ENVIRONING MEDIA

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Datafication of the deep sea

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Introduction: The mediated ocean

Our knowledge about the ocean is perhaps more conditioned by technological mediation than that of any other environment on Earth. As Stacy Alaimo points out in an introduction to "blue humanities," "most aquatic zones, species and topics exist beyond human domains, requiring the mediation of science and technology."[1] Likewise, in *Wild blue media*, Melody Jue emphasises the importance of mediation for knowing the marine environment: "in order to study the ocean – especially the deep ocean – scientists need a variety of instrumentation, satellites, remotely operated vehicles (ROVs), submersibles, sonar, and other technical prostheses for sampling and sensing," meaning that "the (deep) ocean emerges as an object of knowledge only through chains of mediation and remote sensing."[2] Developing these observations, ocean historian Helen Rozwadowski has further noted the central role that this mediated knowledge plays in shaping human relationships to "this vast, trackless and opaque place," enabling people to "exploit marine resources, control ocean space, extend imperial or national power, and attempt to refashion the sea into a more tractable arena for human activity."[3] Governance, exploitation and knowledge of the ocean are thus all fully dependent on processes of mediation, and this is increasingly true as the pace by which the ocean is mapped, sensed and datafied rises and the ocean becomes an environed space rather than a wilderness.

With mediation, we refer to the processes of gathering, processing and disseminating environmental data and information. While our empirical focus is on the development of the Argo program, the autonomous floats that gather and supply global marine data, we place this practice in a longer environing media history, showing how data gathering and processing has been key to producing the ocean as we know and understand it over long periods of time.

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We understand environing to mean the process of both knowing and changing the environment, and environing media to mean the technical means by which this process can take place. Taken together as a theoretical concept, environing media refers to the production of environmental epistemologies understood as an ongoing continuous process with historical roots. It also highlights the fact that an environmental object – such as the world ocean – has been in a process of change throughout Earth's history and that in the very latest part of this history humans have come to have considerable impact on these processes of change. Anthropogenic impacts have evolved through scaling up and accelerating the ways in which humans make use of planetary resources, the ontological precondition of which are environing media. With this theoretical framework, this chapter studies the technological mediation of the marine realm and how specific media technologies condition our understanding of what the ocean is, how it changes and what is considered essential and "actionable" ocean knowledge.

Different historical phases of knowing the ocean can be characterised with reference to developments in and application of sensing technologies. Following a long history of increasing exploration and innovation, the arguably most influential contemporary infrastructure for how the ocean is known and mediated is the Argo program, which has been in operation since the early 2000s. Argo consists of a fleet of around 4,000 autonomous instruments, floating with ocean currents in the upper 2,000 m of the water column, recording key variables such as temperature and salinity, and providing fundamental input for oceanographic research as well as for broader Earth system sciences, including, importantly, climate change models.[4] As such, the Argo floats act as data gatherers and are the first-level interface in the mediation process of knowledge about the Earth system from the oceanic part of the hydrosphere.

The Argo program has been described as arising "opportunistically from the combination of great scientific need and technological innovation."[5] This chapter follows up on that statement by placing Argo in the context of environing media technologies used to study and understand the ocean since the start of the modern period. In this way, we aim to show how a gradual accumulation of ocean data and developing mediating technologies have informed and shaped the Argo program, but also how the modern floats introduce a new era of knowing and mediating the marine environment and, by association, the planetary system as an integrated whole. We discuss how Argo floats and the data flows they generate mediate specific forms of knowledge, with implications for how and in what terms the ocean is perceived as well as for how ideas and practices around ocean governance are formulated. We also consider the reverse; how a perceived need for monitoring and evaluating the ocean influences future developments of the Argo program, to make the ocean fully accounted for in the broader notion and project of the mediated planet.

The chapter begins with two sections looking back at the history of how the ocean has been explored, mapped and known. We first review the most important developments taking place from early modern times and throughout the 19th century, before looking more closely at the technologies that emerged around the mid-20th century that ventured further beneath the surface than before and advanced oceanography as a scientific discipline central to Earth system governance. We then examine the beginnings and nature of the Argo program as emerging from this history, including how the new program was presented, envisioned and motivated. In the penultimate section, we discuss the wider datafication of the marine environment that Argo is at the heart of, and the novel views of the ocean that digital environing media enable. To conclude, we suggest some implications of this digital way of knowing the ocean for ocean governance and stewardship.

Connecting and controlling the continents

Argo emerged as a scientific project in the late 1990s. The initial design described a distribution of floats in a 3° × 3° array in the upper 2,000 m of the ice-free and open ocean between 60°N and 60°S.[6] The theoretical premises for a global grid, encircling not only land but also oceans, can be traced back to the early modern period and Ptomely's projection of the spherical surface of the Earth onto a two-dimensional map, an essential environing medium from the 1500s onwards.[7] The early modern European colonialist expansions were essentially naval operations, and hence completely dependent on constructing accurate ocean knowledge. While humans across the globe had long lived with and by the sea, a radical disruption in human-ocean relations took place during the 1500s with the transoceanic colonial enterprises, which demonstrated the connection of the world oceans. While the history of colonialism has mostly focused on territorial conquests, its true condition of possibility was the combination of scientific advances and navigational practices, often promoted by the same institutions, as was the case in Spain. The Spanish empire worked to increase the number of skilled navigators who could facilitate the transoceanic enterprise by mastering the complexities of a new mathematised system of celestial navigation and the associated instruments and tools.[8] In 1552, the House of Trade in Seville established a formal school with a chair of cosmography through which every navigator and pilot had to pass. The school drew its resources and rationale from aiding the colonial aims, which became a model also for maritime communities across Europe in the following centuries.[9]

It was the pursuit of global colonialist ambitions that confronted competing European state powers with the issue of knowing vast oceans adequately enough to navigate and exploit them – Helen Rozwadowski has noted how scientists were tasked with "creating charts and other representations of the ocean that could be used to extend imperial power."[10] The rise of Spanish, Dutch and British empires was made possible by a spatial revolution that transitioned navigation from approximation to precision in a quest for exactness.[11] Early modern mapping and sensing of the world ocean relied on mechanical instruments, mathematics and continuous first-hand documentation of ocean currents, tides and wind patterns registered in rutters and nautical charts.[12] While finding the latitude of a place is fairly straightforward by measuring the angle between the horizon and the polar star or sun in zenith with an astrolabe or quadrant, longitude is more difficult to establish and is calculated from the difference between local time of a prime meridian and the local time of place, which was unknown at sea. The problem of longitude determination was the most-researched aspect of oceanic life in the early modern period and could not be properly solved until the 18th century, after a long history of transnational efforts. This issue was due to the fact that the only available timekeeping devices – necessary to adequately determine the ship's position at sea – were pendulum clocks that constantly lost their beat due to the rolling of the ship on the ocean. The problem was solved after John Harrison's invention of the marine chronometer, a timepiece that could withstand the motion and temperature shifts of sea voyages. With a reliable timepiece set to a fixed location, like Greenwich (GMT), navigators could calculate their geographical position at sea using the time difference of the ship's local time, since each hour corresponds to 15° (360° divided by 24 hours). With longitude and latitude in place, the understanding of oceanic space could be constructed as a grid with exact addresses. The effects of this transition in spatial perception still form the ontological and epistemological basis for planetary environing media today.

The 19th century saw the beginnings of explorations into ocean depths and the efforts of knowing the sea in all its dimensions that continue today. Scale and opacity made this knowledge production particularly difficult. It was first driven by the booming whaling industry which sought new ocean areas after depleting the whale populations of shallower waters. Early ocean environing media include sounding with lead devices attached to lines, which were hauled after touching bottom and counted in fathoms (1.8 m). Records kept by whalers and navigators formed the basis of scientific progress in knowing the deeper ocean. The Gulf Stream, for instance, was well known to whalers long before any scientists started inquiring into the phenomenon.[13]

The science of oceanography emerged from mid-1800s as part of state initiatives for, and public interest in, transatlantic telegraph cables and other communication media infrastructures being successfully installed at the bottom of the ocean.[14] Rather than as occasional experiments, soundings were now performed on the request of governments and with a clear goal in mind: to find a suitable pathway for cables across the Atlantic seabed. The first bathymetric chart of the North Atlantic basin, reflecting results from about 90 soundings, was completed by Matthew Fontaine Maury, an American hydrographer and naval officer, in 1853.[15] In addition, broken cables that had been laid over the seafloor were recovered with a multitude of unfamiliar creatures attached to them, thus also putting an end to the until then prevailing notion that no life could exist below 300 fathoms. The scientific progress and discoveries made in relation to the cables led to an increased interest in the ocean and the second half of the 19th century saw several cruise ships setting out to further investigate, equipped with dredges, trawls and nets to sample the depths. The most well known is the British 1872–1876 *Challenger* expedition, whose results, eventually documented in 50 volumes, provided a foundation for the new science to build from.[16]

Beneath the surface

In the 20th century, acquiring new ocean knowledge became tightly interwoven with military aims, as sonar and submarines became central wartime technologies. Before the Second World War the ocean floor was little known and perceived as a commons by both scientists and naval officers, but after the war the mapping of ocean depths instead became tied to secrecy and nationalistic ends. A great surge in military support for the Earth sciences emerged in this context, and most oceanographic research efforts depended on these ties, and scientific data became relevant to national security. In 1957 Bruce Heezen and Marie Tharp of Columbia University's Lamont Geological Observatory published the first map of the seafloor of the North Atlantic, followed by seafloor maps of all Earth's ocean basins.[17] After Pentagon classified ocean depth data for security reasons, Heezen and Tharp created a physiographic map to avoid the restriction on bathymetric maps, which also turned out to have great advantages for portraying the seafloor.[18] This mapping program provided critical evidence for the theory of plate tectonics, which became accepted in the 1960s and changed the understanding of Earth's geology. These new insights that resulted from the Heezen–Tharp seafloor maps built on new data points created with new and improved instruments, including sounding devices and automated depth recorders, which were financed by US defence agencies.

The International Geophysical Year (IGY) of 1957–1958 saw a fundamental transition in ocean environing media. The program organised the first globe-spanning set of oceanographic expeditions and included coordinated measurements from a dispersed network of sensors. Through the IGY, scientists managed to create the largest and most thorough dataset on oceanic phenomena to date.[19] The systematic and global-scale collection of geophysical data was made possible not only through new technologies for observing and sensing the ocean, but also through the growing technological capacity of storing and processing data with early supercomputers, which meant that the collected data could be used to mediate the marine environment in entirely new ways. Together, the different new technologies formed the conditions of possibility for global biogeochemical and biogeophysical models that together could visualise an *integrated* planetary environmental system, which increasingly included the oceanic realm.[20] The attempt at an integrated vision of the whole ocean, dependent on a grid-based view of dispersed sensors and data points, was profoundly different than sample-based views of the sea, which also developed around the mid-20th century through technological inventions such as the bathyscaphe and scuba diving equipment. While these technologies made possible novel ways to explore and encounter the marine environment, they were only able to provide individual snapshots of mostly coastal oceans. Monitoring technologies represented a fundamentally different scientific approach.

One critical technology developed within the IGY was the first version of a neutrally buoyant float, invented by British oceanographer John Swallow.[21] The IGY also saw the development of another key technology for studying ocean circulation, the bathythermograph, developed in the US for ship-based temperature measurements. As Lehman notes, both technologies "have enduring legacies"; the bathythermograph is still in use, and the Swallow floats pioneered a series of further developments of floats that were eventually able to perform many more measurements than simply the tracking of currents.[22] After Swallow's initial design, several research groups and institutions contributed to improvements and specialisations of the technology.[23] By the 1970s, the floats could provide a range of scientific measurements, significantly improving understanding of oceanic eddy fields as well as circulation within different ocean basins. A major breakthrough was made in the 1980s, when so-called Profiling Autonomous Lagrangian Circulation floats, or P-ALACE floats, were designed to include added sensors that could collect more data.

The P-ALACE floats were also able to transmit their data directly to satellites when they surfaced, which allowed them to operate without depending on acoustic tracking and data reception by associated ships, as earlier floats had done. The P-ALACE floats were also able to descend and surface repeatedly, which significantly reduced the need for maintenance and re-deployment. This development signified a consequential shift for ocean observing, from relying on expensive and labour-intensive research cruises towards becoming a remote and autonomous operation, a shift that has only become more pronounced in the decades since. The P-ALACE floats were equipped with sensors collecting high-quality data on conductivity, temperature and salinity (CTD), and the oceanographic community quickly recognised them as a key technology for global ocean monitoring, including for climate studies. The P-ALACE floats are the most immediate predecessor to the original Argo floats.

While the technologies developed as part of the IGY helped "to generate an unprecedented amount of oceanographic data" in the late 1950s, they were still only able to sample a miniscule part of the global ocean.[24] This remained true in the following decades, even as attempts were made to follow up on the IGY and increase ocean measurements and observations through other large-scale collaborations and initiatives, including improved designs of the neutrally buoyant floats. Following on these continuous efforts, in the 1990s two sampling programs were initiated within the WCRP to gather measurements on a bigger scale: the Tropical Ocean Global Atmosphere program (TOGA, 1985–1994), and the World Ocean Circulation Experiment (WOCE, 1990–2002), a one-time global hydrographic survey and the first of its kind. Both TOGA and WOCE were primarily motivated by the need for data that could be used to improve and extend climate change predictions, which required more detailed observations of global ocean circulation, a key factor in ocean-atmosphere interactions.

WOCE was envisaged as establishing a baseline against which future changes in circulation could be measured, but the results were not as expected.[25] Rather than a baseline, or "snapshot," of global ocean circulation, the project resulted in a realisation of the extent to which the ocean was characterised by variability, complexity and change; a central insight of the decadal research project was that "it may not be possible to know the ocean on a planetary scale."[26] However, this insight, rather than an impasse, led to new ways of thinking about the ocean. In Lehman's description, it constituted a discovery of "productive limits," in the sense that "ocean variability both prompted new forms of knowledge and the development of a global knowledge infrastructure that is contingent, uneven, and fully entwined with geopolitical dynamics."[27] In other words, from the limits encountered, new avenues of research opened up, including the Argo program.

The period around the turn of the millennium, when WOCE was being conducted, was also the time when practices of "satellite oceanography" took off.[28] While the P-ALACE floats were to an extent part of a satellite-based network of observing technologies, in general satellite oceanography focused on the surface of the ocean. In 1992, the US National Aeronautics and Space Administration (NASA) launched its second major satellite TOPEX/Poseidon, where TOPEX stood for "ocean topography experiment." The TOPEX/Poseidon satellite measured the height of sea levels, as a way to deduce the ocean's heat content, providing an entirely new kind of data for ocean science. The successor to the TOPEX/Poseidon satellite, called Jason, was launched in 2001. While satellites vastly increased the proliferation and coverage of ocean data, as Höhler points out, they "could not 'see' in depth,"[29] which created a strong motivation for a below-the-surface complement to satellite measurements: "The need to observe the global subsurface ocean, together with a fit-for-purpose revolutionary autonomous technology […], led to a multinational proposal for a global subsurface ocean observing system."[30] This proposal was the Argo program, which was both named and viewed as a partner program to the first Jason satellite mission.

The limitation in knowledge extraction and production encountered by WOCE is an important dimension of all environing media; the quest for knowledge about the Earth and its interconnected systems have, since it took off in earnest during the early modern era, time and again encountered limitations of knowing the environment, both in general, and for the oceans and atmosphere in particular. This limitation has often led to new ideas and technologies being innovated that have subsequently added to and built environmental epistemologies. A central limitation that has come to play a key role in both science and policy in recent decades is the practical impossibility to fully model or predict the climate system, a limitation that has been exploited by some to delay climate change mitigation by referring to uncertainties in scientific knowledge. Limitations or biases of knowledge also come through choice; in many cases military technology developed for strategic geopolitical purposes, not least during the cold war, have later become fundamental to scientific inquiry into the Earth system, as was the case with meteorology.[31] For oceanography, several studies have shown how military aims have fundamentally shaped scientific knowledge about the ocean, making the point that limitations in knowledge are not only the result of technological capacity, but also of factors such as funding and geopolitics.[32]

In addition to the influence of military programs, from around the time of the conceptualisation of the Argo program, oceanography has been shaped by increasing concern for how people are changing the planetary environment, including the global ocean; from having been studied as a "matter of fact," scientists, research funders and policymakers increasingly conceived of the ocean also as a "matter of concern."[33] In a study of a satellite-based infrastructure for environmental surveillance, also called "Argos," Etienne Benson has for example shown how that program, initiated in the 1970s, after its first decade of operation underwent a change from being merely focused on collecting environmental and ecological data, towards becoming more "environmental" in its nature, by having its observations directly tied to questions such as pollution and the tracking and protection of biodiversity.[34] The Argo program studied in this chapter, designed in the late 1990s, was explicitly environmental from the start, foremost in its relevance for predictions of climate change.

Scaling up: The Argo program

The Argo program was proposed in 1998 by a team of researchers led by Dean Roemmich at Scripps Institution of Oceanography (SIO) in the US. Their plan is explained in a 35-page report titled "On the design and implementation of Argo: a global array of profiling floats." The document notes the limitations of ship-based studies of global ocean features, pointing out that "WOCE required seven years and the combined resources of many nations to obtain a single sparse realization of temperature, salinity, velocity (T, S, v) and geochemical tracers."[35] The proposal highlights the important institutional as well as technological experiences gained within TOGA and WOCE, as well as the TOPEX/Poseidon mission, but also notes their shortcomings. They validate Lehman's argument that the previous programs encountered "productive limits" by motivating Argo specifically as a strategy for overcoming existing "sampling limitations."[36] Rather than an expensive, one-time ship-based snapshot of a stable ocean, as had been the goal and strategy of WOCE, Argo would coordinate an array of continuously operating profiling floats that would be able to obtain an extended stream of data, reflecting an ocean in constant flux.

Two research networks were responsible for developing the new Argo framework: the Climate Variability and Predictability (CLIVAR) component of the WCRP (also responsible for TOGA and WOCE), and the Global Ocean Data Assimilation Experiment (GODAE), initiated just two years earlier, in 1996. The members of the "science team," later Argo Steering Team (AST), listed as authors of the original proposal were appointed at a workshop in Tokyo in July 1998 convened jointly by CLIVAR and GODAE. The objectives of the new program were clearly identified from the start, including the number of floats imagined to be necessary, the parts of the ocean they would be able to reach, and how the data would be received and managed:

> Based on the information available now, it is proposed that Argo should comprise around 3,300 floats, each profiling through 0–2,000 m around 25 times per year over an estimated lifetime of 3–4 years. Each float will measure both temperature and salinity and will provide estimates of current velocity at the parking depth of the floats (probably around 1,500 m). All data will be telemetered in real time and will be available (and widely distributed) within 1–2 days of capture (or sooner if practical). The quality of the data will be ensured through the establishment of data assembly centres for float data.[37]

The proposal notes that recent technological advancements with regards to float designs, notably the addition of censors and the prolonged lifetime of each float, made the proposed program "a very cost-effective option."[38]

The strategy for deployment focused on expanding existing nodes where floats were already present, before extending the array to new areas. Existing floats operated primarily in the North Atlantic and eastern tropical Pacific Ocean. The Indian and Southern Oceans were identified as initial areas for expansion, with deployments predicted to begin within two years, in 2000. The plan was to reach global coverage as soon as possible, with the central AST coordinating small-scale national or regional contributions of floats to avoid overlaps and fill in gaps, "ensuring global coverage and adequate resolution."[39] The proposal notes that though some regions would be challenging to reach, even with autonomous floats, the program was both doable and necessary:

> It is clear global coverage will not be easy to achieve and it is likely a consortium-like approach will be needed to ensure adequate sampling in data sparse regions. There are also several outstanding technical issues that need to be addressed. However, our best advice at present suggests none of these issues represent an insurmountable obstacle for Argo.[40]

The most important scientific contribution that Argo was forecasted to make was to improve the accuracy of climate prediction models. Interactions between the ocean and the atmosphere are one of the most central dynamics in the climate system, and even more so as the climate changes, as the ocean takes up excess heat and carbon from the air to reach a new equilibrium. The process changes the marine environment, both locally and globally, as added carbon leads to acidification and higher temperatures expands the volume of the water and causes deoxygenation, while also affecting how different water masses move, mix and interact with each other. For example, the Atlantic Meridional Overturning

Circulation (AMOC) has slowed down over the past century and may be at a risk of shutdown, with associated severe climate and ocean effects.[41] The prompt detection of such changes and their development is made possible by the data gathered by the Argo floats. By measuring temperature, salinity and oxygen, key variables for these changes, Argo provides insights into how climate change impacts the water and drives for example sea-level rise. This information is in turn used to constrain climate models with vastly more observational data than had previously been possible with single, ship-based measurements. The program was thus presented as an essential subsurface partner to the Jason satellite altimetry program, which had been measuring sea-level height, a key indicator of warming waters, since 1992. Through combined efforts, Argo and Jason would provide comprehensive and integrated knowledge about the ocean-atmosphere interface, including better understanding of the causes, such as temperature changes, behind the rise of global sea level observed by satellite measurements:

> The combination of *Argo* and altimetry will enable a new generation of applications. Global maps of sea level, on time scales of weeks to several years, will be interpreted with full knowledge of the upper ocean stratification. The vertical dependence of the oceanic response to surface forcing will be in view. Global ocean and climate models will be initialized, tested and constrained with a level of information hitherto not available. An adequate sampling network will be in place as a foundation for future studies of climate variability and predictability.[42]

In other words, Argo helps to bring the three-dimensional ocean into climate science, shedding light both on the ocean's role in climate change mitigation and on the impacts of climate change on the ocean environment and its inhabitants. These contributions were recognised and predicted from the start; the Argo proposal notes that if successfully implemented, the new program represented "a near-revolution in ocean measurement," with profound implications for oceanographers as well as for studies of the climate and other Earth systems.[43] The team of authors concluded confidently that readers would find "the initiative, though ambitious, both doable and worth doing" (Figure 7.1).[44]

The prediction proved accurate. The Argo proposal was quickly approved, with institutional backing from both GODAE and CLIVAR. The first floats were deployed already in 1999, only a year after the official proposal and earlier than predicted, and global deployments have been in place since 2004. The goal of 3,000 individual floats was reached in 2007. From a US-based initiative, the program has developed into an international collaboration, with around 30 countries contributing one or more floats to the global array in the early 2020s. The US remains responsible for about half the total number of floats. After two decades of operation, Roemmich, one of the initiators, could state that "Argo's systematic and regular observation of the global subsurface ocean has transformed ocean observing," while leading "the way among ocean observing networks

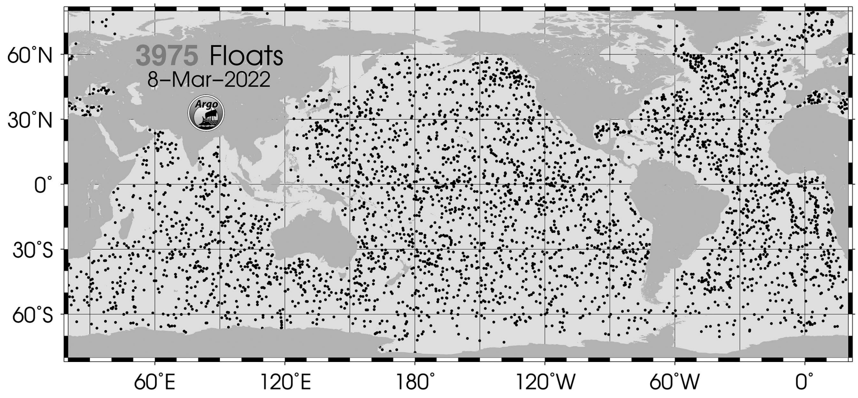

FIGURE 7.1 Map of Argo Floats in operation 2022.

with regard to international cooperation, operations planning, Data Availability, and metadata quality."[45] Keys to the program's success have been identified as the robust and cost-effective technology of the floats, strong consensus on the high value of the program within and beyond the scientific community, and effective partnerships between research teams and commercial suppliers in the continuous development and improvement of float technologies.[46] Argo plays a central role in the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS), as well as the World Climate Research Program (WCRP). In other words, the Argo program is a planetary environing medium, not just for our knowledge of the ocean but also for knowing and observing the climate and the Earth system as a whole.

Argo and the increasing datafication of the marine environment

The environing of the ocean that emerged through post-war and Cold War technologies resulted in scientific understandings fundamentally different from how the marine realm was previously known. Höhler observes that "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."[47] Lehman likewise notes the central importance of the IGY for subsequent developments in oceanographic research and for its role in making what she calls "an Anthropocene ocean" – an ocean that was at the same time better known and further impacted by people, through ventures into the depths, changes to compositions of marine life as well as waters, and extraction of resources. This fundamental change in how the global ocean was observed, sampled and known intensified in the 1990s, as observations and sampling were to a significant extent decoupled from ships. The Argo program played a pivotal role in this development; the global array of autonomous floats was presented as "key to help free the large-scale oceanographic data collection process from the dependency on ships."[48] The Argo proposal explicitly argues for the importance of pursuing and enabling this profound change, predicting that "the oceanographic community is entering a new era where ocean models and data assimilation and ocean state estimation will be the preferred methods for utilizing data."[49]

The Argo program is thus part of a development that has seen the increasing importance of digital data in ocean sciences in the first decades of the 21st century. The networks of sensors made up of Argo floats and other GOOS technologies are "creating a new understanding of the world ocean," as Lehman puts it, that "converts the ocean's properties into flows of information, creating a data double of a dynamic sea."[50] The oceanic network of networks that Argo is part of has been studied by Stefan Helmreich, starting from a different environing medium, the wave buoy. Like the buoy, the Argo floats can be viewed "as a material technology with literary/informational tendrils out into the world, a world stitched together through a media ecology of instruments and social institutions."[51] Through this comprehensive environing media system individual Argo measurements are put together, processed and analysed, and then combined with additional forms of measurements and data to eventually create the "data double" that Lehman refers to (Figure 7.2).

In the environing media of the Argo floats, the actor closest to the floats themselves is the Argo Data Management Team (ADMT), which oversees the flows of data from the physical floats. The original Argo proposal underlines the importance of creating an innovative data management system to make the most of the float recordings, emphasising "the complementary role of the direct and remote observing networks and the role of models and data assimilation in integrating incoming information and producing useful and practical outputs."[52] The ADMT developed a two-step system to achieve this, with one strategy for real time and a second one for delayed-mode data. In the first step, the floats transmit their recordings via satellite to one of several Data Assembly Centres (DACs) around the world, where the data are subjected to automated quality control before being distributed to the Global Telecommunications System (GTS) and then forwarded to two Argo Global DACs (GDACs): one in France and one in the US. This initial process is routinely completed within 24 hours, and primarily serves operational users, such as meteorological agencies who require real-time data for weather forecasting. The second step, performed by the two GDACs, includes thorough quality control and processing to turn the raw data into a user-friendly format. This process produces high-quality data for the scientific community and is usually completed within a year, but may also be revisited at any later date. It was agreed from the start of the Argo program that all data, both raw and processed, "would be publicly available without restriction."[53] This policy has been maintained, making the program "a pioneer in scientific ocean data delivery."[54]

The ocean environing media that the Argo program is a central part of have enacted a large-scale datafication of the marine environment. Höhler describes

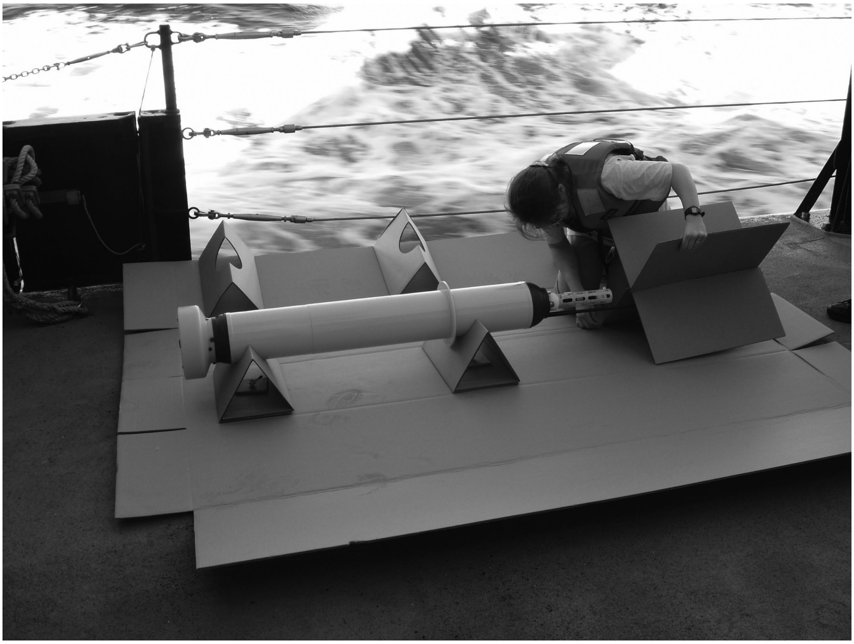

FIGURE 7.2 An Argo float is prepared for deployment.

how over the course of the 20th century, "synoptic images created ocean knowledges that began with digits and ultimately resided in digital data sets and the potentials of data recombination."[55] This datafication, as with other forms of digital media transmissions, is not innocent or neutral in its nature. What is included and represented depends on many factors. Lehman has argued for example that "the IGY's oceanography program reveal the ways in which old and new forms of imperialism were knitted together to produce the world ocean as an object of knowledge in a new era of planetary-scale environmental politics,"[56] and moreover that "synoptic geographies entail not just uneven data coverage of the globe but also unequal geopolitical relationships, serving to further scientific expertise in some geographical areas and not others, at the same time creating a notion of the planet as an object of knowledge for all humanity."[57]

Benson has drawn attention to disciplinary dimensions, in the sense that the power and interests of different user groups shape what is prioritised or made technologically possible. In his study, this is reflected in "the differences between global environmental visions of meteorologists and wildlife biologists,"[58] a disciplinary difference that seems present also in the Argo program; the original floats, or Core Argo, record data on temperature, salinity and pressure, that is, geophysical variables central to climate scientists, but do not provide data on biodiversity, for example, which is more difficult to collect. Another limitation of Core Argo is depth; the original floats only descend to 2,000 m beneath the surface, which means that half the ocean remains unaccounted for. While these limitations of the original Argo program are being addressed, through additional programs that measure more variables in more places (including Biogeochemical Argo, Deep Argo and Polar Argo), limitations will always be a factor and no streams of data will ever represent the ocean in its entirety, regardless of claims of a "digital twin" of the ocean.

Governing a datafied ocean

Looking back at Argo's first decade of operation, Roemmich et al. conclude that "Argo has achieved more than anyone imagined it would ten years ago, but the hardest work lies ahead – sustaining the program, broadening its applications and user base, and ensuring that its global observations benefit people in all nations." Plans for the future include substantial expansion in multiple directions: "The objective is to create a fully global, top-to-bottom, dynamically complete, and multidisciplinary Argo Program that will integrate seamlessly with satellite and with other *in situ* elements of the Global Ocean Observing System."[59] There are also plans to further utilise automated machine learning, according to a recent report:

> Looking forward, advances in machine learning algorithms have the potential to provide an important resource to the Argo community by helping to meet the challenge of maintaining the quality of data from more floats and diversified missions as the program continues to expand.[60]

Others have also suggested that machine learning provides an opportunity for quality control and expansion of ocean data, and, by association, for ocean governance.[61]

Increasing the quantity and quality of global ocean observations and knowledge, not least through more and better data, is seen as central to protecting and governing the marine environment. Under the United Nations Convention of the Law of the Sea (UNCLOS), the acquisition of ocean data is directly linked to obligations to share scientific information and knowledge equitably, captured in concepts such as "technology transfer" and "capacity building."[62] The need to share ocean data openly is recognised in best practices for the field, such as the FAIR (findable, accessible, interoperable and reusable) data principles, as well as in UN initiatives to develop ocean science and sustainability, including SDG target 14a to "increase ocean knowledge, develop research capacity and transfer marine technology," and ongoing negotiations for a legally binding instrument to protect and sustainably use marine biodiversity beyond national jurisdiction (BBNJ treaty).

At the same time, it is recognised that current ocean databases are fragmented, siloed between disciplines, actors and regions, which hinders accessibility and usability.[63] A recent study raises concerns around the use of data-driven optimisation algorithms for marine spatial planning and protection specifically, noting that algorithmic approaches can reinforce existing inequities both through the data themselves, where "exclusionary inputs" lead to "exclusionary outputs," due for instance to certain geographical areas or species being more studied than others, and through differing interpretations of data that become reflected but invisible inside complex algorithms: "the values and positionalities of those funding, designing, and implementing algorithms can shape the encoded objectives of these algorithms at the expense of those whose knowledges and experiences are not represented." The same study notes that algorithmic approaches favour standardised scientific data in ways that risk marginalising other, such as traditional or indigenous, knowledges about marine ecosystems.[64]

The current development towards algorithmic rationality through big data analytics that is increasingly permeating the epistemic object of the world ocean has long historical roots reaching back to the early modern era, as we have attempted to show in this chapter. A shift in perception from qualitative to quantitative observations of the environment that began during the late Middle Ages and the Renaissance can still be seen as ongoing today.[65] Through mastery of new scientific techniques for measurement and calculation, new scales of exploitation and domination have been made possible. As we discussed in the beginning of this chapter, this was particularly true for the colonial developments which depended on a new global nautical infrastructure.

The present datafication of ocean science and observations likewise has implications for contemporary marine governance and geopolitics. Lehman contends that the systematic and networked collection, compilation and analysis of observations turn the ocean's flows, just like the flows of data emanating from the activity of contemporary individuals, into isolated and transformed flows of actionable information.[66] As the ocean is rapidly datafied through big data sets that are increasingly open, questions around the use and interpretation of these data, including who has the ability and power to use them towards their chosen ends, are raised. While we can perhaps model the trajectory of a sustainable ocean with the aid of machine learning, the models themselves do not make the political decision-making around marine sustainable development any less fraught than it has been throughout history, and since the second half of the 20th century in particular. More data does not necessarily entail a more protected ocean, as the environing process always depends on human agency.

Notes

1 Stacy Alaimo, "Science Studies and the Blue Humanities," *Configurations* 27, no. 4 (2019): 429.

2 Melody Jue, *Wild Blue Media: Thinking through Seawater* (Durham, NC: Duke University Press, 2020), 3.

3 Helen Rozwadowski, *Vast Expanses: A History of the Oceans* (London: Reaktion, 2019), 9.

4 Stephen C. Riser, Howard J. Freeland, Dean Roemmich, et al., "Fifteen Years of Ocean Observations with the Global Argo Array," *Nature Climate Change* 6 (2016): 145–153.

5 Dean Roemmich, Matthew H. Alford, Hervé Claustre, et al., "On the Future of Argo: A Global Full-Depth, Multi-Disciplinary Array," *Frontiers in Marine Science* 6 (2019), article no. 439.

6 The Argo Science Team, *On the Design and Implementation of Argo: A Global Array of Profiling Floats* (The Hague: International CLIVAR Project Office, 1998); Annie P.S. Wong, Susan E. Wijffels, Stephen C. Riser, et al., "Argo Data 1999–2019: Two Million Temperature-Salinity Profiles and Subsurface Velocity Observations from a Global Array of Profiling Floats," *Frontiers in Marine Science* 7, no. 700 (2020).

7 Bernhard Siegert, "(Not) in Place: The Grid, or Cultural Techniques for Ruling Spaces," *Cultural Techniques: Grids, Filters, Doors and Other Articulations of the Real* (Fordham: Fordham University Press, 2015).

8 Margaret E. Schotte, *The Sailing School: Navigating Science and Skill 1550–1800* (Baltimore, MD: Johns Hopkins University Press, 2019), 17.

9 Rozwadowski, *Vast Expanses*, 10.

10 Ibid., 102.

11 Bernhard Siegert, "Longitude and Simultaneity in Philosophy, Physics, and Empires," *Configurations* 23, no. 2 (2015): 148.

12 Joaquim Alves Gaspar & Henrique Leitao, "What Is a Nautical Chart, Really? Uncovering the Geometry of Early Modern Nautical Charts," *Journal of Cultural Heritage* 29 (2018): 130–136.

13 Rozwadowski, *Vast expanses,* 108.

14 Helen Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Cambridge, MA: Harvard University Press, 2008), 14.

15 Rozwadowski, *Vast expanses*, 110.

16 Ibid., 122.

17 Ronald E. Doel, Tanya J. Levin, & Mason K. Marker, "Extending Modern Cartography to the Ocean Depths: Military Patronage, Cold War Priorities, and the Heezen-Tharp Mapping Project, 1952–1959," *Journal of Historical Geography* 32, no. 3 (2006): 605–626.

18 Håkon With Andersen, "A Short Human History of the Ocean Floor," *The Law of the Seabed* (Leiden: Brill Nijhoff, 2020), 61–82.

19 Jessica Lehman, "Making an Anthropocene Ocean: Synoptic Geographies of the International Geophysical Year 1957–1958," *Annals of the American Association of Geographers* 110, no. 3 (2020): 606–622.

20 Eva Lövbrand, Johannes Stripple, & Bo Wiman, "Earth System Governmentality: Reflections on Science in the Anthropocene," *Global Environmental Change* 19, no. 1 (2009): 7–13.

21 John C. Swallow, "A Neutral-Buoyancy Float for Measuring Deep Currents," *Deep Sea Research* 3, no. 1 (1955): 74–81.

22 Lehman, "Making an Anthropocene Ocean," 615; see also Jessica Lehman, "A Sea of Potential: The Politics of Global Ocean Observations," *Political Geography* 55 (2016): 113–123.

23 W. John Gould, "From Swallow Floats to Argo – the Development of Neutrally Buoyant Floats," *Deep-Sea Research II* 52 (2005): 537.

24 Lehman, "Making an Anthropocene Ocean," 615.

25 Jessica Lehman, "Sea Change: The World Ocean Circulation Experiment and the Productive Limits of Ocean Variability," *Science, Technology & Human Values* 46, no. 4 (2021): 839–862.

26 Lehman, "Sea change," 850.

27 Ibid., 840.

28 Sabine Höhler, "Knowledges: Creating the Blue Planet from Modern Oceanography," *A Cultural History of the Sea in the Global Age*, ed. Franziska Torma (London: Bloomsbury Academic, 2021), 21–44.

29 Höhler, "Knowledges."

30 Roemmich et al., "On the Future of Argo," 3.

31 Paul Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: MIT Press, 2010), 88; cf. also Friedrich A. Kittler, *Grammophone, Film, Typewriter* (Berlin: Brinkmann & Bose, 1986), 149.

32 Naomi Oreskes, *Science on a Mission: How Military Funding Shaped What We Do and What We Don't Know about the Ocean* (Chicago and London: Chicago University Press, 2021); see also e.g. John Cloud (ed.). "Earth Sciences in the Cold War," special issue of *Social Studies of Science* 33, no. 5 (2003) and Lino Camprubí & Alexandra Hui, "Testing the Underwater Ear: Hearing, Standardizing, and Classifying Marine Sounds from World War I to the Cold War," *Testing Hearing: The Making of Modern Aurality*, eds. Viktoria Tkaczyk, Mara Mills & Alexandra Hui (New York: Oxford University Press, 2020), 301–326.

33 Bruno Latour, "Why Has Critique Run Out of Steam? From Matters of Fact to Matters of Concern," *Critical Inquiry* 30, no. 2 (2004): 225–248.

34 Etienne Benson, "One Infrastructure, Many Global Visions: The Commercialization and Diversification of Argos, a Satellite-Based Environmental Surveillance System," *Social Studies of Science* 42 (2012): 843–868.

35 The Argo Science Team, *On the Design and Implementation of Argo*, 1–2.

36 Ibid., 8.

37 Ibid., 28.

38 Ibid., ii.

39 Ibid., 27.

40 Ibid., 30.

41 Niklas Boers, "Observation-Based Early-Warning Signals for a Collapse of the Atlantic Meridional Overturning Circulation," *Nature Climate Change* 11 (2021): 680–688.

42 The Argo Science Team, *On the Design and Implementation of Argo*, ii.

43 Ibid., 30.

44 Ibid., i.

45 Roemmich et al., "On the Future of Argo."

46 Ibid.

47 Höhler, "Knowledges."

48 The Argo Science Team, *On the Design and Implementation of Argo*, 2.

49 Ibid., ii.

50 Lehman, "A Sea of Potential," 113.

51 Stefan Helmreich, "Reading a Wave Buoy," *Science, Technology & Human Values* 44, no. 5 (2019): 742.

52 The Argo Science Team, *On the Design and Implementation of Argo*, 4.

53 Dean Roemmich, Gregory C. Johnson, Stephen Riser et al., "The Argo Program: Observing the Global Ocean with Profiling Floats," *Oceanography* 22, no. 2 (2009): 34–43.

54 Wong et al., "Argo Data 1999–2019," 6.

55 Höhler, "Knowledges."

56 Lehman, "Making an Anthropocene Ocean," 606.

57 Ibid., 613.

58 Benson, "One Infrastructure, Many Global Visions," 860–861.

59 Roemmich et al., "On the Future of Argo," 2.

60 The National Oceanographic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, "The Argo Program: Two Decades

of Ocean Observations," https://www.aoml.noaa.gov/news/two-decades-argo-program/ (accessed 4 March 2022).

61 E.g. Wong et al., "Argo Data 1999–2019."

62 Harriet Harden-Davies, "Marine Technology Transfer: Towards a Capacity-Building Toolkit for Marine Biodiversity Beyond National Jurisdiction," *Marine Biodiversity of Areas Beyond National Jurisdiction*, eds. Myron H. Nordquist and Ronánn Long (Leiden: Brill Nijhoff, 2021).

63 Annie Brett, Jim Leape, Mark Abbott et al., "Ocean Data Need a Sea Change to Help Navigate the Warming World," *Nature* 582 (2020): 181–183.

64 Cf. Melissa S. Chapman, William K. Oestreich, Timothy H. Frawley, et al., "Promoting Equity in the Use of Algorithms for High-Seas Conservation," *One Earth* 4 (2021): 792.

65 Alfred W. Crosby, *The Measure of Reality: Quantification and Western Society 1250–1600* (Cambridge: Cambridge University Press, 1997).

66 Lehman, "A Sea of Potential," 119.

References

Alaimo, Stacy. "Science Studies and the Blue Humanities." *Configurations* 27, no. 4 (2019): 429–542.

Andersen, Håkon With. "A Short Human History of the Ocean Floor." *The Law of the Seabed*. Leiden: Brill Nijhoff, 2020.

Argo Science Team. *On the Design and Implementation of Argo: A Global Array of Profiling Floats*. The Hague: International CLIVAR Project Office, 1998.

Benson, Etienne. "One Infrastructure, Many Global Visions: The Commercialization and Diversification of Argos, a Satellite-Based Environmental Surveillance System." *Social Studies of Science* 42 (2012): 843–868.

Boers, Niklas. "Observation-Based Early-Warning Signals for a Collapse of the Atlantic Meridional Overturning Circulation." *Nature Climate Change* 11 (2021): 680–688.

Brett, Annie, Jim Leape, Mark Abbott et al. "Ocean Data Need a Sea Change to Help Navigate the Warming World." *Nature* 582 (2020): 181–183.

Camprubí, Lino, & Alexandra Hui. "Testing the Underwater Ear: Hearing, Standardizing, and Classifying Marine Sounds from World War I to the Cold War." *Testing Hearing: The Making of Modern Aurality*, edited by Viktoria Tkaczyk, Mara Mills, & Alexandra Hui, 301–326. New York: Oxford University Press, 2020.

Chapman, Melissa S., William K. Oestreich, Timothy H. Frawley, et al. "Promoting Equity in the Use of Algorithms for High-Seas Conservation." *One Earth* 4 (2021): 790–794.

Cloud, John (ed.). "Earth Sciences in the Cold War." special issue of *Social Studies of Science* 33, no. 5 (2003): 629–633.

Crosby, Alfred W. *The Measure of Reality: Quantification and Western Society 1250–1600.* Cambridge: Cambridge University Press, 1997.

Doel, Ronald E., Tanya J. Levin & Mason K. Marker. "Extending Modern Cartography to the Ocean Depths: Military Patronage, Cold War Priorities, and the Heezen-Tharp Mapping Project, 1952–1959." *Journal of Historical Geography* 32, no. 3 (2006): 605–626.

Edwards, Paul. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming.* Cambridge, MA: MIT Press, 2010.

Gaspar, Joaquim Alves, & Henrique Leitao. "What Is a Nautical Chart, Really? Uncovering the Geometry of Early Modern Nautical Charts." *Journal of Cultural Heritage* 29 (2018): 130–136.

Gould, W. John. "From Swallow Floats to Argo – The Development of Neutrally Buoyant Floats." *Deep Sea Research Part II: Topical Studies in Oceanography* 52 (2005): 529–543.

Harden-Davies, Harriet. "Marine Technology Transfer: Towards a Capacity-Building Toolkit for Marine Biodiversity Beyond National Jurisdiction." *Marine Biodiversity of Areas Beyond National Jurisdiction*, edited by Myron H. Nordquist & Ronánn Long, 231–238. Leiden: Brill Nijhoff, 2021.

Helmreich, Stefan. "Reading a Wave Buoy." *Science, Technology & Human Values* 44, no. 5 (2019): 737–761.

Höhler, Sabine. "Knowledges: Creating the Blue Planet from Modern Oceanography." *A Cultural History of the Sea in the Global Age*, edited by Franziska Torma, 21–44. London: Bloomsbury Academic, 2021.

Jue, Melody. *Wild Blue Media: Thinking through Seawater.* Durham, NC: Duke University Press, 2020.

Kittler, Friedrich A. *Grammophone, Film, Typewriter.* Berlin: Brinkmann & Bose, 1986.

Latour, Bruno. "Why Has Critique Run Out of Steam? From Matters of Fact to Matters of Concern." *Critical Inquiry* 30, no. 2 (2004): 225–248.

Lehman, Jessica. "Sea Change: The World Ocean Circulation Experiment and the Productive Limits of Ocean Variability." *Science, Technology & Human Values* 46, no. 4 (2021): 839–862.

———. "Making an Anthropocene Ocean: Synoptic Geographies of the International Geophysical Year 1957–1958." *Annals of the American Association of Geographers* 110, no. 3 (2020): 606–622.

———. "A Sea of Potential: The Politics of Global Ocean Observations." *Political Geography* 55 (2016): 113–123.

Lövbrand, Eva, Johannes Stripple, & Bo Wiman. "Earth System Governmentality: Reflections on Science in the Anthropocene." *Global Environmental Change* 19, no. 1 (2009): 7–13.

National Oceanographic and Atmospheric Administration (NASA), Atlantic Oceanographic and Meteorological Laboratory. "The Argo Program: Two Decades of Ocean Observations." https://www.aoml.noaa.gov/news/two-decades-argo-program/ (accessed 4 March 2022).

Oreskes, Naomi. *Science on a Mission: How Military Funding Shaped What We Do and What We Don't Know about the Ocean.* Chicago and London: Chicago University Press, 2021.

Riser, Stephen C., Howard J. Freeland, Dean Roemmich, et al. "Fifteen Years of Ocean Observations with the Global Argo Array." *Nature Climate Change* 6 (2016): 145–153.

Roemmich, Dean, Matthew H. Alford, Hervé Claustre, et al. "On the Future of Argo: A Global Full-Depth, Multi-Disciplinary Array." *Frontiers in Marine Science* 6, no. 439 (2019). https://www.frontiersin.org/articles/10.3389/fmars.2019.00439/full

Roemmich, Dean, Gregory C. Johnson, Stephen Riser et al. "The Argo Program: Observing the Global Ocean with Profiling Floats." *Oceanography* 22, no. 2 (2009): 34–43.

Rozwadowski, Helen. *Vast Expanses: A History of the Oceans.* London: Reaktion, 2019.

———. *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea.* Cambridge, MA: Harvard University Press, 2008.

Schotte, Margaret E. *The Sailing School: Navigating Science and Skill 1550–1800.* Baltimore, MD: Johns Hopkins University Press, 2019.

Siegert, Bernhard. “Longitude and Simultaneity in Philosophy, Physics, and Empires.” *Configurations* 23, no. 2 (2015): 145–163.

Siegert, Bernhard. “(Not) in Place: The Grid, or Cultural Techniques for Ruling Spaces.” *Cultural Techniques: Grids, Filters, Doors and Other Articulations of the Real*, edited by Bernhard Siegert, 97–120. Fordham: Fordham University Press, 2015.

Swallow, John C. “A Neutral-Buoyancy Float for Measuring Deep Currents.” *Deep Sea Research* 3, no. 1 (1955): 74–81.

Wong, Annie P.S., Susan E. Wijffels, Stephen C. Riser, et al. “Argo Data 1999–2019: Two Million Temperature-Salinity Profiles and Subsurface Velocity Observations from a Global Array of Profiling Floats.” *Frontiers in Marine Science* 7, no. 700 (2020). https://www.frontiersin.org/articles/10.3389/fmars.2020.00700/full