1.2.4 What is the Most Important Natural Resource Issue that Cuba, Mexico, and the United States, Which Border the Gulf of Mexico, Should Address Together?

A. Knap

Texas A&M University

1.2.4.1 Abstract

Repetitive and long-term time series measurements of ocean parameters provide an opportunity to monitor ocean health. Currently, there are no biogeochemical time series measurements in the deep GOM. This presentation discusses biogeochemical monitoring needs and suggests that Cuba, Mexico, and the United States work in the western and eastern gaps of international jurisdictions in the GOM to establish and maintain a long-term measurement system that uses new technologies.

1.2.4.2 Introduction

My background is in sustained observations in global ocean or ocean time-series measurements. I was privileged to be the founder of one of the major ocean observing systems of the open ocean, the Bermuda Atlantic Time-Series Station (BATS). For 30 years I was also the principal investigator of the Panulirus Hydrographic Station or "Station S" started by Henry Stommel in 1954. These stations still exist today and continue to provide data. I believe the reason that they still exist is that the quality of the data they provide is excellent, and the data are rapidly disseminated, shared, and used by a large research community, not just the principal investigators of the program. The Hawaiian Ocean Time-Series (HOT), was started by David Karl in October 1998 and is similarly successful (Karl et al. 2001). The HOT data are widely used, and there has been roughly 30 years of continuous and generous funding from the US National Science Foundation, because many Division of Ocean Sciences program managers saw the value of continuing the program. The data that have been collected from these programs is exceptional, and what we need in the GOM is a continuous measurement program of the same quality. Throughout this paper I continue to emphasize the importance of sustained observations, because every day you do not start an ocean time series is always one day too late.

I believe that you can manage only what you can measure, and this article is going to focus on the following questions:

- What do we know about the GOM?
- What do we need to know about the GOM?
- What are the impediments to understanding? What is getting in the way?
- How can Cuba, Mexico, and the United States work together to improve our knowledge of the GOM and fill the gaps?

We know a lot about the GOM, and the HRI "State of the Gulf" is an excellent compendium of current knowledge from all three countries that share the Gulf (Yoskowitz et al. 2013). Recently, another excellent study was carried out by The Ocean Conservancy: "Charting the Gulf: Analyzing the Gaps in Long-term Monitoring of the Gulf of Mexico" (Love et al. 2015). It turns out that we know a great deal about GOM ecosystems. In the United States there are literally hundreds of state and federal monitoring programs for fisheries, birds, invertebrates, marine mammals, sea turtles, nearshore sediments and associated resources, oysters, submerged vegetation, shallow and mid-water corals, shorelines, a few deep marine habitats, and the water column, but they may be patchy, intermittent, or duplicative (NASEM 2014, 2015). Continuous deepwater (>200 m) monitoring similar to that provided by BATS and HOT is lacking. Another problem is that monitoring programs for the same resources may not use the same methods and protocols, making Gulf-wide comparisons of important assets difficult or impossible (Love et al. 2015). This is true in the United States and may also be true of programs in Cuba and Mexico. We need to work together with our partners in these countries to make sure we have a holistic assessment of the GOM. Figure 2 provides a schematic of the problem—The Gulf of What? We hope that after the present meeting of GOMWIR we will be able to populate these maps with measurement systems in Mexico and Cuba. It should be noted that today, five years after the DWH oil spill, very few of the assets deployed to determine damage from the spill are still deployed. Some have said that for offshore monitoring we may not be much further ahead of monitoring the deep water of the GOM than we were prior to the spill. With billions of dollars spent on the spill and the subsequent legistlation, there are no commitments to establish a continuous, long-term, deep ocean observation systems. As I will highlight later, new and improving technologies are making these kinds of observations easier and cheaper. A commitment to long-term measurements supported by GCOOS would be a good way to start (GCOOS 2014).

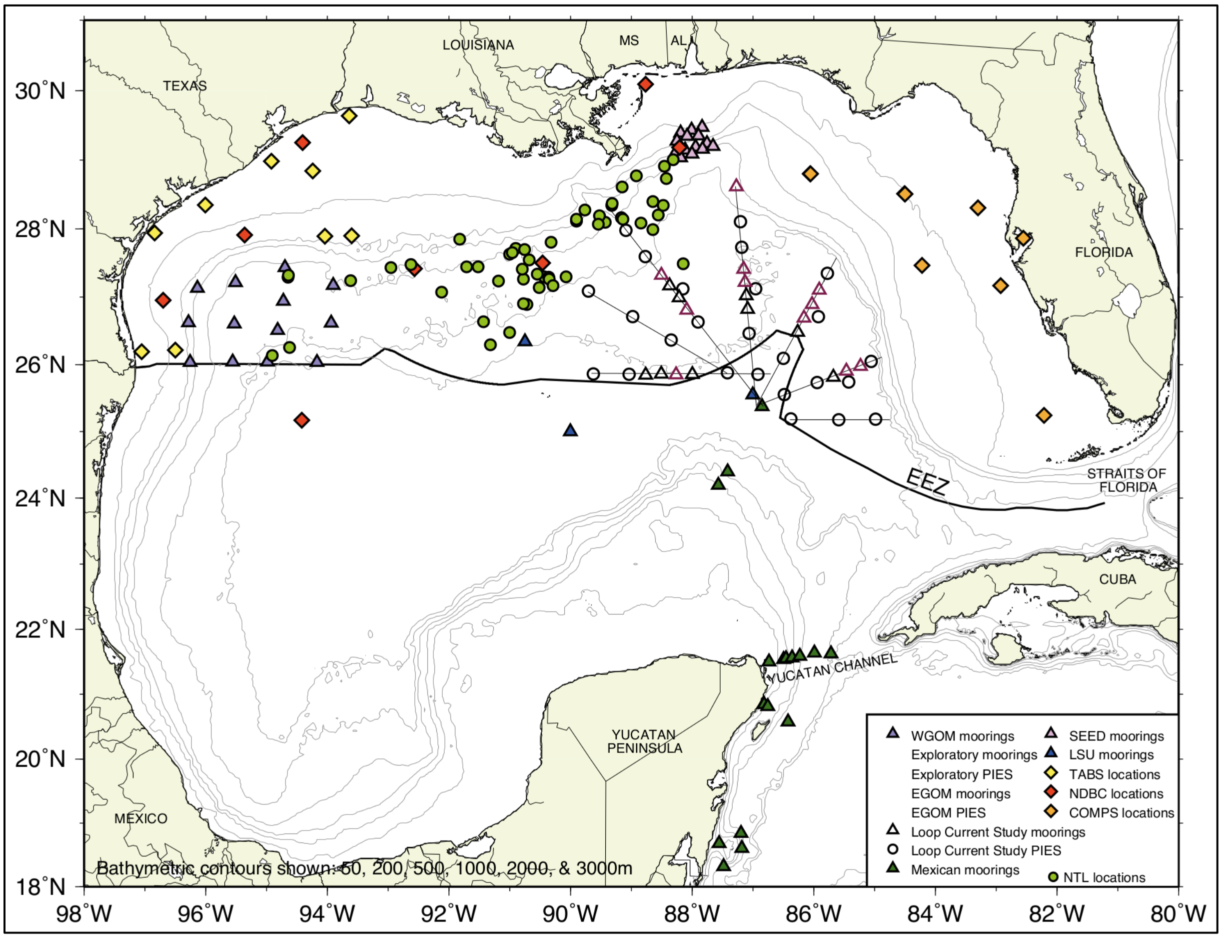

Figure 2. Map of deployed US assets in the GOM after the DWH oil spill.
Note what we know about systems in the holistic GoM. Most of these assets are no longer in place. Map courtesy of Steven DiMarco.

Perhaps one of the main drivers of change in the GOM is a natural phenomenon, the Loop Current. This is a variable current driven by the 20–30 million cubic meters of seawater, which pass through the 200 km-wide Yucatan Channel each second. This oceanographic current provides the major portion of the energy for the GOM. This current sometimes forms a well-described loop with current speeds of over 4 knots and variable direction, but at times the loop pinches off and develops a warm eddy which moves generally to the northwest and sometimes causes chaos to the offshore oil and gas business. Generally, these eddies meander for ~6–10 months and slowly dissipate off the western edge of the Texas–Mexico shelf. There are proprietary models which are used to predict these eddy-shedding events, but they are not 100% accurate. These predictions are provided to oil and gas companies and other operators in the GOM by the Naval Research Laboratory and commercial firms such as Horizon Marine that provide a subscription service. Many other studies are published on the Gulf Loop Current eddy, based on satellite data, but are not predictive (Walker et al. 2003). Recently, the NASEM-GRP established an expert panel to review what is known about the Loop Current and its eddy shedding (NASEM 2016).

1.2.4.3 Long-Term Measurement Programs in the Ocean

Over the past 30 years, ocean measurements have been structured through the Global Ocean Observing System (GOOS) managed by the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Various working groups have also been managed by IOC, for example coastal and ocean panels. IOC does not fund the measurements but expects that the participating countries will provide the funding and that institutions within those countries will carry out the work. In the United States, the Integrated Ocean Observing System (IOOS) funded by NOAA, which is divided into 13 regional alliances, including GCOOS. One of the major global coordinating groups is the Partnership for Observing the Global Ocean (POGO 2017). POGO was initiated in 1999 to coordinate groups taking ocean measurements; currently there are 38 partners including the Bigelow Laboratory for Ocean Sciences, Harbor Branch, Florida Atlantic University, Monterey Bay Aquarium Research Institute, Scripps Institution of Oceanography, TAMU, and the Woods Hole Oceanographic Institution in the United States and the Oceanology Division of CICESE in Mexico. TAMU's GERG and CICESE are the only two members that work in the GOM. POGO has promoted observations underpinning ocean and climate science, interpreted scientific results for decision-makers, provided training and technology transfer to emerging economies, and built awareness of the many challenges still ahead.

POGO, IOC, and the World Meteorogical Organization (WMO) partially fund a sustained measurement program for the global ocean called OceanSITES (Figure 3). OceanSITES is a worldwide system of long-term, open-ocean reference stations that measures dozens of variables and monitors the full depth of the ocean from air-sea interactions to the seafloor. Its network of stations or observatories measure many aspects of the ocean's surface and water column and uses, where possible, automated systems with advanced sensors and telecommunications systems with measurements often available in real time, while building a long record. Observations cover meteorology, physical oceanography, transport of water, biogeochemistry, and parameters relevant to the carbon cycle, ocean acidification, ecosystem, and geophysics. Membership in OceanSITES is free provided data are shared with WMO and made freely available. One of the glaring gaps that can be seen in Figure 3 is that there are no long-term measurement programs in the GOM other than NOAA's National Data Buoy Center (NDBC) weather buoys which are not part of OceanSITES. This needs to be rectified.

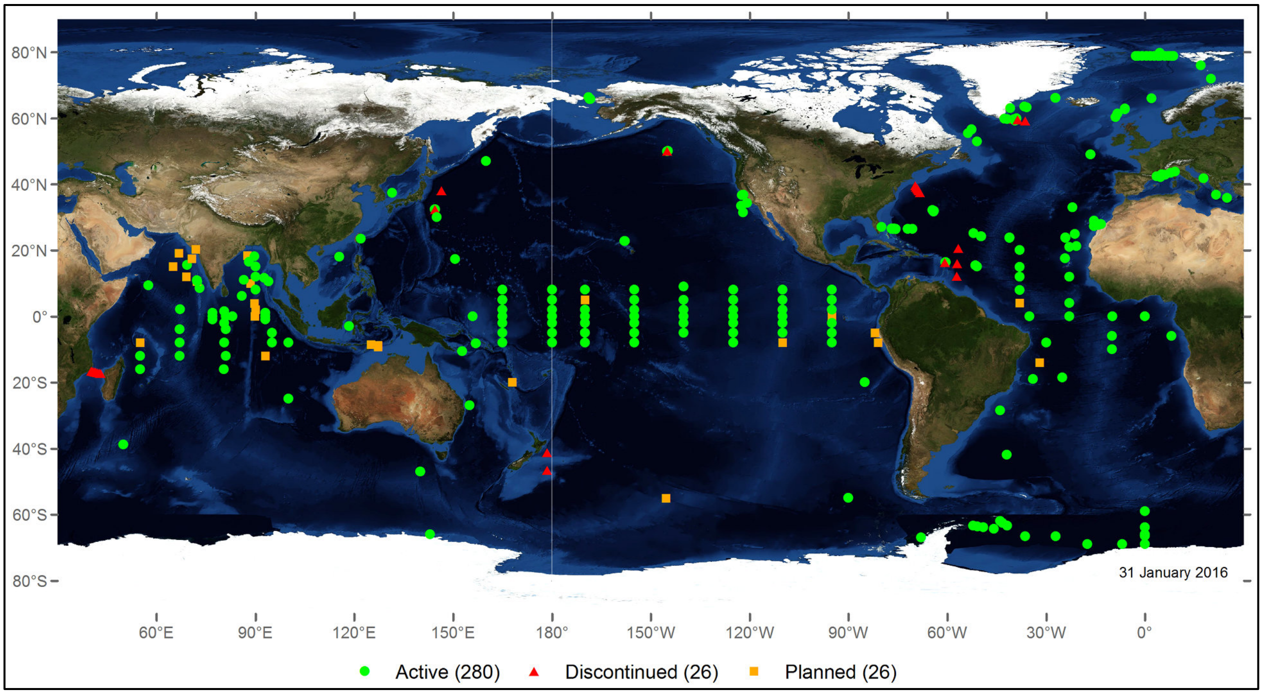

Figure 3. OceanSITES stations around the world as of January 2016.
Green dots represent active stations, red triangles are discontinued stations, and orange squares represent planned stations. Source: OceanSITES Network.

1.2.4.4 The Benefit of Long-Term, Sustained Ocean Observations

The ocean is inherently variable and the parameters that are measured to determine ocean health are also variable and change with seasons, temperature, and location. The preferred strategy to overcome this variability is to make measurements at the same place over time. For example, the 60-year temperature and salinity record of the Panulirus Station near Bermuda (Figure 4) shows an increasing trend over the years. Closer examination of these data shows a seven-year increase in temperature between 1970 and 1977 followed by a sharp decrease in temperature between 1977 and 1984. Short-term measurements in the ocean might show a completely different picture that might raise an alarm about ocean warming or cooling without the benefit of a 60-year perspective. Figure 5 shows the longest continuous record of dissolved CO_2 in the world and while it shows large interannual variability, it also shows a clearly increasing trend in the concentration of CO_2 in both the atmosphere and the water. The effects are clear with pH at the station decreasing over time indicating ocean acidification (Figure 5). This is alarming because even in the open ocean, acidification is a major concern. In addition, phytoplankton communities in the Sargasso Sea around Bermuda have changed over this same 25-year period, shifting from diatoms that make silica tests to cocolithophores to smaller phytoplankton, such as *Synechococcus*, a cyanobacterium (Lomas et al. 2012). We have no idea whether this is a natural shift or caused by changing water chemistry. This illustrates the need for a baseline, which is lacking for most parameters in the GOM!

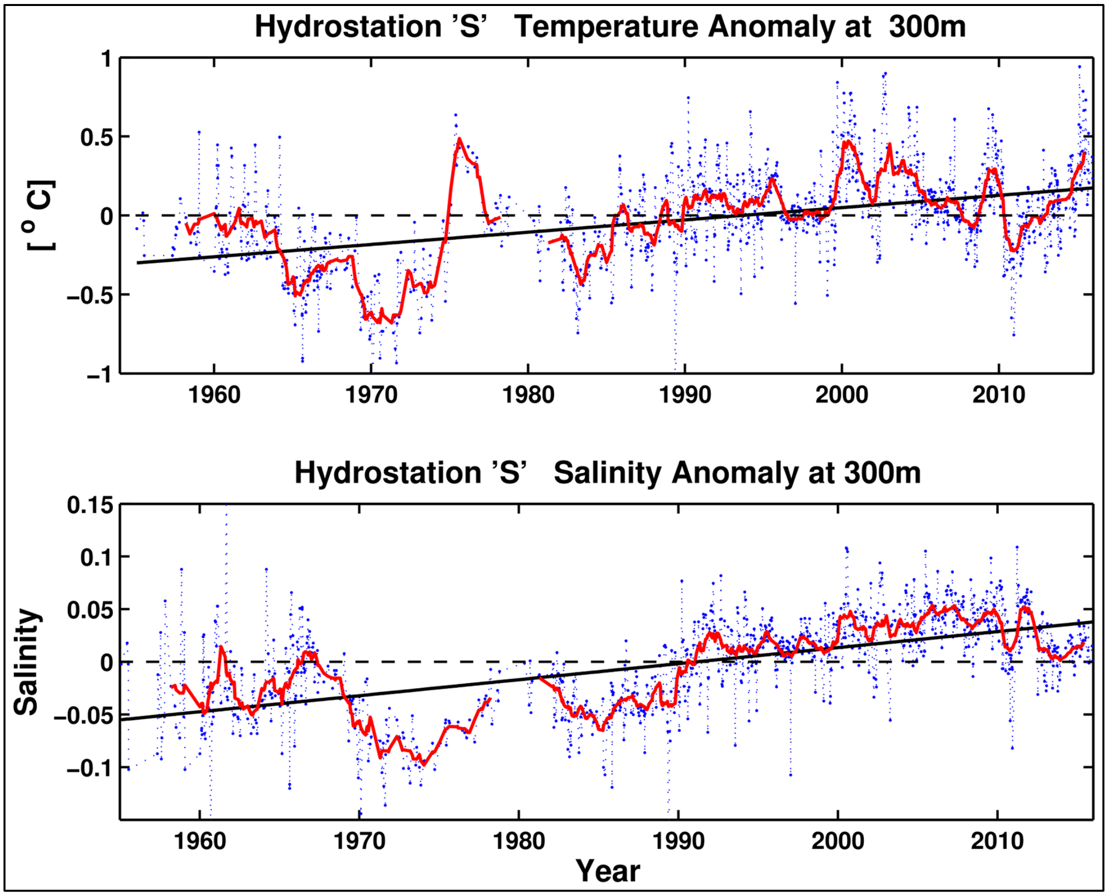

Figure 4. Panulirus Hydrostation S temperature and salinity observations from 1954 to 2010. Note major trends. Observatory Data courtesy of Bates, Johnson and Knap (In prep).

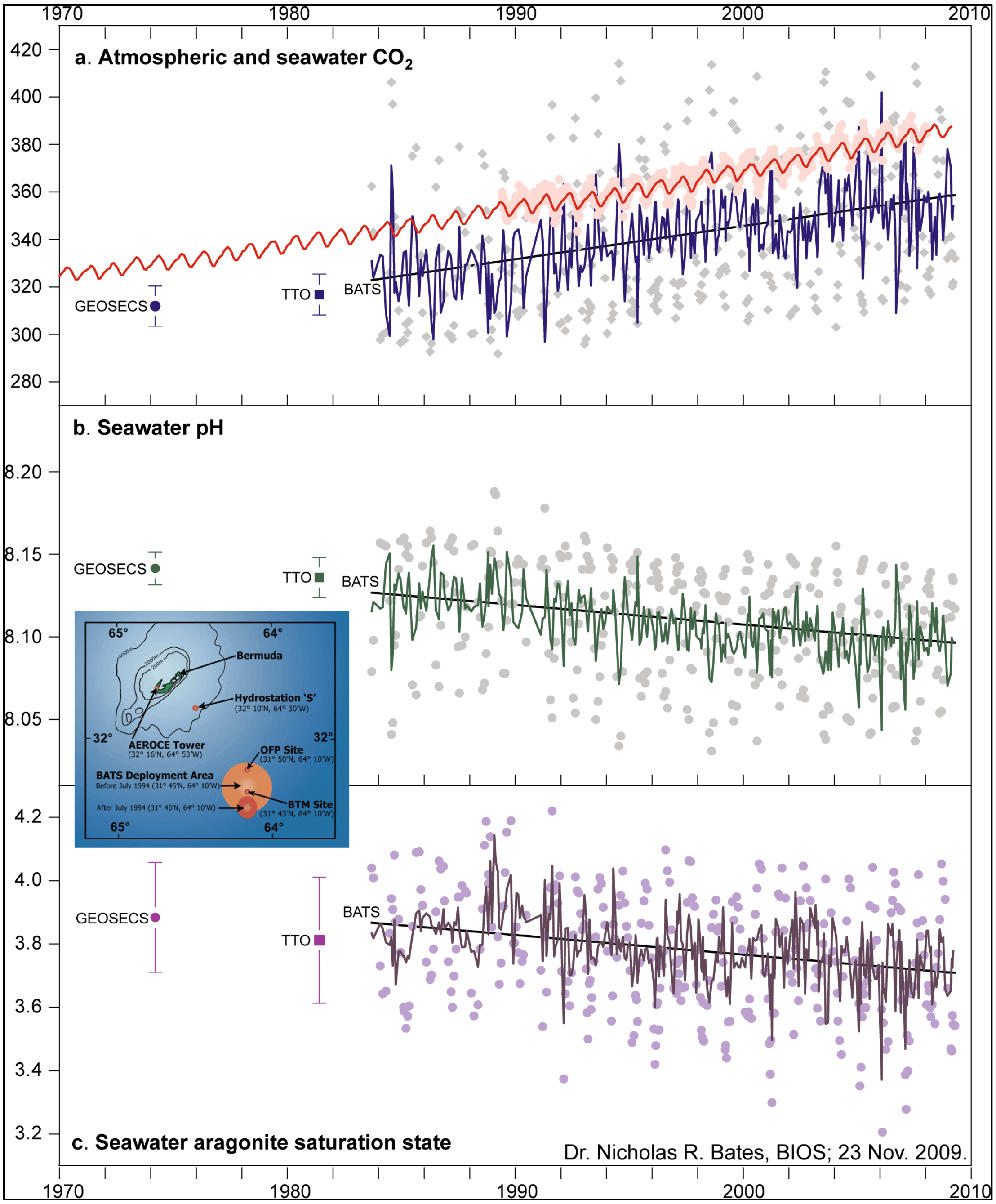

Figure 5. CO_2 and pH at BATS from 1988 to 2009.
The line in the upper panel is the Mauna Loa atmospheric CO_2. Note the variability and trend.

1.2.4.5 Gulf of Mexico

The reasons ocean conditions vary in the GOM are no different than any other area in that physical and chemical conditions are altered by processes such as riverine outflows and changes in water densities and temperatures. In the GOM, currents are dominated by the Loop Current and its eddies. Outflows from the Mississippi and Atchafalya Rivers add significant amounts of fresh water, especially in the nearshore areas, that alter temperatures, densities, and nutrient concentrations. Data such as these are crucial to the development and exploitation of the large oil and gas assets which are dependent on accurate prediction of conditions in the Gulf. When data on the deep GOM are available, they can be quite surprising. For examplec Figure 6 shows variability of currents off Green Knoll during 1999–2000 (Knowlin et al. 2001). These data, collected from current meters deployed every 100 m from near the surface to almost 2,000 m,shows incredible current variability even in deep water. At the surface, an eddy named "Juggernaut" was characterized by high current velocities in the top 400 m from September–November, 1999. During the same time currents were relatively quiescent between 700 and 1,000 m, but below 1,200 m, currents were strong and variable. Later in the year, currents are also not correlated with depth. These observations make it clear that it is difficult to predict current velocities and directions with models especially since useful measurements are few and far between.

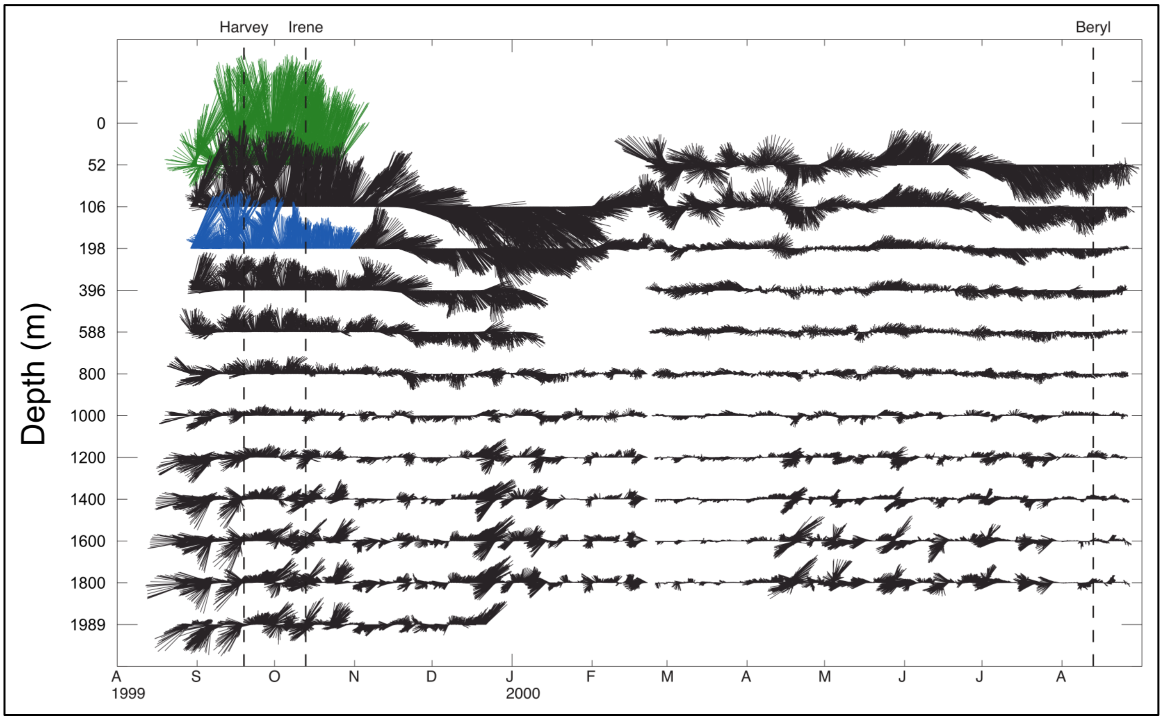

Figure 6. Current speeds at a mooring on a 1-year deployment in GOM waters over 2,000 m deep off Green Knoll (Knowlin et al. 2001).

Sentinel stations in the deepwater GOM need to be established and they must be funded for substantial amounts of time for there to be sufficient data to provide explanations and/or predictions for changing conditions in the area. Just as importantly, these stations should be shared by the three countries that surround the Gulf. The political boundaries of the GOM provide an opportunity for collaboration, because there are two areas of international waters in the area. In 1982, the UN Convention on the Law of the Sea defined a state's (country's) Exclusive Economic Zone (EEZ) as between the seaward limits of a state's territorial sea and 200 nautical miles offshore. In the GOM are areas known as "doughnut holes" which are areas that are disputed by the three countries, but are clearly outside of any national jurisdiction (Figure 7). An opportunity exists to place observing instrumentation in the eastern gap for access by Cuba, Mexico, and the United States and in the western gap by the United States and Mexico. Each country would not be required to transit through any other country's EEZ to do research in these areas.

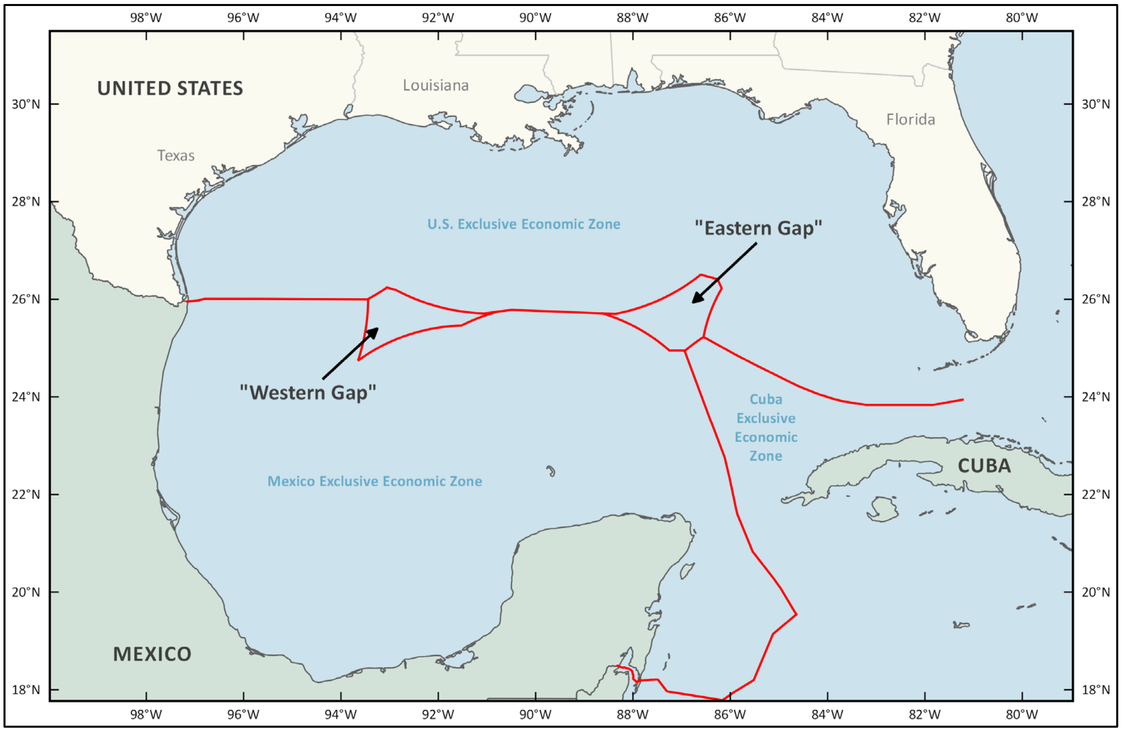

Figure 7. The geopolitical boundaries of the GOM showing the eastern and western gap in the countries' EEZs where research can be conducted.
Source: Basemap shapefiles courtesy of Natural Earth. EEZ boundaries from the Maritime Boundaries Geodatabase managed by the Flanders Marine Institute. Figure prepared by M. Besonen.

One of the main issues with sentinel stations is the cost, because they usually require a great deal of ship time and labor. Fortunately, costs are coming down with development of new technology especially remote vehicles, including remote ships, gliders, unmanned aerial vehicles (UAVs), autonomous underwater vehicles (AUVs), etc. Figure 8 shows some examples of these kinds of vehicles that are currently being used in the GOM and which are owned and operated by GERG. These vehicles require dedicated pilots and engineers, expensive batteries, sophisticated ballasting and engineering, and in most cases insurance, especially for surface vehicles which can be involved in collisions. They are not cheap to operate (about $1,000 per day), but they are much less expensive than chartering a ship. And, the resolution of data that is collected provides a granularity of information that could never be gotten with a ship-deployed rosette and CTD or a fixed mooring with a profiler. Thus, these vehicles represent a very important option to consider in planning future oceanic observations. In the case of the Ocean Observatories Initiative (OOI 2017), gliders are playing a very important role in the collection of very high resolution data including temperature, salinity (Figure 9), chlorophyll, oxygen, colored dissolved organic matter, and CO_2, among others.

Figure 8. Examples of remote Instrumentation at TAMU's GERG.
Clockwise from top: A Teledyne buoyancy Glider (Stommel) rated for 1,000 m depth; "Bubbles" - a research sled designed and built at GERG for investigating bubble plumes in the GOM – towed 1 m off the bottom; Autonaut – a wave-powered surface vehicle owned by the Texas General Land Office and operated by GERG has an Acoustic Doppler Current Profiler (ADCP) to remotely measure currents in the water column; a Liquid Robotics wave-powered surface vehicle fitted for ocean acidification measurements at the Flower Garden Banks 180 km south of Galveston, Texas. Photos by A. Knap and S. DiMarco.

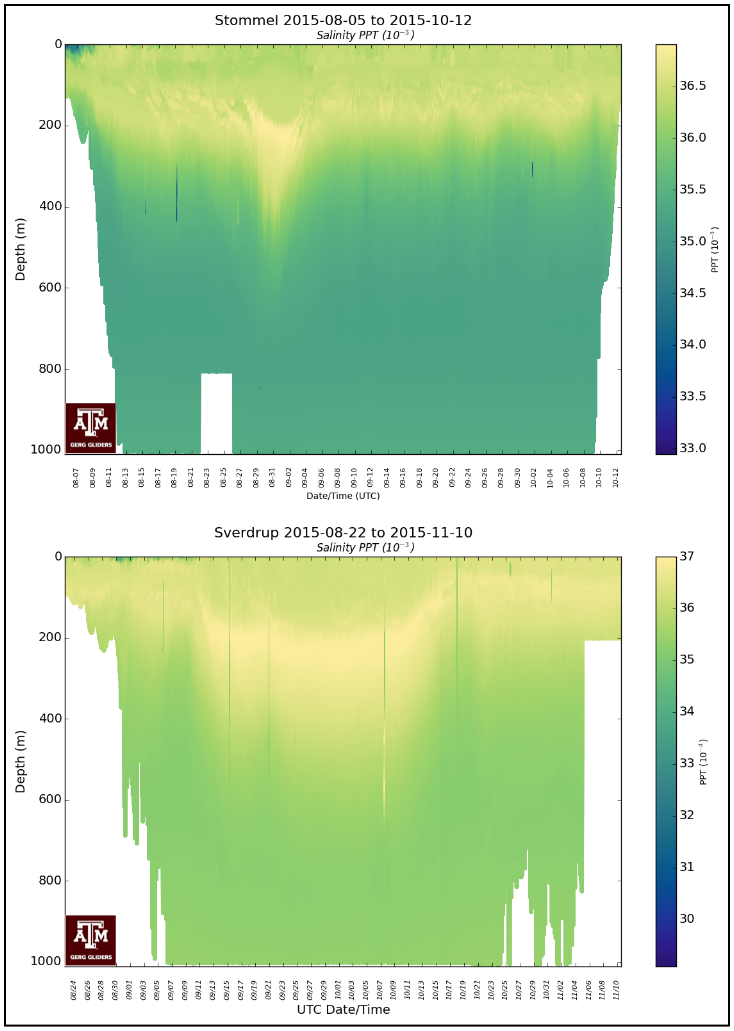

Figure 9. Example salinity data from GERG's Stommel and Sverdrup gliders.

There are also other opportunities for data collection. For example, ships transiting through the GOM ("vessels of opportunity") can be used to provide data by equipping them with various sensors colocated with the cooling intakes for the engines. These so-called "ferrybox" systems have been used in Europe and elsewhere to collect oceanographic data in real time. Improvements in the ability to determine the identity of biological species present by the sounds they make continues. Right now, marine mammals are being tracked effectively using acoustics. Collecting acoustic data at various points in the ocean may provide a better understanding of marine biodiversity as this technology continues to improve. Another tool that may increase knowledge of marine biodiversity is e-DNA (environmental DNA) to determine the species of fish that have been in a specific area. As fish swim, they shed DNA and if there is a good library of DNA fish samples for comparison, this type of data collection could be useful (Thomsen and Willerslev 2015).

1.2.4.6 Conclusion

Sustained ocean observations in the GOM are important to the three countries sharing this resource. Without them, knowledge of issues impacting the ocean will suffer, such as increasing upper ocean heat and its effect on the intensities of hurricanes, or how greater evaporation of seawater and the resulting increase in atmospheric water may increase coastal flooding. Other environmental issues that can be addressed through ocean observations, especially baseline observations, include hypoxia, harmful algal blooms, ocean acidification, and oil spills. Cuba, Mexico, and the United States should come together and establish an integrated ocean observing baseline. The shared geographical provinces known as the eastern and western gaps beyond the EEZs of the three nations are one place to start.

1.2.4.7 References

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