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Honorable Representatives on the Subcommittee on Insular Affairs, Oceans, and Wildlife, Committee on Natural Resources, U.S. House of Representatives; staff and associates, it is my privilege to be here with you today to address the question posed on "Ocean Science and Data Limits in a Time of Crisis: Do NOAA and the Fish and Wildlife Service (FWS) have the Resources to Respond? My succinct and candid reply is that they do not, and I will aim my testimony toward explaining why and offering a solution. I am not intimating that these agencies are not excellent in many respects. Instead, I believe that the resources are presently inadequate. Moreover, this is not a situation that can be remedied overnight. Scientific inquiry takes time, and while we must deal with an unprecedented crisis immediately, we must also lay the groundwork for the future.

In developing my case for improving environmental stewardship I will also address the sub-questions that were posed:

1) Are there existing gaps in observation data needed to predict the extent and trajectory of the oil spill, including information about plume formation and ocean currents?
2) What is the adequacy of pre- and post impact spill data needed for conducting natural resource damage assessments?
3) What additional data are required to understand the impact of the oil spill on the marine environment?

Not all of these questions are within my expertise as a physical oceanographer, one who studies the physics of the ocean circulation, as contrasted with the living marine resources. Nevertheless, I will endeavor to provide my perspective on how the natural system that we call the ocean must be approached.

When describing the workings of the ocean in the context of the Earth system, one word immediately comes to mind: connectivity. Ocean connectivity controls the heat fluxes to the atmosphere and from the tropics to high latitudes, thereby determining the Earth's climate. Ocean connectivity unites nutrients (at depth) with light (at the surface), fueling primary productivity and thence all higher trophic level interactions, thereby determining the Earth's ecology. In fact, it can be stated that without a firm grasp of ocean connectivity concepts like Ecologically-Based-Management and Marine-Spatial-Planning are less than meaningful. The ocean circulation is fundamental to the ocean connectivity.

For the Gulf of Mexico and the southeastern United States, the primary conveyance of mass, momentum, heat and other water properties is the Loop Current-Florida Current-Gulf Stream system. The Loop Current flows into the Gulf of Mexico through the Yucatan Strait, loops around inside the Gulf of Mexico and exits through the Florida Straits as the Florida Current. After rounding the bend near Miami and continuing up the United States east coast it is called the Gulf Stream. It is really one current system, which is always present and with remarkably little variation in total transport. All that really varies is the northward extent into the Gulf of Mexico, i.e., where it makes its loop. Generally, the Loop Current undergoes a cycle, whereby it extends ever farther into the Gulf of Mexico before a piece of it breaks free as a clockwise circulating eddy, that drifts westward and dissipates, while the main body of the Loop Current retreats back to the south. This cycle of eddy shedding occurs roughly every eight to 16 months, but with details that are hardly predictable. Before completely detaching and drifting westward, such eddies can reattach to the Loop Current, after which it is possible for the Loop Current to extend all the way to the Deep Horizon well head. The Loop Current is presently in such a state of eddy shedding. This is why we have not yet seen large quantities of oil transported to the Florida Straits and up the east coast, but this may still happen depending on the evolution of the Loop Current and its shed eddy over the next several weeks to months.

The Loop Current-Florida Current-Gulf Stream system is only one aspect of the circulation that we must be concerned with. It is a deep water current system in that it is constrained by mass and momentum conservation to stay in deep water. Shallow water regions, which I refer to as the coastal oceans of the United States, are where society literally meets the sea. It is within the coastal oceans where maritime commerce takes place, where commercial and recreational fisheries are situated, where environmental concerns, such as harmful algal blooms and over-fishing, abound, and where fossil fuels and alternative energy sources are potentially located. We define the coastal ocean as the region between the shoreline and the shelf break, and we refer to this region as the continental shelf, the relatively shallow water region adjacent to the continent extending seaward to the point where the water depth drops precipitously to the abyss. The region of precipitous drop-off is called the continental slope, and the Deep Horizon well head is situated on the continental slope in the northern Gulf of Mexico.

Deep ocean currents cannot extend onto the continental shelf unless the continental shelf is very narrow. Such is the case at the tip of the Mississippi River Delta, the head of DeSoto Canyon (offshore of Pensacola, Florida) and offshore of Miami, Florida, where the Gulf Stream can at times be almost a stone's throw from the beach. In contrast with these narrow shelf regions the West Florida Continental Shelf (WFS) tends to be very broad (roughly 100 nautical miles) and gently sloping, effectively decoupling the Loop Current from the nearshore. Thus the continental shelf circulation differs from the deep-ocean circulation, and this results in the mechanisms of connectivity also being different for the continental shelf.

The coastal ocean also includes the estuaries, the transition regions between the rivers and the ocean, where density contrasts between fresh and salt water play a major role in the circulation and hence connectivity between the rivers, the estuaries, and the continental shelf. The estuaries are also arguably the most productive and fragile of the ocean environments.

The point of these preliminary discussions is that we are dealing with very complex systems, each related though common physics, but each unique in how the governing physics organize to provide the connectivity within and between each region. Thus describing, understanding and predicting the behaviors of these natural systems are not simple problems with unique, simple answers, and that explains why NOAA and the Fish and Wildlife Service (FWS) do not have all of the resources to respond to the present crisis and why the sub-questions have less than satisfactory answers, and that is just within my own field of expertise, let alone the much broader range of subject matter of concern to this subcommittee.

So what are we to do, immediately and into the future? Immediately we must marshal all of the talent and resource that exists to deal with the environmental crisis at hand. This requires full partnerships between the agencies, the academics, and the private sector, recognizing, of course, that chain of command is of paramount importance. The agencies have organized, and I cannot speak to that. I can at least speak to some of the actions of the academic community, which are being of help in this crisis, and I can also speak to the future of how we can improve our ability to describe, understand and predict the ocean system and thereby become better environmental stewards.

Three particular actions at my own institution, the University of South Florida (USF), warrant mention. These include: 1) oil spill tracking tools that were implemented almost immediately after the Deep Horizon drilling platform sank on April 22, 2010, 2) shipboard surveys of both surface and subsurface hydrocarbons, and 3) deployments of gliders, drifters and profilers to help with sampling. For oil spill tracking we utilized existing numerical circulation models, our own at USF initially, plus several others added later on to produce an ensemble prediction with five different models. These are all re-initialized for surface oil location through the analysis of satellite images and then run forward in time to produce forecasts 3.5 days into the future. The forecast interval is determined by the availability of forecast winds (from NOAA/NCEP). Forecasting more than 3.5 days into the future is of little utility because of the errors inherent to weather prediction. Along with surface trajectories we also implemented the tracking of subsurface trajectories using the same USF numerical circulation model. Not knowing at what depth subsurface hydrocarbons might be located a priori, we chose to consider nine different depths ranging between 1400m and 50m. Virtual particles were released at these depths beginning on April 20, 2010 and then continually ever since, and the movements of these virtual particles were, and continue to be, tracked threedimensionally using the model's velocity field. All of these model predictions and satellite analyses are available on the internet at http://ocgweb.marine.usf.edu and http://optics.marine.usf.edu/events/GOM_rigfire and have been since late April, they are provided to federal and state officials and they are in use as part of the overall forecast system. The subsurface trajectory forecasts were also instrumental in guiding the R/V Weatherbird II to sites where subsurface hydrocarbons were identified. We are also using these models and other observations to help guide the sampling by a combination of gliders, profilers and satellite tracked surface drifters. In fact, presently, the USF surface drifters along with some from the United States Coast Guard (that we helped to deploy) are the ones documenting the evolution of the Loop Current and its shed eddy (these drifter tracks are also posted on the above referenced web site).

Obviously, USF is not the only academic institution to respond. Notable for Florida are activities by the University of Miami (UM) and the Florida State University (FSU). Additionally, the State of Florida University System's Chancellor Frank Brogan facilitated an Academic Oil Spill Task Force situated at FSU to help coordinate and serve materials by all of the academics in the State of Florida from a central location (http://oilspill.fsu.edu). This Academic Oil Spill Task Force, introduced by Chancellor Brogan, briefed the Florida Congressional delegation in Washington DC on May 26, 2010, and its activities continue to be of service in this time of crisis. Other Gulf States have similarly responded, and we are now seeing a convergence of academic resources from states around the nation. My point is that the academic community, in general, has much to offer in bolstering the resources available to NOAA and the Fish and Wildlife Service.

Nevertheless, data gaps abound. Let's first consider data needed to predict the extent and trajectory of the oil spill, including information about plume formation and ocean currents. Predicting into the future requires that we have the best re-initialization data for the present. At USF (and for academics elsewhere) we are limited to what we can glean from satellite image analyses, but these are generally incomplete due to cloudiness and other limitations to interpretation. Satellite data could be supplemented by other means of ground truth; however, such information is not readily disseminated. *One immediate recommendation is that an accessible, easy to use set of surface oil location data be made available on a daily basis for use in surface trajectory modeling.* This will result in more accurate model predictions. The subsurface problem is even more acute because now, 52 days in to spill, we have precious little information on subsurface hydrocarbon location, concentrations, fractionation and decay. There has simply been a dearth of sampling and an even more limited dissemination of results. Being that the scientific method is predicated on observations, these are critical. Similarly, even observations on the ocean currents are sparse. At a time when the evolution of the Loop Current and its shed eddy are determinant to whether or not oil will be entrained and transported to the Florida Straits and then up the east coast, there has been a seemingly lack of concern on the part of some who have even dismissed this as a factor until recently. As stated previously the USF surface drifters were among the first to be deployed in such a way as to outline the Loop Current path at this time of crisis. *Additional satellite tracked drifters, systematically deployed, are needed*. Similarly several organizations regularly post analyses of satellite altimetry used to estimate surface currents via the geostrophic approximation. *There should be an effort to better organize and disseminate these satellite altimetry analyses and also to improve upon some that up until now may even have been misleading.* Satellite altimetry is critical to constrain ocean circulation models via data assimilation (for instance, a reason why the Navy Global HYCOM has been so useful throughout this crisis is that it is well-contrained by satellite altimetry). Unlike the surface, there are very few observations being made subsurface for the Loop Current. With the HYCOM Consortium leading the data assimilation effort, *data assimilative models of the Loop Current would benefit from additional, systematically deployed AXBTs (Aircraft deployed expendable bathythermographs).*

While the previous paragraph dealt with surface spill location data in general and the deep-ocean currents, recall from my introductory remarks on connectivity that we must also be concerned with the continental shelf and the estuaries. Oil is now stretching along the northern Gulf of Mexico shoreline eastward to the northwest Florida beaches as well as westward along the Louisiana coastline. It has already damaged Louisiana wetlands and estuaries, and it is about to do so in Florida. There are very few measurement locations for ocean currents in the coastal ocean, especially for Florida, and there is also a dearth of well-tested and implemented models capable of predicting the interactions that occur between the coastal ocean and the estuaries. These data and model gaps will become increasingly acute as oil continues to impact an ever larger coastal ocean domain. It is not that such observing and modeling tools do not exist. Instead, there has been (over decades in some instances) a lack of commitment on the part of both state and federal agencies to implement and sustain their application and improvement. This may, in part, be a consequence of too many agencies having separate purview on too many related aspects of the coastal ocean and estuaries without adequate coordination between them. *We need to facilitate the implementation of appropriate coastal ocean and estuarine models to deal with the ever expanding domain of the spilled oil. We must then commit to sustaining and improving these into the future.*

Along with the deep-ocean, coastal ocean and estuary circulation inadequacies there are inadequacies for assessing spill impacts on natural resources. Whereas mappings may exist for many of the coastal ocean and estuary natural resources, it may be difficult to assess spill impacts without adequate knowledge on what the natural variability of these resources may be. Granted, catastrophic destruction or collapse will be assessable, but other longer-term or less obvious degradation may not be. Frankly, we do not really understand the natural workings of our coastal ocean and estuarine systems well enough because these have not been studied in a truly systems-wide, multidisciplinary manner. As an example, fisheries are generally studied as fisheries; harmful algal blooms are generally studied as harmful algal blooms; yet, the two are linked, along with intermediate trophic levels, and these linkages can result in trophic cascades affecting all forms of living marine resources.

As regards additional data that are required to understand the impact of the oil spill on the marine environment, this is almost an insurmountable task. I must assume that the state agencies have sufficient data bases to describe what existed pre-spill (although I might question whether or not the natural variability is adequately established). The question then becomes, what will be the impacts and how will these evolve. The first thing that we must recognize is that this is not simply a matter of going to the usual stations and making the usual measurements, whatever these may be. I must again recall my comments about connectivity. From whence will a threat arrive? Will it be from a large massive invasion of surface oil that will cause obvious damage, or will it be more subtle through the delivery of subsurface contaminants with less immediately obvious damage? For instance, the region of the shelf break is where major reef fish communities exist, such as the gag grouper, known to spawn there. Will these communities and their progeny be impacted by subsurface hydrocarbons upwelled across the shelf break? If fish larvae make their way to the near shore via the bottom Ekman layer, as studies (in preparation) suggest, then will they be damaged en route if subsurface hydrocarbons make it onto the continental shelf? *We are now posed with a fully three-dimensional, time dependent sampling problem that must take into account the various connectivities that exist between the deep-ocean, the coastal ocean and the estuaries. This is not business as usual. We must systematically sample our coastal ocean and begin describing the space-time evolution of critical water properties and sentinel species to assess whether or not post-spill impacts will be occurring and where.*

What might be the pathway forward? The concept of an Integrated Ocean Observing System (IOOS) was advanced through the actions of the now disbanded Ocean.US, an interagency planning office established in 2000. Following numerous and broad reaching planning workshops and town hall meetings a document was published on May 23, 2002 putting forth a justification and a plan consisting of both global and coastal components to IOOS. The United States coastal component to IOOS was envisioned to have a federal network, referred to as the national backbone, augmented by Regional Coastal Ocean Observing Systems (RCOOS). Each RCOOS was to be organized through a Regional Association (RA), and there were to be 11 such RAs forming a National Federation of Regional Associations (NFRA). The May 23, 2002 IOOS pamphlet suggested a funding ramp up to 500M per year in support of IOOS, of which 138M would initiate the activity with an initial 50M going to the RAs. On September 20, 2004 the U.S. Commission on Ocean Policy endorsed the IOOS concept in their (An Ocean Blueprint) report and recognized that 500M was too small a ramp up – they recommended 750M per year. Whereas the concept remains valid the progress to implementation is at a stand still.

For the first half decade of the RCOOS process, through around 2005, the United States did organize into RAs and Coastal Ocean Observing System (COOS) assets were implemented, largely through federal earmarks. Beginning in 2005 the academic community at the request of the Consortium for Ocean Leadership agreed to eschew earmarks and look instead to NOAA as the lead agency for IOOS through competitive research grants, and that remains the situation through today. Unfortunately, new money has no materialized, and the funding levels for the RCOOS have diminished to the extent where many of the coastal ocean observing resources that were in place in 2005 are no longer available. Despite the ICOOS Act passed in 2009, which authorized IOOS as a program within NOAA, the activity languishes with little tangible support. Moreover, it is my impression that there may be more concern for the concept of data management than for the actual implementation of additional coastal ocean observations and models, without which there is little data to manage. While many within the agencies, academia and private sector may disagree on the details, *it is time to implement the RCOOS with funding levels sufficient to serve the regions and the nation and with emphases on observations and models*.

Details are always stumbling blocks, but these can be surmounted if we approach the problem in a comprehensive, systems-wide, multidisciplinary manner. The underlying concept is that of coastal ocean state variable estimation. By this I mean all properties pertaining to the coastal ocean, including sea level, velocity, temperature salinity, nutrients, plankton, fish, and surface meteorology; in other words, all variables that pertain to and hence comprise coastal ocean and estuary ecology. After all, coastal ocean ecology is not biology; it is the entire suite of processes that determine coastal ocean state variables. These same principles apply to all of the societal relevant coastal ocean problems espoused in the May 23, 2002 Ocean.US report. They also pertain to the present Deep Horizon oil spill crisis. Regardless of whether the topic is an oil spill, fisheries, harmful algae, search and rescue, etc, the same systems-wide approach is necessary, albeit with subsets highlighted. In other words, to understand our fisheries we must understand all of the connections across space, time and trophic levels. To describe and predict the present oil spill and its effects on the environment we must do similarly. The scientific approach to all of these problems is similar and inter-related.

Coastal ocean state variable estimation requires both observations and models. Observations alone are insufficient because the sampling problem is so enormous – there can never be enough data. Models are therefore required to extend the observations with proper dynamical (and for living resources, proper biological) constraints. However, models alone are less than useful, owing to the need for, and the uncertainties in, model initial and boundary conditions and parameterizations. Thus any coastal ocean observing system must coordinate between observations and models, with the goal of formally linking the two elements through data assimilation. It is a large task, and an evolving one, requiring nurturing and sustenance. There is no point in engaging if there is no commitment to sustain the efforts.

Additionally, it must be recognized that there is no single observing sensor or sensor delivery system that is adequate. Required are arrays of fixed moorings for time series of water column variables and surface meteorology, HF-radar for surface current mapping, gliders and profilers for water column variable mapping, conventional shipboard surveys, satellite imagery with both passive and active sensors, satellite tracked surface drifters for specific applications (as presently being used), and other sensors/sensor delivery systems to fill specific gaps or deal with specific local requirements. Emphasized again are sustained observations. For instance, the ocean circulation varies on times scales from diurnal to interannual. It is therefore impossible to define long term mean circulations, or the seasonal variations about the means, without years of sustained observations. The same can be said of biological variables, as alluded to earlier in my statement about separating natural variability from what may be oil spill related.

Similar can be said of models. No single model is adequate to cover all ocean processes. Deep-ocean models generally require larger domains than coastal ocean models (e.g., the Global HYCOM), but this comes at the expense of resolution. Higher resolution coastal ocean models require connection with deep ocean models, which can be accomplished through nesting (e.g., the WFS model nesting ROMS in HYCOM). Estuarine models require connection with coastal ocean models often though multiple inlets, necessitating unstructured grids and even the facility to flood and dry land. There is no single modeling solution, nor should there be because, given inherent errors, an ensemble of models is a reasonable approach.

Finally, and consistent with the RA/RCOOS concept, there is a compelling need for familiarity and commitment to one's locale. Harmful algal blooms provide a case in point. Not all "red tides" are the same so how one would model Alexandrium in New England is different from Karenia in Florida, two dinoflagellates that make their livings and manifest their toxins in entirely different ways. Processes such as these are just too complex to generalize.

Is the effort worth the cost? Our approach to the questions addressed today would be much different if we had the RCOOS in place so the answer is certainly yes. Moreover, I can testify today from personal experience that the only reason my USF Ocean Circulation Group was able to respond to the crisis, as we did, is because we had resources in place from previous COOS activities, supplemented by many small, competitive research grants. So with some trepidation, I am also here today to tell you that not all earmarks are bad.

The total costs are not insignificant. The original Ocean.US number, especially that for the RCOOS, is woefully small; the U.S. Commission on Ocean Policy number was an improvement, but still too small. Recently, in a N.Y. Times interview, I used a figure of 1B, and depending on how that would be distributed nationally between the RAs and the agencies, that to could be inadequate. In view of a recent estimate of 138B for the ocean-dependent economy in the United States (in normal times), provided to the Council of Environmental Quality by members of Congress, a less than 1% investment on describing, understanding and predicting ocean behaviors does not seen unreasonable. After all, there are individual corporate CEO salaries that have exceeded 100M, and ExxonMobil profits alone have exceeded 40B. Previous BP profits were another 22B. In contrast, a 1B investment in the coastal oceans of the United States does not seem unreasonable. Not only will it provide the knowledge needed to be better environmental stewards, it will help train the next generation of scientists, employ a highly skilled work force, and support the small (mostly United States) businesses that make the sophisticated instruments and instrument delivery systems that are required for implementation.

The discussions on IOOS, RA, RCOOS, and COOS are a pathway forward, but needed right now is an immediate and accelerated response to the Deep Horizon oil spill.

Priority must go to the Gulf of Mexico and Southeastern United States regions while moving toward enabling the entire NFRA concept for the nation as a whole. The crisis now is in the Gulf of Mexico, but the future requires a build-up for the entire nation.

In summary, the unprecedented, Deep Horizon oil spill shed an unwanted light on the environmental stewardship of our nation's oceans extending out beyond the EEZ. An immediate response is required followed by a staged implementation of an RCOOS concept akin to what was advanced by Ocean.US. The immediate response, in addition to the outstanding efforts already in place by the agencies under the unified command, must be directed at the Gulf of Mexico and Southeastern United States, and these should entail individuals and institutions who have demonstrated performance in response to the crisis. Observations in support of oil spill trajectory modeling, both surface and subsurface are essential. Scoping out the nature of a potential subsurface threat, as quickly as possible, is necessary for contingency planning and possible mitigation. Similarly, with oil now approaching new shorelines in addition to those already marred along coastal Louisiana, we must have improved observing and modeling tools in place to plan for the potential invasion of our estuaries by oil. It is not just a matter of taking stock of natural resources to potentially be lost, but understanding how these natural systems work so that maybe more of our natural resource can be spared damage or destruction.

My intention was not to be critical of the agencies, collectively or individually, instead to highlight certain data and model deficiencies as requested and to advance a pathway forward. The response by our agencies has been excellent, so has the response by many outside of the agencies. We must marshal all of our resources if we are to minimize the effects of this tragic occurrence.

I thank you for your invitation to speak and for you attention. I also thank everyone in the federal, state and local agencies, the private sector and the academic institutions who are working tirelessly to assist.