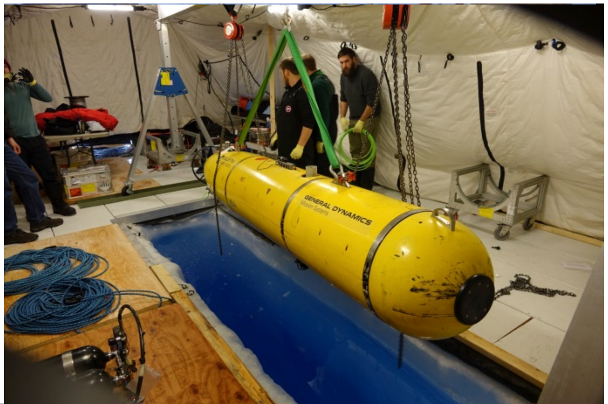


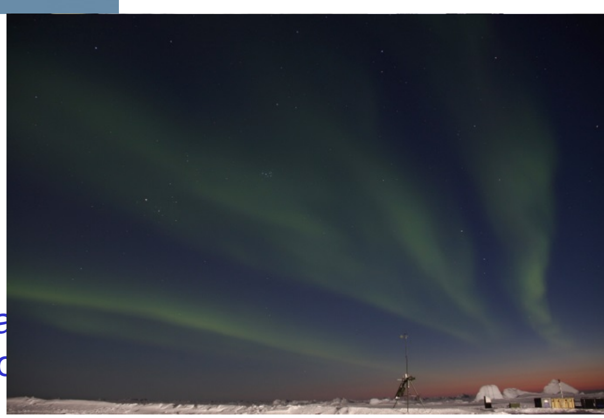
Environmental Acoustics

-

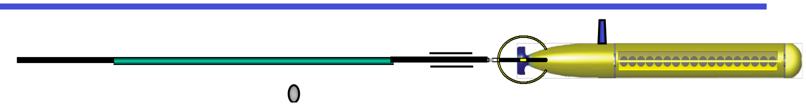
Enabler and Obstacle
for
Undersea (and -ice) UUV Operation

Prof. Henrik Schmidt

Laboratory for Autonomous Marine Sensing Systems
Massachusetts Institute of technology
(henrik@mit.edu)

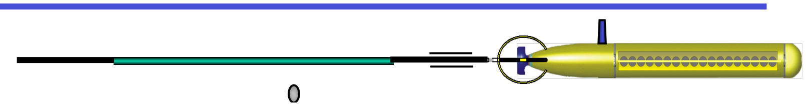


MIT La
Autono



Exploring Ocean Worlds

- Getting there!
  - Extra-terrestrial Oceans
    - Space crafts - ~60 y history
  - Earth Oceans
    - Research Vessels – 4000 y history. Surface, Episodic
    - Cables – Depth, 'Permanent', 'Infinite' power and bandwidth.
  - Point deployment
- Establishing Footprint?
  - Cabled sensors – Fixed, limited footprint.
    - Communication: 'Infinite' bandwidth
  - AUVs – Flexible, wide footprint.
    - Communication:
      - Optics, 'Line-of-sight', high bandwidth. Ranges ~< 100 m
      - Acoustics, Long range, low bandwidth. High spatial variability

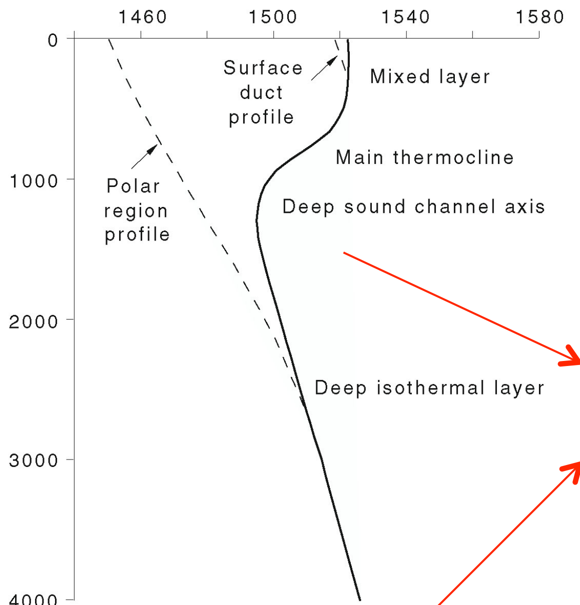


Massachusetts Institute of Technology

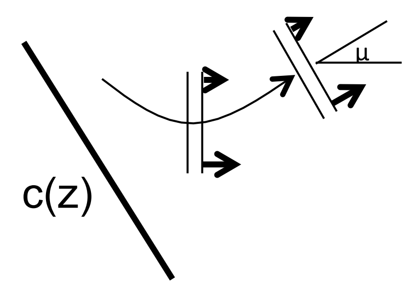
Environmental Ocean Acoustics

Sound Speed Variability

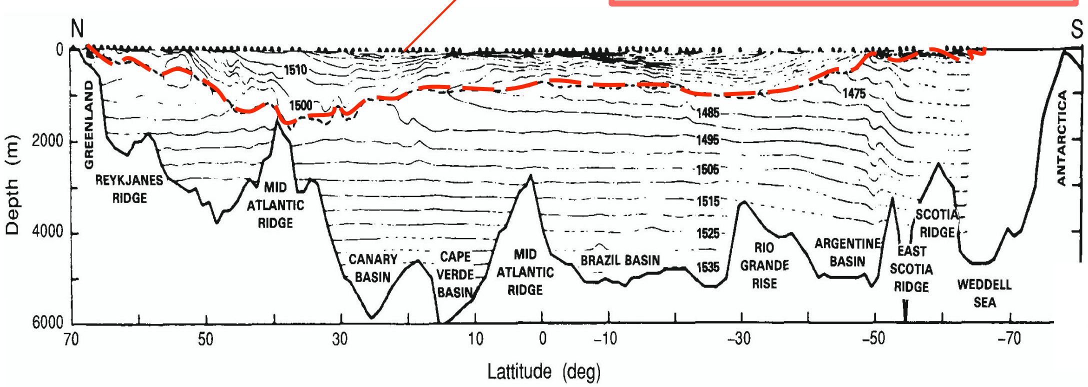
$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016z.$$



Snell's Law

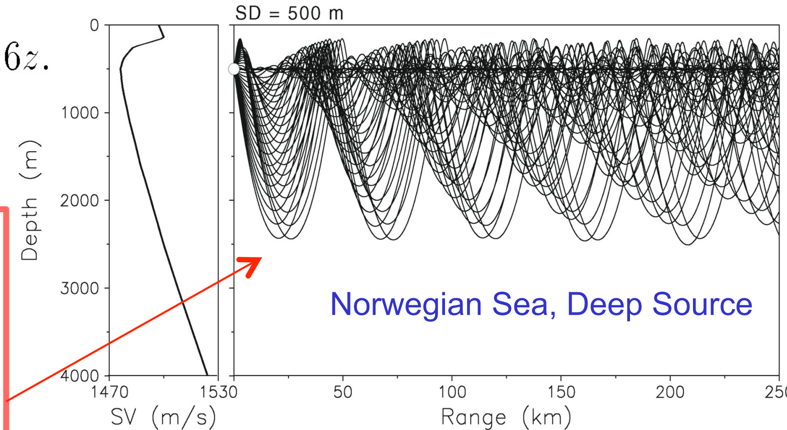


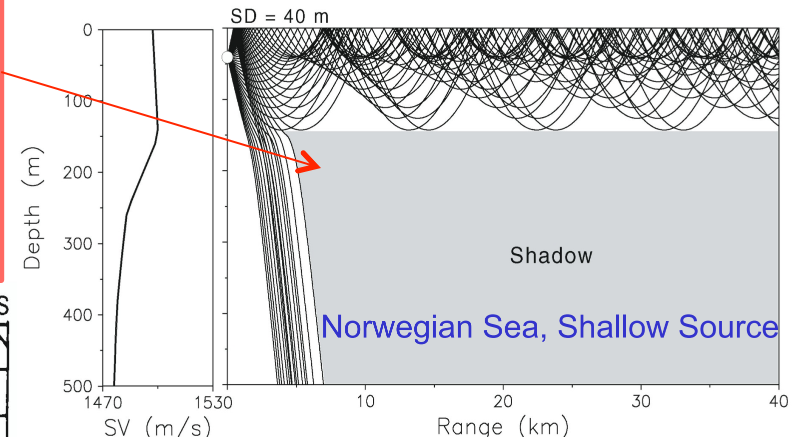
$$\frac{\cos \mu(z)}{c(z)} = \text{const}$$



Autonomous Marine Sensing Systems

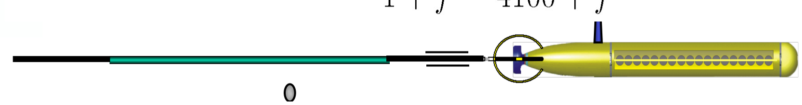
Acoustic Propagation





Attenuation

$$\alpha(dB/km) = 3.3\times10^{-3} + \frac{0.11f^2}{1+f^2} + \frac{43f^2}{4100+f^2} + 2.98\times10^{-4}f^2,$$



0

Distributed Sensing Networks Performance Trade Space

Massachusetts Institute of Technology

Autonomy
Artificial Intelligence

Situational Awareness
- Platform Dynamics
- Environment
- Tactical

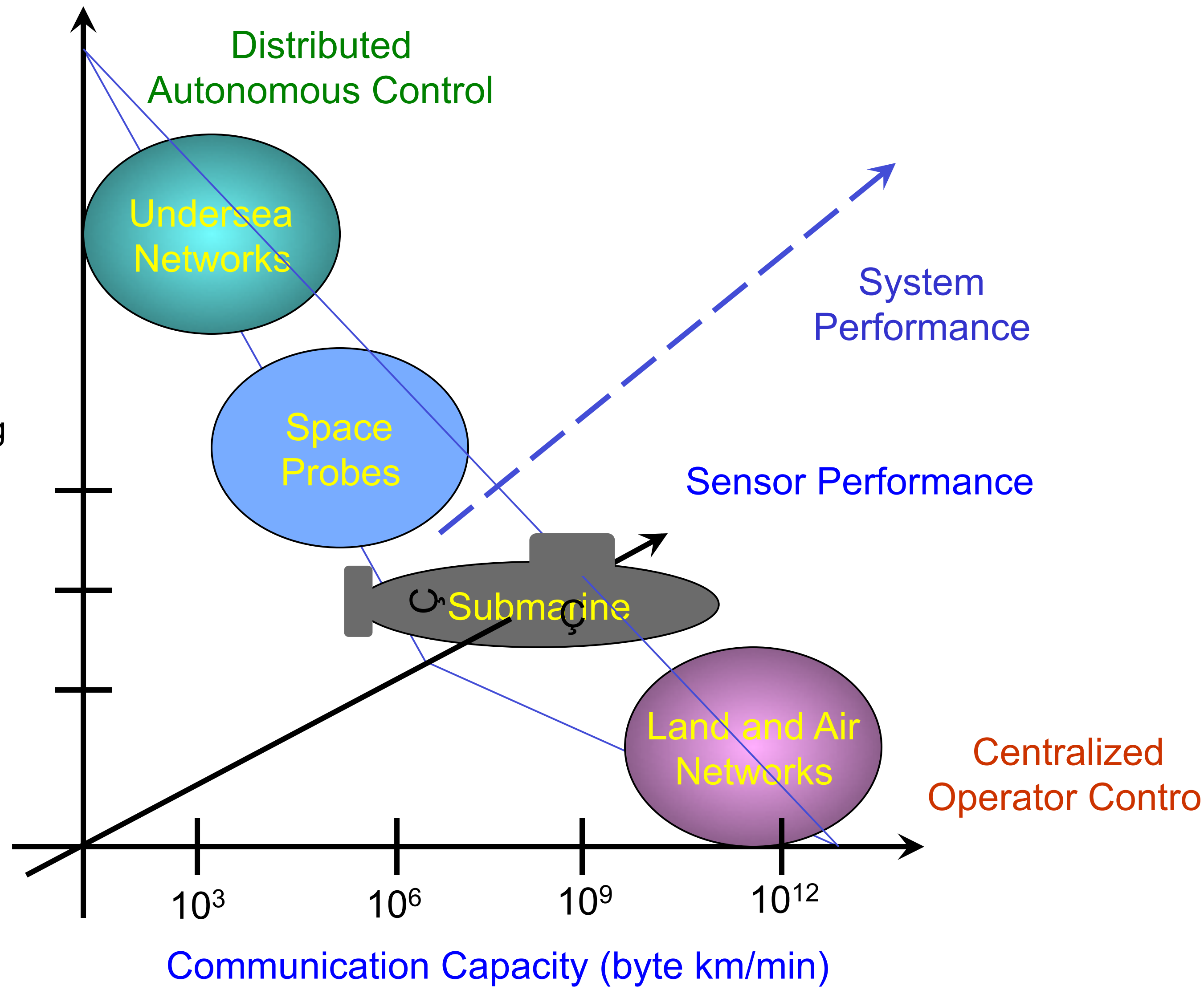
Adaptation
- Tactical
- Environmental

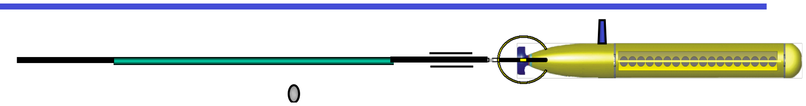
Modeling and Forecasting
- Tactical Forecasting
- Environment
- Sensor performance

Collaboration
- Data fusion
- Team mission

Strategies and Behaviors
- Decision making

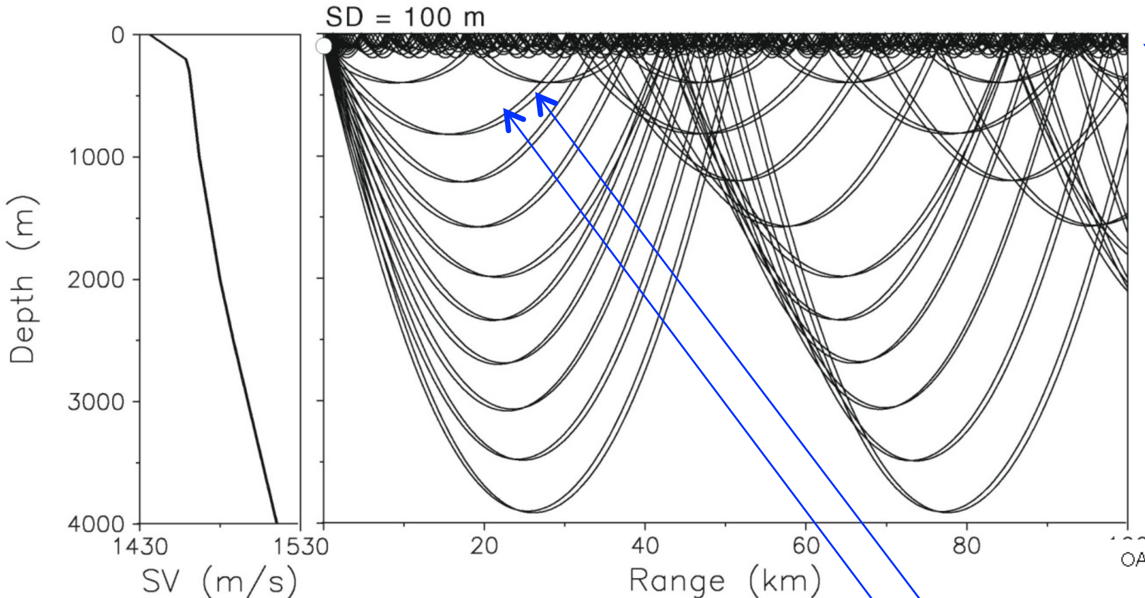
Learning
- Machine learning





Massachusetts Institute of Technology

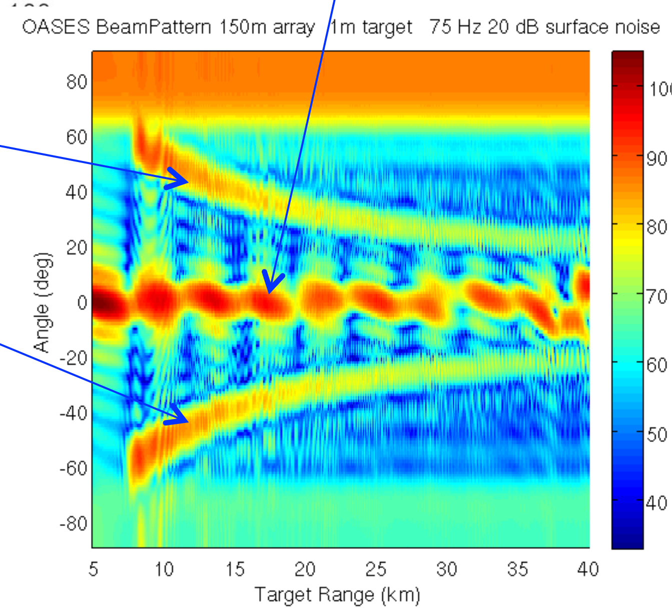
Arctic Acoustic Environment



- Upward refracting SVP yields reliable RAP paths via deep diving rays
- Monotonic relation between elevation angle and range

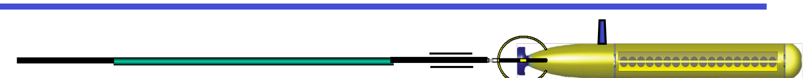
Applications

- Localization and tracking of active ice fracture zones
- ASW
- Acoustic communication
- Navigation



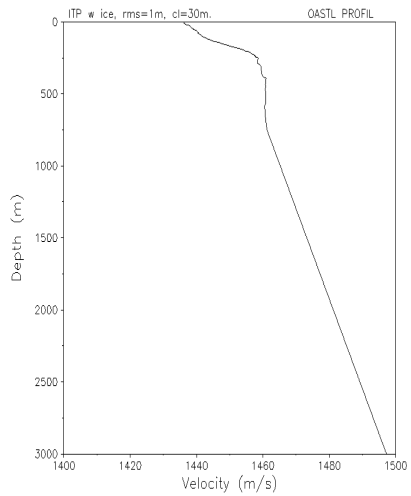
Acoustic Signatures of Arctic Climate Change

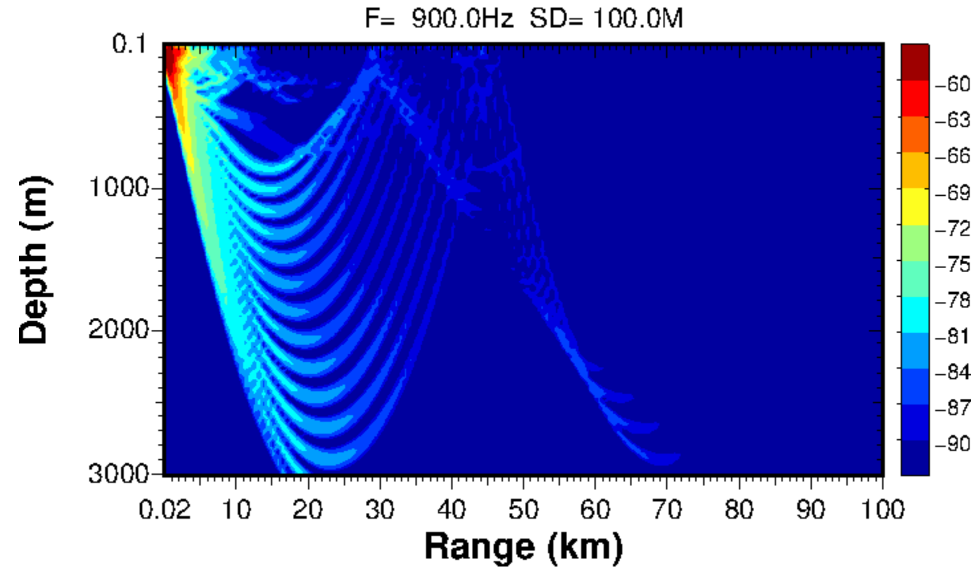
- Sound speed profile
  - Increased average sound speed
  - Increased surface sound speed in open water creates efficient sound channel with reduced surface interaction
  - Recently observed warm water entering through Bering Strait at 100 m depth creates very efficient duct without interaction with ice cover (‘Beaufort Lens’)
  - Complex laterally inhomogeneous propagation environment in MIZ
- Ice cover
  - Retreating ice cover
    - Exposes environment to more atmospheric interactions, resulting in more temporal variability of acoustic environment
    - Exposes seabed for seismic exploration
  - Thinner ice with altered roughness statistics
    - Changes in scattering loss for long-range propagation
    - Changes in modal composition of long range propagation
  - Changes in dominant ice fracturing processes
    - More frequent, mechanical fractural event
    - Less dominance of thermal fracturing processes
  - MIZ ambient noise peak becomes significant throughout Arctic.



The New Arctic Propagation Environment

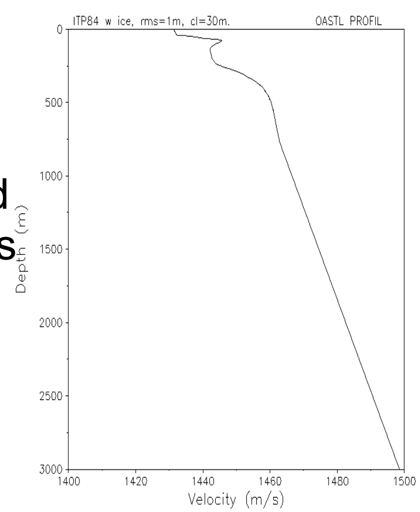
ITP 14
Traditional Arctic SVP

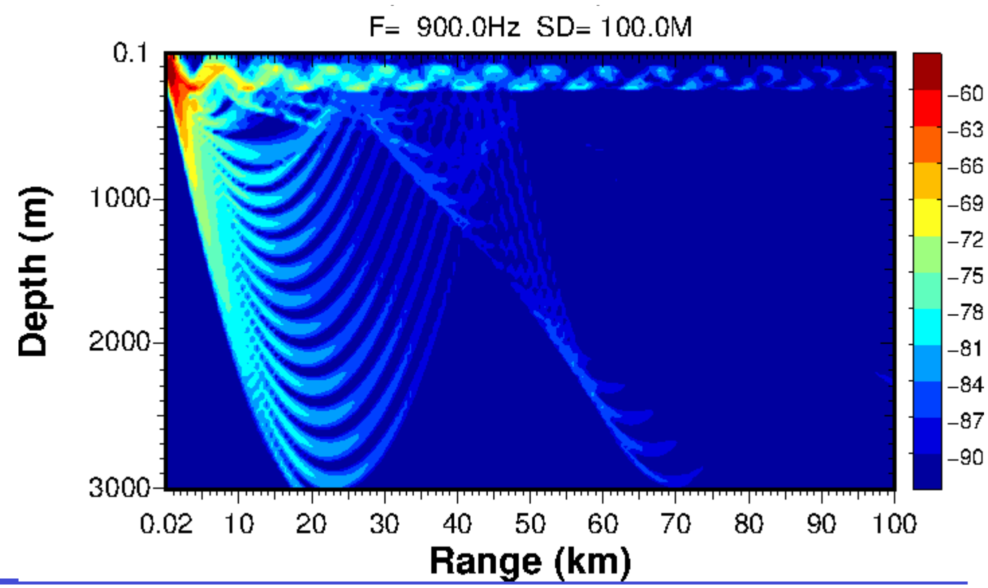


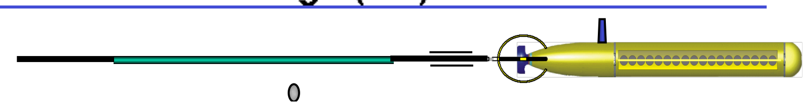


ITP 84
New Arctic SVP
'Beaufort Lens'

Effect
Dramatically improved propagation conditions in duct isolated from surface and bottom interaction







Macrura Survey Mission

March 15, 2016

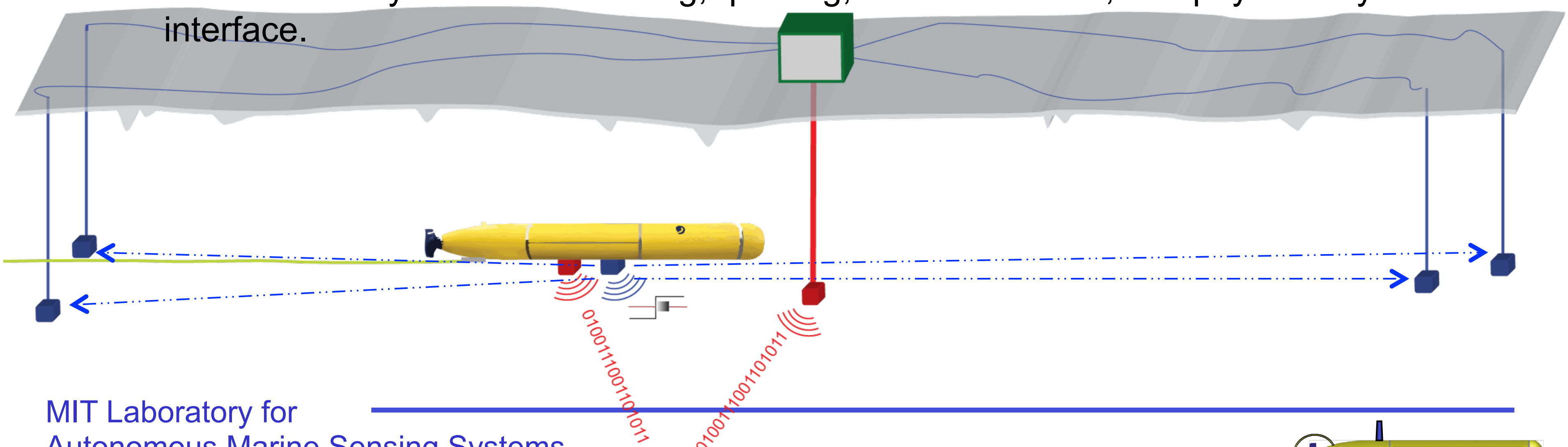
Camp Sargo
Integrated Acoustic Tracking and Communication

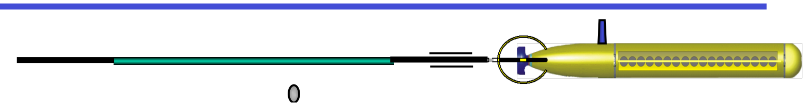
Acoustic Tracking and Navigation

- Integrated with existing ARL/UW submarine tracking
- WHOI HF Micro-Modem on platform emits tracking pulse
  - 1PPS 3.5 ms CW at 13.5kHz with doublet every 10 seconds
  - 10.5Khz carrier, 3kHz bandwidth 10ms FM sweep (“platform”)
- Computed position transmitted back to UUV via acoustic communication to update INS navigation solution

Acoustic Communication

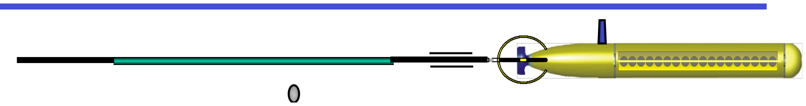
- Hardware: WHOI MF Micro-Modem (3.5 kHz center, 1.25 kHz bandwidth), shared with NUWC Digital Acomms transmit transducer and receive hydrophone
- Software: Goby/DCCL marshalling, queuing, medium access, and physical layer interface.





Tracking Range Performance

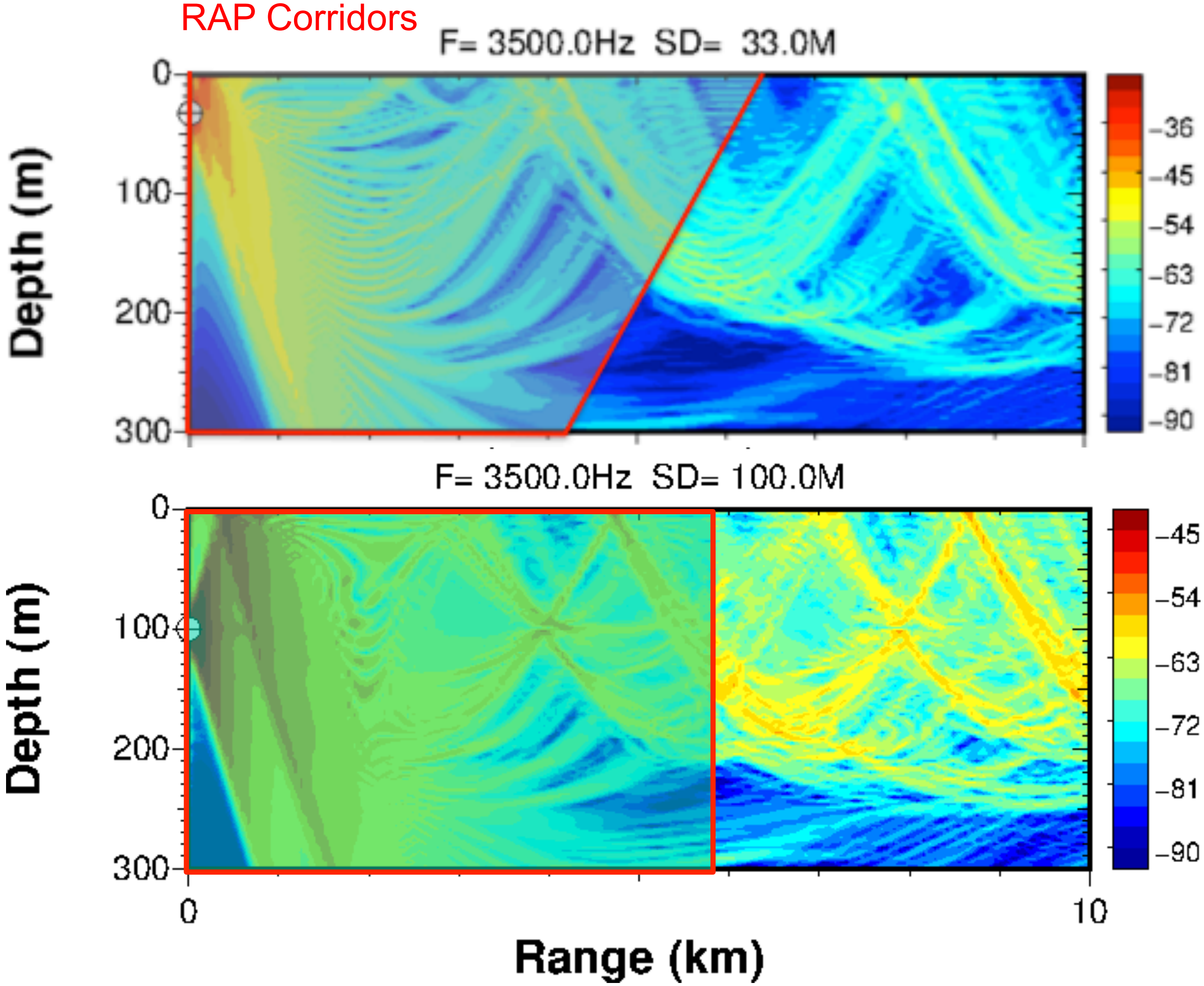
- Tracking range performance inferior to previous ICEX’
  - Tracking range aperture smaller than historical due to ice floe constraints
  - Depth of tracking hydrophones fixed at 33 m
  - Tracking of shallow targets (<80 m) have increased uncertainty beyond a ~ 1 km range and no tracking beyond ~ 2 km
  - No tracking of deep targets (>80 m) beyond 1-1.5 km range
  - Submarines had trouble detecting and localizing camp homing beacon.
  - Modeling confirms that the performance degradation is associated with Beaufort Lens.
- Tracking range performance constrained AUV operations
  - Safe operations restricted to area within range aperture (~ 1 km)



Massachusetts Institute of Technology

ACOMMS and Navigation Historical Arctic

Acomms/Nav Effects

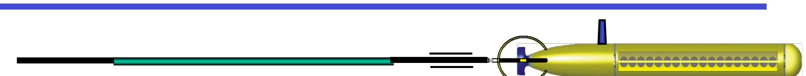


Shallow source/receiver provides direct paths to target at all operational depths out to 6 km range.

No reliance on slower surface duct multipaths.

Deep source provides no advantage, with RAP paths only to 6 km range

ICEX16 tracking range was designed for this environment

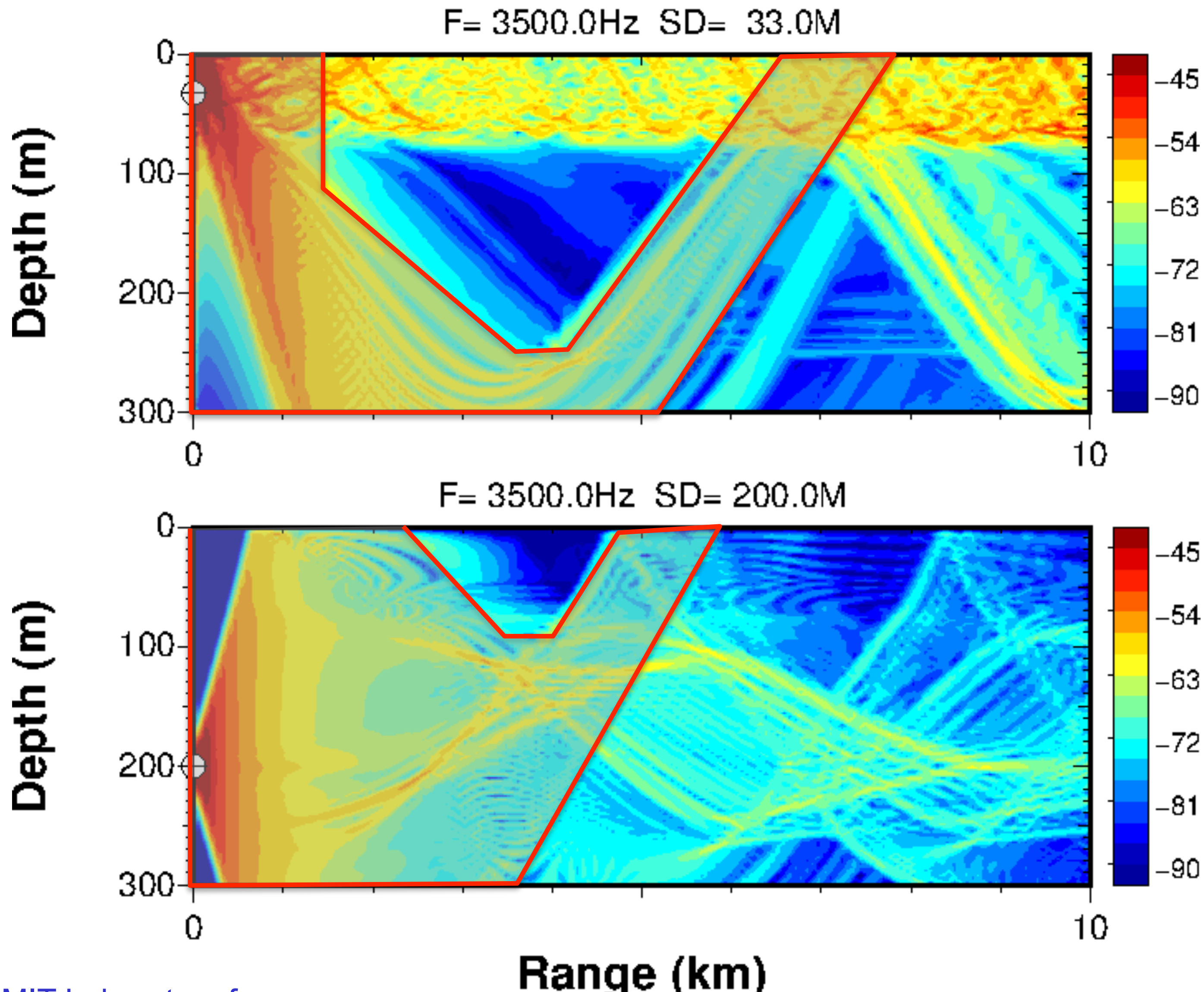


Massachusetts
Institute of
Technology

ACOMMS and Navigation
ICEX16

RAP Corridors

Acomms/Nav Effects

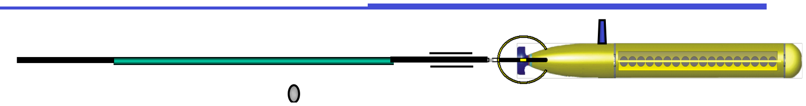


Shallow source/receiver provides NO direct paths to shallow target. Ice interaction degrades coherence beyond a couple of km range. Deeper CZ RAP paths at 6-7 km range. Deep target reachable only at very short range.

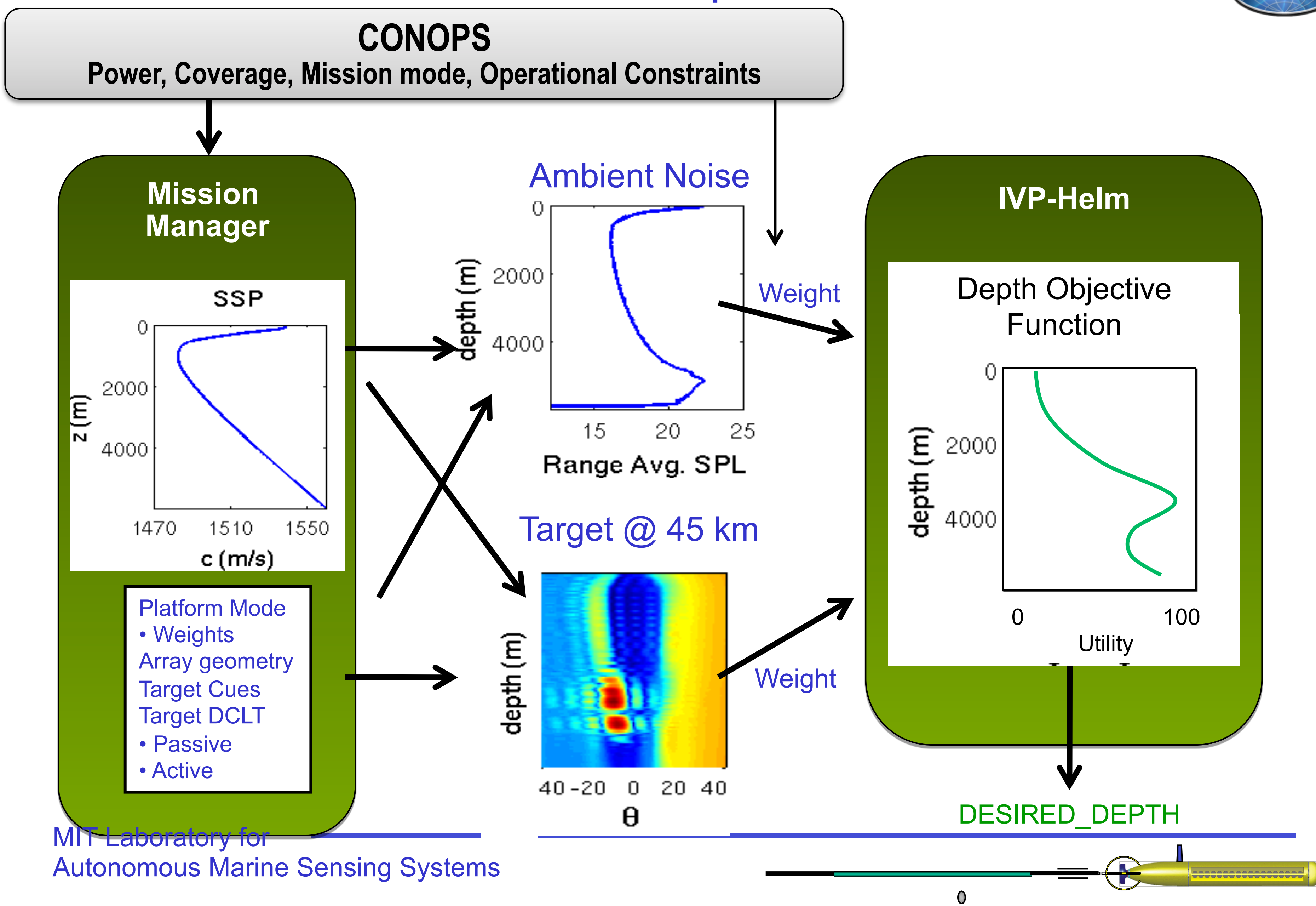
Deep source/receiver required for reaching deep target. Shrinking shadow zone

Confirmed experimentally in ICEX16

Depth Adaptation!

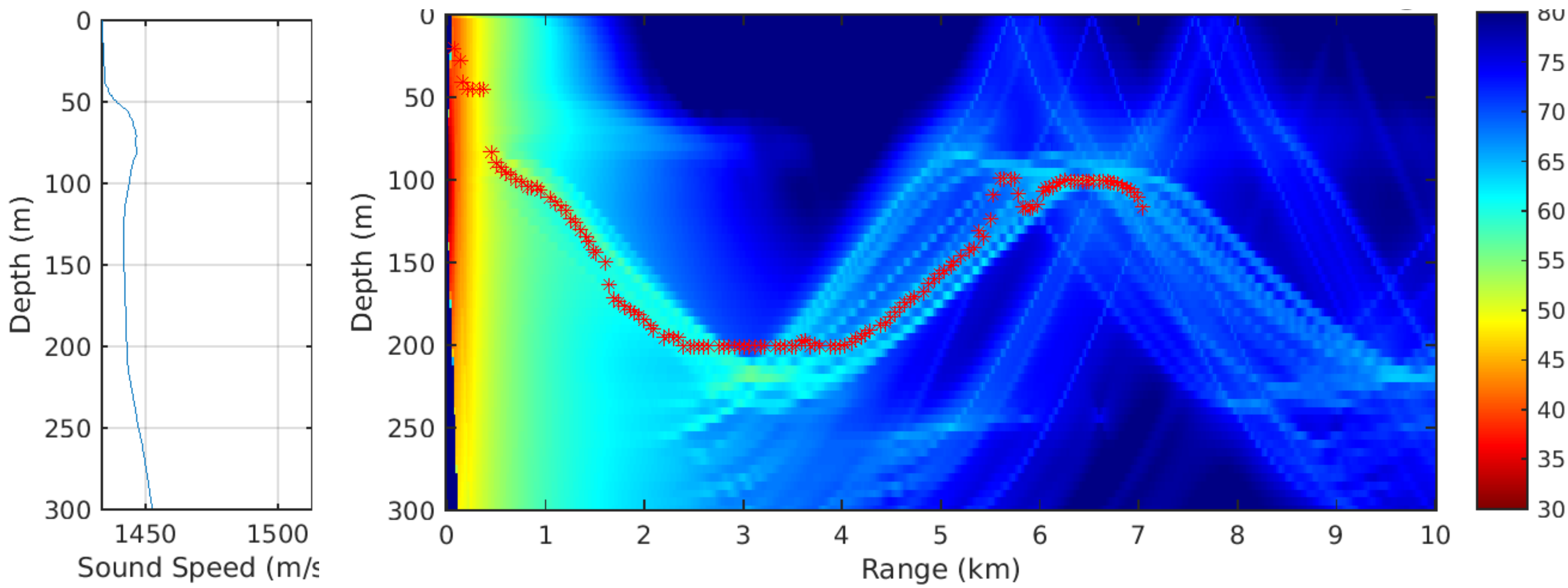


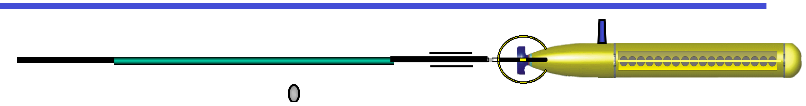
Model-based Environmental Adaptation



Massachusetts Institute of Technology

ICEX16 Environment
Depth Adaptation
for ACOMMS and Tracking





Summary

- Environmental Acoustics is critical to safe and reliable operation of unmanned undersea vehicles
  - Optic systems and high bandwidth acoustic systems only feasible for short ranges, < 100 m.
  - Acoustic sensing, communication and navigation only viable option for longer range operations.
  - Attenuation restricts longer range (10-100 km) communication and sensing to low frequencies (<~1 kHz), limiting information bandwidth
  - High variability of sound speed (~ 10%) yields strong variability and intermittency of reliable acoustic paths.
  - Environmental fluctuations, and roughness of seabed and ice cover leads to loss of spatial and temporal coherence of acoustic signals.
  - Spatial variability of acoustic environment provides opportunity for high system performance gain for autonomous platforms through model-based environmental adaptation.