Using Webb gliders to maintain a sustained ocean presence

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Acknowledgements & salute to fellow glider pilots (Russ
)avis, Charlie Ericksen, David Fratantoni, Mary Jane Perry,
aig Lee, Dan Rudnick, Burt Jones, Jack Barth, Breck Owens,
pp Sherman, Herve Claustre, Gary Kirkpatrick, Chuck Trees
(I am sure I am missing some, sorry)

1) Gliders provide sustained data
2) Control is transitioning to science
3) Sensor suite is expanding
4) Future technology

OCEAN OBSERVATION LAB
COASTAL
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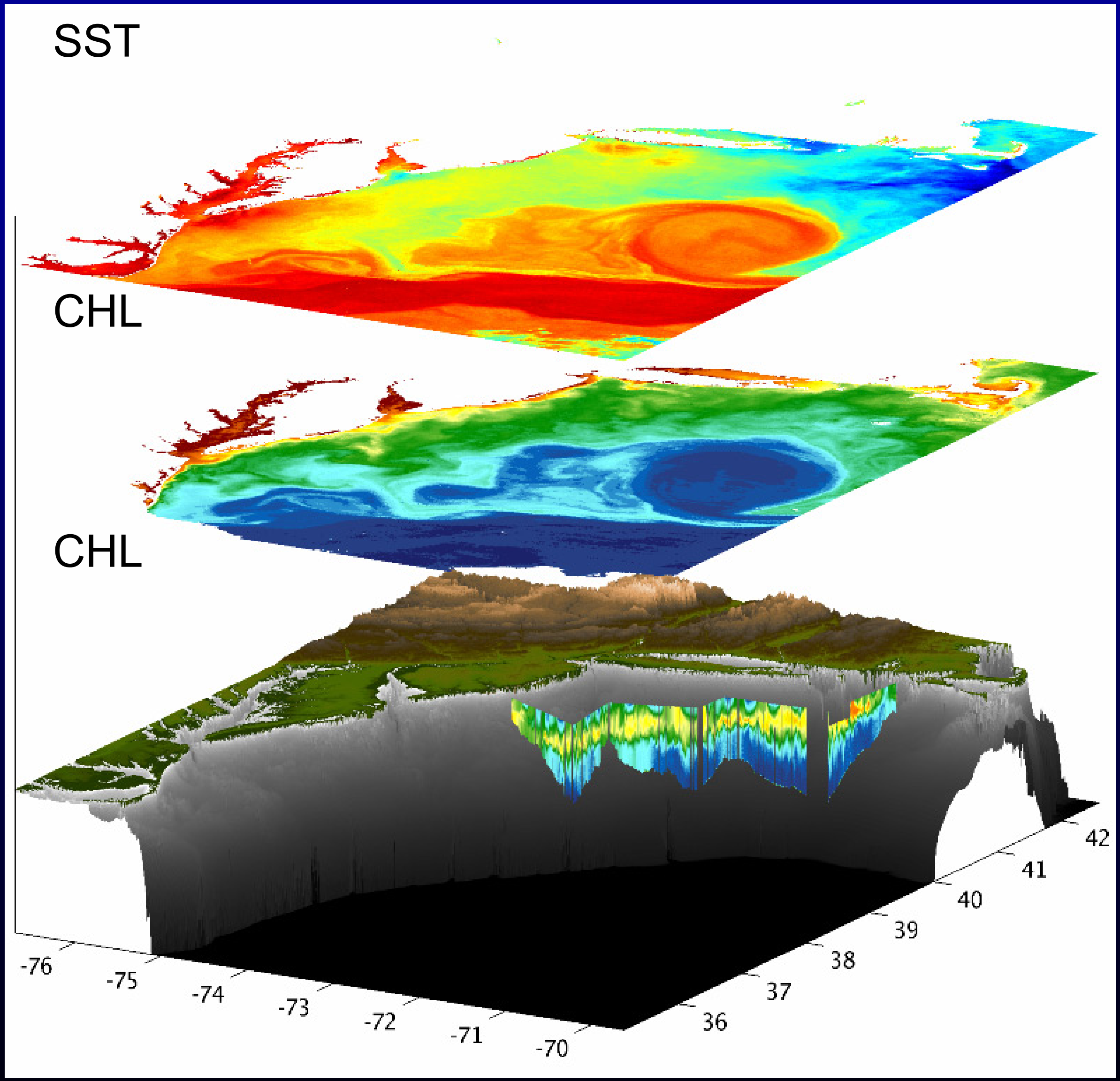
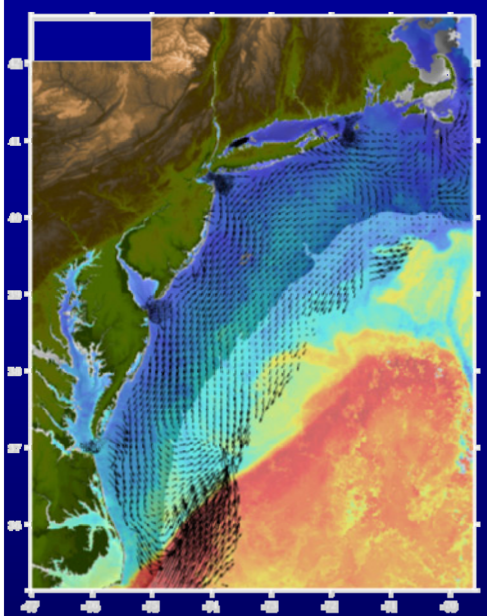
Satellite remote sensing is currently the major data source sustained spatial data appropriate for data assimilative models: however gliders are rapidly transitioning to be the new technology to provide subsurface regional data.



Couple data assimilative models to glider data.



Remote Sensing

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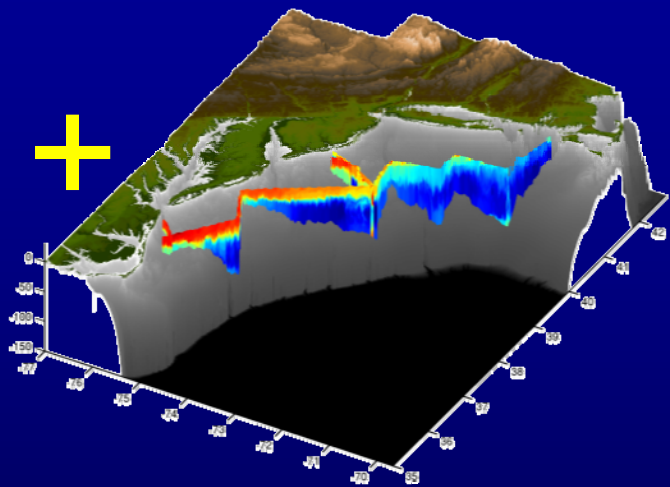

Gliders

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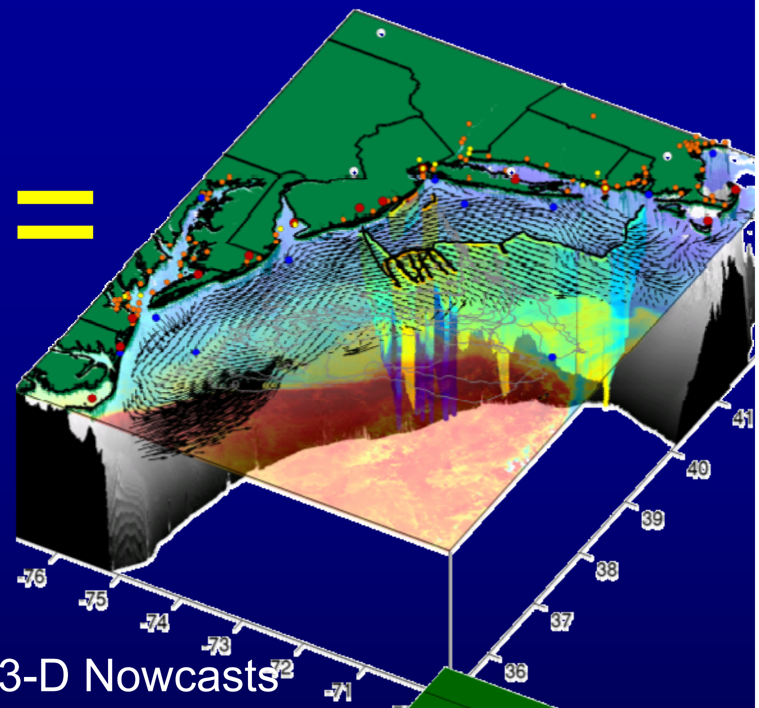
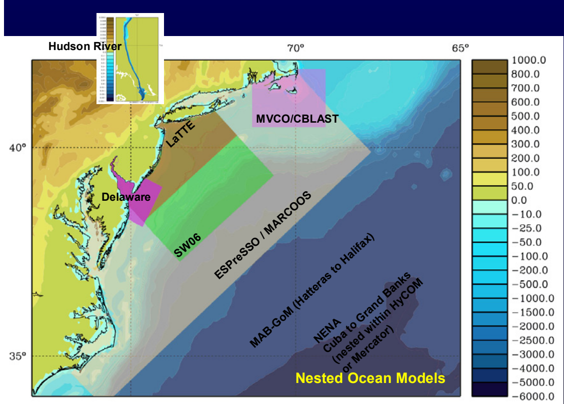


3-D Nowcasts



Nested Models

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S4DVAR procedure

Lagrange function $L = J(\mathbf{x}) + \sum_{i=1}^{N} \boldsymbol{\lambda}_i^T \left(\frac{d\mathbf{x}_i}{dt} - \mathbf{N}(\mathbf{x}_i) - \mathbf{F}_i \right)$ $\mathbf{F}_i = \mathbf{F}(i\Delta t)$ $\mathbf{x}_i \equiv \mathbf{x}(i\Delta t)$

Lagrange multiplier $\boldsymbol{\lambda}_i \equiv \boldsymbol{\lambda}(t_i) \equiv \boldsymbol{\lambda}(i\Delta t)$

At extrema of L, we require:

$$\begin{cases} \frac{\partial L}{\partial \boldsymbol{\lambda}_i} = 0 \Rightarrow \frac{d\mathbf{x}_i}{dt} - \mathbf{N}(\mathbf{x}_i) - \mathbf{F}_i = 0 & \textit{NLROMS} \\ \frac{\partial L}{\partial \mathbf{x}_i} = 0 \Rightarrow -\frac{d\boldsymbol{\lambda}_i}{dt} - \left(\frac{\partial \mathbf{N}}{\partial \mathbf{x}}\right)^T \boldsymbol{\lambda}_i - \delta_{im} \mathbf{H}^T \mathbf{O}^{-1} (\mathbf{H}\mathbf{x}_m - \mathbf{y}_m) = 0 & \textit{ADROMS} \\ \frac{\partial L}{\partial \mathbf{x}(0)} = 0 \Rightarrow \mathbf{B}^{-1}(\mathbf{x}(0) - \mathbf{x}_b) - \boldsymbol{\lambda}(0) = 0 & \textit{coupling of NL \& ADROMS} \\ \frac{\partial L}{\partial \mathbf{x}(\tau)} = 0 \Rightarrow \boldsymbol{\lambda}(\tau) = 0 & \textit{i.c. of ADROMS} \end{cases}$$

S4DVAR procedure:

(1) Choose an $\mathbf{x}(0) = \mathbf{x}_b$
(2) Integrate NLROMS $t \in [0, \tau]$ and compute J
(3) Integrate ADROMS $t \in [\tau, 0]$ to get $\boldsymbol{\lambda}(0)$
(4) Compute $\frac{\partial J}{\partial \mathbf{x}(0)} = \mathbf{B}^{-1}(\mathbf{x}(0) - \mathbf{x}_b) - \boldsymbol{\lambda}(0)$
(5) Use a descent algorithm to determine a "down gradient" correction to $\mathbf{x}(0)$ that will yield a smaller value of J
(6) Back to (2) until converged

Data Assimilation

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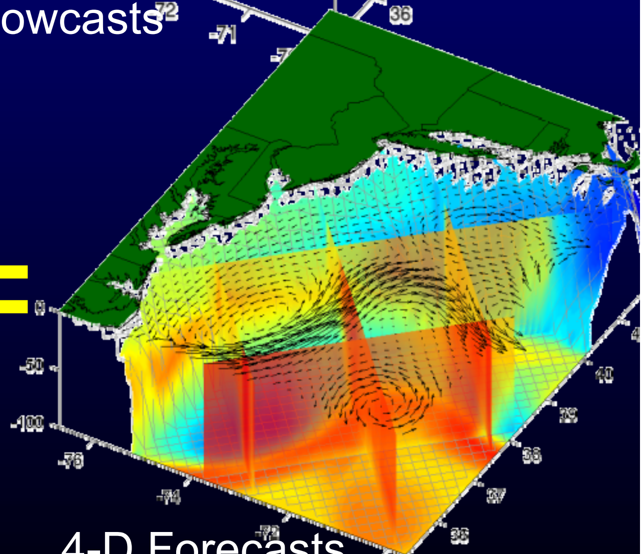
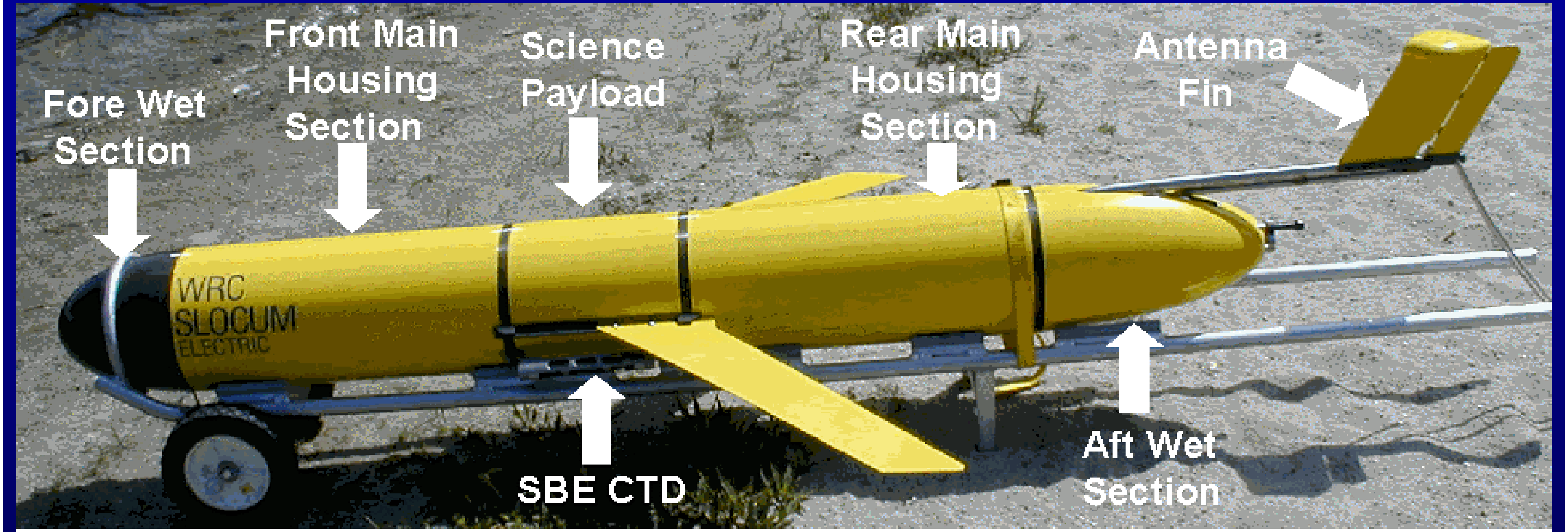


4-D Forecasts

Slocum Coastal Glider



Glider Specs.

Length: 1.5 m Hull Diameter: 21.3 cm

Weight: 52 kg

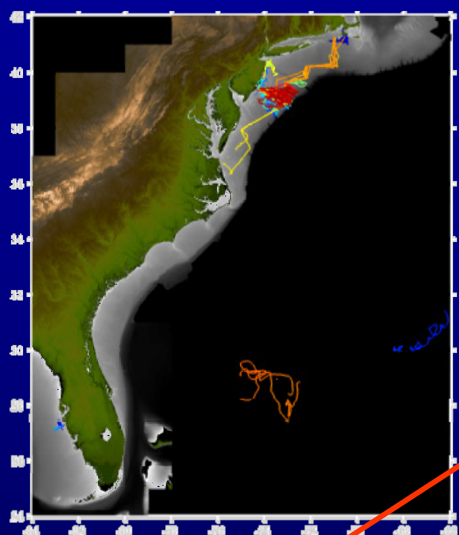
Science Bay Specs.

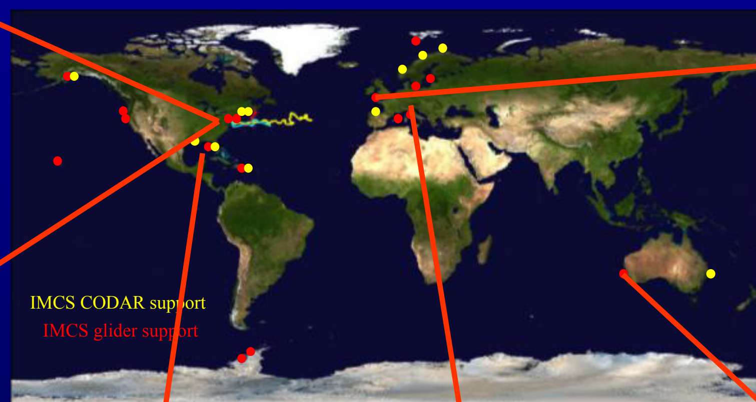
Length: 30 cm Diameter: 21.3 cm

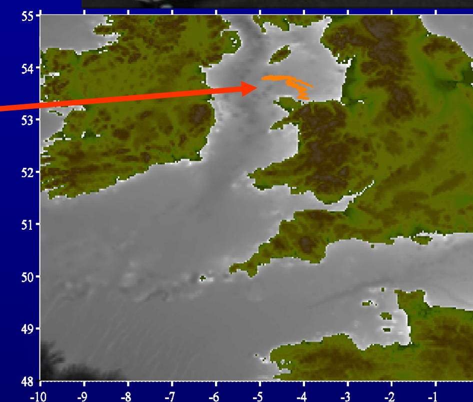
Max. Payload Weight: 4 kg

1)Gliders Provide an Adaptive Global Presence in the Ocean

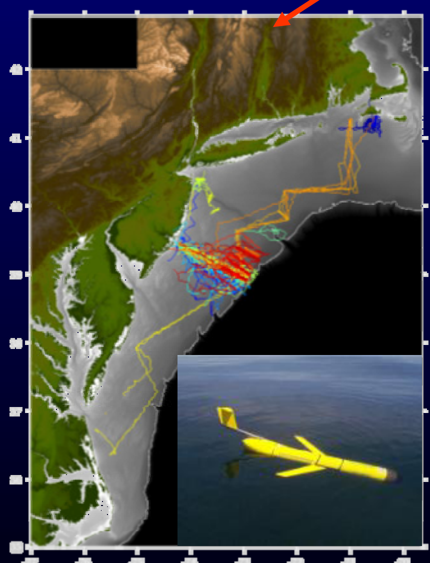
164 deployments worldwide
(Oct. 2003 – Jul. 2009)
Over 62816 km (Earth's circ. ~ 40,000 km)
2800 days at sea, 378671 profiles

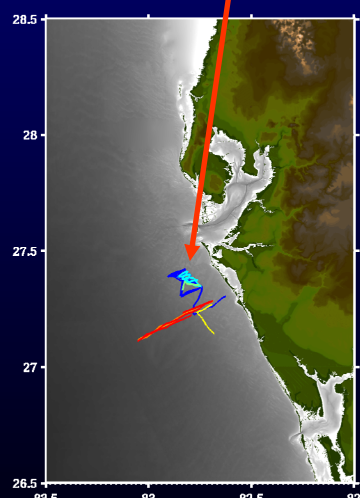


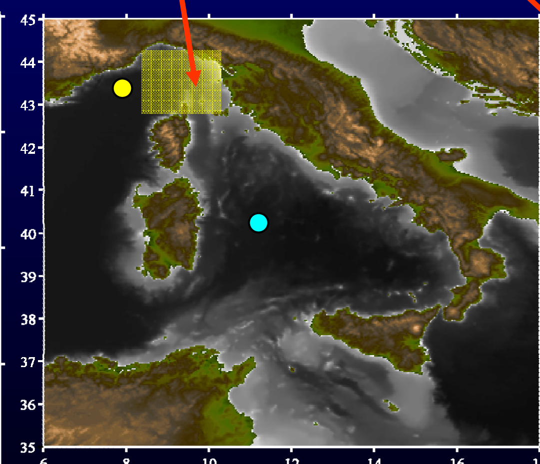


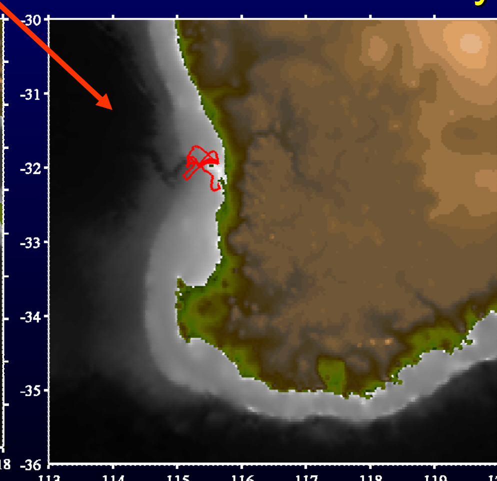


Liverpool Bay
Coastal Observatory



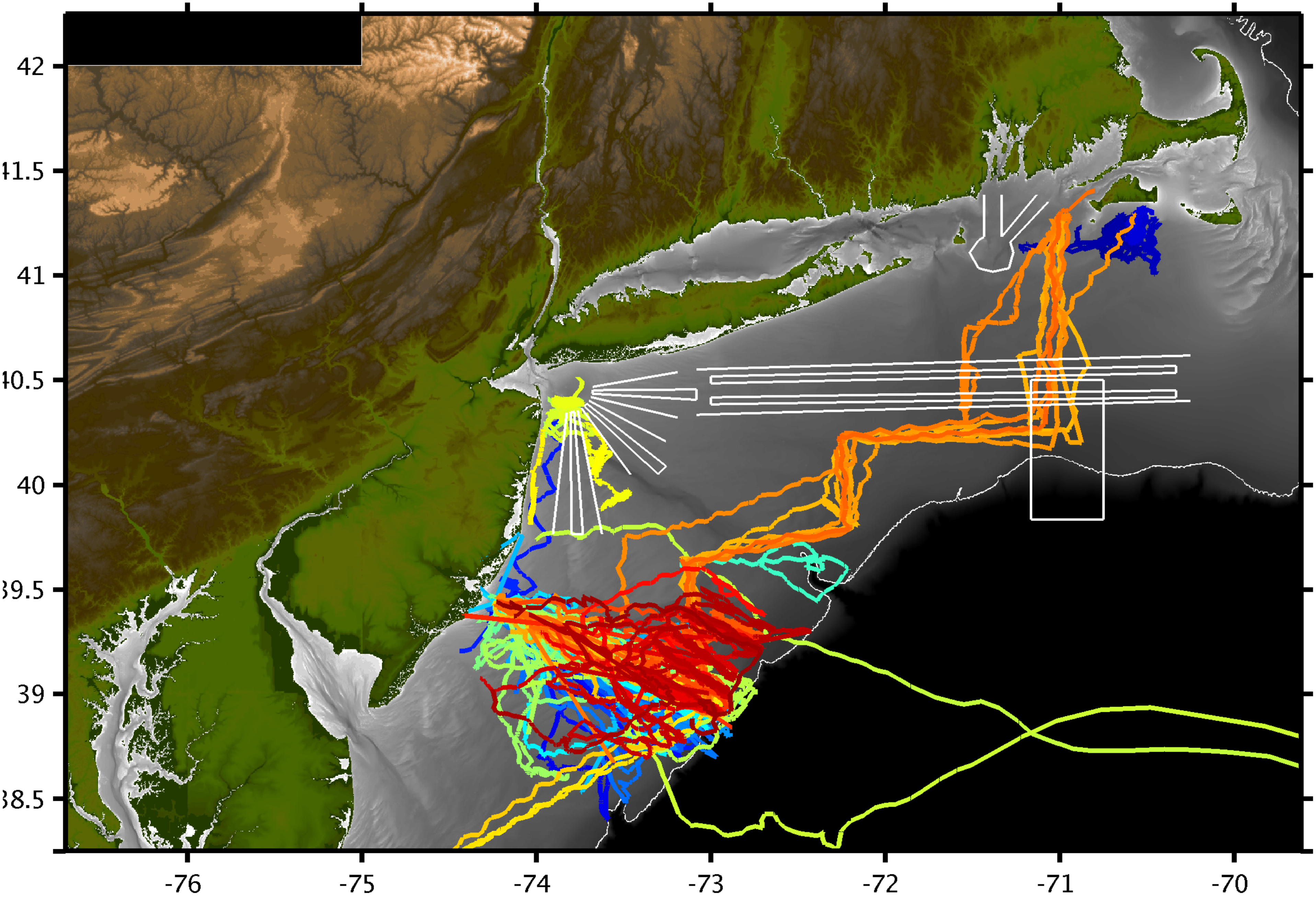




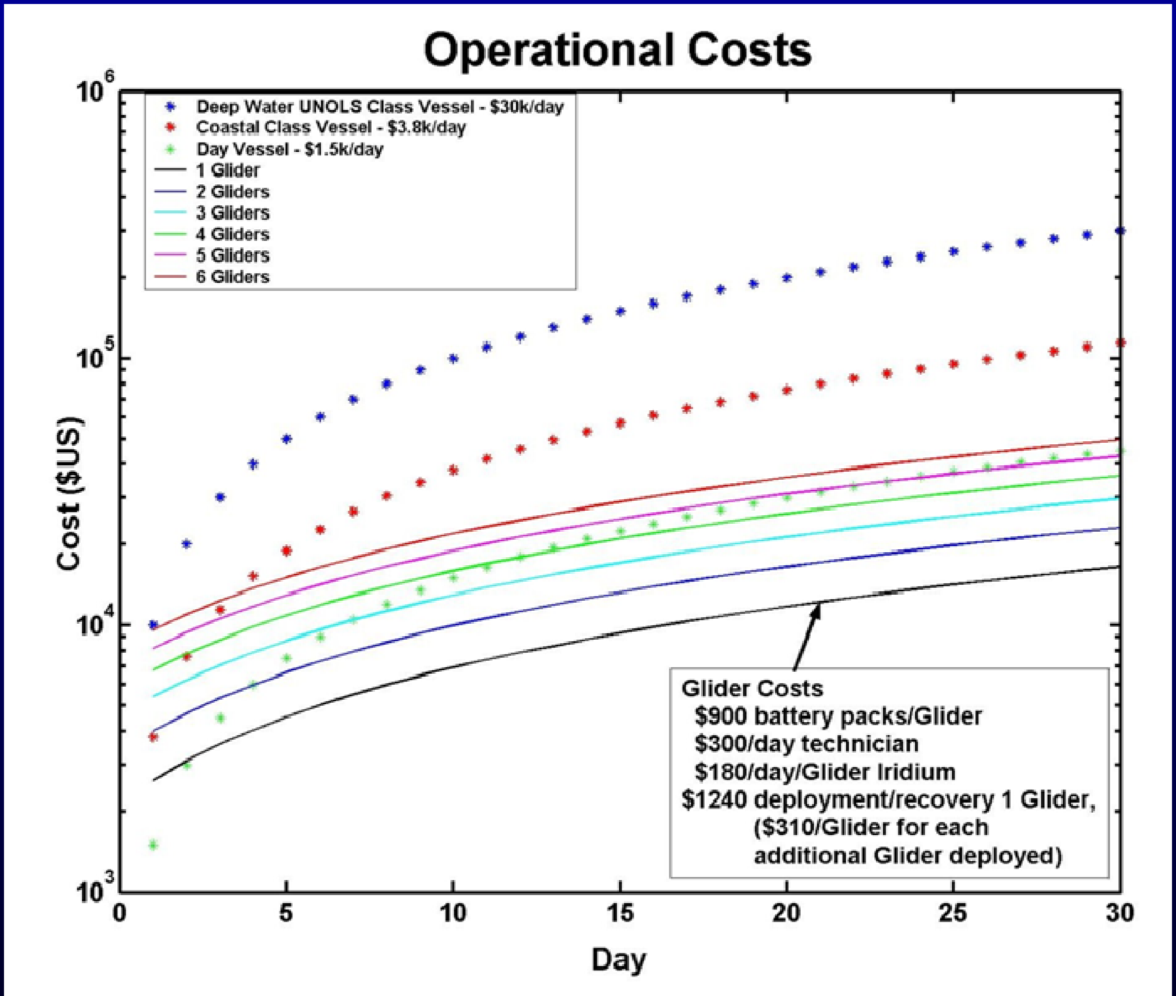


Mid-Atlantic Shelf West Florida Shelf Mediterranean Sea Perth, Australia

2) Gliders can provide a sustained ocean presence. Regional time series in the NorthEast United States.



3) Gliders are cost effective and financially scalable



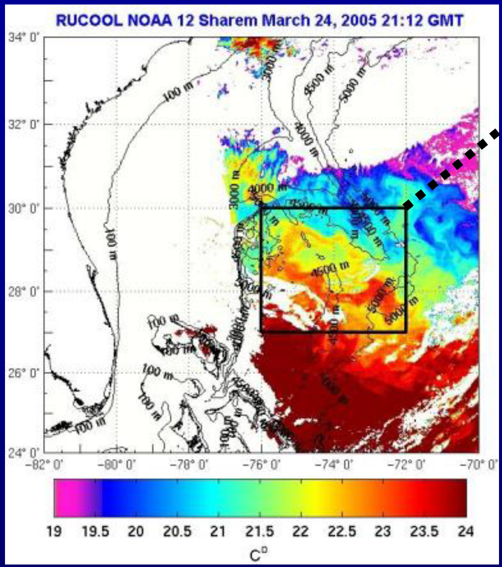
Current lab

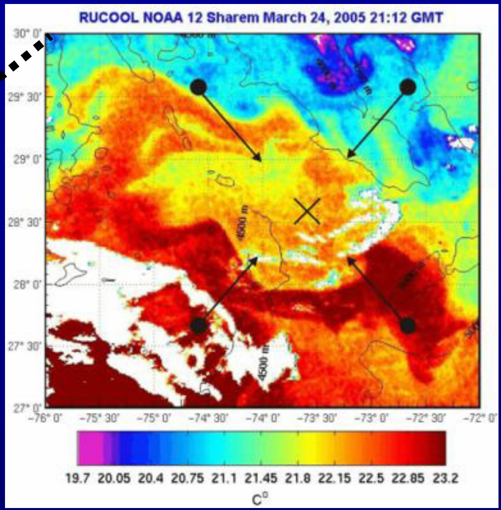
21 Gliders
1 hardware tech
1 software tech
1 field tech

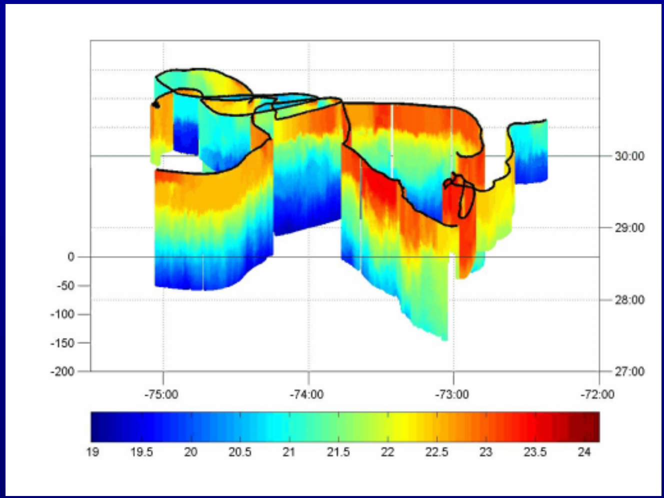
Student interns

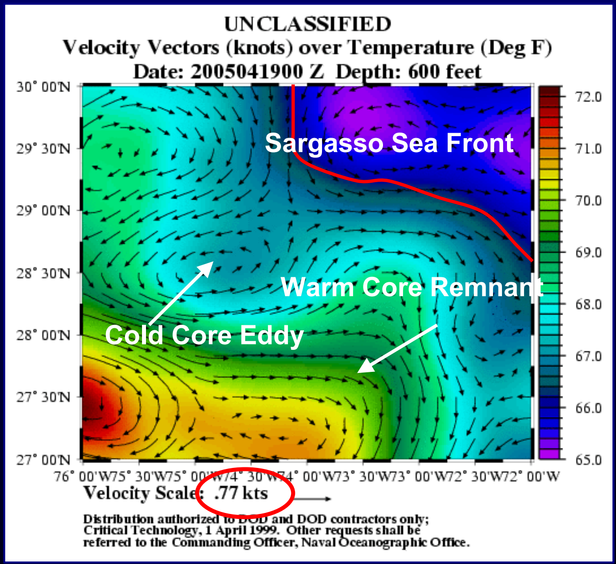
Very tired…

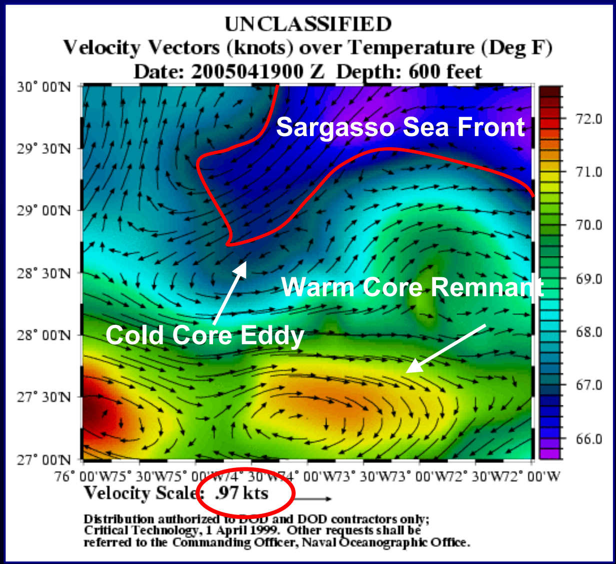
4) Glider swarms are available now: Here 4 gliders changed Naval tactics during a submarine war game 64 times in 1 month.

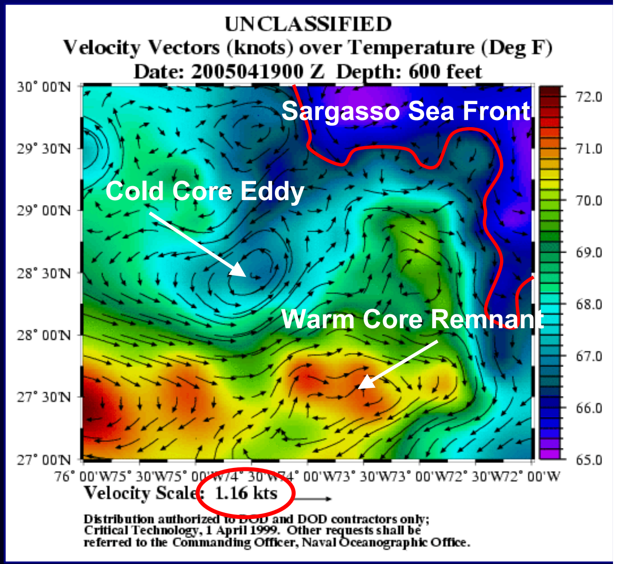






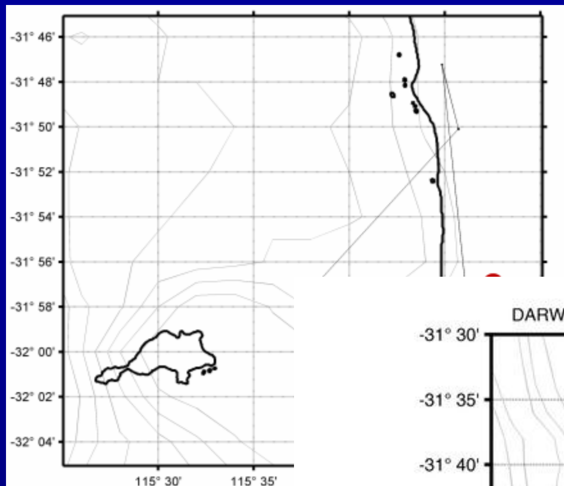


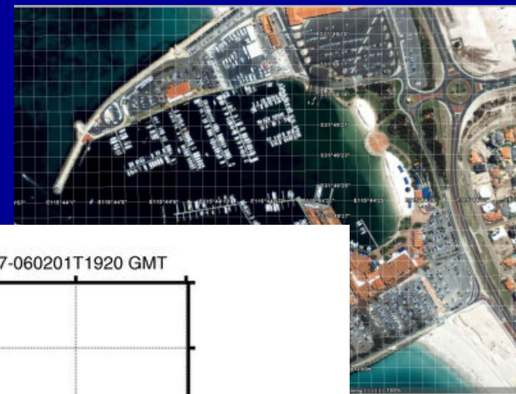


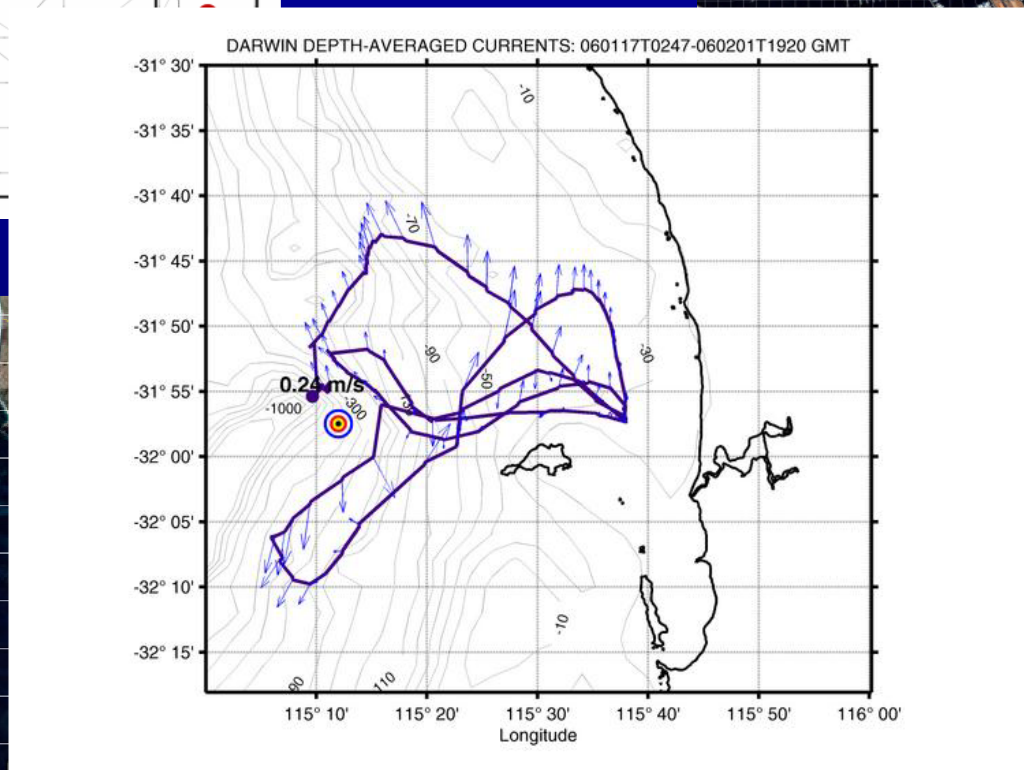


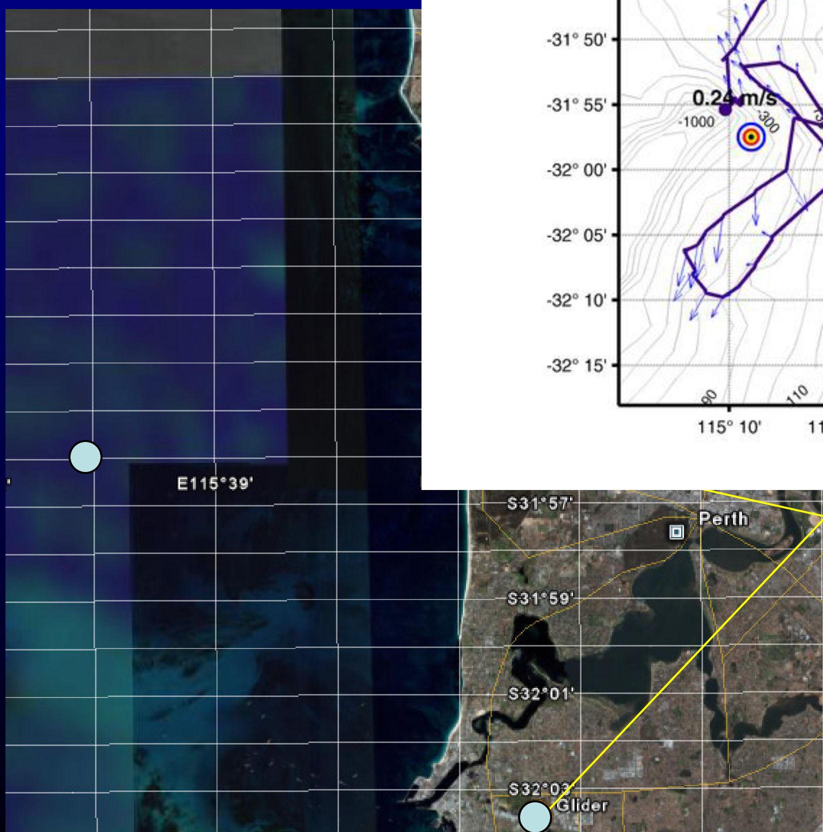
4) Iridium and wireless comms allow distributed glider fleets to be controlled remotely. Summer 2006 (NJ, Monterey, Hawaii)

Darwin's Odyssey – January 11, 2006

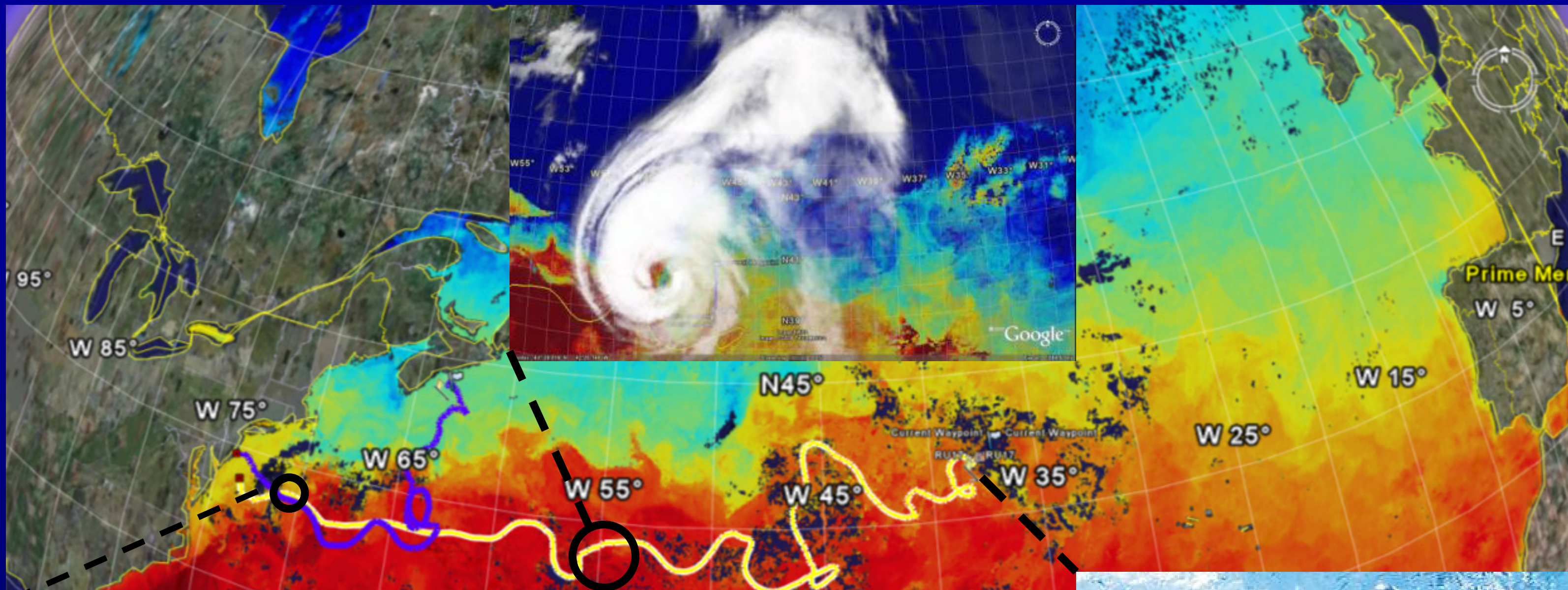


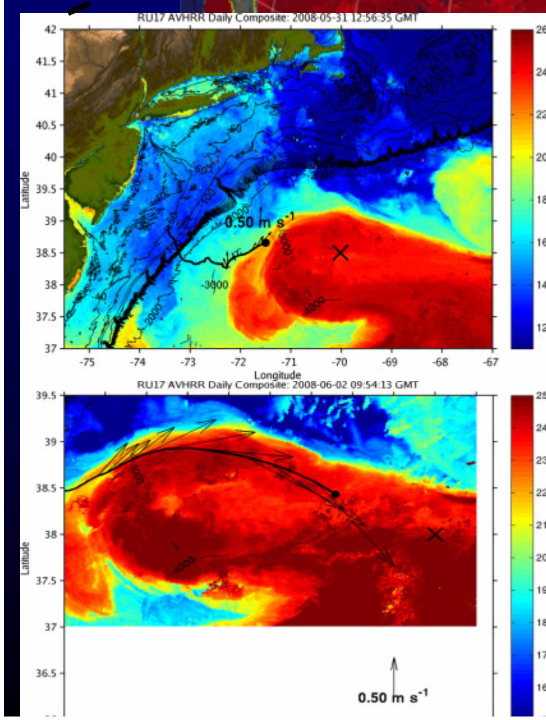


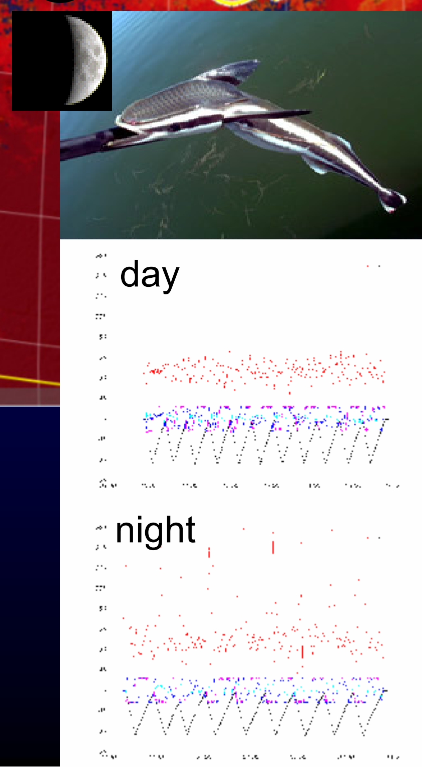




Challenge 1) DURATION

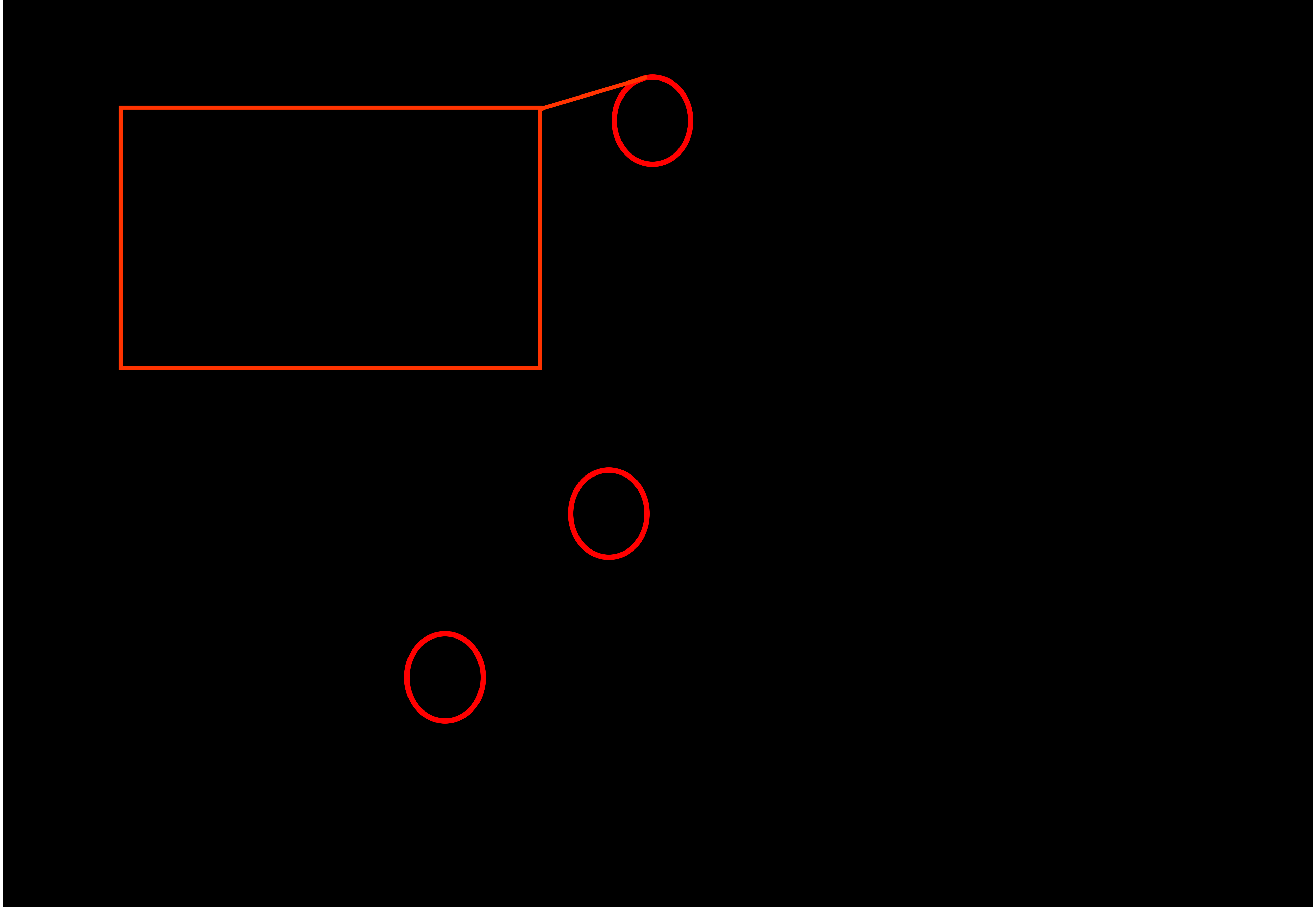






Launched May 25,
Pilots are undergraduate
Students with faculty &
technician mentors

July 2009



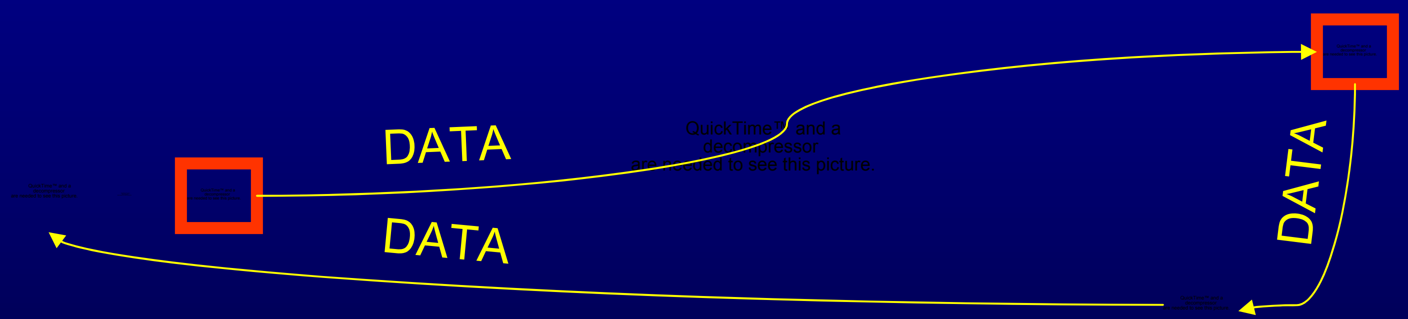
Gliders Provide
A Distributed Subsurface Mobile Sensor Networks:

In Navy talk:
Ideal for asymmetric needs given the ability for sustained persistent and linger capacity

Take home: We are now capable of sustained observations

Challenges?

Challenge 2) Transition from Specialists (key for a global footprint)



ONR Glider RIMPAC 2006
Accomplishments:

1) Over the horizon deployment
2) Adaptive command by field command
3) MCM relevant mission planning

RU Glider training

To be expanded in coming years in collaboration with Teledyne Webb

QuickTime™ and a
decompressor
are needed to see this picture.

QuickTime™ and a
decompressor
are needed to see this picture.

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decompressor
are needed to see this picture.

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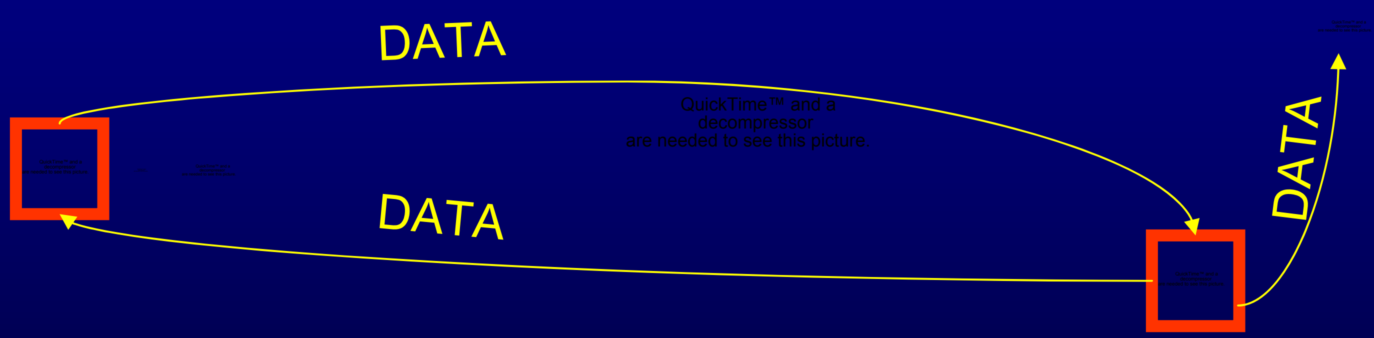
Challenge 2) Transition To new users

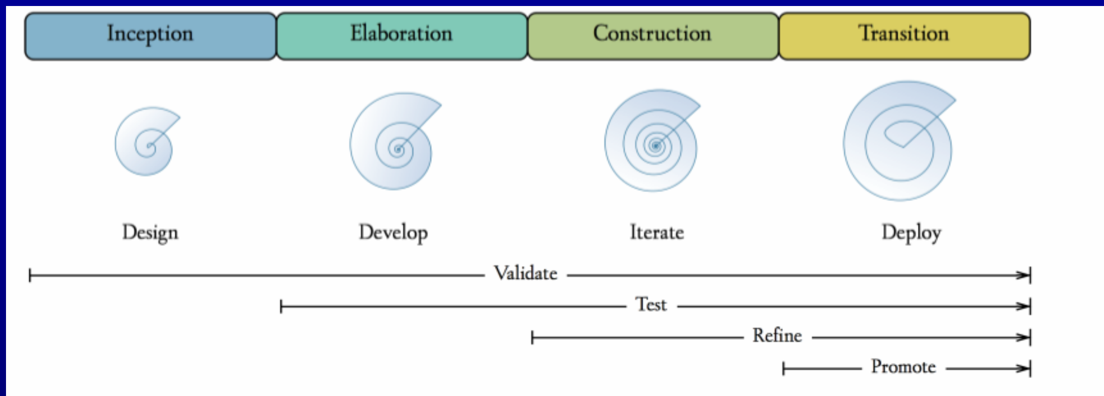


ONR Glider RIMPAC 2008
Accomplishments:

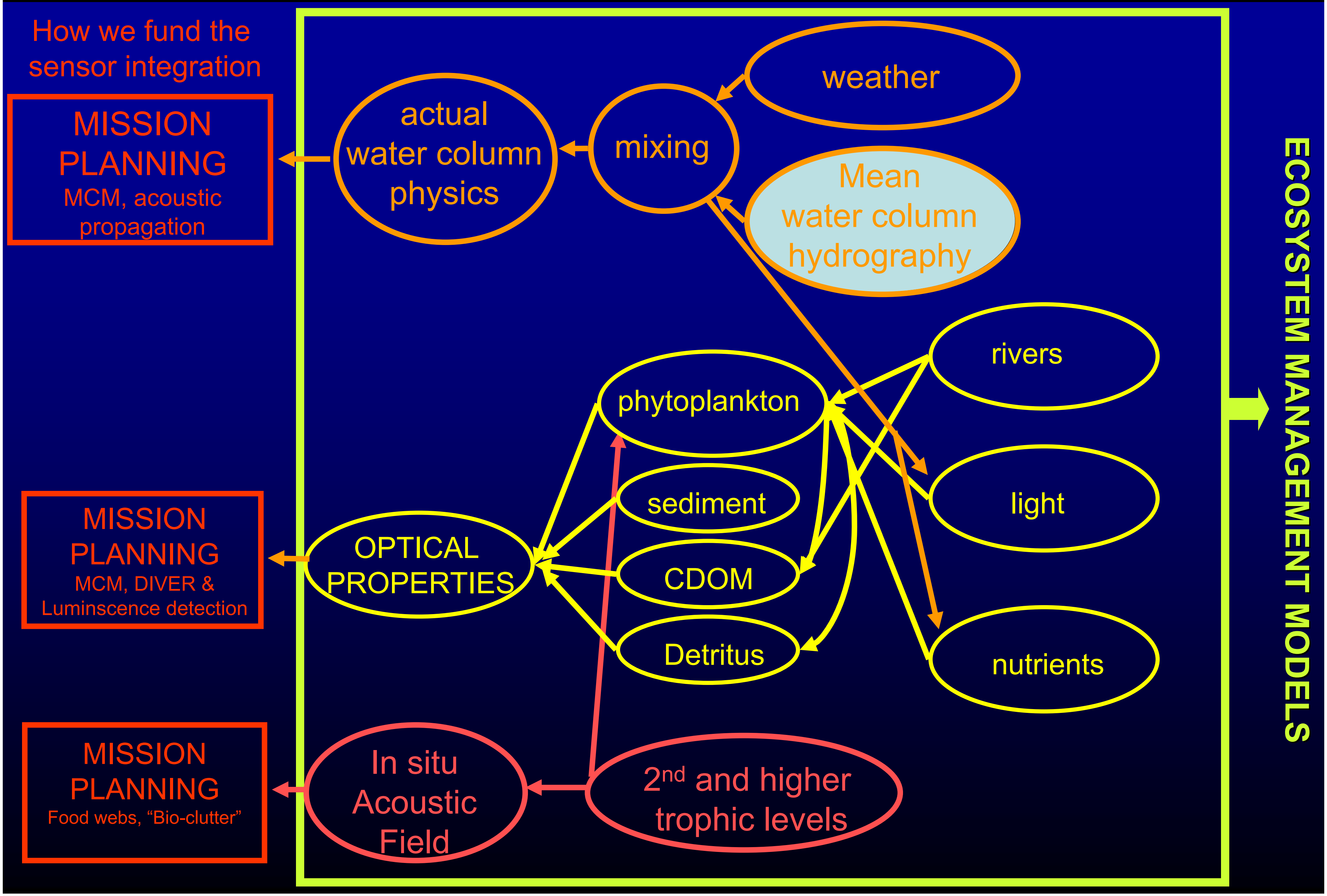
1) Fleet of 4 gliders
2) Naval vessel deployments
3) MCM relevant mission planning

Challenge 3) Gliders are just the platform, what can we measure?

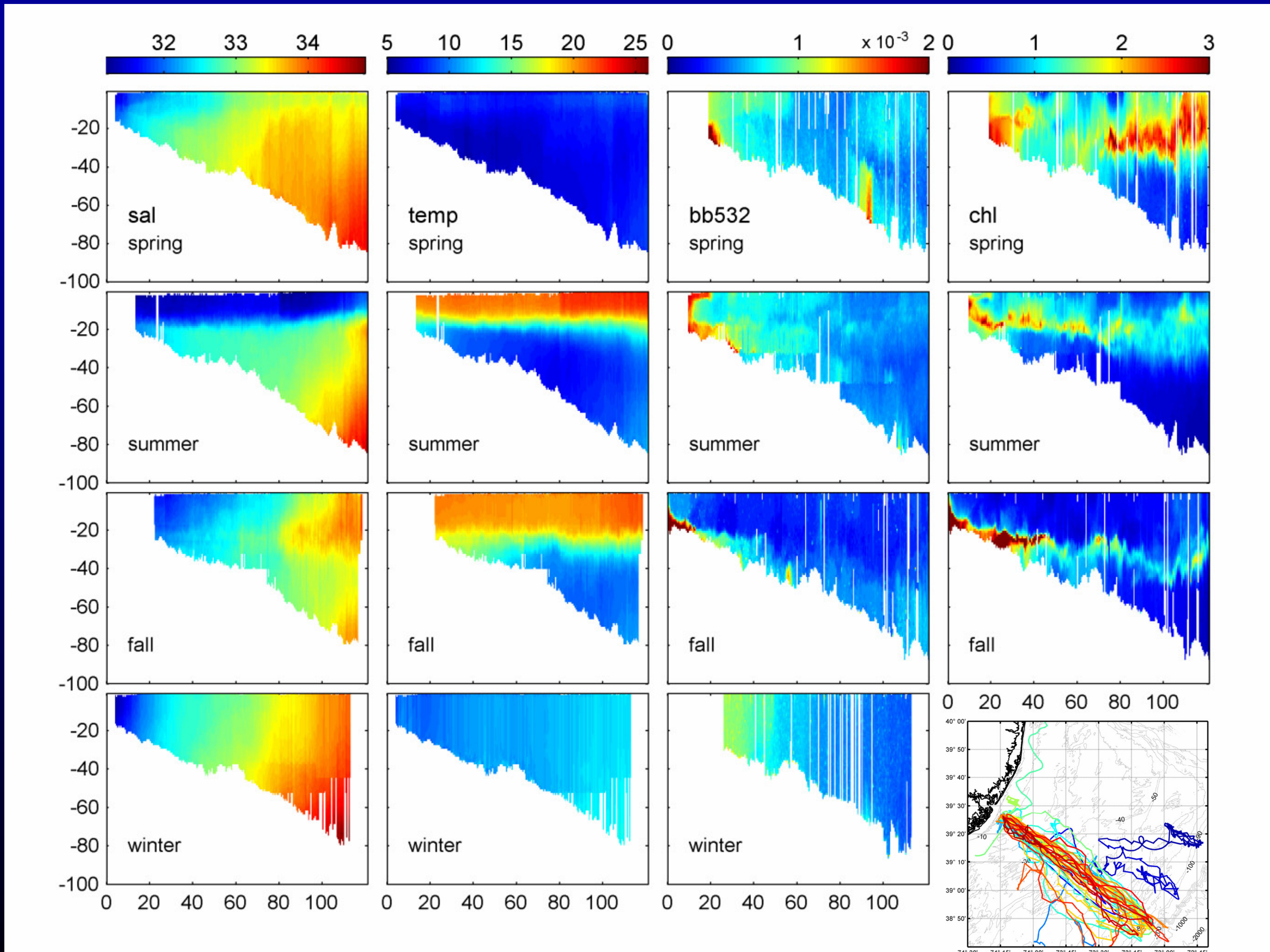
Rutgers, Webb Research, and Instrument Companies
Spiral Development Cycle

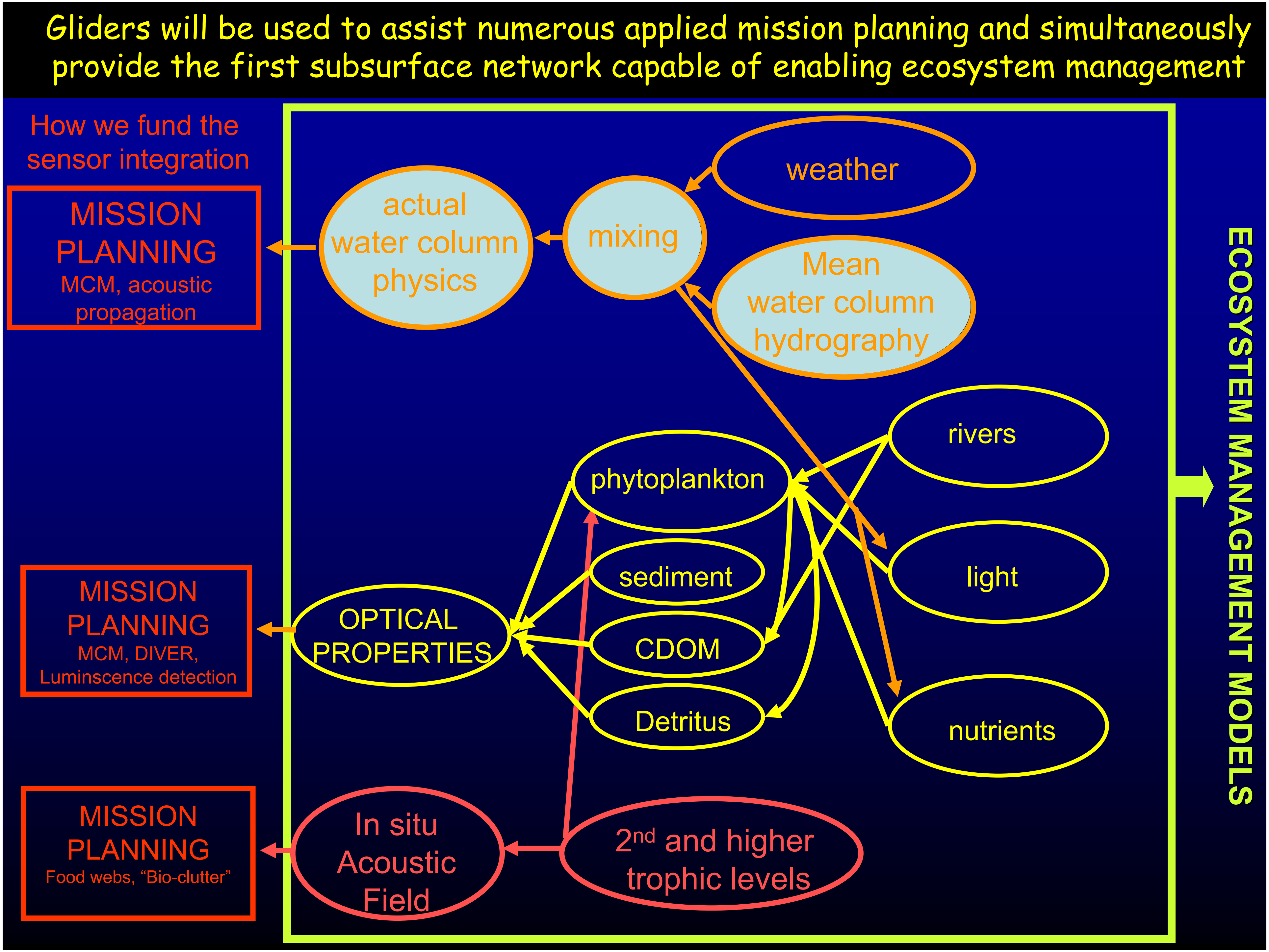


Gliders will be used to assist numerous applied mission planning and simultaneously provide the first subsurface network capable of enabling ecosystem management



Seasonal climatologies (from 42 missions)

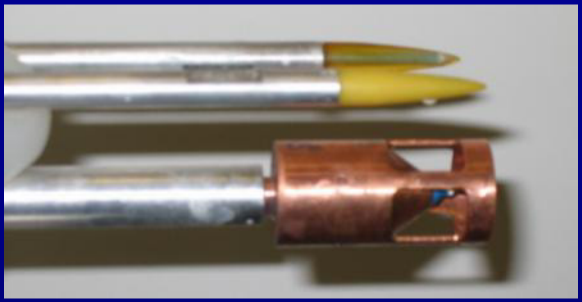


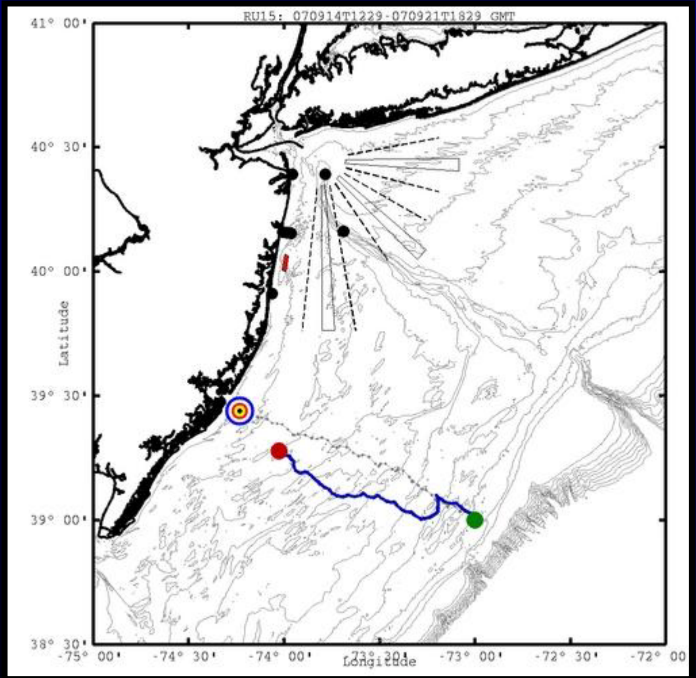

Gliders will be used to assist numerous applied mission planning and simultaneously provide the first subsurface network capable of enabling ecosystem management
How we fund the sensor integration
MISSION PLANNING
MCM, acoustic propagation
MISSION PLANNING
MCM, DIVER, Luminscence detection
MISSION PLANNING
Food webs, “Bio-clutter”
actual water column physics
mixing
weather
Mean water column hydrography
rivers
phytoplankton
light
sediment
OPTICAL PROPERTIES
CDOM
Detritus
nutrients
In situ Acoustic Field
2nd and higher trophic levels
ECOSYSTEM MANAGEMENT MODELS

External Modular Sensors

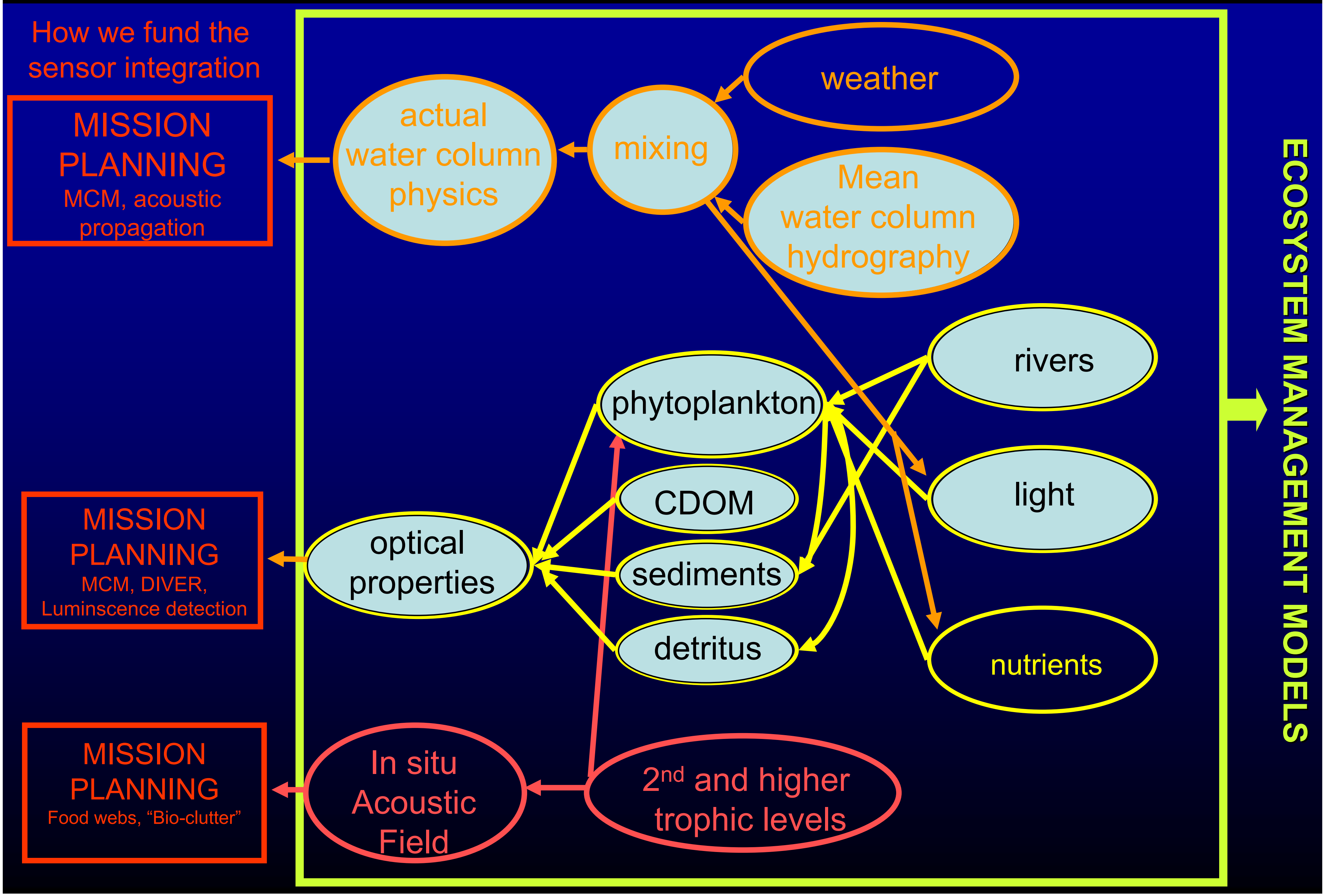
Oregon State University Collaboration

ChiPod attached to glider for 1 and 18 day missions



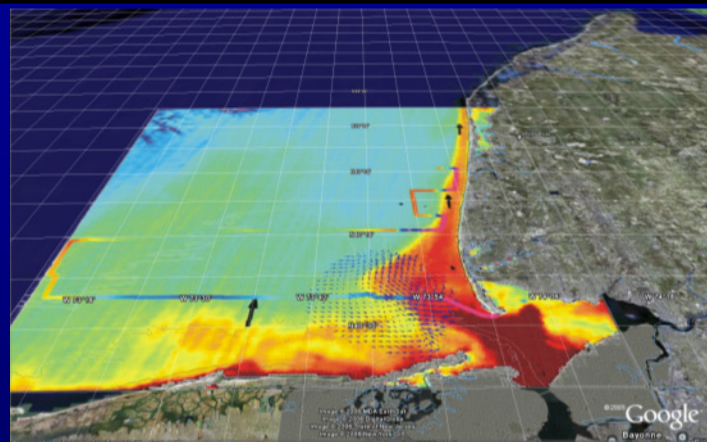


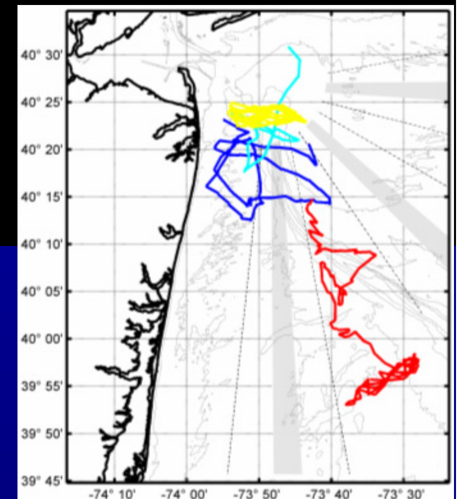
Gliders will be used to assist numerous applied mission planning and simultaneously provide the first subsurface network capable of enabling ecosystem management

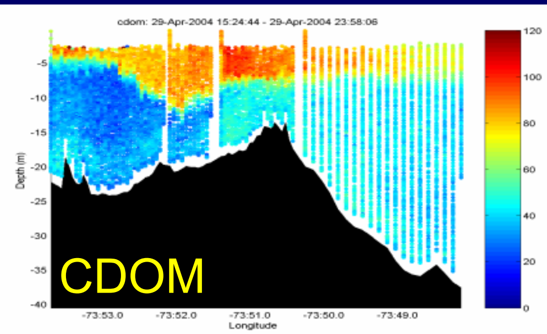


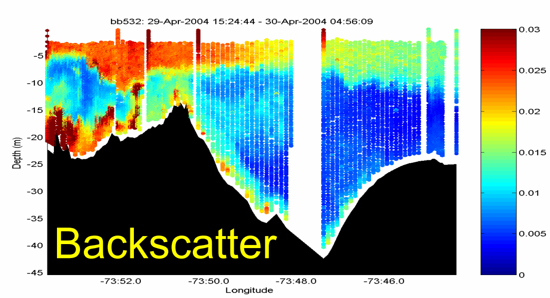
RIVERS

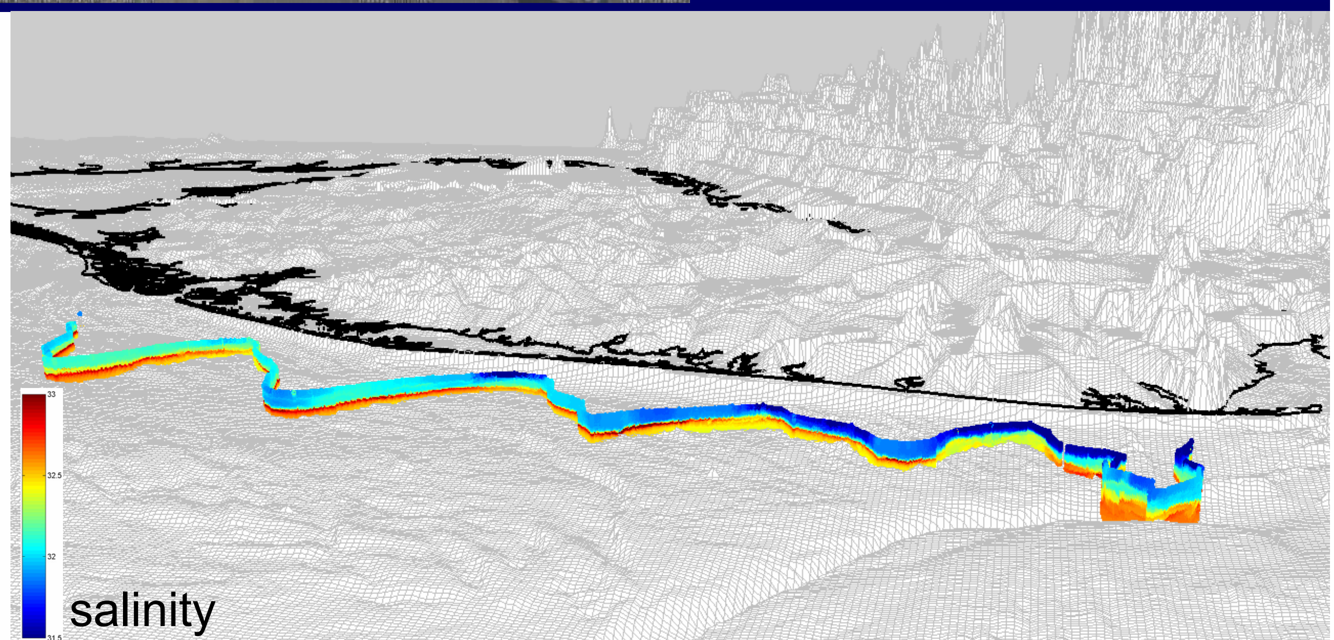
NSF's LaTTE – Under transports and transformations of Hudson River Plume



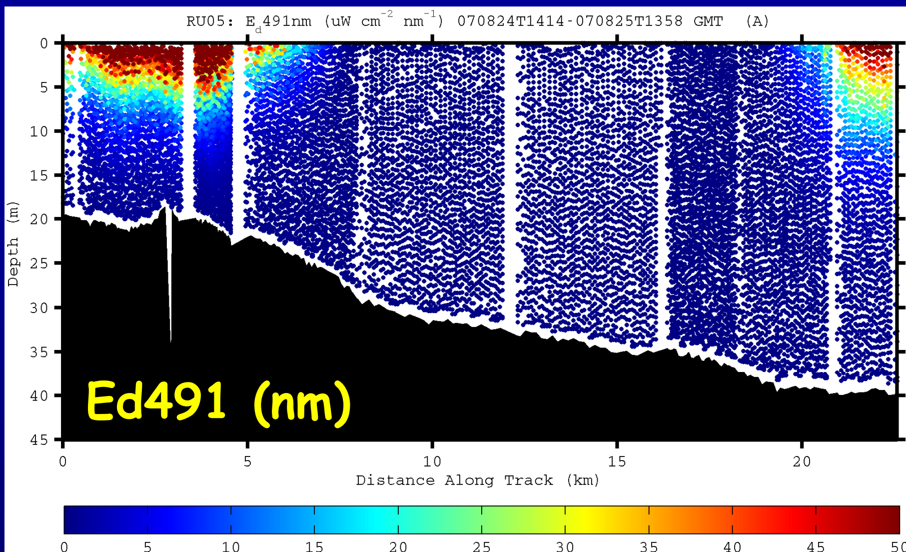


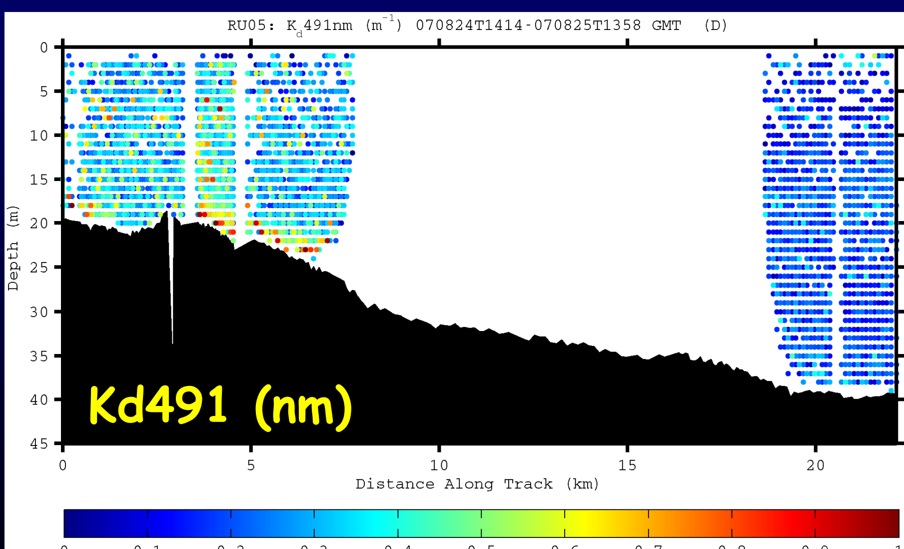


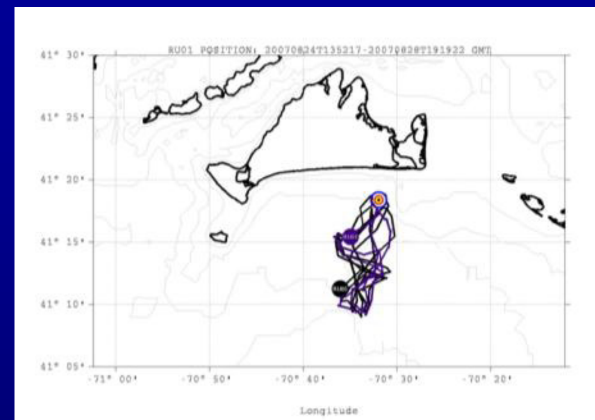




Light: ONR's OASIS experiments at Martha's Vineyard (spectral downwelling irradiance, and the apparent optical properties)

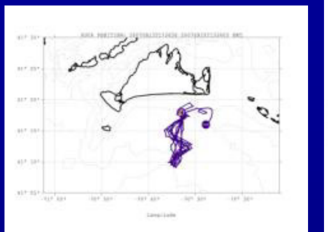




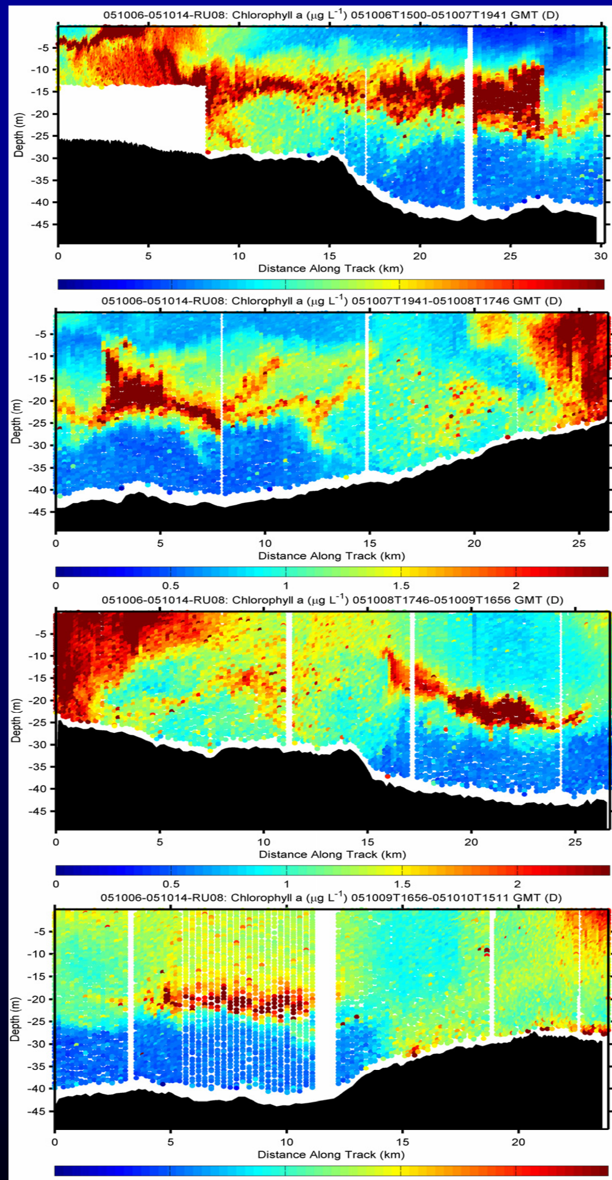


Phytoplankton: ONR's HyCODE & OASIS and NSF's EcoHAB programs (bulk phytoplankton and phytoplankton composition)

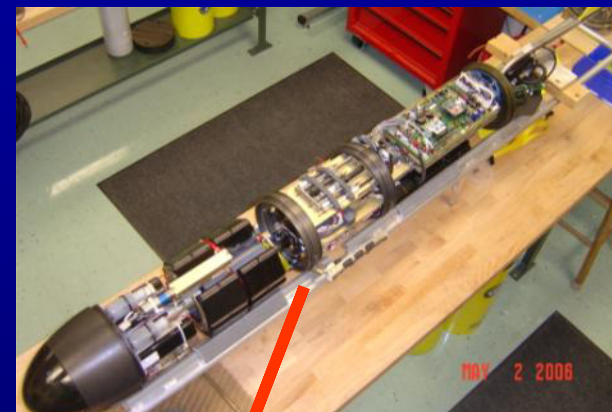
Phytoplankton biomass

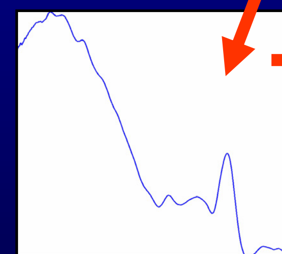


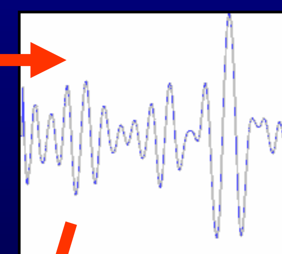
Phtyoplankton response
To passage of
Nor'Easter
storm

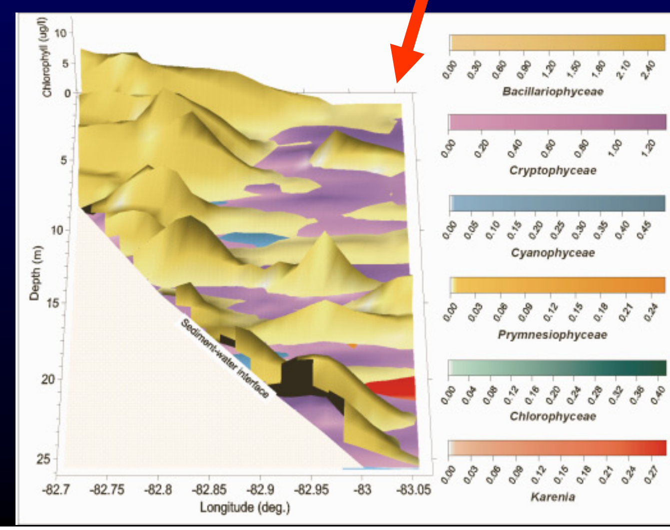


Phytoplankton communities

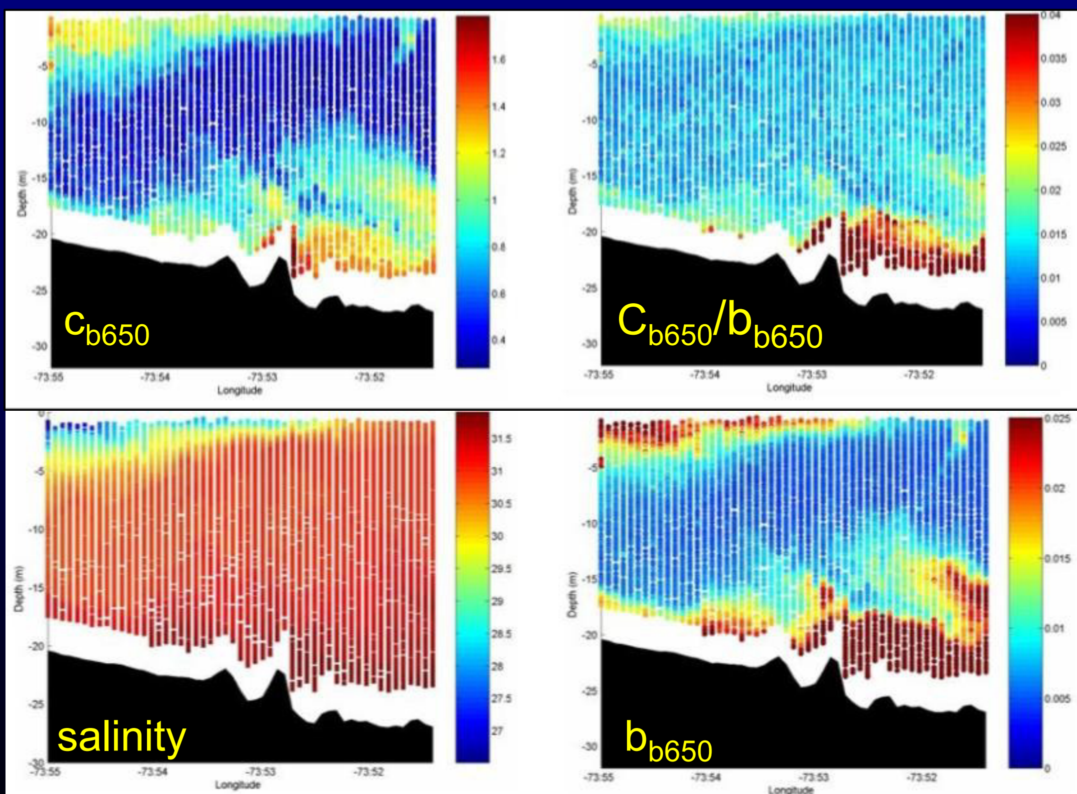




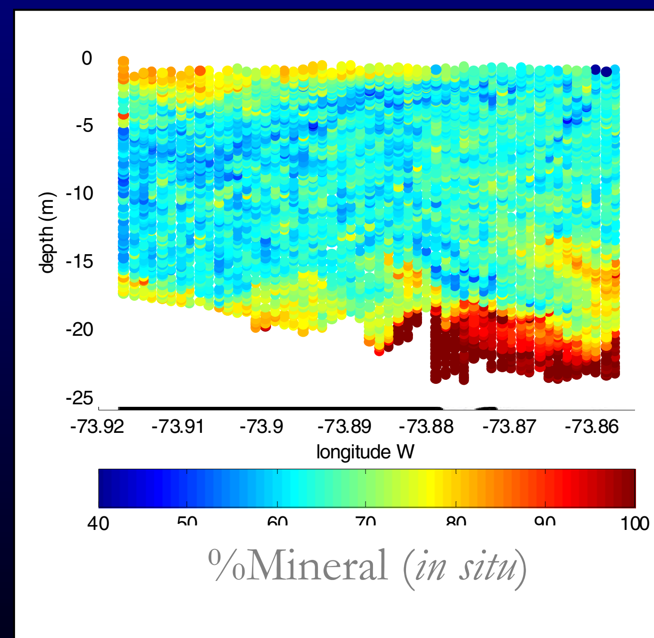




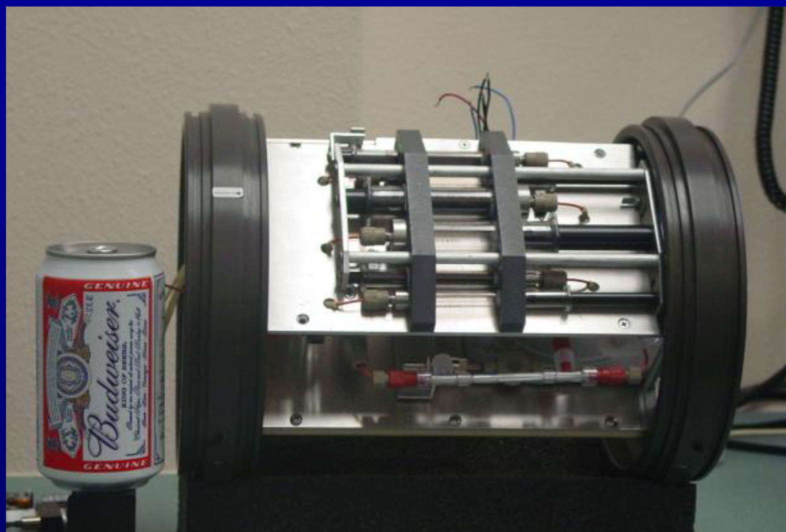
Sediment: ONR's OASIS and MIREM programs focused on refining understanding of nepheloid layers and importance of storms

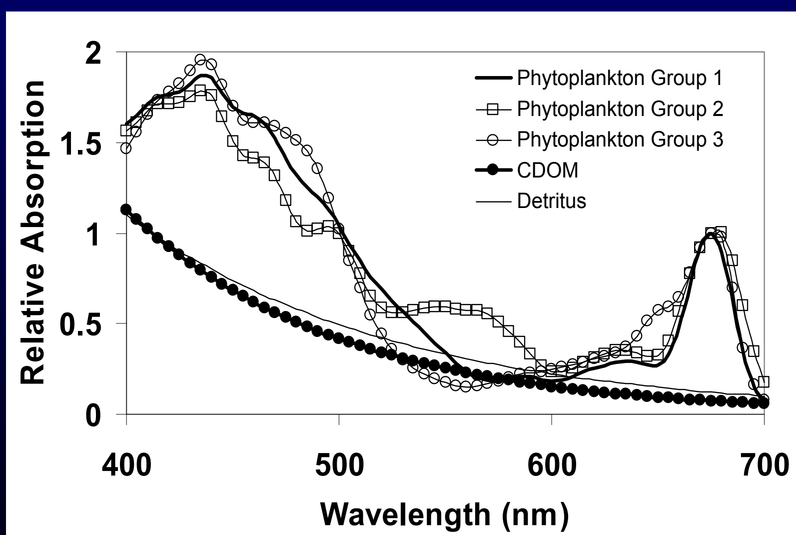


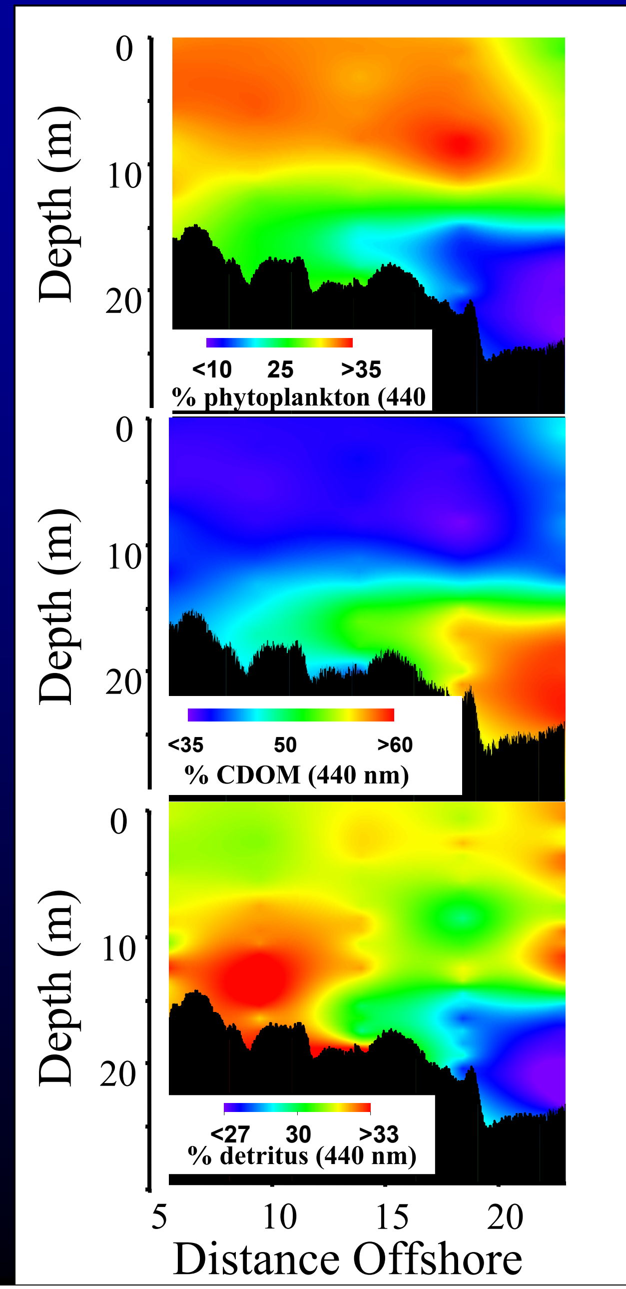
Empirical algorithms



Detritus: With the availability of hyperspectral absorption invert the detrital optical load using techniques developed for ac-9 (ONR HyCODE)







Phytoplankton

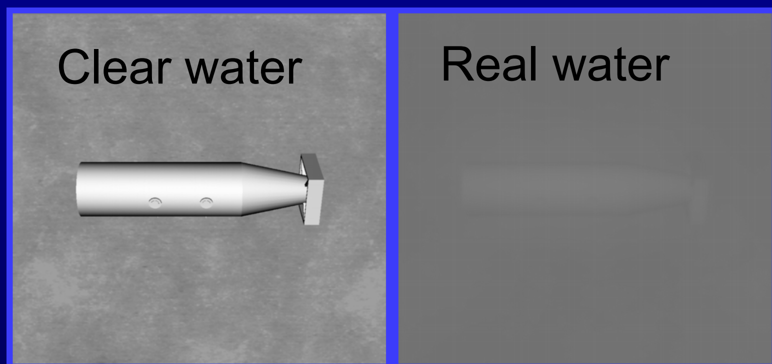
CDOM

Detritus

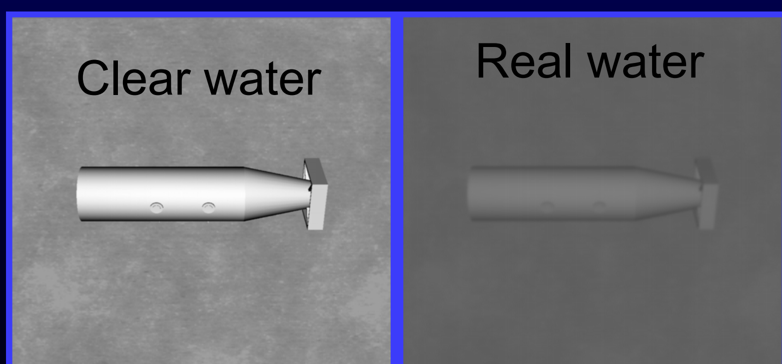
ONR MIREM experiments: The combination of optical parameters can be used to define optically-based mission planning models

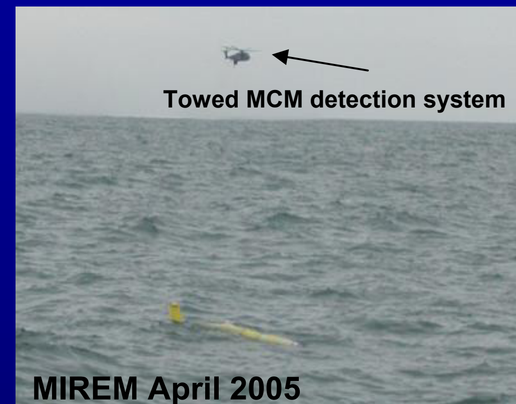
The Problem: What can you see?
Helicopter or diver….

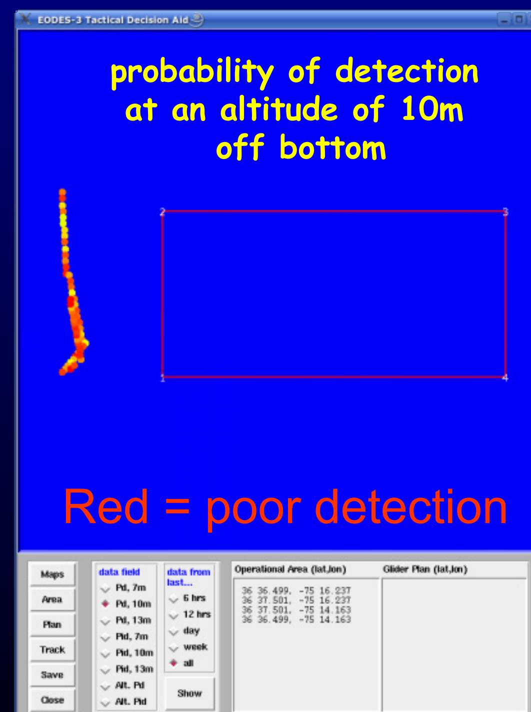
April 24, 2005



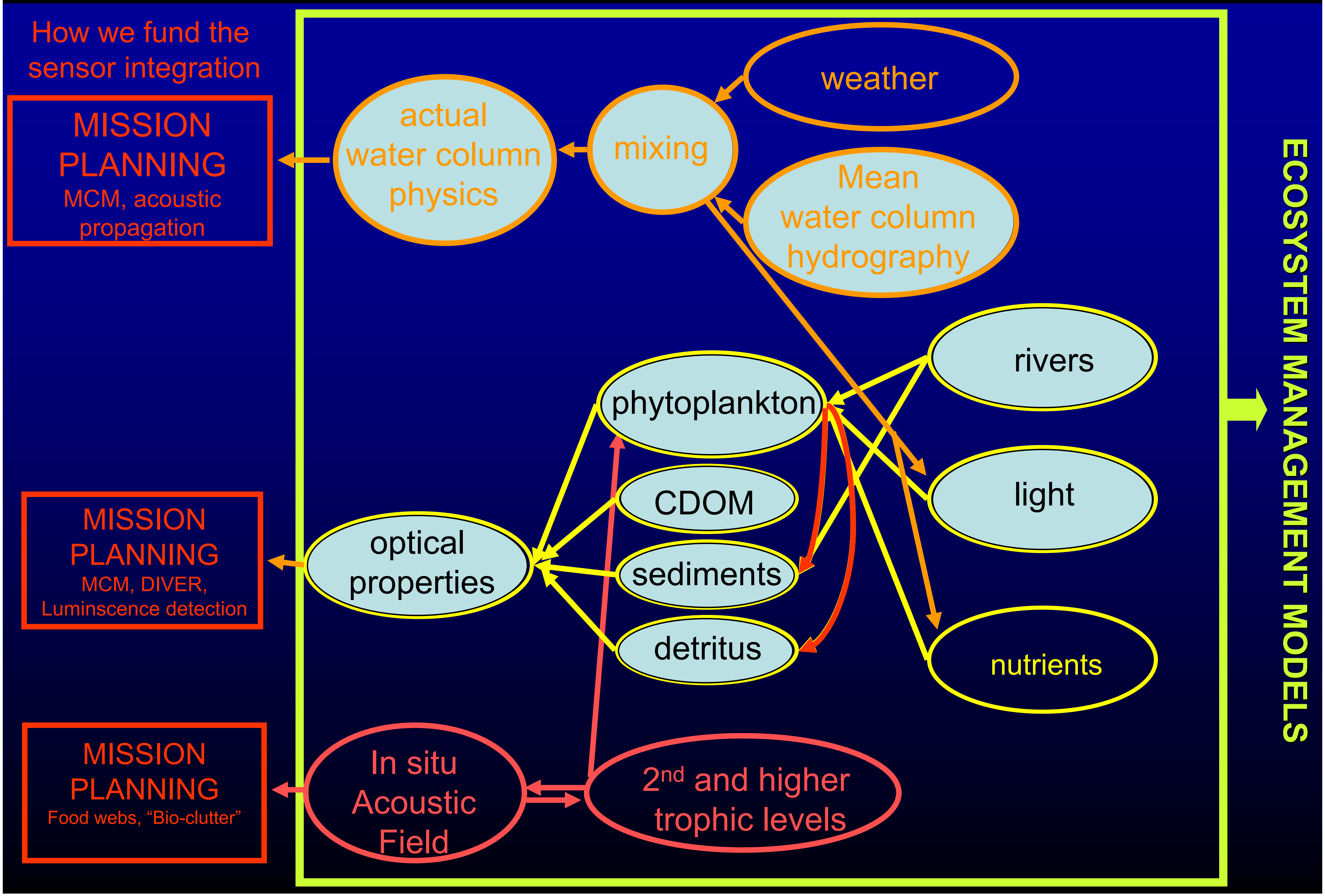
April 26, 2005





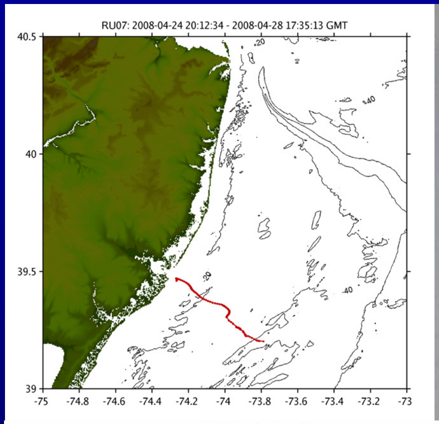


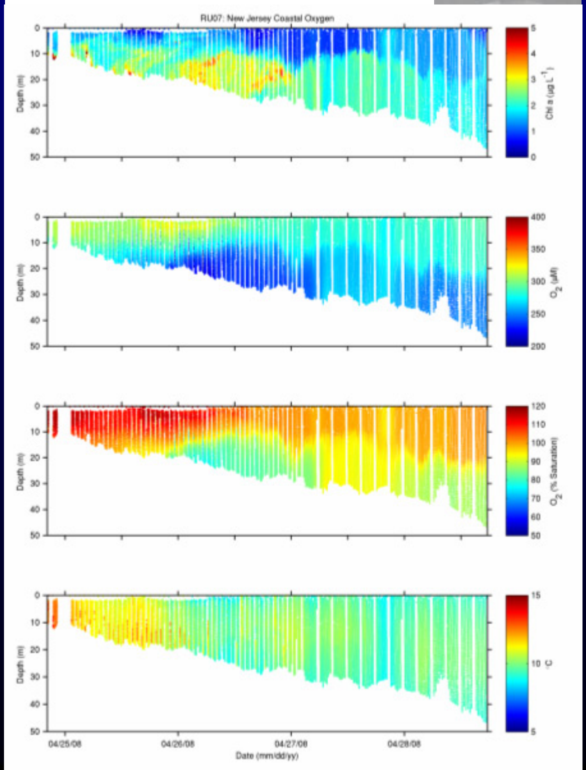
Gliders will be used to assist numerous applied mission planning and simultaneously provide the first subsurface network capable of enabling ecosystem management



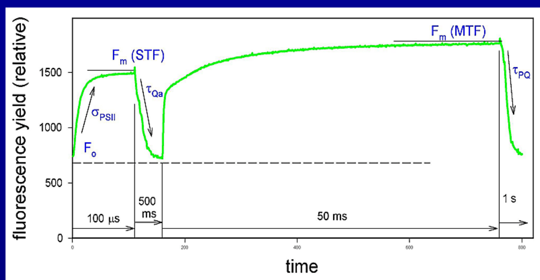
Going after biological rates: Oxygen concentration and potentially production over time

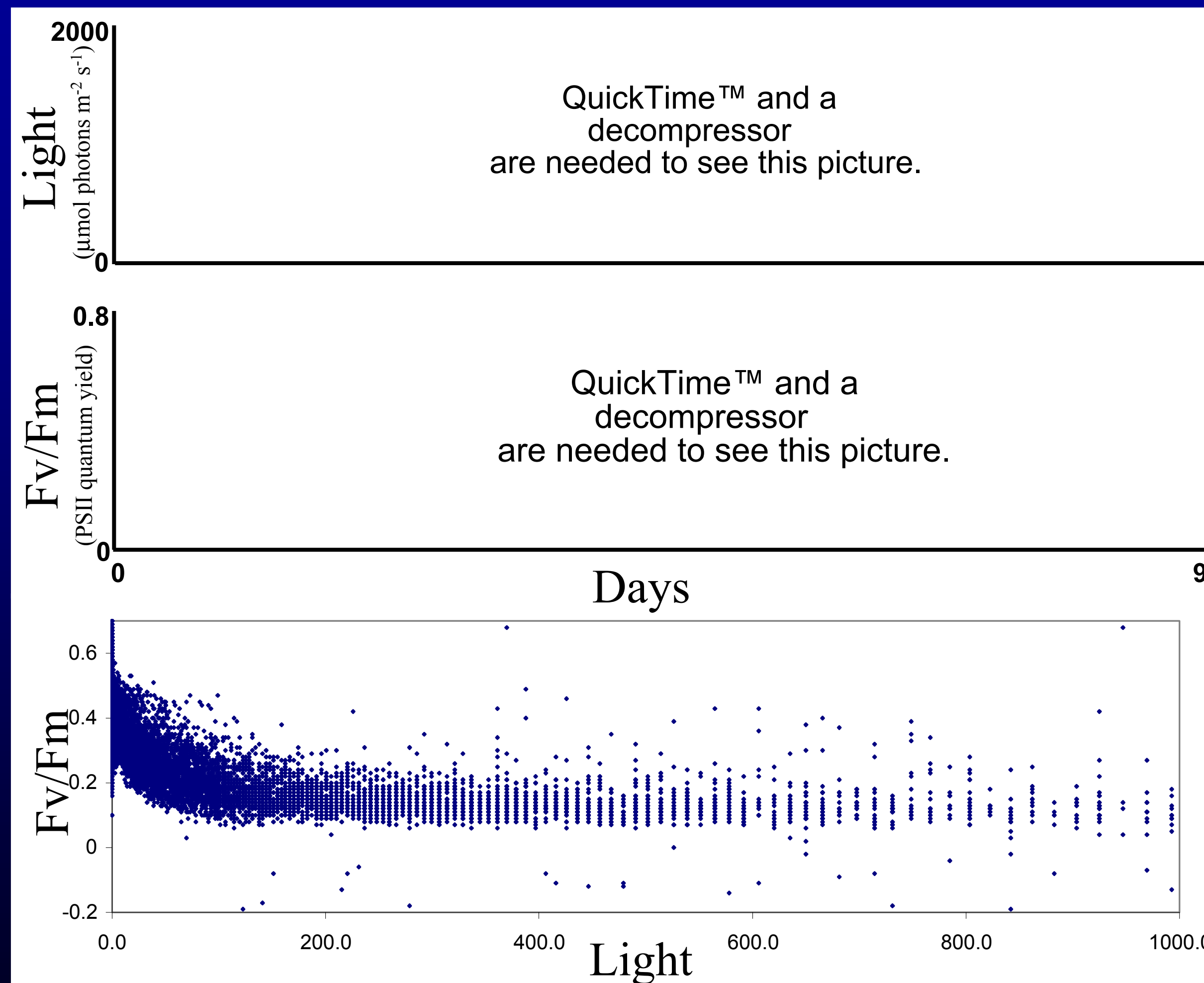
Oxygen



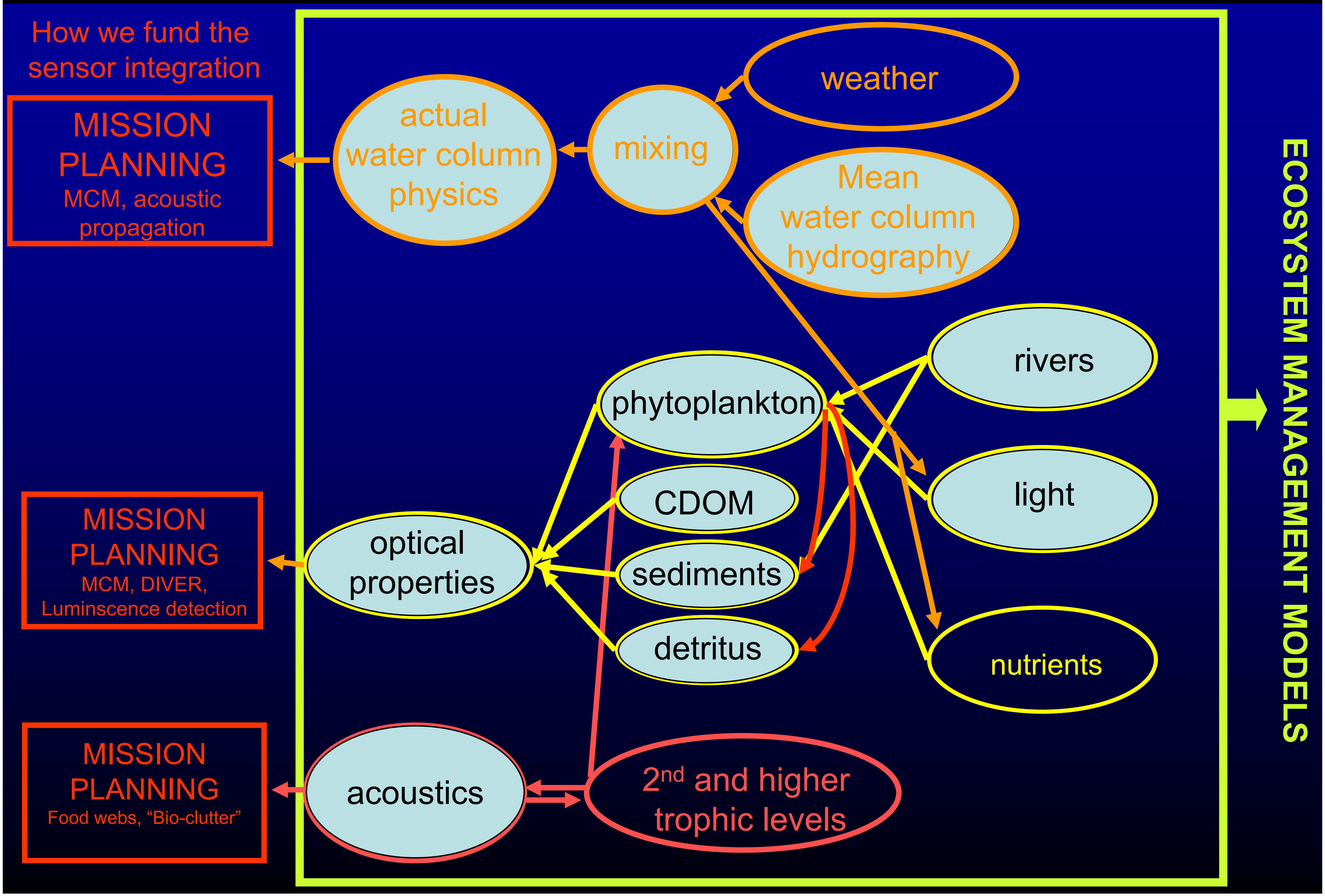


Going after biological rates: Phytoplankton photosynthesis and physiological state
Week of July 10, 2009 FIRe glider demonstrated in NJ test bed

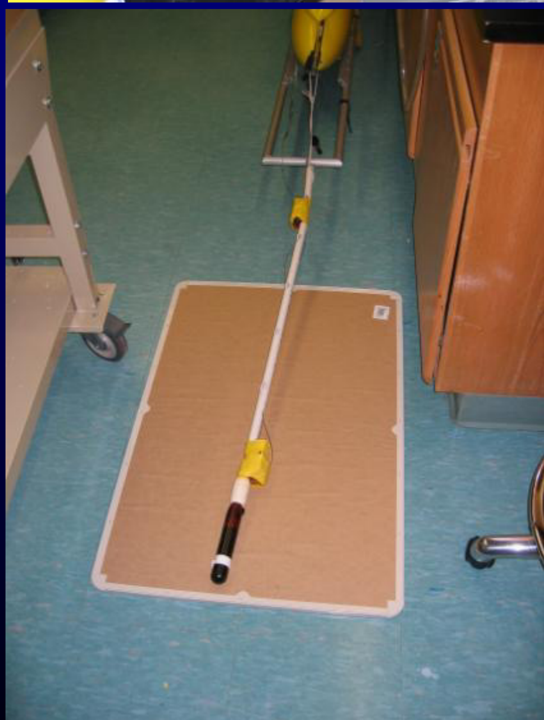




Gliders will be used to assist numerous applied mission planning and simultaneously provide the first subsurface network capable of enabling ecosystem management



Proposed location but vibrations from glider contaminated acoustic signals



- June ’06 URI visits Rutgers with hydrophone
- August ’06 Hydrophone attached to glider for 15 minute segment
- Sept. ’06 Hydrophone attached to glider for 14 day mission
- April ’07 URI visits Rutgers for two days of experiments to test beam forming capability

Final configuration with hydrophone towed behind glider with no rigid connection between the two

Future focus areas will be on recording marine sounds with specific focus on higher trophic levels.

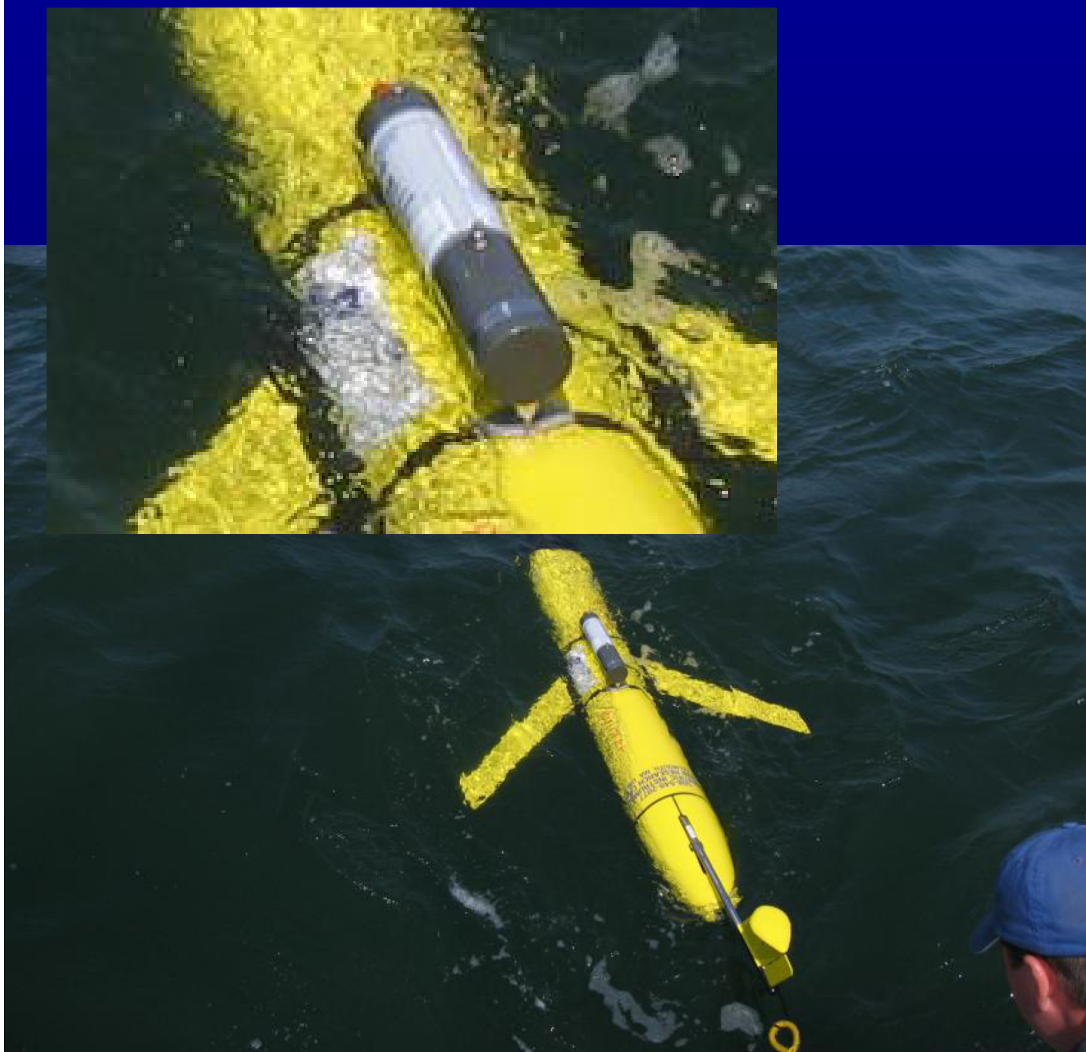
UNIVERSITY OF Rhode Island

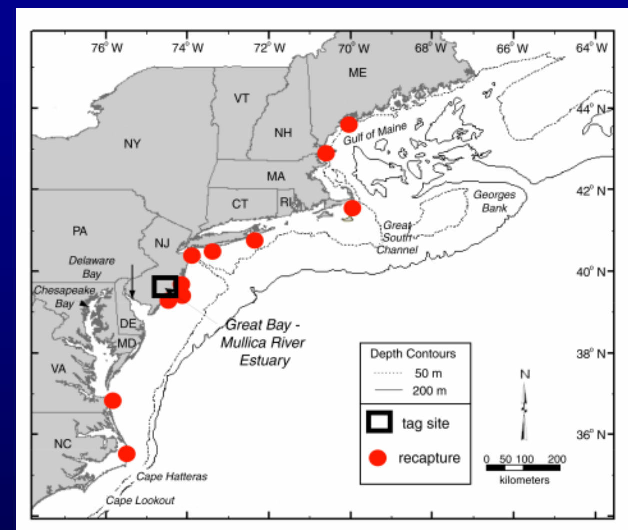
RUTGERS MARINE & COASTAL SCIENCES

External Modular Sensors

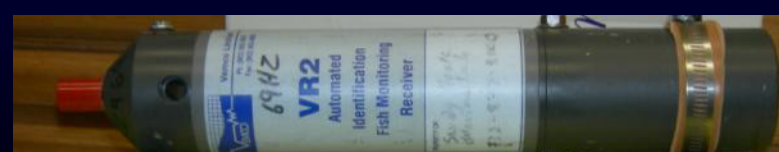
NOAA National Marine Fisheries Service (NMFS) Collaboration

Vemco "Fish Finder" Attached to glider for 1 and 12 day missions





160 Acoustic pings
from transmitter
over 2 hour period



Currently gliders are being outfitted with RDI Explorer ADCP, focus on currents, bottom tracking and zooplankton

1) The sensor

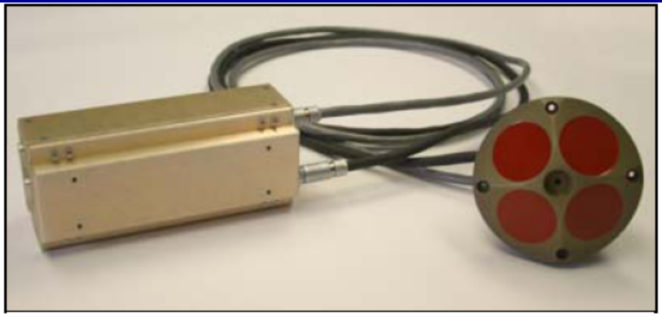


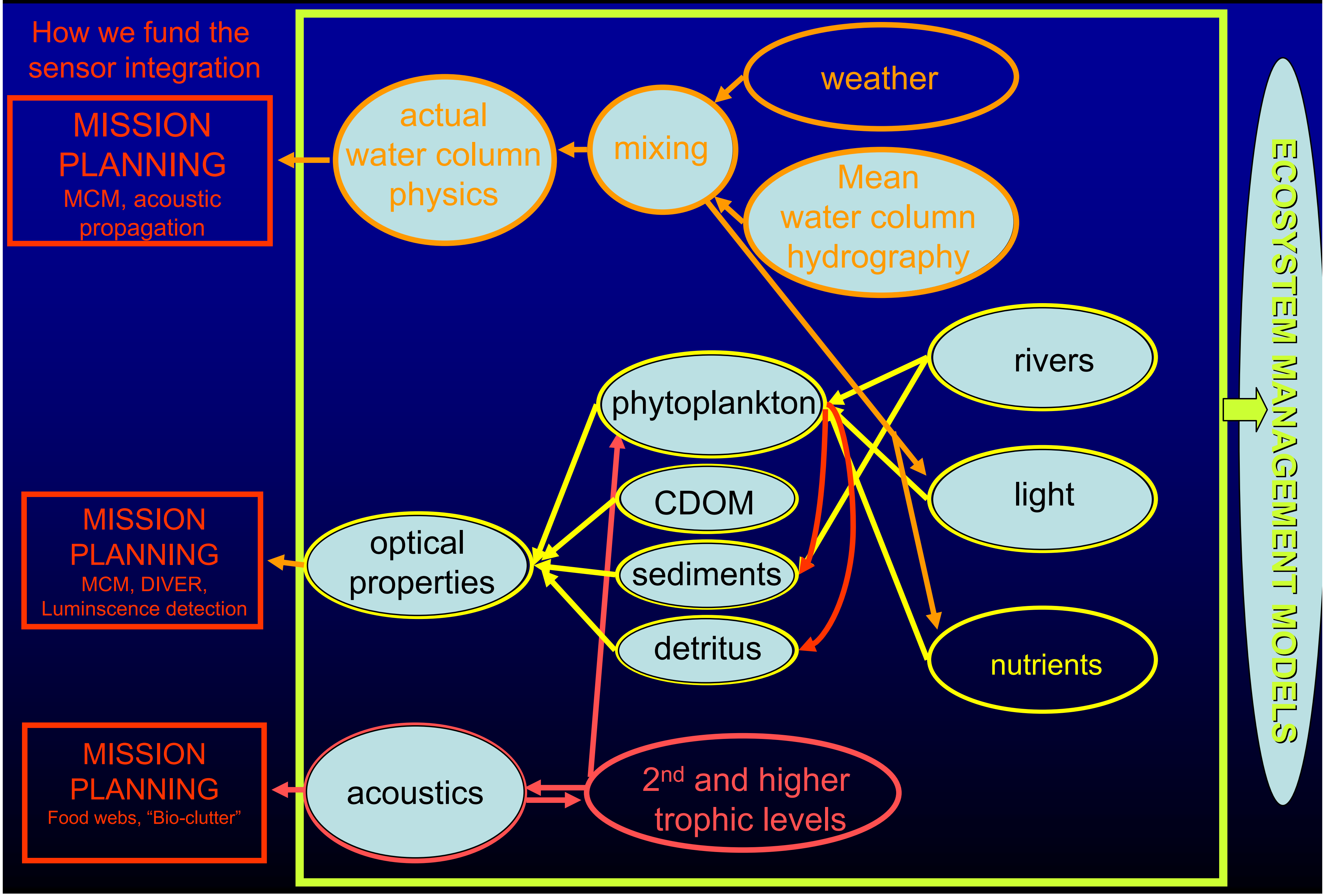
Figure 1: TRDI Explorer DVL

Bottom Tracking	Phased Array	Piston
Maximum Altitude[1]	75m	65m
Minimum Altitude	0.5m	
Velocity Range[2]	± 5m/s	
Long Term Accuracy	± 0.4% ± 0.2cm/s	
Precision[3] @ 1 m/s	± 1.2cm/s	
Resolution	0.1cm/s (default), 0.01mm/s (selectable)	
Ping Rate	7Hz Typical	
Water Profiling		
Maximum Range[1]	30m	20m
Minimum Range	0.7m	
Velocity Range[2]	± 5m/s	
Long Term Accuracy	± 0.75% ± 0.2 m/s	
Precision[3] @ 1 m/s	± 6cm/s	
Resolution	0.1cm/s	
Ping Rate	7Hz Typical	
Acoustic		
Sound Pressure Level	213dB re 1uPa@1m	205dB re 1uPa@1m
1-Way Beam Width (Typical)	2.4°	3.3°
Center Frequency	614.4kHz	
Number of Beams	4	
Beam Angle	30°	
Environmental		
Maximum Operating Depth	100 m	300 m
Operating Temperature	-5°C to 40°C	
Storage Temperature	-25°C to 60°C	
Vibration & Shock (transport)	IEC 60721-3-2, 2nd Ed, 1997-3	
Vibration (operational)	IEC 60945, 4th Ed, 2002-8	

2) Expanded glider payload capacity

320 Alkaline C-cells versus 230

Gliders will be used to assist numerous applied mission planning and simultaneously provide the first subsurface network capable of enabling ecosystem management



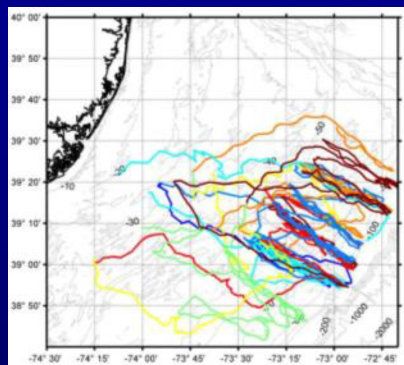
Modeling assimilative efforts will require many gliders carrying different sensors, thus they must fly as a swarm. Also the gliders swarms must be distributed to the span regional scales relevant to ecosystems

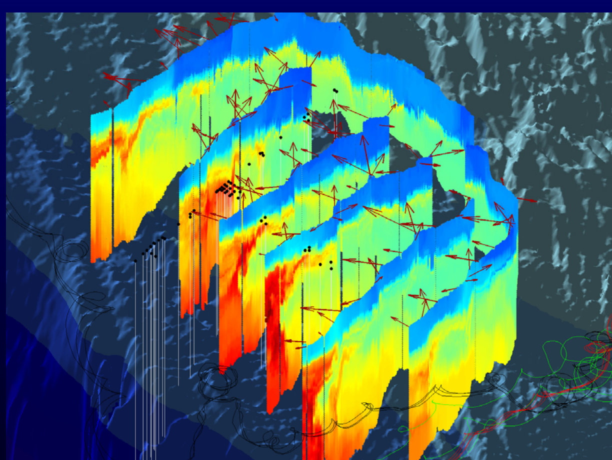
The Ongoing development of Darwin Clusters (ONR SW06, MURI and Moore Foundation)

Flying swarms is doable

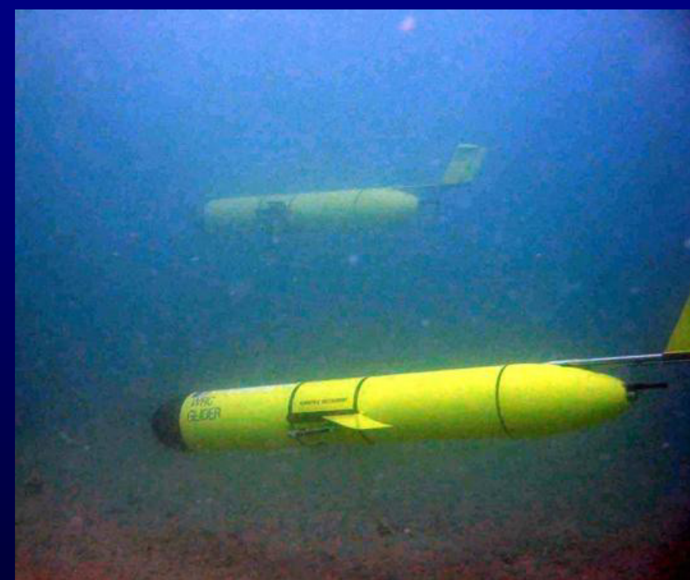
SW06 Glider Statistics

- Deployments: 17
- Km Flown: >6,500
- CTD Profiles: >51,000
- Calendar Days: 93
- Glider Days: 360





Gliders flying a distributed sensor net collecting coherent data with a Darwin Cluster (Antarctic 2010)



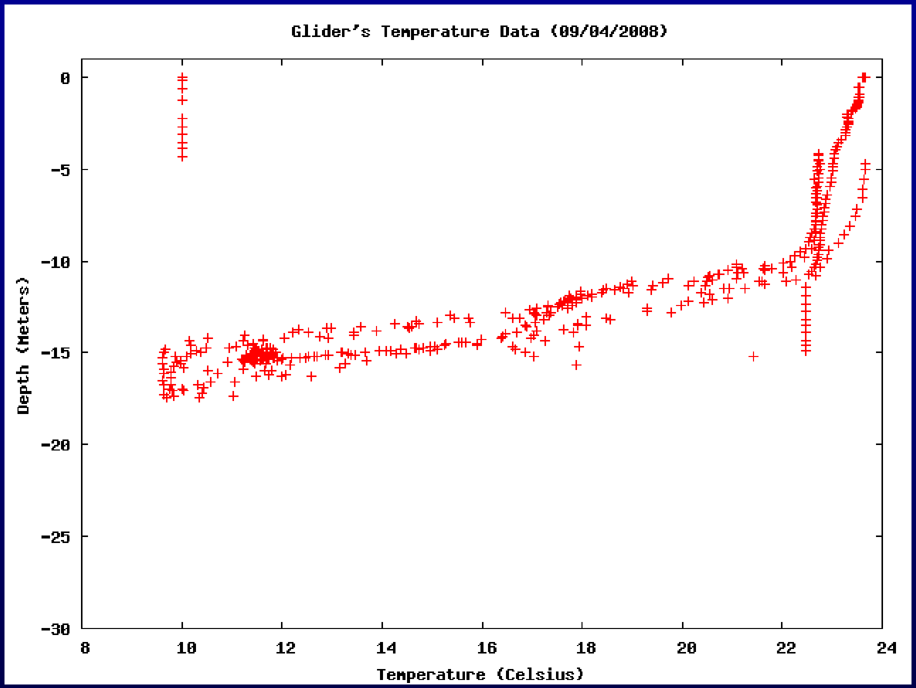
Glider 1; 1000m, physics and optics

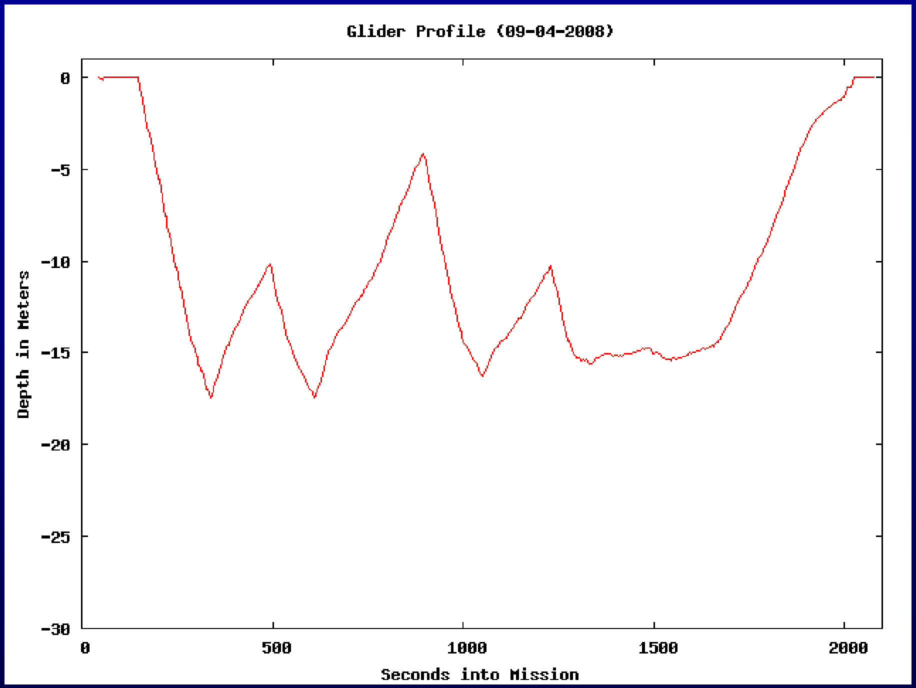
Glider 2; 200m, phyto biomass & metabolism

Glider 3; 200m, active & passive acoustics

For a global footprint and fleet of gliders it would be nice for them to be smart: development of the glider brain, feature tracking

Thanks to Kremer et al . (Rutgers) & NSF Computer Sciences Directorate



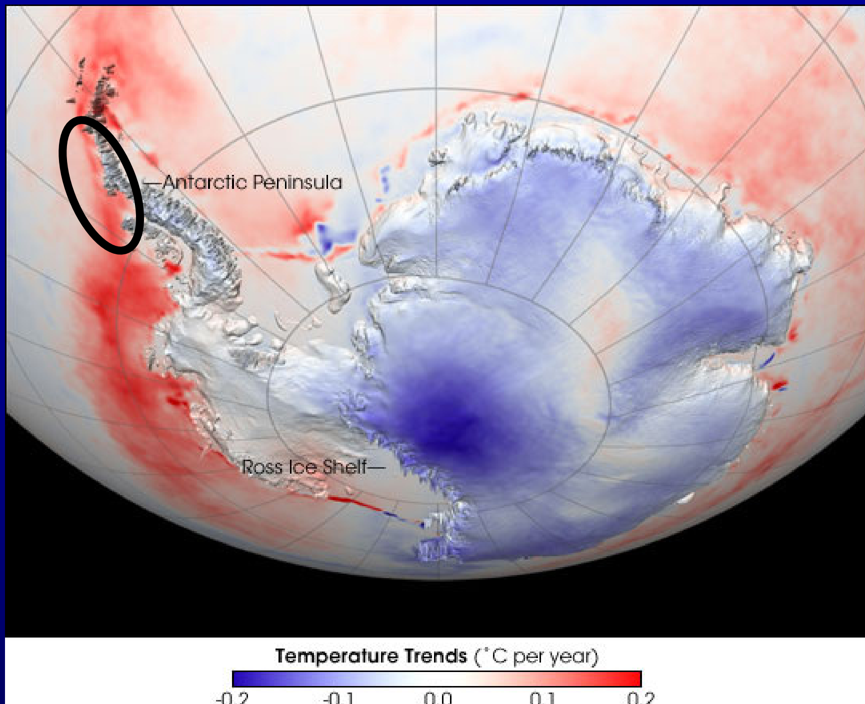


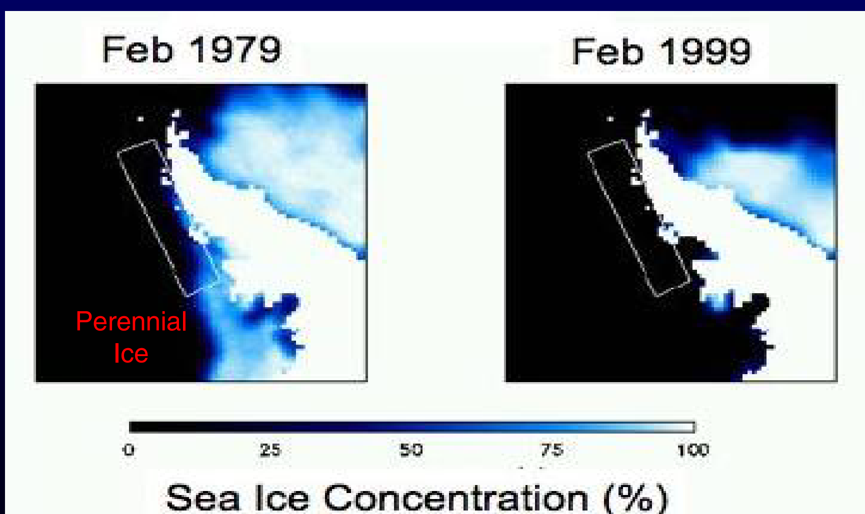
Here glider looked at its own data to make a decision underwater on its own.

The glider brains will be key to provide adaptive sampling of ocean features of high science priority

Future extreme missions in the Poles: Deployments to begin in November 2008

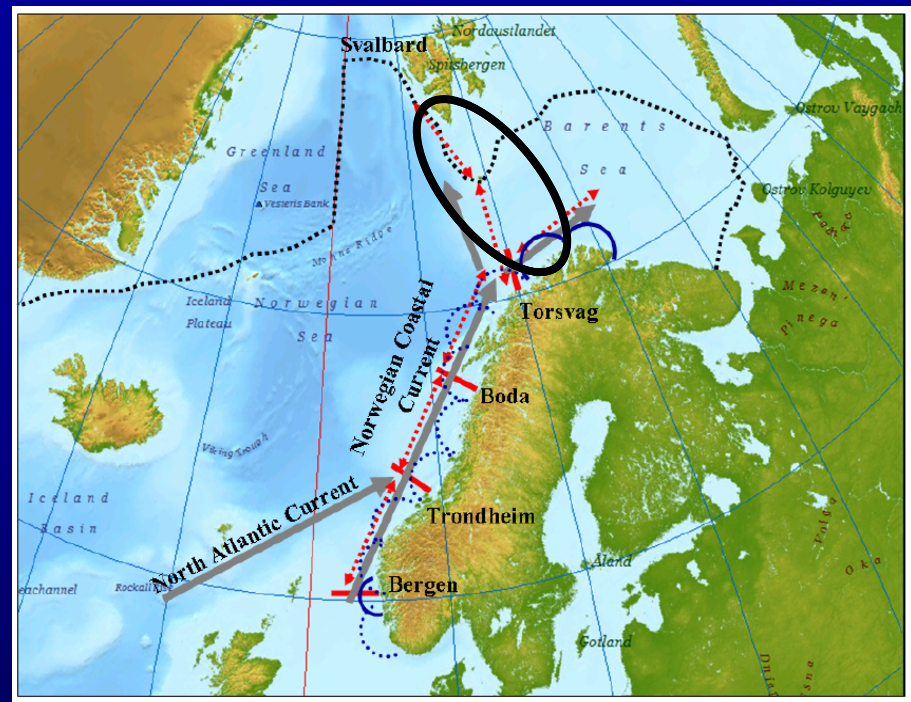
ANTARCTIC (US & England)

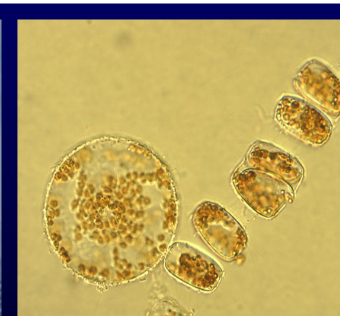


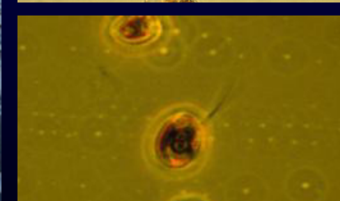


Funded by NSF LTER program & Gordon Betty Moore Foundation

ARCTIC (US & Norway)

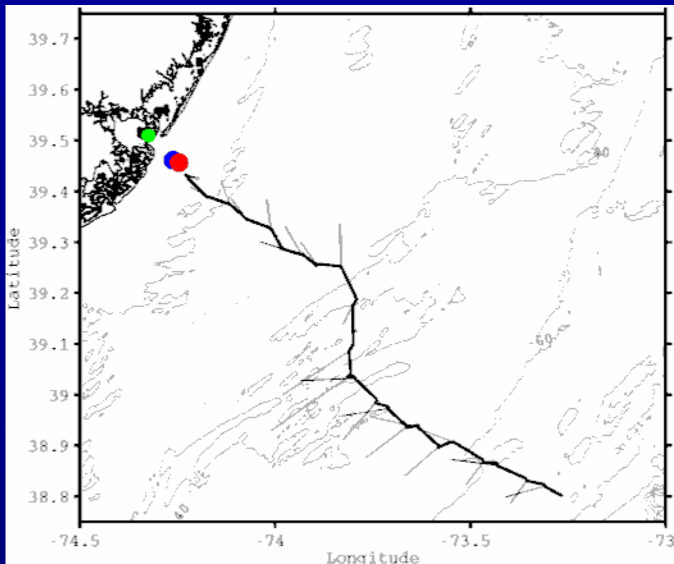


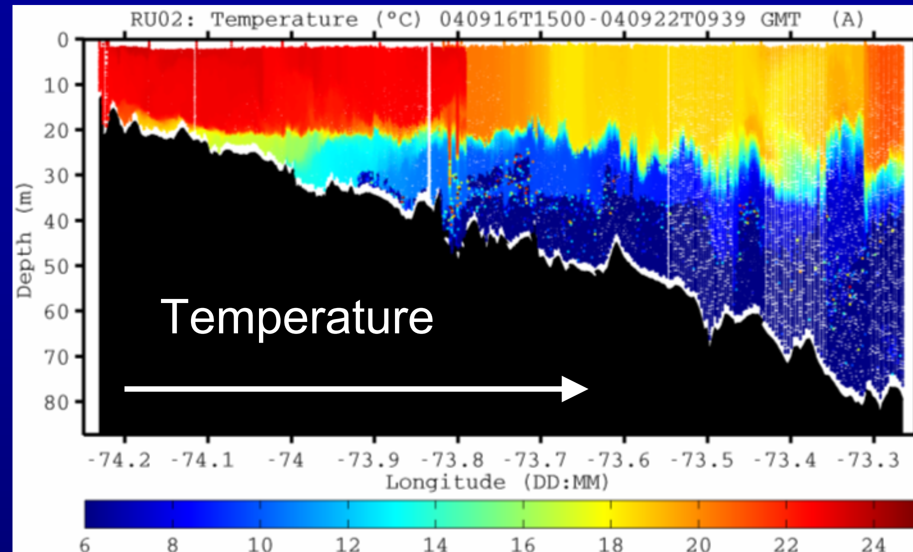


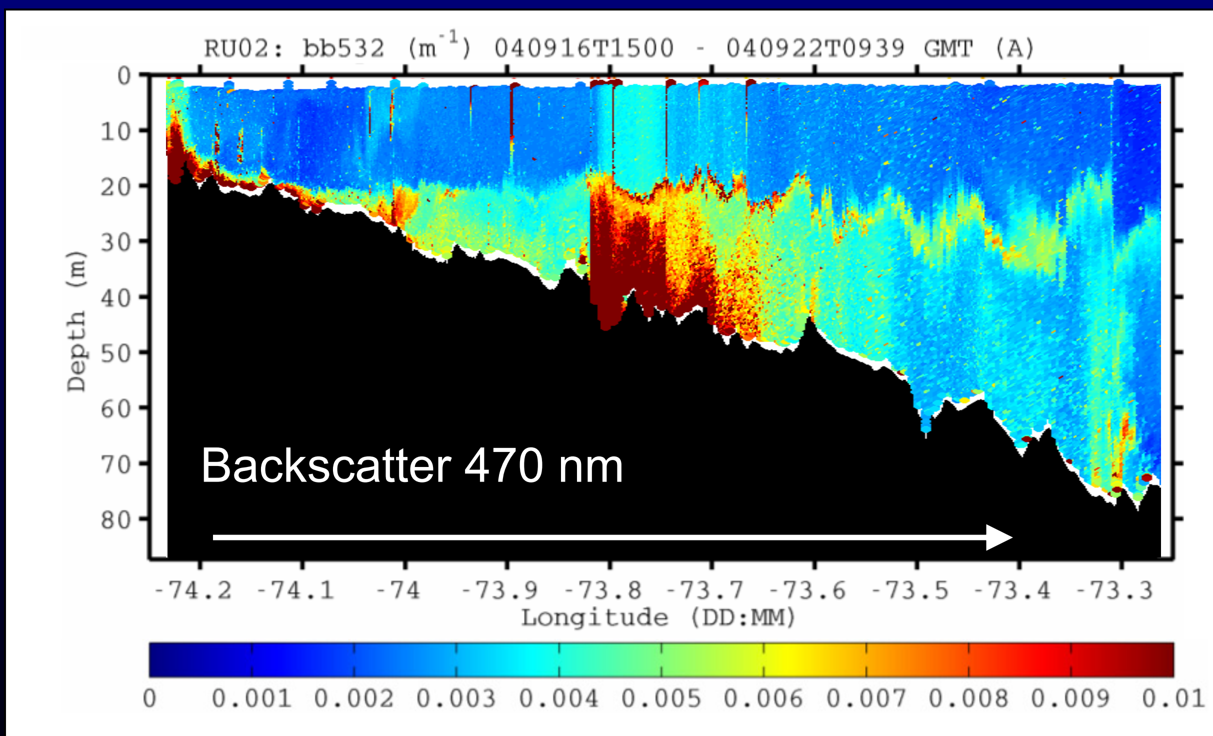


Funded by Norwegian Government Technical Fund

Hurricane Ivan – September, 2004 – Mid-Shelf



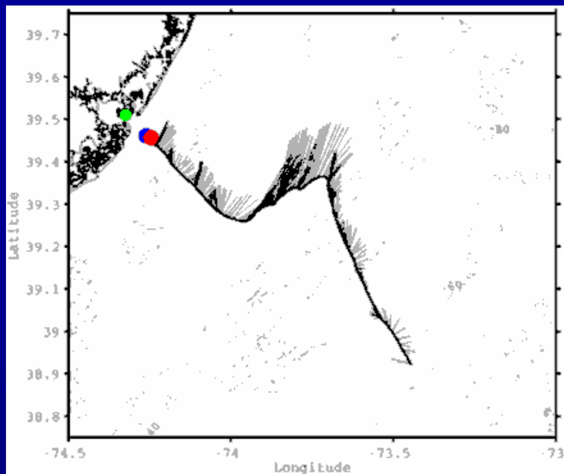


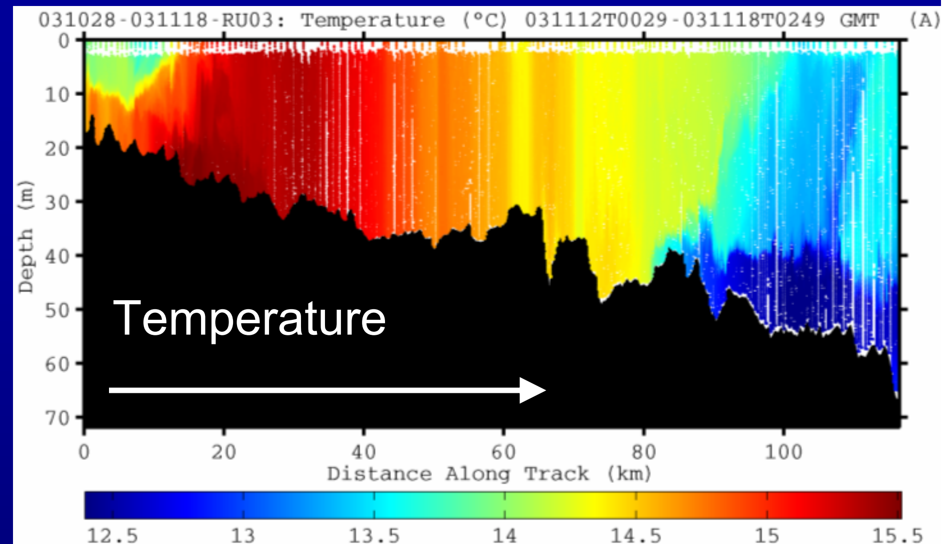


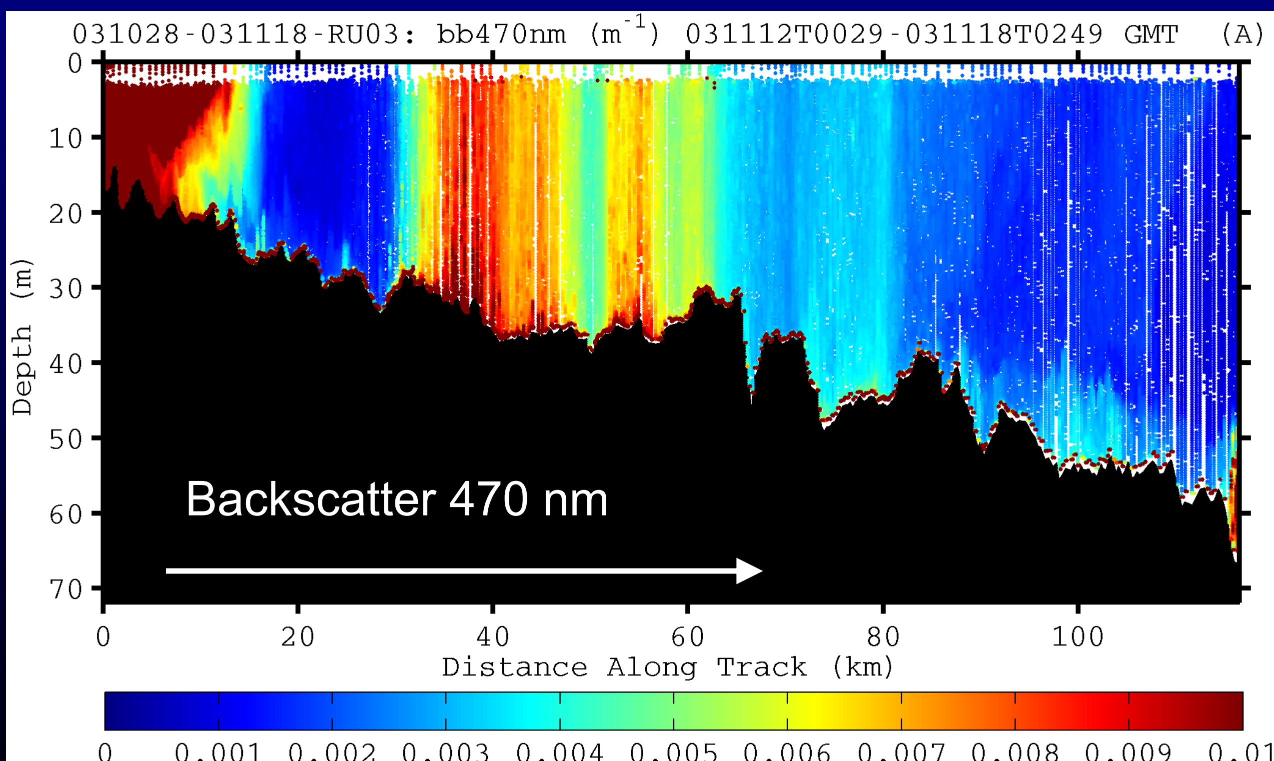
Delaware Bay Buoy

Storm Peak Conditions
Wind Speed = 16 m/s
Wave Height = 3.8 m
Peak Period = 8 s

Northeaster – November 2003

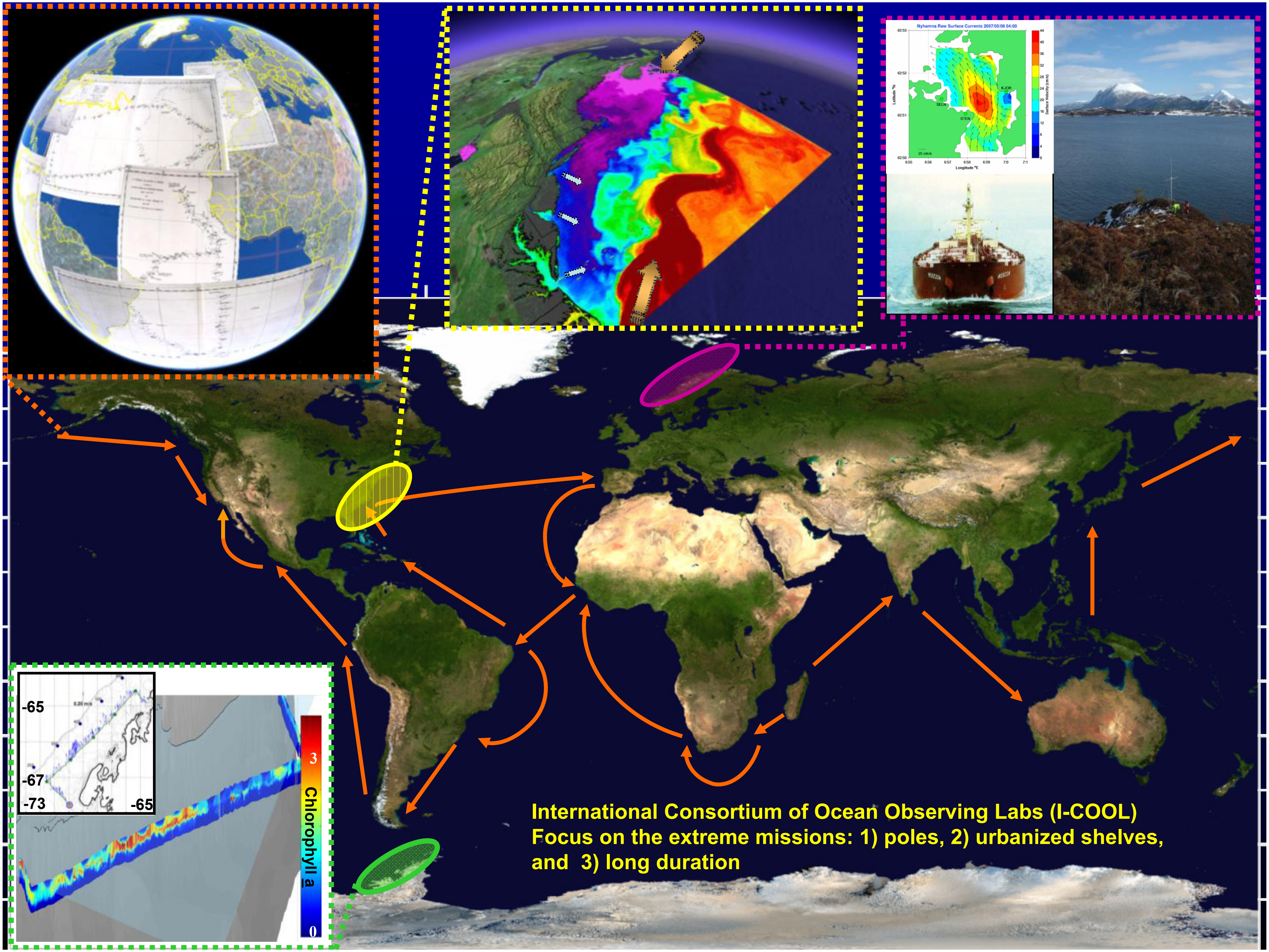






Delaware Bay Buoy

Storm Peak Conditions
Wind Speed = 18 m/s
Wave Height = 3.2 m
Peak Period = 6 s


Nyhamna Raw Surface Currents 2007/05/08 04:00
-65
-67
-73
-65
3
Chlorophyll a
0
International Consortium of Ocean Observing Labs (I-COOL)
Focus on the extreme missions: 1) poles, 2) urbanized shelves,
and 3) long duration

Challenges, many expected…..more unexpected.
The adventure will continue in the coming hours and days

Glider publications (from proof of concept to science)
http://rucool.marine.rutgers.edu

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Glenn, S., Schofield, O., Dickey, T. D., Chant, R. Kohut, Barrier, H., Bosch, J., Bowers, L., Creed, E., Haldeman, C., Hunter, E., Kerfoot, J., Mudgal, C., Oliver, M., Roarty, H., Romana, E., Crowley, M., Barrick D., and Jones C. 2004. The expanding role of ocean color and optics in the changing field of operational oceanography. Oceanography 17: 86-95.

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Schofield, O., Kohut, J., Aragon, D., Creed, L., Graver, J., Haldeman, C., Kerfoot, J., Roarty, H., Jones, C., Webb, D., Glenn, S. M. 2007. Slocum Gliders: Robust and ready. Journal of Field Robotics. 24(6): 473-485. DOI: 10:1009/rob.20200

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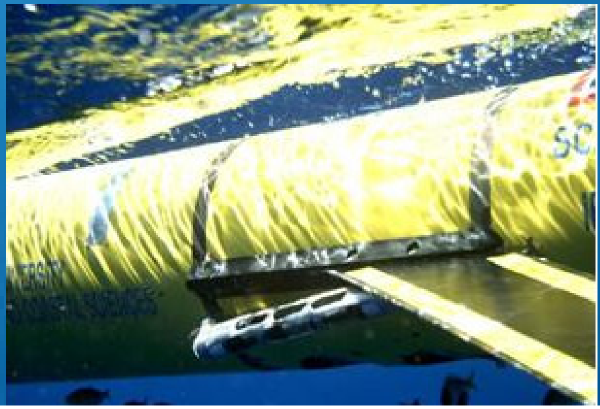
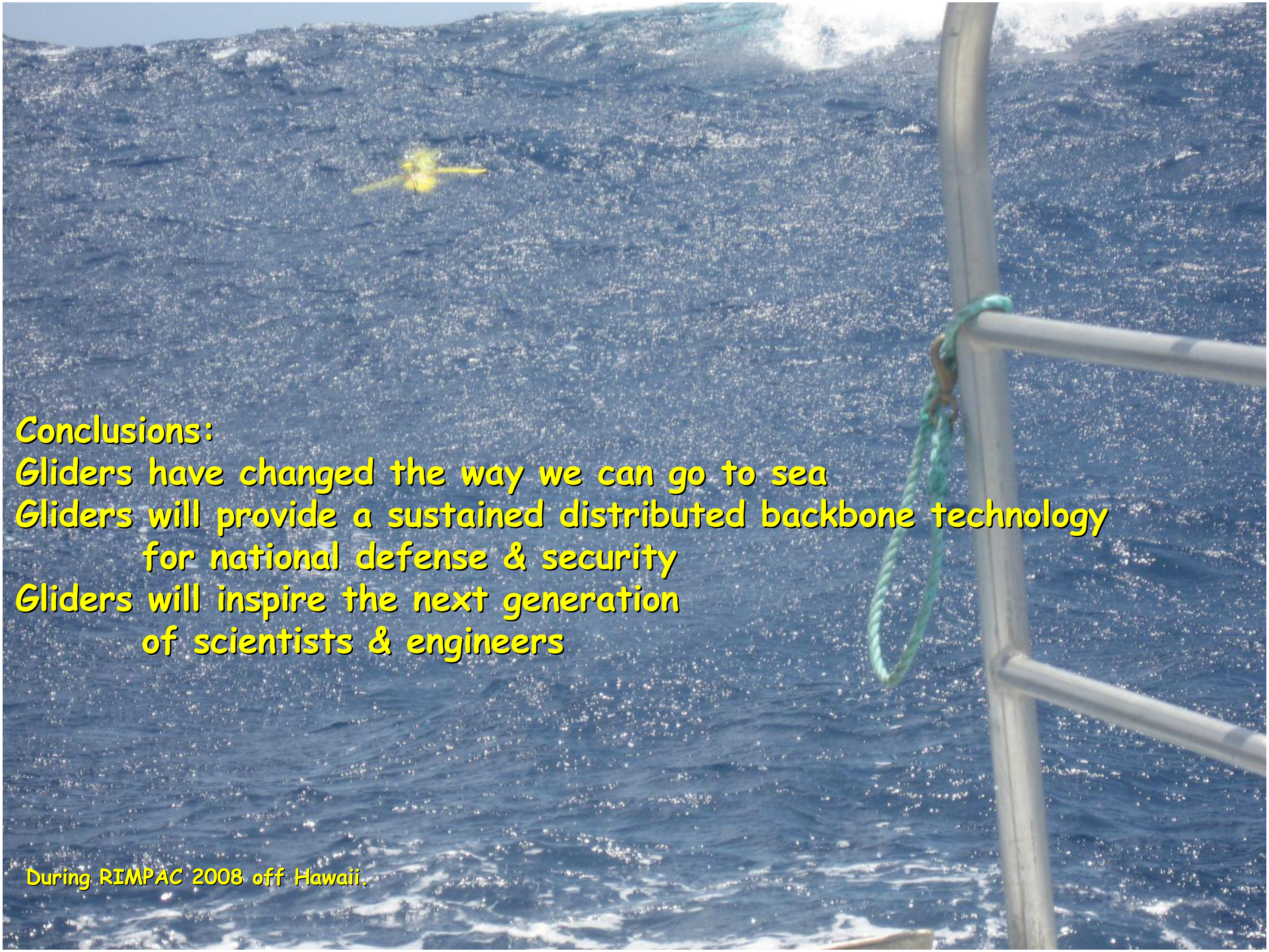
13 peer-reviewed pubs in 6 years
9 more pubs in press or in review
Mean # authors is 7,
<u>very interdisciplinary papers</u>




Conclusions:
Gliders have changed the way we can go to sea
Gliders will provide a sustained distributed backbone technology
for national defense & security
Gliders will inspire the next generation
of scientists & engineers
During RIMPAC 2008 off Hawaii.