OCEANS, BIG DATA, AND THE INTERNET OF THINGS

Master of Arts in Law and Diplomacy Capstone Project

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1. Introduction

As stewards of the earth with limited lifespans, it is the responsibility of each person to seek and apply knowledge that will benefit generations to come. Society faces the trial of unprecedented climate change and deteriorating ocean health. Scientists have attested to chemical and biological changes in the oceans and in critical weather systems, such as El Nino. Surprisingly, we currently know more about the surface of Mars than the floor of our oceans. While the means for global ocean observation have been historically limited, key indicators --such as sea level, temperature, salinity, and acidity-- point to the possible emergence of radical changes in the world's climate. This essay describes the current state of ocean observation and the corresponding gaps in information. New methods of measuring and analyzing the ocean can fill these gaps, including crowdsourcing, third party data collection, global deployment of low-cost sensors, cloud computing, and the Internet of Things (IoT). The IoT is "a networked world of connected devices, objects, and people"(Greengard), which will enable society to "sense, obtain, analyze, monitor, and distribute data on a massive scale" (Maras). A 'sensor' covers the wide range of devices used to measure a vessel's, buoy's, or mooring's physical environment (Lloyd's Register). This essay surveys the current practices of trailblazing ocean scientists and organizations as well as their future aspirations. Scientists have partnered with different industries to pair sensors on freighters, fishing vessels, and ferries, with measurements from buoys and satellites. These existing projects can serve as a models for future networks and networks of networks. Improvements in data collection may lead to better decision making and models of climate change and the consequences for society, such as the migration and depletion of fisheries. Just as one cannot derive the nature of a flock from a single bird, increasing the breadth of our observations across space and time may help us better visualize natural phenomenon and manage human behavior. With patience, a global ocean observation system could give us new insights into longitudinal patterns. While this essay focuses on ocean health, there may be tributary economic benefits associated with a global ocean observation system for industries such as offshore energy, weather prediction, and maritime insurance. Creating a global ocean observation system would not only be a scientific achievement but a diplomatic opportunity. By having a thirst to find, derive, and apply knowledge from complex data, society could benefit the world at a crucial time and leave a legacy of stewardship and responsibility for generations to come.

2. Climate Change, Oceans, and Consequences

Before looking to the future of ocean observation, it is critical to understand current ocean changes. Temperature, salinity, and acidity are the three core variables used by ocean experts to analyze ocean conditions. Definitions for these three metrics (temperature, salinity, and acidity) can be found in Section 3, along with descriptions of their consequences for society. Using these metrics, ocean scientists demonstrate that ocean changes are occurring often exponentially.

This paragraph summarizes in brief some of the latest findings on temperature, salinity, and acidity from leading institutions. Bear in mind that in a complex world “structures can seem almost stable for long periods of time, although micro-changes may be going on under the surface. And then radical change can happen suddenly” (Boulton). The Intergovernmental Panel on Climate Change reported that since 1971, the top 75 meters of the oceans have increased in temperature by 0.44 degrees Celsius (IPCC). According to Ruth Curry of the Woods Hole

Oceanographic Institution (WHOI) salinity has increased by 0.1 to 0.4 Practical Salinity Units over four decades in all Atlantic waters studied (Curry). The National Academy of Science found that, “Ever-increasing levels of atmospheric CO2 are resulting in an acidifying ocean, and this acidification is progressing at a rate not seen in at least the past 800,000 years” (NAS). In conclusion, the core metrics of temperature, salinity, and acidity reveal linear and exponential changes in ocean conditions. These changes may seem inconsequential to some, however they could potentially be small indicators of the radical changes yet to emerge.

What are the consequences for changes in temperature, salinity, and acidity? Not only do these changes often reinforce each other, (for example, increased temperature leads to increased evaporation, which leads to increased salinity) but they also affect important weather systems and fisheries, a key natural resource.

Weather Consequences

In terms of weather systems, changes in atmospheric and oceanic circulation are already affecting systems like the Indian Summer Monsoon and El Nino. Greenhouse gas forcing strengthens the Indian Monsoon System (Future of World’s Climate). El Nino is another system, which depends on ocean and atmospheric variability. Global warming has been linked to increasingly more severe El Nino events. Based on these trends, scientists predict “more persistent or frequent El Nino conditions” in the future (Variability and Change in the Ocean).

And yet, the impact of climate change cannot be predicted with 100% accuracy. While new measurement systems may reduce uncertainty there will always be some elements of the unknown and the potential for surprises. The research does predict that climate change will likely lead to shifts in the location and amplitude of weather systems, like the Indian Summer Monsoon and El Nino. The movement of these weather systems is predicted to have severe impacts on many regions (Variability and Change in the Ocean). Ocean observation can open insights into the past, present, and future. Changes in weather systems demonstrate the necessity of rigorous scientific measurement and deep considerations of the consequences of human behavior. A global ocean observation system may help countries predict and respond to severe weather changes more responsibly and collectively.

Fishery Consequences

Changing ocean conditions are affecting people globally by reducing the abundance of fisheries and causing fish populations to migrate to colder waters. The FAO estimates that one billion people rely upon fish and seafood as their primary source of protein (FAO). Studies show that anthropogenic changes threaten not only the environment, but also society's ability to "continue reaping economically and socially valuable marine resources." (CIERP). According to the FAO in 2009, "warm-water species are being displaced towards the poles and are experiencing changes in the size and productivity of their habitats" (FAO). These changes are affecting entire marine ecosystems. In sum, the availability, stability, and access to aquatic foods will be affected by climate change. Increasing data on fish population size and location may yield economic benefits to society as decisions are made in the fishing industry on where to move and where to invest in equipment and infrastructure. A director of the United States Pacific Coast Federation of Fishermen's Association called for the country to spend more on "real-time" models of fish locations and populations (Bernstein). These possibilities are actualizing through global ocean observation systems in countries like Iceland that depend upon a sustainable and successful fishing industry. With the right direction, science and technology can help society respond to changes in fish stocks and weather systems due to climate change and changing oceans conditions.

3. Key Ocean Indicators and Consequences

To better understand climate change and ocean health, it may be helpful to review the definitions and consequences of changing ocean temperatures, salinity, and acidity.

Ocean temperature is the degree of heat in the water. According to the FAO in 2009, the oceans are warming but not in homogeneous ways. Where warming is occurring, zooplankton populations may be cut, which causes species that feed on them to move elsewhere. For example, scientists have noted "disturbing signs of collapsing fisheries in the northeast region of the United States (US)" (Accelerated Warming). As described in Section 2, the warming is happening at exponential rates. In the area surveyed between the northeast coast of the US and Bermuda, the warming rates were 15 times faster than the previous 100 years, according to Dr. Glen Gawarkiewicz, a WHOI senior scientist (Accelerated Warming). In this study it was clear that warming ocean temperatures extend past the surface all the way down the water column.

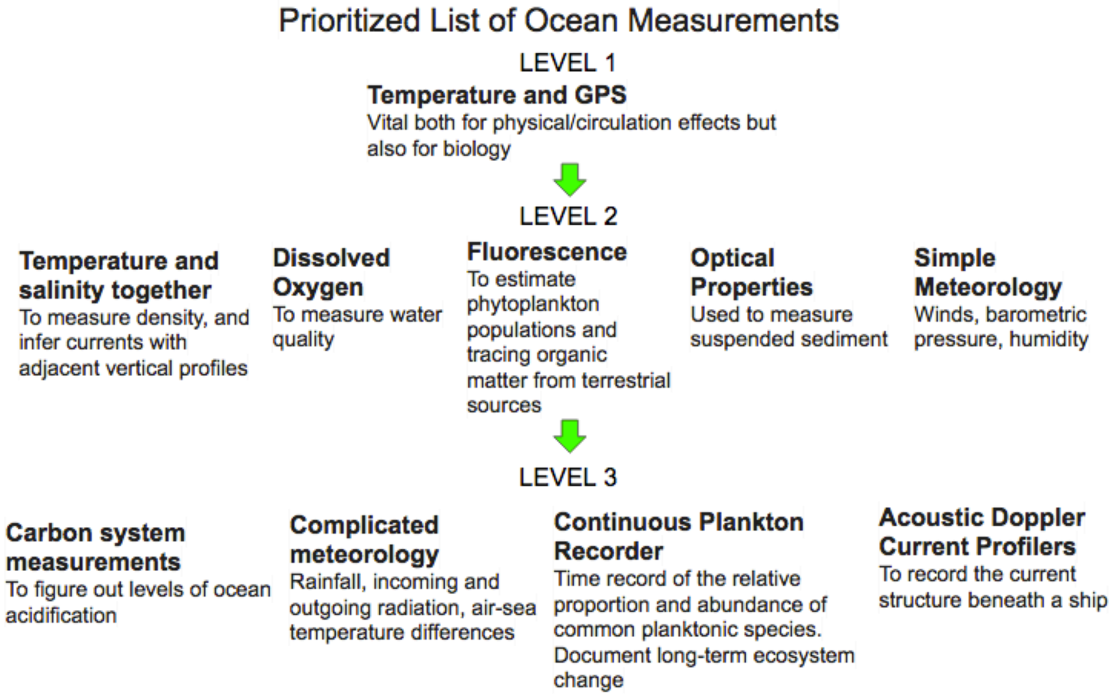
Salinity is the salt content of the water. Like ocean temperature, it is changing in different ways around the world. Growing evidence shows that the "polar seas are decreasing in salinity while waters in lower latitudes are becoming saltier" (Curry). In general this is because freshwater inputs like precipitation and runoff are "shifting to higher latitudes" and increases in ocean and atmosphere temperatures are “resulting in higher rates of evaporation” (Curry). According to CIERP, salinity changes “feed back into climate change... alter marine ecosystems,” and reduce “the ability of the ocean to function as a carbon sink” (CIERP). Additionally, there are more complex interactions in which changes in salinity and temperature combine to alter the density of the surface water and increase vertical stratification. Vertical stratification tends to decrease nutrient availability, which reduces primary and secondary levels of production. While further details are beyond the scope of this paper they can be studied in “The Future of the World’s Climate”.

In this case **acidity** is the level of acid in the water. Acidity is measured on a scale from 0-14 with 7 being neutral. According to National Geographic, “Over the past 300 million years, ocean pH has been slightly basic, averaging about 8.2. Today, it is around 8.1, a drop of 0.1 pH units, representing a 25-percent increase in acidity over the past two centuries” (Ocean Acidification). NAS’s 2010 study affirms the acidity increase and attributes the acidifying ocean to the increasing levels of CO2 in the atmosphere (NAS). According to CIERP, ocean acidification poses a serious threat to fisheries, marine ecosystem services, and the overall resilience of the oceans” (CIERP). Core organisms such as coral, phytoplankton, oysters, and mussels have calcium components that are damaged by increasingly acidic waters.

In conclusion, ocean temperature, salinity, and acidity are all in flux, some increasing at exponential rates. The changes are not theoretical; they are already affecting fishery health and abundance, climate change, the ocean’s function as a carbon sink, and the basic building blocks of marine ecosystems. There is a certain degree of unpredictability in the severity and extent of these consequences. For example, it is hard to determine how climate change will affect marine organisms and whether they will acclimate or adapt. In the words of NAF in 2010, “Based on current knowledge, it appears likely that there will be ecological winners and losers, leading to shifts in the composition of many marine ecosystems.” With increased understanding of the oceans through a global data collection network, society may be able to gain insights that will help it understand and adapt to a changing world.

Visualizing Data Priorities

Image 1 shows the hierarchy of ocean data priorities and sensors according to a Woods Hole Oceanographer.



Prioritized List of Ocean Measurements

LEVEL 1

Temperature and GPS
Vital both for physical/circulation effects but also for biology

LEVEL 2

Temperature and salinity together
To measure density, and infer currents with adjacent vertical profiles

Dissolved Oxygen
To measure water quality

Fluorescence
To estimate phytoplankton populations and tracing organic matter from terrestrial sources

Optical Properties
Used to measure suspended sediment

Simple Meteorology
Winds, barometric pressure, humidity

LEVEL 3

Carbon system measurements
To figure out levels of ocean acidification

Complicated meteorology
Rainfall, incoming and outgoing radiation, air-sea temperature differences

Continuous Plankton Recorder
Time record of the relative proportion and abundance of common planktonic species. Document long-term ecosystem change

Acoustic Doppler Current Profilers
To record the current structure beneath a ship

Image 1.

4. Gaps in Current Ocean Observations

Compared to land and the atmosphere the ocean is poorly sampled. Amidst unprecedented climate and ocean changes there has never been a more critical time to collect ocean data. There are several approaches to collecting ocean data, including dedicated research vessels, moorings, and satellites, however, current data practices are often limited in scope and by cost. For example, dedicated research vessels, like WHOI R/V Atlantis, have standard day rates of $44,500. This figure does not include maintenance costs and dockage costs. For this reason, scientists have had to be very selective about where and how research vessels, and their associated sensors, are deployed. This is an example of the demand for data outweighing the supply of measurements means.

In addition to research vessels several ocean observation stations have been created in the past. Many of these programs had unique strengths. Some systems were regionally focused, like the Tropical Ocean-Global Atmosphere program (1985-1994), which operated along the equator in the Pacific. Other projects like the World Ocean Circulation Experiment (1990-1998) employed the latest technology of the time, such as expendable bathythermographs. This program was both a scientific and diplomatic success because thirty countries participated. Satellites have also been deployed with success, such as the ongoing Soil Moisture Ocean Salinity (SMOS) project (2009-present) which measures the salinity of surface waters. Today, ARGO profiling floats are some of the most advanced research technology in the oceans. ARGO deploys around 3,000 floats that descend 1000-2000 meters for eight to ten days, resurface, and then relay their findings via satellite. The current and past ocean observation systems incorporated various streams of data from research vessels, moorings, satellites, and floats. This information has helped scientists generate new findings and publish peer-reviewed articles.

Learning from past ocean observations, there is still progress to be made in the type and scope of ocean measurements. For example, satellites, like SMOS, make it easy to obtain readings on the ocean surface, but data on subsurface temperature, pH, salinity, and biological measures (such as chlorophyll) is still lacking. According to the Future of the World's Climate, there are large discrepancies in the type of ocean data available today. For example, the global salinity database is only a fraction of the size of the global temperature record (de Boyer Montegut). Furthermore, most databases have short data records lasting less than a decade or two. For this reason long term trends may not be as clearly visible. Scholars argue that it is vital to "maintain the existing observational network and improve it in some important key areas" (Future of the World's Climate). The ocean covers 141,600,000 square miles, so more work can be done to build off successful systems like ARGO and improve the scope and depth of ocean measurements. Sections 5 and 6 outline new methods of data collection including crowdsourcing, third party data collection, global deployment of low-cost sensors, cloud computing, and the Internet of Things (IoT).

5. New Methods

New methods of data collection may help us track the world's unprecedented climate changes and respond to them more resiliently. Low cost sensors cloud computing, and the IOT, and new data collection partnerships may fill in the gaps of existing data sets by enabling wider and deeper data collection. According to Lloyd's Register, the next generation of sensors will be smaller, cheaper, and more energy efficient. They may even be intelligent, meaning that data could be processed within them. The following sections outline people and organizations that are collecting data with new methods. There are four examples of this trend: NOAA's Ship of Opportunity Program, Dr. Kevin Stokesbury shellfish research in New Bedford, Massachusetts, Dr. Glen Gawarkiewicz, and the University of Iceland.

SOOP

Starting in 1981, "The Ship Of Opportunity Program (SOOP) is an international effort that supports the implementation of a network of cargo vessels, cruise ships, and research vessels to deploy scientific instruments that collect oceanographic observations" (Physical Oceanography Division). The key instrument for this partnership is the Expendable Bathythermograph (XBT). XBTs measure the water temperature from the surface temperature down to a depth of 850m. These measurements have lead to over 25 scientific publications per year. Some routes, like Newark to Bermuda, have been measured for over 31 consecutive years. Other primary routes include Miami to Gibraltar and Cape Town to Buenos Aires. A total of 17 routes or transects are measured. According to NOAA, the majority of this data is "distributed onto the Global Telecommunication System (GTS) within 24 hours of its acquisition, thereby providing critical input to weather and climate forecasts models and scientific applications" (NOAA). SOOP is also responsible for the installation and operation of ThermoSalinoGraph, which are instruments that continuously measure the values of sea surface temperature and salinity along the ship path. In addition this project supports other observational networks, such as the global drifter array, and Argo profiling floats.

Dr. Kevin Stokesbury and Shellfish

Dr. Kevin Stokesbury in New Bedford Massachusetts wanted to study and help the Georges Bank (*Placopecten magellanicus*) scallop population. He observed that NOAA estimates and allowances for sustainable fishing were becoming more conservative. Unsure whether NOAA's fish quota studies were completely accurate, Dr. Stokesbury began an independent research project with the cooperation of shell fishermen. Using video techniques and tagging programs, the team discovered that the shellfish population was more abundant than NOAA had estimated. It took years to get the necessary funding to grow the project in scope and for the scientific community to accept his independent research as methodologically sound. However, many people say that by Dr. Stokesbury's work contributed to saving New Bedford's fishing industry. The data gathered through the Stokesbury's Marine Fisheries Field Research Group has improved harvesting, gear effectiveness, and alternative fishing strategies.

Dr. Glen Gawarkiewicz and Ocean Shelves

Woods Hole Oceanographic Institution scientists have studied water temperatures off the Northeast Coast of the US since the late 1970's. Scientific partnerships were formed with the operators of the container ship Oleander, which routinely travels between Bermuda and New Jersey. These research efforts were funded through the National Science Foundation, the University of Rhode Island, and Stony Brook University. Measuring depths of nearly 700 meters, the study found that temperatures throughout the water column have been increasing for the last 13 years. According to Dr. Glen Gawarkiewicz, "The warming rate since 2002 is fifteen times faster than from the previous 100 years". This study also found that Northeast sea level anomalies might serve as a predictor of shelf temperature, with a lag of two years.

University of Iceland

Currently the University of Iceland, and Marsyn, offer public access to large amounts of adaptive grid data on waves, weather, and other dimensions. These data is collected from a combination of buoys, satellites, gliders, and research ships. These data are also collected on fishing ships, with temperature and salinity meters attached to the head pieces of the trawls. These programs offer information on Iceland's coasts, Western Europe, and the globe more broadly. The system incorporates historical data in its "hindcasting" on the mid North Atlantic Ocean with 3D resolution dating back to 1948. The data set also incorporates public data from the Marine Research Institute, ICES, and MyOcean. At the time of this publication, the University of Iceland was looking to partner with subject matter experts in the marine industry to receive data transferred through satellite from ships.

Fish finding is still a work in progress but it is related to forecasting primary and secondary production by measuring chlorophyll. The University of Iceland has two post-doctoral students and two PhD students who discovered a way to fill in gaps due to cloud coverage of satellite data and model the distribution and migration of herring. These types of studies could help governments around the world with their fishery stock assessments. Currently all stock assessments have conservative variables to reduce error. Increasing information may increase the accuracy of stock assessments and lead to a more sustainable fishing and robust fishing industry.

6. Looking Ahead

Many boats already collect data on water temperature and depth through the GPS and consul systems used for navigation. For example, companies like Furuno have fish finders, chart plotters, and radar which have data banks that could imported into a Marine Data Bank for further study. Similarly, Boatracs records data and saves it forever according to a representative, and customers are able to retrieve it for a small fee. Some maritime company representatives are unfamiliar with the data migration process and were unable to comment on who owned the data and how it could be accessed. By creating an industry standard where data collectors maintain ownership of their data it may be possible enable the gathering of data from systems that are already operating. With the right team, it would likely be possible to hindcast huge stretches of ocean.

Inventory of Sensors and Capabilities

Currently there are off the shelf sensors, which measure most of the critical ocean variables. For example, it is possible to measure location, temperature, pH, and salinity, in ways that are scrubbed and encrypted. There are even Simrad camera, which can be attached to nets, trawls, and dredges to see what is going on beneath the surface. These devices range in price, with the Hobo Lodger temperature sensors at the bottom of the bracket at about $125 per sensor. In speaking with scientists and listening to US Congressional Hearings it is clear that groups are working on repurposing the TSA’s facial recognition software so that it could identify and count fish as they are landed in real time. Some of these sensors are hand deployed and others are attached to the vessels themselves. The more automatic and zero-maintenance these systems can be the better. It may be possible to imitate the Icelandic model and have sensors on lobster traps that upload when they go over the side of boats, as proposed by a fisherman from Portland, Maine. By using crowdsourcing, democratic data collections, and sound methodology, the US should be able to scale up its ocean data collection in cost effective ways. These systems could be largely run by volunteers, as evinced by the Oleander study, and in partnerships with public and private entities.

Where to Start?

The global ocean observation concept could be piloted in a top-producing US port, such as New Bedford, which has ferry systems and active fishing and recreational fleets. Based on the findings here, the concept could be exported to New England at large. Another place to leverage data could be the international ports of call along the East Coast, such as Eimskip in Portland, Maine. Throughout this process, new sensors and systems could be developed as lower costs to improve efficiency. Some of the developments could be housed in US innovation clusters such as the IoT IMPACT LABS in New Bedford, MA. To speed up production, rapid prototyping could be done stateside and internationally at maker spaces, such as Maker Labs in Hong Kong. It will be critical to retain strong legal representation and insure IP protection during development and manufacturing. According to the FAO increased data collection could lead to “improved forecasting; early warning systems; safer harbors and landings; and safety at sea” (FAO). This movement towards increased data collection may be enhanced by new technologies such as remote gliders and underwater drones.

In conclusion, as society's capacity to gather data increases, old ways of collecting and processing data may need to adapt. Lloyd Register predicts that the world’s annual data collection will increase by 4,300% by 2020 (Lloyd Register). Combined with the IoT, this may allow for real-time monitoring and the control of systems and processes globally (Lloyd Register). By building on existing and past partnerships, society can refine data collection processes and collect longitudinal and expansive data to reveal and predict ocean and climate changes.

7. Tributary Benefits

Depending on the data collected, a global ocean data collection system could be a value added service to a variety of actors in the private sector. Offshore energy, (tidal, wind, solar, oil, and gas), weather prediction, and marine insurance are three examples of industries that might benefit from better ocean data. Collecting real-time information on tides, wind, ocean floors, and weather, may gave the private sector competitive advantages in forecasting and decision making.

Offshore Energy

The ocean is surging with energy. For example, ocean winds can be measured and harnessed by coastal communities or delivered through electrical grids inland. Tidal power has the potential to generate 64,000 megawatts electrical (MWe) globally (Ocean Energy Council). Bloomberg New Energy Finance predicts that $8 trillion will be invested in renewable energy technologies between now and 2040. These energy sources reduce greenhouse emissions and thus slow down the severe climate changes described above. In addition to renewable energy, offshore oil and gas reserves are another source of energy. For example, in 2011, the Bureau of Ocean Energy Management estimated that there are 88.6 billion barrels of undiscovered technically recoverable oil and 398.4 trillion cubic feet of undiscovered technically recoverable natural gas in the Federal Outer Continental Shelf of the United States. Furthermore, floating solar panel farms are now being installed by companies like Kyocera. New floating solar panel farm sites could be assessed by measuring environmental conditions. In addition to informing our understanding of the unprecedented climate and ocean changes taking place, collecting data about tides, winds, and the ocean floor could unlock and sustain commercial growth.

Weather

Section 2 describes the severe weather consequences resulting from climate change, but what if weather measurements from a global ocean observation system could be sold? Weather reporting and prediction is a $6 billion industry (Wharton). PwC estimates that the weather derivatives market grew to $12 billion in 2011 (Wharton). An ocean observation system with subsurface temperature would provide advantages over existing buoy systems. Vessel equipped with sensors would be another avenue for data collection because they travel off the coast into waters that are too deep for buoys. These activities are already taking place in the SOOP program, which distributes its data to weather and forecast models within 24 hours of its acquisition. Together these approaches could improve the performance of the weather beyond the surface readings of satellites. In addition to sea subsurface temperature, weather experts at the 2016 Connecticut Maritime Association Conference added that wind and pressure measurements would be valuable too. The key to making these sales and partnerships work will be having data collectors who have proprietary ownership, understand the value of their data, and have agency in agreeing to terms and conditions. In addition to private and public weather organizations, the weather data could also be sold to universities involved in meteorology such as SUNY Maritime, UMD, and SMAST. To improve sales, data products could be presented as cost cutting and valuable in terms of the answers and knowledge they provide. The global ocean observation network may be able to function as an early warning system, for both public and private consumers of weather information, thereby saving lives and minimizing damage.

In conclusion, like scientists, private consumers would most likely need the data to be timely and methodologically sound to reap the full benefits. Creating public and private partnerships, during or after the construction of a global ocean data system, may lead to increased economic opportunities, a capitalization of the data, and a bolstering of local, state, and national economies. Cooperation between research organizations and private companies is not unheard of. For example, NOAA is now working with Lockheed Martin Sippican to develop new technologies for climate observations. Maximizing the utility of the global ocean observation system and repurposing data may help justify initial costs and lead society and businesses to become more invested in this plan for the long-term.

Marine Insurance

Shipping delivers ninety percent of world trade (WWF). Fifty percent of annual ship losses are due to rough weather (WWF). A global ocean observation system may offer economic and logistical benefits to the marine insurance industry and other industries affected by the uncertainties of the seas. The University of Southampton, QinetiQ, and the Lloyd's Register co-authored, "Global Marine Technology Trends 2030", which predicts that ships in operation will serve as data terminals leading to pay-as-you-ship insurance premiums and real-time vessel monitoring systems. For cargos and ships themselves, having real time ocean measurements (or measurements of the vessel's conditions), and more accurate forecasts might make the premiums more accurate. Big data analytics may transform ocean data from human driven to machine driven processing and insights. This may offer “instant knowledge and fact-based management” (Lloyd’s Register). The marine insurance industry might be able to benefit from better situation awareness and probability analysis. Ship-owners, merchants, and ship captains, and the fishing industry, might all benefit from a more accurate weather and insurance system, because when ambiguity is reduced costs may be too. Evidence-based coverage for voyages and the transit between ports could become more common, along with monitoring high risk paths and actors. As fleets expand and weather systems become more severe, the planet’s most dangerous oceans may become increasingly perilous. Whether it is the Strait of Malacca or the Suez Canal, if a company can understand dangerous conditions and risks, both natural and human, it may improve operations, deliver savings to its customers, and increase its own profit.

7. Science As Diplomatic Opportunity

Operating a global ocean observation system using the latest technologies in IoT and big data analytics could be seen as a global diplomatic opportunity. Through the development of new programs, international expert institutions, and in day-to-day business, scientific and technological cooperation may lead to increase trust and collaboration (Miller). Science itself is characterized by both competition and cooperation and can be “an effective instrument of peace” (Miller). Given the unprecedented changes in climate and ocean health there are several locations, which could be especially fruitful for peaceful collaboration. For example, the Arctic Ocean is not currently militarized and it is one of the most rapidly changing bodies of water in the world. Looking to the work of Professor Paul Arthur Berkman, the Antarctic could serve as a model for the Arctic because it is a place where science created “bridges across nations” and fostered “stability in the region” (Berkman). In addition to determining policy agendas, Berkman asserts that science is a source of insight, invention, and commercial enterprise, which evolves our foundational knowledge (Berkman). Science diplomacy through a global ocean observation network may lead to improved sustainable development and environmental protection while cultivating common interests in the Arctic and around the world. A global ocean observation system might increase flows of people, information, and contacts across state borders. Expanding scientific ocean collaborations may reduce conflicts and increase peace globally.

8. Conclusion

Human consciousness and the capacity for knowledge distinguish people from the rest of the animal kingdom. As society learns more about the world, the environmental crisis and the consequences of human activity are becoming clearer. By creating institutions and smart systems, society has an opportunity to study and manage complex environmental decisions to become successful business people, leaders, and stewards of the earth. Science and technology might help us adapt to events like intensifying weather systems and migrating fish stocks. As described above, ocean temperature, salinity, and acidity are changing, often at exponential rates. Climate and ocean health changes have reduced fish abundance, phytoplankton health, and the ability of the ocean to function as a carbon sink. Even the best scientists cannot predict the future of these changes or their severity, but to move from a state of ignorance to one of knowledge, society can build upon the successes of past and present ocean observation systems. With enough resources and national will, subsurface temperature, salinity, and biological measures could be measured. One day there may be an international system, which measures all three levels of data priorities (Image 1). Building multi-decade observation and analytic systems starts today. By following in the footsteps of the scientific trailblazers mentioned in Section 5, beneficial data might be gathered in more cost effective and efficient ways. Crowdsourcing, third party partnership, satellite systems, and low cost sensors connected to the IoT may help us understand the oceans and one day predict fish location. The tributary economic benefits of these new observations systems are promising to the weather, energy, and insurance industries. Having a wide and deep international public data set may bolster existing economies and facilitate entrepreneurship. Scientific collaboration may also function as a diplomatic activity, increasing international harmony and peace one person, or project, at a time. By studying our actions and overcoming shortsightedness, society may be better equipped to face the trial of unprecedented climate change, deteriorating ocean health, and the consequences of human activity.

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