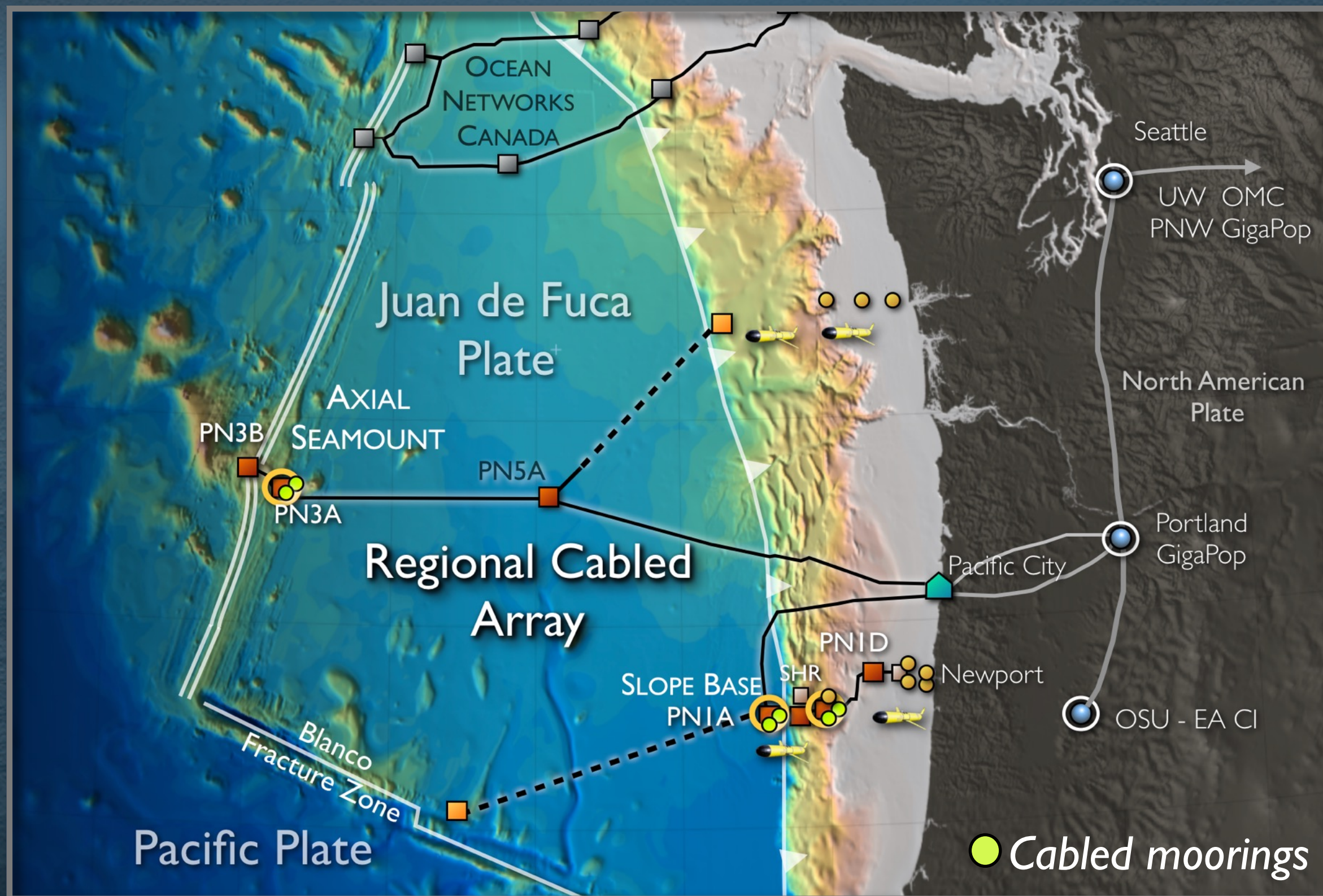


NSF'S Ocean Observatories Initiative Regional Cabled Array: Nearing 10 years of Real-Time Ocean Observations

School of Oceanography and Applied Physics Lab
University of Washington

Dana Manalang , Deborah Kelley & RCA Team

NSF-OOI's Regional Cabled Array



Primary Infrastructure

- 900 km of high bandwidth (10 Gbs) and high power (8 kW) primary backbone cables & nodes designed to operate for 25 years

Secondary Infrastructure

- 33,000 m of extension cables
- 18 junction boxes (smaller substations) provide 375V and 1 Gbs power and communications
- 6, up to 2700 m tall instrumented moorings with wire crawlers connected to the cable
- >150 integrated instruments provide 24/7 real-time data to shore at the speed of light with two-way communication - response capabilities
- Highly expandable for science, industry, education: ~40 awards outside of OOI to add instruments, conduct associated science >\$40M since 2016

BRINGING POWER AND THE INTERNET INTO THE OCEAN

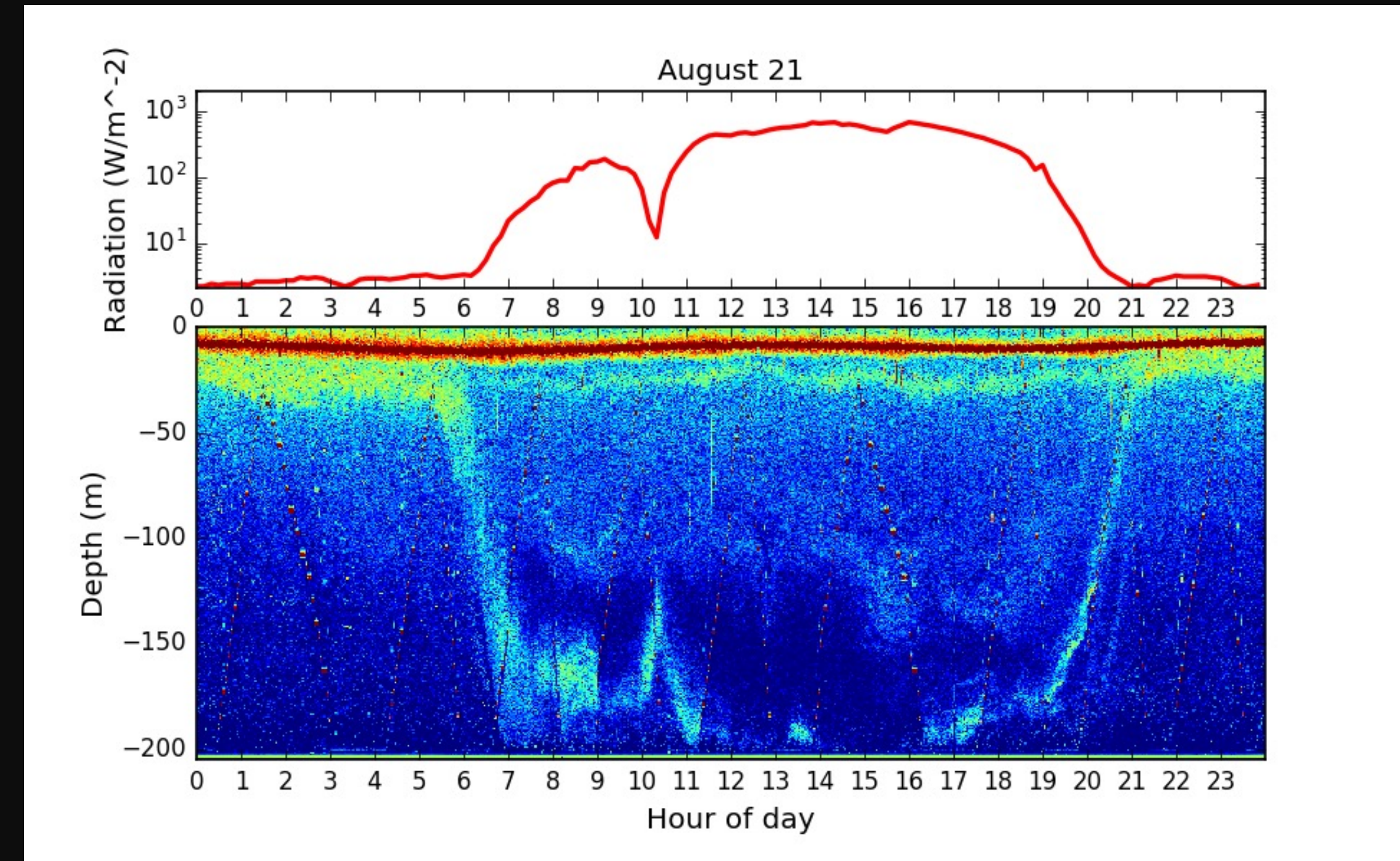
If on land, would span three states



Cabled Observatories have Opened New Observing Opportunities

- Continuous, high power systems
- Increased Sampling Rates
- Real-Time, Accessible Data
- Mid-deployment configuration updates
- Interdisciplinary Sensing

Example: Zooplankton migration captured by cabled Kongsberg EK60 Echosounder on the OOI's Regional Cabled Array (RCA) during solar eclipse on August 21, 2017



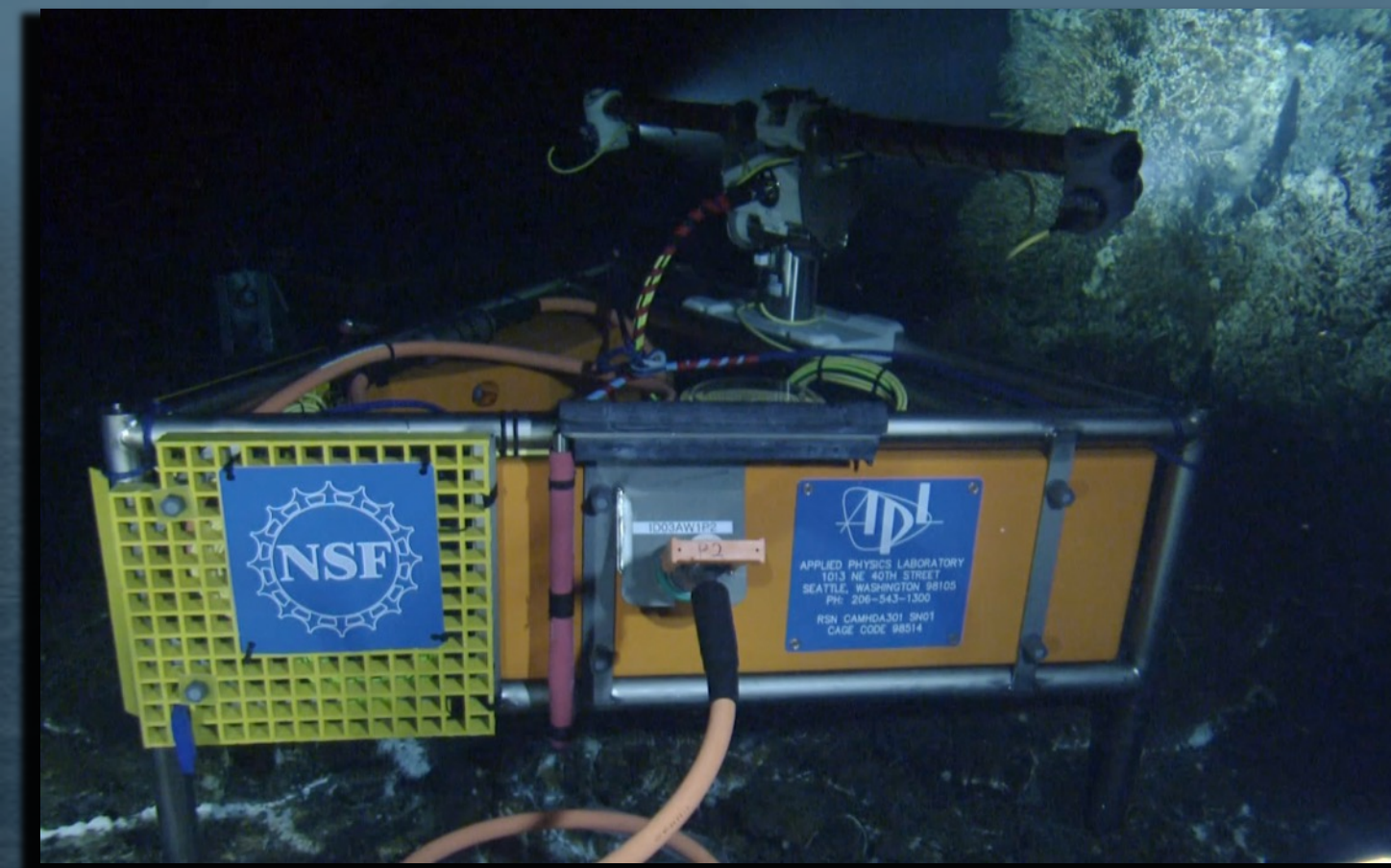
Solar radiation (top) and echosounder data (bottom). The “dip” around 10:15 AM shows the dramatic change of solar radiation level during the time of eclipse. This drop of light intensity induced a “spike” in the echosounder observation due to the brief upward movement of many animals in the ocean. Image Credit: Wu-Jung Lee



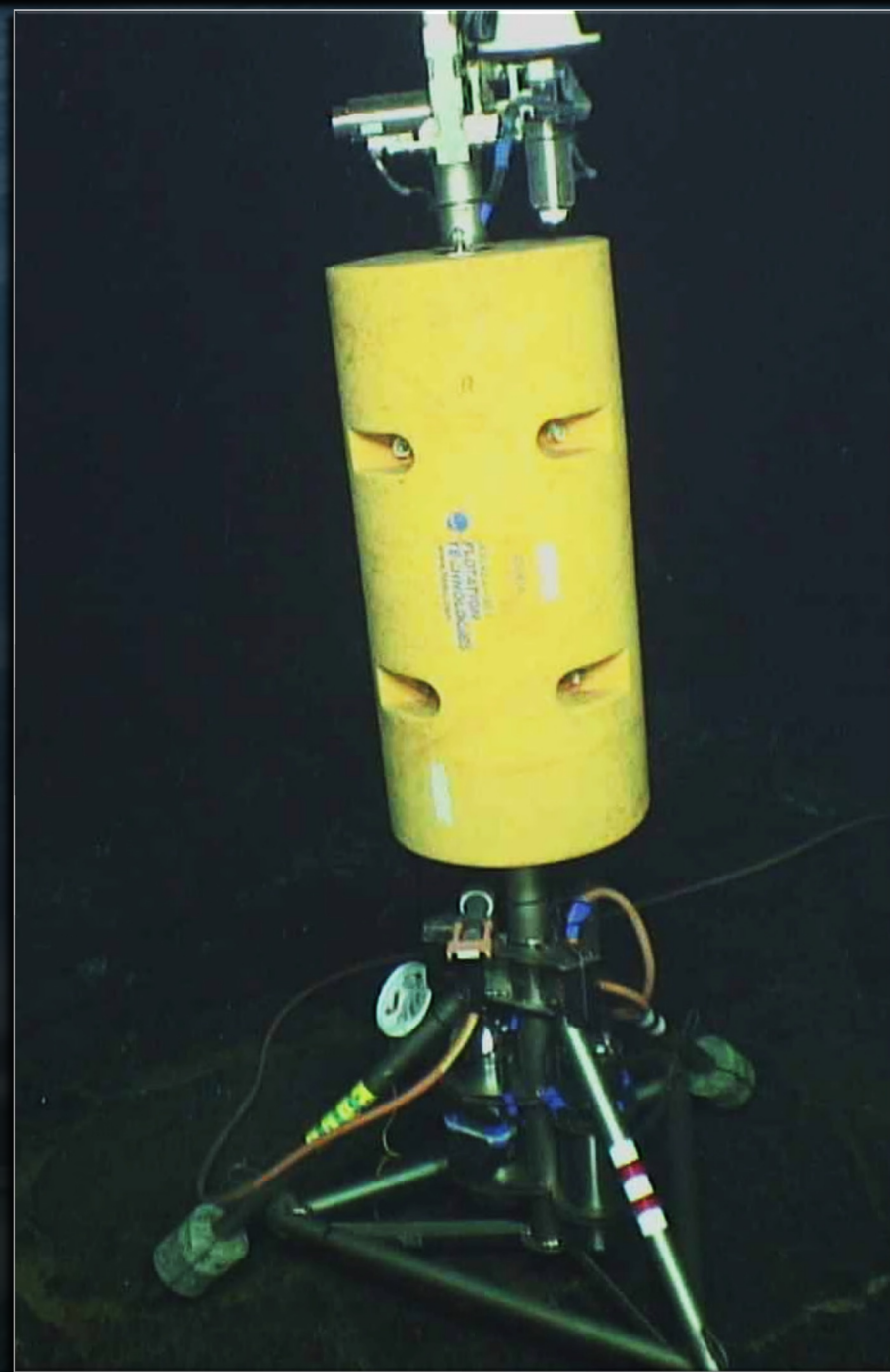
OCEAN
OBSERVATORIES
INITIATIVE



Enabling Advanced Sensing Technologies



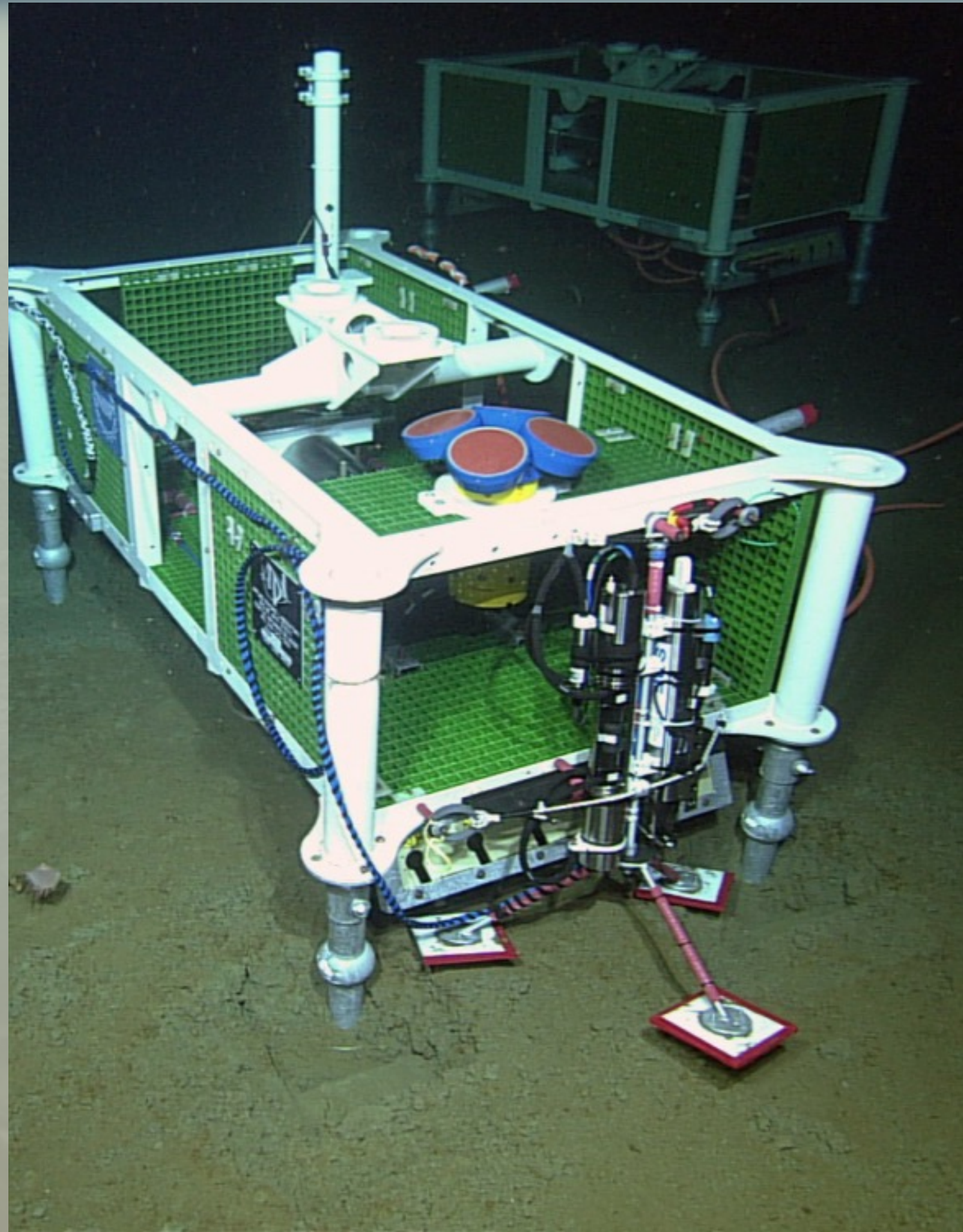
**OOI Cabled Array
Systems**
Top Left: HD video
camera
Right: Shallow
Profiler Mooring



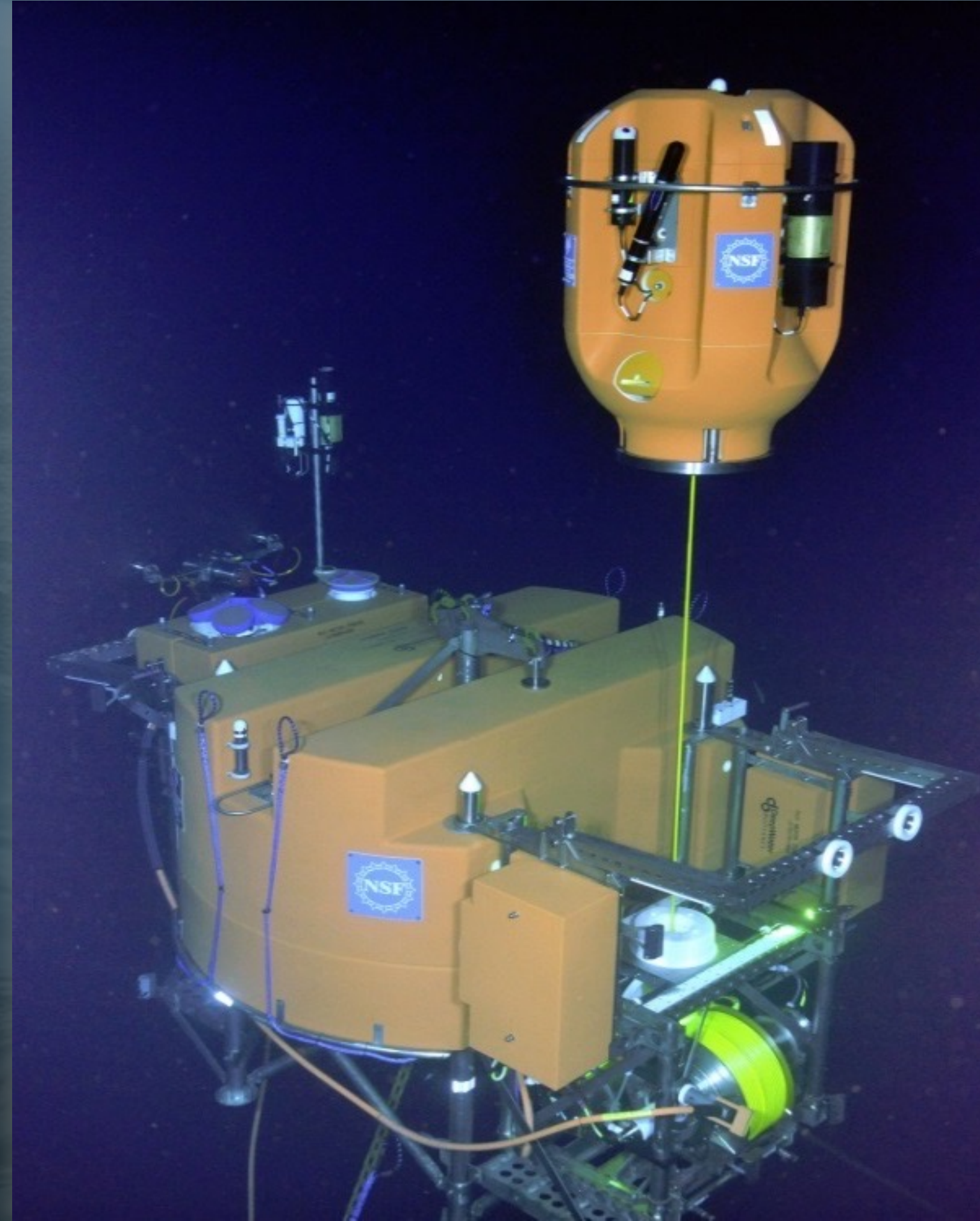
**Bottom Left: Cabled
Array Vent Imaging Sonar
(COVIS)**

*Photos, video courtesy
UW, OOI, NSF*

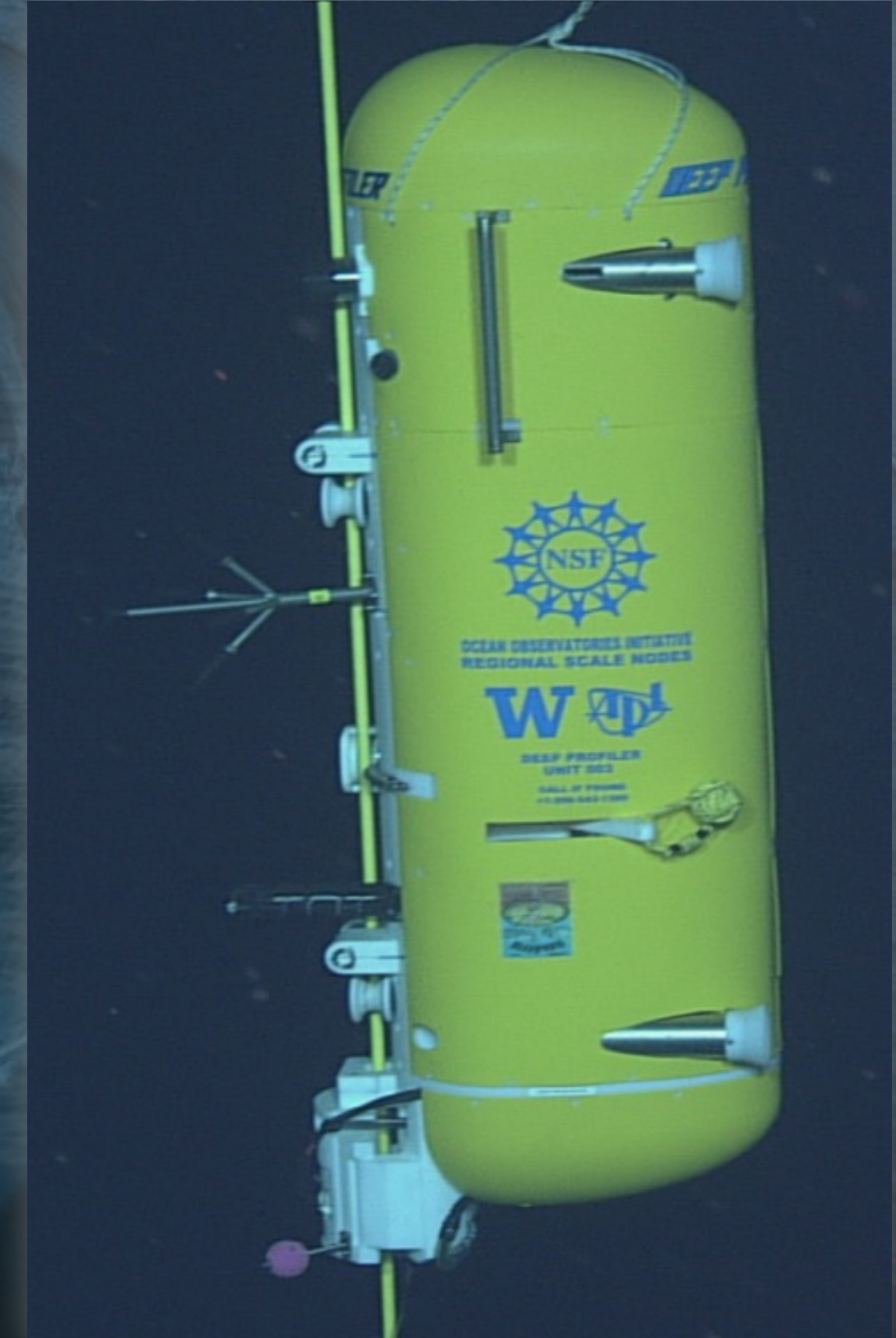
Full Water Column Operations



Seafloor Junction Box
Depth Rating 3500m

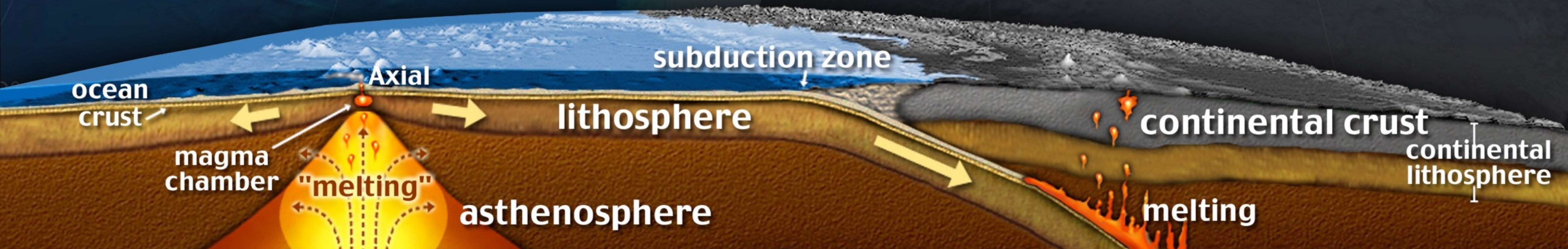


**Mooring Platform/
Winched Profiler, upper 200m**

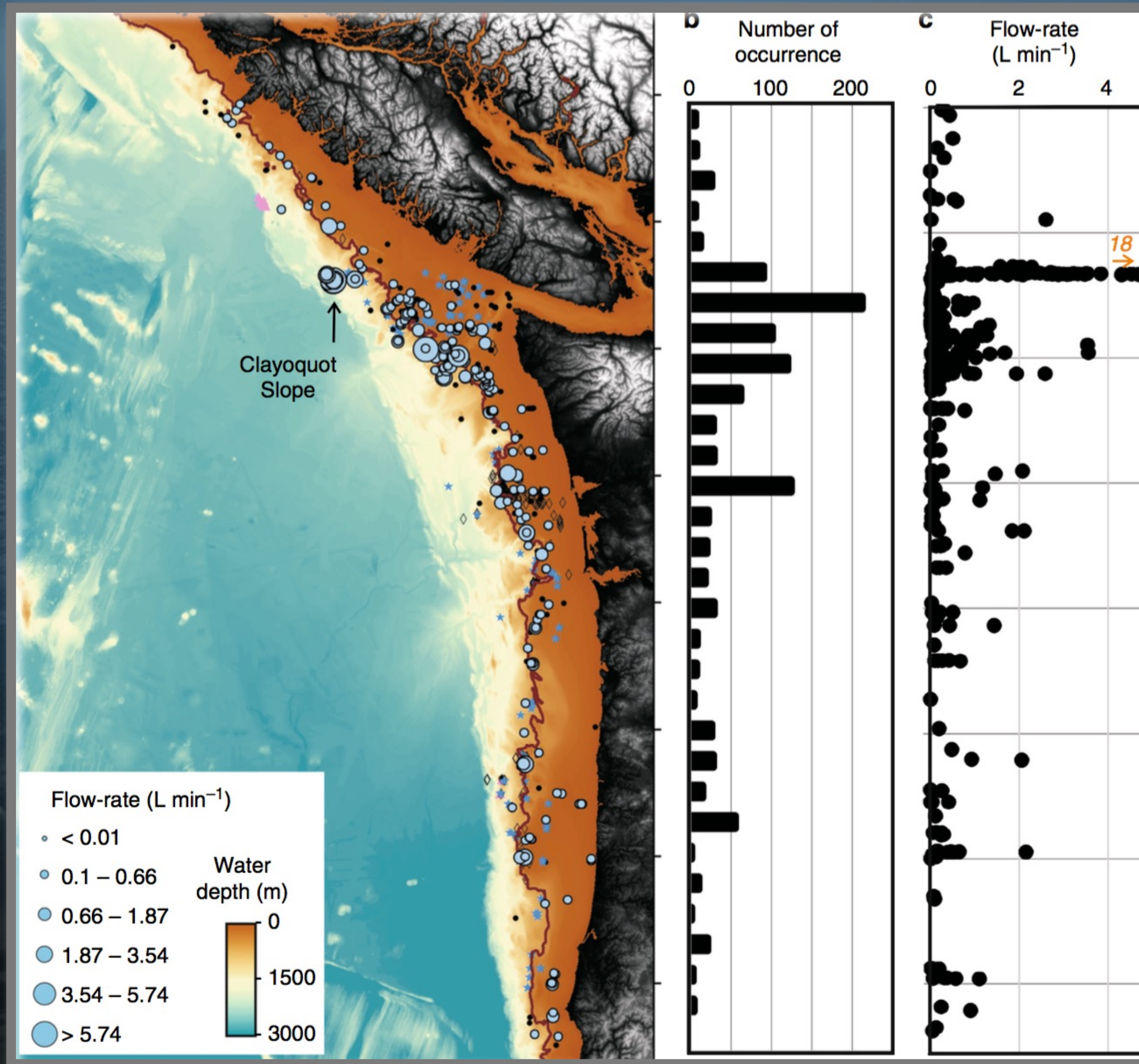


Wire-Crawling Profiler
150m to 3000m

Hydrate Ridge



Methane Seeps Are a Significant Environment Along the Cascade Margin



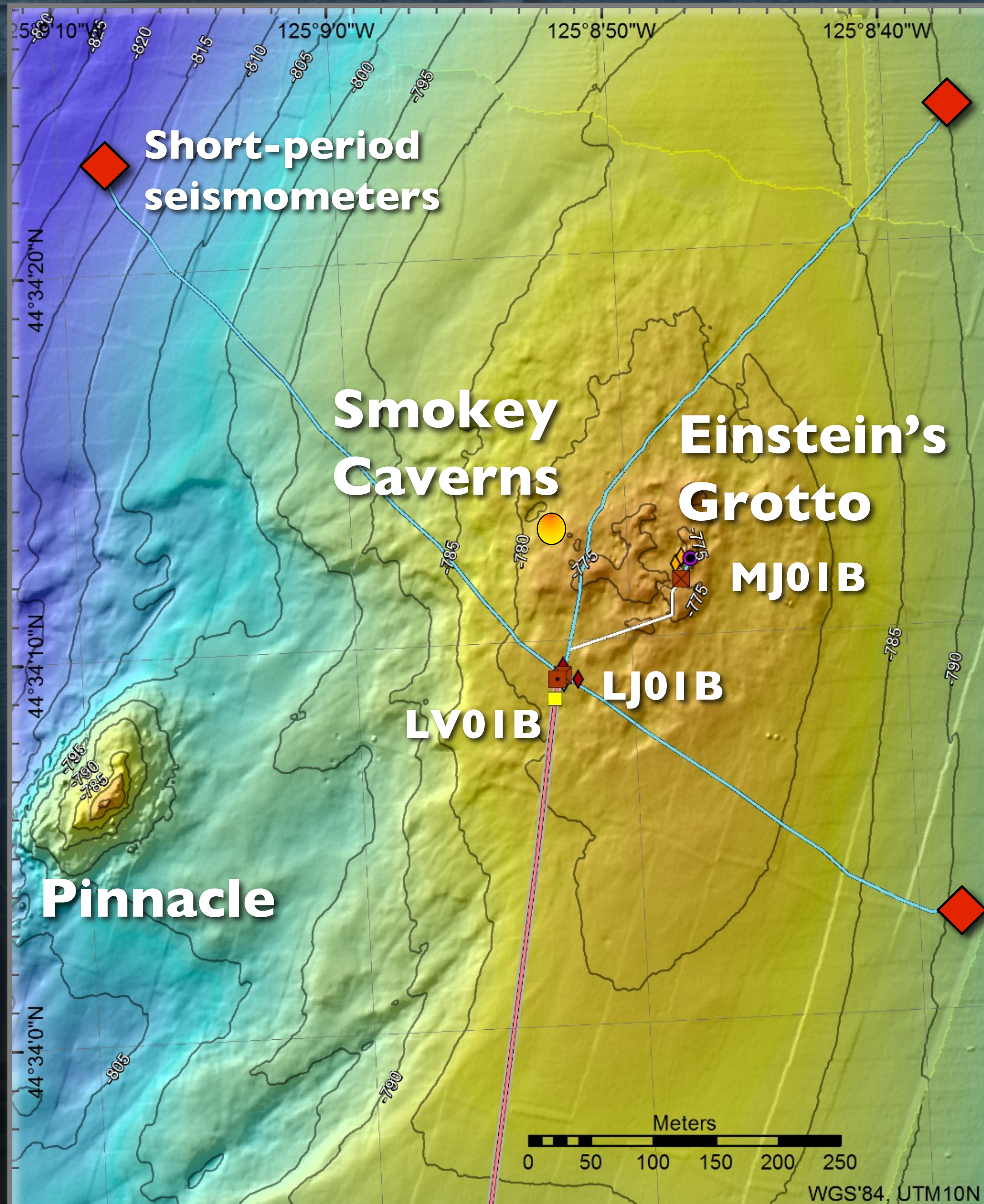
Teratonnes of methane carbon is trapped beneath the seafloor around all continental margins; metastable and may be strongly impacted by ocean warming

- ▶ Over 1100 Acoustic Flares (methane bubble plumes) mapped along the Cascadia Margin (Reidel et al., 2018 Nature)
- ▶ Potential energy reserve, green house gas, slope instability, essential fish habitat
- ▶ Yet only 3 studied in any detail: ONC and Regional Cabled Array

Southern Hydrate Ridge

Infrastructure

- ▶ 3 Junction Boxes with a total of ~ 2 kW power available; 1 Gbs bandwidth each
 - ▶ 10 cabled instruments
 - 3 short-period seismometers 1-100Hz
 - 1 broadband seismometers up to 10 Hz
 - 1 low frequency hydrophone 2 Hz to 20 K Hz
 - 1 Digital Still camera & lights
 - 1 75 kHz upward-looking ADCP
 - 1 Pressure sensor
 - 1 Current meter
 - 1 OSMO fluid sampler (uncabled)
 - 3 flow meters (uncabled)
- PI (MARUM) Overview and Quantification
Sonars, CTD, 4K Camera (2018-2023)





Southern Hydrate Ridge - A Highly Dynamic Methane Seep Environment

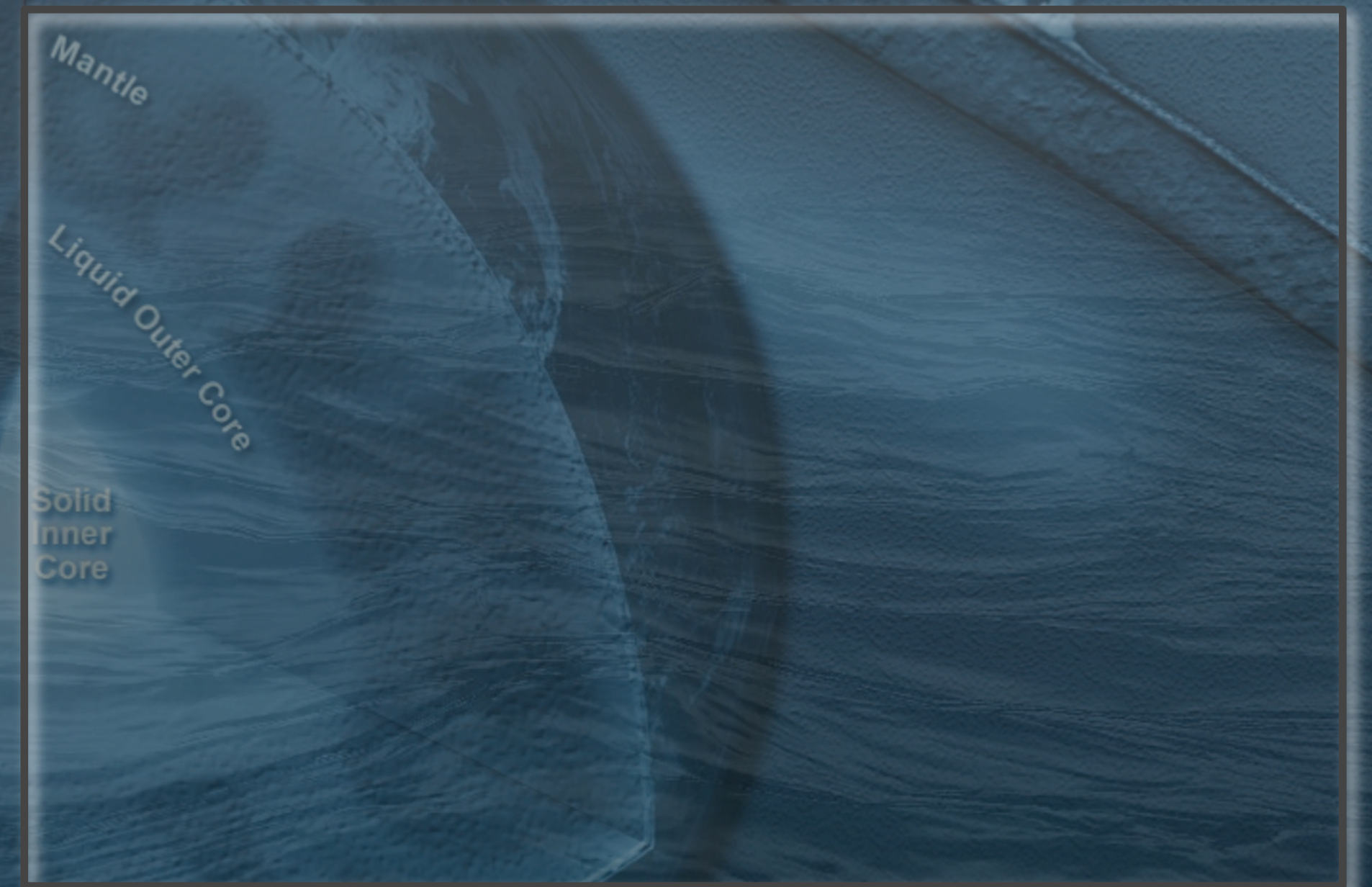
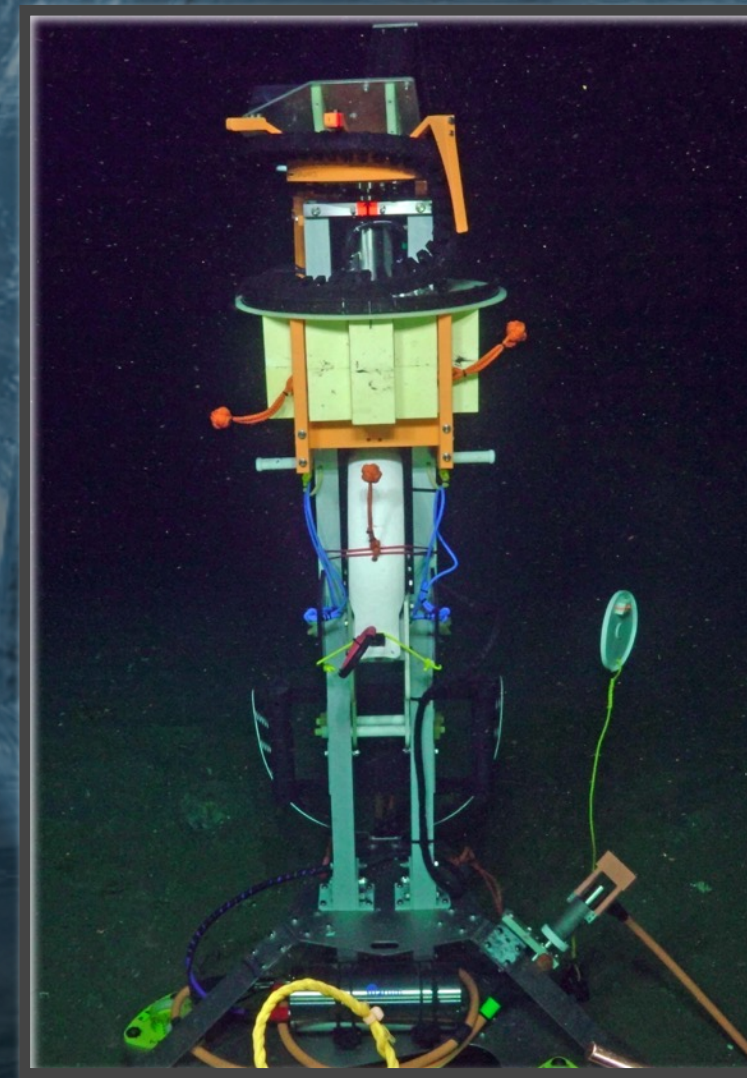
Methane Emissions Increase Biological Productivity

krill &
zooplankton

Mantle
Convection
Processes

Methane
plumes

seafloor

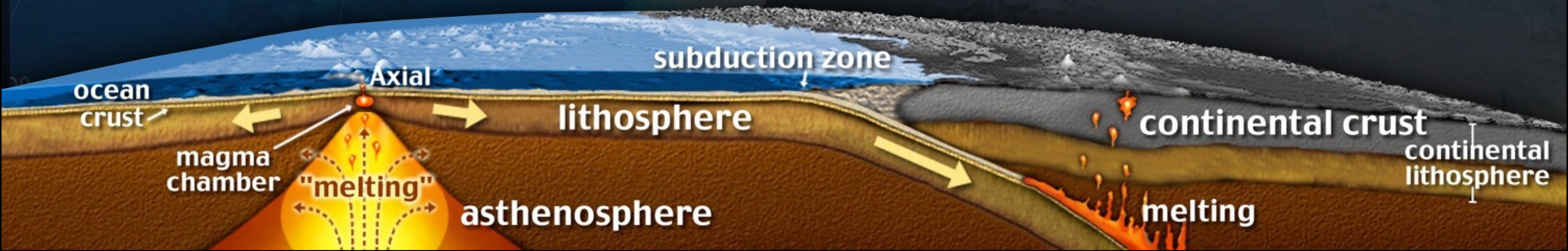


2018-2023 Multibeam 360° imaging of all methane plumes
issuing from SHR First methane flux measurements co-
registered with seismicity - how do earthquakes impact
release of methane from the seafloor?

Marcon, Y, Kelley, D, Thornton, B, Manalang, D
and Bohrmann, G (2021) Variability of natural
methane bubble release at Southern Hydrate
Ridge. *Geochemistry, Geophysics,
Geosystems*. [doi:10.1029/2021GC009894](https://doi.org/10.1029/2021GC009894)



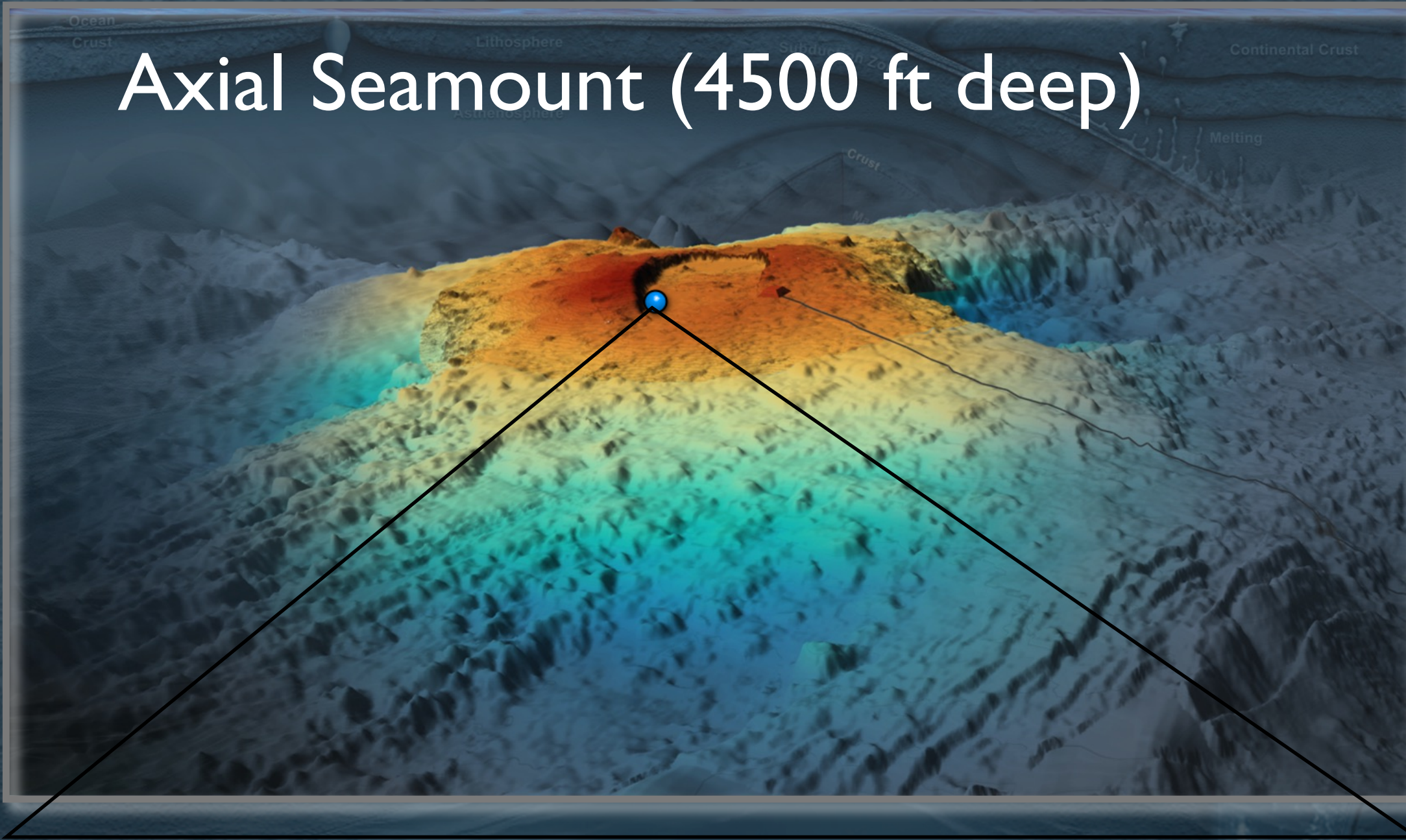
Axial Seamount



Axial Seamount

Most advanced submarine volcanic observatory

Axial Seamount (4500 ft deep)



- ▶ >70% of the volcanism on Earth occurs under water in systems like the one off our coast - largest mountain chain on Earth
- ▶ Emit huge amounts of heat, chemicals and biological material from the seafloor into the overlying ocean, but poorly studied temporally
- ▶ Host underwater hot springs - One of most extreme environments on Earth

Axial is the largest and most magmatically robust volcano off the WA-OR coast

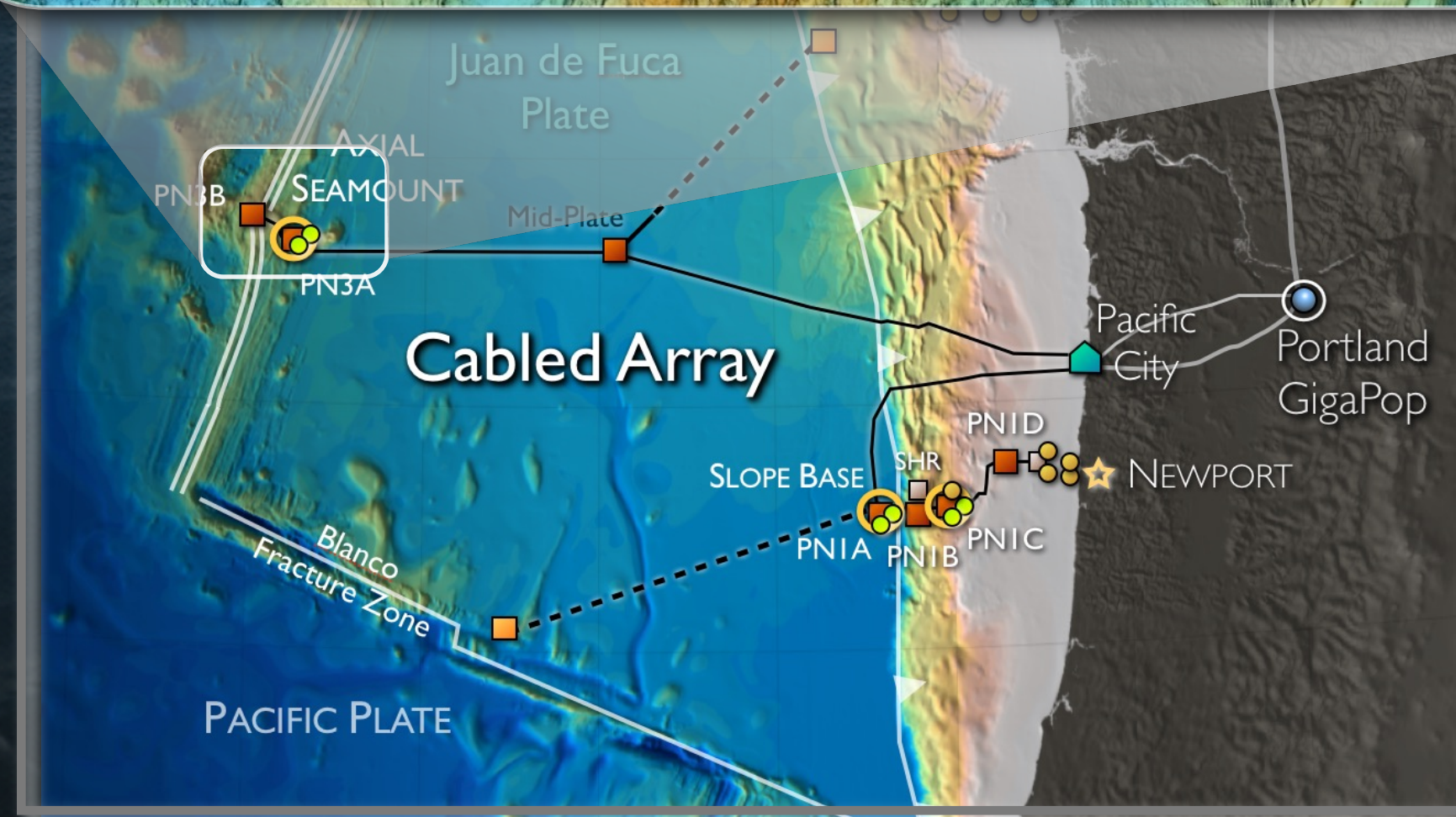
Axial Seamount

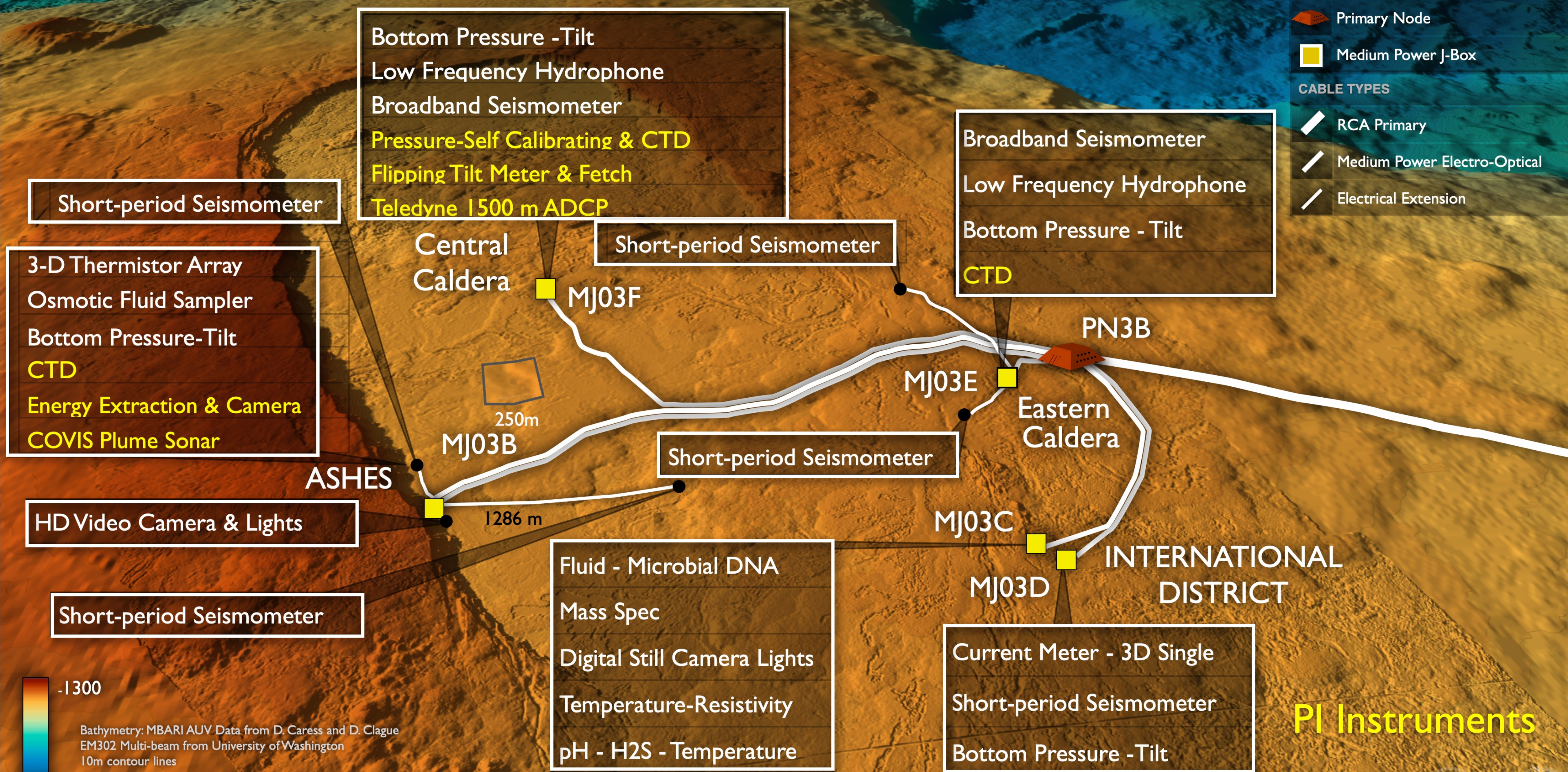
Axial Seamount Most advanced submarine volcanic observatory

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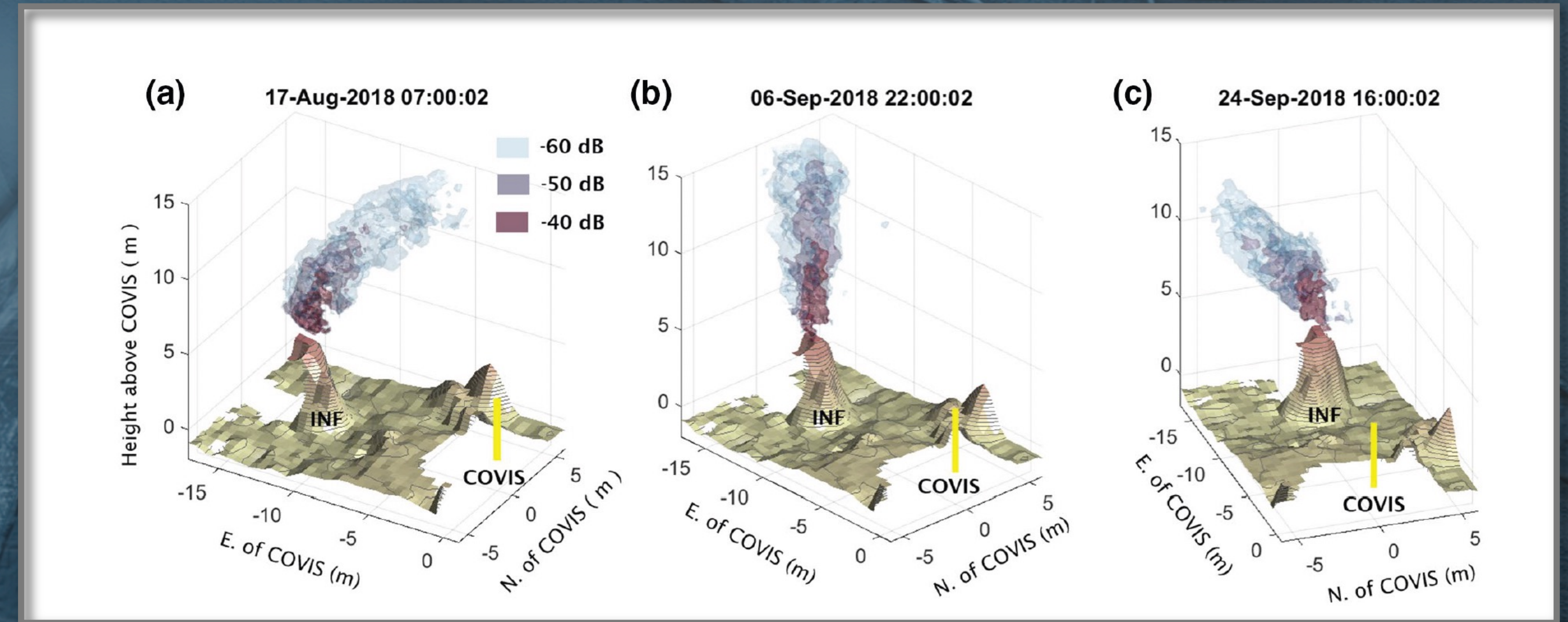
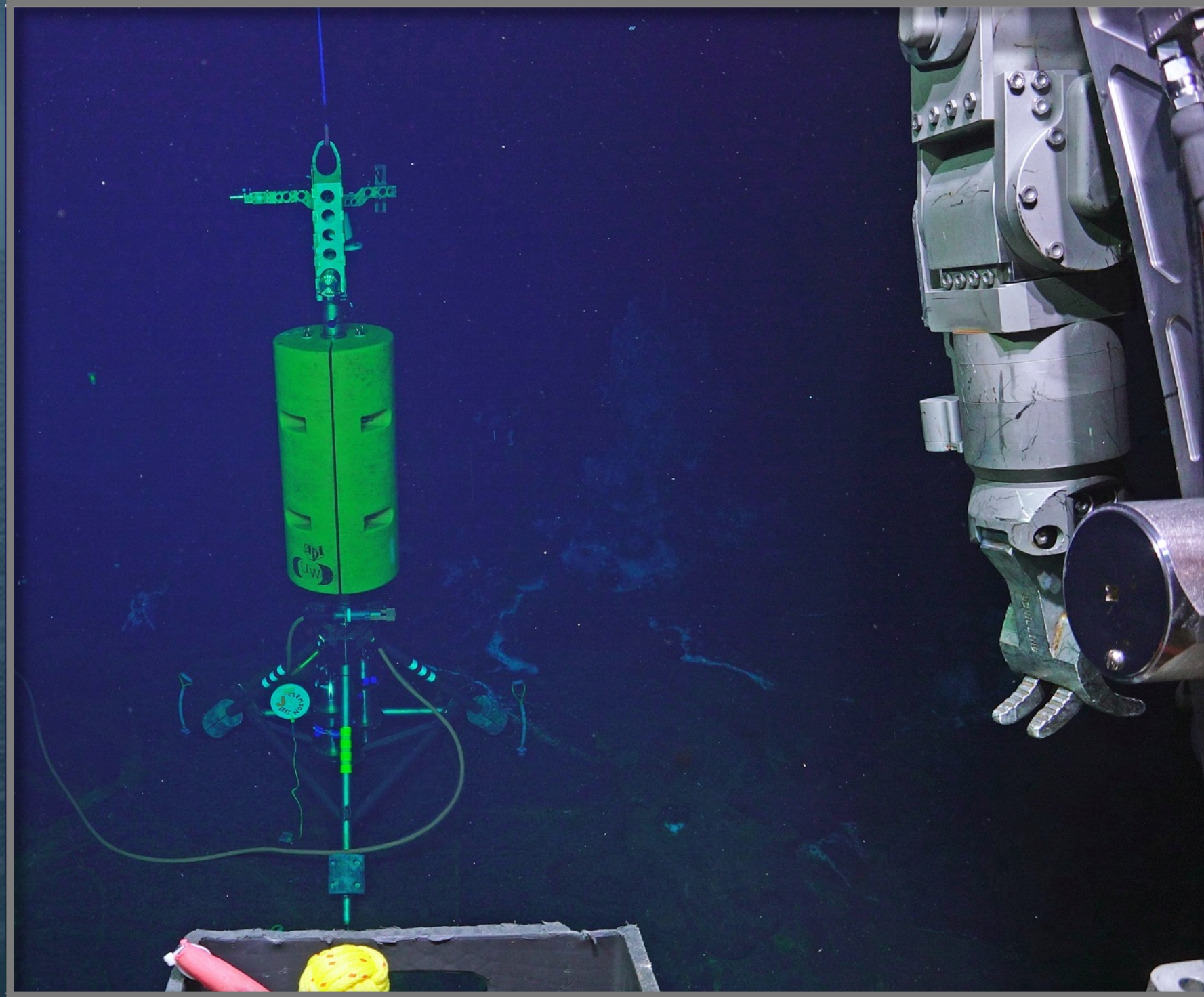
Axial erupted in 1998, 2011, and April 24, 2015 - Poised to Erupt again
Significant focus of research community





Cabled instruments allow co-measure earthquakes, changes in vent fluid temperature-chemistry, seafloor inflation and deflation, and microbial and macrofauna communities

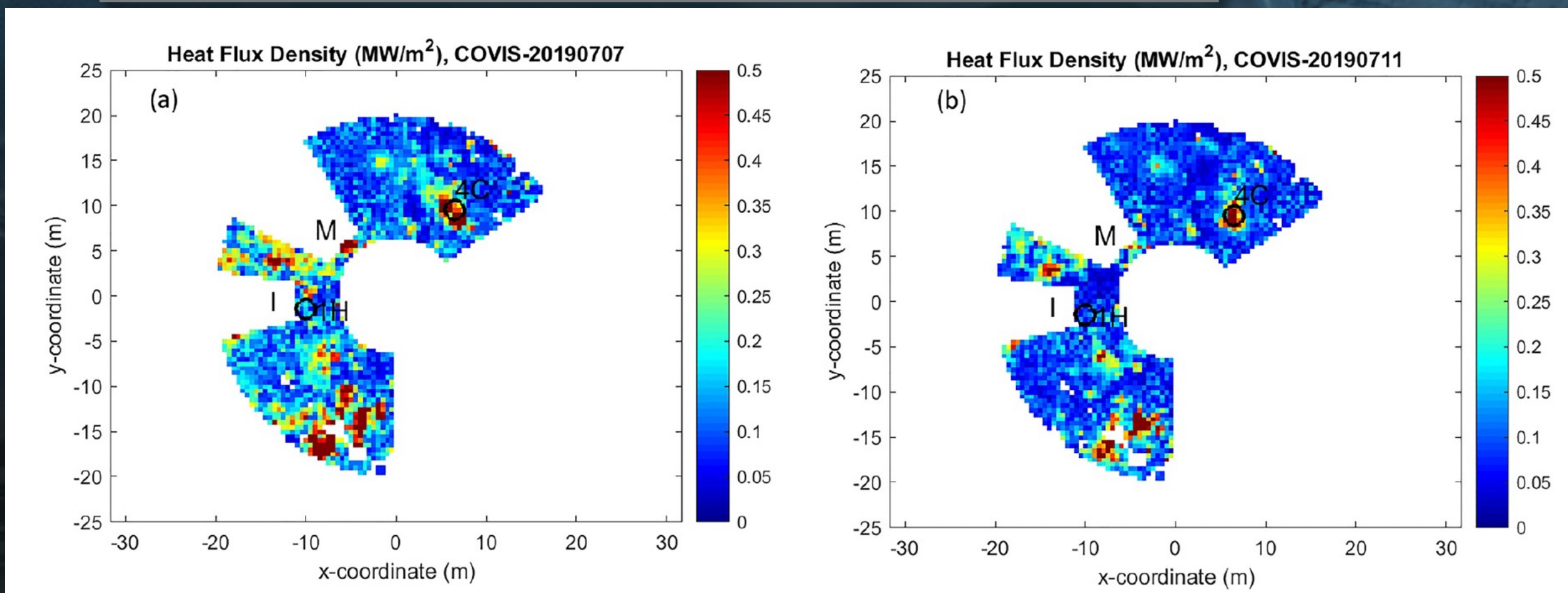
COVIS Heat flow mapping and quantification at ASHES hydrothermal vent field using an observatory imaging sonar



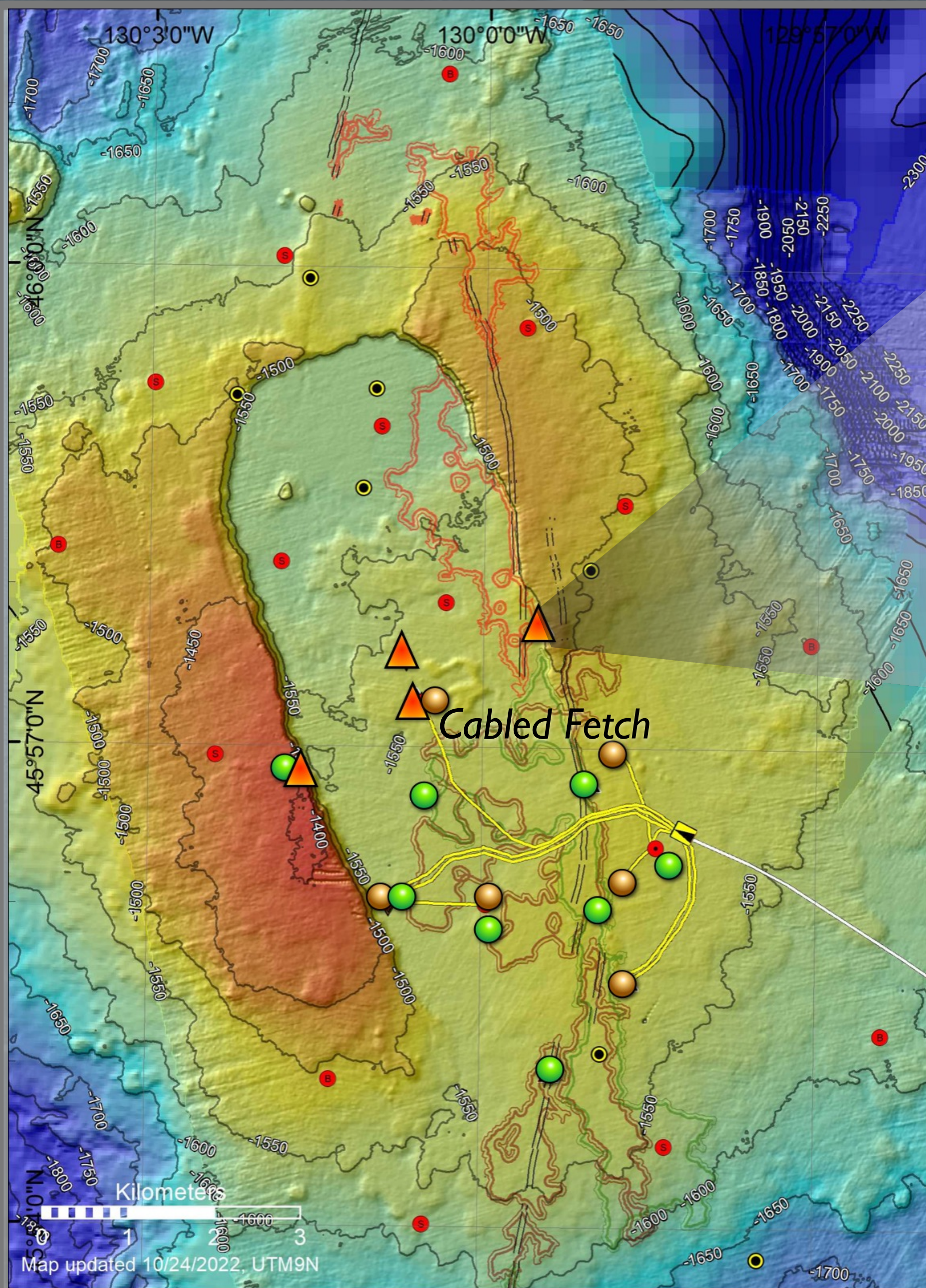
▶ Xu et al., 2021 Acoustic and in-situ observations of deep seafloor hydrothermal discharge: An OOI Cabled Array ASHES vent field case study.

▶ Jackson et al., 2022 Sonar Observation of Heat Flux of Diffuse Hydrothermal Flows

PI: Bemis, deployed 2018-2023



W. Wilcock and D. Manalang (UW) “An Acoustic Array At Axial Seamount for Geodesy and Autonomous Vehicle Support” (OCE2130060-MGG)



- ▶ Monitor horizontal strain along baselines that connect 4 acoustic transponders.
- ▶ Movement of buried outward dipping faults during the volcanic cycle.

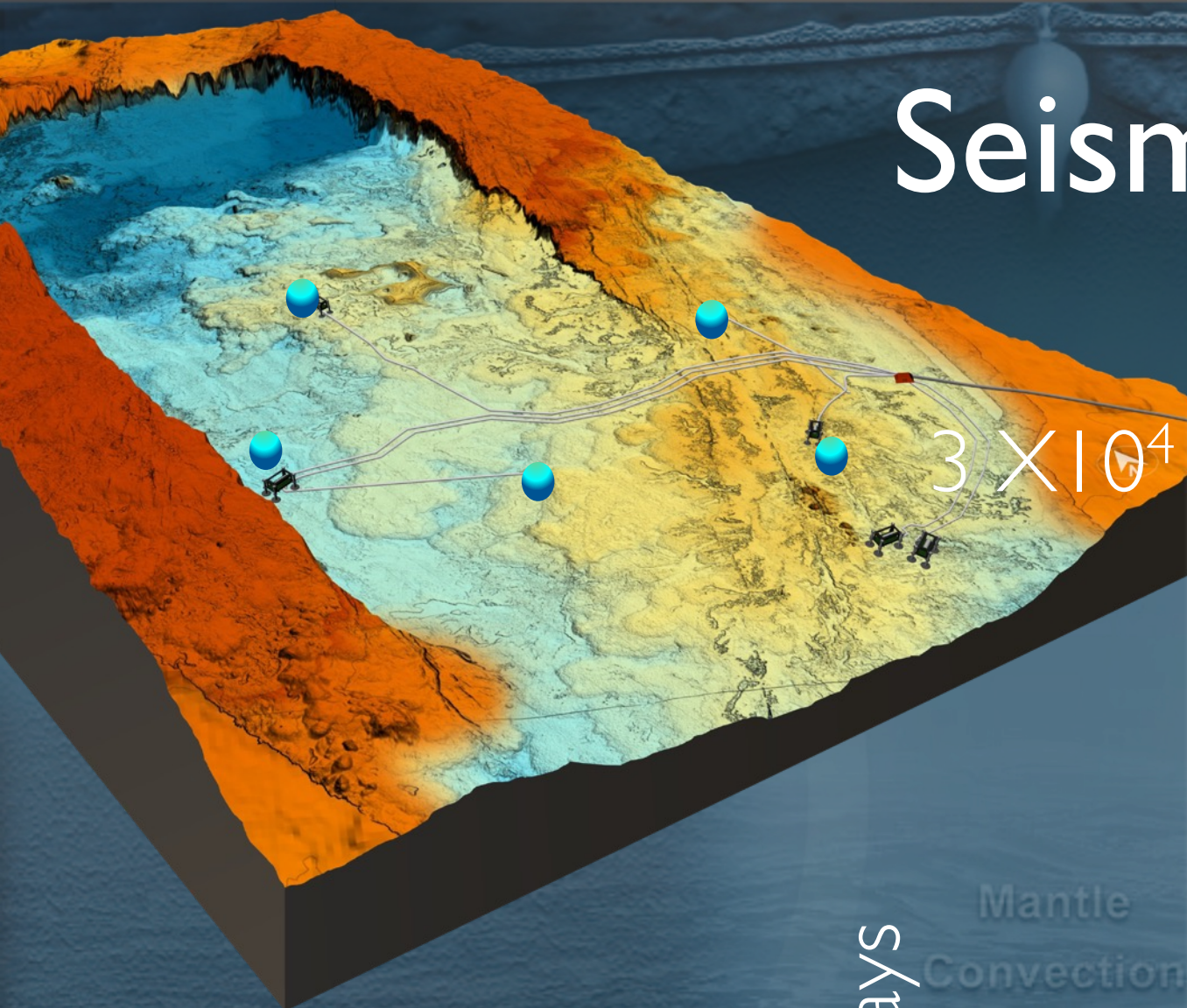
- ▶ Measure rates of fault slip associated with increase in seismicity during inflation.
- ▶ Possible multipurpose as navigation, comms interface for AUV's
- RCA cabled seismometers
- Chadwick bench marks
- ▲ Fetch Acoustic Ranging Transponders
talk to cabled Fetch, temperature, pressure



Seismic Crisis Marked the Start of the 2015 Eruption

Wilcock et al., Science 2016

127 m thick
lava flow



Earthquakes per 10 days

2×10^4

1×10^4

Earthquakes detected
Earthquakes located

2015 eruption
>8,000 earthquakes
in 24 hrs

0
2014 2016 2018 2020 2022

Earthquakes >30,00 explosions

William Wilcock
(UW)
<http://axial.ocean.washington.edu/>

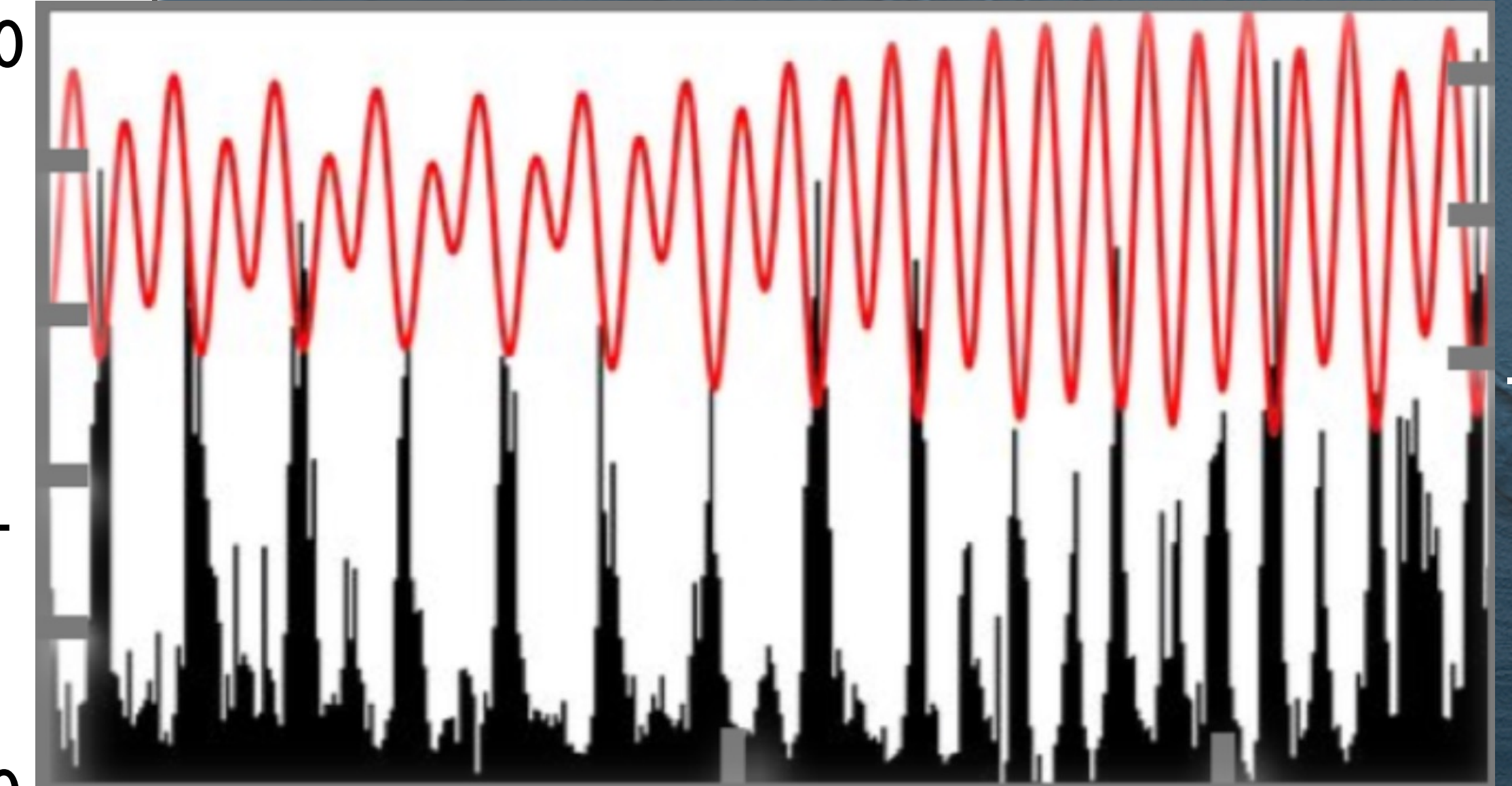
Measuring the heart-beat of a submarine volcano

Full Catalog (10 day bin)

Earthquakes detected
Earthquakes located

500

Earthquake Count/hr



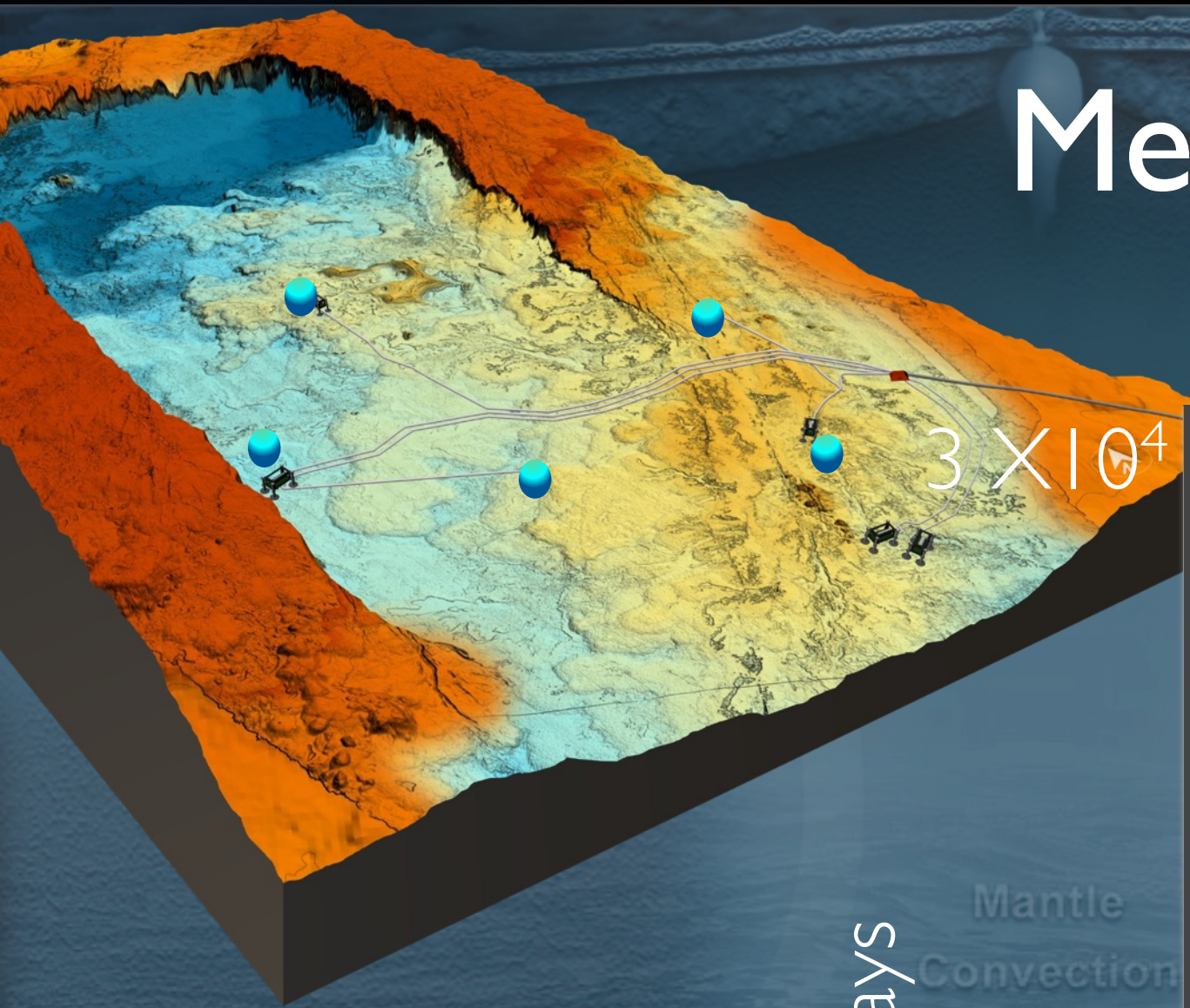
3/10

2015

3/25

- ▶ Earthquakes strongly correlated to tides pre-eruption (6 times higher during low tides)
- ▶ Faults “unclamping” when ocean loading is minimum

Wilcock et al., Science 2016

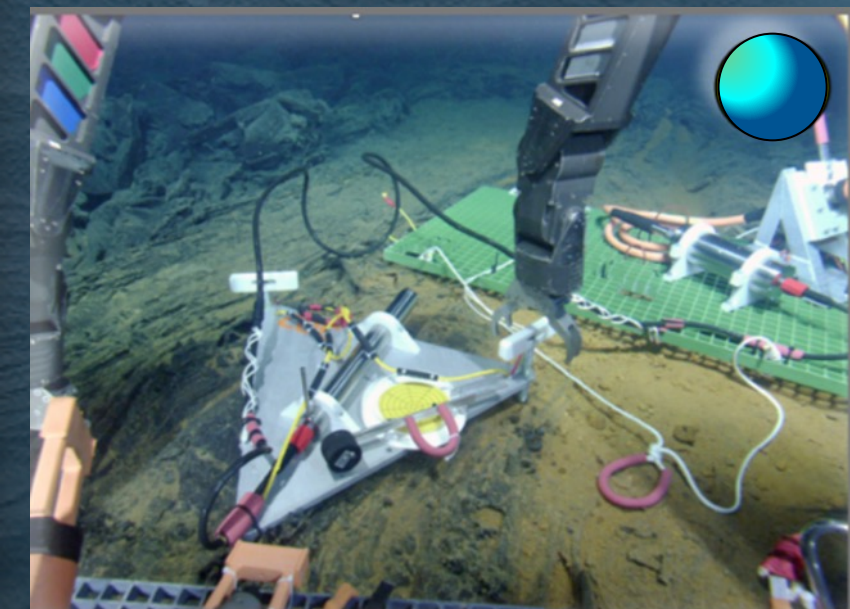


3×10^4

2×10^4

1×10^4

Earthquakes per 10 days

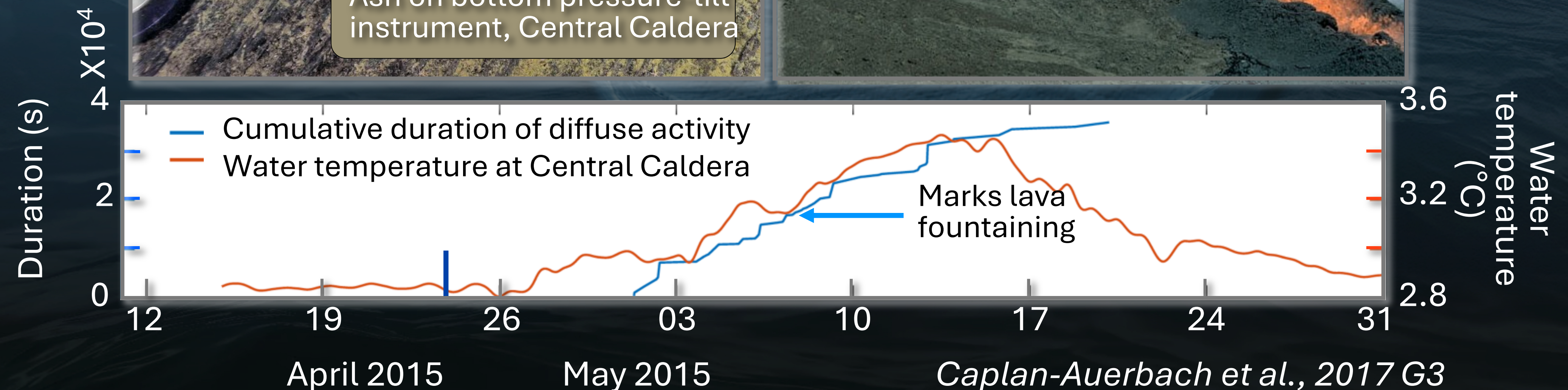


Cabled short-period seismometer being leveled

0
2014 2016 2018 2020 2022

Hawaiian Style Explosions in 2015

Ash and acoustic signals show that fountaining of lava occurred 1 mile beneath the oceans surface! >150 times atmospheric



- ▶ 416 ft thick lava flow
- ▶ Summit covered in acres of microbes 3 months after the eruption, billions of microbes streaming from the seafloor fed by volcanic gases
- ▶ RCA instruments measuring volcanoes deformation and seismic activity show it is poised to erupt again.

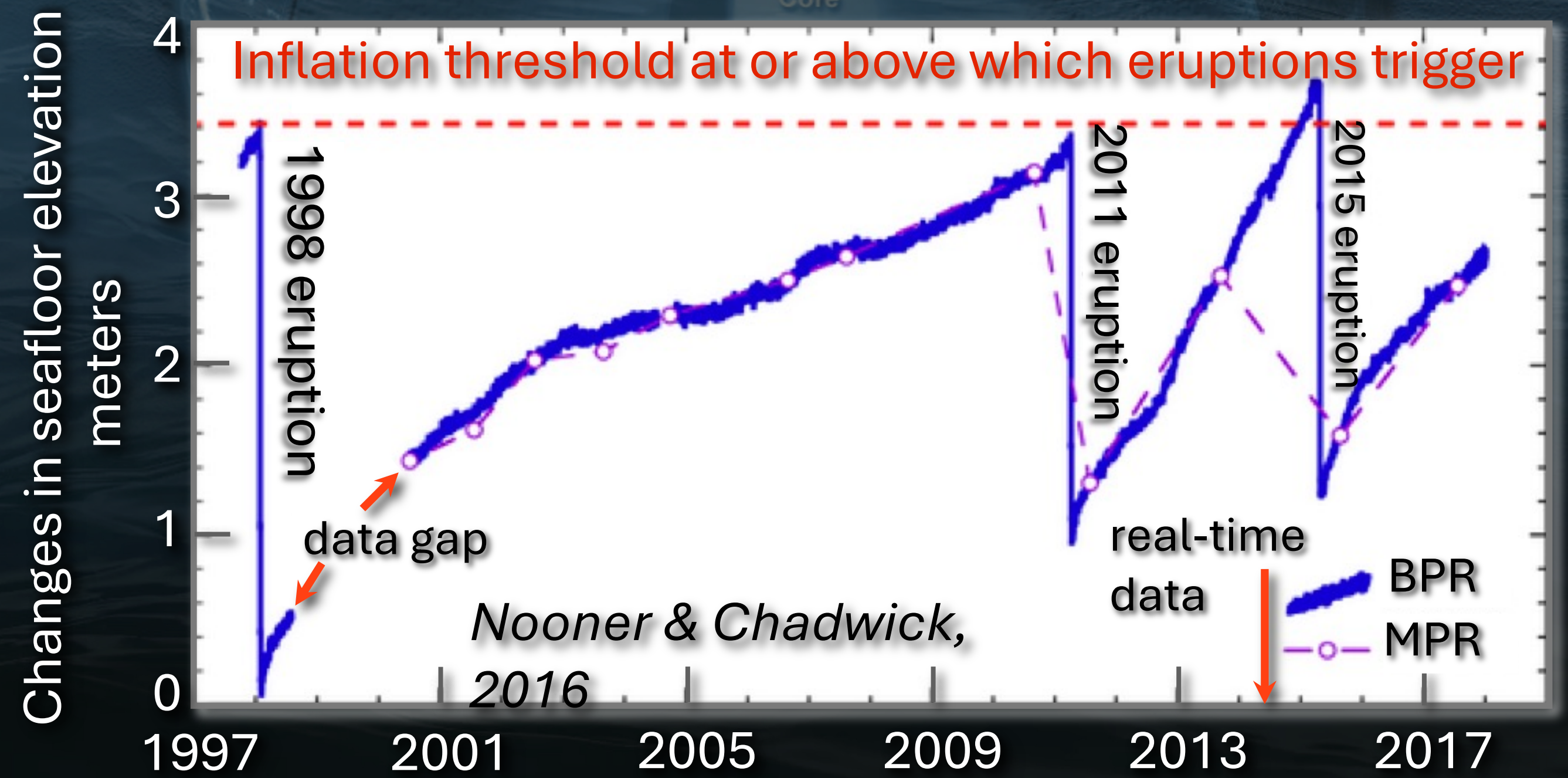
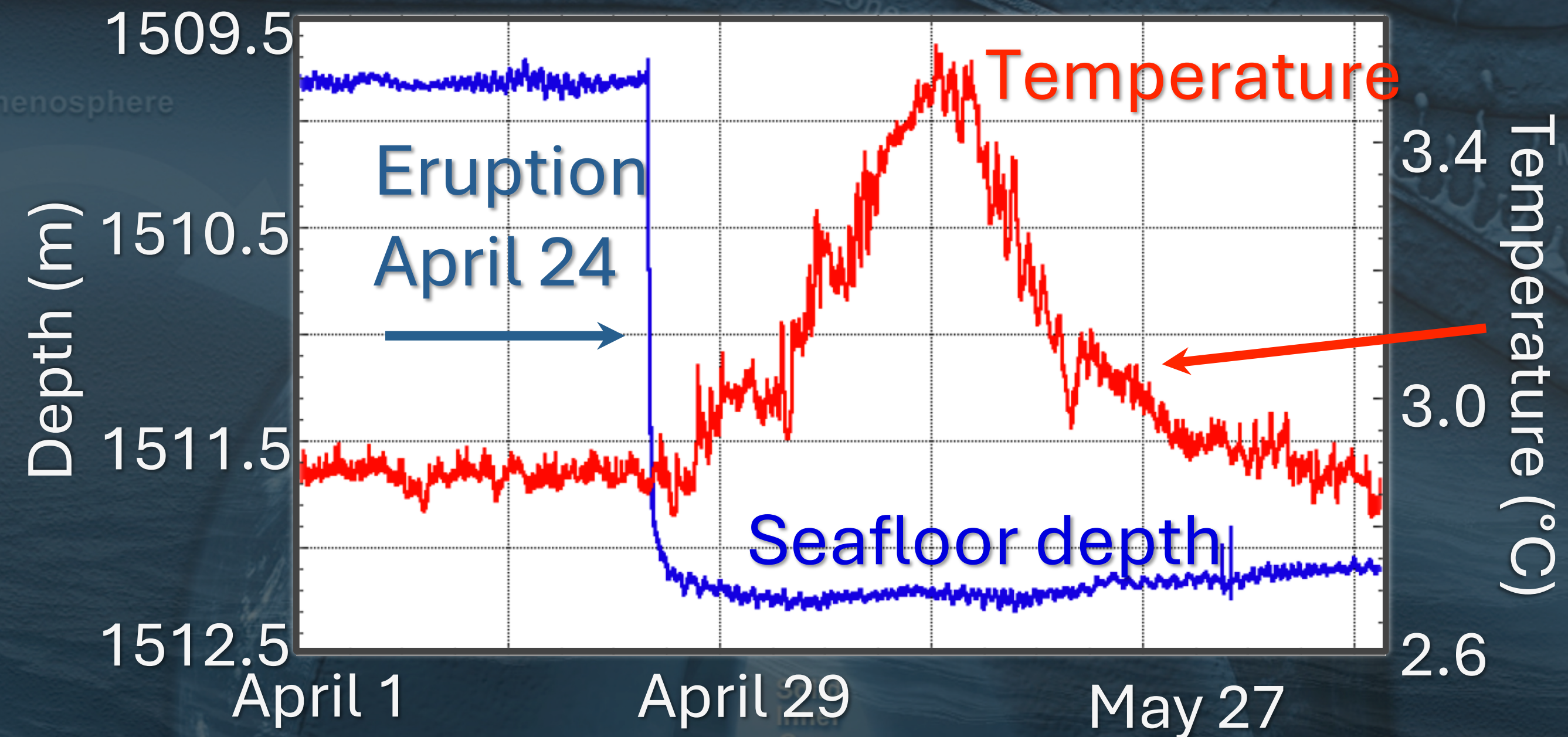
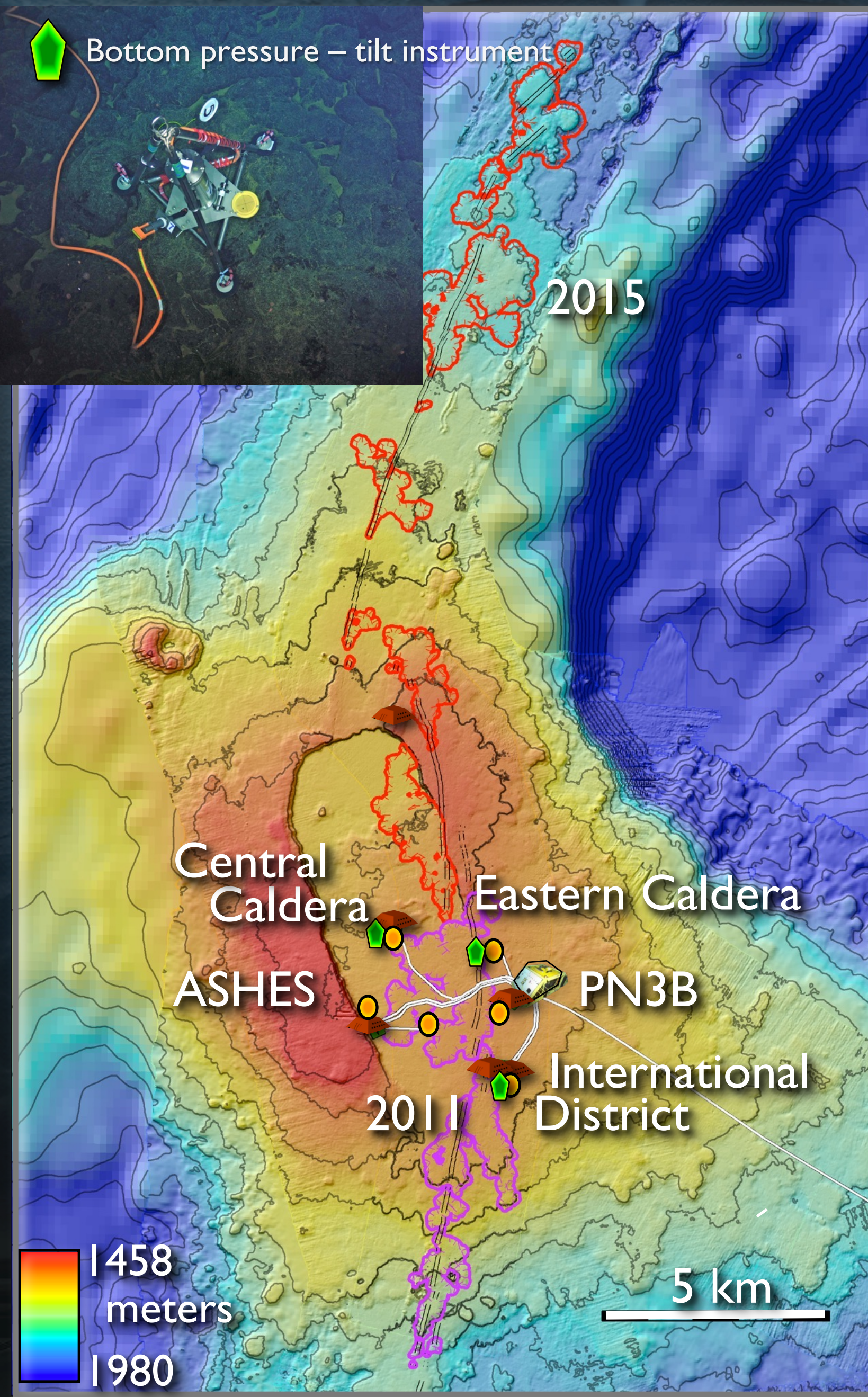
3 km

2015 Eruption

416 ft thick
lava flow

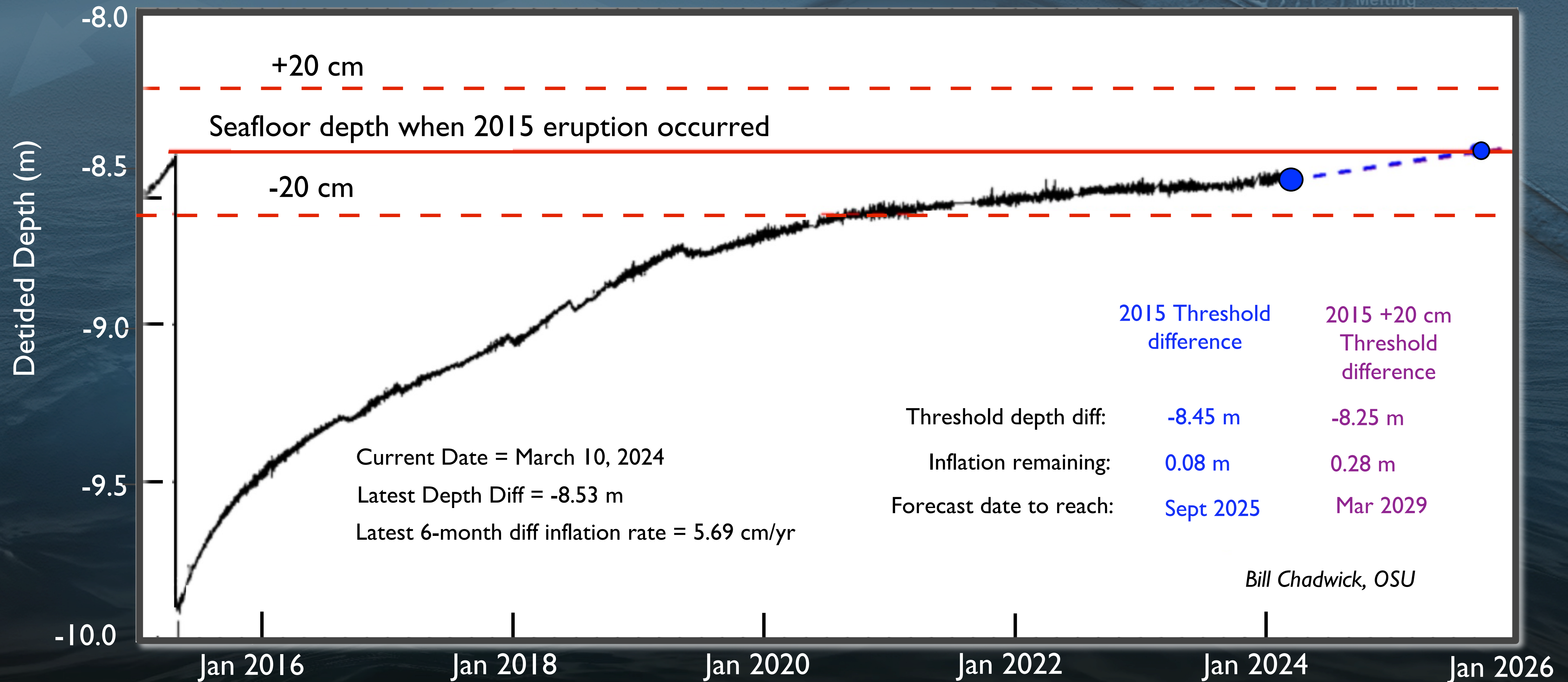


Axial Inflation/Deflation



Axial Seamount Bottom Pressure Tilt

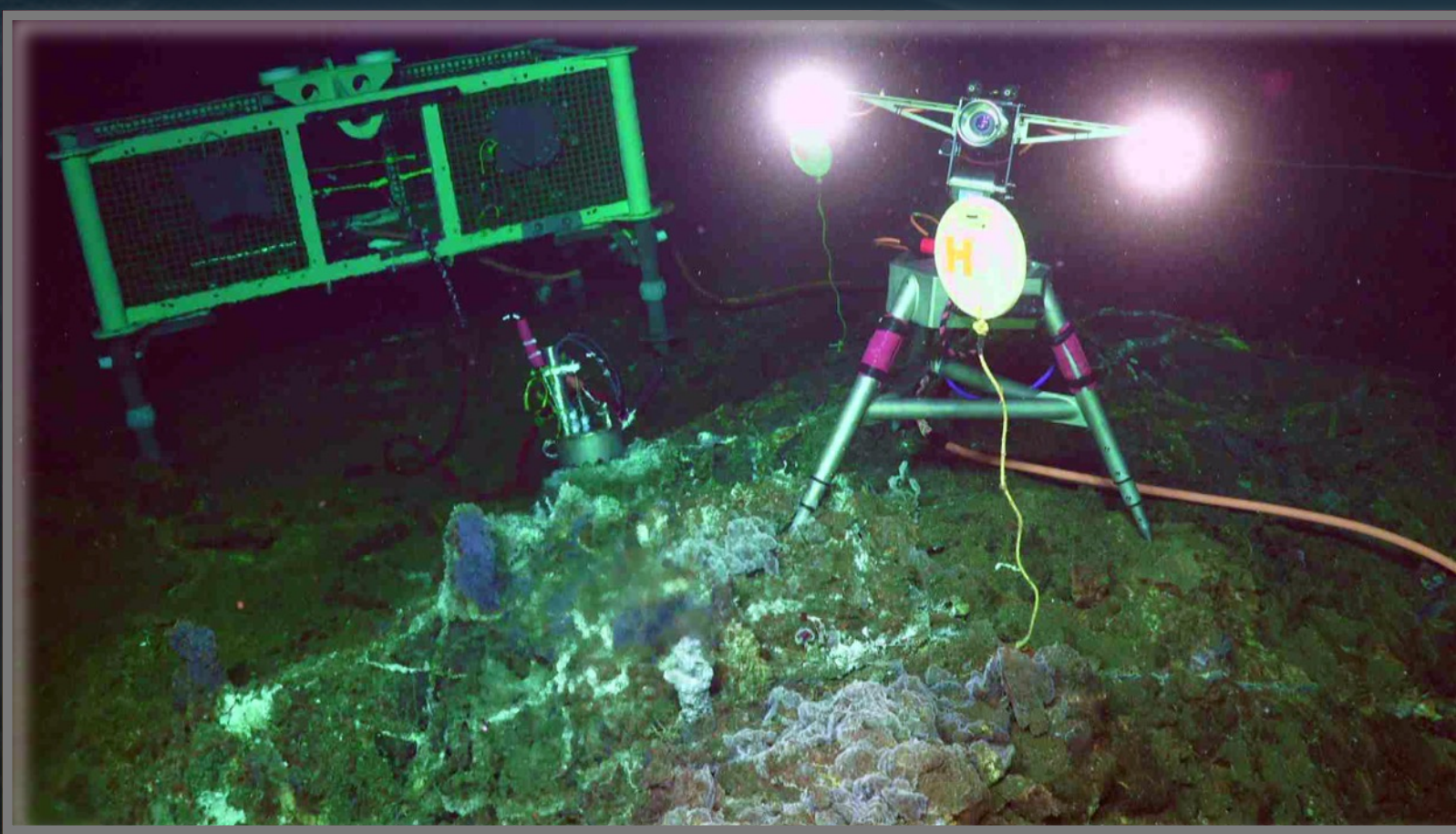
First Volcano Where Eruption May be Forecasted



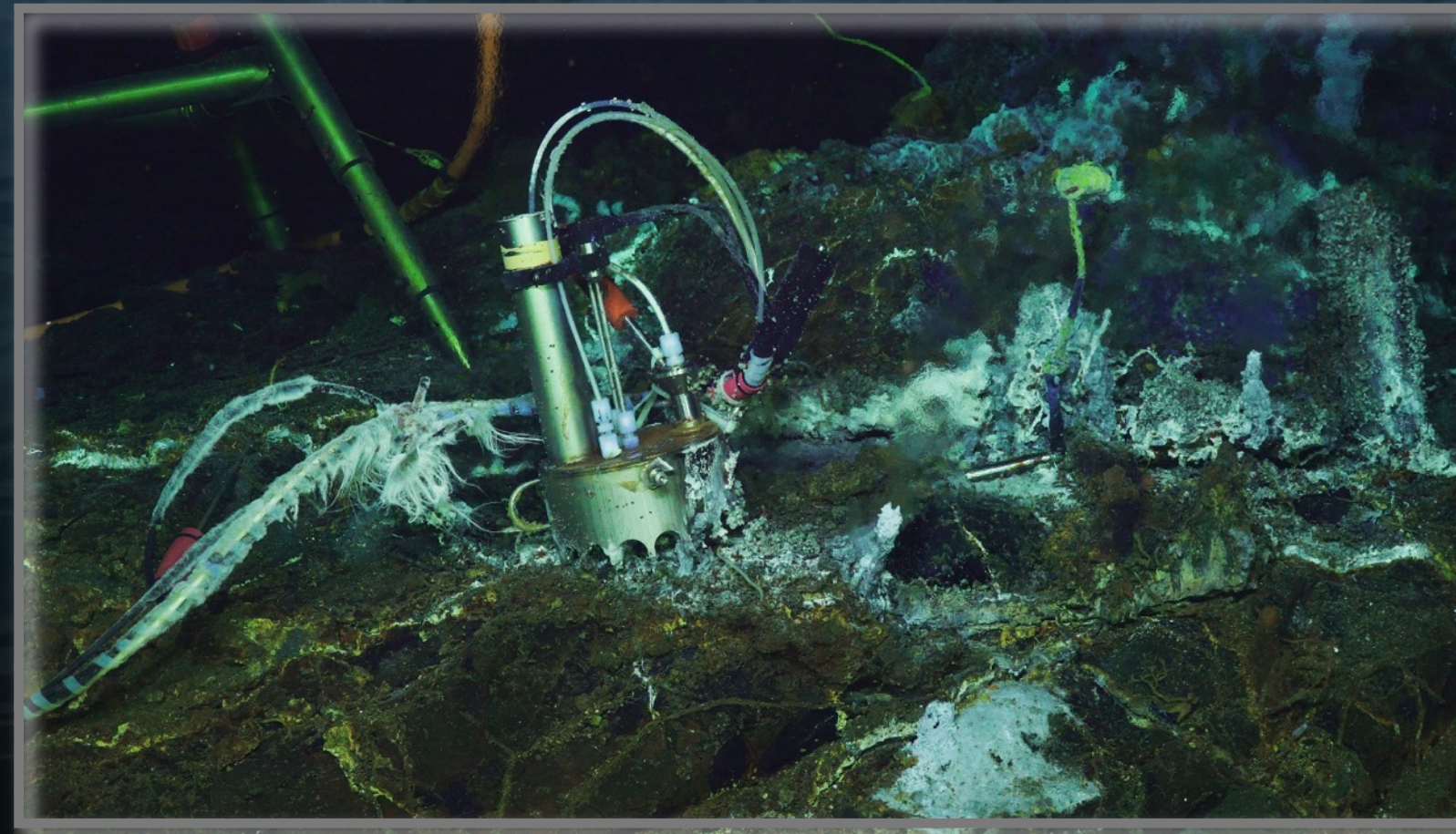
https://www.pmel.noaa.gov/eoi/axial_blog.html

Rika Anderson Carleton College CAREER: Temporal dynamics of microbial and viral function and adaptation in hydrothermal vents Use RCA fluid-microbial DNA instruments, and others in the Axial International District and collect additional samples.

- ▶ Rich time-series of microbial and viral metagenomics every 10-20 days for 3 years
- ▶ Increase understanding of microbial function in subsurface habitats in response to perturbations -help constrain marine biogeochemical cycles
- ▶ New insights into marine viral ecology in habitats outside commonly studied surface oceans
- ▶ Shed light on evolutionary processes most ancient habitats on Earth
- ▶ Generate rich dataset that can be used by others to investigate future questions.



Camera, RAS-PPS, 3 temperatures



Vent cap with inlets to RAS-PPS

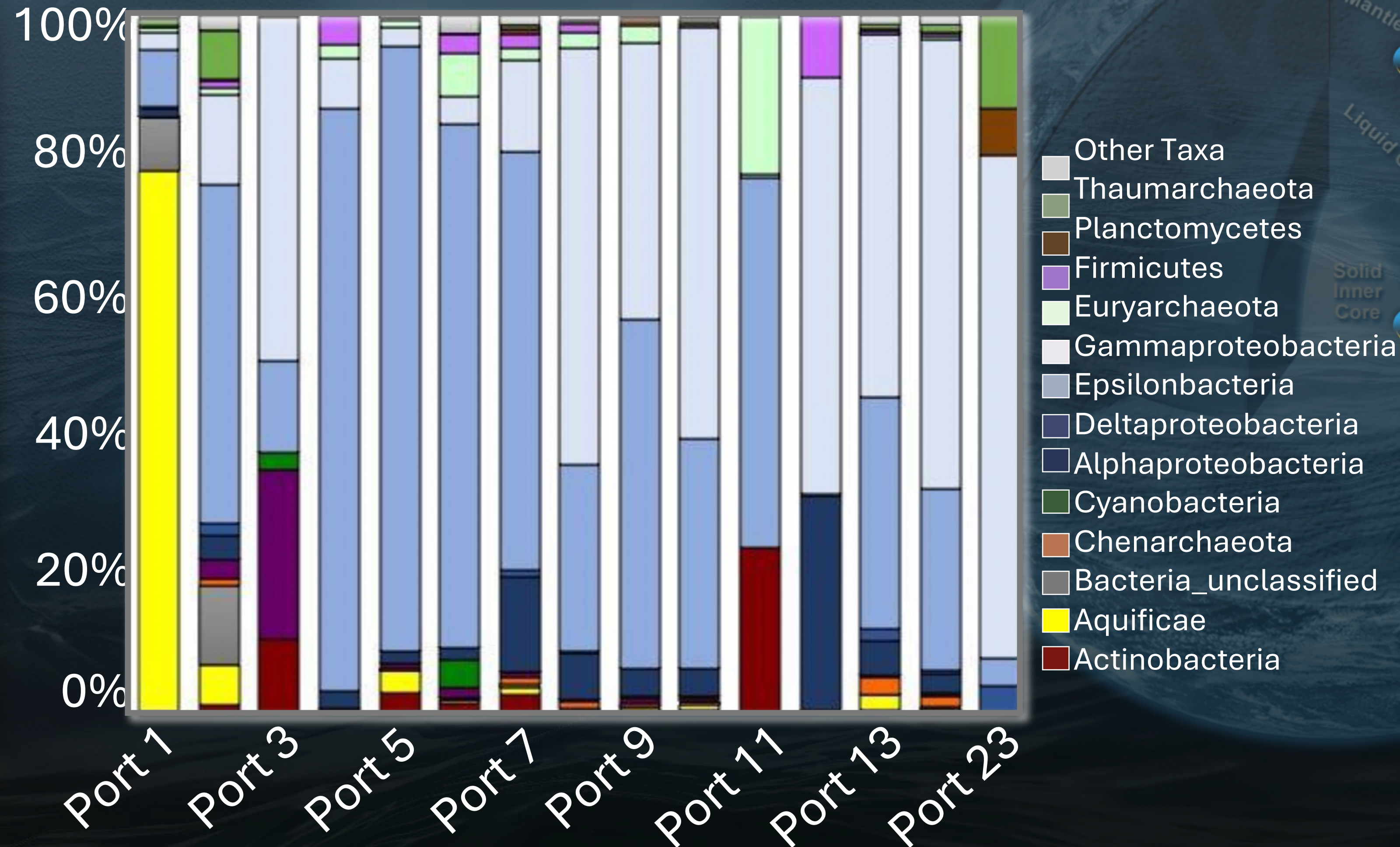


Tiny Towers Community

R. Anderson, Carleton College “CAREER: Temporal dynamics of microbial and viral function and adaptation in hydrothermal vents” 5 years.

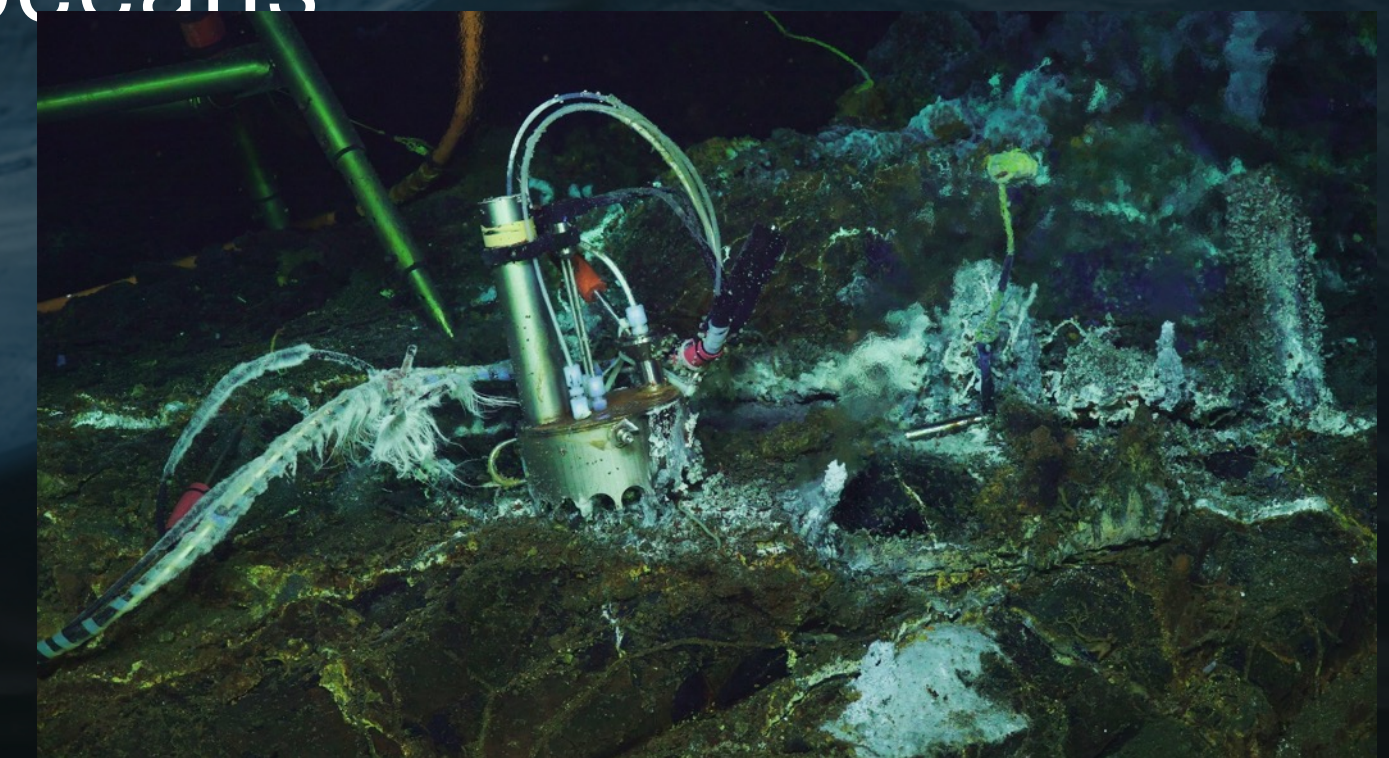
RCA Cabled Microbial In-Situ DNA Sampler A Decade History of Microbial Community

Microbial Taxa El Gordo Diffuse Flow Vent



Times Series DNA Sampling 2016-2017 (Courtesy R. Anderson)

- ▶ Rich time-series of microbial and viral metagenomics every 10-20 days for 3 years
- ▶ Increase understanding of microbial function in subsurface in response to perturbations - help constrain marine biogeochemical cycles
- ▶ New insights into marine viral ecology in habitats outside commonly studied surface oceans

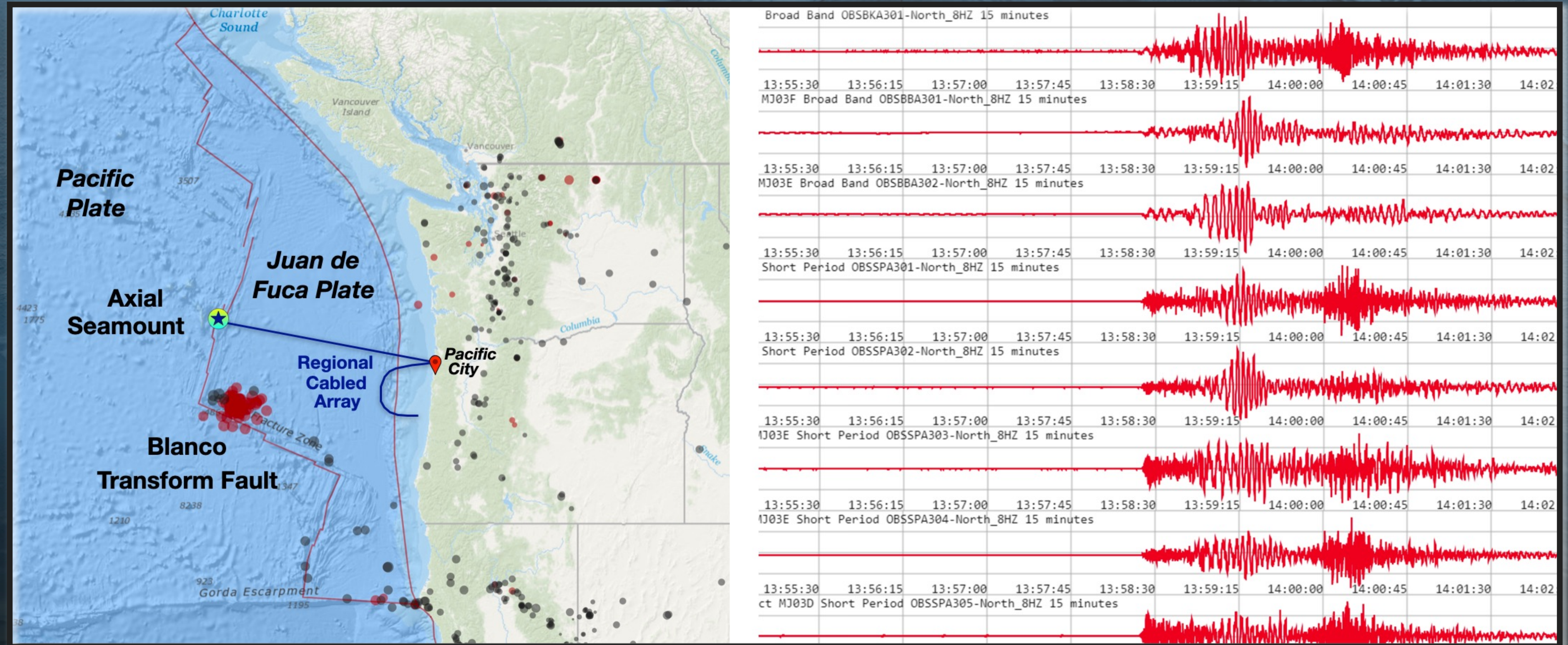


Vent cap with inlets to RAS-PPS

RCA Geohazard Applications: ShakeAlert®

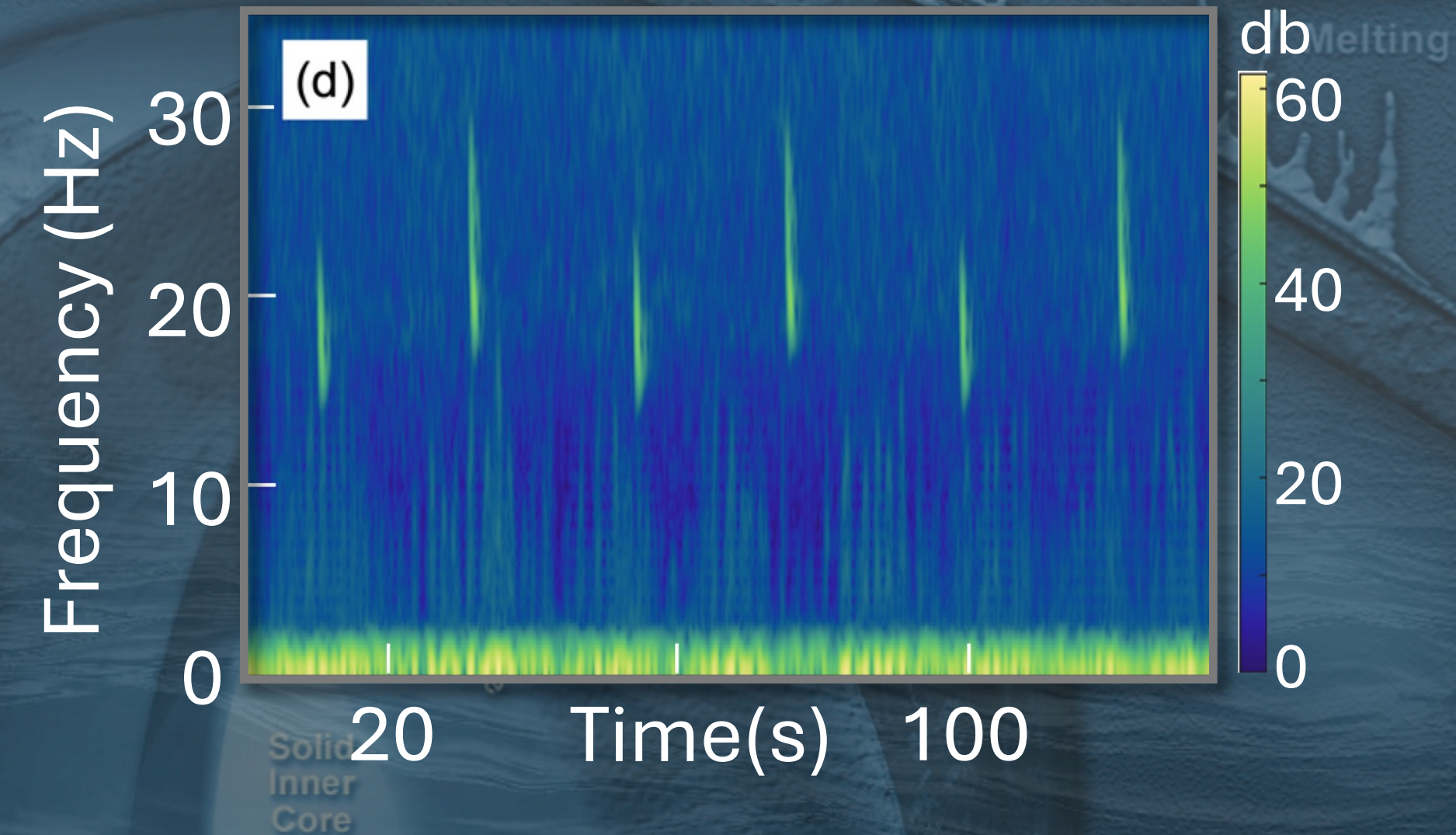
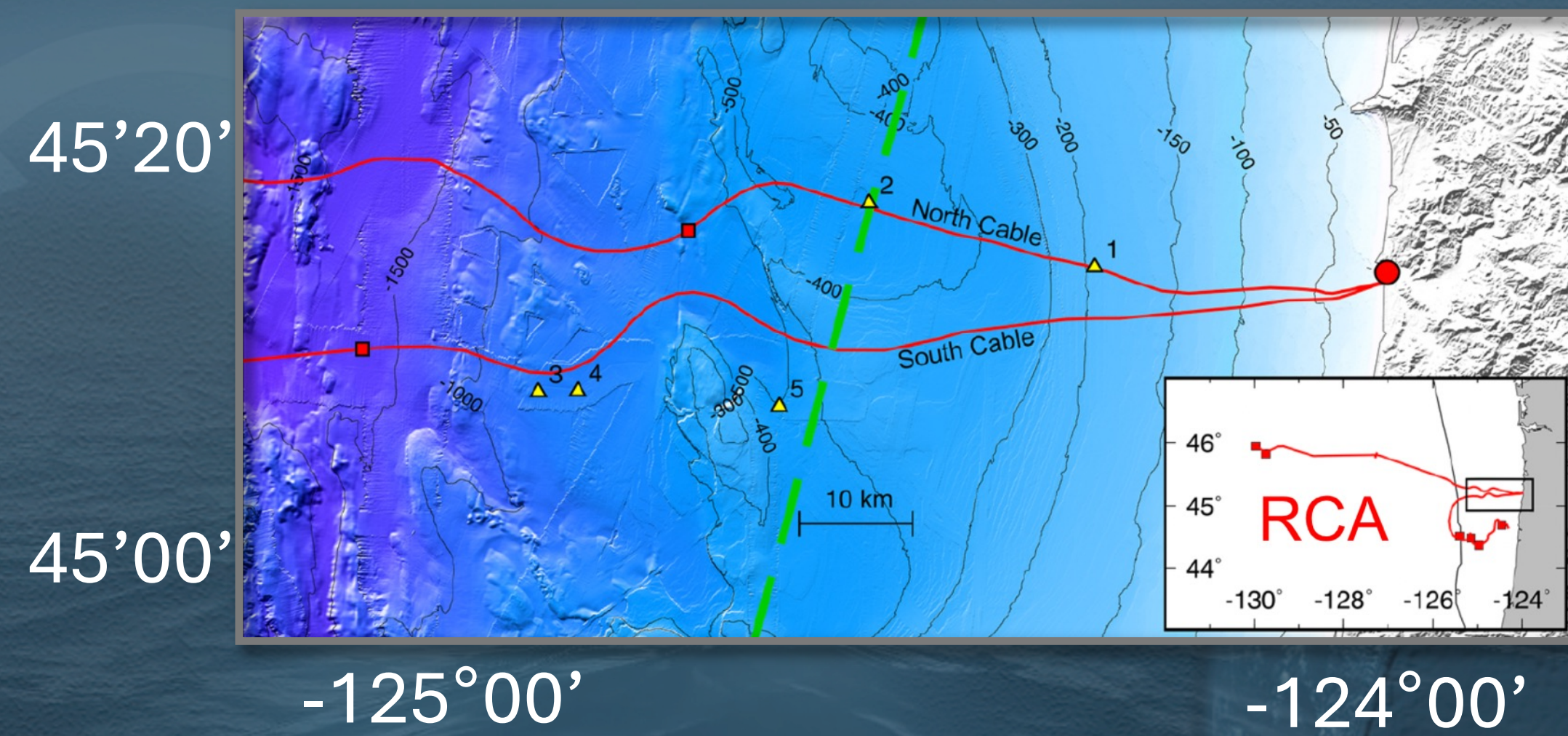
One of few places where seismometers span both down-going plate and margin

OOI RCA Real-Time Seismic Data Display: Axial Seamount, Juan de Fuca Ridge



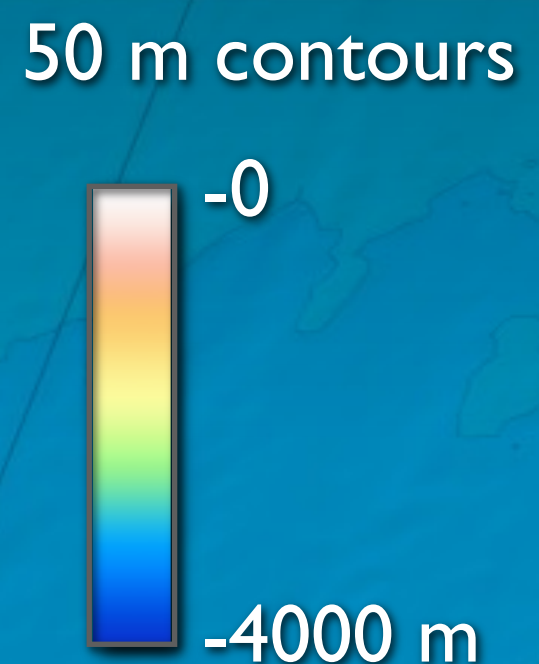
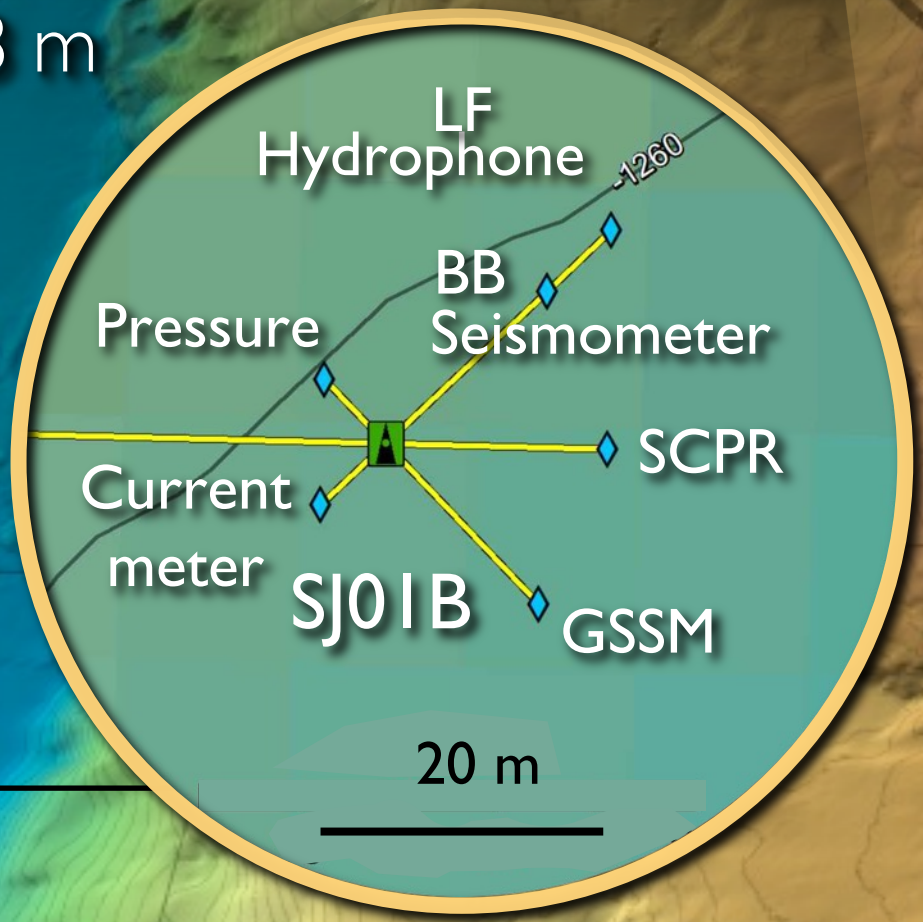
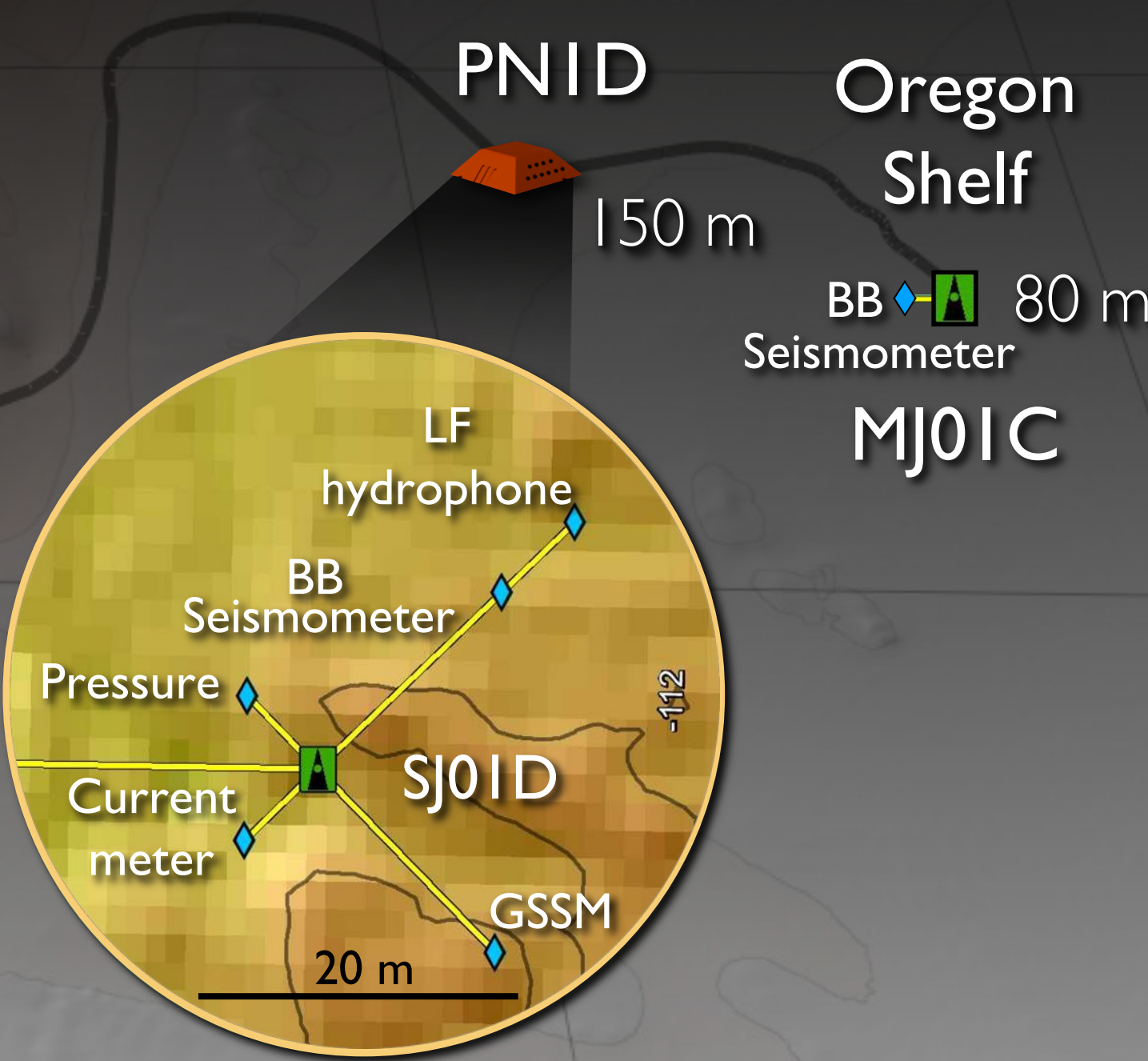
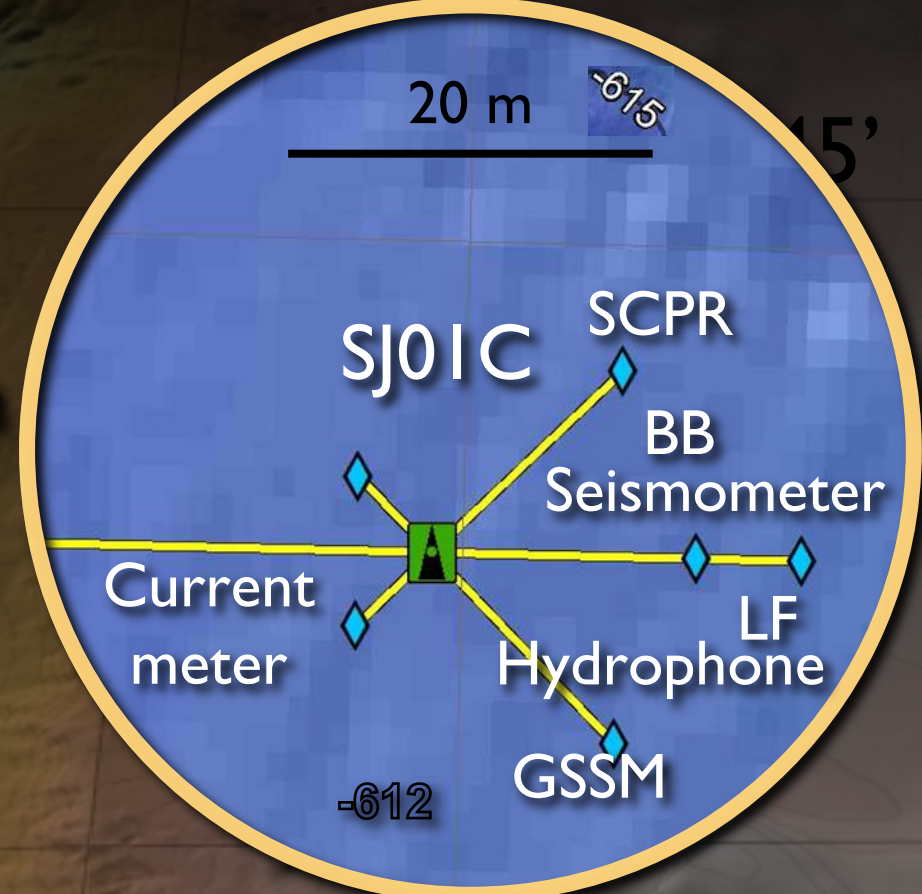
- ▶ Blanco Transform Fault seismic swarm Dec. 2021 produced nearly 100 earthquakes in 48 hrs
- ▶ Discussions underway to get RCA seismic data into ShakeAlert®

Distributed Acoustic Sensing (DAS) : A New Community “Telescope” to View the Oceans



- ▶ A new observational technique revolutionizing how we view the oceans. Interrogates fiber optic cables with repeated laser pulses, allowing measurements at a resolution of a few-10's of meters to 100 km offshore.
- ▶ Allows investigation of earthquakes, volcanic activity, internal-infragravity waves, mammal vocalizations etc...
- ▶ The first community ocean DAS experiment (2021) utilized the two RCA primary cables. 30 Tbytes of data collected in 4 days.
- ▶ During the 4 days, DAS recorded *10's of thousands* of whale calls (Wilcock et al., *J. Acoustic Soc. Amer.*, 2023)
- ▶ All data are available through the OOI website; 12 groups of >20 researchers are working on these data.

Cascadia Offshore Subduction Zone Observatory (COSZO)

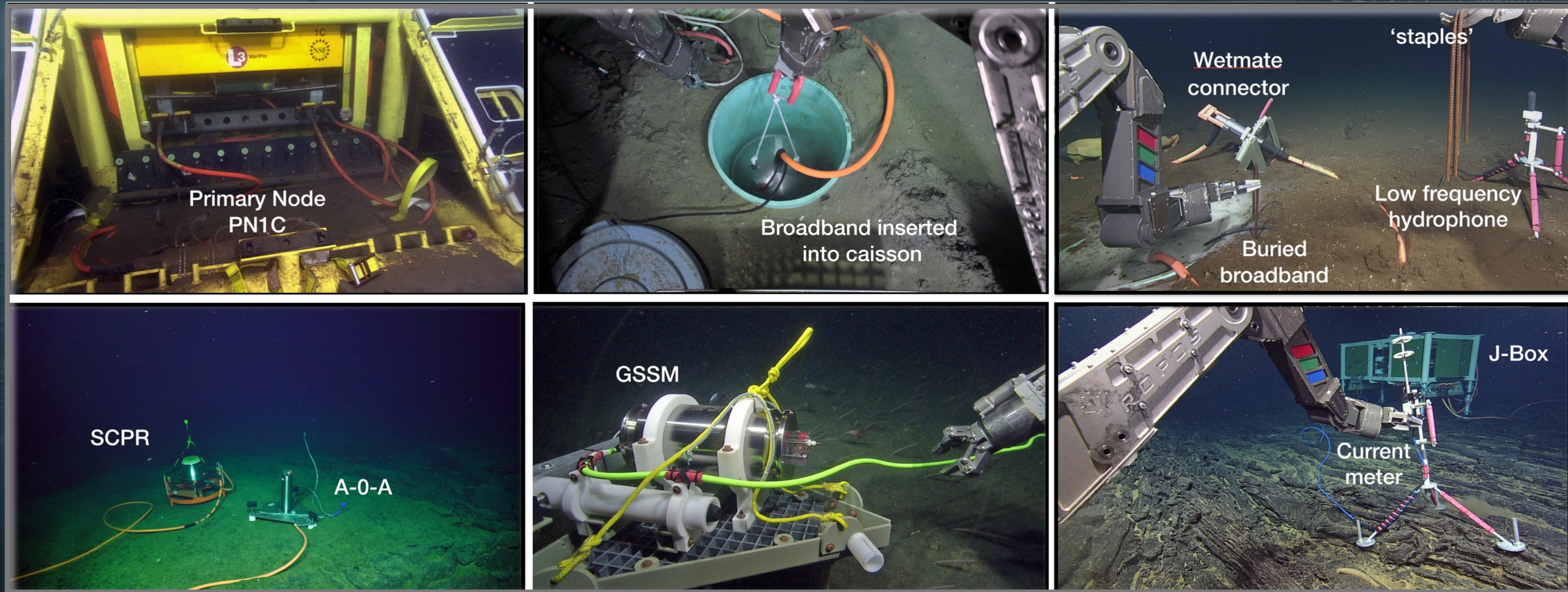


Area coincident with the RCA cable is thought to be the only unlocked portion of the subduction zone

Installation 2026 13 add-on days to the annual RCA cruise

SCPR: Self calibrating pressure sensor (Sasagawa UCSD)

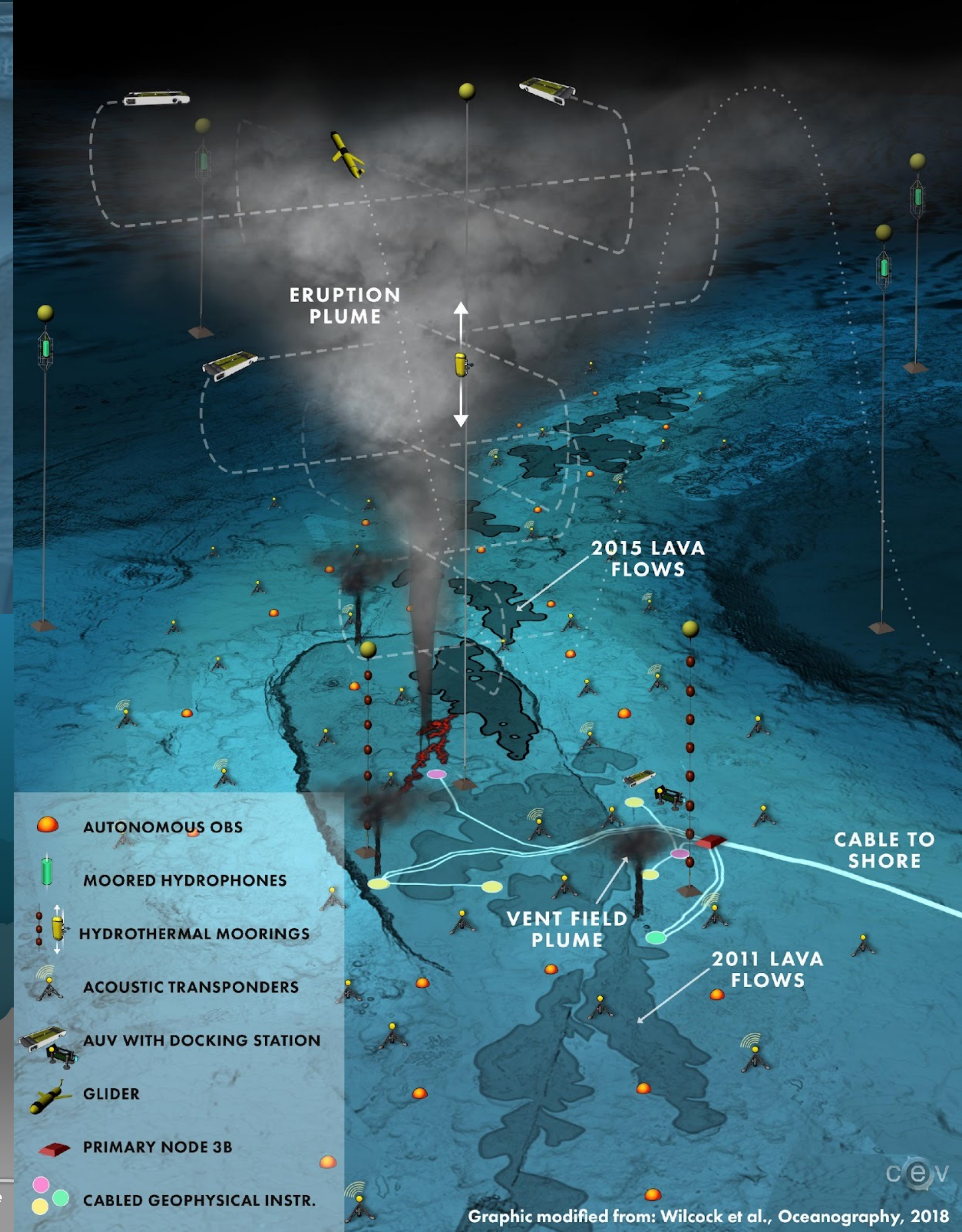
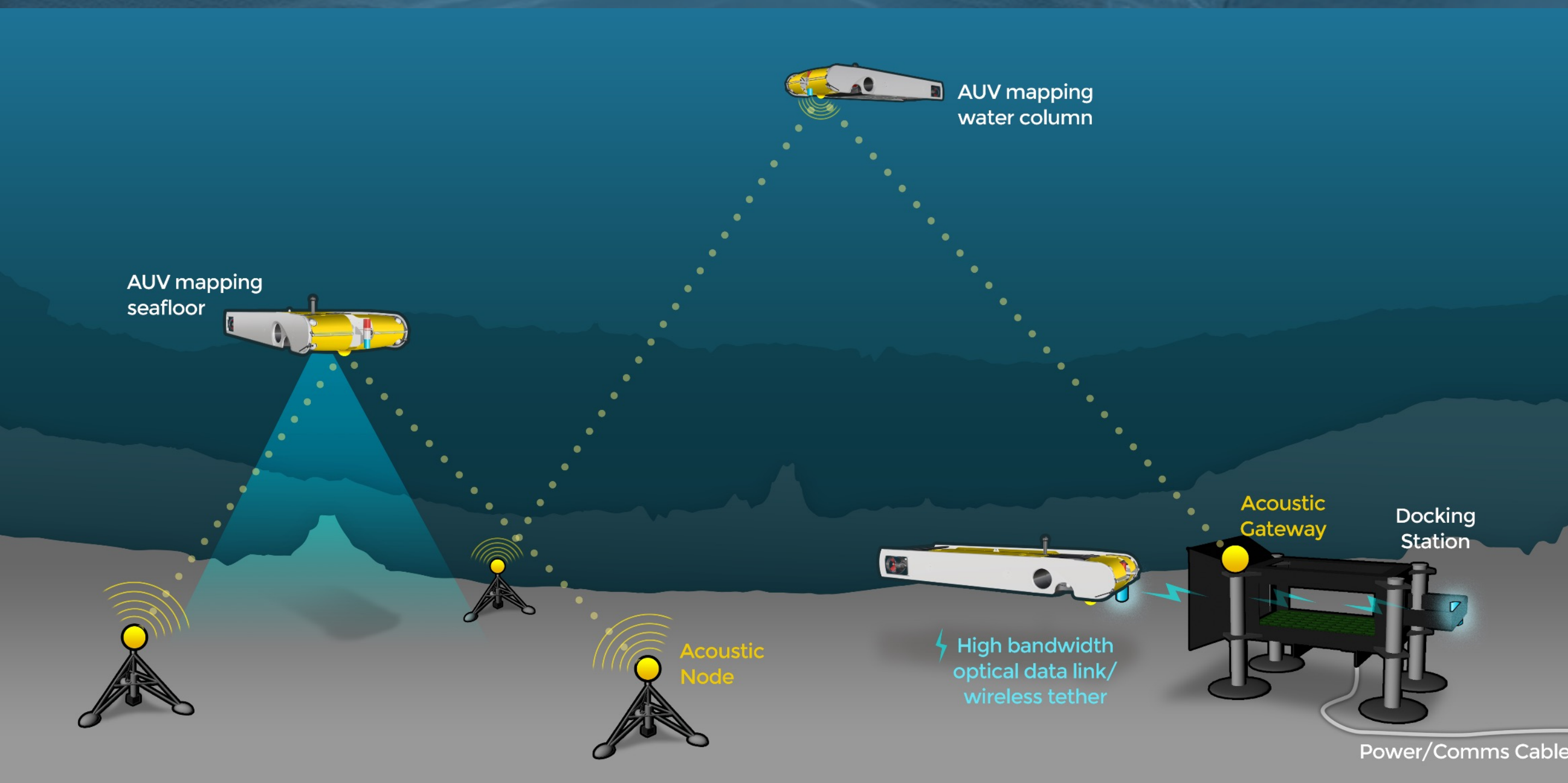
COSZO Instrumentation: Low Risk and success for prior NSF-funded technology awards



- ▶ Broadband seismometer, Low frequency hydrophone and Current meter, RCA core instrumentation
- ▶ Self calibrating pressure sensor (SCPR) and Geodetic and Seismic Sensor Module (GSSM) employs A-0-A and includes a low-noise three-component quartz crystal accelerometer: All already installed on Axial Seamount

Looking to the Future: Resident AUVs

- Routine surveys of seafloor-water column interactions
- Adaptable missions responsive to transient events



The background image is a composite of three scientific illustrations. The top illustration shows a cross-section of the oceanic crust and lithosphere, with labels for 'Ocean Crust', 'Lithosphere', 'Subduction Zone', and 'Continental Crust'. The middle illustration shows a cross-section of the mantle and core, with labels for 'Crust', 'Mantle', 'Liquid Outer Core', 'Solid Inner Core', and 'Mantle Convection Processes'. The bottom illustration shows a cross-section of the mantle and core, with labels for 'Crust', 'Mantle', 'Liquid Outer Core', 'Solid Inner Core', and 'Mantle Convection Processes'.

Thank You!

OOI Website:
<https://oceanobservatories.org/>

OOI Data Explorer:
<https://dataexplorer.oceanobservatories.org/>

UW Interactive Oceans:
<https://interactiveoceans.washington.edu/>

IRIS (OOI-RCA Seismic Data):
<https://www.iris.edu/hq/>