Autonomous Vehicles Workgroup

7th annual NOAA/NGI Hypoxia Research Coordination Workshop:
Building the Cooperative Hypoxia Assessment and Monitoring Program
(CHAMP)

AV WG Members

- Steven F DiMarco (TAMU): LEAD
- John “Chip” Breier (UT-RGV)
- Catherine Edwards (Skiddaway)
- Stephen Howden (USM)
- Andrew Ziegwied (ASV-Global)
- NOAA: David Hilmer, Trevor Meckley, Alan Lewitus

AV Working Group Purpose

- To identify strategies for the use of autonomous vehicles
- To identify potential of new and emerging technologies for applications to autonomous vehicles

Existing Vehicles

- Teledyne Webb Research Slocum Gliders
- Liquid Robotics Wave Rider (SV3)
- ASV Global C-Worker series

- Other vehicle considerations
  - Kongsberg: Coastal Glider
  - Spray
  - MOST Autonaut

AV WG Current Activities

- NOAA CSCOR: Glider Implementation Plan
  - July 2018
- Texas OneGulf Center of Excellence
  - 2016-2018 Field Campaign
- Galveston to FGBNMS Transect
  - Private/Public Partnership with Liquid Robotics and Texas A&M University
- Stones Array
  - PPP Shell/Fugro/USM/TAMU
- Resources: GCOOS GANDALF glider data
- Resources: Stones Mooring
- Resources: NAS Loop Current Report

Glider Implementation Plan

- Define Metrics
- Capability
- Monitoring Design
- Resource Assessment
- Workforce Requirements

Enhanced Buoyancy Control

Depth, Density, Speed

Optimized depth operations:

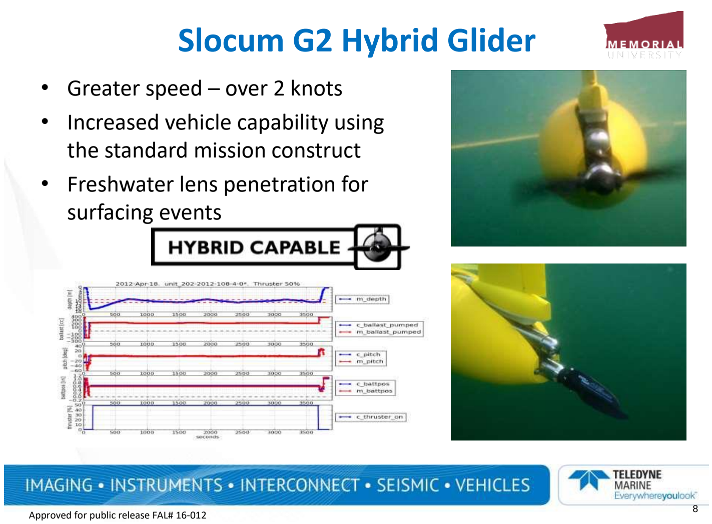
- Shallow family: 30, 50, 100, 200 meters (shallow as 4 m depth)
- Deep family: 350, 1000 meters

Density ranges:

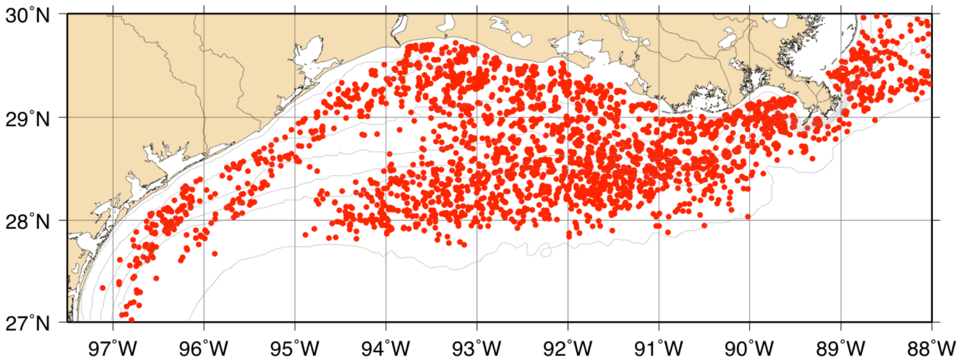
- 800 cc drive: 12 kg/m³ available (reduced by 100 cc drive)
- Thruster: 17 kg/m³ available
- Combined: 29 kg/m³ available

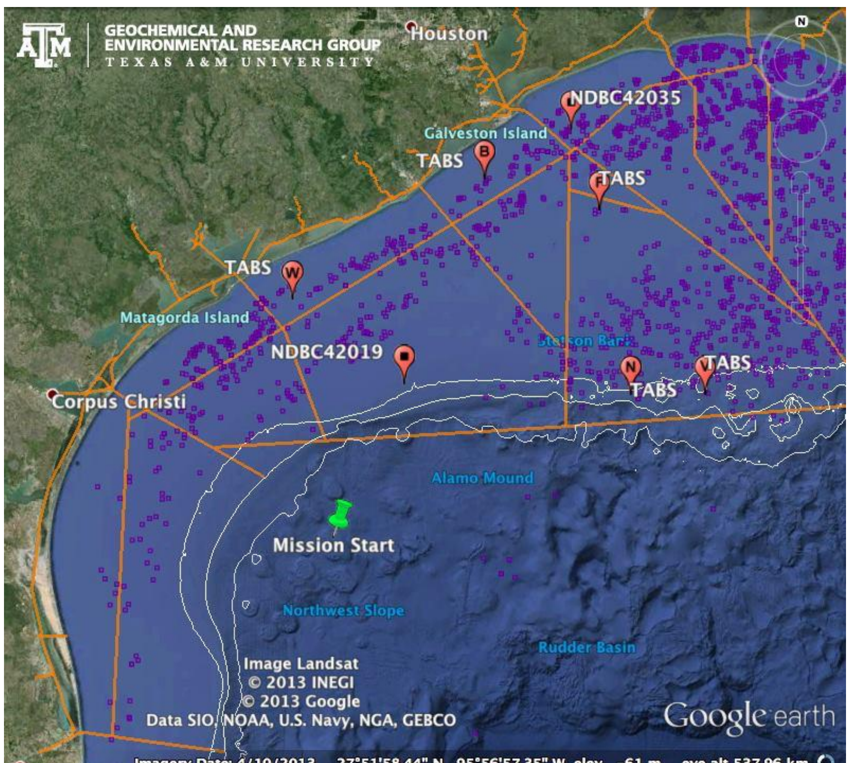
Speed:

- From buoyancy: up to 1 knot (dependant upon density, operational depth, pump speed, and total displacement).
- From thruster: 2 knots (can be combined with buoyancy).
- Energy: Speed adversely impacts endurance.



Glider Challenges





TAMU Slocum Gliders (G2)

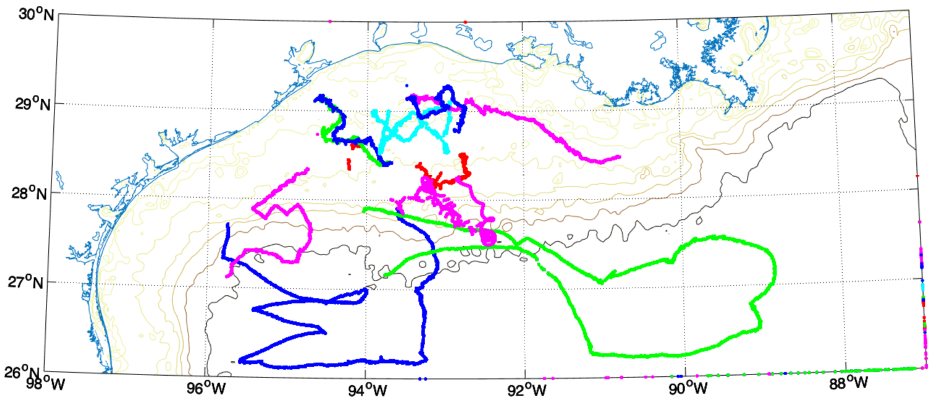
- 307:Reveille
- 308:Howdy
- 540:Stommel
- 541:Sverdrup
- 199:Dora (the Explora)
  - TAMUG (GERG/MARS MOU)

www.webbresearch.com/**slocumglider.aspx**

Facilities

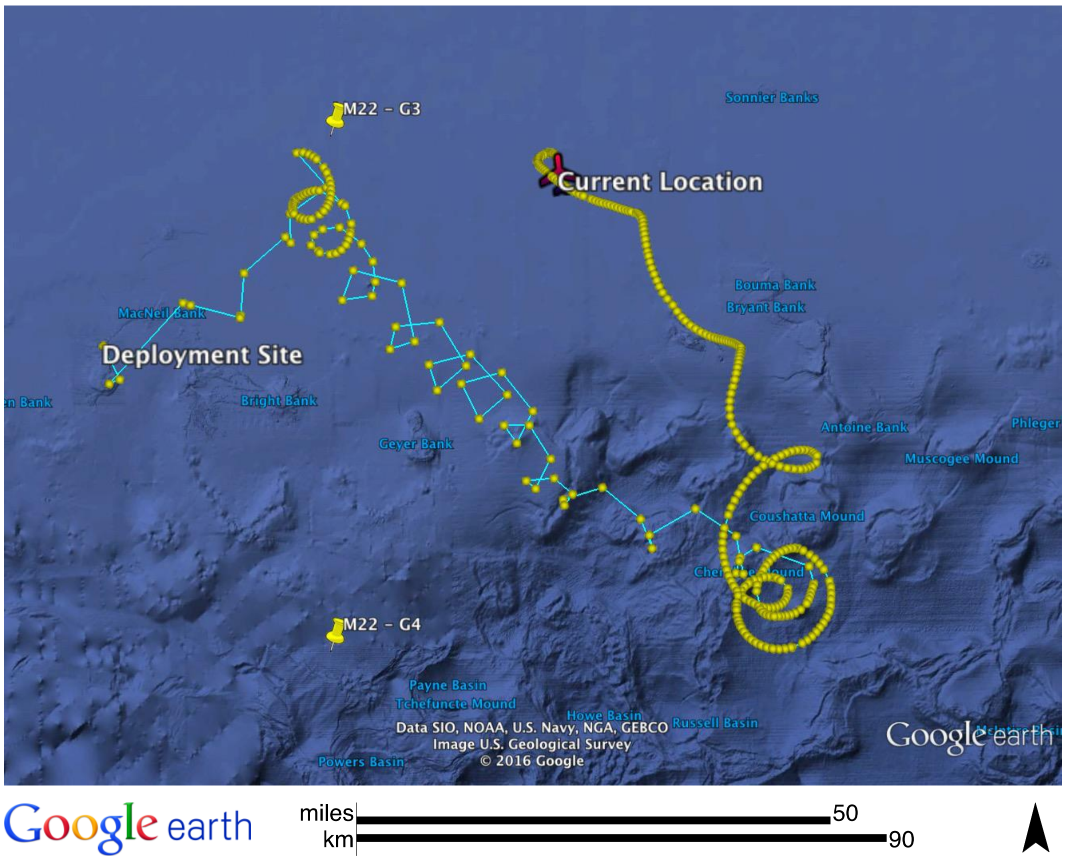
- GERG
  - 833 Graham Road, CS
- Glider Lab
  - aka the Center for Autonomous Vehicle Exploration

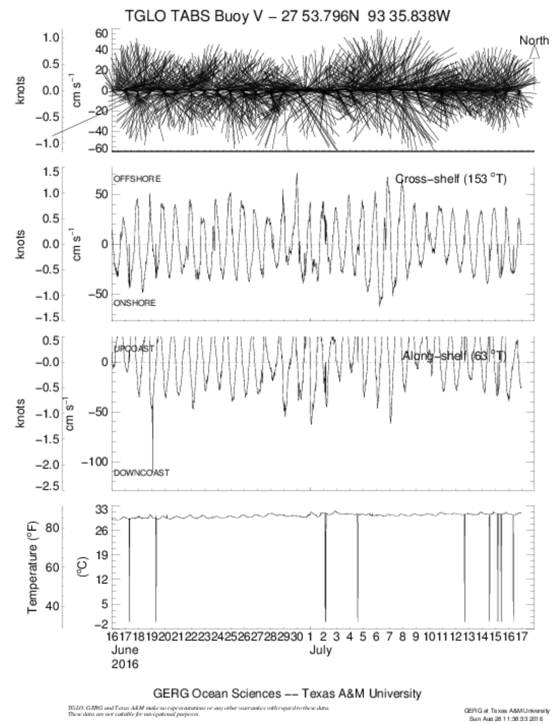
TAMU Glider Missions

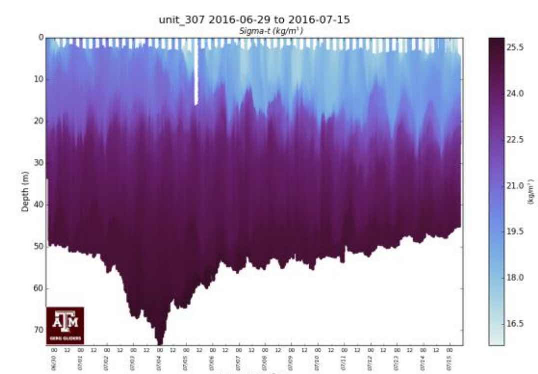


- 34 missions
- 800+ days
- 15000 km traveled
- 20 Coastal missions (< 200 m)
- 14 Deep missions (> 1000 m)

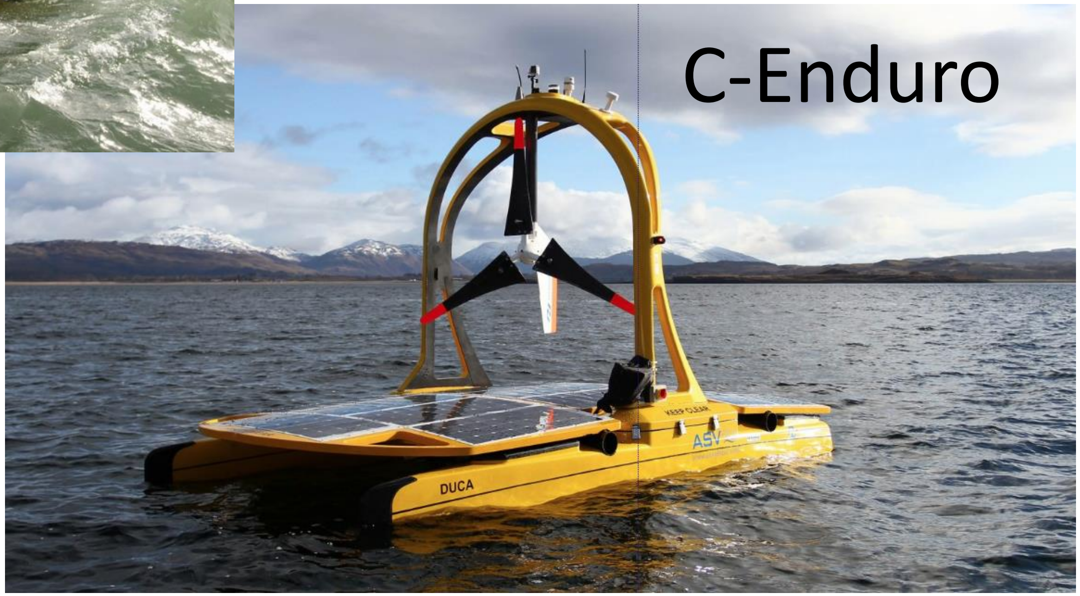
Glider or Surface Drifter?





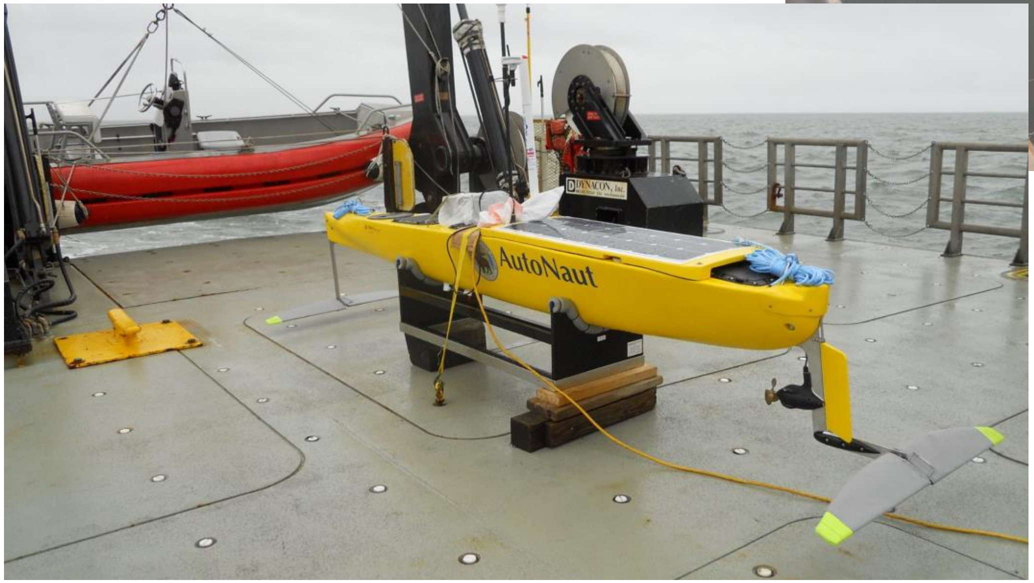


ASV Global vehicles



Surface vehicles

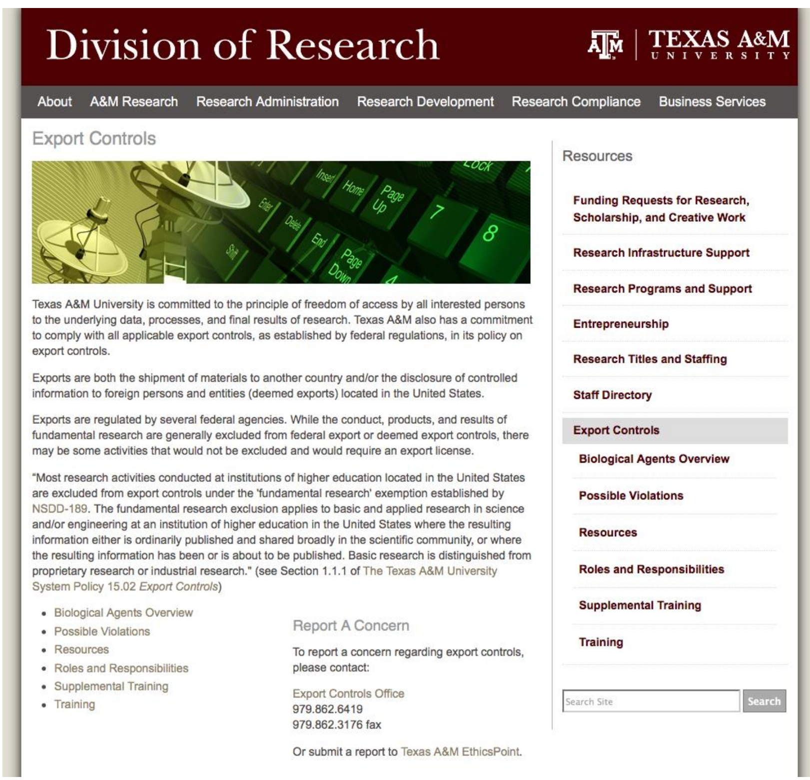
- Autonaut
  - MOST, Inc.
  - www.autonautusv.com

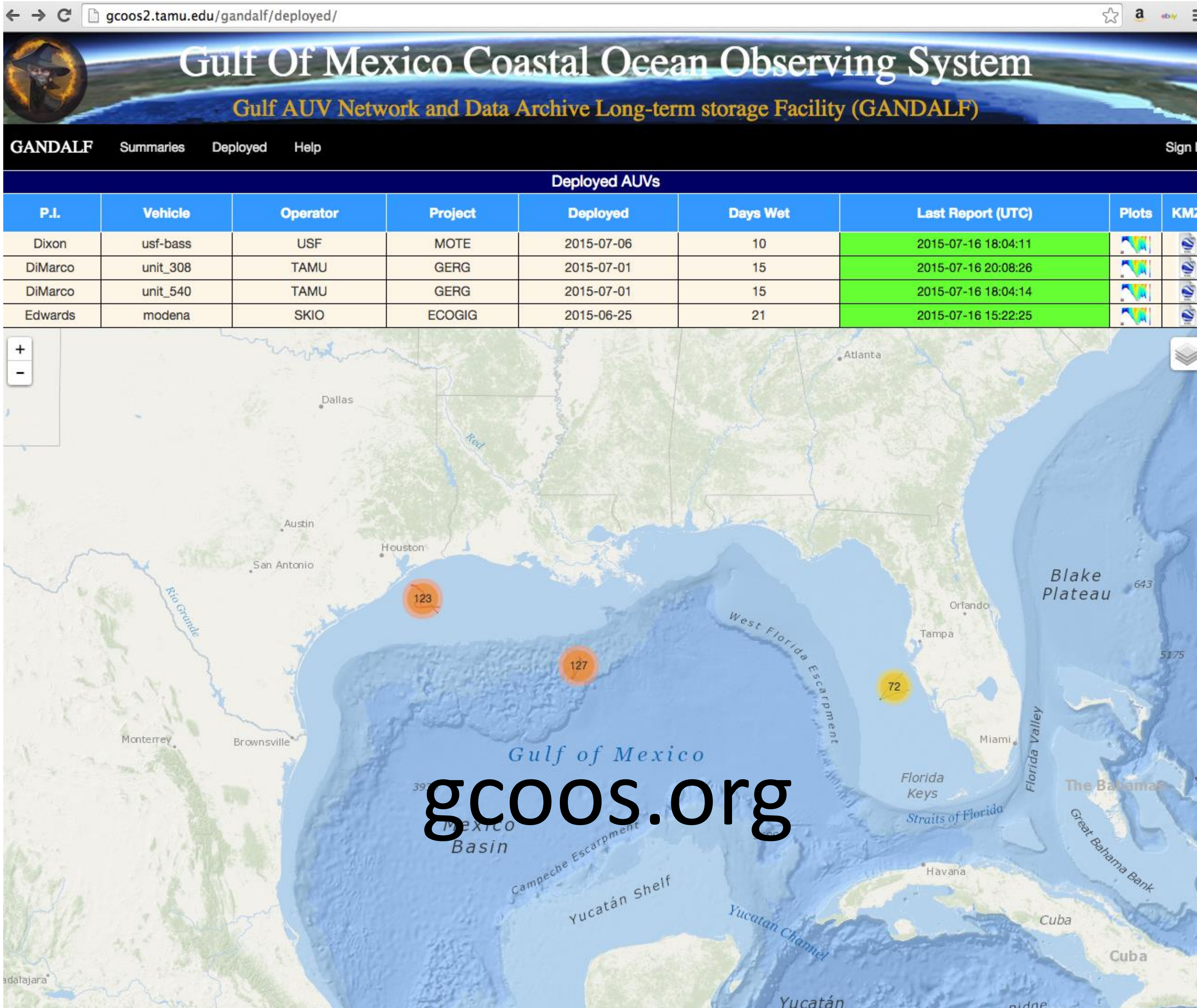


R/V Sharp, Delaware Bay
November 2015
PI: K. Whilden

Export Control

- We embrace a culture of compliance at GERG
- Technology Control Plan





P.I.	Vehicle	Operator	Project	Deployed	Days Wet	Last Report (UTC)	Plots	KMZ
Dixon	usf-bass	USF	MOTE	2015-07-06	10	2015-07-16 18:04:11		
DiMarco	unit_308	TAMU	GERG	2015-07-01	15	2015-07-16 20:08:26		
DiMarco	unit_540	TAMU	GERG	2015-07-01	15	2015-07-16 18:04:14		
Edwards	modena	SKIO	ECOGIG	2015-06-25	21	2015-07-16 15:22:25		

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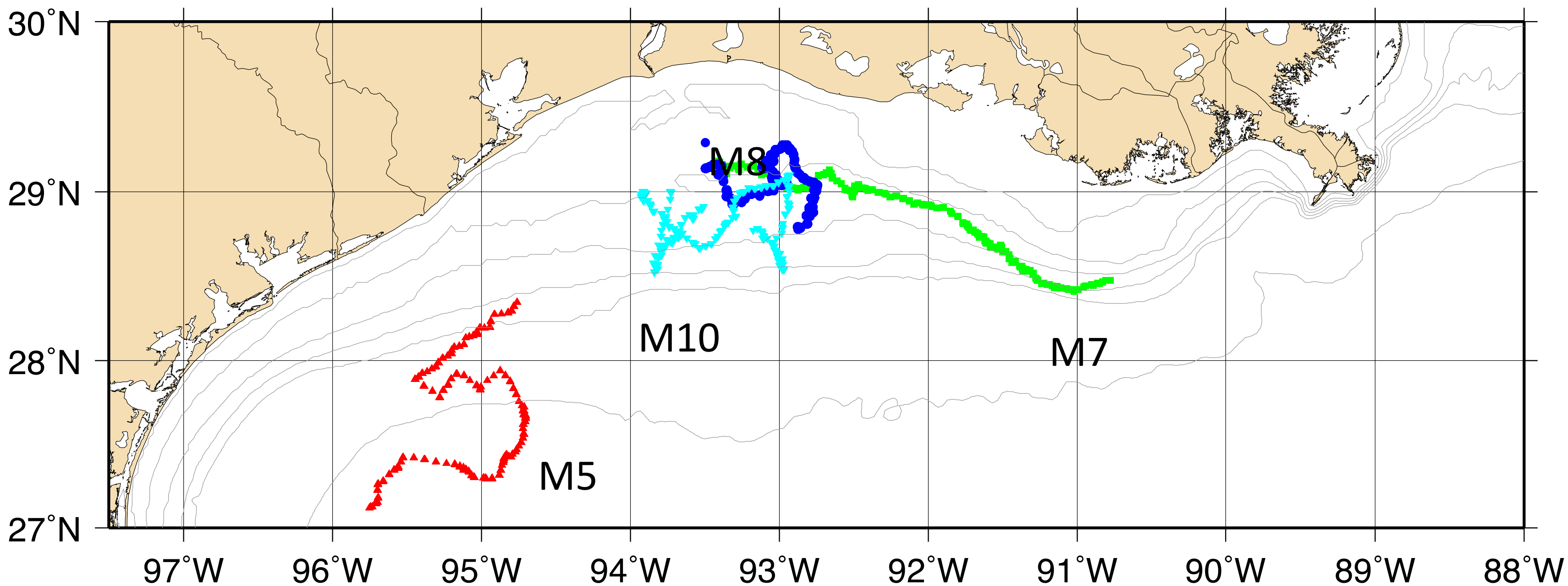
Hypoxia

GLIDER APPLICATIONS

Gulf Glider Hypoxia Experiment Summer 2014

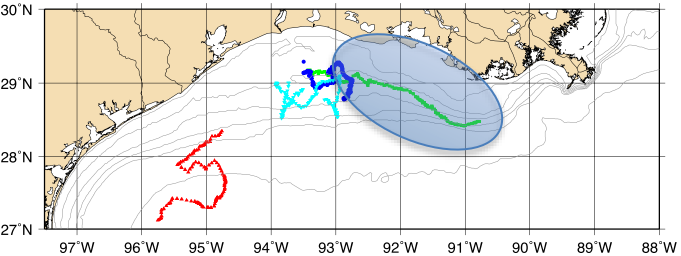


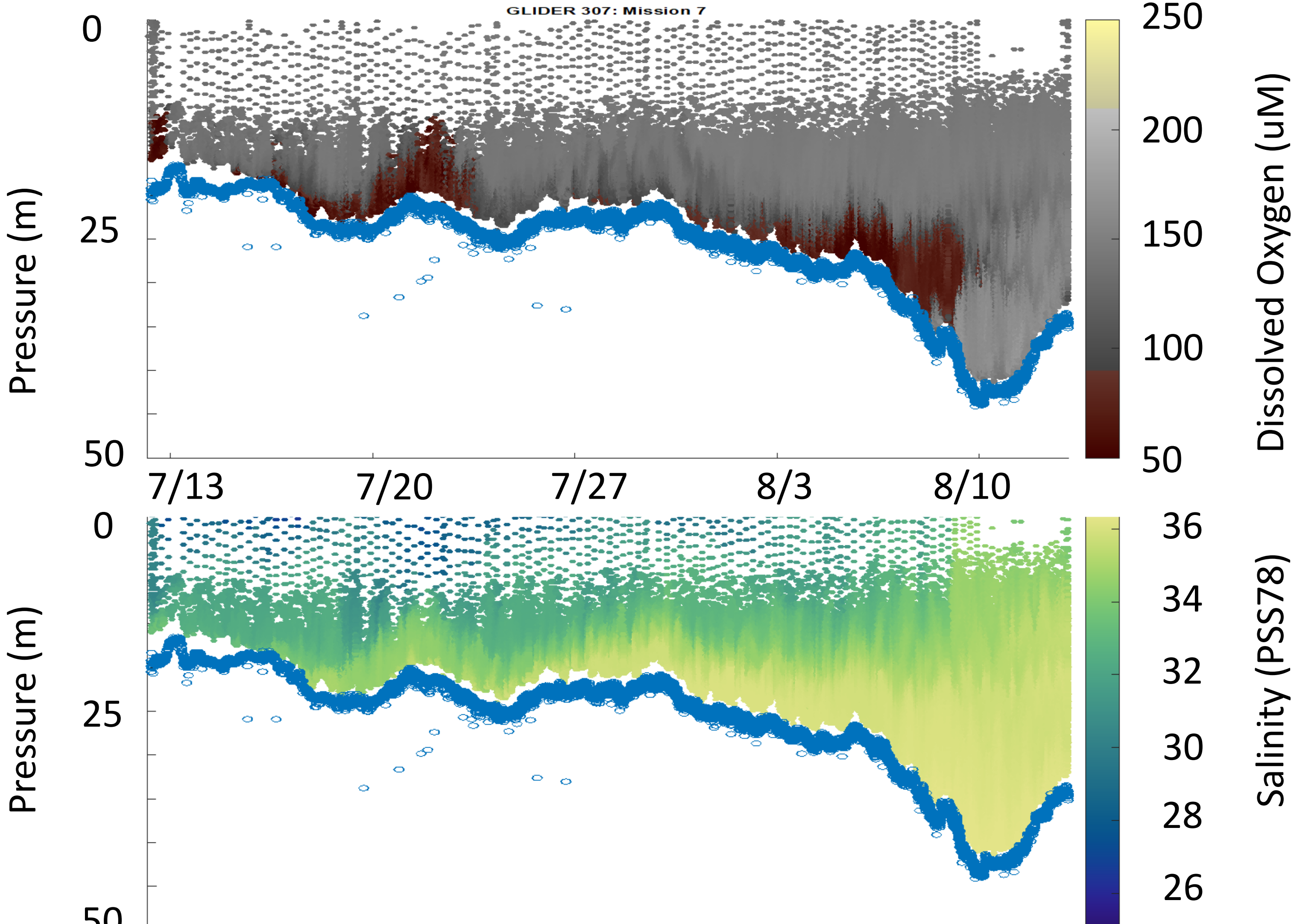
- To coordinate and operate multiple autonomous buoyancy ocean vehicles in the northern Gulf of Mexico hypoxic area during summer 2014
  - Sub-objective: map the hypoxic zone
- Quantify average distance from bottom for glider yo

TEXAS A&M UNIVERSITY

More information on the MCH project at http://hypoxia.tamu.edu

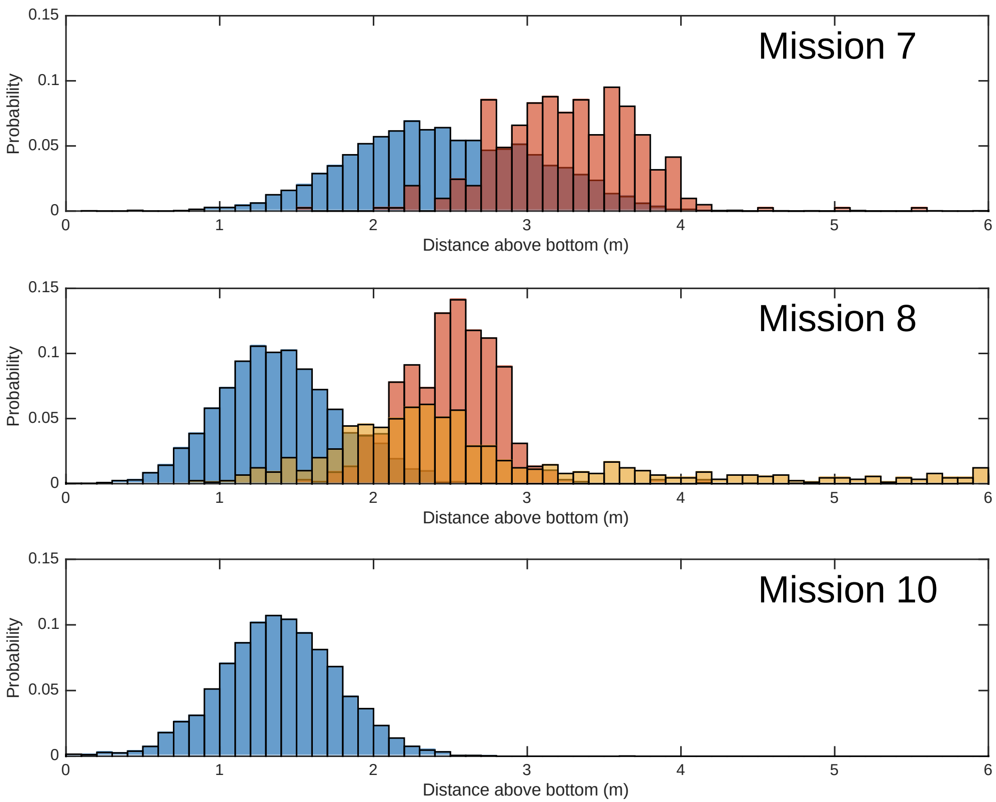
Salinity and Oxygen

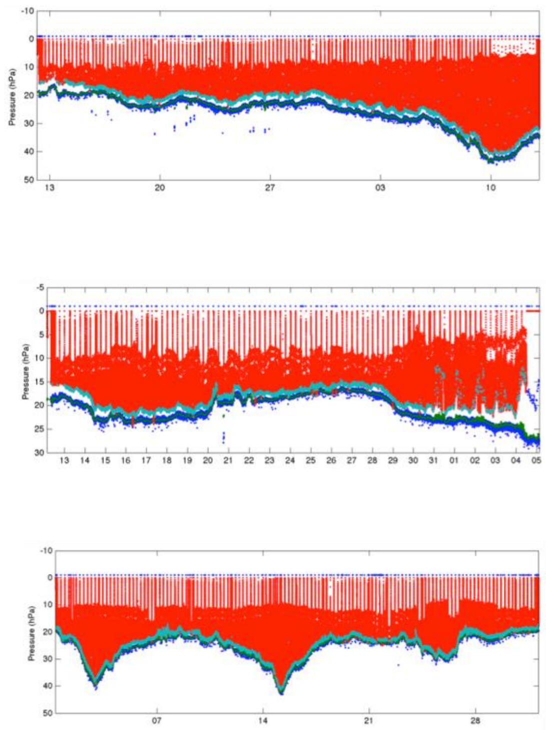




Ramey et al. 2017 (MTSJ)

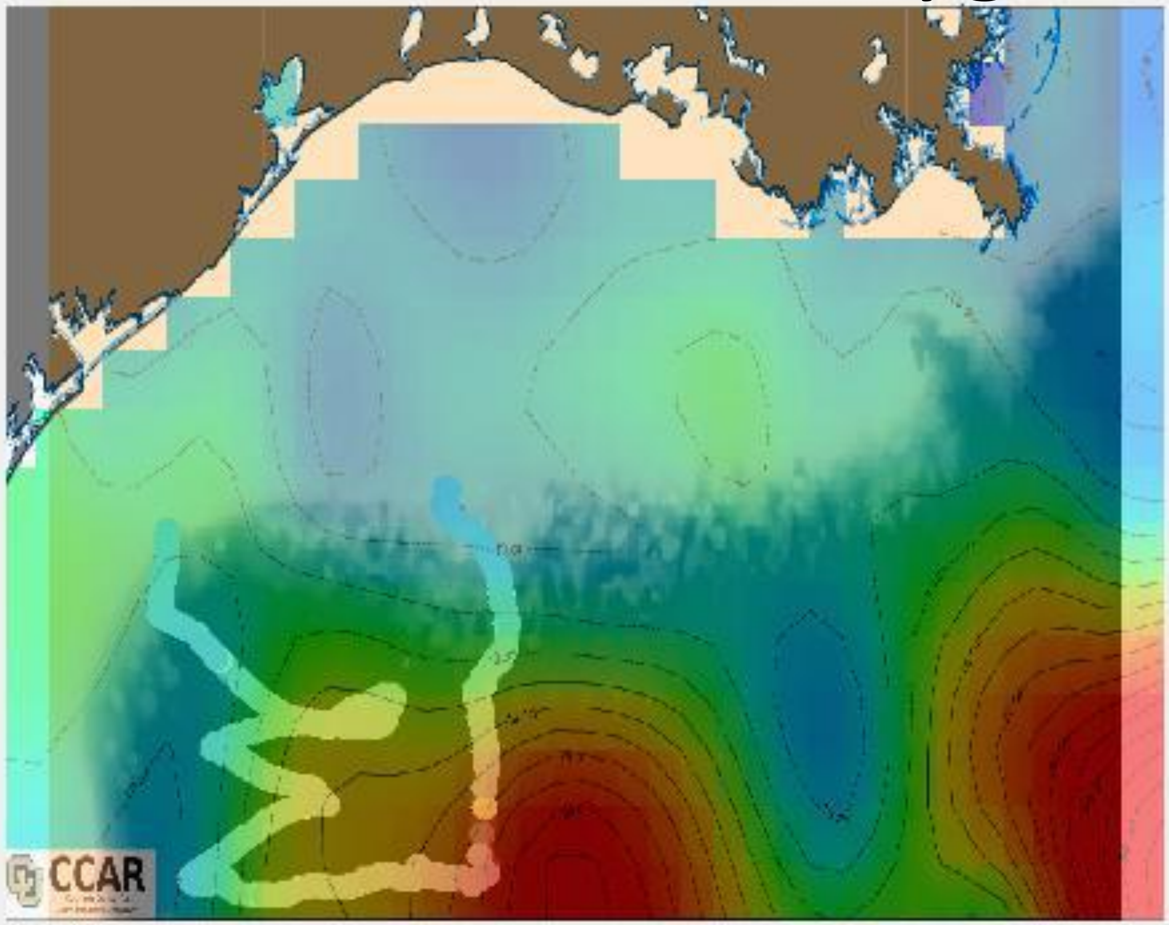
How close to the bottom?

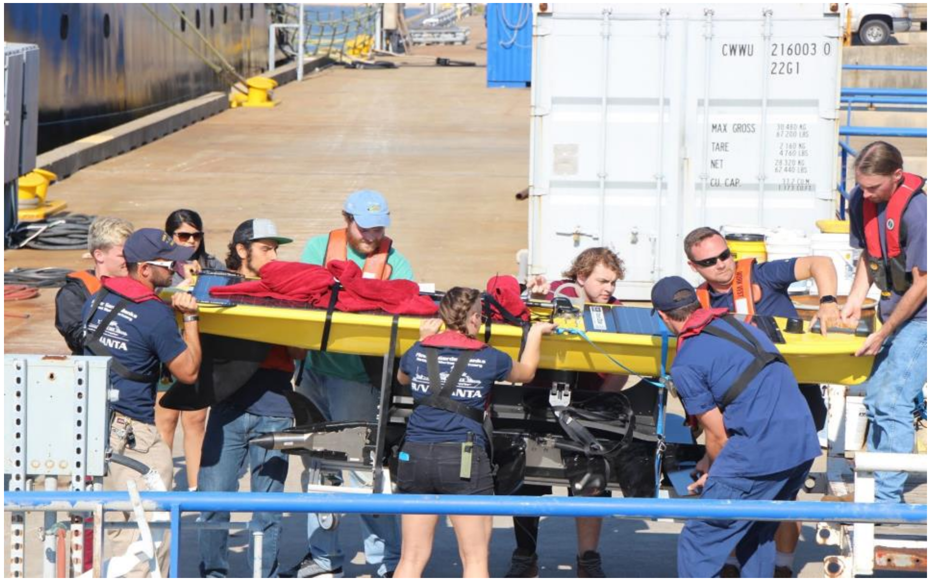




Ramey et al. 2017 (MTSJ)

Glider Dissolved Oxygen



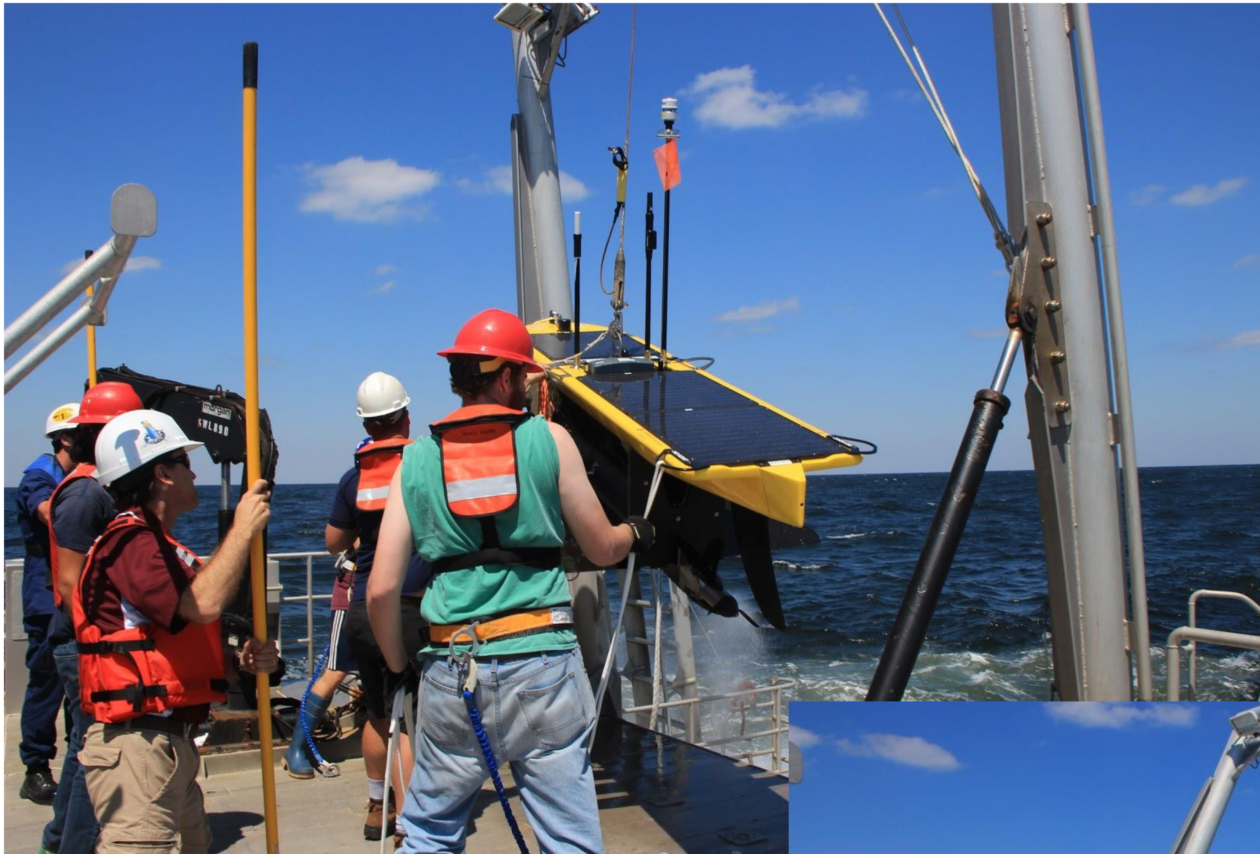


Hurricane Harvey
Rapid response

Deployment of Liquid Robotics SV3: Gulf Explorer

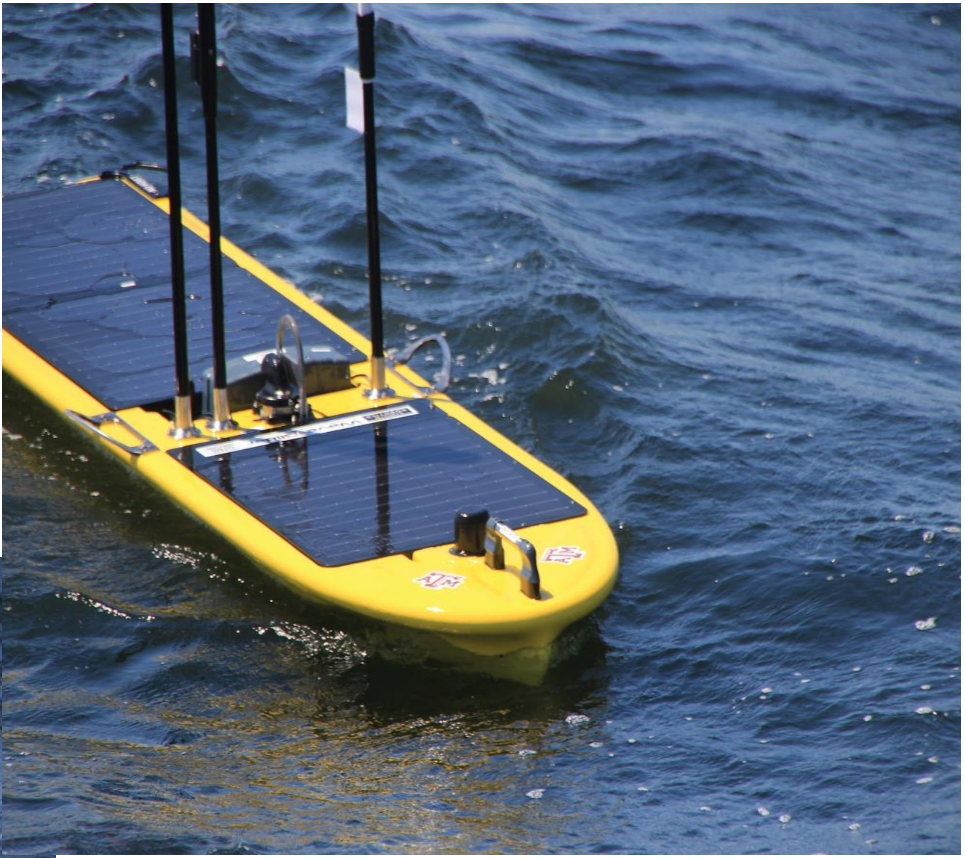
Texas A&M University
Department of Oceanography
Geochemical and Environmental Research Group
College of Geosciences

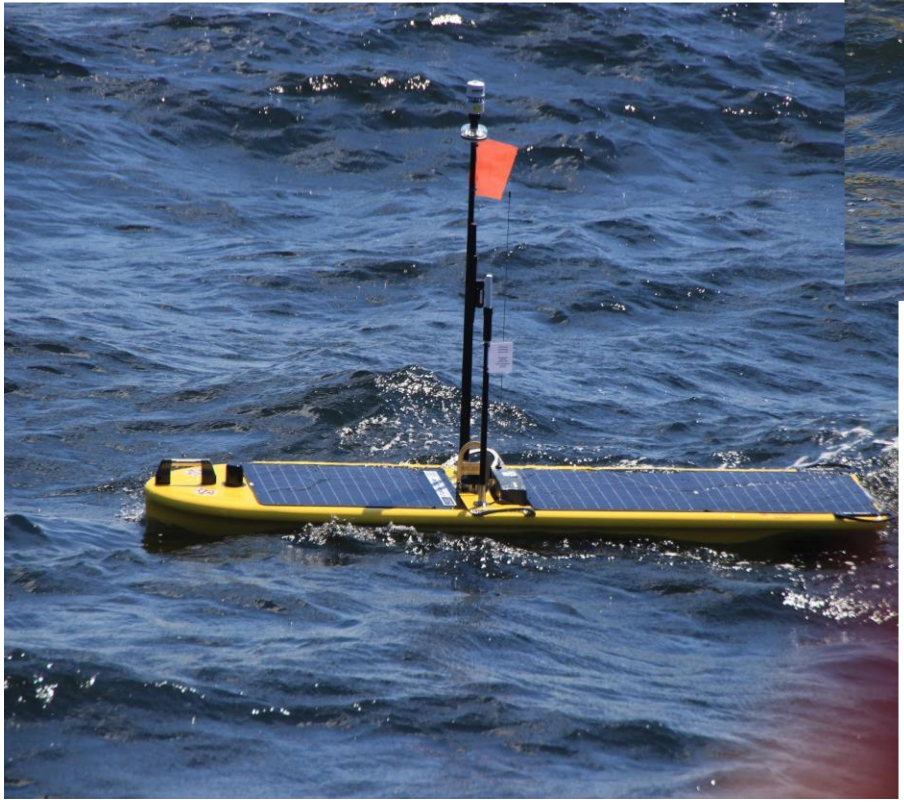
September 8 2017



Deployment

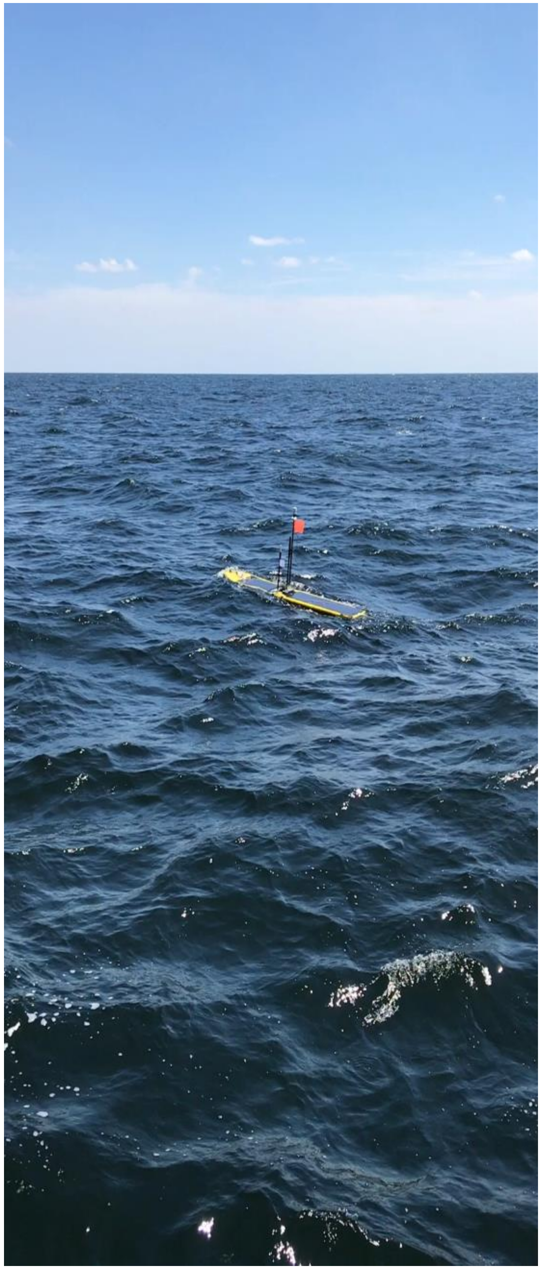
SV3 Gulf Explorer





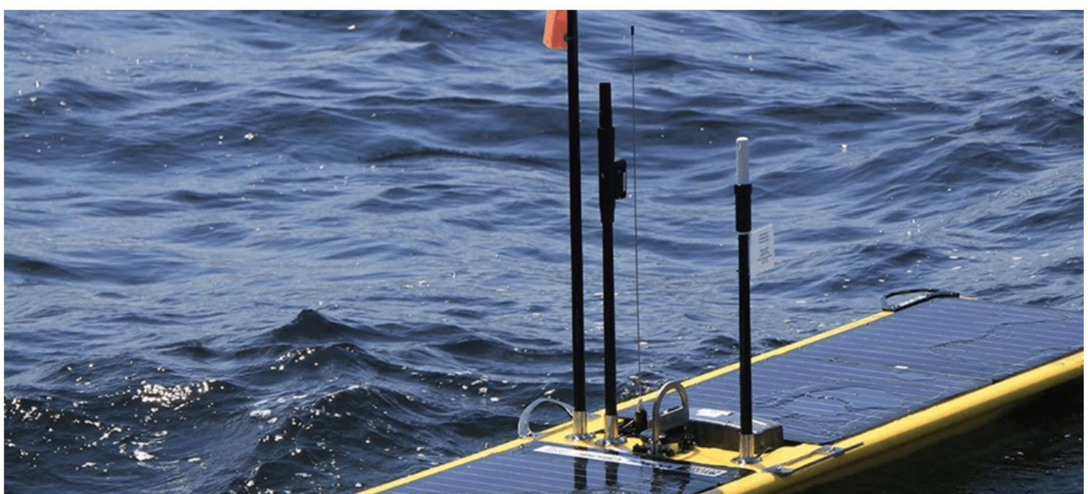
Gulf Explorer at sea

8 September 2017



'Surfing Robot' Tracking Water Data As Harvey's Rains Flow Toward Fragile Coral Reefs

September 18, 2017



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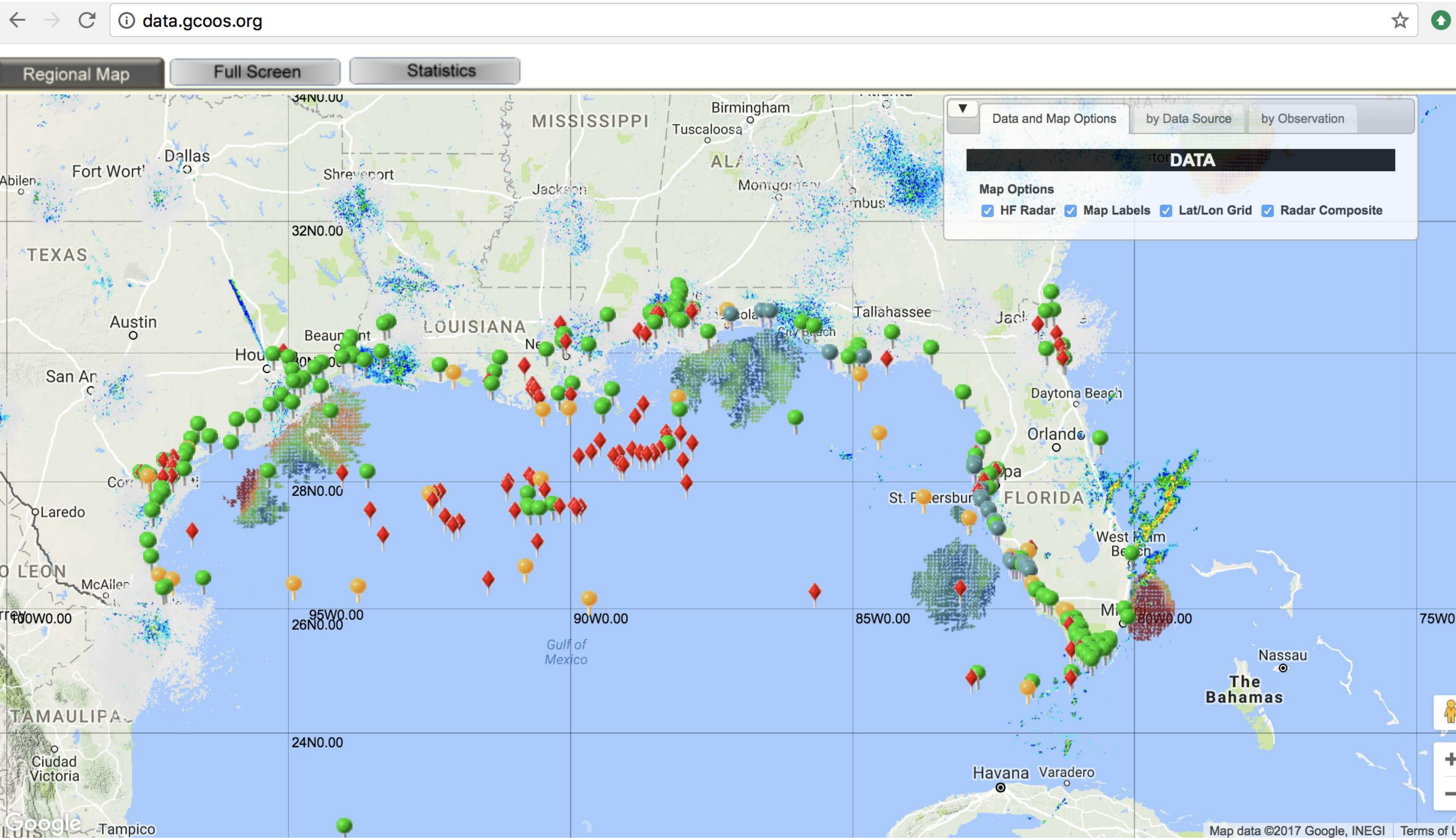
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Map data ©2017 Google, INEGI

gcoos2.tamu.edu/gandalf/deployed/

Gulf Of Mexico Coastal Ocean Observing System

Gulf AUV Network and Data Archive Long-term storage Facility (GANDALF)

GANDALF Summaries Deployed Help Sign In

Deployed AUVs

P.I.	Vehicle	Operator	Project	Deployed	Days Wet	Last Report (UTC)	Plots	KMZ
Dixon	usf-bass	USF	MOTE	2015-07-06	10	2015-07-16 18:04:11		
DiMarco	unit_308	TAMU	GERG	2015-07-01	15	2015-07-16 20:08:26		
DiMarco	unit_540	TAMU	GERG	2015-07-01	15	2015-07-16 18:04:14		
Edwards	modena	SKIO	ECOGIG	2015-06-25	21	2015-07-16 15:22:25		

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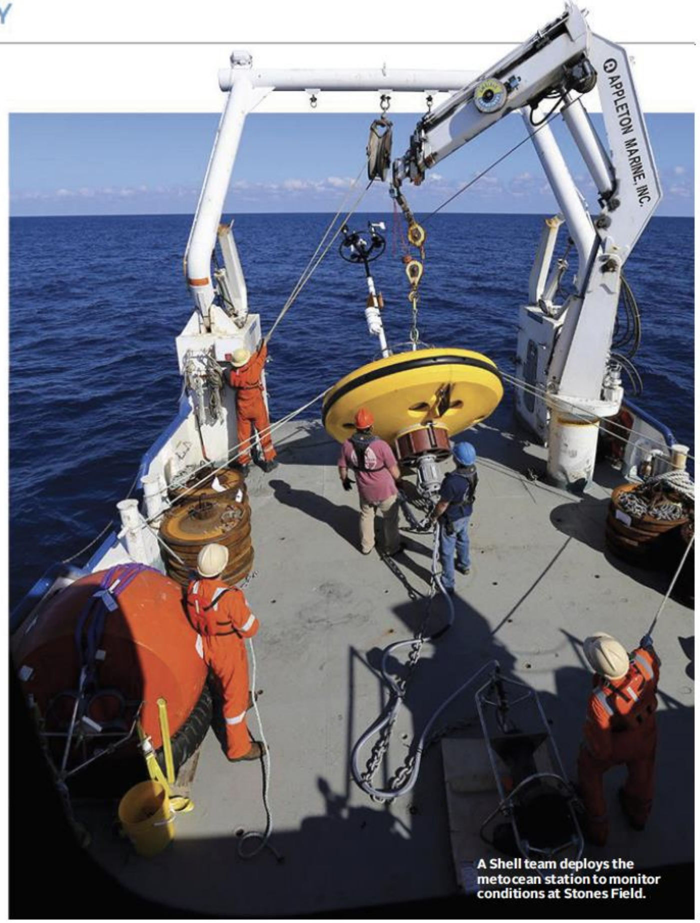
Stones

THE FIRST STORY

What's That, Deep in the Gulf of Mexico?

Scientists don't know as much as they should about the farthest fathoms of a valuable body of water—but that's about to change.

BY KEVIN DUPZYK



A Shell team deploys the metocean station to monitor conditions at Stones Field.

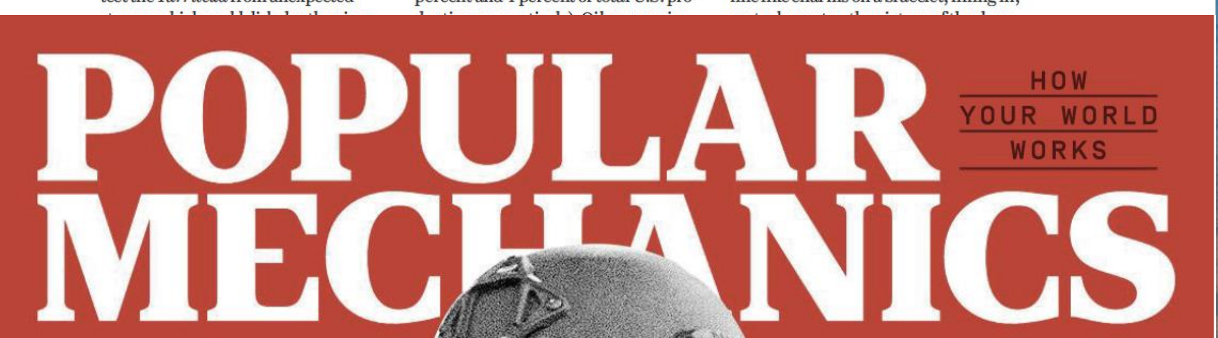
THE SURFACE

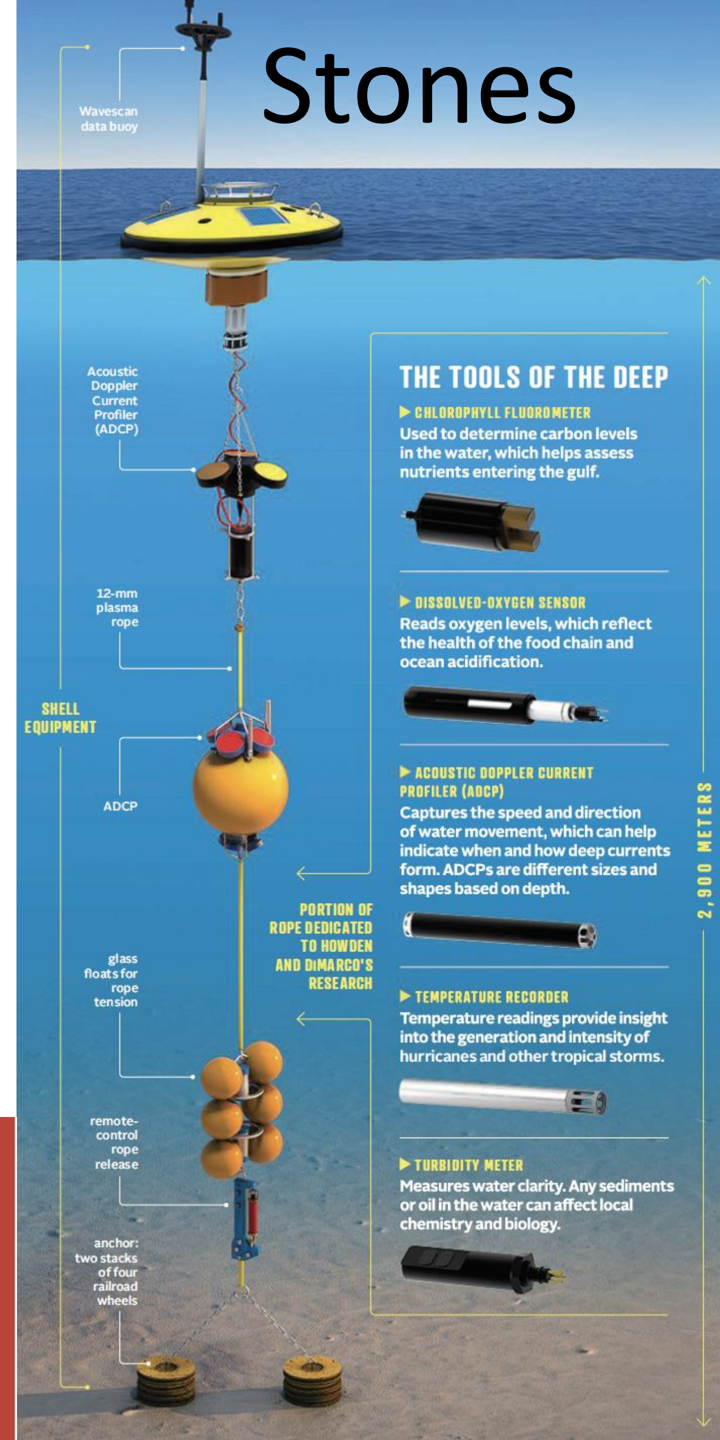
Two hundred thirty miles southwest of New Orleans, a vessel called the *Turritella* floats on the surface of the Gulf of Mexico. It's an FPSO, which stands for floating production, storage, and off-loading facility—basically a cross between an oil platform and a tanker. This particular FPSO belongs to Shell Oil Company, and it is connected by very long pipes to the deepest oil and gas well in the world, in an area called Stones Field. There's just one huge problem: In a strong storm, an FPSO like the *Turritella* can cut loose from the well and run.

One and a half nautical miles away, a yellow sensor buoy called a metocean station monitors meteorological and oceanic conditions. This helps Shell protect the *Turritella* from unexpected

$900 million fishery, and the operation of its wells, which in 2015 produced 553 million barrels of crude oil and 1.3 trillion cubic feet of natural gas (16 percent and 4 percent of total U.S. pro-

metocean station's 2,900-meter tether. This month, Howden and DiMarco plan to journey with Shell to deploy new instruments, which will hang from the line like charms on a bracelet, filling in,

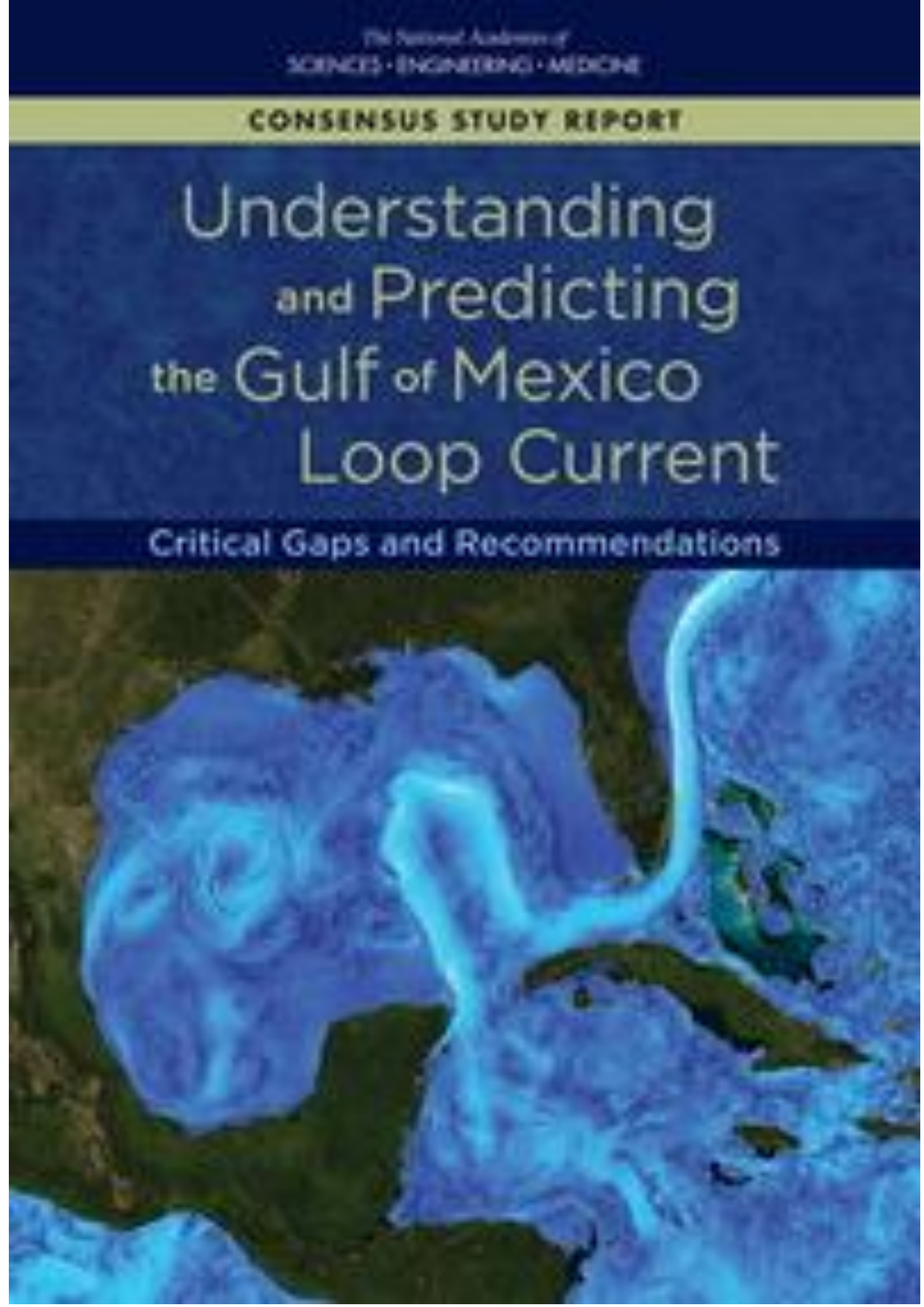




Stones Project Elements

- Long term moorings
  - Full water column
  - Interdisciplinary sensor suite
  - Real-time reporting
- Dedicate glider lines
  - East Line
  - West Line

NAS Report


The National Academies of
SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
Understanding and Predicting the Gulf of Mexico Loop Current
Critical Gaps and Recommendations

Color Maps

True Colors of Oceanography

Guidelines for Effective and Accurate Colormap Selection

By Kristen M. Thyng, Chad A. Greene, Robert D. Hetland, Heather M. Zimmerle, and Steven F. DiMarco

Data graphics shape the way science is communicated, and the color schemes we employ can either faithfully represent or tacitly obscure the data a figure is intended to convey (Tufte, 1983). Tasteful use of color can make data graphics visually appealing and can draw viewers in, engaging the audience and encouraging further inspection of a figure. But wherever color is used to represent numerical values, its role transitions from a mere aesthetic nicety to carrying the responsibility of conveying data honestly and accurately. Yet, biases introduced by some common colormaps have gone widely unrecognized within the oceanographic community. Here, we describe the pitfalls of some commonly used colormaps, provide guidelines on effective, accurate colormap selection, and present a suite of perceptually uniform cmocean colormaps that have been designed for oceanographic data display. The cmocean package is available across multiple software programs, including MATLAB, Python, R, Generic Mapping Tools, and Ocean Data Viewer.

RAINBOW DECEPTION

When color is employed to show numerical data, viewers expect the overall distribution of color they perceive to match the distribution of the underlying data. However, perception of color is often overlooked in oceanography as we continue to rely on colormaps that have complex transfer functions between what is visually perceived and the underlying data being represented. One common colormap that is perceived in false relation to the data it represents is the rainbow-colored *jet* colormap, whose popularity stems largely from its decades-long residence as the default setting in MATLAB and similar programs (Eddins, 2014). The *jet* colormap visually distorts information through two primary mechanisms. First, *jet* places emphasis at arbitrary locations along the color scale corresponding to local maxima and minima in colormap lightness (Rappaport, 2002; Stauffer et al., 2015). This effect leads to higher rates of error in identifying regions of maximum and minimum data values, even among experts who are familiar with the data type under evaluation and who have experience with *jet* colormap (Spence et al., 1999; Borkin et al., 2011; Bryant et al., 2014).

The second mechanism by which *jet* deceives viewers is through false gradients introduced by a non-monotonic lightness profile, which accelerates at a different rate than the data it represents (Light and Bartlein, 2004; Borland and Taylor II, 2007). For oceanographers, the danger of *jet's* false gradient profile is its ability to covertly exaggerate fronts in some regions of the color scale while minimizing the presence of fronts elsewhere (Ware, 1988; Mersey, 1990). Figure 1e shows *jet's* misbehavior, where a cone with linear sloping sides viewed from the top appears smoothly varying when plotted with a simple, unbiased, perceptually uniform, grayscale colormap, yet the same smooth data appear to have sharp edges and broad plateaus when plotted with *jet*. A common argument in favor of *jet* is that its sharp gradients allow proximal colors to be distinguished by a meticulous viewer, and indeed, Figure 1c shows that in some subranges within the color scale, *jet* offers superior point-to-point discrimination. However, the high-performing regions of *jet* are offset by regions elsewhere in the spectrum where changes of the same size are nearly imperceptible.

HOW TO SELECT AN HONEST, EFFECTIVE COLORMAP

To avoid the pitfalls of *jet* and other perceptually nonuniform colormaps, we offer the following guidelines for selecting data-appropriate colormaps that show numerical values effectively, intuitively, and in proper proportion.

Reflect the Nature of the Data

The first step in selecting an appropriate colormap relates to the nature of the data being displayed. Numerical data represented by pseudocolor can typically be categorized as sequential, diverging, or cyclic.

1. Sequential. There is a regular interval relationship in sequential data, such as a range of salinity values. Sequential data should be represented with a monotonically increasing range of lightness values (Stevens and Marks, 1965; Rheingans, 2000), such as in a grayscale colormap, but can also have variations in hue. The

or any given type of data. For fields without strong natural color associations such as salinity or wave height, intuition is developed by consistently associating each variable with its own colormap. This principle can hold true within a single manuscript or may be developed over time as a convention, much like the Greek letters we tend to associate with specific oceanographic variables. Just as we do not use σ to represent temperature, density, and salinity within the same manuscript, each variable plotted in a manuscript should be represented by its own colormap.

Consider Colorblind Viewers

Rates of colorblindness are low among women, but among men, approximately 7% of Northern European descendants, 4% of Asian descendants, and 3% of African descendants have some form of

FIGURE 2. Colormaps available in the cmocean package.

red-green colorblindness (Sharpe et al., 1999). For colorblind viewers, reds and greens of similar lightness values can be difficult to discern. Figure 1f shows example colormaps as perceived with a moderate (50%) deuteranomaly, which is the most common form of color deficiency. The *gray*, *haline*, and *balance* colormaps maintain distinct colors with moderate deuteranomaly so that figures plotted with these colormaps will be readable to color-deficient viewers, though the *balance* colormap has changes in red and green values and a shift in the luminance and saturation. The *phase* colormap appears duller without green and red hue variation, but the colors in the colormap still vary smoothly. Note that the severity of the colorblindness will change how these colormaps appear because the changes are nonlinear with severity.

cmocean: AN OCEANOGRAPHIC COLORMAP PACKAGE

Following the guidelines presented above, we have developed a set of perceptually uniform colormaps tailored for use in oceanography. Figure 2 shows the cmocean collection, which is composed of several sequential colormaps meant to elicit intuitive understanding of common oceanographic variables; three divergent colormaps; one cyclic colormap; and one hybrid colormap designed for the special case of displaying oxygen saturation. The package combines original colormaps developed specifically for this work with several preexisting colormaps (Moreland, 2009; Niccoli, 2012; Brewer, 2013; Samsel et al., 2015; see Acknowledgments); we have altered these maps for perceptual uniformity using viscm. Single-hue and multi-hue colormaps are included, and each of the sequential and diverging colormaps span a wide range of lightness to maximize dynamic range in data display. The cmocean colormaps have been given names such as *thermal*, *haline*, and *ice* to help guide users to intuitive colormaps for common oceanographic variables; however, our nomenclature is not intended to restrict usage to any particular variable.

Figure 3 compares four oceanographic fields plotted with *jet* alongside the same data plotted with cmocean colormaps. At the top of the figure, sea surface anomalies are represented by the divergent *balance* colormap to highlight deviations from a zero reference level. In this context, the *balance* colormap makes it immediately clear to the viewer which values are above the reference level, which values are below, and by how much each location deviates from nominal sea level. Temperature and salinity profiles are shown with *jet* in Figure 3c–f, illustrating the brief confusion that can result from using the same colormap to represent multiple variables within a manuscript. Temperature and salinity have an inverse relationship in these profiles, and as a result, when the same colormap is used to represent both fields, the first impression may be that the ocean has inverted itself. Confusion is cleared up upon inspection of the color bar labels, but comparison to the same data plotted with cmocean colormaps shows artifacts introduced by *jet*. Namely, while *jet* captures most of the features present in the underlying data, it also gives the impression of a series of fronts located near *jet's* band of yellow, where the perceptually uniform cmocean thermal colormap shows that in reality, temperature is smoothly varying and no strong gradients exist.

Figure 3g–h shows a special case of the hybrid *oxy* colormap developed to represent river plume regions that may include both low and supersaturated oxygen conditions. The *oxy* colormap is an example of a specialized colormap designed for a very particular application—highlighting both a critical value that defines hypoxic conditions, with associated water-quality management implications, as well as identifying supersaturated oxygen conditions—while still following the general guidelines for designing good colormaps. Although its inflection point is not centered, *oxy* is a divergent colormap designed to emphasize the critical

AV WG Current Activities

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  - 2016-2018 Field Campaign
- Galveston to FGBNMS Transect
  - Private/Public Partnership with Liquid Robotics and Texas A&M University
- Stones Array
  - PPP Shell/Fugro/USM/TAMU
- Resources: GCOOS GANDALF glider data
- Resources: Stones Mooring
- Resources: NAS Loop Current Report