CHAPTER 3

HYDROGRAPHY

INTRODUCTION

300. Data for Charting

Hydrography is the science of the measurement and description of the features which affect marine navigation, including water depths, shorelines, tides, currents, bottom types, and undersea obstructions. **Cartography** transforms the scientific data collected by hydrographers into data useful to the mariner, and is the final step in a long process that converts raw data into a usable chart.

The mariner, in addition to being the primary user of hydrographic data, is also an important source of data used in the production and correction of nautical charts. This chapter discusses the processes associated with the planning and execution of a hydrographic survey as well as hydrographic surveying methods, types of survey data, and standards for data validation. With this information, mariners can better understand the information presented on charts, and will be better prepared to report new hydrographic information that may be encountered while underway.

HYDROGRAPHIC SURVEYS

301. Depth Information

All nautical charts contain a foundation of depth information that supports navigation. Hydrographic offices gather this depth information from a wide variety of sources, ranging from ship reports and oceanographic measurements to academic or commercially collected SONAR data, previously compiled charts, and hydrographic surveys. While each source plays a critical role in chart compilation, only some hydrographic surveys are designed and executed with nautical charting in mind. It is critical for the mariner to understand how different data sources and survey techniques can impact the degree of seafloor coverage, feature detection, and quality of bathymetric information.

Most modern survey data is collected remotely, using sensors such as SONAR or bathymetric LIDAR (both of which are described in greater detail later in this chapter). This technology allows hydrographers to thoroughly and accurately map sections of the seafloor. However, the sensors that are used today have only been in existence for a few decades. Historical survey methods, which were used for hundreds of years before the invention of modern survey technology, consisted of collecting physical depth measurements with a sounding pole, lead line or wire drag. Although these measurements could be quite accurate, and lead lines and wire drags are still in use for some applications, they do not provide continuous maps of the seafloor, and some features may go undetected. The mariner should understand that in remote or infrequently trafficked areas, much of the information on a nautical chart may still be reflective of surveys conducted using such antiquated techniques.

Even with the advent of modern technology, there are still many different kinds of surveys, collected for a wide variety of purposes, and not all are equally applicable to nautical charts. Oceanographic institutions and universities may conduct surveys of benthic (i.e. relating to, or occurring at the bottom of a body of water) regions for scientific study and/or oil and mineral exploration companies may collect data for resource identification. Marine archaeologists may survey an area to identify and preserve submerged cultural resources, while commercial fishermen may map the seafloor to identify profitable fishing grounds. Communications companies may create a detailed map of the seafloor to identify an appropriate location for cable deployment. While each of these surveys may be well-suited to their purpose, they may be of variable quality and utility for nautical charting. However, if these surveys are made publicly available, some of this information may be incorporated into nautical charts. Hydrographic offices simply do not have the resources to map the world's oceans using dedicated survey vessels, alone.

Understanding these differences in data sources and survey techniques enables the mariner to make informed voyage planning decisions. It is very important to remember that not all data that is used for chart compilation is of equal quality; the hydrographic office will use the best information available at the time of compilation, but the mariner must understand this variability in underlying data quality and coverage, and exercise prudence. **Source diagrams** on nautical charts can provide valuable insight into the age and quality of data used in chart compilation.

HYDROGRAPHIC SURVEY PLANNING

302. Considerations

Many countries with hydrographic offices conduct periodic surveys of their national waters to collect data that will improve and update their own navigational products. Hydrographic surveys that are conducted in support of nautical charting gather information about bathymetric data, hazards to mariners, tides and water levels, shoreline, Aids to Navigation, and other oceanographic data that may be important for chart production. These surveys are usually very time and resource-intensive, and so require careful planning, execution, and analysis to ensure that the data collected is accurate and safe for navigation.

A hydrographic survey begins long before actual data collection starts. Hydrographers must identify an area to be surveyed, determine whether a reconnaissance or full scope survey is needed, and then calculate the amount of time needed to execute the survey. They must select the most appropriate survey methodology, locate a platform that is able to collect the data, and arrange logistics, obtain funding and permits, and form a team of qualified surveyors and support personnel.

Once these planning and preparation issues are decided, the hydrographer reviews all available information in the survey area to gather critical information for safely and effectively executing the survey. Satellite or aerial imagery, topographic maps, nautical charts, geodetic information, oceanographic data, past survey data and information from nautical publications are incorporated into a survey plan. Tidal information is also thoroughly reviewed, and tide gauge locations identified.

With this information in hand, the hydrographer then plans the daily survey operations. When a survey vessel or plane collects data, it is usually collected in a pattern of lines which are predetermined before the survey begins. The scale of the survey, financial resources available, sensor technology, water depth, orientation to the shoreline, method of horizontal and vertical positioning, and the desired level of seafloor coverage all contribute to line planning. The line spacing determines the level of seafloor coverage that the survey will capture.

In an area of critical underkeel clearance, a hydrographer may elect to conduct a high-resolution multibeam sonar survey, with overlapping lines of coverage, to ensure that most significant features are detected. Alternatively, a hydrographer may also execute a combination of non-overlapping singlebeam sonar lines, augmented by full side scan sonar coverage, to image features. In deeper water, where underkeel clearance is less critical, survey data may be collected while the ship is in transit, or in a pattern of lines guided by feature investigation or general depiction of the seafloor, rather than full sea floor coverage.

While there is no "right" answer to survey planning, experienced hydrographers know which combination of sensors, survey plans and resources are best suited to obtaining the desired results in different situations.

HYDROGRAPHIC SURVEY TECHNIQUES

303. Introduction

The earliest depth measurements were collected from sailing vessels using lead lines or sounding poles deployed over the side of the ship. Nautical cartography, positioning, and marine timekeeping have improved greatly over the course of the last several hundred years. Although lead lines and sounding poles are still in limited use, there have been great advances in survey technology. Over the past one hundred years, developments in SONAR, advancements in remote sensing technology, precise positioning and computerized data processing have created a robust body of science dedicated to collecting and analyzing bathymetric information. It is important for the mariner to have a basic understanding of the different techniques employed for collecting depth and seafloor feature information, as any one of these techniques may contribute data to a modern chart.

304. Lead Line

The Lead (pronounced *led*) or lead line is a device consisting of a marked line with a lead weight attached to one end. The user deploys the lead line over the side of the survey vessel, and measures the length of line paid out before the lead touches bottom. The line is marked at set intervals in such a way that the user can quickly determine the water depth by examining the amount of line that has been expended (see Table 304). Most lead lines have a hollow in the end of the lead, which can be filled with wax or some other tractive substance, designed to give the user information about the nature of the bottom. In a sandy or muddy area, the lead will return with sand grains or mud embedded in the wax; in a rocky area, nothing will be returned. The nature of the bottom can be depicted on nautical charts, and is helpful information for determining suitable anchoring areas.

Although the concept behind lead line deployment is simple, users should ensure that markings are applied to the line while it is wet, that the markings are periodically measured against a tape to ensure that the line has not stretched or warped (some lines have a wire core to prevent this), and depth measurements should be taken at slack tide to avoid line curvature from currents.

While the lead line is probably the oldest of all navigational aids, it is still a useful device for confirming depths

Distance from lead in fathoms	*Marking*	*Metric equivalent*
2	two strips of leather	3.66
3	three strips of leather	5.49
5	white rag (usually cotton)	9.14
7	red rag (usually wool)	12.80
10	leather with hole	18.29
13	same as three fathoms	23.77
15	same as five fathoms	27.43
17	same as seven fathoms	31.09
20	a line with two knots	36.58
25	a line with one knot	45.72
30	a line with 3 knots	54.86

Table 304. Example of traditional lead line markings.

alongside piers, determining the nature of the bottom, and checking the depths around a vessel in the event of grounding.

305. Wire Drag

The wire drag was designed to detect submerged features such as wrecks, rocks and obstructions in nearshore areas where underkeel clearance is critical. This technique, like the lead line, has been in use for a very long time. The operating principle is simple; two vessels, a given distance apart, move in the same direction dragging a wire between them that has been set to a predetermined depth (see Figure 305). If an obstacle is encountered, it will strike the wire. The surveyors can then raise the wire to determine the least depth of the feature. In this manner, an area can be confidently verified, or 'swept' as free of hazards to a minimum depth. The exact nature and relief of the seafloor is not known, but the surveyors have physically verified that nothing exceeds the least depth of the wire. When a SONAR survey is performed, a post-survey using a wire drag may be conducted as a quality control measure, to ensure that an area is cleared to minimum depth.

Figure 305. Conducting a wire drag. Image courtesy of NOAA.

306. Singlebeam Echosounders

Single beam echo sounders were developed in the early 1920s, and compute the depth of water by measuring the time it takes for a pulse of sound to travel from the source, to the seafloor, and then back to the source. A device called a transducer, usually mounted on the keel of a vessel, converts electrical energy into sound energy, which then travels through the water column as a compression wave, reflects off the seafloor and is returned to the sensor. This basic SONAR technology is widely used by private and commercial vessels to verify underkeel clearance and water depth when operating in coastal areas. Survey vessels may also use this technology to collect depth information by following a prescribed pattern of survey lines and collecting measurements directly under the vessel.

Although singlebeam SONAR measurements can be very accurate, the sensors are limited in scope because

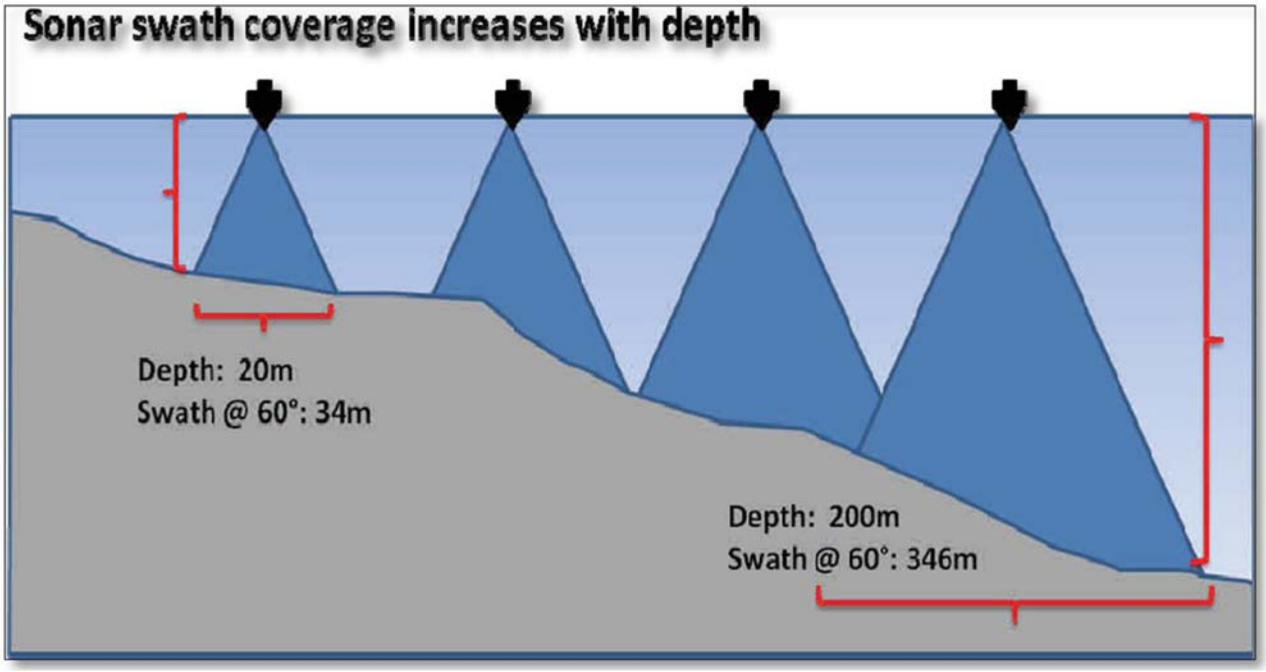

Figure 307. Comparison of sonar swath coverage at different water depths.

they provide information about only a narrow footprint under the vessel. Because they do not fully ensonify the seafloor, it is possible - and even probable - that features will remain undetected between survey lines. To mitigate this, modern hydrographic surveyors often use singlebeam echosounders in tandem with Side Scan Sonar, a towed sensor that creates a photorealistic sonar image of a wide swath of seafloor on either side of the survey vessel. Side scan sonar records can be used for feature identification, but provide only limited depth information. If the two sensors are used in tandem, the hydrographer obtains tracklines of depth information, with sonar images between them. Any hazardous features that are identified in the sidescan record can then be further investigated and developed with the echosounder to obtain a least depth for charting.

307. Multibeam Echosounders

Multibeam echosounders operate on similar principles to singlebeam echosounders, except that they send out many individual sonar pings, at a rate of many pulses per second, in a wide swath on either side of the vessel. This rapid and dense ensonification of the seafloor can produce a very high-resolution three dimensional reproduction of the surface of the seafloor. These data can be made even more accurate by the application of corrections for changes in sound velocity due to water depth, temperature and salinity, and by applying compensation for vessel motion. Precise horizontal positioning from GPS and vertical corrections for tidal variations in coastal waters can also be applied to the data, either in real-time or during data processing. The width of the multibeam sonar swath, and the resolution of the data it collects varies based on the frequency of the sonar and the water depth (see Figure 307). In general, high-frequency, high-resolution sonars are better suited to coastal waters, while lower-frequency, lower-resolution sonars have an extended range that can map the deepest ocean depths. Multibeam sonar may be installed permanently on a vessel, deployed on an ROV, AUV or towed sensor, or may be temporarily operated from a small craft.

308. Bathymetric LIDAR

Airborne Laser Hydrography (ALH), or Bathymetric Light Detection and Ranging (LIDAR), uses laser transmitters to conduct hydrographic surveys from aircraft. It is useful in areas of complex hydrography where rocks, shoals and obstructions pose a danger to traditional survey vessels, and under ideal conditions it can create a high-resolution map of the seafloor (see Figure 309).

Bathymetric LIDAR sensors are mounted on the bottom of an aircraft and usually transmit lasers in two bands of the electromagnetic spectrum: a green laser that penetrates the water column and collects depth measurements, and an infrared laser for sea surface detection. The difference in time between the transmittal of the green laser to its reflected reception is a function of the water depth. These data are correlated with position data obtained from GPS and adjusted for tides and atmospheric conditions.

As with all survey techniques, LIDAR has some limitations. Water penetration is limited by the strength of the laser signal and the clarity of the water. Under ideal conditions, depth measurements have been collected in up to 60 meters of water depth, but in most cases the laser extinction depth is closer to 20m. Feature detection is limited by the footprint of the laser beam when it enters the water, so, as with SONAR, in some cases features may be missed. Very smooth sea surface conditions can prevent data collection because the surface becomes mirror-like, reflecting pulses off the surface instead of penetrating the water column. Conversely, patches of surf, or very rough water, can cause the laser pulse to scatter. Kelp or dense vegetation can also prevent data collection using this method.

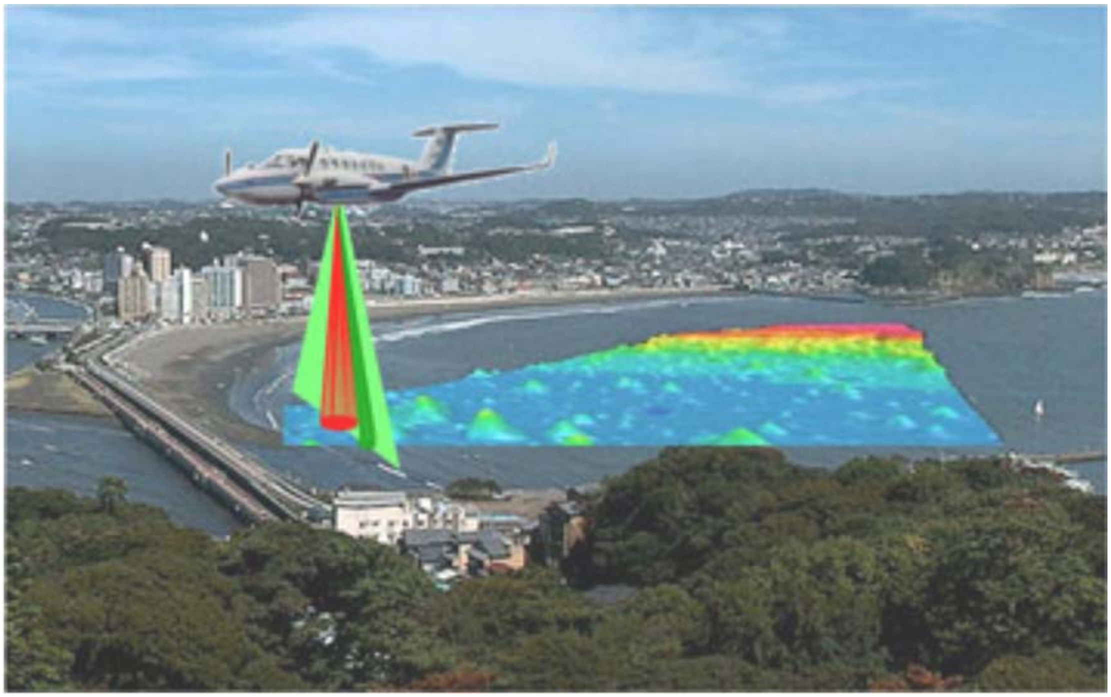

Figure 309. Collecting bathymetric LIDAR data. Image courtesy of NOAA.

PROCESSING HYDROGRAPHIC DATA

310. Introduction

In the past, sounding selection and survey data compilation required creating hardcopy plots of depth information and conducting extensive manual review. Today, hydrographers and bathymetrists use dedicated survey data processing software to model data in *three dimensions*, identify errors in the data, apply corrections and create finished products. Hydrographic offices keep databases of survey data, which are incorporated into nautical charts. Survey data is thoroughly evaluated to determine the degree of accuracy or uncertainty in measurements, the level of confidence in the data, and the area of seafloor coverage. This data quality information can then be relayed to the mariner through a source diagram, chart note, **Zone of Confidence (ZOC) diagram**, or as a layer in digital charts. As previously noted, the degree of seafloor coverage varies widely, based on the technology available and the type of survey technique used (see Figure 310).

311. Zones of Confidence

Category Zones of Confidence (CATZOC) were developed through the efforts of member nations within the International Hydrographic Organization, and they provide information about the quality and coverage of cartographic data in an area. The four criteria based for making assessments include position accuracy, depth accuracy, seafloor coverage and survey characteristics.

There are currently six CATZOC types, ranging from full seafloor coverage with significant feature detection to poor, or unassessed categories. If a nautical chart includes a ZOC diagram or if an ENC has a CATZOC layer, it can help the mariner make informed navigation decisions by highlighting areas that have denser bathymetric data coverage, as well as areas where information may be thinner or of uncertain quality.

In areas of uncertain data quality, mariners should proceed with an extra level of caution. Source diagrams and zones of confidence are discussed more in the next chapter (see Section 428).

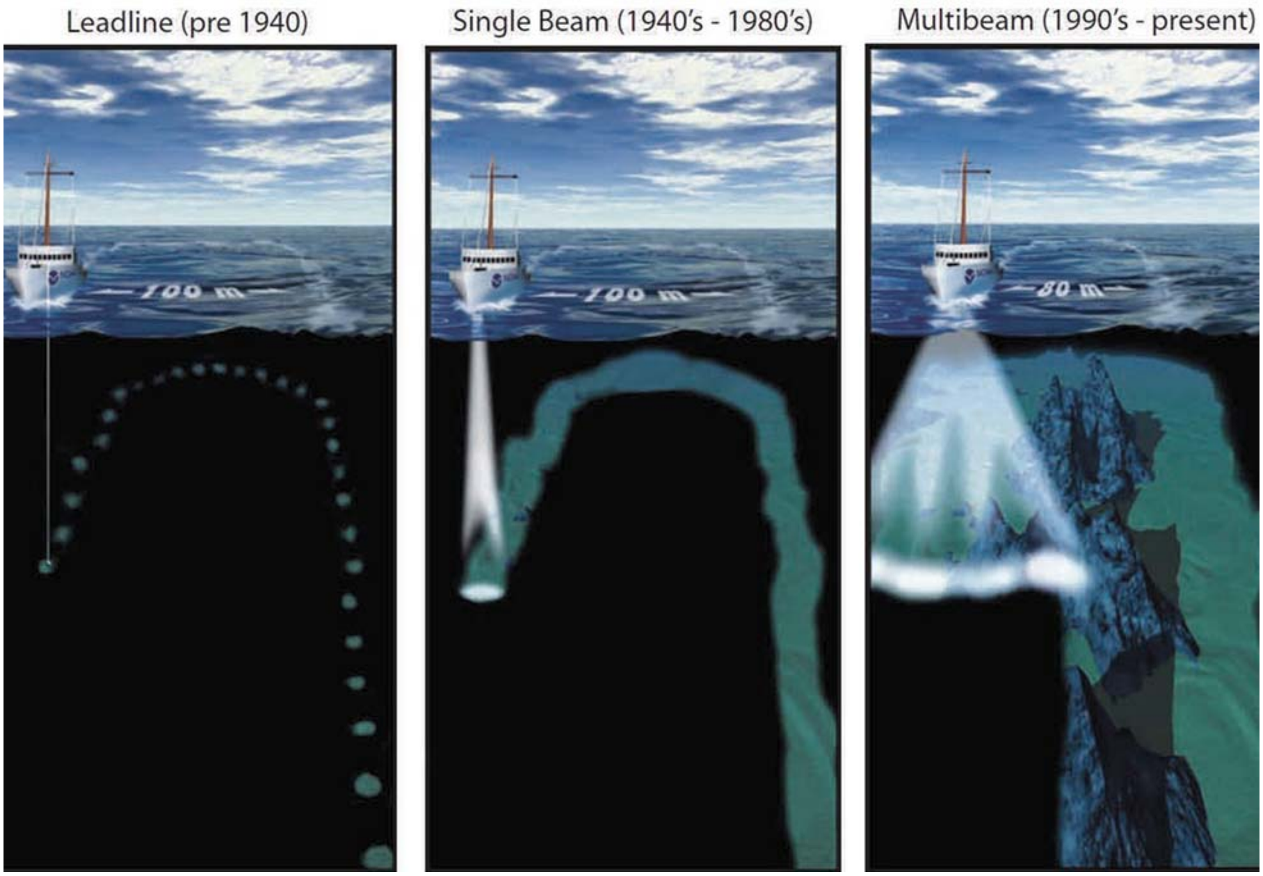

Figure 310. Differences in coverage between hydrographic techniques. Image courtesy of NOAA.

OTHER SOURCES OF BATHYMETRIC DATA

312. Limited Resources Drive Survey Priorities

Hydrographic surveys are expensive and time-consuming to conduct, and even after hundreds of years of seafloor mapping, the vast majority of the Earth's oceans remain a mystery. The extent of the seafloor is simply too vast, and current resources are too limited, to fully image every meter of submerged real estate. For that reason, most high-resolution, dedicated hydrographic surveys are conducted in coastal areas, where dangers to surface navigation is the greatest. In deeper water, scientific surveys, oil and gas exploration, and other surveys of opportunity have also yielded some data. However, even in open ocean areas dangers to navigation exist. Newly forming submerged volcanoes or uncharted seamounts have caused maritime accidents in the past. To mitigate these uncharted hazards, hydrographers have sought alternative methods of data collection, to supplement what is already known.

313. Satellite Altimetry

In some areas of the open ocean there are vertical variations in the sea surface that can provide hydrographers and geodesists with critical information about seafloor features. The presence of massive seamounts or submarine canyons deflects the directional pull of gravity from the vertical, which creates a corresponding bulge or depression of water on the sea surface (see Figure 313). These anomalies can be detected with satellite-mounted radar altimeters. The altimeter sends a radar pulse through the atmosphere to the ocean surface, and the amount of time it takes for the reflected pulse to return to the altimeter provides a measurement of variations in sea surface. These sea surface measurements are translated into a quantification of the “deflection of the vertical” pull of gravity, which in turn is used to create a model of the geoid, or approximate surface of the Earth. For several decades, hydrographers have used these altimetry-derived geoid models to identify large seafloor ridges, seamounts and canyons.

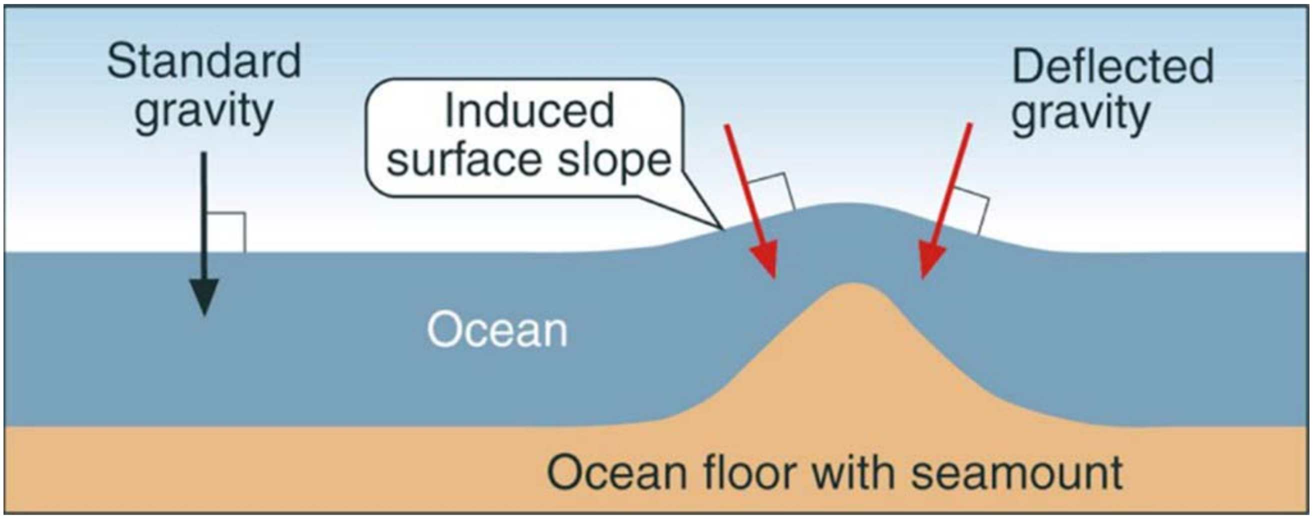

Figure 313. A rise in the ocean surface caused by a large seamount. Image courtesy of NOAA.

314. Marine Gravity

Early shipboard marine gravity measurements were collected in the late 1920s by submariners using pendulum-based apparatus to measure changes in gravitational pull that might indicate a submerged feature. In the 1950's, mariners began collecting gravity measurements from surface vessels as well. Although the technology behind these sensors vary from primitive to highly advanced, they all operate under the basic principle that local variations in gravity can provide information about seafloor features such as seamounts and ridges.

315. Satellite Imagery Derived Bathymetry

Recently, hydrographers have begun exploring the use of satellite-mounted, multispectral optical sensors for deriving remotely detected bathymetry estimates. Satellite sensors have the ability to rapidly image a large area of the seafloor at relatively low cost, which gives them a distinct advantage over traditional survey techniques. Using sunlight as a natural source of illumination, these optical sensors passively measure the wavelength of light that is reflected off the seafloor and back to the sensor. By applying algorithms to the data, relative seafloor depth estimates can be obtained. This technology has been explored by both commercial interests and international hydrographic offices, and although this technology is still developing, it holds promising potential for tracking migrating shoals, identifying uncharted features, and evaluating the need for updated nautical charts in an area. However, the quality of depth measurements are constrained by water depth, bottom type, water clarity and atmospheric conditions. In addition, more research is needed to determine the limitations of different algorithms, and the level of uncertainty in the measurements.

316. Crowd Sourced Bathymetry

For hundreds of years, mariners have contributed information to nautical charts by providing eyewitness reports, depth measurements, chart discrepancies and other information to charting offices. To this day, ship reports from mariners continue to provide hydrographic offices with vital information on emerging hazards, uncharted obstacles and depth discrepancies. This symbiosis between mariner and cartographer is essentially a form of crowd-sourcing nautical information. Crowd-sourced bathymetry is recent initiative that follows in the footsteps of traditional ship reports, but takes it a step further by encouraging mariners to log data directly from their echosounders while underway, and to contribute these data to a publicly available central data repository.

An international group of hydrographers, working under the auspices of the International Hydrographic Organization (IHO), are currently creating a central repository for mariner-contributed data and developing a guidance document for mariners willing to voluntarily collect and contribute their data. It is hoped that this crowd-sourced data could be a key provider of information that will contribute to a better understanding of the seafloor. Mariners interested in participating in this effort can find more information at the International Hydrographic Organization's website.

LOOKING FORWARD

317. New Technology and Approaches

History has taught us to expect that the future will bring many changes and advances in hydrographic survey techniques and technology. If the current trend holds true, surveys of the future will be conducted faster, more accurately, and at a lower cost than in the past, and sensors will become more capable. **Autonomous platforms**, remote sensing, and other technologies are already in play in the world of hydrography, and this technology can only improve. Hydrographers are considering new approaches to data quality analysis, and are seeking better ways to improve global data sharing, leading to the development of a high-resolution global bathymetric surface and improve existing interpolated models. Surveys of the future could be referenced to the ellipsoid, instead of local chart datums, enabling bathymetric surfaces to be vertically linked together in a manner that is currently difficult or impossible on a global scale. Perhaps one day navigation surfaces will be incorporated directly into electronic charting software, allowing the mariner to see seafloor relief directly.

Such advances will benefit the mariner, and the prudent mariner should stay informed of developments in the world of nautical charting and hydrographic surveying. As technology marches on, hydrographic offices will adapt, and will continue to strive to provide the mariner with the most up-to-date information on data quality and data sources in support of safe navigation.