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Sensoring the Oceans: The Argo Floats Array in the Governance of Science Data Infrastructures

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Abstract

What role do governance arrangements, background legal rules, and the core infrastructures play in enabling data collection, determining what "ocean data" is produced, and when and how it is made available? We explore this question by focusing on data about oceanic features produced by Argo – an international program, operationalized by state agencies and research institutions, that comprises arrays of autonomous floats for ocean observation. Through examination of annual meeting notes, interviews, and observation of the Argo Steering Committee's annual meeting, we analyze the techniques and practices involved in planning, testing, calibrating, validating, and error-correcting that ultimately lead to the production, transmission, and dissemination of Argo data. We then position Argo within the institutional governance of oceans, weather, climate and, most recently, earth systems to illustrate both the evolution of Argo's role and its evolving and uneasy position within different governance approaches. In the conclusion, we challenge the utility of "ocean data" as an analytical category and highlight the risks of over-coordination and institutionalization of data infrastructures. We suggest that allowing data infrastructures like Argo to develop organically might lead to productive (if unexpected) connections, fusions, or splits, which might in turn reorient the focus of observation towards unexplored interactions between and within earth systems. We hope that our analysis helps bring to the fore some core data-infrastructural features of planetary governance as it now exists and will (have to) rapidly further evolve.

Keywords: data governance, ocean data, data infrastructure, thinking infrastructurally, Argo, planetary governance

Forthcoming in: Fleur Johns, Gavin Sullivan & Dimitri Van Den Meerssche (eds), Global Governance by Data: Infrastructures of Algorithmic Rule (Cambridge University Press).

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I. Introduction: Data/Infrastructure

'Infrastructures as regulation' and 'governance by data' are suggestive designators of forms of ordering that are not directly legal but relate – as law does – to the generation and allocation of resources and status, the opening or constraining of future possibilities, and the shaping of behavior and all manner of relations.[1] 'Infrastructures' and 'data' have in common that they are relational, material, dynamic, complex, and scalar. A high proportion of infrastructures involve data, and almost all electronic digital data is collected, stored, moved and used within infrastructures. Various melds of data and infrastructures are of tremendous significance in diverse areas of current and future regulatory governance, as well as to the formation and functioning of scientific knowledge. Knowledge and understanding of earth systems, and efforts in planetary and space governance, depend heavily on 'data infrastructures'. For these reasons, the theory and practice of science-related data infrastructures and their governance demand attention.

Scientific data infrastructures are frequently discussed and analyzed as *information* and *knowledge* infrastructures.[2] Data infrastructures are, of course, largely about producing 'knowledge' in the form of scientific insights and understanding of specific natural phenomena: the underlying driver for many participants (not all) is data *as a means* for producing information and then for generating knowledge. At the same time, data can shape imaginaries, define problems, create and "translate" processes and phenomena that are represented in data, draw boundaries (i.e., what is valid and what is "noise"), and embody normativities through choices around datafication (i.e., what becomes data), naming (i.e., what is being measured), standards (i.e., what becomes valid data), and modes of presentation (i.e., formats, visualizations, etc.).[3] Data can also enable action without ever becoming information or knowledge that is legible to humans, such as when data is transmitted between machines or is fed into a computational model. Data generation, processing, movement, and ultimate use is enabled by physical, digital and knowledge infrastructures, each of which individually, collectively,

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[1] See Benedict Kingsbury, Infrastructure and InfraReg: on rousing the international law 'Wizards of Is', 8 Cambridge International Law Journal 171 (2019); Fleur Johns, Governance by Data, 17 Annual Review of Law and Social Science 53 (2021).

[2] See e.g., Florence Millerand, Karen S. Baker, "Data Infrastructures in Ecology: An Infrastructure Studies Perspective", Environmental Science, Oxford Research Encyclopedias (2020); Sabina Leonelli S (2022), "How Data Cross Borders: Globalising Plant Knowledge through Transnational Data Management and its Epistemic Economy", in J Krige J (Ed), Transnational Transactions: Negotiating the Movement of Knowledge Across Borders, Chicago, IL: University of Chicago Press; Paul N. Edwards, "Knowledge infrastructures for the Anthropocene", The Anthropocene Review, 4:1 (2017).

[3] Cf. The Quiet Power of Indicators (2015) (eds. Sally Engle Merry, Kevin E. Davis, Benedict Kingsbury; see also New Perspectives in Critical Data Studies: The Ambivalences of Data Power (2022) (eds. Andreas Hepp, Juliane Jarke, Leif Kramp).

interdependently, and/or in opposition to each other exert regulatory powers. It is through infrastructures that data is configured and reconfigured, channeled, blocked, stored, and made durable over a long time and across extended space -- or fleeting and constrained.

In this paper, we focus on the production of data about the ocean. With the urgencies of climate change and recognition of ocean's importance in regulating climate, global-scale initiatives such as the Ocean Decade,[4] have focused on enhancing production of "ocean data" and improving observational capacities of countries to engage in such data production. Creating "a digital representation of the ocean" is one of the challenges articulated by the Ocean Decade initiative.

What role do governance arrangements, background legal rules, and the core infrastructures play in enabling data collection, determining what "ocean data" is produced, and when and how it is made available? We explore this question by focusing on data about oceanic features produced by the Argo – an international program, operationalized by state agencies and research institutions, that comprises arrays of autonomous floats for ocean observation.[5] The floats, which drift with ocean currents and move vertically between the surface and mid-water levels, generate multi-dimensional spatial, temporal, sensory observation data about certain physical and biogeochemical properties of the oceans. The data is constituted and configured through physical and digital infrastructures that enable generation, transmission, and storage of data, knowledge infrastructures through which sensor data is transformed into data that is legible by scientific communities and usable for delineated purposes. This "sensing" data not only forms part of the ontology of what it is describing but also help make what they are meant to represent (in this case: "the ocean").[6] Data, however, is necessarily reductive, partial, and incomplete – it is never the thing itself that is is meant to represent.[7] What it creates is a function of choices made at various temporal and spatial infrastructural sites: What data can be produced given existing technologies, capacities, needs, legacy infrastructures? What data has

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[4] https://oceandecade.org/.

[5] Scholarship in media studies situate Argo in the context of environing media technologies, developed over time, to show the symbiotic relationship between the Argo program and historic accumulations of data and technological developments to construct and shape both the human perceptions of the ocean and the ideas and practices of ocean governance. *See* Susanna Lidström, Adam Wickberg and Johan Gärdebo, "Datafication of the deep sea", in Adam Wickberg and Johan Gärdebo (eds.) Ocean Environing Media (2023).

[6] See also Stacy Alaimo, "Science Studies and the Blue Humanities," Configurations 27, no. 4 (2019): 42; 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; Irus Braverman, Elizabeth R. Johnson (eds.) Blue Legalities: The Life and Laws of the Sea (2020); David le Breton, Sensing the World: An Anthropology of the Senses (2006).

[7] See e.g., Sabina Leonelli, Data-centric Biology: A Philosophical Study (2016).

inferential potential? What data can be generated in a sustained fashion? How can relationality of (what) data be best leveraged? How can contextual variabilities be accounted for to arrive at commensurability (which itself raises questions of capacity, expertise, etc.)?

Argo's socio-technical practices, aggregated with other 'data infrastructures' across different areas of scientific observational and modelling practice and across different scales, can have an onto-epistemological[8] effect, constructing and crystallizing a particular conception of 'the ocean' (as one comprising sets of datafied physical and biogeochemical parameters) or of the self-reproducing vision of earth system, "consisting of interlinked physical, chemical and biological processes that cycle materials and energy in non-linear, complex and dynamic ways within the system".[9] Argo's emphasis on openness and accessibility of data and generally participatory governance,[10] may enable users to leverage the relationality and recombinant potential of data to open up opportunities to rupture "fixed and bounded systems and the traditional notions of causality and agency, which lie at the heart of an autopoietic framing of the Earth system's functioning" and instead reveal new ways of relating in more-than human worlds.[11] By inverting Argo, we hope to generate insights about its regulatory ambivalence.[12] Thinking across scales – from localized sites of Argo decision-making processes to global aspirations for the development of "trusted, inclusive, and interconnected ocean data and information ecosystem that is actively used for decision making to support sustainable ocean management"[13] – we ask how thinking from infrastructure and data to 'data infrastructure' may contribute to governance arrangements relating to observational science and planetary modelling.

In this spirit and drawing on our earlier work, we endeavor to "think infrastructurally" about Argo (Section 2). Through examination of annual meeting notes, interviews, and remote attendance of the Argo Steering Committee's 2023 annual meeting, we analyze the techniques and practices involved in planning, testing, calibrating, validating, and error-correcting that ultimately lead to the production,

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[8] Karen Barad, "Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter", Signs: Journal of Women in Culture and Society, 28:3 (2003); Karen Bard, Meeting the Universe Halfway (2007) (arguing against representations playing a mediating role in our access to material world and instead positing that a better approach is to think onto-epistemologically: "[t]he separation of epistemology from ontology is a reverberation of a metaphysics that assumes an inherent difference between human and nonhuman, subject and object, mind and body, matter and discourse" (Barad, 2007: 185, and 379–381).

[9] L.J. Kotzé, "Earth system law for the Anthropocene: rethinking environmental law alongside the earth system metaphor", 11 Transnational Legal Theory, 75 (2020).

[10] See discussion *infra*.

[11] Marie-Catherine Petersmann, "Sympoietic thinking and Earth System Law: The Earth, its subjects and the law", Earth System Governance 9 (2021). See also the discussion of infrastructural publics *infra* 3.d.

[12] Bowker & Star, Sorting Things Out (1999), p. 34 ("infrastructural inversión").

[13] UNESCO-IOC (2023). Ocean Decade Data & Information Strategy. Paris, UNESCO. (The Ocean Decade Series, 45)

transmission, and dissemination of Argo data. We analyze (in Section 3) the sites, processes, and interfaces that determine *what* data is being produced *by whom*, *where*, *when*, *how*, and *why*, as well as what data is not being produced, which interests remain neglected, and where and when no data is being generated. We then position Argo within the institutional governance of oceans, weather, climate and, most recently, earth systems to illustrate both the evolution of Argo's role and its evolving and uneasy position within different governance approaches (Section 4). In the conclusion, we challenge the utility of "ocean data" as an analytical category and highlight the risks of over-coordination and institutionalization of data infrastructures. We suggest that allowing data infrastructures like Argo to develop organically might lead to productive (if unexpected) connections, fusions, or splits, which might in turn reorient the focus of observation towards unexplored interactions between and within earth systems. Complementing legal reconstruction projects such as 'earth systems law'[14] and 'more-than-human constitutionalism',[15] we ultimately hope that our analysis helps bring to the fore some core data-infrastructural[16] features of planetary governance as it now exists and will (have to) rapidly further evolve.

II. Thinking Infrastructurally about Argo

"Thinking infrastructurally" entails understanding infrastructure not simply as a thing, but as a set of relations, processes, and imaginations.[17] The field of infrastructure studies has provided one set of observational perspectives: if it is an infrastructure it has technical, social and organizational elements which all go together, and numerous gateways, interfaces, workarounds, alliances, upstream and downstream dependencies, re-purposing, perpetual maintenance and funding needs, and prospects or experience of incompletion, decay, and ruins.[18] The 'actants' – in Actor-Network Theory parlance – include human, non-human, and indeed non-animate participants.[19]

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[14] Louis J. Kotzé et al, "Earth system law: Exploring new frontiers in legal science", *Earth System Governance* 11 (2022) 100126.

[15] Floor Fleurke et al, "Constitutionalising in the Anthropocene", *Journal of Human Rights and the Environment* (forthcoming).

[16] In this respect, we draw on insights from our work on "Global Data Law": www.guariniglobal.org/global-data-law. *See also* Angelina Fisher and Thomas Streinz, "Confronting Data Inequality", 60(3) Columbia Journal of Transnational Law 829 (2022).

[17] Benedict Kingsbury, "Infrastructure and InfraReg: on rousing the international law 'Wizards of Is'", 8 Cambridge International Law Journal 171 (2019).

[18] The report "Understanding Infrastructure: Dynamics, Tensions, and Design" (January 2007) by Paul N. Edwards, Steven J. Jackson, Geoffrey C. Bowker, and Cory P. Knobel developed key insights based on close study of "cyberinfrastructures". The contributions to "The Promise of Infrastructure", edited by Nikhil Anand, Akhil Gupta, and Hannah Apel, reveal how infrastructures are made with fragile and often violent relations among people, materials, and institutions. A continuously updated bibliography is being maintained by the Critical Infrastructure Studies project: https://cistudies.org/critical-infrastructures-bibliography/.

[19] Bruno Latour, Reassembling the Social: An Introduction to Actor-Network Theory (2007).

Like other infrastructures, Argo involves physical components, human labor, and layer upon layer of integrated, partly interconnected, or otherwise interfacing interdependent systems and networks. Like other data infrastructures, Argo is embedded in and constituted by legacy and coterminous knowledge infrastructures, including practices of scientific knowledge production and the larger (geo)political economy. Understanding Argo as an infrastructure entails studying its entangled technical, social, and organizational dimensions, with particular attention to continuities and legacies that shaped its development over time and space. Argo's technical artifacts consist of various configurations of computational hardware and software, float design and sensor selection, satellite constellations, as well as data formats and websites. Argo's social conventions are characteristic of scientific knowledge production and related scientific practices of data collection and verification. Argo's organizational matrix involves research institutions, international organizations, funding structures, and various legal arrangements, ranging from float manufacturing contracts to the UN Convention on the Law of the Sea (UNCLOS).

Like many observational science or information-focused infrastructures, the Argo floats network is a composite, is embedded in other infrastructures, and has links to many more. We will suggest that this network is sustained and extended by the data, that the drive for data is the main precipitator of key components of the infrastructure which interact in the manner of a system, and that the infrastructure boundaries are regularly negotiated and may shift with new data demands and constituencies. A unified purposive agency is supplied by deliberations and decisions in the Argo governance institutions; but the diverse human processes which construct and operate the data infrastructures are fragmented and have multiple referents and interconnections.

For purposes of our analysis, we distinguish between Argo's *data generating* infrastructures (the sensors and their floats, and their launch), Argo's *data transmission, location, and control infrastructures* (enabled by satellites), and Argo's *data processing, storage, and dissemination infrastructures* (provided by so called "data assembly centers").

PHYSICAL Data Generation	DATA Float-Satellite	DATA Management
Sensors	Transmission	Processing
Floats	Location	Storage
Launch	Control	Dissemination

Figure 1: The Argo Stack

One can think of these data infrastructures together as the "Argo stack":[20] without sensors and floats there would be nothing to transmit, locate, or control; without the data transmission infrastructure, the data would be stuck on the floats; without the location infrastructure, "data about the ocean" could be data about anywhere in the ocean; without control infrastructures (e.g., limited directionality of the floats enabled by Iridium satellite two-way connectivity), floats would drift entirely aimlessly; without data storage infrastructure (including backups), data would be transient and could get lost; without data processing infrastructure, no scientifically relevant information could be gained from the data; and without data dissemination infrastructures, no one would be able to access and use the data for scientific research. Each of these infrastructures is itself constituted by a coming-together of the technical, the social, and the organizational. Together, they comprise Argo.

In the following three sub-sections, we navigate the Argo stack by following the "lifecycle" of Argo data,[21] beginning with data generation on the floats, followed by data transmission and float geolocation via satellites, to data processing and dissemination at data assembly centers. As becomes evident, control of data generating and transmission infrastructures is distributed among different public and private actors. Links, connections and inter-operations of different infrastructural components (e.g., satellites, sensors, floats, launching ships) are loosely coordinated by Argo members, often in *ad hoc* fashion. At the same time, durability and resilience of infrastructural inter-dependencies are critical to Argo being able to maintain stable and reliable generation of time-series data. Changes in data generating and transmission infrastructures (such as changes in satellite systems or recalibration of sensors) necessitate reconfiguration and adjustments during data processing (and sometimes changes to data standards) to ensure forward- and backward consistency. In light of scarce resources, Argo teams is often faced with choices and tradeoffs, discussed below, which in turn shape, configure and circumscribe the type of data that is ultimately generated, its potential uses, and its relevant publics.

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[20] Stacks are conventionally understood as inherently vertical. See e.g. Benjamin Bratton, The Stack: On Software and Sovereignty (2015), p. 52: "Stacks are a kind of platform that also happens to be structured through *vertical* interoperable layers, both hard and soft, global and local." (emphasis added) But stacks can arguably also be construed horizontally (or, perhaps even diagonally) without suggesting a strict hierarchy (downstream dependence) between the layers.

[21] *See generally* on the data lifecycle Robert Kitchin, "The End of the Data Lifecycle", in: Data Lives: How Data Are Made and Shape Our World (2021) ch 13.

A. Data Generating Infrastructures: Floats and Sensors

Data does not exist in the state of nature – in contrast to natural resources to which data is sometimes analogized.[22] It is generated – in this case, by Argo sensors and the floats they ride on. Zooming in on *how* and *what* data is produced by Argo floats reveals the immense importance of materialities of data generation. Argo's network of autonomous floats drift with the ocean currents and cycle between the surface and depths of 2,000 meters ('Core Argo', the continuation of the original version initiated in the 1990s) or up to 6000 meters ('Deep Argo').[23] The technology behind the floats was inherited by Argo from the World Ocean Circulation Experiment (WOCE) – the first global hydrographic survey that deployed autonomous floats. Only a small group of manufacturers has the technological sophistication to cater for the relatively low demand for floats – some of them design and equip the floats in dialogue with scientific groups who plan to operate them.[24] Performance assessments, design ideas, and new needs or requirements circulate through industry channels and through the Argo governance structures. Argo's data generating infrastructure is dependent on float manufacturers and their supply chain infrastructures, and also on laboratories for development and testing of floats and instruments, shipping and logistics infrastructures for transporting floats to vessels of launch, and the launching vessels themselves.

Access to vessels that travel at the requisite time needs to match the availability of funding, floats, and the scientific team to specific geographic areas. Where several floats are launched at intervals, the ship needs to be at sea for a sufficient period of time to enable spatial and temporal distribution of the floats.[25] Institutions that have access to funds, or that can partner with other research programs,

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[22] Amber Sinha, Arindrajit Basu, "Why Metaphors for Data Matter", Bot Populi (2021), https://botpopuli.net/why-metaphors-for-data-matter/ [https://perma.cc/X3RY-WX2K]; Cornelius Puschmann & Jean Burgess, "Metaphors of Big Data", 8 Int'l Commc'n 1690 (2014); Jan Nolin, "Data as Oil, Infrastructure or Asset? Three Metaphors of Data as Economic Value", 18 J. Info., Commc'n & Ethics in Soc'y 28 (2019).

[23] https://argo.ucsd.edu [https://perma.cc/62PF-GVME].

[24] Core Argo profiles are currently being supplied by seven different float models; additional models are being developed in China. See Wong et al., "Argo Data 1999–2019: Two Million Temperature-Salinity Profiles and Subsurface Velocity Observations From a Global Array of Profiling Floats", 15 Front. Mar. Sci. (2020, Sec. Ocean Observation Volume 7 – 2020, https://www.frontiersin.org/articles/10.3389/fmars.2020.00700/full.

[25] E.g., in early 2023 a deployment of BGC floats took place aboard IBRV Araon, operated by the Korea Polar Research Institute. IBRV Araon was designed to conduct polar research in the frozen waters of the Arctic and Antarctic, as well as provide personnel transport to Southern Ocean and Arctic bases. IBRV Araon spent half a year in the Arctic and the other half in the Antarctic, stopping at its home port of Incheon, South Korea, in between: https://www.go-bgc.org/expedition-logs/southern-ocean-2023; https://www.go-bgc.org/expedition/southern-ocean-2023/solomon-introduction. *See also* 3. b) and c) blow on when and where Argo data is being generated.

can commission research vessels.[26] In other instances, commercial and tourist cruises,[27] and even military vessels are used for deployment. Lack of reliable launch vessels creates not only geographic but also geopolitical dependencies. Russia's invasion of Ukraine unexpectedly complicated deployment efforts when militaries around the world were put on heightened alert, with some navies no longer willing to have their ships used for Argo float deployment to avoid inadvertent disclosure of their fleets' locations by backtracking public Argo data. The COVID-19 pandemic also complicated deployment efforts with fewer ships going out to sea and quarantine rules preventing researchers from boarding vessels.

With lifespans ranging from five to seven years (and even less for Deep Argo floats) and no opportunity for post-deployment service, every component of the float, its sensors, and communication capabilities through the satellite system needs to be tested pre-launch, and the release of the float needs to be monitored as well. This requires trained human labor and time.[28] The ultimate pre-deployment assessment can take between one and one-and-a-half hours, the last direct human-machine interaction in the series of numerous tests, calibrations, and validations that floats and sensors have undergone at the facilities of their respective manufacturers as well as at the research centers responsible for their deployment.[29]

Once released, the float descends to drifting depth (usually 1000 m), where it drifts for roughly 10 days before descending to profiling depth of 2000 meters (or up to 6000 meters for Deep Argo) before resurfacing. During their ascent, the floats take a series of measurements via sensors (*see discussion below)*, and, once on the surface, transmit the data via satellites, while receiving instructions for their next mission. For the majority of the Argo fleet, this surface interval is between 15 minutes and one hour, after which the float sinks to a drift depth for about 9 days. It then descends anew, repeating the 10-day cycle.

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[26] E.g., a recent launch of BGC floats by the joint mission of the Southern Ocean Carbon and Climate Observations and Modeling project (SOCCOM) and Global Ocean Biogeochemistry Array (Go-BGC). SOCCOM is a multi-institutional program, focused on the study of the Southern Ocean and determining its influence on earth's climate, housed at Princeton University and supported by the U.S. National Science Foundation (NSF). Go-BGC is a $53 million dollar project funded by the NSF, comprising scientists from the Monterey Bay Aquarium Research Institute, the University of Washington, Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, and Princeton University.

[27] https://www.euro-argo.eu/News-Meetings/News/News-archives/2021/Argo-deployment-in-remote-areas

[28] The human monitor on the IRBV Aaron spent 44 days at sea.

[29] https://www.go-bgc.org/expedition/southern-ocean-2023/checking-floats

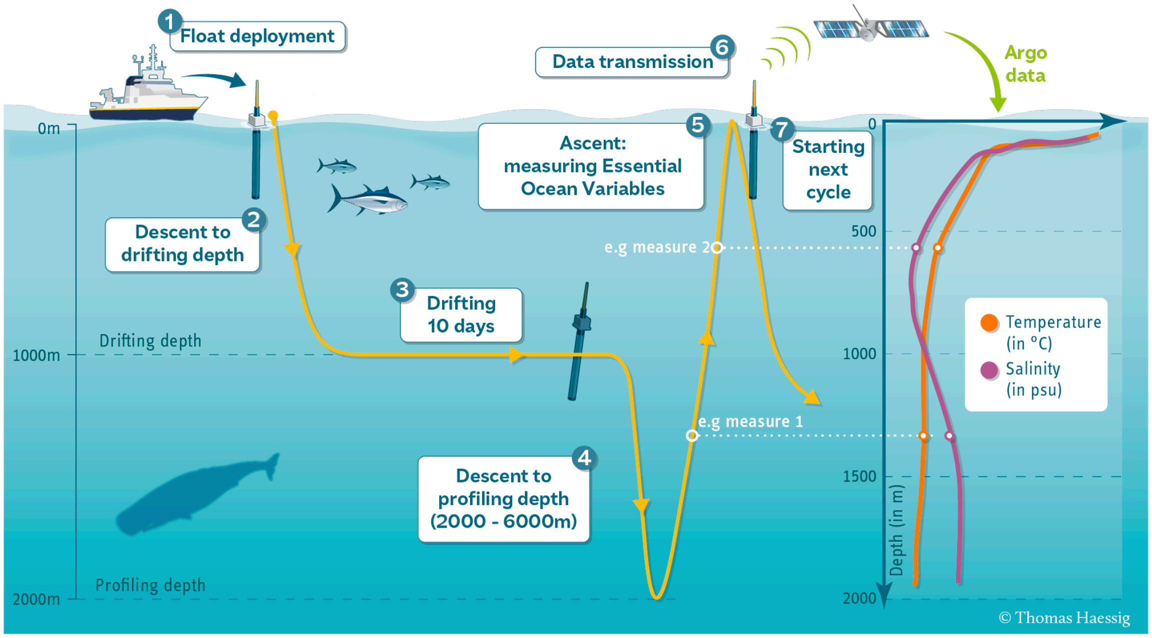

Figure 2: Argo float deployment, data generation, and transmission

The floats are produced by different manufacturers and carry different sensors, which produce what is sometimes termed "raw data"(i.e., pre-processed) about certain physical characteristics of the ocean – for example, temperature and pressure.[30] Given the relatively circumscribed market for floats and sensors, researchers and manufacturers often collaborate in the development, testing, calibration, and customization of relevant instruments. Frictions can arise when instruments fail or produce flawed data, especially about whether the cash-strapped lab or the manufacturer will carry the loss or cost of replacement. A sensor malfunction on an already deployed float can be very costly, as floats are usually not recoverable for repairs or upgrades.[31]

Although all floats are equipped with conductivity-temperature-depth (CTD) sensors, only some floats generate profiles of biogeochemical properties (BGC-Argo). In addition to CTD sensors, BGC-Argo floats can integrate sensors to measure chlorophyll fluorescence, particle backscatter, dissolved oxygen, nitrate, pH, and irradiance. The variability is partly a function of different scientific interests and needs and partly a function of launching parties' capacity and availability of resources. Historically, except for oxygen, a single sensor was used for the other BGC variables. However, increasingly, for

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[30] Lisa Gitelman and Virginia Jackson, "Introduction" in Lisa Gitelman (ed.), "Raw Data" is an Oxymoron (2013) (explaining why data is never "raw").

[31] Manufacturer's warranties typically do not apply to in-water failures, but in at least one instance, where a malfunction was so widespread that the manufacturer recalled all sensors manufactured during a particular year, the manufacturer honored the warranty for the floats that had been already deployed at the time of the recall announcement. AST 24 meeting.

most of these variables there are different types of sensors available, some differing on measurement principles. Introduction of new sensors requires ensuring interoperability with float models and cross-sensor calibration to ensure standardized data output, which depends on the willingness of sensor manufactures to share the necessary metadata among themselves as well as with float manufacturers and Argo scientists. Evaluation of new sensors may also require review of baseline standards: should the first integrated sensor be used as a reference point against which any new entrant is evaluated? Introducing new sensors also requires additional testing, but trials of sensors on floats is a slow and expensive process. Any minor malfunction (e.g., a failure in a trivial connector cable) can lead to loss of data, and since floats are difficult to recover, on-float testing is not an efficient proposition. In-lab testing requires not widely available specialized lab settings that enable sensor testing under controlled circumstances.

B. Data Transmission, Location, and Control Infrastructures: Satellite Systems

To transmit and receive data, Argo relies on satellite infrastructures. The less time a float spends on the sea surface for transmission, the less vulnerable it is to external elements. The Iridium satellite system, which consists of 66 satellites at a height of approximately 781 km, can transmit more data within a shorter period of time than other satellite systems, because Iridium allows "data calls" to be relayed from one satellite to another until they reach the satellite that registers the float. Iridium also allows for two-way communication, making it possible to send instructions to the float for troubleshooting or for changing the float's mission (for example, a float can be redirected to observe a developing hurricane). In this way, Iridium is both a data transmission and control infrastructure.[32] Iridium, however, lacks the ability to geo-locate the floats. Hence, each float with an Iridium modem also includes a Global Positioning System (GPS) receiver to record the location of the float. A controller board on the float interfaces with the GPS receiver, the Iridium modem, the CTD sensors, and any other additionally installed sensors. The GPS receiver and the Iridium modem share an antenna that is connected to the radiofrequency circuit board, which serves as a platform for the GPS receiver, the Iridium modem, and any other communications devices.[33] Every additional instrument mounted on the float comes with a cost that is not purely financial: increased weight of the float, higher energy consumption, and shorter battery lifespan are tradeoffs and compromises that are often

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[32] Iridium satellite constellation is owned and operated by Iridium Communications Inc. (formerly Iridium Satellite LLC), a publicly traded U.S. company.

[33] For more details on float design, see Teledyne Webb Research, "APEX Profiling Float User Manual", P/N 301308, Rev. 9 (2014-2017).

made through discussion among members of Argo. These shape not only *what* data is being generated but also *who* can generate it given capacity constraints.[34]

Once on the surface, floats using the Iridium network perform a series of tasks in sequential order, with the floats creating their own temporality.[35] First, if a float is equipped with an oxygen sensor, it will either collect in-air samples of dissolved oxygen (if it has such capacity) or in-water measurements. Second, it will acquire a position fix using GPS. This typically takes several minutes as the float establishes the connection with the GPS satellites and subsequently determines the position. Third, the float connects with an Iridium satellite and the Iridium gateway, log on to the launching group's data server, and query the server for any changes that might be necessary in the mission configuration for the next profile. Lastly, the float transmits the profile (i.e., data collected from the water column during the float cycle), O_2 samples (if available), GPS, and engineering data (i.e., float diagnostic data), packaged into a series of highly compressed packets,[36] via Iridium (for ways in which stanadards impact data production, see discussion *infra*).[37] Due to interruptions in the transmission process, it is sometimes necessary for the data to be transmitted several times before all data have been successfully uploaded.[38] On average, floats using Iridium spend 20 to 30 minutes on the sea surface for each cycle.[39]

In the early days of Argo, almost all floats transmitted their data via the Système Argos – a location and data transmission system operated by Collecte Localization Satellites based in Toulouse, France and Maryland, United States. Despite the similar name – both inspired by Greek mythology – Argo and Argos developed separately and at different times, although both were motivated by the desire to

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[34] See below 3.a. (Infrastructural Data Inequality).

[35] Stephen C. Riser, Dana Swift, Robert Drucker, "Profiling Floats in SOCCOM: Technical Capabilities for Studying the Southern Ocean", 123 Journal of Geophysical Research: Oceans, 4055 (2018).

[36] Each float manufacturer decides on the way the data is packaged. Argo Data Management Team sets formats for decoded data.

[37] https://www2.whoi.edu/site/argo/operations/ [https://perma.cc/8A3B-AGVN].

[38] Stephen C. Riser, Dana Swift, Robert Drucker, "Profiling Floats in SOCCOM: Technical Capabilities for Studying the Southern Ocean", 123 Journal of Geophysical Research: Oceans, 4055 (2018), p.4061.

[39] Stephen C. Riser, Dana Swift, Robert Drucker, "Profiling Floats in SOCCOM: Technical Capabilities for Studying the Southern Ocean", 123 Journal of Geophysical Research: Oceans, 4055 (2018) (describing data transmission for SOCCOM missions: "There are two general ways that data can be transmitted using Iridium. In the first, known as the Router-Based Unrestricted Digital Internetworking Connectivity Solutions (RUDICS) method, 2-way communication over a circuit-switched data channel is used. While this technique is relatively slow (a throughput of 300 bytes per second), it is possible to routinely transfer files of 100 kilobytes or more with this method at a reasonable cost. After the data are transmitted from the floats to Iridium, the system initiates a connection to a data server located in the [University of Washington] float laboratory and the data are automatically downloaded. At the same time, commands from the float operators to alter the float mission can be uploaded over this path back to the float via the Iridium satellites. A second form of Iridium data transmission, Short-Burst Data (SBD), is available for use where the amount of data being transmitted is relatively small and is analogous to sending a text message. While the SBD method has worked well for basic Argo floats where only CTD data are collected, for SOCCOM we exclusively use the RUDICS method via an Iridium 9523 modem inside the float, due to the large quantity of data being transmitted for each profile…")

enhance opportunities for ocean observing. Argos satellites are one-way, low-bandwidth satellites, with an effective data throughput of no more than 1 bit per second. In contrast to Iridium, Argos satellites have both data transmission and location data capabilities. However, Argos' low data transmission rates required floats to spend between six and eighteen hours at the sea surface to ensure error-free data reception in all weather conditions. A later model (Argos-3) offers bidirectional transmission and a higher throughput, but the high-data-rate mode suffered from electromagnetic noise around Europe.[40] Some of the floats continue to use Argos sattelites, and other satellite transmission systems have also been used on profiling floats, including non-global transmission systems such as BeiDou in Asia[41] and Orbcomm in North America.[42]

C. Data Processing, Storage, and Dissemination Infrastructures: Data Assembly Centers

Data is always stored somewhere (though not necessarily in one place) and needs to be processed and disseminated to render it accessible and useful for scientific knowledge production. Argo float data is transmitted via satellites to eleven national Data Assembly Centers (DACs) for processing, with each float being allocated to a specific DAC. Processed data from the national DACs is subsequently transmitted to two Argo Global Data Assembly Centers (GDACs) – one located at the Coriolis Data Center in France and the other at the US Navy's Fleet Numerical Meteorology and Oceanography Center, where data is checked for format and content consistency.[43] Once per day, data holdings at the two Argo GDACs are being synchronized. The US National Centers for Environmental Information (NCEI) operates and manages the Global Argo Data Repository (GADR), which provides long term archive services to store and preserve data and implements reanalysis updates and corrections provided by the GDACs.[44]

The Argo Data Management Team (DMT) is responsible for coordinating data management and ensuring access to Argo data. The Argo DMT is composed of at least one representative of each

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[40] André, X., Moreau, B., and Le Reste, S., "Argos-3 satellite communication system: implementation on the arvor oceanographic profiling floats", J. Atmos. Ocean. Technol. 32, 1902–1914 (2015).

[41] 2016 Argo Chinese National Report 2015 (Jianping Xu & Zenghong Liu, The Second Institute of Oceanography, SOA), The 17th Argo Steering Team Meeting, Yokohama, Japan, March 22-24.

[42] Dimov Stojce Ilcev, Architecture of ORBCOMM Little LEO Global Satellite System for Mobile and Personal Communications (Feb 10, 2023), www.microwavejournal.com/articles/39512-architecture-of-orbcomm-little-leo-global-satellite-system-for-mobile-and-personal-communications.

[43] Format checks ensure the file formats match the Argo standards precisely. Data consistency checks are performed on a file after it passes the format checks. The data consistency checks enforce data standards and ensure that certain data values are reasonable and/or consistent with other information in the files. Examples of the "data standard" checks are the "mandatory parameters" defined for meta-data files and the technical parameter names in technical data files (Ignaszewski 2020).

[44] https://www.ncei.noaa.gov/products/global-argo-data-repository

institute involved in Argo data management activities.[45] DMT also defines Argo's data management infrastructure, data formats, and quality control procedures.[46] There are numerous publicly available and regularly updated manuals, handbooks, and "cookbooks" [47] addressing all aspects of data processing for each parameter. The Argo data management teams aim to ensure not only that its data is openly available but that its potential users understand what data they receive. Argo data is made available from GDACs in the Network Common Data Format, a file format for storing multidimensional scientific data (variables such as temperature, humidity, pressure, wind speed, and direction).[48] All Argo data is publicly available without charge. Anyone can access Argo data via direct file transfer or via a World Wide Web (WWW) interface. The digital data in this case rapidly becomes part of the public domain, not an accumulating private resource from which other well-funded scientists are excluded; it is a club good in that potential users require research capacity and funding, but not in the sense that non-contributors cannot get access.

III. Argo's Data Infrastructure as Data Regulation

Argo is not representative of an infrastructure-and-data forged together in an intentionally *regulating* unity or in decisive forms of public governance. At the sime, it as an infrastructure with potentially significant *regulatory effects*. As a data infrastructure, Argo determines *what* data is being produced *by whom*, *where*, *when*, *how*, and *why*, as well as what data is not being produced, which interests remain neglected, and where and when no data is being generated. What are the sites, processes, and interfaces where agency over these choices is exercised?

Despite a great deal of organization, labor, sustained effort, and resources that are required to produce reliable and usable data on a limited set of parameters, no single entity controls the whole infrastructure. The Argo Steering Team (AST) provides scientific leadership and oversees the development and implementation of the Argo Program,[49] but its control does not extend to each layer or capillary of the Argo infrastructure.[50] Argo forms part of the Global Ocean Observing System

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[45] DACs, Delayed mode operators (DM), Argo Regional centers (ARC), GDAC, and Global data repository center (GADR). http://www.argodatamgt.org/Data-Mgt-Team/ADMT-team-and-Executive-Committee

[46] http://www.argodatamgt.org/Data-Mgt-Team

[47] http://www.argodatamgt.org/Documentation

[48] https://pro.arcgis.com/en/pro-app/latest/help/data/multidimensional/what-is-netcdf-data.htm

[49] https://argo.ucsd.edu/organization/argo-steering-team/

[50] Each Argo mission have their own mission teams, which act as scientific committees and provide recommendation and guidance on the development and implementation of their respective missions.

(GOOS),[51] whose operational arm ("OceanOPS") acts as a focal point for implementation and operation of relevant observing platforms, monitors the Argo array and liaises with the Argo Steering Team.[52] However, neither GOOS nor OceanOPS controls nor provides funding for the data infrastructure.

Argo has its own participatory governance, is embedded in other infrastructures with their own governance and legal regimes, and has close or distant links with many other scientific groups including climate modelers and some entities with governmental and commercial interests. AST annual meetings proceed rather informally and collaboratively, with decisions made by achieving some form of "rough consensus" without formal votes. When new issues arise and cannot be easily resolved, they can either lead to formation of ad hoc working groups whose task it is to study the issue and come up with recommendations, or they are assigned to certain people for follow-up and reports.[53] Argo participation and governance is emphatically not Mandeville's fable of the bees – there is a great deal of public virtue as well as science- or funding-motivation in the Argo enterprise, together with and a few shades of commercial and geopolitical interest. The whole process is organic and mycelial-like more than it is a planned and well-resourced realization of a grand vision and unified normativity.[54]

In the following sections, we explore four interconnected dimensions of Argo data-infrastructure governance practice that together shape what data is ultimately produced, for whom, and to what ends: infrastructural data inequality, spatial distribution of floats, temporal sampling of data, and catering towards different publics with implications for quality control and data diversification.

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[51] GOOS is a global coordination network aimed at creating a "global ocean observing system that delivers the essential information needed for our sustainable development, safety, wellbeing and prosperity". *See* Intergovernmental Oceanographic Commission, IGOSS and IODE Data Management Goals to Support GOOS, Fifteenth Session of the IOC Committee on International Oceanographic Data and Information Exchange (Athens, Greece, 23-31 January 1996) IOC/IODE-XV/11.

[52] OceanOps is funded by voluntary contributions from IOC/UNESCO and WMO Member States. https://www.ocean-ops.org/board

[53] A detailed agenda with action points is maintained from all the meetings and progress is reviewed at subsequent gatherings. All agendas, presentations, and notes from the annual AST meetings are publicly available on the Argo program website: https://argo.ucsd.edu/. Each national mission submits an annual report following a template that aims to convey the state of the mission, any challenges it has encountered, any issues it wishes to raise, and a list of publications that had used Argo data. All reports are publicly available as well. The AST meeting itself is open to the public, with only certain sessions with manufacturers conducted as closed sessions. Communication during the meeting takes place through presentations, informal live discussions, and conversations on Slack channels.

[54] Deleuze and Gauttari, Thousand Plateaus. Van den Meerssche et all, Is this the rhizome?

A. Infrastructural Data Inequality: Who decides what data is (not) being produced?

Who decides what ocean data is (not) being produced? Although the Argo array currently reflects contributions from thirty countries, significant forms of "data inequality" persist.[55] These inequalities reflect, at least in part, colonial legacies that led to the uneven distribution of oceanographic knowledge, as former colonial powers and dominant trading nations made significant historical investment in oceanography and associated technologies of ocean data generation, recording, and mapping.[56] In 2022, 80% of BGC-Argo float deployments were done by only three countries (US, France, and Canada), with more than 50% of the deployments by the United States.[57] Coverage for different parameters is uneven with only a limited number of BGC-Argo floats carrying the complete suite of sensors (with 40% carrying only oxygen as the only extra sensor in addition to CTD). Overall sampling of the oceans is also unevenly distributed, with the Atlantic Ocean oversampled while the Indian, Pacific, and Southern Oceans remain under-sampled.[58] Only nine countries participate in the Deep Argo array, with the United States, France and Japan being leading national contributors. Some of the undersampled regions – such as the Southern Ocean – are not the priority for main float contributors. As Dean Roemmich – one of Argo founders – noted, "[t[hat is one of the hardest implementation items for the Argo science team. In order to achieve a global array we will need to set some fraction of floats aside for a region that is not the top priority of any single government."[59]

Any decision on which data to produce must take into account technological and funding constraints and the interests of different communities. Expanding data production must be sensitive to the demands imposed on data managers, because additional sensors increase data complexity, which can require new standards, guidelines, and manuals.[60] Originally, Argo floats carried only CTD sensors. However, understanding the role of oceans in regulating climate change and, conversely, the impact of climate change on ocean ecosystem, requires observations of the ocean biogeochemistry. The Intergovernmental Panel for Climate Change's Assessment Report 5 listed temperature, salinity,

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[55] Angelina Fisher and Thomas Streinz, "Confronting Data Inequality", 60(3) Columbia Journal of Transnational Law 829 (2022) (emphasizing the power to decide what becomes data).

[56] Reidy and Rozwadowski (2014).

[57] AST-24 meeting, BGC-Argo Status report.

[58] AST-24 meeting.

[59] Dean Roemmich, Olaf Boebel, Yves Desaubies, Howard Freeland, Kuh Kim,Brian King,Pierre-Yves LeTraon,Robert Molinari,W. Brechner Owens, Stephen Riser,Uwe Send,Kensuke Takeuchi,and Susan Wijffels, "3.2: Argo: The Global Array of Profiling Floats ", in (2001) Observing the Oceans in the 21st Century, C.J. Koblinsky and N.R. Smith (Eds), GODAE Project Office and Bureau of Meteorology, Melbourne.

[60] Roemmich et al, "On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array", 6 Frontiers in Marine Science 439 (2019).

acidification (pH), oxygen, nutrients (nitrate), and light as the major drivers of ocean health. BGC-Argo introduced six new variables (oxygen, nitrate, pH, chlorophyll fluorescence, optical backscatter, and solar irradiance). The choice of these variables (and not others) was based not only on scientific research needs but also on availability of operational sensors.[61] Proponents of BGC-Argo acknowledged that specific scientific goals, regional issues, funding sources, and even sensor configurations may motivate different missions, requiring tradeoffs and compromises. For example, current radiometric sensors on BGC-Argo have four color bands available, which is not sufficient to characterize the spectral variability of the underwater light field and thus cannot capture the diversity of phytoplankton. Hyperspectral radiometry, which captures light over many wavelengths and enables recognition of tens or hundreds of colors, can enable better discrimination among different phytoplankton types, potentially improve knowledge of oceanic carbon stocks, pathways, and fluxes.[62] Enabling BGC-Argo with hyperspectral capability could also produce knowledge useful for the management of living resources and ecosystem services (e.g., habitat suitability, fish stocks, and recruitment) and for biohazard surveillance (i.e., harmful algal blooms). [63] Hyperspectral radiometric sensors, however, are more expensive, require more energy consumption, and impose additional labor costs for the Argo Data Danagement Team. The working group on radiometry, created within the Argo AST, recommended that those programs that have capacity move to hyperspectral radiometry but it could not mandate a wider adoption of the sensors.

Argo floats generate only some "ocean data" *directly* from the sensors (e.g. measuring temperature and electrical conductivity of the seawater sample); other data is *derived* from computations. For example, all Argo floats are equipped with CTD sensors. The "C" in CTD is conductivity, which measures how well a solution conducts electricity. Since dissolved salts and other inorganic chemicals conduct electrical current, conductivity increases as salinity increases. The measure of conductivity thus relates to the measures of salinity. However, salinity is also dependent on pressure and temperature. Whereas "T" measures temperature directly, "D" (depth) actually measures pressure.

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[61] HC Bittig et al, "A BGC-Argo Guide: Planning, Deployment, Data Handling and Usage" 6 Front. Mar. Sci. 502. (2019).

[62] Organelli, E., E. Leymarie, O. Zielinski, J. Uitz, F. D'Ortenzio, and H. Claustre. 2021. Hyperspectral radiometry on Biogeochemical-Argo floats: A bright perspective for phytoplankton diversity. Pp. 90–91 in Frontiers in Ocean Observing: Documenting Ecosystems, Understanding Environmental Changes, Forecasting Hazards. E.S. Kappel, S.K. Juniper, S. Seeyave, E. Smith, and M. Visbeck, eds, A Supplement to Oceanography 34(4),

[63] E. Organelli et al, "Hyperspectral radiometry on Biogeochemical-Argo floats: A bright perspective for phytoplankton diversity" in: Frontiers in Ocean Observing: Documenting Ecosystems, Understanding Environmental Changes, Forecasting Hazards (E.S. Kappel et al, eds.), A Supplement to Oceanography 34(4) (2021), pp. 90-91.

Using temperature and pressure, salinity can be derived via mathematical equations.[64] The density of water is calculated from temperature and salinity, and because pressure increases with increasing depth, depth can be derived in turn. Even with direct measurements, there are accuracy errors.[65] Sensor drift can introduce larger errors, requiring corrections by "experts", which may entail comparing older floats with newly deployed instruments and with ship-based data.

Decisions of how to allocate limited resources – whether to invest in increase of spatial coverage, maintenance of Core Argo, enhanced longevity of floats, enabling more (up to 6) BGC sensors on all BGC floats, expanding the reach and capabilities of Deep Argo, improving sensors to enable better data on specific parameters, or adding resources to data management team – are discussed at annual meetings of Argo AST teams as well at periodic meetings of various working groups formed to focus on specific issues or topics. Limitations and inequalities of funding are a recurring theme in these meetings. The phenomenon of under-funded infrastructures corresponds with broader insights from infrastructure studies that observe and sometimes lament the invisibility of infrastructures that are being "taken for granted" until their break down or fail.[66] Data infrastructures may be particularly susceptible to invisibility (as compared e.g., with physical infrastructures) because their failures and malfunctions are not immediately evident, even to those working directly with data processing and quality control. Errors may be revealed only when data is being validated by comparing it to other data sources (e.g., Argo data is often validated by data from the Global Ocean Hydrographic Investigations Program (GO-SHIP)) or when data from numerous floats is processed in the aggregate (e.g., to reveal a sensor drift). The value-added of the data infrastructure is also not immediately visible. Argo's importance lies in having a reliable time-series data over substantial period of time, which enables comparative, historical and predictive analysis of oceanic temperatures, for example. Yet, on a daily basis, Argo participants have to educate audiences, institutions, policymakers and funders about the program's importance and highlight new, potential or previously unforeseen uses of Argo data in continuous efforts to sustain the program. Without sustained efforts at making Argo data infrastructure *visible*, Argo risks receding not only from public imagination but also from the gaze of those who supply information and knowledge that directly shapes earth systems governance. As a

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[64] Computations of salinity from conductivity are governed by international standards, the most recent adopted in 2010 Intergovernmental Oceanographic Commission (IOC), International Association for the Physical Sciences of the Oceans (IAPSO), and the Scientific Committee on Oceanic Research (SCOR). TEOS-10, https://www.teos-10.org/

[65] The temperatures in the Argo profiles are accurate to ± 0.002°C and pressures are accurate to ± 2.4dbar. https://argo.ucsd.edu/data/data-faq/#rbrpilot

[66] Cf Bowker & Star, Sorting Things Out (1999), p. 34 ("infrastructural inversión").

transnational infrastructure, Argo faces additional challenges that not only require international coordination but would also benefit from transnational cooperation in form of technology-transfers and capacity-building. Governmentally funded research, however, often remains stubbornly territorialized and hence misaligned with the transnational infrastructures necessary for planetary-scale science.[67]

B. Infrastructural Space: Where is data (not) being generated?

Argo seeks to generate ocean data on a planetary scale. Naturally, Argo's floats cannot generate data everywhere as data-generation depends on float location. In this way, data-generation via floats differs from data generation via satellites. While the latter achieves planetary scale more easily by orbiting around the planet, the former manages to reach deeper into the ocean. In its originally proposed design, Argo was to comprise around 3300 floats, each profiling the ocean between the surface and a depth of 2,000 meter around 25 times per year over an estimated lifetime of 3-4 years.[68] The OneArgo program aims to expand the spatial coverage of Core Argo while also increasing the number of BGC and Deep Argo floats. Given the significant financial and human resources involved in procuring, testing, and deploying the floats and processing subsequent data, trade-offs and tensions arise along the way, shaping both the type of data that is produced and the choices about data's target users and uses. By one estimate, given current life expectancies of floats, more than 800 floats per year would need to be deployed to develop OneArgo while maintaining the Core Argo array.[69] Funding remains a core challenge for maintaining and expanding the Argo program's scale. However, spatial distribution is also impacted by natural phenomena, technical limitations, business models, and legal constraints.

Some areas of the ocean require more intense concentration of floats due to natural phenomena. For example, mesoscale variability in the Western Boundary Current regions require enhanced sampling to reduce noise in tracking the largescale temperature and salinity fields.[70] One alternative to increasing float density is to increase the frequency of sampling. Another option is to rely on data

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[67] Cf discussions at the AST 2023 meeting about public procurement rules preventing rich countries from buying floats for poor countries.

[68] Argo Science Team, "On The Design and Implementation of Argo A Global Array of Profiling Floats".

[69] AST 2023 meeting.

[70] Dean Roemmich et al. "On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array", 6 Frontiers in Marine Science 439 (2019).

provided by other instruments, such as gliders[71] or non-human species equipped with sensors,[72] to supplement Argo data. Both choices, however, impose costs associated with data generation, processing, and dissemination (e.g., additional processing to ensure standardization and interoperability of measurements).

Longevity of floats also impacts spatial coverage. Many floats are not recoverable (they can sink, get lost, be collected upon washing on shore and not returned to the owner, etc.) and thus cannot be repaired and redeployed. Areas with lower launch frequencies typically have older floats. Sufficient sampling would require increased float density to replace aging floats as well as to compensate for the original under-sampling. Increasing longevity of floats (and of their components), however, can be difficult both technologically and due to misalignment of incentives. Given the limited demand and supply of floats and sensors, manufacturers do not necessarily have incentives to prolong the life of the float and may need to balance demands for float longevity with demands from wealthier purchasers to enhance float capabilities or to customize floats.

Dependencies on a single producer or a limited group of producers aid in consistency of data and in implementation of uniform procedures for data processing across programs. However, such dependencies also create single points of failure: past incidents of faulty pressure and pH negatively impacted Argo coverage. [73] Greater diversification of sensor manufacturers would alleviate this problem but would also cause challenges relating to interoperability and data standardization.

Lastly, coastal areas remain under-sampled due to uncertainties about whether Argo should be interpreted as "marine scientific research" under the UN Convention on the Laws of the Sea (UNCLOS).[74] Under Article 248 of UNCLOS, states or international organizations that intend to undertake marine scientific research within the exclusive economic zone (EEZ) or on the continental shelf of a coastal state are required to obtain state's consent with at least six-month advanced notice describing the nature and other information regarding the research project. Some states have agreed to deployment of Argo floats in their EEZs under the conditions of free and unrestricted data exchange and the transparent implementation through OceanOPS monitoring (a joint WMO-IOC/UNESCO Support Center for oceanography and marine meteorology). Other coastal states

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[71] https://www.oceangliders.org/

[72] David March, Lars Boehme, Joaquín Tintoré, Pedro Joaquín Vélez-Belchi, Brendan J. Godley, "Towards the integration of animal-borne instruments into global ocean observing systems", 26:2 Global Change Biology, February 2020, 586.

[73] Dean Roemmich et al. "On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array", 6 Frontiers in Marine Science 439 (2019); AST 2024 meeting.

[74] Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 397.

reportedly do not consider Argo to be "marine scientific research" and allow float deployment without consent.[75] Yet other states maintain the position that every float deployment needs to comply with Article 248. Thus, as a practical matter, deployment of Argo floats within EEZ is arranged on a bilateral basis. However, because there is no articulated procedure for "clearing" marine scientific research projects, compliance with Article 248 is cumbersome and deployment of floats in EEZs is often avoided.[76] This leads to significant under-sampling, given that EEZs represent nearly 30% of the world's ocean surface.

C. Infrastructural Time: When is data (not) being generated and transmitted?

Argo generates a set of synoptically sampled time series data that enables ongoing analysis of ocean parameters, over-time comparisons not only over the course of Argo tenure but also retroactively,[77] and forward-looking forecasts, models, and predictions. The timeliness of data generation and transmission are important infrastructural decisions that affect different scientific communities in different ways.

Fluorescence observations obtained as a measure of phytoplankton mass, for example, are best done at night. In contrast, assessment of biomass[78] using radiometry and comparison of BGC-Argo sensor results to satellite remote sensing motivates measurements around noon. [79] When manufacturers set the default for the floats to come up at noon, they put an onus on operators to alter the setting as needed. Lack of standardized guidance on the timing of sampling can create challenges for data comparability. The Argo Steering Committee and the Argo Data Management team are considering whether to adopt a sampling frequency of 10.2 days (245 hours) to ensure profiles are not taken at the same time each day. This compromise ensures temporal compatibility of measurements across the array but potentially comes at the expense of optimizing data of particular interest for

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[75] Reportedly, the following states facilitate Argo deployment within EEZs: Canada, Mauritius, Mozambique, United Kingdom (all UK maritime areas), United States of America, Cook Islands, Fiji, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu. Euro-Argo Research Infrastructure Sustainability and Enhancement Project (EA RISE Project) – 824131, "Best practices document for float deployments into EEZ", Ref.: D8.2_V1.0 (2022).

[76] Euro-Argo Research Infrastructure Sustainability and Enhancement Project (EA RISE Project) – 824131, "Best practices document for float deployments into EEZ", Ref.: D8.2_V1.0 (2022).

[77] For example, Argo CTD data was interpolated to the location and depth measurements taken by the HMS Challenger, 1872–1876. *See* Dean Roemmich, W. John Gould, John Gilson, "135 years of global ocean warming between the Challenger expedition and the Argo Programme", Nature Climate Change: Letters, vol 2 (June 2012).

[78] https://www.apemltd.com/biomass-a-useful-tool-in-assessing-the-quality-of-a-marine-habitat/

[79] HC Bittig et al, "A BGC-Argo Guide: Planning, Deployment, Data Handling and Usage" 6 Front. Mar. Sci. 502. (2019).

specific communities (e.g., those interested in phytoplankton might want all data to be sampled at night).

Measurement of oxygen also poses challenges on temporal scales. Oxygen sensors can be used to measure both changes in global ocean oxygen inventories and local biological activity. Changes in the whole of oxygen inventories, however, are expected on decadal timescales, motivating sustained array observations and requiring significant commitment to sensor stability assessments. In contrast, net community production measurements (i.e., gross oxygen production minus oxygen consumption by all organisms), especially if they are to be scaled to satellite remote sensing of biomass, require high temporal and spatial frequency observations. This is because oxygen shifts throughout the day due to changes in photosynthesis, which rises through the day and falls to zero at night.[80] Frequent sampling increases energy consumption, which may decrease the longevity of the float.

At the time of its founding, the Argo program aimed to meet the requirements of operational oceanographers (i.e., weather monitoring and forecasting) on the one hand and the scientific community engaged in climate monitoring and modeling on the other hand. These two communities and research agendas demand different kinds of data on different time scales. Operational oceanographers need access to Argo data as soon as possible, even if the data is not of the highest quality. In contrast, for climate monitoring and modelling communities, the quality of data is of paramount importance. To meet the objectives of the two communities, Argo's designers decided to make vertical profile and trajectory data available in "real-time" and in "delayed-mode".[81] "Real-time" data is not immediate or continuous but is provided within twelve hours of satellite transmission and is subjected to a set of automatic quality tests, which assign "quality flags" to grossly "bad" data. Flagged data is preliminarily adjusted, if possible,[82] and both the original and the adjusted data are subsequently inserted into the Global Telecommunications System (GTS) used by operational meteorological agencies. In contrast, delayed-mode data is typically made available within a year (or more) after transmission. The quality control for delayed-mode data involves a combination of human

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[80] HC Bittig et al, "A BGC-Argo Guide: Planning, Deployment, Data Handling and Usage" 6 Front. Mar. Sci. 502. (2019); S. Wang, S.A. Kranz, T.B. Kelly, H. Song, M.R. Stukel, N.Cassar (2020), "Lagrangian Studies of Net Community Production: The Effect of Diel and Multiday Nonsteady State Factors and Vertical Fluxes on O2/Ar in a Dynamic Upwelling Region", 125 Journal of Geophysical Research: Biogeosciences (2020).

[81] Note how relative these terms are. What counts as "real-time" data for purposes of weather forecasting would be catastrophically delayed for purposes of high-frequency trading. *See* Donald MacKenzie, *Trading at the Speed of Light: How Ultrafast Algorithms Are Transforming Financial Markets* (2021).

[82] Adjustments can only be made if the sensor has already been delayed mode quality controlled for T/S and after at least six weeks for BGC parameters to allow for additional quality control assessments as well. If no adjustments can be made, just the 'raw' /'original' data is sent. We thank Megan Scanberg for pointing this out to us.

expert review (e.g., data is visually examined by oceanographic experts for additional (re-)flagging) and complex statistical processes.[83] In these ways, Argo creates different kinds of data depending on *when* data is being generated, *when* data is being processed, and *when* it is being made available. These different kinds of data correspond to the needs of diverse scientific communities, or: Argo's infrastructural publics.

D. Infrastructural Publics: Scientific Communities and Beyond

Infrastructures generate publics.[84] Argo's foundation and trajectory as a data infrastructure that is mostly, but not exclusively, used by various scientific communities informs many of the contests about what data is being produced, when, where, how, and for whom.

Argo operates as a self-defined community that formed around the creation and operation of the Argo infrastructure. Argo's trajectory has been shaped by dedicated scientists, many of whom have been deeply involved since the program's inception. Their priorities are animated by the sensibilities of scientific practices and the desire to ensure that users of the data understand *what* the data represents and what its limitations are, with outermost attention placed on the quality and consistency of data.[85] The proposal for the array, put forth in 1998 by a U.S. oceanographer from the Scripps Institution of Oceanography, Dean Roemmich, found resonance with the climate research interests of the Climate Variability and Predictability (CLIVAR)[86] and the operational estimation objectives of the Global Ocean Data Assimilation Experiment (GODAE).[87] Inheriting the legacies and technologies of prior ocean observation infrastructures, and supported by the interests of the Climate Variability and Predictability (CLIVAR) and the Global Ocean Data Assimilation Experiment (GODAE) projects, Argo founders aimed to develop a program that would respond to the needs of meteorologists *and* climate modelling communities. The incorporation of Argo into GOOS further entrenched these twin goals,[88] and the incorporation of Argo into the priorities of the Ocean Decade likely envisions further uses and users of Argo data, including via aggregation with data from other sources and infrastructures.

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[83] For example, float data can also be affected by sensor drift, but because retrieving floats for recalibration is rarely possible, statistical tools and climatological comparisons are used to adjust the data for sensor drift when needed (Wong et al 2020).

[84] Benedict Kingsbury and Nahuel Maisley, "Infrastructures and Laws: Publics and Publicness", 17 Annual Review of Law and Social Science 353 (2021).

[85] AST Meeting

[86] Argo Science Team (1998) "On the design and implementation of Argo - a global array of profiling floats", International CLIVAR Project Office. CLIVAR's mission is to enable a better understanding of climate.

[87] GODAE's mission is to improve global and regional ocean analysis and forecasting systems.

[88] From the days of its inception GOOS was animated by twin goals: understanding and forecasting climate change and operational oceanography and meteorology. *See* IOC, History of Development of GOOS, IOC/INF-1361 (2018).

Fulfilling the needs of different communities, however, presents challenges. Scientific communities deploy different methodologies,[89] pursue divergent political priorities,[90] and encounter variegated funding and organizational problems.[91] To date, neither GOOS nor the IOC provide funding for Argo (or any other ocean observation network), but instead aim to standardize and systematize what knowledge about the ocean is being produced transnationally and for what purpose.[92] Securing funding for Argo hence remains a challenge for the Argo community.

In a quest to ensure its sustainability and in response to growing demand for Argo data from diverse scientific communities, Argo's data infrastructure is constitutive of and responsive to diverse infrastructural publics.[93] Scientific communities interested in operational ocean science and related modeling, for example, are affected when Argo's data is being updated, including retroactively. To better connect with these operational and modeling communities through regular information exchange and communication, the Argo Steering Team created a regular virtual forum for Argo and ForeSea/OceanPredict.[94]

The rarity of having consistent time-series of ocean observations has made Argo infrastructural not only to its intended users (i.e., operational oceanographers, climate modelers, etc.) but also to those who see Argo as a foundation upon which additional types of data can be generated. In this way, Argo's spatial and temporal data generation can generate new or re-make existing publics. For example, Argo's success in creating observations of ocean's interior at "adequate temporal and spatial scales" prompted scientists to note that there were no similar advances in observations of large-scale

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[89] During the First Session of the WMO-IOC Working Group on IGOSS, then-Secretary of the IOC noted the different approaches to observations of meteorologists and oceanographers due to temporal and spatial differences in the observations of the oceans and atmosphere. Joint WMO-IOC Working Committee for IGOSS, First Session (1978).

[90] Discussing ways in which IGOSS can support data management requirements of GOOS, established by the IOC in 1991, the IOC noted the importance of generating both synoptic and predictive products for operational purposes: "This is an obvious area of 'public and commercial benefit'. It is also highly visible and therefore politically important". [90] Joint WMO-IOC Working Committee for IGOSS, First Session (1978).

[91] IOC, History of Development of GOOS, IOC/INF-1361 (2018).

[92] See, e.g., GOOS, Essential Ocean Variables, https://perma.cc/AV7A-WDBM; IOC, Ocean Best Practices System, https://www.oceanbestpractices.org/ and https://ioc.unesco.org/news/streamlining-ocean-observing-around-world-ocean-best-practices; more generally on politics of global ocean observations, *see* Jessica Lehman, "A sea of potential: The politics of global ocean observations", 55 Political Geography 113 (2016).

[93] Benedict Kingsbury, Nahuel Maisley, "Infrastructures and Laws: Publics and Publicness", 17 Annual Review of Law and Social Science, 353 (2021).

[94] See the AST 23 Meeting Report. OceanPredict is an international research and development network to accelerate, strengthen, and increase the impact of ocean prediction. It is a successor of GODAE. ForeSea is a programme of OceanPredict. https://oceanpredict.org/foresea/.

biogeochemical and biological states of the ocean,[95] the only program mapping out the distribution of biogeochemical tracers in the ocean being the global CO2 survey undertaken jointly by WOCE, the Joint Global Ocean Flux Study (JGOFS), and a few other national programs. That program took a decade to complete, and was largely a one-time snapshot, providing limited information about evolution over time. The Repeat Hydrography program suffered from similar temporal challenges, with about a decade between repeats of hydrographic sections.[96] Although such temporal sampling was adequate for determining the long-term increase of the oceanic carbon content in response to the increase of atmospheric CO_2 levels, it was incompatible with the seasonal to sub-decadal timescale of variability in many biogeochemical parameters within the transition layer between warmer mixed water at the surface and cooler deep water.[97] In 2007 it was proposed that oxygen sensors be added onto Argo floats.[98] In the process of discussing the proposal, contemporaneous developments in sensor technologies for oxygen, chlorophyll, particles, and nitrate had enabled the deployment of sensors on long-endurance missions on autonomous platforms.[99] This, in turn led to the creation of BGC-Argo – a program that would see floats carry not only oxygen but other biogeochemical sensors as well, bringing into the collaborative fold of the program various BGC modeling communities and the physical ocean data assimilation community.[100]

The introduction of BGC sensors and the expansion of the originally intended Argo users, however, has introduced new challenges in determining what constitutes "bad" data and based on which criteria "flagging" of such data should occur. For example, bio-optical sensors provide proxy information on the size structure of the phytoplankton assemblage, which are responsible for about half of the biological uptake of CO2 on Earth through photosynthesis.[101] The light from bio-optical sensors, however, often attracts larger mid-water organisms, creating "spikes" in data that would be

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[95] Nicolas Gruber et al, "The Argo-Oxygen Program: A white paper to promote the addition of oxygen sensors to the international Argo float Program" (2007); J. Gould and the Argo Science Team, 2004, "Argo Profiling Floats Bring New Era of In Situ Ocean Observations, EoS, Transactions of the American Geophysical Union, 85(19), 11 (May 2004).

[96] Nicolas Gruber et al, "The Argo-Oxygen Program: A white paper to promote the addition of oxygen sensors to the international Argo float Program" (2007).

[97] Nicolas Gruber et al, "The Argo-Oxygen Program: A white paper to promote the addition of oxygen sensors to the international Argo float Program" (2007).

[98] Nicolas Gruber et al, "The Argo-Oxygen Program: A white paper to promote the addition of oxygen sensors to the international Argo float Program" (2007).

[99] K.S. Johnson et al, "Observing biogeochemical cycles at global scales with profiling floats and gliders: Prospects for a global array", 22(3) Oceanography 216 (2009).

[100] The latter community was relevant because assimilation of biogeochemical data requires detailed knowledge about the physical setting of the observations. See K.S. Johnson et al, "Observing biogeochemical cycles at global scales with profiling floats and gliders: Prospects for a global array", 22(3) Oceanography 216 (2009).

[101] https://biogeochemical-argo.org/scientific-questions-phytoplankton-communities.php

typically flagged as "bad" or "probably bad" data since it is not the type of data *expected*[102] from the sensors. However, this data could be useful to scientists interested in tracking migrating organisms that live in the mesopelagic zone of the ocean (e.g., zooplankton, fish, squids, and jellyfish).[103] The eventual compromise arrived at during the 2023 meeting of the AST was to retain the automated flagging of "bad" or "probably bad" but provide an index file of profiles or data segments that are believed to contain signals of mesopelagic organisms.

Building synergies with other "communities" continues to be a strategy for the Argo program as it struggles to secure consistent and reliable funding. At the Argo Steering Team meeting in March 2023, discussions focused on potential collaboration with other "communities" that could benefit from Argo data and that have access to funding,[104] such as "ocean color" communities that use satellite-based remote-sensing infrastructures to monitor health of the oceans and entities and collectives focused on marine carbon dioxide removal. Diversified uses of Argo data can enrich outcomes of other knowledge infrastructures (e.g. providing the "vertical dimension" for validating satellite data[105]) while also making Argo more relevant and sustainable by creating dependencies with a broader array of users (e.g., Argo's oxygen monitors may become indispensable to CDR projects).

At the same time, the expanded user base can lead to changes in the type of instrumentation and data, creating interoperability issues and requiring additional resources for the data management team, thereby posing governance challenges. Additionally, as data infrastructures expand or are being repurposed, contests over their normative orientation may emerge. Consider, for example, discussions at the Argo Steering Team meeting in March 2023 on potential collaboration with CDR projects. Should BGC Argo act as a neutral "referee", independently evaluating the effects of ocean manipulation associated with CDR on oxygen levels and ecosystems? Such a role would expand uses of Argo data but would not give Argo access to funding associated with CDR initiatives. Or should Argo collaborate with those involved in CDR to open up funding opportunities for Argo? Such an

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[102] The sensor is expected to track passively sinking organic particles.

[103] Nils Haëntjens et al., "Detecting Mesopelagic Organisms Using Biogeochemical-Argo Floats", 47 Geographical Research Letters (2020). These migrating organisms can be attracted to emitted light by sensors mounted on Argo floats and produce anomalous signals that can be used to suggest their presence, which helps scientists study those animals over extended time scales and in remote areas not easily accessible by ships.

[104] A community in this context connotes a group or network of scientists focused on particular issue(s), who presumably share common norms and practices with, and who are generally known to and can be identified by, the Argo scientists ("marine carbon dioxide removal is not a clear community. Ocean color community - we know them."). AST 24 meeting.

[105] AST 23 meeting; on Argo's three-dimensional spatiality *see also above* 3.b).

endeavor would implicate the Argo community in an activity that might not normatively align with its members' priorities and expectations, and might lead to unforeseen externalities.[106]

Argo's infrastructural publics also interact with legal publics (states) and their representatives (governments)[107], as they fund, support, coordinate, prioritize, and otherwise contribute to the array. More attenuated but nonetheless affected publics are the individuals and communities that experience extreme weather conditions and the impacts of climate change and for whom weather and climate forecasts (or absence thereof) can have existential implications.

Given the "openness" (in the sense of public accessibility without charge) of Argo data not all of the data infrastructure's publics may be immediately evident and some may be unintended. The tenor of Argo is one of scientific knowledge production – chief impacts touted by Argo members and documented by states in national reports are the number of scientific publications using Argo data. At the same time, data produced through BGC sensors is relevant for fisheries management,[108] and variability of temperature and salinity with depth contributes to understanding the structure of the sea for the purpose of submarine warfare.[109]

Argo also engages non-human publics – the species and organisms of various sizes inhabiting different layers of the ocean and unwittingly "collaborating" (in a Latourian sense)[110] with the floats and their instrumentation to generate data about themselves (e.g., as in when migrating organisms are attracted to the light sensors to "reveal" their presence to observing scientists), subverting Argo's mission by "polluting" the data or damaging the floats, or complementing and validating Argo data (e.g., where sensor-carrying animals are used to verify or supplant Argo data). At the same time, the interests of the non-human publics are not represented in the Argo data infrastructure except insofar as their datafied representation becomes relevant to the expanded base of users of the Argo data infrastructure (e.g., those concerned with biodiversity conservation or species preservation).

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[106] A discussion at the AST 24 meeting involved funding opportunity from the U.S. Department of Energy for development of CDR-related sensors on an existing ocean observing platform. The question arose as to whether Argo could serve as such platform. This generated a discussion about climate mitigation versus baseline data, with Argo members noting that it should be a priority to have good baseline data against which to measure impacts of climate change and of climate mitigation initiatives.

[107] Where state agencies are involved in directly funding and/or launching floats, they would also constitute infrastructural publics.

[108] "Continued support for the implementation of a Global Biogeochemical Argo Array by 2030", G7 Future of the Seas and Oceans Initiative, Scoping Paper, June 2021. Data generated via BGC sensors can indicate ocean productivity, which are relevant to productivity of fisheries.

[109] Jessica Lehman, "The Technopolitics of Ocean Sensing" in Blue Legalities: The Life & Laws of the Sea (I. Braverman and E. R. Johnson, Eds) (2020).

[110] Bruno Latour, Science in Action How to Follow Scientists and Engineers through Society (1988).

IV. Observational Science Data Infrastructures in Planetary Governance

Argo's development and its positioning within the institutional governance of oceans, weather, climate and, most recently, earth systems, reflects tensions in different understandings of *what* is to be governed, *by whom*, *for whom*, and *how*. Responding to the challenges of observing something so vast and dynamic as oceans,[111] Argo was initially designed to match observations of the ocean sea level obtained from the satellite altimetry project *Jason*.[112] In the early nuclear and space era, efforts to institutionalize transnational data collection, buoyed by collaborative research during the International Geophysical Year (1957-1958), led to establishment of the Intergovernmental Oceanic Commission (IOC) in 1960 under the auspices of UNESCO and ultimately the creation of the Integrated Global Ocean Station System (IGOSS) whose aim was to collate regular observations from ships, buoys, and satellites about tides, temperatures, storm surges and other oceanographic information. IGOSS, together with the International Oceanographic Data and Information Exchange programme (IODE), subsequently became building blocks for a Global Ocean Observing System (GOOS) – a global coordination network aimed at creating a "global ocean observing system that delivers the essential information needed for our sustainable development, safety, wellbeing and prosperity".[113] GOOS envisions an integrated global infrastructure that brings together a wide range of ocean observation data from different sources, including satellites, moored instruments, research vessels, gliders, animal-borne sensors, and autonomous surface and under-surface floats.[114]Globality in this context appears animated not only by the vision of inter-national collaboration but also by the imaginary of one "global" ocean.[115]

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[111] The polymath Cambridge historian and philosopher of science William Whewell (1794-1866), who is thought to have coined the term 'scientist' and whose testamentary legacy provided for the establishment of the Whewell Professorship of International Law, organized one of the first recorded "crowdsourced" research projects as a response to the connectedness and knowledge-challenging scale of the earth's oceans. In William Whewell's "great tide experiment" of 1835, thousands of mariners, surveyors, dockyard officials, and amateur observers measured the tides every fifteen minutes, twenty-four hours a day, for two weeks, with close to seven hundred tidal stations in multiple countries contributing data. Human "calculators" processed the data, not only rendering it legible but also producing tide predictions, which were subsequently published in nautical almanacs. Michael S. Reidy, Tides of History: Ocean Science and Her Majesty's Navy (2008). 92, 115; Michael S. Reidy and Helen M. Rozwadowski, "The Spaces In Between: Science, Ocean, Empire", *Isis* 105 (2014), 338–51.

[112] Argo Steering Team, "On the Design and Implementation of Argo—An Initial Plan for the Global Array of Profiling Floats". International CLIVAR Project Office (1998). On the relationship between Argo and Jason, *see* P.Y.LeTraon, "From satellite altimetry to Argo and operational oceanography: three revolutions in oceanography", 9 Ocean Science 901 (2013).

[113] Intergovernmental Oceanographic Commission, IGOSS and IODE Data Management Goals to Support GOOS, Fifteenth Session of the IOC Committee on International Oceanographic Data and Information Exchange (Athens, Greece, 23-31 January 1996) IOC/IODE-XV/11.

[114] www.goosocean.org [https://perma.cc/Z3AV-CK26].

[115] D. Armitage, A. Bashford, S. Sivasundaram, S. (eds.), Oceanic Histories (2017).

This imaginary found prominence in the framework for the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) ('the Ocean Decade'), proclaimed by the United Nations General Assembly in 2017. The Decade was officially launched in 2021 and envisages "nothing less than a revolution in ocean science that will trigger a step change in humanity's relationship with the ocean".[116] The Implementation Plan describes seven outcomes for the "ocean we want" at the end of the Ocean Decade, each ascribing features to the anthropocentric image of a global object: "clean ocean", "healthy and resilient ocean", "productive ocean", "predicted ocean", "safe ocean", "accessible ocean"[117], and "inspiring and engaging ocean", to be managed, understood, exploited, protected and valued by humans-as-distinct subjects.[118] Two of the ten challenges identified for the Ocean Decade speak specifically to ocean observations and data: expand the global ocean observing system (Challenge 7) and create a digital representation of the ocean (Challenge 8). The two challenges together quite ambitiously seek to create an all-known-at-all-times-past, present, and future-everywhere-to-everyone global ocean.[119]

In May 2023, the IOC published its data and information strategy for the 'ocean decade'. The strategy calls for a shift "towards 'data-first' resource mobilisation".[120] It envisions the creation of a federated digital ecosystem that will "*build on what already exists*, including ongoing data strategies and existing infrastructures" to allow users to combine data from diverse sources, across disciplines and geographic boundaries "as frictionless as possible". (emphasis added)[121] Despite the mobilization being driven by decadal temporality, the strategy aims for the resulting "digital ecosystem" to be sustainable "for years to come". This rhetoric is stunning not only in its naiveté but also in its deployment of "ocean data" as a given ontological phenomenon. The strategy's use of the term "ecosystem" echoes the presumption that "ocean data"[122] exists in nature and that the problem for

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[116] https://oceandecade.org/ocean-decade-alliance/

[117] Accessibility here refers to "open and equitable access to data, information and technology and innovation".

[118] The United Nations Decade of Ocean Science for Sustainable Development (2021-2030): Implementation Plan.

[119] Challenge 7: "Ensure a sustainable ocean observing system across all ocean basins that delivers accessible. timely, and actionable data and information to all users."; Challenge 8: "Through multi-stakeholder collaboration, develop a comprehensive digital representation of the ocean, including a dynamic ocean map, which provides free and open access for exploring, discovering, and visualizing past, current, and future ocean conditions in a manner relevant to diverse stakeholders."

[120] UNESCO-IOC (2023). Ocean Decade Data & Information Strategy. Paris, UNESCO. (The Ocean Decade Series, 45)

[121] UNESCO-IOC (2023). Ocean Decade Data & Information Strategy. Paris, UNESCO. (The Ocean Decade Series, 45) (see esp. Annex 3) (the generation of new ocean data and information "each hour" by observation systems is a key component).

[122] The Ocean Decade Implementation Plan defines "data" as "[a] set of values, symbols or signs (recorded on any type of medium) that *represent* one or more *properties* of an entity" (emphasis added), thus explicitly drawing boundaries between *knowing* (via representation) and *being*. Contrast Barad, *supra* note 8.

ocean management and governance, including climate, fisheries and biodiversity management, is one of epistemology: if only all the "ocean data" were accessible and interoperable, it will be *known* how to answer questions such "Where should a local fisher go today? Where should a marine protected area be placed? Where should infrastructure (e.g. wind farms, resilient shorelines, deep-sea cables) be developed? Is it safe to go to the beach today? What routes should ships take to avoid cetaceans or use less fossil fuels?"[123]

At the same time, earth-systems approaches have come to feature in many institutionalized initiatives of planetary governance. As early as 2014, the Secretary General's report to the UN General Assembly embraced Earth system science, whose "holistic scientific knowledge" paved the way towards earth system governance: "both Earth system science and Earth system governance continually and mutually reinforce each other regarding a holistic vision for the planet." [124] More recently, the World Meteorological Congress conceptualized "earth" as "an integrated system of atmosphere, ocean, cryosphere, hydrosphere, biosphere and geosphere, which informs policies and decisions based on a deeper understanding of the physical, chemical, biological and human interactions that determine the past, current and future states of the Earth."[125] The fundamental importance of oceanic-atmospheric interactions to climate modeling and to earth system governance has also brought Argo and cognate data-knowledge infrastructures into the purview of the climate change regime. Political as well as scientific effort has increasingly focused on what more is needed to build out comprehensive and systematic earth observation gaps for ocean, mountain, desert and polar regions, and the cryosphere.[126] If the details of the Argo program have thus far attracted interest mainly from its users and a small band of others, Argo is arguably of much wider importance.

The Argo program is now one of GOOS' global observation networks,[127] with plans -- under the label "OneArgo" [128]-- to expand its global coverage, extend its span to full ocean depth, add biogeochemical sensors for improved understanding of cycles of carbon and nutrients, as well as

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[123] UNESCO-IOC (2023). Ocean Decade Data & Information Strategy. Paris, UNESCO. (The Ocean Decade Series, 45), p. 10. On this epistemological fallacy see Bruno J. Strasser and Paul N. Edwards, Big Data is the Answer … But What Is the Question?, 32 History of Science Society (2017).

[124] Harmony with Nature, Resolution A/69/322, adopted 18 August 2014, para 50.

[125] WMO Strategic Plan 2020-2023, p. 8, fn 2.

[126] COP 27, Decision -/CP.27 Implementation of the Global Climate Observing System. Decision -/CP.27, Sharm el-Sheikh Implementation Plan (November 2022) noted "existing gaps in the global climate observing system, particularly in developing countries" and called for "coordination of activities by the systematic observation community".

[127] https://argo.ucsd.edu [https://perma.cc/62PF-GVME].

[128] W. Brechner Owens et al, "OneArgo: A New Paradigm for Observing the Global Ocean", 56(3) Marine Technology Society Journal 84 (2022). This agenda was laid out in 2019 at OceanObs'19, linked to the UN Decade of Ocean Science for Sustainable Development (2021-2030).

ecosystems, and consider additional sensors that might be included in the future. Argo's role is thus increasingly central not only in weather forecasting and climate modeling, but also as a component of aspirational planetary data infrastructure. Given Argo's resilience and relative success in sustaining infrastructure for the production of high-quality data, albeit on limited parameters, is also likely to become a model for other networks under GOOS and beyond. Like mycelium, Argo may compose a mycorrhizal network[129] that connects (via interoperability or gateways) diverse data infrastructures to enable exchanges and aggregations of different types of planetary data, or split off fragments of itself to give life to other independent networks.

V. Conclusion: Towards Organic Data/Infrastructure Governance?

Our account of Argo illustrates what it takes to produce useful data about oceanic properties. The program operates under significant capacity constraints. In its quotidian practice, Argo is a product of individual flair and initiatives, lock-in to past practices for data continuity, and the quirks and vagaries of funding and participation, as well as external overlaps of interest. High politics figures only episodically and usually at some remove within and around Argo practices about who decides what data is being produced, by whom, how and for what purpose, where, and when. The different kinds and functions of data that are being generated, transmitted, processed, stored, and disseminated owe much to these features.

We cannot say with certainty what Argo's ultimate contribution will be to the global governance of the ocean, as institutions and frameworks that aim to pivot towards earth-system or planetary governance are still in their incipient stages. At the same time, our analysis suggests caution to those approaches that treats each oceanic observation platform as a separate project that requires macro-level coordination to connect with others into a large-scale, integrated observation systems. Overemphasizing this coordinative approach may overlook concrete funding and maintenance needs within existing infrastructures and entrench choices and tradeoffs without attunement to their

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[129] We use "mycorrhizal network" rather than a more familiar allusion to the rhizome. Whereas a rhizome "sends out roots and shoots from its nodes", a mycorrhizal network comprises tiny threads of a fungal organism (mycelium), which together connect individual plants to transfer water, nitrogen, carbon and other minerals. Mycorrhizal networks are like communication webs through which signals between plants and trees get transmitted, eliciting complex behaviors in plants. M.A. Gorzelak, Asay AK, Pickles BJ, Simard SW. Inter-plant communication through mycorrhizal networks mediates complex adaptive behaviour in plant communities. AoB Plants. 2015 May 15;7: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4497361/. Argo's infrastructure both connects distinct actants and transmits signals, data, and ultimately knowledge, via its constitutive physical, digital and knowledge infrastructures. Through such networked transmissions it also configures governance arrangements ultimately shaping observational science.

cascading impacts on different infrastructural publics. It may also neglect (or even impede) the formation of connections between different producers of data and knowledge about the oceans, its ecosystems and inhabitants, as well as between those studying different elements of the earth systems. Moreover, a collation of "ocean data"-producing infrastructures risks producing highly contingent representation of the oceans, their properties, inhabitants and ecosystems, while reifying the "global ocean" as a bounded anthropocentric object of governance that can be made manageable, predictable, and sustainably exploited for human consumption. Integrating "what exists" and silo-ing earth system components into contingently constructed objects inevitably marginalizes alternative (e.g., indigenous) approaches to planetary governance that emphasize interactions of (eco)systems, species and non-living entities, as well as the historical and cultural significance of oceans.

Not every infrastructure follows (or should follow) the classical trajectory of large-scale network consolidation that Thomas Hughes described for London's electric grid.[130] Data infrastructures, with their constituencies whose kaleidoscopic interests range across many forms of knowledge, often develop organically -- like a mycelial network that sprout in unpredictable fashion.[131] Data infrastructure governance, by extension, particularly in planetary science contexts, requires an understanding of organic (i.e., without global-scale central scheme or planning) data infrastructure development, including the unevenness, choices, inequalities and steep gradients of power which almost inevitably characterize such infrastructures because of the distribution of resources and capacities in the knowledge-generating projects that undergird them.

Argo has been carefully nurtured by various scientific communities that coalesced around Argo as a "data infrastructure". We can and perhaps should think of its role in planetary-scale ocean data governance as a sprouting network that spread out organically, creating unexpected connections and even fusions when interacting with other initiatives interested in ocean observation, and foreclosing other link-ups. It is in focusing on those interfaces where promise lies for planetary governance.[132]

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[130] Networks of Power: Electrification in Western Society, 1880-1930 (1983).

[131] Merlin Sheldrake, Entangled Life (2020).

[132] Cf. Fleur Johns, #Help Digital Humanitarianism and the Remaking of International Order (2023) (exploring the importance of interfaces in digital humanitarianism).