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ARTICLE

Navigating a Hostile Medium: Observations of the Environment As an Aid to Oceanic Voyaging in the Age of Sail

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Abstract

European navigation in the age of sail owes much to the scientific revolution of the seventeenth century and the development of instruments and advanced mathematical techniques. Important though these developments were, it is argued here that close observation of the environment: of the weather, ocean currents, clouds, birds, mammals, and a host of other factors played a far more important role in safe navigation from one part of the globe to another.

Keywords: navigation; meteorology; geomagnetism; winds; currents

Western navigation is a science involving observation, measurement, mathematics, and a range of instruments of varying sophistication. Many aspects can be seen as a part of the scientific revolution of the seventeenth century. However, there are many skills that the experienced mariner could bring to bear on the problem of navigating from one part of the globe to another. These skills, which involve close observation of the environment, are also common to indigenous peoples who navigated the Indian and Pacific Oceans. The experienced mariner is a keen observer of the environment and is able to use his or her observations and experience to navigate safely. The nature and movement of clouds, the colour of the sea, the behaviour of birds and sea mammals, the composition of the sea bed in shallow waters, the temperature of the sea, the direction of waves and sea swell, invisible signs such as the Earth's magnetic field, and many more factors of the marine environment can be deployed to navigate safely. These are elements that contribute to what we might collectively refer to as "seamanship."

In modern times, navigation and seamanship can be seen as distinct and separate skills, even though the experienced mariner will be proficient in both. Modern navigation over recent centuries has made use of instruments such as the sextant and the marine chronometer to fix a position and help determine a course towards a destination. These instruments are used in conjunction with charts of variable accuracy and sailing directions providing recommended routes and approaches to coasts and harbours. In Western culture, these are all developments of the so-called scientific revolution of the seventeenth century, yet they are firmly rooted in the much earlier sciences of Islam and Arabia, particularly astronomy and mathematics. It is these last two that often create the impression that navigation, that is Western navigation, is a complex and difficult skill that requires careful measurement of the altitude of the sun or stars, and sometimes hours of calculation, with reference to tables of logarithms and the application of mathematical techniques such as of spherical geometry. Determining the longitude by a lunar observation, or setting a course by a Great Circle, might be typical examples.

Although many of history's great navigators, such as Cook, Bligh, La Perouse, and many others were skilled in astronomy and mathematics, many equally famous and competent navigators, such as Columbus and Magellan, had fewer of these resources and skills to call upon. Furthermore, the common mariner, including many ships' officers, would have had only a rudimentary education, if any at all, and would have found higher mathematics both baffling and unnecessary. In his biography of Columbus, S. E. Morison remarks that the mathematics and navigational tables of the time were so complicated that the best professional seamen could do little with them.[1] Their navigational skills rested on seamanship. Today we would associate seamanship with boat handling, proficiency with knots, pilotage, steering a vessel, sail handling, and a host of other mundane tasks. In the premodern period and arguably even today, seamanship meant far more than this. Seamanship includes navigational skills not associated with instruments and mathematics, but with the close observation, understanding, and exploitation of the ocean environment.

With few or no instruments for determining position, the mariner needed to rely on best estimates. In early modern Western navigation, this is called "dead reckoning" and gives an approximate position based on speed and direction of travel from a previous position (also estimated), and adjusted if possible to account for leeway, current, and drift. Leeway is the amount of deviation from your intended course due to the force of the wind on the sails and the hull of the ship. Current is the movement of surface water, rather like a river in the ocean. Drift is the movement of the entire body of the ocean, and this latter is impossible to measure. Fixing one's position at sea was not possible with any precision, and navigation always needed to take account of a generous margin of error.

Attempting to work out a daily position was very much a feature of Western navigation. The peoples bordering the Indian Ocean and inhabiting the Pacific islands navigated without instruments, and without them saw no need to try to fix or record a daily position. European navigation was concerned with position finding, Polynesian navigation, for instance, was concerned with the direction of the intended destination, and a daily position while on passage was largely irrelevant. Instead, the indigenous Pacific navigators used star patterns, winds, clouds, birds, floating vegetation, the direction of the ocean swell and a host of other environmental observations in order to make their way from island to island and to undertake more lengthy voyages.[2] Yet despite this fundamental difference in determining a course towards a destination, European navigation and ancient Indo-Pacific navigational techniques had much in common. Europeans also used clouds, birds, ocean swell, and other environmental signposts to help navigate, using these to supplement their instruments and calculations or to act as substitutes when prolonged adverse weather conditions made instrumental navigation difficult or impossible.

Landfalls

A factor common to all navigation, whether ancient or modern, European or non-European, was the use of the landfall. Ancient voyaging consisted largely of coasting, moving along a familiar coastline with short passages out of sight of the land. In the case of the Pacific Islanders, this would mean passages between islands or island groups, with

[1] Samuel Eliot Morison, *Admiral of the Ocean Sea: A Life of Christopher Columbus* (Boston: Little Brown, 1942), 186.

[2] David Lewis, *We the Navigators: The Ancient Art of Landfinding in the Pacific* (Honolulu: University of Hawaii Press, 1994).

frequent periods out of sight of land. Oceanic voyaging was an extension of this, with frequent sightings of landfalls, either an island or an easily identifiable coastal feature such as a headland or cape. For European voyagers, these landfalls were essential. They served the purpose of fixing a position and thereby reducing the accumulated dead reckoning or estimated navigational error to zero. In an early logbook or journal one will find frequent entries stating that some landfall had been sighted from which the vessel had taken a fresh departure. This meant that the commander had reset his dead reckoning estimate from the landfall rather than using his original port of departure. In early English logbooks (prior to the nineteenth century) these points of departure were used as zero meridians for each passage, rather than using a prime meridian such as London or Greenwich. A voyage consisted of separate passages from one landfall to another.[3]

As an example, a voyage to the more southerly part of North America or towards the Caribbean would first make a landfall off Madeira and then one of the Canary Islands, and from there use the northeast trade winds to progress westward before getting into the latitude of the destination port. Following a line of latitude was a common navigating technique, and even without instruments it was possible to make an approximation of latitude from the altitude of the pole star above the northern horizon, if necessary by some crude method such as the number of hand breadths, but more commonly with a quadrant and later a sextant. A ship making a voyage from a European port to Bombay would make landfalls off Madeira, then one of the Canary Islands, one of the Cape Verde Islands, then possibly Trinidada off the coast of Brazil, but more frequently Cape Agulhas at the southern end of Africa, one of the Comoros islands at the northern end of the Mozambique Channel, the Seychelles, then on to Bombay. All of these landfalls served to reduce navigational error to zero and provide a fresh departure point, and in the case of the Comoros islands, a place to stop for refreshment, repair, and to await the onset of the southwest monsoon. It is worth mentioning here that the length of any passage a ship could make was limited by the amount of fresh drinking water the vessel could carry for crew and passengers.[4] The final landfall would be near the vessel's port of destination. It was essential both to recognise the landfall or coastline and to ensure that the landfall was windward of the destination, so that the prevailing winds and currents would favour an approach to the port and not hinder it.

Bearing in mind the importance of making a good landfall, the obvious question is how was this possible, given the very imprecise nature of early navigation, whether using instruments or not? This is where knowledge and understanding of the ocean, the atmosphere, and other environmental factors comes into play. First consider any intended landfall as a target. Although the target landfall might be a cape or an island, it was possible to make the target area much bigger than the landfall itself. If you intended to make a landfall off one of the Canary Islands, Cape Verde Islands, or the Azores, the entire island group was one enlarged target many miles across. The highest point of Tenerife could be seen in ideal conditions more than one hundred miles distant. Tenerife itself could then be considered a target more than two hundred miles across. Under less-than-ideal conditions, the approach to the Canary group as well as the Cape Verde Islands could be determined by the fogs that would frequently occur near these islands. Therefore the navigator did not need to make a precise landfall, but merely achieve the sighting of a target that could be up to one hundred or more miles across.

Some common landfalls were much smaller targets, however, so how could the mariner be sure of making a sighting? Oddly, the answer was to deliberately miss the target, a port for instance, by off-setting or directing a course towards a point on a coastline that

[3] Based on the examination of hundreds of eighteenth-century naval and merchant shipping logbooks.
[4] Andrew S. Cook, personal communication.

would guarantee that you were to windward of your destination. It did not matter where you sighted the coastline as long as you had a favourable wind and current to carry you along the coast to your destination.

As an example of off-setting, in this case a small island, let us look at St. Helena in the South Atlantic, a common landfall for European ships on their homeward passage after rounding the Cape of Good Hope. St. Helena lies in the southeast trade wind belt, meaning that an ideal approach to the island would be to windward, or southeast of the island. Ship tracks often show a direct line northwestward from the Cape to St. Helena. The vessels displaying these tracks would be able to determine their longitude by chronometer or lunar observation and sail directly to the island. However, before the use of chronometers, sailing directions and pilot books would instruct commanders to set a more northerly course from the Cape in order to reach the parallel (latitude) of St. Helena some 60 leagues or 180 miles to the east of the island and then sail westward until sighting the island.[5] It could often be distinguished by clouds hanging over the main part of the island or banks of fog directly to leeward of the island.[6]

Clouds

Clouds and fog banks were one of the many environmental signs used by mariners to navigate. Clouds can indicate the state of the weather, or foretell a change or the onset of a storm. Stacked cumulus clouds result from convection and could indicate the development of a thunderstorm. In mid-latitudes, high cirrus clouds signal an approaching weather front. Clouds also gave clues to the existence of land. A slow moving or stationary cloud amongst faster moving clouds would be a sign that land lay beneath. In the trade wind belts, clouds will pile up on the windward side of an island, especially over high ground, and appear relatively motionless, rather like a standing wave in a river. In other parts of the ocean convective clouds will form over an island, sometimes with a distinctive V shape, the cloud being the result of the heat differential between the land and the ocean. These signs of land were used by Pacific peoples but were also well known to Europeans.[7] Banks of fog could also indicate land nearby. A set of sailing directions for the Cape Verde Islands, probably from the eighteenth or nineteenth century, states: "the making of these islands is often difficult on account of the fogs that hang around them, while these fogs are often a mark of you being near them."[8] In the southeast Pacific, along the coast of Chile, a dense fog bank accompanied by a sharply defined band of high-level cloud defines the approach to the cold Peru Current that runs northward along the coast. It is an infallible sign of an approach to the land, and as the coastal shelf is very steep, there is no possibility of taking soundings to indicate the proximity of the shore. In June 1807, seeking to make landfall at Valparaiso, HMS *Cornwallis* under Captain Charles Johnstone experienced these fogs, a consequence of the thermal front associated with the Peru Current, while cruising north and south of Valparaiso for many days.[9] The fogs indicated the proximity of the shore, even though the land was invisible.

[5] For typical examples, see the georeferenced homeward routes of the East Indiamen *Blessing*, 1630–33, http://gsr.nodegoat.net/viewer.p/57/2230/object/8021-11267615; and *Compton*,1724–26, http://gsr.nodegoat.net/viewer.p/57/2230/object/8021-11879896, in Global Sea Routes (GSR).

[6] Alexander Findlay, *A Sailing Directory of the Ethiopic or South Atlantic Ocean* (London: Richard Holmes Laurie,1867), 156.

[7] Lewis, *We the Navigators*, 216–7.

[8] National Maritime Museum, Greenwich, PLT/77 (undated manuscript), "Directions for the Cape Verde Islands."

[9] The National Archive, London [hereafter TNA], ADM 52/3821, Log of Stephen Thomas, Master, HMS *Cornwallis.*

Soundings

Another sign of approaching land was soundings, or the depth of the water under a ship. As well as sounding for the depth, it was also common to examine the bottom deposits using a tallow covered sinker to retrieve a sample. The nature of the sea bottom can change over short distances, and this information combined with the depth of the water can, with reference to a chart or other set of directions, provide an approximate position, especially in poor visibility. Observations were frequently recorded in logbooks and journals.

As well as shallow coastal waters, soundings could also be used to predict some of the common major landfalls. The Agulhas Bank for instance extends along the southern shore of Africa and on its westward side is made up of mud, while on the eastward side it is composed of sand with small shells like the husks of oatmeal. Directly south of the Cape, the Agulhas Bank is made up of fine sand, and eastward of this, coarse sand, coral, and stone. In addition to the evidence of the sea bottom, there were other signs that you were passing near or over the Agulhas Bank, such as the colour of the sea and sightings of seals and birds.[10]

Birds and Mammals

In his book on navigation, Lieutenant Henry Raper wrote, "the neighbourhood of land is often indicated by the presence of birds, and its position inferred from the direction in which they take their flight at sunset."[11] Land birds sighted at sea were a certain sign of land and their direction of flight at dusk would provide a bearing towards the land. The frigate bird, for instance, will hunt for fish at sea but cannot alight on the water and must return to the land to roost. Sighting one of these birds would mean that land was likely to be under seventy-five miles distant.[12] The Portuguese are said to have discovered the Azores Islands from observing the flights of birds, and the first landfall off the coast of Brazil, by Pedro Cabral in 1500, was preceded by sightings of birds and weed.[13]

On his epic voyage across the Pacific in an open boat, William Bligh recorded many observations of birds. Man-o'-war birds (frigate birds), boobies, and gannets were noted on 15 May 1789. On 19 May Bligh wrote, "saw many boobies and noddies, a sign of being in the neighbourhood of land," and on the 25th, "In the evening, several boobies flying near us, we had the good fortune to catch one of them. This bird is as large as a duck [. . .] they are the most presumptive proofs of being in the neighbourhood of land as any sea fowl we are acquainted with."[14]

Sightings of birds and sea mammals were routinely used, especially when the weather would not permit a sighting of the sun to fix a position. In 1875, the merchant ship *Galatea* under Captain Frederick Wherland, was en route from San Francisco to Liverpool. On 23 February, he rounded Cape Horn, sighting the island of Diego Ramirez which fixed his position. On the 28th, in light winds and overcast conditions, it was impossible to take a noon sighting, but an estimated position placed the *Galatea* at 53º south, 59º 20′ west, somewhere south of the Falkland Islands. Captain Wherland had soundings taken, which indicated no bottom at ninety-three fathoms. In the logbook he recorded, "the birds and seals

[10] Joseph Huddart, *The Oriental Navigator* (London: Robert Laurie and James Whittle, 1801), 46.

[11] Henry Raper, *The Practice of Navigation and Nautical Astronomy* (London:R.B. Bate, 1842), 327.

[12] Lewis, *We the Navigators,* 214.

[13] Morison, *Admiral of the Ocean Sea,* 213; Samuel Eliot Morison, *The European Discovery of America: The Southern Voyages 1492–1616* (Oxford: Oxford University Press, 1974), 222.

[14] William Bligh, *A Voyage to the South Sea in His Majesty's Ship* Bounty (London: George Nicol, 1792), 187, 191, 194.

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around the ship indicate our proximity to Beauchine island."[15] Beauchene Island is about thirty-three nautical miles south of the Falkland Islands, and Captain Wherland's estimated position was seven nautical miles southwest of Beauchene, consistent with his sightings of birds and mammals.

Sea Temperatures

It is not known when the first sea temperatures were recorded, probably in the early eighteenth century, but a Royal Society publication suggests the year 1749 as a possible starting point.[16] Recording the temperature of the sea surface involved the retrieval of a water sample, usually in a wooden but later a canvas bucket, and the immersion of a common thermometer. As an aid to navigation, experiments using sea temperatures to indicate an approach to land began in the late eighteenth century, and were widely published in the 1790s and the early nineteenth century.[17] Andrew Livingston published his conclusions after a voyage from New Orleans to Gibraltar in 1818, observing a drop in surface temperature off the coasts of the United States, the Azores, and Cape St. Vincent. Similar observations had been made off the Agulhas Bank by John Davey in 1816.[18] What these early scientists were observing is now known as coastal upwelling, where winds and currents drive warm surface water away from a coast, with the waters being replaced by colder water from the depths. Whether such observations were a practical aid to navigation is debatable, and probably less useful than soundings and sightings of birds.

Nevertheless the ever resourceful mariner did find practical uses for sea temperatures. Captain J. P. Wilson, commanding the East Indiaman *Hythe,* recorded the temperature of the Agulhas Current off the Cape of Good Hope. The main part of the current follows the edge of the Agulhas Bank and is always warmer than the water flowing over the bank itself. Captain Wilson noted that the waters in the main current were some eight to nine degrees (Fahrenheit) warmer than the surrounding seas, and warmest in the centre of the current. He wrote, "A ship may be kept in it by attending to changes in the temperature of the surface water, and thereby enabled to accelerate her progress to the westward during adverse winds."[19] Observing the sea temperature would also ensure that a ship did not cross the Agulhas Bank too far north and approach too close to the land. "All that is necessary in passing the Cape [in a westerly direction] is to preserve the temperature of the water above 70 degrees which is the temperature of the current setting SW and which will carry a vessel quickly to the west."[20]

Another application of sea temperature to navigation was to provide a warning of ice. The idea was that very low sea temperatures, or a sudden drop in sea temperature, would

[15] National Meteorological Archive, Exeter [hereafter NMA], 3561, Meteorological Logbook *Galatea* 1874–75.

[16] Joseph Prestwich, "Tables of temperatures of the sea at different depths beneath the surface reduced and collated from the various observations made between the years 1749 and 1868," *Philosophical Transactions of the Royal Society of London* 165 (1875).

[17] Some of the more notable authors were William Billings, Andrew Livingstone, James Mease, William Strickland, and Jonathan Williams, writing in such publications as the *Edinburgh Philosophical Journal* (1820) and the *Transactions of the American Philosophical Society* (1793).

[18] Andrew Livingstone, "On the thermometer, as an indicator of a Ship's approach to Land or soundings, with extracts from a Thermometric Journal kept on board the ship *Asia* of Scarborough on a voyage from New Orleans to Gibraltar in August, September and October 1818," *Edinburgh Philosophical Journal* 3 (1820), 247–52; John Davey, "Observations on the Temperature of the Ocean and Atmosphere and on the Density of Seawater made during a Voyage to Ceylon," *Philosophical Transactions of the Royal Society* 107 (1817), 275–92.

[19] James Horsburgh, *The India Directory, or, Directions for sailing to and from the East Indies, China, Australia and the interjacent Ports of Africa and South America,* 2 vols. (London: William H. Allen, 1852), 1: xvi.

[20] W. H. Rosser and J. F. Imray, *The Seaman's Guide to the Navigation of the Indian Ocean and China Sea* (London: James Imray, 1867), 745.

give a forewarning of icebergs, especially in conditions of poor visibility. Again the practical utility of this is debatable, but nevertheless in the second half of the nineteenth century it was widely practised. Ships using steam power as an auxiliary form of propulsion would routinely take sea temperatures to regulate the temperature of the engines and condensers, but sailing vessels would generally only take sea temperatures for some other practical purpose, such as sailing through regions known to have ice hazards. This applied in particular to high-latitude passages across the South Atlantic, Indian, and Pacific Oceans and was probably prompted initially by the 1857 publication of John Towson's "Icebergs in the Southern Ocean."[21] Towson published a list of ice sightings grouped by month to indicate the times of year and places where ice was likely to be encountered. This was accompanied by a chart showing regions where ice and icebergs were to be found, for instance on the eastern side of the Drake Passage and extending from there towards the Cape of Good Hope, and therefore bordering on both the outward and homeward bound tracks of ships taking passage around Cape Horn. Other regions included parts of the southern Indian Ocean and many high-latitude areas of the South Pacific. This information was supplemented over the years and featured prominently in all of the popular editions of sailing directions. There were also many articles published on this subject in professional journals.

Towson demonstrated the usefulness of sea temperatures by recounting the experience of Captain MacDonald of the *James Baines,* who reported that the temperature fell by four degrees Fahrenheit as he approached an iceberg and a further two degrees as he got to leeward of the iceberg. Captain Newland of the *Champion of the Seas* passed thirty-nine icebergs between the latitudes of 50ºS and 47ºS, with the sea and air temperatures dropping to 35 and 36 degrees Fahrenheit, despite the vessel moving northwards towards warmer latitudes. Yet Towson tempered his conclusions by recounting a single instance where an approach to an iceberg had no effect on either the temperature of the air or the sea.[22] Furthermore, on 18 February 1887, the merchant steam barque *Kaikoura* under Captain William Crutchley, sailing from Cape Town to Hobart, passed an iceberg at a distance of a quarter mile shortly after noon, in position 49º29′S and 112º18′E. Crutchley took twenty observations of the sea temperature as the vessel approached and passed the iceberg and noticed no more than half of a degree difference in the temperature.[23] Such examples must cast doubt on the utility of using a thermometer as a warning of ice, but nevertheless the routine observation of sea temperature was a regular occurrence in those places and at those latitudes where there was a history of ice sightings.

Geomagnetism

One element of navigation completely invisible to the eye, but detectable with one of the earliest navigational instruments, is the Earth's magnetic field. It is as much a part of the marine environment as any feature of the ocean or the atmosphere. The compass not only provided a course to follow or a bearing to a landmark, but also gave an indication of the local declination of the Earth's magnetic field, usually referred to as magnetic variation in ships' logs and journals.[24] Magnetic variation could be determined by taking a double altitude of the sun at equal times before and after noon, bisecting the difference (to find the

[21] John Towson, "Icebergs in the Southern Ocean," *Transactions of the Historic Society of Lancashire and Cheshire* 10 (1858), 239–54.

[22] Towson, "Icebergs," 247.

[23] NMA, 6795, Meteorological Logbook RMS *Kaikoura,* 1887.

[24] This should not be confused with magnetic deviation which is a correction applied to a compass due to the attraction of nearby metal objects on the ship.

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true or geographic north), and then comparing the result with the magnetic compass. The difference provided the variation between the north magnetic pole and true north.

Alternatively, comparing the bearing of the polestar with the magnetic compass achieved the same thing. Plotting these differences on an isogonic chart produced a map of the Earth's magnetic field where lines of equal magnetic variation were joined together. One of the earliest isogonic charts was produced by Alonso de Santa Cruz in 1530, and Edmund Halley famously created isogonic charts of the North and South Atlantic after his surveying voyage in 1700.[25]

As early as 1503, João de Lisboa, in his *Tratado da Agulha de Marear,* suggested that the magnetic variation was a solution to the problem of determining the longitude by using the lines of magnetic variation as they crossed the lines of latitude. Alas, such a simple and elegant solution was not to be, as the lines of magnetic declination were not fixed but had a secular variation that changed over time.[26] Despite "isogonic navigation" being impractical, updated isogonic charts continued to be published, and lines of magnetic declination still appear on some modern charts.

Logbooks and journals of vessels heading south towards the Atlantic equator recorded the magnetic variation, usually commencing at or soon after leaving the Cape Verde Islands, so there must have been some practical value to these observations not directly connected with the determination of the longitude. It lay in setting a southward course to pass through the equatorial calms or doldrums. The danger for ships making this passage was to be becalmed or subject to light variable winds for long periods of time. Under these conditions, if a vessel tried to cross the equator too far to the west, the north equatorial current would carry the ship on to the coast of Brazil, where a northward flowing current would then take the vessel in the wrong direction. A crossing too far east and the vessel might find itself subject to the east flowing equatorial counter current and be swept into the Gulf of Guinea. The optimum track southward threaded a course that avoided both of these outcomes, and depending on the season of the year, ensured that the width of the equatorial calms was at a minimum. All of the information needed to determine this optimum course had been carefully compiled over decades of observations recorded in logbooks and journals and collated, notably by Dutch hydrographers, into charts and sailing directions. The Dutch in the mid-eighteenth century gave this optimum track or corridor a name, Wageweg, or Cart Track.[27]

The points and lines delineating the Cart Track seem quite precise, and were plotted from bearings and distances to landmarks in the Cape Verde Islands, the coast of Africa, and St. Paul's Rocks to the west of the track and just north of the equator. At the time, the precise longitude of these landmarks was not known and the position of the Cart Track was therefore an estimate. Despite this, the Cart Track was effective because of the way it was navigated. To enter the northern end of the Cart Track and to stay within the boundaries set out on the chart did not require the estimation of a longitude by the usual means. The navigation of the track was undertaken by observing the magnetic variation of the compass, hence the recording of this information in the ship's log after leaving the Cape Verde Islands. Dutch mariners knew that as they sailed southward to approach the northern end of the Cart Track and as they sailed within the track itself, they needed to keep to a particular magnetic variation of the compass. If they sailed

25 D. Brand, "Geographical Exploration by the Spaniards," in Dennis O'Flynn et al., *European Entry into the Pacific* (Aldershot: Ashgate, 2001), 3; N. Thrower, *The Three Voyages of Edmond Halley in the* Paramore, *1698–1701* (London: Hakluyt Society, 1981).

26 A. R. T. Jonkers, *Earth's Magnetism in the Age of Sail* (London: John Hopkins University Press, 2003), 49.

27 W. F. J. Morzer Bruyns, "Navigation on the Dutch East India Company Ships around the 1740s," *Mariners Mirror* 78 (1992), 143–54. See also Jonkers, *Earth's Magnetism.*

Figure 1. Edmond Halley's isogonic chart of 1700. Reproduced on Wikimedia Commons, https://en.m.wikipedia.org/wiki/File:Halley_isogonic_1701.jpg. An original copy of this chart is held by the Royal Geographical Society, London.

too far westward the variation would diminish, and if they sailed too far eastward, the variation would increase. In the short term, secular changes in the magnetic field were not of concern as this was not an attempt to obtain a position, but rather to maintain a course by keeping the magnetic variation within a range of values. This was just one application.

Other practical applications of magnetic variation can be found in Samuel Dunn's *New Directory for the East Indies.* Dunn explained that it was possible to make a course change by using the variation of the compass instead of sighting a landmark. As an example he cited the islands of Amsterdam and St. Paul in the southern Indian Ocean, a landfall used by some East Indiamen to set a more northerly course towards India and China. It is an

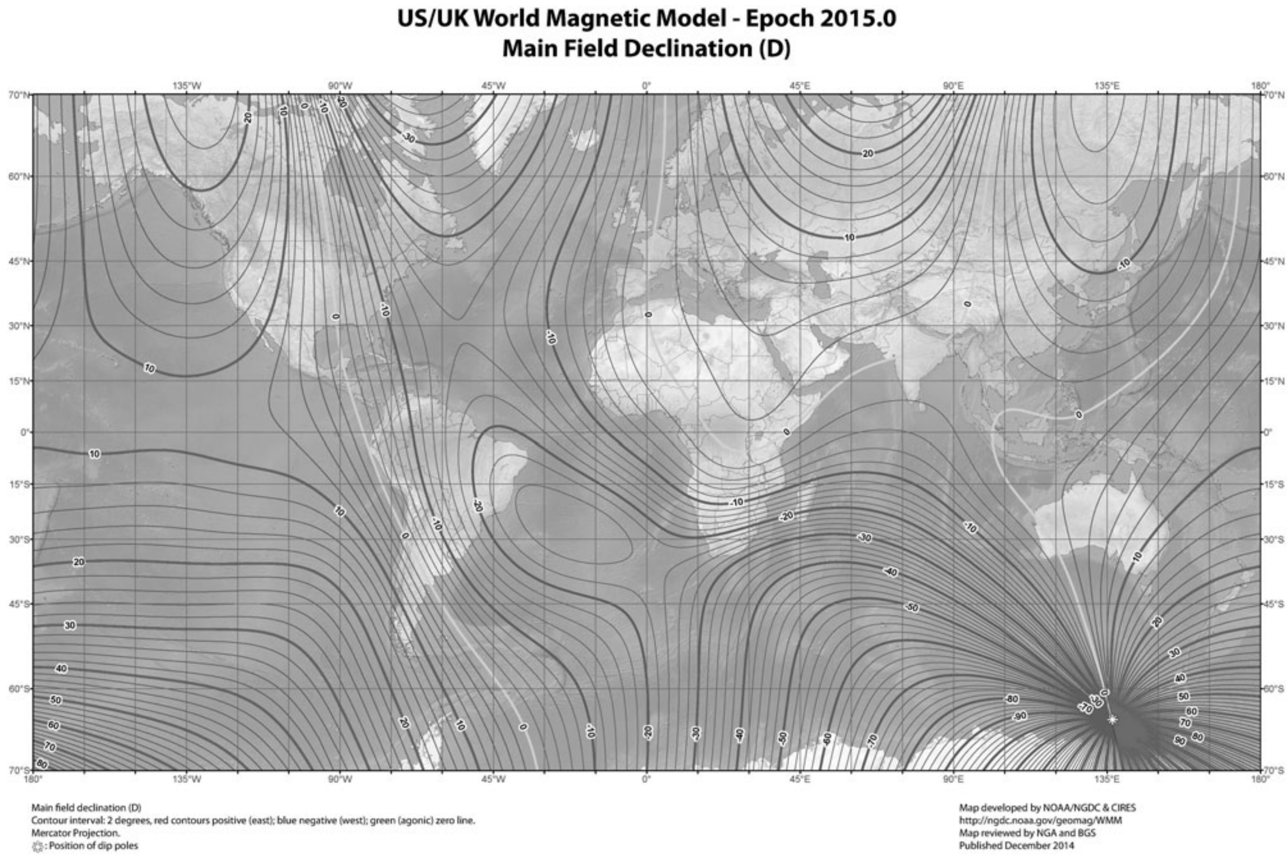

Figure 2. Map of magnetic declination in 2015, NOAA Center for Environmental Information. http://commons.wikimedia.org/wiki/File:World_Magnetic_Declination_2015.pdf

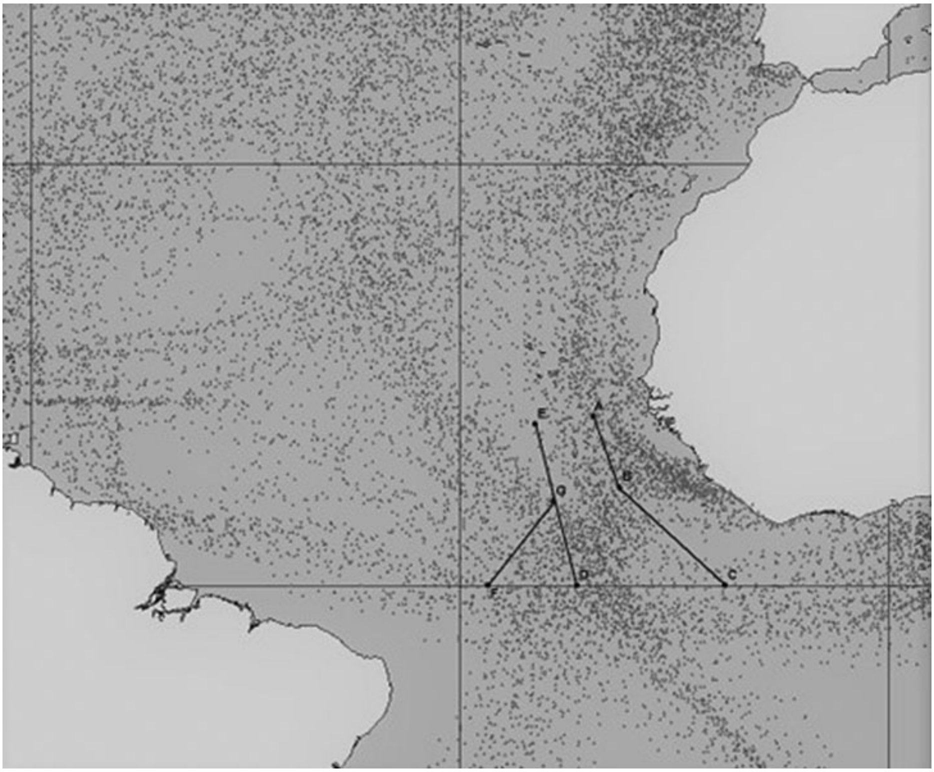

Figure 3. The Wageweg, or Cart Track, providing the optimal southbound approach to the Atlantic equator. Plot by Frits Koek, KNMI, de Bilt, for the author.

extraordinary fact that these islands lie on virtually the same meridian as Cape Comorin at the southern tip of the Indian sub-continent, providing an excellent point of reference to effect a course change. Allowing the magnetic variation near these islands to be 18°45′W or 19°W, it was possible to make the course change without sighting the islands themselves.[28]

Another important course change on the route to India was towards the southern entrance to the Mozambique Channel, after rounding the Cape of Good Hope. It was usual to make at least fifteen degrees of longitude east of Cape Agulhas at the southern tip of Africa before heading north into the Mozambique Channel. Estimating the necessary distance before changing course was complicated as the ship could be impeded by the west flowing current. This is what happened to the East Indiaman *Doddington* in 1755. Thinking he had made fourteen degrees of longitude from the Cape, the Captain set a northerly course, but, having in fact only sailed seven degrees of longitude, he put the ship ashore in Algoa Bay. Samuel Dunn makes reference to this incident in his sailing directions:

> The variation [of the compass] hereabout as well as several other parts, may be looked upon as a principle and sure guide to navigation. This unfortunate ship should be a caution for all navigators to be very cautious not to haul up to the northward

[28] Samuel Dunn, *A New Directory for the East Indies* (London: Gilbert and Wright, 1791), 293.

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> too soon; for the currents are very deceiving [. . .] When a ship in latitude 35ºS has made 15ºE longitude and has increased her [magnetic] variation to 27º, she may haul to the northward in safety.[29]

Dunn was clearly pointing out that the magnetic variation was an infallible indication of the point at which a course change could be safely made whereas the dead reckoning estimate of longitude was at best a poor guess, heavily compromised by the local ocean currents.

Avoiding and Exploiting Weather Systems

For centuries, mariners collected information about the winds in different parts of the globe, and this data, as recorded in logbooks and journals, was collated and analysed by hydrographers and men of science. The results were given formal expression in sailing directions and charts issued by state sponsored hydrographic departments and by private individuals and publishers. Early on, this knowledge was of great commercial advantage, but keeping it secret was nearly impossible. Over the centuries the nature of the trade winds, the Asian monsoon winds, the equatorial calms, and the seasonal nature of hurricanes and typhoons became better known, although the physical processes that produced these phenomena were not known or were only imperfectly understood. Up until the nineteenth century, for instance, storms and hurricanes would still be considered acts of god by many.

Although the nature of many of the wind systems was generally understood and regularly exploited, the refinement of that knowledge through scientific progress led to many improvements in navigation. Scientific societies in Britain, Europe, and the United States were encouraged to engage in the advancement of marine knowledge as both state governments and commercial companies saw the economic and strategic advantages to improvements in navigation. The American naval officer M. F Maury, for instance, analysed ship tracks and wind vectors, producing charts and sailing directions indicating the sailing routes that were likely to encounter the most favourable winds. Thus, the length of voyages could be reduced, sometimes by weeks.[30]

Experienced mariners could anticipate changes in the weather and recognise the portents of storms from the clouds, the feel and the motion of the air, the swell of the sea, and a host of other signs. By the late eighteenth and early nineteenth century, instruments such as the marine barometer and the sympiesometer[31] gave a measurable expression to these portents. Still, the chief source of information for weather advice concerning a voyage was always the sailing directions. These publications and their advice reflected what mariners actually experienced at sea, and scientific refinements were of limited value or relevance to most sailors. An exception to this would be the tropical revolving storm and the mid-latitude storms and depressions. Despite one commentator stating that almost all measures taken to avoid typhoons were of little use,[32] the nineteenth century saw a significant advancement in the understanding of storms and weather systems. Research centred first around determining that storms were cyclonic or rotary in nature

[29] Dunn, *New Directory for the East Indies*, 285–6.

[30] Mathew Fontaine Maury, *Explanations and Sailing Directions to Accompany the Wind and Current Charts* (Washington: C. Alexander, printer, 1851).

[31] The sympiesometer was invented by Alexander Adie in 1818. Using almond oil and hydrogen gas, it was more sensitive than a mercury barometer and was therefore widely used on ships in the second quarter of the nineteenth century as a storm prognosticator.

[32] F. Labrosse, *The Navigation of the Pacific Ocean and China Seas* (Washington: Government Printing Office, 1875), 27, 29.

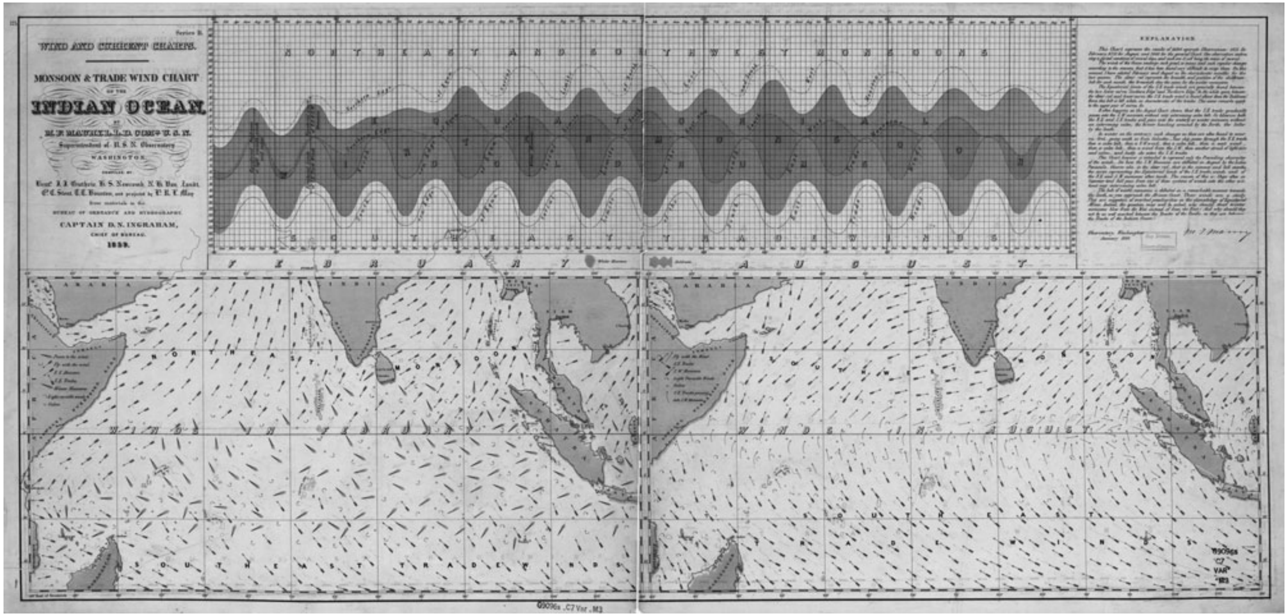

Figure 4. M. F. Maury, Monsoon and Trade Wind Chart of the Indian Ocean 1859, showing the different wind regimes of February and August. Library of Congress. https://www.loc.gov/item/2009575919

and that they followed a predictable pattern and track, the so-called law of storms. Notable among those scientists working on this problem were William Redfield, William Reid, Heinrich Dove, Charles Meldrum, Bernhardus Varenius, Benito Vines, William Birt, Henry Piddington, and John Eliot. A detailed and very useful account of the history and development of the science of cyclones and cyclone theory from the time of Columbus to the later nineteenth century can be found in William Henry Rosser's *The Law of Storms Considered Practically,* published in 1876.[33]

First came the theory that hurricanes and typhoons were rotary storms, a theory confirmed by the accumulation of thousands of observations from logbooks and journals as well as land-based observations, and published for the benefit of mariners and the scientific community, most notably by Charles Meldrum, the director of the Meteorological Observatory at Mauritius, and also Henry Piddington, who wrote twenty-three "storm memoirs" published in the *Journal of the Asiatic Society of Bengal.*[34] The second problem was the storm track and the noted recurvature of hurricanes and typhoons, the latter a phenomena that Maury noted as being a puzzle to both scientists and navigators.[35] The result of this scientific work was not an ability to forecast storms and hurricanes, as that required a network of observers and an effective means of communicating the observations. Instead, the writers of sailing directions and the many iterations of the law of storms were able provide detailed descriptions of the meteorological signs of an approaching hurricane or typhoon, and offer detailed instructions for avoidance or mitigation depending on where a vessel might find itself in relation to the storm and its track.[36]

However, one of the most astonishing discoveries in cyclone research was the potential to exploit depressions and storm tracks. William Birt was probably one of the first to formalise the idea of using the track of a cyclone, in this instance on the passage from the meridian of the Cape of Good Hope towards Australia, in 1853. Bearing in mind that depressions in the southern hemisphere rotate in a clockwise direction, Birt wrote:

> by sailing on a course nearly parallel with the centre of the storm and at such a distance from it on the northern radius as to get a steady breeze from the westward, they will make very good runs, and reach their destination with but little if any delay.[37]

The genesis of the idea of "storm sailing" may have come from Captain John Erskine of HMS *Havannah* in 1848. In a letter to Henry Piddington, Erskine discussed how he was not only able to corroborate the rotary theory of storms, but also use a barometer to anticipate and exploit the expected winds.

> The winds we experienced were a succession of cyclones, and [. . .] by paying attention to the barometer and sympiesometer, and keeping in the left-hand semicircle or

[33] Fiona Williamson and Clive Wilkinson, "Asian Extremes: Experience, Exchange and Meteorological Knowledge in Hong Kong and Singapore c. 1840–1939," in M. Mahoney and A. M. Caglioti, eds., *Relocating Meteorology: History of Meteorology* 8 (2017), 165; W. H. Rosser, *The Law of Storms Considered Practically* (London: Charles Wilson, 1876).

[34] Williamson and Wilkinson, "Asian Extremes," 165.

[35] M. F. Maury, *Explanations and Sailing Directions to Accompany the Wind and Current Charts* (Washington: William A. Harris, printer, 1858) vol.1, 262.

[36] Rosser and Imray, *Seaman's Guide,* 148–9; W. H. Rosser, *The Law of Storms Considered Practically* (London Charles Wilson, 1876); William Birt, *Handbook of the Law of Storms* (London: George Philip, 1853); and William Reid, *Progress of the Development of the Law of Storms* (London: John Weale, 1850).

[37] William Birt, *Handbook,* 88.

> that of the westerly winds, I was enabled to make passage from Simon's Bay to Port Jackson in comparatively moderate weather in 34 days including 3 or 4 days of light winds.

When HMS *Havannah* was overtaken by a third cyclone, Erskine went on to describe how the cyclone

> made known its approach by a gradual fall of the barometer . . . the glasses rising and falling occasionally as she [the ship] outstripped or fell short of the velocity of the storm. . . . on heaving to for an hour and a half on the night of the seventeenth, to allow the centre to pass ahead, the barometer rose immediately and continued steady. [. . .] It [the cyclone] finally got ahead on the 21st, having apparently run 1,185 miles in five days or at the rate of nearly ten knots an hour.[38]

Erskine's careful observations and detailed analysis of the winds and barometric pressures are remarkable, but typical of the scientifically minded naval and merchant naval officer of the time.

An article on storm sailing published in 1854 refined the process further. An anonymous writer took wind and pressure data from the logbook of the merchant ship *Duke of Richmond,* Captain T. Barclay, on her passage across the high latitudes of the South Pacific in July 1853. This data was then used to reconstruct the track of a cyclone encountered by the vessel at 53º south latitude, and between the longitudes of 154º and 120º west.

Once this reconstruction was completed, it enabled the writer to formulate a strategy or principle by which a ship could use the winds circulating around a depression. This included how to identify if the vessel was in the most favourable quadrant of the cyclone.

If the ship found itself in the wrong quadrant, for instance on the southern side of the depression, the winds could be used to temporarily reverse course and use the wind circulation to sail around the back of the cyclone and into the northern quadrant, and there await the next depression to arrive along the storm track.[39] These were the very principles used to great effect in the extraordinary voyages of some of the great nineteenth-century clipper ships such as the *Lightning, Marco Polo, Thermopylae, Cutty Sark,* and others.

The Importance of the Environment to Navigation

We can summarise the chief environmental considerations in navigating a route from one part of the world to another. Two points stand out above all others: firstly the expected direction and force of the wind, and secondly the expected state of the weather on the intended route. The diagram below shows the most efficient direction of the wind in relation to a vessel, in black, grey, and white. A square rigged vessel is illustrated but the extent of the areas of most efficiency [white] will vary according to the type of ship and the rig.

Sailing ship routes differ significantly from steamship routes because a sailing vessel must follow the circulation of the atmosphere and attempt to keep the aspect of the winds in the white zone illustrated below. Working out the best routes to cross the oceans and making best use of the environmental conditions was a matter of gathering and analysing individual experiences and weather data from thousands of logbooks and journals

[38] TNA, ADM 53/3629 & 3630, Ship's Logbook HMS *Havannah* Jan 1848–Jan 1849; Henry Piddington, *The Sailor's Horn-book for the Law of Storms* (London: Williams and Norgate, 1860), 40–41.

[39] Anonymous, "On the Occurrence of a Revolving Storm in the South Pacific Ocean," *Mercantile Marine Magazine* 91 (1854).

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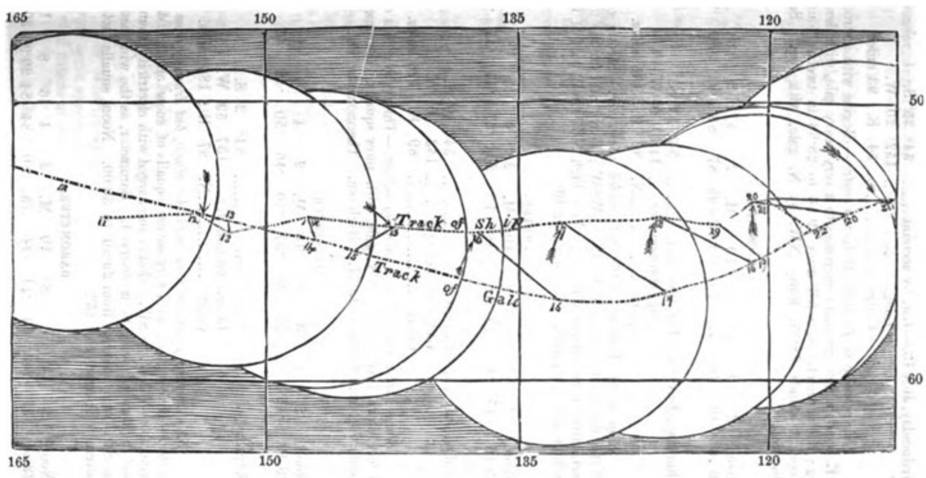

Figure 5. Track of the *Duke of Richmond* and Cyclone, South Pacific July 1853, from *Mercantile Marine Magazine* 91 (1854).

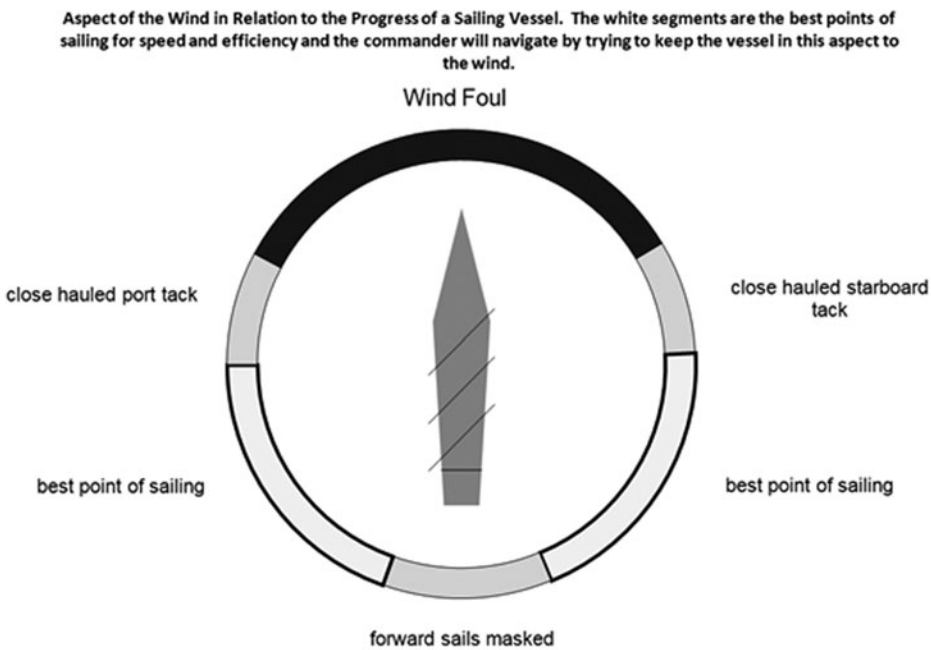

Figure 6. Wind Directions and the Progress of a Sailing Vessel. Diagram by the author.

and publishing the results in sailing directions and charts. Over decades and centuries an accretion of knowledge and experience based on close observation of the environment led to improvements in navigation. Arguably this is as important as the development of sophisticated navigational instruments such as the quadrant, sextant, and chronometer. It was Mathew Maury's analysis of the winds and currents that led to shortened journey times, not improvements in instruments. It was a better understanding of cyclones,

https://doi.org/10.1017/S016511532400007X Published online by Cambridge University Press

hurricanes, typhoons, and their storm tracks that led to safer navigation, not improvements in instruments. In fact, the benefits that the perfection of the chronometer and the improved determination of longitude brought to safe navigation are over-rated.

The chronometer in fact created a whole new set of problems. In 1792, the East Indiaman *Winterton* took the middle passage northwards through the Mozambique Channel. Captain Dundas was confident in his two timepieces, and his calculation of the longitude was almost certainly correct. He believed himself to be some sixty miles off the land and therefore took no soundings. During the night the *Winterton* struck a reef six miles off the shore of Madagascar, and about sixty-three miles north of St. Augustine.[40] The position of the ship was correct, but the position of the shore, according to the chart, was not, because at that time charts had not been drawn with the benefit of chronometer positions. This is why there was a flurry of hydrographic work and the production of new improved charts in the nineteenth century.

Successfully navigating the hostile medium of the world's oceans under sail meant doing so both safely and efficiently. Every commander would do his best to achieve this, and some would even experiment with unusual routes to meet this end. We can conclude with the notes from the logbook written by Captain C. Grey (RNR), commanding the merchant sailing ship *MacMillan* on a voyage from Flushing (Vlissingen, Netherlands) to San Diego, California, in 1881. One would expect a voyage of this sort to go westward via Cape Horn, but Captain Grey took an eastward passage via the Cape of Good Hope and south around Australia and thence across the Pacific to California. In the meteorological logbook, Captain Grey made the following notes:

> From Flushing to San Diego sailed 21,983 miles in 130 days or 169.1 miles per day.
>
> From Equator (Atlantic) to Equator (Pacific) total distance sailed 14,303 miles in seventy-two days or 198.65 miles per day.
>
> The last average is probably the greatest ever made by a sailing ship for as many days. The route via Cape of Good Hope was chosen to prove how easy a ship could make the passage with the strong westerly winds about the latitude of 40^{0} South without any loss of spars and sails, instead of beating against the westerly gales off the Horn in the winter times. Being winter in the southern hemisphere, the route through Bass Straits and north New Zealand and Kermadec Islands, etc. was taken. In the summer months I would recommend the route south of Tasmania and New Zealand and Pitcairn Island.[41]

Captain Grey's chosen route was unusual. As an experiment, it was motivated by a need for passages with favourable winds and a desire to preserve the ship's masts and spars and the safety of the ship and cargo. The environment was paramount in these considerations.

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[40] T. Harrington, *Remarkable Account of the loss of the ship Ganges* [. . .]. *Also the wreck of the Winterton, East Indiaman* (London: printed for Thomas Tegg, 1808), 14–15.

[41] NMA, 5574, Meteorological Logbook *MacMillan* 1881–82.

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