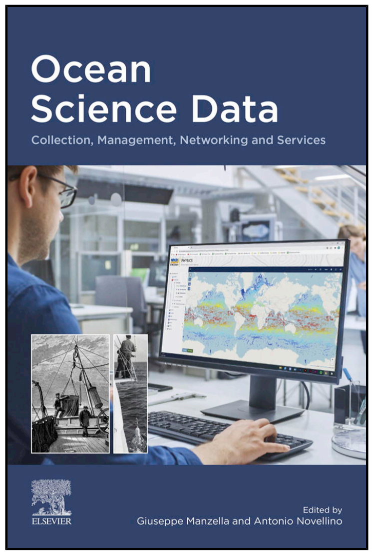

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CHAPTER ONE

A narrative of historical, methodological, and technological observations in marine science

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Introduction

> Our planet is invested with two great oceans; one visible, the other invisible; one underfoot, the other overhead; one entirely envelops it, the other covers about two thirds of its surface.
>
> Matthew Fontaine Maury, *The Physical Geography of the Sea and Its Meteorology*, 1855

The earliest studies of the oceans date back to Aristotle (384 BC–322 BC), but a true methodological approach only began about two millennia after his death. Initially, ocean science derived from the practical arts of navigation and cartography (Henry, 2008). During the 15th century, logbooks and annotated navigation maps began to be collected systematically. Unfortunately, few early travel records have survived due to physical deterioration, loss of logbooks or privacy policies (Peterson et al., 1996). With the Portuguese exploration of new lands and seas, important advances were made in one branch of science in particular: the geography of the sea.

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The first methodological and technological approach to observing the sea was established at the meeting of the Royal Society of London on June 14, 1661. The document *Propositions of Some Experiments to Be Made by the Earl of Sandwich in His Present Voyage* (Birch, 1760) defined the guidelines for data collection.

"Diligent observations" were required by Galilei (1564–1642) and were the basis of his experimental method. The concept was underlined, inter alia, in the "Forth Day" chapter, discussing the causes of the tides, in the famous book *Dialogue on the Two Chief World Systems* (Galilei, 1632). The "Propositions" were asking for "diligent observations" and their recommendations were subsequently included in the *Directions for the Observations and Experiments to Be Made by Masters of Ships, Pilots, and Other Fit Persons on Their Sea-Voyages* by Murray and Hooke (1667) on behalf of the Royal Society. Seafarers were asked to

- Observe the declination and variations of the compass or needle from the meridian exactly, in as many places as they can, and in the same place, every several voyage,
- Carry dipping-needles with them,
- Mark carefully the flowings and ebbings of the sea, in as many places as may be,
- Sound the deepest seas without a line, …
- Keep a register of all changes of wind and weather …,
- Observe and record all extraordinary meteors, lightnings, thunders, …
- Carry with them good scales and glass-viols of a pint or so, with very narrow mouths, which are to be filled with sea water in different degrees of latitude, and the weight of the viol full of water taken exactly at every time, and recorded; marking withal the degrees of latitude and longitude of the place, and the day of the month, and the temperature of the weather: and as well of water near the top, as at a greater depth,
- Fetch up water from any depth of the sea.

The "Directions" were accompanied by instructions on the use of methods and instruments. Theoretically, they constituted a systematization of a general request by several European scientists made explicit by Vincenzo Viviani (a pupil of Galileo Galilei), on behalf of the Accademia del Cimento to gather knowledge of the variability of ocean circulation by means of "diligent" observations of the sea (see Pinardi et al., 2018). It is worthwhile to mention that the Accademia del Cimento motto was "by trying and trying again" (e.g., Magalotti, 1667).

A further step toward a more "diligent" observational methodology was made by Ferdinando Marsili (1658–1730) with his famous treatise "Osservazioni intorno al Bosforo Tracio" (Marsili, 1681). For the first time, an appropriate observation strategy was defined in order to understand the effects of density differences on the circulation of water masses (Pinardi et al., 2018; Peterson et al., 1996; Deacon, 1971).

The efforts of the Royal Society to gain greater knowledge of the physical characteristics of the sea met with little success. However, an important contribution came from William Dampier (1651–1715), who was the first person to circumnavigate the globe three times (Dampier, 2012). In Dampier's records, data were not reported as requested in the "Directions," but contained substantial information on winds and currents. The essay "A New Voyage Round the World" (Dampier, 1703) was sent to the Royal Society with the aim to promote "useful knowledge, and of anything that may never so remotely tend to my Countries advantage." During his voyages, Dampier found that currents in the equatorial region were driven by the trade winds (Deacon, 1971).

The westward currents in the north equatorial region were used during the discovery of America and were associated with the Aristotelian conception of sea motion. In actual fact, Aristotle never spoke of a westward sea flow, but this was the scholarly interpretation of a passage in the second book of *Meteorologica* (e.g., Aristotle, 1952):

> *The whole Mediterranean flows according to the depth of the sea-bed and the volume of the rivers. For Lake Maeotis* (Azov Sea) *flows into the Pontus and thus into the Aegean … In the seas mentioned it* (the flow) *takes place because of the rivers—for more rivers flow into the Euxine and Lake Maeotis than into other areas many times their size—and because of their shallowness. For the sea seem to get deeper and deeper than Lake Maeotis, the Aegean deeper than the Pontus and the Sicilian Sea deeper than the Aegean, while the Sardinian and Tyrrhenian are the deepest of all. The water outside the pillars of Heracles is shallow because of the mud but calm because the sea lies in a hollow.*

The westward flow of the surface currents in the north equatorial region was noted by Pietro Martire d'Angera (1457–1526) in De Orbe Novo, 3rd "Decade," Book 4 of the English translation by MacNutt (Martyr d'Anghiera, 1912):

> *It was in the year of salvation 1502 on the sixth day of the ides of May that Columbus sailed from Cadiz with a squadron of four vessels of from fifty to sixty tons burthen, manned by one hundred and seventy men. Five days of favourable*

weather brought him to the Canaries; seventeen days' sailing brought him to the island of Domingo, the home of the Caribs, and from thence he reached Hispaniola in five days more, so that the entire crossing from Spain to Hispaniola occupied twenty-six days, thanks to favourable winds and currents, which set from the east towards the west. According to the mariners' report the distance is twelve hundred leagues.

Pietro Martire d'Angera in the same "Decade" (from Latin "decas"—group of 10) analyzed the consequences of this flow in terms of the conservation of water masses and wrote explicitly in Book 6:

The time has come, Most Holy Father, to philosophise a little, leaving cosmography to seek the causes of Nature's secrets. The ocean currents in those regions run towards the west, as torrents rushing down a mountain side. Upon this point the testimony is unanimous. Thus, I find myself uncertain when asked where these waters go which flow in a circular and continuous movement from east to west, never to return to their starting-place; and how it happens that the west is not consequently overwhelmed by these waters, nor the east emptied. If it be true that these waters are drawn towards the centre of the earth, as is the case with all heavy objects, and that this centre, as some people affirm, is at the equinoctial line, what can be the central reservoir capable of holding such a mass of waters? And what will be the circumference filled with water, which will yet be discovered? The explorers of these coasts offer no convincing explanation. There are other authors who think that a large strait exists at the extremity of the gulf formed by this vast continent and which, we have already said, is eight times larger than the ocean. This strait may lie to the west of Cuba, and would conduct these raging waters to the west, from whence they would again return to our east. Some learned men think the gulf formed by this vast continent is an enclosed sea, whose coasts bend in a northerly direction behind Cuba, in such wise that the continent would extend unbrokenly to the northern lands beneath the polar circle bathed by the glacial sea. The waters, driven back by the extent of land, are drawn into a circle, as may be seen in rivers whose opposite banks provoke whirlpools; but this theory does not accord with the facts. The explorers of the northern passages, who always sailed westwards, affirm that the waters are always drawn in that direction, not however with violence, but by a long and uninterrupted movement. Amongst the explorers of the glacial region a certain Sebastiano Cabotto, of Venetian origin, but brought by his parents in his infancy to England, is cited. It commonly happens that Venetians visit every part of the universe, for purposes of commerce. Cabotto equipped two vessels in England, at his own cost, and first sailed with three hundred men towards the north, to such a distance that he found numerous masses of floating ice in the middle of the month of July. Daylight lasted nearly twenty-four hours, and as the ice had melted, the land was free. According to his story he was obliged to tack and take the direction of west-by-south. The coast bent to about the degree of the strait of Gibraltar.

Cabotto did not sail westward until he had arrived abreast of Cuba, which lay on his left. In following this coast-line which he called Bacallaos, he says that he recognised the same maritime currents flowing to the west that the Castilians noted when they sailed in southern regions belonging to them. It is not merely probable, therefore, but becomes even necessary to conclude that between these two hitherto unknown continents there extend large openings through which the water flows from east to west. I think these waters flow all round the world in a circle, obediently to the Divine Law, and that they are not spewed forth and afterwards absorbed by some panting Demogorgon. This theory would, up to a certain point, furnish an explanation of the ebb and flow.

Soon after the discovery of the new land mass named "America", one of the most exciting and tragic adventures in the history of seafaring began: the search for the passage from the Atlantic to the Pacific. Martire D'Angera hypothesized that this passage was in Central America, but the idea of a "passage to the East Indies by the North Pole was suggested as early as the year 1527 by Robert Thorn, merchant, of Bristol" (Phipps, 1774, see also McConnell, 1982). The polar passage would have allowed England to shorten the travel time to the Spice Islands, compared to the circumnavigation of South America through the Strait of Magellan or South Africa around the Cape of Good Hope. A chronological history of travel to the Arctic regions and the polar passage between the Atlantic and Pacific Oceans was given by Barrow (1818). Ross (1835) (Fig. 1.1) provided a map showing the possible location of the north-west passage.

This chapter shows how observation technologies and methodologies are important for understanding oceanic phenomena. It provides a general overview of the consequences of the rapid evolution of knowledge and technology's impact on work practices. Our knowledge of ocean science is based on scientific debates that began centuries ago, a cultural aspect that should not be overlooked and should be included in academic courses.

Margaret Deacon (1971) in her *Scientists and the Sea* wrote: Oceanography is a descriptive and environmental science; as such it depends for its existence on the application of knowledge already gained in physical and other sciences. However, observations in the sea are very difficult and expensive, and the data collected cannot be reproduced. Technological and methodological advances were key points of progress in ocean science.

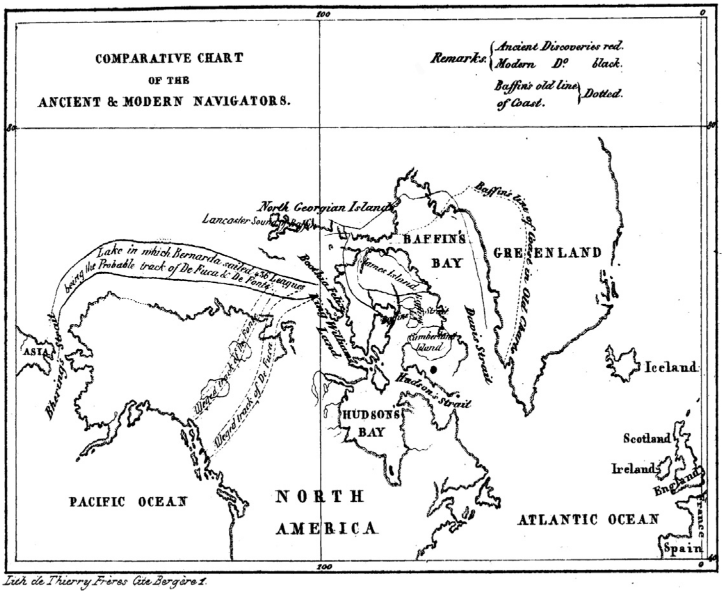


Figure 1.1 The possible location of the north-west passage from Atlantic to Pacific as in the book of John Ross (1835).

The Renaissance brought about an epochal change in human thinking that resulted in the rise of a humanistic culture and major scientific discoveries. The experimental method initiated by Galileo required a procedural systematization which began to take shape in the 17th century. Important cultural and scientific institutions were founded for the advancement of thought and to debate methodologies and technologies. Florence's Accademia del Cimento was founded in 1657 and the Royal Society of London in 1660; both were incubators of ideas on natural sciences.

Methodologies and technologies developed during the 17th to 19th centuries are presented with particular attention to their applications in the northern polar regions. These extreme areas, on account of their oceanographic and meteorological peculiarities, represent interesting case studies for the validity of those methodologies and technologies.

This chapter provides some important historical elements on data collection methods and technologies from the 17th century to the beginning of the 20th century in the science later known as oceanography. In order to evaluate and compare past and present technologies and methods, the data collected in particular areas of the Arctic Sea are presented.

17th century: *Summum frigidum*

> Show us the sensible experience, that the ebb and flow of the sea water is not a swelling, or shrinking of the parts of it element, similar to what we see taking place in the water placed in the heat of the fire, while it for vehement heat becomes rarefied, and rises, and in reducing itself to natural Coldness it reunites, and lowers; but in the Seas there is a true local motion, and so to speak progressive, sometime towards one, sometime towards the other extreme term of the Sinus of the Sea, without any alteration of this element, coming from other accident than from Local Mutation.
>
> Galileo Galilei's speech over the ebb and flow of the sea, 1616; Acts and unpublished memoirs of the Accademia del Cimento, 1780

Speculation on the properties of the oceans during the 17th century was provided by many skilled people ("*virtuosi*"). Galileo's studies (1638) on falling bodies were the basis of many "inquiries" relating to surveys of the sea. Boyle (1627−1691) and Hooke (1635−1703) spent considerable time testing and applying the concept of "gravitation" to ocean studies.

Boyle asked navigators to explore the different aspects of the oceans: with regard to the water are to be considered the sea, its depth, specific gravity, difference of saltness in different places, the plants, insects, and fishes to be found in it, tides, with respect to the adjacent lands, currents, whirlpools, &c (Shaw, 1738). The requirements for these observations were explained in detail in the "Directions for the observations and experiments to be made by masters of ships, pilots, and other fit persons in their sea-voyages" that also contained information on the instruments that should be used routinely for the collection of geographical, atmospheric, oceanographic, and biological data.

The "Directions" were the first step in the creation of a data quality management system:

- essential information describing the sensors and platforms,
- measurement position,
- measurement units,
- processing, date and time information.

During the 17th century, scientists began to define some specific inquiries on natural phenomena (e.g., tides, currents, winds). The diverse interpretations of observations or results of "experiments" made it necessary to adopt precise experimental methodologies. The concept of standards agreed upon by the scientific community and now adopted in everyday practice did not exist then. The "best practices" were defined by one or more highly reputable people (persons of great repute), one of whom was Robert Hooke, who presented the "Method of Making Experiments" to the Royal Society (Derham, 1726). Hooke's experimental method included some specific recommendations:

- After finishing the Experiment, to discourse, argue, defend, and further explain, such Circumstances and Effects in the preceding Experiments, as may seem dubious "or difficult": and to propound what new Difficulties and Queries do occur, that require other Trials and Experiments to be made, in order to their clearing and answering: And farther, to raise such Axioms. and Propositions, as are thereby plainly demonstrated and proved.
- To register the whole Process of the Proposal, Design, Experiment, Success, or Failure: the Objections and Objectors, the Explanation and Explainers, the Proposals and Propounded of new and farther Trials; the Theories and Axioms, and their Authors; and, in a Word, the History of every Thing and Person, that is material and circumstantial in the whole Entertainment of the said Society which shall be prepared and made ready, fairly written in a bound Book, to be read at the Beginning of the Sitting of the said Society.

Sounding: *Nuntius Inanimatus, Esplorator Distantiae*

One of the major problems of the 17th century was the lack of good maps with marine topography for use in the *Art of Navigation*, *one of the most useful in the World* (Derham, 1726).

The sounding instrument illustrated in the "Directions" was a ball made of waterproofed light wood (e.g., maple), to which an iron or stone weight was tied. When it touched the seabed, the wooden ball came off and rose to the surface (Fig. 1.2). The depth was calculated with tables on the basis of the time taken by the ball to descend and ascend. The "Directions" provided warnings on the weights and dimensions of the different parts of the apparatus.

Hooke gave precise indications on the different components of "instruments for sounding the great depth of the sea", and highlighted two possible technological sources of errors: The first was, that "it was necessary to make

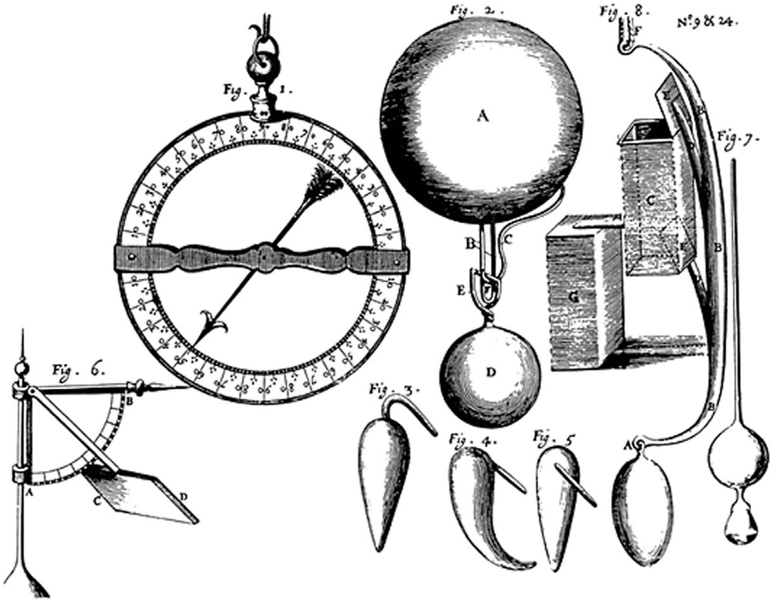


Figure 1.2 Instruments for measurements to be done during voyages, as from "Directions" by Murray and Hooke (1667): Dipping-needle (Fig. 1), Deep sea sounding without a line (Fig. 2) with different forms of weights (Fig. 3, Fig. 4, Fig. 5) substituting the ball D in Fig. 2, Instrument measuring wind strength (Fig. 6), water sampler (Fig. 7). The sounding principle was very simple: a buoyant object attached to a weight that came off in contact with the seabed.

the Weight, that was to sink the Ball, of a certain Size and Figure, so proportioned to the Ball, as that the Velocity of them, downwards, when united, should be equal to the Velocity of the Ball alone, when it ascended in its Return; in Order to which, it required to be prepared with Care, and required also some Charge, it being almost necessary to make it of Lead, of a certain Weight and Figure. The other was, the Difficulty of discovering the Ball at the first Moment of its Return, which was likewise of absolute Necessity; and it was likewise necessary to keep the Time most exactly of its Stay, or Continuance, under the Surface of the Water, by the Vibrations of a Pendulum, held in one's Hand …" (Derham, 1726).

While Hooke acknowledged the error introduced if the ball was not detected immediately upon reaching the surface, he did not realize the difficulty of doing so in anything but a totally calm sea. Many were the complaints as to the difficulties in locating the ball upon its return to the surface.

Hooke was aware of the errors associated with calculations of descent and ascent speeds and of the need to consider the buoyancy of the materials used for the various components of the sounding apparatus. On the contrary, he was confident of the use of the "pendulum clock" described in "Philosophical Experiments" (Derham, 1726). To avoid problems, he proposed a cone-shaped sounding machine (Fig. 1.3) with a small hole to receive water based on external pressure (*Nuntius Inanimatus* or *Explorator Distantiae*). In Hooke's idea, the increasing pressure of sea water at depth would fill the sounding machine in proportion to the actual depth. Therefore, by weighing the content of the water in it after it returned to the surface, it would be possible to have a measurement of the depth of the water.

Whatever the operation of this *Nuntius*, Hooke was sure that the sea temperature would influence the results, as the heat or the cold caused the air contained in the machine to expand or contract. For this reason, he thought of adding a temperature sensitive apparatus. However, there was another important question to answer before evaluating the results of a sounding apparatus, *that is*, "Whether the Gravitation, towards the Center of the Earth, do continue the same, at any Depth; or whether it do increase

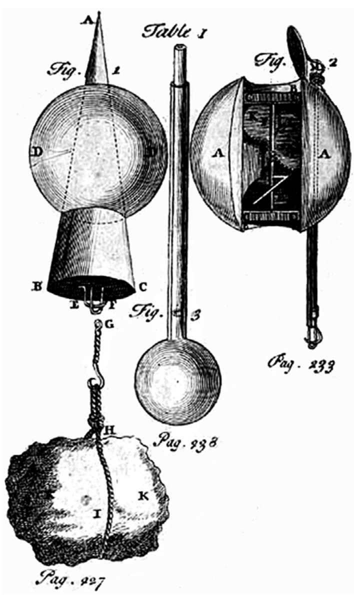


Figure 1.3 The *Nuntius Inanimatus* (on the left) and *Explorator Profunditatis* (on the right) proposed by Hooke (Derham, 1726).

or diminish, according as the Body is posited lower and lower, beneath the Surface of the Sea; for if Gravity do increase, then the Body will move downwards, or sink faster, than at the Top; and if it decreases, it will do the Contrary."

The solution was in the so-called *Explorator Profunditatis*, which consisted of a ball of a selected material with holes allowing the passage of water. The ball had pinions and cogwheels that turned during the descent and during the ascent (Fig. 1.3). The apparatus described by Murray (1912) was composed of two clockwork odometers, one for the descent and another for the ascent. The number of revolutions of the rotors gave values proportional to the depth of the sea.

Esplorator temperature

The history of temperature measurements, from the thermoscope to the thermometer, has been presented in many books (e.g., Knowles Middleton, 2003). Despite still imperfect technology and methodology, temperature measurements revealed some aspects of the marine environment which were analyzed by Boyle, a scientist whose interests ranged from human to natural, chemical and physical sciences. Boyle obtained information on temperature and salt from various sailors and divers and concluded that *sea water is not the summum frigidum*. Therefore, the sea was made up of a surface layer whose temperature was influenced by the atmosphere and a deeper and colder layer (Shaw, 1783). From this information a question arose: why was the deep sea, despite being cold, not frozen? Boyle's conclusion was, "so, I have more than once try'd that salt-water will, without freezing, admit a much greater degree of cold, that is necessary to turn fresh water into ice."

Hooke described a thermometer that was nothing "but a small Bolthead, filled up with Spirit of Wine, to a convenient Height of the Stem, with a small Embolus and Valve; the Embolus is made so, as to be thrust down the Neck, as the Spirit of Wine shall be contracted by Cold; and the Valve is to let out the Spirit of Wine, when it is again expanded with Heat, in its Ascent". It is important to note that the effect of the pressure on the volume of the Spirit was very well known: "It may, possibly, be thought that the great Pressure, of the incumbent Body of Water, may contribute somewhat to the Contraction, or Shrinking, of the Spirit" (Derham, 1726).

Esplorator Qualitatum

The measurements of sea gravity and saltness were done with a vial of known magnitude having a narrow neck or a graduated glass-tube. The gravity was determined by the weight of the water and the saltness by the weight of substance remaining after evaporation of the water. Water at depth was sampled with a "Square Wooden Bucket" having two valves that remained open during the descent of the sampler and closed in the ascent (Fig. 1.2).

Boyle described various experiments for the calculation of the specific gravity: "We took a vial, with a long and strait neck, and having counter pois'd it, we filled it to a certain height with common conduit-water: we noted the weight of that liquor; which being poured out, the vial was filled to the same height with sea-water, taken up at the surface; and by the difference between the two weights, the sea-water appeared to be about a forty-fifth part heavier than the other."

Having compared the results of different experiments that were giving slightly different results, Boyle deduced that the seawater during the weight operation was "*rarified*" by the effect of the sun. In one experiment Boyle used "distilled rain" as reference, but there were no indications that this water was assumed to be a standard. Boyle gave some values of the gravity of sea water weight using units of measurement from the old English avoirdupois measurement system derived from the Anglo-Norman French "aveir de peis," a derivation of the Latin "habere de pensum."

Specific gravity

The scales used to weigh specific gravity took various forms and Hooke presented some to the Royal Society (Fig. 1.4). The position of the reference weights along the arms (Fig. 1.4a) would provide "the proportionate Weight of those two Bodies" (Derham, 1726). In order to obtain a greater precision, a scale with the beam "in the Form of a Cross, equilibrated upon a sharp Edge in the Center" was proposed, but it is not known if it was actually used (Fig. 1.4b).

Hooke received samples of sea surface water and fresh water, the latter for use as a reference. Unfortunately, there were no indications in the text on the location of the sea sampling location, while the reference fresh water was collected in the Thames River at Greenwich during low tide (which is very likely not completely fresh). The salt content found by Hooke was about 22 parts per 1000, a fairly good value, given the many uncertainties and factors and the use of water from the Thames as reference.

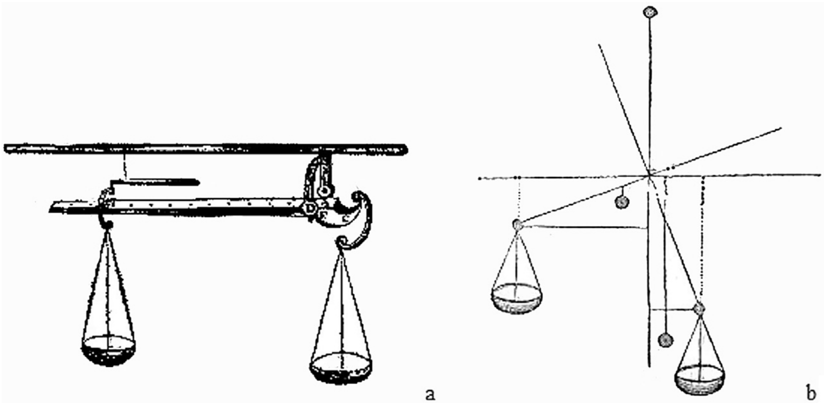


Figure 1.4 Two balances by Hooke. The one on the left is a typical steelyard balance. On the right is a balance proposed by Hooke to improve precision in weight measurements (Derham, 1726).

It can be anticipated that the value of specific gravity measured in the 18th century in Nore, a sandbank in the Thames estuary, ranged from 1000 to 1024.6 and in the North Sea 1000 to 1028.02. These values were provided in the appendix "Account of Doctor Irving's Method of Obtaining Fresh Water from the Sea by Distillation" of "A Voyage towards the North Pole" (Phipps, 1774). One of the many methodologies for the preparation of a reference water is presented in paragraph 18th century: Polar explorations - Distilled water.

18th century: Polar explorations

> The usefulness of physical geography is manifest. It teaches us to know the workshop of nature in which we find ourselves, its instruments, its first laboratory, and its attempts.
>
> Immanuel Kant, Physische Geografie (from Augusto Eckerlin edition), 1807

A letter by Stephen Hales (1677−1761) dated June 8, 1751, appeared in the *Philosophical Transaction* (Hales, 1753), which describes a "bucket sea-gage" used by Henry Ellis during his voyage to Hudson's Bay in 1746. This apparatus was used to collect temperature, salinity, and specific gravity information at various depths. The sea-gage "was a common household pail or bucket, with two heads in it; which heads had each a round hole in the middle, near four inches diameter, which were cover'd with valves which open'd upwards; and that they might both open and shut together." The water temperature was measured on board with a mercury thermometer. However, Hales advised users to be very careful since the measurement was altered by contact with air.

Important steps forward in technology and methodology are described in the book *A Voyage towards the North Pole - 1773* (Fig. 1.5), by Phipps (1774). The methodology used during that expedition was based on an intercomparison of measurements made by different people, e.g., longitude was calculated by different people making astronomical observations and timekeepers, and when all the results were reported and compared, corrections made were described in detail.

Temperature

Temperature was measured with Cavendish's overflow thermometers, which were presented to the Royal Society on June 30, 1757 (Fig. 1.6). Cavendish (1704−1783) wrote: "The instrument for finding the greatest heat might be made just like that of Fig. 1. only leaving the top open. It is to be filled with mercury only, as is also the lower part of the ball at top, but not near so high as the end of the capillary tube. The upper part of that ball, being left open, will in a great measure be filled with the seawater, which will be forced into it by the pressure … The thermometer for finding the greatest cold, if applied to this purpose, must also be left open at top … the most convenient construction, which occurs to me, is that of Fig. 4" (Cavendish, 1757). The thermometer was filled with mercury (the dark part of the figure) and "spirit of wine" (the gray part).

Soon after the publication of the Cavendish report by the Royal Society, it was noted that "spirits of wine" and other fluids were compressible and that, furthermore, corrections to temperature measurements were necessary. The corrections were presented in an appendix to Phipps' book. The corrected temperature data collected during the Phipps voyage to the North Pole are shown in Table 1.1 (details on Cavendish thermometers and corrections are presented in McConnell, 1982).

The quality of the data can be discussed on the basis of the temperature collected at 780 fathoms (about 1426 m) which, after correction, turned out to be −3.3°C, a very low value in light of current knowledge. The corrections to temperatures made by Dr. Irving, a scientific member of Phipps' crew, considered *compression and unequal expansion of spirits*.

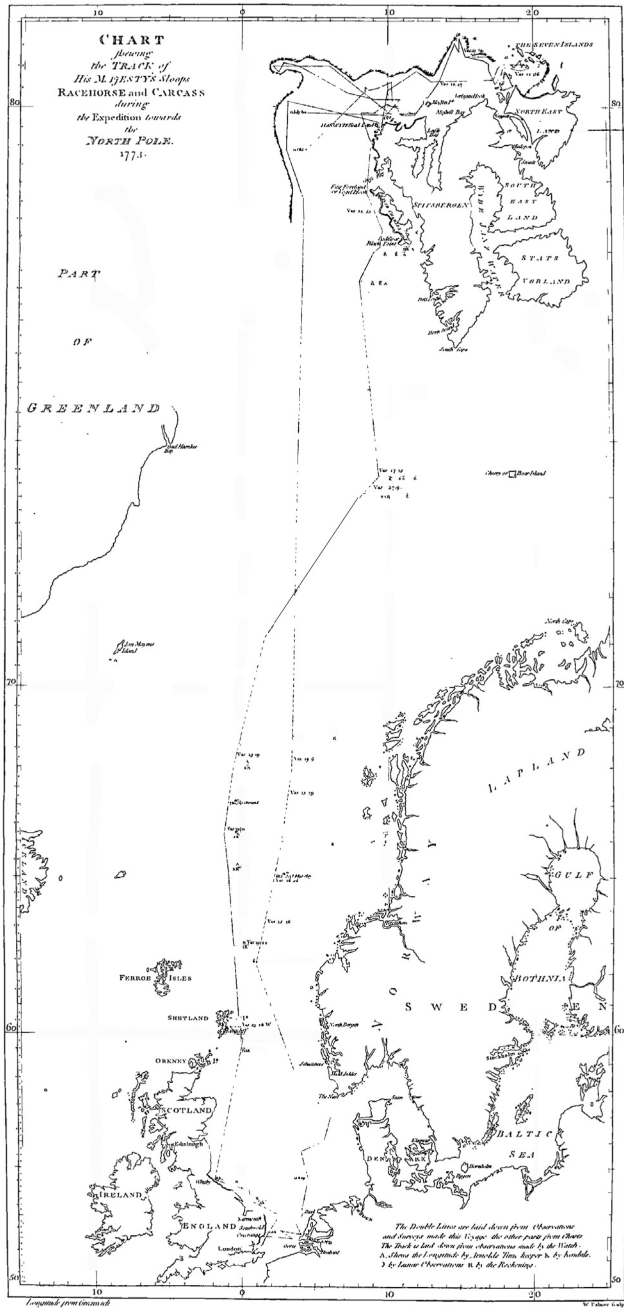


Figure 1.5 Chart of *A Voyage toward the North Pole* by Phipps (1774).

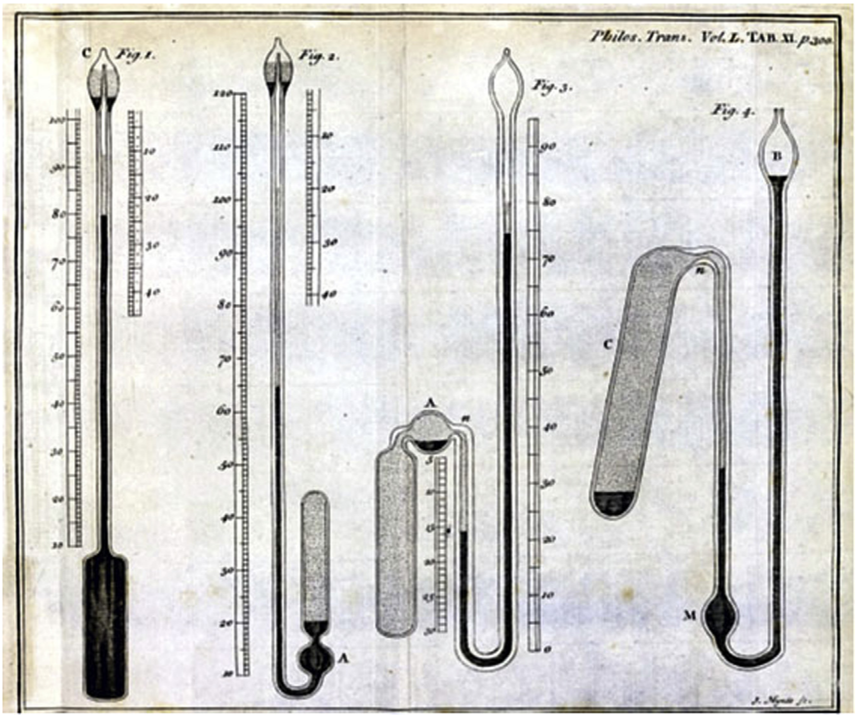


Figure 1.6 Cavendish thermometers. The "minimum thermometer" used by Phipps is presented in "Fig. 4". The gray part was "spirit of wine" and the dark part was mercury. Note the opening on top of "Fig. 4". Cavendish was aware of the effect of pressure on the apparent volume of liquids, causing a shift in reading. Following Cavendish, the pressure exerted on the top causes mercury to pass into the alcohol tank C. Initially C contained "spirit of wine." As the temperature fell, the spirit is contracted and the mercury flows into C where it is trapped. The reading of the mercury in the shorter limb would give a measure of the temperature. More details are in McConnell (1982). (Note the references to figures in the text refer to the numbers next to the thermometers in the figure.). *From Cavendish, C., 1757. A description of some thermometers for particular uses. Phil. Trans. 50, 300–310.*

However, based on some indications provided by Abbe (1888), the temperature should be corrected by more than 0.5°F, probably greater than 2°F, as shown by Fig. 1.7.

To understand the quality of these first observations of the thermal content of the sea in the polar regions, the temperature values collected by Phipps (Table 1.1) are compared with the data collected in recent years (Fig. 1.7). Data above 120 fathoms correspond to the temperature values collected at the beginning of the 21st century, but data for the deepest point are completely out of acceptable ranges. The navigation journal reported

Table 1.1 Temperature data collected during the voyage to North Pole by Phipps in 1774.

Year	Month	Day	Hour	Latitude	Longitude	Depth (fms)	°F corrected	Comments (corrections made by Phipps)
1775	6	20	12	66,9065	−0,9742	780	26	For the position provided on day 19.
	6	30	9	78,1333	9,4742	118	31	
	6	30	14	78,1333	9,4742	115	33	

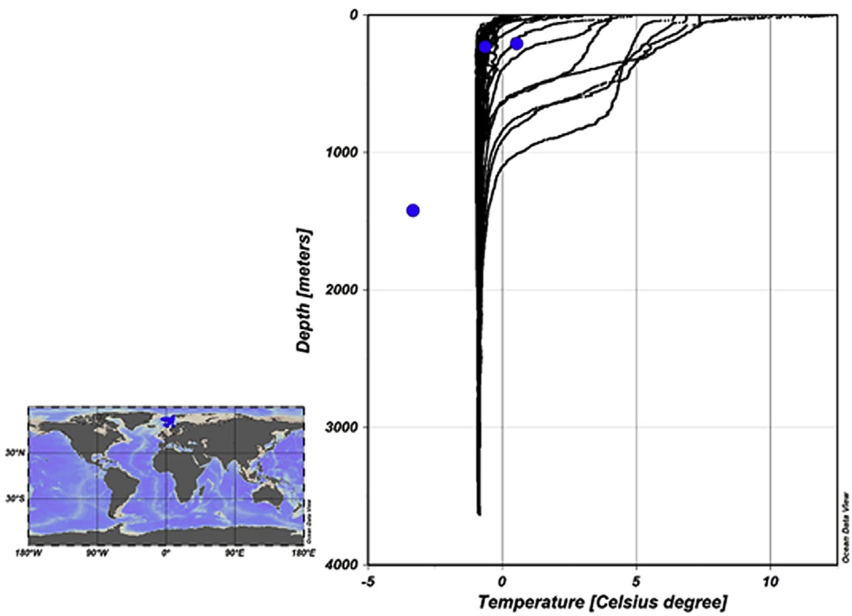


Figure 1.7 Vertical profiles of potential temperatures collected in June in polar regions during the years 2000–05 compared with data collected by Phipps in June 1774 (*blue dots*: *black dots* in printed version). The vertical profiles were downloaded from SeaDataNet (www.seadatanet.org). The graph has been obtained using Ocean Data View software. *Courtesy Schlitzer, Reiner, 2020. Ocean Data View, https://odv.awi.de.*

that the air temperature was 48.5°F and was calm almost all day; consequently, the low temperature at 780 fathoms was not contaminated by weather events. Any quality problems must be attributed to the measuring device.

The problems in using the thermometers are clearly presented by Camuffo (2002). Members of many societies (e.g., Accademia del Cimento in Florence, The Royal Society of London, and later Societas Meteorologica Palatina in Mannheim) stressed the need to have *a perfectly cylindrical tube … or at least a tube with a constant internal section along its entire length*. Improvements in glassmaking technology enabled scientists and technicians to confirm that the liquid inside the thermometer and the glass both expanded when the heat increased. Fahrenheit used two different liquids, mercury and spirit, to evaluate the law of expansion, obtaining different results. At the end of the 18th century, various volumetric expansions of spirit and mercury were verified, and calibration methods were suggested (Camuffo, 2002).

James Six (1731–1793) invented a maximum and minimum thermometer (Six, 1794) which began to be a commonly used tool during most voyages of exploration. The thermometer was invented in 1782, but the book that described it was published 12 years later, post-mortem. The thermometer contained mercury (the colored or gray part in Fig. 1.8) and spirit

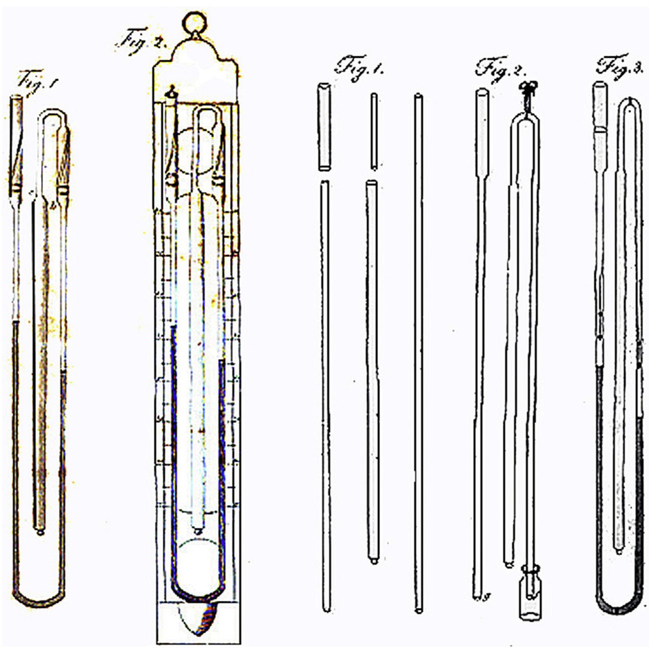


Figure 1.8 The Six's thermometer and the different parts showing the sections of the different parts of it (Six, 1794).

of wine. The expansion of the latter pushed the mercury upwards into the tube on the right. "Within the small tube of the Thermometer, above the surface of the mercury, immersed in the spirit of wine, is placed, on either side, a small index, so fitted as to be moved up and down as occasion may require" (Six, 1794). A magnet was used to restore the position of the metal needle (McConnell, 1982).

Specific gravity and salinity

Specific gravity was measured instead of gravity. A definition of specific gravity was given (among others) by Becket (1775): "that which meant by the term Specific Gravity of bodies, being nothing more than the difference, or comparative weight of those bodies to that of a common water, we might easily find the specific gravity of any fluid, by weighing a quantity of it against an equal quantity of water." In a note, the author provided additional useful information: in hydrostatic calculation, water, as the standard from which all the respective gravities are taken, is reckoned as unity or 1, 10, 100, 1000, &c. as the case requires. The reference liquid selected was distilled water, differently from Marsili, who used rain-water (Marsili, 1681). From a practical point of view, there were many advantages in using distilled water, since it could be obtained by each "weight-keeper," also on board a ship at sea for many months, as was common at that time.

In the 18th century precision balances were introduced in response to scientific as well as commercial needs. They furnished accurate measurements of the specific gravity by defining a standard temperature for the reference water.

Phipps (1744–1792) provided, among other seafarers, information on the salt contained in sea water: "Sea-water contains chiefly a neutral salt, composed of fossil alcali and marine acid (muriatic or hydrochloric acid). It likewise contains a salt which has magnesia for its basis, and the same acid … The mother liquor now remaining, being evaporated, affords a vitriolic magnesia salt, which in England is manufactured in large quantities, under the name of Epsom salt (magnesium sulphate). Besides these salts, which are objects of trade, sea-water contains a selenitic salt (calcium sulphate), a little true Glauber's salt (sodium sulphate), often a little nitre, and always a quantity of gypseous earth suspended (sulphate mineral) by means of fixed air" (Phipps 1774). The measurements of salts in sea water were obtained by dissolving them in alcohol after evaporation of the water.

Distilled water

In *A Voyage toward the North Pole* Phipps (1774) mentioned the participation of experts in various scientific and engineering disciplines, including Dr. Irving who, in an appendix, examined the different methods of obtaining distilled water on board a ship. The distiller was a boiler with openings (the two holes on the back of Fig. 1.9) for cocks. The water was evaporated and forced into tubes that decreased in size and at the end of which distilled water was collected. To clean the tube, steam was forced through for one minute. To ensure maximum purity, the water was distilled until a third of the water originally introduced remained in the boiler.

The text interestingly notes that "The principal intention of this machine, however, is to distil rum and other liquors; for which purpose it has been employed with extraordinary success, in preventing an 'empyreuma' or 'fiery' taste."

Marine zoology

In that historical period, it was normal practice to collect samples of flora and fauna in order to acquire knowledge of the new lands that were discovered. During the voyage, Phipps' crew also recorded biological observations of mammals, fishes, amphibians, insects, etc. Flora and fauna were described and depicted in tables of high artistic value. Examples can be seen in Fig. 1.10.

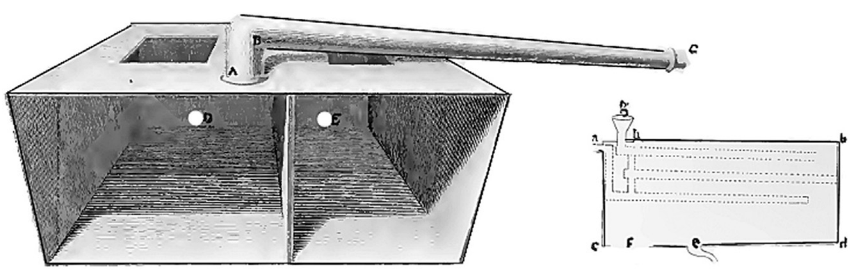


Figure 1.9 The distiller used by Dr. Irving on board the H.M.S. *Racehorse* and *Carcass* during the voyage toward North Pole in 1773.

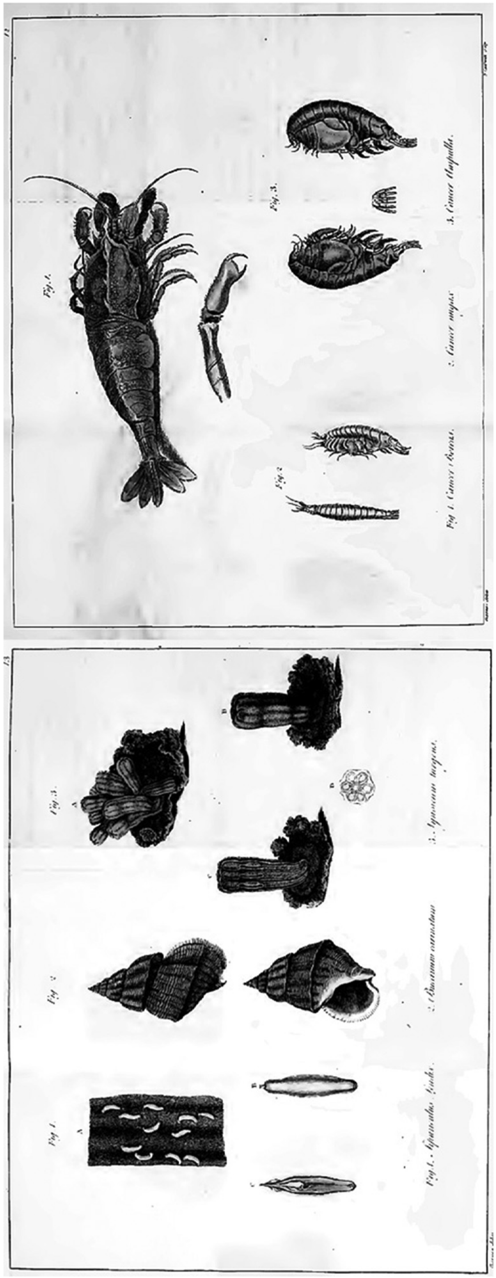


Figure 1.10 Biological observations during the voyage toward the North Pole by Phipps (1774).

19th century: A century of changes

> The correct analysis of sea-water being a difficult problem, the usual measure of the saltness of the sea, is by its specific gravity; this, though but an approximation to the truth, when the quantity of any particular salt only is considered, gives the saline contents in the gross with tolerable accuracy.
>
> William Scoresby, *An Account of the Arctic regions with a History and Description of the Northern Whale-Fishery*, 1820

The scientific revolution that began in the 16th century saw continuous and increasingly faster advances in mathematics, physics, chemistry, and biology (Preti, 1975). At the same time, there were far-reaching changes in industry, commerce and finance, and, in particular, a surge in the development of commercial relations between Europe and overseas lands that led to the construction of vast and efficient merchant and military fleets (AAVV, 2004). In the mid-19th century, the first submarine telegraph cables were laid. This made bathymetric knowledge increasingly necessary even in the deep sea.

The whaling industry increased significantly during this period. The search for new hunting grounds for the whale fishery led to the exploration of unknown regions, as in the case of William Scoresby Junior, who was cited by Melville (1851) in *Moby Dick or The Whale* ('*No branch of Zoology is so much involved as that which is entitled Cetology,' says Captain Scoresby, AD 1820*).

Whaling, an ancient activity that was practiced in the Basque region in the Middle Ages and later moved to the North Atlantic, was carried out in a predatory way. The hunting grounds were depleted considerably in number of animals to the extent that Maury published a map in 1851 showing that the best hunting region was no longer the Atlantic but the Pacific Ocean (https://commons.wikimedia.org/wiki/File:Maurys_whale_chart-1851.jpg; accessed September 2020).

Maury (1806−1873) was an important figure in the history of oceanography. His work *The Physical Geography of the Sea*, dated 1855, marked the boundaries between a geographical description of the seas and oceans and modern oceanography. (Note this book is still in print.)

He promoted the First International Maritime Conference (Houvenaghel, 1990; WMO, 1973), held in Brussels in 1853, "at the invitation of the Government of the United-States of America, for the purpose of concerting a systematical and uniform plan of meteorological observation at sea" (De Groote, 1853). The delegates of Belgium, Denmark, France, Great Britain, the Netherlands, Norway, Portugal, Russia, Sweden, and the United States agreed "on a plan of uniform observation, in which all nations might be engaged in order to establish a concerted action between the meteorologist on land and the navigator at sea."

During the conference, difficulties in concerting comparable and compatible observations were discussed. These difficulties were the variety of scales in use in different countries, the equipment used for observations, and their accuracy. With regard to scales, it was decided that each country could use its own, except for temperature, for which the use of the centigrade scale was agreed, possibly together with the scales of the different countries. The establishment of a *universal system of meteorological observations* was left to future initiatives. With reference to instruments, it was noted that barometers were approximate and gave poor results. It was therefore recommended to accurately determine the errors in them.

It was also noted that the errors for thermometers had been accurately determined. Furthermore, the use of *mercurial thermometers* was recommended. However, the delegates added that the data they produced was of little value, probably referring to their use for navigation. As for wind measurements, the conference decided that the use of anemometers on board ships was a *desideratum*.

The conclusion on instrumentation was important: "In bringing to a conclusion the remarks upon instruments, the Conference considered it desirable, in order the better to establish uniformity, and to secure comparability among the observations, to suggest as a measure conducive thereto, that a set of the standard instruments used by each of the cooperating Governments, together with the instructions which might to given to such Government for their use, should be interchanged."

The conference recommended to carry out the observations reported in Table 1.2. The conference also defined sampling intervals: "at least the position of the vessel and the set of the current, the height of the barometer, the temperature of the air and water should each be determined once a day, the force and direction of the wind three times a day, and the observed variation of the needle occasionally."

Table 1.2 Measurements to be done on board of ships as agreed at the First International Maritime Conference held in Brussels from August 23 to September 8, 1853.

Column 1 Date	Column 2 Hour	Column 3 Latitude Observed	For dead reckoning	Column 4 Longitude Observed	For dead reckoning	Column 5 Currents Directions	Velocity	Column 6 Magnetic variation observed
Column 7 Magnetic variation adopted or used	Column 8 Form and direction of the clouds	Column 9 Part of the sky not obscured	Column 10 Quantity of rain	Column 11 and 12 Winds Direction	Force	Column 13 Barometer Barometer	Temperat.	Reduced to the Temperat. of zero
Column 14 Thermometer for the air	Column 15 Thermometer with the wet bulb	Column 16 Temperature of the water at surface	Column 17 Temperature of the water at certain depth	Column 18 Specific gravity of the water				

It was also stated that any additional information reported in logbooks would be of great value.

The Brussels conference was a beginning for international marine meteo-oceanographic cooperation, and was followed by a series of initiatives having the aim to establish a uniform system of meteorological observations (Ballot, 1872). An international coordination and standardization of climatological practices was established during the First International Meteorological Congress held in Vienna in September 1873. The congress was a starting point for the establishment of the International Meteorological Organisation (WMO, 1973), that in 1952 was reestablished as an intergovernmental body: the World Meteorological Organisation (Zillman, 2009).

Deep sea soundings

Difficulties in sounding the deep sea were clearly indicated in this statement by Hjoert (1912): "It has often been said that studying the depths of the sea is like hovering in a balloon high above an unknown land which is hidden by clouds, for it is a peculiarity of oceanic research that direct observations of the abyss are impracticable."

The exploration and study of new lands and oceans sparked an interest in maps describing the trend of the seabed (Fig. 1.11). The methodology for determining the depth of the sea was described by Thomson (1873).

Traditional methodology consisted of a weight attached to a graduated line with strips of variously colored fabric. The distance and the color of the stripes indicated fathoms, tens of fathoms, and hundreds of fathoms, or, for the deep sea, the white stripes were fixed every 50 fathoms, the black every 100 fathoms, and the red every 1000 fathoms. When the weight (*a prismatic leaden block about two feet in length and 80 to 120 lbs in weight*) touched the seabed, an approximative measure of the depth of the sea could be made.

The maximum depth measurement with this system was about 3200 fathoms, beyond which a symbol was used on the bathymetric chart that was $\frac{\cdot}{3200}$ meaning *no bottom at 3200 fathoms*.

Deep-sea sounding was done while the ship was moving. When an accurate position was required, as in the case of bathymetric measurements near the coast, the position made reference to some fixed objects on the shore.

The measurements of the depth of the sea with this method were distorted by the currents that inclined the wire, and consequently provided

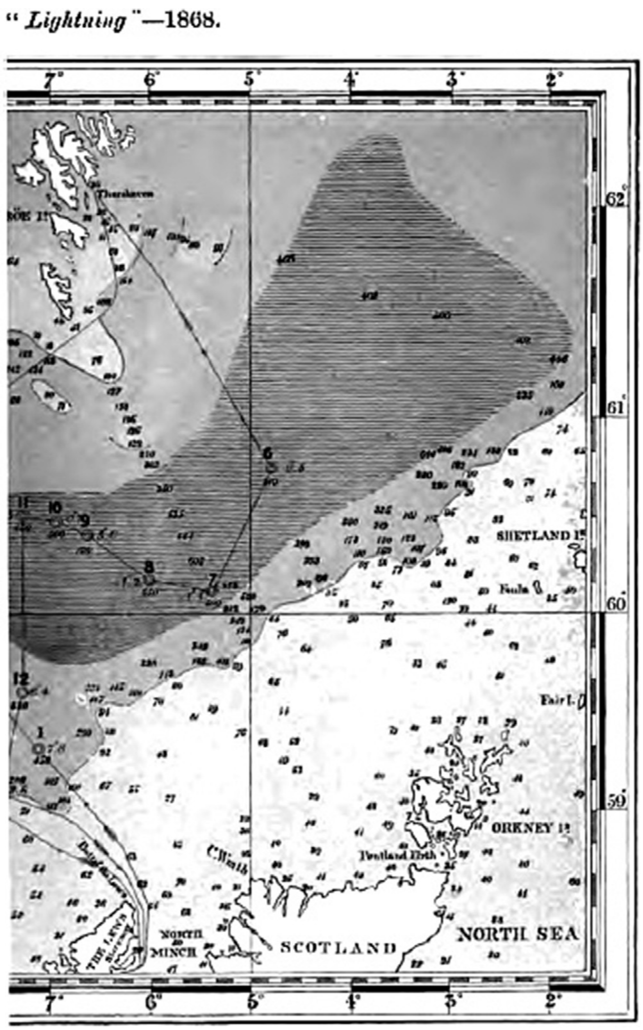


Figure 1.11 Soundings of the North Atlantic from Thomson on board the *Lightning* in 1868 (Thomson, 1873).

measurements higher than the true values. Thomson was aware of this and described another method adopted by the United States Navy. A 32- or 68-pound weight was attached to a fine line and thrown into the water. When the descent speed began to decrease significantly, the wire was cut. The depth of the sea was calculated from the length of the thread left on board the ship. Thomson reported soundings of up to 50,000 fathoms produced by US Navy officers.

During the century, the sounding machine became more sophisticated. Sir William Thomson (Lord Kelvin, 1824–1907) developed a sounding machine using a steel wire instead of a hemp line, thus reducing friction in the water and the weight of the entire apparatus (Fig. 1.12). The Thomson sounding machine took up less space than the previous models, enabled greater speed, and due to less friction, a more perpendicular line and therefore greater precision (McConnell, 1982).

Temperature in the polar regions

In a sea perpetually covered by sea ice, there was initially considerable surprise in finding a sea surface temperature of about 2 ÷ 3.5°C at a latitude of 76–78°N. Measurements made in the polar regions showed that temperature increased with depth. The son of a whaler, William Scoresby Junior (1789–1857), made a significant contribution to the knowledge of the properties of the sea and currents in his book *An account of the Arctic Regions with a History and Description of the Northern Whale-Fishery* (Scoresby, 1820).

The recurrent problem with this type of measurement was to avoid contaminating the temperature at a certain depth with the sea water temperature detected by the thermometer during its rise to the surface. Scoresby devised an apparatus consisting of a fir cask, considered a poor heat

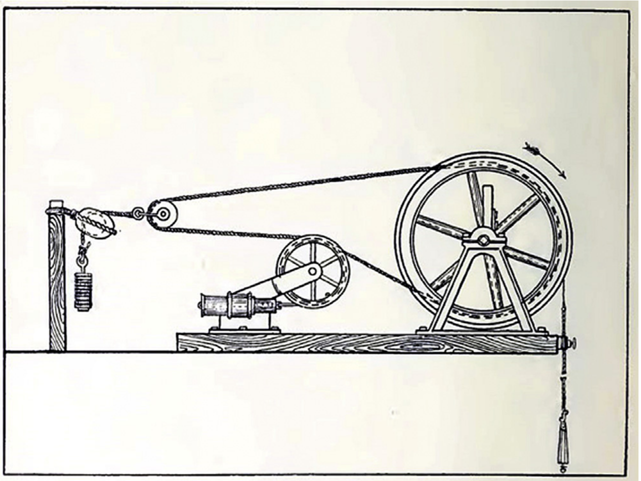


Fig. 5.—Thomson's Sounding Machine. (From Sigsbee.)

Figure 1.12 The Thomson (Lord Kelvin) sounding machine. *From Hjort, J., 1912. The ship and its equipment. In: Murray, J., Hjort, J. (Eds.), Chapter II in the Depths of the Ocean. MacMillan and Co., London, pp. 22–51).*

conductor, containing a thermometer and with two valves at its extremities. The cask was lowered to the desired height and left there for half an hour. During the ascent, the valves closed, maintaining the temperature value. But "… after a few experiments had been made, the wood of the cask became soaked with water; several of the staves rent from end to end; and the apparatus became leaky and useless." This was also a problem with Hooke's wooden balls that became water-logged at depth.

Subsequent experiments were not successful, despite the numerous suggestions of many marine experts including Cavendish; moreover, the use of Six thermometers proved to be problematic as they were extremely fragile.

To avoid any problems, Scoresby built an apparatus called "marine diver" (Fig. 1.13), which had the shape of an octagonal prism with a length

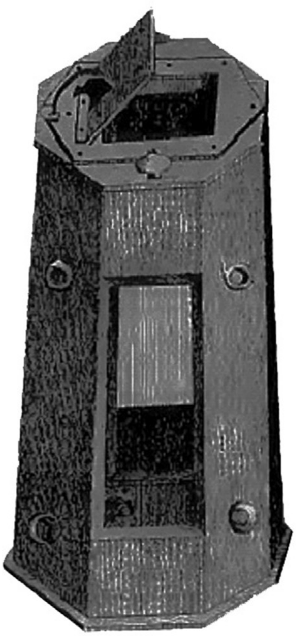


TABLE.

Lat.	Long.	Experiments on Sea-water.				Tem. of Air.	TIME. Da. Mo. Yr.	Situation of the Vessel.
		Depth in Feet.	Temp.	Specific gravity.	Colour.			
69.16'	9. 0' E	Surface	28.8	1.0261	Blue	12°	19 Apr. 1810	Ship beset in ice
—	—	300	31.8	—	—	—	—	—
—	—	738	33.8	1.0250	—	—	—	—
—	—	1380	33.3	1.0269	—	—	—	—
76.16	10.50	Surface	28.3	—	—	16	23 Apr. 1810	Ship frozen up
—	—	120	28.0	—	—	—	—	—
—	—	300	28.3	—	—	—	—	—
—	—	738	30.0	—	—	—	—	—
76.34	10. 0	Surface	30.0	1.0265	—	25	23 Apr. 1811	Ship frozen up
—	—	120	31.0	1.0264	—	—	—	—
—	—	240	35.0	1.0266	—	—	—	—
—	—	360	34.0	1.0268	—	—	—	—
*—	—	600	34.7	1.0267	—	—	—	—
77.15	8.10	Surface	29.3	1.0267	—	16	1 May 1811	Ship beset in ice
—	—	120	29.3	—	—	—	—	—
—	—	240	29.3	—	—	—	—	—
—	—	360	30.0	—	—	—	—	—
—	—	600	30.0	—	—	—	—	—
77.40	2.30	Surface	29.0	1.0267	Greenish	30	20 May 1813	Am. floes, &c.
—	—	300	29.3	1.0265	—	—	—	—
—	—	600	31.0	1.0262	—	—	—	—
79. 0	5.40	Surface	29.0	—	Olive gr.	34	20 May 1816	Moored to a floe
—	—	78	31.0	—	—	—	—	—
—	—	222	33.8	—	—	—	—	—
—	—	342	31.5	—	—	—	—	—
—	—	600	36.0	—	—	—	—	—
—	—	2100	36.0	—	—	—	—	—
79. 4	5.38	Surface	29.0	1.0269	—	38	21 May 1816	Am. floes & ice
—	—	4380	37.0	1.0265	—	—	—	—
80. 0	5. 0	Surface	28.7	—	—	40	7 June 1816	Ship beset
—	—	120	36.3	—	—	—	—	—
78. 2	0.10W	Surface	34.0	—	Blue	35	7 June 1817	Ice near
—	—	4566	38.0	—	—	—	—	—

* Down to this experiment, the apparatus used for bringing up the water, was the fir-cask; and the mode of finding the temperature, was by a common thermometer, after it came to the surface. Hence some slight change in the temperature might possibly take place during its passage upward; but, in all the subsequent experiments, a Six's thermometer accompanied the marine-diver, and consequently marked with accuracy the extremes of temperature through which it passed.

Figure 1.13 The marine diver constructed by Scoresby to measure temperatures at depths below the sea surface (left) and specific gravities and temperatures collected in the Arctic regions. *From Scoresby, W, 1820. An Account of the Arctic Regions with a Description of the Northern Whale-Fishery. Archibald Constable & Co. Edinburg, Hurts, Robinson & co, London.*

of approximately 35.5 cm, a diameter of approximately 13 cm at the top and 15.25 cm at the bottom. On opposite sides there were glass panes approximately 5.5 cm thick. With this apparatus and a reinforced "fir cask" Scoresby collected water samples and measured temperatures at various depths. In a certain sense, these were measurements made with protected thermometers, as the insulating material used for the "marine diver" ensured protection, but it isn't clear that they were protected from pressure.

The temperature values collected in the spring from 1810 to 1816 by Scoresby are shown in Fig. 1.14 and are compared with profiles collected in the same areas in the summer of 2006 and 2007. The differences are very significant and may be due to the annual/seasonal variability and the insulating capacity of the materials of the "marine diver" was most likely far from optimal.

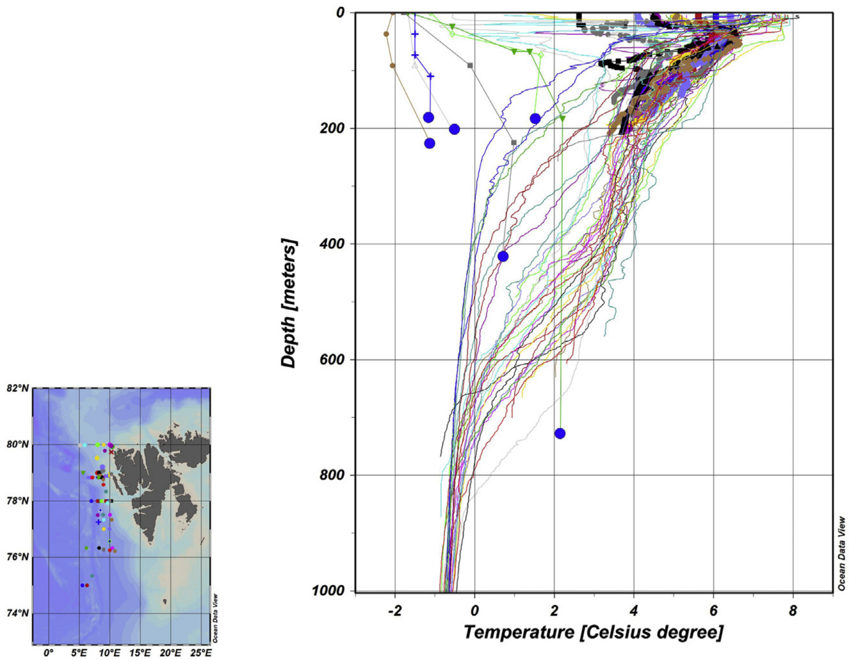


Figure 1.14 Comparison of potential temperature data collected by Scoresby (*lines* with *blue* [black in printed version] *big dots* at their end) with profiles collected in the same regions during summers 2006–07. These data are free and open in SeaDataNet (www.seadatanet.org). The graph has been obtained with the Ocean Data View software. The potential temperature was computed by using the thermodynamic equation of seawater (IOC, SCOR and IAPSO, 2010). *Courtesy Schlitzer, Reiner, 2020. Ocean Data View, https://odv.awi.de.*

The use of thermometers for the observation of air and water temperatures became part of data collection practice that was widely used, resulting in the recording of measurement errors. However, deep sea temperatures began to be measured accurately when thermometers protected from the effects of pressure came into use. The first to use this type of protected thermometer was probably a certain Captain Pullen in 1857 (Murray, 1912).

Detailed instructions for the measurement of sea temperatures were provided by Abbe (1838–1916). The methodology recommended for the acquisition of sea surface data consisted in a thermometer case to be lowered "to a slight depth below the surface." The case would "allow the water to flow freely through it, but shall then close and bring up from a given depth a sufficient amount of water with the enclosed thermometer, so that no change of temperature can possibly take place before the thermometer is read off" (Abbe, 1888).

Abbe was critical about the usual method "of rising a bucketful from the surface of the water and dipping the thermometer into it for a minute or less." Abbe considered that the errors associated with this latter method were greater than 0.5°F (about 0.3°C).

An interesting presentation of methodologies used to measure the sea surface temperature of the sea from uninsulated buckets has been provided by Folland and Parker (1995). Wooden buckets were recommended as a type to use in instructions derived from the First International Maritime Conference. These instructions were including location of sampling the sea surface temperature, location of the bucket after withdrawal from the sea, time-lapse between withdrawal from the sea and reading the thermometer, stirring and attempts to reduce the influence of the initial temperature of the thermometer and bucket. Correction to sea surface temperature were calculated by Folland and Parker by considering the bucket geometry and physical phenomena such as sensible heat transfer between the bucket or water surface and the ambient air, heat transfer by longwave radiation, influence of solar radiation from monthly 24-hour climatological averages of incident shortwave solar intensity over the sea surface, change in bucket temperature during the time lapse and influence of inserted thermometer on heat transfer rate and water temperature. The sea surface temperature was also affected by the ship speed. The errors associated with sea surface temperature were calculated to be around 0.11–0.30°C for data collected at the sea surface in the northern hemisphere in the period 1850–1900. In conclusion, the Folland and

Parker calculations are more optimistic than Abbe's ones, but questions on errors associated with measurements below the sea surface remained unanswered.

Abbe described a protected thermometer for deep sea measurements by means of which "the pressure effect is wholly annulled by adopting a special protection for the bulb. The whole thermometer is placed within a strong bottle or cylinder, which is then partly filled with water or mercury, above which some air remains; the protecting cylinder is hermetically sealed, and when lowered to the ocean depths the external pressure, compressing the cylinder somewhat, causes the water to rise and compress the air slightly. This latter slight increase of pressure is the only one that affects the thermometer bulb."

A functioning maximum and minimum protected thermometer (i.e., providing maximum and minimum temperature measurements in deep water) based on Six thermometers previously adopted by most investigators was described by Negretti and Zambra (Fig. 1.15) in a report to the Royal Society. An article on the instrument was published in the *Chemical News Magazine* (Negretti and Zambra, 1874).

A kind of in situ calibration was done by many scientists who compared the temperature near the seabed with that of the mud in the same place. For example, Ross (1777–1856) "employed, a register thermometer, the indications of which were occasionally compared with the temperature of the mud and earthy fragments of various kinds which he raised from the bottom of the sea, by an appropriate instrument of his own contrivance; as this mud, both from the quantity raised, and from the manner in which it was confined, retained its temperature for a sufficient length of time not to be materially altered on reaching the surface" (Marcet, 1819).

Specific gravity and salinity

In an appendix to the book *A Voyage of Discovery*, Ross (1819a) presented an instrument, called hydraphorus (Fig. 1.16), for the collection of water samples at various depths, "during the voyage, with a view of ascertaining its specific gravity … This Instrument consists of a copper vessel, the body of which is cylindrical. The upper part, where the machinery is fixed, is square, having on one side a small aperture to admit water. This is covered by a circular plate in which another aperture is made to coincide with the former, when placed opposite the fleur-delis; a cover is fitted to protect this plate, the edge of which being divided into 800 equal parts, the aperture on the

NEW DEEP-SEA THERMOMETER.

MESSRS. NEGRETTI and ZAMBRA have recently communicated to the Royal Society the description of a new Deep-Sea Thermometer. For the purpose of ascertaining the temperature of the sea at various depths, and on the bottom itself, a peculiar thermometer was, and is, used, having its bulb protected by an outer bulb or casing, in order that its indications may not be vitiated by the pressure of the water at various depths, that pressure being about 1 ton per square inch to every 800 fathoms. This thermometer, as regards the protection of the bulb and its non-liability to be affected by pressure, is all that can be desired; but unfortunately the only thermometer available for the purpose of registering temperature and bringing those indications to the surface is that which is commonly known as the Six's thermometer—an instrument acting by means of alcohol and mercury, and having movable indices with delicate springs of human hair tied to them. This form of instrument registers both maximum and minimum temperatures, and as an ordinary out-door thermometer it is very useful; but it is unsatisfactory for scientific purposes, and for the object which it is now used it leaves much to be desired. Thus the alcohol and mercury are liable to get mixed in travelling, or even by merely holding the instrument in a horizontal position; the indices are also liable either to slip if too free, or to stick if too tight. A sudden jerk or concussion will also cause the instrument to give erroneous readings, by lowering the indices if the blow be downwards, or by raising them if the blow be upwards. Besides these drawbacks, the Six's thermometer causes the observer additional anxiety on the score of inaccuracy; for, although we get a *minimum* temperature, we are by no means sure of the point where this minimum lies. Messrs. Negretti and Zambra have constructed an instrument on a plan different from that of any other self-registering thermometers. Its construction is most novel, and may be said to overthrow our previous ideas of handling delicate instruments, inasmuch as its indications are only given by upsetting the instrument. Having said this much, it will not be very difficult to guess the action of the thermometer; for it is by upsetting or throwing out the mercury from the indicating column into a reservoir, at a particular moment and in a particular spot, that we obtain a correct reading of the temperature at that moment and in that spot. The instrument has a protected bulb thermometer, like a syphon with parallel legs, all in one piece, and having a continuous communication, as in the annexed figure. The scale of this thermometer is pivotted on a centre, and being attached in a perpendicular position to a simple apparatus (presently described), is lowered to any depth that may be desired. In its descent the thermometer acts as an ordinary instrument, the mercury rising or falling according to the temperature of the stratum through which it passes; but so soon as the descent ceases, and a reverse motion is given to the line, so as to pull the thermometer to the surface, the instrument turns once on its centre, first bulb uppermost, and afterwards bulb downwards. This causes the mercury, which was in the left-hand column, first to pass into the dilated syphon bend at the top, and thence into the right-hand tube, where it remains, indicating on a graduated scale the exact temperature at the time it was turned over. The woodcut shows the position of the mercury after the instrument has been thus turned on its centre. A is the bulb; B the outer coating, or protecting cylinder; C is the space of rarefied air, which is reduced if the outer casing be compressed; D is a small glass plug, on the principle of Negretti and Zambra's patent maximum thermometer, which cuts off, in the moment of turning, the mercury in the column from that of the bulb in the tube, thereby insuring that none but the mercury in the tube can be transferred into the indicating column; E is an enlargement made in the bend, so as to enable the mercury to pass quickly from one tube to another in revolving; and F is the indicating tube, or thermometer proper. In its action, as soon as the thermometer is put in motion, and immediately the tube has acquired a slightly oblique position, the mercury breaks off at the point D, runs into the curved and enlarged portion E, and eventually falls into the tube F, when this tube resumes its original perpendicular position. The contrivance for turning the thermometer over may be described as a short length of wood or metal having attached to it a small rudder or fan: this fan is placed on a pivot in connection with a second; on the centre of this is fixed the thermometer. The fan or rudder points upwards in its descent through the water, and necessarily reverses its position in ascending. This simple motion, or half-turn of the rudder, gives a whole turn to the thermometer, and has been found very effective. Various other methods may be used for turning the thermometer, such as a simple pulley with a weight which might be released on touching the bottom, or a small vertical propeller which would revolve in passing through the water. Messrs. Negretti and Zambra have also adopted a very simple and inexpensive clock-work to their thermometer, and by these means an observer may have a record of the exact temperature at any hour of the day or night. We need hardly say of what utility the instrument will prove to meteorologists, and even manufacturers, to whom an exact *record* of temperature is of importance. Hitherto we have had no simple and inexpensive instrument adapted for this purpose: the thermograph in use at most observatories is an elaborate and expensive apparatus, which, in connection with photography, will record on paper the temperature during day or night; it necessitates the use of gas, or any artificial light, and of course is only available to persons who can have a building specially adapted for it.

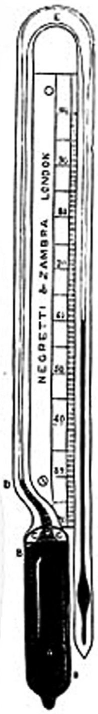
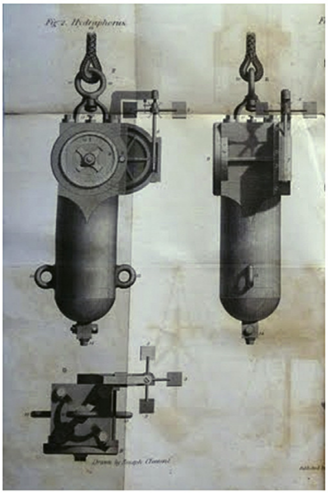


Figure 1.15 The Negretti and Zambra thermometer. It was an improvement of the Six thermometer which was *very fragile*.

outside can be set to the required position. On the opposite side of the instrument there is a similar plate or wheel, which moves the former; and both are turned by the rotator as the Instrument descends, by the action of the water, the former in a proportion as 1 is to 100. The vanes of the rotator are made to fix in any position, which by actual experiment may be found to be applicable to a graduated wheel; and it is evident, that by placing them in a more vertical or horizontal position, a greater or lesser depth may be obtained during a revolution of the graduated plate; but when it has been once regulated, to agree in a convenient proportion, to these divisions, it will not be necessary to alter the vanes, as the aperture may be easily set to the exact



DESCRIPTION. FIG. 2.

F — Section of the machinery.
G — Upper part or rope of the instrument.
E — The instrument complete.
No. 5 — Vanes of the rotator.
6 — Rotator with spiral wheel.
7 — First large wheel turned by the rotator.
8 — Small wheel on the same axis, a. No. 7.
9 — Second large wheel turned by No. 8.
10 — Swivel to which the rope is attached.
11 — Spring air valve.
12 — Aperture in the wheel coinciding with one in the cylinder to admit water.
13 — The ears for attaching additional weights.
14 — Stop cock.
15 — Rope.

Figure 1.16 The hydraphorus invented by John Ross to sample waters at different depths. *From Ross, J, 1819b. A description of the deep sea clams, hydraphorus and marine artificial horizon. Strahan and Spottiswoode, London.*

depth from which the water is required. At the top of the instrument there is a spring valve, for the double purpose of allowing the air to escape when the water enters, and to let the air enter when the water is drawn off by the stop cock at the bottom, and in the latter case the valve must be moved up by hand."

Many sea water samples were not analyzed by scientists participating in the expeditions. In an article of the "Philosophical Transactions," Marcet (1819) noted this fact by expressing concerns about the loss of data and information: "In the course of few years I became possessed, through the kindness of several friends, of a great variety of specimens of sea water; and I was preparing to examine them, when a most deplorable accident deprived science of the sagacious philosopher from those friendship and enlightened assistance I had anticipated so much advantage. Procrastination and delay were the natural consequence of this misfortune; and I should probably have entirely lost sight of the subject, had not my intention been again directed to it by the late expeditions to the Arctic regions, and the great zeal and kindness of some of the officers engaged in them, in procuring for me specimens of sea water, collected in different latitudes, and under peculiar circumstances, so as to add greatly to the value of those which I previously possessed."

Another problem that was given considerable attention in Marcet's analysis concerned the conservation of sea water specimens. The water collected at depth by a "cylindrical vessel having an opening at the top, and a similar one at the bottom, each closed by a flap or valve opening only upwards, and moving freely upon hinges" was poured into a corked bottle. The sample taken at the desired depth could be contaminated by other water during the ascent of the "vessel" (container). Various improvements to the water collection devices were therefore proposed. Furthermore, the conservation of the samples in corked bottles could be imperfect and therefore cause the evaporation (or contamination) of the water they contained. Marcet remarked that in the records of the Arctic explorers there was a wealth of information about the weather, the state of the sea, and details of navigation, i.e., what we now call "metadata" (Fig. 1.17).

Alexander Marcet (1770–1822) and later John Murray (1841–1914) came to the conclusion that salinity could not be determined by the direct evaporation of sea water. The best solution was to determine salinity by precipitating the components. In 1865 Georg Forchhammer (a Danish chemist) proposed to define a salinity value proportional to hydrochloric acid or chlorine content in sea water, as this was the most abundant and easiest to determine. The reagent for precipitating chlorine was silver nitrate for use in highly acidified sea water (Wallace, 1974).

A little-known Italian chemist, Giulio Usiglio (Sobrero, 2006), carefully analyzed the results obtained by Murray and Marcet, as well as the method proposed by Forchhammer, and suggested a method to find the saline composition using nonconcentrated sea water and then apply the precipitative method (Wallace, 1974).

Friedrich Mohr (1806–1879) was the first to introduce titrimetric analysis. He added a solution of potassium chromate to the sample of sea water, which colored the solution a light yellow. After a process with silver nitrate of known concentration, the solution turned a light pink-hazel color and all the chloride was precipitated (Wallace, 2002).

Marine zoology

Marine zoology observations were made on many expeditions. John Ross (1819a) probed Baffin Bay and Davis Strait for white coral, shells, mud worms, snakes, and shrimps. Ross invented an apparatus called "Deep-Sea Clam" (Fig. 1.18) "to procure substances from the bottom of the sea in

Table I. *Specific Gravities of Sea Waters.*

Designation of Seas.	Nos. of Specimens.	Latitude.	Longitude.	Specif. Grav.	OBSERVATIONS.
Arctic Ocean.	1	66,50	68,30W	1025,55	Taken up by Captain Ross, in Sept. 1818, from a depth of 80 fathoms, with Sir Humphry Davy's apparatus. Temperature of the water at 80 fms. 30° ; at 200 fms. 29° ; at 400 fms. 28,5 ; at 670 fms. 25° ; at the surface 33°. Temperature of the air, 36°. Bottle labelled in Capt. Ross's own hand-writing, with all the above particulars.
	2	74,0	—	1025,46*	By Lieut. Parry, from the surface. The ship surrounded by ice in every direction. Temperature of the water 31°, of the air 34° ; 8 July, 1818.
	3	74,50	59,30	1026,19	By Lieut. Parry. Temperature of water 32°, of air 36°.
	4	75,14	4,49E	1027,27	By Lieut. Franklin, from the surface, 10 Sept. 1818.
	5	75,14	4,49	1027,27	By Lieut. Franklin, raised with the cylindrical machine, from a depth of 756 fms. Temperature of the water brought up 36°, of the air 35° ; 10 September, 1818.
	6	75,54	65,32W	1022,7 *	By Captain Ross, from the surface, 4 miles from the land ; 12 August, 1818.
	7	75,54	65,32	1025,9	By Capt. Ross ; from a depth of 80 fms. with Sir H. Davy's machine. Soundings 150 fms. 12 August, 1818.
	8	76,32	76,46	1024,05*	By Capt. Ross ; from the surface. Soundings 109 fms. 22 August, 1818.
	9	76,32	76,46	1026,22	By Capt. Ross ; from a depth of 80 fms. Temperature 30,5° ; 22 August, 1818.
	10	76,33	—	1026,64	By Lieut. Parry ; with Sir H. Davy's machine, from a depth of 80 fms. Temperature of the water 32°, of air 36° ; 21 Aug. 1818.
	11	79,57	11,15E	1026,7	By Lieut. Franklin, from a depth of 34 fms. Temperature of the sea at the surface 30,3°, at 34 fms. 33,2° ; of the air 35,2°.
	12	80,26	10,30	1022,55*	By Lieut. Franklin, 13 July, from the surface ; ship beset with ice ; 12 leagues from the Coast of Spitzberg. Temperature of the surface, 32,5°, of air 38°.
	13	80,26	10,30	1027,14	By Lieut. Franklin ; from the bottom, depth of 237 fms.
	14	80,26	10,30	1027,15	By Lieut. Franklin : from the bottom, depth of 237 fms. with Dr. Marcet's machine. Temperature of the bottom 35,5° ; 13 July, 1818.
	15	80,28	10,20	1026,8	By Lieut. Franklin ; from bottom, depth of 185 fms. surface being frozen. Temperature of the bottom 36⅝°, surface 32⅝° ; 15 July, 1818.
	16	80,29	11,0	1026,84	By Lieut. Franklin ; from a depth of 305 fms. being the bottom. Temperature of the air 36°, of the surface of the sea 32,2° ; 18 July, 1818.

N. B. The specimens marked * in the three first tables, cannot be taken into account in calculating the mean specific gravity of the waters of the ocean, their saline contents being much diminished either by the vicinity of large masses of ice, or of great rivers, which reduce them much below the average standard of density of sea water.

Figure 1.17 A table of water samples analyzed by Marcet and coming from many different voyages in the Arctic regions.

deep water." The instrument was able to take samples of substances at any depth and preserve the mud temperature on the bottom, allowing a comparison with the water temperature near the seabed.

The "marine diver" built by Scoresby for temperature measurements was also used to collect small fishes at different depths. The upper valve was replaced by a wire gauze, so that any animal that entered the apparatus during its descent was brought back to the surface together with the sea

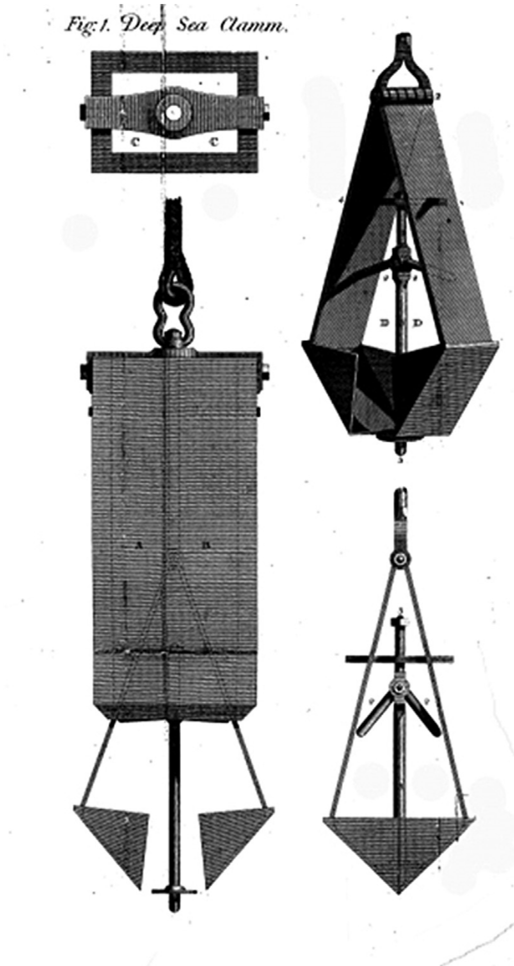
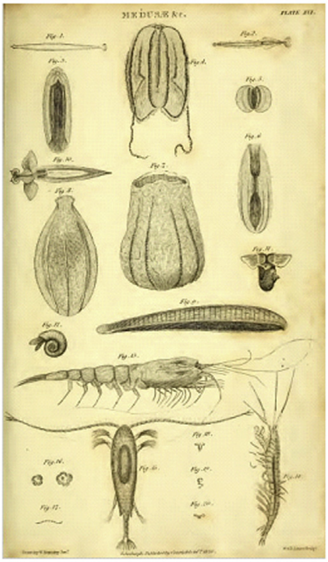


Figure 1.18 Ross' deep sea clam sounder and sampler (Ross, 1819b).

water. Examples of jellyfish and other animals observed by Scoresby are shown in Fig. 1.19. As he was the son of a whaler, he was very attentive to whale food.

"Deep-Sea Dredging Experiments" were conducted from 1868 to 1870 to explore the distribution of living things in the sea. The main questions behind the experiments were:

- the bathymetric limits of life
- laws governing geographic distribution



XVI. Figures of Medusæ and other animals, constituting the principal food of the whale.
1, 2. {Natural size.}
3, 4, 5, 6, 7 and 8. Medusæ, described in Vol. I. p. 548–550.
9. An orange-coloured animal, possibly of the same genus. I. p. 550.
10. Clio borealis or C. limacina. I. 544.
11, 12. Clio helicina. I. 543.
13. Cancer boreas. I. 542.
14. Squilla.
15. Beautiful little animal brought up by the marine-diver I. 545.
16, 17, 18, 19 and 20. Minute medusæ and animalcules. I. 545.

Figure 1.19 Figures of Medusae and other animals, constituting the principal food of the whale. On the right the description given by Scoresby (1820).

- representative species and zoological provinces
- influence of pressure, temperature, absence of light on life at great depths

The experiments were conducted in the Arctic regions, across the Atlantic, and in the Mediterranean. The main problems that needed to be solved to carry out the experiments lay in the possibility of dredging the bottom of the sea and of "send down water bottles and registering instruments to settle finally the question of zero animal life" (Thomson, 1873).

The first step in sampling the seabed was obviously to determine the depth of the sea. This was done with the method described in section 'Deep-sea sounding'. Thomson (1873) described many sampling tools, from the simple "Cup Lead" (Fig. 1.20a), for use in shallow water, to Brooke's sound apparatus (Fig. 1.20b), to the Bull-dog probing machine (Fig. 1.20c), a modification of John Ross' Deep-Sea Clam (McConnell, 1982).

Thomson also described other devices adapted to dredge the seabed. Some were simple "oyster dredges," or modifications of these with scrapers on both sides of the apparatus. In this way, regardless of which part touched the bottom, dredging was always possible. One of these apparatuses was

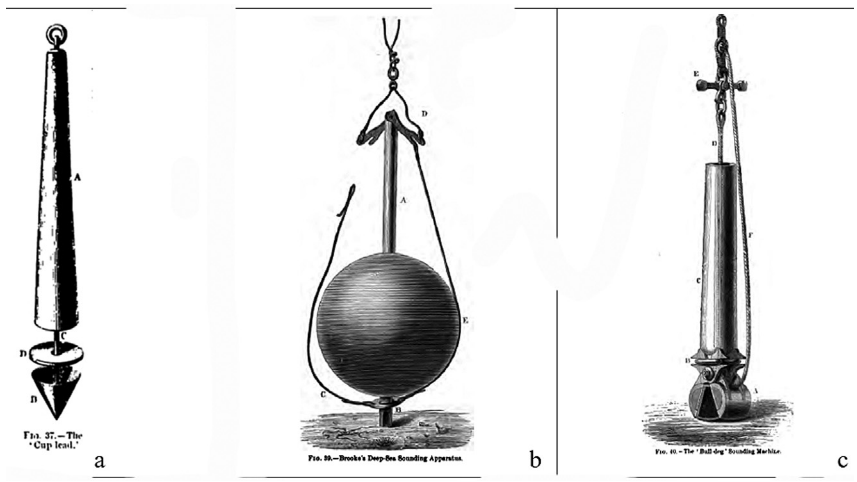


Figure 1.20 Sounding apparatus described by Thomson (1873). The Cup Lead was ending with an iron cup that was penetrating the mud or the sand at the sea bottom. As soon as the line to which the apparatus was attached was pulled up, sand or mud entered the cup and, theoretically, remained protected there by the shape of the instrument. The Brook deep sea sounding was composed by a hollow iron bar inside a shot. Touching the bottom, the tube filled with sand or mud and when it was pulled upwards it released itself from the round-shaped weight. The modified Deep-Sea Clam functioning like marine buckets used today.

introduced in 1838 by Robert Ball, a naturalist whose dredge (Fig. 1.21) was described in a section of the *Zoologist*: *A Popular Miscellany of Natural History* (Hepburn, 1847).

The other apparatus shown in Fig. 1.21 was designed to dredge the deep sea. The ship's engine was used to descend and retrieve the barge. An "accumulator," consisting of a weight anchored to the ship, supported the sampling apparatus and guaranteed the amortization of the impacts that could occur when the apparatus hit the seabed.

Surface currents

William Scoresby Junior was a true marine science enthusiast, and he was also the author of a description of surface currents derived from his own observations and from the drift of his ship or of shipwrecks. In his book, he also reported that a sinking area of polar waters (the black circle in Fig. 1.22) lay between Norway and Greenland.

Maps of surface currents were produced by many authors on the basis of information on the drift of bottles thrown into the sea by sailors. The bottles

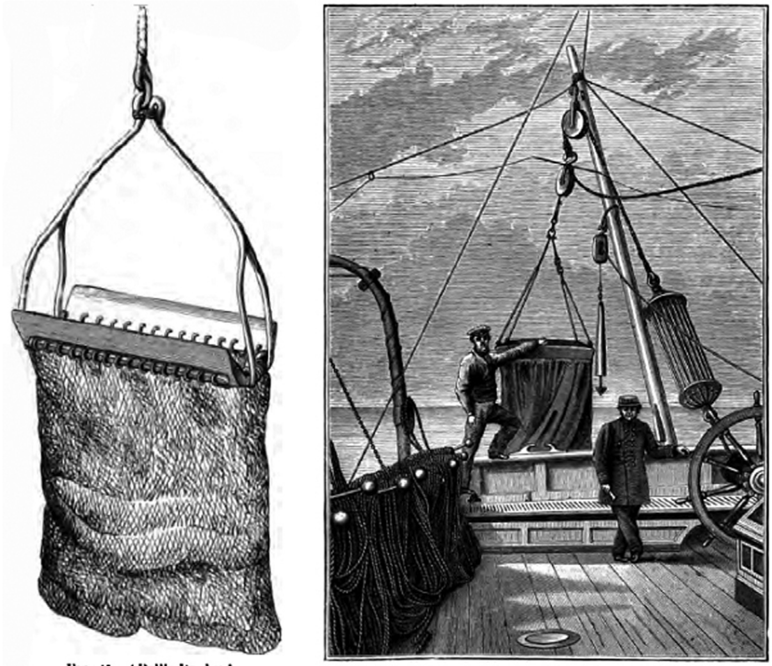


Fig. 45.—'Ball's Dredge.'

Fig. 46.—The Stern Derrick of the 'Porcupine,' showing the 'accumulator' the dredge, and the mode of stowing the rope.

Figure 1.21 Some dredging systems described by Thomson. The Ball's dredge (on the left) was a modification of the usually used oyster dredge. The deep sea dredging apparatus (on the right).

contained a document with the date and location of the release point. When collected by other sailors, the finding date and location were reported in logbooks. One of the maps derived from this measurement methodology was made by Maury (1855) and is shown in Fig. 1.22.

Around 1840, Matthew Fontaine Maury, a United States Navy lieutenant, conceived the idea of collecting information from logbooks to map winds and ocean currents with the aim of reducing ship travel time. He came upon this idea while he was serving as the director of the Depot of Charts and Instruments where he was assigned after a carriage accident that broke his legs and made it impossible for him to go to sea. This agency collected all of the ship logs and Maury realized that there was a lot of information there on winds and currents that he could share with the clipper fleet sailing from the east coast to San Francisco. Initially his results were shunned but when one clipper ship captain used them and cut 30 days off his transit, they became very popular. The popularity of Maury's analysis was such that

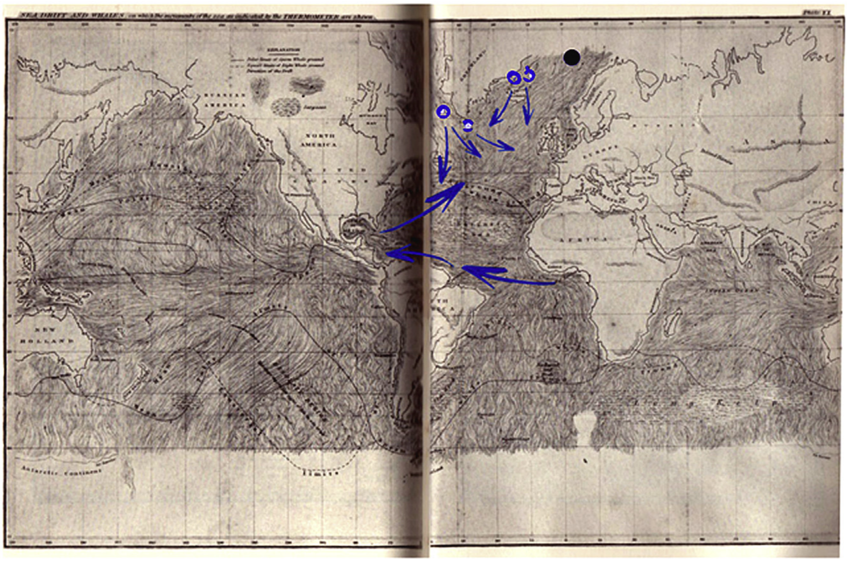


Figure 1.22 Map of surface currents derived from the indications in the book *An Account of the Arctic Regions with a Description of the Northern Whale-Fishery* by Scoresby (1820). The underlying map is by Maury (1855). The arrows indicate the currents as derived from descriptions in Scoresby's book or from indication of movements of wrecks (indicated by ships inside blue [dark gray in printed version] *circles*). The black *circle* indicates the area of waters' sinking. The Maury's map shows surface drifts and areas of whale catches.

he was later invited to visit Europe to share his methods. One of the best-known results is the book published in 1855, *The Physical Geography of the Sea and Its Meteorology*, in which Maury recorded observations during many voyages. The book was a popular success, but it also contained many errors in the interpretation of the observations. For example, Maury linked the Gulf Stream to the trade winds, an idea that was contested by Herschel (1867), who attributed the current to *an impulse that acts horizontally on surface waters* within a closed area. Herschel explained the concept with the analogy of billiard balls that slide on a plane following an impulse induced by the blow of the cue. Maury also wrongly attributed the salinity of the ocean to an undiscovered "salt fountain" somewhere in the ocean not realizing how the salts leached from the land and accumulated in the ocean after they were deposited by the rivers.

Farthest north

And you are to understand, that although the finding a passage from the Atlantic to the Pacific is the main object of this Expedition, and that the ascertaining the Northern boundary of the American Continent is the next, yet that the different observations you may be enabled to make, with regard to the magnetic influence, as well as such other observations as you may have opportunities of making in Natural History, Geography, &c. in parts of the globe so little known, must prove most valuable and interesting to science.

William Edward Parry, *Journal of a Second Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific*, 1824.

Farthest North is the book, written by Fridtjof Nansen (1861−1930), that describes the audacious voyage toward the North Pole from 1894 to 1896 (Nansen, 2020). On board of the topsail schooner *Fram* ("Forward" in Norwegian), the 13 crew members collected data on weather, drift currents, bathymetry. This ship was a unique attack on the rush to the pole. It was made out of green wood and had a rounded bottom so that when frozen into the ice the ship would rise up and not be crushed by the ice. The rudder could be raised into the ship and the propeller was shrouded for protection. The expedition was an attempt to reach the geographical North Pole by means of the east-west Transpolar Drift Stream (e.g., Damm et al., 2018). Nansen had surmised from evidence of wood from ship wrecks found on the coast of Greenland that the ice was flowing from east to west with a slight northward component. He planned to sail north-eastward as far as possible and then use a dog sled to reach the North Pole. He took along a number of Siberian huskies for this purpose. When it became evident that *Fram* was as far north as possible, Nansen departed the ship together with Hjalmar Johansen. The ice conditions were terrible with ridges and rafting, and the two explorers never did reach the North Pole and they had to return south to Franz Josef Land where they survived until a British Expedition found them and returned them to Oslo just a few days before the *Fram* and its crew also returned home to Oslo. The expedition was one of the most fascinating human adventures and was regarded as a *pioneer undertaking* (Nansen, 1900). The *Fram* was later used by Amundsen and his party in their successful trip to be the first to the South Pole.

During the expedition, Petterson insulated bottles were used to sample Arctic waters at various depths (https://folk.uib.no/ngfso/The_Norwegian_Sea/TNS-0330.htm; accessed August 2020). The complete set of measurements done during the *Fram* expedition to North Pole is available in the National Oceanic and Atmospheric Administration NOAA—National Snow and Ice Center NSDIC portal (https://nsidc.org/data/g02120; accessed August 2020). A representative temperature profile in the Arctic region has been provided by Nansen in his book *Farthest North* and is shown in Fig. 1.23.

The Nansen temperature data was collected during 2 days with a thermometer attached to a Petterson water bottle. The profile obtained with the data is compared with two temperature profiles collected with XCTD (eXpendable Conductivity—Temperature Depth) probes in September 1997 and available in the US National Oceanographic Data Center—World Data Center (NODC-WDC). Nansen modified the Petterson water sampling bottle to create the reversing Nansen bottle which became a standard in collecting routine hydrographic measurements.

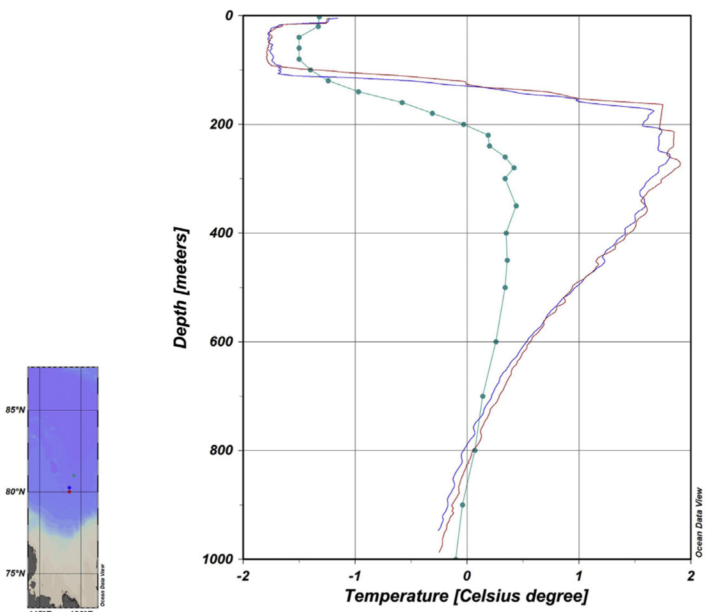


Figure 1.23 Comparison of temperature data collected by Nansen (*lines* with *dots*) with profiles collected in the same regions during September 1997. These data are free and open in NODC-WDC (https://www.nodc.noaa.gov/access/index.html). The graph has been obtained with the Ocean Data View software. *Courtesy Schlitzer, Reiner, 2020. Ocean Data View, https://odv.awi.de.*

Finally, there is a relatively good agreement between data collected at the end of the 19th century and those collected about 100 years later.

From physical geography of the sea to oceanography

Nature presents itself to meditative contemplation as a unity in diversity.

Alexander von Humboldt, *COSMOS: A Sketch of the Physical Description of the Universe*, 1844

Two apparently contrasting but complementary aspects coexisted in studies of the seas and oceans. Observations of currents and winds on the sea surface were obviously useful for navigation and, therefore, a geographical description facilitated "the art of navigation." At the same time, ideas and theories were presented on the relationships between winds and currents, currents and temperatures, and the consequences of density stratification.

These two aspects in the study of the sea were noted by Margaret Deacon (1971), who compared the work of Edmund Halley, a scientist, and the actions of William Dampier, a pirate, navigator, and explorer who wrote about the sea from a purely empirical and utilitarian point of view.

Papers on the physical geography of the sea (which included maps of winds, currents, and tides) were published during the 19th century (Murray, 1912; Deacon 1971). The meaning of the term "physical geography," a branch of "descriptive geography," was well explained, among others, by Herschel (1867) who wrote that it is "the business of a perfect 'descriptive geography' to exhibit a true and faithful picture, a sort of daguerreotype, without note or comment. Such comment, or at least one of such comments, it is the object of Physical Geography to supply." He added that any comment should be based on knowledge of the general laws of physics.

In his general considerations about winds and currents, Herschel specified the role of currents in the dispersion of material of terrestrial origin: "From meteorology we learn to refer the great system of aquatic circulation, which transfers the waters of every one region of the ocean, in the course of time, to every other, to the action of our trade-winds, and their compensating currents, the anti-trades; themselves the results of solar action in combination with the earth's rotation on its axis. By the oceanic currents thus arising, the material carried down by rivers, or abraded by the action of the waves (increased in their efficiency by the extent of sloping beach produced by the rise and fall of the tides), is carried off and dispersed abroad, or, it may be, collected by subsidence in deep and comparatively motionless hollows, or in eddy-pools."

Alexander von Humboldt (1769—1859) had a wider concept of physical geography: "Physical geography is not limited to elementary inorganic terrestrial life, but, elevated to a higher point of view, it embraces the sphere of organic life, and the numerous gradations of its typical development. Animal and vegetable life. General diffusion of life in the sea and on the land; microscopic vital forms discovered in the polar ice no less than in the depths of the ocean within the tropics" (Humboldt, 2005).

In the second half of the 19th century, scientists turned their attention to the physical structure of the world and the interrelationships between different natural phenomena. Alexander von Humboldt's ambition was to explain the entire physical world in his work *Cosmos*: *Essay for a Physical Description of the World* (Humboldt, 2005).

This "new geography," which appeared at the end of the century, placed cartography and discoveries in a more specialized and different context with respect to the new science: oceanography.

Helland-Hansen (1877—1957), in Chapter 5 "Physical Oceanography" of the book *The Depths of the Ocean*, clarified the temporal origin of the term *oceanography*: "In the middle of last century the idea of "physical oceanography"' did not exist, but in the course of a few decades it has become a widespread branch of knowledge, with a copious literature and bulky textbooks" (Helland-Hansen,1912).

The term "oceanography" appears to have been coined by John Murray (Rehbock and Benson, 2002), and in the 19th century *the development of the modern science of oceanography* began (Murray, 1912). The various passages were highlighted in a brief historical excursus by this scientist, who summarized them in three main elements (McConnell, 1982):

- scientific observations that have given a great boost to the study of marine biology;
- surveys in marine laboratories and international initiatives on the biological aspects of marine sciences and fisheries;
- physical exploration of the deep seas and their bathymetries, also in connection with the need to lay submarine telegraph cables.

In the second half of the 19th century, important institutes were established in Europe and in the United States for the study of ocean life (see Chapter 2: Data services in ocean science with a focus on the biology). An International Commission for Scientific Investigations of the North Sea was established at the end of the century with the participation of Great Britain, Germany, Holland, Belgium, Russia, Denmark, Sweden, and Norway. It should be noted that at that time the fields of marine biology, marine geology and marine chemistry were fairly well established leaving the term of oceanography to apply primarily to physical oceanography. This was basically the status in the early 20th century. It is important to realize that the emphasis in oceanography was the collection of new data from dedicated research ships and their analysis. The first group to involve dynamical analyses was the Geophysical Institute at the University of Bergen, Norway, which was founded in 1917.

The birth of modern oceanography

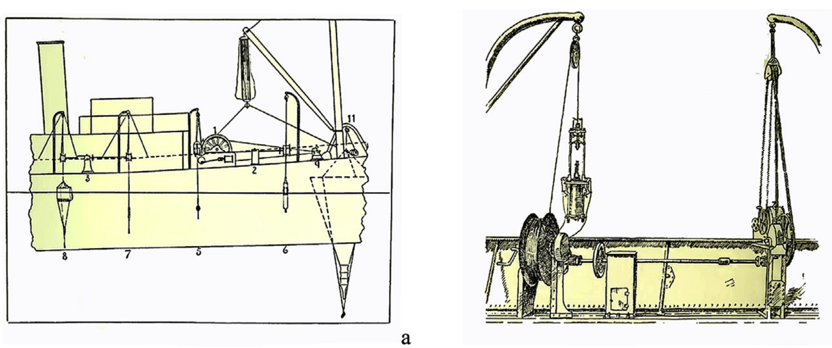
> Proud of our splendid, strong ship, we stand on her deck watching the ice come hurtling against her sides, being crushed and broken there and having to go down below her, while new ice-mass tumble upon her out of the dark, to meet the same fate.
>
> Fridtjof Nansen, *Farthest North*, 1897

Advances in oceanography were achieved with new instruments and increasingly diligent fieldwork, and also due to the development of mechanical tools. Steam winches began to be used from the end of the nineteenth century and, in calm weather, it was possible to operate different apparatuses simultaneously, as in the case of the Norwegian steamship "*Michael Sars*". Hjort (1912) provided an enlightening sketch of the "steamer" that had the ability to carry out physical investigations, as well as fishing and biology experiments: "On the starboard side there are two small winches, the forward one of 3 horsepower and the aft one of 1 horsepower. The forward winch (2), by means of a long axle drives a big reel with 6000 metres of wire, 3.5 mm. in diameter, for the hydrographical instruments and the Lucas sounding machine (6 and 5), and it can also be used to drive the big centrifuge (10) by means of a hemp line. By a similar arrangement the aft winch drives two drums with 2000 metres of wire, 3 and 4 mm. in diameter, for the vertical nets and hydrographical work in moderate depths" (Fig. 1.24).

Pelagic fish were caught with trawl nets; otter trawls were used to catch fish on the seabed, as well as plankton nets and other net systems that eventually made it possible to move from marine zoology to marine biology studies. Deep sea surveys made it possible to produce maps of physical properties and deposits of organic and nonorganic origin on the seabed.

New dredging apparatuses were built to take samples of the seabed containing animals to be classified, measured, counted, weighed, and subjected to chemical analysis. To obtain a good measurement of the depth of any instrument, the hemp lines marked at regular intervals were substituted by meter-wheels, communicating "with a clock-work arrangement with dials and hands, by means of which the length of wire run out can always be read off correct to within a metre" (Helland-Hansen, 1912).

At the beginning of the 20th century, scientists built several new tools. The Petterson-Nansen bottles had a very high insulating capacity and were equipped with a closure system activated with a messenger invented by Meyer, a scientist from Kiel, Germany, and with inversion thermometers (Fig. 1.25). Nansen observed that when "a water-sample is drawn up in an insulating water-bottle from a depth of 1000 metres, the temperature of the



a b

Figure 1.24 A sketch of the different apparatus on board the Norwegian steamer *Michael Sars*. Explanation in the text. In 1.24b on the left a Petterson-Nansen water bottle is represented, while on the right there is a sounding machine. A sketch of the different apparatus on board the Norwegian steamer 'Michael Sars'. Explanation in the text. In 1.24b on the left a Petterson − Nansen water bottle is represented, while on the right there was a sounding machine.

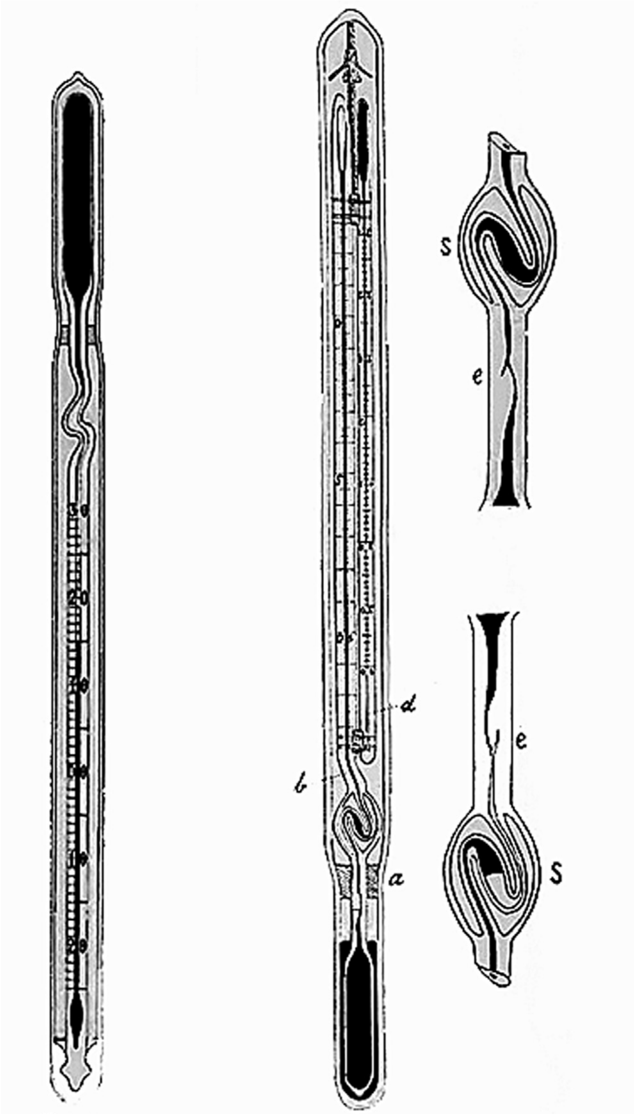


FIG. 155.
NEGRETTI-ZAMBRA
THERMOMETER

FIG. 156.—RICHTER'S REVERSING THERMOMETER.

Figure 1.25 The Negretti-Zambra (on the left) and Richter (on the right) reversing thermometers. Note both of these thermometers are completely enclosed in glass, making them protected from the ocean's pressure. *From Helland-Hansen, B., 1912. Physical oceanography. In: Murray, J., Hjort J. (Eds), Chapter V in the Depths of the Ocean. MacMillan and Co., London, pp. 210–306.*

water sample sinks a little." He also discovered that this temperature difference varies in different seas, for example, it was 0.06°C in the Norwegian Sea and 0.17°C in the Mediterranean.

The Negretti-Zambra reversing thermometers, widely used by early 20th century oceanographers, occasionally malfunctioned: sometimes the "mercury broke off not exactly at the narrowing" or there was an overflow of mercury "during the process of hauling up." An improvement was due to "C. Richter of Berlin, who altered the breaking-off arrangement so as to render it quite reliable, and formed the tube in such a way that no superfluous mercury could enter it during the ascent" (Helland-Hansen, 1912 – Fig. 1.25).

During the *Michael Sars* expedition in the North Atlantic, Helland-Hansen highlighted the difference between "the temperature (measured in situ), and the temperature that the water would acquire on account of the reduction of pressure if it were raised to the surface. The latter temperature has by the author of the present chapter been called the potential temperature, a term used in meteorology." Lord Kelvin studied the problems related to sea water pressure on volumes and temperatures and provided a formula by which changes in temperature were calculated. In order to determine the precision, both Negretti-Zambra and Richter reversing thermometers were used in about 600 *double determinations*, and differences of about 0.001°C were found, when using the Lord Kelvin corrections.

It is important to note that in the Richter thermometer there are essentially two thermometers with one having the "pig-tail" and one being a straight thermometer. The straight thermometer is known as the auxiliary thermometer and is used to correct the reversing thermometer reading for the warming of the thermometer that takes place at the surface. The procedure for reading reversing thermometers is that two people read each thermometer twice and the readings are averaged together for the final value. This reduces the errors introduced by humans reading thermometers. Realizing that the temperature would be affected by the pressure, unprotected versions of the Richter thermometers were introduced that were open at the top to allow the ocean to exert its pressure upon the thermometer. As a result, by properly processing the protected and unprotected thermometer readings it was possible to compute a very accurate estimate of the depth at which the sample had been collected.

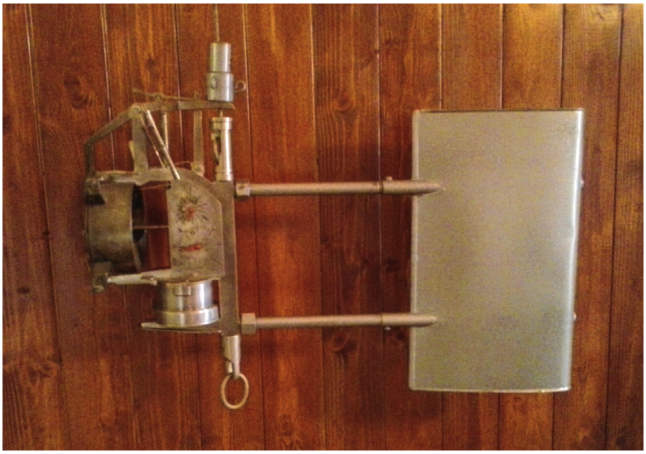


Figure 1.26 Ekman current meter. *Courtesy Enrico Muzi, The Historical Oceanography Society.*

Ekman, a Swedish student of Nansen's at the Bergen Geophysical Institute, built a current meter (Svensson, 2002), which was used for years by physical oceanographic communities (Fig. 1.26). It consisted of a propeller oriented by a vane and a mechanism that recorded the number of revolutions, a compass, and a recorder that provided a statistical indication of the current directions. Inside the current meter, metal balls in a reservoir fell, one at a time, onto sectors of the compass. The number of balls in each sector provided an indication of the direction of the main currents. For the German *Meteor* expedition (1925–27) Ekman built a repeating current meter that could be used when the *Meteor* was anchored in the middle of the Atlantic Ocean. Alfred Merz also built a modified version of Ekman's current meter.

An improved color titration method allowed the calculation of salinity in less than five minutes with an accuracy of one centigram of salt per kilogram of sea water (Fig. 1.27; that is a fairly low accuracy when compared with modern electronic methods). Precise instructions for the determination of salinity were given in the 'Bulletin de l'Institut Océanographique: Instructions pratiques sur la détermination de la salinité de l'eau de mer par la méthode de titrage de Mohr-Knudsen' (Thomsen, 1954). The density of the water was calculated by means of "Knudsen tables" after measuring the temperature and determining the salinity.

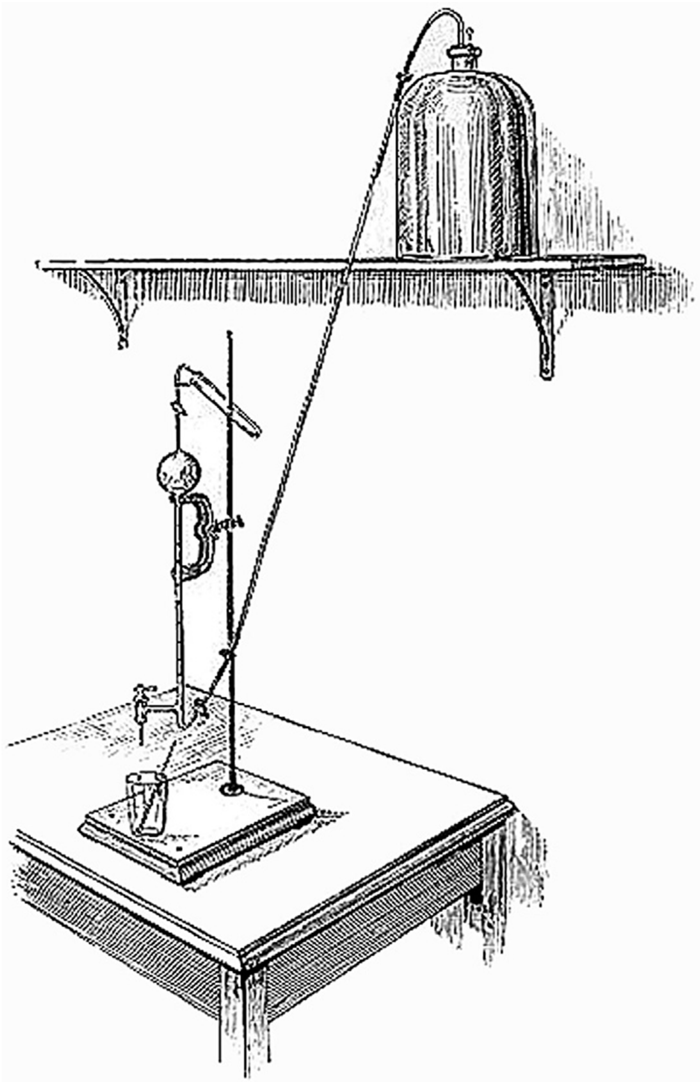


Figure 1.27 The titration apparatus for the determination of salinity. The reservoir above the burette was containing silver nitrate. The water sample was within the sphere of the burette. *From Hales, S., 1753. A letter to the president, from Stephen Hales. Phil. Trans. XVLII. For the years 1751 and 1752.*

Crossing the north-west passage

> From the days when the Phoenician sailors groped along the coasts of the Mediterranean, in the early dawn of civilisation, up to the present time, explorers have ever forged their way across unknown seas and through dark forests—sometimes slowly, and with centuries of intermission, at other times with giant strides, as when the discovery of America and the great voyages round the world dispersed clouds of ignorance and prejudice even in reference to the globe itself.
>
> Roald Amundsen, *The North West Passage*, 1908

The age-old dream was fulfilled by Roald Amundsen (1872–1928), who gave an idealistic aura to the quest for the passage to the north-west: "It is in the service of science that these numerous and incessant assaults have been made upon what is perhaps the most formidable obstacle ever encountered by the inquisitive human spirit, that barrier of millennial, if not primaeval ice which, in a wide and compact wall, enshrouds the mysteries of the North Pole" (Amundsen, 1908).

In the spring of 1903, Amundsen began preparations for the journey through the north-west passage. He chose a 45-meter fishing vessel (the Gjöa), embarking enough food and equipment so that the seven crew members could survive for 5 years. They set sail on June 16, 1903, from Christiania (Oslo) and, after 25 days, the explorers arrived near Cape Farewell, Greenland. During the night of July 25, the Gjöa was anchored in Godhaven, in the western part of Greenland.

The journey continued north and on August 8 the Gjöa entered Melville Bay, where the journey was slowed by icebergs and ice. On August 20, the seven men of the Gjöa reached Lancaster Sound and 2 days later Beechey Island, where the tragic fate of Franklin's lost Polar expedition aboard two ships, H.M.S. *Erebus* and H.M.S. *Terror*, had begun years earlier. This tragedy has inspired writers (e.g., Cussler and Cussler, 2009) and directors (e.g., *The Terror* [TV series]) and solicited many archaeological researches (e.g., Hickey et al., 1993).

On September 14, Amundsen and his men began preparing their first winter quarters in Gjöahavn (Fig. 1.28) in the southern part of King William Island, where they made a fortuitous encounter with the indigenous Eskimo

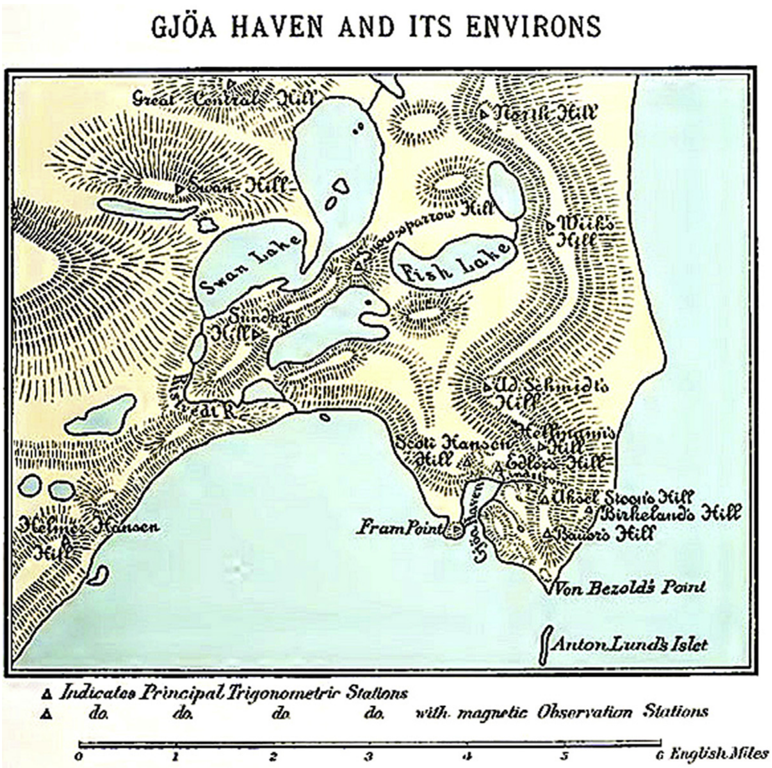


Figure 1.28 The position of Gjoahavn winter quarter south of King Williams Island. *From Amundsen, R., 1908. The North West Passage. E.P. Dutton Company, New York.*

people from whom the seven men learned how to survive in an Arctic environment with temperatures as low as −76°F (−60°C). The Norwegian team also learned how to use a dog sleigh pulled by sled dogs for transportation and animal skins for protection from the bitterly cold winter weather.

The summer of 1904 was dedicated to exploring and mapping the area and to the measurement of magnetic fields and meteorology. The Norwegians spent their second winter in Gjöahavn together with their Eskimo friends.

In the summer of 1905, the explorers continued their journey on the Gjöa westward through the Canadian Arctic Archipelago, reaching Herschel Island off the coast of Yukon in August (Fig. 1.29). The dream had come true and the north-west Passage had been fully explored!

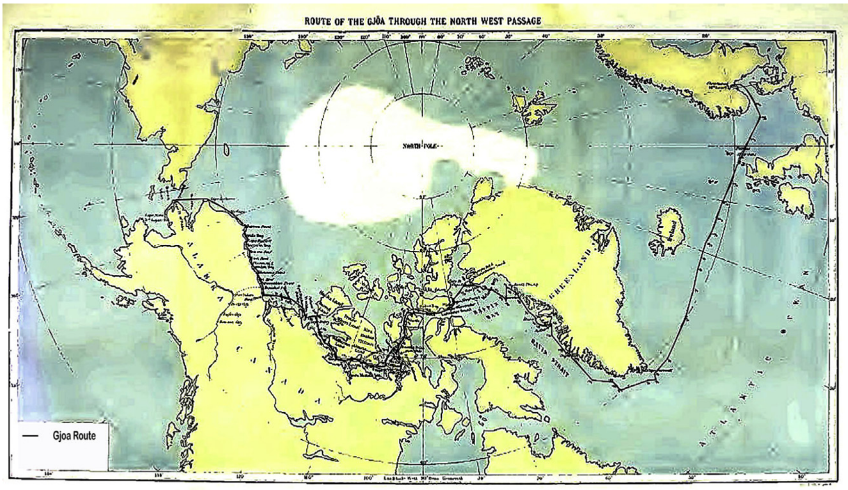


Figure 1.29 The Gjöa route from Christiania (Oslo) to Alaska's Pacific coast.

The deep sea, the global ocean, the physics of the straits, the dense formation of water, the functioning of the marine ecosystem now became new challenges.

Lesson learned

> I am confidently of opinion, that the greatest Credit belongs to those learned Men who have forced their Way through all Difficulties, and have preferred the Profit of instructing to the Grace of pleasing.
>
> Pliny, *Natural History*, 77 AC, translation by Philemon Holland, 1601

Oceanography began to be a science when a viable set of observations collected from learned people from different countries became available to scientific communities around the world. These early datasets grew out of practitioners of physical geographers who applied their interests to the ocean. From the outset, it required collaboration among observers, scientists, and laboratories. It soon became clear that a fundamental requirement in collaborative marine studies is the comparability of the data obtained from the participating research groups, regardless of the country of origin.

An official starting point for effective international collaboration was marked by the Congress held in Brussels in 1853, motivated by the works of Maury. Under the aegis of King Leopold, the nations interested in trade (Belgium, France, Great Britain, Norway, Russia, Sweden, the Netherlands) agreed to establish a uniform system of observations. Other countries subsequently offered their collaboration: Austro-Hungarian Empire, Brazil, Chile, Kingdom of Sardinia, Prussia, Spain, the free cities of Hamburg and Bremen, as well as the Papal States (Manzella, 1992).

The first phase in the history of oceanography was an empirical knowledge resulting from surveys of navigators and explorers. Physical geography was followed by the study of flora, fauna, and geological surveys, and finally a marine science was established with the foundation of marine laboratories and stations, university curricula, and national research programs.

We can reasonably believe that the beginning of "best practices" stems from investigations that were established in the 17th century by *persons of great repute*, such as Boyle and Hooke (e.g., Shaw, 1738).

Best practices

Phipps (1774), Scoresby (1820), and collaborators identified one of the actions to be performed before and during data collection, i.e., a knowledge of the measuring apparatus and related work methodology. Dr. Irving, a member of Phipps' scientific team, was familiar with the functioning of Cavendish thermometers, the nonlinearity of the responses, and the compression effects. Scoresby, after experiences with various devices, invented the "marine diver" that, to a certain extent, protected the thermometer from the effects of compression. To collect animals from the bottom of the sea, Ross (1819a,b) invented the Deep-Sea Clam.

Intercomparison of instruments was another element of attention by many scientists. During the voyage toward the North Pole, Irving conducted experiments with the Cavendish and Fahrenheit thermometers at different temperature values (called *heats* by the author) and found significant differences. However, the consistency of the comparison cannot be assessed, as no details have been provided (Phipps, 1774). It should be remembered that these early instrument comparisons were very new because there were no established standards against which any of the observations could be measured.

It is not easy to define what "heat" in the ocean is. Since the 17th century, "heat" was empirically measured with physical parameters such as the height of the mercury column in a glass tube. In principle, the concept of temperature is linked to the thermodynamic properties of bodies (e.g., Rumer and Ryvkin, 1980). The temperature can therefore be considered as an empirical measure of the level of thermal energy. The advection/diffusion of "potential temperature" introduced by Helland-Hansen (1912), has been interpreted as advection/diffusion of heat, as in (for example) MacDonald et al. (1994), where the heat flux was calculated by multiplying the potential temperature flux per unit area. McDougall (2003) demonstrated that the potential enthalpy flux can be called "heat flux" and introduced the "conservative temperature" a variable proportional to the potential enthalpy.

The concepts underlying the methodologies and technologies are therefore necessary to make the right measurements and since the 17th century *Persons of Best Repute* have recommended some specific actions to ensure the correctness of the experiments (observations), identify and deal with errors and omissions, and finally document experimental activities (paragraph 2).

The expertise of scientists and staff with a hands-on knowledge of tools and data has been fundamental to ensure the highest possible quality of the data with the technologies existing at that time.

Importance of standards

Chapter 4 of this book discusses the data quality dimensions. Three main pillars form the basis of collaborative studies, as part of the lesson learned from the history of oceanography:

- Common standards: there is a minimum level of quality control to which all oceanographic data must be subjected. The data must be qualified by further information relating to the measurement methods and subsequent data processing compared against some well-established standards.
- Consistency: the data collected by different groups should be as consistent as possible.
- Reliability: to serve the research community and others, the data must be reliable and this can be best achieved if the data has been analyzed against internationally accepted standards.

These requirements lead to the definition of common units, certified reference materials and analysis techniques, including sampling, pretreatment of samples, transport, and storage. From a historical point of view, the first attempt to define several standard procedures to be adopted internationally was made during the First International Maritime Conference, held in Brussels in 1853.

More effective resolutions were agreed during the International Conference for the Exploration of the Sea, held in Stockholm, 1899 (Trybom, 1900). In particular, it was stressed that "international co-operation is the best way of arriving at (scientific) satisfactory results." It was important to have common "meters" for measurements of the many properties of sea water. The agreements included hydrographic and biological works "in the northern parts of the Atlantic Ocean, the North Sea, The Baltic and adjoining seas." The establishment of a central office responsible for, among other things, *the control of the apparatus to ensure the uniformity of methods*, was recommended.

In Appendix II of the conference recommendations, Nansen stated the need for standards (Fig. 1.30) and, in particular, he recommended that there should be a central laboratory to produce and distribute standard sea water.

On the basis of this recommendation, a standard sea water called "Normal Water" was subsequently produced initially by the Hydrographic Laboratory in Charlottenlund (Denmark) and after by the Danish Biological Station housed in Charlottenlund Slot (e.g., Charlottenlund Palace), from 1935 (Thomson and Emery, 2001; Thomsen, 1954). This "standard" was also called "Copenhagen Water."

APPENDIX II.

In connection with the central bureau there should be a central laboratory, where, amongst other things, the following work might be carried out:—

1. The various methods for determining salinity, temperature, gases, plankton, etc., of the sea should be carefully tested, in order that standard methods may be fixed.

2. The various apparatus and instruments now used for hydrographical and biological research should be examined in order to settle which are the most trustworthy. Experiments may also be made to improve the apparatus and instruments, or to construct new and better ones.

3. Instruments and apparatus used in the investigations should be approved and tested at certain intervals at the central laboratory.

4. The water-samples sent by the workers of the participating states should be analysed and examined at the central laboratory, from which also samples of standard water should be provided. (See A. IV.).

Figure 1.30 The recommendations for standards agreed during the International Conference for the Exploration of the Sea, held in Stockholm, 1899). The appendix was written by Fridtjof Nansen.

Conclusions

Today many marine observation and data collection initiatives are promoting the free sharing of data with the main objectives of supporting research, making data available to the public, promoting innovation, and supporting the blue economy. This is, in part, a consequence of the abundance of data available today with satellites transferring data from a variety of autonomous platforms resulting in a plethora of data that greatly exceeds the number of interested oceanographers today ready to analyze these data.

The use of data requires well-defined quality assessment and quality control procedures, reference methods, and interlaboratory exercises. All these elements are essential components of oceanographic data management.

The reuse of data normally involves the use of data collected for purposes that vary from researcher to researcher. Reuse therefore requires the integration and harmonization of data from different sources (see Chapter 4 of this book). This is particularly important for the production of historical series (Fichtinger et al., 2011).

The need for standards has been addressed as one of the most important actions in collaborative studies (e.g., Tenopir, 2011). Use of internationally agreed upon standards allows the creation of products "by knitting together data from different sources, ensuring continuity and coherence across borders and across different disciplines" (Shepherd, 2018).

The comparison of measurements made by different laboratories and different campaigns in many cases led to the identification of discrepancies that indicate inconsistencies in the preparation of calibration standards. Intercalibrations, certified reference materials, clean room techniques, qualified personnel, etc., were not sufficient to guarantee good data quality. Sampling strategies and methodologies for data collection, sample pretreatment, transport and storage have been identified as an integral part of quality assurance and good measurement practices.

Data quality control aims to provide users with information on the errors they contain (IOC and CEC, 1993; Consortium for Ocean Leadership, 2013). Fichtinger et al. (2011) analyzed problems related to the combination and integration of data from different sources. The authors stressed that data integration also requires their harmonization, and they defined an abstract data management scheme derived from data and product quality specifications. The complete abstract scheme includes data evaluation to ensure relevance, reliability and fitness for purpose, adequacy, comparability, and compatibility (see Chapter 4 for further details).

The Scientific Committee for Ocean Research (SCOR) is today the most relevant international organization for the development of marine observation norms and standards. Within the SCOR, dedicated working groups are developing and making available algorithms for calculating oceanographic parameters. Among the most important results of the SCOR working groups worth mentioning are the thermodynamic equation of state of sea water and the numerous studies on the harmonization of data that underpin the development of best practices.

The United States Integrated Ocean Observation System (IOOS) has instituted an authoritative Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD). The procedures include information on sensors and measurement methodologies to ensure the best use of the data. The QARTOD documents and INSPIRE data specifications (https://inspire.ec.europa.eu/data-specifications/2892) are based on the same concepts and schemes that allow for easy interoperability.

To conclude this chapter, it would be fair to say that today's practices on the use of scientific data of the ocean are the natural evolution of the debates that began centuries ago. The methodological and technological changes have been very rapid over the past century, and there is the risk of not understanding how and why we have reached our current situation. The introduction of electronic methods and satellite data transfer has revolutionized the data collection platforms making many of them autonomous. The necessarily brief presentation of this chapter aims to provide some bibliographic elements that students and scholars can use to deepen their understanding of the themes they prefer.

Acknowledgments

Public and private libraries and collections have provided the materials for this chapter, including the libraries of the Italian National Research Council (CNR), the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), and the National Institute of Geophysics and Volcanology (INGV). During their activities, the authors had the opportunity to consult the libraries of many institutes and, in many cases, they were struck by the beauty of the hand-coloured drawings contained in antique biology books. Reproduction work carried out by both the public and private sectors is of inestimable cultural importance for the dissemination of knowledge. Reiner Schlitzer and his team have kindly allowed the use of Ocean Data View in this chapter.

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