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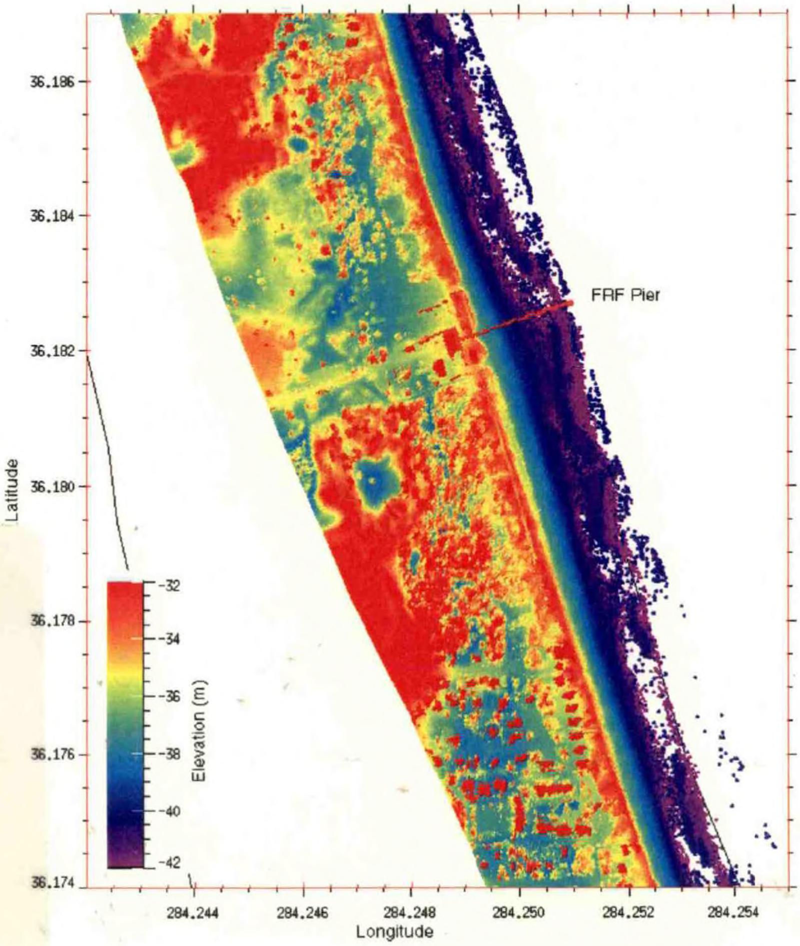
AN ASSESSMENT OF NASA'S AIRBORNE TOPOGRAPHIC MAPPER INSTRUMENT FOR BEACH TOPOGRAPHIC MAPPING AT DUCK, NORTH CAROLINA



AN ASSESSMENT OF NASA'S AIRBORNE TOPOGRAPHIC MAPPER INSTRUMENT FOR BEACH TOPOGRAPHIC MAPPING AT DUCK, NORTH CAROLINA

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1.0 INTRODUCTION

This introductory section provides some background about the need and potential benefits from successfully applying LIDAR beach topographic mapping and presents a brief overview of the Airborne LIDAR Assessment of Coastal Erosion (ALACE) Project.

1.1 Background

Beaches are some of the earth's most dynamic geologic features. Beach morphology fluctuates over a wide range of time scales, varying from periods of hours associated with diurnal tides and storm events, to years and decades associated with long-term erosional trends. Human actions, especially during the last 100 years, have created a situation in which beach erosion can have severe economic consequences. Currently 55 to 60 percent of the U.S. population lives within the nation's 772 coastal counties, with projections of 75 percent by 2025 (Hinrichsen 1998). Estimates reveal that approximately $3 trillion worth of U.S. coastal development is potentially vulnerable to erosion. It is also estimated that 70 percent of the world's beaches are undergoing erosion, with percentages approaching 90 percent along the Atlantic coastal plain (Bird 1985).

Accurate and timely assessment of erosion conditions and storm impacts is needed to assist decision making on land use, beach renourishment, erosion calculations, insurance compensation, and property value estimation. Proper storm damage assessment is an enormous task for emergency and disaster response agencies and personnel. Federal, state, and local agencies have traditionally used aerial photographs and land surveys to assess the overall impact of storms. Although these measurement methods provide valuable information, they are often not precise enough to describe specific coastal topographic changes that enable implementation of fully effective shoreline emergency response, or development planning along with beach renourishment programs.

1.2 Airborne LIDAR Assessment of Coastal Erosion Project

The ALACE project is a partnership between the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) in Charleston, South Carolina; NASA Goddard Space Flight Center, Wallops Flight Facility (WFF) in Wallops, Virginia; and U.S. Geological Survey (USGS) Center for Coastal Geology in St. Petersburg, Florida. The project's goal is to establish the capability of aircraft laser swath mapping to provide highly accurate, cost-effective information on coastal topography, erosion, and shoreline position. In working toward this goal, NOAA, NASA, and USGS have conducted several mapping missions along significant portions of U.S. coast using the NASA Airborne Topographic Mapper (ATM) flown aboard a NOAA Twin Otter aircraft.

During the fall of 1997, dense beach topographic data were collected with the NASA ATM mounted aboard the NOAA Twin Otter for a contiguous region of the east coast from Cape Henlopen, Delaware to the South Carolina/Georgia border and three sections along the west coast: Point Grenville, Washington to Cape Blanco, Oregon; Bodega Head to Big Sur, California; and Cayucos, California to the U.S./Mexico border. Coincident with the NOAA Twin Otter ATM overflights, along a 70-kilometer section of the Outer Banks in North Carolina extensive beach ground survey data were collected as a part of the SandyDuck 1997 coastal field experiment sponsored by USGS and U.S. Army Corps of Engineers (USACE). Data were collected from Corolla, North Carolina to Oregon Inlet, North Carolina using differential global positioning system (GPS), Total Station, and other survey techniques.

2.0 OBJECTIVE

The goal of this report is to validate the potential of airborne LIDAR as a technology for highly accurate and detailed topographic beach surveys. The primary objective is to verify both the accuracy of airborne LIDAR in relation to current ground survey data collection techniques and its ability to produce consistent repeat measurements over the same location. Krabill, *et al.* (in prep.), Krabill, *et al.* (1995), and Carter and Shrestha (1997) all have presented papers assessing the accuracy of LIDAR surveying techniques, but the evaluations were either not over beaches or they lacked intensive ground survey data to fully evaluate the LIDAR surveys. This report evaluates intensive ATM beach surveys in comparison to multiple ground surveys collected coincident with the ATM surveys and using a variety of accepted data collection methods.

3.0 METHODS

The following section describes the methods and instruments used for the collection of ground surveys and ATM data along with maps depicting the locations of each survey. The four investigators responsible for acquiring ground surveys included Rob Holman from Oregon State University (OSU), Jeff List of the USGS Woods Hole Field Center, Mark Hansen of the USGS Center for Coastal Geology, and Thomas Reiss of the USGS Western Region Coastal and Marine Geology Center.

3.1 Ground Survey Data Collection

Rob Holman's group used their Trimble 4000 GPS survey system mounted on a beach buggy for the acquisition of a detailed grid of elevations about 3 kilometers north and south of the Duck Field Research Facility (FRF) pier (Figures 1 and 2a). The September 26, 1997 survey area extended from the dune line to waterline. Real-time differential corrections were obtained from a base station set up over an established benchmark on the FRF pier.

Jeff List used an all-terrain beach buggy outfitted with an Ashtech GPS receiver to obtain differentially corrected longshore elevation data for a 70-kilometer stretch of coast from Corolla, North Carolina to Oregon Inlet, North Carolina (Figure 1). The longshore pass was made northbound over the high beach on September 26, 1997. Four Ashtech base stations were established at locations along the beach to ensure the buggy was no more than 10 kilometers from a base station. The List raw GPS data were differentially corrected using the same processing methods as applied in the correction of the ATM data.

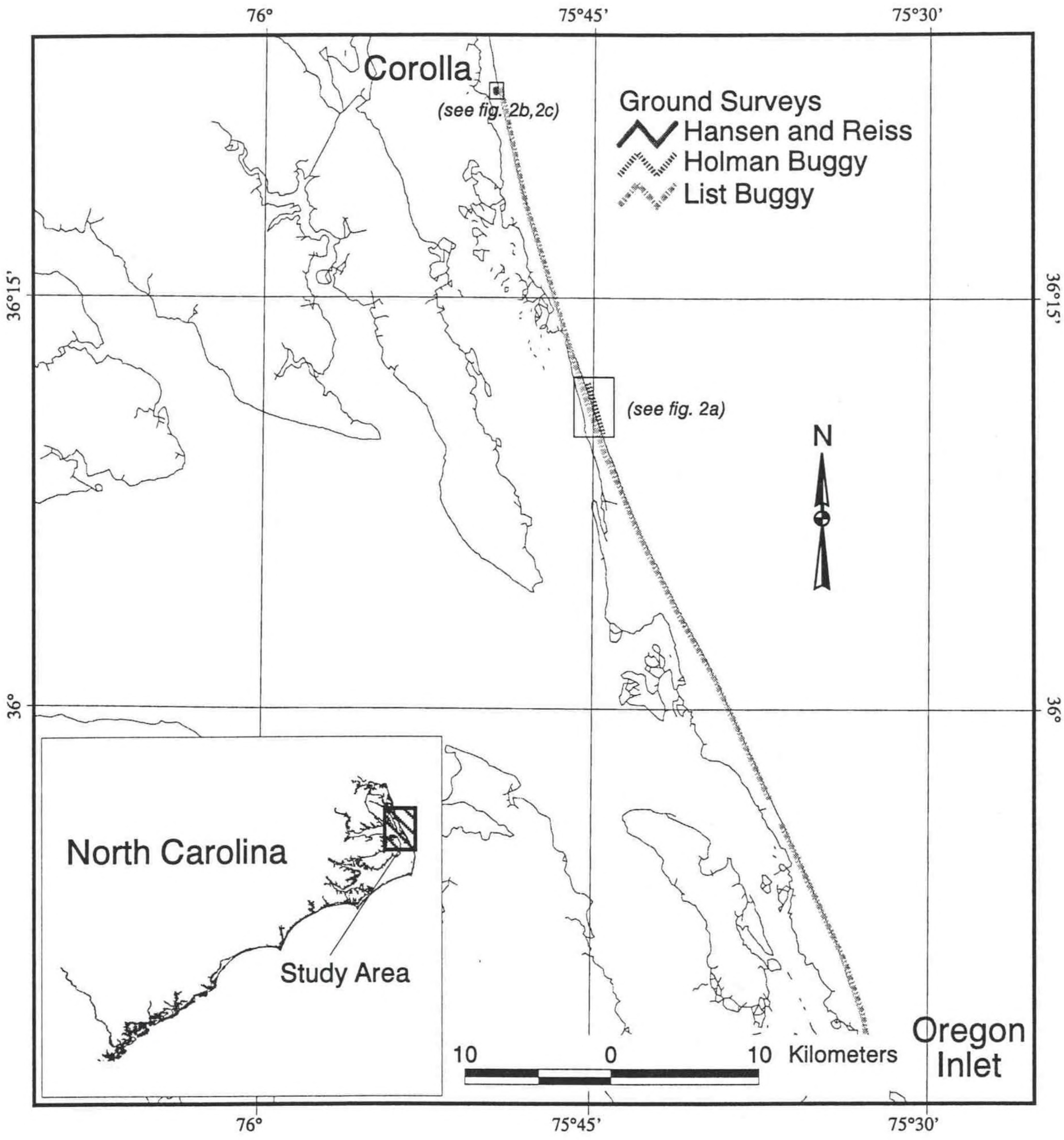


Figure 1. Map showing the location of ground surveys between Corolla, North Carolina and Oregon Inlet, North Carolina made September 26 and 27, 1997. Refer to Figure 2 for additional detail of the Holman, Hansen, and Reiss surveys.

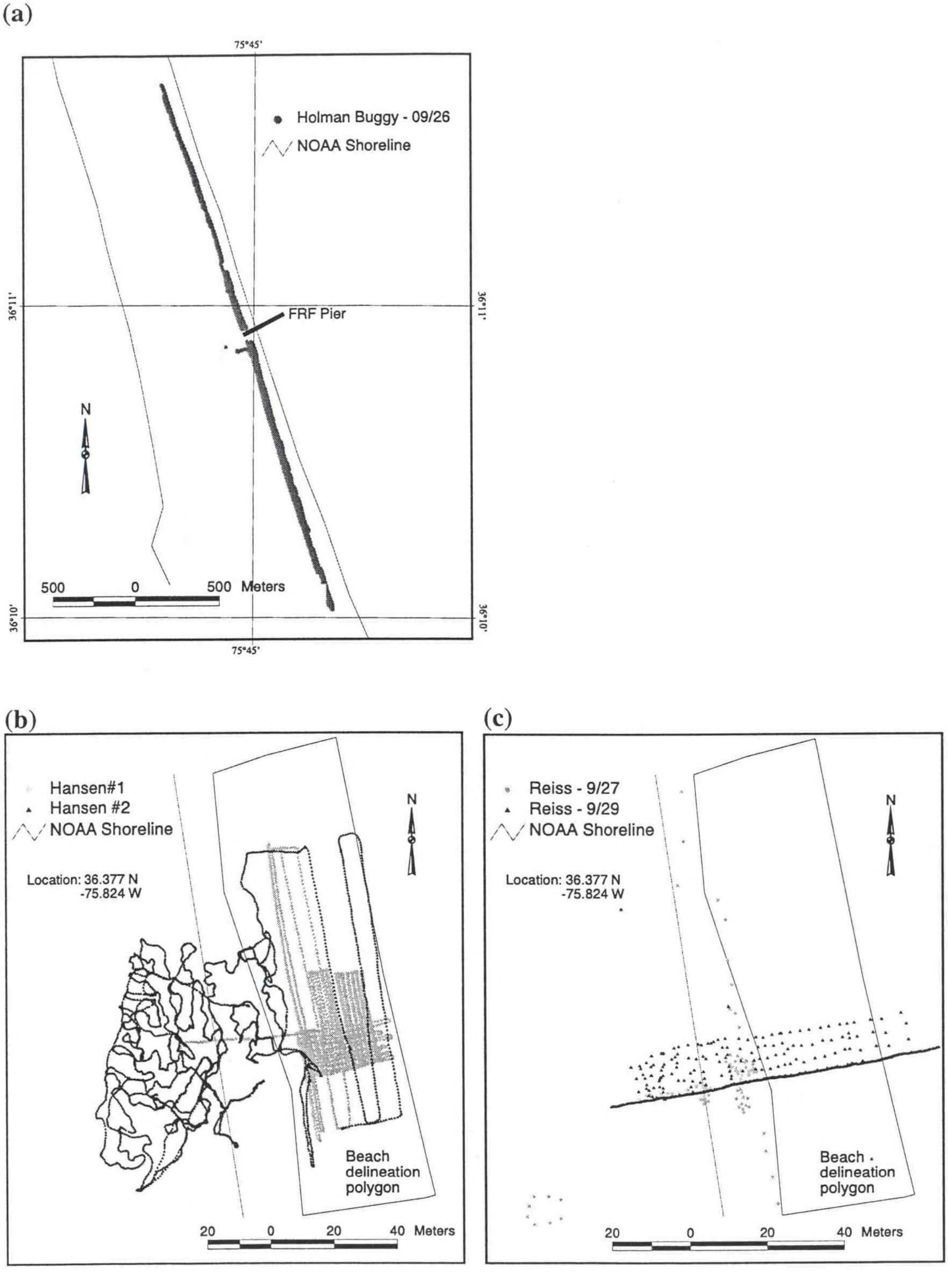


Figure 2. (a) Map showing the extent of the Holman buggy survey centered on the FRF pier. (b) Map showing the extent of the Hansen ground surveys around Corolla. (c) Map showing the extent of the Reiss ground surveys around Corolla.

Mark Hansen coordinated the collection of differentially corrected GPS beach and dune data using an Ashtech GPS receiver and an antenna mounted on a wheeled rod around Corolla (Figures 1 and 2b). Data were collected along several hundred meters of beach from the dunes to the waterline on September 27, 1997. An Ashtech base station was set up within several kilometers of the survey area.

Thomas Reiss of USGS collected beach and dune data around Corolla using a Total Station on September 27 and 29, 1997 (Figures 1 and 2c). The same GPS base station set up for the Hansen survey was used in the Reiss surveys.

3.2 LIDAR Data Collection

This section discusses details of the ATM instrument, the methods applied in ATM data collection and processing, and it presents details of the 1997 LIDAR beach surveys analyzed within this report.

3.2.1 <u>Instrumentation</u>

The ATM is continually evolving as a result of technological improvements that primarily result in reductions in the instrument size. Version 2 of the ATM (ATM-II) (Figure 3) was used during the fall 1997 beach surveys.

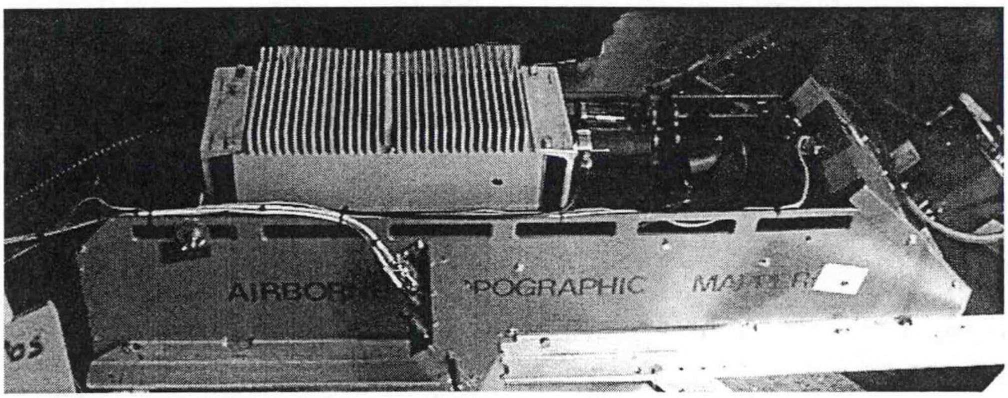


Figure 3. Airborne Topographic Mapper

The ATM is currently operated with a Spectra Physics TFR laser transmitter that provides a 7-nanosecond wide, 250-micro-joule pulse at a frequency-doubled wavelength of 523 nanometers (nm) in the blue-green spectral region. The laser transmitter can operate at pulse rates from 2 to 10 kilohertz (kHz). It was operated at 5 kHz during fall 1997 beach mapping surveys. The transmitted laser pulse is reflected to the earth's surface using a small folding mirror mounted on the back of the secondary mirror of a 9-centimeter diameter Newtonian reflector telescope that views the laser footprint on the earth's surface. The co-axial LIDAR transmit and receive path facilitates changing altitude above the topographic target without the need to realign the transmitter and receiver optics. The transmitted laser pulse and receiver field-of-view (FOV) are directed earthward by a nutating scan mirror assembly that is mounted directly in front of the telescope. The scan mirror, which is rotated as 20 hertz (Hz), is made from a section of 15-centimeter diameter round aluminum stock, machined to a specific off-nadir angle. A scan mirror with an off-nadir angle of 15 degrees was used in the ALACE beach mapping surveys, producing an elliptical scan pattern with a swath width equal to approximately 50 percent of the approximately 700-meter aircraft altitude. The ATM-II receiver is composed of the Newtonian reflector telescope, a single photomultiplier tube (PMT), and various other low cost, off-the-shelf optical components. The 2.1-milliradian FOV of the system is established by the thickness of a fiber optic cable situated at the focal plane of the telescope. The fiber transmits the reflected laser pulse to the photomultiplier assembly, which consists of a lens, a narrow band filter, and the PMT (Krabill *et al.*, in prep.).

For the fall 1997 mapping missions, a passive channel sensor was added to the ATM. This sensor collects geo-referenced panchromatic (excluding 523 nm) data along the same elliptical scan path as the active laser. Images created from the passive channel data help identify ground features, and are used to assist in the delineation of the beach region.

The major components of the data acquisition system are a 133-megahetz (MHz) Pentium PC and a Computer Automated Measurement and Control (CAMAC) crate, which houses the time-interval counter, receiver power supply, pulse digitizer, inertial navigation interface, and pulse amplifiers. Output from an onboard Ashtech GPS receiver is collected by a separate PC (Krabill *et al.*, in prep.).

3.2.2 Calibration

Two types of calibrations are necessary for the topographic mapping system. The first is necessary to develop a correction for the laser range determination. The ATM uses a leading edge discriminator in timing the laser range measurement. It must be calibrated for a systematic error in range, which consists of a fixed part, or "zero-set," and a part related to the amplitude of the received laser pulse, or "range-walk." During pre-mission and post-mission calibrations, the outgoing laser beam is reflected horizontally via a folding mirror to a flat target board. Range measurements are then recorded while modulating the strength of the laser beam exiting the aircraft, which effectively produces a wide range of amplitude in the received laser signal. The distance between the scan mirror and the horizontal target board is measured both with a steel tape and independently with an electronic range finder. A correction table used in post-flight processing is developed from this ground calibration.

The second type of calibration is designed to determine the angular mounting biases of the ATM sensor relative to the inertial navigation system (INS) from which the aircraft attitude (roll, pitch, and heading) are determined. INS pitch and roll uncertainties are generally the limiting factors in ATM survey accuracy and are thus a primary source of concern. The roll and pitch orientation of the ATM scanner platform relative to the INS reference system must be determined to somewhat better than 0.1 degrees because, for an aircraft altitude of 700 meters and an off-nadir angle of 15 degrees, a 0.1-degree mounting error would introduce a height error of 32 centimeters and a horizontal displacement error of 131 centimeters. Because the ATM is a conical scanning sensor, the relative orientation between the ATM platform and the INS reference can be determined by flying over either a flat surface such as a water body or a known reference, and comparing the observed ranges with those computed on the basis of the determined position of the aircraft GPS antenna, the measured position of the scanner mirror relative to the GPS antenna in the aircraft (INS) coordinate system, the INS attitude measurements, and a model of the scanner measurement system. A large aircraft parking apron at WFF, which has been densely surveyed, served as the reference surface after installation of the ATM within the NOAA Twin Otter aircraft. It may be noted that these mounting biases can include small day-to-day variations in INS pitch, roll, and heading zero-set. Nonetheless, the ATM mounting biases are generally stable enough during a particular aircraft installation for a single set of numbers to be utilized for an entire campaign (Krabill *et al.*, in prep.).

3.2.3 Navigation

The ability to precisely follow specific flight lines is an important facet in beach mapping, both to ensure that data are collected over the desired site, as well as to ensure repeated coverage for change detection. Aircraft INSs are not sufficiently accurate to ensure that flights are precisely navigated along prescribed routes because of drift in their position estimates determined through accelerometers. Consequently, a navigation system based upon real-time GPS information was developed by the ATM group (Wright and Swift 1996). Associated software utilizes coarse acquisition (C/A) code positional output from the on-board GPS receiver that can supply data to an autopilot and provide the pilots with a real-time visual display of the flight line and current offset from the desired track. This system enables the pilot to maintain the aircraft within 30 to 50 meters of the desired flight track during missions lasting several hours and covering 100 to 200 kilometers of beach.

3.2.4 Aircraft Trajectory Determination

In order to measure topography to the desired accuracy of less than 10 centimeters, the vertical and horizontal location of the GPS antenna mounted on the aircraft must be known to approximately 5 centimeters. This goal was achieved using kinematic GPS techniques (Krabill and Martin, 1987) that use the difference in the GPS dual frequency carrier-phase-derived ranges from the mobile receiver in the aircraft and from a fixed receiver located over a precisely known benchmark. Throughout the flight, the bank angle of the aircraft is limited to less that 10 degrees to avoid loss of carrier phase lock on the airborne GPS receiver. GPS data sets were obtained with the aircraft parked close to the fixed receiver for about 45 minutes before and after each survey flight. These stationary data sets are used to resolve ambiguities in carrier phase for each frequency between the fixed and mobile receivers for subsequent application during the processing of the in-flight data. Additionally, the local meteorological conditions (pressure, temperature, and humidity) were recorded for subsequent application during post-mission processing. These data are combined with a precise C/A code of the GPS constellation into a point-to-point range difference solution for the trajectory of the aircraft. Because of the relatively low noise in the phase data, no filtering or smoothing is required. The use of a precise *post facto* ephemeris is required for operations in which the baseline between the aircraft and the fixed receiver exceeds 30 to 40 kilometers, and is recommended for all operations. These are available from several sources on the Internet within 2 to 10 days. The ATM surveys discussed in this report set up a base station using an Ashtech GPS receiver over an established survey mark located at the airport in Manteo, North Carolina, about 50 kilometers from the farthest end of the study area.

3.2.5 ATM Beach Surveys

To ensure complete beach coverage over a section of beach, a typical ATM beach survey consists of two passes, a landward and a waterside pass. The flight lines are designed to produce an approximate 30 percent swath overlap between the two passes. The waterside pass is conducted within an hour or so of low tide. Wider beaches may require additional passes to ensure complete survey coverage.

For purposes of this assessment, very dense coverage was obtained from 22 ATM passes acquired on September 26 and 27, 1997. Nine of the passes ran normal to the shoreline in an approximate east-west direction; the other passes ran shore-parallel, favoring either the landward or ocean side. The shore-parallel passes ranged in length from 70 kilometers, covering the entire study area, to less than 20 kilometers. On September 26, between 9:00 a.m. and noon, 10 passes resulted in over 16.5 million measurements for the study area from Corolla to Oregon Inlet (Figure 4). Over 25 million measurements were collected in 12 passes between 9:00 a.m. and 3:00 p.m. on September 27 for the same study area (Figure 5).

3.2.6 Generation of Raw Elevation File

At the completion of the data collection, computer programs developed at the NASA WFF are used for mission post-processing to transform the data into binary files containing International Terrestrial Reference Frame 1994 (ITRF94) / World Geodetic System 1984 (WGS84) geo-reference elevation measurements and additional ancillary data recorded at the time of the measurement. Post-processing involves the application of (1) calibration corrections using previously collected pre- and post-mission calibration data; (2) differential corrections to each geo-referenced elevation measurement using both the aircraft GPS and base station GPS values; (3) INS measurements to correct for pitch, roll, and heading; and (4) aircraft mounting-bias parameters. The resulting file is composed of a variable length header followed immediately by the fixed length data records. Header information includes the number of words per data record and the header length in bytes. The format of the data portion of the raw elevation file, also referred to as the "qfit" format, is shown in Table 1. For purposes of the analysis within this report, a subset of the data within the full 14-word raw elevation file was extracted, including latitude, longitude, and elevation.

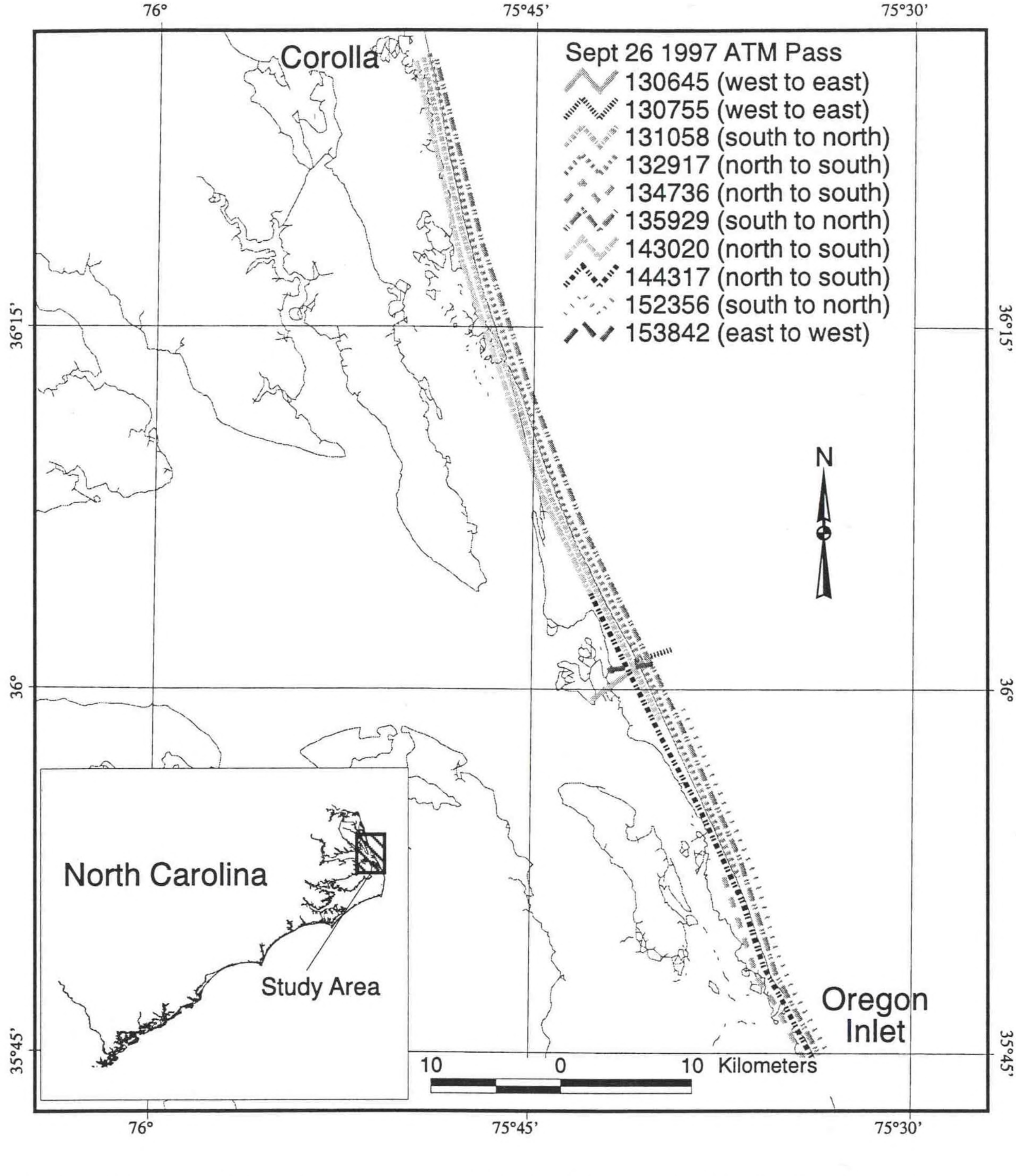


Figure 4. Map showing the extent of the individual passes between Corolla, North Carolina and Oregon Inlet, North Carolina made during the September 26, 1997 ATM survey. The direction of each pass is listed in parentheses.

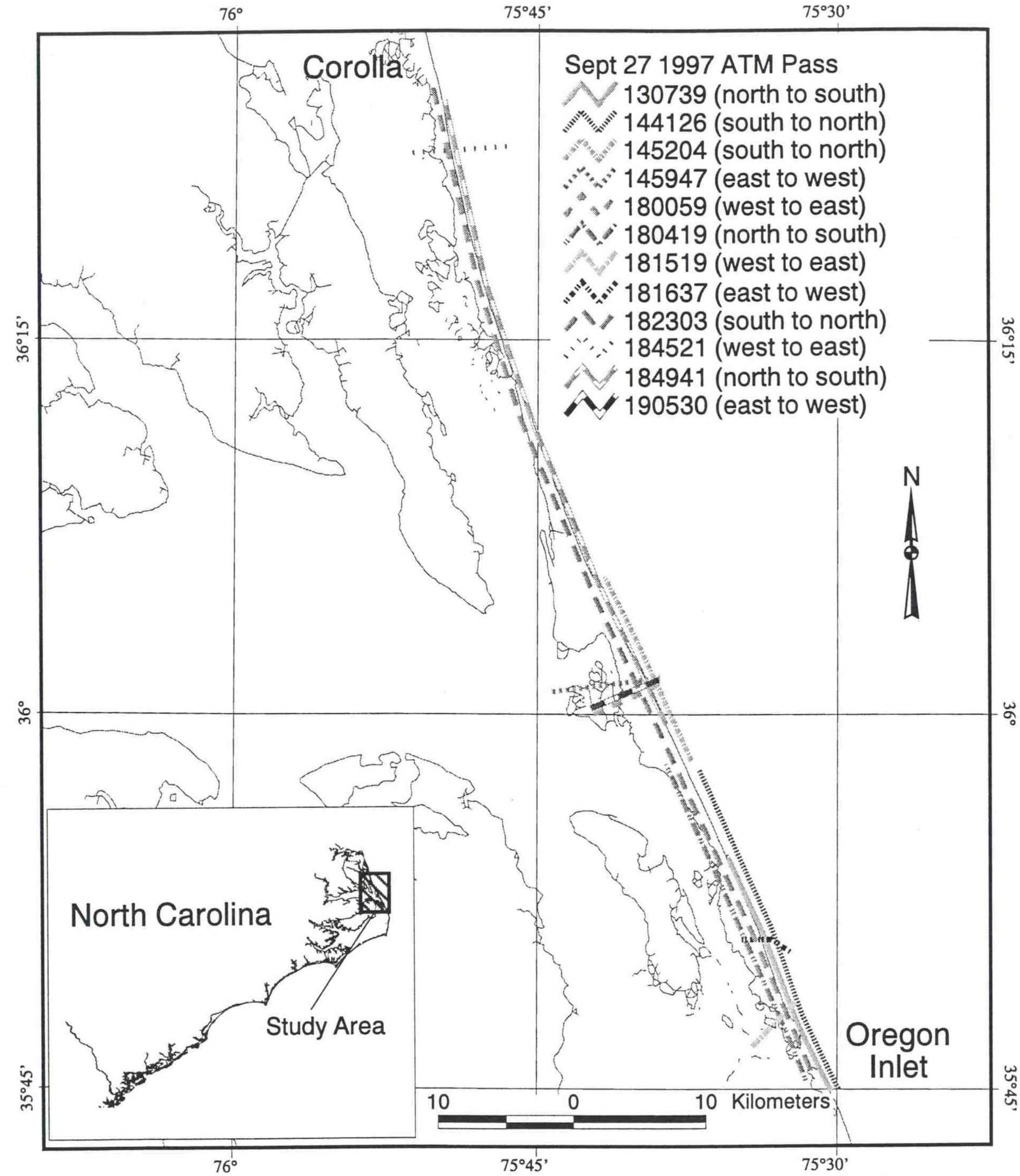


Figure 5. Map showing the extent of the individual passes between Corolla, North Carolina and Oregon Inlet, North Carolina made during the September 27, 1997 ATM survey. The direction of each pass is listed in parentheses.

Word	Field description	Units
0	relative time	milliseconds
1	latitude	microdegrees
2	longitude	microdegrees
3	elevation	millimeters
4	transmit energy	counts
5	receive energy	counts
6	scan azimuth	millidegrees
7	pitch	millidegrees
8	roll	millidegrees
9	passive brightness	counts
10	passive latitude	microdegrees
11	passive longitude	microdegrees
12	rough elevation	millimeters
13	GPS time	hhmmss

Table 1. Raw elevation data record format ("qfit" format)

3.3 Coordinate Transformation

ATM data is expressed in ITRF94 with the coordinates referencing the WGS84 ellipsoid. Survey data collected by List, Hansen, and Reiss were received within the same reference frame as the ATM data and required no conversion. The Holman buggy data required a transformation before direct comparisons between the data could be performed.

The Holman survey data were expressed in a local cartesian coordinate system used by USACE for research around the Duck FRF pier. The data were globally referenced to the North American Datum of 1983 (NAD83) with orthometric height based on the National Geodetic Vertical Datum of 1929 (NGVD29). The original Matlab script used to convert the data from geographic latitude and longitude coordinates to X and Y coordinates was rewritten to reverse the original transformation. The NGVD29 orthometric heights were converted to Geodetic Reference System of 1980 (GRS80) ellipsoid heights by adding the geoid heights, calculated using the National Geodetic Survey's "VERTCON" and "GEOID96" programs, to the orthometric heights. In the final step the NAD83 coordinates were converted to ITRF94 using published methods (Dana 1997).

3.4 Data Comparisons

To fully assess ATM beach surveys, intercomparisons of overlapping ATM swaths collected on the same day and on different days were conducted to assess repeatability of ATM measurements. In addition, intercomparisons were made to ATM and ground survey data collected using various beach survey methods to assess ATM measurement accuracy in relation to the ground surveys. Data comparisons were constrained to the subaerial beach between the dune line and waterline. This data delineation was accomplished by creating beach-only polygons for the study area. Any data falling outside the polygons were discarded. The data were further filtered to eliminate outlier elevation measurements beyond the bounds of reasonable beach elevations for the area

(-45 to -32 meters WGS84 ellipsoid heights). ATM to ground survey comparisons were restricted to surveys collected on the same day in order to eliminate the influence of day-to-day beach change except for the List buggy survey, which was collected on the relatively stable upper beach.

Elevation measurements within two data sets were compared by selecting each point from one data set and locating all points in the second data set within a fixed horizontal radius of the point. Elevation differences were calculated between the locating point in the first data set and each of the identified points in the second data set. For these comparisons, a 1-meter radius was used because it closely correlates with the size of the laser footprint.

Three basic statistics are used to examine differences between surveys:

(1) "Mean" difference, μ, refers to the mean elevation difference, or offset, between compared data sets.

(2) "Random" difference, σ, is the standard deviation about the mean of the elevation differences between data sets.

(3) "Total" difference is the root-mean-squared (RMS) of differences, or deviation of the differences about zero, which reflect combined mean difference and random differences.

Statistics were generated for individual ATM pass intercomparisons as well as summary statistics generated by combining all matching points from all passes for a set of comparisons (i.e., September 26 to September 27 ATM comparisons). This process resulted in each overlapping point having an equal weight in the generation of the summary statistics.

As a verification of the validity of the comparison method and program, Table 2 shows the statistics from intra-file comparisons for two ATM passes.

ATM Pass	μ (cm)	σ (cm)	RMS (cm)	# Points
09/26 135929 pass	0.0	4.7	4.7	6,638
09/27 182303 pass	0.0	4.4	4.4	5,829

Table 2. Intra-file comparison results

The results of the comparison of points in a file to the same set of points are consistent with the expected results (i.e., mean difference = 0.0). The 4.4 to 4.7-centimeter variation in the data can be attributed to the 1-meter search radius and the data density, which cause the inclusion of points other than the exact matching point in the comparisons (Figures 6 and 7). It should be noted that this variation accounts for between 23 and 60 percent of the random differences seen in the ATM comparisons. Figure 8 shows the effects of reducing the search radius size on the random difference.

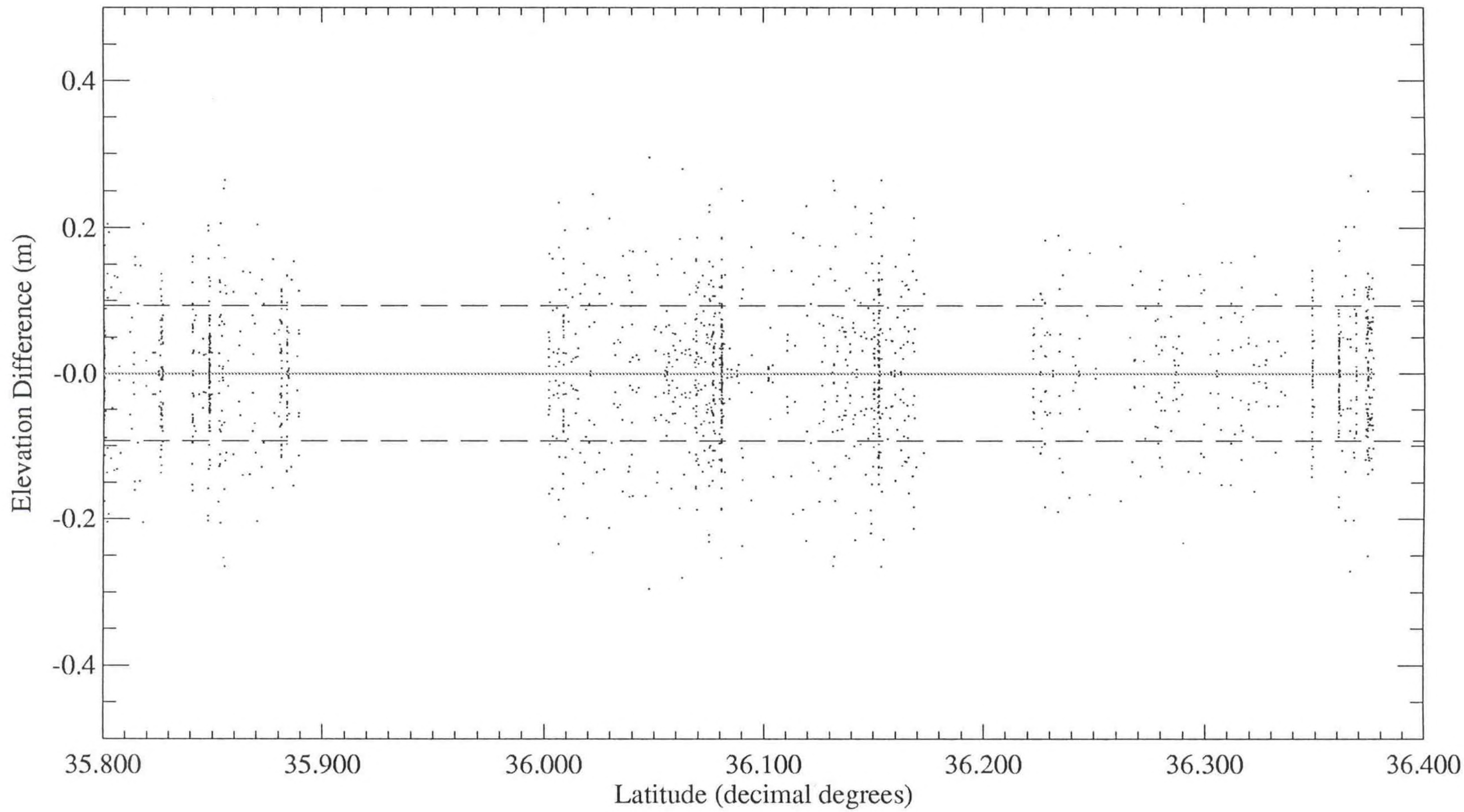


Figure 6. Difference plots from an intra-pass comparison of ATM measurements from pass 135929 on September 26. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

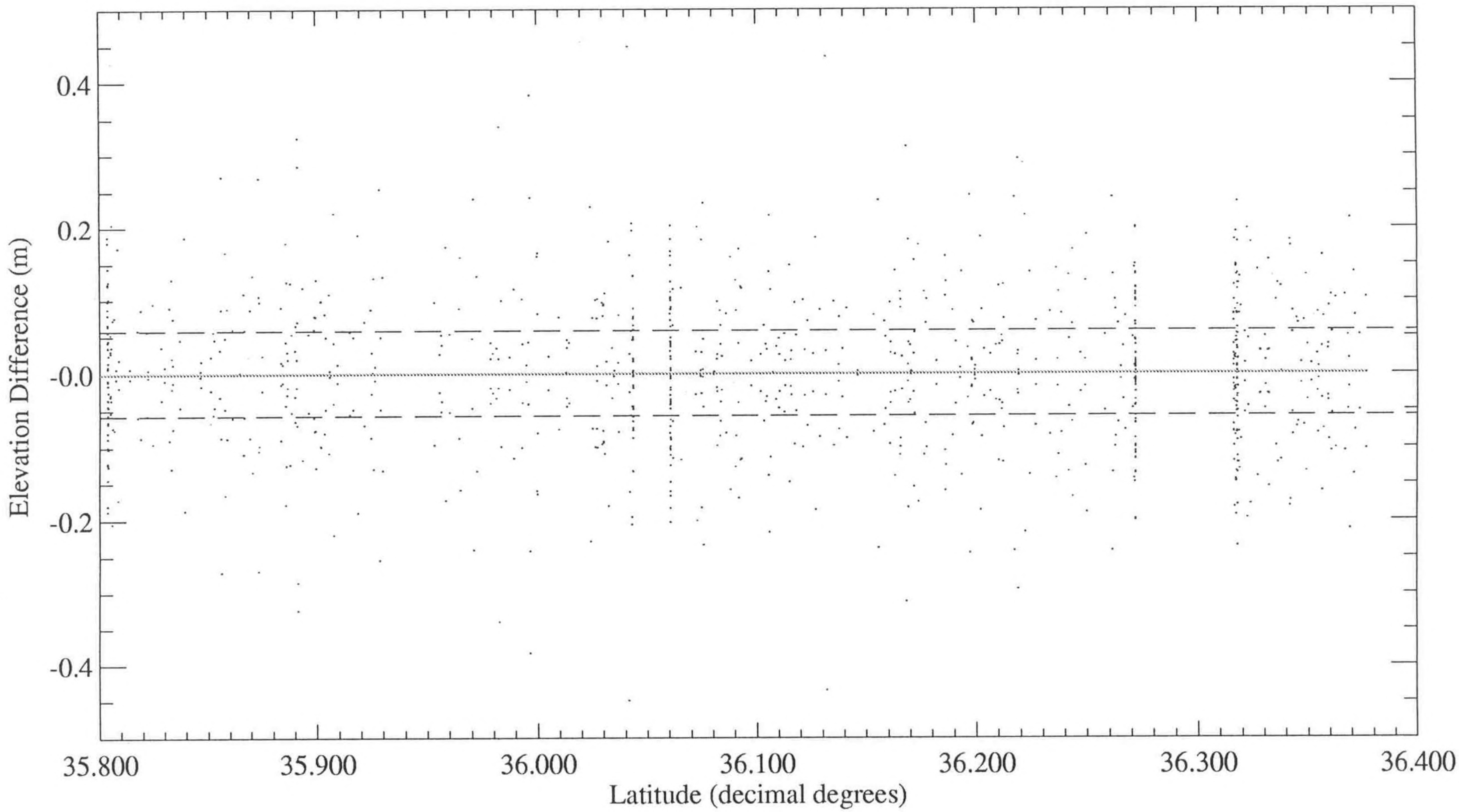


Figure 7. Difference plots from an intra-pass comparison of ATM measurements from pass 182303 on September 27. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

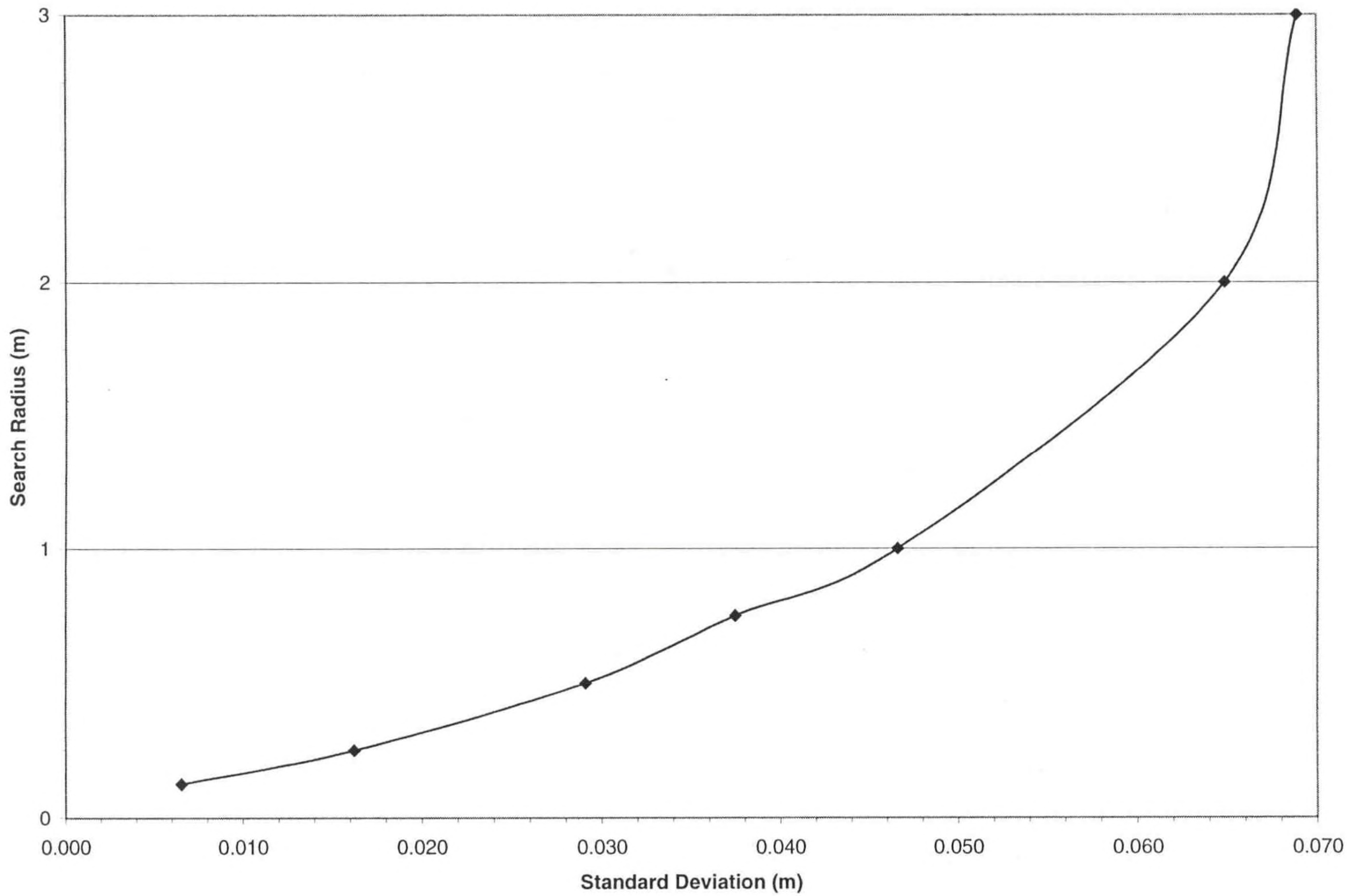


Figure 8. Graph showing the relationship between changes in the horizontal search radius and standard deviation (random difference) from the intra-file comparison of ATM pass 135929.

4.0 RESULTS AND DISCUSSION

The results from the three types of survey comparisons, ATM to ATM, ATM to ground surveys, and ground surveys to ground surveys, are presented in the following section. The labels identifying individual ATM passes refer to the time of the pass in Greenwich Mean Time (GMT) (e.g., 135929 equals 1:59:29 PM GMT).

4.1 ATM to ATM Comparisons

The ability of the ATM to provide consistent repeat measurements was evaluated by comparing overlapping ATM swaths. Comparing results from a survey over a stable flat surface with beach surveys provides the opportunity to assess the impact of the unique beach morphology on the survey measurements while overlapping ATM comparisons assess the capability to consistently repeat measurements over time.

4.1.1 ATM to ATM Over a Stable Geomorphological Feature

A flat short-grass section of the Wright Memorial was selected as a stable geomorphological feature over which to compare elevation measurements from overlapping ATM passes. Two passes from September 26 and three from September 27 contained elevation data for the selected area. Table 3 presents the results of the pass comparisons for each day and between days. The mean difference for all comparisons is between 3.4 centimeters and 9.2 centimeters and the RMS range is 8.3 to 14.3 centimeters. Between 62 and 82 percent of all observations are within 10 centimeters of the mean. Figure 9 shows a plot of the elevation differences and Figure 10 presents associated histograms from the September 26 to September 27 comparison. A graph of the statistics from the individual pass comparisons (Figure 11) indicates excellent agreement between all passes except pass 145947 on September 27, which indicates an offset 10 centimeters higher than other intercomparisons. Discarding pass 145947 produces a mean difference of 4.6 centimeters and a standard deviation of 8.7 for between-day comparisons.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
All 9/26 passes	3.4	7.6	8.3	7,113
All 9/27 passes	8.0	11.4	14.0	21,085
All 9/26 minus all 9/27 passes	9.2	11.0	14.3	48,154

Table 3. Summary of ATM to ATM comparisons for the Wright Memorial

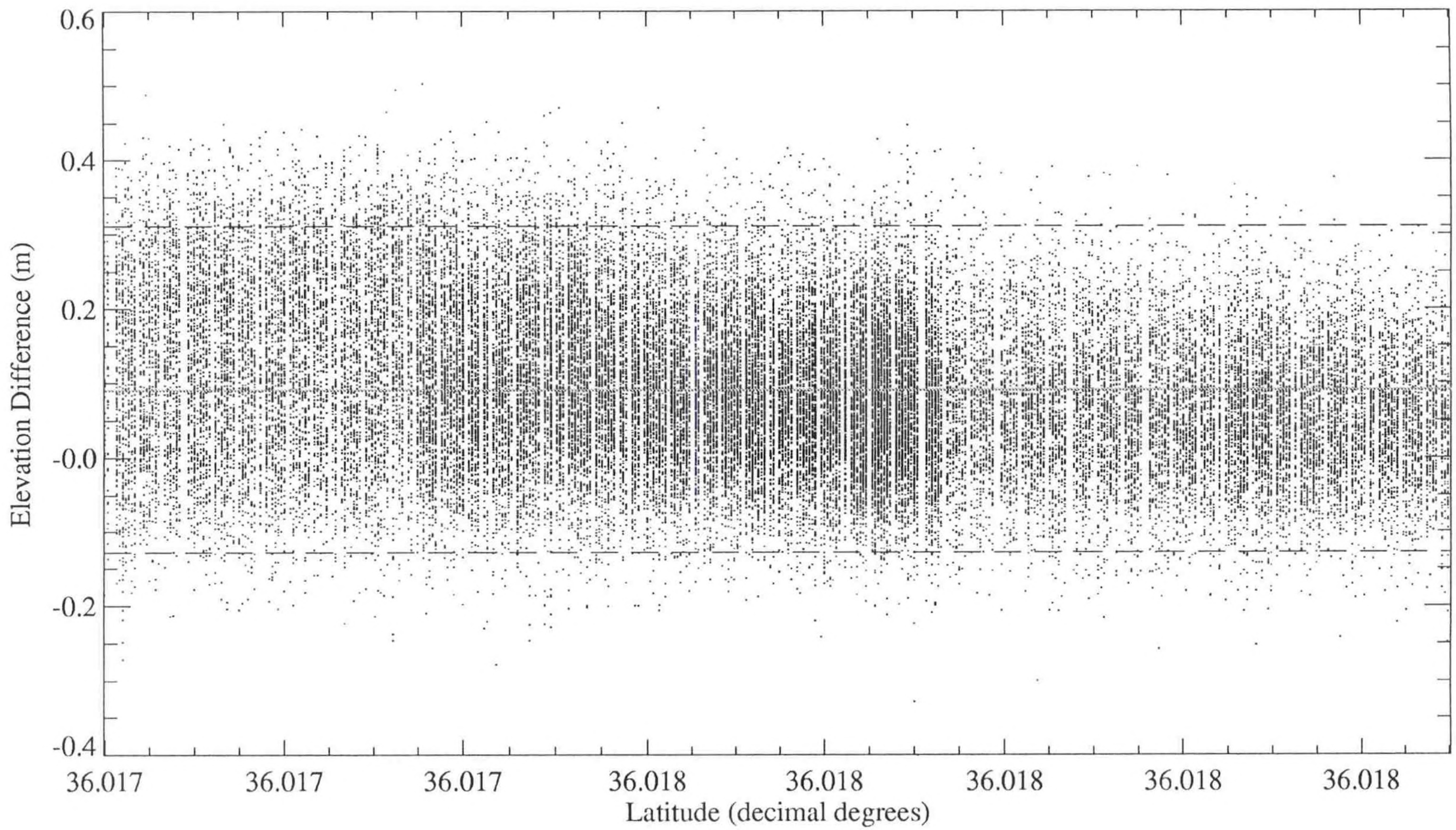
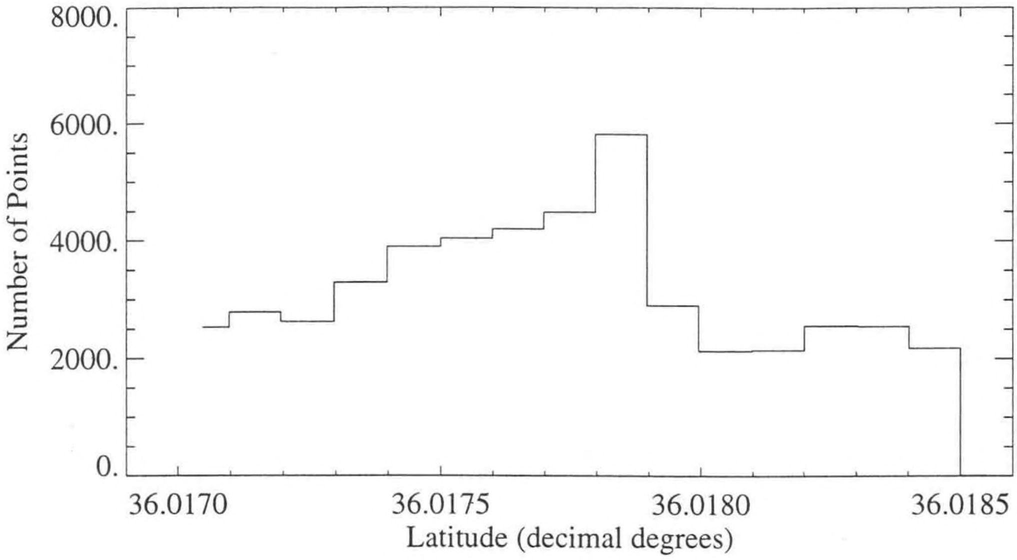


Figure 9. Difference plot from a comparison of ATM measurements for September 26 and 27 over a section of the Wright Memorial. The positive offset in difference values indicates measurements from September 26 tended to be higher than September 27 elevations. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

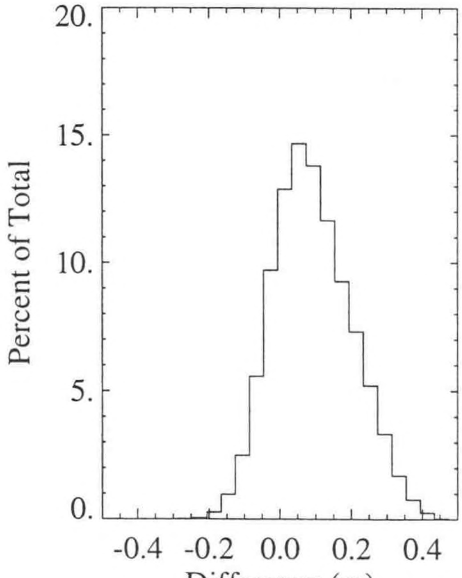
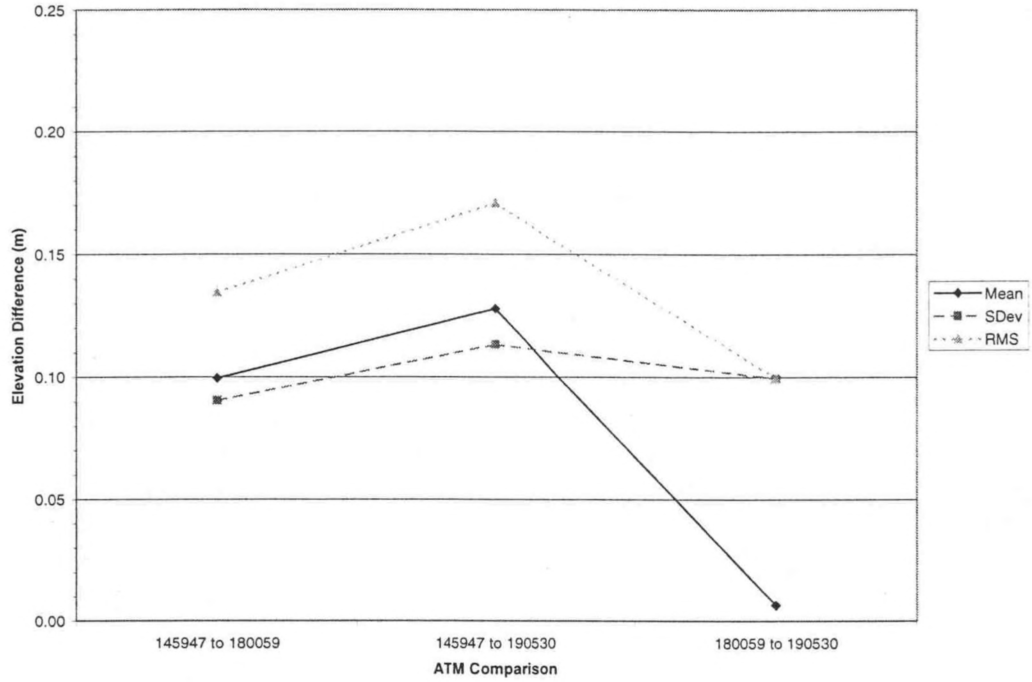


Figure 10. (a) Data density by latitude and (b) data density by elevation differences from the comparison of ATM measurements for September 26 and 27 over a section of the Wright Memorial.

(a)



(b)

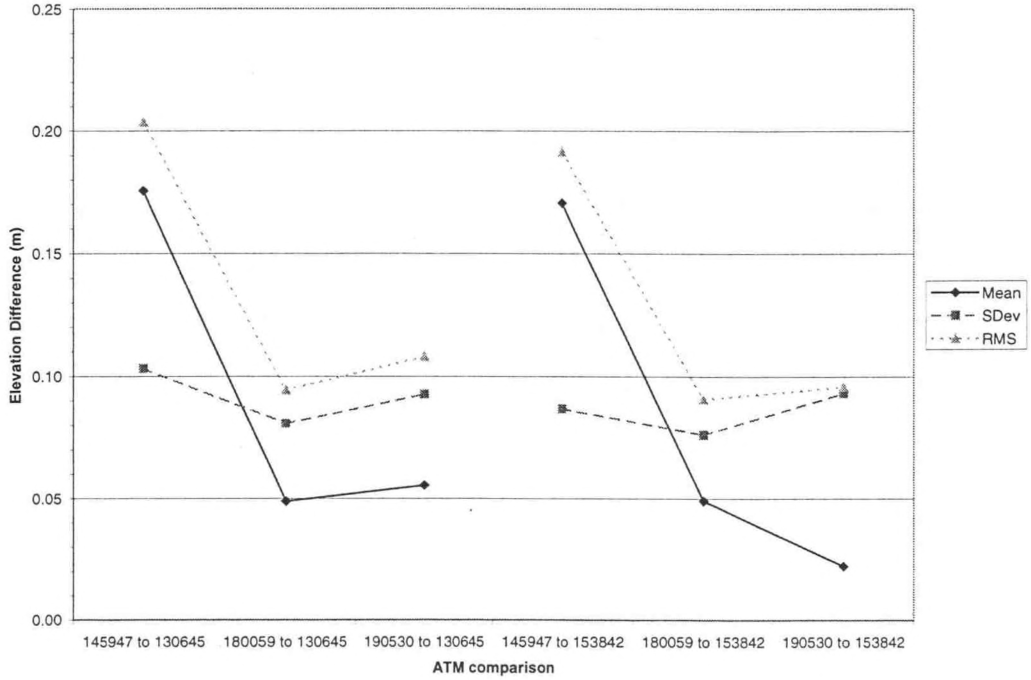


Figure 11. Graph of the statistics (mean difference, standard deviation, and RMS) from individual ATM pass comparisons for (a) the same day comparisons on September 27 and (b) September 26 and 27 between-day comparisons.

4.1.2 ATM to ATM Same-Day Comparisons

Intra-day comparisons of measurements over the beach surface were made with ATM passes conducted on September 26 and September 27. Two sets of comparisons were made. First, the ATM data were constrained to a 1-meter horizontal radius of all 70-kilometer List buggy data points. This produced a shore-parallel line along the high beach with results that are directly comparable to the results of all List buggy survey comparisons. The second set of comparisons was made for elevation measurements constrained to the beach surface between the waterline and dune line. Results from these comparisons provided an assessment of the ATM over a wider range of beach morphology than the first method and greatly increased the number of points used within the comparisons.

After the data sets were delineated, all passes for September 26 excluding 135929, were compared with the September 26 135929 pass (Figure 4) and all passes for September 27 excluding 182303 were compared with the September 27 182303 pass (Figure 5). The 135929 and 182303 passes were selected for comparison against the other passes for the day because they generally included coverage along the entire length of the study area. Table 4 presents summary statistics of the results. Figures 12 to 19 show difference plots by latitude and their associated histograms for the two sets of comparisons for September 26 and 27. Between 54 and 62 percent of all observations agreed within 10 centimeters of the mean difference. The slope of the regression line in the September 26 plots (Figures 12 and 16) indicate a trend of increasing elevation differences with latitude (i.e., from south to north). This same trend is not as apparent in the September 27 plots (Figures 14 and 18) for several reasons. Firstly, each of the individual passes making up the summary plots cover varying portions of the entire latitude bounds presented in the summary plots. Secondly, each of the individual pass intercomparisons have a unique mean difference or offset. When summarizing the elevation differences in a single plot, these two conditions results in a canceling of the actual trends observed in separate plots of individual pass intercomparisons (Figures 20 to 24). Good agreement exists between September 26 and 27 beach and List constrained data sets, although there is a higher random difference for surveys over the entire beach surface.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
135929 pass minus all 9/26 passes along List buggy track	-6.1	12.1	13.5	8,939
182303 pass minus all 9/27 passes along List buggy track	0.9	13.8	13.8	4691
135929 pass minus all 9/26 passes over beach surface	-6.7	14.8	16.2	1,092,692
182303 pass minus all 9/27 passes over beach surface	-0.8	19.0	19.1	535,803

Table 4. Summary of ATM to ATM comparisons for September 26 and 27, 1997

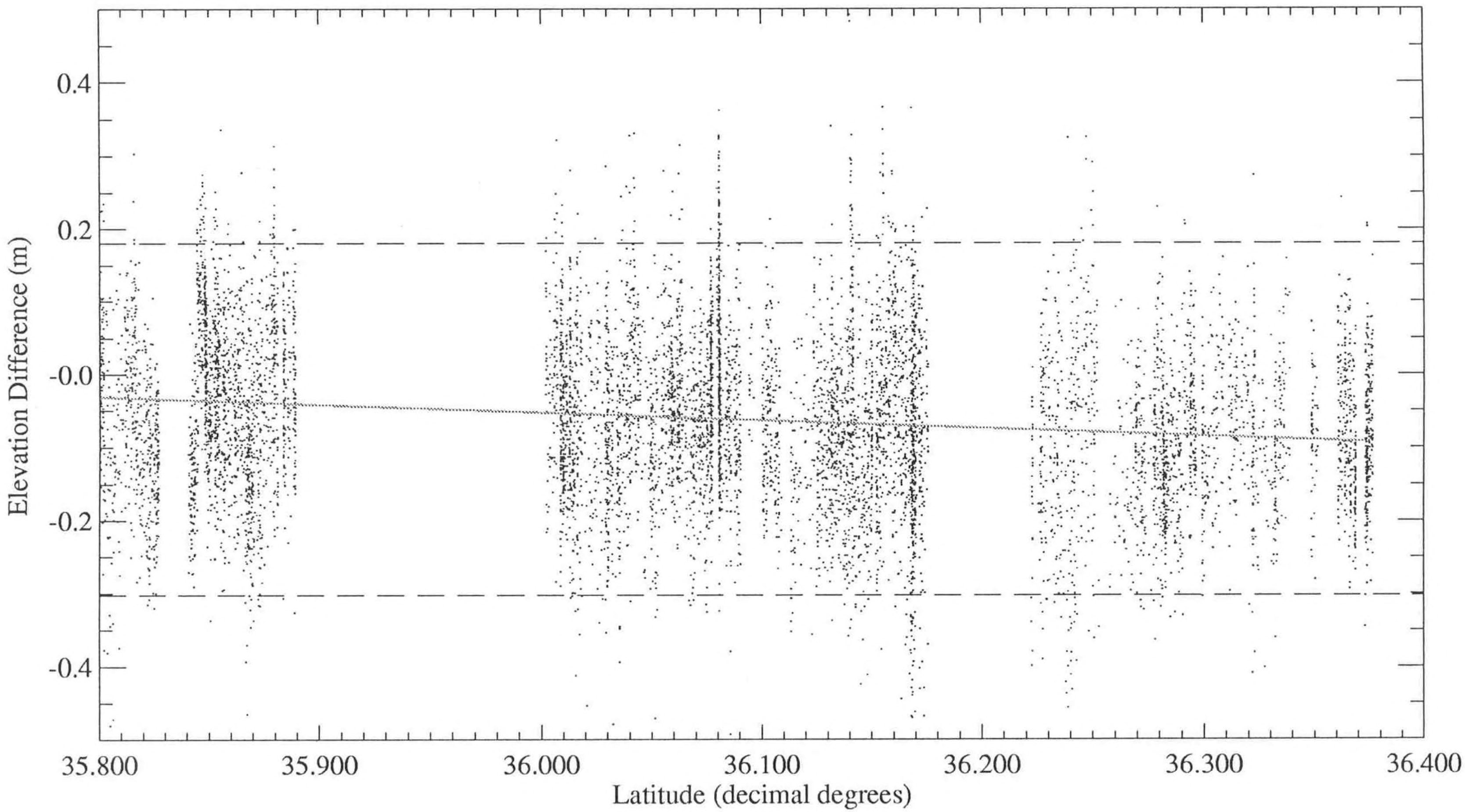
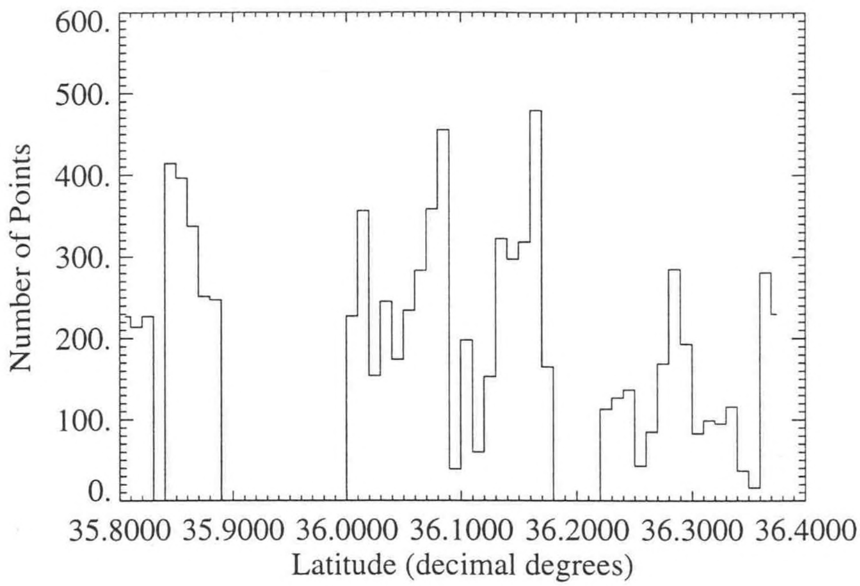


Figure 12. Difference plot from the comparison of all ATM passes for September 26 to the September 26 135929 pass along the 70-kilometer List buggy track from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

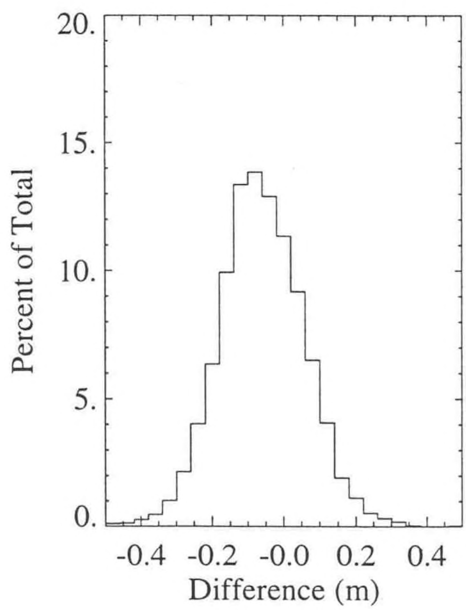


Figure 13. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to the September 26 135929 pass along the 70-kilometer List buggy track from Corolla to Oregon Inlet.

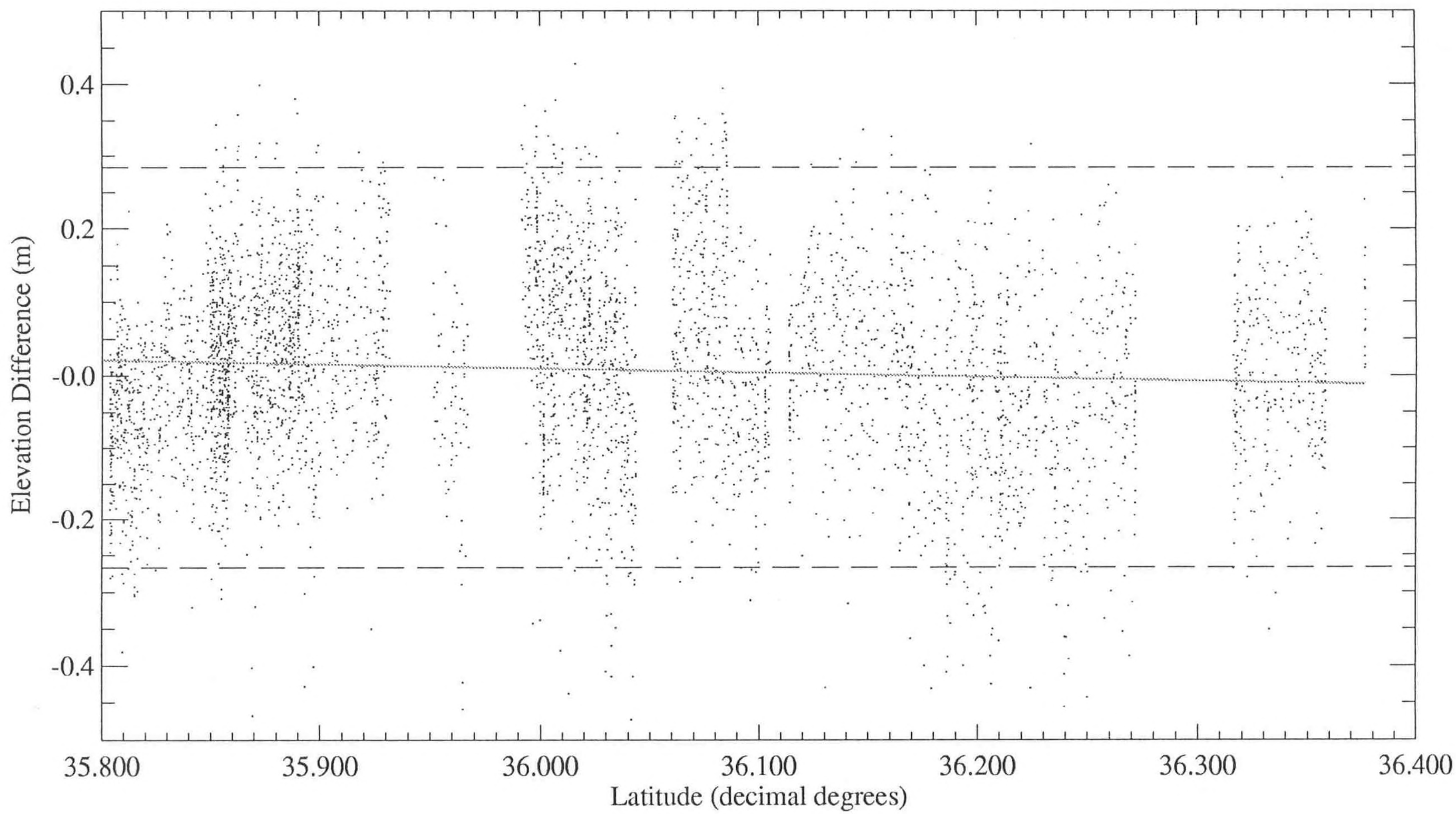
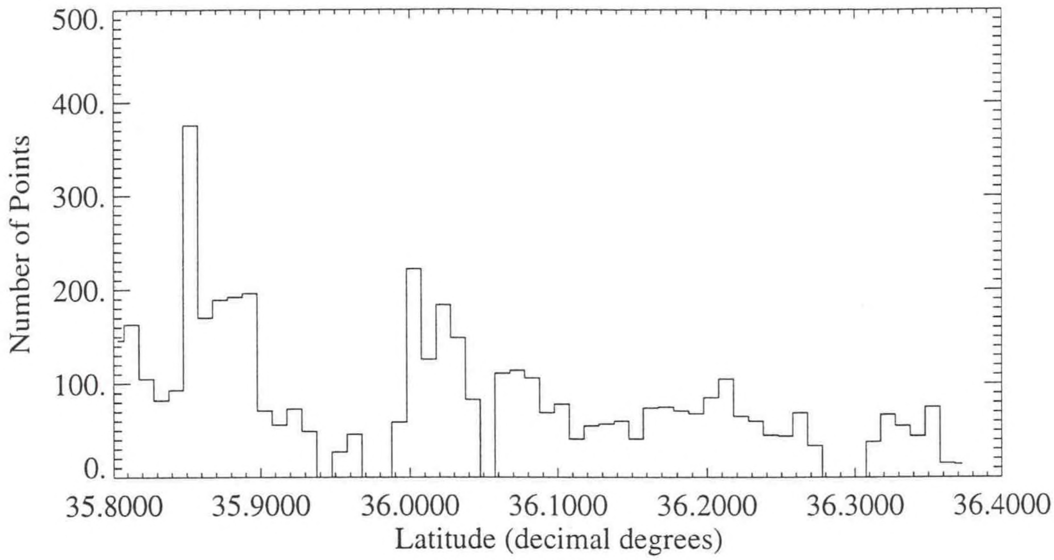


Figure 14. Difference plot from the comparison of all ATM passes for September 27 to the September 27 142303 pass along the 70-kilometer List buggy track from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

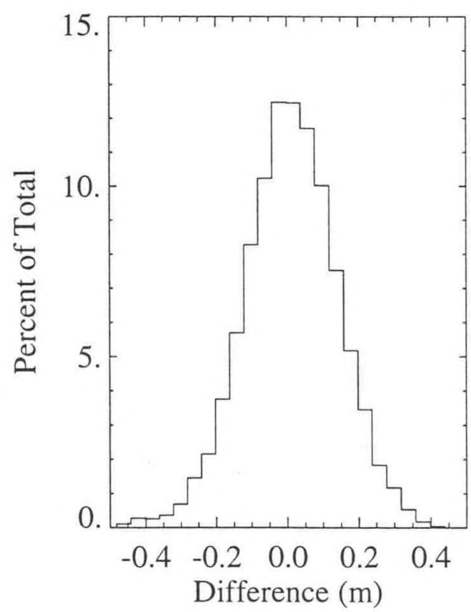


Figure 15. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 27 to the September 27 142303 pass along the 70-kilometer List buggy track from Corolla to Oregon Inlet.

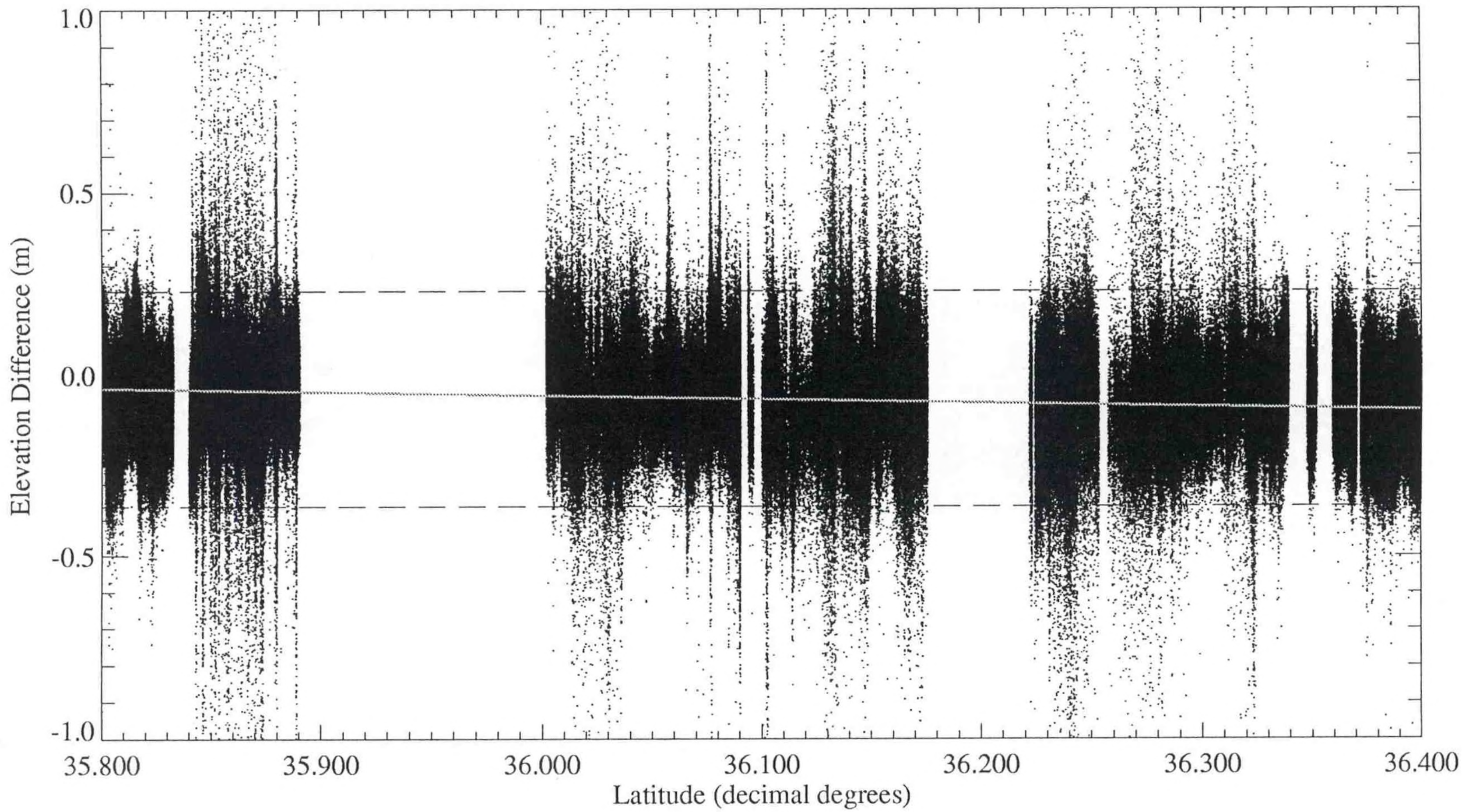
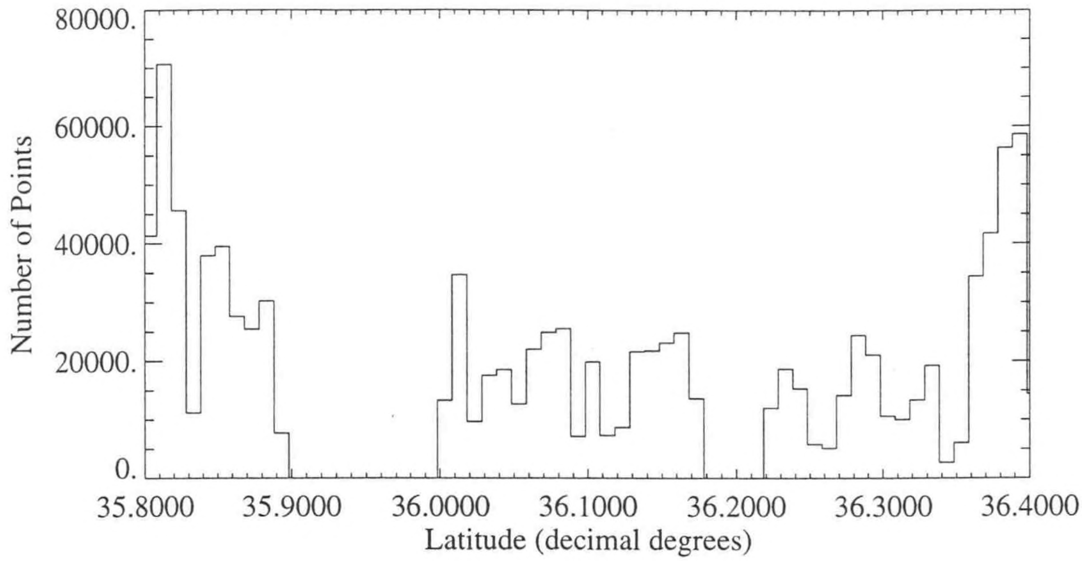


Figure 16. Difference plot from the comparison of all ATM passes for September 26 to the September 26 135929 pass over a section of beach from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

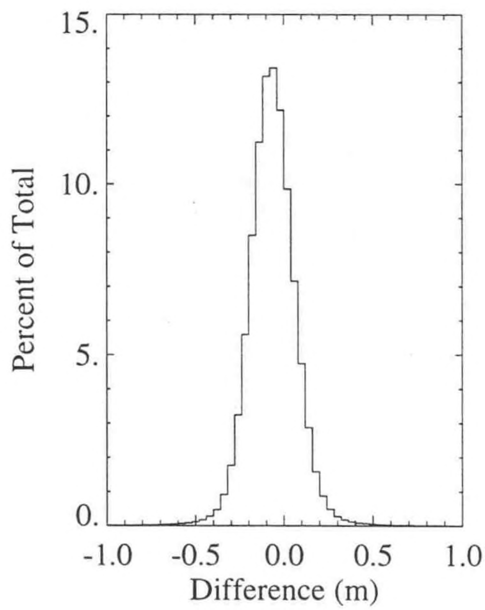


Figure 17. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to the September 26 135929 pass over a section of beach from Corolla to Oregon Inlet.

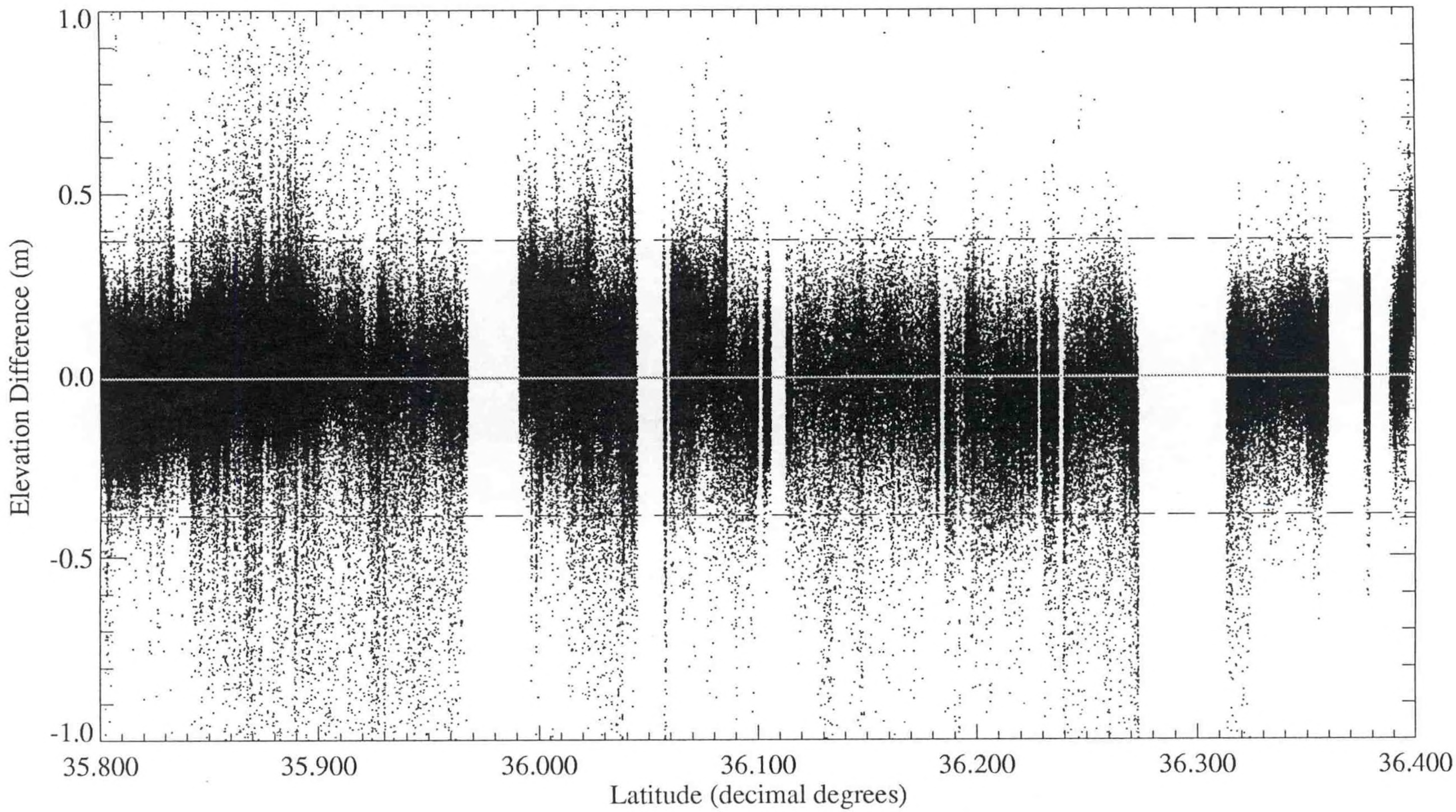
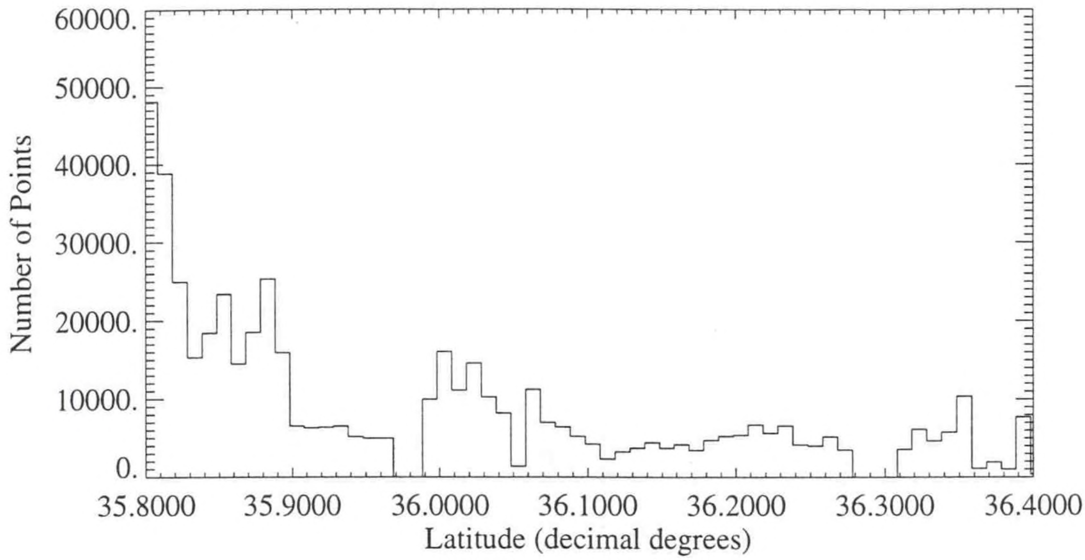


Figure 18. Difference plot from the comparison of all ATM passes for September 27 to the September 27 142303 pass over a section of beach from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

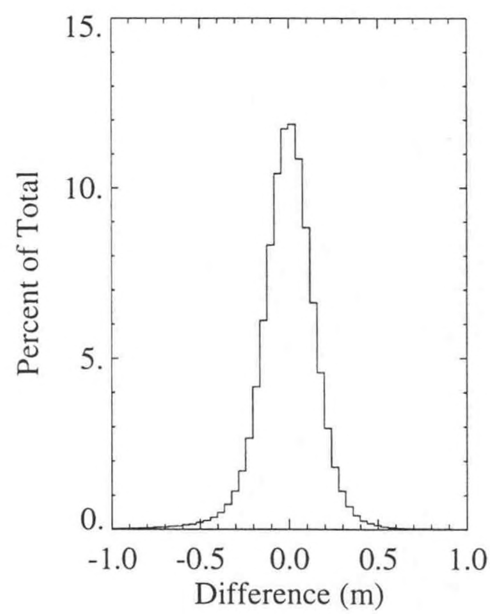


Figure 19. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 27 to the September 27 142303 pass over a section of beach from Corolla to Oregon Inlet.

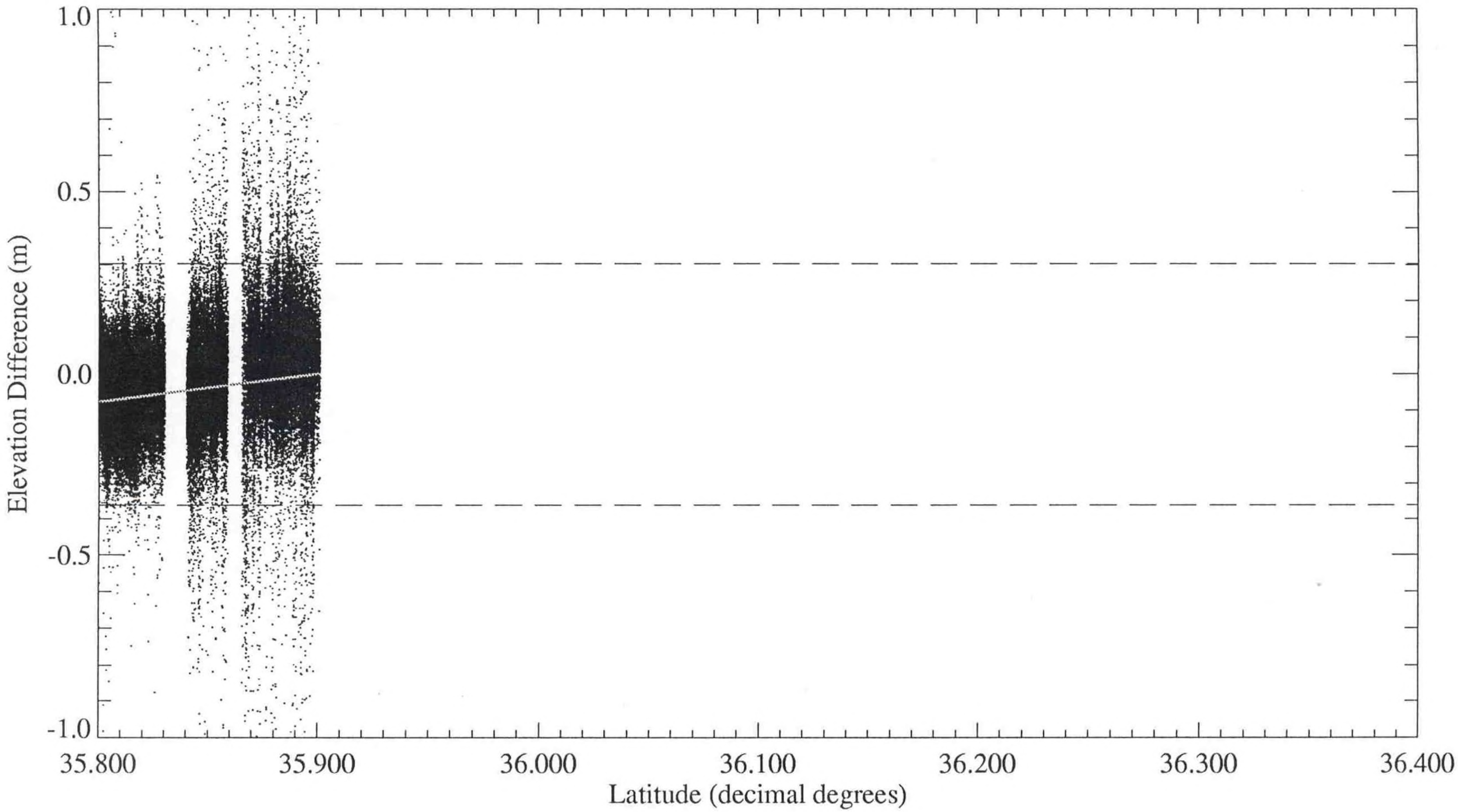


Figure 20. Difference plots from the comparison of the individual September 27 130739 ATM pass to the September 27 182303 ATM pass over the beach surface. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

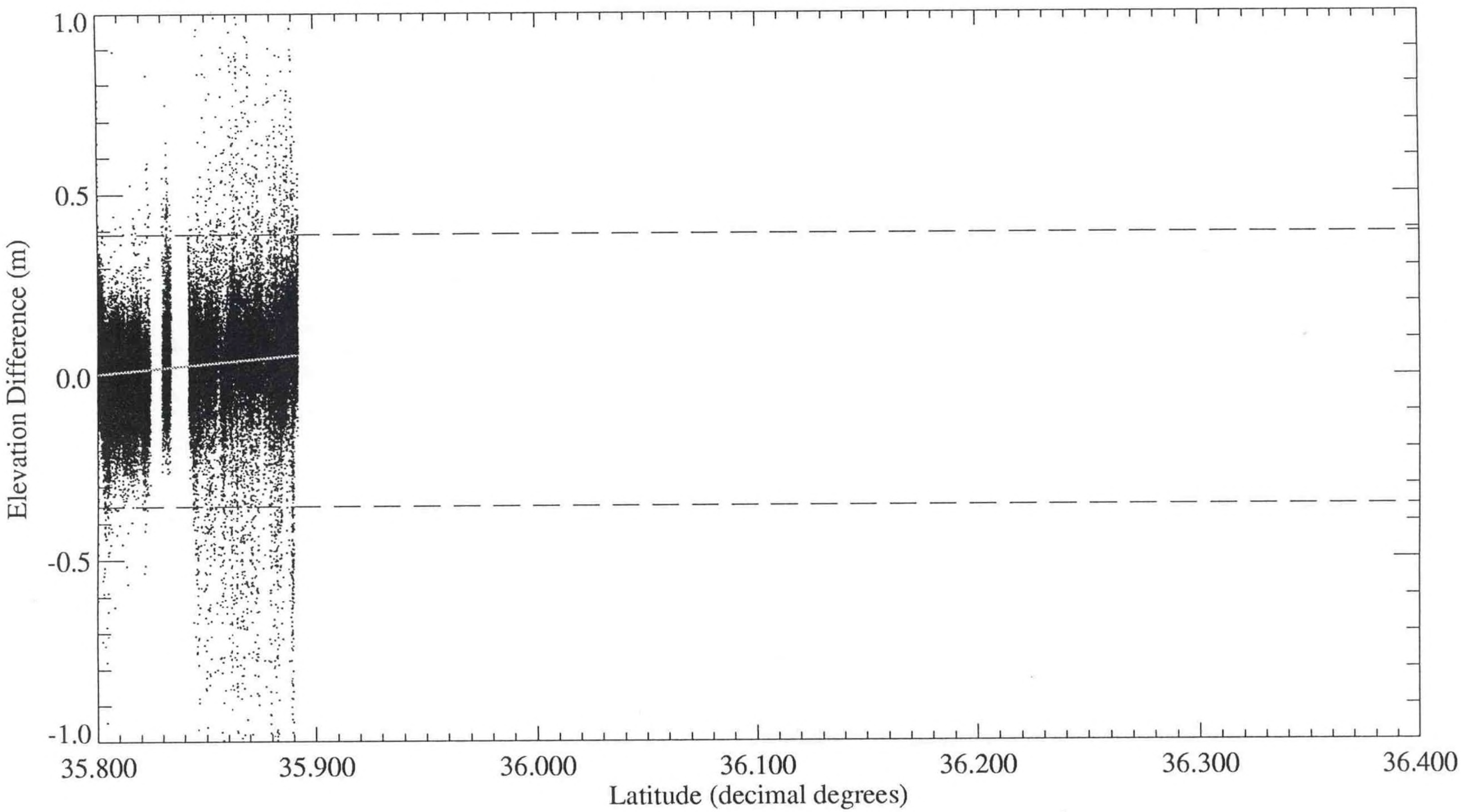


Figure 21. Difference plots from the comparison of the individual September 27 144126 ATM pass to the September 27 182303 ATM pass over the beach surface. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

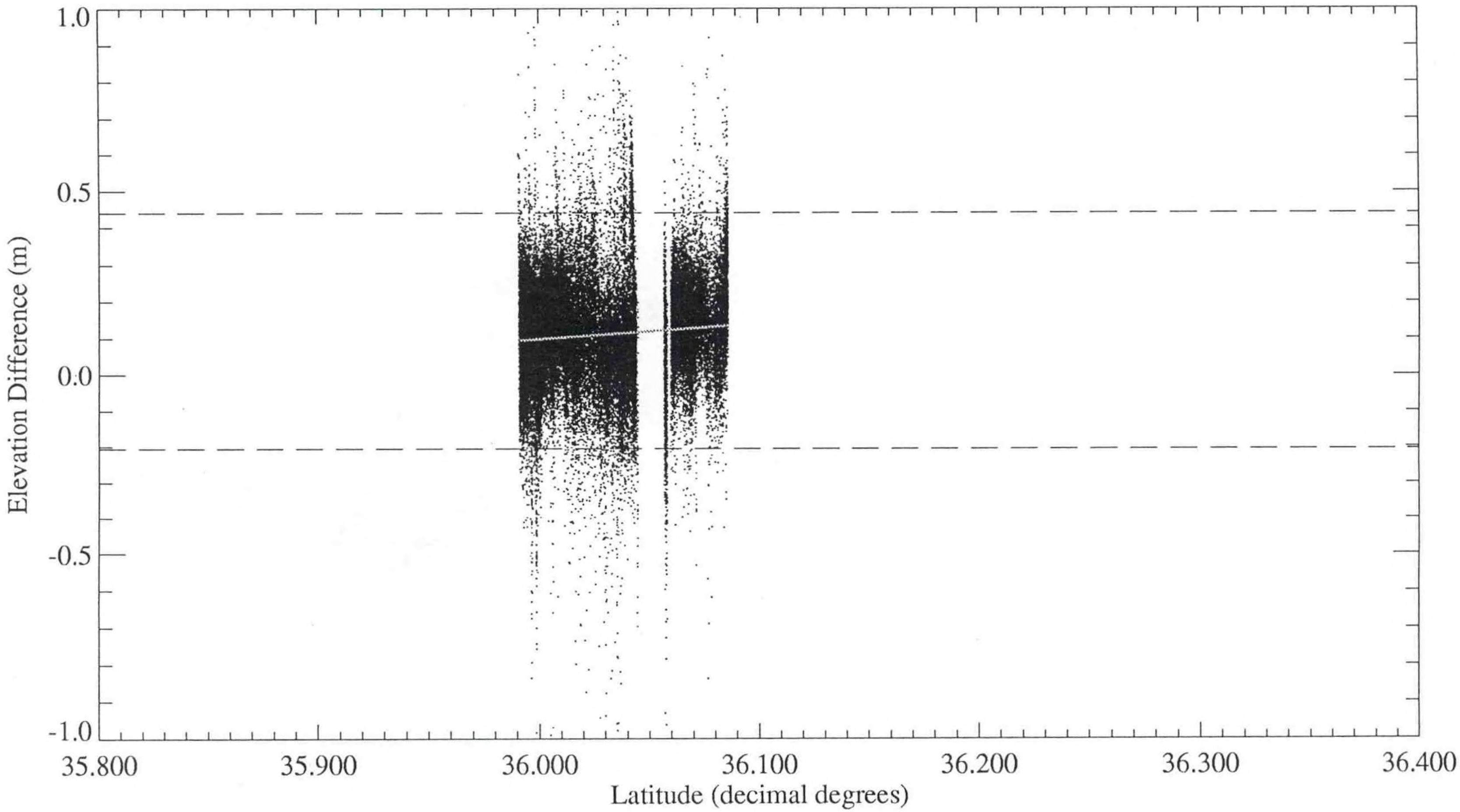


Figure 22. Difference plots from the comparison of the individual September 27 145204 ATM pass to the September 27 182303 ATM pass over the beach surface. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

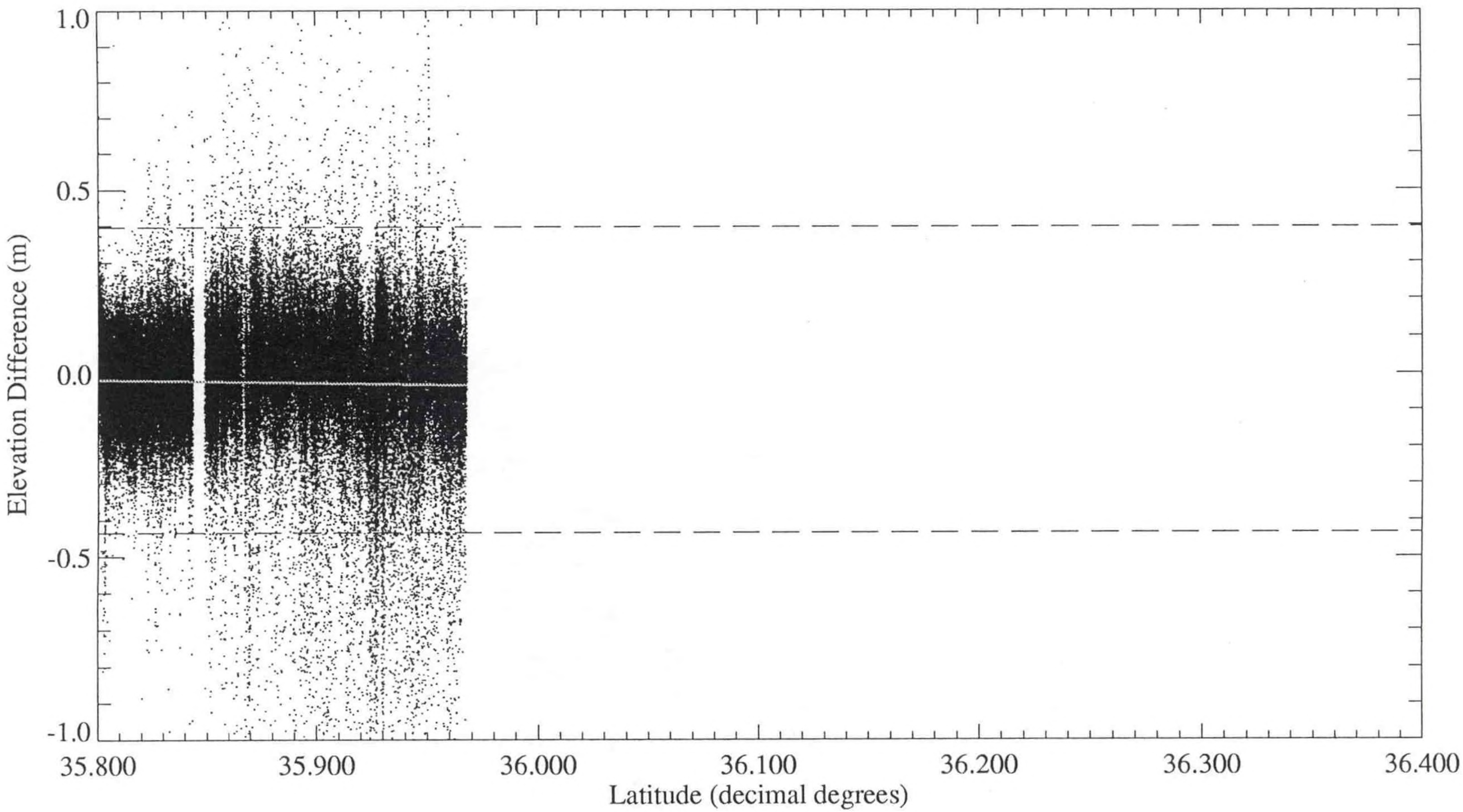


Figure 23. Difference plots from the comparison of the individual September 27 180419 ATM pass to the September 27 182303 ATM pass over the beach surface. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

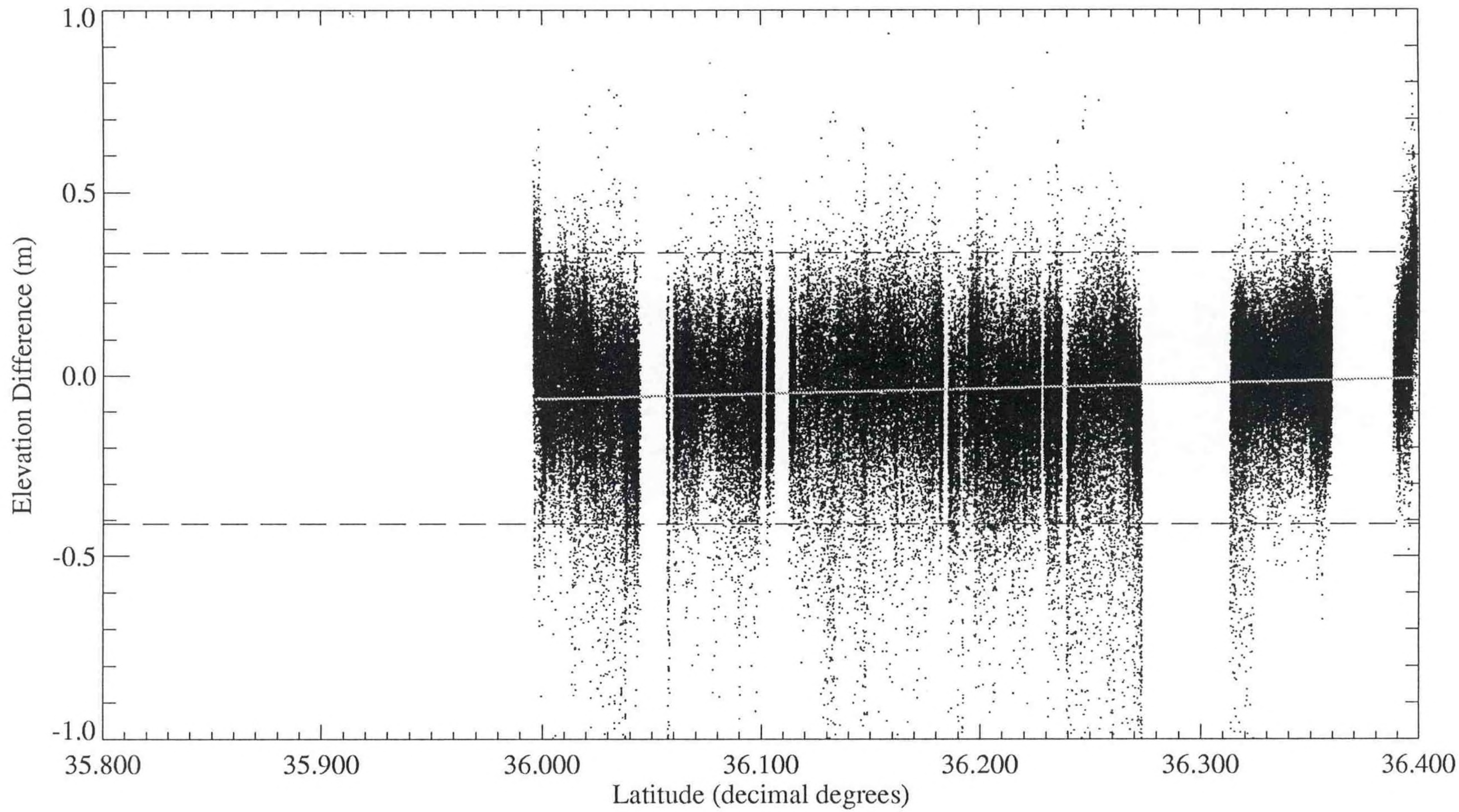
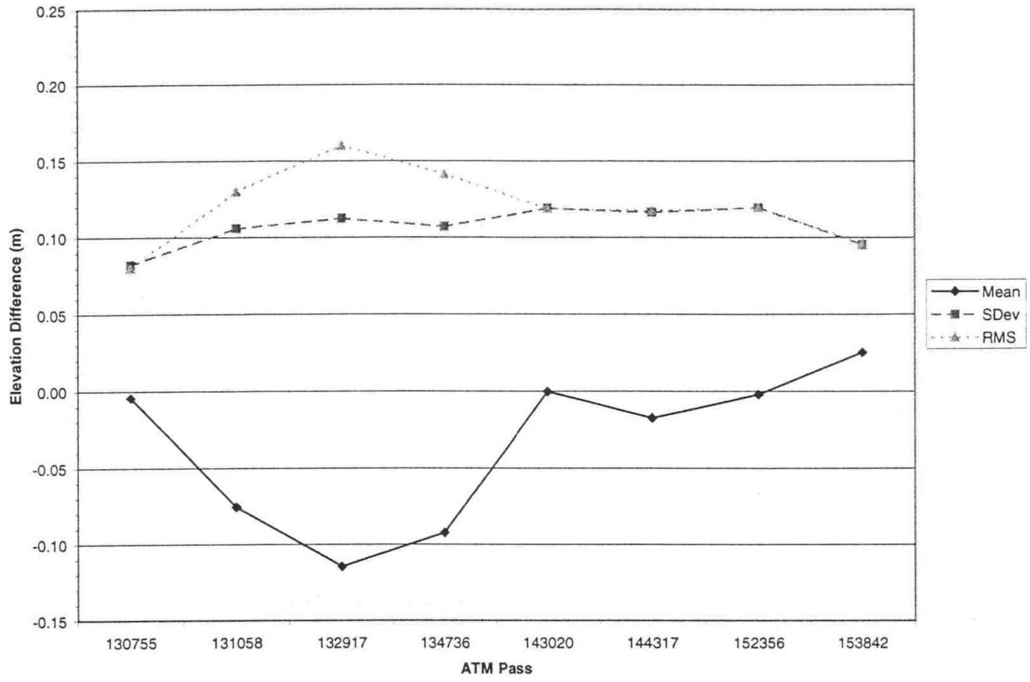


Figure 24. Difference plots from the comparison of the individual September 27 184941 ATM pass to the September 27 182303 ATM pass over the beach surface. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

Figure 25 presents the comparison statistics for each September 26 ATM pass compared to the September 26 135929 pass. The negative offset, or mean difference, indicates measurements for the 135929 pass were generally lower than the other passes for the day. The passes are ordered in chronological sequence, the pass identifier being the time of the pass in GMT; therefore, the graphs indicate trends over time. A trend can be observed in both graphs beginning with the 130755 pass, where there is an increase in the mean difference and RMS over time, peaking at pass 132917, then decreasing to mean differences between ±5 centimeters for the remaining four passes. The time between the first and last pass is approximately 2.5 hours. There is little variation in the random difference from pass to pass.

Figure 26 shows the comparison statistics for each September 27 ATM pass compared to the September 27 182303 pass. The passes 144126, 145204, and 145947 show a general increase in the mean difference and RMS over the 19 minutes between the three passes. In sequential passes beginning three hours after pass 145947, less variation is seen in the mean difference. This trend is apparent in both the List track and beach constrained data sets, although the peak offset is lower (12.4 centimeters versus 16.5 centimeters) and occurs in the 145204 pass of the List track comparison (Figure 26a) as opposed to the 145947 pass in the beach surface comparison (Figure 26b).

(a)



(b)

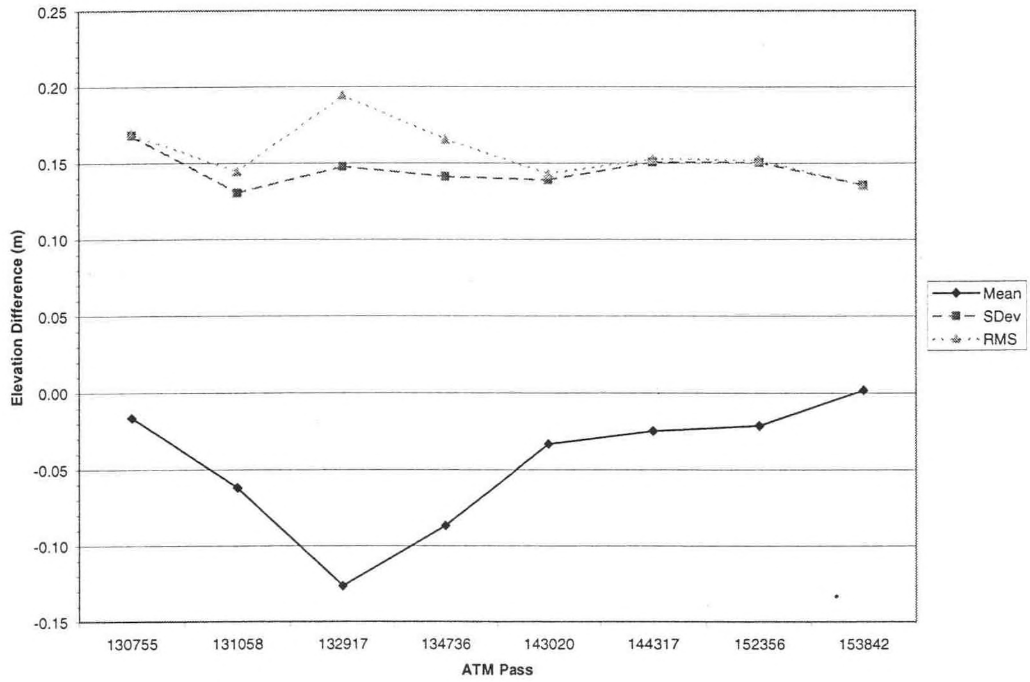
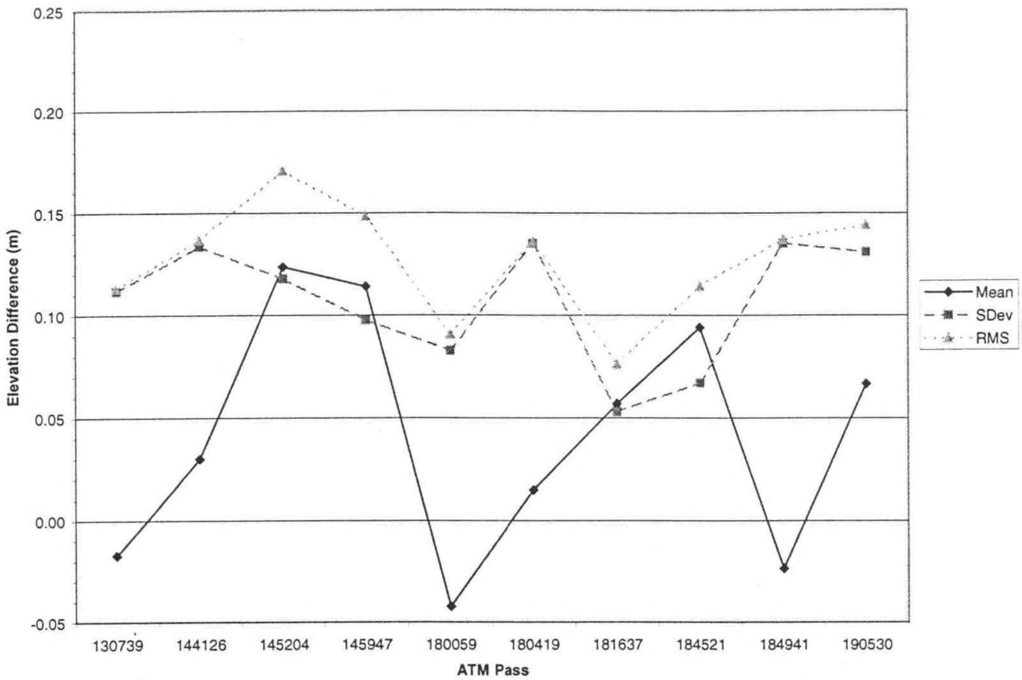


Figure 25. Graph of the statistics (mean difference, standard deviation, and RMS) from the individual ATM passes for September 26 compared to ATM pass 135929 (a) along the List buggy track and (b) over the beach surface.

(a)



(b)

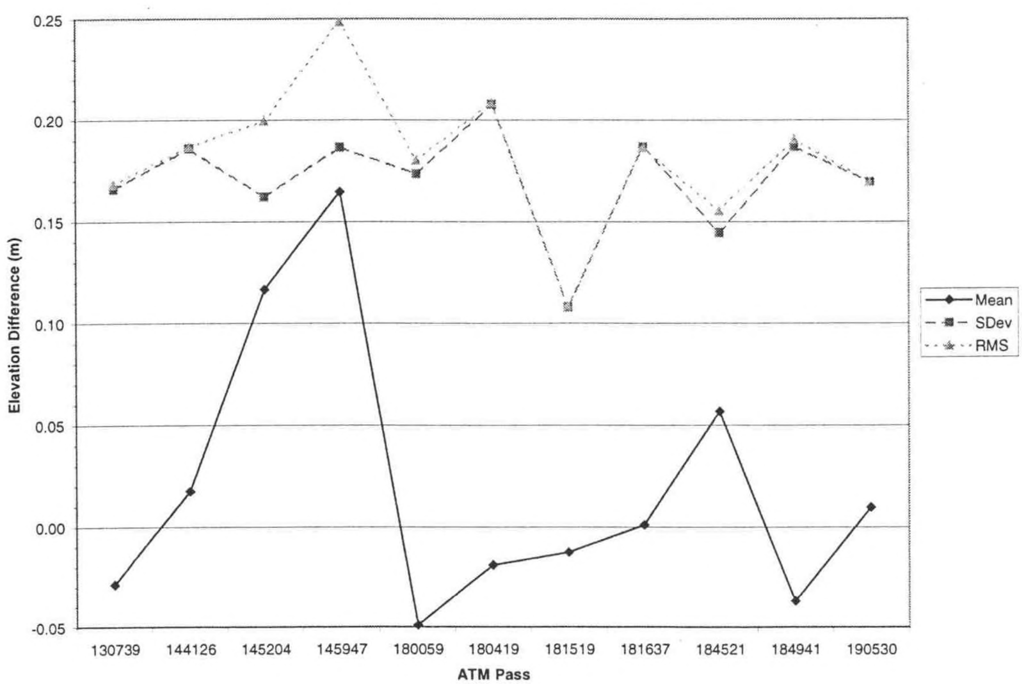


Figure 26. Graph of the statistics (mean difference, standard deviation, and RMS) from the individual ATM passes for September 27 compared to ATM pass 182303 (a) along the List buggy track and (b) over the beach surface. The 181519 pass seen in Figure 26b contained no overlapping points with the List buggy track.

4.1.3 ATM to ATM Multiple Day Comparisons

Analysis of ATM measurements collected on different days provides a method by which to evaluate measurement repeatability over time and between different flight missions. Intercomparisons were made between measurements restricted to the beach surface and the 70-kilometer List buggy track collected on the September 26 and 27. Table 5 presents the summary statistics from the comparisons. Figures 27 to 30 show difference plots by latitude and histograms of the results for both sets of comparisons. Between 48 and 52 percent of the all observations agreed within 10 centimeters of the mean difference. The differences in elevation measurements between days show a distinct increase from south to north. The September 26 surveys are on average 9.4 to 12.1 centimeters above the September 27 surveys with greater differences occurring in the northern portion of the survey area. As seen in the same day comparisons, random difference is higher for comparisons of the entire beach surface as opposed to the List buggy track.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
Individual 09/27 passes minus all combined 9/26 passes along List buggy track	-12.1	14.7	19.1	32,700
Individual 09/27 passes minus all combined 9/26 passes over beach surface	-9.4	20.0	22.1	3,768,656

Table 5. Summary of between-day ATM comparisons for September 26 and 27, 1997

Graphs of the comparison statistics for the individual September 27 passes compared to the combined September 26 passes are presented in Figure 31. The trends observed in the September 27 graphs (Figure 26) are also apparent in the between-day comparison, although inverted as a result of the file comparison method. Generally, the random difference, as represented by the standard deviation, is constant with the exception of the last four passes pictured in Figure 31a. This trend is not mirrored for the points constrained to the List track (Figure 31b) where pass 184521 shows a reduction in random difference. A noticeable difference between the List track and beach surface comparisons for pass 184521 is the number of points used to calculate the statistics, 41 and 20139, respectively.

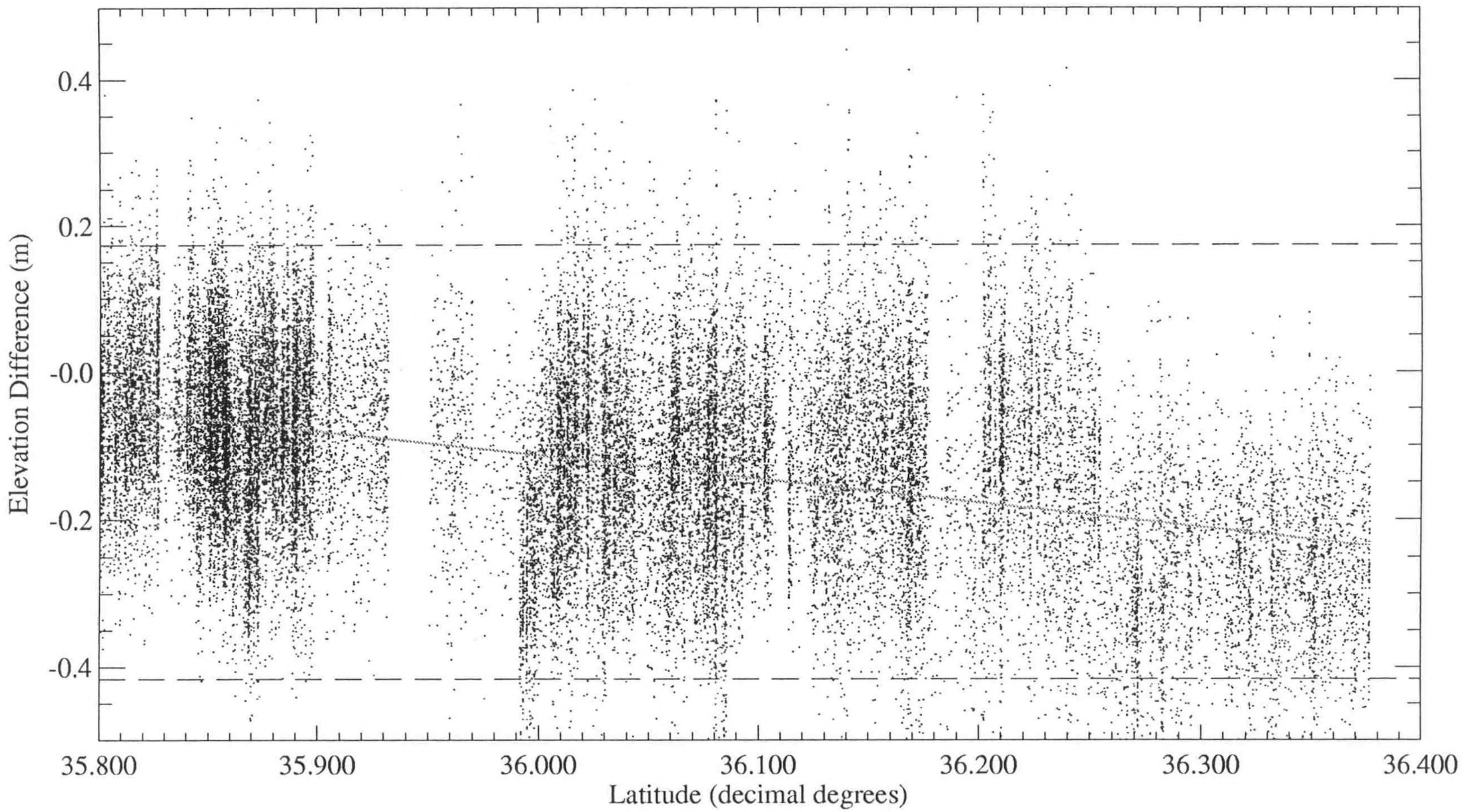
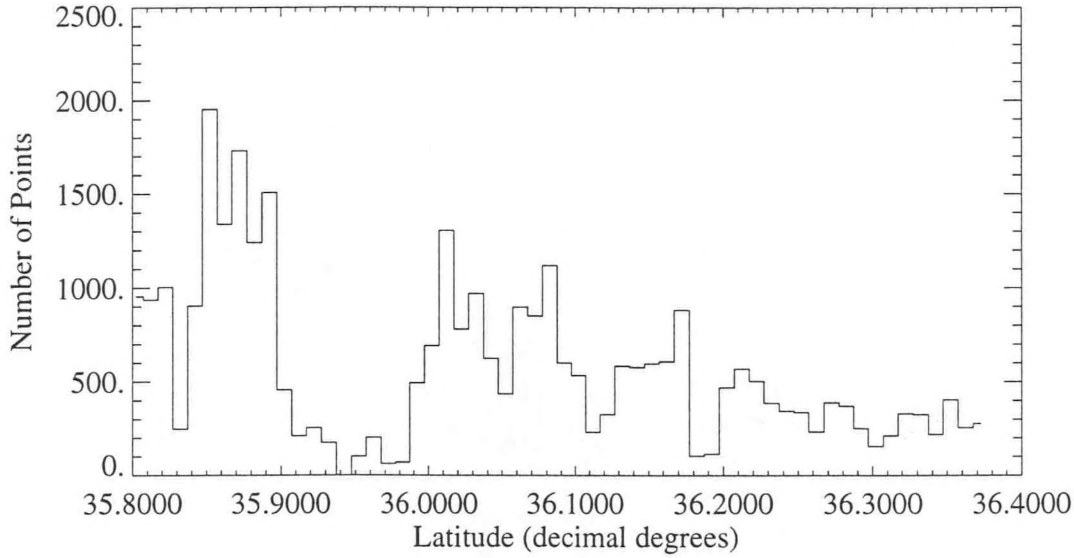


Figure 27. Difference plot from the comparison of all ATM passes for September 26 to all passes for September 27 along the 70-kilometer List buggy track from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

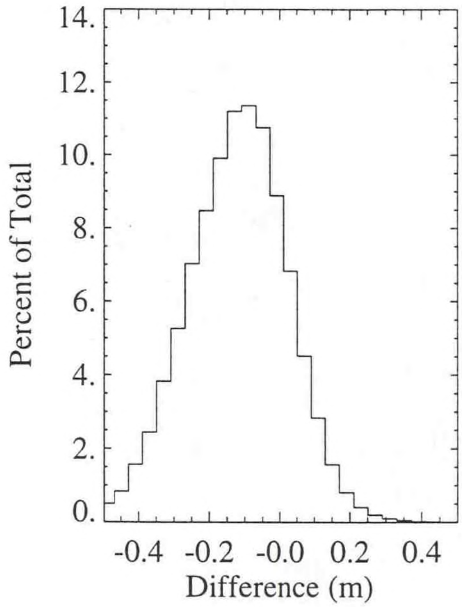


Figure 28. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to all passes for September 27 along the 70-kilometer List buggy track from Corolla to Oregon Inlet.

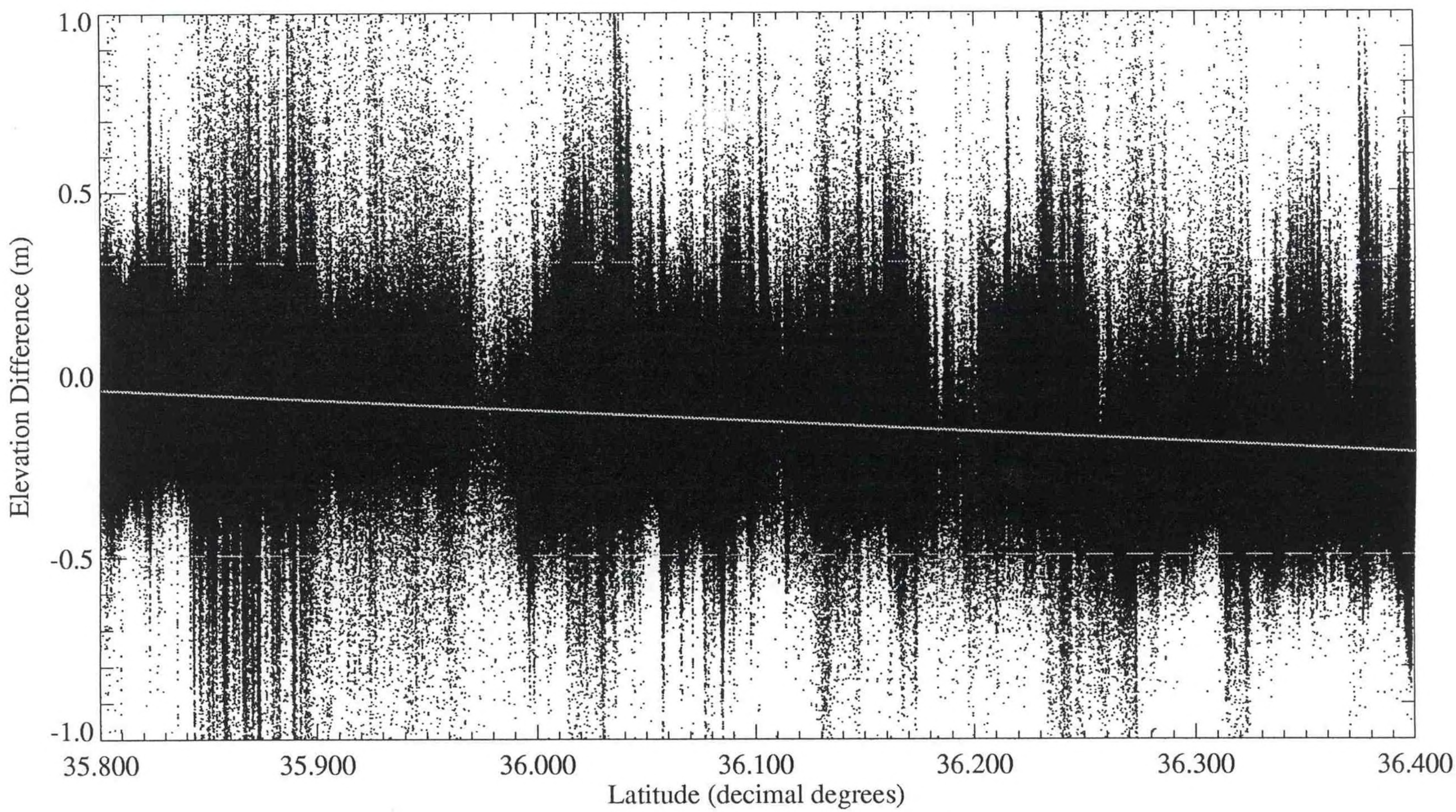
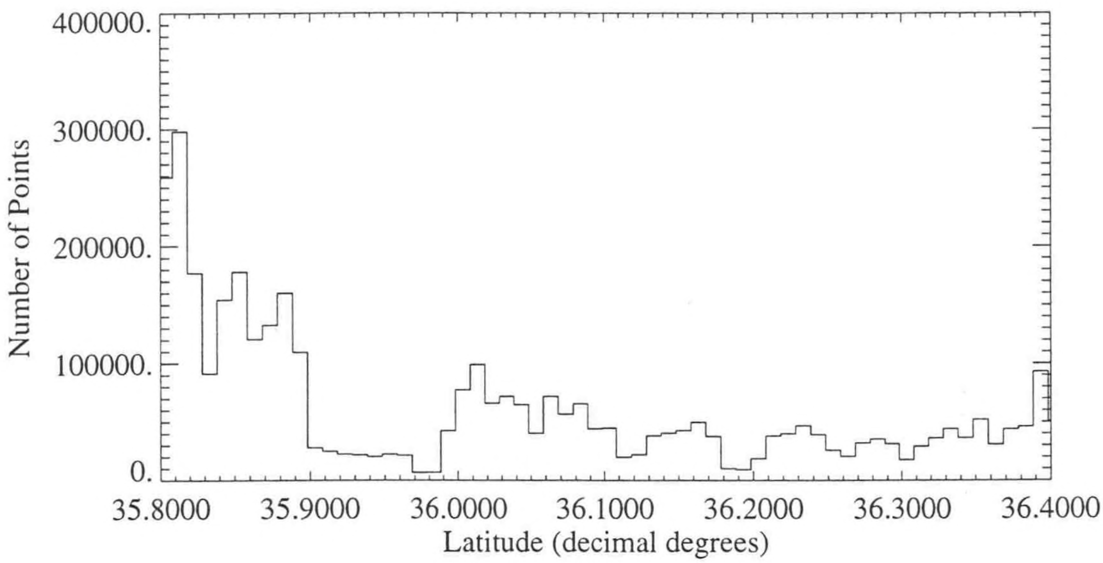


Figure 29. Difference plot from the comparison of all ATM passes for September 26 to all passes for September 27 over the beach from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The solid gray line is the regression line calculated from the difference values.

(a)



(b)

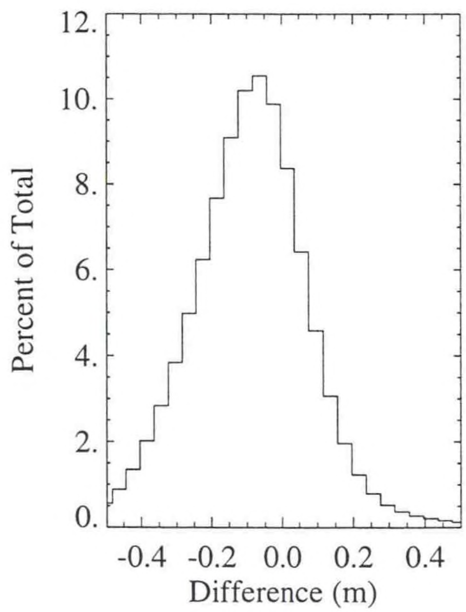
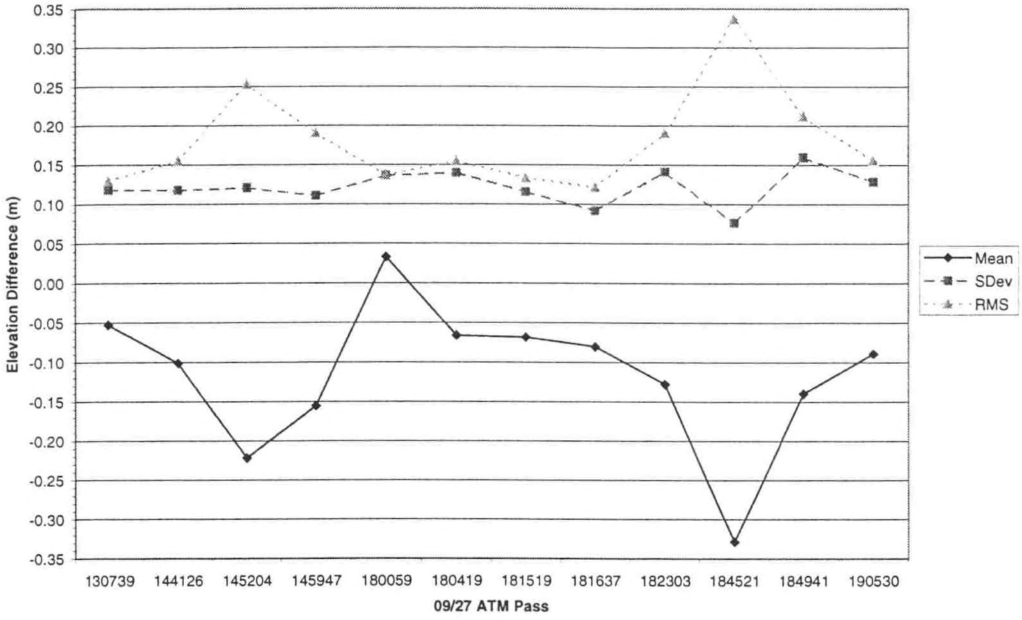


Figure 30. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to all passes for September 27 over the beach from Corolla to Oregon Inlet.

(a)



(b)

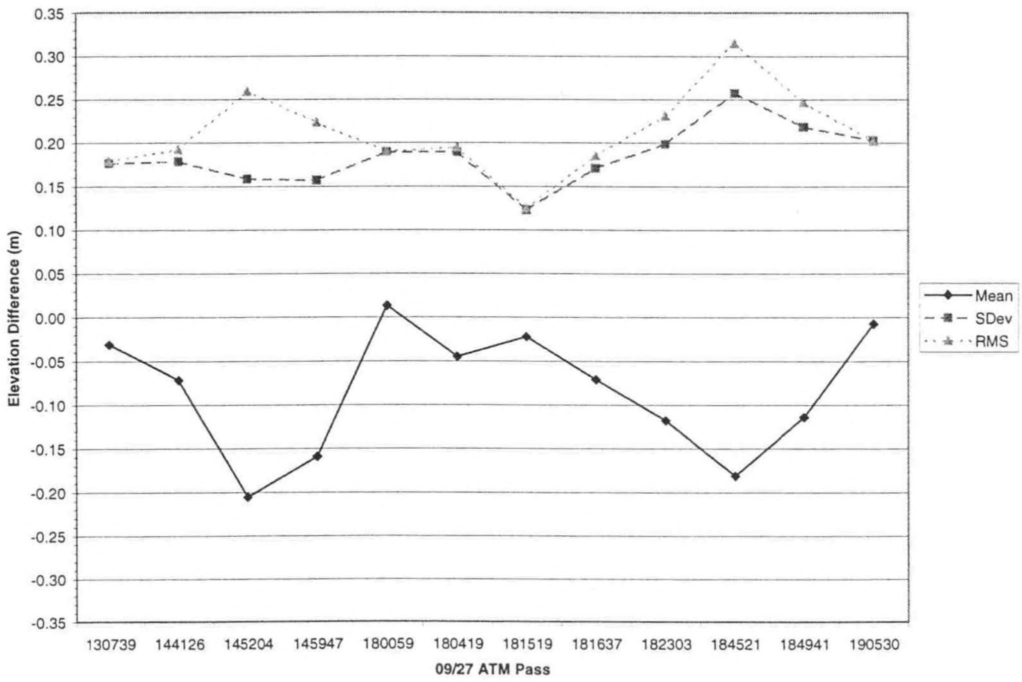


Figure 31. Graph of the statistics (mean difference, standard deviation, and RMS) from the individual September 27 ATM passes compared to all September 26 ATM passes (a) over the beach surface and (b) along the List buggy track.

4.2 ATM to Ground Survey Comparisons

The comparison of ATM surveys to survey data collected from instruments set up on the ground offers a chance to validate the accuracy of ATM measurements against traditional and more widely accepted beach survey practices. Although some ground surveys were conducted for beach and dune areas, the comparisons were made for measurements constrained to the beach surface, eliminating the variability in ATM measurements from vegetation within the dune areas.

4.2.1 ATM to 70-Kilometer List Buggy Survey

The September 26 List buggy survey was compared with the September 26 and 27 ATM passes, producing the results summarized in Table 6. The 12.9-centimeter difference in the mean differences between the two days is consistent with the between-day ATM to ATM mean difference for the List buggy track comparisons (μ=12.1). The mean List buggy measurements fall between the mean ATM measurements from September 26 and 27, on average lower than the September 26 and higher than the September 27 surveys. Between 60 and 70 percent of all observations agreed within 10 centimeters of the mean difference. The difference plots in Figures 32 and 34 indicate a change in elevation differences by latitude, especially in the September 27 to List intercomparison. Histograms of the comparison data are presented in Figure 35.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
All 9/26 passes minus List buggy survey	8.7	10.4	13.6	29,588
All 9/27 passes minus List buggy survey	-4.2	13.0	13.6	19,783

Table 6. Summary of ATM to List buggy survey comparisons

The statistics from the comparisons of individual ATM passes to the List buggy survey are graphed in Figure 36. The mean difference is between -0.1 and 16.0 centimeters and little change in measurement variation (random difference) is observed between passes for the September 26 to List survey comparisons (Figure 36a). For the September 27 ATM to List survey comparisons, the mean difference range is -25.0 to 5.9 centimeters. Excluding pass 184521, which had a mean difference 10 centimeters higher than any other pass, the mean difference range is -15.4 to 5.9 centimeters. Similar trends observed between passes in Figure 25a and Figure 26a are apparent for both days of comparisons.

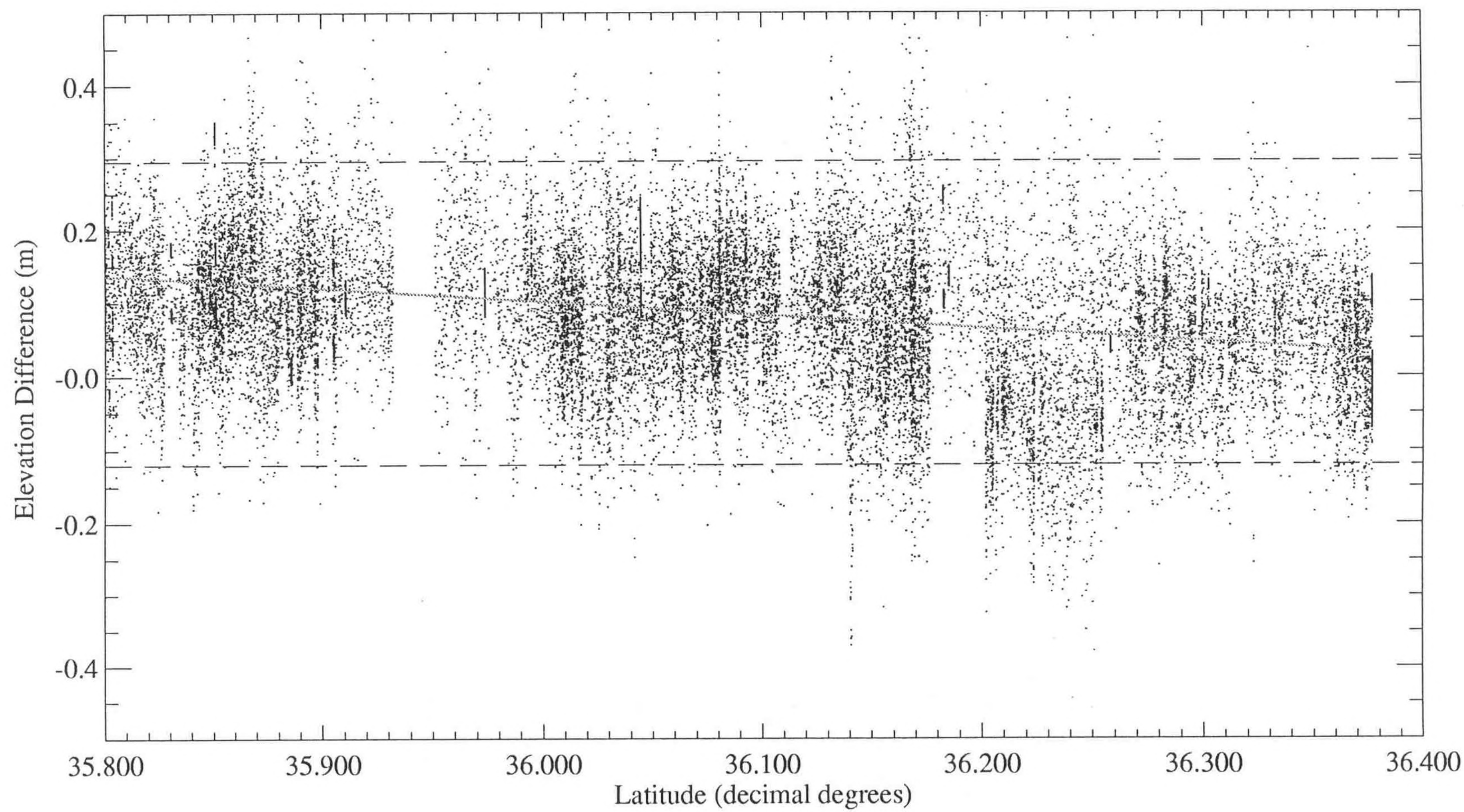
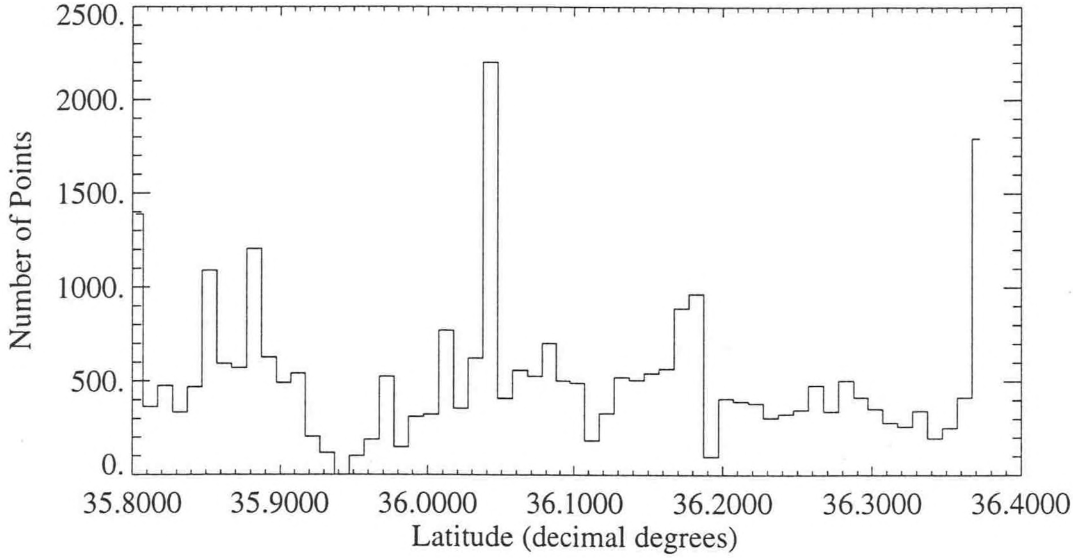


Figure 32. Difference plot from the comparison of all ATM passes for September 26 to List buggy survey for September 26 over a section of beach from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

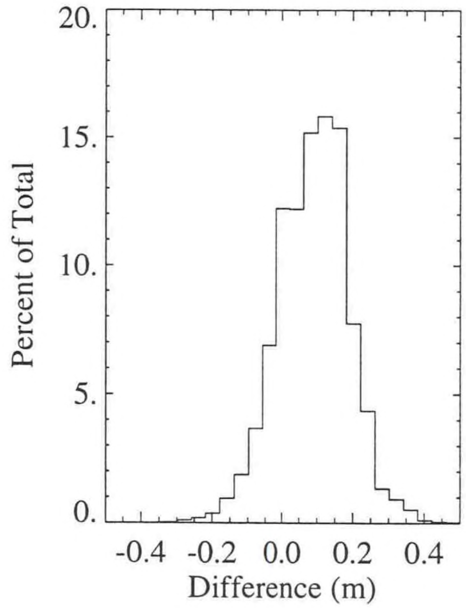


Figure 33. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to List buggy survey for September 26 over a section of beach from Corolla to Oregon Inlet.

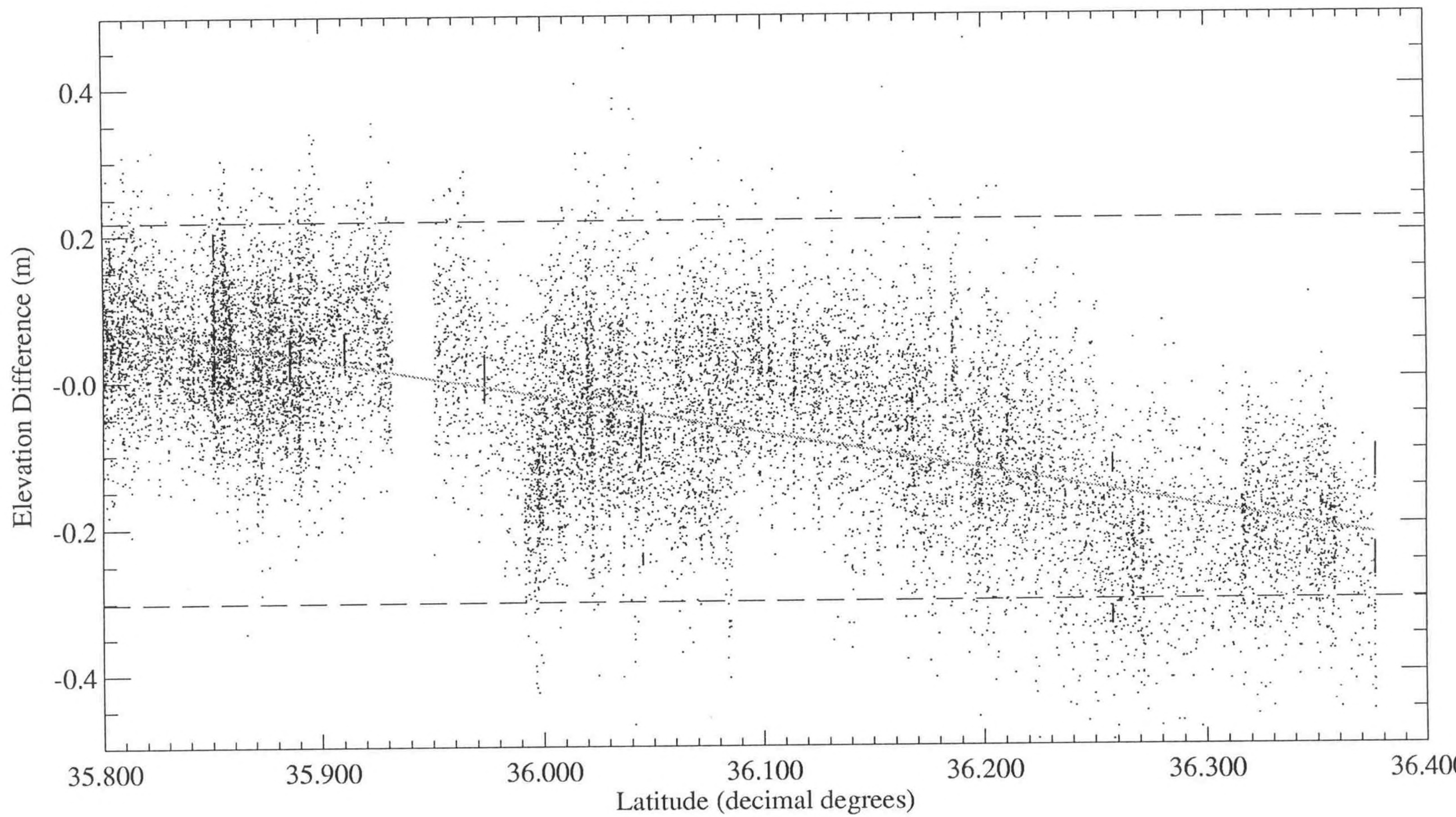
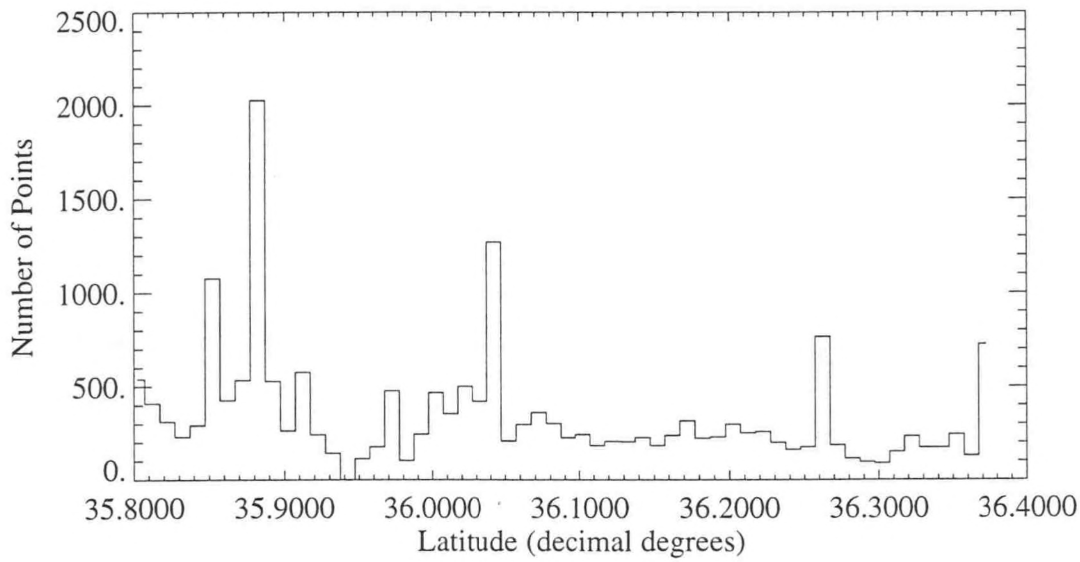


Figure 34. Difference plot from the comparison of all ATM passes for September 27 to List buggy survey for September 26 over a section of beach from Corolla to Oregon Inlet. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

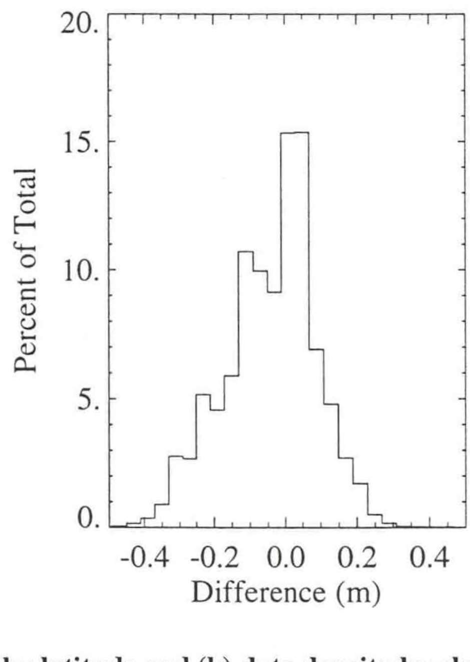
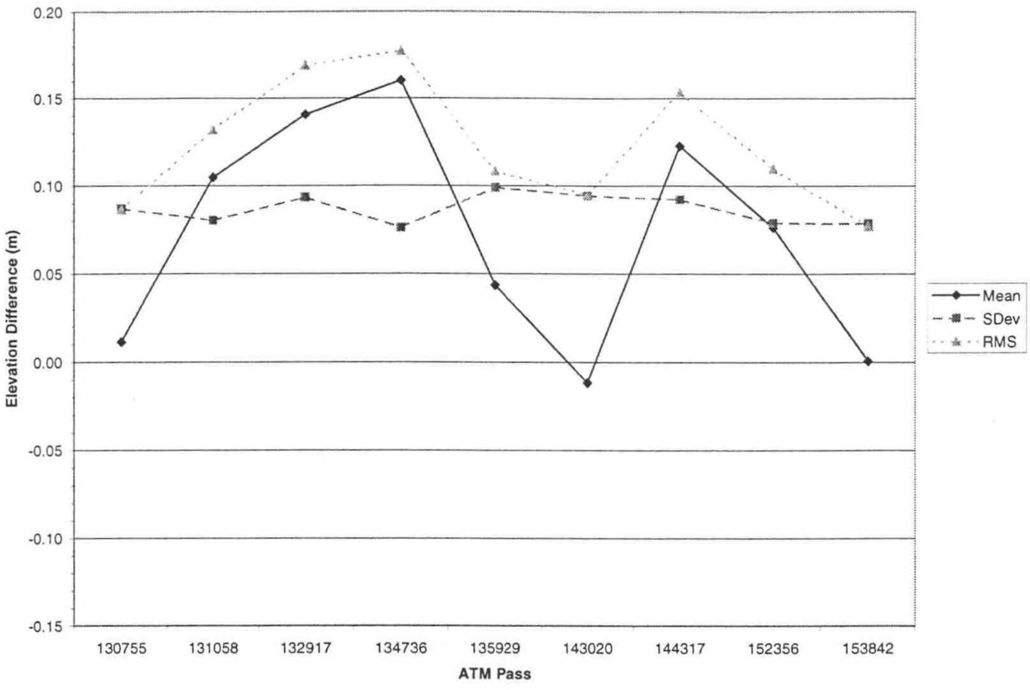


Figure 35. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 27 to List buggy survey for September 26 over a section of beach from Corolla to Oregon Inlet.

(a)



(b)

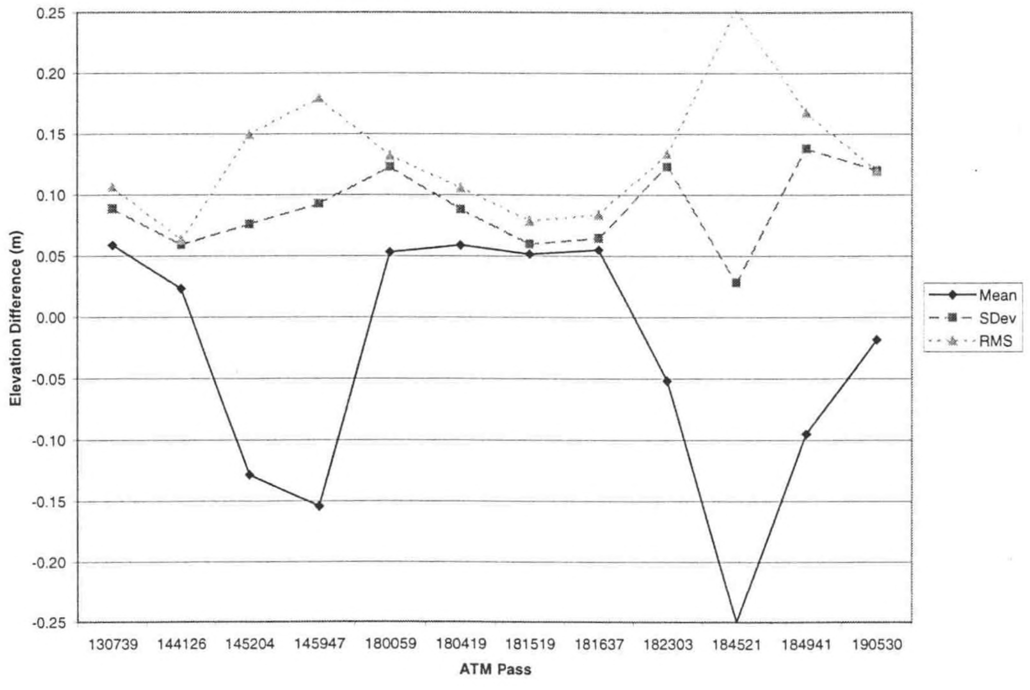


Figure 36. Graph of the statistics (mean difference, standard deviation, and RMS) from the List buggy data compared to individual ATM passes for (a) September 26 and (b) September 27.

4.2.2 ATM to Holman Buggy Survey

The Holman buggy survey contained a large number of duplicate elevation measurements for the same point location created when the buggy was stopped for any period. These duplicates were averaged into a single elevation observation.

Table 7 presents the summary statistics from the Holman survey comparisons with the September 26 ATM surveys. As with the ATM to ATM comparisons, two sets of comparisons were made. First, the ATM data were constrained to a 1-meter horizontal radius of all 70-kilometer List buggy data points. ATM data sets constrained in this manner were compared with the Holman survey, producing a shore-parallel line along the high beach with results that are directly comparable to the List buggy data set comparisons. The second set of comparisons was made for elevation measurements constrained to the beach surface, between the dune line and the waterline.

The mean difference in the September 26 ATM to Holman comparison constrained to the List buggy track is 6.2 centimeters greater than for the same List to ATM comparison. Between 54 and 60 percent of all observations agreed within 10 centimeters of the mean difference. The random difference is consistent in both comparisons. What appears to be a deterioration in measurements from south to north, visible in the difference plots for September 26 (Figures 37 to 40), results from the influence of one pass, 132917. This pass has a mean difference of 24.0 centimeters, almost twice that of the other passes, and unlike the other passes contains overlapping points over the entire latitude range of the Holman survey. The other passes only overlap the southern half of the Holman survey. Viewing difference plots of the individual September 26 passes (Figures 41 to 44) shows there is little actual change in elevation differences with latitude.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
All 9/26 passes minus Holman buggy survey constrained to List buggy track	14.9	13.5	20.1	163
All 9/26 passes minus Holman buggy survey over the beach surface	14.1	14.4	20.1	7,957

Table 7. Summary of ATM to Holman buggy survey comparisons

Graphs of the statistics from the comparison of the four overlapping September 26 ATM passes to the Holman survey indicate little change in the random difference from pass to pass (Figure 45). The familiar trend in the deterioration then improvement of the measurement agreement centered on pass 132917 is visible.

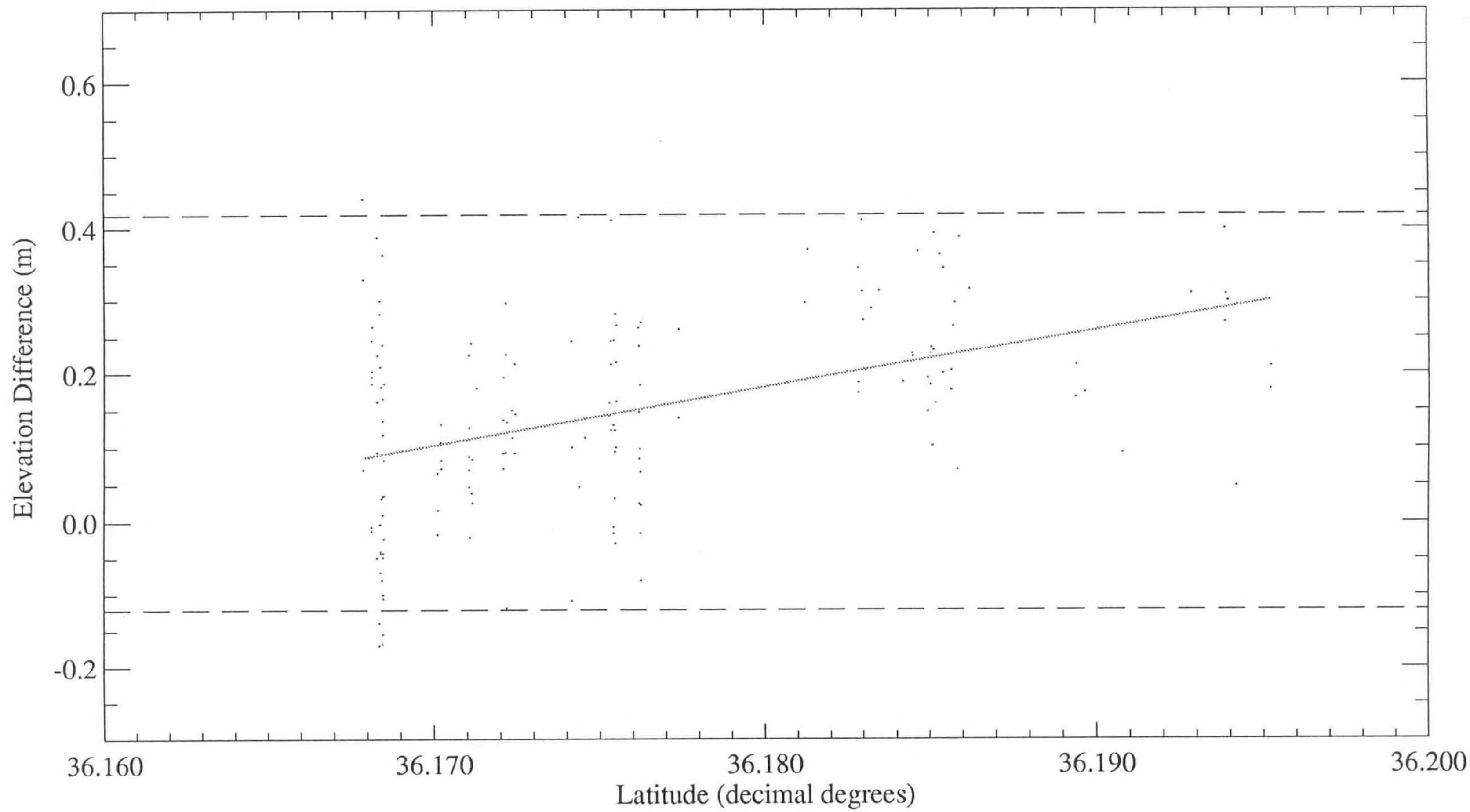
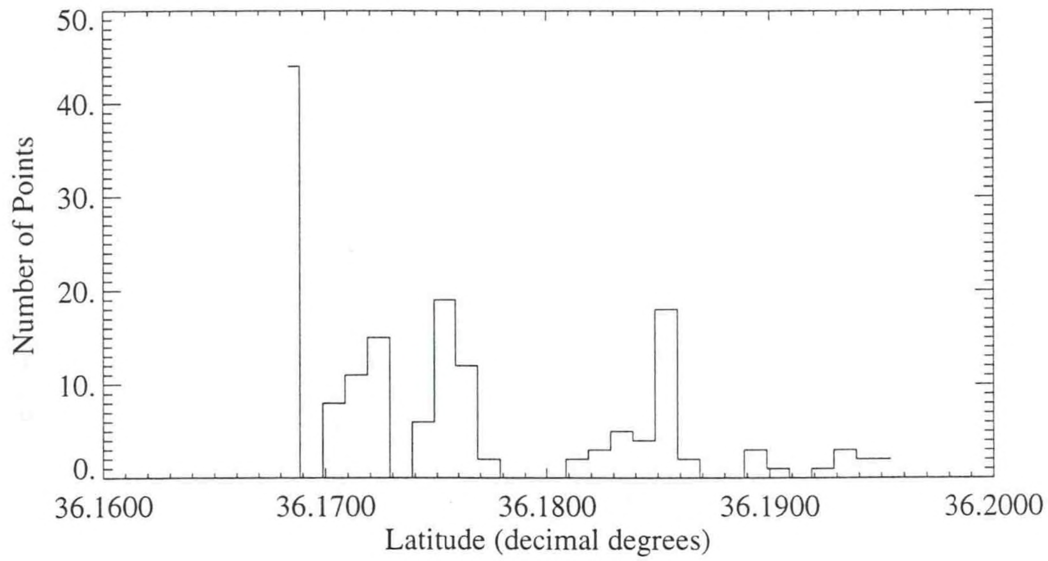


Figure 37. Difference plot from the comparison of all ATM passes for September 26 to Holman buggy survey for September 26 over the beach centered around the FRF pier at Duck, North Carolina and constrained to the List buggy track. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

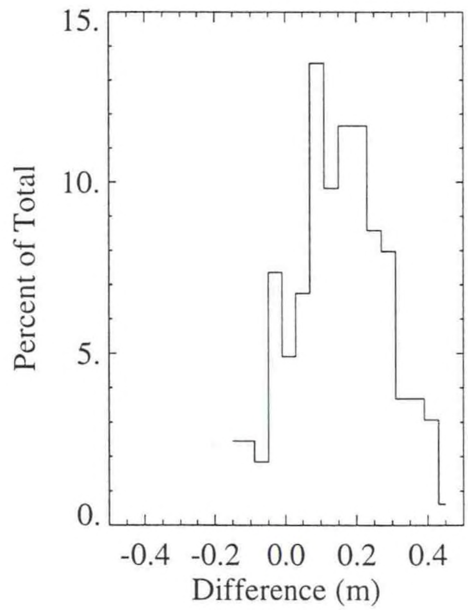


Figure 38. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to Holman buggy survey for September 26 over the beach centered around the FRF pier at Duck, North Carolina and constrained to the List buggy track.

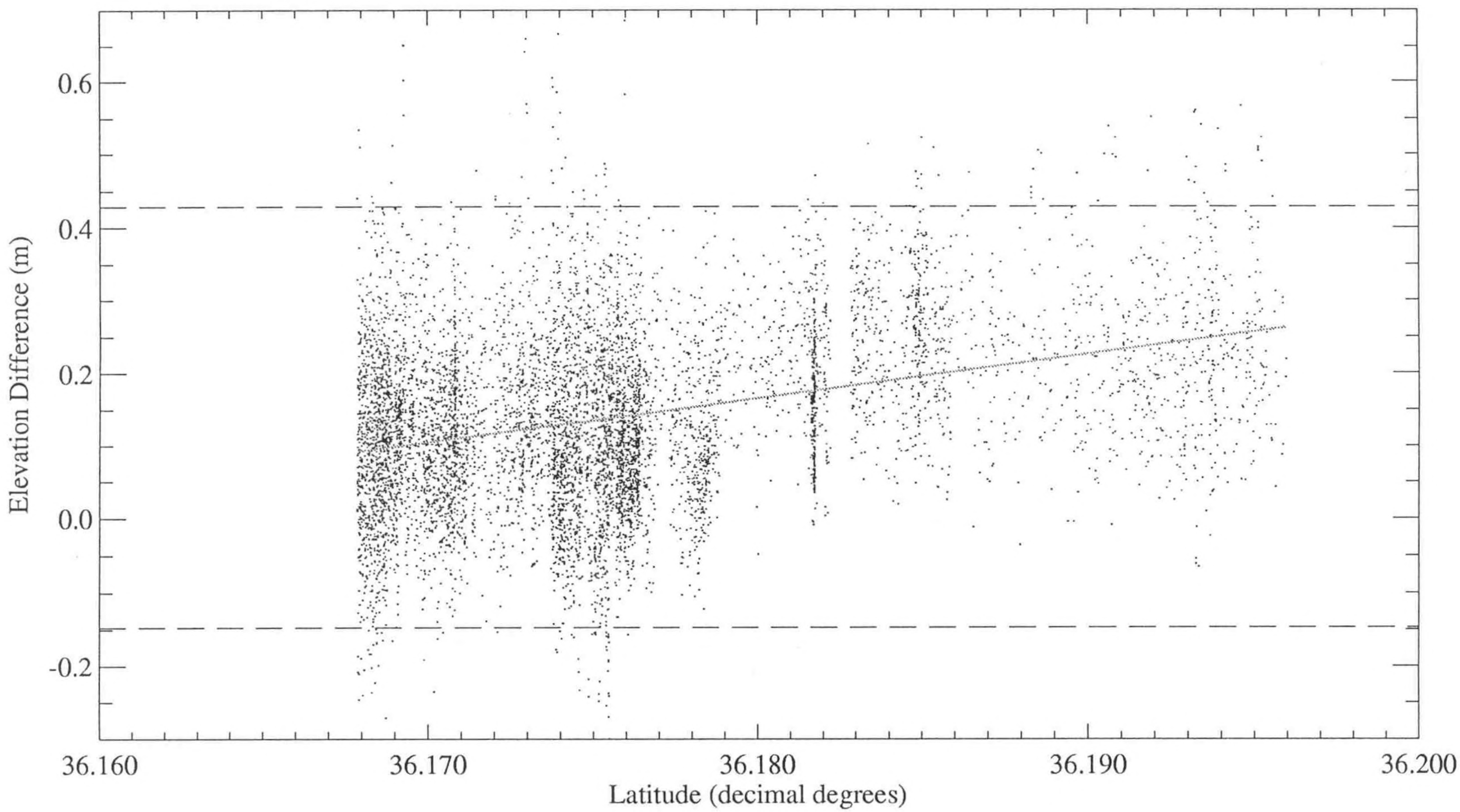
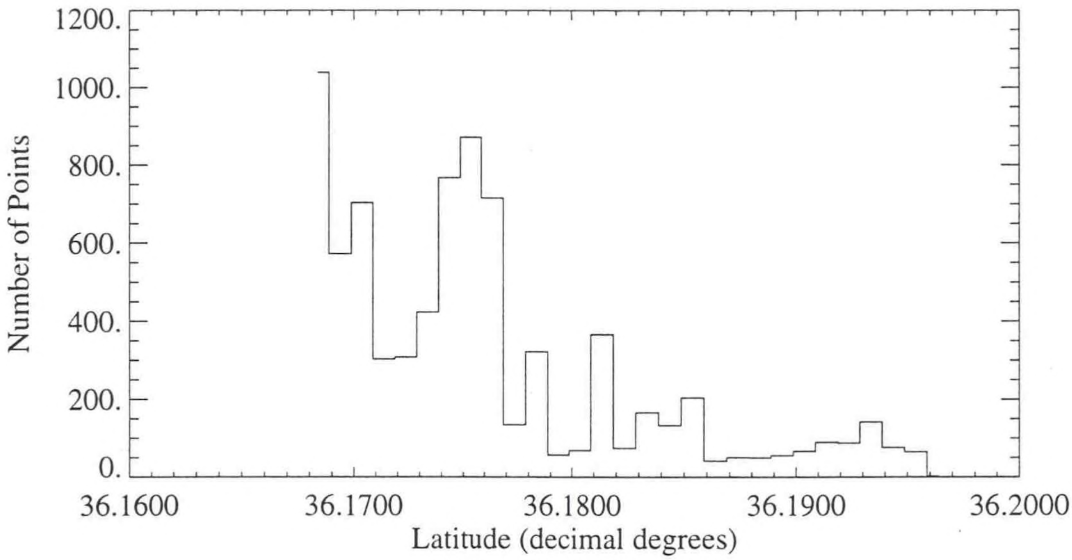


Figure 39. Difference plot from the comparison of all ATM passes for September 26 to Holman buggy survey for September 26 over the beach centered on the FRF pier at Duck, North Carolina. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

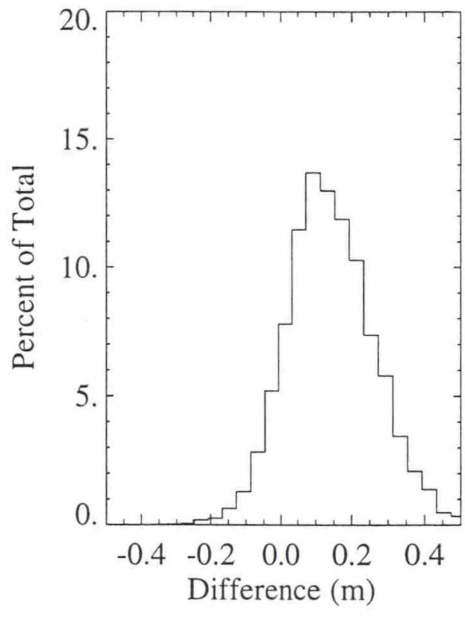


Figure 40. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 26 to Holman buggy survey for September 26 over the beach centered on the FRF pier at Duck, North Carolina.

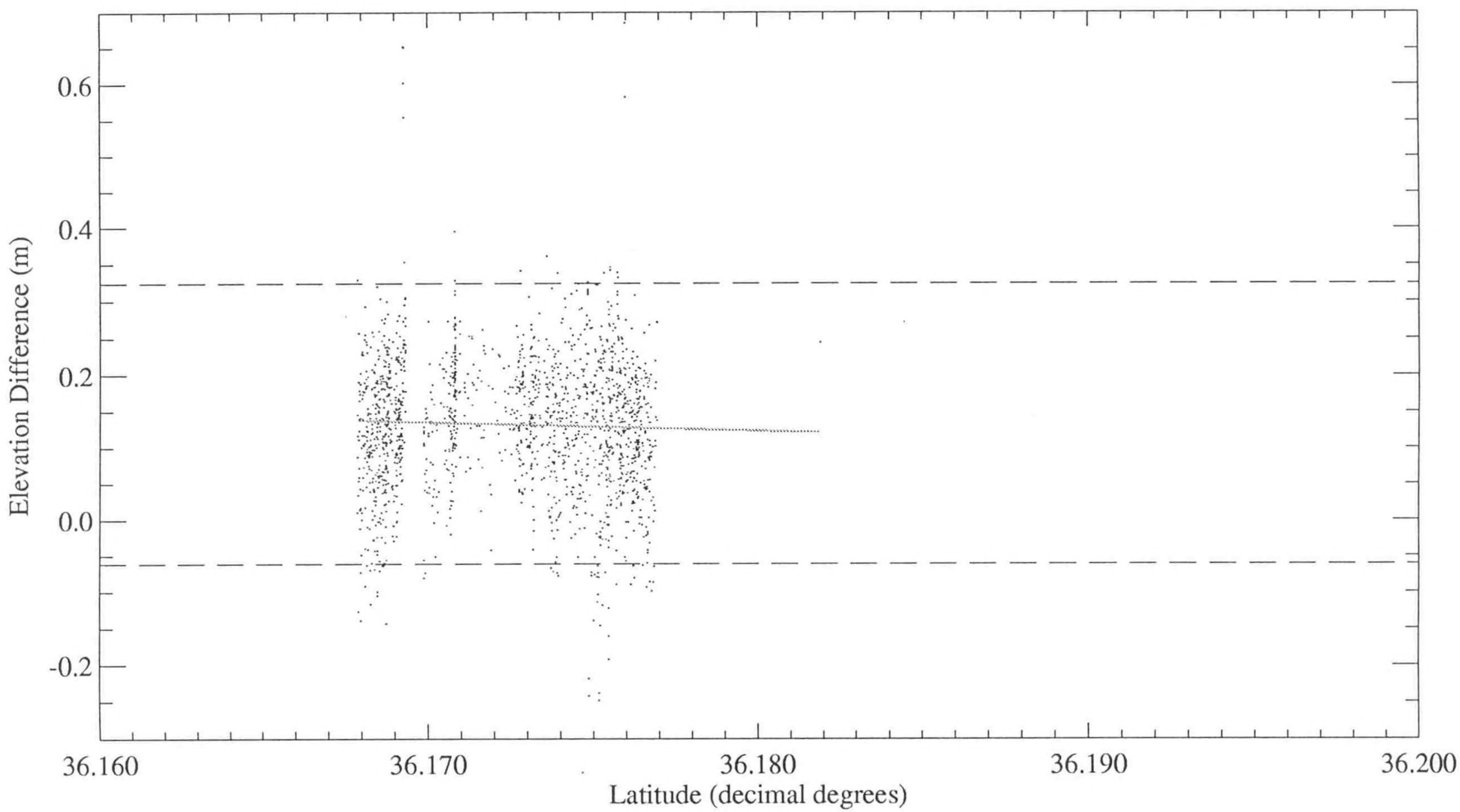


Figure 41. Difference plots from the comparison of the individual September 26 131058 ATM pass to the Holman buggy survey for September 26 over the beach surface centered on the FRF pier at Duck, North Carolina. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

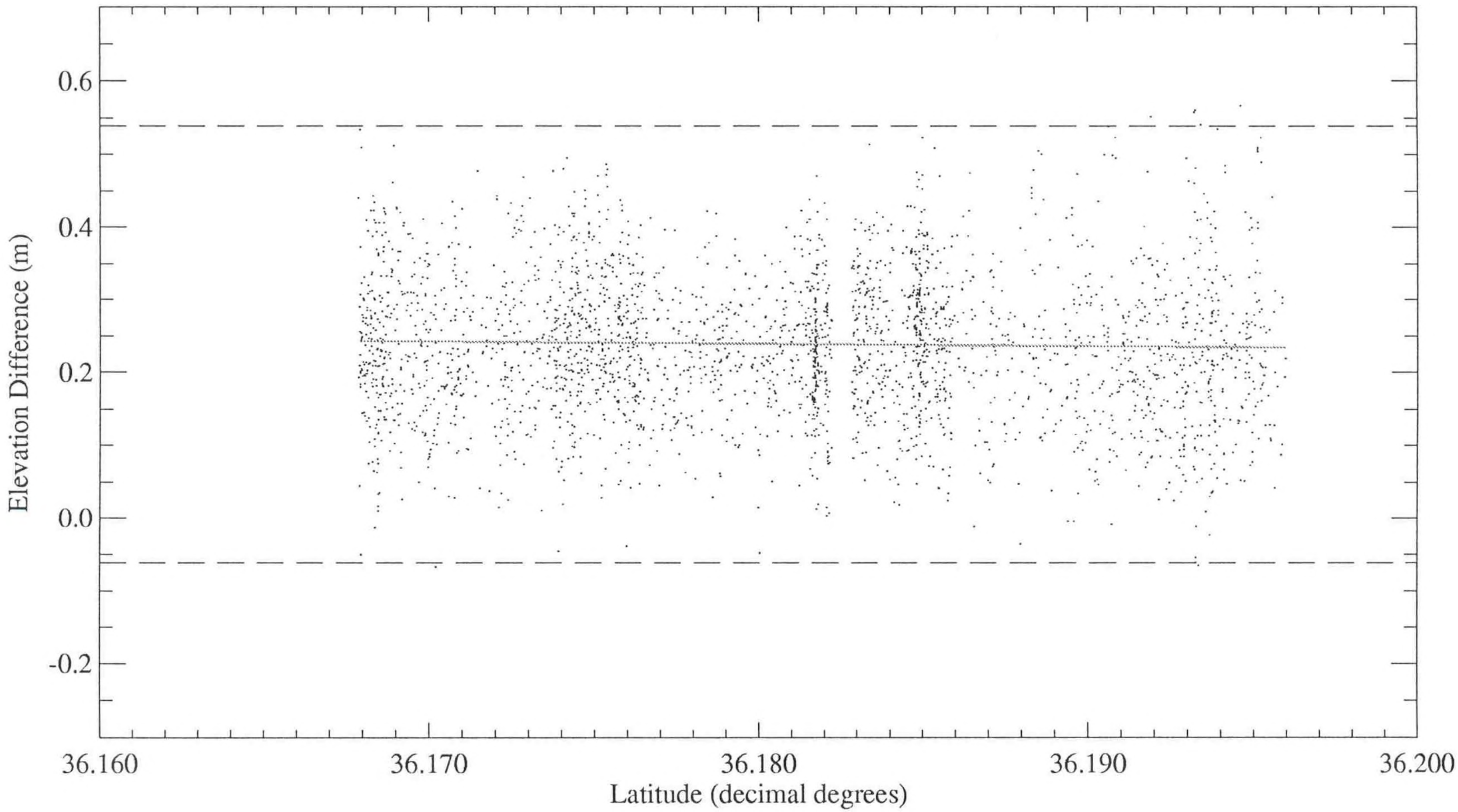


Figure 42. Difference plots from the comparison of the individual September 26 132917 ATM pass to the Holman buggy survey for September 26 over the beach surface centered on the FRF pier at Duck, North Carolina. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

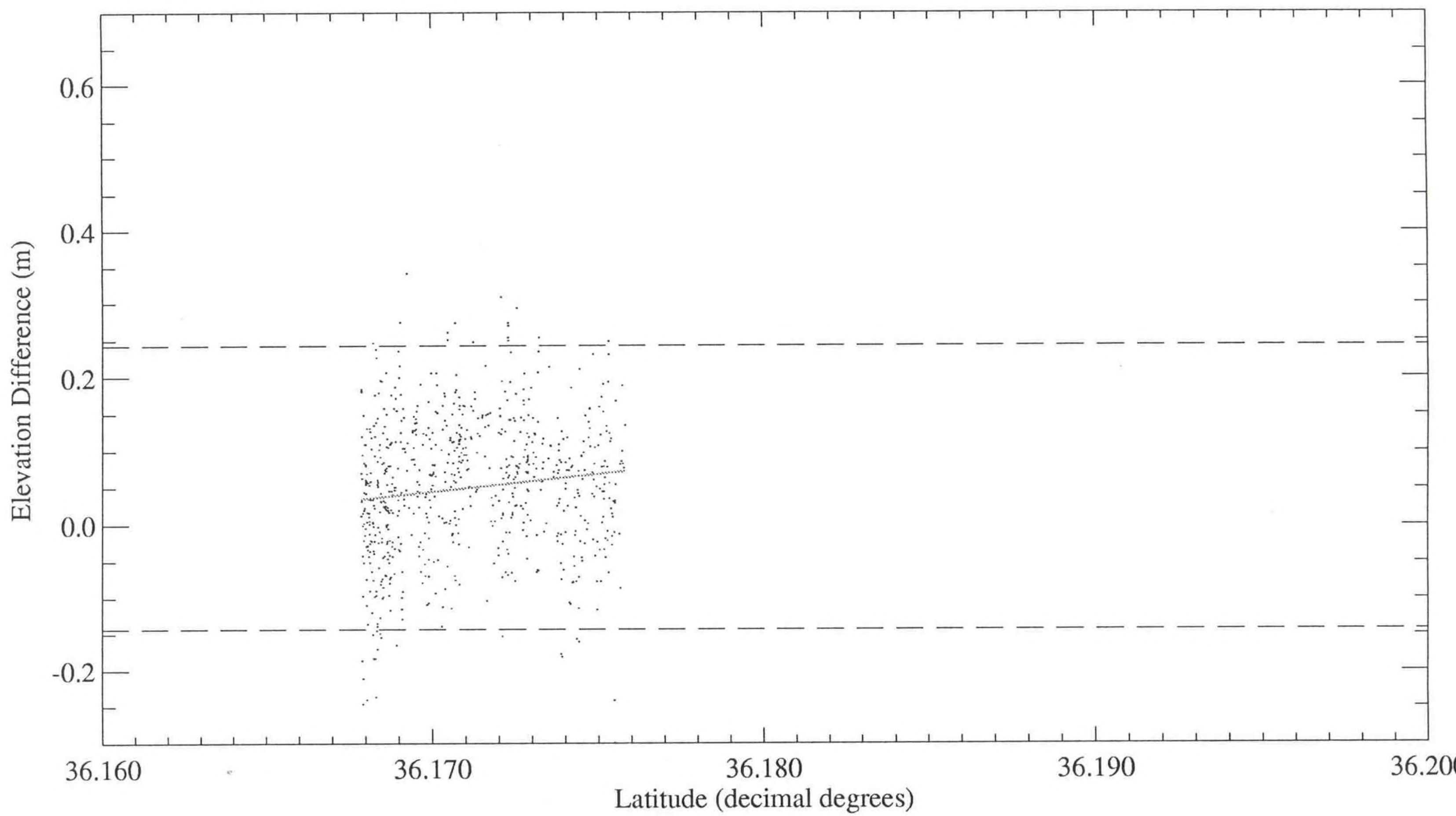


Figure 43. Difference plots from the comparison of the individual September 26 135929 ATM pass to the Holman buggy survey for September 26 over the beach surface centered on the FRF pier at Duck, North Carolina. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

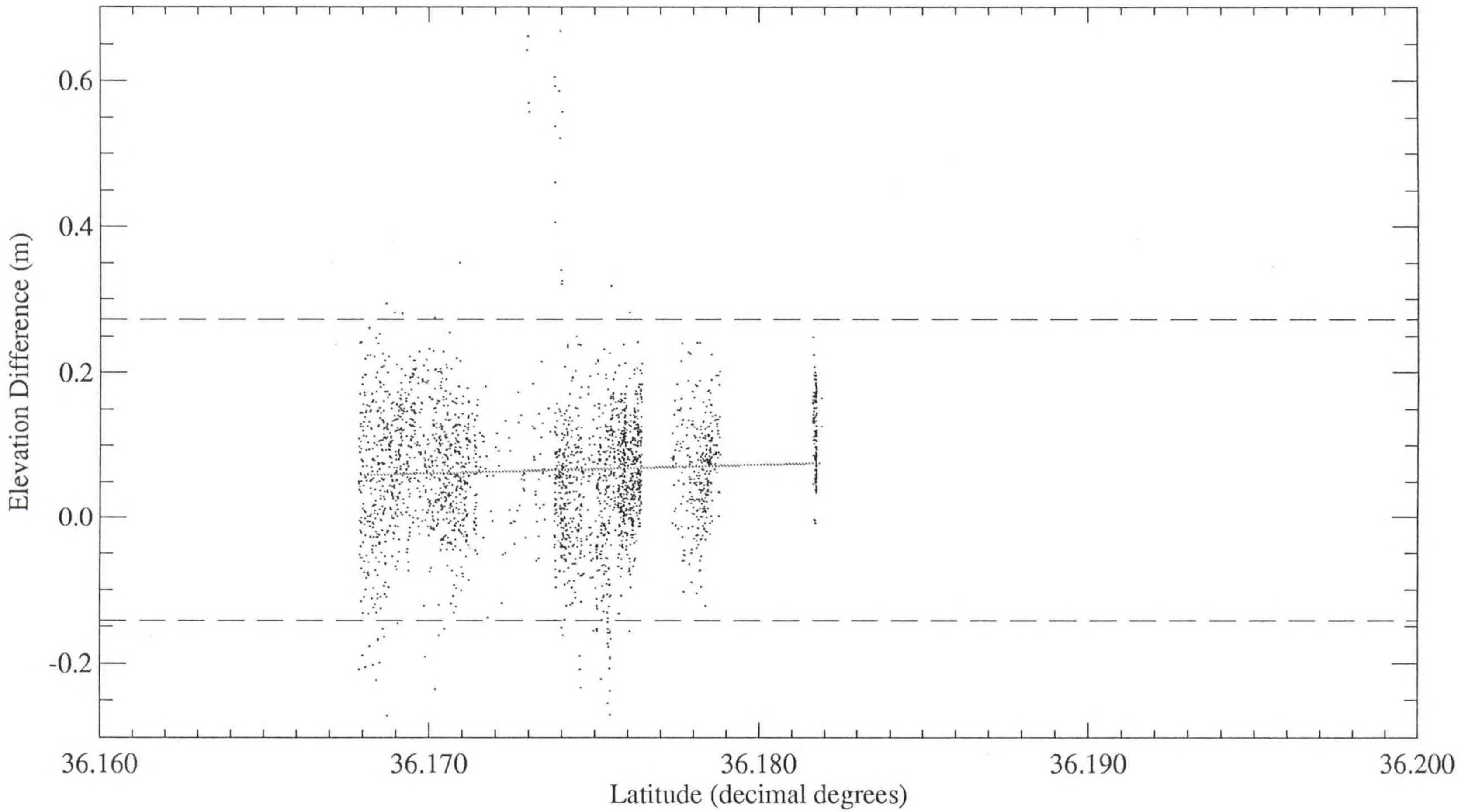
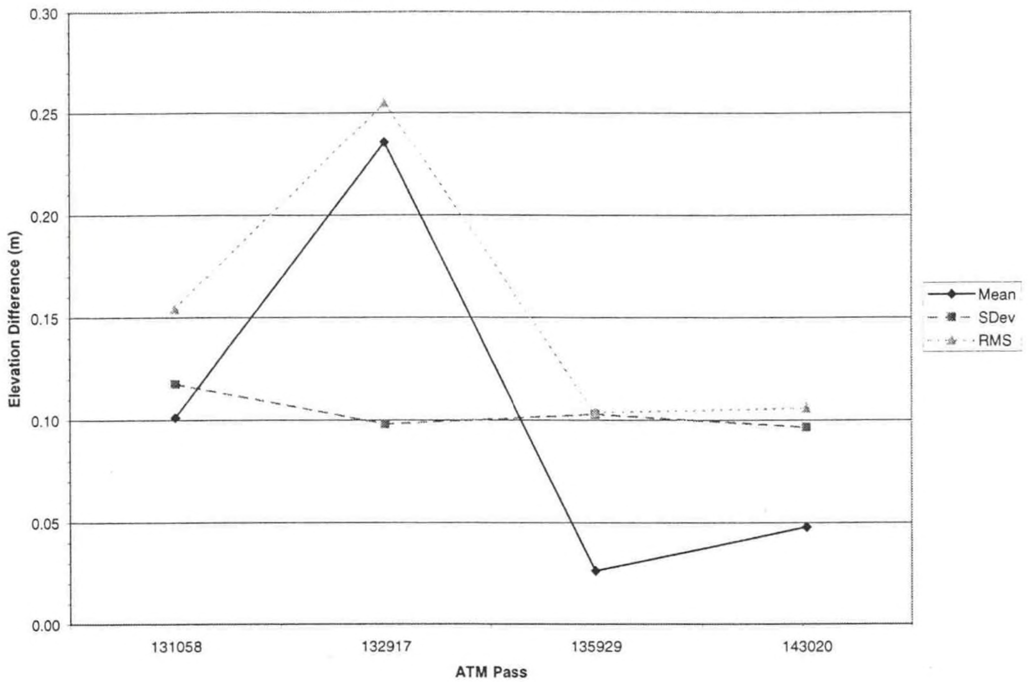


Figure 44. Difference plots from the comparison of the individual September 26 143020 ATM pass to the Holman buggy survey for September 26 over the beach surface centered on the FRF pier at Duck, North Carolina. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

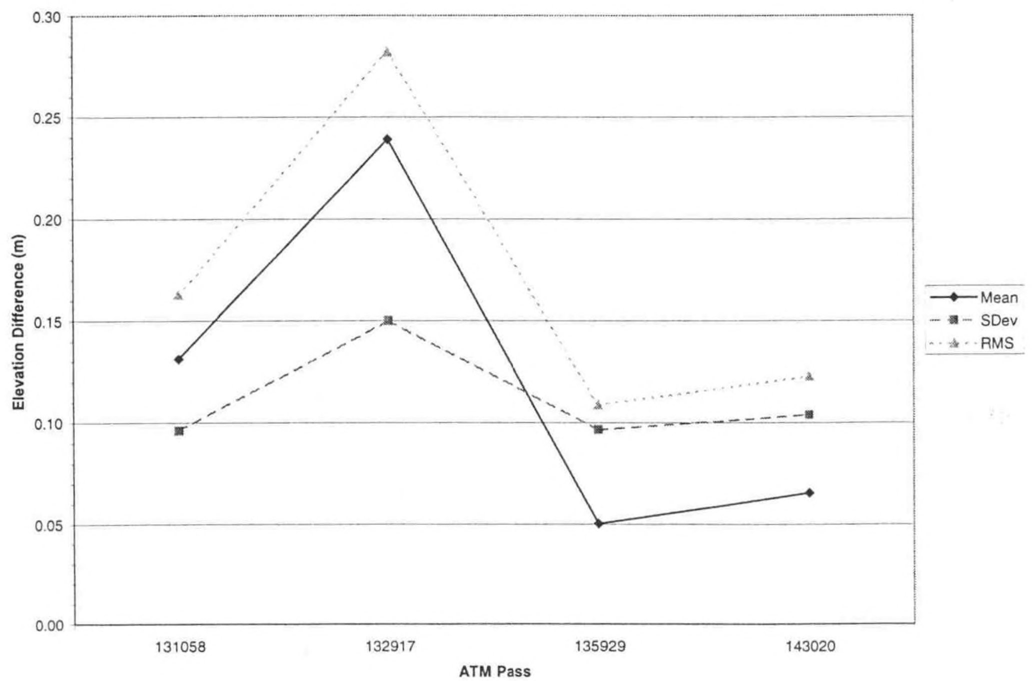


Figure 45. Graph of the statistics (mean difference, standard deviation, and RMS) from the September 26 Holman buggy data compared to individual ATM passes for September 26 (a) constrained to List buggy track and (b) with no constraints.

4.2.3 ATM to Reiss Total Station Survey

The summary statistics from the comparison of the September 27 Reiss survey to the two overlapping September 27 ATM passes, 182303 and 184521, are presented in Table 8. Most Reiss elevation measurements were collected within dunes and were thus excluded, leaving few overlapping points. However, the few overlapping points indicate good agreement with a mean difference equal to 8.5 centimeters, the positive offset indicating ATM elevations on average above the Reiss measurements. Sixty-four percent of the observations agreed within 10 centimeters of the mean difference. No differences plot and histograms are shown because of the few matching elevation points.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
All 9/27 passes minus 9/27 Reiss survey	8.5	16.0	17.5	11

Table 8. Summary of ATM to Reiss total station survey comparisons

The graphs of the statistics from the comparison of the two ATM passes are presented in Figure 46. It is interesting to note that ATM pass 184521 does not indicate the large mean differences seen in the ATM to ATM multiple day comparisons (Figure 31a) and the ATM to List buggy comparisons (Figure 36b). The statistics for the individual ATM passes, 182303 and 184521, to September 27 Reiss comparisons only include five and six points, respectively.

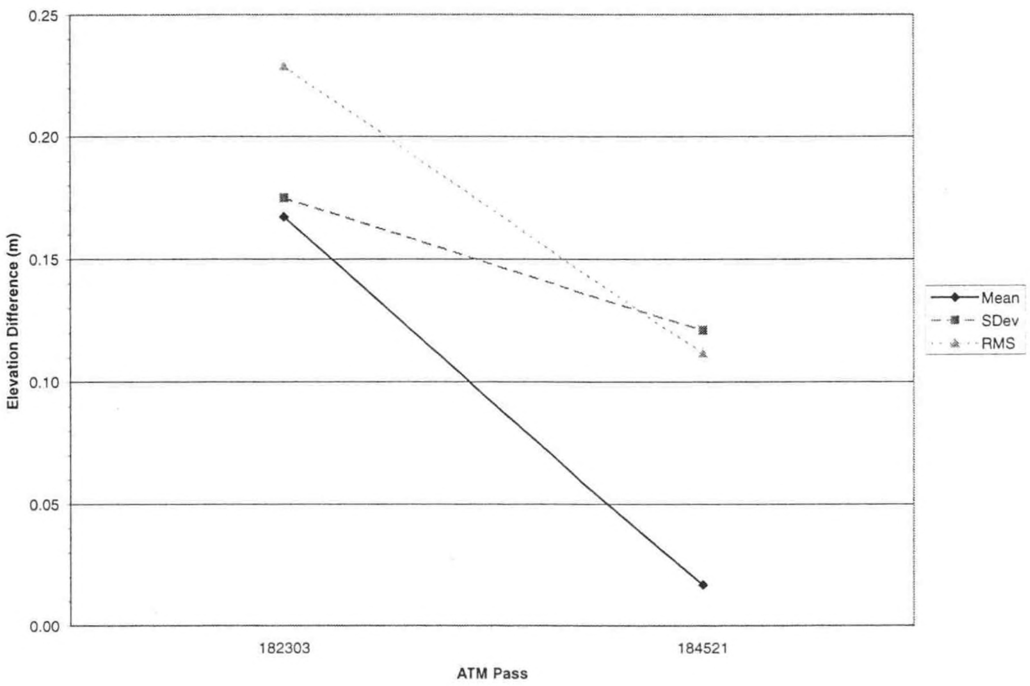


Figure 46. Graph of the statistics (mean difference, standard deviation, and RMS) from the September 27 Reiss survey compared to individual ATM passes for September 27.

4.2.4 ATM to Hansen Survey

The Hansen data set contained a large number of duplicate data points, which were combined into single points with the average elevation before processing. Table 9 presents the summary statistics for the comparison of the two September 27 Hansen surveys with the overlapping September 27 ATM passes, two of which contained matching points, pass 182303 and pass 184521. The 8.6-centimeter mean difference and 12.8 standard deviation indicate good agreement between the two survey methods. Sixty-five percent of all observations agreed within 10 centimeters of the mean difference. A difference plot and histograms are presented in Figures 47 and 48.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
All 9/27 passes minus 9/27 Hansen survey	8.6	12.8	15.4	2,592

Table 9. Summary of ATM to Hansen survey comparisons

A graph of the comparison statistics from each ATM pass to each of the September 27 Hansen surveys is shown in Figure 49. As in the ATM to Reiss comparisons, ATM pass 184521 does not indicate the large mean differences seen in the ATM to ATM multiple day comparisons (Figure 31a) and the ATM to List buggy comparisons (Figure 36b).

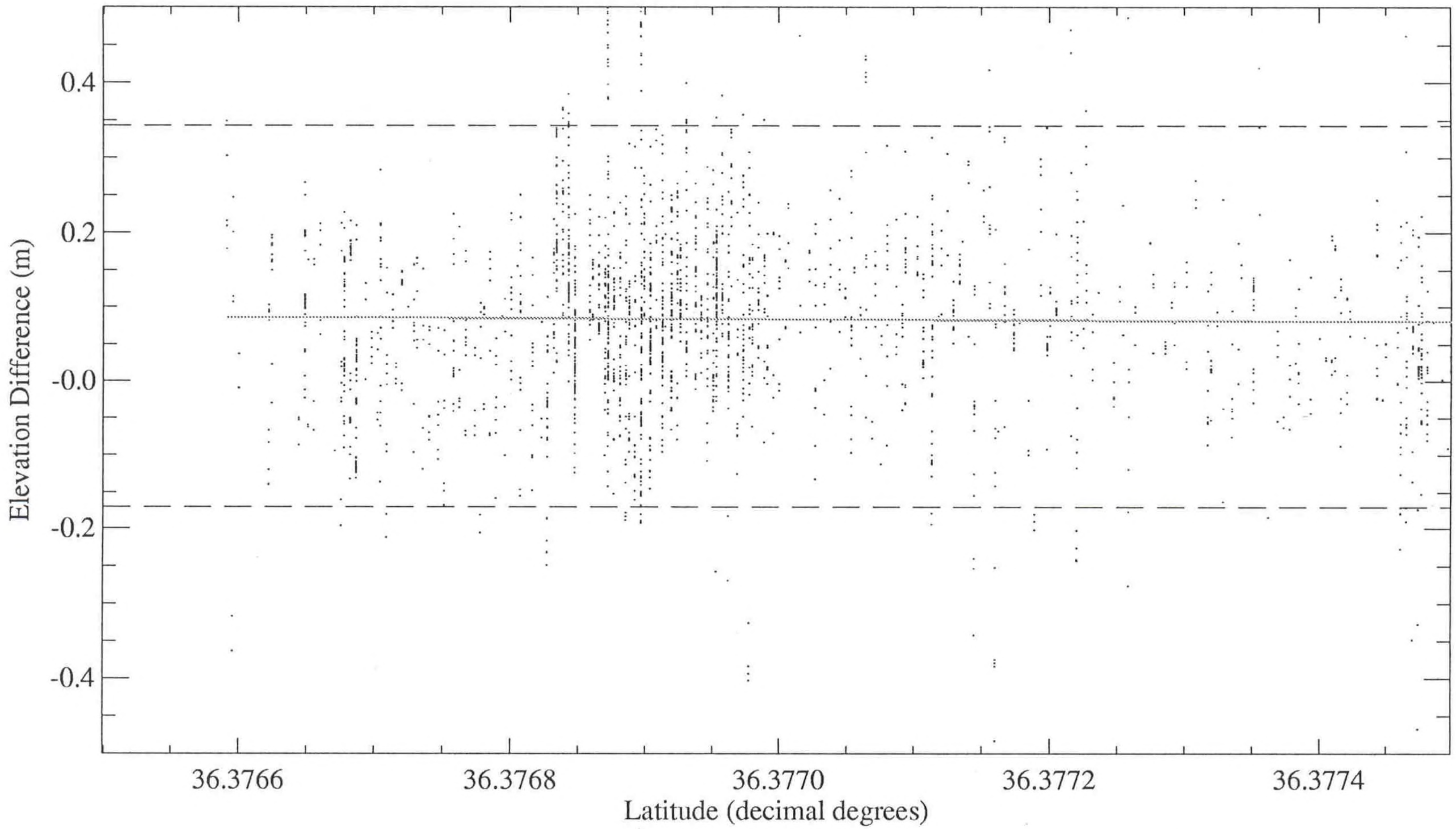
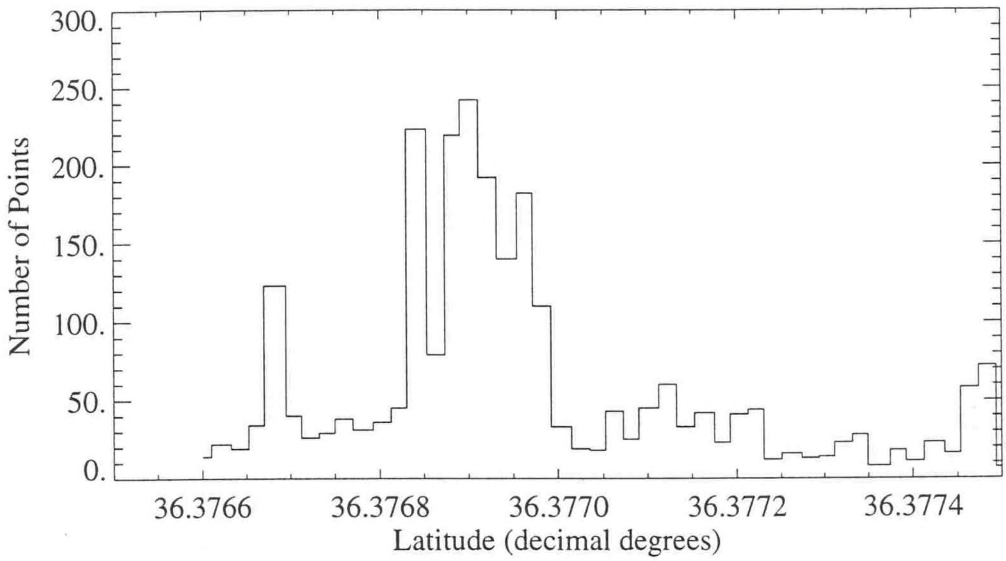


Figure 47. Difference plot from the comparison of all ATM passes for September 27 to Hansen beach surveys for September 27 over a section of beach around Corolla, North Carolina. The two dashed lines bound elevation differences between two standard deviations. The gray line is the regression line calculated from the difference values.

(a)



(b)

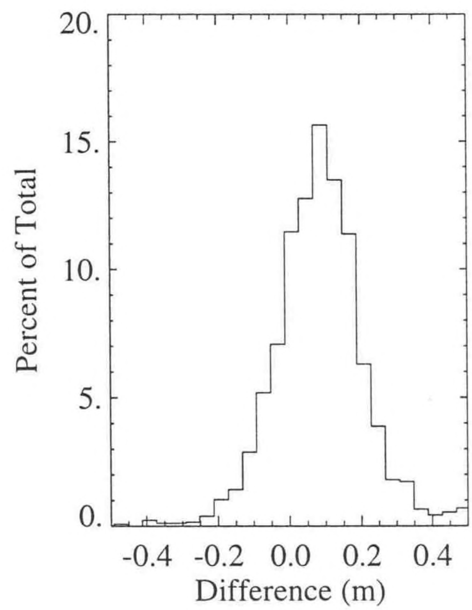


Figure 48. (a) Data density by latitude and (b) data density by elevation differences from the comparison of all ATM passes for September 27 to Hansen beach surveys for September 27 over a section of beach around Corolla, North Carolina.

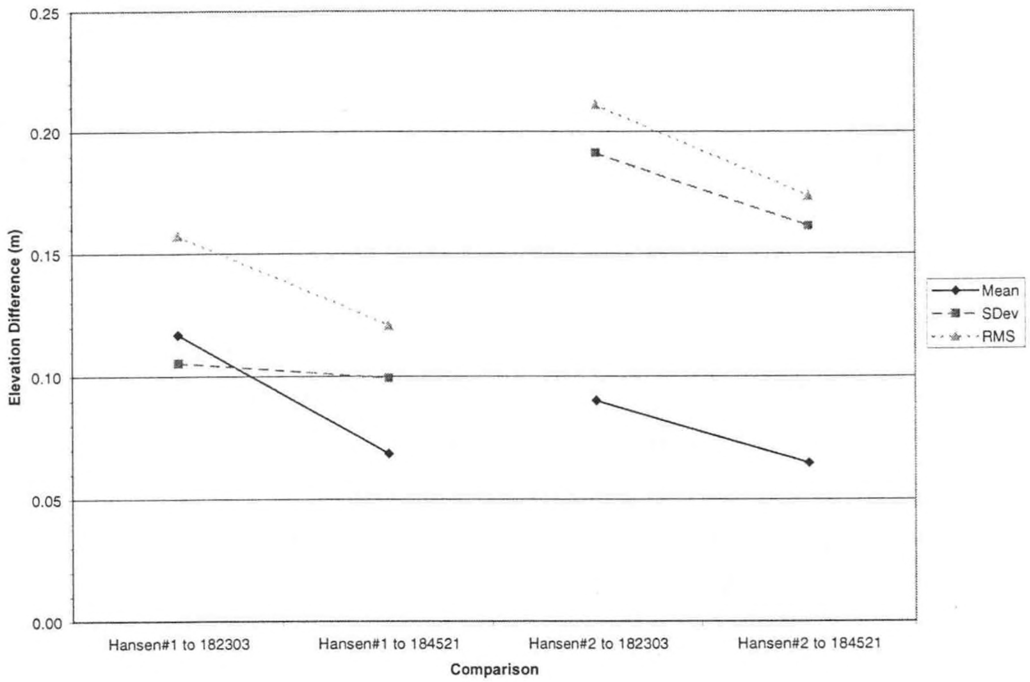


Figure 49. Graph of the statistics (mean difference, standard deviation, and RMS) from the September 27 Hansen surveys compared to individual ATM passes for September 27.

4.3 Ground Survey Comparisons

Intercomparison of overlapping ground surveys provides an evaluation of the accuracy and variability of the surveys to which the ATM surveys are being compared. The summary statistics from the non-ATM comparisons are presented in Table 10 and indicate good agreement where surveys overlap. The List buggy to Holman buggy show the highest offset, 6.2 centimeters, although the random difference is small, 5.4 centimeters. The random difference is generally 8.6 centimeters or less with the exception of the Reiss to Reiss survey comparisons, where significantly more variation is observed between measurements,
$\sigma = 15.6$.

Comparison	μ (cm)	σ (cm)	RMS (cm)	# Points
09/27/97 Hansen minus 09/27/97 Reiss	-4.8	7.9	9.2	790
09/27/97 Hansen minus 09/29/97 Reiss	-2.7	8.6	9.1	3,955
List buggy minus Holman buggy	6.2	5.4	8.2	471
Hansen#2 minus Hansen#1	0.4	8.6	8.6	13,491
09/27/97 Reiss minus 09/29/97 Reiss	-0.5	15.6	15.6	149

Table 10. Summary of non-ATM survey comparisons

5.0 SUMMARY

The statistical results from the ATM comparisons presented in the previous section are summarized in Table 11 and 12. The desired agreement of less than 10 centimeters for ATM measurements is achieved in all ground survey comparisons except the September 26 ATM to Holman survey comparisons. The higher 14.1 to 14.9-centimeter mean difference, or offset, may result from a compounding of offsets from the individual Holman and September 26 ATM surveys. The September 26 Holman to List comparison indicates the Holman survey is 6.2 centimeters below the List survey while the September 26 ATM to List comparison places the ATM survey 8.7 centimeters above the List survey. The 14.9-centimeter offset identified by this method matches very closely the 14.1 to 14.9-centimeter mean difference seen in the comparisons.

ATM Comparisons	μ (cm)	σ (cm)	RMS (cm)	# Points	Comments
09/26/97 ATM minus 09/26/97 ATM	3.4	7.6	8.3	7,113	Over Wright Memorial
09/27/97 ATM minus 09/27/97 ATM	8.0	11.4	14.0	21,085	Over Wright Memorial
09/26/97 ATM minus 09/27/97 ATM	9.2	11.0	14.3	48,154	Over Wright Memorial
135929 ATM minus all 09/26/97 ATM	-6.1	12.1	13.5	8,939	Constrained to List buggy track
182303 ATM minus all 09/27/97 ATM	0.9	13.8	13.8	4,691	Constrained to List buggy track
Individual 09/27/97 ATM passes minus combined 09/26/97 ATM	-12.1	14.7	19.1	32,700	Constrained to List buggy track
135929 ATM minus all 09/26/97 ATM	-6.6	14.8	16.2	1,097,154	Beach surface
182303 ATM minus all 09/27/97 ATM	-0.8	19.0	19.1	535,803	Beach surface
Individual 09/27/97 ATM passes minus combined 09/26/97 ATM	-9.4	20.0	22.1	3,788,375	Beach surface

Table 11. Summary of statistics from ATM to ATM survey comparisons

ATM Comparisons	μ (cm)	σ (cm)	RMS (cm)	# Points	Comments
09/26/97 ATM minus List buggy	8.7	10.4	13.6	29,588	
09/27/97 ATM minus List buggy	-4.2	13.0	13.6	19,783	
09/26/97 ATM minus Holman buggy	14.1	14.4	20.1	7,957	
09/26/97 ATM minus Holman buggy	14.9	13.5	20.1	163	Constrained to List buggy track
09/27/97 ATM minus 09/27/97 Reiss	8.5	16.0	17.5	11	Beach surface
09/27/97 ATM minus 09/27/97 Hansen	8.6	12.8	15.4	2,592	Beach surface

Table 12. Summary of statistics from ATM to ground survey comparisons

The random difference in ATM to ground survey comparisons is consistent, ranging between 10.4 and 16.0 centimeters, with an average equal to 13.0 centimeters. The higher variation observed in the ATM to Reiss comparisons (σ=16.0) appears to be a product of the variation within the Reiss measurements themselves (σ=15.6) and the limited number of overlapping points between surveys.

Observing the consistency of repeat ATM measurements over time, the maximum mean difference is 12.1 centimeters for the between-day ATM to ATM comparison constrained to the List buggy track. Comparing measurements over the entire beach surface, where there are 535,000 or more individual measurement comparisons, the maximum mean difference is 9.4 centimeters or less. The random difference indicates a tendency to increase over more morphologically diverse surfaces. The flat surface of the Wright Memorial has the lowest variation in measurements, ranging between 7.6 and 11.4 centimeters while the entire beach surface has a random difference between 14.8 and 20.0 centimeters.

Many of the ATM data comparisons indicate a change in measurement agreement with latitude. The best agreement is typically seen toward the southern end of the study area, which is closer to the GPS base station at the Manteo airport. Partitioning the study area into four equal sections by latitude and then calculating statistics for each of the sections indicates the largest changes in offset or mean difference with latitude are in the September 27 ATM survey. In the individual September 27 ATM pass to List buggy survey comparisons, the difference in the offset between the southern and northern end of the study area is between -24.8 and -19.4 centimeters (μ=-22.1) (Figure 50). For the individual September 26 ATM pass to List survey comparisons, the difference is between -0.9 and 6.4 centimeters (μ=4.7) (Figure 51). The large difference by latitude observed for the September 27 ATM passes may result from a weather front that passed through the survey area during the day. The random difference shows a tendency to decrease from south to north. Similar trends are observed for other ATM survey comparisons.

The change in mean difference from pass to pass for specific comparisons, as seen in the graphs of the statistical results from individual ATM passes (e.g., Figure 25), indicates a tendency toward gradual variations in mean differences with time. The general trends observed for both days of ATM to ATM comparisons similarly appear in the ATM to ground survey comparisons, confirming a drift in ATM measurements offset over time. The time over which the drifts occur before returning to "normal" ranges from approximately 45 minutes to two hours. Figure 52 demonstrates this drift for the September 26 ATM pass intercomparisons constrained to the List buggy track where the successive passes, 131058 and 132917, indicate a steady increase in the mean difference followed by a similar reduction in the mean difference with successive passes, 134736 and 143020. The same September 26 ATM passes compared to the List buggy survey demonstrate similar trends although offsets are inverted as a result of the comparison method (Figure 53).

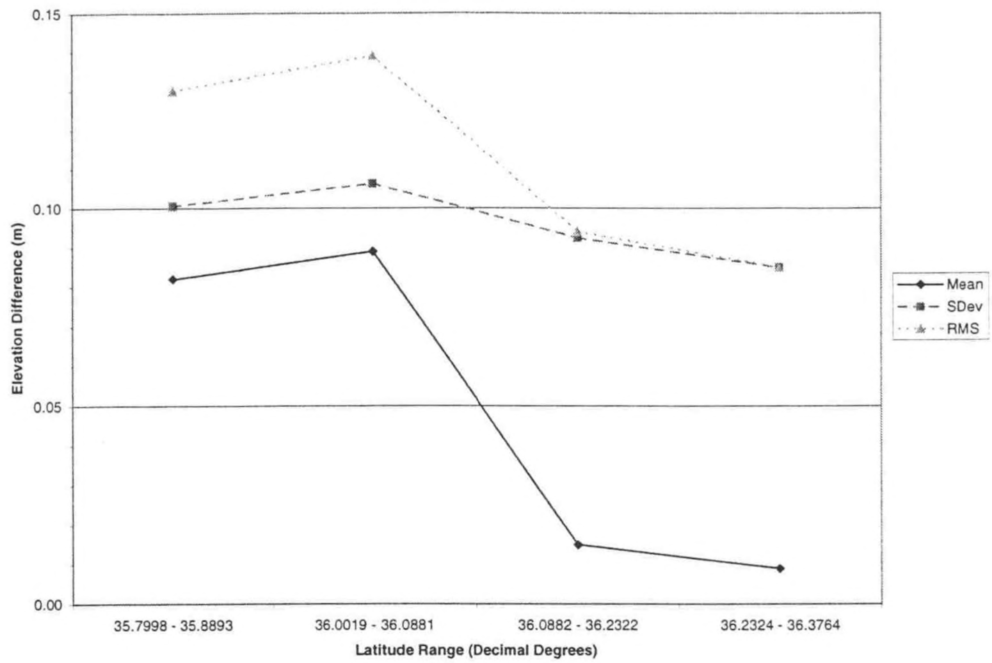


Figure 50. Statistics generated after a partitioning of the results by latitude into four equal brackets from the September 26 135929 ATM pass minus List buggy survey comparison. Two trends also observed in other similar comparisons are illustrated, the change in mean difference by latitude and lower random difference to the north.

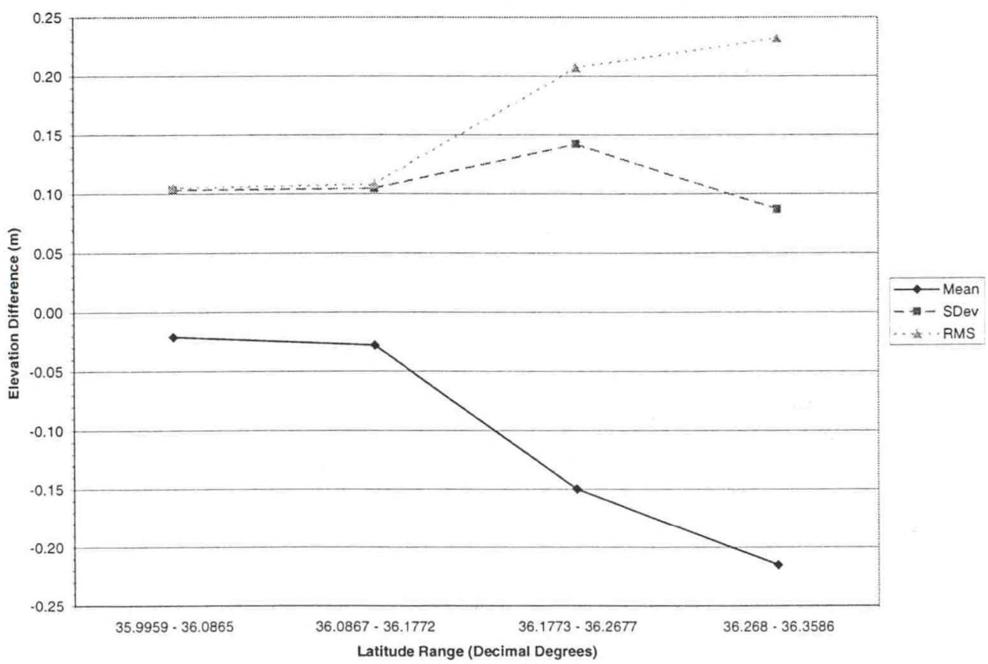


Figure 51. Statistics generated after a partitioning of the results by latitude into four equal brackets from the September 27 184941 ATM pass minus List buggy survey comparison. Note the change in mean difference by latitude.

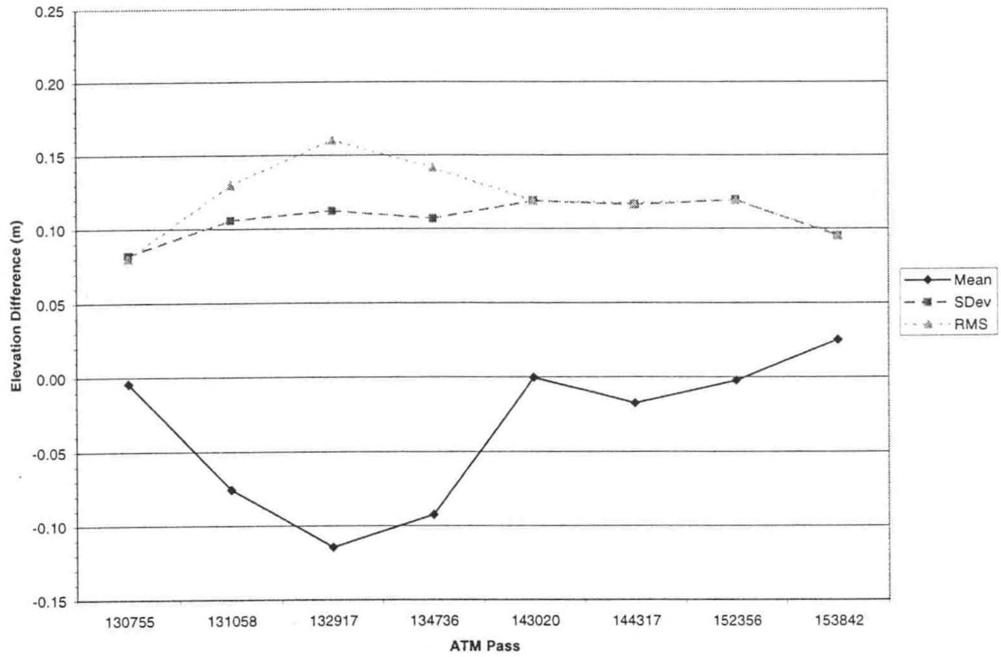


Figure 52. Graph of the statistics (mean difference, standard deviation, and RMS) from the individual ATM passes for September 26 compared to ATM pass 135929 constrained to the List buggy track.

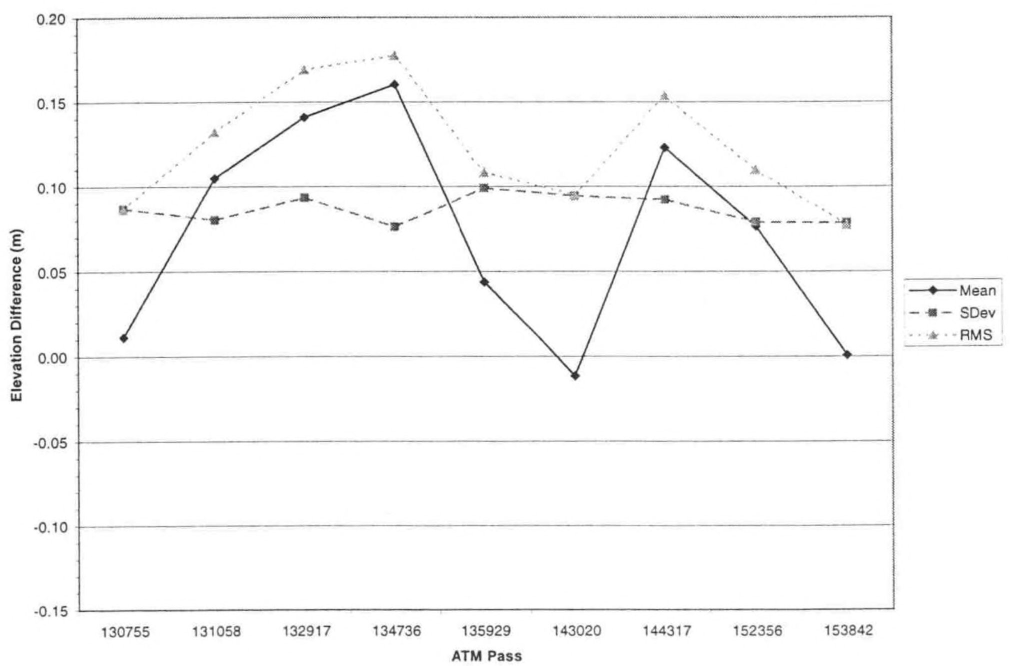


Figure 53. Graph of the statistics (mean difference, standard deviation, and RMS) from the List buggy data compared to individual ATM passes for September 26.

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7.0 APPENDIX: DETAILED COMPARISON RESULTS

The following pages contain spreadsheets detailing the statistical results for all comparisons. The columns fileA and fileB indicate the two files used in the comparison; mean, SD, and RMS are the statistics mean difference, standard deviation, and root mean squared, respectively; MinD and MaxDz are the minimum and maximum differences (in meters) in the elevation values of all matching points for the specific comparison; MinLat, MaxLat, MinLon, and MaxLon are the latitude and longitude bounds (in decimal degrees) of all matching points; MinZ and MaxZ are the minimum and maximum elevation measurements (in meters) in fileB; #elem is the number of matching points from the comparison of fileA and FileB; #Disc is the number of points discarded because they were outside the elevation bounds defined as -45 to -32 meters below the WGS84 ellipsoid.

Wright Memorial - 09/26/97 130645 ATM pass minus 09/26/97 153842 ATM pass

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970926atm2_153842	970926atm2_130645	0.034	0.076	0.083	-0.651	0.362	36.017	36.018	-75.669	-75.668	-38.559	-37.285	7,113	0
All surveys weighted equally		0.034	0.076	0.083									7,113	0

Wright Memorial - 09/27/97 ATM passes to 09/27/97 ATM passes

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970927atm2_145947_	970927atm2_180059_	0.100	0.090	0.135	-0.572	0.404	36.017	36.019	-75.669	-75.668	-38.658	-37.483	6,890	0
970927atm2_145947_	970927atm2_190530_	0.128	0.113	0.171	-0.290	0.487	36.017	36.019	-75.669	-75.668	-38.470	-37.360	7,542	0
970927atm2_180059_	970927atm2_190530_	0.007	0.099	0.100	-0.351	0.407	36.017	36.019	-75.669	-75.668	-38.470	-37.492	6,653	0
All surveys weighted equally		0.078	0.101	0.135									21,085	0
All matching points weighted equally		0.080	0.114	0.140										

Wright Memorial - 09/26/97 ATM passes minus 09/27/97 ATM passes

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970927atm2_145947_	970926atm2_130645_	0.176	0.103	0.204	-0.525	0.629	36.017	36.019	-75.669	-75.668	-38.559	-37.285	11,194	0
970927atm2_180059_	970926atm2_130645_	0.049	0.081	0.094	-0.543	0.807	36.017	36.019	-75.669	-75.668	-38.559	-37.474	9,053	0
970927atm2_190530_	970926atm2_130645_	0.055	0.093	0.108	-0.646	0.420	36.017	36.019	-75.669	-75.668	-38.559	-37.285	10,480	0
970927atm2_145947_	970926atm2_153842_	0.171	0.087	0.191	-0.188	0.450	36.017	36.018	-75.669	-75.668	-38.207	-37.337	5,950	0
970927atm2_180059_	970926atm2_153842_	0.049	0.076	0.091	-0.328	0.833	36.017	36.018	-75.669	-75.668	-38.207	-37.455	5,534	0
970927atm2_190530_	970926atm2_153842_	0.022	0.093	0.096	-0.278	0.356	36.017	36.018	-75.669	-75.668	-38.207	-37.414	5,943	0
All surveys weighted equally		0.087	0.089	0.131									48,154	0
All matching points weighted equally		0.092	0.110	0.143										

(excluded 970927atm_145947 comparisons)

All matching points weighted equally		0.046	0.087	0.099	31,010	0

ATM to ATM - 09/26/97 ATM 135929 pass minus all 09/26/97 ATM passes - Constrained to List Buggy Track

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970926atm2_130755	970926atm2_135929_	-0.004	0.082	0.080	-0.211	0.112	36.021	36.023	-75.660	-75.659	-39.500	-38.949	18	0
970926atm2_131058	970926atm2_135929_	-0.075	0.106	0.130	-1.539	0.365	36.002	36.376	-75.824	-75.648	-39.658	-36.566	2,460	0
970926atm2_132917	970926atm2_135929_	-0.114	0.112	0.160	-0.612	0.298	35.871	36.374	-75.823	-75.575	-39.622	-36.566	2,331	3
970926atm2_134736	970926atm2_135929_	-0.092	0.107	0.141	-0.481	0.265	35.800	35.871	-75.575	-75.540	-39.894	-37.512	757	0
970926atm2_143020	970926atm2_135929_	0.000	0.119	0.119	-0.468	0.574	36.075	36.376	-75.824	-75.696	-39.331	-36.713	1,341	0
970926atm2_144317	970926atm2_135929_	-0.017	0.116	0.117	-0.479	0.331	35.814	36.064	-75.688	-75.548	-39.755	-36.870	1,334	0
970926atm2_152356	970926atm2_135929_	-0.002	0.120	0.119	-0.286	1.755	35.800	35.889	-75.585	-75.540	-39.999	-37.512	680	2
970926atm2_153842	970926atm2_135929_	0.025	0.095	0.096	-0.114	0.221	36.016	36.017	-75.657	-75.656	-39.331	-38.679	18	0
All surveys weighted equally		-0.035	0.107	0.120									8,939	5
All matching points weighted equally		-0.061	0.121	0.135										

ATM to ATM - 09/26/97 ATM 135929 pass minus all 09/26/97 ATM passes - Beach Only

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970926atm2_130755	970926atm2_135929	-0.016	0.168	0.169	-1.207	1.091	36.021	36.023	-75.660	-75.659	-40.729	-34.388	1,669	0
970926atm2_131058	970926atm2_135929	-0.062	0.130	0.144	-5.105	6.794	36.002	36.425	-75.837	-75.648	-41.847	-32.164	254,783	64
970926atm2_132917	970926atm2_135929	-0.126	0.148	0.194	-6.480	6.357	35.871	36.426	-75.837	-75.574	-42.022	-32.004	280,752	52
970926atm2_134736	970926atm2_135929	-0.087	0.141	0.165	-6.006	4.100	35.788	35.872	-75.575	-75.534	-41.225	-32.086	101,811	12
970926atm2_143020	970926atm2_135929	-0.033	0.139	0.143	-5.938	4.850	36.072	36.426	-75.837	-75.693	-42.022	-33.054	197,684	20
970926atm2_144317	970926atm2_135929	-0.025	0.151	0.153	-6.425	6.437	35.804	36.044	-75.675	-75.543	-41.605	-32.086	134,563	54
970926atm2_152356	970926atm2_135929	-0.021	0.150	0.152	-6.366	6.382	35.788	35.891	-75.585	-75.534	-41.301	-32.043	123,099	26
970926atm2_153842	970926atm2_135929	0.002	0.136	0.136	-1.945	0.935	36.016	36.017	-75.657	-75.656	-40.727	-34.115	2,793	0
All surveys weighted equally		-0.046	0.145	0.157									1,097,154	228
All matching points weighted equally		-0.066	0.148	0.162										

ATM to ATM - 09/27/97 ATM 182303 pass minus all 09/27/97 ATM passes - Constrained to List Buggy Track

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970927atm2_130739	970927atm2_182303	-0.017	0.112	0.113	-0.321	0.318	35.798	35.901	-75.591	-75.540	-39.966	-38.113	616	0
970927atm2_144126	970927atm2_182303	0.030	0.134	0.137	-1.722	0.380	35.799	35.891	-75.586	-75.540	-39.966	-38.312	494	0
970927atm2_145204	970927atm2_182303	0.124	0.118	0.171	-0.278	0.394	35.992	36.085	-75.702	-75.642	-39.694	-36.784	535	0
970927atm2_145947	970927atm2_182303	0.114	0.098	0.148	-0.097	0.265	36.022	36.023	-75.660	-75.660	-39.541	-38.860	17	0
970927atm2_180059	970927atm2_182303	-0.042	0.083	0.091	-0.148	0.133	36.020	36.021	-75.659	-75.658	-39.456	-39.054	18	0
970927atm2_180419	970927atm2_182303	0.015	0.135	0.136	-0.468	1.787	35.798	35.967	-75.628	-75.540	-39.966	-37.815	912	0
970927atm2_181637	970927atm2_182303	0.057	0.053	0.076	-0.053	0.140	35.859	35.861	-75.570	-75.569	-39.192	-38.635	11	0
970927atm2_184521	970927atm2_182303	0.094	0.067	0.114	0.010	0.240	36.376	36.376	-75.824	-75.824	-39.137	-38.607	14	0
970927atm2_184941	970927atm2_182303	-0.023	0.135	0.137	-0.801	0.428	35.996	36.359	-75.819	-75.645	-39.710	-36.639	2,054	0
970927atm2_190530	970927atm2_182303	0.067	0.131	0.144	-0.141	0.303	36.021	36.022	-75.660	-75.659	-39.541	-38.983	20	0
All surveys weighted equally		0.042	0.107	0.127									4,691	0
All matching points weighted equally		0.009	0.138	0.138										

ATM to ATM - 09/27/97 ATM 182303 pass minus all 09/27/97 ATM passes - Beach Only

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
970927atm2_130739	970927atm2_182303	-0.029	0.166	0.168	-6.683	5.290	35.788	35.901	-75.591	-75.534	-41.093	-32.082	103,440	59
970927atm2_144126	970927atm2_182303	0.018	0.186	0.187	-6.211	5.286	35.788	35.892	-75.586	-75.534	-41.160	-32.082	76,888	18
970927atm2_145204	970927atm2_182303	0.117	0.162	0.200	-3.579	7.310	35.991	36.086	-75.702	-75.641	-41.602	-32.166	47,878	4
970927atm2_145947	970927atm2_182303	0.165	0.186	0.249	-1.292	1.139	36.022	36.023	-75.660	-75.659	-40.455	-34.448	1,254	0
970927atm2_180059	970927atm2_182303	-0.049	0.173	0.180	-0.872	0.855	36.020	36.021	-75.659	-75.658	-40.539	-34.580	1,302	0
970927atm2_180419	970927atm2_182303	-0.019	0.208	0.209	-6.742	6.593	35.788	35.968	-75.629	-75.534	-41.244	-32.082	125,271	98
970927atm2_181519	970927atm2_182303	-0.013	0.108	0.109	-0.588	0.507	35.800	35.804	-75.543	-75.541	-39.251	-37.268	4,261	0
970927atm2_181637	970927atm2_182303	0.001	0.187	0.187	-2.769	3.103	35.859	35.861	-75.570	-75.568	-40.617	-35.657	1,653	0
970927atm2_184521	970927atm2_182303	0.057	0.144	0.155	-0.609	0.751	36.376	36.379	-75.825	-75.823	-40.569	-37.693	2,814	0
970927atm2_184941	970927atm2_182303	-0.037	0.187	0.190	-6.803	7.012	35.996	36.399	-75.829	-75.644	-41.459	-32.300	169,882	7
970927atm2_190530	970927atm2_182303	0.010	0.169	0.170	-1.059	0.959	36.021	36.023	-75.660	-75.659	-40.455	-34.377	1,160	0
All surveys weighted equally		0.020	0.171	0.182									535,803	186
All matching points weighted equally		-0.008	0.190	0.191										

ATM to ATM - 092697 passes to 092797 passes - Constrained to List Buggy Track

Individual 970927 passes to all 970926

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
all_970926atm.:	970927atm2_130739	-0.053	0.118	0.130	-0.473	0.348	35.798	35.901	-75.591	-75.540	-39.964	-37.839	3,752	2
all_970926atm.:	970927atm2_144126	-0.102	0.118	0.156	-0.466	1.599	35.799	35.891	-75.586	-75.540	-39.967	-37.122	2,640	2
all_970926atm.:	970927atm2_145204	-0.222	0.121	0.252	-2.017	0.287	35.992	36.085	-75.702	-75.642	-39.931	-36.690	2,928	0
all_970926atm.:	970927atm2_145947	-0.156	0.111	0.190	-0.437	0.036	36.022	36.023	-75.660	-75.659	-39.742	-38.925	76	0
all_970926atm.:	970927atm2_180059	0.033	0.136	0.137	-0.210	0.338	36.020	36.021	-75.659	-75.658	-39.543	-38.598	22	0
all_970926atm.:	970927atm2_180419	-0.066	0.140	0.155	-1.993	0.975	35.798	35.967	-75.628	-75.540	-40.902	-37.382	3,852	0
all_970926atm.:	970927atm2_181519	-0.068	0.116	0.134	-0.375	0.128	35.801	35.804	-75.542	-75.541	-39.459	-38.879	78	0
all_970926atm.:	970927atm2_181637	-0.080	0.092	0.122	-0.288	0.103	35.859	35.861	-75.570	-75.569	-39.356	-38.514	66	0
all_970926atm.:	970927atm2_182303	-0.128	0.141	0.190	-1.889	0.581	35.797	36.376	-75.824	-75.540	-39.867	-36.548	9,879	2
all_970926atm.:	970927atm2_184521	-0.328	0.076	0.337	-0.531	-0.165	36.376	36.376	-75.824	-75.824	-39.335	-38.623	41	0
all_970926atm.:	970927atm2_184941	-0.140	0.159	0.212	-3.109	0.566	35.996	36.359	-75.819	-75.645	-39.800	-36.677	9,299	3
all_970926atm.:	970927atm2_190530	-0.089	0.129	0.156	-0.381	0.221	36.021	36.022	-75.660	-75.659	-39.589	-38.909	67	0
All surveys weighted equally		-0.117	0.121	0.181									32,700	9
All matching points weighted equally		-0.121	0.147	0.191										

Individual 970926 passes to all 970927

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
all_970927atm.:	970926atm2_130755_	0.072	0.116	0.136	-0.223	0.324	36.021	36.023	-75.660	-75.659	-39.574	-38.858	170	0
all_970927atm.:	970926atm2_131058_	0.191	0.138	0.236	-0.358	0.778	35.987	36.376	-75.824	-75.639	-39.658	-36.447	4,543	1
all_970927atm.:	970926atm2_132917_	0.202	0.139	0.245	-0.566	0.758	35.871	36.374	-75.823	-75.575	-39.672	-36.413	6,761	3
all_970927atm.:	970926atm2_134736_	0.125	0.129	0.179	-0.813	2.001	35.798	35.871	-75.575	-75.540	-39.781	-37.269	2,471	0
all_970927atm.:	970926atm2_135929_	0.081	0.136	0.158	-0.843	1.758	35.800	36.376	-75.824	-75.540	-39.999	-36.566	7,440	1
all_970927atm.:	970926atm2_143020_	0.100	0.146	0.177	-0.555	1.443	36.075	36.376	-75.824	-75.696	-39.468	-36.608	3,599	0
all_970927atm.:	970926atm2_144317_	0.064	0.130	0.145	-1.642	0.615	35.797	36.064	-75.688	-75.541	-39.892	-36.608	4,634	0
all_970927atm.:	970926atm2_152356_	0.053	0.113	0.124	-1.404	0.609	35.799	35.970	-75.630	-75.540	-39.876	-37.667	3,398	3
all_970927atm.:	970926atm2_153842_	0.020	0.146	0.146	-0.386	0.305	36.016	36.017	-75.657	-75.656	-39.409	-38.467	62	0
All surveys weighted equally		0.101	0.132	0.172									33,078	8
All matching points weighted equally		0.121	0.146	0.190										

ATM to ATM - 09/27/97 passes minus 09/26/97 passes - Constrained to Beach

(merged all beach only 970926atm files into 'all970926atm_bch.rqfil' and compared with 970927atm*.rq)

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
all970926atm_bch	970927atm2_130739	-0.031	0.176	0.179	-6.663	6.733	35.788	35.901	-75.591	-75.534	-41.559	-32.043	529,538	321
all970926atm_bch	970927atm2_144126	-0.072	0.178	0.192	-6.620	6.334	35.788	35.892	-75.586	-75.534	-43.814	-32.015	414,498	484
all970926atm_bch	970927atm2_145204	-0.206	0.158	0.259	-7.006	5.730	35.991	36.086	-75.702	-75.641	-41.670	-32.094	235,006	101
all970926atm_bch	970927atm2_145947	-0.159	0.157	0.223	-1.572	0.877	36.022	36.023	-75.660	-75.659	-40.846	-34.466	5,607	0
all970926atm_bch	970927atm2_180059	0.013	0.189	0.190	-1.414	0.749	36.020	36.021	-75.659	-75.658	-40.475	-34.409	3,370	0
all970926atm_bch	970927atm2_180419	-0.045	0.190	0.195	-6.730	6.469	35.788	35.968	-75.629	-75.534	-41.795	-32.056	560,027	438
all970926atm_bch	970927atm2_181519	-0.022	0.123	0.125	-1.677	1.545	35.800	35.804	-75.543	-75.540	-40.296	-36.885	17,716	1
all970926atm_bch	970927atm2_181637	-0.071	0.171	0.185	-2.764	2.778	35.859	35.861	-75.570	-75.568	-40.645	-35.289	10,669	0
all970926atm_bch	970927atm2_182303	-0.118	0.199	0.231	-7.284	7.229	35.788	36.414	-75.834	-75.534	-41.779	-32.082	1,148,349	632
all970926atm_bch	970927atm2_184521	-0.181	0.258	0.315	-2.073	0.944	36.376	36.379	-75.825	-75.823	-40.766	-37.259	20,139	15
all970926atm_bch	970927atm2_184941	-0.114	0.219	0.247	-6.328	7.632	35.996	36.399	-75.829	-75.644	-41.780	-32.050	837,824	254
all970926atm_bch	970927atm2_190530	-0.007	0.202	0.203	-1.389	1.114	36.021	36.023	-75.660	-75.659	-40.530	-34.348	5,632	0
All surveys weighted equally		-0.084	0.185	0.212									3,788,375	2,246
All matching points weighted equally		-0.094	0.200	0.221										

09/26/97 ATM passes minus List Buggy Survey

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
buggy70_combined_	970926atm2_130755_	0.011	0.087	0.086	-0.139	0.226	36.021	36.023	-75.660	-75.659	-39.555	-38.930	33	0
buggy70_combined_	970926atm2_131058_	0.105	0.080	0.132	-0.361	0.692	35.987	36.376	-75.824	-75.639	-39.658	-36.447	5111	0
buggy70_combined_	970926atm2_132917_	0.141	0.093	0.169	-0.172	2.909	35.871	36.374	-75.823	-75.575	-39.672	-35.795	6465	2
buggy70_combined_	970926atm2_134736_	0.160	0.076	0.177	-0.048	0.504	35.798	35.871	-75.575	-75.540	-39.793	-38.074	1143	0
buggy70_combined_	970926atm2_135929_	0.044	0.099	0.108	-0.311	1.842	35.800	36.376	-75.824	-75.540	-39.999	-35.173	6522	2
buggy70_combined_	970926atm2_143020_	-0.012	0.094	0.095	-0.378	1.375	36.077	36.376	-75.824	-75.696	-39.426	-36.651	3394	0
buggy70_combined_	970926atm2_144317_	0.123	0.092	0.154	-0.247	1.951	35.797	36.064	-75.688	-75.540	-39.832	-36.666	3942	0
buggy70_combined_	970926atm2_152356_	0.076	0.079	0.110	-0.165	1.818	35.799	35.970	-75.630	-75.540	-39.820	-36.073	2947	3
buggy70_combined_	970926atm2_153842_	0.001	0.079	0.077	-0.113	0.127	36.016	36.017	-75.657	-75.656	-39.226	-38.602	31	0
All surveys weighted equally		0.072	0.087	0.123									29,588	7
All matching points weighted equally		0.087	0.104	0.136										

09/27/97 ATM passes minus List Buggy Survey

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
buggy70_combine(	970927atm2_130739	0.059	0.089	0.106	-0.254	0.338	35.798	35.901	-75.591	-75.540	-39.961	-38.113	1332	0
buggy70_combine(	970927atm2_144126	0.023	0.059	0.064	-0.214	1.707	35.799	35.891	-75.586	-75.540	-39.970	-37.122	2631	0
buggy70_combine(	970927atm2_145204	-0.128	0.076	0.149	-0.406	0.221	35.992	36.085	-75.702	-75.642	-39.829	-36.690	1691	0
buggy70_combine(	970927atm2_145947	-0.154	0.092	0.179	-0.312	-0.004	36.022	36.023	-75.660	-75.659	-39.742	-39.090	43	0
buggy70_combine(	970927atm2_180059	0.053	0.123	0.132	-0.162	0.310	36.020	36.021	-75.659	-75.658	-39.606	-38.598	32	0
buggy70_combine(	970927atm2_180419	0.059	0.088	0.106	-0.343	1.002	35.798	35.967	-75.628	-75.540	-39.873	-37.632	2367	0
buggy70_combine(	970927atm2_181519	0.052	0.060	0.079	-0.168	0.196	35.801	35.804	-75.542	-75.541	-39.407	-38.879	72	0
buggy70_combine(	970927atm2_181637	0.055	0.065	0.084	-0.036	0.176	35.859	35.861	-75.570	-75.569	-39.302	-38.561	24	0
buggy70_combine(	970927atm2_182303	-0.052	0.123	0.133	-0.611	0.499	35.797	36.376	-75.824	-75.540	-39.966	-36.548	5974	0
buggy70_combine(	970927atm2_184521	-0.250	0.028	0.252	-0.453	-0.227	36.376	36.376	-75.824	-75.824	-39.335	-38.649	331	0
buggy70_combine(	970927atm2_184941	-0.095	0.138	0.168	-0.504	0.796	35.996	36.359	-75.819	-75.645	-39.786	-36.473	5254	1
buggy70_combine(	970927atm2_190530	-0.018	0.120	0.119	-0.218	0.271	36.021	36.022	-75.660	-75.659	-39.618	-38.920	32	0
All surveys weighted equally		-0.033	0.088	0.131									19,783	1
All matching points weighted equally		-0.042	0.130	0.136										

09/26/97 ATM passes minus 09/26/97 Holman - Beach Only

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
wgs_g96_navd88_ç	970926atm2_131058	0.131	0.096	0.163	-0.248	0.935	36.168	36.182	-75.752	-75.745	-40.324	-35.585	1690	0
wgs_g96_navd88_ç	970926atm2_132917	0.239	0.150	0.282	-0.067	6.330	36.168	36.196	-75.756	-75.745	-40.167	-32.743	2881	0
wgs_g96_navd88_ç	970926atm2_135929	0.050	0.097	0.109	-0.567	0.342	36.168	36.176	-75.748	-75.745	-40.354	-36.583	742	0
wgs_g96_navd88_ç	970926atm2_143020	0.065	0.104	0.123	-0.330	0.984	36.168	36.182	-75.752	-75.745	-40.117	-34.417	2644	0
All surveys weighted equally		0.121	0.112	0.169									7957	0
All matching points weighted equally		0.141	0.144	0.201										

09/26/97 ATM passes minus 09/26/97 Holman - Constrained to List Buggy Track

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
wgs_g96_navd88_ç	970926atm2_131058	0.101	0.118	0.154	-0.105	0.329	36.168	36.176	-75.748	-75.745	-39.312	-36.713	39	0
wgs_g96_navd88_ç	970926atm2_132917	0.236	0.098	0.255	0.010	0.440	36.168	36.195	-75.756	-75.745	-39.061	-36.468	79	0
wgs_g96_navd88_ç	970926atm2_135929	0.026	0.103	0.104	-0.170	0.195	36.168	36.175	-75.748	-75.745	-39.250	-36.719	21	0
wgs_g96_navd88_ç	970926atm2_143020	0.048	0.097	0.106	-0.168	0.240	36.168	36.172	-75.747	-75.745	-39.150	-36.745	24	0
All surveys weighted equally		0.103	0.104	0.155									163	0
All matching points weighted equally		0.149	0.135	0.201										

09/27/97 ATM passes minus 09/27/97 Reiss

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
27reiss_corolla	970927atm2_182303_	0.167	0.175	0.229	-0.012	0.345	36.377	36.377	-75.824	-75.824	-38.494	-37.318	5	0
27reiss_corolla	970927atm2_184521_	0.017	0.121	0.112	-0.133	0.156	36.377	36.377	-75.824	-75.824	-38.590	-37.581	6	0
All surveys weighted equally		0.092	0.148	0.170									11	0
All matching points weighted equally		0.085	0.160	0.175										

09/27/97 ATM passes minus 09/27/97 Hansen Corolla - Beach Only

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
crod1270_:	970927atm2_182303_hansen.	0.117	0.105	0.157	-0.243	0.583	36.377	36.378	-75.824	-75.824	-39.222	-36.531	845	0
crod1270_:	970927atm2_184521_hansen.	0.069	0.099	0.121	-0.257	0.400	36.377	36.378	-75.824	-75.824	-39.163	-36.344	1,053	0
crod2270_:	970927atm2_182303_hansen.	0.090	0.191	0.211	-0.572	0.589	36.377	36.378	-75.824	-75.824	-39.223	-35.561	309	5
crod2270_:	970927atm2_184521_hansen.	0.065	0.161	0.174	-0.467	0.764	36.377	36.378	-75.824	-75.824	-39.376	-35.516	385	3
All surveys weighted equally		0.085	0.139	0.166									2,592	8
All matching points weighted equally		0.086	0.128	0.154										

Ground Survey Intercomparisons

List Buggy minus 09/26/97 Holman

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
wgs_g96_navd8	buggy70_combined	0.062	0.054	0.082	-0.188	0.227	36.168	36.195	-75.756	-75.745	-39.188	-36.822	471	0

09/27/97 Hansen#2 minus 09/27/97 Hansen#1

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
crod1270.rq	crod2270.rq	0.004	0.086	0.086	-0.545	0.398	36.377	36.378	-75.825	-75.824	-39.211	-34.318	13,491	0

09/27/97 Hansen minus 09/27/97 Reiss

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
27reiss_corolla.r	crod1270.rq	-0.035	0.061	0.070	-0.271	0.095	36.377	36.377	-75.824	-75.824	-39.088	-37.698	190	0
27reiss_corolla.r	crod2270.rq	-0.052	0.083	0.098	-0.436	0.175	36.377	36.377	-75.825	-75.824	-38.632	-33.650	600	0
All surveys weighted equally		-0.044	0.072	0.084									790	0
All matching points weighted equally		-0.048	0.079	0.092										

09/27/97 Hansen minus 09/29/97 Reiss

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
29reiss_corolla.r	crod1270.rq	-0.024	0.062	0.066	-0.285	0.436	36.377	36.377	-75.825	-75.824	-39.357	-34.399	2,342	0
29reiss_corolla.r	crod2270.rq	-0.033	0.113	0.117	-0.539	0.409	36.377	36.377	-75.825	-75.824	-39.156	-33.650	1,613	0
All surveys weighted equally		-0.028	0.087	0.092									3,955	0
All matching points weighted equally		-0.027	0.086	0.091										

09/27/97 Reiss minus 09/29/97 Reiss

fileA	fileB	Mean	SD	RMS	MinDz	MaxDz	MinLat	MaxLat	MinLon	MaxLon	MinZ	MaxZ	#elem	#Disc
29reiss_corolla.r	27reiss_corolla.rq	-0.005	0.156	0.156	-0.456	0.525	36.377	36.377	-75.825	-75.824	-38.941	-33.650	149	0