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Coastal Ocean Data Systems Program

Data Integration Framework Data Management Plan

Remote Sensing Dataset

Nicholas J. Spore and Katherine L. Brodie

July 2016



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Data Integration Framework Data Management Plan

Remote Sensing Dataset

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Abstract

This Data Management Plan (DMP) details the Remote Sensing dataset which is maintained at the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center's Coastal and Hydraulics Laboratory (ERDC-CHL) Field Research Facility (FRF). Information is organized within the following categories: General Description, Points of Contact, Data Stewardship, Data Documentation, Data Sharing, Initial Data Storage and Protection, Long-Term Archiving and Preservation, Hardware and Software Requirements, Products/Programs, Tools, Data Catalog, and Abbreviations and Acronyms.

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Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE) under the Coastal Ocean Data Systems (CODS) Program, Work Unit H7oH6B, "Field Research Facility Data Integration Framework." The technical monitor was Dr. J. P. Waters.

The work was performed by the Coastal Observations and Analysis Branch (CEERD-HFA) of the Flood and Storm Protection Division (CEERD-HF), U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Dr. J. P. Waters was Chief, CEERD-HFA, and Dr. T. Wamsley was Chief, CEERD-HF. The Director of CHL was José E. Sánchez.

The USACE CODS Program is administered at CHL under the USACE Navigation Research, Development, and Technology Transfer (RD&T) Program. At the time this effort was conducted, Jeffrey A. McKee was the Headquarters, USACE (HQUSACE) Navigation Business Line Manager overseeing the CODS Program. W. Jeff Lillycrop, CHL, was the ERDC Technical Director for Civil Works and Navigation. Dr. Waters was the USACE CODS Program Manager.

COL Bryan S. Green was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Abbreviations and Acronyms

AMD	advanced micro devices
AOI	area of interest
ASA	(See RPS ASA)
asc	ASCII (file format)
ASCII	American Standard Code for Information Interchange
BIN	binary (file format)
CEERD-HF	U.S. Army Corps of Engineers, Engineer Research and Development Center, Flood and Storm Protection Division
CEERD-HF-A	U.S. Army Corps of Engineers, Engineer Research and Development Center, Flood and Storm Protection Division, Coastal Observations and Analysis Branch
CESAM	U.S. Army Corps of Engineers, Mobile District
CESAM-OP-J	U.S. Army Corps of Engineers, Mobile District, Operations Division, Spatial Data Branch
CHL	Coastal and Hydraulics Laboratory
CHS	Coastal Hazards System
CLARIS	Coastal Lidar and Radar Imaging System
COAB	Coastal Observation and Analysis Branch
CORS	Continuously Operating Reference Station
CRREL	Cold Regions Research and Engineering Laboratory
CS-W	Catalog Service for the Web
DEM	digital elevation model
DMZ	demilitarized zone
DSM	digital surface model
DTM	digital terrain model
EO	electro-optical
ERDC	U.S. Army Engineer Research and Development Center

ERDC-CHL	U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory
ESRI	Environmental Systems Research Institute
FDIF	Field Research Facility Data Integration Framework
FGDC	Federal Geographic Data Committee
FRF	Field Research Facility
FTP	file transfer protocol
GAMS	GPS Azimuth Measurement System
GB	gigabyte
GHz	gigahertz
GNSS	Global Navigation Satellite System
GPS	global positioning system
GRASS	Geographic Resources Analysis Support System
grd	grid (file format)
GRiD	Geospatial Repository and Data
ICP	iterative closest point
IMU	inertial measurement unit
INS	inertial navigation system
IR	infrared
ISO	International Organization for Standardization
JPG	joint photographic experts group (file format)
km	kilometer
LAS	laser (file format)
LAZ	laser zip (file format)
m	meters
MATLAB	Matrix Laboratory
MB	megabyte
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
OGC	Open Geospatial Consortium

PII	personally identifiable information
png	portable network graphics (file format)
POC	point of contact
POS LV	Position and Orientation System LV
QA/QC	quality assurance/quality control
QT Modeler	Quick Terrain Modeler
R&D	research and development
RAM	random access memory
rpp	Riegl proprietary file format
RPS ASA	RPS Applied Science Associates
RTK-GPS	Real-Time Kinematic Global Positioning System
rxp	Riegl eXtended Packets (file format)
SBET	smoothed best estimate of trajectory
TBD	to be determined
TR	technical report
UI	user interface
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator
WIS	Wave Information Studies

1 General Description

The U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL) operates the Field Research Facility (FRF), an internationally recognized coastal observatory established in 1977 and located on the Atlantic Ocean near Duck, NC. The ERDC-CHL Coastal Observations and Analysis Branch (COAB) maintains a number of remotely sensed datasets, including mobile and stationary lidar, X-band radar, and electro-optical (EO) and infrared (IR) imagery at the FRF. These datasets provide near real-time observations of the littoral zone throughout the year as well as during storm events. They have become an important national resource for the coastal engineering and scientific communities as a means of providing necessary in situ data for numerical model development, calibration, and verification.

To protect and preserve this important national archive, COAB has been charged with developing a Field Research Facility Data Integration Framework (FDIF), providing a modern, discoverable archive with easily accessible information for strategic analysis and reporting. To accomplish this, COAB has partnered with the USACE Mobile District, Spatial Data Branch (CESAM-OP-J) and Applied Science Associates (RPS ASA). The ERDC-CHL Wave Information Studies (WIS) and Coastal Hazards System (CHS) will also be incorporated into the framework. It is intended that the results of this project will provide a framework that can be utilized by other data management groups within both ERDC-CHL and its District partners.

This plan addresses the management of remote sensing data within the FDIF. Additional plans will be prepared simultaneously for the management of survey and oceanographic data. The project is being conducted in multiple phases. Phase I addresses mobile terrestrial lidar datasets collected between 2011 and 2013. Phase II addresses datasets collected during and after 2014 along with stationary lidar and mobile radar data collections.

This plan addresses the management of only the Phase I datasets. It will be updated once Phase II is in operation and released as a separate report.

1.1 Dataset name

Field Research Facility Remote Sensing Data

1.2 Data keywords

- bathymetry inversion
- Field Research Facility
- FRF
- dune
- foredune
- beach
- foreshore
- subaerial
- CLARIS
- LAS/LAZ
- lidar
- point cloud
- profile
- sand bar
- surf zone morphology
- survey
- topography
- digital elevation model
- DEM/DSM/DTM
- radar

1.3 Data description

The initial remote sensing dataset includes beach topography collected from a terrestrial lidar scanner on both a mobile (CLARIS—Coastal Lidar And Radar Imaging System) and stationary platform. The data is from site-specific project sites; recurring bi-monthly surveys along the town of Duck, NC; and storm surveys conducted before, during, and after storms. Terrestrial lidar data generates *x,y,z point clouds*, which are classified and edited. Bare earth points are then gridded into digital elevation models (DEMs) to generate topographic surfaces.

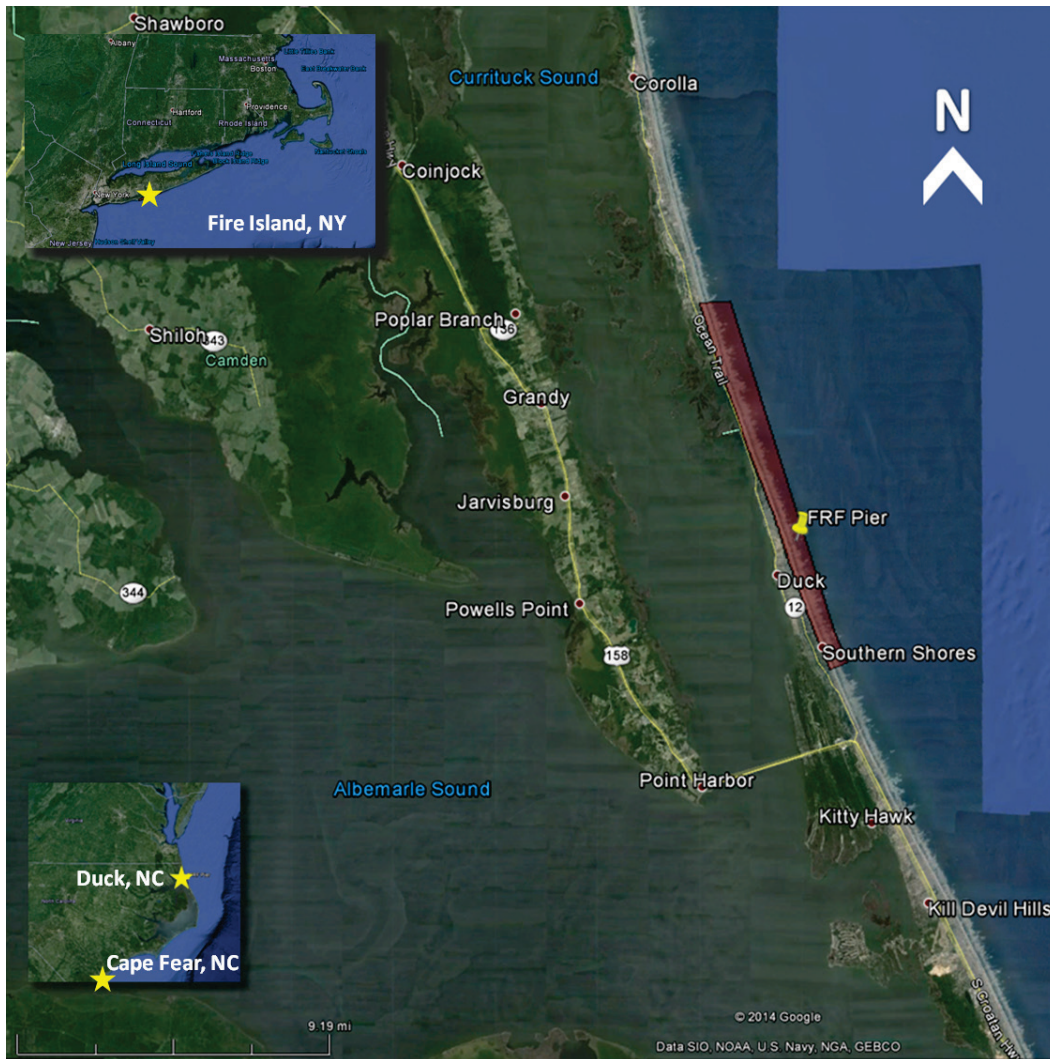
1.4 Data temporal extent

This dataset includes data collected intermittently from 2011 to 2013. Each collection typically comprises 2–4 hours of surveying time and is usually centered around low tide for imaging the beach at its widest, most exposed state.

1.5 Data geographic extent

This dataset includes various coastal areas along the East Coast of the United States, including Fire Island, NY, and Oak Island and Bald Head Island, NC. However, the majority of the data was collected near USACE's Field Research Facility in Duck, NC (highlighted in red, Figure 1).

Figure 1. Geographic extent of mobile terrestrial lidar data collected at Duck, NC.



1.6 Data types

Lidar data products include RXP binary raw files, rectified point clouds (.las/.laz), and gridded surface digital elevation model (ASCII) files, as shown in Table 1.

Table 1. Remote sensing data types.

Data Type	Data Host	Expected FDIF Ingestion
Mobile lidar	.las/.laz = Geospatial Repository & Data (GRiD) DEMs = Mobile District DMZ	End of November 2014
Stationary lidar	DEMs = Mobile District DMZ	July 2015
Mobile radar	GRiD [TBD]	TBD
EO/IR imagery	GRiD [TBD]	Summer 2016
Raw data (.rxp, .rpp, .bin)	GRiD [TBD]	TBD

1.7 Data capture/creation method

Lidar data was captured by a Riegl VZ-1000/z390i terrestrial lidar scanner system with an Applanix POS LV inertial navigation system (INS).

1.8 Data volume

Approximately 220 gigabytes (GB) of mobile terrestrial lidar data will be uploaded to the Geospatial Repository & Data (GRiD) database. Smaller DEM products will be derived from these data and uploaded to the Mobile District demilitarized zone (DMZ) for visualization within the FDIF user interface. These products include full-survey-extent DEMs broken up into tiles of smaller size for more efficient downloading and processing time. Full-extent DEMs are 1–2 GB each, with each tile at approximately 100 MB. Stationary lidar DEMs are approximately 25–50 MB each. The workflow for DEM generation is in the final stages of development, and more precise data size requirements will be available.

1.9 Data restrictions

No personally identifiable information (PII) or other information whose distribution may be restricted by law or national security is included in this dataset.

1.10 Plan storage

This plan will be stored at the USACE FRF in Duck, NC, and at the ERDC in Vicksburg, MS.

2 Points of Contact (POC)

2.1 Project POC

Katherine L. Brodie, Research Oceanographer, USACE Field Research Facility, 1261 Duck Road, Kitty Hawk, NC 27949; Katherine.L.Brodie@usace.army.mil, (252) 261-6840 x233.

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2.2 Overall POC

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2.3 Data Quality POC

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2.4 Data Collection POC

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2.5 Documentation/Metadata POC

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2.6 Data Storage/Disaster Recovery POC

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2.7 Data Management Plan (DMP) Adherence/Implementation POC

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261-6840 x228.

3 Data Stewardship

3.1 Quality control

3.1.1 Mobile lidar

The following quality assurance/quality control (QA/QC) procedures are followed when validating the integrity of terrestrial lidar data due to its structure and large spatial domain. The trajectory information used to rectify the point data is first analyzed for obvious faults, satellite drop-outs, global positioning system (GPS) Azimuth Measurement Subsystem (GAMS) ambiguities, and positional error root mean square (RMS) for latitude, longitude, and elevation through the entire trajectory. The rectified, georeferenced point cloud is then compared to previously validated surveys along fixed structures, such as rooflines and road centerlines, to quantify the survey accuracy and repeatability. Control points positioned along the trajectory that were surveyed with real-time kinematic (RTK)-GPS are also used as an accuracy check. In addition, transects are extracted perpendicular to the trajectory to measure temporal variance due to changes in the satellite constellation and GPS signal quality along the survey route, and overlapping regions are compared for vertical closure.

3.1.2 Stationary lidar

For the stationary lidar scans, QA/QC flags are implemented into the processing workflow. Iterative closest point (ICP) algorithms are applied to adjust each successive scan's roll, pitch, and yaw relative to a stable and verified baseline survey. After the ICP adjustment is performed, an indicator flag that represents the quality of the adjustment is attached to the metadata and is used to pass acceptable scans further into the processing regime or less-than-acceptable scans passed to the user for visual inspection.

3.2 Data lifecycle

3.2.1 Mobile lidar

Terrestrial GPS data is postprocessed with either National Geodetic Survey's (NGS) Continuously Operating Reference Stations (CORS) or a static, local base station and integrated with postprocessed inertial measurement unit (IMU) data through Applanix's POSpac Global

Navigation Satellite System (GNSS) software to derive a smoothed best estimate of trajectory (SBET). After processing, quantitative quality metrics are analyzed to ensure the trajectory accuracy meets the manufacturer's specified values.

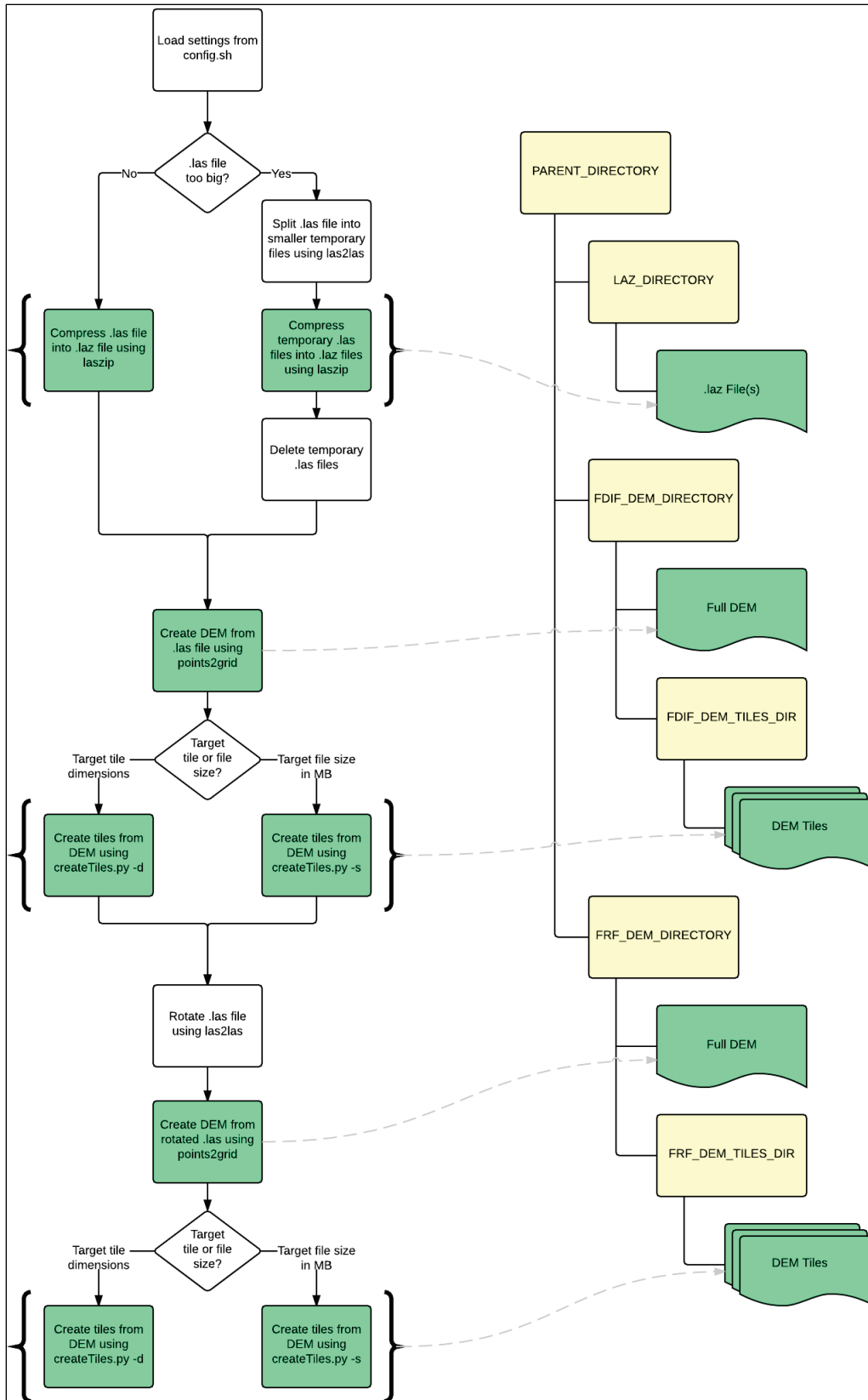
The SBET is imported into Riegl's RiProcess lidar software program, where the lidar point cloud is rectified and georegistered to a particular coordinate system, projection, and geoid model, and boresight values for roll, pitch, and yaw are applied. Control monuments and previously validated datasets are used for comparison to determine the accuracy of the survey. These are measured by cutting cross sections of the current survey overlaid on previously validated data within the software through stable structures, such as houses, monuments, and road centerlines.

The processed point cloud is manipulated within RiProcess to delineate the shoreline, filter structures, and vegetation, and to classify points as American Society for Photogrammetry and Remote Sensing (ASPRS) classification standards for water, vegetation, structures, and ground. The classified point cloud is exported as a .las(1.1) file, which is then ingested into the workflow described in Figure 2, where it is gridded into a DEM. The DEM is created with the Points2Grid algorithm utilized by USACE's GRiD geospatial archiving system at 0.5 m resolution at mean elevation within each grid cell.

3.2.2 Stationary lidar

The stationary lidar data lifecycle is still in development and follows a different workflow. After the initial collection, data is coregistered to a baseline survey using carefully selected permanent structures (i.e., control regions) for either ICP or plane fitting/matching algorithms. Afterwards, the point cloud is passed through noise, range, and classification filters to correctly trim and classify the points. Bare earth points are then saved as a .laz file and gridded into a DEM using the same process as used for mobile data (Figure 2).

Figure 2. Workflow for continuous stationary lidar data products.



4 Data Documentation

4.1 Metadata repository

The Environmental Systems Research Institute's (ESRI) Geoportal Server, which has been set up by CESAM-OP-J, is used as the FDIF metadata repository. Geoportal is a free, open-source product for managing and publishing metadata. It facilitates discovery of resources, including datasets and web services.

Geoportal Server can be used to create a Geoportal website, where data managers can register data resources for discovery by users. Geoportal stores and catalogs metadata and access information for each registered data resource. All metadata is contained in an Open Geospatial Consortium (OGC)-compliant geoportal CS-W 2.0.2 catalog service.

4.2 Additional metadata

Additional raw field metadata can be provided via scanned field log books that can be linked within the original metadata files. The feasibility of using these scanned images, as well as where they would be stored, is still yet to be determined.

Hourly metadata, which is automatically generated after each collection, accompanies each hourly stationary lidar scan. This metadata provides all parameters used for each collection, including all postprocessing information.

4.3 Data/Metadata standards

In an effort to catalog and properly manage multiple types of remote sensing datasets, detailed metadata files are included within each location or project-specific data collection. This promotes easily recognized search queries by users from a multitude of agencies, backgrounds, or professions who are interested in particular types of data. The current International Standards Organization (ISO) metadata standards have been adopted as the standard format for all metadata files, and any existing non-ISO compliant files have been updated to meet the ISO 19115 metadata standard. CatMDEdit—the software package used for metadata editing, template building, and populating—promotes efficiency with regard to user input, adaptability, and conversion of older Federal Geographic Data Community (FGDC) standards into the current ISO standards.

5 Data Sharing

5.1 Data availability

Access to this dataset is currently restricted to collaborators until research goals are completed. Data is routinely collected bimonthly with additional extreme events captured when feasible. Data will be generally available on the FDIF after research goals have been satisfied.

5.2 Data availability restrictions

This dataset is not currently available to the public because it is stored on an FRF Research and Development (R&D) server, which has no public access. Recently collected data will not be available until specific research goals are completed and published. Restricted access privileges may be provided to collaborators and contributors on a case by case basis.

5.3 Data access restrictions

Full acknowledgement of observational and modeling data supplied by the FRF provides an important metric to assess, and ultimately continue, its service to the coastal research community.

The following citation should be included in any use of these data:

Data are provided by the Coastal and Hydraulics Laboratory, U.S. Army Corps of Engineers, Field Research Facility, Duck, North Carolina.

Specific investigators and/or relevant research programs should also be acknowledged for their contributions.

5.4 Data access protocols

All data processed by the FRF Survey Application will be accessible from an enterprise database through the use of standardized web mapping services. At a minimum, the survey points (SurveyPoints), extent of survey polygons (SurveyJob), and raster grid surface will be accessible.

5.5 Catalogue registration

These data will be registered through a geoplatform available at <http://geoplatform.usace.army.mil/>.

6 Initial Data Storage and Protection

6.1 Initial data storage location

Data is currently stored at the FRF in Duck, NC; however, the goal is to store it in a database in the USACE CESAM DMZ, in Mobile, AL, with a separate schema to solely support the CHL. The CESAM-OP-J will serve as the database administrator.

6.2 Data storage protection

Data protection is provided by a firewall between the R&D server and the general public and through an offsite mirror.

6.3 Data access protection

Access to restricted data will be managed via password. Additional details will be provided if and when restricted data is designated to be included in the FDIF system. Otherwise, there are no limitations to data access.

7 Long-Term Archiving and Preservation

7.1 Data archiving location

Long-term archival is planned for the USACE Cold Regions Research and Engineering Laboratory (CRREL) GRiD system. This location has been notified and fully supports ingesting mobile and static lidar point clouds in FY15 with continued support for other remote sensing products in subsequent years. The USACE Mobile District (CESAM) will provide additional archiving on CESAM DMZ servers of DEMs generated by the point clouds hosted on GRiD for use within the FDIF portal for calculating volumes, slopes, profile comparisons, and other measurements.

7.2 Data archiving strategy

The immediate archiving strategy focuses on off-site data hosting by CRREL's GRiD system and CESAM's DMZ servers. Due to the high volume and continuous collection regime at the FRF, the feasibility of setting up an instance of GRiD locally at the facility in Duck, NC, is currently being investigated. This would allow for faster and more efficient data uploading as well as reducing bandwidth limitations when accessing large amounts of data for internal research interests.

7.3 Data archiving costs

Costs of long-term data archiving will be provided and maintained by the USACE Coastal Field Data Collection Program.

7.4 Data archiving procedures

In addition to the data files, data descriptions and metadata will be submitted to the archive to assist those using the data in the future. The data will be sent to CRREL (GRiD) via external hard disk drives containing point cloud data.

The DEMs for all of the mobile lidar data will initially be sent to CESAM (DMZ) via external hard disk drives. Subsequent mobile data and continuous stationary data will be pushed from a local directory that is continuously monitored for new file updates. After proper QA/QC is completed, the new files will be added to this directory and will be available for upload to the Mobile DMZ servers.

7.5 Data retention period

Due the importance of collecting and maintaining a long-term morphological record, the data retention period is indefinite.

8 Hardware and Software Requirements

8.1 Hardware requirements

Due to the large amount of point data stored within each dataset and the resources required to visualize a point cloud with over 400 million points, the user should have a computer with at least 15 GB of free hard disk space, a minimum of 8 GB of RAM (16 GB for faster visualization), and a multicore Intel or AMD processor operating at 2 gigahertz or faster.

8.2 Software requirements

8.2.1 Server software requirements

Server software requirements will be specified by CRREL.

8.2.2 Client-side software requirements

- Web browser (such as Chrome or Firefox)
- Data visualization program for point clouds and surfaces (such as QT Modeler, ArcMap, or Geographic Resources Analysis Support System [GRASS])
- Data analysis tools of choice (such as ArcMap, Matrix Laboratory (MATLAB), or Python)

9 Products/Programs

Phase I data products primarily focus on elevation data derived from the mobile terrestrial lidar surveys as well as the near real-time stationary lidar surveys. The elevation data is represented in its original form and position from the scanner as well as interpolated surface products. CRREL is hosting the original point cloud data in GRiD, and CESAM is hosting the interpolated DEMs used for analysis in the CESAM DMZ.

Phase II data products will potentially include more recent mobile lidar surveys, mobile radar imagery, and EO/IR imagery.

10 Tools

10.1 Visualization tools

The FDIF user interface (UI) tools serve as the primary visualization tools for the FRF remote sensing data. The UI is a map-based view that shows the location of all FRF assets and provides tabular and graphical summaries of the various data types. Color-shaded DEMs for elevation, slope, aspect, and other data are available with an adjustable/configurable color scale and gradients. Transparency options for adjusting overlay opacity and a time slider bar for available data are also implemented.

10.2 Analysis tools

10.2.1 Transect tool

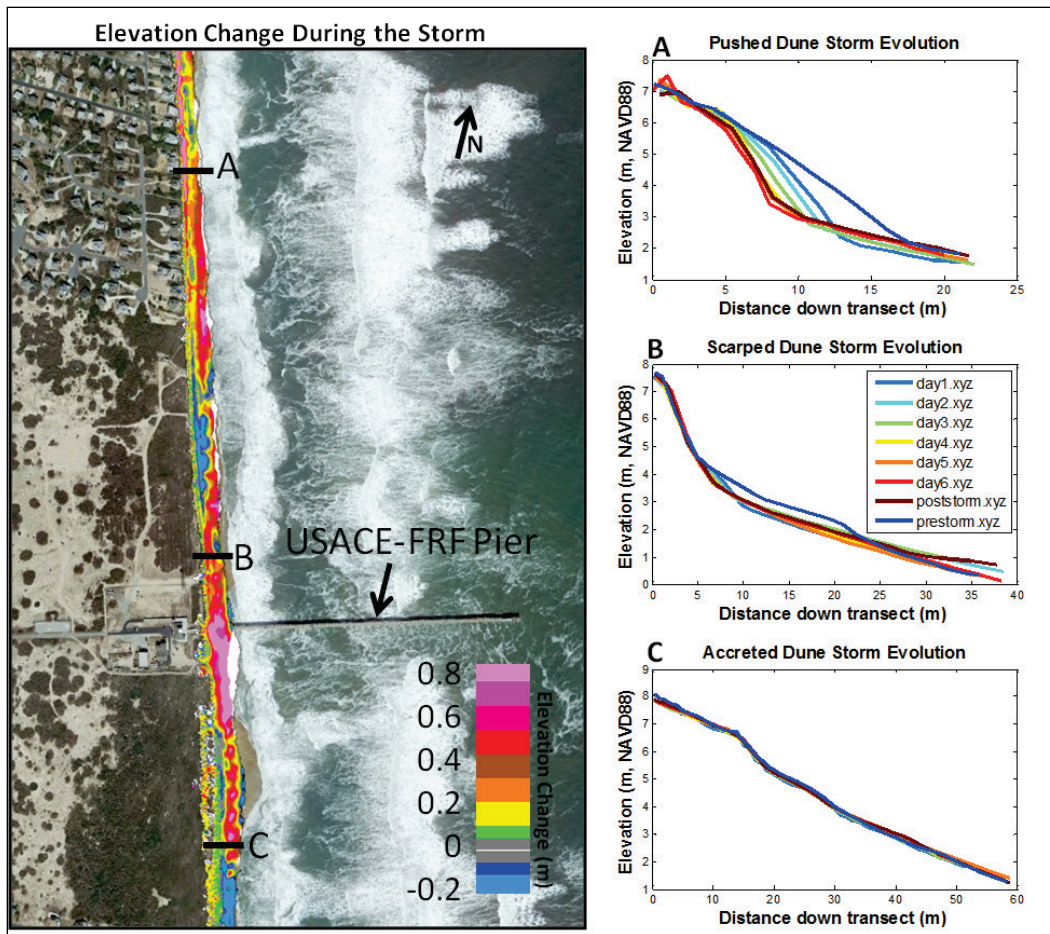
Users can draw a transect or input coordinate end points to extract profiles from multiple DEMs in the same location over a user-specified time range.

User Inputs

1. End points of transect
 - Click points on the map
 - Manually input coordinates
 - Identify an FRF survey line number or click a survey line
2. Dates of interest
 - Default: most recent DEM
 - Input a start and end date (all datasets that reside within that date range)
 - Input a date interval (hourly/daily/monthly/yearly)

Plot Output: Refer to Figure 3.

Figure 3. Map and transect views of three separate transects of interest.



Data Download

- ASCII file containing a date, X, Y, distance along transect, and Z of the displayed transect
- .jpg or .png of the generated plot

Future Products

- Multiple-points definition of the transect path
- Left/right offset from the initial transect given an input of distance to offset and number of lines
- Transect elevation and change through time as timestack (PColor) plots, where the representative transect is plotted as distance along the transect on the y -axis and time on the x -axis and colored by elevation or elevation change

10.2.2 Elevation time series tool

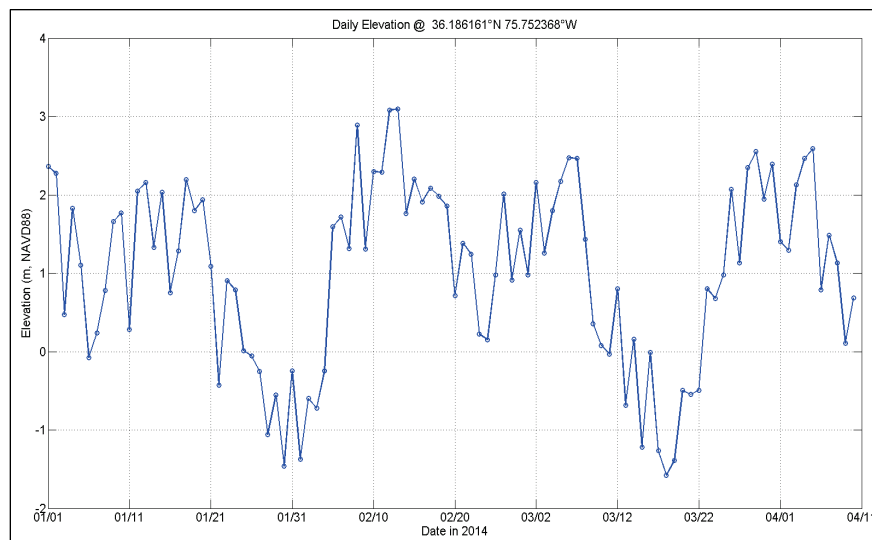
Users can pick a point within the data extents and specify a time range to plot the elevation as a function of time over all data available for the point of interest.

User Inputs

1. Location for the time series (that is, the point of interest)
 - Click on the map
 - Input coordinates
 - Click multiple points for comparing different locations and their respective elevation time-series
2. Dates of interest
 - Input a start and end date (all datasets that reside within that date range)
 - Input a date interval (hourly/daily/monthly/yearly)

Plot Output: Refer to Figure 4.

Figure 4. Elevation time series at a specified point.



Data Download

- ASCII file containing a date, X, Y, Z, and point number or unique (user-specified) identifier
- .jpg or .png of the generated plot

10.2.3 DEM visualization/download tool

User can visualize a color-shaded digital elevation model on a map and manipulate its representation for a particular application.

User Inputs

1. Boundary

- Default: maximum extent of the data
- Draw a box on the map for an area of interest
- Input bounding coordinates

2. Dates of interest

- Default: most recent DEM
- Input a start and end date (all datasets that reside within that date range)
- Input a date interval (hourly/daily/monthly/yearly)

Plot Output: Refer to Figure 5.

Display Properties

- User-defined color axes
- Ability to edit the color map
- No-data values display as transparent

Data Download

- ASCII grid file of elevations
- .jpg or .png of the generated plot

Figure 5. Color-shaded elevation raster displayed over aerial imagery.



10.2.4 Surface difference tool

Two specified datasets from different collection dates but overlapping geographic extents can be subtracted with respect to each other to produce a change map with customizable colors, color scale, and gradient. Areas that do not geographically overlap are represented as 100% transparent.

User Inputs

1. Boundary
 - Default: maximum extent of data
 - Draw a box on the map for an area of interest
 - Input bounding coordinates
2. Dates of interest (two are required for differencing)
 - Default: most recent two dates
 - Input a start and end date (all datasets that reside within that date range)
 - Input a date interval (hourly/daily/monthly/yearly)
 - Plot Output: Refer to Figure 6.

Figure 6. Color-shaded surface elevation difference map between pre- and post-storm dates.



Display Properties

- User-defined color axes
- Ability to edit the color map
- Areas of no data or no data overlap are transparent
- No-data values are transparent

Data Download

- ASCII grid file of elevation differences
- .jpg or .png of the generated plot

10.3 Upload tools

FRF staff will upload new datasets to the host site via file transfer protocol (FTP) or, when necessary due to the size of the dataset or a limited local bandwidth, delivery of an external hard disk drive.

10.4 Download tools

10.4.1 Rectangular/Polygon areas of interest (AOIs)

Users can draw an AOI on the map interface to display a table that identifies all data available for download directly from the FDIF portal and also other datasets available within GRiD.

10.4.2 Coordinate system conversion

Data can be reprojected into a multitude of coordinate systems for download, with initial emphasis on Universal Transverse Mercator (UTM), State Plane Systems, Geographic, and local FRF coordinates.

10.5 Other tools

Depending upon FDIF development completed this year, additional tools may be developed—for example, a tool to create custom plots from blank axes with options for time, distance along transect, elevation, volume, slope, and elevation change. The ability to add oceanographic data as a subplot would help analyze morphologic changes with respect to the oceanographic/environmental forcing (for example, a time series of wave height as a subplot under a time series of elevation change).

Appendix A: Data Catalog

A.1 Mobile terrestrial lidar data 2011–2013 – Point clouds

Description: High-resolution lidar point cloud data (total 220 GB)

Table A1. Mobile terrestrial lidar data 2011–2013 – Point clouds.

Survey Date	Scanner Type	Duration/Length	Classification Scheme	Formats	Archive Size	Products/Notes
25 Aug 2011	Z390i	11 km	None	.las/.laz	0.80 GB	Pre-Hurricane Irene, Duck, NC
28 Aug 2011	Z390i	4.5 km	None	.las/.laz	0.50 GB	Post-Hurricane Irene, Duck, NC
31 Jan 2012	VZ1000	30 km	Yes	.las/.laz	23.9 GB	Fire Island, NY (winter)
13 Jun 2012	VZ1000	FRF property	Yes	.las/.laz	0.49 GB	Summer beach conditions
14 Aug 2012	VZ1000	10 km	Yes	.las/.laz	11.3 GB	Oak Island, NC (summer)
15 Aug 2012	VZ1000	10 km	Yes	.las/.laz	10.4 GB	Bald Head Island, NC (summer)
06 Nov 2012	VZ1000	12 km	Yes	.las/.laz	8.75 GB	Post-Hurricane Sandy, Duck, NC
06 Jan 2013	VZ1000	10 km	Yes	.las/.laz	10.6 GB	Oak Island, NC (winter)
07 Jan 2013	VZ1000	10 km	Yes	.las/.laz	11.2 GB	Bald Head Island, NC (winter)
06 Mar 2013	VZ1000	12 km	Yes	.las/.laz	9.69 GB	Pre-Nor'easter, Duck, NC
07 Mar 2013	VZ1000	12 km	Yes	.las/.laz	6.20 GB	4 m Nor'easter, Duck, NC
08 Mar 2013	VZ1000	12 km	Yes	.las/.laz	6.13 GB	4 m Nor'easter, Duck, NC
09 Mar 2013	VZ1000	12 km	Yes	.las/.laz	6.57 GB	4 m Nor'easter, Duck, NC
10 Mar 2013	VZ1000	12 km	Yes	.las/.laz	7.64 GB	4 m Nor'easter, Duck, NC
11 Mar 2013	VZ1000	12 km	Yes	.las/.laz	6.61 GB	4 m Nor'easter, Duck, NC
13 Mar 2013	VZ1000	12 km	Yes	.las/.laz	8.82 GB	4 m Nor'easter, Duck, NC
20 Mar 2013	VZ1000	12 km	Yes	.las/.laz	6.97 GB	Post-Nor'easter, Duck, NC
10 Apr 2013	VZ1000	30 km	Yes	.las/.laz	14.5 GB	Fire Island, NY (storm)
11 Apr 2013	VZ1000	30 km	Yes	.las/.laz	15.7 GB	Fire Island, NY (storm)
12 Apr 2013	VZ1000	30 km	Yes	.las/.laz	11.8 GB	Fire Island, NY (storm)
13 Apr 2013	VZ1000	30 km	Yes	.las/.laz	12.0 GB	Fire Island, NY (storm)
17 Jun 2013	VZ1000	FRF property	None	.las/.laz	1.11 GB	NOAA tri-lidar target flights
17 Jul 2013	VZ1000	10 km	Yes	.las/.laz	7.32 GB	Oak Island, NC (summer)
18 Jul 2013	VZ1000	10 km	Yes	.las/.laz	4.35 GB	Bald Head Island, NC (summer)
04 Sep 2013	VZ1000	10 km	Yes	.las/.laz	6.03 GB	Bi-monthly morphology, Duck, NC
12 Dec 2013	VZ1000	20 km	Yes	.las/.laz	11.5 GB	Bi-monthly morphology, Duck, NC

A.2 Mobile terrestrial lidar data 2011–2013 – Digital elevation models

Description: Mean elevation grid at 0.5 m resolution interpolated from the point clouds referenced in A.1

Table A2. Mobile terrestrial lidar data 2011–2013 – Digital elevation models.

Survey Date	Scanner Type	Duration/Length	Classification Scheme	Formats	Archive Size	Products/Notes
25 Aug 2011	Z390i	11 km	None	.asc/.grd	TBD	Pre-Hurricane Irene, Duck, NC
28 Aug 2011	Z390i	4.5 km	None	.asc/.grd	TBD	Post-Hurricane Irene, Duck, NC
31 Jan 2012	VZ1000	30 km	Yes	.asc/.grd	TBD	Fire Island, NY (winter)
13 Jun 2012	VZ1000	FRF property	Yes	.asc/.grd	TBD	Summer beach conditions
14 Aug 2012	VZ1000	10 km	Yes	.asc/.grd	TBD	Oak Island, NC (summer)
15 Aug 2012	VZ1000	10 km	Yes	.asc/.grd	TBD	Bald Head Island, NC (summer)
06 Nov 2012	VZ1000	12 km	Yes	.asc/.grd	TBD	Post-Hurricane Sandy, Duck NC
06 Jan 2013	VZ1000	10 km	Yes	.asc/.grd	TBD	Oak Island, NC (winter)
07 Jan 2013	VZ1000	10 km	Yes	.asc/.grd	TBD	Bald Head Island, NC (winter)
06 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	Pre-Nor'easter, Duck, NC
07 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	4 m Nor'easter, Duck, NC
08 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	4 m Nor'easter, Duck, NC
09 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	4 m Nor'easter, Duck, NC
10 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	4 m Nor'easter, Duck, NC
11 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	4 m Nor'easter, Duck, NC
13 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	4 m Nor'easter, Duck, NC
20 Mar 2013	VZ1000	12 km	Yes	.asc/.grd	TBD	Post-Nor'easter, Duck, NC
10 Apr 2013	VZ1000	30 km	Yes	.asc/.grd	TBD	Fire Island, NY (storm)
11 Apr 2013	VZ1000	30 km	Yes	.asc/.grd	TBD	Fire Island, NY (storm)
12 Apr 2013	VZ1000	30 km	Yes	.asc/.grd	TBD	Fire Island, NY (storm)
13 Apr 2013	VZ1000	30 km	Yes	.asc/.grd	TBD	Fire Island, NY (storm)
17 Jun 2013	VZ1000	FRF property	None	.asc/.grd	TBD	NOAA tri-lidar target flights
17 Jul 2013	VZ1000	10 km	Yes	.asc/.grd	TBD	Oak Island, NC (summer)
18 Jul 2013	VZ1000	10 km	Yes	.asc/.grd	TBD	Bald Head Island, NC (summer)
04 Sep 2013	VZ1000	10 km	Yes	.asc/.grd	TBD	Bi-monthly morphology, Duck, NC
12 Dec 2013	VZ1000	20 km	Yes	.asc/.grd	TBD	Bi-monthly morphology, Duck, NC

A.3 Continuous tower-mounted stationary lidar – Digital elevation models

Description: Mean elevation grid at 0.5 m resolution interpolated from hourly framescan point clouds

Table A3. Continuous tower-mounted stationary lidar data – Digital elevation models.

Survey Date	Scanner Type	Duration/ Length	Classification Scheme	Formats	Archive Size	Products/Notes
TBD	VZ1000/2000	500 m	Yes	.asc/.grd	TBD	Hourly beach framescans

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