# AUV Technology and Application Basics

## Section 1

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# Course Outline

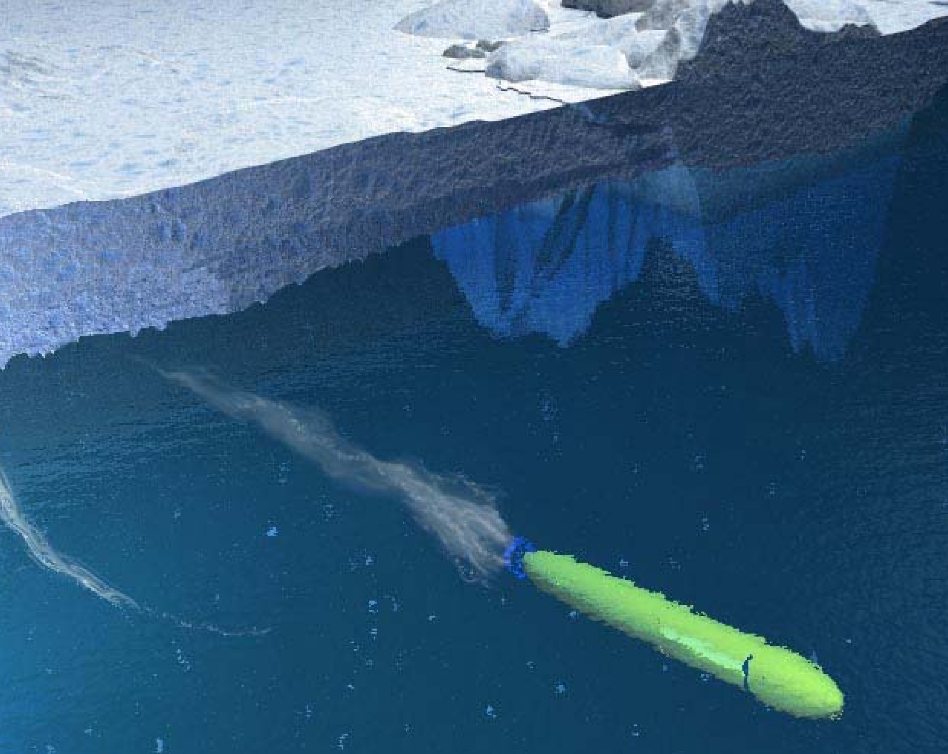
Section 1 – AUV Overview
- Applications and Motivations
- Operational Overview
- Application Examples

Section 2 – Basic Configuration
- Payload Configuration
- Propulsion
- Things That Affect Control
- At Sea Operations

Section 3 - Energy
- Timing
- Electrical Connectors
- Instrumentation

Section 4 – Software
- Data review and Analysis
- Navigation and Acoustics

Section 5 – AUV Frontiers: Next Generation Observing Systems



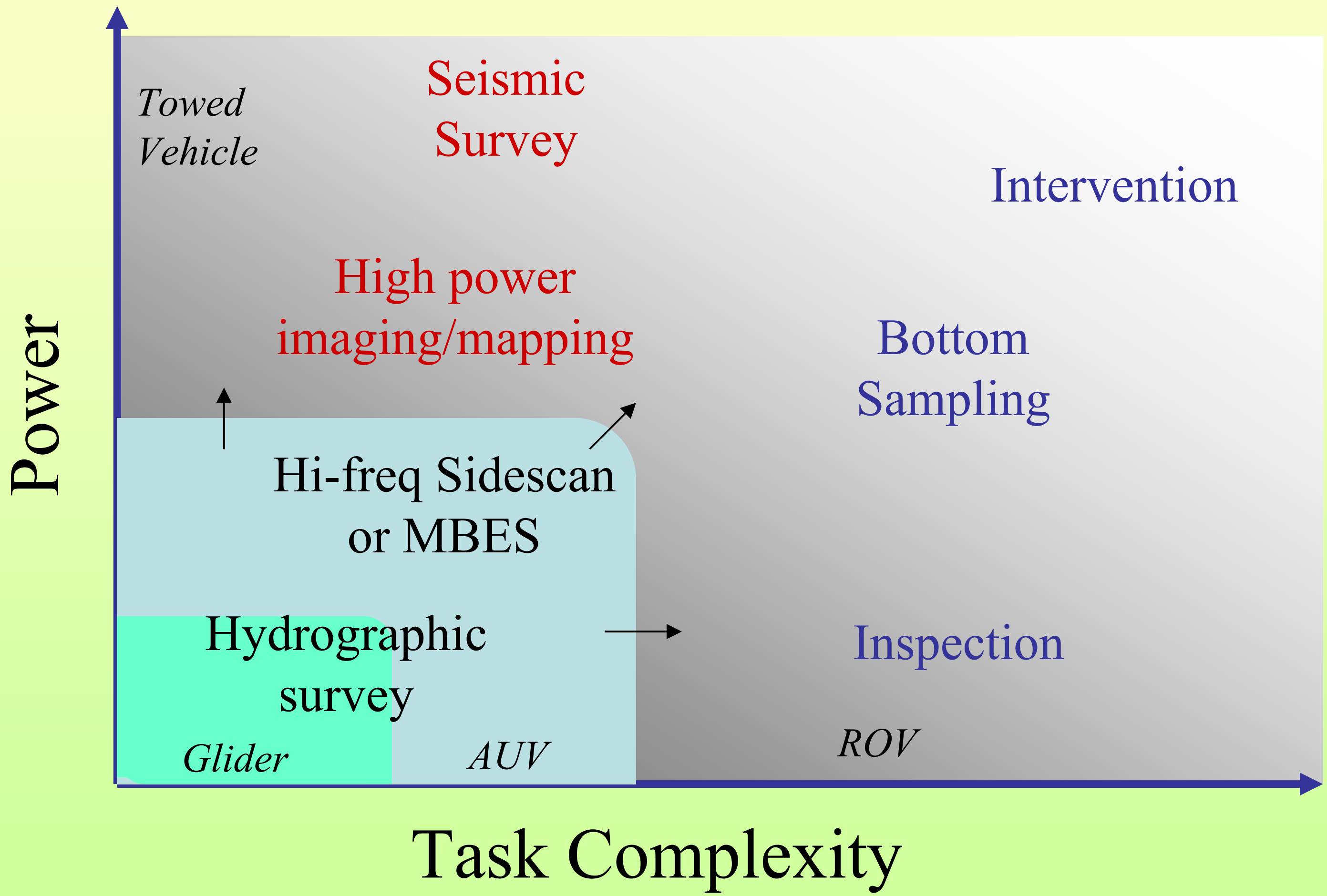

Odyssey II, MIT

ALTEX, MBARI

Dorado, MBARI

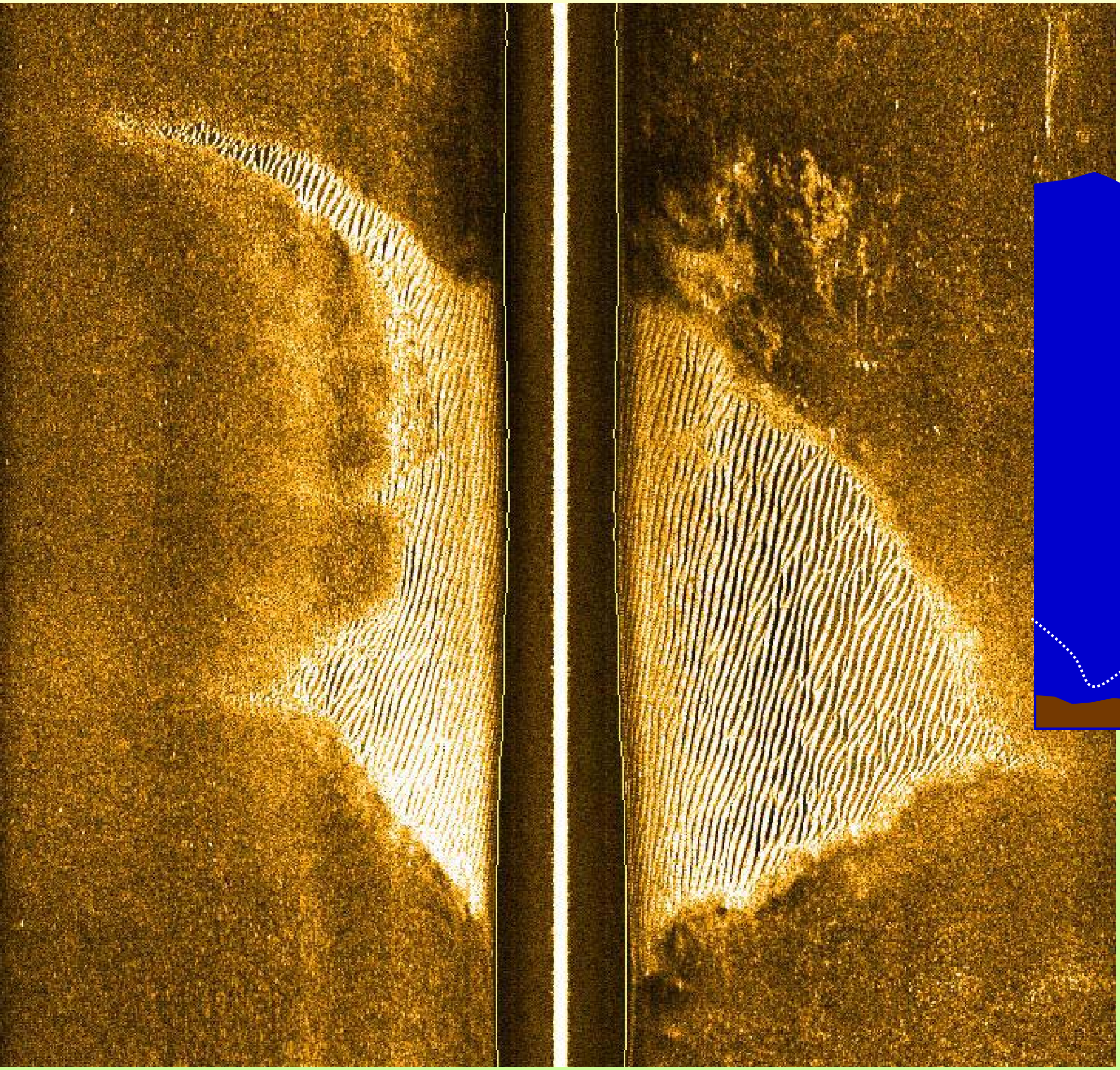
# AUV Applications & Motivations

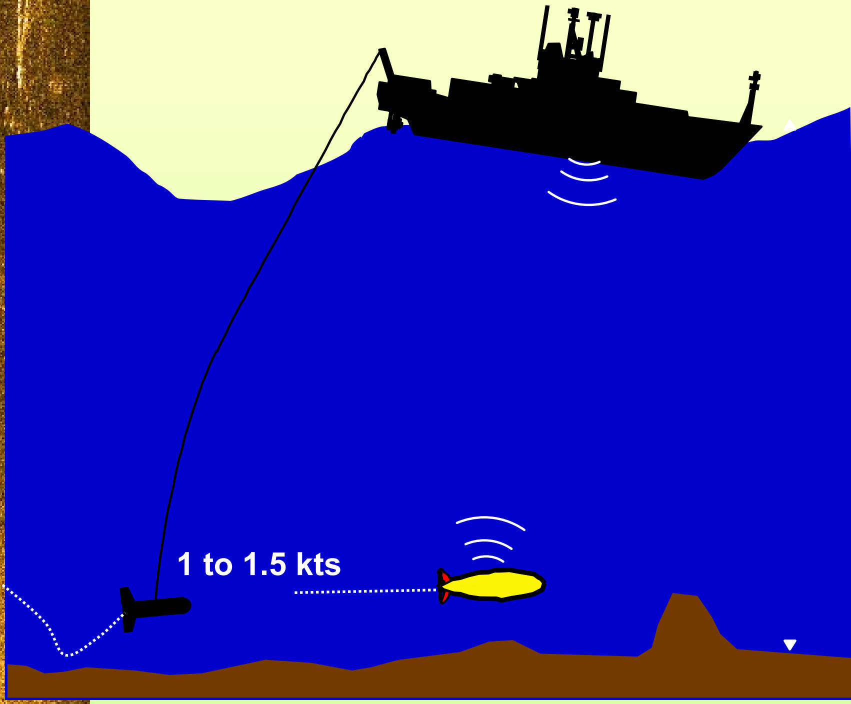
# AUV Operational Domain



# Data Quality

150 m






Courtesy Bluefin
BPAUV dataset

# Upper Ocean Processes

Side-scan images of sea surface at front in Haro Strait

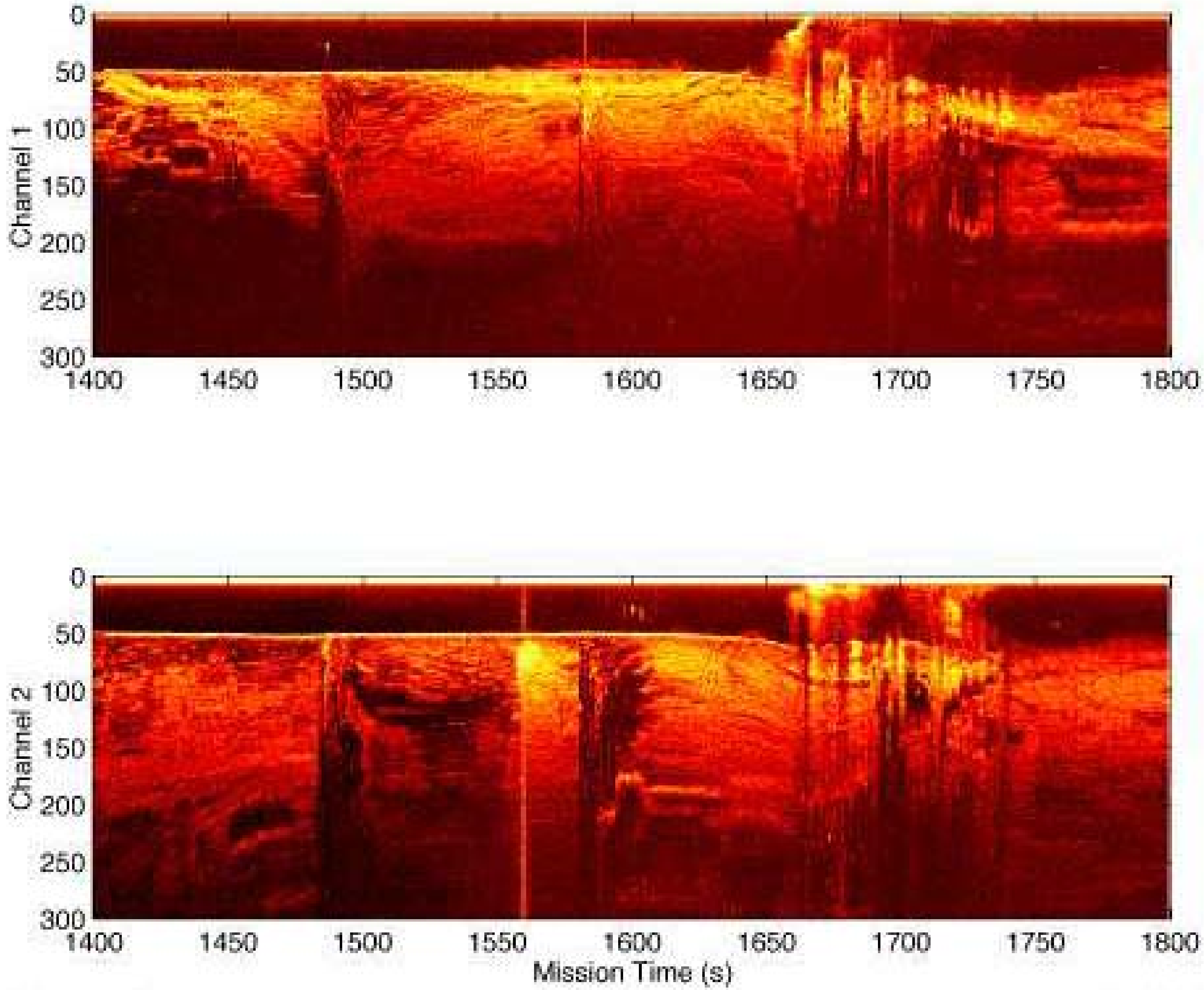
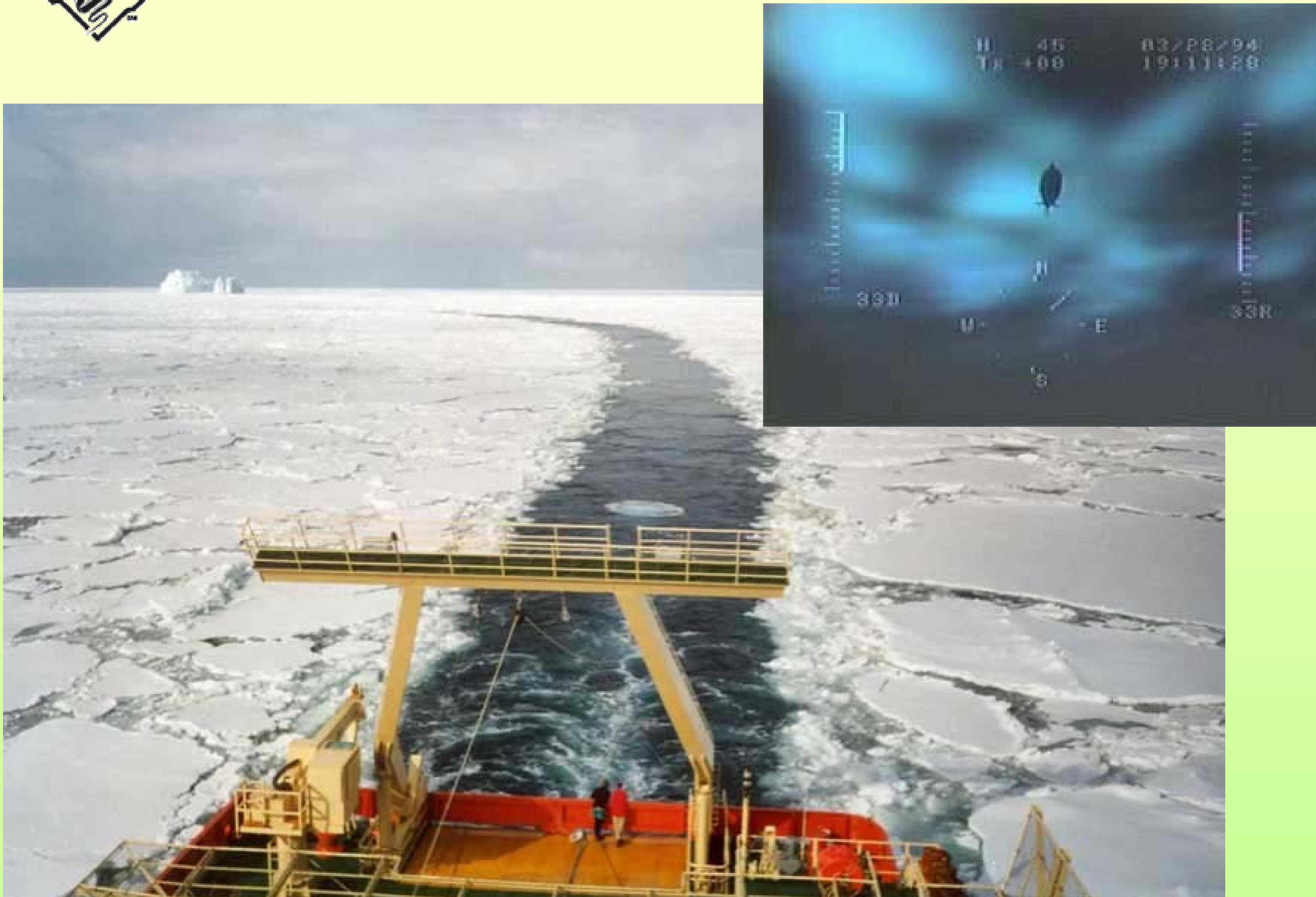


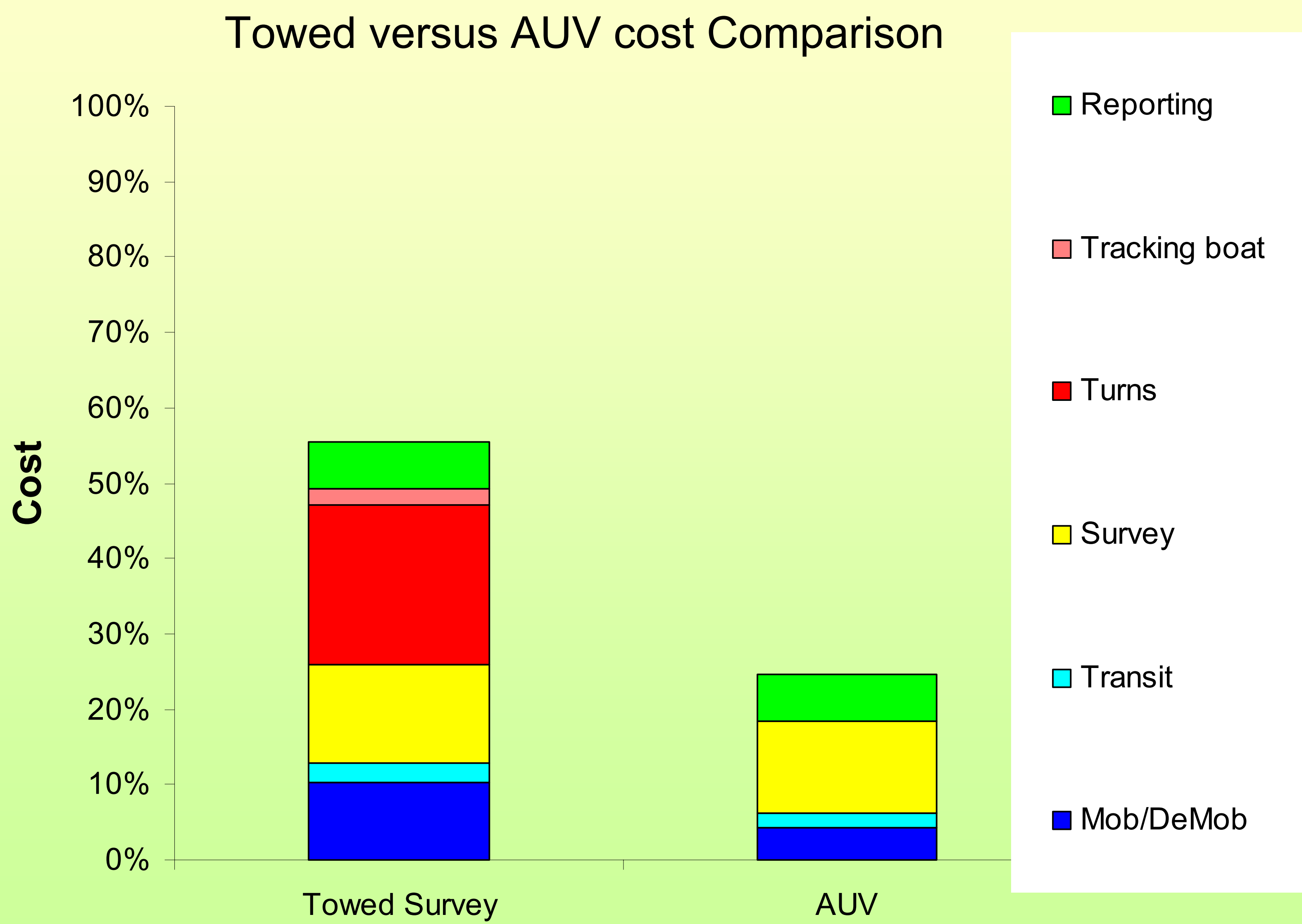

Figure 4

MIT Sea Grant AUV Lab 1996

# Under Ice Operations



# Economics



Towed versus AUV cost Comparison
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cost
Towed Survey
AUV
Reporting
Tracking boat
Turns
Survey
Transit
Mob/DeMob

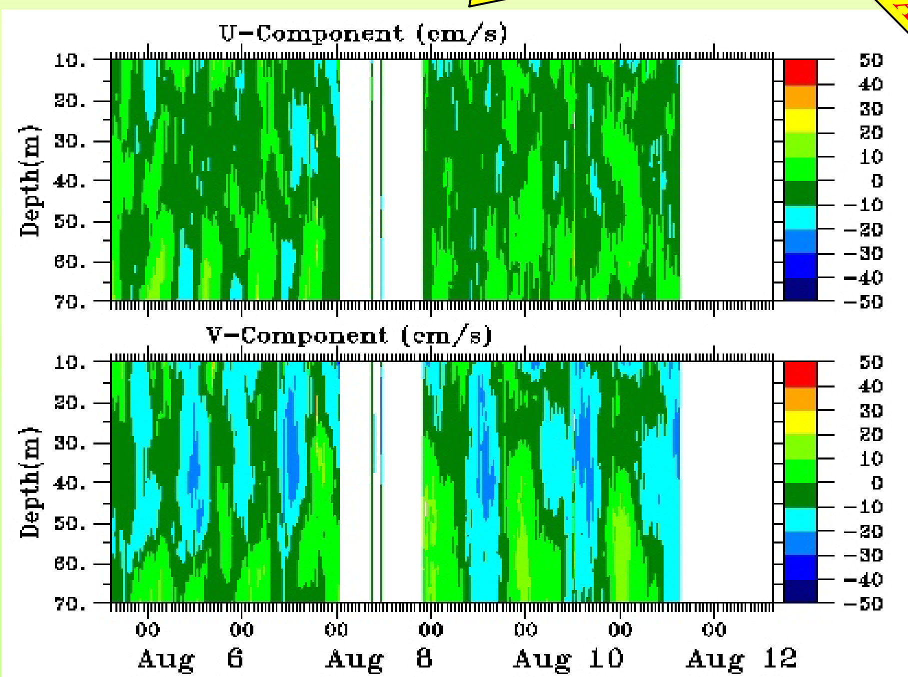
# Covert Operations

**_DATA BUS EXPERIMENT:_ Real-Time Data from Bottom-Mounted Profiler**

***ARIES AUV***


DATA

DATA




***Current Profiler***

***Housing***

*Tony Healey, Steve Ramp*

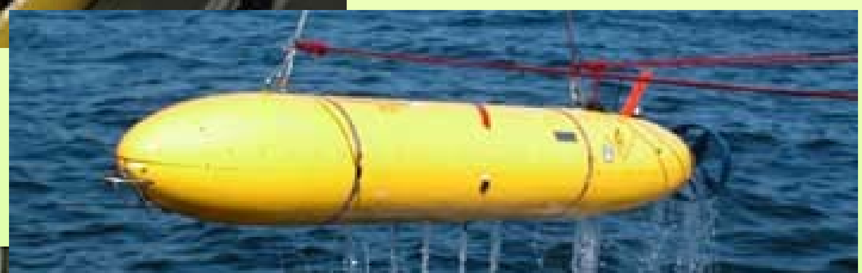
***Data Modem***

# AUV Status

- Depth ratings typically either 100-300 m or 3000-6000 m
- Typical endurance O(100 km) @ 5km/hr
- Operational experience growing.
- Market pull in oceanographic, military and commercial domains
- Rate of advancement VERY fast….
- Unattended deployment in development
- Long range systems (1000 km +) in development

# Modular AUVs - Dorado





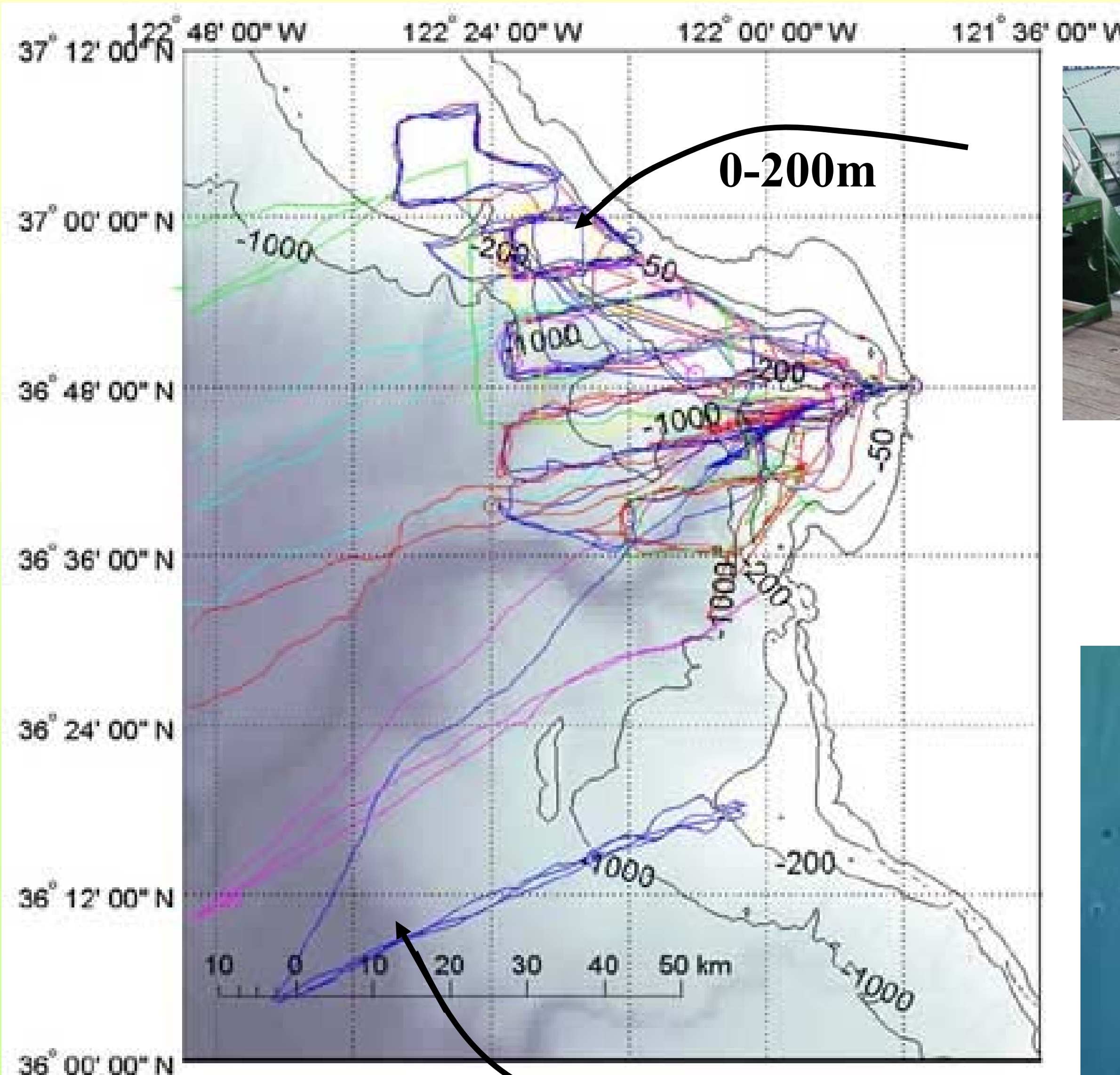
# Autonomous Benthic Explorer (ABE)

- Deep ocean benthic survey operations
- Highly maneuverable, near bottom operations
- Sensors: Stereo CCD imaging, magnetometer, bathymetry, OBS and CTD
- Navigation systems include low and high frequency LBL
- 6000 m rated.

# Gliders

- CTD platforms
- Range up to 1000s of km...
- Weight about 50 kg
- Speed < 1 kt
- Communication:
  - ORBCON
  - Iridium

# AOSN II Glider Operations – Monterey Bay 2003

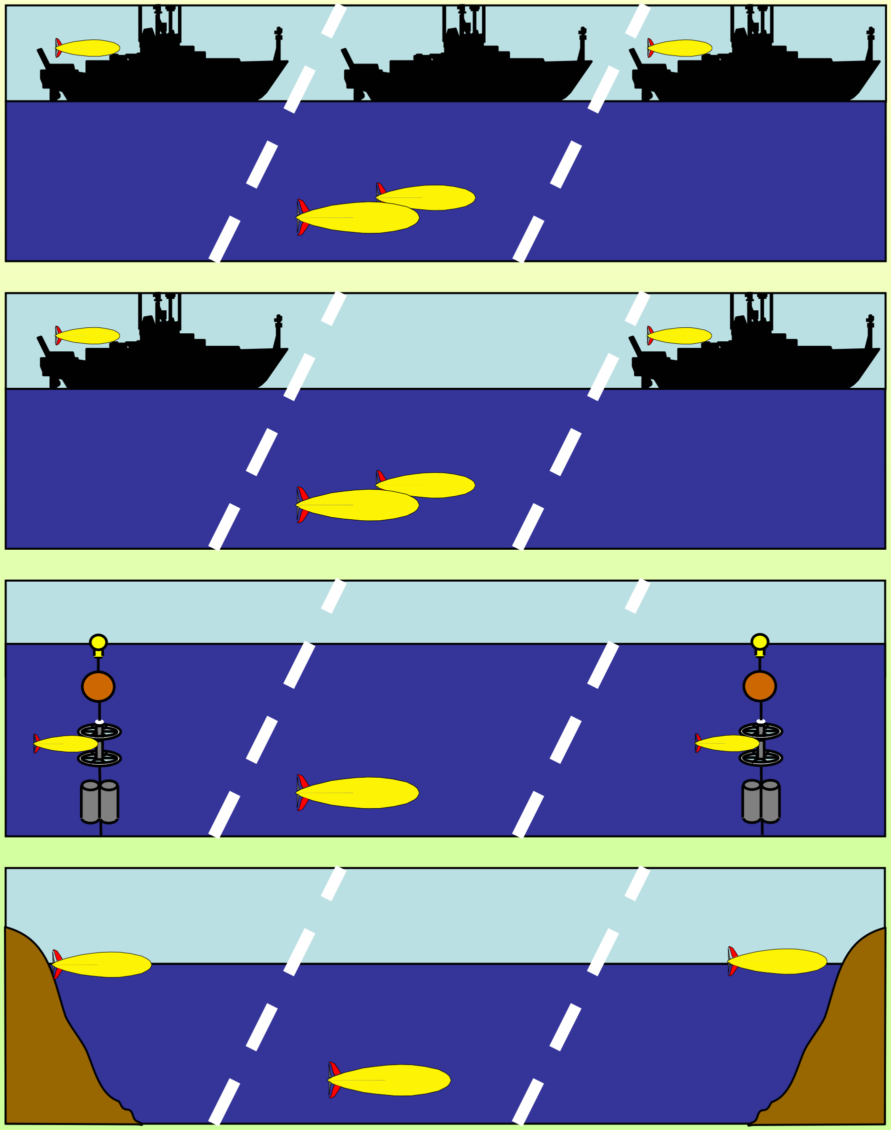



**August 2003**
**Glider Tracks**

**0-400m**

# AUV Operational Overview

# Operational Scenarios

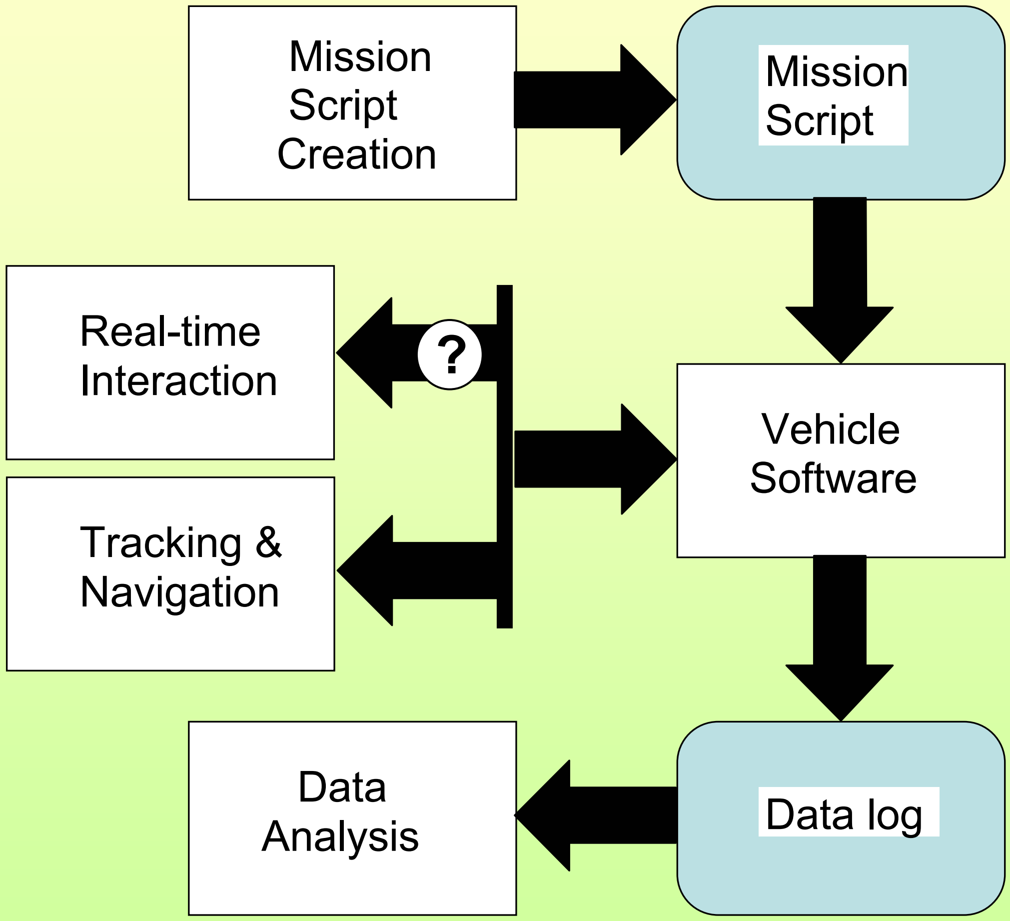


| Pro | Con |
| --- | --- |
| * Navigation by tracking<br>* Faster deep survey<br>* Multiple platforms | * Ship costs dominate |
| * Ship free for additional activity | * Navigation an issue |
| * Episodic response<br>* Rough weather ops<br>* Multiple platforms<br>* Space-time cov. | * Complex<br>* Dock expensive<br>* Deployment and recovery |
| * No ship! | * Energy required for transit<br>* Navigation an issue |

# A day in the life of an AUV…

1. Vehicle preparation
   a. Check batteries
   b. Close pressure vessels
   c. Check vehicle trim
   d. Vehicle self-test
2. Mission configuration
3. Pre-launch
   a. Check tracking
   b. Check navigation
   c. Check location devices
   d. Run vehicle self-test
4. Position ship/boat for launch
5. Launch vehicle
6. Command mission start via rf communications
7. Track vehicle or commence other operations
8. Mission end
   a. Locate vehicle if unattended
   b. Recover data subset if operations to continue or
9. Recover vehicle
10. Download and review data

# AUV Software - User Interactions



# Mission configuration

Behavior-based arbitrated control architecture:

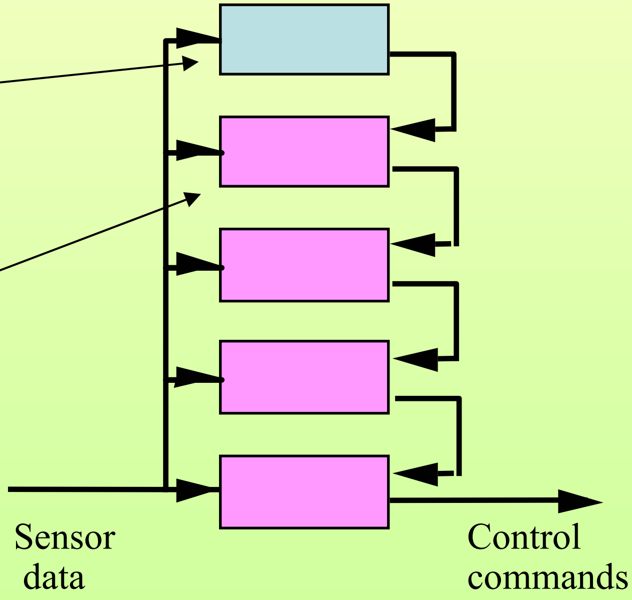
- missions are configured from a library of ‘behaviors’
- multiple behaviors can run at once
- combinations of behaviors can give
- behaviors are prioritized

Goal oriented behavior examples:

descend to a set depth
run in a particular direction and speed
go to a particular location
home on a transponder

Safety behavior examples:

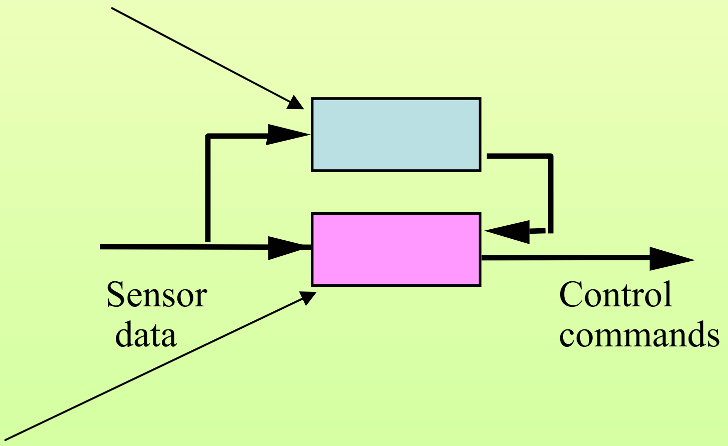
avoid hitting the bottom
don’t let the batteries get too low
time out after a certain period



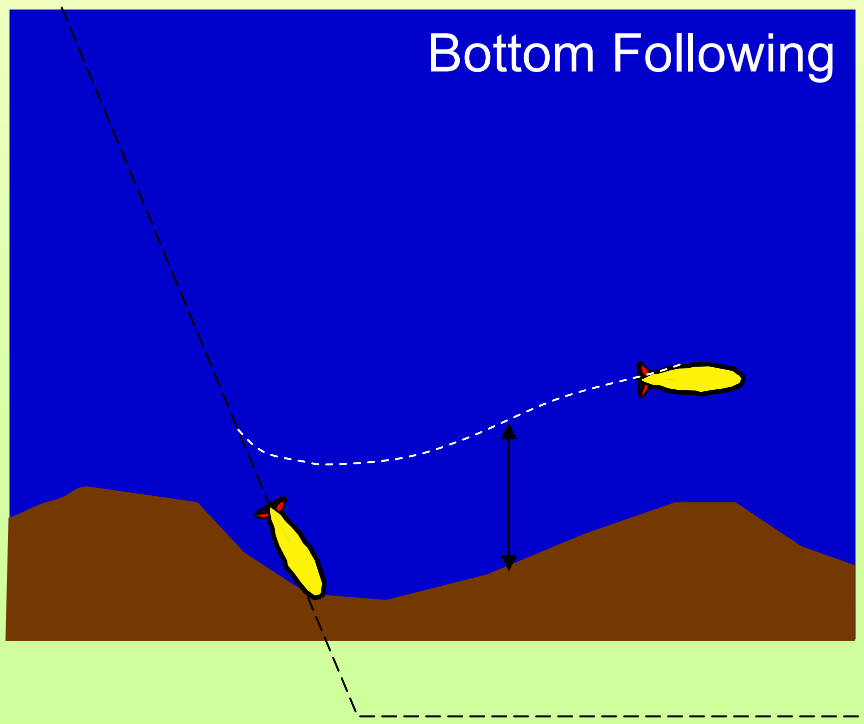
# Combining Behaviors

More complex performance can be obtained by combining behaviors…

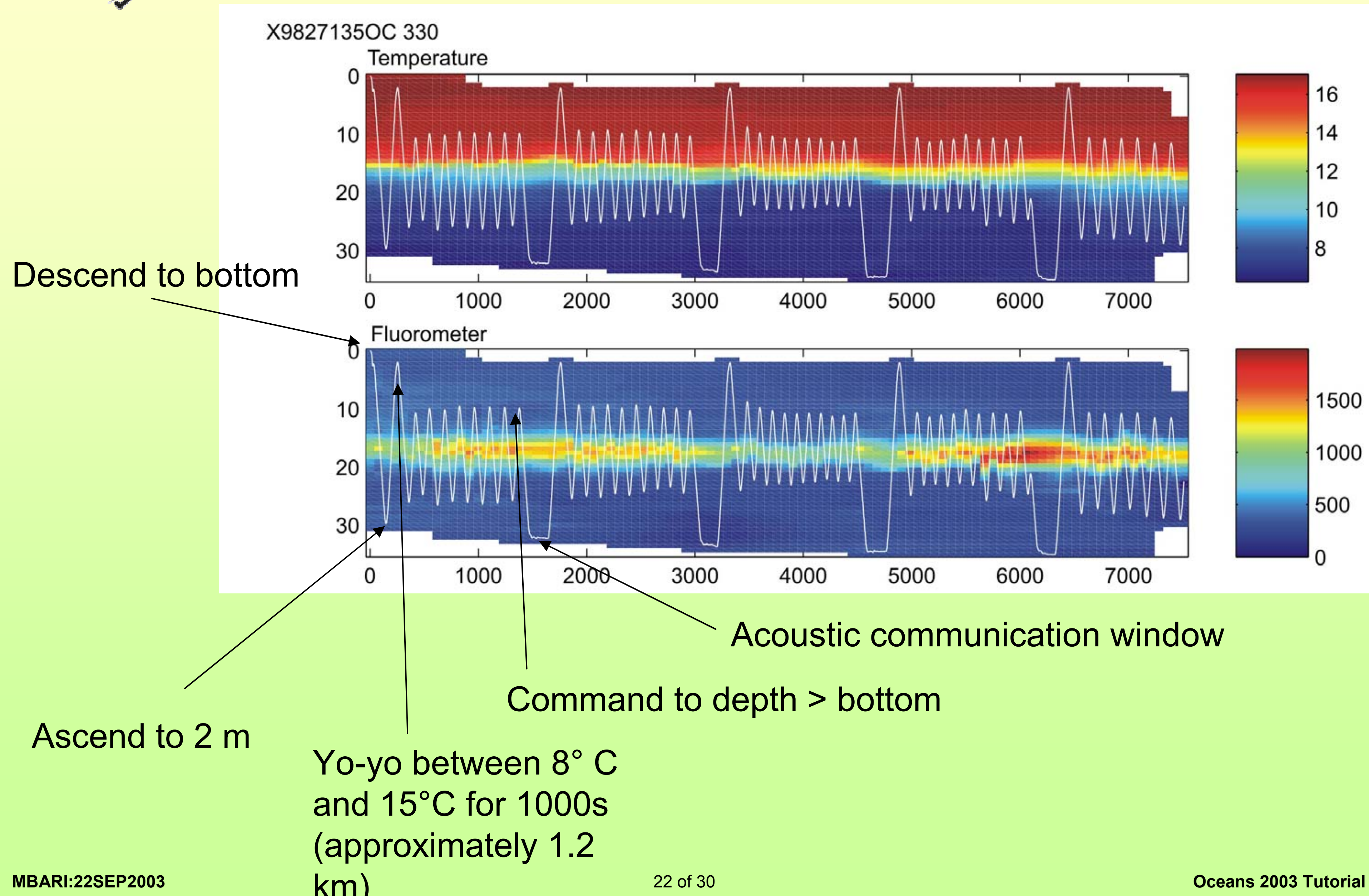
Setpoint – run at a particular direction, depth and speed.
INTENTIONALLY SET TO RUN THROUGH BOTTOM




Depth Envelope – keep vehicle from approaching to close to bottom



# Sequencing mission tasks



Applications Example:

Optimizing AUV Surveys of Dynamic Processes
(I.e. mapping a changing ocean)

# Range/Speed Relationships

**Power consumption:**

$$P_T = \frac{1}{2}\frac{\rho\, C_d\, S}{\eta} v^3 + P_h$$

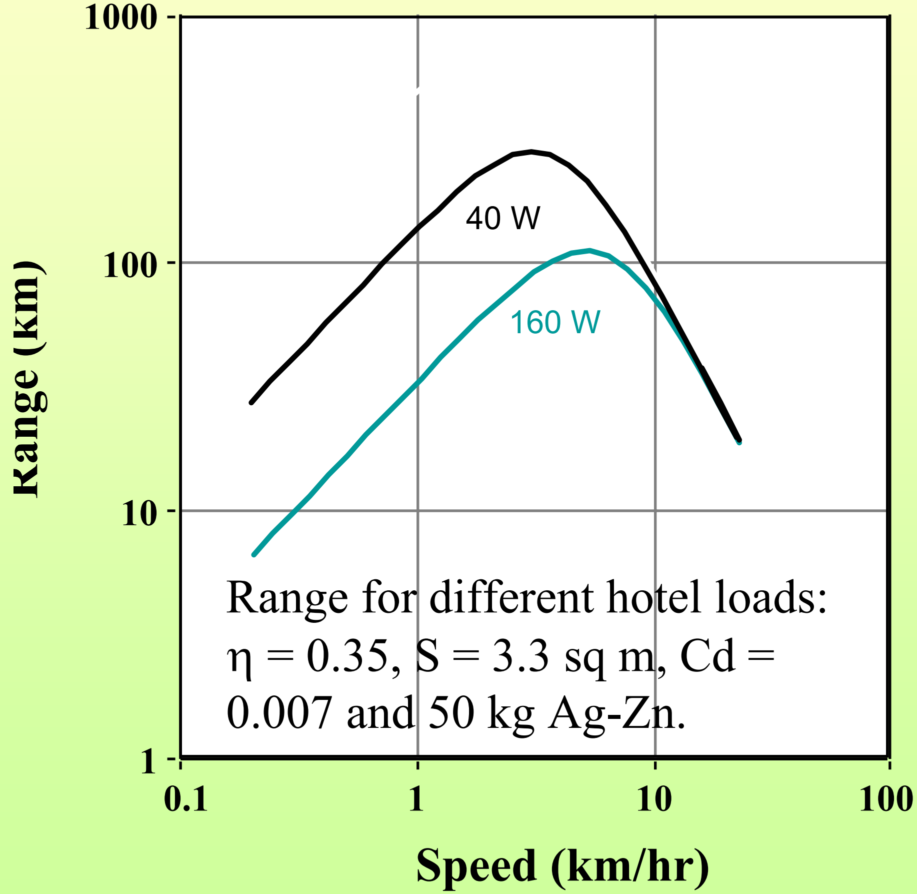
**Energy per distance traveled:**

$$e = \frac{1}{2}\frac{\rho\, C_d\, S}{\eta} v^2 + \frac{P_h}{v}$$

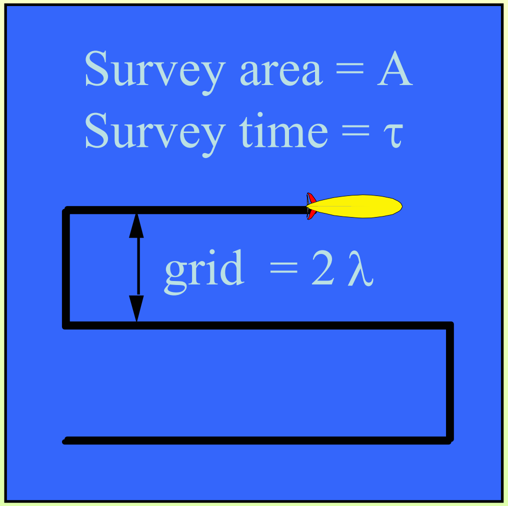
**Best speed:**

$$v_{opt} = \left(\frac{P_h\, \eta}{\rho\, C_d\, S}\right)^{1/3}$$

**when** $P_p = \frac{P_h}{2}$



# The Grid Survey



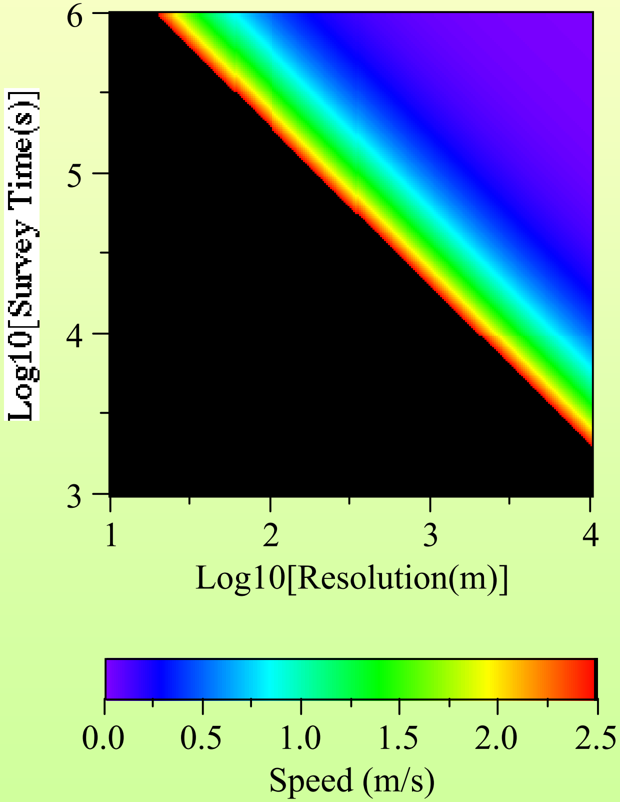

Total Survey Distance

$$\mathbf{d = A/2\lambda}$$

Required Speed

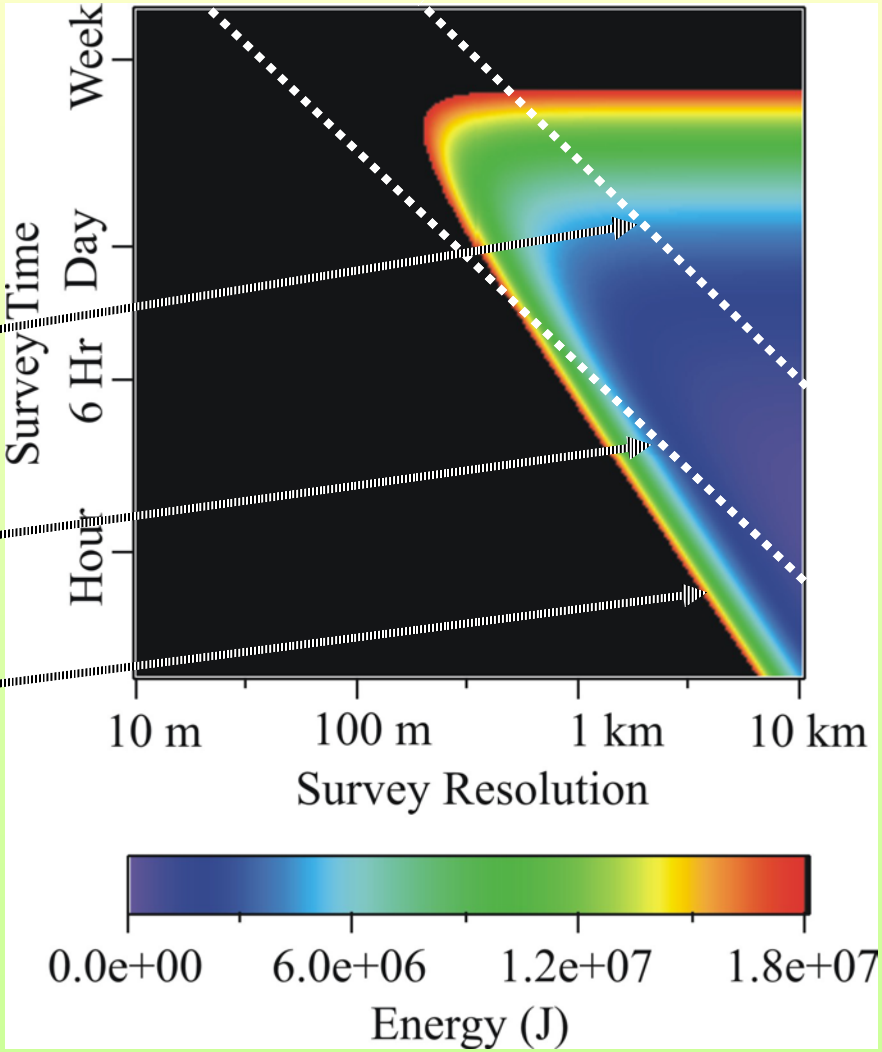
$$\mathbf{v = A/2\lambda\tau}$$

Example - 100 sq km Area



# Survey Envelope

Determining the accessible survey space




Minimum vehicle velocity

Maximum vehicle velocity

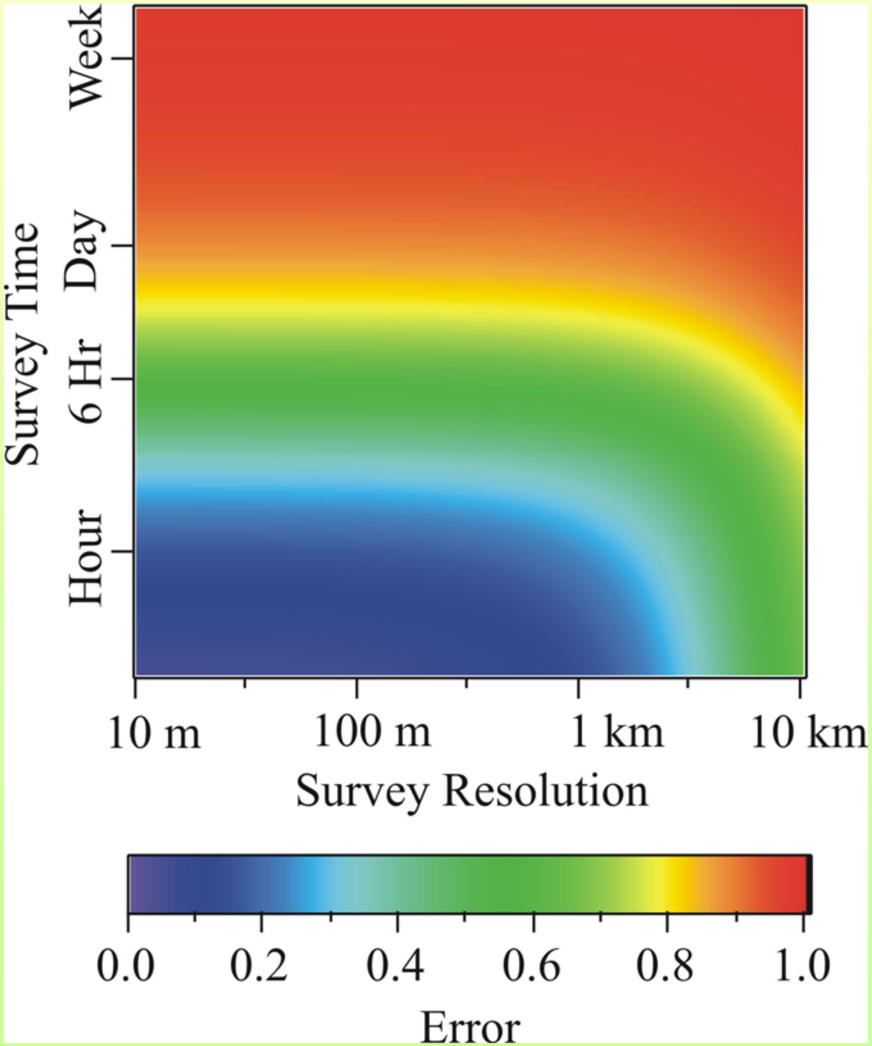
Energy limit of vehicle

$E_{total}$ = total energy available.

$$(P_{total})\tau = \left( \frac{\rho\, C_d S V^3}{2\eta} + P_h \right)\tau$$

# Survey Error

## Computation for a Time-Varying Oceanographic Field




Temporal Error Contribution:

$$\varepsilon_\tau = \int_{-\tau/2}^{\tau/2} R(t)\,dt$$

Spatial Aliasing Contribution:

$$\varepsilon_\lambda = \frac{\int_{\Omega} P(\mathbf{k})\,d\mathbf{k}}{\int_{\Omega+\Psi} P(\mathbf{k})\,d\mathbf{k}}$$

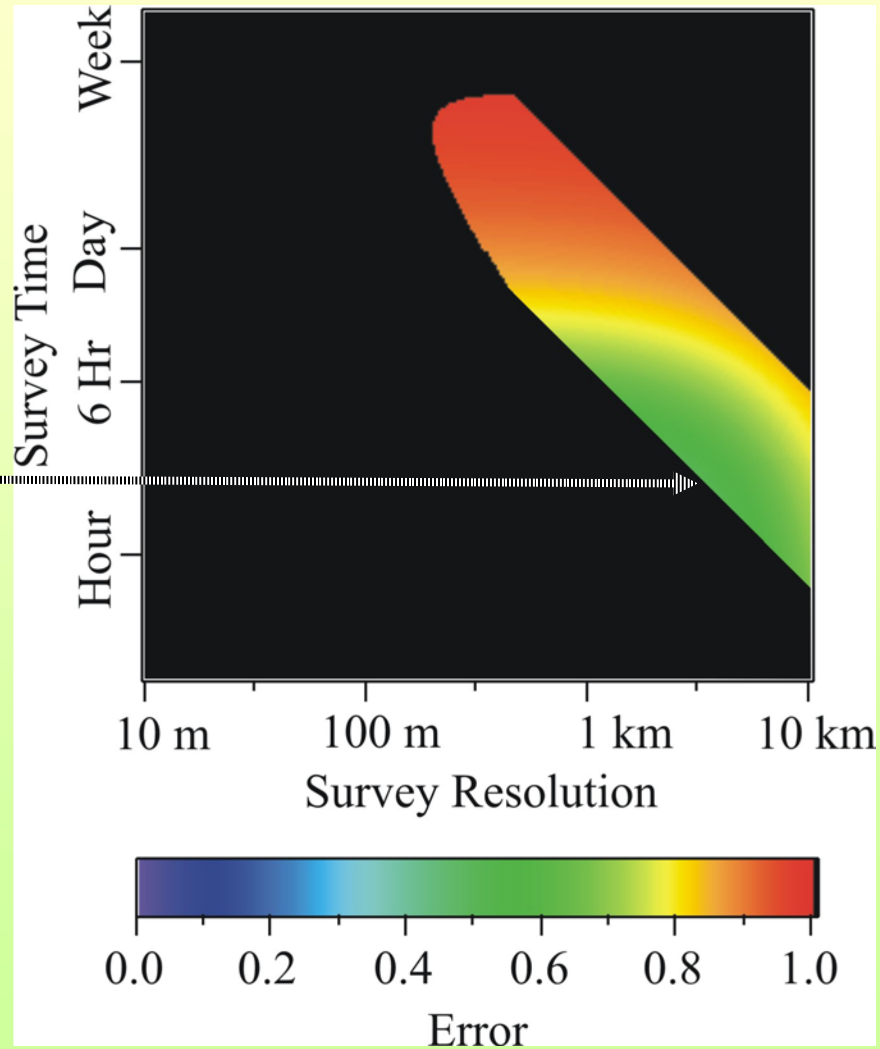
Cumulative Error:

$$\varepsilon_{total} = 1-(1-\varepsilon_\lambda)(1-\varepsilon_\tau)$$

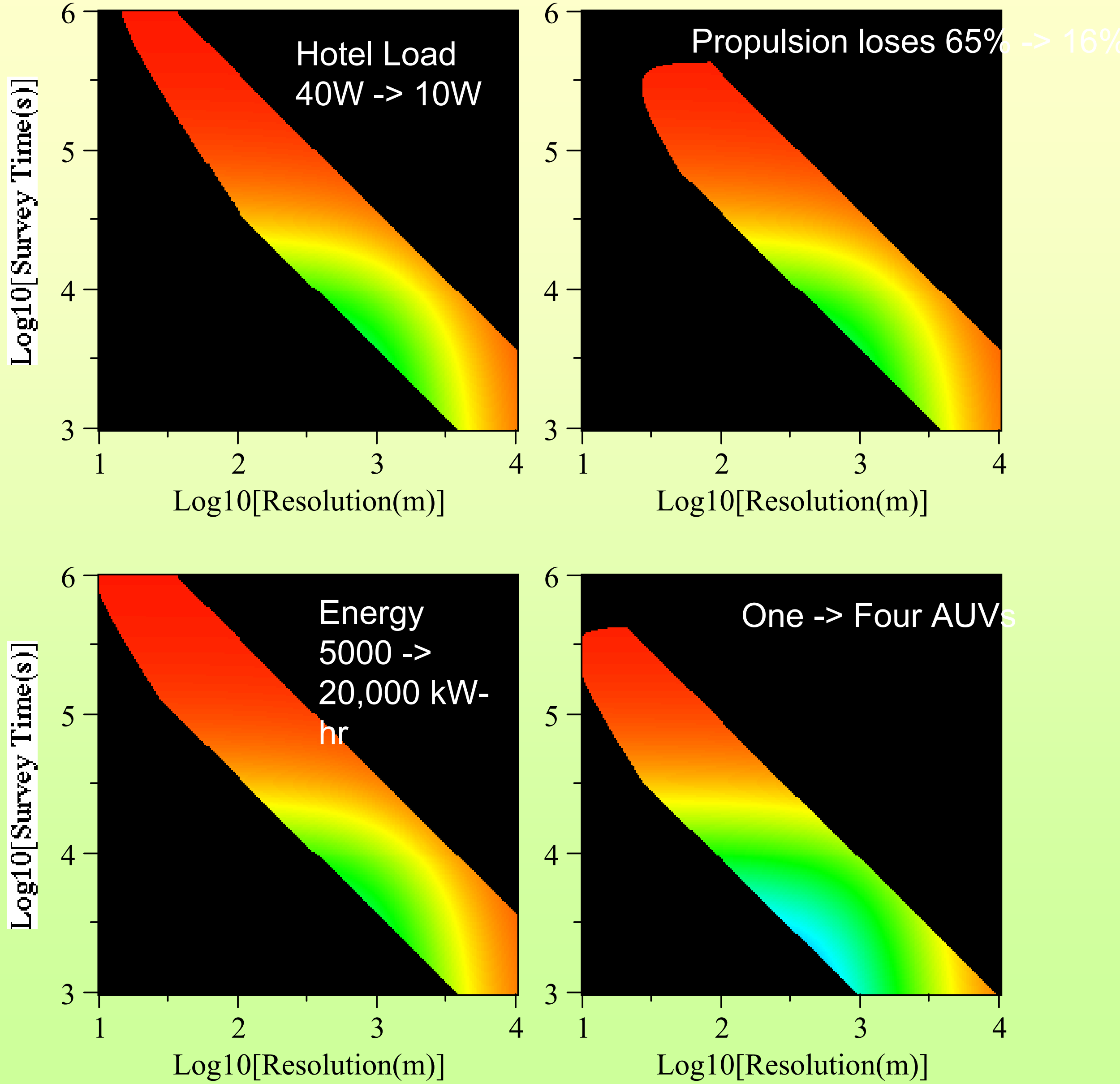
*R*(*t*) = temporal correlation function.
*P*(k) = spatial energy density spectrum

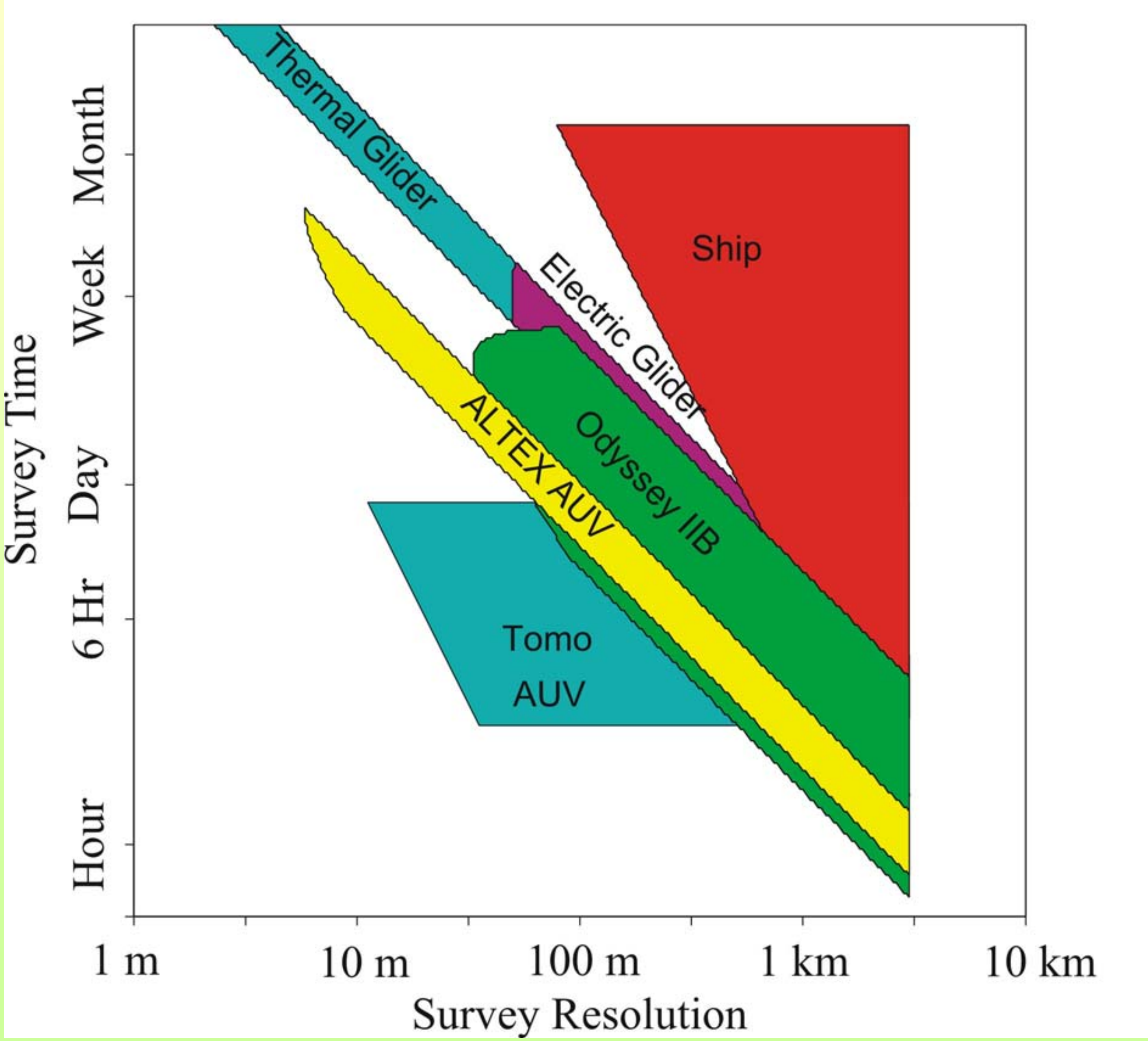
# Picking the Optimum Survey

Optimum survey
to minimize error



Exploring Design Space with Survey Envelope Analysis




Thermal Glider
Electric Glider
Ship
Odyssey IIB
ALTEX AUV
Tomo
AUV
Survey Time
Month
Week
Day
6 Hr
Hour
1 m
10 m
100 m
1 km
10 km
Survey Resolution