Knowledges

How Oceanography made the Sea Legible

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"Ocean Literacy", Present and Past: An Introduction

"The ocean is the defining feature of our planet." Based on this central insight from the earth sciences, a number of renowned US national organizations published a programmatic list of principles in October 2005 to promote the concept of "Ocean Literacy".[1] The institutional network of governmental organizations, environmental foundations, learned societies, educational institutions and conservation organizations campaigns for a national standard of ocean science education that shifts the focus from the earth's landmasses to the earth's water bodies. In the aim to render the sea intelligible in the same way that the land became "legible" through modern surveying and mapping techniques (Scott 1998) the network strives to raise attention to the circumstance that the sea covers about 70 percent of the earth's surface. Planet Earth is a Planet Ocean; it literally is the Blue Marble that was perceived first from outer space in the 1960s and continues to attract our attention [Figure 1.1]. The iconic display of blue and white, brown and green was perceived as signifying intricate processes of life on earth that were held to be unique in the known universe. Meanwhile the color blue has moved to center-stage. The network's seven essential principles highlight this contemporary understanding of the earth's "one big ocean" and its climate and ecosystem functions, its wealth of nutrient, mineral and energy resources and its increasing exploitation as the planet's largest dumping site.

The Ocean Literacy network's call for a deeper ocean knowledge and mastery connects to the rising fields of "Blue Ecology" on the ocean as an environmentally critical infrastructure and "Blue Economy" on the ocean as economic resource (Armitage et al. 2018; Holm et al. 2001; Rozwadowski 2018). Recently, also the "Blue Humanities" have formed to address ways of knowing the sea through the arts and literature and through historicizing the ocean (Gillis 2013; Gillis/Torma 2015; Mentz 2015). Evidently, the significance of the sea in culture and society has not diminished but increased over time. And yet, Ocean Literacy principle no. 7 acknowledges that "the ocean is largely unexplored". Ocean-going expeditions have been surveying the sea in breadth and depth since the mid-nineteenth century. Nevertheless, human access to the oceans has remained so limited that until the present, ships and planes can disappear in abysmal depths without a trace. When Malaysia Airlines flight MH370 vanished on March 8, 2014, on its way from Kuala Lumpur to Beijing, there were good reasons to assume that the aircraft had disappeared in the Southern Ocean region southwest of Australia. As it were, this region continues to be one of the deepest and least explored ocean regions in the world. To the present day the aircraft has not been found.

Despite accumulated rich ocean knowledge, the sea is anything but clear and transparent. Until the modern age a main approach to the sea has been to cross its surface as fast as possible to reach safe haven. Humans are terrestrially bound creatures. The sea remained literally superficial even to local fishing communities whose livelihood has depended on the sea for centuries. And to a large extent, the sea remains literally opaque also to oceanographers and their scientific instruments. Water absorbs not only visible light but also radio waves, microwaves and X-rays. It is impermeable to electromagnetic radiation which forms the basis of modern radar, GPS and telecommunication technologies. At depths of 100 meters, the sea is pitch black. In the search for flight MH370 an autonomous underwater vehicle (AUV) was deployed. In a course of three weeks the unmanned mini-submarine scanned an area of roughly 400 square kilometers of the Southern Ocean in depths of nearly 5000 meters. It would take two hours to descend before it could scan the sea floor for 16 hours. It took another two hours to return to the surface. An area of some five by eight kilometers could be searched in a day. Reading out and analyzing the data from the device took another four hours. According to Dutch physical oceanographer Erik van Sebille (2014) from the University of New South Wales, Australia, the search became “a game of blind man’s bluff”. In many regards, ocean exploration is a venture undertaken by blindfolded scientists groping around in a vast dark expanse of which less than 5 percent has been explored.

This chapter sets out to explain how despite these conditions of opaqueness the sea has emerged as a comprehensible and communicable object of knowledge in the long twentieth century. It expands the notion of the “short” century of 1914 to 1991 (Hobsbawm 1994) which bracketed historical developments by a series of world wars. To understand how the earth’s “one big ocean” became evident the politics of the ocean need to be studied and also the modern ocean sciences and their practices of measuring, scaling, visualizing and legitimizing ocean knowledge. The long twentieth century takes into consideration that major developments in modern oceanography were instigated with national ocean-going expeditions in the late nineteenth century. It also acknowledges that the ripples of “high-modern” (Scott 1998) oceanography which built up at the turn of the century and reached its peak during the Cold War have expanded into the twenty-first century and inform current environmental ocean sensing and monitoring. The chapter will explore how national endeavors of ocean sounding and charting at the heights of European imperialism created the conditions and the demands for international collaboration that developed well before World War I. The internationalization of ocean research in turn made scientific data the basis of both ocean territorialization and commoning strategies. As marine resources of oil and ore became technologically accessible, these conflicting views culminated in the UN Law of the Sea conventions and regulations of the oceans after World War II. In the latter part of the twentieth century, the ocean became the object of environmental surveillance and the subject of moderating and regulating the earth's climate systems. Physical oceanography was refashioned as a climate science that researched ocean-atmosphere interactions.

Much like oceanographic research itself, the chapter combines in-depth and surface accounts to span time and space. To sketch this global knowledge of the sea I will tap into the history of physical oceanography, the sciences of the non-living sea. I will focus on practices of ocean depth measuring, data processing routines and visual tools of ocean knowledge like graphs, maps and images. Inspired by science studies scholar Stefan Helmreich's (2011) notion of the "sensory trajectory" I trace processes of making a sea legible that had been marvelous and alien for centuries. The trajectory leads from the tactile sense of probing to the auditory sense and the soundscapes of echo sounding to the visual sense of translating tactile and auditory information into text and image. As versatile data became decipherable ocean landscapes, or seascapes, this "architecture for perception" (Goodwin 1995: 254) fostered imagined ocean futures based on modelling and forecasting practices. While the oceanographic perspectives discussed in this chapter are largely based on the credibility and dominance of (Western) science, their interactions and frictions with other forms of ocean knowledge were historically pervasive. Non-scientific ocean knowledges will come to the fore by situating scientific knowledge in its geographical, political and cultural contexts.

Taking a multidisciplinary approach inspired by historical science and technology studies as well as by the environmental humanities, the chapter attempts to shift perspective from the national frameworks of knowing the sea to the inter-, trans- and supranational oceans, ocean sciences and modes of ocean governance. The sections revolve around three related aspects of ocean knowledge that place the qualities of the sea in the center: depth, resourcefulness and power. As the sea changed from an unfathomable and treacherous immensity to traverse to a deep volume to gauge and lay bare, the deep sea became imagined as a space complementary to the land. It became a source and a sink of extractive industries, an arena for legal regulations and a potent climate moderator that could be modeled and forecasted but that continues to resist its categorizations and predictions.

The Deep Sea

When Malaysia Airlines flight MH370 disappeared from the global flight monitoring screens in 2014, a Swedish journalist contemplated the unlikely possibility of disappearing for good in our present time of allegedly seamless satellite monitoring, national intelligence and global surveillance systems (Wahllöf 2014). In this residue of remoteness, he found not only grief but also consolation and dream-inspiring hope. The intimacy of rigorous scientific precision and mythical vagueness, of enlightenment and obscurity could be observed already in the nineteenth century when physical oceanography was just about to form into a scientific discipline. Jules Verne's novel *20,000 Leagues Under the Sea* from 1870 mediated well between different images of the sea prevalent in his time. In a short passage on the Atlantic Ocean, Verne praised the sea's immense spatial and temporal span with mathematical exactness: "The Atlantic! A vast expanse of water whose surface covers 25 million square miles, 9,000 miles long, with an average width of 2,700" (Verne [1870] 2001: 284). The modern sciences of the sea did not replace but reclaimed the marvelous and fantastic views on the nature of the sea, and they did so by applying precise figures and vast data sets. Like the science fiction genre he established, Verne presented two closely related narratives of the ocean spaces to be outlined, the spectacular and the scientific.

The oceans were deep well before the founding of the ocean sciences in the mid-nineteenth century. What lay beneath the waves out on the sea, however, had hardly ever been tangibly experienced. Far into the modern era the world's oceans were perceived mainly as transit spaces dividing the continental landmasses. Fishermen and whalers were well experienced with their fishing and hunting grounds. Largely, however, ocean knowledge concerned sea surface matters of marine trade, naval wars and colonial expansion. Shipping routes relied on astronomical knowledge, nautical skills, navigational tools as well as on detailed coastal charts. This section explores how the oceans became deep as scientific tools of depth sounding and depth representation were developed in systematic ocean-going expeditions, which I will study in relation to national and imperial ambitions of the European states in the time period between 1870 and 1945.

To gauge the deep ocean, a groping and probing tactile approach prevailed until the turn to the twentieth century. Measurements with a lead weight attached to a line to fathom ocean depths of several kilometers could take several hours and involve the entire ship's crew. The leadsman would take the line towards the bow of the ship. The sailors took up the line in coils and arranged themselves along the side of the ship from bow to stern. Upon releasing the line, the crewmen counted the knots in the line passing their hands and memorized their succession collectively in the form of a song, then to enter the depth in fathoms into a chart. Ocean literacy at this time was built on digits. While sailors were often illiterate, they were generally numerate (Rozwadowski 2005).

Instruments, theories, skills and routines needed to come together to perceive underwater features clearly. The operational knowledge-generating device at this time was the research vessel itself: the ship was a scientific instrument, a probe, a collecting and ordering device and a field laboratory in which hierarchy and discipline ruled. The emerging ocean depths were the results of organized collective practices and they served not only scientific but also commercial interests. The telegraph industry was a late-nineteenth century endeavor that depended heavily on accurate depth measurements. The effort of laying a transatlantic submarine telegraph cable across the so-called Telegraphic Plateau in the 1850s, a submarine expanse between Newfoundland and the British Islands in the North Atlantic Ocean, motivated further development of sounding techniques (Hanlon 2016). In the late nineteenth century, when national survey missions of land and sea were underway, the techniques of line-and-lead sounding were systematically refined. Rope was replaced by wire, sinkers detaching mechanically from the sounding line were introduced, and the steam-powered winch replaced the tremendous manual labor of hauling up miles of heavy line. Such changes made large national ocean charting projects more efficient and attractive for governmental funding.

The British *Challenger* expedition of the early 1870s illustrates how the newly formed science of oceanography proved itself worthy of national support by symbolically appropriating the earth's ocean floors. The *Challenger* was the first expedition equipped solely for the purpose of deep-sea research. Its deep-sea soundings accounted for hitherto abyssal oceanic depth in the language of precise scientific measurements (Hsü 1992). Travelling nearly 70,000 nautical miles (130,000 kilometers) across the globe between 1872 and 1876, the *Challenger* catalogued about 4,000 new species and took about 400 deep-sea soundings. The circa 40 nautical charts resulting from the expedition were the co-production of an evolving and specializing deep-sea research and a national investment to appropriate the sea as an expression and a means of imperial power. In 1875 its crew sounded the Mariana Trench in the western Pacific Ocean, the deepest part of the world oceans. The estimated deepest point of more than 8,000 kilometers at the trench's southern end was named the *Challenger* Deep. Utopian sites persisted as ocean science moved across the earth's surface, meticulously fathoming its remotest places and crevices to part with curiosity and wonder.

Ocean sounding devices remained unreliable and tedious until the early twentieth century when acoustic sounding technology put observations into practice that seawater was an almost perfect sound medium. Sound waves travelled much faster in water than in air and they propagated practically without loss with a velocity of ca. 1,5 kilometers per second that increased with pressure and salinity, echoing an acoustic signal off the ocean floor in a matter of seconds [Figure 1.2]. The AUV searching for the remains of flight MH370 could map dozens of square kilometers per day because it carried a "side-scan sonar", an acoustic device that could create a much wider sound image of the sea floor than any on-board optical camera, let alone pointwise measurements with line and lead. The technological shift from sounding with slow and heavy winches and weights to swift and comparatively precise acoustic and electroacoustic sounders around 1900 also meant a shift in the medium and in the sensory arrangement of approaching ocean depths: sound waves are material waves; they propagate by the medium of water itself. The ocean became a sounding body.

The first acoustic sounding experiments involved simple sound sources like underwater gunshots, and the first receivers were human listeners who picked up the signals with their bare ears or with earphones. The German physicist Alexander Behm secured a patent on an "echo sounder" in 1913 which employed a siren as sound emitter and a mechanical "sonometer" as receiver determining depth based on signal strength (Behm 1913). At the same time, acoustic sounding devices were developed in the US which used electric underwater sound emitters and receivers. All devices had in common that complicated manual conversions of measurements had to be performed *ex-post*, to translate measures of time into units of distance and to derive the actual depth at a certain position (Höhler 2002a).

The question of precision of acoustic navigation and positioning became urgent "as a result of two modern catastrophes – the sinking of the *Titanic* in 1912 and the onset of World War I in 1914" (Beyer 1999: 197). Acoustic depth measurement benefited enormously from the sound transmitter and receiver technology developed for submarine communication and for the localization of ships and submarines, especially in the UK, in France, Germany and the USA. The echo depth sounder was the first peaceful application of the new technology. With the increasing automation of acoustic depth measurement confidence in the method grew. The procedure of humans audio-monitoring great depths was considered imperfect since “the subjective moment of human listening to the echo” had not yet been “eliminated”, as Gerhard Schott from the Deutsche Seewarte, the German Sea Observatory, admitted in 1926 (Schott 1926: 142). But Schott was confident and assured that “the purely mechanical registration also at the end of the process, i.e. of the echo, is likely to be achieved” (Schott 1926: 142). Self-registering echo sounders that actively sent out and recorded sound pulses to determine the distance of a ship or submarine to the seabed were developed in the 1920s, but did not come into use before the 1930s.

The “German Atlantic Expedition” conducted on board the survey vessel *Meteor* between 1925 and 1927 was the first expedition to apply the new technology of acoustic sounding to a systematic deep-sea survey. Travelling the South Atlantic Ocean, the *Meteor* scientists made use of all hydrographic observations of the Atlantic since the British *Challenger* expedition by ordering them into a “Kartothek”, a register of maps that upon departure in 1925 contained about 10,000 sheets (Merz 1925). Alfred Merz, the scientific head of the expedition, set up research “stations” in advance, creating a dense sampling grid of fixed, equidistant points spanning the terrain under oceanographic investigation [Figure 1.3]. Merz arranged stations in 14 cross-sections, narrowly spaced in intervals of 5 degrees in latitude. 20 to 30 stations, 150 to 350 kilometers apart, were aligned on each cross-section, adding up to a total of 310 stations between the coasts of South America and Africa. The total length of the voyage of the *Meteor* proceeding from station to station encompassed about 130,000 kilometers. At each station hydrographic series were run, including deep-sea soundings with line and lead to check the three different acoustic sounding devices aboard. Deep-sea measurements during the voyage amounted to roughly 60,000 soundings at 30,000 spots no more than 20 minutes apart. According to Hans Maurer, the scientist concerned with the *Meteor*’s soundings, 67,388 soundings were taken during the expedition (Maurer 1933:

24), a precision that recalls Jules Verne's scientific spirit and a survey density that would have been science fiction in Verne's time. This sounding enterprise would have taken seven years of sounding day and night, had it been conducted with line-and-lead sounding.

Measuring separate physical ocean qualities along the water column at each station, the "German Atlantic Expedition" analyzed the ocean into a large array of physical information in three dimensions. The physical oceanographers onboard the *Meteor* worked with a model of the "Atlantic Circulation", which had first been theoretically outlined by the Norwegian physicist Vilhelm Bjerknes in the early years of the 1900s in his circulation theorem of atmospheric and oceanic motion (Bjerknes et al. 2010/11). The *Meteor* oceanographers set out to compare the theory and corresponding calculations of ocean drifts and ocean circulation to a range of new measurements in which quantitative methods replaced former qualitative approaches. Their extensive instrumental gear included deep-sea thermometers, current meters, water samplers, closing nets, bottom samplers, and coring tubes. To determine the direction and velocity of Atlantic seawater, current measurements were obtained directly and indirectly through observation and determination of water temperature, salinity and density. Chemical investigations concerned seawater qualities like alkalinity (the water's capacity to resist acidity) and contents of oxygen, nitrogen and minerals. By relating their station work on the water columns to their depth measurements, the oceanographers onboard the *Meteor* combined the emerging depth charts of the Atlantic Ocean and the more abstract isoline-charts which displayed the contents and distributions of different measured quantities. They arranged the (same) data visually in all conceivable ways intelligible to conventional three-dimensional spatial imagination: into cross sections, longitudinal sections and horizontal sections, representing different strata of ocean depth. In doing so, they supplemented the existing maps of ocean coastlines and depths with a picture of the ocean water body. The seemingly empty space between the sea's surface and its bottom was filled by an ocean of data.

Mapping, as James Corner has argued, "*unfolds* potential: it re-makes territory over and over again, each time with new and diverse consequences" (Corner 1999: 213). Following Corner, maps are constructed from sets of techniques, instruments and conventions which make the spaces they describe derive from those aspects of 'reality' that are susceptible to the techniques. Corner identifies three mapping operations which can describe the *Meteor*'s framing and knowing of the Atlantic Ocean (Corner 1999: 231). First, the oceanographers created a field, set rules and established a system, including a graphic system encompassing the frame, orientation, coordinates, scale, units of measurement, and graphic projection. Second, they extracted parts, isolated or "de-territorialized" as data. And third, they plotted relationships between the parts and "re-territorialized" these parts into a whole. From the complex fabric of single data, the Atlantic Ocean was reterritorialized as a scientific volume.

Among the numerous charts and maps the *Meteor* returned to Germany were 14 spectacular morphological profiles of the South Atlantic Ocean [Figure 1.4]. These depth charts were intended to give evidence of Germany's unbroken scientific excellence after the First World War. They also acquired substantial meaning within German after-war struggles to regain lost colonial authority and military strength in symbolic fashion. The unprecedented comprehensiveness of the expedition framed the South Atlantic Ocean and ocean floor as territory under (national) control. The "German Atlantic Expedition" was a prestigious project of the "Notgemeinschaft der Deutschen Wissenschaft", the German association promoting the continuance of the sciences, strong before the war, after the reparation payments, disarmament requirements, and territorial concessions imposed by the Allied Powers. The Notgemeinschaft contributed to the prevalent post-war rhetoric of (spatial) deprivation, economic impoverishment, and exhausted resources brought upon the Germans through the reparation demands and the military restrictions by the Treaty of Versailles (Höhler 2002b). The German geographer Albrecht Penck, at the time the director of the Institute of Geography at the University of Berlin and of the Berlin Institute of Maritime Research, explicitly connected oceanic space to lost scientific and colonial territory. “The field of work of the German colonies was lost, the largest part of the country in the possession of powers that had been hostilely confronting Germany during the war, so that only few areas stood open to the German scientist” (Penck 1925: 243). This situation, according to Penck, was “different on the seas”. Penck projected the open sea as a “field Germans could engage on unobstructed” (ibid.). The *Meteor* itself was a decommissioned battle ship provided by German navy and refurbished as a research vessel, which saved it from being demolished according to the terms of the Versailles Treaty.

Indicative of the close relations of ocean scientific and military purposes, acoustic sounding became an important application of ocean knowledge in World War II. Promoted by the *Meteor* expedition, echo sounding was refined and put into practice in German and British submarine warfare. While the German Navy brought the technology of passive underwater hearing by sound receivers, or “hydrophones,” to perfection, the British Navy worked on more refined active echo search systems. The acoustic echo location system ASDIC (an acronym which resolved to Anti-Submarine Detection Investigation Committee[2]) held a once-established acoustic contact and fixed the object as if caught in a search beam. The technology of active echolocation also materialized in the technology of SONAR (Sound Navigation and Ranging). The US Sonar system was the auditory equivalent to the better-known RADAR (Radio Detection and Ranging), which locates objects with radio waves. In the second half of the twentieth century, “sonar” became the collective term for all sound-based remote sensing techniques, whether horizontal or vertical, active or passive. The oceanographic success story of “seeing in depth” was dampened, however, when global campaigns by animal and environmental organizations drew attention to the fact that underwater noise acoustically tortures and misleads whales, dolphins and other marine mammals. To conclude this section, it is not without irony that the increasing probing of the oceans since the late 1800s and their insetting acoustic penetration since the early 1900s revitalized the emptied sea of physical oceanography precisely by disturbing oceanic life.

The Resourceful Sea

At the turn to the twentieth century, the imperial scramble for space reached the very few remote areas that were left to be charted on earth: the heart of Africa, the extremes of the polar regions and the depths of the oceans. For the fledgling European nation states, "to rule the waves" had everything to do with military dominance. At the same time, national control of the seas was associated with scientific ambitions and with access to ocean spaces and resources at the peak of imperialism. Ocean nationalism created a volatile constellation on the eve of World War I that spilled over to World War II and its severe marine and submarine battles. While national competition remained strong in the after-war years, international collaboration became equally powerful in shaping the world oceans. This section explores ocean internationalization as the flip side of ocean nationalism following World War II. Opening with an outline of the first international oceanographic efforts at the turn to the twentieth century, the section's main focus will be on the Cold War period between 1945 and 1990, when international regulations became increasingly important to govern access to oceanic resources. The section discusses the role of physical oceanography in providing the parameters and the tools both for ocean internationalization and ocean territorialization.

The national formation of the earth and ocean sciences depended on international communication and exchange. The growing numbers of international scientific organizations at the end of the nineteenth century illustrate the difficulties of nationally operating sciences to observe atmospheric, oceanic and tectonic phenomena which frequently transgressed national boundaries. The First International Polar Year (IPY) launched by the International Meteorological Congress and the International Polar Commission in the early 1880s presents a vivid example of the need and desire for collaboration within the professionalizing earth sciences. The earth-spanning observation effort carried out between August 1882 and 1883 provided the technological and metrological infrastructure to the growing scientific internationalism (Lüdecke 2004). This infrastructure allowed for the concerted collation of measurements and a common metrics, calibrated instruments and the coordination and processing of measurements following international conventions. In 1899 the International Congress of Geography commissioned a general map of the earth's ocean basins and standardized the terminology of the deep sea. By the early twentieth century, maps of all ocean basins existed, based on some 18,000 soundings (Rozwadowski 2002).

The "mechanics of internationalism" (Geyer/Paulmann 2001) in marine research were fraught with friction, however. Firstly, the new ocean observation regimes rested heavily on military, economic and technological structures which enabled and constrained collaborative research. Observation infrastructure development followed the dominant European shipping transport and communication routes and the imperial gradients of military and economic power by sea. The topologies of ocean knowledge emanating from the infrastructural networks were all but global. These networks operated from the European centers, and they entailed governance structures that were predicated on political power relations. Secondly, international scientific coordination did not necessarily imply cooperation. Global oceanographic surveys mostly collected information from arrays of single national contributors. Under the umbrella of the International Council for the Exploration of the Seas (ICES), founded in 2002, national institutions were able to obtain vessels dedicated to marine research. Unlike other international scientific organizations of this time, ICES was composed not of individual scientists but of eight founding states in Northern Europe. ICES was concerned primarily with the North and Baltic seas, including Norwegian and Barents seas, in its stated aim to promote and coordinate scientific work among its member countries (Rozwadowski 2002). In many regards, ICES was the first intergovernmental marine science organization and presented a model for international scientific coordination. Yet, ICES also displayed the frictions of internationalism in marine research by exposing the inadequacies of ocean governance structures beyond the immediate national shorelines.

Further need for political negotiation and regulation became particularly apparent when, thirdly, new technologies of marine resource extraction made new large-scale extractive operations possible and profitable for commercial purposes. The advent of industrial-scale trawl fisheries in the first decades of the twentieth century and of sea-bed mining prospects in the 1960s contested century-old traditions and agreements about access and property rights in the high seas. One of the oldest attempts of sea regulation was the "freedom of the sea" principle, *mare liberum*. In the colonial dispute about trade routes between the Netherlands and Portugal Hugo Grotius resolved in 1609 that the high sea, according to the Roman concept of *ius naturale* or natural law, was "common to all and proper to none": "The sea therefore is in the number of those things which are not in merchandise and trading, that is to say, which cannot be made proper. Whence it followeth, if we speak properly, no part of the sea can be accompted in the territory of any people" (Grotius [1609] 2004). In the nineteenth century, the widely accepted international law of the seas recognized the principle of limited national rights to a coastal zone of three nautical miles (5,6 kilometers). This definition of territorial waters corresponded to the range of cannons at the time and answered to the contemporary technical possibilities and needs of national defense. The law of the seas also regulated deep-sea fishing and merchant shipping.

The seabed and the subsoil played no role, neither in economic nor in military terms. Like the high sea, the deep sea remained ‘free’ in Grotius’ sense.

The twentieth century challenged these centuries-old arrangements technologically and scientifically. The sheer number of marine activities during the second large international earth survey event, the International Geophysical Year (IGY) of 1957 and 1958, can be read as a strategy of making the oceans “legible for geopolitical reasons” (Dodds 2010: 65; Barr/Lüdecke 2010). Ocean literacy and ocean access were closely related and they became increasingly important in the 1960s when undersea oil and gas production increased and manganese finds in the deep sea promised a rich new source of ore. By the 1970s, the problem of regulating access to the seafloor and subsoil moved onto the agenda of the United Nations, which had been founded in 1945 as an international and intergovernmental organization to reestablish and maintain peace and security after World War II. Offshore oil and gas operations, at the time only projected in the negotiations, would take off in the 1980s (Avango/Högselius 2013). Moreover, in the face of a rapidly growing world population, experiments with underwater habitations and laboratories and new techniques for extracting plankton and krill from the seas heightened the hopes for the oceans as a protein storage and a supplementary human living space (Hamblin 2005; Kehrt/Torma 2014). Plans for military applications as well as the increasingly apparent flip side of post-war affluence, the sea as a growing landfill (or rather, seafill), further fueled the struggle over the world’s oceans in the international arena, between highly technologized and “developing” states, between coastal states – those states that had a coastline – and those states with no access to territorial waters.

All of these disputes were settled in the form of property regulations. As legal scholar Scott Shackelford has observed, in the Western world the establishment of property rights was not seen as the problem, but as the (only) rational solution for managing resources outside of national jurisdiction. As soon as the harvesting or extraction of a resource was in sight, property rights seemed to be necessary to catalyze resource "development" (Shackelford 2008). It is not coincidental that the discussions over a new international maritime law fell into the decades of the 1950s to the 1980s. Three major United Nations conferences held in 1956, 1960 and again in 1973 discussed the reorganization of ocean ownership and use rights. At their preliminary end stood the United Nations Convention on the Law of the Sea (UNCLOS), agreed on in 1982 and ratified in 1994. The convention newly defined territorial waters and established the system of Exclusive Economic Zones (EEZs). This new zoning system granted a coastal country sovereign rights of offshore fishing and resource extraction measured from the sea surface to the seabed up to an extent of 200 nautical miles from the coastline, or up to the limits of the "continental shelf," the edge of the continental landmass that was submerged under water but geologically attributed to the land (Miles 1998). The system concluded the question of whether to expand territorial waters or preserve the sea as a commons in a management scheme that was both protective and expansive. For one, the international agreements on economic zones practically invited further efforts of national fishing and trawling, probing and drilling of hydrocarbon resources, both within and beyond the territorial waters. Moreover, the legal frameworks were not independent of scientific definitions. The definition and legal concept of "continental shelf" itself changed over the decades, as both measurement and extraction technologies advanced. The determination of the extent of a continental shelf to demarcate an economic zone rested entirely on the perception of subsea geomorphological features, which in turn invited further oceanographic research to corroborate a country's claims.

The increasingly dense and versatile plot sheets of physical oceanography became powerful scientific evidence in the controversies about continental shelf extents. Accurate gathering and analyzing of data were required to determine the outer edges of continental margins, and physical oceanographers could provide the necessary set of tools to determine depths and slopes, mineral composition and sediment thickness to differentiate continental crusts from oceanic crusts and ridges. In 1977, American geologists and oceanographic cartographers Bruce Heezen and Marie Tharp at the US Lamont-Doherty Geological Observatory published a topographical map of the world ocean floor (Doel at al. 2006) [Figure 1.5]. This map became famous because it exposed a vast undersea landscape that had hitherto been ‘invisible’. The map also exhibited the enormous expansion oceanography and other earth sciences saw during the Cold War, primarily for military motives (Doel 2003). In the 1950s Heezen and Tharp had begun to assemble a map of the Mid-Atlantic Ridge, an undersea mountain range in the middle of the Atlantic Ocean formed by the boundary of two continental plates, the North American and the Eurasian plate. The Mid-Atlantic ridge had been mapped first as part of the *Challenger* expedition in the 1870s with the aim of sounding the ocean floor for the optimal position of the planned transatlantic telegraph cable. The subsequent *Meteor* expedition had confirmed the existence and detailed the extent of the ridge by acoustic sounding measurements in the 1920s. Based on this elaborate data archive of the earth’s ocean floors from line-and-lead and sonar soundings, Heezen and Tharp found that the ridge formed a part of an extensive system of seismologically active ocean ridges across the earth’s surface. Their topographical map of the world ocean floor clearly displayed these undersea features. Additionally, the map gained reputation from supporting the theory of seafloor spreading and of the continental drift that had been proposed decades earlier – unsuccessfully – by the German geophysicist Alfred Wegener.[3]

Despite the rich archive of depth measurements, Heezen and Tharp had to compile their map by extrapolating depths across vast data voids. Nevertheless, their map was visually impressive; it carried the topographical sensation of an emerging underwater space. It presented an ocean floor panorama perceived as ‘continuous’ while technically, the data continued to reflect single measurements. The map was a result of several steps of translation, from painstakingly plotting available depth soundings manually to the polished relief painting (Höhler/Wormbs 2017). “Optical consistency” is Bruno Latour’s (1986) term for a synopsis created from single measurements drawn together into a stable visual form. The topographical map became an operational device to move further along the sensory trajectory of knowing the sea, from the tactile to the auditory to the visual sense. Optical consistency highlights more than the unity and integrity of a map made from an abstraction of single data points. It stresses its stability in translation and transport. Such “immutable mobiles” (Latour 1990) reconciled the scientific-technical representation of the abstract object of the ocean floor with its new visual reality. Heezen’s and Tharp’s ocean map did not remain with the community of physical oceanographers but found entrance into geographical textbooks and popular atlases where it reflected the US oceanographic institutions’ dominance and territorial coverage at the time of the Cold War.

The Heezen-Tharp topographical map of the world ocean floor exhibited the geological features that shifted scientific assumptions about plate tectonics and about shelf extent at one glance. Thereby, the map literally opened up the space for technoscientific prospecting and projecting of the resourceful sea. Outlining the continental shelf regulations in UNCLOS in such a way that access claims could be made (only) on scientific grounds resulted in a proliferation of scientific demarcation attempts. Coastal countries continue submitting their claims to the UN Commission on the Limits of the Continental Shelf (CLCS), which was established at the third UNCLOS conference in 1982 to decide on shelf extent on the basis of oceanographic measurements. Currently, we can watch a genuine race for oceanic resources by shelf measurement. Especially in the Arctic, melting ice caps have opened up new shipping routes and resource fields to tap into that have attracted state and private investors. Paradoxically, under UNCLOS, established to safeguard the fair use and management of marine resources, very little of the Arctic Ocean is left unclaimed. In summary, scientific surveys were and are neither politically neutral nor objective. Assigning an oceanic area to a country has never been a strictly geological process but happens in the context of scientific definitions, political conventions and economic or military motives. International oceanic coordination has not only supported ocean protection but also aggravated the problem of ocean exploitation. Legitimating international institutions like the United Nations became indispensable for the regulation of growing claims on the sea in the second half of the twentieth century, but they were hardly sufficient to settle territorial disputes once and for all.

The Powerful Sea

Oceanographic probing and observing the sea in breadth and depth in the second half of the twentieth century provided global overviews which in their geographic and scientific scope increasingly diverged from other established local experiences of the sea. This discrepancy became even more pronounced with the formation of earth system science in the 1980s. Among a range of fields, earth system science took a systems approach to the planet's hydrosphere and atmosphere and their interactions as a climate indicator, a climate regulator and a climate generator (Edwards 2010; 2017). The new technology of satellite remote sensing spurred oceanography's turn into a subfield of the climate sciences by combining physical oceanography and space technology. This section explores how "satellite oceanography" and its observational techniques, measurements, imagery and forecasting efforts collected distant local measurements into wholly new data fabrics from which, so the contemporary expectation, the texture of the earth's climatic cycles became visible. Since the 1990s and until the present, as this section will show, satellite oceanography has fed high hopes of climate modelling, weather forecasting and disaster management through ocean data storage and processing facilities.

Satellite oceanography gained ground at the end of the Space Race between the two superpowers, which had absorbed much of early Cold War military investment and scientific attention. When the last Apollo flight returned from its trip to the moon in December 1972, public interest and governmental funding in space flight had already waned. American and European space programs had to refashion themselves as earth programs, "changing the mission", as Naomi Oreskes (2014) so aptly termed it. In the 1980s, NASA, the US National Aeronautics and Space Administration, launched its "Mission to Planet Earth" program. Mission to Planet Earth was designed as a long-term international research project in the earth sciences, and it marked NASA's change from a space agency to an environmental agency. Its second major satellite mission was the joint US-French project "TOPEX/Poseidon" (Krige 2014; Conway 2006). TOPEX stood for "Ocean Topography Experiment". Radar technology was employed to monitor ocean current and wave patterns as well as sea level increase. Active self-registering satellite sensors provided altimetric (altitude) and gravimetric (gravity) data which were read out in digital form as the satellite was downlinked to receiver stations on the ground. In August 1992 the orbital satellite TOPEX/Poseidon was launched with the aim of taking sea surface height measures as indicators of the oceans' heat content [Figure 1.6]. The mission's overall goal was to understand global ocean dynamics. A more specific goal was to improve the scientific knowledge of upper-ocean circulation in the tropical Pacific that was deemed essential for the reliable prediction of El Niño events (Höhler 2017).

El Niño is the expression for a recurring warm-water period in the Pacific Ocean region. El Niño had been locally awaited and dreaded for centuries for the extreme weather events these warm water streams triggered. In the coastal states of South America, Indonesia and Southeast Asia, memories and stories of El Niño's arrivals are cultivated to convey both the bliss of rich harvests and catch of fish and the disasters of tropical winter storms and floods, droughts and famines (Philander 2004; Schwartz 2015). To the earth sciences El Niño arrived in the form of observed differences in Pacific Ocean surface temperatures. Oceanographic records of ocean warming go back to the eighteenth century. From this time, however, only single temperature readings from sporadic ships and merchant ships exist. As outlined in the first section of this chapter, the formation of physical oceanography as a disciplinary field in the second half of the nineteenth century did not instantaneously fill the vast measurements gaps. Oceanographic records provided no immediately intelligible story. Well into the twentieth century, temperature recordings were interpreted as indicators of El Niño events in hindsight only. An encompassing international oceanographic research network was in place first by the late 1950s. This close scientific ocean observation program was established in relation to the IGY 1957-58, as mentioned in the previous section. Partly also, the program was as a result of the strong El Niño year of 1957-58 which happened to coincide with the IGY.

The increasing measurement density of the twentieth century was complemented by ocean circulation theory. In the 1960s the Norwegian-American meteorologist Jacob Bjerknes attended to the phenomenon of El Niño in the tropical Pacific. Jacob was son to the Norwegian physicist Vilhelm Bjerknes who had first outlined the “Atlantic Circulation.” Based on oceanographic sea-surface temperature readings and long-term weather recordings Jacob Bjerknes connected the atmospheric pattern of temperature, pressure and rainfall variations in the Indian and Pacific Oceans, as identified by the British meteorologist Gilbert Walker in the 1920s, with data from the strong El Niño episodes of the 1950s and 1960s. By relating the El Niño phenomenon to Walker’s “Southern Oscillation” Bjerknes could establish a pattern of ocean-atmosphere interaction in the Pacific Ocean that became known as “Southern Oscillation El Niño” (Mills 2009).

Satellite oceanography provided ocean circulation models with vast geographical coverage and proliferation of ocean temperature measurements. Satellites could not “see” in depth, to echo Charles Goodwin's (1995: 254) reflections on the technoscientific "architecture for perception", the specific set of research interests, conceptual assumptions, instruments and research activities that needed to be in place to render oceanic and atmospheric phenomena visible to the human eye. SInce seawater proved opaque to electromagnetic radiation satellites skimmed sea surfaces; they took their readings off the near-surface layers of the sea. In return they covered enormous ocean regions, as becomes visible in the TOPEX/Poseidon satellite image from 1997 with its terrific view of the planet and its focus on the Southern Pacific Ocean [Figure 1.7]. The process of weaving satellite data into a comprehensive fabric and view of the Blue Planet was by no means self-evident, however. The satellite image does not display the intricate routines that enabled its fabrication. Several steps of conversion were required to compute sea surface temperatures from satellite readings. Measurements of time had to be converted to distances and translated to units of temperature. The measurement principle of TOPEX/Poseidon's radar worked similar to the sonar technology explained in the first section of this chapter. The time of the reflected radio signal to travel to the sea surface and back translated to a distance which in turn translated to the sea surface temperature based on empirical knowledge about the expansion of water bodies with temperature.

The TOPEX/Poseidon image does not give away that data were gathered not in one moment but in separate satellite orbits. Data points had to be interpolated across large time spans. Like earlier ocean charts relying on single-spot measurements, synopsis was created retrospectively. Single data points had to be arranged into the hemispherical form to represent the planet. The coloring scheme was designed to follow the contemporary conventions of temperature coloring and coding. Together, these practices created the impressive satellite view that indicated that an El Niño situation was approaching. By delivering such images satellite oceanographers could promise to provide early warnings of natural weather disasters like storms and floods from an early discovery of a developing El Niño episode. Optical consistency made the images legible and plausible. To speak with Latour again, they presented "a new way of accumulating time and space" in a transportable and stable form (Latour 1990, 31ff.).

Satellite imagery, made openly accessible by NASA, seems to present the preliminary end of the sensory trajectory of knowing the sea that I began this chapter with. Charts, maps and satellite data images were visual devices to understand and communicate the sea. In the increasingly digital cultures of the late twentieth century, the visual sense superseded tactile and auditory perceptions. The power of ocean literacy, however, lay not in the data images but in the data archives. The standardized and centralized satellite data held much greater authority and power than the satellite images. Driven by remote sensing technology and by the availability of ever larger computing capacity, a new operational device changed physical oceanography: the digital database. Its power resided in data versatility. Satellite information and computer power invited the infinite conversion, aggregation and recombination of data to operationalize ocean-atmosphere forecasting. More data would allow for more extensive information processing, so the optimistic hopes of oceanographers. Better information and better simulation tools would enable oceanography to convert and recombine oceanographic data to make El Niño predictions based on probabilistic models.

The sea surface temperature databases entailed another crucial shift in ocean knowledge, the shift towards future ocean projections and predictions. Satellite oceanography entangled formerly distant events into a new analytic fabric, which far exceeded the "global synoptic descriptions" of the ocean-atmosphere circulation that oceanographers had envisioned in the mid-1980s (Revelle 1985). NOAA, the US National Oceanic and Atmospheric Administration, hosted the aggregated comprehensive collections of El Niño-related data gathered in a huge database on ocean-atmosphere circulation. From these data sets, El Niño emerged not as the catastrophic exception but as part of a quasi-periodic, regular climate pattern. El Niño turned into a veritable climate engine that today drives the Earth's global climate system. Invented by the World Climate Research Program (WCRP) in the 1980s and in close reference to Jacob Bjerknes, this climate engine was called ENSO – El Niño Southern Oscillation (Reeves/Gemmill 2004). ENSO became a major reference in the emerging discourse on the earth's climate cycles. ENSO also fundamentally reoriented the understanding of rising world ocean temperatures and more generally of current global climate change.

The record-breaking El Niño winter of 1997-98, which has been termed the "climate event of the century" (Changnon 2000), was hardly apparent neither in the images provided by TOPEX/Poseidon nor in the cautious forecasts the satellite data entailed. Only in retrospect did the world experience one of the most violent winters in recorded weather history with floodings and droughts, tornados and ice storms in the Pacific region but also globally, natural disasters which widely changed public perceptions of weather and climate. While ENSO has become the dominant scientific signature of the global climate pattern, devastating weather incidents have impressed themselves on local communities ever since and will most likely continue to do so as the oceans are heating up and the atmosphere carries more water. To summarize, physical oceanography since the late twentieth century has supported an understanding of the earth's climate through remote-sensing tools enabled by the earth and ocean sciences as well as by space technology. Satellite oceanography contributed to shifting the focus to ocean modeling and forecasting based on continuously augmented digital databases that in their practical power have by and large replaced previous tools of ocean probing and perception. The scientific regularity of ocean-atmosphere interaction as a climate factor, however, is in a peculiar incongruence to the powerful interventions of the oceans that seem to belittle any managerial or engineering thought of ocean control.

Conclusion

In the course of the twentieth century, physical oceanography compiled data records and edited an ever more encompassing and complex ocean volume. The sea, formerly a vast realm filled with imagination but largely opaque to humans, turned into a seemingly transparent three-dimensional physical space that meets the eye in the form of ocean charts, maps and satellite images. To return to the contemporary network and project of Ocean Literacy I began this chapter with, physical oceanography helped turning the sea into a legible environment. The scientific tools of oceanographers employed the human senses from the tactile to the auditory to the ultimately privileged visual sense. Surveying techniques and synoptic images created ocean knowledge that began with digits and ultimately resided in digital data sets and the potentials of data recombination.

Oceanographers never worked in isolation. They worked in close alliance to national, military, technological and commercial endeavors. They hooked into developments in other fields of modern science and technology, from electroacoustics to space technology to information technology. And they helped to create the networks and frameworks in which the sea shifted from a national object of prestige to an international object of juridification to a global object of environmental governance. Oceanographical data sets formed the fundament for disputing claims on the oceans as national or corporate territories. Data bases also enabled and faciliated ocean access, extraction, modelling and, in recent climate mitigation strategies for carbon removal, also ocean engineering. The shifting architectures for perception, this chapter has attempted to demonstrate, stabilized the legibility both of scientific knowledge and of the sea as a scientific object.

Do we know the sea? Today's AUVs can store sonar information of hundreds of square kilometers of sea floor topography on a small hard drive that can be downloaded and utilized for scientific, commercial or military uses. Yet, large ocean areas remain unexplored.

Humans know more about the surface of the moon than about the ocean depths. If there is something to conclude at this point it would be that the place and significance of the sea in science, culture and society has not diminished but increased. At the turn to the twenty-first century, the sea has lost its status of ungovernable forceful nature to be admired and feared and passive resource to be annexed, exploited and managed. The sea has turned into a powerful actor that itself intervenes on the global scale and governs the global water cycles and global climates. While current geoengineering schemes continue to take a managerial perspective to the sea with the idea to harness the oceans as carbon storage facilities, the sea of today in many ways is not less but more powerful than the abysmal sea of our ancestors.

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Notes

1 The Ocean Literacy campaign's institutional network includes the National Oceanic and Atmospheric Administration (NOAA), the National Geographic Society, USC Sea Grant, Centers for Ocean Sciences Education Excellence (COSEE), the College of Exploration, and The National Marine Educators' Association. Ocean Literacy Network, www.oceanliteracy.net (accessed April 10, 2019).

2 The resolution of the acronym ASDIC is contested since archival traces of such a committee have not been found. It is probable that the name was meant to camouflage ongoing British Naval work on active sound detection.

3 Wegener's continental drift theory of 1912 contended that the Earth's continents, once a single landmass, had drifted away from one other over geological time, a process which the oceanic ridges gave an indication of.