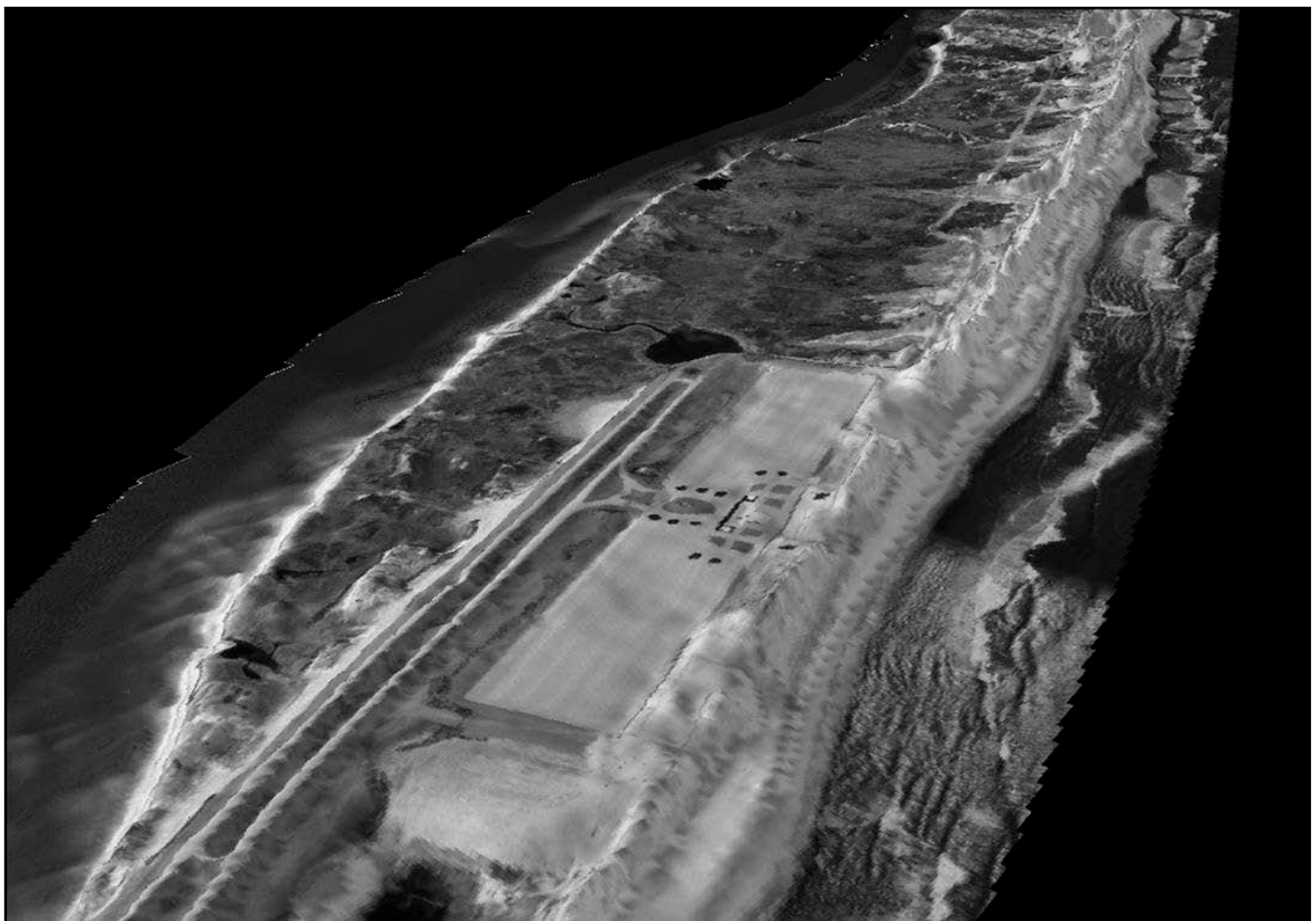




Development of Historical Topographic Models of the Beach/Dune System in Northeast Coastal and Barrier Network Parks

Natural Resource Report NPS/NCBN/NRR—2017/1411



ON THE COVER

FHIS 1969 orthophotomosaic draped over 1969 digital terrain model.
NPS photo.

Development of Historical Topographic Models of the Beach/Dune System in Northeast Coastal and Barrier Network Parks

Natural Resource Report NPS/NCBN/NRR—2017/1411

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March 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Hehre, R., and C. Hapke. 2017. Development of historical topographic models of the beach/dune system in Northeast Coastal and Barrier Network parks. Natural Resource Report NPS/NCBN/NRR—2017/1411. National Park Service, Fort Collins, Colorado.

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Executive Summary

The USGS Patuxent Wildlife Research Center Coastal Field Station, located at the University of Rhode Island, in collaboration with the Northeast Coastal and Barrier Network (NCBN) of the National Park Service (NPS), recently completed a study to develop a baseline of historical topography to be utilized in long-term topographic change analyses in four coastal National Parks in the Northeast U.S: Fire Island National Seashore (FIIS), Cape Cod National Seashore (CACO), Gateway National Recreation Area (GATE), and Assateague Island National Seashore (ASIS) (Figure 1).

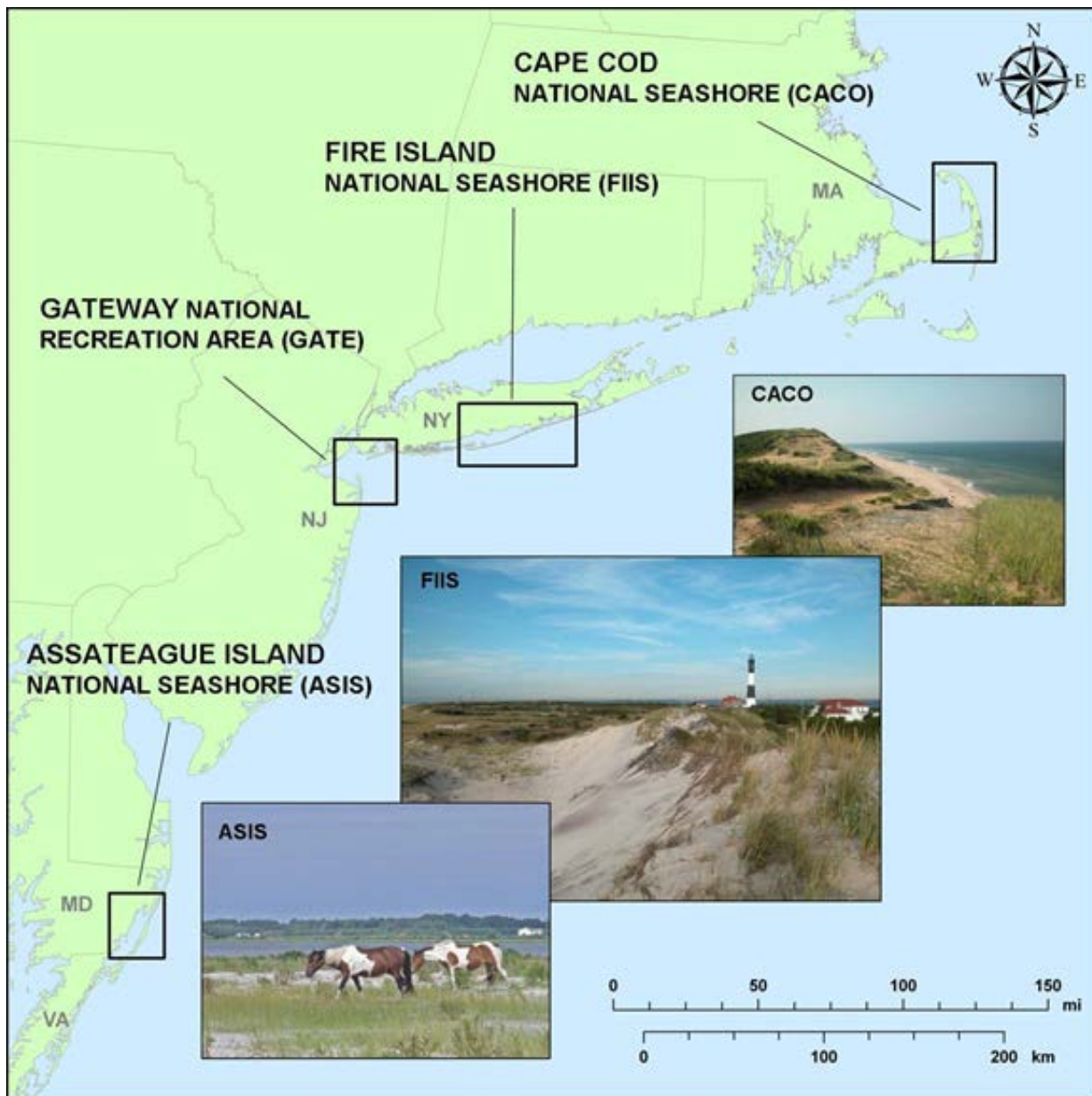


Figure 1. Location map of selected National Park Service units within the North East Coastal and Barrier Network that have been selected for long term topographic change analysis.

The dynamic nature of coastal barriers is a defining characteristic influencing nearly every aspect of their ecology. Fundamentally disturbance driven systems, barrier islands and their endemic biota are continually shaped by physical forces on much faster time scales compared to mainland systems. Because of the rapid pace and scope of change, long term monitoring is crucial towards understanding natural barrier island conditions as well as anthropogenic influences.

The historical topographic models produced for this project will provide baseline information for incorporation into analyses that will further the understanding of the potential impacts of sea-level rise and increased storminess to the coastal parks. The most fundamental knowledge required for understanding how coastal systems may behave in the future is how they have behaved in the past. Historical shoreline change data exist for most areas, but analyses of such data are restricted to 2-dimensional assessments of a line near water level on the beach, thus providing little information on the back beach and dune areas. The 3-dimensional models developed for this study can be integrated with modern topographic data, such as LiDAR, to measure volumetric change. The photogrammetric products generated for this project are the only available source of historical topographic data for these areas, and include not only historical digital terrain models but also the generation of historical orthophotographs.

Historical aerial photography for each park was obtained from agencies such as the U.S. National Archives, NOAA, USGS, and other local and state agencies. Aerial photographs were chosen for each park to provide the oldest possible topographic database, while maintaining an acceptable accuracy. The dates of the photography chosen for each park are: FIIS, 1969; CACO, 1951; GATE, 1953; and ASIS, 1976. In order to maintain a pixel resolution and vertical accuracy of 0.50 m or less, all imagery has a nominal scale of 1:12000 (see Hapke, 2005; Hapke and Green, 2005) and was scanned (converted from film to digital) at resolutions >1200 dpi. The photographs are obtained as film diapositives to minimize errors associated with distorted media.

Recommendations and Usage

Ideas of what this data should be used for:

Topographic data

- Volume change analysis of the beach and dune system.
- Comparison of the historical dune and beach systems with modern LiDAR data.
- Beach width and dune elevation change studies.

Orthophotographs

- Shoreline change studies (HWL delineated from orthos).
- Vegetation change studies

This data should NOT be used for:

- Topographic change analyses landward of the primary dune. The topographic models underwent detailed manual editing in the beach and dune areas as part of the processing; equivalent editing was not performed for the interior portions of the island due to: project time constraints/goals and issues with editing in highly vegetated or developed areas.
- Marsh surface elevation change. Ground control data used for establishing the historical model was modern LiDAR data, therefore, marsh surface elevations would reflect the control data elevations, rather than the precise elevation of historical marsh surface.
- Extraction of a MWH elevation from the elevation dataset. Where applicable, the high water line (HWL) was used as a proxy for mean high water, and an elevation of 0.46 m (NAVD88) was applied for this feature. Due to difficulty resolving stereo models in/near the swash zone where wave interference occurs on the beach face, elevation values for the lower beach face are estimates.

Fire Island National Seashore (FIIS)

Data Collection

Historical aerial photography

Historical aerial imagery (1969, B&W, 1:12,000) for Fire Island National Seashore was acquired from Michael Baker Jr. Inc (2009; Table 1). A total of 74 images scanned using a photogrammetric-grade scanner were delivered. Coverage of FIIS consists of seven overlapping flight lines. Each flight line was compiled as an individual project using SOCET SET (BAE Systems, 2007) photogrammetric software and the resulting topographical models are organized by flight line (Figure 2).

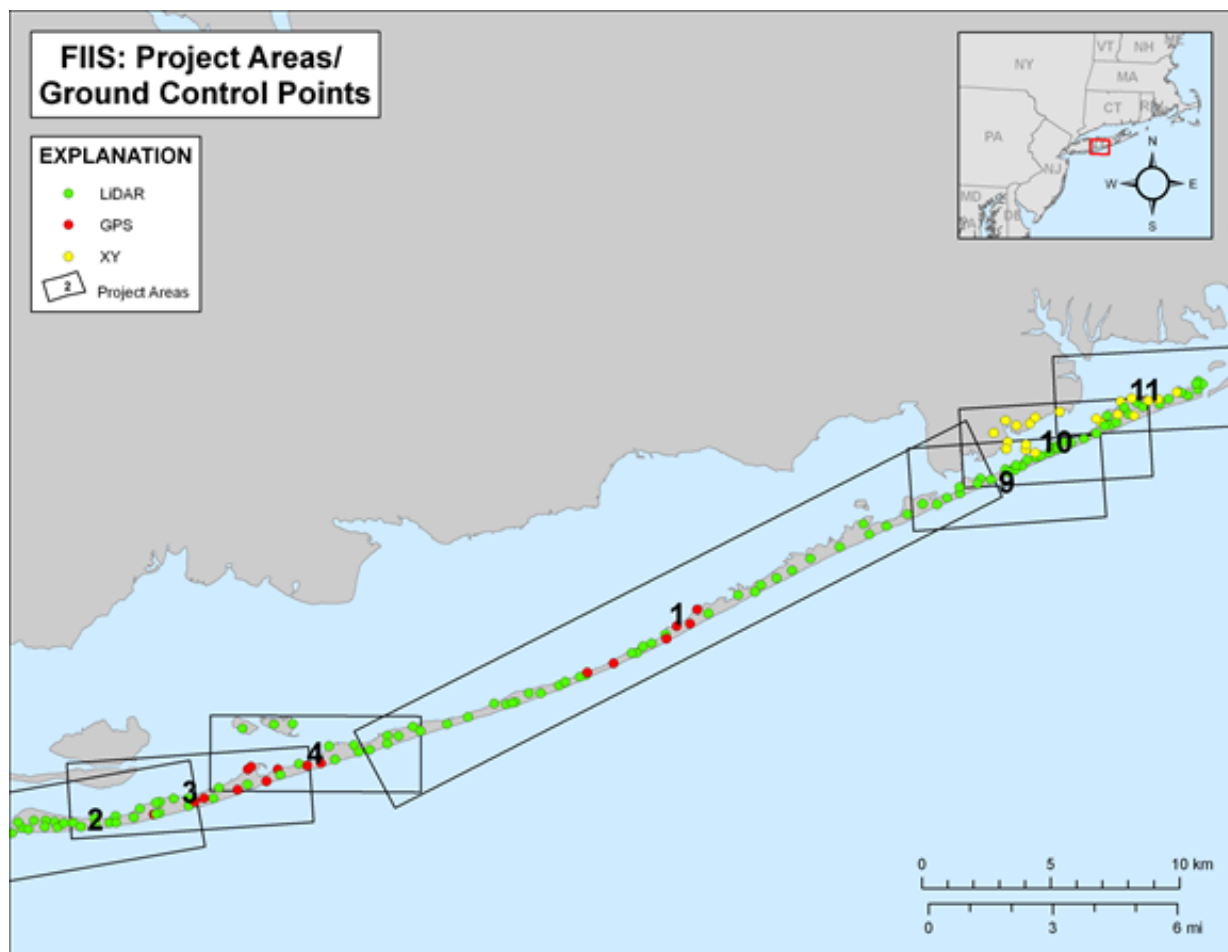


Figure 2. Project areas for Fire Island National Seashore, with location of field collected and LiDAR extracted ground control points.

Table 1. Air Photo Inventory as of December 1, 2009.

Park	Source	Photo Year	Date	Scale	Description	Number	Status	Historical Topography
FIIS	Michael Baker Jr. Inc. (2009)	1969	03/23/1969 03/28/1969	1:12,000	B&W Film scans	74	Acquired	complete
CACO	NOAA/NOS (2009a)	1951	10/01/1951	1:10,000	B&W Film scans	63	Acquired	complete
GATE – Rockaway, NY	NOAA/NOS (2009b)	1953	10/09/1953	1:10,000	B&W Film scans	17	Acquired	complete
GATE –Sandy Hook, NY	NOAA/NOS, GATE (2009c)	1951, 1940s	4/20/1951 Multiple	1:20,000	Scanned Unknown	-	Unusable scale/ quality	NA
ASIS	USGS/EROS (2009)	1976	8/04/1976	1:10,000	CIR Film scans	60	Acquired	incomplete

Ground control data

The historical imagery was first georeferenced using Arc Map v9.2 (ESRI, 2007) for assessment of features - prior to collection of ground control points, a network of suitable points were located by identifying unique features visible in historical imagery and modern imagery. Surveyed ground control points were collected using an RTK GPS system. Control points are ideally collected in the field. However, if point locations are inaccessible, or additional ground control points are needed, they can be extracted from available LiDAR data of the area. For FIIS, 2002 LiDAR (Brock, 2004) was used in these cases. A ground control point dataset (FIIS GCP 1969-2008) was created by assembling data points from digital resources (orthophotography, georeferenced aerial imagery, LiDAR data), and field resources (RTK GPS data collection) (Figure 2).

Photogrammetric Analysis

Project set-up

SOCET SET photogrammetry software (BAE Systems) 5.4.0 was used to create orthoimagery and digital elevation models for the seven project areas in FIIS. Imagery for each flight line was imported and a new project was created in SOCET SET. Interior orientation was performed by manually measuring the locations of the fiducial marks and using information on fiducial location and camera radial distortion that was provided in the camera calibration report. Interior orientation is used to compare the film frame to the camera frame, and make adjustments for differences between the two that can result in errors in the photogrammetric model.

The UTM coordinates of the ground control points were organized with unique ID values to build a ground control file that could then be imported into SOCET SET. Interactive Point Measurement (IPM) was then used to match ground control coordinates with the locations in historical imagery (Figure 3A). Additional tie points were added as necessary to obtain a dense network of match points. Once a sufficient number of points were added, aerotriangulation was applied to transform the imagery from arbitrary frame coordinates to real-world coordinates. The model was refined by discarding or adjusting points with high root mean square error (RMS) until the RMS of the x, y, values were <1 (m), and the z value was <0.5 (m).

Digital terrain model creation

After images are assigned ground control points and an aerotriangulation solution is obtained, the sequence of overlapping images is processed using Automatic Terrain Extraction (ATE) to generate a Digital Terrain Model (DTM). ATE identifies conjugate points, and then determines the elevations (from the historical imagery) by measuring x-shifts (x parallax) in the rectified images. The measurement of these shifts is made possible because of the image matching technology. As a part of this process, a "seed" (or modern DTM from LiDAR) is used optionally to help the ATE produce a more accurate DTM.

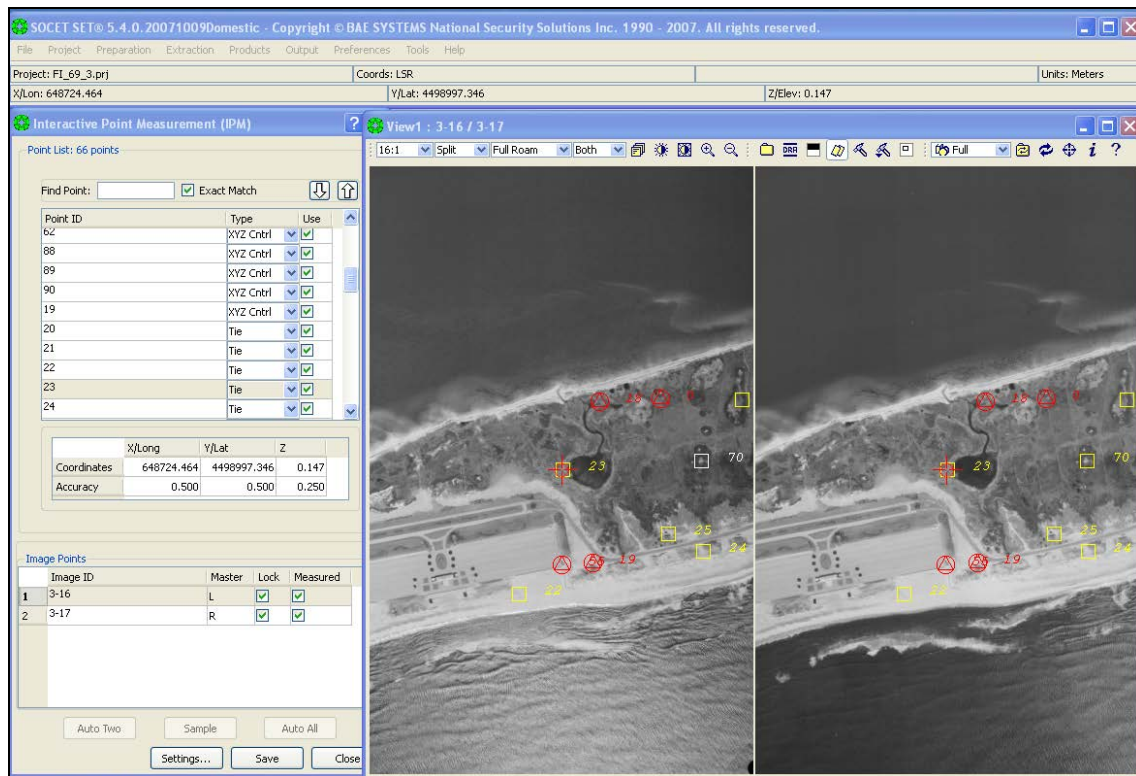


Figure 3A. An example of the Fire Island project in SOCET SET software. Assignment of ground control (red) and tie points (yellow) between stereo pairs of historical imagery.

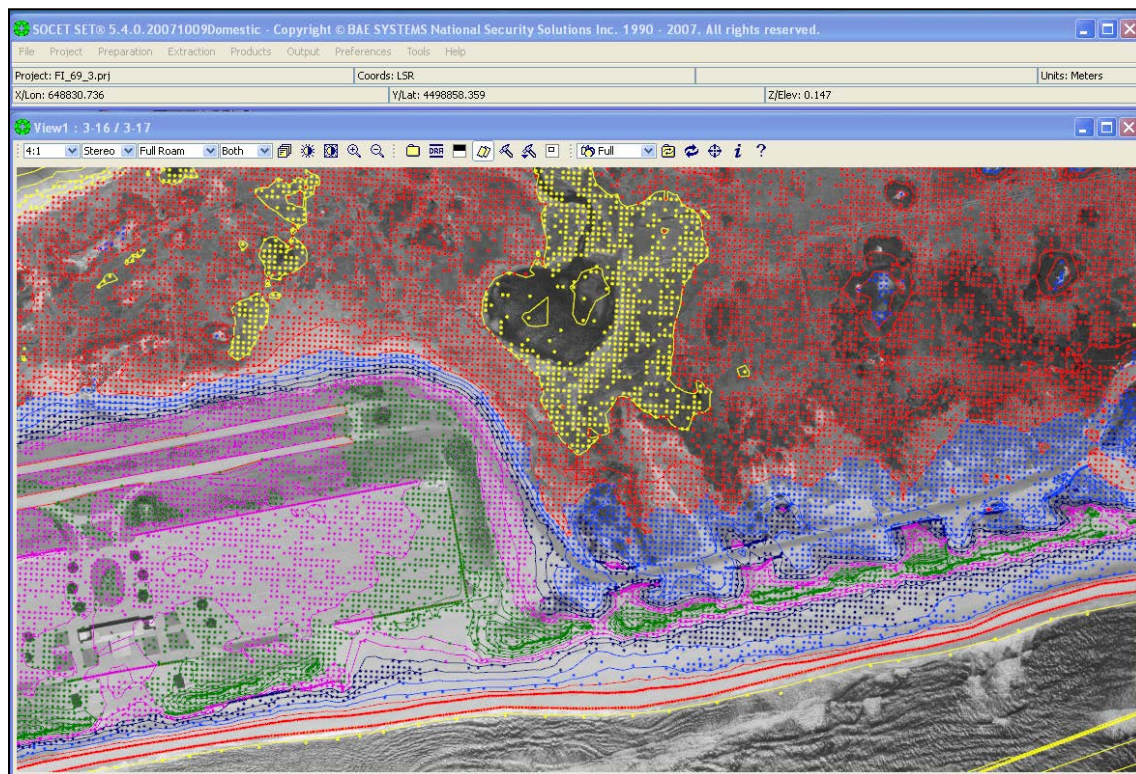


Figure 3B. Initial digital terrain model in Terrain Editing mode.

Interactive terrain editing

After the ATE has generated a surface of points, the Interactive Terrain Editing (ITE) tool allows for manual adjustment of the elevation and position of points (Figure 3B). Because the primary focus of this project is the historical terrain of the beach and dune system, the majority of detailed editing took place within this area. One important feature edit was the use of a breakline on the beach face to represent the mean high water (MHW) elevation. For Fire Island National Seashore, as defined by Weber, *et al.* (2005), MHW is approximately 0.46 m above NAVD88. Historical records from Sandy Hook, NJ and Montauk Point, NY indicate that for the range of dates (3/23/1969- 3/28/1969) the predicted higher high tide approximates the MHW elevation. Therefore, where applicable, the high water line (HWL) was used as a proxy for mean high water, and an elevation of 0.46 m (NAVD88) was applied for this feature. Due to difficulty resolving stereo models where wave interference occurs on the beach face, elevation values for the beach face are estimates.

Feature extraction

DTMs created in SOCET SET consist of point (xyz) and polyline (breakline) features. These features were exported directly to shapefiles. These shapefiles were imported into ArcMAP and 3D Analyst (ESRI, 2007) tools were used to create historical topographic surfaces (Figure 4).

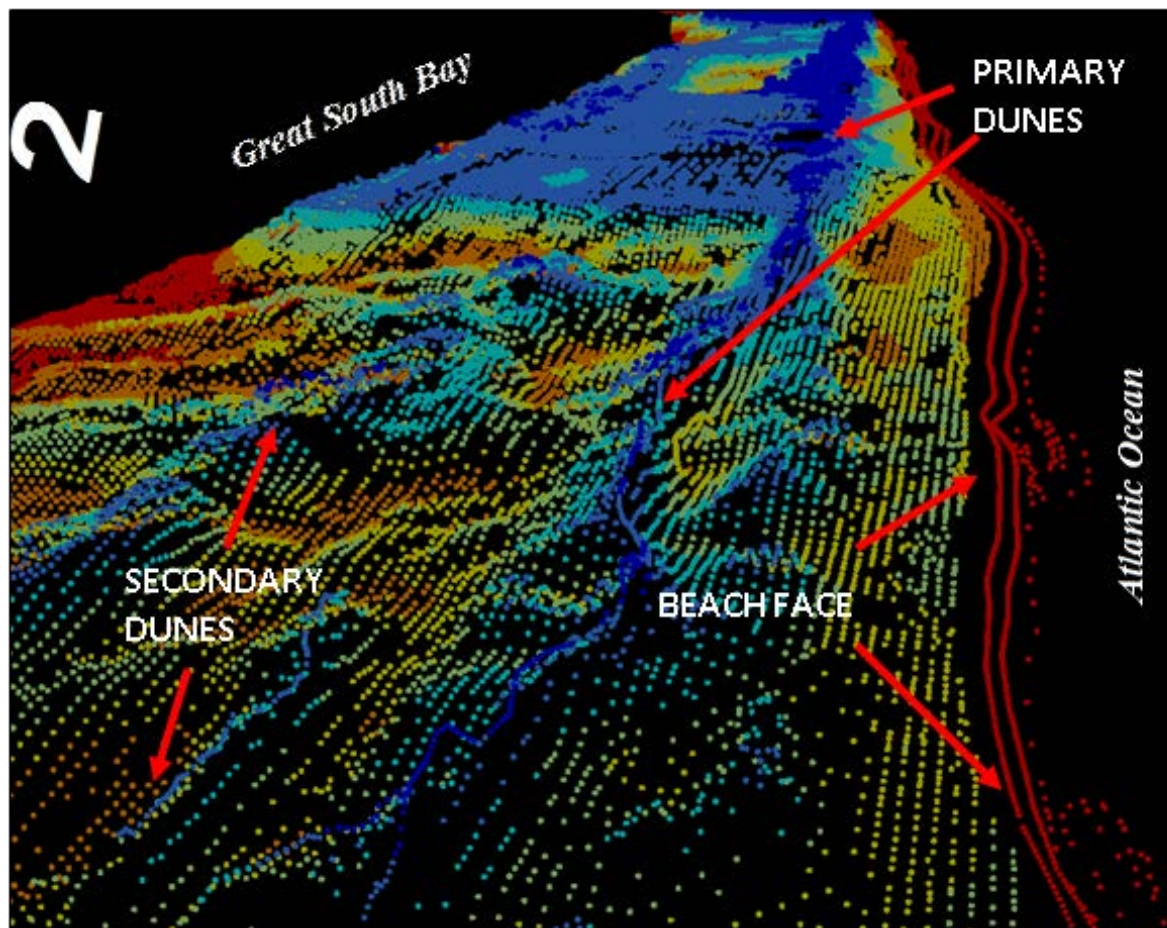


Figure 4. Example of FIIS DTM points and polylines (breaklines) exported from SOCET SET displayed in ArcScene (ESRI, 2007). View is to the east from Fire Island Inlet.

Orthophoto generation

Once the DTM is finalized, orthophoto mosaics of each flight line were created using a mosaicking tool within SOCET SET (Figure 5A-B). Orthomosaics were then imported into ArcMap 9.2, where they were clipped and imported into a geodatabase.

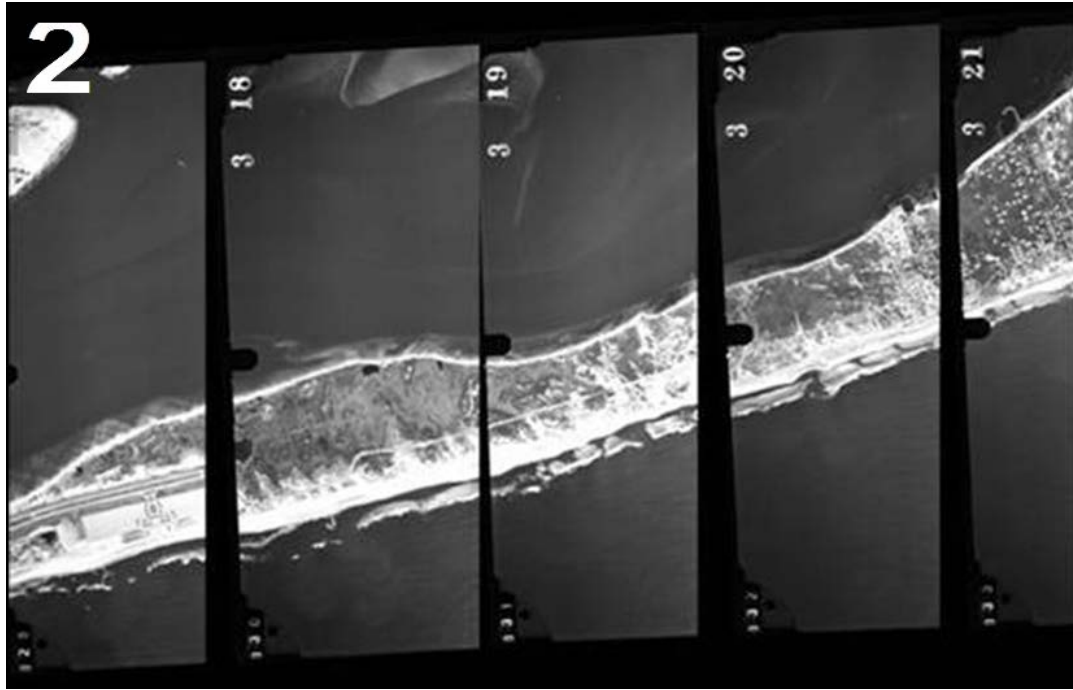


Figure 5A. An example of georeferenced aerial imagery, FIIS 1969.

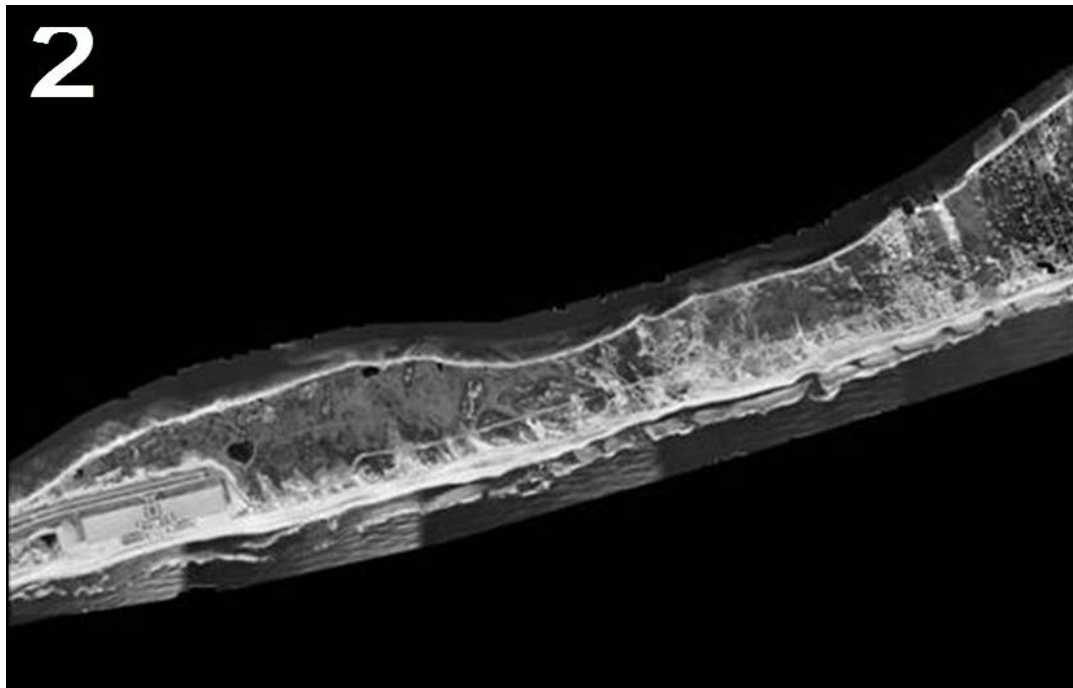


Figure 5B. An example of orthomosaicked imagery, FIIS 1969.

GIS Analysis

DEM products

For each flight line points and polylines (breaklines) were exported as shapefiles from SOCET SET. These shapefiles were used with ArcMap 3D Analyst to create historical topographic surfaces. First a triangulated irregular network (TIN) was generated using the posts for points and the contours as breaklines. The TIN was then converted into a raster dataset, with a cell size of 2 m (Figure 6). All raster datasets were then reviewed to assess the quality of features represented by the topography. This was done using 3D Analyst tools such as the interpolate line tool to assess the profile characteristics from the dune to the beach face. After assessment, the grids were mosaicked into East and West sections of Fire Island. Finally, the completed DTMs were imported into a geodatabase.

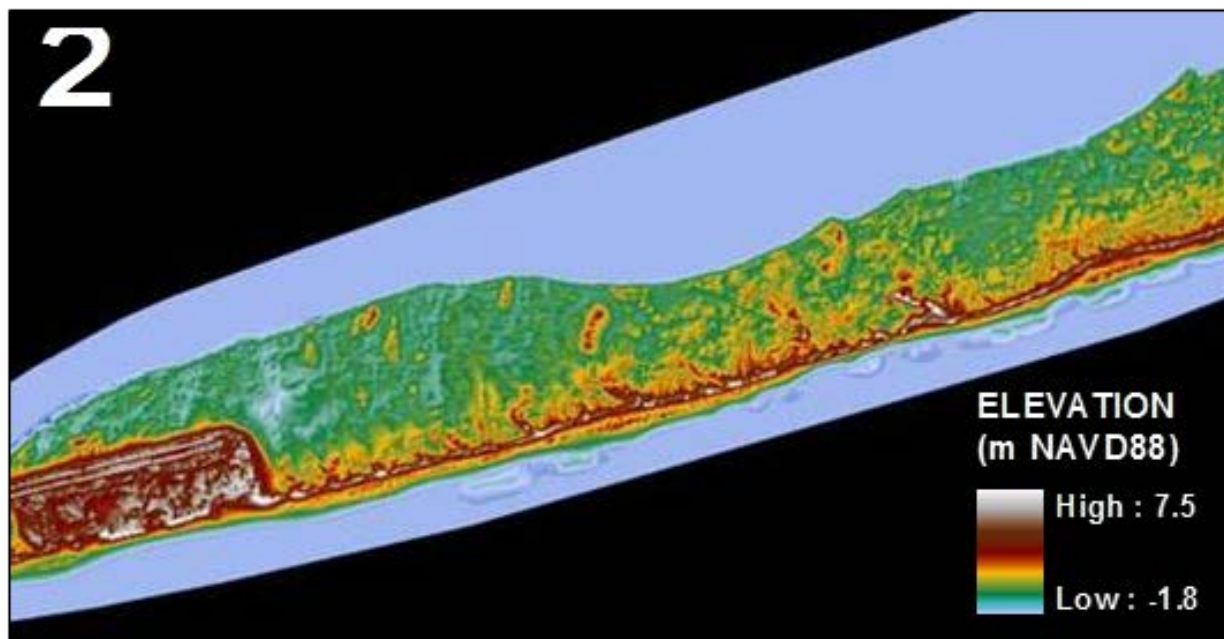


Figure 6. Example of historical digital terrain model for FIIS.

DEM subtractions

Surfaces have been created that are the result of the subtraction of FIIS Digital Terrain Model 1969, from FIIS 2002 LiDAR data (Figure 7).

Three-dimensional renderings

In addition to displaying two-dimensional elevations, the historical DTMs allow other raster data (elevation, mosaics and subtractions) to be displayed with three-dimensional elevation exaggeration (Figure 7&8).

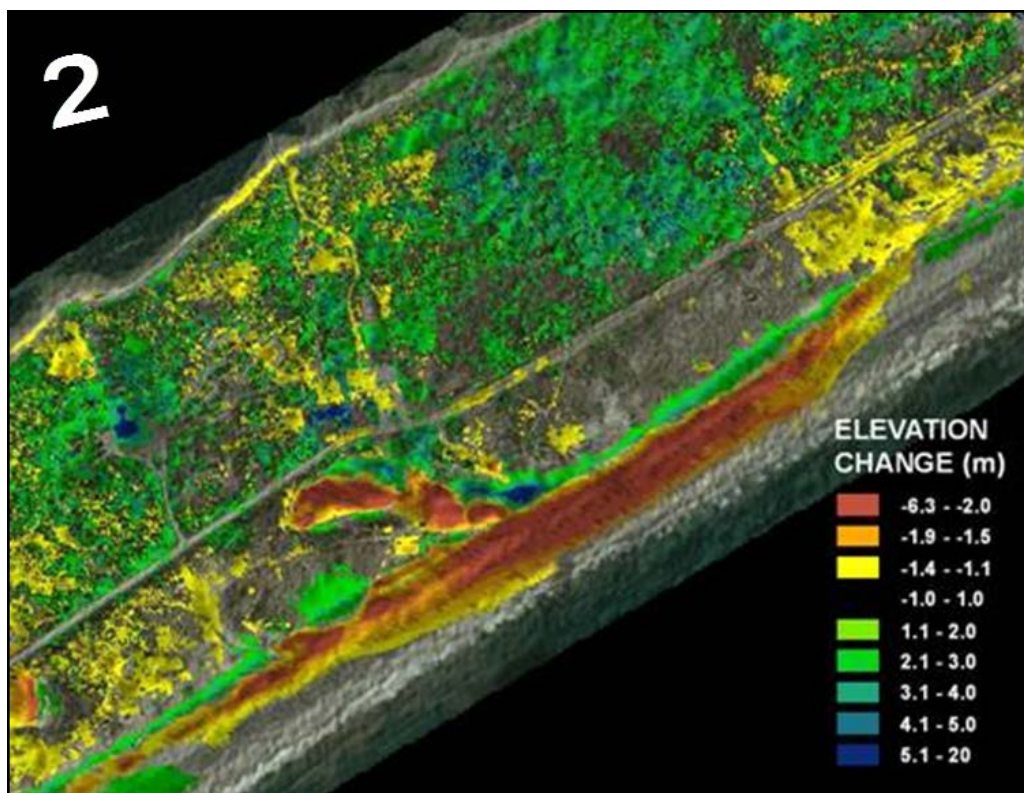


Figure 7. FIIS: Example of raster subtraction of historical digital terrain model (1969) from modern LiDAR (2002) data. Cool colors indicate accretion and warm colors indicate erosion. The entire surface is overlain onto 2002 LiDAR topography and orthophotography.

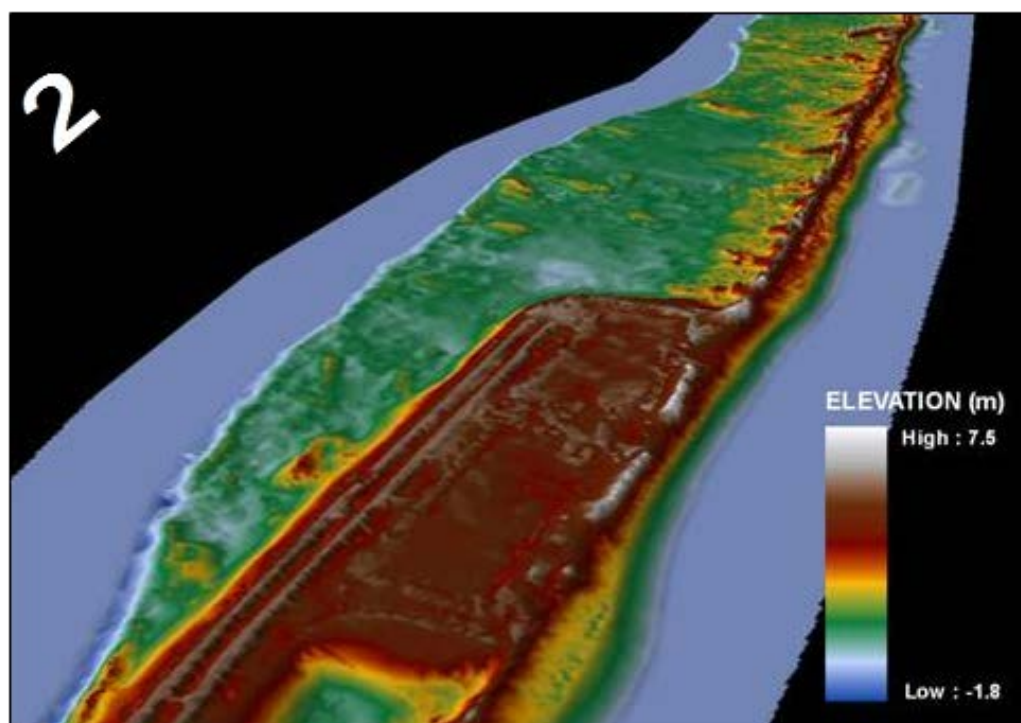


Figure 8A. FIIS historical topography shown with a three-dimensional vertical exaggeration of 1:10.

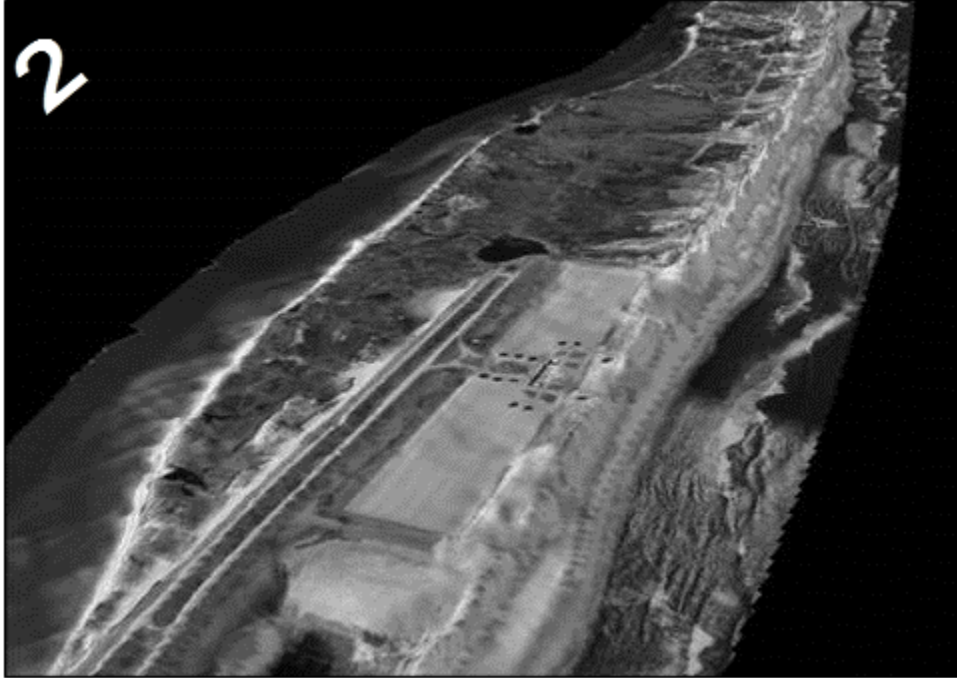


Figure 8B. FIIS 1969 orthophotomosaic draped over 1969 digital terrain model. (Vertical exaggeration is 1:10).

Accuracy Report

Positional error (E_{xy}) is calculated from a combination of terms: the 1969 image resolution (0.25 m), the accuracy of the ground control used in the processing (LiDAR xy, 1.5 m), and the average positional (xy) errors associated with the photogrammetric processing (1.06 m). Similar to the methods used by Hapke et al., (2006) the square root of the sum of the squares of these terms (RSS) is used to calculate a single term to represent the combination of positional errors of the dataset. This value applies to the positional accuracy of the DTM models, terrain data, and orthophotomosaics.

$$E_{xy} = \sqrt{0.25^2 + 1.5^2 + 1.06^2} = 1.85 \text{ m}$$

Vertical accuracy (E_z) is calculated from a combination of terms, as well: a term that correlates to the photo scale, in this case 1/10,000 of the flying height of 6000ft, or 0.18 m (Maune, *et. al.*, 2001); the LiDAR vertical error (0.20 m); the average z error from photogrammetric processing (0.23 m); and the RMS value of the historical DTM surface (0.17 m). By calculating the square root of the sum of the squares of these terms (RSS), a single term is created to represent the combination of vertical errors of the dataset. This value applies to the vertical elevation of the DTM models and the terrain data.

$$E_z = \sqrt{0.18^2 + 0.20^2 + 0.23^2 + 0.17^2} = 0.39 \text{ m}$$

Metadata

FGDC compliant metadata was created for FIIS orthophoto mosaics, digital elevation files, and digital elevation models.

Cape Cod National Seashore (CACO)

Data Collection

Historical aerial photography

Historical aerial imagery (1951, B&W, 1:10,000) for Cape Cod National Seashore (CACO) was purchased from NOAA/NOS/National Geodetic Survey (2009a; Table 1). A total of 63 images scanned using a photogrammetric-grade scanner were delivered. Coverage of CACO consists of five overlapping flight lines from Chatham to North Truro. Each flight line was compiled as an individual project using SOCET SET photogrammetric software and the resulting topographical models are organized by flight line. A data gap of two kilometers is present over the North Truro Air Force Station. (Figure 9).

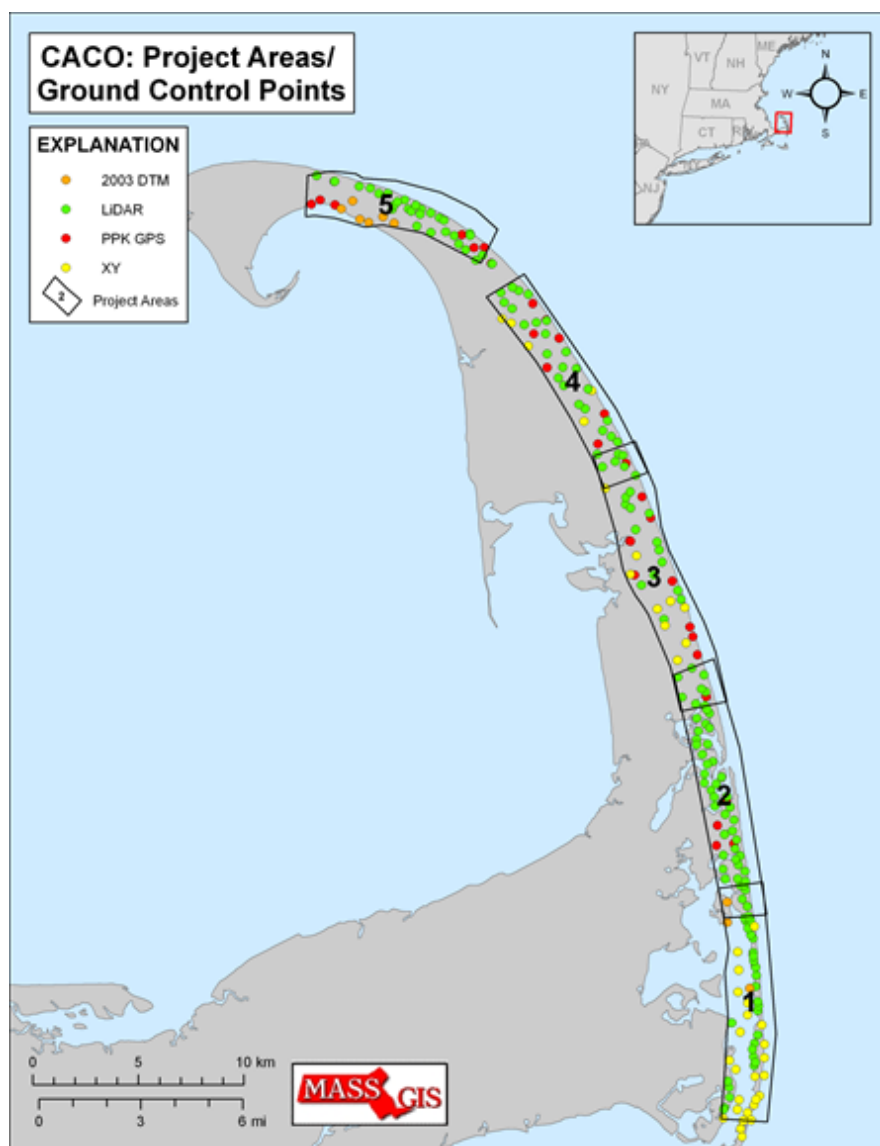


Figure 9. Project areas for Cape Cod National Seashore, with location of field-collected and LiDAR ground control points.

Ground control data

The historical imagery was first georeferenced using Arc Map v9.2 for assessment of features - prior to collection of ground control points, a network of suitable points were located by identifying unique features visible in historical imagery and modern imagery. Surveyed ground control points were collected using a post processing kinematic survey method during the summer of 2008. Post processed kinematic or PPK, is similar to RTK in that a base station is deployed for the length of the survey, but the rover and base are not in communication. During the post processing, baselines are established between rover and base files that sync the two systems. Manipulation of the base station file with standard Online Positioning User Service (OPUS) corrections (NOAA, 2009) prior to establishing and baselines allows the software to update the corrected locations when processing baselines.

In addition to points collected in the field, modern orthophotographs (Sanborn LLC, 2005) were used in collaboration with georeferenced historical aerial imagery and modern LiDAR data (CACO 2005 LiDAR; Brock et al., 2007a) to photo-locate ground control points. A ground control point dataset (CACO GCP 1951-2008) was created by assembling data points from digital resources (orthophotography, georeferenced aerial imagery, LiDAR data), and field resources (PPK GPS data collection) (Figure 9).

Photogrammetric Analysis

Project set-up

SOCET SET photogrammetry software (BAE Systems) 5.4.0 was used to create orthoimagery and digital elevation models for five project areas in CACO (Figure 9). Imagery for each flight line was imported and a new project was created in SOCET SET. Interior orientation was performed by manually measuring the location of the fiducial marks. Interior orientation is used to compare the film frame to the camera frame, and make adjustments for differences between the two that can result in errors in the photogrammetric model. No camera calibration report was provided. Information about the camera set-up, including focal length (152mm) was provided by the NOAA/National Geodetic Survey.

The UTM coordinates of the ground control points (CACO GCP 1951-2008) were organized with unique ID values to build a ground control file that could be imported into SOCET SET. IPM was then used to match ground control coordinates with the locations in historical imagery (See example from FIIS Figure 3A). Additional tie points were added as necessary to obtain a dense network of match points. Once a sufficient number of points were added, aerotriangulation was applied to transform the imagery from arbitrary frame coordinates to real-world coordinates. The model was refined by discarding or adjusting points with high root mean square error (RMS) until the RMS of the x, y, values were <1 (m), and the z value was <0.5 (m).

Digital terrain model creation

After images are assigned ground control points and an aerotriangulation solution is obtained, the sequence of overlapping images are processed using ATE to generate a DTM. ATE identifies conjugate points, and then determines the elevations (from the historical imagery) by measuring x-shifts (x parallax) in the rectified images. The measurement of these shifts is made possible because

of the image matching technology. As a part of this process, a "seed" (or modern DTM derived from LiDAR) is used optionally to help the ATE produce a more accurate DTM.

Interactive terrain editing

After the ATE has generated a DTM, consisting of a surface of points, the ITE tool allows for manual adjustment of the elevation and position of points (See example from FIIS, Figure 3B). Because the primary focus of this project is the historical terrain of the beach and dune system, the majority of detailed editing took place within this area. One important feature edit was the use of a breakline on the beach face to represent the mean high water (MHW) elevation. For Cape Cod National Seashore, as defined by Weber, *et al.* (2005), MHW is approximately 0.98m above NAVD88. Historical records from Boston, MA and Wellfleet, MA indicate that for the range of dates of the historical photography (10/20/1951-10/23/1951) the predicted higher high tide approximates the MHW elevation of 0.98m (NAVD88). Therefore, where applicable the high water line (HWL) was used as a proxy for mean high water, and an elevation of 0.98 m (NAVD88) was applied for this feature. Due to difficulty resolving stereo models where wave interference occurs on the beach face, elevation values for the beach face are estimates.

Feature extraction

DTMs created in SOCET SET consist of point (xyz) and polyline (breaklines) features. These features were exported directly to shapefiles. These shapefiles were imported into ArcMAP and 3D Analyst tools were used to create historical topographic surfaces (See example from FIIS, Figure 4).

Orthophoto generation

Once the DTM is finalized, orthophoto mosaics of each flight line were created using a mosaicking tool within SOCET SET (See example from FIIS, Figure 5A-B). Orthophotographs were then imported into ArcMap 9.2, where they were clipped and imported into a geodatabase.

GIS Analysis

DEM products

For each flight line points and polylines (breaklines) exported as shapefiles from SOCET SET were used with ArcMap 3D Analyst to create historical topographic surfaces. These shapefiles were used with ArcMap 3D Analyst to create historical topographic surfaces. First a triangulated irregular network (TIN) was generated using the posts for points and the contours as breaklines. The TIN was then converted into a raster dataset, with a cell size of 2 m (See example from FIIS, Figure 6). All raster datasets were then reviewed to assess the quality of features represented by the topography. This was done using 3D Analyst tools such as the interpolate line tool to assess the profile characteristics from the dune to the beach face. After assessment all grids were mosaicked into North and South sections of CACO. The gap in DTM coverage between north and south units is due to the gap in aerial coverage. Finally, the finished DTMs were imported into a geodatabase.

DEM subtractions

Surfaces have been created that are the result of the subtraction of CACO Digital Terrain Model 1951, from CACO 2005 LiDAR data (Figure 10).

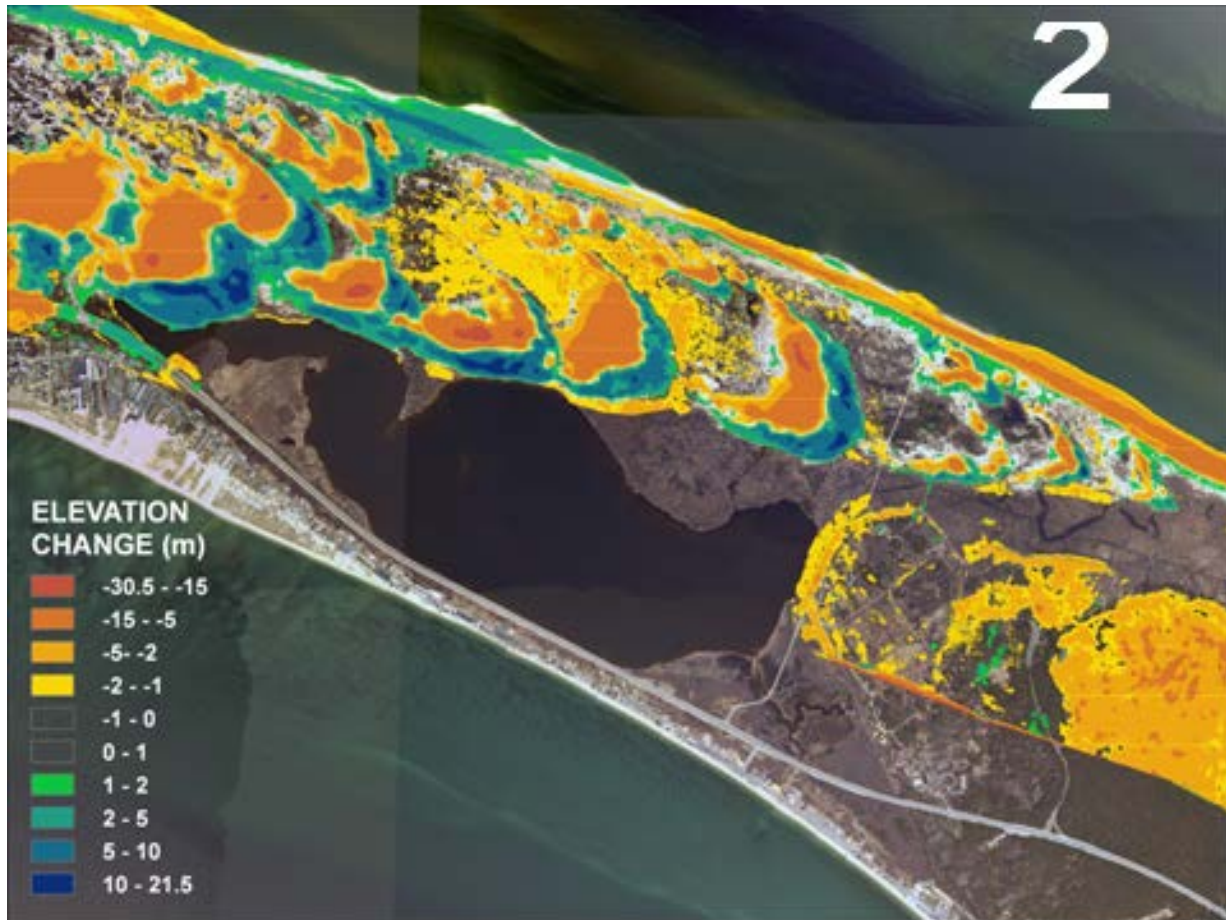


Figure 10. CACO: Example of raster subtraction of historical terrain model (1951) from modern LiDAR (2005) data. Cool colors indicate accretion and warm colors indicate erosion.

Three-dimensional renderings

In addition to displaying two-dimensional elevations, the historical DTMs allow other raster data (e.g., elevation, mosaics and subtractions) to be displayed with three-dimensional elevation exaggeration (See example from FIIS, Figure 8A-8B).

Accuracy Report

Positional error (xy) is calculated from a combination of terms: the 1951 image resolution (0.30m), the accuracy of the ground control used in the processing (LiDAR xy, 1.0 m), and the average positional (xy) errors associated with the photogrammetric processing (2.70 m). Similar to the methods used by Hapke *et al.*, (2006) the square root of the sum of the squares of these terms (RSS) is used to calculate a single term to represent the combination of positional errors of the dataset. This value applies to the positional accuracy of the DTM models, terrain data, and orthophotomosaics.

$$E_{xy} = \sqrt{0.30^2 + 1.0^2 + 2.7^2} = 2.89 \text{ m}$$

Vertical accuracy (z) is calculated from a combination of terms, as well: a term that correlates to the photo scale, in this case 1/10,000 of the flying height of 6000ft (Maune, *et. al.*, 2001), or 0.18 m; the

LiDAR vertical error (0.15 m); the average z error from photogrammetric processing (0.40 m); and the RMS value of the historical DTM surface (0.20 m). By calculating the square root of the sum of the squares of these terms (RSS), a single term is created to represent the combination of positional errors of the dataset. This value applies to the vertical elevation of the DTM models and the terrain data.

$$E_z = \sqrt{0.18^2 + 0.15^2 + 0.40^2 + 0.20^2} = 0.51 \text{ m}$$

Metadata

FGDC compliant metadata was created for CACO orthophoto mosaics, digital terrain data, and DTMs.

Gateway National Recreation Area (GATE)

SANDY HOOK, NJ

Data Collection

Historical aerial photography

Appropriate imagery for the generation of historical terrain models at Sandy Hook was not located for the purposes of this analysis. Available datasets include a set of incomplete 1940's 1:20,000 imagery obtained from Gateway National Recreation Area . Other imagery found through NOAA/NOS/ National Geodetic Survey included 1951 B&W imagery, at 1:20,000 (NOAA NOS, 2009c). Both datasets are not appropriate for historical DTM generation due to scale and/or poor coverage.

ROCKAWAY/ BREEZY POINT, NY

Data Collection

Historical aerial photography

Historical aerial imagery (1953, B&W, 1:10,000) for Gateway National Recreation Area, Rockaway Point, was acquired from NOAA/NOS/National Geodetic Survey (NOAA NOS, 2009b; Table 1). A total of 17 images scanned using a photogrammetric-grade scanner were delivered. Coverage consists of one flight line. This flight line was compiled as an individual project using SOCET SET photogrammetric software (Figure 11).

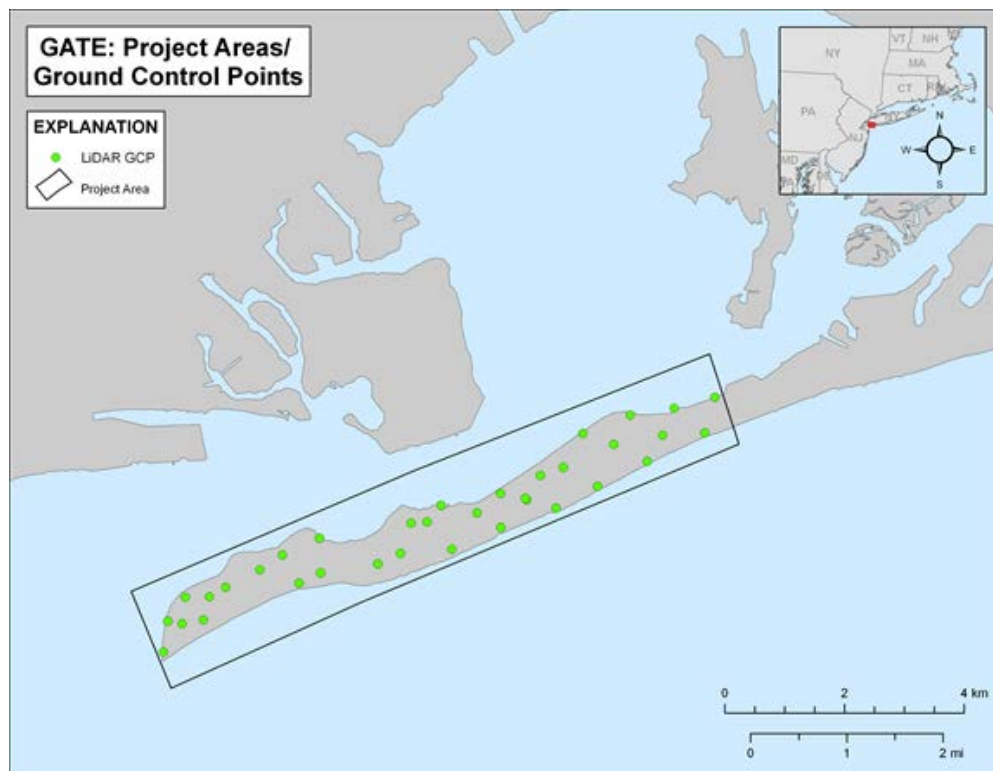


Figure 11. Project area for Gateway National Recreation Area, Breezy Point Unit, with locations of LiDAR ground control points.

Ground control data

The historical imagery was first georeferenced using Arc Map v9.2 for assessment of features - a network of suitable points were located by identifying unique features visible in both historical imagery and modern imagery. Because of the success of using LiDAR-derived ground control data in other project areas (FIIS, CACO), and in order to be more efficient with time and funding, no field surveys were conducted to collect ground control points. GATE ground control was derived from the most recent available LiDAR data (USACE, 2005), in combination with modern, high resolution orthophotos (USGS, 2006). A ground control point dataset (GATE GCP 1953-2006) was created by assembling data points from these digital resources (Figure 11).

Photogrammetric Analysis

Project set-up

SOCET SET photogrammetry software (BAE Systems) 5.4.0 was used to create orthoimagery and digital elevation models for GATE. Imagery was imported and a project was created in SOCET SET. Interior orientation was performed by manually measuring the location of the fiducial marks. Interior orientation is used to compare the film frame to the camera frame, and make adjustments for differences between the two that can result in errors in the photogrammetric model. No camera calibration report was available. Information about the camera set-up, including focal length (152mm) was provided by NOAA/National Geodetic Survey.

The UTM coordinates of the ground control points (GATE GCP 1953-2006) were organized with unique ID values to build a ground control file that could be imported into SOCET SET. IPM was then used to match ground control coordinates with the locations in historical imagery (See example from FIIS, Figure 3A). Additional tie points were added as necessary to obtain a dense network of match points. Once a sufficient number of points were added, aerotriangulation was applied to transform the imagery from arbitrary frame coordinates to real-world coordinates. The model was refined by discarding or adjusting points with high root mean square error (RMS) until the RMS of the x, y, values were <1 m, and the z value was < 0.5 m.

Digital terrain model creation

After images are assigned ground control points and an aerotriangulation solution is obtained, the sequence of overlapping images is processed using ATE to generate a DTM. ATE identifies conjugate points, and then determines the elevations (from the historical imagery) by measuring x-shifts (x parallax) in the rectified images. The measurement of these shifts is made possible because of the image matching technology. As a part of this process, a "seed" (or modern DTM- from LiDAR) is used optionally to help the ATE produce a more accurate DTM.

Interactive terrain editing

After the ATE has generated a DTM consisting of a surface of points, the ITE tool allows for manual adjustment of the elevation and position of points (See example from FIIS, Figure 3B). Because the primary focus of this project is the historical terrain of the beach and dune system the majority of detailed editing took place within this area. One important feature edit was the use of a breakline on the beach face to represent the mean high water (MHW) elevation. For Gateway National Recreation Area, (Rockaway Point), as defined by Weber, *et al.* (2005), MHW for Zone 9 (Coney Island NY, to

Princes Bay, NY) is approximately 0.59 m above NAVD88. Historical records from Sandy Hook, NJ indicate that for date of imagery (10/09/1953) the observed higher high tide reaches approximately 0.5 m (NAVD88). Therefore, where applicable the high water line (HWL) was used as a proxy for mean high water, and an elevation of 0.5 m (NAVD88) was applied for this feature. Due to difficulty resolving stereo models where wave interference occurs on the beach face, elevation values for the beach face are estimates.

Feature extraction

DTMs created in SOCET SET consist of point (xyz) and polyline (breaklines) features. These features were exported directly to shapefiles. These shapefiles were imported into ArcMAP and 3D analyst tools were used to create historical topographic surfaces (See example from FIIS, Figure 4).

Orthophoto generation

Once the DTM was finalized, an orthophoto mosaic of the flight line was created using a mosaicking tool with in SOCET SET (See example from FIIS, Figure 5A-5B). Orthophotographs were then imported into ArcMap 9.2, where they were clipped and imported into a geodatabase.

GIS Analysis

DEM products

Points and polylines (breaklines) were exported as shapefiles from SOCET SET. These shapefiles were used with ArcMap 3D analyst to create historical topographic surfaces. First a triangulated irregular network (TIN) was generated using the posts for points and the contours as breaklines. The TIN was then converted into a raster dataset, with a cell size of 2 m (See example from FIIS, Figure 6). All raster datasets were then reviewed to assess the quality of features represented by the topography. This was done using 3D tools such as the interpolate line tool to assess the profile characteristics from the dune to the beach face. Finally, the finished DTM was imported into a geodatabase.

DEM subtractions

Surfaces have been created that are the result of the subtraction of GATE Digital Terrain Model 1953, from GATE 2005 USACE LiDAR data (Figure 12).

Three-dimensional renderings

In addition to displaying two-dimensional elevations, the historical DTMs allow other raster data (e.g., elevation, mosaics and subtractions), to be displayed with three-dimensional elevation exaggeration (See example from FIIS, Figure 8A-8B).



Figure 12. GATE: Example of raster subtraction of historical digital terrain data (1953) from modern LiDAR (2006) data. Cool colors indicate accretion and warm colors indicate erosion.

Accuracy Report

Positional error (xy) is calculated from a combination of terms: the 1953 image resolution (0.25 m), the accuracy of the ground control used in the processing (LiDAR xy, 3.0 m), and the average positional (xy) errors associated with the photogrammetric processing (1.25 m). Similar to the methods used by Hapke *et al.*, (2006) the square root of the sum of the squares of these terms (RSS) was used to calculate a single term to represent the combination of positional errors of the dataset. This value applies to the positional accuracy of the DTM models, terrain data, and orthophotomosaics.

$$E_{xy} = \sqrt{0.25^2 + 3.0^2 + 1.25^2} = 3.26 \text{ m}$$

Vertical accuracy (z) is calculated from a combination of terms, as well: a term that correlates to the photo scale, in this case 1/10,000 of the flying height of 6000ft (Maune, *et. al.*, 2001), or 0.18 m; the LiDAR vertical error (0.30 m); the average z error from photogrammetric processing (0.21 m); and the RMS value of the historical DTM surface (0.27 m). By calculating the square root of the sum of the squares of these terms (RSS), a single term was created to represent the combination of positional

errors of the dataset. This value applies to the vertical elevation of the DTM models and the terrain data.

$$E_z = \sqrt{0.18^2 + 0.30^2 + 0.21^2 + 0.27^2} = 0.49 \text{ m}$$

Metadata

FGDC compliant metadata was created for GATE orthophoto mosaics, digital terrain data, and DTMs.

Assateague Island National Seashore (ASIS)

Data Collection

Historical aerial photography

Historical aerial imagery (1976, CIR, 1:10,000) for Assateague Island National Seashore was acquired from USGS EROS historical film archive (USGS/EROS, 2009; Table 1). A total of 60 images scanned using a photogrammetric-grade scanner were delivered. Coverage of ASIS consists of six overlapping flight lines. Each flight line was compiled as an individual project using SOCET SET photogrammetric software and the resulting topographical models are organized by flight line (Figure 13).

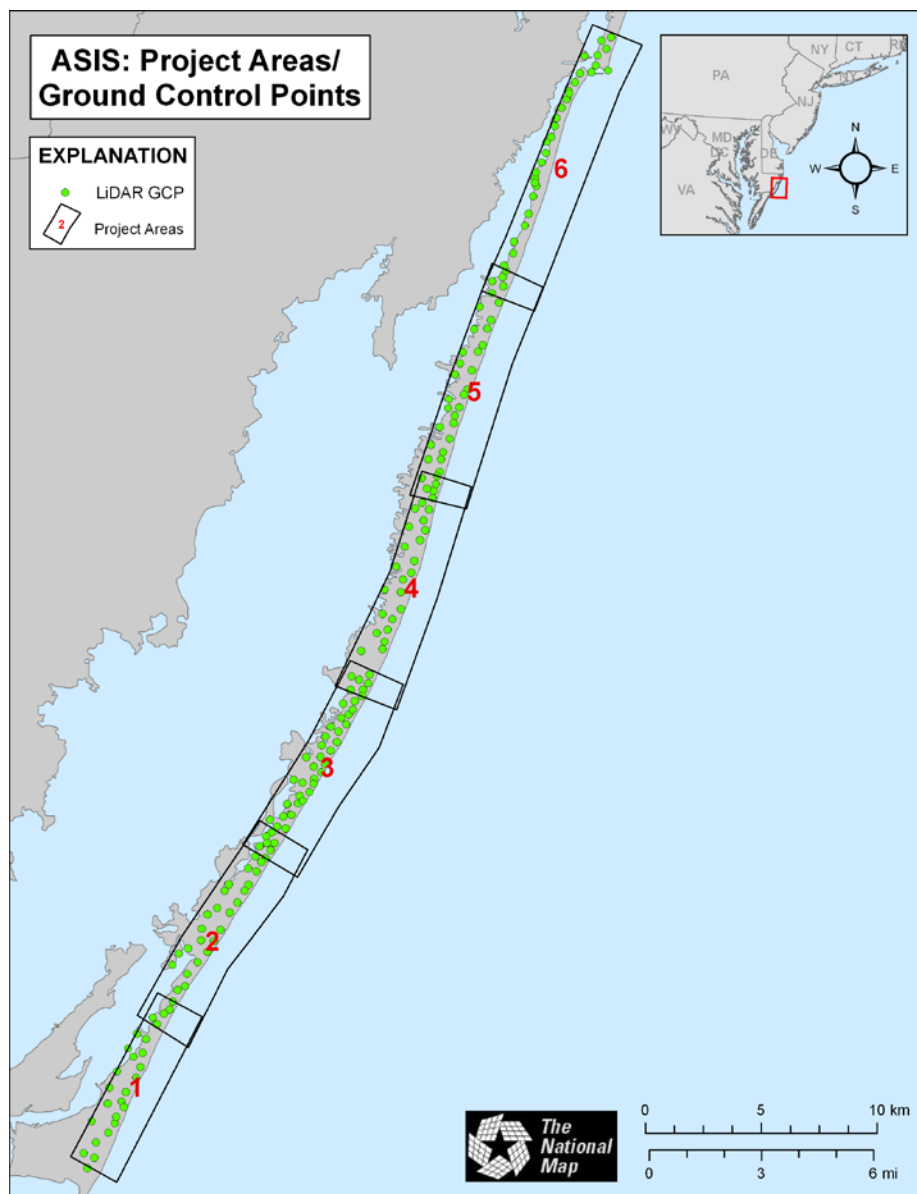


Figure 13. Project areas for Assateague Island National Seashore, with locations of LiDAR ground control points.

Ground control data

The historical imagery was first georeferenced using Arc Map v9.2 for assessment of features. A network of suitable points were located by identifying unique features visible in historical imagery and modern imagery. Because of the success of using LiDAR-derived ground control data in other project areas (FIIS, CACO), and in order to be more efficient with time and funding, no field surveys were conducted to collect ground control points. Furthermore, the lack of easily photo-identifiable points in the remote areas of ASIS would have made field location and collection difficult. ASIS ground control was instead derived from the most recent available LiDAR data (ASIS 2004 LiDAR, Brock et al., 2007b), in combination with modern, high resolution orthophotos (EarthData International, 2003). A ground control point dataset (ASIS GCP 1976-2003) was created by assembling data points from these digital resources.

Photogrammetric Analysis

Project set-up

SOCET SET photogrammetry software (BAE Systems) 5.4.0 was used to create orthoimagery and digital elevation models for the seven project areas in ASIS. Imagery for each flight line was imported and a new project was created in SOCET SET. Interior orientation was performed by manually measuring the location of the fiducial marks. A calibration report, including only the focal length (154.14mm), AWAR (area weighted average resolution), and a few distortion parameters, was provided by the USGS Optical Science Lab, Reston, VA.

The UTM coordinates of the ground control points (ASIS GCP 1976-2003) were organized with unique ID values to build a ground control file that could be imported into SOCET SET. IPM was then used to match ground control coordinates with the locations in historical imagery (See example from FIIS, Figure 3A). Additional tie points were added as necessary to obtain a dense network of match points. Once a sufficient number of points were added, aerotriangulation was applied to transform the imagery from arbitrary frame coordinates to real-world coordinates. Aerotriangulation was attempted in order to reach the desired RMS values ($x, y, <1 \text{ m}$, $z < 0.5 \text{ m}$), however, a solution was never obtained.

Digital terrain model creation

Due to non-systematic errors present in the original imagery dataset (ASIS 1976 aerial imagery), an accurate, reliable DTM could not be created using the 1976 images. Models generated resulted in DTMs with errors that could not be removed using the photogrammetric processing method, and therefore could not be used to create a final DTM for ASIS. Although the historical terrain model of ASIS was deemed unusable, the model was sufficient to create an orthophoto mosaic of ASIS.

Orthophoto generation

Orthophoto mosaics of each flight line were created using a mosaicking tool within SOCET SET (See example from FIIS, Figure 5A-5B). Orthophotographs were then imported into ArcMap 9.2, where they were clipped and imported into a geodatabase.

Accuracy Report

Positional error (xy) is calculated from a combination of terms: the 1953 image resolution (0.30 m); the accuracy of the ground control used in the processing (LiDAR xy, 1.5 m); and the average positional (xy) errors associated with the photogrammetric processing (1.52 m). Similar to the methods used by Hapke *et al.*, (2006) the square root of the sum of the squares of these terms (RSS) is used to calculate a single term to represent the combination of positional errors of the dataset.

$$E_{xy} = \sqrt{0.30^2 + 1.5^2 + 1.52^2} = 2.15 \text{ m}$$

Metadata

FGDC compliant metadata was created for ASIS orthophoto mosaics.

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NPS 962/137422, March 2017

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