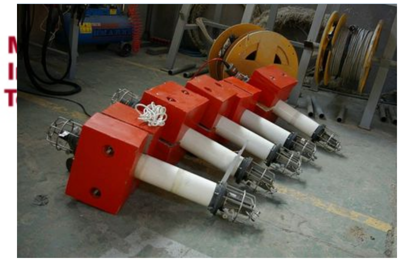
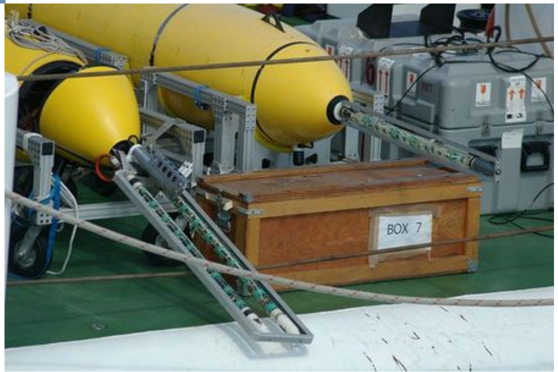


Model-based Adaptive Acoustic Sensing and Communication in the Deep Ocean with MOOS-IvP



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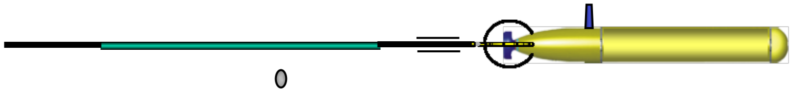
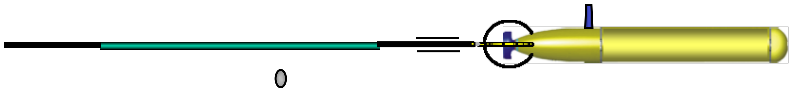
MOOS-DAWG'11
July 19-20, 2011



Outline

- The Nested Autonomy Paradigm
    - Integrated Sensing, Modeling and Control
    - Payload Autonomy
- Sensor-based environmental adaptation
    - Noise-interference optimization
- Model-based environmental adaptation
    - Shallow water communication connectivity
    - Deep ocean acoustic environment
    - Autonomous depth adaptation for maintaining connectivity



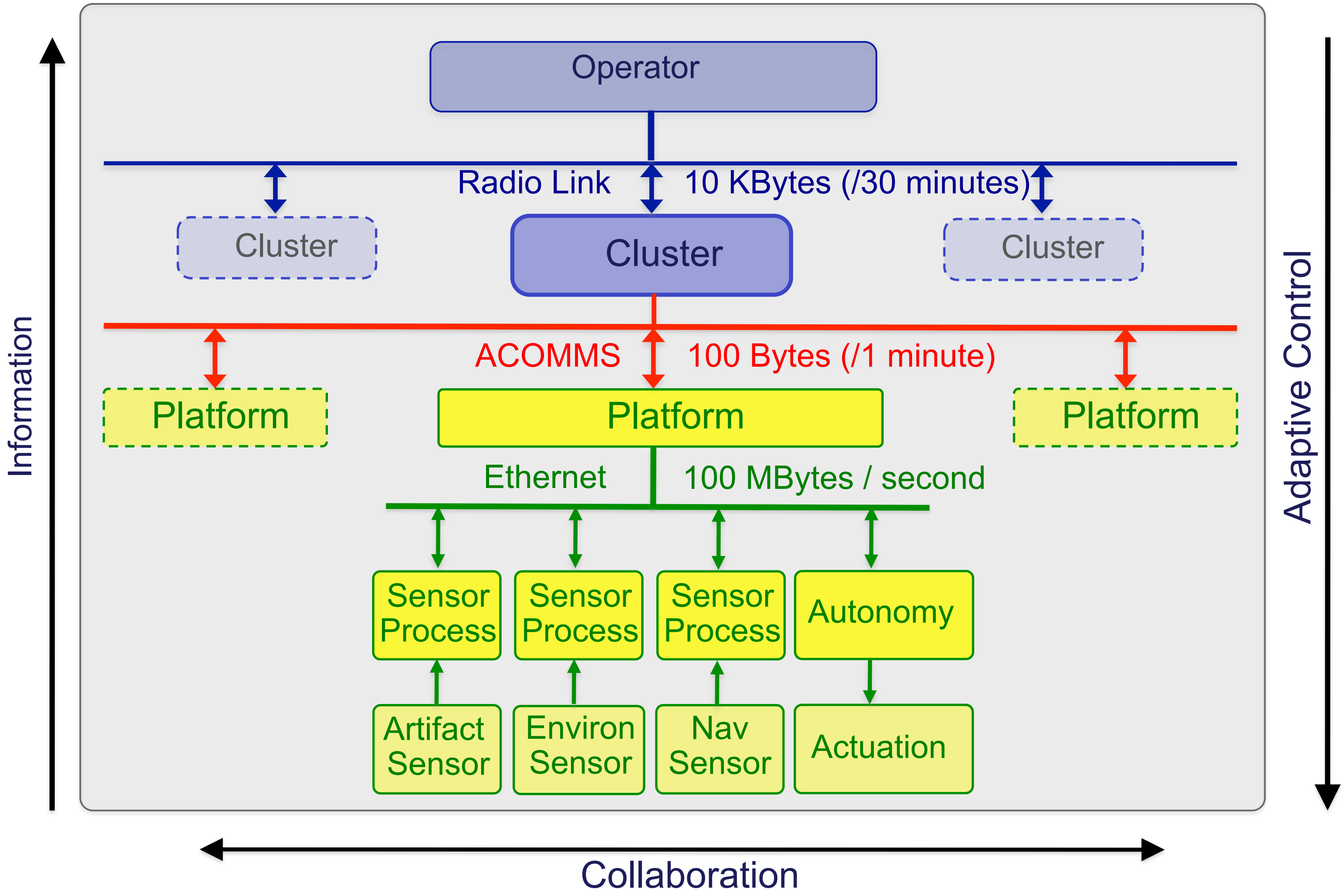
Undersea Distributed Sensing Networks
Communication Infrastructure

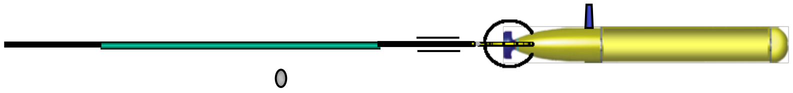
Field Control
- Modeling
- Mission Control
- Planning/Sched

Clusters
- Collaboration
- Convergence

Nodes
- Modeling
- Sensor Processing
- Navigation
- Autonomy
- Actuation/Control

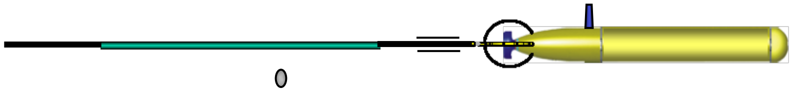
Hardware
- Sensors
- Actuators





Nested Autonomy
Command and Control Architecture

- Network Command and Control
  - Managed through communication gateways via RF above sea level and acoustic communication (ACOMMS) underwater
  - The underwater ACOMMS connectivity organized through a slotted MAC scheme with self discovery and organization
- Clusters
  - Autonomous platforms and acoustic gateways with current ACOMMs connectivity will self-organize through distributed control into clusters exploiting collaborative behaviors for improved sensing performance
  - Dynamic clustering topology depending on current ACOMMS connectivity
- Platforms
  - Each platform must be capable of completing mission objectives in absence of communication connectivity
  - Each platform will broadcast status reports at regular intervals in the communication slot assigned by its current cluster



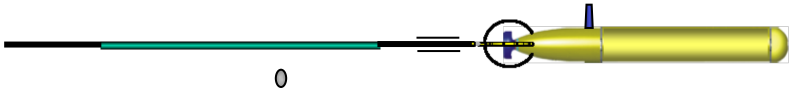
What is Intelligent Autonomy?

Integrated Sensing, Modeling and Control

Automated processing of sensor data for detection, classification and localization of tactical or environmental event

Data-driven modeling for forecasting of tactical and environmental situation

Intelligent decision-making based on situational awareness, adaptive and collaborative strategies (behaviors), and learning, to adapt to forecast for enhanced performance



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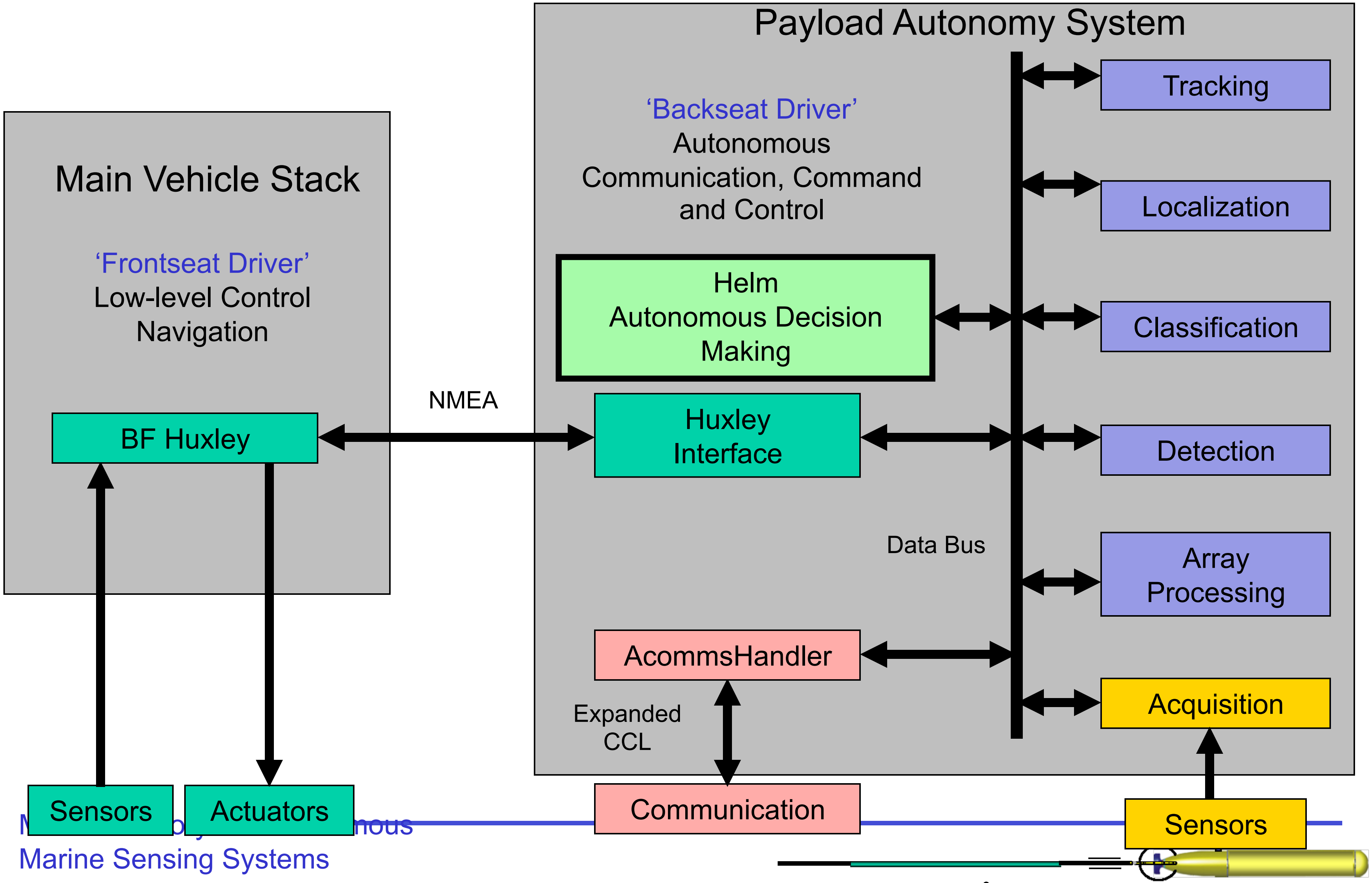
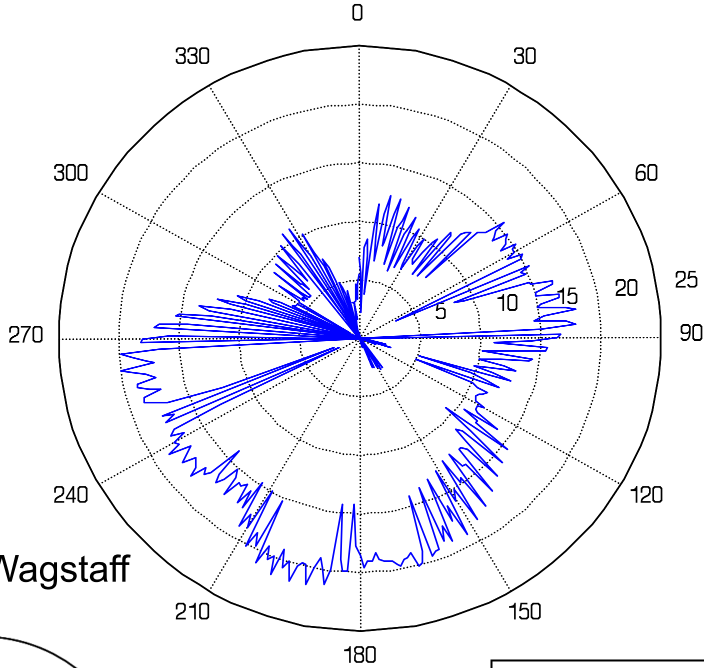
Payload Autonomy Architecture
Integrated Sensing, Modeling and Control



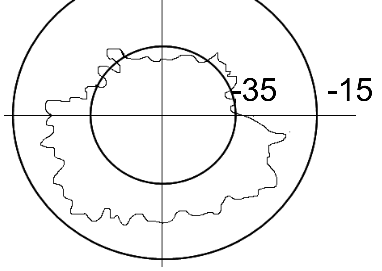
Model-based Environmental Adaptation

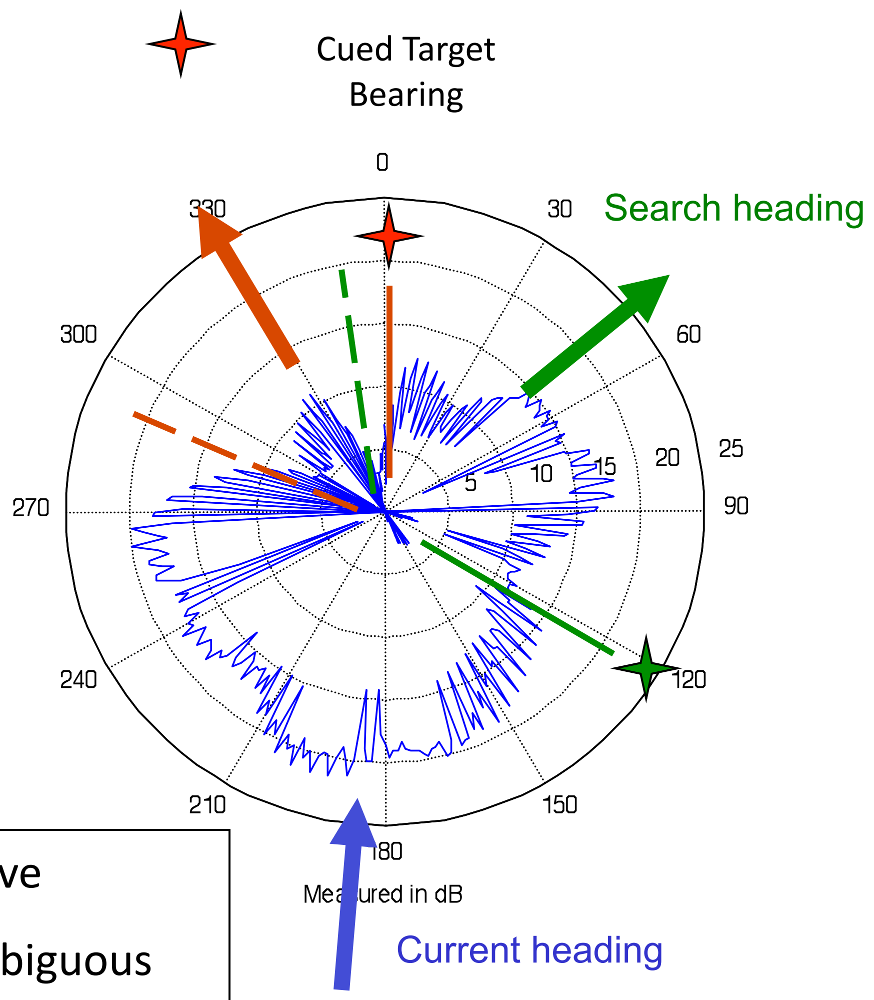
On-Board Estimation of
Ambient Noise Directionality
MOOS-SEALAB Simulation



Measured in dB

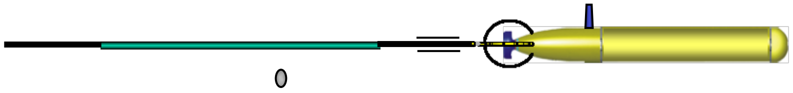
Pacific -Wagstaff



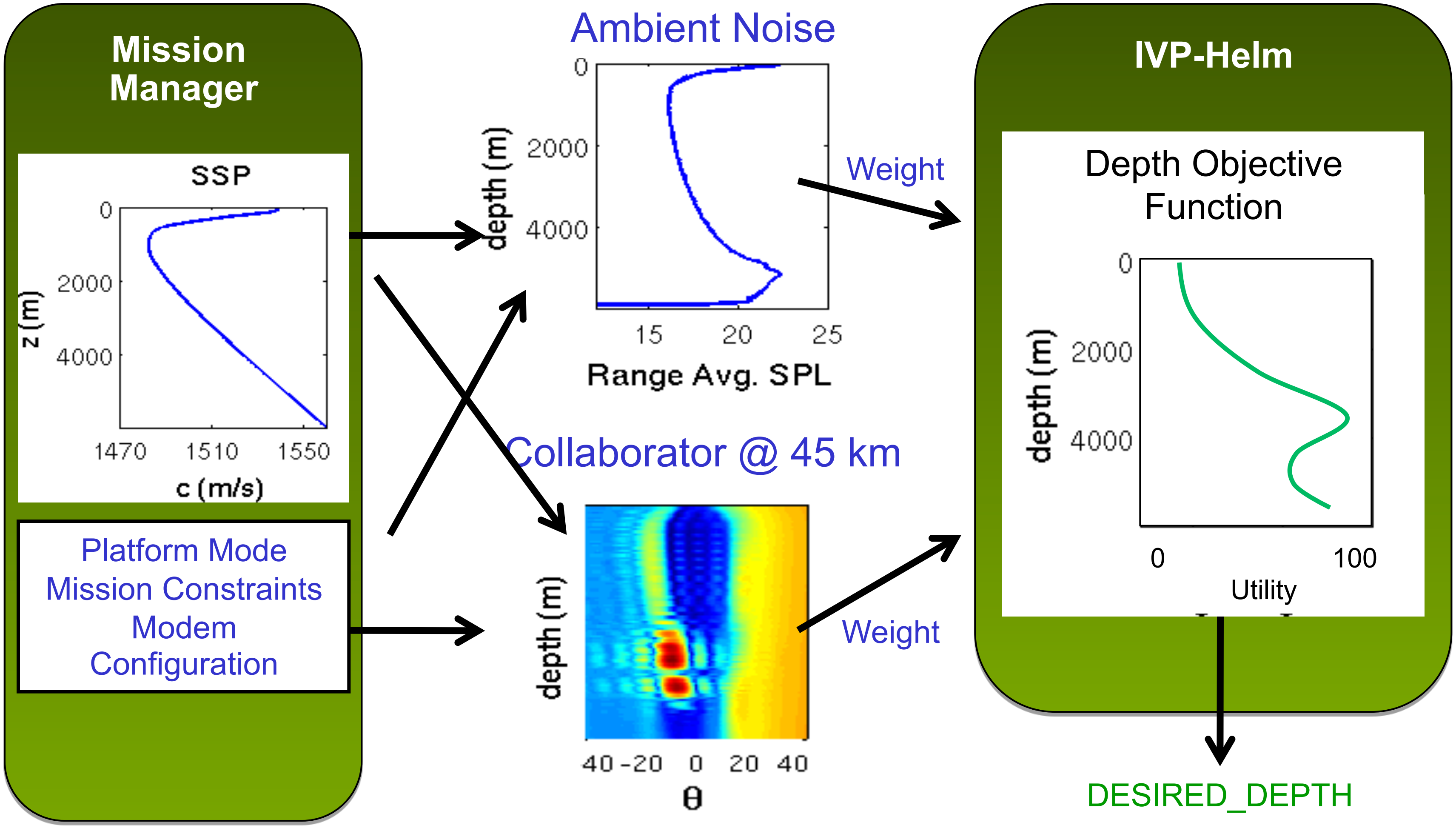


Objective

Minimize ambiguous
beam power



Model-based Environmental Adaptation



Mission Manager

Platform Mode
Mission Constraints
Modem
Configuration

Ambient Noise

Collaborator @ 45 km

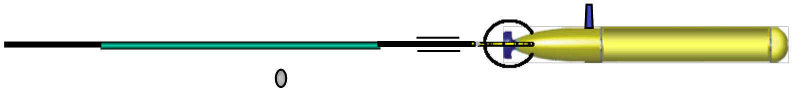
Weight

Weight

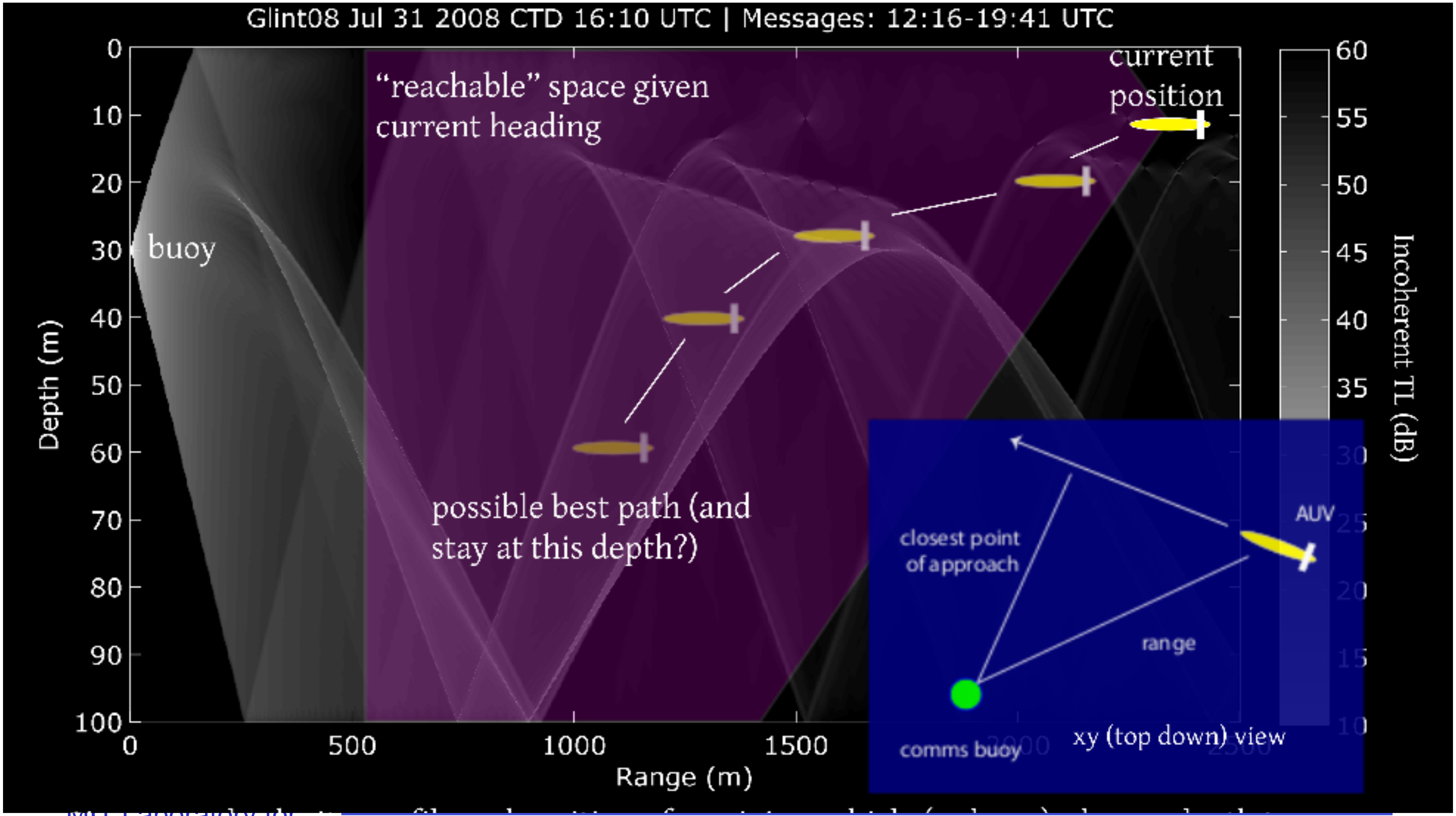
IVP-Helm

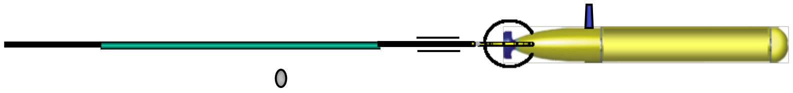
Depth Objective
Function

DESIRED_DEPTH

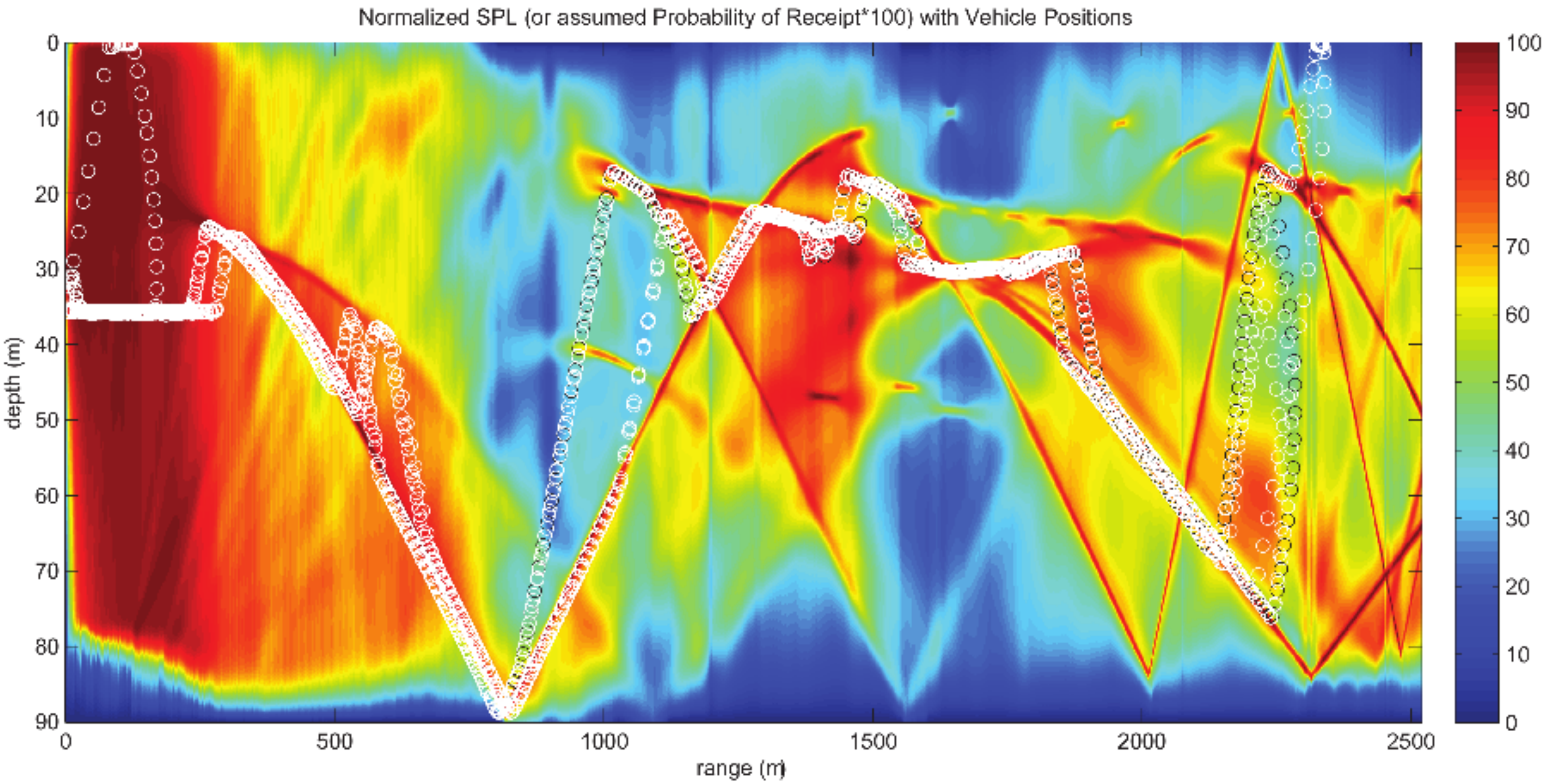


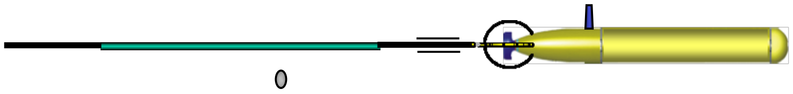
Environmentally Adaptive ACOMMS Connectivity





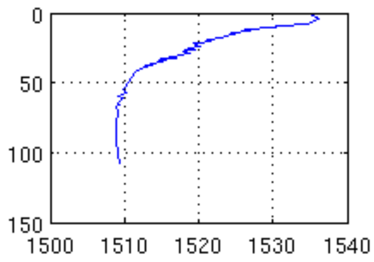
Connectivity-Optimal Survey Path



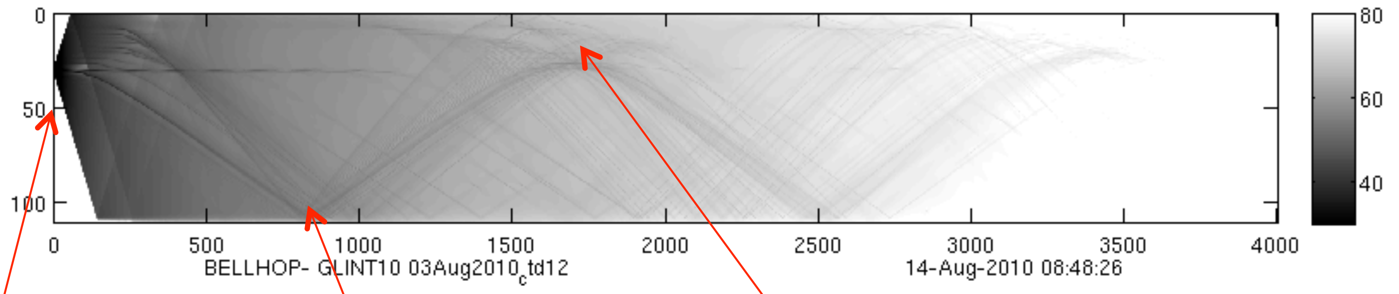


GLINT’10 – Adaptive ACOMMS

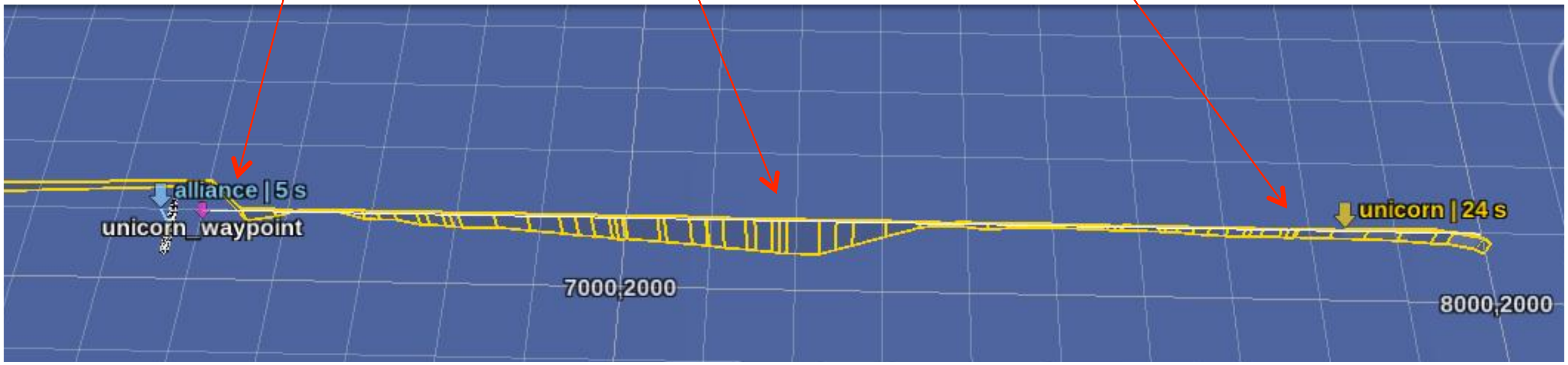
In-situ SVP

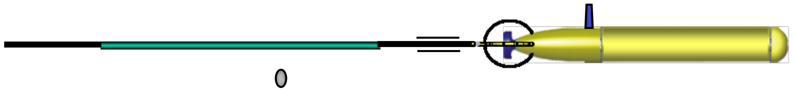


On-board Ray-trace Modeling (Bellhop)



Topside Situational Display





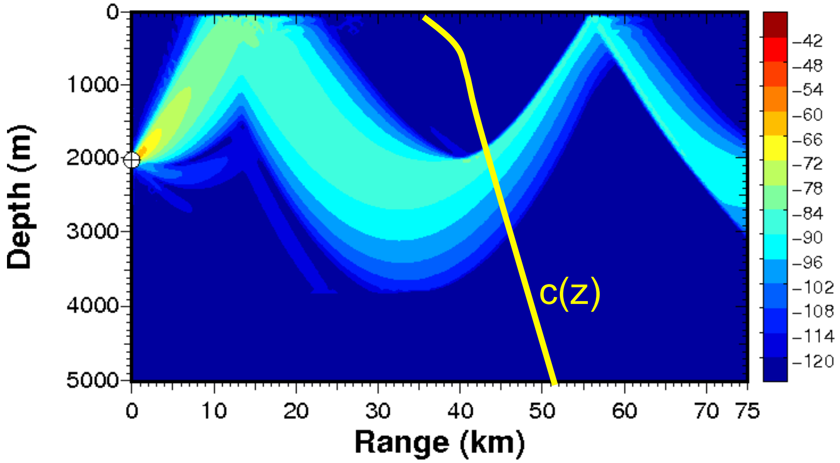
Deep Ocean Array Performance
Arctic Environment

Exploiting Environmental Acoustics

- Environmental Focusing
- Vertical Beamforming
    - Range scanning
    - Optimize Detection performance
- Depth mobility
    - Synthetic aperture
    - Control range and depth focus
    - Performance/Persistence tradeoff

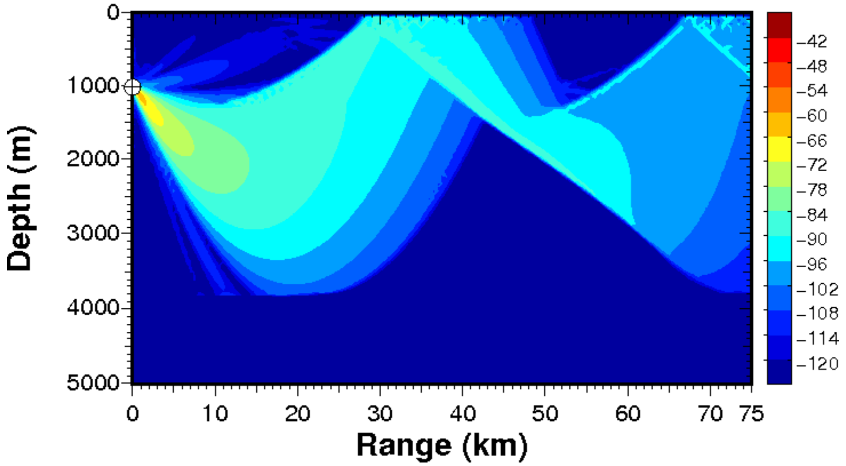
FRAM IV. 1400–2100. –5 deg. – Szz

F= 1000.0Hz SD=2000.0M



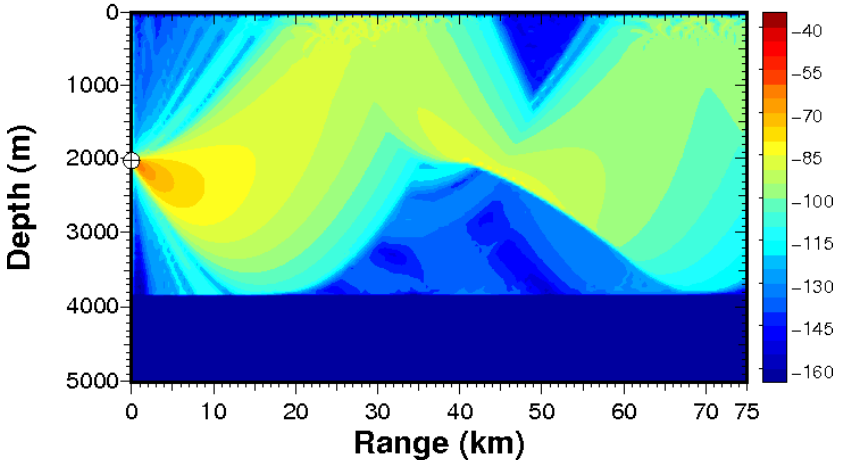
FRAM IV. 8 deg. – Szz

F= 1000.0Hz SD=1000.0M

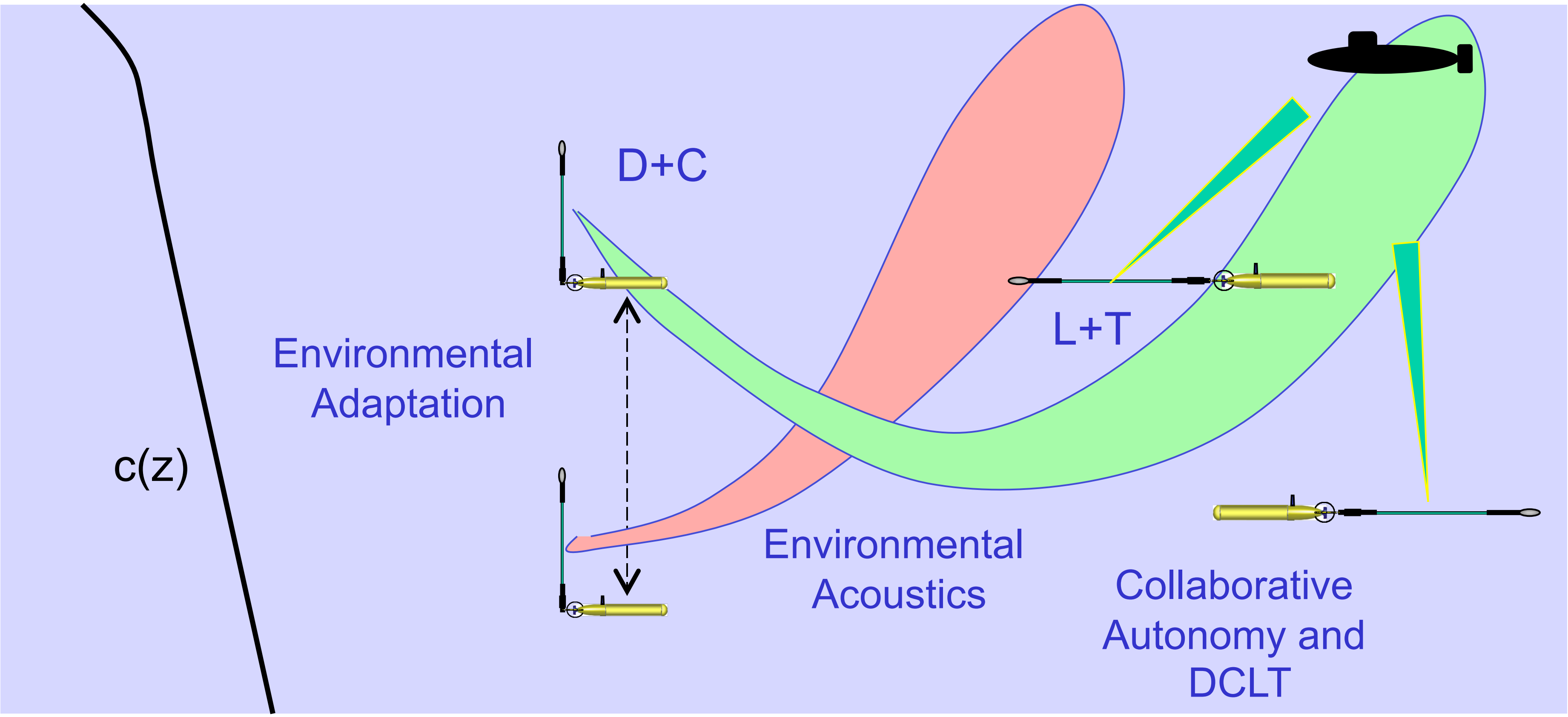


FRAM IV. 1400–2100. 5 deg. – Szz

F= 1000.0Hz SD=2000.0M



Deep Ocean Environmental Adaptation
Adaptive and Collaborative DCLT

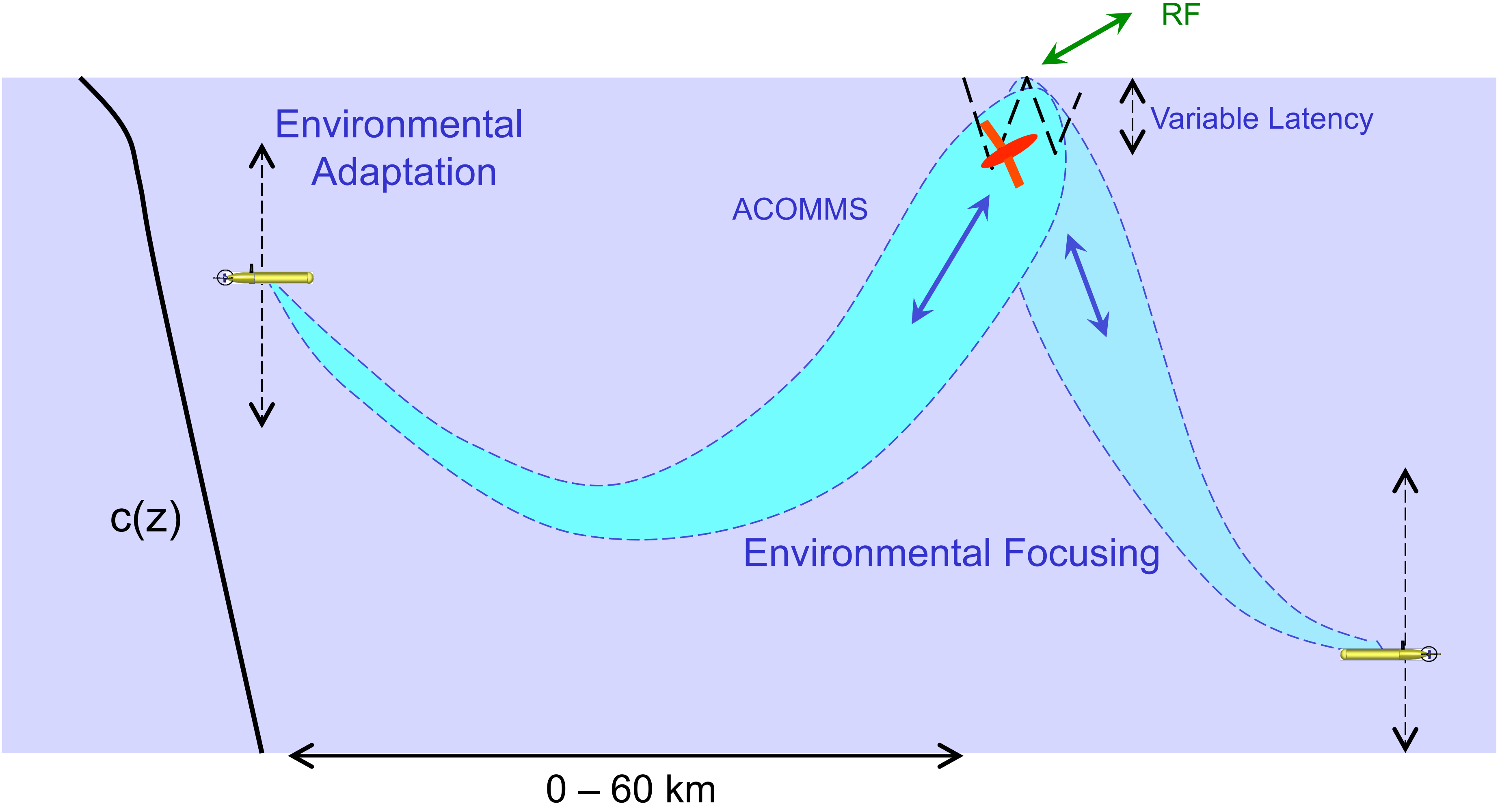


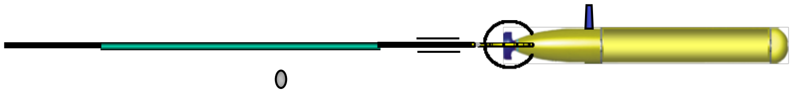
Environmental Adaptation

Environmental Acoustics

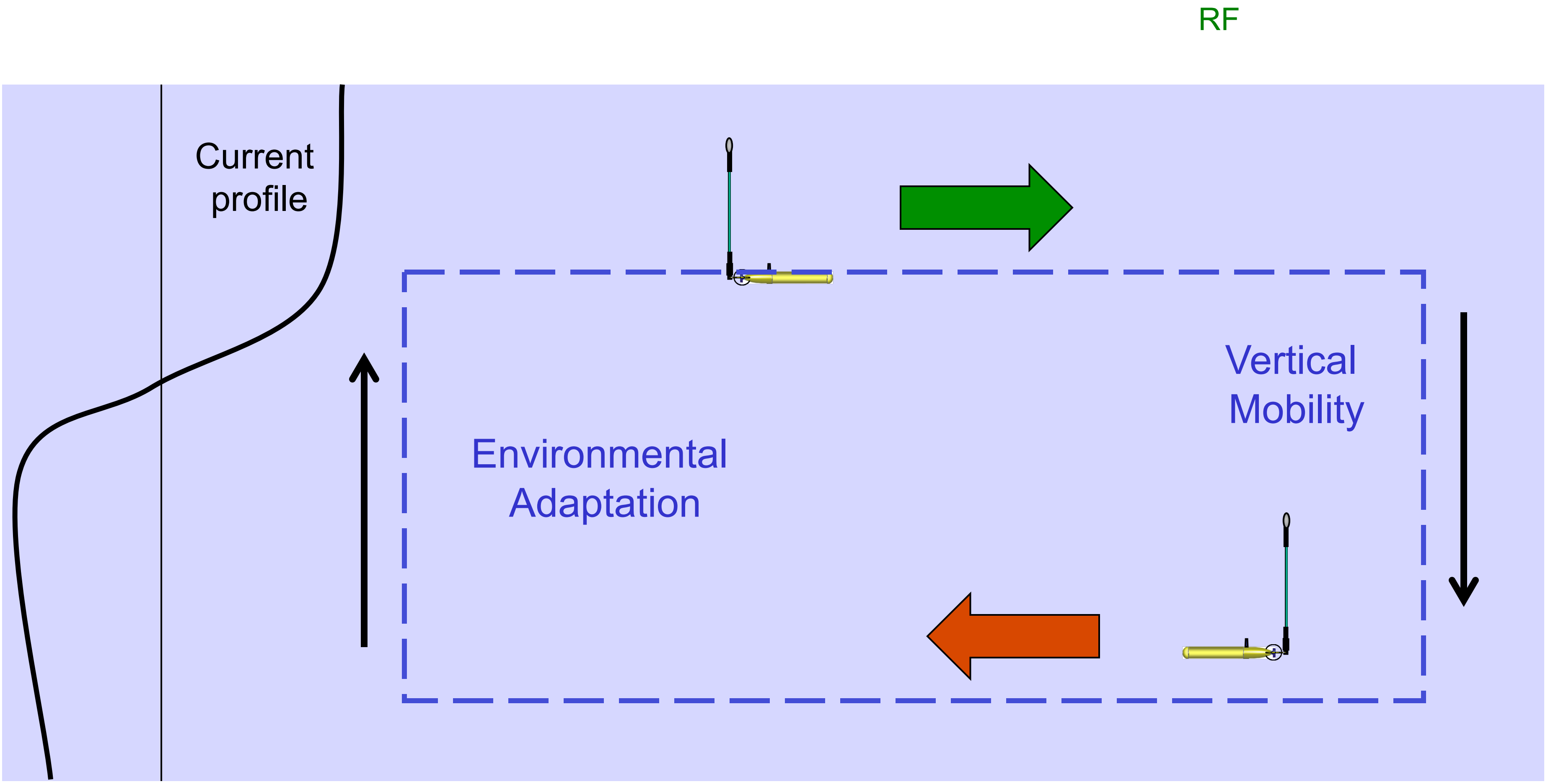
Collaborative Autonomy and DCLT

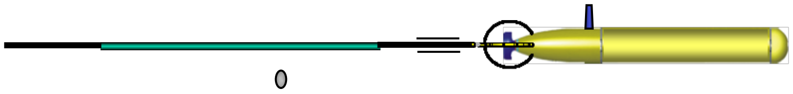
Deep Ocean Environmental Adaptation Communication and Navigation





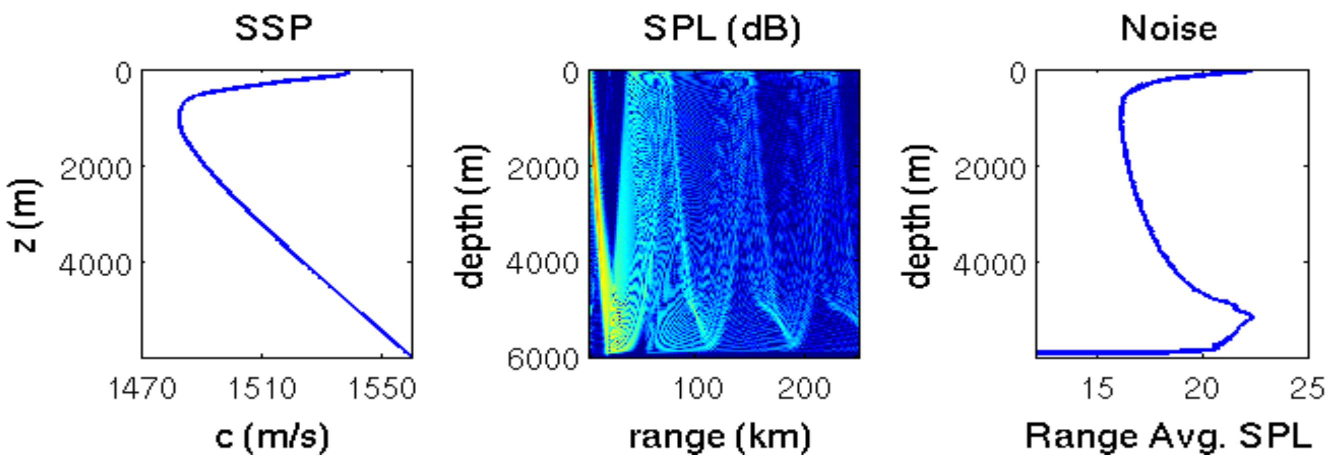
Deep Ocean Environmental Adaptation Persistence



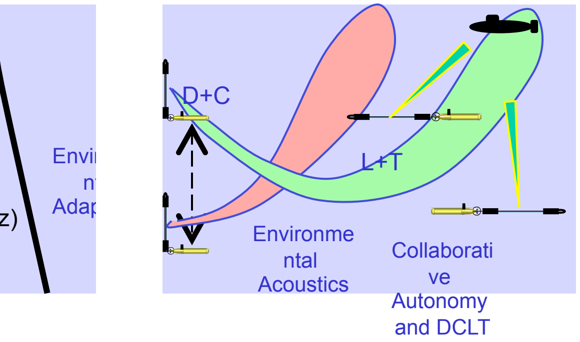


Optimal VLA Depth Analysis

Full Angular Spectrum Signal and Noise Modeling

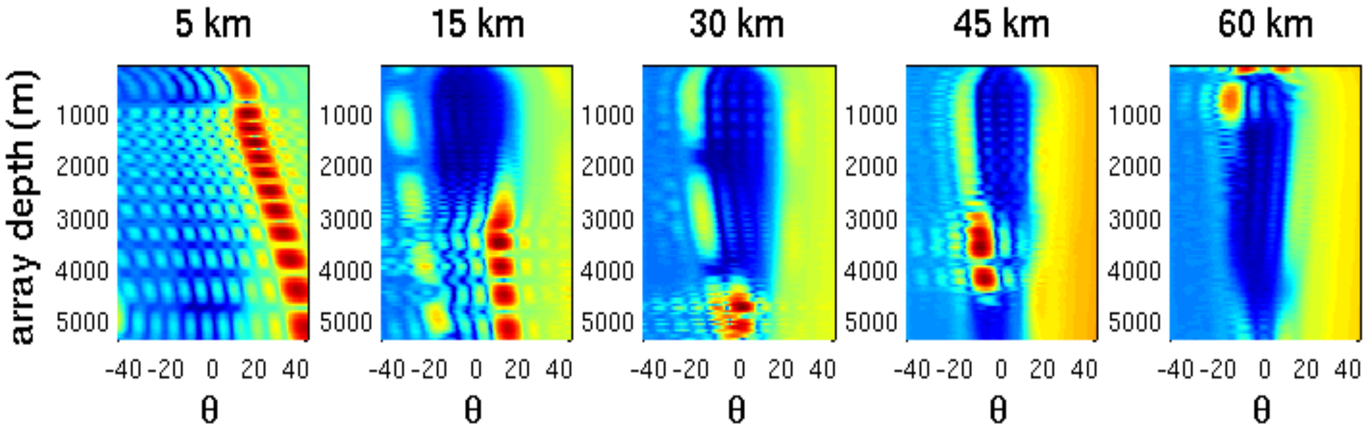


Array Performance exploiting vertical mobility



Environmental Acoustics

Collaborative Autonomy and DCLT



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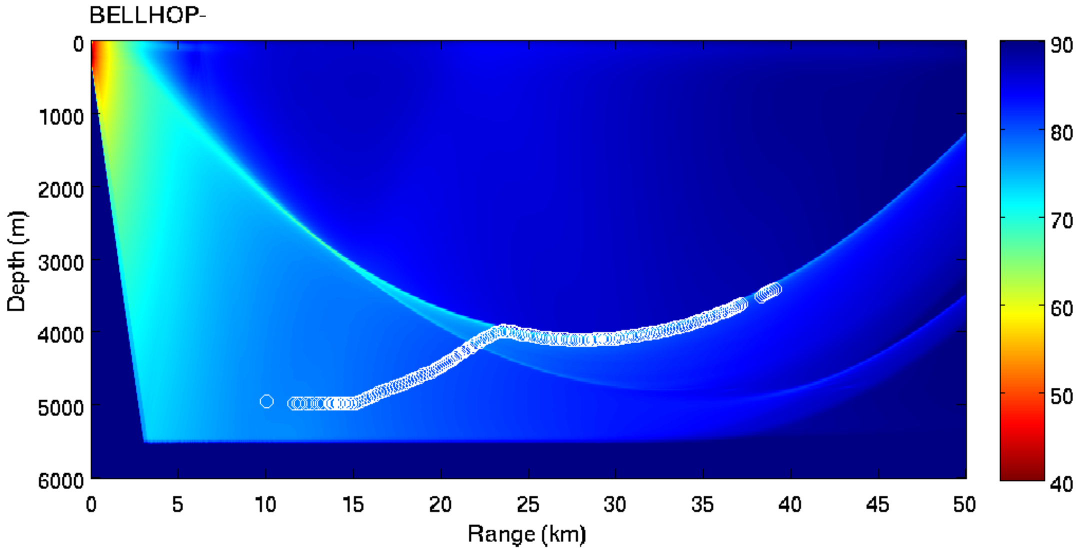
Deep Ocean Communication Connectivity



Transmission Loss

Target depth: 200 m
Target speed: 16 kn
Frequency: 800-1000 Hz

- Adaptive Communication Connectivity
  - Establish Connection: Elevate/dive to depth with minimum ambient noise level and loiter until connectivity is established
  - Maintain Connectivity: After connection established, maintain depth and track collaborator until range exceeds ~15 km, then change depth dynamically to minimum transmission loss predicted for collaborator track.

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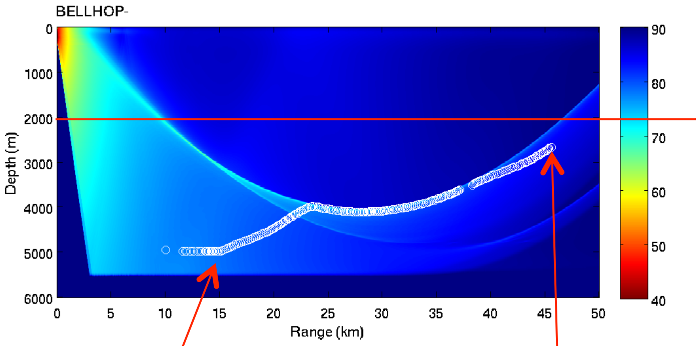
Deep Ocean Communication Connectivity

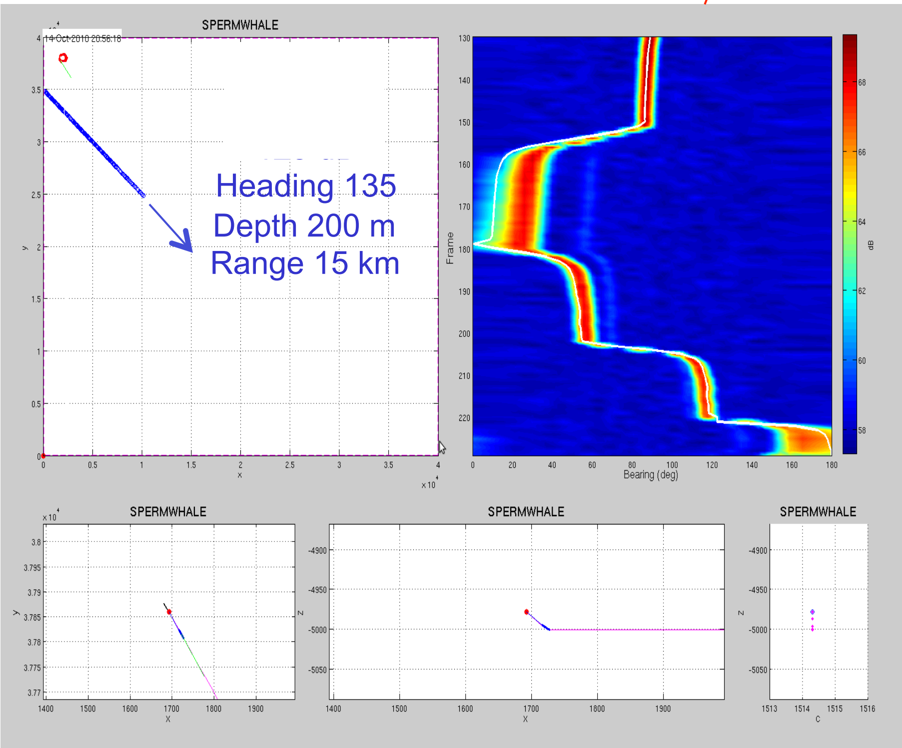
AUV with Towed array



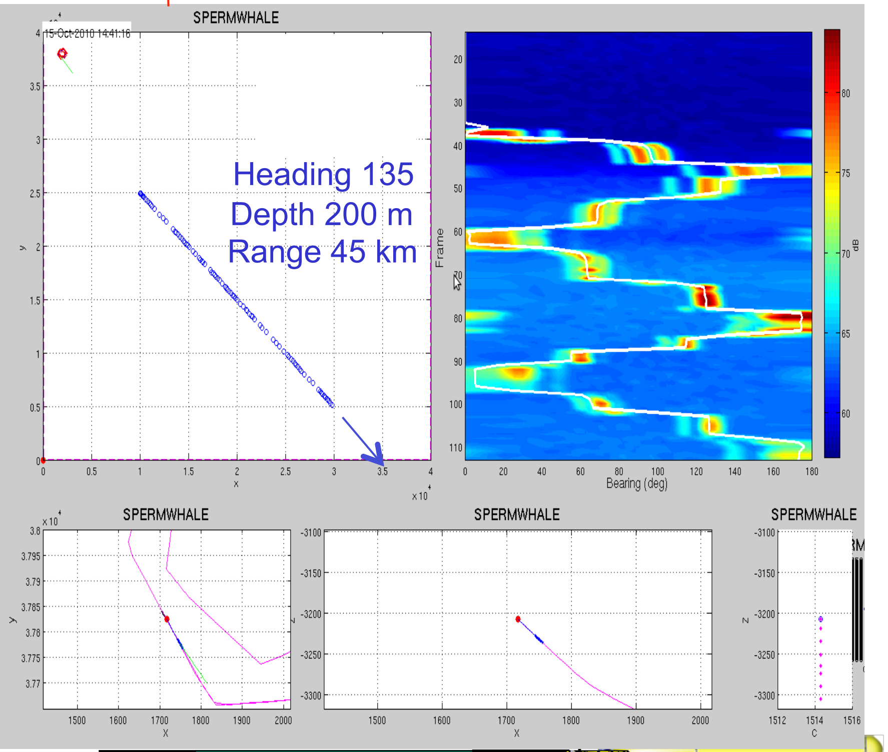
Upper depth limit 2000 m

Collaborator Range 15 km

Collaborator Range 45 km



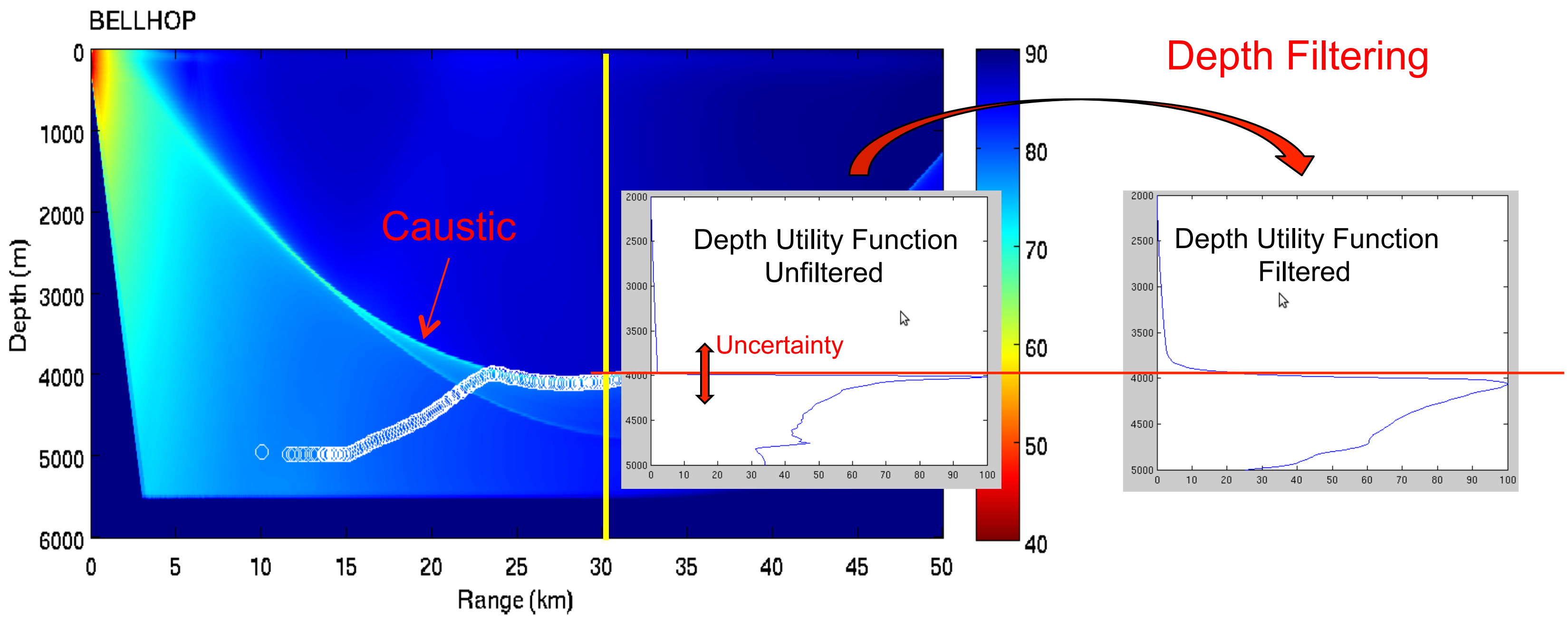
Heading 135
Depth 200 m
Range 15 km



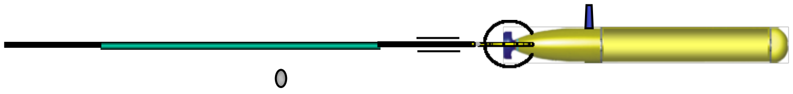
Heading 135
Depth 200 m
Range 45 km

Deep Ocean Communication Connectivity

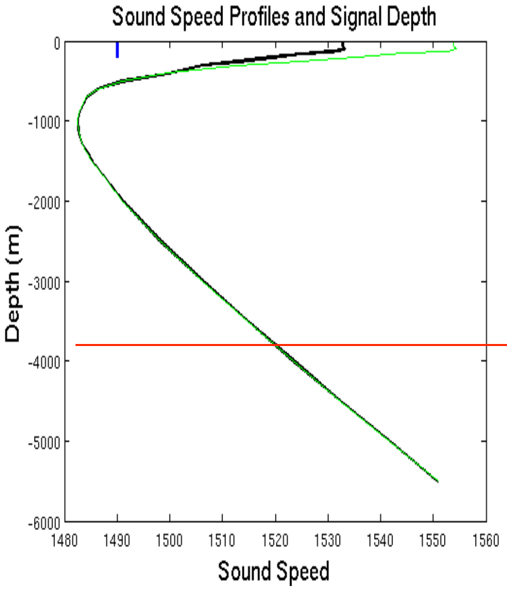
Robust Model-based Adaptation

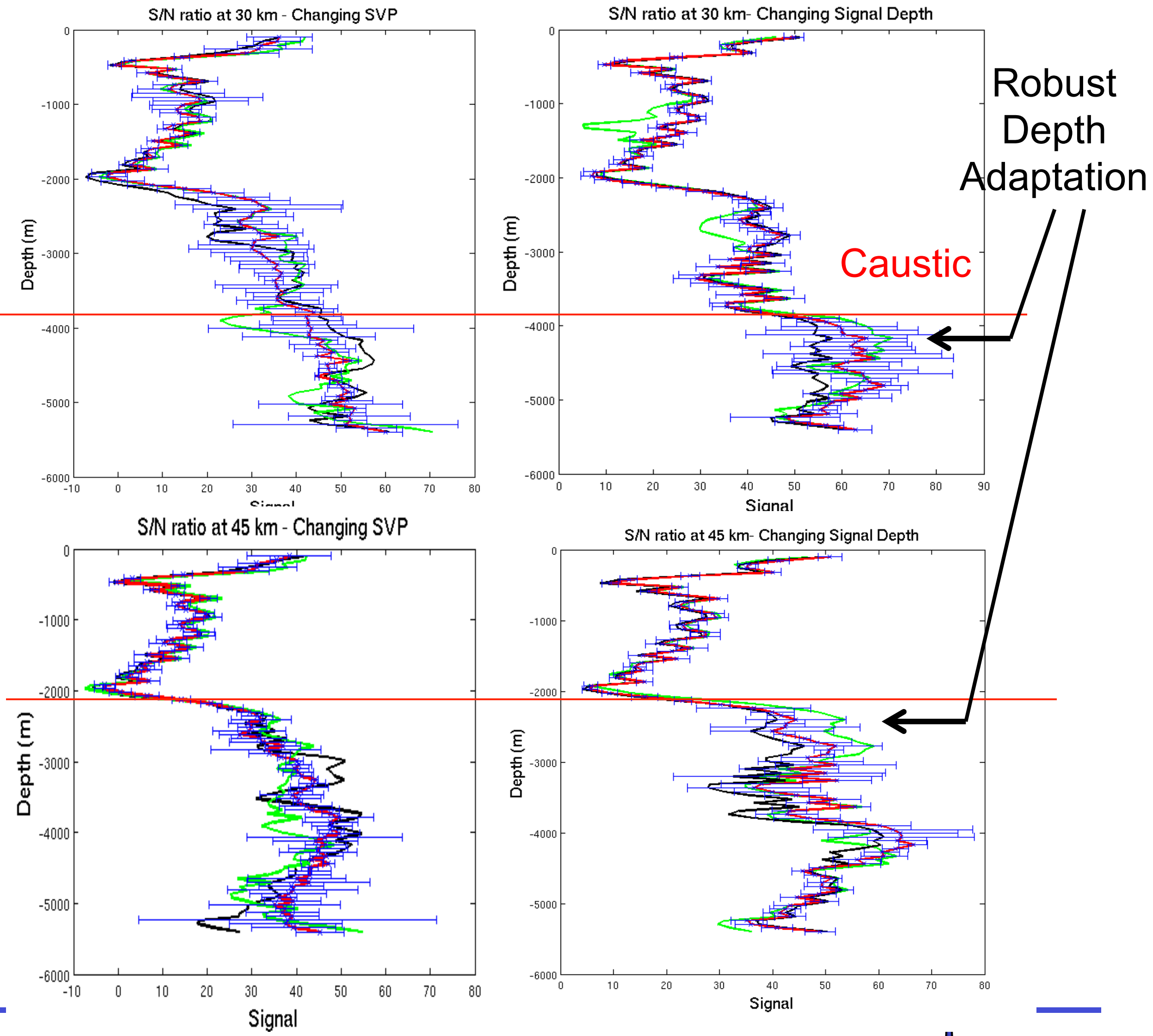


- Depth-filtering of utility function
  - Avoid non-symmetric caustics – Must stay on ‘good side’
  - Filtering consistent with statistics of environmental acoustics



Deep Ocean SNR Statistics



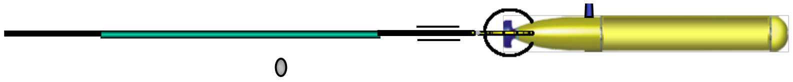


SVP/SD Variation:

Black: Minimum

Green: Maximum

Red: Mean



Summary

- The deep ocean sound speed is stable temporally and spatially and the associated environmental acoustics is robustly predictable.
  - Below the SOFAR channel, the dominant environmental acoustic effect is the pressure gradient.
  - The near-surface environmental variability is relatively insignificant to the deep refracted acoustic paths, in particular for systems operating below or at the critical depth.
- Significant acoustic system performance gain can be achieved by depth mobility
  - Ambient noise level changes significantly with depth, with minimum below the critical depth.
  - Depth-dependent, vertical noise directionality may also be exploited for sonar and communication performance gain.
- Helm-IvP ideal for developing environmentally adaptive acoustic sensing and communication networks
  - Behaviors based on scaled version of TL, NL or SNR have been developed and validated in both simulation and field deployments.