MEASURING TOTAL LONGSHORE SEDIMENT TRANSPORT WITH A LISST INSTRUMENTED MINI-SLED

A Thesis

by

ERICK KARL HUCHZERMEYER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2005

Major Subject: Oceanography

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Approved by:

Chair of Committee,	William Bryant
Committee Members,	Tom Ravens
	Wilford Gardner
	Timothy Dellapenna
Head of Department,	Wilford Gardner

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ABSTRACT

Measuring Total Longshore Sediment Transport with a

LISST Instrumented Mini-Sled. (December 2005)

Erick Karl Huchzermeyer, B.S., Texas A&M University Galveston

Chair of Advisory Committee: Dr. Bill Bryant

A surf zone sediment transport study was conducted in Jamaica Beach, Texas, using new oceanographic equipment. A mini-sled was constructed and outfitted with an instrument package that consisted of two velocimeters, one current profiler, three OBS's (Optical Back Scatter), and a Sequoia Instruments LISST (Laser *in situ* Scatterometer and Transmissometer). This instrumented sled was used to measure sand concentration and flow velocity across the surf zone. Using these two parameters we were able to determine longshore sand transport.

The study provided an accurate measurement of sand transport on a muddy coast. Previous methods for measuring total longshore sediment transport did not quantify the effect that mud-sized particles would have on OBS's. To circumvent this issue we used the LISST to measure sand concentration in the water. The LISST can measure sand concentration despite the presence of mud.

During this study it appeared that sand transport peaks 10 cm above the sea bottom. The measured total longshore transport rate closely matched results from one equation for determining total longshore transport (Kamphius, 1991). The CERC equation was also compared to the measured result.

ACKNOWLEDGEMENTS

There have been many people who have contributed to the success of my graduate education at Texas A&M University. Each has offered advice, encouragement, financial support and above all, patience during this endeavor.

Working between Galveston and College Station I have received guidance from both Dr. William R. Bryant and Dr. Tom Ravens. Each assisted me in different ways. Dr. Bryant helped secure funding for the project and stipend for my work. He also was very supportive during this long journey. Dr. Ravens also secured funding for the project, assisted me in the field, provided lab space in Galveston, and helped me plan the entire experienment from beginning to end. To both men, I am thankful.

Dr. Wilford Gardner provided me with invaluable advice while writing and completing my thesis manuscript. He also introduced me to the LISST instrument which became the heart of my thesis.

Dr. Timothy Dellapenna allowed me to use some of his equipment in his laboratory. Results from that work were used in my thesis.

Administrative assistants with the Oceanography Department, Sandy Drews, Laura Caldwell and Amanda Schwede helped me along the way by providing assistance with academic registration and paying tuition. I am indebted to them for basically lighting the way while trying to navigate through the labyrinth of rules and regulations that come with a huge state-run-university.

I also would like to thank the dozens of un-named undergraduates who assisted in the field and lab.

Without my family's support this thesis never would have gotten off the ground or I would have given up a long time ago.

My mother, Mandi Greene, who has a tenacious drive, has inspired me to work hard and stick to my guns. My mother and step-father Gary Greene, along with my father Richard Huchzermeyer have provided not only financial support, but also valuable emotional backing. I also would like to thank my uncle, Brian Meagher, for directing me toward the field of geosciences.

My wife, Laura Huchzermeyer, helped edit my thesis and refused to let me stray off course … too much.

My friends are a big part of my life and I would be remiss if I didn't mention them here. First, I thank Matt Meyer and Ryan Thomas who not only are good friends but continually reminded they had finished their master's degree, and I had not. Bob Miller helped me with a place to live and provided lots of support. Dan and Debora Bean were part of the "deep tow crew" and are valuable friends to have.

Thanks to my band mates in SUPERSTRUCTURE. You never stopped believing in me and provided a much-needed diversion from school.

Finally, two strange thank yous go to Chrysler who broke the mold when they built my black Jeep Wrangler which was present in all field missions. And to Dudley's Draw which provided chicken sandwiches and other things that may (or may not) have assisted me in my studies.

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INTRODUCTION

Longshore transport of sediment occurs when waves encounter a beach at an oblique angle. The amount of sediment, usually sand, that is transported via these waves is called total longshore sediment transport (TLST). The relationship between TLST and the wave condition that generated it is a top priority of many coastal geologists and engineers. The accurate measurement or calculation of TLST is very important as it forms the basis for many public works projects, coastal structure engineering, and predicting shoreline change. For instance a measurement of TLST would form the basis for predicting the lifespan of a beach replenishment program or the predicted impact that a coastal structure would have on the surrounding beach. However the physical measurement of TLST is difficult to obtain and is usually not attempted.

The goal of this thesis was to develop a new method using a combination of optical and acoustic instruments to measure TLST. Furthermore, this new method should be economical, should be able to operate in storm conditions, and remain accurate in a muddy coast environment.

This thesis follows the style of *Journal of Coastal Research*.

In order to achieve these goals we built a miniature sled, much smaller than sleds used in previous studies (Sallenger *et al.*,1983). The mini-sled was outfitted with instruments that would allow the measurement of sand concentration and flow velocity. Using the data from these instruments we are able to calculate TLST. We then compared this result to popular models for calculating TLST.

Previous Work

For about six decades scientists have tried to measure TLST. First attempts to physically measure TLST came by using impoundment and sediment tracer techniques (explained later). Eventually a relationship between wave power and transport was determined (Figure 1). Since then most of the scientific effort has been applied to making TLST equations more dependable. The following is a brief discussion of several different methods of physically measuring TLST followed by a discussion on two equations to determine TLST.

Physical Measurement

Several methods have been created to physically measure TLST: impoundment (Wang 1999); sediment tracer (Komar and Inman 1970); measurements using sediment streamer traps (Wang 1998); and measurement using optical devices (Sternberg *et al.*, 1984).

Impoundment was the first technique used to measure TLST, and was developed in the 1950's (Caldwell, 1956). Impoundment is the physical blocking of the surf zone,

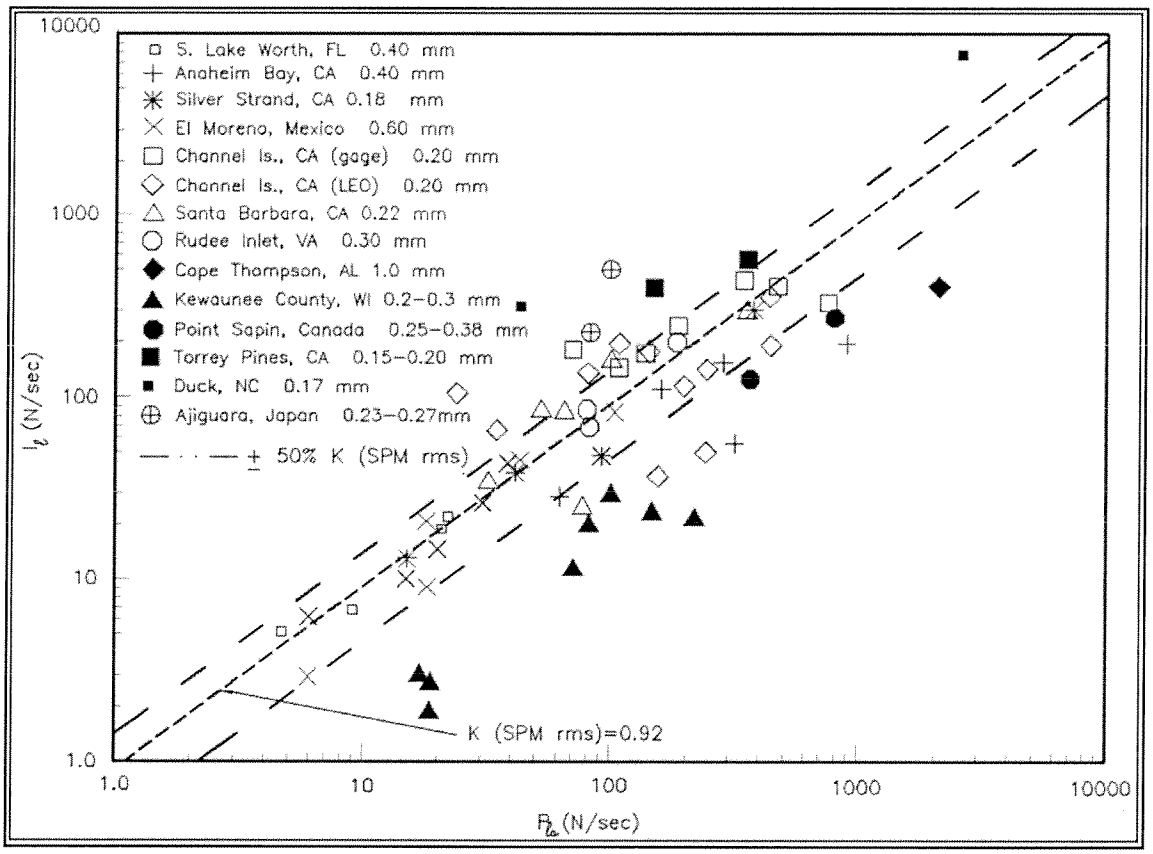

Figure 1: A comparison of wave power versus immersed weight of sand. A trend is obvious, however there is considerable scatter in the data. For example values for immersed weight of sand range from 10 to 400 N/sec for wave powers of 100 N/s (U.S. Army Corps of Engineers, 2002).

temporarily or permanently with groins, jetties, or other similar structures (White 1998). The structure limits or stops the flow of the longshore current and any sand previously in transport is deposited. The volume of this deposit is measured via survey methods and then divided by the amount of time that the structure has been in place. Impoundment experiments can be used over long amounts of time and in almost all weather conditions. Some drawbacks include: cost, labor, the fact that instantaneous loads cannot be measured, and interference from the impoundment structure which can influence the local current regime. Also as an impoundment structure ages it is also quite possible that one side of it can accrete enough sand so that the impoundment structure is bypassed.

Sediment tracer experiments are executed by releasing specially tagged sand and then tracking the movement of this sand. The sand is usually dyed a fluorescent color, but there have been other experiments that use radioactive sand. Sediment tracer experiments lead to the discovery of the relationship between wave energy flux and TLST (Komar and Inman,1970). The CERC (Coastal Engineering Research Center) equation (described later) is based on these findings.

Sediment tracer experiments have several logistical disadvantages such as manpower requirements, expense, and the inability to sample during storm conditions. One of the advantages of a tracer study is that the experiment's design includes bedload as well as suspended sediment transport mode. This is the reason that sediment tracer experiments are considered to be the only correct method to measure TLST by the majority of investigators.

The use of sediment streamers is another method to determine TLST (Krause, 1987). Sediment streamers are sock-like traps that are made of 63 μm nylon mesh. Sediment streamers have the ability to measure TLST quickly and therefore are considered to be an instantaneous method. Other advantages include their low cost and simplicity. Measurements can be made with a minimum amount of manpower. Some disadvantages include the fact that the entire surfzone can only be measured during low energy wave conditions. Streamers may also over sample by trapping any sand that enters the streamer, not allowing the usual back and forth motion of the surf zone. Also the streamers tend to disrupt the bottom, leading to scour pits.

Instrumentation of the surf zone using oceanographic type instruments is another method to measure TLST (Sallenger *et al.*,1983). It is the method utilized in this study. Usually this requires a velocimeter mated with optical backscatter instrument (OBS) to measure flow velocity and sediment concentration within the flow. The instruments are sometimes moored to the bottom or are mounted on a platform that can be moved about the surf zone. Instrumentation allows a near instantaneous measurement of TLST. Depending on the type of deployment, the instruments can measure during storm conditions (Miller 1999). Unfortunately the cost of the instruments and their platforms usually are prohibitively expensive.

The use of instrumentation also comes with a major problematic issue. No existing sediment detection instruments (OBS, Transmissometer, LISST, etc.) can measure bedload as they simply can not get close enough to the sea bed or have sufficient resolution to measure the transport of a few grains thickness. This has led to a

debate of their usefulness as there is uncertainty about the relative importance of bedload and suspended load.

TLST Models

Several formulas have been developed to calculate TLST. The most common formula to predict TLST is known as the CERC formula. The CERC formula is based on the relationship between wave power and sediment transport that was determined during tracer studies (Figure 1). It is given by the U.S. Army Corps of Engineers (2002) as,

$$I_\ell = KP_\ell \tag{1}$$

where I_ℓ is the longshore immersed weight transport of sand, P_ℓ is the longshore component of wave energy flux, and K is an empirical coefficient. Both sides have the same units (power/time).

We can calculate the longshore component of wave power as,

$$P_\ell = \left(EC_g\right)_b \sin\alpha_b \cos\alpha_b \tag{2}$$

where E_b is the wave energy at the breaker line, C_g is the wave group celerity at the breaker line, and α_b is the wave breaker angle relative to the shore line.

Wave energy can be calculated by,

$$E_b = \frac{\rho g H_b^2}{8} \tag{3}$$

where ρ is the density of seawater, g is gravity, H_b is the rms wave height at the breaker line. Wave group celerity can be calculated by,

$$C_{gb} = \sqrt{gd_b} = \left(g \frac{H_b}{\gamma} \right)^{\frac{1}{2}} \tag{4}$$

where d_b is the depth of water at the breaker line and γ is the wave breaker index. The breaker index is 0.78 for flat beaches but can change as the slope of the beach increases (Weggel, 1972).

When all these equations are put together we have,

$$I_\ell = K \left(\frac{\rho g^{\frac{3}{2}}}{16\gamma^{\frac{1}{2}}} \right) H_b^{\frac{5}{2}} \sin(2\alpha_b) \tag{5}$$

we can convert I_ℓ to a volume transport rate (Q_ℓ) which yields,

$$Q_\ell = K \left(\frac{\rho\sqrt{g}}{16\gamma^{\frac{1}{2}}(\rho_s - \rho)(1-n)} \right) H_b^{\frac{5}{2}} \sin(2\alpha_b) \tag{6}$$

where n in the equation is the *in situ* porosity of sand, given as 0.32.

The version of the CERC equation that we use later in this thesis (Kamphuis, 1986) is:

$$Q_s = 128 H_b^{5/2} \gamma^{-1/2} \sin 2\alpha_{bs} \tag{7}$$

where Qs is the mass sediment transport rate in kg/s, K=0.77.

Another popular equation to determine transport rates was developed by Kamphius *et al.* (1986). His equation was an attempt to determine which variables influence the coefficient *K*. Using a wave tank he was able to calculate that beach slope and grain size affect *K*. His equation (Kamphius, 1991) is given by:

$$Q = 6.4 \times 10^4 H_{sb}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6}(2\alpha_b) \tag{8}$$

Where H_{sb} is the significant wave height at breaking, T_p is the peak period, m_b is the beach slope at breaking, and D_{50} is the mean sediment size of the beach. This equation in this form gives Q in m^3/yr and assumes a porosity of about 32%.

Statement of Problem

The dimensionless variable *K* in the CERC equation is our problem. It is given as 0.77 by Komar and Inman (1970) and as 0.93 by the U.S. Army Corps of Engineers (2002). Other investigators have come up with values from 0.2 to 1 (Bodge and Krause, 1991). A look at Figure 1 shows that for some values of wave power there can be a one and a half order of magnitude scatter in the amount of immersed weight of sand.

It is apparent then that the use of the CERC equation, with default values for K, might lead to incorrect values of TLST. In fact there are many scientists that advise against the use of the CERC equation and other formulas stating that the data used to create the formulas are incomplete and have too much scatter to be useful (Theiler *et al.*, 2000). Even the U.S. Army Corps of Engineers (2002) warns of the use of the CERC

equation by pointing out that the data used to determine the relationship between wave power and transport has a large scatter to it.

The fact that the CERC equation also has an empirical coefficient is one of the equation's failings and shows our limited knowledge of which variables are important in the calculations of TLST. As it stands the CERC equation only uses wave height at breaking and wave direction as its variables (the other variables such as water density and sand porisity do not change much from beach to beach). Many scientists point out that there must be several other variables that are important in TLST such as mean particle size and beach slope (Theiler *et al.*, 2000). Many contributors have tried to find a formula for determining *K* (Kamphius *et al.*,1986). But their methods have not become widely accepted.

Nevertheless, the search for a working model to calculate TLST has been one of the major goals of coastal science since its inception. We believed that an attempt to measure TLST was warranted for our beach in Galveston as there are limited measurements of TLST in the Gulf of Mexico. We would then compare the measured TLST to calculated values using the CERC equation, a slightly modified CERC equation and the Kamphius 91 equation. Our hypothesis is that the mini-sled will be an effective way to measure TLST and that the CERT equation and others will prove to be unsuitable due to this location's low energy and wide surf zone.

THE STUDY

Study Area

The study took place in Jamaica Beach, Texas on Galveston Island (Figure 2). This part of Galveston has a beach that is uninterrupted by man-made obstructions and has very pronounced bars and toughs. The water of the Gulf of Mexico is muddy in this area. Visibility is commonly just a few inches in the water column. This usually is attributed to the nearby inlets of Bolivar Roads and San Luis Pass, the mouth of the Brazos River, and from circulation of the Gulf that brings turbid water from the Mississippi over towards Galveston. The physical makeup of the beach is very fine sand.

Methods

In this study, optical devices were mounted on a small sled (the mini-sled) to determine TLST. Two versions of the sled were used. A prototype sled (the Mk. I) constructed by Dr. Ravens and myself was used to test out methods and to measure TLST (Figure 3). This sled was used on 5 different occasions but only one tow acquired suitable data for use in determining TLST. The second sled (the Mk. II) was constructed by Dr. Ravens and Randall Thomas (Figure 4). It corrected many of the shortcomings that were observed in the original model. This sled was used over five times but only data from two tows are presented.

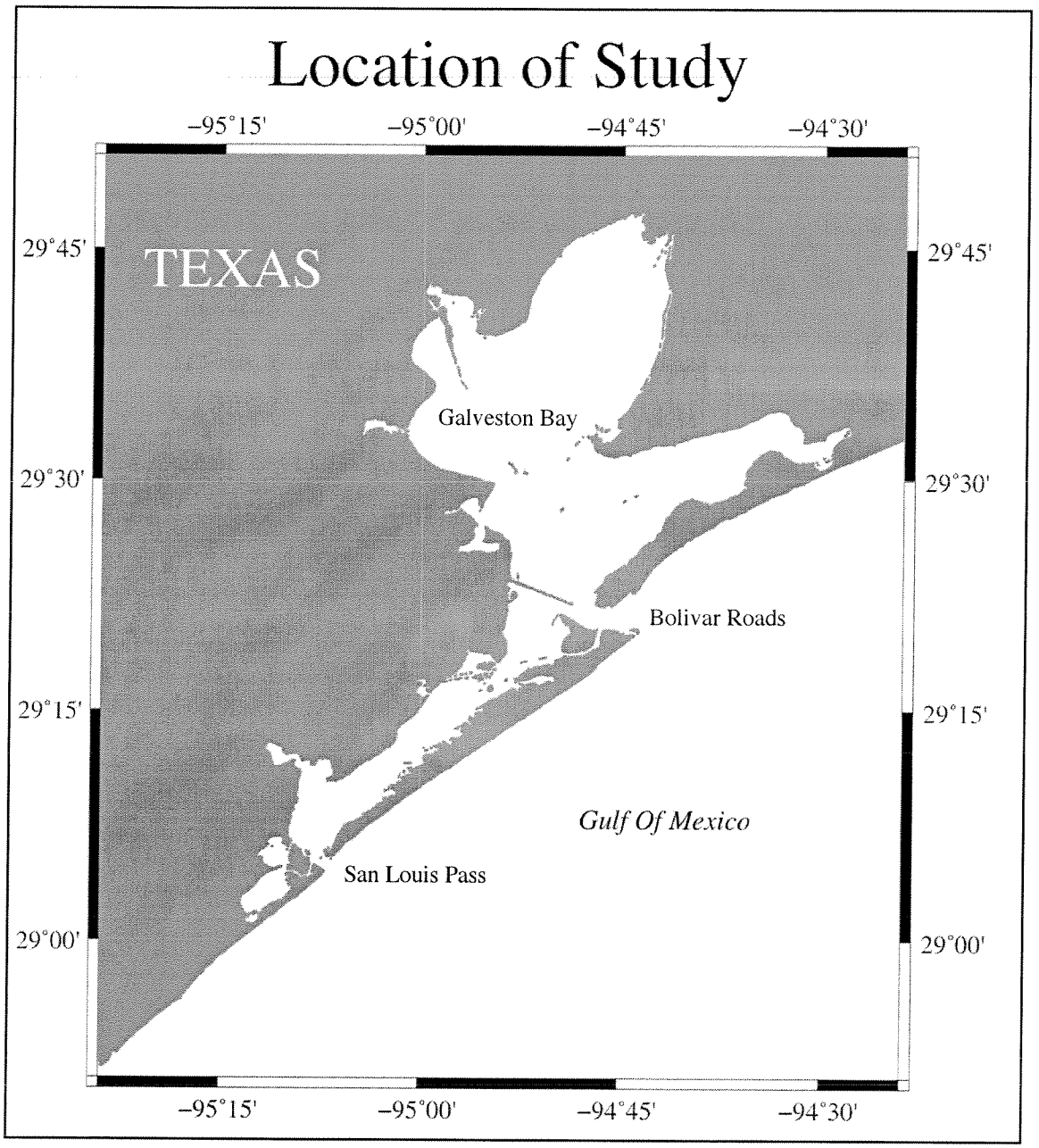

Figure 2: Location of study. The red dot is Jamaica Beach, Texas. This is where we conducted the study.

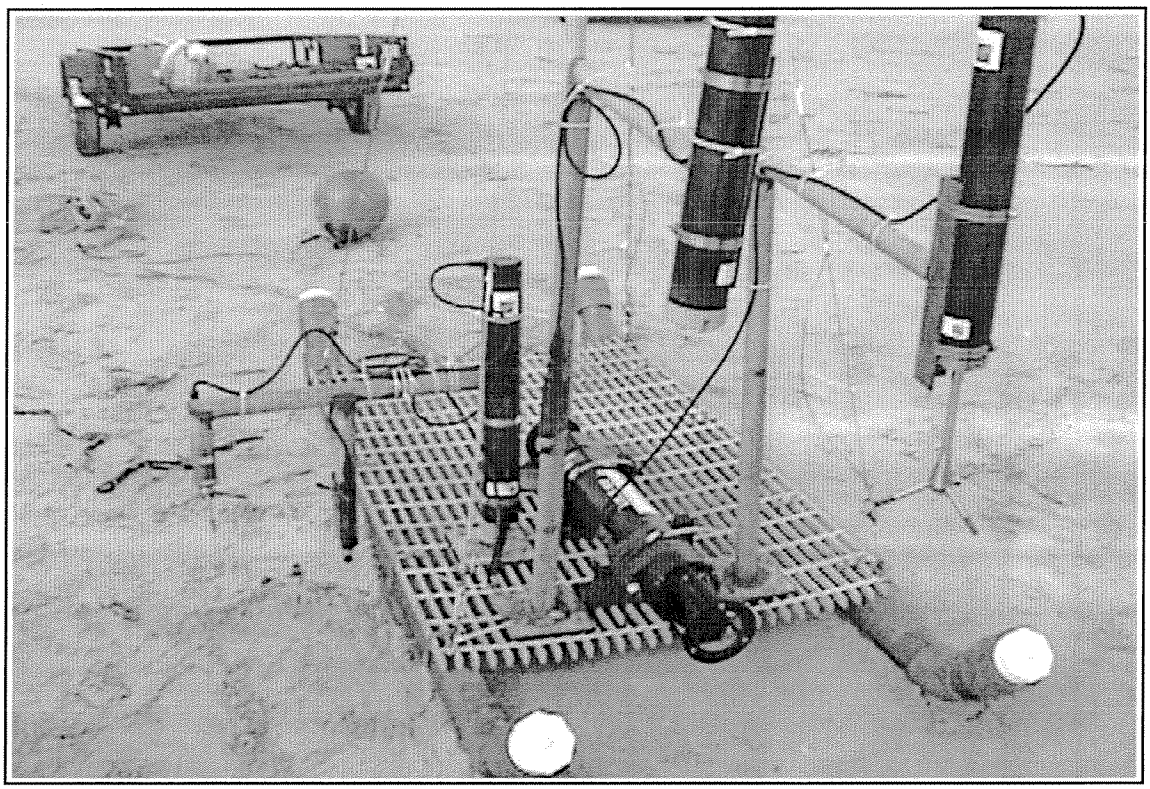

Figure 3: A photograph of the Mk. I sled. The large black instrument that is lying on its side is the LISST. There is an OBS attached to it at the same level.

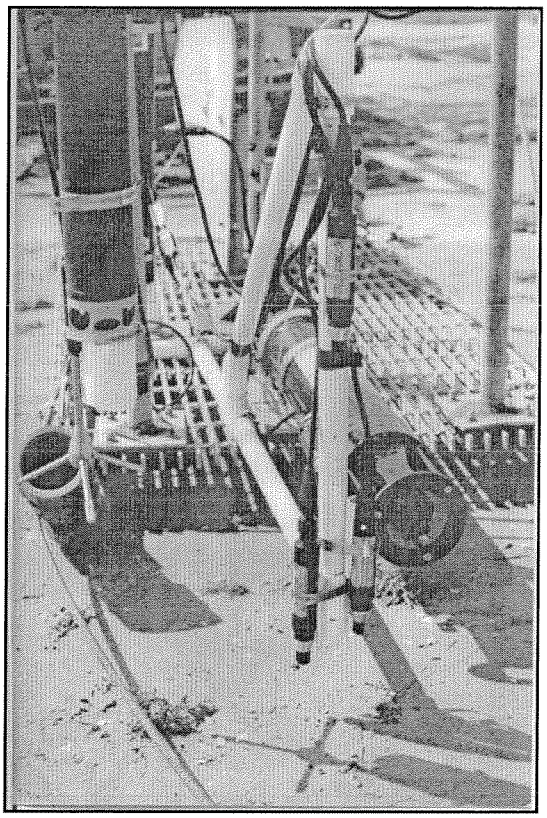

Figure 4: A photograph of the Mk. II sled.

The Mk. I sled measured 5 feet by 3 feet, has a mast of about 4 meters in height and hosted two Nortek "Vector" Acoustic Doppler Velocimeters (ADV) capable of measuring flow at 32Hz (normally sampling at 1Hz for our project); a Nortek "Aquadopp" Acoustic Doppler Current Profiler (ADCP) which samples 15 ten cm bins at 2Hz; three D&A OBS-3 turbidity sensors which sample at three different depths and record data at 1Hz (four on the Mk. II) ; and a Sequioa LISST-100, modified for extremely turbid waters which samples at 1Hz. The entire setup was designed to be placed on a small trailer for movement from the lab to the site. The Mk. I sled used a polypropylene tow rope.

The Mk. II sled is basically the same sled with some improvements. An extra OBS is used and the Nortek ADCP was converted into a velocimeter. The Mk. II sled also sports a fin that keeps the instruments pointed into the current and an improved release mechanism on the jet ski. The greatest improvement is that the polypropylene rope has been replaced with steel cable. The steel cable is resistant to the actions of the current as it does not float. The Mk. II sled also has had its OBS's "matched," that is all the OBS's have been adjusted so they have the same gain and calibration.

Table 1 has the positions for all the instruments on all the sleds.

Positioning for both sleds is determined by a Nikon DTM-A5LG total station that measures the distance and angle to prisms placed atop the mast of the sled. This study employed a local grid where Northing is perpendicular to the beach and Easting is distance parallel to the beach. A benchmark was set in the dunes and was made to be the origin of the local grid. Elevation was set to zero at the benchmark, later the benchmark

Table 1: Locations and use of instruments on the sled. All measurements are in meters from the sea bottom. Also are listed rejected instruments. OBS 1613 was mounted on the LISST. Waveheights were measured from the pressure sensor on Vector 190.

Instrument and S/N	2/28/2002	5/28/2003	5/30/2003
OBS 1259	0.15	0.07	0.07
OBS 1789	N/A	REJECTED (0.10)	REJECTED (0.10)
OBS 1613	0.23	0.15	0.15
OBS 1614	0.50	0.46	0.46
LISST	0.23	0.15	0.15
VECTOR 190	0.15	0.07	0.07
VECTOR 188	0.50	REJECTED (0.15)	0.15
ADCP	0.96	N/A	N/A
AQUADOPP	N/A	0.35	REJECTED

elevation was tied into the North American Vertical Datum of 1988 (NAVD 88) using a nearby National Geodetic System (NGS) benchmark and a Trimble RTK-GPS system. The elevations presented in this study are in the NAVD 88 system.

The tows were conducted in the same basic manner. A jet ski would tug the sled out to a point just outside the surf zone. The jet ski would then disconnect from the sled. A tow rope would remain connected to the sled from the shore. Using this tow rope the sled would then be dragged back onto shore, pausing for approximately three minutes at each station to collect data. The positions of the stations were not planned in advance, however an attempt was made to keep them approximately ten meters apart.

The Mk. I sled had several design problems. First, the polypropylene tow rope floated. The floating rope would get caught in the longshore current and could physically provide enough tension to move the sled while it was at a station. It would also move the sled offline. However, the sled moving offline was not a problem as the bar system is the same down the beach but the control of the sled was compromised. Another problem with this sled was that during very heavy surf it was impossible to disconnect the jet ski from the sled. This was because the jet ski pilot had to use considerable strength to remove a hook that held the tow line.

During the data processing stage it became apparent that the LISST was highly susceptible to bubbles. The LISST would record zeros or improbably high numbers. To counter this I developed a Practical Extraction and Report Language (PERL) script that would edit out all the zero values and any outliers. The OBS data was also run through a similar program.

Another program, developed by Dr. Ravens, calculated the direction of the waves and currents from our velocity measurements. The program also calculates wave spectra. This program was developed from contributions of Madsen *et al.* (1993). To calculate significant wave height ($H_{1/3}$) I wrote a small PERL script that selected wave heights and averaged out the top one third. H_{rms} was determined by dividing $H_{1/3}$ by 1.4.

In addition to the sled we also tried some other methods to measure sand concentration and TLST. Sediment streamers were deployed by hand into the surf zone to physically measure the sand transport at different stations. These streamers were developed to the specifications of Krause (1987). This was only achieved at the shallower stations as it was difficult or impossible to get to the deeper stations. The sand concentration also was measured by a hand held pumping rig that would take a water sample. This apparatus allowed us to take a water sample at a site and compare it to the LISST data. Later we found that our positioning of the pump might have been a source of error. We positioned the pump so it would sample horizontally. This was 90 degrees from the flow direction. It has been pointed out by Black (1994) that the pump intake should have been facing downwards.

Operation of LISST

Because the ADCP, OBS, and ADV are common oceanographic instruments I will skip a detailed explanation of their operation. However, the LISST is a newer and less common oceanographic instrument so a brief explanation of its operation is in order.

The LISST was designed to determine sediment distribution *in situ.* It accomplishes this using a laser diffraction technique. The LISST transmits a collimated laser through a small window into the water. Particles in the water column cause the laser light to scatter. The scattered light then re-enters the LISST instrument through another window. Behind this window a lens focuses the light onto a ring detector. The ring detector has a series of 32 logarithmically spaced rings that represent 32 bins of particle sizes.

Depending on the size of the particle, the angle of scattered light will vary. Smaller mud-sized particles will scatter light with a larger angle, while larger sand-sized particles will scatter light with a smaller angle. Therefore, detection of light on the centermost rings is from larger particles, while light scattered from smaller particles will be detected on the outermost rings. For our LISST these sizes were from 2.5 μm to 500 μm with the terminus of each bin 1.18 times larger then the previous bin.

LISSTs have been tested by several contributors (Agrawal and Pottsmith, 2000) and perform reasonably well in the open ocean and in the lab. The use of a LISST in the surf zone is new so we had to improvise some processing steps to overcome interference from bubbles in the water. There also is an issue with bins "bleeding" into each other, during which a peak in one bin spreads into its neighboring bins. The manual for the LISST suggests that with 32 bins an operator should only expect 12 – 14 independent sizes.

Calibration

Calibration of the OBS's for the Mk. I sled was preformed using sand that was sieved to different sizes. Mud also was used from a donated offshore core. Its size was determined using a sedigraph particle size analyzer (Welch *et al.*, 1979). The OBS's were placed into a calibration bucket that contained water and an amount of calibration material. This was well mixed using a paint stirrer connected to an electric drill.

Initially a calibration technique that involved pipettes was used. This method gave spurious results, possibly because of restrictive flow around the pipette's tip. Future investigators may want to use caution when calibrating OBS's with sand sized particles and using a pipette. Therefore, I used an easier calibration technique in which known amounts of sand were added to the known volume of the calibration bucket.

The OBS's used on the Mk. II sled were calibrated together so they all had the same gains. This helped in later processing to have intercallibrated OBS's.

During calibration it became obvious that we did not know what effect a mud/sand mixture would have on OBS performance. For example, would the OBS report a signal that was equal to the sum of both the mud signal and sand signal or would the mixture distort the signals? These concerns were evaluated by calibrating the OBS's (with sand) in different concentrations of mud. The results are displayed in Figure 5. The sand calibration slope was the same for all concentrations of mud. In this process the conclusions of Ludwig and Hanes (1990) were verified.

The LISST was calibrated at the factory. However uncertainties were raised on the ability of the LISST to measure sand. A short field campaign was launched during

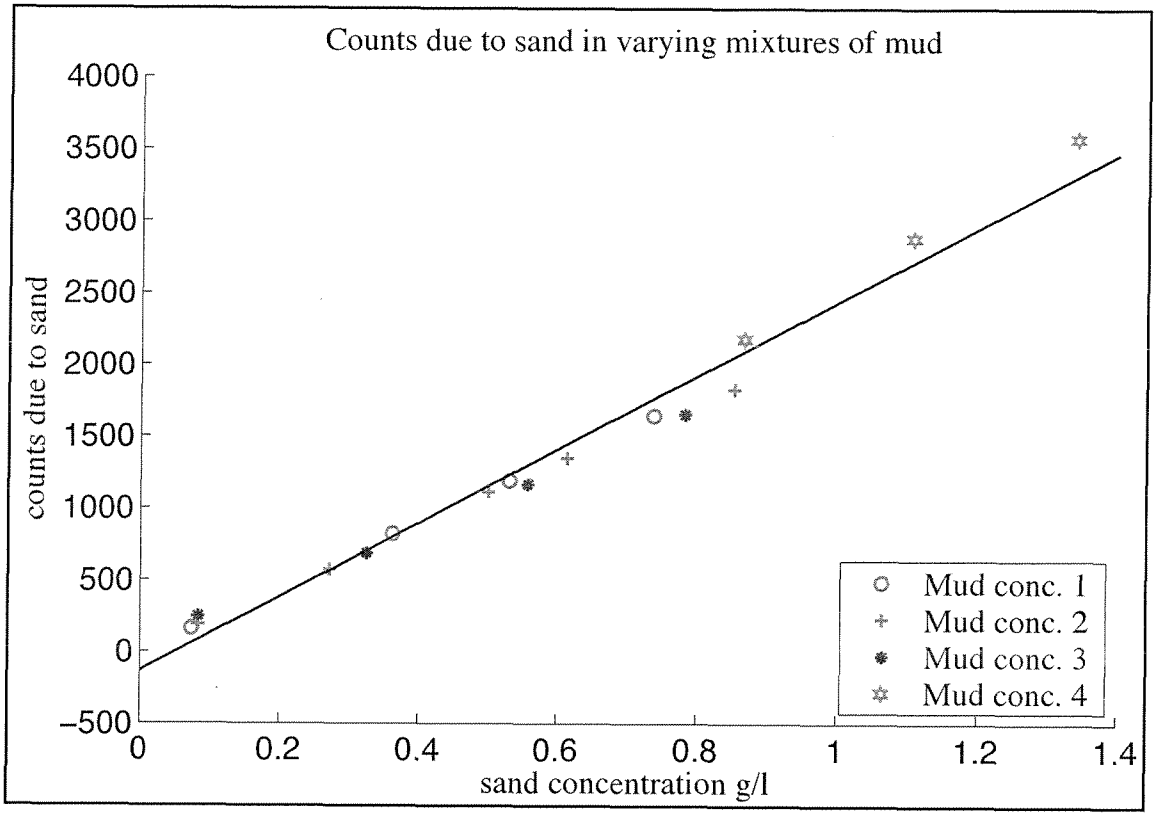

Figure 5: Counts due to sand in varying mixtures of mud.

which the LISST alone was placed on the mini-sled and a water sample was taken directly next to the LISST using the hand held pump. In conjunction some pump samples were taken in this fashion during tows.

This was done over several different wave conditions so as to expose the LISST to various concentrations of sand. The sample recovered by this pump was sieved with a 63 micron sieve and this sieved fraction was considered to contain only sands. Unfortunately only three points were measured using this method (Figure 6) making for a sparse calibration curve. Through these observations I decided that I would sum the peak value of the sand particles with its larger and smaller neighbor bins. This was mainly because it seemed to fit our limited calibration dataset and I knew that there was only a limited range of sand sized particle on the beach.

Figure 7 is a plot of a sediment size analysis that we ran as reconnaissance into the study area. A sand sample was taken from the beach and ran through a Rapid Sediment Analyser (RSA). The average size is about 140 μm. Figure 7 also has a plot of the three LISST bins that I summed to calculate sand concentration. The three LISST bins nearly account for the entire sand spike.

All other attempts to calibrate the LISST in the lab failed usually due to sand falling out of suspension in the LISST's manufacturer supplied calibration chamber. Given the problems with our calibration I elected to use the manufacturer's calibration for the duration of the experiment.

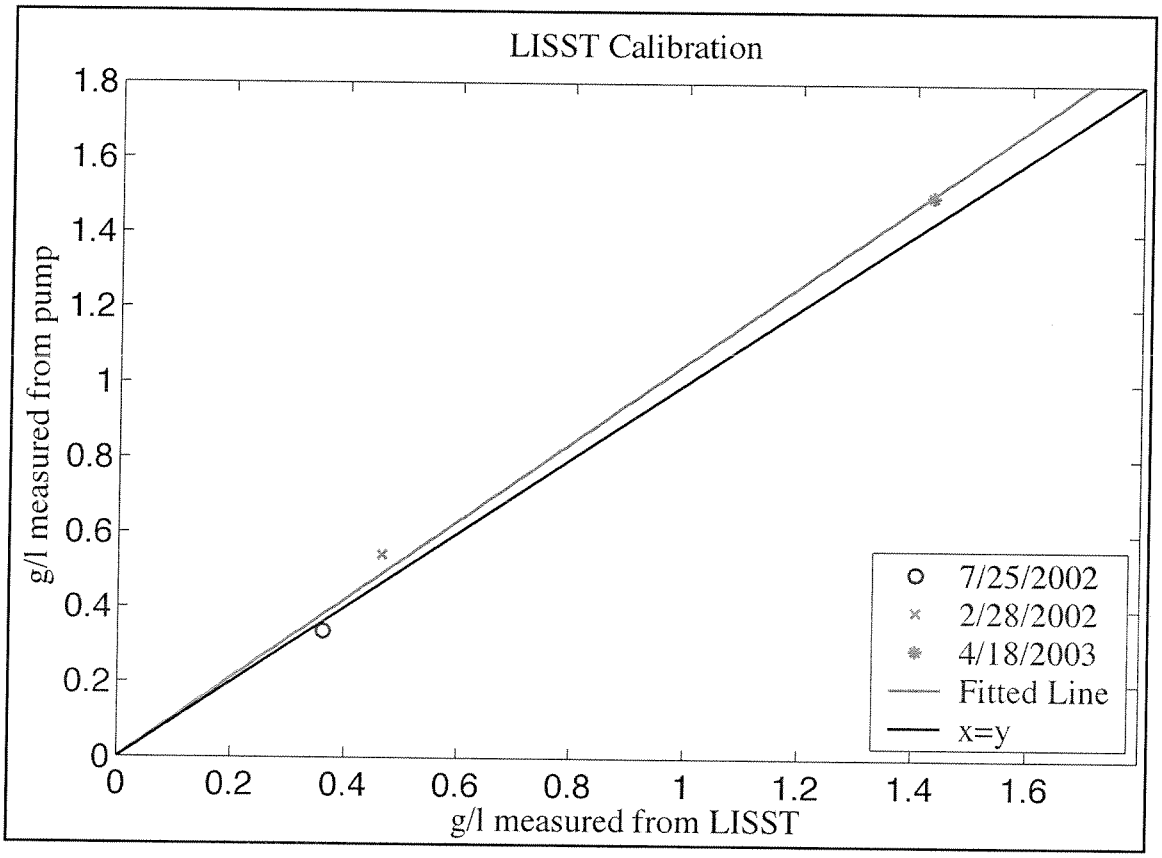

Figure 6: LISST calibration.

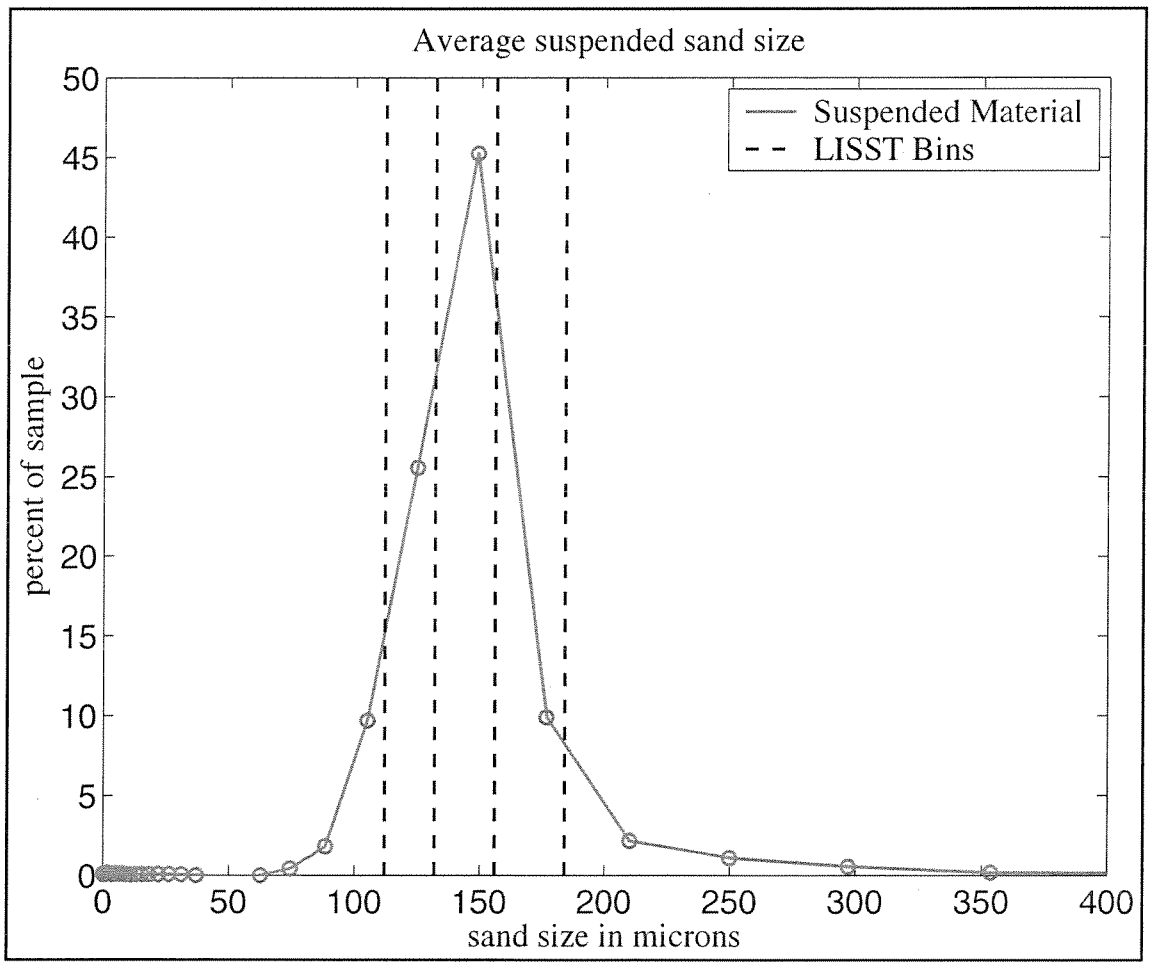

Figure 7: Average suspended sand size. The striped black lines are the three LISST bins that were summed to calculate sand concentration.

Calculations

To calculate TLST we split the water column into .1 m bins. The velocity was calculated from the center of each bin. These same points were later used for the concentration calculations.

Profiles of flow velocity were generated using the findings of Faria *et al.* (1998). Faria showed that profiles of average current were logarithmic in nature in the surf zone and presented this equation:

$$V_{(z)} = \frac{U^*}{\kappa} \ln\left(\frac{z+h}{z_0}\right) \tag{9}$$

where z is position above the sea bed, U^* is the shear stress velocity, κ is the Von Karman constant (0.4), z_0 is the physical roughness height, and h is the depth of water.

Calculating the flow velocity profile started by time averaging the magnitude of the flow recorded by the two vectors. The two time averaged flow magnitude values were then plotted on a semilog plot of z versus $V_{(z)}$. The slope and intercept of this plot were determined by linear regression. We can then calculate U* from the slope of the line and the flow profile is calculated from the equation of the line.

On the Mk. I sled the OBS gains did not match. Two of the OBS's had the same gains with one OBS constantly having counts twice as high. This happened in all concentrations and sizes of material. To make the gains of all three OBS's match I simply halved the counts from the higher reading OBS. In the Mk. II sled this step was not necessary because the OBS's previously were matched in the lab.

LISST sand concentration from the three bins shown in Figure 7 were plotted against the LISST mounted OBS count data for each respective station (Figure 8). Linear regression provided an equation that was used for the remaining OBS's on the sled in order to determine sand concentration at each OBS.

The profile of $C(z)$ was determined based on linear interpolation between measured points. The topmost OBS's data was linearly extrapolated to zero at the water's surface. The profile of concentration below the bottom most OBS is an extrapolation of the slope between the bottom most OBS and the OBS just above it.

To calculate TLST, a method similar to Wang (1998) was used. This equation has been modified to suit our needs, yielding

$$Q = \int_0^x \int_0^d U(x,z)C(x,z)dxdz \tag{9}$$

where Q is TLST; d is water level (measured from the bottom), U is flow velocity, C is concentration of sand, and x represents the length of the tow and position along the line. This differs from Wang's equation in that the concentration and velocity profiles are time averaged and depth of active sand movement, b, has been removed.

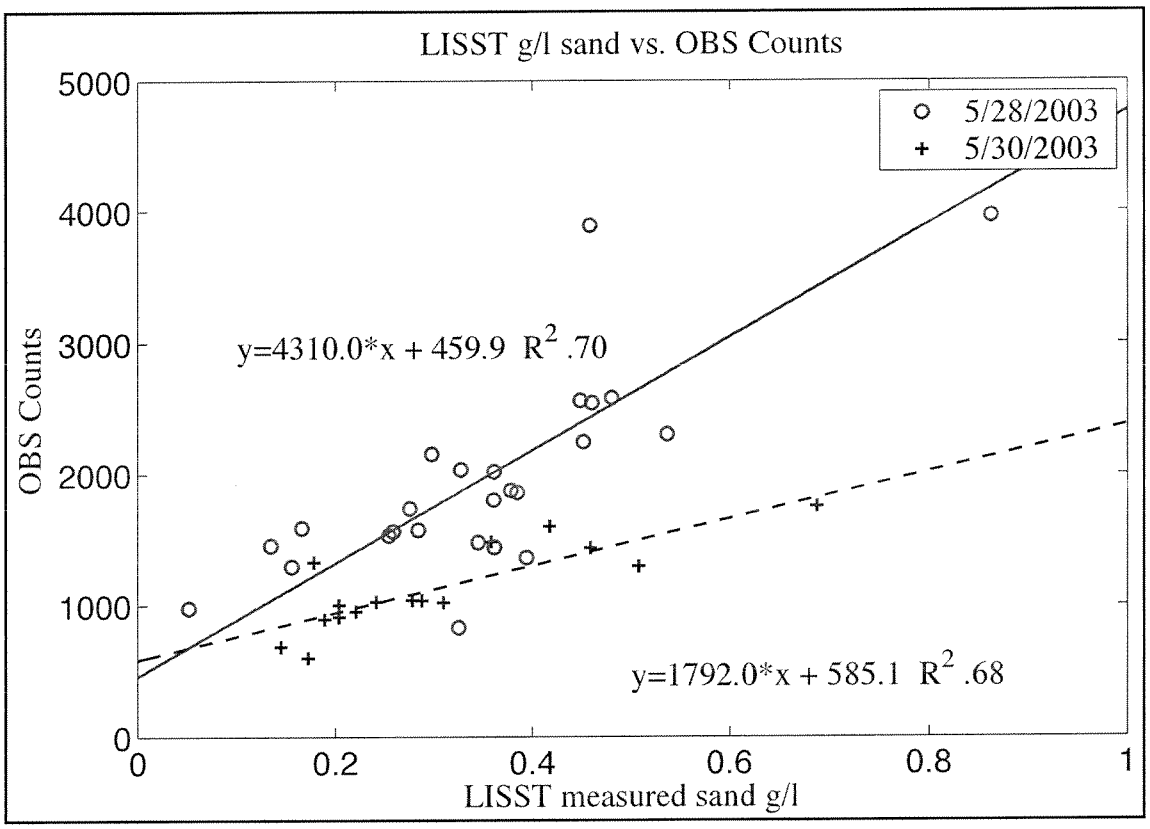

Figure 8: LISST g/l sand vs. OBS counts.

RESULTS

The Tows

Overall there were seven tows made. Five tows were conducted with the Mk. I sled, one being suitable for presentation. Two tows (both suitable) were run with the Mk. II sled. Multiple logistical problems and problems with our LISST made four tows unsuitable. These problems mostly were caused by an incorrect program that was shipped with the LISST from the factory. This program forced the LISST to overwrite its memory after a short period of time. The three tows that are presented were taken during low, medium and high energy events. I will present them separately.

2/28/2002 Tow

The 2/28/2002 tow was conducted during a high energy event. Table 2 has a compilation of wave buoy data from the National Data Buoy Center. On this day buoy 42035 reported $H_{1/3}$ of 1.26m, a wave direction heading towards Galveston, and wind at 17 knots heading towards Galveston. Our measured $H_{1/3}$ was 0.75m on the outside bar. The surf zone was typical of Galveston with waves breaking at the bars and then spilling across the rest of the large surf zone. The waves were approaching at a high angle and were large enough to be plunging waves at the offshore bar. Larger waves were observed breaking further offshore. The water was muddy. During this tow we operated the hand held pumping rig but did not use the sand streamers. All the instruments

Table 2: Buoy data for the tows. Data from NOAA buoy 42035 for days with tows. On 2/28/2002 and 5/25/2003 the waves were heading towards Galveston and the data depicted above is similar to what we saw at the beach. On 5/30/2003 the wind had shifted blowing offshore, causing a confused sea at the beach. The buoy data for this day is different from the observed conditions at the beach because of the shifting weather.

	2/28/2002	5/28/2003	5/30/2003
Wave Height $H_{1/3}$ (m)	1.26	0.71	0.7
Wave Direction	100	103	229
Wind Speed (Knots)	17	15.5	8.3
Wind Direction	92	97	192

operated normally and the LISST did not succumb to its programming bug as the tow was completed before it could overwrite its memory.

Unfortunately, because of the design of our sled and jet ski system there were several large parts of the surf zone that were not sampled. Also the sea state was rough enough that the jet ski could not be disconnected from the sled. Therefore the jet ski moved the sled to different locations in the surf zone. Then the jet ski pilot would have to try to keep the sled from not moving for three minutes.

Five stations were measured. The sled was estimated to be close to the end of the surf zone at the first station. I believe that this is because wave and current energy were not sufficient to move the larger sand, and resembled what you would expect at closure depth. This was verified by particle size measurements by the LISST which detected the sediment peak to be a finer sand than at the rest of the stations.

Because this tow only had five stations most of the graphs that are shown on the other tows are not presented because of their poor quality. In Figure 9 we see the LISST data across the surf zone. Particle size is across the x-axis and sediment concentration varies with color. The y-axis is distance offshore. On this plot I have also added red circles to show the location (in the offshore direction only) of the stations. It is very apparent that this tow has a very limited number of stations and most of the plot is just contouring from MATLAB.

Figure 10 contains wave height, U*, and sand transport data. The dashed line represents the large data gap. A beach profile is depicted using the left-handed y-axis scale while varying oceanographic data are plotted using the right hand y-axis scale. It

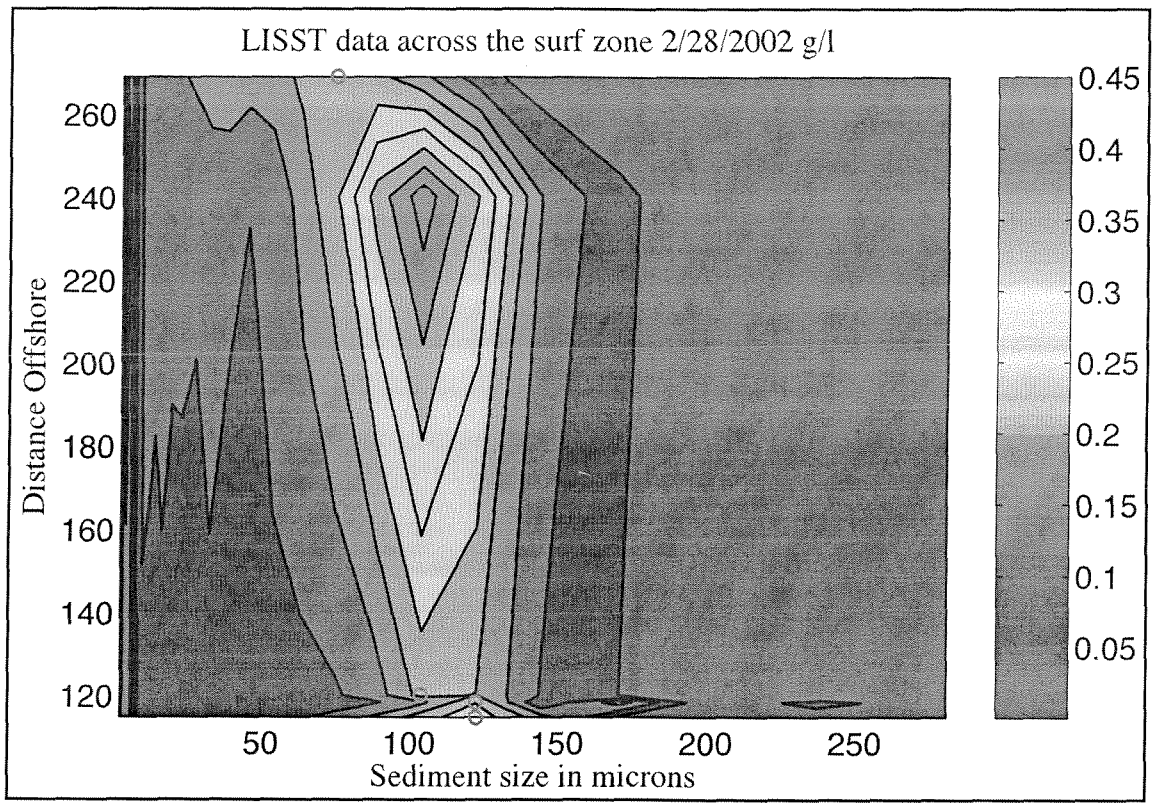

Figure 9: LISST data across the surf zone 2/28/2002. The red circles show the limited number of stations. Between 240m and 120m there are no stations and the data presented there is artificial.

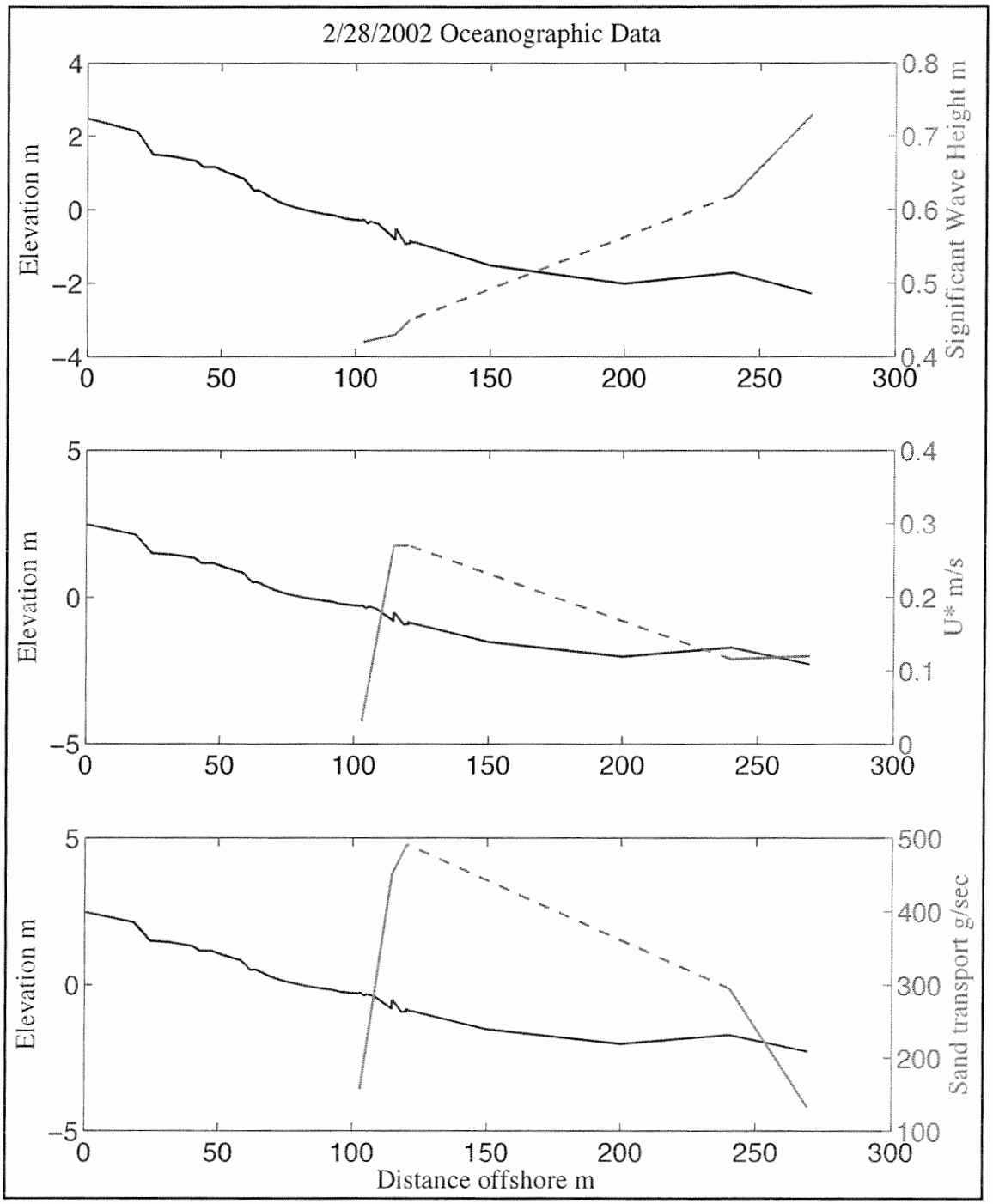

Figure 10: Oceanographic data from 2/28/2002. Dashed line is a data gap.

is obvious that the far sand bar is absorbing much of the wave energy as the first plot shows the wave height decreases quickly across the surf zone. The second plot shows U* and therefore current across the surf zone. There is a peak of current at the nearshore sandbar. The transport of sand is in the third plot. The peak of sand transport coincides with the peak in flow.

The total transport for this flow was calculated to be 70.7 kg/sec.

5/28/2003 Tow

The 5/28/2003 tow was conducted by Dr. Ravens and Randall Thomas. I was not present. The measured waves were 0.6 m in height and were breaking over the bars but reforming into non broken waves in the trough. This is different to the 2/28/2002 tow where the waves spilled throughout the surf zone. Buoy 42035 reported 0.7 m waves, a wave direction that was towards Galveston, and a wind speed of 15 knots towards Galveston (Table 2).

This tow was run using the Mk. II sled. The sled had no problems during the deployment and was able to stop at 32 stations. The instruments performed well except for the LISST which ran out of memory before the end of the tow, limiting the complete dataset to 25 stations. The area missed by the LISST was the swash zone. It is unclear what impact this had on our result. A list of instruments and their position on the sled is given in Table 1.

In Figure 11 general oceanographic data are displayed. The wave height is about 0.6 m and stays constant until after the most inshore bar. The first bar (most inshore) is therefore most likely to be affected by the most energy. This is backed up by a peak of U* at the first bar. Sediment transport peaks in the trough at about 170 m.

In Figure 12 we see LISST concentration data (in color) vs. distance offshore and particle size. The LISST detected a peak sand concentration at 170 m. This is surprisingly in the trough. The LISST had a second peak at the first bar.

Figure 13 backs up the peaks in sediment concentration detected by the LISST. In Figure 13 we have OBS concentration of sand verses depth and distance offshore. Note that this profile is from three OBS's and the highest OBS is only 46 cm from the bottom. OBS data from four OBS sensors were collected for this tow. During processing it became apparent that one of the OBS's was malfunctioning. It's data were rejected. The topmost OBS showed a rapid decrease in concentration compared to the other OBS's and it's doubtful that there was much sand in suspension above it. My calculated concentration above this OBS decreases rapidly towards zero and I don't expect much error from my calculation method.

A section of the currents is shown in Figure 14. Note on this tow the currents were calculated from the bottom-most velocimeter and the Aquadopp, which is rarely used for current calculation. During data processing it was observed that the top velocimeter has flow magnitudes less than the bottom most velocimeter. This was not expected. The Aquadopp, which is the highest velocimeter on the sled, had flow magnitudes which were higher than the bottom most velocimeter. Because the

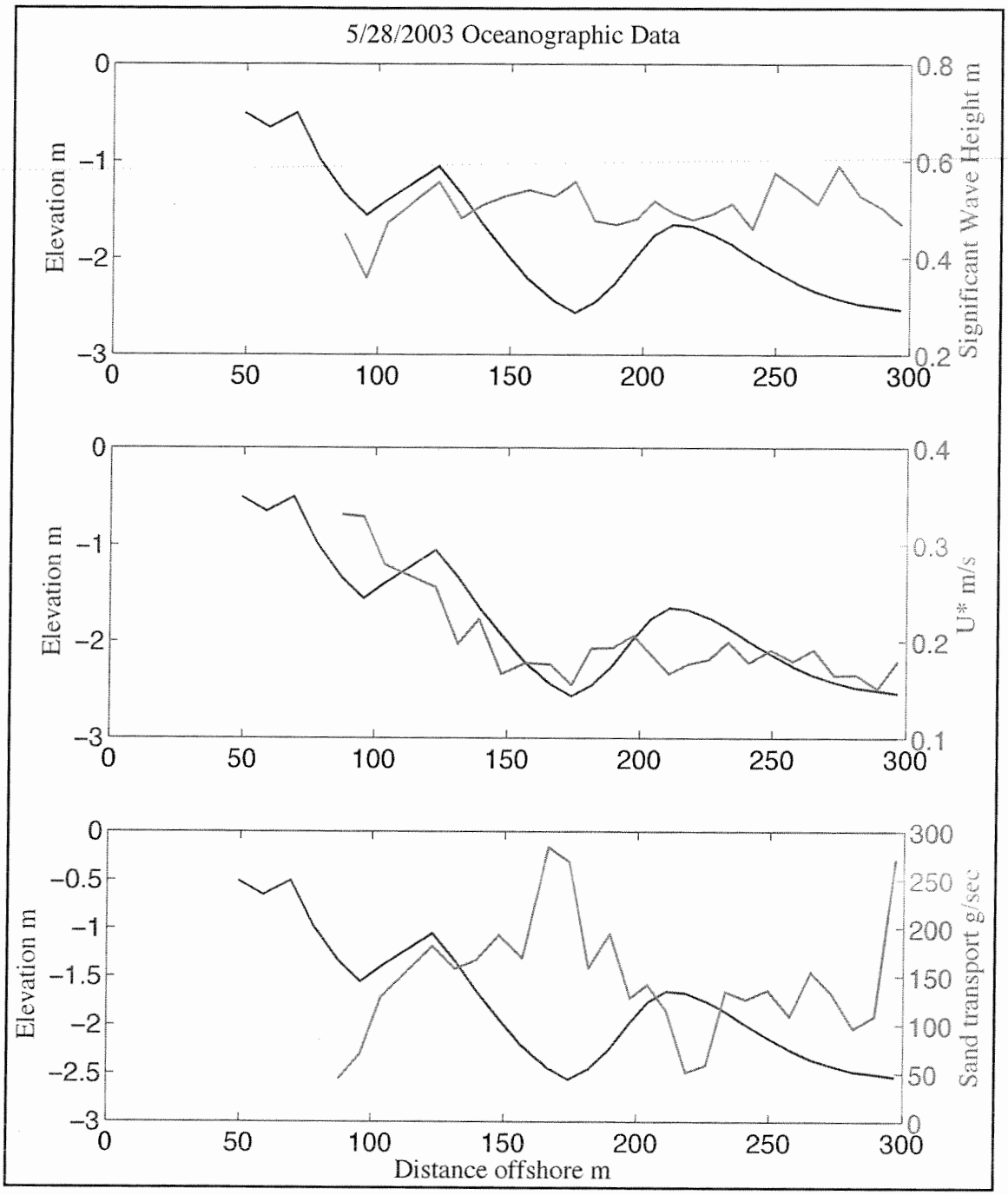

Figure 11: Oceanographic data from 5/28/2003.

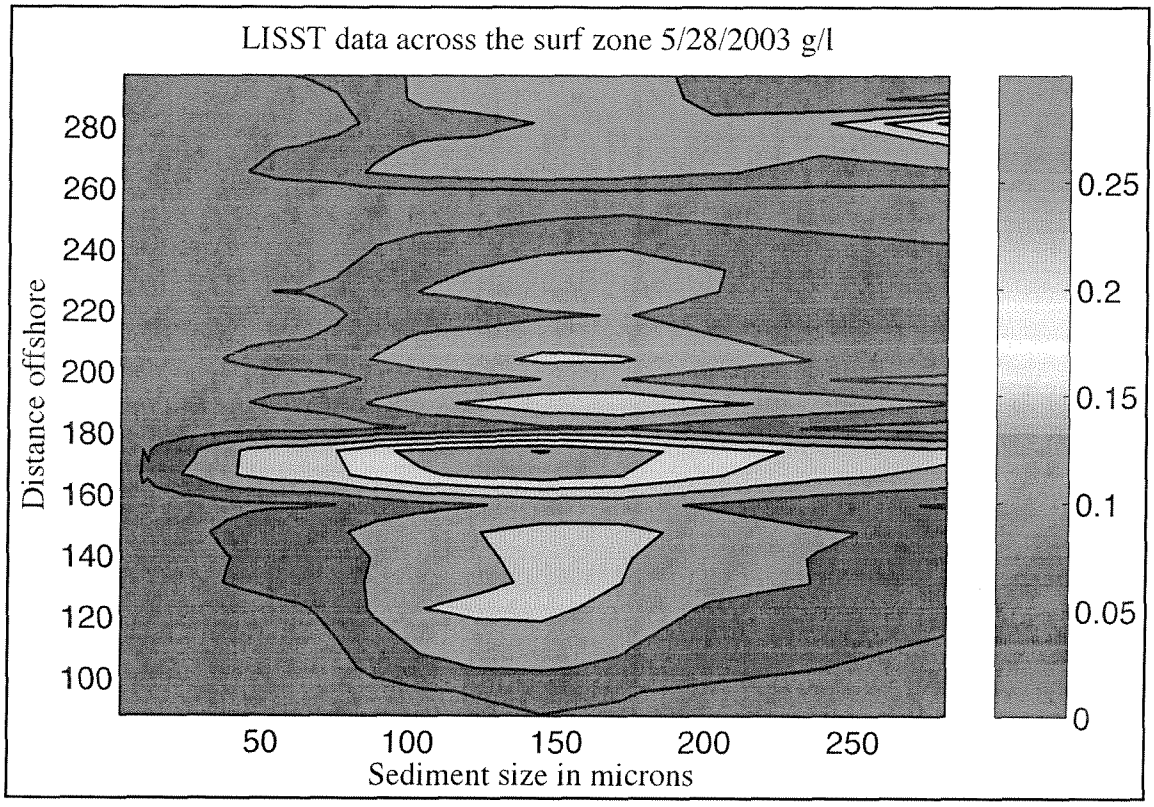

Figure 12: LISST data across the surf zone 5/28/2003. The peak in in the trough.

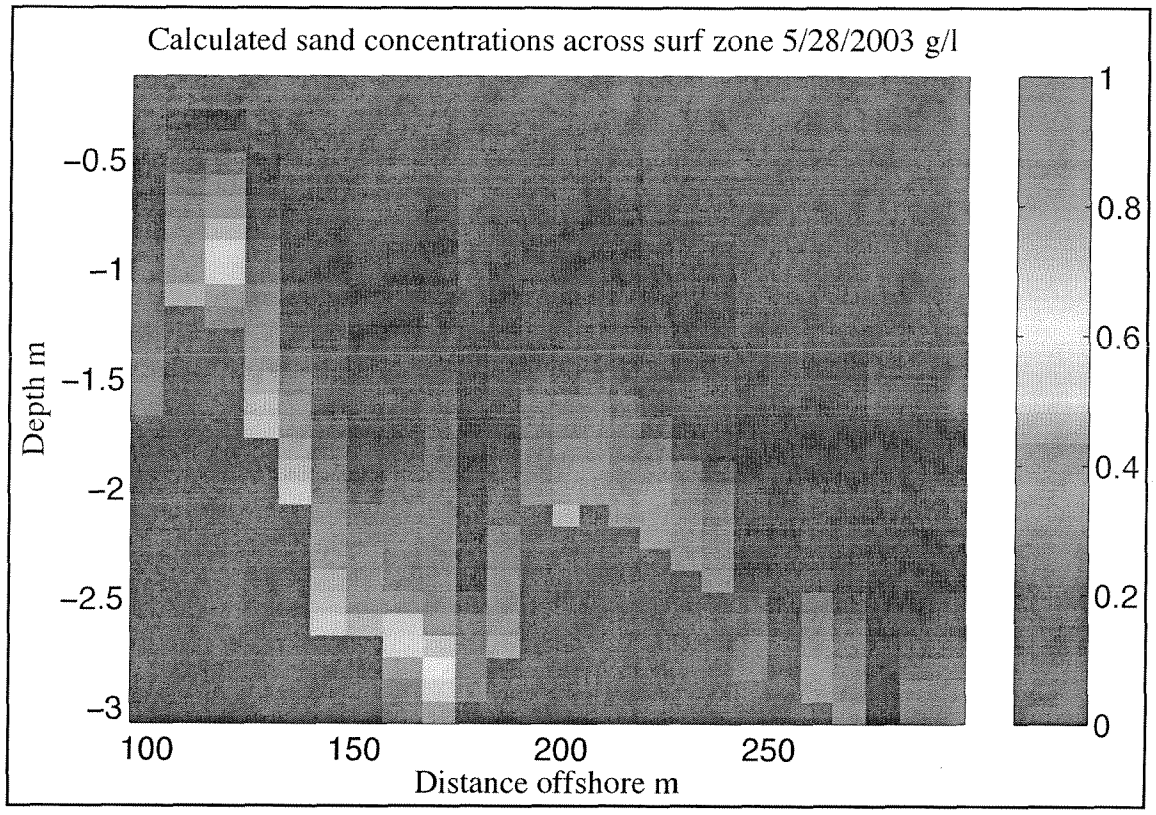

Figure 13: Calculated sand concentration across surf zone 5/28/2003 g/l.

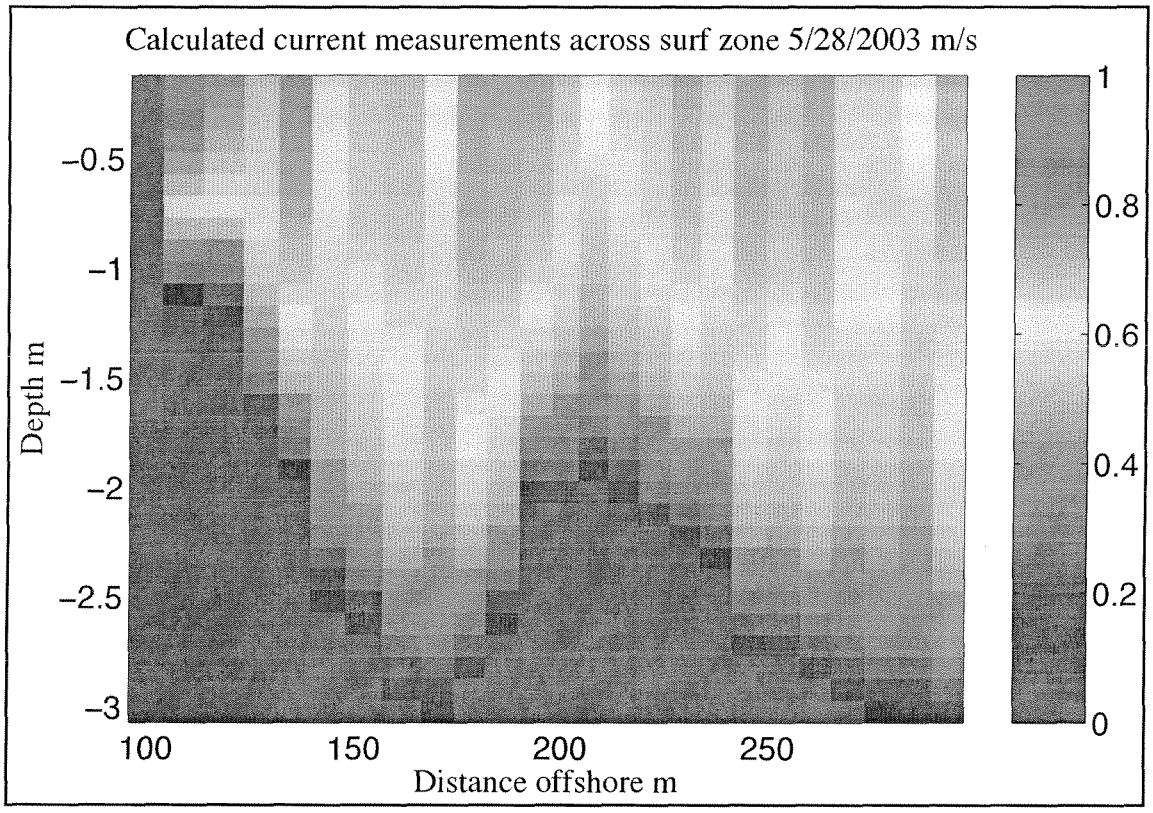

Figure 14: Calculated current measurements across surf zone 5/28/2003 m/s.

Aquadopp data are what we would expect to see, I rejected the top velocimeter's data. It should be restated that the exact logarithmic nature of the profiles is artificial, with most of the points determined from equations. In future studies it would be better to use more velocimeters.

The current section shows a surfzone with considerable flow. In some areas the flow is over one meter a second. This is most likely because of two factors. In Figure 15 we see power and wave spectra versus distance offshore. On this day the frequency spectrum is very tight, meaning that the waves were almost all of the same period and not confused. This is also reflected in Figure 16 which is velocity due to wave action and angle versus distance offshore. Again we see a tight picture of waves coming into shore at about a 20 degree angle. The large approach angle of the waves along with swell-like properties combine to produce a high current field in the surf zone.

Figure 17 shows the profile of transport on this tow. There are two peaks, one in the trough at about 22 g/s/m and another one at the first bar at 25 g/s/m. The interesting thing to note about the profile of transport is how all the peak transport happens well above the bottom. This is counter to most studies where the peak transport is near the bottom.

The TLST for 5/28/03 was calculated to be 28.8 kg/s.

5/30/2003 Tow

The 5/30/2003 tow was executed with Randall Thomas and myself. The sled was set up the same as the 5/28/2003 tow (Table 1). Waves are measured as having .3 m

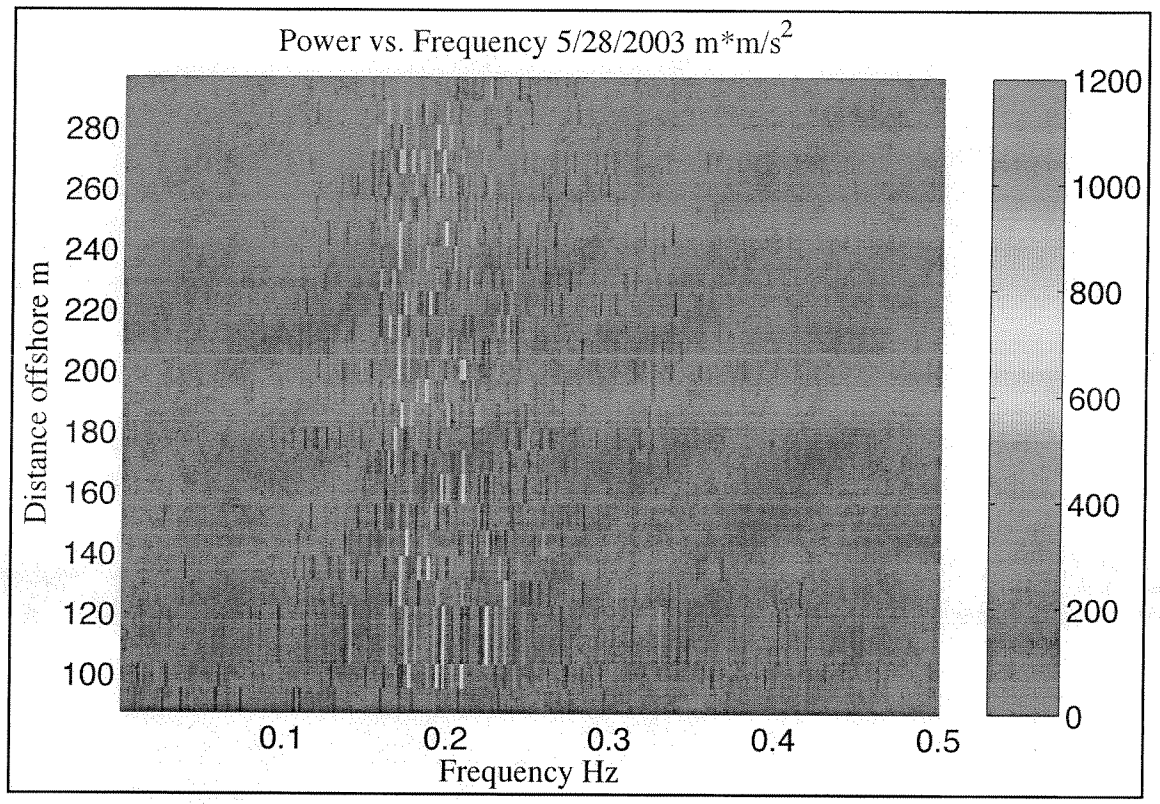

Figure 15: Power vs. frequency vs. distance offshore 5/28/2003

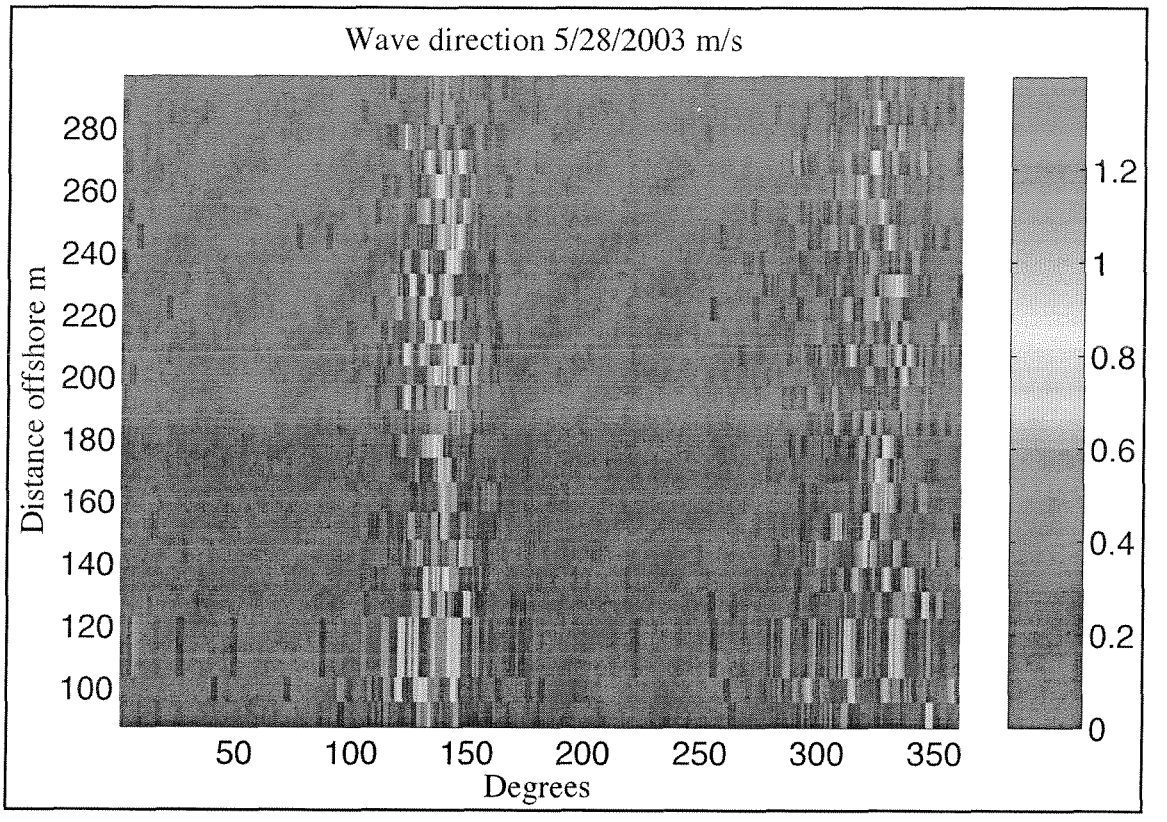

Figure 16: Wave direction 5/28/2003.

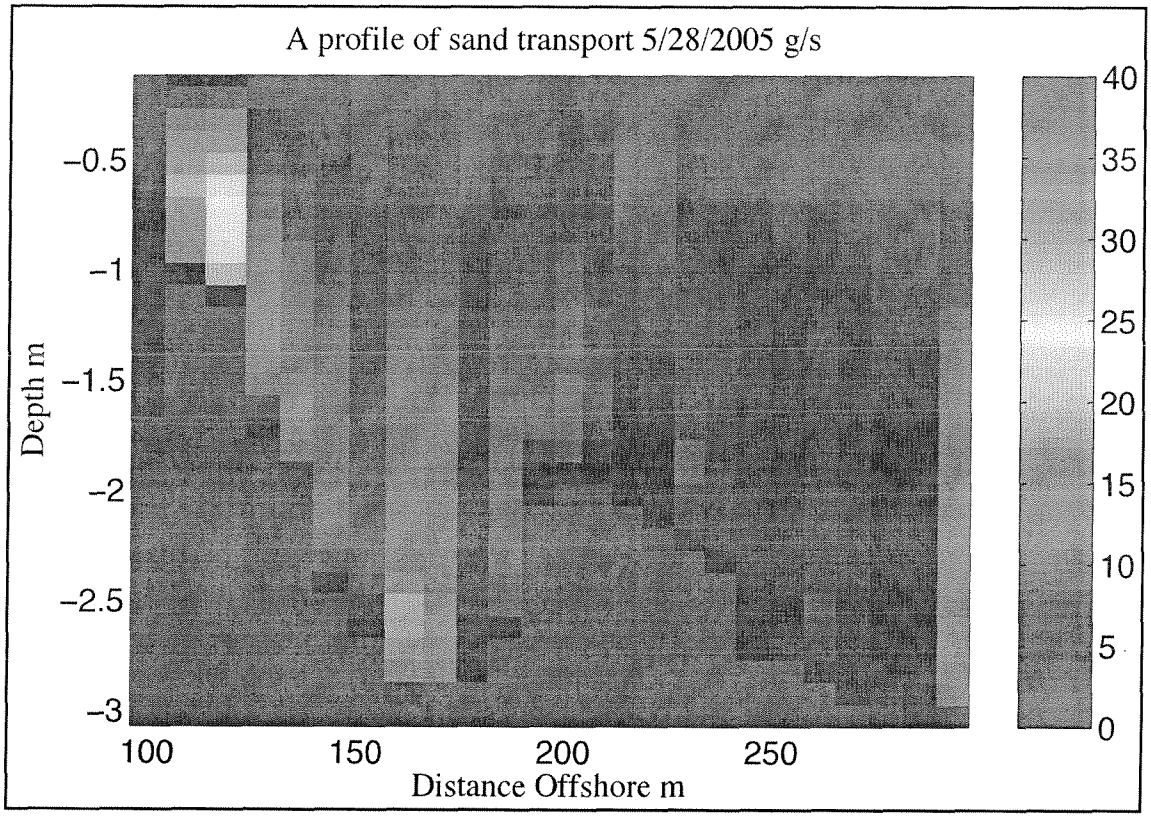

Figure 17: Profile of sediment transport 5/28/2005 g/s.

$H_{1/3}$. The waves were approaching at an angle that was 10 degrees to the beach. Buoy 42035 measured a wave height of 0.7 m, however the wave direction was away from Galveston. The wind was also blowing away from Galveston. This led to a confused sea state.

Figure 18 displays relevant oceanographic data. On this tow we can see that the wave height, and therefore one of the main driving factors for transportation, is diminished compared to the 5/28/2003 tow. During this tow the wave height peaks at about 0.4 m at the outermost bar. It was observed that waves were occasionally breaking at the offshore bar, but most of the action was at the first bar. This is revealed by U* peaking at the innermost bar and the transport peaks in this area as well.

Figure 19 is the plot of LISST data. The LISST data peaks at the location of the first bar. There again is another peak of sediment concentration in the trough. There is also a increase in concentration from 260 m to 170 m at sediment sizes of about 240 μm. This is interesting because it is about twice the size of the sand at 120 μm. I believe that these data are spurious and I did not use them.

Figure 20 is the plot of OBS sand concentration in the surf zone. I again had to reject the data coming from OBS 1786 as it was reading lower than the other OBS's. The data shows peaks at the first bar and in the trough, which agrees with the LISST data. The concentration of the sand drops off rapidly to close to zero as you get away from the bottom. Again I don't think that my method of calculating sand concentration in the water column will add much error to TLST.

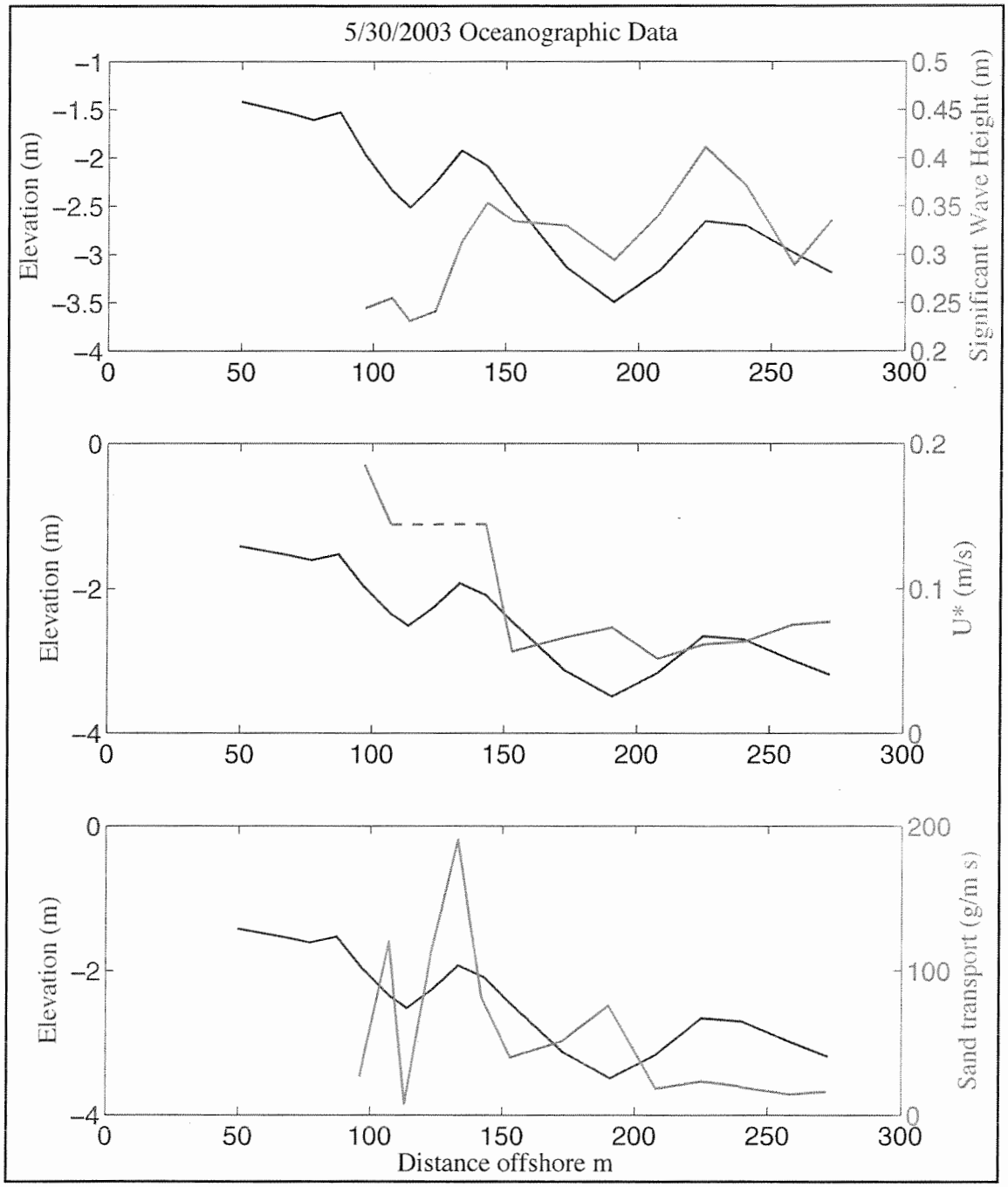

Figure 18: Oceanographic data for 5/30/2003. Dashed line is a data gap.

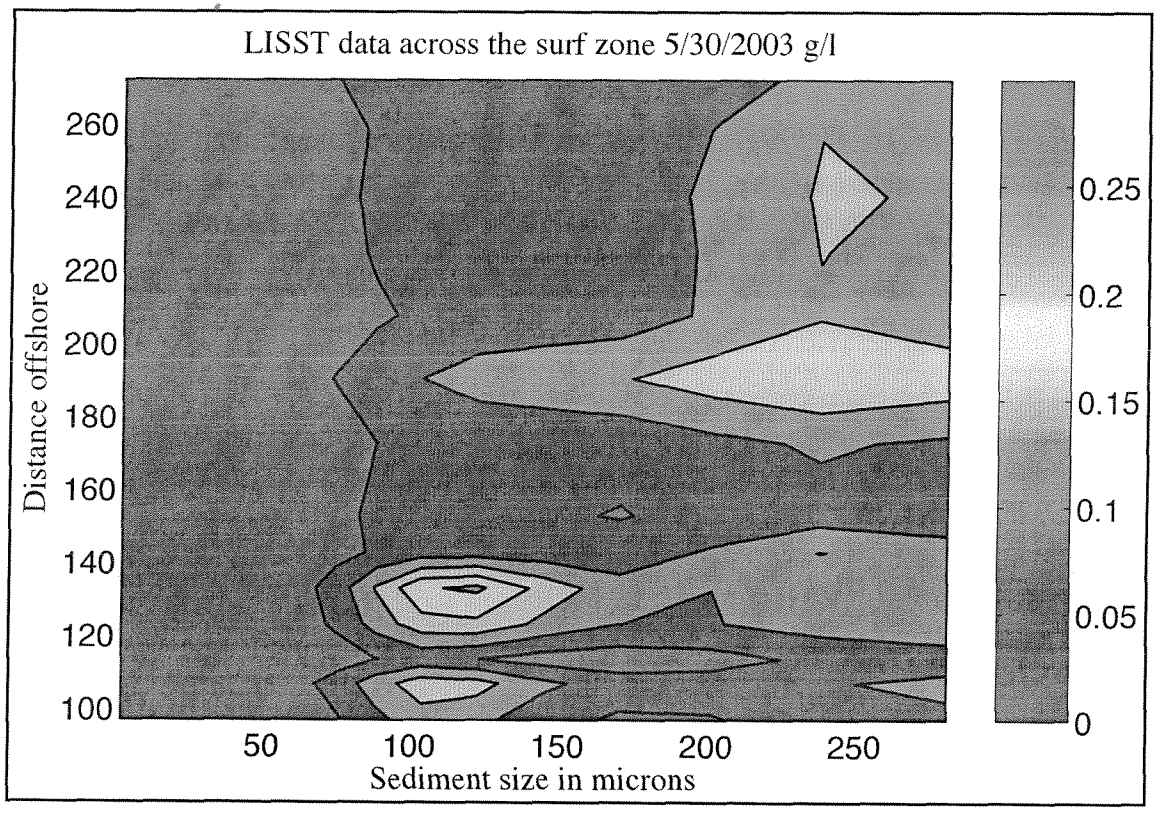

Figure 19: LISST data across the surf zone 5/30/2003.

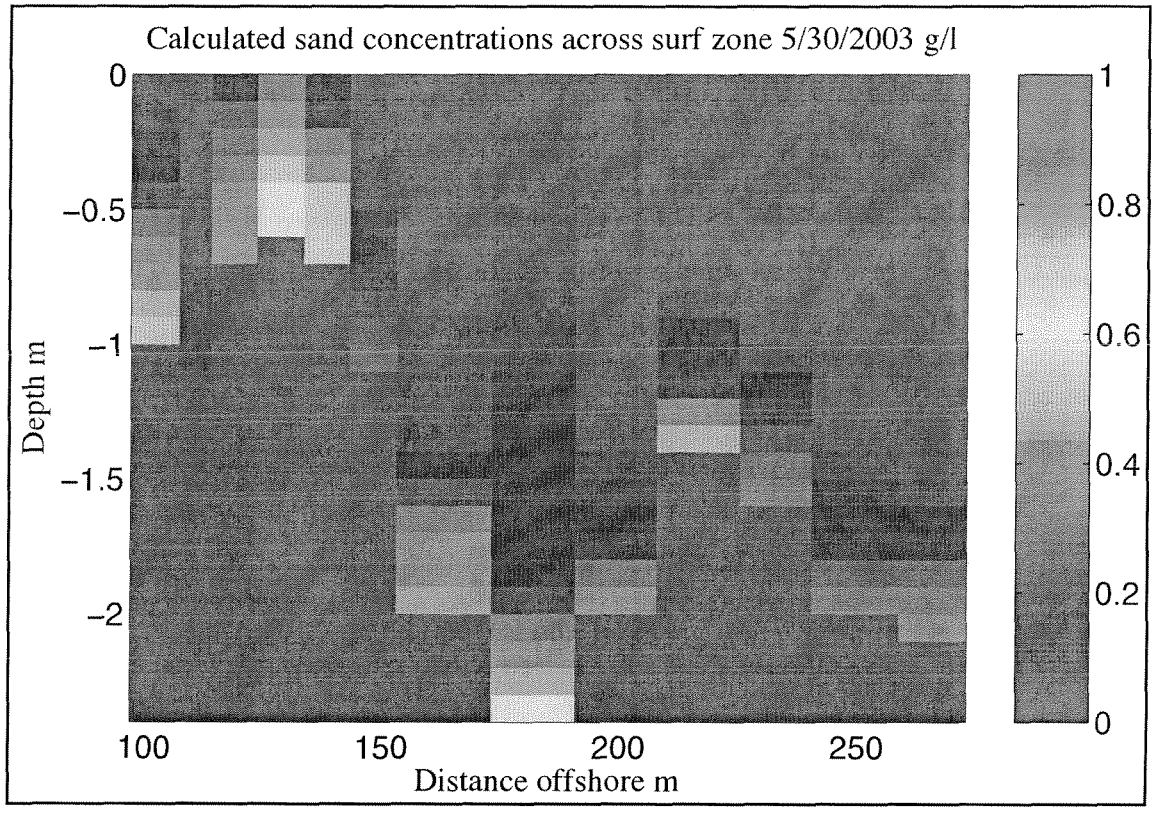

Figure 20: Calculated sand concentration across surf zone 5/30/2005 g/l.

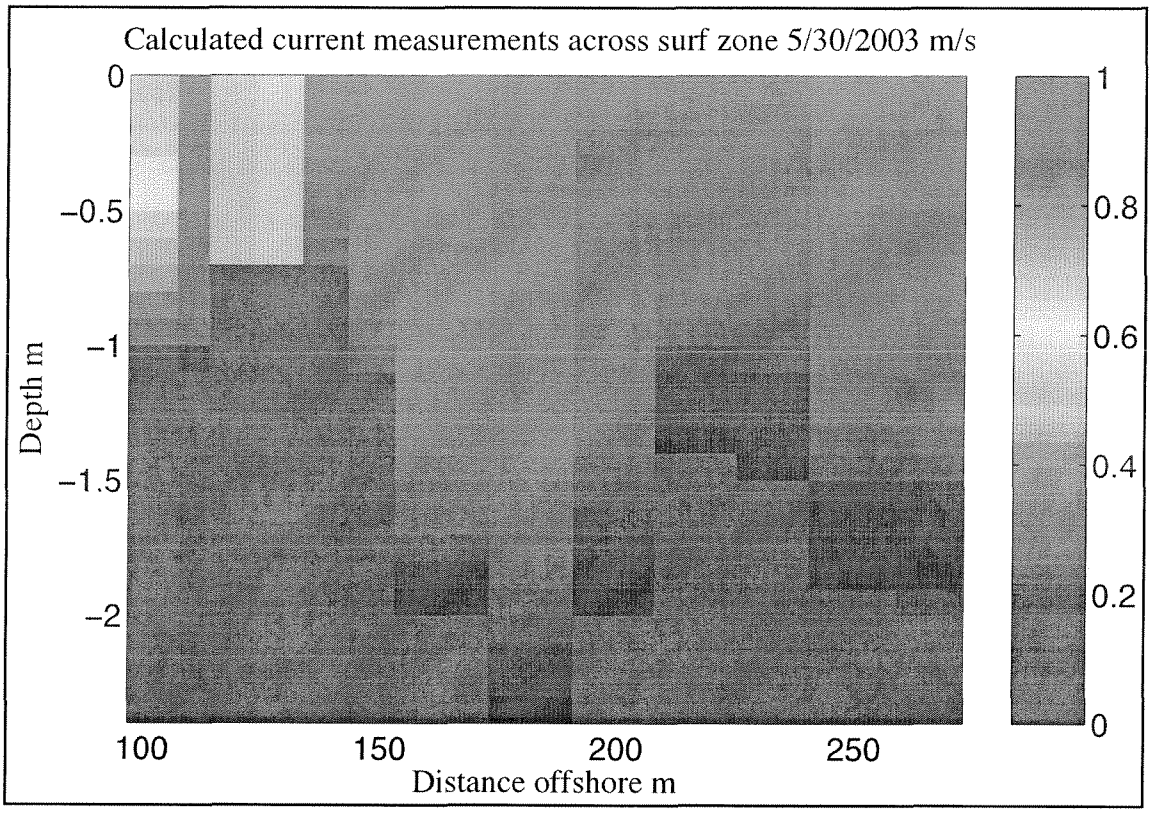

Figure 21: Calculated current measurements across surf zone 5/30/2003 m/s.

In Figure 21 is a plot of currents through the surfzone. The highest currents are associated with the first bar. The rest of the surf zone is slow compared to the 5/28/2003 tow. This is most likely due to one of two reasons. First, as observed in Figure 22, we see that during this day the waves were very confused and there is almost no peak to the wave frequencies. This is backed up by Figure 23, which shows a large range of directions for oncoming waves. The second reason is that the approach angle of the waves is only 10 degrees.

The transport profile is given in Figure 24. The peak of transport is at the first bar. Overall this is the only transport of mention in the entire surf zone this day. The peak of transport is near the bottom at the first bar not in the water column such as the 5/28 tow.

The calculated transport for this tow was 9.2 kg/sec.

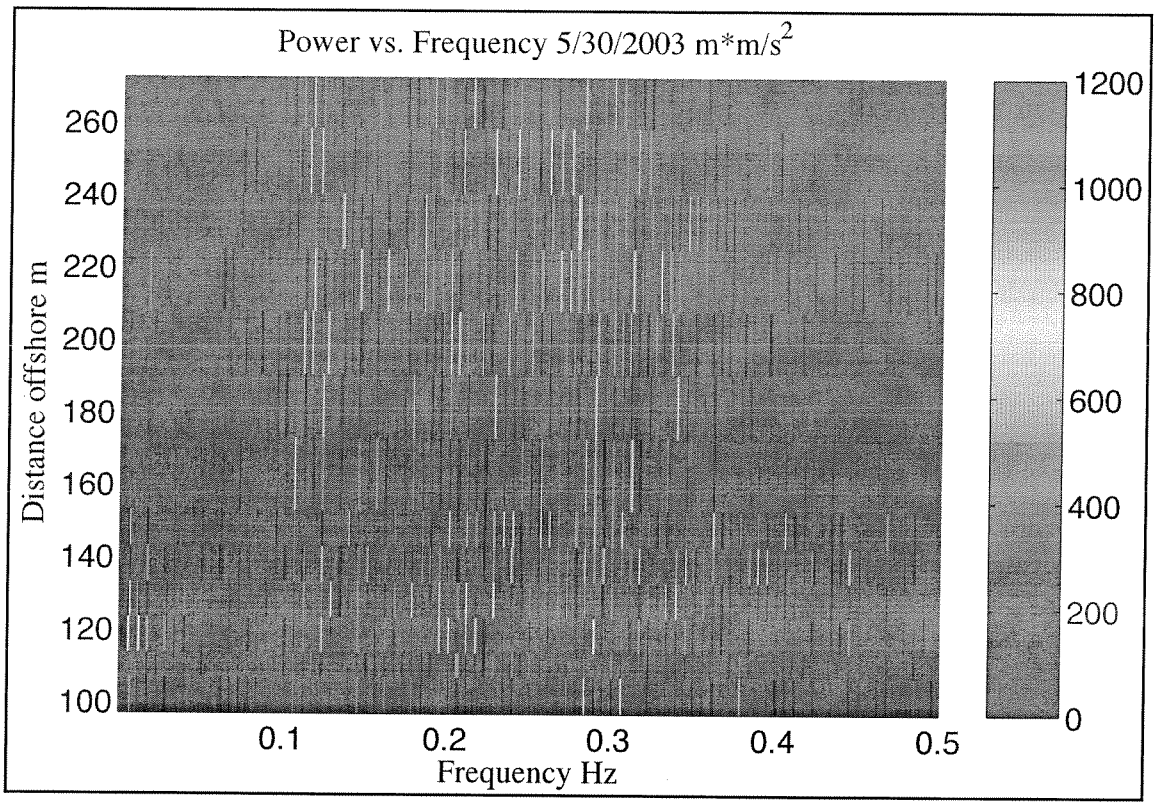

Figure 22: Power vs. frequency vs. distance offshore 5/30/2003.

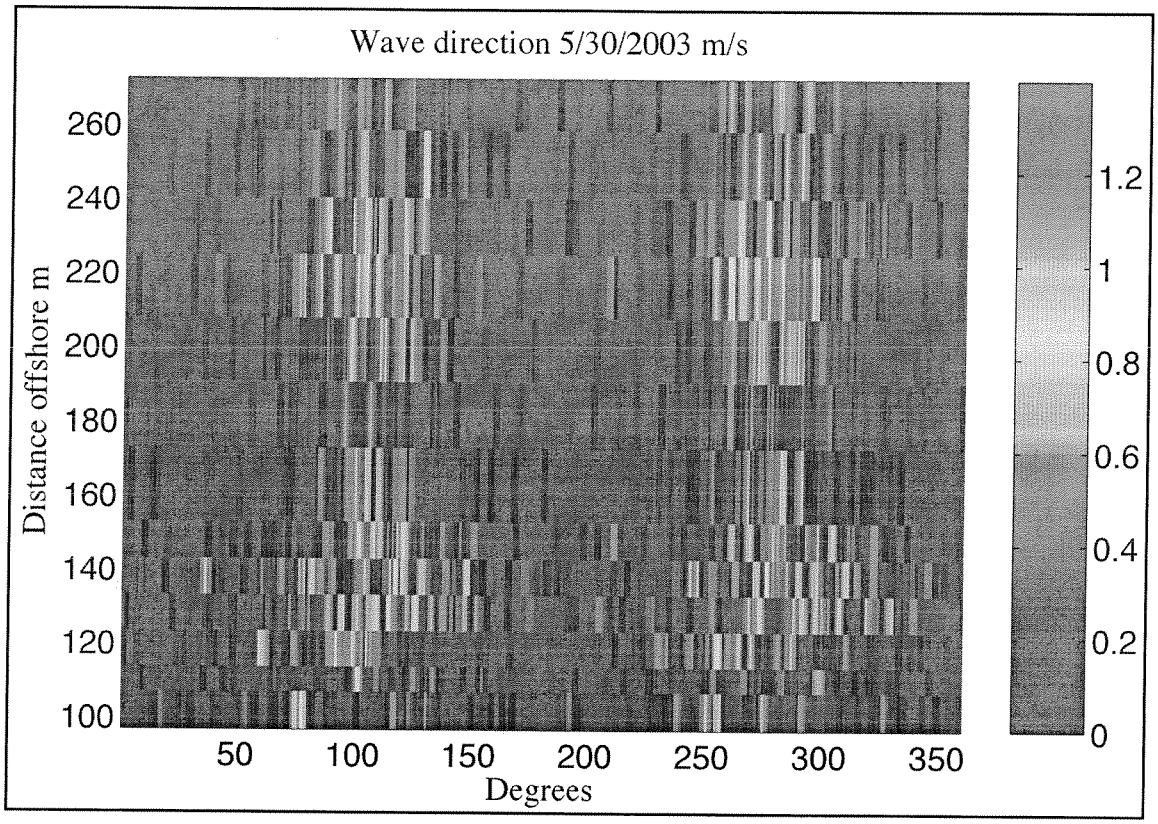

Figure 23: Wave direction 5/30/2003.

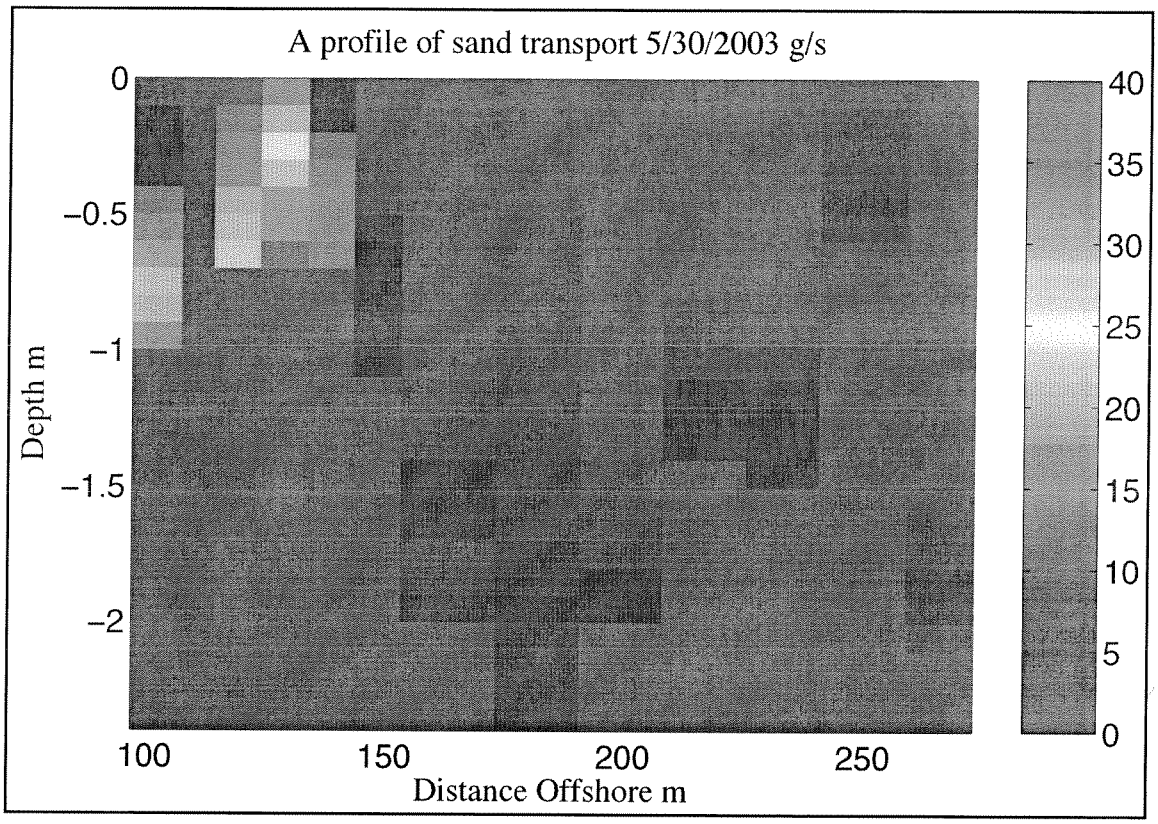

Figure 24: A profile of sediment transport 5/30/2003.

DISCUSSION

Fortuitously we were able to measure TLST during a low, medium, and high energy event. While the 2/28/2002 lacks any grace as a dataset the other two datasets show just what a LISST instrumented mini-sled can do. The profiles of currents and sand concentration are very detailed. As always, in the future it would be recommended that more instruments be placed on the sled for greater spatial resolution.

With any new system for measuring TLST the need always arises to compare the result to accepted models. We did this with the CERC equation, a modified CERC, and the Kamphius 91 equation. It was my hypothesis that the three equations would be different from my sled measurements and from each other. To my surprise the models faired very well against the sled and against each other.

Table 3 shows the important constants that were used to calculate TLST from the equations. The results are also listed. Note how much lower our calculated breaker index, for all three experiments at different energy levels, is than the accepted value of about 0.8 (Weggel, 1972).

In Figure 25 the modeled values for TLST is plotted against the measured values of TLST. While there are only three tows to compare the models by it seems that the Kamphius 91 calculation is the closest to matching the mini-sled.

Despite the reasonably good fit of the data there are numerous sources of error that are difficult to quantify. For instance, 1) the LISST is basically uncalibrated and is

Table 3: A table of important constants used for TLST models and results. Constants used for the various TLST models and their results. The CERC equation uses a breaker index that is given as 0.78 while the CERC BI equation uses the observed breaker index shown in the table. Measured values are also shown. Beach slope, wave period, and D_{50} are only used in the Kamphius '91 equation. *K* is only used in the CERC equation.

	2/28/2002	5/28/2003	5/30/2003
Wave Approach Angle (Deg).	20.0	20.0	10.0
H_s (m)	0.73	0.59	0.41
H_{rms} (m)	0.52	0.42	0.29
Breaker Index γ	0.22	0.17	0.13
K (CERC only)	0.77	0.77	0.77
CERC (kg/s)	18.06	10.61	2.27
CERC BI (kg/s)	34.22	23.10	5.57
Beach Slope	3/200	3/200	3/200
D_{50} (μm)	120	120	120
Peak Wave Period (sec).	5	5	5
Kamphius '91 (kg/s)	59.40	38.80	12.83
Measured (kg/s)	66.70	28.80	9.20

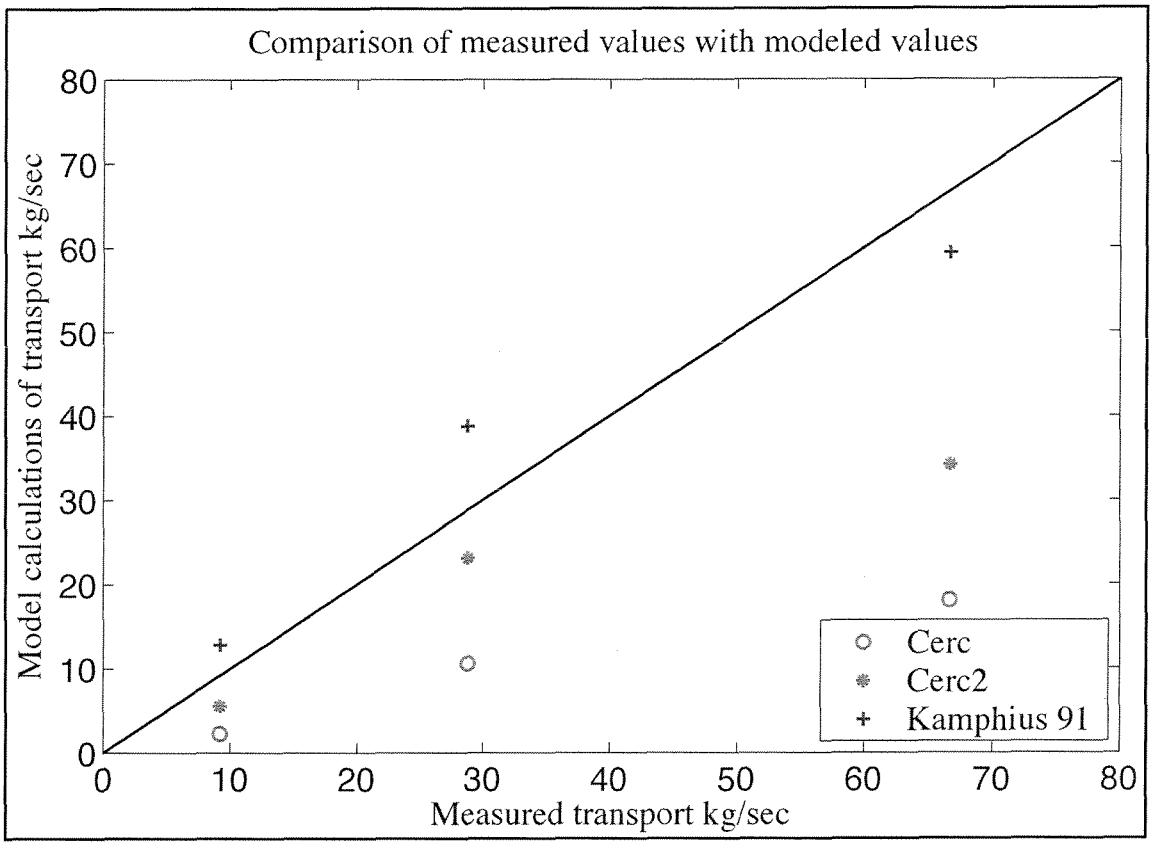

Figure 25: Comparison of measured values with modeled values.

untested in the surfzone, 2) the swash zone went unmeasured and might be a large source of transport, and 3) the largest source of uncertainty is the question of bedload. Bedload was not measured at all during these tests. While my measurements have unquantified sources of error, the model results also have sources of error. The CERC equation was developed using tracer data from the west coast, not the multi-barred beaches of the Texas coast. The fact that the published values of K range from 0.08 to 1 hurts the credibility of the CERC equation (Theiler *et al.*, 2000).

Figure 26 is a plot of calculated wave power against measured immersed weight sediment transport in the surf zone. This type of plot is used to determine the K value for the CERC equation (such as in Figure 1). With a line fitted to this data the K value is 0.70. It should be noted that the wave power for these data were computed using observed values for breaker index, not a static value of 0.8.

Figure 27 shows our data plotted on top of Figure 1. This figure shows that our data is in line with other measurements of TLST.

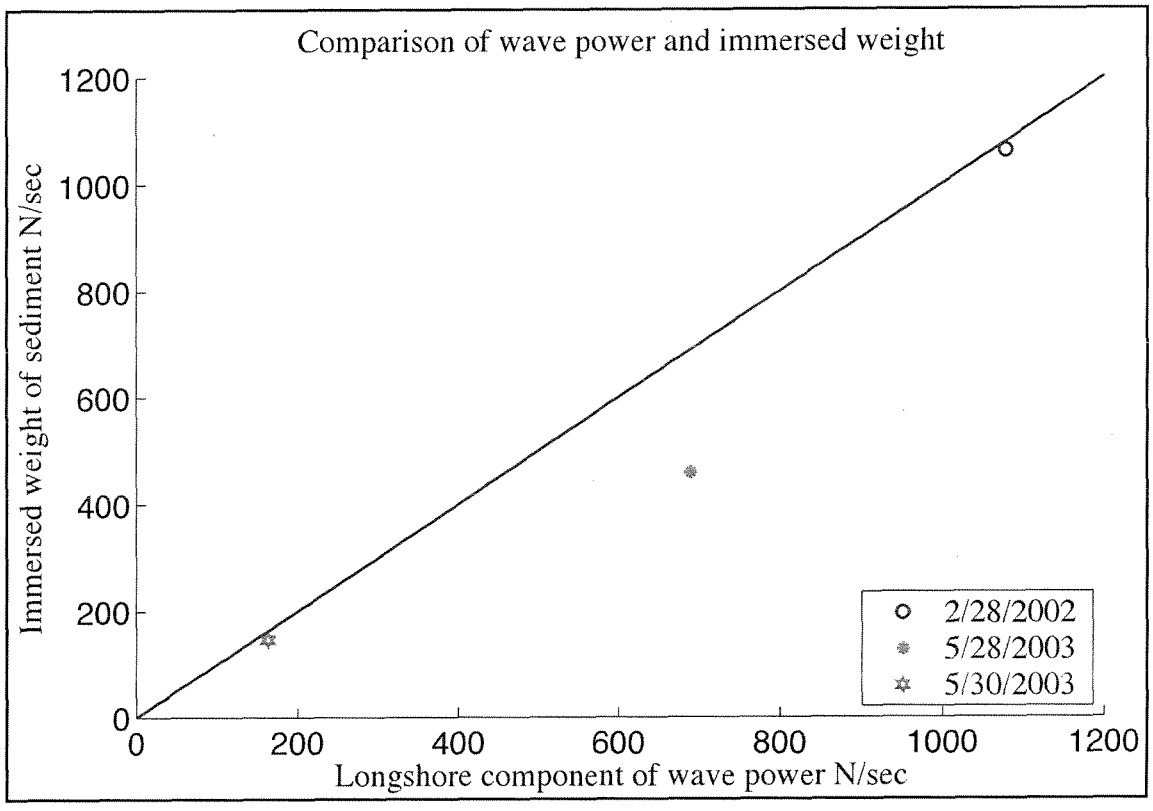

Figure 26: Comparison of wave power and immersed weight.

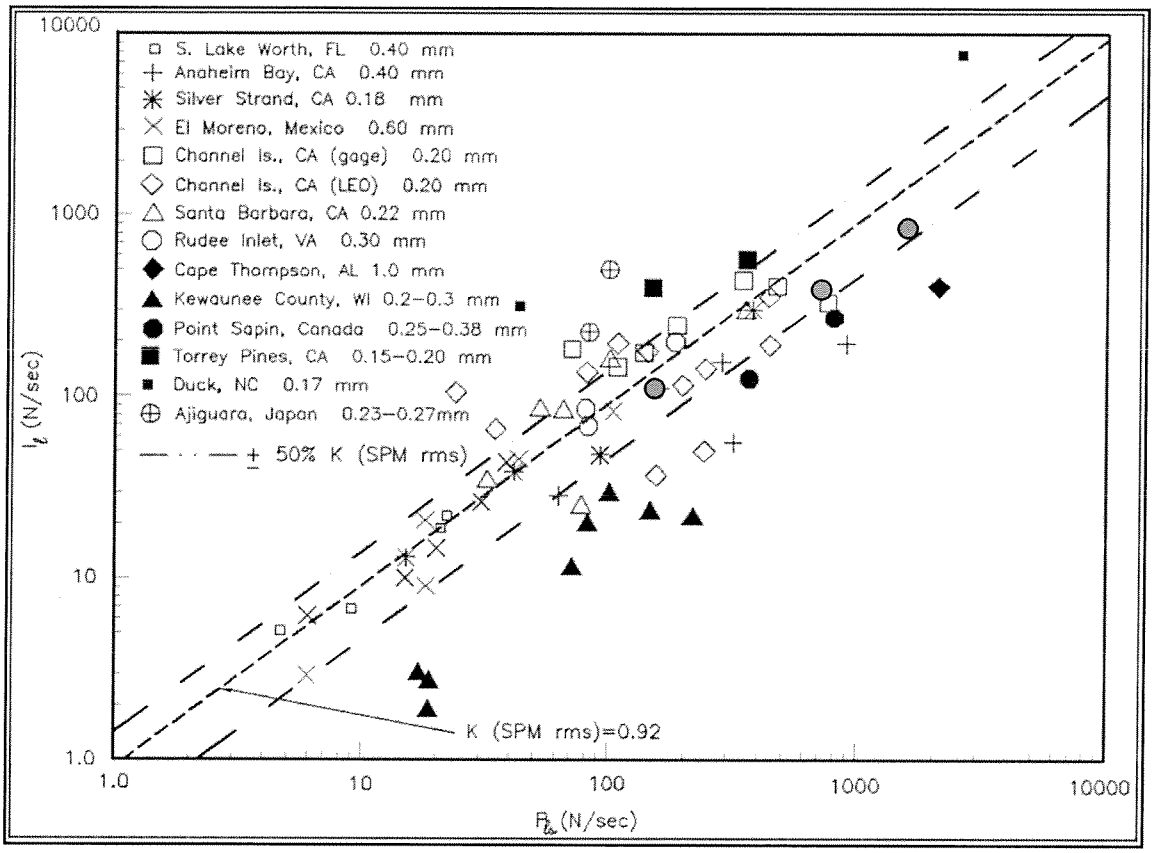

Figure 27: Results of this study plotted against previous studies. This study's data are plotted as red dots (U.S. Army Corps of Engineers, 2002).

CONCLUSIONS

The MKII mini-sled performed well. The MKI sled left something to be desired as the small size of the sled and the floating rope caused the sled to move during the tow. Once the bugs were worked out the instrument package worked well but special care must be taken to "massage" the data into a workable form. Bubbles, trash, seaweed and other objects found in the surf zone tend to induce considerable scatter in the data. Overall the instruments produced a profile of transport that is reminiscent of other studies in the surf zone (Wang 1998). Almost all of the studies in the literature have shown that most of the transport takes place on the sea ward side of the sandbars. This holds true for our results. However if it holds true that bedload is small, then it will be the first time that a maximum in vertical transport has been shown to reside in a peak above the bottom. Further tows should be run to test the validity of these results.

We feel the most important result from our data is the ability to separate the amount of sand in an OBS signal that has been contaminated by mud. The LISST is indispensable for this function. It is interesting to note that most oceanographers have very little idea what is passing in front of their OBS's when they are taking data. In coastal areas this could certainly invalidate any result. For instance if an OBS is placed in a tidal inlet with the assigned task to measure sand movement and is not calibrated with a LISST or other mud sensing instrument it is very likely the OBS will only detect mud, not sand.

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VITA

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