SUBSEA

- Funded July 2017 by NASA SMD ROSES-2016 Program Element C.14 Planetary Science and Technology Through Analog Research (PSTAR)
- In-Kind support from NOAA OER and OET

PRESENTING: Drs. Darlene Lim (NASA Ames) & Chris German (WHOI)

Systematic Underwater Biogeochemical Science and Exploration Analog

SUBSEA research

Ultimately, the results of SUBSEA's research will inform both strategies for conducting science via teleoperations at deep-space destinations and scientists' understanding of a wider range of deep-sea analogs for Ocean Worlds.

Science – SUBSEA is anchored by a Science program that will both:

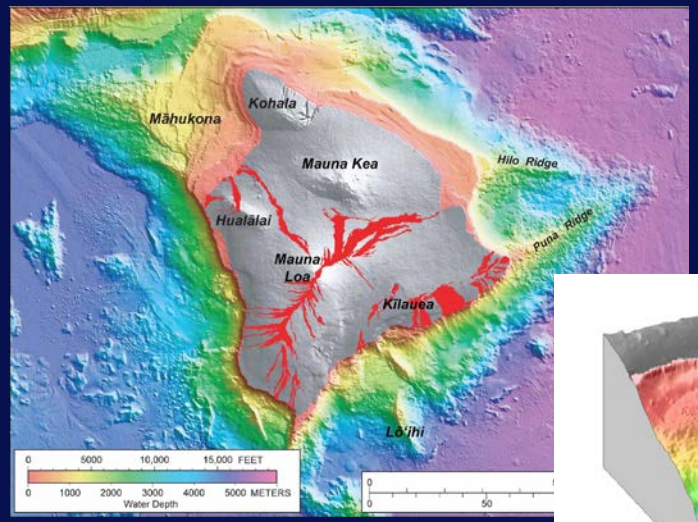
1. Broaden our understanding of the potential habitability of other Ocean Worlds in our Solar System, and
2. Characterize novel deep sea environments on our own planet.

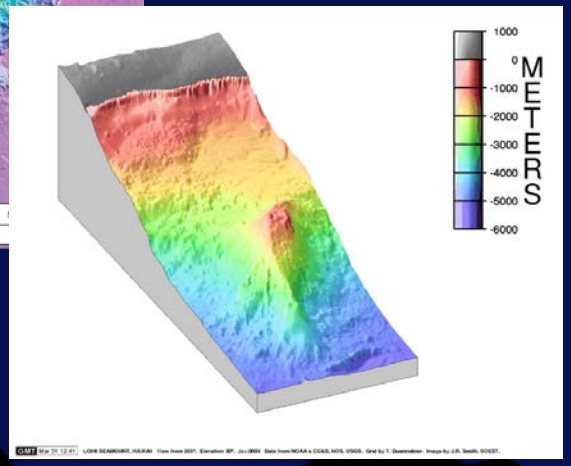
Science Operations: SUBSEA will leverage the high-fidelity Low-Latency Telerobotics analog environment of the *Nautilus* tele-presence mission architecture and the real (non-simulated) SUBSEA science activities to evaluate and identify specific concepts of operations (ConOps) and capabilities that will have enabling and enhancing value for science-driven LLT exploration of Deep Space and Mars

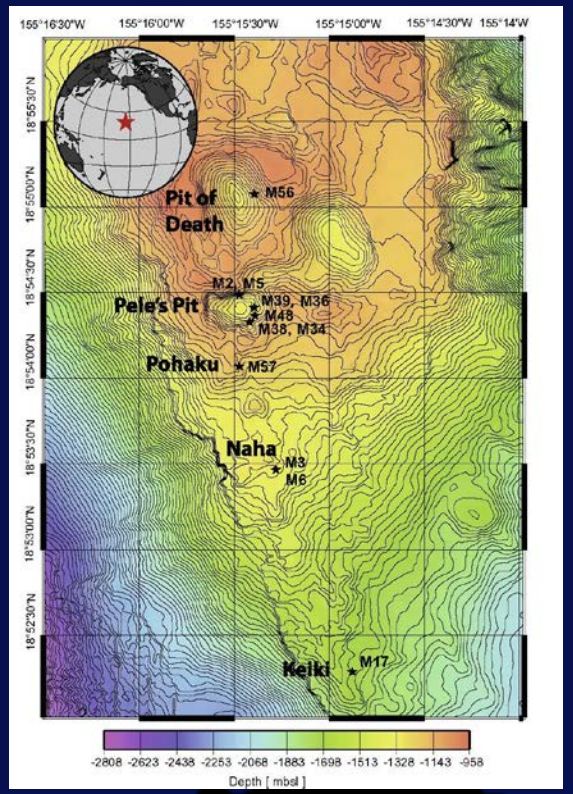
Technology: SUBSEA will use NASA developed information technologies that will be evaluated and iterated upon based on their ability to support science-driven telepresence/LLT operations. xGDS will provide human/robotic software functionality to support integration and visualization of diverse data products relevant to future human exploration of deep space.

SUBSEA Cruise A Lo`ihi 2018

SUBSEA's first field campaign was focused on characterizing the geology, energetics, and microbial communities associated with the Lō`ihi seamount.



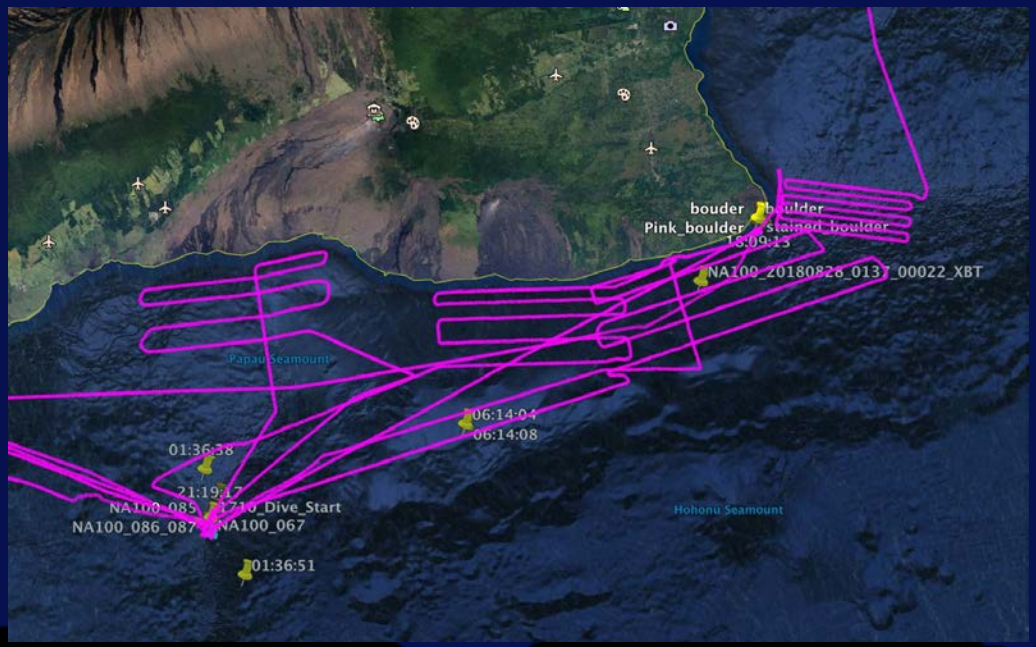




SUBSEA team

Output and Outcomes of Cruise A Deployment

- 4 Hurricanes, 10 ROV dives; 110 hours of ROV bottom time
    - Loihi: 9 Dives, 5 GeoTransects, 5 known fluid flow sites sampled
    - Ocean EntrySite: 1 Dive, 1 GeoTransect, 1 fluid flow site sampled
    - Mapping Surveys: During down-time (10 Weather Days)
- 126 individual samples collected; 131 with subsamples
- All research (Science, Ops, Tech) objectives completed plus bonus dive



SUBSEA SCIENCE OBJECTIVES

★ **Seafloor Morphology**

★ **Seafloor Fluid Flow**

★ **Fluid biogeochemistry**

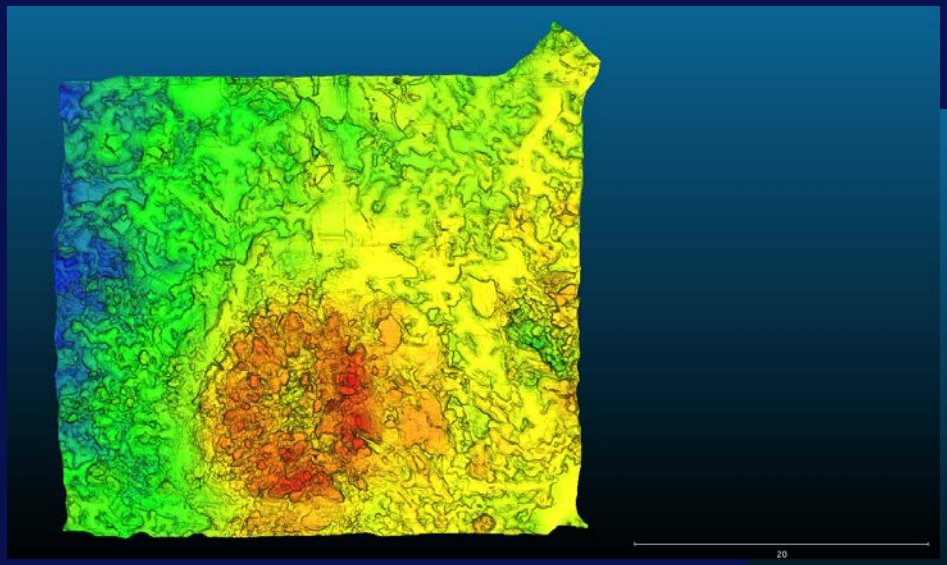
★ **Fluid microbiology**

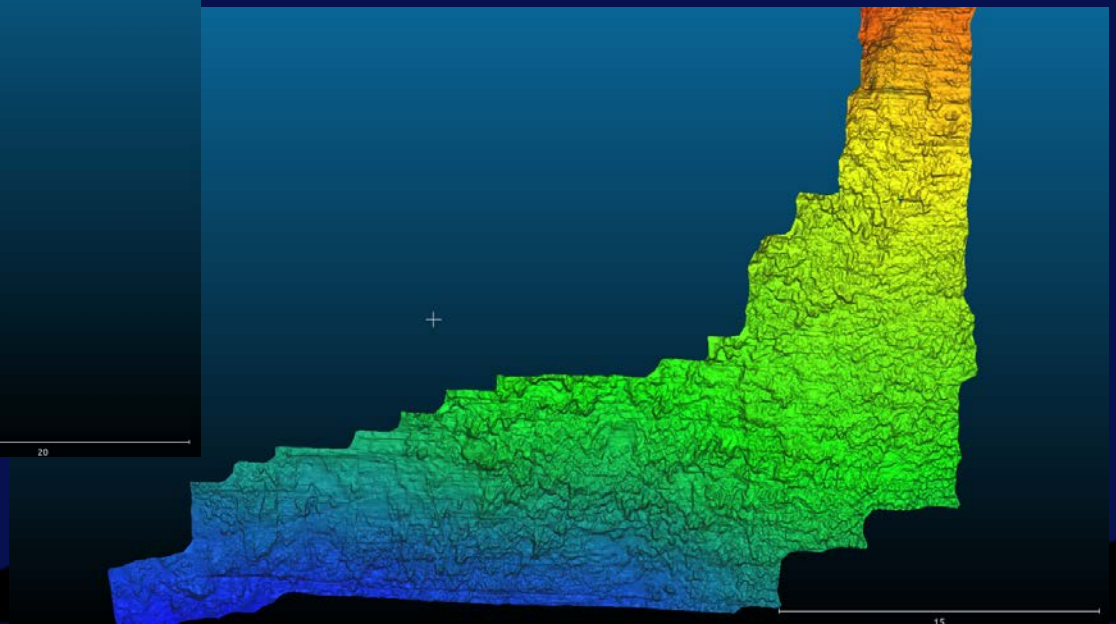
★ **Sensors & Autonomy**

Science Outcomes - Morphology & Fluid Flow

URI (Roman Lab) laser-mapping system:

- three distinct lava morphologies
  - >100 morphology tags across field area for correlation
  - some correlations already predictable from Sentry DTM
- two primary fluid-flow locations mapped
  - hi-res bathymetry AND fluid flow distributions (aerial extent)
  - will allow integrated vent-flux calculations

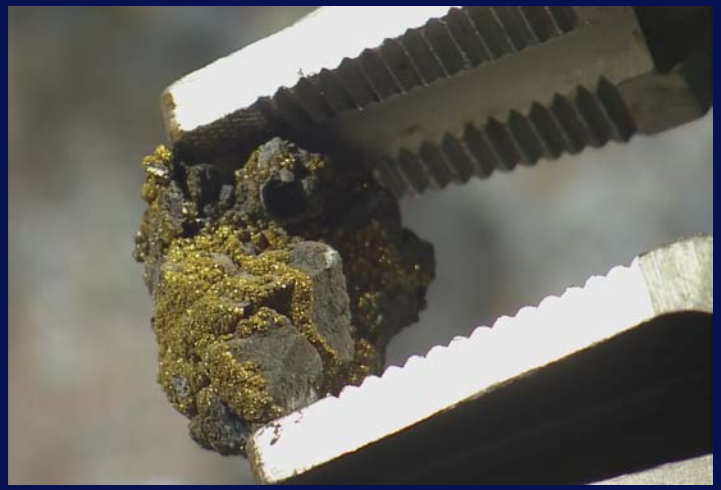




Science Outcomes - Geology

Petrologic Sampling:

1) Collected minimum 3 samples each from lobate, smooth, and jumbled textures
2) Collected a sample from almost all five vent sites studied
3) Collected samples for several targets of opportunity (pyrite, visually distinct rocks, etc.)

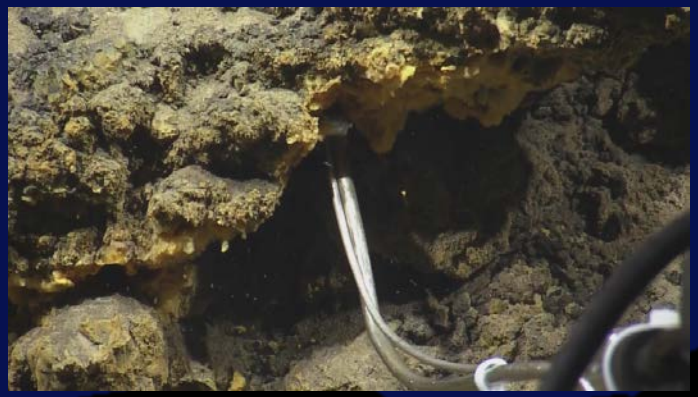


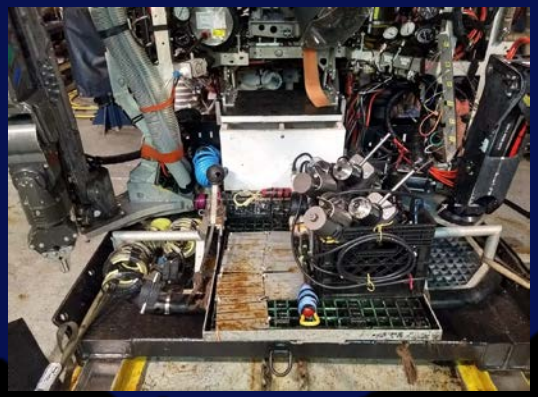
Science Outcomes - Fluid Chemistry

Shipboard fluid Chemistry:

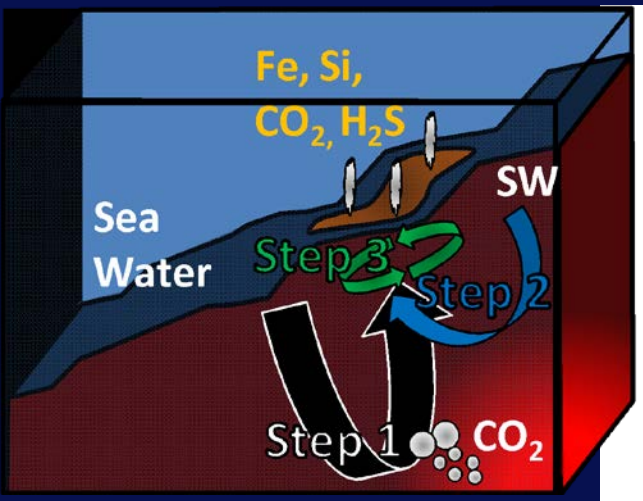
- 5 known sites / 7 discrete locations (13 of 14 IGT samples successful)
- Temperatures from 6 to 41 C (systematic cooling, 2006/7-2013-2018)
- Range of fluid compositions from shipboard chemistry:

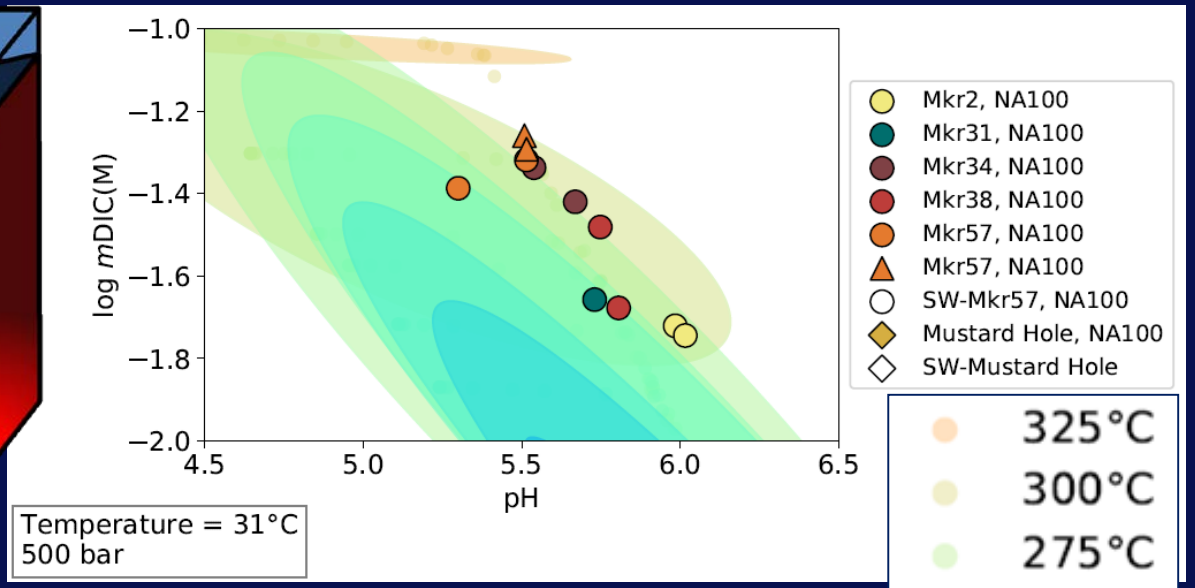
pH (25 C):	5.4 to 7.8
alkalinity:	2.5 to 14.3 meq/L
Fe:	32 to 1062 umol/L
CH4:	0.06 to 4.3 umol/L
H2:	below detection (<3 umol/L)
H2S:	below detection (<< 2 umol/L)





Science Outcomes - Fluid Chemistry





The lowest T°C fluid may have experienced the highest T°C of W-R reaction

Science Outcomes - Microbiology

COMPLETED DURING CRUISE:

Samples from 6 Loihi vent sites, 1 ocean entry site & 2 background sites.

Sample TOTALS:

- 30 filters for metagenomics/ metatranscriptomics/metabolomics
- 30 prokaryotic cell count samples
- 27 eukaryotic cell count samples
- 27 single cell genomics samples
- 18 carbon samples
- 10 chemistry samples
- 7 arsenic samples
- 64 RNA-SIP experiments for carbon fixation
- 108 NanoSIMS experiments for activity
- 223 cultures inoculated (30, 55, and 80 deg C)

Science Outcomes - Sensors/Autonomy

Robotic Oceanography:

In situ sensors: pH, H2S and low-level O2 all tested for first time.

Water (O, H) isotope study: samples from vents, plumes and water collected to test viability of future in situ Raman, CRDS.

Iron partitioning study: samples for unfiltered water, filtered water and particulates collected from vents & plumes.

Adaptive sampling not tested on Cruise A.

Bonus Science: Ocean Entry Site

Science Operations

Data collection objectives and status

1. *In situ* observations
   a. on ship
      i. control van ✓
      ii. lab workspaces ✓
   b. on shore
      i. ISC control room ✓
      ii. remote from ISC x
2. OET/ISC telepresence video and audio recordings
   a. dives ✓
   b. daily telecons ✓
3. Interviews ✓
4. Photographs
   a. ship: control van, lab workspaces ✓ ✓
   b. shore: ISC control room, remote from ISC ✓ *
5. Science team communication modalities form ✓

3-month look forward

October 2018

- Oct. 2 - 4 In-person debrief, and publication research, at Human Factors and Ergonomics Conference
- Oct. 8 - 12 NASA Ames Ops and Tech Workshop
- Review data collection and data management
- Extrapolate preliminary findings for Cruise B planning
- Cruise B latency planning

November 2018

- Data management and analysis
- Follow-up questions for Science and Tech teams (phone or email)
- Cruise B latency planning

December 2018

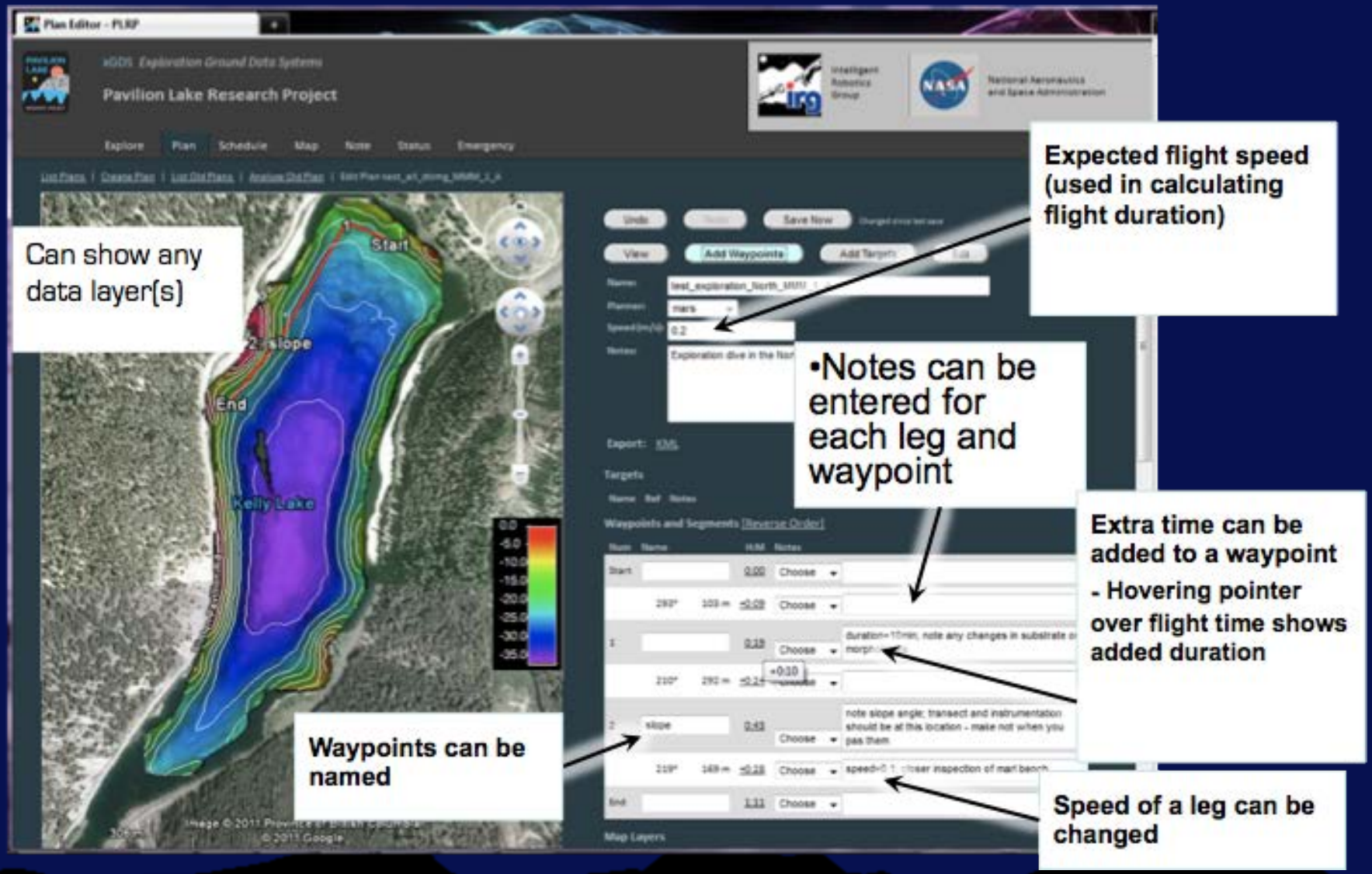
- Data management and Analysis
- Draft write-up on Cruise A

SUBSEA TECHNOLOGY

Scientific research under teleoperation mission conditions will require software tailored to the different space exploration contexts that may arise, with their own unique requirements. SUBSEA will use prototype information technologies to evaluate which software capabilities are required for missions with long communication delays and to improve upon these tools based on their ability to support science-driven LLT operations.

The Exploration Ground Data Systems (xGDS) software developed at NASA Ames will be integrated with the *Nautilus*'s own telepresence mission support systems. The researchers will then systematically evaluate the technology during the SUBSEA field campaigns. xGDS will provide software functionalities that allow integration and visualization of diverse data relevant to future human exploration of deep space.

xGDS for Planning



xGDS for execution

Output and Outcomes from xGDS Group

- Observations
  - Observed dive operations from ISC throughout the deployment
  - Recorded ~550 observations and ~70 related questions.

- User feedback Survey
  - Measurable differences in situation awareness (SA) between teams
    - A lot of SA comes from direct inquiry from someone in the van

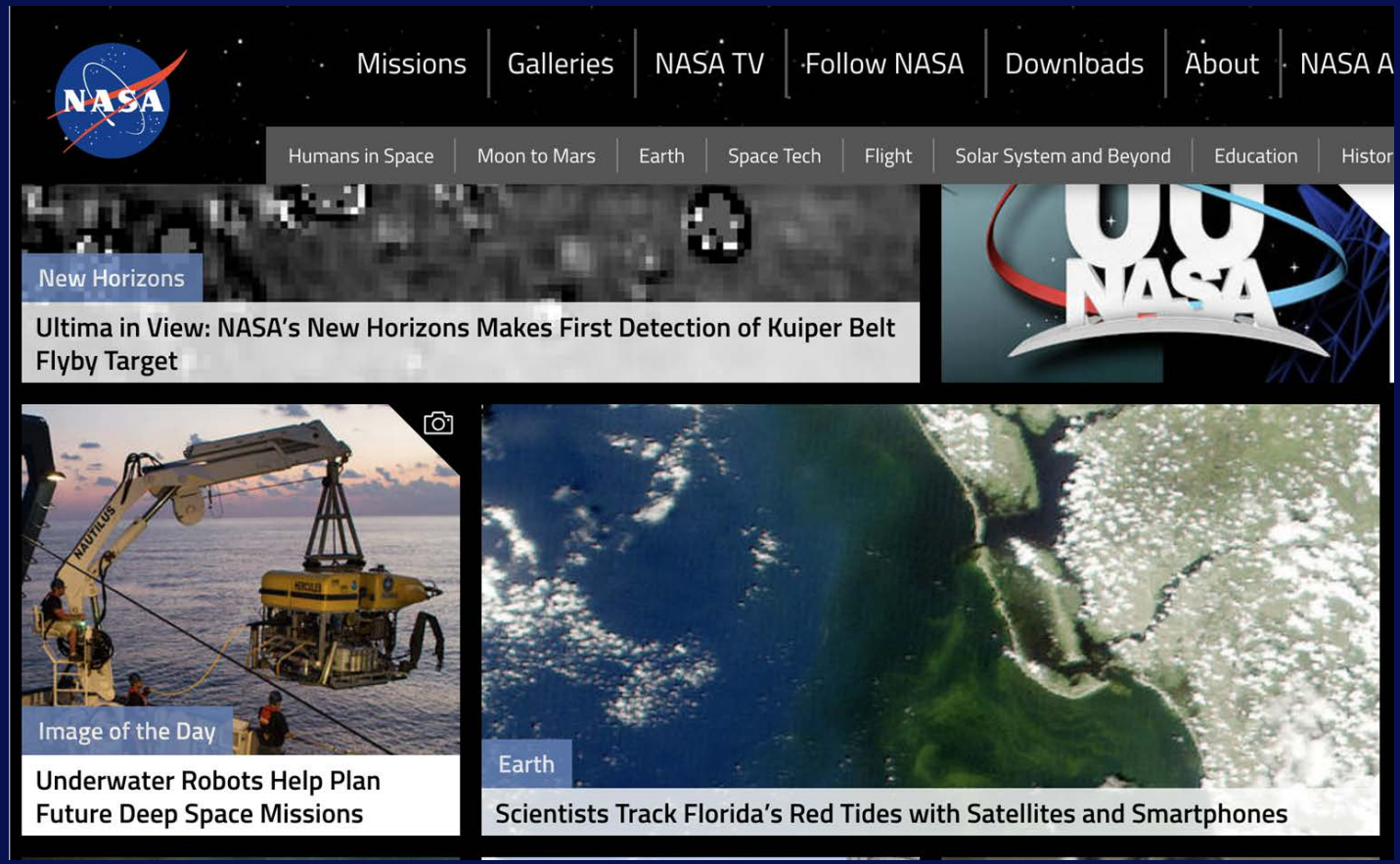
- 'Inherent latencies' and temporal offsets that affect SA within current telepresence architecture quantified and qualified

- Archive Data Import underway

SUBSEA Outreach

- Anecdotally, the merger between Ocean and Space science is like ‘peanut butter and chocolate’

NASA.GOV Image of the Day & Feature



NASA 360 Live

Live stream NASA talk show featuring research from across the agency. Over 2 million viewers were live streaming the SUBSEA interview.

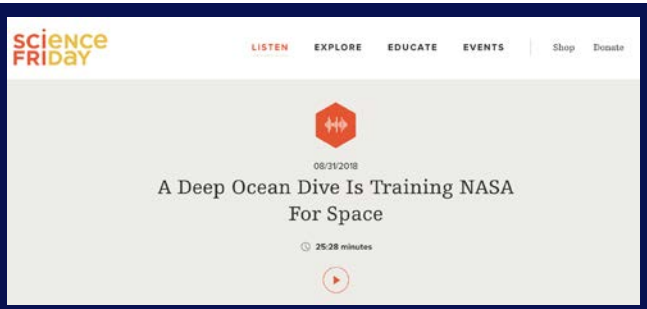
https://www.twitch.tv/videos/303882219

NASA PAO - OET - NOAA Outreach

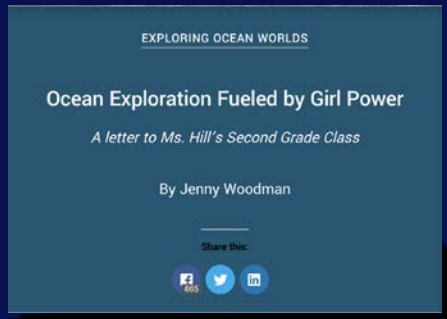
SUBSEA

NPR Science Friday
NBC News
Popular Science
Popular Mechanics
NASA.gov

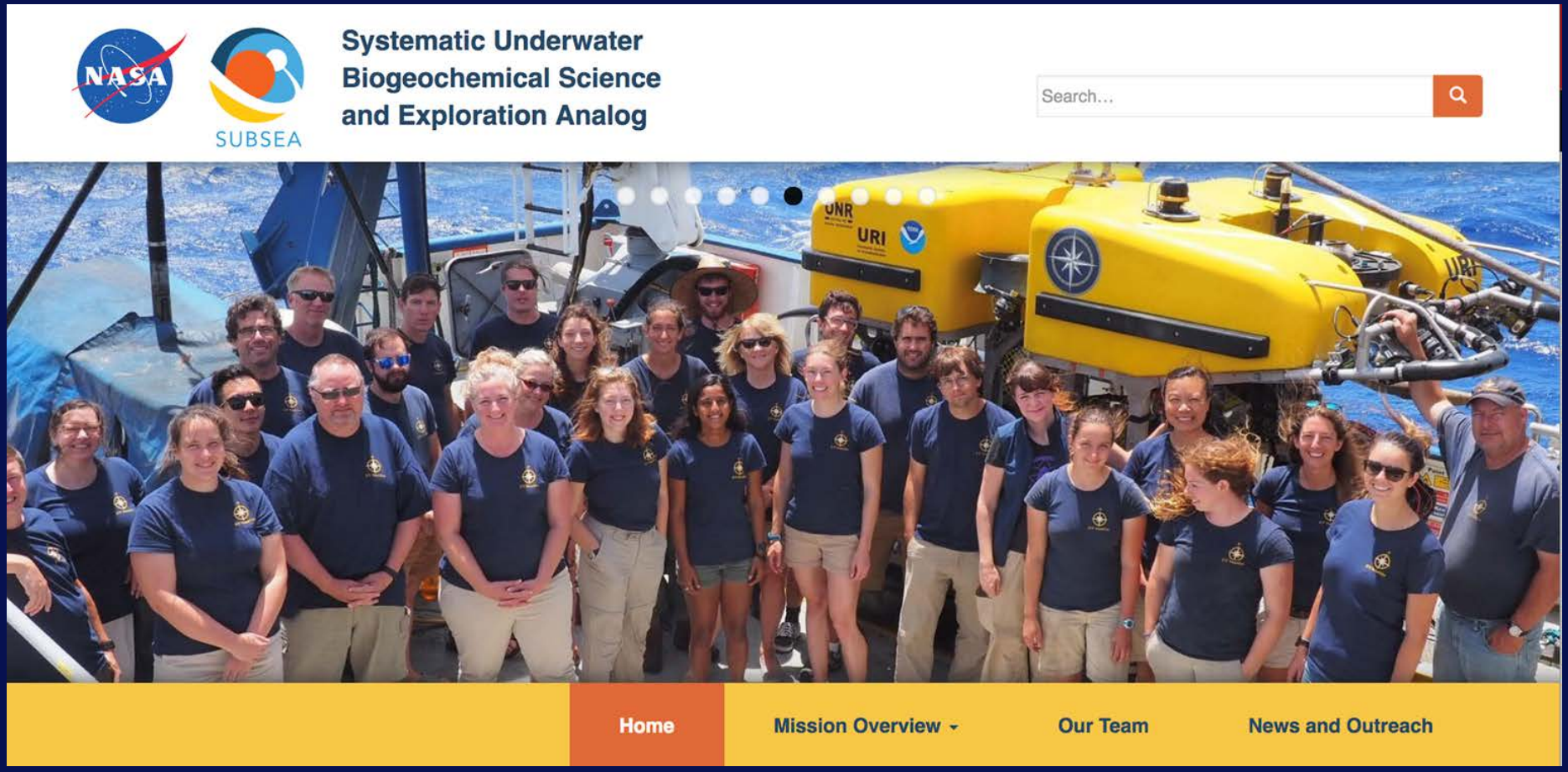
During the SUBSEA cruise, the team on board conducted 34 ship-to-shore interactions with schools and public audiences in Hawai'i, California, Alaska, Oregon, Florida, Louisiana, Tennessee, Rhode Island, Texas, Massachusetts, Washington--and France! The total reach for live interactions during NA100 is ~1,120 students and general public.



Great article by OET Science Communicator Jenny Woodman on Women in STEM leadership gained broad readership.



Questions?



https://spacescience.arc.nasa.gov/subsea/