# Ocean Modeling and Data Assimilation for the Maritime Industry


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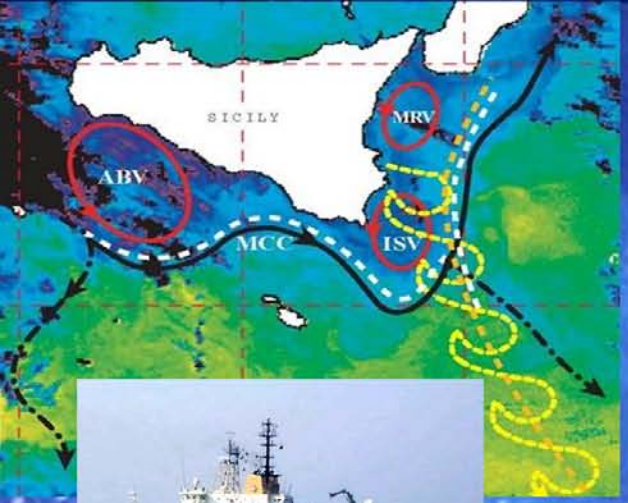
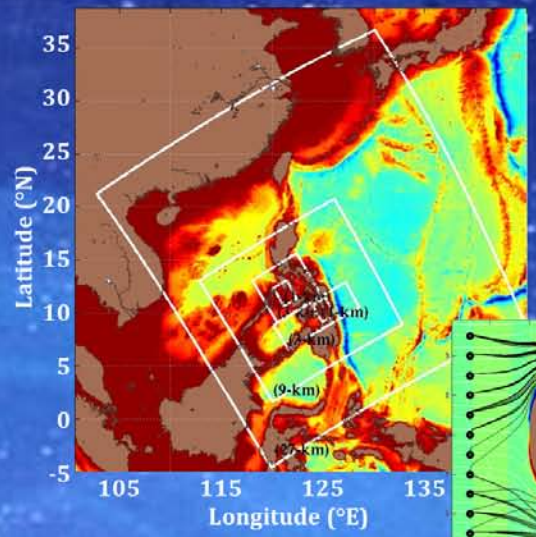
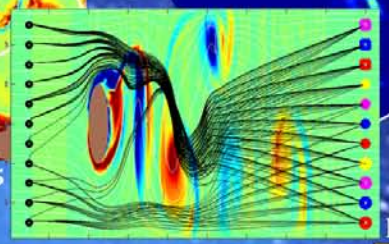
Multidisciplinary Simulation, Estimation and Assimilation Systems (MSEAS)
http://mseas.mit.edu/

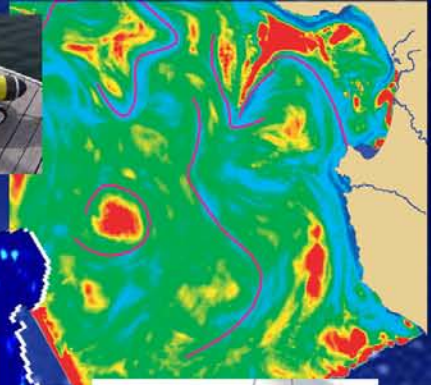


Thanks to MIT, ONR and NSF

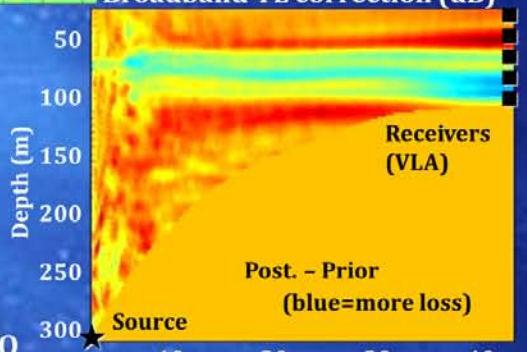








Broadband TL correction (dB)

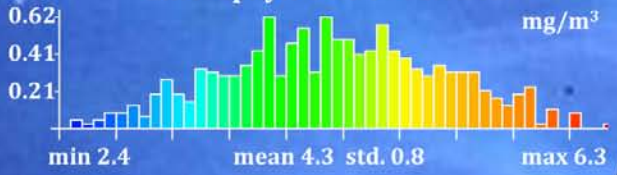



Physics

Biology

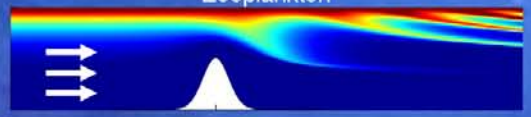
Acoustics

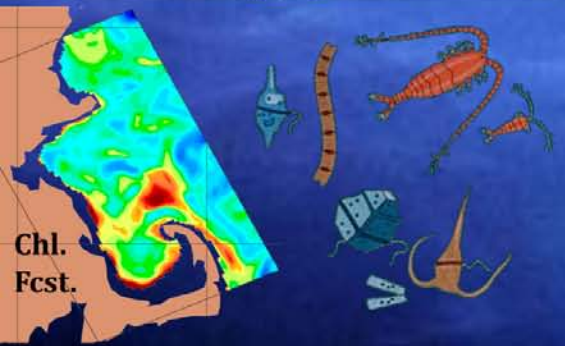
Chlorophyll PDF Prediction



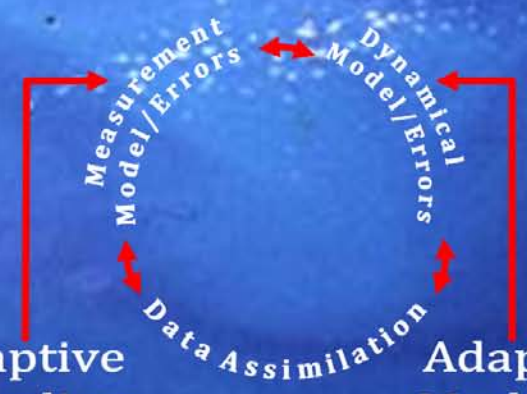

$$\frac{\partial \phi_i}{\partial t} + \mathbf{u}\cdot\nabla\phi_i - \nabla_h(A_i\nabla_h\phi_i) - \frac{\partial K_i\,\partial\phi_i/\partial z}{\partial z} = \mathcal{B}_i(\phi_1,\ldots,\phi_i,\ldots,\phi_j)$$

Zooplankton

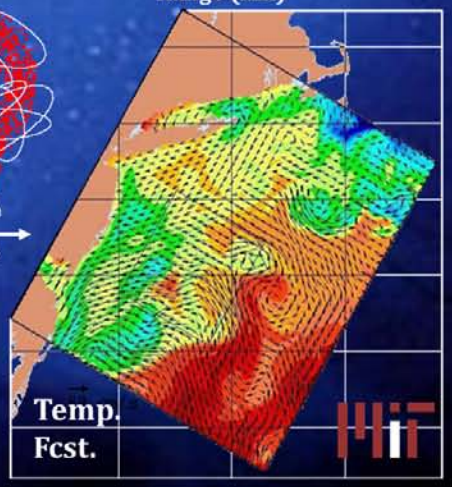




Chl. Fcst.




GMM-DO



Temp. Fcst.

# Our Research Thrusts

## ❖ Numerical Modeling: “The Internal Weather of the Sea”

- Challenge: Develop a new generation of computational regional ocean models, integrating multiscale phenomena and using efficient numerics

## ❖ Uncertainty Quantification and Assimilation Schemes

- Challenge: Quantify and predict uncertainties based on PDEs and reduce these by nonlinear non-Gaussian data assimilation
- Results determine critical observation needs (adaptive sampling, control) and inspire model improvements (model learning or adaptive modeling)

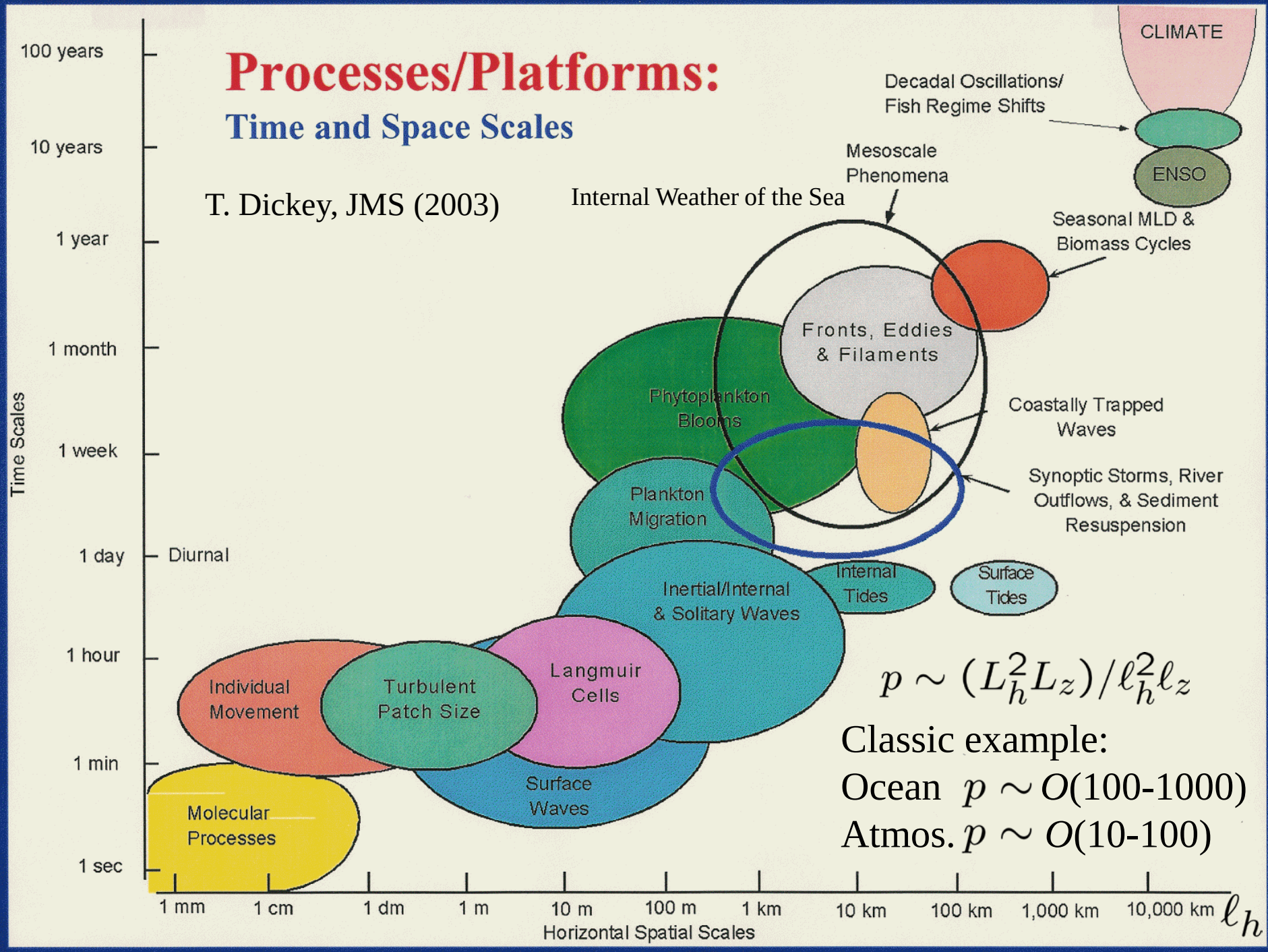
## ❖ Applications to Ocean Dynamics

- Challenge: Quantify multiscale regional processes and interactions, including biological-physical and acoustical-physical dynamics
- Curiosity-driven, but vital for society, industries, security and conservation

# Processes/Platforms:

## Time and Space Scales

T. Dickey, JMS (2003)




$$p \sim (L_h^2 L_z)/\ell_h^2 \ell_z$$

Classic example:

Ocean $p \sim O(100\text{-}1000)$

Atmos. $p \sim O(10\text{-}100)$

# Biogeochemical-Ecosystem-Physical Processes

## Oceanic Food Web and its Multiple Trophic Relations

## e.g. leading to adult herring (arrows show energy flow)

- **Interactions of Physical and Biological/Chemical Dynamical Processes, e.g.**
  - **Primary Productivity**
  - **The Biological Pump and its Role in the Changing Global Carbon Cycle**

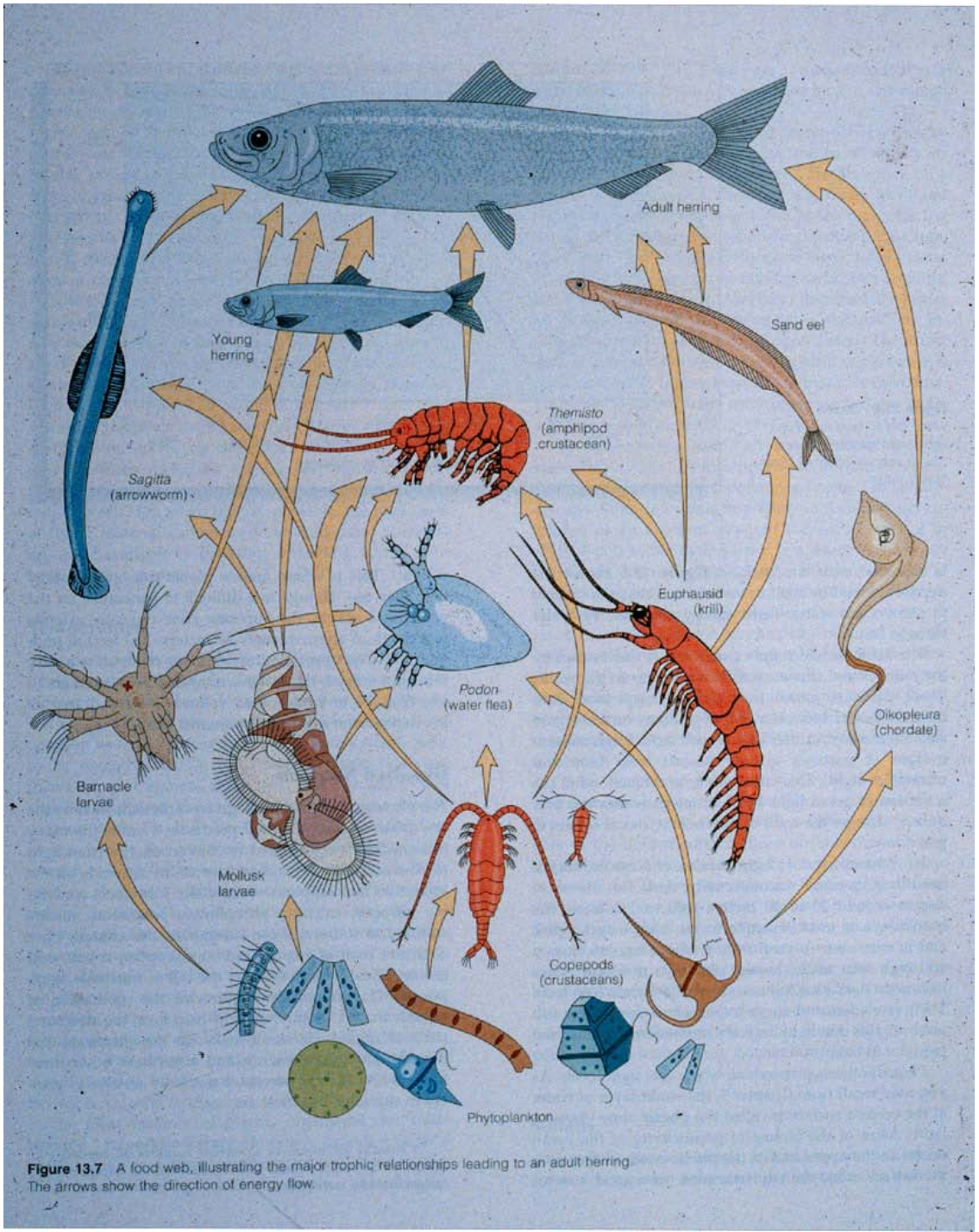



**Figure 13.7** A food web, illustrating the major trophic relationships leading to an adult herring. The arrows show the direction of energy flow.

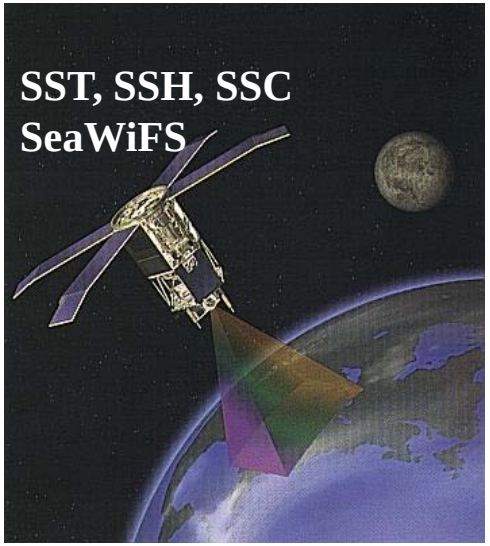
# Physical and Multidisciplinary Observations

## AUV

## Aircraft

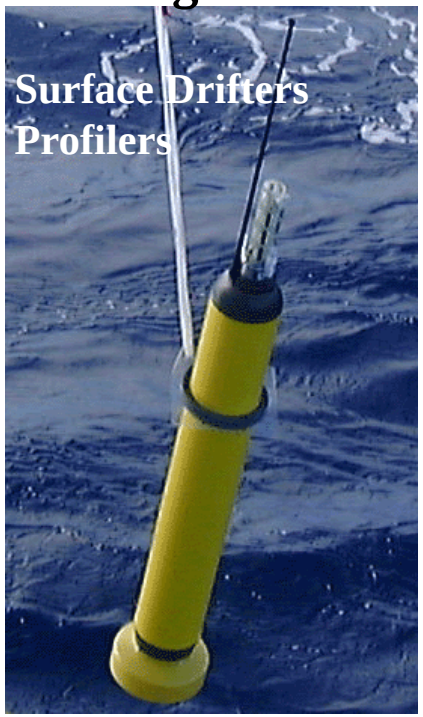
## Ships

## Satellite




## Moored/Fixed

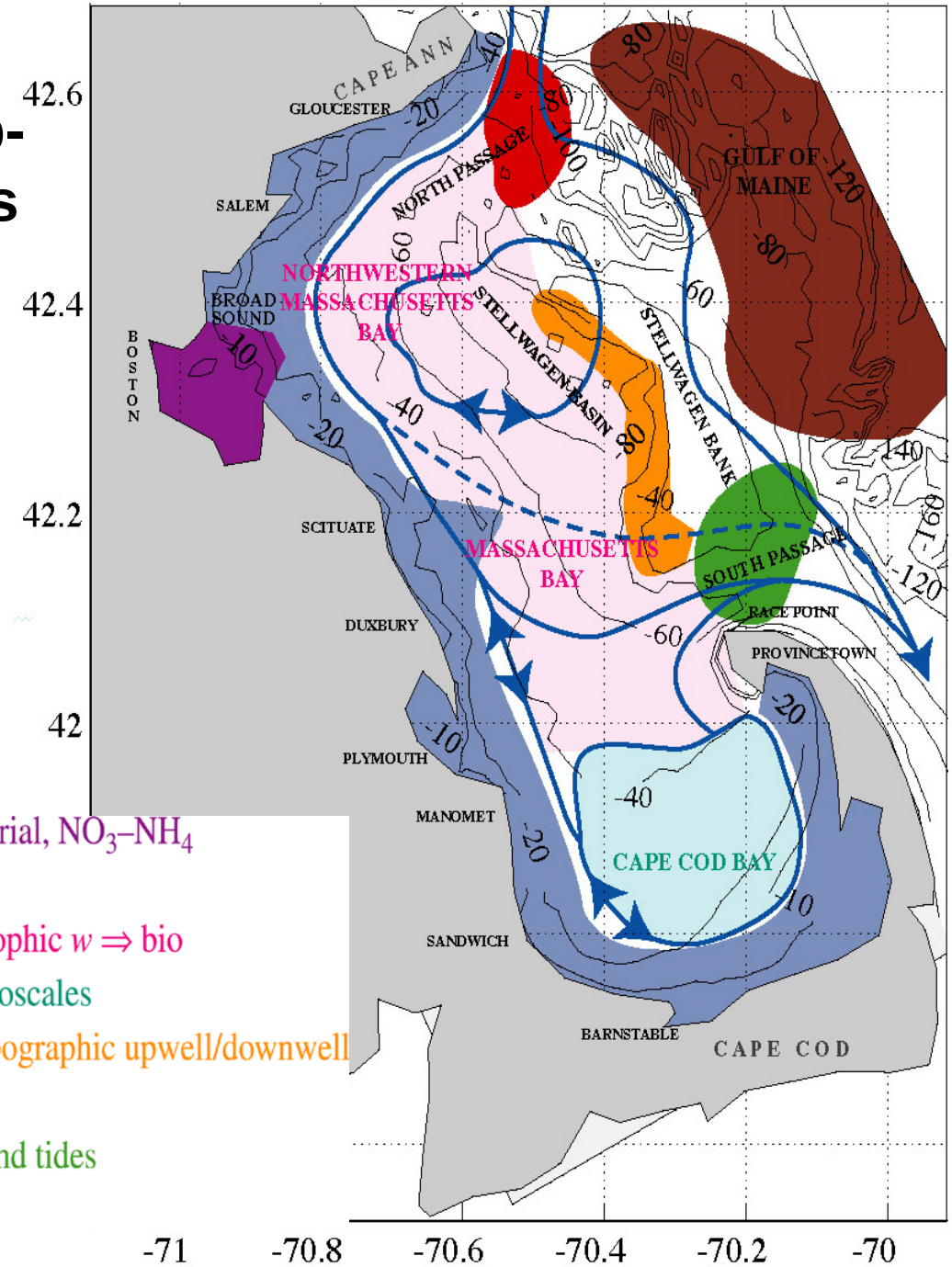
## Drifting



R/V Alliance (NATO) in Massachusetts Bay (June 2001)

Dr. Pat Haley and Wayne Leslie

# Coupled bio-physical sub-regions of Massachusetts Bay in late summer: Dominant dynamics for trophic enrichment and accumulation




**Boston Harbor:** Charles River, sediments, toxic material, $NO_3$–$NH_4$

**Along Coast:** upwelling/downwelling ⇒ bio ↑/↓

**Open Bay:** submesoscale/mesoscale eddies. Ageostrophic $w$ ⇒ bio

**Cape Cod Bay:** Horizontal bio advection and submesoscales

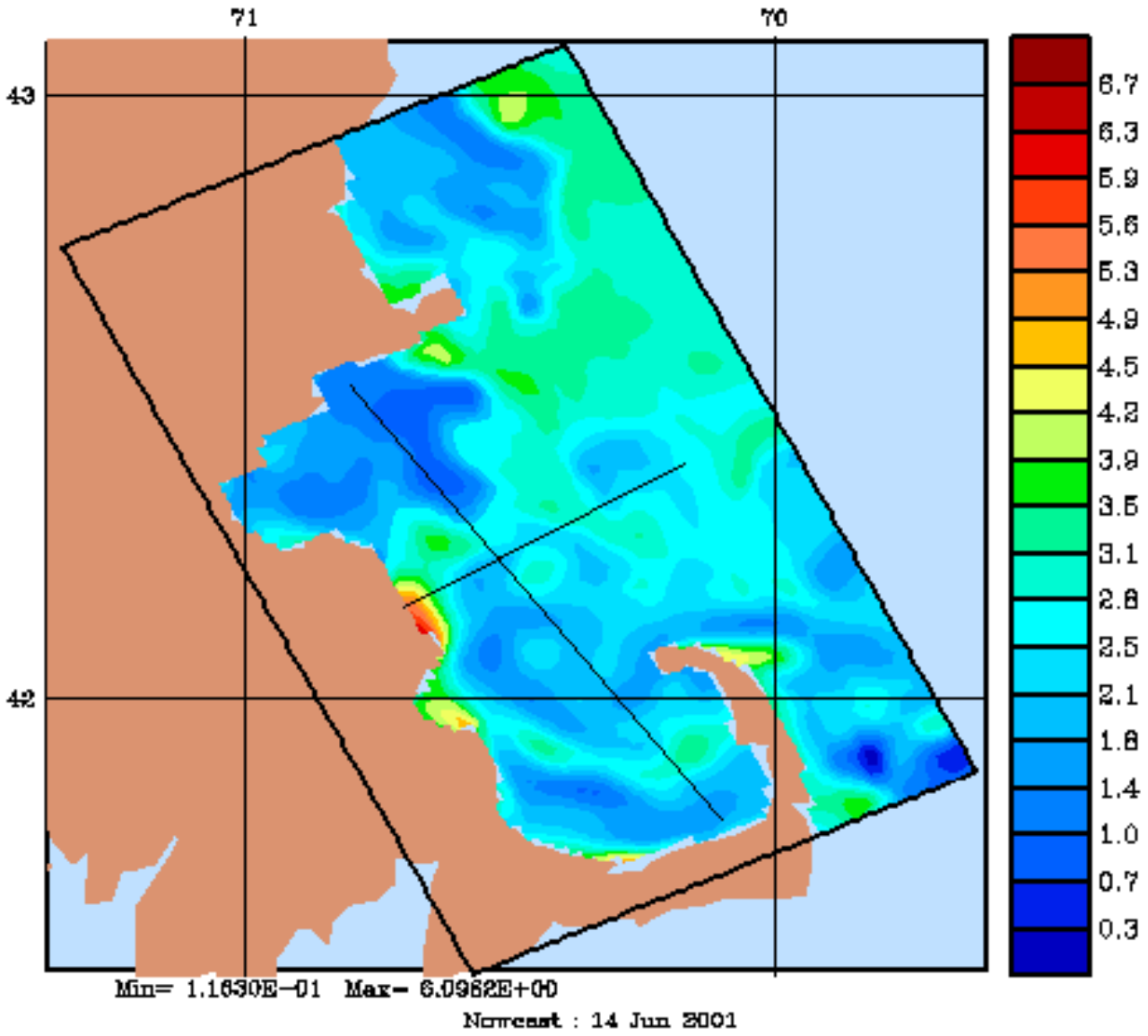
**West of Stellwagen Bank:** GOM meanders, tides, topographic upwell/downwell

**Offshore:** GOM meanders

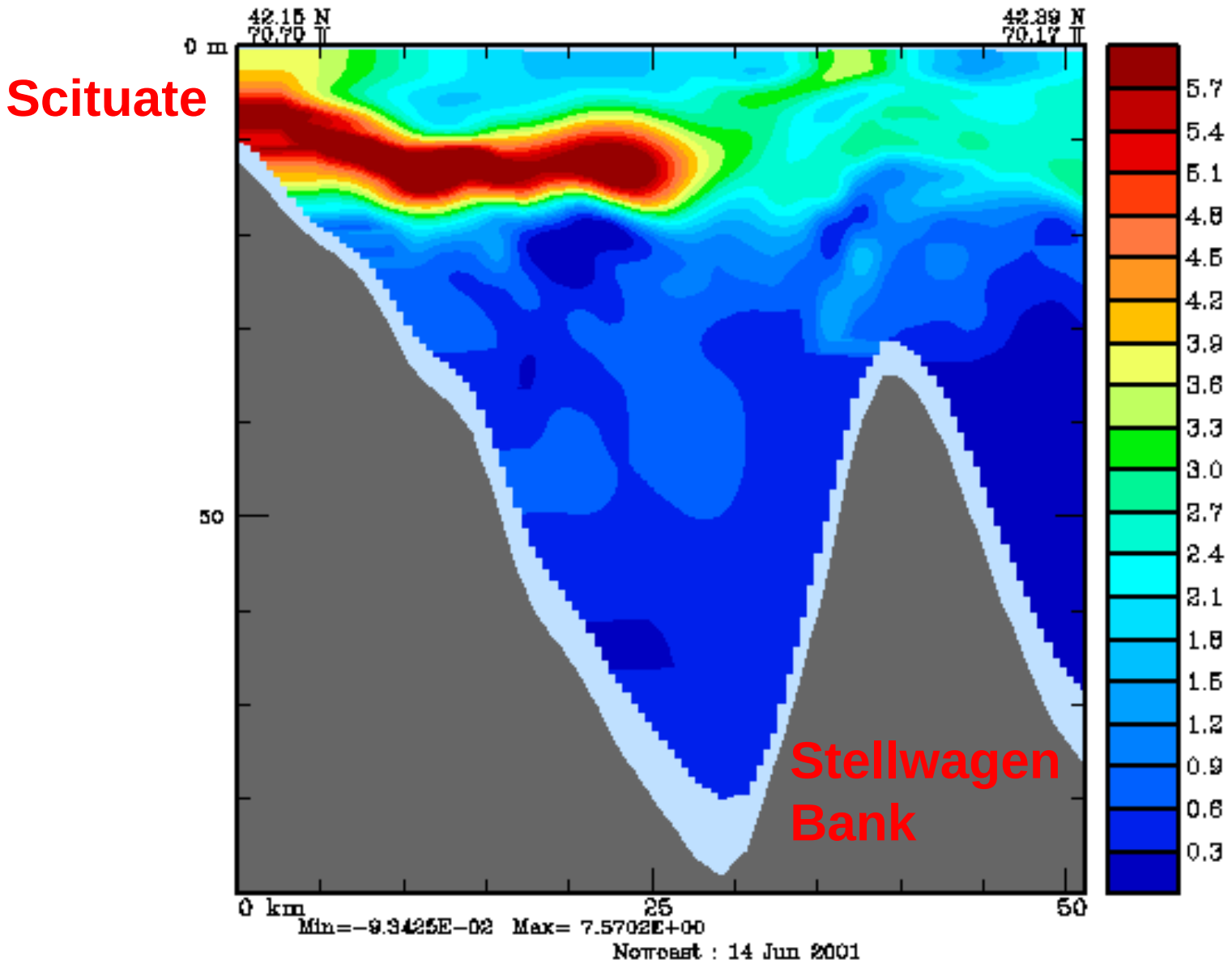
**Race Point:** Multiple bio advections, accumulation, and tides

**Cape Ann:** Physical instabilities at GOM inflow

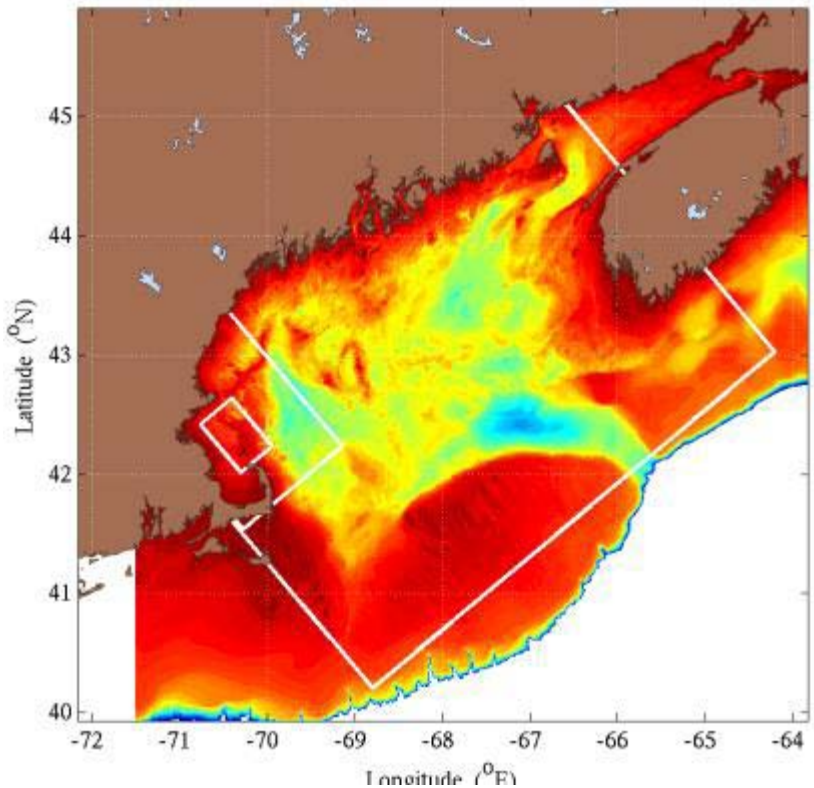
# Chlorophyll at 5m, from June 14 to June 28, 2001

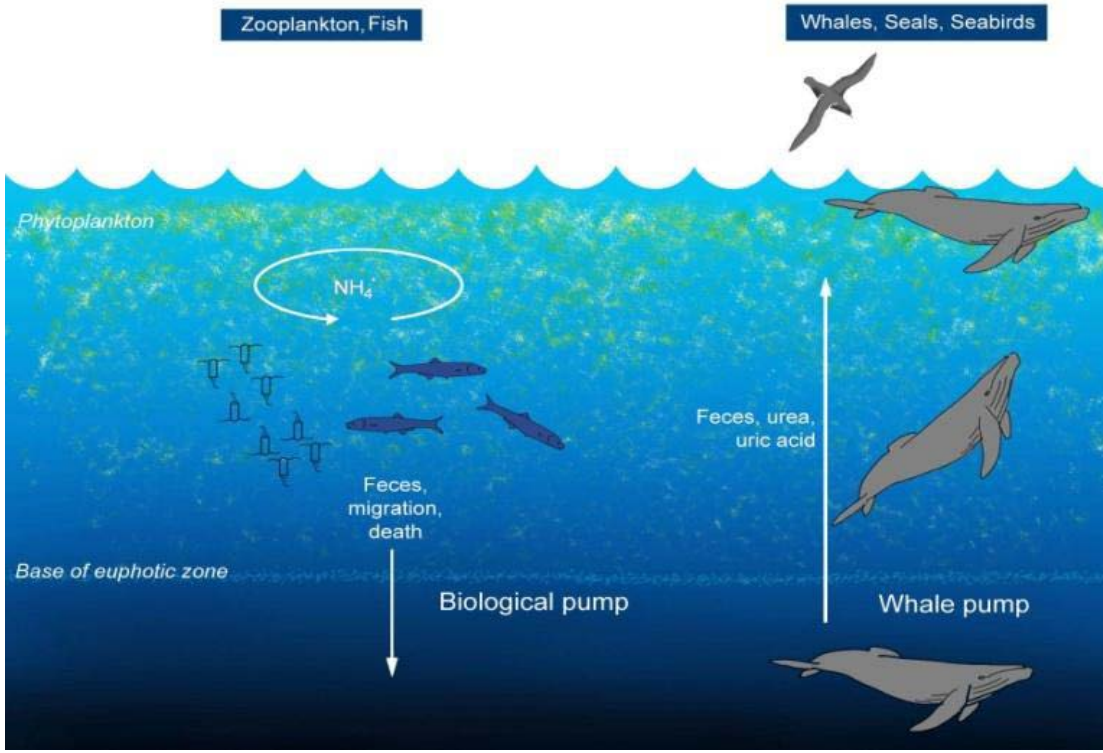


# Chlorophyll cross-section, from June 14 to June 28, 2001



# High Productivity on a Coastal Bank: Physical and Biological Interactions, from plankton to whales

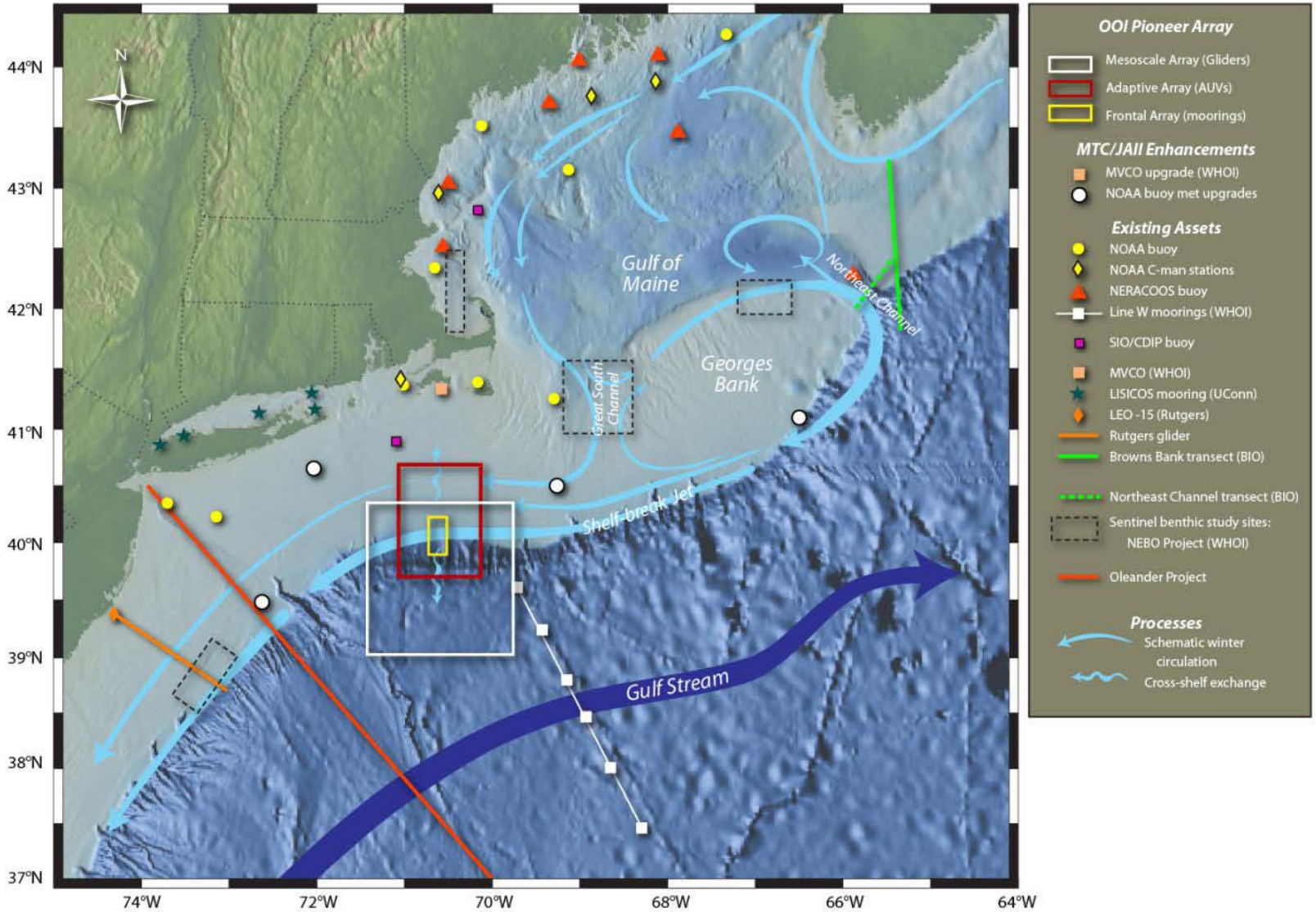


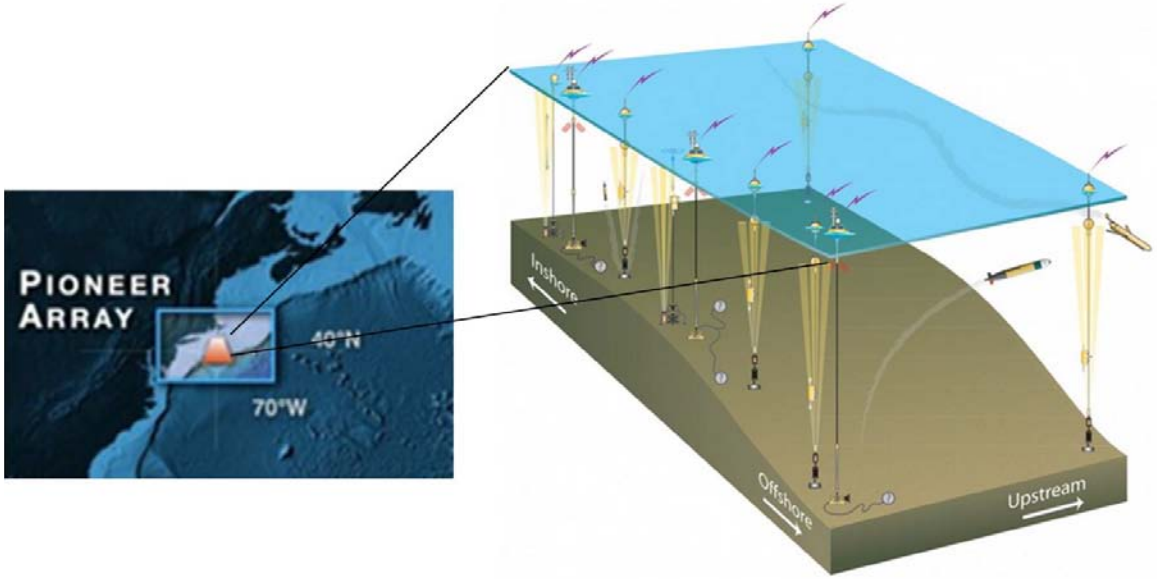

McCarthy, Lermusiaux and Roman, NSF project

Zooplankton feed in the upper euphotic zone and export nutrients through defecation and death. On average, fish release nutrients at the same level as where they feed. Marine mammals and seabirds, tethered to the surface for respiration, excrete higher in the water column than where they feed.

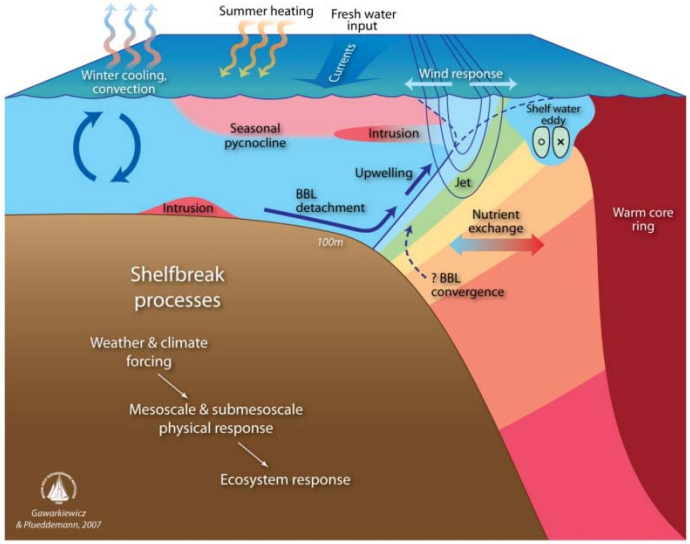
# NSF PIONEER Array - 2012-2017



# NSF PIONEER Array - 2012-2017




Shelf/Slope Processes: Science Opportunities and Issues Relating to the OOI Pioneer Array

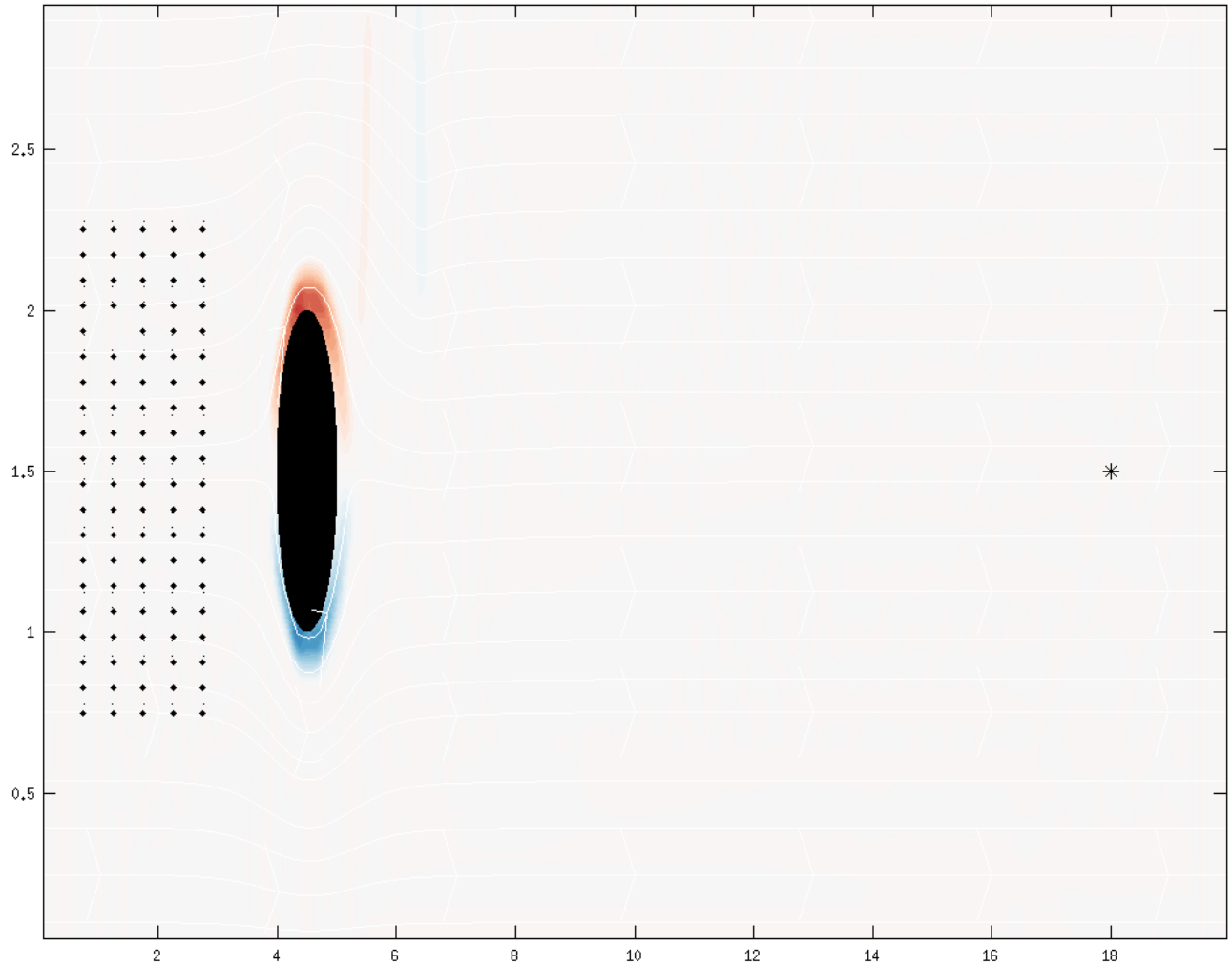



Gawarkiewicz et al, 2011

# “All Back to Ship”: Optimal Recovery of Large Swarm Formation of Vehicles

- **A formation of 100 vehicles need return to ship for pick-up**
- **They need to avoid the island**
- **Utilize the eddies/wakes behind the islands to reach the ship in shortest time**

Legend: Island (black), flow streamlines overlaid on vorticity



# Persistent Littoral Undersea Surveillance (PLUS)

- **End-to-end System components**
  - Adaptive Environmental and Tactical Assessment and Predictions with distributed network of fixed and mobile sensors for improved DCL
  - Coordination via network control architecture and covert communications
  - System level concept demonstration in three years
- **Lermusiaux's group Research Thrusts**
  - Multi-scale and non-hydrostatic nested ocean modeling
  - Coupled physical-acoustical DA in real-time
  - Acoustical-physical nonlinear adaptive sampling with ESSE and AREA

# Conclusions: A few ideas for the future

- **Ocean and Uncertainty Predictions for Maritime Industries**
  - Science and Engineering for Gloucester
- **Ecosystem Based Fisheries Management**
- **Ocean Security**
- **Intelligent Ocean Operations: the Science of Autonomy**
  - Path Planning and Adaptive Sampling
- **Multiple Applications**
  - Fisheries, energy, security and conservation
  - Sustainable Maritime Industry
  - Ultimately for the management of human impacts on the ocean's health and climate