Lidar Data Integration for Nautical Publication and Spatial Data Infrastructure (SDI) Workflows-Common Issues and Experiences at NOAA and CHS

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Description

Over the last 10 years, enhancements to lidar sensors have encouraged the increased use of bathymetric lidar for a variety of applications. As a result, the volume of bathymetric lidar data acquired has increased substantially. Today, there remains an overwhelming struggle to fully integrate this data into a wide variety of data products with standard accuracy and attribution requirements. In the case of hydrographic office workflows, the lidar data format must work within the current software applications used to produce Nautical Publications and is highly tied to the need to produce standard results that follow IHO standards (S-57). When lidar data enters the SDI data workflow, the needs are somewhat different and are oriented around more general uses of the data; however, elements such as detailed attribution are more important. This paper describes the common issues and experiences to both workflows that have been identified between NOAA and the CHS over the last several years. It presents a comprehensive, current approach to data integration that addresses the needs and improvements required for an efficient and beneficial application of bathymetric lidar to a wider range of end users.

Part 1: Lidar and Hydrographic Data Integration in the Canadian Hydrographic Service

The Canadian Hydrographic Service (CHS) is the national organization in Canada responsible for the creation and maintenance of the nautical charts and related publications used for safely navigating our oceans and waterways. The extensive and varied Canadian coastline is the longest in the world at 243,042 kilometers, encompassing three oceans that span arctic to temperate climates, with almost every conceivable combination of existing coastal characteristics. The challenge of mapping this coastline and providing accurate navigational products is a very significant task, requiring hydrographic data collected from many sources.

Over the last 10 years, bathymetric lidar has become more readily available and its reliability has improved to the extent that it is now being used in the production of nautical charts. It is also a fundamental part of the overall hydrographic survey tool kit used by the CHS that includes:

a) Airborne lidar Bathymetry (ALB)
b) Multibeam Echo Sounders (MBES) and other Acoustic Soundings
c) Remote Sensing Imagery and Satellite Derived Bathymetry (SDB)
d) Integrated topographic lidar (with MBES systems)
e) Autonomous underwater or surface vehicles (e.g. AUVs equipped with sonar)
f) Photogrammetric point clouds from images (Structure-in-Motion).

MBES and acoustic sounding data has formed the traditional foundation of CHS's bathymetric layers, but as new technologies evolve, the availability and possibility of integrating other types of datasets must be more seriously considered. From a data workflow perspective, this can be a significant challenge. The discussion that follows relates to how CHS has tried to integrate and validate Bathymetric lidar into our current workflow, and the resulting challenges that we have faced.

MBES, Acoustic Soundings and Bathymetric Lidar Data Workflow for Nautical Publications

The CHS is divided into 5 Regional offices, as well as one headquarters office in Ottawa that performs coordination tasks and some core shared functions. Each regional office is responsible for a certain geographic area of the country, providing hydrographic surveying services, data management and nautical publication production. This means that hydrographic surveying and data collection are tightly coupled with the chart production functions, and often share staff and resources through a project-based approach when creating or updating a specific nautical product.

Integrating lidar data into the workflow of nautical publications has not been a simple process. The difference between the optically derived lidar and acoustically derived MBES data means that a direct comparison of the two as completely equal bathymetric data sets is not generally possible. Acoustic bathymetry is not nearly as prone to the same signal interferences as optically derived bathymetry, and as such is more likely to penetrate aquatic vegetation and profile the seafloor quite accurately in areas where the MBES system can manage to survey. In very shallow water MBES becomes increasingly inefficient and is often restricted to surveying critical channels and waterways. Lidar is prone to optical interference and thus it tends to detect objects in the water such as vegetation and has difficulty with poor water clarity, which can leave localized holidays (or gaps) in the bathymetric coverage. In good conditions, ALB is very effective in mapping shallow water areas not accessible by MBES equipped survey launches and is now regularly being used to pre-establish nautical hazard maps prior to conducting planned MBES surveys.

It is important to note that the CHS does not have its own ALB capacity and is fully dependent on contracted services. The core processing of all lidar data is performed by the service provider and CHS is a recipient of a completed data product as outlined in our specification. Currently we request various formats of data from our contractors which may include:

a) CARIS HIPS format data, which consists of a cleaned bathymetric and intertidal layer with manmade or floating objects removed and an unclassified topographic data layer. Uncertainty values are included to permit the TPU computations.
b) A 2 or 5 meter density grid surface.
c) Unclassified LAS data (on either ellipsoid or reduced to a vertical chart datum model)
d) X,Y,Z and DEM data representing the bathymetric surface and nearshore topography.
e) Ortho-rectified mosaics of imagery collected during flight sorties.
f) Reflectivity data in the form of a image file (e.g. 3D geotiff)
g) Vector point, line, area (PLA) files describing the nature of data coverage and/or identifying specified features as outlined in the contract work statements (e.g. Shoreline, rocks, man-made features, etc.)
h) Any potential notices to shipping (on-going delivery during the survey).

The first stage of our workflow, upon receipt of the data, is our internal quality control step (Figure 1). During this stage, the data is reviewed and further assessed for any potential notices to shipping. Any required modifications to the deliverable would also be addressed with the contractor. Once the final deliverables are accepted, the data is archived (e.g. imagery, x,y,z, DEMS, LAS, raw data) and a final bathymetric surface is submitted to the Bathymetric Database (BDB) as a new source of validated data. Any PLA data that was generated will be reviewed, possibly enhanced by CHS staff, properly encoded for S-57 and placed in the Hydrographic Products Database (HPD).

Creating a suitable surface for submission to the BDB is the first challenge. The surface must be shoal-biased and of a suitable density to be representative of the data, while serving the need of the proposed chart construction scale. Generally a two to five meter surface/grid will suffice, but it is important that any gaps or holidays are noted so as not to interpolate data into areas where data does not exist. In cases where data density supports one meter grids, these can used to better represent larger scale features.

Given the low density of data, a minimal search radius is generally used to reduce the impact of nearby data points on the overall surface. Unlike MBES data that has very high density data in shallow water, ALB is of much lower density and thus gridding or surface generation techniques and parameters suitable for the redundancy available in MBES data are not as suitable for the lower density bathymetric lidar data. Currently, surfaces or grids are the best mechanism to compare MBES data and lidar when making decisions on which soundings to select (or designate) as a part of the bathymetry mosaic used for the sounding selection in a nautical chart.

This preference towards the use of surfaces when comparing various data sets is largely based upon the workflows used in the CHS' current software, and the desire to apply uncertainty models and data redundancy in the creation of a bathymetric surface estimation. These are definitely good things and work very well for MBES type data, but the application of TPU in bathymetric lidar and the parameters for creating Combined Uncertainty and Bathymetric Estimator (CUBE) surfaces are not as well known. CUBE surfaces can be used with lidar but the bathymetric layer must be already well-identified or separately classified. Noise, water levels or other point objects in lidar would be confusing to the CUBE algorithm, as they are not oriented around bathymetry and they may have alternate physical properties that actually do exist in the lidar data set (e.g. a large buoy or a floating structure).

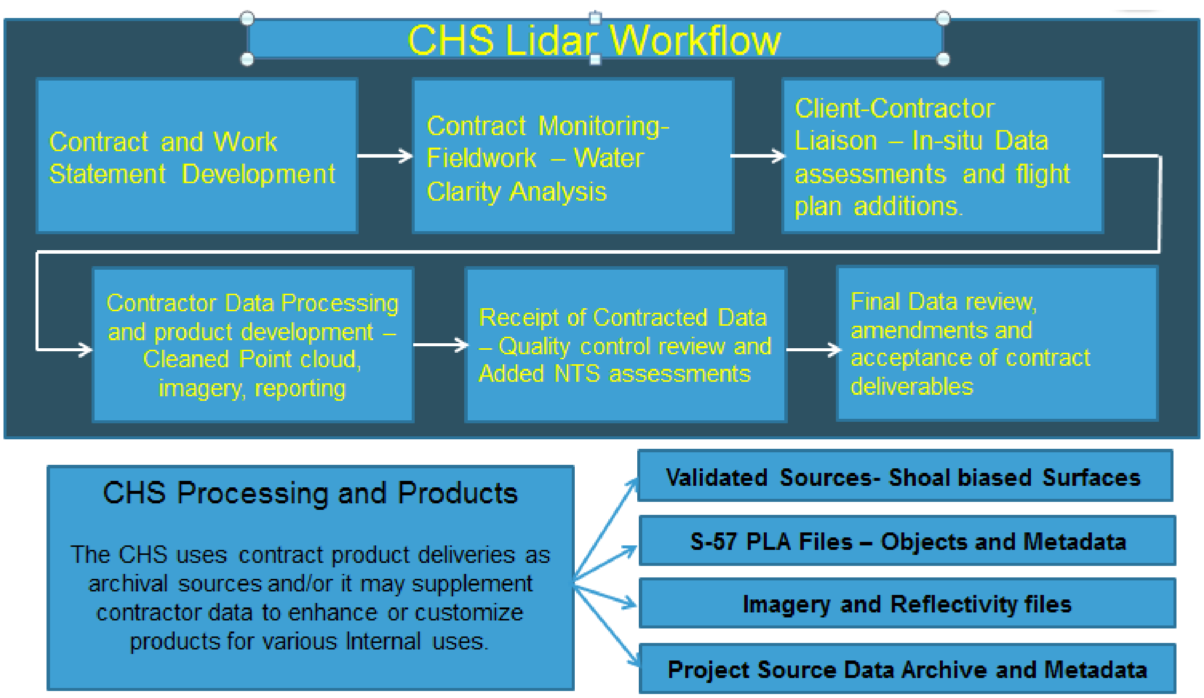

Figure 1 – CHS Lidar Workflow

The Workflow Requirements of an MSDI

In Canada, a Marine Spatial Data Infrastructure (MSDI) is an officially governed framework upon which standardized data and information will be made accessible to a variety of users, using spatial and thematic query tools to locate specific information. These tools are usually composed of a GIS-backed webmap application that can be used to find, and at times analyze, results of user queries. The current initiative in Canada is at an advanced development stage where a prototype is now active and certain data sets that will aid in the delivery of some specific Ocean Protection Plan objectives will be added as a proof of concept.

From the perspective of the CHS, the MSDI is an opportunity to provide a wider range of data services to larger client base with marginal additional effort and cost, using existing sources of data in our archives or new sources as we collect them. Currently, CHS is undergoing a very large increase in funding for data acquisition through external contractors, while continuing to conduct select internally-run surveys in various Canadian locations as we have always done.

One of the largest external survey projects involves an extensive coastal mapping program using airborne lidar bathymetry (ALB). This program will generate massive data sets in areas where modern survey data has not been available and will also identify the vast majority of navigational hazards under 15-20 meters over thousands of kilometers of coastline. As we collect this data, the handling and review tasks will require very significant levels of internal human resources, making it extremely important to identify potential users and identify needs during these initial assessment workflow stages. It will be far more difficult to reopen all data later to serve specific requests, so it is important that the general needs for an MSDI and associated data portals can be identified early on.

The coastal mapping data that is being collected during our recent and upcoming lidar campaigns is not limited to lidar point cloud data. It is normal practice to collect high resolution, low altitude, RGB or RGB (IR) data and to create ortho-mosiacs of the survey areas from this. It is also possible to include multi-spectral and hyper-spectral sensors to supplement the core RGB imagery. Another significant product that is generated is reflectivity images of the survey area. All of the raw project data collected by CHS contractors is also archived, but the need for specialized commercial software and massive amounts of data storage make this data hard to access, let alone readily share. The primary products that most external clients will require are derivatives which are very similar to the ones that CHS requires for its own review and analysis. It is important to note that only marginal extra effort is required to save data in sharable formats and organize it in such a fashion that it can be distributed with appropriate metadata suitable to both CHS and our external client base.

	CHS Requirement	Client Requirement (SDI)
Meta Data	Internal Meta Data for CHSDIR database. ISO 19115 is of value but not mandatory.	ISO 19115 compliant is normally preferred.
Lidar data format	CHS prefers HIPS format data to facilitate integration and comparison to existing MBES data sets in its current workflow. LAS has not been used extensively.	LAS format data is the preferred especially if classification of data is present. Simpler formats are also requested such as XYZ and gridded compilations
Data Products	Surfaces are the preferred type of data product for CHS workflows. Point clouds are also becoming more widely used.	Classified LAS data is widely used. Gridded XYZ data sets are also very useful as they reduce ASCII files

		sizes from original XYZ point clouds.
Imagery	Ortho-mosaics and individual geo-referenced images. Geotiffs and other formats are commonly used. Internally, large file sizes can be accommodated	Ortho-rectified imagery in a geotiff format or other geo-referenced format. Image size is an issue; systematic, indexed coverage needed.
Reflectivity	Imagery primarily used to identify objects or the nature of seabed and coastline.	Images are used for interpretation, meta data is important. Further interpretation requires field observations.
Point, Line Area (PLA data)	PLA data derived from lidar data and imagery interpretation primarily oriented around Chart objects and metadata describing data coverage.	Final product deliverables may include metadata relating to lidar coverage and derived PLA depicted coastline, features, thematic interpretations, etc.

Table 1 – Lidar Project Deliverables – A comparison of CHS versus Client Requirements

Currently, within the CHS, client data requests are handled on an individual basis by our Hydrographic Data Centers (HDC) located in each of our regional offices. These requests are generally customized toward client needs but are quite time consuming and do require a formal data exchange agreement between the CHS and the client. The opportunity to use an MSDI infrastructure would not only reduce the workload surrounding the large quantities of lidar data, but would improve access, automate queries and encourage data use and distribution in a more timely and controlled manner.

With minimal additional effort, saving and formatting data so it can be used both for internal hydrographic products and external distribution is a very basic and fundamental task which can greatly benefit the CHS as well as a diverse client base.

Hydrographic Point Clouds and the LAS Exchange Format

The LASer (LAS) file exchange format is a fundamental method in which to exchange and preserve lidar related information for various applications utilizing spatial data. It is by far the most popular method of handling and sharing lidar data outside of core processing applications used during data collection. The ability to have an expanded point cloud classification schema in the LAS 1.4 specification and the ability to customize this using a LAS Domain Profile is a major step forward. An example of this flexibility is the use of the use of the Topo-Bathy Domain Profile Description.

Bathymetric data, whether it be collected via MBES system, lidar or photogrammetric/optical analysis, results in the creation of a detailed spatial point cloud with associated data point attributions. In hydrography, the primary point classification is seafloor bathymetry (LAS classification 40 – Bathymetric Point), although there are many other detectable and classifiable objects picked up using both acoustic and optical techniques which are a major part an overall data set. Objects such wharves, pilings, under/above water structures, wrecks, debris and vegetation can all be detected by both techniques and it is advantageous to be able to distinguish these from the seafloor classification. This is where acoustic hydrographic applications and optical lidar (largely topographic) approaches have tended to diverge.

In hydrography, the focus has always strictly been on obtaining an accurate bathymetric point cloud or surface representation of the seafloor. The development of CUBE very much improved the way that the seafloor can be represented and how uncertainties can be modelled. Point data classification in hydrography has however remained relatively simplistic with the approach that all good bathymetry is classified as accepted (with some additional flags such as designated) while all other acoustic data is generally given a rejected classification flag.

In MBES, acoustic objects in the water column (which can also be viewed and flagged) would benefit from advanced classification since this non-bathymetry can represent many other relevant things. In lidar analysis classification has always been fundamental, so labelling or classifying the various multiple returns on a waveform is common practice. Distinguishing high vegetation from topography is a one example of typical classification on land; on the water side, distinguishing water surface versus seafloor bathymetry is another.

The classification of point data in the underwater domain, as it has been common to do in the topographic world, is a practice that may not just apply to lidar in the future. When combining various data sets such as MBES, lidar and other point clouds in a combined workflow, classifications may become a way of better identifying critical objects or soundings. In this combined data set, classification of all data points which include acoustic data (e.g. MBES, water column, sub-bottom) and optically derived data (e.g. classified lidar, satellite derived bathymetry (SDB) or derived S-57 vector objects) could greatly facilitate the creation of various products and potentially improve interpretation in the overall hydrographic data workflow.

Part 2: NOAA's Remote Sensing Division Mission and Multi-use products

NOAA's Remote Sensing Division (RSD) is responsible for mapping the national shoreline of the USA and its territories. RSD acquires aerial imagery and topographic-bathymetric (topobathy) lidar to assess, compile and update the nation's shoreline. RSD acquires topobathy lidar through a combination of in-house and contract resources and its contract workflow is similar to CHS'.

While RSD's primary mission is to produce shoreline for the nautical charts produced by NOAA's Office of Coast Survey (OCS), the topobathy lidar datasets have the added benefit of providing near-shore bathymetric data to OCS as well. This data has been used as reconnaissance data for NOAA hydrographic ship operations to increase efficiency and situational awareness. As with any new data being introduced to an already rigid workflow, it has been through many experimental stages to see how to best insert this data without further straining limited resources.

Testing and Evaluation

RSD uses a combination of software such as: Riprocess, GeoCue, Terra Solid (Terra-Scan, Terra-Photo and occasionally Terra-Model), LP360 within ArcMap, VDatum, QT Modeler and Global Mapper. This is important to note because only one of these software packages is also in use at OCS, which receives the ALB data. Thus over the past three years, RSD, OCS, and the Joint Hydrographic Center at the University of New Hampshire (UNH) (Figure 2) have tested and evaluated three different ALB workflows (using both RSD and JALBTCX data) to try to find an efficient path forward. Below is a simplified list:

1. RSD sent LAS files directly to the Atlantic Hydrographic Branch (AHB) under OCS (e.g. Barnegat Bay, NJ and Palm Beach, FL)
2. RSD sent LAS files directly to Integrated Ocean and Coastal Mapping (IOCM) contractors at UNH to help the Atlantic Hydrographic Branch (AHB) with feature extraction (e.g. Post-Hurricane Sandy RSD ALB data)
3. RSD sent MLLW gridded DEMs to OCS (e.g. Tampa Bay JALBTCX ALB, Dry Tortugas, FL RSD ALB and St. Joe's, FL RSD ALB)

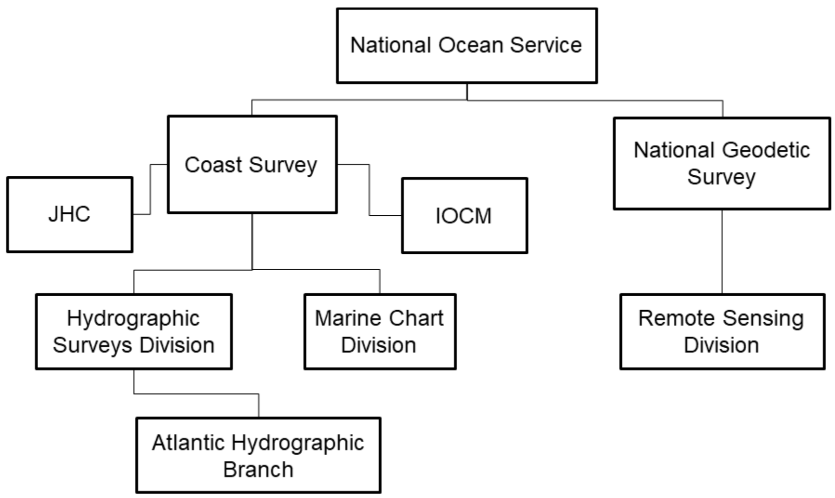

Figure 2. NOAA organizational diagram for workflow testing and evaluation of RSD ALB data for application to NOAA Charts

In the first trial, AHB, which resides under the Hydrographic Surveys Division (HSD), was able to utilize the ALB data but the workflow was not efficient, as the LAS files were not easily ingested into OCS' current software or workflow. RSD and AHB held several training sessions to share knowledge and AHB provided feedback about the RSD ALB data and deliverables.

In the second trial, AHB suggested that the RSD Hurricane Sandy ALB data be sent to the IOCM contractors at UNH, since the dataset was unusually large (covering Murrells Inlet, South Carolina to Montauk, New York) and AHB needed help with ALB feature extraction. Feedback from RSD and OCS maintained that this solution, while relieving AHB of being inundated with data, lacked efficiency as well.

At the end of the third trial, explained in detail in the NOAA Technical Memorandum NOS CS-36, OCS, JHC and RSD leadership agreed that because of RSD's ALB expertise, the data should not undergo interrogation again and that deliverables should be modified such that geotiff grids (1 meter and 5 meter) should be sent, rather than the full LAS dataset. In the interest of utilizing this data quickly, as RSD can quickly re-survey or do transects over the same area if needed, this appeared to be the most efficient approach. Additionally, RSD and JALBTCX are considered authorized federal data sources and those data specifically intended for navigational use do not need a rigorous data review. Little was found to be gained by additional rigorous review, instead evaluation of previous tests found that latency issues were multiplied. Furthermore, the revised Marine Chart Division charting policies now being employed allow the incorporation of surveys using new CATZOC B technologies (namely, SDB and ALB). This means that OCS is only using the bathymetry from the ALB and this data is not held to the more stringent IHO S-44 Order 1a survey standards (equivalent to IHO CATZOC A1) to resolve all hydrographic features. Figure 3 shows a simplified workflow of hydrographic Order 1a data and Order 1b data (e.g. bathy ALB from RSD and USACE). With this new policy and AHB's positive review of using a gridded DEM, the workflow was determined to be more efficient while adequately meeting OCS' charting requirements.

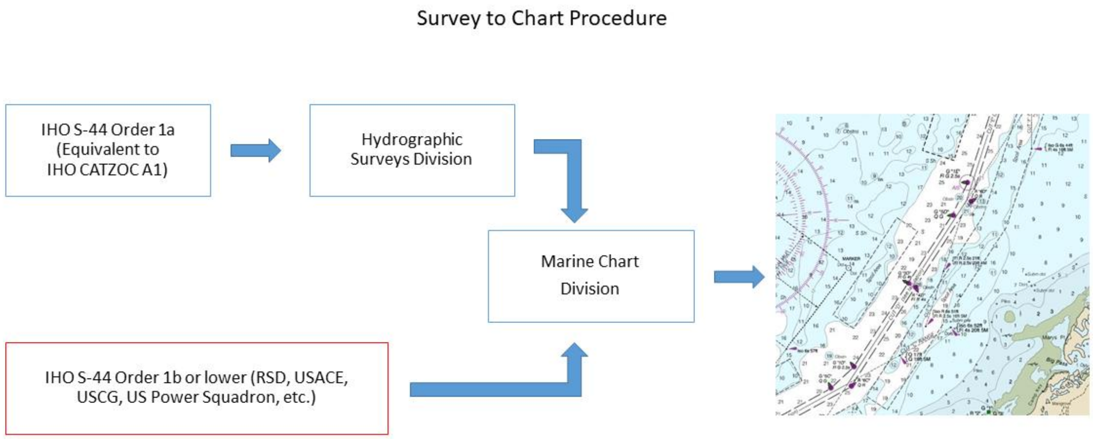

Figure 3. Surveys to Chart workflow into MCD's chart pipeline

RSD's and JALBTCX ALB data will also feed into OCS' Hydro Health Model and eventually the bathy database. These ALB data can fill in large near-shore gaps where it is inefficient and/or dangerous to send small hydrographic vessels (e.g. outer reef, FL or ICW). It can also be used as a reconnaissance tool for hydrographic vessels to further investigate features/ hazards found on the seafloor with ALB.

Since the third trial, RSD has continued to streamline its workflow with the help of AHB, JHC and the MCD to come up with the following deliverables listed in this policy:

- **1 meter original DEM:** this grid is created as part of our delivery package for Digital Coast and provides more detail if needed
- **5 meter MLLW shoal biased grid:** This grid was determined to be adequate since it covered both the need for shoal-biased soundings and was at MLLW with little gaps in coverage. This grid will be clipped to ENC boundaries and sparse data will be removed.
- **Feature shapefile:** This shapefile will include the following information: the least depth of the feature (at MLLW) and its location in degrees-minutes-seconds to at least two decimal places. Any feature identified in a lidar report will have a minimum size of $3m^3$ and will be navigationally significant. Features not found on overlapping flight lines and imagery will not be included in the survey report or submerged object shapefile. RSD has concluded that these are likely fish or some other free-floating objects in the water column.
- **CUSP Shoreline:** With the addition of the CUSP shoreline, RSD no longer needs to clip the topobathy gridded data at the MHW line. It should be noted however; that CUSP shoreline can be utilized at the discretion of OCS, when the GC is not available for consumption. CUSP is currently not a replacement for the standard official RSD GC. RSD's GC will supersede the CUSP shoreline when it becomes available. RSD is making the CUSP shoreline part of its deliverable because it has been created by RSD using approved consistent methodologies. This alleviates OCS from expending extra resources to create a shoreline or do transformations.

- **Metadata:** users of this data should use the dates of acquisition found under the Beginning Date and Ending Date.
- **Short report:** This report will include the RSD project number, the dates of acquisition, information regarding large features found (e.g. geographic position, a top down/ side view image of any large features found in both the point cloud and the RSD imagery, dimensions and least depth).

Below is the workflow from RSD to Coast Surveys' Marine Chart Division (MCD) (Figure 4). RSD is providing lidar data to MCD, in part, to streamline the data directly to NOAA end-user products. MCD has added a lidar Analyst to help create other required products such as the MQual (which denotes the quality of the survey), contours and depths. The MCD lidar Analyst then provides a complete package to MCD's Nautical Data Branch (NDB). All data going to MCD must go through NDB first for initial evaluation. When NDB receives the data, evaluates it to make sure everything needed for registration is present and the data has no issues, the data is registered as source in DREG (database). NDB then determines which products the data covers using an AOI (area of interest) and they release the data to the teams for compilation.

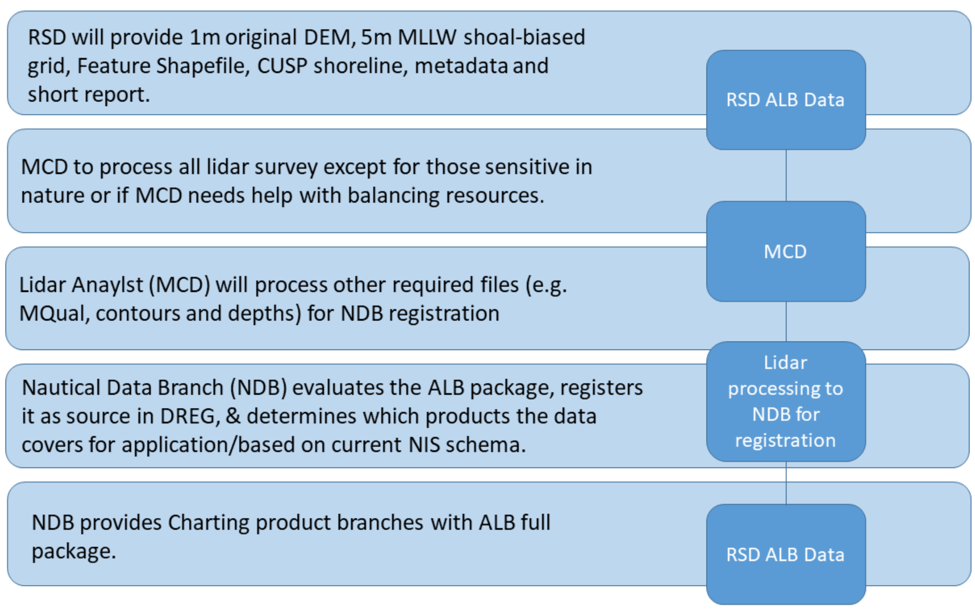

Figure 4. RSD to MCD current ALB workflow

RSD and OCS also use a tracking spreadsheet (Figure 5) to maintain communications regarding where the surveys were delivered (AHB or MCD), the survey location, delivery date, issues etc.

RSD Survey number	Delivery date	To MCD or AHB	Survey Location	HSD Registry number	Reviewer	Survey dates	Issues	Notes
NJ1301	3/20/2014	AHB	Barnegat Bay, NJ	W00279	Gene Parker	9/23/2013 - 9/29/2013	can't open img fil	Time intensive - need to make deliv
FL1423	11/5/2014	AHB	Lake Worth/Palm Beach, FL	W00287	Tyanne Faulkes	8/12/2014	ground data in ba	VQ-820 used
NC1408-TB-C	1/5/2016	AHB	Winyah Bay, SC to Norfolk, VA	W00300	IOCM contractors/James Mil	11/25/2013 - 7/20/2014	too much data - I	1st of 4 regions of Sandy contract s
		AHB		W00331				
		AHB		W00332				
		AHB		W00333				
		AHB		W00334				
		AHB		W00335				
		AHB		W00336				
		AHB		W00337				
		AHB		W00338				
		AHB		W00339				
		AHB		W00340				

Figure 5. RSD surveys tracking spreadsheet

Additionally, because the deliverables have changed over time RSD and OCS also track these as well (Figure 6):

Project ID	Location Name	MLLW las	Tile Scheme	1 meter MLLW DEM	5 meter Shoal Biased MLLW DEM	DEM Metadata	Submerged Object Shapefile	CUSP Shoreline	Imagery	Report	Delivered
NJ1301	Barnegat Bay, NJ	X	X	N/A	N/A	N/A	N/A	X	X	N/A	X
FL1423	Lake Worth/Palm Beach, FL	X	X	N/A	N/A	X	N/A	X	X	X	X

Figure 6. Deliverables tracking spreadsheet

Data Delivery to the Public

RSD sends all of its ALB and imagery data to NOAA's Digital Coast where it is freely accessible to the public. Digital Coast is an enabling platform developed to deliver data, tools, training, and information most needed by the coastal resource management community. Content comes from many sources, all of which are vetted by NOAA. The benefit of having data on Digital Coast is that it is a user-friendly website which provides easy access to the data.

Internally to Digital Coast, for the most part, things are automated and data is stored in a common format, projection, and datum. NAD83 geographic is the standard storage datum and projection while outputs can be in either NAD83 or WGS84 and in a multitude of projections. Additionally, Digital Coast has started including pre-made DEMs however they are listed as a separate data set.

Regarding downloading point cloud data, Digital Coast currently limits the request to 1.5 billion points per job, however there is no limit on the number of jobs. There is a limit to how many Digital Coast jobs will run for a requestor at one time, but the additional jobs are queued up and run as jobs finish. This decreases the risk of a denial of service to other users. If an entire large data set is required, it is recommended to go to the bulk download site, grab the data, and have the user do the needed conversions; it's a lot faster. Before anyone downloads this much data, however, it is recommended that one pay considerable attention to how one plans to work with it.

Common Experiences and Issues for NOAA and CHS

Both CHS and NOAA have met with similar issues when trying to insert nearshore ALB into the hydrographic and charting pipeline. These experiences and issues include:

1) **The challenges of gaining trust and acceptance for utilizing lidar data on chart products.** There are indeed trust issues with ALB because data with a lot more uncertainty is being assessed for inclusion on the chart.

This means we have to be more thoughtful as to how the data is applied and interpreted. This lack of trust is also, in part, due to the uncertainty that sometimes arises when comparing acoustically obtained data with lidar and the lack of accompanying background information that would make the sounding selection decisions easier.

2) **The need for standardized approaches and well-documented workflows.** As with any major change, creating a standardized approach takes time and can be a resource-heavy endeavor. Do S-44 and CATZOC adequately describe the nature of lidar uncertainty and provide appropriate categories?
3) **The handling of large data quantities, along with the inevitable storage and analysis requirements.** Lidar data collection is very efficient and the initial processing workflows can bring data to a level where it is ready to be viewed relatively quickly. When data is being thoroughly reviewed and reformatted to fit into operational workflows used in chart construction, the amount of data starts to become a major issue. There is far more data than can be rapidly assessed, which inevitably causes backlogs. Lidar data is extremely effective at depicting rapid change and loses value the longer it takes to process and fit it into a rigid workflow for various applications. In today's world, that timeline expectation has shortened dramatically compared to 30-40 years ago.
4) **The need to provide continuous training and the problem of maintaining expertise due to staff turnover.** There is limited expertise available and high resolution shallow water ALB is relatively new type of data source in the hydrographic/charting world, so adaptation is still underway. Training for experienced hydrographers and cartographers is limited and often CHS and OCS have had to rely on external expertise as internal skill sets have developed. RSD continues to work at maintaining internal expertise but CHS is very much in need of fundamental LiDAR training and practical experience.
5) **The questions of whether surfaces and grids are the best way to represent data and how these should be created in the future**. Technical challenges such as how to deal with sparse data when laser signal loses its ability to penetrate into deep or turbid waters (e.g. depth extinction). We can create a 5 meter grid to give the cartographer a general idea of the bathymetry, but is this the best product in the long term? What role can classified point clouds play in future data representations and how can these be assessed against other sources of hydrographic information? Can we automate feature detection for charted items (e.g. wrecks with a position approximate (PA) or position doubtful (PD)) to confirm their existence in LAS data and extract positions for those not found for further investigation with MBES since pulling features from a grid is not ideal?
6) **The treatment of uncertainty/TPU, which is not addressed as thoroughly as it is with MBES (but it really should be).** We use CATZOC B and S-44 1b as a generic descriptor of ALB, but it may be better than this in many locations. RSD is working towards improving lidar accuracy analysis and CHS also realizes the importance this issue in future error modelling and data categorizations.
7) **The incompatibility of traditional hydrographic and lidar software, the treatment of LAS data and the impact this has on data workflow.** Hydrographic software is beginning to make changes to be able to handle full LAS classifications, but improvements to the ability to really interrogate the data needs to be developed further. The LAS 1.4 definition seems to solve a lot of issues, but the tools for analyzing and validating various hydrographic data need to be friendlier to this format. Trying to compare MBES data and lidar in most software is still like comparing apples to oranges. In truth, they are more like two varieties of apples (i.e. they are just different types of point clouds) and share a great deal in common from a data workflow perspective. Being able to see both data sets and integrate them together into a common workflow is an upcoming challenge.

Future Steps

CHS and NOAA must continue to acquire and utilize ALB data to help the overall efforts to update our charting products quickly and more efficiently. Even if the grid product approach works now, we need to continue to consider more efficient and effective ways to get ALB data to our charts quickly and smoothly. Coast Survey is interested in going back to our older ALB data to extract features, but cannot do so using a grid. Current hydrographic software, while it has improved, does not fully incorporate all the lidar software components, such as those to QC data and extract least depths on features quickly. Also, we must have plans ready for increased capacity to meet changing requirements (e.g. multiple massive hurricanes) and continue to work with our international partners to share and improve workflows together. It is time to discuss how to pull together or leverage resources to create a lidar training course similar to the multibeam training course as demand for ALB data has increased. The JALBTCX workshop is a great venue that we look forward to utilizing to develop the steps and discuss the necessary components for a valuable lidar training course. Standardization is a key component for us to focus on for future steps as well. We recommend that LAS and some sort of tiling be a standard. This should not be just for lidar software but for hydrographic software as well. This is a practical first step for success. Also, we recommend steps for the continuation of research and integration of total propagated uncertainty (TPU) into software as well as the las standard itself. The hydrographic community has been doing this for a while and we have made some progress but we need to continue to push forward. There is a LAS github site (https://github.com/ASPRSorg/LAS/issues) where issues are being reported and tracked. We recommend the hydrographic and lidar community note the need for LAS to have TPU in the standard and help discussion on how it should ultimately look in the standard. Also, we should keep tabs on progress of variable gridding for multibeam data. We do not recommend this path for shallow ALB currently because as many are aware, multibeam and lidar are not one-to-one systems however we must continue to be open to ideas as we move forward.