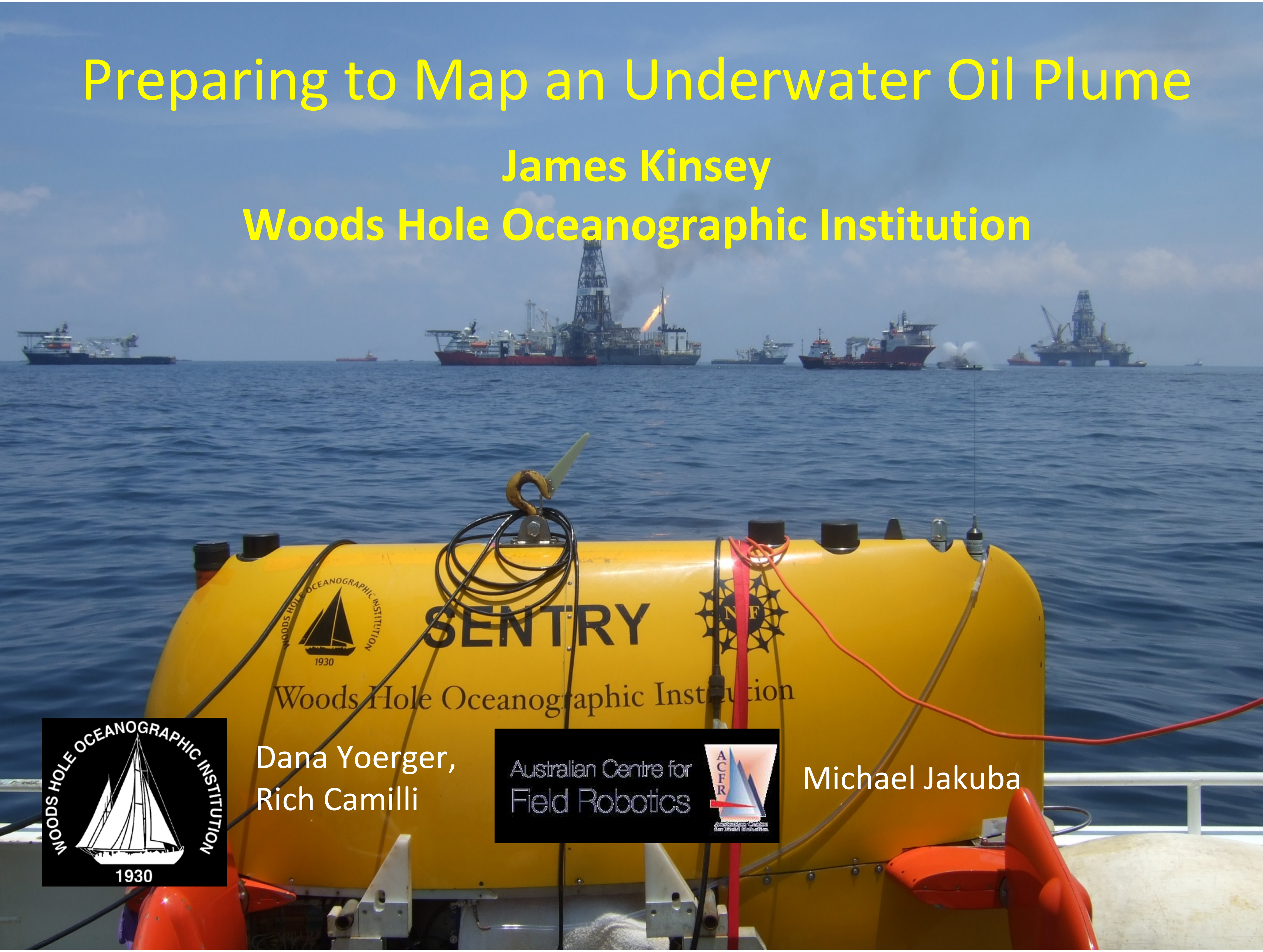
Preparing to Map an Underwater Oil Plume

James Kinsey
Woods Hole Oceanographic Institution



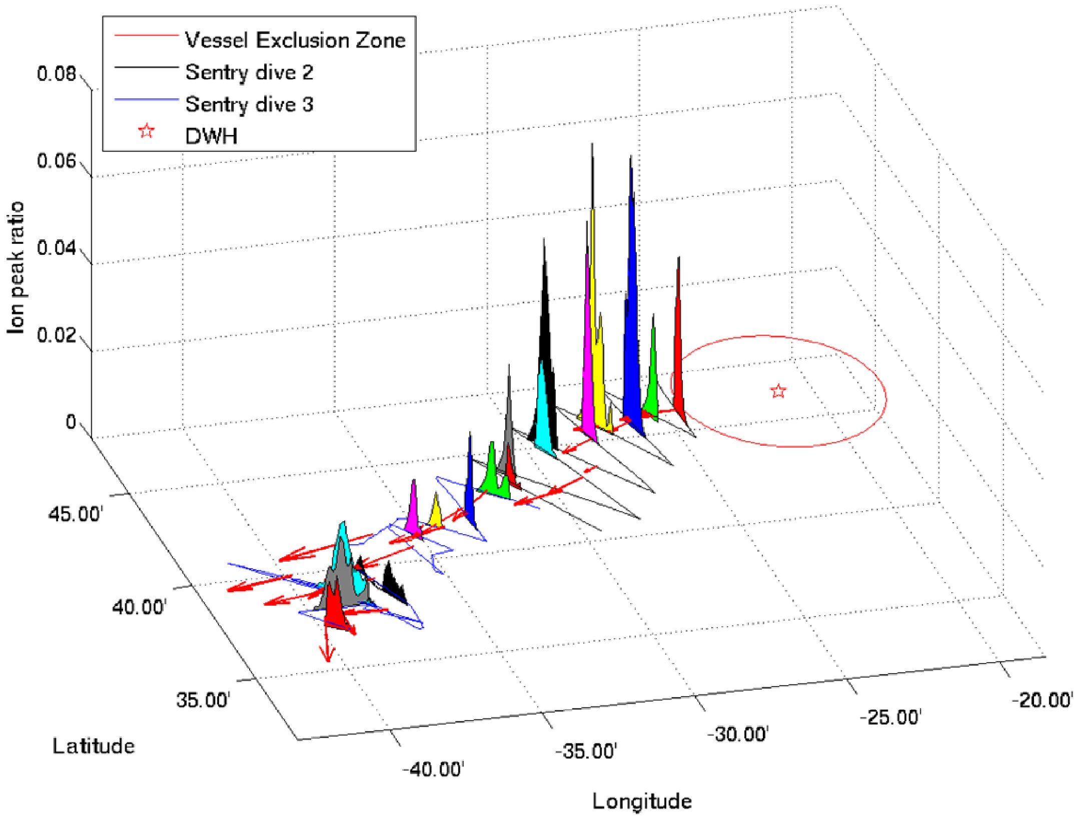
WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Dana Yoerger,
Rich Camilli

Australian Centre for Field Robotics
ACFR

Michael Jakuba

What went into this figure?



- Is there oil?
- If so, what is the horizontal and vertical extent of the subsea oil?
- Does the structure of the oil plume correlate with the water velocity?

Enabling Technologies

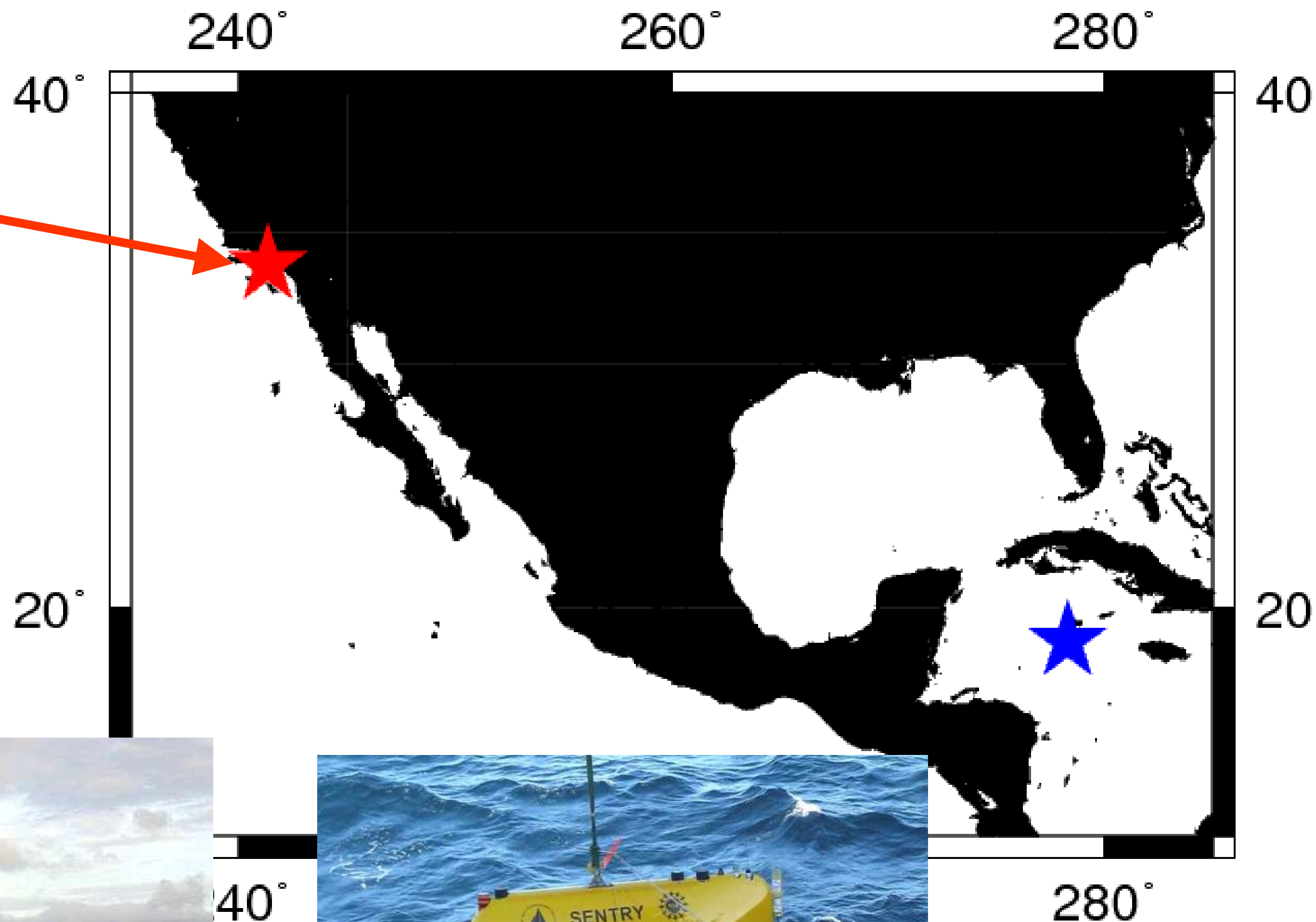
- Acoustic telemetry
- Mid-water column navigation
- In-situ data visualization
- Vehicle re-tasking

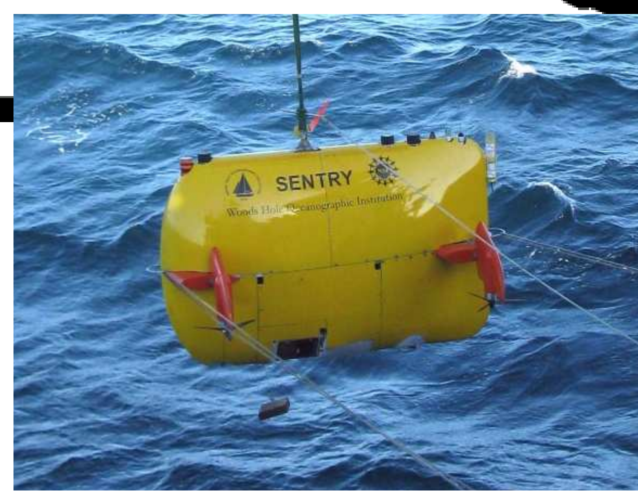
In this talk, we will discuss our advances in these technical areas over the past year and how they played a role in mapping the subsea oil plume with Sentry.

- 2009 SEEPS Expedition with Sentry
- 2009 OASES Expedition with Nereus

2009 SEEPS Expedition

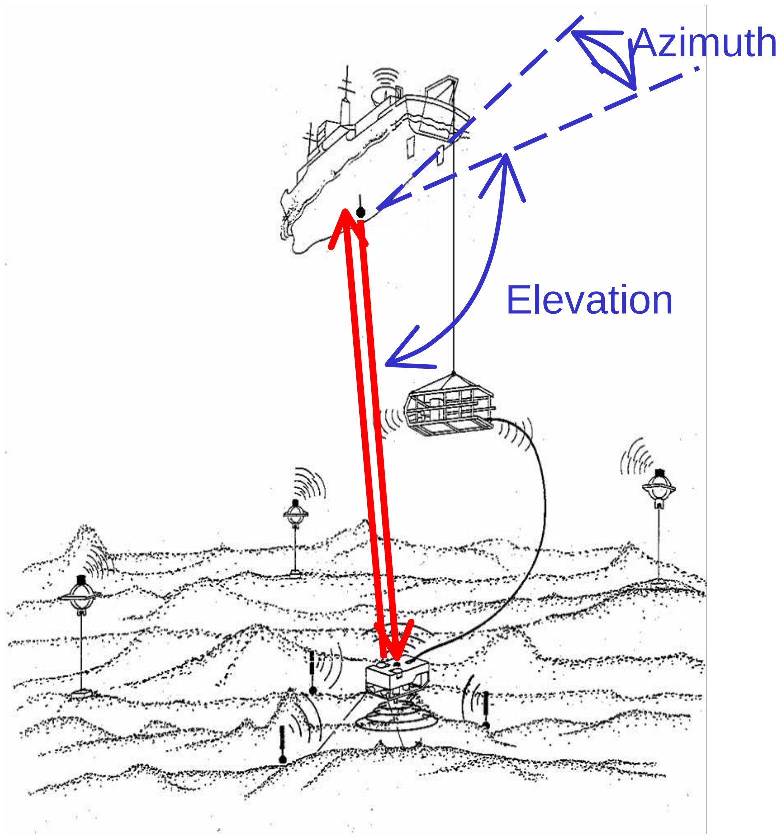
- 16 day cruise to the Santa Barbara Basin in September 2009 aboard the R/V Atlantis.
- Combined operations with DSV Alvin and the Sentry AUV.
- Cruise funded by both NSF and NASA ASTEP programs.





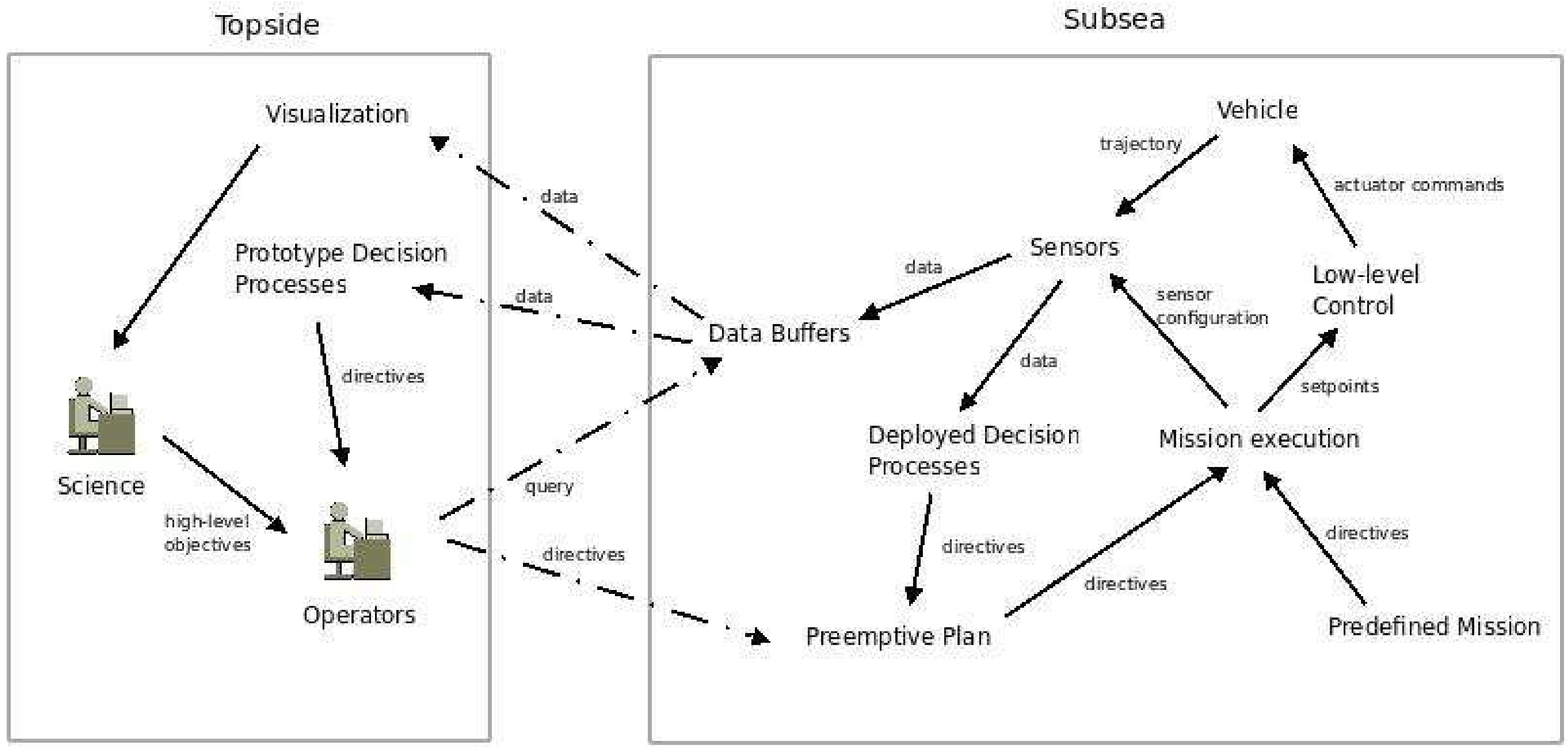
SEEPS 2009 – First Time Using USBL and Acomms

- In Summer 2009, we integrated a Sonardyne USBL system into Sentry
- Provides both vehicle tracking and acoustic telemetry in a single unit



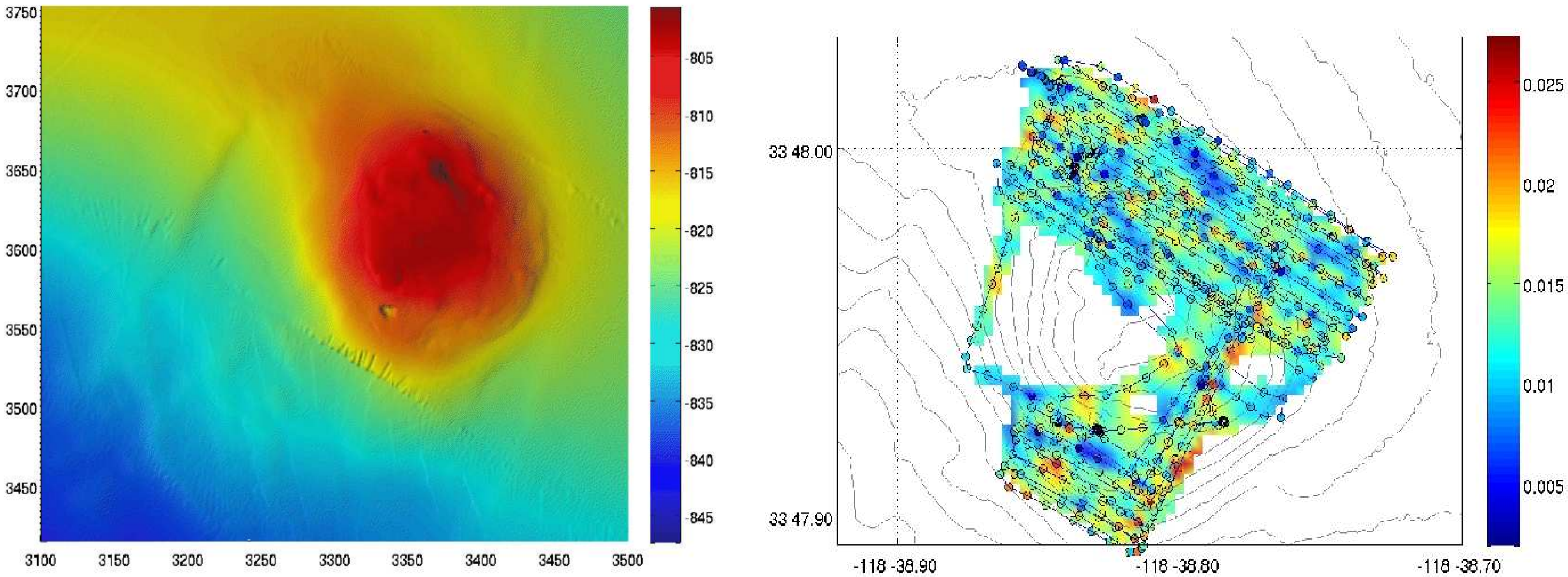
Sonardyne USBL Transreceiver

Acoustic Telemetry – Architecture



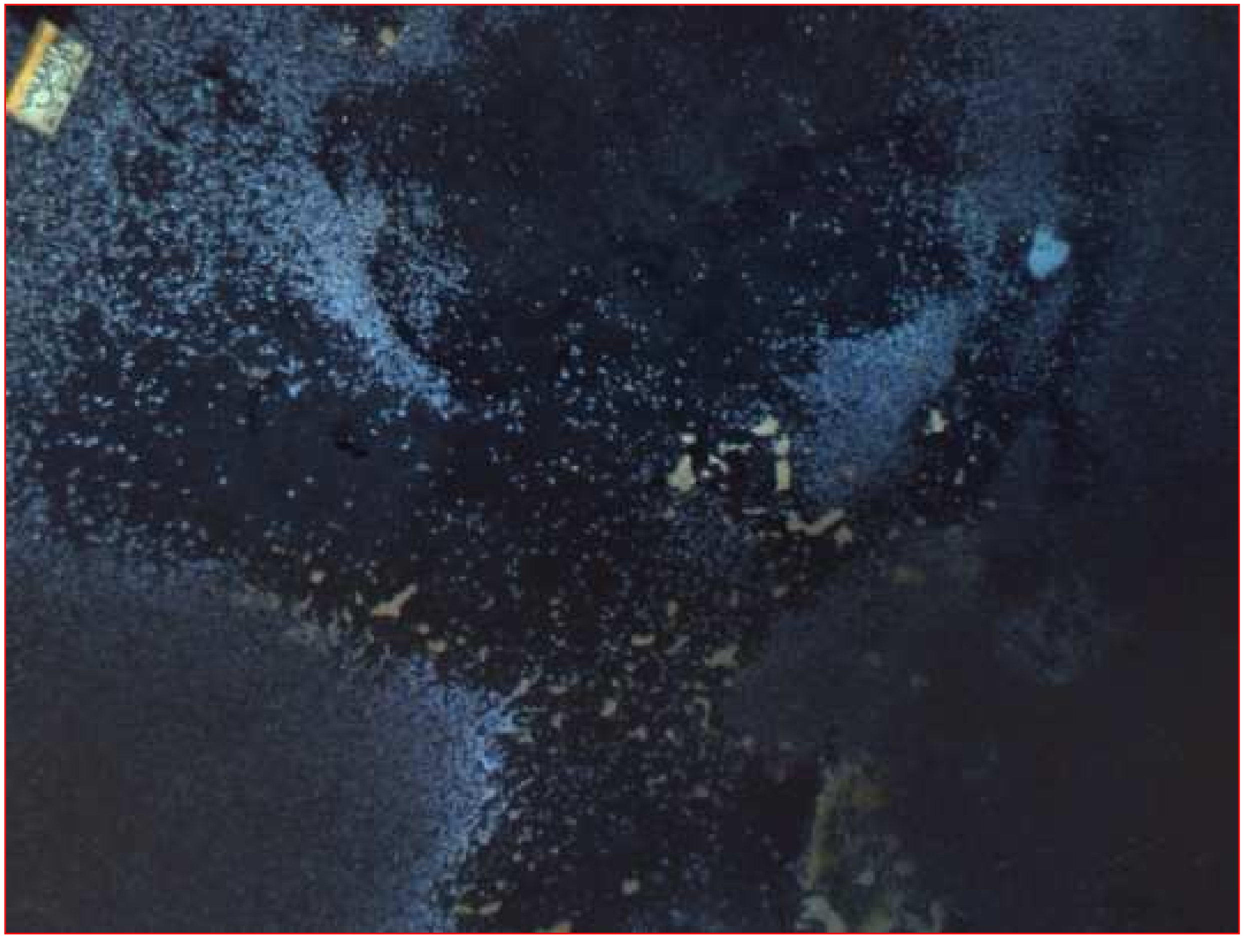
Control and communications architecture utilizing a limited-bandwidth acoustic link with acoustic transmission indicated by dashed lines. Scientific personnel monitor real time visualized mission data and recommend high-level alterations to the mission plan to operators that translate these objectives into low-level mission directives for transmission. Autonomous decision processes either topside or subsea also generate directives with these being directly entered into the preemptive execution queue or upon approval by operators.

Acoustic Telemetry – Field Results



Left – bathymetry of Pauls Pingo, a seafloor cold seep feature located at 850m depth in the Santa Monica Basin. Right, Vehicle trajectory and normalized methane TETHYS mass spectrometer data.

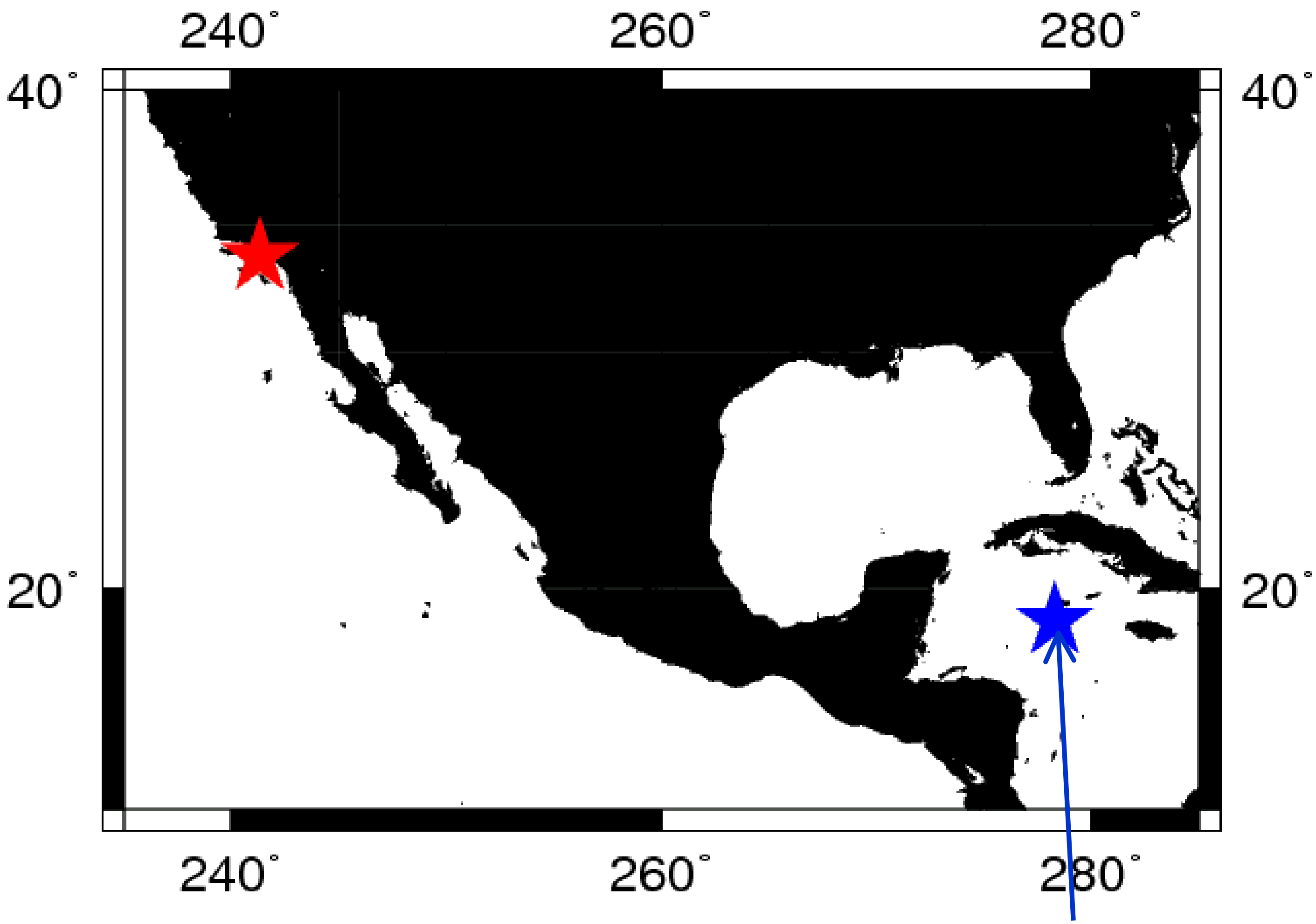
Acoustic Telemetry – Enabled Demonstrations in autonomously identifying and returning to features



The photo was recorded while conducting an autonomous near-field analysis of a cold seep target site. Vehicle positioning during this photo was based on the estimated location of cold seep source, as determined in real-time by the AUV's mass spectrometer payload. Various types of microbial mats are visible through the photo.

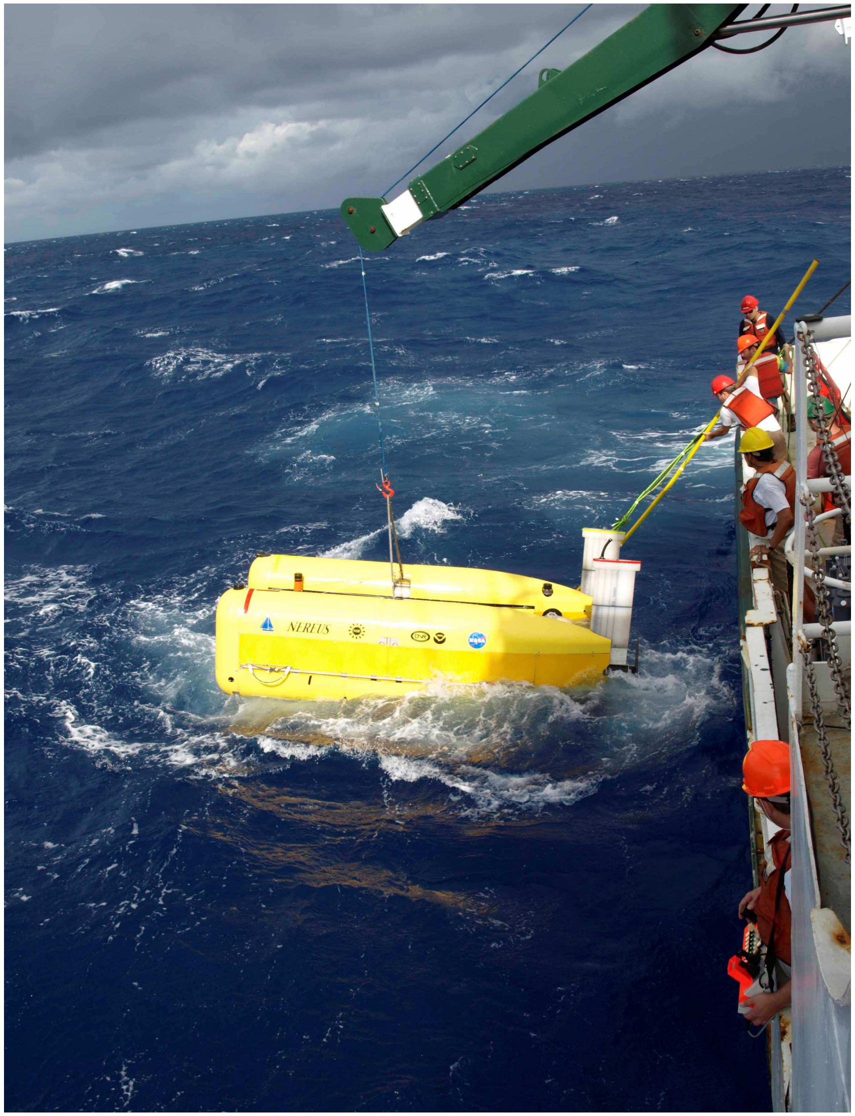
2009 OASES Expedition

- 5 week cruise to the Mid-Cayman Rise to search for the world's deepest hyrdothermal vents
- Deployed Nereus from the 135' R/V Cape Hatteras
- Cruise funded by the NASA ASTEP program

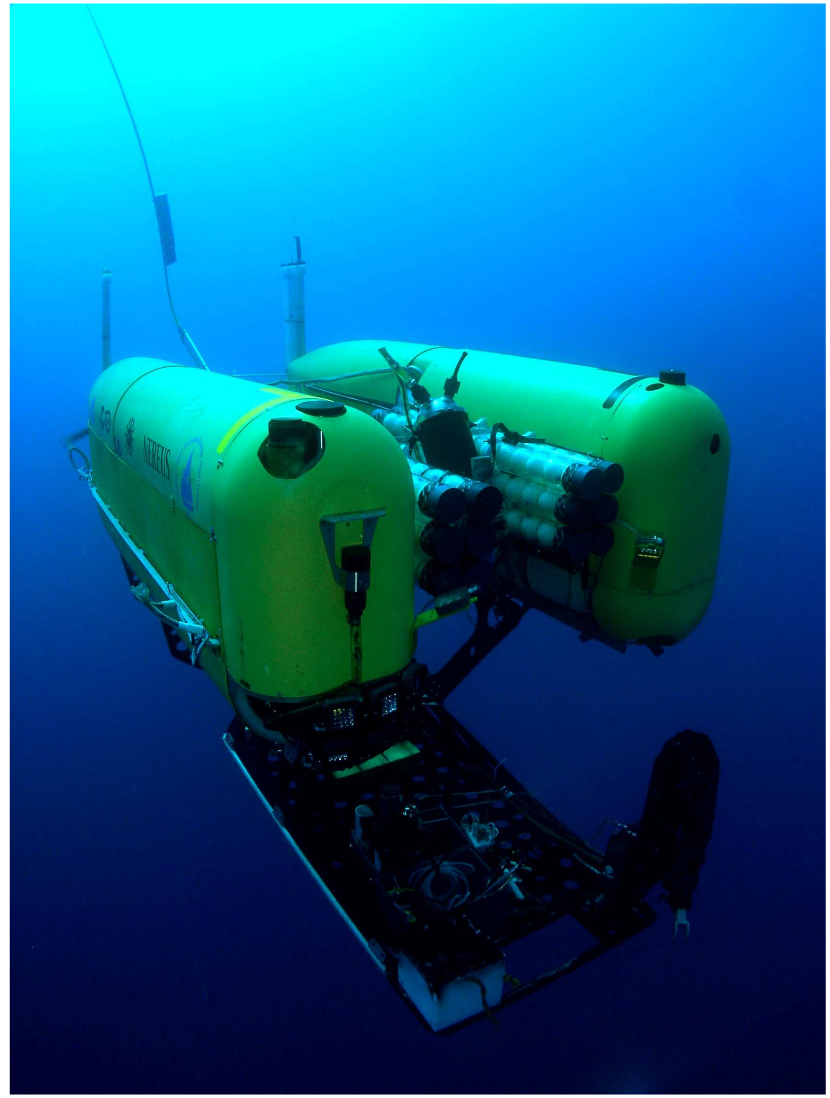


Much of the vehicle controls and acoustic telemetry capability developed on the SEEPS cruise (just 2 weeks earlier) was used with the Nereus vehicle on the ASTEP funded OASES cruise to the Cayman Trough.

Nereus Hybrid ROV

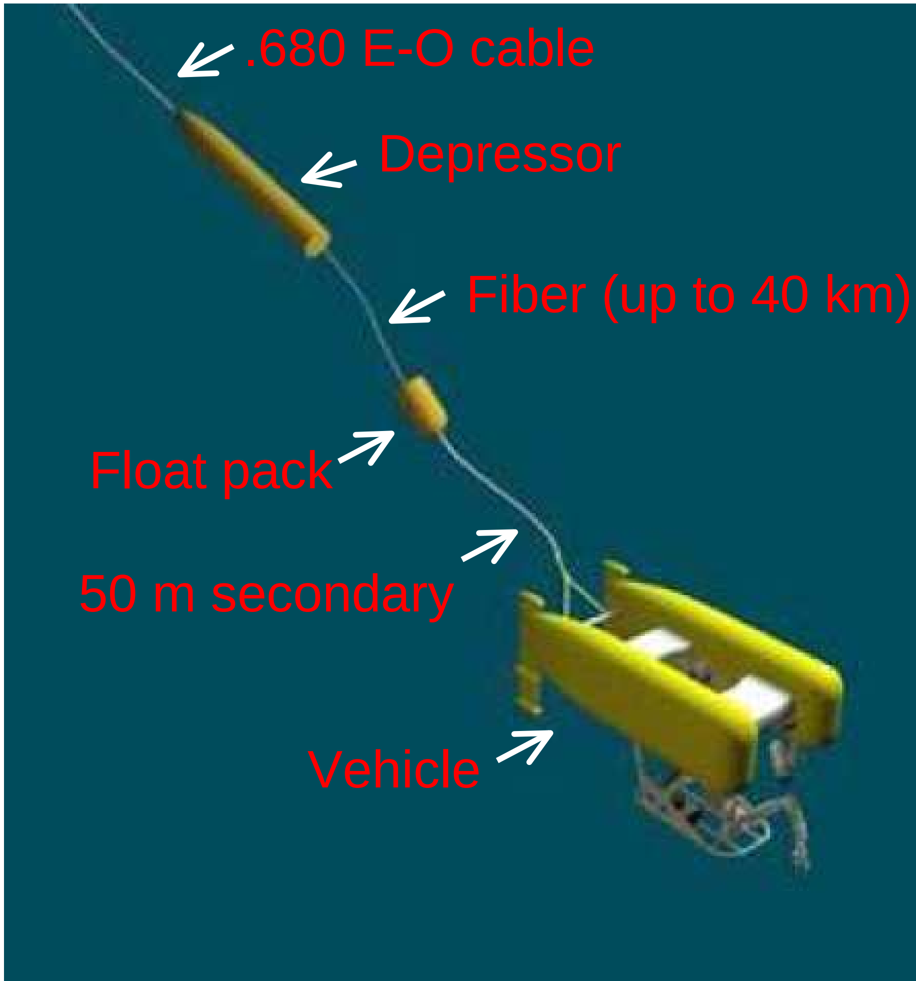


<u>Untethered AUV Mode</u>
- 2625 kg
- 1472 ceramic spheres
- 30 kg (wet wt) payload

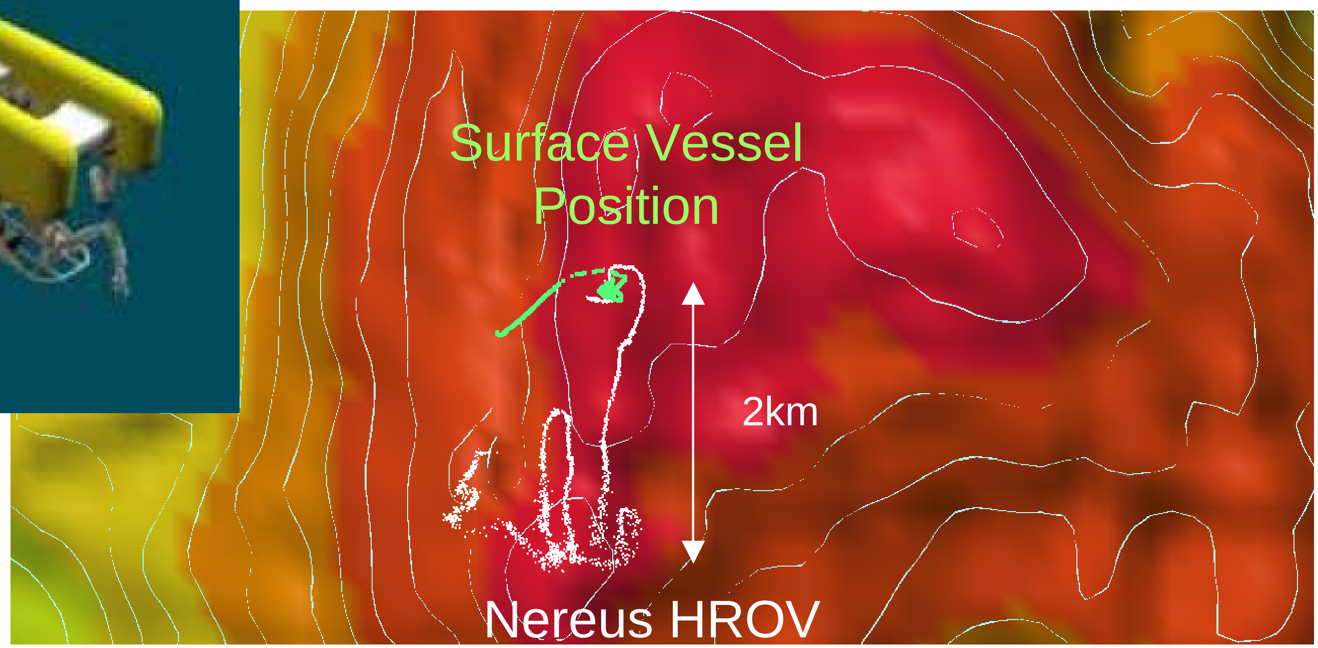


<u>Tethered ROV Mode</u>
- 2920 kg
- 1680 ceramic spheres
- 30 kg (wet wt) payload

Light Fibre Tether



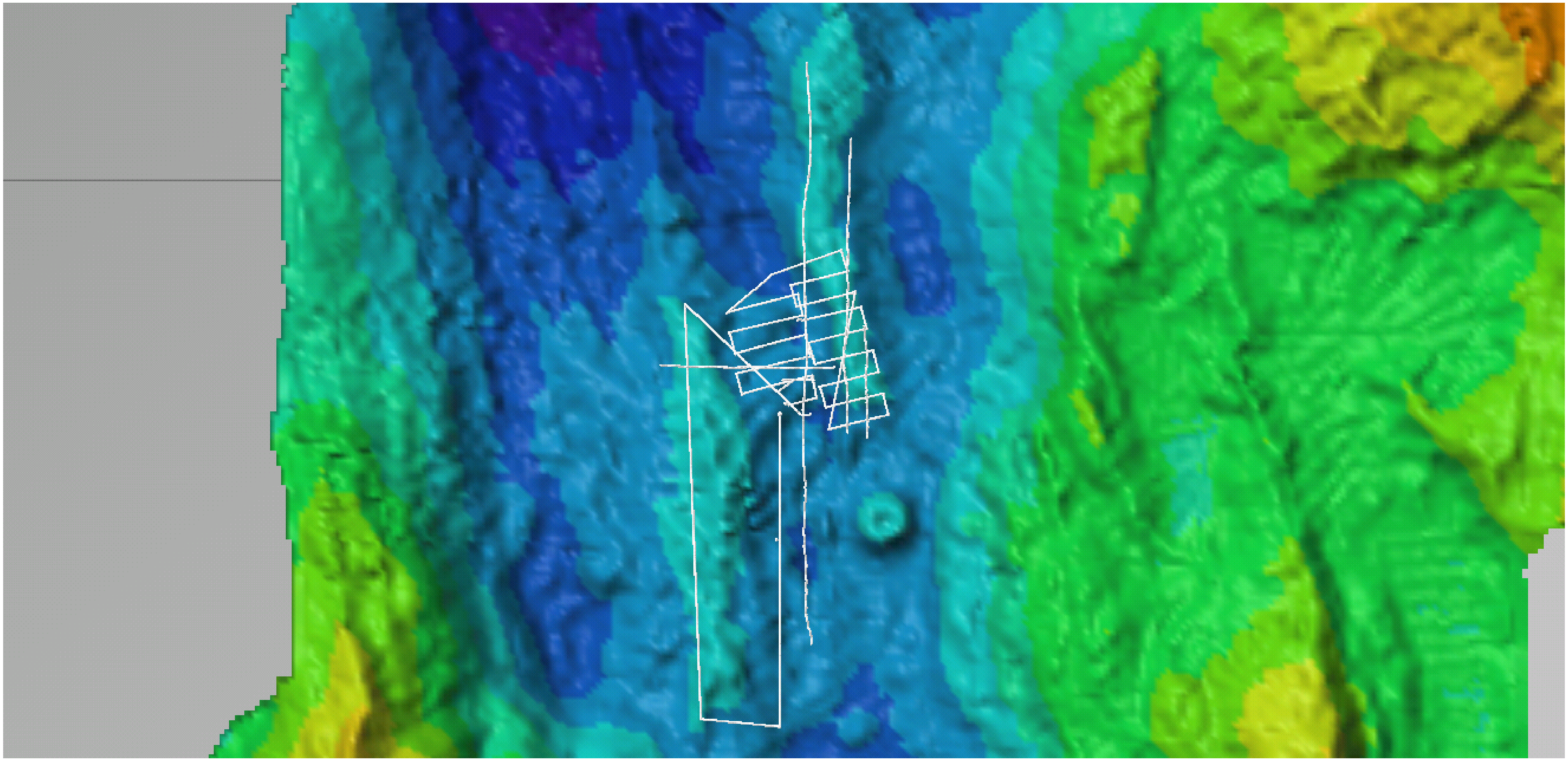
- High bandwidth (GigE) communications
- Unconstrained by surface ship
- Operable from non-DP vessels



Mid-Water Navigation

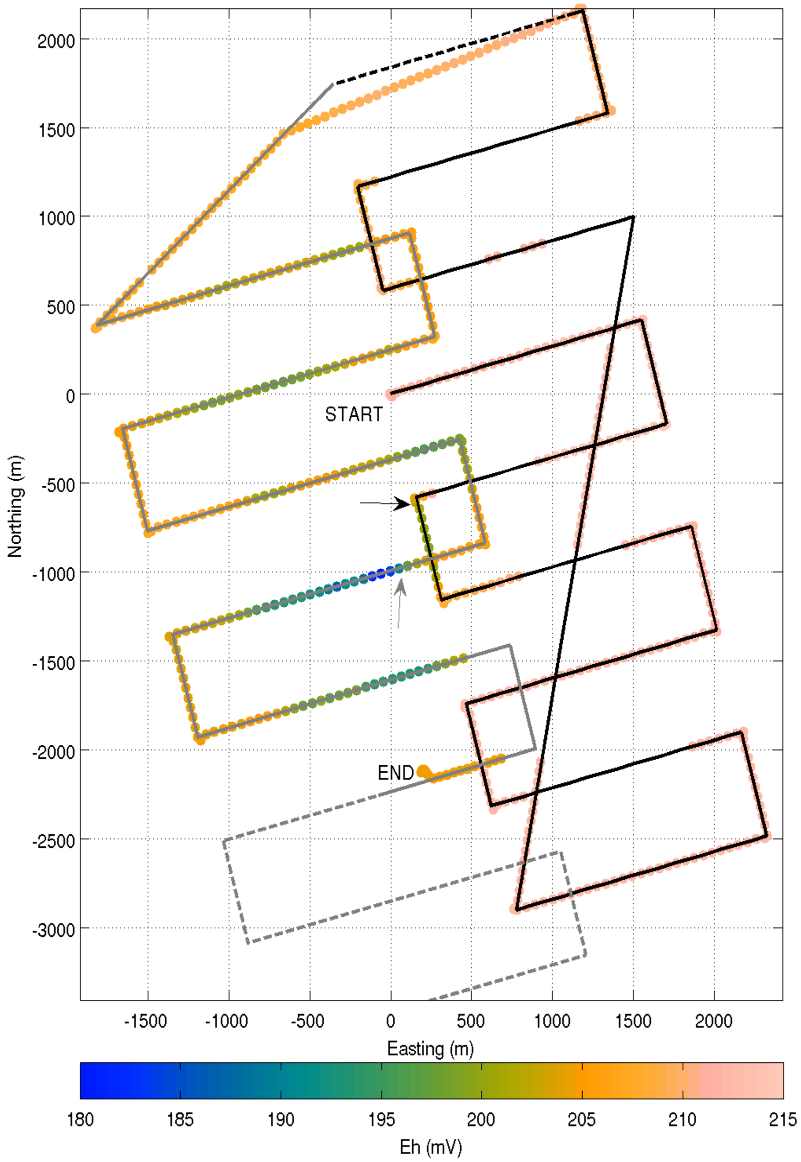
- CTD casts indicated the plume in the Cayman Trough was over 700m above the seafloor – out of range of the DVL
- In the mid-water column, conventional near-bottom navigation methods are unavailable (Bottom-Lock Doppler, SLAM, Terrain Relative, etc).
- Mid-water sensing is limited:
  - Depth
  - Heading and Attitude
  - Acoustic LBL and USBL
  - Inertial (but limited by lack of Doppler Correction)
- We used dynamic model estimates of the vehicle velocity to dead-reckon vehicle position
- Vehicle was tracked with USBL from topside and position corrections could be sent via the acoustic modem.

Mid-Water Navigation



- Two 24 hour dives at altitudes exceeding 500m refined our estimate of the vent location.
- USBL tracking of the vehicle at depths exceeding 5000m

Acoustic Telemetry – Field Results

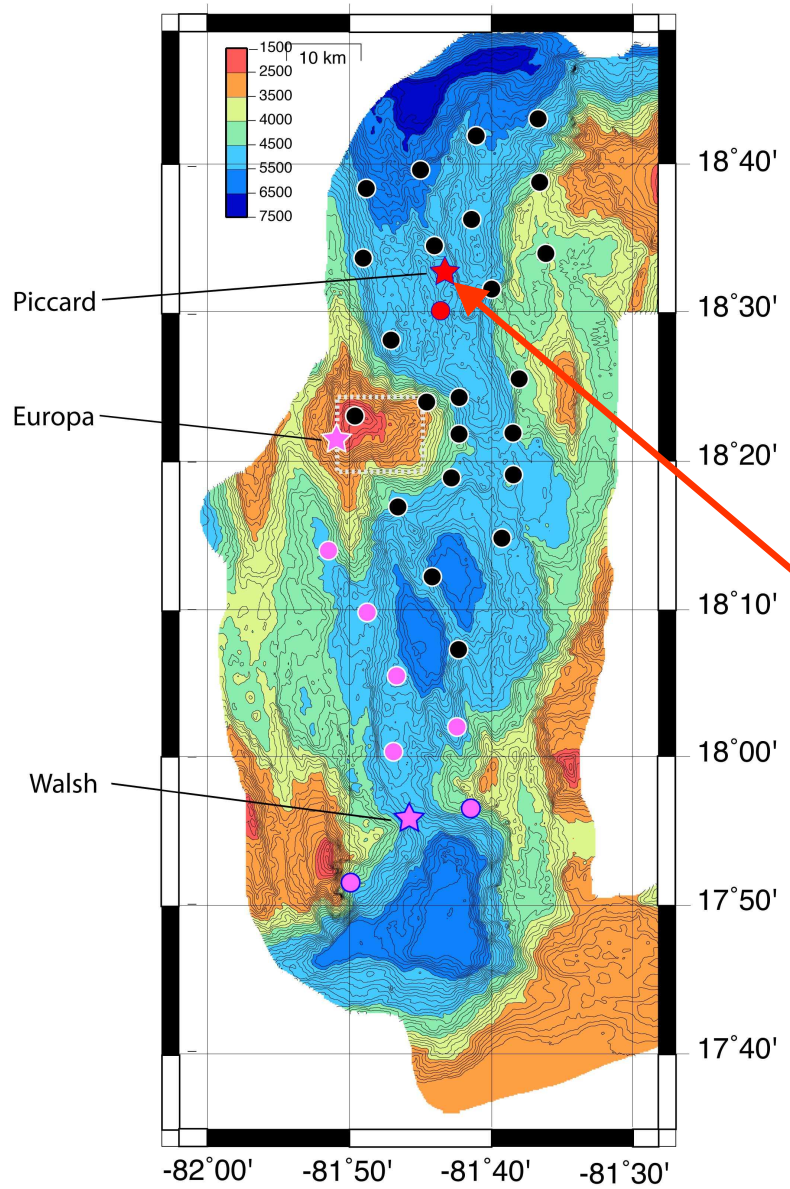


•Dive plan and telemetered redox potential (Eh) during a Nereus dive in AUV mode on the Cayman Trough.

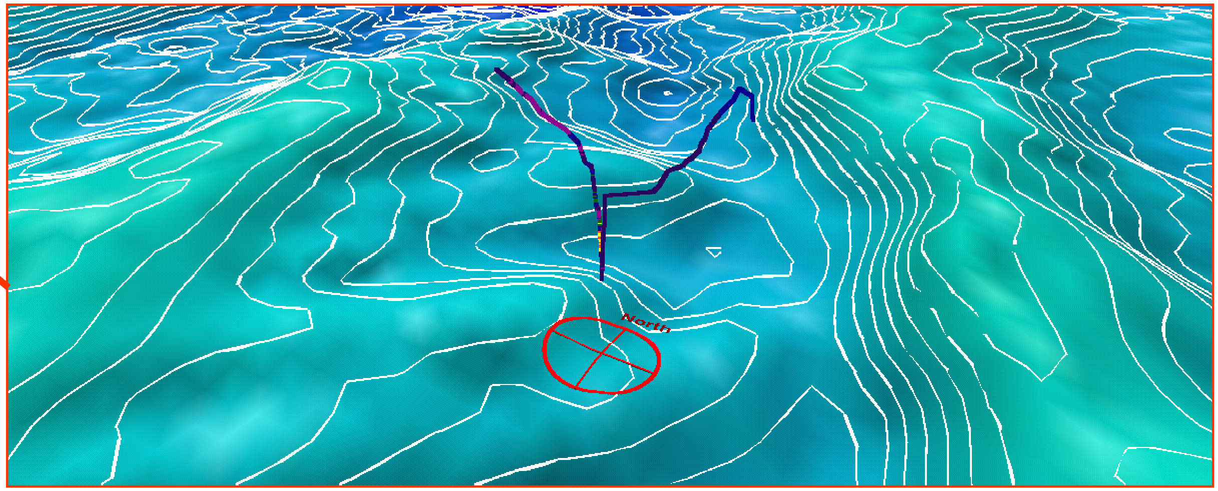
•The arrows indicate rapid decreases in Eh characteristic of nascent hydrothermal plume.

•The second half of the dive was based on a mission telemetered to the vehicle during the dive.

2009 OASES Expedition



- Poor weather ended the cruise before we could find the “Piccard” vent site.
- Shared information helped our British colleagues discover the vent in March 2010.



[German, et al, PNAS 2010]

2010 Gulf of Mexico Cruise: Goals

- In June, WHOI researchers embarked on a 14 day voyage on the R/V Endeavor to investigate underwater oil plumes.
- Two Important Questions:
  - Where is the oil?
  - What is the flavor of the oil?
- To answer these questions, we need:
  - Chemical sensor measurements of the water
  - Water samples for later analysis in the lab

R/V Endeavor

Conventional Methods

- ❑ Traditionally scientists have obtained water measurements from a Conductivity-Temperature-Density (CTD) rosette lowered from the ship on a wire.
- ❑ These rosettes are routinely equipped with chemical sensors and sampling bottles
- ❑ A time-consuming process

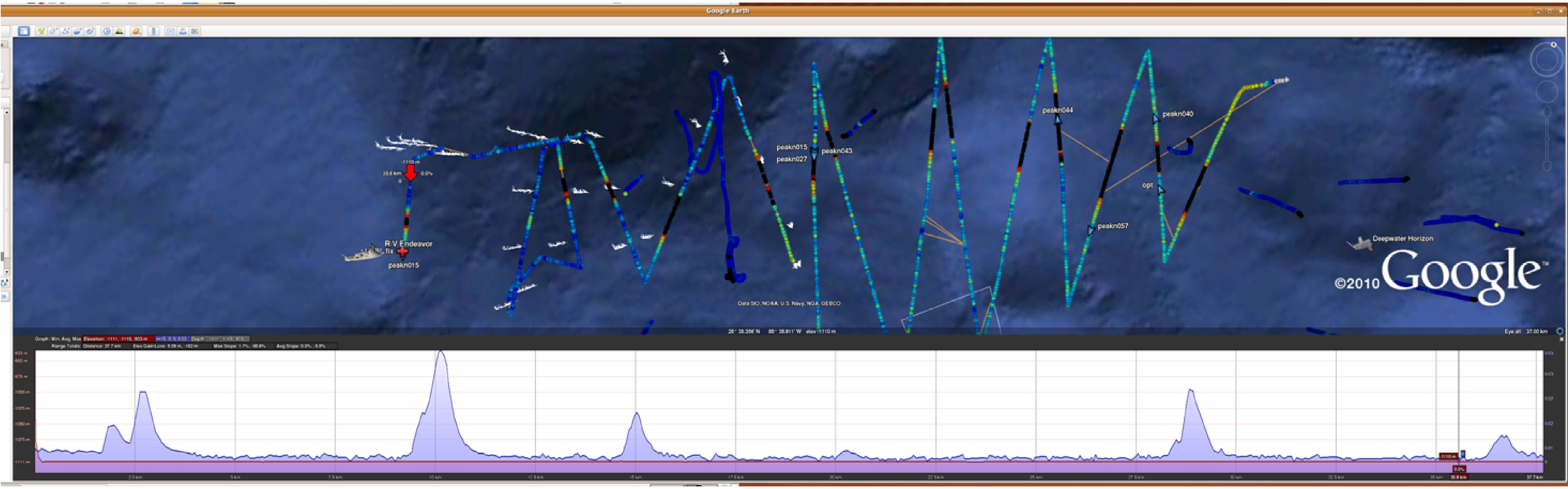
DWH 2010 – Years of Work Helped Prepare Us

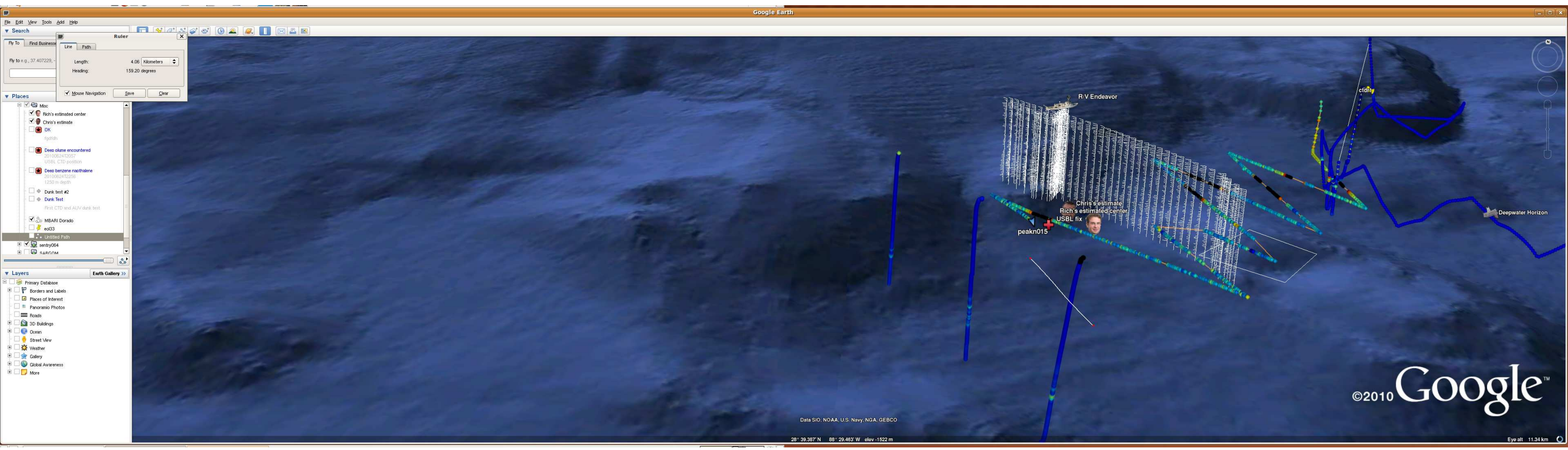
- ❑ The Sentry/Tethys combination was ideally suited for the task.
- ❑ In the *days* of planning we had for this cruise, we determined and had to:

    1. Search for a plume potentially hundreds of meters off of the seafloor
    2. Rapidly respond to data (often while the vehicle was still in the water) to inform our sampling program.
    3. Optimize every minute of our time on station. If we were no longer tracking the plume, we needed to change vehicle trajectory to re-acquire the plume

- ❑ The methods we had developed with ABE over the last 15 years and the new technologies developed for Sentry and Nereus proved essential.

In-Situ Data Visualization Tools

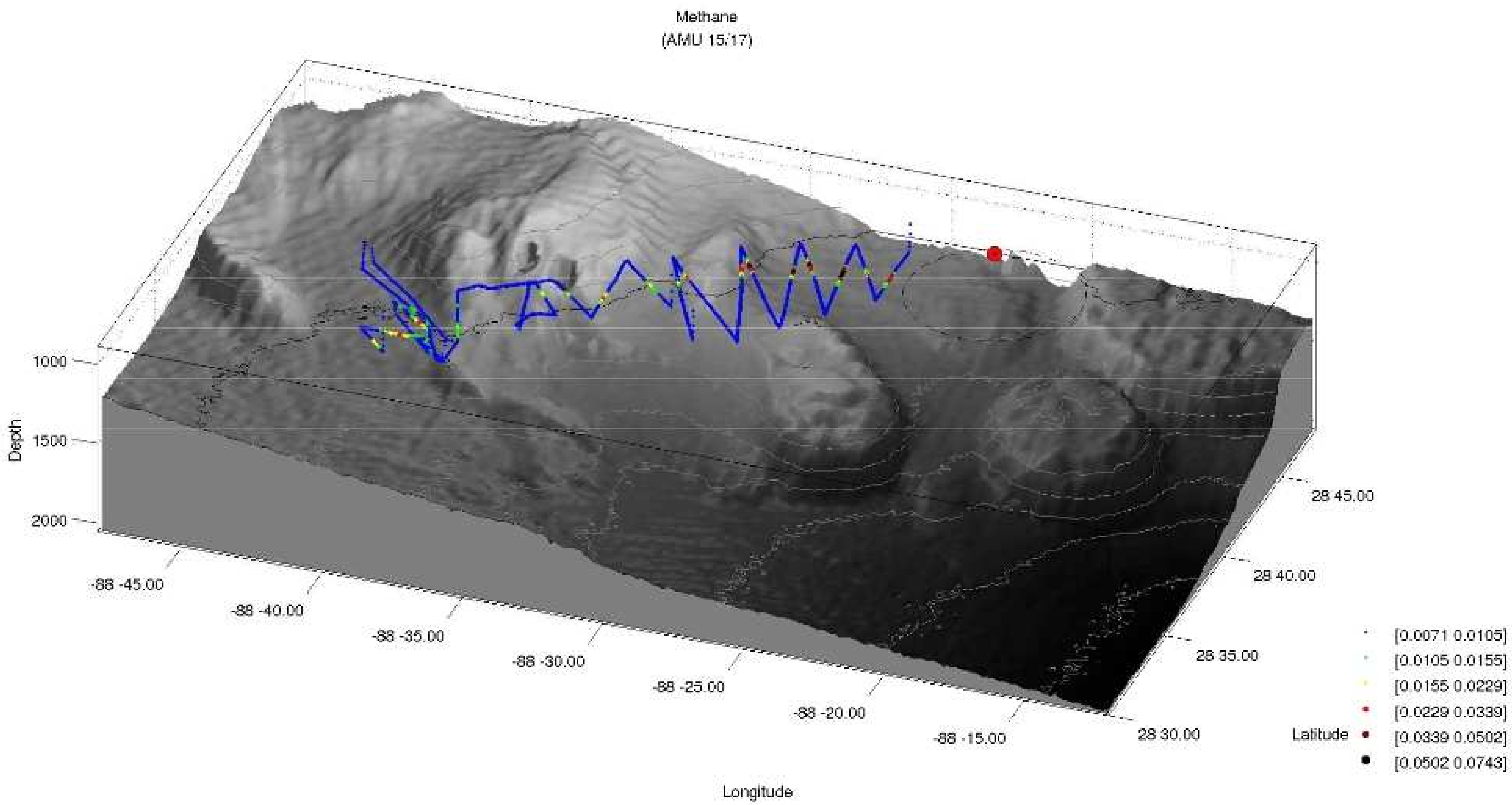




Gulf of Mexico 2010 - Data

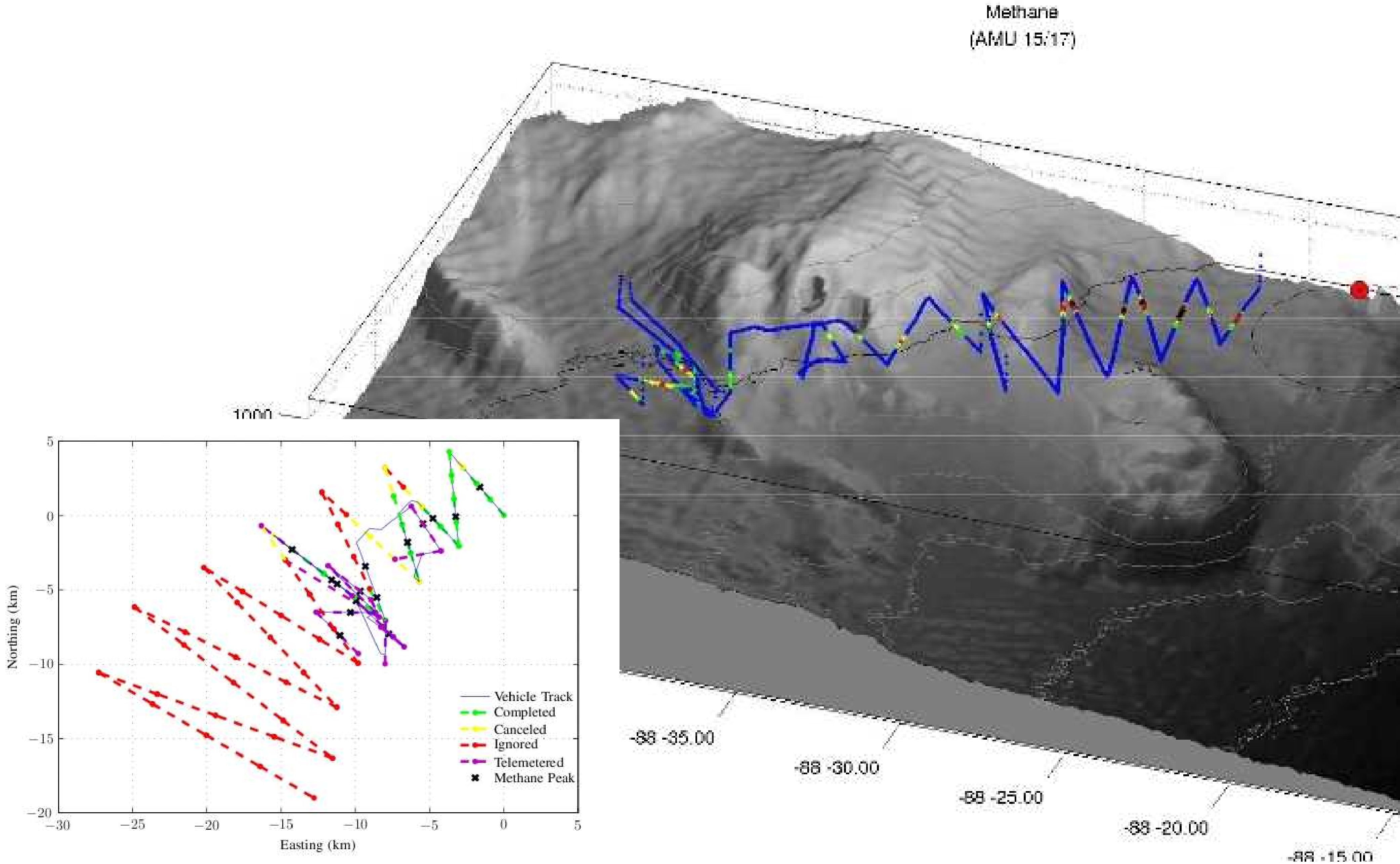
- ❑ Over a million individual chemical sensor were obtained on the cruise.
  - Initial analysis informed where to deploy the CTD and Sentry next.
  - Often retasked Sentry on the fly (an untethered ROV?)

Sentry 064 and 065



Jakuba, et al. IROS 2010

Sentry 065 – Boxing in the Plume

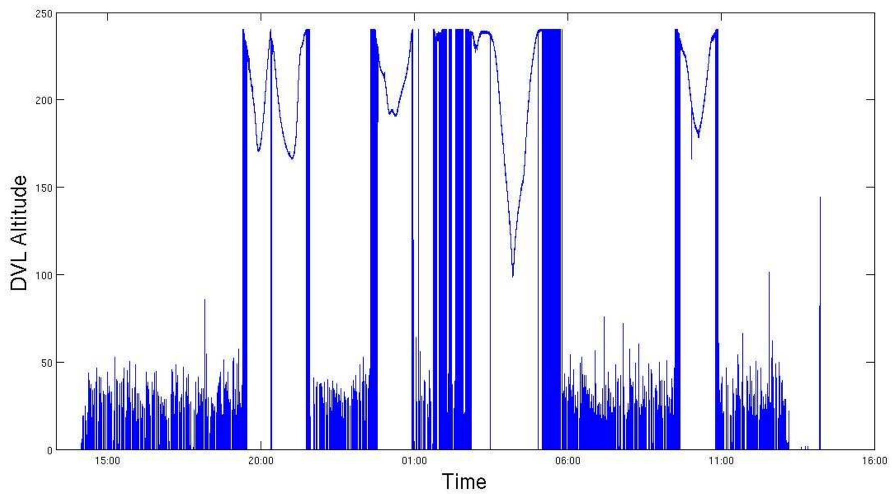


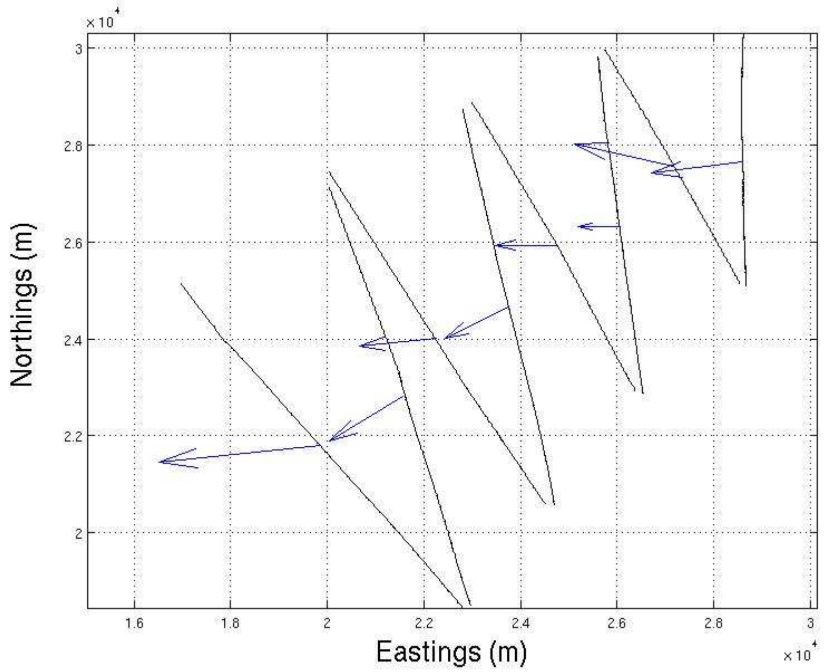
ADCP Measurements

• Using ADCP data from the 300kHz TRDI DVL, we were able to measure the water velocity relative to the vehicle.

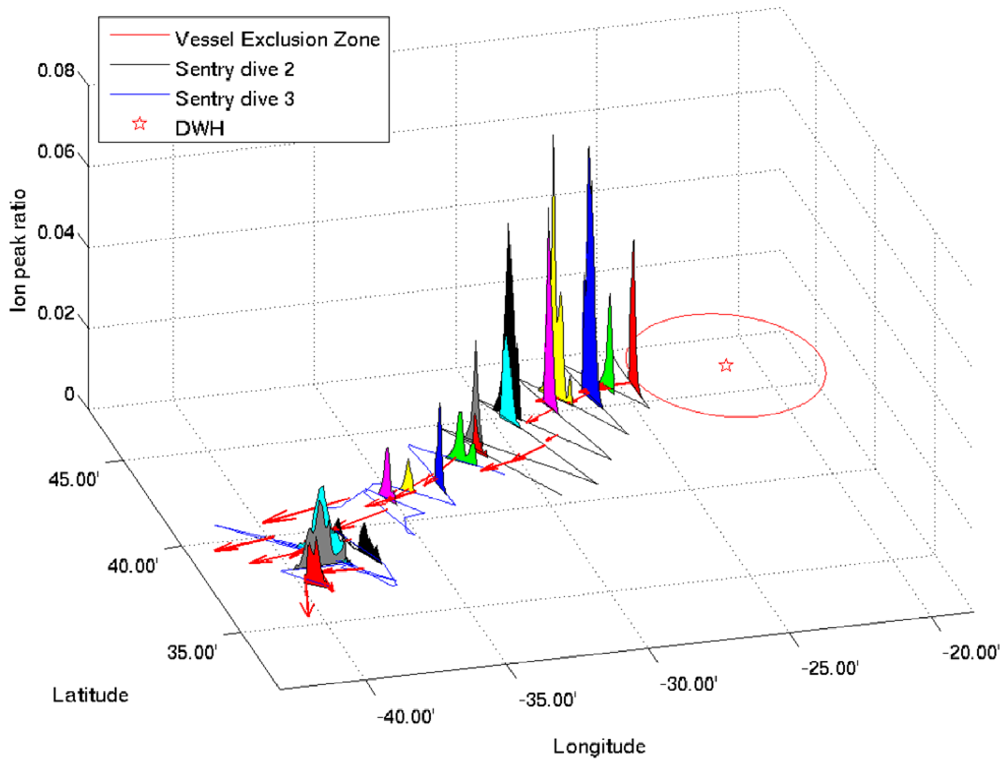
• Most of the time, we were out of DVL bottom-lock – i.e., No bottom velocity measurements

• Used the model velocity estimates and the USBL positions to provide estimates of the vehicle velocity over the trackline.





The Final Product



• Using the acoustic telemetry, navigation, and in-situ data visualization and retasking, we were able to spatially constrain the plume.

•The course over ground of these velocity measurements corresponds to the observed structure of the plume.

• These observations, combined with the mass spectrometer data, informs us about the extent of the plume and where to obtain samples.

Concluding Remarks

- The Sentry AUV and the TETHYS mass spectrometer are an optimal and unique combination for mapping underwater oil plumes.
- During the cruise, Sentry obtained over a million chemical sensor data measurements – all of them spatially referenced to within a few meters.
- The acoustic telemetry and re-tasking capabilities proved crucial in mapping the plume.
- This architecture enables future work in supervised autonomy.
- This data enables us to find and spatially map underwater oil plumes.
- The robotic technology employed here was developed for basic ocean science yet was directly applicable to a crucial national issue.