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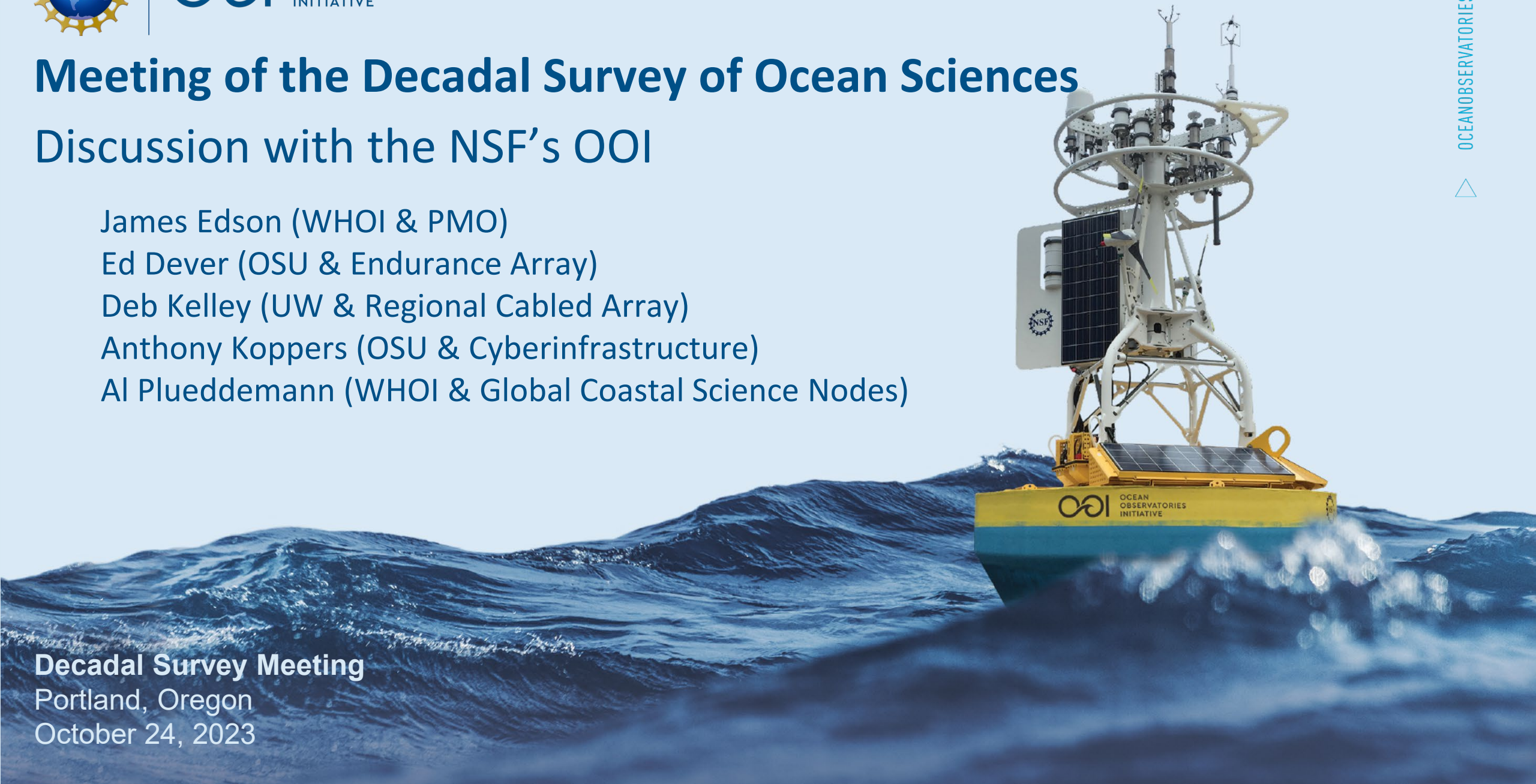
Meeting of the Decadal Survey of Ocean Sciences

Discussion with the NSF's OOI

James Edson (WHOI & PMO)
Ed Dever (OSU & Endurance Array)
Deb Kelley (UW & Regional Cabled Array)
Anthony Koppers (OSU & Cyberinfrastructure)
Al Plueddemann (WHOI & Global Coastal Science Nodes)



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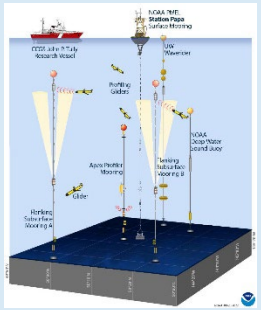
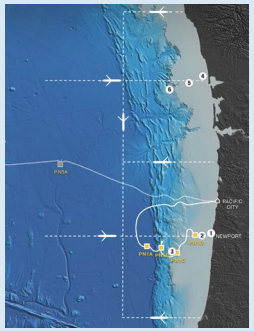
Decadal Survey Meeting
Portland, Oregon
October 24, 2023

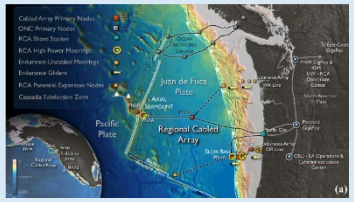
Questions for OOI

- Most significant scientific findings from researchers using OOI infrastructure.
- Most significant broader impacts (e.g. use of the research by fishers).
- Which subfields of ocean science (biology, chemistry, physics, geology, multidisciplinary)) have benefitted the most from research using OOI infrastructure?
- What ocean life observations are included in the OOI framework?
- How many researchers and others are using data from the OOI data system? What other metrics are you tracking to demonstrate OOI use?
- Does OOI have sufficient resources to support the current infrastructure assets or are cuts to infrastructure deployments anticipated if budgets do not increase?
- If additional resources were provided, which OOI components would be enhanced and what additional research would be possible?
- Are there discussions between those involved with the seafloor observatory on the Juan de Fuca plate with those planning the SZ4D research program and with IODP researchers?

The OOI: A System of Observatories







Global Station Papa Array

Regional Cabled Array

Coastal Endurance Array

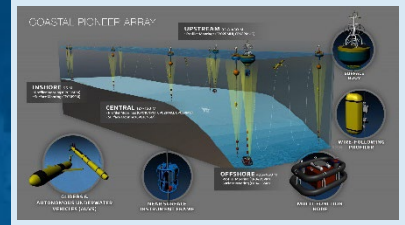
Global Irminger Sea Array

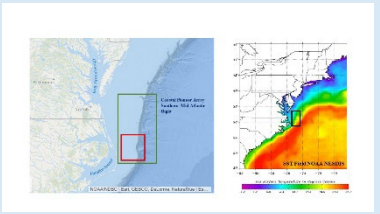
Coastal Pioneer Array

5 active arrays supporting
900 sensors on
80 platforms for
30 years starting in 2016

Global Argentine Basin Array
(Discontinued in 2018)

Global Southern Ocean Array
(Discontinued in 2020)





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WOODS HOLE OCEANOGRAPHIC INSTITUTION

UNIVERSITY of WASHINGTON

Oregon State University

OOI operates & maintains sophisticated instrumentation in demanding locations

Hydrothermal Vents

Atmosphere-Ocean Exchange

From Seafloor to Lower Atmosphere

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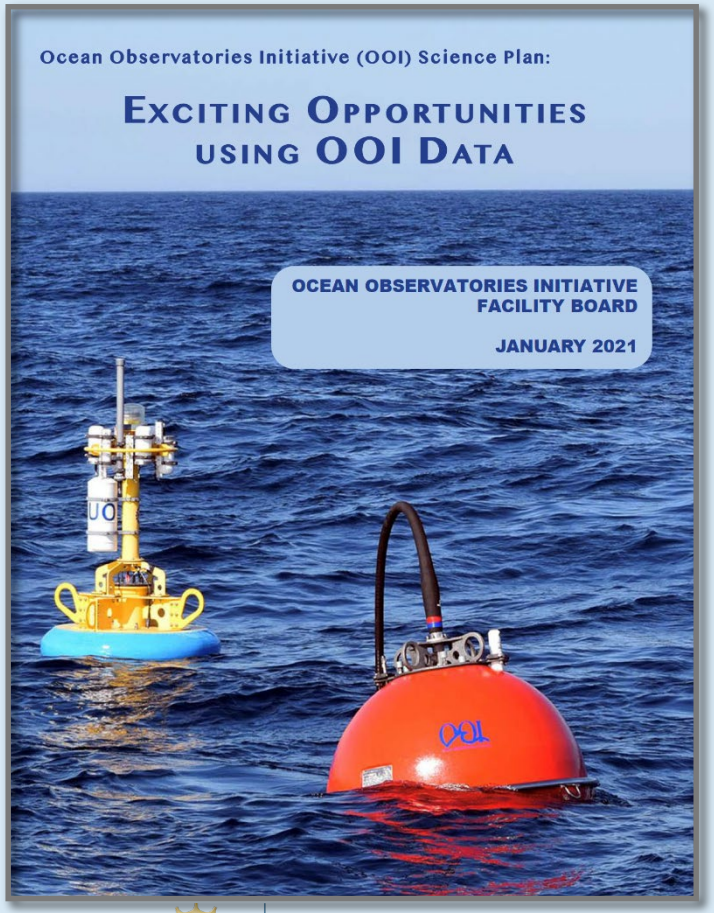
The Ocean Observatories Initiative

A science-driven ocean observing network delivering real-time data from >900 instruments to address critical science questions regarding the world's ocean.



Science Themes

- Climate variability, ocean food webs, and biogeochemical cycles
- Ocean-atmosphere exchange
- Coastal ocean dynamics and ecosystems
  Turbulent mixing and biophysical interactions
- Global and plate-scale geodynamics
- Fluid-rock interactions and the sub-seafloor biosphere

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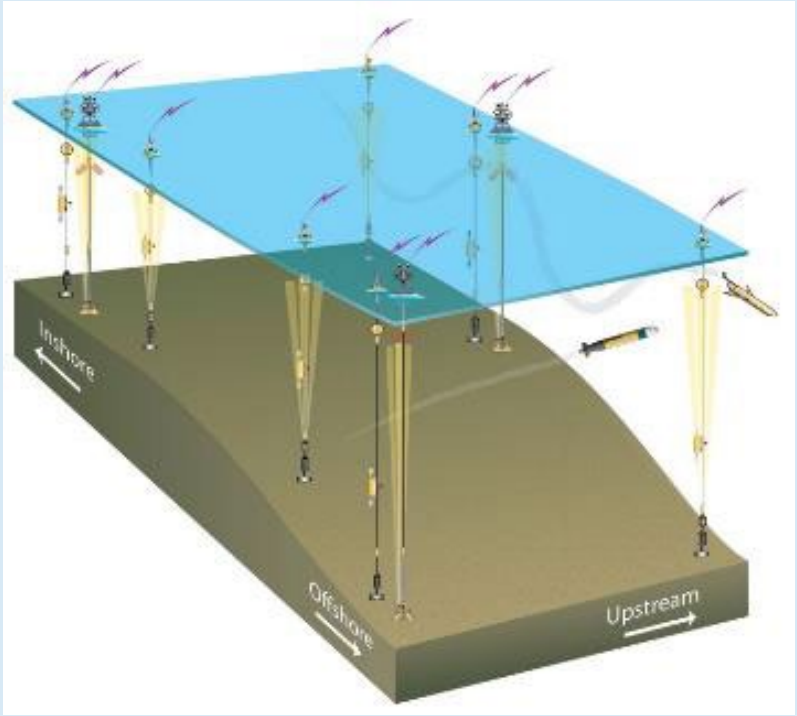
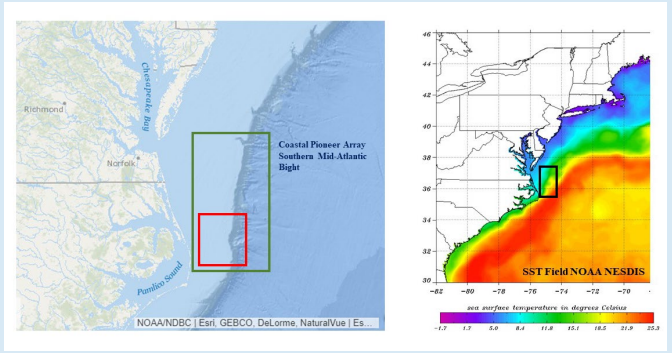
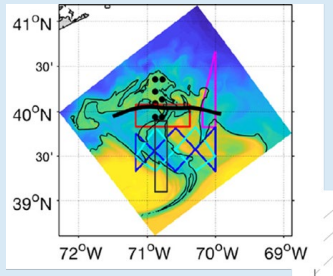
Pioneer NES Science Highlights

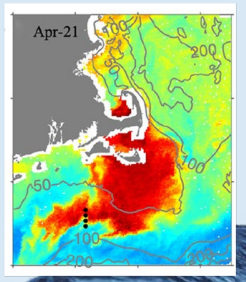
- First sustained, interdisciplinary shelfbreak observatory
- Over 20 publications showing:
  - New frontal dynamics and exchange mechanisms
  - Intrusions, subduction, warm core rings
  - Changing shelf water properties
  - Primary production on shelf and at shelfbreak
- First glimpse of a changing coastal regime
- More to come
  - BGC processes
  - Carbon cycling
  - Relocation
  - …

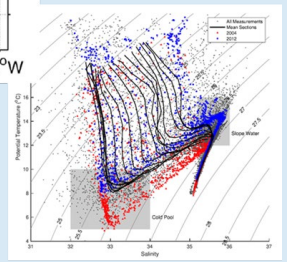




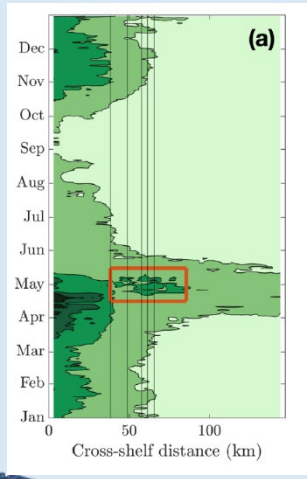


Levin et al., 2020a; 2020b





Harden et al., 2020



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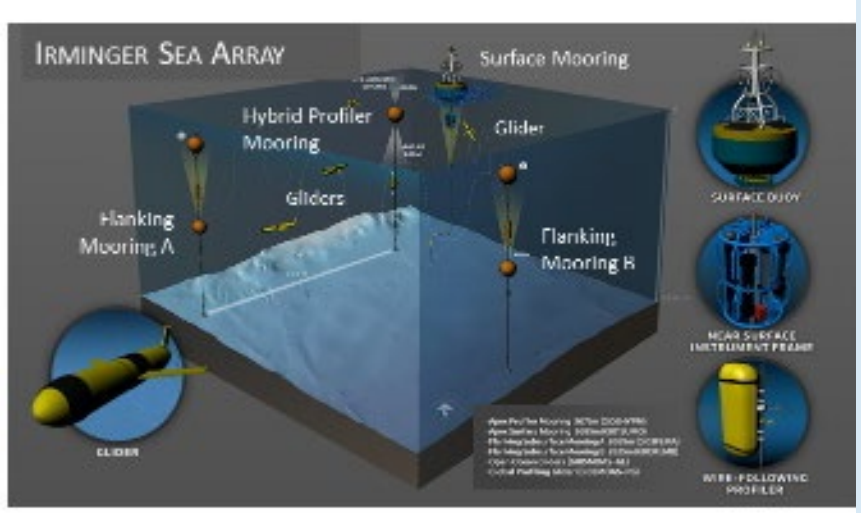
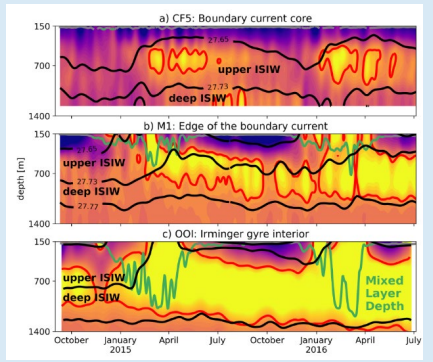
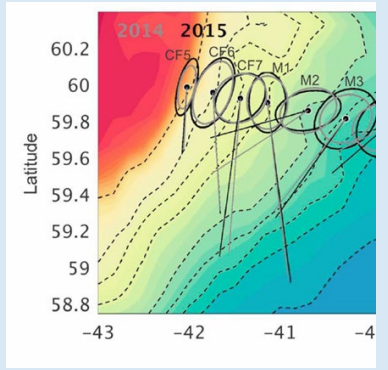
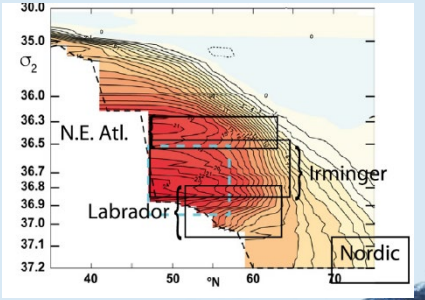
Irminger Science Highlights

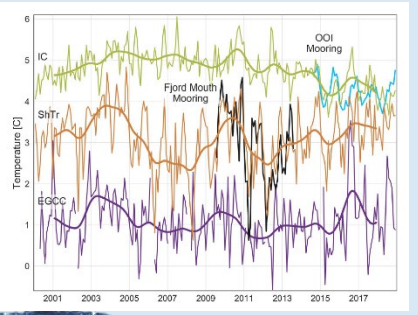
- Sustained surface/subsurface array in a challenging environment
- Over 20 publications showing:
  - First evidence of Irminger deep water formation
  - First direct observations of winter heat loss
  - First long-term estimate of DWBC transport
  - First estimate of seasonal carbon cycle
- Controversial in 2003, now unequivocal that Irminger plays key role in AMOC
- Collaborative science
  - OSNAP instruments, moorings, drifters
  - OSNAP Post-processed CTD data with DOIs











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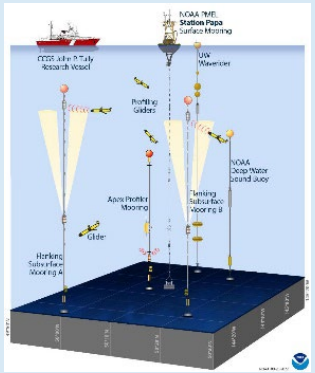
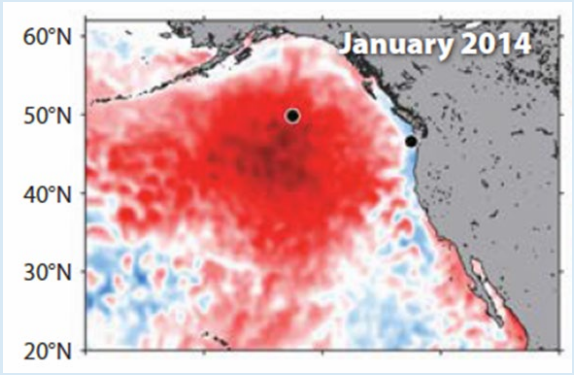
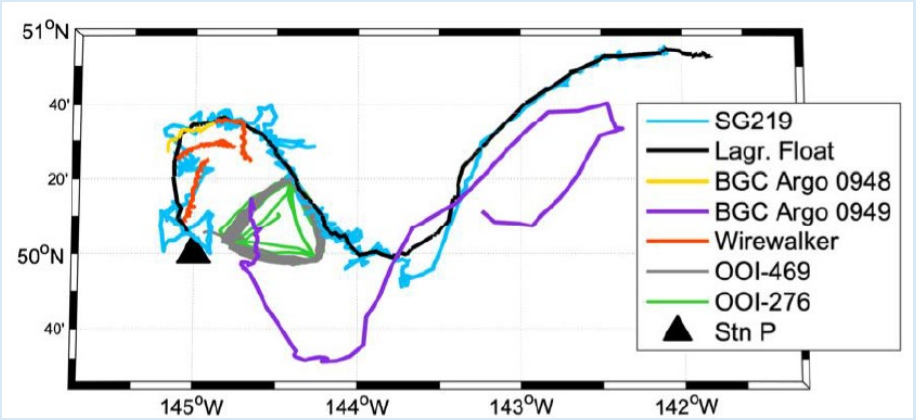
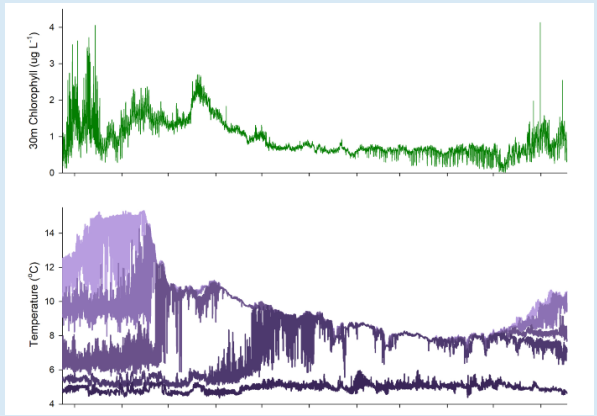
Papa Science Highlights

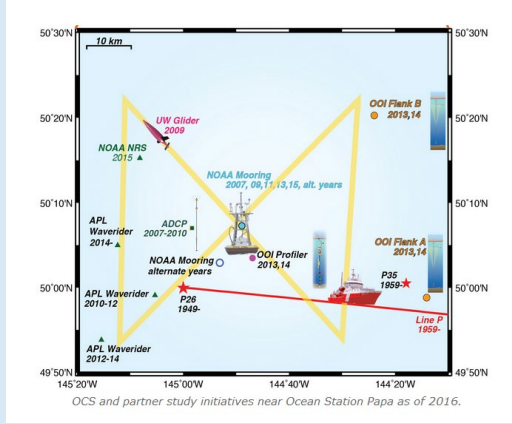
- **Collaborative site with historical continuity**
- **Multiple studies exploring:**
  - NE Pacific heat waves and ecosystem impacts
  - Fate of primary production (EXPORTS)
- **Seasonal cycle of primary production**
- **Internal wave propagation**
- **Regional connectivity (EA, RCA, IOOS)**
- **Collaborative science**
  - NOAA, PMEL, UW, DFO field operations
  - NE Pacific Workshop – modeling interest











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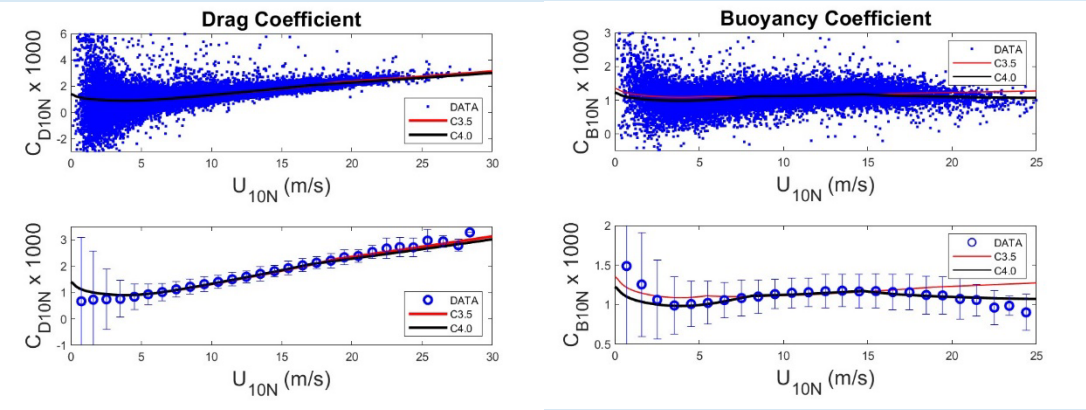
Marine Meteorology: Improved Weather & Climate Forecasts

- Only continuous network of directly measured momentum and heat fluxes.
- Used to improve flux parameterization for numerical models and bulk formula.
- The OOI is actively engaged with external PIs to develop a system that directly measures CO_2 fluxes from surface moorings.



Atmosphere-Ocean Exchange

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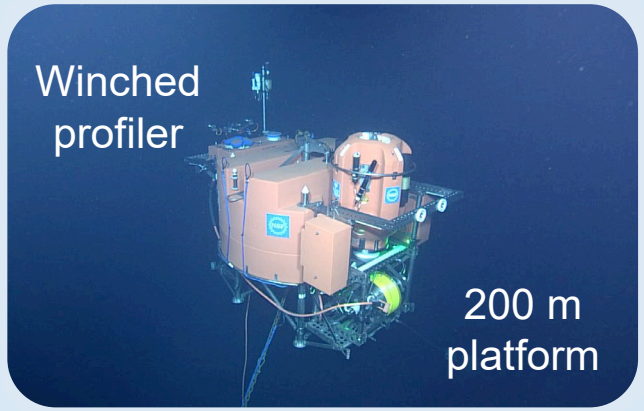
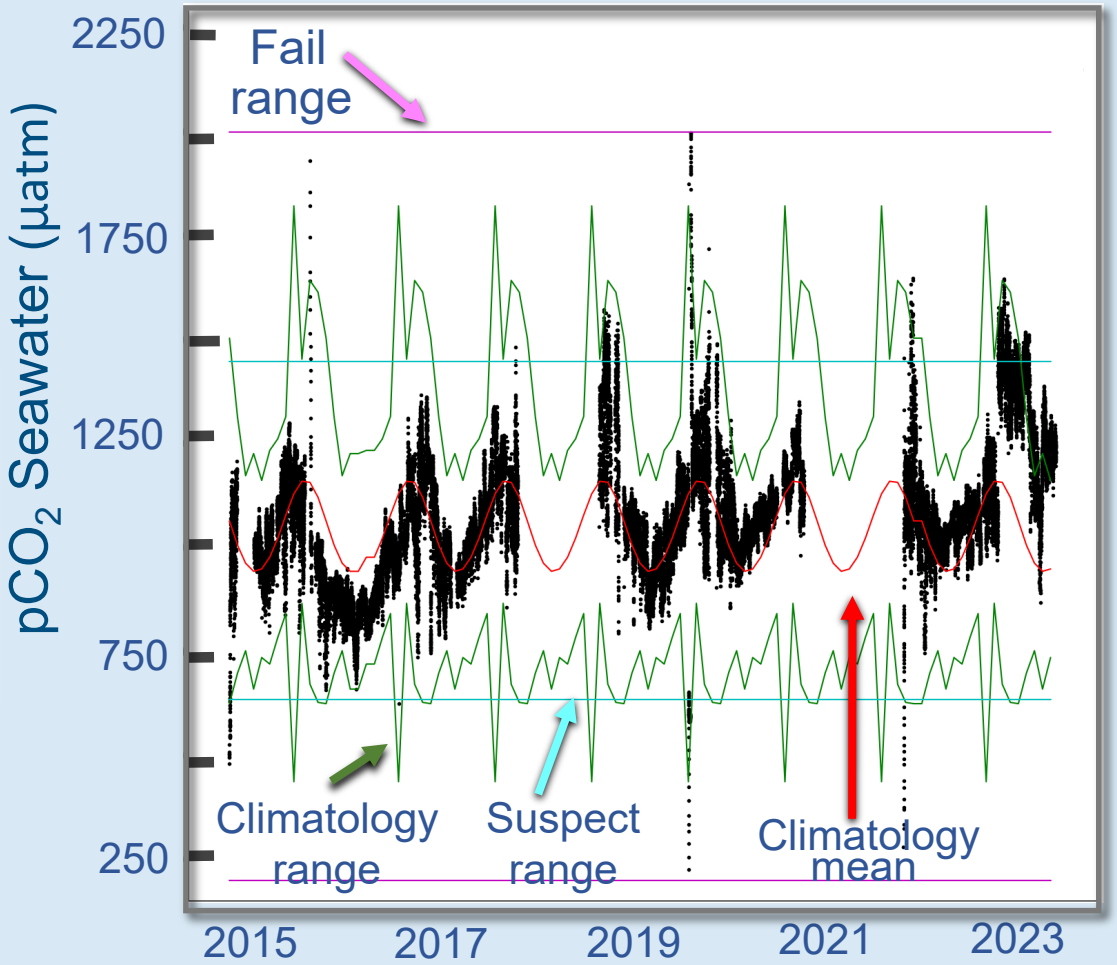
Unprecedented Full Ocean Depth, High Resolution Measurements of Ocean Acidification



One-of-a-kind RCA Cabled Shallow Profiler Moorings

Two legs, 12 ft across, 7,000 lb platform at 200 m water depth



Profiler on Oregon Offshore 200 m platform

- Three cabled shallow profilers span coastal to blue water environments have provided >45,000 profiles with real-time data flow
- High-resolution multi-parameter datasets allow study of key climate variables on timescales of hours-days-weeks-years
- **Highest resolution and nearly continuous record of CO_2 to full ocean depth in the oceans**
- Coupled pCO_2 and pH measurements co-registered in space and time with 16 biological, chemical, and physical environmental measurements

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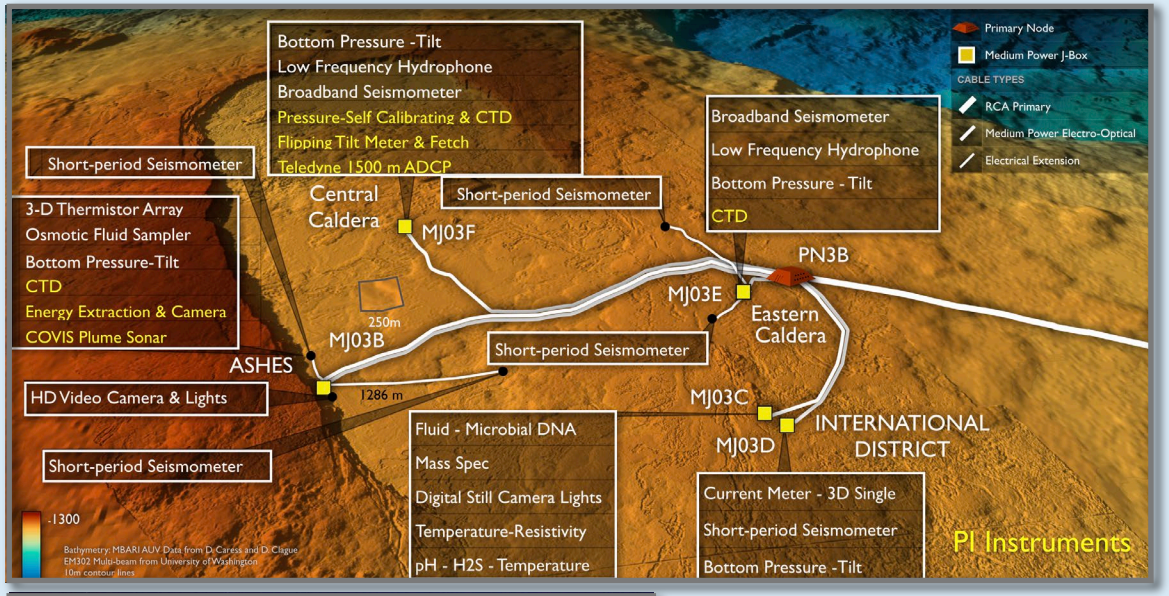
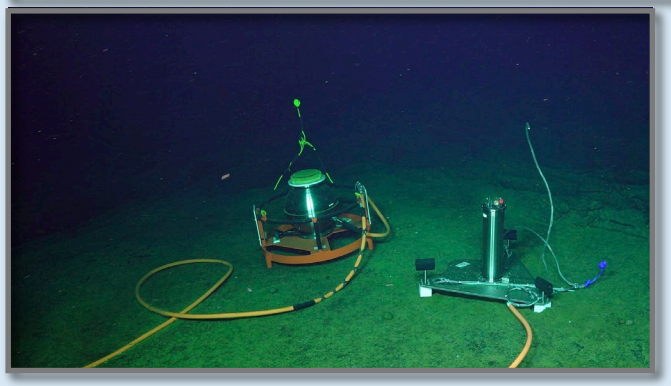
Axial Seamount: The First Real-Time Capture of Evolving Events During an Underwater Eruption & Forecasting of Next Eruption





NSF-OTIC PI-funded instruments on Axial(self-calibrating pressure sensor and A-0-A) have allowed technology transfer to the Cascadia Subduction Zone

- >70% of the volcanism on Earth occurs along mid-ocean ridge spreading centers - the longest mountain chain. Eruptions form the face of our planet
- This is the most advanced volcanic observatory in both terrestrial and oceanic environments.
- Repeat subsurface imaging showing stacked magma chambers has changed how we view submarine volcanoes. Thought to occur in terrestrial environments but not imaged.
- Since the RCA was installed in 2014, nearly a decade of multidisciplinary studies have been funded with over 30 awards to 43 investigators from 23 institutions and 2 from industry. Diverse funding sources include NSF, ONR, NASA, and BOEM totaling >$21M (excluding ship-ROV costs)
- Approved for IODP 955 Full: Integrating subseafloor microbial, hydrological, geochemical, and geophysical processes in hydrothermal active oceanic crust at Axial Seamount, Juan de Fuca Ridge; Huber et al.,

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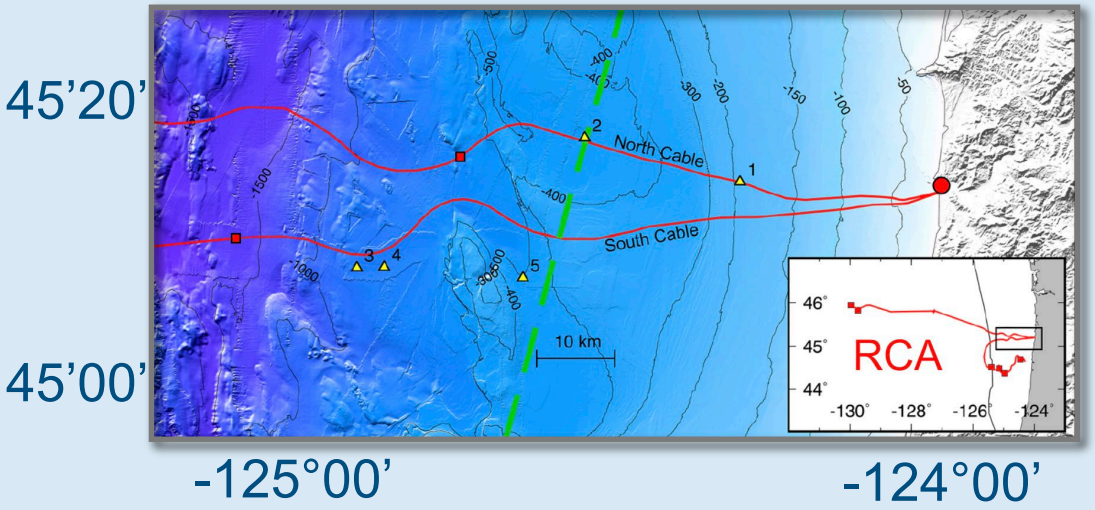
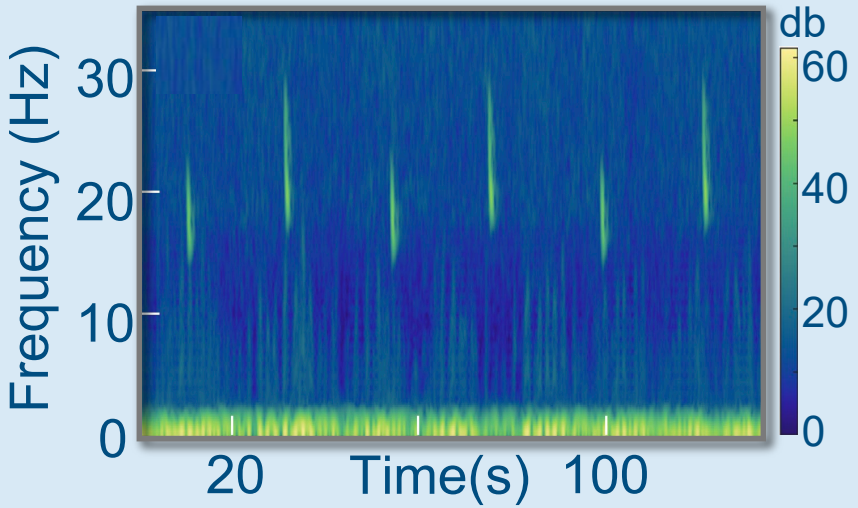
The Future - A New Community "Telescope" to Revolutionizing How We View the Oceans; Distributed Acoustic Sensing (DAS)





- Interrogates fiber optic cables with repeated laser pulses – every few meters to 10's of meters is an "instrument" reaching 100 km offshore
- Real-time monitoring of earthquakes, volcanoes, internal waves, mammal vocalizations etc..
- 1st community ocean DAS experiment 2021 utilized 2 RCA primary cables. 30 TB data in 4 days (Wilcock et al., OCE2141047)
- In 4 days, DAS recorded 10's of thousands of whale calls (*Wilcock et al., J. Acoustic Soc. Amer., 2023*)
- All data available through OOI; 12 groups of>20 researchers are working on these data.

DAS can now be used on 'live' cables - 24/7 presence in the oceans

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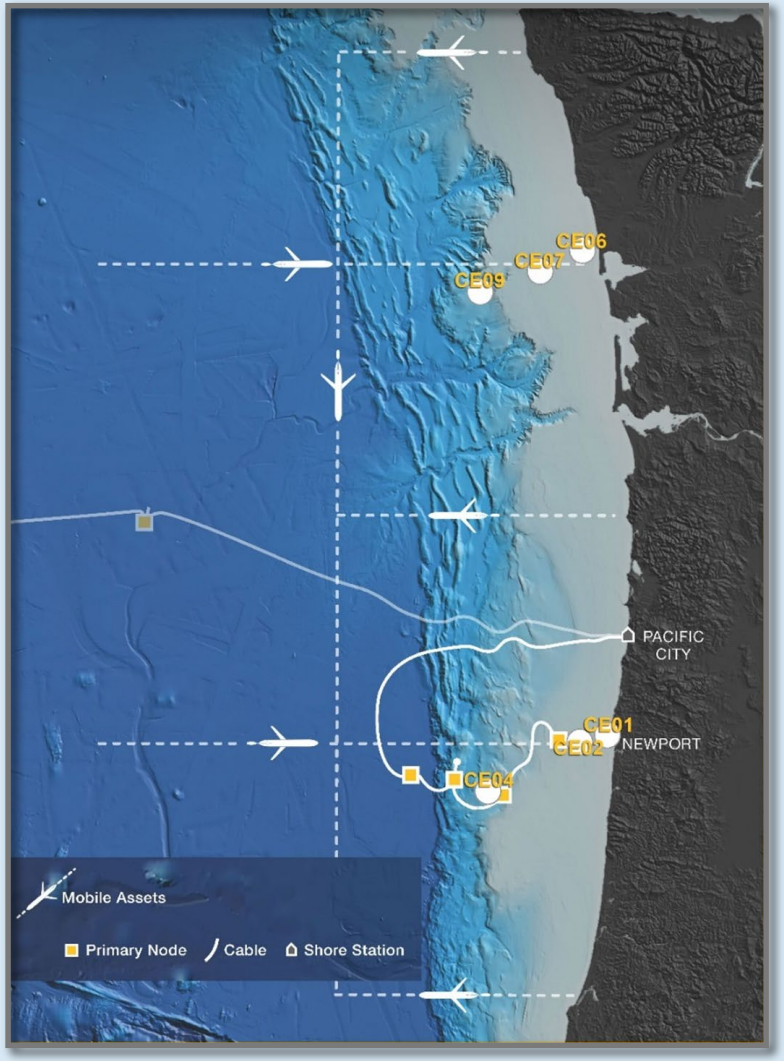
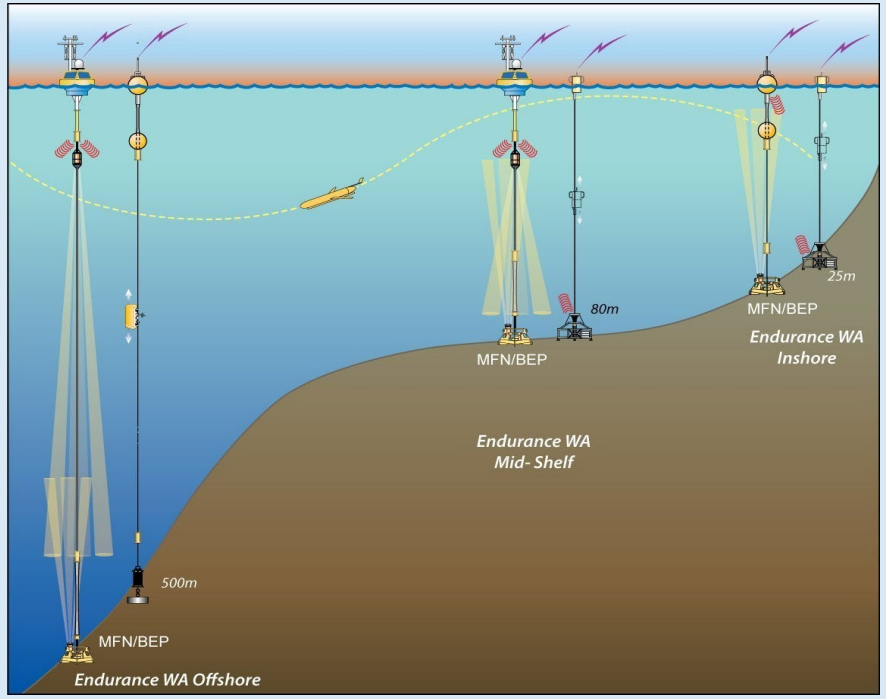
OOI Coastal Endurance Array



Operated by OSU (uncabled, PI Ed Dever) and UW (cabled, PI Deb Kelley)

- Consists of surface and profiling moorings, gliders, and seafloor instrumentation. Platforms, instrumentation, data formats and quality control is consistent and documented across OOI.
- Long-term observations of fundamental scientific and societally relevant processes including ocean heat waves, hypoxia and ocean acidification
- Background environmental information potential insights into marine carbon dioxide removal, wave energy and offshore wind energy



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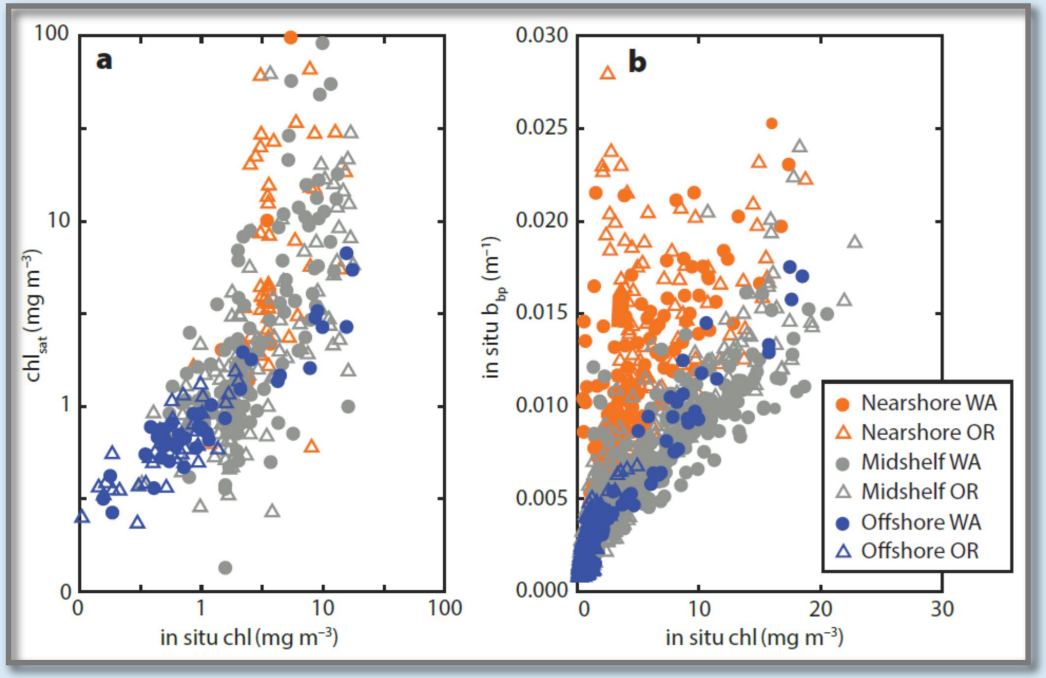
Validation and Extrapolation of In-situ Measurements

- Satellite chl estimates can differ from glider and mooring chl. In contrast to satellite estimates, in situ fluorescence-based chl is similar across the Oregon and Washington shelves.
- Indicates potential contamination of satellite chlorophyll due to CDOM and suspended materials.
- OOI letters of collaboration for several NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) validation proposals submitted in 2023.
- *In-situ* measurements can also distinguish between surface and subsurface anomalies (e.g., the 2014-2016 marine heat wave or MHW) and the shallower more ephemeral 2019 MHW (Scannell et al. (2020), https://doi.org/10.1029/2020GL090548)



Mooring in-situ chl vs satellite chl

Mooring in-situ chl vs satellite particulate backscattering (b_{bp})

Hendrikx-Freitas et al. (2018) https://doi.org/10.5670/oceanog.2018.113

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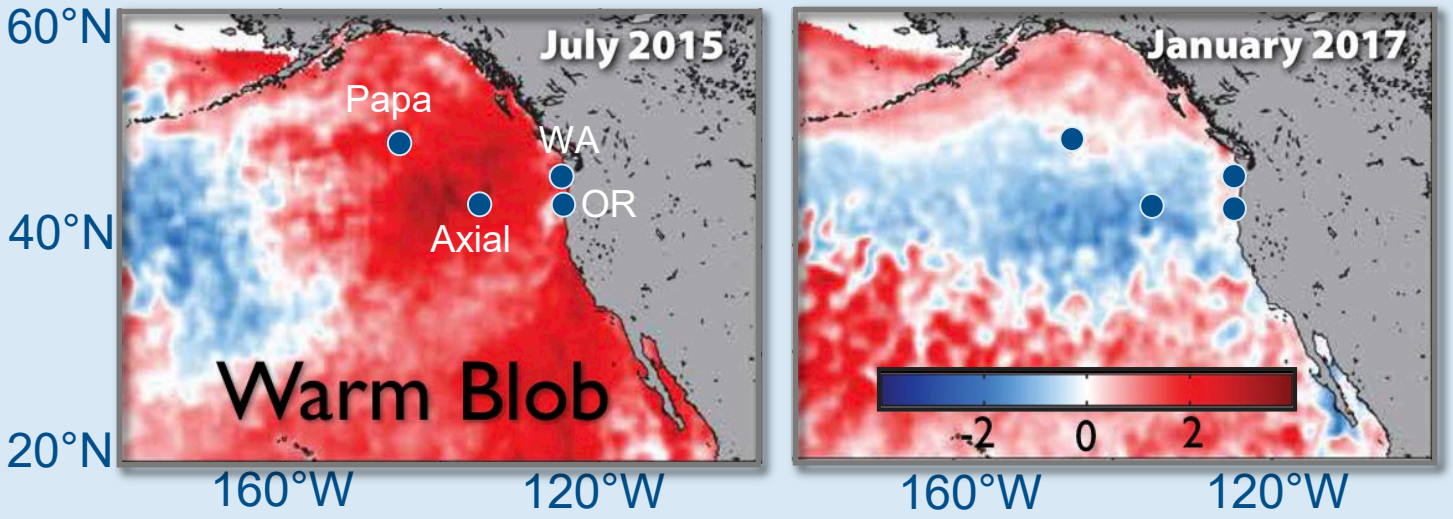
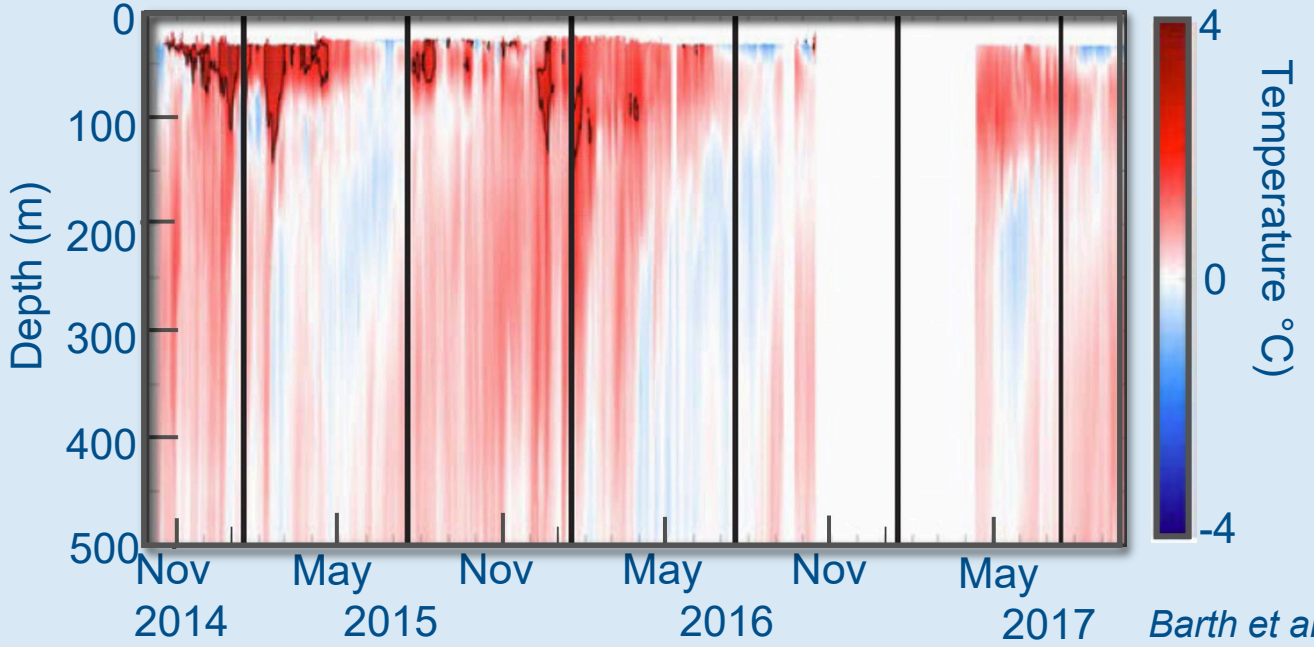
NE Pacific Science

Heat Waves: Identification Requires Depth Measurements, Satellites are not enough

- NE Pacific “Warm Blob” 2014
  - SST change observed at Papa
  - Anomaly tracked by satellite
  - Vertical extent (150 m) seen by RCA and Endurance Arrays Offshore profilers
- NE Pacific “Warm Blob” 2019
  - Surface and subsurface signal
- Ecosystem impacts
  - Low chlorophyll
  - Zooplankton changes
  - Enhanced algal blooms
  - Fisheries and marine mammals



Washington Offshore Profiler Mooring Daily Temperature Anomalies



Barth et al., 2016

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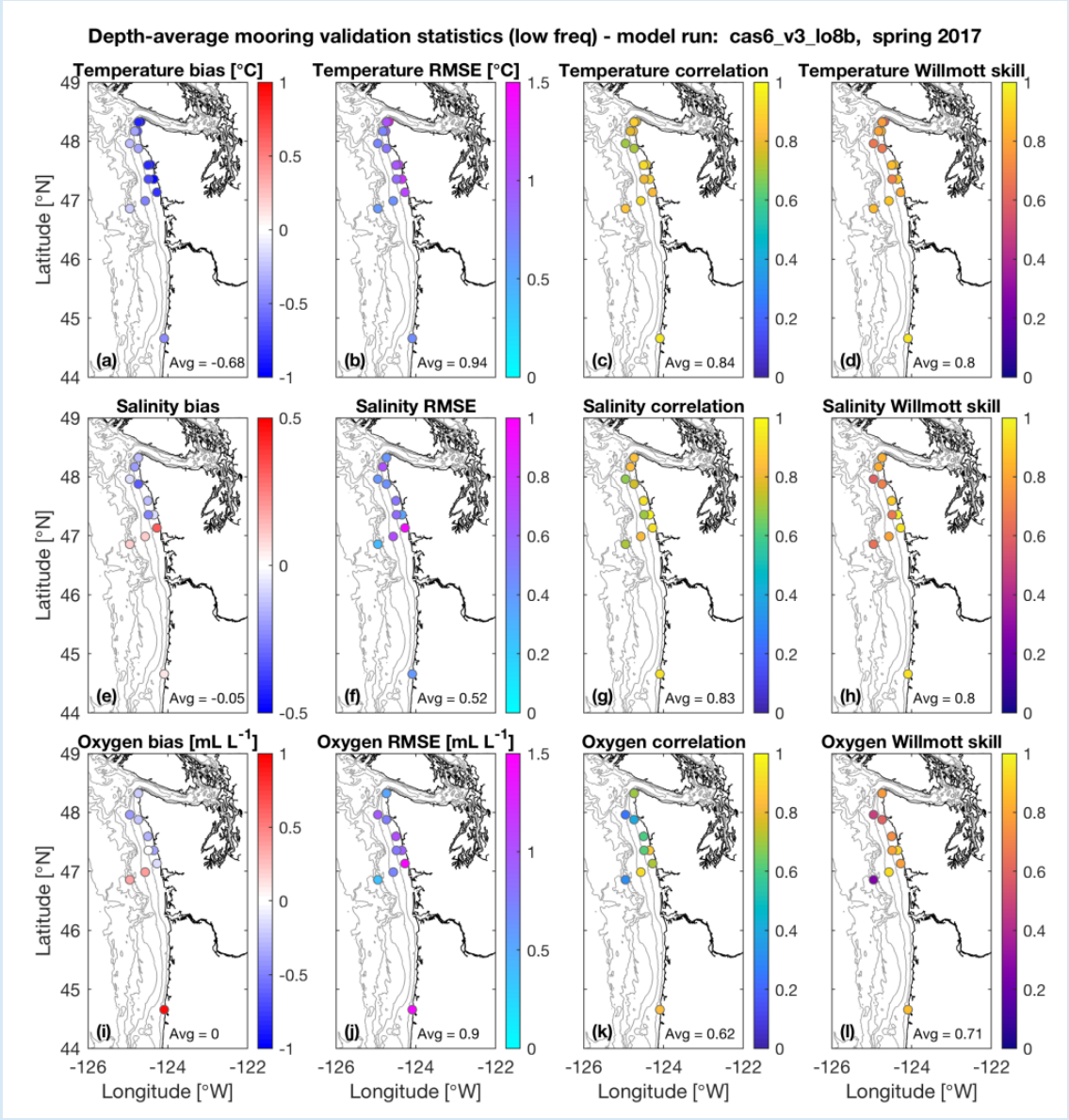
Ongoing Innovations in Ocean Observing

- Cross networking of ocean observations across national and indigenous boundaries (regional OOS'es, Data Assembly Centers, IRIS), *e.g.*, Barth *et al.* (2019)
- Lower cost, more reliable solid-state sensors for chemical and biological oceanographic measurements (e.g., pH, pCO2)
- Better profiling technologies (higher reliability, increasing profile numbers, sensor payload, surface interface data)
- *In situ* detection and identification of changes in ocean ecosystems (community composition, productivity, HAB's etc.)

Left: The Northeast Pacific contains ocean observing assets funded by the Canadian and United States governments, the private Hakai Institute, and two major ocean observing programs: Ocean Networks Canada and the Ocean Observatories Initiative.

Model Use of Observatory Data

- Physical models (e.g., Kurapov *et al.*, Amos et al.)
- Biogeochemical models (e.g., MacCready *et al.*)
- Larval transport models (e.g., Wong-Ala *et al.*)
- Many modelers prefer curated data sets with:
  - Quality controlled data
  - Regular time and space interpolation
  - Embedded metadata including error bounds



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Long-term Working Relationships with Manufacturers Improve Instrument Maintainability and Reliability

- Vendor dissolved oxygen two-point calibration procedure improvement
- Glider firmware updates to lower power consumption and meet specifications
- Ground fault testing on externally powered instruments
- Annual meetings with vendors to coordinate maintenance schedules and discuss product updates and issues

Observatories Foster Student Research and Workforce Development

- Accessibility to observatory data enables student research and use by investigators and educators from outside traditional oceanographic programs.

- Data lend themselves to development of undergraduate labs and online explorations as developed by the Rutgers Ocean Data Lab.

- At right, work by Ocean Data Lab 2020 REU program student Brianna Velasco working with Prof. Rachel Eveleth (Oberlin) used Endurance Washington offshore mooring pCO2 data.

- Observatory data used in numerous other REU projects, other undergraduate research, graduate theses, and post-doctoral work. Undergraduates employed in observatory maintenance have gone on to graduate school, technical careers in ocean sciences, Knauss fellowships etc.

- Observatories also offer opportunities for fieldwork participation through MATE internships, the UNOLS cruise volunteer program etc.

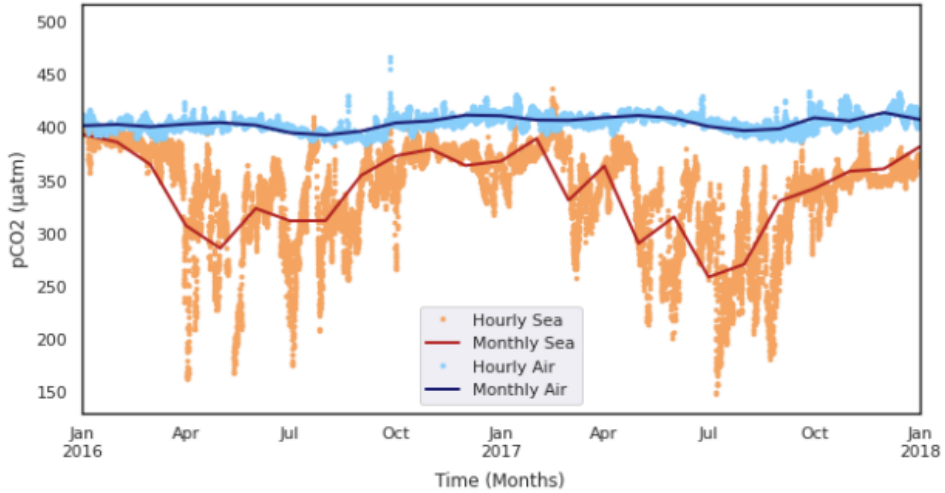


Figure 2. 2016-2017 seasonal cycle and variability of air and seawater pCO_2. Ocean pCO_2 tends to decrease during late spring and summer, then increases for fall and winter, when it approaches equilibrium with the air. There is more variability of values during late spring and summer, with more constant levels during fall and winter. This seasonal cycle is relatively consistent between the two years; however, the lowest pCO_2 levels are found in late spring for 2016 and mid-summer for 2017.

Velasco et al., (2020) Magnitude and Drivers of the Seasonal Cycle and Interannual Variability of pCO2 in the Washington Coast OOI Endurance Array, American Geophysical Union, Fall Meeting 2020, abstract #ED004-0045

VISIONS 23 Students

21 Undergraduate students and 4 graduate students participated on VISION'23 spanning oceanography, engineering, neuroscience, informatics, geology etc.

Nearly a Decade of Taking Students to Sea

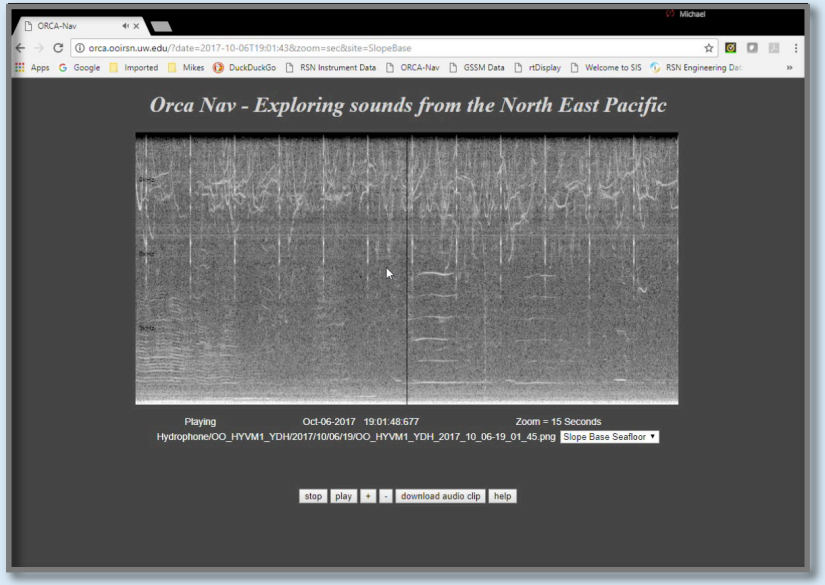
Since 2017, 124 undergraduate students have participated in the UW-RCA VISIONS program spanning oceanography, geology, engineering, neuroscience, informatics, computer sciences, biology, communications etc.

VISIONS Workforce development examples:

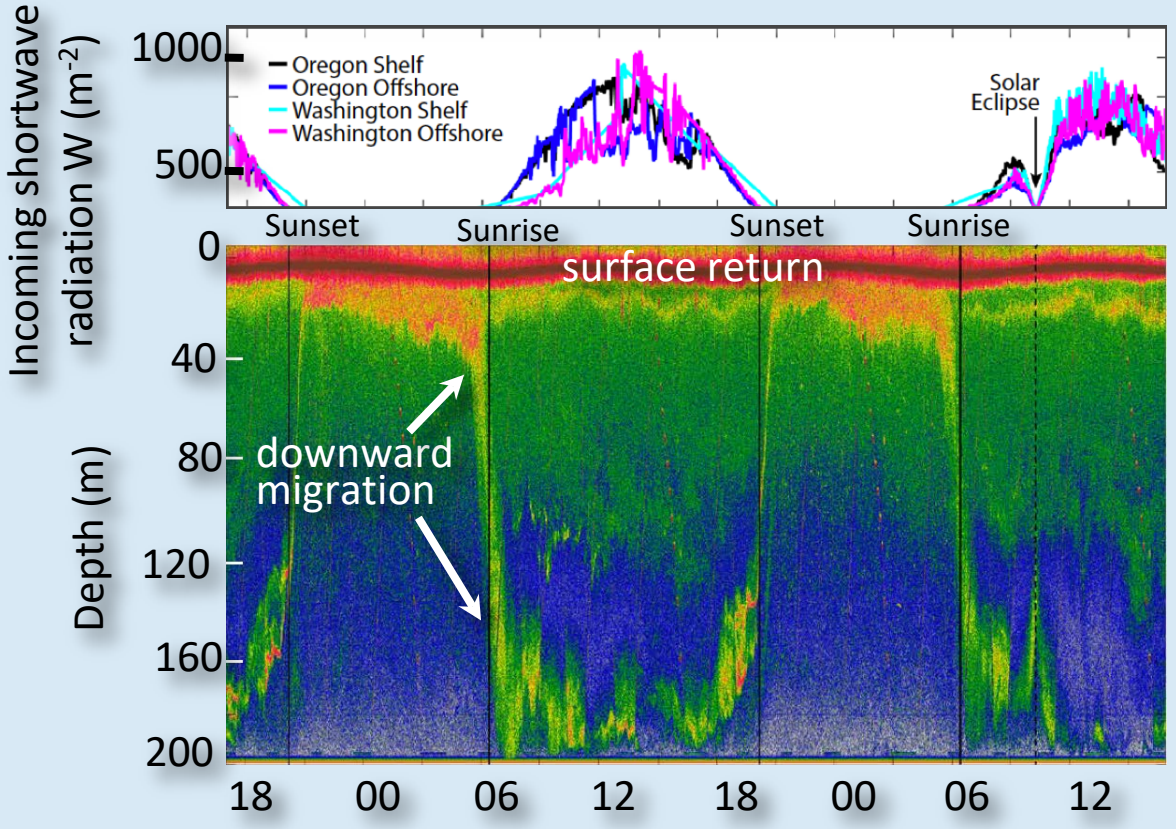
- Director Earth Sciences and Resources: National Academies Board
- Deputy Director for Water Infrastructure – White House
- Young Investigator NSF Postdoctoral Fellowship at UW utilizing RCA data. at Southern Hydrate Ridge developing AI for understanding macrofaunal communities and changing environments
- Three VISIONS students transferred to engineering at the Applied Physics Lab
- VISIONS gone on to work for ocean technology companies, geotechnical firms, academics (faculty and staff), Coast Guard, Data Science companies etc…

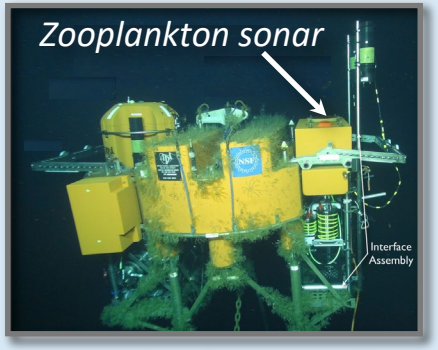
Nearly a Decade of Ocean Life Observations

Listening to the Deep



- RCA hydrophones tracking of mammals offshore
- Finn whales vocalizations have changed over the last decade
- During a 4 day Distributed Acoustic Sensing experiment on the RCA, 10's of thousands of whale calls detected





RCA Shallow Profiler
OR Offshore (200 m)

- EK60 Sonar: First real-time documentation of eclipse impacts on zooplankton migration (*Barth et al., 2016)*
- EK80 Sonar: Technical refresh – new cabled sonars at 80 m and 200 m water depth also allow quantification of fish abundances (NOAA Fisheries application)

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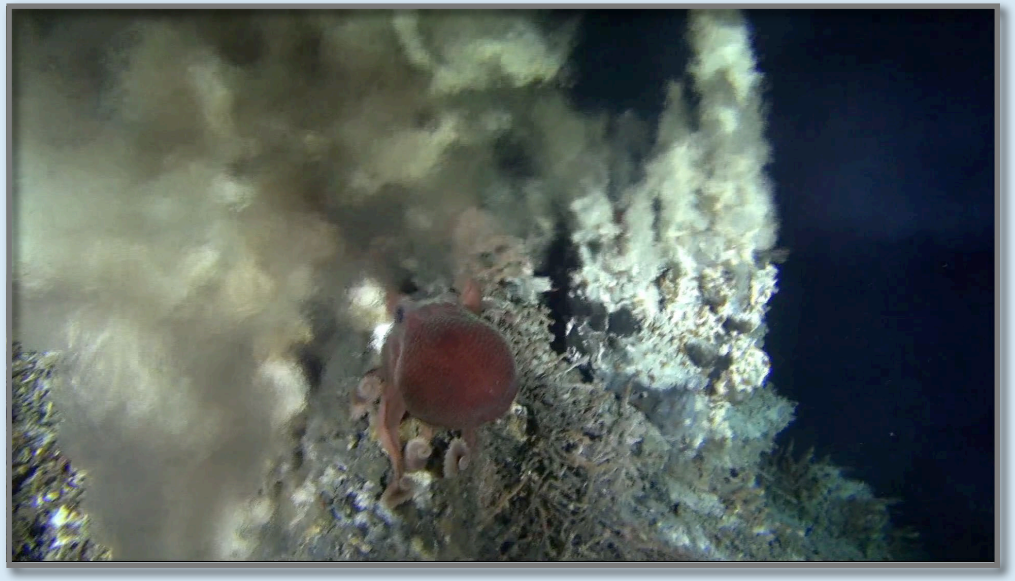
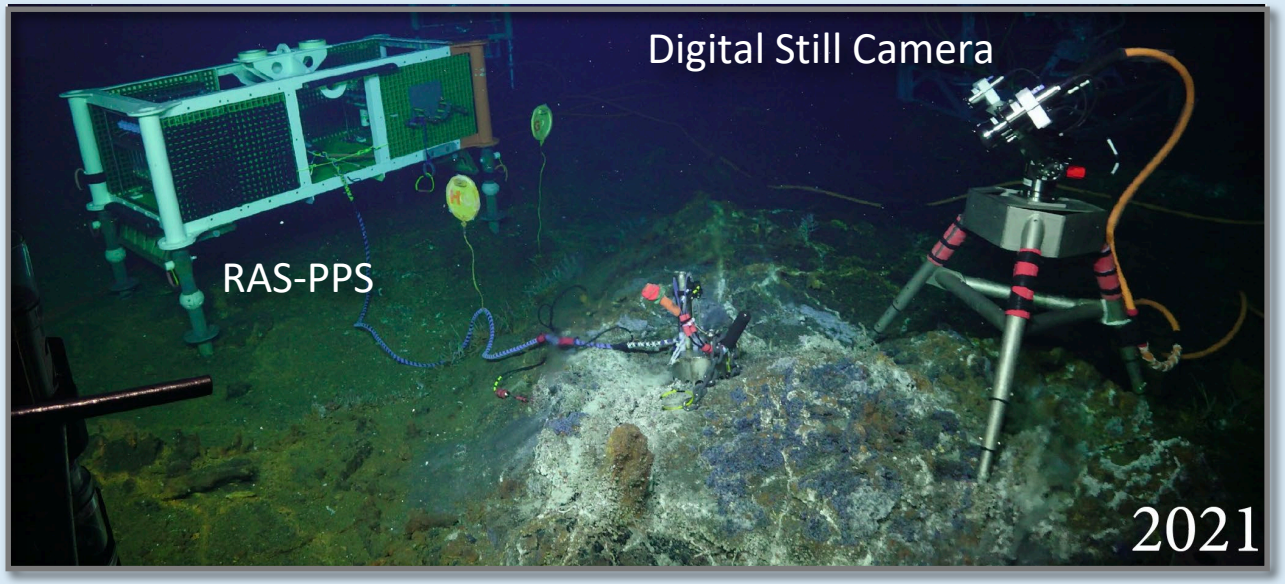
OOI Ocean Life Observations

Daily Imagery of Life and the Environment for Nearly a Decade





- Live streaming of HD video and digital still imagery from Axial Seamount to the Oregon Shelf
- Quantification of temporal and spatial changes in vent organisms and chimney growth and active methane seep sites (Marcon et al., 2021) since 2014.

- In situ DNA and Fluid Sampler Axial Seamount hydrothermal vent (RAS-PPS): microbial DNA, vent fluid chemistry and temperature
- R. Anderson, Carleton College (OCE2045697-Bio) “CAREER: Temporal dynamics of microbial and viral function and adaptation in hydrothermal vents”
- Rich time-series of microbial and viral metagenomics every 10-20 days for 3 years

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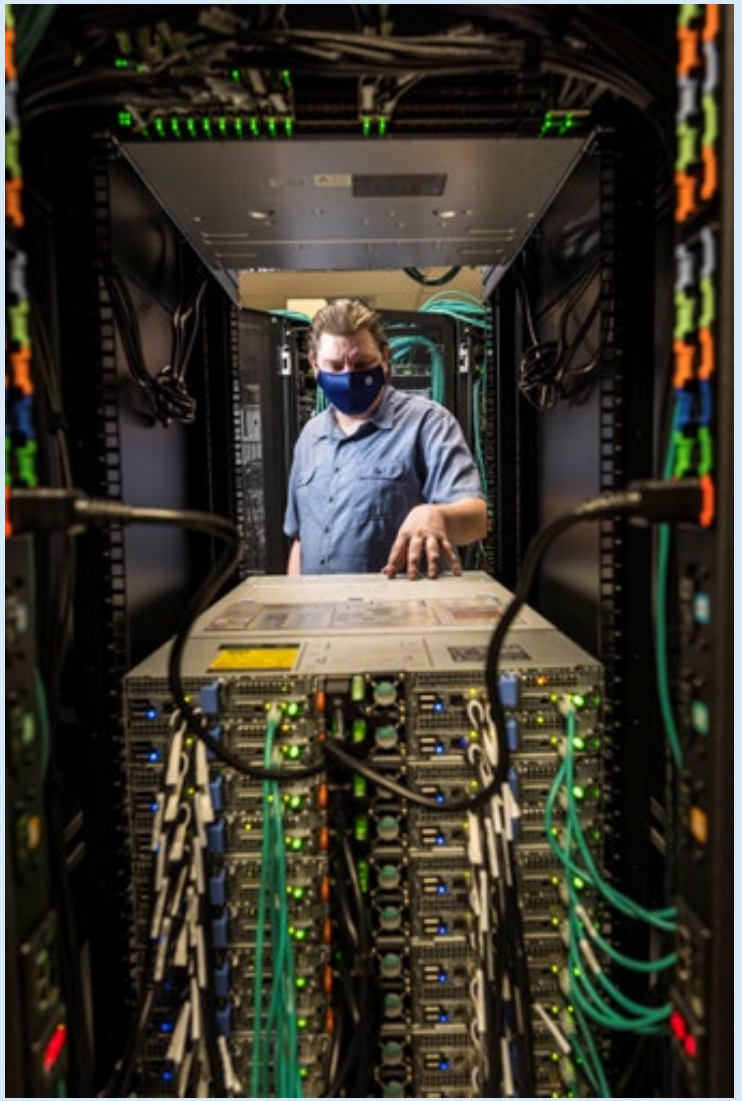
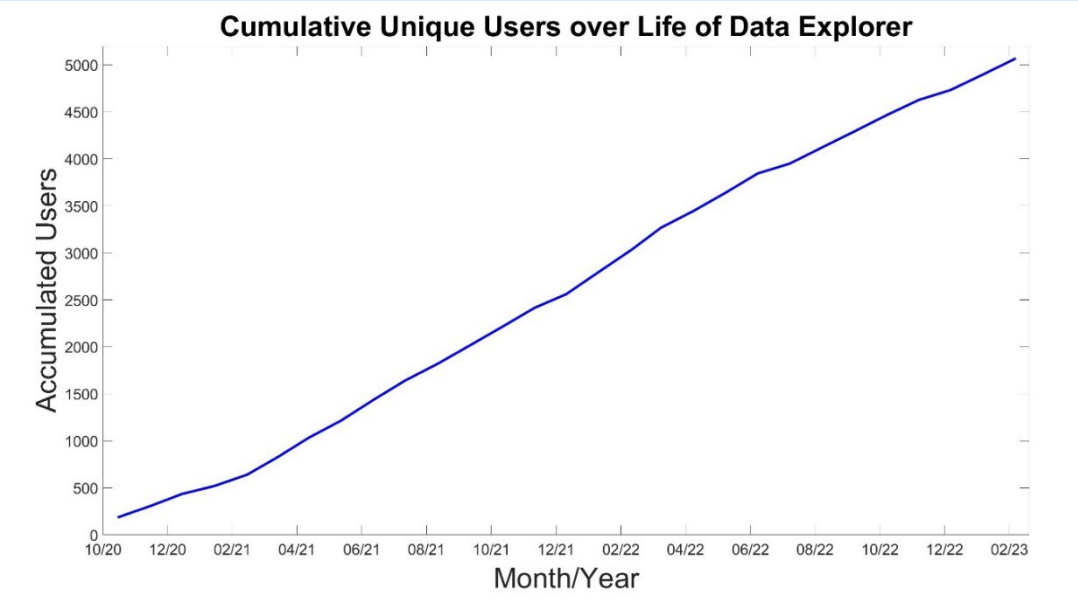
OOI 2.5: Cyberinfrastructure Goals

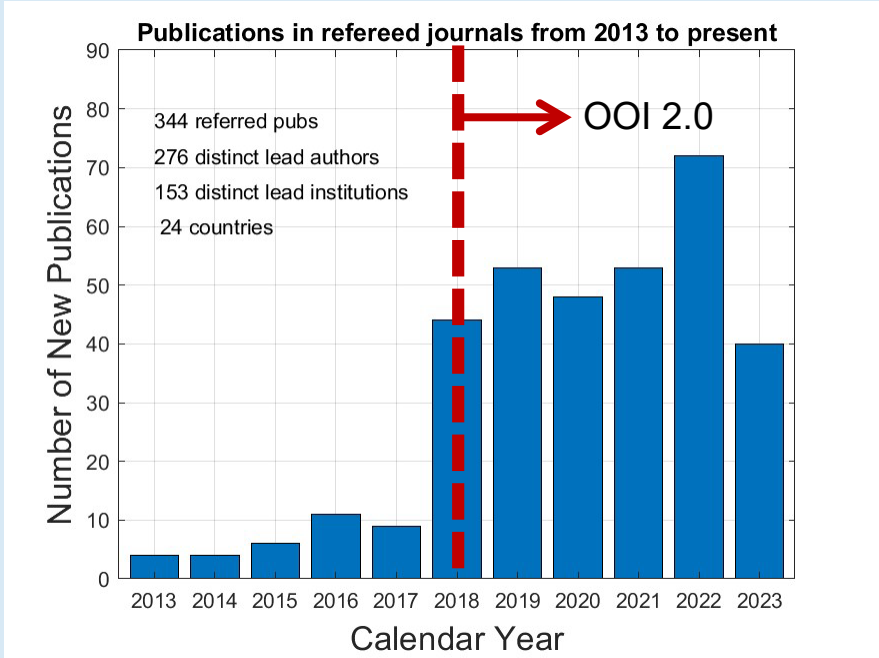
- Provide data collected from the OOI arrays **freely** over the internet to researchers, students, and educators in real-time via a **common integrated cyberinfrastructure** that provides web-based visualization and analysis tools for and data accessibility to the user community.

- Provide a **low-risk** and **cost-effective** OOI Data Center that introduces large **increases** in **compute power**, **modernize storage** solutions, and **improve backup** and disaster recovery.
- Provide a **secure data store** with multiple layers of redundancy to significantly **reduce system downtime**.
- Provide data following **FAIR** and **TRUST** principles.
- Provide the **secure storage** that will keep up with the expected **quadrupling of data** over the next five years.

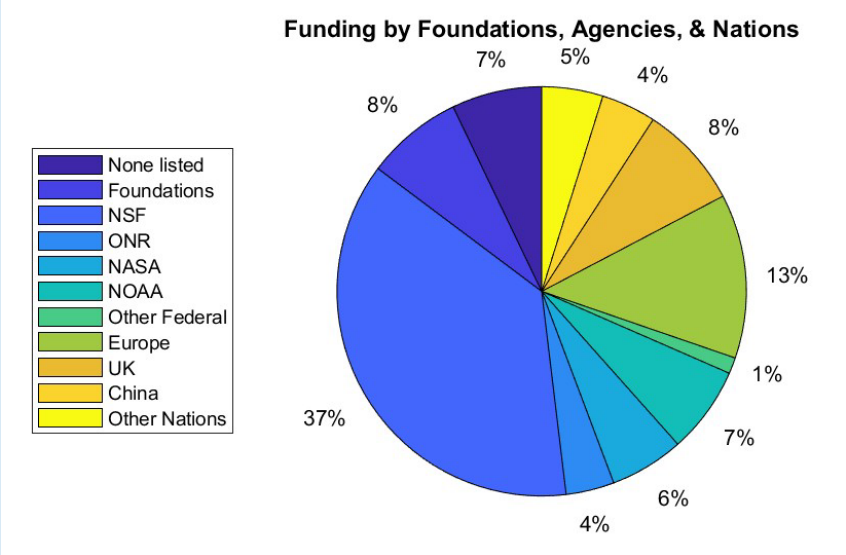


How many researchers and others are using data from the OOI data system? What other metrics are you tracking to demonstrate OOI use?





- The OOI does not require user to register before downloading data.
- A unique user is defined as an individual that comes to the Data Explorer website at least once as defined by Google Analytics.
- Each user is counted only once, i.e., a person who visits Data Explorer a hundred times is counted as one unique user.
- These numbers do not include users who access OOI data via distributors such as IRIS, NDBC, IOOS, and the Glider DAC.



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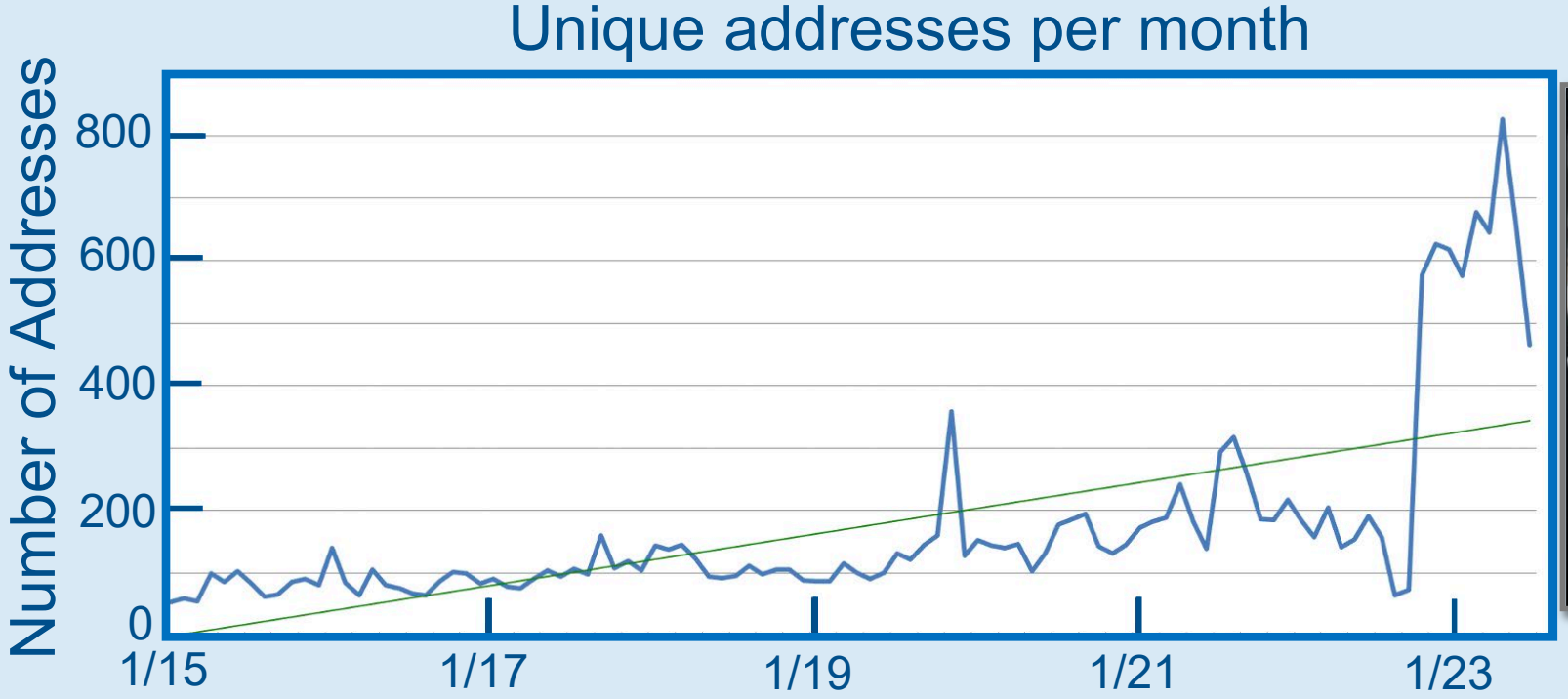
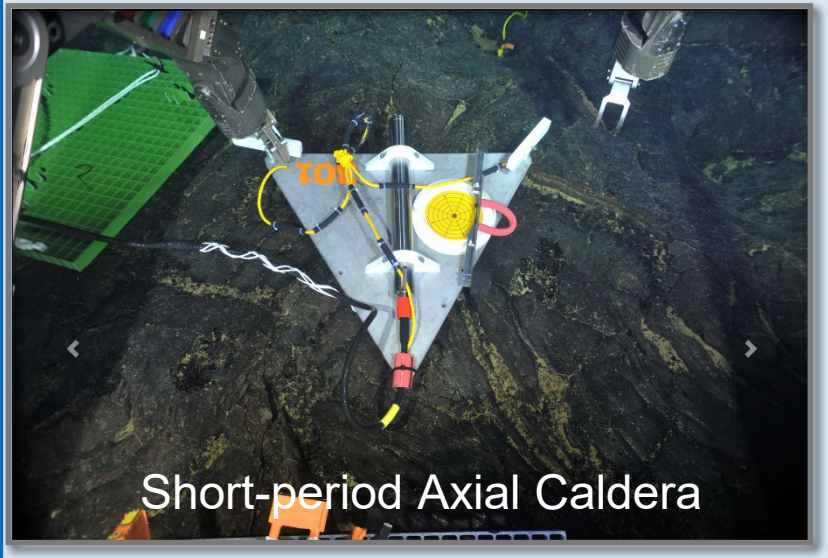
The Seismic Community is an Important User





12 seismometers on RCA currently

- **RCA seismic, low frequency hydrophone, and some pressure data are available through IRIS (Incorporated Research Institutions for Seismology)**
- **Planning is underway to incorporate RCA seismic data into ShakeAlert earthquake early warning system**

Note: Pressure data flow to NOAA's tsunami warning system

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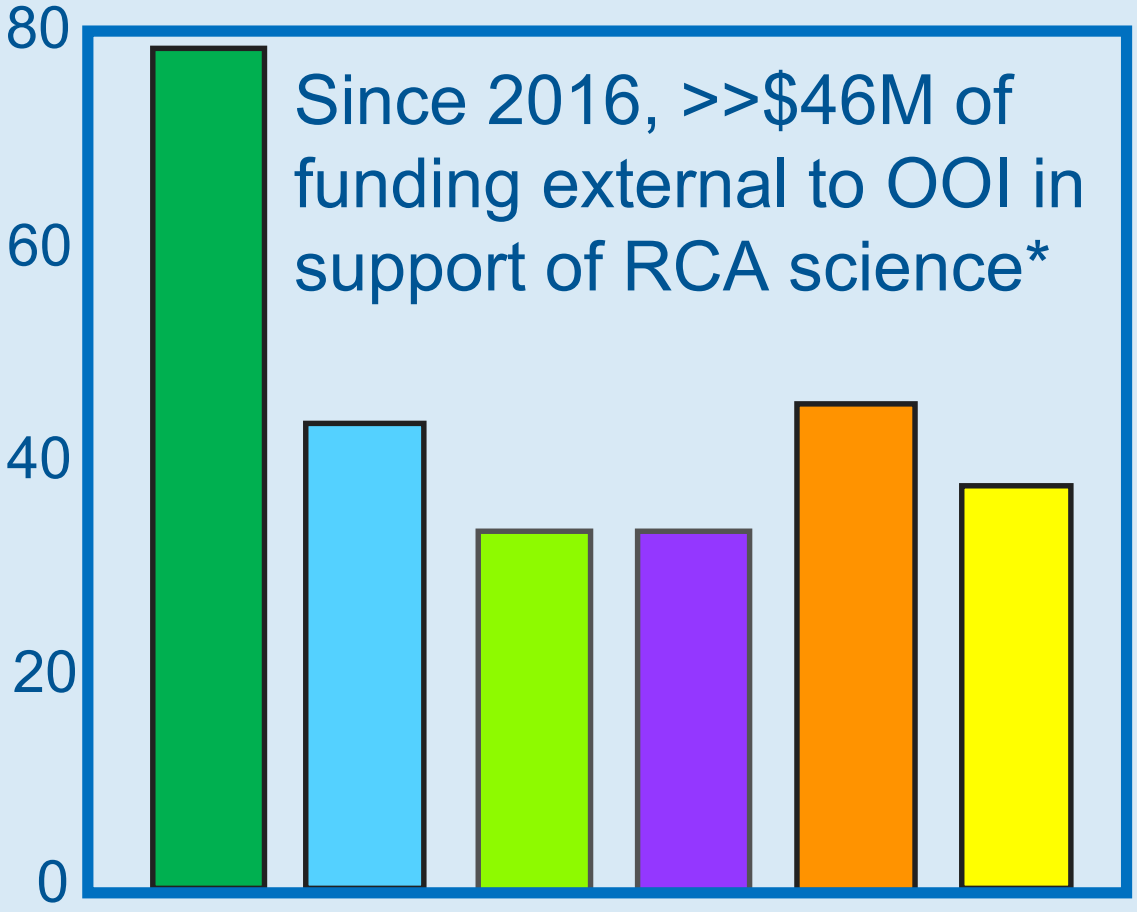
Significant Funding Success to a Large Community

RCA Diverse Portfolio for Funding External To OOI



78 Total Funded awards (PI and Subawards)

44 PI awards

34 Co-PI awards

34 Different PI's

45 Different Co-PI's

38 Institutions

Agencies include NSF, ONR, BOEM, NASA

** >$60M if include ship and ROV time*

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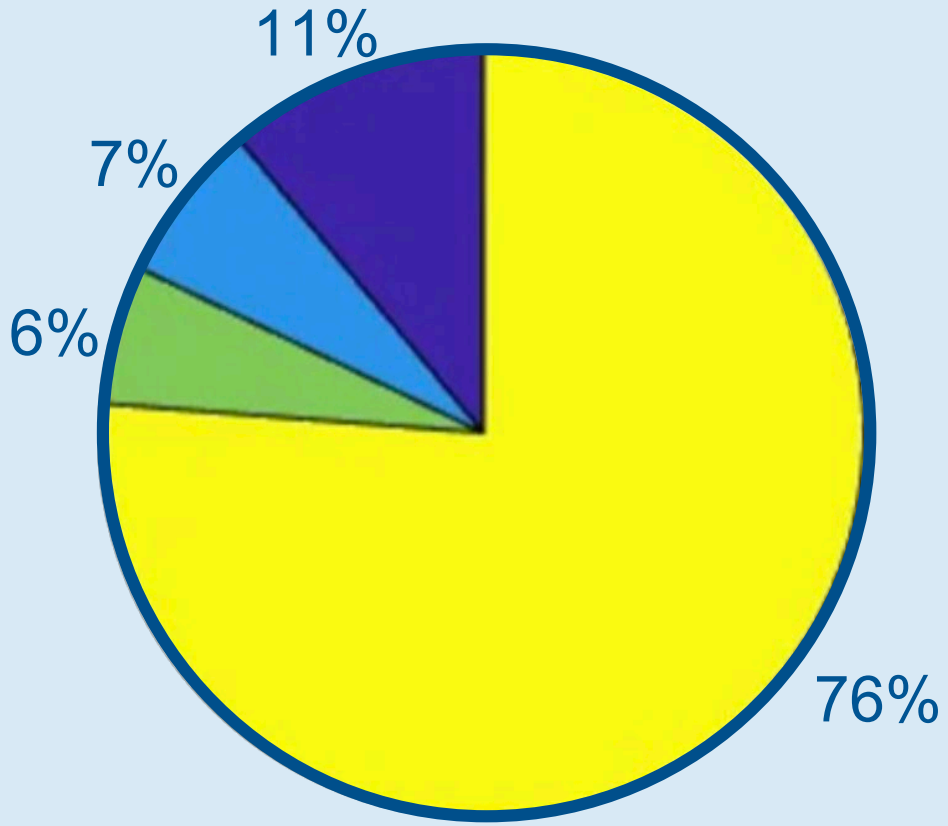
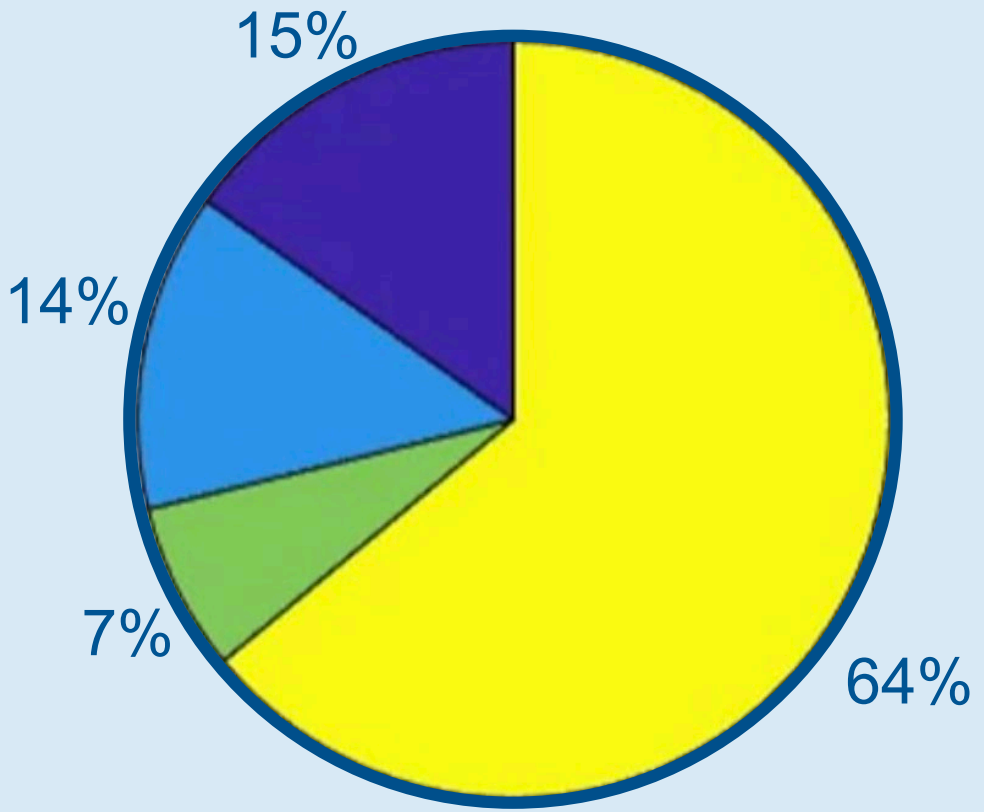
OOI Community Publications and NSF Awards

Publications by Institution



NSF Awards by Institution



WHOI
OSU
UW
Other

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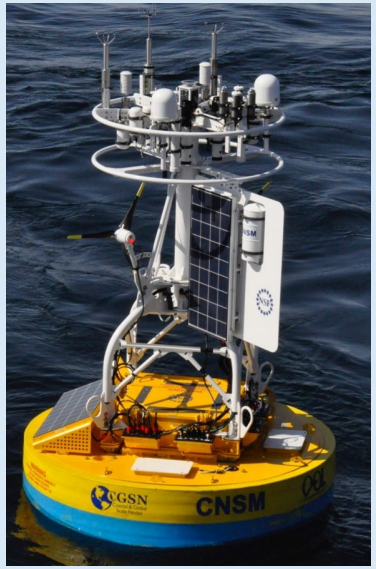
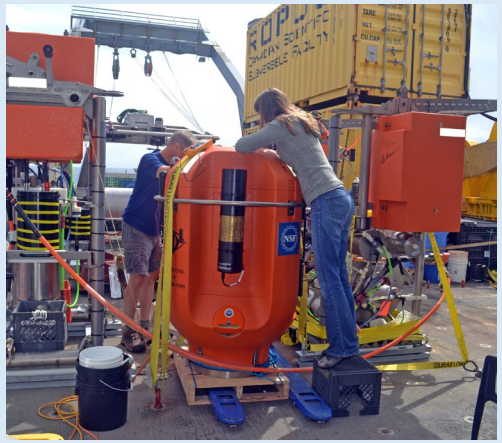
The OOI2.5 Was Renewed at $220M 2023-2028





- The program celebrates the increased funding to OOI2.5.
- Funding is sufficient to maintain the arrays and to keep them operational over the next 5 years.
- Significant support for increased capacity to the Cyberinfrastructure.
- Supports a small data team for QA/QC activities and “data ambassadors.”
- PI succession at the MIO’s: Three Associate Project Scientists planned for OOI2.5

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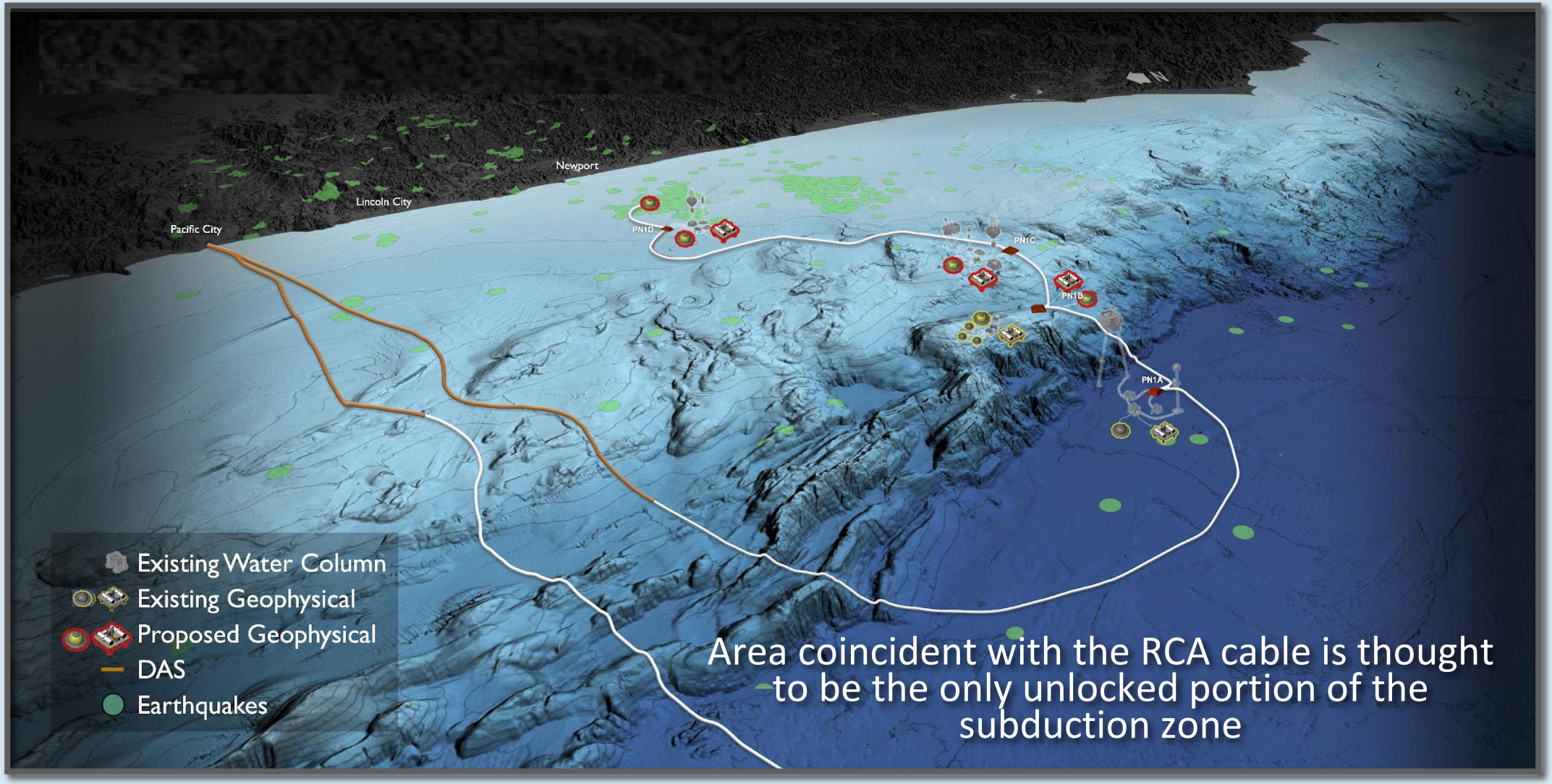
Future Opportunities for Growth

McClane: Imaging Flow Cytobot
Pioneer Move

- **OOI Team has significant breadth, but little depth**
  - OOI Team add critical team members to reduce risk
- **Enhance Data Team Members**
  - We are not in a position to provide fully processed data to the community: Would significantly increase user base – modelers, scientists, grad students etc.
- **Capital Investment and Technical Refresh**
  - Much of the infrastructure/instruments were procured over a decade ago – aging. Numerous instruments no longer supported by the vendors (e.g. ADCP's, sonars, etc).
- **Exciting New Technologies Coming Online**
  - Technologies are rapidly changing, Opportunities for new biological instruments (e.g. Imaging FlowCytobot - Pioneer Array, Distributed Acoustic Sensing RCA). OOI2.5 developing a plan to address new instruments

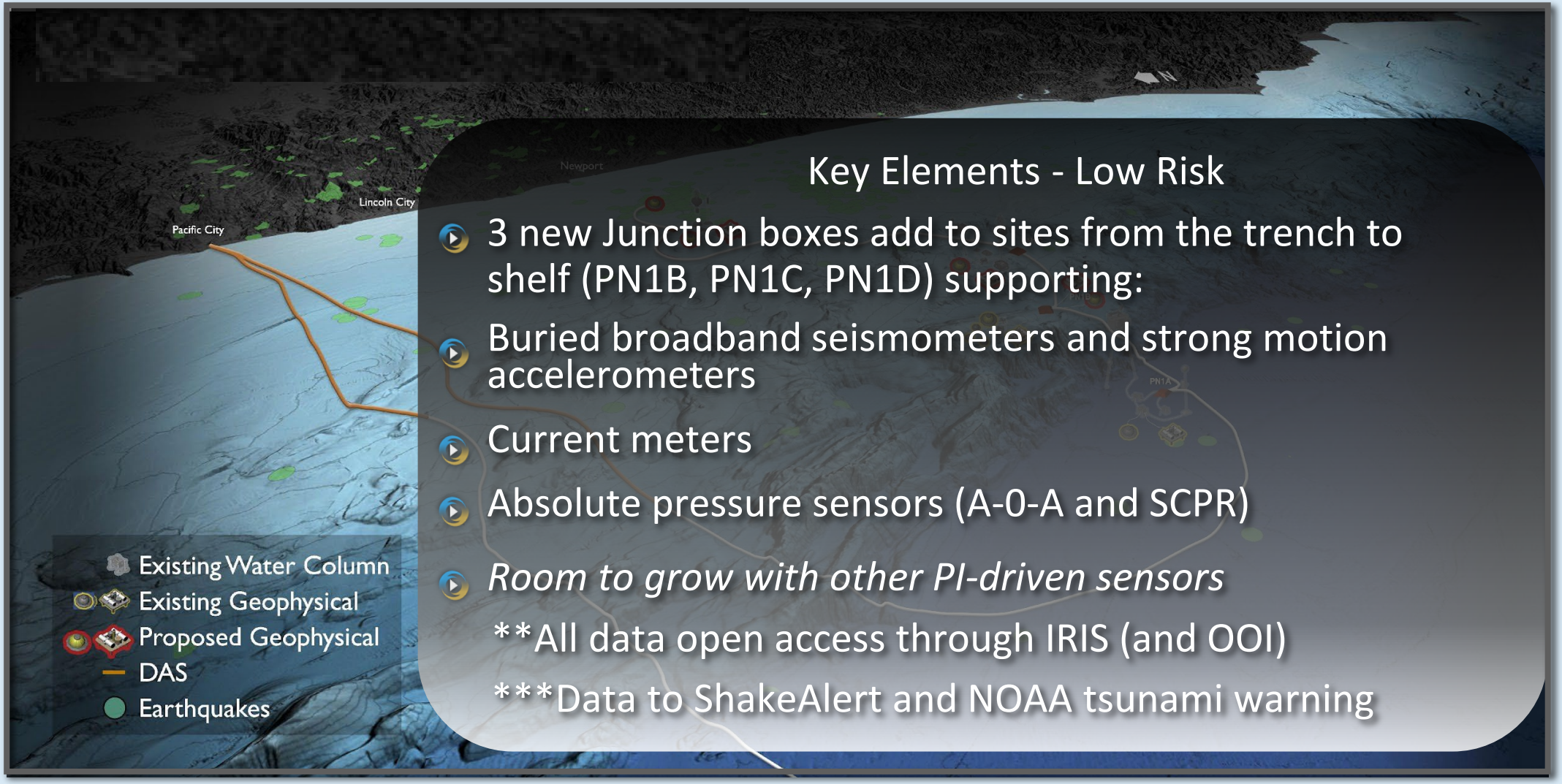
RCA Interactions with the SZ4D Community



New NSF MSRI Award 2023: Wilcock et al., $10.6M – “Creating an Offshore Subduction Zone Observatory in Cascadia with the Ocean Observatories Initiative Regional Scale Array (COSZO):

COSZO - An Early Success for the SZ4D Initiative

Installed over 13 days in 2026



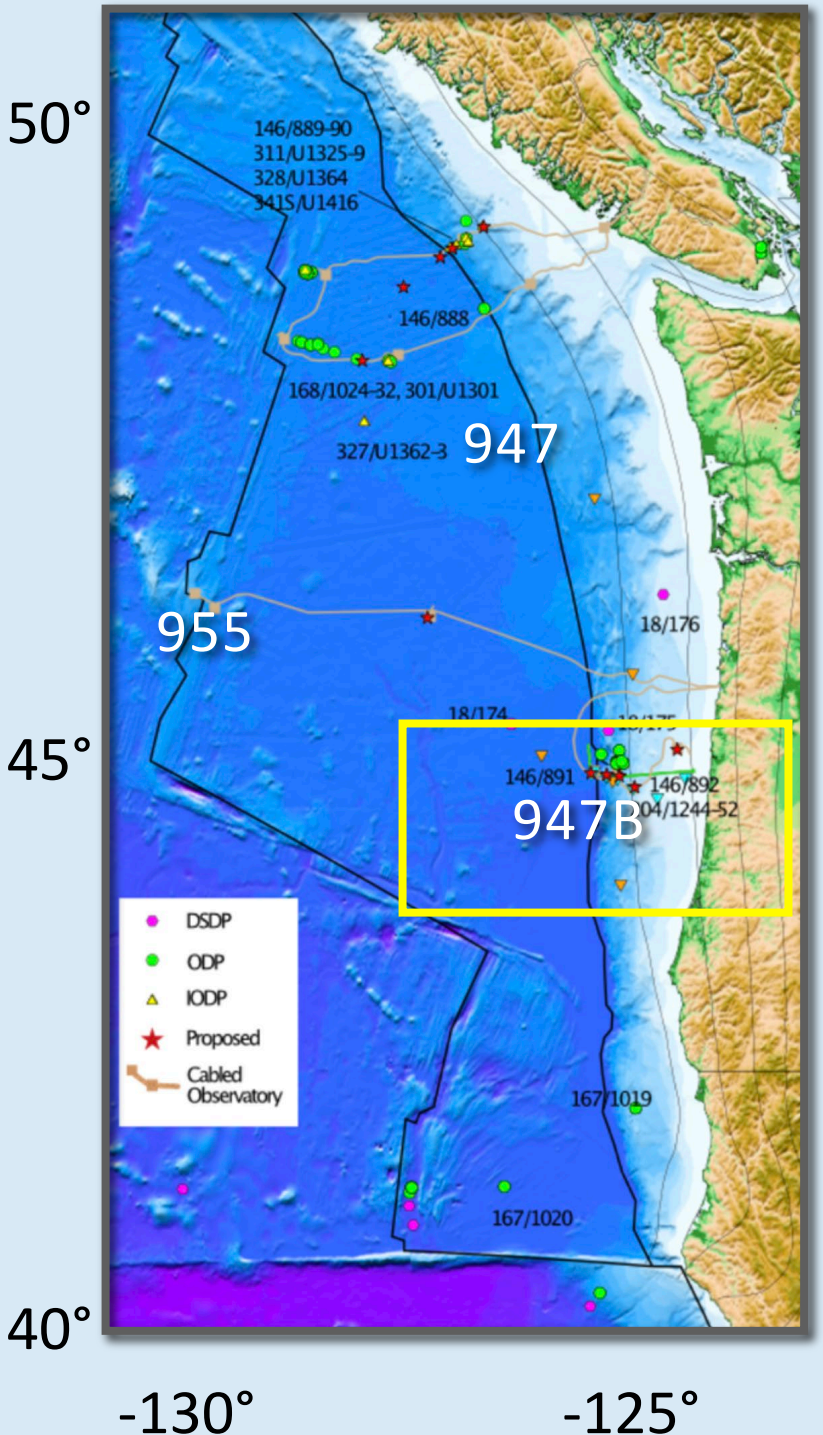
Key Elements - Low Risk

- 3 new Junction boxes add to sites from the trench to shelf (PN1B, PN1C, PN1D) supporting:
- Buried broadband seismometers and strong motion accelerometers
- Current meters
- Absolute pressure sensors (A-0-A and SCPR)
- *Room to grow with other PI-driven sensors*

**All data open access through IRIS (and OOI)

***Data to ShakeAlert and NOAA tsunami warning

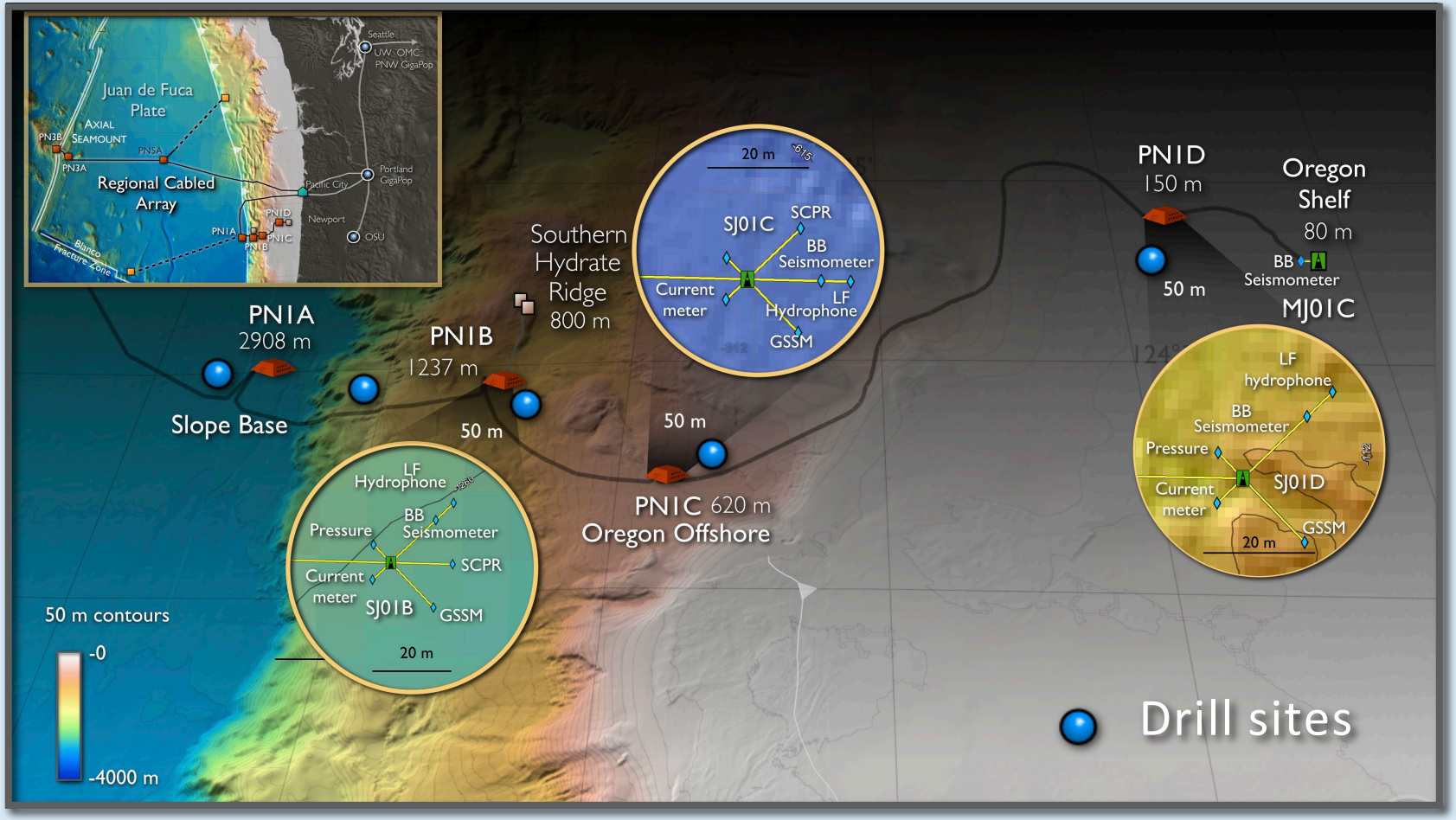
Includes involvement in CRESCENT (NSF - Cascadia Region Earthquake Science Center - OSU); NSF Cascadia Coastlines and Peoples (CoPe) Hazards Research Hub



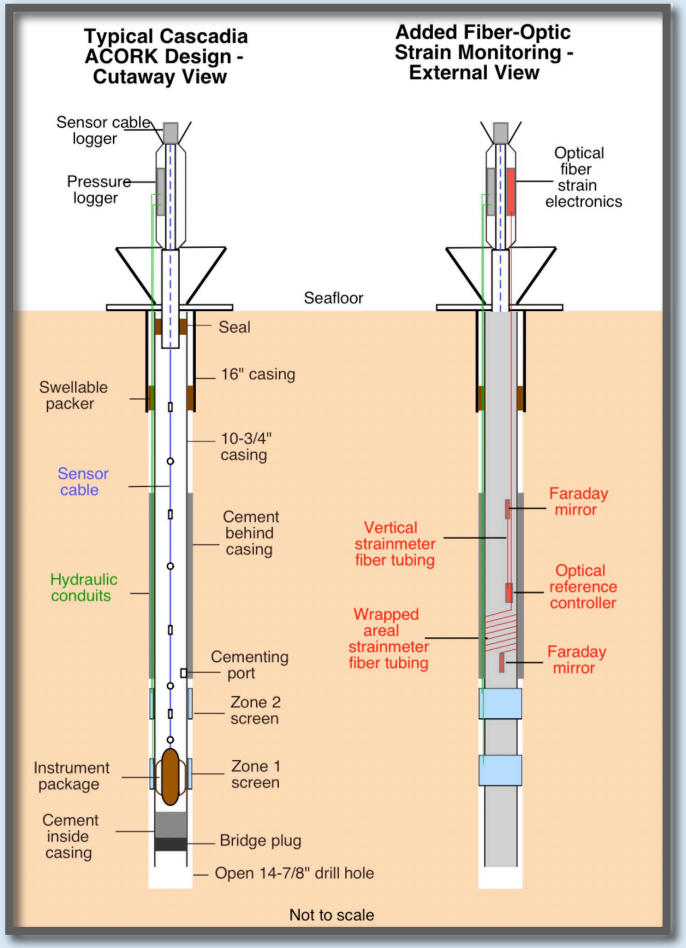
There is significant RCA involvement with IODP

- IODP 947 Full: CCBO: Cascadia Cabled Borehole Observatories to Investigate Plate Boundary Mechanics and Test Models for Along-Strike Segmentation of the Megathrust; Tobin et al.,
- 947B Pre: Cabled Borehole Observatories to Investigate Plate Boundary Mechanics of the Cascadia Subduction Zone - Oregon Transect; Wilcock et al.,* Pre because was missing some survey data
- 955 Full: Integrating subseafloor microbial, hydrological, geochemical, and geophysical processes in hydrothermal active oceanic crust at Axial Seamount, Juan de Fuca Ridge; Huber et al., passed environmental review, ready to go

947B Pre: Cabled Borehole Observatories to Investigate Plate Boundary Mechanics of the Cascadia Subduction Zone - Oregon Transect



OOI RCA and COSZO infrastructure



Cabled Corked Observatories

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Thank you!

Questions?