Remote Operations: Connecting Sea & Shore to Expand the Footprint of Ocean Exploration

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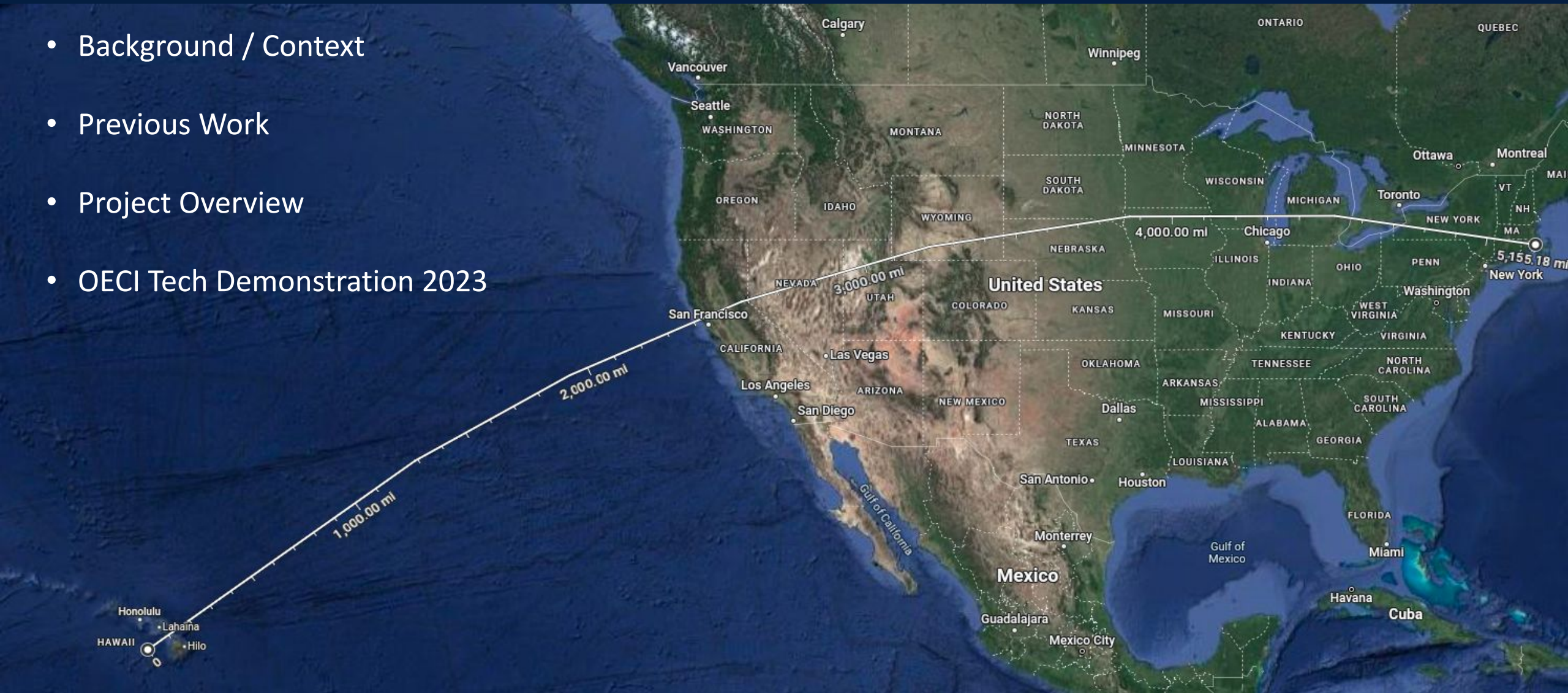
WOODS HOLE OCEANOGRAPHIC INSTITUTION

OCEAN EXPLORATION COOPERATIVE INSTITUTE oeci EXPLORING THE NATION'S BLUE FRONTIER

NOAA OCEAN EXPLORATION

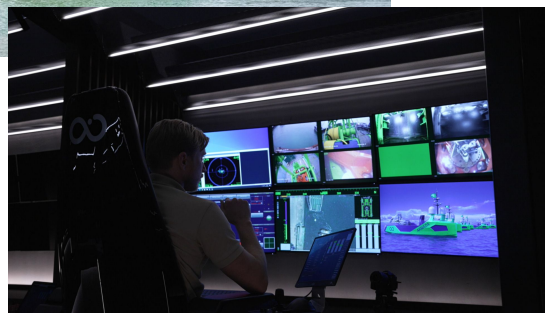
Overview

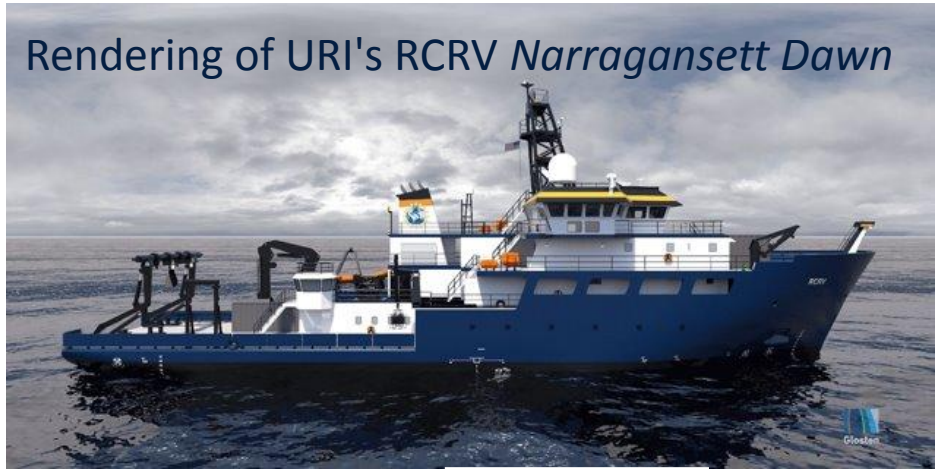
- Background / Context
- Previous Work
- Project Overview
- OECI Tech Demonstration 2023



Background

- **Telepresence** has existed for more than 2 decades – focused on bringing scientific expertise from shore to the ship
- **Teleoperations** involves direct operational actions or interacting with technical aspects of the vehicles themselves from shore
- **Motivation / Broader Impacts**
  - Upcoming Regional Class Research Vessels (RCRVs) have a smaller footprint
  - Push towards multi-vehicle, long duration operations
  - Distributing senior level engineer expertise across multiple assets
  - Enabling a more diverse workforce





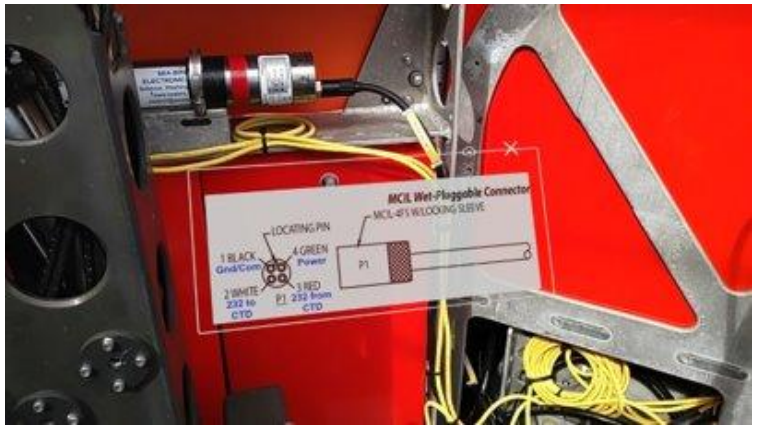
Previous Work

Exploratory Phase

- Tech Demo 1: Fall 2021

  Target Areas
  - Real-Time Engineering and Troubleshooting
  - Predive Checkouts
  - Remote Operations (e.g., piloting)
  - Data Services

- Tech Demo 2: Spring 2022
  - Real-Time Engineering and Troubleshooting via Augmented Reality
  - Network Infrastructure



Nautilus Live / Ocean Exploration Trust

Current Phase Objectives

- Remote Ops "fly-away" system
  - Define requirements (network, audio, visual, etc.)
  - Suite of tools and recommendations

- Navigational situational awareness tool capable of handling vehicles of different types, manufacturers, and software architectures

- Network performance/monitoring

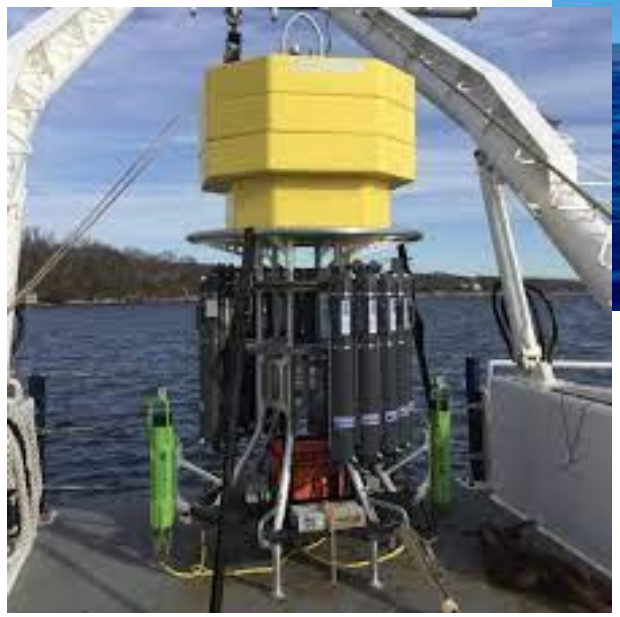
- Begin testing Low Earth Orbit Satellite (LEOS) capabilities

Tech Demonstration Overview

- E/V Nautilus, Oct. 1st – 19th 2023
- Vehicles: Drix (UNH), Mesobot (WHOI), Deep Autonomous Profiler (DAP) (URI)
- Multi-vehicle exploration

Nautilus

Drix



DAP

Mesobot

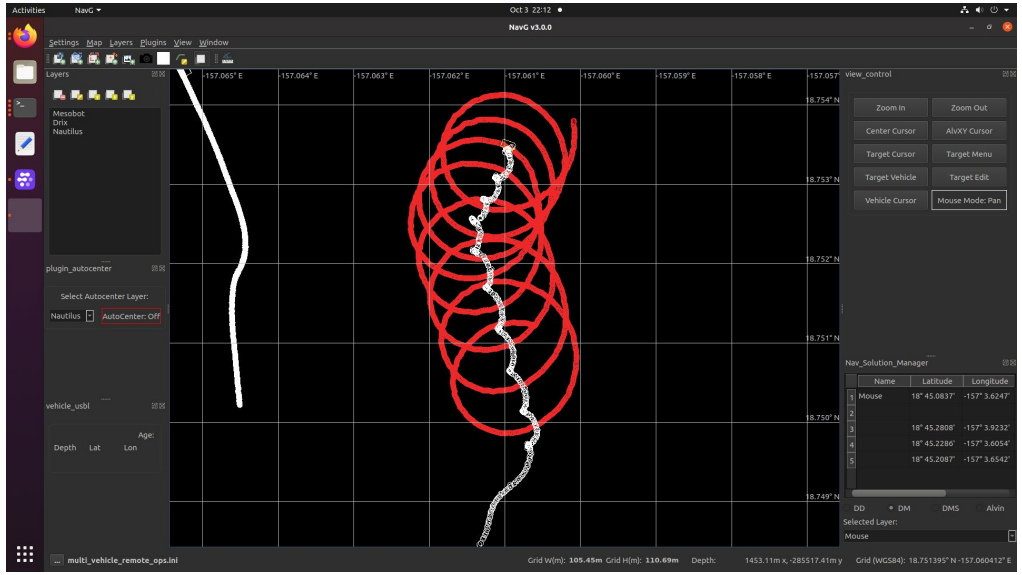
NavG

NavG: Navigational situational awareness tool

Objectives

- Demonstrate the ability to handle data from different vehicle types, manufacturers, and software architectures
- Plot real time position of the ship, Mesobot, Drix, and DAP

NavG



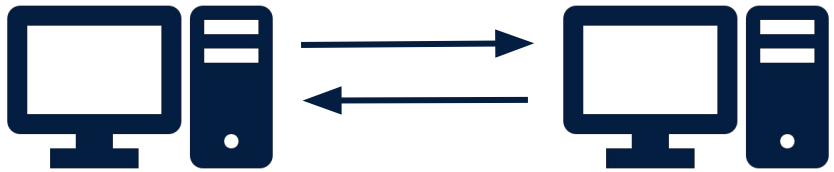
WHOI Shoreside

Network Monitor

- ROS-based
- Logged network data and published as ROS messages
- Alert Node subscribed and took warning actions based on values
  - Audio (beeping)
  - Visual (pop-up messages)
- Open-source visualization tool: Foxglove Studio

Network Setup

- 2 connection options used
  - Wireguard
    - Software VPN
    - Operates at Level 3 (IP)
    - WHOI IS now supports a server and has standardized a setup process for creating peers
  - DCB
    - Bridges two LANs
    - Hardware connection
    - Operates at Level 2 (Ethernet)



WIREGUARD
FAST, MODERN, SECURE VPN TUNNEL

- One onboard machine handled all VPN traffic and network configurations to link data (e.g., Drix network)

Network Satellite Links

- **Mostly operated over Marlink VSAT**
  - 20 Mb upload/download bandwidth
  - Latencies between WHOI/Ship measured roughly between 600-800 ms
- **Initial issues with testing VPN over Starlink**
  - Starlink changes IP addresses often
    - CGNAT (Carrier-grade NAT)
    - Starlink uses CGNAT to avoid the need for 1,000s of IPv4 addresses
    - Shared public IP address with multiple users
  - Difficult for organizational firewalls
  - Latencies between WHOI/Ship measured roughly 100-200 ms on average
  - Saw up to 40 Mbps upload/download
  - Current users noted issues with out of order packets / dropped packets -- connection works well for some type of data but not all (e.g., video)

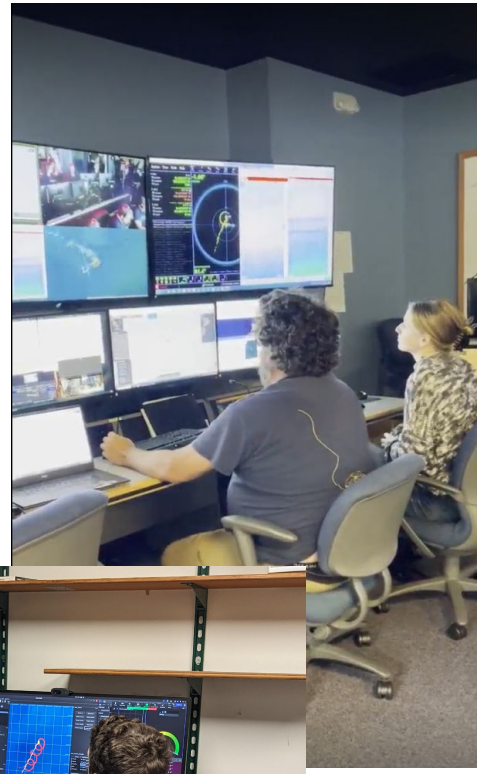
Live Demonstration

Shore Participants:

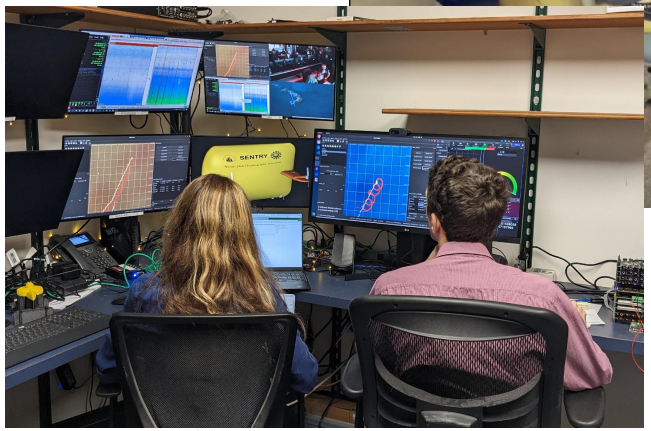
- *Greensea*
  - Engaging Blue Economy
  - Explore future partnerships/collaborations
  - Monitored vehicle positions through data sent from the ship

- *UNH*
  - Provided an overview of their remote operations setup
  - Shore operator took control and directed Drix in support of Mesobot

- *WHOI*
  - Determined sample location based on the situational awareness tools available (NavG, EK80 stream, network monitor, etc.)
  - Depth and sampling commands executed on shore and passed through Drix to Mesobot



UNH Shoreside



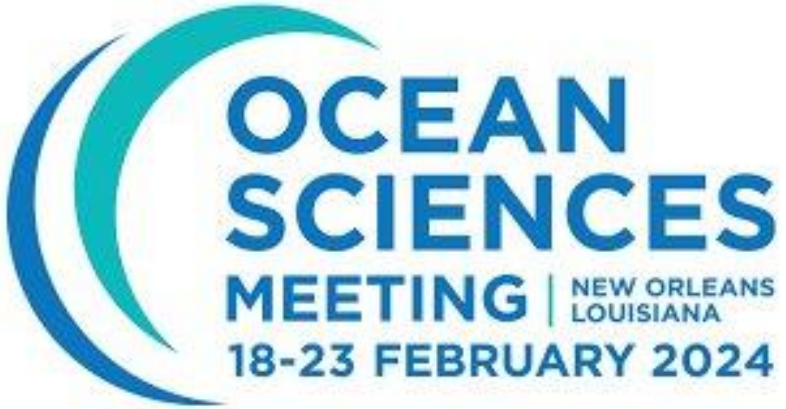
WHOI Shoreside

Summary/Conclusions

- Shifting vehicle operations to shore can act as a force-multiplier in terms of personnel, time, and area coverage

- Power of collaboration between different vehicle groups and operators – the "middleware" is the crucial component

- Some next steps:
  - Create technical document outlining workflows, recommended setup, and specific requirements for remote ops
  - Continue to develop a remote operations "fly-away" system for easy integration onto any ship
  - Apply lessons learned and tools implemented towards a future cruise and integrate into standard operations – preliminary planning with an AUV Sentry cruise this upcoming fall



- Session: Collective Solutions to Global Deep-Sea Challenges: Advancing Ocean Exploration and Observing Through Large-Scale Collaborations and Technological Advances
- Presentation: Tuesday, Feb 22 08:50am

Acknowledgements

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NA155
Photo Credit: Ocean Exploration Trust / Nova West