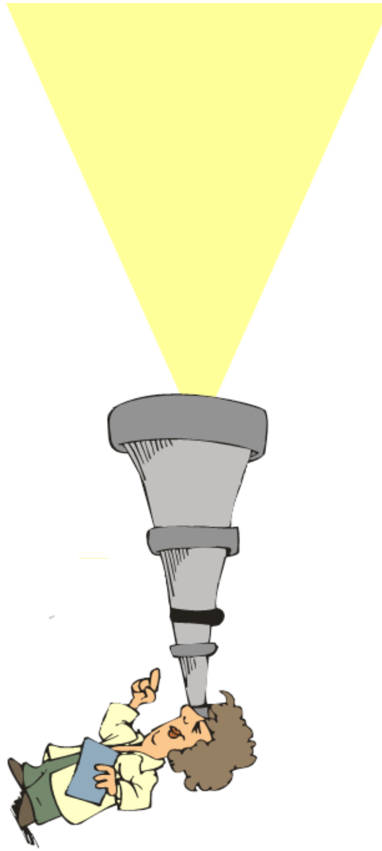
Biological Acoustic Monitoring



LO: Identify potential uses and limitations of acoustic technologies to monitor biological quantities of interest

John K. Horne

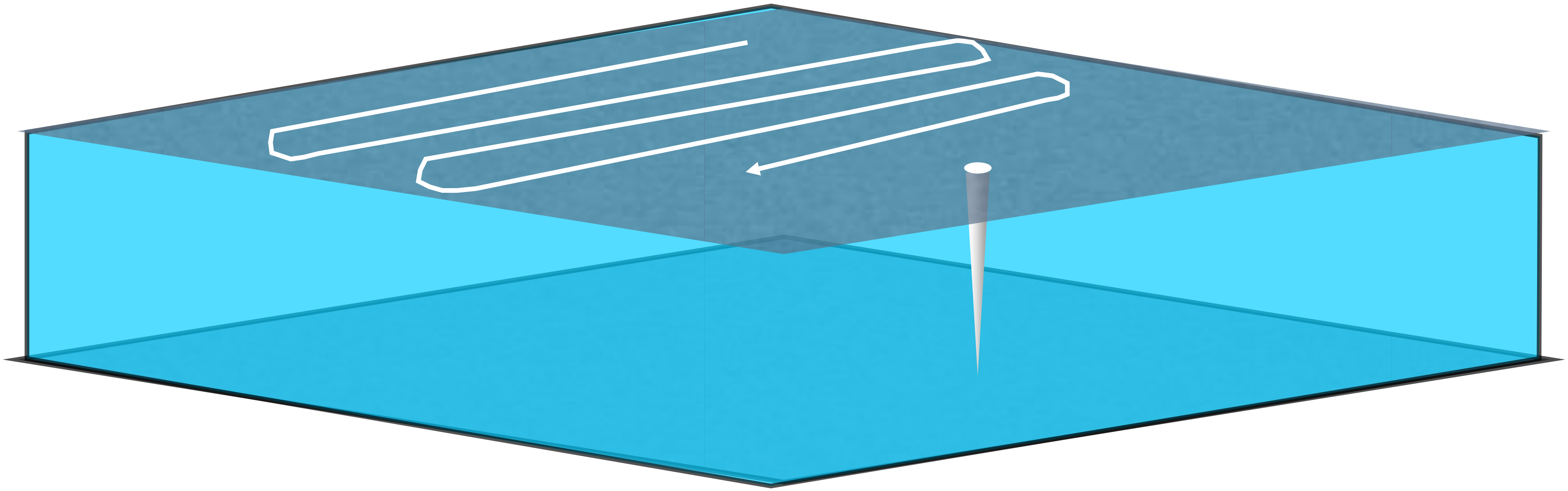
Applications & Objectives

Application	Objective(s)
Ocean Observing	Temporal trend , Environmental covariates
Hydropower Dams	Fish passage routes, abundance
Nuclear water cooling	Clogging intakes
Marine Renewable Energy	Device collisions, biological impacts, abundance
Environmental Impact	Pre/post disturbance

Sampling the Ocean

Spatially-indexed vs. temporally-indexed data

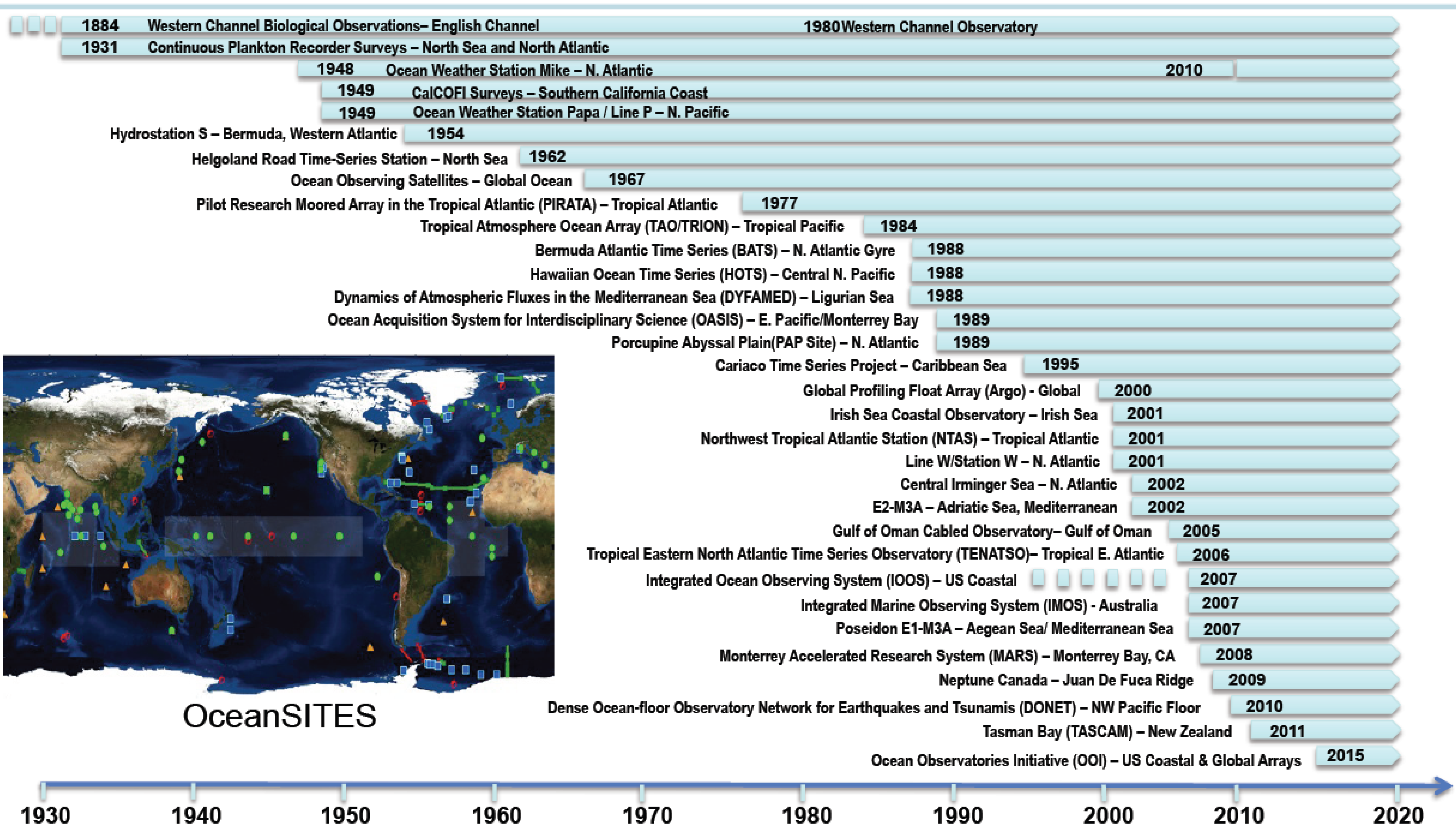
Mobile: large space, short time, convolve space and time



Stationary: long time, small space

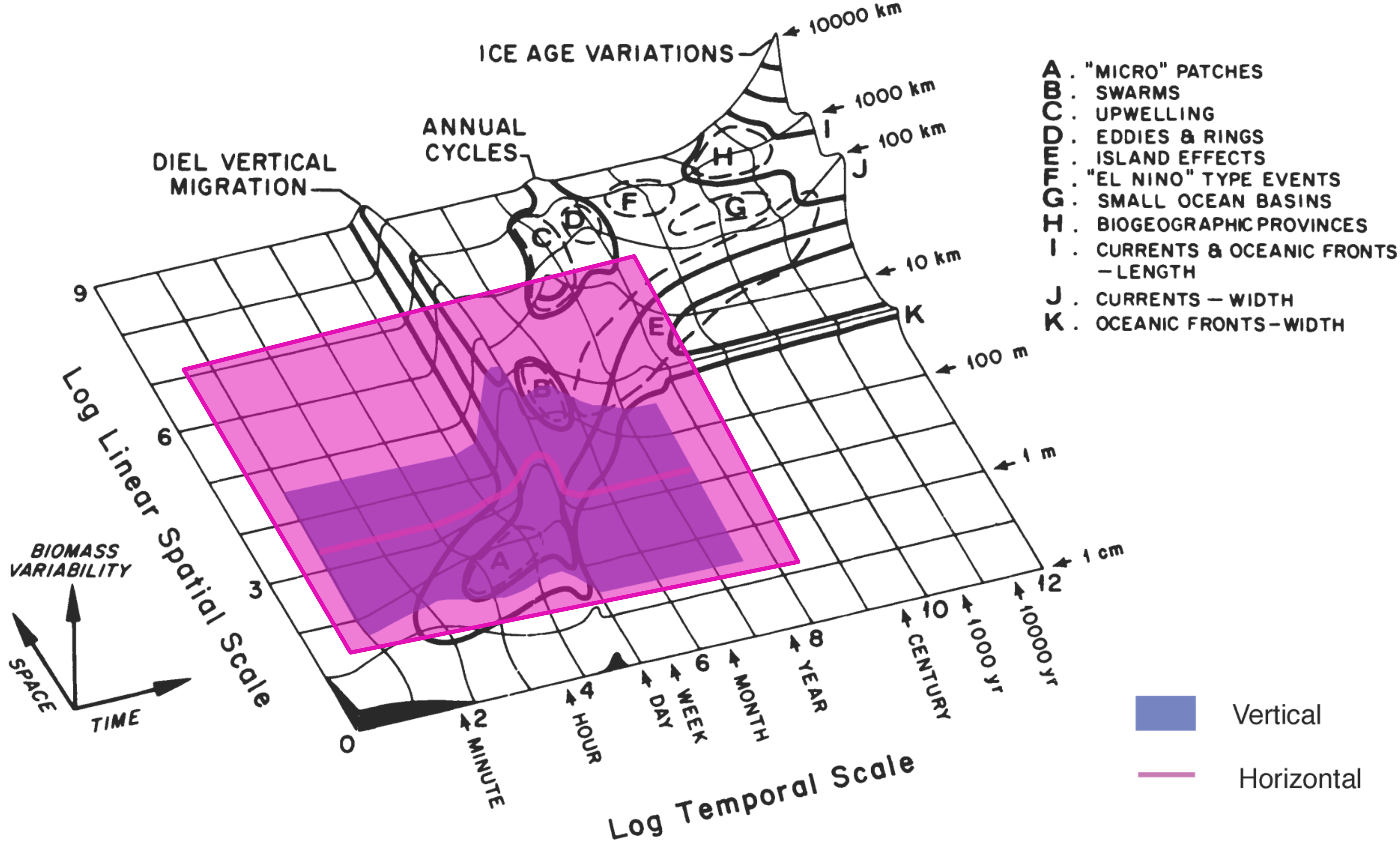
Hybrid: mobile platform (slow) over long time

Ocean Observing Time Series



Steven Ackleson, US Consortium for Ocean Leadership

Expanding Scales in Ocean Observing



Ocean Observing, Observatories, and Observing Systems

Classic:

Ocean observing: instruments used to observe water properties or water contents

Observatory: central node(s) supplying power & communications to instrument(s)

Evolving:

Observatory: stationary or mobile instruments using node infrastructure

Observing system: regional infrastructure or platform(s) supporting instrument clusters

What's Changed?

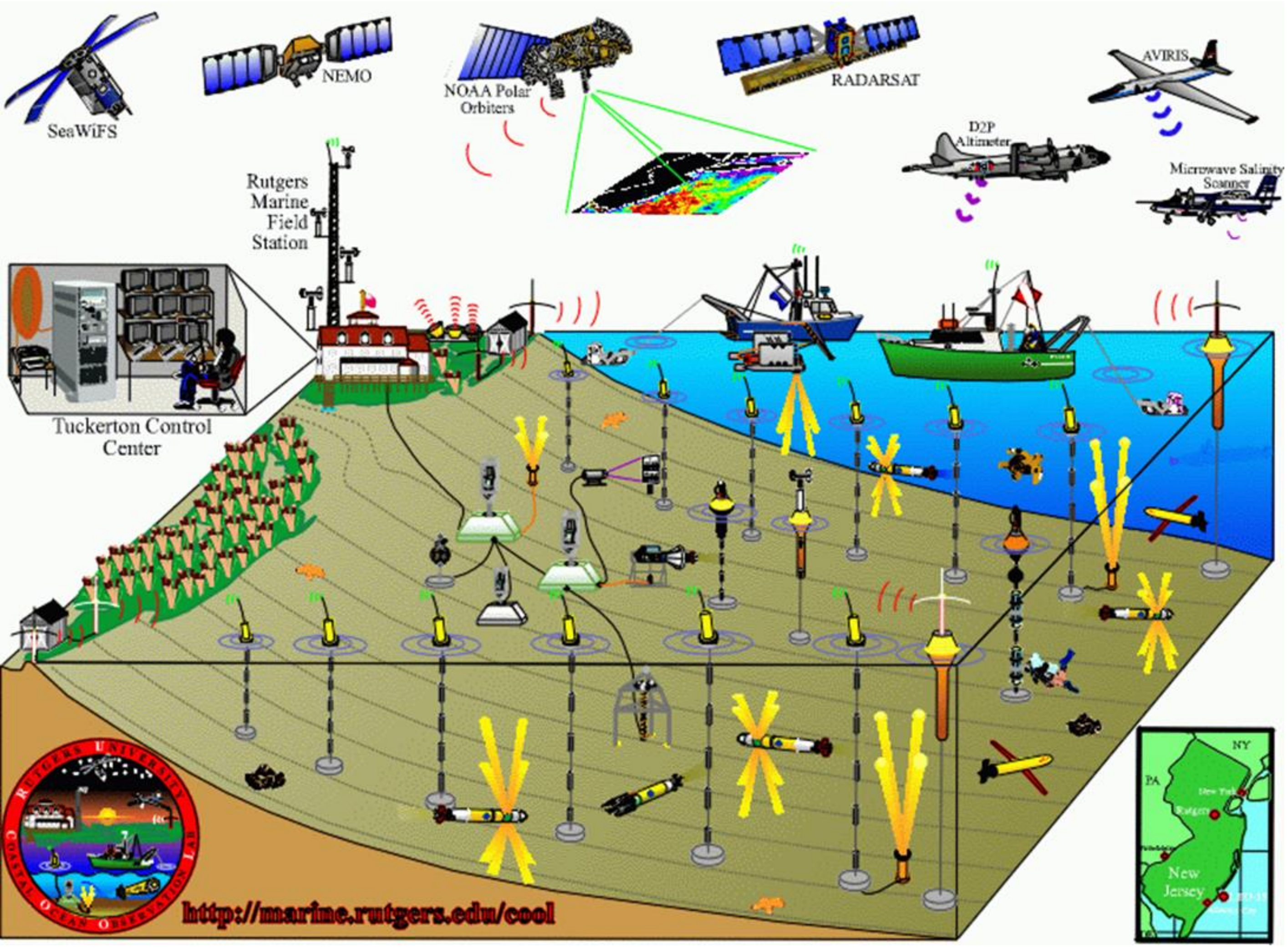
Infrastructure: from project based to program

- expansion from single site up to ocean basin, linking site infrastructures
- expansion and inclusion of mobile instruments, winched platforms
- expansion of infrastructure from surface or submerged node

Objectives: from explicit science and monitoring, to data acquisition for data acquisition or modeling

Early Conceptual/Actual Observatories

LEO 15: Rutgers University, 1998 - 2001

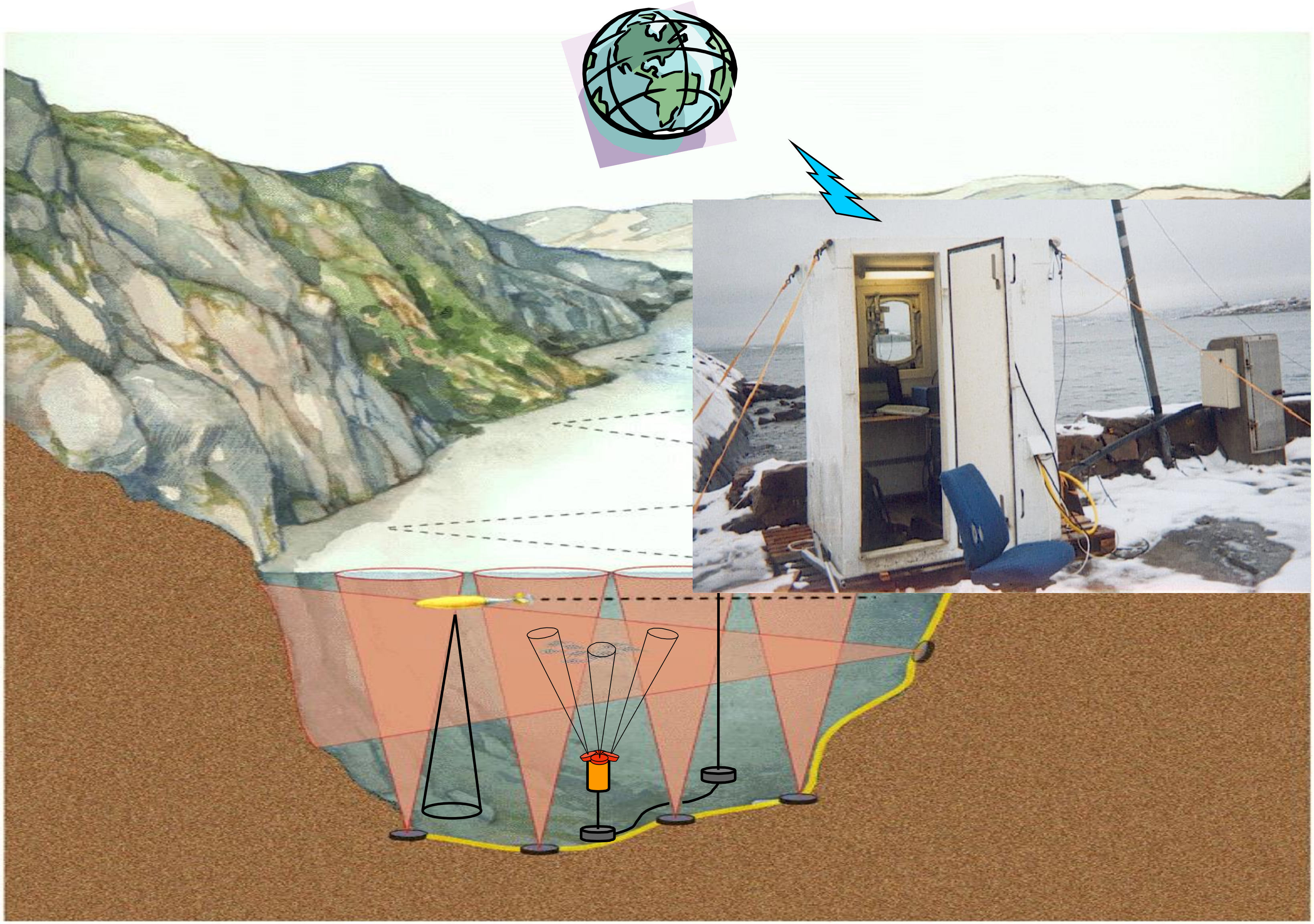


Predictive
Coastal
Experiments

Power
Communication
Platforms
Instruments
Network

Early Conceptual/Actual Observatories

Ocean Hub Monitoring, IMR, Norway, 2002-2008



Progression of Ocean Observing

ADCP: Krill DVM

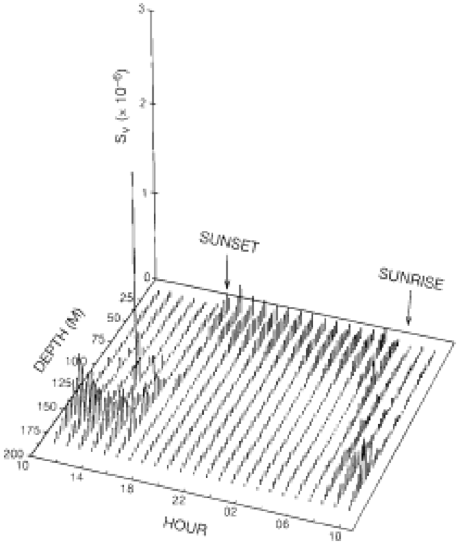


Fig. 4. Stick plot of averaged hourly s_v vs depth and time of day over Hours 505 to 840 inclusive without smoothing

Cochrane et al. 1994

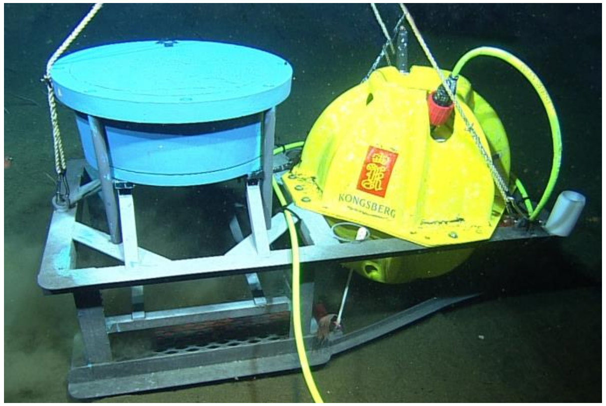
MOOS: 38 kHz

MBARI: 1989 -

Acoustic Lander: 38 kHz

MarEco 2004-2005

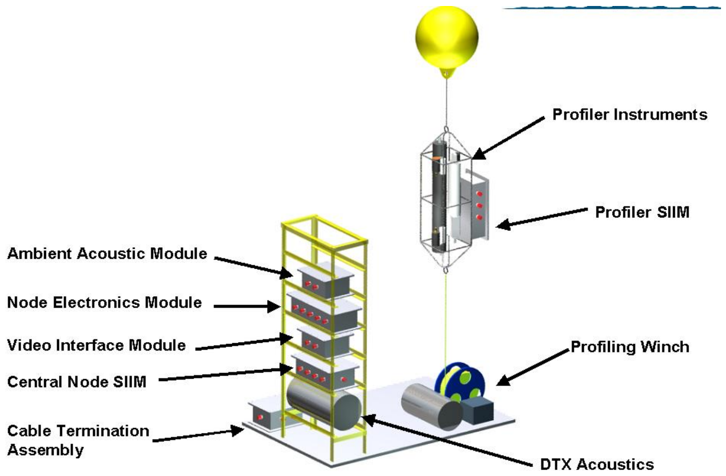
DEIMOS: 38 kHz



MARS-UW, 2009-2012

Progression of Ocean Observing

Single Node Observatory



Memorial University, 2004-2005

Autonomous Deployment
for tidal energy baseline

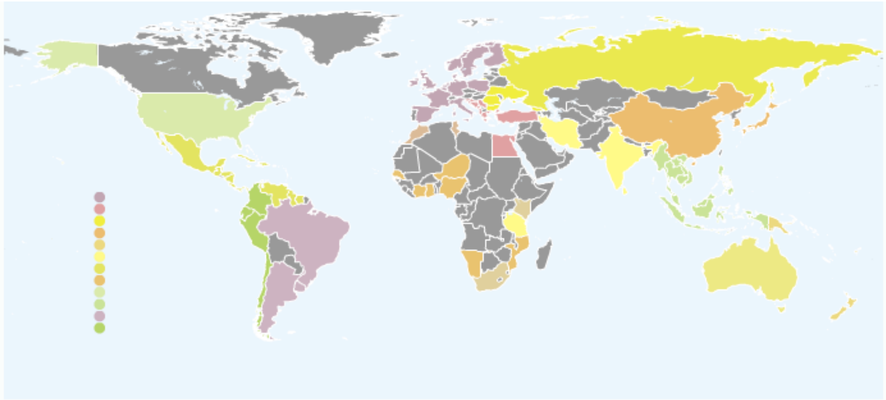
University of Washington, 2011

Ocean Observing Systems

Multi-National or Global

Eurosites: 9 deep (>1000m)

GOOS: Global Ocean Observing System



- EuroGOOS
- Mediterranean GOOS
- Black Sea GOOS
- NEAR (North-East Asian Regional)-GOOS
- PI-GOOS
- Indian Ocean GOOS
- IOCARIBE-GOOS
- GOOS-Africa
- USA IOOS
- Southeast Asian GOOS (SEA-GOOS)
- OCEATLAN
- GRASP

Ocean Observing Systems

National or Bi-Lateral

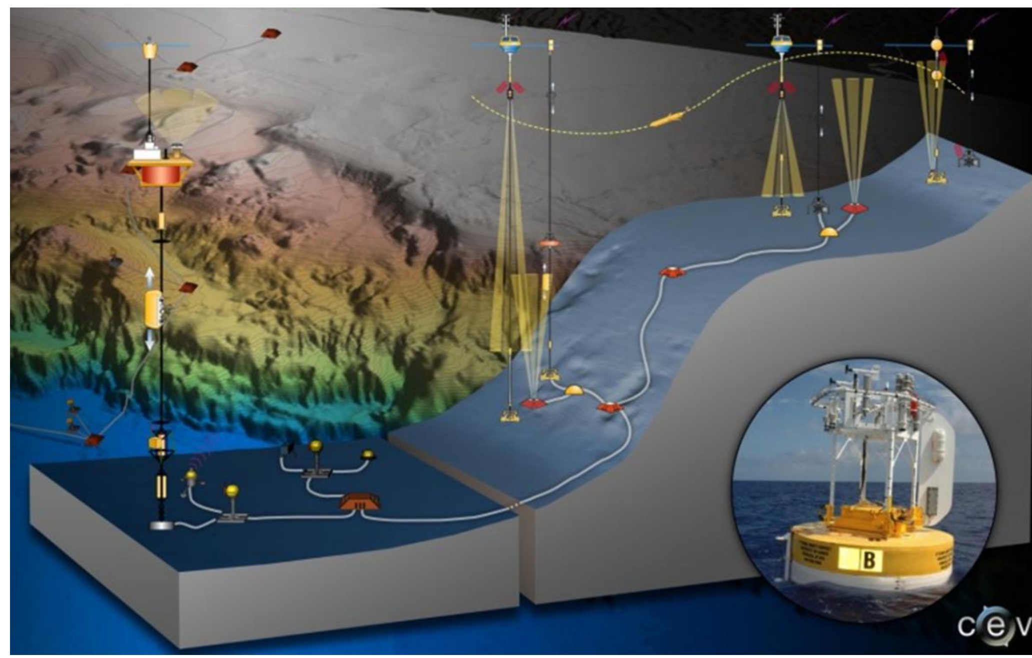
RCOS: Regional Coastal Observing Systems

IMOS: Integrated Marine Observing System

OOI: Ocean Observatory Initiative 2015

Global (3), Regional (1), Coastal (2)

Coastal Instrument Array



www.orionprogram.org/OOI/default.html

Acoustic Technologies Deployed

ADCP
Manufacturers: Aanderaa, Nortek, RDI, Seaguard
Frequency Range: 150 – 1200 kHz
Depths: 15 - ?

Echosounders
Manufacturers: ASL Environmental, BioSonics, Simrad
Frequency Range: 38 – 200 kHz
Depths: 20 - 1000 m

Deployment Platforms

Surface:
Stationary: buoys, moorings
Mobile: ships, waveglider, saildrone

Bottom:
dedicated cables; cabled nodes; autonomous packages

Inbetween: stationary or winched platforms; gliders; ROVs; AUVs

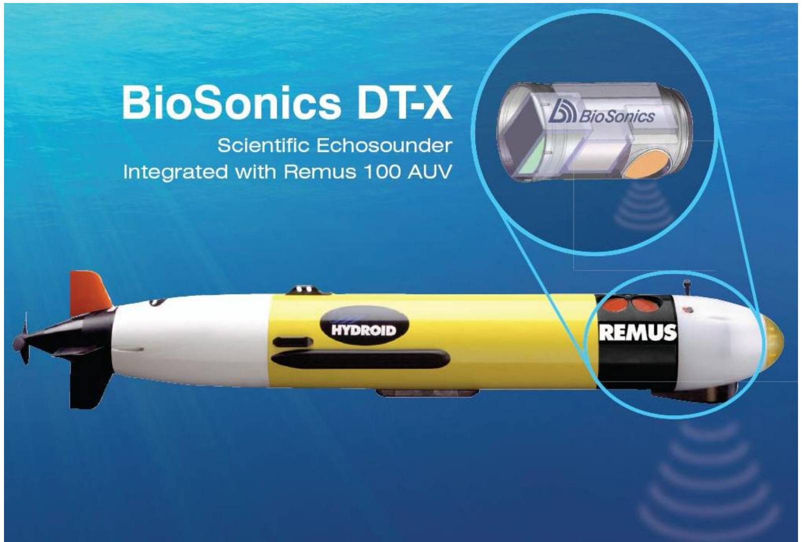
Alternate Platforms

Early

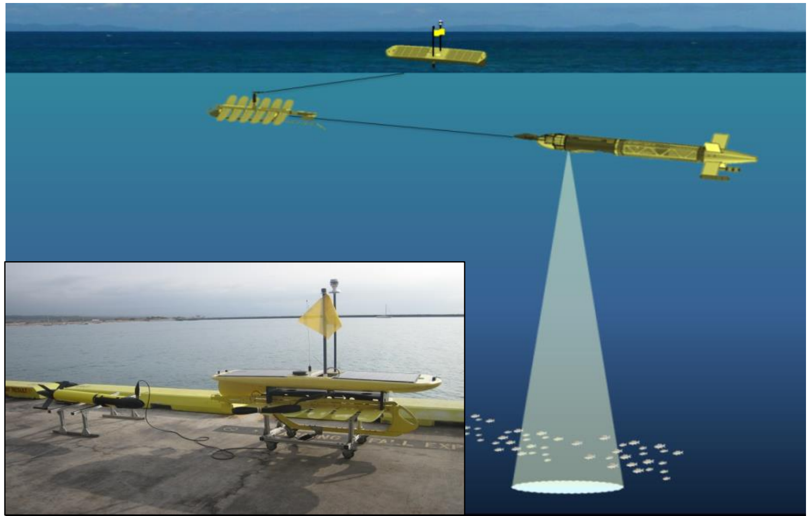
Autosub 2000

Current

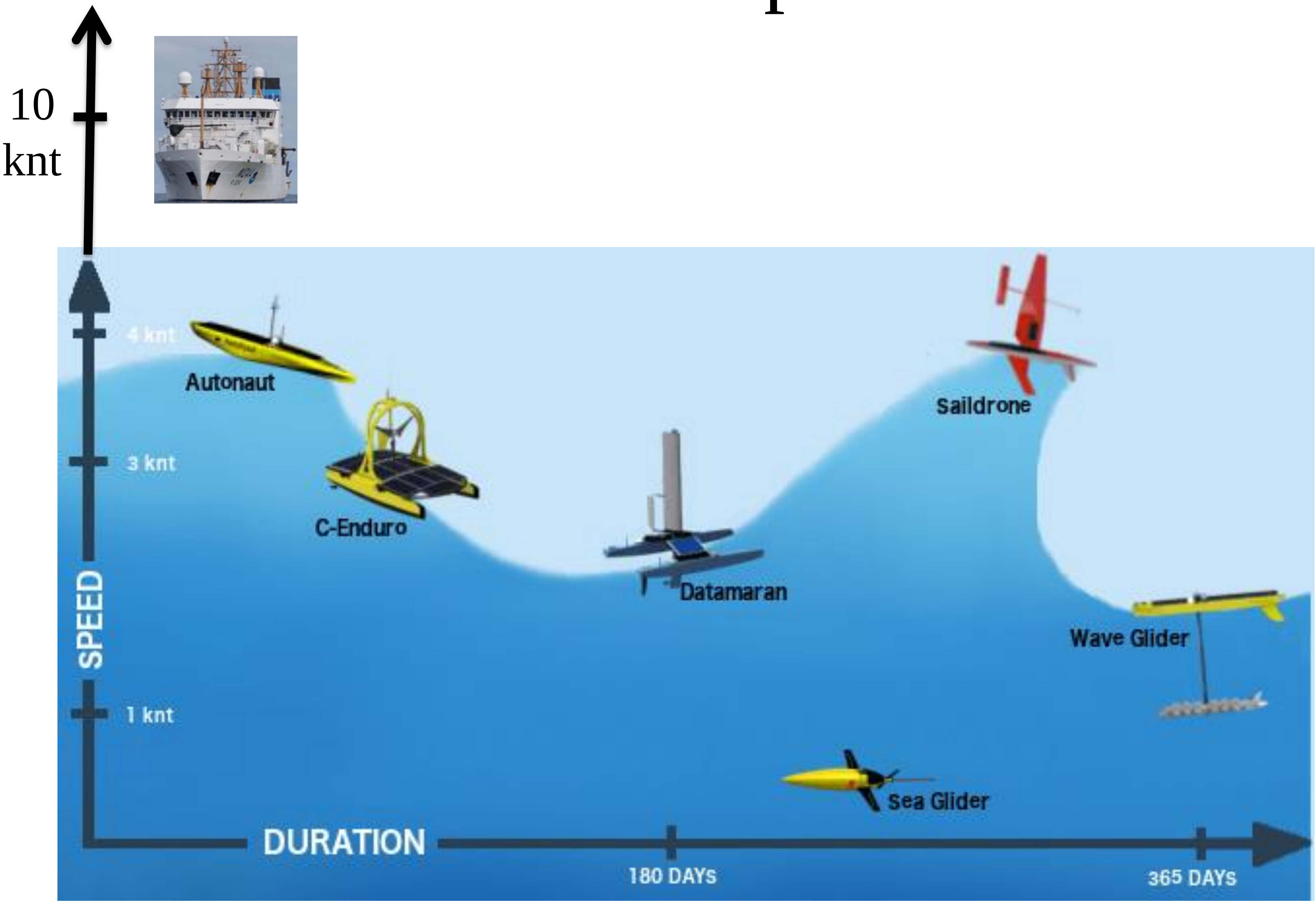
AUV - Remus



Waveglider

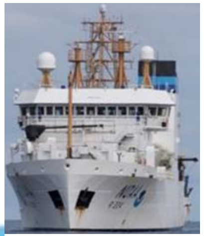


Alternate Platform: Speed & Duration

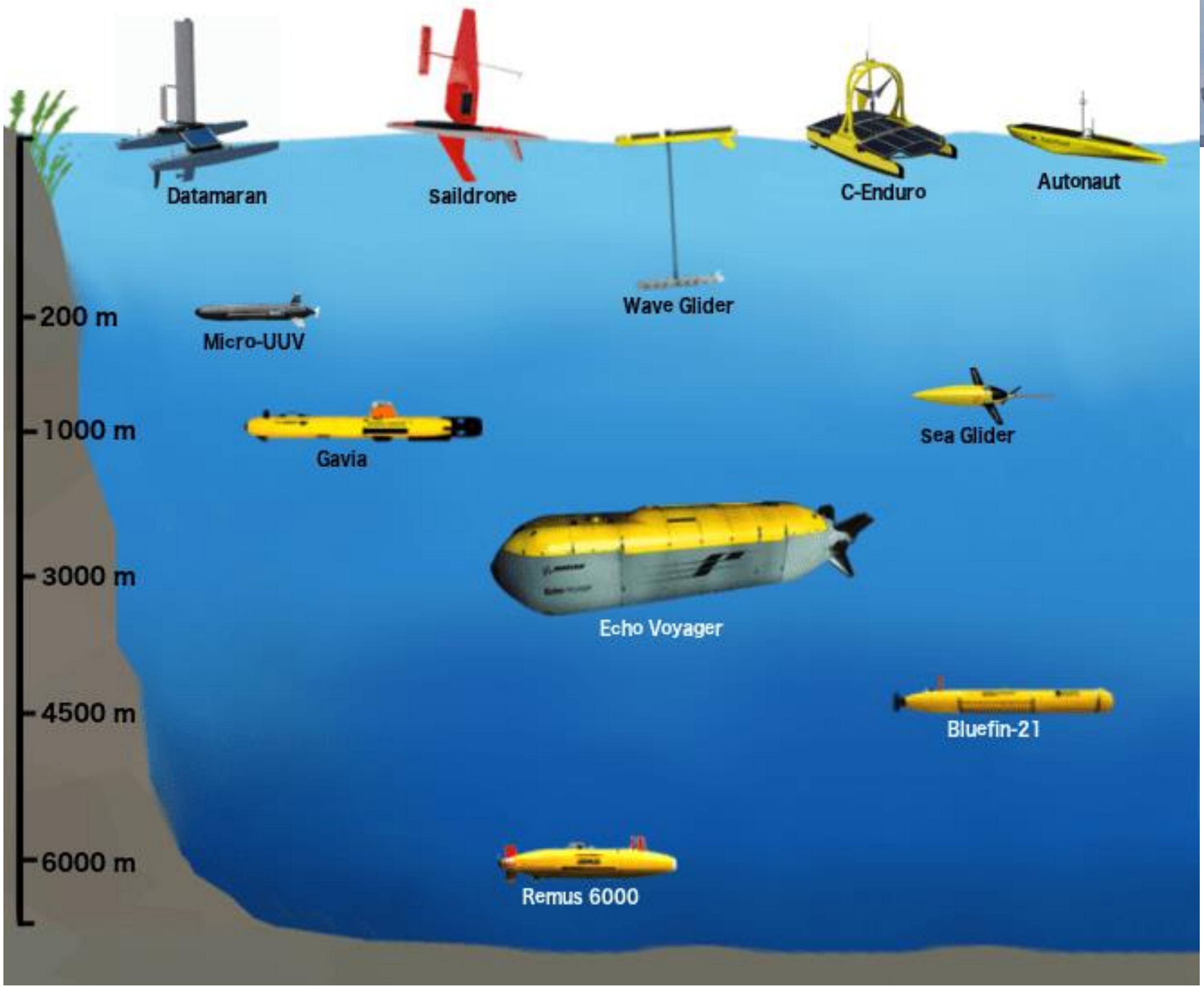


Graphics: D. Hume

Alternate Platform: Maximum Depths



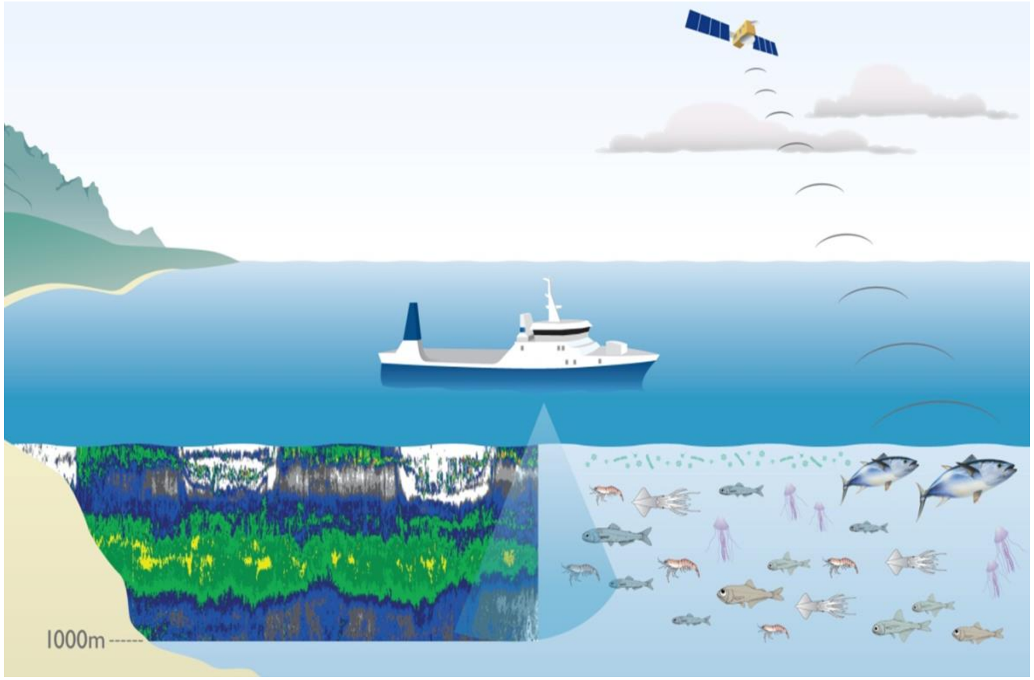
Depth

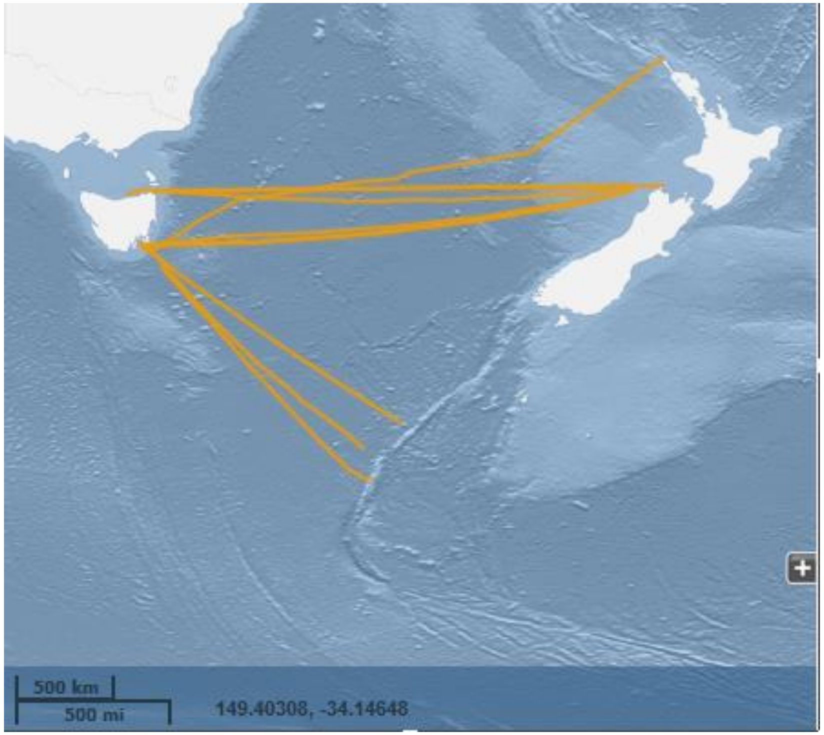


Graphics: D. Hume

Dedicated or Opportunistic Platforms

IMOS: Integrated Marine Observing System

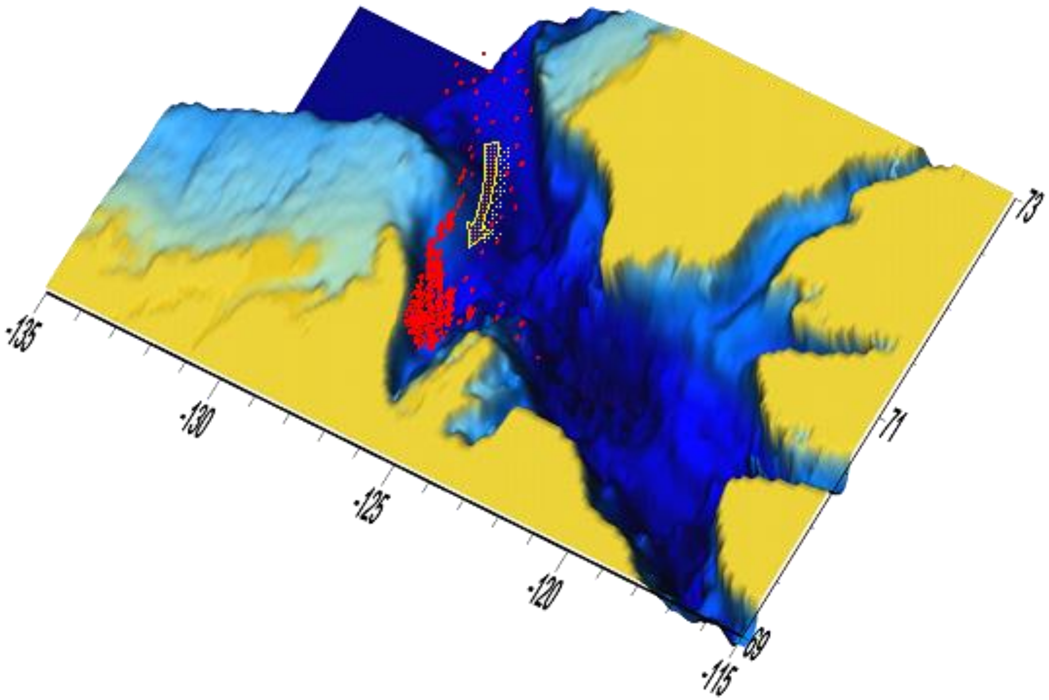


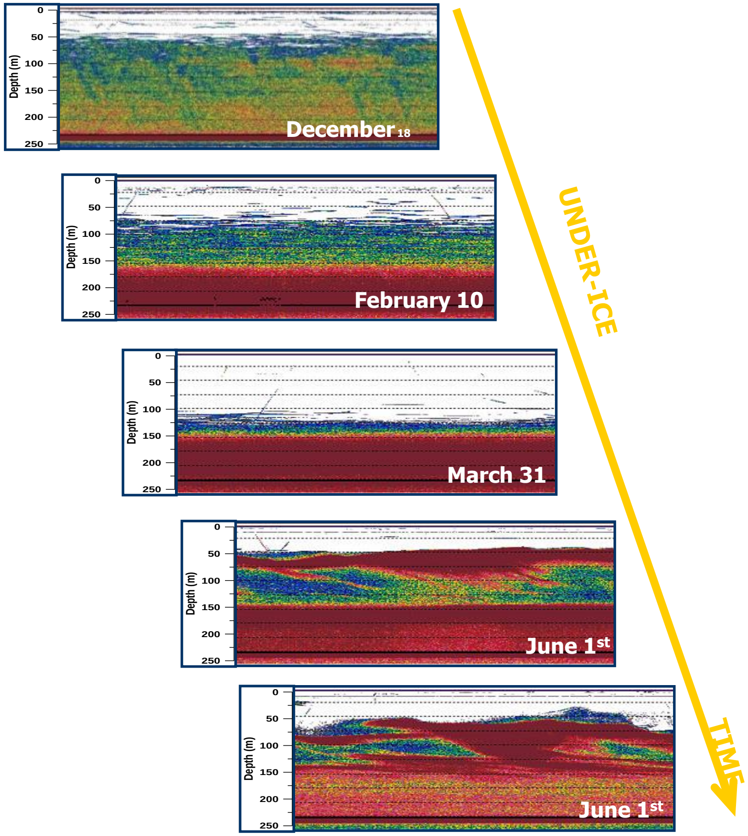


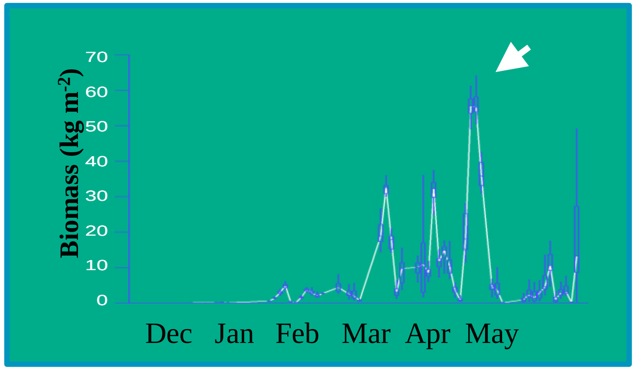
Rudy Kloser, Ryan Downing, Gordon Keith, Tim Ryan www.imos.org.au

Vessel as Observatory Platform

Overwintering Aggregation of
Arctic Cod (*Boreogadus saida*)



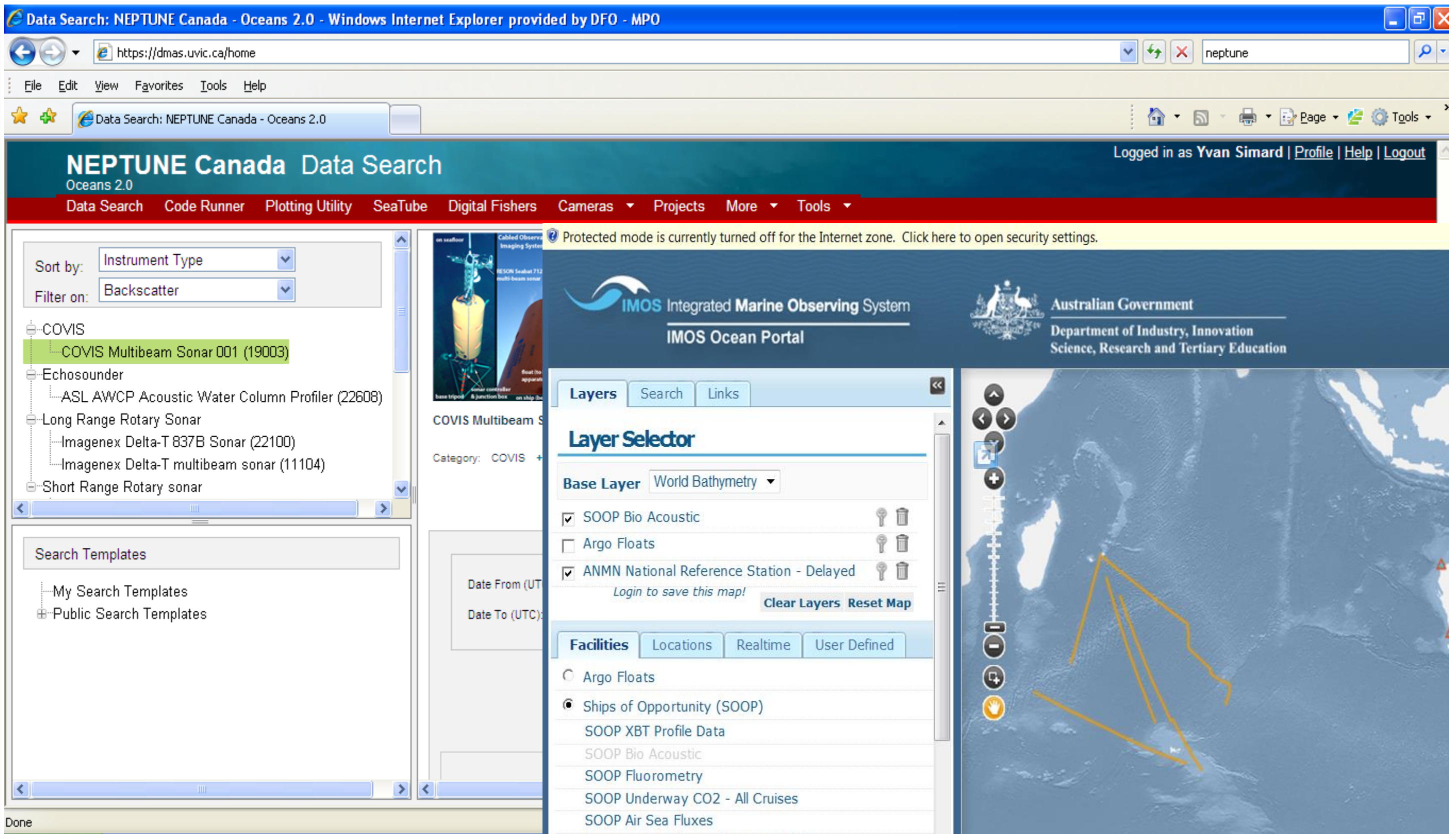




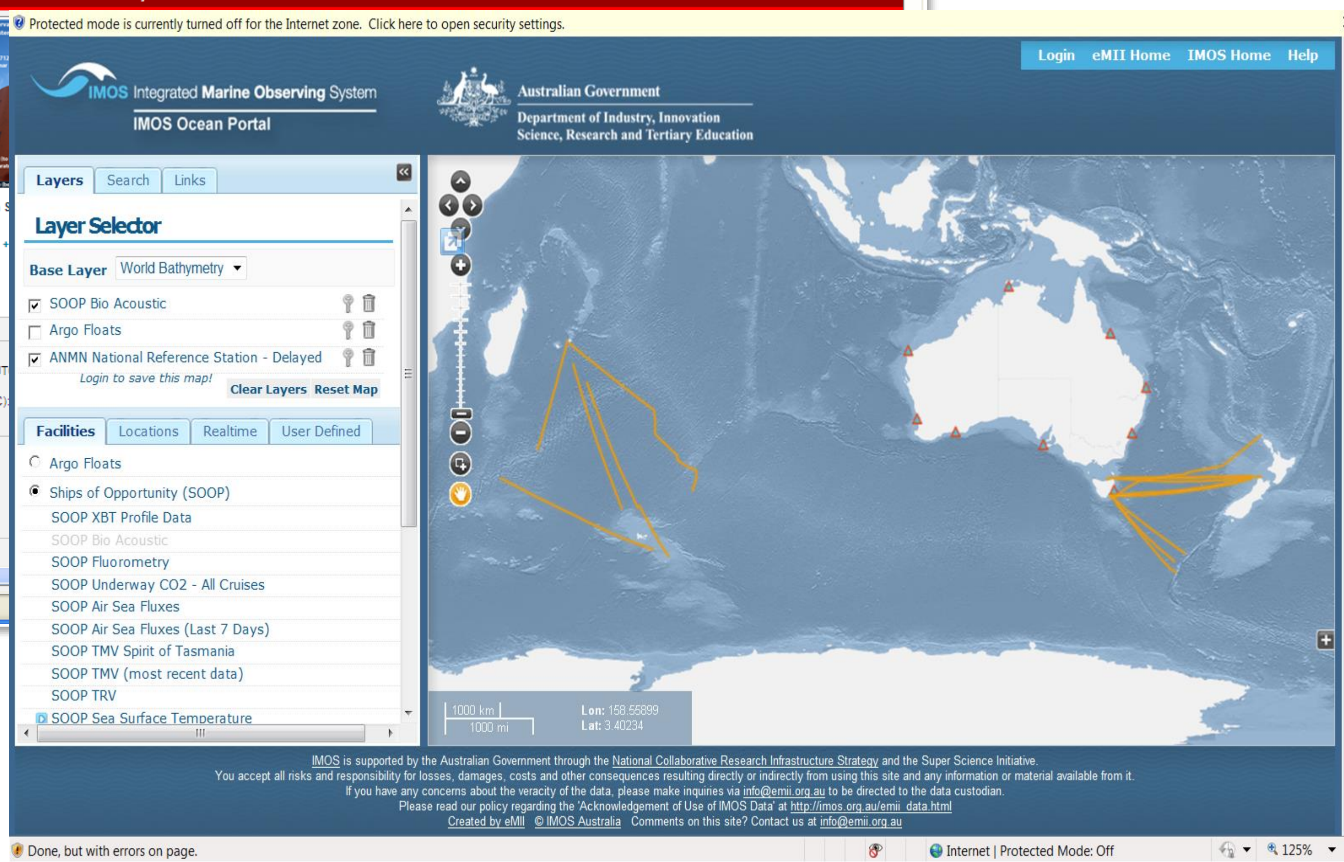
Laval University: L. Fortier, D. Benoit,
M. Geoffrey, Y. Simard

Observing System Data Portals

NEPTUNE Canada



IMOS Australia

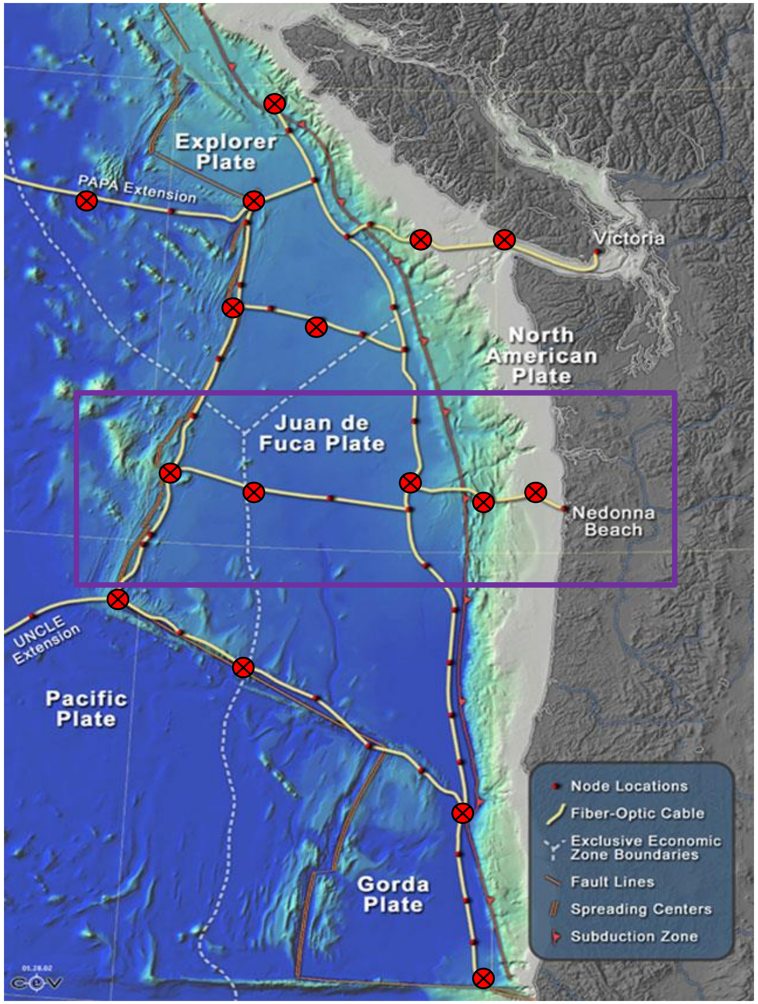


Observing Project vs Observatory Program

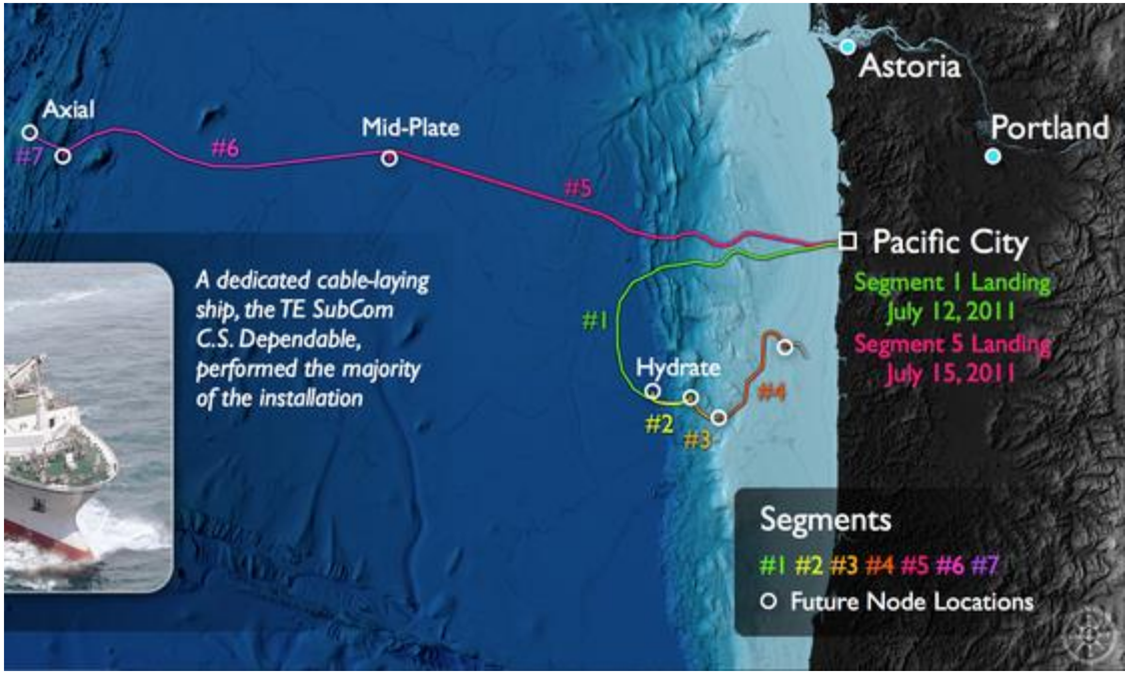
Attribute	Project	Program
Capital Cost	10 – 100s k USD	1000s k USD
Infrastructure	moderate	LARGE
Duration	months - years	10’s years
Footprint	moderate	LARGE
Goal	science objectives	monitoring, testbed
Participation	PI centric	purchase entry
Data Policy	PI centric	constrained open
Sustainable?	funding cycle	Infrastructure, funding cycles

NEPTUNE Regional Observatory

Envisioned circa 2001

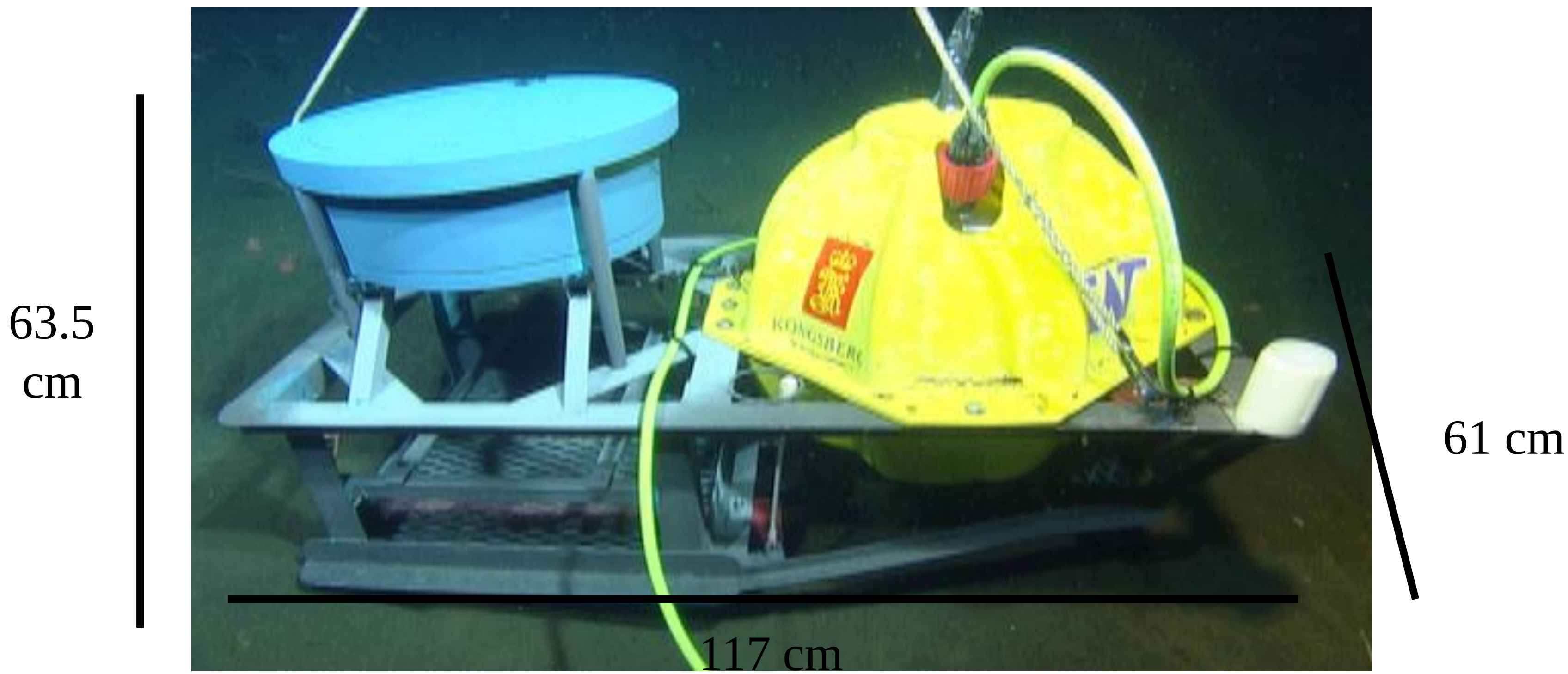


Realized circa 2012

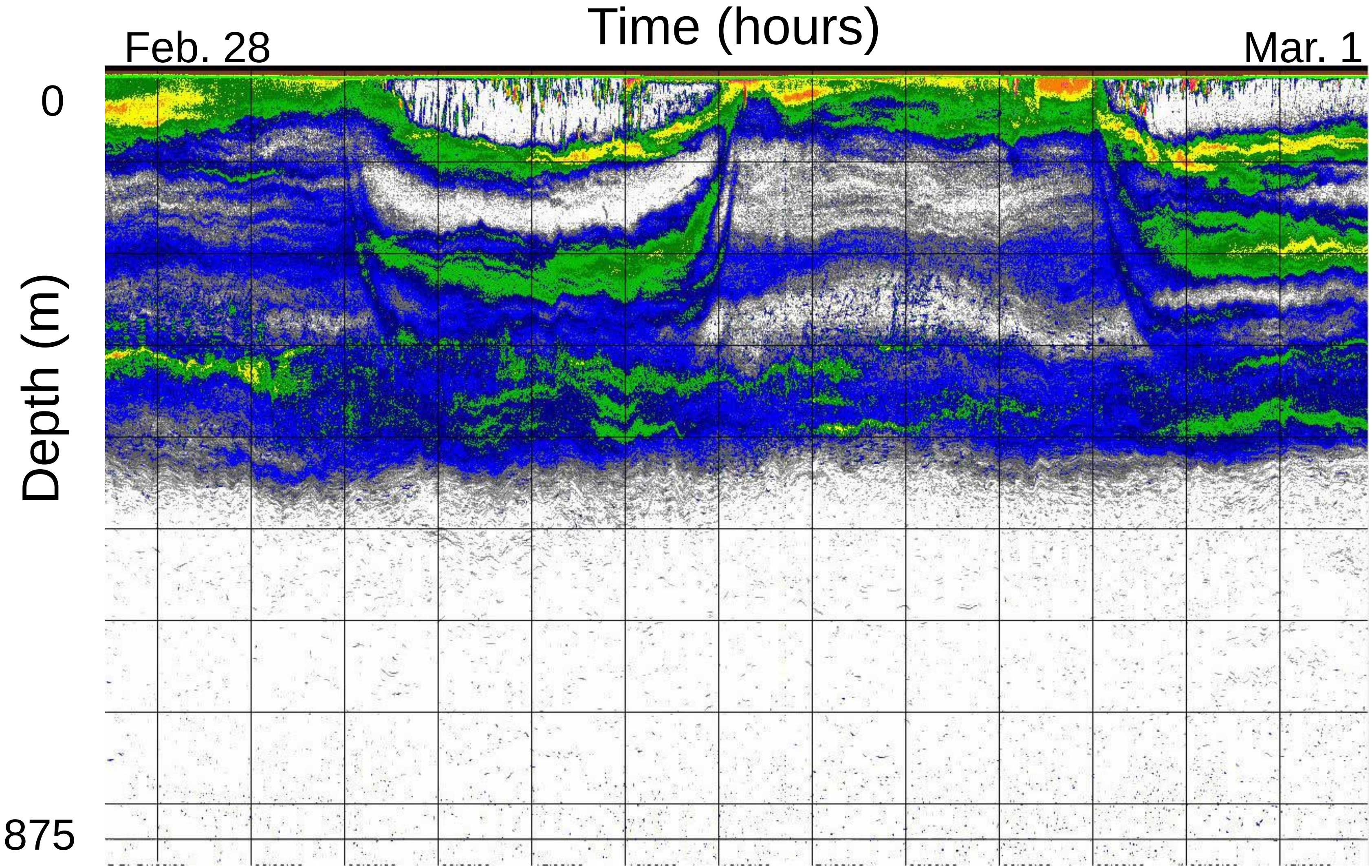


DEIMOS Science Objectives

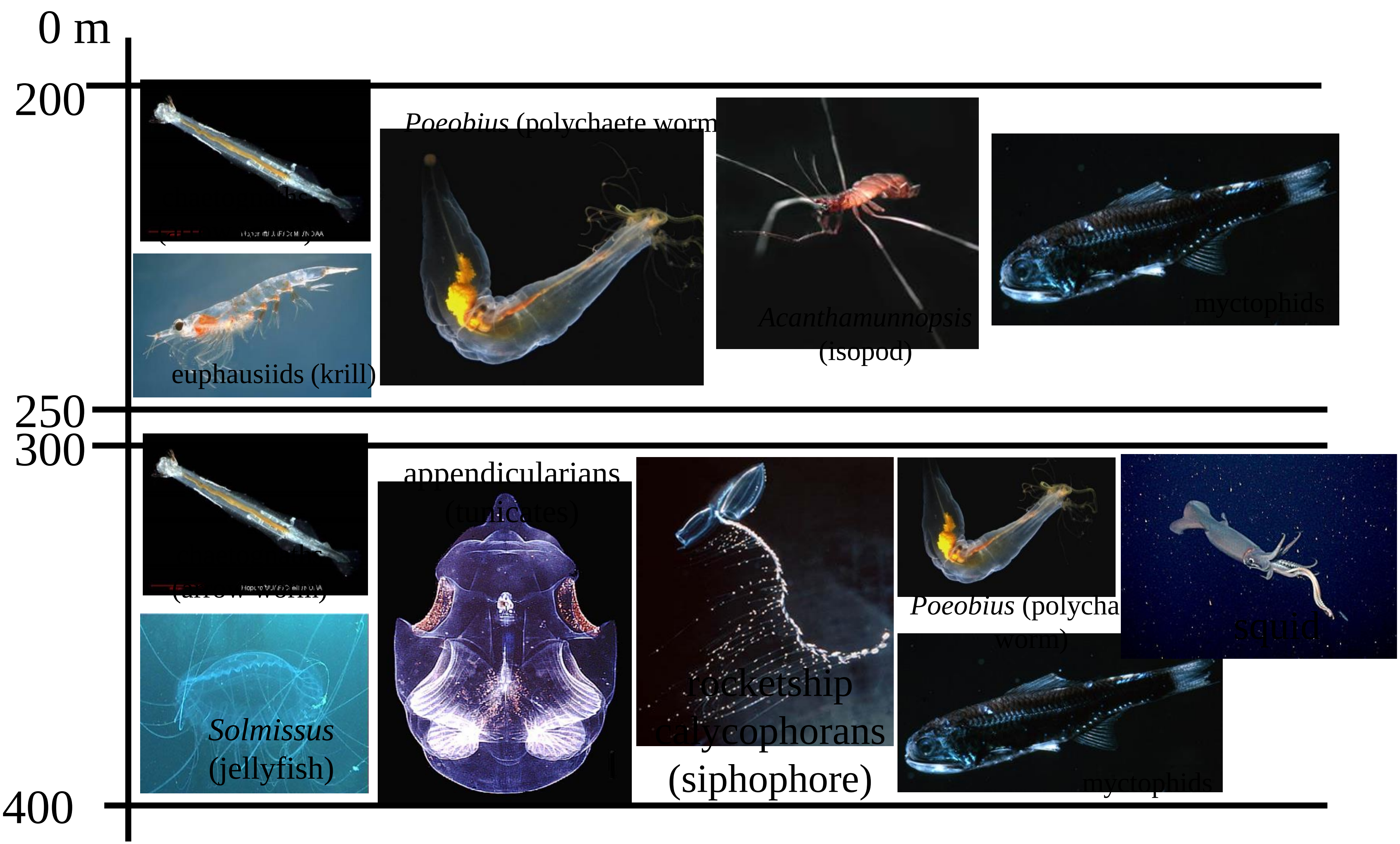
- daily vertical migrations
- predator-prey interactions (e.g. whale-krill)
- biological flux
- use of acoustics in Ocean Observatories



DEIMOS Echosounder Data



Composition of Backscatter Layers



ROV dive data May 6, 2009 Bruce Robison, MBARI

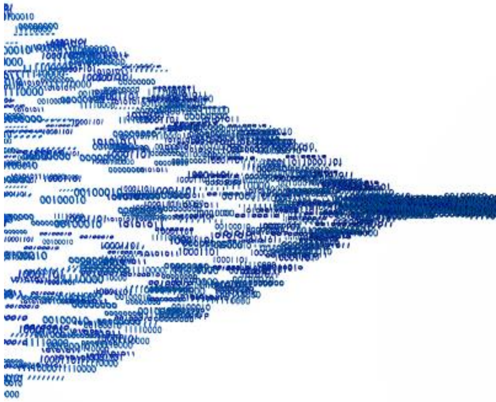
Data Volume

Monterey Data (1 frequency, 0.2 Hz sampling rate):

365 d x 24 h x 60 m x 12 pings/h x 875 m / 0.5 m resolution

= 1.104×10^{10} data points

How to characterize distribution patterns for data analysis (and avoid data bottlenecks)?



Echometrics: Distribution Characterization

Quantity	Metric	Formula
Density	Mean volume backscattering strength	$10 \times log_{10}(\frac{\int s_v(z)dz}{H})$
Location	Center of mass	$\frac{\int z\ s_v(z)dz}{\int s_v\ (z)dz}$
Dispersion	Inertia	$\frac{\int (CM - z)^2 s_v(z)dz}{\int s_v(z)dz}$
Occupied Area	Proportion occupied	$\frac{\int z \| s_v(z) > s_{v,thresh} dv}{H}$
Evenness	Equivalent area	$\frac{(\int\ s_v(z)dz)2}{\int s_v\ (z)^2 dz}$
Aggregation	Aggregation index	$\frac{\int s_v(z)^2 dz}{(\int s_v(z)\ dz\ )^2}$

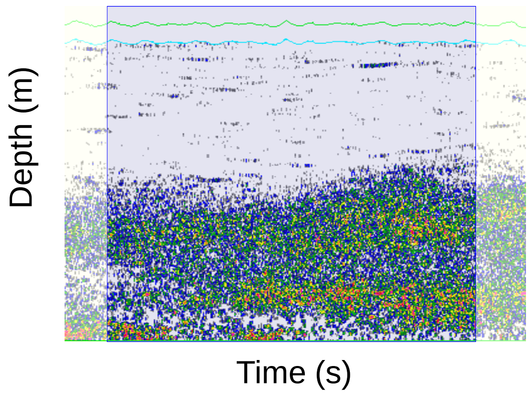
where: s_v volume backscattering coefficient, z depth, H total water column depth

Urmy et al.

Echosystem Metrics

Structure

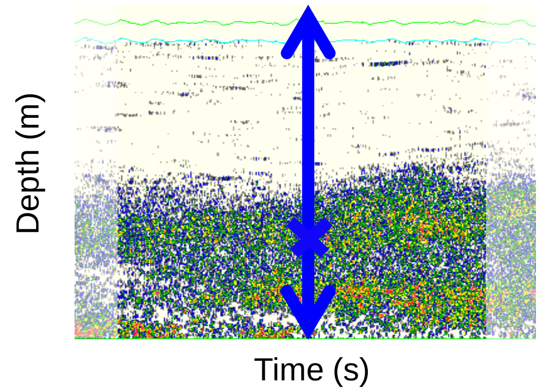
Density



Mean volume backscattering strength (S_v).

Units: dB re 1 m^{-1}

Center of Mass

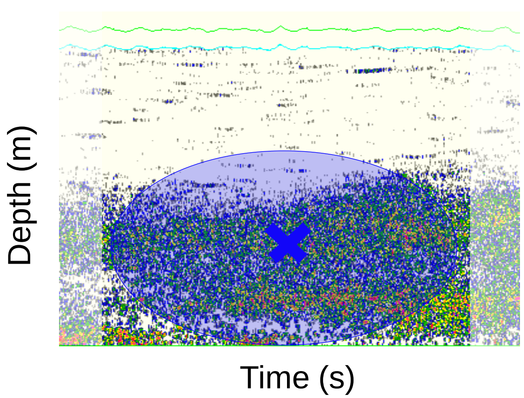


Depth mean weighted center.

Units: m

Function

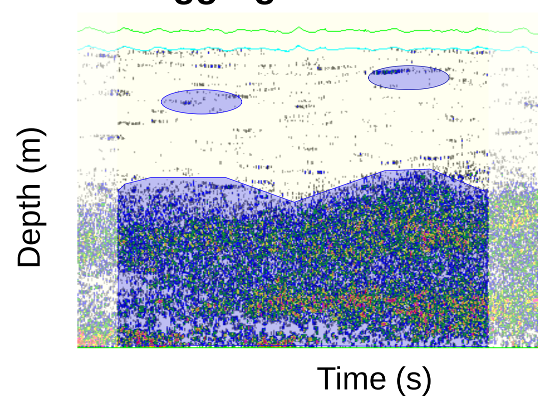
Inertia



Variance of biomass around center of mass

Units: m^2

Aggregation Index

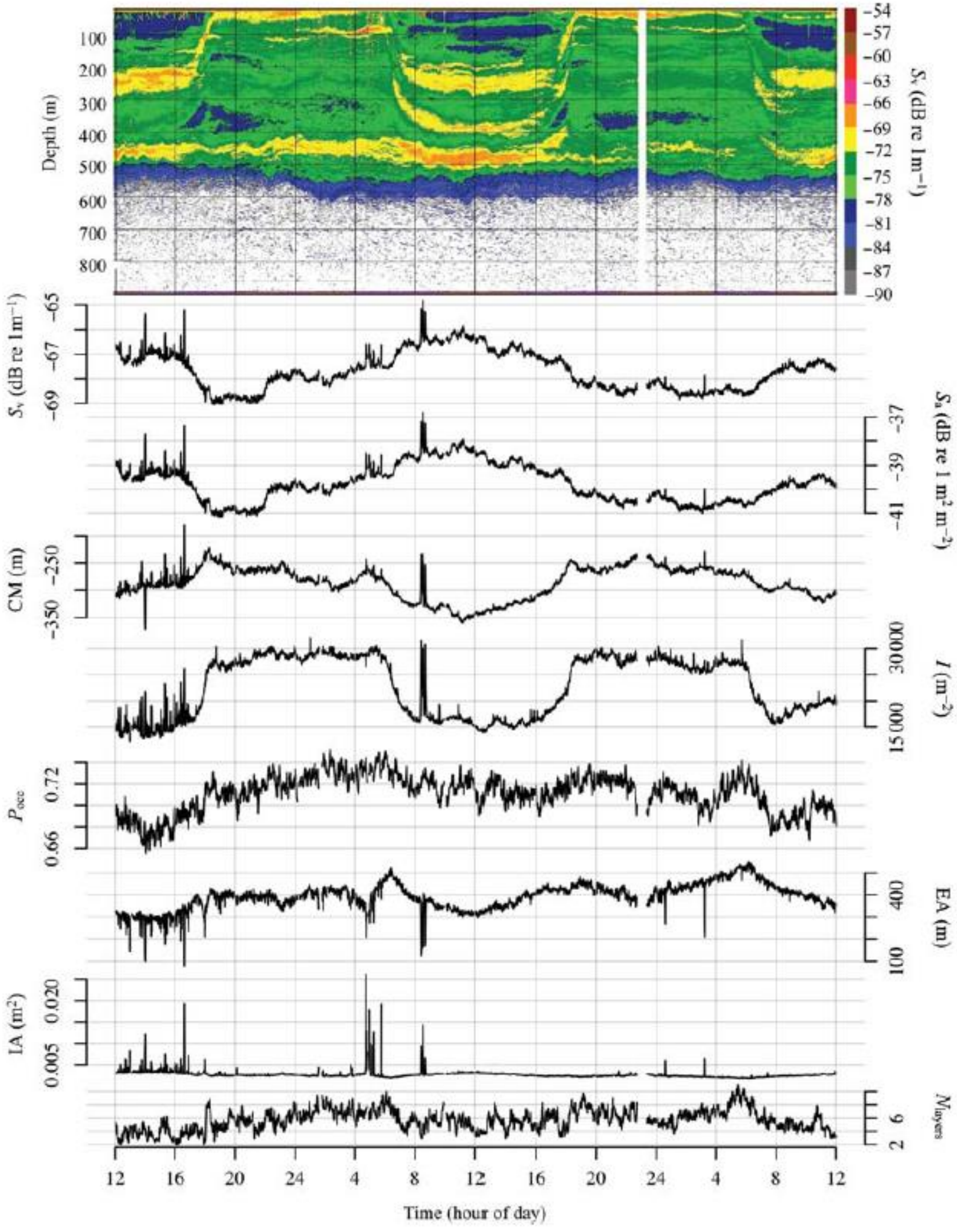


Patchiness, on a scale of 0 to 1

Units: m^{-1}

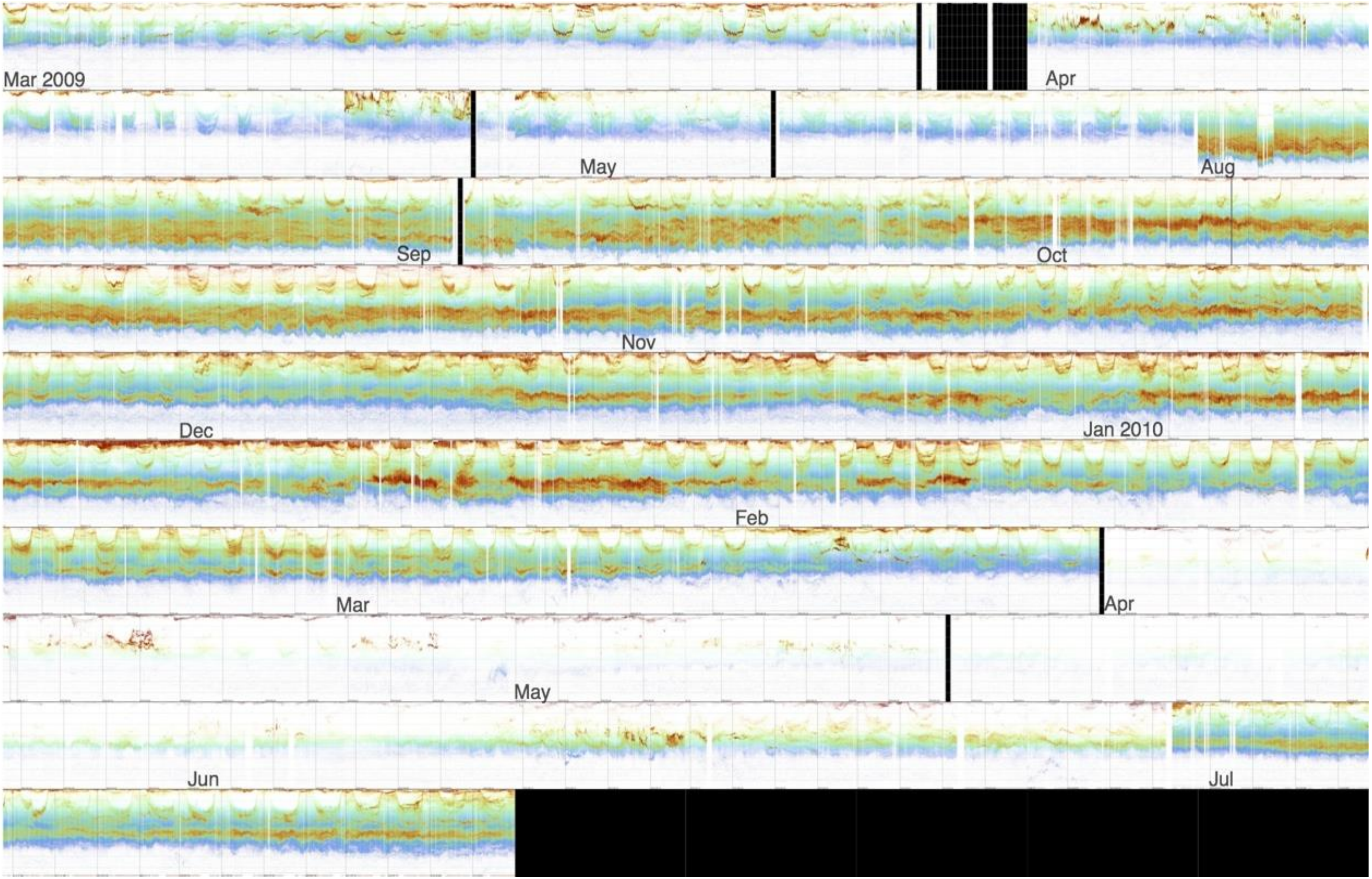
Metric Summary

March 2-4, 2009



Urmy et al. 2012

A Year in the Life of Monterey Bay



Digital Year in the Life of Monterey Bay

Volume Density

Areal Density

Center of Mass

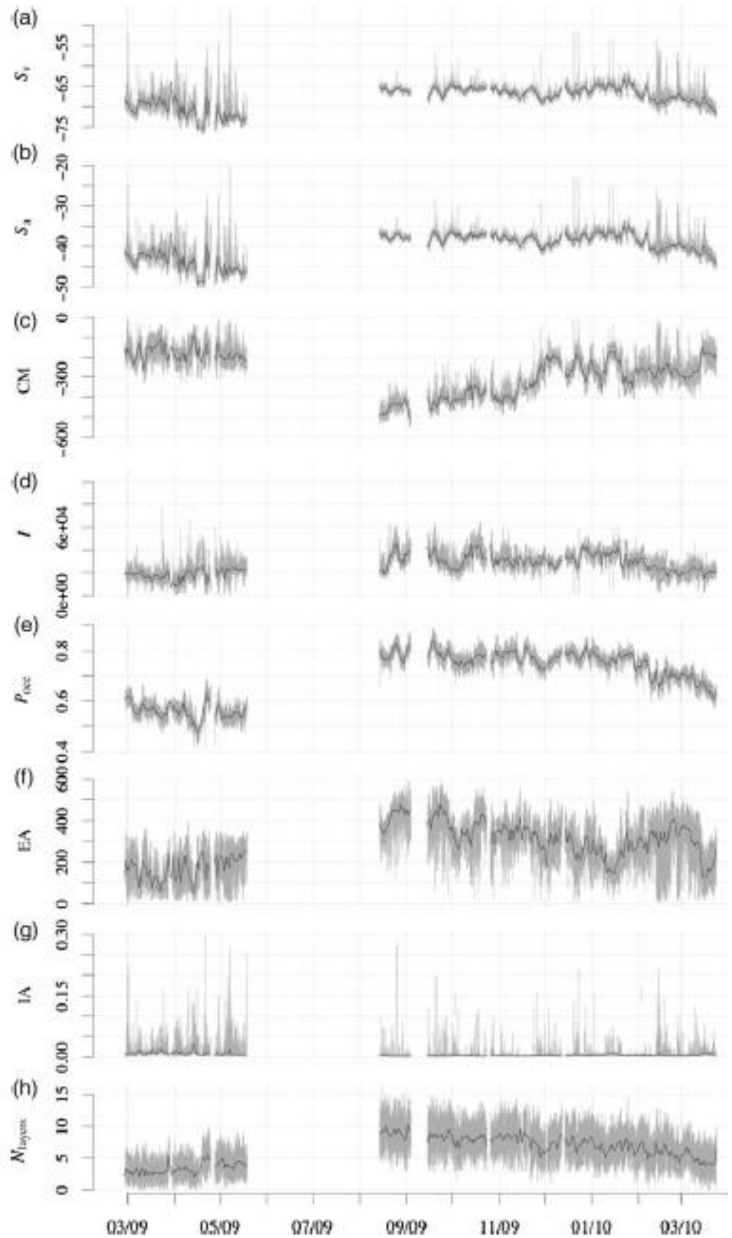
Inertia

% Occupied

Evenness

Index of Aggregation

Layers



10 min bins for daily average

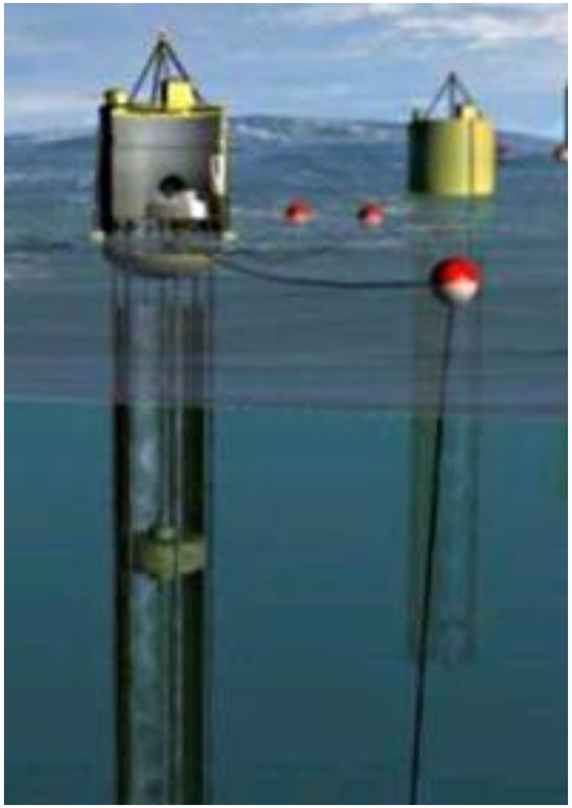
365 days x 8 metrics = 2,920 data points

Data volume reduction: 7 orders of magnitude

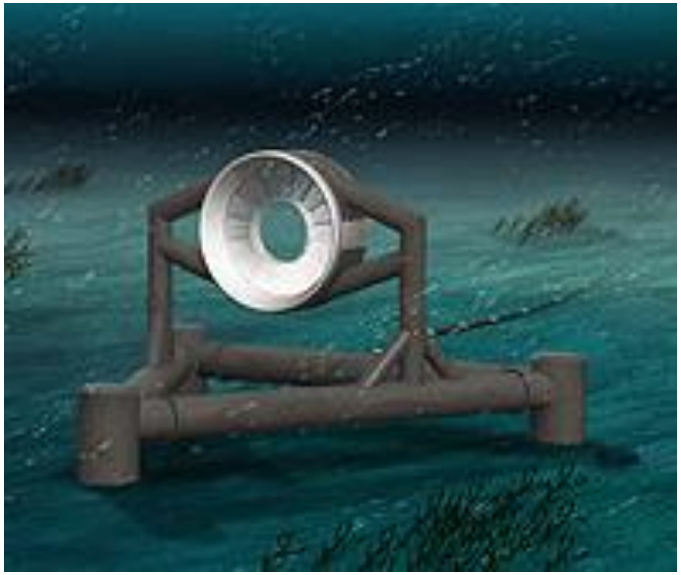
Marine Renewable Energy

Offshore Wind

Surface Wave



Tidal Turbine



MRE Factoids

- global consumption 15 TW (Arbic and Garrett 2010)
- current 70% of US electricity demand met by fossil fuels
- 0.3 TW global hydroelectric electricity production
- Potential: worldwide tidal dissipation 3.7 TW
- Condition: min 2 m/s tidal speed

“Environmental effects of tidal devices as one of top three barriers to development” (Bedard 2008)

Biological Monitoring

Evolution of Perception:

Impact **on** devices to impact **of** devices

Research Needs:

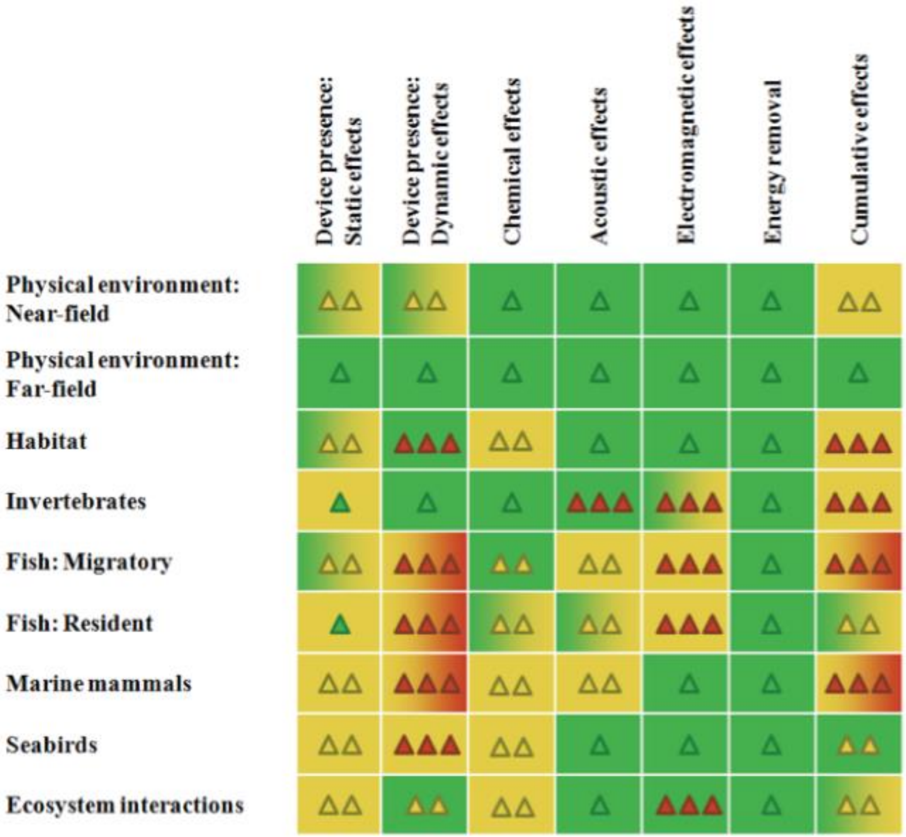
who to monitor, what technologies to use, what metrics to measure, when and where to sample, how to model pattern, what covariates matter, how to interpret data

Evaluation:

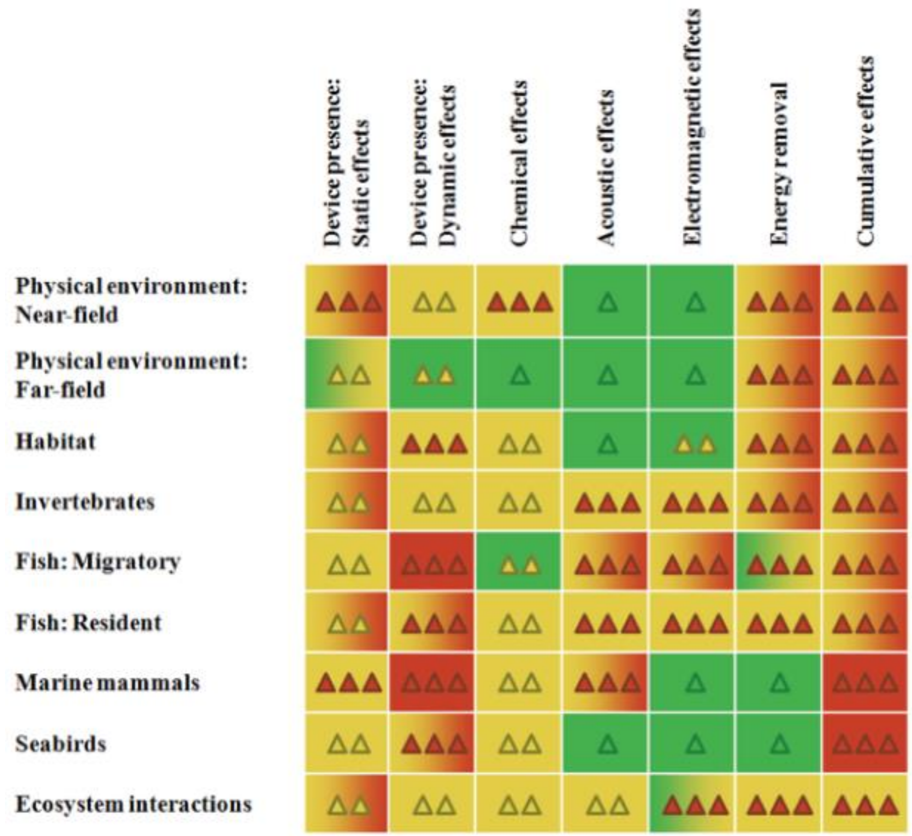
Quantify and compare variance in density distributions relative to baseline

Who/What to Monitor

Pilot Scale



Commercial Scale



Significance: green=low, red = high

Uncertainty: 1 green =low; 2 yellow moderate; 3 red = high

Polagye et al. 2011

Site Characteristics & Sampling Decisions

Site Characteristics: high flow environments; little previous biological sampling

Field: instrument choice & deployment, sample duty cycle

Analytic: modeling, detecting change, identifying causes of change, determining impacts

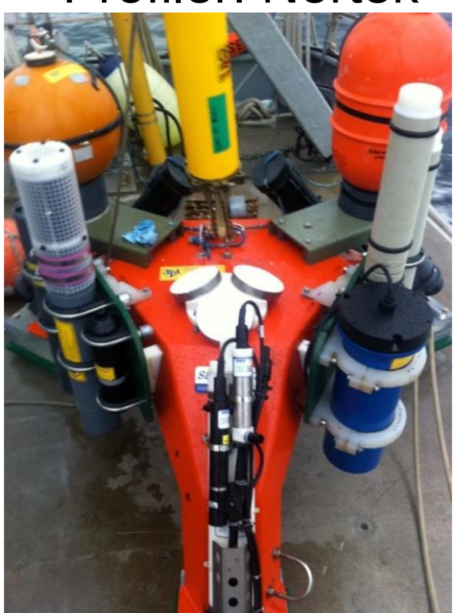
Applications: scaling up results from samples to site

Bottom Instrument Packages

Multibeam sonar: RESON 7128

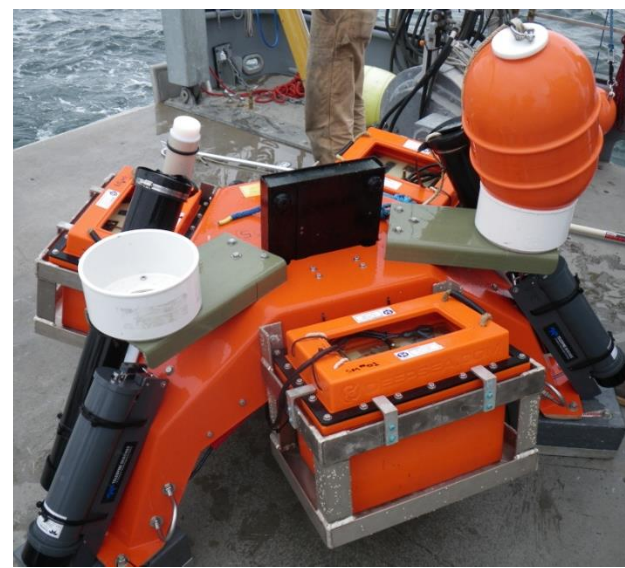
Splitbeam echosounder:
Biosonics 120 kHz

Acoustic Doppler Current
Profiler: Nortek



Hydrophone,
CTD, CPOD

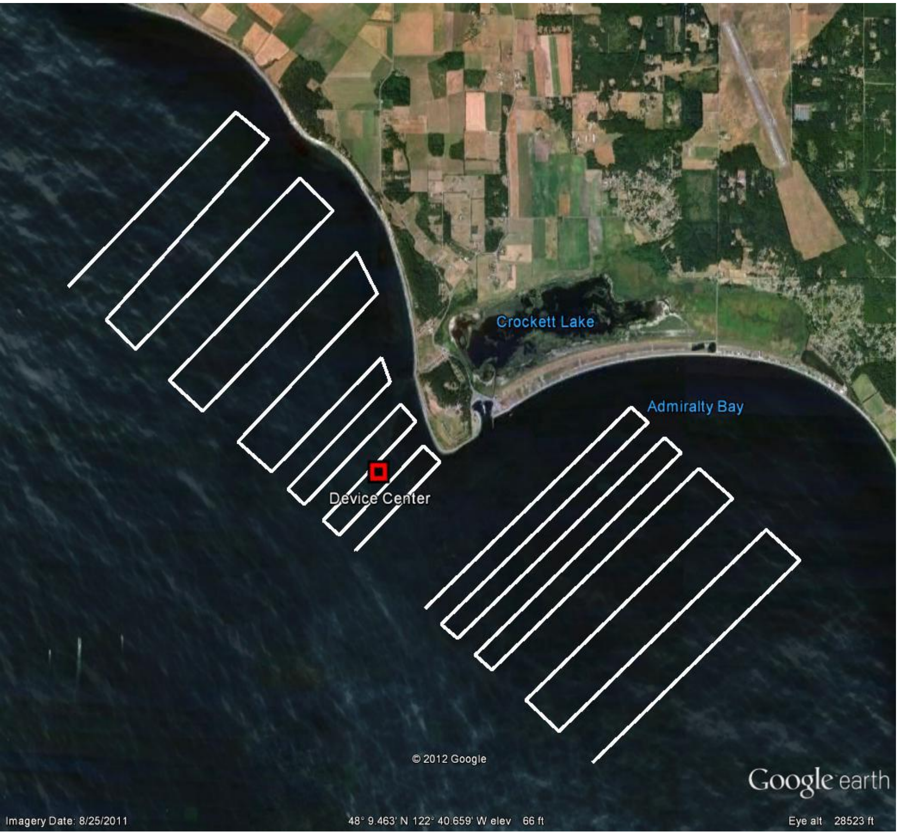
Acoustic camera:
SoundMetrics DIDSON



Survey Design: Surface

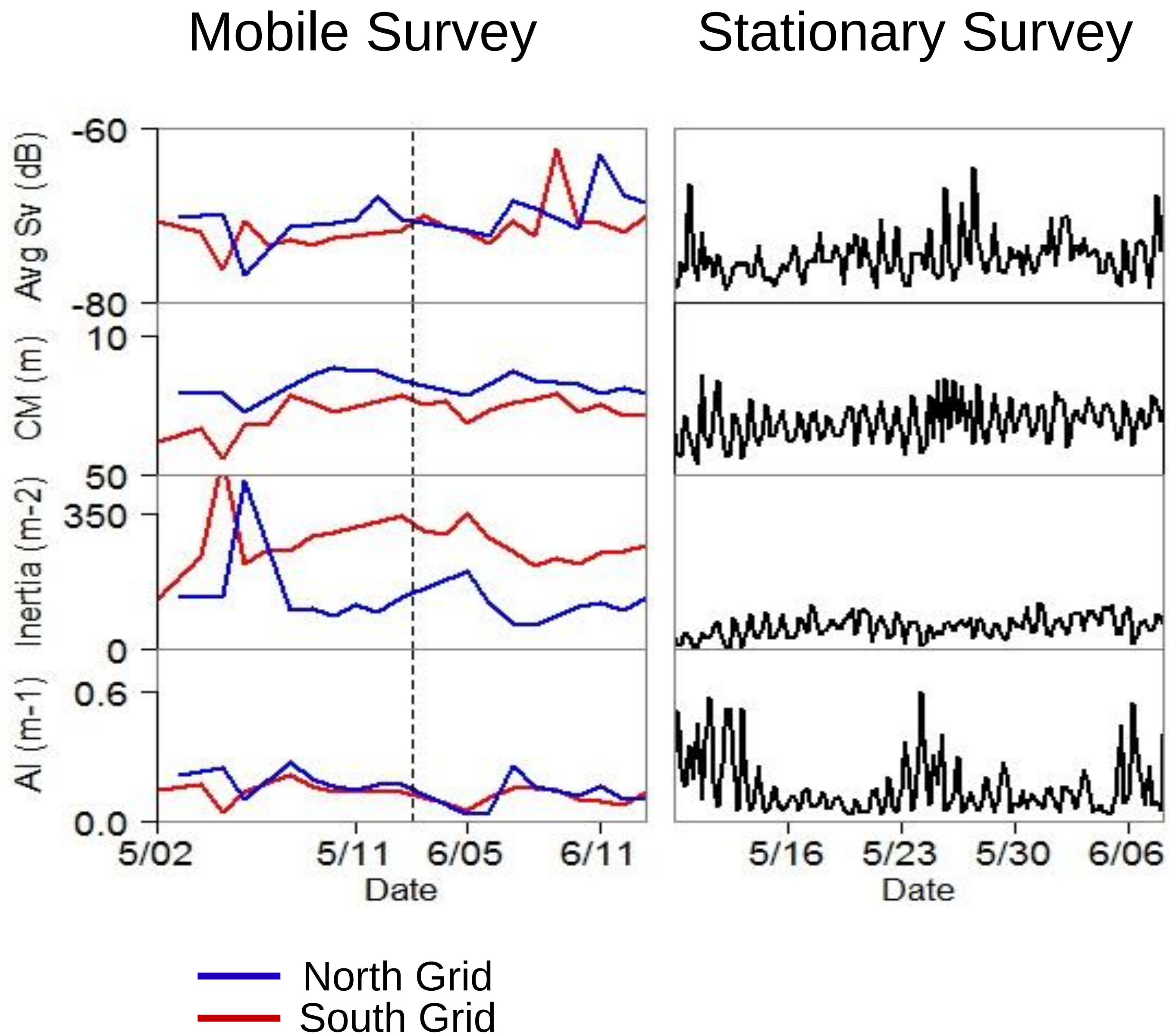
Acoustic, midwater trawl, seabird, marine mammal surveys

- before, during, after bottom package deployment
- cycles: lunar, tidal, diel
- animal behavior: day, dusk, night samples
- spatial variability: representative spot, site characterization



- 2 weeks May, 2 weeks June
- day, dusk (drift), night surveys
- 2 grids: north south
- midwater trawls when possible (1 knt)
- sample north or south grids on consecutive days to cover all tidal stages x time of day

Metric Value Comparison

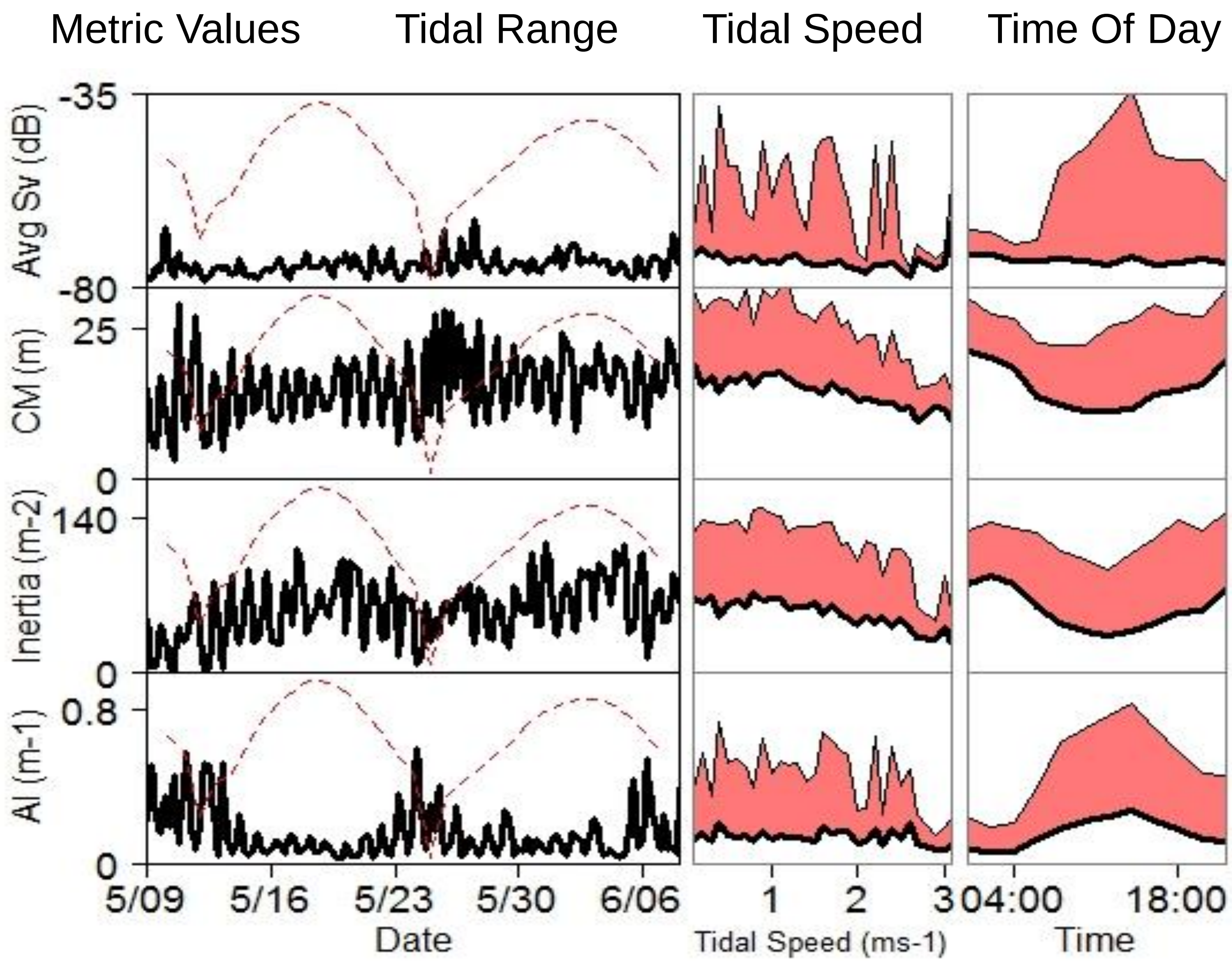


Scaling Up: Representative Ranges

What does a single point represent in space?

Method	Representative Range (meters)	Devices per km^2	Estimated Cost/km^2
Coefficient of Determination Model	288.65	3.90	$292,500
Gray's Sample Size Calculation	403.90	1.95	$146,250
t-test Sample Size Calculation	30.57	340.61	$25.5 million
Power Analysis	88.45	40.68	$3.0 million
Theoretical Spectra	1,388.10	0.015	$1,125
Corresponding Spatial and Temporal Scales	648.70	0.75	$56,250

Stationary Metrics: Covariates



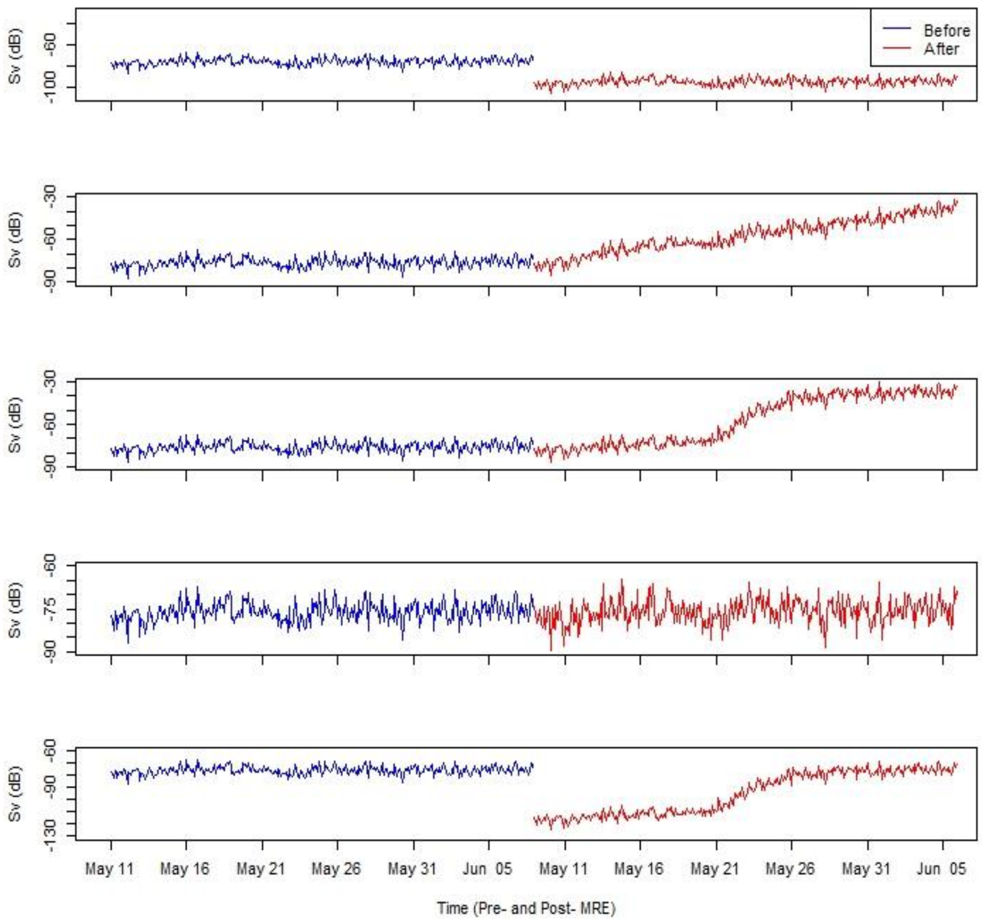
mean ± 2 std. dev.

Modeling Metric Patterns

Model	Form	Parametric/ Nonparametric	Variance	Includes Autocorrelation?	Error Distribution
Linear Regression	Linear	Parametric	Observation error only	No	Normal
Generalized Least Squares (GLS)	Linear	Parametric	Observation error only	In correlation structure	Normal
Generalized Linear Model (GLM)	Linear	Parametric	Observation error only	No	Exponential family
Generalized Linear Mixed Model (GLMM)	Linear	Parametric	Observation error only	In correlation structure	Exponential family
Generalized Additive Model (GAM)	Non-linear	Semi-parametric	Observation error only	No	Exponential family
Generalized Additive Mixed Model (GAMM)	Non-linear	Semi-parametric	Observation error only	In correlation structure	Exponential family
Multivariate Auto-Regressive State-Space (MARSS)	Linear	Parametric	Observation and process error	Yes	Normal
Auto-Regressive Integrated Moving Average (ARIMA)	Linear	Parametric	Process error and observation error	Yes	Normal
ARIMA + Generalized Auto-Regressive Conditional Heteroskedasticity (GARCH)	Linear	Parametric	Process error and observation error	Yes	Generalized extensions of normal
Random Forest	N/A	Non-parametric	N/A	Yes- lagged variables	None
Support Vector Regression	N/A	Non-parametric	N/A	Yes- lagged variables	None

Scenarios of Change

Stressor | **Change**



Stressor	Change
Noise	Step
Static Device	Linear
Static Device	Nonlinear
Dynamic	Periodic
Chemical Spill	Step + Nonlinear

Effect Size
- 10%
- 25%
- 2SD

Lag
- No lag
- 1 year

Signal-to-Noise Ratio
- Initial values of error
- High error
- Low error

What Constitutes Change?

Change: deviation from a reference

Challenge: How to choose a reference/threshold?

Objective Threshold: Extreme Value Analysis
- rare but important events, high risk
- can have large impacts (e.g. 100 year flood)

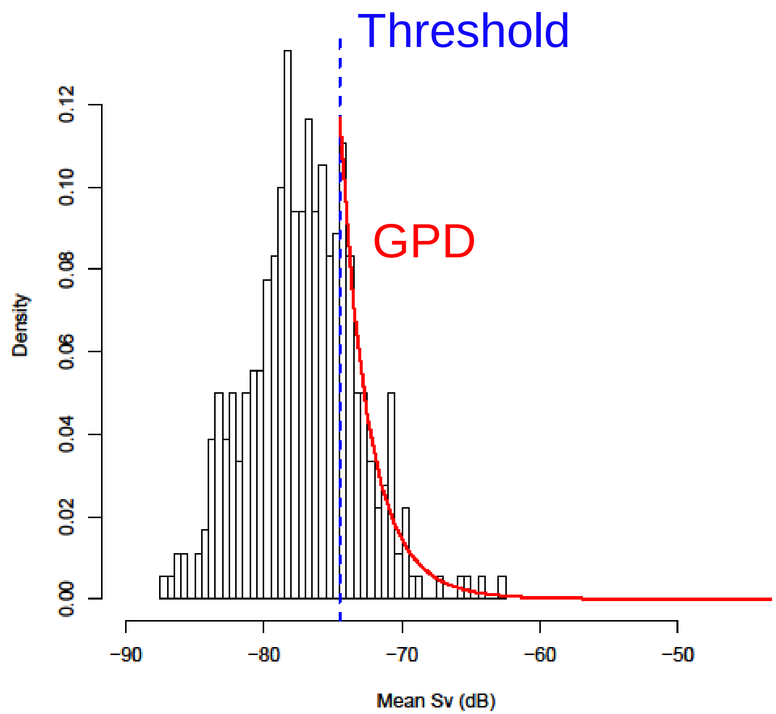
Extreme Value Analysis

Extreme Value Analysis (EVA) models rare values in distribution tails.

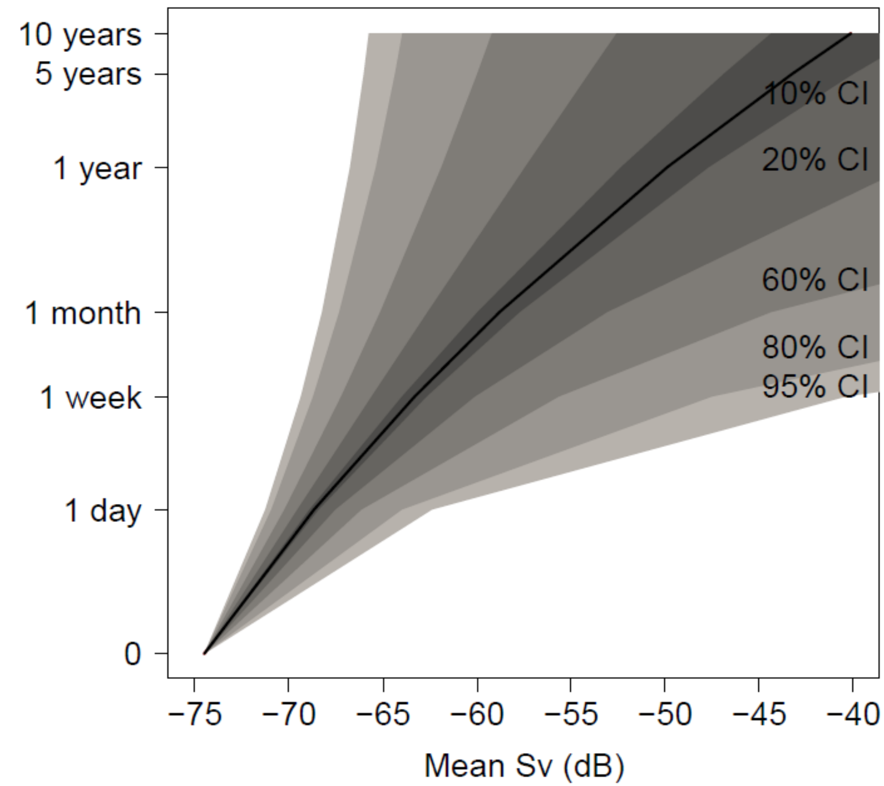
Peaks-Over-Threshold defines extreme values above threshold. Fits Generalized Pareto Distribution (GPD) to extreme values.

Return Levels are average periods of extreme values + Bayesian Confidence Intervals.

EVA of Baseline Tidal Turbine Site Data

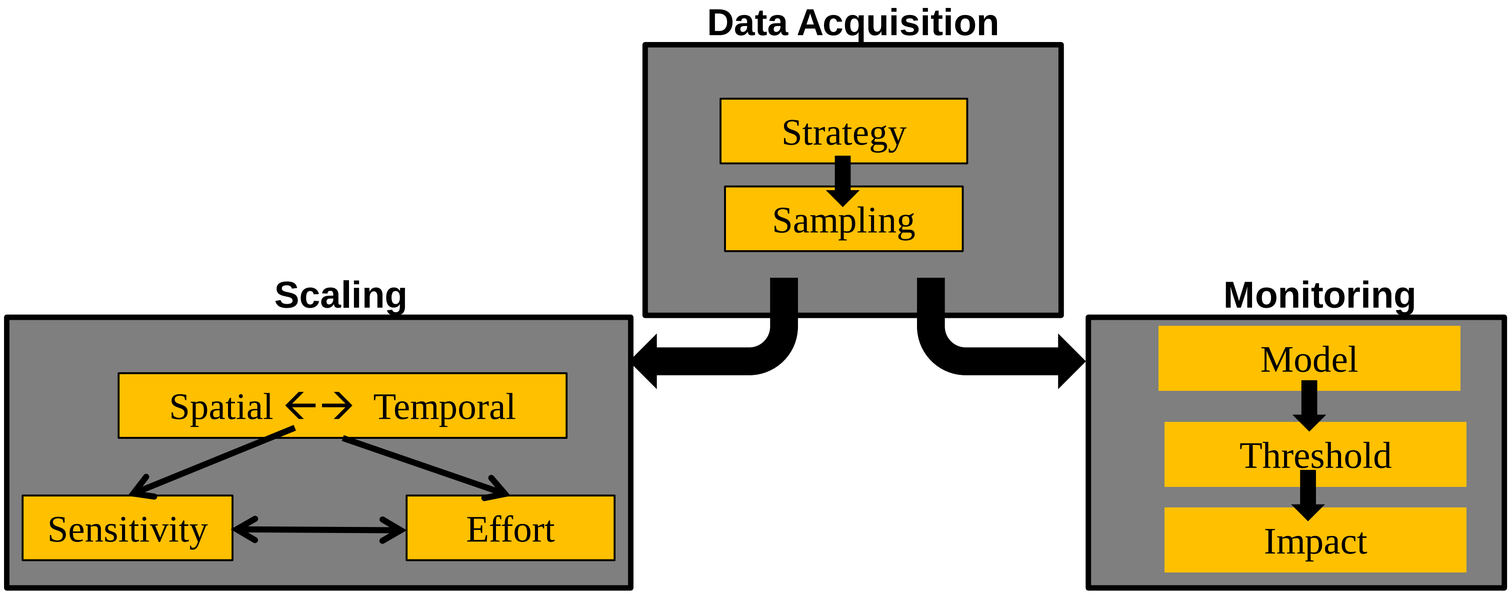


Confidence Levels of Return Levels



Wiesebron et al. 2016a

Significance and Applications



- quantifies baseline, variability, and impacts
- site evaluation, pilot project, commercial scale
- monitoring density of instrumentation packages
- enables comparison within and among sites
- developers and regulator common language
- all marine renewable technologies
- ocean observing and environmental monitoring