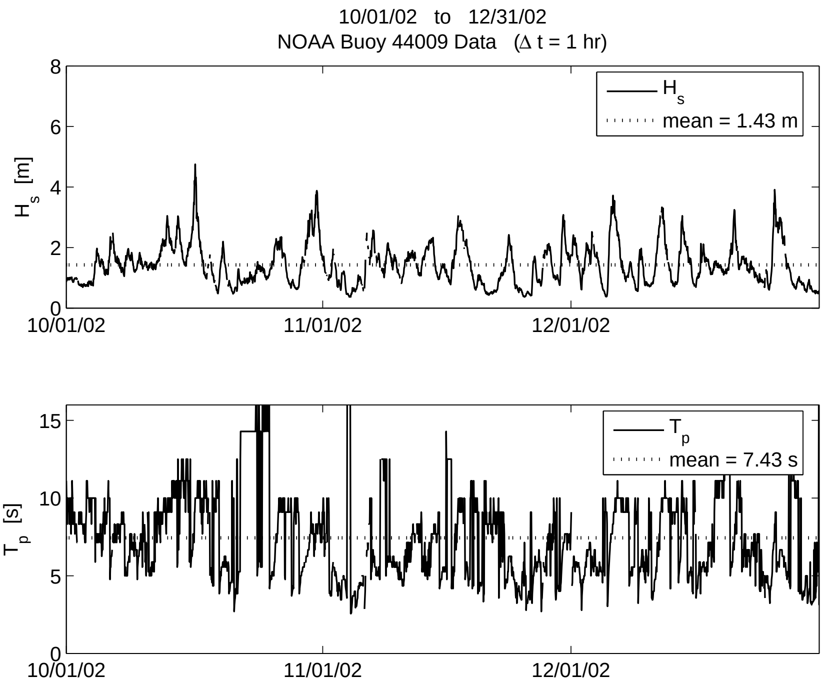

07/01/01 to 09/30/01
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.15 m
07/01/01
08/01/01
09/01/01
T_p [s]
T_p
mean = 7.74 s

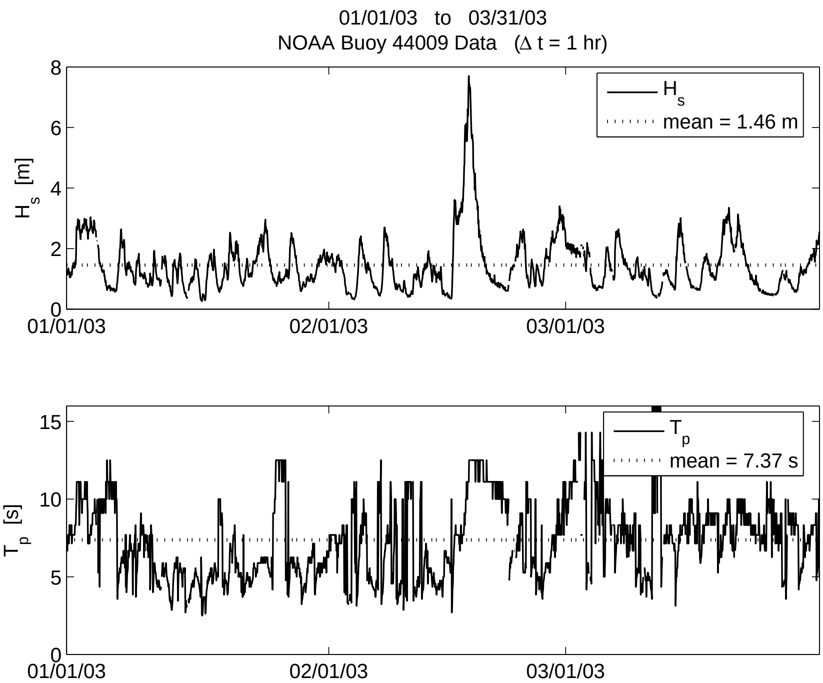

10/01/01 to 12/31/01
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.24 m
10/01/01
11/01/01
12/01/01
T_p [s]
T_p
mean = 7.84 s
10/01/01
11/01/01
12/01/01

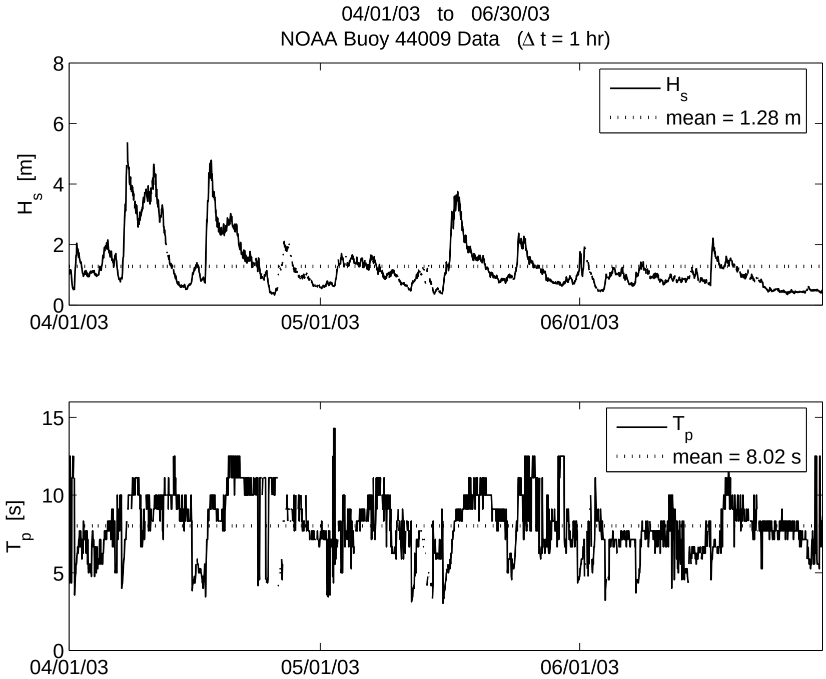

01/01/02 to 03/31/02
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.36 m
01/01/02
02/01/02
03/01/02
T_p [s]
T_p
mean = 7.07 s
01/01/02
02/01/02
03/01/02

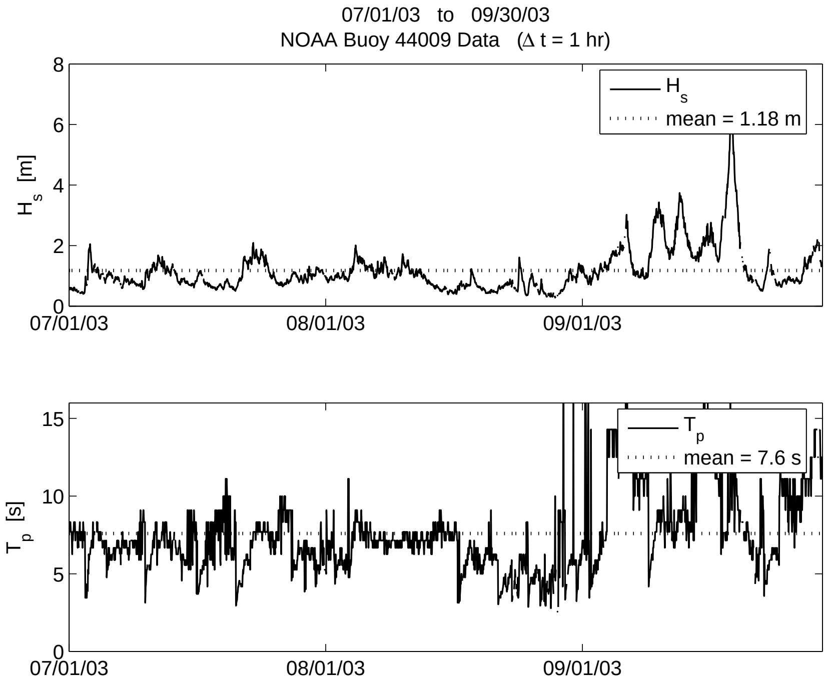

04/01/02 to 06/30/02
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.13 m
04/01/02
05/01/02
06/01/02
T_p [s]
T_p
mean = 7.01 s
04/01/02
05/01/02
06/01/02

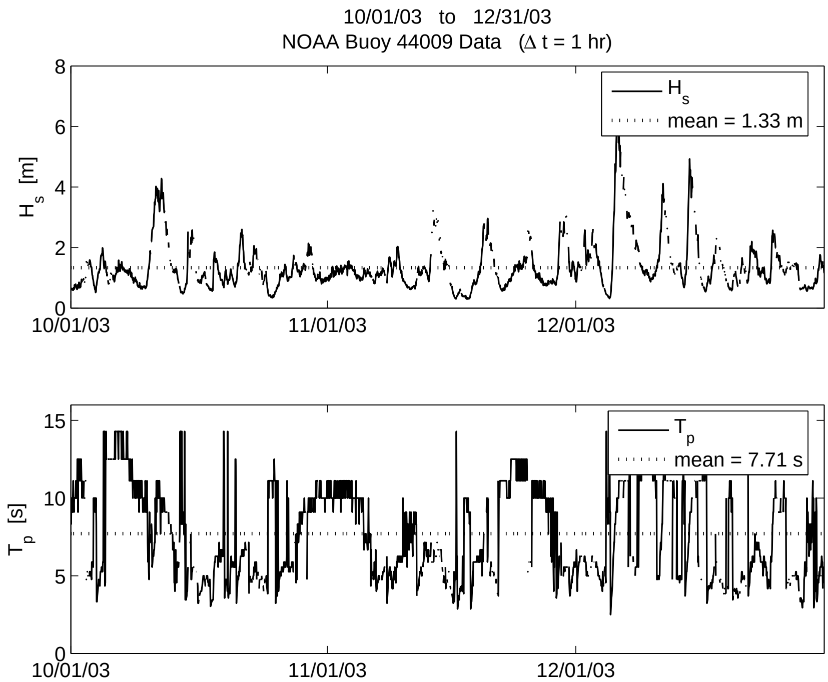

07/01/02 to 09/30/02
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.04 m
07/01/02
08/01/02
09/01/02
T_p [s]
T_p
mean = 7.4 s
07/01/02
08/01/02
09/01/02

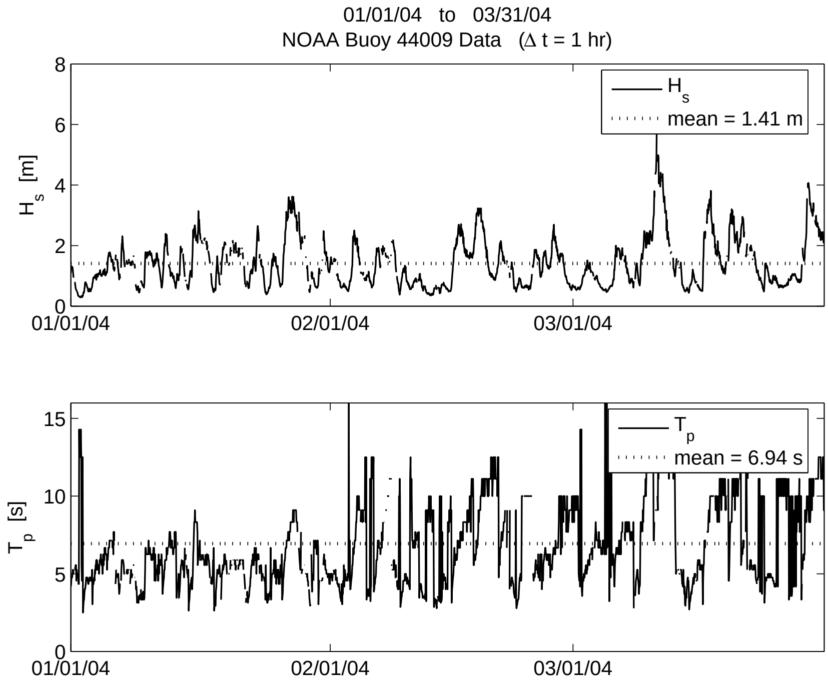

10/01/02 to 12/31/02
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.43 m
T_p [s]
T_p
mean = 7.43 s
10/01/02
11/01/02
12/01/02

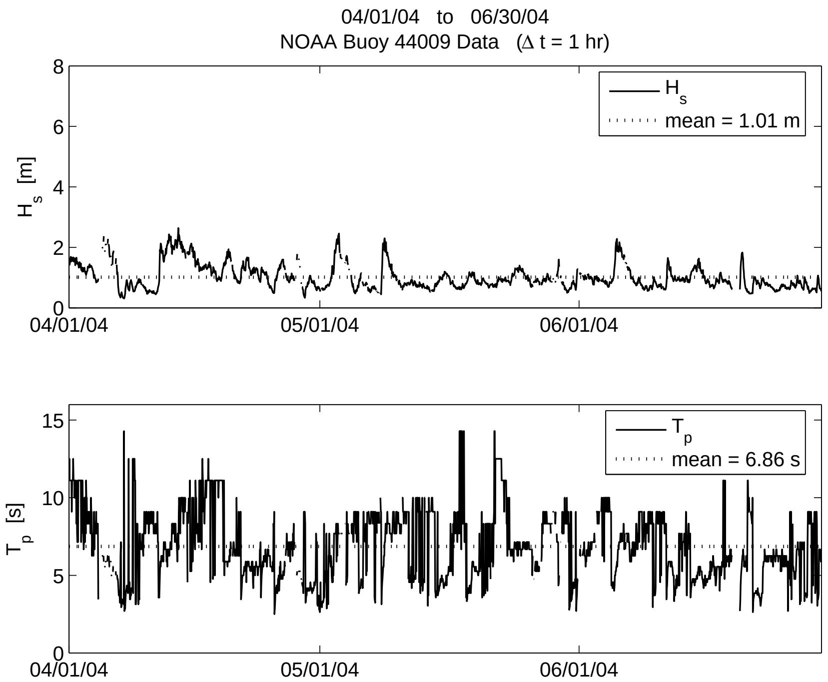

01/01/03 to 03/31/03
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.46 m
T_p [s]
T_p
mean = 7.37 s
01/01/03
02/01/03
03/01/03

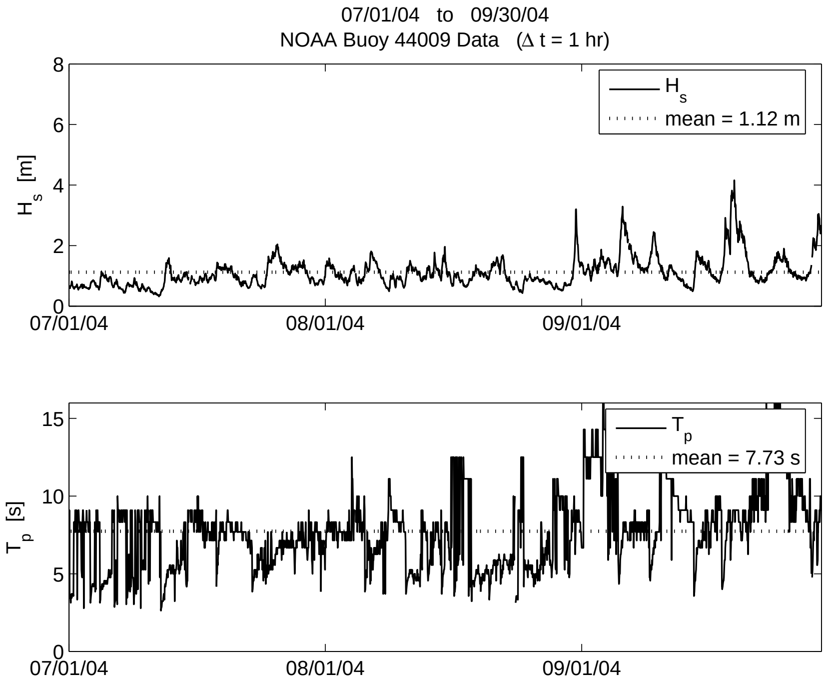

04/01/03 to 06/30/03
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s
mean = 1.28 m
H_s [m]
T_p
mean = 8.02 s
T_p [s]
04/01/03
05/01/03
06/01/03

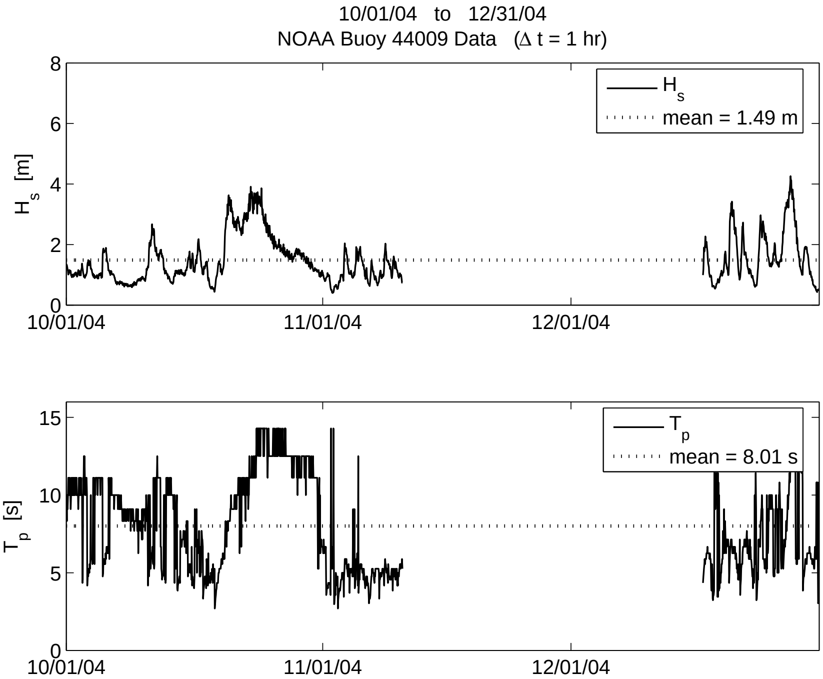

07/01/03 to 09/30/03
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s
mean = 1.18 m
H_s [m]
T_p
mean = 7.6 s
T_p [s]
07/01/03
08/01/03
09/01/03

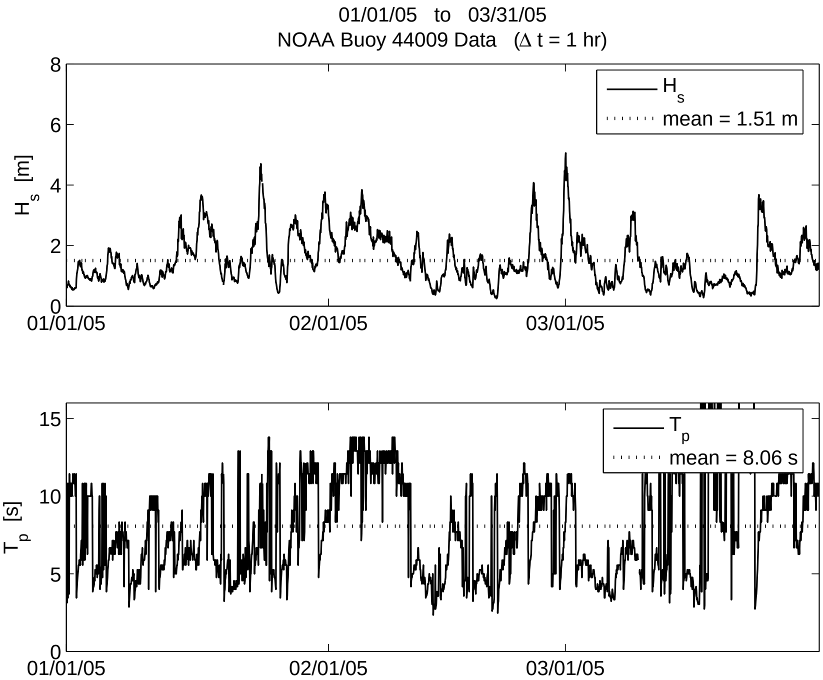

10/01/03 to 12/31/03
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.33 m
10/01/03
11/01/03
12/01/03
T_p [s]
T_p
mean = 7.71 s

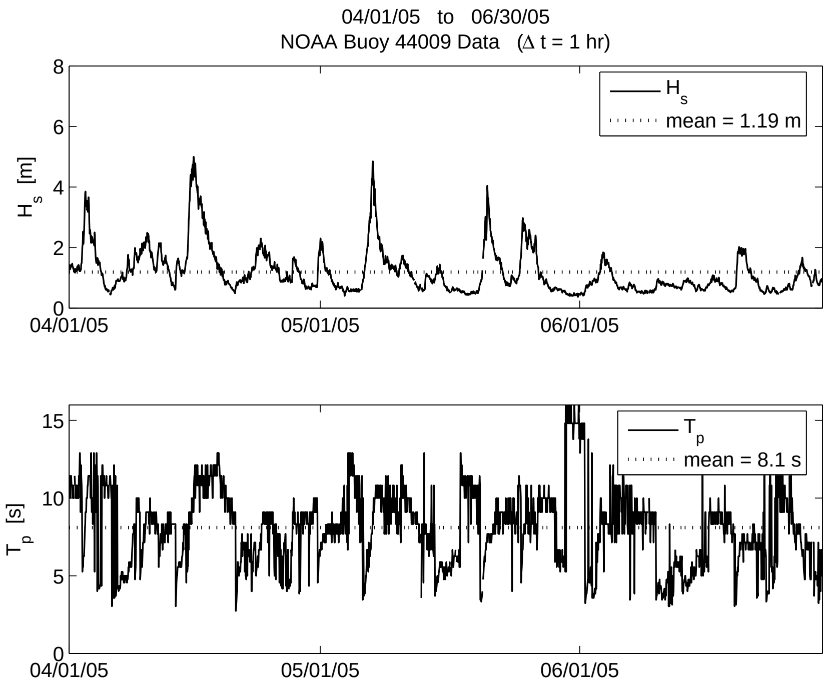

01/01/04 to 03/31/04
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.41 m
01/01/04
02/01/04
03/01/04
T_p [s]
T_p
mean = 6.94 s

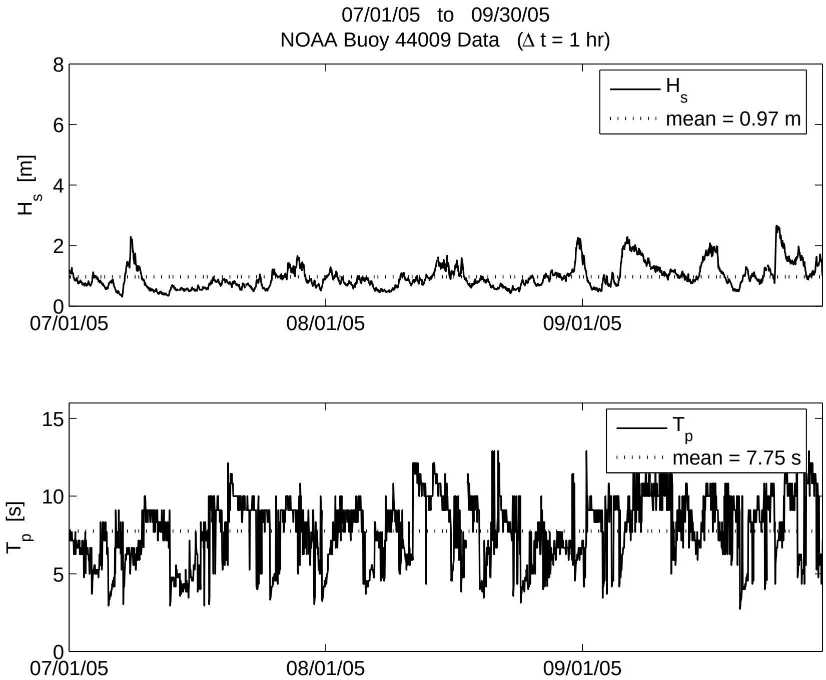

04/01/04 to 06/30/04
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.01 m
04/01/04
05/01/04
06/01/04
T_p [s]
T_p
mean = 6.86 s
04/01/04
05/01/04
06/01/04

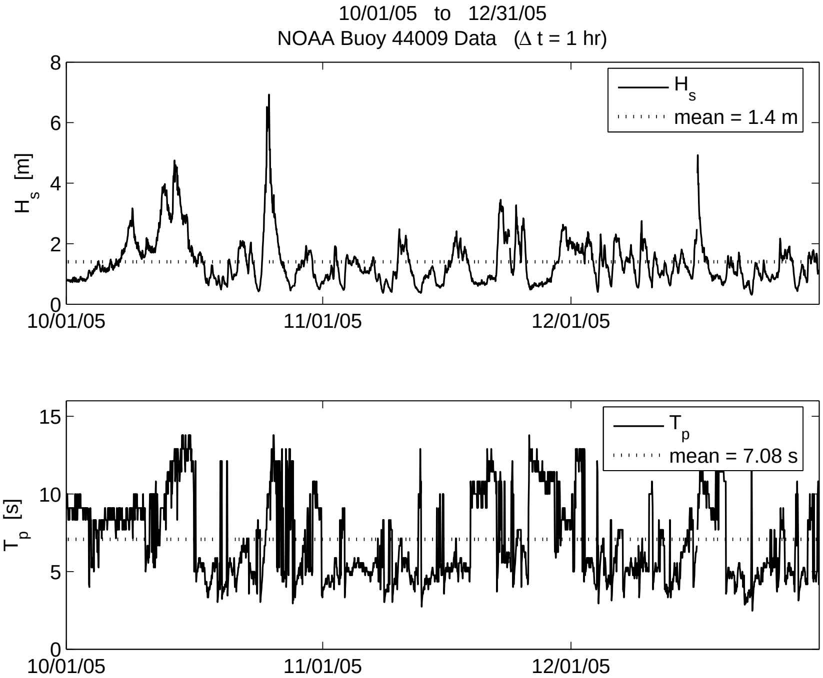

07/01/04 to 09/30/04
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.12 m
07/01/04
08/01/04
09/01/04
T_p [s]
T_p
mean = 7.73 s
07/01/04
08/01/04
09/01/04


10/01/04 to 12/31/04
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.49 m
10/01/04
11/01/04
12/01/04
T_p [s]
T_p
mean = 8.01 s


01/01/05 to 03/31/05
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.51 m
01/01/05
02/01/05
03/01/05
T_p [s]
T_p
mean = 8.06 s

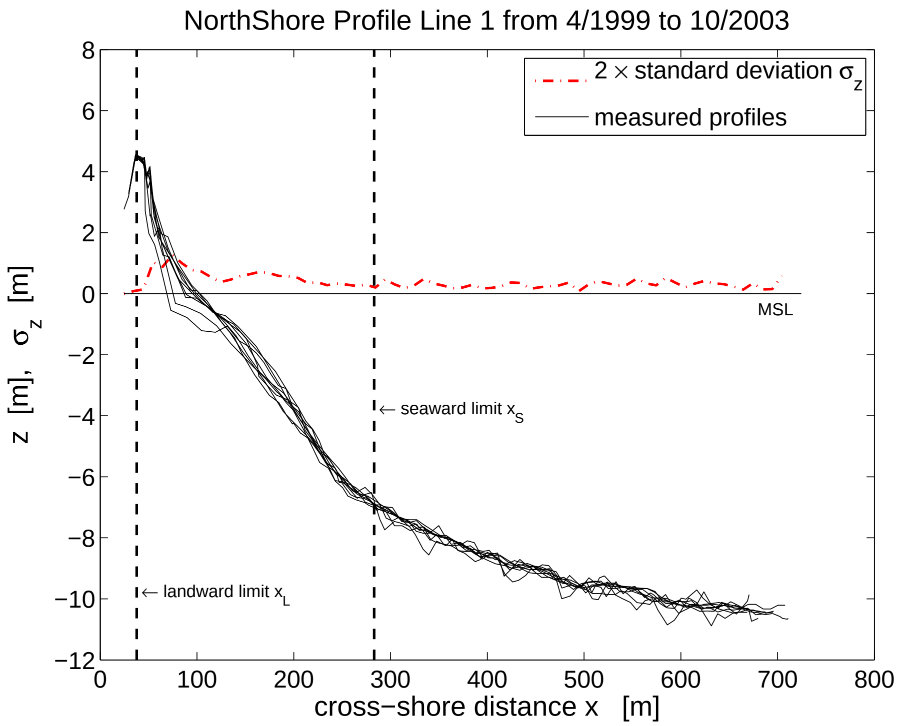

04/01/05 to 06/30/05
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 1.19 m
04/01/05
05/01/05
06/01/05
T_p [s]
T_p
mean = 8.1 s
04/01/05
05/01/05
06/01/05

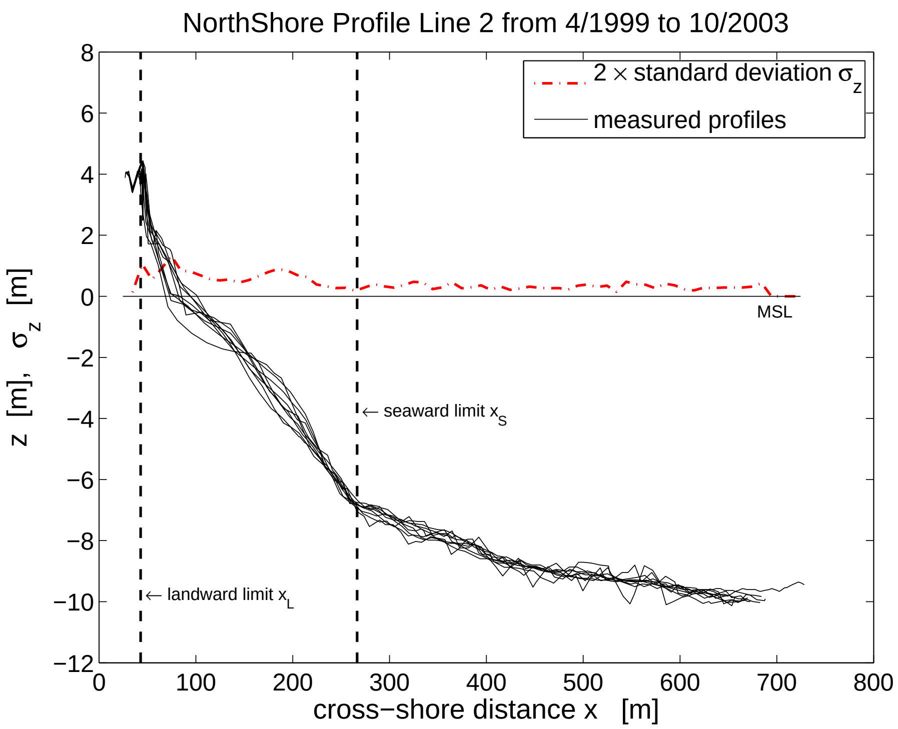

07/01/05 to 09/30/05
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s [m]
H_s
mean = 0.97 m
07/01/05
08/01/05
09/01/05
T_p [s]
T_p
mean = 7.75 s
07/01/05
08/01/05
09/01/05

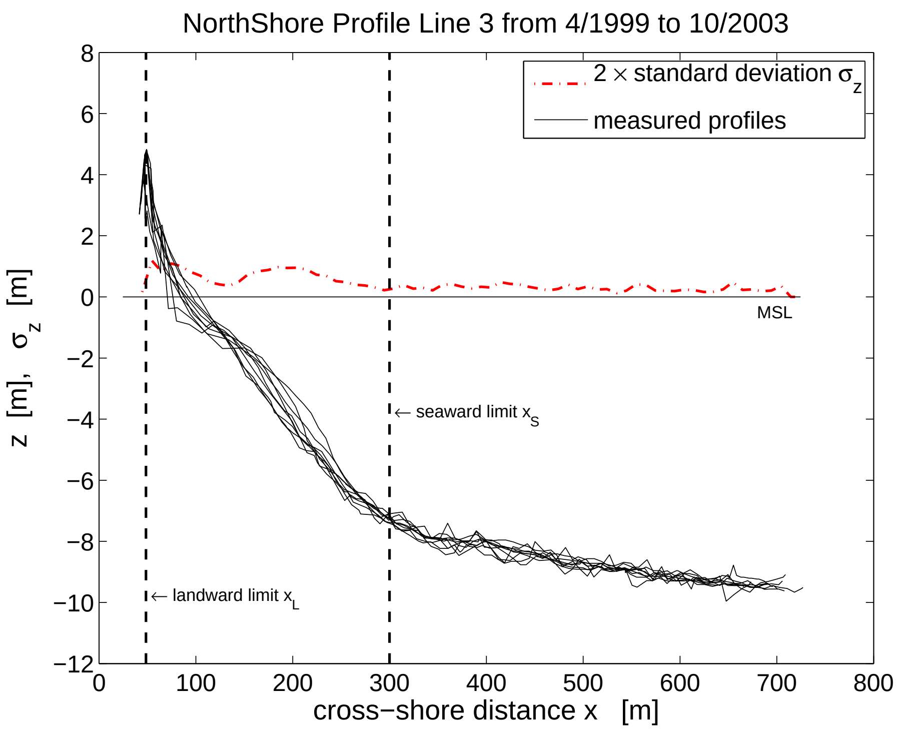

10/01/05 to 12/31/05
NOAA Buoy 44009 Data (Δ t = 1 hr)
H_s
mean = 1.4 m
H_s [m]
0
2
4
6
8
10/01/05
11/01/05
12/01/05
T_p
mean = 7.08 s
T_p [s]
0
5
10
15
10/01/05
11/01/05
12/01/05

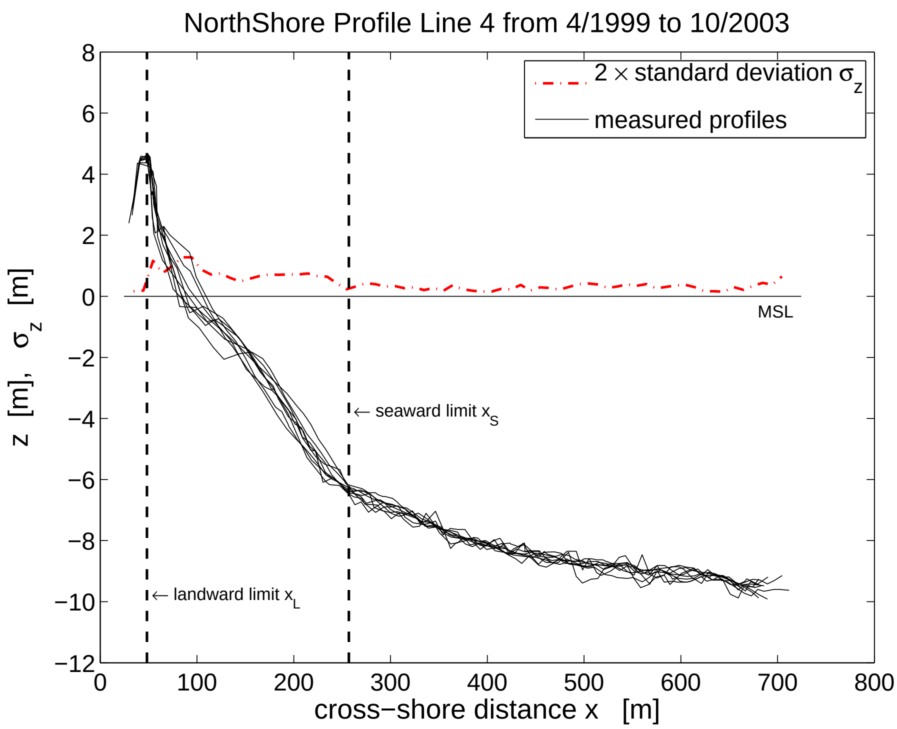
Appendix C

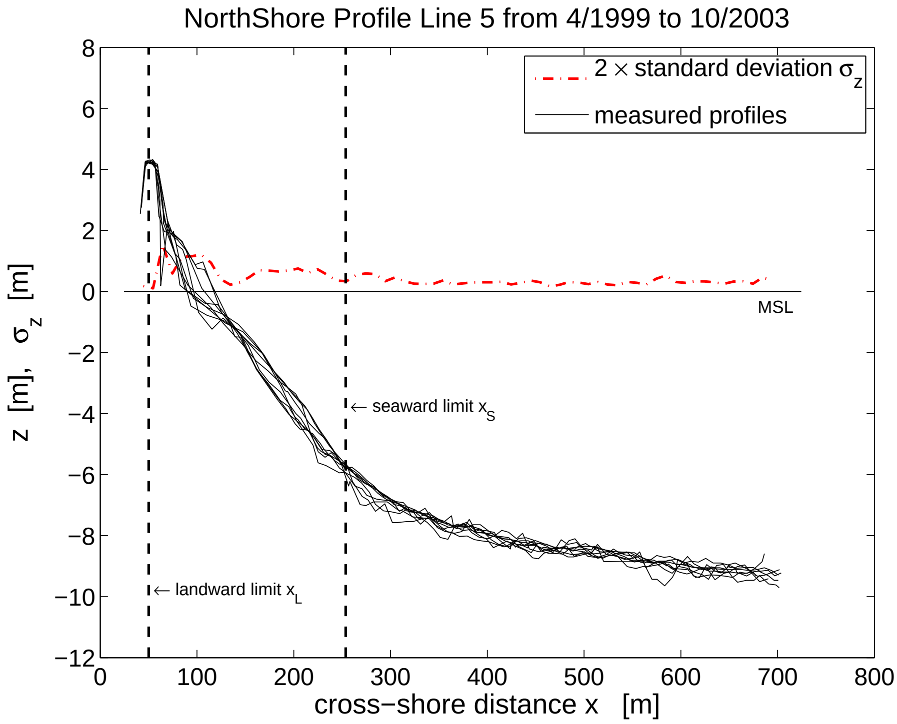
MEASURED PROFILES AT EACH PROFILE LINE

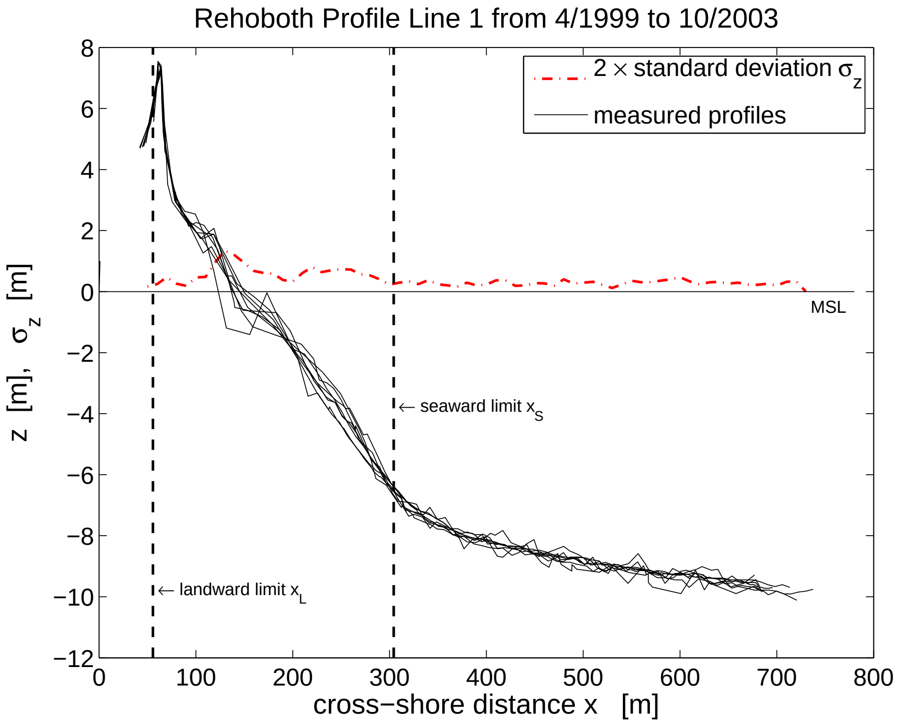


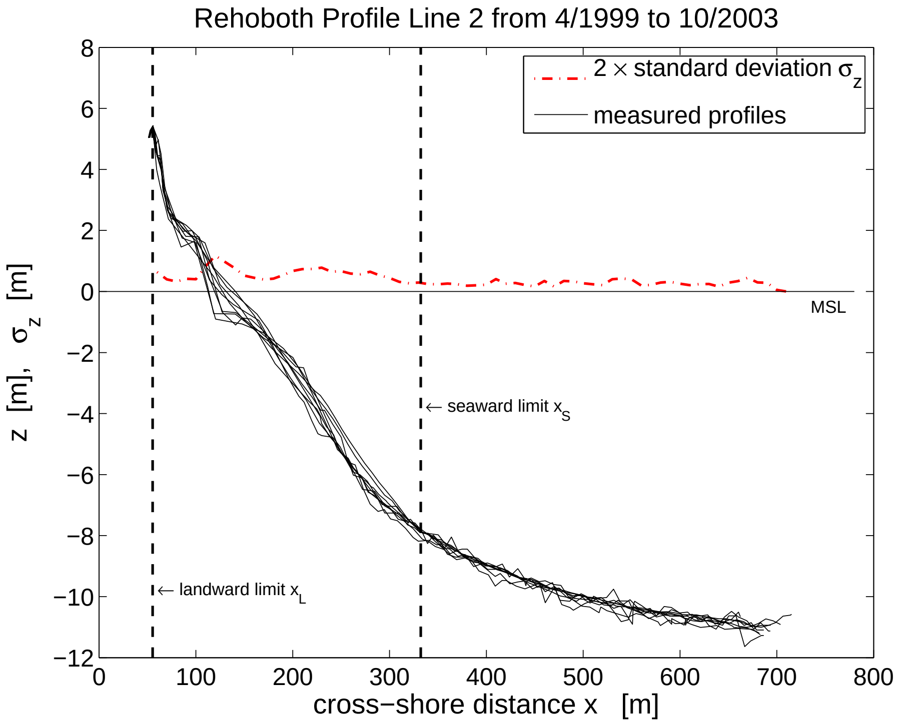

NorthShore Profile Line 2 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800

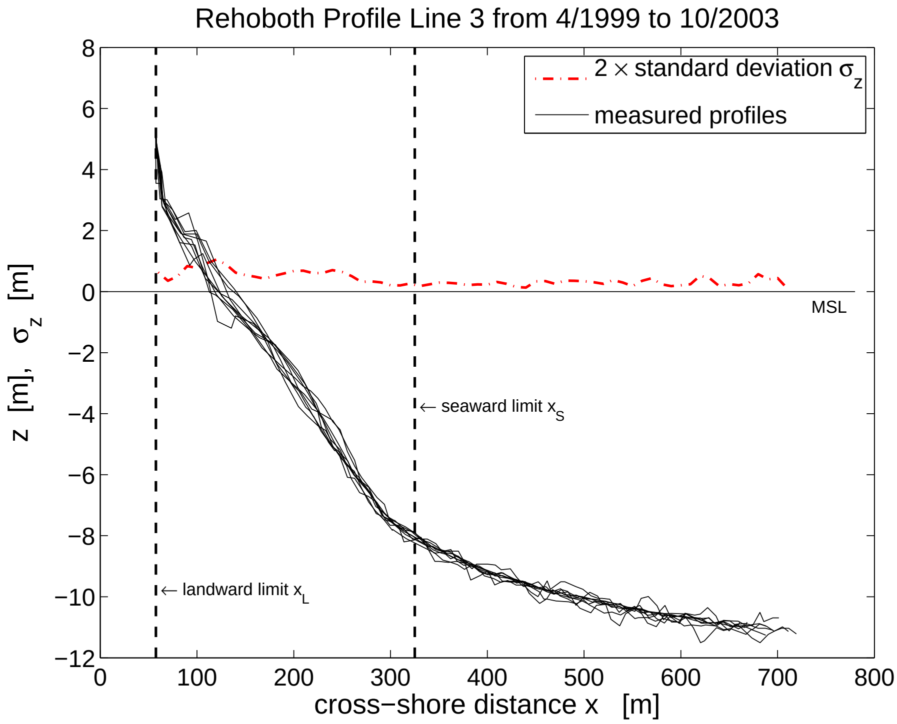

NorthShore Profile Line 3 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800


NorthShore Profile Line 4 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

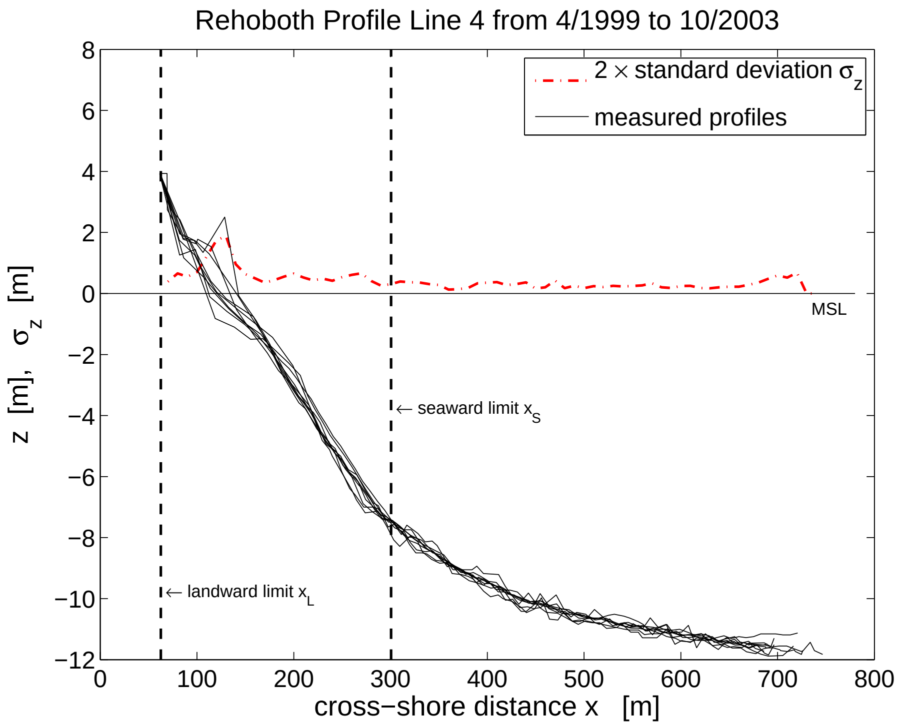

NorthShore Profile Line 5 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]


Rehoboth Profile Line 1 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800

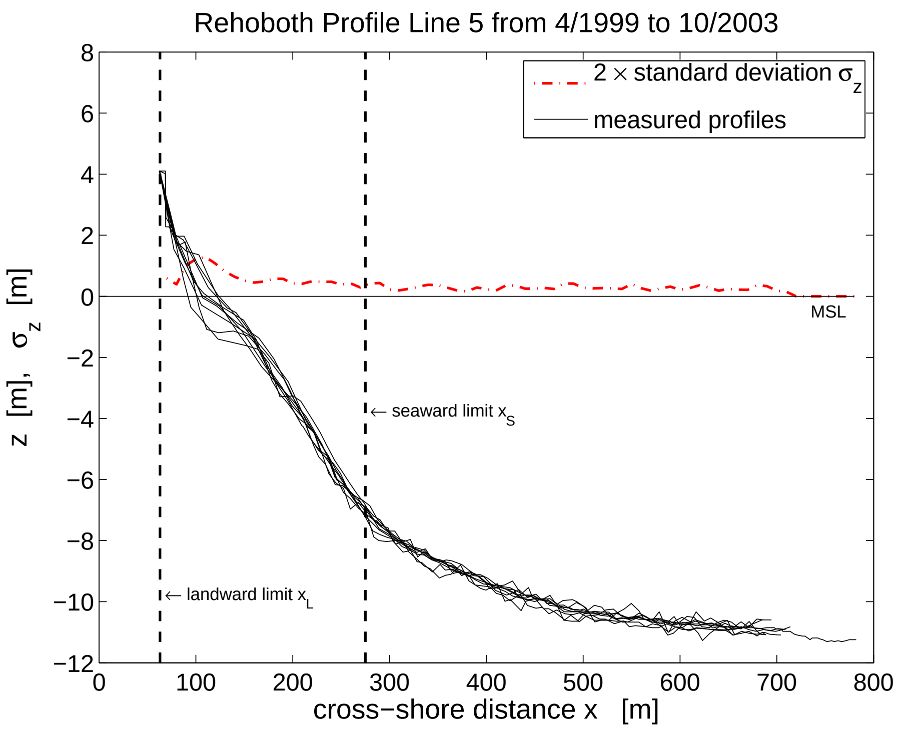

Rehoboth Profile Line 2 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800

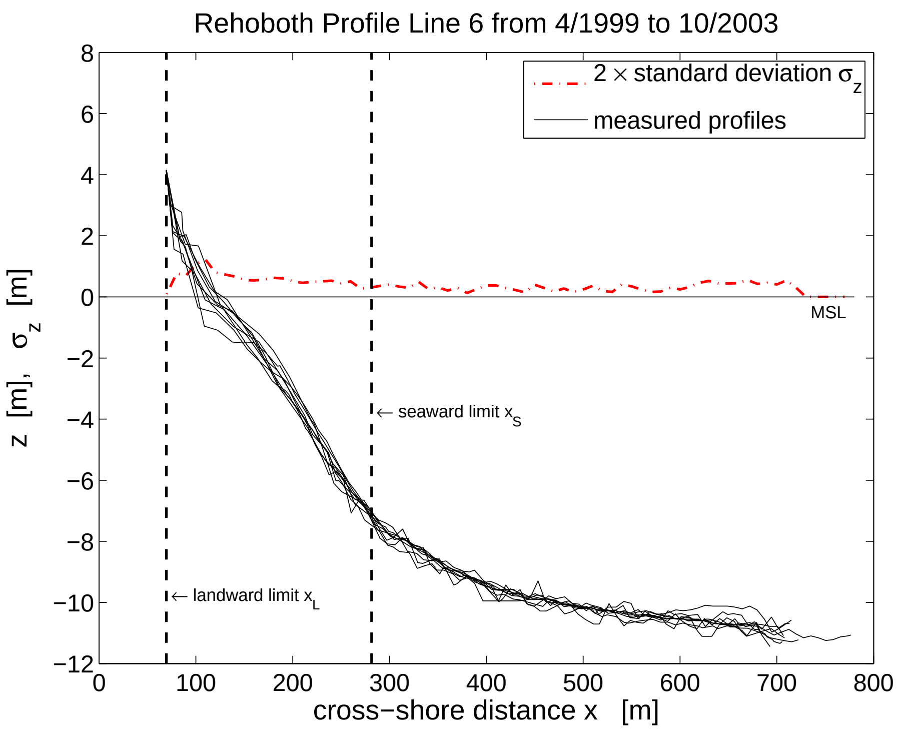


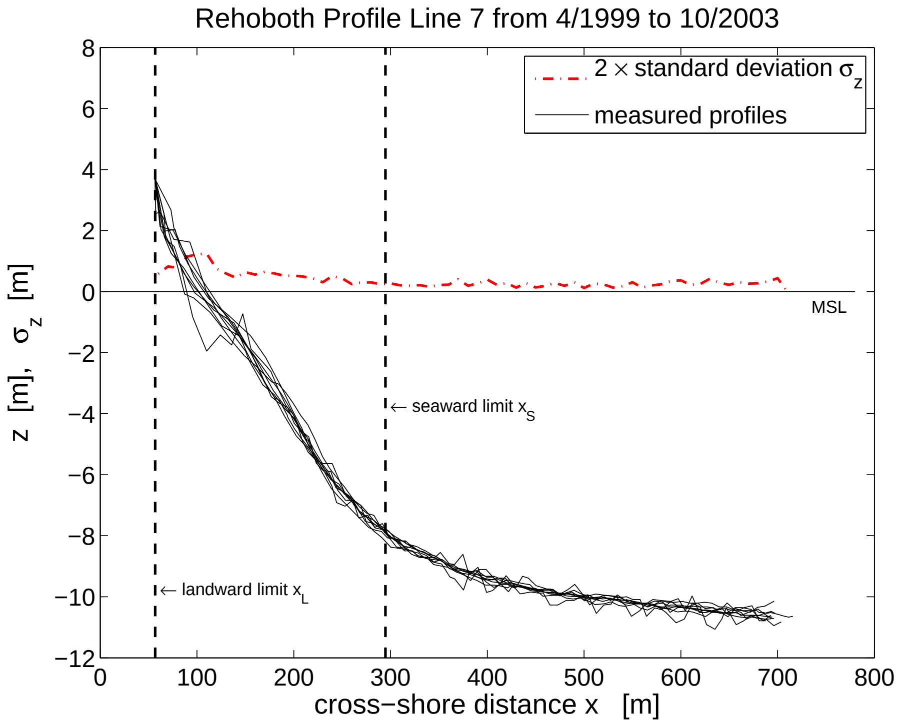
Rehoboth Profile Line 3 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]



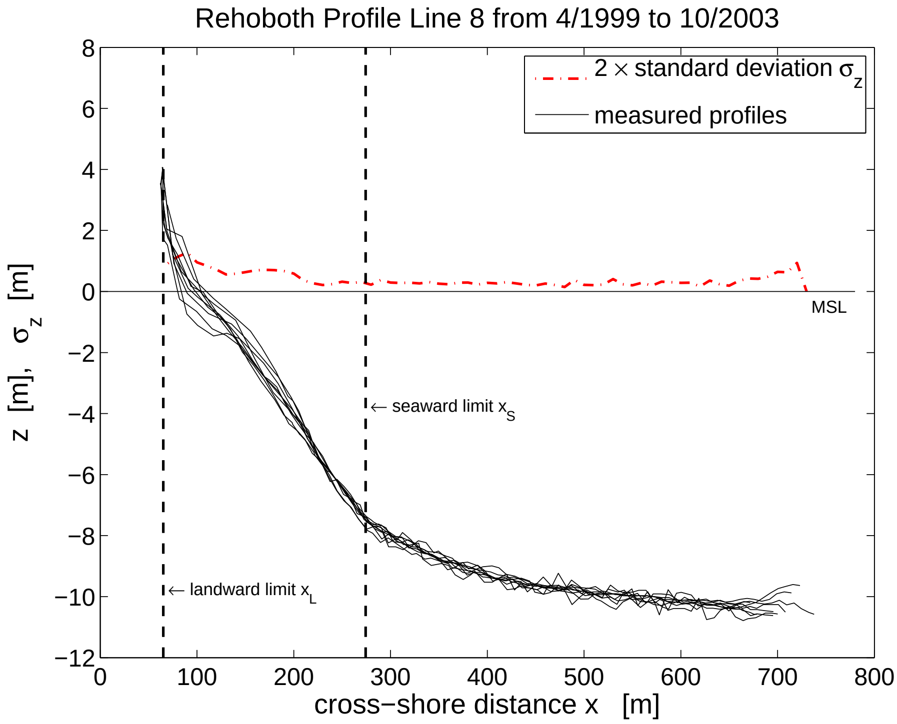
Rehoboth Profile Line 4 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]


Rehoboth Profile Line 5 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800

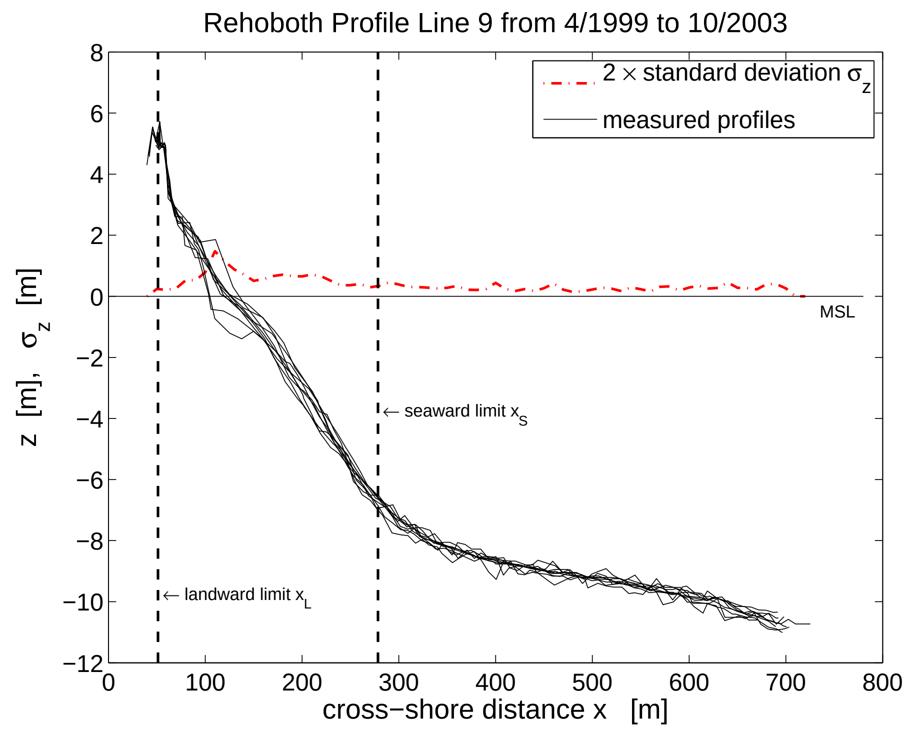

Rehoboth Profile Line 6 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800



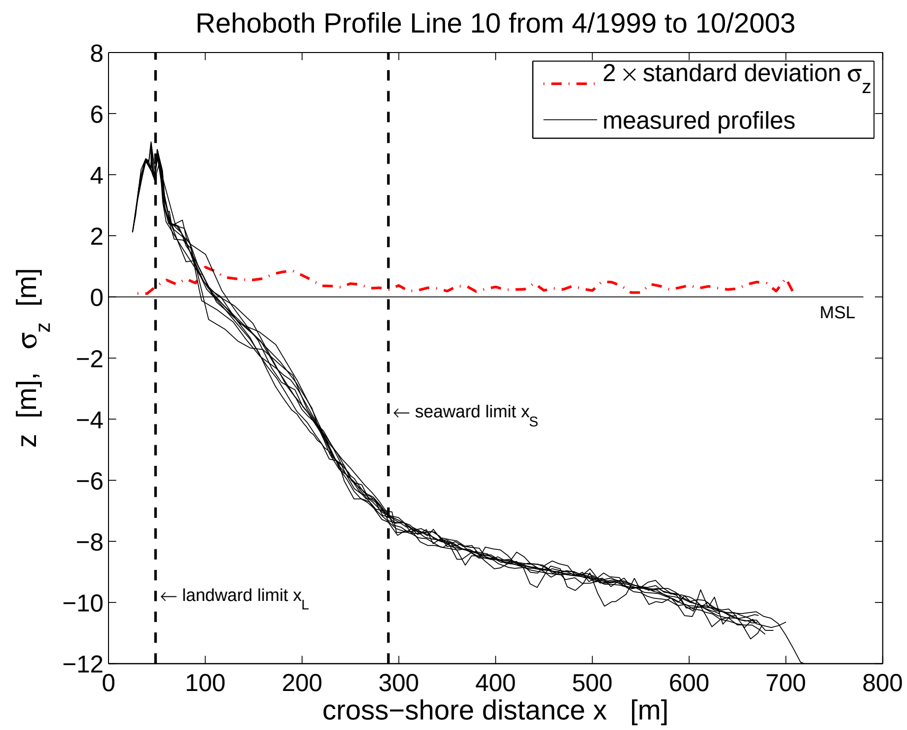
Rehoboth Profile Line 7 from 4/1999 to 10/2003
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]



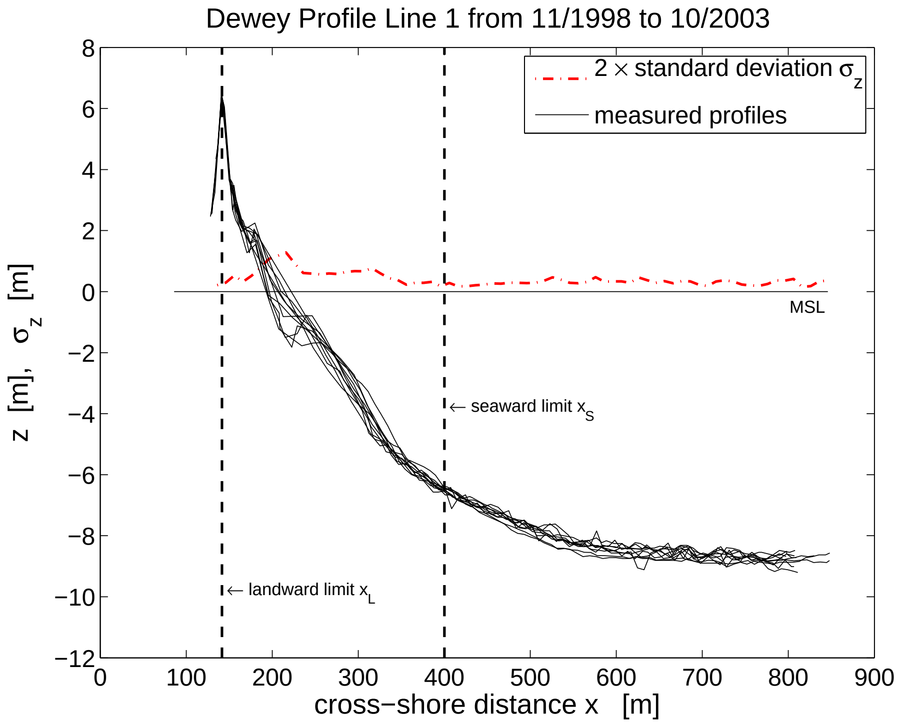
Rehoboth Profile Line 8 from 4/1999 to 10/2003
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]

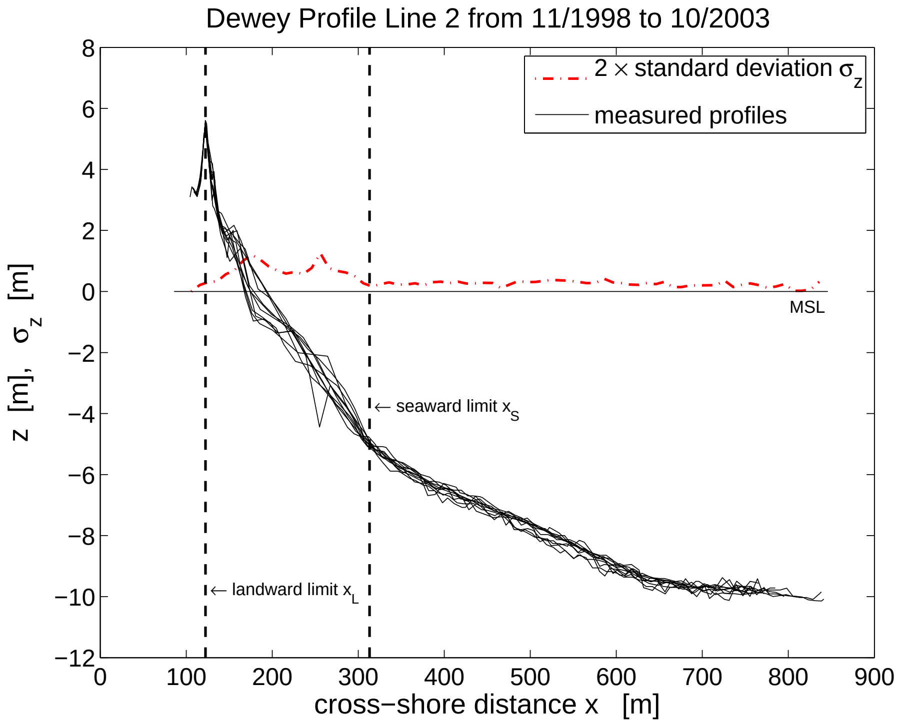


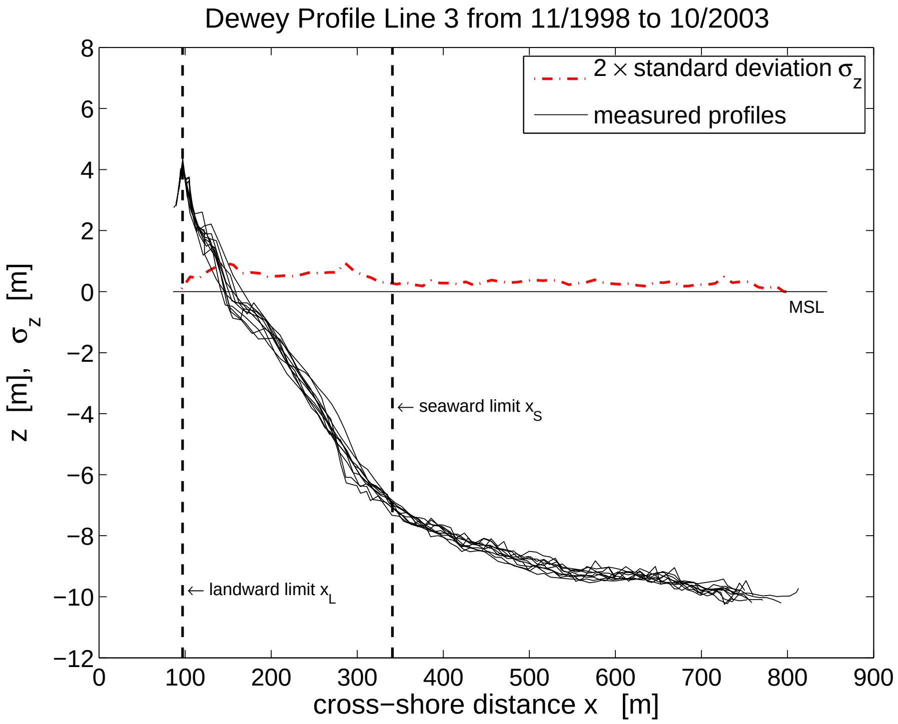
Rehoboth Profile Line 9 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800

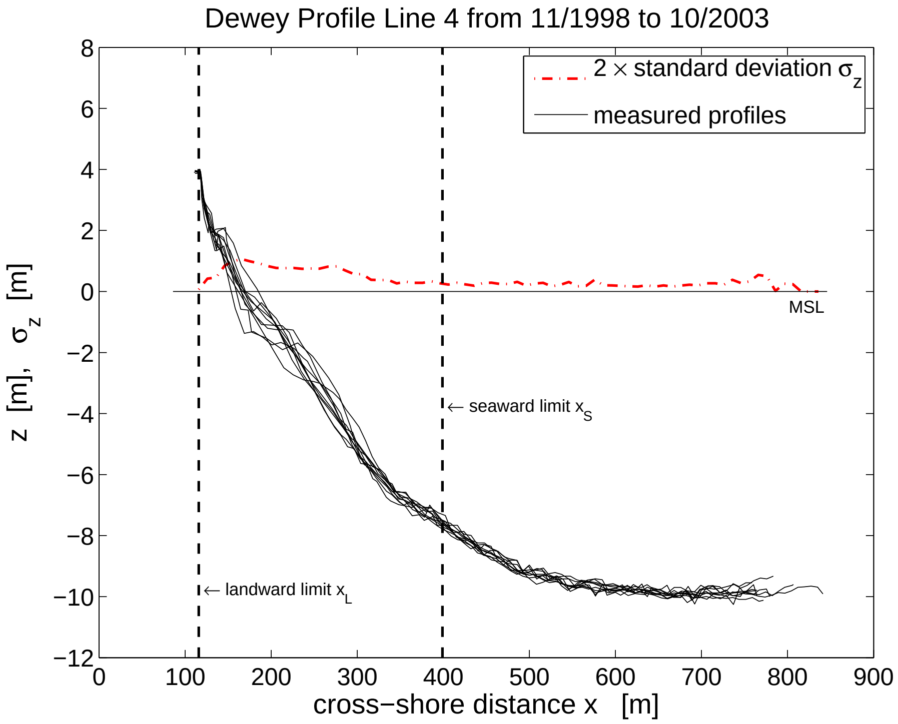


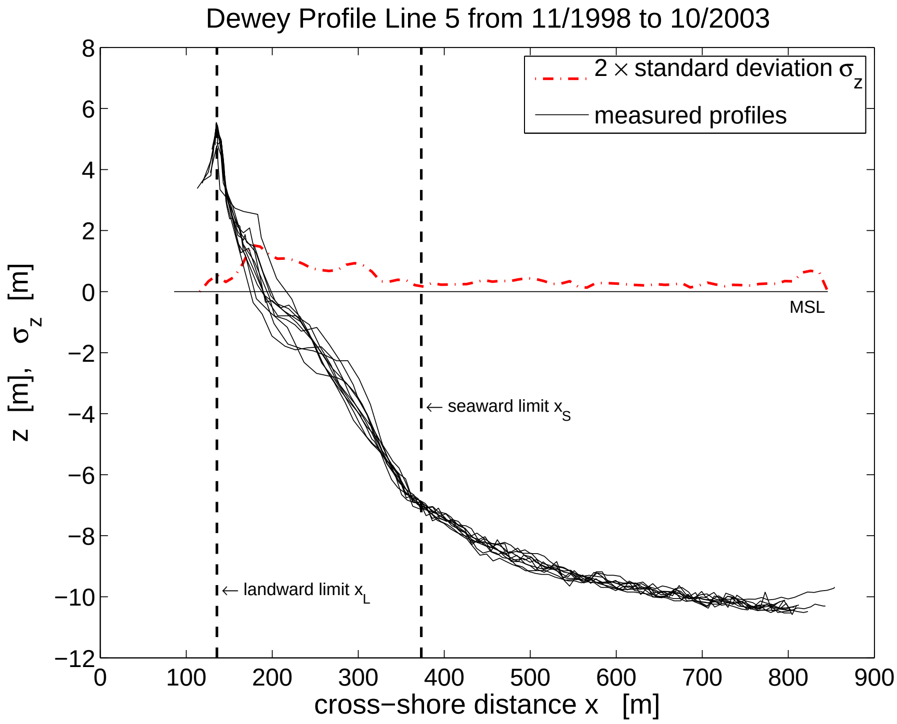
Rehoboth Profile Line 10 from 4/1999 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800

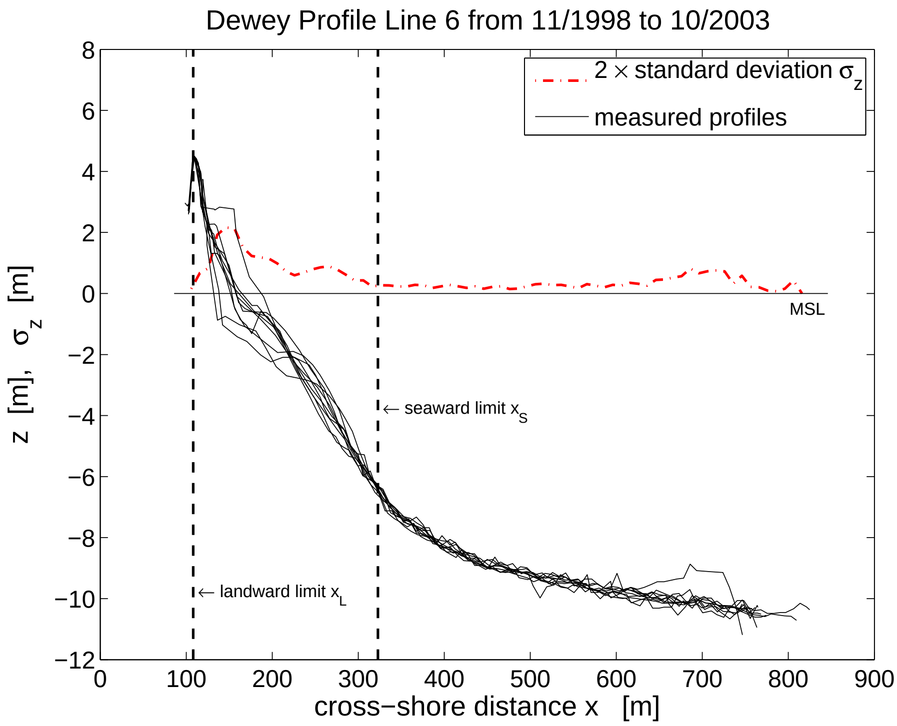

Dewey Profile Line 1 from 11/1998 to 10/2003
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

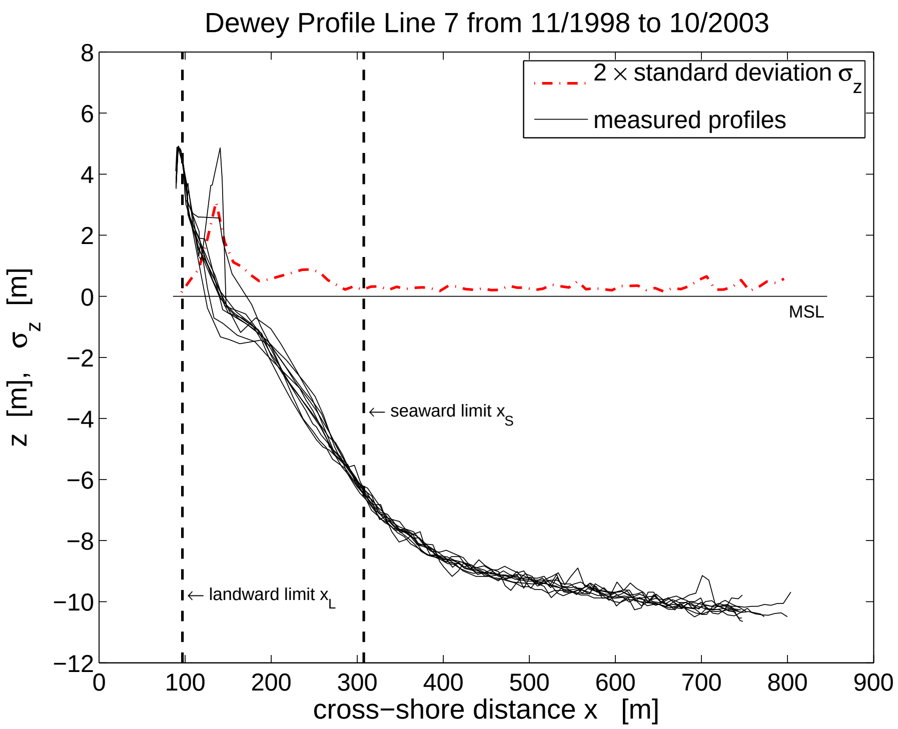

Dewey Profile Line 2 from 11/1998 to 10/2003
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

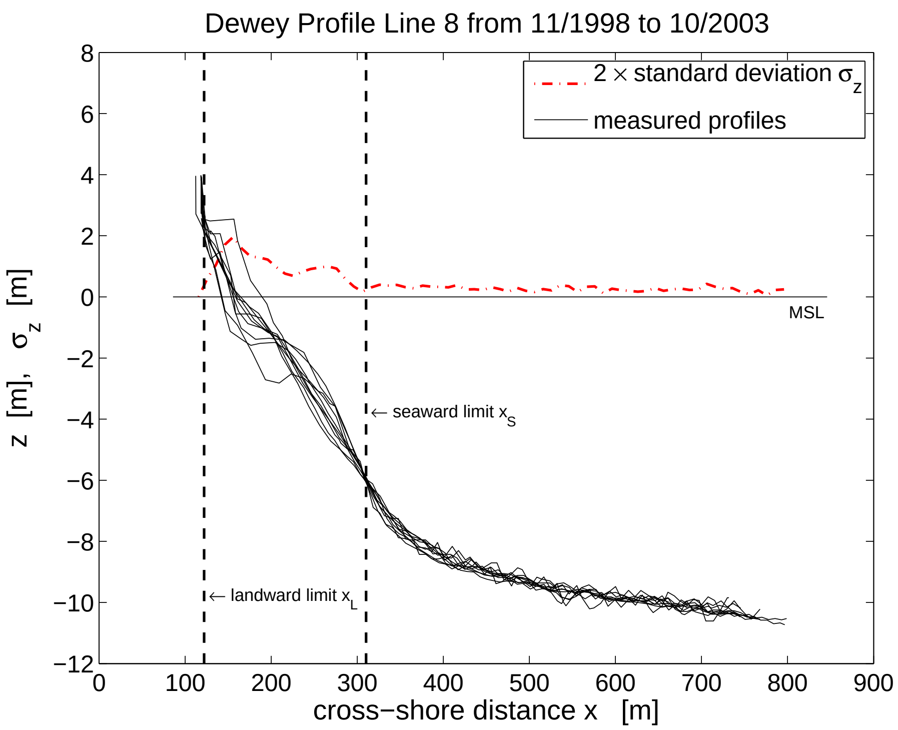

Dewey Profile Line 3 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

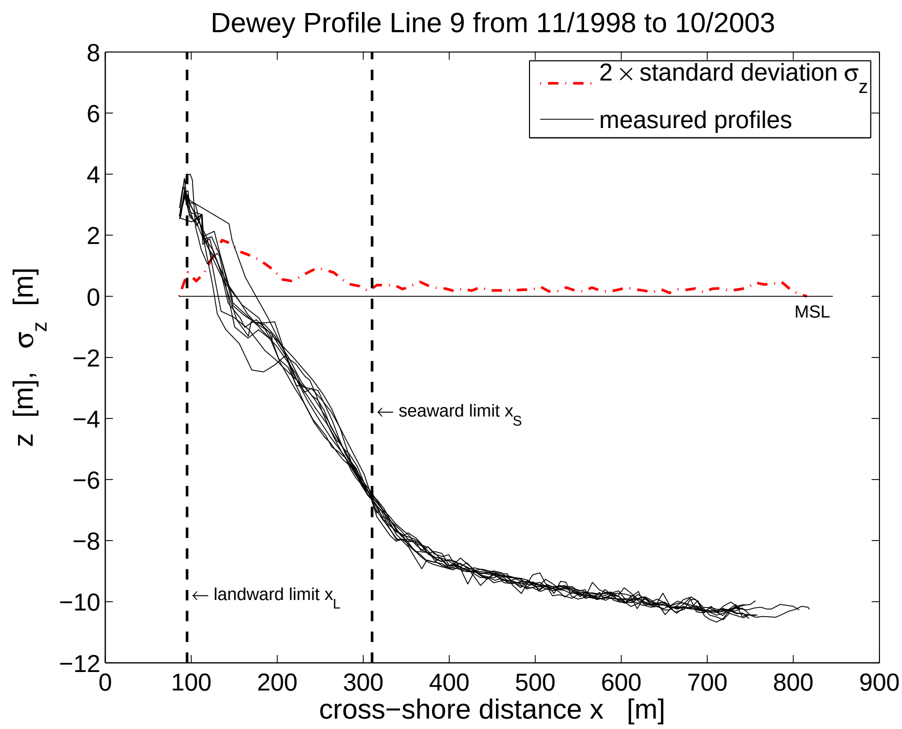

Dewey Profile Line 4 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

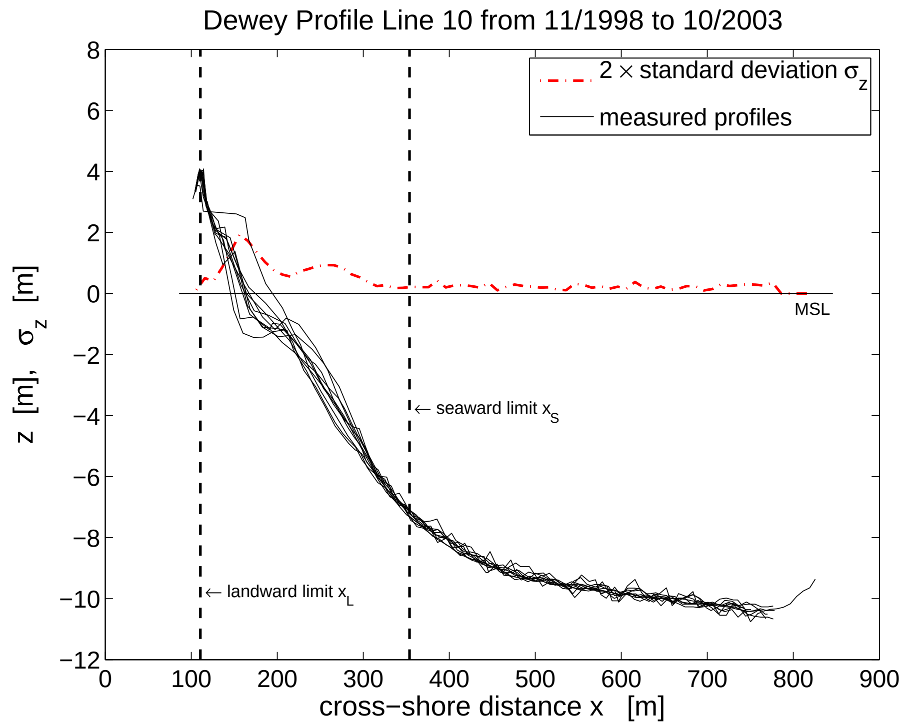

Dewey Profile Line 5 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

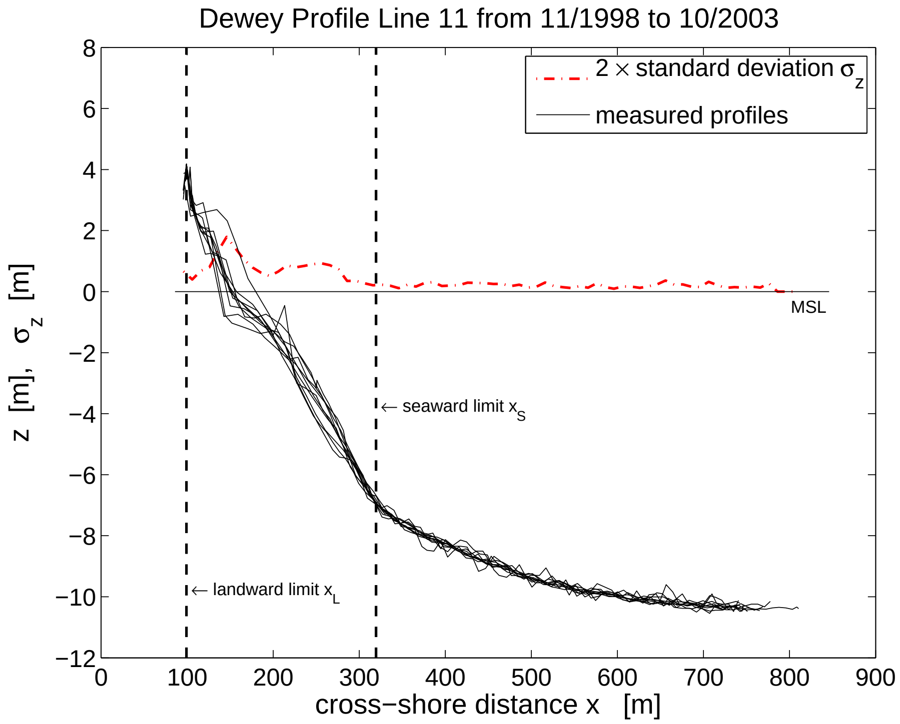

Dewey Profile Line 6 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

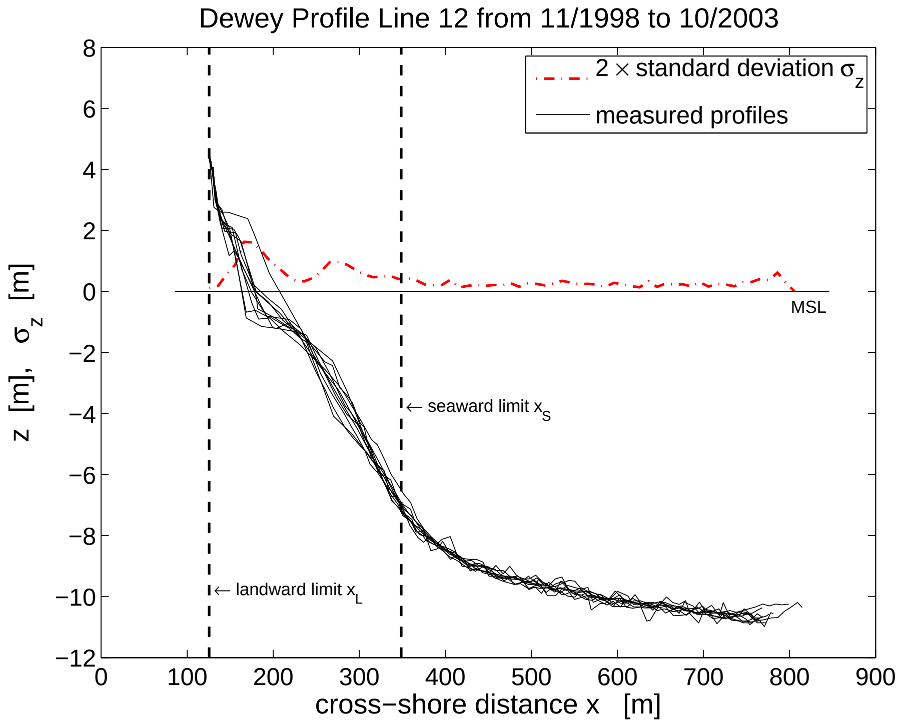

Dewey Profile Line 7 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

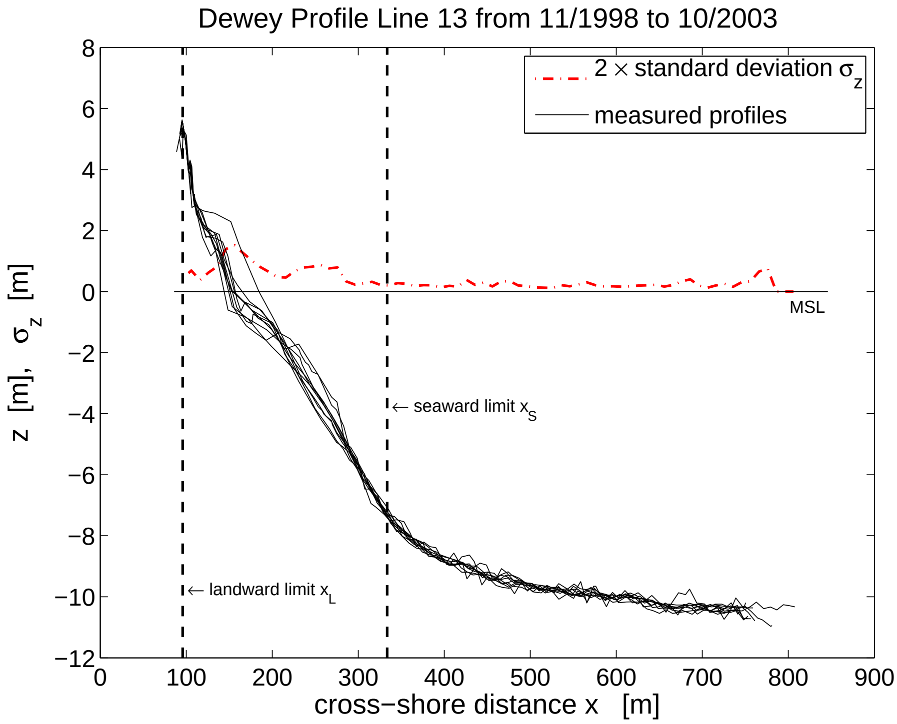

Dewey Profile Line 8 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900


Dewey Profile Line 9 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

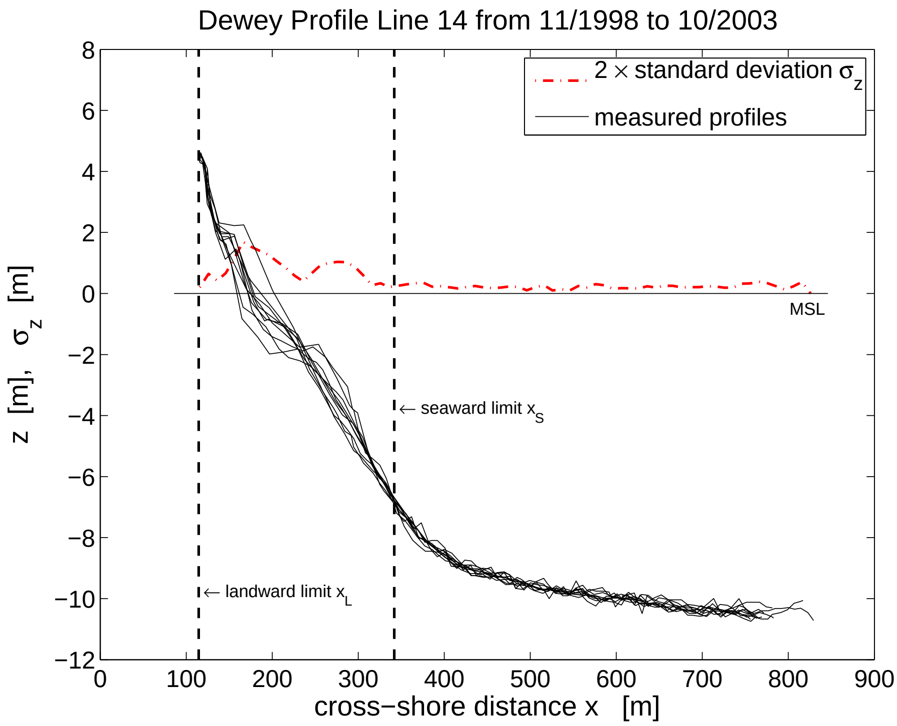

Dewey Profile Line 10 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]


Dewey Profile Line 11 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

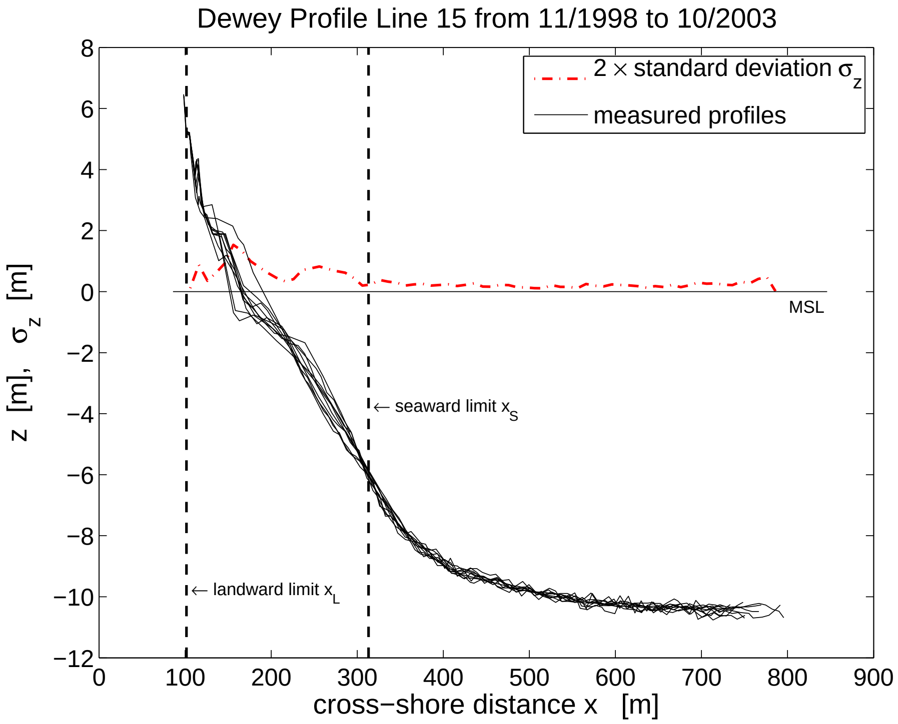

Dewey Profile Line 12 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900



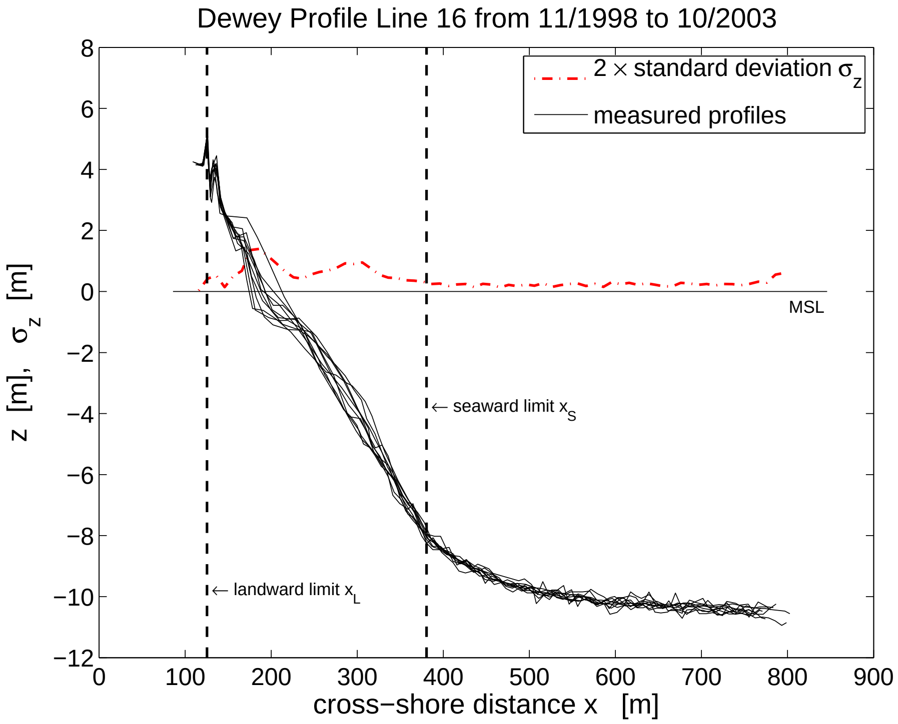
Dewey Profile Line 13 from 11/1998 to 10/2003
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]



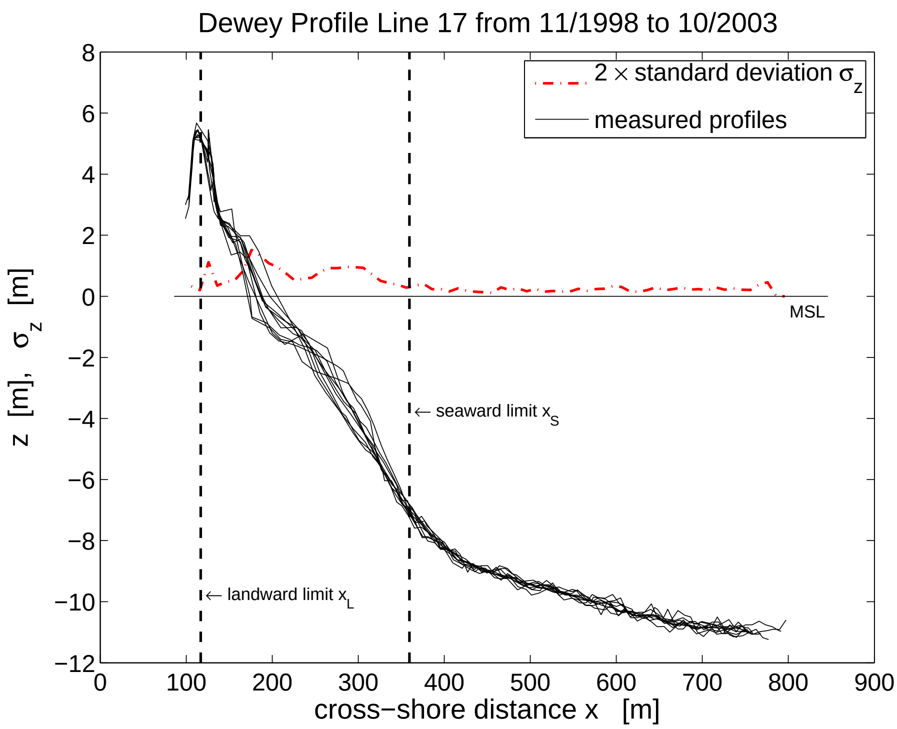
Dewey Profile Line 14 from 11/1998 to 10/2003
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]

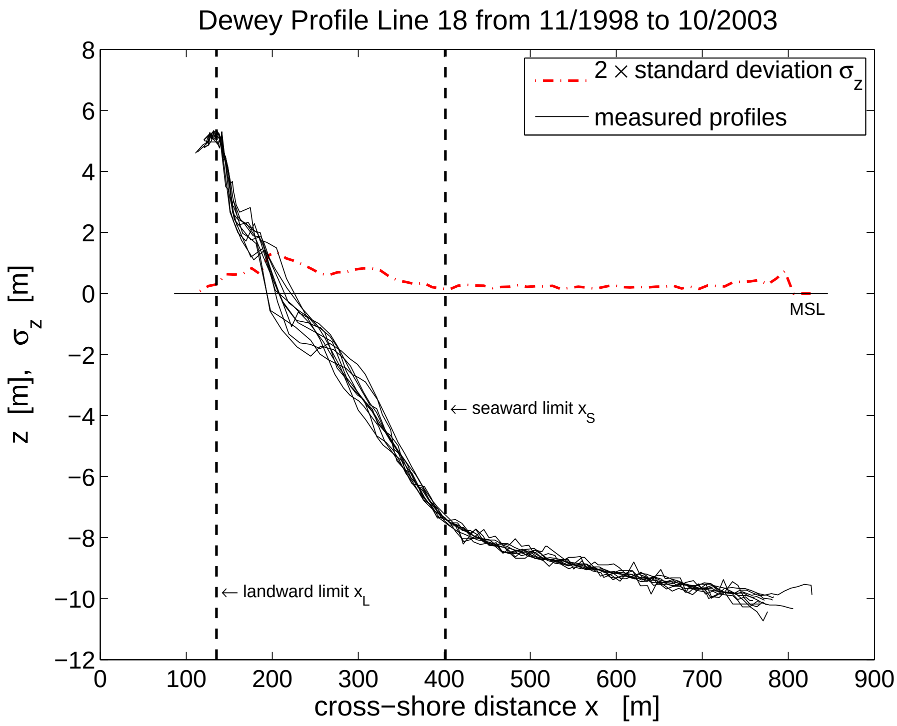


Dewey Profile Line 15 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]



Dewey Profile Line 16 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]


Dewey Profile Line 17 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900


Dewey Profile Line 18 from 11/1998 to 10/2003
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
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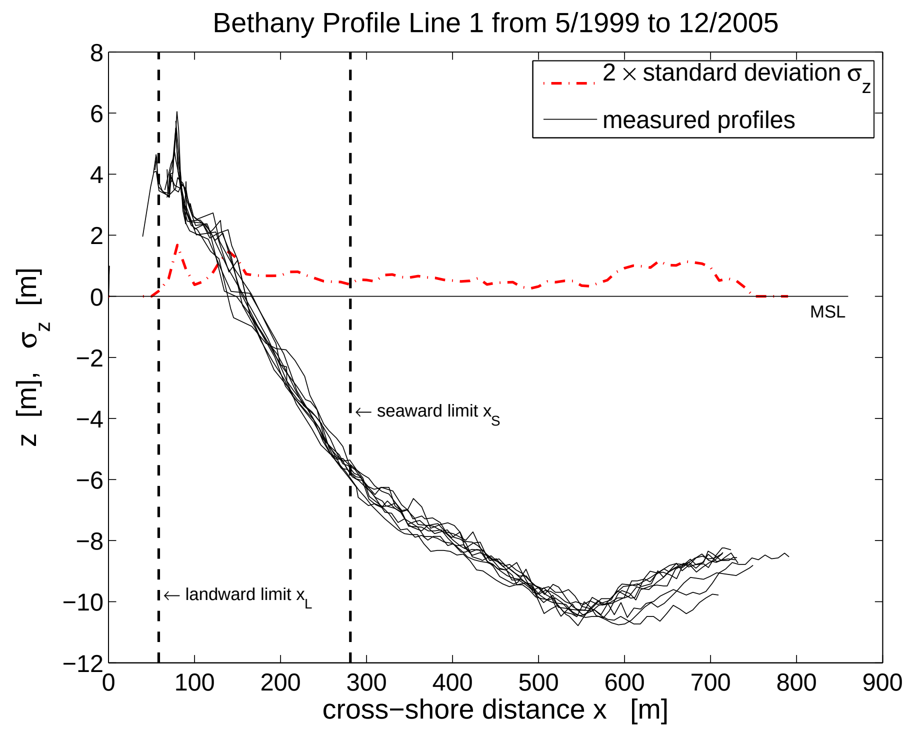
600
700
800
900


Bethany Profile Line 1 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
z [m], σz [m]
cross−shore distance x [m]
MSL
← seaward limit xS
← landward limit xL
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
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600
700
800
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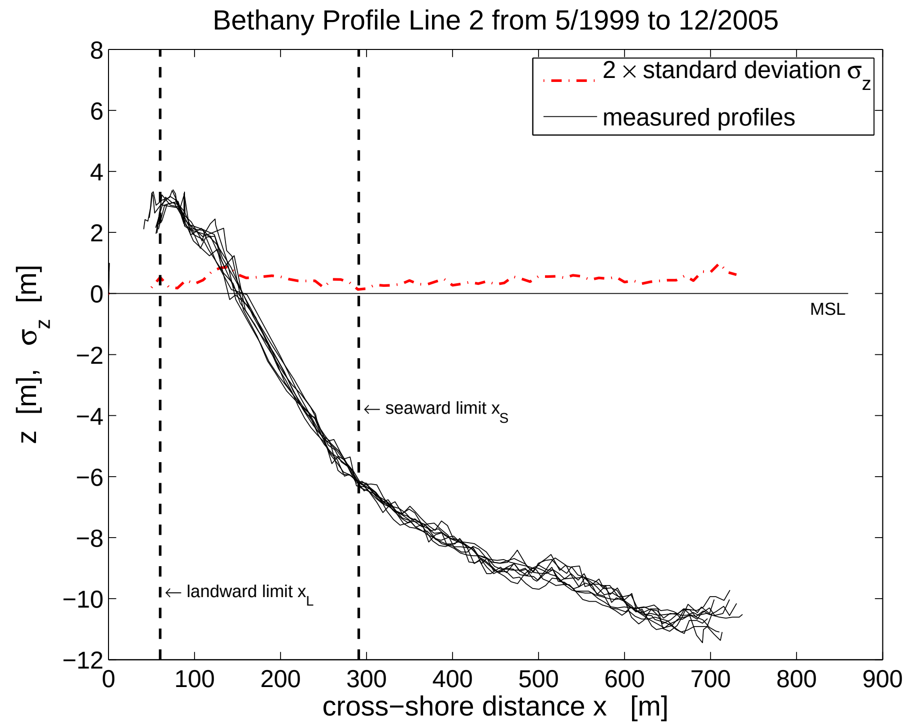
Bethany Profile Line 2 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
z [m], σz [m]
cross−shore distance x [m]
MSL
← seaward limit xS
← landward limit xL
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
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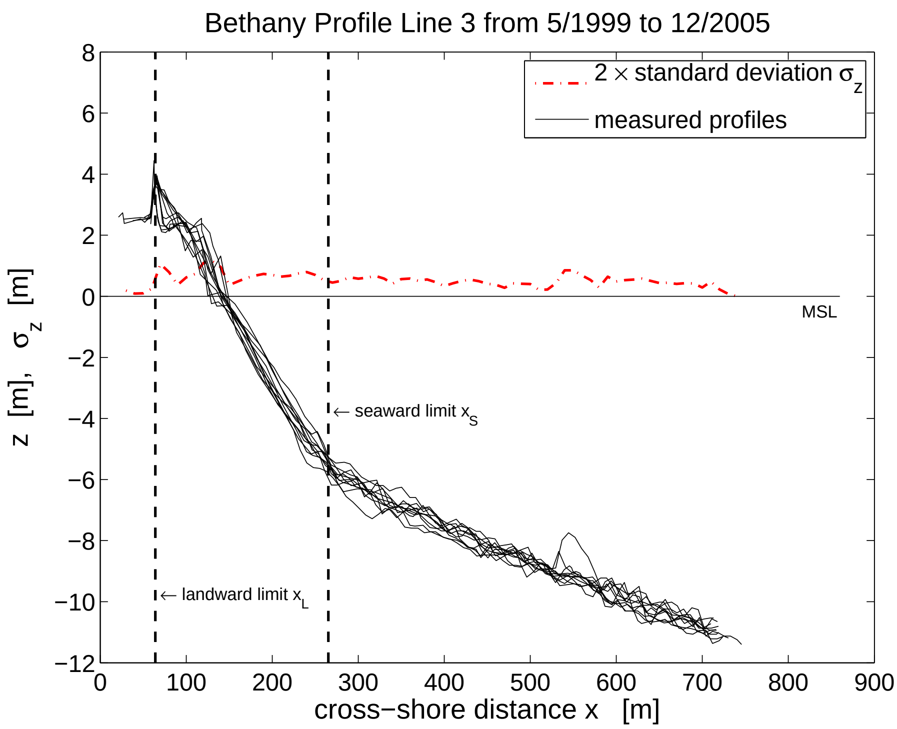
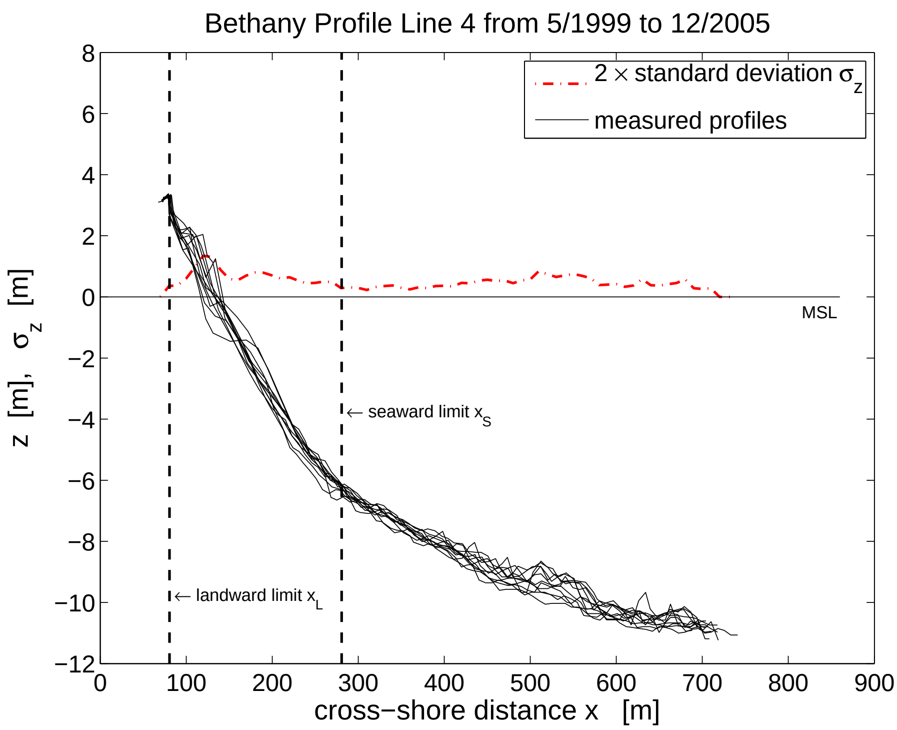
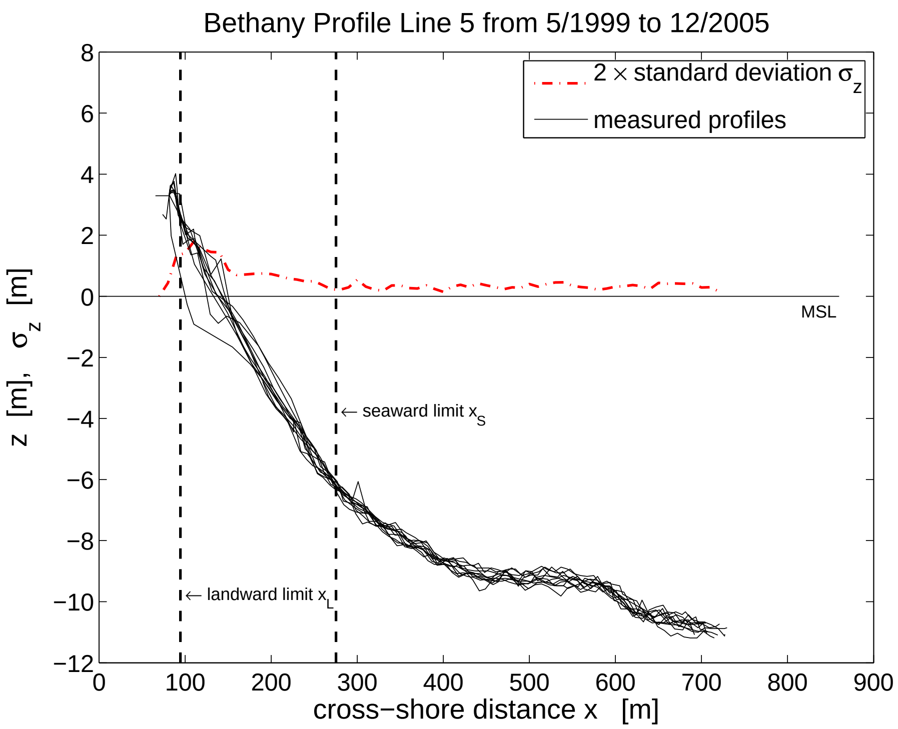
700
800
900



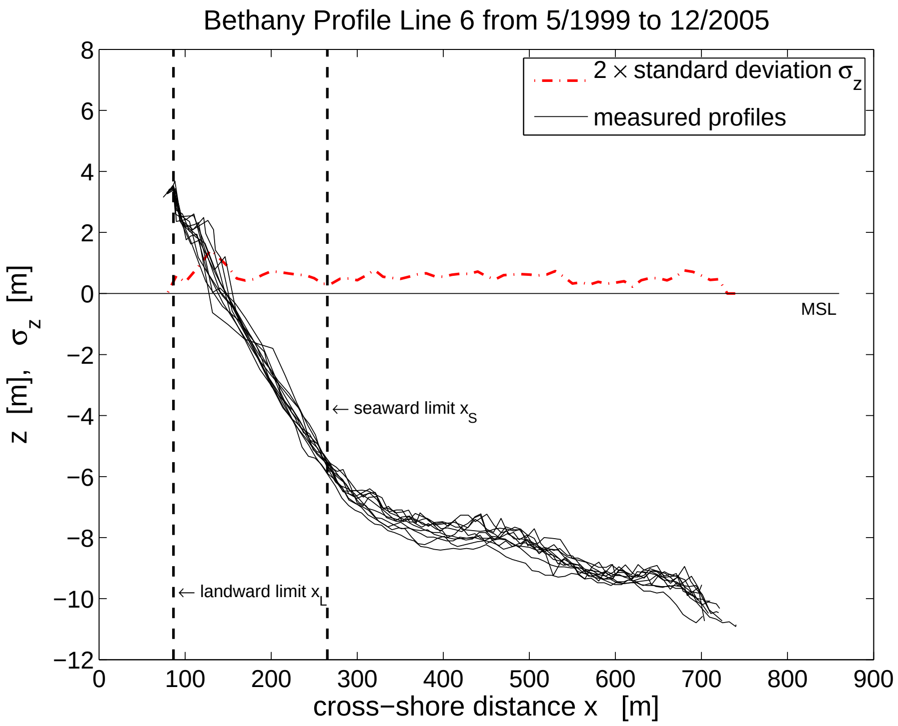
Bethany Profile Line 3 from 5/1999 to 12/2005
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]



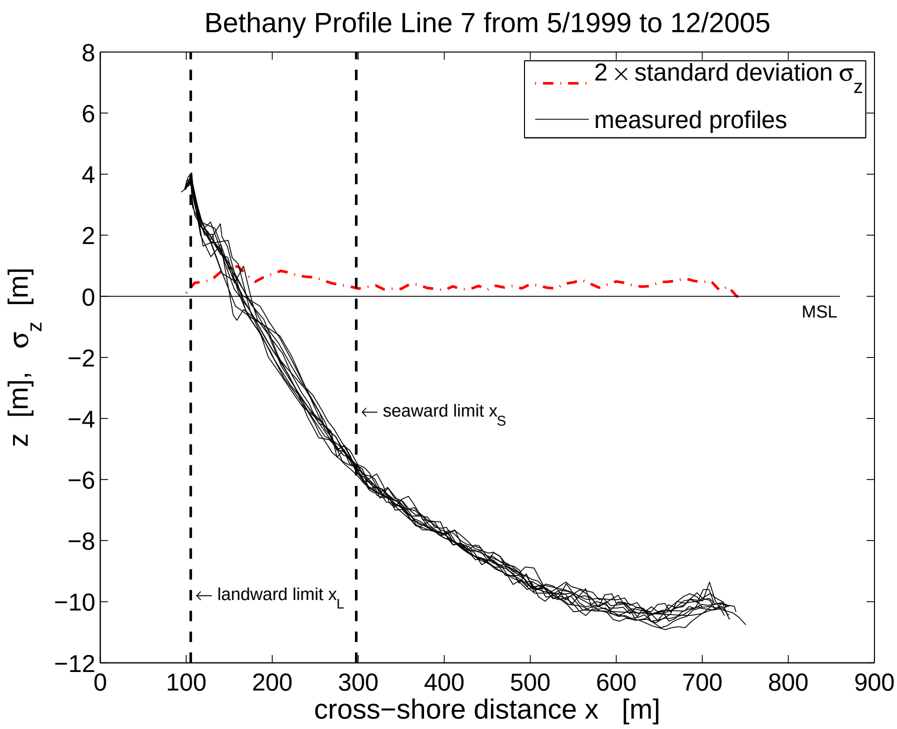
Bethany Profile Line 4 from 5/1999 to 12/2005
2 × standard deviation σ_z
measured profiles
MSL
← seaward limit x_S
← landward limit x_L
z [m], σ_z [m]
cross−shore distance x [m]



Bethany Profile Line 5 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]



Bethany Profile Line 6 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]


Bethany Profile Line 7 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
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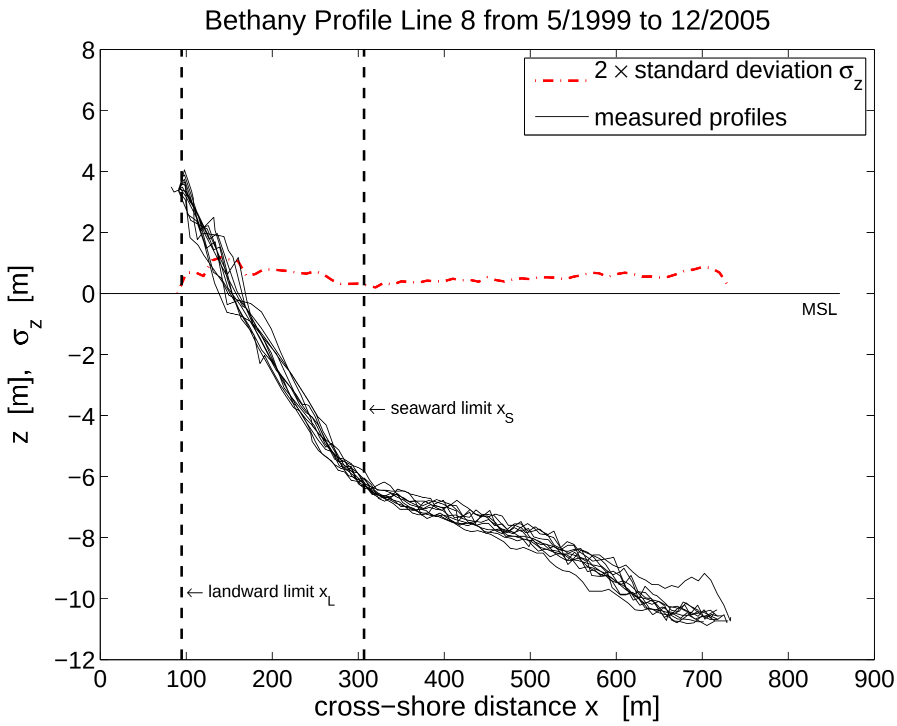
700
800
900


Bethany Profile Line 8 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
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700
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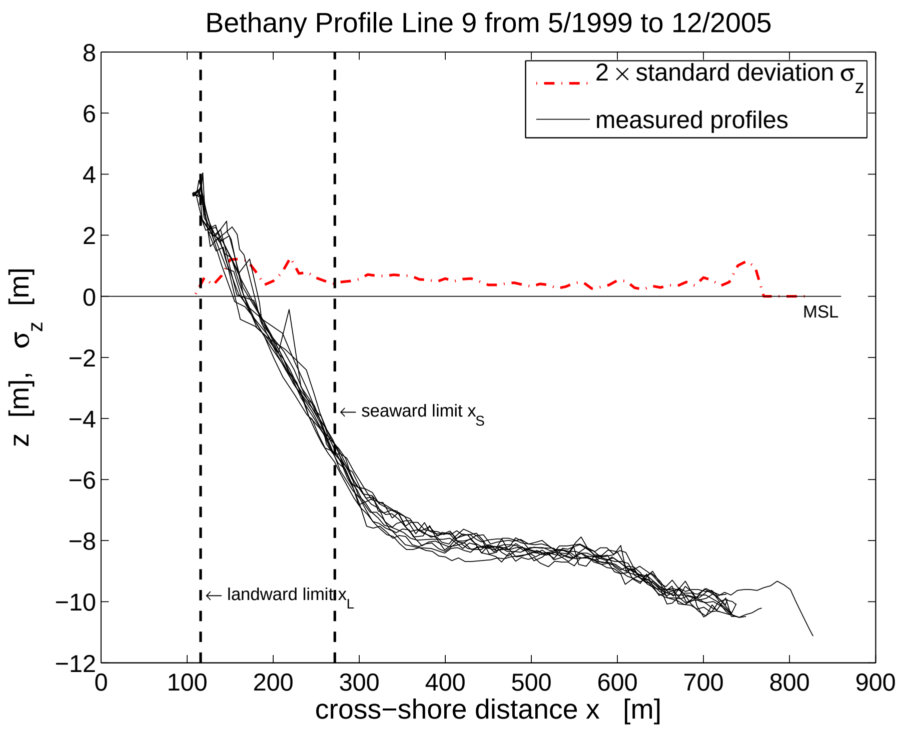
Bethany Profile Line 9 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
← seaward limit xS
← landward limit xL
MSL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
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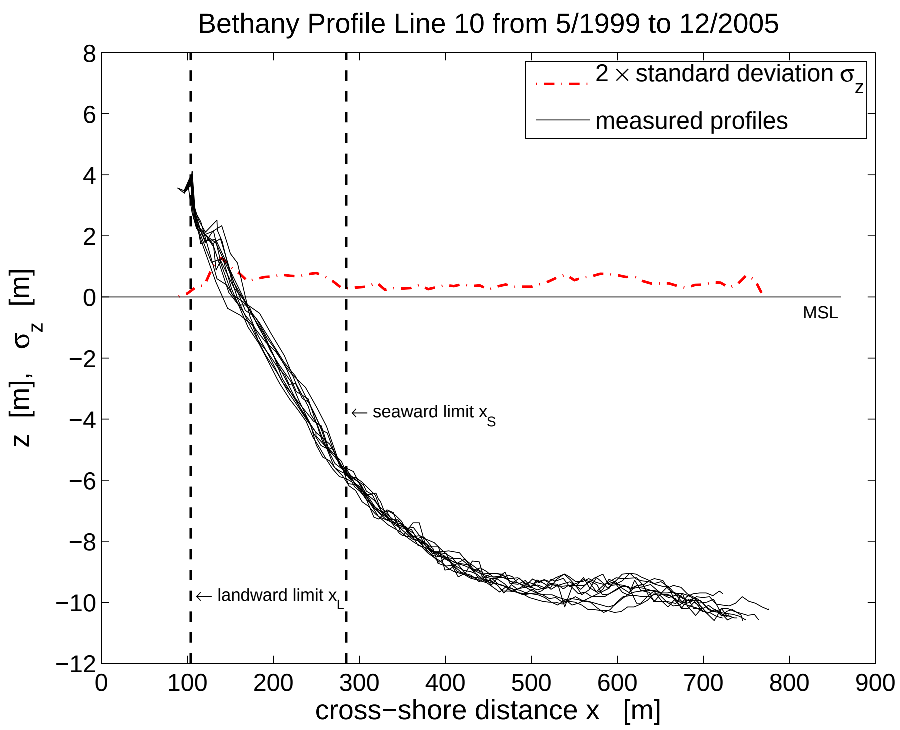
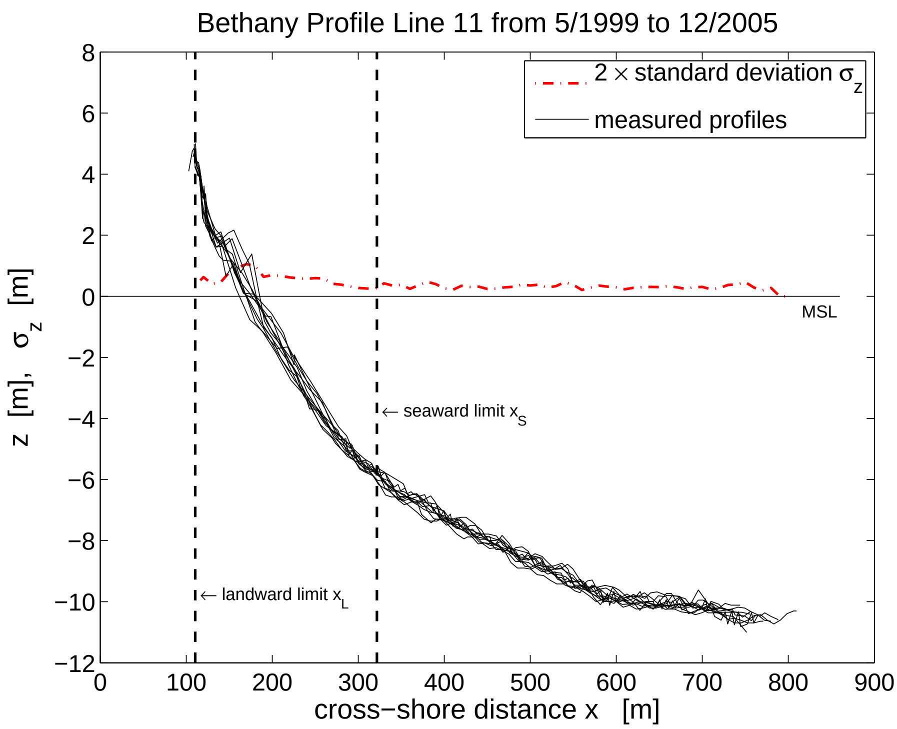
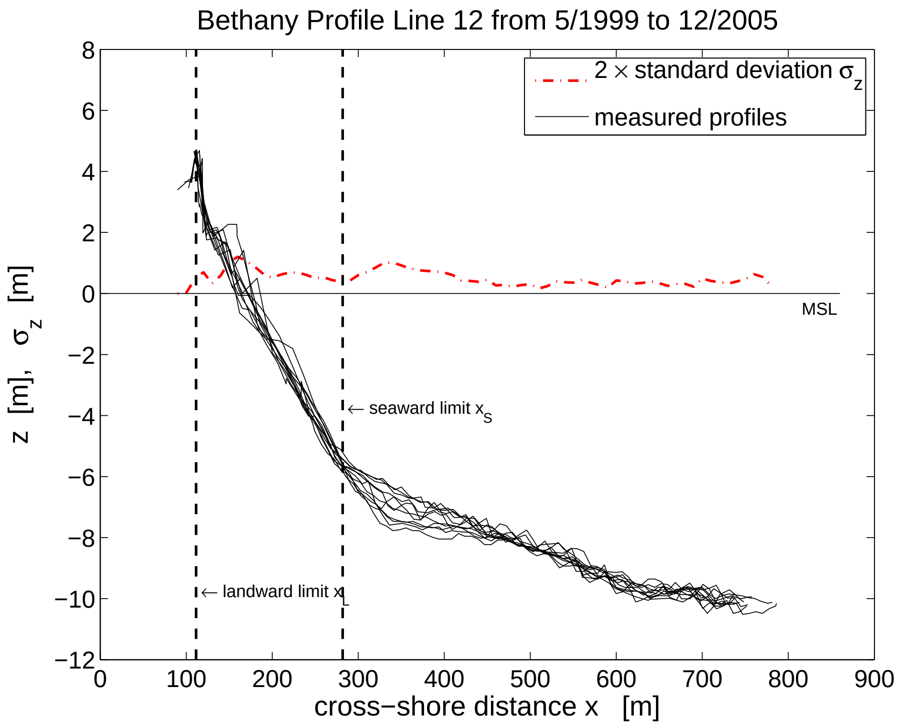
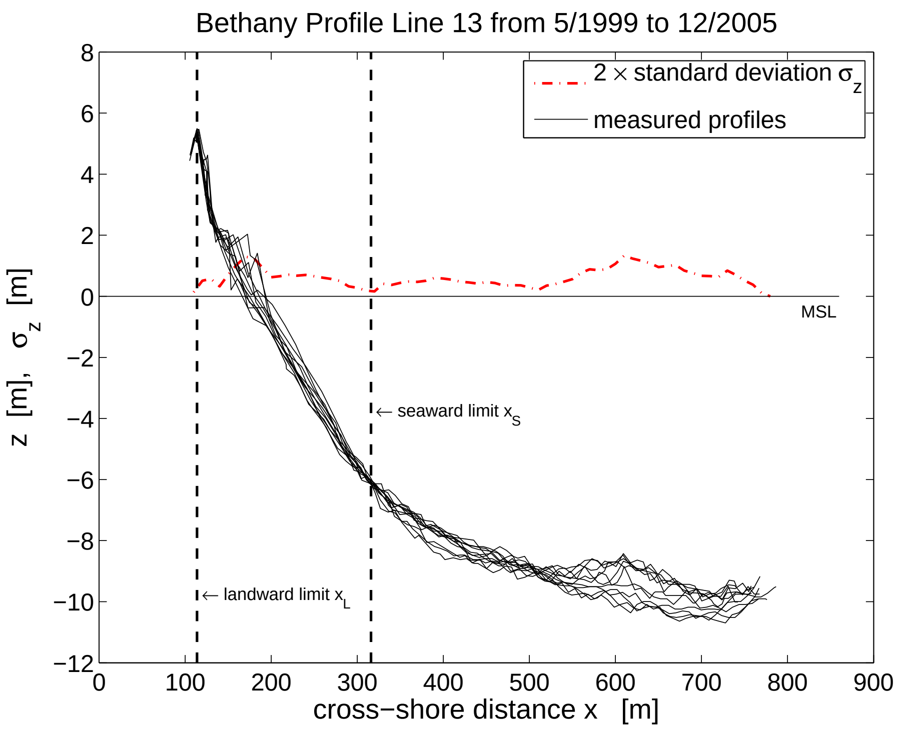
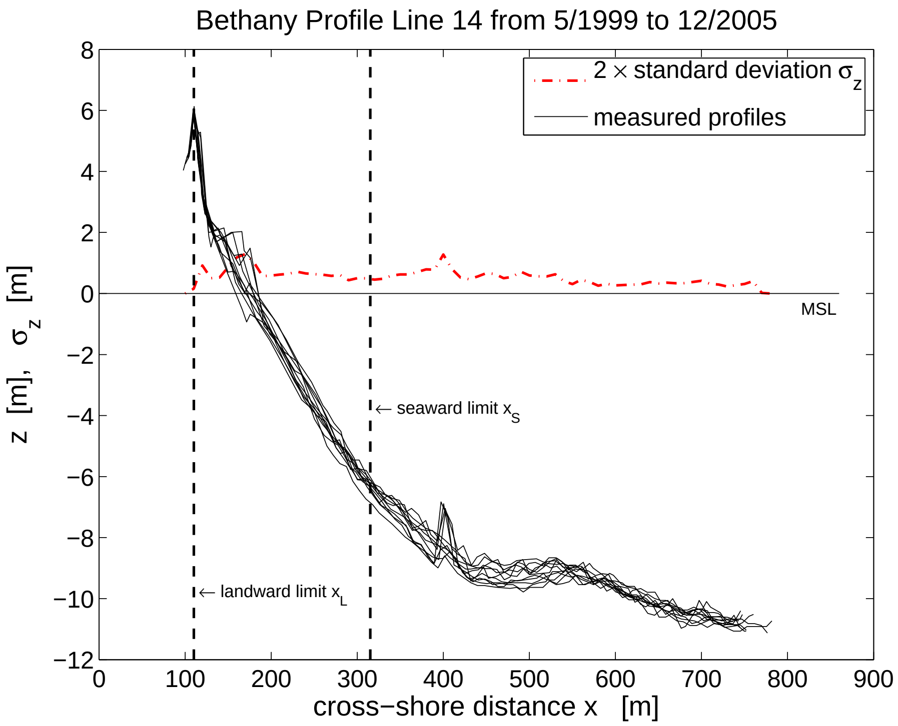
600
700
800
900

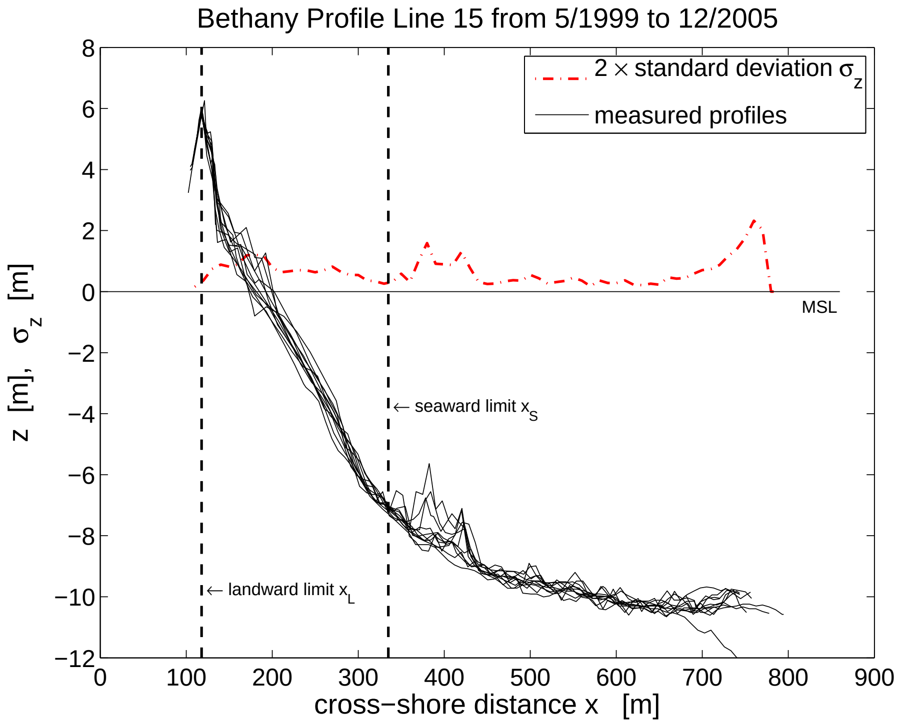

Bethany Profile Line 10 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
← seaward limit xS
← landward limit xL
MSL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

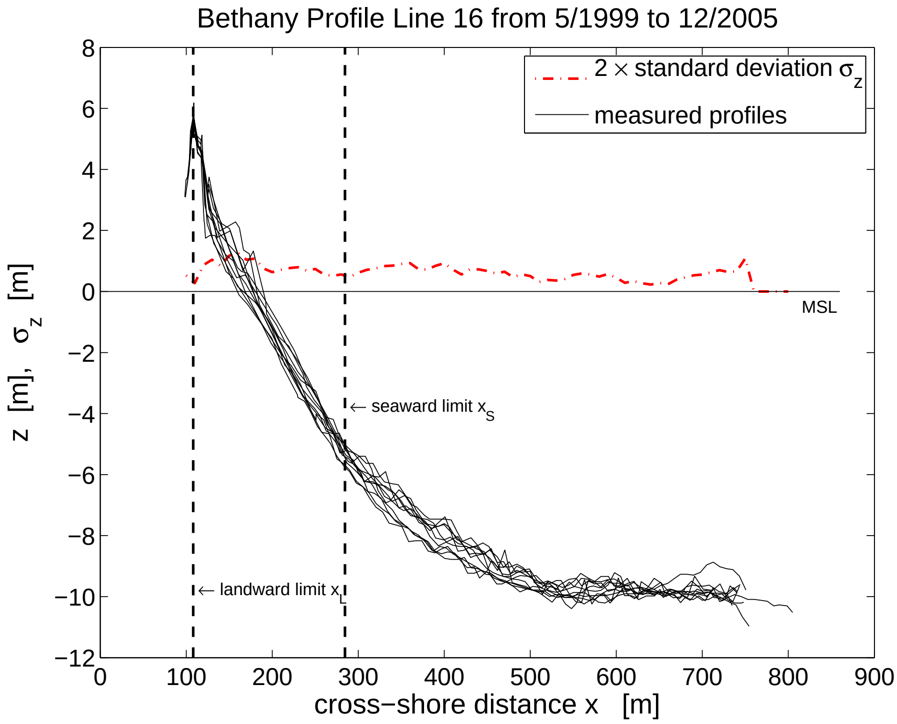

Bethany Profile Line 11 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

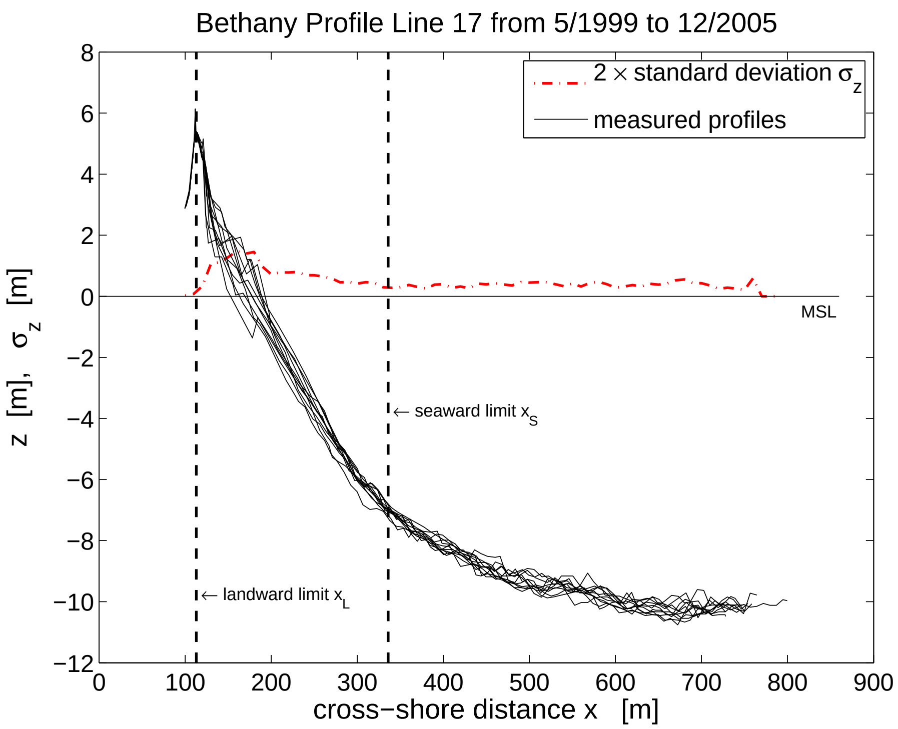

Bethany Profile Line 12 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

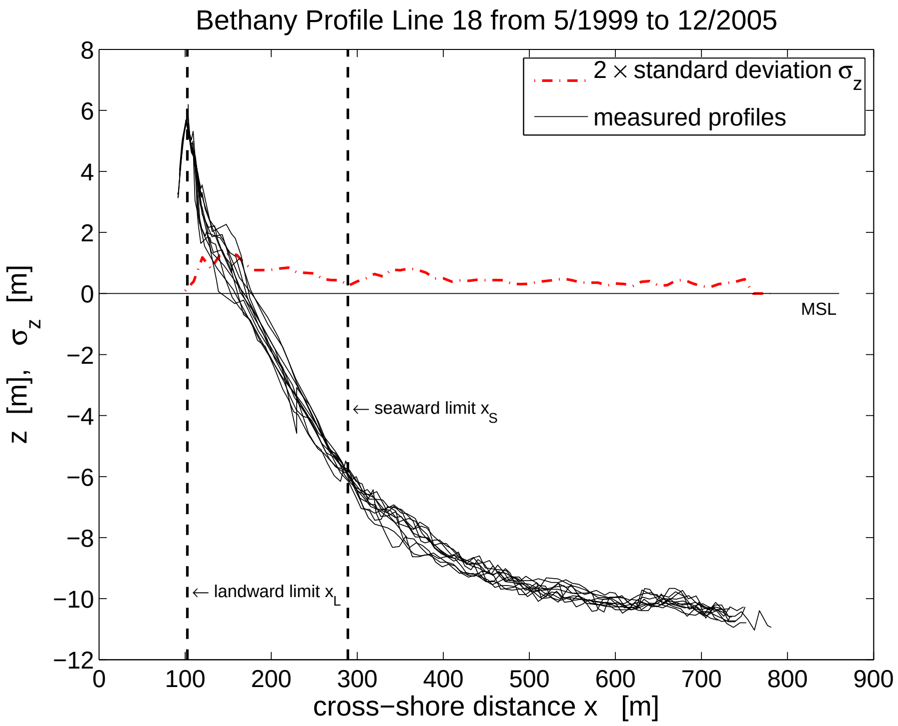

Bethany Profile Line 13 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

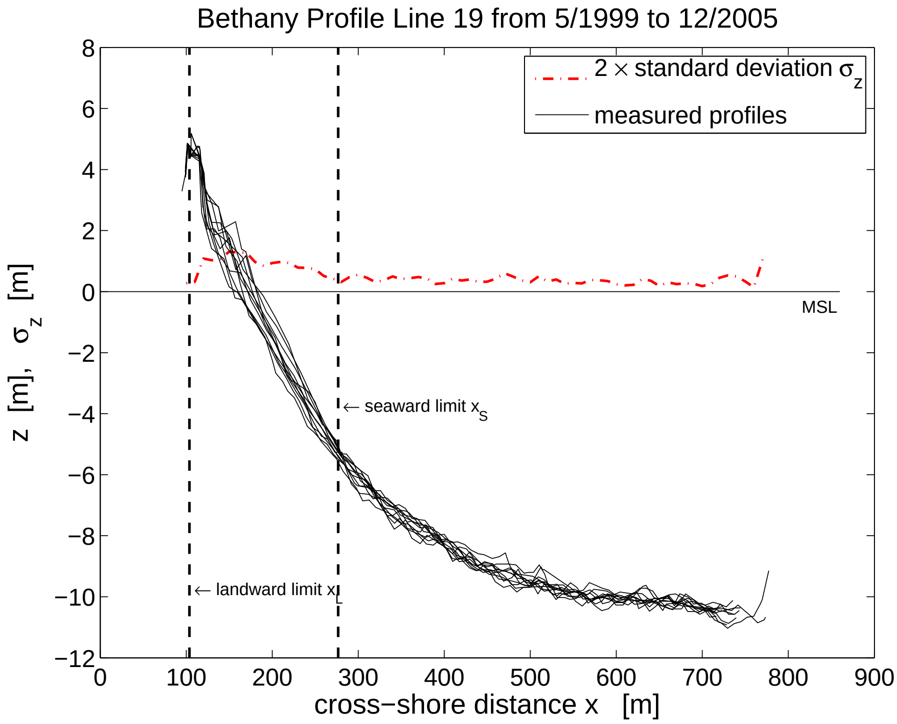

Bethany Profile Line 14 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

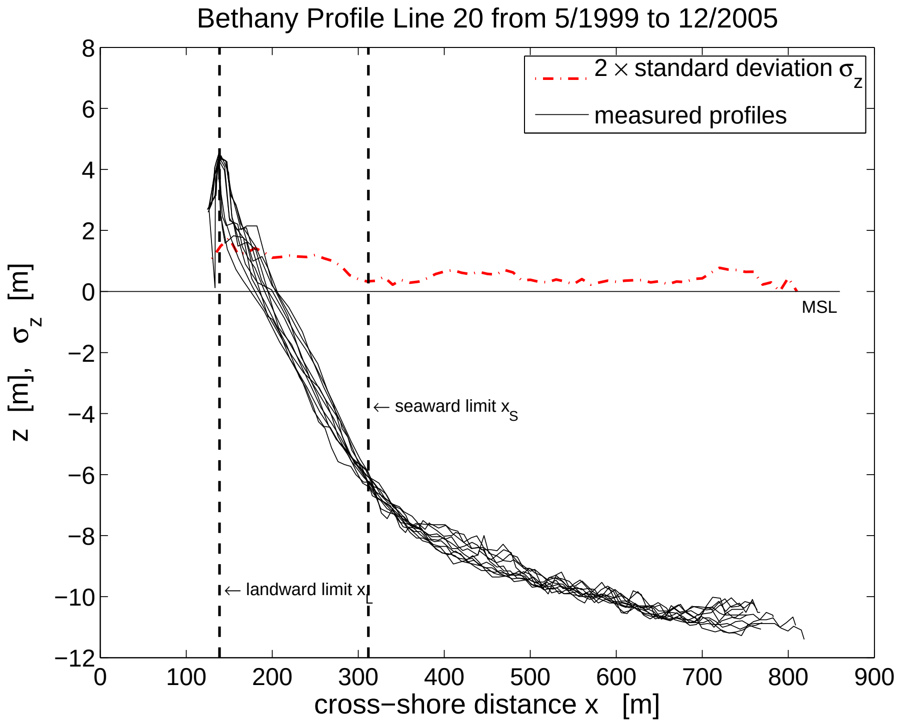

Bethany Profile Line 15 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

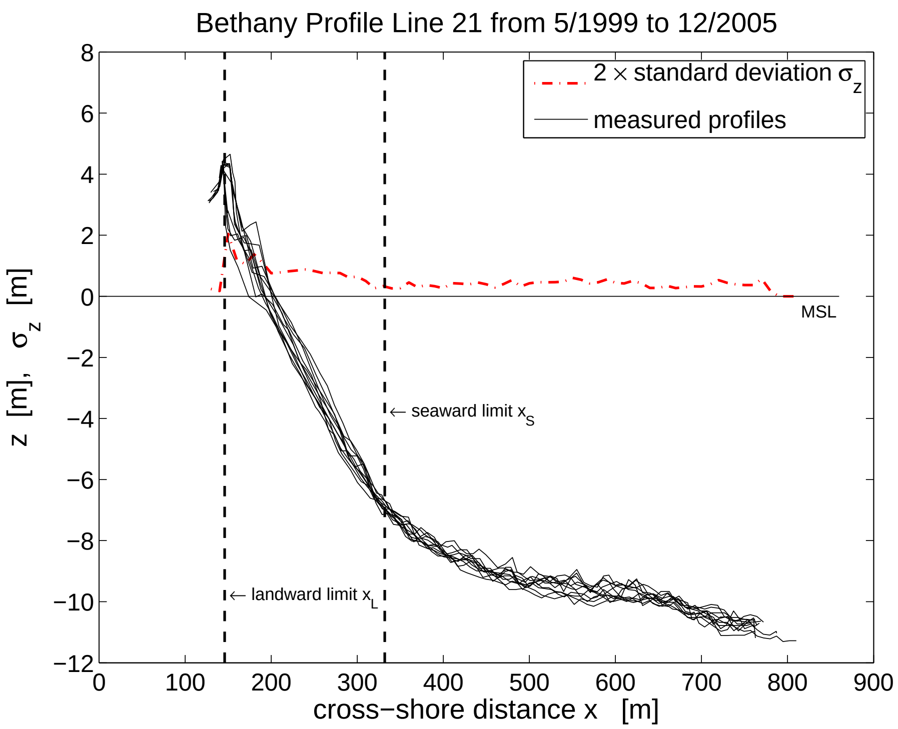

Bethany Profile Line 16 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

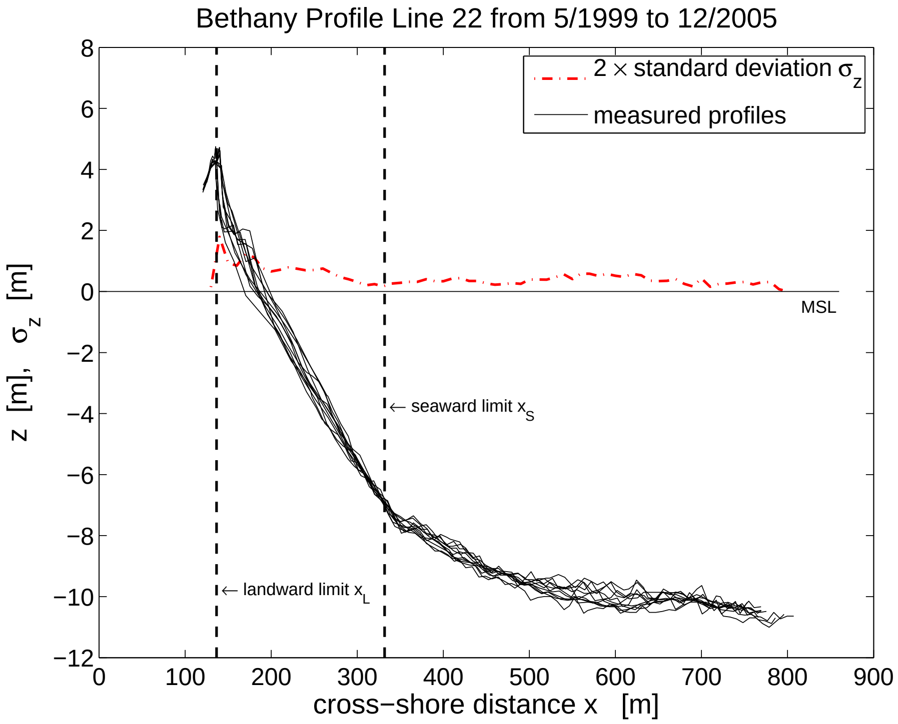

Bethany Profile Line 17 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

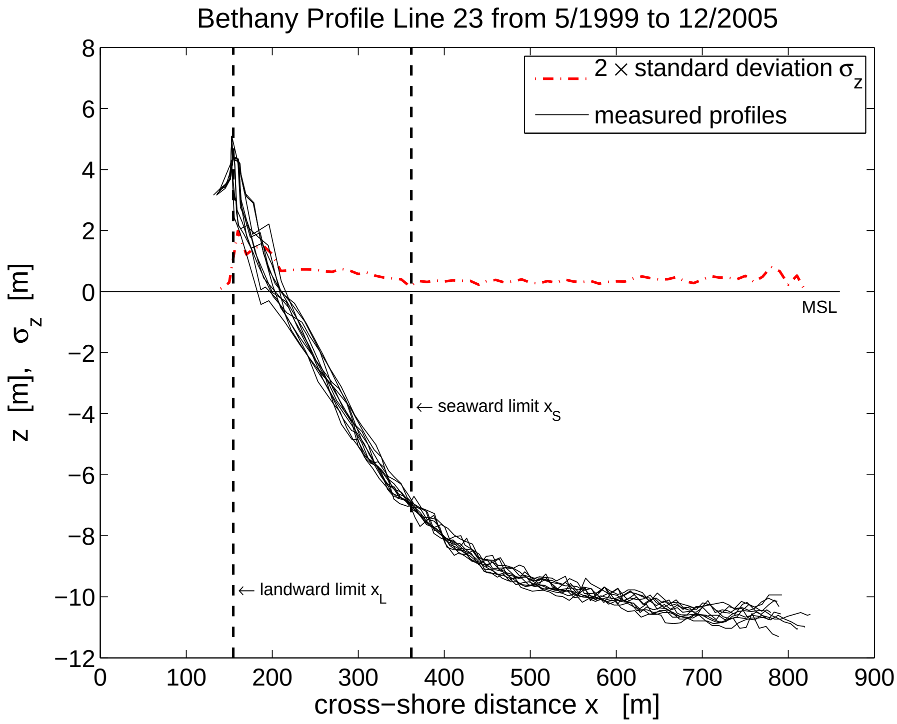

Bethany Profile Line 18 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

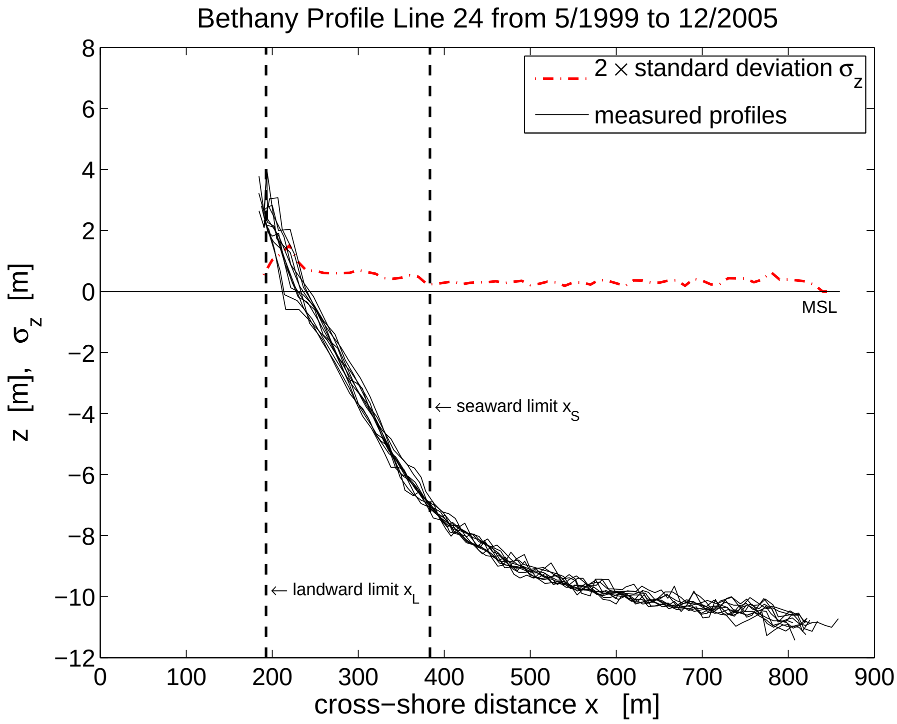

Bethany Profile Line 19 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

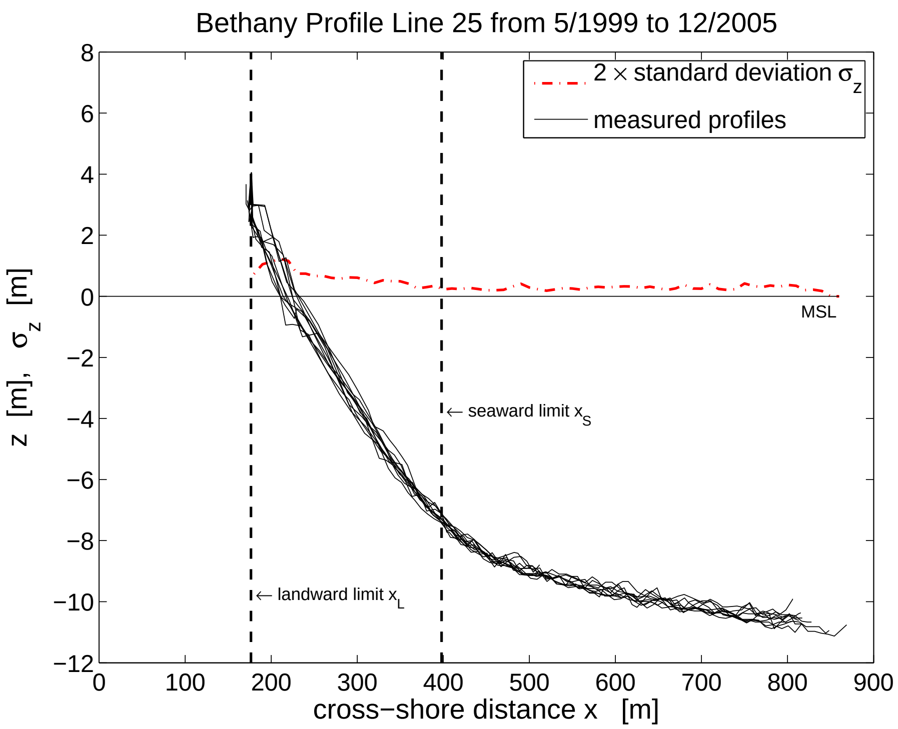

Bethany Profile Line 20 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

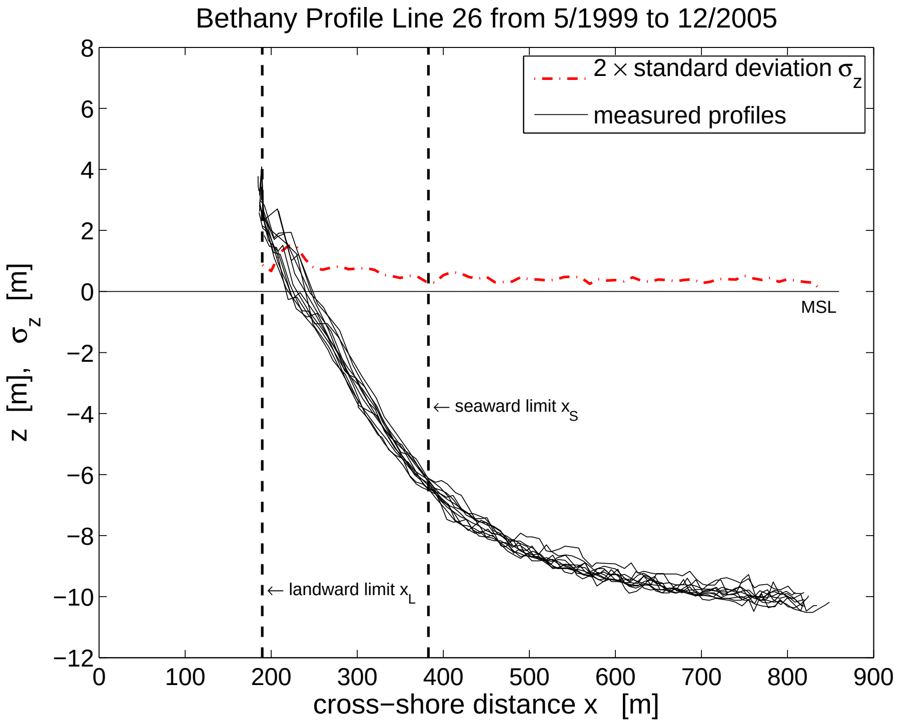

Bethany Profile Line 21 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

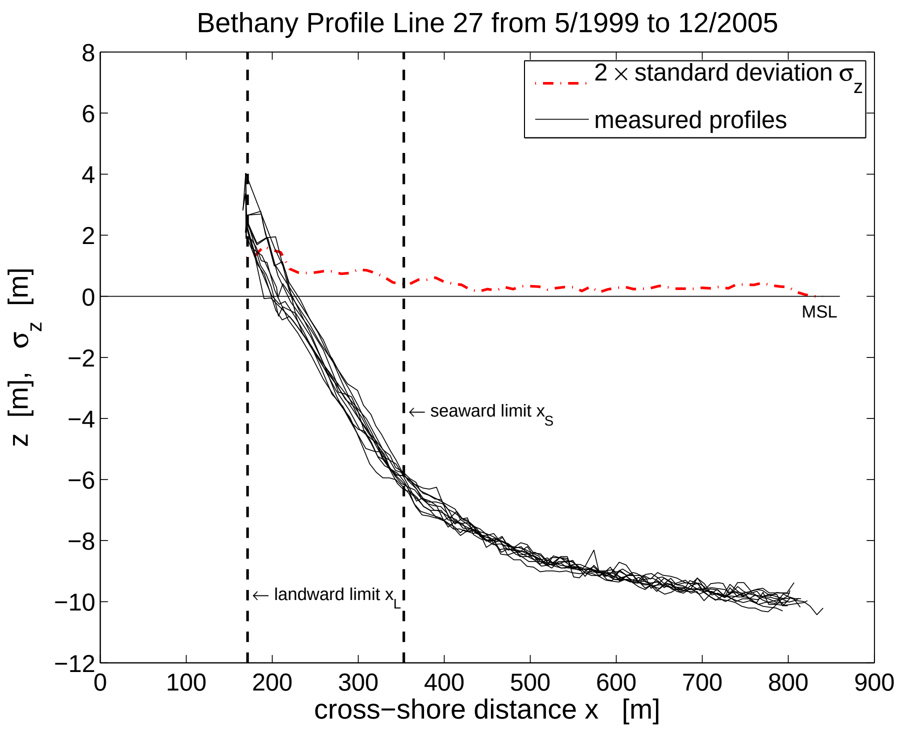

Bethany Profile Line 22 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

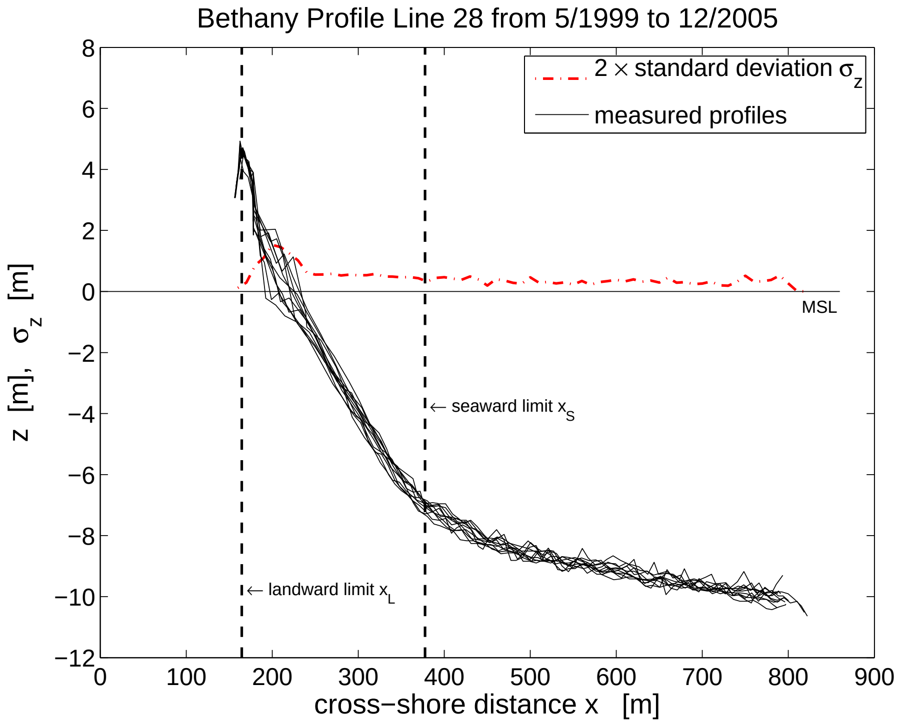

Bethany Profile Line 23 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

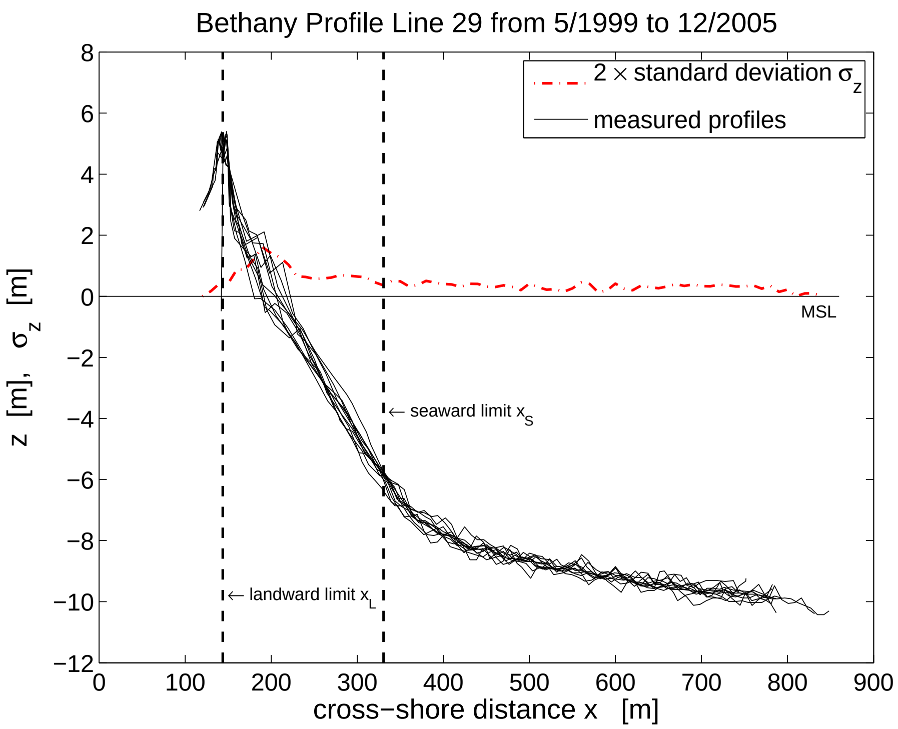

Bethany Profile Line 24 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

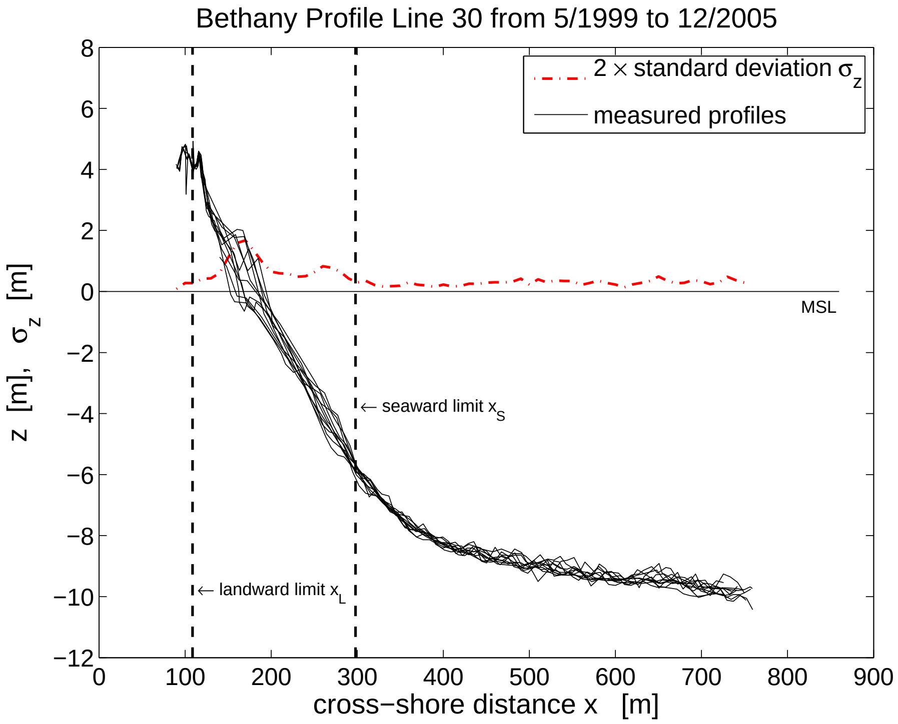

Bethany Profile Line 25 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
z [m], σz [m]
MSL
← seaward limit xS
← landward limit xL
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

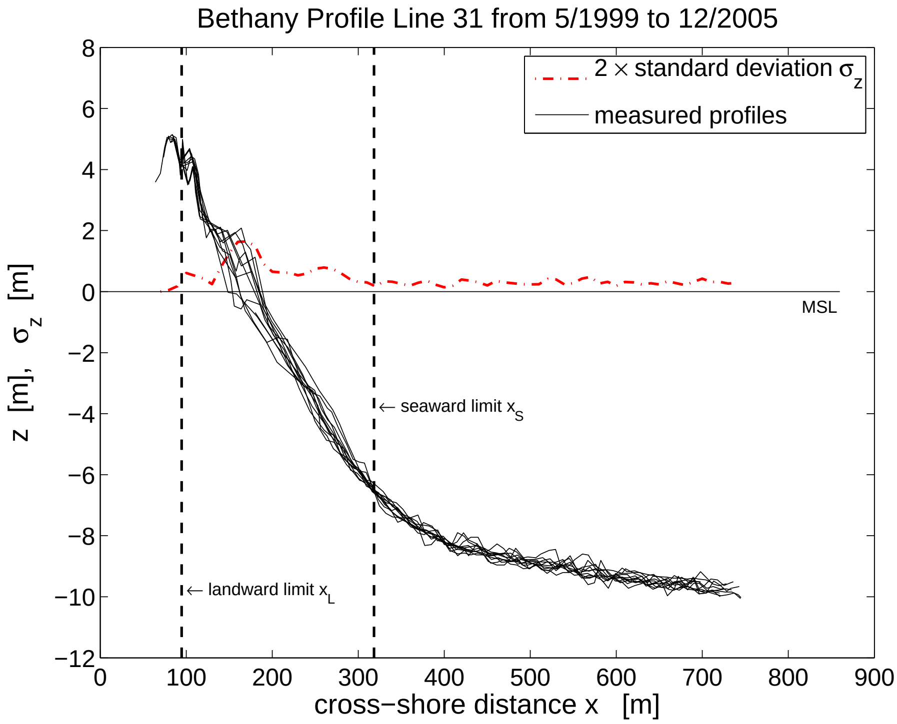

Bethany Profile Line 26 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
z [m], σz [m]
MSL
← seaward limit xS
← landward limit xL
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900

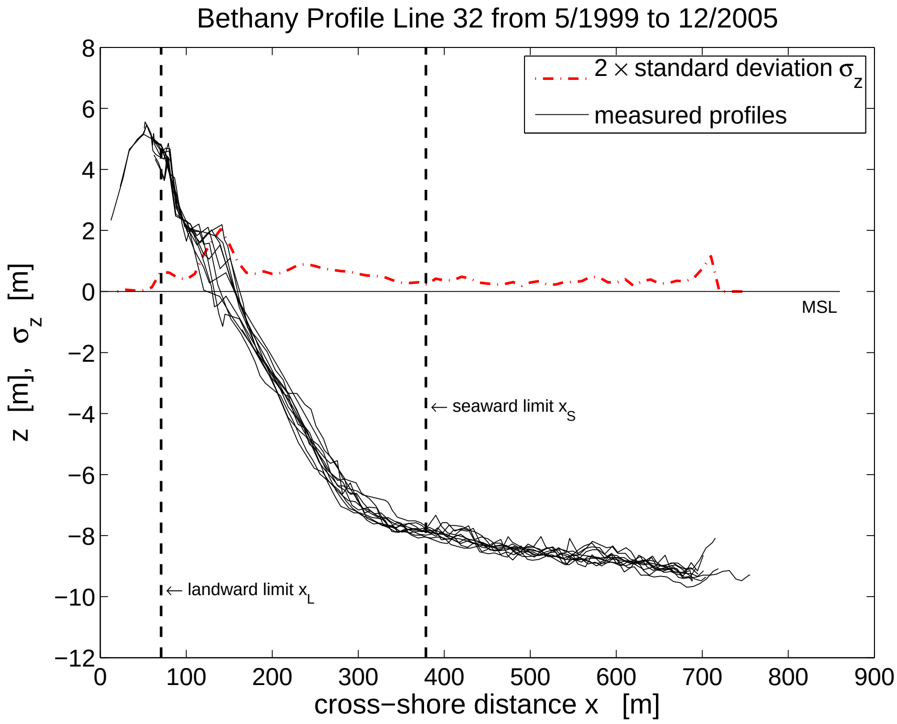

Bethany Profile Line 27 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900


Bethany Profile Line 28 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
100
200
300
400
500
600
700
800
900


Bethany Profile Line 29 from 5/1999 to 12/2005
2 × standard deviation σ z
measured profiles
MSL
← seaward limit x S
← landward limit x L
z [m], σ z [m]
cross−shore distance x [m]


Bethany Profile Line 30 from 5/1999 to 12/2005
2 × standard deviation σ z
measured profiles
MSL
← seaward limit x S
← landward limit x L
z [m], σ z [m]
cross−shore distance x [m]


Bethany Profile Line 31 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]


Bethany Profile Line 32 from 5/1999 to 12/2005
2 × standard deviation σz
measured profiles
MSL
← seaward limit xS
← landward limit xL
z [m], σz [m]
cross−shore distance x [m]

Appendix D

EROSION AND ACCRETION AT EACH PROFILE LINE

Table D.1: Erosion and Accretion of Each Profile Line at Rehoboth

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
1	4/1999	10/1999	6	6.4	-1.5	39.5	3.6	43.1
1	10/1999	4/2000	6	-0.2	-1.3	-23.4	12.3	-11.0
1	4/2000	11/2000	7	-6.8	-0.6	6.3	-14.8	-8.6
1	11/2000	5/2001	6	-1.9	-0.6	-5.6	-17.7	-23.3
1	5/2001	5/2002	12	16.0	-2.0	29.8	-35.3	-5.5
1	5/2002	10/2002	5	-3.0	-2.1	-8.8	7.7	-1.1
1	10/2002	5/2003	7	N/A	N/A	N/A	N/A	N/A
1	5/2003	10/2003	5	N/A	N/A	N/A	N/A	N/A
2	4/1999	10/1999	6	3.3	-1.3	32.3	-29.2	3.1
2	10/1999	4/2000	6	-21.6	-1.2	-57.8	23.6	-34.2
2	4/2000	11/2000	7	11.7	-1.5	43.9	-29.7	14.2
2	11/2000	5/2001	6	-3.5	-1.4	-10.9	42.6	31.7
2	5/2001	5/2002	12	14.9	-2.3	39.3	-11.6	27.7
2	5/2002	10/2002	5	3.1	-0.4	1.2	-21.6	-20.4
2	10/2002	5/2003	7	-27.5	-1.9	-54.6	75.0	20.5
2	5/2003	10/2003	5	5.7	-3.1	31.5	-16.5	15.0

Table D.1: Erosion and Accretion of Each Profile Line at Rehoboth (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
3	4/1999	10/1999	6	7.6	-3.7	0.7	44.0	44.7
3	10/1999	4/2000	6	-9.8	-3.9	-2.4	-33.9	-36.3
3	4/2000	11/2000	7	-1.3	-1.5	5.5	-35.1	-29.6
3	11/2000	5/2001	6	-4.8	-1.6	-12.1	38.1	26.0
3	5/2001	5/2002	12	17.3	-1.8	54.2	-16.3	37.8
3	5/2002	10/2002	5	2.7	-0.4	2.3	-9.1	-6.8
3	10/2002	5/2003	7	-27.4	-2.4	-72.7	48.3	-24.4
3	5/2003	10/2003	5	-2.7	-3.1	26.3	-24.8	1.5
4	4/1999	10/1999	6	8.8	-0.5	29.3	-23.2	6.1
4	10/1999	4/2000	6	-13.9	-1.1	-53.8	-22.2	-76.0
4	4/2000	11/2000	7	4.6	-2.1	35.6	-0.2	35.4
4	11/2000	5/2001	6	-7.8	-1.6	-24.3	27.2	2.9
4	5/2001	5/2002	12	21.8	-1.9	88.4	-13.2	75.2
4	5/2002	10/2002	5	-6.0	-2.3	-17.4	8.2	-9.2
4	10/2002	5/2003	7	-28.3	-1.8	-77.2	44.5	-32.6
4	5/2003	10/2003	5	-3.4	-3.3	10.2	-10.7	-0.5
5	4/1999	10/1999	6	11.0	-0.5	21.1	-16.3	4.9
5	10/1999	4/2000	6	-21.9	-0.9	-50.1	15.1	-35.0
5	4/2000	11/2000	7	10.1	-1.5	28.2	-21.3	6.9
5	11/2000	5/2001	6	-5.1	-2.5	-18.2	13.0	-5.3
5	5/2001	5/2002	12	10.6	-2.6	39.6	-9.7	29.8
5	5/2002	10/2002	5	2.2	-2.4	-0.3	9.3	9.1
5	10/2002	5/2003	7	-32.0	-1.8	-95.2	25.4	-69.8
5	5/2003	10/2003	5	8.8	-3.3	48.8	-21.5	27.3

Table D.1: Erosion and Accretion of Each Profile Line at Rehoboth (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
6	4/1999	10/1999	6	2.5	-0.3	11.8	-53.4	-41.6
6	10/1999	4/2000	6	-12.8	-1.0	-42.4	15.3	-27.0
6	4/2000	11/2000	7	0.7	-1.5	14.0	-9.2	4.8
6	11/2000	5/2001	6	-7.2	-2.3	-11.7	7.6	-4.1
6	5/2001	5/2002	12	12.6	-2.6	31.5	-7.1	24.4
6	5/2002	10/2002	5	4.6	-2.1	-7.8	2.4	-5.4
6	10/2002	5/2003	7	-26.5	-2.7	-74.1	39.2	-34.9
6	5/2003	10/2003	5	-0.1	-3.0	12.5	-8.0	4.4
7	4/1999	10/1999	6	2.2	-4.6	-50.7	16.6	-34.2
7	10/1999	4/2000	6	-11.4	-1.3	-41.4	5.6	-35.9
7	4/2000	11/2000	7	-1.0	-1.8	5.7	5.0	10.7
7	11/2000	5/2001	6	-3.9	-1.9	-9.3	3.8	-5.6
7	5/2001	5/2002	12	9.7	-1.9	29.6	-11.2	18.4
7	5/2002	10/2002	5	2.9	-3.2	-5.0	-5.6	-10.6
7	10/2002	5/2003	7	-26.7	-2.4	-65.6	53.9	-11.7
7	5/2003	10/2003	5	-2.3	-3.0	-8.0	-21.2	-29.1
8	4/1999	10/1999	6	-5.4	0.5	3.7	-50.7	-47.0
8	10/1999	4/2000	6	-17.8	-0.9	-38.7	27.8	-11.0
8	4/2000	11/2000	7	10.2	-1.5	17.4	-14.3	3.0
8	11/2000	5/2001	6	-9.2	-2.9	-20.7	2.6	-18.1
8	5/2001	5/2002	12	3.0	-0.3	-5.8	-27.7	-33.4
8	5/2002	10/2002	5	6.2	-4.0	7.3	-2.4	5.0
8	10/2002	5/2003	7	-22.0	-1.8	-55.8	20.4	-35.5
8	5/2003	10/2003	5	0.4	-4.6	12.0	-4.8	7.3

Table D.1: Erosion and Accretion of Each Profile Line at Rehoboth (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
9	4/1999	10/1999	6	6.6	-0.2	37.0	-27.3	9.7
9	10/1999	4/2000	6	-17.8	-1.0	-51.9	14.9	-37.0
9	4/2000	11/2000	7	5.7	-1.4	20.2	-17.7	2.5
9	11/2000	5/2001	6	-7.6	-2.8	-25.2	6.4	-18.8
9	5/2001	5/2002	12	4.0	-0.2	7.3	-28.3	-21.0
9	5/2002	10/2002	5	2.6	-1.9	5.8	-3.8	2.0
9	10/2002	5/2003	7	-23.0	-1.7	-50.0	50.2	0.2
9	5/2003	10/2003	5	-0.5	0.2	7.0	-28.5	-21.5
10	4/1999	10/1999	6	10.0	-1.0	43.8	-31.6	12.2
10	10/1999	4/2000	6	-14.1	-1.3	-41.6	11.7	-29.9
10	4/2000	11/2000	7	5.6	-1.6	24.9	-1.8	23.1
10	11/2000	5/2001	6	-4.1	-3.0	-1.7	-1.4	-3.0
10	5/2001	5/2002	12	-3.3	-5.3	-60.0	1.7	-58.3
10	5/2002	10/2002	5	7.3	-4.8	21.1	-3.0	18.1
10	10/2002	5/2003	7	-19.0	-2.0	-33.1	48.9	15.8
10	5/2003	10/2003	5	-2.3	0.4	10.5	-20.6	-10.1

Table D.2: Erosion and Accretion of Each Profile Line at Dewey

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
1	11/1998	4/1999	5	-18.3	-1.1	-51.3	30.2	-21.1
1	4/1999	10/1999	6	10.0	-1.1	40.5	-14.5	26.1
1	10/1999	4/2000	6	-12.7	-1.2	-57.2	34.1	-23.1
1	4/2000	11/2000	7	6.8	-1.9	50.1	-20.1	29.9
1	11/2000	4/2001	5	4.2	1.5	2.2	22.2	24.4
1	4/2001	5/2002	13	9.0	-2.0	34.1	-28.7	5.4
1	5/2002	10/2002	5	-11.7	-4.6	-30.5	6.1	-24.4
1	10/2002	5/2003	7	-17.8	-1.6	-41.9	60.4	18.5
1	5/2003	10/2003	5	-2.0	-1.7	-30.8	-14.4	-45.1
2	11/1998	4/1999	5	-23.9	-2.0	-69.9	37.4	-32.5
2	4/1999	10/1999	6	9.8	-2.0	52.5	-41.0	11.4
2	10/1999	4/2000	6	-5.5	-1.3	-39.8	56.0	16.2
2	4/2000	11/2000	7	-0.9	-0.1	13.0	-40.5	-27.5
2	11/2000	4/2001	5	-0.2	-0.1	-6.3	31.1	24.7
2	4/2001	5/2002	13	7.5	-1.7	29.0	-15.3	13.6
2	5/2002	10/2002	5	-6.5	0.9	3.7	-9.6	-5.9
2	10/2002	5/2003	7	-18.5	-2.5	-73.3	30.4	-43.0
2	5/2003	10/2003	5	-2.4	-2.8	25.0	-16.4	8.6
3	11/1998	4/1999	5	-21.6	-0.6	-51.0	27.4	-23.5
3	4/1999	10/1999	6	10.7	-0.6	26.7	-22.8	3.8
3	10/1999	4/2000	6	-8.8	-1.5	-42.3	9.3	-33.0
3	4/2000	11/2000	7	-1.4	-1.5	14.8	-14.0	0.8
3	11/2000	4/2001	5	3.8	-1.8	16.1	26.8	42.8
3	4/2001	5/2002	13	7.8	-0.4	13.2	-8.9	4.3
3	5/2002	10/2002	5	-3.8	-0.8	9.0	0.3	9.3
3	10/2002	5/2003	7	-12.6	-2.4	-54.2	52.1	-2.1
3	5/2003	10/2003	5	4.7	-2.5	23.7	-16.1	7.6

Table D.2: Erosion and Accretion of Each Profile Line at Dewey (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
4	11/1998	4/1999	5	-19.9	-1.3	-52.3	40.2	-12.1
4	4/1999	10/1999	6	2.7	-1.3	20.1	-12.1	8.0
4	10/1999	4/2000	6	-10.1	-1.8	-56.3	35.1	-21.2
4	4/2000	11/2000	7	5.1	-1.8	41.7	-24.3	17.4
4	11/2000	4/2001	5	1.4	-2.8	0.9	0.5	1.3
4	4/2001	5/2002	13	1.2	-1.7	19.1	-33.2	-14.1
4	5/2002	10/2002	5	1.5	-2.0	5.1	6.6	11.7
4	10/2002	5/2003	7	-15.1	-2.9	-84.2	52.3	-31.8
4	5/2003	10/2003	5	-8.2	-3.0	13.0	-29.2	-16.2
5	11/1998	4/1999	5	-22.4	-1.3	-77.0	53.9	-23.1
5	4/1999	10/1999	6	-4.2	-1.2	12.9	-24.7	-11.8
5	10/1999	4/2000	6	-2.6	-2.1	-60.6	36.9	-23.7
5	4/2000	11/2000	7	-1.5	-2.1	41.9	-40.3	1.6
5	11/2000	4/2001	5	0.9	-0.9	7.0	-6.6	0.4
5	4/2001	5/2002	13	9.2	-1.5	24.6	-35.4	-10.7
5	5/2002	10/2002	5	-2.1	-2.5	-5.7	10.0	4.3
5	10/2002	5/2003	7	-17.4	-2.8	-89.9	20.8	-69.0
5	5/2003	10/2003	5	-6.4	-1.9	-32.2	15.0	-17.2
6	11/1998	4/1999	5	-29.5	-0.8	-86.6	42.6	-44.0
6	4/1999	10/1999	6	0.9	-0.2	14.4	-36.3	-21.9
6	10/1999	4/2000	6	-8.7	-1.9	-57.7	34.9	-22.8
6	4/2000	11/2000	7	1.7	-1.9	33.6	-30.3	3.4
6	11/2000	4/2001	5	5.1	-1.0	17.3	-8.6	8.8
6	4/2001	5/2002	13	3.7	-1.3	11.7	-40.6	-29.0
6	5/2002	10/2002	5	-6.6	-0.7	-8.3	11.4	3.1
6	10/2002	5/2003	7	-26.2	-2.8	-120.5	55.3	-65.2
6	5/2003	10/2003	5	4.5	-3.1	9.1	-23.2	-14.1

Table D.2: Erosion and Accretion of Each Profile Line at Dewey (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
7	11/1998	4/1999	5	-27.1	-0.8	-86.3	46.4	-39.9
7	4/1999	10/1999	6	-3.5	-1.0	2.3	-11.2	-8.9
7	10/1999	4/2000	6	7.5	-4.4	84.7	-2.9	81.8
7	4/2000	11/2000	7	-7.5	-1.4	-46.9	-40.4	-87.3
7	11/2000	4/2001	5	-1.7	-0.3	-3.0	9.2	6.2
7	4/2001	5/2002	13	5.6	-1.0	14.3	-51.7	-37.5
7	5/2002	10/2002	5	-2.4	-0.5	-3.1	16.7	13.5
7	10/2002	5/2003	7	-14.8	-2.4	-65.5	48.4	-17.1
7	5/2003	10/2003	5	-6.2	-1.5	-24.5	-1.6	-26.1
8	11/1998	4/1999	5	-27.1	-1.4	-101.4	49.3	-52.1
8	4/1999	10/1999	6	-2.2	-1.2	18.8	-32.9	-14.1
8	10/1999	4/2000	6	-9.0	-1.4	-53.6	39.9	-13.7
8	4/2000	11/2000	7	4.6	-1.4	31.1	-58.2	-27.1
8	11/2000	4/2001	5	-3.2	-1.0	-14.3	4.1	-10.2
8	4/2001	5/2002	13	8.4	-1.1	17.5	-45.7	-28.3
8	5/2002	10/2002	5	-8.2	-1.3	-5.6	11.9	6.3
8	10/2002	5/2003	7	-13.1	-2.6	-103.0	53.3	-49.7
8	5/2003	10/2003	5	-0.0	-2.9	46.7	-17.5	29.2
9	11/1998	4/1999	5	-23.7	-0.9	-99.6	31.7	-67.9
9	4/1999	10/1999	6	-6.1	-2.2	-5.8	20.7	14.9
9	10/1999	4/2000	6	-2.9	-1.4	-37.1	14.6	-22.5
9	4/2000	11/2000	7	4.3	-1.6	38.4	-41.8	-3.4
9	11/2000	4/2001	5	-4.3	-0.9	-28.2	12.6	-15.6
9	4/2001	5/2002	13	7.9	-1.0	25.2	-57.1	-31.9
9	5/2002	10/2002	5	-11.2	-1.0	-18.0	8.2	-9.8
9	10/2002	5/2003	7	-12.5	-2.6	-40.8	35.5	-5.3
9	5/2003	10/2003	5	-5.5	-2.2	-56.7	7.6	-49.1

Table D.2: Erosion and Accretion of Each Profile Line at Dewey (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
10	11/1998	4/1999	5	-27.7	-0.8	-103.7	63.0	-40.6
10	4/1999	10/1999	6	-3.3	-0.9	9.2	-49.2	-39.9
10	10/1999	4/2000	6	-3.2	-1.4	-33.6	51.2	17.6
10	4/2000	11/2000	7	-2.2	-1.4	28.9	-34.2	-5.3
10	11/2000	4/2001	5	-4.4	-5.6	-30.0	-0.8	-30.8
10	4/2001	5/2002	13	14.8	-1.3	42.2	-48.3	-6.1
10	5/2002	10/2002	5	-13.4	-2.3	-32.5	1.3	-31.1
10	10/2002	5/2003	7	-13.1	-2.0	-35.5	49.5	14.0
10	5/2003	10/2003	5	-5.9	-1.3	-27.2	1.7	-25.4
11	11/1998	4/1999	5	-26.5	-0.8	-92.4	55.9	-36.5
11	4/1999	10/1999	6	-5.9	0.3	6.3	-27.3	-21.0
11	10/1999	4/2000	6	2.3	-1.1	-7.8	25.2	17.3
11	4/2000	11/2000	7	-5.2	1.1	11.7	-46.1	-34.3
11	11/2000	4/2001	5	-5.9	-1.2	-8.0	-12.4	-20.5
11	4/2001	5/2002	13	8.3	-1.6	26.1	-39.2	-13.1
11	5/2002	10/2002	5	-8.1	-4.0	23.8	4.1	28.0
11	10/2002	5/2003	7	-17.8	-2.2	-74.1	60.9	-13.2
11	5/2003	10/2003	5	1.7	-2.2	20.6	-23.5	-2.8
12	11/1998	4/1999	5	-27.9	-1.5	-86.4	57.7	-28.8
12	4/1999	10/1999	6	0.1	-1.1	12.0	-22.5	-10.5
12	10/1999	4/2000	6	-10.4	-1.5	-46.3	18.7	-27.6
12	4/2000	11/2000	7	3.3	-1.7	27.8	-29.2	-1.4
12	11/2000	4/2001	5	1.8	-1.4	-10.1	0.5	-9.6
12	4/2001	5/2002	13	7.1	-1.3	30.6	-38.0	-7.4
12	5/2002	10/2002	5	-7.3	0.6	4.0	-13.4	-9.4
12	10/2002	5/2003	7	-14.5	-2.1	-46.2	74.6	28.4
12	5/2003	10/2003	5	-0.5	-2.8	13.0	-25.1	-12.1

Table D.2: Erosion and Accretion of Each Profile Line at Dewey (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
13	11/1998	4/1999	5	-30.9	-1.8	-103.4	64.7	-38.7
13	4/1999	10/1999	6	0.8	-0.7	11.1	-37.4	-26.3
13	10/1999	4/2000	6	-5.3	-1.4	-48.2	37.3	-10.9
13	4/2000	11/2000	7	3.1	-1.4	40.3	-53.0	-12.7
13	11/2000	4/2001	5	-3.4	-1.3	-16.4	15.7	-0.7
13	4/2001	5/2002	13	11.5	-1.1	29.7	-41.5	-11.8
13	5/2002	10/2002	5	-8.0	-0.6	-4.1	13.8	9.8
13	10/2002	5/2003	7	-14.3	-2.6	-56.5	26.9	-29.6
13	5/2003	10/2003	5	-6.3	-0.8	-10.2	22.8	12.6
14	11/1998	4/1999	5	-27.8	-1.7	-111.1	72.3	-38.8
14	4/1999	10/1999	6	2.6	-1.5	27.2	-33.1	-6.0
14	10/1999	4/2000	6	-9.8	-1.8	-50.7	50.0	-0.7
14	4/2000	11/2000	7	0.2	-1.8	39.9	-44.3	-4.4
14	11/2000	4/2001	5	1.6	-0.6	2.7	-8.0	-5.3
14	4/2001	5/2002	13	11.3	-1.4	17.3	-39.8	-22.5
14	5/2002	10/2002	5	-9.7	0.8	7.8	-10.5	-2.8
14	10/2002	5/2003	7	-15.6	-2.3	-72.3	42.2	-30.2
14	5/2003	10/2003	5	-2.6	-1.9	-21.7	0.5	-21.2
15	11/1998	4/1999	5	-21.5	-1.4	-76.8	69.2	-7.6
15	4/1999	10/1999	6	-1.7	-1.4	22.4	-33.7	-11.3
15	10/1999	4/2000	6	-1.7	-1.6	-27.9	21.9	-6.0
15	4/2000	11/2000	7	-4.3	-0.9	9.7	-30.2	-20.4
15	11/2000	4/2001	5	-1.1	-0.9	-4.1	16.8	12.7
15	4/2001	5/2002	13	10.3	-1.2	30.1	-40.9	-10.9
15	5/2002	10/2002	5	-11.0	-2.5	-13.4	8.4	-5.1
15	10/2002	5/2003	7	-13.9	-2.2	-52.4	36.2	-16.2
15	5/2003	10/2003	5	-1.9	-2.8	22.8	-7.5	15.3

Table D.2: Erosion and Accretion of Each Profile Line at Dewey (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
16	11/1998	4/1999	5	-19.6	-0.9	-66.6	68.0	1.4
16	4/1999	10/1999	6	-3.8	-0.8	11.9	-31.9	-19.9
16	10/1999	4/2000	6	-10.7	-1.3	-48.1	42.8	-5.3
16	4/2000	11/2000	7	2.8	-1.8	34.1	-23.7	10.4
16	11/2000	4/2001	5	1.5	-1.3	-12.8	-13.9	-26.6
16	4/2001	5/2002	13	14.5	-1.4	33.3	-34.1	-0.8
16	5/2002	10/2002	5	-9.7	0.9	2.0	-4.1	-2.1
16	10/2002	5/2003	7	-20.6	-2.5	-57.9	72.3	14.4
16	5/2003	10/2003	5	0.6	-2.9	34.4	-23.9	10.5
17	11/1998	4/1999	5	-25.3	-1.3	-83.0	66.6	-16.4
17	4/1999	10/1999	6	5.6	-1.4	39.3	-10.8	28.5
17	10/1999	4/2000	6	-6.4	-1.9	-44.5	29.8	-14.7
17	4/2000	11/2000	7	6.2	-1.9	54.6	-27.6	27.0
17	11/2000	4/2001	5	-0.1	-1.6	-7.3	1.6	-5.7
17	4/2001	5/2002	13	8.6	-1.4	19.1	-41.8	-22.7
17	5/2002	10/2002	5	-9.0	-1.0	-17.8	17.0	-0.8
17	10/2002	5/2003	7	-19.0	-2.5	-77.2	74.9	-2.3
17	5/2003	10/2003	5	2.9	-2.7	44.3	-32.6	11.7
18	11/1998	4/1999	5	-17.5	-0.8	-59.9	61.4	1.4
18	4/1999	10/1999	6	-1.0	-0.8	27.1	-20.9	6.2
18	10/1999	4/2000	6	-4.2	-1.7	-46.6	40.6	-6.0
18	4/2000	11/2000	7	3.4	-1.7	51.9	-36.5	15.4
18	11/2000	4/2001	5	-0.3	-0.1	-5.0	5.7	0.7
18	4/2001	5/2002	13	12.8	-1.1	34.3	-38.6	-4.3
18	5/2002	10/2002	5	-7.5	-2.7	-9.7	15.8	6.1
18	10/2002	5/2003	7	-22.2	-2.3	-82.2	62.6	-19.6
18	5/2003	10/2003	5	0.1	-2.7	7.1	-25.8	-18.7

Table D.3: Erosion and Accretion of Each Profile Line at Bethany

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
1	5/1999	7/1999	2	-6.7	0.1	33.9	-13.0	20.9
1	7/1999	10/1999	3	0.3	-0.6	16.5	-28.2	-11.7
1	10/1999	4/2000	6	-21.2	-1.3	-71.8	69.4	-2.4
1	4/2000	10/2000	6	13.2	-1.5	61.5	-67.6	-6.0
1	10/2000	6/2001	8	-1.2	-0.2	-22.9	-1.0	-24.0
1	6/2001	9/2002	15	N/A	N/A	N/A	N/A	N/A
1	9/2002	4/2003	7	N/A	N/A	N/A	N/A	N/A
1	4/2003	10/2003	6	N/A	N/A	N/A	N/A	N/A
1	10/2003	9/2004	11	8.4	-0.3	41.1	-32.4	8.7
1	9/2004	12/2005	15	11.1	1.0	-1.9	37.1	35.1
2	5/1999	7/1999	2	-1.8	0.0	26.8	-13.7	13.1
2	7/1999	10/1999	3	-1.7	0.9	15.9	-34.7	-18.9
2	10/1999	4/2000	6	-14.8	-0.3	-43.0	58.3	15.3
2	4/2000	10/2000	6	15.2	-0.7	37.1	-40.5	-3.4
2	10/2000	6/2001	8	-0.3	-0.1	-2.3	7.4	5.1
2	6/2001	9/2002	15	N/A	N/A	N/A	N/A	N/A
2	9/2002	4/2003	7	N/A	N/A	N/A	N/A	N/A
2	4/2003	10/2003	6	N/A	N/A	N/A	N/A	N/A
2	10/2003	9/2004	11	-3.2	0.2	29.6	-22.5	7.1
2	9/2004	12/2005	15	3.7	0.4	-15.1	-1.5	-16.6
3	5/1999	7/1999	2	3.1	-0.1	31.0	-22.9	8.2
3	7/1999	10/1999	3	-3.4	1.2	25.7	-35.1	-9.4
3	10/1999	4/2000	6	-20.1	-0.6	-58.0	60.4	2.4
3	4/2000	10/2000	6	7.3	-0.7	31.7	-54.7	-23.1
3	10/2000	6/2001	8	-0.4	-3.6	6.1	-10.3	-4.2
3	6/2001	9/2002	15	-3.6	-2.1	-0.7	4.1	3.4
3	9/2002	4/2003	7	-11.8	-0.3	-40.4	64.6	24.2
3	4/2003	10/2003	6	7.7	-0.4	15.9	-55.2	-39.3
3	10/2003	9/2004	11	3.3	-0.2	36.6	-30.8	5.8
3	9/2004	12/2005	15	1.2	0.1	-23.3	4.6	-18.7

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
4	5/1999	7/1999	2	15.7	-0.3	36.4	-30.4	6.0
4	7/1999	10/1999	3	-1.6	0.9	17.2	-34.6	-17.5
4	10/1999	4/2000	6	-24.9	-1.4	-84.4	42.0	-42.4
4	4/2000	10/2000	6	19.1	-1.4	65.3	-39.8	25.6
4	10/2000	6/2001	8	-0.4	-0.0	-14.9	0.5	-14.3
4	6/2001	9/2002	15	-1.2	-2.0	8.3	-15.4	-7.1
4	9/2002	4/2003	7	-14.1	-2.7	-44.9	44.6	-0.3
4	4/2003	10/2003	6	5.1	-0.7	7.0	-22.6	-15.6
4	10/2003	9/2004	11	6.4	-1.6	41.5	-25.7	15.7
4	9/2004	12/2005	15	-2.3	-0.2	-24.5	-15.0	-39.5
5	5/1999	7/1999	2	10.1	-0.3	28.0	-23.4	4.6
5	7/1999	10/1999	3	-5.5	0.9	10.4	-39.1	-28.7
5	10/1999	4/2000	6	-21.7	-0.7	-57.6	69.2	11.6
5	4/2000	10/2000	6	18.5	-0.8	37.4	-41.6	-4.3
5	10/2000	6/2001	8	-1.0	-5.3	-25.7	2.4	-23.3
5	6/2001	9/2002	15	-4.9	-0.4	-2.4	0.4	-2.0
5	9/2002	4/2003	7	-44.1	-3.5	-149.2	23.5	-125.7
5	4/2003	10/2003	6	32.2	-3.9	106.5	-8.2	98.3
5	10/2003	9/2004	11	N/A	-4.6	-15.1	2.7	-12.4
5	9/2004	12/2005	15	N/A	N/A	N/A	N/A	N/A
6	5/1999	7/1999	2	8.1	-0.3	26.1	-13.1	13.0
6	7/1999	10/1999	3	-5.0	0.8	17.0	-22.8	-5.7
6	10/1999	4/2000	6	-23.0	-1.5	-81.9	50.5	-31.4
6	4/2000	10/2000	6	17.0	-1.6	51.2	-48.0	3.2
6	10/2000	6/2001	8	-0.7	1.2	1.4	-16.1	-14.7
6	6/2001	9/2002	15	-4.9	-4.2	10.0	-11.2	-1.2
6	9/2002	4/2003	7	-9.6	-1.1	-36.5	43.8	7.3
6	4/2003	10/2003	6	5.0	-0.6	15.9	-23.4	-7.5
6	10/2003	9/2004	11	7.6	-1.1	35.8	-24.0	11.8
6	9/2004	12/2005	15	-5.3	-0.3	-29.9	2.2	-27.7

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
7	5/1999	7/1999	2	8.0	-0.2	12.5	-29.7	-17.3
7	7/1999	10/1999	3	-5.1	0.4	8.9	-31.4	-22.4
7	10/1999	4/2000	6	-20.5	-0.8	-51.7	50.9	-0.8
7	4/2000	10/2000	6	12.7	-0.9	36.0	-43.3	-7.3
7	10/2000	6/2001	8	-0.3	-3.0	8.8	-1.7	7.1
7	6/2001	9/2002	15	-8.4	-2.5	-22.9	-13.5	-36.4
7	9/2002	4/2003	7	-9.4	-0.8	-28.8	63.3	34.5
7	4/2003	10/2003	6	12.2	-0.8	14.8	-28.6	-13.8
7	10/2003	9/2004	11	-1.0	0.1	27.3	-37.5	-10.1
7	9/2004	12/2005	15	-1.9	-1.1	-23.6	-15.5	-39.1
8	5/1999	7/1999	2	19.1	-0.3	54.2	-23.3	30.9
8	7/1999	10/1999	3	-3.9	0.5	25.1	-18.5	6.6
8	10/1999	4/2000	6	-21.1	-0.7	-46.3	45.3	-1.0
8	4/2000	10/2000	6	5.3	-0.7	23.9	-51.8	-27.9
8	10/2000	6/2001	8	-2.8	-0.5	-1.3	-11.3	-12.6
8	6/2001	9/2002	15	-4.6	0.9	0.1	-28.6	-28.5
8	9/2002	4/2003	7	-16.0	-0.9	-46.5	65.2	18.7
8	4/2003	10/2003	6	12.9	-0.8	22.5	-33.0	-10.6
8	10/2003	9/2004	11	2.4	-0.5	33.5	-27.6	5.9
8	9/2004	12/2005	15	-2.1	-1.1	-15.3	-16.5	-31.8
9	5/1999	7/1999	2	20.5	-0.7	33.8	-18.1	15.7
9	7/1999	10/1999	3	-3.6	0.7	19.1	-21.2	-2.0
9	10/1999	4/2000	6	-22.6	-1.4	-66.9	37.0	-29.9
9	4/2000	10/2000	6	14.3	-1.5	45.2	-39.9	5.3
9	10/2000	6/2001	8	0.9	-2.9	4.5	-5.9	-1.4
9	6/2001	9/2002	15	-10.4	-0.1	-10.2	-6.6	-16.7
9	9/2002	4/2003	7	-13.0	-1.8	-39.3	47.0	7.7
9	4/2003	10/2003	6	10.1	-0.6	19.5	-35.8	-16.2
9	10/2003	9/2004	11	2.5	-0.8	29.5	-26.4	3.1
9	9/2004	12/2005	15	-1.0	-1.2	-22.7	12.4	-10.3

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
10	5/1999	7/1999	2	6.8	-0.2	20.8	-12.4	8.5
10	7/1999	10/1999	3	5.6	-0.5	23.8	-28.1	-4.3
10	10/1999	4/2000	6	-11.7	-0.5	-53.2	42.9	-10.3
10	4/2000	10/2000	6	7.7	-0.4	26.5	-45.7	-19.2
10	10/2000	6/2001	8	1.2	-0.5	0.3	5.6	5.9
10	6/2001	9/2002	15	-1.8	-0.2	-4.5	-10.0	-14.4
10	9/2002	4/2003	7	-21.8	-1.5	-58.6	54.9	-3.7
10	4/2003	10/2003	6	13.2	-0.9	26.3	-37.4	-11.1
10	10/2003	9/2004	11	3.7	-0.5	36.8	-25.6	11.2
10	9/2004	12/2005	15	-3.8	3.2	0.6	-58.0	-57.4
11	5/1999	7/1999	2	6.3	-0.2	25.8	-25.3	0.5
11	7/1999	10/1999	3	-4.1	1.2	15.8	-20.5	-4.6
11	10/1999	4/2000	6	-8.9	-0.3	-41.0	61.0	20.0
11	4/2000	10/2000	6	4.3	-0.3	22.1	-52.8	-30.7
11	10/2000	6/2001	8	1.1	-3.4	3.7	-2.3	1.4
11	6/2001	9/2002	15	-4.0	1.3	7.4	-27.9	-20.5
11	9/2002	4/2003	7	-14.4	-1.7	-47.6	42.5	-5.2
11	4/2003	10/2003	6	8.4	-1.5	18.6	-13.2	5.4
11	10/2003	9/2004	11	-1.4	1.0	9.6	-27.3	-17.7
11	9/2004	12/2005	15	0.2	-0.0	0.5	-26.3	-25.9
12	5/1999	7/1999	2	2.0	-0.1	32.4	-36.8	-4.3
12	7/1999	10/1999	3	2.9	-1.5	22.2	-0.6	21.7
12	10/1999	4/2000	6	-20.9	-1.5	-71.1	43.4	-27.7
12	4/2000	10/2000	6	13.5	-1.5	40.7	-41.8	-1.1
12	10/2000	6/2001	8	-1.3	-1.6	-7.8	-8.4	-16.1
12	6/2001	9/2002	15	-11.1	-0.1	0.4	-2.7	-2.3
12	9/2002	4/2003	7	-6.5	-2.5	-27.7	32.7	5.0
12	4/2003	10/2003	6	5.2	-0.6	12.1	-12.3	-0.2
12	10/2003	9/2004	11	23.2	-1.7	41.7	-21.5	20.2
12	9/2004	12/2005	15	-21.9	0.3	1.2	-46.7	-45.5

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
13	5/1999	7/1999	2	1.6	-0.1	38.2	-37.4	0.8
13	7/1999	10/1999	3	0.9	-3.4	-4.5	8.4	3.9
13	10/1999	4/2000	6	-24.5	-0.8	-59.5	44.0	-15.5
13	4/2000	10/2000	6	16.2	-0.4	35.4	-47.9	-12.5
13	10/2000	6/2001	8	-5.2	0.5	-7.7	-23.3	-31.1
13	6/2001	9/2002	15	-2.5	-3.7	8.7	-5.4	3.3
13	9/2002	4/2003	7	-14.6	-1.8	-54.3	34.8	-19.5
13	4/2003	10/2003	6	4.1	-1.1	13.4	-13.2	0.3
13	10/2003	9/2004	11	2.9	-1.7	12.0	-19.4	-7.4
13	9/2004	12/2005	15	-2.6	0.1	8.8	-19.7	-10.9
14	5/1999	7/1999	2	2.1	-0.1	25.2	-24.2	1.1
14	7/1999	10/1999	3	-0.0	-1.3	11.3	-16.3	-5.0
14	10/1999	4/2000	6	-15.8	-0.3	-46.3	53.8	7.5
14	4/2000	10/2000	6	5.4	-0.2	25.7	-34.3	-8.5
14	10/2000	6/2001	8	-0.3	0.1	-4.9	-28.3	-33.2
14	6/2001	9/2002	15	-4.6	-3.6	3.9	-11.8	-7.9
14	9/2002	4/2003	7	-15.9	-1.3	-52.0	35.8	-16.2
14	4/2003	10/2003	6	11.8	-1.2	21.5	-8.2	13.3
14	10/2003	9/2004	11	1.7	-0.2	19.9	-41.5	-21.6
14	9/2004	12/2005	15	-6.1	-3.8	-19.3	-24.9	-44.2
15	5/1999	7/1999	2	0.1	-0.0	19.6	-13.4	6.2
15	7/1999	10/1999	3	0.3	-0.9	10.2	-12.0	-1.9
15	10/1999	4/2000	6	-27.1	-0.7	-67.0	38.6	-28.4
15	4/2000	10/2000	6	8.6	-0.7	24.3	-37.4	-13.2
15	10/2000	6/2001	8	-0.1	0.0	0.4	-5.4	-5.0
15	6/2001	9/2002	15	-8.2	-3.5	1.2	-29.2	-28.1
15	9/2002	4/2003	7	-6.0	-0.5	-38.5	37.5	-1.0
15	4/2003	10/2003	6	-2.0	-2.6	-17.5	-4.6	-22.0
15	10/2003	9/2004	11	5.2	-2.4	25.3	-10.1	15.2
15	9/2004	12/2005	15	-6.9	-5.7	-64.8	-4.6	-69.4

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
16	5/1999	7/1999	2	4.4	-0.3	20.2	-18.1	2.1
16	7/1999	10/1999	3	-7.6	1.0	16.4	-29.3	-12.9
16	10/1999	4/2000	6	-4.1	-0.4	-54.2	30.0	-24.2
16	4/2000	10/2000	6	-1.3	0.1	20.6	-41.0	-20.4
16	10/2000	6/2001	8	0.6	-0.2	-0.0	-13.7	-13.7
16	6/2001	9/2002	15	-4.8	-2.1	-13.2	-2.2	-15.3
16	9/2002	4/2003	7	-7.3	-0.5	-38.8	40.3	1.5
16	4/2003	10/2003	6	-2.2	-3.1	-24.5	-4.4	-28.9
16	10/2003	9/2004	11	4.3	-1.0	22.8	-31.7	-8.9
16	9/2004	12/2005	15	-9.4	-1.1	-28.5	-14.0	-42.5
17	5/1999	7/1999	2	3.4	-0.4	8.1	-22.1	-14.0
17	7/1999	10/1999	3	-1.8	-4.0	-23.1	6.8	-16.2
17	10/1999	4/2000	6	-4.7	-0.7	-51.7	22.5	-29.2
17	4/2000	10/2000	6	-5.6	0.4	16.3	-37.9	-21.6
17	10/2000	6/2001	8	9.3	-5.3	53.7	2.1	55.9
17	6/2001	9/2002	15	-9.0	2.2	-2.3	-86.7	-89.0
17	9/2002	4/2003	7	-8.6	-3.2	-65.5	23.1	-42.4
17	4/2003	10/2003	6	-16.0	-0.7	-18.5	14.7	-3.8
17	10/2003	9/2004	11	19.5	-0.9	43.4	-30.0	13.4
17	9/2004	12/2005	15	-10.6	1.4	-11.4	-73.3	-84.8
18	5/1999	7/1999	2	-1.4	1.2	6.5	-8.3	-1.7
18	7/1999	10/1999	3	-2.8	0.2	23.3	-38.6	-15.3
18	10/1999	4/2000	6	-7.0	-1.1	-51.8	8.9	-42.9
18	4/2000	10/2000	6	-2.9	-0.9	19.9	-13.2	6.7
18	10/2000	6/2001	8	3.9	-0.6	8.6	-8.5	0.1
18	6/2001	9/2002	15	-5.2	-1.2	-12.0	-13.6	-25.6
18	9/2002	4/2003	7	-8.9	-3.4	-69.7	18.2	-51.5
18	4/2003	10/2003	6	-16.4	-0.3	-7.6	17.0	9.4
18	10/2003	9/2004	11	18.4	-0.2	34.7	-25.4	9.3
18	9/2004	12/2005	15	-8.1	-0.9	-22.3	-24.7	-47.0

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
19	5/1999	7/1999	2	2.9	-2.2	13.5	-9.4	4.1
19	7/1999	10/1999	3	-4.1	0.2	10.5	-40.7	-30.2
19	10/1999	4/2000	6	-5.7	-0.8	-55.1	19.6	-35.5
19	4/2000	10/2000	6	-3.3	0.6	21.7	-43.7	-22.0
19	10/2000	6/2001	8	5.0	1.5	-4.7	17.6	12.9
19	6/2001	9/2002	15	-5.8	-1.6	-12.4	-6.9	-19.2
19	9/2002	4/2003	7	-17.5	-3.6	-73.0	12.5	-60.5
19	4/2003	10/2003	6	1.7	-2.0	-0.8	15.5	14.7
19	10/2003	9/2004	11	9.3	-0.5	33.1	-33.9	-0.7
19	9/2004	12/2005	15	-8.7	-1.4	-21.6	-17.7	-39.3
20	5/1999	7/1999	2	-2.0	-1.9	8.7	-12.5	-3.8
20	7/1999	10/1999	3	-1.1	0.1	13.9	-30.9	-17.0
20	10/1999	4/2000	6	-4.4	-1.0	-56.3	13.7	-42.6
20	4/2000	10/2000	6	-2.0	0.1	21.9	-31.8	-9.9
20	10/2000	6/2001	8	-1.0	0.2	-11.0	-28.5	-39.4
20	6/2001	9/2002	15	-3.8	-0.9	-15.8	-2.6	-18.4
20	9/2002	4/2003	7	-16.4	-4.5	-98.4	-1.8	-100.2
20	4/2003	10/2003	6	5.1	-5.2	49.8	-1.9	47.9
20	10/2003	9/2004	11	6.0	-0.7	23.1	-36.6	-13.4
20	9/2004	12/2005	15	-1.6	-0.2	-15.3	-10.4	-25.7
21	5/1999	7/1999	2	-0.4	-1.5	4.9	-20.8	-15.9
21	7/1999	10/1999	3	-1.9	0.2	20.0	-25.8	-5.7
21	10/1999	4/2000	6	-1.0	-0.1	-26.1	52.2	26.1
21	4/2000	10/2000	6	-11.6	0.9	-2.9	-78.5	-81.4
21	10/2000	6/2001	8	5.9	-0.5	17.8	-16.1	1.7
21	6/2001	9/2002	15	-18.6	-0.5	-34.0	19.3	-14.7
21	9/2002	4/2003	7	-19.1	-3.9	-91.8	-7.0	-98.8
21	4/2003	10/2003	6	15.3	-5.4	76.6	-3.4	73.2
21	10/2003	9/2004	11	3.6	-0.4	6.2	-32.5	-26.3
21	9/2004	12/2005	15	-0.6	1.5	0.2	-24.0	-23.8

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
22	5/1999	7/1999	2	-3.7	-0.4	-4.0	-11.1	-15.1
22	7/1999	10/1999	3	-0.7	0.2	9.0	-18.4	-9.4
22	10/1999	4/2000	6	-8.6	-0.9	-47.0	34.4	-12.5
22	4/2000	10/2000	6	-1.9	0.2	17.3	-38.1	-20.8
22	10/2000	6/2001	8	3.8	-0.3	13.2	-30.0	-16.8
22	6/2001	9/2002	15	-12.2	-0.6	-27.9	10.5	-17.4
22	9/2002	4/2003	7	-17.2	-3.4	-74.0	23.2	-50.8
22	4/2003	10/2003	6	14.0	-5.0	55.0	-6.1	49.0
22	10/2003	9/2004	11	3.3	-0.4	19.8	-42.7	-22.9
22	9/2004	12/2005	15	-2.3	-0.6	-2.4	-9.2	-11.6
23	5/1999	7/1999	2	-4.5	-4.4	-21.4	8.3	-13.1
23	7/1999	10/1999	3	4.6	-0.4	11.5	-6.2	5.2
23	10/1999	4/2000	6	-17.7	-0.9	-70.4	42.3	-28.1
23	4/2000	10/2000	6	10.7	-1.1	31.0	-39.0	-8.1
23	10/2000	6/2001	8	-2.3	0.2	6.7	-44.7	-38.1
23	6/2001	9/2002	15	-8.8	-0.2	-26.6	3.9	-22.7
23	9/2002	4/2003	7	-21.7	-2.8	-78.8	8.7	-70.1
23	4/2003	10/2003	6	14.4	-5.5	51.5	3.1	54.5
23	10/2003	9/2004	11	10.3	-2.1	27.0	-22.0	5.0
23	9/2004	12/2005	15	-0.3	0.0	5.3	-33.8	-28.5
24	5/1999	7/1999	2	1.6	-4.3	-15.4	15.5	0.2
24	7/1999	10/1999	3	-1.7	0.3	16.1	-4.1	12.0
24	10/1999	4/2000	6	-12.2	-4.6	-17.2	-28.4	-45.6
24	4/2000	10/2000	6	4.7	-1.1	9.9	-30.7	-20.8
24	10/2000	6/2001	8	-4.3	0.5	1.8	-37.1	-35.3
24	6/2001	9/2002	15	-3.5	-0.3	-21.0	26.1	5.1
24	9/2002	4/2003	7	-18.5	-2.4	-51.0	22.3	-28.8
24	4/2003	10/2003	6	1.8	-1.3	10.2	-14.4	-4.2
24	10/2003	9/2004	11	13.9	-2.6	36.6	-21.9	14.7
24	9/2004	12/2005	15	-0.2	0.0	-2.6	-23.9	-26.5

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	$[m]$	$[m]$	$[m^2]$	$[m^2]$	$[m^2]$
25	5/1999	7/1999	2	-0.9	-0.1	-10.3	4.4	-6.0
25	7/1999	10/1999	3	-2.0	-3.3	-27.2	4.5	-22.7
25	10/1999	4/2000	6	-12.0	-1.2	-57.9	55.2	-2.7
25	4/2000	10/2000	6	6.7	-1.5	38.1	-45.3	-7.2
25	10/2000	6/2001	8	-2.8	0.4	2.2	-58.3	-56.1
25	6/2001	9/2002	15	-14.4	-0.5	-40.6	19.8	-20.8
25	9/2002	4/2003	7	0.1	-2.4	-16.9	33.8	16.9
25	4/2003	10/2003	6	4.0	-1.3	6.4	-19.1	-12.7
25	10/2003	9/2004	11	-4.1	-2.7	13.7	-17.3	-3.6
25	9/2004	12/2005	15	2.2	-0.2	8.2	-38.5	-30.3
26	5/1999	7/1999	2	-5.2	-0.4	-6.5	-4.1	-10.5
26	7/1999	10/1999	3	-0.0	0.0	2.2	-17.4	-15.2
26	10/1999	4/2000	6	-16.5	-1.1	-57.7	39.0	-18.7
26	4/2000	10/2000	6	9.3	-1.2	27.6	-44.9	-17.3
26	10/2000	6/2001	8	0.3	-0.0	8.3	-51.5	-43.2
26	6/2001	9/2002	15	-17.8	-0.8	-51.4	8.4	-42.9
26	9/2002	4/2003	7	0.4	-1.6	-1.0	44.6	43.6
26	4/2003	10/2003	6	-6.1	-0.2	-4.1	-24.1	-28.2
26	10/2003	9/2004	11	2.6	-2.0	8.5	-24.4	-15.9
26	9/2004	12/2005	15	4.9	-0.1	7.9	-34.8	-26.8
27	5/1999	7/1999	2	-2.8	0.7	1.0	-10.8	-9.8
27	7/1999	10/1999	3	-3.4	-3.4	-26.2	8.7	-17.5
27	10/1999	4/2000	6	-18.3	-0.2	-38.9	40.7	1.8
27	4/2000	10/2000	6	12.2	0.0	24.4	-55.9	-31.5
27	10/2000	6/2001	8	3.6	-0.3	18.1	-33.5	-15.4
27	6/2001	9/2002	15	-20.0	-0.6	-76.7	-11.3	-88.1
27	9/2002	4/2003	7	-1.8	-2.3	-23.0	28.4	5.3
27	4/2003	10/2003	6	-9.4	-1.1	-2.5	-8.8	-11.3
27	10/2003	9/2004	11	2.2	-1.8	11.6	-20.7	-9.2
27	9/2004	12/2005	15	5.0	-0.2	11.6	-42.3	-30.7

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
28	5/1999	7/1999	2	1.9	-0.2	7.4	-15.9	-8.5
28	7/1999	10/1999	3	-9.9	0.8	0.9	-12.8	-11.9
28	10/1999	4/2000	6	-0.7	-0.0	-28.6	20.5	-8.1
28	4/2000	10/2000	6	-2.4	0.2	17.5	-49.4	-31.9
28	10/2000	6/2001	8	-1.7	0.1	-5.5	-38.4	-43.8
28	6/2001	9/2002	15	-14.2	-0.5	-37.4	2.7	-34.6
28	9/2002	4/2003	7	-9.7	-2.7	-32.3	56.1	23.8
28	4/2003	10/2003	6	-10.7	-1.1	-21.3	-11.7	-33.0
28	10/2003	9/2004	11	17.1	-2.5	31.6	-25.2	6.4
28	9/2004	12/2005	15	-2.0	0.2	6.3	-36.0	-29.8
29	5/1999	7/1999	2	3.8	-0.7	7.8	-6.2	1.6
29	7/1999	10/1999	3	-5.7	1.1	2.3	-19.5	-17.2
29	10/1999	4/2000	6	-10.5	-0.7	-54.8	47.2	-7.6
29	4/2000	10/2000	6	3.8	-0.5	21.6	-56.4	-34.7
29	10/2000	6/2001	8	-3.6	0.6	6.2	-38.9	-32.8
29	6/2001	9/2002	15	-15.5	-1.3	-52.3	14.3	-38.0
29	9/2002	4/2003	7	-2.5	-0.4	-20.8	18.2	-2.6
29	4/2003	10/2003	6	-9.5	-0.2	-10.2	-3.5	-13.7
29	10/2003	9/2004	11	8.3	-2.9	36.2	-18.6	17.6
29	9/2004	12/2005	15	5.9	-0.3	7.6	-26.4	-18.9
30	5/1999	7/1999	2	2.7	-0.5	0.9	-0.3	0.6
30	7/1999	10/1999	3	-4.9	0.7	11.7	-9.8	1.9
30	10/1999	4/2000	6	-6.9	-0.5	-51.9	35.1	-16.8
30	4/2000	10/2000	6	2.5	-0.7	30.5	-47.9	-17.4
30	10/2000	6/2001	8	0.8	-0.1	18.3	-21.9	-3.6
30	6/2001	9/2002	15	-17.8	-3.4	-38.6	-15.0	-53.6
30	9/2002	4/2003	7	-8.5	-2.3	-30.2	54.3	24.1
30	4/2003	10/2003	6	-8.9	-5.8	-31.8	0.0	-31.8
30	10/2003	9/2004	11	10.2	-2.7	43.4	-22.6	20.8
30	9/2004	12/2005	15	6.2	-0.4	11.4	-22.8	-11.4

Table D.3: Erosion and Accretion of Each Profile Line at Bethany (Continued)

Prof.	t_1	t_2	Δt	Δx	z_3	A_L	A_S	$A_L + A_S$
[#]	[mo/yr]	[mo/yr]	[mo]	[m]	[m]	[m^2]	[m^2]	[m^2]
31	5/1999	7/1999	2	3.6	-0.6	16.7	-3.5	13.2
31	7/1999	10/1999	3	-2.1	-3.2	1.3	32.4	33.8
31	10/1999	4/2000	6	-0.4	-0.1	-36.3	32.6	-3.7
31	4/2000	10/2000	6	-2.0	0.1	44.6	-59.7	-15.2
31	10/2000	6/2001	8	-0.7	0.3	-0.7	-27.0	-27.7
31	6/2001	9/2002	15	-16.6	-1.5	-50.3	5.4	-44.8
31	9/2002	4/2003	7	N/A	-2.7	-7.5	31.1	23.6
31	4/2003	10/2003	6	N/A	-3.3	-7.2	-1.8	-8.9
31	10/2003	9/2004	11	2.4	-2.6	26.2	-26.1	0.0
31	9/2004	12/2005	15	7.8	-0.5	15.0	-28.5	-13.5
32	5/1999	7/1999	2	5.0	-3.9	26.8	-3.9	22.9
32	7/1999	10/1999	3	-2.5	-3.3	1.5	73.9	75.4
32	10/1999	4/2000	6	-3.4	-0.4	-46.2	-3.5	-49.8
32	4/2000	10/2000	6	-0.3	0.1	45.9	-61.4	-15.5
32	10/2000	6/2001	8	-0.1	0.0	6.8	-26.9	-20.1
32	6/2001	9/2002	15	-24.4	-7.1	-119.0	10.4	-108.6
32	9/2002	4/2003	7	N/A	-6.1	40.7	-25.5	15.2
32	4/2003	10/2003	6	N/A	-4.4	-6.4	8.3	1.9
32	10/2003	9/2004	11	2.9	-2.8	27.6	-2.0	25.6
32	9/2004	12/2005	15	8.2	-0.4	21.8	-53.3	-31.5

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