NOS PRIORITY:

SAFE AND EFFICIENT TRANSPORTATION AND COMMERCE

SHIPS MOVE $1.5 TRILLION worth of products in and out of U.S. ports every year. Every ship moving in and out of U.S. ports relies on navigation charts and water level information that NOS alone provides. All mapping, charting, and transportation activities and infrastructure are founded on a reliable, accurate national coordinate system. NOS is solely responsible for maintaining that system, which provides more than $2.4 billion in potential annual benefits to the U.S. economy. Businesses in the maritime community rely on NOS for a range of decisions, from how much cargo to load to choosing the safest and most efficient route between two points. They use NOS data, tools, and services to plan seasonally for ship schedules to service global trade more safely and efficiently as significantly larger vessels transit through U.S. ports.

Following are transportation and commerce themed projects organized according to two primary scientific priorities of the National Centers for Coastal Ocean Science (NCCOS) strategic plan.

Advanced Observation Technologies

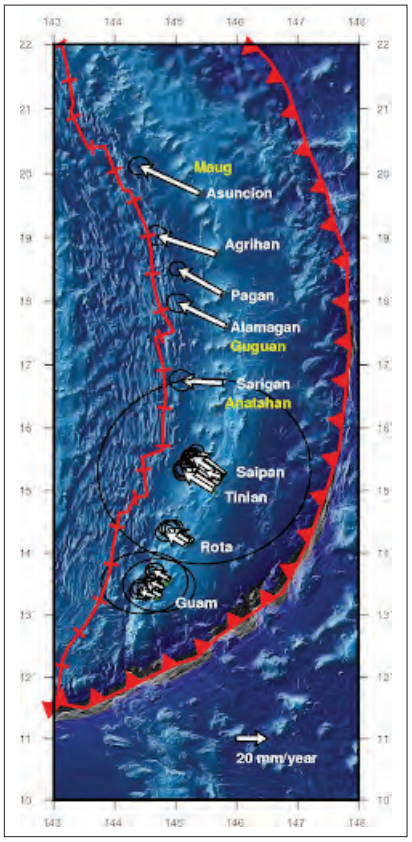
Included below are nine highlighted scientific projects by NGS, OCS, and IOOS researchers and their partners, which are focused on advanced observation technologies.

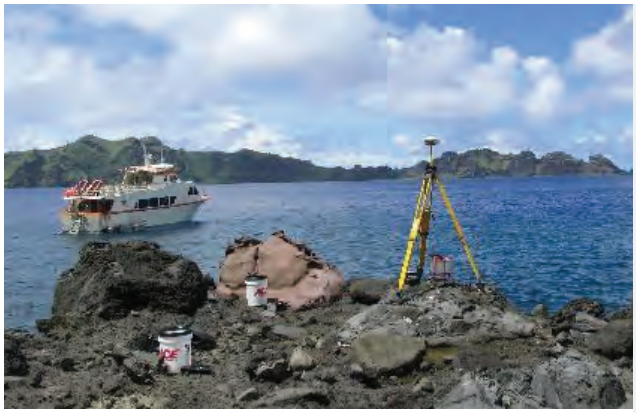
Determining the Rotation of the Mariana tectonic plate

In a few years, **NGS** will modernize the National Spatial Reference System (NSRS). This system will include the definition of a plate-fixed reference frame for Guam and the Commonwealth of the Northern Mariana Islands (CNMI) called the Mariana Terrestrial Reference Frame of 2022 or MATRF2022. To define such a frame, the absolute rotation of the underlying tectonic plate (Mariana) must be known relative to a global plate-independent frame, such as the International Terrestrial Reference Frame. Very few studies of the Mariana plate have ever been performed, and most are only relative to other plates. To address this situation, NGS in 2017 performed a complicated GPS survey of geodetic control points on numerous islands on the plate. This survey collected data on points that had been previously surveyed by GPS between 2003 and 2014. By differencing these various surveys, linear velocities were implied and subsequently used to define the rotation of the plate. This estimate of the plate's rotation was the most accurate and data-rich estimate ever performed for this small tectonic plate and will serve as the underlying model for MATRF2022. The results were published in the NOAA Technical Report series in August 2020.

FY21 ACCOMPLISHMENT:
Peer reviewed publication in the NOAA Technical Report series quantifying the absolute rotation of the Mariana plate.

NOAA Technical Memorandum: https://geodesy.noaa.gov/library/pdfs/NOAA_TR_NOS_NGS_0074.pdf





GPS-implied velocities on the Mariana plate (left), and some of the ground truth surveys which generated them in Maug (top right) and Alamagan (bottom right), CNMI.

Image credit: NOAA/NOS/NGS.

Machine Learning Applications for the Effective Operation of Autonomous Surface Vessels in Ocean Mapping Missions

In FY 2021, the NOAA/University of New Hampshire Joint Hydrographic Center and Center for Coastal and Ocean Mapping Autonomous Surface Vessel (ASV) Team, together with OCS, achieved significant improvements in the use of Machine Learning for ASV operations. The team has developed a software framework based on the Robotics Operating System, integrating cameras, swath mapping echo-sounders, marine radar, lidar, marine automatic identification service (AIS), National Marine Electronics Association (NMEA) based sensors for engine monitoring and vehicle health. The software framework builds on the open source nature of ROS with algorithms for object detection and classification and system control and includes a custom operator's interface and map-based mission planning software. Its modular architecture allows for rapid integration of new algorithms and technologies into robotic vessels and for collaboration and sharing of those algorithms with others.

The Joint Hydrographic Center uncrewed surface vessel underway off Portsmouth, New Hampshire. *Image credit: NOAA/NOS/OCS.*

FY21 ACCOMPLISHMENT:

The program achieved significant improvements in autonomous surface vessel operation for hydrographic survey and ocean mapping.

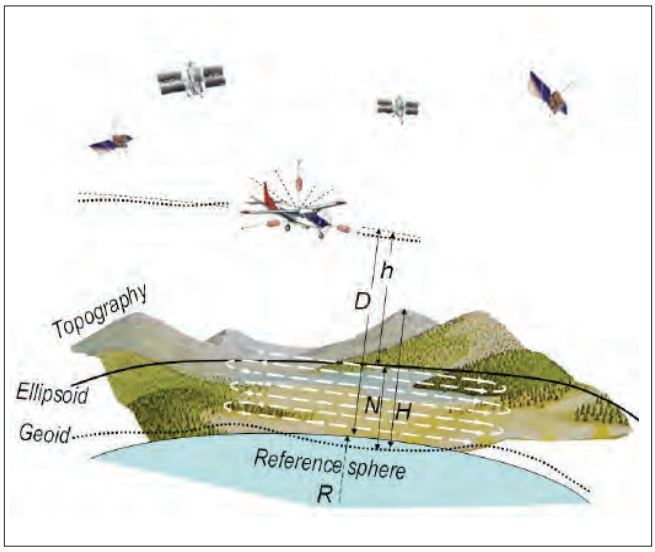
Project URL: https://www.unh.edu/unhtoday/2021/01/seas-day

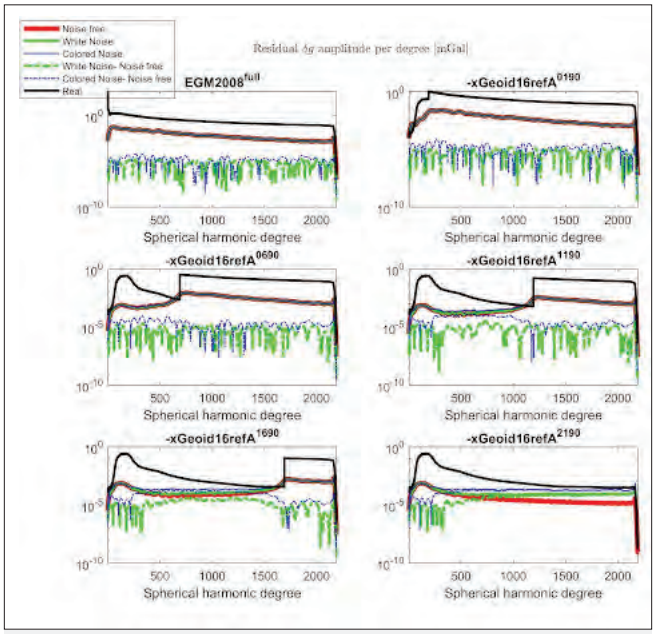
AWARDS:

The project team won first place in the Virtual Ocean Robotics Challenge (https://www.oceanroboticschallenge.com) sponsored by Open Robotics, the Naval Post Graduate School and the Office of Naval Research.

Downward continuation of airborne gravity data for vertical datum determination

NGS is conducting a large-scale campaign, called Gravity for the Redefinition of the American Vertical Datum (GRAV-D), to collect airborne gravity data over wide areas at a nominal flight height of 6 km. This project started in 2007 and has currently flown 86% of the U.S. and its territories. The flights also extend 100 km over the border into Mexico and Canada as well as into the open ocean areas. These newly acquired gravity data will serve as the backbone for computing the forthcoming vertical datum in North America (the North American-Pacific Geopotential Datum of 2022). How to downward continue the gravity data from flight trajectories to a reference ellipsoid surface, and how to render the 3D scattered data into a 2D grid with regular grid intervals, have been difficult problems in the field of physical geodesy for many decades. It is important to find the optimal solution to derive the best information from these aerial gravity data for the vertical datum computation. An **NGS** research geodesist has led an international working group within the International Association of Geodesy to tackle this problem. The group includes professors and scientists from numerous universities and agencies in the United States, Europe, Taiwan, and Canada. The working group has used both simulated data, and real GRAV-D data in the Colorado area, as a test bed to analyze various downward continuation methods. The resulting geoid models agreed at the mm-level, once data editing problems were addressed. The analysis also showed that there are spectrum leakage problems for some of the methods. The group developed high-performance-computation (HPC) software packages for comparing the six different methods, and these will be shared with the global geodetic community.





Schematic of airborne data collection and software outputs for vertical datum determination. *Image credit: NOAA/NOS/NGS.*

FY21 ACCOMPLISHMENT:

Established solid theoretical background to downward continue aerial gravity data for geoid modelling; developed HPC software to share; obtained 1mm model agreements from the different formulizations; found and fixed the spectral leakage problem in the current NGS operational tools.

Published Abstract: Li, X., Huang, J., Willberg, M., Pail, R., Slobbe, C., Klees, R., Forsberg, R., Hwang, C., and Hilla, S.: On Downward Continuing Airborne Gravity Data for Local Geoid Modeling, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2706, https://meetingorganizer.copernicus.org/EGU21/session/39915

Multi-Constellation GNSS Calibration of User/Receiving Antennas at the National Geodetic Survey

Sub-centimeter positions with the Global Navigation Satellite System (GNSS) require modeling and correction for the electrical properties of the receiving antenna. Creating a correction table for the antenna's electrical properties is called antenna calibration. Although **NGS** has calibrated GPS user antennas since 1994, recent acquisition and programming of a 6-axis industrial robotic arm (a device capable of achieving positions with sub-mm accuracy) and tunable multi-GNSS receivers has allowed NGS to increase the capabilities of the antenna calibration program. The NGS calibration system has successfully demonstrated that it will be able to calibrate user antennas for all GNSS frequencies, with results that agree well with community standards.

Top: KUKA 6-axis robotic arm, as installed at NGS's Testing and Training Facility, with a chokering GNSS antenna mounted on the robot's tool end. Bottom: The robotic arm is housed inside a retractable dome, and is pictured here with several antennas used to validate the system's results. *Image credit: NOAA/NOS/NGS.*

FY21 ACCOMPLISHMENT:
Achieved multi-GNSS, full-spectrum calibrations with new high-accuracy 6-axis robotic arm.

Project URL: https://www.ngs.noaa.gov/ANTCAL/

AWARDS:
A previous, less accurate system using a 2-axis robot won a 2014 Bronze Medal "for the design and implementation of a NOAA absolute GPS/GNSS antenna calibration program to improve GPS positioning accuracy for all users."

Modeling Geoid Change in Alaska at Higher Resolution

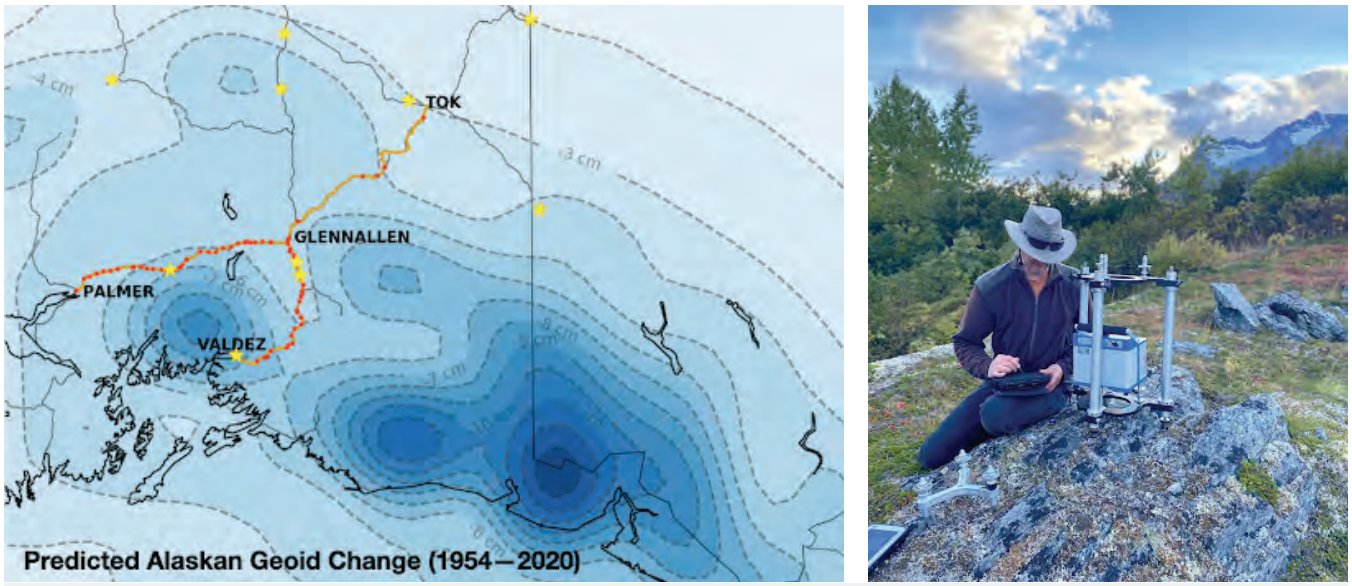
NGS' upcoming geopotential datum requires a dynamic component to ensure it matches the changing shape of the geoid—the level surface formed by Earth's gravity that best describes mean sea level—with centimeter accuracy. NASA's GRACE and GRACE-FO satellites have provided a record of changes to Earth's gravity field due to ice mass loss, hydrology, and solid-Earth processes. While they adequately capture these changes over most of North America, ice mass loss in Alaska changes the gravity field at much smaller scales than these satellites can resolve, resulting in errors of omission of more than 1 centimeter per decade. NGS scientists augmented the spatial resolution of the satellite models with predictions of geoid change derived from glacier elevation change measured with airborne altimetry and photogrammetry. These models were used to generate predictions of geoid change in southern Alaska since the mid-20th century that will be compared with historical gravity, elevation, and astronomical measurements.

FY21 ACCOMPLISHMENT:
Created models of geoid change in Alaska with enhanced spatial resolution and developed and carried out a survey campaign to validate the models against historical measurements.

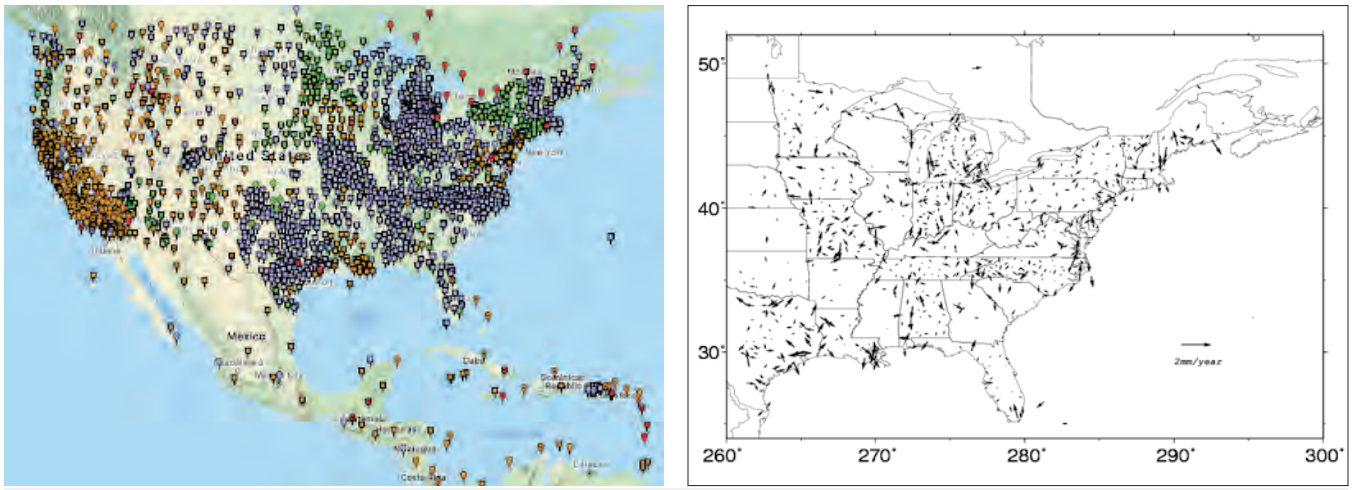
Presentation URL: https://www.ngs.noaa.gov/web/science_edu/presentations_library/files/agu2019_hardy.pdf

New position time series, velocities and quality measures for the CORS Network

The NOAA Continuously Operating Reference Station (CORS) network is a volunteer-based network of Global Positioning System (GPS) reference stations located mainly in the US and its territories. **NGS** scientists have reprocessed all GPS data collected via this network since 1996. Daily data



Left panel: A map of predicted geoid change in southern Alaska from ice mass loss with sites of historical gravity, elevation, and astronomical measurements. Right panel: NGS scientist collecting gravity measurements using a relative gravimeter during an Alaska survey. *Image credit: NOAA/NOS/NGS.*



Left panel: Major part of the NOAA CORS Network. Right panel: Velocity noise east of the Rockies (RMS ~0.2 mm/yr). Image credit: NOAA/NOS/NGS.

for GPS weeks 834 through 1933 were reprocessed leading to reference coordinates and velocities for 3049 stations aligned to the global reference frame IGS14. The derived velocity field was compared to several other solutions and to three regional geophysical and geodetic velocity models. These comparisons uncovered unstable stations which move differently than the regional kinematics around them. Once these were identified and excluded, we estimated the horizontal and vertical stability of this updated realization to be better than ~0.3 and ~0.6 mm/year, respectively. We used the position residuals and estimated uncertainties from this reprocessing to derive long-term stability measures for all active stations. These measures exposed ~60 CORS with the poorest long-term stability, which have been consequently excluded from serving as mapping control.

FY21 ACCOMPLISHMENTS:

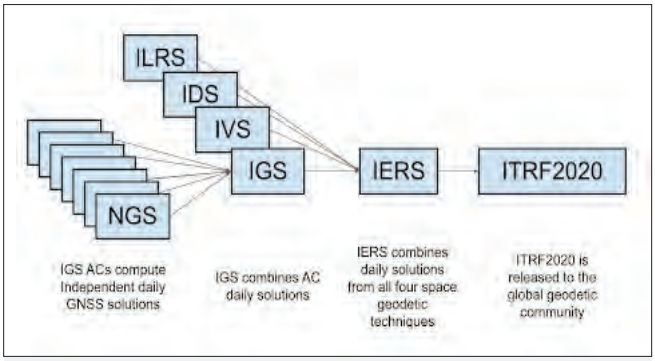
(1) The updated realization of the US National Spatial Reference System derived in this work is now officially in use; (2) This work was published in the Journal of Applied Geodesy in January 2021; (3) The work is based on intensive use of estimation theory and statistical analysis and successfully incorporated concepts and in-house developed Artificial Intelligence tools: edge detection, cluster analysis and information theory.

Peer reviewed journal article: https://www.degruyter.com/document/doi/10.1515/jag-2020-0041/html

NGS participation in the 3rd IGS reprocessing of GNSS data (REPRO3)

In early 2022, the International Earth Rotation and References Systems Service (IERS) will release the 2020 iteration of the International Terrestrial Reference Frame (ITRF2020). The forthcoming realization of ITRF2020 will combine observations from all of the major space geodetic techniques, including data from global navigation satellite systems (GNSS). The international body responsible for coordinating the GNSS contribution to ITRF2020 is the International GNSS Service (IGS). This effort by the IGS, completed in April 2021, was called the 3rd IGS reprocessing campaign. **NGS** is one of several IGS Analysis Centers (ACs) that participated in this campaign. To do so, we reprocessed all available GNSS data from 533 global continuously operating reference stations for the period between January 1, 1994, through December 31, 2020. These data were reprocessed using the most up-to-date techniques and models to produce three primary products: daily ground station positions, daily Earth-orientation parameters, and daily precise orbit solutions. These products, representing 27 years of daily solutions, were then sent to the IGS and were combined with independently computed solutions from the other IGS ACs. The combined IGS daily solutions were then sent to the IERS to be incorporated into ITRF2020. ITRF2020, much like previous iterations

of the ITRF, will form the backbone for all scientific positioning applications around the globe. It will also be the basis for the modernized U.S. National Spatial Reference System (NSRS), the official U.S. reference frame for all federal civilian applications. By participating in this campaign, NGS has ensured that there is superb representation of GNSS data from ground stations within the U.S. and our areas of interest (e.g. Caribbean, Pacific islands, etc.). This will allow NGS to very strongly tie the upcoming modernized NSRS to ITRF2020.



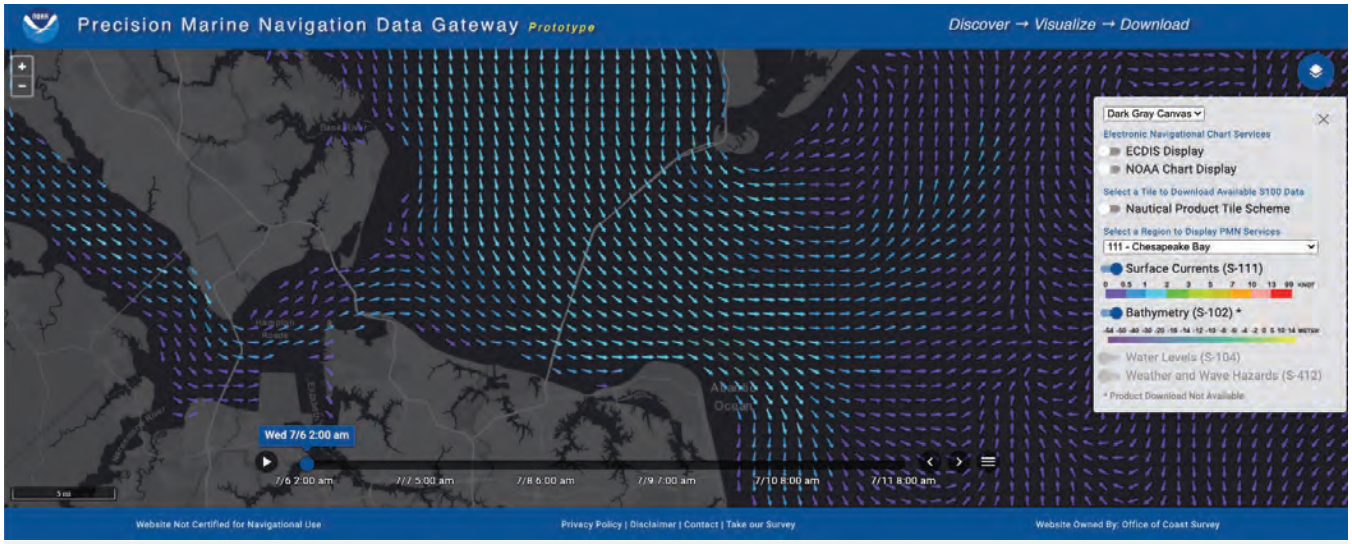
IGS ACs, including NGS, submitted 27 years of daily GNSS solutions to the IGS. The combined daily IGS solutions were then sent to the IERS for combination with solutions from the International Laser Ranging Service (ILRS), the International DORIS Service (IDS), and the International VLBI Service (IVS).

Image credit: NOAA/NOS/NGS.

FY21 ACCOMPLISHMENT:
NGS reprocessed 27 years of daily GNSS solutions dating back to January 1, 1994. These solutions will contribute directly to the forthcoming ITRF2020 reference frame.

Precision Marine Navigation Data Gateway Viewer

NOAA and **OCS** have developed a web-mapping application that enables users to explore NOAA's navigation datasets that are formatted based on international standards. The Data Gateway Viewer provides an easy-to-use, interactive resource for discovering NOAA's navigation data products. Users can navigate to a region of interest, find the data that are available for that area, and access downloadable versions of the data in the cloud through the NOAA Big Data Program. It also uses new visualization techniques to make the data easy to comprehend. The beta version of the Data Gateway is one piece of NOAA's larger effort to integrate marine navigation data services. The Data Gateway provides a visualization of the data NOAA is also serving via the cloud in a machine-to-machine readable format for software companies to utilize in various navigation software applications from portable pilot units to electronic charting systems and even mobile applications. The Data Gateway Viewer is an important tool



Screen grab from the Precision Marine Navigation Data Gateway Viewer. *Image credit: NOAA/NOS/OCS.*

for making the maritime community aware of NOAA's navigation data, and it represents the continued commitment to ensure precision marine navigation in U.S. waters.

FY21 ACCOMPLISHMENT:

A beta version of the Precision Marine Navigation Data Gateway Viewer was launched in January 2021 that provides surface current forecast guidance (S-111 data).

Data Gateway Viewer Application URL: https://beta.marinenavigation.noaa.gov/gateway/

Data Gateway Viewer Press Release URL: https://nauticalcharts.noaa.gov/updates/noaa-releases-new-visualization-resources-precision-navigation-data-gateway-and-data-dashboard/

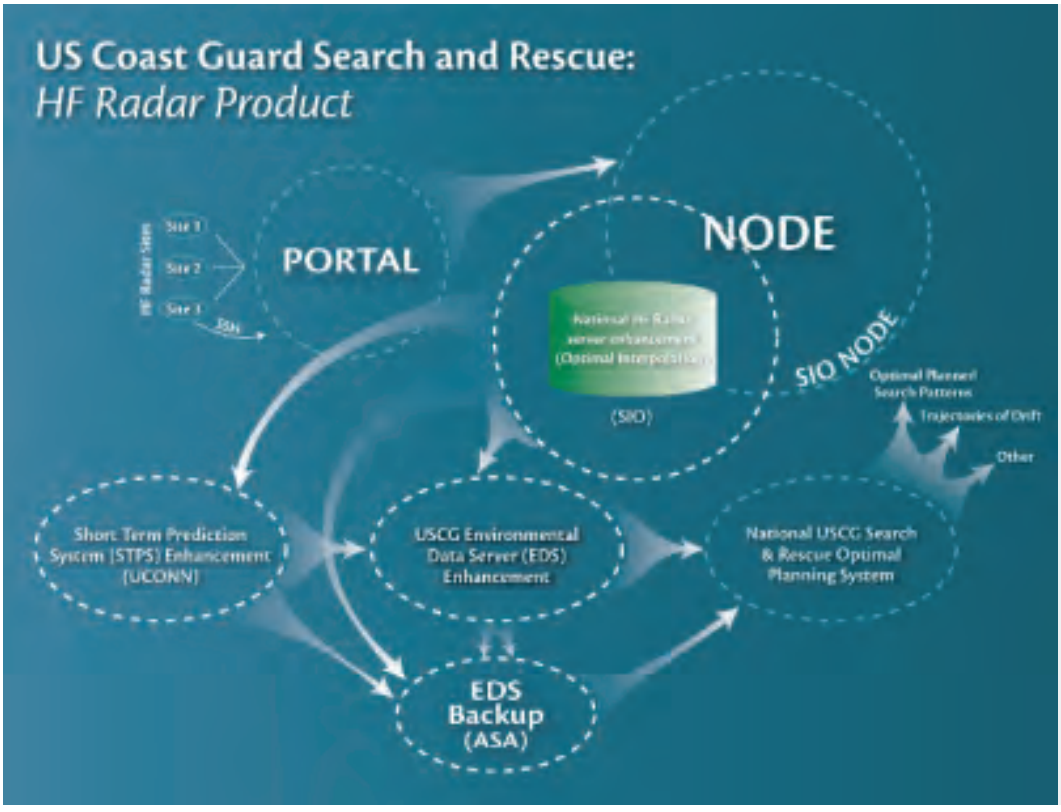
Short Term Predictive System (STPS) Enhancing Search-and-Rescue Nationwide with IOOS Oceanographic High Frequency Radar

In FY 2021 the Short Term Predictive System model (STPS) footprint expanded to cover the entire continental United States, Hawaii, and Puerto Rico. The model now assimilates data from newly added IOOS High-Frequency (HF) radar sites around the country into surface current forecasts for the U.S. Coast Guard's (USCG) Search and Rescue Optimal Planning System (SAROPS) and also provides the framework to deliver data from future IOOS HF radar installations to the system. In 2000, the USCG Research & Development Center began a multi-year investigation into the utility of NOAA IOOS real-time HF radar surface current measurements for search and rescue. This assessment showed HF radar derived currents performed better when compared against available NOAA tidal current predictions. A team at the University of Connecticut, with IOOS funding, developed the STPS empirical statistical model to deliver these HF radar current forecasts; in May 2009 the STPS forecasts went live in the SAROPS for the mid-Atlantic, and later expanded to the U.S. West Coast in 2012.

FY 2021 ACCOMPLISHMENT:

The STPS ocean surface current forecast model expands to provide IOOS HF radar data nationwide for improving U.S. Coast Guard search-and-rescue.

Technical Paper: https://rucool.marine.rutgers.edu/media/downloads/papers/National%20IOOS%20High%20Frequency%20Radar%20SAR%20Project.pdf



Schematic of the data pathways and components of the IOOS enhancements to the HF radar component of USCG SAROPS. The blue dotted lines enclose components that existed prior to the project. The enhancements are shown within the white dotted lines.

Image credit: NOAA/NOS/IOOS.

Ecosystem Science for Conservation and Sustainable Use

Below is a highlighted scientific project by OCS researchers and their partners, which is focused on ecosystem science for conservation and sustainable use of coastal systems.

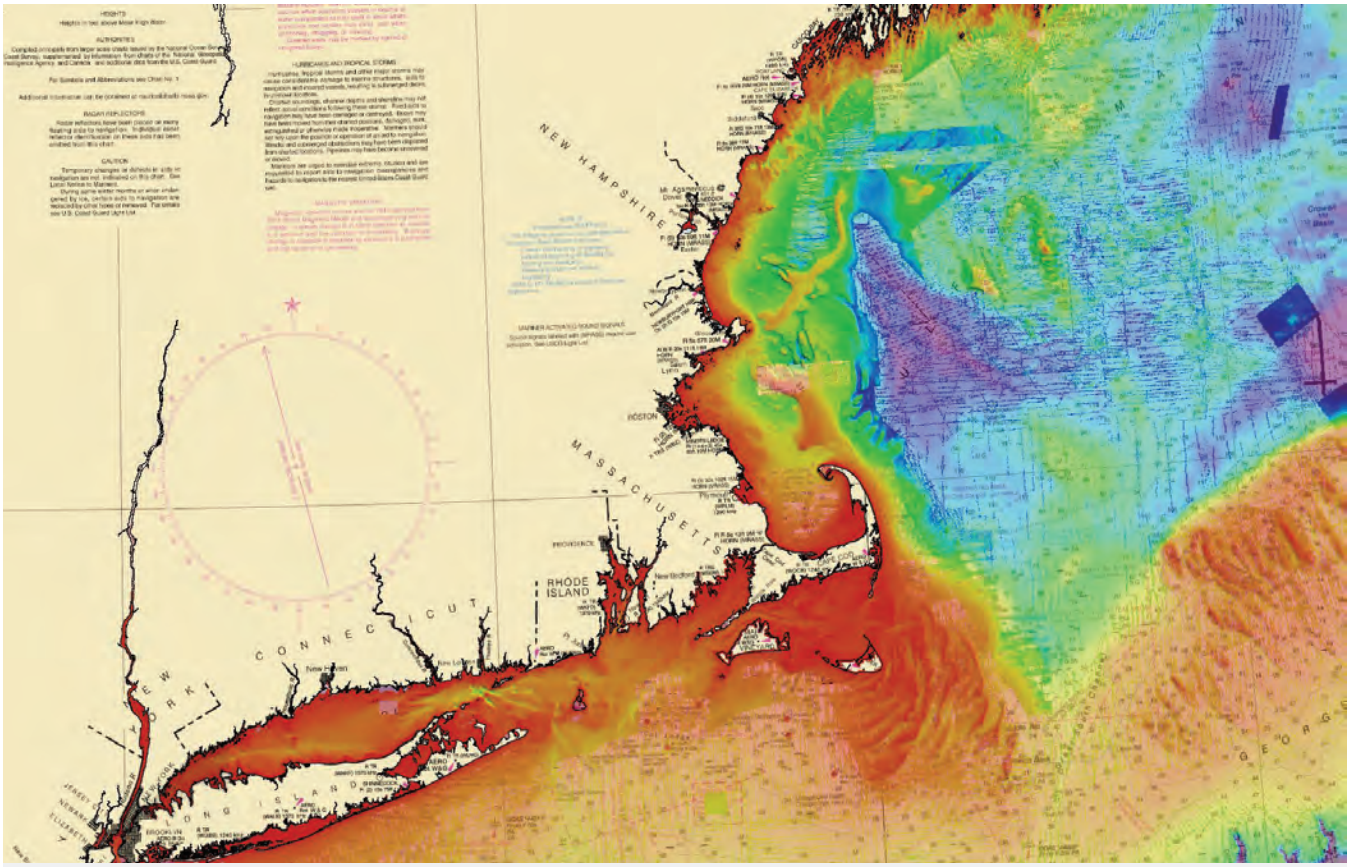
Building the National Bathymetry

The National Bathymetry is a foundational dataset that supports the next-generation of navigation services as well as commerce, science, industry, and public curiosity. OCS compiles disparate hydrographic and LIDAR source surveys based on standard metrics like resolution, accuracy, survey date, and data license. In fiscal year 2020, the team built the New England dataset and that region is now being updated monthly as new sources are available. This year, the team is building out the National Bathymetry for the Gulf of Mexico region and work is underway to distribute products of this critical bathymetric compilation in various datum, formats, and resolutions. The establishment of a data-driven workflow through automation and expertise allows for increased quality, accessibility, and timeliness of bathymetric source data.

FY21 ACCOMPLISHMENT:

The National Bathymetry is being built out for the Gulf of Mexico region while the already built New England region is regularly updated with newly available source surveys.

Project URL: https://nauticalcharts.noaa.gov/updates/building-the-national-bathymetry/



A preliminary build of the bathymetry for New England. Image Credit: NOAA/NOS/OCS.