SCHMIDT OCEAN INSTITUTE

ANNUAL REPORT

2016

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Falkor steams away from Guam during ROV SuBastian's sea trials in July 2016.
Front Cover: Crew of the R/V Falkor recovering ROV SuBastian during the vehicle's first science cruise in the Pacific Ocean off Guam.

DIVE IN

The oceans cover 71% of our planet, produce 50% of the oxygen we breathe, and draw 25% of carbon dioxide from the atmosphere. Billions of people rely on seafood for nutrition. Oceans absorbed 93% of the excess heat trapped by greenhouse gases since 1955, protecting us from extreme environmental shifts. All of our livelihoods depend on the oceans, yet we are just beginning to understand them.

Schmidt Ocean Institute's new ROV SuBastian is submerged for testing at the Monterey Bay Aquarium Research Institute's tank testing facility. This was the ROV's first time in water, preparing for its future scientific cruises.

Falkor cruises over the South China Sea off Vietnam during the Changing River: Measuring Nutrient Fluxes to the South China Sea expedition.

Only a few dozen research vessels around the world can support in-depth science in remote parts of the ocean. They are too few for adequate coverage, very expensive to operate, and can stay at sea no more than a couple of months at a time. In response to these issues, in 2009, Eric and Wendy Schmidt founded Schmidt Ocean Institute (SOI) to accelerate the pace of understanding the world's oceans by innovating in scientific marine operations, developing and applying breakthrough research technologies, and openly sharing the resulting scientific data and knowledge with everyone around the world. To fulfill this broad charter, SOI supports a diverse range of scientific projects, focusing on innovation in research technologies, operations, and analytical workflows.

2016 marked the first external review of SOI's program and operations. An independent international review panel was impressed with the institute's rapid maturation, international recognition, excellent team, and the success of refitting R/V *Falkor*. The review endorsed the Institute's vision of supporting distributed researchers and technologists over remote links to the ship and robotic networks. Beginning to implement this vision has enabled SOI to quickly establish a visible presence within the marine research and development domain. This recognition was further strengthened by an effectively coupled outreach program, and a concerted effort to share gathered data through public repositories. Among the development opportunities, the review suggested focus on capturing scientific metadata and data quality assurance and control procedures, steadfast commitment to a culture of health and safety in ship operations, and a better alignment of the Institute's mission (for SOI to lead in technology development in ocean sciences) with its operational mode (of using *Falkor* as a platform to support its mission).

Throughout 2016, we interviewed nearly 60 of the world's top oceanographers to learn about the highest priority issues in ocean sciences that could inform the development of new strategic initiatives at SOI. There was little overlap among the suggested priorities highlighting the diversity of research needs and opportunities in marine science. However, some common non-scientific issues were clear. Greater coverage, resolution, and diversity of observations are needed to characterize the ocean's intricate dynamics. Interpreting the rapidly growing volumes of acquired instrument data require powerful analytical techniques to make useful inferences and forecasts. By supporting multidisciplinary and international research collaborations in hard to reach parts of the ocean, SOI targets the technological, operational, and analytical gaps between traditional oceanographic approaches and what is needed to succeed in understanding and protecting our oceans.

A host of breakthrough innovations was demonstrated on *Falkor* in 2016, from the application of innovative protein biomarkers to identify and track long term changes in microbial communities in the world's expanding oxygen minimum zones to innovative imaging technology that can better characterize benthic ecosystems. Dr. Oliver Wurl, from the University of Oldenburg lead an international research team from the United States, United Kingdom, and Germany to investigate the biological, chemical, microbial, and physical processes regulating heat and gas exchange through the air-sea boundary. For the first time, scientific sea surface surveys were performed with a ship-deployed long endurance vertical take-off and landing (VTOL) robotic aircraft. The successful aerial surveys earned the researchers a $3.7M grant from the Moore Foundation to support drone-based ice observation in the Arctic, which was acknowledged in a White House press release three weeks after the cruise.

This year, SOI completed the construction and delivery of the brand new 4,500 meter depth rated remotely operated vehicle (ROV) SuBastian. ROV SuBastian was tank tested at the Monterey Bay Aquarium Research Institute's research and development facility in April and underwent sea acceptance trials on *Falkor* in the waters off Guam in July and August. In December, Drs. David Butterfield and William Chadwick took ROV SuBastian to survey hydrothermal vents in the Mariana Back-Arc that they discovered during a 2015 cruise on *Falkor*, while also proving vehicle functionality as a state of the art deep sea robotic research platform. ROV SuBastian completed 13 dives that were live broadcast on the institute's YouTube channel in high definition. Within three months of the cruise, NOAA placed the Marianas Monument on the national inventory for possible sanctuary designation.

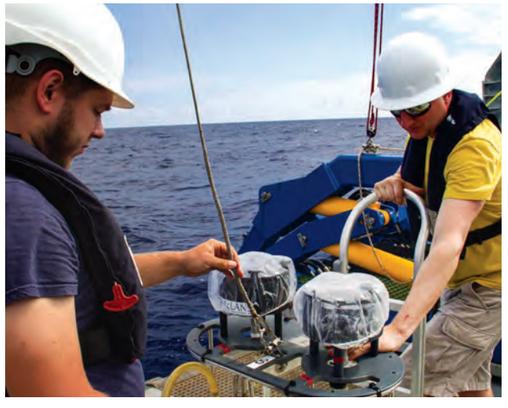
SOI is thrilled to be a global oceanographic institution. Since 2012 we have hosted more than 465 scientists representing nearly 138 institutions from 27 countries. Our mission to accelerate the pace of understanding the oceans is fueled by our philosophy of open data and knowledge sharing. This year more than 65 ROV dives were broadcast live from *Falkor* for the world to see. All scientific data acquired on *Falkor* is made available online once processed. We reach out to new audiences through such programs as Artist-at-Sea. Six different artists have participated in research cruises on *Falkor* to help interpret and share the science through music, paintings, fiber arts, digital animations, cartoons, and photographs.

All of us at SOI remain committed to advancing ocean science and technology as research vessel *Falkor* enters her fifth full year of service. We are grateful to our partners and collaborators supporting our pursuit to Innovate. Explore. Share.

Schmidt Ocean Institute founders Eric and Wendy Schmidt.

2016 WHAT WE ACCOMPLISHED

ACCOMPLISHMENTS NEXT STEPS WHY WE CARE

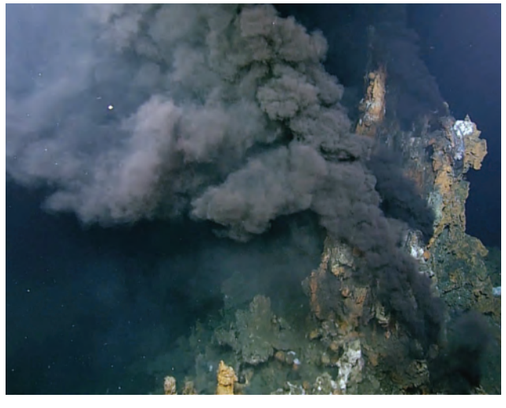


MARINE LIFE WITHOUT OXYGEN IN THE TROPICAL PACIFIC

The use of proteomics - analysis of organisms' proteins - was demonstrated during the study of how hypoxia in oxygen minimum zones influences microbial growth and functions. Critical nutrient recycling reactions enabled by metal-containing enzymes have been identified.

In-depth proteomic and genomic analyses of the samples gathered during the expedition are under way. In combination, they will provide the ability to better understand the metabolism of the oceans in the expanding oxygen minimum zones.

Marine microbial life greatly influences global biogeochemical cycles. With deoxygenation now occurring across large areas of the ocean, novel in situ biomedical techniques, such as proteomics, will allow scientists to make inferences about the evolving role of microbes in reduced oxygen environments.

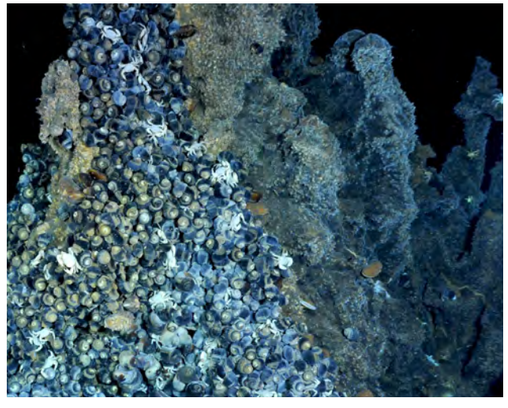


VIRTUAL VENTS: THE CHANGING FACE OF HYDRO-THERMALISM REVEALED

An entire active hydrothermal vent field at Niua South submarine volcano in Northwestern Lau Basin was imaged with an ROV for subsequent reconstruction into a digital 3D model with sub-centimeter resolution. The digital model will offer a holistic view of these unique deep sea ecosystems and enable their exploration and analysis in virtual reality.

The team is exploring options for linking the panoramic ROV video with the release of an interactive virtual reality model of the entire hydrothermal vent field. These materials will serve as a citizen science platform for deep sea exploration and research and as a portal to the raw data for scientists around the world.

The newly demonstrated high resolution ROV imaging and digital modeling methodology makes deep sea ecosystems much more amenable to quantitative analytical research, for example, by visualizing seafloor models in 3D virtual reality and subjecting them to appropriate numeric analyses.



ECOSYSTEM DYNAMICS OF HYDROTHERMAL VENT COMMUNITIES

Nineteen long term study sites on the Eastern Lau Spreading Center were re-surveyed contributing to a long term hydrothermal vent ecosystem monitoring program. Most vents were found to be long-lived, stable habitats, not changing after more than a decade.

Assembled ecological, geochemical and geophysical data are being combined into a new vent ecosystem model. It will include high resolution seafloor photomosaics reconstructed from the ROV imagery, maps of animal communities, as well as physical and chemical environmental parameters.

Increasing worldwide demand for precious metals is driving industry to seek out new mining sites. Deep sea vents enriched in metals are prime targets for seafloor mining. The industry has based its environmental impact assessments on possibly outdated ideas that these vents form frequently. The vent communities in the western Pacific do not conform to this model, and the extent to which they would be impacted by seafloor mining must be reconsidered.

A CHANGING RIVER: MEASURING NUTRIENT FLUXES TO THE SOUTH CHINA SEA

The Mekong River is rapidly changing due to increased sewage and fertilizer loading, mangrove destruction, and new dams. Nutrient and isotope samples were gathered to investigate the role of the changing river plume in structuring coastal and offshore ecosystems and supplying nutrients into these waters. It was the first time in many years that an American research vessel operated in this region.

Genomic and isotopic samples, nutrient and hydrographic data will be analized following the cruise. Several scientific publications on the diversity of nitrogen-fixing organisms in this region and the role of physical processes in structuring the biological communities are in preparation.

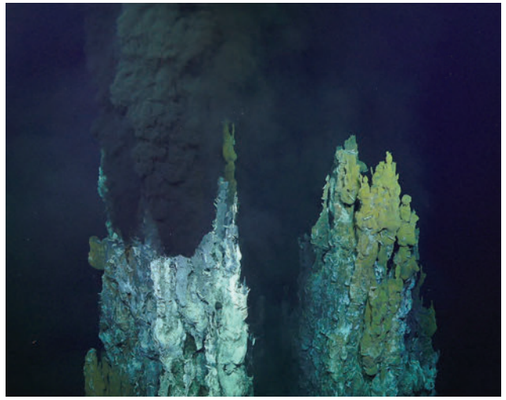
This research provides a rare benchmark of the region's biological state in advance of large scale anthropogenic changes in the delivery of freshwater, sediments, and nutrients from the Mekong River to the South China Sea. This is important considering that South China Sea is a major food source for Vietnam and nearby coastal states.

STUDY OF THE SEA SURFACE MICROLAYER AND AIR SEA BOUNDARY

Biologically essential trace metal dynamics, greenhouse gas exchange rates, and microbial communities in the sea-surface microlayer were characterized at 17 stations across the Indian and Pacific Oceans. For the first time, wide area scientific sea surface surveys were performed with a ship-deployed long endurance vertical take-off and landing robotic aircraft.

Gathered microbiological, chemical, and physical data will help scientists model and evaluate the interactions between the chemistry and microbiology of the sea surface microlayer. Heat and gas exchange rates in relation to driving environmental forces, such as wind and evaporation are also being considered in the analysis of microlayer interactions.

This research will strengthen the foundations for weather and climate forecasting by refining the models for air-sea gas and heat exchange parameterization, and will help scientists better understand the role of the air-sea microlayer in marine biogeochemical and climate processes on a global scale.



SEARCHING FOR LIFE IN THE MARIANA BACK-ARC

The first science cruise with ROV SuBastian revealed a very consistent Mariana Back-arc vent fauna community across fields spaced ~170 km apart. The Back-arc vent fauna and fluid chemistry are significantly different from the shallower nearby volcanic arc sites.

The samples are being analyzed for vent fluid/gas composition, biological and microbial species identification, and volcanic rock and hydrothermal mineral composition. Within three months of the cruise, NOAA placed the Marianas Monument on the national inventory for possible sanctuary designation.

We learned that large-scale tectonic processes create diverse geochemical conditions that differentiate vent biological communities. Understanding the drivers of diversity for hydrothermal vent ecosystems is critical for environmental assessments to help minimize anthropogenic harm to the marine environment.

BUILD AND DELIVERY OF ROV SUBASTIAN

ROV SuBastian was built and delivered on schedule and successfully passed the tank and sea trials. This allowed for a smooth first science mission including navigating around hydrothermal vents and using a full suite of scientific instruments integrated onto the vehicle. SuBastian successfully accomplished all of the cruise objectives.

In early 2017, the ROV support team will perform necessary inspections and maintenance on the vehicle, winch, and docking head, as well as some upgrades based on the lessons learned in 2016 and in preparation for the planned 2017 research cruises.

The successful delivery, integration, and initial scientific operations of SuBastian on *Falkor* allows scientists and the public to see the new deep sea robotic capability of Schmidt Ocean Institute in action. Its many planned future deployments will help us better understand and care about our oceans.

2016 IN NUMBERS AND FIGURES

59K+ KM TRAVELED

MORE THAN ONE TIME AROUND THE WORLD

185 SCIENCE DAYS

95 SCIENTISTS ON BOARD

contributing to 138 institutions
from 27 different countries

21 STUDENTS SAILED

6 RESEARCH CRUISES

11 UAVS LAUNCHED

Totalling 23 hours

2 SEA TRIALS

8 HYDROTHERMAL SITES SURVEYED

80 CTD CASTS

ROV SUBASTIAN

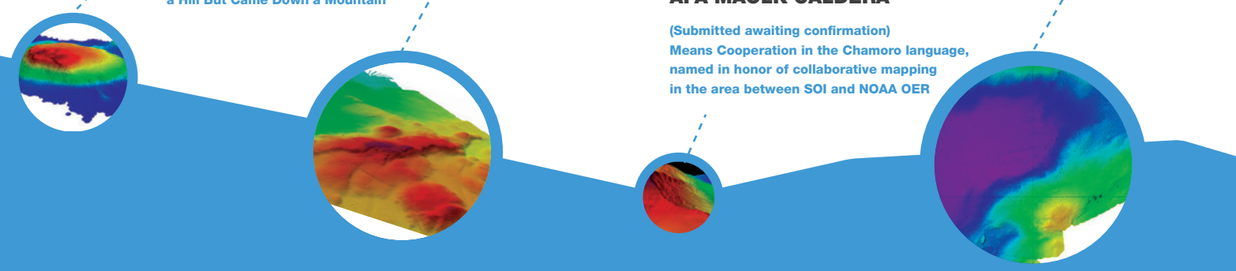
49 SUCCESFUL DIVES

260 HOURS DIVE TIME

4501 METERS DEEPEST DIVE

220 SAMPLES TAKEN

1 NEW CHIMNEY DISCOVERED



DATA

105Tb
OF DATA PRODUCED ON *FALKOR*

6670
HOURS VIEWED IN YOUTUBE

218K
METEOROLOGY DATA POINTS SUBMITTED TO SAMOS

93Gb
DATA ACQUIRED BY *FALKOR* DOWNLOADED FROM MARINE GEOSCIENCE DATA SYSTEM

2,782Km2
BATHYMETRIC DATA ADDED TO GLOBAL MULTI-RESOLUTION TOPOGRAPHY

13
PROJECT'S DATA CONTRIBUTED TO GENERAL BATHYMETRIC CHART OF THE OCEANS FOR 2017

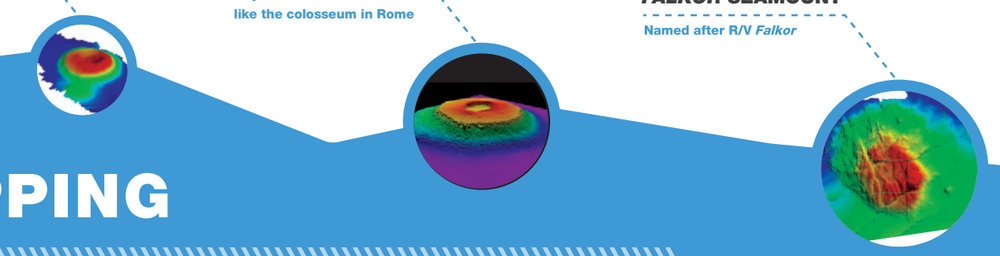
MAPPING

FALKOR'S MULTIBEAM AND ECHO SOUNDER SYSTEM MAPPED APPROXIMATELY...

14x THE GRAND CANYON

70k SQUARE KM

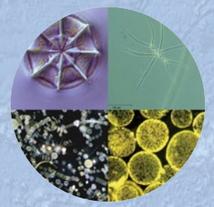
WE MAPPED A NEWLY DEVELOPED ISLAND: HUNGA TONGA HUNGA HA'APAI AND SANTA ROSA REEF



OUR EXPEDITIONS 2016

SEARCHING FOR LIFE IN THE MARIANA BACK-ARC

Mariana Back-Arc, Port: Hagatna, Guam
Nov. 29 — Dec. 21



MARINE LIFE WITHOUT OXYGEN IN THE TROPICAL PACIFIC

Central Pacific, Port: Honolulu, Hawaii
Jan. 15 — Feb. 11

A CHANGING RIVER: MEASURING NUTRIENT FLUXES TO THE SOUTH CHINA SEA

South China Sea, Port: Nha Trang, Vietnam
Jun. 3 — Jun. 19

ECOSYSTEM DYNAMICS OF HYDROTHERMAL VENT COMMUNITIES

Lau Basin, Port: Suva, Fiji
Apr. 7 — Apr. 19

STUDY OF THE SEA-SURFACE MICROLAYER & AIR-SEA BOUNDARY

Australian Coast, Port: Darwin, Australia
Oct. 10 — Nov. 9

VIRTUAL VENTS: CHANGING FACE OF HYDROTHERMALISM REVEALED

Lau Basin, Port: Suva, Fiji
Mar. 15 — Apr. 11

ROV · UAS · CTD · Mapping · Hydrothermal Vents · Remotely Controlled Catamaran · Expedition's Tracks

MARINE LIFE WITHOUT OXYGEN IN THE TROPICAL PACIFIC

JANUARY 15 - FEBRUARY 11, 2016

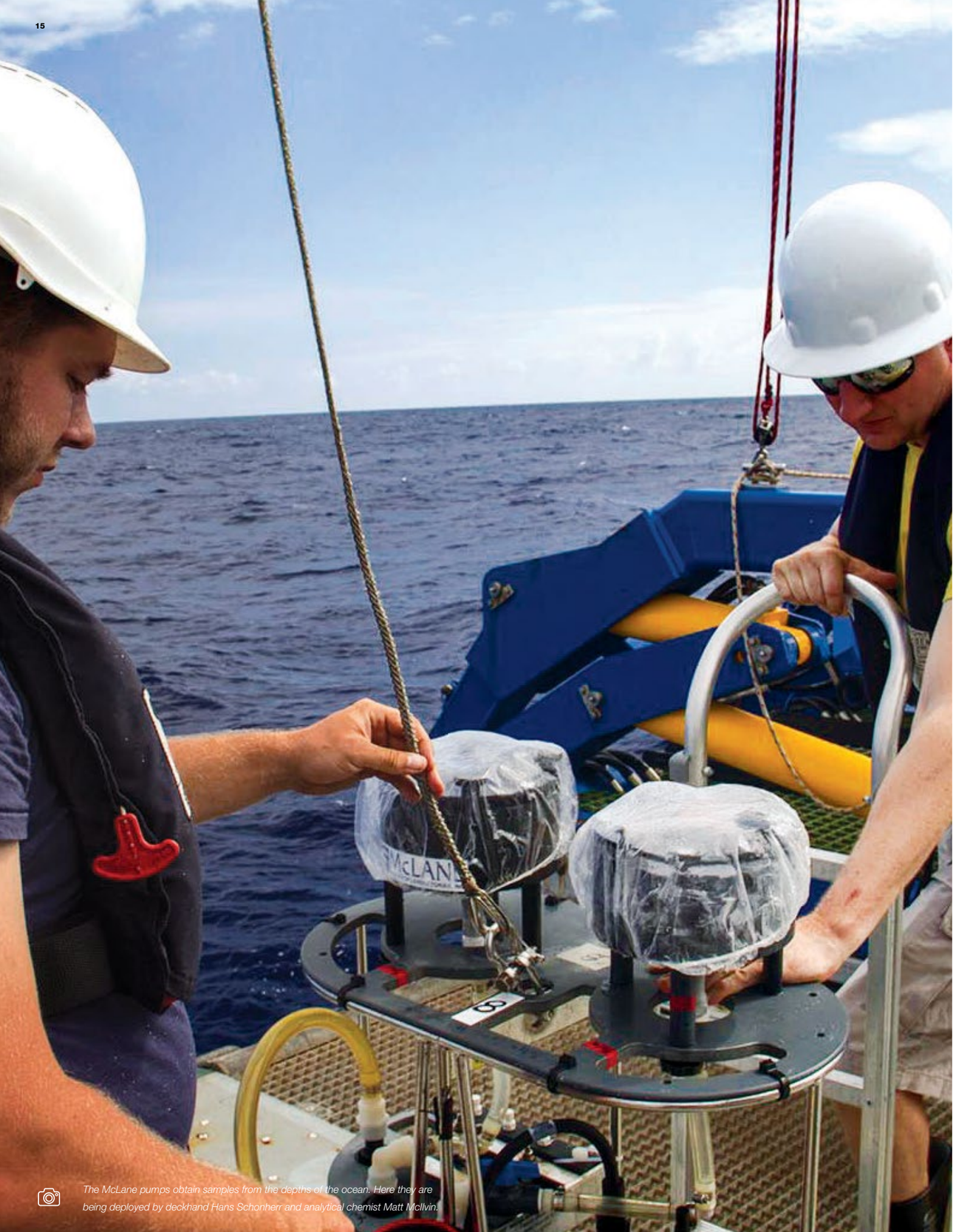
MAK SAITO
Chief Scientist

HONOLULU, HAWAII TO PAPE'ETE, TAHITI

DOI: 10.7284/906661

COLLABORATING INSTITUTIONS

- Woods Hole Oceanographic Institution
- University of Washington
- University of Santa Cruz
- National Science Foundation
- University of Maryland Center for Environmental Sciences
- Moore Foundation



The McLane pumps obtain samples from the depths of the ocean. Here they are being deployed by deckhand Hans Schonherr and analytical chemist Matt McIlvin.

Most of life as we know it depends on carbon, nitrogen, oxygen, and iron; elements that get cycled throughout the planet and transported by microorganisms. There are four unique locations in the ocean where oxygen concentration gets particularly low; these places have been labeled oxygen minimum zones (OMZs).

OMZs can occur naturally due to large-scale ocean circulation, yet the biogeochemistry is significantly different compared to oxygen-rich areas. This biogeochemistry, the cycling of carbon and nutrients, is the very foundation of marine ecosystems and has a huge impact on all life on Earth. OMZs appear to be getting bigger based on historical measurements and scientists are trying to understand what this means for general ocean functions.

During the first cruise of 2016, *Falkor* traveled 7,000 kilometers between Hawaii and Tahiti, to the largest OMZ on the planet to investigate its impacts. The team led by Dr. Mak Saito from Woods Hole Oceanographic Institution, along with scientists from University of Maryland's Center for Environmental Science and the University of Southern California, used new biomedical methods to examine this unique area.

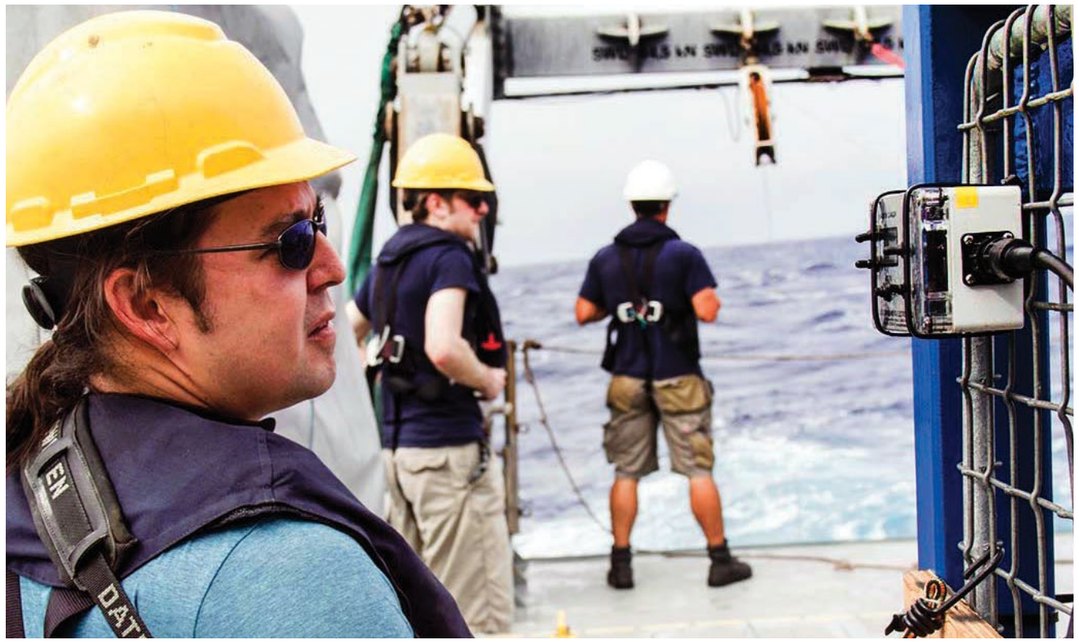
To understand what controls microbe growth and productivity in the OMZ, the scientists used a new method called Proteomics, to look at the proteins inside an organism. By measuring these proteins, the team was able to observe microbial function and track the deficiencies that may be limiting growth. Proteomics has the capability to identify environmental stresses acting on the abundant microbial populations, allowing a diagnostic capability for detecting changes in ocean diversity and function.

Over the course of the 22-day expedition, the team used CTDs to sample the upper layer of the ocean's microbial microbiome filtering 85,000 liters of seawater at 17 different stations. "It is hoped that this large dataset will become a valuable resource for others studying a variety of ocean processes and topics," said Chief Scientist Mak Saito. "We need to be able to understand the myriad of impacts our global human society is having on the chemistry of the planet, and how can we pull back on unintended negative consequences."

The research completed on this cruise will provide a better grasp of the critical chemical processes being conducted by microbial organisms that live within OMZs, and could eventually help to identify long-term changes in these poorly understood regions. Additionally, because the expedition occurred during a strong El Niño year, the samples gathered will allow for studies on how the warmer seawater conditions influence key microbial processes. Comparisons of this dataset with more typical years will provide valuable insight into ecosystem responses to El Niño.

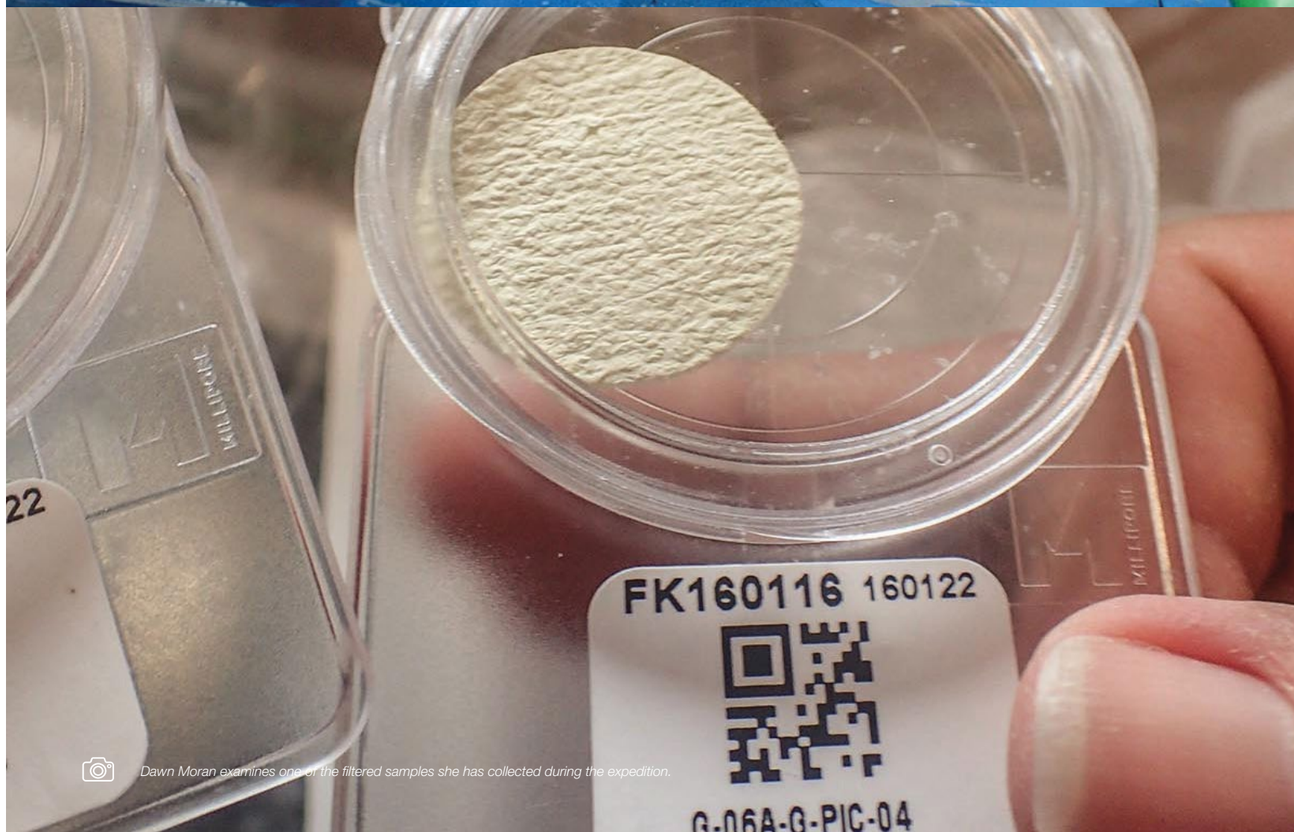
85k

LITERS OF SEAWATER AT 17 DIFFERENT STATIONS



Chief Scientist Dr. Mak Saito handles the winch and lowers the aft rosette.

Superficial water samples rest on incubators after being supplemented with nutrients.



Dawn Moran examines one of the filtered samples she has collected during the expedition.

VIRTUAL VENTS: THE CHANGING FACE OF HYDRO-THERMALISM REVEALED

MARCH 20 - APRIL 1, 2016

TOM KWASNITSCHKA
Chief Scientist

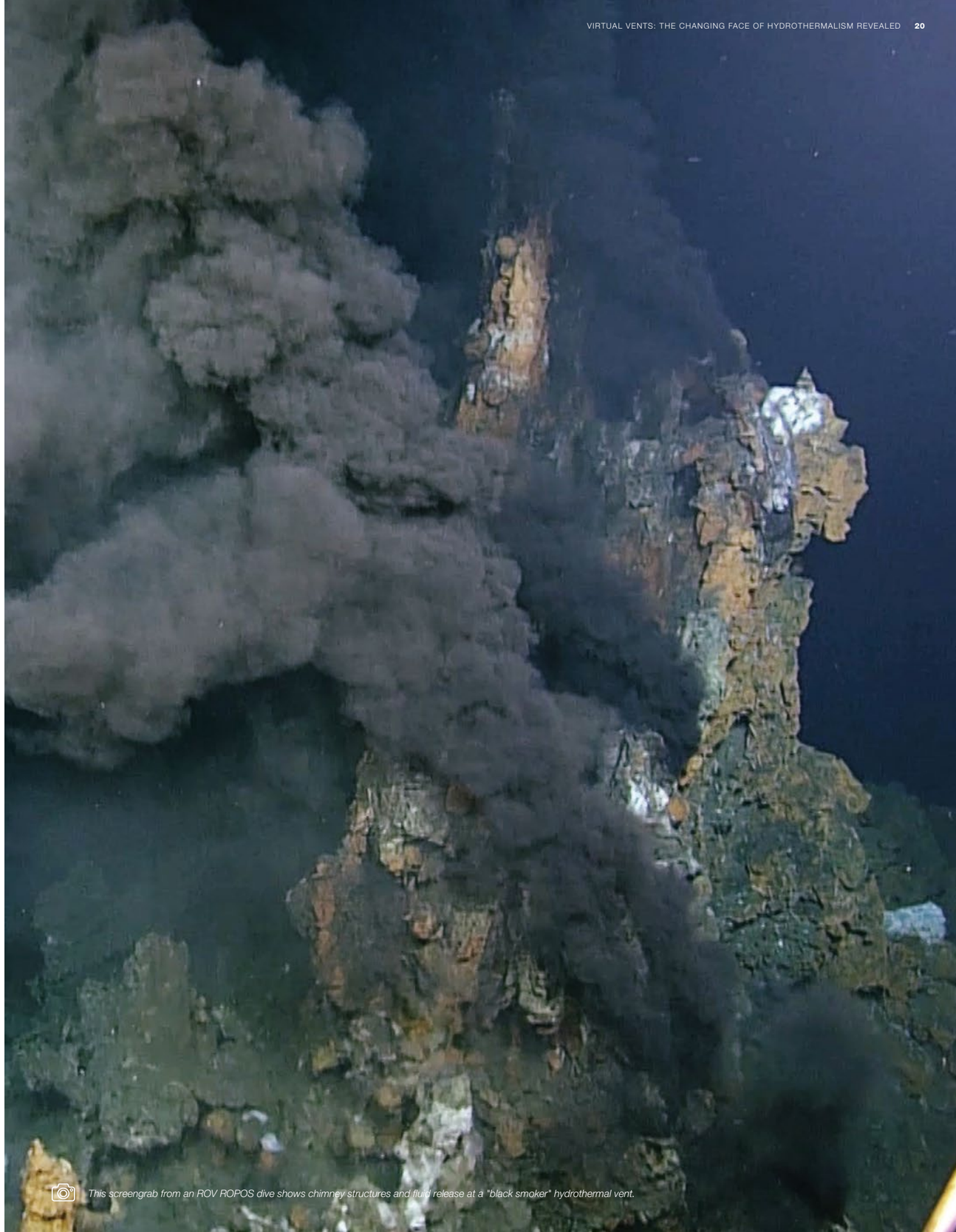
SUVA, FIJI

DOI: 10.7284/906663

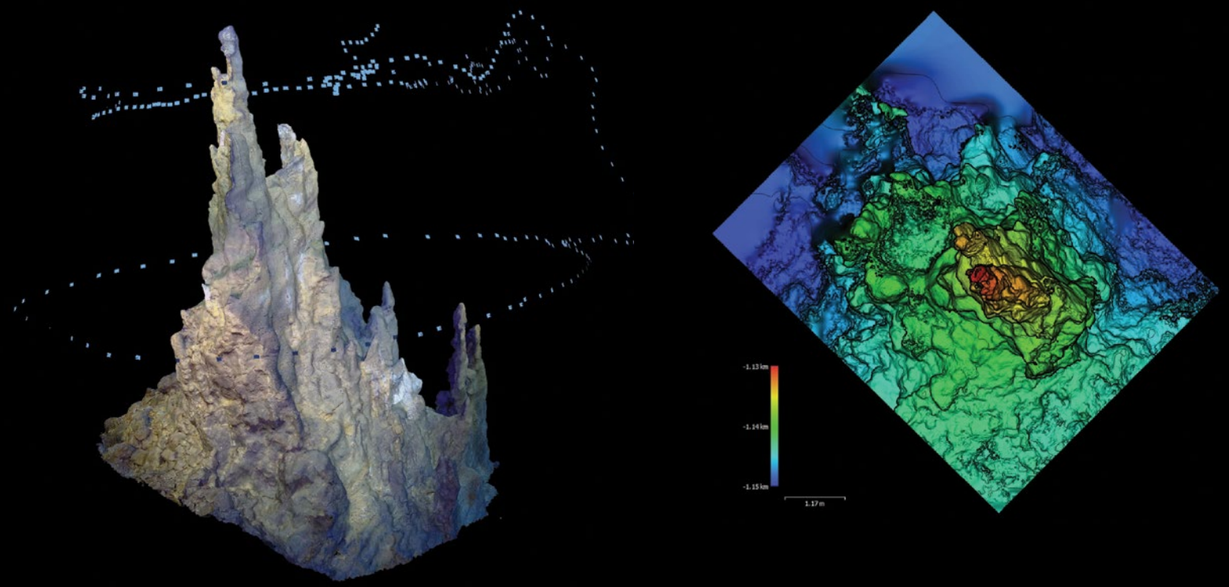
COLLABORATING INSTITUTIONS

- GEOMAR Helmholtz Centre for Ocean Research, Kiel
- Memorial University
- Deutsche Forschungszentrum für Künstliche Intelligenz GmbH
- University of Victoria
- University of Ottawa
- United States Geological Survey

Ocean water is opaque to electromagnetic waves. This complicates remote mapping and research of the seafloor. A new ROV imaging and modeling approach was demonstrated by Dr. Tom Kwasnitschka from GEOMAR Helmholtz Centre for Ocean Research Kiel to create a three-dimensional (3D) high definition digital photorealistic model of a complete deep sea hydrothermal vent system. This approach makes deep sea ecosystems amenable to analytical research, for example, by visualizing seafloor models in 3D virtual reality and applying appropriate numeric analyses.



This screengrab from an ROV ROPOS dive shows chimney structures and fluid release at a "black smoker" hydrothermal vent.



219,000 digital single lens reflex camera images were made over five days. Combining these photographs with photogrammetric and acoustic data has allowed for the creation of extremely detailed 3D images, such as these.

In Falkor's dry lab, researcher Rachel Boschen tries out the Virtual Reality simulation of the hydrothermal vents by wearing goggles to immerse herself in the experience.

The researchers applied high definition panoramic imaging technology to survey a hydrothermal vent site at Niua South volcano in the Northeastern Lau Basin off Tonga and create a digital model of an entire hydrothermal vent field that can be explored using virtual reality simulators. Amid concerns over the impact of deep sea mining upon marine ecosystems, such 3D models and visualizations can provide granular information about these habitats and their susceptibility to perturbations.

The study created the first data set of its kind, with a multi-perspective 3D terrain reconstruction of the vent field at sub-centimeter scale across 25 acres. The previously unparalleled resolution will allow researchers to define the attributes of venting, fluid temperature/chemistry, and animal clusters, and has already revised scientists understanding of the hydrothermal structure. "The biological, chemical and geological relationships in these areas are complicated and intricate, in ways that are not completely understood. Being able to view the whole system has evaded most scientists as

There are still many mysteries surrounding seafloor hydro-thermal vent complexes.

— Chief Scientist Tom Kwasnitschka

they are unable to experience this deep sea environment, until now", said Dr. Kwasnitchka.

Remotely Operated Vehicle (ROV) ROPOS, supported by Schmidt Ocean Institute, was fitted with a quiver of survey cameras. A high-resolution camera with a LED strobe flash was used to survey the site while two machine vision cameras gathered stereo still images as part of the real-time 3D scanning workflow. A workstation outfitted with specialized software modified the wide-angle distorted images in real-time so that the vents could be experienced using a virtual reality head-mounted display. *Falkor*'s high-performance

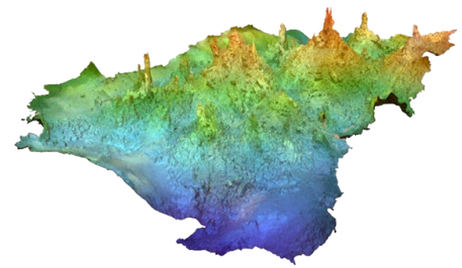
100
HOURS OF ULTRA-HD VIDEO RECORDED

229k
NUMBER OF SLR IMAGES RECORDED

149
HOURS OF DIVE TIME

computing system helped to process the data and create a first version of the terrain model. To identify expected gaps around the chimney walls, a laser based light system on the ROV registered the vents from all sides, delivering a near real-time 3D preview of the structures. Imaging sonar was also integrated into this task, delivering additional information that will be fused with the stereo camera data.

The ROV video was streamed live to Schmidt Ocean Institute's YouTube page to be viewed worldwide, and several live connections with museums, college classrooms, and planetariums were made. A 74-hour marathon dive set a new dive time record for ROV ROPOS. With the data collected, the team is working on creating the first ever open-access, virtual model representing an entire vent field.



A photogrammetric model of the central part of the Niua South hydrothermal field with better than 5 cm resolution. Individual chimneys are shown on mounds of talus, broken-off pieces of their precessors.

ECOSYSTEM DYNAMICS OF HYDROTHERMAL VENT COMMUNITIES

APRIL 7 - 19, 2016

CHARLES FISHER
Chief Scientist

PETER GIRGUIS
Chief Scientist

SUVA, FIJI TO NUKU'ALOFA, TONGA

DOI: 10.7284/906664

COLLABORATING INSTITUTIONS
- Columbia University
- Harvard University
- Pennsylvania State University
- Woods Hole Oceanographic Institution

Image from the first visit to Tahi Moana vent field. On the left, all three of the Lau Basin foundation species can be seen clustering on top of each other: Alviniconcha spp. snails, Ifremeria nautilei snails, and Bathymodiolus septemdierum mussels.

The second hydrothermal vent cruise of the year continued in the Lau Basin off Fiji and Tonga. The team of interdisciplinary scientists led by Drs. Peter Girguis from Harvard University and Charles Fisher from Pennsylvania State University focused on the huge animal communities living in the vent system, contributing to a long term monitoring dataset.

Using Canadian Scientific Support Facility's ROV ROPOS, supported by Schmidt Ocean Institute, high-resolution bathymetry was collected from four key sites that can be compared to data collected in 2006, allowing the research team to identify changes at these locations, presumably caused by tectonic or volcanic activity.

ROV ROPOS was used to perform a range of tasks including visual and sonar surveys, collecting specimens, as well as transporting sensors to record environmental measurements. The camera systems on ROV ROPOS were used to gather imagery, which was stitched together to create high-resolution 2D and 3D photomosaics. All dives were live streamed on

Schmidt Ocean Institute's YouTube page, sharing over 170 hours of footage. "There is one moment where it is all black and then suddenly there they are, giant chimneys covered in life," said Rachel Boschen, one of the scientists on the expedition.

Based on initial comparisons of the imagery, the long-term study sites are much more stable than previously thought. This is an important finding as it challenges previous understanding that vent environments are highly dynamic, causing concern over potential environmental impacts from deep-sea industrial mining. Our limited knowledge of hydrothermal vent ecosystems is a key obstacle in effectively measuring, managing, or predicting man-made effects in this area. The data gathered on this cruise will be helpful in providing a baseline for creating conservation strategies for vent sites.

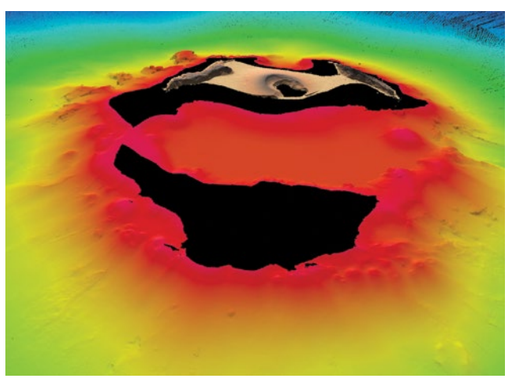
Additionally, the science team was able to characterize the physical-chemical environment, emphasizing the dynamic aspects of the habitat and animal communities. Using an in situ mass spectrometer with a new device built especially for this study, scientists were able to acquire high-quality chemical measurements of hydrothermal fluid ranging from a few degrees above ambient temperature to over 300°C. High quality samples of corrosive hydrothermal vent fluids taken at high temperature and pressure were collected from three sites. The collections are expected to provide some of the best datasets on the impact of these animal communities on the flux of chemicals from diffuse flow.

A mobile laboratory was set up on *Falkor* replicating pressure at depth so shipboard scientists could observe collected species in conditions close to their deep-sea habitat. The team examined the symbiotic and chemosynthetic relationships that giant snails and miniature tube worms have with the microbes present, making life possible in extreme vent environments. Ground-breaking studies were also conducted using particle exposure to study the impact of natural and anthropogenic particles on the health of vent animals. Early insights point towards the idea that the metabolic activity of many faunae living in hydrothermal fields is more diverse than previously thought.

While in Tongan waters, *Falkor* conducted the first high-resolution undersea mapping of a newly developed island — unofficially named Hunga Tonga Hunga Ha'apai (HTHH). This mission of opportunity allowed the team to explore one of the newest islands on Earth. The island surfaced in early 2015 as a result of a "surtseyan" eruption - a violent interaction of searing molten material and cool seawater that results in an original land mass. The data collected will contribute to a project with NASA and Columbia University's Lamont-Doherty Earth Observatory to create a three-dimensional character of the new island at meter-scale resolution.

ROV ROPOS is launched from the aft deck of Falkor into the Pacific.

> You know you are probably the first to see this, and in that moment of discovery, you realize that there are still places on this planet that we haven't explored.
>
> — Rachel Boschen



The first high-resolution undersea map of Hunga Tonga Hunga Ha'apai (HTHH) which ranges from the seafloor to its 130 m. tall summit. The map will serve as a topographical baseline as scientists explore how volcanic islands evolve and dissolve.

This encounter with a Cirroteuthis muelleri (Dumbo Octopus) and Ophidiidae (Cusk Eel) was filmed at 2100m depth.

Grimpoteuthis is a genus of pelagic umbrella octopus that live in the deep sea, also called "Dumbo Octopus" because of the prominent ear-like fins that protrude from the mantle.

Vent animals piling on top of one another, competing for position over the hot, diffuse vent. The dominant snail Alvinichoncha was discovered to be three different but closely related species.

A CHANGING RIVER: MEASURING NUTRIENT FLUXES TO THE SOUTH CHINA SEA

JUNE 3 - 19, 2016

JOSEPH MONTOYA
Chief Scientist

NHA TRANG, VIETNAM

DOI: 10.7284/906918

COLLABORATING INSTITUTIONS

- Georgia Institute of Technology
- Vietnam Academy of Science and Technology
- Leibniz-Institut für Ostseeforschung Warnemünde
- Stockholm University
- Lamont-Doherty Earth Observatory

The Mekong River flows nearly 4,100 kilometers through six countries, and is the twelfth longest river in the world. In June, Dr. Joseph Montoya from Georgia Institute of Technology and his team explored how one of the world's great river systems influences the ocean and surrounding seas.

The Mekong River has been significantly influenced by anthropogenic impacts including sewage loading, fertilizer use, mangrove destruction, and dam construction, and more than 60 dams are planned to be built along the river in the next 20-30 years. The rapid changes to this environment provide an important area of study for understanding how these riverine inputs impact the nearby ocean.

The South China Sea is of particular interest due to its natural upwelling, which brings water and nutrients from the depths of the ocean to the surface. A variety of biological processes are affected by the circulation of the South China Sea, especially during upwelling, which has a strong effect on the spatial distribution of phytoplankton biomass and activity. The science team wanted to better understand how contributions

Andreas Novotny works with Ajit Subramaniam on incubator experiments.

The river plume is visibly distinct from ocean water by a marked change in water color.

from the Mekong River's plume and the natural upwelling interact and promote the growth of plankton, fish, and other organisms.

Scientists aboard *Falkor* completed over 112 net tows and more than 48 CTD casts, allowing for 21,000 square kilometers of ocean to be surveyed for biological, chemical, and physical measurements. "Every time we dropped the rosette, we were seeing a new part of the ocean that had never been sampled before," said Chief Scientist Joseph Montoya. "These are fascinating waters, we found something unexpected almost every day," echoed Dr. Ajit Subramaniam.

The team located many phytoplankton communities in unexpected and different places than hypothesized. The data collected will allow them to look at the exchange of nitrogen and carbon between cells in the phytoplankton community. The expedition was one of the few opportunities to study this area before significant changes in nutrient and organic matter loading materialize from adjustments in the river basin. The data acquired provides a crucial overview of the South China Sea early in this transition, helping scientists better understand how man-made activities enacted deep inland have repercussions in the ocean.

48

CTD CASTS AND 112 NET TOWS

21k

km² OF OCEAN TO BE SURVEYED

Scientist Hoi Nguyen works to make sure that samples are adequately collected and preserved, or analyzed in outdoor incubators and onboard labs.

STUDY OF THE SEA SURFACE MICROLAYER AND AIR SEA BOUNDARY

OCTOBER 10 - NOVEMBER 9, 2016

OLIVER WURL
Chief Scientist

DARWIN, AUSTRALIA
Location

DOI: 10.7284/907180

COLLABORATING INSTITUTIONS

- Universität Oldenburg
- The Marine Biological Association
- Lamont-Doherty Earth Observatory

An Unmanned Aerial Vehicle carries scientific instruments from a research vessel for the first time, without the help of any catapult or launching system. It was also the first time the HQ-60B model supported ship-based aerial operations.

The sea-surface microlayer has a significant impact on marine biogeochemical and climate-related processes on a global scale. Understanding this boundary and its workings is critical, as everything that enters the water column goes through and is affected by this “skin” of the ocean. The multidisciplinary scientific team collected important observations that have implications for understanding ocean properties and their role in climate change.

The 31-day “Air to Sea” cruise traveled from Darwin, Australia, through the Timor Sea and Pacific Ocean before ending in Guam. Chemists, biologists, geologists, and oceanographers used sensors attached to a range of vehicles, some for the first time. One of the most exciting was a fleet of hybrid Unmanned Aerial Vehicles (UAVs), fixed-wing aircraft with an attached quad rotor. Three different types of instruments were incorporated onto the UAVs during the cruise: cameras, spectrometers, and radiation sensors. Once the UAVs launched from *Falkor*, the instruments mapped the ocean below and the atmosphere above, acquiring data that will help researchers understand complex processes that affect air-sea exchange. “It has been almost six years since the design of the instruments began,” said Co-Chief Scientist Dr. Christopher Zappa from Columbia University’s Lamont-Doherty Earth Observatory. “The vehicles and instrument

Janina Rahlff and Chief Scientisr Oliver Wurl collect surface microlayer samples just before dawn.

The Remotely Operated Catamaran, driven by Dr Mariana Ribas, working in moderate sea states in the Pacific Ocean. The catamaran collects samples of the Sea Surface Microlayer through a system of rotating glasses.

payloads performed how they were supposed to, allowing us to gather some very interesting data of the ocean's surface in high resolution."

A remote-controlled catamaran was also deployed, using six parallel rotating glass plates that collect microlayer water. The "oily" microlayer stuck to the plates, and samples were passed through a series of sensors on the catamaran. The catamaran took one meter deep samples to compare with the simultaneously collected samples on the surface. Additionally, an in situ autonomous drifting buoy measured CO_2 exchange between the ocean and the atmosphere. By correlating the partial pressure of CO_2 in the air, surface, and water at the same time, researchers were able to determine the velocity of the CO_2 exchange between the atmosphere and the ocean.

The specialized tools collected data at 17 sampling stations capturing different aspects of the sea surface microlayer including biologically-essential trace metals, greenhouse gas exchange rates, processes affecting air-sea transfer, and microbial communities. Some surprising results came from the first air-sea investigation within a cyanobacteria bloom (a potentially toxic blue-green bacteria), as well as the discovery of tiny blue copepods (extremely small crustaceans) living in the microlayer, demonstrating a previously unknown distribution.

To interpret these distinct but interconnected data sets, a massive amount of data was processed using *Falkor's* high-performance computing system. Over 900 kilograms of seawater was filtered, and more than 400 samples were collected from the sea-surface microlayer; the team has over 500,000 in situ data points. "This data set will be the first of its kind, where we are including the chemistry, biology, and physics of what is actually happening in the microlayer," noted Co-Chief Scientist Dr. Bill Landing from Florida State University. "We've gotten just about every sample we need and more."

This is the first time that Wurl's team has found copepods in the samples since they first started using the catamaran.

The main purpose of this cruise was to bring different teams together, taking a holistic approach to studying the sea surface, and we certainly accomplished that.

— Chief Scientist Oliver Wurl

400

WATER SAMPLES COLLECTED FROM THE CATAMARAN

Justin Amer, Joe McDaniel and Scott Bowers next to the UAV which was flown and launched off a ship for the first time. The radiometers on the UAV will yield key information to understand heat exchange between the ocean and the atmosphere.

SEARCHING FOR LIFE IN THE MARIANA BACK-ARC

NOVEMBER 29 - DECEMBER 20, 2016

DAVID BUTTERFIELD
Chief Scientist

WILLIAM CHADWICK
Chief Scientist

HAGATNA, GUAM
Location

DOI: 10.7284/907181

COLLABORATING INSTITUTIONS

- University of Washington
- National Oceanic and Atmospheric Administration
- Oregon State University
- Pacific Marine Environmental Laboratory
- Marine Biological Laboratory

The first-ever science cruise with Schmidt Ocean Institute's in-house designed and built ROV SuBastian took place in the Mariana Back-arc. A multidisciplinary team of geologists, chemists, and biologists departed Guam to begin surveying the largely unexplored Mariana Back-arc region in and around the Marianas Trench Marine National Monument for life at depths greater than 4,000 meters.

In 2015, the first "Hydrothermal Hunt" research cruise aboard *Falkor* located new hydrothermal vents in the region, including evidence of recent lava flows. Chief Scientists Drs. David Butterfield, Joint Institute for the Study of the Atmospheric and the Ocean (JISAO), University of Washington, and William Chadwick, NOAA Pacific Marine Environmental Laboratory (PMEL), Oregon State University, led the science team in completing the second phase of this two-part exploration of the region: returning to these vents to characterize the water chemistry and biodiversity, thereby filling a gap in knowledge about the biogeography of these unique deep-sea ecosystems.

The new vent sites featured spectacular chimneys made of sulfide minerals up to 30 meters tall with vent fluid pouring forth at temperatures up to 365°C. Hairy snails, shrimp, crabs, mussels, limpets, squat lobsters, anemones, and polychaete worms were also viewed and sampled. The scientists onboard

A black smoker chimney, part of the "Two Towers" formation, from which ROV SuBastian gathered fluid samples

ROV SuBastian prepares to take a sample from one of the newfound deep-sea vents.

Falkor hypothesized that some of the observed animals at these sites are new species, but are awaiting verification as the team continues their analysis shoreside. The results provide a foundation to advance research on how life thrives around these extreme deep-sea hydrothermal vents.

The observations from this expedition demonstrate that the recently discovered vent sites have an ecosystem that is solely characteristic of the Mariana Back-arc. Video captured during dives with ROV SuBastian enabled the team of researchers aboard *Falkor* to make observations that suggest the Back-arc vent sites are relatively long-lived and that each site has biological "connectivity" with the others despite the long distances. Each vent site is relatively small and isolated, with many sites separated from others by up to 161 kilometers. The study also confirmed that the Back-arc ecosystems are distinct and different from the nearby Volcanic Arc hydrothermal ecosystems, supporting the idea that geological and chemical environment play a key role in selecting animal community composition at hydrothermal vents.

This year's results combined with the surveying completed last year with *Falkor's* CTD and Woods Hole Oceanographic Institute's AUV Sentry, supported by Schmidt Ocean Institute, will be used to create the first comprehensive view of the geologic, chemical, and biologic diversity that exists along the Mariana Back-arc.

[This expedition] Might help us to learn what might be the traits that are going to be in species that persist in a global ocean that is going to be changing markedly.

— Dr. Amanda Bates, National Oceanography Centre, University of Southampton

Lars Tönsfeldt and the ROV team guide SuBastian safely back to the ship after the first science dive at Daikoku.

Researchers and crew watch live video from ROV SuBastian's cameras in the control room on Falkor during the Mariana Back-arc expedition.

A NEW VEHICLE FOR *FALKOR*: ROV SuBASTIAN

It has been a whirlwind of a year for ROV SuBastian.

The new in-house built ROV was completed in early April for its first in-water testing at Monterey Bay Aquarium Research Institute (MBARI) tank testing facility.

A formal naming announcement and press event were held with co-founder Wendy Schmidt and select media. "This is an important next step for Schmidt Ocean Institute in terms of what we can offer the world's leading scientists aboard our research vessel *Falkor*," said Wendy Schmidt. "Being able to collect scientific observations and data with our own ROV will help us better understand rarely observed oceanic processes and phenomena."

The ROV engineering team designed the vehicle with the needs of the oceanographic community in mind. Engineers worked closely with an international group of scientific advisors including experts in marine biology, geology, ecology, and other fields to develop the vehicle design and operational requirements. As a result of this process, all major vehicle subsystems were procured to ensure the best overall vehicle performance. The ROV's imaging system includes state-of-the-art science cameras, capable of capturing both 4K ultra high definition video and 20 megapixel still images. The ROV has also been outfitted with a suite of sensors and equipment to support data and sample collection, as well as interactive research, experimentation, and technology development.

After successful tank testing, SuBastian was shipped to Guam where it met *Falkor* for integration and mobilization. Engineers and *Falkor* crew spent 25 days over the summer testing the ROV and placing SuBastian in real-world conditions. The ROV trials included 22 dives and more than 100 hours underwater. The team used the information collected to make tweaks and improvements that were further tested during an additional six dives in November. An additional six days were spent offshore testing SuBastian's subsystems, and conducting extensive crew training for new ROV Pilot Technicians. Observations were made by external science experts and team members bringing attention to areas of improvements, which were addressed.

SuBastian's first science expedition was to explore the hydrothermal vents in the Mariana Back-arc region off the coast of Guam and four cruises utilizing SuBastian are planned for 2017.

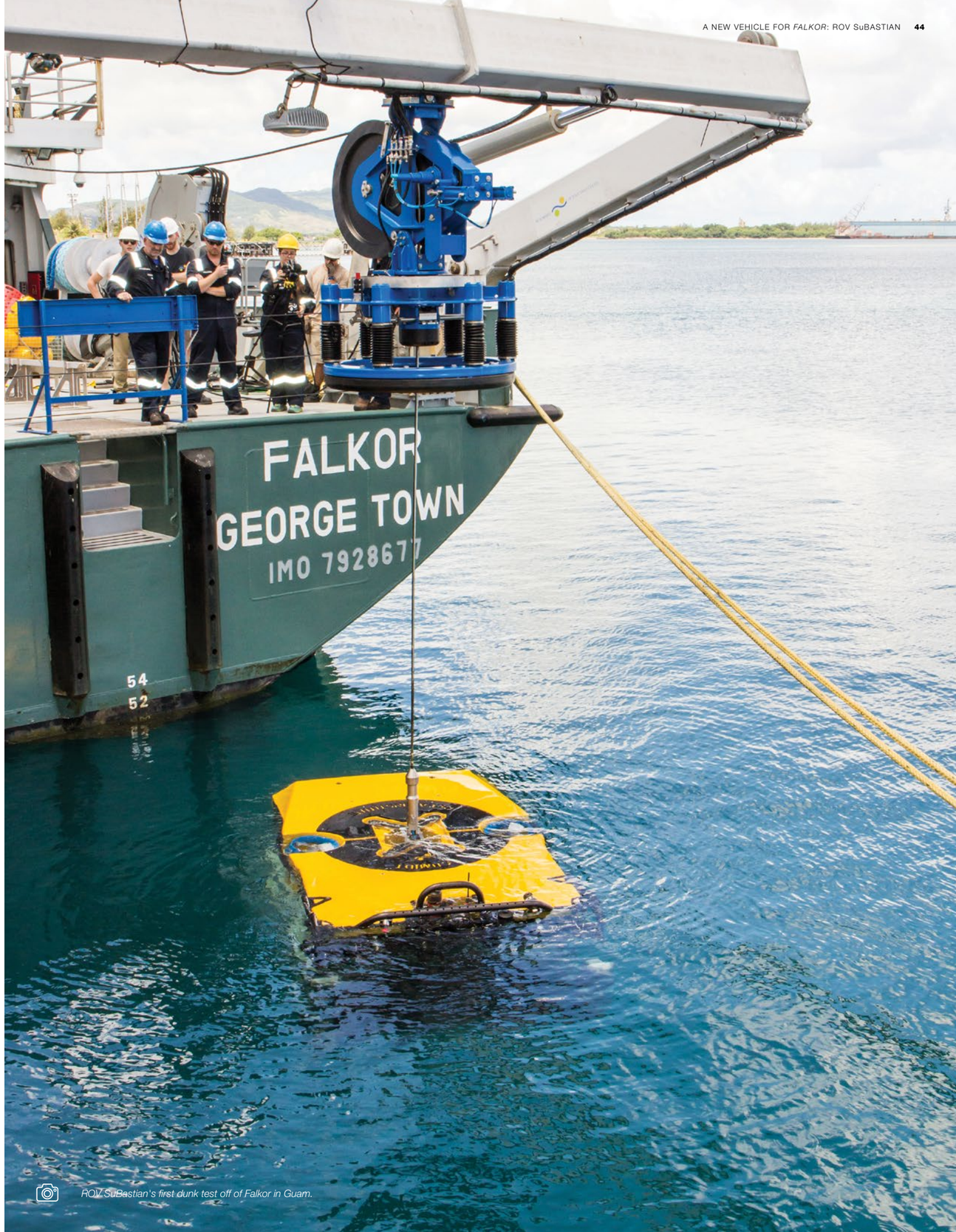
SuBASTIAN'S FIRSTS

APRIL 7
1st DUNK TEST

JULY 20
1st OCEAN DUNK

JULY
1st 4500m DEPTH

2016
50 TOTAL DIVES



ROV SuBastian's first dunk test off of Falkor in Guam.

Jacki Clueard and Lars Tönsfeldt prepare the umbilical floats for ROV SuBastian's sea trails off Guam

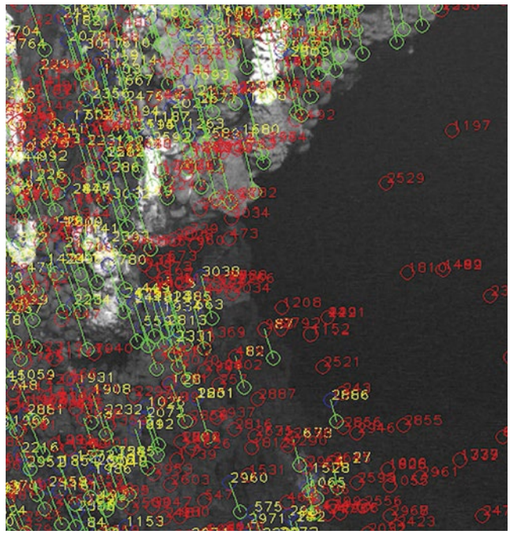
DATA STEWARDSHIP

In 2016, Schmidt Ocean Institute enabled users to easily access and understand the data coming from *Falkor*. Our partnership with Google Cloud Platform allowed us to store all raw data from the ship into the cloud, providing data to collaborators through weblinks.

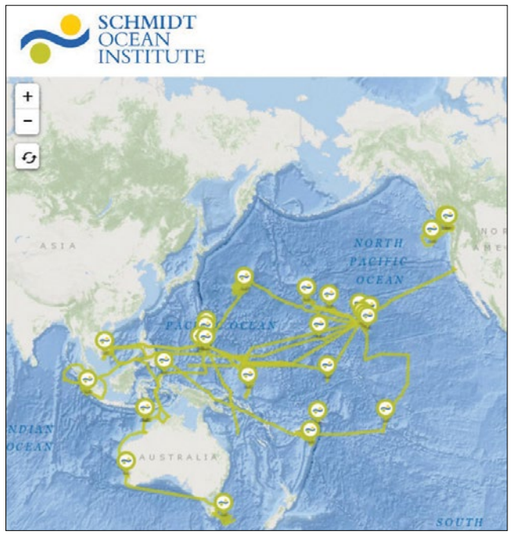
Utilizing cloud infrastructure decreases maintenance costs of at-risk storage devices that will reach their life expectancy within a few years. Additionally, the *Falkor* Status Page[1] received upgrades this year, including updated cruise maps and data visualization improvements. We continue to better data stewardship with new developments underway for 2017; this includes plans to build an ROV SuBastian Status Page with similar logging and archiving capabilities as our current *Falkor* page. This information will provide further insight into the conditions being experienced at sea and where the ROV is operating.

With each of *Falkor*'s exciting expeditions comes an abundance of data ripe for analysis, visualization, and ultimately, discovery. Using the tools on board, many of the scientists were better equipped to work with their data while at sea, creating visualization tools, maps, and processing infraspectral data, below are some examples.

During the Virtual Vent cruise, Dr. Tom Kwasnitchka conducted a microbathymetrical survey of the Niua South hydrothermal vent field in the Lau Basin. The numerous high definition images are being used to create a digital model



Digital maps were created after a number of sequences were recorded using the stereo camera on the Virtual Vents expedition. Falkor's High-Performance computing system made it possible to do the 3D reconstruction on board.



The new map interface on the Schmidt Ocean Institute website allows users to see all cruise tracks or search by region, year, or topic.

Tom Kwasnitschka works on setting up four cameras and a laser line on ROPOS during the Virtual Vents expedition. These cameras are synchronized with a flash (mounted on the swing arms of the robot) firing every 1.5 seconds, and assist with photogrammetric reconstruction of the seafloor.

of the vents that can be explored using virtual reality tools. The extremely high resolution data collected from ROPOS with specialized cameras created a full-color textured, 5 centimeter resolution photogrammetrical 3D model. The model incorporated an outstanding amount of data, which formed the basis for high detailed geological and biological studies resulting in 3D maps of the entire field. The first attempt at creating a photogrammetic model was conducted on board *Falkor* during the cruise and can be viewed on YouTube.[2] Additionally, based on the experiences of this cruise Dr. Kwasnitchka provided a white paper to the German Federal Ministry of Research and Education on the possibility of using telepresence on their fleet.

The following cruise in the same region of the Lau Basin, also collected imagery with the goal of creating high resolution 2D and 3D photomosiacs. Dr. Charles Fisher and his team collaborated with Dr. Oscar Pizarro, who had conducted photomosiacing of imagery collected onboard *Falkor* in 2015, to help with the data processing. Dr. Pizarro developed customized computer software for the reconstruction of 2D and 3D models of the underwater environments from image data. The software incorporates navigation data, sensor logs, and seafloor images for input into the model's reconstruction algorithms and produces digital models of underwater environments in the form of 3D textured meshes and 2D orthographic seafloor mosiacs. Dr. Pizarro will also deliver technical documentation of the structure and workflow of the photomosiacing software to enable future use by others and provide online access to the data and annotation tools.

During *Falkor*'s transit from Australia to Guam, a variety of forward-thinking technology was used to conduct a holistic study of the sea surface. High-endurance marine aerial vehicles were used by the interdisciplinary team for the first time to collect large amounts of data about the air-sea boundary. *Falkor*'s high performance computing was heavily utilized during this cruise for onboard data processing.

1. https://schmidtocean.org/rv-falkor/status/
2. https://www.youtube.com/watch?v=Ki8ly9gW3dM&t=28s

SHARING THE PASSION

Schmidt Ocean Institute continues bring our passion for technology and science to the public through numerous outreach programs. 2016 was a particularly busy year with dedicated public events in locations such as Fiji, Tonga and Guam.

Our focus is to reach communities that do not have exposure to the science conducted at Schmidt Ocean Institute, and share the importance of understanding our oceans.

During the two hydrothermal vent cruises this spring, Schmidt Ocean Institute held 15 events in Fiji and Tonga, reaching more than 1,700 students. Further development of community relations took place in Tonga with an open tour day aboard *Falkor* as well as presentations to students and marine managers. Over the summer, 300 people toured *Falkor* through a dedicated program introducing Guam to Schmidt Ocean Institute's brand new ROV SuBastian. While in Guam a welcome event was held at Underwater World, who also broadcasts all of the live dives with ROV SuBastian. Several presentations were given at the war in the Pacific National Park as well.

OUTREACH

Schmidt Ocean Institute Co-founder Wendy Schmidt hosted a student discussion following her presentation at the University of Hawaii Manoa.

Schmidt Ocean Institute is unique in that we support the communications and outreach for the scientists onboard *Falkor* with dedicated multimedia correspondence team. However, we encourage participating scientists to engage in outreach and offer a science communications training in advance of their expedition. In February, training was provided to the chief scientist and co-chief scientist teams at the Ocean Sciences Meeting in New Orleans, Louisiana. An alumni event at the meeting brought together past and future *Falkor* science parties to share their experiences and build networks within the *Falkor* science teams.

Schmidt Ocean Institute maintains connections to both academic and community audiences through conference presentations, panel discussions, museum and aquarium talks, and classroom connections; presenting to more than 12,000 people since 2014. This year Schmidt Ocean Institute co-founder Wendy Schmidt gave a presentation about the

> Being in this program has given me a realistic and authentic experience of science-at-sea and a chance to apply what I've learned in class. Research is something I'd like to continue in my future years.
>
> — Caleb Hsu

Communications Manager Carlie Wiener presented to hundreds of students in Fiji about the research being conducted aboard Falkor in the Lau Basin.

importance of our oceans to students at the University of Hawaii after talking live to *Falkor* through a Ship-to-Shore connection, and led a follow-up discussion for female students in science.

Training the next generation of ocean scientists is a high priority for Schmidt Ocean Institute, as demonstrated by the 198 graduate students who have participated in expeditions aboard *Falkor*, and through our Student Opportunities program. In January, we hosted our youngest student since the program began – Caleb Hsu, a freshman in University of Hawaii's Global Environmental Sciences Program.

WEB PRESENCE

Schmidt Ocean Institute's R/V Falkor participated in the first Tri-Ship Ocean Exploration Hangout live on World Ocean Day with Ocean Exploration Trust's E/V Nautilus and NOAA Okeanos Explorer. The event has received over400 views and is available to the public.

For those who cannot come aboard *Falkor*, our growing online presence invites students and community all over the world to participate in the science activities on *Falkor*. Our new website design attracted over 97,000 new visitors and over 400,000 page views this year. The website features a search function for cruises and publications, image and video gallery, and a live *Falkor* status page.

This year we doubled our live Google Hangouts On Air reaching 94,090 viewers, and hosted several new programs including a dedicated series of virtual fieldtrips with EarthEcho International and our first Reddit "Ask Me Anything" about ROV SuBastian. Live weekly Hangouts were conducted with the ROV SuBastian Engineering Team, scientists onboard of *Falkor*, and the Artist-at-Sea participants.

Our blogs and videos provide real time accounts of the research taking place, and engaging with our public audiences. This year we added an Instagram account to our social media quiver sharing the incredible photography and video captured while at sea. Our other social media accounts continue to grow with the development of our themed #TechTuesday and #ScienceArtFriday posts. Online competitions help to engage our audiences with screen shot competitions during the live broadcast of our ROV dives.

With the build of ROV SuBastian, a 16 part video series was constructed following the vehicles fabrication and assemblage. This allowed the public to follow ROV SuBastian's progress and learn about the exciting challenges of building an ROV. This year 43 ROV dives were broadcast live from *Falkor*, totaling more than 400,000 minutes watched in 159 different countries. These broadcasted videos along with our other shipboard data remains freely available online.

PRESS

Lead Mechanical Engineer Jason Williams talks with press while in Guam about the new ROV SuBastian.

In 2016, Schmidt Ocean Institute received over 1,000 news media stories in international and national television, radio, print, and web publications. We were proud to be featured for a second year in a row in the Marine Technology Reporter's annual Top 100 innovators in the maritime industry. Additionally, the science conducted on *Falkor* appeared in several magazine articles in Wired, Smithsonian, Inverse, and in a variety of television series such as Animal Planet.

Crew aboard Falkor display the newly made Lego model during ship tours in Tonga. From left to right: Oliver Hurdwell (2nd Officer), Jason Garwood (2nd Officer), Heiko Volz (Senior Captain) and Paul Shepherd (Chief Officer).

Chief Officer Paul Shepherd gives students in Tonga a tour of Falkor.

ARTIST-AT-SEA

2016 marked the first year of our Artist-at-Sea program, bringing together scientists and artists on board of *Falkor*. The idea came from co-founder Wendy Schmidt as a way for participating artists to broaden the impact and accessibility of ocean science data by communicating the research being conducted in new and unique ways.

The artist's complete a community outreach component and produce a final art piece that is left on board to contribute to the growing Artist-at-Sea installation. Six artists have been aboard *Falkor* this year, with with projects ranging from the first crocheted CTD data, to music composition, to painting bathymetric maps in beautiful abstract arts. Other visual innovations have been created with pH data obtained from the Wendy Schmidt Ocean Health XPRIZE pH sensor, photographic-based images treated with seawater, digital animation, and cartoon arts. These artists tell the stories of the scientists and the research being conducted at sea in a unique, engaging, and accessible manner to reach audiences that normally would not be attracted to numerical figures or raw oceanographic data. The goal of the artists is to reach people who might not be interested in science, but with an artistic approach, participants can digest the research in an accessible format, raising interest in science and highlighting the importance of our ocean.

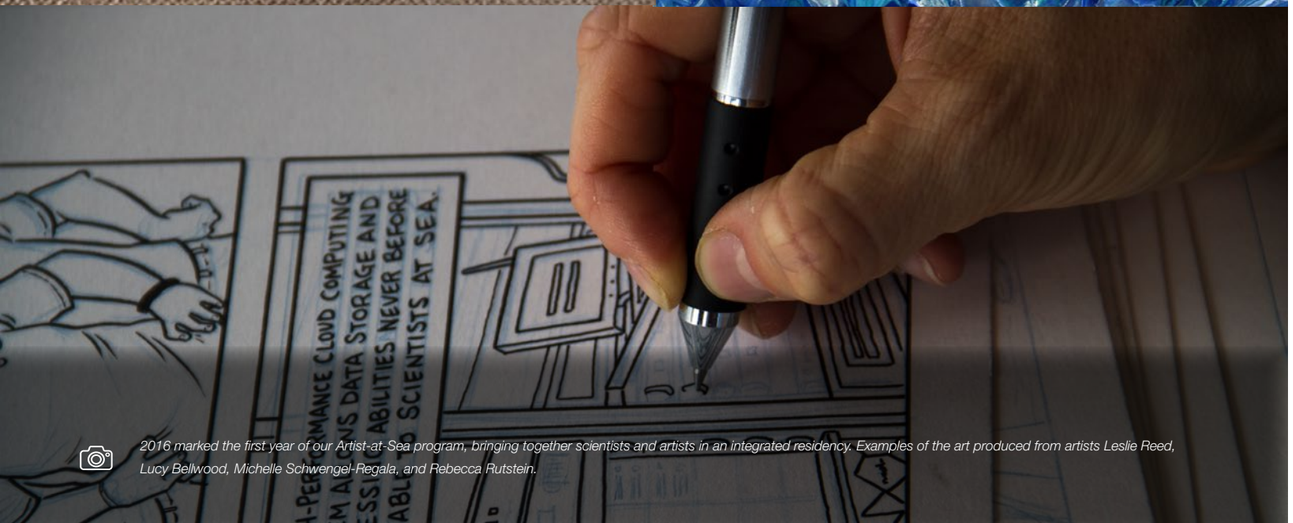
One of the first participants was fiber-artist Michelle Schwengel-Regala, who sailed on the Life Without Oxygen cruise in January. While her initial ideas referenced a period of historical naval camouflage called “dazzle,” she became inspired by features of the data being collected by the science crew, and began producing yarn-based designs and patterns from numerical data. “Working with sets of numerical data opens up interesting artistic pathways for me,” said Michelle. “Notably, my idea to create textiles containing information graphics in seemingly abstract patterns.”

Rebecca Rutstein was another artist aboard *Falkor* during the ship’s transit from Vietnam to Guam. Her method was to incorporate assets of data - recorded and compiled by researchers on *Falkor* into layered, acrylic paintings on canvas. She set up a temporary studio in the ship’s Wet Lab and used collected data from the Changing River cruise including satellite imagery, CTD measurements, and multibeam sonar readings of never-before-seen ocean floor bathymetry. Rebecca used these maps as overlays in her paintings on top of layers of poured paint where color

It is exciting to have access to the multibeam sonar technology and incorporate data that has just been collected into my paintings. Just as areas of science can benefit from the communicative nature of the artist’s work, the artist can benefit from technology in their own process.

—Rebecca Rutstein

2016 marked the first year of our Artist-at-Sea program, bringing together scientists and artists on board of Falkor.



2016 marked the first year of our Artist-at-Sea program, bringing together scientists and artists in an integrated residency. Examples of the art produced from artists Leslie Reed, Lucy Bellwood, Michelle Schwengel-Regala, and Rebecca Rutstein.

dispersed in response to the ship's rocking motion.

Ben Cosgrove, a musical composer, spent his time on *Falkor* traveling from Vietnam to Australia this past September. Ben wrote several musical pieces inspired by ship data collected while in transit. "The goal of any art made in response to science or fact," he said, "should be to identify a particular story or message within that data, and seek to enlarge that narrative in a way that resonates with some other, less cerebral, part of the human experience." Ben's piano piece was influenced by *Falkor*'s speed. The music's structure reflects the variance between the ship's speed through water and its speed over ground; the drag of the water between the ship and the ocean floor creates this simultaneous disparity.

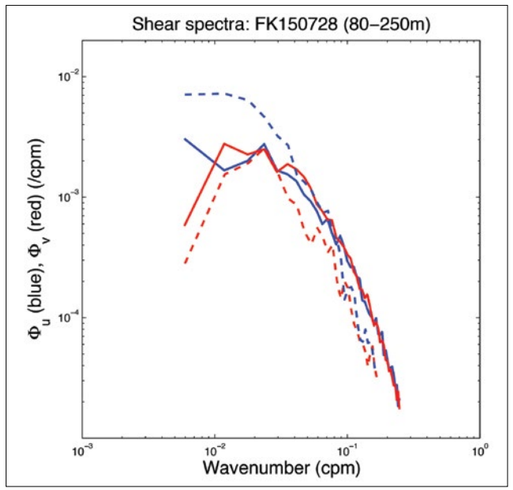
In the piece, each of the pianist's hands is mapped to one of the speeds. Cosgrove hopes the results leads the listener "to perceive a broad, shifting, undulating texture that illustrates the influence of the ocean on the ship's forward motion while also viscerally evoking the waves that gently rocked the ship throughout this journey."

Artist evaluations showed an improved understanding of science and a new interest to incorporate more ocean conservation and science into their work. The program will continue in 2017 as an avenue of enlightenment and exposure to complex ocean issues.

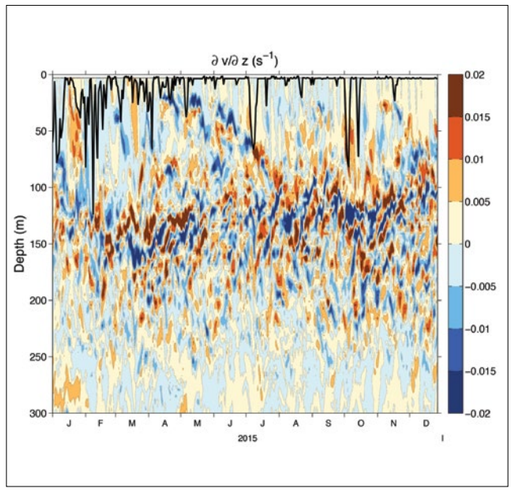
Artist-at-Sea participant and fiber artist Michelle Schwengel-Regala translated data into art during the Mixing Up The Tropical Pacific expedition, of the experience she says "Working with sets of numerical data opens up interesting artistic pathways for me, notably my idea to create textiles containing information graphics in seemingly abstract patterns."

UPDATE FROM MIXING UP THE TROPICAL PACIFIC

DR. KELVIN RICHARDS, UNIVERSITY OF HAWAII



Comparison of vertical shear spectra at 170W, 1N (blue: du/dz, red: dvdz) measured on the Falkor cruise (solid lines) and from the model (dashed lines) in August 2015. The shape and amplitude agree very well.



Vertical shear of the meridional (northward) component of the flow (dv/dz) from the model for 2015. The plot shows the variability in the shear (that induces turbulent mixing: not shown) during the year. The Falkor cruise took place in August 2015. Black line: depth of mixed layer.

In July 2015, Schmidt Ocean Institute supported an expedition to the central equatorial Pacific to give researchers their first view of the small scale turbulence that occurs in the region. Dr. Richards from the University of Hawaii hypothesized that current climate models may have been missing the important effects of turbulent mixing, and hoped that his work aboard *Falkor* could contribute to overall improvements in the models and their ability to forecast the size and timing of El Nino Southern Oscillation (ENSO) events. The three-week cruise occurred during strong ENSO conditions, giving the science team a glimpse of the mixing occurring in the region during such conditions.

Once home from the expedition, a high-resolution ocean model of the central equatorial Pacific was run for the three-week period during which the cruise occurred. The model successfully reproduced the characteristics of the small vertical scale flow features observed during the cruise and emphasized that high resolution is needed in both observations and models to accurately capture the relevant structure of this small vertical scale flow. The model is now being used to identify periods of strong turbulent mixing and to put the flow observations into the context of more long-term variations.

UPDATE FROM UNLOCKING TSUNAMI SECRETS

DR. SATISH SINGH, EARTH OBSERVATORY OF SINGAPORE, NANYANG TECHNICAL UNIVERSITY

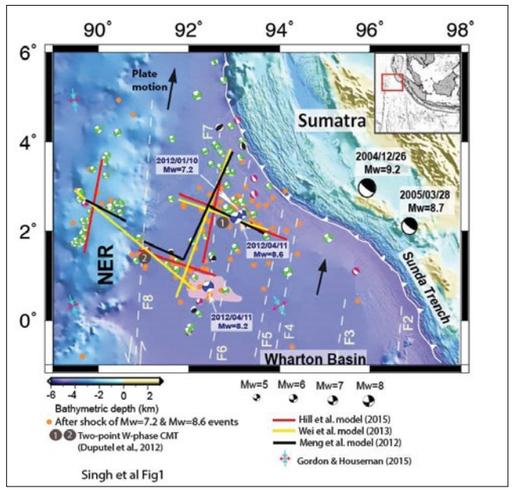


Fig. S1: Different models of the 2012 Mw=8.6 earthquake: *The blue beach balls are the 2012 earthquakes. NER: Ninety-East Ridge. The blue dashed lines indicate fracture zones F2 to F8. The colored lines and contours indicate different models and the result of back projection. The black beach balls indicate great Sumatran earthquakes.*

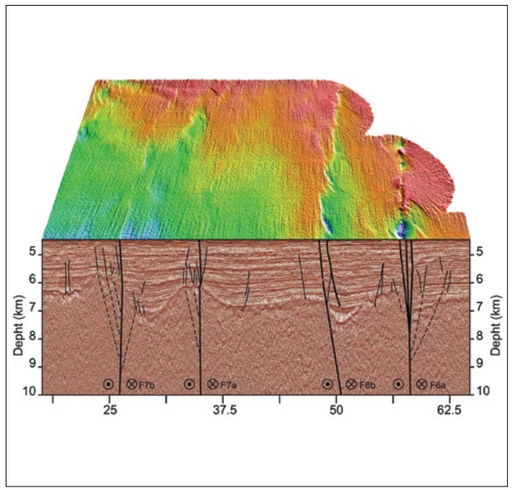


Fig. S2: Seismic reflection images of F7b: *A)Bathymetry and location of seismic profiles. Seismic images of F7b along profiles WB16 (B), WB2 (C), WB5 (D) and WB7 (E). Green lines mark sediment horizons and black dotted lines mark faults.*

The southwest region of Sumatra, Indonesia, hosts some of the biggest earthquakes in the world. Last year, scientists from the Earth Observatory of Singapore, in partnership with the Institut de Physique du Globe de Paris and the Indonesian Institute of Sciences came aboard *Falkor* to learn more about what kinds of earthquakes happen in this area and if and when they might cause future tsunamis. The expedition focused on two areas: the Mentawai Gap and the Wharton Basin. The Mentawai Gap is a locked area along the Sunda Megathrust that hasn't ruptured in 200 years. Experts expect the next great earthquake will happen along this section. Additionally, the Wharton Basin has played host to the largest intraplate earthquakes ever recorded. In 2012, an 8.6-magnitude earthquake and an 8.2-magnitude aftershock ruptured in the Wharton Basin, baffling scientists because most great earthquakes typically happen on plate boundaries, not in a plate's interior.

Scientists on board *Falkor* imaged the Mentawai Gap and Wharton Basin in the highest resolution ever captured for the region. They acquired 17,597 square kilometers of bathymetric data and 2,665 kilometer of seismic reflection profiles. With these data, they are mapping faults on and below the seafloor surface. An upcoming publication will identify the mechanism and faults responsible for the Wharton Basin earthquakes of 2012. Singh and his co-authors found new faults in the Wharton Basin that are perpendicular to the Sunda Megathrust. They propose that these faults occur because different areas of the main thrust are subducting at different rates, creating strain that must be released elsewhere. New findings also suggest that the Wharton Basin may be the site of a future plate boundary between the Indian and Australian plates. These findings will update hazard models and help protect lives across Sumatra and Southeast Asia.

2016 PRESENTATIONS

Ajemian, M., Wetz, J., Brewton, R., Streich, M., Downey, C., and Stunz, G. (2016). Relative Value of Rigs-to-Reefs Habitats to Red Snapper (Lutjanus campechanus) Stock Building in the Western Gulf of Mexico. Oral Presentation at Benthic Ecology Meeting, Portland, ME, USA.

Aleman, M., Subramaniam, A., and Hay, I. (2016). Characterizing the Phytoplankton Community of the South China Sea. Poster Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

Anderson, R., Reveillaud, J., Eren, A., McDermott, J., Seewald, J., Stepanauskas, R., and Huber, J. (2016). Strain-level variation of subseafloor microbial populations from venting fluids at the Mid-Cayman Rise. Oral Presentation at International Society for Microbial Ecology General Meeting, Montreal, CAN.

Baker, E., Walker, S., Resing, J., Chadwick, W., Merle, S., and Anderson, M. (2016). Hydrothermal Plume Surveys of the Mariana Backarc (12.7°-18.3°N) by Surface-Ship and AUV Find an Unexpectedly High Spatial Frequency of Vent Sites, Oral Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

Clague, D., Paduan, J., Moyer, C., Glazer, B., Caress, D., Yoerger, D., and Kaiser, C. (2016). Structure and Evolution of Hawaii's Loihi Seamount from High-resolution mapping, Oral Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

Fortunato, C., Butterfield, D., Larson, B., Algar, C., Vallino, J., and Huber, J. (2016). Microbial Metabolic Potential and Gene Expression Patterns across Geochemical Gradients in the Deep Ocean, Oral Presentation at International Society for Microbial Ecology Meeting, Montreal, CAN.

Girard, F., Fu, B., Boyer, T., Curtis, C., and Fisher, C. (2016). Using Image-based Long-term Monitoring to Understand the Biology and Recovery of Deep-sea Coral Communities after the Deepwater Horizon Oil Spill, Oral Presentation at the 6th International Symposium on Deep-sea Corals, Boston, MA, USA.

Hirsh, H., Chadwick Jr., W., Fryer, P., Villagomez, A., Beauregard, L., Cabrera, I., and Peterka, L. (2016). Exploring and Protecting the Marvelous Marianas Trench Marine National Monument, Poster Presentation at International Union for Conservation of Nature World Conservation Congress, Honolulu, HI, USA.

Huber, J. (2016). Life Beneath the Seafloor. Oral Presentation at Microbial Sciences Initiative, Cambridge, MA, USA.

Huber, J. (2016). Microbes, Fluids, and Rocks: Life Beneath the Seafloor. Invited Lecturer, University of Southern California, CA, USA.

Lowe, R. (2016). Oceanic Drivers of a Remote Atoll Reef System: Browsing Scott Reef. Oral Presentation at Shell EMI Seminars, Perth, AUS.

Kelly, S., et. al. (2016). Uncertainties of Internal Tide Generation and Energy Flux in the Tasman Sea, Poster Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA.

Kelly, S. (2016). The Moon, Climate, and Ocean Turbulence, Guest Lecturer at University of Wisconsin La Crosse, La Crosse, WI, USA.

Kelly, S. (2016). The Moon, Climate, and Ocean Turbulence, Guest Lecturer at St. Olaf College, Northfield, MN, USA.

Kelly, S. (2016). The Moon, Climate, and Ocean Turbulence, Guest Lecturer at Gustavus Adolphus College, St. Peter, MN, USA.

Kelly, S. (2016). The Moon, Climate, and Ocean Turbulence, Guest Lecturer at Concordia College, Moorhead, MN, USA.

Kelly, S. (2016). The Moon, Climate, and Ocean Turbulence, Guest Lecturer at University of Minnesota Duluth, Duluth, MN, USA.

Maticka, S. (2016). Hydrodynamics and Thermal Regime of a Shallower Reef-Atoll Rim. Oral Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA.

McBee, J., Mitchell, G., Brumley, K., Gharib, J., and Paull, C. (2016). New Insights into the Campeche Escarpment Post-Chicxulub Impact Using Multibeam Echo Sounder (MBES) Bathymetry and Backscatter Data, Poster Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

McCulloch, M., Holcomb, M., D'Olivo Cordero, J., Falter, J., Montagna, P., Taviani, M., and Trotter, J. (2016). How Corals Control Calcification in a High CO2 World, Oral Presentation at International Coral Reef Symposium, Honolulu, HI, USA.

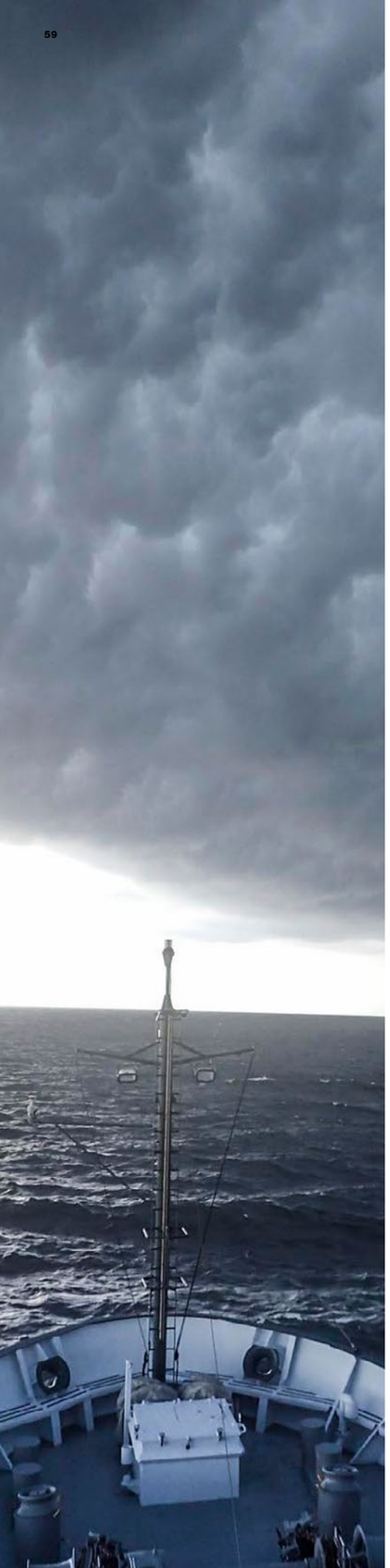
Miller, J., Puotinen, M., Thumbs, M., Radford, B., and Heyward, A. (2016). Innovation in Spatial Analysis Using Examples from Scott Reef and the Kimberly's. Oral Presentation as part of Woodside Science Seminar Series, Perth, AUS.

Moore, C., Heyward, A., and Radford, B. (2016). Comprehensive and Accessible Information Promoting the Biodiversity, Heritage and Value of our North West Marine Region. Guest Lecturer, Charles Darwin University, Darwin, AUS.

Moore, C., Heyward, A., and Radford, B. (2016). Comprehensive and Accessible Information Promoting the Biodiversity, Heritage and Value of our North West Marine Region. Oral Presentation at Guest Atlas of Living Australia Workshop, Perth, AUS.

Moore, C., Heyward, A., and Radford, B. (2016). Comprehensive and Accessible Information Promoting the Biodiversity, Heritage and Value of our North West Marine Region. Oral Presentation at PTTEP Australia Science Seminar, Perth, AUS.

Pinkel, R., et. al. (2016). The Tasman Tidal Dissipation Experiment: Tidal Mixing, Scattering, and Reflection on the East Tasman Slope, Oral Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA.



Falkor encounters an interesting cloud formation during the Sea Surface Microlayer expedition.

Multimedia Correspondent Thom Hoffman and Systems Engineer Todor Gerasimov work with the Schmidt Ocean Institute Outreach waterproof AUV (Aerial Unmanned Vehicle) on Falkor's Aft deck.

Rayson, M. (2016). Observations of High-frequency Internal Waves and Strong Turbulent Dissipation Rates Generated by a Constriction between Two Coral Atolls. Oral Presentation at 8th International Symposium on Stratified Flows, San Diego, CA, USA.

Resing, J., Chadwick, W., Baker, E., Butterfield, D., Baumberger, T., Buck, N., Walker, S., and Merle, S. (2016). Hydrothermal exploration of the Mariana Back-Arc Basin: Chemical Characterization, Poster Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

Simmons, H., et. al. (2016). The Internal Tide of the Tasman Sea, Poster Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA.

Streich, M., Wetz, J., Ajemian, M., and Stunz, G. (2016). Relative Abundance, Age, and Growth of Red Snapper: A Comparison between Artificial and Natural Habitats in the Western Gulf of Mexico. Oral Presentation at Southern Division of the American Fisheries Society Annual Meeting, Wheeling, WV, USA.

Subramaniam, A., Hay, I., Aleman, M., Bracco, A., Voss, M., and Montoya, J. (2016). Bio-optical Provinces of the Bien Dong. Poster Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

Urschel, M., Moyer, C., Glazer, B. and Rogers, K. (2016). Cryptic Anaerobic Metabolisms in the Deep Subsurface. Oral Presentation at Center for Dark Energy Biosphere Investigations All-hands Meeting, Monterey, CA, USA.

Vohsen, S., Baums, I., and Fisher, C. (2016). High-throughput Metabolomics Identifies Species- and Habitat - Specific Metabolites in Corals, Oral Presentation at 13th International Coral Reef Symposium, Honolulu, HI, USA.

Walker, S., Baker, E., Resing, J., Chadwick, W., Merle, S., and Kaiser, C. (2016). High resolution mapping of hydrothermal plumes in the Marian Back-arc Relate Seafloor Sources to Above-bottom Plumes, Poster Presentation at American Geophysical Union Fall Meeting, San Francisco, CA, USA.

Waterhouse, A., et. al. (2016). Observations of an Internal Tide Beam in the Tasman Sea, Oral Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA.

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Chaytor, J., Geist, E., Paull, C., Caress, D., Gwiazda, R., Fucugauchi, J., and Vieyra, M. (2016). Source Characterization and Tsunami Modeling of Submarine Landslides Along the Yucatán Shelf/Campeche Escarpment. Southern Gulf of Mexico: Pure and Applied Geophysics, pp. 1–16, doi: 10.1007/s00024-016-1363-3[1].

Fortunato, C. and Huber, J. (2016). Coupled RNA-SIP and Metatranscriptomics of Active Chemolithoautotrophic Communities at a Deep-sea Hydrothermal Vent, The ISME Journal, pp 1-14, doi: 10.1038/ismej.2015.258[2].

Girard, F., Fu, B., and Fisher, C. (2016). Mutualistic Symbiosis with Ophiuroids Limited the Impact of the Deepwater Horizon Oil Spill on Deep-sea Octocorals, Marine Ecology Progress Series, 549: 89-98, doi: 10.3354/meps11697[3].

Kleindienst, S., Grim, S., Sogin, M., Crespo-Medina, M., and Joye, S. (2016). The Responses of Diverse Low-abundance Bacteria to a Deep-sea Hydrocarbon Plume, The ISME Journal, 10, 400-415, doi: 10.1038/ismej.2015.121[4].

Klymak, J., Simmons, H., Braznikov, D., Kelly, S., MacKinnon, J., Alford, M., et. al. (2016). Reflection of Linear Internal Tides from Realistic Topography: The Tasman Continental Slope. Journal of Physical Oceanography, 46(11), 3321-3337, doi: 10.1175/JPO-D-16-0061.1[5].

Linley, T., Gerringer, M., Yancey, P., Drazen, J., Weinstock, C., and Jamieson, A. (2016). Fishes of the Hadal Zone Including New Species, in situ Observations and Depth Records of Hadal Snailfishes, Deep Sea Research, 114, 99-110, doi: 10.1016/j.dsr.2016.05.003[6].

Rayson, M., Bleuteau, C., Ivey, G., and Jones, N. (2015). Observations of High-frequency Internal Waves and Strong Turbulent Mixing in a Channel Flow between Two Coral Atolls, Conference Proceedings of the 8th International Symposium on Stratified Flows.

Topcuoglu, B., Stewart, L., Morrison, H., Butterfield, D., Huber, J., and Holden, J. (2016). Hydrogen Limitation and Syntrophic Growth among Natural Assemblages of Thermophilic Methanogens at Deep-sea Hydrothermal Vents, Front. Microbiol, 7:1240, doi: 10.3389/fmicb.2016.01240[7].

USES OF DATA

Cooper, C. and Sautter, L. (2016). Geomorphic Analysis of Deep Coral Habitat in the Kaiwi Channel, Hawaiian Islands, Poster Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA. *[Student at College of Charleston used data from Falkor as part of a class project in their Benthic Acoustic Mapping and Survey Program]*

Crenshaw, G., and Sautter, L.. (2016). Geomorphology of the Sumatra Subduction Zone: Expressions of Tectonic and Seismic Activity, Poster Presentation at the Canadian Hydrographic Conference, Halifax, NS, CAN. *[Student at College of Charleston used data from Falkor as part of a class project in their Benthic Acoustic Mapping and Survey Program]*

Carruth, M., and Sautter, L. (2016). Geomorphology of the Kroenke Canyon on the Ontong Java Plateau, Poster Presentation at the Canadian Hydrographic Conference, Halifax, NS, CAN. *[Student at College of Charleston used data from Falkor as part of a class project in their Benthic Acoustic Mapping and Survey Program]*

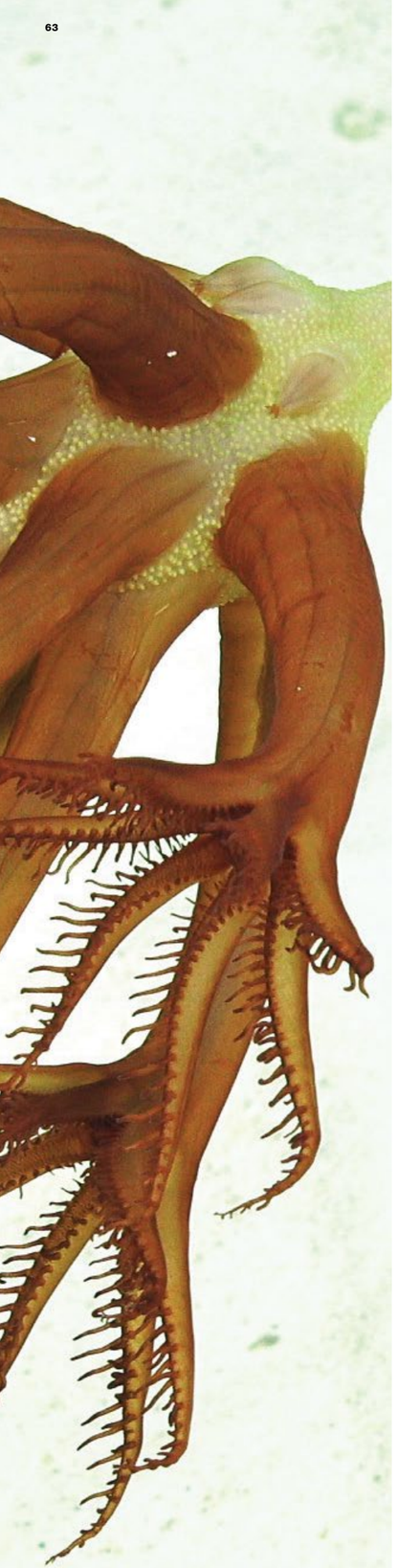
Fitzgerald, R. (2016). The Mariana Trough, Physics Today, 69(8), 76(2016), doi: 10.1063/PT.3.3278[8]. *[Data from R/V Falkor and NOAA ship Okeanos Explorer were combined in this 1-page spread.]*

Foxworth, L., and Sautter, L. (2016). Deep Coral Habitat Characterization of the North End of Raita Bank, Papahanaumokuakea Marine National Monument in the Northwestern Hawaiian Islands, Poster Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA. *[Student at College of Charleston used data from Falkor as part of a class project in their Benthic Acoustic Mapping and Survey Program]*

Freeman, E., et. al. (2016). ICOADS Release 3.0: A Major Update to the Historical Marine Climate Record. International Journal of Climatology, doi: 10.1002/joc.4775[9]. *[The most recent release of the complete marine climate database, which is used worldwide for research applications and numerical modeling, contains data collected by R/V Falkor]*

Falkor sails in the Pacific Ocean early in the morning.

Boobie on Falkor's mast as she transits from Honolulu to Tahiti during the Investigating Life without Oxygen Expedition.



Johnston, T.M.S., Rudnick, D., and Kelly, S. (2015). Standing Internal Tides in the Tasman Sea Observed by Gliders, J. Phys. Oceanography, 45, 2715 - 2737, doi: 10.1175/JPO-D-15-0038.1. *[Modeling results from Tracking the Tasman Sea Internal Tides contributed to this publication]*

Klymak, J., et. al. (2016). Reflection of Linear Internal Tides from Realistic Topography: The Tasman Continental Slope, J. Phys. Oceanography, 46, 3321-3337, doi:10.1175/JPO-D-16-0061.1 *[Modeling results from Tracking the Tasman Sea Internal Tides contributed to this publication]*

Meyers, H. and Sautter, L. (2016). Submarine Channel Association with Seamount Chain Alignment on the Ontong Java Plateau, Poster Presentation at Ocean Sciences Meeting 2016, New Orleans, LA, USA. *[Student at College of Charleston used data from Falkor as part of a class project in their Benthic Acoustic Mapping and Survey Program]*

Smith, S., Lopez, N., and Bourassa, M. (2016). SAMOS Air-sea Fluxes: 2005-2014. Geoscience Data Journal, 3:9-19, doi: 10.1002/gdj3.34[10]. *[This along-ship-track air-sea flux product, which will have wide applications in the satellite and ocean modeling communities, includes data collected by R/V Falkor]*

1. http://dx.doi.org/10.1007/s00024-016-1363-3
2. http://www.nature.com/ismej/journal/v10/n8/abs/ismej2015258a.html
3. http://www.int-res.com/articles/meps_oa/m549p089.pdf
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5. http://journals.ametsoc.org/doi/10.1175/JPO-D-16-0061.1
6. http://www.sciencedirect.com/science/article/pii/S0967063716300656
7. http://journal.frontiersin.org/article/10.3389/fmicb.2016.01240/full
8. http://scitation.aip.org/content/aip/magazine/physicstoday/article/69/8/10.1063/PT.3.3278;jsessionid=1akE-9RjijcjsYQ1mWAeih--.x-aip-live-03
9. http://onlinelibrary.wiley.com/doi/10.1002/joc.4775/full
10. http://onlinelibrary.wiley.com/doi/10.1002/gdj3.34/full

Sea Pen examined with ROV SuBastian's brand new cameras during sea trials in Guam.

Chief Engineer Allan Watt and Fitter Edwin Pabustan work together to repair the remotely operated Catamaran

PHOTO CREDITS

Cover: Thom Hoffman

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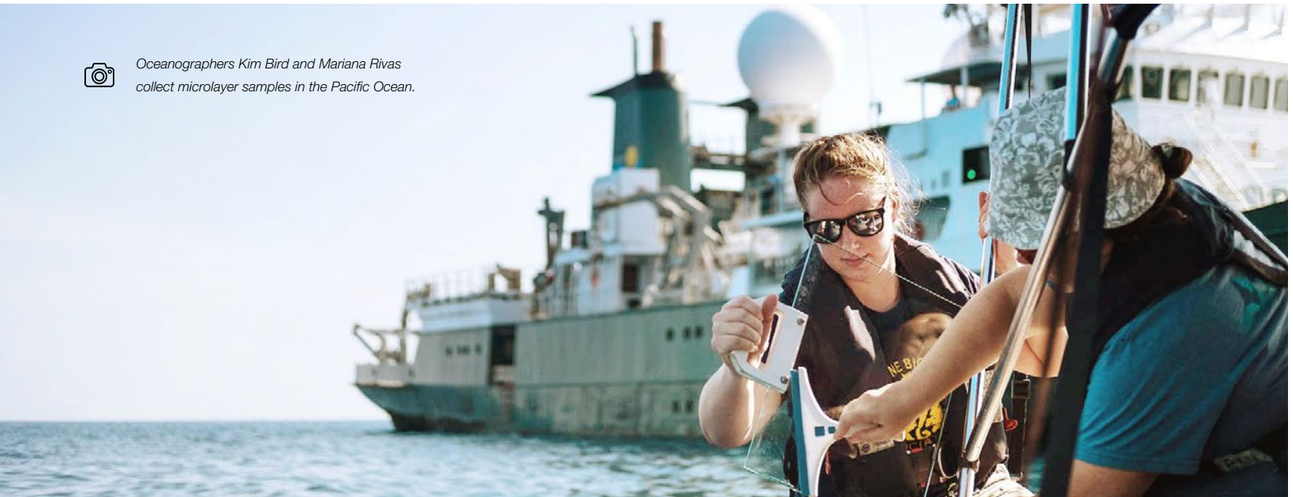

Oceanographers Kim Bird and Mariana Rivas collect microlayer samples in the Pacific Ocean.

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