Ocean Remote Sensing from Space: 
A Tale of Three Commons

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Introduction

The uniqueness of the ocean lies in its vastness, its constant movement, flow, and circulation. This seems to elude graphic illustration on a static map with point markings and line drawings, or image capture of the watery element, particularly when it takes the form of currents, waves, fog or clouds, or when it is precipitating, melting or blowing. Geometric representations and instant snapshots of the ocean are ephemeral and fleeting, subject to interpolation and interpretation. Exploring, representing and articulating the dynamics of ocean space is a challenging endeavor that can be enriched by the view from above—high above—from outer space, via the pathways of cyberspace.¹

The View from Above

Viewing the ocean from outer space is an unusual, formidable perspective. It differs profoundly from that of the traditional lookout in the mast of a sailing vessel or present-day, ship-based radar instruments, horizontally scanning their immediate surroundings and committing important observations and positions to a log. By contrast, modern satellite-based sensors are pointed downward. The vertical perspective permits map-like arrangements of data collections. These are scalable and in effect comparable with other geospatial information as it relates to marine surveillance, mapping, and synoptic views of environmental conditions. Moreover, while confined by Kepler’s Laws to orbital motion several hundred kilometers high above the rotating Earth, optical and radar remote sensing systems can effortlessly repeat their measurement.

¹ P. Meyer, “Outer Space and Cyberspace: A Tale of Two Security Realms,” in, International Cyber Norms: Legal, Policy & Industry Perspectives, eds., A.-M. Osula and H. Rõigas (Tallinn: NATO CCD COE Publications, 2016), 155–169, https://ccdcoe.org/sites/default/files/multimedia/pdf/InternationalCyberNorms_Ch8.pdf.
cycle, covering vast swaths of ocean surface and eventually the entire globe on a regular basis.

In a typical scenario, satellite-based sensors transform the radiation or backscatter response to a stream of electrons. Data streams are rapidly transmitted to a ground-based facility and processed by algorithms that record them as ocean color, temperature, sea surface elevation, or sea ice, as the case may be. Over the past decades, scientists and mariners have learned to utilize and interpret wide-area coverage of ocean remote sensing data, often in conjunction with in situ validation data from a buoy or Argo float network. They study spatial and temporal dimensions of biophysical and chemical processes, measure trends of global sea level rise, and monitor oscillations, such as El Niño and La Niña events (Figure 1). They routinely assess the risk of operating in remote and harsh marine environments by integrating up-to-date satellite data into mapping, modeling, and forecasting activities.²

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² I.S. Robinson, Discovering the Ocean from Space: The Unique Applications of Satellite Oceanography (Heidelberg: Springer, 2010).
Advanced satellite technologies and constellations of high-precision sensor systems are revolutionizing the way we can observe the ocean surface on a daily basis at spatial resolutions that range from a few hundred meters to several kilometers. Microwave scatterometers provide detailed global data on near-surface wind fields and on sea ice distribution. Altimeters observe ocean circulation patterns, measure significant wave height, and monitor sea levels at centimeter accuracy. Synthetic aperture radars are similar ‘weather-independent’ instruments generating detailed imagery of coastal wind fields, waves, frontal currents, surface oil pollution, and sea ice. Along-track scanning radiometers provide accurate sea surface temperature maps. Ocean color radiometry is essential in coastal regions for measuring parameters such as chlorophyll-\(a\) concentration, primary productivity, and suspended matter. Many of these ‘surficial’ data sets and time series are used for validating multidimensional marine ecosystem models of ocean space.\(^3\)

Over the coming years, public and private sector investments in Earth observation technology and geospatial infrastructure will amount to billions of dollars, supporting the scenarios and applications mentioned above. They hold promise for more capable sensors, more frequent and detailed observations, and more timely delivery of related products and services originating from the increasingly crowded precinct of low Earth orbits. Going beyond the view from above and rapid development of space technology, how will policy-makers, managers, and the public-at-large receive and react to scientific evidence of ocean change? What societal benefits might be gained, given the coveted view from above?\(^4\) And, conversely, can Earth observation technologies help to sustain the health of the ocean, given open and reliable access to online data streams and scientific research into essential ocean variables?\(^5\)

Digital Pathways across the Global Commons

One might address the concerns related to ocean science policy, societal benefits, and ocean health from a global commons point-of-view by following the pathways of digital data and image representations of ocean space, as they

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\(^3\) Task Team for an Integrated Framework for Sustained Ocean Observing, *A Framework for Ocean Observing*, IOC/INF-1284 rev. (Paris: UNESCO, 2012), doi: 10.5270/OceanObs09-FOO, http://unesdoc.unesco.org/images/0021/002121/212126e.pdf.

\(^4\) S. Djavidnia, V. Cheung, M. Ott and S. Seeyave, eds., *Oceans and Society: Blue Planet* (Newcastle upon Tyne: Cambridge Scholar Press, 2014).

\(^5\) P.F. Uhlir, *The Value of Open Data Sharing* (Geneva: Group on Earth Observations/codata, 2015), https://www.earthobservations.org/documents/dsp/20151130_the_value_of_open_data_sharing.pdf.
accumulate from sensors based in *outer space* and enter a third domain of the global commons, namely, *cyberspace*. Cyberspace has rapidly emerged as the main vector for transmitting electronic signals, processing data, and accessing information. Satellite oceanography worldwide is thriving in this man-made domain; scientists and fast-growing users groups by and large depend on open access to it.

One of the essential infrastructure elements of cyberspace is the intercontinental fiber-optic cable network. It shuttles more than 90 percent of the world-wide Internet traffic across the ocean floor; the remaining traffic is handled by high-speed data links via communication satellites. Once more, the cybernetic pathways of Earth observation data—this time processed data to end users—transects the global commons of ocean space and outer space. While both of these domains are governed by international treaties, cyberspace is not, at least not yet. A significant challenge to the viability of the emerging cyber-common is inadequate security, insufficient norms and regulations, and ineffective mechanisms of enforcement. Restriction or outright disruption of access to Earth observation data would significantly blindside our ability to monitor vast areas of ocean space.

Meanwhile, satellite remote sensing is accumulating enormous data sets, filling archival storage vaults by the petabyte; many of them are openly available online. Data volumes have already reached a critical mass to be used in interoperable ways for large-scale syntheses and big data analytics. Assimilation with a host of other geospatial records is an exciting and demanding element of future interdisciplinary scientific research and operational oceanography. It relies on improved connections between data repositories and automated, custom-made queries so as to extract, reveal, and quantify relationships.

Approaching the topic from a social justice perspective, Elisabeth Mann-Borgese recognized the value of, and the all-important access to, Earth observation data at a very early stage of its development. Two years after the 1972

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6 N. Starosielski, *The Undersea Network* (Durham: Duke University Press, 2015).
7 M. Barrett, D. Bedford, E. Skinner and E. Vergeles, *Assured Access to the Global Commons* (Norfolk, VA: Supreme Allied Command Transformation, North Atlantic Treaty Organization, 2011), http://www.act.nato.int/globalcommons; see also D. Livingstone and P. Lewis, *Space, the Final Frontier for Cybersecurity?* (London: Chatham House, 2016).
8 Examples include the US National Oceanographic and Atmospheric Agency Centers for Environmental Information (https://www.nodc.noaa.gov/), the US National Aeronautics and Space Agency’s (NASA) WorldView portal (https://worldview.earthdata.nasa.gov), or the European Union’s Copernicus Marine Environmental Monitoring Service (http://marine.copernicus.eu); some non-governmental organizations are focusing on specific themes, for example, the Global Fishing Watch (http://globalfishingwatch.org) and https://windy.com.
launch by the United States of their first civilian Earth Resource Technology Satellite (ERTS-1, later re-named LANDSAT-1), and four years before their pioneering SEASAT radar satellite returned a bounty of ocean measurements, she asserted, “only when satellite detection of natural resources is governed by international law will it benefit mankind.”

Her 1987 proposal for the establishment of a World Space Organization (WSO) under the auspices of the United Nations was informed by experience gained during the negotiations leading up to the United Nations Convention on the Law of the Sea. Mann Borgese’s overarching and principled WSO framework did not find support then. Instead, smaller and voluntary non-binding international and intergovernmental arrangements started to emerge at the time, as the initial scope of satellite observation and resource mapping was broadening to include environmental assessment and monitoring activities.

During the 1980s, the Group of Seven (G7) countries established partnerships in the international arena to “coordinate comprehensive and sustained Earth observations for the benefit of humankind.” The G7 Committee on Earth Observation Satellites (CEOS) was initially formed in 1984 as a mechanism for national space agencies to collaborate on missions and data systems. Under the United Nations umbrella, the Global Ocean Observing System (GOOS) informs environmental management policies and agreements and co-ordinates observations for climate, ocean health, and real-time services. The Group on Earth Observations (GEO) is a voluntary intergovernmental partnership of more than 100 nations pursuing the creation of an ambitious Global Earth Observation System of Systems, connecting Earth observation resources with a wide range of designated societal benefit areas. More often than not, these exemplary efforts of governance, collaboration and regulatory capacity-building are struggling to keep up with the relentless pace of ocean-related activities and technology development.

9 Elisabeth Mann Borgese documented her points of view in two papers: “The Common Heritage,” CERES: FAO Review on Development (November/December 1974): 55–57; “Towards a World Space Organization,” Canadian Institute for International Peace and Security Points of View No. 5 (November 1987): 1–7. Both papers are available at https://findingaids.library.dal.ca/elisabeth-mann-borgese-fonds/.

10 CEOS has been in operation since 1984 (http://www.ceos.org); GOOS (http://www.goosocean.org) was established in 1992 by the Intergovernmental Oceanographic Commission of UNESCO; the intergovernmental Group on Earth Observations (http://www.earthobservations.org) first came together in 2003, adopted a Framework Document in 2004 defining scope and intent of the Global Earth Observation System of Systems (http://www.geoportal.org) and endorsed the GEOSS 10-year implementation plan in 2005.
Prospects for Observing Ocean Space from Outer Space through Cyberspace

Not unlike ocean circulation, the oceanic circle of satellite remote sensing data is also a continuous system: from surface to sensor to user, driven by the quest for a constant supply of reliable data and image products. Uninterrupted flow is the key to its function, and open access is essential for widespread applications in the near future. Scientists, researchers, and operational managers will continue to be leaders in marine monitoring activities and forecasting services. Citizen science is likely to join in these efforts, taking advantage of data democratization and data access opportunities. Emergency responders will focus on near real-time analysis for natural and human-made disasters, such as major storms, oil spill pollution, harmful algal blooms, or oxygen-depleted dead zones.

At the institutional level, satellite data are increasingly used in conjunction with other geospatial tools to assess regulatory regime performance and to enforce rules concerning large marine protected areas or illegal, unreported and unregulated fishing. The growing body of spatial-temporal information derived from ocean observing satellite sensors will continue to challenge conventional assumptions of movement and circulation patterns. Many efforts are bound to move beyond co-ordinating the activities of Earth observation producers.\(^1\) Examples include Copernicus, The European Earth Observation Programme\(^2\) and its Marine Environment Monitoring Service,\(^3\) and the Global Fishing Watch.\(^4\) They will involve a complex combination of actors, mandates and authorities. As a case in point, one might consider a private company launching a satellite sensor into space on an Indian or Russian rocket, providing environmental monitoring services and geospatial products via Internet to government or non-governmental organizations concerned with the implementation, enforcement, or monitoring of international regimes.

The role of satellite observations in addressing marine surveillance and environmental issues at local, regional, and global scales could be viewed as being largely instrumental, or technical, complemented by advanced methodological

\(^{1}\) M. Onoda and O. Young, eds., *Satellite Earth Observations and Their Impact on Society and Policy* (Singapore: Springer, 2017), https://link.springer.com/book/10.1007/978-981-10-3715-9; see also D.J. Whalen, "For All Mankind: Societal Impact of Application Satellites," in *Societal Impact of Spaceflight*, eds., S.J. Dick and R.D. Launius (Washington, DC: NASA, 2007), 289–312, https://history.nasa.gov/sp4801-part1.pdf.

\(^{2}\) See Copernicus, http://copernicus.eu/.

\(^{3}\) *Supra* note 8.

\(^{4}\) *Supra* note 8.
approaches first to identify, then classify, and eventually model the magnitude, characteristics, and extent of ocean features. As such, the observations from outer space cannot solve problems of climate change, marine habitat loss, ocean acidification, or overfishing. Yet, reliable satellite data and time series of ocean space will frequently form the geospatial backbone when it comes to addressing, alleviating, and solving these problems. How beneficial the view from above and how useful the digital manifestations of the oceanic satellite data circle can be for humankind will in no small part rely on open access and emerging governance regimes of the cyberspace common.