FUNDAMENTALS

CHAPTER 1

INTRODUCTION TO MARINE NAVIGATION

DEFINITIONS

100. The Art and Science of Navigation

Marine navigation is a blend of both science and art. A key union between the knowledge of theory, the application of mathematics and the exercise of seafaring instincts that have proven to be the crucial elements behind successful maritime voyages for millennia.

A good navigator is one who plans each voyage carefully. As the vessel proceeds, he or she gathers navigation information from a variety of sources and then evaluates this information to determine the ship's position. The navigator then compares that position against the voyage plan, operational commitments, and their pre-determined “dead reckoning” position. A good navigator also anticipates dangerous situations well before they arise, and always stays “ahead of the vessel,” ready to address navigational emergencies at any time. The navigator is increasingly a manager of a diverse assortment of resources-electronic, mechanical, and human. Navigation methods and techniques vary with the type of vessel, the conditions, and the navigator's experience. The navigator uses the methods and techniques best suited to the vessel, its equipment, and conditions at hand.

Some important elements of successful navigation cannot be acquired from any book or instructor. The science of navigation can be taught, but the art of navigation must be developed from experience.

101. Types of Navigation

Methods of navigation have changed throughout history. New methods often enhance the mariner’s ability to complete their voyage safely and expeditiously, and make the job easier. One of the most important judgments the navigator must make involves choosing the best methods to use. Each method or type has advantages and disadvantages, while none is effective in all situations. Some commonly recognized types of navigation include:

- **Bathymetric navigation** uses the topography of the sea floor to acquire positioning data. A vessel's position is determined with respects to known locations of geographic features of the ocean bottom.
- **Celestial navigation** involves reducing celestial measurements taken with a sextant to lines of position using calculators or computer programs, or by hand with almanacs and tables or using spherical trigonometry.
- **Dead reckoning (DR)** determines a predicted position by advancing a known position for courses and distances. A position so determined is called a dead reckoning (DR) position. It is generally accepted that only course and speed determine the DR position. Correcting the DR position for leeway, current effects, and steering error result in an **estimated position (EP)**.
- **Inertial navigation** is accomplished by integrating the output of a set of sensors to compute position, velocity and attitude. These sensors include gyros and accelerometers. Gyros measure angular rate with respect to inertial space and accelerometers measure linear acceleration with respect to an inertial frame.
- **Piloting** involves navigating in restricted waters with frequent or constant determination of position relative to nearby geographic and hydrographic features.
- **Radio navigation** uses radio waves to determine position through a variety of electronic devices.
- **Radar navigation** uses radar to determine the distance from or bearing to objects whose position is known. This process is separate from radar’s use in collision avoidance.
- **Satellite navigation** uses radio signals from satellites for determining position.

Electronic systems and integrated bridge concepts are driving navigation system planning. Integrated systems take inputs from various ship sensors, electronically and automatically chart the position, and provide control signals required to maintain a vessel on a preset course. The navigator becomes a system manager, choosing system presets, interpreting system output, and monitoring vessel response.

In practice, a navigator synthesizes different methodologies into a single integrated system. He or she should never feel comfortable utilizing only one method when others are also available. Since each method has advantages and disadvantages, the navigator must choose methods appropriate to each situation, and never rely completely on only one system.

With the advent of automated position fixing and electronic charts, modern navigation has become an almost completely electronic process. The mariner is constantly tempted to rely solely on electronic systems. But electronic navigation systems are always subject to potential failure, and the professional mariner must never forget that the safety of their ship and crew may depend on skills that differ little from those practiced generations ago. Proficiency in conventional piloting and celestial navigation remains essential.

102. Phases of Navigation

Four distinct phases define the navigation process. The mariner should choose the system mix that best meets the accuracy requirements of each phase.

- **Inland Waterway Phase**: Piloting in narrow canals, channels, rivers, and estuaries.
- **Harbor/Harbor Approach Phase**: Navigating to a harbor entrance through bays and sounds, and negotiating harbor approach channels.
- **Coastal Phase**: Navigating within 50 miles of the coast or inshore of the 200 meter depth contour.
- **Ocean Phase**: Navigating outside the coastal area in the open sea.

The navigator's position accuracy requirements, fix intervals, and systems requirements differ in each phase. The following table can be used as a general guide for selecting the proper system(s).

	Inland	*Harbor/ Approach*	*Coastal*	*Ocean*
Bathy			X	X
Celestial			X	X
DR	X	X	X	X
Inertial			X	X
Piloting	X	X	X	
Radio		X	X	X
Radar	X	X	X	
Satellite	X*	X	X	X

*Table 102. The relationship of the types and phases of navigation. * With SA off and/or using DGPS.*

NAVIGATION TERMS AND CONVENTIONS

103. Important Conventions and Concepts

Throughout the history of navigation, numerous terms, techniques, and conventions have been established which enjoy worldwide recognition. The professional navigator, to gain a full understanding of this field, should understand the origin of certain terms, techniques, and conventions. The following section discusses some of these important factors.

Defining a **prime meridian** is a comparatively recent development. Until the beginning of the 19th century, there was little uniformity among cartographers as to the meridian from which to measure longitude. But it mattered little because there existed no method for determining longitude accurately.

Ptolemy, in the 2nd century AD, measured longitude eastward from a reference meridian 2 degrees west of the Canary Islands. In 1493, Pope Alexander VI established a line in the Atlantic west of the Azores to divide the territories of Spain and Portugal. For many years, cartographers of these two countries used this dividing line as the prime meridian. In 1570 the Dutch cartographer Ortelius used the easternmost of the Cape Verde Islands. John Davis, in his 1594 *The Seaman's Secrets*, used the Isle of Fez in the Canaries because there the magnetic variation was zero. Most mariners paid little attention to these conventions and often reckoned their longitude from several different capes and ports during a voyage.

The meridian of London was used as early as 1676, and over the years its popularity grew as England's maritime interests increased. The system of measuring longitude both east and west through 180° may have first appeared in the middle of the 18th century. Toward the end of that century, as the Greenwich Observatory increased in prominence, English cartographers began using the meridian of that observatory as a reference. The publication by the Observatory of the first British *Nautical Almanac* in 1767 further entrenched Greenwich as the prime meridian. An unsuccessful attempt was made in 1810 to establish Washington, D.C. as the prime meridian for American navigators and cartographers. In 1884, the meridian of Greenwich was officially established as the prime meridian. Today, all maritime nations have designated the Greenwich meridian the prime meridian, except in a few cases where local references are used for certain harbor charts.

Charts are graphic representations of areas of the Earth, in digital or hard copy form, for use in marine or air navigation. Nautical charts, whether in digital or paper form, depict features of particular interest to the marine navigator. Charts probably existed as early as 600 B.C. Stereographic and orthographic projections date from the 2nd century B.C. In 1569 Gerardus Mercator published a chart using the mathematical principle which now bears his name. Some 30 years later, Edward Wright published corrected mathematical tables for this projection, enabling other cartographers to produce charts on the Mercator projection. This projection is still the most widely used.

Sailing Directions or ***pilots*** have existed since at least the 6th century B.C. Continuous accumulation of navigational data, along with increased exploration and trade, led to increased production of volumes through the Middle Ages. "Routiers" were produced in France about 1500; the English referred to them as "rutters." In 1584 Lucas Waghenaer published the *Spieghel der Zeevaerdt (The Mariner's Mirror)*, which became the model for such publications for several generations of navigators. They were known as "Waggoners" by most sailors.

The **compass** was developed more than 1000 years ago. The origin of the magnetic compass is uncertain, but Norsemen used it in the 11th century, and Chinese navigators used the magnetic compass at least that early and probably much earlier. It was not until the 1870s that Lord Kelvin developed a reliable dry card marine compass. The fluid-filled compass became standard in 1906.

Variation was not understood until the 18th century, when Edmond Halley led an expedition to map lines of variation in the South Atlantic. **Deviation** was understood at least as early as the early 1600s, but adequate correction of compass error was not possible until Matthew Flinders discovered that a vertical iron bar could reduce certain types of errors. After 1840, British Astronomer Royal Sir George Airy and later Lord Kelvin developed combinations of iron masses and small magnets to eliminate most magnetic compass error.

The **gyrocompass** was made necessary by iron and steel ships. Leon Foucault developed the basic gyroscope in 1852. An American (Elmer Sperry) and a German (Anshutz Kampfe) both developed electrical gyrocompasses in the early years of the 20th century. Ring laser gyrocompasses and digital flux gate compasses are gradually replacing traditional gyrocompasses, while the magnetic compass remains an important backup device.

The **log** is the mariner's speedometer. Mariners originally measured speed by observing a chip of wood passing down the side of the vessel. Later developments included a wooden board attached to a reel of line. Mariners measured speed by noting how many knots in the line unreeled as the ship moved a measured amount of time; hence the term **knot.** Mechanical logs using either a small paddle wheel or a rotating spinner arrived about the middle of the 17th century. The taffrail log still in limited use today was developed in 1878. Modern logs use electronic sensors or spinning devices that induce small electric fields proportional to a vessel's speed. An engine revolution counter or shaft log often measures speed aboard large ships. Doppler speed logs are used on some vessels for very accurate speed readings. Inertial and satellite systems also provide highly accurate speed readings.

The common measure of distance at sea is the **nautical mile** which is now defined as exactly 1,852 meters. Nautical charts may show depths in meters, fathoms, or feet. The **fathom** as a unit of length or depth is of obscure origin. Posidonius reported a sounding of more than 1,000 fathoms in the 2nd century B.C. How old the unit was then is unknown. A fathom is a unit of length equal to 6 feet.

Most National Oceanographic and Atmospheric Administration (NOAA) charts have depths recorded in feet or fathoms. About two dozen of NOAA's 1,000 plus charts show depths in meters. The National Geospatial-Intelligence Agency (NGA) continues to produce and convert chart depths entirely to meters.

The sailings refer to various methods of mathematically determining course, distance, and position. They have a history almost as old as mathematics itself. Thales, Hipparchus, Napier, Wright, and others contributed the formulas that permit computation of course and distance by plane, traverse, parallel, middle latitude, Mercator, and great circle sailings.

104. The Earth

The Earth is an irregular oblate spheroid (a sphere flattened at the poles). Measurements of its dimensions and the amount of its flattening are subjects of geodesy. However, for most navigational purposes, assuming a spherical Earth introduces insignificant error. The Earth's axis of rotation is the line connecting the north and south geographic poles.

A **great circle** is the line of intersection of a sphere and a plane through its center. This is the largest circle that can be drawn on a sphere. The shortest line on the surface of a sphere between two points on the surface is part of a great circle. On the spheroidal Earth the shortest line is called a **geodesic**. A great circle is a near enough approximation to a geodesic for most problems of navigation. A **small circle** is the line of intersection of a sphere and a plane which does not pass through the center. See Figure 104a.

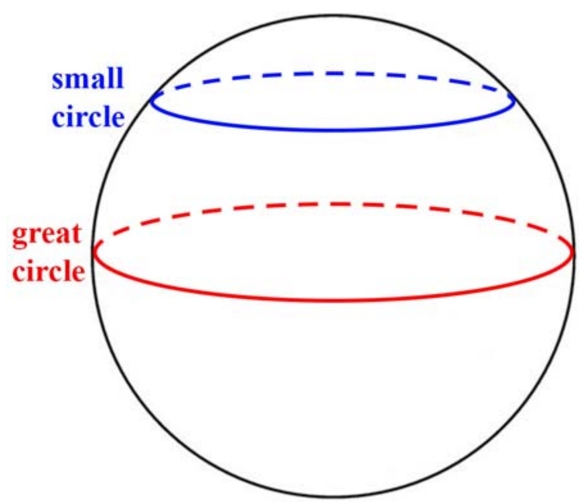


Figure 104a. Great and small circles.

The term **meridian** is usually applied to the **upper branch** of the half-circle from pole to pole which passes through a given point. The opposite half is called the **lower branch.**

A **parallel** or parallel of latitude is a circle on the

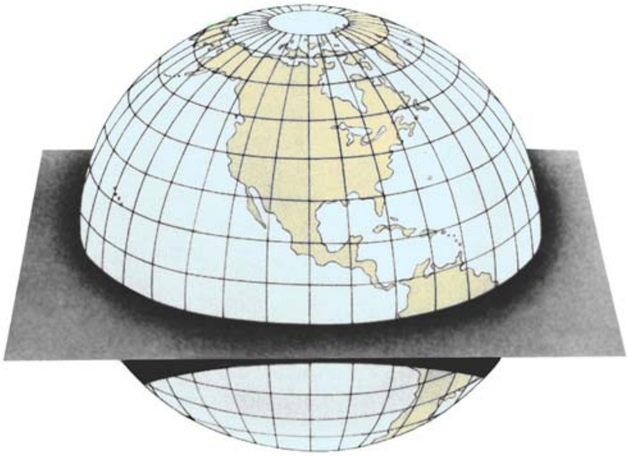


Figure 104b. The equator is a great circle midway between the poles.

surface of the Earth parallel to the plane of the equator. It connects all points of equal latitude. The **equator** is a great circle at latitude 0° that bisects the Northern and Southern Hemispheres. See Figure 104b. The poles are single points at latitude 90°. All other parallels are small circles.

105. Coordinates

Coordinates of latitude and longitude can define any position on Earth. **Latitude (L, lat.)** is the angular distance from the equator, measured northward or southward along a meridian from 0° at the equator to 90° at the poles. It is designated north (N) or south (S) to indicate the direction of measurement.

The **difference of latitude (*l*, DLat.)** between two places is the angular length of arc of any meridian between their parallels. It is the numerical difference of the latitudes if the places are on the same side of the equator; it is the sum of the latitudes if the places are on opposite sides of the equator. It may be designated north (N) or south (S) when appropriate. The middle or **mid-latitude (Lm)** between two places on the same side of the equator is half the sum of their latitudes. Mid-latitude is labeled N or S to indicate whether it is north or south of the equator.

The expression may refer to the mid-latitude of two places on opposite sides of the equator. In this case, it is equal to half the difference between the two latitudes and takes the name of the place farthest from the equator.

Longitude (l, long.) is the angular distance between the prime meridian and the meridian of a point on the Earth, measured eastward or westward from the prime meridian through 180°. It is designated east (E) or west (W) to indicate the direction of measurement.

The **difference of longitude (DLo)** between two places is the shorter arc of the parallel or the smaller angle at the pole between the meridians of the two places. If both places are on the same side (east or west) of Greenwich, DLo is the numerical difference of the longitudes of the two places; if on opposite sides, DLo is the numerical sum unless this exceeds 180°, when it is 360° minus the sum.

The distance between two meridians at any parallel of latitude, expressed in distance units, usually nautical miles, is called **departure (p, Dep.)**. It represents distance made good east or west as a craft proceeds from one point to another. Its numerical value between any two meridians decreases with increased latitude, while DLo is numerically the same at any latitude. Either DLo or p may be designated east (E) or west (W) when appropriate.

106. Distance on the Earth

Distance, as used by the navigator, is the length of the **rhumb line** connecting two places. This is a line making the same angle with all meridians. Meridians and parallels which also maintain constant true directions may be considered special cases of the rhumb line. Any other rhumb line spirals toward the pole, forming a **loxodromic curve** or **loxodrome**. See Figure 106a below for image depicting

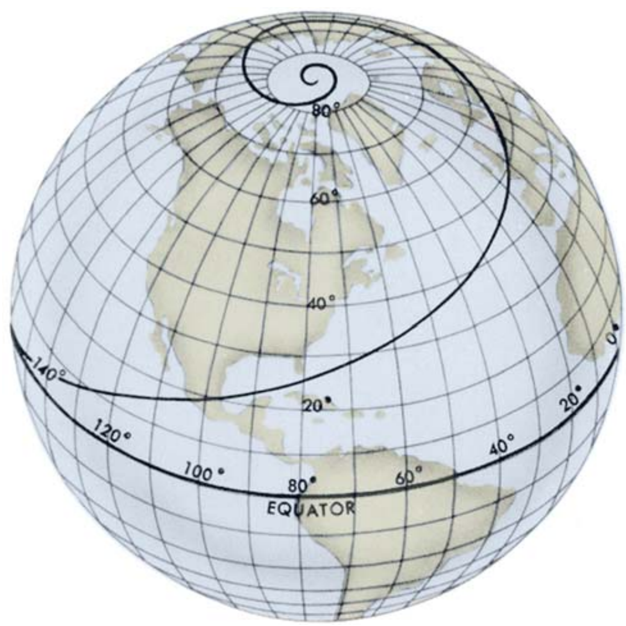


Figure 106a. A loxodrome.

a loxodrome curve.

Distance along the great circle connecting two points is customarily designated **great-circle distance**. For most purposes, considering the nautical mile the length of one minute of latitude introduces no significant error.

Speed (S) is rate of motion, or distance per unit of time. A **knot (kn.)**, the unit of speed commonly used in navigation, is a rate of 1 nautical mile per hour. The expression **speed of advance (SOA)** is used to indicate the speed to be made along the intended track. **Speed over the ground**

(SOG) is the actual speed of the vessel over the surface of the Earth at any given time. To calculate **speed made good (SMG)** between two positions, divide the distance between the two positions by the time elapsed between the two positions.

Figure 106b. For more information concerning loxodromes and projections go to: http://www.progonos.com/furuti/MapProj/Normal/CartProp/Rhumb/rhumb.html

107. Direction on the Earth

Direction is the position of one point relative to another. Navigators express direction as the angular difference in degrees from a reference direction, usually north or the ship's head. **Course (C, Cn)** is the horizontal direction in which a vessel is intended to be steered, expressed as angular distance from north clockwise through 360°. Strictly used, the term applies to direction through the water, not the direction intended to be made good over the ground. The course is often designated as true, magnetic, compass, or grid according to the reference direction.

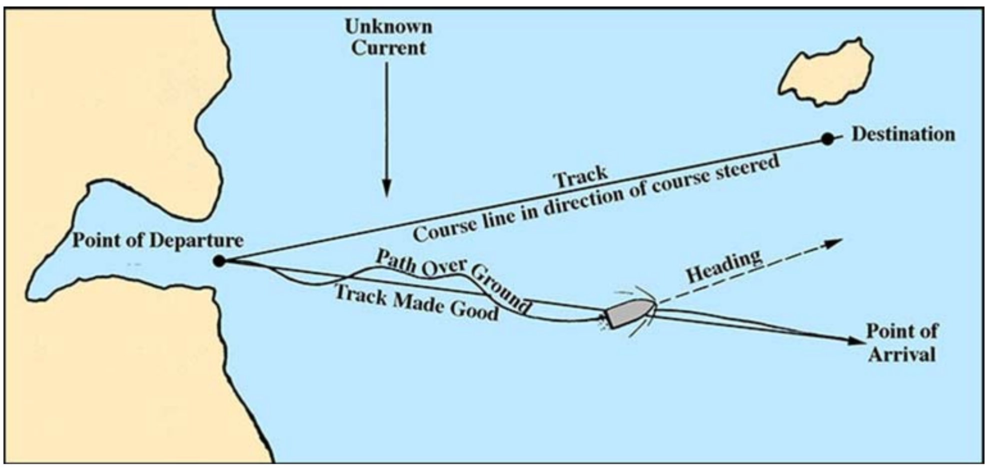


Figure 107a. Course line, track, track made good, and heading.

Track made good (TMG) is the single resultant direction from the point of departure to point of arrival at any given time. The use of this term is preferred to the use of the misnomer "course made good." **Course of advance (COA)** is the direction intended to be made good over the ground, and **course over ground (COG)** is the direction between a vessel's last fix and an EP. A **course line** is a line drawn on a chart extending in the direction of a course. It is sometimes convenient to express a course as an angle from either north or south, through 90° or 180°. In this case it is designated course angle (C) and should be properly labeled to indicate the origin (prefix) and direction of measurement (suffix). Thus, C N35°E = Cn 035° (000° + 35°), C N155°W = Cn 205° (360° - 155°), C S47°E = Cn 133° (180° - 47°). But Cn 260° may be either C N100°W or C S80°W, depending upon the conditions of the problem.

Track (TR) is the intended horizontal direction of travel with respect to the Earth. The terms intended track and trackline are used to indicate the path of intended travel. See Figure 107a. The track consists of one or a series of course lines, from the point of departure to the destination, along which one intends to proceed. A great circle which a vessel intends to follow is called a **great-circle track**, though it consists of a series of straight lines approximating a great circle

Heading (Hdg., SH) is the direction in which a vessel is pointed at any given moment, expressed as angular distance from 000° clockwise through 360°. It is easy to confuse heading and course. Heading constantly changes as a vessel yaws back and forth across the course due to sea, wind, and steering error.

Bearing (B, Brg.) is the direction of one terrestrial point from another, expressed as angular distance from 000° (North) clockwise through 360°. When measured through 90° or 180° from either north or south, it is called bearing angle (B). Bearing and azimuth are sometimes used interchangeably, but the latter more accurately refers to the horizontal direction of a point on the celestial sphere from a point on the Earth. A relative bearing is measured relative to the ship's heading from 000° (dead ahead) clockwise through 360°. However, it is sometimes conveniently measured right or left from 000° at the ship's head through 180°. This is particularly true when using the table for Distance of an Object by Two Bearings.

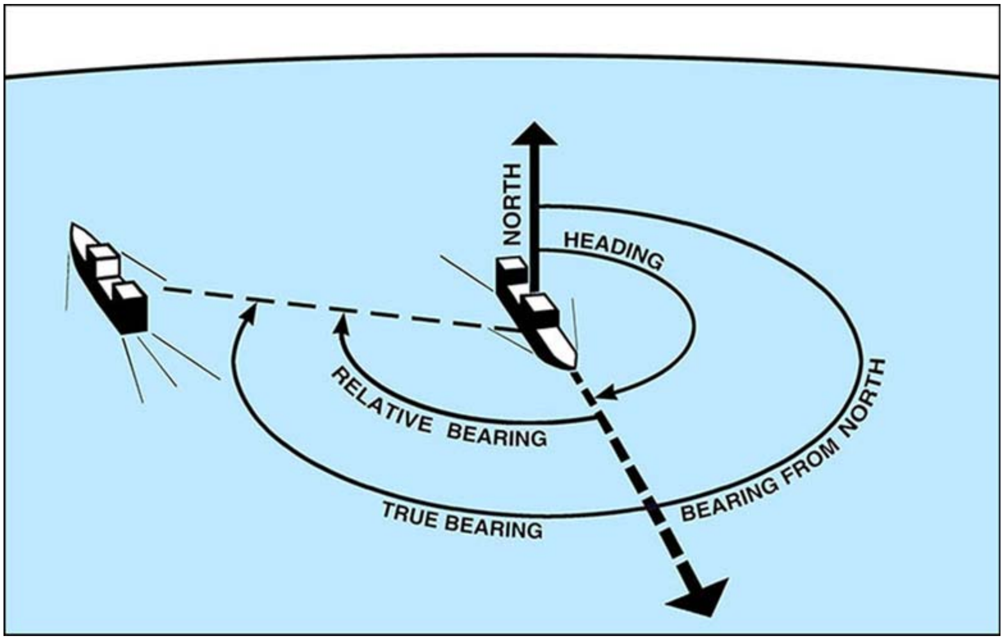


Figure 107b. Relative Bearing

To convert a relative bearing to a true bearing, add the true heading. See Figure 107b.

True Bearing = Relative Bearing + True Heading.
Relative Bearing = True Bearing - True Heading.

108. Finding Latitude and Longitude

Navigators have made latitude observations for thousands of years. Accurate declination tables for the Sun have been published for centuries, enabling ancient seamen to compute latitude to within 1 or 2 degrees. Those who today determine their latitude by measuring the Sun at their meridian and the altitude of Polaris are using methods well known to 15th century navigators.

A method of finding longitude eluded mariners for centuries. Several solutions independent of time proved too cumbersome. Finding longitude by magnetic variation was tried, but found too inaccurate. The lunar distance method, which determines GMT by observing the Moon's position among the stars, became popular in the 1800s. However, the mathematics required by most of these processes were far above the abilities of the average seaman. It was apparent that the solution lay in keeping accurate time at sea.

In 1714, the British Board of Longitude was formed, offering a small fortune in reward to anyone who could provide a solution to the problem.

An Englishman, John Harrison, responded to the challenge, developing four chronometers between 1735 and 1760. The most accurate of these timepieces lost only 15 seconds on a 156 day round trip between London and Barbados. The Board, however, paid him only half the promised reward. The King finally intervened on Harrison's behalf, and at the age of 80 years Harrison received his full reward of £20,000.

Rapid chronometer development led to the problem of determining **chronometer error** aboard ship. **Time balls**, large black spheres mounted in port in prominent locations, were dropped at the stroke of noon, enabling any ship in harbor which could see the ball to determine chronometer error. By the end of the U.S. Civil War, telegraph signals were being used to key time balls. Use of radio signals to send time ticks to ships well offshore began in 1904, and soon worldwide signals were available.

109. The Navigational Triangle

Modern celestial navigators reduce their celestial observations by solving a **navigational triangle** whose points are the elevated pole, the celestial body, and the zenith of the observer. The sides of this triangle are the polar distance of the body (**codeclination**), its zenith distance (**coaltitude**), and the polar distance of the zenith (**colatitude** of the observer).

A spherical triangle was first used at sea in solving **lunar distance** problems. Simultaneous observations were made of the altitudes of the Moon and the Sun or a star near the ecliptic and the angular distance between the Moon and the other body. The zenith of the observer and the two celestial bodies formed the vertices of a triangle whose sides were the two coaltitudes and the angular distance between the bodies. Using a mathematical calculation the navigator "cleared" this distance of the effects of refraction and parallax applicable to each altitude. This corrected value was then used as an argument for entering the almanac. The almanac gave the true lunar distance from the Sun and several stars at 3 hour intervals. Previously, the navigator had set his or her watch or checked its error and rate with the local mean time determined by celestial observations. The local mean time of the watch, properly corrected, applied to the Greenwich mean time obtained from the lunar distance observation, gave the longitude.

The calculations involved were tedious. Few mariners could solve the triangle until Nathaniel Bowditch published his simplified method in 1802 in *The New American Practical Navigator*.

Reliable chronometers were available by1800, but their high cost precluded their general use aboard most ships. However, most navigators could determine their longitude using Bowditch's method. This eliminated the need for parallel sailing and the lost time associated with it. Tables for the lunar distance solution were carried in the American nautical almanac into the 20th century.

110. The Time Sight

The theory of the **time sight** had been known to mathematicians since the development of spherical trigonometry, but not until the chronometer was developed could it be used by mariners.

The time sight used the modern navigational triangle. The codeclination, or polar distance, of the body could be determined from the almanac. The zenith distance (coaltitude) was determined by observation. If the colatitude were known, three sides of the triangle were available. From these the meridian angle was computed. The comparison of this with the Greenwich hour angle from the almanac yielded the longitude.

The time sight was mathematically sound, but the navigator was not always aware that the longitude determined was only as accurate as the latitude, and together they merely formed a point on what is known today as a **line of position**. If the observed body was on the prime vertical, the line of position ran north and south and a small error in latitude generally had little effect on the longitude. But when the body was close to the meridian, a small error in latitude produced a large error in longitude.

The line of position by celestial observation was unknown until discovered in 1837 by 30-year-old Captain Thomas H. Sumner, a Harvard graduate and son of a United States congressman from Massachusetts. The discovery of the "**Sumner line**," as it is sometimes called, was considered by Maury "the commencement of a new era in practical navigation." This was the turning point in the development of modern celestial navigation technique. In Sumner's own words, the discovery took place in this manner:

> *Having sailed from Charleston, S. C., 25th November, 1837, bound to Greenock, a series of heavy gales from the Westward promised a quick passage; after passing the Azores, the wind prevailed from the Southward, with thick weather; after passing Longitude 21° W, no observation was had until near the land; but soundings were had not far, as was supposed, from the edge of the Bank. The weather was now more boisterous, and very thick; and the wind still Southerly; arriving about midnight, 17th December, within 40 miles, by dead reckoning, of Tusker light; the wind hauled SE, true, making the Irish coast a lee shore; the ship was then kept close to the wind, and several tacks made to preserve her position as nearly as possible until daylight; when nothing being in sight, she was kept on ENE under short sail, with heavy gales; at about 10 AM an altitude of the Sun was observed, and the Chronometer time noted; but, having run so far without any observation, it was plain the Latitude by dead reckoning was liable to error, and could not be entirely relied on. Using, however, this Latitude, in finding the Longitude by Chronometer, it was found to put the ship 15' of Longitude E from her position by dead reckoning; which in Latitude 52° N is 9 nautical miles; this seemed to agree tolerably well with the dead reckoning; but feeling doubtful of the Latitude, the observation was tried with a Latitude 10' further N, finding this placed the ship ENE 27 nautical miles, of the former position, it was tried again with a Latitude 20' N of the dead reckoning; this also placed the ship still further ENE, and still 27 nautical miles further; these three positions were then seen to lie in the direction of Small's light. It then at once appeared that the observed altitude must have happened at all the three points, and at Small's light, and at the ship, at the same instant of time; and it followed, that Small's light must bear ENE, if the Chronometer was right. Having been convinced of this truth, the ship was kept on her course, ENE, the wind being still SE., and in less than an hour, Small's light was made bearing ENE 1/2 E, and close aboard.*

In 1843 Sumner published a book, A *New and Accurate Method of Finding a Ship's Position at Sea by Projection on Mercator's Chart*. He proposed solving a single time sight twice, using latitudes somewhat greater and somewhat less than that arrived at by dead reckoning, and joining the two positions obtained to form the line of position.

The Sumner method required the solution of two time sights to obtain each line of position. Many older navigators preferred not to draw the lines on their charts, but to fix their position mathematically by a method which Sumner had also devised and included in his book. This was a tedious but popular procedure.

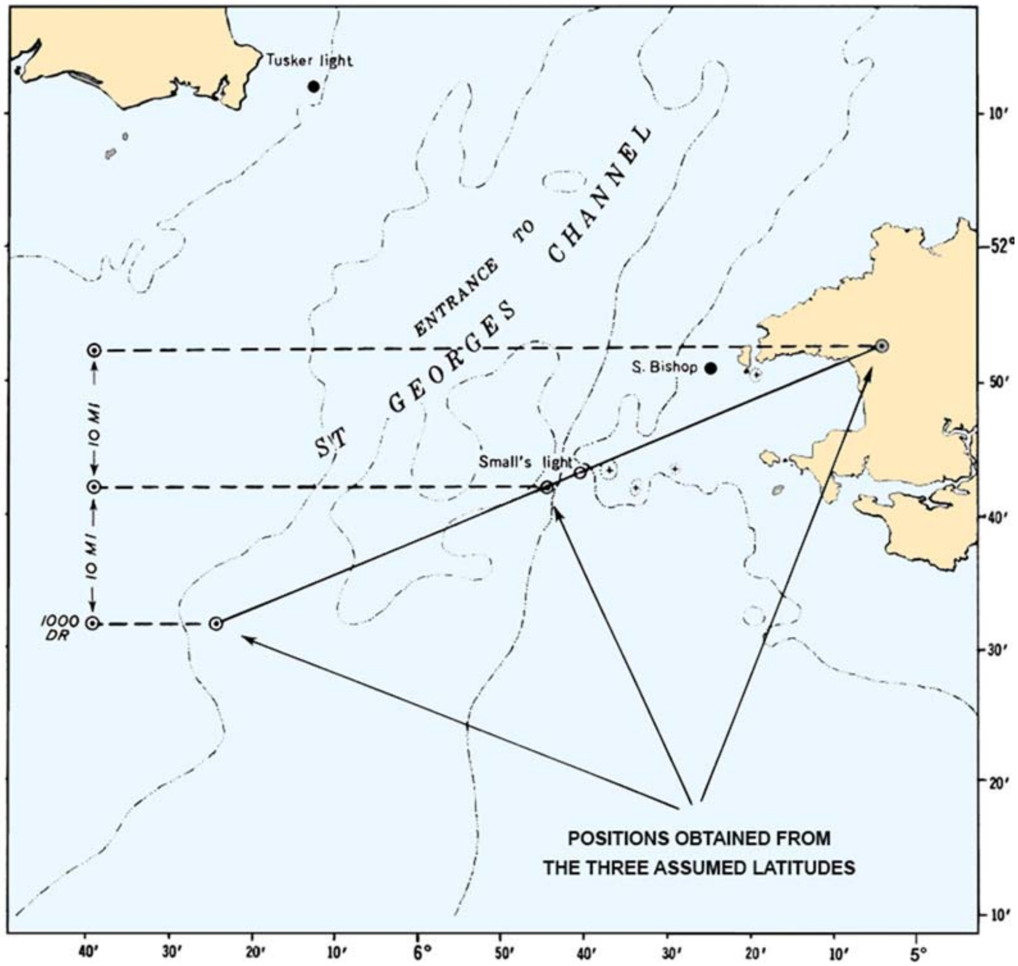


Figure 110. The first celestial line of position, obtained by Captain Thomas Sumner in 1837.

111. Navigational Tables

Spherical trigonometry is the basis for solving every navigational triangle, and until about 80 years ago the navigator had no choice but to solve each triangle by tedious, manual computations.

Lord Kelvin, generally considered the father of modern navigational methods, expressed interest in a book of tables with which a navigator could avoid tedious trigonometric solutions. However, solving the many thousands of triangles involved would have made the project too costly. Computers finally provided a practical means of preparing tables. In 1936 the first volume of *Pub. No. 214* was made available; later, *Pub. No. 229, Sight Reduction Tables for Marine Navigation*, has replaced *Pub. No. 214*. Pub. No 249 was provided for air navigators (*Pub. No. 249 Volume I* is now published as *UK Rapid Sight Reduction Table for Navigation NP 303/AP 3270*).

Today, electronic navigation calculators have mostly replaced navigation tables. Scientific calculators with trigonometric functions can easily solve the navigational triangle. Navigational calculators readily solve celestial sights and perform a variety of voyage planning functions. Using a calculator generally gives more accurate lines of position because it eliminates the rounding errors inherent in tabular inspection and interpolation.

112. Development of Electronic Navigation

Perhaps the first application of electronics to navigation occurred in 1865, when were first used to check chronometer error. This was followed by the transmission of radio time signals for chronometer checks dates to 1904. Radio broadcasts providing navigational warnings, begun in 1907 by the U.S. Navy Hydrographic Office, helped increase the safety of navigation at sea.

By the latter part of World War I the directional properties of a loop antenna were successfully used in the radio direction finder. The first radiobeacon was installed in 1921. Early 20th century experiments by Behm and Langevin led to the U.S. Navy's development of the first practical echo sounder in 1922. Radar and hyperbolic systems grew out of WWII.

Today, electronics touches almost every aspect of navigation. Hyperbolic systems, satellite systems, and electronic charts all require an increasingly sophisticated electronics suite and the expertise to manage them. These systems' accuracy and ease of use make them invaluable assets to the navigator, but there is far more to using them than knowing which buttons to push.

113. Development of Radar

As early as 1904, German engineers were experimenting with reflected radio waves. In 1922 two American scientists, Dr. A. Hoyt Taylor and Leo C. Young, testing a communication system at the Naval Aircraft Radio Laboratory, noted fluctuations in the signals when ships passed between stations on opposite sides of the Potomac River. In 1935 the British began work on radar. In 1937 the USS Leary tested the first sea-going radar, and in 1940 United States and British scientists combined their efforts. When the British revealed the principle of the multicavity magnetron developed by J. T. Randall and H. A. H. Boot at the University of Birmingham in 1939, microwave radar became practical. In 1945, at the close of World War II, radar became available for commercial use.

114. Development of Hyperbolic Radio Aids

Various hyperbolic systems were developed beginning in World War II. These were outgrowths of the British GEE system, developed to help bombers navigate to and from their missions over Europe. Loran A was developed as a long-range marine navigation system. This was replaced by the more accurate Loran C system, deployed throughout much of the world. Various short range and regional hyperbolic systems have been developed by private industry for hydrographic surveying, offshore facilities positioning, and general navigation.

115. Other Electronic Systems

The underlying concept that led to development of satellite navigation dates to 1957 and the first launch of an artificial satellite into orbit. The first system, NAVSAT, has been replaced by the far more accurate and widely available **Global Positioning System (GPS)**, which has revolutionized all aspects of navigation

The first **inertial navigation system** was developed in 1942 for use in the V2 missile by the Peenemunde group under the leadership of Dr. Wernher von Braun. This system used two 2-degree-of-freedom gyroscopes and an integrating accelerometer to determine the missile velocity. By the end of World War II, the Peenemunde group had developed a stable platform with three single-degree-of-freedom gyroscopes and an integrating accelerometer. In 1958 an inertial navigation system was used to navigate the USS *Nautilus* under the ice to the North Pole.

NAVIGATION ORGANIZATIONS

116. Governmental Role

Navigation only a generation ago was an independent process, carried out by the mariner without outside assistance. With compass and charts, sextant and chronometer, he or she can independently travel anywhere in the world. The increasing use of electronic navigation systems has made the navigator dependent on many factors outside their control. Government organizations fund, operate, and regulate satellites and other electronic systems. Governments are increasingly involved in regulation of vessel movements through traffic control systems and regulated areas. Understanding the governmental role in supporting and regulating navigation is vitally important to the mariner. In the United States, there are a number of official organizations which support the interests of navigators. Some have a policy-making role; others build and operate navigation systems. Many maritime nations have similar organizations performing similar functions. International organizations also play a significant role.

117. The Coast and Geodetic Survey

The **U.S. Coast and Geodetic Survey** was founded in 1807 when Congress passed a resolution authorizing a survey of the coast, harbors, outlying islands, and fishing banks of the United States. President Thomas Jefferson appointed Ferdinand Hassler, a Swiss immigrant and professor of mathematics at West Point, the first Director of the "Survey of the Coast." The name was changed to the "U.S. Coast Survey" in 1836.

Figure 117. https://www.ngs.noaa.gov

The approaches to New York were the first sections of the coast charted, and from there the work spread northward and southward along the eastern seaboard. In 1844 the work was expanded and arrangements made to simultaneously chart the gulf and east coasts. Investigation of tidal conditions began, and in 1855 the first tables of tide predictions were published. The California gold rush necessitated a survey of the west coast, which began in 1850, the year California became a state. *Coast Pilots*, or *Sailing Direc-*

tions, for the Atlantic coast of the United States were privately published in the first half of the 19th century. In 1850 the Survey began accumulating data that led to federally produced *Coast Pilots*. The 1889 *Pacific Coast Pilot* was an outstanding contribution to the safety of west coast shipping.

In 1878 the survey was renamed "Coast and Geodetic Survey." In 1970 the survey became the "National Ocean Survey," and in 1983 it became the "National Ocean Service" (NOS). Under NOS, the Office of Charting and Geodetic Services accomplished all charting and geodetic functions. In 1991 the name was changed back to the original "Coast and Geodetic Survey," organized under the National Ocean Service along with several other environmental offices. In 1995 the topographic and hydrographic components of the Coast and Geodetic Survey were separated and became the "National Geodetic Survey" (NGS) and the "Office of Coast Survey," (OCS). The Center for Operational Oceanographic Products and Services (CO-OPS) was also established. All three of these organizations are now part of NOS.

Today OCS supports safe and efficient navigation by maintaining over 1,000 nautical charts and Coast Pilots for U.S. coasts and the Great Lakes, covering 95,000 miles of shoreline and 3.4 million square nautical miles of waters. The charts are distributed in a variety of formats, which include electronic navigational charts (ENCs), raster navigational charts (RNCs), print on demand (POD) paper charts, and a digital chart tile service.

NGS provides shoreline surveys, which OCS compiles onto its nautical charts, and also maintains the National Geodetic Reference System. CO-OPS provides tides, water levels, currents and other oceanographic information that are used directly by mariners, as well as part of the hydrographic surveys and chart production processes that OCS carries out.

118. The National Geospatial-Intelligence Agency

In the first years of the newly formed United States of America, charts and instruments used by the Navy and merchant mariners were left over from colonial days or were obtained from European sources. In 1830 the U.S. Navy established a "Depot of Charts and Instruments" in Washington, D.C., as a storehouse from which available charts, pilots and sailing directions, and navigational instruments were issued to Naval ships. Lieutenant L. M. Goldsborough and one assistant, Passed Midshipman R. B. Hitchcock, constituted the entire staff.

The first chart published by the Depot was produced from data obtained in a survey made by Lieutenant Charles Wilkes, who had succeeded Goldsborough in 1834. Wilkes later earned fame as the leader of a United States expedition to Antarctica. From 1842 until 1861 Lieutenant Matthew Fontaine Maury served as Officer in Charge. Under his command the Depot rose to international prominence.

Maury decided upon an ambitious plan to increase the mariner's knowledge of existing winds, weather, and currents. He began by making a detailed record of pertinent matter included in old log books stored at the Depot. He then inaugurated a hydrographic reporting program among ship masters, and the thousands of reports received, along with the log book data, were compiled into the "*Wind and Current Chart of the North Atlantic*" in 1847. This is the ancestor of today's pilot chart.

Figure 118. https://www.nga.mil

The United States instigated an international conference in 1853 to interest other nations in a system of exchanging nautical information. The plan, which was Maury's, was enthusiastically adopted by other maritime nations. In 1854 the Depot was redesignated the "U.S. Naval Observatory and Hydrographical Office." At the outbreak of the American Civil War in 1861, Maury, a native of Virginia, resigned from the U.S. Navy and accepted a commission in the Confederate Navy. This effectively ended his career as a navigator, author, and oceanographer. At war's end, he fled the country, his reputation suffering from his embrace of the Confederate cause.

After Maury's return to the United States in 1868, he served as an instructor at the Virginia Military Institute. He continued at this position until his death in 1873. Since his death, his reputation as one of America's greatest hydrographers has been restored.

In 1866 Congress separated the Observatory and the Hydrographic Office, broadly increasing the functions of the latter. The Hydrographic Office was authorized to carry out surveys, collect information, and print every kind of nautical chart and publication "for the benefit and use of navigators generally."

The Hydrographic Office purchased the copyright of ***The New American Practical Navigator*** in 1867. The first *Notice to Mariners* appeared in 1869. Daily broadcast of navigational warnings was inaugurated in 1907. In 1912, following the sinking of the *Titanic*, the International Ice Patrol was established.

In 1962 the U.S. Navy Hydrographic Office was redesignated the U.S. Naval Oceanographic Office. In 1972 certain hydrographic functions of the latter office were transferred to the Defense Mapping Agency Hydrographic Center. In 1978 the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) assumed hydrographic and topographic chart production functions. In 1996 the

National Imagery and Mapping Agency (NIMA) was formed from DMA and certain other elements of the Department of Defense. In 2003 NIMA changed its name to **National Geospatial-Intelligence Agency (NGA)** to reflect its changing primary GEOINT mission. NGA continues to produce charts and nautical publications and to disseminate maritime safety information in support of the U.S. military and navigators generally.

119. The United States Coast Guard

Alexander Hamilton established the **U.S. Coast Guard** as the Revenue Marine, later the Revenue Cutter Service, on August 4, 1790. It was charged with enforcing the customs laws of the new nation. A revenue cutter, the *Harriet Lane*, fired the first shot from a naval unit in the Civil War at Fort Sumter. The Revenue Cutter Service became the U.S. Coast Guard when combined with the Lifesaving Service in 1915. The Lighthouse Service was added in 1939, and the Bureau of Marine Inspection and Navigation was added in 1942. The Coast Guard was transferred from the Treasury Department to the Department of Transportation in 1967, and in March of 2003 transferred to the Department of Homeland Security.

Figure 119. http://www.uscg.mil

The primary functions of the Coast Guard include maritime search and rescue, law enforcement, and operation of the nation's aids to navigation system. In addition, the Coast Guard is responsible for port safety and security, merchant marine inspection, and marine pollution control. The Coast Guard operates a large and varied fleet of ships, boats, and aircraft in performing its widely ranging duties

Navigation systems operated by the Coast Guard include the system of some 40,000 lighted and unlighted beacons, buoys, and ranges in U.S. and territorial waters; differential GPS (DGPS) services in the U.S.; and Vessel Traffic Services (VTS) in major ports and harbors of the U.S.

120. The United States Navy

The **U.S. Navy** was officially established in 1798. Its role in the development of navigational technology has been singular. From the founding of the Naval Observatory to the development of the most advanced electronics, the U.S. Navy has been a leader in developing devices and techniques designed to make the navigator's job safer and easier.

Figure 120. http://www.navy.mil

The development of almost every device known to navigation science has been deeply influenced by Naval policy. Some systems are direct outgrowths of specific Naval needs; some are the result of technological improvements shared with other services and with commercial maritime industry.

121. The United States Naval Observatory

One of the first observatories in the United States was built in 1831-1832 at Chapel Hill, N.C. The Depot of Charts and Instruments, established in 1830, was the agency from which the U.S. Navy Hydrographic Office and the **U.S. Naval Observatory** evolved 36 years later. In about 1835, under Lieutenant Charles Wilkes, the second Officer in Charge, the Depot installed a small transit instrument for rating chronometers.

Figure 121. http://www.usno.navy.mil/USNO

The Mallory Act of 1842 provided for the establishment of a permanent observatory. The director was authorized to purchase everything necessary to continue astronomical study. The observatory was completed in 1844 and the results of its first observations were published two years later. Congress established the Naval Observatory as a separate agency in 1866. In 1873 a refracting telescope with a 26 inch aperture, then the world's largest, was installed. The observatory, located in Washington, D.C., has occupied its present site since 1893.

122. The Royal Greenwich Observatory

England had no early privately supported observatories such as those on the continent. The need for navigational advancement was ignored by Henry VIII and Elizabeth I, but in 1675 Charles II, at the urging of John Flamsteed, Jonas Moore, Le Sieur de Saint Pierre, and Christopher Wren, established the **Greenwich Royal Observatory**. Charles limited construction costs to £500, and appointed Flamsteed the first Astronomer Royal, at an annual salary of £100. The equipment available in the early years of the observatory consisted of two clocks, a "sextant" of 7 foot radius, a quadrant of 3 foot radius, two telescopes, and the star catalog published almost a century before by Tycho Brahe. Thirteen years passed before Flamsteed had an instrument with which he could determine his latitude accurately.

Figure 122. http://www.rmg.co.uk/royal-observatory

In 1690 a transit instrument equipped with a telescope and vernier was invented by Romer; he later added a vertical circle to the device. This enabled the astronomer to determine declination and right ascension at the same time. One of these instruments was added to the equipment at Greenwich in 1721, replacing the huge quadrant previously used. The development and perfection of the chronometer in the next hundred years added to the accuracy of observations.

Other national observatories were constructed in the years that followed: at Berlin in 1705, St. Petersburg in 1725, Palermo in 1790, Cape of Good Hope in 1820, Parramatta in New South Wales in 1822, and Sydney in 1855.

123. The International Hydrographic Organization

The **International Hydrographic Organization (IHO)** was originally established in 1921 as the International Hydrographic Bureau (IHB). The present name was adopted in 1970 as a result of a revised international agreement among member nations. However, the former name, International Hydrographic Bureau, was retained for the IHO's administrative body of three Directors and their staff at the organization's headquarters in Monaco.

Figure 123. https://www.iho.int

The IHO sets forth hydrographic standards to be agreed upon by the member nations. All member states are urged and encouraged to follow these standards in their surveys, nautical charts, and publications. As these standards are uniformly adopted, the products of the world's hydrographic and oceanographic offices become more uniform. Much has been done in the field of standardization since the Bureau was founded.

The principal work undertaken by the IHO is:

- to bring about a close and permanent association between national hydrographic offices;
- to study matters relating to hydrography and allied sciences and techniques;
- to further the exchange of nautical charts and documents between hydrographic offices of member governments;
- to circulate the appropriate documents;
- to tender guidance and advice upon request, in particular to countries engaged in setting up or expanding their hydrographic service;
- to encourage coordination of hydrographic surveys with relevant oceanographic activities;
- to extend and facilitate the application of oceanographic knowledge for the benefit of navigators; and
- to cooperate with international organizations and scientific institutions which have related objectives.

During the 19th century, many maritime nations established hydrographic offices to provide means for improving the navigation of naval and merchant vessels by providing nautical publications, nautical charts, and other navigational services. There were substantial differences in hydrographic procedures, charts, and publications. In 1889, an International Marine Conference was held at Washington, D.C., and it was proposed to establish a "permanent international commission." Similar proposals were made at the sessions of the International Congress of Navigation held at St. Petersburg in 1908 and again in 1912.

In 1919 the hydrographers of Great Britain and France cooperated in taking the necessary steps to convene an international conference of hydrographers. London was selected as the most suitable place for this conference, and on July 24, 1919, the First International Conference opened, attended by the hydrographers of 24 nations. The object of the conference was "To consider the advisability of all maritime nations adopting similar methods in the preparation, construction, and production of their charts and all hydrographic publications; of rendering the results in the most convenient form to enable them to be readily used; of instituting a prompt system of mutual exchange of hydrographic information between all countries; and of providing an opportunity to consultations and discussions to be carried out on hydrographic subjects generally by the hydrographic experts of the world." This is still the major purpose of the International Hydrographic Organization.

As a result of the conference, a permanent organization was formed and statutes for its operations were prepared. The

International Hydrographic Bureau, now the International Hydrographic Organization, began its activities in 1921 with 18 nations as members. The Principality of Monaco was selected because of its easy communication with the rest of the world and also because of the generous offer of Prince Albert I of Monaco to provide suitable accommodations for the Bureau in the Principality. There are currently 59 member governments. Technical assistance with hydrographic matters is available through the IHO to member states requiring it.

Many IHO publications are available to the general public, such as the International Hydrographic Review, International Hydrographic Bulletin, Chart Specifications of the IHO, Hydrographic Dictionary, and others. Inquiries should be made to the International Hydrographic Bureau, 7 Avenue President J. F. Kennedy, B.P. 445, MC98011, Monaco, CEDEX.

124. The International Maritime Organization

The **International Maritime Organization (IMO)** was established by United Nations Convention in 1948. The Convention actually entered into force in 1959, although an international convention on marine pollution was adopted in 1954. (Until 1982 the official name of the organization was the Inter-Governmental Maritime Consultative Organization.) It is the only permanent body of the U. N. devoted to maritime matters, and the only special U. N. agency to have its headquarters in the UK.

Figure 124. http://www.imo.org

The governing body of the IMO is the **Assembly** of 137 member states, which meets every two years. Between Assembly sessions a Council, consisting of 32 member governments elected by the Assembly, governs the organization. Its work is carried out by the Maritime Safety Committee, with subcommittees for:

- Safety of Navigation
- Radiocommunications
- Life-saving
- Search and Rescue
- Training and Watchkeeping
- Carriage of Dangerous Goods
- Ship Design and Equipment
- Fire Protection
- Stability and Load Lines/Fishing Vessel Safety
- Containers and Cargoes
- Bulk Chemicals
- Marine Environment Protection Committee
- Legal Committee
- Technical Cooperation Committee
- Facilitation Committee

IMO is headed by the Secretary General, appointed by the council and approved by the Assembly. He or she is assisted by some 300 civil servants.

To achieve its objectives of coordinating international policy on marine matters, the IMO has adopted some 30 conventions and protocols, and adopted over 700 codes and recommendations. An issue to be adopted first is brought before a committee or subcommittee, which submits a draft to a conference. When the conference adopts the final text, it is submitted to member governments for ratification. Ratification by a specified number of countries is necessary for adoption; the more important the issue, the more countries must ratify. Adopted conventions are binding on member governments.

Codes and recommendations are not binding, but in most cases are supported by domestic legislation by the governments involved.

The first and most far-reaching convention adopted by the IMO was the International Convention for the **Safety of Life at Sea (SOLAS)** in 1960. This convention actually came into force in 1965, replacing a version first adopted in 1948. Because of the difficult process of bringing amendments into force internationally, none of subsequent amendments became binding. To remedy this situation, a new convention was adopted in 1974 and became binding in 1980. Among the regulations is V-20, requiring the carriage of up-to-date charts and publications sufficient for the intended voyage.

Other conventions and amendments were also adopted, such as the International Convention on Load Lines (adopted 1966, came into force 1968), a convention on the tonnage measurement of ships (adopted 1969, came into force 1982), The International Convention on Safe Containers (adopted 1972, came into force 1977), and the convention on **International Regulations for Preventing Collisions at Sea (COLREGS)** (adopted 1972, came into force 1977).

The 1972 COLREGS convention contained, among other provisions, a section devoted to Traffic Separation Schemes, which became binding on member states after having been adopted as recommendations in prior years.

One of the most important conventions is the **International Convention for the Prevention of Pollution from Ships (MARPOL 73/78)**, which was first adopted in 1973, amended by Protocol in 1978, and became binding in 1983. This convention built on a series of prior conventions and agreements dating from 1954, highlighted by several severe pollution disasters involving oil tankers. The MARPOL convention reduces the amount of oil discharged into the sea by ships, and bans discharges completely in certain areas. A related convention known as the London Dumping Convention regulates dumping of hazardous chemicals and other debris into the sea.

The IMO also develops minimum performance standards for a wide range of equipment relevant to safety at sea. Among such standards is one for the **Electronic Chart Display and Information System (ECDIS)**, the digital display deemed the operational and legal equivalent of the conventional paper chart.

Texts of the various conventions and recommendations, as well as a catalog and publications on other subjects, are available from the Publications Section of the IMO at 4 Albert Embankment, London SE1 7SR, United Kingdom.

125. The International Association of Marine Aids to Navigation and Lighthouse Authorities

The **International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)** brings together representatives of the aids to navigation services of more than 80 member countries for technical coordination, information sharing, and coordination of improvements to visual aids to navigation throughout the world. It was established in 1957 to provide a permanent organization to support the goals of the Technical Lighthouse Conferences, which had been convening since 1929. The General Assembly of IALA meets about every 4 years. The Council of 20 members meets twice a year to oversee the ongoing programs.

Figure 125. http://www.iala-aism.org

Five technical committees maintain the permanent programs:

- The Marine Marking Committee
- The Radionavigation Systems Committee
- The Vessel Traffic Services (VTS) Committee
- The Reliability Committee
- The Documentation Committee

IALA committees provide important documentation to the IHO and other international organizations, while the IALA Secretariat acts as a clearing house for the exchange of technical information, and organizes seminars and technical support for developing countries.

Its principle work since 1973 has been the implementation of the IALA Maritime Buoyage System described in Chapter 7- Short Range Aids to Navigation. This system replaced some 30 dissimilar buoyage systems in use throughout the world with 2 major systems.

IALA is based near Paris, France in Saint-Germaine-en-Laye.

126. The Radio Technical Commission for Maritime Services (RTCM)

The **Radio Technical Commission for Maritime Services** is a non-profit organization which serves as a focal point for the exchange of information and the development of recommendations and standards related to all aspects of maritime radiocommunications and radionavigation.

Figure 126. http://www.rtcm.org

Specifically, RTCM:

- Promotes ideas and exchanges information on maritime radiocommunications and radionavigation.
- Facilitates the development and exchange of views among and between government and non-government interests both nationally and internationally.
- Conducts studies and prepares reports on maritime radiocommunications and radionavigation issues to improve efficiency and capabilities.

Both government and non-government organizations are members, coming from the U.S. and many other nations. The RTCM organization consists of a Board of Directors, and the Assembly consisting of all members, officers, staff, technical advisors, and working committees.

Working committees are formed as needed to develop official RTCM recommendations regarding technical standards and regulatory policies in the maritime field. Currently committees address such issues as maritime safety information, electronic charts, emergency position-indicating radiobeacons (EPIRB's), personal locator beacons, ship radars, differential GPS, GLONASS (Russia's version of GPS), and maritime survivor locator devices.

The RTCM headquarters office is in Alexandria, VA.

127. The National Marine Electronic Association

The **National Marine Electronic Association (NMEA)** is a professional trade association founded in 1957 whose purpose is to coordinate the efforts of marine electronics manufacturers, technicians, government agencies, ship and boat builders, and other interested groups. In addition to certifying marine electronics technicians and professionally recognizing outstanding achievements by corporate and individual members, the NMEA sets standards for the exchange of digital data by all manufacturers of marine electronic equipment. This allows the configuration of integrated navigation system using equipment from different manufacturers.

Figure 127. http://www.nmea.org

NMEA works closely with RTCM and other private organizations and with government agencies to monitor the status of laws and regulations affecting the marine electronics industry.

It also sponsors conferences and seminars, and publishes a number of guides and periodicals for members and the general public.

128. International Electrotechnical Commission

The **International Electrotechnical Commission (IEC)** was founded in 1906 as an outgrowth of the International Electrical Congress held at St. Louis, Missouri in 1904. Some 60 countries are active members. Its mission is to develop and promote standardization in the technical specifications of electrical and electronic equipment among all nations. These technologies include electronics, magnetics, electromagnetics, electroacoustics, multimedia, telecommunications, electrical energy production and distribution, and associated fields such as terminology and symbology, compatibility, performance standards, safety, and environmental factors.

Figure 128. http://www.iec.ch

By standardizing in these areas, the IEC seeks to promote more efficient markets, improve the quality of products and standards of performance, promote interoperability, increase production efficiency, and contribute to human health and safety and environmental protection.

Standards are published by the IEC in the form of official IEC documents after debate and input from the national committees. Standards thus represent a consensus of the views of many different interests. Adoption of a standard by any country is entirely voluntary. However, failure to adopt a standard may result in a technical barrier to trade, as goods manufactured to a proprietary standard in one country may be incompatible with the systems of others.

IEC standards are vital to the success of ECDIS and other integrated navigation systems because they help to ensure that systems from various manufacturers in different countries will be compatible and meet required specifications.

CHAPTER 2

GEODESY AND DATUMS IN NAVIGATION

GEODESY, THE BASIS OF CARTOGRAPHY

200. Definition

Geodesy is the application of mathematics to model the size and shape of the physical earth, enabling us to describe its magnetic and gravitational fields and a coordinate referencing system to precisely position and navigate globally using one 3-dimensional coordinate system.

Today's modern Global Navigation Satellite Systems (GNSS), such as GPS, have made it possible to establish a truly global geocentric reference system which can be quickly adapted for precise positioning and navigation over long distances.

Thus, the precision of today's navigation systems and the global nature of satellite and other long-range positioning methods demand a more complete understanding of geodesy by the navigator than has ever before been required.

201. The Shape of the Earth

In geodetic applications, three primary reference surfaces for the Earth are used (See Table 201):

1. a **physical surface**,
2. an **ellipsoid of revolution**, which is a reference surface of purely mathematical nature, and
3. the **geoid** (an irregular surface, which has no complete mathematical expression).

A physical surface is tangible, it can be traversed and measurements can be made on it. The topography, ice caps, or sea surface area all physical surfaces.

An equipotential surface is one where the force of gravity is always equal and the direction of gravity is always perpendicular. The **geoid** is a particular equipotential surface that would coincide with the mean ocean surface of the Earth if the oceans and atmosphere were in equilibrium, at rest relative to the rotating Earth, and extended through the continents (such as with very narrow canals).

In common practice, an **ellipsoid height** is the distance a given point is above or below the ellipsoid surface, whereas a **geoid height** is the distance the geoid surface is above or below the ellipsoid surface. Determination of a "mean sea level" is a difficult problem because of the many factors that affect sea level. Sea level varies considerably on several scales of time and distance and the extent of this variability is the result of seas that are in constant motion, affected by the solar and lunar tides, wind, atmospheric pressure, local gravitational differences, temperature, and salinity. In geodetic applications, the geoid is then used to serve as the vertical reference surface to approximate measure mean sea level (MSL) heights and a height measured from the geoid to a point is called an **orthometric height**. In areas where elevation data are not available from conventional geodetic leveling, an approximation of MSL heights using orthometric heights from the geoid can be obtained from the equation listed in Table 201. This equation

H = h - N
where
H = orthometric height (the height relative to the geoid)
h = ellipsoid (geodetic) height (the height relative to the ellipsoid)
N = geoid height (undulation)

Table 201. Relations between orthometric, ellipsoid and geoid heights.

illustrates the determination of the orthometric height (H) of a point as a subtraction of the geoid height (N) from the ellipsoid height (h).

202. Defining the Ellipsoid

An **ellipsoid** is uniquely defined by specifying two parameters. Geodesists, by convention, use the **semi-major axis** and either **eccentricity** or **flattening**. The size is represented by the radius at the equator, the semi-major axis. The shape of the ellipsoid is given by the flattening, which indicates how closely an ellipsoid approaches a spherical shape. The flattening (f) is the ratio of the difference between the semi-major (a) and semi-minor (b) axes of the ellipsoid and the semi-major axis.

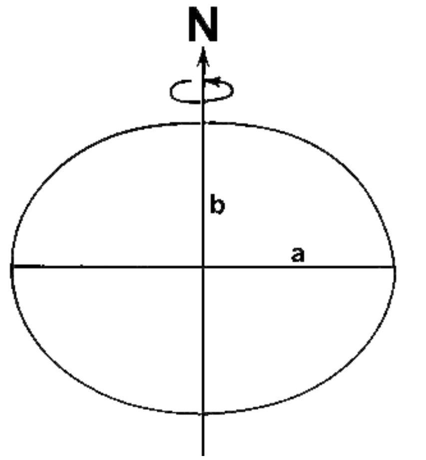


Figure 202. An ellipsoid of revolution, with semimajor axis (a), and semiminor axis (b).

$$f = \frac{a - b}{a} .$$

The ellipsoidal Earth model has its minor axis parallel to the Earth's polar axis. Rotating the ellipse about the semi-minor axis gives the ellipsoid of revolution. See Figure 202.

203. Ellipsoids and the Geoid as Reference Surfaces

Since the surface of the geoid is irregular and the surface of an ellipsoid is regular, no ellipsoid can provide more than an approximation of part of the geoidal surface. Historically, ellipsoids that best fit the geoid regionally were employed. The widespread use of GNSS has facilitated the use of global, best fitting ellipsoids. The most common are the World Geodetic System 1984 (WGS 84) and the Geodetic Reference System of 1980 (GRS 80) ellipsoids. See Table 203 for WGS 84 defining parameters.

Parameter	Symbol	Value	Units
Semi-major Axis (Equatorial Radius of the Earth)	a	6378137.0	m
Flattening factor of the Earth	1/f	298.257223563	
Geocentric Gravitational Constant	GM	$3.986004418 \quad 10^{+14}$	m^3/s^2
Nominal Mean Angular Velocity of the Earth	ω	$7.292115 \quad 10^{-05}$	rads / s

Table 203. WGS 84 defining parameters.

204. Coordinates

The **astronomic latitude** is the angle between a plumb line and the plane of the celestial equator. It is the latitude which results directly from observations of celestial bodies, uncorrected for deflection of the vertical component in the meridian (north-south) direction. Astronomic latitude applies only to positions on the Earth. It is reckoned from the astronomic equator (0°), north and south through 90°.

The **astronomic longitude** is the angle between the plane of the celestial meridian at a station and the plane of the celestial meridian at Greenwich. It is the longitude which results directly from observations of celestial bodies, uncorrected for deflection of the vertical component in the prime vertical (east-west) direction. These are the coordinates observed by the celestial navigator using a sextant and a very accurate clock based on the Earth’s rotation.

Celestial observations by geodesists are made with optical instruments (theodolite, zenith camera, prismatic astrolabe) which all contain leveling devices. When properly adjusted, the vertical axis of the instrument coincides with the direction of gravity, which may not coincide with the plane of the meridian. Thus, geodetically derived astronomic positions are referenced to the geoid. The difference, from a navigational standpoint, is too small to be of concern.

The **geodetic latitude** is the angle which the normal to the ellipsoid at a station makes with the plane of the geodetic equator. In recording a geodetic position, it is essential that the geodetic datum on which it is based also be stated. A geodetic latitude differs from the corresponding astronomic latitude by the amount of the meridian component of the local **deflection of the vertical**. See Figure 204.

The **geodetic longitude** is the angle between the plane of the geodetic meridian at a station and the plane of the geodetic meridian at Greenwich. A geodetic longitude differs from the corresponding astronomic longitude by the prime vertical component of the local deflection of the

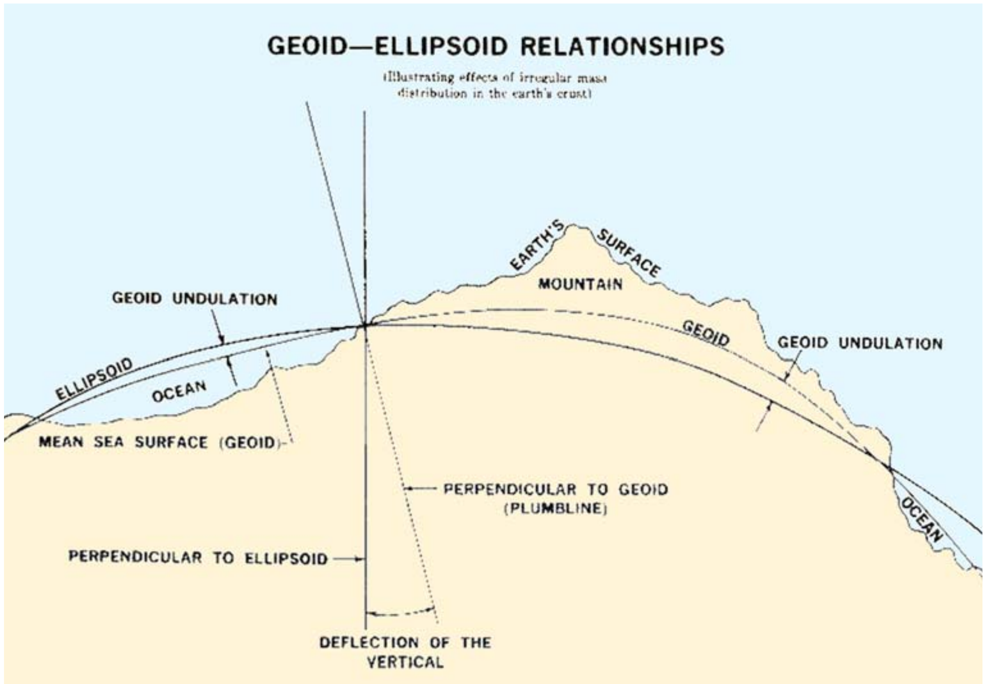


Figure 204. Geoid-ellipsoid relationships.

vertical divided by the cosine of the latitude. The geodetic coordinates are used for mapping.

The **geocentric latitude** is the angle at the center of the ellipsoid (used to represent the Earth) between the plane of the equator, and a straight line (or radius vector) to a point on the surface of the ellipsoid. This differs from geodetic latitude because the Earth is approximated more closely by a spheroid than a sphere and the meridians are ellipses, not perfect circles.

Both geocentric and geodetic latitudes refer to the reference ellipsoid and not the Earth. Since the parallels of latitude are considered to be circles, geodetic longitude is geocentric, and a separate expression is not used.

Because of the oblate shape of the ellipsoid, the length of a degree of geodetic latitude is not everywhere the same, increasing from about 59.7 nautical miles at the equator to about 60.3 nautical miles at the poles.

A classic regional **horizontal geodetic datum** usually consists of the astronomic and geodetic latitude, and astronomic and geodetic longitude of an initial point (origin); an azimuth of a line (direction); the parameters (radius and flattening) of the ellipsoid selected for the computations; and the geoidal separation at the origin. A change in any of these quantities affects every point on the datum.

For this reason, while positions within a given datum are directly and accurately relatable, those from different datums must be transformed to a common datum for consistency.

TYPES OF GEODETIC SURVEY

205. Satellite Positioning

The use of artificial satellite signals allows positioning without the necessity of line-of-sight. Positions (including heights) determined in this manner are *directly* referred to the ellipsoid. Static precise positioning is commonly employed to determine or extend geodetic control.

Absolute positioning uses a single stationary receiver to determine a position with respect to the center of the Earth. Relative static positioning determines a position with respect to another station and involves multiple receivers operating simultaneously. Specialized processing is required for these highly accurate survey methods.

The position of a moving receiver often depends on a reference receiver at a known point that broadcasts corrections in some fashion. The corrections are derived from the difference between the known position of the base and the position determined by the current constellation.

The electro-optical survey methods discussed following this section on satellite positioning must be *reduced* to the ellipsoid for computations.

206. Triangulation

The most common type of geodetic survey is known as **triangulation**. Triangulation consists of the measurement of the angles of a series of triangles. The principle of triangulation is based on plane trigonometry. If the distance along one side of the triangle and the angles at each end are accurately measured, the other two sides and the remaining angle can be computed. In practice, all of the angles of every triangle are measured to provide precise measurements. Also, the latitude and longitude of one end of the measured side along with the length and direction (azimuth) of the side provide sufficient data to compute the latitude and longitude of the other end of the side.

The measured side of the base triangle is called a **baseline**. Measurements are made as carefully and accurately as possible with specially calibrated tapes or wires of Invar, an alloy with a very low coefficient of expansion. The tape or wires are checked periodically against standard measures of length.

To establish an arc of triangulation between two widely separated locations, the baseline may be measured and longitude and latitude determined for the initial points at each location. The lines are then connected by a series of adjoining triangles forming quadrilaterals extending from each end. All angles of the triangles are measured repeatedly to reduce errors. With the longitude, latitude, and azimuth of the initial points, similar data is computed for each vertex of the triangles, thereby establishing triangulation stations, or geodetic control stations. The coordinates of each of the stations are defined as geodetic coordinates.

Triangulation is extended over large areas by connecting and extending series of arcs to form a network or triangulation system. The network is adjusted so as to reduce observational errors to a minimum. A denser distribution of geodetic control is achieved by subdividing or filling in with other surveys.

There are four general classes or orders of triangulation. **First-order** (primary) triangulation is the most precise and exact type. The most accurate instruments and rigorous computation methods are used. It is costly and time-consuming, and is usually used to provide the basic framework of control data for an area, and the determination of the figure of the Earth. The most accurate first-order surveys furnish control points which can be interrelated with an accuracy ranging from 1 part in 25,000 over short distances to approximately 1 part in 100,000 for long distances.

Second-order triangulation furnishes points closer together than in the primary network. While second-order surveys may cover quite extensive areas, they are usually tied to a primary system where possible. The procedures are less exacting and the proportional error is 1 part in 10,000.

Third-order triangulation is run between points in a secondary survey. It is used to densify local control nets and position the topographic and hydrographic detail of the area. Error can amount to 1 part in 5,000.

The sole accuracy requirement for **fourth-order** triangulation is that the positions be located without any appreciable error on maps compiled on the basis of the control. Fourth-order control is done primarily as mapping control.

207. Trilateration, Traverse, And Vertical Surveying

Trilateration involves measuring the sides of a chain of triangles or other polygons. From them, the distance and direction from A to B can be computed. Figure 207 shows this process.

Traverse involves measuring distances and the angles between them without triangles for the purpose of computing the distance and direction from A to B. See Figure 207.

Vertical surveying is the process of determining elevations above mean sea-level. In geodetic surveys executed primarily for mapping, geodetic positions are referred to an ellipsoid, and the elevations of the positions are referred to the geoid. However, for satellite geodesy the geoidal heights must be considered to establish the correct height above the geoid.

Precise geodetic **leveling** is used to establish a basic network of vertical control points. From these, the height of other positions in the survey can be determined by supplementary methods. The mean sea-level surface used as a reference (vertical datum) is determined by averaging the hourly water heights for a specified period of time at specified tide gauges.

There are three leveling techniques: **differential**, **trigonometric**, and **barometric**. Differential leveling is the most accurate of the three methods. With the instrument locked in position, readings are made on two calibrated staffs held in an upright position ahead of and behind the instrument. The difference between readings is the difference in elevation between the points.

Trigonometric leveling involves measuring a vertical angle from a known distance with a theodolite and computing the elevation of the point. With this method, vertical measurement can be made at the same time horizontal angles are measured for triangulation. It is, therefore, a somewhat more economical method but less accurate than differential leveling. It is often the only mechanical method of establishing accurate elevation control in mountainous areas.

In barometric leveling, differences in height are determined by measuring the differences in atmospheric pressure at various elevations. Air pressure is measured by mercurial or aneroid barometer, or a boiling point thermometer. Although the accuracy of this method is not as great as either of the other two, it obtains relative heights very rapidly at points which are fairly far apart. It is used in reconnaissance and exploratory surveys where more accurate measurements will be made later or where a high degree of accuracy is not required.

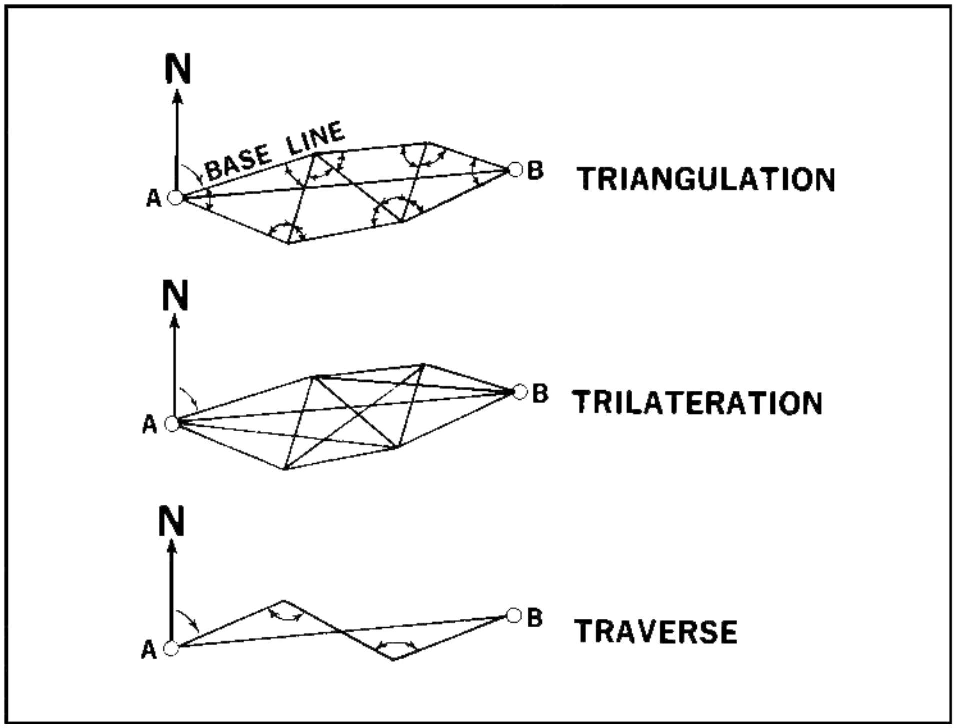


Figure 207. Triangulation, trilateration, and traverse.

MODERN GEODETIC SYSTEMS

208. Development of the World Geodetic System

By the late 1950's the increasing range and sophistication of weapons systems had rendered local or national datums inadequate for military purposes; these new weapons required datums at least continental, if not global, in scope. In response to these requirements, the U.S. Department of Defense generated a geocentric (earth-centered) reference system to which different geodetic networks could be referred, and established compatibility between the coordinate systems. Efforts of the Army, Navy, and Air Force were combined, leading to the development of the DoD **World Geodetic System of 1960 (WGS 60)**.

In January 1966, a World Geodetic System Committee was charged with the responsibility for developing an improved WGS needed to satisfy mapping, charting, and geodetic requirements. Additional surface gravity observations, results from the extension of triangulation and trilateration networks, and large amounts of Doppler and optical satellite data had become available since the development of WGS 60. Using the additional data and improved techniques, the Committee produced **WGS 66** which served DoD needs following its implementation in 1967.

The same World Geodetic System Committee began work in 1970 to develop a replacement for WGS 66. Since the development of WGS 66**,** large quantities of additional data had become available from both Doppler and optical satellites, surface gravity surveys, triangulation and trilateration surveys, high precision traverses, and astronomic surveys.

In addition, improved capabilities had been developed in both computers and computer software. Continued research in computational procedures and error analyses had produced better methods and an improved facility for handling and combining data. After an extensive effort extending over a period of approximately three years, the Committee completed the development of the Department of Defense **World Geodetic System 1972 (WGS 72)**.

Further refinement of WGS 72 resulted in the new **World Geodetic System of 1984 (WGS 84),** now referred to as simply WGS. For surface navigation, WGS 60, 66, 72 and the new WGS 84 are essentially the same, so that positions computed on any WGS coordinates can be plotted directly on the others without correction.

The WGS system is not based on a single point, but many points, fixed with extreme precision by satellite fixes and statistical methods. The result is an ellipsoid which fits the real surface of the Earth, or geoid, far more accurately than any other. The WGS system is applicable worldwide. All regional datums can be referenced to WGS once a survey tie has been made.

209. The North American Datum Of 1983

The Office of Coast Survey of the National Ocean Service (NOS), NOAA, is responsible for charting United States waters. From 1927 to 1987, U.S. charts were based on North American Datum 1927 (NAD 27), using the Clarke 1866 ellipsoid. In 1989, the U.S. officially switched to **NAD 83** (navigationally equivalent to WGS) for all mapping and charting purposes, and all new NOAA chart production is based on this new standard.

The grid of interconnected surveys which criss-crosses the United States consists of some 250,000 control points, each consisting of the latitude and longitude of the point, plus additional data such as elevation. Converting the NAD 27 coordinates to NAD 83 involved recomputing the position of each point based on the new NAD 83 datum. In addition to the 250,000 U.S. control points, several thousand more were added to tie in surveys from Canada, Mexico, and Central America.

Conversion of new edition charts to the new datums, either WGS 84 or NAD 83, involves converting reference points on each chart from the old datum to the new, and adjusting the latitude and longitude grid (known as the graticule) so that it reflects the newly plotted positions. This adjustment of the graticule is the only difference between charts which differ only in datum. All charted features remain in exactly the same relative positions.

The Global Positioning System (GPS) has transformed the science of surveying, enabling the establishment of precise ties to WGS in areas previously found to be too remote to survey to modern standards. As a result, new charts are increasingly precise as to position of features. The more recent a chart's date of publishing, the more likely it is that it will be accurate as to positions. Navigators should always refer to the title block of a chart to determine the date of the chart, the date of the surveys and sources used to compile it, and the datum on which it is based.

DATUMS AND NAVIGATION

210. Datum Shift

One of the most serious impacts of different datums on navigation occurs when a navigation system provides a fix based on a datum *different* from that used for the nautical chart. The resulting plotted position may be different from the actual location on that chart. This difference is known as a **datum shift**.

Modern electronic navigation systems have software installed that can output positions in a variety of datums, eliminating the necessity for applying corrections. All electronic charts produced by NGA are compiled on WGS and are not subject to datum shift problems as long as the GPS receiver is outputting WGS position data to the display system. The same is true for NOAA charts of the U.S., which are compiled on NAD 83 datum, very closely related to WGS. GPS receivers default to WGS, so that no action is necessary to use any U.S.-produced electronic charts.

To automate datum conversions, a number of datum transformation software programs have been written that will convert from any known datum to any other, in any location. MSPGEOTRANS is such a program. The amount of datum shift between two different datums is not linear. That is, the amount of shift is a function of the position of the observer, which must be specified for the shift to be computed. Varying differences of latitude and longitude between two different datums will be noted as one's location changes.

There are still a few NGA-produced paper charts, and a number of charts from other countries, based on datums other than WGS. If the datum of these charts is noted in the title block of the chart, most GPS receivers can be set to output position data in that datum, eliminating the datum shift problem. If the datum is not listed, extreme caution is necessary. An offset can sometimes be established if the ship's actual position can be determined with sufficient accuracy, and this offset applied to GPS positions in the local area. But remember that since a datum shift is not linear, this offset is only applicable locally.

Another effect on navigation occurs when shifting between charts that have been compiled using different datums. If a position is replotted on a chart of another datum using latitude and longitude, the newly plotted position will not match with respect to other charted features. The datum shift may be avoided by transferring positions using bearings and ranges to common points. If datum shift conversion notes for the applicable datums are given on the charts, positions defined by latitude and longitude may be replotted after applying the noted correction.

The positions given for chart corrections in the *Notice to Mariners* reflect the proper datum for each specific chart and edition number. Due to conversion of charts based on old datums to more modern ones, and the use of many different datums throughout the world, chart corrections intended for one edition of a chart may not necessarily be safely plotted on any other.

As noted, datum shifts are not constant throughout a given region, but vary according to how the differing datums fit together. For example, the NAD 27 to NAD 83 conversion resulted in changes in latitude of 40 meters in Miami, 11 meters in New York, and 20 meters in Seattle. Longitude changes for this conversion amounted to 22 meters in Miami, 35 meters in New York, and 93 meters in Seattle.

Most charts produced by NGA and NOAA show a "datum note." This note is usually found in the title block or in the upper left margin of the chart. According to the year of the chart edition, the scale, and policy at the time of production, the note may say "World Geodetic System 1972 (WGS-72)", "World Geodetic System 1984 (WGS-84)", or "World Geodetic System (WGS)." A datum note for a chart for which satellite positions can be plotted without correction will read: "Positions obtained from satellite navigation systems referred to (Reference Datum) can be plotted directly on this chart."

NGA reproductions of foreign charts will usually be in the datum or reference system of the producing country. In these cases a conversion factor is given in the following format: "Positions obtained from satellite navigation systems referred to the (Reference Datum) must be moved X.XX minutes (Northward/Southward) and X.XX minutes (Eastward/ Westward) to agree with this chart."

Some charts cannot be tied in to WGS because of lack of recent surveys. Currently issued charts of some areas are based on surveys or use data obtained in the Age of Sail. The lack of surveyed control points means that they cannot be properly referenced to modern geodetic systems. In this case there may be a note that says: "Adjustments to WGS cannot be determined for this chart."

A few charts may have no datum note at all, but may carry a note which says: "From various sources to (year)." In these cases there is no way for the navigator to determine the mathematical difference between the local datum and WGS positions. However, if a radar or visual fix can be accurately determined, and an offset established as noted above. This offset can then be programmed into the GPS receiver.

To minimize problems caused by differing datums:

- Plot chart corrections only on the specific charts and editions for which they are intended. Each chart correction is specific to only one edition of a chart. When the same correction is made on two charts based on different datums, the positions for the same feature may differ slightly. This difference is equal to the datum shift between the two datums for that area.
- Try to determine the source and datum of positions of temporary features, such as drill rigs. In general they are given in the datum used in the area in question. Since these are precisely positioned using satellites, WGS is the normal datum. A datum correction, if needed, might be found on a chart of the area.
- Remember that if the datum of a plotted feature is not known, position inaccuracies may result. It is wise to allow a margin of error if there is any doubt about the datum.
- Know how the datum of the positioning system you are using relates to your chart. GPS and other modern positioning systems use WGS datum. If your chart is on any other datum, you must program the system to use the chart's datum, or apply a datum correction when plotting GPS positions on the chart.

For more information regarding geodetic datums visit the link provided in Figure 210.

Figure 210.
http://www.colorado.edu/geography/gcraft/notes/datum/datum_f.html

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 of these sources play 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

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.

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 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 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.

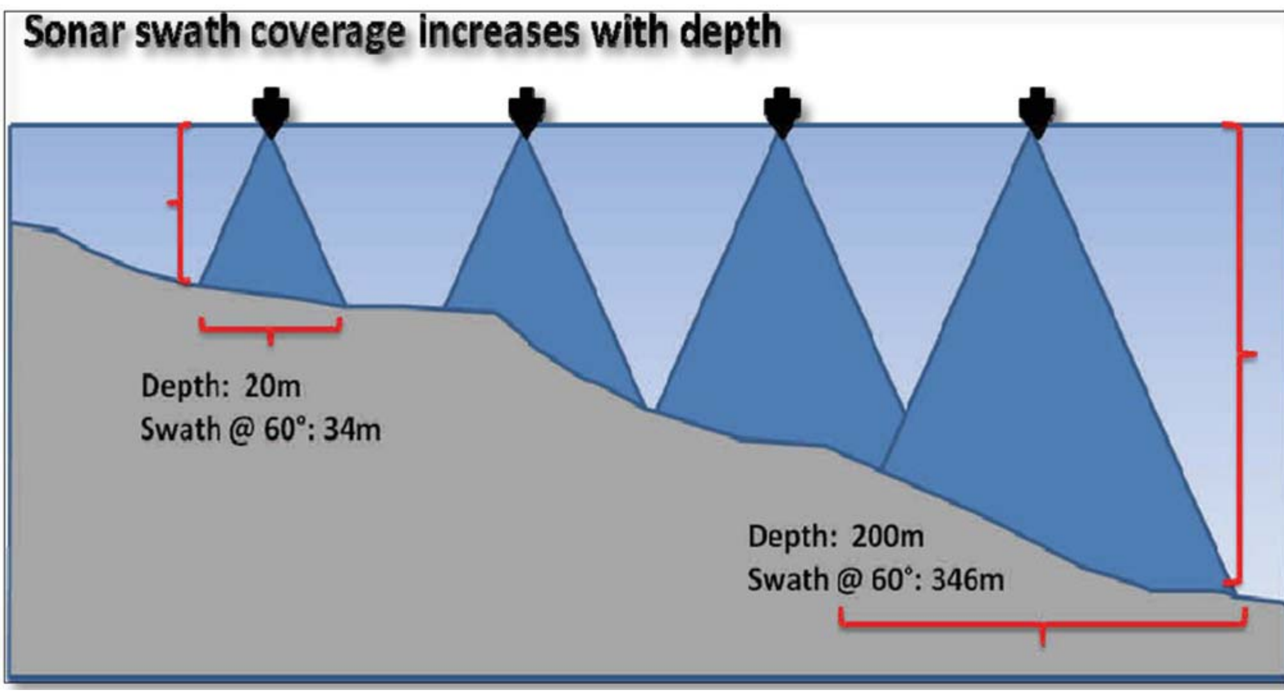


Figure 307. Comparison of sonar swath coverage at different water depths.

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 308).

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.

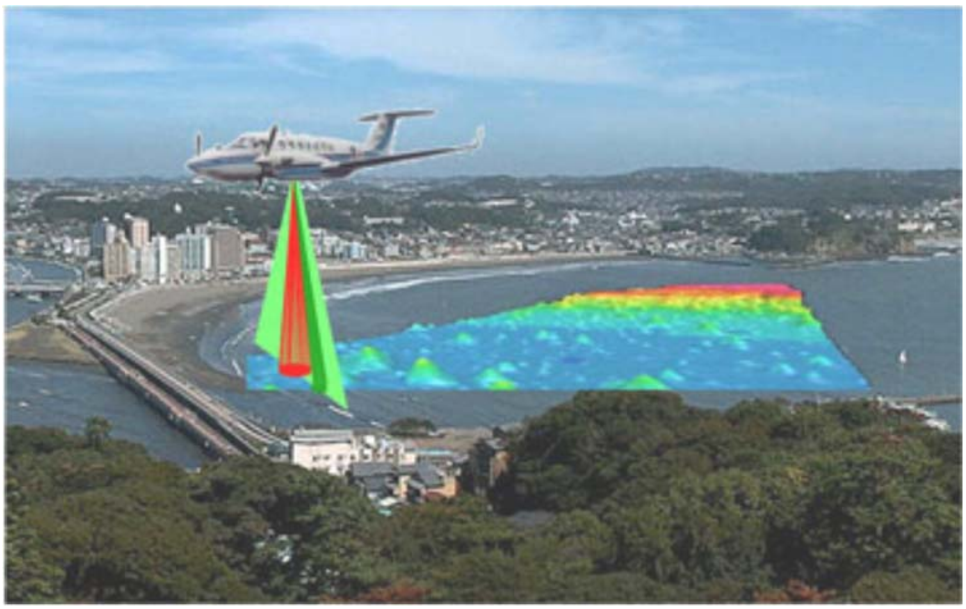


Figure 308. Collecting bathymetric LIDAR data. Image courtesy of NOAA.

PROCESSING HYDROGRAPHIC DATA

309. 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 309).

310. 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

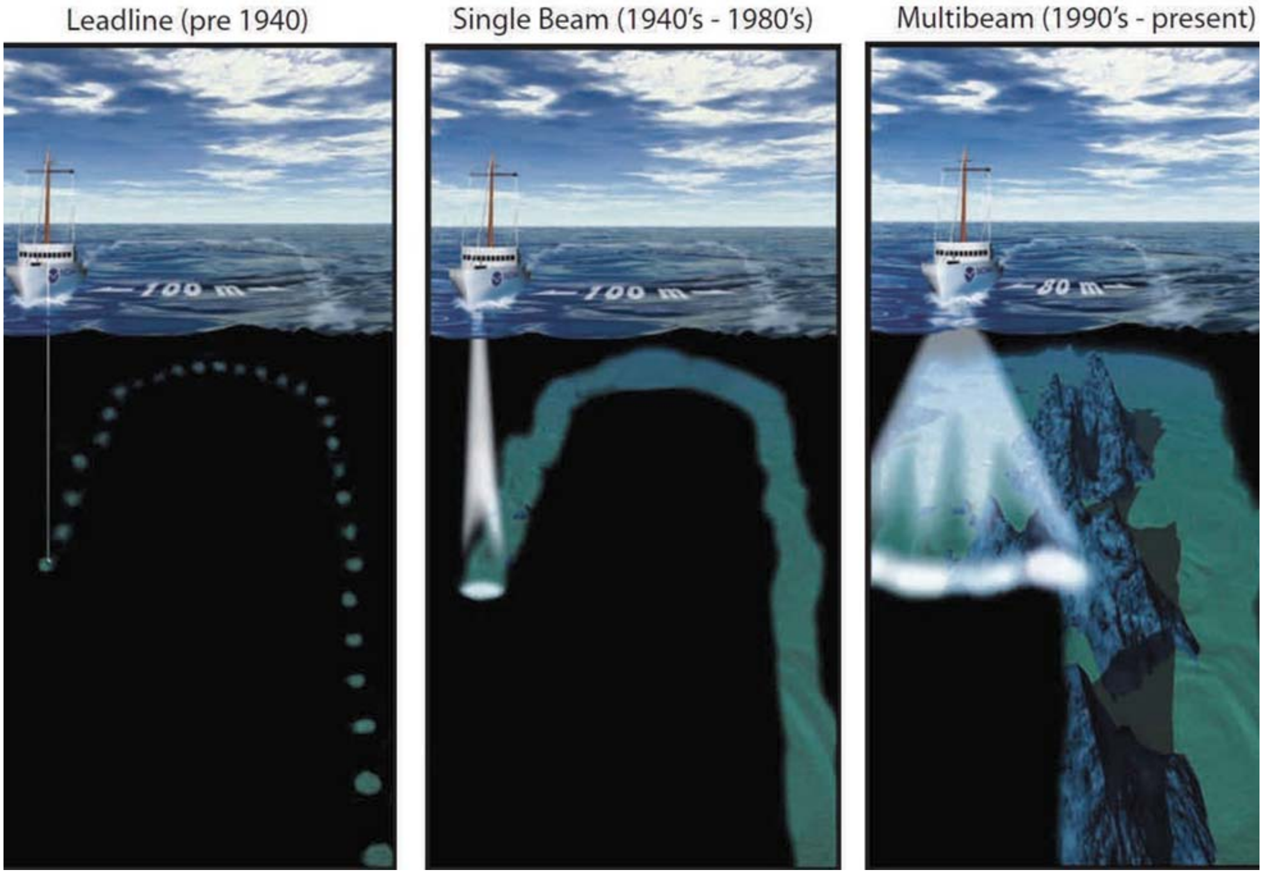


Figure 309. Differences in coverage between hydrographic techniques. Image courtesy of NOAA.

zones of confidence are discussed in greater detail in the next chapter (see Section 428).

OTHER SOURCES OF BATHYMETRIC DATA

311. 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.

312. 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 312). 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.

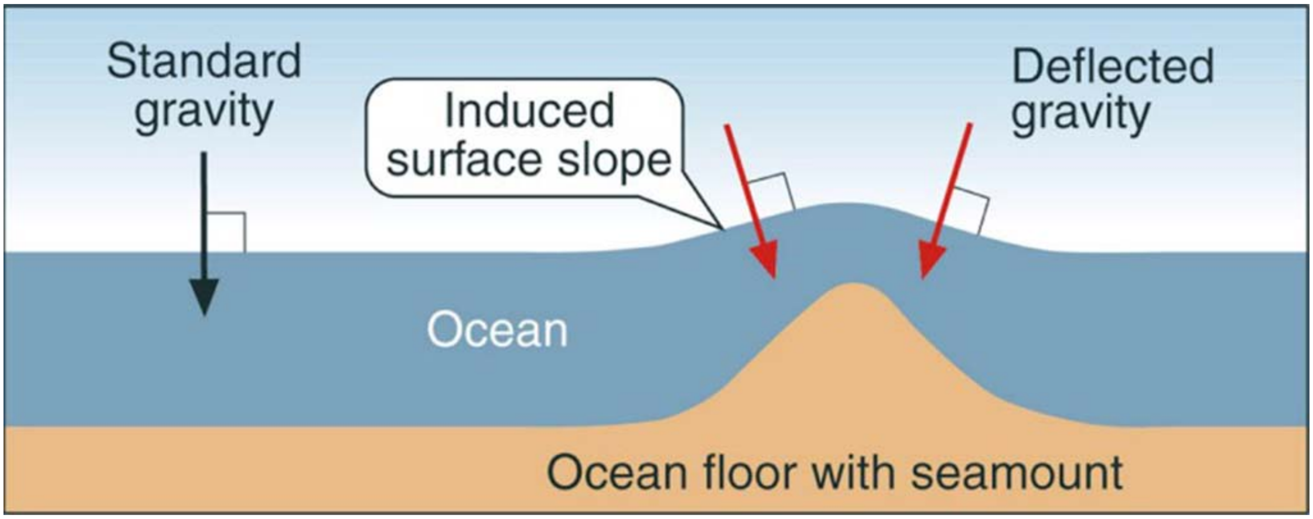


Figure 312. A rise in the ocean surface caused by a large seamount. Image courtesy of NOAA.

313. 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.

314. 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.

315. 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

316. 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.

CHAPTER 4

NAUTICAL CHARTS

CHART FUNDAMENTALS

400. Definitions

A **nautical chart** represents part of the spherical earth on a plane surface. It shows water depth, the shoreline of adjacent land, prominent topographic features, aids to navigation, and other navigational information. It is a work area on which the navigator plots courses, ascertains positions, and views the relationship of the ship to the surrounding area. It assists navigators in avoiding dangers and arriving safely at their destination.

Should a marine accident occur, the nautical chart in use at the time takes on legal significance. In cases of grounding, collision, and other accidents, charts become critical records for reconstructing the event and assigning liability. Charts used in reconstructing the incident can also have tremendous training value.

Originally hand-drawn on sheepskin, traditional nautical charts have for generations been printed on paper. **Electronic Charts** consisting of a digital data base and a display system are commonly in use today and are replacing paper charts aboard many vessels. An electronic chart is not simply a digital version of a paper chart; it introduces a new navigation methodology with capabilities and limitations very different from paper charts. The electronic chart is the legal equivalent of the paper chart if it meets certain International Maritime Organization specifications. See Chapter 5 - ECDIS for a detailed information regarding electronic charts.

401. Projections

Because a cartographer cannot transfer a sphere to a flat surface without distortion, he or she must project the surface of a sphere onto a **developable surface**. A developable surface is one that can be flattened to form a plane. This process is known as **chart projection**. If points on the surface of a sphere are projected from a single point, the projection is said to be **perspective** or **geometric**.

As the use of electronic charts becomes increasingly widespread, it is important to remember that the same cartographic principles that apply to paper charts apply to their depiction on video screens.

402. Selecting a Projection

Each projection has certain preferable features. However, as the area covered by the chart becomes smaller, the differences between various projections become less noticeable. On the largest scale chart, such as that of a harbor, projections are practically identical. Some desirable properties of a projection are:

1. True shape of physical features
2. Correct angular relationships
3. Equal area (Represents areas in proper proportions)
4. Constant scale values
5. Great circles represented as straight lines
6. Rhumb lines represented as straight lines

Some of these properties are mutually exclusive. For example, a single projection cannot be both conformal and equal area. Similarly, both great circles and rhumb lines cannot be represented on a single projection as straight lines.

403. Types of Projections

The type of developable surface to which the spherical surface is transferred determines the projection's classification. Further classification depends on whether the projection is centered on the equator (equatorial), a pole (polar), or some point or line between (oblique). The name of a projection indicates its type and its principal features.

The **Mercator projection** is classified as a **cylindrical projection** upon a plane, the cylinder tangent along the equator. Similarly, a projection based upon a cylinder tangent along a meridian is called **transverse** (or inverse) **Mercator** or **transverse** (or inverse) **orthomorphic**. The Mercator is the most common projection used in maritime navigation, primarily because rhumb lines plot as straight lines.

In a **simple conic projection**, points on the surface of the earth are transferred to a tangent cone. In the **Lambert conformal projection**, the cone intersects the earth (a secant cone) at two small circles. In a **polyconic projection**, a series of tangent cones is used.

In an **azimuthal** or **zenithal projection**, points on the earth are transferred directly to a plane. If the origin of the projecting rays is the center of the earth, a **gnomonic pro-**

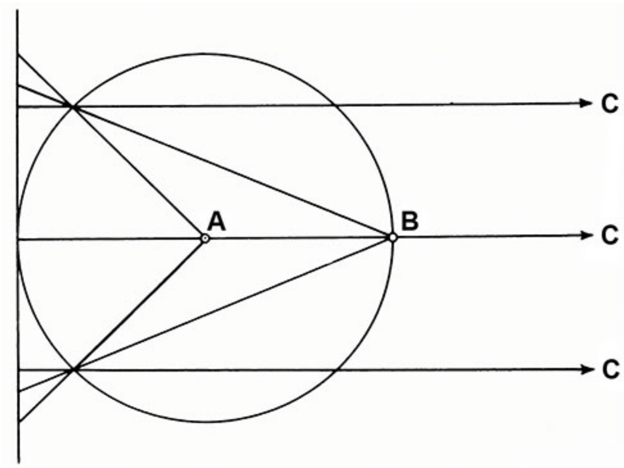


Figure 403. Azimuthal projections: A, gnomonic; B, stereographic; C, (at infinity) orthographic.

jection results; if it is the point opposite the plane's point of tangency, a **stereographic projection**; and if at infinity (the projecting lines being parallel to each other), an **orthographic projection**. The gnomonic, stereographic, and orthographic are **perspective projections**. In an **azimuthal equidistant projection**, which is not perspective, the scale of distances is constant along any radial line from the point of tangency. See Figure 403.

Cylindrical and **plane projections** are special conical projections, using heights infinity and zero, respectively.

A **graticule** is the network of latitude and longitude lines laid out in accordance with the principles of any projection.

404. Cylindrical Projections

If a cylinder is placed around the earth, tangent along the equator, and the planes of the meridians are extended, they intersect the cylinder in a number of vertical lines. See Figure 404. These parallel lines of projection are equidistant from each other, unlike the terrestrial meridians from which they are derived which converge as the latitude increases. On the earth, parallels of latitude are perpendicular to the meridians, forming circles of progressively smaller diameter as the latitude increases. On the cylinder they are shown perpendicular to the projected meridians, but because a cylinder is everywhere of the same diameter, the projected parallels are all the same size.

If the cylinder is cut along a vertical line (a meridian) and spread out flat, the meridians appear as equally spaced vertical lines; and the parallels appear as horizontal lines. The parallels' relative spacing differs in the various types of cylindrical projections.

If the cylinder is tangent along some great circle other than the equator, the projected pattern of latitude and longitude lines appears quite different from that described above, since the line of tangency and the equator no longer coincide. These projections are classified as **oblique** or **transverse projections**.

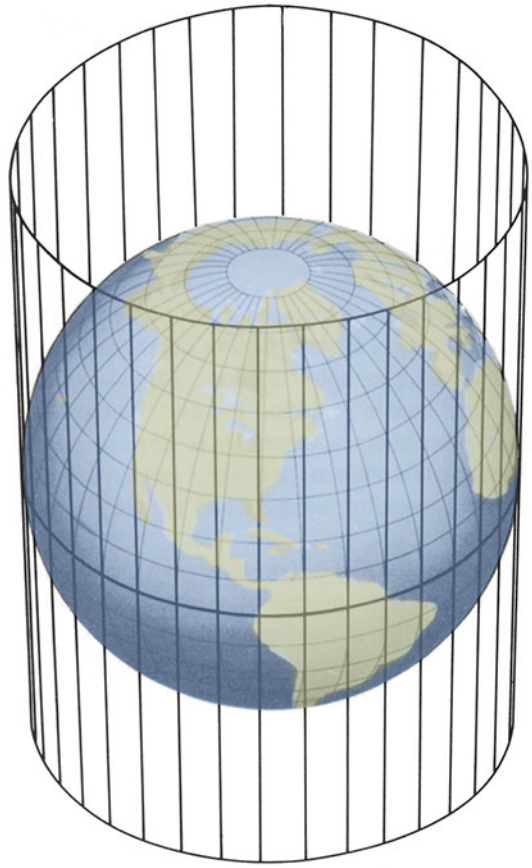


Figure 404. A cylindrical projection.

405. Mercator Projection

Navigators most often use the plane conformal projection known as the **Mercator projection**. The Mercator projection is not perspective, and its parallels can be derived mathematically as well as projected geometrically. Its distinguishing feature is that both the meridians and parallels are expanded at the same ratio with increased latitude. The expansion is equal to the secant of the latitude, with a small correction for the ellipticity of the Earth. Since the secant of 90° is infinity, the projection cannot include the poles. Since the projection is conformal, expansion is the same in all directions and angles are correctly shown. Rhumb lines appear as straight lines, the directions of which can be measured directly on the chart. Distances can also be measured directly if the spread of latitude is small. Great circles, except meridians and the equator, appear as curved lines concave to the equator. Small areas appear in their correct shape but of increased size unless they are near the equator.

406. Meridional Parts

At the equator a degree of longitude is approximately

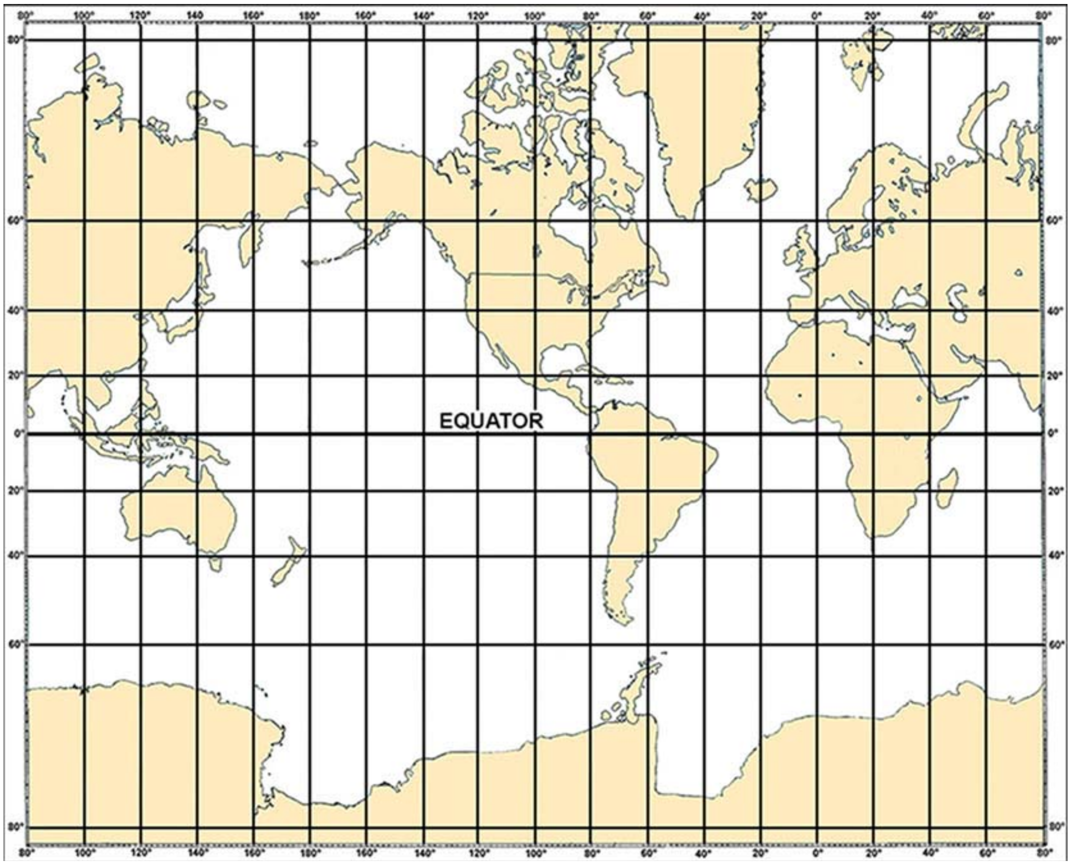


Figure 405. A Mercator map of the world.

equal in length to a degree of latitude. As the distance from the equator increases, degrees of latitude remain approximately the same, while degrees of longitude become progressively shorter. Since degrees of longitude appear everywhere the same length in the Mercator projection, it is necessary to increase the length of the meridians if the expansion is to be equal in all directions. Thus, to maintain the correct proportions between degrees of latitude and degrees of longitude, the degrees of latitude must be progressively longer as the distance from the equator increases. This is illustrated in Figure 405.

The length of a meridian, increased between the equator and any given latitude, expressed in minutes of arc at the equator as a unit, constitutes the number of meridional parts (M) corresponding to that latitude. Meridional parts, given in Table 6 for every minute of latitude from the equator to the pole, make it possible to construct a Mercator chart and to solve problems in Mercator sailing. These values are for the World Geodetic System (WGS) ellipsoid of 1984.

407. Transverse Mercator Projections

Constructing a chart using Mercator principles, but with the cylinder tangent along a meridian, results in a **transverse Mercator** or **transverse orthomorphic projection**. The word "inverse" is used interchangeably with "transverse." These projections use a fictitious graticule similar to, but offset from, the familiar network of meridians and parallels. The tangent great circle is the fictitious equator. Ninety degrees from it are two fictitious poles. A group of great circles through these poles and perpendicular to the tangent great circle are the fictitious meridians, while a series of circles parallel to the plane of the tangent great circle form the fictitious parallels. The actual meridians and parallels appear as curved lines.

A straight line on the transverse or oblique Mercator projection makes the same angle with all fictitious meridians, but not with the terrestrial meridians. It is therefore a fictitious rhumb line. Near the tangent great circle, a straight line closely approximates a great circle. The projection is most useful in this area. Since the area of minimum distortion is near a meridian, this projection is useful for charts covering a large band of latitude and extending a relatively short distance on each side of the tangent meridian. It is sometimes used for star charts showing the evening sky at various seasons of the year. See Figure 407.

408. Universal Transverse Mercator (UTM) Grid

The **Universal Transverse Mercator (UTM)** grid is a military grid superimposed upon a transverse Mercator grati-

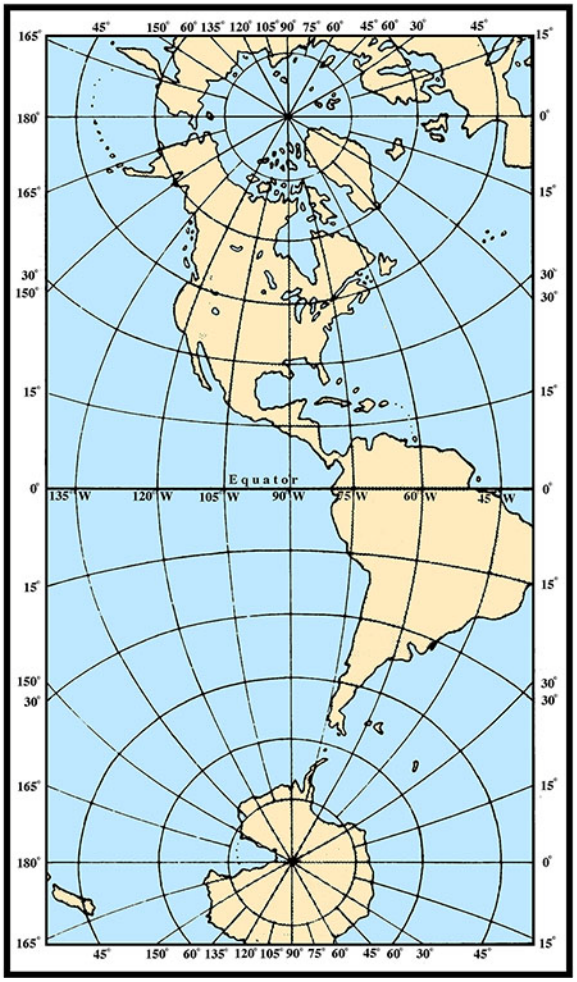


Figure 407. A transverse Mercator map of the Western Hemisphere.

cule, or the representation of these grid lines upon any graticule. This grid system and these projections are often used for large-scale (harbor) nautical charts and military charts.

409. Oblique Mercator Projections

A Mercator projection in which the cylinder is tangent along a great circle other than the equator or a meridian is called an **oblique Mercator** or **oblique orthomorphic projection**. See Figure 409a and Figure 409b. This projection is used principally to depict an area in the near vicinity of an oblique great circle. Figure 410, for example, shows the great circle joining Washington and Moscow. Figure 409c shows an oblique Mercator map with the great circle between these two centers as the tangent great circle or fictitious equator. The limits of the chart of Figure 410 are indicated in Figure 409c. Note the large variation in scale as the latitude changes.

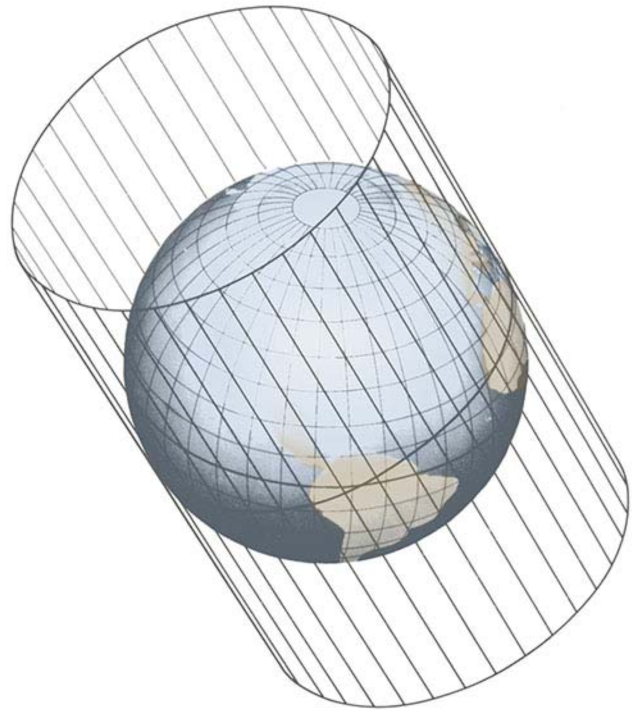


Figure 409a. An oblique Mercator projection.

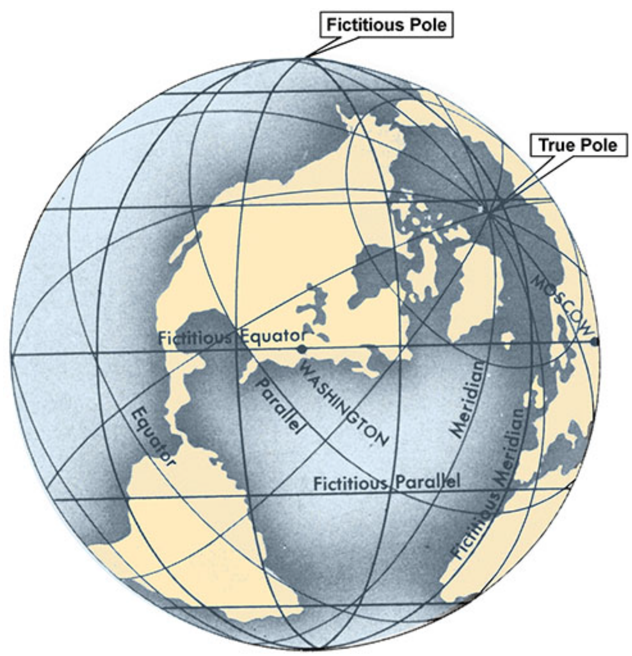


Figure 409b. An oblique Orthomorphic projection.

410. Rectangular Projection

A cylindrical projection similar to the Mercator, but with uniform spacing of the parallels, is called a **rectangular projection**. It is convenient for graphically depicting information where distortion is not important. The principal

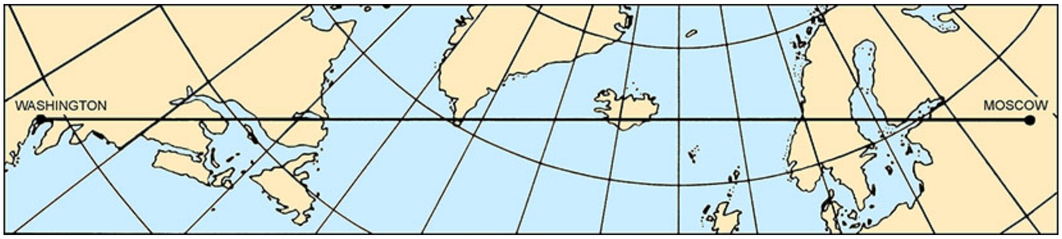


Figure 409c. An oblique Mercator map based upon a cylinder tangent along the great circle through Washington and Moscow. The map includes an area 500 miles on each side of the great circle. The limits of this map are indicated on the Mercator map of Figure 410.

navigational use of this projection is for the star chart of the Air Almanac, where positions of stars are plotted by rectangular coordinates representing declination (ordinate) and sidereal hour angle (abscissa). Since the meridians are parallel, the parallels of latitude (including the equator and the poles) are all represented by lines of equal length.

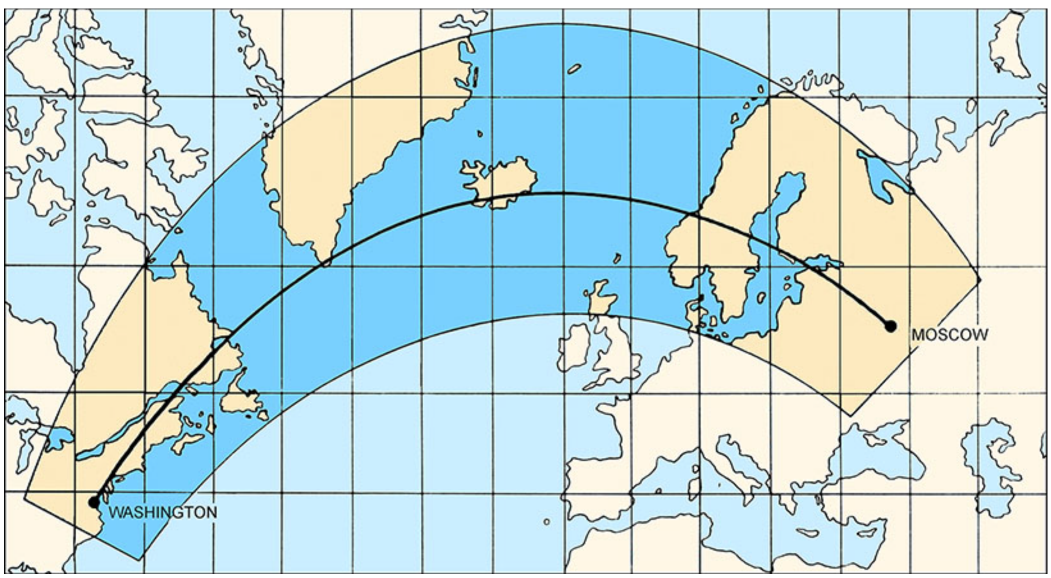


Figure 410. The great circle between Washington and Moscow as it appears on a Mercator map.

411. Conic Projections

A **conic projection** is produced by transferring points from the surface of the earth to a cone or series of cones. This cone is then cut along an element and spread out flat to form the chart. When the axis of the cone coincides with the axis of the earth, then the parallels appear as arcs of circles, and the meridians appear as either straight or curved lines converging toward the nearer pole. Limiting the area covered to that part of the cone near the surface of the earth limits distortion. A parallel along which there is no distortion is called a **standard parallel**. Neither the transverse conic projection, in which the axis of the cone is in the equatorial plane, nor the oblique conic projection, in which the axis of the cone is oblique to the plane of the equator, is ordinarily used for navigation. They are typically used for illustrative maps.

Using cones tangent at various parallels, a secant (intersecting) cone, or a series of cones varies the appearance and features of a conic projection.

412. Simple Conic Projection

A conic projection using a single tangent cone is a **simple conic projection** (Figure 412a). The height of the cone increases as the latitude of the tangent parallel decreases. At the equator, the height reaches infinity and the cone becomes a cylinder. At the pole, its height is zero, and the cone becomes a plane. Similar to the Mercator projection, the simple conic projection is not perspective since only the meridians are projected geometrically, each becoming an element of the cone. When this projection is spread out flat

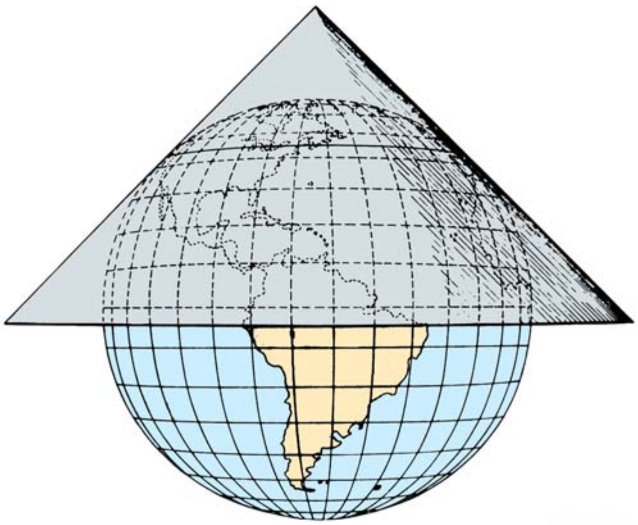


Figure 412a. A simple conic projection.

to form a map, the meridians appear as straight lines converging at the apex of the cone. The standard parallel, where the cone is tangent to the earth, appears as the arc of a circle with its center at the apex of the cone. The other parallels are concentric circles. The distance along any meridian between consecutive parallels is in correct relation to the distance on the earth, and, therefore, can be derived mathematically. The pole is represented by a circle (Figure 412b). The scale is correct along any meridian and along the standard parallel. All other parallels are too great in length, with the error increasing with increased distance from the standard parallel. Since the scale is not the same in all directions about every point, the projection is neither a conformal nor equal-area projection. Its non-conformal nature is its principal disadvantage for navigation.

Since the scale is correct along the standard parallel and varies uniformly on each side, with comparatively little distortion near the standard parallel, this projection is useful for mapping an area covering a large spread of longitude and a comparatively narrow band of latitude. It was developed by Claudius Ptolemy in the second century AD to map just such an area: the Mediterranean Sea.

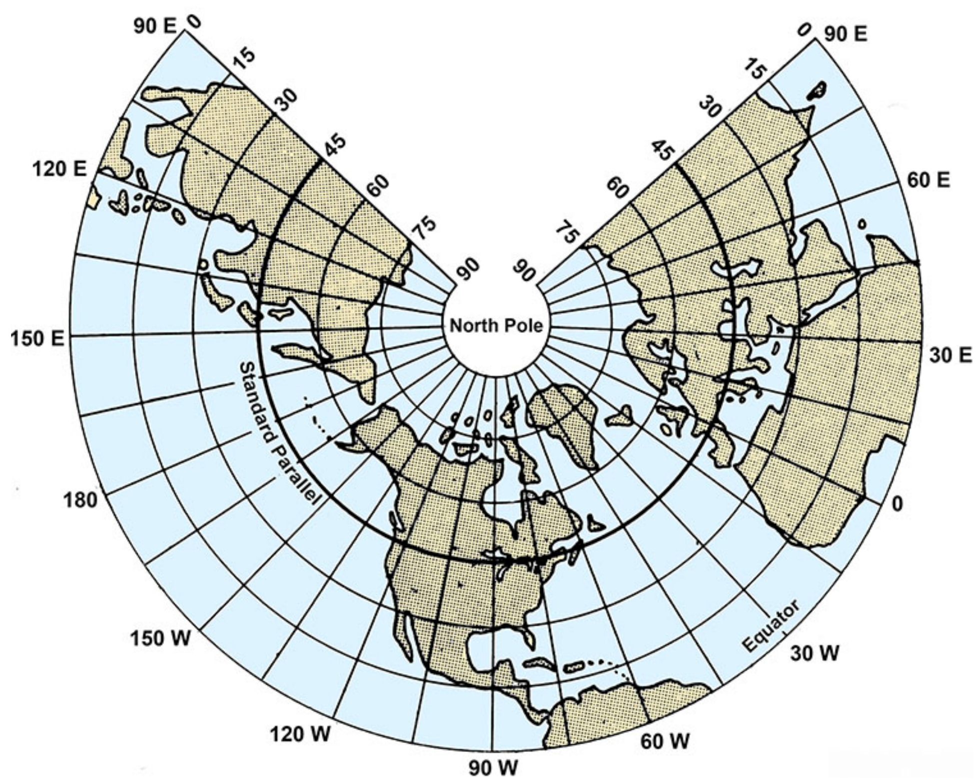


Figure 412b. A simple conic map of the Northern Hemisphere.

413. Lambert Conformal Projection

The useful latitude range of the simple conic projection can be increased by using a secant cone intersecting the earth at two standard parallels (see Figure 413). The area between the two standard parallels is compressed, and that beyond is expanded. Such a projection is called either a **secant conic** or **conic projection with two standard parallels**.

If in such a projection the spacing of the parallels is altered, such that the distortion is the same along them as along the meridians, the projection becomes conformal. This modification produces the **Lambert conformal pro-**

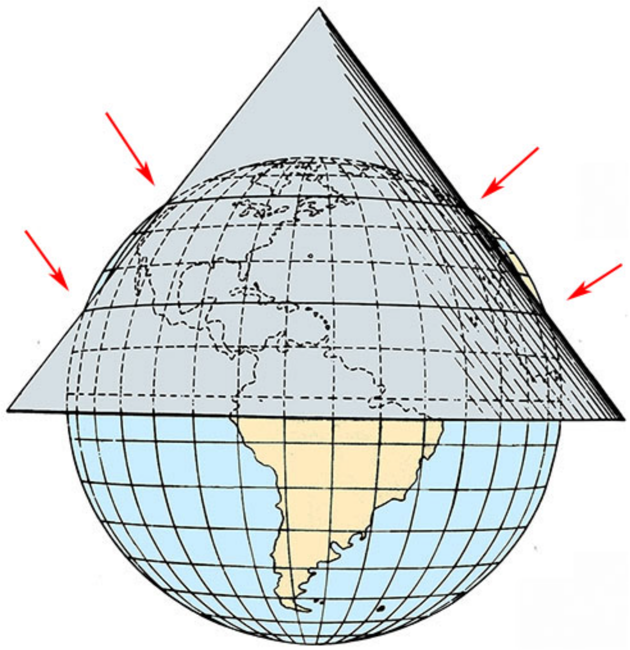


Figure 413. A secant cone for a conic projection with two standard parallels.

jection. If the chart is not carried far beyond the standard parallels, and if these are not a great distance apart, the distortion over the entire chart is small.

A straight line on this projection so nearly approximates a great circle that the two are nearly identical. Radio beacon signals travel great circles; thus, they can be plotted on this projection without correction. This feature, gained without sacrificing conformality, has made this projection popular for aeronautical charts because aircraft make wide use of radio aids to navigation. Except in high latitudes, where a slightly modified form of this projection has been used for polar charts, it has not replaced the Mercator projection for marine navigation.

414. Polyconic Projection

The latitude limitations of the secant conic projection can be minimized by using a series of cones. This results in a **polyconic projection**. In this projection, each parallel is the base of a tangent cone. At the edges of the chart, the area between parallels is expanded to eliminate gaps. The scale is correct along any parallel and along the central meridian of the projection. Along other meridians the scale increases with increased difference of longitude from the central meridian. Parallels appear as nonconcentric circles, meridians appear as curved lines converging toward the pole and concave to the central meridian.

The polyconic projection is widely used in atlases, particularly for areas of large range in latitude and reasonably large range in longitude, such as continents. However, since it is not conformal, this projection is not traditionally used in navigation.

415. Azimuthal Projections

If points on the earth are projected directly to a plane surface, a map is formed at once, without cutting and flattening, or "developing." This can be considered a special case of a conic projection in which the cone has zero height.

The simplest case of the **azimuthal projection** is one in which the plane is tangent at one of the poles. The meridians are straight lines intersecting at the pole, and the parallels are concentric circles with their common center at the pole. Their spacing depends upon the method used to transfer points from the earth to the plane.

If the plane is tangent at some point other than a pole, straight lines through the point of tangency are great circles, and concentric circles with their common center at the point of tangency connect points of equal distance from that point. Distortion, which is zero at the point of tangency, increases along any great circle through this point. Along any circle whose center is the point of tangency, the distortion is constant. The bearing of any point from the point of tangency is correctly represented. It is for this reason that these projections are called **azimuthal**. They are also called **zenithal**. Several of the common azimuthal projections are perspective.

416. Gnomonic Projection

If a plane is tangent to the earth, and points are projected geometrically from the center of the earth, the result is a **gnomonic projection** (see Figure 416a). Since the projection is perspective, it can be demonstrated by placing a light at the center of a transparent terrestrial globe and holding a flat surface tangent to the sphere.

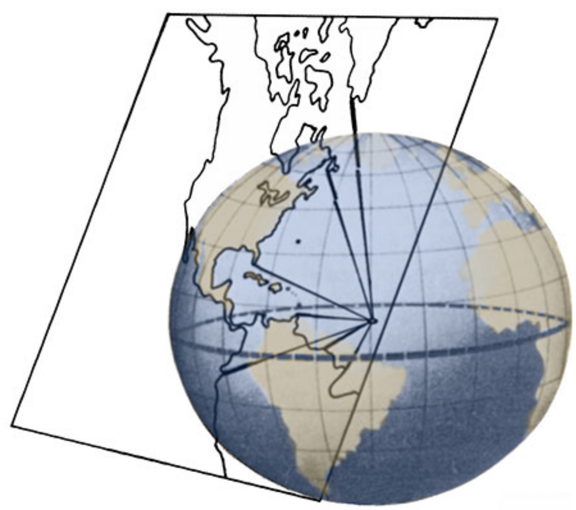


Figure 416a. An oblique gnomonic projection.

In an **oblique gnomonic projection** the meridians appear as straight lines converging toward the nearer pole. The parallels, except the equator, appear as curves (Figure 416b).

As in all azimuthal projections, bearings from the point of tangency are correctly represented. The distance scale, however, changes rapidly. The projection is neither conformal nor equal area. Distortion is so great that shapes, as well as distances and areas, are very poorly represented, except near the point of tangency.

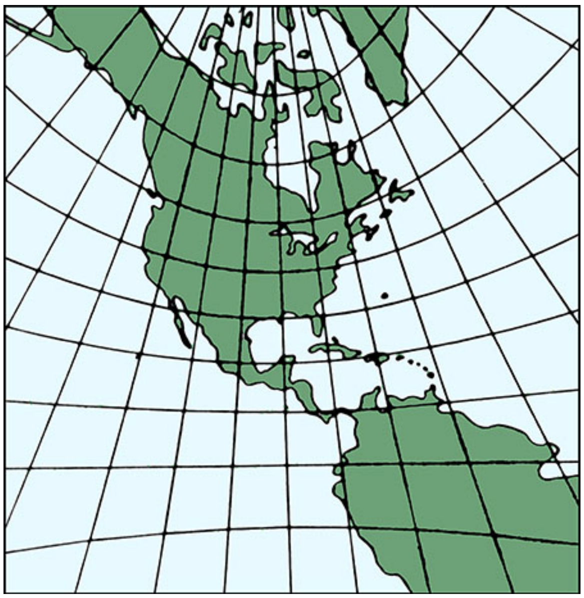


Figure 416b. An oblique gnomonic map with point of tangency at latitude 30°N, longitude 90°W.

The usefulness of this projection rests upon the fact that any great circle appears on the map as a straight line, giving charts made on this projection the common name **great-circle charts**.

Gnomonic charts are most often used for planning the great-circle track between points. Points along the determined track are then transferred to a Mercator projection. The great circle is then tracked by following the rhumb lines from one point to the next. Computer programs which automatically calculate great circle routes between points and provide latitude and longitude of corresponding rhumb line endpoints are quickly making this use of the gnomonic chart obsolete.

417. Stereographic Projection

A **stereographic projection** results from projecting points on the surface of the earth onto a tangent plane, from a point on the surface of the earth opposite the point of tangency (see Figure 417a). This projection is also called an **azimuthal orthomorphic projection**.

The scale of the stereographic projection increases with distance from the point of tangency, but it increases more slowly than in the gnomonic projection. The stereographic projection can show an entire hemisphere without excessive distortion (see Figure 417b). As in other azimuthal projections, great circles through the point of tangency appear as straight lines. Other circles such as meridians and parallels appear as either circles or arcs of circles.

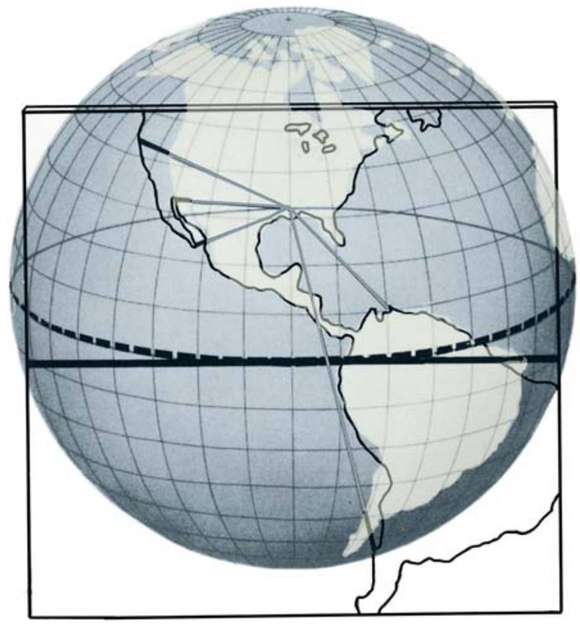


Figure 417a. An equatorial stereographic projection.

The principal navigational use of the stereographic projection is for charts of the polar regions and devices for mechanical or graphical solution of the navigational triangle. A **Universal Polar Stereographic (UPS)** grid, mathematically adjusted to the graticule, is used as a reference system.

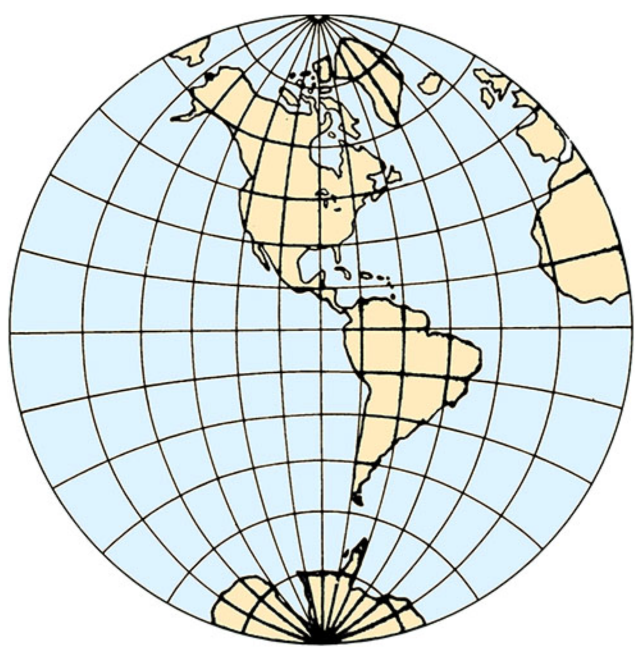


Figure 417b. A stereographic map of the Western Hemisphere.

418. Orthographic Projection

An **orthographic projection** is created by projecting

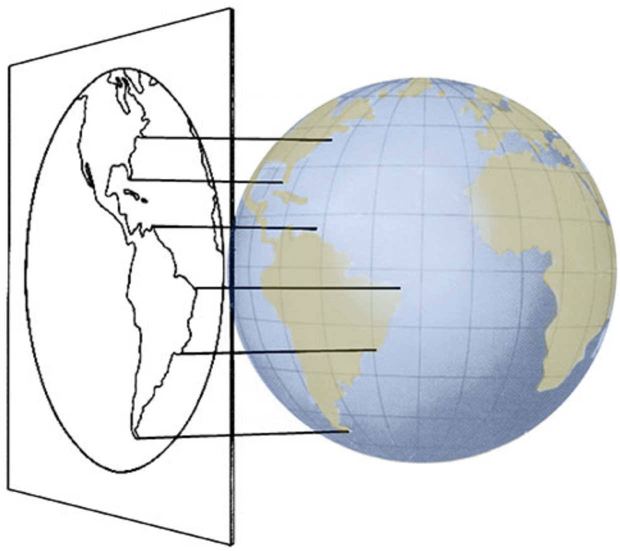


Figure 418a. An equatorial orthographic projection.

Figure 418b. An orthographic map of the Western Hemisphere.

terrestrial points from infinity to a tangent plane (see Figure 418a). This projection is not conformal, nor does it result in an equal area representation. Its principal use is in navigational astronomy because it is useful for illustrating and solving the navigational triangle. It is also useful for illustrating celestial coordinates. If the plane is tangent at a point on the equator, the parallels (including the equator) appear as straight lines. The meridians would appear as ellipses, except that the meridian through the point of tangency would appear as a straight line and the one 90° away would appear as a circle (see Figure 418b).

419. Azimuthal Equidistant Projection

An **azimuthal equidistant projection** is an azimuthal projection in which the distance scale along any great circle through the point of tangency is constant. If a pole is the point of tangency, the meridians appear as straight radial lines and the parallels as equally spaced concentric circles. If the plane is tangent at some point other than a pole, the concentric circles represent distances from the point of tangency. In this case, meridians and parallels appear as curves.

The projection can be used to portray the entire earth, the point 180° from the point of tangency appearing as the largest of the concentric circles. The projection is not conformal, equal area, or perspective. Near the point of tangency distortion is small, increasing with distance until shapes near the opposite side of the earth are unrecognizable (Figure 419). The projection is useful because it combines the three

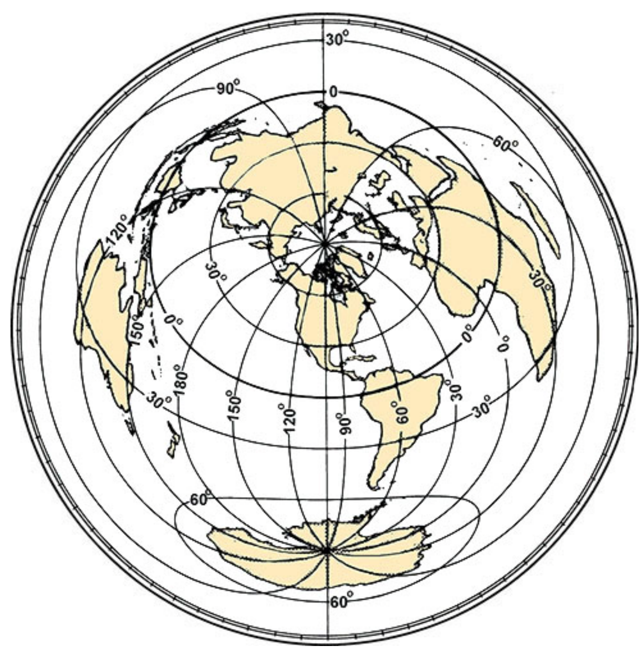


Figure 419. An azimuthal equidistant map of the world with the point of tangency latitude 40°N, longitude 100°W.

features of being azimuthal, having a constant distance scale from the point of tangency, and permitting the entire earth to be shown on one map. Thus, if an important harbor or airport is selected as the point of tangency, the great-circle course, distance, and track from that point to any other point on the earth are quickly and accurately determined. For communication work with the station at the point of tangency, the path of an incoming signal is at once apparent if the direction of arrival has been determined and the direction to train a directional antenna can be determined easily. The projection is also used for polar charts and for the star finder, No. 2102D.

POLAR CHARTS

420. Polar Projections

Special consideration is given to the selection of projections for polar charts because the familiar projections become special cases with unique features.

In the case of cylindrical projections in which the axis of the cylinder is parallel to the polar axis of the earth, distortion becomes excessive and the scale changes rapidly. Such projections cannot be carried to the poles. However, both the transverse and oblique Mercator projections are used.

Conic projections with their axes parallel to the earth's polar axis are limited in their usefulness for polar charts because parallels of latitude extending through a full 360° of longitude appear as arcs of circles rather than full circles. This is because a cone, when cut along an element and flattened, does not extend through a full 360° without stretching or resuming its former conical shape. The usefulness of such projections is also limited by the fact that the pole appears as an arc of a circle instead of a point. However, by using a parallel very near the pole as the higher standard parallel, a conic projection with two standard parallels can be made. This requires little stretching to complete the circles of the parallels and eliminate that of the pole. Such a projection, called a **modified Lambert conformal** or **Ney's projection**, is useful for polar charts. It is particularly familiar to those accustomed to using the ordinary Lambert conformal charts in lower latitudes.

Azimuthal projections are in their simplest form when tangent at a pole. This is because the meridians are straight lines intersecting at the pole, and parallels are concentric circles with their common center at the pole. Within a few degrees of latitude of the pole they all look similar; however, as the distance becomes greater, the spacing of the parallels becomes distinctive in each projection. In the polar azimuthal equidistant it is uniform; in the polar stereographic it increases with distance from the pole until the equator is shown at a distance from the pole equal to twice the length of the radius of the earth; in the polar gnomonic the increase is considerably greater, becoming infinity at the equator; in the polar orthographic it decreases with distance from the pole (Figure 420). All of these but the last are used for polar charts.

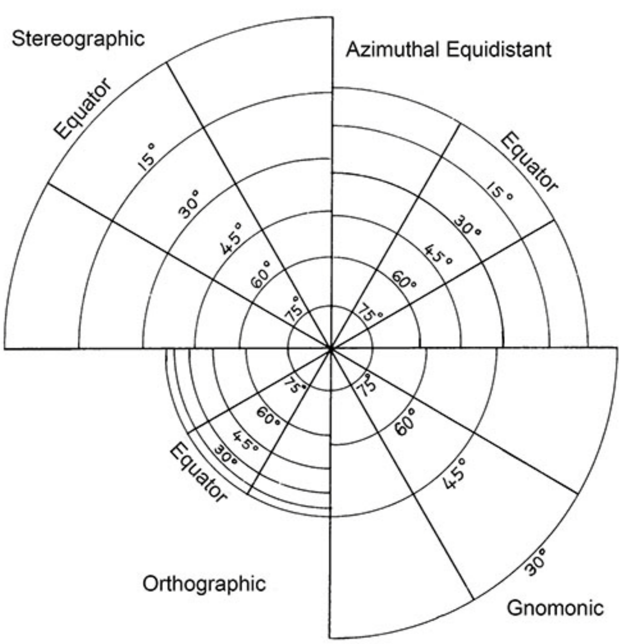


Figure 420. Expansion of polar azimuthal projections.

421. Selection of a Polar Projection

The principal considerations in the choice of a suitable projection for polar navigation are:

1. Conformality: When the projection represents angles correctly, the navigator can plot directly on the chart.
2. Great circle representation: Because great circles are more useful than rhumb lines at high altitudes, the projection should represent great circles as straight lines.
3. Scale variation: The projection should have a constant scale over the entire chart.
4. Meridian representation: The projection should show straight meridians to facilitate plotting and grid navigation
5. Limits: Wide limits reduce the number of projections needed to a minimum.

The projections commonly used for polar charts are the modified Lambert conformal, gnomonic, stereographic, and azimuthal equidistant. All of these projections are similar near the pole. All are essentially conformal, and a great circle on each is nearly a straight line.

As the distance from the pole increases, however, the distinctive features of each projection become important. The modified Lambert conformal projection is virtually conformal over its entire extent. The amount of its scale distortion is comparatively little if it is carried only to about 25° or 30° from the pole. Beyond this, the distortion increases rapidly. A great circle is very nearly a straight line anywhere on the chart. Distances and directions can be measured directly on the chart in the same manner as on a Lambert conformal chart. However, because this projection is not strictly conformal, and on it great circles are not exactly represented by straight lines, it is not suited for highly accurate work.

The polar gnomonic projection is the one polar projection on which great circles are exactly straight lines. However, a complete hemisphere cannot be represented upon a plane because the radius of 90° from the center would become infinity.

The polar stereographic projection is conformal over its entire extent, and a straight line closely approximates a great circle (see Figure 421). The scale distortion is not excessive for a considerable distance from the pole, but it is greater than that of the modified Lambert conformal projection.

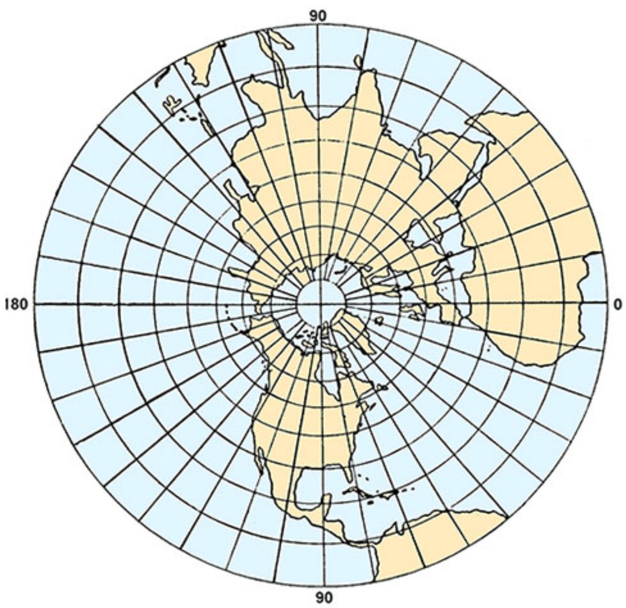


Figure 421. Polar stereographic projection.

The polar azimuthal equidistant projection is useful for showing a large area such as a hemisphere because there is no expansion along the meridians. However, the projection is not conformal and distances cannot be measured accurately in any but a north-south direction. Great circles other than the meridians differ somewhat from straight lines. The equator is a circle centered at the pole.

The two projections most commonly used for polar charts are the modified Lambert conformal and the polar stereographic. When a directional gyro is used as a directional reference, the track of the craft is approximately a great circle. A desirable chart is one on which a great circle is represented as a straight line with a constant scale and with angles correctly represented. These requirements are not met entirely by any single projection, but they are approximated by both the modified Lambert conformal and the polar stereographic. The scale is more nearly constant on the former, but the projection is not strictly conformal. The polar stereographic is conformal, and its maximum scale variation can be reduced by using a plane which intersects the earth at some parallel intermediate between the pole and the lowest parallel. The portion within this standard parallel is compressed, and that portion outside is expanded.

The selection of a suitable projection for use in polar regions depends upon mission requirements. These requirements establish the relative importance of various features. For a relatively small area, any of several projections is suitable. For a large area, however, the choice is more difficult. If grid directions are to be used, it is important that all units in related operations use charts on the same projection, with the same standard parallels, so that a single grid direction exists between any two points.

SPECIAL CHARTS

422. Plotting Sheets

Position plotting sheets are "charts" designed primarily for open ocean navigation, where land, visual aids to navigation, and depth of water are not factors in navigation. They have a latitude and longitude graticule, and they may have one or more compass roses. The meridians are usually unlabeled, so a plotting sheet can be used for any longitude. Plotting sheets on Mercator projection are specific to latitude, and the navigator should have enough aboard for all latitudes for their voyage. Plotting sheets are less expensive than charts.

A plotting sheet may be used in an emergency when charts have been lost or destroyed. Directions on how to construct plotting sheets suitable for emergency purposes are given in Chapter 28 - Emergency Navigation.

423. Grids

No system exists for showing the surface of the earth on a plane without distortion. Moreover, the appearance of the surface varies with the projection and with the relation of that surface area to the point of tangency. One may want to identify a location or area simply by alpha-numeric rectangular coordinates. This is accomplished with a **grid**. In its usual form this consists of two series of lines drawn perpendicularly on the chart, marked by suitable alpha-numeric designations.

A grid may use the rectangular graticule of the Mercator projection or a set of arbitrary lines on a particular projection. **The World Geodetic Reference System (GEOREF)** is a method of designating latitude and longitude by a system of letters and numbers instead of by angular measure. It is not, therefore, strictly a grid. It is useful for operations extending over a wide area. Examples of the second type of grid are the **Universal Transverse Mercator (UTM)** grid, the **Universal Polar Stereographic (UPS)** grid, and the **Temporary Geographic Grid (TGG)**. Since these systems are used primarily by military forces, they are sometimes called military grids.

For more information on chart projections see The Map Projections Catalog. The catalog offers examples of a broad range of publicly available projection types.

Figure 423. Map Projections Catalog.
http://www.csiss.org/map-projections

CHART SCALES

424. Types Of Scales

The **scale** of a chart is the ratio of a given distance on the chart to the actual distance which it represents on the earth. It may be expressed in various ways. The most common are:

1. A simple ratio or fraction, known as the **representative fraction**. For example, 1:80,000 or 1/80,000 means that one unit (such as a meter) on the chart represents 80,000 of the same unit on the surface of the earth. This scale is sometimes called the **natural** or **fractional** scale.
2. A **statement** that a given distance on the earth equals a given measure on the chart, or vice versa. For example, “30 miles to the inch” means that 1 inch on the chart represents 30 miles of the earth’s surface. Similarly, “2 inches to a mile” indicates that 2 inches on the chart represent 1 mile on the earth. This is sometimes called the **numerical scale**.
3. A line or bar called a **graphic scale** may be drawn at a convenient place on the chart and subdivided into nautical miles, meters, etc. All charts vary somewhat in scale from point to point, and in some projections the scale is not the same in all directions about a single point. A single subdivided line or bar for use over an entire chart is shown only when the chart is of such scale and projection that the scale varies a negligible amount over the chart, usually one of about 1:75,000 or larger. Since 1 minute of latitude is very nearly equal to 1 nautical mile, the latitude scale serves as an approximate graphic scale. On most nautical charts the east and west borders are subdivided to facilitate distance measurements.

On a Mercator chart the scale varies with the latitude. This is noticeable on a chart covering a relatively large distance in a north-south direction. On such a chart the border scale nearest the latitude in question should be used for measuring distances.

Of the various methods of indicating scale, the graphical method is normally available in some form on the chart. In addition, the scale is customarily stated on charts on which the scale does not change appreciably over the chart.

The ways of expressing the scale of a chart are readily interchangeable. For instance, in a nautical mile there are about 72,913.39 inches. If the natural scale of a chart is 1:80,000, one inch of the chart represents 80,000 inches of the earth, or a little more than a mile. To find the exact amount, divide the scale by the number of inches in a mile, or 80,000/72,913.39 = 1.097. Thus, a scale of 1:80,000 is the same as a scale of 1.097 (or approximately 1.1) miles to an inch. Stated another way, there are: 72,913.39/80,000 = 0.911 (approximately 0.9) inch to a mile. Similarly, if the scale is 60 nautical miles to an inch, the representative fraction is 1:(60 x 72,913.39) = 1:4,374,803.

A chart covering a relatively large area is called a **small-scale chart** and one covering a relatively small area is called a **large-scale chart**. Since the terms are relative, there is no sharp division between the two. Thus, a chart of scale 1:100,000 is large scale when compared with a chart of 1:1,000,000 but small scale when compared with one of 1:25,000.

As scale decreases, the amount of detail which can be shown decreases also. Cartographers selectively decrease the detail in a process called **generalization** when producing small scale charts using large scale charts as sources. The amount of detail shown depends on several factors, among them the coverage of the area at larger scales and the intended use of the chart.

425. Chart Classification by Scale

Charts are constructed on many different scales, ranging from about 1:2,500 to 1:14,000,000. Small-scale charts covering large areas are used for route planning and for offshore navigation. Charts of larger scale, covering smaller areas, are used as the vessel approaches land. Several methods of classifying charts according to scale are used in various nations. The following classifications of nautical charts are used by the National Ocean Service (NOS).

Sailing charts are the smallest scale charts used for planning, fixing position at sea, and for plotting the dead reckoning while proceeding on a long voyage. The scale is generally smaller than 1:600,000. The shoreline and topography are generalized and only offshore soundings, principal navigational lights, outer buoys, and landmarks visible at considerable distances are shown.

General charts are intended for coastwise navigation outside of outlying reefs and shoals. The scales range from about 1:150,000 to 1:600,000.

Coastal charts are intended for inshore coastwise navigation, for entering or leaving bays and harbors of considerable width, and for navigating large inland waterways. The scales range from about 1:50,000 to 1:150,000.

Harbor charts are intended for navigation and anchorage in harbors and small waterways. The scale is generally larger than 1:50,000.

In the classification system used by the National Geospatial-Intelligence Agency (NGA), the sailing charts are incorporated in the general charts classification (smaller than about 1:150,000); those coastal charts especially useful for approaching more confined waters (bays, harbors) are classified as approach charts. There is considerable overlap in these designations, and the classification of a chart is best determined by its purpose and its relationship to other charts of the area. The use of insets complicates the placement of charts into rigid classifications.

426. Small-Craft Charts

NOS publishes a series of small craft charts sometimes called "strip charts." These charts depict segments of the Atlantic Intracoastal Waterway, the Gulf Intracoastal Waterway and other inland routes used by yachtsmen, fishermen, and small commercial vessels for coastal travel. They are not "north-up" in presentation, but are aligned with the waterway they depict, whatever its orientation is. Most often they are used as a piloting aid for "eyeball" navigation and placed "course-up" in front of the helmsman, because the routes they show are too confined for taking and plotting fixes.

Although NOS small-craft charts are designed primarily for use aboard yachts, fishing vessels and other small craft, these charts, at scales of 1:80,000 and larger, are in some cases the only charts available depicting inland waters transited by large vessels. In other cases the small-craft charts may provide a better presentation of navigational hazards than the standard nautical chart because of better scale and more detail. Therefore, navigators should use these charts in areas where they provide the best coverage.

CHART ACCURACY

427. Factors Relating to Accuracy

The accuracy of a chart depends upon the accuracy of the hydrographic surveys and other data sources used to compile it and the suitability of its scale for its intended use.

One can sometimes estimate the accuracy of a chart's surveys from the source notes given in the title of the chart. If the chart is based upon very old surveys, use it with caution. Many early surveys were inaccurate because of the technological limitations of the surveyor.

The number of soundings and their spacing indicates the completeness of the survey. Only a small fraction of the soundings taken in a thorough survey are shown on the chart, but sparse or unevenly distributed soundings indicate that the survey was probably not made in detail. See Figure 427a and Figure 427b. Large blank areas or absence of depth contours generally indicate lack of soundings in the area. Operate in an area with sparse sounding data only if required and then only with extreme caution. Run the echo sounder continuously and operate at a reduced speed. Sparse sounding information does not necessarily indicate an incomplete survey. Relatively few soundings are shown when there is a large number of depth contours, or where the bottom is flat, or gently and evenly sloping. Additional soundings are shown when they are helpful in indicating the uneven character of a rough bottom.

Even a detailed survey may fail to locate every rock or pinnacle. In waters where they might be located, the best method for finding them is a wire drag survey. Areas that have been dragged may be indicated on the chart by limiting lines and green or purple tint and a note added to show the effective depth at which the drag was operated.

Changes in bottom contours are relatively rapid in areas such as entrances to harbors where there are strong currents or heavy surf. Similarly, there is sometimes a tendency for dredged channels to shoal, especially if they are surrounded by sand or mud, and cross currents exist. Charts often contain notes indicating the bottom contours are known to change rapidly.

The same detail cannot be shown on a small-scale chart as on a large scale chart. On small-scale charts, detailed information is omitted or "generalized" in the areas covered by larger scale charts. The navigator should use the largest scale chart available for the area in which he or she is operating, especially when operating in the vicinity of hazards.

Charting agencies continually evaluate both the detail and the presentation of data appearing on a chart. Development of a new navigational aid may render previous charts inadequate. The development of radar, for example, required upgrading charts which lacked the detail required for reliable identification of radar targets.

After receiving a chart, the user is responsible for keeping it updated. Mariner's reports of errors, changes, and suggestions are useful to charting agencies. Even with modern automated data collection techniques, there is no substitute for on-sight observation of hydrographic conditions by experienced mariners. This holds true especially in

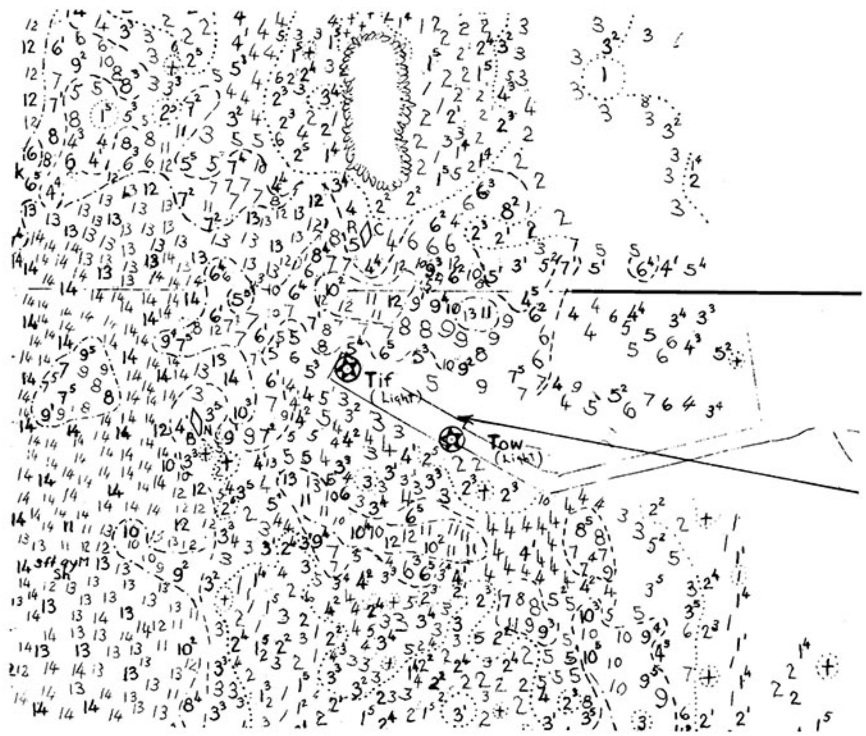


Figure 427a. Part of a "boat sheet," showing the soundings obtained in a survey.

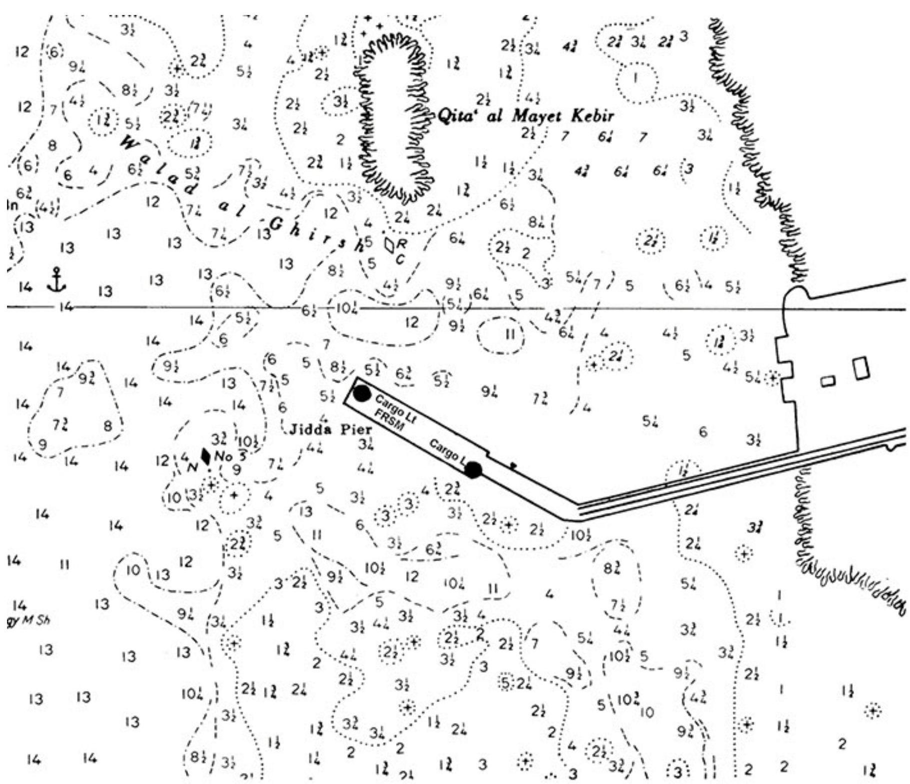


Figure 427b. Part of a nautical chart made from the boat sheet of Figure 427a*. Compare the number of soundings in the two figures.*

less frequently traveled areas of the world.

428. Source Diagrams and Zones of Confidence

All charts, whether paper or electronic, contain data which varies in quality due to the age and accuracy of individual surveys. A chart can be considered as a patchwork of individual surveys pieced together to form a single image. A **source diagram** only shows who supplied a survey, and possibly how old that survey is, but provides nothing about the quality of the survey. Where source diagrams are based on inexact and sometimes subjective parameters, a new **zone of confidence (ZOC)** system (exclusive to electronic charts in the United States) is derived more consistently, using a combination of survey data, position accuracy, depth accuracy, and sea floor coverage.

The ZOC assessments within each chart enable mariners to assess the limitation of the hydrographic data from which the chart was compiled and to assess the associated level of risk to navigate in a particular area. In ENC the various assessment areas and ratings appear across the entirety of the ENC and are therefore embedded in their true positions, rather than in a small diagram. This information layer can be displayed or hidden as planning and route monitoring requirements change.

Assessments are made based upon four criteria, following which a single ZOC rating is derived for each area of differing quality, based upon the lowest individually assessed criteria for that area. Individual criteria are:

1. Position accuracy.
2. Depth accuracy (in reference to what has been detected, not what might or might not have been missed).
3. Seafloor coverage, i.e. the certainty of feature detection (this is not related to depth accuracy, but relates only to what might or might not have been missed).
4. Typical survey characteristics.

Of these, the most important is the assessment of seafloor coverage, as this determines how much clearance should be maintained between a ship's keel and the seabed in most areas, and where any additional precautions may need to be taken.

Each surveyed area will be assigned to one of five

ZOC	*Position Accuracy*	*Depth Accuracy*		*Seafloor Coverage*	*Typical Survey Characteristics*
A1	*± 5 m*	= 0.50 + 1% d		Full area search undertaken. All significant seafloor features detected and depths measured.	Controlled, systematic survey high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.
		Depth (m)	Accuracy (m)		
		10	± 0.6		
		30	± 0.8		
		100	± 1.5		
		1000	± 10.5		
A2	*± 20 m*	= 1.00 + 2% d		Full area search undertaken. All significant seafloor features detected and depths measured.	Controlled, systematic survey high position and depth accuracy achieved less than ZOC A1 and using a modern survey echosounder and a sonar or mechanical system.
		Depth (m)	Accuracy (m)		
		10	± 1.2		
		30	± 1.6		
		100	± 3.0		
		1000	± 21.0		
B	*± 50 m*	= 1.00 + 2% d		Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.	Controlled systematic survey achieving similar depth but lessor position accuracies than ZOC A2, using modern survey echosounder, but no sonar or mechanical sweep system.
		Depth (m)	Accuracy (m)		
		10	± 1.2		
		30	± 1.6		
		100	± 3.0		
		1000	± 21.0		

Table 428. Zones of Confidence category explanations.

ZOC	Position Accuracy	Depth Accuracy		Seafloor Coverage	Typical Survey Characteristics
C	± *500 m*	= 2.00 + 5% d		Full area search not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.
		Depth (m)	Accuracy (m)		
		10	± 2.5		
		30	± 3.5		
		100	± 7.0		
		1000	± 52.0		
D	Worse than ZOC	Worse than ZOC C		Full area search not achieved, large depth	Poor quality data or data that cannot be quality assessed due
U	Unassessed - The quality of the bathymetric data has yet to be assessed				

Table 428. Zones of Confidence category explanations.

quality categories for assessed data (ZOC A1, A2, B, C, D), with a sixth category used for data which has not been assessed (ZOC U). See Table 428 for an explanation of each category. The standard is detailed in the International Hydrographic Organization (IHO) S-57 Edition 3.1 Supplement 2, publication.

CHART READING

429. Chart Dates

NOAA charts have two areas where dates are shown. At the top center of the chart is the date of the first edition of the chart. In the lower left corner of the chart is the current edition number and date. Additionally, NOAA charts show the "cleared through" dates in the lower left corner of the chart to indicate what *Notice to Mariner* dates the chart is updated too (i.e. *Notice to Mariner* and *Local Notice to Mariner)*. See Figure 429a. Any subsequent change will be published in the *Notice to Mariners*. Any notices which accumulate between the chart date and the announcement date in the *Notice to Mariners* will be given with the announcement.

NGA charts similarly have two dates as well. At the top center of the chart is the date of the first edition of the chart. In the lower left corner of the chart is the current chart edition number, date, and barcode information. See Figure 429b. The edition date will contain a statement indicating what Notice to Mariner the NGA chart has been corrected too. Any subsequent change will be published in the Notice to Mariners. Any notices which accumulate between the chart date and the announcement date in the Notice to Mariners will be given with the announcement. NGA charts do not contain a "cleared through" date like NOAA charts because NGA does not have a program in place for producing weekly digital updates to the chart files.

Certain NGA charts are reproductions of foreign charts produced under joint agreements with a number of other

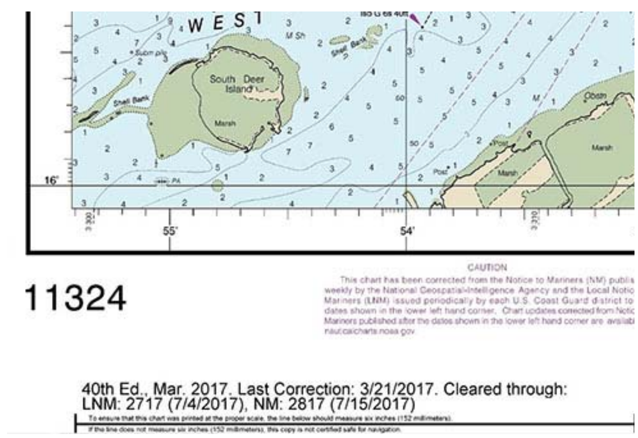


Figure 429a. NOAA chart dates.

countries. These bilateral foreign chart reproductions will also include an NGA chart number, edition number, user note, and barcode information. These charts, even though of recent date, may not be based on the most recent edition of the foreign chart. Further, new editions of the foreign chart will not necessarily automatically result in a new edition of the NGA reproduction, especially in cases where the foreign chart is the better chart to use.

Comparing the difference of edition numbers and dates between the first and current editions on the chart, gives an indication of how often the chart is updated. Charts of busy areas are updated more frequently than those of less trav-

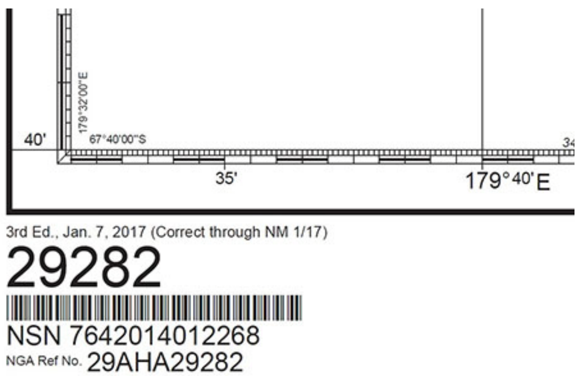


Figure 429b. NGA chart dates.

eled areas. This interval may vary from 6 months to more than ten years for NOAA charts, and may be much longer for certain NGA charts in remote areas.

New editions of charts are both demand and source driven. Receiving significant new information may or may not initiate a new edition of a chart, depending on the demand for that chart. If it is in a sparsely-traveled area, production priorities may delay a new edition for several years. Conversely, a new edition may be printed without the receipt of significant new data if demand for the chart is high and stock levels are low. Notice to Mariners corrections are always included on new editions.

430. Title Block

The chart title block should be the first thing a navigator looks at when receiving a new edition chart (refer to Figure 430). The title itself tells what area the chart covers. The chart's scale and projection appear below the title. The chart will give both vertical and horizontal datums and, if necessary, a datum conversion note. Source notes or diagrams will list the date of surveys and other charts used in compilation.

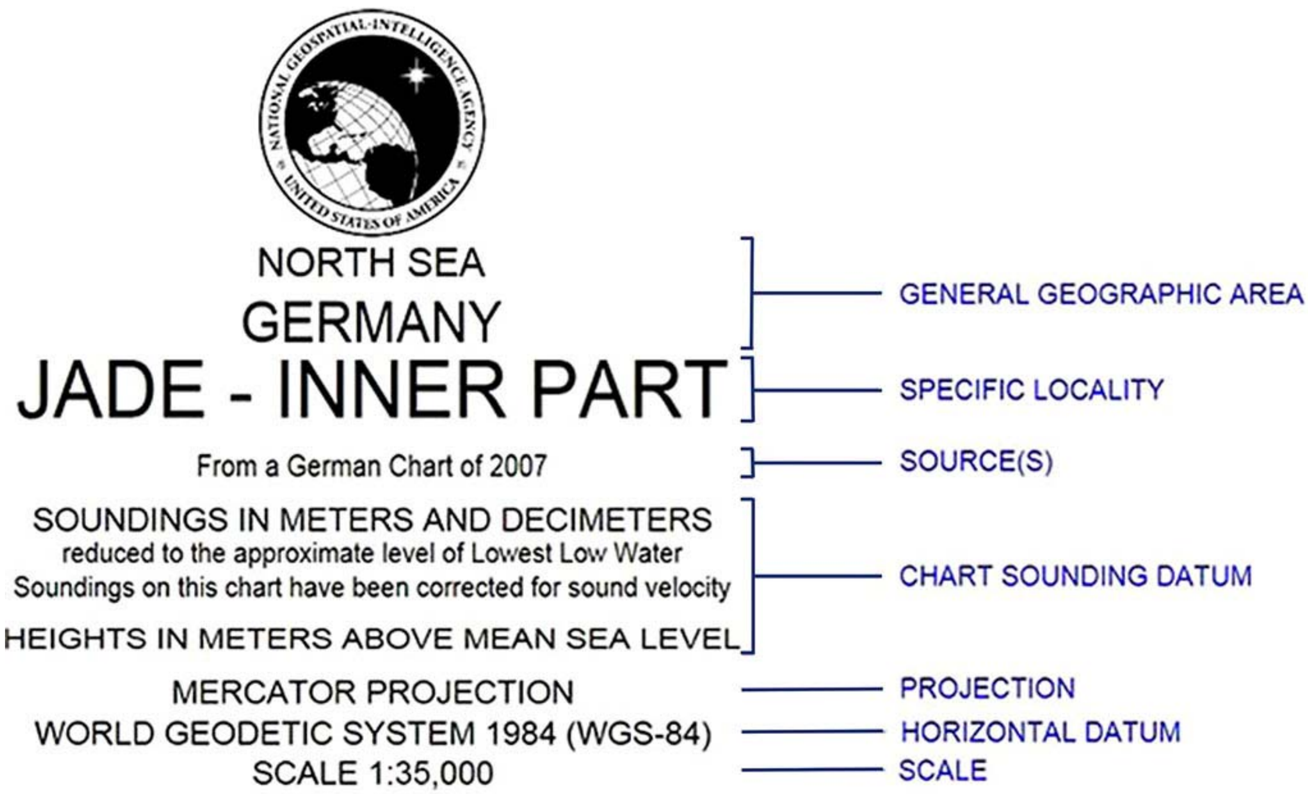


Figure 430. A chart title block.

431. Shoreline

The shoreline shown on nautical charts represents the line of contact between the land and water at a selected vertical datum. In areas affected by tidal fluctuations, this is usually the mean high-water line. In confined coastal waters of diminished tidal influence, a mean water level line may be used. The shoreline of interior waters (rivers, lakes) is usually a line representing a specified elevation above a selected datum. A shoreline is symbolized by a heavy line. A broken line indicates that the charted position is approximate only. The nature of the shore may be indicated.

If the low water line differs considerably from the high water line, then a dotted line represents the low water line. If the bottom in this area is composed of mud, sand, gravel or stones, the type of material will be indicated. If the bottom is composed of coral or rock, then the appropriate symbol will be used. The area alternately covered and uncovered may be shown by a tint which is usually a combination of the land and water tint.

The apparent shoreline shows the outer edge of marine vegetation where that limit would appear as shoreline to the mariner. It is also used to indicate where marine vegetation prevents the mariner from defining the shoreline. A light line symbolizes this shoreline. A broken line marks the inner edge when no other symbol (such as a cliff or levee) furnishes such a limit. The combined land-water tint or the land tint marks the area between inner and outer limits.

432. Chart Symbols

Much of the information contained on charts is shown by symbols. These symbols are not shown to scale, but they indicate the correct position of the feature to which they refer. The standard symbols and abbreviations used on charts published by the United States of America are shown in *Chart No. 1, Symbols, Abbreviations* and *Terms used on Paper and Electronic Navigation Charts*. See Figure 432a for link.

Figure 432a. Link to Chart No. 1.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0004

Electronic chart symbols are, within programming and display limits, much the same as printed ones. The less expensive electronic charts have less extensive symbol libraries, and the screen's resolution may affect the presentation detail.

Most of the symbols and abbreviations shown in *U.S. Chart No. 1* agree with recommendations of the International Hydrographic Organization (IHO), these are often called INT1 symbols. The symbols and abbreviations on any given chart may differ somewhat from those shown in *U.S. Chart No. 1*. In addition, foreign charts may use different symbology. When using a foreign chart, the navigator should have available the Chart No. 1 from the country which produced the chart.

The symbols in *U.S. Chart No. 1* are organized by type in separate sections. For example, "natural features," "landmarks," "depths," "rocks, wrecks, obstructions, aquaculture," etc. Each section has a separate letter designator.

Information and examples of each symbol are displayed in eight columns. These show the IHO number code for the symbol; the INT1 symbol; a textual description of the symbol, term, or abbreviation; NOAA and NGA symbols if they are different from the INT1 symbol (the NOAA and NGA columns are combined if the charts from each of these agencies s use the same symbol. If the symbols are different, two separate columns are shown). The next column shows any symbols used on foreign charts that NGA reproduces. The final two columns show the ECDIS symbols used to portray ENC data. The layout is explained in the introduction section of *U.S. Chart No. 1*.

Chart No. 1 is organized according to subject matter, with each specific subject given a letter designator. The general subject areas are General, Topography, Hydrography, Aids and Services, and Indexes. Under each heading, letter designators further define subject areas, and individual numbers refer to specific symbols. See Figure 432b.

Information in *Chart No. 1* is arranged in columns. The first column contains the IHO number code for the symbol in question. The next two columns show the symbol itself, in NOS and NGA formats. If the formats are the same, the two columns are combined into one. The next column is a text description of the symbol, term, or abbreviation. The next three columns contain the IHO standard symbolized on charts produced by NOAA or NGA. The last column contains the symbol used on electronic charts displayed on an ECDIS with a text description to the right of the symbol.

433. Lettering

Except on some modified reproductions of foreign charts, cartographers have adopted certain lettering standards. Vertical type is used for features which are dry at high water and not affected by movement of the water; slanting type is used for underwater and floating features.

There are two important exceptions to the two general rules listed above. Vertical type is not used to represent heights above the waterline, and slanting type is not used to indicate soundings, except on metric charts. Section 434 discusses the conventions for indicating soundings.

Evaluating the type of lettering used to denote a feature, one can determine whether a feature is visible at high tide. For instance, a rock might bear the title "Rock" whether or not it extends above the surface. If the name is given in vertical letters, the rock constitutes a small islet; if in slanting type, the rock constitutes a reef, covered at high water.

434. Soundings

Charts show soundings in several ways. Numbers denote

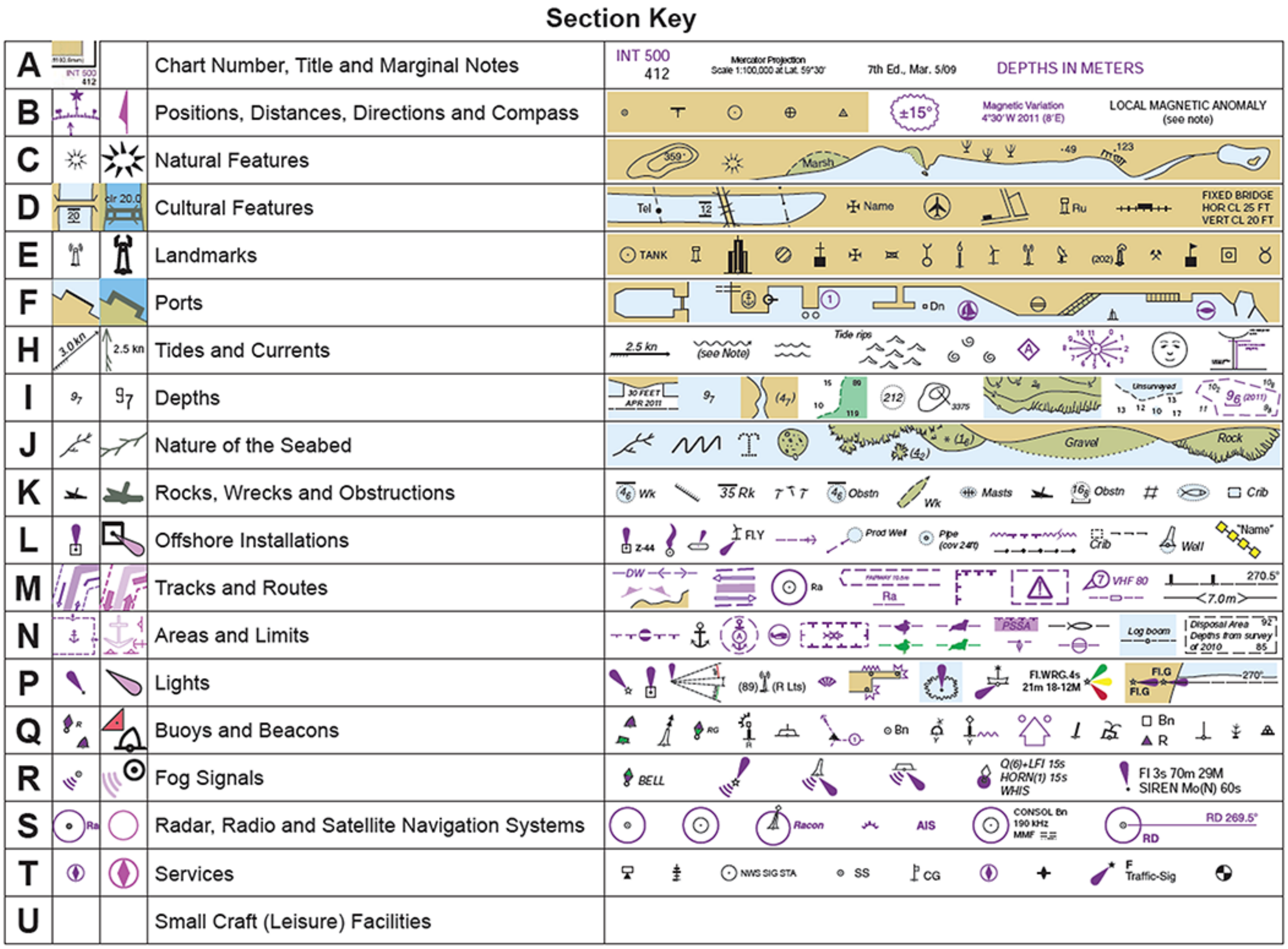


Figure 432b. Contents of U.S. Chart No. 1.

individual soundings. These numbers may be either vertical or slanting; both may be used on the same chart, distinguishing between data based upon different U.S. and foreign surveys, different datums, or smaller scale charts.

Large block letters at the top and bottom of the chart indicate the unit of measurement used for soundings. SOUNDINGS IN FATHOMS indicates soundings are in fathoms or fathoms and fractions. SOUNDINGS IN FATHOMS AND FEET indicates the soundings are in fathoms and feet. A similar convention is followed when the soundings are in meters or meters and tenths.

A **depth conversion scale** is placed outside the neatline on the chart for use in converting charted depths to feet, meters, or fathoms. “No bottom” soundings are indicated by a number with a line over the top and a dot over the line. This indicates that the spot was sounded to the depth indicated without reaching the bottom. Areas which have been wire dragged are shown by a broken limiting line, and the clear effective depth is indicated, with a characteristic symbol under the numbers. On NGA charts a purple or green tint is shown within the swept area.

Soundings are supplemented by **depth contours**, lines connecting points of equal depth. These lines present a picture of the bottom. The types of lines used for various depths are shown in Section I of *Chart No. 1*. On some charts depth contours are shown in solid lines; the depth represented by each line is shown by numbers placed in breaks in the lines, as with land contours. Solid line depth contours are derived from intensively developed hydrographic surveys. A broken or indefinite contour is substituted for a solid depth contour whenever the reliability of the contour is questionable.

Depth contours are labeled with numerals in the unit of measurement of the soundings. A chart presenting a more detailed indication of the bottom configuration with fewer numerical soundings is useful when bottom contour navigating. Such a chart can be made only for areas which have undergone a detailed survey

Shoal areas often are given a blue tint. Charts designed to give maximum emphasis to the configuration of the bottom show depths beyond the 100-fathom curve over the entire chart by depth contours similar to the contours shown on land areas to indicate graduations in height. These are called **bottom contour** or **bathymetric charts**.

On electronic charts, a variety of other color schemes may be used, according to the manufacturer of the system. Color perception studies are being used to determine the best presentation.

The side limits of dredged channels are indicated by broken lines. The project depth and the date of dredging, if known, are shown by a statement in or along the channel. The possibility of silting is always present. Local authorities should be consulted for the controlling depth. NOS charts frequently show controlling depths in a table, which is kept current by the *Notice to Mariners*.

The chart scale is generally too small to permit all soundings to be shown. In the selection of soundings, least depths are shown first. This conservative sounding pattern provides safety and ensures an uncluttered chart appearance. Steep changes in depth may be indicated by more dense soundings in the area. The limits of shoal water indicated on the chart may be in error, and nearby areas of undetected shallow water may not be included on the chart. Given this possibility, areas where shoal water is known to exist should be avoided. If the navigator must enter an area containing shoals, they must exercise extreme caution in avoiding shallow areas which may have escaped detection. By constructing a "safety range" around known shoals and ensuring their vessel does not approach the shoal any closer than the safety range, the navigator can increase their chances of successfully navigating through shoal water. Constant use of the echo sounder is also important.

Abbreviations listed in Section J of *Chart No. 1* are used to indicate what substance forms the bottom. The meaning of these terms can be found in the Glossary of this volume. While in ages past navigators might actually navigate by knowing the bottom characteristics of certain local areas, today knowing the characteristic of the bottom is most important when anchoring.

435. Depths and Datums

Depths are indicated by soundings or explanatory notes. Only a small percentage of the soundings obtained in a hydrographic survey can be shown on a nautical chart. The least depths are generally selected first, and a pattern built around them to provide a representative indication of bottom relief. In shallow water, soundings may be spaced 0.2 to 0.4 inch apart. The spacing is gradually increased as water deepens, until a spacing of 0.8 to 1.0 inch is reached in deeper waters offshore. Where a sufficient number of soundings are available to permit adequate interpretation, depth curves are drawn in at selected intervals.

All depths indicated on charts are reckoned from a selected level of the water, called the **sounding datum**, (sometimes referred to as the **reference plane** to distinguish this term from the geodetic datum). The various sounding datums are explained in Chapter 35- Tides and Tidal Currents. On charts produced from U.S. surveys, the sounding datum is selected with regard to the tides of the region. Depths shown are the least depths to be expected under average conditions. On charts compiled from foreign charts and surveys the sounding datum is that of the original authority. When it is known, the sounding datum used is stated on the chart. In some cases where the chart is based upon old surveys, particularly in areas where the range of tide is not great, the sounding datum may not be known.

For most NOAA charts of the United States and Puerto Rico, the sounding datum is indicated as Mean Lower Low Water (MLLW). Most NGA charts are based upon mean low water, mean lower low water, or mean low water springs. The sounding datum for charts published by other countries varies greatly, but is usually lower than mean low water. On charts of the Baltic Sea, Black Sea, the Great Lakes, and other areas where tidal effects are small or without significance, the sounding datum adopted is an arbitrary height approximating the mean water level.

The sounding datum of the largest scale chart of an area is generally the same as the reference level from which height of tide is tabulated in the tide tables.

The chart datum is usually only an approximation of the actual mean value, because determination of the actual mean height usually requires a longer series of tidal observations than is normally available to the cartographer. In addition, the heights of the tide vary over time.

Since the chart datum is generally a computed mean or average height at some state of the tide, the depth of water at any particular moment may be less than shown on the chart. For example, if the chart datum is mean lower low water, the depth of water at lower low water will be less than the charted depth about as often as it is greater. A lower depth is indicated in the tide tables by a minus sign (–).

436. Heights

The shoreline shown on charts is generally mean high water. A light's height is usually reckoned from mean sea level. The heights of overhanging obstructions (bridges, power cables, etc.) are usually reckoned from mean high water. A high water reference gives the mariner the minimum clearance expected.

Since heights are usually reckoned from high water and depths from some form of low water, the reference levels are seldom the same. Except where the range of tide is very large, this is of little practical significance.

437. Dangers

Dangers are shown by appropriate symbols, as indicated in Section K of *Chart No. 1*.

A rock uncovered at mean high water may be shown as an islet. If an isolated, offlying rock is known to uncover at the sounding datum but to be covered at high water, the chart shows the appropriate symbol for a rock and gives the height above the sounding datum. The chart can give this height one of two ways. It can use a statement such as "Uncov 2 ft.," or it can indicate the number of feet the rock protrudes above the sounding datum, underline this value, and enclose it in parentheses (i.e. (2)). A rock which does not uncover is shown by an enclosed figure approximating its dimensions and filled with land tint. It may be enclosed by a dotted depth curve for emphasis.

A tinted, irregular-line figure of approximately true dimensions is used to show a detached coral reef which uncovers at the chart datum. For a coral or rocky reef which is submerged at chart datum, the sunken rock symbol or an appropriate statement is used, enclosed by a dotted or broken line if the limits have been determined.

Several different symbols mark wrecks. The nature of the wreck or scale of the chart determines the correct symbol. A sunken wreck with less than 30 meters of water over it is considered dangerous and its symbol is surrounded by a dotted curve. The curve is omitted if the wreck is deeper than 30 meters. The safe clearance over a wreck, if known, is indicated by a standard sounding number placed at the wreck. If this depth was determined by a wire drag, the sounding is underscored by the wire drag symbol. An unsurveyed wreck over which the exact depth is unknown but a safe clearance depth is known is depicted with a solid line above the symbol.

Tide rips, eddies, and kelp are shown by symbol or legend. Piles, dolphins (clusters of piles), snags, and stumps are shown by small circles and a label identifying the type of obstruction. If such dangers are submerged, the letters "Subm" precede the label. Fish stakes and traps are shown when known to be permanent or hazardous to navigation.

438. Aids to Navigation

Aids to navigation are shown by symbols listed in Sections P through S of *Chart No. 1.* Abbreviations and additional descriptive text supplement these symbols. In order to make the symbols conspicuous, the chart shows them in size greatly exaggerated relative to the scale of the chart. "Position approximate" circles are used on floating aids to indicate that they have no exact position because they move around their moorings. For most floating aids, the position circle in the symbol marks the approximate location of the anchor or sinker. The actual aid may be displaced from this location by the scope of its mooring.

The type and number of aids to navigation shown on a chart and the amount of information given in their legends varies with the scale of the chart. Smaller scale charts may have fewer aids indicated and less information than larger scale charts of the same area.

Lighthouses and other navigation lights are shown as black dots with purple disks or as black dots with purple flare symbols. The center of the dot is the position of the light. Some modified facsimile foreign charts use a small star instead of a dot.

On large-scale charts the legend elements of lights are shown in the following order:

Legend	*Example*	*Meaning*
Designation	"6"	Light number 6
Characteristic	F1(2)	group flashing; 2 flashes
Color	R	red
Period	10s	2 flashes in 10 seconds
Height	80m	80 meters
Range	19M	19 nautical miles

The legend characteristics for this light would appear on the chart:

"6" Fl(2) R 10s 80m 19M

As chart scale decreases, information in the legend is selectively deleted to avoid clutter. The order of deletion is usually height first, followed by period, group repetition interval (e.g. (2)), designation, and range. Characteristic and color will almost always be shown.

Small triangles mark red daybeacons; small squares mark all others. On NGA charts, pictorial beacons are used when the IALA buoyage system has been implemented. The center of the triangle marks the position of the aid. Except on Intracoastal Waterway charts and charts of state waterways, the abbreviation "Bn" is shown beside the symbol, along with the appropriate abbreviation for color if known. For black beacons the triangle is solid black and there is no color abbreviation. All beacon abbreviations are in vertical lettering.

Radiobeacons are indicated on the chart by a purple circle accompanied by the appropriate abbreviation indicating an ordinary radiobeacon (R Bn) or a radar beacon (Ramark or Racon, for example).

A variety of symbols, determined by both the charting agency and the types of buoys, indicate navigation buoys. IALA buoys (see Chapter 7- Short Range Aids to Navigation) in foreign areas are depicted by various styles of symbols with proper topmarks and colors; the position circle which shows the approximate location of the sinker is at the base of the symbol.

A mooring buoy is shown by one of several symbols as indicated in *Chart No. 1*. It may be labeled with a berth number or other information.

A buoy symbol with a horizontal line indicates the buoy has horizontal bands. A vertical line indicates vertical stripes; crossed lines indicate a checked pattern. There is no significance to the angle at which the buoy symbol appears on the chart. The symbol is placed so as to avoid interference with other features.

Lighted buoys are indicated by a purple flare from the buoy symbol or by a small purple disk centered on the position circle.

Abbreviations for light legends, type and color of buoy, designation, and any other pertinent information given near the symbol are in slanted type. The letter C, N, or S indicates a can, nun, or spar, respectively. Other buoys are assumed to be pillar buoys, except for special buoys such as spherical, barrel, etc. The number or letter designation of the buoy is given in quotation marks on NOS charts. On other charts they may be given without quotation marks or other punctuation.

Aeronautical lights included in the light lists are shown by the lighthouse symbol, accompanied by the abbreviation "AERO." The characteristics shown depend principally upon the effective range of other navigational lights in the vicinity and the usefulness of the light for marine navigation.

Directional ranges are indicated by a broken or solid line. The solid line, indicating that part of the range intended for navigation, may be broken at irregular intervals to avoid being drawn through soundings. That part of the range line drawn only to guide the eye to the objects to be kept in range is broken at regular intervals. The direction, if given, is expressed in degrees, clockwise from true north.

Sound signals are indicated by the appropriate word in capital letters (HORN, BELL, GONG, or WHIS) or an abbreviation indicating the type of sound. Sound signals of any type except submarine sound signals may be represented by three purple 45° arcs of concentric circles near the top of the aid. These are not shown if the type of signal is listed. The location of a sound signal which does not accompany a visual aid, either lighted or unlighted, is shown by a small circle and the appropriate word in vertical block letters.

Private aids, when shown, are marked "Priv" on NOS charts. Some privately maintained unlighted fixed aids are indicated by a small circle accompanied by the word "Marker," or a larger circle with a dot in the center and the word "MARKER." A privately maintained lighted aid has a light symbol and is accompanied by the characteristics and the usual indication of its private nature. Private aids should be used with caution.

A light sector is the sector or area bounded by two radii and the arc of a circle in which a light is visible or in which it has a distinctive color different from that of adjoining sectors. The limiting radii are indicated on the chart by dotted or dashed lines. Sector colors are indicated by words spelled out if space permits, or by abbreviations (W, R, etc.) if it does not. Limits of light sectors and arcs of visibility as observed from a vessel are given in the light lists, in clockwise order.

439. Land Areas

The amount of detail shown on the land areas of nautical charts depends upon the scale and the intended purpose of the chart. Contours, form lines, and shading indicate relief.

Contours are lines connecting points of equal elevation. Heights are usually expressed in feet (or in meters with means for conversion to feet). The interval between contours is uniform over any one chart, except that certain intermediate contours are sometimes shown by broken line. When contours are broken, their locations are approximate.

Form lines are approximations of contours used for the purpose of indicating relative elevations. They are used in areas where accurate information is not available in sufficient detail to permit exact location of contours. Elevations of individual form lines are not indicated on the chart.

Spot elevations are generally given only for summits or for tops of conspicuous landmarks. The heights of spot elevations and contours are given with reference to mean high water when this information is available.

When there is insufficient space to show the heights of islets or rocks, they are indicated by slanting figures enclosed in parentheses in the water area nearby.

440. Cities and Roads

Cities are shown in a generalized pattern that approximates their extent and shape. Street names are generally not charted except those along the waterfront on the largest scale charts. In general, only the main arteries and thoroughfares or major coastal highways are shown on smaller scale charts. Occasionally, highway numbers are given. When shown, trails are indicated by a light broken line. Buildings along the waterfront or individual ones back from the waterfront but of special interest to the mariner are shown on large-scale charts. Special symbols from *Chart No. 1* are used for certain kinds of buildings. A single line with cross marks indicates both single and double track railroads. City electric railways are usually not charted. Airports are shown on small-scale charts by symbol and on large-scale charts by the shape of runways. The scale of the chart determines if single or double lines show breakwaters and jetties; broken lines show the submerged portion of these features.

441. Landmarks

Landmarks are shown by symbols in *Chart No. 1*.

A large circle with a dot at its center is used to indicate that the position is precise and may be used without reservation for plotting bearings. A small circle without a dot is used for landmarks not accurately located. Capital and lower case letters are used to identify an approximate landmark: "Mon," "Cup," or "Dome." The abbreviation "PA" (position approximate) may also appear. An accurate landmark is identified by all capital type ("MON," "CUP," "DOME").

When only one object of a group is charted, its name is followed by a descriptive legend in parenthesis, including the number of objects in the group, for example "(TALLEST OF FOUR)" or "(NORTHEAST OF THREE)."

442. Miscellaneous Chart Features

A measured nautical mile indicated on a chart is accurate to within 6 feet of the correct length. Most measured miles in the United States were made before 1959, when the United States adopted the International Nautical Mile. The new value is within 6 feet of the previous standard length of 6,080.20 feet. If the measured distance differs from the standard value by more than 6 feet, the actual measured distance is stated and the words “measured mile” are omitted. Periods after abbreviations in water areas are omitted

TIDAL INFORMATION						
Place	Position		Height above datum of soundings			
			Mean High Water		Mean Low Water	
	N. Lat.	E. Long.	Higher	Lower	Lower	Higher
			meters	meters	meters	meters
Olongapo	14°49'	120°17'	. . . 0.9 . . .	. . . 0.4 . .	. . . 0.0 .	. . . 0.3 . .

Figure 442a. Tidal box.

because these might be mistaken for rocks. However, a lower case i or j is dotted.

Commercial radio broadcasting stations are shown on charts when they are of value to the mariner either as landmarks or sources of direction-finding bearings.

Lines of demarcation between the areas in which international and inland navigation rules apply are shown only when they cannot be adequately described in notes on the chart.

Compass roses are placed at convenient locations on Mercator charts to facilitate the plotting of bearings and courses. The outer circle is graduated in degrees with zero at true north. The inner circle indicates magnetic north.

On many NGA charts magnetic variation is given to the nearest 1' by notes in the centers of compass roses. the annual change is given to the nearest 1' to permit correction of the given value at a later date. On NOS charts, variation is to the nearest 15', updated at each new edition if over three years old. The current practice of NGA is to give the magnetic variation to the nearest 1', but the magnetic information on new editions is only updated to conform with the latest five year epoch. Whenever a chart is reprinted, the magnetic information is updated to the latest epoch. On some smaller scale charts, the variation is given by isogonic lines connecting points of equal variation; usually a separate line represents each degree of variation. The line of zero variation is called the agonic line. Many plans and insets show neither compass roses nor isogonic lines, but indicate magnetic information by note. A local magnetic disturbance of sufficient force to cause noticeable deflection of the magnetic compass, called local attraction, is indicated by a note on the chart.

Currents are sometimes shown on charts with arrows giving the directions and figures showing speeds. The information refers to the usual or average conditions. According to tides and weather, conditions at any given time may differ considerably from those shown.

Review chart notes carefully because they provide important information. Several types of notes are used. Those in the margin give such information as chart number, publication notes, and identification of adjoining charts. Notes in connection with the chart title include information on scale, sources of data, tidal information, soundings, and cautions. Another class of notes covers such topics as local magnetic disturbance, controlling depths of channels, hazards to navigation, and anchorages.

A datum note will show the geodetic datum of the chart (Do not confuse with the sounding datum. See Chapter 2 - Geodesy and Datums in Navigation). It may also contain instructions on plotting positions from the WGS 84 or NAD 83 datums on the chart if such a conversion is needed.

Anchorage areas are labeled with a variety of magenta, black, or green lines depending on the status of the area. Anchorage berths are shown as purple circles, with the number or letter assigned to the berth inscribed within the circle. Caution notes are sometimes shown when there are specific anchoring regulations.

Spoil areas are shown within short broken black lines. Spoil areas are tinted blue on NOS charts and labeled. These areas contain no soundings and should be avoided.

Firing and bombing practice areas in the United States territorial and adjacent waters are shown on NOS and NGA charts of the same area and comparable scale.

Danger areas established for short periods of time are not charted but are announced locally. Most military commands charged with supervision of gunnery and missile firing areas promulgate a weekly schedule listing activated danger areas. This schedule is subjected to frequent change; the mariner should always ensure they have the latest schedule prior to proceeding into a gunnery or missile firing area. Danger areas in effect for longer periods are published in the *Notice to Mariners*. Any aid to navigation established to mark a danger area or a fixed or floating target is shown on charts.

Traffic separation schemes are shown on standard nautical charts of scale 1:600,000 and larger and are printed in magenta.

A logarithmic time-speed-distance nomogram with an explanation of its application is shown on harbor charts.

Tidal information boxes are shown on charts of scales 1:200,000 and larger for NOS charts, and various scales on NGA charts, according to the source. See Figure 442a.

Tabulations of controlling depths are shown on some

NANTUCKET HARBOR Tabulated from surveys by the Corps of Engineers - report of June 1972 and surveys of Nov. 1971							
Controlling depths in channels entering from seaward in feet at Mean Low Water					Project Dimensions		
Name of Channel	Left outside quarter	Middle half of channel	Right outside quarter	Date of Survey	Width (feet)	Length (naut. miles)	Depth M. L. W. (feet)
Entrance Channel	11.1	15.0	15.0	11 - 71	300	1.2	15
Note.-The Corps of Engineers should be consulted for changing conditions subsequent to the above.							

Figure 442b. Tabulations of controlling depths.

NOS harbor and coastal charts. See Figure 442b.

Study *Chart No. 1* thoroughly to become familiar with all the symbols used to depict the wide variety of features on nautical charts.

REPRODUCTIONS OF FOREIGN CHARTS

443. Modified Facsimiles

Modified facsimile charts are modified reproductions of foreign charts produced in accordance with bilateral international agreements. These reproductions provide the mariner with up-to-date charts of foreign waters. Modified facsimile charts published by NGA are, in general, reproduced with minimal changes, as listed below:

1. The original name of the chart may be removed and replaced by an anglicized version.
2. English language equivalents of names and terms on the original chart are printed in a suitable glossary on the reproduction, as appropriate.
3. All hydrographic information, except bottom characteristics, is shown as depicted on the original chart.
4. Bottom characteristics are as depicted in *Chart No. 1*, or as on the original with a glossary.
5. The unit of measurement used for soundings is shown in block letters outside the upper and lower neatlines.
6. A scale for converting charted depth to feet, meters, or fathoms is added.
7. Blue tint is shown from a significant depth curve to the shoreline.
8. Blue tint is added to all dangers enclosed by a dotted danger curve, dangerous wrecks, foul areas, obstructions, rocks awash, sunken rocks, and swept wrecks.
9. Caution notes are shown in purple and enclosed in a box.
10. Restricted, danger, and prohibited areas are usually outlined in purple and labeled appropriately.
11. Traffic separation schemes are shown in purple.
12. A note on traffic separation schemes, printed in black, is added to the chart.
13. Wire dragged (swept) areas are shown in purple or green.
14. Corrections are provided to shift the horizontal datum to the WGS (1984).

INTERNATIONAL CHARTS

444. International Chart Standards

The need for mariners and chart makers to understand and use nautical charts of different nations became increasingly apparent as the maritime nations of the world developed their own establishments for the compilation and publication of nautical charts from hydrographic surveys. Representatives of twenty-two nations formed a Hydrographic Conference in London in 1919. That conference resulted in the establishment of the **International Hydrographic Bureau (IHB)** in Monaco in 1921. Today, the IHB's successor, the **International Hydrographic Organization (IHO)** continues to provide international standards for the cartographers of its member nations. (See Chapter 1 - Introduction to Marine Navigation, for a description of the IHO.)

Recognizing the considerable duplication of effort by member states, the IHO in 1967 moved to introduce the first **international chart**. It formed a committee of six member states to formulate specifications for two series of international charts. Eighty-three small-scale charts were approved; responsibility for compiling these charts has subsequently been accepted by the member states' Hydrographic Offices.

Once a Member State publishes an international chart, reproduction material is made available to any other Member State which may wish to print the chart for its own purposes.

International charts can be identified by the letters INT before the chart number and the IHO seal in addition to other national seals which may appear.

PRINT ON DEMAND CHARTS

445. NOAA Print-on-Demand Paper Charts

NOAA's paper nautical charts are available as “print-on-demand,” up-to-date to the time of purchase. Coast Survey reviews charts weekly, and applies all critical corrections specified in Notices to Mariners. NOAA print-on-demand paper charts must be printed by NOAA-certified agents to meet the requirements for the mandatory carriage of nautical charts.

Figure 445. NOAA Print-on-Demand charts.
http://www.charts.noaa.gov/InteractiveCatalog/nrnc.shtml

446. NOAA PDF Nautical Charts

NOAA provides about a thousand high-resolution printable nautical charts - almost the entire NOAA suite of charts - as PDF files. The PDF nautical charts are exact images of NOAA's traditional nautical charts. Coast Survey checks each chart weekly, and applies all critical corrections. Most charts can be printed from any plotter capable of plotting 36" width to achieve 1:1 scale. (NOTE: Mariners using paper charts to meet chart carriage requirements under federal regulations should use printed charts provided by NOAA-certified print-on-demand vendors).

Figure 446. NOAA PDF charts.
https://nauticalcharts.noaa.gov/

447. NGA Enterprise Print on Demand Service (ePODs)

The Enterprise Print on Demand Service (ePODs) is NGA’s effort to expedite and modernize the creation of legacy chart formats based on geospatially enabled database information. ePODs is a revolutionary concept that utilizes evolutionary methods to provide hardcopy charts built from digital data to the customer. ePODs are print-ready nautical chart files generated directly from existing vector data sets of foundation feature data. The system produces print-ready files that can be delivered directly to DoD and other authorized customers, or stored at a Remote Replication Service (RSS) sites for printing products “on demand.”

CHART NUMBERING

448. The Chart Numbering System

NGA and NOS use a system in which numbers are assigned in accordance with both the scale and geographical area of coverage of a chart. With the exception of certain charts produced for military use only, one- to five-digit numbers are used. With the exception of one-digit numbers, the first digit identifies the area; the number of digits establishes the scale range. The one-digit numbers are used for certain products in the chart system which are not actually charts.

Number of Digits	*Scale*
1	No Scale
2	1:9 million and smaller
3	1:2 million to 1:9 million
4	Special Purpose
5	1:2 million and larger

Two- and three-digit numbers are assigned to those small-scale charts which depict a major portion of an ocean basin or a large area. The first digit identifies the

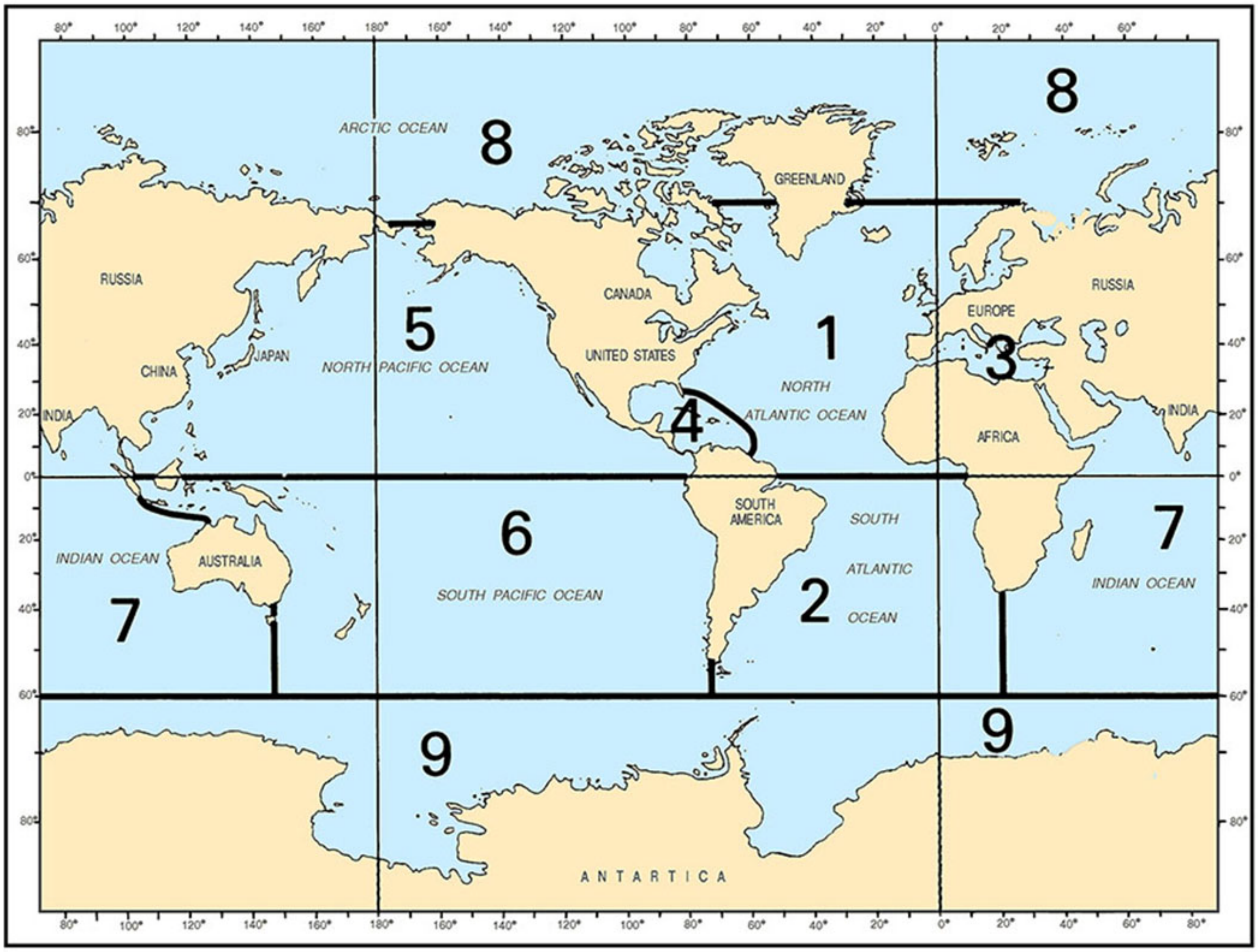


Figure 448a. Ocean basins with region numbers.

applicable ocean basin. See Figure 448a. Two-digit numbers are used for charts of scale 1:9,000,000 and smaller. Three-digit numbers are used for charts of scale 1:2,000,000 to 1:9,000,000.

Due to the limited sizes of certain ocean basins, no charts for navigational use at scales of 1:9,000,000 and smaller are published to cover these basins. The otherwise unused two-digit numbers (30 to 49 and 70 to 79) are assigned to special world charts.

One exception to the scale range criteria for three-digit numbers is the use of three-digit numbers for a series of position plotting sheets. They are of larger scale than 1:2,000,000 because they have application in ocean basins and can be used in all longitudes.

Four-digit numbers are used for non-navigational and special purpose charts, such as chart 5090, *Maneuvering Board*.

Five-digit numbers are assigned to those charts of scale 1:2,000,000 and larger that cover portions of the coastline rather than significant portions of ocean basins. These charts are based on the regions of the nautical chart index. See Figure 448b.

The first of the five digits indicates the region; the second digit indicates the subregion; the last three digits indicate the geographical sequence of the chart within the subregion. Many numbers have been left unused so that any future charts may be placed in their proper geographical sequence.

In order to establish a logical numbering system within the geographical subregions (for the 1:2,000,000 and larger-scale charts), a worldwide skeleton framework of coastal charts was laid out at a scale 1:250,000. This series was used as basic coverage except in areas where a coordinated series at about this scale already existed (such as the coast of Norway where a coordinated series of 1:200,000 charts was available).

Within each region, the geographical subregions are numbered counterclockwise around the continents, and within each subregion the basic series also is numbered counterclockwise around the continents. The basic coverage is assigned generally every 20th digit, except that the first 40 numbers in each subregion are reserved for smaller-scale coverage. Charts with scales larger than the basic coverage are assigned one of the 19 numbers following the number assigned to the sheet within which it falls. Figure 448c shows the numbering sequence in Iceland. Note the sequence of numbers around the coast, the direction of numbering, and the numbering of larger scale charts within the limits of smaller scales.

Five-digit numbers are also assigned to the charts produced by other hydrographic offices. This numbering system is applied to foreign charts so that they can be filed in logical sequence with the charts produced by the NGA and the NOS.

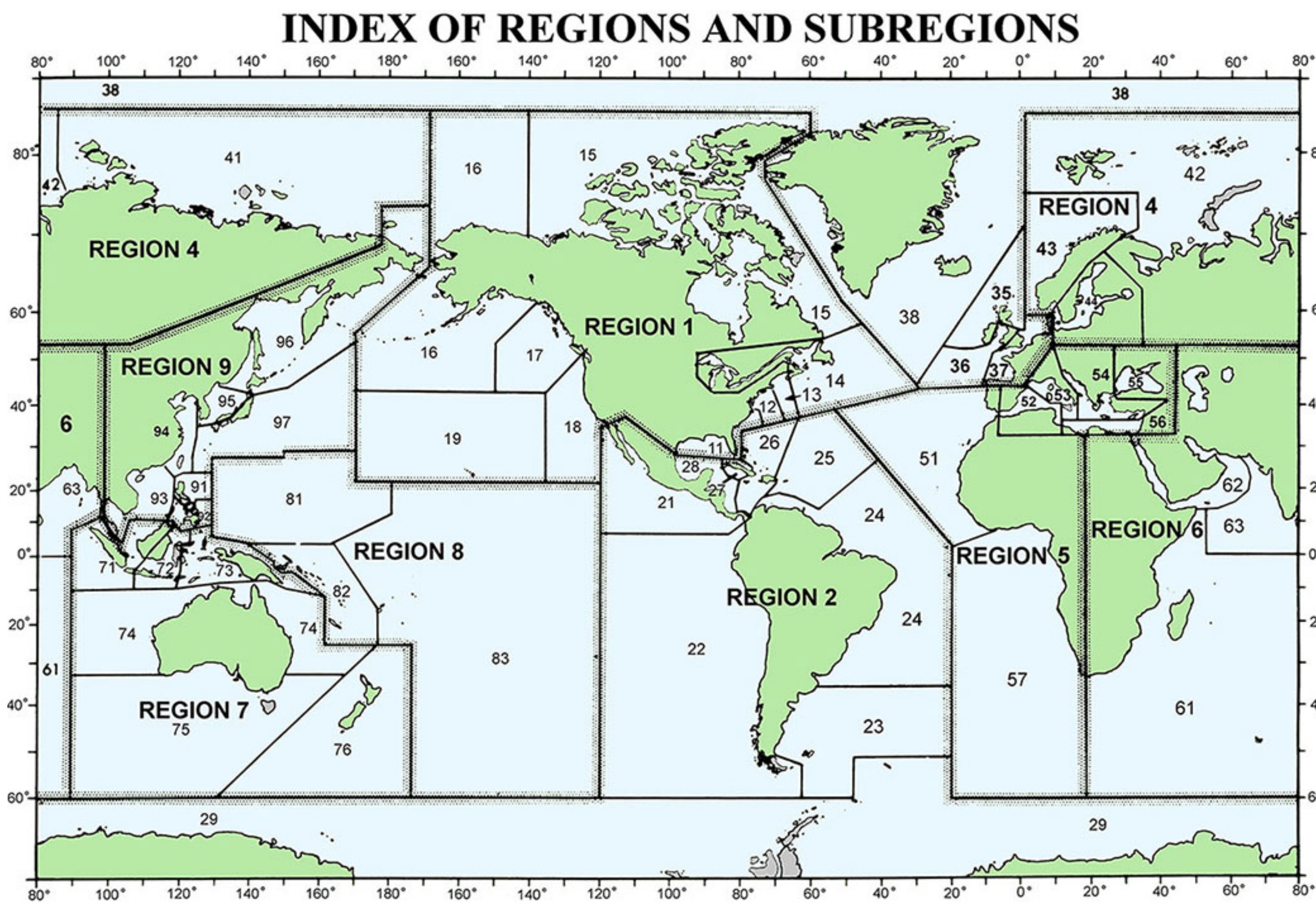


Figure 448b. Regions and subregions of the nautical chart index.

Certain exceptions to the standard numbering system have been made for charts intended for the military. Bottom contour charts depict parts of ocean basins. They are identified with a letter plus four digits according to a scheme best shown in the catalog, and are not available to civilian navigators. Combat charts have 6-digit numbers beginning with an "8." Neither is available to civilian navigators.

449. Catalogs and Stock Numbers

The *NGA/DLIS Catalog of Maps, Charts and Related Products* is available on CD only. It is reserved for military and government agencies, which possess access to limited distribution data. New versions of the catalog are released every six months with corrections published in the weekly *Notice to Mariners.* The standalone CD in interactive with a robust Table of Contents. The digital catalog has the ability to pan across the Pacific Ocean. Military navigators receive their nautical charts and publications automatically; civilian navigators purchase them from chart sales agents.

NOAA charts are available digitally through its *Nautical Products Catalog* or by selecting one of the five regional chart catalogs. There is also a print-at-home option for NOAA chart catalogs. By visiting the NOAA nautical charts and publications website, users can select their region of interest and download a PDF. The *Nautical Product Catalog* provides access to paper charts (RNC & PDF) as well as Electronic Charts (ENC). See Figure 449 for a link to the NOAA chart catalog.

The stock number and bar code are generally found in

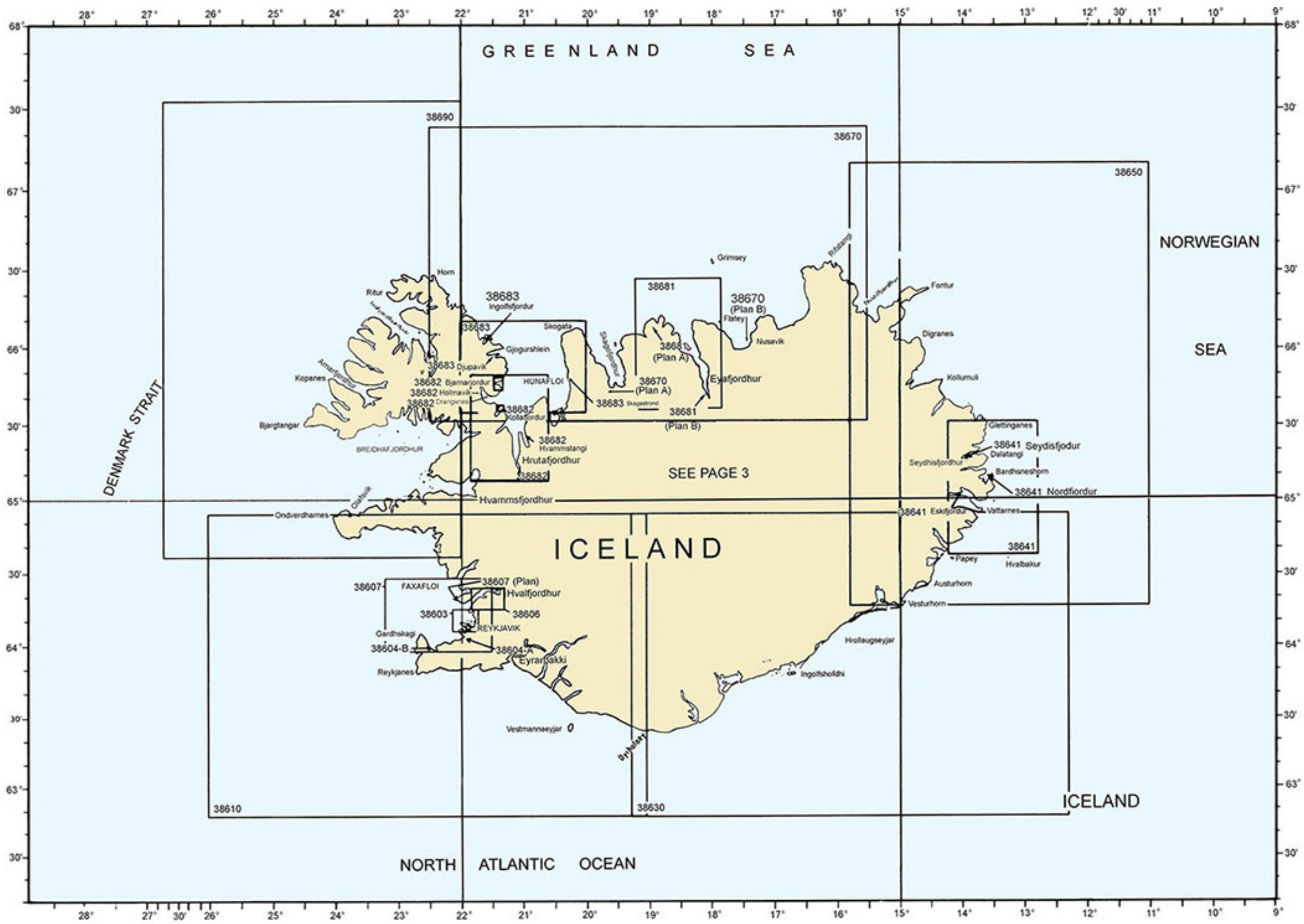


Figure 448c. Chart coverage of Iceland, illustrating the sequence and direction of the U.S. chart numbering system.

Figure 449. NOAA Nautical Chart Catalogs.
http://www.charts.noaa.gov/ChartCatalog/MapSelect.html

the lower left corner of a NGA chart. The first two digits of the stock number refer to the region and subregion. These are followed by three letters, the first of which refers to the portfolio to which the chart belongs; the second two denote the type of chart: CO for coastal, HA for harbor and approach, and OA for military operating area charts. The last five digits are the actual chart number.

USING CHARTS

450. Preliminary Steps

Before using a new edition of a chart, verify its announcement in the *Notice to Mariners* and correct it with all applicable corrections. Read all the chart's notes; there should be no question about the meanings of symbols or the units in which depths are given. Since the latitude and longitude scales differ considerably on various charts, carefully note those on the chart to be used.

Place additional information on the chart as required. Arcs of circles might be drawn around navigational lights to indicate the limit of visibility at the height of eye of an observer on the bridge. Notes regarding other information from the light lists, tide tables, tidal current tables, and sailing directions might prove helpful.

451. Maintaining Charts

A mariner navigating on an uncorrected chart is courting disaster. The chart's print date reflects the latest *Notice to*

Mariners used to update the chart; responsibility for maintaining it after this date lies with the user. The weekly *Notice to Mariners* contains information needed for maintaining charts. Radio broadcasts give advance notice of urgent corrections. Local *Notice to Mariners* should be consulted for inshore areas. The navigator must develop a system to keep track of chart corrections and to ensure that the chart they are using is updated with the latest correction.

For vessels still using paper charts a convenient way of keeping this record is with a **Chart/Publication Correction Record Card** system. Using this system, navigators do not immediately update every chart in their portfolio when they receive the *Notice to Mariners.* Instead, they construct a card for every chart in their portfolio and notes the corrections on this card. When the time comes to use the chart, they pull the chart and the chart's card, and they makes the indicated corrections on the chart. This system ensures that every paper chart is properly corrected prior to use.

Electronic and printed chart correction card forms are available through the NGA Maritime Safety Information web portal under the miscellaneous products tab. See Figure 451 for the link.

With Notice to Mariners available on the internet, mariners have the ability to see all applicable corrections to a chart by a specified date range, all corrections and also for multiple charts at a time.

A Summary of Corrections, containing a cumulative listing of previously published Notice to Mariners corrections, is published annually in 5 volumes by NGA. Thus, to fully correct a chart whose edition date is several years old, the navigator needs only the Summary of Corrections for that region and the notices from that Summary forward; the navigator does not need to obtain notices all the way back to the edition date. See Chapter 6, Nautical Publications, for a description of the Summaries and Notice to Mariners.

Figure 451. Chart correction forms.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_69&prodCode=03

When a new edition of a chart is published, it is normally furnished automatically to U.S. Government vessels. It should not be used until it is announced as ready for use in the *Notice to Mariners*. Until that time, corrections in the Notice apply to the old edition and should not be applied to the new one. When it is announced, a new edition of a chart replaces an older one.

Commercial users and others who don’t automatically receive new editions should obtain new editions from their sales agent. Occasionally, charts may be received or purchased several weeks in advance of their announcement in the *Notice to Mariners*. This is usually due to extensive rescheming of a chart region and the need to announce groups of charts together to avoid lapses in coverage. The mariner bears the responsibility for ensuring that their charts are the current edition. The fact that a new edition has been compiled and published often indicates that there have been extensive changes that cannot be made by hand corrections.

452. Using and Stowing Charts

Use and stow charts carefully. This is especially true with digital charts contained on electronic media. Keep optical and magnetic media containing chart data out of the sun, inside dust covers, and away from magnetic influences. Placing a disk in an inhospitable environment may destroy the data.

Make permanent corrections to paper charts in ink so that they will not be inadvertently erased. Pencil in all other markings so that they can be easily erased without damaging the chart. Lay out and label tracks on charts of frequently-traveled ports in ink. Draw lines and labels no larger than necessary. Do not obscure sounding data or other information when labeling a chart. When a voyage is completed, carefully erase the charts unless there has been a grounding or collision. In this case, preserve the charts without change because they will play a critical role in the investigation.

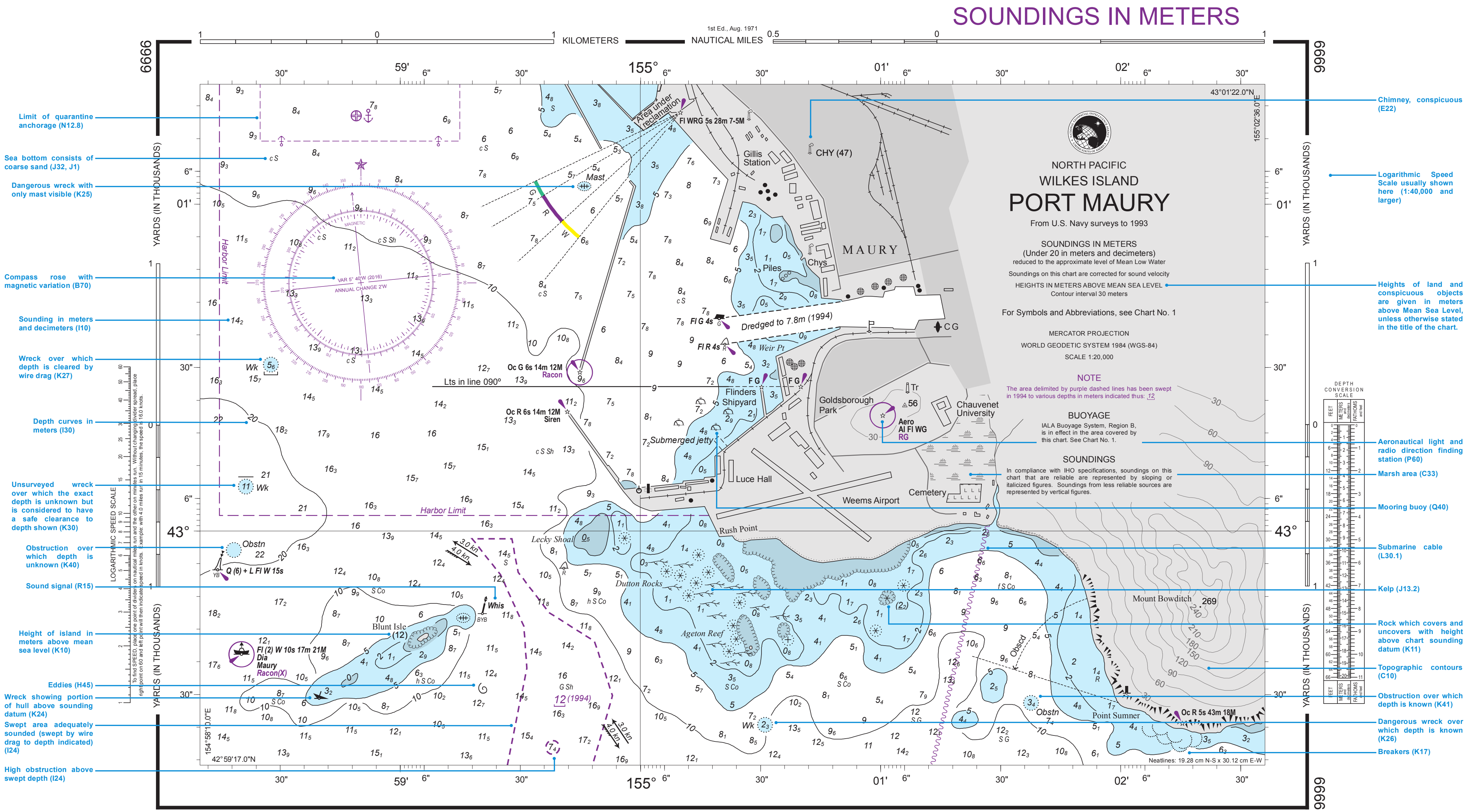
When not in use, stow charts flat in their proper portfolio. Minimize their folding and properly index them for easy retrieval.

453. Chart Lighting

Mariners often work in a red light environment because red light is least disturbing to night adapted vision. Such lighting can significantly affect the appearance of a chart. Before using a chart in red light, test the effect red light has on its markings. Do not outline or otherwise indicate navigational hazards in red pencil because red markings disappear under red light.

454. Port Maury Sample Chart

U.S. Chart No. 9999 - Port Maury (Wilkes Island, North Pacific) is produced by NGA and NOAA for training purposes, This fictitious sample of a nautical chart depicts a typical harbor area. The chart symbology is annotated to include references to U.S. Chart No. 1 and is meant to be a beginners guide and teaching reference to students of marine navigation.



8th Ed., Sept. 3, 2016 (Correct through NM 36/16)

9999

NSN 7642019999999

NGA Ref No. W0XZC9999

References to U.S. Chart No. 1 are shown in parentheses.

SOUNDINGS IN METERS

Prepared and published by the NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

WARNING

The prudent mariner will not rely solely on any single aid to navigation, particularly on floating aids. See paragraph No. 1 of Notice to Mariners No. 1 or Sailing Directions Planning Guides for information relative to NGA Charts.

Port Maury

SOUNDINGS IN METERS - SCALE 1:20,000

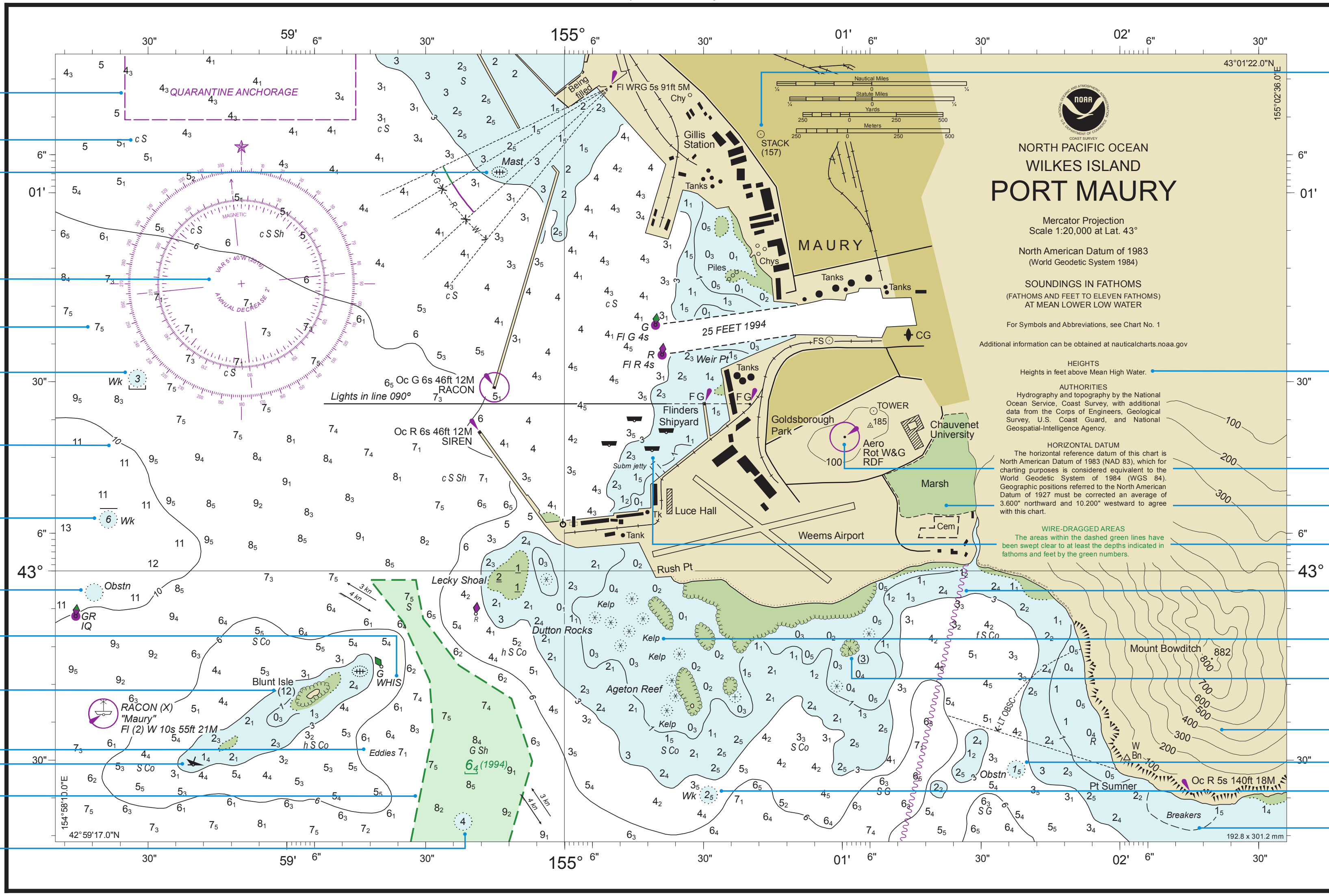
USERS SHOULD REFER CORRECTIONS, ADDITIONS, AND COMMENTS TO NGA'S MARITIME OPERATIONS DESK: TOLL FREE, 1-800-362-6289; COMMERCIAL, 571-557-5455; DSN 547-5455; SEND EMAIL TO NAVSAFETY@NGA.MIL; USE CONTACT LINKS FOR DNC AND MARITIME WEBSITES LOCATED AT http://msi.nga.mil/NGAPortal/MSI.portal; OR WRITE TO OFFICE OF MARITIME SAFETY, NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY, MAIL STOP N65, 7500 GEOINT DRIVE, SPRINGFIELD VA 22150-7500.

NOAA encourages users to submit inquiries discrepancies or comments about this chart at http://www.nauticalcharts.noaa.gov/staff/contact.htm.

SOUNDINGS IN FATHOMS

(FATHOMS & FEET TO 11 FATHOMS)

Formerly C&GS 4196, 1st Ed., Aug. 1971



- Limit of quarantine anchorage (N12.8)
- Sea bottom consists of coarse sand (J32, J1)
- Dangerous wreck with only mast visible (K25)
- Compass rose with magnetic variation (B70)
- Sounding in fathoms and feet (I10)
- Wreck over which depth is cleared by wire drag (K27)
- Depth curves in fathoms (I30)
- Unsurveyed wreck over which the exact depth is unknown but is considered to have a safe clearance to depth shown (K30)
- Obstruction over which depth is unknown (K40)
- Sound signal (R15)
- Height of island in feet above mean sea level (K10)
- Eddies (H45)
- Wreck showing portion of hull above sounding datum (K24)
- Swept area adequately sounded (swept by wire drag to depth indicated) (I24)
- High obstruction above swept depth (K1)
- Chimney, conspicuous (E22)
- Heights of land and conspicuous objects are given in feet above Mean High Water, unless otherwise stated in the title of the chart.
- Aeronautical light and radio direction finding station (P60)
- Marsh area (C33)
- Mooring buoy (Q40)
- Submarine cable (L30.1)
- Kelp (J13.2)
- Rock which covers and uncovers with height above chart sounding datum (K11)
- Topographic contours (C10)
- Obstruction over which depth is known (K41)
- Dangerous wreck over which depth is known (K26)
- Breakers (K17)

NSN 7642019999999
NGA Ref No. W0XZC9999

8th Ed., Sep. 2016

9999

Last Correction: 9/3/2016. Cleared through:
LNM: , NM: 3616 (9/3/2016)

References to U.S. Chart No. 1 are shown in parentheses.

CAUTION

This chart has been corrected from the Notice to Mariners (NM) published weekly by the National Geospatial-Intelligence Agency and the Local Notice to Mariners (LNM) issued periodically by each U.S. Coast Guard district to the dates shown in the lower left hand corner. Chart updates corrected from Notice to Mariners published after the dates shown in the lower left hand corner are available at nauticalcharts.noaa.gov.

Published at Washington, D.C.
U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
COAST SURVEY

WARNING

The prudent mariner will not rely solely on any single aid to navigation, particularly on floating aids. See U.S. Coast Guard Light List and U.S. Coast Pilot for details.

Port Maury

SOUNDINGS IN FATHOMS - SCALE 1:20,000

9999

CHAPTER 5

ECDIS

ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEMS

500. The Importance of Electronic Charts

From the very beginning of the human quest to travel by water, the core desire of the navigator has always been to answer the fundamental question, “Where, exactly, is my vessel?” As navigators labored to answer this question through the ages, increasingly more sophisticated fix positioning methods were developed. Techniques matured from the simple use of plotting by visually observing objects ashore, to understanding how to mathematically translate the observed altitudes of celestial bodies, and eventually fix in a position using radio and satellite signals. Regardless the method, until the development of electronic charting technologies, the end result was always the same: calculate latitude and longitude, then plot the vessel’s position on a paper chart. Only then could they begin to assess the safety of the ship and its progress toward its destination. Far more time was spent taking fixes, working out solutions, and plotting the results than on making assessments; and the fix only indicated where the ship was at the time the fix was taken, not where the vessel was in real time. The navigator was always “behind the vessel.” On the high seas this may be of little importance, but near shore, it becomes vitally essential.

Electronic charts automate the process of integrating real-time positions with the chart display and allow the navigator to continuously assess the position and safety of the vessel. Further, the GPS/DGPS fixes are far more accurate and taken far more often than any navigator ever could using manual methods. A good piloting team is expected to take and plot a fix every three minutes. An electronic chart system can do it once per second to a standard of accuracy at least an order of magnitude better.

An Electronic Chart Display and Information System (ECDIS) allows the integration of other operational data, such as ship's course and speed, depth soundings, automatic identification systems (AIS) information, and radar data into the display. Further, ECDIS allows automation of alarm systems to alert the navigator to potentially dangerous situations. Navigation with an ECDIS can also provide enhanced situational awareness of important events.

Finally, the navigator has a complete instantaneous picture of the instantaneous situation of the vessel and all charted dangers in the area. With a radar overlay, the tactical situation with respect to other vessels is clear as well. This chapter will discuss the various types of electronic charts, the **requirements** for using them, and their characteristics, capabilities and limitations.

501. Terminology

Before understanding what an electronic chart is and what it does, one must learn a number of terms and definitions. We must first make a distinction between official and unofficial charts. Official charts are those, and only those, issued officially by, or on the authority of, a Government authorized Hydrographic Office (HO), or other relevant government institution, and are designed to meet the requirements of marine navigation. Unofficial charts are produced by a variety of private companies and may or may not meet the same standards used by HO’s for data accuracy, currency, and completeness.

An **electronic chart system (ECS)** is a computer assisted navigation system capable of displaying electronic nautical charts and the vessel's position in near real time. An ECS does not meet all the input, display and functionality of an Electronic Chart Display and Information System.

An **electronic chart display and information system (ECDIS)** is a navigation information system which with adequate back-up arrangements can be accepted as complying with the up-to-date chart required by the 1974 SOLAS Convention, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation-related information.

An **electronic chart (EC)** is any digitized chart intended for display on a computerized navigation system.

An **electronic chart data base (ECDB)** is the digital database from which electronic charts are produced.

An **electronic navigational chart (ENC)** is the database, standardized as to content, structure and format, issued for use with ECDIS on the authority of government authorized hydrographic offices. The ENC contains all the chart information necessary for safe navigation and may contain supplementary information in addition to that contained in the paper chart (e.g. sailing directions) which may be considered necessary for safe navigation.

The **system electronic navigation chart (SENC)** means a database resulting from the transformation of the

ENC by ECDIS for appropriate use, updates to the ENC by appropriate means and other data added by the mariner. It is this database that is actually accessed by ECDIS for the display generation and other navigational functions, and is the equivalent to an up-to-date paper chart. The SENC may also contain information from other sources.

A **raster navigation chart (RNC)** is a raster-formatted chart produced by a national hydrographic office.

A **raster chart display system (RCDS)** is a system which displays official raster-formatted charts on an ECDIS system. Raster charts cannot take the place of paper charts because they lack key features required by the IMO, so that when an ECDIS uses raster charts it operates in the ECS mode.

Overscale and **underscale** refer to the display of electronic chart data at too large and too small a scale, respectively. In the case of overscale, the display is "zoomed in" too close, beyond the standard of accuracy to which the data was digitized. Underscale indicates that larger scale data is available for the area in question. ECDIS provides a warning in either case.

Raster chart data is a digitized image of a chart comprised of millions of pixels. All data is in one layer and one format. The video display simply reproduces the picture from its digitized data file. With raster data, it is difficult to change individual elements of the chart since they are not separated in the data file. Raster data files tend to be large, since a data point with associated color and intensity values must be entered for every pixel on the chart.

Vector chart data is data that is organized into many separate files or layers. It contains graphics files and programs to produce certain symbols, points, lines, and areas with associated colors, text, and other chart elements. The navigator can selectively display vector data, adjusting the display according to voyage needs. Vector data supports the computation of precise distances between features and can provide warnings when hazardous situations arise.

502. Components of ECS and ECDIS

The terms ECS and ECDIS encompasses many possible combinations of equipment and software designed for a variety of navigational purposes. In general, the following components comprise an ECS or ECDIS.

- **Computer processor, software, and network**: These subsystems control the processing of information from the vessel's navigation sensors and the flow of information between various system components. Electronic positioning information from GPS or DGPS, contact information from radar, and digital compass data, for example, can be integrated with the electronic chart data.

- **Chart database**: At the heart of any ECS lies a database of digital charts. It is this dataset, or a portion of it, that produces the chart seen on the display screen.

- **System display**: This unit displays the electronic chart and indicates the vessel's position on it, and provides other information such as heading, speed, distance to the next waypoint or destination, soundings, etc. There are two modes of display, **relative** and **true**. In the relative mode the ship remains fixed in the center of the screen and the chart moves past it. This requires a lot of computer power, as all the screen data must be updated and re-drawn at each fix. In true mode, the chart remains fixed and the ship moves across it. The display may also be north-up or course-up, according to the availability of data from a heading sensor such as a digital compass.

- **User interface**: This is the user's link to the system. It allows the navigator to change system parameters, enter data, control the display, and operate the various functions of the system. Radar may be integrated with the ECDIS or ECS for navigation or collision avoidance, but is not required by SOLAS regulations.

503. Legal Aspects of Using Electronic Charts

Requirements for carriage of charts are found in SOLAS Chapter V, which states in part: "All ships shall carry adequate and up-to-date charts... necessary for the intended voyage." As electronic charts have developed and the supporting technology has matured, regulations have been adopted internationally to set standards for what constitutes a "chart" in the electronic sense, and under what conditions such a chart will satisfy the chart carriage requirement.

Figure 503. USCG (NVIC 01-16) - Use of Electronic Charts and Publications in Lieu of Paper Charts, Maps and Publications.
http://www.dco.uscg.mil/Our-Organization/NVIC/

An extensive body of rules and regulations controls the production of ECDIS equipment, which must meet certain high standards of reliability and performance. Only those systems identified by the U.S. Coast Guard can relieve the navigator of the responsibility of maintaining a corrected paper chart. Certain U.S. flagged vessels are subject to domestic chart and publication carriage requirements codified in Titles 33 and 46 of the Code of Federal Regulations (C.F.R.). In February 2016, the U.S. Coast Guard issued Navigation and Vessel Inspection Circular (NVIC) 01-16, which states SOLAS-compliant equipment, three specific Radio Technical Commission for Maritime Services (RTCM) classes of ECS, and certain publications, will be accepted as the equivalent of the requirements described in the aforementioned C.F.R.s. NVIC 01-16 can be found at the link provided in Figure 503.

The presence of an electronic chart system is not, however, a substitute for good judgment, sea sense, and taking all reasonable precautions to ensure the safety of the vessel and crew.

An electronic chart system should be considered a navigational aid, one of many navigators might have at their disposal to help ensure a safe passage. While possessing revolutionary capabilities, it must be considered as a tool, not an infallible answer to all navigational problems. The rule for the use of electronic charts is the same as for all other navigational aids: The prudent navigator will never rely completely on any single one.

CAPABILITIES AND PERFORMANCE STANDARDS

504. ECDIS Performance Standards

The specifications for ECDIS consist of a set of interrelated standards from three organizations, the International Maritime Organization (IMO), the International Hydrographic Organization (IHO), and the International Electrotechnical Commission (IEC). The IMO published a resolution in November 1995 to establish performance standards for the general functionality of ECDIS, and to define the conditions for its replacement of paper charts. It consisted of a 15-section annex and 5 original appendices. Appendix 6 was adopted in 1996 to define the backup requirements for ECDIS. Appendix 7 was adopted in 1998 to define the operation of ECDIS in a raster chart mode. Previous standards related only to vector data.

The IMO performance standards refer to IHO Special Publication S-52 for specification of technical details pertaining to the ECDIS display. Produced in 2014, the 6th edition of S-52 includes appendices includes the Presentation Library and specifies updating, display, color, and symbology of official electronic navigational charts (ENC), as well as a revised glossary of ECDIS-related terms. The IMO performance standards also refer to IEC International Standard 61174 for the requirements of type approval of an ECDIS. Published in 1998, the IEC standard defines the testing methods and required results for an ECDIS to be certified as compliant with IMO standards. Accordingly, the first ECDIS was given type approval by Germany's classification society (BSH) in 1999. Since then, multiple other makes of ECDIS have gained type approval by various classification societies.

The IMO performance standards specify the following general requirements: Display of government-authorized vector chart data including an updating capability; enable route planning, route monitoring, manual positioning, and continuous plotting of the ship's position; have a presentation as reliable and available as an official paper chart; provide appropriate alarms or indications regarding displayed information or malfunctions; and permit a mode of operation with raster charts similar to the above standards.

The performance standards also specify additional functions, summarized as follows:

- Display of system information in three selectable levels of detail
- Means to ensure correct loading of ENC data and updates
- Apply updates automatically to system display
- Protect chart data from any alteration
- Permit display of update content
- Store updates separately and keep records of application in system
- Indicate when user zooms too far in or out on a chart (over- or under-scale) or when a larger scale chart is available in memory
- Permit the overlay of radar image and ARPA information onto the display
- Require north-up orientation and true motion mode, but permit other combinations
- Use IHO-specified resolution, colors and symbols
- Use IEC-specified navigational elements and parameters (range & bearing marker, position fix, own ship's track and vector, waypoint, tidal information, etc.)
- Use specified size of symbols, letters and figures at scale specified in chart data
- Permit display of ship as symbol or in true scale
- Display route planning and other tasks
- Display route monitoring
- Permit display to be clearly viewed by more than one user in day or night conditions
- Permit route planning in straight and curved segments and adjustment of waypoints
- Display a route plan in addition to the route selected for monitoring
- Permit track limit selection and display an indication if track limit crosses a safety contour or a selected prohibited area
- Permit display of an area away from ship while

continuing to monitor selected route

- Give an alarm at a selectable time prior to ship crossing a selected safety contour or prohibited area
- Plot ship's position using a continuous positioning system with an accuracy consistent with the requirements of safe navigation
- Identify selectable discrepancy between primary and secondary positioning system
- Provide an alarm when positioning system input is lost
- Provide an alarm when positioning system and chart are based on different geodetic datums
- Store and provide for replay the elements necessary to reconstruct navigation and verify chart data in use during previous 12 hours
- Record the track for entire voyage with at least four hour time marks
- Permit accurate drawing of ranges and bearings not limited by display resolution
- Require system connection to continuous position-fixing, heading and speed information
- Neither degrade nor be degraded by connection to other sensors
- Conduct on-board tests of major functions with alarm or indication of malfunction
- Permit normal functions on emergency power circuit
- Permit power interruptions of up to 45 seconds without system failure or need to reboot
- Enable takeover by backup unit to continue navigation if master unit fails,

Before an IMO-compliant ECDIS can replace paper charts on vessels governed by SOLAS regulations, the route of the intended voyage must be covered completely by ENC data, that ENC data must include the latest updates, the ECDIS installation must be IMO-compliant including the master-slave network with full sensor feed to both units, and the national authority of the transited waters must allow for paperless navigation through published regulations. Certified training in the operational use of ECDIS is required as per STCW 2010 when an ECDIS is installed. The U.S. Coast Guard also requires training for ECS-A in U.S. waters. Certification may include alternate forms of the same ECDIS family, such as Multifunction Display, chart administration and route planning application, electronic logbook functionality, radar overlay functionality, VDR via Ethernet, and AIS keyboard plus display function.

The certifying agency issues a certificate valid for five years. For renewal, a survey is conducted to ensure that systems, software versions, components and materials used comply with type-approved documents and to review possible changes in design of systems, software versions, components, materials performance, and make sure that such changes do not affect the type approval granted.

Manufacturers have been willing to provide type-approved ECDIS to vessel operators, but in a non-compliant installation. Without the geographical coverage of ENC data, the expensive dual-network installation required by ECDIS will not eliminate the requirement to carry a corrected portfolio of paper charts. These partial installations range from approved ECDIS software in a single PC, to ECDIS with its IEC-approved hardware. In these instances, plotting on paper charts continues to be the primary means of navigation. NOAA has been providing an ENC data sets for all US waters since 2014; NGA supplies ENC data sets where NGA is the prime charting authority (See Section 517). In June 2009, IMO SOLAS Chapter V was approved and states ships engaged in international voyages must be fitted with ECDIS by July 2018. This is driving the need for readily available ENCs worldwide. As governments regulate paperless transits, vessel operators are upgrading their installations to meet full IMO compliance, making ECDIS the primary means of navigation.

505. ECS Standards

Although the IMO has declined to issue guidelines on ECS, in the United States the Radio Technical Commission for Maritime Services (RTCM) developed a voluntary, industry-wide standard for ECS. At the time of publication, the RTCM Standard recognized three classes of ECS that have varying levels of navigation functionality. This construct provided greater flexibility for manufacturers and provided the U.S. Coast Guard with the opportunity to allow an ECS, which meets the RTCM standard, to replace the paper charts (Navigation and Vessel Inspection Circular 01-16). The RTCM ECS standard follows the international standards for either raster or vector data display, and includes the requirement for simple and reliable updating of information, or an indication that the electronic chart information has changed. The three classes of ECS recognized by the U.S. Coast Guard are described in Table 505.

The term ECS, however, includes a multitude of systems, including highly complex charting systems that display vector charts issued by an authorized hydrographic office on an environmentally hardened box, to a software system displaying propriety charts on a user-selected hardware. Those ECS not adhering to the RTCM standard identified by U.S. Coast Guard policy to replace paper charts must be considered a navigational aid, and should always be used with a corrected chart from a government authorized hydrographic office.

Some classes of RTCM ECS do not meet the performance standards of either ECDIS or RCDS. But an ECDIS can operate in ECS mode when using raster charts or when using unofficial vector charts. When a type-approved ECDIS is installed without being networked to a backup

USCG Recognized Classes of Electronic Chart Systems		
Class	Description/Purpose	Training
A	System is very similar to full ECDIS but does not meet full requirements. With required equipment interface (e.g. position fixing system, AIS, heading device, etc.), it can be primary means of navigation for non-SOLAS vessels.	Watch stander must have successful completion certificate from Coast Guard approved ECDIS course and endorsement on MMC.
B	Typically has less functionality than ECS 'A.' With required equipment interface (e.g. position fixing system, AIS, heading device, etc.), it can be primary means of navigation for non-SOLAS vessels operating within 12NM of territorial sea baseline.	Familiar with system prior to assuming watch duties.
C	Primarily designed as navigational aid to plot and monitor vessels position. With required equipment interface (e.g. position fixing system, AIS, heading device, etc.), it can be primary means of navigation for non-SOLAS vessels operating within 12NM of territorial sea baseline.	Familiar with system prior to assuming watch duties.

Table 505. RTCM ECS class type and description.

ECDIS, or when it is using unofficial ENC data, or ENC data without updates, it can be said to be operating in an ECS mode. In this configuration, the system cannot be substituted for official, corrected paper charts.

506. Display Characteristics

While manufacturers of electronic chart systems have designed their own proprietary colors and symbols, the IMO Performance Standard requires that all IMO approved ECDIS and some RTCM ECS follow the International Hydrographic Organization (IHO) S-52 publication, Specifications for Chart Content and Display Aspects of ECDIS. These specifications are embodied in Annex A of S-52, the ECDIS Presentation Library, most recently updated in 2014. Their development was a joint effort between Germany, Canada, and Australia during the 1990s. In order for ECDIS to enhance the safety of navigation, every detail of the display should be clearly visible, unambiguous in its meaning, and uncluttered by superfluous information. Some ECS continue to be free to develop independent of IHO control. In general, they seek to emulate the look of the traditional paper chart.

To reduce clutter, the IMO Standard lays down a permanent display base of essentials such as depths, aids to navigation, shoreline, etc., making the remaining information selectable. The navigator may then select only what is essential for the navigational task at hand. A black background display for night use provides good color contrast without compromising the mariner's night vision. Similarly, a “bright sun” color table is designed to output maximum luminance in order to be daylight visible, and the colors for details such as buoys are made as contrasting as possible.

The symbols for ENCs are based on the familiar paper chart symbols, with some optional extras such as simplified buoy symbols that show up better at night. Since ECDIS and ECS can be customized to each ship's requirements, new symbols were added such as a highlighted, mariner selectable, safety contour and a prominent isolated danger symbol. See Figure 506a and Figure 506b for an examples.

The Presentation Library is a set of colors and symbols together with rules relating them to the digital data of the ENC, and procedures for handling special cases, such as priorities for the display of overlapping objects. Every feature in the ENC is first passed through the look-up table of the Presentation Library that either assigns a symbol or line style immediately, or, for complex cases, passes the object to a symbology procedure. Such procedures are used for objects like lights, which have so many variations that a look-up table for their symbolization would be too long. The Presentation Library includes a Chart 1, illustrating the symbology. Given the IHO S-57 data standards and S-52 display specifications, a waterway should look the same no matter which hydrographic office produced the ENC, and no matter which manufacturer built the ECDIS.

The overwhelming advantage of the vector-based ECDIS or ECS display is its ability to remove cluttering information not needed at a given time. By comparison, the paper chart and its raster equivalent is an unchangeable diagram. A second advantage is the ability to orient the display course-up when this is convenient, while the text remains screen-up.

Taking advantage of affordable yet high-powered computers, some ECDIS and ECS now permit a split screen display, where mode of motion, orientation and scale are individually selectable on each panel. This permits, for example, a north-up small-scale overview in true motion alongside a course-up large-scale view in relative motion. Yet another display advantage occurs with zooming, in that symbols and text describing areas center themselves automatically in whatever part of the area appears on the screen. None of these functions are possible with raster charts.

The display operates by a set of rules, and data is arranged hierarchically, For example, where lines overlap, the less important line is not drawn. A more complex rule always places text at the same position relative to the object it applies to, no matter what else may be there. Since a long name or light description will often over-write another object, the only solution is to zoom in until the objects separate from each other. Text is written automatically when the object it refers to is on the display. Because it causes so much clutter, and is seldom vital for safe navigation, it, text portrayal is an option under the "all other information" display level.

Flexibility in display scale requires some indication of distance to objects seen on the display. Some manufacturers use the rather restrictive but familiar radar range rings to provide this, while another uses a line symbol keyed to data's original scale. The ECDIS design also includes a one-mile scalebar at the side of the display, and an optionally displayed course and speed-made-good vector for own ship. There may be a heading line leading from the vessel's position indicating her future track for one minute, three minutes, or some other selectable time.

To provide the option of creating manual chart corrections, ECDIS includes a means of drawing lines, adding text and inserting stored objects on the display. These may be saved as user files, called up from a subdirectory, and edited on the display. Once loaded into the SENC, the objects may be selected or de-selected just as with other objects of the SENC.

Display options for ECDIS and ECS include transfer of ARPA-acquired targets and radar image overlay. IMO standards for ECDIS require that the operator be able to deselect the radar picture from the chart with a single operator action for fast "uncluttering" of the chart presentation.

In the 2014 Presentation Library update, several changes were made to include:

- A new "Detection and Notification of Navigational Hazard" section: For each ENC feature and its associated attributes, ECDIS will define the priority of an alert to be raised when a navigational hazard is detected.
- A new "Detection of Areas, for which Special Conditions Exist" section: This lists the ENC features and attributes that will raise an indication or alert in the ECDIS as defined by the mariner.
- The ability to turn on and off isolated dangers in shallow water.
- New standardized symbols to identify where automatic ENC updates have been applied and indicate where features with temporal attributes are located.
- Display names of anchorage areas and fairways.
- A means for the mariner to insert a date or date range within the ECDIS to display date dependent features.

507. Units, Data Layers and Calculations

ECDIS uses the following units of measure:

- **Position:** Latitude and longitude will be shown in degrees, minutes, and decimal minutes, normally based on WGS-84 datum.
- **Depth:** Depths will be indicated in meters and decimeters.
- **Height:** Meters
- **Distance:** Nautical miles and tenths, or meters
- **Speed:** Knots and tenths

ECDIS requires data layers to establish a priority of data displayed. The minimum number of information categories required and their relative priority from highest to lowest are listed below:

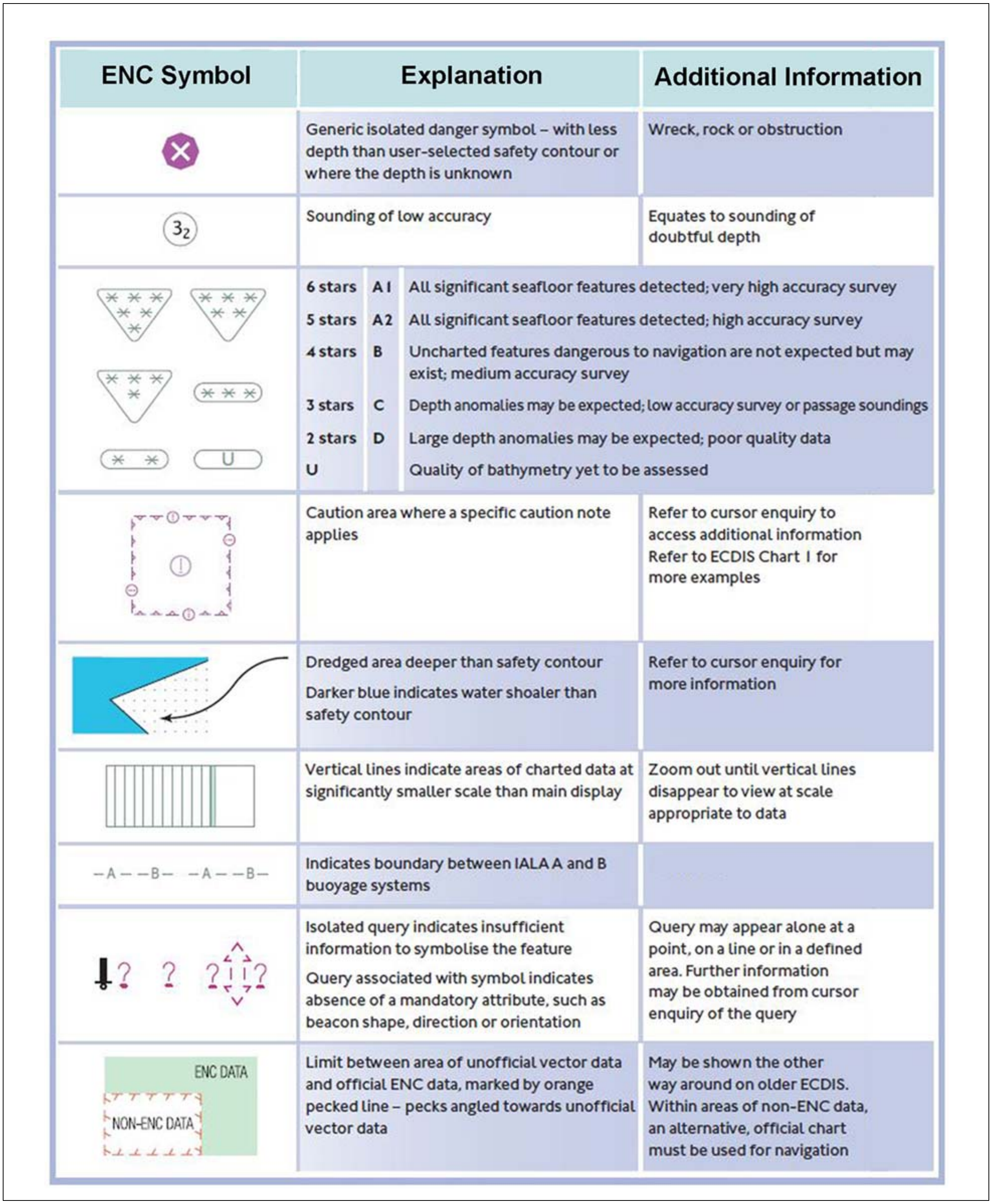
- ECDIS warnings and messages
- Hydrographic office data
- *Notice to Mariner*s information
- Hydrographic office cautions
- Hydrographic office color-fill area data
- Hydrographic office on demand data
- Radar information
- User's data
- Manufacturer's data
- User's color-fill area data
- Manufacturer's color-fill area data

As a minimum, an ECDIS system must be able to perform the following calculations and conversions:

- Geographical coordinates to display coordinates, and display coordinates to geographical coordinates.
- Transformation from local datum to WGS-84.
- True distance and azimuth between two geographical positions.
- Geographic position from a known position given distance and azimuth.
- Projection calculations such as great circle and rhumb line courses and distances.

508. Alerts and Indications

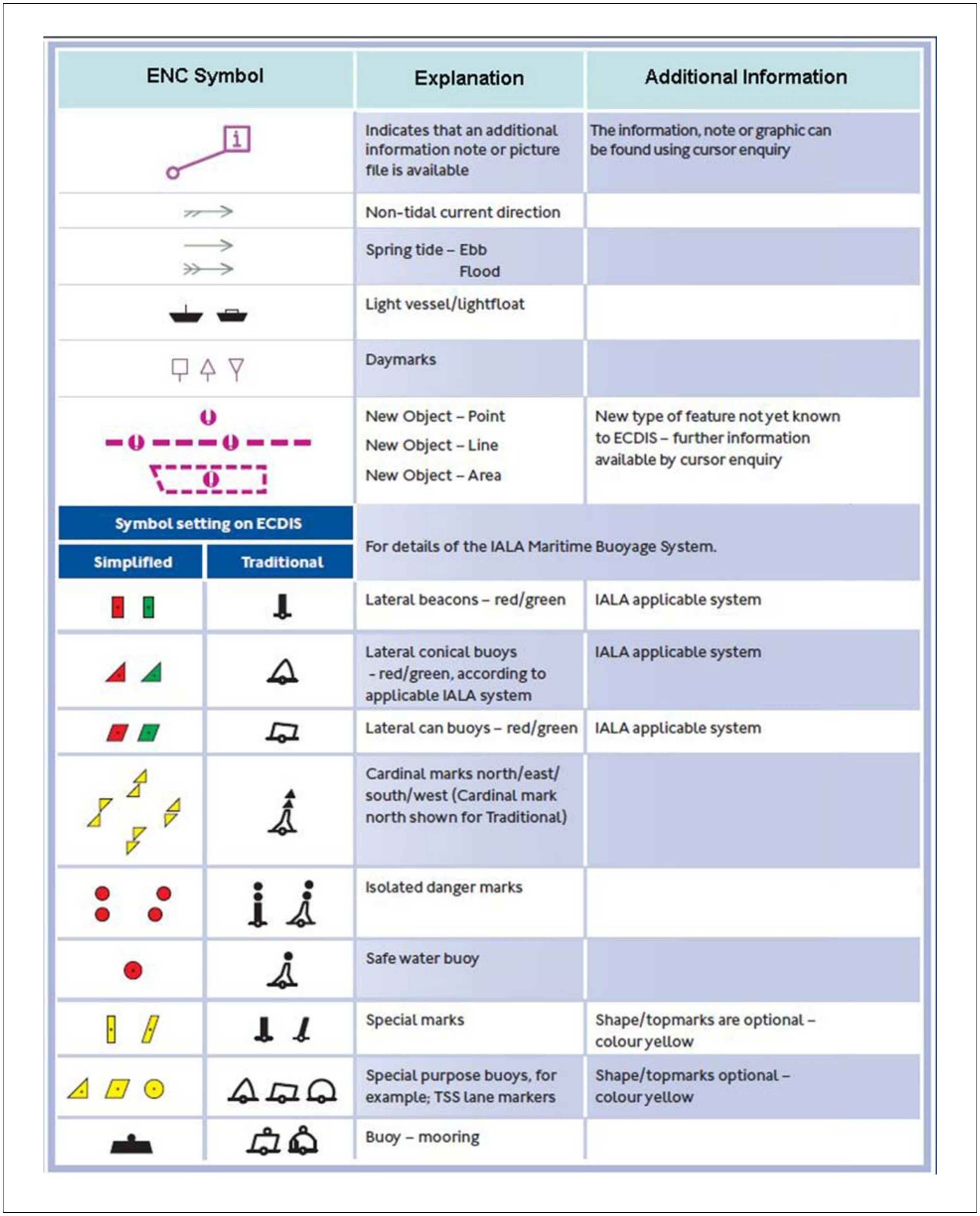
Knowledge and ability to interpret and react to the



ENC Symbol	Explanation	Additional Information
	Generic isolated danger symbol – with less depth than user-selected safety contour or where the depth is unknown	Wreck, rock or obstruction
3_2	Sounding of low accuracy	Equates to sounding of doubtful depth
	6 stars — A1	All significant seafloor features detected; very high accuracy survey
	5 stars — A2	All significant seafloor features detected; high accuracy survey
	4 stars — B	Uncharted features dangerous to navigation are not expected but may exist; medium accuracy survey
	3 stars — C	Depth anomalies may be expected; low accuracy survey or passage soundings
	2 stars — D	Large depth anomalies may be expected; poor quality data
U	U	Quality of bathymetry yet to be assessed
	Caution area where a specific caution note applies	Refer to cursor enquiry to access additional information Refer to ECDIS Chart I for more examples
	Dredged area deeper than safety contour Darker blue indicates water shoaler than safety contour	Refer to cursor enquiry for more information
	Vertical lines indicate areas of charted data at significantly smaller scale than main display	Zoom out until vertical lines disappear to view at scale appropriate to data
—A— —B— —A— —B—	Indicates boundary between IALA A and B buoyage systems	
	Isolated query indicates insufficient information to symbolise the feature Query associated with symbol indicates absence of a mandatory attribute, such as beacon shape, direction or orientation	Query may appear alone at a point, on a line or in a defined area. Further information may be obtained from cursor enquiry of the query
ENC DATA / NON-ENC DATA	Limit between area of unofficial vector data and official ENC data, marked by orange pecked line – pecks angled towards unofficial vector data	May be shown the other way around on older ECDIS. Within areas of non-ENC data, an alternative, official chart must be used for navigation

Figure 506a. Example of ENC symbology.

ECDIS alarms requires the understanding the conditions that trigger alarms or indications. Appendix 5 of the IMO Performance Standard specifies that ECDIS must monitor the status of its systems continuously, and must provide alarms and indications for certain functions if a condition occurs that requires immediate attention. Indications may be either visual or audible. An alarm must be audible and may be visual as well (It is important to note significant changes are coming to this crucial functionality in new ECDIS on August 1, 2017 and not currently reflected here).



ENC Symbol		Explanation	Additional Information
		Indicates that an additional information note or picture file is available	The information, note or graphic can be found using cursor enquiry
		Non-tidal current direction	
		Spring tide – Ebb Flood	
		Light vessel/lightfloat	
		Daymarks	
		New Object – Point New Object – Line New Object – Area	New type of feature not yet known to ECDIS – further information available by cursor enquiry
Symbol setting on ECDIS		For details of the IALA Maritime Buoyage System.	
Simplified	Traditional		
		Lateral beacons – red/green	IALA applicable system
		Lateral conical buoys – red/green, according to applicable IALA system	IALA applicable system
		Lateral can buoys – red/green	IALA applicable system
		Cardinal marks north/east/south/west (Cardinal mark north shown for Traditional)	
		Isolated danger marks	
		Safe water buoy	
		Special marks	Shape/topmarks are optional – colour yellow
		Special purpose buoys, for example; TSS lane markers	Shape/topmarks optional – colour yellow
		Buoy – mooring	

Figure 506b. Example of ENC symbology.

An alarm is required for the following:

- Exceeding cross-track limits
- Crossing selected safety contour
- Deviation from route
- Position system failure
- Approaching a critical point
- Chart on different geodetic datum from positioning system

An alarm or indication is required for the following:

- Largest scale for alarm (indicates that presently loaded chart is too small a scale to activate anti-grounding feature)
- Area with special conditions (means a special type of chart is within a time or distance setting)
- Malfunction of ECDIS (means the master unit in a master-backup network has failed)

An indication is required for the following:

- Chart overscale (zoomed in too close)
- Larger scale ENC available
- Different reference units (charted depths not in meters)
- Route crosses safety contour
- Route crosses specified area activated for alarms
- System test failure

As these lists reveal, ECDIS has been programmed to constantly "know" what the navigation team should know, and to help the team to apply its experience and judgment through the adjustment of operational settings.

This automation in ECDIS has two important consequences: First, route or track monitoring does not replace situational awareness; it only enhances it. The alarm functions, while useful, are partial and have the potential to be in error, misinterpreted, ignored, or overlooked.

Secondly, situational awareness must now include, especially when ECDIS is used as the primary means of navigation, the processes and status of the electronic components of the system. This includes all attached sensors, the serial connections and communication ports and data interfaces, the computer processor and operating system, navigation and chart software, data storage devices, and power supply. Furthermore, these new responsibilities must still be balanced with the traditional matters of keeping a vigilant navigational watch.

ECDIS or not, the windows in the pilothouse are still the best tool for situational awareness. Paradoxically, ECDIS makes the navigator's job both simpler and more complex.

It is expected the **new ECDIS standards** when released and implemented (August 1, 2017) will provide better alarm management. Reducing alarm fatigue, the ECDIS will produce audible alarms for only three conditions: Anti-grounding, anti-route, and anti-collision. Visual alerts and indications will display in four categories: Warning, Caution, Indication, and Permanent. Aiding the mariner with alarm privatization, the new ECDIS will use a color coding system:

- Red - visible and audible alarm that will require immediate action
- Orange - visual indication that needs attention
- Yellow - visual indication that needs to be addressed in time

Orange and yellow indications can be upgraded to red if not addressed.

509. ECDIS Outputs

During the past 12 hours of the voyage, ECDIS must be able to reconstruct the navigation and verify the official database used. Recorded at one minute intervals, the information includes:

- Own ship's past track including time, position, heading, and speed
- A record of official ENC used including source, edition, date, cell and update history

It is important to note that if ECDIS is turned off, such as for chart management or through malfunction, voyage recording ceases, unless a networked backup system takes over the functions of the master ECDIS. In that case, the voyage recording will continue, including an entry in the electronic log for all the alarms that were activated and reset during the switchover. Voyage files consist of logbook files, track files and target files. The file structure is based on the date and is automatically created at midnight for the time reference in use. If the computer system time is used for that purpose, the possibility exists for overwriting voyage files if the system time is manually set back. Allowing GPS time as the system reference avoids this pitfall.

In addition, ECDIS must be able to record the complete track for the entire voyage with time marks at least once every four hours. ECDIS should also have the capability to preserve the record of the previous 12 hours of the voyage. It is a requirement that the recorded information be inaccessible to alteration. Preserving voyage files should follow procedures for archiving data. Unless radar overlay data is being recorded, voyage files tend to be relatively small, permitting backup onto low-capacity media, and purging from system memory at regular intervals. (This form of backing up should not be confused with the network master-slave backup system.)

Adequate backup arrangements must be provided to ensure safe navigation in case of ECDIS failure. This includes provisions to take over ECDIS functions so that an ECDIS failure does not develop into a critical situation, and a means of safe navigation for the remaining part of the voyage in case of complete failure.

510. Voyage Data Recorder (VDR)

The purpose of the voyage data recorder (VDR) is to provide accurate historical navigational data in the investigation of maritime incidents. It is additionally useful for system performance monitoring. A certified VDR configuration records all data points, as per IMO Resolution A.861(20) & EC Directive 1999/35/EC. Some of the voyage data can be relayed through ECDIS. A fully IEC compliant data capsule passes fire and immersion tests.

SOLAS chapter V, regulation 20 affects ships more than 3,000 gross tons sailing internationally. As of 2010, these ships are required to properly install a VDR or simplified Voyage Data Recorder (s-VDR). Ship owners may apply for an exemption through their Administration.

VDR features include:

- Navigation information recording: ship's position, date and time, current chart, last chart update, speed heading, radar data, Automatic Identification System data, echo depth sounder.
- Internal conditions recording: bridge audio, ship's alarm system, rudder order and response, engine order and response, hull openings (door) status, watertight and fire door status, accelerations and hull stress.
- External conditions recording: communications audio, wind speed and direction.
- Uninterruptible power supply (UPS): provided through battery operated UPS or through ship's emergency electrical power supply.
- Hardened fixed data capsule.
- Remote data recovery and shoreside playback: Options available in several systems.
- Annual system certification: The IMO requires that the VDR system, including all sensors, be subjected to an annual performance test for certification.

DATA FORMATS

511. Official Vector Data

How ECDIS and ECS operate depends on what type of chart data is used. ENC's (electronic navigational charts) and RNC's (raster navigational charts) are approved for use in ECDIS. By definition both ENC's and RNC's are issued under the authority of national hydrographic offices (HO's). ECDIS functions as a true ECDIS when used with corrected ENC data, but ECDIS operates in the less functional raster chart display system (RCDS) mode when using corrected RNC data. When ECDIS is used with non-official vector chart data (corrected or not), it operates in the ECS mode.

In vector charts, hydrographic data is comprised of a series of files in which different layers of information are stored or displayed. This form of "intelligent" spatial data is obtained by digitizing information from existing paper charts or by storing a list of instructions that define various position-referenced features or objects (e.g., buoys, lighthouses, etc.). In displaying vector chart data on ECDIS, the user has considerable flexibility and discretion regarding the amount of information that is displayed.

An ENC is vector data conforming to the IHO S-57 ENC product specification in terms of content, structure and format. An ENC contains all the chart information necessary for safe navigation and may contain supplementary information in addition to that contained in the paper chart. In general, an S-57 ENC is a structurally layered data set designed for a range of hydrographic applications. As defined in IHO S-57 Edition 3, the data is comprised of a series of points, lines, areas, features, and objects. The minimum size of a data set is a cell, which is a spherical rectangle (i.e., bordered by meridians and latitudes). Adjacent cells do not overlap. The scale of the data contained in the cell is dependent upon the navigational purpose (e.g., general, coastal, approach, harbor).

Under S-57, cells have a standard format but do not have a standard coverage size. Instead, cells are limited to 5mb of data. S-57 cells are normally copy protected and therefore require a permit before use is allowed. These permits are delivered as either a file containing the chart permits or as a code. In both cases the first step is to install the chart permit into the ECDIS. Some hydrographic offices deliver S-57 cells without copy protection and therefore permits are not required.

Any regional agency responsible for collecting and distributing S-57 data, such as PRIMAR and IC-ENC, will also maintain data consistency. National hydrographic offices are responsible for producing S-57 data for their own country area. Throughout the world, hydrographic offices have been slow to produce sufficient quantities of ENC data. This is the result of standards that have been evolving over several years, and that vector data is much harder to collect than raster data.

Several commercial manufacturers have developed non S-57 vector databases beyond those that have been issued by official hydrographic offices. These companies are typically manufacturers of ECDIS or ECS equipment or have direct relationships with companies that do, and typically have developed data in proprietary format in order to provide options to raster charts in the absence of ENC data. HO-issued paper charts provide the source data for these formats, although in some cases non-official paper charts are used. In some cases, ECS manufacturers provide a regular updating and maintenance service for their vector data, resulting in added confidence and satisfaction among users. The manufacturer's source of the updates is through the HO. Hence, these two particular non-official formats allow for a very high degree of confidence and satisfaction among mariners using this data.

ECS sometimes apply rules of presentation similar to officially specified rules. Thus information is displayed or removed automatically according to scale level to manage clutter. The same indications pertinent to overscaling ENC apply to private vector data. Since the chart data is not ENC, the systems must display that nonofficial status when used in an ECDIS.

512. IHO S-100

S-57, the current IHO Transfer Standard for Digital Hydrographic Data, adopted in 1992, was created to support multiple hydrographic data types and associated software. It is an encapsulation and encoding specification guide used for ENC and ECDIS. The S-57 limitations in flexibility stem not from updating the specifications, but from the manufacturer and shipping company update cycles; this potential time gap puts the mariner to sea with systems in non-compliance with current specification. In 2001, S-100, the IHO Universal Hydrographic Data Model, was put into the work plan of the IHO Transfer Standards Maintenance and Applications Development (TSMAD) Working Group. In 2010, it was adopted by the IHO and became an active international encapsulation standard. In order to ensure the mariner has the most up to date information that can be displayed properly, S-100 aligns with international geospatial standards, in particular ISO19100. This will allow easier integration of data and applications into GIS based solutions. S-100 will eventually replace the encapsulation segment S-57 while S-101 will replace the encoding segment of S-57.

S-100 supports a broader base of data sources, such as imagery, gridded data, high-density bathymetry, 3-D, and data with time variances. S-57 is limited with its fixed maintenance system and it cannot support future requirements without manufacturer development. One of the new features of S-100 will be the addition of the portrayal catalog, a rule set for depicting encoded features as graphics. This eliminates the dependency of updates to the specifications on manufacturer development. This allows the mariner access to the latest specification updates outside of bridge maintenance cycles. As geospatial information has become more and more prevalent in the maritime world, S-100 allows for a common encapsulation for the various data streams including charts, bathymetry, messages, and aids to navigation. Improvements and extensions will be developed with the help of the GIS domain, instead of isolated from it. S-100 will also allow government and commercial organizations to better support the applications, bringing the cost of upkeep lower and reaching a broader spectrum of clients and allow for data sharing. It will be well-suited for use with web-based applications to better acquire, process, analyze and present data.

Benefits of S -100 include:

- Portrayal catalogs
- Feature catalogs
- Flexible version control
- Improved metadata storage
- Spatial geometry
- Use of imagery and gridded data
- Multiple encodings
- Standardized product specifications
- Continuous maintenance

From the S-100 framework, the S-101 ENC Product Specification is being developed. It will take several years before S-100 and S-101 are fully implemented; development of the S-101 test bed, ECDIS on-shore and sea trials, Original equipment manufacturer (OEM) development of ENC Production Systems are still in work. After S-101 is released for operational use, projected for 2019, conversion of data from S-57 to S-101 data will need to take place as well as Electro-optical multifunction system (EOMS) executing S-100 based ECDIS for use.

Additional information about S-100 is available for download from the web via the link provided in Figure 512.

Figure 512. IHO information on the S-100 Universal Hydrographic Data Model.
https://www.iho.int/srv1/index.php?option=com_content&view=article&id=586&Itemid=1011&lang=en.

513. Raster Data

Raster navigational chart (RNC) data is stored as picture elements (pixels). Each pixel is a minute component of the chart image with a defined color and brightness level. Many new RNC are created from the vector data used for ENC and DNC. However, raster-scanned images are derived by scanning paper charts to produce a digital photograph of the chart. In either case, raster data may appear more familiar, but it presents many limitations to the user.

The official raster chart formats are:

ARCS (British Admiralty)
Seafarer (Australia)
BSB (U.S., NOAA)

These charts are accurate representations of the paper chart with every pixel geographically referenced. Where applicable, horizontal datum shifts are included with each chart to enable referencing to WGS84. This permits compatibility with information overlaid on the chart. *Note: Not all available charts have WGS84 shift information.* Extreme caution is necessary if the datum shift cannot be determined exactly.

Raster nautical charts require significantly more computer memory than do vector charts to be displayed. Whereas a world portfolio of more than 7500 vector charts may occupy about 500mb, a typical coastal region in raster format may consist of just 40 charts and occupy more than 1000mb of memory. For practical reasons, most of a portfolio of raster charts should not be loaded into the ECDIS hard drive unless one is route planning or actually sailing in a given region. To update RNC the user typically must load a new version of the chart.

Certain non-official raster charts are produced that cover European and some South American waters. These are scanned from local paper charts. Additionally, some ECDIS and ECS manufacturers also produce raster charts in proprietary formats.

In 1998 the IMO's Maritime Safety Committee (MSC 70) adopted the Raster Chart Display System (RCDS) as Appendix 7 to the IMO Performance Standards. The IMO-IHO Harmonization Group on ECDIS (HGE) considered this issue for over three years. Where IHO S-57 Ed. 3 ENC data coverage is not available, raster data provided by official HO's can be used as an interim solution. But this RCDS mode does not have the full functionality of an otherwise IMO-compliant ECDIS using ENC data. Therefore, RCDS does not meet SOLAS requirements for carriage of paper charts, meaning that when ECDIS equipment is operated in the RCDS mode, it must be used together with an appropriate portfolio of corrected paper charts.

Some of the limitations of RCDS compared to ECDIS include:

- Chart features cannot be simplified or removed to suit a particular navigational circumstance or task.
- Orientation of the RCDS display to course-up may affect the readability of the chart text and symbols since these are fixed to the chart image in a north-up orientation.
- Depending on the source of the raster chart data, different colors may be used to show similar chart information, and there may be differences between colors used during day and night time.
- The accuracy of the raster chart data may be less than that of the position-fixing system being used.
- Unlike vector data, charted objects on raster charts do not support any underlying information.
- RNC data will not trigger automatic alarms. (However, some alarms can be generated by the RCDS from user-inserted information.).
- Soundings on raster charts may be in fathoms and feet, rather than meters.

The use of ECDIS in RCDS mode can only be considered as long as there is a backup folio of appropriate up-to-date paper charts.

INTEGRATED BRIDGE SYSTEMS

514. Description

An Integrated Bridge System (IBS) is a combination of equipment and software that use interconnected controls and displays to present a comprehensive suite of navigational information to the mariner. Rules from classification societies such as Det Norske Veritas (DNV) specify design criteria for bridge workstations. Their rules define tasks to be performed, and specify how and where equipment should be sited to enable those tasks to be performed. Equipment carriage requirements are specified for ships according to the requested class certification or notation. Publication IEC 61029 defines operational and performance requirements, methods of testing, and required test results for IBS.

Classification society rules address the total bridge system in four parts: technical system, human operator, man/machine interface, and operational procedures. The DNV classifies IBS with three certifications: NAUT-C covers bridge design; W1-OC covers bridge design; instrumentation and bridge procedures; W1 augments certain portions of W1-OC.

An IBS generally consists of at least:

- Dual ECDIS installation – one serving master and the other as backup and route planning station
- Dual radar/ARPA installation
- Conning display with a concentrated presentation of navigational information (the master ECDIS)
- DGPS positioning
- Ship's speed measuring system
- Auto-pilot and gyrocompass system
- Full GMDSS functionality

Some systems include full internal communications, and a means of monitoring fire control, shipboard status alarms, and machinery control. Additionally, functions for the loading and discharge of cargo may also be provided.

An IBS is designed to centralize the functions of monitoring collision and grounding risks, and to automate navigation and ship control. Control and display of component systems are not simply interconnected, but often share a proprietary language or code. Several instruments and indicators are considered essential for safe and efficient performance of tasks, and are easily readable at the navigation workstation, such as heading, rudder angle, depth, propeller speed or pitch, thruster azimuth and force, and speed and distance log.

Type approval by Det Norske Veritas for the DNV-W1-ANTS (Automatic Navigation and Track-Keeping System) certification is given to ship bridge systems designed for one-man watch (W1) in an unbounded sea area. DNV also provides for the other two class notations, NAUT-C and W1-OC. The W1 specifications require the integration of:

- CDIS (providing the functions of safety-contour checks and alarms during voyage planning and execution)
- Manual and automatic steering system (including software for calculation, execution and adjustments to maintain a pre-planned route, and including rate of turn indicator)
- Automatic Navigation and Track-keeping System (ANTS)
- Conning information display
- Differential GPS (redundant)
- Gyrocompass (redundant)
- Radar (redundant) and ARPA
- Central alarm panel
- Wind measuring system
- Internal communications systems
- GMDSS
- Speed over ground (SOG) and speed through water (STW or Doppler log)
- Depth sounder (dual transducer >250m)
- Course alteration warnings and acknowledgment
- Provision to digitize paper charts for areas not covered by ENC data

The W1 classification requires that maneuvering information be made available on the bridge and presented as a pilot card, wheelhouse poster, and maneuvering booklet. The information should include characteristics of speed, stopping, turning, course change, low-speed steering, course stability, trials with the auxiliary maneuvering device, and man-overboard rescue maneuvers.

The W1-OC and W1 classifications specify responsibilities of ship owner and ship operator, qualifications, bridge procedures, and particular to W1, a requirement for operational safety standards. The W1 operational safety manual requires compliance with guidelines on bridge organization, navigational watch routines, operation and maintenance of navigational equipment, procedures for arrival and departure, navigational procedures for various conditions of confinement and visibility, and system fallback procedures. Both classifications also require compliance with a contingency and emergency manual, including organization, accident, security, evacuation, and other related issues.

MILITARY ECDIS

515. ECDIS-N

In 1998, the U.S. Navy issued a policy letter for a naval version of ECDIS, called ECDIS-N, and included a performance standard that not only conforms to the IMO Performance Standards, but extends it to meet unique requirements of the U.S. Department of Defense.

A major difference from an IMO-compliant ECDIS is the requirement that the ECDIS-N SENC must be the Digital Nautical Chart (DNC) issued by the National Geospatial-Intelligence Agency (NGA). The DNC conforms to the U.S. DoD standard Vector Product Format (VPF), an implementation of the NATO DIGEST C Vector Relational Format..

The U.S. Navy uses the Voyage Management System (VMS) software as the ECDIS-N compliant system. Greater than 95% of the fleet is certified to operate without paper charts. VMS was selected for use by the Navy in 2002, based on the large presence of VMS in the surface fleet Integrate Bridge Systems and in the submarine fleet BPS radar system. The current series of VMS software, the 9.x series, is being fielded in 2017. This will replace the 6.x, 7.x and 8.x versions in the fleet and reduce the number of fielded variants of VMS. In addition to VMS, many ships and combatant craft use the Common Geospatial Extensible Navigation Toolkit (COGENT) 2.4 software for electronic chart navigation situational awareness and mission support.

The Navy plans to replace the ECDIS-N with a new program of record called **Navy ECDIS**. Navy ECDIS will be based on the NATO Warship ECDIS (WECDIS) standard and also on a U.S. Navy specific Software Requirements Document (SRD). The Navy ECDIS software is being procured competitively and is expected to start fielding in 2019.

516. The Digital Nautical Chart

NGA produces DNC, a vector-based digital product housed in a global database designed to support marine navigation and Geographic Information Systems (GIS) applications. This product contains vector data and feature content thematically layered and relationally structured to support ECDIS. DNC is produced in the standard VPF, a non s-57 data format, and conforms to DNC (MIL-PRF-80923) specifications, which allows for modeling real world features in digital geographic databases. The database underlying the DNC portfolio uses a table-based geo-relational data model containing significant maritime features considered essential for safe marine navigation. It is designed to conform to the IMO Performance Standard and IHO specifications for ECDIS.

The DNC database is based on and developed with feature content from traditional paper charts produced by NGA and NOS. This content is updated regularly with both foreign partner charts and NOS charts to reflect the latest information from the various charting authorities. Although the majority of the DNC portfolio is unclassified, a significant portion is labeled Limited Distribution (LIMDIS) to protect the copyrights and sensitive feature data provided by NGA's foreign partners, therefore, DNC is primarily developed and maintained for use by Department of Defense (DoD) agencies and departments including, the U.S. Navy, U.S. Coast Guard, government agencies, and government/US military sponsored contractors. DNC data for U.S. waters is generally available for public use and is available for download from NGA's website.

DNC Library Categories		
Library Category	Scale	Purpose
General	> 1:500K	The smallest scale charts used for planning, fixing position at sea, and for plotting while proceeding on an ocean voyage. The shoreline and topography are generalized and only offshore soundings, the principal navigational lights, outer buoys, and land-marks visible at considerable distances are shown.
Coastal	1:75K - 1:500K	Intended for inshore coastwise navigation where the course may lie inside outlying reefs and shoals, for entering or leaving bays and harbors of considerable width, and for navigating large inland waterways.
Approach	1:25K - 1:75K	Intended for approaching more confined waters such as bays or harbors.
Harbor	1 < 1:50K	Intended for navigation and anchorage in harbors and small waterways
Browse Index	1:3,1000,000	Provides a global overview of the DNC coverage displaying geographical boundaries.

Table 516a. DNC library categories according to scale.

The DNC database consists of 29 DNC geographic regions that provide a worldwide footprint containing over 5,000 charts of varying scales resulting in global coverage between 84 degrees N and 81 degrees S. The 29 regions are further broken down by libraries. The DNC portfolio comprises some 3,800 or more DNC libraries created from over 8,600 Standard Nautical Charts (SNC). Each DNC library represents a different geographic area of interest and level of detail (i.e. scale). The libraries are organized as tiles according to the World Geodetic Reference System (GEOREF) tiling scheme. The libraries have been designed to support various navigation and piloting maneuvers as well as GIS applications.

The Horizontal datum in DNC is WGS 84 (considered equivalent to NAD 83 in the U.S.). There are three vertical datums within the DNC database; two vertical datums related are topographic and the third is hydrographic. Topographic features are referenced to Mean Sea Level, and the shoreline is referenced to Mean High Water. Hydrography is referenced to a low water level most suitable for the region being charted. All measurements are metric.

The DNC data is stored in libraries; each library represents a different geographic area of interest and level of detail (i.e. scale). The libraries are as tiles according to the World Geodetic Reference System (GEOREF) tiling scheme. The DNC contains four library categories: Harbor, Approach, Coastal, and General, based on scale (from largest to smallest scale, respectively) and purpose. A Browse Index provides library names and footprints.

The DNC data is grouped and stored in the following five library scales in Table 516a. For voyage planning NGA provides a DNC Regions graphic, which is available on the DNC website (see Figure 516a).

The naming convention used for Harbor and Approach libraries are the same (e.g., H0145820 or A1708470). The first character signifies the category type (Harbor or Ap-

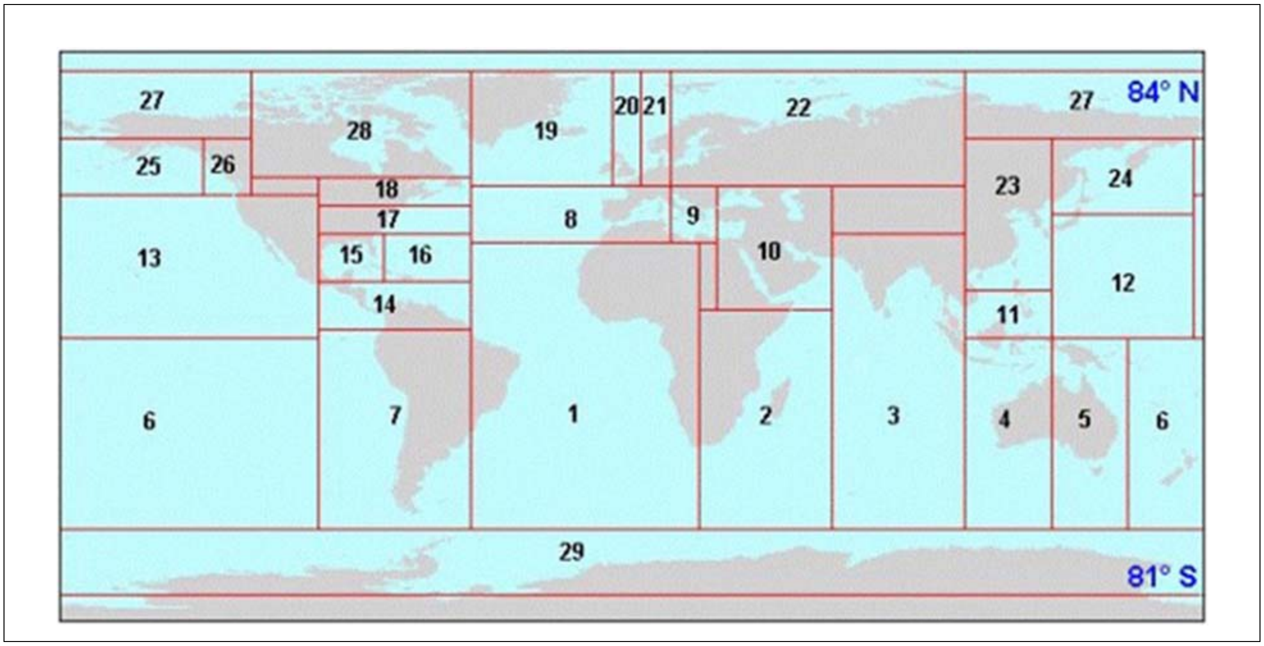


Figure 516a. DNC Regions graphic.

proach). The next two characters are the DNC geographic region number (e.g., 17 is the East Coast of the United States). The last five characters are the five-digit World Port Index (WPI) number.

The naming convention used for Coastal and General libraries start with a three letter code (COA or GEN) followed by the two-digit disc/geographic region number and a letter if the disc includes more than one library of that type (e.g., GEN1720a and GEN20b). The World Port Index reference is not included in the Coastal and General library naming convention.

DNC data is classified into and layered in 12 related feature class thematic layers:

- Cultural Landmarks (CUL)
- Data Quality (DQY)
- Earth Cover (ECR)
- Environment (ENV)
- Hydrography (HYD)
- Inland Waterways (IWY)
- Landcover (LCR)
- Limits (LIM)
- Aids to Navigation (NAV)
- Obstructions (OBS)
- Port Facilities (POR)
- Relief (REL)

Also, there are two additional layers found within the DNC data structure called Library Reference (LIBREF) and Tile Reference (TILEREF). These layers are used within the ECDIS-N to find the stored DNC data. DNC content is generally aligned to mirror what is found on a Standard Nautical Chart (SNC) printed on paper. However, one of the advantages of a digital product is the ability to provide the mariner with additional information when necessary to help them augment their understanding of the navigation space.

The publicly releasable DNC data is available for download at the following web location:

WWW: https://dnc.nga.mil

The full set of DNC data, to include the Limited Distribution information, is available via the following web locations:

NIPRNET:
https://dnc.geo.nga.mil

SIPRNET:
http://dnc.nga.smil.mil

JWICS:
https://dnc.nga.ic.gov

Tactical Ocean Data (TOD) is an overlay to DNC. TOD data is bathymetric in nature and intended to support naval operations. Original TOD specifications provide for a total of six levels as outlined below:

Level 0 - OPAREA, Range, and Naval Exercise Areas (NAVEX) charts
Level 1 - Bottom Contour Charts (BC)
Level 2 - Bathymetric Navigation Planning Charts (BNPC)
Level 3 - Shallow Water Charts
Level 4 - Hull Integrity Test Charts
Level 5 - Strategic Straits Charts

In recent years, change in policy resulted in the combination of TOD levels 1, 3 and 5 into TOD Level 2. The current TOD Levels are referenced below:

Level 0 - OPAREA, Range, and Naval Exercise Areas (NAVEX) charts

- TOD0 provides worldwide databases of nautical information in Vector Product Format (VPF). The data content and coverage is intended to closely replicate NGA's Naval Operating Area (OPAREA) Chart, Range Chart, and Naval Exercise Area (NAVEX) Chart series.

Level 2- Bathymetric Navigation Planning Charts (BNPC)

- TOD2 provides worldwide databases of nautical information in Vector Product Format (VPF). The data content and coverage is intended to closely replicate NGA's Bathymetric Navigation Planning Chart (BNPC) series. includes data from:
  - — Bottom Contour Charts (BC)
  - — Shallow Water Charts
  - — Strategic Straights Charts

Level 4- - Hull Integrity Test Charts (HITS)

- TOD4 is a vector-based digital product that portrays detailed bathymetric data for submarine Hull Integrity Test Sites (HITS) in a format suitable for computerized subsurface navigation. TOD4 data is designed for use during submarine hull integrity tests conducted as a part of builder's trials and after submarine hull maintenance. TOD4 data is provided primarily to support deep submergence rescue vessel operations and to enhance coordination between units during escorted test dives.

517. Differences Between NOAA ENC and DNC

The NOAA ENC is based on the International Hydrographic Organization Transfer Standard for Digital Hydrographic Data, Publication S-57 and is approved by the International Maritime Organization for SOLAS class vessels to use for navigation in an ECDIS. NOAA and the U.S. Army Corps of Engineers (USACE) are producing ENCs for the coastal and inland waters of the U.S. Most hydrographic offices throughout the world are producing vector charts in ENC format.

NGA produces ENC cells over areas where NGA is considered the charting authority such as Haiti, the Pacific Islands, and parts of Antarctica. In these areas, NGA is responsible for civilian shipping and is required to provide ENC to facilitate the International Maritime Organization (IMO) mandate for electronic charting. NGA ENC cells are available for download through the NOAA website.

DNC produced by the NGA, is unclassified, vector-based, digital database containing maritime significant features essential for safe marine navigation. The DNC uses the Vector Product Format, which is a NATO standard for digital military map and chart data. NGA produces DNCs for worldwide coverage.

ENC was developed for civil navigation, with an initial emphasis on commercial navigation. DNC was developed for the military user for multiple roles; it can be combined with land, air and tactical data layers for various military uses such as littoral warfare.

During the creation of a NOAA ENC, high-resolution source information was used in portraying channels, aids to navigation, and other important features. Today, NOAA ENC data is updated by incorporating high resolution source information from a variety of sources. DNCs covering U.S. waters were created by digitizing paper NOAA charts.

The NOAA ENC files are updated using weekly USCG Local Notice to Mariners and NGA Notice to Mariners. DNCs are updated on a monthly basis using NGA Notice to Mariners. For US Waters, NGA updates the data inside the 12' contour by using USCG local notices.

518. Warship ECDIS (WECDIS)

WECDIS is defined by NATO Standard ANP-4564. WECDIS is a system which takes inputs from and provides information to disparate tactical sources (including the Command System), providing the user with a controllable set of information additions to overlay onto electronic charting and position displays for safety of navigation and enhanced tactical awareness. WECDIS is delivered via a dedicated user interface and chart display. When required by the user (for example in a benign tactical environment) WECDIS shall be capable of operation as an IMO compliant ECDIS. The primary function of WECDIS is to enhance military mission effectiveness by supporting safe and efficient navigation.

The IMO Performance Standards for ECDIS define the minimum requirements for functionality with respect to route planning, monitoring, alarms and voyage recording. However, warships can be operated under circumstances not anticipated by IMO, to include the core WECDIS capabilities of dived navigation, high speed navigation, waterspace management, integration of Additional Military Layers (AML) and the transfer of NATO User Defined Layers (NUDL) between NATO units. These circumstances impose additional requirements on WECDIS beyond those mandated by IMO.

WECDIS based solely on IMO specifications will not achieve the functionality required in a wartime scenario. Therefore NATO adds its own requirements in this WECDIS standard; these can be further expanded based on national requirements.

Although warships, naval auxiliaries, other ships owned or operated by a contracting government and used only on governmental non-commercial service are exempt from the provisions of SOLAS Chapter V Regulations 18 and 19 (Ref A). WECDIS shall have the capability to be functionally compliant with the requirements of the latest IMO ECDIS performance and IHO chart presentation standards when selected by the user. Nations shall ensure that appropriate verification is completed to ensure functional compliance with IMO performance standards when operating in this mode.

Two operational modes, WECDIS mode and IMO compliant mode, categorize the requirements listed in this standard:

WECDIS mode: the system is operating in this mode when any of the currently activated system functionalities render it non ECDIS IMO compliant.

IMO compliant mode: the system is operating in this mode when all the currently activated system functionalities do not compromise ECDIS IMO regulations compliance.

CORRECTING ELECTRONIC CHARTS

519. ECDIS Correction Systems

ECDIS software creates a database from the ENC data called the SENC and from this selects information for display. The ECDIS software meanwhile receives and processes serial data from navigational sensors and displays that textual and graphical information simultaneously with the SENC information.

It is the SENC that is equivalent to up-to-date charts, as stated by the Performance Standards. As originally conceived, ECDIS was designed to use internationally standardized and officially produced vector data called the ENC (electronic navigational chart). Only when using ENC data can ECDIS create a SENC, and thereby function in the ECDIS mode.

Updates for ENC are installed into the ECDIS separate from the ENC data itself. For the mariner, this involves activating a special utility accompanying the ECDIS and following the on-screen prompts. Within this same utility, update content and update log files in textual form can be viewed. Once the ECDIS software itself is reactivated, the update information is accessed in conjunction with the ENC data and the SENC database is created.

Just as ENC and updates are transformed into the SENC, so too are other data types accessed and combined. The user has the option to add lines, objects, text and links to other files supported by application. Referred to in the Performance Standards as data added by the mariner, these notes function as layers on the displayed chart. The user can select all or parts of the layers for display to keep clutter to a minimum. The mariner's own layers, however, must be called into the SENC from stored memory. As a practical matter, not only must the mariner take care to associate file names with actual content, such as with manually created chart corrections, but also must realize that the files themselves do not have the tamper-proof status that ENC and official updates have. Special care should be given when cells are canceled in the SENC database. These cells will not be subject to further updates and the cell will become out-of-date. The mariner should remove the ENC from the SENC when prompted to avoid accidental future use.

Within the SENC resides all the information available for the display. The Presentation Library rules such as Standard Display and Display Base define what levels of information from the SENC can be shown. An ENC updating profile is contained within the IHO S-57 Edition 3.0 specification. This enables the efficient addition, removal or replacement of any line, feature, object or area contained within the ENC dataset. Guidance on the means and process for ENC updating is provided in IHO S- 52, Appendix 1. In terms of what is called for in the IMO Performance Standards, an ENC dataset being used in an ECDIS must also have an ENC updating service providing the most current information. The service permits the ENC and the SENC to be corrected for the intended voyage, and thus achieves an important component of SOLAS compliance..

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Accordingly, ECDIS must be capable of accepting official updates to the ENC data provided in conformity with IHO standard. Updated cells are stored in a file and transmitted by e-mail, floppy disk or CD-ROM, or satellite. For example, PRIMAR charts and updates are delivered on two CDs: the Base CD contains the PRIMAR database at the time indicated on the label and the second CD contains the updates for those charts. However, the update CD also contains new charts issued since the base CD was printed. Since the operator must acquire the files and then initiate the update functions of the ECDIS software, this form of updating is referred to as semi-automatic. The two other types of updates include manual and automatic. Manual updating consists of the mariner entering printed NTMs, verbal communication or any other unformatted information. This method requires special attention to the reference-ellipsoid conformity and to conformity of the measurement units and the correction text. Automatic updating consists of updating the SENC through files obtained through electronic data communication lines, such as satellite.

ECDIS will reject updates if the update issuing authority is different from the cell issuing authority. It will also reject corrupted update files and files with an incorrect extension. ECDIS checks that updates are applied in the right sequence. If one update is missing the next update is rejected. An update CD-ROM should contain all available updates for all S-57 cells. Under normal circumstances, ECDIS will automatically run all updates in the right order for all cells.

For S-57 data, the content of updates in text form can be viewed from within the utility that permits the management of chart data. The utility can only be run when ECDIS is terminated. ECDIS is also capable of showing or hiding S-57 updates on a given chart or cell. The update should run via the chart utility. After restarting ECDIS, and after loading into the display the selected chart with the correction, the correction should be manually accepted. That enables the function in S-57 chart options to show or hide the symbol indicating the location of the correction.

NGA DNC Corrections

NGA produces the DNC Vector Product Format Database Update (VDU) to support worldwide DNC navigation requirements of the U.S. Navy, the Military Sealift Command (MSC), the U.S. Coast Guard, and certain foreign partners. Outside US Waters NGA does not distribute DNC to other than U.S. government agencies and foreign governments having data exchange agreements with NGA. The DNC maintenance system is able to apply new source materials such as bathymetry, imagery, Notice to Mariners, local notices, new foreign chart sources, etc. for inclusion in the DNC database. These updates are then provided to the mariner via the VDU process.

The VDU system works by performing a binary comparison of the corrected chart library with the previous latest released baseline edition version. The differences are then written to a binary "patch" file with instructions as to its exact location. The user then applies this patch file by specifying the proper path and filename to their DNC on the ships ECDIS-N and the data is updated with the VDU patch file. These VDU patch files are cumulative so every new change incorporates all previous changes, so navigators are assured that, having received the latest change, they have all the changes issued to date. The mariner is not required to do weekly incremental updates to apply all the previous update information.

The VDU patch file sizes are small enough to support the bandwidth limitations of ships at sea, and require only one-way communication. The updated patch files are posted every four weeks in groups of seven to eight DNCs per week. The VDU patch files are available as either an individual library patch file, or a full edition patch file to update the whole DNC from the previous edition to the current edition. The DNC VDU patch files are available via the following web locations:

WWW: https://dnc.nga.mil
NIPRNET: https://dnc.geo.nga.mil
SIPRNET: http://dnc.nga.smil.mil
JWICS: https://dnc.nga.ic.gov

See Figure 519a for a screen capture from the VDU patch web portal.

A separate layer within DNC provides the user with identification of where changes have been made during the updating process.

British Admiralty Raster and Vector Chart Corrections

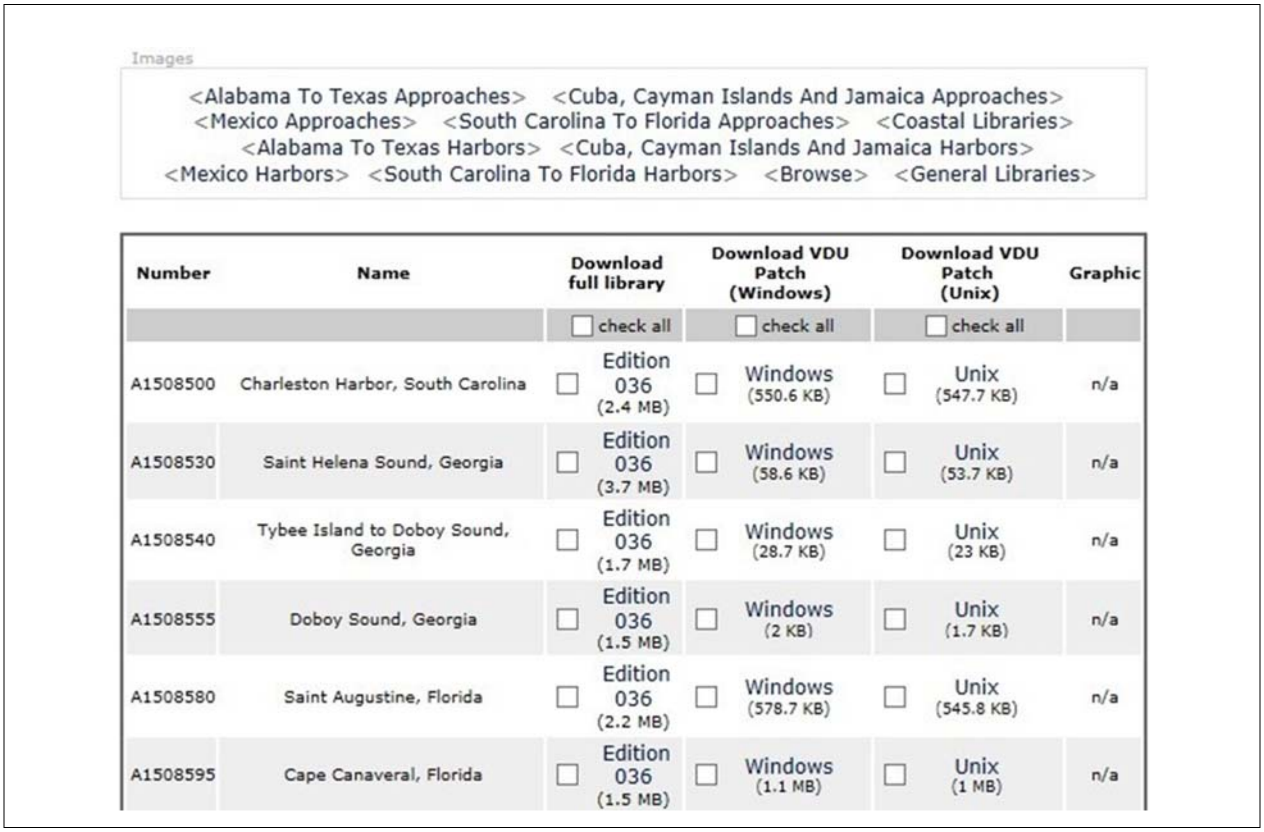
The Admiralty Raster Chart Service (ARCS) is the UKHO's paper chart portfolio presented in a digital format. The Admiralty Vector Chart Service (AVCS) is composed of official ENC delivered to industry standards (S-63/S-57) formats and compatible with ECDIS. All ENCs in AVCS satisfy the mandatory chart carriage requirements of SOLAS Chapter V. Both ARCS and AVCS provide worldwide coverage and have weekly online updating services. AN interface guides users through the process of selecting and downloading updates, which can then be transferred to an ECS or ECDIS on CD, DVD or USB memory stick. IN addition to the online update service, weekly CD and DVD update disks provide all the latest *Notice to Mariner* corrections.

NOAA Corrections

In the U.S., NOAA provides updates based on information from USCG, NGA, Canadian Hydrographic Service (CHS) notice to mariners and information that is ready for publication from other sources such as NOAA hydrographic surveys, NOAA shoreline surveys, USACE hydrographic surveys and other features submitted from federal, state and private organizations. Updates are available via the links provided in Figure 519b and Figure 519c.

Commercial Systems

There are a variety of ECS systems available for small



Images

<Alabama To Texas Approaches> <Cuba, Cayman Islands And Jamaica Approaches> <Mexico Approaches> <South Carolina To Florida Approaches> <Coastal Libraries> <Alabama To Texas Harbors> <Cuba, Cayman Islands And Jamaica Harbors> <Mexico Harbors> <South Carolina To Florida Harbors> <Browse> <General Libraries>

Number	Name	Download full library	Download VDU Patch (Windows)	Download VDU Patch (Unix)	Graphic
		check all	check all	check all	
A1508500	Charleston Harbor, South Carolina	Edition 036 (2.4 MB)	Windows (550.6 KB)	Unix (547.7 KB)	n/a
A1508530	Saint Helena Sound, Georgia	Edition 036 (3.7 MB)	Windows (58.6 KB)	Unix (53.7 KB)	n/a
A1508540	Tybee Island to Doboy Sound, Georgia	Edition 036 (1.7 MB)	Windows (28.7 KB)	Unix (23 KB)	n/a
A1508555	Doboy Sound, Georgia	Edition 036 (1.5 MB)	Windows (2 KB)	Unix (1.7 KB)	n/a
A1508580	Saint Augustine, Florida	Edition 036 (2.2 MB)	Windows (578.7 KB)	Unix (545.8 KB)	n/a
A1508595	Cape Canaveral, Florida	Edition 036 (1.5 MB)	Windows (1.1 MB)	Unix (1 MB)	n/a

Figure 519a. DNC website screen capture.

Figure 519b. NOAA ENC Chart Downloader. http://www.charts.noaa.gov/ENCs/ENCs.shtml.

Figure 519c. NOAA RNC Chart Downloader. http://www.charts.noaa.gov/RNCs/RNCs.shtml.

craft, often found aboard fishing vessels, tugs, research vessels, yachts, and other craft not large enough to need SOLAS equipment but wanting the best in navigation technology. Given that these systems comprise a single navigation aid and do not represent a legal chart in any sense, it is probably not a critical point that correction systems for these products are not robust enough to support regular application of changes.

In fact, often the only way to make changes is to purchase new editions, although the more sophisticated ones allow the placement of electronic "notes" on the chart. The data is commonly stored on RAM chips of various types, and cannot be changed or without re-programming the chip from a CD-ROM or disk containing the data. If the data is on CD-ROM, a new CD-ROM is the update mechanism, and they are, for the most part, infrequently produced. Users of these systems are required to maintain a plot on a corrected paper chart.

USING ELECTRONIC CHARTS

520. Digital Chart Accuracy

As is the case with any shipboard gear, the user must be aware of the capabilities and limitations of digital charts. The mariner should understand that nautical chart data displays possess inherent accuracy limitations. Because digital charts are primarily based on paper charts, many of these limitations have migrated from the paper chart into the electronic chart. Electronic chart accuracy is, for the most part, dependent on the accuracy of the features being displayed and manipulated. While some ECDIS and ECS have the capability to use large-scale data produced from recent hydrographic survey operations (e.g., dredged channel limits or pier/terminal facilities) most raster and vector-based electronic chart data are derived from existing paper charts.

Twenty years ago, mariners were typically obtaining position fixes using radar ranges, visual bearings or Loran. Generally, these positioning methods were an order of magnitude less accurate than the horizontal accuracy of the survey information portrayed on the chart. For example, a three-line fix that results in an equilateral triangle with sides two millimeters in length at a chart scale of 1:20,000 represents a triangle with 40-meter sides in real-world coordinates.

A potential source of error is related to the system configuration, rather than the accuracy of electronic chart data being used. All ECDISs and most ECSs enable the user to input the vessel's dimensions and GPS antenna location. On larger vessels, the relative position of the GPS antenna aboard the ship can be a source of error when viewing the “own-ship” icon next to a pier or wharf.

In U.S. waters, the Coast Guard's DGPS provides a horizontal accuracy of +/-10 meters (95 percent). However, with selective availability off, even the most basic GPS receiver in a non-differential mode may be capable of providing better than 10 meter horizontal accuracy. In actual operation, accuracies of 3-5 meters are being achieved. As a result, some mariners have reported that when using an electronic chart while moored alongside a pier, the vessel icon plots on top of the pier or out in the channel.

Similarly, some mariners transiting a range that marks the centerline of a channel report that the vessel icon plots along the edge or even outside of the channel. Mariners now expect, just as they did 20 years ago, that the horizontal accuracy of their charts will be as accurate as the positioning system available to them. Unfortunately, any electronic chart based on a paper chart, whether it is raster or vector, is not able to meet this expectation.

The overall horizontal accuracy of data portrayed on paper charts is a combination of the accuracy of the underlying source data and the accuracy of the chart compilation process. Most paper charts are generalized composite documents compiled from survey data that have been collected by various sources over a long period of time. A given chart might encompass one area that is based on a lead line and sextant hydrographic survey conducted in 1890, while another area of the same chart might have been surveyed in the year 2000 with a full-coverage shallow-water multibeam system. In the U.S., agencies have typically used the most accurate hydrographic survey instrumentation available at the time of the survey.

While survey positioning methods have changed over the years, standards have generally been such that surveys were conducted with a positioning accuracy of better than 0.75 millimeters at the scale of the chart. Therefore, on a 1:20,000-scale chart, the survey data was required to be accurate to 15 meters. Features whose positions originate in the local notice to mariners, reported by unknown source, are usually charted with qualifying notations like position approximate (PA) or position doubtful (PD). The charted positions of these features, if they do exist, may be in error by miles.

In 2017, less than 30 percent of the depth information found on NOAA charts was based on hydrographic surveys conducted before 1940. Surveys conducted many years ago with lead lines or single-beam echo sounders sampled only a tiny percentage of the ocean bottom. Hydrographers were unable to collect data between the sounding lines. Depending on the water depth, these lines may have been spaced at 50, 100, 200 or 400 meters. As areas are re-surveyed and full-bottom coverage is obtained, uncharted features, some dangerous to navigation, are discovered quite often. These features were either: 1) not detected on prior surveys, 2) objects such as wrecks that have appeared on the ocean bottom since the prior survey or 3) the result of natural changes that have occurred since the prior survey.

In a similar manner, the shoreline found on most U.S. charts is based on photogrammetric or plane table surveys that are more than 20 years old. In major commercial harbors, the waterfront is constantly changing. New piers, wharves, and docks are constructed and old facilities are demolished. Some of these man-made changes are added to the chart when the responsible authority provides as-built drawings. However, many changes are not reported and therefore do not appear on the chart. Natural erosion along the shoreline, shifting sand bars and spits, and geological subsidence and uplift also tend to render the charted shoreline inaccurate over time.

Another component of horizontal chart accuracy involves the chart compilation process. For example, in the U.S. before NOAA's suite of charts was scanned into raster format, all chart compilation was performed manually. Projection lines were constructed and drawn by hand and all plotting was done relative to these lines. Cartographers graphically reduced large scale surveys or engineering drawings to chart scale. Very often these drawings were referenced to state plane or other local coordinate systems. The data would then be converted to the horizontal datum of the chart, for example, the North American Datum1927 (NAD 27) or the North American Datum 1983 (NAD 83). In the late 1980s and early 1990s, NOAA converted all of its charts to NAD 83. In accomplishing this task, averaging techniques were used and all of the projection lines were redrawn.

When NOAA scanned its charts and moved its cartographic production into a computer environment, variations were noted between manually constructed projection lines and those that were computer generated. All of the raster charts were adjusted or warped so that the manual projection lines conformed to the computer-generated projection. In doing so, all information displayed on the chart was moved or adjusted.

Similar processes take place during NGA's digital chart production, but involving more complexity, since NGA cartographers must work with a variety of different datums in use throughout the world, and with hydrographic data from hundreds of official and unofficial sources. While much of NGA's incoming data was collected to IHO standards during hydrographic surveys, several sources are questionable at best, especially among older data.

Today, when survey crews and contractors obtain DGPS positions on prominent shoreline features and compare those positions to the chart, biases may be found that are on the order of two millimeters at the scale of the chart (e.g., 20 meters on 1:10,000-scale chart). High accuracy aerial photography reveals similar discrepancies between the true shoreline and the charted shoreline. It stands to reason that other important features such as dredged channel limits and navigational aids also exhibit these types of biases. Unfortunately, on any given chart, the magnitude and the direction of these discrepancies will vary by unknown amounts in different areas of the chart. Therefore, no systematic adjustment can easily be performed that will improve the inherent accuracy of the paper or electronic chart.

Some mariners have the misconception that because charts can be viewed on a computer, the information has somehow become more accurate than it appears on paper. Some mariners believe that vector data is more accurate than paper or raster data. Clearly, if an electronic chart database is built by digitizing a paper chart, it can be no more accurate than the paper chart.

Once ENCs are compiled, they may be enhanced with higher accuracy data over time. High resolution shoreline data may be incorporated into the ENCs as new photogrammetric surveys are conducted. Likewise, depths from new hydrographic surveys will gradually supersede depths that originated from old surveys.

521. Route Planning and Monitoring

The *IMO Guidelines for Voyage Planning Res. A.893(21)* state “the development of a plan for voyage or passage, as well as the close and continuous monitoring of the vessel's progress and position during the execution of such a plan, are of essential importance for the safety of life at sea, safety and efficiency of navigation and protection of the marine environment.” The use of ECDIS for route planning automates many navigational processes, from plotting legs between waypoints to the ability to scan the route for navigational hazards based on selected safety parameters and areas for which special conditions exist. The mariner now has greater control with the electronic chart over that of the paper chart with the selection of the display of safe and unsafe water along with other objects in the chart database. Ultimately, the revised *IMO Performance Standards for ECDIS MSC.232(82)* state that “it should be possible to carry out route planning and monitoring in a simple and reliable way.”

Route planning with ECDIS takes place before the start of the voyage, except in situations where major changes or deviations in the route are required while the ship is underway. In either case, ECDIS allows the display of both small scale and large scale charts of the operating area and the selection of waypoints from those charts. The determination of the safety contour and safety depth by the mariner, which can be set similar to the minimum depth contour with paper charts, play a critical role during route planning and monitoring (See Section1002, 1004, and 1018). The safety contour (in ECDIS, the contour related to the own ship, selected by the mariner from the contours provided for in the SENC) is to be used by ECDIS to distinguish on the display between safe and the unsafe water, and for generating anti-grounding alarms.

During route planning with ECDIS as per MSC.232(82):

- An indication is required if the mariner plans a route across an own ship's safety contour.
- An indication should be given if the mariner plans a route closer than a user-specified distance from the boundary of a prohibited area or geographic area for which special conditions exist...
- An indication should also be given if the mariner plans a route closer than a user-specified distance from a point object, such as a fixed or floating aid to navigation or isolated danger.
- It should be possible for the mariner to specify a cross track limit of deviation from the planned route at which an automatic off-track alarm should be activated.

While route or voyage planning encompasses many tasks and has many requirements, the following discussion generally focuses on the use of electronic charts through ECDIS. (Please review Vol I - Chapters 6, 10, 27, and Vol II - Chapter 3 for more detailed discussion on voyage planning.)

Based on the smaller relative size of the ECDIS screen as compared to equivalent paper charts, the mariner needs to be more accustomed to zooming (increasing or decreasing the chart display scale) and scrolling about the electronic charts during route planning, but must also exercise care to not overuse the zoom function of electronic charts due to overscale and underscale considerations (see Section 501). The mariner has the ability to add, delete, and change the position of waypoints along the route. After the preliminary waypoints have been positioned, the largest scale charts with due regard to the chart's compilation scale are used to further refine the waypoints and resultant legs in between. Additionally, the placement of waypoints should also consider, but not be limited to, traffic patterns and integrated navigation components of visual and radar navigation.

The mariner may need to zoom in and out while reviewing and revising the waypoints along with the resultant route legs. This process should include reviewing the integrity of chart data along with the quality of the bathymetric data of the charts through the display of the category of zone of confidence in data (CATZOC) symbols. The ZOC provides the position and depth accuracy of the ENC cell seafloor coverage, and typical survey characteristics (see Section 428 for more information on ZOC for paper charts).

Accordingly, the accuracy of the areas within the electronic chart may differ from that of GPS/DGPS positioning; therefore, this information, coupled with the CATZOC, will assist in the determination of planned distances off navigational hazards, ECDIS safety settings and other risk management such as routing measures. The horizontal and vertical datum of the chart data must be closely inspected and noted as it may require increased positional cross check procedures. Since planning is normally conducted in advance of the voyage, ECDIS allows for the display of date-dependent objects. This assists the mariner by displaying future changes that may affect a route being planned, provided the new objects are in the database.

When reviewing and refining the position of waypoints, the cross-track distances (XTD) of each leg can be modified to take into consideration safe navigation through the areas of transit ranging from open sea to restricted waterways. The determination of these values should also consider, but be not be limited to, ECDIS look-ahead functions through the alarm settings for deviation from route, crossing safety contour, areas with special conditions, indication settings for crossing isolated dangers, along with safe distances from dangers to navigation and other acceptable and approved distance values.

At each waypoint, a wheel over point/line can be displayed to visually indicate when to start a turn. ECDIS typically allows for the mariner to select and display a turn radius for each waypoint. The turn radius is instrumental in the placement and adjustment of waypoints. Accordingly, the mariner must consider at each waypoint involving a change of course whether to use a wheel over based on the advance and transfer calculated from the appropriate turning circle diagram or a constant radius turn (see Section 1002). The ECDIS also provides the capability for route planning in both straight and curved segments such as rhumb lines and great circles. Depending on the capabilities of the respective ECDIS, the great circle route may require that the route be modified into rhumb line segments based on longitude and limiting latitude requirements (See Section 1206).

When the mariner is satisfied with the planned route, an automatic route check based on appropriate safety values should be conducted. Based on the results of this check, a closer inspection of route details and revisions may be necessary. Notwithstanding the automatic ECDIS route check function, a visual check of the entire route using the largest scale charts should be conducted. The use of the *All Other Information* display, aids the mariner in the display of dangers detected by the route check(s). The systematic and detailed visual check should also consider, but not be limited to, the compilation scale of the charts, alarm parameters, turn radius at each waypoint, critical points and areas along with the reviewing if the route crosses dangers of navigation such as safety contours, isolated dangers, and limits of prohibited and geographical areas for which special purpose areas exist based on the settings of cross-track distances. Upon completion of the visual check and after any route modifications, additional follow-up route checks should then be completed until the plan is finalized and approved.

ECDIS also provides the capability for creating schedules based on values such as ETD, speed, time zone and ETA. Scheduling features can vary among ECDIS manufacturers but ultimately allow for assisting in the calculations for speed of advance and safe speed(s) at various points along the route.

The ship's master should review, revise if necessary, and approve the ECDIS route prior to departure. The route should be saved according the bridge procedures or company policy onboard and properly annotated with any safety-related settings and other pertinent information.

After route planning is complete and prior to departure, the chart display should be set up for underway use to minimize clutter while balancing the need for information to maintain safe navigation. This could require the mariner to carefully select between the *Standard Display* and the on-demand features of the *All Other Information* display based on open sea and restricted waterway/pilotage requirements. Various members of the bridge team will be viewing the ECDIS for different navigational purposes such as route monitoring, looking ahead, and target tracking/monitoring. Accordingly, it must be set up to convey information that is useful and relevant for each bridge team member.

The ECDIS also allows for the display alternate routes as long as the monitored route is clearly distinguishable from the planned routes. The alternate routes display separate routes or passages that can be planned in advance and checked through both automatic and visual methods against the ship's safety parameters and maneuvering characteristics. For example, alternative routes can be created for contingency or risk management procedures such as deviations or anchorages. See Chapter 10 Piloting and Chapter 41 Weather Routing for more information.

During route monitoring, the ECDIS shows the own ship's position whenever the display covers that area. Although the mariner may choose to “look-ahead” while in route monitoring, it is possible to return to own ship's position with a single operator action. Key information provided during route monitoring includes a continuous indication of vessel position, course, and speed. The display of own ship can be selected by the mariner of either true scale or as a symbol (see Figure 521a and Figure 521b). ECDIS can also provide distance right/left of intended track, planned course and speed to make good, distance to run, position and time of “wheel-over,” and past track history.

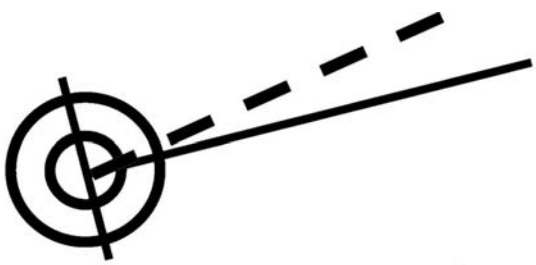


Figure 521a. Example of Own Ship symbol with speed vector (dashed line) and heading line (solid line) From IMO SN.1/Circ. 243/Rev.1 adapted with permission.

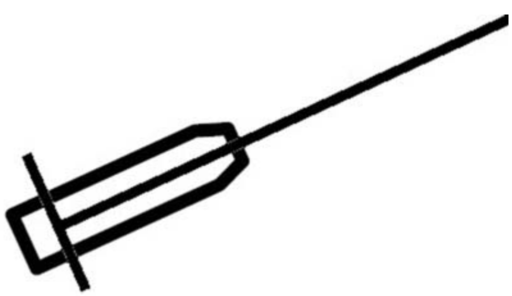


Figure 521b. Example of Own Ship True scale outline (symbol) oriented along own ship’s heading. From IMO SN.1/Circ. 243/Rev.1 adapted with permission.

When own ship is approaching a waypoint, the mariner may need to zoom in on each waypoint if the chart scale from which it is selected is very small, such that the navigational picture in the area can be seen at a reasonable scale, while being careful not to overscale (Section 501). This can be done either manually or though automated ECDIS features.

To plot the ship's position by alternative means, the ECDIS offers manual position fixing capabilities as defined by MSC.232 (82). The functionality of this feature may vary based on the ECDIS manufacturer. Manually obtained lines of position (LOP) can span from visual bearings and radar ranges to the input of position(s) calculated through celestial navigation. These positions can then be compared against the position provided by the GPS/DGPS. The ECDIS provides the capability to indicate discrepancies between the manual observations and that of the positions obtained by continuous positioning.

As specified in Appendix 5 of the MSC.232(82) *IMO ECDIS Performance Standards*, the ECDIS must provide an indication of the condition of the system and its components. An alarm must be provided if there is a condition that requires immediate attention. An indication can be visual, while an alarm must be either audible or both audible and visual.

The operator can control certain settings and functions, some of the most important of which are the parameters for certain alarms and indications, including:

- **Crossing safety contour**: As per MSC.232(82), “ECDIS should give an alarm if, within a specified time set by the mariner, own ship will cross the safety contour.” The safety contour (shown as an extra thick line for the depth contour) is set to emphasize on the SENC the limits between safe and unsafe water. It is based on the available contours as provided for by the SENC. For example, when the mariner selects two-depth area shades to be displayed, the water deeper than the safety contour is shown in an off-white color while the water shallower than the safety contour is blue when using the day display mode (see Figure 521c).

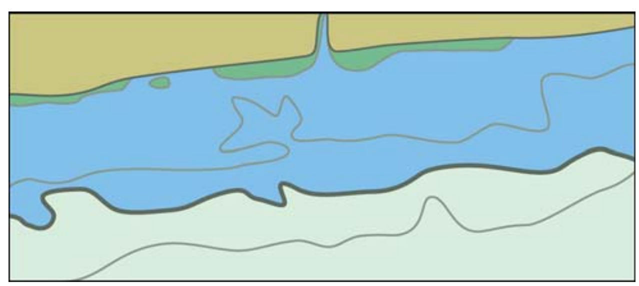


Figure 521c. Portrayal of depth areas with 2-color settings. Image courtesy of NOAA.

- **Area with special conditions**: As per MSC.232(82), “ECDIS should give an alarm or indication, as selected by the mariner, if, within a specified time set by the mariner, own ship will cross the boundary of a prohibited area or of a geographical area for which special conditions exist...” The areas for which special conditions exist are contained within Appendix 4 of MSC.232(82).

- **Deviation from route**: As per MSC.232, “An alarm should be given when the specified cross track limit for deviation from the planned route is exceeded." The value is determined as part of route planning, and is the distance to either side of the route leg that the vessel is allowed to deviate before an alarm sounds.

- **Approach to critical point**: The ECDIS provides an alarm when the own ship will be within a specified time or distance to a critical point on the planned route. This alarm can be used for advanced notice of approaching a waypoint or based on a user added point, line, or area.
- **Different geodetic datum**: If the geodetic system used by the positioning system is not the same as the SENC, the ECDIS should give an alarm.
- **Isolated Dangers**: ECDIS can display small shoals, wrecks, rocks and other obstructions with a special symbol, different from their paper chart equivalents. The *Isolated Danger* symbol (see Figure 521d) is displayed to indicate dangers to navigation of a depth equal to or less than the safety contour and also lying within the 'safe' water defined by the safety contour. As per MSC.232(82), "an indication should be given to the mariner if, continuing on its present course and speed, over a specified time or distance set by the mariner, own ship will pass closer than a user-specified distance from a danger (e.g., obstruction, wreck, rock) that is shallower than the mariner's safety contour or an aid to navigation." It may also be displayed as selected by the mariner in the "unsafe" water between the displayed safety contour and zero meter contour. Additionally, the symbol will be displayed if the depth of the navigational danger is unknown.

Figure 521d. Isolated danger symbol. Image courtesy of NOAA.

The pick report or cursor picking of the ECDIS should be used to determine additional information about it and whether the danger might impact the safe navigation of the vessel. (For more information about the display of this symbol and that of other ENC data on ECDIS as specified by the IHO, consult *U.S. Chart No 1*, available online via the links provided in Figure 521e below.

Other settings that will affect the display of the electronic chart as compared to the paper chart include:

- **Safety depth**: This setting allows for soundings of equal to or less than the mariner-inputted safety depth value to be made more conspicuous than deeper soundings. Therefore, the mariner can use the safety depth setting to provide crucial depth information while sailing in proximity to and between the available contours (see Figure 521f). When using the safety depth feature the mariner is reminded that spot sounding are not included in the *Display Base* and *Standard Display*.

Figure 521e. U.S. Chart No. 1. https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0004

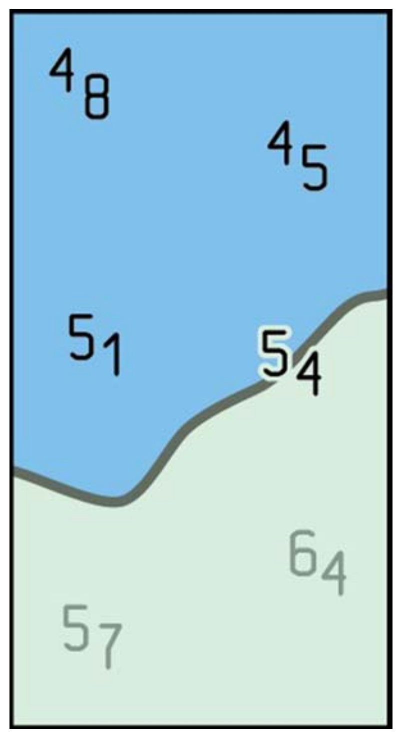


Figure 521f. This image shows depth labels (with a light "halo" to set them apart) and soundings both deeper and shallower than the safety depth. Image courtesy of NOAA.

- **Four shades**: a shallow and deep contour, which defines additional depth areas for medium-deep and medium-shallow water can be selected by the mariner to add further detail to the chart display. This chart setting is useful during confined waterway transits such as harbor and coastal areas by providing enhanced awareness of the gradient of depth area.

- Shallow Contour: This setting is usually set as the own ship's deep draft (plus calculated squat) to emphasize the contour shallower than the safety contour.
- Deep Contour: This setting is normally set to twice to ship's deep draft (plus calculated squat) to indicate areas where the vessel may experience squat.

When the four shades option is selected, the safety contour is displayed between the medium deep and medium shallow contours. Similar to the safety contour, if the SENC in use does not have a contour line equal to the selected shallow or deep contour, the ECDIS will default to the next deeper contour. Consequently, the mariner should carefully inspect the contour intervals and sounding data to determine the impact on the safe navigation of the vessel. See Figure 521g.

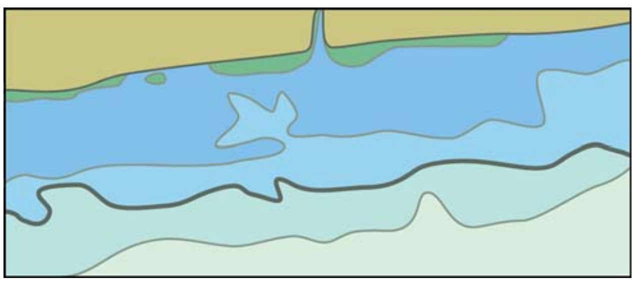


Figure 521g. Portrayal of depth areas with 4-color setting. Image courtesy of NOAA.

- **Areas Boundaries (Plain and Symbolized)**: Because the ECDIS screen is smaller than the equivalent paper chart, the density of data must be considered. The plain area boundaries are intended for use at smaller scales as they can reduce the overall clutter of the charts against the backdrop of the other charted symbols. Symbolized area boundaries can be used on larger scales for display to aid in the identification of areas.
- **Chart Symbols (Traditional-Paper Chart and Simplified)**: The selection of the chart symbols is the preference of the mariner based on operational considerations. The traditional symbols for point objects are most similar to paper chart symbols. See Figure 506b.

522. Waypoints and Routes

In the route planning mode, the ECDIS allows the entry of waypoints alphanumerically as coordinates of latitude and longitude or the selection of waypoints by moving a cursor around on the charts. It allows the creation and storage of numerous pre-defined routes, which can be combined in various ways to create complex voyages (review Chapter 27 Navigation Processes).

Routes created from berth to pilot station (or pilot station to berth) should also take into account the maneuvering characteristics of the vessel in restricted and/or confined waterways (review Chapter 10 Piloting). Turn radius used at each waypoint must be closely inspected to insure acceptable clearance throughout the turn with reference to "unsafe" water and other dangers to navigation. During these transits, depending on the availability of contour intervals in the SENC, the mariner with the display of the safety depth has the ability to add additional no-go areas with the mariner's navigational objects or user chart function. Additionally, notes and features can include: Ship Reporting Systems, VTS call-in points, speed limits, expected traffic areas, clearing bearings, DR and EP positions, etc., along with contingency plans such as anchorages, abort and point(s) of no-return.

Coastal and open sea routes can be developed using the vessel's characteristics for route monitoring in addition to using autopilot along with track control (if fitted) considerations. Depending on the sophistication of the autopilot system and integration with other bridge equipment, some ECDIS units, in conjunction with GPS, compare the ship's observed position with that of the intended leg. The units with proper weather, rudder and rate of turn settings then determine the level of compensation for wind and current to ensure the heading and COG are appropriate to maintain the ship on track. The cross-track distance may be set to consider the vessel's operating procedures concerning leeway and course XTD allowance. Berth to sea buoy and coastal/open sea routes can be combined or linked with the ECDIS to establish integrated routes from berth to berth. Route checking and scanning procedures still apply to the newly created route to insure that the routes linked at the appropriate waypoint and other safety settings are considered as discussed in Section 521.

Company procedures regarding **cyber-security** will normally apply to the transferring of data between ECDIS and other computers with internet access. Virus scanning of USBs and other approved media along with the organization of update and route files in paramount. Route files and user chart/notes should be saved and backed up to external media to help insure availability in the event of ECDIS malfunction, failure, transfer to backup system and after a restart/reboot. Based on the individual ECDIS manufacturer, the options for adding notes and descriptions to each saved route can vary. Naming conventions for route names differ based on the operational procedures but can include voyage number, UN/LOCODE for ports, and current year. For example, a voyage between San Francisco and Honolulu could be named 17Voy1USSFOtoUSHNL.

Regardless of whether the route is planned for confined/restricted waterways or open sea, each plan must take into account the principles of safe navigation (review Chapter 10, 27, and in Vol II - Chapter 3).

523. Training and Simulation

The STCW Code as amended in 1995 first introduced the concept of ECDIS being considered within the term "charts." The 2010 Manila Amendments to the STCW further revised the ECDIS training requirements, which are included in Tables A-II/1, A-II/2 and A-II/3. The training and assessment in the operational use of ECDIS should also conform to revised guidelines as defined by Table B-I and B-II assessment in navigational watchkeeping and evaluation of competence of the STCW Code. Specifically, the 2010 amendments added ECDIS competency requirements for chief mates, masters and officers in charge of a navigational watch on vessels 500 gross tons (GT) or more.

The current curriculum guidance for USCG course approval of ECDIS states the "course should be at least 35 hours and be substantially similar to IMO Model Course 1.27 The Operational Use of the Electronic Chart Display and Information System (ECDIS) (2012 Edition)." The course should also include the "applicable assessments of competence for STCW endorsements for Officer in Charge of a Navigational Watch (OICNW) and Chief Mate and Master." The ECDIS course should include the Table A-II Column 1 Competencies, which also contains Column 2 Knowledge, Understanding and Proficiency components:

- Knowledge of the capability and limitations of ECDIS, and sub-topics 1 through 3
- Proficiency in the operation, interpretation, and analysis of information obtained from ECDIS, and subtopics 1 through 6
- Management of operational procedures, system files and data, and subtopics 1 through 7

Current training requirements for mariners on ECDIS-equipped vessels includes both generic and familiarization components. The generic training currently follows the ECDIS IMO Model Course 1.27 (2012) Edition. The ECDIS course is typically designed to emphasize the application and learning of ECDIS in the underway context. There are five primary stages of the ECDIS Course:

1. Elements of ECDIS
2. Watchkeeping with ECDIS
3. ECDIS Route Planning
4. ECDIS Charts, Targets & System
5. ECDIS Responsibility

As per Section B-I/12 of the STCW Code, as amended, ECDIS training should be structured to include the theory and demonstration of the principal types of ECDIS and their display characteristics, risks of over-reliance on ECDIS, detection of misrepresentation of information and factors affecting system performance and accuracy. Simulator exercises of the ECDIS training further demonstrate and, through practical opportunities, allow the trainee to attain knowledge and skills in the setup and maintenance of display, operational use of electronic charts, route planning, route monitoring, alarm handling, manual correction of a ship's position and motion parameters, records in the ships' log, chart updating, operational use of ECDIS where radar/ARPA is connected, operational use of ECDIS where AIS is connected, operational warnings, their benefits and limitations, and system operational tests.

The training requirements for the use of the ECS to meet US domestic paper chart requirements are currently found in Navigation and Vessel Inspection Circular (NVIC) 01-16 as follows:

- "RTCM class 'A' training is met through the successful completion of a USCG-Approved ECDIS course and having an the appropriate endorsement on their Merchant Mariner Credential (MMC)
- "RTCM class 'B' and 'C' training is through the familiarization requirement of 46 CFR 15.405. As per NVIC 01-16, this familiarity can be accomplished through the company following the manufacturer's standards, user's manuals, and company policies to document competency.

While ECDIS can be viewed from a standardized perspective due to the IMO Performance Standards and other IHO and IEC requirements, individual manufacturers have some degree of freedom in their menu structure and terminology used for required functions. This particular aspect and specific installations underlies the need for familiarization to specific ECDIS equipment. Additionally, familiarization with the ECDIS should include reviewing the backup arrangements, sensors and related peripherals. Conversely, generic training in ECDIS has a broader focus on the theory and operational use of ECDIS in the context of navigation.

Familiarization requirements follow STCW Regulation A-I/14 Responsibilities of Companies, International Safety Management (ISM) 6 Resources and Personnel 6.3, 6.5 and 46 CFR 15.405.

Due to advances in navigational technologies, mariners are encouraged to consult USCG, IMO, IHO and manufacturer websites to stay abreast of electronic chart and ECDIS developments. Links to additional information are provided in Figure 523a, Figure 523b and Figure 523c.

524. Reference Note

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Figure 523a. USCG - Navigation Center *http://www.navcen.uscg.gov/.*

Figure 523b. NOAA Nautical Charts. *https://www.nauticalcharts.noaa.gov/index.html*

Figure 523c. IHO homepage. Select the ENCs, ECDIS & S-100 tab for more information. *https://www.iho.int/srv1/index.php?lang=en*

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CHAPTER 6

NAUTICAL PUBLICATIONS

INTRODUCTION

600. Publications

The navigator uses many textual information sources to plan and conduct a voyage. These sources include notices to mariners, summary of corrections, sailing directions, light lists, tide tables, sight reduction tables, and almanacs.

While it is still possible to obtain hard-copy or printed nautical publications, increasingly these texts are found online or in other digital formats, including Compact Disc-Read Only Memory (CD-ROM's) or Digital Versatile Disc (DVD's). Digital publications are much less expensive than printed publications to reproduce and distribute, and online publications have no reproduction costs at all for the producer, and only minor costs to the user. Also, one DVD can hold entire libraries of information, making both distribution and on-board storage much easier.

The advantages of electronic publications over hard-copy go beyond cost savings. They can be updated easier and more often, making it possible for mariners to have frequent or even continuous access to a maintained publications database instead of receiving new editions at infrequent intervals and entering hand corrections periodically. Generally, digital publications also provide links and search engines affording quick access to relevant information.

Navigational publications are available from many sources. Military customers automatically receive or requisition most publications. The civilian navigator obtains publications from a publisher's agent. Larger agents representing many publishers can completely supply a ship's chart and publication library. On-line publications produced by the U.S. government are available on the Web.

601. Maintenance and Carriage Requirements of Navigation Publications

Vessels may maintain the navigation publications required by Title 33 of the Code of Federal Regulations Parts 161.4, 164.33, and 164.72 and SOLAS Chapter V Regulation 27 in electronic format provided that they are derived from the original source, are currently corrected/up-to-date, and are readily accessible on the vessel's bridge by the crew. Adequate independent back-up arrangements shall be provided in case of electronic/technical failure. Such arrangements include: a second computer, CD, or portable mass storage device readily displayable to the navigation watch, or printed paper copies.

Since most required publications are only available in electronic format, the U.S. Coast Guard considers electronic publications of the U.S. Coast Pilots, U.S. Coast Guard *Light Lists*, NGA *Sailing Directions*, NGA *List of Lights*, tide-current and river-current tables, *Local Notice to Mariners, Notice to Mariners, Notices to Navigation Interests*, and *Vessel Traffic Service Rules* to be an acceptable equivalent means of meeting the publication carriage requirements set forth in Titles 33 and 46 of the Code of Federal Regulations and SOLAS Chapter V Regulation 27.

NAUTICAL TEXTS

602. *Sailing Directions*

National Geospatial-Intelligence Agency (NGA) *Sailing Directions* consist of 37 ***Enroutes*** and 5 ***Planning Guides***. *Planning Guides* describe general features of ocean basins; *Enroutes* describe detailed coastal and port approach information designed to supplement the largest scale charts produced by the NGA.

The *Sailing Directions (Planning Guides)* are relatively static; however, by contrast, *Sailing Directions (Enroute)* are frequently updated.

603. *Sailing Directions (Planning Guide)*

Planning Guides assist the navigator in planning an extensive oceanic voyage. Each of the Guides provides useful information about all the countries adjacent to a particular ocean basin. The limits of the *Sailing Directions* in relation to the major ocean basins are shown in Figure 603b.

Planning Guides are a series of five regional volumes, structured in the alphabetical order of countries contained within the region. Information pertaining to each country includes Buoyage Systems, Currency, Government, Industries, Holidays, Languages, Regulations, Firing Danger

Figure 603a. *Sailing Directions (Planning Guides)*
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0011

Areas, Mined Areas, Pilotage, Search and Rescue, Reporting Systems, Submarine Operating Areas, Time Zone, and the location of the U.S. Embassy.

The entire collection of *Sailing Directions (Planning Guides)* volumes is available online via the link found in Figure 603a.

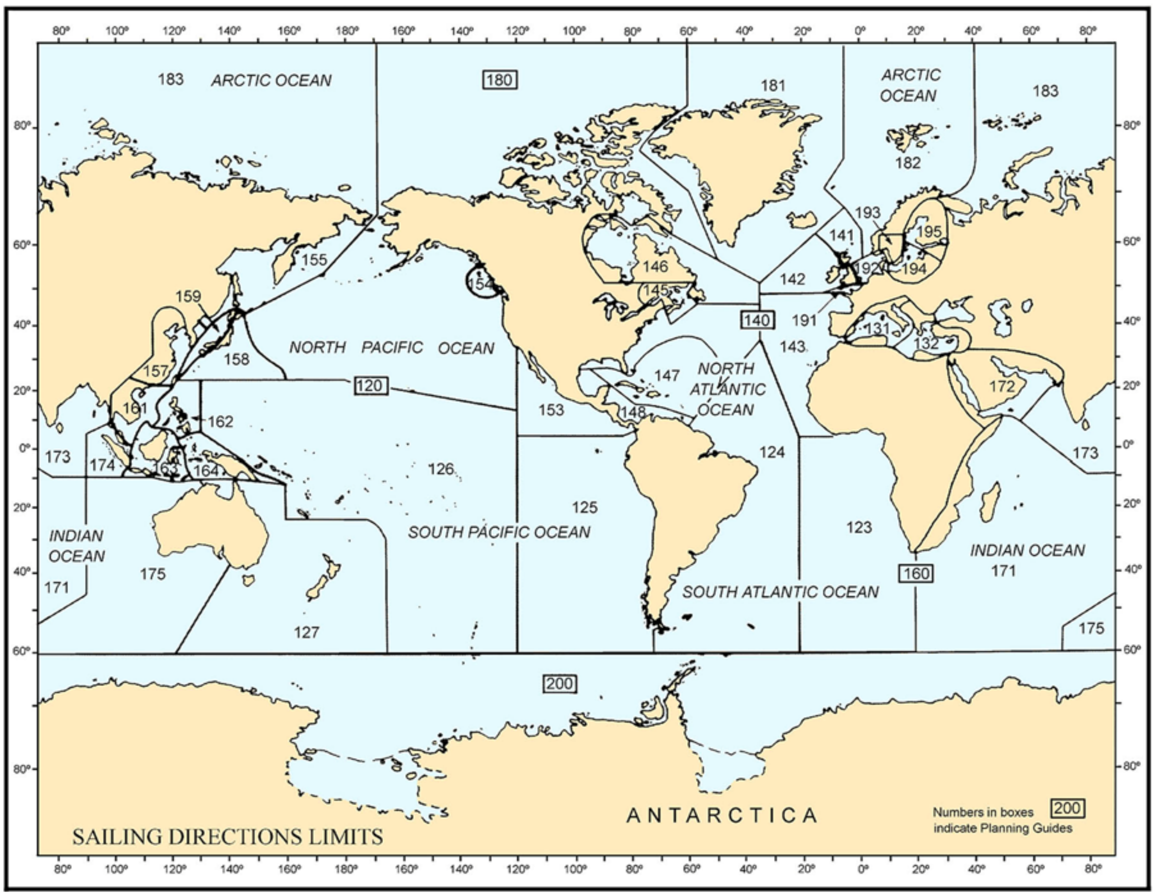

Figure 603b. Sailing Directions limits in relation to the major ocean basins.

604. *Sailing Directions (Enroute)*

Sailing Directions (Enroute) publications are a series of 37 volumes organized geographically, and include additional information about coastal and port approach not depicted on nautical charts, including winds, weather, tides, currents, ice, dangers, navigational aids, procedures, regulations, and port facilities. These publications also include some images of navigational aids and port facilities, as well as a graphic key to chart coverage of the region

Each volume of the *Sailing Directions (Enroute)* contains numbered sections along a coast or through a strait. Figure 604a illustrates this division. A preface with information about authorities, references, and conventions used in each book precedes the sector discussions. Each sector is sub-divided into paragraphs and discussed in turn. Each book provides conversions between feet, fathoms, and meters. A list of abbreviations that may be found in the text follows the conversion tables.

A *Chart Information* graphic and *DNC Library Information* graphic begin each sector. They provide a graphical key for charts (both paper and digital) pertaining to the area. See Figure 604c and Figure 604b. The graduation of the border scale on each of these graphics enable navigators to identify the largest scale chart or DNC library for a partic-

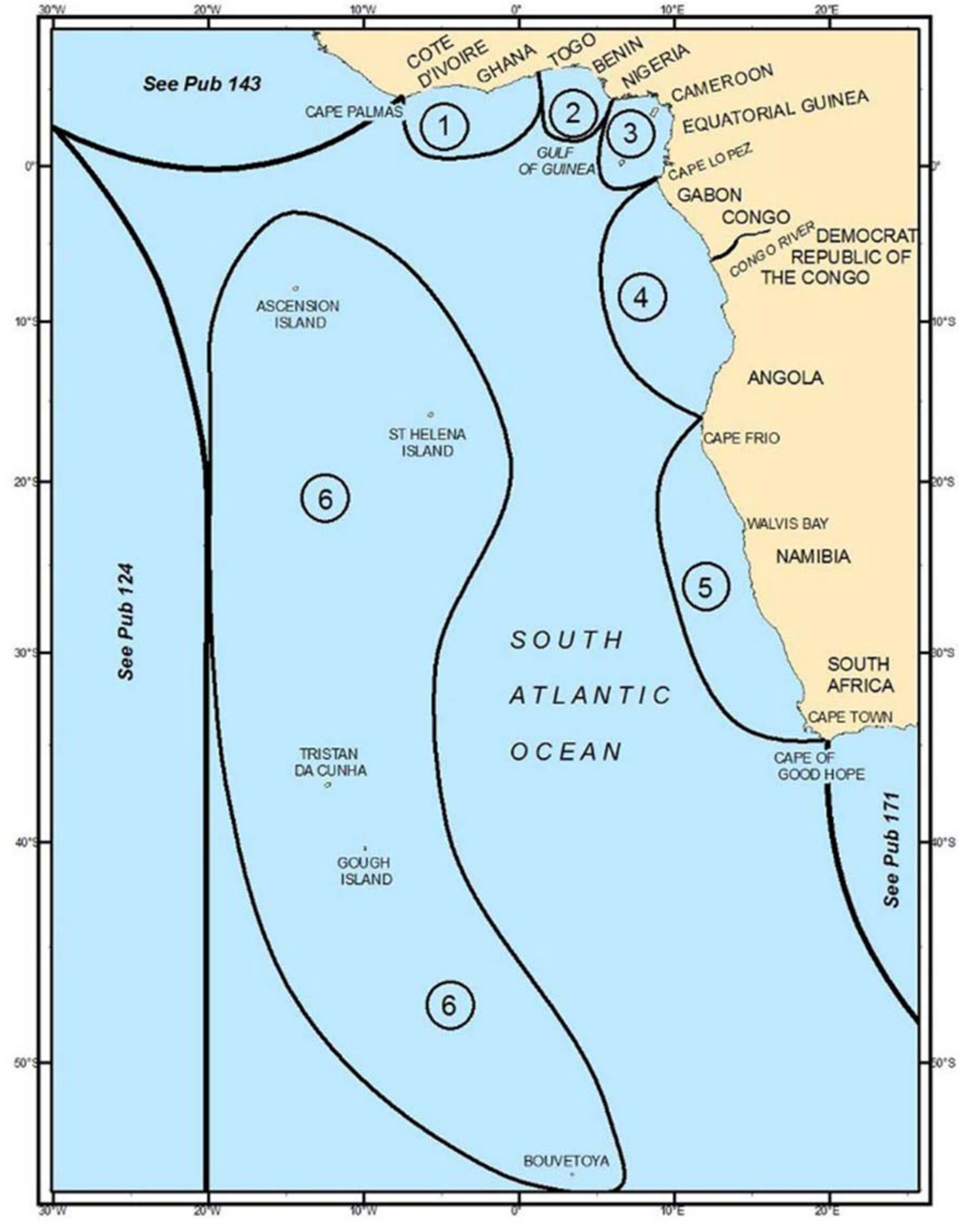

Figure 604a. Example of a typical sector limits graphic.

ular location, in addition to identifying features listed in the Index-Gazetteer. These graphics are not maintained by *Notice to Mariners*, therefore, one should refer to the chart catalog for updated chart listings. Other graphics found in the publication may contain special information on anchorages, significant coastal features, and navigation dangers.

A foreign terms glossary and a comprehensive Index-Gazetteer follow the sector discussions. The Index-Gazetteer is an alphabetical listing of described and charted features. The Index lists each feature by geographic coordinates and sector paragraph number.

U.S. military vessels have access to special files of data reported via official messages known as Port Visit After Action Reports. These reports, written in text form accord-

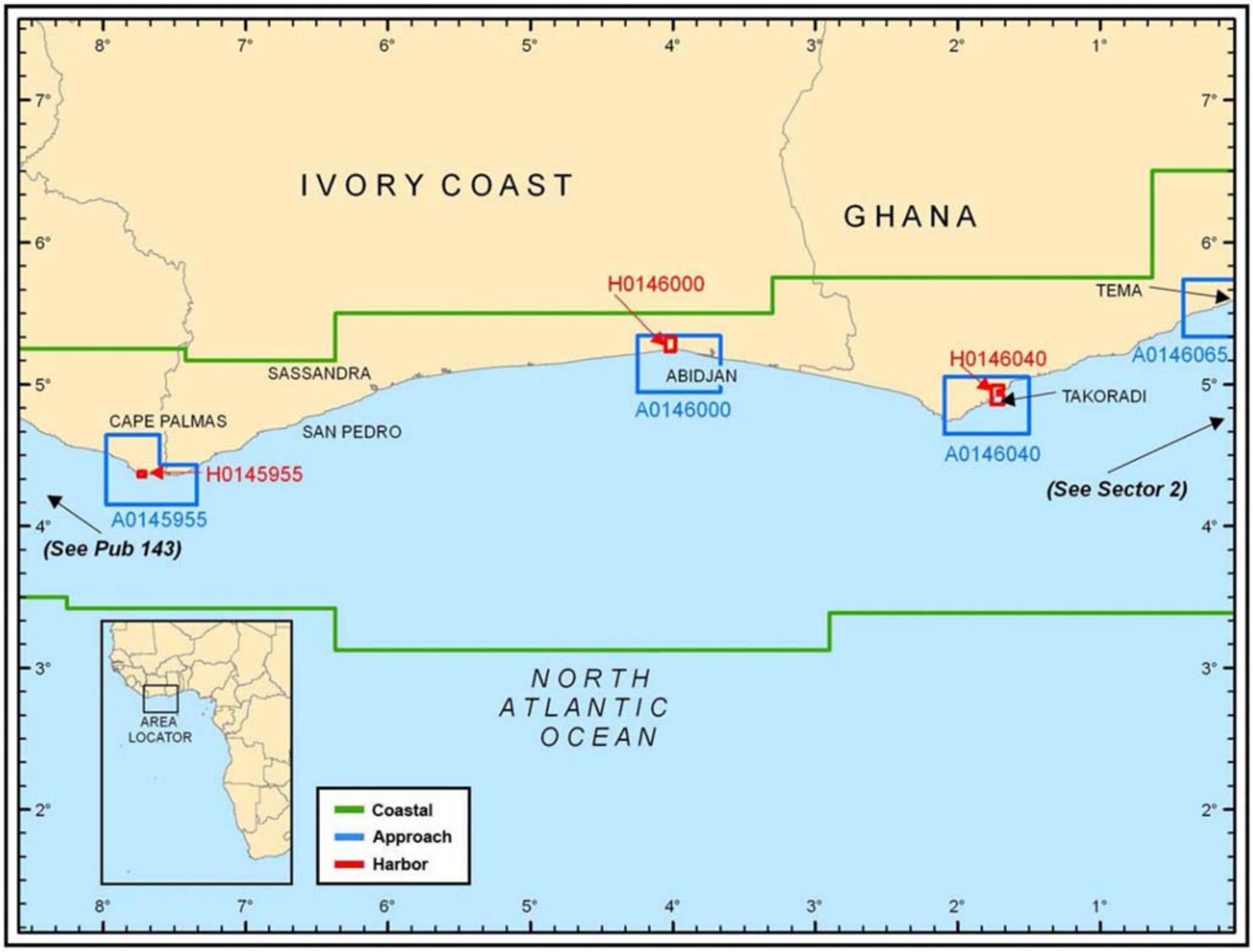

Figure 604b. Library information graphic.

ing to a standardized reporting format, give complete details of recent visits by U.S. military vessels to all foreign ports visited. Virtually every detail regarding navigation, services, supplies, official and unofficial contacts, and other matters are reported in detail, making these documents an extremely useful adjunct to the *Sailing Directions*. These files are available to ".mil" users only, and may be accessed on the Web at: http://cnsl.spear.navy.mil, under the "Force Navigator" link. They are also available via DoD's classified Web.

The entire collection of *Sailing Directions* (Enroute) volumes is available online via the link provided in Figure 604d.

To accommodate customers who experience difficulty accessing the World Wide Web, NGA provides a **Subscription Service** whereby notification of publication updates are delivered via email message to the requesting address. Additionally, subscribers will receive email notification when a publication new edition is released. The **Publication Updates Subscription** page may be accessed via the Publications tab on the Maritime Safety Information website.

605. *U.S. Coast Pilots*

The National Oceanic and Atmospheric Administration (NOAA) publishes nine *U.S. Coast Pilots* to supplement nautical charts of U.S. waters. Information comes from field inspections, survey vessels, and various harbor authorities. Maritime officials and pilotage associations provide additional information. *U.S. Coast Pilots* provide more detailed information than *Sailing Directions* because *Sailing Directions* are intended exclusively for the oceangoing mariner. The *Notice to Mariners* updates *U.S. Coast Pilots*.

Each volume contains comprehensive sections on local operational considerations and navigation regulations. Following chapters contain detailed discussions of coastal navigation. An appendix provides information for obtaining additional weather information, communications services, and other data. An index and additional tables complete the volume.

The entire collection of *U.S. Coast Pilots* can be found via the link provided in Figure 605.

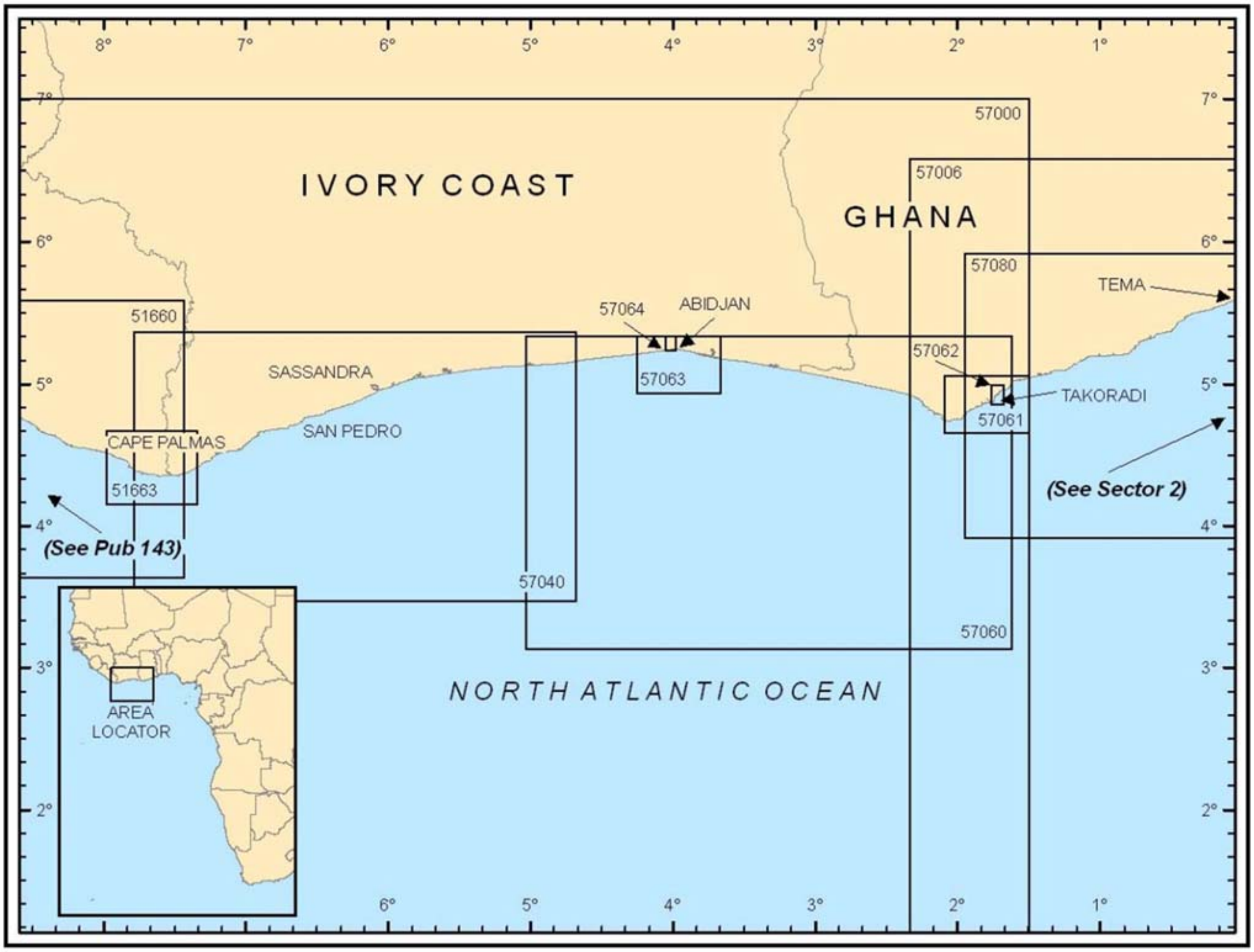

Figure 604c. Chart information graphics depict hardcopy charting boundaries.

Figure 604d. Sailing Directions (Enroute)
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0010

Figure 605. U.S. Coast Pilots.
https://nauticalcharts.noaa.gov/publications/coast-pilot/index.html

606. Other Nautical Texts

The federal government publishes several other nautical texts. NGA, for example, publishes *Pub. 1310, Radar Navigation and Maneuvering Board Manual* and *Pub. No. 9, American Practical Navigator*.

The U.S. Coast Guard publishes the *Navigation Rules and Regulations Handbook* for international and inland waters. This publication contains the Inland Navigation Rules enacted in December 1980 and effective on all inland waters of the United States including the Great Lakes, as well as the *International Regulations for the Prevention of Collisions at Sea*, enacted in 1972 (1972 COLREGS). Mariners underway should ensure that they possess the latest updated issue, which can be found on the Coast Guard's Navigation Center website: http://www.navcen.uscg.gov/. The Coast Guard also publishes the *Light Lists*, *Navigation and Vessel Inspection Circulars*; and the *Chemical Data Guide for Bulk Shipment by Water.*

The Government Publishing Office provides several publications on navigation, safety at sea, communications, weather, and related topics. Additionally, it publishes provisions of the Code of Federal Regulations (CFR) relating to maritime matters. In addition to official U,S, publications, there are a number of private publishers also provide maritime publications not referenced herein.

The International Maritime Organization (IMO), International Hydrographic Organization (IHO), and other governing international organizations publish information on international navigation regulations. Regulations for various Vessel Traffic Services (VTS), canals, lock systems, and other regulated waterways are published by the authorities who operate them. Nautical chart and publication sales agents are a good source of information about publications required for any voyage. Increasingly, many regulations, whether instituted by international or national governments, can be found on-line. This includes regulations for VTS, Traffic Separation Schemes (TSS), special regulations for passage through major canal and lock systems, port and harbor regulations, and other information. A Web search can often find the textual information the navigator needs.

Vessel Traffic Services (VTS) are discussed in greater detail in Chapter 29 - Navigation Regulations. The U.S. Coast Guard's Navigation Center (NAVCEN) provides access to detailed information websites and/or user manuals regarding Vessel Traffic Services for twelve VTS locations throughout the Unites States. A link to the NAVCEN website may be found in Figure 606.

Figure 606. U.S. Coast Guard - Navigation Center. https://www.navcen.uscg.gov/?pageName=vtsMain

USING THE LIGHT LISTS

607. Light Lists

The United States publishes two different light lists. The U.S. Coast Guard publishes the *Light List* for lights in U.S. territorial waters; NGA publishes the *List of Lights* for lights in foreign waters.

Light lists furnish detailed information about navigation lights and other navigation aids, supplementing the charts, *Coast Pilots*, and *Sailing Directions*. Consult the chart for the location and light characteristics of all navigation aids; consult the light lists to determine their detailed description.

The *Notice to Mariners* corrects both lists. Corrections which have accumulated since the print date are included in the *Notice to Mariners* as a *Summary of Corrections*. All of these summary corrections, and any corrections published subsequently, should be noted in the "Record of Corrections."

A navigator needs to know both the identity of a light and when s/he can expect to see it; s/he often plans the ship's track to pass within a light's range. If lights are not sighted when predicted, the vessel may be significantly off course and standing into danger.

A circle with a radius equal to the visible range of the light usually defines the area in which a light can be seen. On some bearings, however, obstructions may reduce the range. In this case, the obstructed arc might differ with height of eye and distance. Also, lights of different colors may be seen at different distances. Consider these facts both when identifying a light and predicting the range at which it can be seen.

Atmospheric conditions can have a major effect on a light's range. For example, fog, haze, dust, smoke, or precipitation can obscure a light, or a light may even be extinguished. Always report an extinguished light so maritime authorities can issue a warning and make repairs.

On a dark, clear night, the visual range is normally only limited by luminous intensity, or curvature of the Earth. However, regardless the height of eye, one cannot see a weak light beyond its luminous range. Assuming that light travels linearly, an observer located below the light's visible horizon cannot see it. The Distance to the Horizon table gives the distance to the horizon for various heights of eye. The light lists contain a condensed version of this table. Abnormal refraction patterns might change this range; therefore, one cannot exactly predict the range at which a light will be seen.

608. Finding Range and Bearing of a Light at Sighting

A light's **luminous range** is the maximum range at which an observer can see a light under existing visibility conditions. This luminous range ignores the elevation of the light, the observer's height of eye, the curvature of the Earth, and interference from background lighting. It is determined from the known **nominal range** and the existing visibility conditions. The nominal range is the maximum distance at which a light can be seen in weather conditions where the visibility is 10 nautical miles.

The U.S. Coast Guard *Light List* usually lists a light's nominal range. Use the Luminous Range Diagram shown in the *Light List* and Figure 608a to convert this nominal range to luminous range. Remember that the luminous ranges obtained are approximate because of atmospheric or background lighting conditions. To use the Luminous Range Diagram, first estimate the meteorological visibility by the Meteorological Optical Range Table, See Table 608. Next, enter the Luminous Range Diagram with the nominal range on the horizontal nominal range scale. Follow a vertical line

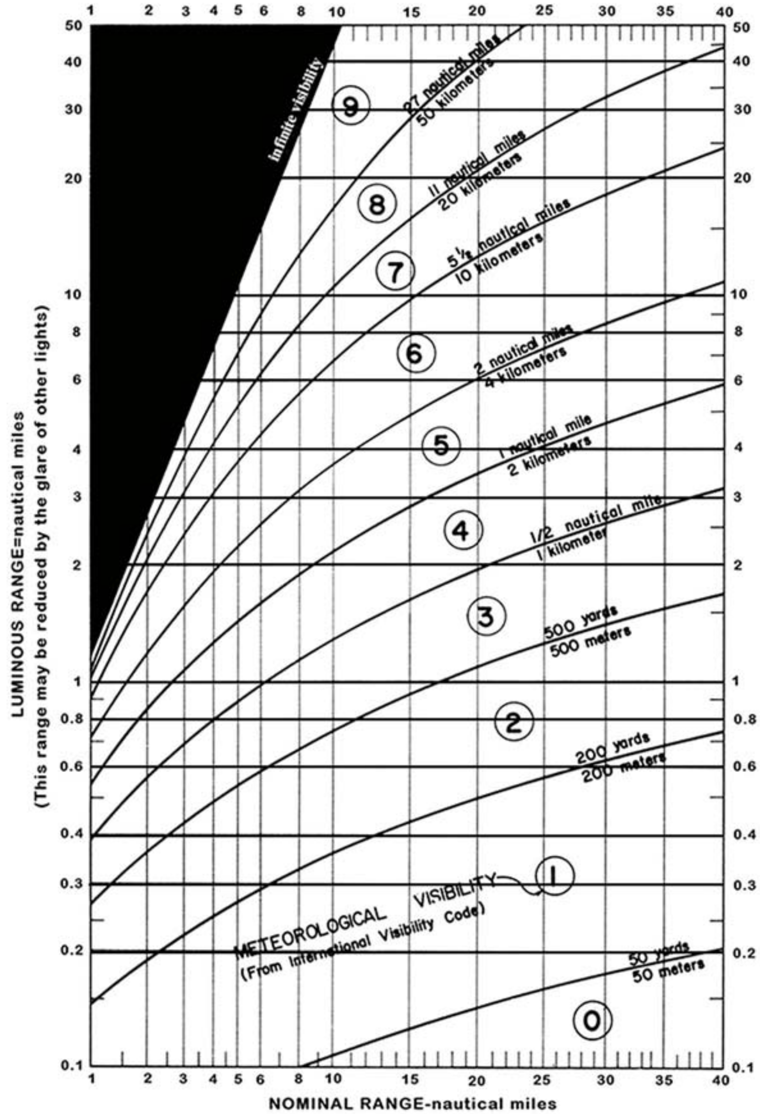

Figure 608a. Luminous Range Diagram.

until it intersects the curve or reaches the region on the diagram representing the meteorological visibility. Finally, follow a horizontal line from this point or region until it intersects the vertical luminous range scale.

Example 1: *The nominal range of a light as extracted from the Light List is 15 nautical miles.*

Required: *The luminous range when the meteorological visibility is (1) 11 nautical miles and (2) 1 nautical mile.*

Solution: *To find the luminous range when the meteorological visibility is 11 nautical miles, enter the Luminous Range Diagram with nominal range 15 nautical miles on the horizontal nominal range scale; follow a vertical line upward until it intersects the curve on the diagram representing a meteorological visibility of 11 nautical miles; from this point follow a horizontal line to the right until it intersects the vertical luminous range scale at 16 nautical miles. A similar procedure is followed to find the luminous range when the meteorological visibility is 1 nautical mile.*

Answers: *(1) 16 nautical miles; (2) 3 nautical miles.*

Code No.	Weather	Yards
0	Dense fog	Less than 50
1	Thick fog	50-200
2	Moderate fog	200-500
3	Light fog	500-1000
		Nautical Miles

From the International Visibility Code.

Table 608. Meteorological Optical Range.

Code No.	Weather	Yards
4	Thin fog	1/2-1
5	Haze	1-2
6	Light Haze	2-5 1/2
7	Clear	5 1/2-11
8	Very Clear	11.0-27.0.
9	Exceptionally Clear	Over 27.0

From the International Visibility Code.

Table 608. Meteorological Optical Range.

A light's **geographic range** depends upon the height of both the light and the observer. The sum of the observer's distance to the visible horizon (based on their height of eye) plus the light's distance to the horizon (based on its height) is its geographic range. See Figure 608b. This illustration uses a light 150 feet above the water. Entering Table 13 - *Distance of the Horizon* (in Volume 2), yields a value of 14.3 nautical miles for a height of 150 feet. Within this range, the light, if powerful enough and atmospheric conditions permit, is visible regardless of the height of eye of the observer. Beyond 14.3 nautical miles, the geographic range depends upon the observer's height of eye. Thus, by the Distance of the Horizon table mentioned above, observers with a height of eye of 5 feet can see the light on their horizon if they are 2.6 miles beyond the horizon of the light. The geographic range of the light is therefore 16.9 miles. For a height of 30 feet the distance is 14.3 + 6.4 = 20.7 miles. If the height of eye is 70 feet, the geographic range is 14.3 + 9.8 = 24.1 miles. A height of eye of 15 feet is often assumed when tabulating lights' geographic ranges.

To predict the bearing and range at which a vessel will initially sight a light first determine the light's geographic range. Compare the geographic range with the light's luminous range. The lesser of the two ranges is the range at which the light will first be sighted. Plot a visibility arc centered on the light and with a radius equal to the lesser of the geographic or luminous ranges. Extend the vessel's track until it intersects the visibility arc. The bearing from the intersection point to the light is the light's predicted bearing at first sighting.

If the extended track crosses the visibility arc at a small angle, a small lateral track error may result in large bearing and time prediction errors. This is particularly apparent if the vessel is farther from the light than predicted; the vessel may pass the light without sighting it. However, not sighting a light when predicted does not always indicate the vessel is farther from the light than expected. It could also mean that atmospheric conditions are affecting visibility.

Example 1: *The nominal range of a navigational light 120 feet above the chart datum is 20 nautical miles. The meteorological visibility is 27 nautical miles.*

Required: *The distance at which an observer at a height of eye of 50 feet can expect to see the light.*

Solution: *The maximum range at which the light may be seen is the lesser of the luminous or geographic ranges. At 120 feet the distance to the horizon, by table or formula, is 12.8 miles. Add 8.3 miles, the distance to the horizon for a height of eye of 50 feet to determine the geographic range. The geographic range, 21.1 miles, is less than the luminous range, 40 miles.*

Answer: *21 nautical miles. Because of various uncertainties, the range is rounded off to the nearest whole mile.*

When first sighting a light, observers can determine if it is on the horizon by immediately reducing their height of eye. If the light disappears and then reappears when the observer returns to their original height, the light is on the horizon. This process is called **bobbing a light**.

If a vessel has considerable vertical motion due to rough seas, a light sighted on the horizon may alternately appear and disappear. Wave tops may also obstruct the light periodically. This may cause the characteristic to appear different than expected. The light's true characteristics can be ascertained either by closing the range to the light or by increasing the observer's height of eye.

If a light's range given in a foreign publication approximates the light's geographic range for a 15-foot observer's height of eye, one can assume that the printed range is the light's geographic range. Also assume that publication has listed the lesser of the geographic and nominal ranges. Therefore, if the light's listed range approximates the geographic range for an observer with a height of eye of 15 feet, then assume that the light's limiting range is the geographic range. Then, calculate the light's true geographic range using the actual observer's height of eye, not the assumed height of eye of 15 feet. This calculated true geographic range is the range at which the light will first be sighted.

Example 2: *The range of a light as printed on a foreign chart is 17 miles. The light is 120 feet above chart datum. The meteorological visibility is 10 nautical miles.*

Required: *The distance at which an observer at a height of eye of 50 feet can expect to see the light.*

Solution: *Calculate the geographic range of the light assuming a 15 foot observer's height of eye. At 120 feet the distance to the horizon is 12.8 miles. Add 4.5 miles (the distance to the horizon at a height of 15 feet) to 12.8 miles; this range is 17.3 miles. This approximates the range listed on the chart. Then assuming that the charted range is the geographic range for a 15-foot observer height of eye and that the nominal range is the greater than this charted range, the predicted range is found by calculating the true geographic range with a 50*

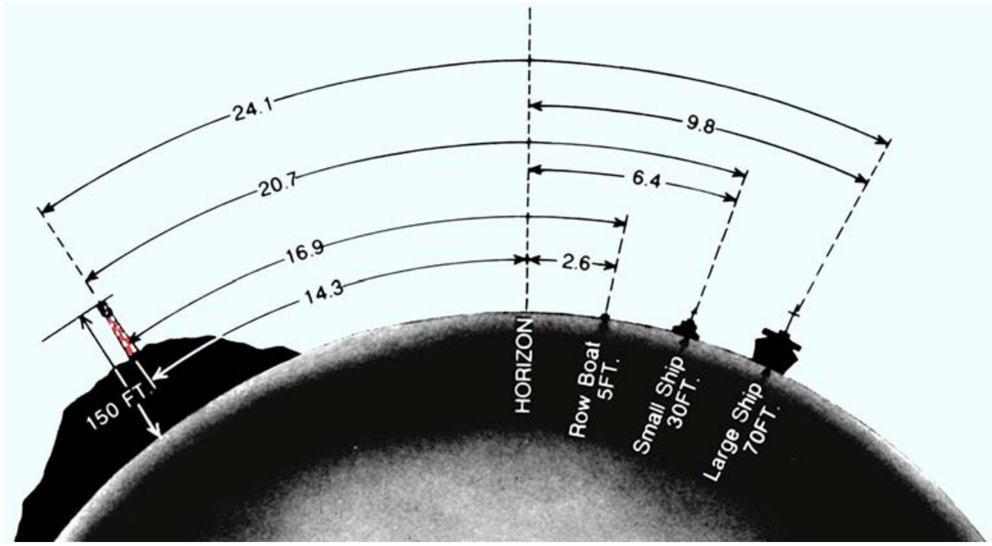

Figure 608b. Geographic Range of a light.

foot height of eye for the observer.

Answer: *The predicted range = 12.8 mi. + 8.3 mi. = 21.1 mi. The distance in excess of the charted range depends on the luminous intensity of the light and the meteorological visibility.*

609. USCG *Light Lists*

The U.S. Coast Guard *Light List* (7 volumes) gives information on lighted navigation aids, unlighted buoys, daybeacons, racons, and the Automatic Identification System (AIS). For a graphical depiction of the limits of each volume, see Figure 609a.

Each volume of the *Light List* contains aids to navigation in geographic order from north to south along the Atlantic coast, from east to west along the Gulf coast, and from south to north along the Pacific coast. It lists seacoast aids first, followed by entrance and harbor aids listed from seaward. Intracoastal Waterway aids are listed last in geographic order in the direction from New Jersey to Florida to the Texas/Mexico border.

The listings are preceded by a description of the aids to navigation system in the United States, luminous range diagram, geographic range tables, and other information.

The entire collection of USCG *Light Lists* can be found on NGA's Maritime Safety Information website via the link provided in Figure 609b.

610. NGA *List of Lights, Radio Aids, and Fog Signals*

The National Geospatial-intelligence Agency (NGA) publishes the *List of Lights, Radio Aids, and Fog Signals* (usually referred to as the *List of Lights*, not to be confused with the Coast Guard's *Light List*). In addition to information on lighted aids to navigation and sound signals in foreign waters, the NGA *List of Lights* provides information on storm signals, signal stations, racons, radiobeacons, radio direction finder calibration stations located at or near lights, and DGPS stations. For more details on radio navigational aids, consult *Pub. 117, Radio Navigational Aids.*

The NGA *List of Lights* generally does not include information on buoys, although in certain instances, a large offshore buoy with a radio navigational aid may be listed. It does include certain aeronautical lights situated near the coast. However, these lights are not designed for marine navigation and may be subject to unreported changes.

For a graphical depiction of the limits of each of the seven volumes (*Pub. 110* through *Pub. 116*) of NGA's *List of Lights* see Figure 610a.

Foreign notices to mariners are the main correctional information source for the NGA *List of Lights*; other sources, such as ship reports, are also used. Many aids to navigation in less developed countries may not be well maintained; they are also susceptible to damage by storms and vandalism, and repairs may be delayed for long periods.

The entire collection of NGA *List of Lights* can be found via the link in Figure 610b.

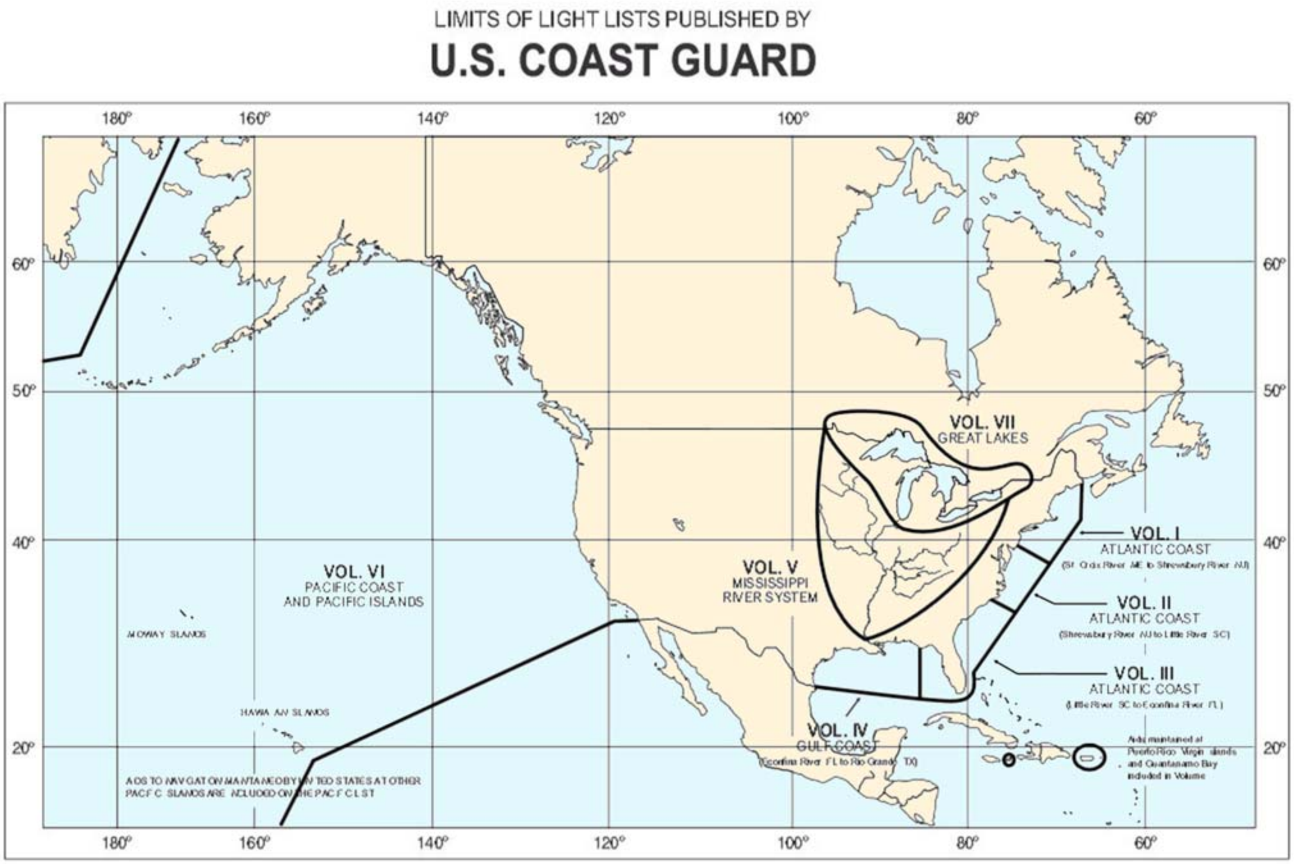

Figure 609a. USCG Light List limits.

Figure 609b. U.S. Coast Guard - Light Lists.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0014

MISCELLANEOUS NAUTICAL PUBLICATIONS

611. NGA *Radio Navigational Aids (Pub. No. 117)*

This publication is a selected list of worldwide radio stations which perform services to the mariner. Topics covered include radio direction finder and radar stations, radio time signals, radio navigation warnings, distress and safety communications, medical advice via radio, long-range navigation aids, the AMVER system, and interim procedures for U.S. vessels in the event of an outbreak of hostilities. *Pub. No. 117* is corrected via the *Notice to Mariners* and is updated periodically with a new edition.

Though *Pub. No. 117* is essentially a list of radio stations providing vital maritime communication and navigation services, it also contains information which explains the capabilities and limitations of the various systems.

The online version of NGA *Radio Navigational Aids (Pub. No. 117)* can be found via the link in Figure 611.

612. *Chart No. 1*

Chart No. 1 is not actually a chart, but a book containing a key to the symbols, abbreviations, and terms

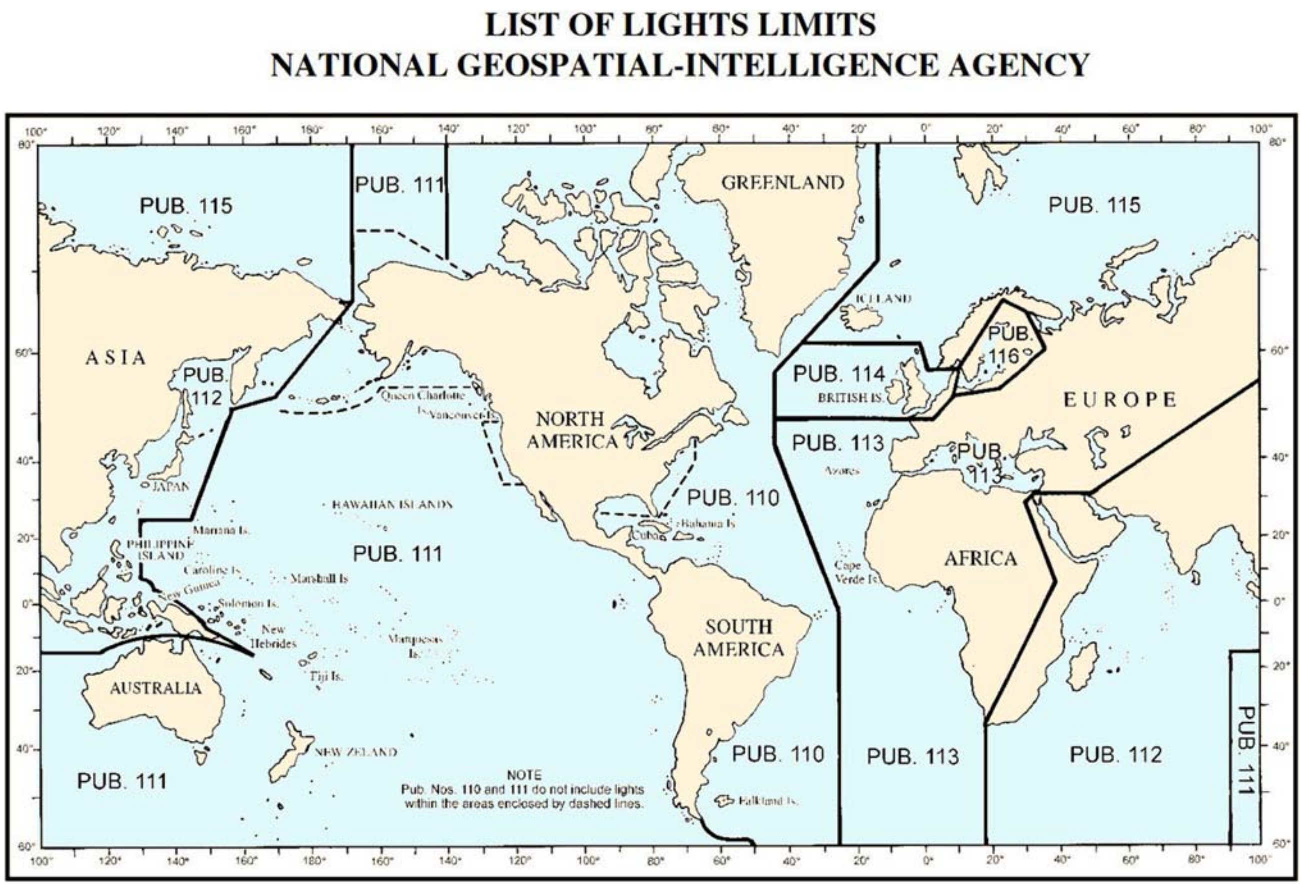

Figure 610a. NGA List of Light limits.

Figure 610b. NGA- List of Lights.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0007

Figure 611. NGA- Radio Navigational Aids (Pub. No. 117).
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0009

used on nautical charts. Most countries that produce charts also produce such a document. The U.S. *Chart No. 1* contains a listing of chart symbols in five categories:

- Symbols used on NOAA charts
- Symbols used on NGA charts
- Symbols used on foreign charts reproduced by NGA
- Symbols recommended by the International Hydrographic Organization (INT1 symbols)
- Symbols specified for use in ECDIS to display ENCs

Subjects covered include general features of charts, topography, hydrography, and aids to navigation. Several pages are devoted to explaining unique features of ECDIS displays, including color palettes, simplified and “traditional” symbology, and safety contours. There is also a complete index of abbreviations and an explanation of the IALA buoyage system.

Chart No. 1 can be found online via the link in Figure 612.

Figure 612. Chart No. 1.
https://nauticalcharts.noaa.gov/publications/us-chart-1.html

613. NGA *World Port Index (Pub. 150)*

The *World Port Index* contains a tabular listing of thousands of ports throughout the world, describing their locations, characteristics, facilities, and services available. Information is arranged geographically; the index is arranged alphabetically.

Coded information is presented in columns and rows. This information supplements information in the *Sailing Directions*. The applicable volume of *Sailing Directions* and the number of the harbor chart are given in the *World Port Index*. The *Notice to Mariners* corrects this book.

The World Port Index can be found online via the link provided in Figure 613.

Figure 613. Pub. 150 World Port Index.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0015

614. NGA *Distances Between Ports (Pub. 151)*

This publication lists the distances between major ports. Reciprocal distances between two ports may differ due to different routes chosen because of currents and climatic conditions. To reduce the number of listings needed, junction points along major routes are used to consolidate routes converging from different directions.

This book can be most effectively used for voyage planning in conjunction with the proper volume(s) of the *Sailing Directions (Planning Guide)*. It is corrected via the *Notice to Mariners*.

The *Distances Between Ports* can be found online via the link provided in Figure 614.

Figure 614. Pub. 151 Distances Between Ports.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0005

615. NOAA *Distances Between United States Ports*

Distances Between United States Ports contains distances from a port of the United States to other ports in the United States, and from a port in the Great Lakes in the United States to Canadian ports in the Great Lakes and St. Lawrence River.

The 2012 edition of this publication is 56 pages in length and can be found online via the link provided in Figure 615.

Figure 615. NOAA Distances Between US Ports.
https://nauticalcharts.noaa.gov/

616. NGA *International Code of Signals (Pub. 102)*

This book lists the signals to be employed by vessels at sea to communicate a variety of information relating to safety, distress, medical, and operational information. This publication became effective in 1969.

According to this code, each signal has a unique and complete meaning. The signals can be transmitted via Morse code light and sound, flag, radio telegraph and telephone, and semaphore. Since these methods of signaling are internationally recognized, differences in language between sender and receiver are immaterial; the message will be understood when decoded in the language of the receiver, regardless of the language of the sender. The *Notice to Mariners* corrects *Pub. 102*.

The *International Code of Signals (Pub. 102)* can be found online via the link provided in Figure 616.

Figure 616. Pub. 102 - International Code of Signals.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0006

617. Almanacs

For celestial sight reduction, the navigator needs an **almanac** for ephemeris data. The *Nautical Almanac*, produced jointly by the Nautical Almanac Office of the United States Naval Observatory in Washington, and Her Majesty's Nautical Almanac Office of the United Kingdom in Taunton, is the most common almanac used for celestial navigation. It also contains information on sunrise, sunset, moonrise, and moonset, as well as compact sight reduction tables. The *Nautical Almanac* is published annually.

The *Air Almanac* contains slightly less accurate ephemeris data for air navigation, but can be used for marine navigation if slightly reduced accuracy is acceptable.

More detailed information on using the *Nautical Almanac* is located in the Celestial Navigation part of this text. See Chapter 17.

618. *Sight Reduction Tables for Marine Navigation*

Without a calculator or computer programmed for sight reduction, the navigator needs ***sight reduction tables*** to solve the celestial triangle. Two different sets of tables are commonly used at sea.

NGA *Pub. No. 229, Sight Reduction Tables for Marine Navigation*, consists of six volumes of tables designed for use with the *Nautical Almanac* for solution of the celestial triangle by the **Marcq Saint Hilaire** or **intercept** method. The tabular data are the solutions of the navigational triangle of which two sides and the included angle are known and it is necessary to find the third side and adjacent angle.

Each volume of *Pub. No. 229* includes two 8° degree zones, comprising 15° degree bands from 0° to 90° degrees, with a 1° degree overlap between volumes. *Pub. No. 229* is a joint publication produced by the National Geospatial-Intelligence Agency, the U.S. Naval Observatory, and the Royal Greenwich Observatory.

The complete set of *Pub. No. 229* volumes can be found online via the link in Figure 618.

Figure 618. Pub. No. 229 - Sight Reduction Tables for Marine Navigation.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0006

619. *Sight Reduction Tables for Air Navigation*

Sight Reduction Tables for Air Navigation, Pub. No. 249, is a joint production effort between the Nautical Almanac Office of the U.S. Naval Observatory and Her Majesty's Nautical Almanac Office. It is issued in three volumes. The title to Volume 1 changed in 2012 to *Rapid Sight Reduction Tables for Navigation.*

Volume 1 contains, for any given position and time, the best selection of seven stars available for observation and, for these seven stars, data for presetting before observation and for accurate reduction of the sights after observation. Volume 1 is updated every five years and may be used without reference to an almanac.

Volumes 2 and 3, primarily used by the air navigator, cover latitudes 0°-40° and 39°-89° respectively and are permanent tables for integral degrees of declination. They provide sight reduction for bodies with declinations within 30° north or south of the equator, which includes the Sun, the Moon, the navigational planets and many navigational stars.

Pub. No. 249 - Volumes 2 and 3 are available online at the link provided in Figure 619.

Figure 619. Pub. No. 249 - Sight Reduction Tables for Air Navigation.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0012

620. Catalogs

Military and U.S. Government customers can place orders for NGA products with the Defense Logistics Agency. Ordering information is available on the Defense Supply Center Richmond website.

NGA Hydrographic Products are no longer offered for sale to civilian customers by the National Aeronautical Charting Office (NACO) or the U.S. Government Publishing Office (GPO); however, authorized reproductions of these products can still be purchased from commercial venders. A list of vendors is available on NGA's Maritime Safety Information website under the Product Catalog tab. See Figure 620a for the link.

Figure 620a. NGA Products - Venders List.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_68

When navigating in U.S. territorial waters civilian mariners should be using products produced by the National Oceanic and Atmospheric Administration (NOAA) which can be found on the Nautical Charts & Publications website (see Figure 620b for the link). Details for where to buy and download charts and publications are found here. Chart data is distributed every week with the latest updates. The site also offers other products and services including online chart viewers and an interactive nautical chart catalog.

Figure 620b. NOAA - Office of Coast Survey Charts & Publications website.
https://nauticalcharts.noaa.gov/

MARITIME SAFETY INFORMATION

621. *Notice to Mariners*

The *Notice to Mariners* is published weekly by the National Geospatial-Intelligence Agency (NGA), prepared jointly with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Coast Guard. It advises mariners of important matters affecting navigational safety, including dangers to navigation, new hydrographic information, changes in shipping channels and aids to navigation, and other important data. The information in the *Notice to Mariners* is formatted to simplify the correction of paper charts, sailing directions, light lists, and other publications produced by NGA, NOAA, and the U.S. Coast Guard.

It is the responsibility of users to decide which of their charts and publications require correction. Suitable records of *Notice to Mariners* should be maintained to facilitate the updating of charts and publications prior to use.

Information for the *Notice to Mariners* is contributed by: NGA (Department of Defense) for waters outside the territorial limits of the United States; National Ocean Service (National Oceanic and Atmospheric Administration, Department of Commerce), which is charged with surveying and charting the coasts and harbors of the United States and its territories; the U.S. Coast Guard (Department of Homeland Security) which is responsible for, among other things, the safety of life at sea and the establishment and operation of aids to navigation; and the Army Corps of Engineers (Department of Defense), which is charged with the improvement of rivers and harbors of the United States. In addition, important contributions are made by foreign hydrographic offices and cooperating observers of all nationalities.

Of the more than 60 countries that produce nautical charts also produce a notice to mariners. About one third of these are weekly, another third are bi-monthly or monthly, and the rest irregularly issued according to need. Much of the data in the U.S. *Notice to Mariners* is obtained from these foreign notices.

U.S. charts must be corrected only with a U.S. *Notice to Mariners* and U.S. *Local Notice to Mariners*. Similarly, correct foreign charts using the foreign notice because chart datums often vary according to region and geographic positions are not the same for different datums.

The *Notice to Mariners* consists of a page of **Hydrograms** listing important items in the notice, a chart correction section organized by ascending chart number, a publications correction section, and a summary of broadcast navigation warnings and miscellaneous information.

Mariners are requested to cooperate in the correction of charts and publications by reporting all discrepancies between published information and conditions actually observed and by recommending appropriate improvements. A convenient reporting form is provided in the back of each *Notice to Mariners*.

Notice to Mariners No. 1 of each year contains important information on a variety of subjects which supplements information not usually found on charts and in navigational publications. This information is published as ***Special Notice to Mariners Paragraphs***. Additional items considered of interest to the mariner are also included in this *Notice*.

U.S. *Notice to Mariners* can be found via the link provided in Figure 621.

Figure 621. U.S. Notice to Mariners.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_61

622. *Local Notice to Mariners*

The *Local Notice to Mariners* is issued by each U.S. Coast Guard District to disseminate important information affecting navigational safety within that District. This Notice reports changes and deficiencies in aids to navigation maintained by the Coast Guard. Other marine information such as new charts, channel depths, naval operations, and regattas is included. Because these announcements are normally temporary and of short duration they are not included in the NGA *Notice to Mariners*, therefore the *Local Notice to Mariners* may be the only source for that information.

The *Local Notice to Mariners* may be viewed on the Coast Guard Navigation Center website. Mariners can register on the Coast Guard Navigation Center website for a list server subscription where they will be notified when new editions of the *Local Notice to Mariners* are available. Vessels operating in ports and waterways in several districts must separately obtain the *Local Notice to Mariners* from each district. See Figure 622a and Table 622a for a map and complete listing of U.S. Coast Guard Districts.

Figure 622a. U.S. Coast Guard Districts.

COMMANDER, FIRST COAST GUARD DISTRICT 408 ATLANTIC AVENUE BOSTON, MA 02110-3350 PHONE: DAY 617-223-8356, NIGHT 617-223-8555	COMMANDER, NINTH COAST GUARD DISTRICT 1240 EAST 9TH STREET CLEVELAND, OH 44199-2001 PHONE: DAY 216-909-6060, NIGHT 216-902-6117
COMMANDER, FIFTH COAST GUARD DISTRICT FEDERAL BUILDING 431 CRAWFORD STREET PORTSMOUTH, VA 23704-5004 PHONE: DAY 757-398-6229, NIGHT 757-398-6390	COMMANDER, ELEVENTH COAST GUARD DISTRICT COAST GUARD ISLAND BUILDING 52. ALAMEDA, CA 94501-5100 PHONE: DAY 510-437-2980, NIGHT 510-437-3701

Table 622a. U.S. Coast Guard Districts.

COMMANDER, SEVENTH COAST GUARD DISTRICT
BRICKELL PLAZA FEDERAL BUILDING
909 SE 1ST AVENUE
MIAMI, FL 33131-3050
PHONE: DAY/NIGHT 305-415-6800

COMMANDER, SEVENTH COAST GUARD DISTRICT
BRICKELL PLAZA FEDERAL BUILDING
909 SE 1ST AVENUE, RM: 406
MIAMI, FL 33131-3050
PHONE: DAY 305-536-5621, NIGHT 305-536-5611

COMMANDER, EIGHTH COAST GUARD DISTRICT
HALE BOGGS FEDERAL BUILDING
500 POYDRAS STREET
NEW ORLEANS, LA 70130-3330
PHONE: DAY 504-671-2118, NIGHT 504-589-6225

COMMANDER, THIRTEENTH COAST GUARD DISTRICT
FEDERAL BUILDING
915 SECOND AVENUE
SEATTLE, WA 98174-1067
PHONE: DAY 206-220-7280, NIGHT 206-220-7004

COMMANDER, FOURTEENTH COAST GUARD DISTRICT
PRINCE KALANIANAOLE FEDERAL BLDG. 9TH FL 9-204
ALA MOANA BLVD.
HONOLULU, HI 96850-4982
PHONE: DAY 808-535-3409, NIGHT 808-535-3333

COMMANDER, SEVENTEENTH COAST GUARD DISTRICT
P.O. BOX 25517
JUNEAU, AK 99802-5517
PHONE: DAY 907-463-2269, NIGHT 907-463-2000

Table 622a. U.S. Coast Guard Districts.

Local Notice to Mariners can be obtained online via the link provided in Figure 622b.

Figure 622b. Local Notice to Mariners.
https://www.navcen.uscg.gov/?pageName=lnmMain

623. *Summary of Corrections*

A close companion to the *Notice to Mariners* is the ***Summary of Corrections***. The *Summary* is published in five volumes. Each volume covers a major portion of the Earth including several chart regions and their subregions. Volume 5 also includes special charts and publications corrected by the *Notice to Mariners*. Since the *Summaries* contain cumulative corrections, any chart, regardless of its print date, can be corrected with the proper volume of the *Summary* and all subsequent *Notice to Mariners*.

The *Summary of Corrections* is available via the link provided in Figure 623.

Figure 623. Summary of Corrections.
https://msi.nga.mil/MSISiteContent/StaticFiles/SOCDownloadPage.htm

624. The Maritime Safety Information Website

The NGA Maritime Safety Information website provides worldwide remote query access to extensive menus of maritime safety information 24 hours a day. The Maritime Safety Information website can be accessed via the NGA Homepage under Mission > Products & Services > Maritime Safety Products and Services > http://msi.nga.mil/NGAPortal/MSI.portal.

Databases made available for access, query and download include Chart Corrections, Publication Corrections, Chart and Publication Reference Data (current edition number, dates, title, scale), NGA *List of Lights*, U.S. Coast Guard *Light Lists*, World Wide Navigational Warning Service (WWNWS) Broadcast Warnings, Maritime Administration (MARAD) Advisories, Department of State Special Warnings, Mobile Offshore Drilling Units (MODUs), Anti-Shipping Activity Messages (ASAMs), *World Port Index*, and *Radio Navigational Aids*. Publications that are also made available as Portable Document Format (PDF) files include the U.S. *Notice to Mariners,* U.S. *Chart No. 1*, *The American Practical Navigator, International Code of Signals, Radio Navigational Aids, World Port Index, Distances Between Ports, Sight Reduction Tables for Marine Navigation, Sight Reduction Tables for Air Navigation*, and the *Radar Navigation and Maneuvering Board Manual.*

Access to the Maritime Safety Information website is available free to the general public via the internet. Users can provide suggestions, changes, corrections or comments on any of NGA's Maritime Safety Information products and services by submitting the appropriate online reporting form.

Questions concerning the Maritime Safety Information website may be directed to NGA's Maritime Safety Office, MS N64 SFH, National Geospatial-Intelligence Agency, 7500 GEOINT Drive, Springfield, VA, 22150. Email address: Webmaster_NSS@nga.mil.

625. International Convention for the Safety of Life at Sea (SOLAS), 1974

The SOLAS Convention is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The main objective of the SOLAS Convention is to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety. A general breakdown of convention chapters are provided in Table 625.

Chapter I - General Provisions	Surveying the various types of ships and certifying that they meet the requirements of the convention.
Chapter II-1 - Construction - Subdivision and stability, machinery and electrical installations.	The subdivision of passenger ships into watertight compartments so that after damage to its hull, a vessel will remain afloat and stable.
Chapter II-2 - Fire protection, fire detection and fire extinction	Fire safety provisions for all ships with detailed measures for passenger ships, cargo ships and tankers.
Chapter III - Life-saving appliances and arrangements	Life-saving appliances and arrangements, including requirements for life boats, rescue boats and life jackets according to type of ship.
Chapter IV - Radiocommunications	The Global Maritime Distress Safety System (GMDSS) requires passenger and cargo ships on international voyages to carry radio equipment, including satellite Emergency Position Indicating Radio Beacons (EPIRBs) and Search and Rescue Transponders (SARTs).
Chapter V - Safety of navigation	As it relates to manning, voyage planning, dangers, weather, tides and the obligation to assist those in distress
Chapter VI - Carriage of cargoes	Requirements for the stowage and securing of all types of cargo and cargo containers except liquids and gases in bulk
Chapter VII - Carriage of dangerous goods	Requires the carriage of all kinds of dangerous goods to be in compliance with the International Maritime Dangerous Goods Code (IMDG Code).
Chapter VIII - Nuclear ships	Nuclear powered ships are required, particularly concerning radiation hazards, to conform to the Code of Safety for Nuclear Merchant Ships
Chapter IX - Management for the Safe Operation of Ships	Requires every ship owner and any person or company that has assumed responsibility for a ship to comply with the International Safety Management Code (ISM).
Chapter X - Safety measures for high-speed craft	Makes mandatory the International Code of Safety for High-speed craft (HSC Code).
Chapter XI-1 - Special measures to enhance maritime safety	Requirements relating to organizations responsible for carrying out surveys and inspections, enhanced surveys, the ship identification number scheme, and operational requirements.
Chapter XI-2 - Special measures to enhance maritime security	International Ship and Port Facility Security Code (ISPS Code), the role of the Master in maintaining the security of the ship is not, and cannot be, constrained by the Company, the charterer or any other person; Port facilities security assessments and security plans; Delay, detention, restriction, or expulsion of a ship from a port; and ship security alert system requirements.
Chapter XII - Additional safety measures for bulk carriers	Specific structural requirements for bulk carriers over 150 meters in length.
Chapter XIII - Verification of compliance.	Makes mandatory from 1 January 2016 the IMO Member State Audit Scheme.

Table 625. SOLAS Convention outline.

Chapter XIV - Safety measures for ships operating in polar waters.	Float-free, automatically activated EPIRB. Detectable by Inmarsat geostationary satellite.

Table 625. SOLAS Convention outline.

The IMO publishes the *SOLAS (Consolidated Edition, 2014)*, which is an easy reference to all SOLAS requirements.

The Centre for International Law website provides an unofficial text of the SOLAS treaty. See Figure 625 for a link to this document.

Figure 625. SOLAS Convention.
Link

The Federal Register outlines in detail the *Implementation of the Amendments to the International Convention on Standards of Training, Certification and Watchkeeping (STCW) for Seafarers, 1978, and Changes to National Endorsements.* The document is available via the link provided in Figure 626.

Figure 626. STCW Convention.
https://www.federalregister.gov/articles/2013/12/24/2013-28032/implementation-of-the-amendments-to-the-international-convention-on-standards-of-training

626. Standards of Training, Certification and Watchkeeping (STCW)

The 1978 STCW Convention was the first to establish basic requirements on training, certification and watchkeeping for seafarers on an international level. Previously the standards of training, certification and watchkeeping of officers and ratings were established by individual governments, usually without reference to practices in other countries. As a result standards and procedures varied widely, even though shipping is the most international of all industries.

The convention prescribes minimum standards relating to training, certification and watchkeeping for seafarers which countries are obliged to meet or exceed. The STCW Convention is arranged by the following chapter outline:

1. General Provisions
2. Master and Deck Department
3. Engine Department
4. Radio Communications and Radio Personnel
5. Special Training Requirements for Personnel on Certain Types of Ships
6. Emergency, Occupational Safety, Medical Care and Survival Functions
7. Alternative Certification
8. Watchkeeping

627. International Convention for the Prevention of Pollution from Ships (MARPOL)

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. The convention includes regulations aimed at preventing and minimizing pollution from ships and currently includes six technical Annexes according to various categories of pollutants, each of which deals with the regulation of a particular group of ship emissions. Special Areas with strict controls on operational discharges are included in most Annexes.

A copy of the MARPOL convention can be found at the Centre for Marine Technology and Ocean Engineering website via the link provided in Figure 627.

Figure 627. MARPOL Convention.
http://www.mar.ist.utl.pt/mventura/Projecto-Navios-I/IMO-Conventions%20%28copies%29/MARPOL.pdf