SCHMIDT OCEAN INSTITUTE

VISIONS TO REALITY

Scaling Up Marine Science and Conservation

2018

VISIONS TO REALITY

COVER

Main Image: In early March (two months before *Falkor* departed for the same mission), two saildrones were deployed from San Francisco to be a part of the "Voyage to the White Shark Café" expedition.They transmitted data in real-time since their departure, listening for the acoustic tags that were attached to sharks, while also scanning with a sonar to detect the deep scattering layer.

Hexagon 1: A cirrate octopus has ear-like fins that they use for propulsion.

Hexagon 2: Dr. Camilli directs the delicate deployment of a glider from *Falkor*'s aft deck.

Hexagon 3: A tall chimney in a new hydrothermal vent field discovered in 2018.

Hexagon 4: Trent Lukaczyk prepares a Flightwave Edge for a test flight from the storage deck of the R/V *Falkor*.

THIS PAGE

Researchers and ship crew inspect an AUV at the beginning of the "Pescadero Vent" expedition.

Table of
CONTENTS

Falkor sails at sunset in Hawaiian waters.

John Ryan and Brian Kieft, of Monterey Bay Aquarium Research Institute (MBARI), and Gabe Foreman, of University of Hawaii Manoa, guide LRAUV Opah off R/V *Falkor*'s aft deck during the autonomous robot's deployment.

VISIONS COMING TRUE

Artificial Intelligence and Robotics Begin to Transform Ocean Conservation and Research

The ocean gives life. It is no surprise that the abundance of liquid water is the principal habitability criterion in astrobiology. From the earliest emergence of life on Earth, the ocean has played a crucial part in sustaining it. For millennia, the seas have produced most of the oxygen we breathe, regulated our weather, and supplied critical nutrients and resources - despite the global disturbances from human activity in the recent decades.

Rapid ocean warming, acidification, deoxygenation, pollution, and overexploitation push marine life to the edge of survival. More than a quarter of all known oceanic species are losing a place to call home. Global scale and furious rate of change call for dramatic acceleration in our ability to understand, foresee, and avert their harmful effects. The developments in robotics, artificial intelligence (AI), and other technology frontiers can offer effective tools to accelerate ocean research, conservation, and management at scale.

Established nearly a decade ago to advance ocean research with innovation, Schmidt Ocean Institute completed its busiest and most productive year in 2018. Research vessel *Falkor* spent 243 days at sea supporting 11 select research projects, including 135 days with remotely operated vehicle SuBastian onboard.

These are all records for SOI. However, what hides behind these numbers is the true impact of the program. In this report, we discuss a series of transformative innovations demonstrated by SOI in 2018 to illustrate how we can scale our capacity to understand and better conserve our ocean. One example of this transformation took place in February when two Saildrones, unmanned surface wind and solar powered vehicles, were launched to the White Shark Café to study why this remote area attracts white sharks. Traversing thousands of miles halfway between Hawaii and California, Saildrones surveyed the region for a month ahead of *Falkor's* arrival. Their early entrance informed the scientific sampling plans, gathering rich sensor data that showed how small-scale eddies draw nutrients closer to the surface to enhance biological production; a good reason why the sharks may be drawn to this area. Following the expedition, the Saildrones duties were extended to track an oceanic front for SOI's next project a couple thousand miles away. These examples show how the Saildrones can be applied to future seagoing oceanography, where operational flexibility, endurance, low environmental impact, and excellent observational data can reduce operational costs and risks. This shift will make critical elements of marine field science accessible to oceanographic researchers around the world.

> At SOI, we are gearing up for the future, and the new ways oceanography will be done. We are always excited and curious to see what scientists who conduct research on board *Falkor* will come up with, and how, together, we can push the existing boundaries of marine research.
>
> - Wendy Schmidt.

Co-founders Eric and Wendy Schmidt.

Dr. Blair Thornton guides one of ROV SuBastian's dives during the "Adaptive Robotics" expedition in R/V *Falkor's* control room, using the maps and images acquired by the AUVs and processed by unsupervised algorithms. The expedition used a suite of AUVs with different mapping capabilities and specialties to gather the bathymetry data for the experimental Artificial Intelligence software to decipher.

Several projects this year focused on developing AI and machine learning tools to support marine science and management in near real time. In January, teams from Massachusetts Institute of Technology (MIT) and University of Sydney tested artificial intelligence (AI) -based multi-vehicle ocean survey software from aboard *Falkor* using SOI's high performance computer. The model was analyzed to inform real time planning of operations to collect valuable data as the survey progressed. SOI, in collaboration with the University of Porto, also developed Ocean Space Center software that was used in May to automatically guide dozens of aerial, surface, and submarine robots as they mapped the dynamic subtropical pacific ocean front in high resolution and 3D. The advanced software managed successful multi-robotic ocean surveys while requiring only one human observer in *Falkor's science* control room.

In July, teams from the Universities of Southampton and Tokyo, compiled the largest known centimeter-resolution color 3D map of deep seafloor from 1.3 million photos acquired on site at Hydrate Ridge off the coast of Oregon. They used unsupervised machine learning at sea to quickly find the areas of scientific interest and study rapidly changing seafloor that would otherwise be virtually impossible to find and sample within the cruise timeframe.

During the final expedition of the year, *Falkor* hosted a team of roboticists developing advanced AI for autonomous planetary exploration in deep space that will tolerate large communications latencies. The researchers tested non-deterministic ocean surveying, where robots could "locate gas seeps", "find rock formations", and "survey biological hotspots" without being explicitly programmed to do so and by having to learn the specifics of such tasks from diverse ocean data and expert annotations. In a successful demo, 11,000 square miles of ocean were intelligently surveyed within nine days. Highlighted by these projects, AI and machine learning are on the path to become indispensable for the future of oceanography.

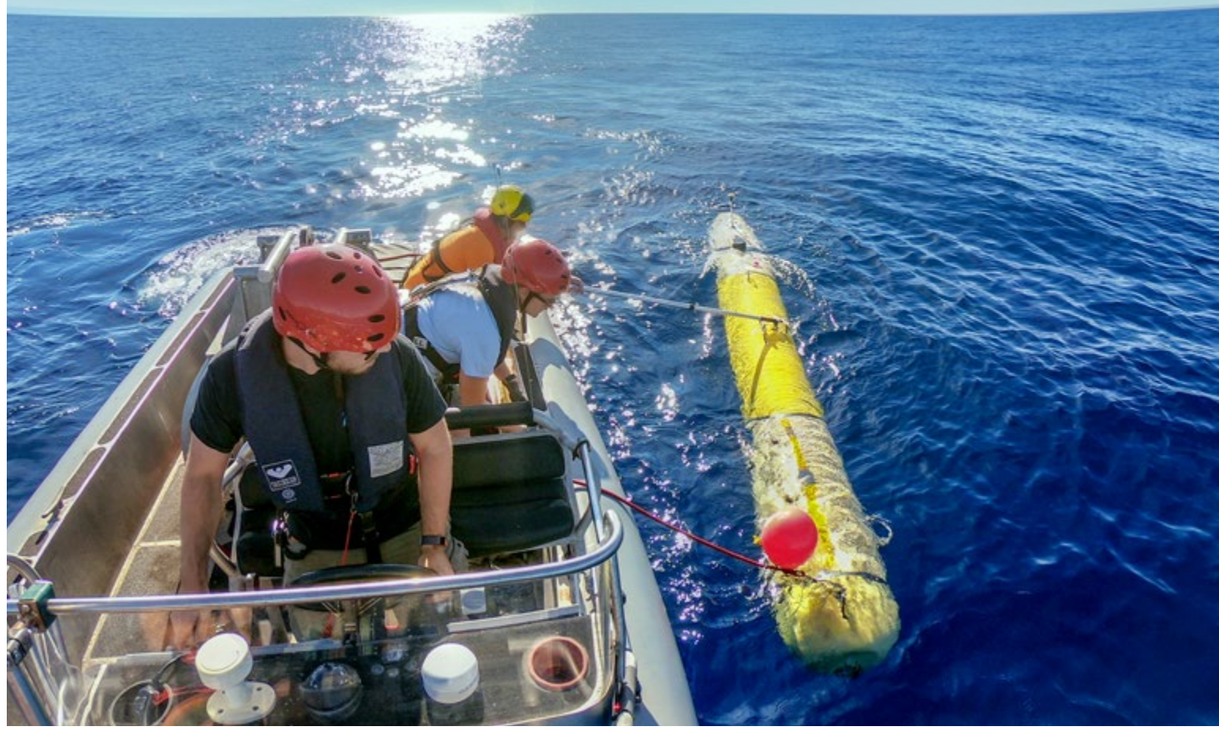
With these unique journeys of discovery and development, SOI continues to bring the ocean to people in their communities, schools, workplaces, and recreation groups. With these unique journeys of discovery and development, SOI continues to bring the ocean to people in their communities, schools, workplaces, and recreation groups. High-resolution imagery from ROV SuBastian has been viewed in real time on our YouTube channel by more than half a million people and featured in 15 documentaries this year. New collaborations with the Smithsonian Museum and Aquarium of the Pacific have allowed us to connect scientists with greater numbers of people on shore.

And SOI helps to make *Falkor*-related scientific articles open access so anyone can read the details from research done at sea.

2018 was a remarkably productive year for science, and for sharing the joy and excitement of our discoveries and achievements. This is just one of the reasons SOI was named by Marine Technology Reporter as one of the Top 10 Ocean Influencers.

This year our report is organized by themes that are building a foundation of success for the future. Readers will find details on how we are contributing to the arts, advancing ROV SuBastian's capabilities, sharing our incredible footage, and connecting with the public. We hope you will be inspired as much as we have been by our supported projects and research teams, technical innovations, and wondrous marine discoveries that have marked 2018.

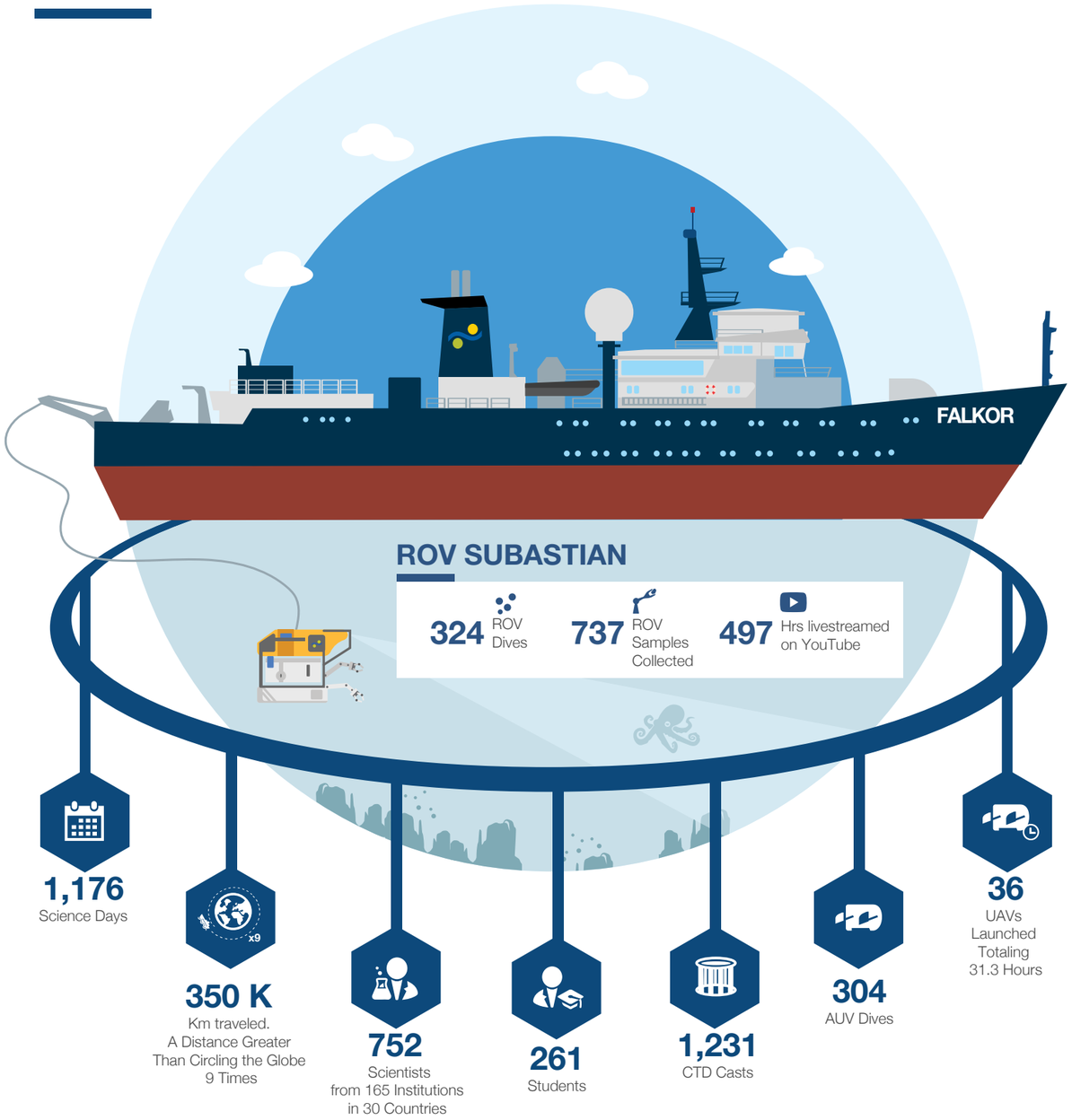
Crew of the "Pescadero Vent" expedition recover the mapping AUV D. Allan B. This autonomous underwater vehicle is equipped with four mapping sonars that operate simultaneously during a mission: a swath multibeam sonar, two sidescan sonars, and a sub-bottom profiler. The multibeam sonar produces high-resolution bathymetry (analogous to topography on land), the sidescan sonars produce imagery based on the intensity of the sound energy's reflections, and the sub-bottom profiler penetrates sediments on the seafloor, allowing the detection of layers within the sediments, faults, and depth to the basement rock.



AE2000f was the "Adaptive Robotics" expedition's scout. It would cruise at about 20km/h, collecting preliminary images of the seafloor: this data was then used to determine where the rest of the robots should focus their efforts.

NUMBERS AND METRICS

2013-2018



2018 OUTREACH

128 BLOGS

121 EXPEDITION VIDEOS

1,716,000 MINUTES of YouTube Video Watched

90 LIVE SHIP TO SHORE CONNECTIONS Viewed By 8,187 People

2,741 PEOPLE REACHED Through Community Presentations

1,000 PEOPLE WELCOMED onto *Falkor* for Tours

38 DOCUMENTARIES AND EXHIBITS Using SOI footage

531,460 Used the SOI Website

528,475 VIEWS on YouTube, 51% Increase from 2017

2018 SOCIAL MEDIA

REACHED **1 million+** People on Facebook

1,990,900 Impressions on Twitter

20,308 Instagram Likes

2018 DATA

272,160 REPORTS Sent to and Quality Processed by SAMOS

763 GB *Falkor* and SuBastian Data Downloaded from MGDS

7, 326 DATA FILES Downloaded from MGDS

573,590 KM2 of *Falkor* Mapping Data Merged into GMRT since 2012

203 DAYS OF DATA Sent to SAMOS

74TB of Data

ARTIST-AT-SEA

21 ARTISTS

99 PIECES OF ARTWORK Created through the Program

14 EXHIBITS in 10 Different Cities

WHERE
we have been

01
Coordinated Robotics: ‘Au‘Au Channel
Number: FK180119
Location: Honolulu, United States
Date: January - February

02
Eddy Exploration and Ecosystem Dynamics
Number: FK180310
Location: Honolulu, United States
Date: March - April

03
Voyage to the White Shark Café
Number: FK180420
Location: Honolulu to San Diego, United States
Date: April - May

04
Exploring Fronts with Multiple Robots
Number: FK180528
Location: San Diego, United States
Date: June

05
Solving Microbial Mysteries with Autonomous Technology
Number: FK190624
Location: San Diego, United States
Date: June - July

06
The Seeping Cascadia Margin
Number: FK180722
Location: San Diego to Astoria, United States
Date: July - August

07
Adaptive Robotics at Barkley Canyon & Hydrate Ridge
Number: Fk180731
Location: Astoria, United States
Date: August

08
Hunting Bubbles: Understanding Plumes of Seafloor Methane
Number: FK190824
Location: Astoria to San Francisco, United States
Date: August - September

09
Characterizing Venting and Seepage Along the California Coast
Number: FK181005
Location: San Francisco to San Diego, United States
Date: October

10
Interdisciplinary Investigation of a New Hydrothermal Vent Field
Number: FK181031
Location: San Diego, United States to Manzanillo, Mexico
Date: November

Conducted research in Mexican waters working closely with the U.S. Embassy in Mexico City. Hosted a foreign observer from the Deputy General Directorate of Oceanography, Hydrography and Meteorology onboard Falkor for the cruise and will be sharing the expedition data with local scientific agencies.

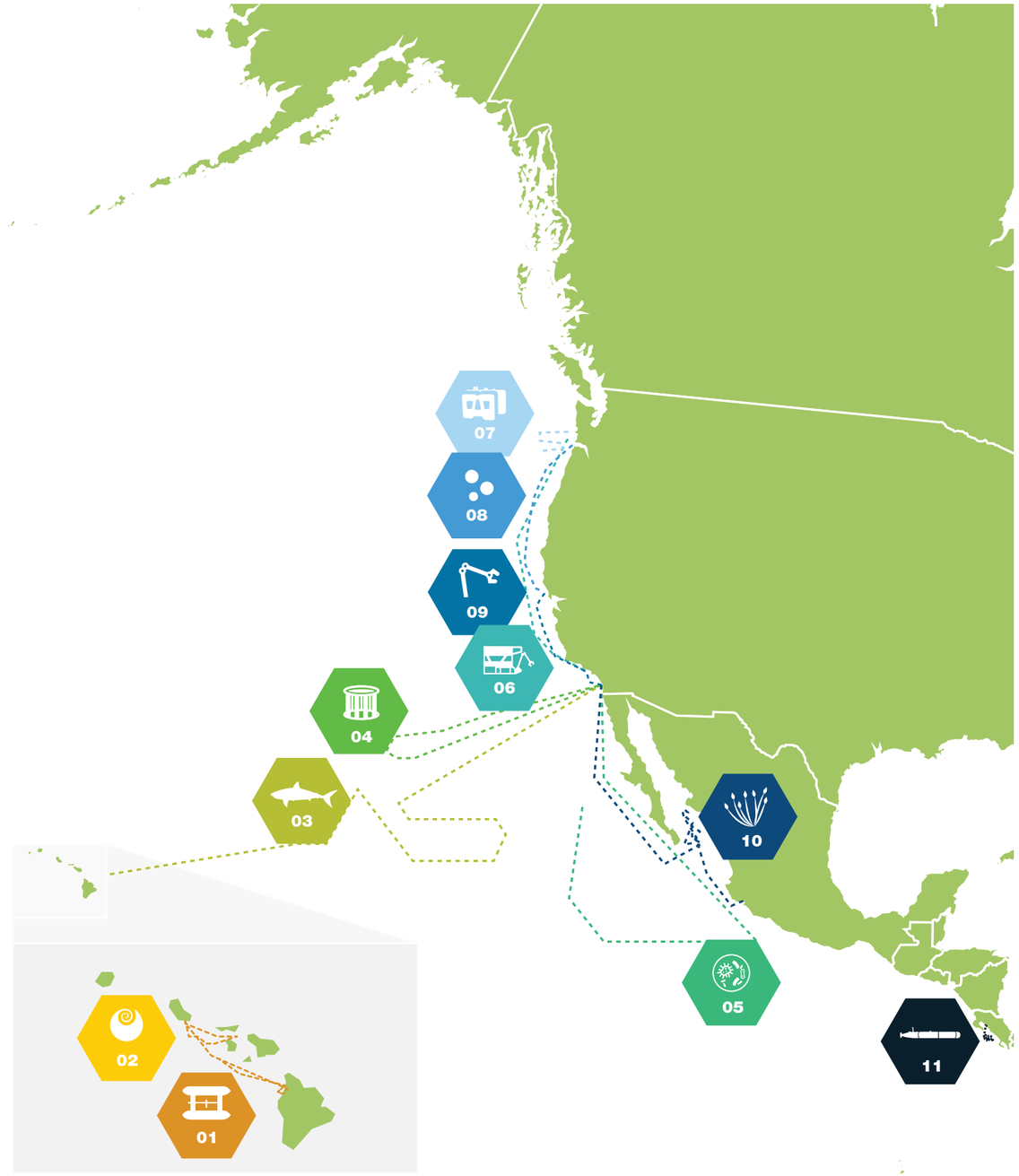
11
New Approaches To Autonomous Exploration At The Costa Rican Shelf Break
Number: FK181210
Location: Puntarenas, Costa Rica
Date: December

Hosted tours on Falkor for several Costa Rican dignitaries and U.S. Embassy affiliates in San Jose.

“

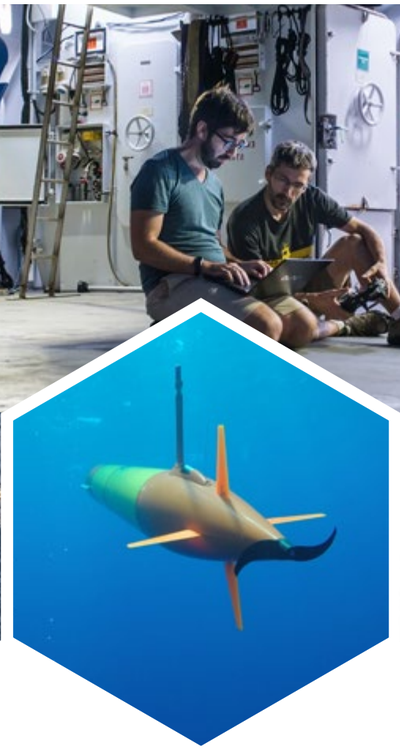
The deep ocean is still one of the least explored frontiers in the solar system. Maps of our planet are not as detailed as those of Mercury, Venus, Mars or the Moon, because it is hard to map underwater. This is the frontier.

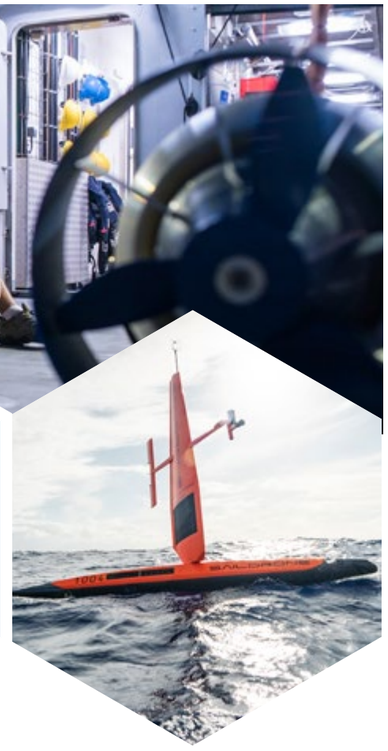
- Robert Zierenberg,
Principal Investigator.



MAKING WAVES

2018 Highlights





Prof. Williams and Dr. Lachlan Toohey continue their work with the NextGen vehicle, long after dark.

Improved marine surveys by teaching robots to collaborate and share knowledge

Coordinated Robotics 2, Hawaii

Demonstrated from aboard *Falkor* coordinated operations and data-driven site selection with multiple autonomous underwater vehicles. Refining techniques using several vehicles will make habitat mapping simpler and easier for a more scalable approach that can present follow-on benefits for management and policy-making.

Achieved the longest deployment of Environmental Sampling Processors on Long Range AUVs

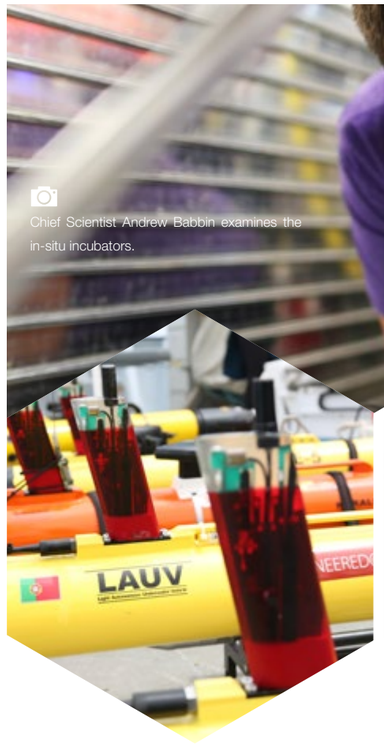
Eddy Exploration & Ecosystem Dynamics, Hawaii

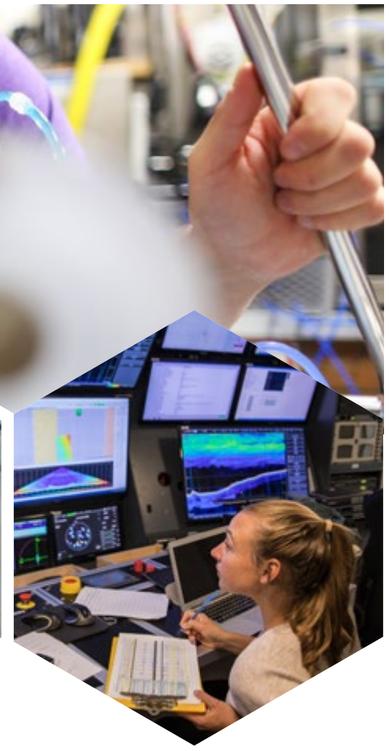
Completed the first open ocean deployment of long range autonomous underwater vehicles (LRAUVs); they are the only AUVs that can survey filtered seawater in situ and allow for sampling in remote or dangerous locations. Seawater collected with the LRAUVs is being sequenced to determine microbial communities found at the ocean surface, this is important baseline information to have as seawater temperatures increase.

Protected white sharks with Saildrones and shipboard eDNA

Voyage to the White Shark Cafe, California

Documented the oceanographic conditions and biological productivity of a white shark congregation zone. This was achieved with a multi-platform sampling program coupling *Falkor*, SuBastian, and two Saildrone autonomous surface vehicles, gathering crucial ocean currents and animal density data. The data will illuminate this little-studied ecosystem and contribute to the conservation efforts of the high seas.





Chief Scientist Andrew Babbin examines the in-situ incubators.

Located and mapped a Pacific subtropical ocean front using a coordinated fleet of robots

Exploring Fronts with Multiple Robots, California

Tracked, mapped, and sampled a mesoscale filament of a major ocean front with multiple autonomous underwater, surface, and aerial vehicles using open-source communication. The technologies represent an important step towards achieving the levels of persistence, spatial and temporal resolution, as well as coverage, required for ocean studies in a changing climate.

Tested in situ microbial incubators to understand how marine life adapts to oxygen depletion in the ocean

Solving Microbial Mysteries, California

Tested and refined an autonomous in situ incubation device allowing shipboard scientists near-continuous monitoring in an oxygen deficient ocean system. The seawater incubations will provide better insight into how microbes interact with each other and their chemical environment. The refinements in low oxygen marine system operations will help scientists better understand the ocean's role in moderating climatic changes.

Reached non-science audiences with artistic visualization of marine data

The Seeping Cascadia Margin, Oregon

Created detailed mid-water and seafloor maps in an unsurveyed methane seep region with six artists and two Student Opportunities participants. The maps will be used to identify where hydrocarbon seeps are occurring and their flow activity for future observation and research. The artists captured the mapping work of *Falkor's* shipboard marine technicians with striking art forms including a light painting performance, oceanscape resin art, woodworking sculpture, portrait painting, cyanotype prints, and a life-size mural of the *Pseudoliparis swirei* ghost fish.

Dr. Scott Wankel preparing the mass spectrometer that will live on SuBastian during the next month - giving near real time continual measurements of methane.

Guided exploration and research of changing seafloor habitats with AI

Characterizing Venting and Seeping, California

Gained insight into the role of gas vents and seeps in the ecology of the Southern California Borderland, using ROV SuBastian and the advanced seafloor observatory (ABISS). The ABISS lander deployments showed that methane venting is more episodic than previously known, which changes assumptions about methane escape from the seafloor to the atmosphere. The science team is producing a map of the contiguous seeps and analyzing the relationships among the animals, including potentially new species, to understand the connectivity of these habitats.

Developed new ways to understand ocean cycles via methane bubbles

Hunting Bubbles: Understanding Plumes of Seafloor Methane, Oregon

Installed a novel bubble capture system on ROV SuBastian to take chemical measurements of bubble composition and gather data on the chemical dynamics of bubbles. The development of this equipment (and cutting-edge sensors) is important in illustrating changes in methane from venting locations across a spatial scale and over time. The large flux of this methane into the ocean may indirectly play an important part in the carbon cycle, which is closely linked to Earth's climate.

Revealed new sites and species in the California Borderland

Adaptive Robotics at Hydrate Ridge, Oregon

Used unsupervised learning techniques with 3D reconstruction pipelines to analyze imagery collected between AUV deployments. As a result, the largest known continuous photogrammetric reconstruction of seafloor mapped at sub-centimeter resolution was created, including an 11.4 hectare dense 3D image reconstruction. Developing end-to-end autonomy is critical to scale robotic operations so that hundreds may be deployed simultaneously in the future, giving scientists the ability to monitor larger areas and understand the ocean more efficiently.

Richard Camilli, Principal Investigator of the "New Approaches To Autonomous Exploration At The Costa Rican Shelf Break" and David Pinga assemble a Slocum glider in R/V *Falkor*'s wet lab.

Conducted centimeter-scale AUV survey of hydrothermal vents in Pescadero Basin

Interdisciplinary Investigation of a New Hydrothermal Vent Field, Mexico

Completed centimeter scale resolution mapping resulting in the discovery of a new vent field (JaichMaat). The list of species occurrences for the area was significantly expanded and the team collected several animals that may represent new species. The discovered site is an important location to try to understand how vent fauna colonize, evolve, and speciate.

Tested AI-driven robots for a possible extraterrestrial mission

New Approaches to Autonomous Exploration, Costa Rica

Operated multiple self-controlled robotic vehicles while successfully developing AI for autonomous exploration and research of remote uncharted environments. This technology will support future oceanographic and planetary exploration, where due to communications latencies robots routinely need to make tactical decisions without human intervention.

Broadened participation in ocean sciences

Doubled viewership of incredible 4K deep-sea imagery from ROV SuBastian. This resulted in the use of footage in documentaries, television, and museum exhibits at the Dundee Heritage Trust, and Barbican Museum. We also hosted public ship tour days during US port calls, bringing more than 1,000 people on board. Additionally, SOI continued our traveling Artist-at-Sea exhibit showcasing 11 new artists at venues including Aquarium of the Pacific, Exploratorium, and the NOAA Exploration Forum. The works incorporate data collected during expeditions and have been used for outreach by the scientists as well.

The challenge is trying to do as much as we can to help people make sensible decisions. Having more ocean observations is critical to good science and providing a comprehensive view of what is happening, and how things are changing. This will build our ability to understand the ocean, and to make wiser decisions and policies in the future.

- Oscar Pizarro,
Principal Investigator.

The autonomous vehicles - aerial and underwater - utilized by the Ocean Robots Team line the aft deck of R/V *Falkor.*

SCALABLE OCEAN RESEARCH WITH

AUTONOMOUS ROBOTS

SCALABLE OCEAN RESEARCH

with Autonomous Robots

The ocean is too large to observe with conventional means. SOI recognizes that in order to make meaningful advances there must be more agile, resilient, and robust platforms. Robots and AI can greatly improve coverage and cost-efficiency for select ocean observations by reducing risk, and facilitating high resolution spatially distributed surveys of dynamic marine processes, as illustrated by the projects discussed in this section.

DATA-DRIVEN CORAL REEF SURVEYS WITH COORDINATED ROBOTIC TEAMS

In January, SOI welcomed Dr. Oscar Pizarro, Australian Centre for Field Robotics (ACFR), and his collaborators from MIT and the University of Sydney back aboard *Falkor* to research and demonstrate multi-robotic surveys of coral reefs. As part of this project, SOI supported the development and testing of data-driven planning algorithms for autonomous marine surveys completed by heterogeneous robots.

This was illustrated by running a consolidated model of a coral reef (in the 'Au'Au channel off Maui, HI) on *Falkor's* high performance computer that was continuously updated with new data gathered by the robotic systems. As each vehicle transmitted fresh observational data to the common model, the software algorithms updated the estimates of uncertainty for each feature of scientific interest. This resulted in identified locations and parameters to be surveyed next by each vehicle, taking in account their operational status, positions, and sensing capabilities. The coordinated robots collected over half a million georeferenced images covering 77,453 square meters of seafloor.

"The challenge is trying to do as much as we can to help people make sensible decisions," said Dr. Pizarro. "This expedition was an opportunity to try techniques that automate science plans. Having more ocean observations is critical to good science and providing a comprehensive view of what is happening, and how things are changing. This will build our ability to understand the ocean, and to make wiser decisions and policies in the future."

Researchers work on a programming and optimizing an Iver autonomous vehicles in *Falkor*'s Wet Lab.

COLLECTED MORE THAN 500,000
georeferenced images along the the 'Au'Au Channel covering 77,453 m^2 of seafloor

ADAPTIVE MICROBIAL SAMPLING OF OCEANIC EDDIES WITH LONG RANGE AUVS

The second *Falkor* expedition of the year was led by Drs. Sam Wilson and Steve Poulos, University of Hawaii, in collaboration with the Monterey Bay Aquarium Research Institute (MBARI), giving way to the first-ever open ocean deployment, microbial sampling, and in situ data analysis by long range autonomous underwater vehicles (LRAUVs). The LRAUVs are a great engineering feat that enable ocean observation and sampling in remote locations.

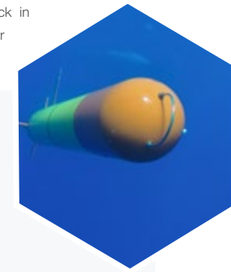
Deploying multiple LRAUVs simultaneously allowed the research team aboard *Falkor* to adaptively sample a moving ocean eddy field. This research set a new record for the duration of this type of mission, and characterized in unprecedented detail microbial communities found in eddy fields. The vehicles captured and analyzed environmental samples in situ while being able to amend and guide their own sampling patterns based on onboard data analyses. The three LRAUVs were fitted with next generation Environmental Sample Processors (ESPs) and other sensors to monitor seawater parameters and identify hydrographic features that are likely to host interesting microbial processes.

The results were stunning, never before in microbial oceanography have researchers been able to sample the open ocean deep chlorophyll maximum and other parameters with this level of precision.

The vehicles offer a novel perspective of these common yet poorly understood oceanic microbial processes. Seawater collected with the LRAUVs is being sequenced and analyzed to determine the structure and composition of the resident marine microbial communities. The samples will help tell us how marine microbes interact with each other in space and time.

We need to understand these microscale processes in order to comprehend bigger processes such as carbon cycling across the global ocean basins.

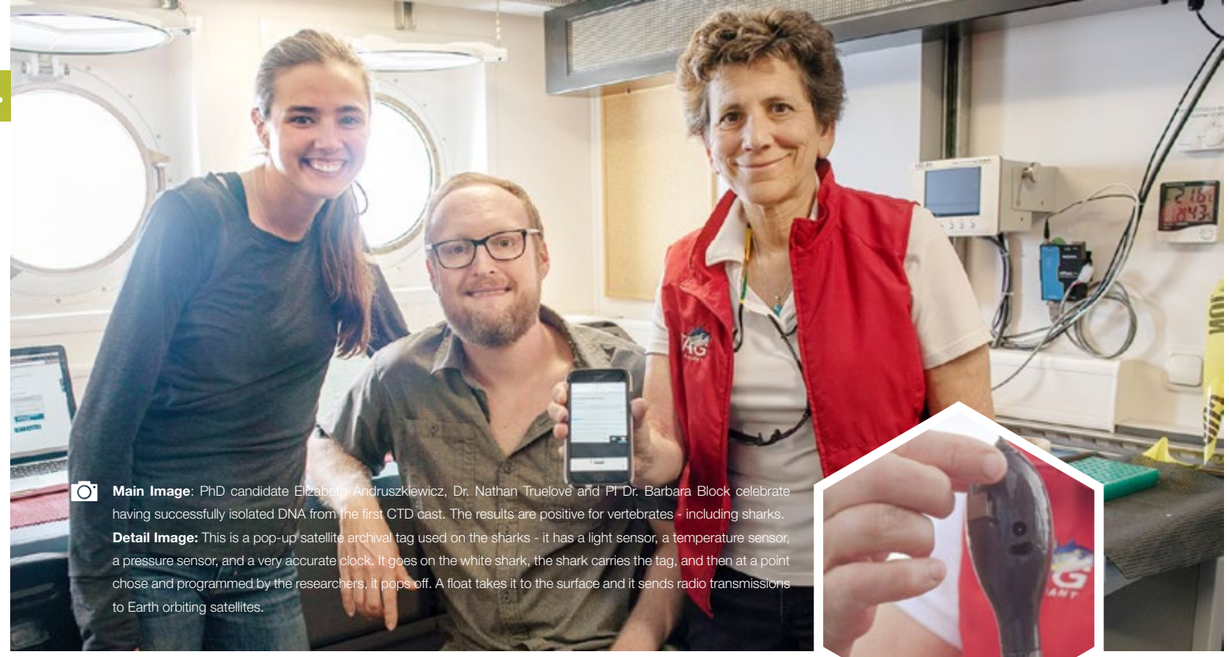
LRAUVs were programmed with missions to detect features inside eddys. When a feature is discovered, the LRAUVs lock in and can track the feature for days at a time.



LRAUVs sample to depths of **300 m**

with an operational range of **1,000 km**

Researchers prepare to launch a LRAUV from *Falkor*'s midship.



Main Image: PhD candidate Elizabeth Andruszkiewicz, Dr. Nathan Truelove and PI Dr. Barbara Block celebrate having successfully isolated DNA from the first CTD cast. The results are positive for vertebrates - including sharks.
Detail Image: This is a pop-up satellite archival tag used on the sharks - it has a light sensor, a temperature sensor, a pressure sensor, and a very accurate clock. It goes on the white shark, the shark carries the tag, and then at a point chose and programmed by the researchers, it pops off. A float takes it to the surface and it sends radio transmissions to Earth orbiting satellites.

MID-OCEAN RESEARCH AND MONITORING OF WHITE SHARKS WITH SAILDRONES

Science on *Falkor* was guided for the first time by two sensor-laden Saildrones, autonomous surface vehicles with unlimited range and endurance.

These long-range vehicles were launched from San Francisco Bay, reaching the White Shark Café a month ahead of *Falkor's* arrival to characterize oceanographic conditions, currents, and animal densities in the open ocean region halfway between Hawaii and the Baja California Peninsula.

The data gathered was critical for the shipboard research team to accurately identify the white shark congregation area that was later studied with *Falkor* and SuBastian.

Dr. Barbara Block, Stanford University, and her international team, led this study to understand why this remote and desolate area attracts massive-sized white sharks each year. A greater understanding of this otherwise unknown habitat for sharks was achieved with a multi-platform sampling program coupling *Falkor* with shore-launched robotic vehicles working in tandem. The shipboard team was able to locate all shark tags that were deployed in the previous fall off the coast of California.

Scientific observations, data collection, and sample analysis, including shipboard eDNA sequencing, continued on *Falkor*. The data provided important new insights into the habitat and white shark behavior.

For instance, Saildrone data showed how small-scale ocean eddies draw nutrients closer to the surface, enhancing biological production, which could make this region more appealing for sharks. This finding offered a valuable head start to the scientists in addressing the key questions of their study.

"We have doubled the current 20-year data set on white shark diving behaviors and environmental preferences in just three weeks using tools that provided a rapid census of the predators and prey of a remote ocean region," said Dr. Block. "This helps establish observations that will allow for better understanding of this environment and why it attracts large predators."

80 data stations

28 CTD casts

10 shark satellite pop-up tags recovered

9 SuBastian Dives yielding 70+ hours of midwater observations in habitat never before surveyed

STRETCHING THE LIMITS OF ROBOTIC AUTONOMY FOR OCEAN SURVEYING

While returning to California, the two Saildrones were remotely re-tasked to support a project led by Dr. João de Sousa, University of Porto. The robust multi-vehicle mission used planning and control algorithms to enable real-time analysis of complex ocean dynamics, specifically locating, tracking, and measuring the North Pacific Subtropical Front.

This multi-platform approach was completed with many low cost vehicles deployed from *Falkor* in different mediums, including underwater, surface and air. More than a dozen robotic systems were deployed and simultaneously operated by an SOI-supported Ocean Space Center software running aboard *Falkor*, allowing the researchers to map the oceanic feature in high, sub-mesoscale resolution, including space and time.

To coordinate the operations of multiple robotic platforms, the team flew unmanned aerial vehicles (UAVs) over the areas of operations to collect oceanographic observations, serving as "mules" to ferry data between distant AUVs and the *Falkor*. By the end of the expedition, the AUVs traveled over 3,430 kilometers for approximately 500 hours; and the UAVs performed over 25 flawless flights totaling 10 hours.

The technologies used on this expedition represent an important step towards achieving the levels of persistence, spatial and temporal resolution, as well as coverage, required for scalable ocean studies in a changing climate . "Oceans are the Earth's life support system. To be properly taken care of, they need to be characterized with much higher resolution and coverage in time in space than what's possible with ships," said Dr. de Sousa.

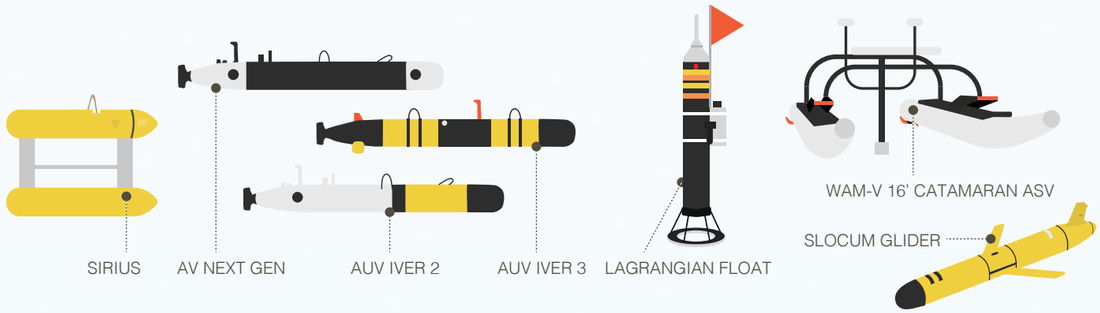
Top Image: Trent Lukaczyk prepares a Flightwave Edge for a test flight from the storage deck of the R/V *Falkor*.

Middle Image: Crew and science team including John Ryan (MBARI), Allan Doyle (Chief officer *Falkor*), Brian Kieft (MBARI), and Gabe Foreman (of University of Hawaii Manoa) begin to guide LRAUV Opah off R/V *Falkor*'s aft deck during the autonomous robot's deployment.

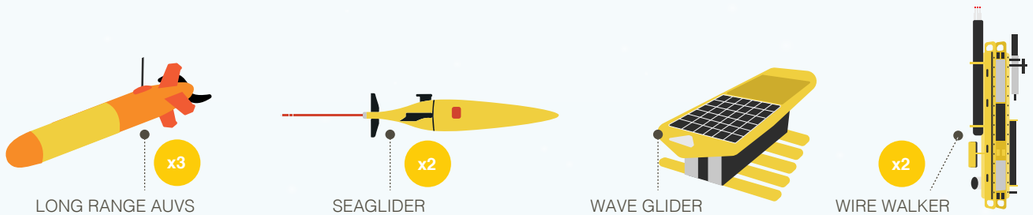
Bottom Image: A Flightwave Edge UAV, piloted by Trent Lukaczyk, flies towards R/V *Falkor*. The Unmanned Aerial Vehicle worked in concert with underwater robotics and the crew onboard the ship gathering data.

A WORKING PLATFORM

COORDINATED ROBOTICS: 'AU'AU CHANNEL

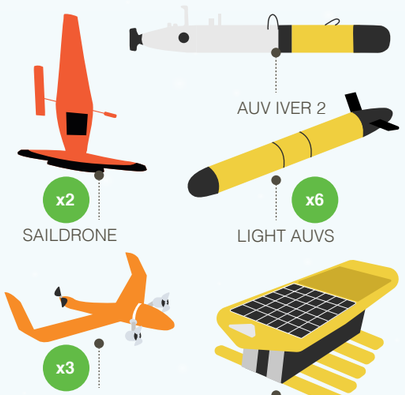


EDDY EXPLORATION AND ECOSYSTEM DYNAMICS

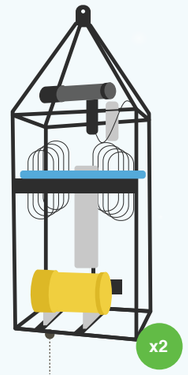


VOYAGE TO THE WHITE SHARK CAFÉ

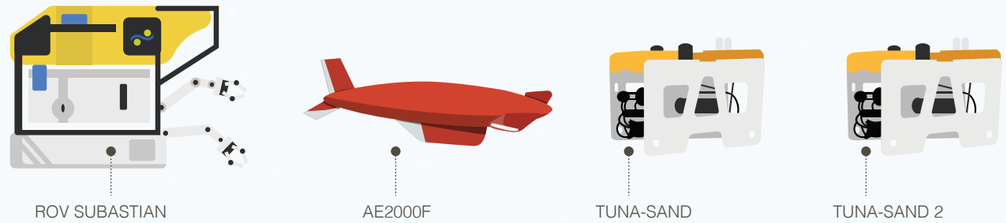
EXPLORING FRONTS WITH MULTIPLE ROBOTS



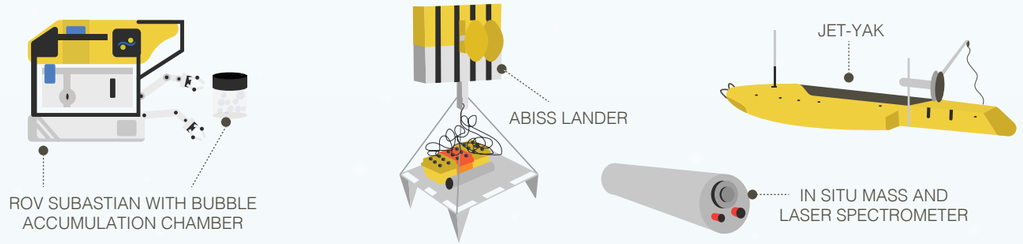
SOLVING MICROBIAL MYSTERIES WITH AUTONOMOUS TECHNOLOGY



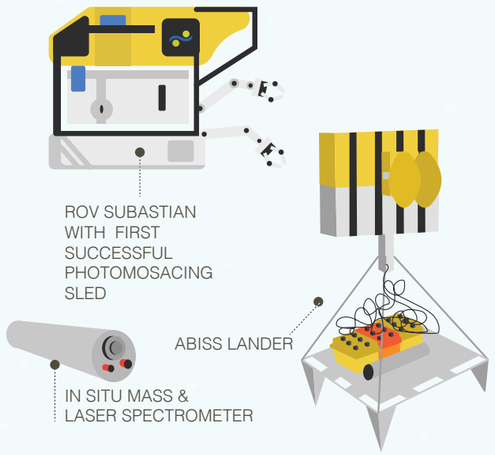
ADAPTIVE ROBOTICS AT BARKLEY CANYON & HYDRATE RIDGE



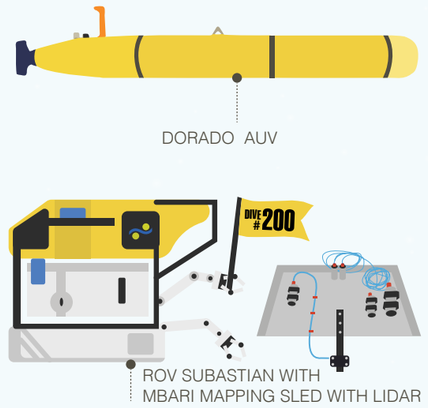
HUNTING BUBBLES: UNDERSTANDING PLUMES OF SEAFLOOR METHANE



CHARACTERIZING VENTING AND SEEPAGE ALONG THE CALIFORNIA COAST



INTERDISCIPLINARY INVESTIGATION OF A NEW HYDROTHERMAL VENT FIELD



It is amazing to see large areas of the seafloor mapped only days after the raw data was collected. It is not just the size of the map, but the way we used it to inform our on-site decisions. This makes a real difference as the technology allows us to visualize wide areas at high resolution, and select where we should collect data. This has not previously been possible.

- Blair Thornton,
Principal Investigator.

Chief Scientist Blair Thornton consults the visual map of the seafloor, in order to confirm the location to send ROV SuBastian.

ARTIFICIAL INTELLIGENCE AND
DATA ANALYTICS
ACCELERATE MARINE SCIENCE

ARTIFICIAL INTELLIGENCE

and Cloud Data Analytics Accelerate Marine Science

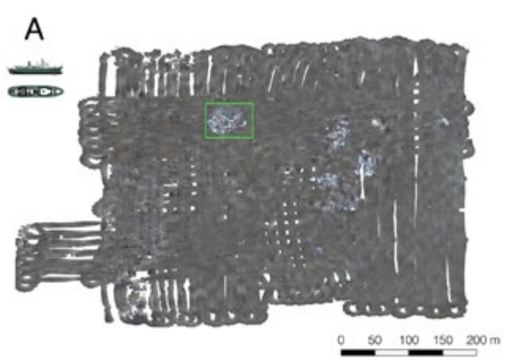
Ocean observing data is growing at an accelerating pace, however, more is needed to enable well informed, ocean conservation and management. Many conventional workflows for marine data processing in ocean conservation and research are not automated, inhibiting the productivity of researchers and managers. This year SOI focused on projects leveraging the utilization of *Falkor* and ROV SuBastian that worked towards automating marine data analysis workflows to accelerate the understanding of our rapidly changing marine habitats and multiply the conservation benefits.

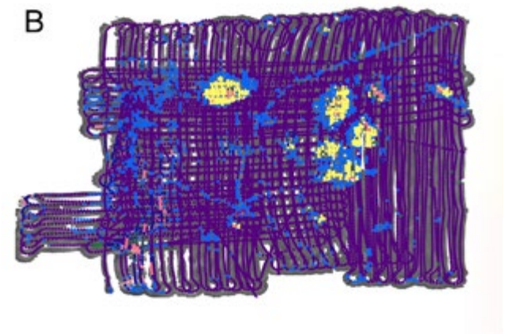
SOI-SUPPORTED SCIENTIFIC IMAGE ANNOTATION SOFTWARE BECOMES A NATIONAL STANDARD

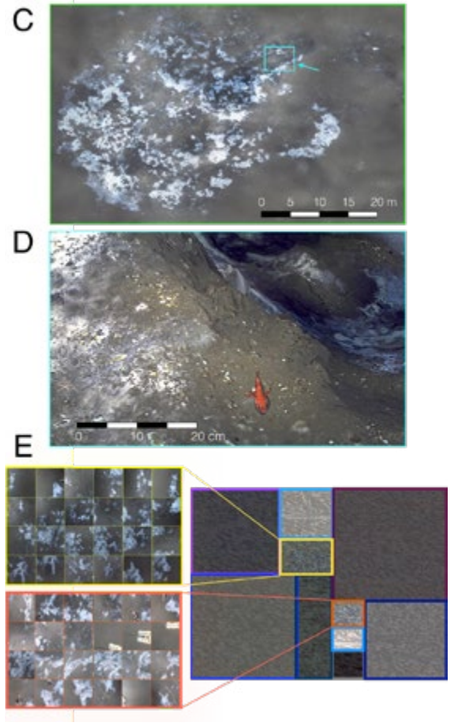
Squidle+ is a web-based open source software for the annotation of marine scientific images, videos, and photomosaics. SOI has supported the development of this software since 2015 when it was initially deployed as part of a *Falkor*-hosted R&D project. The near-real-time crowd-sourced annotation of AUV acquired seafloor imagery has been further developed by SOI for shipboard ROV SuBastian annotation and event logging.

The enhanced version of *Squidle+* has been adopted by the Australian National Environmental Science Program and Japan Agency for Marine Science and Technology as the preferred platform for annotating images. Other government agencies such as Canada's Department of Fisheries and Oceans and U.S.'s National Oceanic and Atmospheric Administration are exploring using the platform for their image annotation purposes as well.

Dr. Richard Camilli directs the deployment of a Slocum glider from *Falkor*'s aft deck off the coast of Costa Rica.







A) 3D photogrammetric reconstruction of the Southern Hydrates Ridge (depth 780 m) that was generated by the AUV Ae2000f. The mapped area covers 11.8 ha at an average resolution of 6 mm and is the largest known expanse of seafloor that has been visually mapped in colour. The *Falkor* shown to scale in the top left of the panel.
B) Outputs of an unsupervised classifier that was used to analyze the imagery between deployments and generated information summaries such as the image class matrix **E)**.
C) White bacterial mat that was identified by the classifier, which was subsequently surveyed by the AUV Tuna-sand at sub-millimeter resolution to gather more detailed information. The arrow in **C)** illustrates the direction from which the isometric view of the reconstruction is viewed in **D).**

COMPILING AND ANALYSING THE LARGEST KNOWN CENTIMETER-RESOLUTION MODEL OF SEAFLOOR

In August, Dr. Blair Thornton, University of Southampton, and his collaborators from the UK and Japan deployed two AUVs from *Falkor* to acquire 1.3 million seafloor images of changing microbial habitats surrounding methane seeps off the U.S. West Coast. The team used shipboard high performance computers to rapidly compose these images into the largest known centimeter-resolution color 3D model of 11.4 hectares of the seafloor. An unsupervised machine learning algorithm was used to cluster the images by visual similarity and locate continuously changing microbial hotspots on the seafloor. Detailed surveys were conducted using ROV SuBastian the following day.

This project demonstrated how throughput data processing and machine learning can multiply the productivity of marine scientists. It allowed the team to make quick and well-informed sampling decisions and conduct fine scale surveys to study habitats that would otherwise be virtually impossible to observe in detail. The resulting composite map was invaluable in planning operations, including the recovery of seafloor instruments, re-visiting active bubble plumes, and made the entire operation more efficient. Using AI, scientists have the ability to gather data and make decisions in expedition relevant time frames, prompting better use of the robotic systems deployed at sea.

> Ultimately, our goal is to use what we have learned to inform the design of fully autonomous robots that will one day explore the oceans of Europa and Enceladus.
>
> - Richard Camili,
> Principal Investigator.

TEACHING ROBOTS TO LEARN FROM DATA TO PLAN AND EXECUTE OCEAN SURVEYS

Falkor's last expedition of 2018 hosted specialized teams, including computer scientists, roboticists, and oceanographic researchers from Woods Hole Oceanographic Institution (WHOI), MIT, NASA, ACFR, and the University of Michigan. The groups worked together, developing advanced AI for autonomous robotic exploration of remote uncharted environments. This technology will support future planetary exploration in space and in deep sea habitats, where due to communications latencies, robots need to make tactical decisions without human intervention.

One of the developed science software tools, the AI/machine learning-based autonomous planner "Spock," was tested aboard *Falkor* in December. Deployed on the high performance computer, "Spock" parsed large volumes of diverse marine data from the ship's and robots' instruments, earlier surveys, and scientific annotations to suggest what new sites may be of potential interest for scientific surveys. Instead of traditional localization programming to avoid hazards, "Spock" let the shipboard researchers task the robots at much higher levels by simply asking them to "locate gas seeps", "find rock formations", or "survey biological hotspots."

All other mission details such as where to look for such features and how to survey them with available sensors were determined by AI.

The researchers led by Dr. Richard Camilli were fascinated to see the robotic systems demonstrating the ability to find and map rocky outcrops and biological hotspots without being directed where to search. Rapid, AI-driven data analysis more than doubled the utilization of robots during this expedition and allowed the researchers to survey 28,490 square kilometers of ocean within only nine days.

Left Image: Navigator Officer Marissa Judkins is part of the team performing final checks before launching TUNA-SAND. With its systems and navigation capabilities tested and confirmed, it is ready to begin work at the sea floor.

Top Image: Richard Camilli, Principal Investigator of the "New Approaches To Autonomous Exploration At The Costa Rican Shelf Break" and David Pinga assemble a Sloucm glider in R/V *Falkor's* wet lab.

Hexagon 1: Technicians Tetsu Koike and Kazunori Nagano work on the camera load onboard AE200f, which is advancing visual recordings made while exploring the ocean floor.

Hexagon 2: ROV pilot Jason Rodriguez wears eye detection glasses, which record his eye motions and focus, as part of the data that will be used to train robotic algorithms.

We are taking the latest and greatest technologies and using it to understand the relationships among the geology, chemistry, and the animal life.

- Peter Girguis,
Principal Investigator.

ROV Subastian retrieves a carbonate chimney from the ocean floor (roughly 700 meters deep, near Point Dume, California)

SCALING UP MARINE CONSERVATION WITH

TECHNICAL INNOVATION

Scaling up Marine Conservation with

TECHNICAL INNOVATION

SOI is dedicated to using and supporting the advancement of the latest technology to better assess and broaden the understanding of marine habitats in an era of rapid global change. Ocean managers urgently need swift monitoring and improved tools to track and counter declining ecosystem conditions. Better data and observation capacity will play a central role in improving protection.

In 2018, SOI collaborated with scientists and engineers to build and test new instruments that provide the ability to broaden the reach and quicken the pace of important research dedicated to pressing ocean issues, such as increased methane release into the atmosphere and declining coral reefs.

SHIPBOARD EDNA SEQUENCING AND DATA LOGGERS PROTECT WHITE SHARKS

White sharks led Dr. Barbara Block, Stanford University, and her team aboard *Falkor* to a unique part of the ocean, the White Shark Café. This little-studied and remote high seas region was found to have surprising biodiversity. The completed research will contribute imperative information for a draft proposal to the UNESCO World Heritage team justifying extension of conservation efforts to the high seas and nominate the area as a World Heritage site.

In a location that scientists thought was a nutrient-poor desert due to satellite underestimates, the team, using ROV SuBastian and a suite of other data collection instruments, found impressive levels of biodiversity and a more interesting structure of mesoscale eddies and ocean convergences than previously thought. There appears to be plenty of food to support a population of hungry top predators who might graze while they meet in the Café.

The white sharks were successfully identified in the region using eDNA, a technique that allows scientists to sample from the environment (i.e. ocean water) rather than directly from the sharks' bodies. Scientists were also able to collect 90% of the pop-up satellite archival tags, a small "wearable" tag that were placed on the sharks in California before the expedition, demonstrating a connection between the California sharks and the café.

Main Image: A stunning jellyfish image taken with ROV SuBastian in the White Shark Cafe. / **Hexagon:** Elizabeth (Eily) Andruszkiewicz is a PhD candidate under Dr. Alexandria Boehm at Stanford University in the Civil and Environmental Engineering Department. Her research focuses on using environmental DNA (eDNA) to track marine vertebrates.

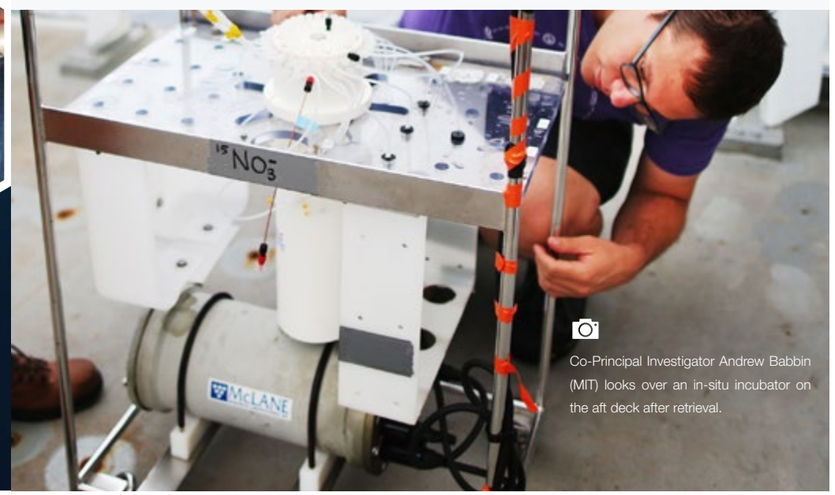
IN SITU INCUBATORS STUDY MICROBIAL RESPONSE TO OCEAN DEOXYGENATION

In July, an interdisciplinary team of scientists and students led by Dr. Andrew Babbin, MIT, set out aboard *Falkor* to test new in situ microbial incubators in low-oxygen ocean regions off the coast of California. The incubators were replaced with oxygen impermeable versions and provided high temporal and spatial resolution of the upper ocean. The near-continuous monitoring will help provide answers on how oxygen-requiring organisms can survive in a low oxygen environment. This is critical as marine microbes control the chemical landscape of the ocean that other species like phytoplankton, fish, corals, etc. adapt. The refinements in how low oxygen marine systems operate will help scientists better understand the ocean's role in moderating climatic changes.

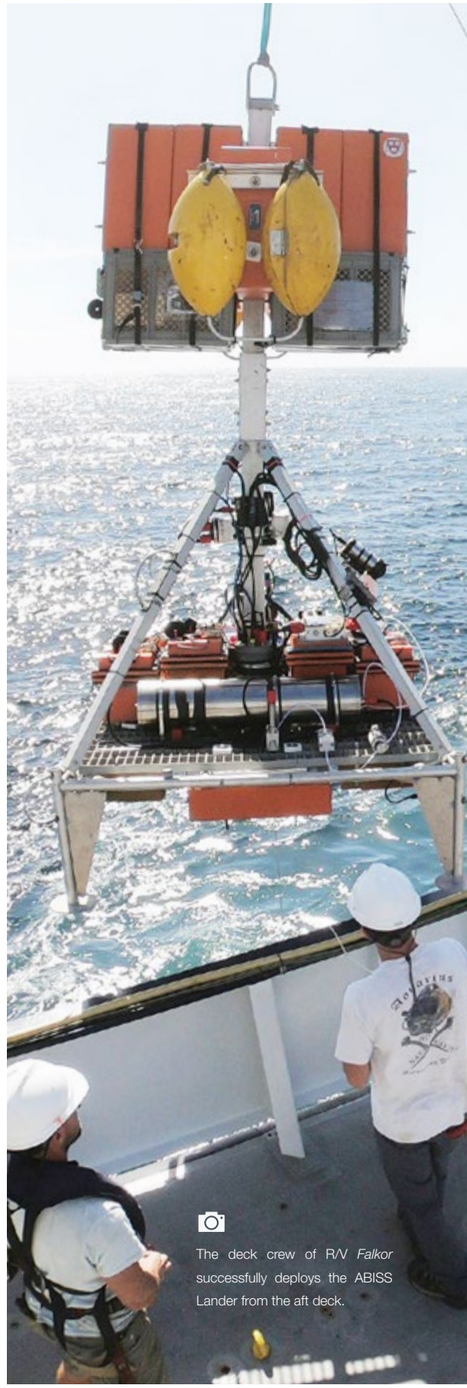
As a result of the expedition, the team was able to iteratively test and improve the new incubators, making them more precise. During the two weeks aboard *Falkor*, an impressive dataset was generated investigating how chemical cycles and microorganisms interact in the ocean. These collections allowed the science party to obtain a valuable time series characterizing the dynamics of more than a dozen chemical parameters that will improve our understanding of the role of fixed nitrogen and microbial interactions in oxygen deficient waters.

600 chemical analyses
for acidity, nutrients, and dissolved gases

325 shipboard experiments
gathering 15,000 bottles of seawater for further analysis



Co-Principal Investigator Andrew Babbin (MIT) looks over an in-situ incubator on the aft deck after retrieval.



The deck crew of R/V *Falkor* successfully deploys the ABISS Lander from the aft deck.

ROV crew helps Dr. Scott Wankel diagnose a component of the methane gas sensors before a dive.

WARMING GAS HYDRATES LEAK METHANE TO THE OCEAN SURFACE

Methane greatly impacts our climate system, but the processes that transfer methane from the deep sea into the ocean and atmosphere remains poorly understood. Where this methane goes and how it is transformed in the water ultimately dictates the magnitude of its role in the global carbon cycle, which is closely linked to Earth's climate. Drs. Scott Wankel and Anna Michel of WHOI and their team developed new ways to understand ocean cycles by studying methane bubbles in the water column while on *Falkor*. The multidisciplinary expedition tested new instruments and techniques to better comprehend this process, and the researchers discovered that, contrary to popular opinion, methane does reach the sea surface in detectable amounts, although the exact rates are yet to be quantified.

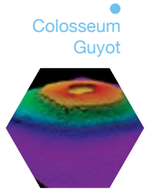
Three sensors were integrated into ROV SuBastian including a stereo-camera to look at methane bubbles and an in situ mass spectrometer. This was complemented with gas measure of bubbles underwater (characterizing the relative amount of methane, nitrogen, oxygen, argon, and carbon dioxide), while periodically measuring the isotopic fingerprints of the methane. The stereo-camera enabled the scientists to better understand the nature of methane transfer from bubbles into the surrounding water. The development of this equipment and sensors is important in illustrating changes in methane from venting locations across a spatial scale as well as over time.

Main Image: Abby Keller carries biological samples collected from ROV SuBastian. With SuBastian able to use the "slurp" system, biologists can capture and study a variety of life in deep sea ecosystems.
Top Hexagon: Gas bubble capture in a repurposed push core to observe hydrate formation.
Middle Hexagon: Diana Dumit connects water samples to her purge rack in the Dry Lab. Bubbling the sample with helium removes the oxygen, which allows Dumit and other members of the team to conduct their oxygen-deficient experiments.
Bottom Hexagon: Methane bubbles form into hydrate upon capture in a sample.

> Our focus on rising seafloor bubbles stems from the recognition that methane is an important player in the global atmosphere-climate system and the fact that the seafloor in many regions of the global ocean houses enormous amounts of it.
>
> - Scott Wankle,
> Principal Investigator.

WHAT WE FOUND

2013-2018



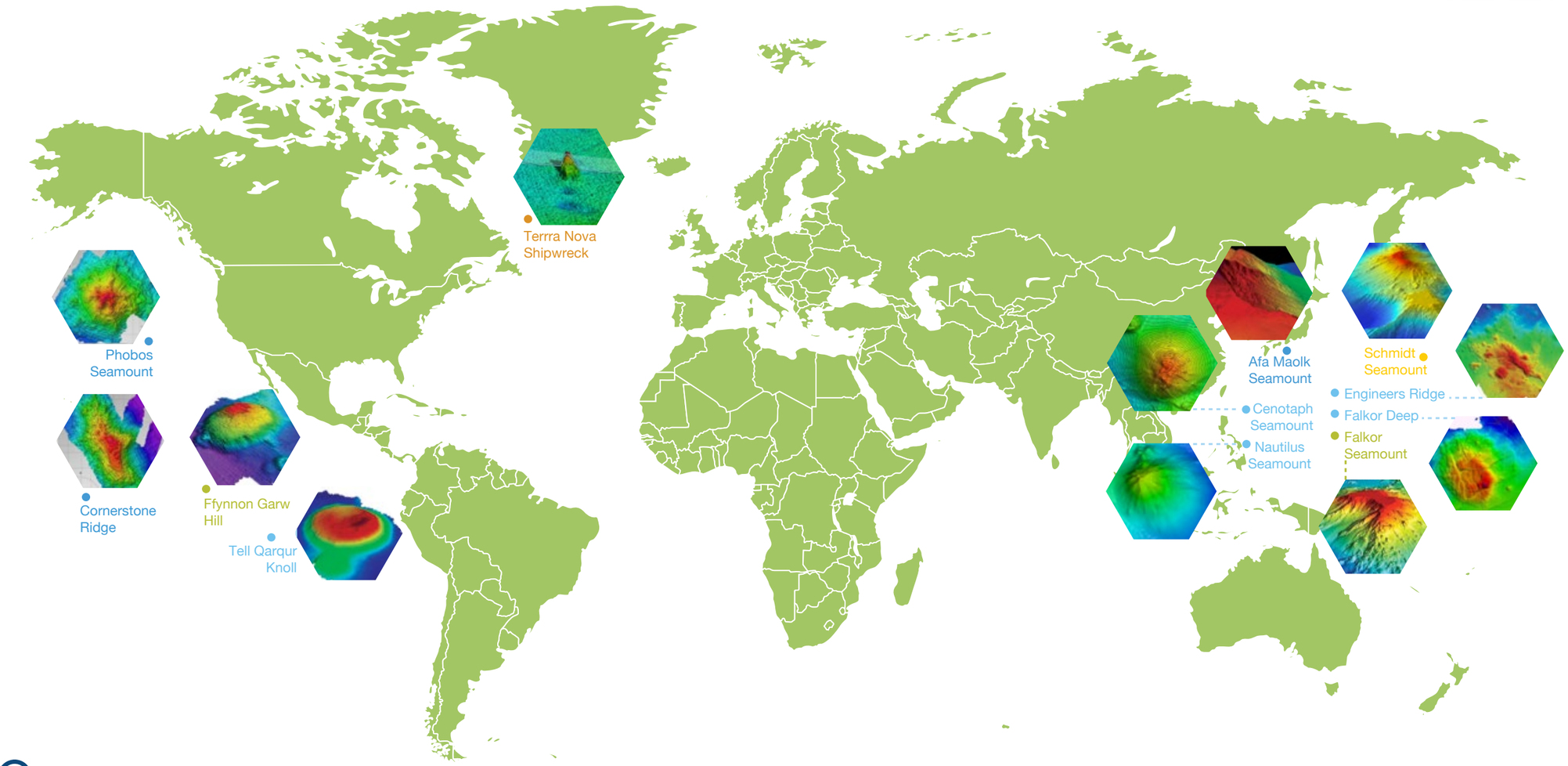
Colosseum Guyot

HOW WE NAME SEAMOUNTS

1) Honor the local dialect where possible, for this we confirm correct language with a local team. For example, Afa'Molek Sea Mount (Cooperation Seamount).

2) If in the EEZ of a country, we look for a historical event in the nation on the day of the seamount discovery. For example, Cornerstone Ridge was found on the anniversary of the laying of the cornerstone in the Washington, DC Capitol Building.

3) If in international waters, we look for historic science events on the day of the seamount discovery. For example, Phobos Seamount was found on the anniversary of the Phobos moon being identified.



DISCOVERY
of new underwater features

626,618 km²
mapped

2012
Terra Nova Shipwreck
Location: Off the coast of Greenland

2014
Schmidt Seamount
Location: Papahānaumokuākea Marine National Monument, Northwestern Hawaiian islands - Pacific Ocean
Depth range: 5,200 m - 117 m
Size: 1,480 km² - 70 km long x 35 km wide

2015
Falkor Seamount
Location: Off of Guam near the Mariana Trench
Depth range: 8,700 m
Size: 2,100 m

2015
Ffynnon Garw Hill
Location: Central Pacific between Hawaii and Tahiti
Depth range: Summit 4,354.0 m; Deepest Point 5,290 m
Size: 940 m

2016
Cenotaph Seamount
Location: Between Guam and the Philipenes
Depth range: 1,974 m - 3,546 m
Size: 8.5 km x 12 km

2016
Colosseum Guyot
Location: The feature is located on the Tamu Massif, Northwest Pacific Ocean.
Depth range: 5,220 m
Size: 5.2 km x 8.4 km

2016
Engineers Ridge
Location: South of Guam, Marianas Trench Marine National Monument
Depth range: 4,100 m
Size: 4.5 km x 3 km

2016
Falkor Deep
Location: Philippine Sea
Depth range: 8,001 m
Size: 40 km x 22 km

2016
Nautilus Seamount
Location: Between Guam and the Philippines
Depth range: 2,541 m - 4,133 m
Size: 7 km x 7.4 km

2016
Tell Qarqur Knoll
Location: Central Pacific
Depth range: 4,751 m
Size: 7.8 km x 6.5 km

2017
Afa Maolk Seamount
Location: Northern Mariana Islands
Depth range: 876 m - 4,228 m
Size: 3.7 km x 11.1 km

2017
Cornerstone Ridge
Location: Near Palmyra
Depth range: 1,074 m - 4,935 m
Size: 31.5 km x 58.3 km

2017
Phobos Seamount
Location: North Pacific Ocean (NE of Hawaii)
Depth range: 5,001 m
Size: 26.7 km x 25.3 km

Haliphron atlanticus (also know as the seven-arm octopus) spotted near Crespi Knoll (approximately 40 miles off southern California) by ROV SuBastian. This is believed to be only the fourth known sighting of the animal alive.

We are seeing these sites right now as they are in their full glory, and that let's us make comparisons to the past and future, with an eye on scientific decisions about conservation, management, or places for further investigation

- Charlotte Seid,
Scientist.

DIGITIZING MARINE LIFE
AND SEAFLOOR HABITATS

DIGITIZING MARINE LIFE

and Seafloor Habitats

A plethora of submarine activity can be found on the seafloor where heat, water, and gases interact creating otherworldly ecosystems that host unique organisms and structures. Unfortunately, available observations of these marine habitats are patchy, discontinuous, and scarce.

More quality data is needed to inform effective conservation and management. SOI is helping to expand the data available through digital characterization of marine habitats and processes for subsequent research, analysis, and open sharing.

METHANE SEEPS AND MICROBIAL "CASTLES" IN THE SOUTHERN CALIFORNIA BORDERLAND

In October, *Falkor* sailed down the coast of California, taking ROV SuBastian and NASA's Planetary Science Technology Analogue Research (PSTAR) funded Autonomous Biogeochemical in situ Sensing System lander "ABISS" into the Southern California Borderland. The three-week expedition led by Dr. Peter Girguis, Harvard University, documented this important region through 17 ROV dives, including four sites that had never been visited by humankind.

These exploratory dives revealed extraordinary microbial communities. For example, the team discovered a site where microbes build "castles" through methane-rich water that the microbes consume.

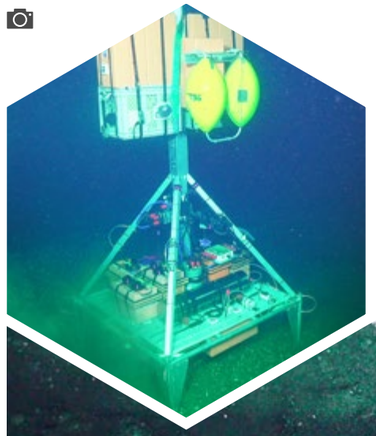
ROV SuBastian spent nearly 200 hours on the ocean floor observing many rare species, including the seven-legged octopus (the fourth time the species has ever been seen alive).

The team of shipboard researchers were joined by NASA engineer Betsy Pugel who participated in the deployments of the ABISS lander to further understanding of how seep communities function.

This expedition served as a testbed for studying microbial life on other ocean worlds, such as the moons of Jupiter and Saturn. Europa, for example, has a thick icy crust, but beneath that crust there may be life at the bottom, much like what the team observed during the ROV dives on this expedition. By working in the deep ocean waters on Earth, scientists can push the limits of understanding in existing hardware designs and engineering choices for missions in outer space.

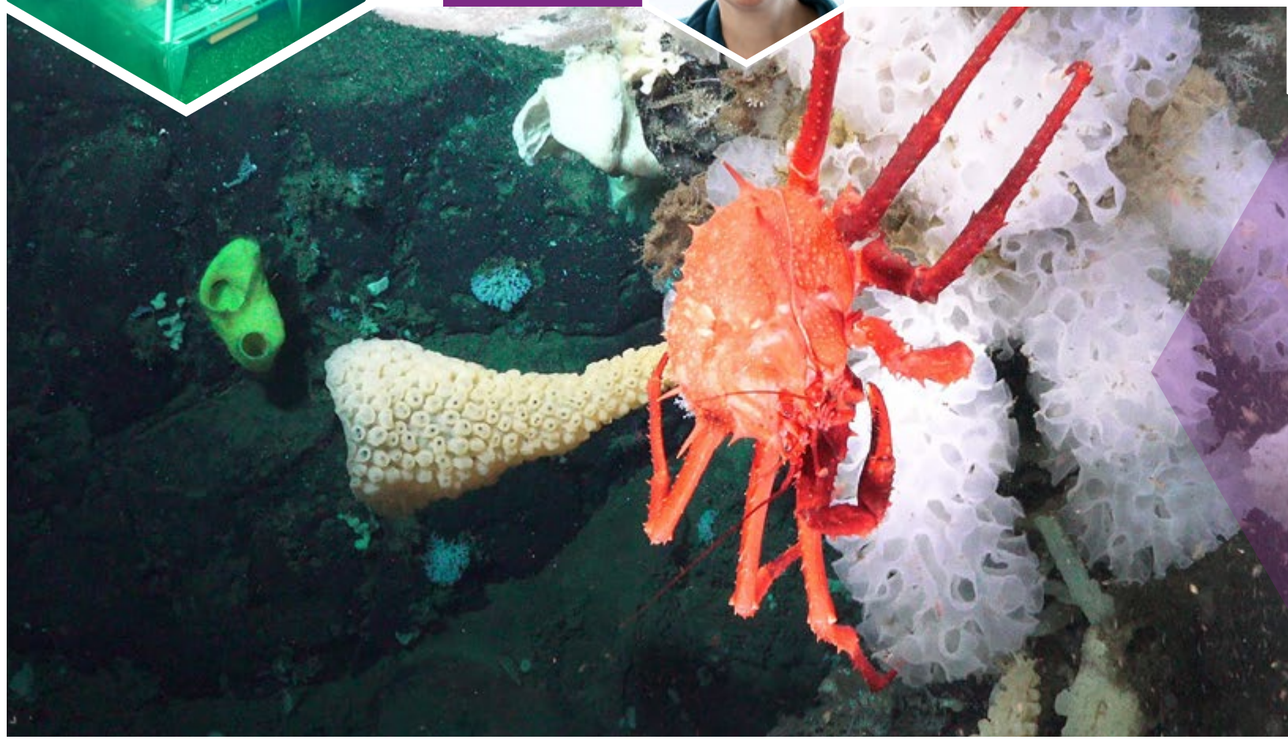
The ABISS deployments have shown that methane venting is more episodic than previously known, which changes assumptions about methane escape from the seafloor to the atmosphere.

The ABISS lander on the ocean floor (captured by ROV Subastian).



> The path to developing technology starts here with sophisticated tools like the ABISS and ROV SuBastian. We have to think about new ways to operate and communicate.
>
> -Betsy Pugel,
> NASA Scientist.

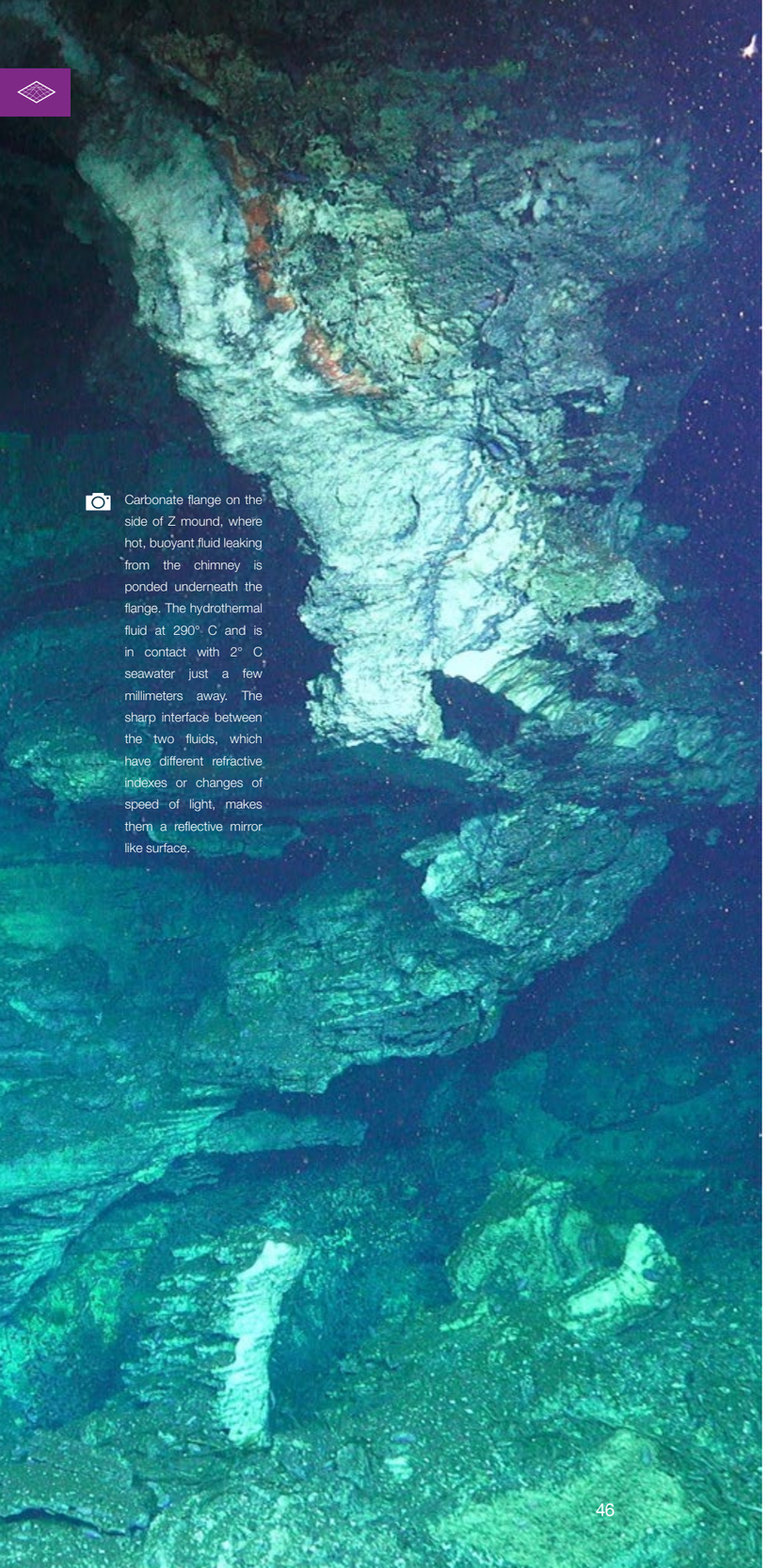
The science team is now working to produce a map of the contiguous seeps in the Southern Borderland, reshaping our understanding of connectivity among these habitats. They will analyze the animal relationships from the 300 open-access samples collected, including potentially new species found on the expedition. This data is critical to understanding connectivity of these habitats and the impact that the deeper communities have for lucrative fisheries.



Main Image: An ROV dive at the Emery Knoll revealed a Seussian wonderland of life, including crabs, sponges, deep-water corals, and basaltic cliffs. With bathymetric relief, there is a higher cross section for filter feeders.

Hexagon 1: Researchers, including Dr. Ronald Spelz Madero, aim to characterize the kinematics and past rupture history of several important fault systems in northern Baja California.

Hexagon 2: Final group photo of science team and crew



Carbonate flange on the side of Z mound, where hot, buoyant fluid leaking from the chimney is ponded underneath the flange. The hydrothermal fluid at 290° C and is in contact with 2° C seawater just a few millimeters away. The sharp interface between the two fluids, which have different refractive indexes or changes of speed of light, makes them a reflective mirror like surface.

CENTIMETER SCALE SEAFLOOR MAPPING IN THE SOUTHERN PESCADERO BASIN

At the end of October, *Falkor* sailed further south to the Southern Pescadero Basin within the Gulf of California, carrying Principal Investigators Drs. Robert Zierenberg, University of California Davis, Victoria Orphan, California Institute of Technology, and David Caress, MBARI. Autonomous and interactive seafloor mapping systems enabled the research team to discover a new hydrothermal vent and multiple new deep-sea organisms. The nested-scale mapping approach gave exploratory seafloor coverage to precision targeted sampling on the vents. The detailed maps provided a quantification of various microbial and animal communities in precise relation to geologic features and areas of focused hydrothermal fluid flow.

The new vent, JaichMatt, was identified using MBARI's AUV that conducted exploratory seafloor surveys with one meter lateral resolution. Simultaneously, MBARI's new Low Altitude Survey System was used on ROV SuBastian to map the previously discovered Auka Vent field at centimeter scale resolution using co-located multibeam sonar, light detection and ranging scanning laser, and stereo photography.

These three instruments worked in concert offering a holistic view of the seafloor. The biological communities and the geological and geochemical characteristics of these vent fields were then explored and sampled using ROV SuBastian. JaichMatt translates to “liquid metal” in one of the indigenous native languages to the Baja Peninsula.

The name references the reflective hydrothermal fluid and seawater interface that was found pooled along the roof of a large cavern in the hydrothermal mound.

The new vent field consists of multiple hydrothermal calcite mounds up to 25 meters high that vent fluids up to 287°C. Groups of animals common in non-hydrothermal settings, including anemones, were observed in dense accumulations at the base of the mounds.

Collected volcanic rocks from the North and South Pescadero Basins confirmed the continental rifting that formed the Gulf of California has transitioned to seafloor spreading and the creation of new oceanic crust. The team also obtained the first documentation of hydrothermal hydrocarbon escaping from the seafloor in the Pescadero Basin area. This has only been sampled from a few such thermal systems, and the process is not well understood – yet it is a significant part of the carbon cycling story for the Gulf.

The Pescadero Basin is an important location to try to understand how vent fauna colonize similar sites around the globe. The detailed mapping will further allow investigation of the geological and geochemical controls on habitat suitability for different animal and microbial communities. Hydrothermal vents are an expression of submarine volcanism that is a globally important process and play a vital part in shaping the surface of our planet.

Main Image: Dynamic ecosystems with multiple organisms found just off the coast of Los Angles in the Southern California Borderland.
Hexagon: A colorful squid seen on the "Backyard Deep" expedition of California.

INSPIRING
and sharing

Every day SOI aims to inspire a passion for the ocean by sharing enthralling footage and brings the latest in ocean research to people all over the globe. Our communication and outreach encourages engagement across all ages through a multitude of programs including student and artist berths of opportunity, live at-sea broadcasts and connections, image and data sharing, social media campaigns, and science communications training.

NEW CONNECTIONS BRING *FALKOR* SHORESIDE TO LARGE AND DIVERSE AUDIENCES

Falkor's first expeditions in Mexican and Costa Rican waters prompted bilingual outreach with videos, blogs, and live narration of ROV dives conducted in both English and Spanish. Breathtaking methane seeps, hydrothermal vents, and rare organisms attracted viewers to watch both on SOI's YouTube channel and Facebook Live, leading to a worldwide audience watching more than 2.9 million minutes of live streaming from ROV SuBastian's dives. Several dives this year were re-shared by iFLS, attracting more than 500,000 viewers.

SOI continues to broaden its connection to aquariums, museums, and learning centers across the country, and around the world, through our Ship-to-Shore program. These 30-minute connections allow viewers to see the science happening on board in real time and engage with the scientists live for a question and answer session.

Throughout the year, SOI participated in several new connections reaching larger, diverse audiences. In May, we teamed up with 11th Hour Racing to broadcast live during the Volvo Ocean Race stopover in Newport, Rhode Island.

SOI also held its third tri-ship hangout on World Ocean Day, connecting three research vessels including *Falkor*, and broadcasting live online to more than 4,000 people. *Falkor* connected live with the Prime Minister of Portugal during his visit to MIT, sharing the success of the multiple robotics expedition. Another highlight was in May when the ship was part of a live presentation with UNESCO and Dr. Sylvia Earle discussing the expedition to the White Shark Café. Finally, SOI entered into a new partnership with the Smithsonian National Museum of Natural History, linking the researchers on the ship to the audience at the prestigious museum's Sant Ocean Hall once per expedition. The Sant Ocean Hall is the National Museum of Natural History's largest exhibit, and averages six million visitors each year bringing a new interested audience to engage in these connections.

Scientists on *Falkor*
REACHED MORE THAN 100 GROUPS

LINKING OVER 8,000
students and members of the public to the research happening on board

Main Image: Students enjoy a trip to *Falkor*'s bridge during a "Science Sunday classroom series" tour given while the ship was in Honolulu.

Hexagon 1: Volvo Ocean Race Newport sailors and visitors connect with the Schmidt Ocean Institute R/V *Falkor*, located in the NE Pacific, to learn about sharks in the area known as the White Shark Cafe.

Hexagon 2: Keila Lima gives a Ship to Shore presentation to a school in Cape Verde, Portugal.

OPENING *FALKOR'S* DOORS

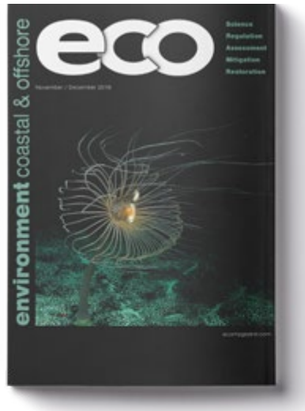
In 2018, *Falkor* welcomed 1,000 public visitors to tour the ship in California, Oregon, and Hawaii. Returning to San Francisco for the first time in five years, *Falkor* celebrated with two days of ship tours. An evening event was held at the interactive museum, the Exploratorium, which included demonstration tables, an Artist-at-Sea exhibit, presentations from previous principal scientists, and a talk by co-founder Wendy Schmidt.

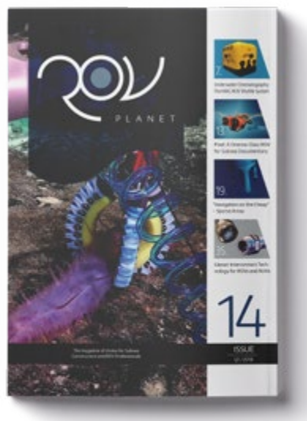
Public engagement may start on the ship, but a major focus has been to bring science and process into the communities in which we work, as exemplified by the 2,700 people reached this year through in-person public presentations.

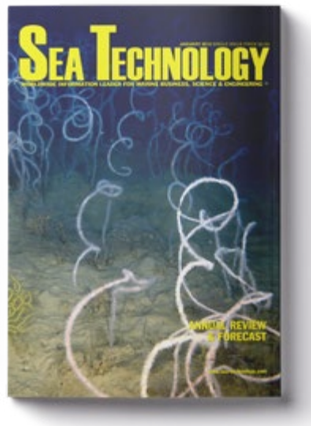
TRAINING THE NEXT GENERATION

SOI encourages student learning with hands-on opportunities to provide experience and career guidance. Forty-five university students sailed on *Falkor* in 2018, including five Student Opportunities program participants. SOI also welcomed a new Science Communications Intern, Katherine Herries. Katherine is the third intern in the program emphasizing direct training and mentoring. Feedback on the internship has indicated greatly increased comfort and interest in science communication and writing. Katherine has been busy authoring three published articles, participating in community outreach, all while learning how to analyze social media metrics. "This internship has let me to see a different side of science," said Katherine. "The program has strengthened my communications skills allowing me to connect with audiences around the globe. I will leave this experience feeling well prepared to embark on a science communications career."

Top Image: R/V *Falkor* makes her way into San Francisco Bay after sailing under the Golden Gate Bridge.
Hexagon 1: Science communications intern Katherine Herries stands in front of Falkor during ship tours in Honolulu.
Hexagon 2: Navigator Officer Marissa Judkins leads an evening tour of R/V *Falkor* during the San Francisco stopover.
Bottom image: Co-Founder Wendy Schmidt with SOI staff and ship's crew at the Exploratorium event in San Francisco showcasing the latest science and technology accomplishments completed on *Falkor*.







FRONT
and center

Cutting-edge research and technology development undertaken aboard *Falkor* led to 1,062 news stories in 2018, including six magazine covers as well as articles in National Geographic, Wired, Scientific American, ECO Magazine, and Nature, just to name a few. SOI's breathtaking footage from the Pescadero Basin and Costa Rica was used by BBC, The Weather Channel, Discovery Channel Canada, and NHK. Video footage from ROV SuBastian was showcased at the Berlin Atonal Festival and the International Ocean Film Tour, and has been requested for 38 upcoming education films, documentaries, and exhibits including an IMAX museum film on volcanoes, a documentary for PBS Nature on underwater volcanoes, and a natural history documentary for BBC. Additionally, expedition images (from both above and below the ocean's surface) have been used recently in a National Geographic book for kids, a report on deep sea mining by the International Union for Conservation of Nature, and in the 2019 Encyclopedia of Ocean Science.

IMAX · NATIONAL GEOGRAPHIC · BBC Blue Planet 2 · AQUARIUM OF THE PACIFIC · PBS · IUCN Global Marine and Polar Programme · ENCYCLOPEDIA OF OCEAN SCIENCES · Berlin atonal · Seeker · eco environment coastal & offshore

SuBastian dive footage played at the 2018 Berlin Atonal Festival.

Artist-at-Sea Lily Simonson manipulates the controls of ROV Subastian to create an original painting on the aft deck of R/V *Falkor*.

ARTISTIC
ENDEAVORS

I have dedicated my career to painting creatures from the most remote depths of the ocean that never would have been discovered without submersibles like SuBastian. These deep-sea vehicles have brought countless muses into my world, and in that way, they occupy an almost mythological status in my mind. Creating a painting with such a legendary machine was the experience of a lifetime.

-Lily Simonson
Artist-at-Sea.

ARTISTIC
endeavors

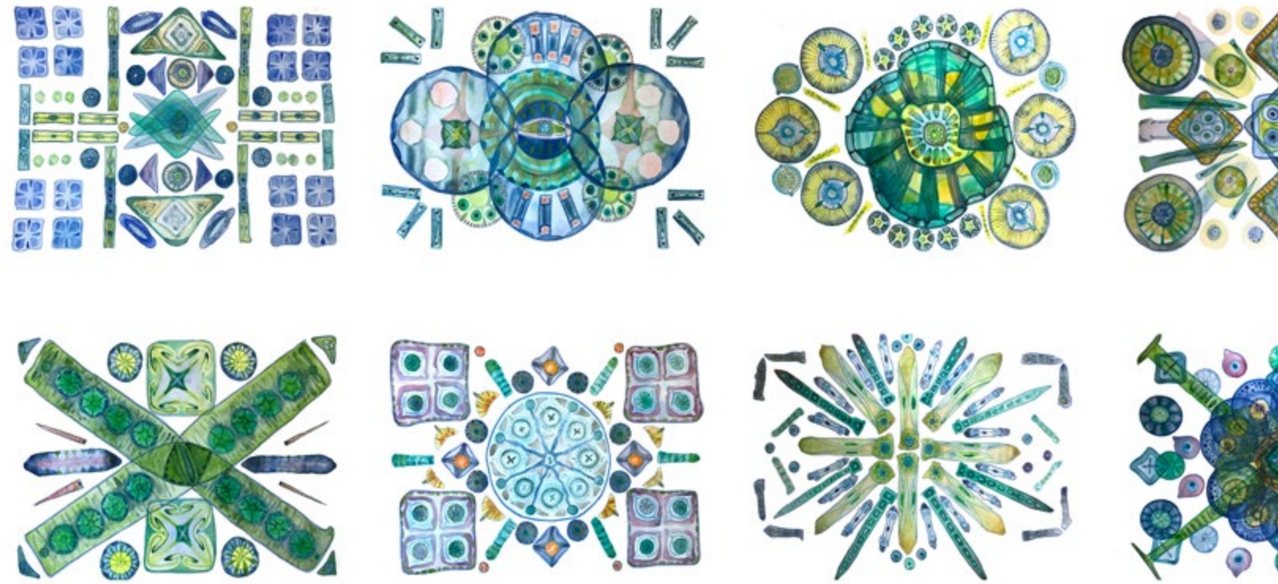
SOI's maturing Artist-at-Sea program is receiving global recognition and has become a model emulated by others, including the ArtBerth Collective. We welcomed a record number of applications this year, and have now hosted a total of 21 artists on *Falkor*. The artists' participation on science expeditions resulted in truly unique pieces that capture the innovative research being conducted.

This was exemplified by artist participants like Lily Simonson who used ROV SuBastian's manipulator arm to paint dramatic hydrothermal landscapes, and Fernanda Oyarzun who sculpted scientists' hands with clay collected from the ocean floor, 1,740 meters below the sea surface.

Another artist, Jessica Orfe, created a series of 15 watercolor paintings representing microbes collected at each station during the 2018 "Microbial Mysteries" expedition.

The imaginative designs were painted using scientific instruments as stencils to mimic the shapes of microscopic life forms that form the basis of marine ecosystems. Jessica also created an adult coloring book, *Microbial Mysteries: In Situ in the OMZ*, giving a behind-the-scenes look into a research expedition. The first ever Artist-at-Sea expedition was completed this past July, bringing six unique artists on *Falkor* during a transit with mapping, allowing them to work with and incorporate the multibeam data collected on the trip.

Work by Jessica Orfe



Main Image: Resin paintings by Sarah Caudle dry in *Falkor*'s wet lab.
Top Hexagon: Principal Investigator Susan Merle standing in a projection of light paintings based on the data collected.
Left Hexagon: Roger Peet works on a mural devoted to Ghostfish in the hallway leading to the aft deck.
Right Hexagon: Artists-at-Sea expedition participants (L-R) Roger Peet, Lori Hepner, Lauren Salm, Lizzy Taber, Sarah Caudle, and Rebecca Welti.
Bottom image: Artist-at-Sea Adam Swanson works on painting his pieces in the wet lab, where he converse with the science team while seeing the research happening firsthand.

Main Image: D'amy Steward participates in a workshop led by Artist-At-Sea Sarah Caudle, creating resin paintings at a workspace in R/V ***Falkor's*** wet lab.
Hexagon 1: Fernanda X. Oyarzun works on sculpting clay aboard R/V *Falkor* while participating in Schmidt Ocean Institute's Artist-at-Sea program.
Hexagon 2: Artist-at-Sea Lauren Salm and SOI cofounder Wendy Schmidt pose in front of Artist-at-Sea exhibit at Exploratorium in San Francisco.

Artists included Sarah Caudle, a jewelry designer who works with epoxy beachscapes; Lori Hepner, a performance artist who showcases LED movement with data streams; Lauren Salm, a portrait artist; Rebecca Welti, a sculptor; as well as artist and student Lizzy Taber who worked with cyanotype prints and pastel color studies. A commemorative mural of our 2014 discovery of the world's deepest fish was made by Roger Pete and unveiled during *Falkor's* stopover in San Francisco.

The Artist-at-Sea exhibit continues to travel across the country, and has now been displayed in 14 different locations across 10 different cities. The artwork totaling more than one hundred pieces was displayed at several large meetings and public centers, often accompanying special events and interactions. For example, in February cartoonist Lucy Bellwood signed copies of her multibeam mapping comic at the Ocean Sciences meeting in Portland, Oregon. SOI cofounder Wendy Schmidt gave a public lecture and welcome remarks in March to open the three-month long exhibit at the Aquarium of the Pacific in Long Beach, California. In September, the art was displayed at the Exploratorium as part of the welcoming events for *Falkor*, and was then put on view at the NOAA All Hands on Deck forum at the MIT Media Lab in November. The exhibit can also be seen online at SOI's gallery website.

FALKOR ENGINEERING DEPARTMENT

Main Engines
Performed major overhaul of 14 cylinder heads.

Port Main Engine Clutch
Conducted major overhaul.

Sea Water Cooler
Replaced all of the cooler plates.

Emergency Generator
Implemented upgrades to increase main buss capacity and the supply air ventilation fan capacity.

FALKOR SCIENCE DEPARTMENT

ROV Event Logger
Developed software logging system to track vehicle technical and scientific operations as well as scientific ROV operations, allowing for easy annotation, time stamping and geo stamping of ROV science events. Online access to this information allows review by shoreside collaborators and staff.

Irradiance Sensors
Falkor's suite of sunlight sensors were relocated and expanded, allowing for better exposure to the sky and the collection of important new data. Data are saved in a repository allowing their use by scientists around the globe and providing historical data for future studies.

FALKOR AUDIO VISUAL / INFORMATION TECHNOLOGY / ELECTRONICS

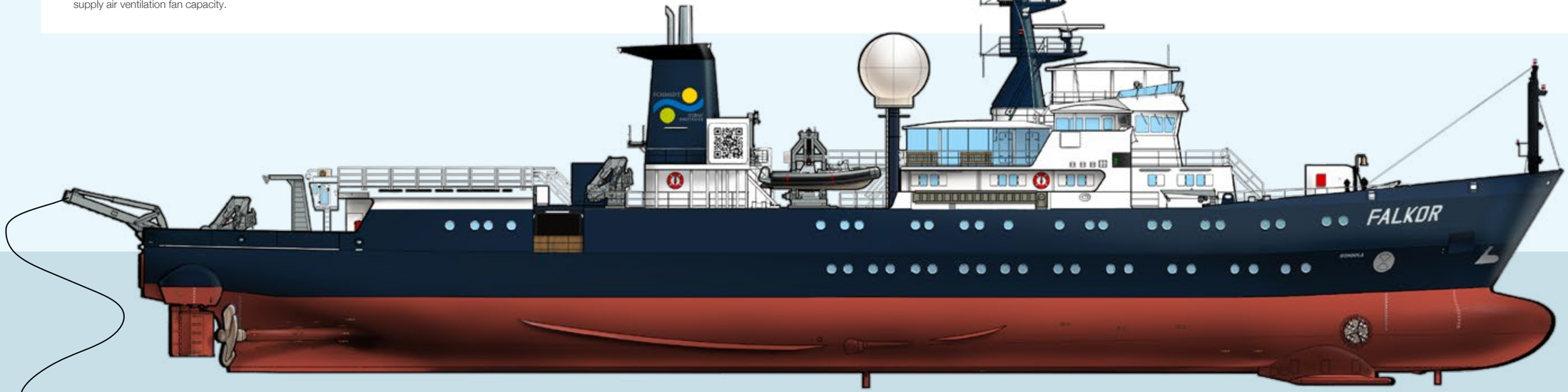
High Performance Computing
Installed Graphics Processing Unit power to *Falkor's* High Performance Computer system to support scientists' and researchers' new emerging technologies. A research vessel first!

Cybersecurity & Falkor's Network Enrollment
Redesigned the enrollment process for wireless and wired networks through implementation of a sophisticated software system that protects the entire network from unauthorized computers or users.

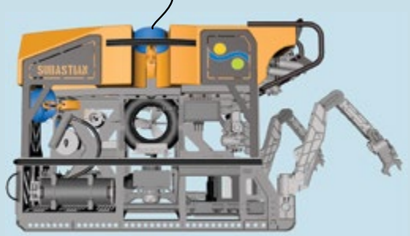
Ship-to-Shore Video Enhancements
By using the core video matrix and cutting edge audio distribution Falkor crewmembers can now route real-time events to the encoders and push them straight to the internet over the satellite connection.

Advanced Shipboard Monitoring
All shipboard network devices are in constant 24/7 monitoring, from servers to the HVAC systems. New network sensors were added to ensure proper functionality of shipboard critical systems. Soon all devices aboard Falkor will send problem alerts to shoreside technical teams.

Faster Internet
Commissioned hardware and software aboard Falkor for using 4G data service up to 25 nautical miles offshore; speed rates are now up to 160 Mbps. The new shipboard system uses four internal modems to the packages between the modems and service providers. A research vessel first!



ROV SUBASTIAN



Remote Operation of ROV SuBastian
Designed and tested in-house architecture allowing control of SuBastian tethered to Falkor from a land-based operating station.

Seafloor Stereo Imagery Capability
SOI's engineers developed a photomosaicing skid mounted under SuBastian to collect high resolution stereo-imagery of the seafloor around seeps, vents, and whale falls. This skid utilizes SuBastian's new automated line following capability to combine these image sets into detailed 3D and 2D models for interactive research and analysis of the seafloor.

Better Vehicle Control
Added new waypoint execution mode for much tighter line following and control over the speed at which waypoints are executed.

Operational Procedures
Added new operational procedures to maximize ship time and dive efficiencies working simultaneously with AUVs using reconnaissance mapping to pinpoint subsea targets, and directing the ROV to key study sites.

More Power Options
Installed a science transformer to allow researchers' instruments to have a greater power range for sensor integration (i.e. 110v - 220v) and added voltage regulators to provide lower voltage range (i.e 5v, 6v, 12v & 24v).

Equipment
Expanded growing inventory of scientific instrumentation, including the integration of 19 new pieces of equipment onto SuBastain on a single dive.

Catenary Float Rack For Umbilical
Falkor's Engine Department fabricated a float rack for the Aft Deck to allow for a more ergonomic, safe and efficient method of stowing and installing the floats during vehicle deployment and recovery operations.

NOTEWORTHY UPDATES

Falkor's work boat Atreyu, returns to the ship in the Hawaiian Islands.

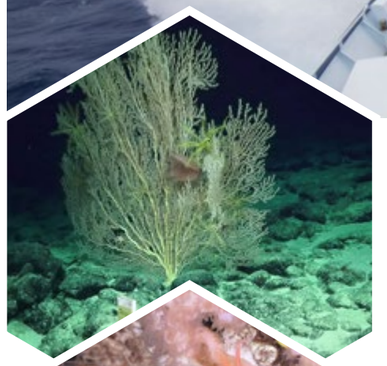
Sea to Space Particle Investigation

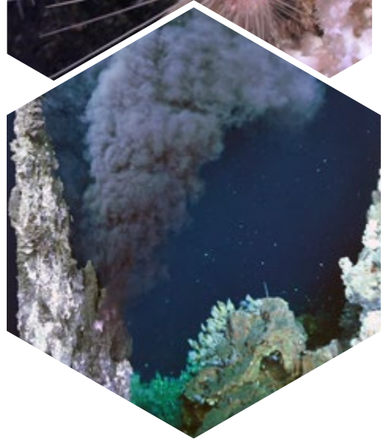
Dr. Colleen Hansel (Moss Landing Marine Laboratory), who participated in the expedition, has developed an innovative molecular method to sequence the DNA extracted from individually isolated particles connecting organic matter at the surface to that found below (sinking). The innovative method has been adopted by the NASA EXPORTS field program this year. Additionally, during the expedition, images were taken of sinking particles captured in sediment gel traps in order to better understand driving carbon flux. Jessica Sheu, a Master's student at San Jose State University studying computer science, is working to advance the manual methodology using the existing data to train a machine learning algorithm to assign identifications to the particles.

Unraveling Ancient Sea level Secrets

Coral fossils collected on the expedition were a key component of Katherine Herries' MS thesis, *Biogeochemical alteration effects on U-Th dating of Pleistocene corals*. Katherine is now a science communications intern at SOI and the data has been shared at a University of Hawaii seminar.

The Bow of R/V *Falkor* riding some lively waves on the way to our target eddy.





Discovering Deep Sea Corals of the Phoenix Islands

A team from Boston University collected and cultured microbes during their expedition to understand deep-sea coral wound healing. The group has generated preliminary data on 200 bacteria strains and to their knowledge, it is the largest library of its kind; as well as the largest deep-sea lipid A structures. Using cutting-edge techniques in bioinformatics, the strains have been entered into a newly developed data extraction pipeline. This library has the potential to disrupt and transform advances in bioprospecting because, despite the clear clinical importance of bacterial lipopolysaccharide, the field has worked with only a small set of commonly studied bacteria. However, the preliminary results has been demonstrated that exploration of diverse environments (e.g. deep sea) will identify many novel lipopolysaccharide structures.

Other expedition participants at Temple University have analyzed seafloor video footage and generated a preliminary deep-sea coral species distribution dataset between 152 - 2,439 meters for the Phoenix Islands Protected Area. Over 8,000 records of coral occurrences were counted and more than 10,000 new deep-sea coral records were identified. Some species that were previously unknown are undergoing description including rarely observed species, and significant range extensions for known species. Genomic DNA has also been isolated for 121 of the collected corals, providing insight into their phylogenetic diversity. These records will help scientists better understand the oceanographic and environmental factors influencing deep-sea coral community assembly in the protected area.

Underwater Fire: Studying the Submarine Volcanoes of Tonga

Rock, biological, and sulfide specimens collected during the expedition have been examined, categorized and curated. The observations were used to inform a subsequent expedition on R/V Sonne that Dr. Rubin participated in. This data has been shared publicly through the article, *Exploring submarine volcanoes*, published in the October issue of *Environmental Scientist* and in several presentations.

Mushroom soft coral with feeding polyps extended.

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Sager, W., Huang, Y., Tominaga, M., Greene, J., Nakanishi, M., and J. Zhang. (2018). Linear magnetic anomalies over Tamu and Ori massifs (Shatsky Rise Ocean Plateau) imply formation by seafloor spreading, Oral Presentation, AGU Fall Meeting, Washington, DC.

Savage, A., Waterhouse, A., Kelly, S., and J. MacKinnon. (2018). Noncoherence of low mode internal tides in the Tasman Sea. Oral Presentation, Ocean Sciences Meeting, Portland, OR, USA.

Smith, J. and J. Tree. (2018). New Marine Geological Maps for the Northwestern Hawaiian Ridge promote a detailed reexamination of giant landslides and their source volcanoes within a 25 Myr context. Oral Presentation, AGU Fall Meeting, Washington, D.C.

Smith, J. and J. Tree. (2018). New Marine Geological maps reveal the complexity and deep-sea habitability of the northwestern Hawaiian Ridge. Oral Presentation, Symposium on Science in Support of Archipelagic Management, Honolulu, HI, USA.

Smith, J. (2018). Geological Mapping of Seamounts and Other Features in the Pacific Marine Protected Areas. Oral Presentation, NOAA Inouye Regional Center distinguished lecture series, Honolulu, HI, USA.

Smith, J. (2018). Collaborative Seamount Studies in the Johnston Atoll Marine Monument. Oral Presentation, University of Hawaii seminar series, Honolulu, HI, USA.

Su, J. (2018). An evaluation of vertical nitrate fluxes and biological demand in the tropical Pacific and Tasman Sea. Poster presentation, Australian Meteorological and Oceanographic Society Annual Conference, New South Wales, AUS.

Thornton, B. (2018). #Adaptive Robotics. Invited Lecture, 62nd Ocean and Seafloor Engineering Forum, Tokyo, Japan.

Thornton, B. (2018). Whole site multi-resolution photogrammetric surveys of deep-sea vents and cold seeps. Invited Lecture, Beyond Challenger: A new age of deep-sea science and exploration meeting hosted by the Royal Society, London, UK.

STUDENT DISSERTATIONS

Herries, K. (2018). Biogeochemical alteration effects on U-Th dating of Pleistocene Corals, M.S Thesis, University of Hawaii.

Huang, Y. (2018). Magnetic anomaly map and magnetic structure of Shatsky Rise (Northwest Pacific) and the implications for oceanic plateau formation, Ph.D. Dissertation, Texas A&M University.

Reed, W. (2018). Variable resolution bathymetry and geomorphology of Tamu Massif, M.S. Thesis, University of Houston.

Su, J. (2018). An evaluation of vertical nitrate fluxes and biological demand in the tropical Pacific and Tasman Sea. BSc. Hons. Thesis, University of Tasmania.

Coral and associate (Squat Lobster) found during the "Autonomous Exploration at the Costa Rican Shelf Break" expedition.

Exploring fronts with multiple robots" expedition used new network strategies to manage multiple autonomous vehicles simultaneously.

PHOTO
credits

COVER

Main Image	Monika Naranjo Gonzalez
Hexagon 1	ROV SuBastian
Hexagon 2	Leighton Rolley
Hexagon 3	Mary Lide Parker
Hexagon 4	ROV SuBastian

PAGES

1- Main Image	Monika Naranjo Gonzalez
4- Main Image	Leighton Rolley
6- Main Image	Thom Hoffman
7- Main Image	Drew Altizer
8- Main Image	Monika Naranjo Gonzalez
9- Main Image	Monika Naranjo Gonzalez
10 - Main Image	Monika Naranjo Gonzalez
16- Main Image	Monika Naranjo Gonzalez
16- Hexagon 1	Leighton Rolley
16- Hexagon 2	Elisha Wood-Charlson
16- Hexagon 3	Monika Naranjo Gonzalez
17- Main Image	Mary Lide Parker
17- Hexagon 1	Mary Lide Parker
17- Hexagon 2	Mary Lide Parker
17- Hexagon 3	Chris Teufel
18- Main Image	Kevin McHugh
18- Hexagon 1	ROV SuBastian
18- Hexagon 2	Kevin McHugh
18- Hexagon 3	Monika Naranjo Gonzalez
19- Main Image	Monika Naranjo Gonzalez
19- Hexagon 1	ROV SuBastian
19- Hexagon 2	Monika Naranjo Gonzalez
19- Hexagon 3	Jon Tadiello
20- Main Image	Leighton Rolley
22- Bottom Image	Leighton Rolley
23- Hexagon	Elisha Wood-Charlson
23- Bottom Image	Thom Hoffman
24- Main Image	Monika Naranjo Gonzalez
24- Hexagon	Monika Naranjo Gonzalez
25- Top Image	Mary Lide Parker
25- Hexagon	Thom Hoffman
25- Bottom Image	Manuel Ribeiro
28- Main Image	Monika Naranjo Gonzalez
30- Main Image	Monika Naranjo Gonzalez
31- Main Image	Blair Thornton and Jin Wei Lim
32- Main Image	Monika Naranjo Gonzalez
33- Main Image	Monika Naranjo Gonzalez
33- Hexagon 1	Monika Naranjo Gonzalez
33- Hexagon 2	Monika Naranjo Gonzalez
34- Main Image	ROV SuBastian
36- Main Image	ROV SuBastian
36- Hexagon	Monika Naranjo Gonzalez
37- Right Image	Mary Lide Parker
37- Bottom Image	Mary Lide Parker
38- Main Image	Kevin McHugh
39- Main Image	Kevin McHugh
39- Hexagon 1	ROV SuBastian
39- Hexagon 2	Mary Lide Parker
39- Hexagon 3	ROV SuBastian
42- Main Image	ROV SuBastian
44- Hexagon	ROV SuBastian
45- Main Image	ROV SuBastian
45- Hexagon 1	Monika Naranjo Gonzalez
45- Hexagon 2	Mary Lide Parker
46- Main Image	ROV SuBastian
47- Main Image	ROV SuBastian
47- Hexagon 1	ROV SuBastian
48- Main Image	Logan Mock-Bunting
48- Hexagon 1	Cory Silken
48- Hexagon 2	Mary Lide Parker
50- Top Image	Noah Berger
50- Bottom Image	Nano Visser
50- Hexagon 1	Schmidt Ocean Institute
50- Hexagon 2	Nano Visser
53- Main Image	Adriano Rosselli
54- Main Image	Mary Lide Parker
55- Main Image	Work by Jessica Orfe
56- Main Image	Logan Mock-Bunting
56- Hexagon 1	Logan Mock-Bunting
56- Hexagon 2	Logan Mock-Bunting
56- Hexagon 3	Logan Mock-Bunting
56- Hexagon 4	Kevin McHugh
57- Main Image	Chris Teufel
57- Hexagon 1	Monika Naranjo Gonzalez
57- Hexagon 2	Nano Visser
60- Main Image	Leighton Rolley
60- Hexagon 1	Monika Naranjo Gonzalez
60- Hexagon 2	Kevin McHugh
61- Main Image	Thom Hoffman
61- Hexagon 1	ROV SuBastian
61- Hexagon 2	ROV SuBastian
61- Hexagon 3	ROV SuBastian
62- Main Image	ROV SuBastian
65- Main Image	ROV SuBastian
66- Main Image	Mary Lide Parker
68- Main Image	ROV SuBastian
70- Main Image	Leighton Rolley

BACK COVER

Main Image	Connor Gallagher
Hexagon 1	Kevin McHugh
Hexagon 2	Kevin McHugh
Hexagon 3	Mary Lide Parker
Hexagon 4	Monika Naranjo Gonzalez
Hexagon 5	Jennifer Berglund

Lush communities of Oasisia tube worms are bathed in hot venting fluids, living where scientists used to believe no animal could thrive.

COLLABORATORS

11th Hour Racing
Aquarium of the Pacific
Argos
Aspen High Seas Initiative
Bishop Museum
CCMAR
CICESE
California Institute of Technology
Dundee Heritage Trust
EarthEcho International
U.Porto FEUP Faculdade de Engenharia Universidade do Porto
Harvard
Institute of Industrial Science The University of Tokyo
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JAMSTEC
MBARI
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Woods Hole Oceanographic Institution
National Oceanography Centre
NSF
NTNU
Ocean Data Rat.org
Occidental College Los Angeles
PMEL
Papahānaumokuākea Marine National Monument Mokupāpapa Discovery Center
Scripps Institution of Oceanography UCSD
SCOPE
Simons Foundation
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OSU Oregon State University
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exploratorium
GREY BITS Engineering
IMOS Integrated Marine Observing System
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Kyutech Kyushu Institute of Technology
Lamont-Doherty Earth Observatory
LSTS
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Exploring by the Seat of Your Pants Question | Explore | Conserve
University of Aberdeen
University of Hawai'i
University of Michigan
University of Rhode Island
University of Oxford
Hellenic Republic National and Kapodistrian University of Athens

R/V *Falkor* sails near the Hawaiian Island of Maui while on the 2018 "Coordinated Robotics" research cruise.

2018

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