2003

Charting Neptune's Realm: From Classical Mythology to Satellite Imagery

Osher Map Library and Smith Center for Cartographic Education

CHARTING NEPTUNE'S REALM:

FROM CLASSICAL MYTHOLOGY TO SATELLITE IMAGERY

APRIL 4, 2000 TO JANUARY 11, 2001

OSHER MAP LIBRARY AND SMITH CENTER FOR CARTOGRAPHIC EDUCATION

http://usm.maine.edu/maps/exhibit8

USM | UNIVERSITY OF Southern Maine

The Osher Library Associates

The Associates of the Osher Map Library of the University of Southern Maine is an organization of interested persons formed to support the Osher Map Library and Smith Center for Cartographic Education and its activities. Incorporated as a not-for-profit 501(c)3 corporation, it is legally separate from both the map library and the University. Its mission is to support and promote the interests and continuity of the map library in every way possible.

The Osher Library Associates, formed in 1990, have grown from a small group of interested people to a diverse, international collection of scholars, map collectors, and people from all walks of life. The organization's membership continues to expand and diversify as visitors to the Osher Map Library's facilities and its Web site discover the library's treasures and elect to participate in and support its activities.

Initially, the Osher Library Associates were closely involved with planning, fundraising for, and constructing the Osher Map Library. During this early period, the Osher Library Associates sponsored cooperative exhibitions and lectures at the Portland Museum of Art. Since the Osher Map Library opened in 1994, the Osher Library Associates have undertaken a wide array of activities in support of the library, including funding lectures and exhibitions, staffing and funding educational outreach programs, assisting in the production of catalogs and posters, funding acquisitions and conservation, and acquiring and distributing grant funds for library development. They have also supported and sponsored a number of activities for the benefit of members and the general public, including local, regional, and international cartographic conferences, public lectures on cartographic themes, and field trips and tours of cartographic and geographic interest in New England.

The purpose of this occasional publication series is to stimulate public interest in and awareness of maps and cartography. It seeks to provide meaningful contributions to the cartographic literature that can be appreciated by both the layperson and scholar.

Osher Library Associates, c/o Osher Map Library, University of Southern Maine,
Portland, ME 04104-9301

www.usm.maine.edu/maps

Charting Neptune's Realm: From Classical Mythology to Satellite Imagery

Osher Library Associates, Occasional Publication No. 2

Charting Neptune's Realm:
From Classical Mythology to Satellite Imagery

Exhibition catalog by Donald S. Johnson

Osher Map Library
and Smith Center for Cartographic Education
at the University of Southern Maine

April 4, 2000 to January 11, 2001

Osher Library Associates, Occasional Publication No. 2

In memory of
Sumner T. Bernstein
Founding member and valued counselor
to the Osher Library Associates

Osher Map Library
and Smith Center for Cartographic Education
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Acknowledgements

This catalog of nautical charts is published to commemorate the exhibition the Osher Map Library produced in support of OpSail Maine 2000, a celebration of Maine's rich maritime history. With *Charting Neptune's Realm*, the staff of the Osher Map Library has once again been privileged to work with a guest curator whose historical interests, combined with his sailing experience, provide a unique insight into the cartographic collections. We wish to express our deep gratitude to Donald S. Johnson, author of *Phantom Islands of the Atlantic* (1994), and *Charting the Sea of Darkness: The Four Voyages of Henry Hudson* (1993), for his sustained commitment and dedication to this exhibition over the past several years. For this catalog, Mr. Johnson expanded the original text he wrote for the exhibition, to give a more comprehensive understanding of the history of the nautical chart. He also created all the technical line drawings which appear in this catalog without specific attribution.

To see color images of the items discussed in this catalog, refer to the Osher Map Library's Web site, http://usm.maine.edu/maps/exhibit8. Valuable assistance was given by Dr. Harold L. Osher, Professor Matthew Edney, and George Carhart. We also wish to thank the staff and student assistants of the Osher Map Library, in particular Tim Nason, Daryl Sasser, and Nell Blodget for their help, and Nancy Kandoian of the New York Public Library Map Division for her research assistance. This exhibition has also benefited from the professional assistance of the staffs of Media and Community Relations and the Publications and Marketing Departments of the University of Southern Maine, in particular, Libby Barrett. The technical assistance of Stuart Hunter and Jay York is also gratefully acknowledged. Lastly, we wish to thank the Osher Library Associates, whose generous gift supported publication of the exhibition catalog.

Yolanda Theunissen
curator, Osher Map Library and
Smith Center for Cartographic Education

Introduction

When the Osher Map Library bestowed upon me the honor of being guest curator, it naturally followed that, with my background in maritime history, the central theme for the exhibition would be of a nautical nature. From there, however, the choices of a specific topic, and how to organize and structure it, were boundless. With over 60,000 pre-1900 maps and charts in the collection to choose from it was essential to have a nodal point—an anchor, as it were—around which to make the selection. In the end, it was my own personal experience in a small sailboat, battling the furies of the open ocean, and appreciation of its multitude of moods, that provided the answer. The present-day nautical chart and ocean pilot chart—my constant helpmates—would become this anchor.

These charts depict the characteristics peculiar to the oceans, winds, currents, depths, etc., which the mariner must know in order to navigate safely across the trackless open sea. On this basis, the selected charts show the origin of the special iconography developed over the centuries to depict each of these phenomena.

Knowledge about the oceans, from conjecture and philosophical constraint, to first-hand information gleaned from voyaging and scientific investigation, is a continuous process. Through modern technology, new and more highly refined data can be gathered and rapidly disseminated to the mariner. Transitory features, such as sea-surface temperature, hurricanes, and icebergs, can not only be shown, but with the aid of computer models, predicted for the future.

This exhibition, *Charting Neptune's Realm*, takes the viewer on a voyage over twenty-three centuries of the cartographic history of the nautical chart.

Donald Johnson
guest curator
Charting Neptune's Realm

Classical Mythology

Quos ego—Sed motos praestat componere fluctus . . . "But first — it is better to calm the turbulent seas." Sparing no time for words, Neptune, god of the deep, helper of those who voyage in ships across his domain, brought order to the motion of the waves. Then he spoke to Aeolus, king of the winds, who had unleashed the fury of the brawling winds and howling storms to overwhelm and sink the ships of Aeneas. Aeolus had no right, he was told, to impinge on Neptune's jurisdiction of the sea, nor would he be allowed, by bringing forth the winds, to forestall the destiny of the Trojans in their founding of the future Rome.

1. François Boucher
French, 1703-1770
[frontispiece]
Copper engraving, 46.4cm x 30.5cm
From: *Le Neptune Oriental* (Paris: Jean Baptiste Nicolas Denis D'Après de Mannevillette Demonville, and Brest: Malassis, 1775)

To gods and men alike, winds could alter their fortune, and were thought of as deities in their own right. In the remote past—our legacy from Greco-Roman culture—gods and goddesses descended from their celestial realm to earth. There, they wielded their heavenly powers and passions to control events.

In balance to the *mythic* significance of gods and goddesses in the Greco-Roman world, scholars of antiquity had their explanations for the phenomena of wind and wave. Aristotle, in his treatises *De caelo*, and *Meteorologica*, put forth his notions of the geography of the known world. It was a small world, bounded by lands familiar from colonization, conquest, and trade. Aristotle's concept of the earth was one of an ordered architecture, in which masses of land were distributed over the surface of the earth in a balanced fashion, and all the waters were interconnected and in constant flow. Pliny the Elder *(Historia naturalis)*, Seneca *(Quaestiones naturales)*, and Pythagoras all made contributions toward a comprehension of the planet earth. Their speculations, however, were based on philosophy and logic, rather than by physical and experimental proofs. Nonetheless, this tradition of theoretical geography continued well into the fourteenth century.

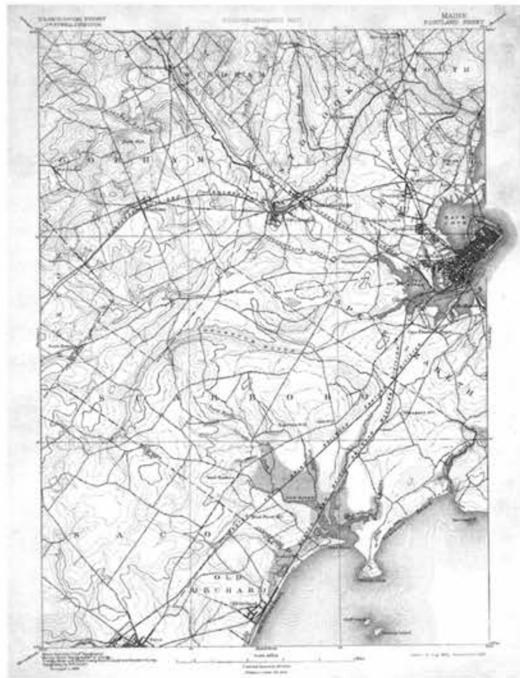
As mariners ventured beyond familiar coasts into the illimitable seas and oceans, they made discoveries and brought back observations of the earth's fluid envelope. Their new-found information could not be explained by the theories of the ancients, and required re-thinking into a body of knowledge we call science. In the sixteenth and seventeenth centuries, philosophers of natural science described the phenomena of winds and currents from empirical evidence, rather than by the philosophical construct of the ancients; yet their theories to explain them were basically unchanged from the time of Aristotle.

The collective experience of sea-farers, when connected with advances made in the sciences of chemistry and physics, produced new interpretations of the world. This knowledge of the physical geography of the sea grew from many simultaneous lines of investigation, sometimes overlapping, sometimes containing large gaps, and even on occasion contradicting one another. But through the centuries one goal remained constant and undiminished in strength—to bring order out of chaos. Given expression in the form of cartography, these graphic images reveal more succinctly than the written word, and convey more quickly to the mind, mankind's search for, and knowledge about the watery sector of our globe—Neptune's Realm.

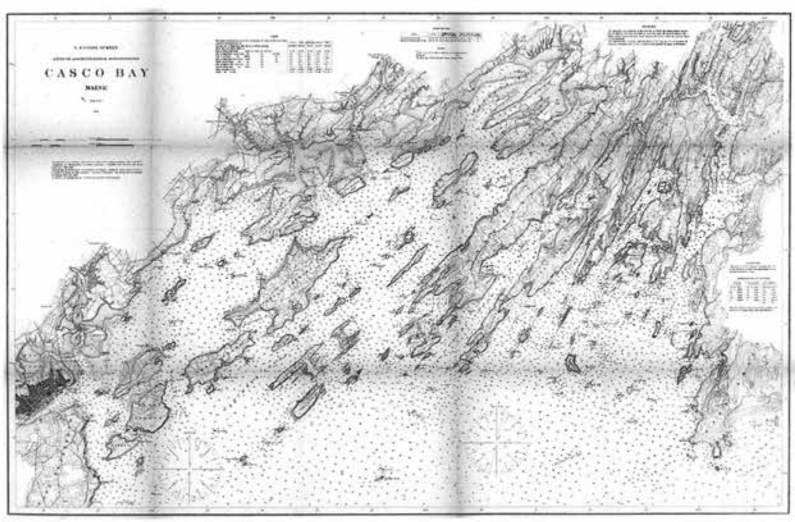
Maps and Charts

For most persons, the words *Map* and *Chart* are freely interchangeable. However, a distinction may be made between the two. Concern of landsmen is with the geographic characteristics within their realm—its rivers, mountains, forests and swamps, along with man-made features of roads and towns—in order to grasp the nature and extent of the land and know how to move around within it. Maps provide that information. Oceans are considered merely as blank spaces separating the land-masses. The mariners' interest is the reverse; their primary domain is the ocean, and land is portrayed only to define the outer bounds of that region. Interest in land is confined to that thin strip containing harbors of refuge at the end of a voyage. Only those features of land visible from the sea, such as headlands and prominent features, which enable them to identify correctly a landfall, are of importance. Charts, then, are a "mapping" of the ocean.

Everyone is familiar with maps and the information they contain, but few are aware of the nautical chart with its special characteristics and iconography. In the absence of land, one piece of water looks like any other, leading one to ask, "what is there that can be delineated on the vast, trackless ocean?" And, "how did this notation arise and develop?" The charts in this exhibition answer these questions.



2. United States Geological Survey
Maine Portland Sheet and Maine Casco Bay Sheet
Lithograph, 44.5cm x 64.8cm
Washington, DC: United States Geological Survey, 1889/1892/1906



3. United States Coast and Geodetic Survey
Casco Bay Maine
Electrotype, 62.7cm x 98.6cm
Washington, DC: United States Coast and Geodetic Survey, 1870

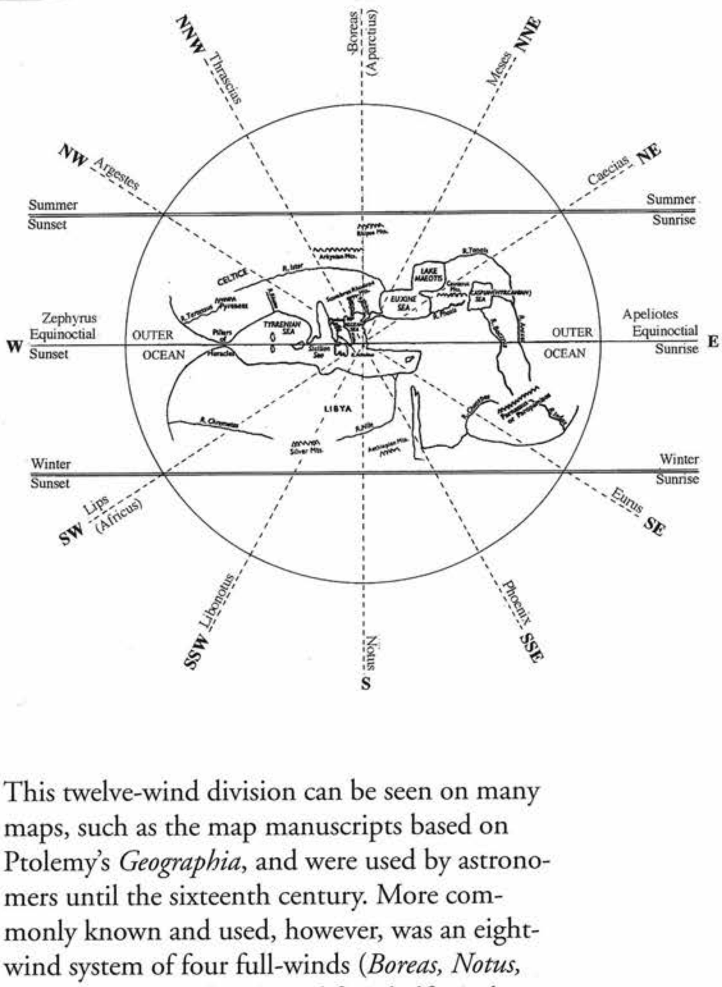
I. WHERE THE WINDS BLOW

King Aeolus, lord of wind and cloud, ruler of contending winds and moaning gales, controlled their fury lest they flay the sea into a great uproar. So great was his power, that Agamemnon, leader of the Greek expedition to destroy Troy, sacrificed his daughter Iphigeneia to secure favorable winds for their journey across the sea. This was the war (c.1200 BC) now remembered by the ruse of a giant wooden horse filled with warriors, and given as a "gift" to gain entrance to the walled city of Troy.

Winds, and the place from which they blew, were the earliest means of dividing the horizon into named parts in order to express direction. The ancients used various forms of wind systems: Homer described four winds, consisting of the four cardinal points we now call north, south, east, and west; Pliny and Posidonius recognized eight winds; whereas Aristotle enumerated twelve winds and the quarter from which they blew. Four of the winds had directly opposite counterparts. *Boreas (Aparctias)* was the north wind, as it blew from the region of *Ursus Major*, the Great Bear. Opposite it was *Notus*, the south wind. *Apeliotes*, and its counterpart *Zephyrus*, respectively blew from the east and the west, where the sun rose and set during the equinoxes. Sunset and sunrise at the summer and winter solstices filled in the intermediate points between the four cardinal directions.

All but the south wind, *Notus*, were derived from an astronomical position. This wind was not conceived by Aristotle to blow from the south pole, nor from the winter Tropic of Capricorn, for then there would have to be a corresponding wind from the summer Tropic of Cancer. As there was already a north wind, denoted by *Boreas*, this would create two winds for north. He believed the south wind to arise from the region of the torrid zone, lying halfway between the habitable north and south zones.

Because its proximity to the sun was greater, it was thought to be stronger and warmer than the north wind. The world known to Aristotle lay in latitudes north of the equator. His schema lacked in true symmetry and balance, and did not divide the horizon into exactly equal segments corresponding with present-day coordinates of northeast, southeast, southwest, and northwest.



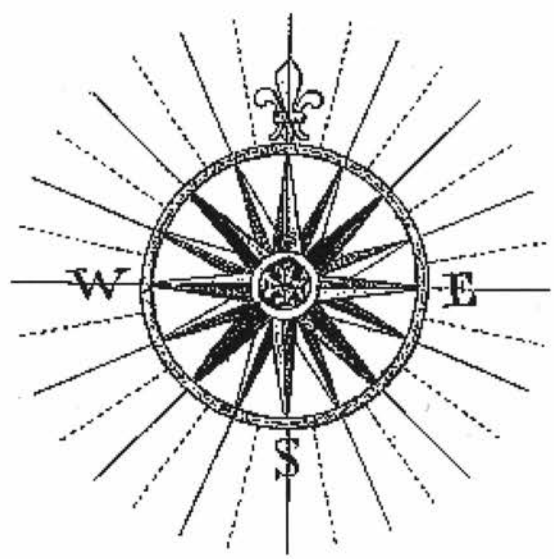
This twelve-wind division can be seen on many maps, such as the map manuscripts based on Ptolemy's *Geographia*, and were used by astronomers until the sixteenth century. More commonly known and used, however, was an eight-wind system of four full-winds (*Boreas, Notus, Apeliotes,* and *Zephyrus*), and four half-winds (*Caecias, Eurus, Lips,* and *Argestes*). Whether the simplification was for graphic (aesthetic) reasons, in an attempt to represent the winds in a geometric pattern of equal sectors, or had a practical purpose is not known.

Astronomical positions, other than the solstices and equinox, were used to indicate wind direction. *Septentrio* designated north, since that wind blew from the direction of the seven stars in the constellation of *Ursa Major*—the north-pointing Big Dipper. Some wind names had no set bearing, but were identified and personified according to the weather they brought with them. Other directions were named after the gods who reigned in each region.

During the Middle Ages, a different set of wind terms for direction arose. Though it, too, was an eight-wind system, instead of taking their origin from seasonal solar positions, or named after mythological personifications believed to blow from given directions, this new set of winds took as its reference general *geographic* regions. Mediterranean mariners named winds after the lands from which they originated. Thus, the southwest wind, *Libeccio,* came from Libya (at the time, a general term referring to all of Africa). *Greco,* from Greece, designated the northeast wind, and *Tramontana* which came from 'across the mountains,' a north wind. This new direction naming system is indicative of the vastly increased number of voyages made in the Mediterranean, and the new-found knowledge gained of winds from direct, personal observation.

As if this nomenclature weren't complicated enough, different names were often used to indicate the same direction, or the same name for different directions. In Roman usage, *Boreas* reigned in the north; whereas to the Greeks, *Boreas'* realm was in the northeast. *Septentrio, Tramontana, Hyperboreas,* or *Aquilo* were all used as names for north.

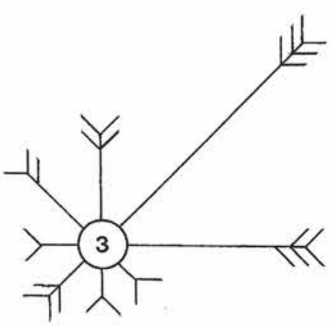
The wind rose appeared late in the thirteenth century on sea charts (called "portolan" charts) of the Mediterranean. Enclosed within a circle were the four cardinal points of north, east, south, and west, each cardinal point representing one of the "full winds." This was bisected with intermediate points of "half-winds," and further bisected into "quarter-winds," and "eighth-winds." The division of the circle into thirty-two equally spaced segments, or points, became the basic directional schema, and persisted in use through the nineteenth century. A network of fine lines—vestigial remnants of personified wind gods—converged inward from the edge of the chart to the points; the wind rose being the center in which all the lines intersected. Variously called rhumb lines, wind lines, or loxodromes, historians believe them to have functioned in aiding the navigator to project his course according to his destination and the direction from which the wind was blowing. In actual practice at sea, however, the lines are of little use to the navigator.



Two other features are invariably present on the wind rose; a mark in the form of a cross on the right side, that is, east, and a north-pointing *fleur-de-lis* at the top of the rose. It is generally agreed that the cross symbolized Jerusalem, the most holy of Christian cities, located at the eastern end of the Mediterranean; its importance attested to by early Medieval maps being "oriented" with east at the top. The distinctive shape of this cross (a *crux quadrata,* or Greek cross) is believed by some to be derived from the emblem worn by the Knights Templar, who during the crusades defended the temple of Jerusalem. However, the origin of the *fleur-de-lis* as a symbol for north is more elusive. One suggestion is that it developed from the combination of a broad spearhead (resembling the flattened iron leaf used as a needle in early compases) with the letter "T" for *Tramontana,* the north wind. Another possibility is that the

fleur-de-lis was associated with the kings of France who also participated in the crusades.

As the result of voyages beyond the confines of the Mediterranean and into the outer ocean, the portolan chart expanded its boundary to include a much larger area of the earth's surface. On these new world charts, the wind rose—often in multiple form—with its radiating lines continued to be shown. Here, one could conjecture a different function for the wind lines—to break up the unknown and seemingly endless vastness of the open ocean into smaller segments more easily comprehended by the mind. Eventually, the wind rose was replaced with the dial system of the compass. Even so, it is still an important part of Ocean Pilot Charts used by mariners. The wind rose on these charts is not used as a direction finding device, but for indicating the percentage of time the wind will blow from any direction, thus enabling the navigator to choose a route with the most advantageous winds. They lack the tremendous aesthetic appeal of their prototypes, but in the simplest possible graphic form these wind roses manage to convey a great amount of information.



Each 5° square of the ocean is marked off on the Pilot Charts with a wind rose showing distribution of the winds for each month that have prevailed in that area over a considerable time. The wind percentages are summarized for each of the eight points. The arrows fly *with* the wind, indicating the direction from which the wind blows, and the length of the shaft, measured against a scale provided, gives the percentage of time it blows from that direction. Average wind strength (on the Beaufort wind scale) is indicated by the number of "feathers" on the arrow. The figure in the center of the circle gives the percentage of calms.

Queen of the Winds

No wind was of greater importance to sailors of the North Atlantic than the Trade Winds; their near constancy in strength, position, and direction might well earn for them the title of "Queen of the Winds." To the mariner it mattered little what caused these winds, as long as they propelled his ship with surety and swiftness to the New World. Well into the seventeenth century, writers of manuals for navigation were satisfied merely to describe the winds. Aristotle's ideas, dating back to the second century BC, were accepted and sufficient.

According to Aristotle, winds were "vapors and exhalations of the earth" that rose to the sphere of air surrounding the earth. In the atmosphere they were propelled around the earth, following the motion of the heavens. Even the revolutionary changes made by Copernicus about the universe did little to advance knowledge in the cause of winds. It only shifted the primary mover from the sphere of air to that of the earth; winds were thought by Copernicus to be caused by the sphere of air lagging behind the motion of the rotating earth.

In the sixteenth century, minds of observing and questioning men began to take notice of the pattern of winds—especially the Trade Winds—and to speculate on their cause. André Thevet, cosmographer to King Henry III of France, noted that heat caused the vapors [air] of the earth to rise. In 1590, the Spanish Jesuit, Joseph de Acosta, published his book on natural history, wherein he described with reasonable accuracy the limits of the Trade Winds region, as well as those of the prevailing Westerlies in northern latitudes. His explanation for *why* they occurred, however, hardly changed from that of Aristotle. More than three-quarters of a century elapsed before there was any real insight into the dynamics of wind production.

The French philosopher of natural history, René Descartes, published in 1668 his premise that the heat of the sun causes the vapors and exhalations of the earth to rise, and he related it to the diurnal progression of night and day. He reasoned that since the amount of air raised aloft is greatest at noon, and least at midnight, a depression is created on the opposite side of the earth, causing the air to flow "downhill" toward this depression. The wind, then, "follows the sun towards both its setting and rising directions; that of the east wind [Trade Winds] is stronger, as it is enhanced by the general motion of the atmosphere." Descartes was wrong in his deductions, but the truth was almost within his grasp. He came closer in attempting to explain how winds from the north and the south are caused. The vapors, he said, are drawn upward at the equator, where the heat is greatest, and flow toward the poles where they fall; this is true in both hemispheres. At night, the vapors cool, and condense themselves, causing a reversal of the flow. Thus, Descartes introduced two new notions about the movement of air: one, there exists a meridional (north/south) flow; two, the idea of a convection cell, whereby a continuous circulation is maintained. It was apparent to him that these were but broad, general patterns, and they varied in different parts of the earth according to irregularities of the earth's surface and differences in the supply of vapor.

Not until the mechanics of atmospheric pressure and gravity were formulated, and the means to measure pressure by a barometer invented, could the kinetics of general wind systems be fully understood.

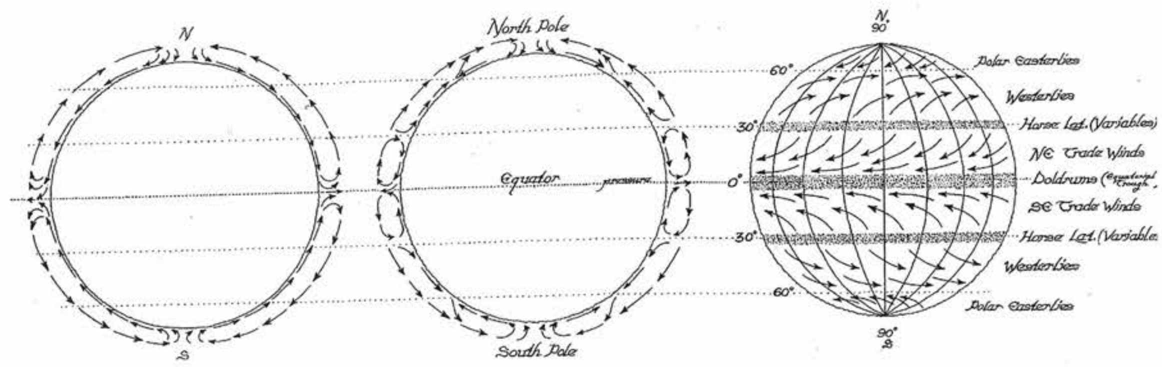
Wind Systems of the Earth

The earth's atmosphere is composed of several layers that are not static, but in constant motion. It is this planetary circulation of air that controls our weather, produces the major high and low pressure systems of the earth, and is responsible for belts of calms, variables, and the persistent flow of Trade Winds. Indeed, the Troposphere (lowest six to ten miles of the atmosphere) derives its name from the Greek *tropos*, meaning to turn or change.

The basic pattern of circulation results from air being heated in the tropical zone and rising to higher altitudes. These winds aloft flow toward the polar regions. The rising currents near the equator produce a permanent belt of low pressure in the lower latitudes, while the descending currents produce high pressure in the polar zones. Cooler, thus heavier, air from the polar zones flows down over the surface of the earth to replace that which has risen. Thus, a constant balance of heat is maintained. René Descartes came this far in his understanding of the winds. But this simplified pattern is rendered more complex by two major factors; the rotation of the earth, spinning on its axis, and the angle of that axis relative to the Sun.

In 1835, Gustav-Gaspard Coriolis, a French engineer, introduced the concept that takes his name—the Coriolis effect. He stated that a moving body on the earth's surface is deflected by the rotation of the earth. In the northern hemisphere the deflection is to the right (to the left in the southern hemisphere). This accounts for direction in circulation of major water and air currents. As a result, air aloft, in its trajectory toward the poles, flows almost due east by the time it reaches a latitude of 30° in the northern hemisphere, and almost due west in the southern hemisphere. Due to the conservation of angular momentum, the sheer weight of this mass of air is overcome by gravity causing the air to descend to the earth's surface where it then spreads both north and south. Where this occurs (in a region called the "Horse Latitudes") a belt of high pressure is created, with its calms or light and variable winds. Thus, the major flow of air from the poles back toward the equator is broken up into several important sub-groups. In the northern hemisphere, these sub-groups are: Polar Easterlies, Westerlies, and Northeast Trade Winds.

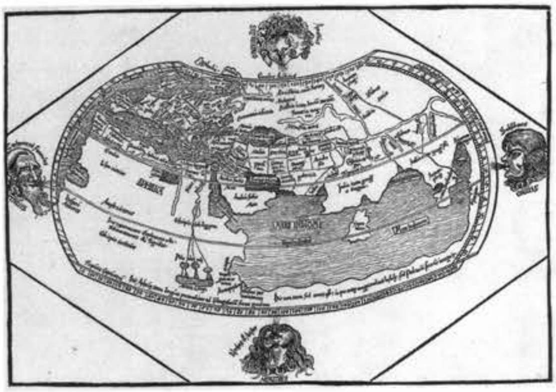
Basic Pattern of the Earth's Air Flow



Flow of returned air toward the equator is deflected westward by the Coriolis effect, producing the Trade Winds in both the northern and southern hemnispheres. At lower levels, the air that flows toward the pole is deflected eastward, producing the predominating Westerlies in both hemispheres. Occasionally, masses of cold air pour down from the polar region into lower latitudes, where the Coriolis effect sets them spinning, creating high pressure cells.

Above the Troposphere, in the lower levels of the Stratosphere, exists the jetstream. A rapidly moving, narrow band of air, it flows from west to east above the temperate zone and influences both the high pressure and low pressure cells that greatly affect the weather in temperate latitudes. One other major variable must be accounted for, that is, the earth's axis. This is a fixed angle, tilted at 23.50°, but in its annular orbit around the Sun it changes relative to the Sun. Between March 21 (Vernal equinox) to September 23 (Autumnal equinox) the northern point of its axis is inclined toward the Sun. This is the period when the Sun is relatively high in the sky in the northern hemisphere, and summer weather is experienced. From September 23 to March 21, the situation is reversed. This shift in the declination of the Sun creates a likewise shift in the equatorial belt of heating and causes a corresponding move in the belts of pressure with their associated winds.

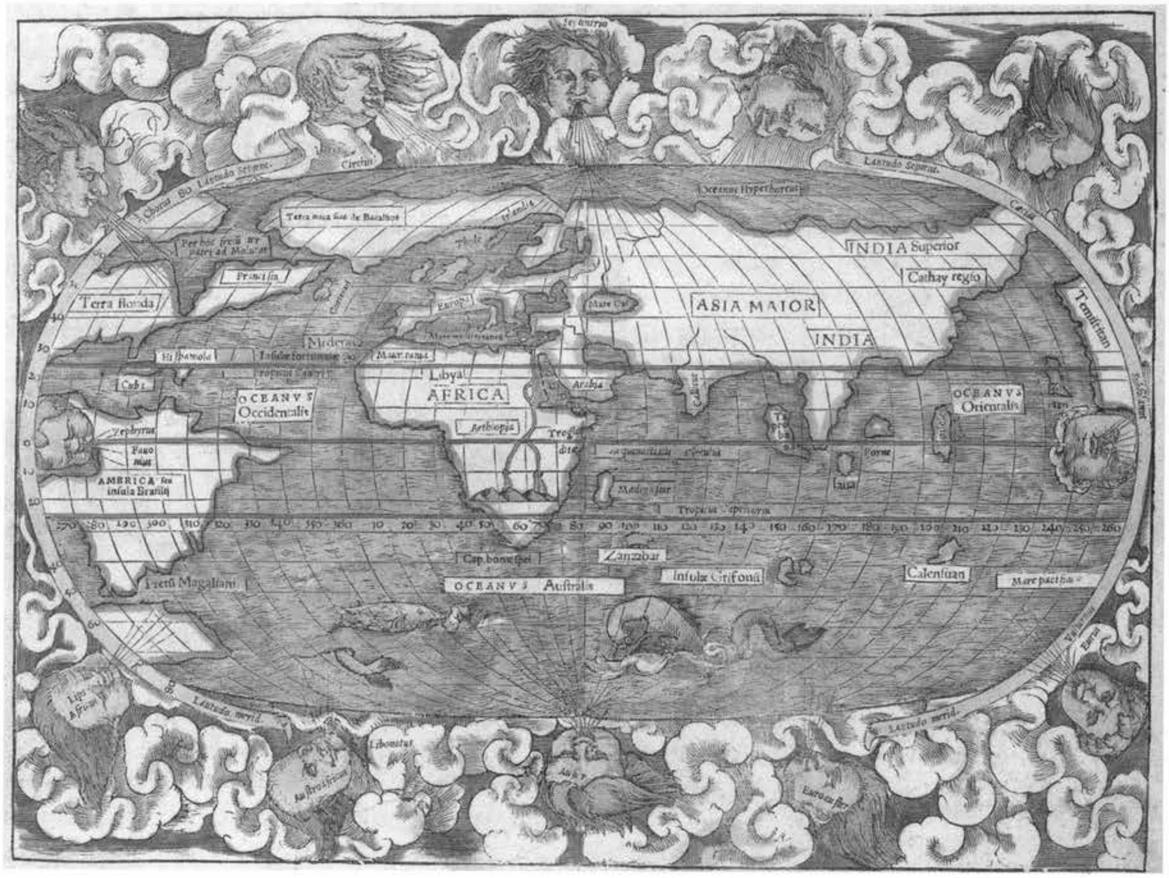
This planetary circulation explains the general pattern of surface winds as they flow over the open ocean. Superimposed upon this pattern, however, are winds caused by islands and continental land masses.



4. Gregor Reisch
German, ca. 1470-1525
[untitled map of the ecumene]
Woodcut, 27.9cm x 40.5cm
From: *Margarita Philosophica* (Strassburg Johan Grüniger, 1504)

Claudius Ptolemaeus (commonly called Ptolemy) lived in Alexandria, Egypt, during the second half of the second century AD. The greatest of all geographers and cartographers of classical antiquity, Ptolemy created a body of astronomical and geographic knowledge of unrivaled extent. Renaissance scholars reproduced Ptolemy's Atlas, *Geographia,* in many editions throughout the fifteenth, sixteenth, and early seventeenth centuries. These served as the basis for development in western cartography.

On Reisch's 1504 version of Ptolemy's world map, the four sides are embellished with personifications of the four primary winds, to which the cartographer gives both their Latin and Greek names. Additionally, he uses the regional names of *Septentrio, Oriens, Occidens,* and *Meridies. Meridies,* designating south, is the position of the Sun at its meridian—midday.



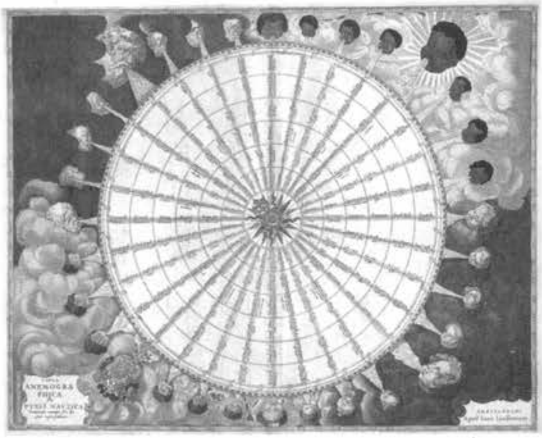
5. Sebastian Münster
German, 1489-1552
Typvs Vniversalis
Wood-cut, hand-colored,
25.5cm x 34.4cm
From: *Geographia vniversalis, vetvs et nova, complectens Clavdii Ptolemaei Alexandrini enarratio. Nis libros VIII.* (Basle: Hinrich Petri, 1540/42)

This world map of Ptolemy, from 1540/1542 edition of Ptolemy's *Geographia*, shows the full twelve winds designated by Aristotle. The twelve-wind system remained in use throughout the Middle Ages. In keeping with the mythologic origin of winds for direction, by necessity they are placed beyond the confines of the known world—beyond the earth itself, in an outer celestial sphere.

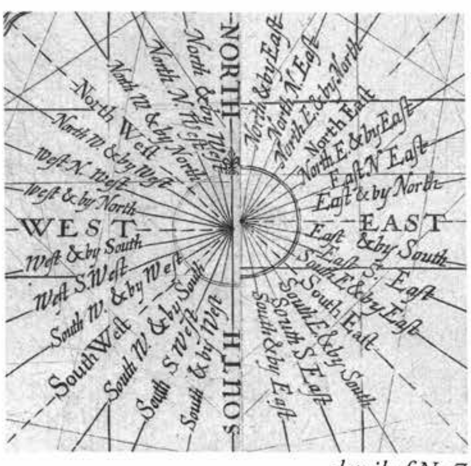
Over the centuries an increased diversity of names for the winds and ambiguity about the direction they came from, produced a multitude of different wind systems. No longer were there eight, or even twelve winds to contend with. The division and re-division of the four cardinal points (winds) into thirty-two points, created a tangled confusion of names and directions. To create a sense of order, cartographers produced wind roses such as this one by Jan Jansson (No. 6) in 1650. The thirty-two compass points are shown with the various directional names of the winds.

But to sailors plying the waters of the open oceans, a wind blowing from Thrace (*Thracias*) lost all relevance in defining direction. Eventually, the wind rose, overburdened by a multiplicity of names and obtuse symbolism gave way to the directional system of north, east, south, and west, with their intermediate compounds, as used today.

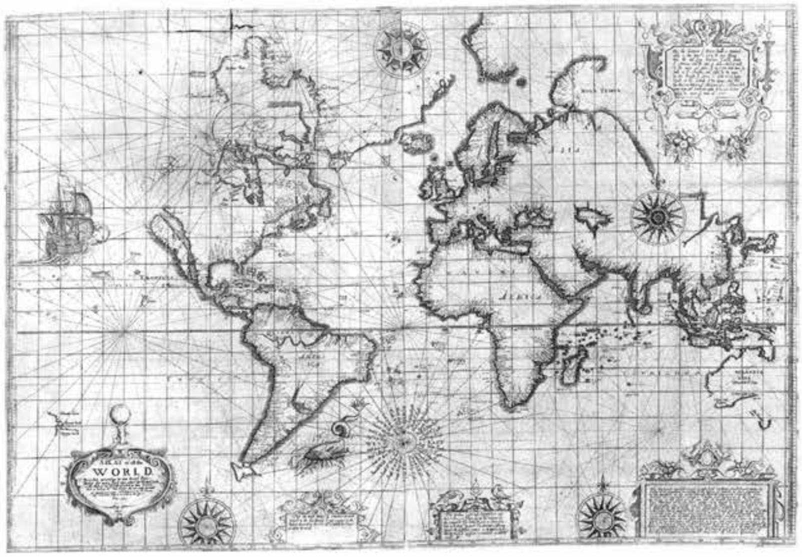
Note the fledgling emergence at the perimeter of the circle of an even more abstract directional system—degrees of arc of a circle. Even here, the cartographer is unable to resist introducing variations. The innermost ring uses north as 00°, and moves clockwise through 11.25° increments (360° ÷ 32 = 11.25°) until reaching north again. Outside this ring, north begins at 00° and increases in 11.25° increments until east is reached at 90°. Each successive quadrant restarts the numbering from 00° to 90°. Finally, in the outermost ring, the same is repeated, but the numbering moves counter-clockwise.



6. Jan Jansson
Dutch, 1588-1664
Tabular Anemographica Seu Pyxis Nautica
Copper engraving, hand-colored,
43.3cm x 54.2cm
From: *Ianssonii Novus Atlas, sive Theatrum Orbis Terrarum,* vol. 5 (Amsterdam: Jansson Heirs, 1650/ca. 1680)



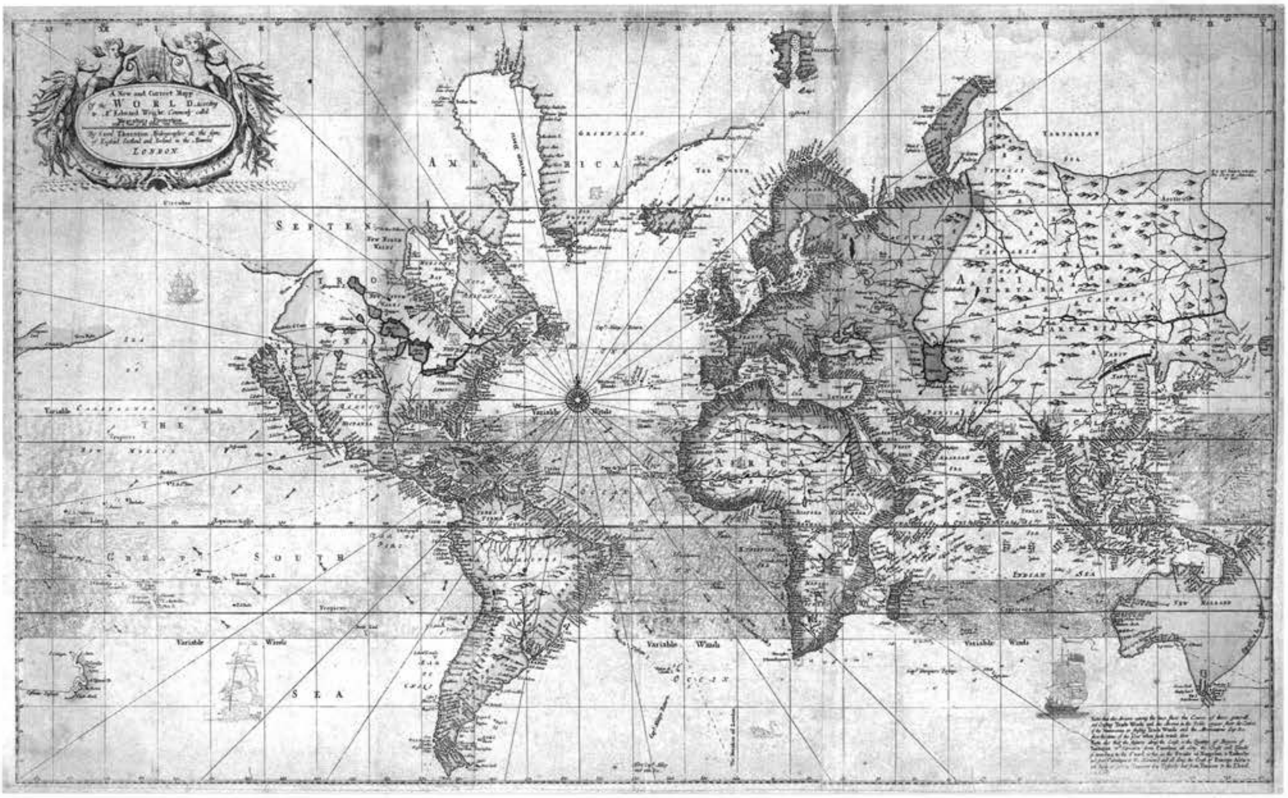
detail of No.7



7. Edward Wright
English, 1558-1615
Plat of All The World
Copper engraving, 52.7cm x 77.8cm
From: *Certaine Errors in Navigation* (London: Joseph Moxon, 1655/1657)

Gone now are *personifications* of the winds, to be replaced by the more abstract wind rose arrangement, with its equally spaced thirty-two winds, or points. Although a conveniently simple arrangement, the problem nonetheless remained of what name to give to all the intermediate winds, or directions. In the time of Charlemagne (768-814AD), Frankish and Flemish mariners in the North had a different system of direction naming. They used the Teutonic monosyllabic words of *Nord, Est, Sund* and *Oëst* (north, east, south, and west) for the four cardinal points. The etymological significance of these four words has long been lost. West and east were apparently originally "evening" and "morning," while south may have been "noon."

Remaining intermediate directions were designated by simple compounds of these four words. This nomenclature was adopted for the standard directional schema, and is still in use throughout the world. It was supplanted in the nineteenth century by the addition of a circle marked in degree increments.



8. John Thornton
English, 1641-1708
Samuel Thornton
English, d. 1715
New and Correct Map of the World
Copper engraving, hand-colored, 52cm x 87cm
From: [*English Pilot*] (London: Mount & Page, ca. 1700/ after 1708)

Although this late version of Thornton's "Map of the World" shows major land masses and some of their interior detail, it still can properly be called a chart, since the predominant emphasis is on those features relevant only to the navigator afloat. It contains the elements necessary to locate one's position on the ocean, and plot the course to a destination. A grid plan of latitude and longitude marked in degrees of arc provides the former, and a compass rose the latter.

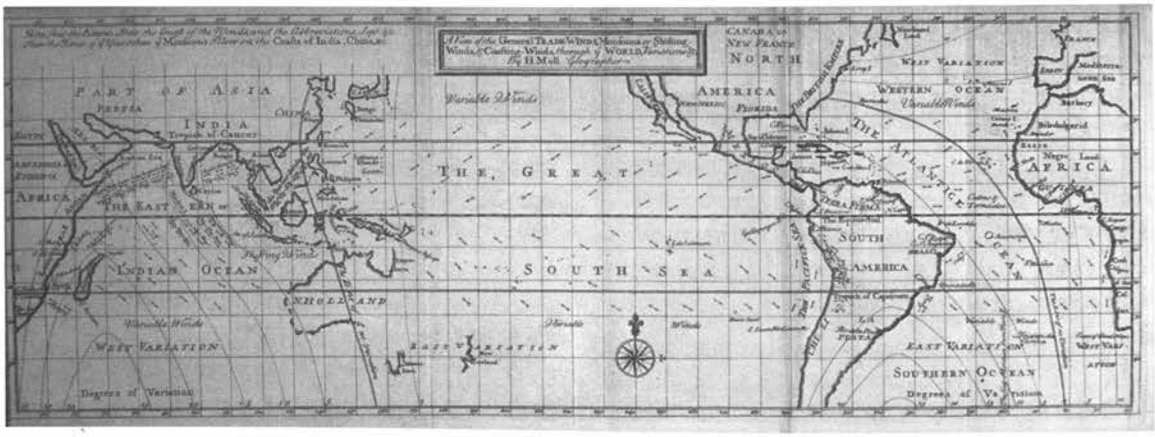
Thornton's map shows how little was known at the beginning of the eighteenth century about the continent of North America beyond its eastern seaboard. Indeed, fully 225 years after Christopher Columbus's encounter with the New World, it was still questioned whether America joined with Asia. This issue is noted in a legend at the northeast corner of Asia. Greenland also presented a problem to cartographers at the time; among the many theories about its geographical relationship to other continents is the one shown here, where it is part of North America. There are other interesting features: Hudson Bay is shown to connect by Frenchman's River with the St. Lawrence River at Quebec; California is still considered to be a large island, separated from the mainland by the Vermilion Sea; and the Mississippi River enters into the Gulf of Mexico at its far western shore, near the Rio Grande.

In contrast to the depiction of land masses, Thornton's representation of the winds of the oceans is remarkably thorough and accurate. A broad band of fine, closely spaced lines shows the extent of the Northeast Trade Winds, and the Southeast Trade Winds (respectively north and south of the equator). Arrows within these bands show the direction of the wind. Though unnamed, the doldrums at the Intertropical Convergence Zone can be inferred by the complete lack of lines and arrows. The regions of Variables, sometimes called the Horse Latitudes, poleward of the Northeast and Southeast Tradewinds, are prominently labeled. Thornton carefully notes how the land mass of Africa alters the direction of winds along its shore.

Three things are missing on this chart about wind systems in the North Atlantic. The Polar Easterlies, and the prevailing Westerlies north of the Variables are neither labeled, nor graphically shown. And, although the seasonal pattern of the monsoons in the Arabian Sea is clearly traced, no mention is made about the seasonal variation in the Trade Winds. These, as well as the Variables, move toward or away from the equator with a change in the seasons. In August, the southerly limit of the Trade Winds shifts northward to about 13.5°N latitude, compared to its 3.5° limit in February. The change in declination of the Sun not only produces a north/south change of the band of Trade Winds, but also a shift in the direction from which they blow. In winter months the Northeast Trade Winds incline more toward the north, and blows more strongly. During the summer months they are more easterly in direction.

By the end of the fifteenth century mariners extended their travels beyond the confines of the Mediterranean and began to explore the oceans of the world. By the mid-sixteenth century, all the major powers of the world—Spain, Portugal, France, and England—were sending forth their ships.

In the desire to seek riches and expand their empires, nations of the world needed more than a wind system based on mythology of the ancients. Voyagers, in the great Age of Discovery, brought back with them new information and observations. General patterns of the ocean's winds began to be understood, and were placed on new charts of the world. Herman Moll's map of 1736 accurately depicts the extent and direction of the Trade Winds, the belt of Variables and Calms, as well as the seasonal variation of the Monsoons in the Indian Ocean. With this knowledge, a safe voyage and speedy return could be anticipated. The wind rose now becomes only a small, decorative element on the nautical chart.



9. Hermann Moll
English, d. 1732
A View of the General Trade-Winds, Monsoons or Shifting-Winds
Copper engraving, 18.1cm x 50.7cm
London, 1736

II. THE ENIGMA OF CURRENTS

In the sixteenth, and well into the seventeenth century, the course of ocean currents was virtually unknown. But as European ships left the familiar shores of continental Europe and their trade routes in the Mediterranean to venture out into the Sea of Darkness, or Great Green Sea of Gloom, as Arab geographers called the Atlantic Ocean, they encountered great rivers within the sea—the ocean currents. With an ever increasing number of expeditions to discover new lands and a sea route to the East Indies, mariners slowly accumulated new knowledge of these currents.

Peter Martyr, eminent cartographer and humanist at the Spanish court of King Ferdinand V, wrote about the exciting new discoveries made in the Western Atlantic. In his *De Orbe Novo* (The New World) published in 1515, Martyr elaborated his theory that "it is only more like to be true, but is also of necessity to be concluded that . . . there should be certain great open places whereby the waters continually pass from the east to the west, which waters I suppose to be driven about the globe of the earth by the incessant motion and impulsion of the heavens." Martyr based his concept of general ocean circulation on prevalent geographical theory which had its roots in an Aristotelian construction of the universe. Accordingly, everything moved from east to west with the rotation of the concentric spheres of planets and stars surrounding the earth. All these spheres were controlled by the outermost sphere, called *Primum mobile*, itself controlled by "divine power." Currents and winds were all under control of the motions of the heavens.

Even the revolutionary departure by Copernicus in 1543, when he proposed a heliocentric universe with the sun, rather than earth, at its center, did not change the cosmological pattern set forth by Aristotle. The Copernican system explained the year as one complete circuit of the earth around the sun, and accounted for the alternating pattern of night and day in rotation of the earth; but the basic structure was unchanged. The universe was still conceived as a finite whole, constructed of heavenly bodies moving in circles, all controlled by the *Primum mobile*. This movement was considered "perfect," that is, it always moved equal distances in equal times.

Nearly half a century later, Giordano Bruno totally rearranged this well-established order of the world when he conceived the universe as "a vast interrelationship through space and time." He considered the universe to be infinite, with an infinity of worlds. In his philosophical system each world moved as an individual, as part of the whole; direction and position were all relative. Bruno conceived that even time was relative. For his heretical philosophy, Giordano Bruno was burned at the stake.

The mariner, however, had a more pragmatic interest in currents. He was less interested in speculating on their cause than how they affected the movement of his ship. Without this knowledge, the navigator's estimate of position could be thrown off by as much as thirty miles in a single day. To know the currents, and use them to advantage in their voyages, was important for the speedy return of vessels filled with precious cargo.

Flowing westward in the North Atlantic Ocean, the North Equitorial Current propelled the ships of Christopher Columbus and Spanish explorers to the New World. From the very start, they recognized and made use of this current. What happened to that water, though, when it reached the other side of the ocean remained unanswered for almost three centuries. Since it was neither depleted at its source in the east, nor

piled up in the west, philosophers of natural history concluded that there must be some means of egress, some strait or river in the Americas through which the water could escape, to flow continuously around the world.

The most plausible location for such an opening in the newly discovered continent was the western end of the Gulf of Mexico. Alonso Alvarez de Piñeda soon disproved this when he set out in 1520 expressly to discover a passage between the Atlantic and Pacific Oceans yielding a way to the East Indies and Cathay. Piñeda sailed nine hundred miles, from Juan Ponce de León's "island" of Florida, to the river of Panuco in Mexico (the northerly limit of exploration by Cortez), and found no egress of currents westward from the Gulf.

Giovanni da Verrazzano, a Florentine navigator, also felt that somewhere in the middle area of the North American Continent lay a passage to Cathay. Under the French flag (for King Francis I) he set sail for America in 1524. In accordance with his plans, Verrazzano closed with the coast at about 34°N, which placed him near Cape Fear, the most southern of Carolina's three capes. From there he headed south until he came as close as he dared to Spanish-held land. Then Verrazzano returned to his northward search and followed the coast until he reached the northern end of Newfoundland before turning back to France. Though he failed to realize his goal, Verrazzano did complete the exploration of the coastline of North and South America. This new continent, extending from the southern tip of Patagonia to within 1,200 miles of the North Pole was shown to be one long, continuous coastline, unbroken by any strait or passage leading to the Pacific Ocean.

Since there was no opening through the Americas for the North Equatorial Current to pass, other explanations were put forth to explain the fate of the westward flowing water. One theory proposed that the waters, following the sun from east to west, were held captive in cavernous spaces and grottoes on the western shore; another, that upon reaching the west, they were confined by the land masses on one side, and submarine mountains on the other. Peter Martyr astutely conjectured that the American Continent deflected the current northward. But then rejected the notion based on John Cabot's claim that when he sailed with his father to Newfoundland in 1508, they found the same westward flowing current in the northerly latitudes as did the Spanish sailing farther south.

Gradually, general patterns began to emerge. William Bourne, in his *A Regiment for the Sea* (1580), described how the Portuguese in sailing toward the East Indies kept away from the westward setting Agulhas Current off *Cabo bone sperance* (Cape of Good Hope) by sailing a hundred or a hundred and fifty leagues south of the cape. On the return trip they made use of this self-same current to speed their passage by sailing close to the cape. When they entered the northern Atlantic, mariners avoided the contrary Northeast Tradewinds and the Canary Current by making a wide sweep to the northwest until halfway to America, before setting a final course homeward.

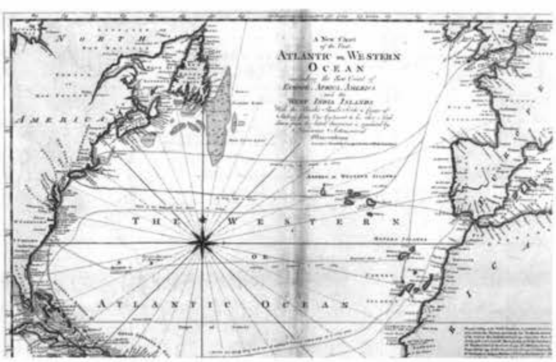
The Spanish also gained knowledge of this invisible mover of ships—the great clockwise gyre of water in the North Atlantic. On their way to the West Indies, Spanish ships sailed south past the Canary Islands, then turned west to take advantage of the westward flowing North Equatorial Current. Returning, they sailed north with the Florida Current (between the Bahamas and Florida) to higher latitudes, then headed homeward. Christopher Columbus followed this route on his voyages, but he attributed the favorable eastward set of the Gulf Stream to the effect of tides, rather than recognizing it as part of the continuous circle of current in the North Atlantic.

In 1593, Sir Richard Hawkins left England on a voyage "to the kingdoms of China and the East Indies by way of the Strait of Magellan and the South Seas." In his observations on the

voyage, published in 1622, Hawkins summed up the difficulties created by the Atlantic currents:

> When the currant runneth north or south, it is easily discovered, by augmenting or diminishing the height [finding latitude by celestial navigation], but how to know the setting of the currant from east to west in the mayne sea is difficult. I have not knowne any man, or read any author, that hath prescribed any certaine meane or way to discover it; and that therefore the best and safest rule to prevent the danger is carefull and continuall watch by day and night, and upon the east and west course ever to bee before the shipp.
>
> Sir Richard Hawkins,
> *The Observations of Sir Richard Hawkins*
> (London: Argonaut, 1933), 15:39

In other words—always be on watch, anticipating an early arrival at land on account of the currents, lest you run aground thinking you still have sea-room.



10. Carington Bowles
English, 1724-1793
A New Chart of the Vast Atlantic or Western Ocean
(detail of Plate No. 10)
Copper engraving, hand-colored,
44.7cm x 55.1cm
London, 1762

The British mapmaker, Carington Bowles, produced this chart in 1762 "to show the course of sailing from one continent to the other." He incorporated an improved delineation of the geography of the North American coast from Newfoundland to the Caribbean Islands as taken from the latest surveys and astronomical observations for latitude and longitude.

Sailing from Europe, ships made a stop in the Madeira Archipelago or Canary Islands for final provisioning of food and water before heading south to pick up the Northeast Tradewinds. Then, they altered course to the west for the West Indies, Carolina, and Virginia. The tradewinds and North Equatorial Current always ensured a swift and dependable voyage. If headed for the port of Boston, or the cod fishing grounds on the Grand Banks of Newfoundland, they took a direct course in more northerly waters. As long as they did not wander too far south to encounter the Gulf Stream, ships made acceptable progress in the passage.

On the return voyage, Portuguese and Spanish ships rode the strength of the Gulf Stream northward from Florida until they reached the latitude of Virginia. There, they turned east to sail directly to the Azores, and back to their home ports. The choice for an eastward passage at this latitude was determined less by any knowledge of a favorable current, then fear of the risk of meeting with English or French vessels. With piracy and privateering the order of the day, any ship of another nation was considered fair prey.

An example of how much was still to be learned about ocean currents is provided by the proscribed course on this chart for vessels sailing from England to New York. By taking the route suggested, ships sailing to New York had to battle against the prevailing southwest wind, as well as the Gulf Stream. At best it is ill-conceived, and exceeded only in inappropriateness by the course given to reach Virginia. Euclid's theorem that "the shortest distance between two points is a straight line" obviously prompted the suggestion for these two routes. But the shortest distance does not always equate with the shortest time. Nor does the theorem hold true for long passages on the open ocean, for here the shortest distance is a bowed line over the curved

surface of the earth. Following it, rather than a straight line, saves many miles, and is called great circle sailing.

None who have entered the region proposed on Bowles's chart for sailing from Madeira, past Bermuda, to Virginia, would ever recommend it. There is no current in this region either to speed or hinder progress. The greatest drawback, however, is the almost complete lack of wind. Centered in the middle of the Azores-Bermuda high-pressure cell, winds here are very light, and subjected to prolonged periods of calm. There are as well, huge masses of seaweed caught in the middle of the Atlantic's clockwise gyre of currents to slow progress. This might well be the origin for Arab geographers calling the Western Ocean (Atlantic) the Great Green Sea of Gloom. Al-Mas'ûdî, a tenth-century historian, philosopher, and scientist, who wrote thirty-six books on history, geography, and astronomy, said: the Western Ocean is "impossible of navigation—an *impenetrable green swamp* filled with monsters."

Great River in the Ocean

Early explorers of the North American coast were quick to note the Gulf Stream, with its swiftness of current, distinctive color and temperature. In 1513, the Spanish Cavelier, Juan Ponce de León, left Puerto Rico with three vessels to explore lands to the north, especially Bimini, the island that possessed a never-failing spring of running water that bestowed everlasting youth upon those who drank from it. He never found the rejuvenating fountain, but his exploration produced a more thorough knowledge of the Florida peninsula with its many offshore islands and reefs. Ponce de León also met with the Florida Current that sweeps between Cuba and Florida toward the Bahaman Islands. He found the current so swift that his vessels could not stem the flow, although he had a good wind. In attempting to anchor along the coast, one of his ships could not hold to her anchor, and was carried away, quickly disappearing.

Nearly a century later, the French explorer and historian, Marc Lescarbot, wrote about his experiences with the Gulf Stream in far more northerly waters. He marveled at how warm the water was east of the Grand Banks of Newfoundland, even though the air was cold; yet quite suddenly they were in a sea where the water was extremely cold, and surrounded by such fogs and cold that "they thought it to be in the month of January."

It remained until nearly the end of the eighteenth century before the general path of the Gulf Stream was worked out, and realized to be part of the large gyre of current in the North Atlantic. Two men, William De Brahm (Surveyor General of the Southern Coast of North America), and Benjamin Franklin, working independently, both published charts showing the path of the Gulf Stream. Of the two, Franklin's chart is better known.

In 1746, Franklin observed that ships bound eastward from America to England took considerably less time than on the return voyage. Later, when he served in London as Deputy Postmaster General for the American Colonies the problem of differences in passage-making time across the Atlantic arose once again. Mail packets from Falmouth to New York were taking considerably longer for the voyage than merchant vessels took from London to Rhode Island, though the distances were much the same. A Nantucket whale-man (and distant cousin to Franklin) by the name of Captain Timothy Folger, pointed out to Franklin that the answer lay in sailing north of the Gulf Stream to avoid being pushed backward by it. Like others in his trade of seeking the whale, Folger was familiar with the course, strength, and extent of the Gulf Stream. Benjamin Franklin took this information and had a chart printed showing the general course of the current; but it had a limited edition, and its importance was not fully realized for a long time.

11. Benjamin Franklin
American, 1706-1790
A Chart of the Gulf Stream
Copper engraving, 20.7cm x 25.5cm
In: *American Philosophical Society Transactions*, vol. 2
(Philadelphia: Robert Atkien, 1786)

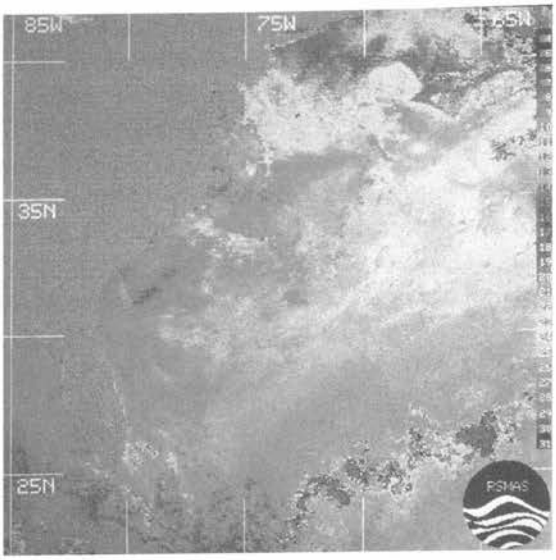
The key to determining the position of the Gulf Stream was the warmth of its water, as noted in 1606 by Marc Lescarbot. During voyages taken in 1775, 1776, and 1785, Franklin took daily water temperature readings. In 1786 he published the results of his research, and included a new map of the Gulf Stream.

He recommended that westward headed vessels sail between the Grand Banks of Newfoundland and the north edge of the Gulf Stream, then keep south of Nantucket Shoals to avoid the current and shorten the passage considerably. This way, progress would not be impeded by the Gulf Stream, and even enhanced by a back-eddy, or counter-current, running close inshore all the way down to Virginia. One would know, he said, when they were within the Gulf Stream by the temperature, for it is much warmer than the water on each side of it.

Fully 104 years after Benjamin Franklin published the results of his study of the Gulf Stream, its position as charted by the U.S. Coast and Geodetic Survey remains virtually unchanged; testimony to Franklin's thorough and correct observations.

The landward edge of the Gulf Stream, referred to as the North Wall, closely follows the 100 fathom (600 feet) curve. Running less than a hundred miles offshore, one would believe that the Gulf Stream warms the east coast of the United States as it does for the west coast of the United Kingdom, Europe, and Norway. This would be true, but for two important considerations. Prevailing winds on this side of the Atlantic—the combined result of the Bermuda/Azores High Pressure cell, and the rotation of the earth—blow from the southwest. Blowing over the warm sea-surface of the Gulf Stream, these winds divert its benign heat away from the land and toward the sea. A cold water counter-current, running close inshore as far south as Cape Hatteras, creates an additional barrier to the Gulf Stream's heat reaching the shores of North America.

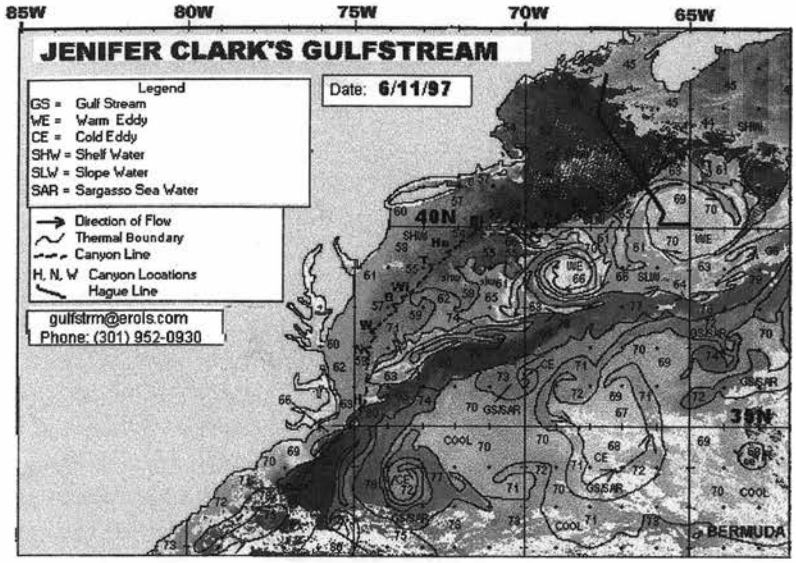
12. John Elliott Pillsbury, Lieutenant
U. S. Navy, later Rear Admiral
American, 1846-1919
Chart of the Gulf Stream (detail)
Lithograph, 44.8cm x 34.2cm
In: United States Coast and Geodetic Survey, *The Gulf Stream: Methods of the Investigation and Results of the Research* (Washington: Government Printing Office, 1890)



12a. Rosentiel School of Marine
Atmospheric Science
East Coast Direct Broadcast
SST Image Daily Composite
University of Miami
www.rsmas.miami.edu

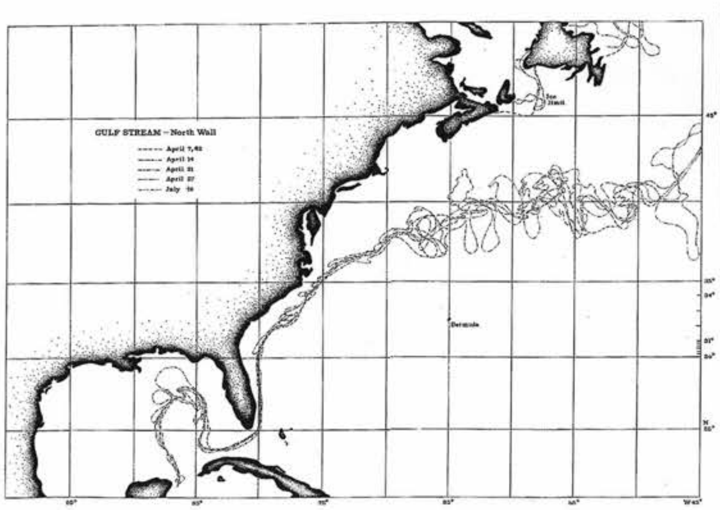
Today, charts of the Gulf Stream and all the major currents of the world are prepared from satellite imagery, and made available daily to mariners by single side-band radio and fax transmission.

Though the technology used to gather the data is much more sophisticated than in Benjamin Franklin's time, the principle has remained unchanged—currents are still measured by differences in temperature. Instead of a thermometer to take readings of surface water, infrared photographs are taken from satellites. These black and white images are then converted by arbitrarily assigning colors to different values of gray; alternately, differing values of gray are separated by isotherms—lines of equal temperature.



12b. Jenifer Clark
Jenifer Clark's Gulfstream 6/11/97
http://users.erols.com/gulfstrm/

For twenty-six years Jenifer Clark was a professional satellite oceanographer for NOAA (National Oceanic and Atmospheric). Now her work is available on a commercial basis to mariners, professional fishermen, and yachtsmen. Her charts combine infrared imagery with satellite altimetry data, and surface isotherm lines to produce a clearly understandable chart of the Gulf Stream's boundaries and travel. Temperatures are in degrees Fahrenheit. Isotherm are included, and arrows indicate the direction of flow. Occasional loops and swirls break off the main current to become self-contained eddies. Clockwise circulating Warm-core Eddies (WE) north of the Gulf Stream are represented in orange and yellow. Counter-clockwise circulating Cold-core Eddies (CE) south of the Gulf Stream are in light orange. Continental Shelf Water (SHW) is depicted in blue, and Continental Slope Water (CLW) in green. The blotchy white areas are caused by cloud cover preventing temperature sensing.



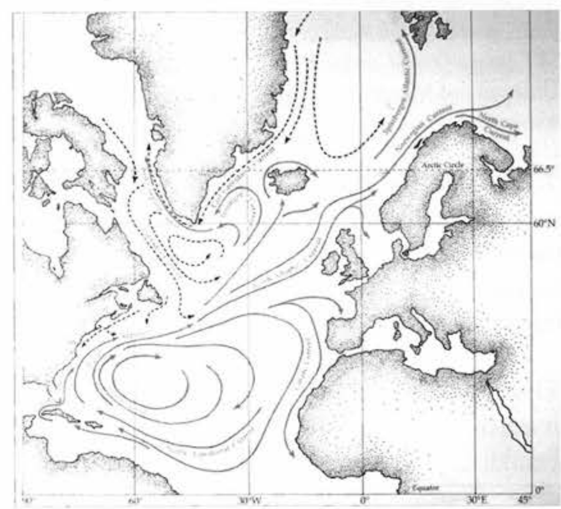
Gulf Stream-North Wall

To show the extent of changes in the course of the Gulf Stream, the chart above superimposes five successive images of its North Wall in 1982. At its southern limit in the Strait of Florida, and north to the Georgia coast, it is virtually unvaried. Thereafter, to a position south of Cape Cod the shift is minimal, not exceeding a distance of thirty nautical miles. As the current is deflected by the Carolina Capes and the shallow banks off Cape Cod, it moves eastward and begins to fan out with a considerable change in boundary. Here, within three and a half months, its North Wall can vary by as much as five degrees of latitude—equal to three hundred nautical miles. East of 50° West Longitude, the amplitude of change increases almost twice that amount.

Major Surface Currents of the North Atlantic

In its simplest form, the general surface current of the North Atlantic Ocean is one, large, clockwise gyre; divided into various segments, each carries a different name and set of characteristics. The southern portion of this gyre, called the North Equatorial Current, sweeps from east to west with a consistent set (direction) and velocity. Within its central axis the speed is about 0.5 knot. Upon reaching the Caribbean, and Bahama Islands, it curves northward, where it is joined by the Florida Current originating in the Gulf of Mexico.

These combined currents shoot through the strait between Florida and the western edge of the Bahamas to achieve a maximum velocity of 3.0 knots. Moving northward, paralleling the United States coastline, now properly called the Gulf Stream, it has a velocity ranging from 2.0 knots at the southern end to about 0.6 knot near Cape Cod. The Cape, and its nearby shallow banks, deflect the current to begin an eastward journey. Now the boundaries of the Gulf Stream begin to change considerably, fanning out and becoming more complex. In its movement from west to east there are large meanders, swirls, and loops. These loops break off to become self-contained eddies—some rotating clockwise, others counter-clockwise—but all generally moving eastward.



East of Newfoundland, at roughly 45° West Longitude, the Gulf Stream divides into two major parts. The more northerly one, called the North Atlantic Drift Current, heads toward the British Isles, where it again splits into two portions—a Norwegian Current, and Spitzbergen Current—until it finally dissipates far north of the Arctic Circle. The other part moves toward the Iberian Peninsula and travels south along the coast of Africa to become the Canary Current. Near the Cape Verde Islands (about 15° North Latitude) it again changes course westward, becoming the North Equatorial Current. Thus, the circle is completed. Around Iceland, Greenland, and Labrador, the

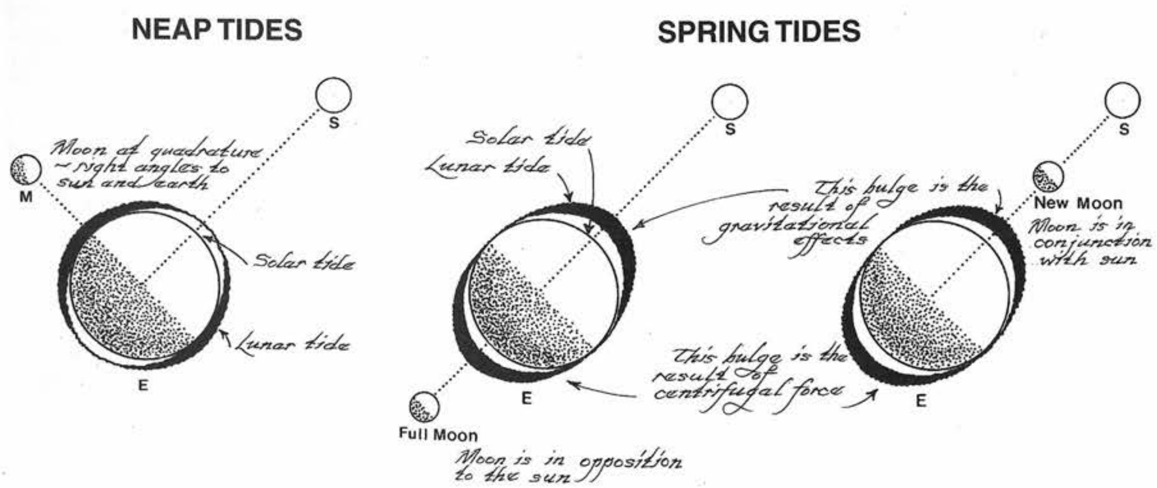
pattern of currents becomes more complex. Early voyagers to these regions were aware of the currents, but there were insufficient voyages to bring back enough information to produce a comprehensive pattern.

Tides

Tides occur in all oceans, whereas currents are limited to specific regions. That tides are affected by astrological, or lunar, events was realized as early as the first century BC by Posidonius of Rhodes, and affirmed a century later by Pliny the Elder in his *Historia naturalis*. In the early years of Christianity, church fathers rejected much of the intellectual and artistic legacy of Greece and Rome, along with its paganism. Yet they accepted the notion that the moon exerted a physical attraction on the ocean that somehow produced tides. The Venerable Bede, an early eighth-century Benedictine scholar and historian, as well as other Christian scholars, believed that the moon causes tides.

Not all men of learning accepted this notion. The eminent Christian philosopher, Macrobius, who wrote during the late Roman Empire, thought that tides were produced by colliding currents. The geographical theories of Macrobius may have been borrowed from Homer's description of the ocean currents. Paul, the Deacon (c. 725-799) attributed tides to gigantic whirlpools off the coast of Norway or Ireland. In the twelfth century, Richard, Prior of St. Victor in Paris, believed that the tides were produced by a great submarine monster.

Explaining exactly *how* the moon acted to exert its influence on tides was much more difficult than *stating* the postulate. Not until the seventeenth century, with an understanding of the principles of fluid mechanics, and of gravitational forces, was an answer provided.
Along the entire coast of Maine, and extending into the Bay of Fundy, the semi-diurnal type of tide, having two high tides and two low tides in 24 hours, is the predominant type. These tides are produced by the gravitational effect of the sun and the moon upon the water. By themselves, they would create a progressively moving standing wave. However, the major ocean basins are complex in shape and interrupted by land masses which modify the movement of water. Acting upon these bodies of water is the Coriolus force created by the rotation of the earth. This causes a high water crest to move continually in a counter-clockwise direction around a central, or nodal, point. In the North Atlantic Ocean, tides oscillate around one major node located south of Greenland. It is this rotary current that is responsible for the tidal action upon Maine's coast. As this crest of high water sweeps along, the phenomenon at shore is observed as a reversing current, flooding and ebbing out of the bays, sounds, and rivers.



Depths

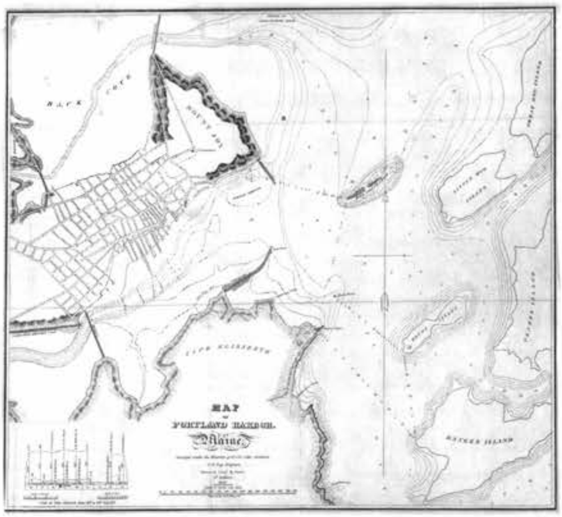
During the great Age of Discovery as mariners began to traverse the Atlantic, and were beyond the sight of land, many fears beset them. They believed that grotesque monsters lay in wait: giant squid would crush their ship in its powerful tentacles, or the raging Kraken of Scandanavian tales would smash them with its thrashing spikes and shining horns.

But the dangers uppermost in sailors' minds were the hidden rocks and uncharted reefs that, with seeming malice, lay in wait to destroy their frail vessel. The approach to land was always filled with apprehension, and a careful watch was kept to avoid any peril. Lest they should run aground, depths were determined by tossing a line weighted with lead forward of the ship. Markings of the line in fathoms (one fathom equals six feet) enabled the navigator to know whether or not it was safe to proceed farther on the present course. These soundings were carefully recorded, and marked on charts to aid future navigators.

13. Cyprian Southack
English, 1662-1745
M. Sartine
French, fl. 1769-1780
Plan de la Baie et du Havre de Casco (detail)
Copper engraving, 41.0cm x 58.1cm
From: Neptune Americo-Septentrional (Paris: Dépôt Général de la Marine, 1779)

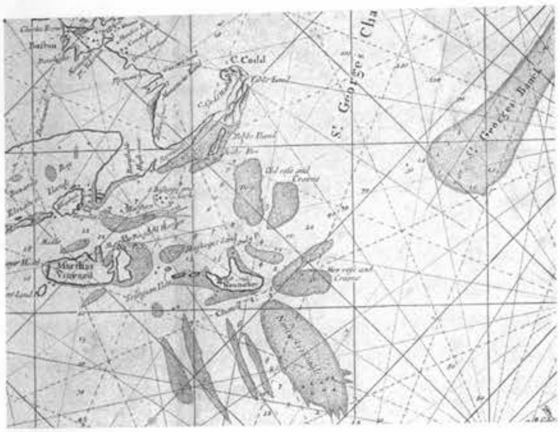
Navigating a safe passage through Casco Bay requires more than the avoidance of its multitude of islands. The greatest dangers are those hidden from view—the rocks and ledges covered by varying depths of water according to the state of the tide. Besides covering and uncovering rocky ledges and a shallow shore, unseen currents produced by the tide can put a vessel off course. To alert the navigator about the possibility of being taken unawares, the set (direction) of tidal currents in Casco Bay are indicated with arrows.

By 1833 sufficient soundings taken in Portland harbor enabled the cartographer of this large-scale chart to create a topographic map of the sea bottom. Isobars—lines of equal depth—give the navigator a comprehensive description of what he will encounter on all routes and points of sailing. As a further aid, the position of buoys are shown to warn the navigator of danger.



14. John Anderson, Lt. Col. U. S. Army Engineers
B. Pool, Lieut. U. S. Army Artillery
Map of Portland Harbor . . . 1833
Lithograph, 45.8cm x 51cm
From: *Report of the Survey of Stanford's Ledge, Portland Harbor, Maine, 1832,* Congressional Series 259 (23rd Congress, 1st Session), House Document 491 (Washington, DC: Government Printing Office, 1834).

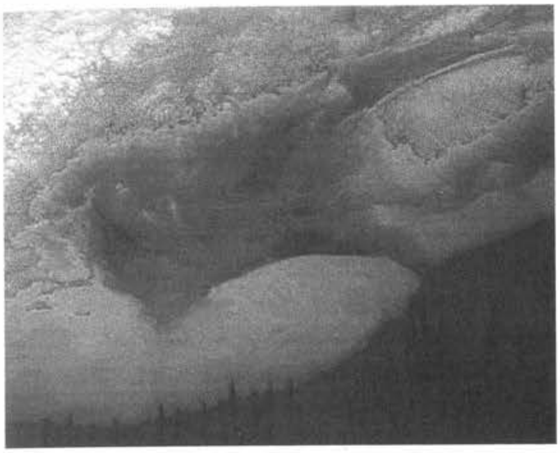
Depths are indicated in fathoms at low water. Strong winds, however, can augment or diminish these soundings. A graphic depiction of the effect of wind on the tide is presented in the lower left corner of the chart (No. 14).



15a. John Thornton
English, 1641-1708
William Fisher
English, fl.1669-1691
Part of New England (detail of Plate No. 15a)
Copper engraving, 42.4cm x 47.1cm
From: *The English Pilot. The Fourth Book* (London, 1689)

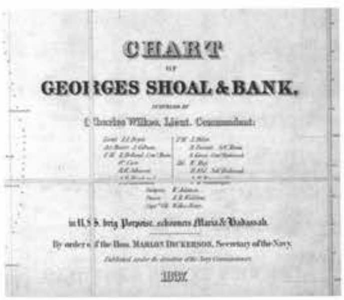
Beyond the coast, far from shore, there are still no assurances that the water is deep and safe for navigation. Whereas at one moment the leadline reveals no soundings, suddenly the sea can shallow, threatening to rent the bottom of any vessel caught unawares. The many dangerous reefs and shoals off the New England coast were carefully delineated by cartographers to prevent such disasters.

Henry Hudson, during his 1609 voyage, eager to avoid the already well know Georges Bank was caught on Nantucket Shoals. The force of the current brought him so close to breaking waves on the shoal that he was forced to anchor for two days until a favorable wind and tide enabled him to gain the release of his ship.



15b. Gulf of Maine
Courtesy of: Maine Coastal Program, Maine State Planning Office

Computer-generated graphics allow new ways of charting old data. In the relief map shown above of the Gulf of Maine, the lighter tone represents shallow depths, and the darker tone, deeper water. It is easy to visualize that in the geological past Georges Bank and Nantucket Shoals were connected to the mainland. Note, also, the steepness of the continental shelf.



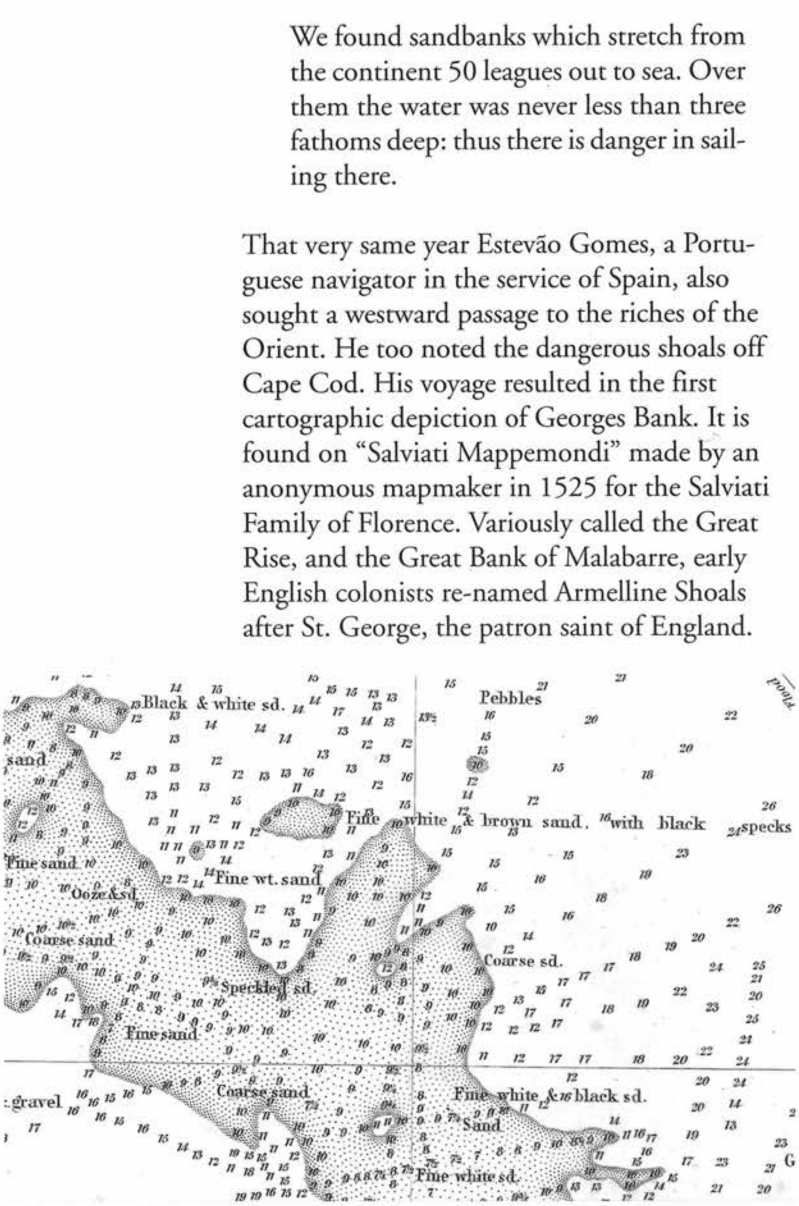
16. Charles Wilkes, Lieutenant U. S. Navy, later Rear Admiral
American, 1798-1877
Chart of Georges Shoal & Bank (detail)
Copper engraving, 99.1cm x 111.1cm
Washington DC: The Navy Commissioners, 1837

In the distant geological past, Georges Bank was part of the mainland, connected to Cape Cod. As the ice-sheet over the land retreated, and the sea level rose to flood low-lying ground, it became an island, and was eventually submerged—but just barely—to become the shoal it is today.

In 1524, Giovanni da Verrazzano, a Florentine navigator, sailed under the flag of France in an attempt to find a mid-latitude passage to Cathay. On the homeward passage, he encountered Georges Bank and named it Armelline Shoals (after a villainous papal tax collector). Upon his return to France, Verrazzano wrote to King Francis I:

> We found sandbanks which stretch from the continent 50 leagues out to sea. Over them the water was never less than three fathoms deep: thus there is danger in sailing there.

That very same year Estevão Gomes, a Portuguese navigator in the service of Spain, also sought a westward passage to the riches of the Orient. He too noted the dangerous shoals off Cape Cod. His voyage resulted in the first cartographic depiction of Georges Bank. It is found on "Salviati Mappemondi" made by an anonymous mapmaker in 1525 for the Salviati Family of Florence. Variously called the Great Rise, and the Great Bank of Malabarre, early English colonists re-named Armelline Shoals after St. George, the patron saint of England.

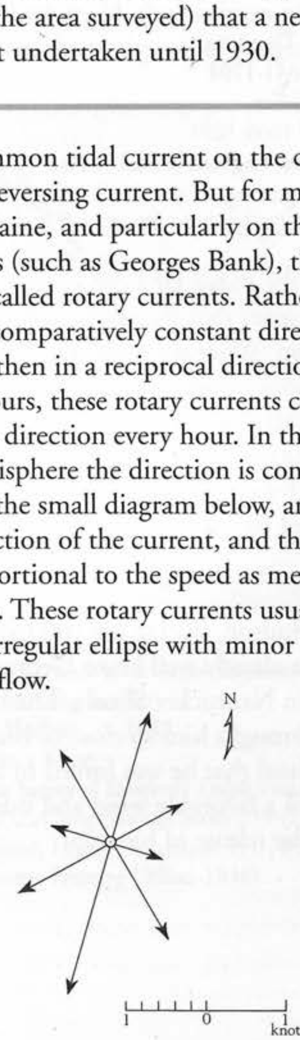


detail of No. 16

In the days before Loran and satellite navigation it was easy enough to determine latitude and longitude by celestial navigation. But the fog-shrouded region of Georges Bank rarely allowed it. Instead, the mariner had to rely on an intimate knowledge of the character of the ocean floor to gain his bearings. This was attained by filling the small hollow at the bottom of the lead-line weight with tallow or wax. Samples of the seabed stuck to the tallow, and were brought to the surface for inspection. Small differences in the composition of the aggregate were telling signs to determine position.

By 1832, as testimony to its importance in the fishing industry, virtually every square foot of Georges Bank had been sounded and charted. Charles Wilkes' "Chart of Georges Shoal and Bank," with over 1,000 soundings, and multitude of bottom composition recordings, was so thorough (in the area surveyed) that a new survey was not undertaken until 1930.

The most common tidal current on the coast of Maine is the reversing current. But for much of the Gulf of Maine, and particularly on the offshore banks (such as Georges Bank), there is another type called rotary currents. Rather than running in a comparatively constant direction for six hours, then in a reciprocal direction for another six hours, these rotary currents continually shift their direction every hour. In the northern hemisphere the direction is constantly clockwise. In the small diagram below, arrows show the direction of the current, and their length is proportional to the speed as measured against a scale. These rotary currents usually appear as an irregular ellipse with minor and major axes of flow.



III. THE COMPASS
North Seeking—but Never Finding

In navigating long distances, the compass was as important an instrument for indicating direction as the sand-glass for marking time. Developed in China around AD 1100, and independently in northern Europe shortly thereafter, the compass was used by mariners for navigation in the Mediterranean by the end of the twelfth century.

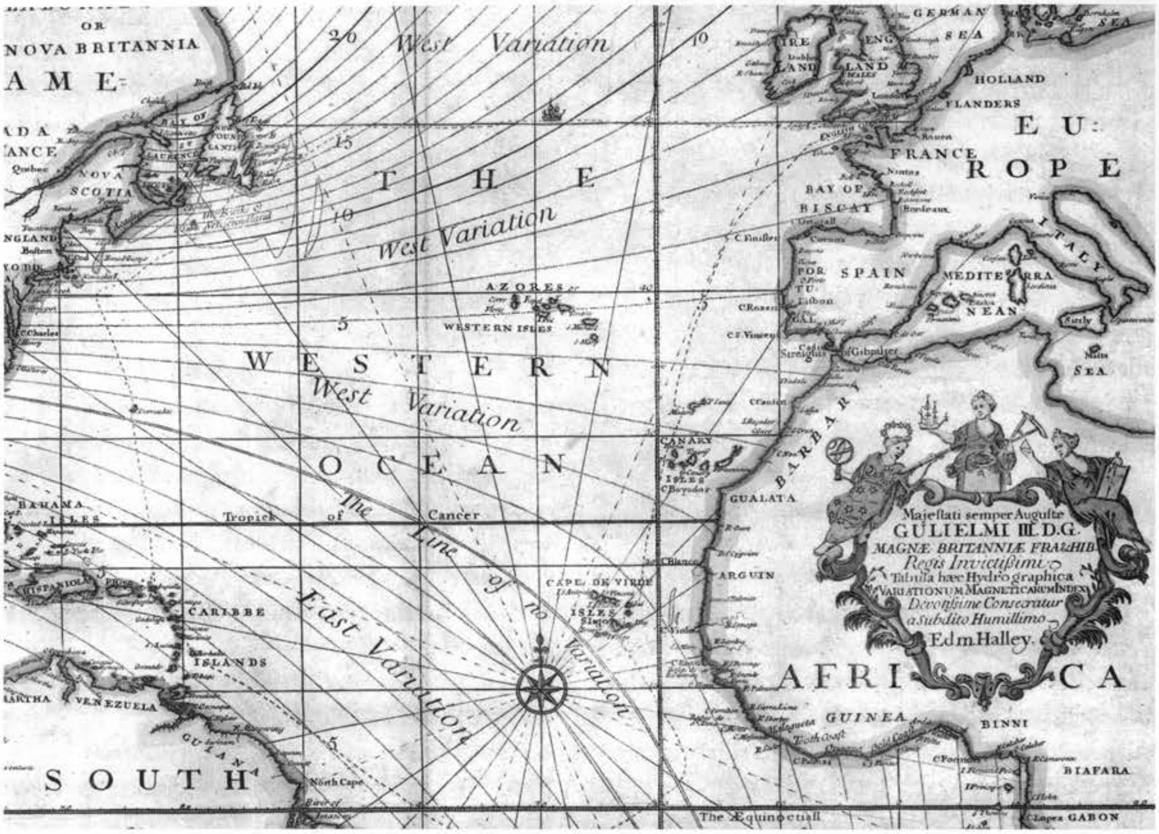
As long as voyages in the Atlantic were confined to routes along the west coasts of Africa and Europe, the compass served navigators well in guiding their course. But when they began to venture west *across* the ocean, it no longer seemed to read correctly. Until then, everyone believed that magnetic north coincided with true north at the geographical pole. They soon found out this was not so. Not only did the two norths not coincide, but the difference between them increased the farther west and north they sailed. In northern waters east of Ireland, the change was in the opposite direction. The closer one approaches the Magnetic North Pole, the greater is the amount of difference between the two norths. This discrepancy between magnetic north and geographic north is called magnetic variation, and it varies in different parts of the world according to regional influences. Furthermore, it changes with time in a given region.

In 1999 the Magnetic North Pole was located in the Canadian Northwest Territories about 800 miles north-northwest of Hudson Bay, and the Magnetic South Pole at the edge of the Antarctic continent. Their exact position, however, is subject to yearly change as the result of fluctuations in the flow of electrical current in the earth's molten core. There are, as well, rapid daily shifts in the pole's position caused by emissions of charged particles from the Sun acting upon the upper atmosphere of the earth. Within the past century, migration of the earth's Magnetic North Pole has been in a generally northerly direction at the rate of about 6.4 miles per year.

Until the mid-sixteenth century, mariners were unaware of magnetic variation; consequently, as they sailed west they found their position did not correspond with where they ought to be, according to their charts. If a navigator departed England and followed his compass due west, his course would take him on a gradual curve south; instead of arriving in Newfoundland as intended, the landfall would be somewhere along the mid-Atlantic coast of the United States.

Having learned that true, or geographic north, differed from magnetic north, instrument makers in some of the northern countries produced compasses in which the compass card (the flye) was mounted on the magnetic needle in alignment with the amount of magnetic variation. Thus, while the needle pointed to magnetic north, the *fleur de lis* on the compass card indicated true north. These were called a "varied compass." By this arrangement the compass had a built-in correction value for the amount of magnetic variation. This was fine, as long as voyages were limited to regions where the amount of variation did not appreciably change. On other compasses, the position of the card on the needle as it pointed to magnetic north could be changed according to the amount of local variation. These were called "true compasses."

In 1580, Robert Norman published *The New Attraction*, containing observations on the variation and dip of the magnetic compass. Twenty years later, a general concept of the world distribution of magnetism was postulated by William Gilbert in his *De Magnete*. A physician to Elizabeth I and James I, Gilbert is now remembered most for his work on magnetism and electricity. He attempted to explain

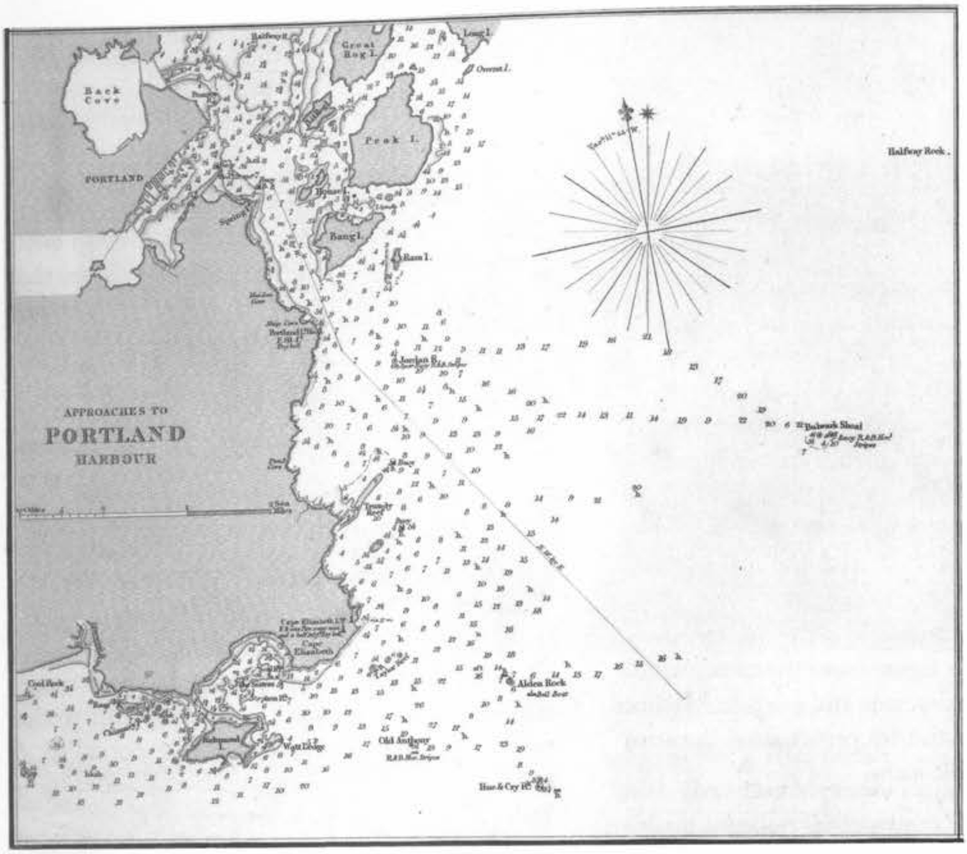


planetary motions on the principle that the earth was a huge magnet. It also accounted, he said, for the action of the compass in pointing toward north. In his treatise, Gilbert described the importance of this magnetism in practical problems of navigation.

Mariners attempted to correlate the amount of easterly or westerly variation of the compass with longitude. But the pattern of variation over the earth's surface made the correlation unreliable, and the method was finally discredited in 1634. Likewise, endeavors to use magnetic dip (variation of the compass needle in the vertical plane) as a means to establish longitude, proved unsound.

17. Edmund Halley
English, 1656-1742
A New and Correct Chart Shewing the Variations of the Compass (detail of Plate No. 17)
Copper engraving, hand-colored,
58.5cm x 49 cm
From: *The English Pilot. The Fourth Book*
(London, Mount & Page, 1701/1720)

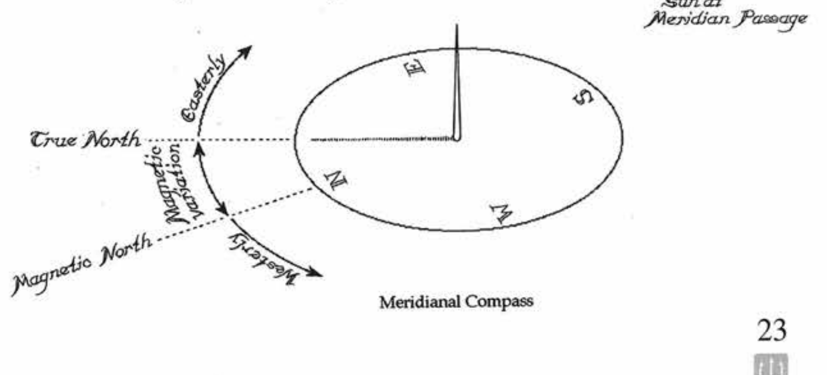
By the beginning of the eighteenth century there was a full and accurate plotting of lines of magnetic variation, as shown above on Edmund Halley's chart of the Atlantic. This knowledge enabled the navigator to make the appropriate correction to the ship's course.



18. U. K., H. M. Admiralty Hydrogaphic Office
America East Coast/Portland Harbor From The United States Coast Survey Published in 1854 *(inset)*
Steel engraving, 63.5cm x 47.9cm
London: J. D. Potter, 1857

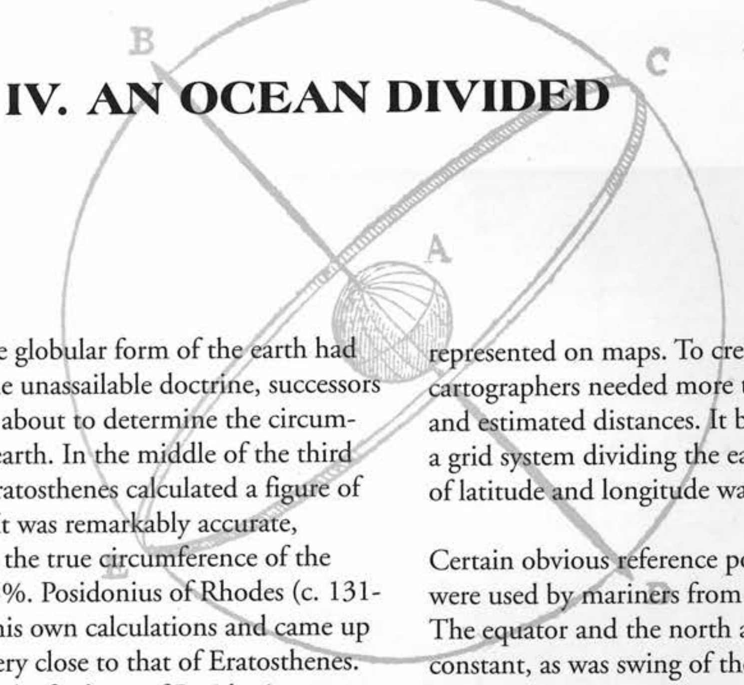
On this Admiralty chart published in 1854, magnetic variation is shown on the compass rose in dotted lines, with the *fleur-de-lis* pointing toward magnetic north. Here, the amount of variation for Portland Harbor, Maine, is 11°15'West. By the year 2000, however, this variation will have changed to 16°52'West. Solid lines on the rose are oriented to geographic, or *true* north. With this arrangement, unless the navigator used extreme caution it would be easy to confuse the two and plot an erroneous course. Present-day charts reduce this problem by using two concentric rings: the outer ring for plotting by geographic coordinates, and an inner ring for plotting with the magnetic compass.

Since maps and charts are drawn with meridian lines of *true* north and south, and parallels of *true* east and west, the navigator needs to know the amount of magnetic variation at his position. Only then can he correctly plot the ship's course by continually changing the magnetic course heading relative to true north. To determine the amount of variation, the navigator uses a meridianal compass which has a special attachment casting a shadow to true north when the sun reaches its meridian at noon. This arrangement allows him to read the amount of variation directly off the compass.



Meridianal Compass

IV. AN OCEAN DIVIDED



Once the globular form of the earth had become unassailable doctrine, successors to Aristotle set about to determine the circumference of the earth. In the middle of the third century BC, Eratosthenes calculated a figure of 26,291 miles. It was remarkably accurate, deviating from the true circumference of the earth by only 5%. Posidonius of Rhodes (c. 131-51 BC) made his own calculations and came up with a figure very close to that of Eratosthenes. Unfortunately, the findings of Posidonius were incorrectly reported by Strabo in his seventeen volume *Geographica*, resulting in a world 28% smaller in circumference. Ptolemy accepted this smaller, inaccurate figure from the cartographic theories of his predecessor and teacher, Marinus of Tyre, and his authority perpetuated the error through the Middle Ages.

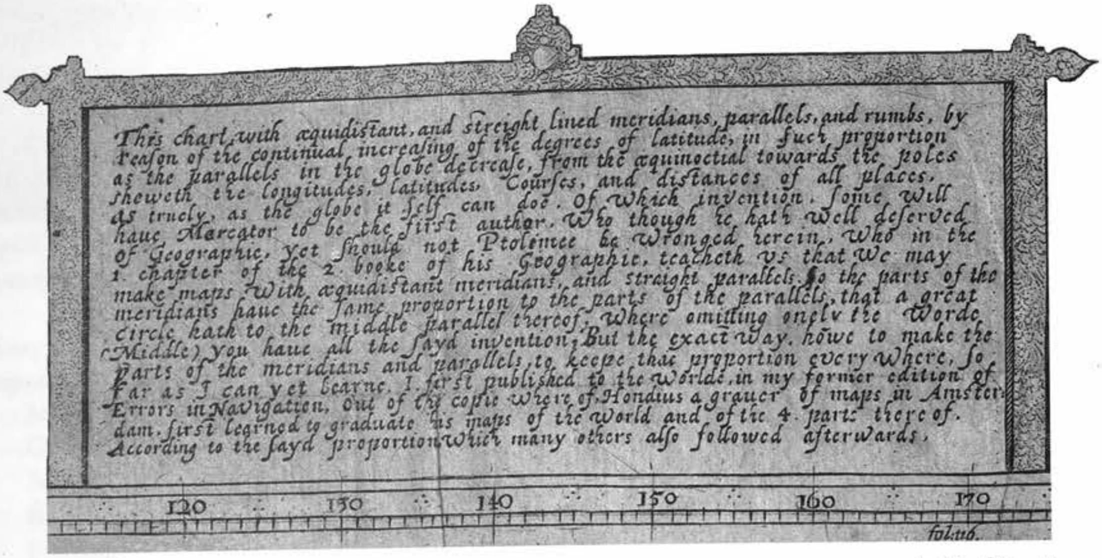
In gathering information, and assimilating current geographical concepts for his own theories about the size of the world, Christopher Columbus accepted the erroneous figure. Conclusions about the distance between Europe and Asia reached by the Florentine cosmographer, Paolo del Pozzo Toscanelli, and convincing "proofs" by Marco Polo in his book, *Il Milione*, about the shortness of distance to Japan, also contributed to Columbus's misconception about the width of the Atlantic and shortness of his proposed voyage.

Latitude and Longitude

To make open ocean voyages, the navigator had to know his exact position at sea, and, its corollary, be able to return whence he started in order to bring back information about his discoveries. For short voyages, the mariner could rely largely upon visual memory for fixing the ship's position. As voyaging increased into the uncharted regions, the mariner brought back his findings to be retained in written records and represented on maps. To create accurate maps, cartographers needed more than recounted tales and estimated distances. It became apparent that a grid system dividing the earth into coordinates of latitude and longitude was necessary.

Certain obvious reference points for latitude were used by mariners from the earliest of times. The equator and the north and south poles were constant, as was swing of the sun from its most northerly declination of 23°28' (Tropic of Cancer) at the summer solstice, through the equinox to, its most southerly declination (Tropic of Capricorn) at the winter solstice. Dividing the globe into horizontal, circumferential lines, equally spaced from the equator to the poles, was a logical construct. These are called parallels of latitude. Hipparchus of Rhodes (c. 167-127 BC), one of the greatest of Greek astronomers, had marked off the earth's circumference at the equator into 360 parts—the "degrees" of modern geography. Ptolemy followed this plan, subdividing each of the degrees into *partes minutae primae* ("minutes" of arc) and *partes minutae secundae* ("seconds" of arc). He created vertical, circumferential lines, equally spaced at the equator and passing through both poles. These are the meridians of longitude. Each 15° interval represents one hour of the twenty-four hours during one full rotation of the earth.

From the seventh through the twelfth centuries, the most prominent mathematicians and astronomers were Arabs. As early as the eighth century, the Muslim astronomer Msha'allah described how to determine latitude from the meridian altitude of the sun and its declination. In the following centuries, even after simplified solar tables made determination of latitude from the sun an easier task, *Polaris*, the North Star continued to be the preferred celestial body. It



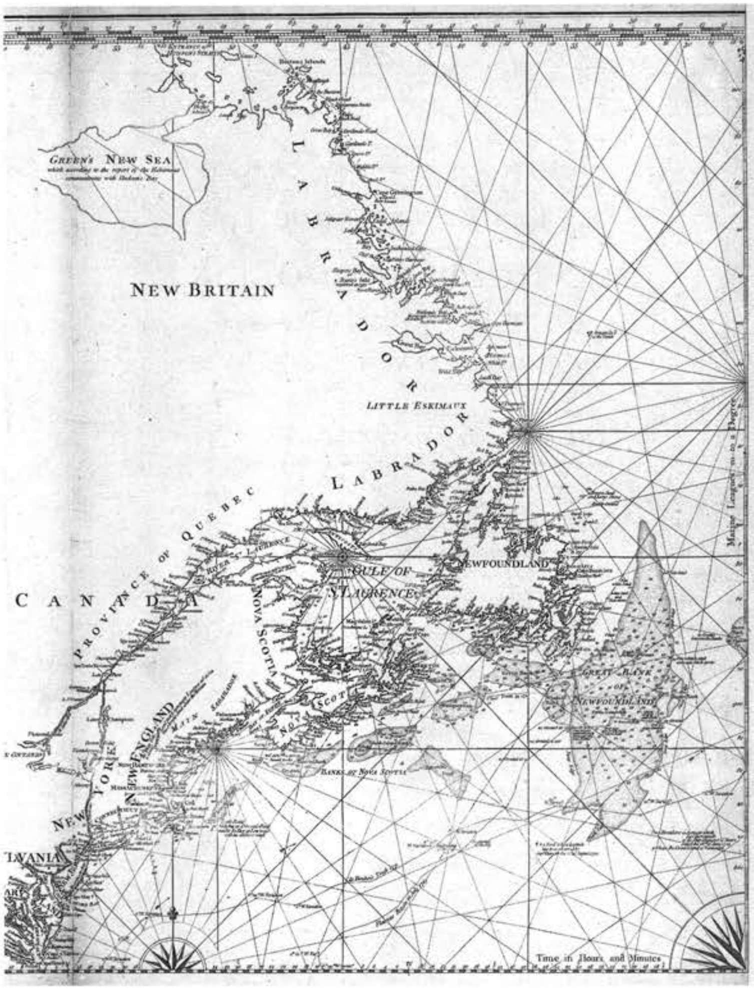
detail of No. 7

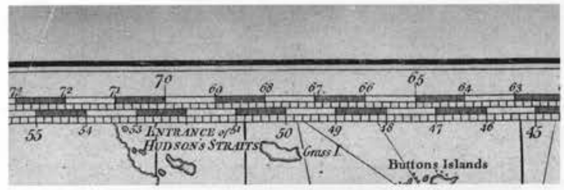
was the easiest to use and required no tables of declination. In spite of the long established knowledge, it wasn't until the early sixteenth century that a scale of latitude was provided on charts.

Accurate determination of longitude at sea was much more difficult than finding latitude and continued to elude navigators well into the eighteenth century. In 1530 the Flemish mathematician and geographer, Gemma Frisius, successfully devised a method of determining longitude based on time, but it wasn't until an accurate timepiece, the marine chronometer, was constructed in 1761 that his theory could be put into practice.

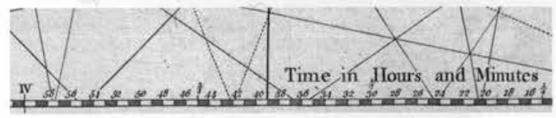
Mercator Projection

Cartographers conceived many methods for projecting the spherical surface of the earth onto the flat plane of a map or chart. There was no perfect answer; in some way all caused distortion, skewing relationships and distances. In 1569, Gerardus Mercator came up with a brilliant solution for mariners. He kept all the meridional lines (lines of longitude) parallel and equidistant from each other, instead of converging at the poles. To compensate for the greater space between the lines of longitude near the pole, he proportionally increased the distances between the lines of latitude from the equator toward the pole. Although the relative sizes and shapes of landmasses are markedly enlarged and distorted as they become closer to the polar regions, the Mercator projection had one distinct advantage over all other projection plans: it allowed the navigator to plot a ship's course (rhumb line) that remained a straight line and a constant angle, no matter how it cut across the meridians. Technically called an isogonic cylindrical projection, it is now simply referred to as Mercator's projection. For ease of navigation, it has not been improved upon to this day.

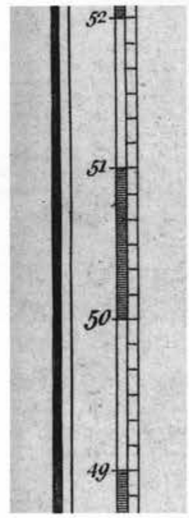




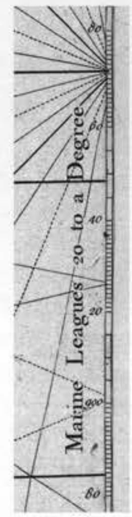
[A]



[B]



[C]



[D]

19. Charles Pierre Claret de Fleurieu
French, 1738-1810
A New General Chart of the Atlantic or Western Ocean and Adjacent Seas *(detail)*
Copper engraving, 49.1cm x 69.9cm
London: Sayer and Bennet, 1777

In his "New General Chart of the Atlantic or Western Ocean and Adjacent Seas" de Fleurieu placed great emphasis on geographic accuracy as determined by astronomical observations for latitude and longitude. Those places where the information was incomplete or in doubt, were noted as well. On this English edition of one of his charts, two prime meridians—the starting line of zero degrees longitude—are indicated by longitude scales at the top of the chart: the upper, located at the Greenwich Observatory in England, the lower positioned at Ferro in the Azores Islands [see detail A].

At the bottom of the chart, a third scale shows Time in hours and minutes, [B] in effect another way of indicating longitude. The earth makes one complete rotation on its axis in twenty-four hours. Thus, in one hour the earth has rotated 15° (360° ÷ 24 = 15°). On the right-hand side of the chart there is a vertical line at 3 hours and 39 minutes. One hour equals 15°, therefore, one minute of time equals 0.25° (15° ÷ 60 = 0.25°). The 3 hours and 39 minutes equates to 54.75° (39 X 0.25 = 9.75° + 45° = 54.75°)—the identical point on the longitude scale using Greenwich, England, for the prime meridian.

Each 1 hour time zone is equally spaced at 15°, but the marking of hours in Roman numerals [B] on this chart does not represent time zone boundaries. The first time zone of 0 hours straddles the Greenwich meridian; its western edge at 7.5°W longitude and its eastern edge at 7.5°E longitude. Here, the eastern edge of the first hour begins at the Greenwich meridian.

Even latitude, with its fixed reference points of the equator and poles, is marked off in two different scales. Latitude on the left-hand margin of the chart [C] is measured in degrees, each with six increments of 10 minutes of arc (60 minutes of arc = 1°). Latitude on the right-hand margin [D] is expressed in marine leagues. Latitude is also expressed in leagues near the bottom of the chart. It begins at 800 leagues, equal to 40° north of the equator. There are twenty leagues to a degree, so 20 X 40 = 800.

Many other features of the ocean—all of importance to the mariner—are indicated:

- Magnetic variation
- Ocean currents
- Soundings (or lack of)
- Bottom character
- Fog-bank limit
- Tidal effects
- Landmarks as viewed from seaward

Prime Meridian

Even though the calculation of longitude was accomplished, meridians of longitude lacked any predetemined, natural starting point (prime meridian) for measurement, such as the equator provided for parallels of latitude. The earliest maps used Alexandria, that great seat of ancient learning, as the prime meridian. Other important geographic points such as Rhodes, Carthage, the Pillars of Hercules (Strait of Gibralter), and Rome, were also used.

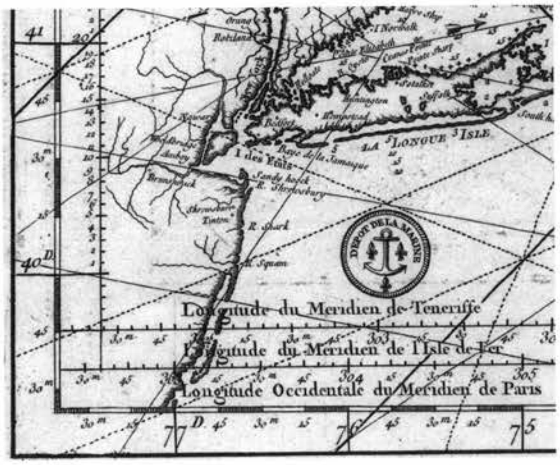
Ptolemy used Ferro, one of the Canary Islands, (*Insulae Fortunatae*, or Fortunate Islands, as they were called) for his prime meridian because it was the westernmost land then known. Following Ptolemy, European geographers, such as Coronelli, also used Ferro. This prime meridian placed London at 18° East Longitude.

20. Vincenzo Coronelli
Venetian, 1650-1718
Mare Del Nord *(detail of Plate No. 20)*
Copper engraving, hand-colored,
44.9cm x 59.9cm
Venice, 1690

By the eighteenth century, maps and charts used many different prime meridians, defined by prominent landmarks, capitals, or astronomical observatories. Thus, English charts placed the zero meridian at the Lizard, England's most southwesterly point, or London, defined as St. Paul's Cathedral, or Greenwich Observatory. On Bellin's chart of the east coast of North America, five different prime meridians of longitude are shown: Paris, London, the Lizard, Teneriffe, and Ferro (islands of the Canaries archipelago).

21. Jacques Bellin
French, 1703-1772
Carte Reduite des Costes Orientales de L'Amerique Septentrionale *(detail of Plate No. 21)*
Copper engraving, 54.6cm x 88.6cm
Paris: Department de la Marine, 1757

The inexactitude of geographic positions and the lack of an agreed upon prime, or zero, meridian continued to hamper navigators computing their courses between places of known latitude and longitude. Obviously, a universally accepted starting point for the meridians of longitude was necessary to convert relative values into absolute values. Worldwide acceptance of Greenwich, England, as the datum point (0°) for measurement of longitude did not occur until 1884.

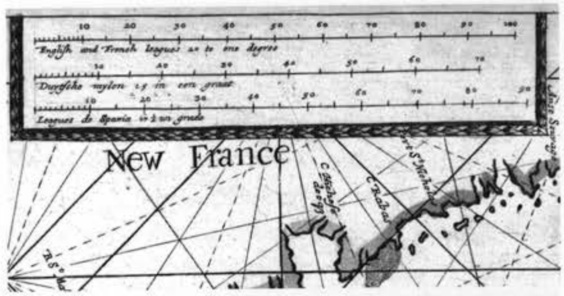


detail of Plate No. 21

Distances

The measurement of distances at sea differs from that on land. The statute, or English mile, was originally the Roman linear measurement of 1000 paces—about 4,854 feet. Today, in the United Kingdom, some parts of the Commonwealth, and the United States, the statute mile used for land measurement has been standardized at 5,280 feet.

The nautical, or sea mile, is based on the circumference of the earth. Each degree of a 360 degree circle around the Earth contains 60 nautical miles. The degree is further subdivided into 60 minutes of arc, therefore, one minute of arc of latitude equals one nautical mile. At 24,859 miles for the Earth's circumference, one nautical mile equals 6,076 feet.



22. John Seller
English, d.1697
A Chart of the Coast of America *(detail of Plate No. 22)*
Copper engraving, hand-colored,
42.2 x 54cm
London, 1675

Distances at sea, however, were usually expressed in leagues rather than in nautical miles. Portu-guese navigators estimated one degree of latitude at 17 $^1/_2$ leagues, making a single league equal to 3.43 nautical miles. This measurement remained in use throughout the fifteenth and sixteenth centuries. Initially, Spain used the same measurement, then changed to 16 $^2/_3$ leagues in a degree, making one league equal to 3.67 nautical miles. English mariners computed 20 leagues to the degree; this made one league equivalent to 3.0 nautical miles.

Political Divisions

Marking charts with limits of the sun's declination to determine latitude, and lines of latitude and longitude as a grid on which to locate position, were not the only guides navigators heeded in crossing the trackless, open seas. Yet another invisible line divided the ocean. Neither astronomical nor mathematical in origin, this line was a political one, placed by papal bull (decree) and mutual consent of the two great Iberian powers—Spain and Portugal. As their mariners ventured westward into the uncharted Atlantic to seek riches and expand their sovereigns' empires, they made discoveries that changed the known face of the earth. Their explorations revealed the existence of an entire New World. Spain and Portugal quickly made known their claims of ownership to these newly discovered lands.

Under the direction of Prince Henry the Navigator, Portuguese mariners explored the Atlantic coast of Africa and its offshore islands, establishing colonies and trading posts. On each voyage they advanced a little farther, and in 1434 Gil Eanes made the then unprecedented journey as far south as Cape Bojador on the western bulge of Africa. Eventually, two Portuguese mariners, Bartholomeu Diaz and Pèro da Covilhã, doubled the Cape of Good Hope and entered the Indian Ocean. In 1497, Vasco da Gama set sail from Lisbon, and in the following year not only rounded the cape, but sailed all the way to Calicut, India. The wealth extracted from these discoveries raised Portugal to a world power.

On the return passage, fifteenth and sixteenth century caravels could not beat against the Northeast Tradewinds in the Atlantic. But by making a wide, crescent sweep, they were able to gain enough northing to obtain the latitude of the prevailing westerly winds, enabling them to head eastward to the home ports of Lisbon or Lagos. This roundabout search for favorable winds led to the discovery of the Atlantic Archipelagos: Madeiras, Cape Verde Islands, and the Azores. These islands had been visited centuries before by Carthaginian and Arab sailors, but it remained for Spanish and Portuguese mariners to firmly fix their identity and location. As each island group was rediscovered and colonized, claims of possession were sought from the Vatican. As a global sovereign power, Rome had the right to divide the newly discovered world. Spain and Portugal justified their requests for ownership on the grounds that "as crusaders, they were doing the Church's work and therefore entitled to some secular perquisites."

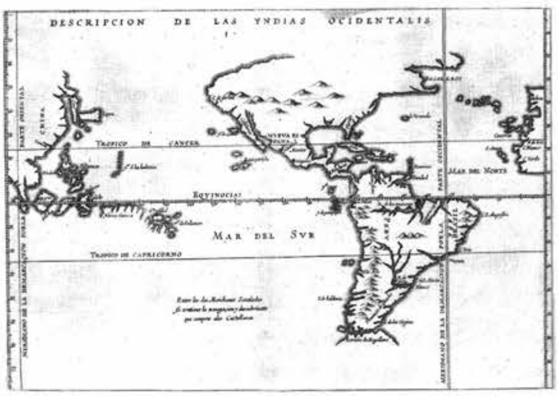
The first of several papal bulls—*Romanus pontifex*—to back Portugal's aspiration for power was issued by Pope Nicholas in 1455. It gave Portugal exclusive rights to the conquest and possession of land along the African coast from Cape Bojador as far as Guinea, and beyond toward the southern shore. Each new island discovery required a realignment of ownership, and further papal bulls or treaties were issued: in 1455, the bull *Inter caetera* was issued by Pope Calixtus III; there was the Treaty of Alcáçovas in 1479; and in 1493, a second bull of *Inter caetera* was issued by Pope Alexander VI. Lines were drawn across the Ocean Sea (as the Atlantic Ocean was then called) marking the territorial limits of Spain and Portugal. None of the divisions was totally acceptable; either they gave away too much land to one power, or took away dominion from a power whose ownership had already been established.

In 1481, Portugal again petitioned Rome for exclusive monopoly in the Ocean Sea "toward the regions lying southward and eastward." This was granted in the bull *Aeterni regis,* and confirmed lands given to Portugal in the Treaty of Alcáçovas. Based on discovery and colonization, sovereignty of the archipelagoes of Madeira, Azores, Cape Verde Islands, and "any other islands, coasts or lands, discovered or to be discovered, and from the Canary Islands down toward Guinea" was given to Portugal. The Canary Islands undisputedly belonged to Spain.

When Christopher Columbus reached the West Indies in 1492, he could not claim them for the Catholic monarchs of Spain, since under the bull of *Aeterni regis,* and bulls of Nicholas V extending back to 1452, they belonged to Portugal. Concerned over their sovereign rights, Ferdinand and Isabella inveighed upon Pope Alexander VI, a Spaniard to issue a second bull of *Inter caetera.* This produced in 1493 a vertical line "at one hundred leagues toward the west and south from any of the islands commonly known as the Azores and Cape Verde." The location of this line was ambiguous, but it unquestionably gave more territory to Spain than to Portugal.

For the sake of peace and accord, the following year Spain and Portugal resolved their differences independent of the Papacy. They reached a compromise in the 1494 Treaty of Tordesillas, where each power agreed that:

> ...a boundary or straight line be determined and drawn north and south, from



23. Antonio de Herrera y Tordesillas
Spanish, 1559-1625
Descripción de las Yndias Ocidentalis
Copper engraving, 22.5cm x 31.8cm
From: Descripción de las Yndias Ocidentalis (Spain, 1622)

> pole to pole, on the Ocean Sea, from the Arctic to the Antarctic Pole. This line shall be drawn straight...at a distance of 370 leagues west of the Cape Verde Islands. And all lands on the eastern side of the said bound...shall belong to the said King of Portugal and his successors. And all other lands shall belong to the said King and Queen of Castile.
>
> Paul Gottschalk
> "The Earliest Diplomatic Documents on America:The Papal Bulls of 1493 and the Treaty of Tordesillas Reproduced and Translated."
> Berlin, 1927

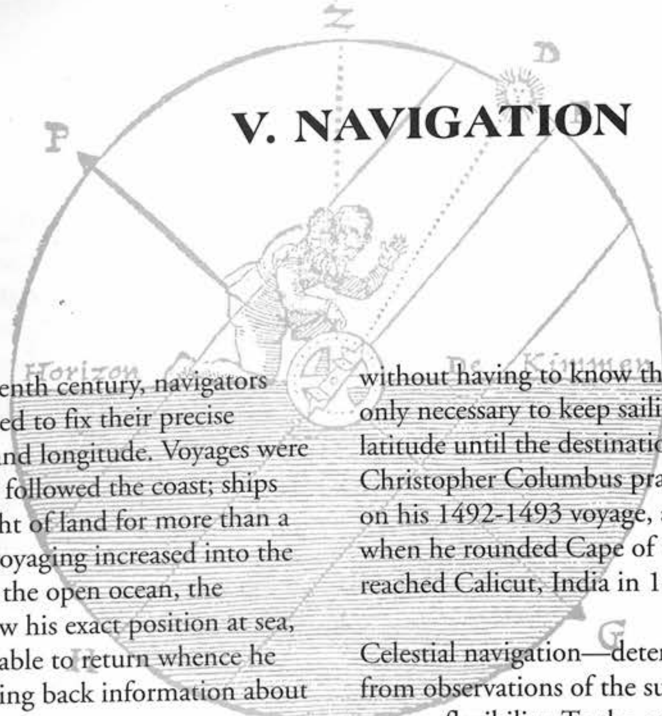
This new, definitive line, at 47°27'West longitude, through Brazil on the eastern bulge of South America, was located farther west than the 1493 line. It divided the entire Atlantic Ocean between Spain and Portugal.

For a while the line created by the Treaty of Tordesillas quieted disputes of territorial ownership. But when Vasco da Gama led Portugal to India and the Far East in his epic voyage of 1497-1498, the question arose whether the Ocean Sea extended to the opposite side of the earth to the Pacific Ocean. With Magellan's 1519-1522 voyage, a southwest passage around Cape Horn to the Orient was finally achieved, making the region accessible to Spain as well. Dividing the world into east-west regions with a vertical line running from the Arctic Pole to the Antarctic Pole no longer sufficed. Each nation, keeping within its proscribed domain—Portugal sailing eastward of the Tordesillas line, and Spain sailing west of it—arrived at the same place on the opposite side of the world. Both powers laid claim to the Moluccas (Spice Islands), and desired the fabulous wealth to be gained from them.

Over the next three decades Spain and Portugal attempted to resolve the question of ownership of the Moluccas (not to be confused with Malacca, on the west coast of the Malay peninsula). Incompleteness of the treaty, and ambiguity in its wording, even as to the exact location of the line, left much room for interpretation, and placed the two nations in a state of tension in regard to commerce and the spices. Though the Portuguese were the first to reach the Moluccas, they did not take them by conquest, nor did they occupy them. Their claim to ownership was based on being the first to discover the lands. Spain felt that since it now occupied the islands they should own them until definitive boundaries were established. Spain also believed that since there was no conquest of the islands by the Portuguese, they did not deserve them. In essence, no one knew with any certainty whose territory the islands fell within. In the Herrera chart, this is confirmed in the notation in *Mar del Sur* (Pacific Ocean) which reads: "Between the two fixed meridians is contained the navigation and discoveries competed for with the Spanish."

Regardless of the difficulties between these two nations, they had effectively sealed off the seas south of the Canary Islands preventing incursion by the vessels of any other nation. If England and France wished to reach the East Indies, they could only do so by finding a route north of Canada (the Northwest Passage), or over the top of Norway and Russia (the Northeast Passage). The economic and political balance in Europe shifted, and the maritime supremacy of Spain and Portugal remained unchallenged until the very end of the sixteenth century.

V. NAVIGATION



Until the sixteenth century, navigators had scant need to fix their precise position by latitude and longitude. Voyages were short and principally followed the coast; ships were rarely out of sight of land for more than a few hours' time. As voyaging increased into the uncharted regions of the open ocean, the navigator had to know his exact position at sea, and, its corollary, be able to return whence he started in order to bring back information about his discoveries.

The most basic method used by the navigator to plot the course on a chart is called "deduced" (or "dead") reckoning. Continuous records were made of the direction traveled, provided by the magnetic compass, and distance as the result of time elapsed (measured by a sand-glass) multiplied by speed. The compass and sandglass, along with a chiplog to measure speed, enabled the navigator to plot his ship's position on a chart. Speed multiplied by time gave the distance, and the compass showed the direction of the course sailed. This simple method of navigation is called dead reckoning, short for deduced reckoning. The course was calculated hourly. When conditions were right for taking celestial sightings, the dead reckoning course was updated and corrected.

Another method is known as "latitude sailing" or "running down your easting (or westing)." Once the navigator reached a desired latitude, which he determined by sightings of a celestial body (Sun or the Pole Star), he maintained his course on that latitude by sailing due east or west. This method required no elaborate tables of declination or complex mathematical calculations; all that was needed was to keep that celestial body at the same declination, its angular height above the horizon. Latitude sailing enabled the mariner to reach his objective without having to know the longitude—it was only necessary to keep sailing at the same latitude until the destination was reached. Christopher Columbus practiced latitude sailing on his 1492-1493 voyage, as did Vasco da Gama when he rounded Cape of Good Hope and reached Calicut, India in 1498.

Celestial navigation—determining one's position from observations of the sun or stars—provided greater flexibility. To the end of the fifteenth century, the celestial body most often used was *Polaris*, the North Star, for this was the easiest to use and required no tables of declination. At first, only the meridian altitude of *Polaris* was used—that point when it reached its zenith in the sky. Later, navigators were able to use *Polaris* at any time of the night without having to wait for it to reach its zenith. By the end of the fifteenth century, mariners could determine their latitude position from the sun as well as from the stars. And finally, with the development of the marine chronometer in 1761, navigators could also determine longitude.

With a grid pattern to mark their position on the surface of the earth, and the means to plot a course, mariners confidently moved across the trackless, open ocean.

A really good navigator has an instinctive sixth sense for when to trust his observations; it is as much an art as it is a science. Some navigators have a definite feel for their work and consistently get good results while others never quite manage. One navigator who could not "get the hang of it" was Captain Bartholomew Gilbert. In 1603 he made a voyage to Virginia in the Bark *Elizabeth*. The ship left Plymouth, England on May 10th and sailed south to pick up the Trade Winds. Sixteen days later they were at the latitude of 32°N, but failed to sight the island of

Madeira. Missing the island, the *Elizabeth* was turned westward, and on the 1st of June land was sighted. According to Gilbert's navigation it was the island of Bermuda. But upon landing he found that the island was St. Lucia, one of the most southerly Windward Islands of the West Indies; an extraordinary error, since St. Lucia is 1,100 miles south of Bermuda. Describing this remarkable event, Samuel Purchas (the English historian and a contemporary of Gilbert) said: "That does scant credit to their navigational skill, and speaks volumes for their courageous ignorance."

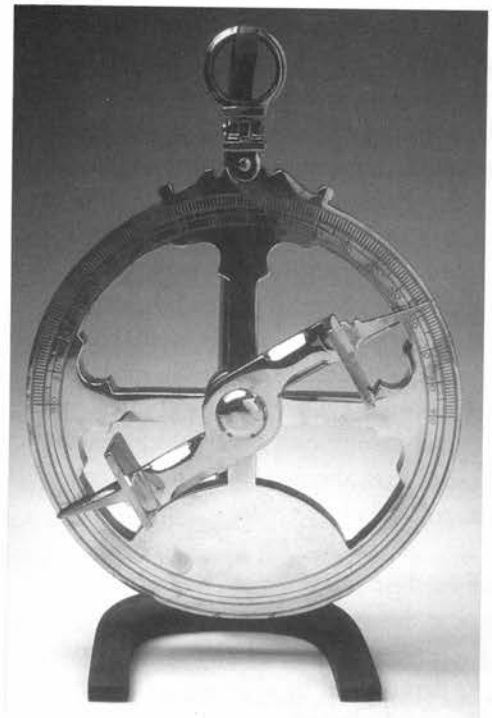
Determining Position at Sea

To determine latitude by celestial observation, very little is needed in the way of instruments. All that is required is a means of measuring the altitude of a celestial body above the horizon at its point of meridian passage, that is, when it reaches its highest point (zenith) in the sky. This altitude is compared with tables of declination, the vertical angle of a celestial body above the horizon, on that particular day. Since the celestial equator corresponds with the earth's equator, declination coincides with latitude on the earth's surface.

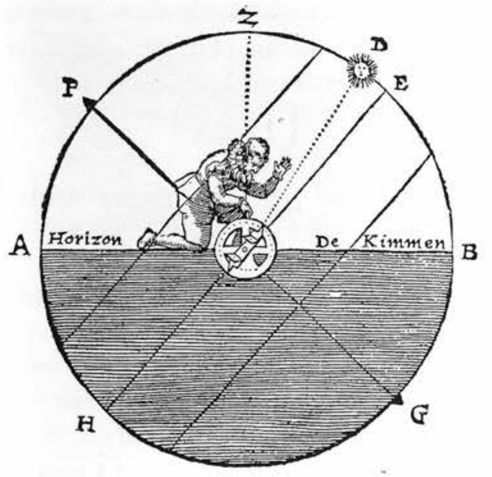
For example, if the altitude of the sun (its vertical angle above the horizon) is observed at 40°26'34", it is subtracted from 89°59'60" (90°), with the resultant difference of 49°33'26". From almanac tables of the sun's declination on that day, that figure is added to 49°33'26" to give the latitude. If the sun's declination in this example was 3°41'34", the total would be 53°15'00"—the latitude of Galway Bay, Ireland.

Astrolabe

In the Middle Ages, the instrument used for measuring the angular height of a celestial body above the horizon was the planispheric astrolabe. This instrument was adapted to one more suitable for "taking the height" while at sea—the nautical astrolabe. Consisting of a perforated disc made of bronze or brass, which gave it weight, the astrolabe was suspended from a ring at the top. Affixed to the centre of the disc was a sighting bar called the alidade, which could be turned in a complete circle. The navigator aimed the alidade at the heavenly body, either the sun during the day or the pole star at night, aligning it by sighting through holes or notches in plates at each end. He read the altitude in degrees directly off a scale inscribed around the circumference of the disc.



24. Anonymous
Mariners Astrolabe
Brass
Modern replica



25. Willem Janszoon Blaeu
Dutch, 1571-1638
[Illustration]
Woodcut
From: Le Flambeav de la Navigation, (Amsterdam, 1619)

In the illustration here, from *The Light of Navigation* (1612) by Willem Janszoon Blaeu, line P-G is the angle of the axis of the earth at the time the celestial observation is made; this angle taken from astronomical tables. Z equals zenith, and D is the observed altitude of the sun. To obtain a noon position fix from the sun at its meridian passage, the observed altitude of the sun is subtracted from 90° and the declination of the sun is added algebraically to the result.

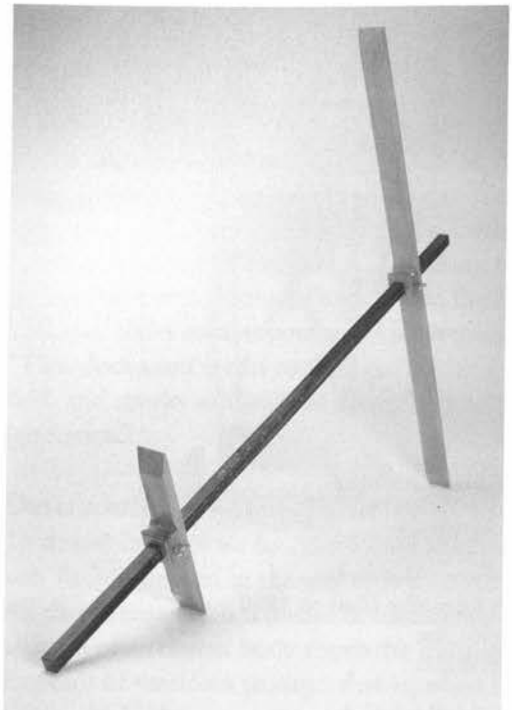
In navigation long distances across the open ocean, the sandglass for making time was as important an instrument as the compass for showing direction. Filed with the amount of sand to measure a half hour of time, each emptying of the sand was called a "glass," and eight glasses (four hours) made up one "watch."

26. Authentic Models, Inc.
French Admiralty Glass ca. 1800
Brass and Glass
Modern replica

Cross-staff

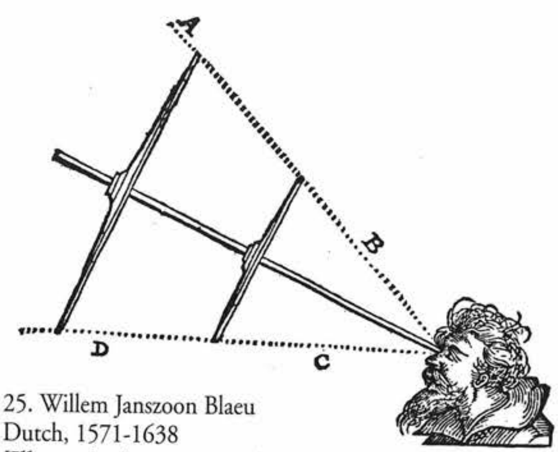
The cross-staff, originating sometime in the thirteenth or early part of the fourteenth century, was a better instrument for taking readings of the altitude of a celestial body than the quadrant or the astrolabe. The ultimate in simplicity, it was but a long stick with a movable cross-bar called the transversary. The navigator aimed the lower point of the cross-bar at the horizon and moved the cross-bar until its upper tip touched the celestial body; then he read the altitude on the scale inscribed along the length of the staff. To prevent painful damage to the eyes by having to look directly at the sun, a small shield blocked the sun (except its upper-most edge), and the navigator made a correction value to find the true reading. Alternatively, a small piece of smoked glass was used.

In spite of the knowledge of how to determine latitude by means of celestial observations, and the existence of nautical instruments to take these measurements, there was a vast difference between theory and practice. The instruments themselves caused a certain amount of error; with the astrolabe, this could be as great as one whole degree of arc, equal to an error of sixty



27. Harriet Wynter Ltd
English, 20th Century
Cross-Staff
Rosewood and Cherry
Modern replica

nautical miles. It was no small feat for the navigator to keep the cross-staff aimed at the horizon, while at the same time moving the cross-bar so as to have its upper tip touch the celestial body, all the while trying to brace himself on the pitching and rolling deck of a

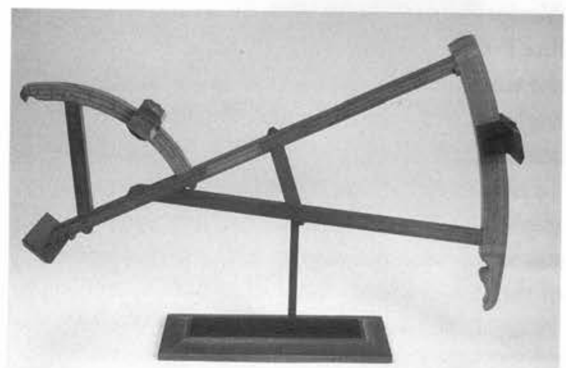


25. Willem Janszoon Blaeu
Dutch, 1571-1638
[Illustration]
Woodcut
From: Le Flambeav de la Navigation, (Amsterdam, 1619)

ship. Under these conditions it was no easier to maintain a star or the sun in the sighting holes of the alidade of an astrolabe.

Back-staff

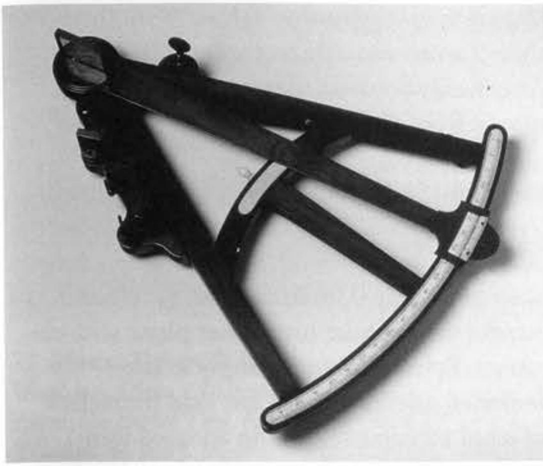
Essentially, the back-staff was a modification of the cross-staff, having a sliding half-transom in the form of an arc, and a horizon vane at its proximal end. Instead of looking directly at the sun, the observer turned his back toward the sun (hence the name back-staff) and moved a cross-piece along the arc. When the shadow cast by the sun was aligned with the horizon on the horizon vane, a reading was taken off a scale. This eliminated the problem caused by the cross-staff of having to look in two directions at the same time, as well as distortion and errors caused by irregularities in the glass. It also prevented temporary blindness by having to look directly at the sun.



28. William Hart
American, 1734-1812
Back-staff
Rosewood, Walnut, and Mahogany
Portsmouth, NH, 1767

Octant

Obtaining measurements of the angular height of a celestial body above the horizon is not difficult, as attested to by the early development of the cross-staff, back-staff, and marine astrolabe. The real problem lies in being able to achieve this with great accuracy, and under the difficult conditions of being at sea on a small boat.



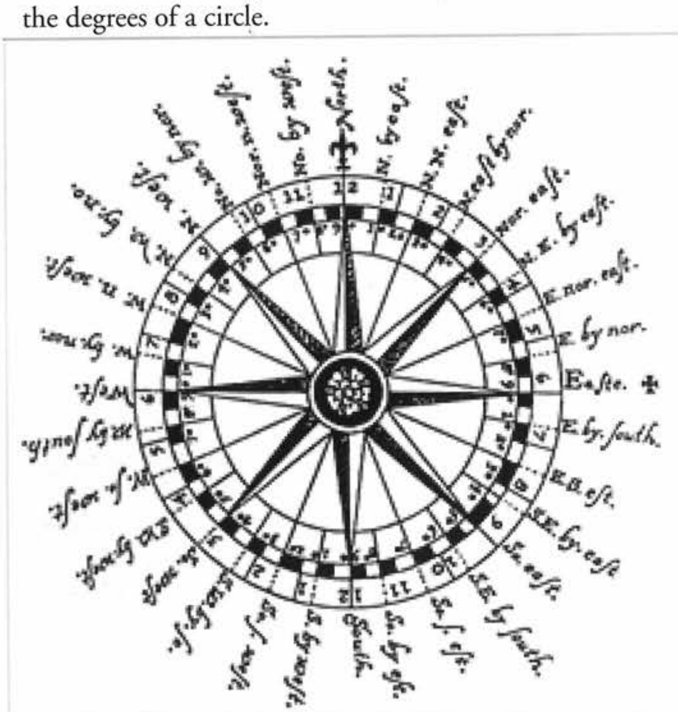
29. Anonymous
Octant (Hadley's Quadrant)
Rosewood with ivory scales and brass fittings
46.4cm
English, ca. 1780

30. Stanley London Brass Compass
White Star Line Gimbaled Boxed Compass
Brass and Wood 16cm.
Modern replica

With the rise of exploration during the seventeenth century, maritime nations of the world encouraged the development of navigational instruments. Voyages of increased distance and duration required being able to more correctly plot position at sea, and to locate newly discovered lands that they may be accurately shown on maps. In 1731, John Hadley, an English astronomer, mathematician, and physicist invented the Octant. He added optics to the simple quadrant, and a reflecting mirror to bring a body in the heavens into coincidence with the horizon, thereby turning the quadrant into a reflecting telescope. At nearly the same time, Thomas Godfrey, in Philadelphia, arrived at the same solution. This instrument, the octant, is the predecessor of our present-day sextant.

Compass

By the fourteenth century, the eight primary points of the compass were sub-divided into sixteen and then thirty-two points; each point equally spaced at 11°15'. By the end of the sixteenth century, compass cards carried a dual system of points and degrees. Any good sailor could "box the compass," giving the name of each point in turn: north, north by east, north northeast, northeast by north, etc., until all the points were covered. This arrangement of compass points remained until the first half of the twentieth century, when it was replaced with the degrees of a circle.



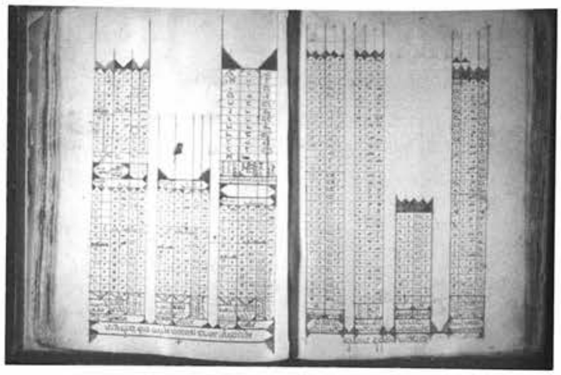
Astronomical Tables

As early as the eighth century the Muslim geographer Msha'allah described how to determine latitude from the meridian altitude and declination of the sun. By the late fifteenth century, the daily declination of the sun had been recorded on simplified solar tables derived from these early works. The noted Jewish astronomer and historian, Abraham Ben Samuel Zacuto, produced tables of declination of the sun in his major astronomical work, *Ha-Hibbur ha-Gadol (Rules for the Astrolabe)*. These were used by Christopher Columbus on his voyages, and were the basis for the *Regimento do Astrolabio do Quadrante* (Regiment for the Astrolabe and Quadrant) prepared for Portuguese mariners under Prince Henry the Navigator. Zacuto's works on astronomy were used throughout the Christian and Islamic world, and he was personally consulted by Vasco da Gama before he undertook his voyage around the Cape of Good Hope to Calicut, India in 1498.

Solar Declination

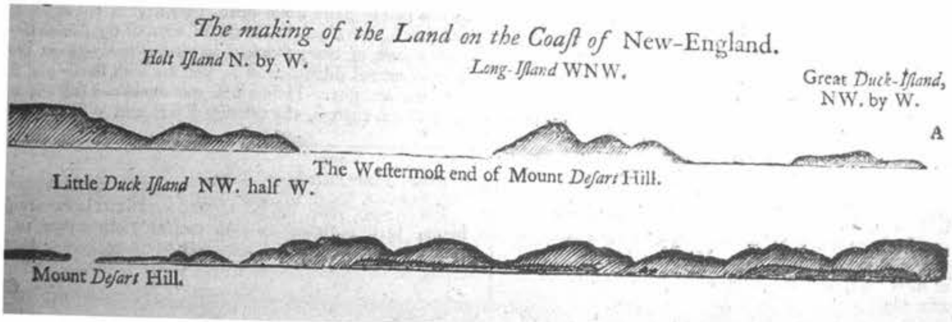
Tables of declination of the sun were produced in 1473-1478 by Abraham Ben Samuel Zacuto. In order to create these tables—necessary for an accurate calculation of latitude—other advances in astronomy first had to be made. Foremeost, was an accurate solar calendar, and a determination of the Sun's position relative to the Earth's seasons. The Roman Republican year was based on lunar reckoning, creating a year containing 366.25 days. To keep the calendar in phase with the seasons, Julius Caesar (mid-first century BC) abandoned the lunar calendar in favor of one based on the solar year. Though it was an improvement on the old system, it still created a year that was too long by 11 minutes and 14 seconds. This seemingly short time cumulatively amounted to seven days in a thousand years. In the mid-thirteenth century, Alfonso X of Castile, Spain gathered together 50 astronomers to compile new astronomical tables for the positions and movement of the planets. These were completed in 1252, and are subsequently referred to as Alphonsine Tables. With these tables Zacuto was able to produce the first scientifically accurate means of calculating latitude from the Sun.

Not until 1582 did the Christian world institute a revised, more accurate solar calendar. Issued by Pope Gregory XIII, it differed from the Julian calendar by only 0.0078 days per year, but it brought the calendar into better phase with the seasons. Referred to now simply as the Gregorian calendar, it did not gain immediate universal acceptance. Britain adopted it in 1762, Sweden in 1753, and Soviet Russia as late as 1918.



31. Abraham Ben Samuel Zacuto
ca.1452-1515
[tables of declination of the sun]
Manuscript
From: Ha-Hibbur ha-Gadol,
(Salamanca, 1491)
Photograph courtesy of the Library of the Jewish Theological Seminary

The photograph displayed here is of a page from Zacuto's tables of declination of the sun. Zacuto also wrote a book on the influence of the stars, which included a treatise on solar and lunar eclipses. Originally written in Hebrew, it was translated into Spanish as *Tratado breve en las influencias del cielo*. Christopher Columbus used these tables, and the solar declination tables, on his voyages.



33. **Mount Desart Hills**
Wood cut, 1.5cm x 20.0cm
From: *The English Pilot, Fourth Book* (detail)
(London: W. and J. Mount, T. Page, and Son, 1760)

Coastal Views

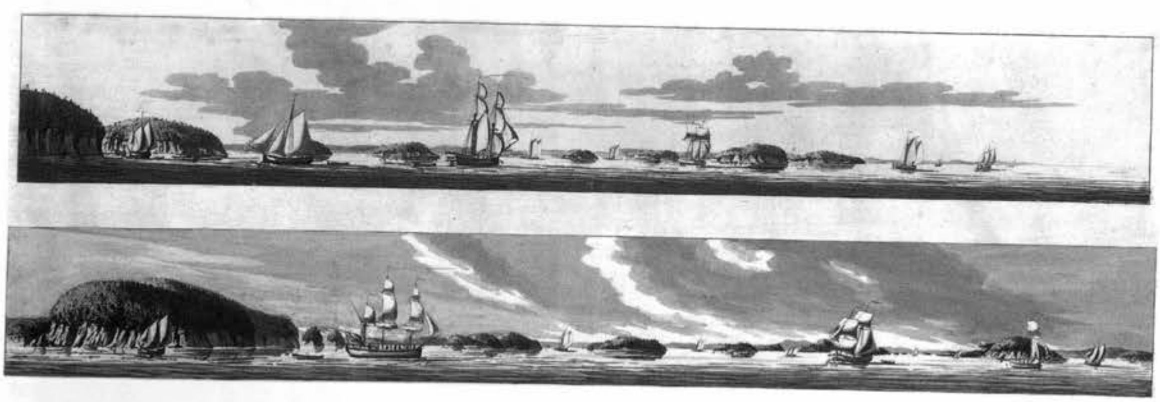
Plan, or bird's-eye, views of land on nautical charts and in pilot books were often accompanied by horizon profiles of the coast. These small scenes depicted the land as a mariner would see it when approaching from seaward, and aided him in identification to assure a proper landfall.

In order for England to achieve mastery of the seas, and wrest her share of profit from trade on the far side of the world, she could no longer rely upon the expertise of her competitors—Spain and Portugal. William Bourne was among the first in England to promote the "New Navigation." This depended upon a thorough knowledge of astronomy, coupled with the application of mathematics. In his *A Regiment for the Sea*, published in1574, Bourne had this to say about coastal views:

> There is nothing more needful and necessary for seamen than this, to know the land when he seeth it, and there is no better way to make him remember it than to have notes how the land doth rise upon every side.

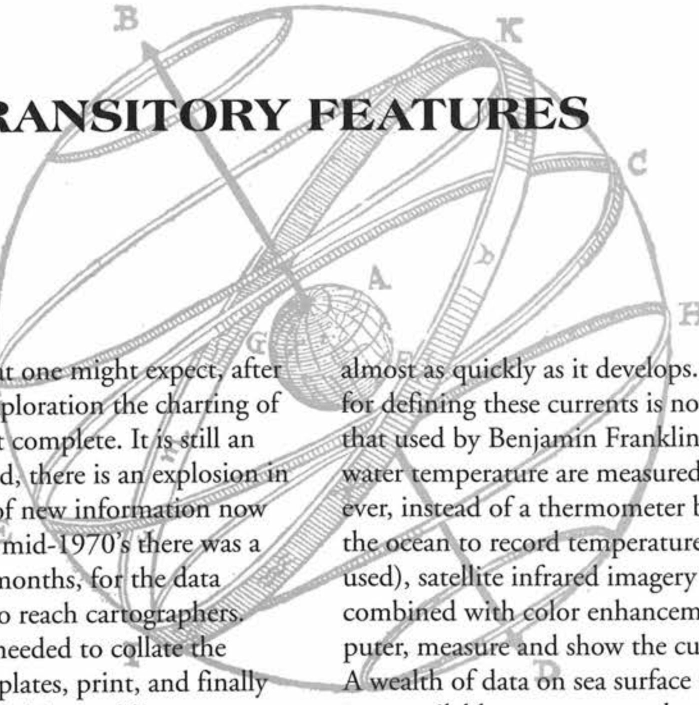
Bourne's advice was well heeded, both in England and in Holland, and coastal views began to be copiously depicted.

In the centuries following their introduction they were sometimes elevated to exquisitely detailed landscape engravings or watercolor drawings, far surpassing in aesthetic appeal their original intended function.



34. Joseph F. W. DesBarres
Swiss/English, ca. 1729-1827
[untitled views of Porcupine Islands, Frenchman Bay]
Copper engraving, hand-colored,
9.2cm x 71.3cm
From: The Atlantic Neptune
(London, 1781)

VI. TRANSITORY FEATURES



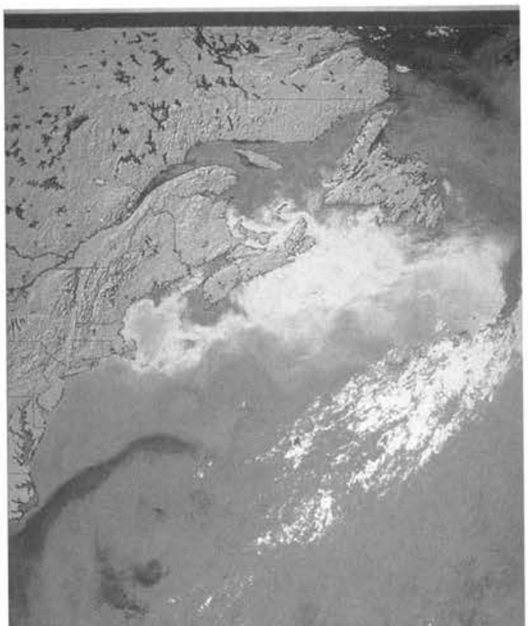
Contrary to what one might expect, after centuries of exploration the charting of Neptune's Realm is not complete. It is still an ongoing process; indeed, there is an explosion in the amount and kind of new information now available. Up until the mid-1970's there was a delay of weeks, if not months, for the data acquired by mariners to reach cartographers. Then, more time was needed to collate the material, engrave new plates, print, and finally dispense charts to the waiting public.

Now, satellites commonly circle our globe, taking photographs, measuring many of the ocean's characteristics with special sensors. Much of this material is then organized and transformed by computer. Data that at one time was too transitory in nature to be disseminated in a timely fashion is instantly accessible electronically. Commercial shippers, commercial fishermen, research scientists, and recreational sailors all benefit from this new era in marine cartography.

Editor's Note: The items in this section were taken from Internet sites that existed at the time of the original exhibition. While some of the URLs specified may no longer be valid, similar images of the same phenomena are available at other Web sites. The color keys mentioned in the text can be viewed at http://usm.maine.edu/maps/exhibit8.

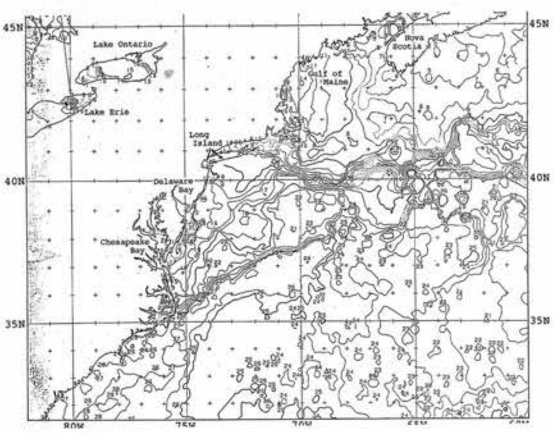
Sea Surface Temperature

Throughout the centuries mariners have used their knowledge of the ocean currents to plan speedy voyages. This body of knowledge grew slowly, dependent on many voyages over the years before general patterns were discerned. Today, Government agencies continuously moniter the major cold water and warm water currents of the oceans with great accuracy. Each meander and eddy of the Gulf Stream is mapped almost as quickly as it develops. The procedure for defining these currents is no different from that used by Benjamin Franklin—differences in water temperature are measured. Today, however, instead of a thermometer being placed in the ocean to record temperature (as Franklin used), satellite infrared imagery and altimetry, combined with color enhancement by computer, measure and show the current's location. A wealth of data on sea surface temperature is now available to oceanographers and marine biologists. Commercial fishermen, as well, have a vital interest in the unceasing shift of warm and cold water currents. Cold water is more nutrient rich, sustaining greater populations of phytoplankton and zooplankton. These microscopic plants and animals are at the base of a long food chain for all of life in the seas.



T1. Johns Hopkins University
Space Oceanography Group
Applied Physics Laboratory
http://www.jhuapl.edu/weather/main/index.html

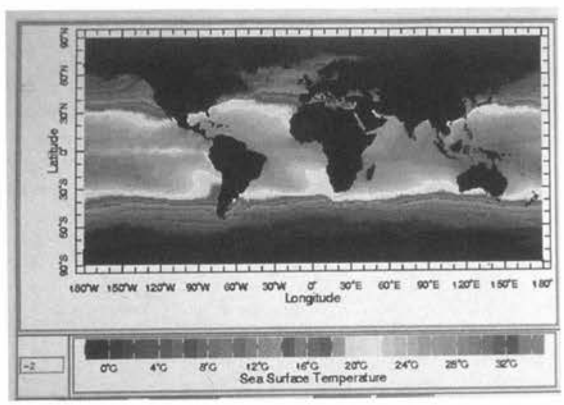
Chart T1, provided by the Space Oceanography Group, Johns Hopkins University Applied Physics Laboratory, shows a portion of the Gulf Stream in the northwest quadrant of the Atlantic Ocean. Note how sharply the stream's north wall is confined, and how the banks of Cape Hatteras deflect the stream eastward. Nantucket Shoals and Georges Bank prevent any incursion of the Gulf Stream's warm water into the Gulf of Maine. Two warm water eddies, circulating clockwise, have broken off the main stream, and can be seen east of Chesapeake Bay and southeast of Cape Cod. The white blotches on the picture are the result of cloud cover preventing the sensing of temperature.



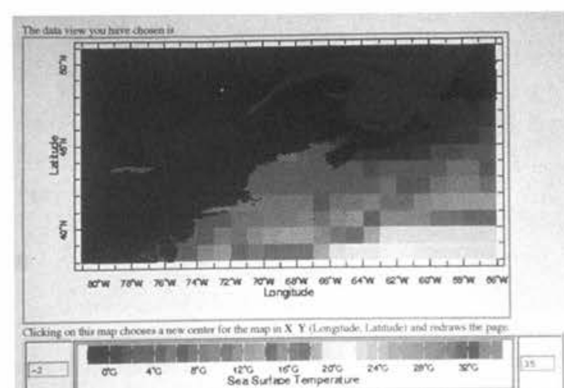
T2. National Oceanic and Atmospheric Administration (NOAA)
Water Temperature Chart: N.E. Atlantic Coast, 6 June 1987
http://www.noaa.gov

Chart T2, from the National Oceanic and Atmospheric Administration, is of the same area covered by chart T1. Here, isobars of like temperature are depicted, and their numerical value given in degrees centigrade. Though lacking the drama of the color image, it nonetheless has its own beauty, and shows water temperature more precisely.

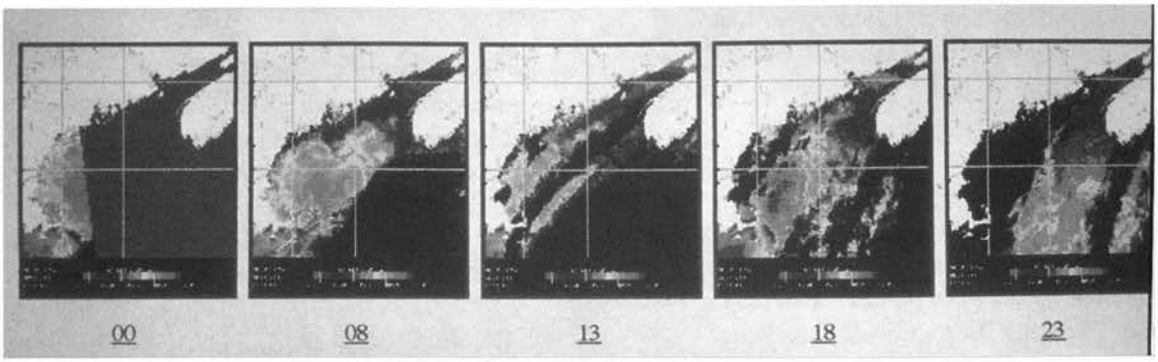
Canada Space Agency's Center for Remote Sensing provided images (T3, T4) of world-wide sea surface temperature, taken on January 13, 1999. It is particularly interesting that the Internet site from which these pictures were obtained (http://ingrid.ldgo.columbia.edu/SOURCES/IGOSS/nmc/climatology/sst/) enables the viewer to participate as cartographer by selecting the parameters, and modifying the view.



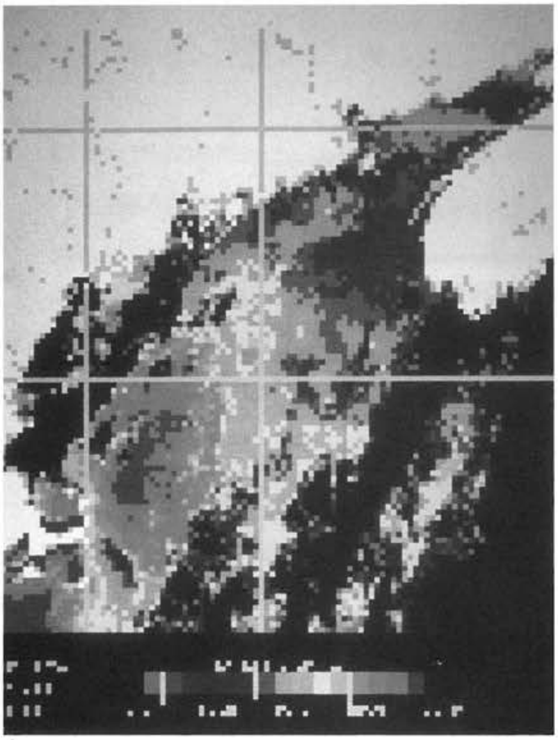
T3. Canada Space Agency's Center for Remote Sensing
Sea Surface Temperature, 13 January 1999
http://ingrid.ldgo.columbia.edu/
SOURCES/IGOSS/nmc/climatology/sst/



T4. Canada Space Agency's Center for Remote Sensing
Sea Surface Temperature, 13 January 1999
http://ingrid.ldgo.columbia.edu/
SOURCES/IGOSS/nmc/climatology/sst/



T5. National Oceanic and Atmospheric Administration (NOAA), Coastwatch Northeast Regional Node
Gulf of Maine Sea Surface Temperature, Thumbnails, August 5, 1999
http://www.noaa.gov (archive)



T5a. National Oceanic and Atmospheric Administration (NOAA), Coastwatch Northeast Regional Node
Gulf of Maine Sea Surface Temperature, Thumbnails, August 5, 1999
http://www.noaa.gov (archive)

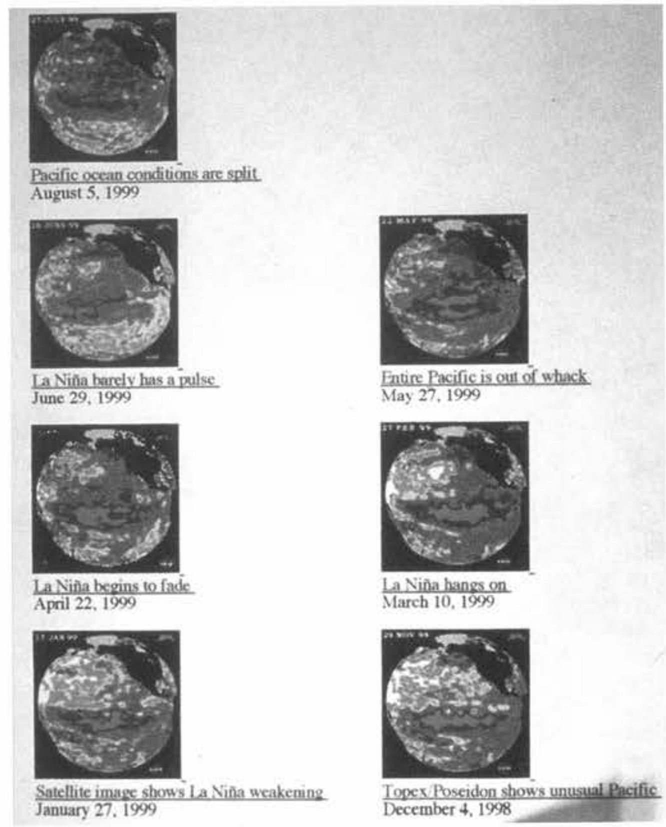
From NOAA Coastwatch Northeast Regional Node come images T5 and T5a showing sea surface temperature in the Gulf of Maine. One can retrieve archived photos made daily for the past several years.

El Niño/La Niña

The importance of changes in sea surface temperature was dramatically thrust into general public awareness by the 1997-1998 occurance of the El Niño phenomenon. Oscillations in the locus of normal water temperatures in the equatorial Pacific, along with attendant changes in sea level height and wind patterns, are normal occurrences. Periodically, these changes become exaggerated; when they do they result in the condition called El Niño, characterized by unusually warm temperatures along the west coast of North America at the equator, and its corollary, La Niña, with abnormally cold temperatures there. When these anomalous conditions occur, climate systems around the entire globe are affected. In some areas the result is excessive rainfall with destructive flooding, in others, severe drought producing extensive forest fires. Commercial fishermen are also affected. Higher water temperatures reduce the supply of nutrients, which in turn, adversely affects marine ecosystems and fish populations.

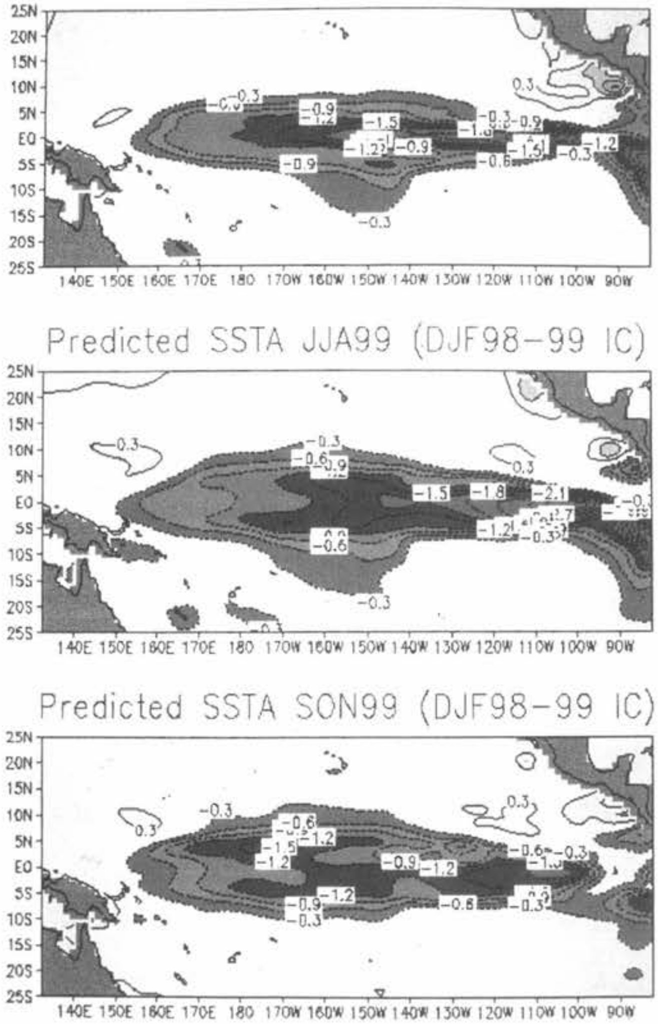
Normally, easterly tradewinds pile up warm surface water in the western part of the Pacific, resulting in a higher sea level there. On maps T6 and T6a the La Niña condition of cool water (indicated in blue and purple) off the coast of South America is clearly apparent. Satellite measurements that made these maps include the height and temperature of the sea with incredible accuracy. The red areas are four inches above normal, and the purple areas seven inches below normal. Differences in height as seemingly insignificant as these nevertheless affect the temperature of surface waters.

T6. El Niño/La Niña Watch
Measuring the Ocean's Height and Temperature
http://www.jpl.nasa.gov/earth/ocean_motion/el_nino_index.cfm
Image provided by TOPEX/Poseidon
Courtesy of NASA/JPL/California Institute of Technology



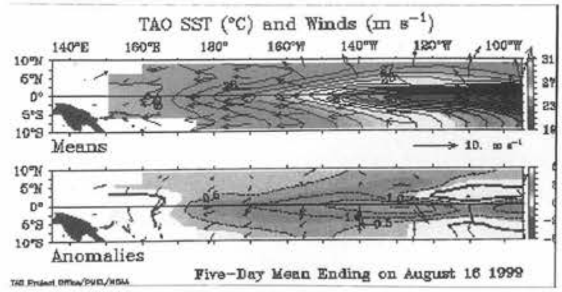
T6a. El Niño/La Niña Watch
Measuring the Ocean's Height and Temperature
http://www.jpl.nasa.gov/earth/ocean_motion/el_nino_index.cfm
Image provided by TOPEX/Poseidon
Courtesy of NASA/JPL/California Institute of Technology

Editor's Note: The color keys mentioned in the text can be viewed at http://usm.maine.edu/maps/exhibit8.



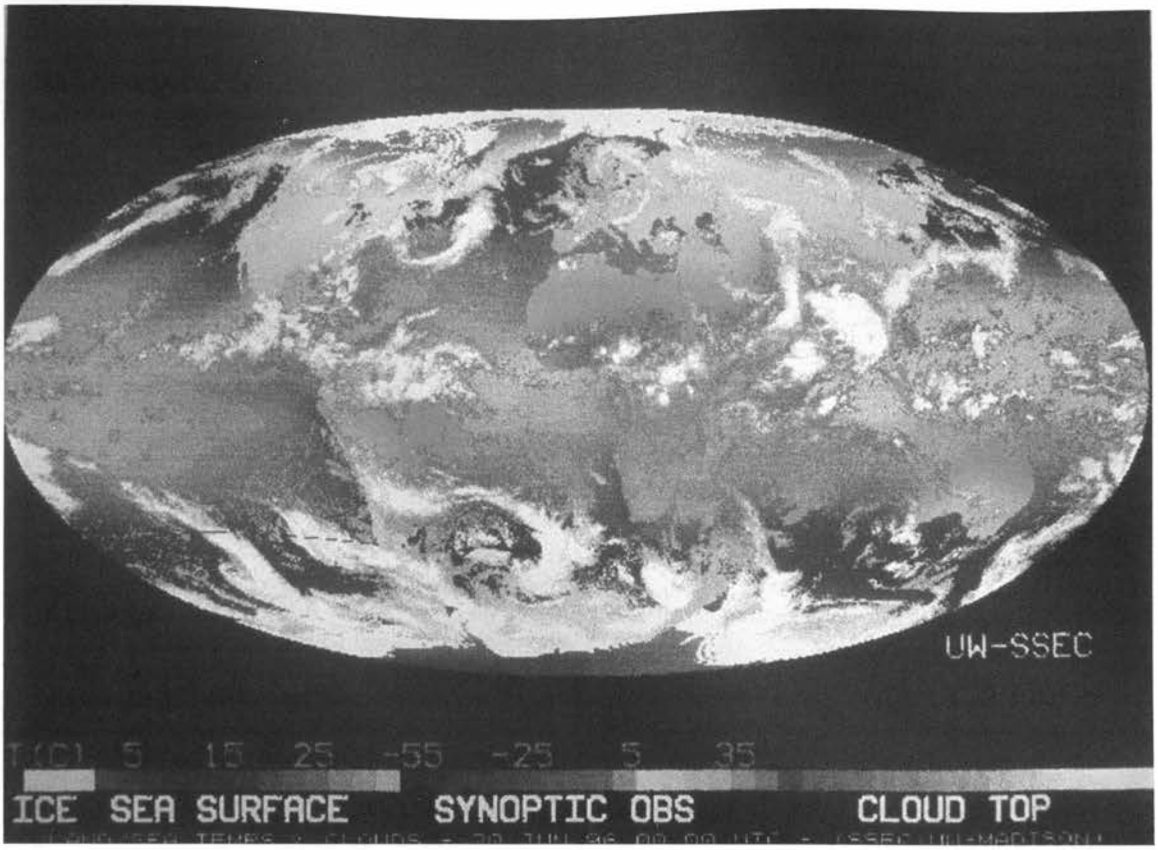
T7. Institute of Global Environment and Society
Center for Ocean-Land-Atmosphere Studies (COLA)
Sea Surface Temperatures
http://grads.iges.org/cola.html

T7 Shows predictions of sea surface temperature for the equatorial Pacific made in December of 1998. In the top two panels, covering the months of March through August, cold water anomalies are predicted to dominate the scene. In the fall, however, they will begin to degrade and break up.



T8. National Oceanic and Atmospheric Administration (NOAA), Tropical Atmosphere Ocean (TAO Project)
Sea Surface Temperature and Winds
http://www.pmel.noaa.gov/toga-tao/home.html

The latest sea surface temperature maps (T8) are available online. Not only can one see what is happening at the moment, but through time-lapse animation loops it is possible to view transitory changes as they occur over the course of a year. The introduction of the element of time is a major revolution in cartography. Changes in temperature over the entire equatorial Pacific Ocean during the course of a year can presently be seen at:
http://iri.ldeo.columbia.edu/climate/dictionary/lanina/now/sst.html
http:// www.pmel.noaa.gov/toga-tao/realtime.html/



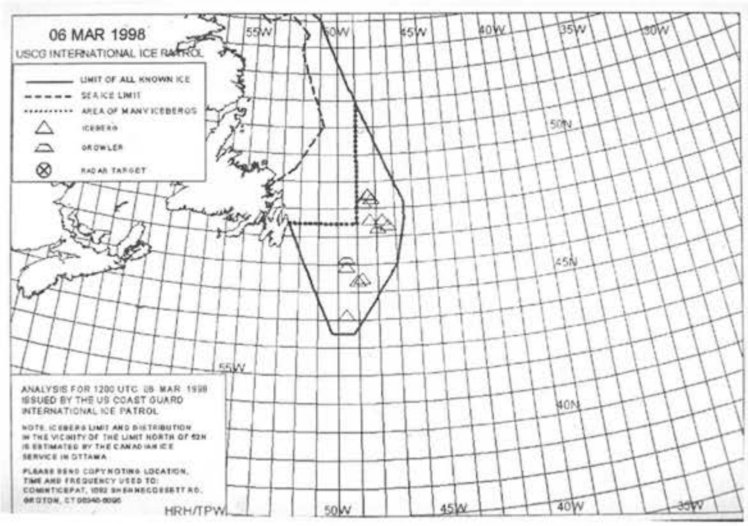
T9. University of Wisconsin at Madison
Ice Sea Surface synoptic OBS
http://ftp:ssec.wisc.edu/gopher/gsdc

The University of Wisconsin at Madison created this composite map (T9) of the world for June of 1996. It shows land temperatures, sea temperatures, ice fields at the poles, and cloud cover with their altitudes.

Icebergs

Every spring icebergs calve off the Greenland glacier and drift into the Labrador Sea where they are carried south along the coast of Labrador and Newfoundland by the Labrador Current. When they reach southeast Newfoundland their path splits to either side of the Grand Banks. At this point they are now far enough south to pose a serious threat to trans-oceanic shipping. Environment Canada Ice Centre, in conjunction with the U.S. Coast Guard International Ice Patrol, issues daily bulletins of the distribution and limits of icebergs between latitudes 40°N and 52°N, and longitudes 39°W and 57°W. Ships transiting this region report all sightings of icebergs, sea surface temperature, and weather. This information, along with satellite observations is used to produce charts of iceberg locations.

Radar is an unreliable means of detecting icebergs. Since they are only composed of water, albeit in a solid state, radar signals tend to pass right through, rather than reflecting off them. However, radar will pick up icebergs with varying degrees of clarity if their surface is particularly corrugated or rough, or a large amount of gravel is embedded in them.

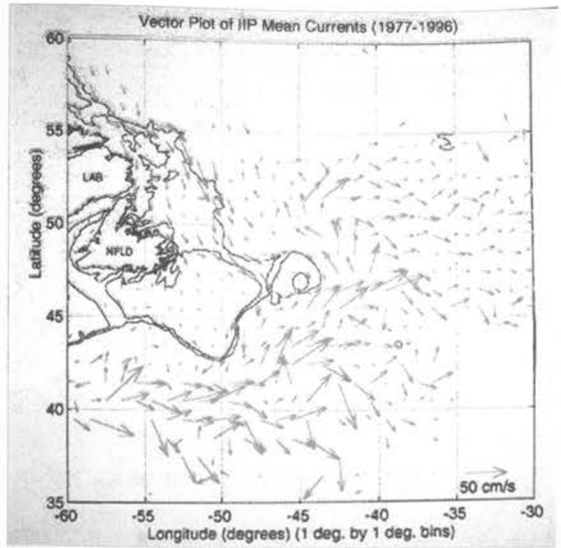


T10. USCG, International Ice Patrol
Analysis for 1200UTC, 06 March 1998
http://www.uscg.mil/lantarea/iip/home.html

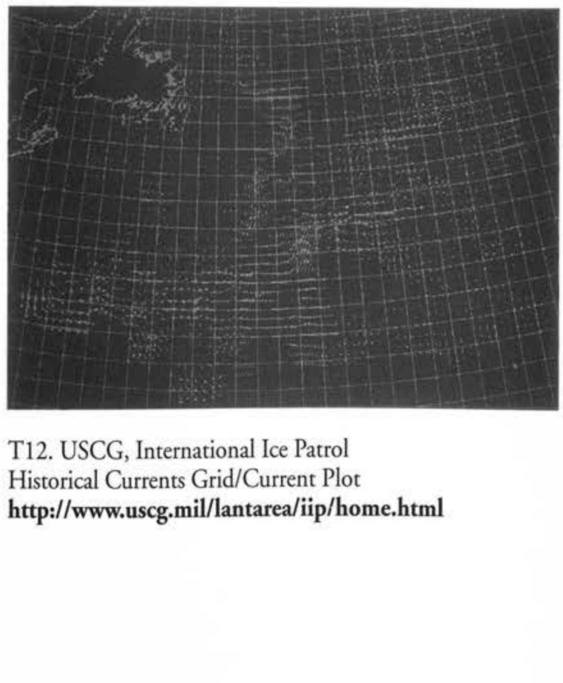
T10 - On March 6, 1998, solid sea ice extends northward from Bonavista Bay along the Newfoundland and Labrador shore. In open water, seaward of the ice, the number of icebergs is too great to show. No radar targets (ships) are present at this time. East of the Grand Banks there are ten icebergs and two smaller chunks of ice, called growlers. Distinction is made by length:

Growler—up to 16 metre—up to 52.53 ft.
Small Iceberg—16-60 metres—52.53-197.00 ft.
Medium Iceberg—60-122 metres—197.00-400.56 ft.
Large Iceberg—122-225 metres—400.56-738.75 ft.

Unless icebergs become trapped in bays along the coast, or ground out on the edge of the banks, they continue moving southward with the Labrador Current until they encounter the Gulf Stream. There, they rapidly melt in the warm waters. On rare occasions, a few, either due to their great size, or the benefit of a particularly strong cold-water eddy, survive this barrier. In 1926, one iceberg reached to within 150 nautical miles of Bermuda, and icebergs have been sighted as far east as the Azores, 900 miles off the coast of Portugal.

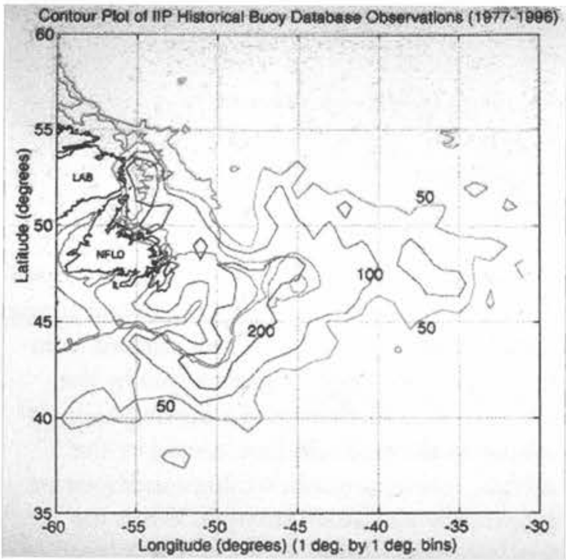


T11. Vector Plot of IIP Mean Currents (1977-1996)
International Ice Patrol
http://www.uscg.mil/lantarea/iip/home.html



T12. USCG, International Ice Patrol
Historical Currents Grid/Current Plot
http://www.uscg.mil/lantarea/iip/home.html

Plotting where icebergs are likely to be in the near future is as important as knowing their position at the moment. Though ocean currents are the major force controlling their movement, strong winds, and wave motion also have an effect. To monitor these influences, buoys dropped from planes transmit via VHF radio a continuous record of the buoy's latitude and longitude, as well as a reading of the sea surface temperature. From this information detailed charts of the currents (T11 and T12) are made, allowing prediction of the most likely direction the icebergs will take. On both charts, note the weakness of currents directly over the shallow Grand Banks and Flemish Cap.



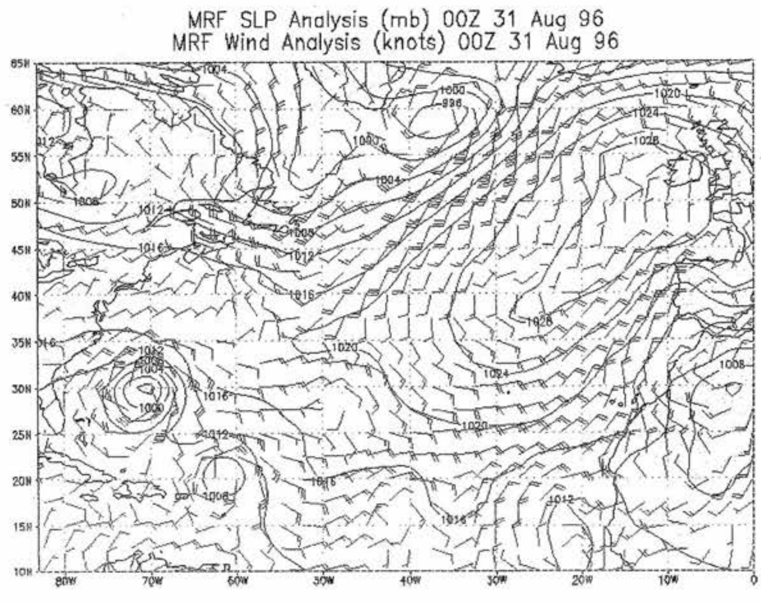
T13. USCG, International Ice Patrol
Contour Plot of IIP Historical Buoy Database Observation (1977-1996)
http://www.uscg.mil/lantarea/iip/home.html

The topography of the ocean floor, and the flow of the Labrador Current with its interaction with the warm water of the Gulf Stream, are readily apparent in T13: a chart of iceberg distribution in the North Atlantic.

Wind and Wave

The earth's seasons are produced by its annual orbit around the sun, while the rotation of the earth on its axis is responsible for the alternation of night and day; both influence wind regimes of the earth. Within the major general flow of air about the planet are numerous smaller masses of air, all in constant motion, both horizontally and vertically. This flow, at the same time creates changes in pressure, with concomitant low pressure and high pressure cells.

Everything is in motion, everything flowing, trying to reach some state of equilibrium. Wind, pressure, temperature, and the amount of moisture in the air, are all interrelated and part of one large cyclical pattern. To understand that basic pattern is to understand its variations, which, in turn, is to understand weather.



T14. Oceanweather Inc.
Significant Wave Height and Directions
http://www.isle.net

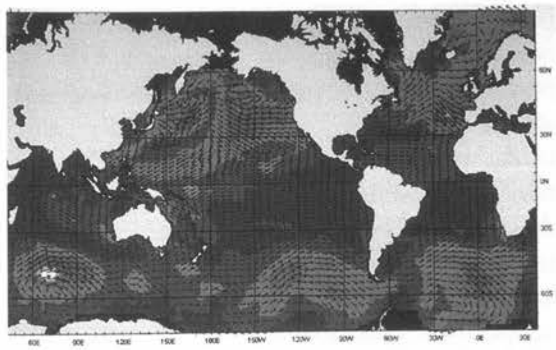
Charted on T14 is one moment (midnight, GMT of Aug. 31, 1996) in this continually shifting pattern of pressure cells and winds. The Bermuda/Azores high pressure system that dominates weather patterns in the North Atlantic is clearly visible as a broad band extending from the Azores to Ireland. In its center the winds are light and variable. Winds move outward and clockwise from high pressure cells. Since Maine lies in the northwest quadrant of this system, the predominant summertime winds are from the southwest.

Three migratory lows—a large, weak low just off the coast of Africa, another east of Puerto Rico, and a third, deeper low off the coast of Florida—will move westward with the Northeast Trade Winds. Another low of 998 millibars pressure, southeast off the tip of Greenland, will move eastward with the prevailing Westerlies. In low pressure cells, winds move inward toward the center, and counterclockwise. Note the tightly compressed isobars between the low off Greenland and the Bermuda/Azores high, where winds reach 45 knots. Similar wind speeds are present around the low pressure cell east of Florida. On the Beaufort Wind Scale, 45 knots is Force 9, and called a strong gale, producing wave heights of 23 to 32 feet.

Ocean-going vessels rely on hourly updated charts, and up to 7 day forecasts of global marine wind and wave conditions to help determine the fastest route, or the route least costly in fuel consumption.

In chart T14, one is left to interpolate wave height and wave direction from the barometric pressure and wind strength.

Here, in T15, wave heights are graphically depicted by the use of color, and wave direction is shown with arrows. An intense low pressure cell east of Newfoundland dominates the

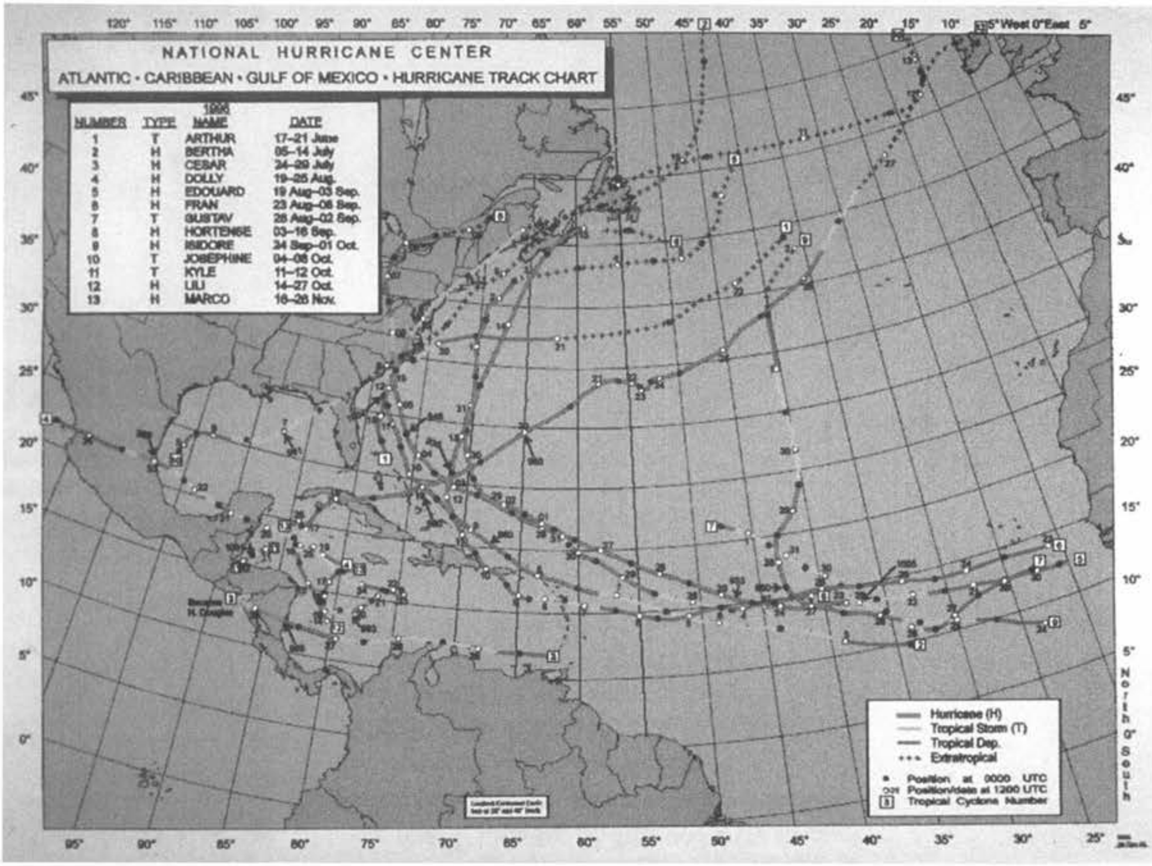


T15. Oceanweather Inc.
Significant Wave Height and Directions
http://www.oceanweather.com/data

Atlantic Ocean scene. Although the two areas south of Iceland, and west of Ireland, appear innocuous, nevertheless, with their wave heights of 15 feet, they would be of concern to fishing vessels.

Atlantic Tropical Cyclones

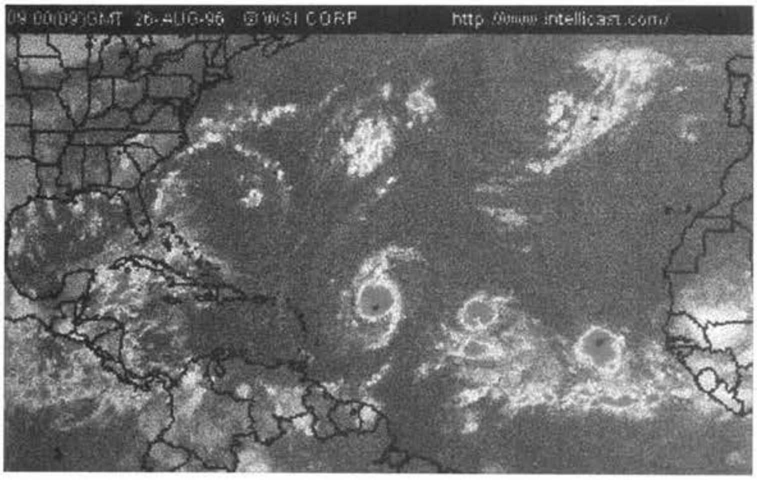
The ultimate winds mariners in the North Atlantic must contend with are tropical cyclones, more commonly called hurricanes. Spawned in the warm equatorial waters, most often near the coast of Africa, they begin life as a weather disturbance—thunderstorms and strong surface winds. Fed by latent heat released from the water vapor, they are given a spin by the Coriolis effect (deflection of a moving body relative to the earth's surface, caused by the earth's rotation) and when other conditions are proper they increase in strength. When the winds in these storms reach a constant speed of 74 miles per hour or more, they are termed hurricanes; their greatest wind speed can be too high to be recorded. Pushed westward by the flow of upper atmosphere winds (10-40,000 feet) cyclones eventually die out when they reach land, or when their path takes them into the colder waters of the North Atlantic where they are robbed of their warm-water source of energy. Hurricanes at sea have the power to destroy any vessel unfortunate enough to come within its range; upon mainland coasts and islands they leave a path of destruction and death.



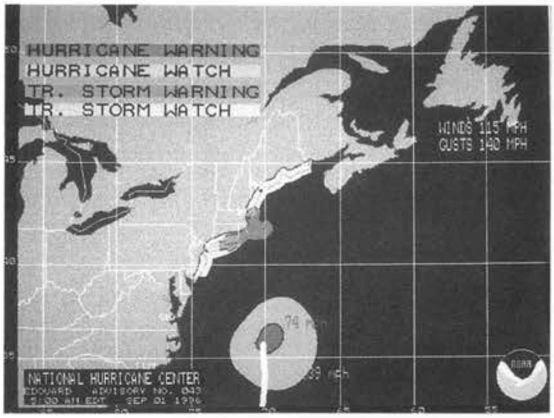
T16. National Oceanic and Atmospheric Administration (NOAA), National Hurricane Center Atlantic-Caribbean-Gulf of Mexico Tracking Chart
http://www.nhc.noaa.gov/

An active hurricane season in 1996 is evident by tracking chart T16 of all hurricanes for that year. Not all have their origin in the far eastern part of the North Atlantic; some begin life in the warm waters of the Caribbean or the Gulf of Mexico.

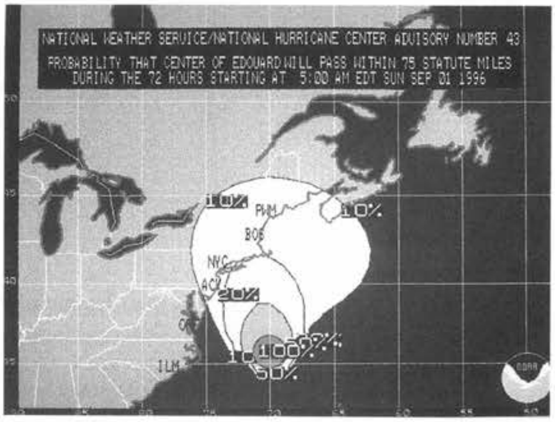
During the time of early exploration and colonization in the New World, hurricanes have been responsible for events that changed the emerging balance of power. Had the ability existed then to chart hurricanes and predict their path, France, instead of Spain, might have controlled the southeast coast of North America. In 1564, French Huguenots established Fort Caroline (near present-day Jacksonville, Florida), the first European settlement on the mainland of North America. Without warning, in September of the following year, a hurricane dispersed France's fleet, destroying most of its vessels. This left the Spanish fleet, under command of Pedro Menendez de Avila, free to capture Fort Caroline. And in 1640 a Dutch fleet would have survived to attack Havana, as originally planned, and Cuba would not have been relinquished to the Spaniards. The seventeen ships, with 2,000 troops of fleet of Lord Willoughby (Governor of Barbados) were almost totally lost to a hurricane in 1666, allowing the control of Guadeloupe to be taken by the French.



T17. Atlantic Hurricane Satellite Imagery
August 26, 1996
http://www.intellicast.com



T18. National Oceanic and Atmospheric Administration (NOAA), National Hurricane Center
Edouard Advisory #43, 1 September 1996
http://www.nhc.noaa.gov/1999.html

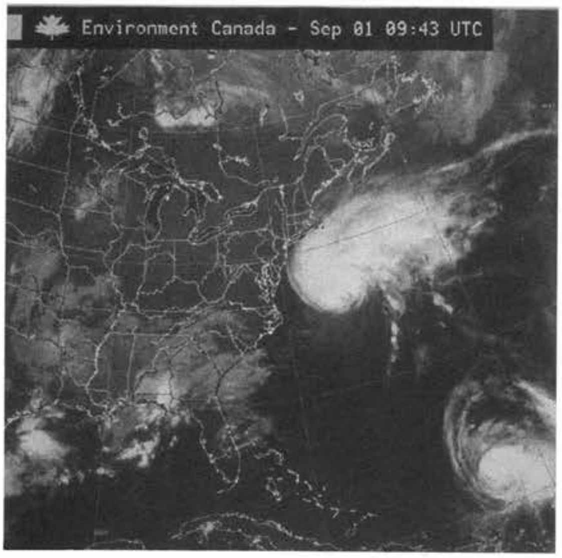


T18a. National Oceanic and Atmospheric Administration (NOAA), NOAA, National Hurricane Center
Advisory #43, 1 September 1996 6:38:06:
Probability that center of Edouard will pass within 75 statute miles during the 72 hours starting at 5AM EDT Sun., Sept. 1, 1996
http://www.nhc.noaa.gov/1999.html

On August 26, 1996, three hurricanes at one time are seen proceeding toward the Caribbean (T17); from west to east they are Edouard, showing the classical spiral-shaped cloud mass and a well defined eye, Fran, and Gustav. Hurricane Edouard started as a tropical wave in western Africa on Aug 17-18 with typical thunderstorms and squalls. Upon entering the Atlantic southeast of the Cape Verde Islands it increased in strength, and by noon (GMT) on August 22nd strengthened into a hurricane. Its highest wind speed, reported on August 28th was 163 mph.

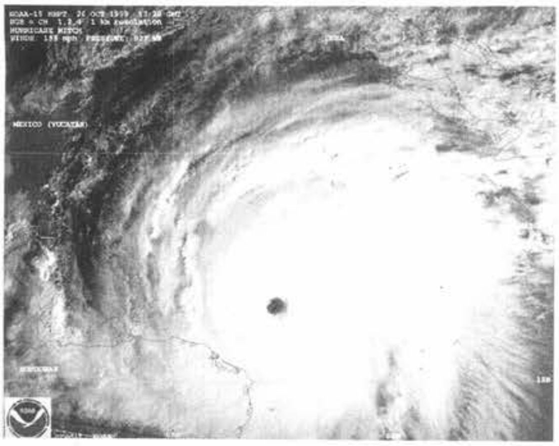
Keeping well to the northeast of the Caribbean Islands, Edouard headed west until north of Hispaniola, then turned to take a more northerly course. The track of hurricane Edouard (T17), and its potential for landfall on the northeast coast of North America (T18), were fully charted. The actual course taken by Edouard was fairly consistent with the predictions, allowing ships to seek timely refuge.

Though hurricane Edouard never touched the mainland coast, it came close enough to produce gusts of hurricane force at Nantucket, and unofficially, wind gusts of 80 MPH at Martha's Vinyard and 77 MPH on Cape Cod. The satellite image on September 1st (T18b), provided by Environment Canada, shows Edouard centered east of the Chesapeake. It was downgraded to a tropical storm two days later as it approached the coast of Nova Scotia, and finally expired when well east of Newfoundland. In the six days between August 26th and September 1st, Edouard travelled over 2,100 nautical miles.



T18b. Global Weather Chart
University of Hawaii-Manoa Department of Meteorology
http://lumahai.soest.hawaii.edu/

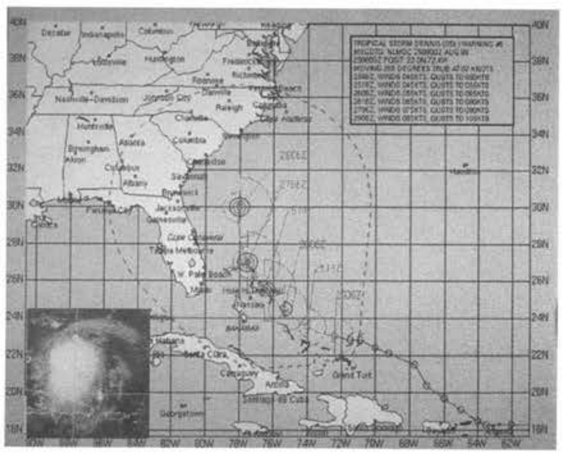
Hurricane Mitch (T19) in 1998 was one of the deadliest in history, with wind speeds reaching a peak of 180 MPH. Over 9,000 lives were lost in Honduras and Nicaragua. In Honduras alone, 50% of the agricultural crop was wiped out, 70,000 houses destroyed or damaged, and 92 bridges made impassable, isolating communities and preventing aid from reaching them. The loss of life and extensive damage came not from the force of Mitch's winds, which were diminished once over land, but the very slow rate of movement as it hovered there. This produced 35.89 inches of rain, causing flash floods and mud slides.



T19. Hurricane Mitch
Roy Sterner and Steve Babin, Johns Hopkins University Applied Physics Laboratory
http://www.jhuapl.edu/weather/main/index.html

The image here was produced from data received from the Geostationary Operational Environmental Satellite-8 (GOES-8) and the Polar Orbiting Environmental Satellites (POES) NOAA-12 and NOAA-14.

GOES satellites orbit the earth at the same speed as the earth's orbit, thus allowing the view to be kept constant.



T20. National Oceanic and Atmospheric Administration (NOAA)
Hurricane Mitch, 26 October 1998
http://www.noaa.gov

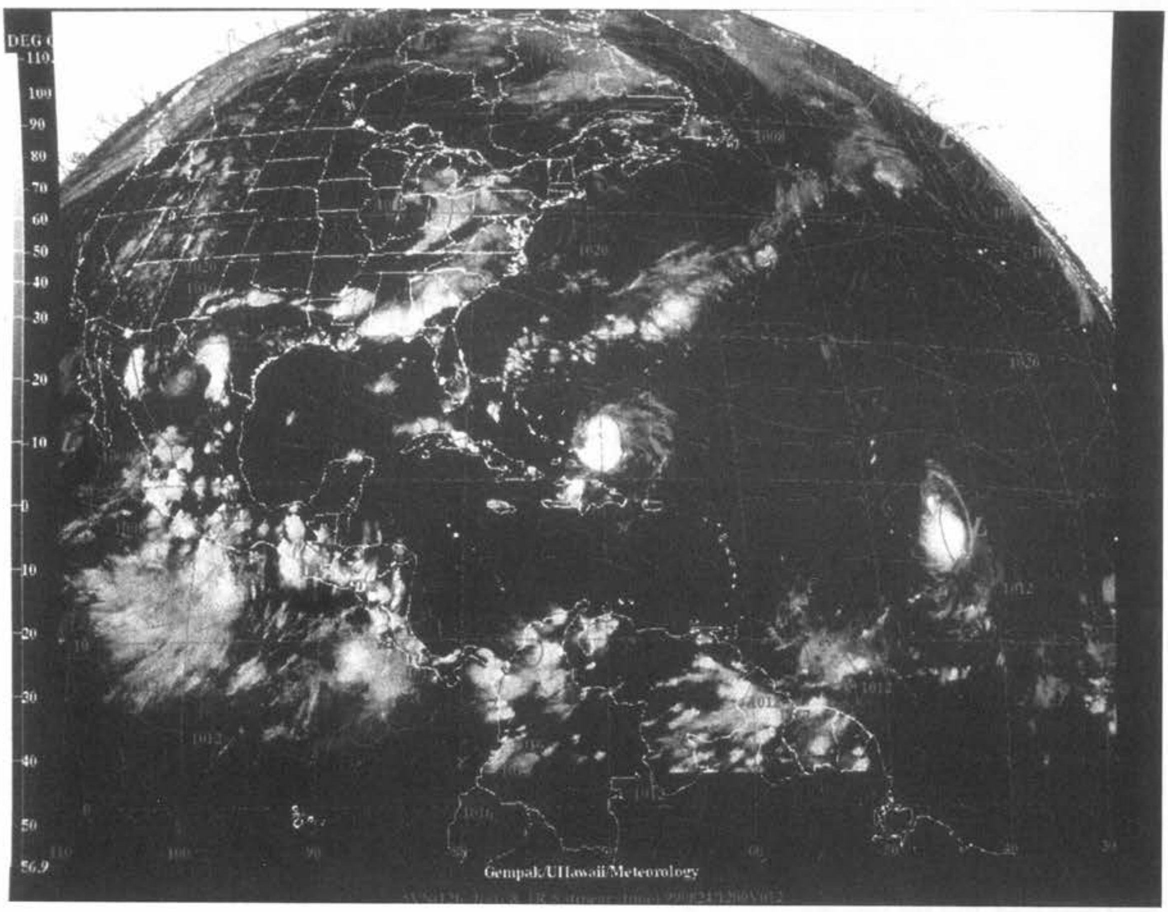
After Mitch's destructive path through Honduras, Nicaragua, and the Yucatan (T20), it curved back toward the northeast and gained strength from the warm water of the Gulf of Mexico. Cutting across the southern tip of Florida, it generated five tornados, then re-entered the Atlantic and lost its strength. The track charted covers the period from October 22nd to November 5th.

Global Forecasts

Today, computer models allow the meteorologist to forecast winds, and other oceanic characteristics, up to four days in advance. Using the combined resources of satellite images, fixed-position telemetry, and reports from vessels, an accurate representation of weather systems (with their attendant winds) is produced. These are updated hourly, and transmitted by radio fax to ships at sea.

This composite global view (T21) of temperature, visible cloud, and water vapor, was produced by the University of Hawaii at Manoa, Department of Meteorology. Using infrared photographs received from a GOES satellite, the image is color enhanced to clearly distinguish temperatures of various features.

Except for the position of the upper atmosphere jet streams (available on other Web sites) everything the mariner, or landsman, needs to forecast the weather is present here. All the elements in T21 (temperature, visible cloud, and water vapor) are rendered in a grey scale (instead of color) on the left side of the chart so as not to obscure all other information.



T21. Global Weather Chart
University of Hawaii-Manoa Department of Meteorology
http://lumahai.soest.hawaii.edu/

Barometric pressure—with isobars—(e.g. 1020), and identification of high (H) and lows (L) pressure cells, wind direction and speeds, a latitude and longitude grid, and outlines of land, all come together on this composite chart. Hurricane Dennis is visible north of Hispaniola at 23.1°N, 72.8°W; Hurricane Cindy is farther east at 18.6°N, 45.3°W; and the more loosely organized Tropical Storm Emily is at 8.0°N, 53.0° W.

Meteorology practiced today has its own symbols and conventions for depicting winds. As in the wind rose of Pilot Charts, winds are depicted by an arrow, with the shaft flying in the direction the wind is blowing toward. The number of feathers indicate the wind strength; each feather being ten knots of wind, half a feather is five knots.

Computer models allow the meteorologist to forcast winds throughout the ocean up to four days in advance. Using the combined resources of satellite images, fixed-position telemetry, and reports from vessels, an accurate representation of weather systems, with their attendant winds, is produced. They are updated hourly, and transmitted by radio fax to ships at sea. On land, they are available by telephone fax or through the Internet.

With all the information now available, there is still an element of unpredictability in the science of meteorology. No better advice can be give today than that of the Greek philosopher, Aratus Solensis, 2300 years ago in his treatise on weather signs. "Make light of none of the warnings. It is a good rule to look for sign confirming sign. When two point the same way, forecast with hope. When three point the same way, forecast with confidence."

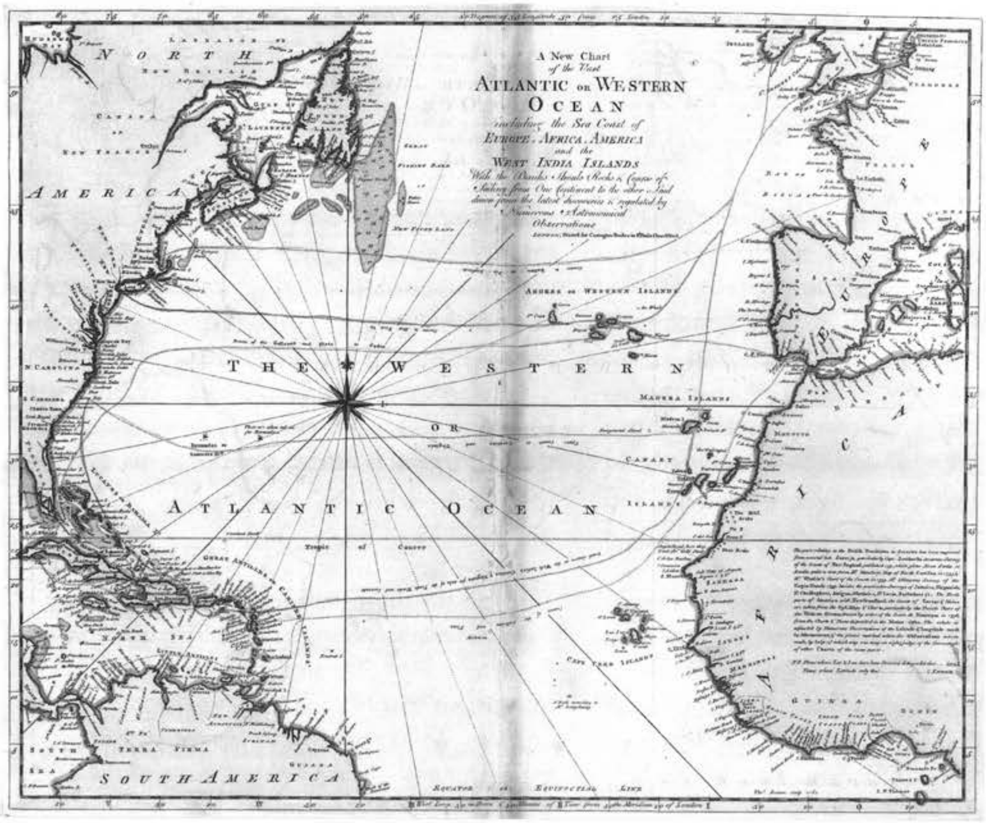


Plate 10

Carington Bowles, English, 1724-1793, **A New Chart of the Vast Atlantic or Western Ocean,** copper engraving, hand-colored, 44.7cm x 55.1cm, London, 1762

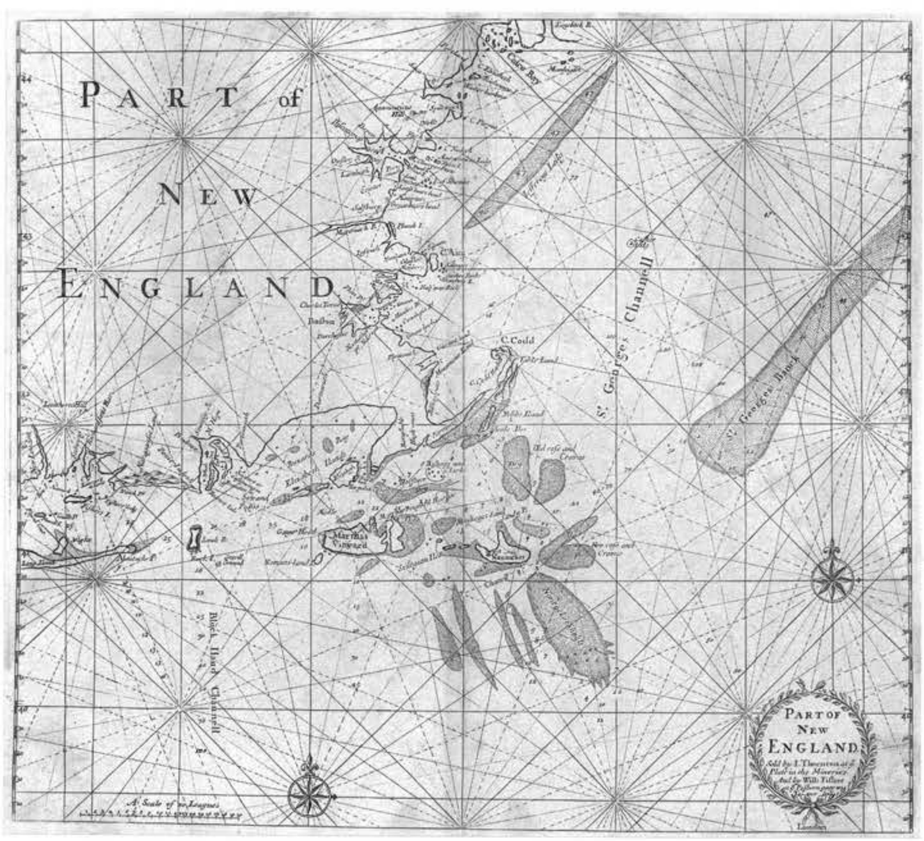


Plate 15a

John Thornton, English, 1641-1708, William Fisher, English, fl.1669-1691, **Part of New England** copper engraving, 42.4cm x 47.1cm. From: *The English Pilot. The Fourth Book* (London, 1689)

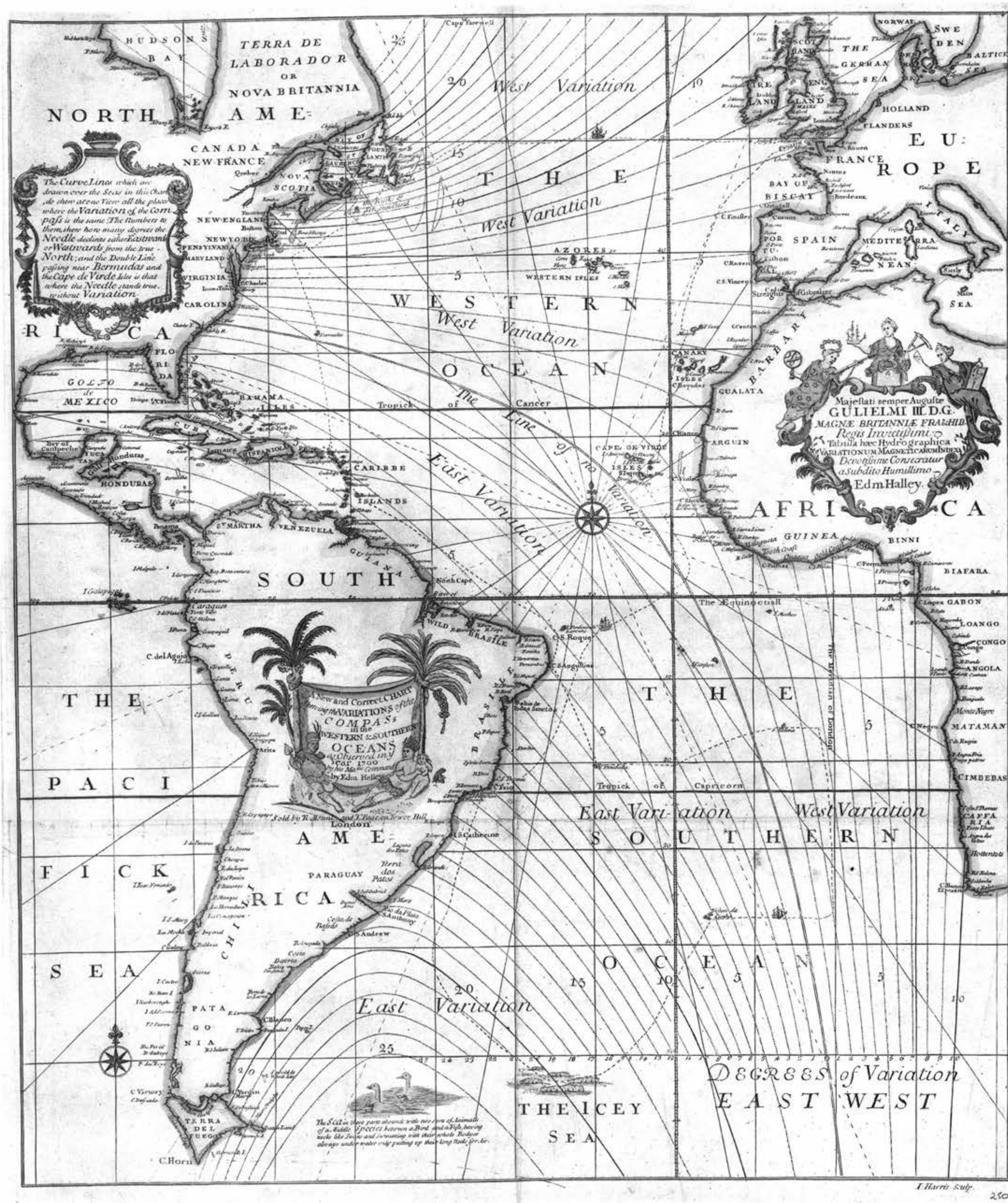


Plate 17

Edmund Halley, English, 1656-1742, **A New and Correct Chart Shewing the Variations of the Compass**, copper engraving, hand-colored, 58.5cm x 49 cm. From: *The English Pilot. The Fourth Book*, (London, Mount & Page, 1701/1720)

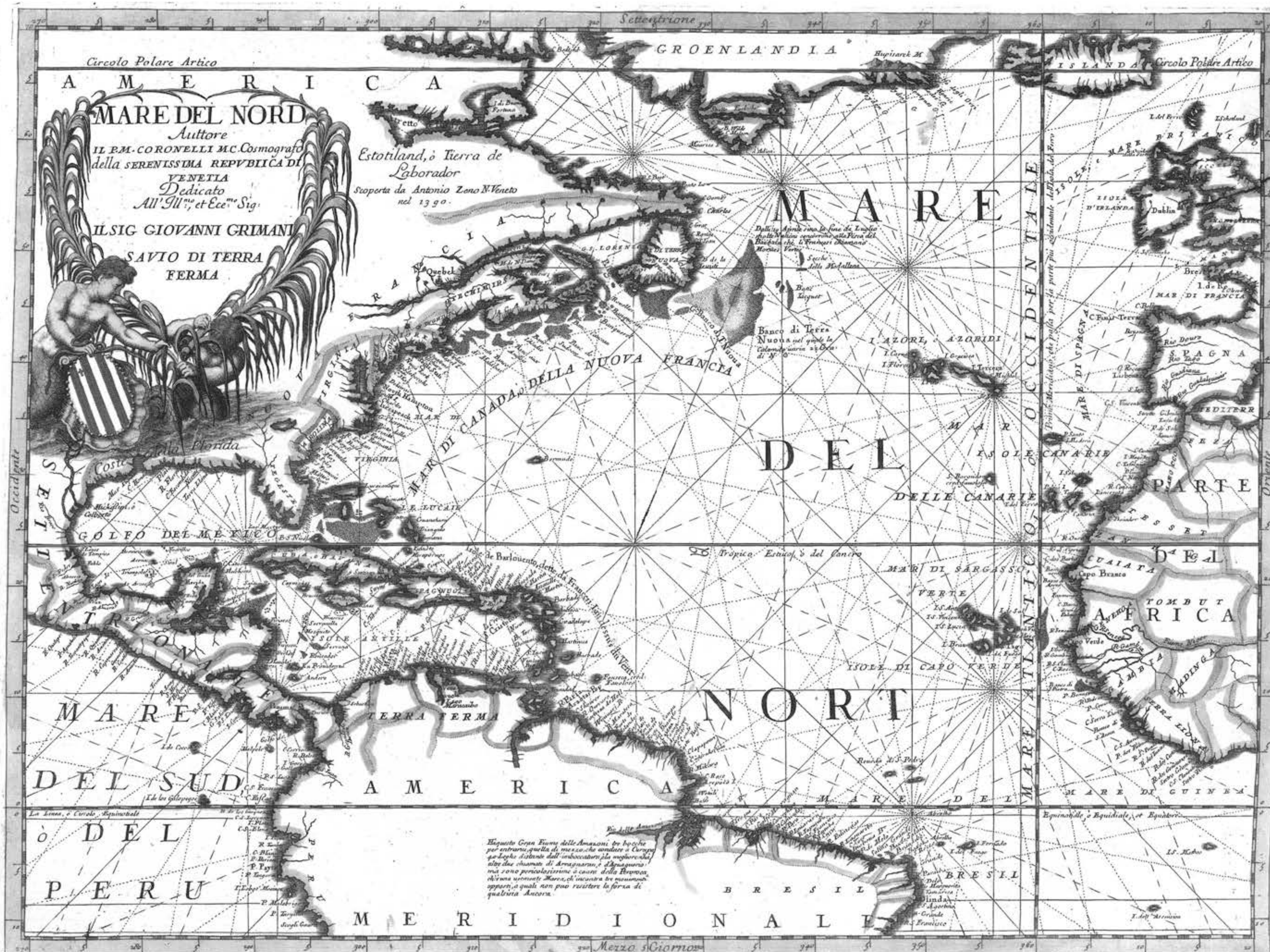


Plate 20

Vincenzo Coronelli, Venetian, 1650-1718, **Mare Del Nord,** copper engraving, hand-colored, 44.9cm x 59.9cm, Venice, 1690

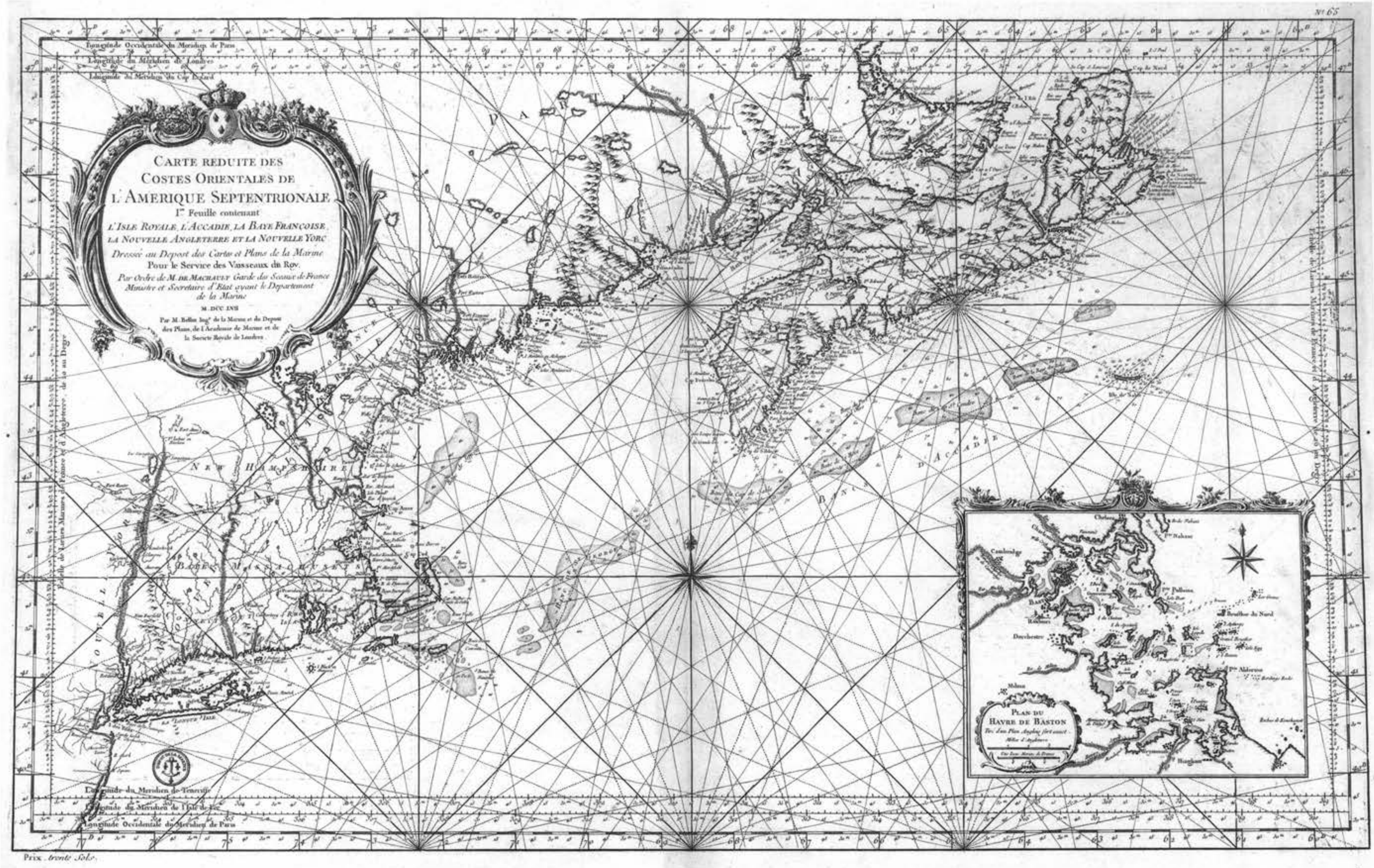


Plate 21

Jacques Bellin, French, 1703-1772, **Carte Reduite des Costes Orientales de L'Amerique Septentrionale**, copper engraving, 54.6cm x 88.6cm
Paris: Department de la Marine, 1757

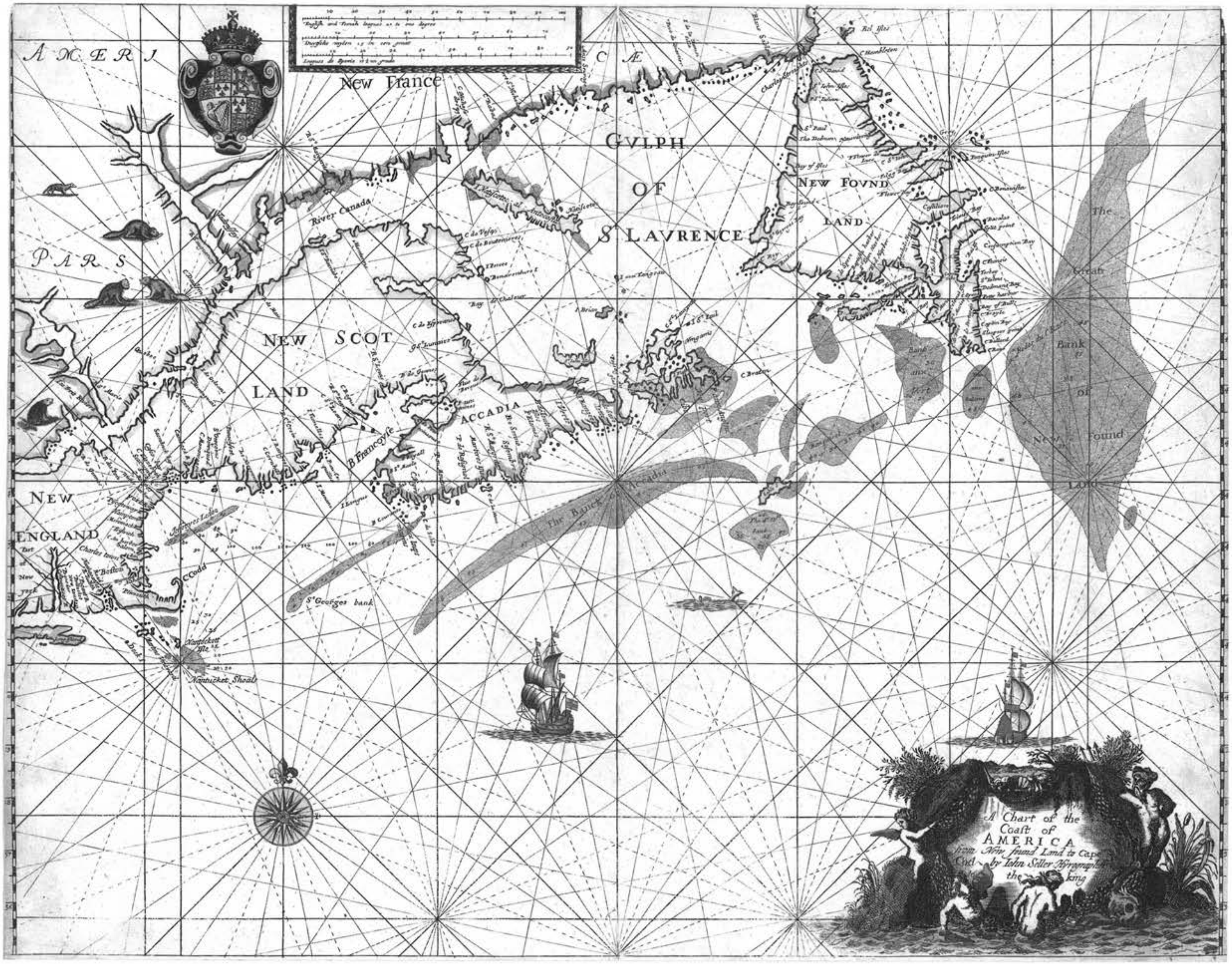


Plate 22

John Seller, English, d.1697, **A Chart of the Coast of America**, copper engraving, hand-colored, 42.2 x 54cm, London, 1675

The Osher Map Library and Smith Center for Cartographic Education University of Southern Maine

The Osher Map Library and Smith Center for Cartographic Education is the only separately established rare map library in northern New England. The cartographic collections comprise fine examples of original maps, atlases, geographies, and globes spanning the years from 1475 to the present. They constitute a rich and multifaceted resource for the study and teaching of a number of subjects, especially geography, history, and art. These materials offer such compelling insights that anyone, regardless of age or educational level, can enjoy and learn from them. For the University, the people of Maine, scholars, students, and visitors, the collections are indeed a treasure.

The Collections

The cartographic collections were formed from two major gifts, the first from the late Lawrence M. C. and Eleanor Houston Smith, and the second from Dr. Harold L. and Mrs. Peggy L. Osher. Other generous gifts from several individual donors, notably Professor Peter H. Enggass and Tony Naden, have substantially augmented the collections. The combined collections contain approximately 60,000 maps, as separate sheets or bound in books and atlases. These books include works on cosmography, astronomy, and navigation, as well as geography and cartography. While the collections possess a global scope, they emphasize the discovery, exploration, and mapping of North America. The original materials are supplemented by many facsimile maps and atlases in reprint editions, together with a reference collection containing monographs and journals on the history of cartography, cartobibliographies, regional histories, and exhibition catalogs.

The Mission

As an integral part of a comprehensive regional university, the Osher Map Library is committed to sharing its collection with a broad constituency by means of exhibitions, publications, lectures, conferences, and other special events. It encourages collaborative efforts with other institutions including museums, historical societies, and teaching institutions ranging from primary schools to the university level. It serves the University community and residents of Maine and northern New England, including the general public and local school systems. Indeed, by means of its Web site, it serves the global community of scholars and researchers.

The Facilities

The Osher Map Library is located on the ground floor of the Glickman Family Library on the Portland campus of the University of Southern Maine. In addition to the collections and reference materials, the Osher Map Library contains exhibition areas, a seminar room, and facilities for research and study. The Osher Map Library provides access to its resources to the general public and scholars alike.

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