December, 2009

ATTACHMENT Y
Light Detection and Ranging (LIDAR) Requirements

SCOPE OF WORK FOR SHORELINE MAPPING
UNDER THE
NOAA COASTAL MAPPING PROGRAM

REMOTE SENSING DIVISION
NATIONAL GEODETIC SURVEY
NATIONAL OCEAN SERVICE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

LIDAR REQUIREMENTS

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APPENDICES:

1. GENERAL

The National Geodetic Survey (NGS) Remote Sensing Division's (RSD) primary motivation to collect airborne topographic lidar data is to enable accurate and consistent measurement of the national shoreline. The shoreline is defined as the land water interface at a specific tidal datum. Topographic LIDAR is employed as an accurate, efficient way to collect data for generation of a DEM which is in turn used to compile vectors for generating the Mean High Water (MHW) level at the shoreline. This includes areas of wave run up. The Coastal Mapping Program (CMP) works to provide a regularly-updated and consistent national shoreline to define America's marine territorial limits and manage coastal resources. This shoreline is applied to National Oceanic and Atmospheric Administration (NOAA) nautical charts and is considered authoritative when determining the official shoreline for the United States. The CMP is administered by the NGS, the National Ocean Service (NOS), and the NOAA.

This Scope of Work defines requirements for LIDAR data acquisition and processing to support the CMP. In addition, NOAA participates with the Interagency Working Group on Ocean and Coastal Mapping and the Committee on Marine Transportation Safety (IWG-OCM) to develop common standards for airborne coastal mapping and charting data and products. These standards were developed in conjunction with the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) partner agencies (U.S. Army Corps of Engineers (USACE), U.S. Naval Oceanographic Office), and the U.S. Geological Survey (USGS) Center for Coastal and Watershed Studies.

Project Instructions will provide project-specific information.

The following conventions have been adopted for this document. The term "shall" means that compliance is required. The term "should" implies that compliance is not required, but is strongly recommended. All times shall be recorded in Coordinated Universal Time (UTC).

2. GOVERNMENT

2.1 PROPERTY OF DATA

All original data, from the instant of acquisition, and other deliverables required through this contract including final data, are and shall remain the property of the United States Government. This includes data collection outside the project area. These items include the contractor-furnished materials.

2.2 PROVIDED BY GOVERNMENT

The government will provide to the Contractor:

A. PROJECT INSTRUCTIONS – Project Instructions are a separate document providing specific project information, containing any unique project requirements, and may have the following attachments:

i. Small scale maps showing the coastline and/or coastal ports to be acquired
ii. Tide coordination time windows for data acquisition, see Section 8

B. LIDAR ACQUISITION REQUIREMENTS (this document)

C. REJECTED DATA – If data are rejected by NGS, NGS will send sample data upon request showing the problem areas.

3.0 DELIVERY SCHEDULE AND DATA FLOW

3.1 REGULAR PRODUCTION

Any request to deviate from these standards shall be submitted, in advance of data acquisition, to NGS for written approval.

3.1.1 DATA ACQUISITION STANDARDS

A. Position Dilution of Precision (PDOP) shall be <3.

B. LIDAR point cloud post spacing shall not exceed limits defined in separate Project Instructions.

C. Digital Surface Model (DSM) grid size (spatial resolution) shall not exceed limits defined in separate Project Instructions. The DSM is defined as a regular grid of elevations that depict heights of the top surfaces of vegetation, buildings, towers and other elevated features above the bare earth. Additional guidance on the gridding, vertical datum, and processing instruction may be defined further in the Project Instructions.

Aircraft bank angle shall not exceed 15 degrees.

3.1.2 DATA PROCESSING

A. The point cloud and DSM data shall be projected in Universal Transverse Mercator (UTM) and referenced to the North American Datum 1983 (NAD 83). Only one UTM zone shall be used, even if the project area splits zones.

B. The vertical datum for the point cloud shall be Ellipsoid North American Datum 1983 (NAD 83), whereas the DSM vertical datum will be specified further in the Project Instructions.

C. Contractor shall remove outliers in raw data prior to interpolation. Outliers include obvious noise or clutter in the data such as returns from birds or atmospheric particles, or due to electronic noise; however be careful to not reclassify real features such as offshore rocks. In the LAS file, no points shall be permanently removed; rather they should be assigned to the appropriate class. Interpolation shall be completed with industry standard software to facilitate validation of DSM. Contractor shall provide details of interpolation process (software and method). If possible, the contractor should utilize Delaunay triangulation with linear interpolation for the gridding of these data sets. This is performed by first creating a Triangular Irregular Network (TIN) from the LIDAR point data. A filter or constraint should be applied to the TIN that limits the length of a triangle side in the surface being created. The maximum triangle side shall be 3X the resolution of the grid being created. Therefore no triangle side greater than 3X the resolution of the grid in meters will be created. In areas beyond 3X the resolution of the grid in any direction of a LIDAR return where another LIDAR return cannot be found, a null value is specified to that particular portion of the surface being generated. A regular grid is then populated through the extraction of elevation information for each grid cell from the corresponding TIN using linear interpolation.

D. There shall be no holidays in the data (no data gaps) unless unavoidable (e.g., water areas) in which case other mapping methods may be used if approved by NGS. Interpolation across or smoothing over holidays is unacceptable and may result in rejection of the data by NGS. Any holidays shall be filled with additional data collection unless approved by NGS.

E. Contractor shall record all process steps and software used including version number.

F. Contractor shall use either the rapid or precise ephemeris for Global Positioning System (GPS) processing.

3.1.3 ACCURACY STANDARDS / SPECIFICATIONS

Accuracy reporting, i.e. Root Mean Square Error (RMSE) $_{X,Y,Z}$, shall follow methods set forth by the American Society of Photogrammetry and Remote Sensing (ASPRS) Lidar Committee (PAD) at http://www.asprs.org/society/committees/lidar/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf.

Accuracy shall be determined by the following methods:

A. The contractor shall obtain a minimum of 30 validation check points using geodetic quality measurements distributed throughout the project area on flat terrain, or on uniformly sloping terrain along the entirety of the project area. The X, Y, and Z components shall all be referenced to the NSRS (National Spatial Reference System) and in the same coordinate system and datum used in the rest of the project. As a rule of thumb, the accuracy of the check points should be an order of magnitude better than the LIDAR data. At a minimum, based on the ASPRS LIDAR guidelines, the check point accuracy should be at least three times better than the accuracy of the LIDAR data they are being used to test.

B. Contractor shall verify internal consistency of range measurements in areas of overlap among swaths that shall agree with system specifications of the LIDAR instrument.

C. Computing Errors:

Errors shall be calculated for both Point Clouds and DSM deliverables.

Point Cloud:

The difference or error for each checkpoint shall be computed by subtracting the surveyed elevation of the checkpoint from the LIDAR dataset elevation interpolated at the x/y coordinate of the checkpoint.

DSM:

The difference or error for each checkpoint shall be computed by subtracting the surveyed elevation of the checkpoint from the DSM grid cell that corresponds with the x/y coordinate of the checkpoint.

$\text{Vertical Error}_{(i)} = (Z_{data(i)} - Z_{check(i)})$

Where:

$Z_{data(i)}$ is the vertical coordinate of the i^{th} checkpoint in the data set.

$Z_{check(i)}$ is the vertical coordinate of the i^{th} checkpoint in the independent source of higher accuracy.

i is the integer from 1 to n; n = the number of points being checked

D. Systematic errors shall be identified and eliminated from the delivered data set

E. Calculating and Reporting Vertical Accuracy:

The fundamental vertical accuracy of a dataset must be determined with the checkpoints only in open terrain. Fundamental vertical accuracy shall be calculated at the 95 percent confidence level as a function of $RMSE_{z.}$

i. Compute $RMSE_{(z)} = \text{Sqrt}[(\sum(Z_{data(i)} - Z_{check(i)})^2)/n]$

ii. Compute $\text{Accuracy}_{(z)} = 1.9600 * RMSE_{(z)}$ = Vertical Accuracy at 95 percent confidence level.

iii. Report $\text{Accuracy}_{(z)}$ as:

"Tested ________ (meters) fundamental vertical accuracy at 95 percent confidence level in open terrain using RMSE(z) x 1.9600."

F. All validation data shall be submitted to the NGS, as well as an accuracy report that includes a statistical summary of the data quality. This shall include presentation of the $RMSE_{(z)}$, a table summarizing the overall statistics of both the $RMSE_{(Z)}$ consisting of: number of points, mean, median, mode, skewness, standard deviation, minimum, and maximum representative of the $RMSE_{(z)}$ calculation, as well as a table and separate histogram that illustrate the derived delta between each validation checkpoint and that of both the LIDAR mass point cloud and the derived DSM.

G. The expected horizontal accuracy of elevation products as determined from system studies or other methods shall be reported.

The contractor shall adhere to the LIDAR Common Specifications issued by JALBTCX as outlined in Table 1 and which can be found in entirety at: http://www.jalbtcx.org/Standards.aspx

Vertical Accuracy	15cm RMSE
Horizontal Accuracy	1m RMSE
Spot Spacing	1m
Percent Coverage	Ensure 100% coverage
Percent Overlap	Ensure 100% coverage
Effective Footprint	10cm
Tide Coordination	When possible low tide
Pulse Width	NA
Return Logic	Threshold detect -2 returns
Classification	LAS 1 and 2

Table 1 Coastal Mapping Specific LIDAR Standard

In addition to LIDAR data, the contractor may supply ortho-imagery. The standards for the imagery shall adhere to or supersede those outlined in Table 2 below (from JALBTCX, Draft Common Specifications Matrix http://www.jalbtcx.org/Standards.aspx).

Horizontal Accuracy	2m
Spatial resolution	20cm RGB, 1m
Spectral Resolution	19nm FWHM
Spectral Range	VNIR
Spectral Bands	36
Tide Coordination	When possible low tide
Camera Calibration	Yes
Stereo Coverage	Yes
Endlap / Sidelap	60% / 30%
Sun Angle	>20° elevation
Max Cloud Cover	10%
Patch	Yes
Visibility	8miles

Table 2 Ortho-Imagery Specifications

3.2 DATA FORMAT AND STANDARDS

A. Format of deliverables shall be:

i. Point Cloud: LAS 1 and 2 in addition to any more recent version of the LAS standard at time of delivery will be required and specified further in the Project Instructions. The LAS file shall contain all recorded returns (i.e. first, last, and any intermediate returns), return number, scan angle, scan direction, GPS time, intensity, X, Y, Z, and the edge of the flight line (if available) for points used to generate the DSM. If digital aerial imagery is collected concurrently the LAS file should be version 1.2 and contain an associated RGB and/or IR value for each LIDAR point. Details on LAS format standards can be found at:
http://www.asprs.org/society/committees/lidar/lidar_format.html

ii. ASCII files

iii. Laser reflectance images

iv. Shoreline output in NAVD 88

v. Land Cover Classification

vi. Hyperspectral reflectance (standards TBD)

vii. Digital Surface Model (DSM) and Digital Elevation Model (DEM): GEOTIFF.

viii. Orthomosaics

ix. Shoreline vectors: shape file.

B. The media for deliverable shall be a portable hard drive formatted as NTFS.

Contractor shall maintain a copy of the data until NGS acknowledges receipt.

3.3 DATA FLOW

A. Acquisition Contractor (AC) acquires data,

B. AC processes data to NGS specifications,

C. AC validates data versus check points,

D. AC ships data to NGS,

E. NGS receives data, acknowledges receipt, reviews data, notifies AC of review outcome.

F. If during the NGS review, the data are found to not meet the Scope of Work (SOW), the contractor may be required to re-acquire the data.

3.4 COMPLETION DATE

All deliverables shall be received by NGS, as specified, no later than the date in the Project Instructions.

<u>4. EQUIPMENT AND MATERIAL</u>

4.1 INERTIAL MEASUREMENT UNIT

The Inertial Measurement Unit (IMU) employed in the LIDAR system shall meet or exceed the following performance specifications:

A. Accuracy in roll and pitch (RMS): 0.015^{o}

B. Accuracy in heading (RMS): 0.050^{o}

4.2 LIDAR SENSOR

A. MAINTENANCE – Prior to commencing data acquisition, the contractor shall provide the following to NGS: certification that both preventive maintenance and factory calibration have been completed either in accordance with the manufacturer's scheduled intervals, or as justified by apparent lack of calibration stability, whichever interval is shorter.

B. DATA COLLECTION

i. Carrier-phase L1 and L2 kinematic GPS shall be acquired and used in processing the trajectories. See section 9 for further details.

ii. The LIDAR system must acquire and output "intensity" data (i.e., data values proportional to the amplitude of each received laser echo).

iii. The LIDAR system shall record the "true" last pulse. For example, in a system that collects three returns, the third return must correspond to the last detectable pulse within the return waveform to maximize the probability of getting the true (or closest to true) terrain measurement below the vegetation; it is not acceptable to simply record the first three events.

C. MALFUNCTIONS – All LIDAR system malfunctions shall be recorded, and NGS notified. A malfunction is defined as a failure anywhere in the LIDAR sensor that causes an interruption to the normal operation of the unit Also, record and report any malfunctions of the GPS or IMU collection systems.

4.3 AIRCRAFT

A. PLATFORM TYPE – The type of aircraft and the aircraft tail number used shall be stated on the LIDAR Flight Log (Appendix A) and all aircraft used in the performance of this Project shall be maintained and operated in accordance with all regulations required by the Federal Aviation Administration. Any inspection or maintenance of the aircraft for performance of this Project which results in missed data collection shall not be considered as an excusable cause for delay. The contractor shall ensure that the aircraft has a proven service ceiling, with operating load (fuel, crew, sensor, and other required equipment), of not less than the highest altitude required to acquire the data.

B. PORT OPENING – The design of the port opening(s) in the aircraft shall be such that the field of view is unobstructed when a sensor is mounted with all its parts above the outer structure. The field of view shall, so far as is practicable, be shielded from air turbulence and from any outward flows, such as exhaust gases, oil, etc.

C. OPTICAL FLAT – NGS recommends that an optical flat not be used. If an optical flat is used, the physical characteristics of the window (such as size, thickness, smoothness, flatness, parallelism, glass quality, and optical transmissivity) shall be reported to NGS prior to use. The optical flat shall meet the following specifications:

i. High transmittance at the laser wavelength;

ii. Mounted in material eliminating mechanical stress to the window;

iii. Free of blemishes, dirt, significant scratches, etc.;

iv. Not degrade the accuracy of the range measurements.

<u>5. SYSTEM CALIBRATION</u>

Inadequate calibration or incomplete calibration reports shall be cause for rejection of the data by NGS. Calibration reports for each LIDAR system used shall be supplied to NGS at the beginning and end of the project. The calibration reports shall cover each of the following types of calibration:

A. FACTORY CALIBRATION – Factory calibration of the LIDAR system shall address both radiometric and geometric performance and calibration. The following briefly describes the parameters to be tested according to test procedures defined by the manufacturer. Some of these procedures and parameters may be unique to a manufacturer since hardware varies from manufacturer to manufacturer.

i. Radiometric Calibration (sensor response):

- Ensure that the output of the laser meets specifications for pulse energy, pulse width, rise time, frequency, and divergence for the model of LIDAR being tested.
- Measure the receiver response from a reference target to ensure that the response level of the receiver is within specification for the model of LIDAR system being tested.
- Check the alignment between transmitter and receiver and certify that the alignment is optimized and within specification. (Misalignment can lead to poor signal to noise ratios, as well as intensity “banding” or “striping” artifacts.)
- Measure T0 response of receiver (i.e., the response at the time the laser is fired) to ensure that the T0 level is within specification.

ii. Geometric Calibration:

- Range Calibration – Determine rangefinder calibrations including first/last range offsets, temperature dependence, and frequency offset of rangefinder electronics, range dependence on return signal strength. Provide updated calibration values.
- Scanner Calibration – Verify that the scanner passes accuracy and repeatability criteria. Provide updated scanner calibration values for scanner offset and scale (or additional parameters [coefficients], if a higher order polynomial correction is used).
- Position Orientation System (POS)-Laser Alignment – Alignment check of output beam and POS. Also, provide updated POS misalignment angles.

Overall, the system shall be tuned to meet the performance specifications for the model being calibrated. The contractor shall ensure that, for each LIDAR system used, factory calibration has been performed within the 12 month period preceding the data collection. Recalibration is required at intervals no greater than 12 months. Contractors who wish to apply for a waiver to this requirement must send a written request to NGS stating the date of the last factory calibration and a detailed justification for the waiver.

B. FIELD CALIBRATION – Field calibration is performed by the system operator through flights over a calibration site that has been accurately surveyed using GPS or conventional survey techniques such as triangulation or spirit leveling. The calibration may include flights over the site in opposing directions, as well as cross strips. The field calibration is used to determine corrections to the roll, pitch, and scale calibration parameters. Field calibration must be performed for each project or every month, whichever is shorter.

C. DETERMINATION of sensor-to-GPS-antenna offset vector components ("lever arm"): The offset vector shall be determined with an absolute accuracy (1σ) of 1.0 cm or better in each component. Measurements shall be referenced to the antenna phase center. The offset vector components shall be determined each time the sensor or aircraft GPS antenna is moved or repositioned in any way.

D. SPECIAL CONSIDERATIONS – Wavelength
It is recommended that in the majority of shoreline applications, 1.5 micron systems not be used, or at least tightly constrained to NOAA specified operating envelopes.

Eye safety in the deployment of laser-based remote sensing systems is a critical consideration. While 1.5microns are well-suited to providing low-altitude eye safe deployment, they are not necessarily effective in providing reasonable signal returns from the shoreline/littoral zone.

Application (to the shoreline) of LIDAR systems based on lasers with a 1.5micron wavelength is likely to prove problematic.[1] The 1.5micron systems are inherently inferior to 1micron based systems due to the phenomenology of the interaction of the wavelengths with water and surfaces covered in water, such as shorelines. Due to the absorption characteristics of 1.5micron wavelengths, only a fraction of the available energy emitted is available for return to the sensor. This results in drastic reduction in the number of "returns" or points available for mapping the shoreline. Additionally, it implies that to become more effective, the 1.5micron based sensor must be flown at a

[1] *High-Level Analysis & Scientific Assessment of the Utility of Applying a 1.5Micron-Range Wavelength Laser Based Airborne LIDAR System to Shoreline Mapping*, John F. Hahn, August, 2009.

reduced altitude, thereby substantially reducing flight economics and creating potential reduced safety conditions due to the lower altitudes.

The selection of eye-safe wavelengths is based in the ability of water to absorb the energies at 1.5 microns. This means that 1.5 micron based systems will require approximately 10 times the power of a comparably configured 1micron system The inverse way to look at this is that 2 similarly powered systems will result in $1/10^{th}$ the number of available returns in the case of the 1.5micron system.

Additionally, the detectors typically associated with 1.5micron based systems are usually inferior to the types integrated into 1micron based systems (based primarily on available detector surface area). Therefore, it makes it even more unlikely that 1.5 micron based systems will perform as effectively (collect suitable amount of return signal) as 1micron based systems.

The one area where the disparity between 1micron and 1.5micron is much smaller is in the mapping of wet vegetation. Due to the tendency of water to bead on vegetation/foliage, there remains a large amount of "dry" surface area of the foliage available as a surface to provide a decent return signal.

(See: *High-Level Analysis & Scientific Assessment of the Utility of Applying a 1.5Micron-Range Wavelength Laser Based Airborne LIDAR System to Shoreline Mapping*, John F. Hahn, August, 2009.)

6. MISSION PLANNING AND CLEARANCES

6.1 MISSION PLANNING

A. COVERAGE AND PARAMETERS – The Contractor shall plan flight lines for the project area (described in the Project Instructions) and ensure complete coverage of the project area. The mission planning parameters of: point cloud post spacing, swath width, swath overlap, navigation, GPS, visibility, and tide-coordination shall be considered in planning. NGS may supply recommendations and/or requirements for planning parameters in the Project Instructions. The separate Project Instructions may define the point density of the point clouds, DSM, and other requirements.

B. OVERLAP – Adjacent swaths shall have a minimum overlap of no less than 25% of the mean swath width, all the while maintaining 100% coverage.

C. FLIGHT DIRECTION – Flight lines shall be flown in either direction, but adjacent, parallel lines should be flown in opposite directions to help identify systematic errors.

D. LIDAR SURVEY PLAN REPORT

i. PROPOSED FLIGHT LINES – Prior to data acquisition, the Contractor shall submit paper map(s) clearly showing all proposed flight lines, and include coverage, scale, tide stage, proposed ground control, and project area boundaries. Also included shall be information about scan angle, pulse repetition frequency (PRF), flying height, and flying speed over ground. Prepare a separate, one-sheet map for each stage of the tide. The base map shall be the largest scale nautical chart covering the entire project area, if possible.

ii. ACTUAL LINES FLOWN – Similar map(s) showing the actual flight lines shall be included in the Final Report, see Section 13 U 3.

E. CROSS LINES – At least one cross line (i.e., perpendicular to the primary flight lines) is required per survey. For longer survey areas, one cross line is required every 25 km.

6.2 FLYING HEIGHT

Sensor shall not be flown at an altitude that exceeds that given in the manufacturer's specifications or that results in a significant number of "drop-outs" (i.e., pulses for which no return is received.) The altitude must be low enough such that the average laser footprint (per survey block) is ≤ 10cm diameter.

6.3 FLIGHT CLEARANCES

The Contractor shall comply with all required Federal Aviation Administration Regulations, including obtaining all required clearances.

7. WEATHER AND TIME OF YEAR

7.1 WEATHER CONDITIONS

LIDAR data acquisition missions shall be flown in generally favorable weather. Inclement weather conditions such as rain, snow, fog, mist, high winds, and low cloud cover shall be avoided. Such weather conditions have been known to affect or degrade the accuracy of the LIDAR data. If clouds are present, data capture is only permitted if cloud coverage is above the height of the sensor and airborne platform. LIDAR shall not be conducted when the ground is covered by water (flood), snow, or ice, and shall not be conducted when the land-water interface is obscured by snow, ice, etc. Storm systems and events (e.g. hurricanes, northeasters, and frontal boundaries) that may cause an increase in water levels, tidal heights, and wave activity shall be avoided.

7.2 TIME OF DAY

Data acquisition operations may occur during either day or night, unless specifically called out in the Project Instructions. Unlike aerial photography, sun angle is not a factor unless supplemental imagery (e.g., digital imagery) is required to be acquired concurrently with the capture of

LIDAR data to help assist in identifying features in post-processing production. Digital imagery should only be acquired simultaneously with LIDAR during the day.

8. TIDE COORDINATION

8.1 DATA COLLECTION AND TIDE CONDITIONS

All data collection shall be at or below Mean Lower Low Water (MLLW), unless otherwise specified in the individual project instructions. Data shall not be collected during strong onshore winds, high waves or other anomalous weather conditions. Contractor shall acquire and submit an offshore buoy report for the project area during time of data acquisition http://www.ndbc.noaa.gov/ .

8.2 NGS SUPPLIED WINDOWS

The government will supply data acquisition time/tide windows for each coastal area to be mapped. These "windows" cover an extended range of possible flying dates. These time/tide windows will be determined by NGS initially to help ensure that all data meet the NGS tolerances for tide–coordinated data acquisition. If tide windows for additional dates are required, contact NGS.

8.3 CONTRACTOR-DETERMINED WINDOWS

If required by the Project Instructions, the contractor shall determine predicted or actual acquisition time/tide windows (data acquisition times for tide coordination) for Mean High Water (MHW) and/or MLLW. Note, MHW is the mean of 19 years of high water and is not the high water level for any given day, except by coincidence. The same holds true for MLLW time/tide windows. The Project Instructions may also require the Contractor to install and/or monitor tide gages in the project areas for either real–time or post–flight tidal height comparisons.

A recommended approach to tide coordination and suggested software is described in Appendix 3. This method is only an example of how NOAA NGS currently is able to coordinate surveys around tide states. The contractor may elect use their own methods, but they must be approved by NGS prior to commencing project work. The contractor is solely responsible for tide planning, unless otherwise stated in the individual project instructions.

The contractor must account for wave run-up in ensuring continuous coverage across the land-datum interface within the lidar dataset. This is critically important and if not adhered to may be cause for NGS to reject the data.

8.4 REQUIREMENTS

The Contractor shall acquire all data within the given time/tide windows and shall produce a table showing the times of the time/tide windows and the times of the data acquisition. Be sure to take into account time zones and daylight savings time, and to use UTC time.

9. POSITIONING AND ORIENTATION FOR THE DATA

9.1 POSITIONING

A. GPS COLLECTION

i. All LIDAR data shall be positioned using kinematic GPS using dual frequency receivers and oriented with an inertial navigation system.

ii. All kinematic GPS (KGPS) solutions should use differential, ionosphere-free, carrier-phase combinations with phase ambiguities resolved to their integer values.

iii. Aircraft trajectories shall be processed using carrier-phase GPS. Dual L1 and L2 frequency receivers and one-second or better collection shall be used.

iv. All KGPS shall use at least two ground stations. The ground stations shall be accurately tied to the NSRS (stations in the NGS database); shall be positioned to 0.05 meter accuracy, or better; shall be within or near the project area; and shall be within 50 kilometers of the entire project area. Additional ground GPS stations may be required, and Continuously Operating Reference Stations (CORS) can be used as ground stations. The ground stations should be positioned on opposite sides of the operating area. The ground stations shall be positioned, or the flight path arranged, so that during flight operations the aircraft will pass within 10 kilometers of each ground station at least once.

v. The maximum GPS baseline shall not exceed 50 kilometers at any time during flight. Regardless of aircraft flight time, GPS ground station data shall be collected for a minimum of four hours.

vi. Ground station data shall be submitted to Online Positioning User System (OPUS) – http://www.ngs.noaa.gov/OPUS/) for positioning in the NSRS,

B. GPS SOLUTION PROCESSING

i. The Contractor shall collect, process, and submit the ground and airborne GPS data, both raw data and final processed data.

ii. Differential KGPS solutions for the aircraft shall be obtained independently using each ground station.

iii. These independent KGPS solutions shall be compared and any differences in the north-south, east-west, and vertical components during the operational portions of the flights shall be displayed and reported.

iv. The RMS of these differences shall not exceed 5cm in the horizontal and 10cm in the vertical.

v. The KGPS solutions shall model the tropospheric delay using average surface meteorological values at the ground stations collected near the midpoint of operations.

vi. The final KGPS solution will be an average of the separate ground station solutions.

C. ANTENNA

i. The GPS receivers should be equipped with antennas that have been calibrated by NGS. A choke-ring antenna to minimize multipath is preferred but not required.

ii. The antenna height shall be accurately measured.

9.2 GROUND-BASED GPS RECEIVERS

A. MARK – The ground-based receiver shall be set up over a known (or to-be determined) marked ground station and shall run continuously during the mission. If a known ground station is used, it shall be in the NGS database and hence part of the NSRS. If a new ground station is used, it shall be marked permanently (to NGS specifications) or temporarily marked (such as a PK type nail or iron pin). Specifications on the accuracy of horizontal and vertical positioning of the mark will be further defined in the Project Instructions.

B. OBSERVATIONS – The position of an existing mark shall be checked by processing one GPS session and comparing the computed position with the NGS published position. A new mark shall be referenced to the NSRS by tying to one or more NGS CORS by static GPS methods. If the distance to the nearest NGS CORS is less than 50 miles, use at least two independent sessions, each 2 hours long. If the distance to the nearest NGS CORS is greater than 50 miles, use at least two sessions, each 4 hours long. **Make a separate tripod set-up and height measurement for each session.** Take care in the accurate recording of the height of the antenna both before and after the flight (i.e. before and after each GPS recording session). Record all heights, equipment serial numbers, etc. on the NGS forms: Visibility Obstruction Diagram and GPS Observation Log. For a listing of these and other forms on the NGS WWW site see: http://www.ngs.noaa.gov/PROJECTS/FBN/ . Also, static observations may be processed using the NGS "On-Line User Positioning Service" (OPUS) found at: http://www.ngs.noaa.gov/OPUS/ . Observations to establish a new, permanent mark shall be submitted in NGS "Blue Book" format.

C. RECOVERY – For an existing NSRS station, write a digital recovery note in NGS format using NGS software WDDPROC. For a new, permanent station write a digital station description in NGS format using Windesc. For a new, temporary mark write a brief description adequate to recover the station. Take three photographs of the ground station (photographs of the CORS station are not required). For additional specification guidance on mark setting, GPS observations, data processing, and data submittal in NGS format, see: http://www.ngs.noaa.gov/ContractingOpportunities/ReferencedLinks!.htm

9.3 AIRCRAFT GPS RECEIVER

A. GPS OBSERVATIONS – The aircraft's GPS receiver shall be able to collect carrier phase observations and record, at least once per second, from a minimum of four satellites (five or more preferred) at both the aircraft and the ground GPS receivers, for off-line processing. All data shall be collected with a Position Dilution of Precision (PDOP) of less than 3. After the post–processing, the GPS observation and ephemeris files shall be used to determine a flight path trajectory.

B. GPS LOCK – The aircraft shall maintain GPS satellite lock throughout the entire flight mission. If satellite lock is lost, on-the-fly ambiguity resolution methods may be used to recapture lock while airborne. Report these instances, procedures used, and any other unusual occurrences. The GPS post-processing software may be capable of providing an output log of all incidents, such as loss of GPS satellite lock. The formatted output log is acceptable as the report.

9.4 AIRBORNE ORIENTATION

An Inertial Measurement Unit (IMU) shall be incorporated into the LIDAR unit. The IMU system shall be capable of determining the absolute orientation (roll, pitch, and yaw) at a minimum of 50Hz. See Section 4.1.

9.5 AIRBORNE POSITIONING AND ORIENTATION REPORT

The Report shall include at least the following paragraphs:

- Introduction
- Positioning
    - Data Collection
    - Static Processing
    - Kinematic Processing
    - Data Sets
- Orientation
    - Data Collection
    - Data Processing
    - Data Sets
- Final Results

A. INTRODUCTION - Provide an overview of the project and the final processed data sets and list the data sets in table form with the following columns: Dataset ID, Date of

Acquisition, Projects covered by the data set, and Description/Flight Line(s) Identification.

B. POSITIONING – Discuss the methodology, the hardware and software used (including models, serial numbers, and versions), the CORS station(s) used, a general description of the data sets, flight lines, dates and times of sessions, the processing (including the type of solution–float, fixed, ion–free, etc.), and the results (discussion of the coordinates and accuracy). Submit a description of the data sets, and the raw and processed data. If the NGS OPUS website was used to process the static data, the Contractor shall provide a copy of the OPUS report. If a known station was used from the NGS database, the Contractor shall identify the station by name and Permanent IDentifier (PID), and provide the published coordinates used in the kinematic position step. If multiple ground stations were used, provide processing details, coordinates, and accuracy for all stations.

C. ORIENTATION – Discuss the factors listed above for Positioning.

D. FINAL RESULTS - Describe any unusual circumstances or rejected data, and comment on the quality of the data.

10. EYE SAFETY

Because LIDAR systems typically employ Class 4 lasers, safety is a paramount concern. ANSI standards for safety shall be followed. See ANSI Z136.1 Safe Use of Lasers and ANSI Z136.6 Safe Use of Lasers Outdoors. For further details regarding safety issues in LIDAR data collection, refer to *Eye Safety Concerns in Airborne Lidar Mapping* (Flood, 2001, ASPRS Conference Proceedings). The contractor shall assume sole responsibility for adherence to all safety regulations and shall implement necessary internal controls to ensure the safety of all persons in the aircraft and in the survey area below.

11. DATA LABELING

All portable hard drives shall be labeled with the project name, collection date(s), contractor name, and disk contents. LIDAR data Portable Hard Drives shall be able to be easily matched with the corresponding LIDAR flight log(s).

12. DATA SHIPMENT AND PROCESSING

12.1 SHIPMENT

The contractor shall ship final deliverables in NGS format (on hard disk), directly to NGS, to arrive at NGS within ten working days from the date of completion of data processing. Copies of the LIDAR Flight Log and the raw navigation files may be made and used by the contractor to produce and check the final deliverables.

12.2 NGS NOTIFICATION

The same day as shipping, the contractor shall notify NGS of the data shipment's contents and date of shipment by transmitting to NGS a paper or digital copy of the data transmittal letter via email or fax.

13. DELIVERABLES

13.1 LABOR, EQUIPMENT AND SUPPLIES – The Contractor shall provide all labor, equipment (including aircraft and LIDAR system), supplies and material to produce and deliver products as required under this document.

13.2 LIDAR SURVEY AND QUALITY CONTROL PLAN – Prior to data acquisition, submit a proposed LIDAR Survey and Quality Control Plan which specifies the data collection parameters to be used and contains a map of the flight lines and the project coverage area, including flying height and speed over ground, scan angle, and Pulse Repetition Frequency (PRF). The separate Project Instructions supplied by NGS will define the project area(s) and may define the point density of the point clouds, DEMs/DSMs, and other requirements. See Section 6. NGS will review the proposed mission planning reports, normally within five business days, and will respond in writing with approval and/or comments. The Final Report shall contain map(s) showing the flight lines and boundaries of LIDAR data actually collected.

13.3 LIDAR TEST – The Contractor shall acquire and deliver an example dataset over a section of coastline and/or coastal ports which are similar to the contract work (see separate Project Instructions). VDatum shall be utilized in the project area to convert to the specified vertical datum as stated in the Project Instructions. VDatum is a software tool that converts elevation data (heights and soundings) among 28 different vertical datums (http://vdatum.noaa.gov). Tide coordination and Ellipsoid/Tidal relationship support may be required, and will be further defined in the Project Instructions.

13.4 LIDAR RAW DATA – Submit the completed data collection raw output.

13.5 LIDAR PRODUCTS – Required products may include: Shoreline shape files, LAS files, and DSM. The Project Instructions will specify which additional products, if any, are required.

13.6 FLIGHT REPORTS – Submit the completed, original LIDAR Flight Logs with the data, as well as a copy directly to NGS. For a sample flight log see Appendix A.

13.7 GLOBAL POSITIONING SYSTEM (GPS)/INERTIAL MEASUREMENT UNIT (IMU) FILES – The contractor shall submit the original, raw data files and processed trajectory files directly to NGS, to arrive at NGS along with the raw data points and final products. The raw data files shall include RINEX files generated from each receiver's proprietary data files. See sections 9.1 and 9.4.

13.8 AIRBORNE POSITIONING AND ORIENTATION REPORT – Submit raw GPS and IMU data (in the manufacturer's format) along with the final processed GPS trajectory and post processed IMU data. Also submit a report covering the positioning and orientation of the LIDAR. See Section 9.5.

13.9 RANGE AND SCANNER ANGLE FILES – The contractor shall submit the original, raw data files directly to NGS, to arrive at NGS along with the raw data points and final products.

13.10 GPS CHECK POINTS – Submit an organized list of all GPS points used for the project as ground stations and check points. Indicate which GPS points are pre-existing ground control and which stations are new, and positioned relative to the NSRS. See Project Instructions and sections 3.1 C and 9.2 A and B.

13.11 NGS SURVEY FORMS – The Contractor shall prepare and submit the following NGS forms for each GPS check point and the GPS ground station(s): Visibility Obstruction Diagram, GPS Observation Log, Recovery Note or Station Description. See Section 9.2.

13.12 TIDE COORDINATION TABLE – Supply table(s) showing the actual times of acquisition flights and the tide coordination time "windows." See Section 8. Explain any discrepancies.

13.13 CALIBRATION REPORTS – There is no standard format for the calibration reports. However, the calibration reports shall contain, at a minimum, the following information:

A. The date the calibration was performed.

B. The name of the person, company, or organization responsible for performing the calibration.

C. The methods used to perform the calibration.

D. The final calibration parameters or corrections determined through the calibration procedures.

13.14 SENSOR MAINTENANCE – Provide maintenance history directly to NGS of the sensor to be used for acquiring LIDAR. See Section 4.2 A.

13.15 SENSOR PORT WINDOW – Report the physical characteristics of any port window used to NGS. See Section 4.3 B.

13.16 DATA SHIPMENT – See Sections 3, 12, and 15 for instructions.

13.17 DATA SHIPMENT REPORTING – The Contractor shall notify NGS of each data shipment's contents and date of shipment by transmitting to NGS a paper or digital copy of the LIDAR Flight Log (marked "copy" at the top) and a copy of the data transmittal letter via email or facsimile. This shall be done the same day the data is shipped to the data processing contractor. See Section 12.

13.18 UNUSUAL CIRCUMSTANCES – The contractor shall also notify NGS of any unusual circumstances that occur during the performance of this project which might affect the deliverables or their quality and especially of any deviation from this project. This may be included in the weekly email required below, unless urgent.

13.19 DEVIATIONS FROM SCOPE OF WORK – Requests to exceed or deviate from the Project Instructions will be considered if written justification is provided to NGS in advance. No deviation is permitted until written approval is received from NGS.

13.20 STATUS REPORTS – The Contractor shall submit project status reports via email to the Contractor Officer's Representative (COR) contacts in Section 15 every week, until the work is complete. **These reports are due at NGS by 2:00 p.m. EST each Monday.** These reports shall include a summary of completed data acquisition, with dates completed; data shipped, and dates; and any unusual circumstances, equipment malfunctions, and/or any disturbance of the sensor. **A weekly status report is required even if no progress has been made.**

13.21 FINAL REPORT - The Contractor shall supply to NGS a Final Report incorporating all of the information in this Deliverables section including, at least, the sections suggested below:

A. For work performed under this contract, discuss each deliverable including: the maximum range from the ground station, the minimum swath overlap, percent of good laser returns (if available), standard deviation and residuals in GPS trajectories, and an explanation of the Portable Hard Drive labeling;

B. Equipment used to perform this work, including hardware models and serial numbers, calibration reports, and software names and versions (include aircraft and LIDAR info);

C. Flight line map(s), and project coverage area;

D. Discussion of data quality including Quality Assurance (QA)/Quality Control (QC) procedures;

E. Ground Control Report, including a station list in table format;

F. Aircraft Navigation;

G. Airborne kinematic GPS Report, including ground stations;

H. Weather, solar altitude, and time of year;

I. Tide Coordination Report and Table;

J. Any unusual circumstances or problems, including equipment malfunctions (including those already reported);

K. Any deviations from this LIDAR SOW, including those already reported;

L. Any recommendations for changes in the LIDAR SOW for future work.

13.22 PROPERTY OF DATA – All original data, from the instant of acquisition, and other deliverables required through this contract including raw data and final products, are and shall remain the property of the United States Government. This includes data collection outside the project area.

14. REVIEW

Data and other deliverables not meeting these specifications may be rejected.

15. POINTS OF CONTACT

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16. REFERENCES

Flood, M. *Eye Safety Concerns in Airborne Lidar Mapping*. Proceedings of the ASPRS 2001 Annual Convention, 23-27 April, St. Louis, Missouri (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM, 2001.

Hahn, John F., *High-Level Analysis & Scientific Assessment of the Utility of Applying a 1.5Micron-Range Wavelength Laser Based Airborne LIDAR System to Shoreline Mapping*, August, 2009.

Appendix 1 – LIDAR Flight Log (NOT YET CREATED)

Appendix 2 – JALBTCX Draft Common Specifications Matrix

Draft Common Specification Matrix for Airborne Coastal Mapping and Charting

Survey type	**Engineering**	**Charting**	**Environmental Assessment, Modeling, Regional Coastal Mapping**	**Emergency Response, Reconaissance**
Bathy Lidar				
Vertical accuracy		50 cm 2s	15 RMSE	
Horizontal accuracy		5 m 2s	1 m RMSE	
spot spacing		2 X 2,3X3	4 m	
Percent coverage		100,200	100	
Percent overlap		30?	ensure 100% coverage	
Effective footprint		NA	NA	
tide coordination		NA	when possible high tide	
Pulse width		NA	NA	
Topo Lidar		shoreline mapping		
Vertical accuracy		15 cm RMSE	15 cm RMSE	
Horizontal accuracy		1 m RMSE	1 m RMSE	
spot spacing		1 m	1 m	
Percent coverage		100	ensure 100% coverage	
Percent overlap		30	ensure 100% coverage	
Effective footprint			10 cm	
tide coordination		yes	when possible low tide	
Pulse width		NA	NA	
Return logic		"true" last	threshhold detect -2 returns	
Classification		not required	LAS 1 and 2	
QA/QC				
GPS PDOP		<= 3	<=3.5	
Crossline spacing		25 km	25 km	
Crossline number		1 per alongshore block	1 per alongshore block	
Combine separation		10 cm	10 cm	
Ground control		30 checkpoints	20 points/3 classes/100 miles	
TPE Horizontal & vertical		no	no	
Qualitative assessment		targeted to shoreline	yes	
Imagery				
Horizontal accuracy		2 pixels	2 m	2 m
Spatial resolution		50 cm	20 cm RGB, 1 m	35-50 cm
Spectral resolution		NIR >740 nm	19 nm FWHM hyperspectral	
spectral range		VNIR	VNIR	RGB
Spectral bands		4	36	3
Tide coordination		yes low tide	when possible low tide	NO
Camera callibration		yes and certification	yes	yes
Stereo coverage		yes	yes	yes
Endlap sidelap		60%/30%	60%/30%	60%/30%
Sun angle		>30 elevation	>20 elevation	>10 elevation
Max cloud cover		no on shoreline	10%	avoid where possible
Patch		yes	yes	yes
Visibility		8 miles	8 miles	see the ground
Products			ASCII	orthomosaics
			LAS	mosaics
			DEM	
			DSM	
			orthomosaic	
			laser reflectance images	
			NAVD88 shoreline	
			land cover classification	
			hyperspectral reflectance mosaics	

Appendix 3 - Tide Coordination

NGS Remote Sensing Division's Coastal Mapping Program

Tide coordination of Airborne Topographic LIDAR collection using TCARI

The NGS Remote Sensing Division's primary motivation to collect airborne topographic lidar data is to enable accurate and consistent measurement of the national shoreline. The shoreline is defined as the land water interface at a specific tidal datum. NOAA charts both MHW and MLLW shoreline vectors on its nautical charts. This is not trivial as a tidal datum is by definition local, meaning that the vertical reference is only valid for a specific location. In order to define a tidal datum, a gauge must be installed and used to collect data for up to 18.6 years (an astronomical tidal epoch) depending upon the required level of accuracy. Throughout a survey project area of any useful size, the tidal datum can vary significantly. As a matter of practice, it is not viable to measure the MLLW shoreline using topographic lidar. The MHW shoreline however, can be extracted from lidar data so long as the data is collected at a sufficiently low tide stage. In order to accomplish this, NOAA has developed tools for airborne survey planning, as well as data quality assurance. Tidal Constituent and Residual Interpolator (TCARI) is an algorithm that models the tidally driven water level in space and time. It is an efficient method to determine when the water level in a specified area is predicted to be at, above, or below a certain tide level. Following a survey, it can also be used to check the actual water level at time of collection, which can deviate from predictions due to meteorological phenomena.

TCARI begins by establishing a boundary for a particular area using the shoreline vector (Fig 1).

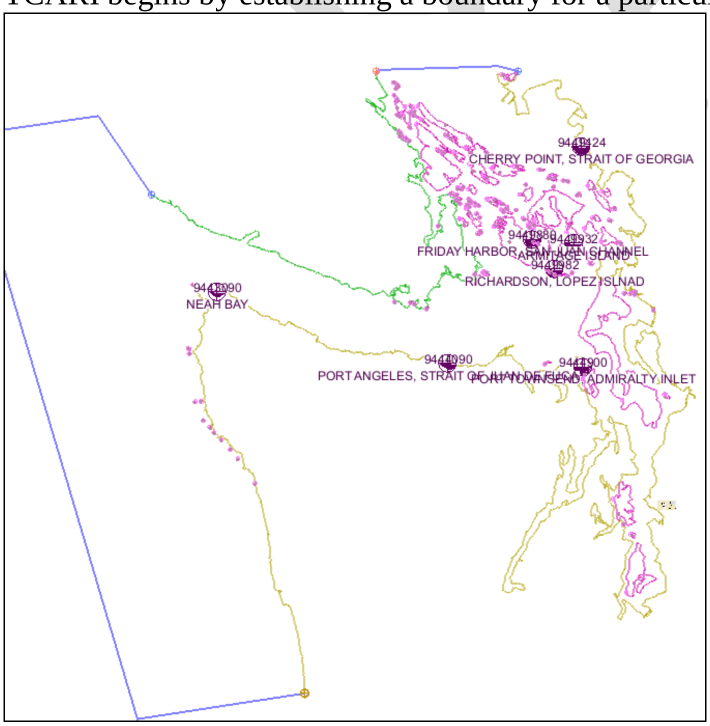

Figure 1 – Example of a TCARI grid boundary

Tidal datum locations as well as active water level gauge sites are applied, and a triangular network is created to enable the constituent and residual interpolation (Fig 2).

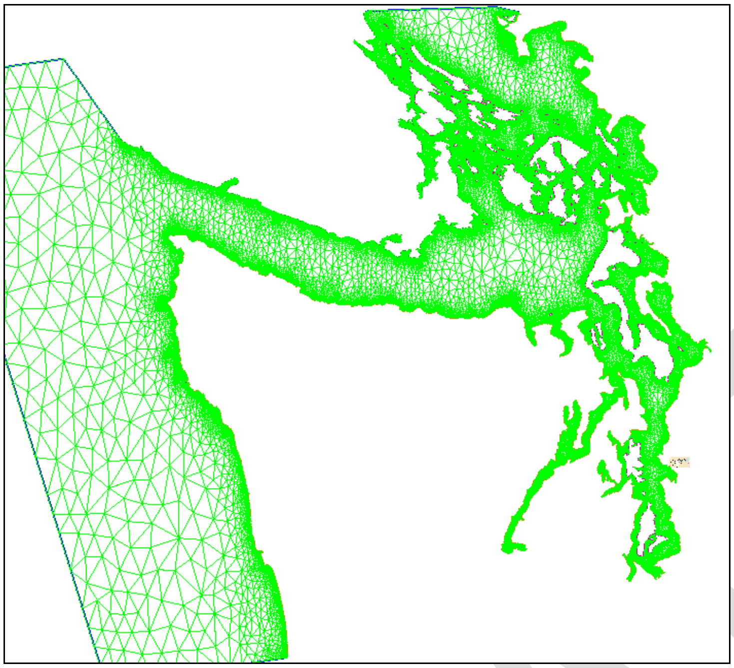

Figure 2 – Triangular network of example area

Once this is done, a predicted or actual (predicted plus residual) water level model can be created (Fig 3).

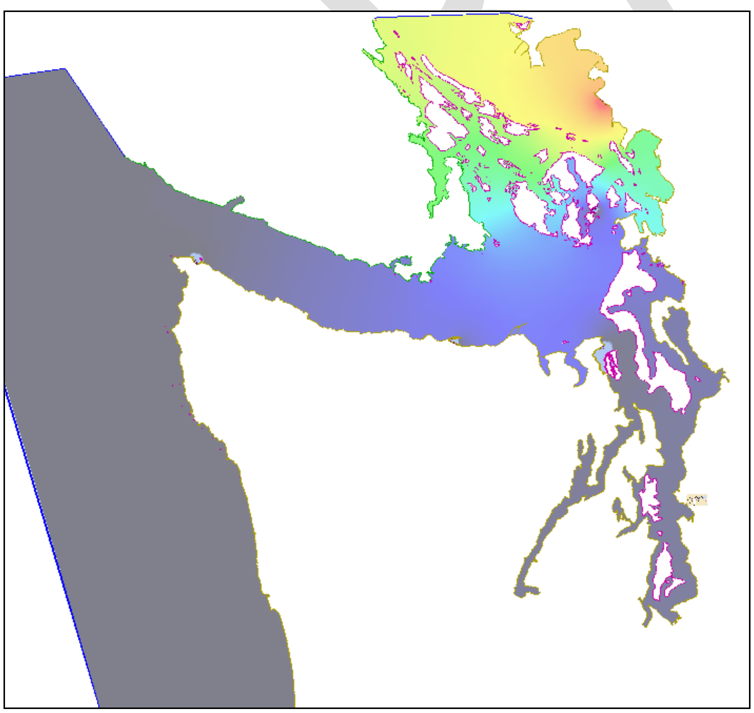

Figure 3 – Color ramped example of water level prediction using TCARI

The technique is scalable and can be used for small and very large project areas. In the case of topographic lidar collection, the requirement is to collect data when the water level is a pre-defined margin below the desired datum. In the case of MHW collection, this can be expressed as WL<(MHW – x), where x is the predefined margin. This margin value will depend upon both the specific instrument characteristics, as well as the meteorological conditions, specifically wave height and run-up on the open coast.

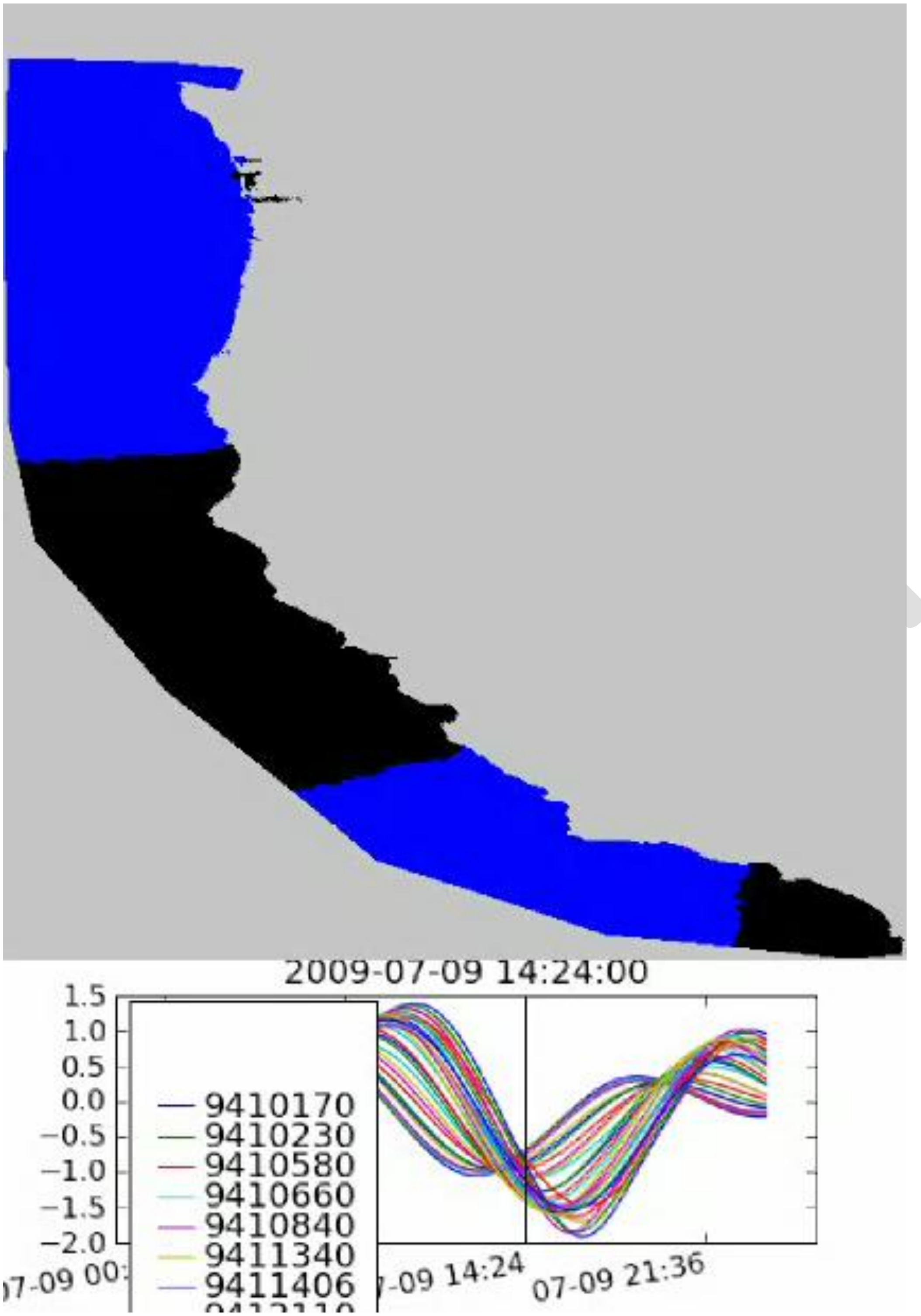

Figure 4 – Map of water level meeting a pre-defined survey condition

Figure 4 above depicts areas that meet a pre-defined water level condition. Using the NOAA developed Pydro software, TCARI is exploited to perform survey planning and QA. Initially, survey lines are planned and imported into Pydro (Fig 5).

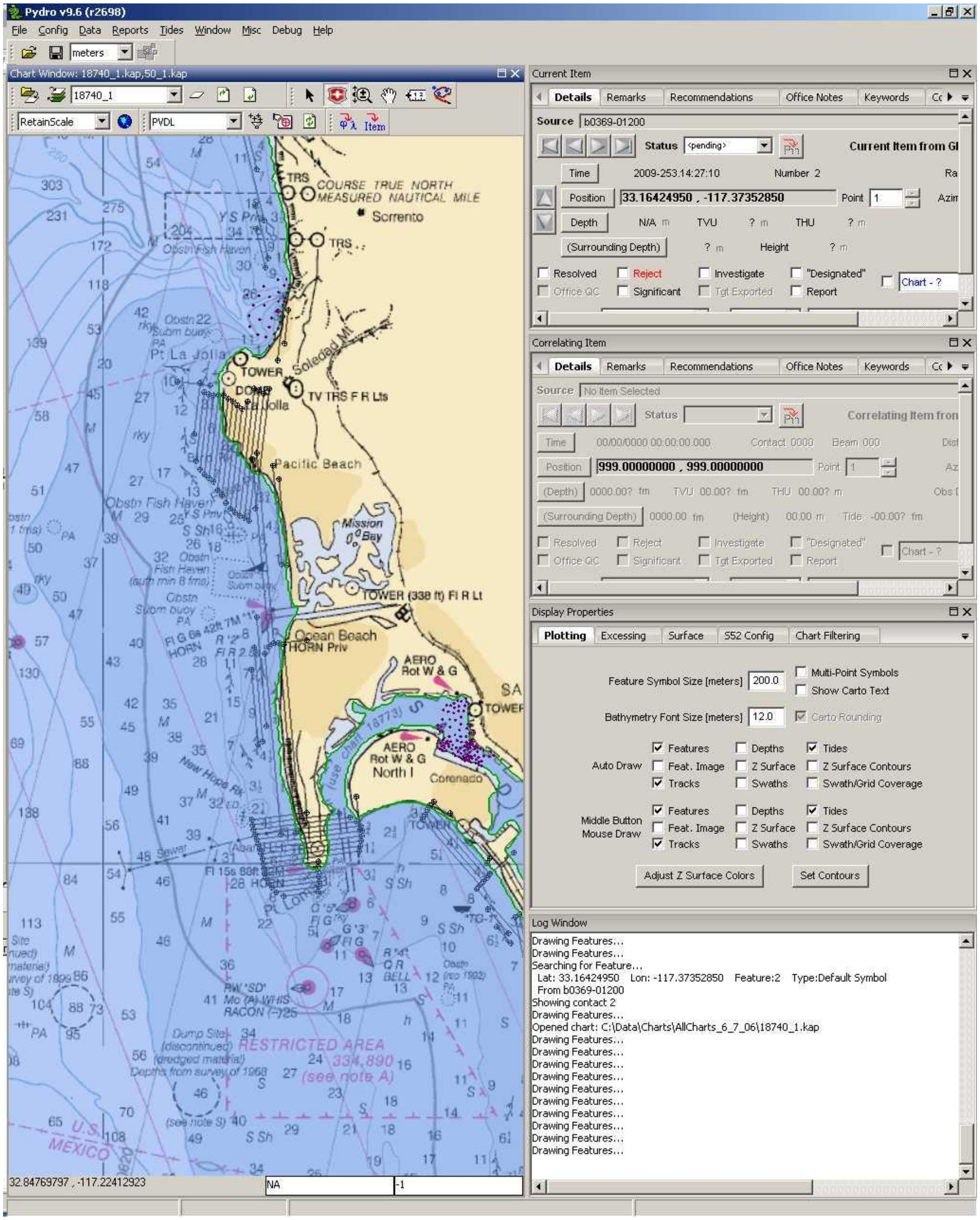

Figure 5 – Survey flight lines imported into Pydro

Once the flight lines are loaded, Pydro can be used to compute time of day windows over a specified interval that satisfy a predefined condition – in this case WL<(MHW-50cm) (Fig 6).