Web-based Visualization of Integrated Next-Generation S-100 Hydrographic Datasets

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***Abstract*— This paper discusses a variety of next-generation data products for marine navigation, many of which are encompassed by existing or planned S-100 standards developed by the International Hydrograph Organization. This includes electronic charts, bathymetric surfaces, shoreline lidar, and marine traffic and infrastructure features extracted from textual publications. A web-based visualization interface is presented, which demonstrates how these different data sources can be integrated together to support safer marine navigation, illustrate sailing directions, and aid efficient voyage planning.**

Keywords—web-based visualization, S-100, ENC, marine navigation, shoreline lidar, streamline flow visualization

I. INTRODUCTION

The International Hydrographic Organization has been developing the S-100 framework of standards for the next generation of hydrographic and maritime navigation data products. These standards cover a wide range of data sources, from electronic navigational charts, to forecasts from oceanic and atmospheric simulation models, and information about features and infrastructure that has traditionally been disseminated in purely textual publications. While some of these standards are already well-defined, many are still in early stages of development, and some new data sources have yet to be formally proposed as a target for standardization.

The concept of precision-navigation is a significant driver of these next-generation data sets. Precision-navigation requires providing mariners with accurate forecast data from atmospheric and oceanographic simulations, along with precise, high-resolution observations of bathymetry depths, tides, and wave heights. This combination empowers mariners to more safely and efficiently navigate in closer proximity to the seafloor, river beds, and infrastructure.

This paper focuses on the lower Mississippi River area, which has been a target of NOAA's Precision Navigation surveying and forecasting efforts. The river is highly-congested, and a single accident could significantly disrupt its multi-billion dollar shipping industry.

With the increased availability of broadband data access near shore (e.g. 5G) and offshore (e.g. Starlink), mariners can receive real-time weather and oceanographic observations. Much of the other data mariners rely on in their ECDIS (Electronic Chart Display and Information System) or PPU (Portable Pilot Unit) can also now be downloaded or streamed as needed. Compared to storing files locally, this ensures data is always up-to-date.

The 3D, web-based interface presented in this paper was created as a sandbox for experimenting with the integration of various data sources, and to permit anyone to easily view these extensive datasets without the need to download and store large files or use expensive software. Future uses of this system could support include voyage planning, familiarizing mariners with new ports, and providing a PPU style navigational aid using the browser's ability to share real time location data.

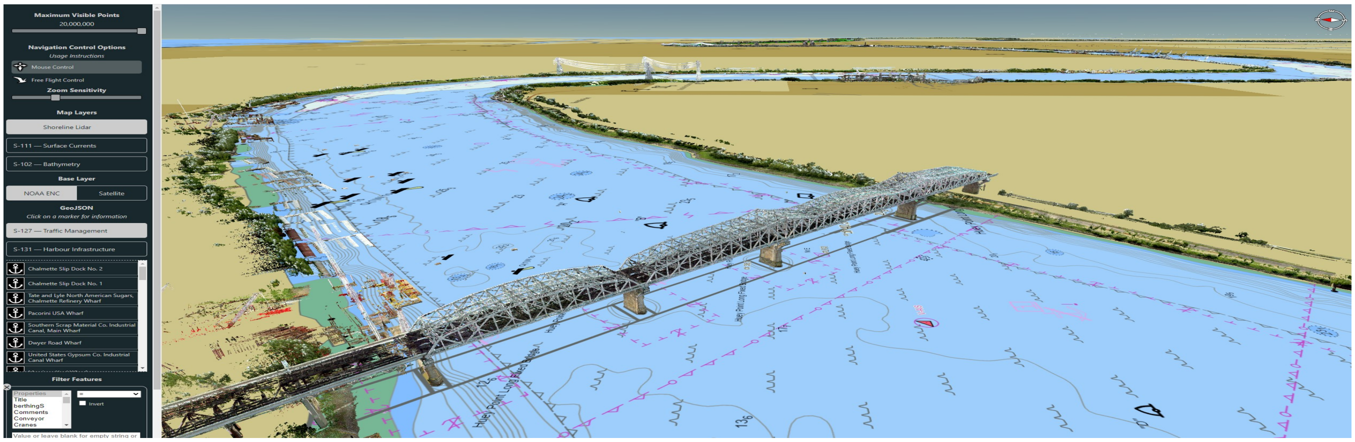


Figure 1: Screenshot of the web-based visualization interface, showing a section of the lower Mississippi River.

II. MAPPING INTERFACE & DATA SOURCES

The web-based visualization interface, developed to experiment with ways to integrate and use new marine navigation data sources together, is shown in Figure 1. It was built using the open source Potree [1] and CesiumJS [2] JavaScript libraries. Potree handles the 3D point cloud rendering, as detailed in the following subsection, and Cesium provides accompanying base layers and 3D bathymetry, as described in later subsections.

A. Shoreline Lidar Point Clouds

This project began by experimenting with ways to visualize and make use of a fairly unique data product: shoreline lidar scans. These colored point clouds provide extraordinary detail of above-water hazards and shoreline features, with accuracy sufficient to perform real-time clearance calculations. Because they were captured sideways from a boat rather than downward from an aircraft, they are much more useful for providing visual reference and understanding the coastal environment as it appears from a mariner's perspective on the water.

The point clouds used in this project were collected by David Evans and Associates for NOAA's Lower Mississippi Precision Navigation project. They used a combination of a RIEGL VUX-1HA high accuracy lidar sensor and a FLIR Ladybug5 360° color camera to collect and produce the colored lidar point clouds.

The large file sizes of these point clouds (about 120GB for the 260 miles of river) makes them slow to download, and most users are probably only interested in seeing rather small portions of the data in high detail. Thus, it makes sense to stream only what users want/need to see. To stream the point clouds and render them efficiently and effectively in the user's web browser, we utilized the Potree library.

Potree provides a PotreeConverter tool that is used to pre-process large collections of point clouds into spatial data structures that enable their content to be streamed at various levels of detail. These files are then pulled from a standard web server by the Potree JavaScript library which uses WebGL to efficiently render the point cloud data in user's web browsers, with visual enhancements such as "eye-dome lighting" to better reveal the contents of the point cloud. These visual enhancements are important, as simply rendering points as colored dots does not produce such aesthetically pleasing or useful visualizations. For example, Potree examines the relative depth between adjacent points on screen, and adds some black between them to highlight their depth differences.

Potree provides an extensive interface to control visual parameters, camera movement and projection, etc. However, for our application, many of these controls are not relevant and were removed. Optimal visual parameters (e.g. lighting and point size) were determined and then hard-coded, with the controls for the point clouds reduced to a simple "maximum visible points" slider, which allows users to adjust the trade-off between visual quality and graphics performance depending on their available hardware. Control over the camera was simplified to two options that retain full functionality. Camera parameters are converted for use with Cesium and passed to it for rendering the layers under the point clouds.

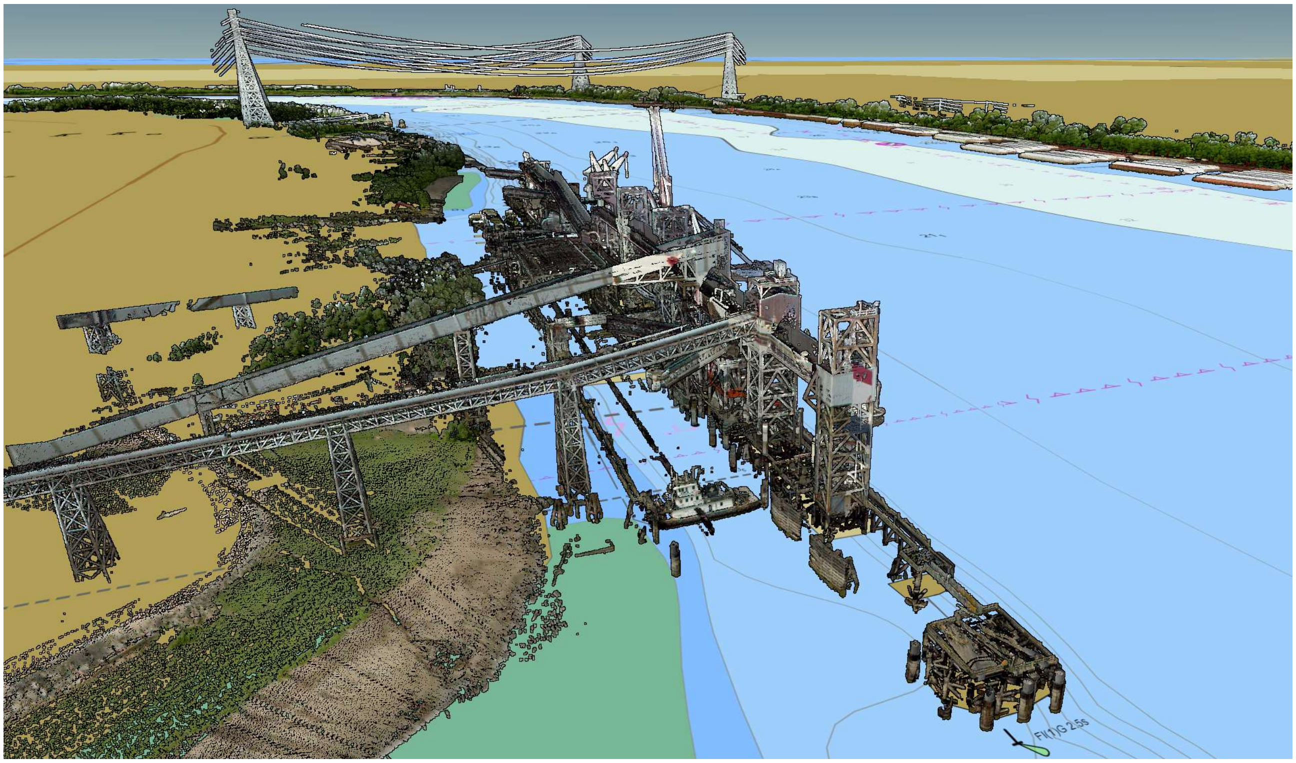


Figure 2: Example of shoreline lidar data, showing detailed harbor infrastructure and overhead power lines, drawn over NOAA ENC tiles.

B. Electronic Navigational Charts

To add context to our shoreline lidar point clouds, a standard ECDIS style electronic chart was desirable, since the intended audience is mariners. Rather than try to implement a browser based S-57 or S-101 ENC renderer, a web-service was used to stream nautical chart images to the browser as needed.

NOAA's Office of Coast Survey provides an ECDIS Display Service [3] in the form of a Web Map Service (WMS) server. Clients can request an image of a particular size for a desired geographic bounding box, and get back a rendered on-demand image of a nautical chart that uses standard IHO ECDIS symbology. This enables one to offload the work of rendering S-57/S-101 ENC data to the cloud, reducing the workload on client web browsers and avoiding responsibility to handle changes to ECDIS portrayal requirements.

Because these images are rendered on demand (as opposed to pre-rendered tile services such as WMTS), users can also request particular layers or visual parameters, such as day/dusk/night color schemes. One can even request specific "shallow", "safety", and "deep" depths for setting contour colors to match their vessel draft. This feature enables one to make the visualization vessel-specific, by entering the vessels draft and retrieving a current (or forecasted) water level, e.g. from NOAA PORTS [4]

Vessel draft would ideally be specified by uploading an S-129 (under keel clearance management) file, which encodes information about a vessel's under keel clearance. However, that standard is still in testing, and only limited sample data is currently available.

While not intended to replace an ECDIS or PPU for navigational use, this web interface can serve as a supplemental display on mobile devices (e.g. a tablet). Such devices can provide websites with location information, which can be used to position a vessel marker and move the map to follow the vessel's path. We have experimented with adding 3D vessel models (which would need to be uploaded by users) to the web interface, and have demonstrated in a separate desktop application how such models can be used with shoreline lidar and water level and air gap sensor data to calculate real-time clearances, shown in Figure 3.

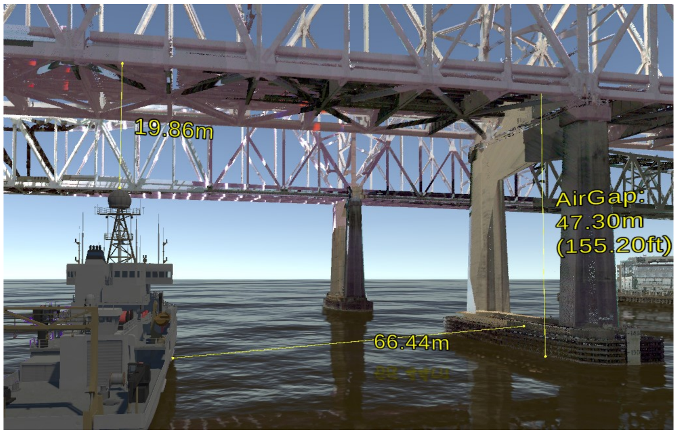


Figure 3: Example from a separate desktop application showing real-time clearance calculations using a 3D vessel model, lidar point clouds, and water level data downloaded from a NOAA PORTS air gap sensor.

Visually combining the actual observations of shoreline lidar with the idealized chart can reveal common transient objects and potential inconsistences or variations that mariners need to be aware of. For example, in Figure 4, one can see that the location of some buoys do not always match the charted positions, and common locations for mooring barges are not depicted on the chart. Satellite photos are also provided for cases where users wish to see something not depicted on the chart or captured by the shoreline lidar. These photos also provide another time step of observations that can be used to see if objects move around or have stable positions.

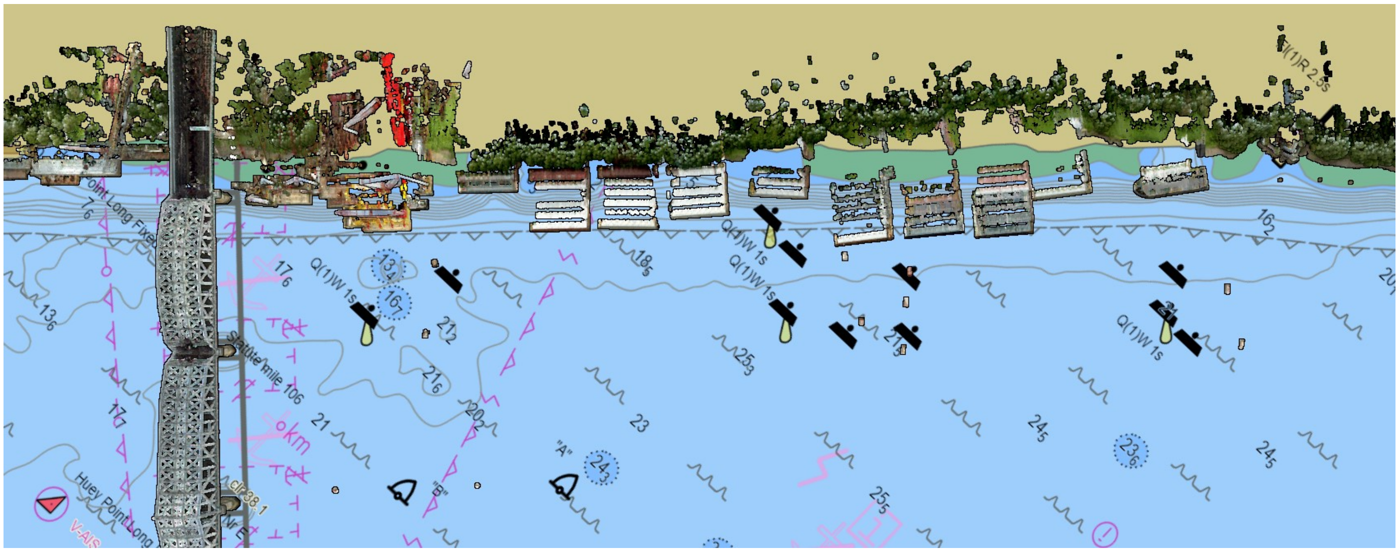


Figure 4: Shoreline lidar data over NOAA ECDIS Display Service nautical chart imagery, showing differences between charted buoy locations and actual observations, as well as uncharted barge mooring locations.

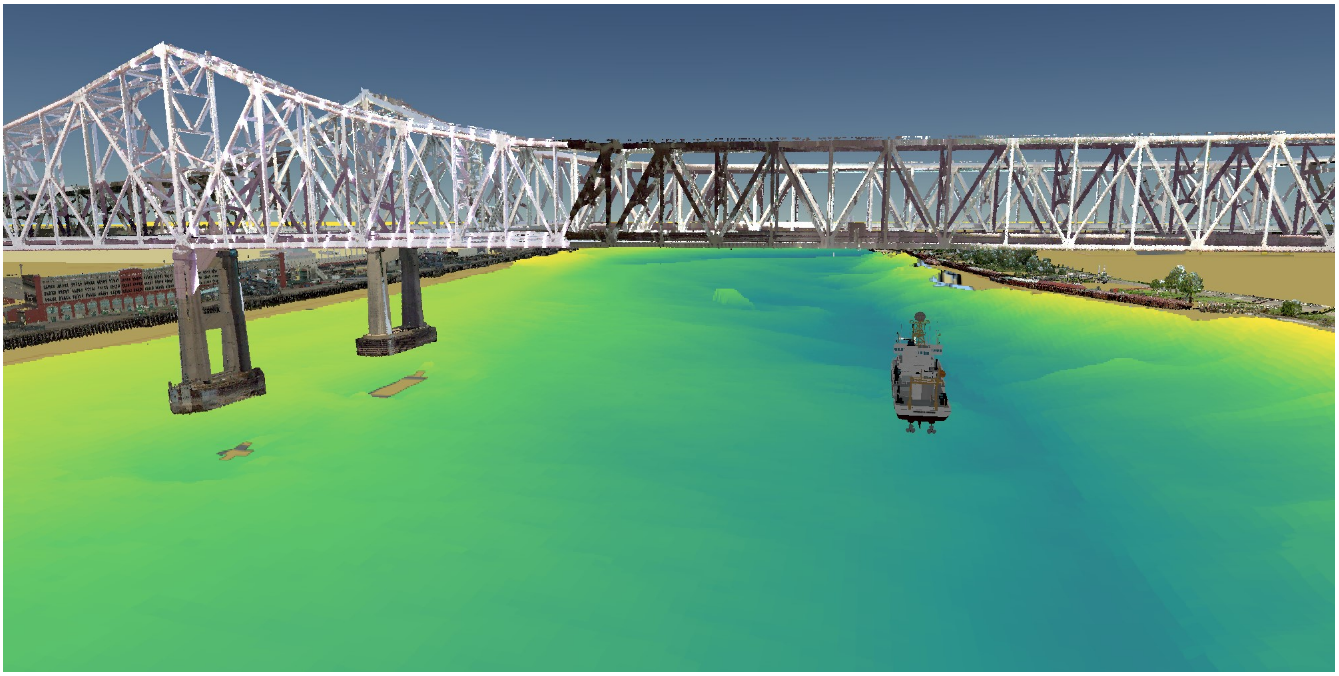


Figure 5: A 3D model of a vessel positioned over 3D bathymetry and below a lidar point cloud of a bridge.

C. S-102 Bathymetric Surface

While the nautical chart layer provides colored depth contours and selected soundings, more-detailed bathymetric information is available from S-102 datasets. This data can be streamed to a web map in a variety of formats, depending on the use case.

For viewing of 2D bathymetric maps, i.e. flat maps with color coded depths, pre-rendered image tiles can be streamed from a WMS or tile service. We use the open source geospatial server software GeoServer [5] to host and stream S-102 datasets, provided from NOAA in .bag (Bathymetric Attributed Grid) format, and then converted to GeoTIFF using GDAL [6].

We have also tested streaming bathymetric depth maps from The Office of Coast Survey's new BlueTopo service [7], which, as part of the National Bathymetric Source project, aims to compile and maintain a seamless nationwide dataset of the highest quality bathymetric data available for US waters. However, BlueTopo's nationwide data service is not yet publicly available.

3D bathymetry is another available option in our web mapping interface. S-102 BAG files are uploaded into the Cesium ion cloud service, which handles the conversion into optimized 3D Tiles. These 3D Tiles can then be streamed into the web interface as 3D terrain, showing the actual shape of the seafloor or riverbed. An example of this 3D Tiles bathymetry combined with shoreline lidar and a 3D vessel model is shown in Figure 5.

D. S-111 Surface Currents

The S-111 standard currently provides portrayal specifications for using grids of arrows to visualize gridded surface current data. However, perceptual studies have shown such techniques are poorly suited for some flow visualization tasks [8], and that streamline based techniques can be more effective at conveying flow patterns [9][10].

The Center for Coastal and Ocean Mapping's Roland Arsenault developed a free open-source S-111 Streamline library [11], which converts ocean flow data (e.g. from NOAA's Operational Forecast System) into streamline geometry using the Jobard and Lefer algorithm [12]. However, operationalizing this visualization technique is more complicated than the already-established gridded arrows technique, and thus it has not been widely adopted yet, despite its perceptual advantages.

A new approach to distributing S-111 streamlines was developed to take advantage of the ability to stream tiles of 3D geometry to web mapping clients. An S-111 data source, in this case, NetCDF files from the NOAA NGOFS2 [13] THREDDS server, is downloaded. The surface currents are then cropped out as needed (e.g. the Mississippi River is cropped out and processed separately from the rest of the Gulf of Mexico) and interpolated using SciPy into a regular grid, and saved to an S-111 conforming HDF5 file.

This is fed into the S-111 Streamlines library, which outputs streamline geometry as a GeoJSON. This geometry is then broken up into smaller GeoJSON tiles, with sizes based on streamline complexity and zoom levels.

Colors are assigned to the geometry based on speed using a modified (to increase contrast with ECDIS colors) IHO S-111 color scale. Placement of arrow heads along the streamline are pre-determined, and during rendering in Cesium, the arrow heads are instanced in these locations to increase performance versus drawing each individually.

Examples of this technique being used to distribute and visualize NGOFS2 data in the Mississippi River and CBOFS data in the Chesapeake Bay can been seen in Figures 6 and 7.

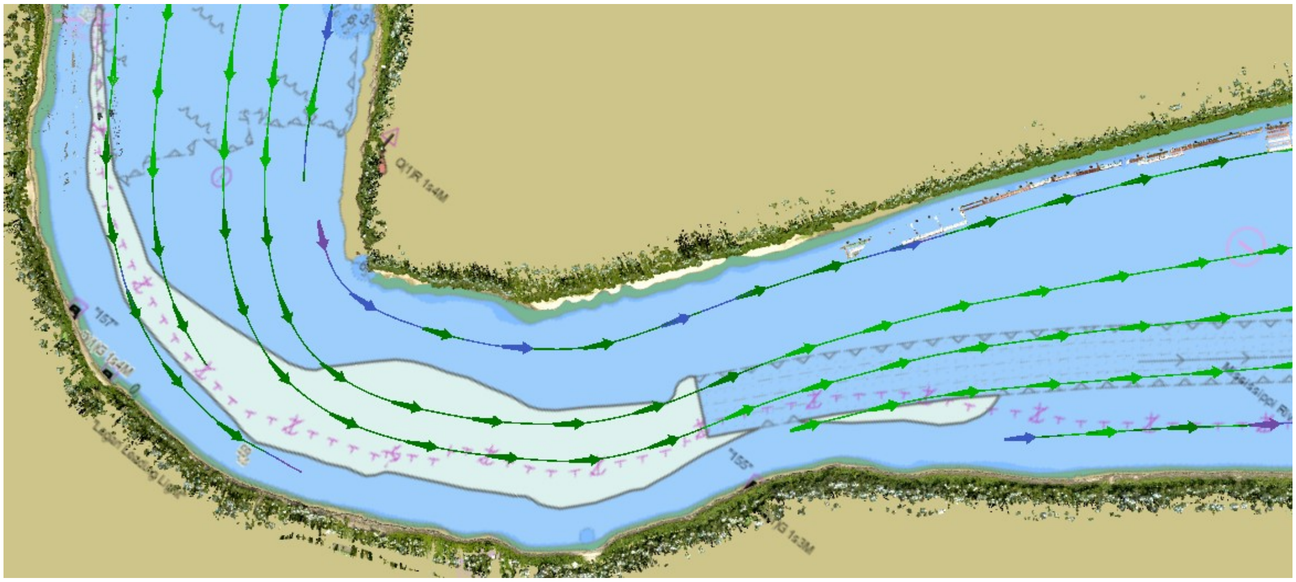


Figure 6: Streamlines showing S-111 Surface Current data from NGOFS2.

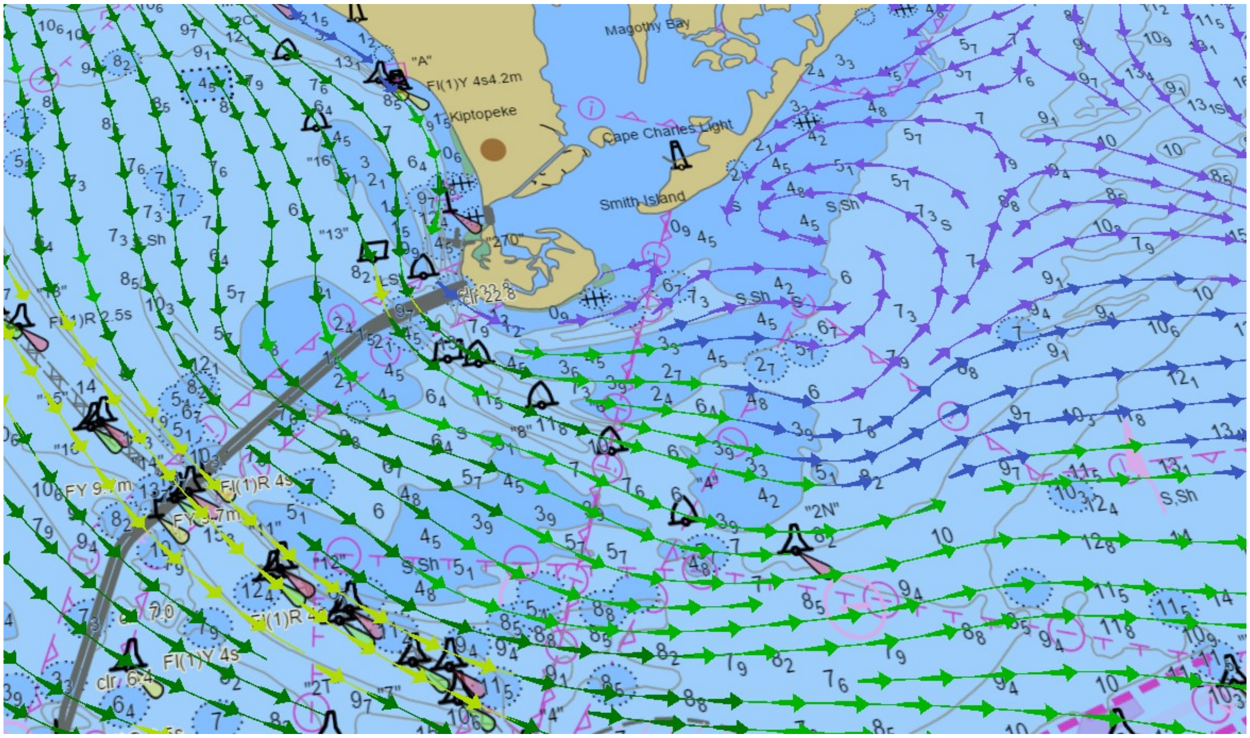


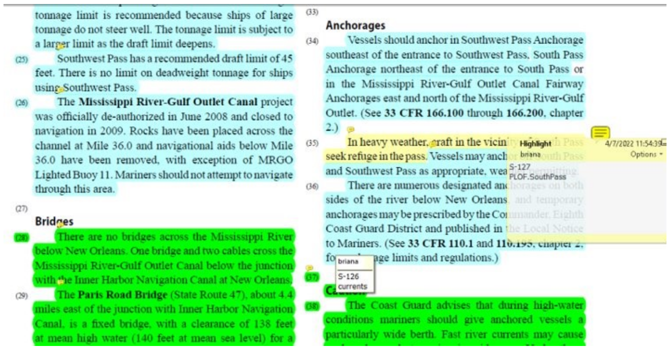
Figure 7: Streamlines showing S-111 Surface Current data from CBOFS.

E. Textual Nautical Information

There is a wealth of local knowledge contained within textual publications, such as Coast Pilot and Notice to Mariners. Much of this information can be difficult to digitize, geo-locate, and plot on a chart, often because it contains vague or general descriptions of applicable locations, or applies to very wide areas.

Our project experimented with how to create, display, and interact with such data, focusing primarily on the S-131 Marine Harbor Infrastructure standard, which is still in development.

First, using US Coast Pilot 5 as a text data source for the Mississippi River, the various types of data were identified, noting which S-100 products they corresponded to and the features and attributes described. Figure 8 shows an example of the process of marking up the document, where blue denotes S-131 Marine Harbour Infrastructure, green—S-126 Marine Physical Data, and yellow—S-127 Marine Traffic Management. Notes were added to keep track of the features and the attributes found in each highlighted group of text.



tonnage limit is recommended because ships of large tonnage do not steer well. The tonnage limit is subject to a larger limit as the draft limit deepens.

(25) Southwest Pass has a recommended draft limit of 45 feet. There is no limit on deadweight tonnage for ships using Southwest Pass.

(26) The **Mississippi River-Gulf Outlet Canal** project was officially de-authorized in June 2008 and closed to navigation in 2009. Rocks have been placed across the channel at Mile 36.0 and navigational aids below Mile 36.0 have been removed, with exception of MRGO Lighted Buoy 11. Mariners should not attempt to navigate through this area.

(27)

Bridges

(28) There are no bridges across the Mississippi River below New Orleans. One bridge and two cables cross the Mississippi River-Gulf Outlet Canal below the junction with the Inner Harbor Navigation Canal at New Orleans.

(29) The **Paris Road Bridge** (State Route 47), about 4.4 miles east of the junction with Inner Harbor Navigation Canal, is a fixed bridge, with a clearance of 138 feet at mean high water (140 feet at mean sea level) for a

(33)

Anchorages

(34) Vessels should anchor in Southwest Pass Anchorage southeast of the entrance to Southwest Pass, South Pass Anchorage northeast of the entrance to South Pass or in the Mississippi River-Gulf Outlet Canal Fairway Anchorages east and north of the Mississippi River-Gulf Outlet. (See **33 CFR 166.100** through **166.200**, chapter 2.)

(35) In heavy weather, craft in the vicinity of South Pass seek refuge in the pass. Vessels may anchor off South Pass and Southwest Pass as appropriate, weather permitting.

(36) There are numerous designated anchorages on both sides of the river below New Orleans, and temporary anchorages may be prescribed by the Commander, Eighth Coast Guard District and published in the Local Notice to Mariners. (See **33 CFR 110.1** and **110.195**, chapter 2, fo age limits and regulations.)

(37)

Ca

(38) The Coast Guard advises that during high-water conditions mariners should give anchored vessels a particularly wide berth. Fast river currents may cause

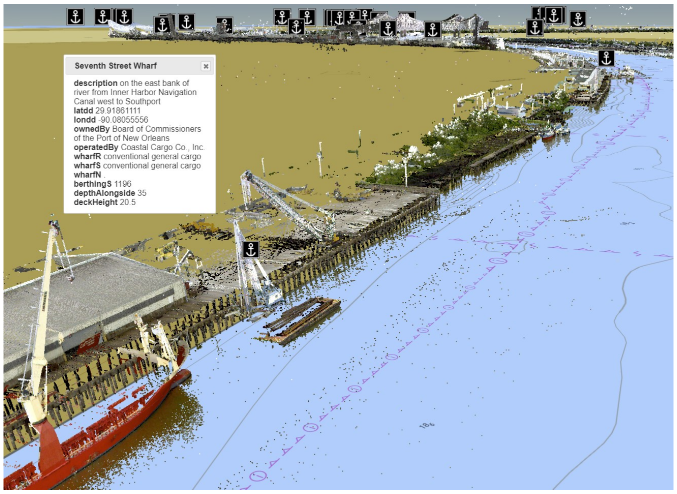
Highlight
briana
4/7/2022 11:54:39
Options ▾
S-127
PLOF.SouthPass

briana
S-126
currents

Figure 8: Example of marking up text (in this case Coast Pilot) to identify information by S-100 product, feature, and attribute.

Once all the elements were identified, IIC's Feature Builder software [14] was used to aid in the capture and formatting process. Feature Builder can generate S-100 complaint files, however we also considered connecting the web mapping interface directly to the same PostgreSQL database server used by Feature Builder, such that we could not only load the features as they are authored, but edit them within the web interface as well. The shoreline lidar is particularly attractive for helping to verify and refine feature locations, as it allows for easy repositioning of feature markers to be exactly on the objects described.

Our interface plots a collection of S-131 Marine Harbour Infrastructure features for the lower Mississippi directly within the 3D visualization using interactive markers. Figure 9 shows an example of an S-131 feature being queried by the user to view the facilities available at a particular wharf.



Seventh Street Wharf

description on the east bank of river from Inner Harbor Navigation Canal west to Southport
latdd 29.91861111
londd -90.08055556
ownedBy Board of Commissioners of the Port of New Orleans
operatedBy Coastal Cargo Co., Inc.
wharfR conventional general cargo
wharfS conventional general cargo
wharfN .
berthingS 1196
depthAlongside 35
deckHeight 20.5

Figure 9: Example of S-131 Marine Harbour Infrastructure features plotted within shoreline lidar of docks and cranes, with a feature marker selected to display an info box showing more details about that wharf's facilities.

Marker placement for features with locations specified as a single point is trivial, but there is no simple answer for where markers should be drawn for features that have locations specified by extremely large polygons covering entire regions, or many disconnected polygons. To address this issue, an "onscreen features" list appears in the sidebar interface, which automatically updates with the map to show any features that are at least partially onscreen at the time.

To assist in searching feature catalogs, a manual filtering interface is provided. Here users can search for features matching specific attributes, for example, to find a facility that sells a required type of fuel.

Because the S-126, S-127, and S-131 standards are still under development, there are no existing symbol sets available for the features they contain. Our center's cartographer, Christos Kastrisios, designed a new set of symbols, some of which are shown in Figure 10, to represent these new feature types, based on existing ECDIS and chart symbology where possible. The bold black and white markers containing these symbols were designed to contrast with ECDIS maps and other data in our application, such that they clearly stand out to the user as interactive elements.

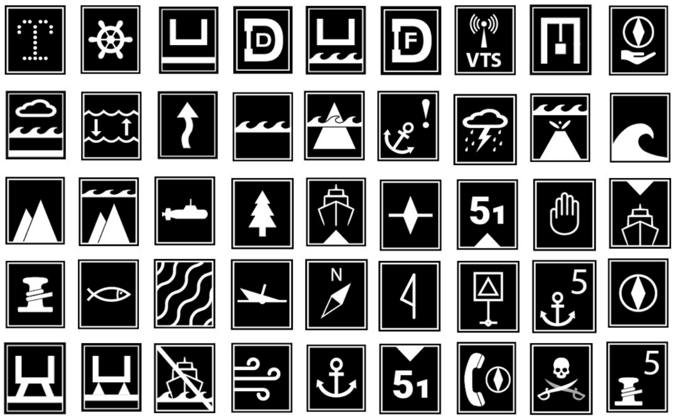


Figure 10: Proposed symbols for a variety of S-126, S127, and S-131 features.

III. STANDARDIZING SHORELINE POINT CLOUDS

The shoreline lidar data in this project is not currently covered under any S-100 standard. However, it is clear that it can provide helpful visual reference of a waterway's features and environment, as well as provide accurate high-resolution observations of obstacles and built infrastructure, which can be used for real-time clearance calculations, to assist docking, etc.

The first challenge that is encountered when working with this data is the need to clean it. Lidar data is inherently noisy, and while some noise, such as isolated fliers, can be easily cleaned automatically with various algorithms, many types of embedded and other undesirable noise, such as boat wakes and repeated returns from moving objects, must be manually removed.

Furthermore, lidar scans capture many transient objects, such as moored vessels, that arguably should not be retained in data products, but which are legitimate objects and thus likely impossible to identify automatically, as such classification is highly subjective. Policy as to what to remove and what to keep would need to be standardized. A guiding principle might be "Does this provide useful visual reference to aid navigation?" Some transient objects might be representative of what is commonly encountered at a location, and therefore might be a useful reference if properly flagged.

We cleaned the Mississippi River data shown in this paper using a freeware virtual reality point cloud cleaner [15] that was originally developed for cleaning multi-beam sonar data and was experimentally shown to be significantly faster than traditional desktop point cloud editing interfaces. [16]

We propose tiling shoreline point cloud data to match NOAA's existing ENC tile structure, and using the water polygons in S-57/S-101 ENCs to divide each tile's point cloud into two separate products:

First, a smaller file containing just the points within the waterway and a few meters inland from the waterline, i.e. the points necessary for safety of navigation tasks like performing clearance calculations and docking maneuvers.

Second, a larger file containing the rest of the point cloud that provides visual reference of inland features. Because these point clouds can be quite large and contain much redundant detail, some simplification is necessary. The points can be filtered to reduce point density based on distance to the waterway. This can be done without significant loss of visual quality, because distant objects further away from potential viewing locations within the waterway require fewer points to appear solid than objects closer to the waterway.

Users could then choose to download whichever combination of these products the available storage and computational capabilities of their navigational device permits.

Data could potentially be stored and distributed using the Cloud Optimized Point Cloud format [17] which is a variation on the common LAS/LAZ format that includes a pre-calculated octree data structure and is optimized for the partial reading on servers that stream portions of the data to web-based geospatial visualizations, such as those presented in this paper.

IV. CONCLUSION

This paper presented an experimental web-based interface for visualizing next-generation hydrographic data, including shoreline lidar, cloud-rendered ENCs, streamline-based surface currents, and features sourced from traditional textual publications. It demonstrates the advantages of integrating these datasets together in a coherent 3D visualization, increasing their potential usefulness for mariners, hydrographers, and marine planners.

It is our hope that this work helps guide the development of the unfinished S-100 standards, particularly in terms of their portrayal specifications.

The experimental web interface featured here is accessible to the public through The CCOM Data Visualization Research Lab's website: https://ccom.unh.edu/vislab/

ACKNOWLEDGMENT

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