Ocean Observatories Initiative

Adaptive Oceanographic Sampling with Mobile Assets

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CONSORTIUM FOR Ocean Leadership

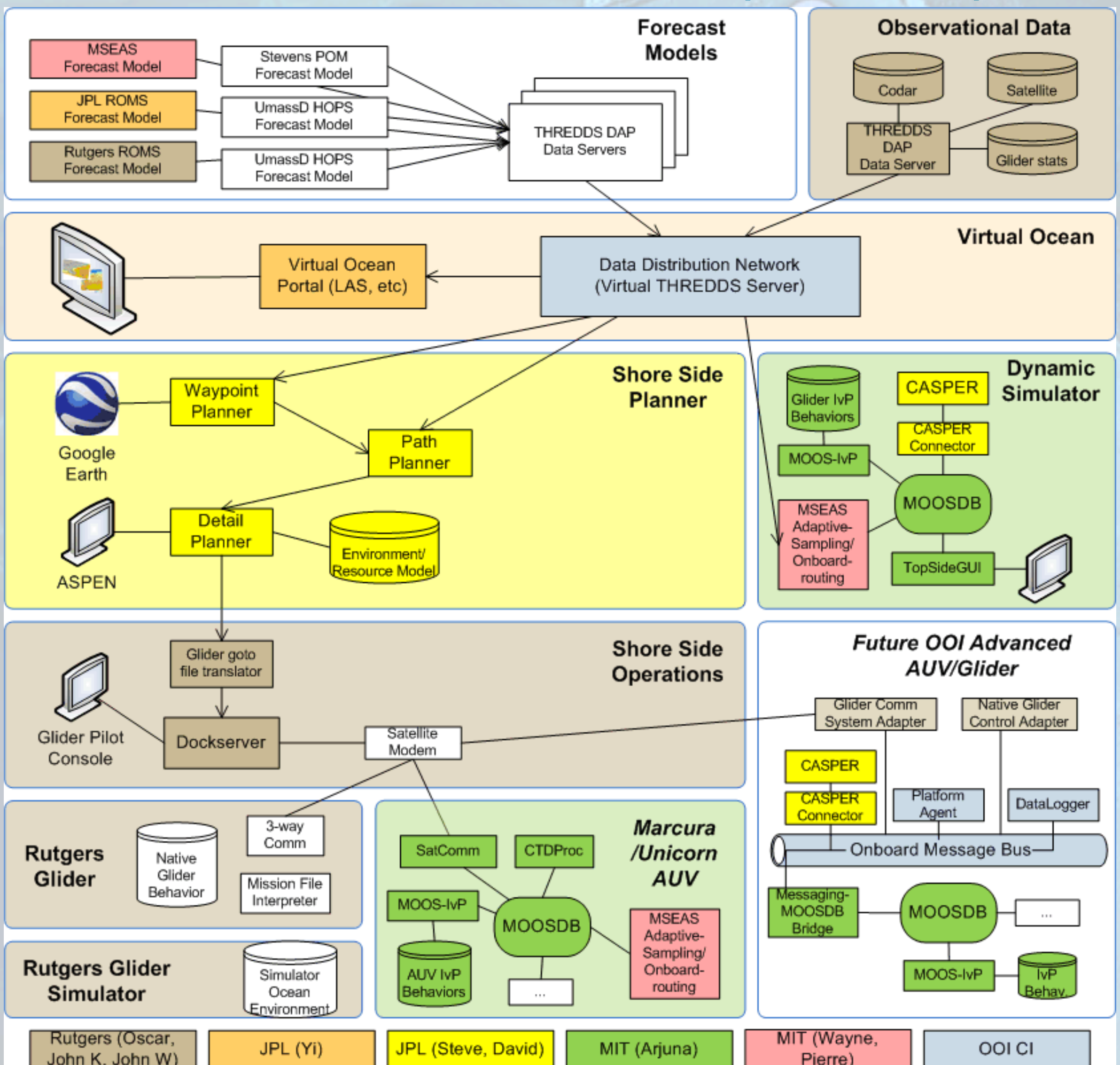
OSU Oregon State UNIVERSITY

UCSD

UNIVERSITY of WASHINGTON

OOI CI Kick-Off Meeting
Devils Thumb Ranch, Colorado
September 9-11, 2009

Observing System Simulation Experiment (OSSE)



Partners:
- MIT
- JPL
  - Model Integration
  - Autonomy
- Rutgers
- UCSD

Deployments:
- Virtual Simulation Sept 2009
- Field Deployment Nov 2009

Nested Autonomy Implementation

Backseat Driver Paradigm - ASTM F41

Three components of the overall vehicle architecture.

- ***Control and Navigation*** *(frontseat driver)*

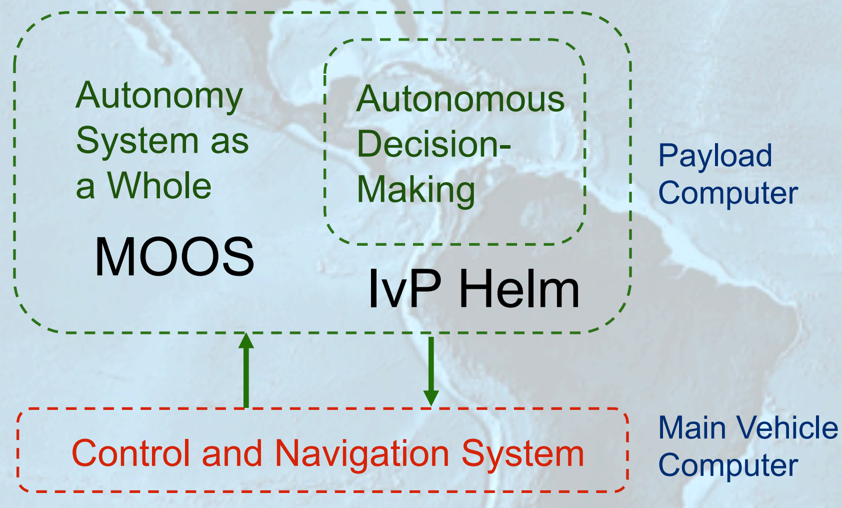
  Actuator control, inertial navigation, GPS,compass, DVL, dead-reckoning systems, vehicle safety.

- ***Autonomy System as a Whole***

  Sensor processing, sensor fusion, autonomy, contact management, data logging, system monitoring, mission control, communication.

- ***Autonomous Decision-Making*** *(backseat driver)*

  Deciding vehicle heading, speed, and depth.



MOOS

Three components of the overall vehicle architecture.

- *Control and Navigation (frontseat driver)*
  Actuator control, inertial navigation, GPS, compass, DVL, dead-reckoning systems, vehicle safety.
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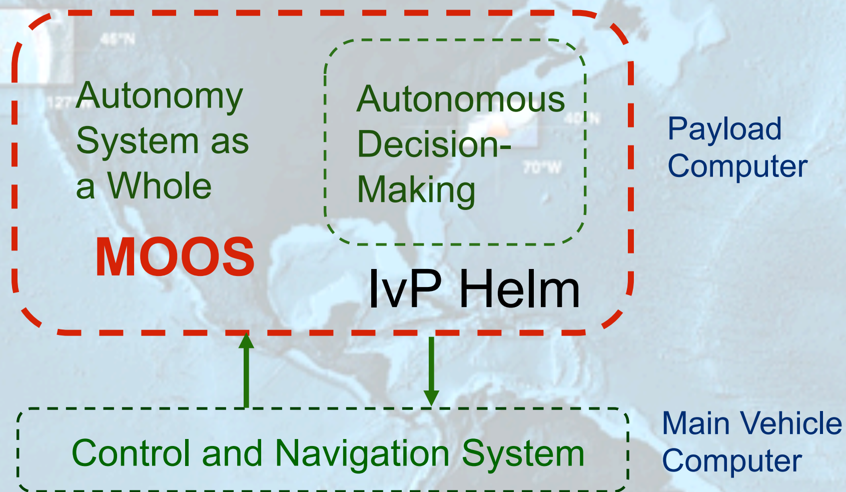
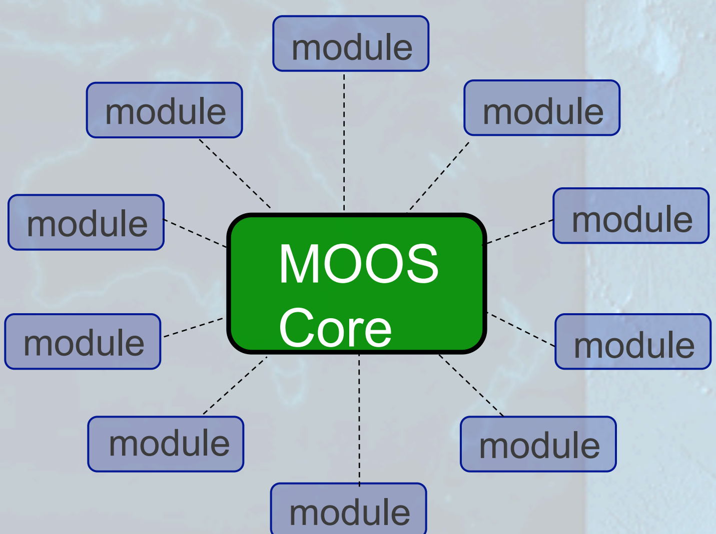
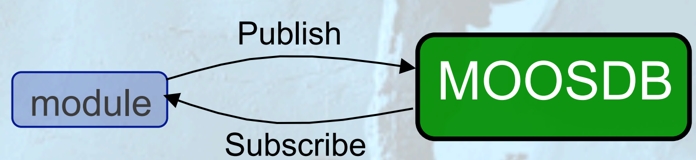




MOOS The “glue” for the autonomy system as a whole.

- *Modules coordinated through a publish and subscribe interface.*
- *Overall system is built incrementally.*



MOOS-IvP

Three components of the overall vehicle architecture.

- *Control and Navigation (frontseat driver)*

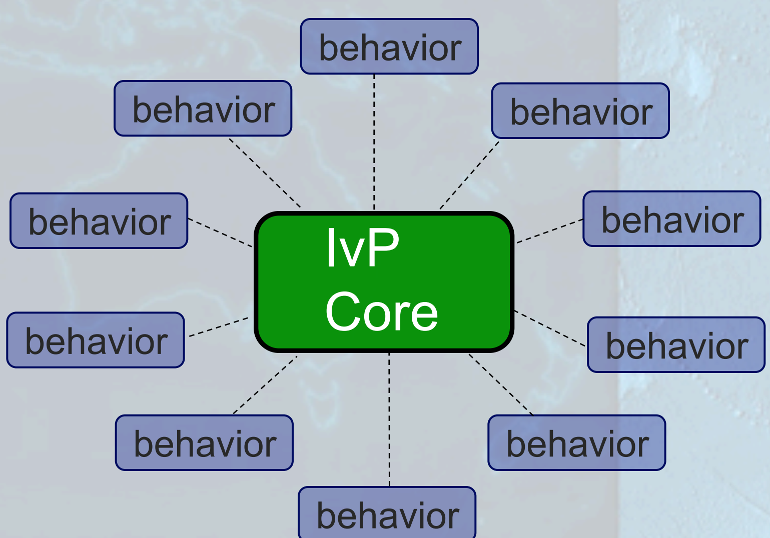
  Actuator control, inertial navigation, GPS, compass, DVL, dead-reckoning systems, vehicle safety.

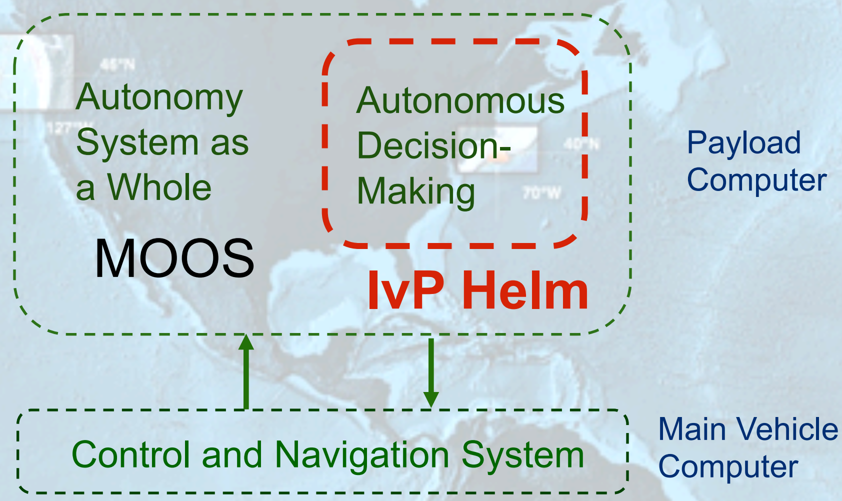
- *Autonomy System as a Whole*

  Sensor processing, sensor fusion, autonomy, contact management, data logging, system monitoring, mission control, communication.

- *Autonomous Decision-Making (backseat driver)*

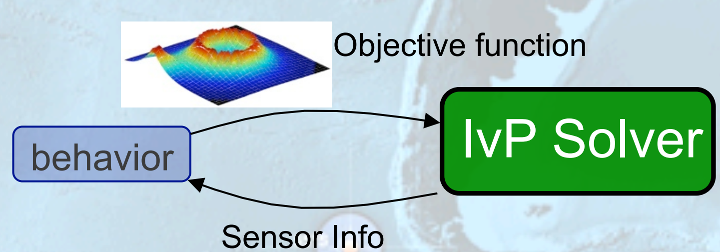
  Deciding vehicle heading, speed, and depth.





IvP Helm The “glue” for the autonomous decision-making engine

- *Modules coordinated through logic (behavior algebra), objective functions and multi-objective optimization.*
- *Overall system is built incrementally.*

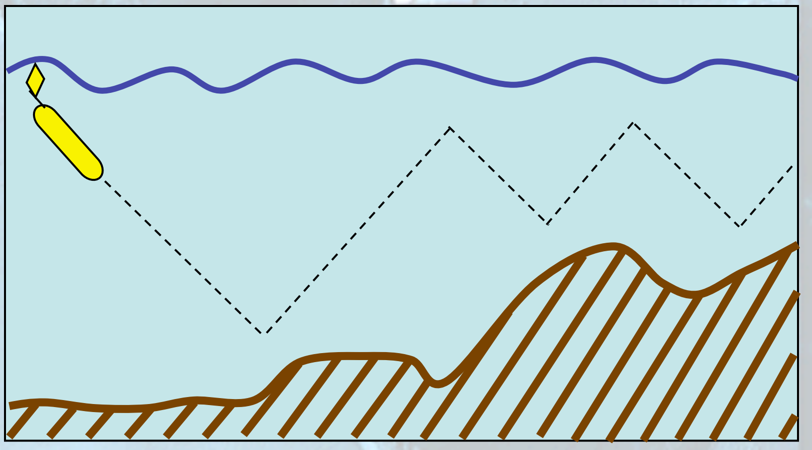


Adaptive Environmental Sampling

- Rapid Environmental Assessment (REA)
- Incorporate real-time CTD & other instrumental data into adaptive sampling behaviors onboard a vehicle using the MOOS IvP architecture
  - Track oceanographic features
    - Sound speed
    - Fronts
    - Thermoclines, haloclines, pycnoclines
    - O_2 & Cl concentrations, flourescence
    - Light attenuation
    - Currents

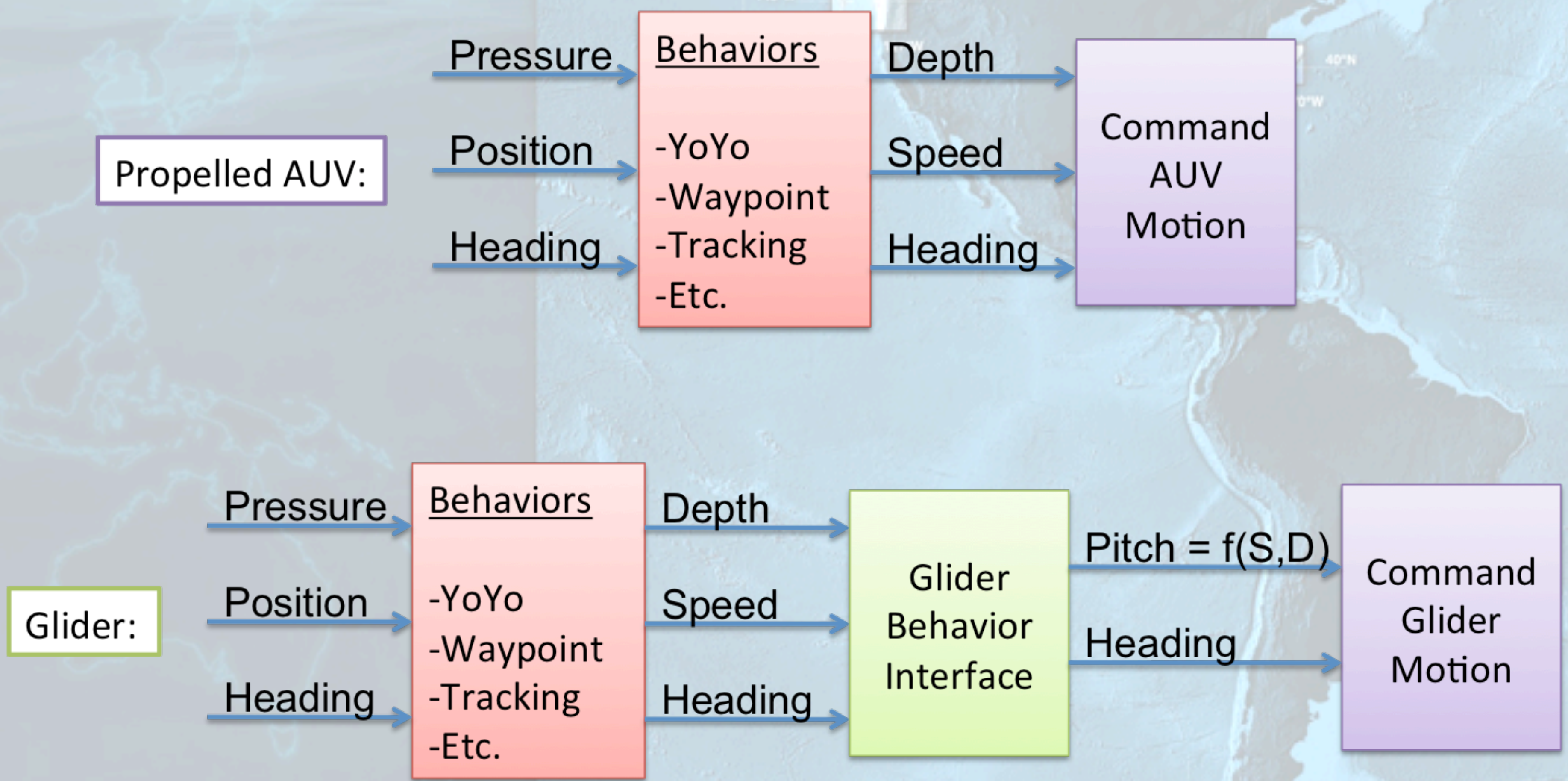
Behavior Implementation

- Gliders vs. (actively propelled) AUVs
- Currently have a library of AUV behaviors (basic & advanced) in MOOS IvP
  - Yoyo
  - Waypoint
  - Tracking
  - etc.
- Approach
  - Created a glider behavior interface for MOOS IvP
  - Use existing AUV behaviors



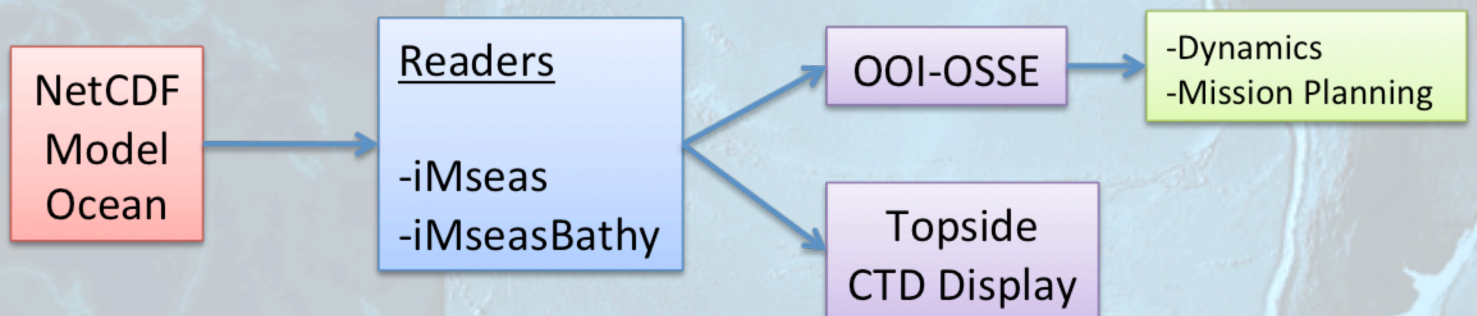
Glider dynamics restrict its motion to a yo-yo pattern through the water column, requiring a different set of motion commands from those of a propelled AUV.

Behavior Interfaces



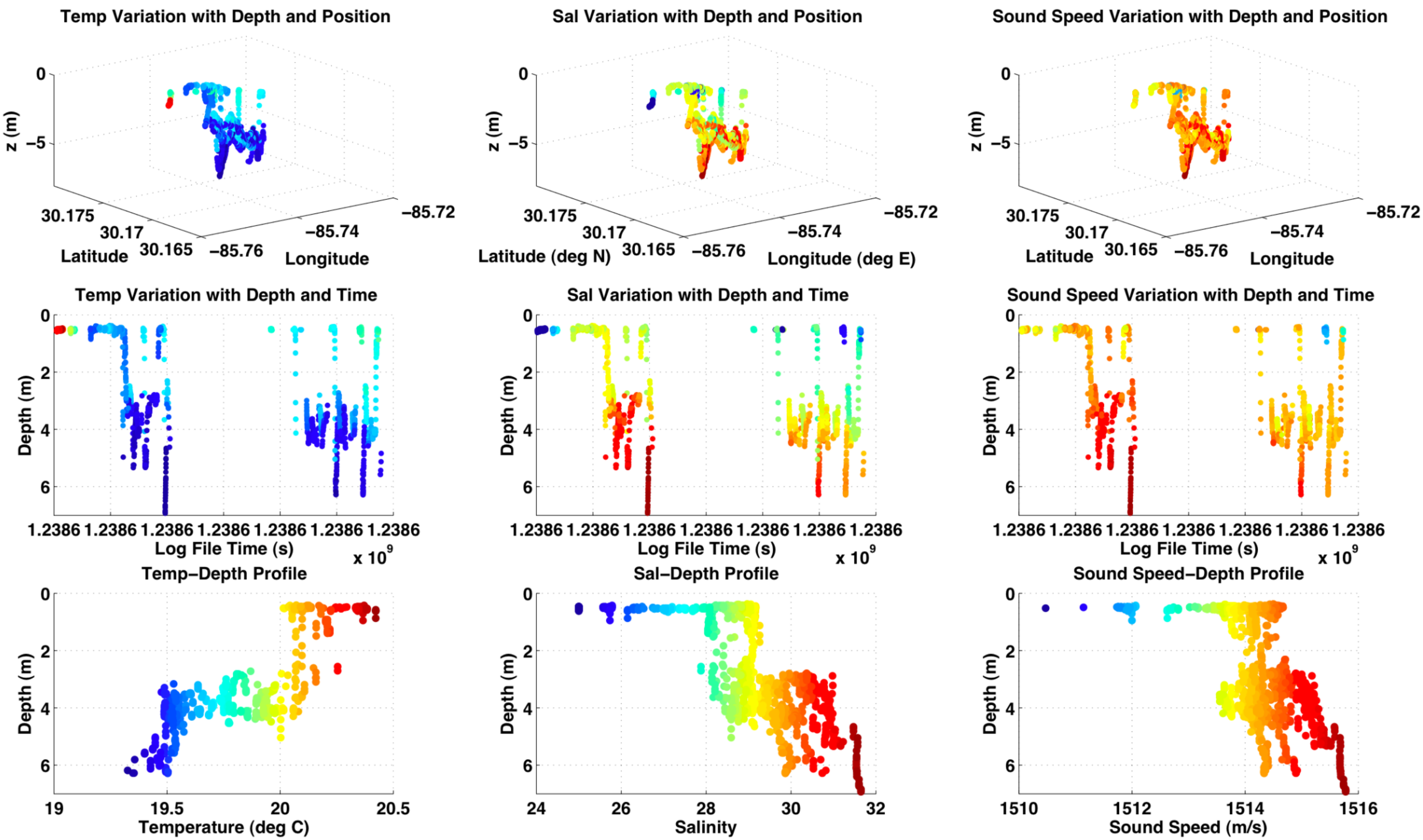
Current Developments with MOOS to Enable Environmental Monitoring

- Topside CTD display
- iMseas – MOOS interface for MSEAS model ocean reader (readhopspe.m)
- iMseasBathy – gets local bathymetry from MSEAS model ocean NetCDF file

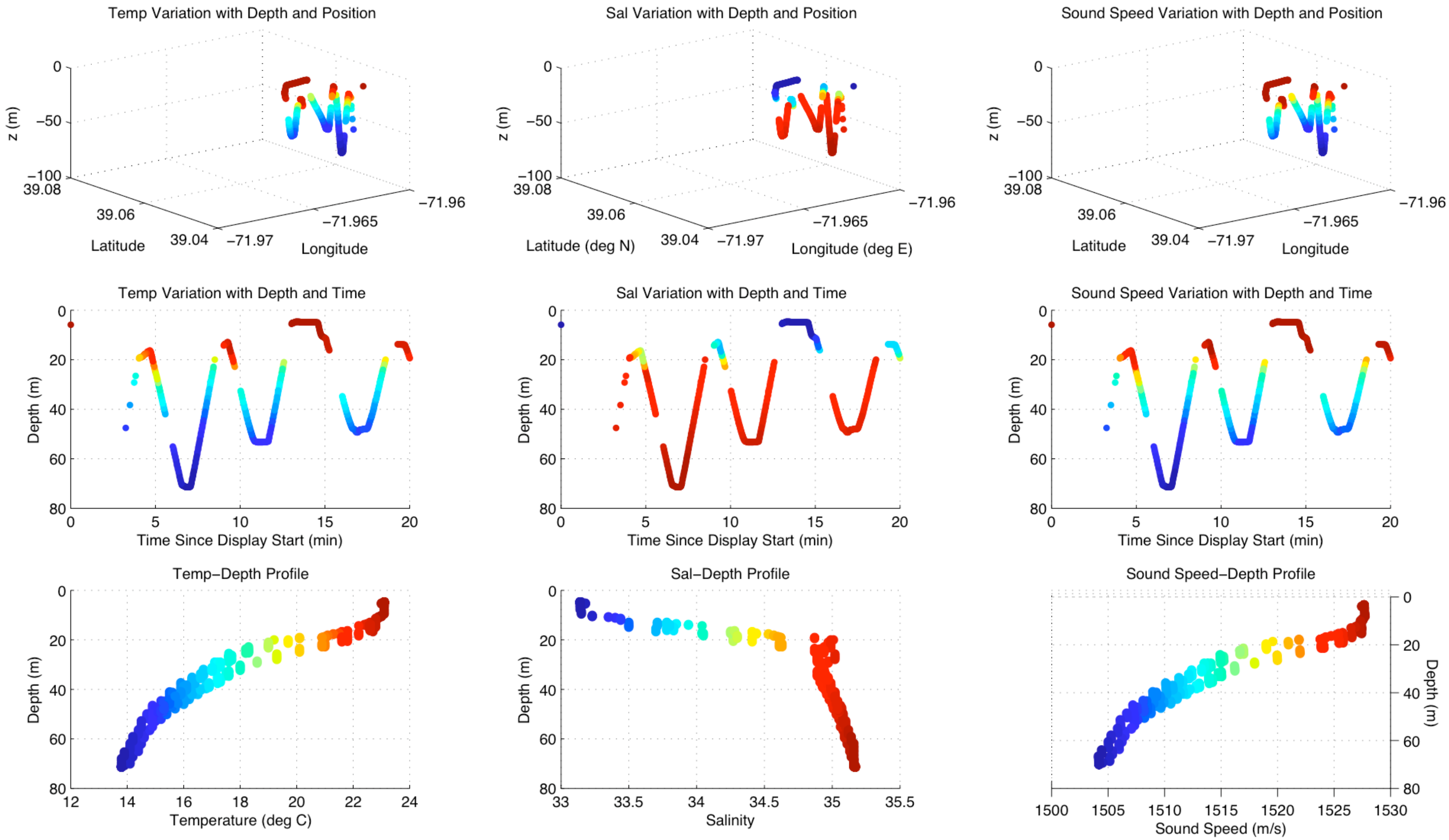


- pEnvtGrad + Adaptive Env't Yoyo behavior – tracks gradients through the water column

Real-Time CTD Display – SWAMSI '09

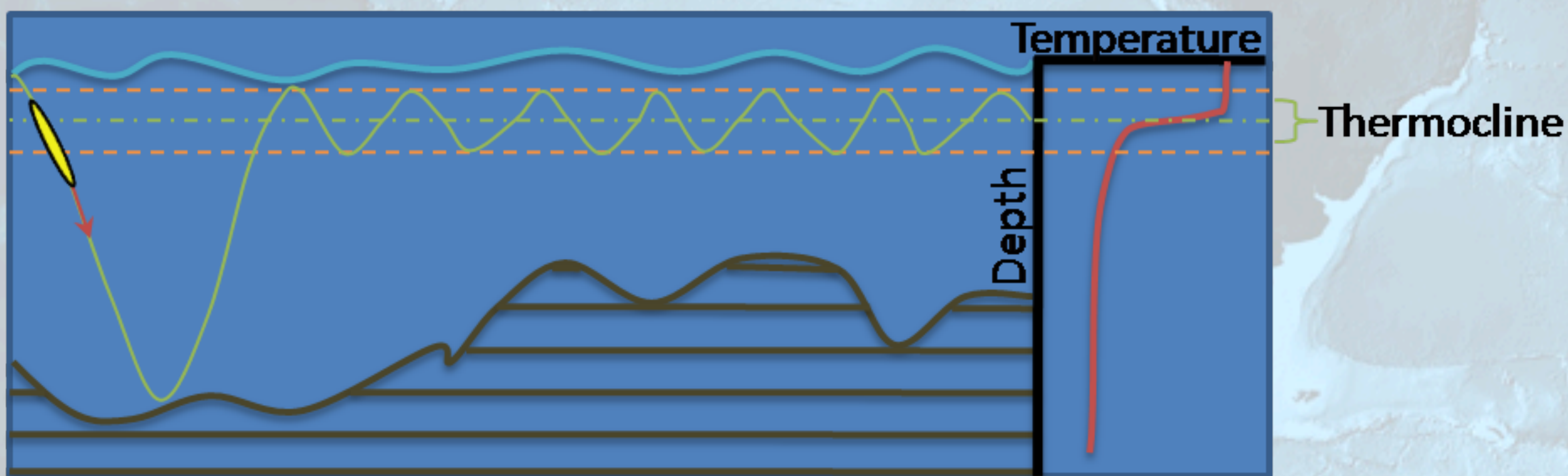


CTD Display – Simulated AUV in MSEAS Environment

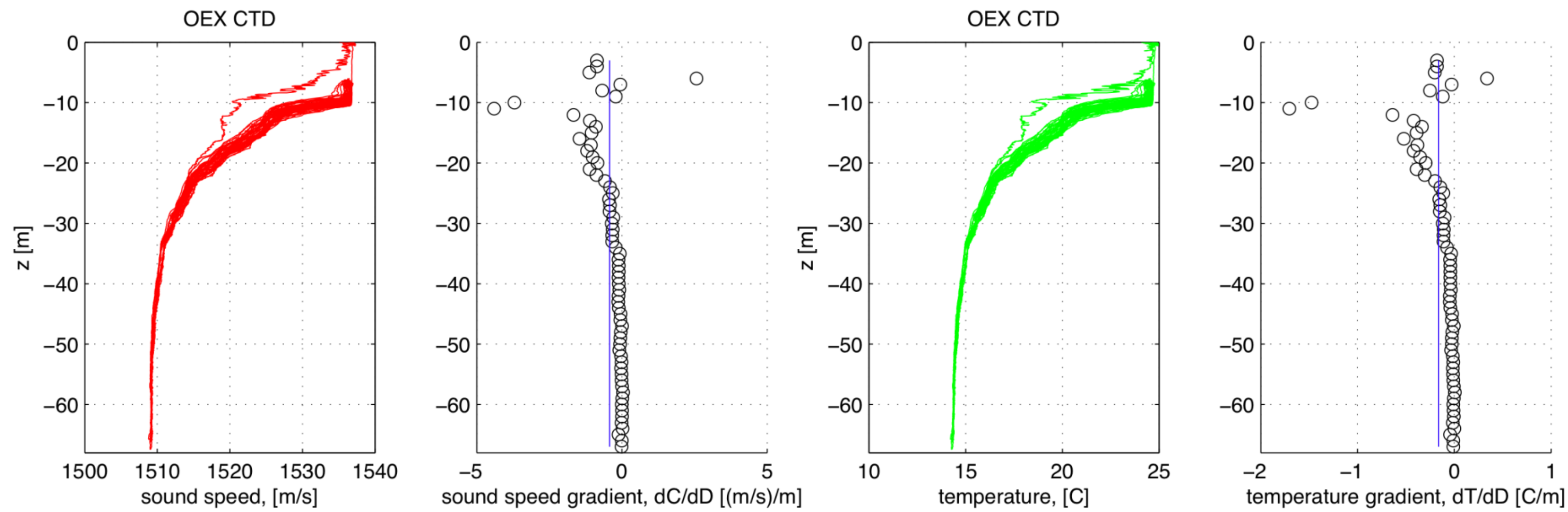


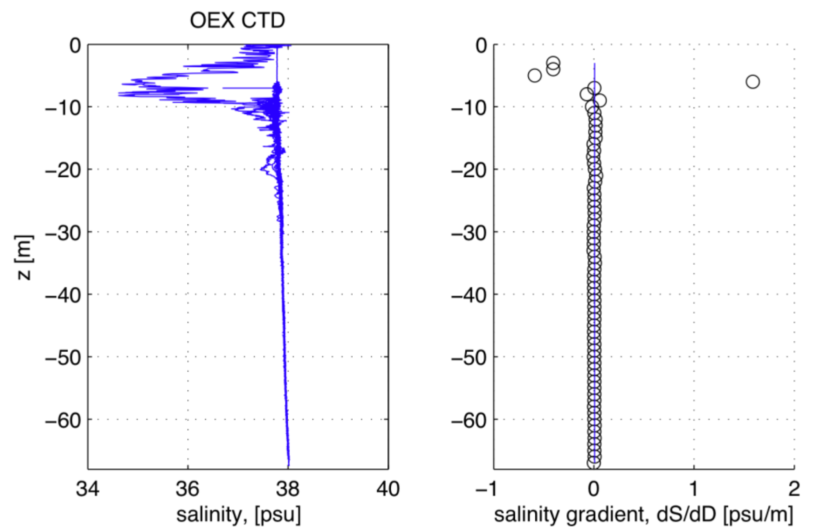
Example: Thermocline Tracking

- An adaptive environmental sampling and tracking behavior employing REA
- Calculates and monitors the changing temperature gradient through the water column
  - based on the depth vs. temperature profile
- Vehicle autonomously adapts the depth range of its yo-yo to more closely sample and track a thermocline
- Successfully executed during the GLINT '09 experiment



In Situ CTD
Gradient Determination





Sound Speed (m/s)

$$\left(\frac{\Delta C}{\Delta D}\right)_{avg} = -0.4269$$

Max gradient range: [3 28]m

Temperature (C)

$$\left(\frac{\Delta T}{\Delta D}\right)_{avg} = -0.1621$$

Max gradient range: [3 23]m

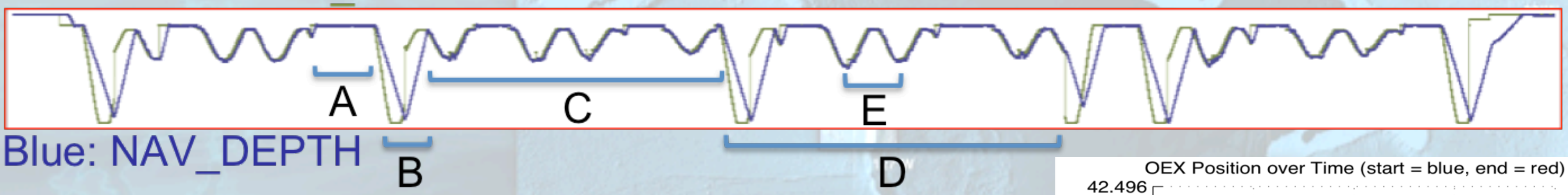
Salinity (psu)

$$\left(\frac{\Delta S}{\Delta D}\right)_{avg} = 0.0067$$

Max gradient range: [6 66]m

GLINT '09 Results

Green: DESIRED_DEPTH

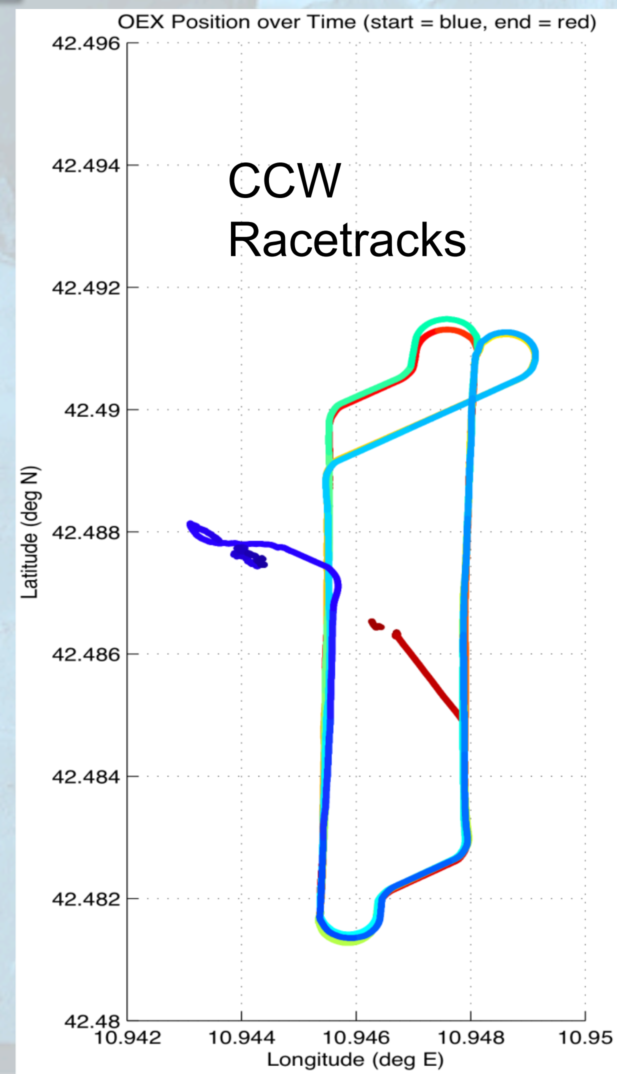


Blue: NAV_DEPTH

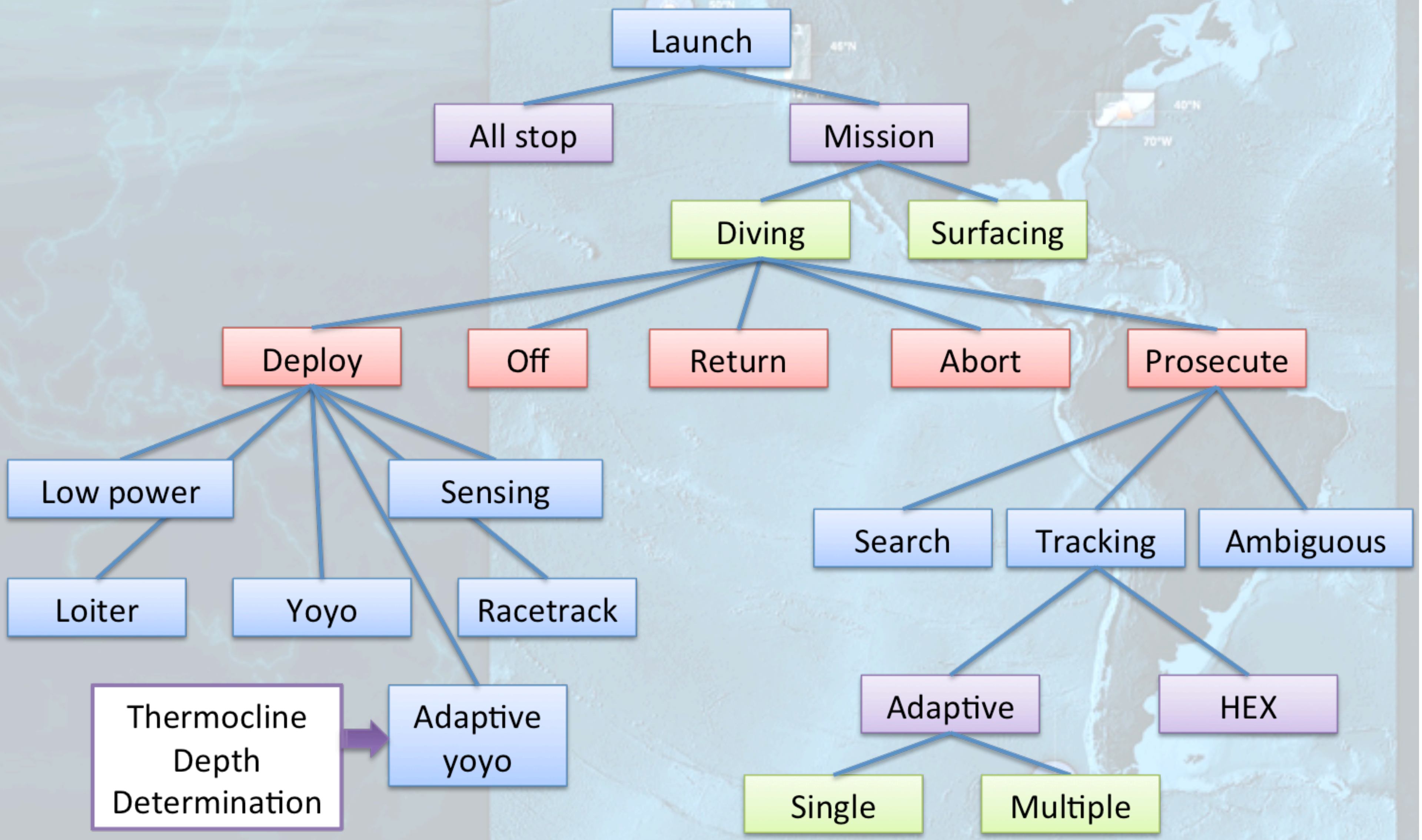
<u>Adaptive Yoyo & Racetrack</u>
MOOS behaviors

<u>Mission</u>: Track the depth range of the maximum sound speed gradient.

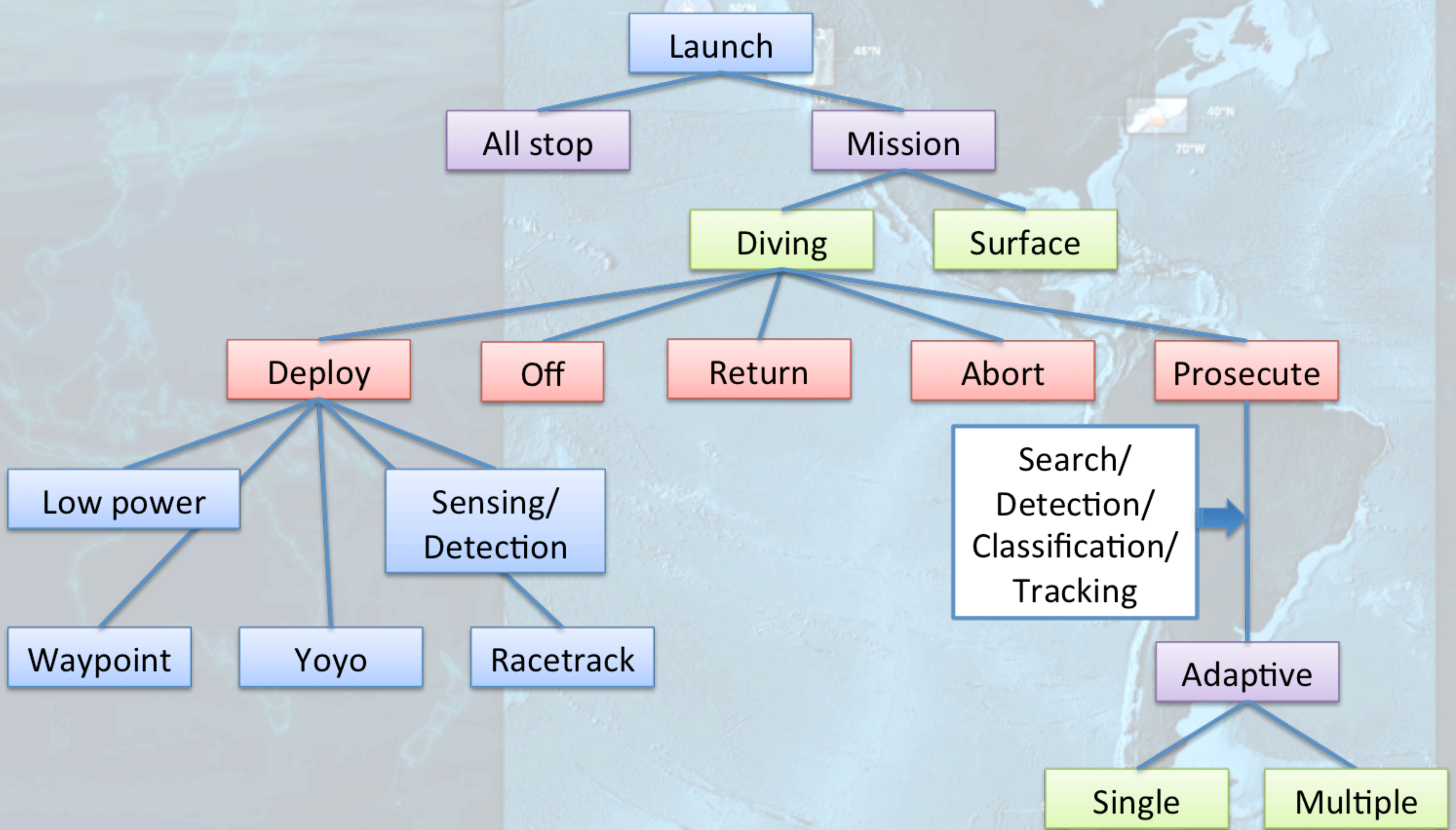
A: cornering, 7m depth
B: initial yoyo, 7-70m depth
C: tracking max sound speed gradient, 9-28m depth
D: 1800-second timeout resets yoyo depth limits
E: 400-meter yoyo period with flattened peaks



AUV Mission Structure



Glider Mission Structure



Future Work

- Do feature following with MOOS IvP behavior objective functions reasoning over environmental variables (T, Sal, sound speed, density) directly
  - Thermocline tracking behavior vs. thermocline depth calculating process + adaptive yo-yo behavior
- More topside display tools for post-mission or real-time visualization/playback of collected environmental data and determined regions of interest

Thanks !