Supported by
NSERC, ONR, NOPP, CFCAS

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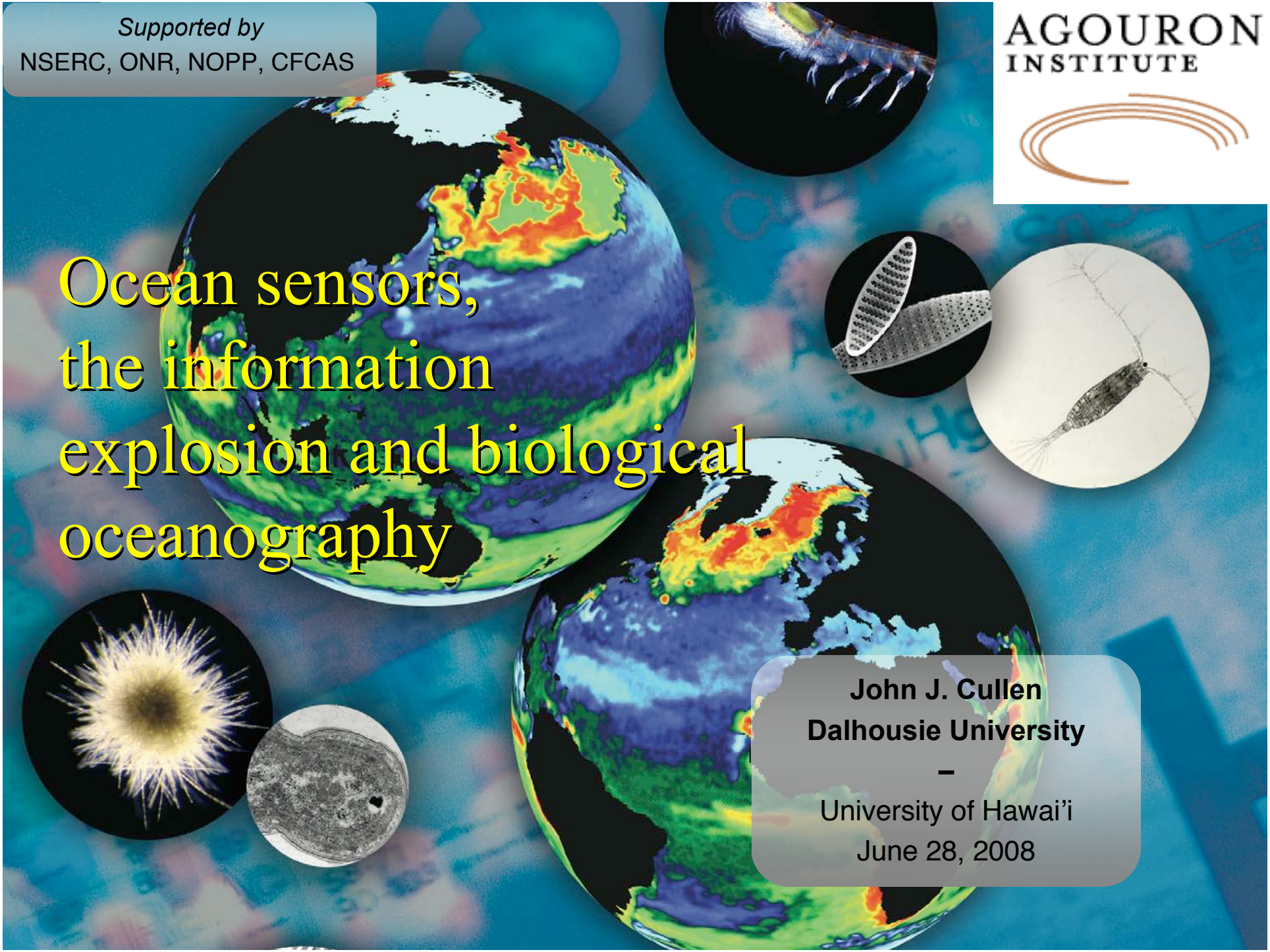
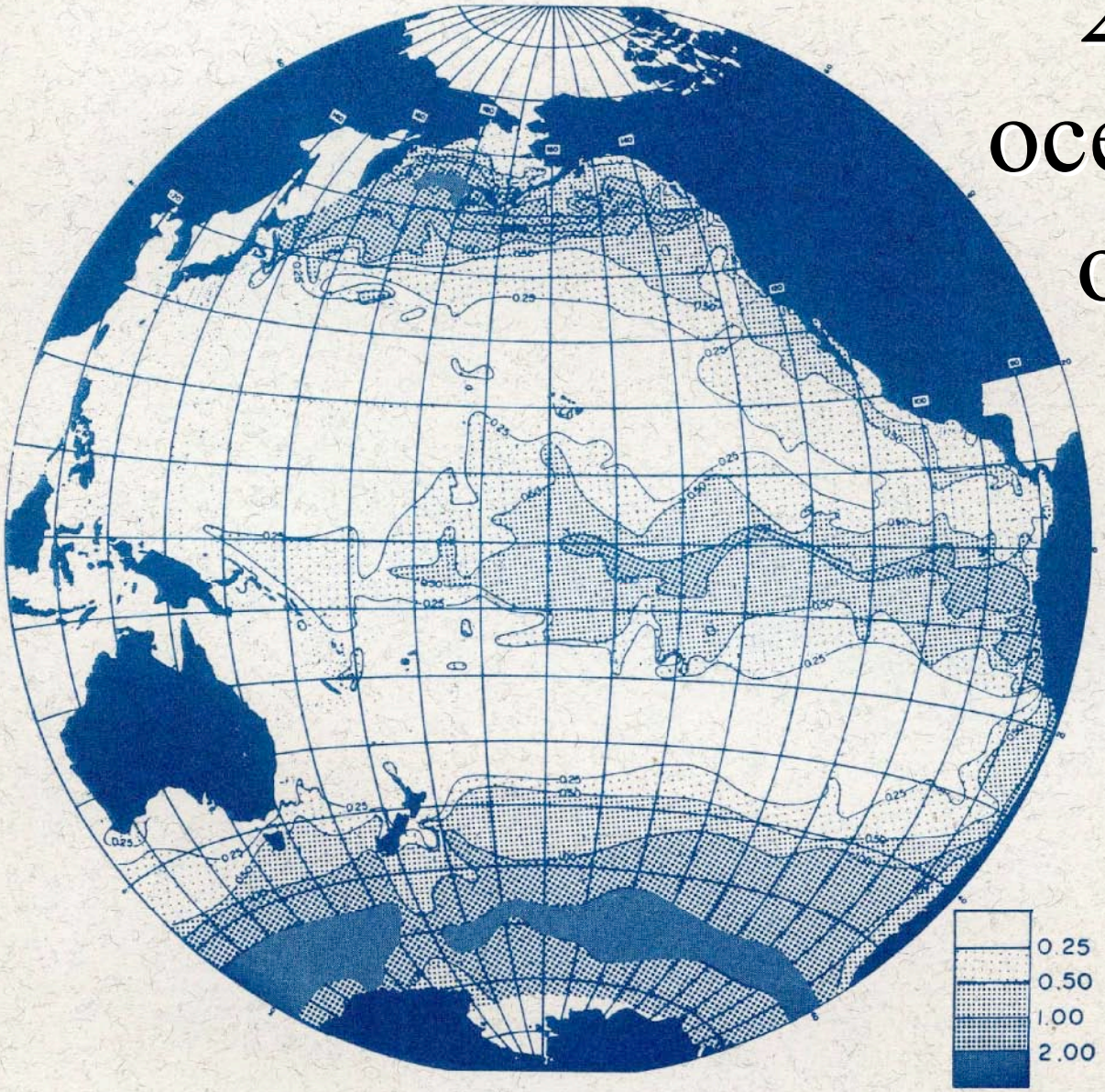


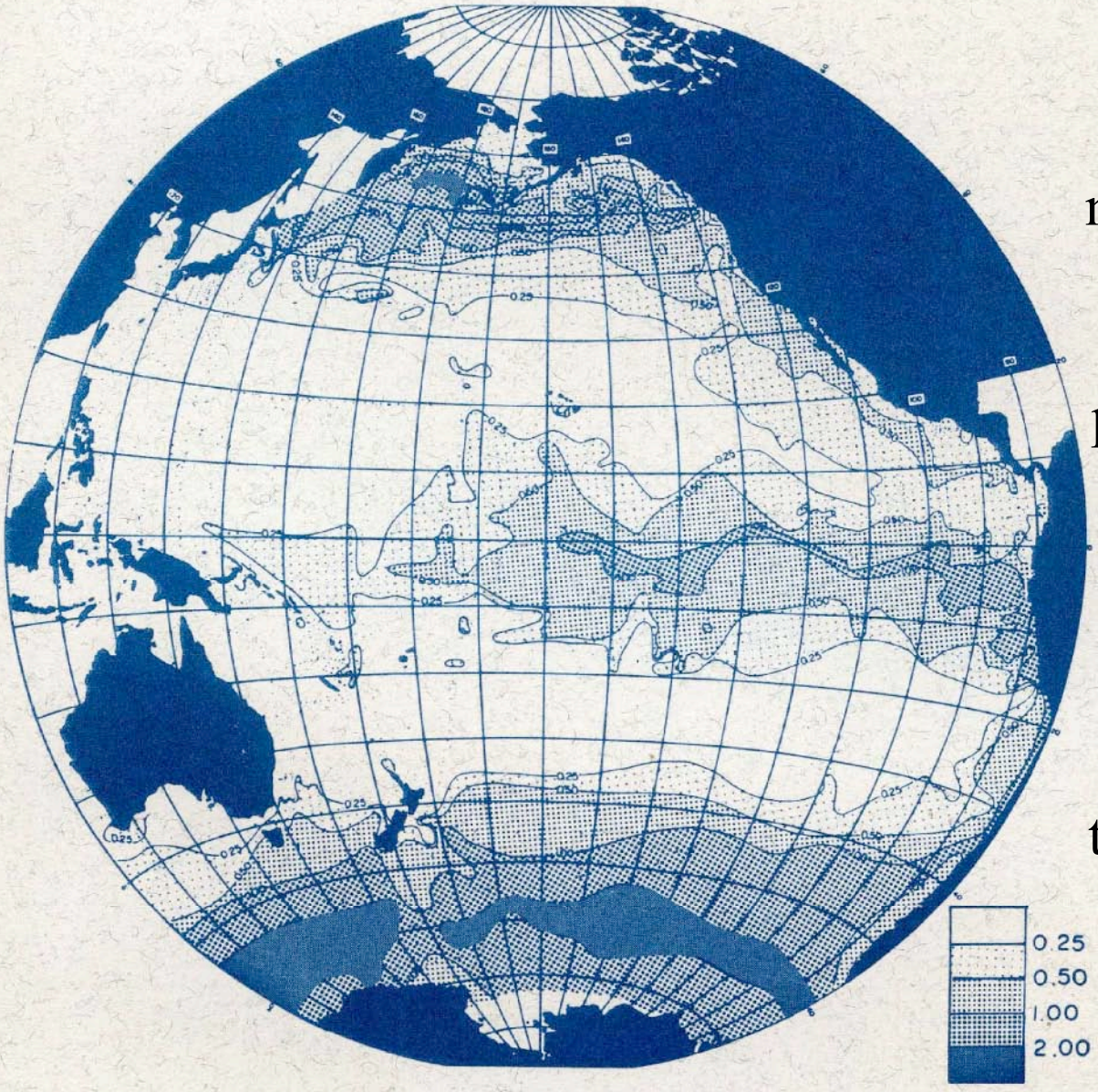
Ocean sensors, the information explosion and biological oceanography

John J. Cullen
Dalhousie University
–
University of Hawai'i
June 28, 2008

20th century oceanography: observations were scarce



Distribution of inorganic phosphate-phosphorus (μg-at/l) at the surface of the Pacific Ocean (Reid, J.L., 1962).

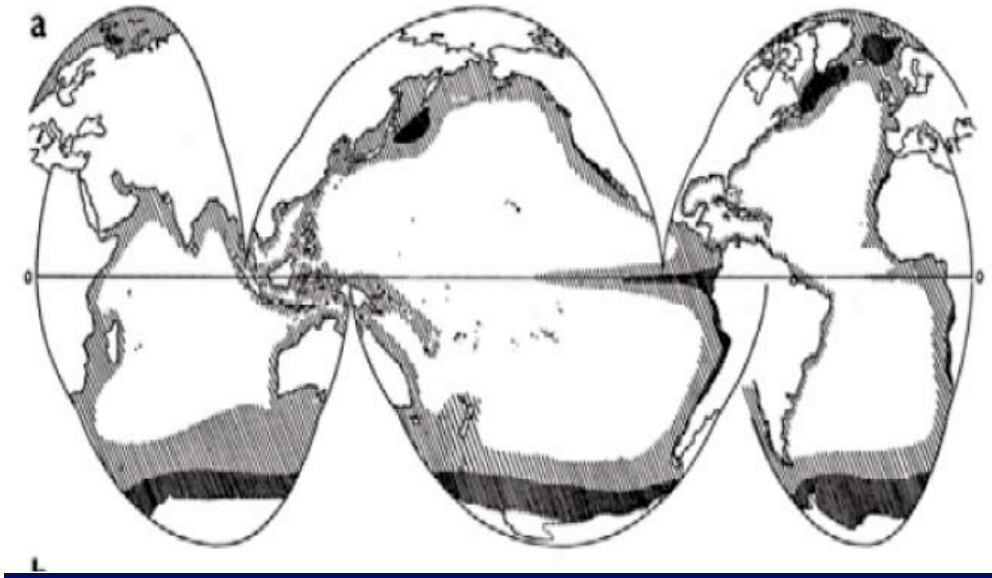


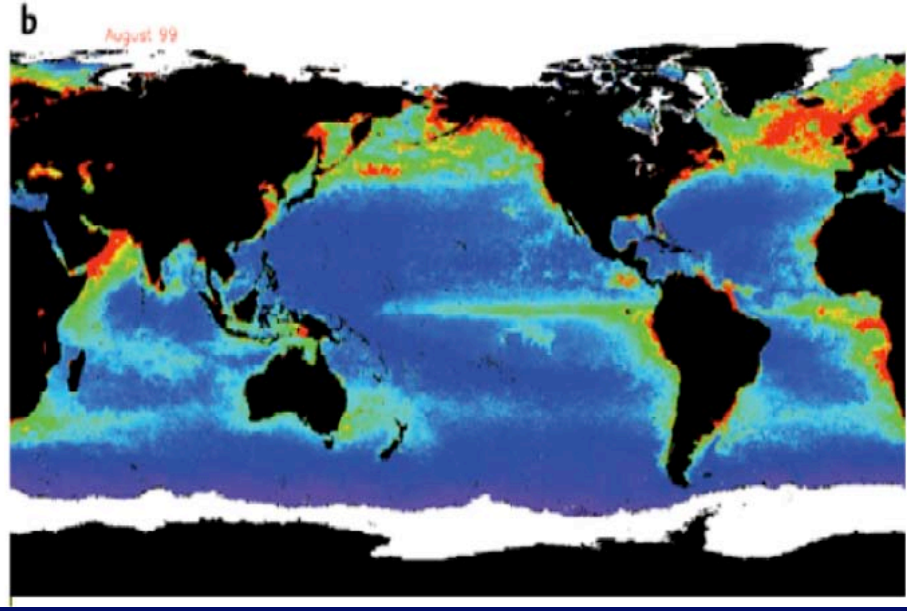
Distribution of inorganic phosphate-phosphorus (µg-at/l) at the surface of the Pacific Ocean (Reid, J.L., 1962).

"In retrospect, physical charts of temperature, salinity, nutrients, and currents were so unrealistic that they could not possibly have been of any use to the biologists. Similarly, scientists could find experimental support for their favorite theory no matter what the theory claimed".

Walter Munk, 2002

But insight went a very long way



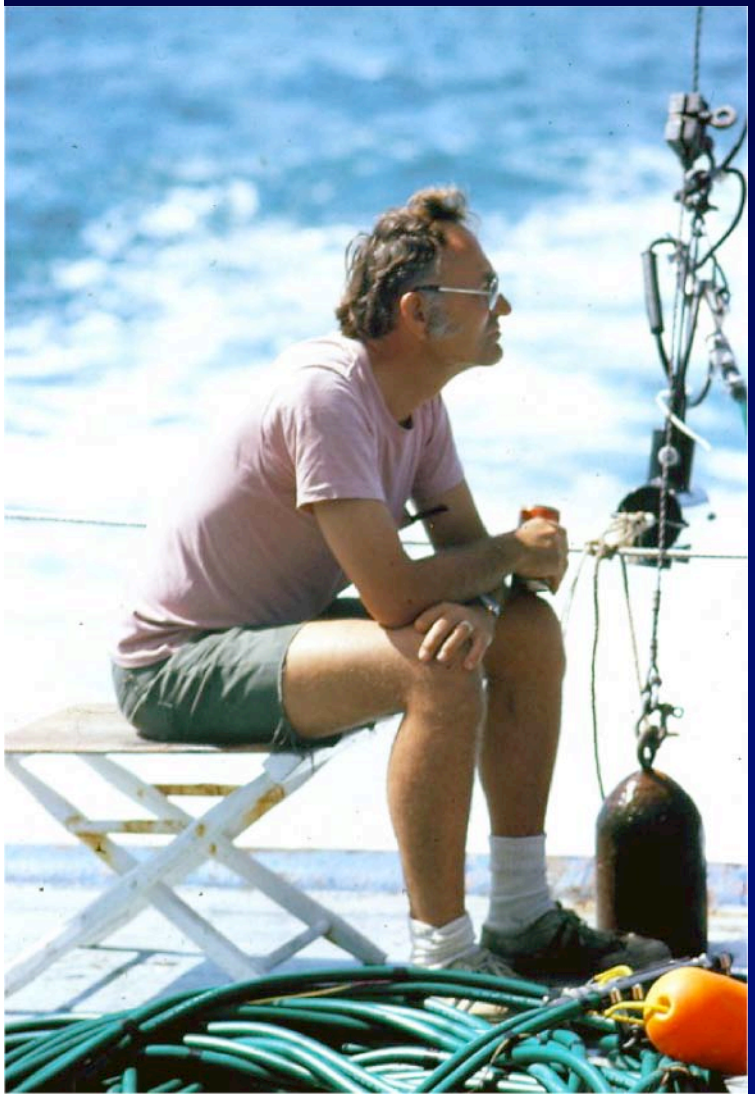


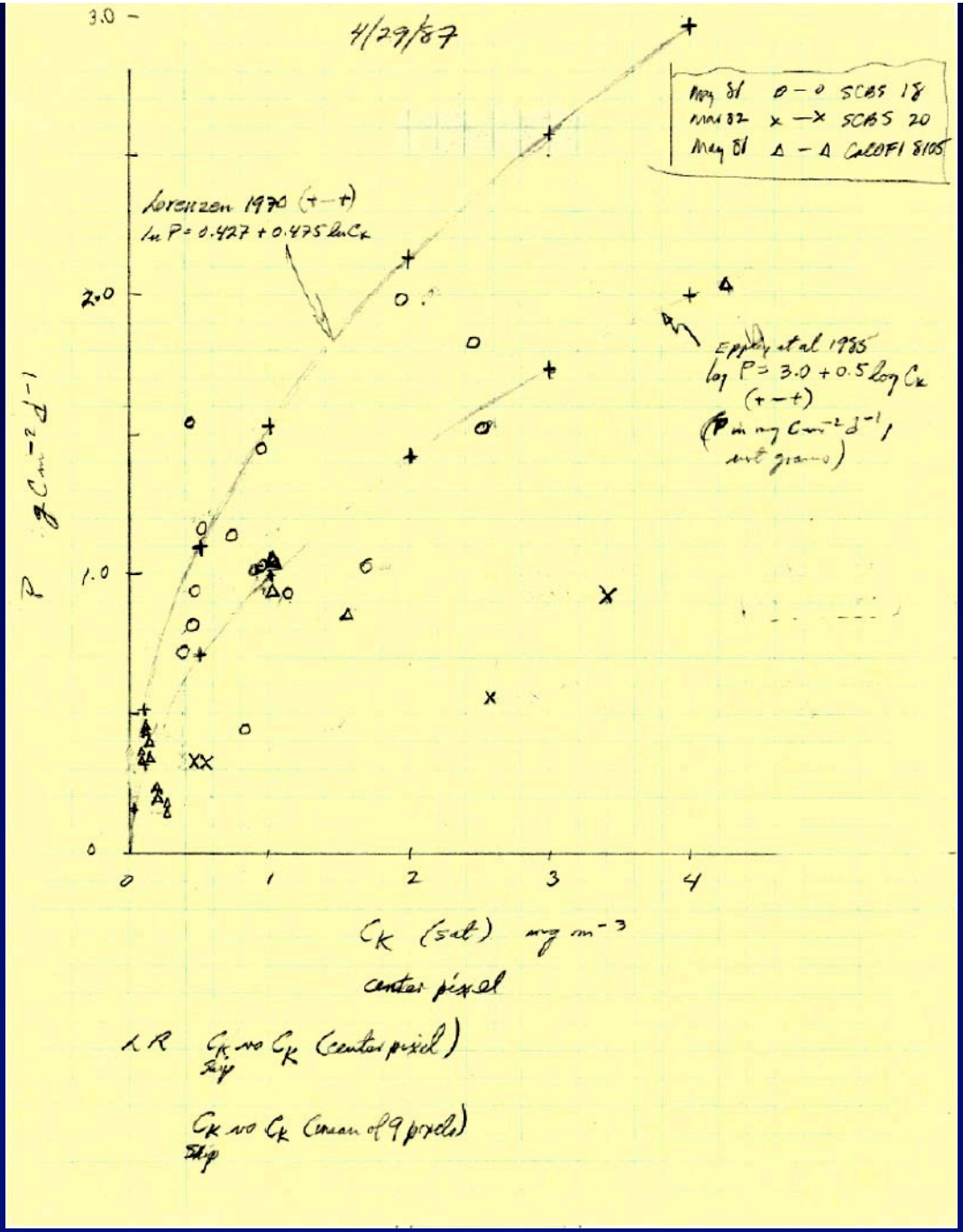
Sverdrup's (1955) map of productivity based on vertical convection, upwelling and turbulent diffusion

Global productivity estimated from remote sensing (Falkowski et al. 1998).

As presented by John McGowan (Oceanography Mag., 2004)

Technical approach: **Thinking**





R.W. Eppley

John Cullen: Agouron Symposium 2008

Products of
20th century oceanography:

UNDERSTANDING
and
KNOWLEDGE

New Production

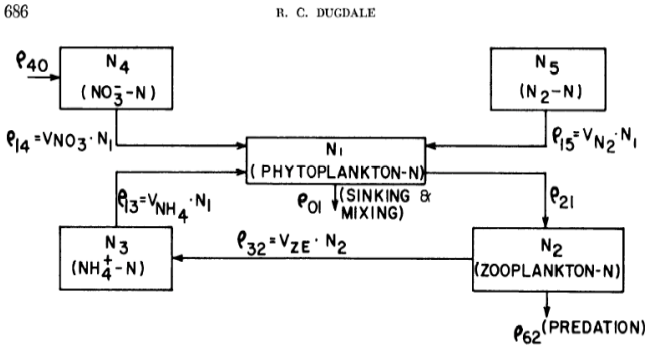
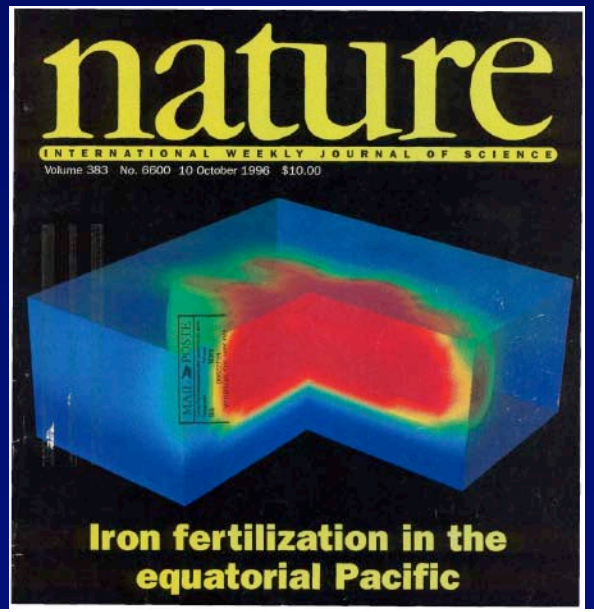
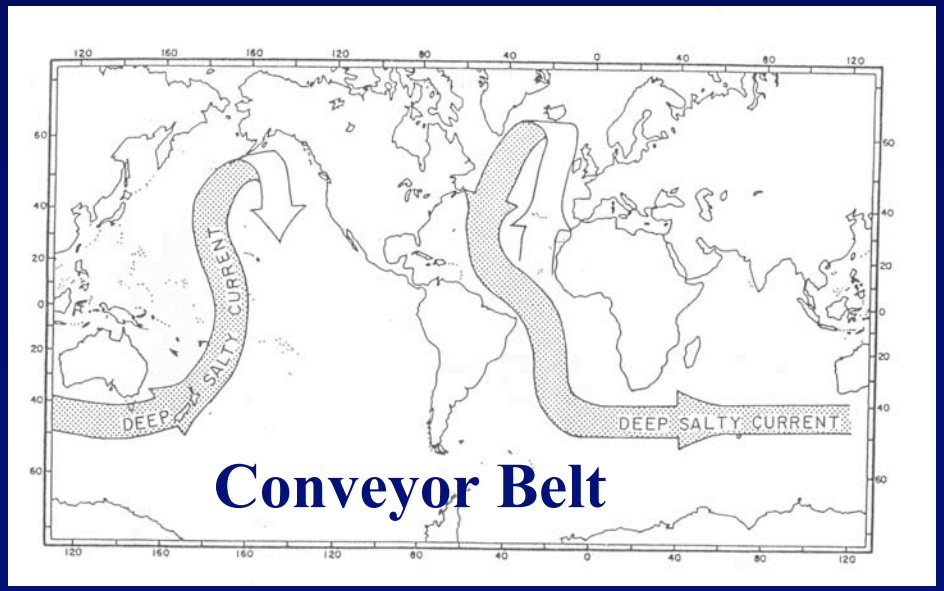


FIG. 1. Flow of nitrogen in the euphotic zone.

Producers: John Martin, Wally Broecker, Dick Dugdale, Dick Eppley…





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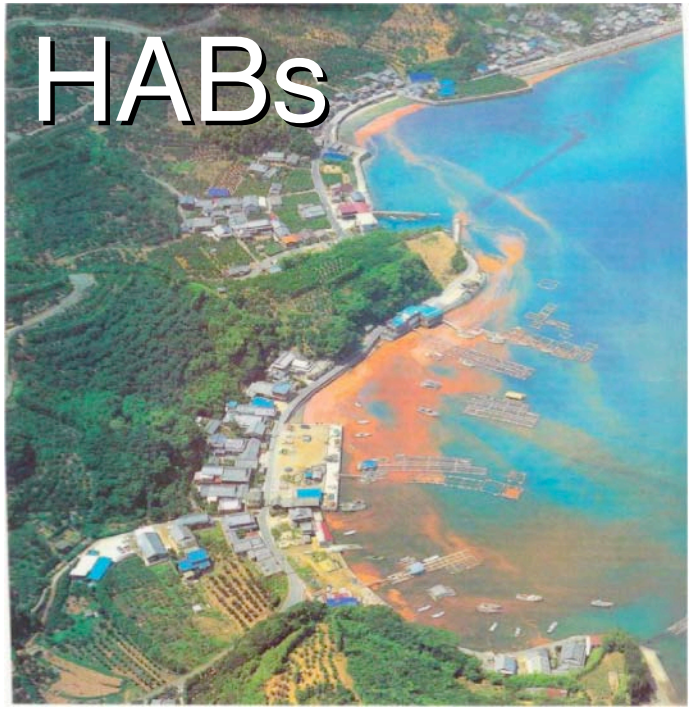
The bar has been raised

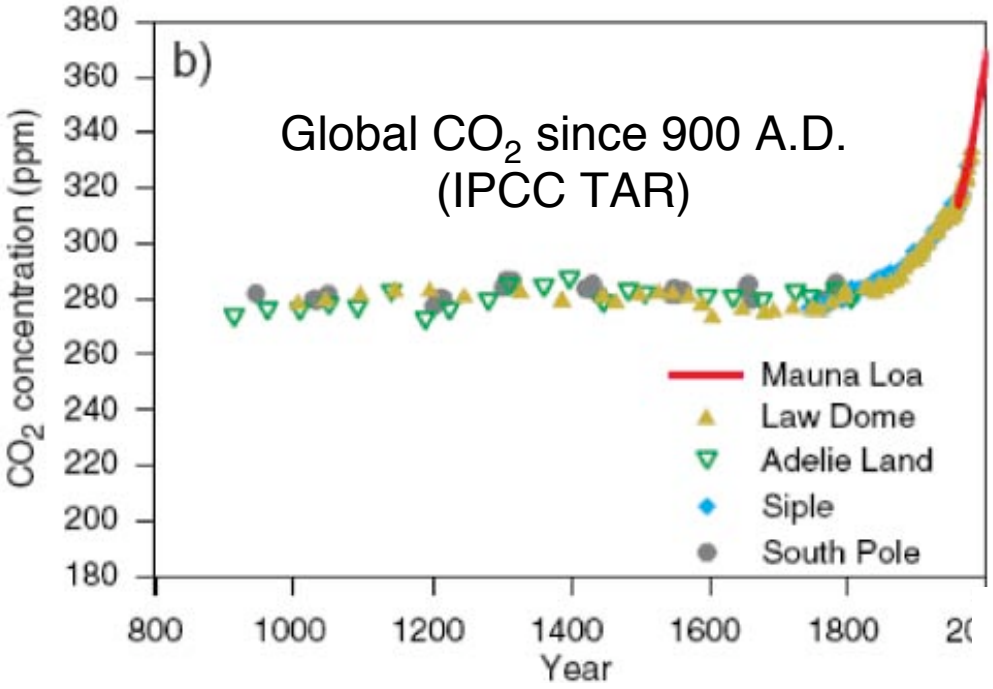
We need:

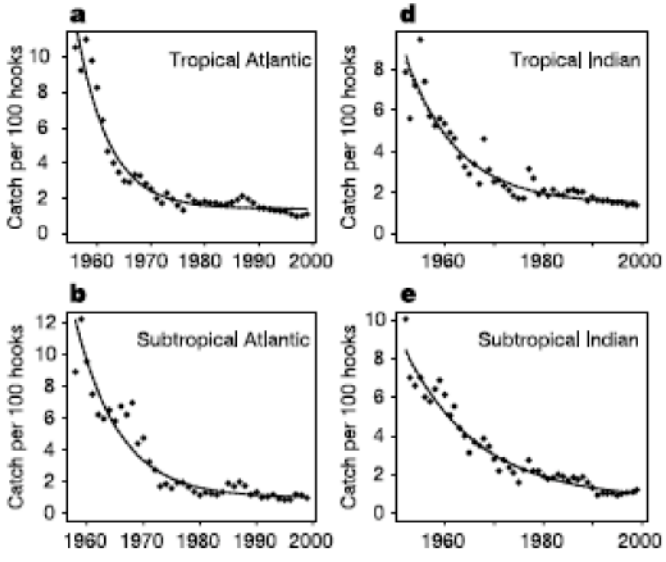
PREDICTIVE CAPABILITY



http://ic.ucsc.edu/~flegal/etox80e/Spec Topics/AlgalBlooms/alg_p1.jpg

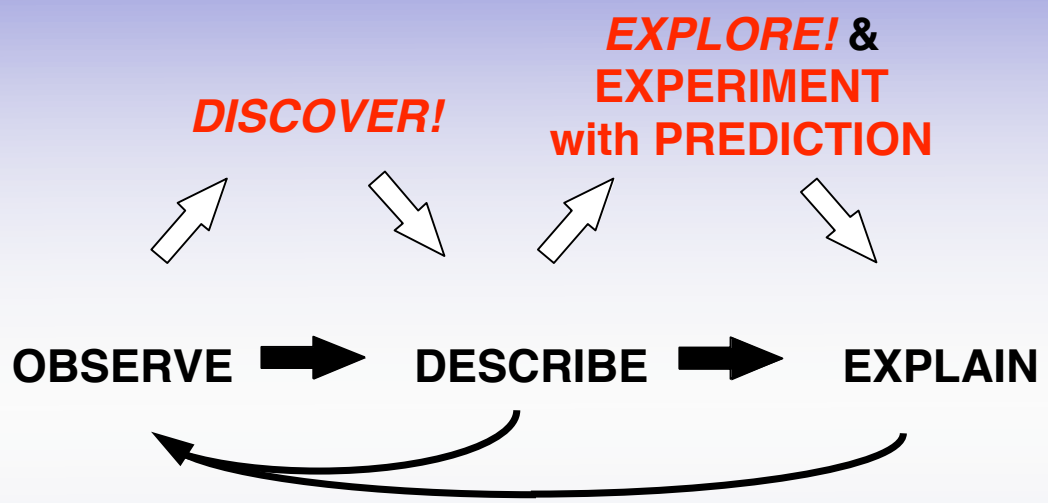
Decline of fish stocks since 1960





Myers and Worm Nature 2003

Marine Environmental Prediction



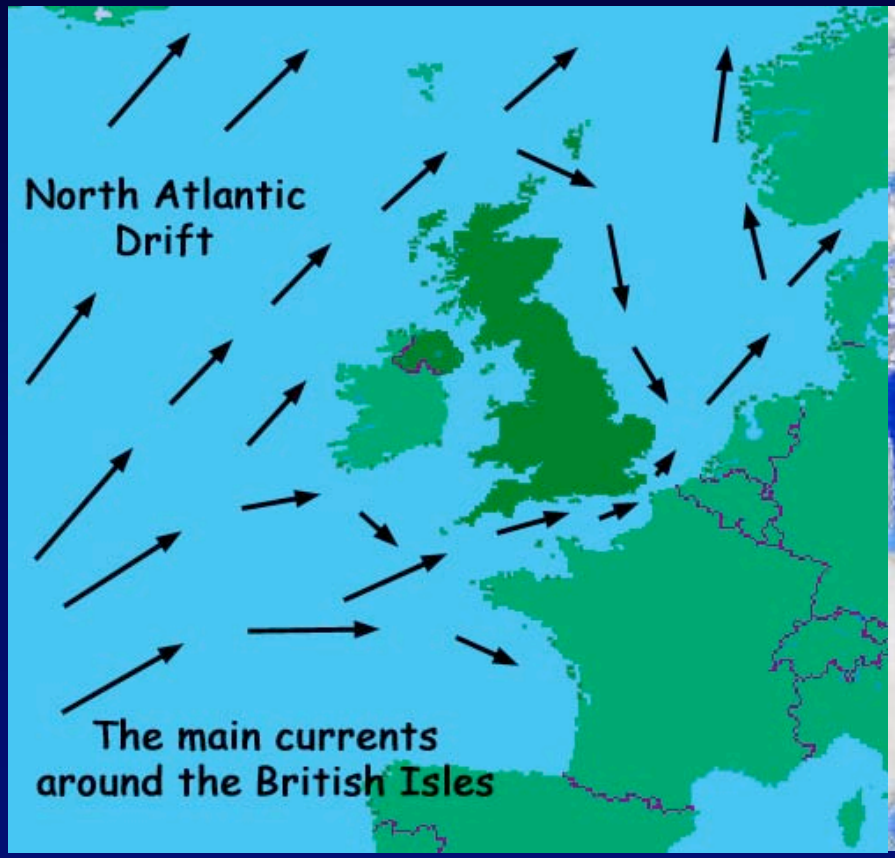
GOAL: PREDICTION WITH MEASURABLE SKILL

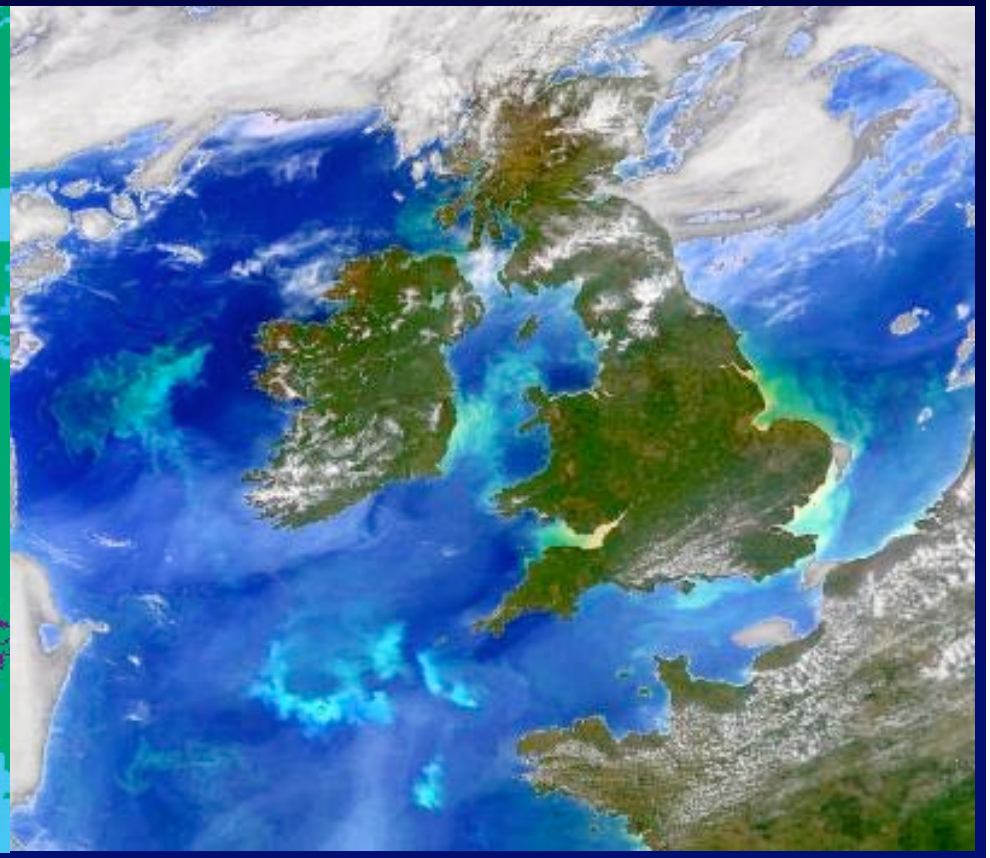
Needs: **Technology for observations**
Integration of knowledge → Insight
(opportunity to think)

Requirements for quantitative marine environmental prediction

- Resolve mesoscale variability
  - Ocean surface
  - Ocean interior (highly resolved vertically)
- Take bio-optics “beyond biomass”
- Describe biodiversity and understand its significance
- Integrate observations and knowledge in interdisciplinary data assimilative ecological and biogeochemical models

Remote sensing is revolutionary

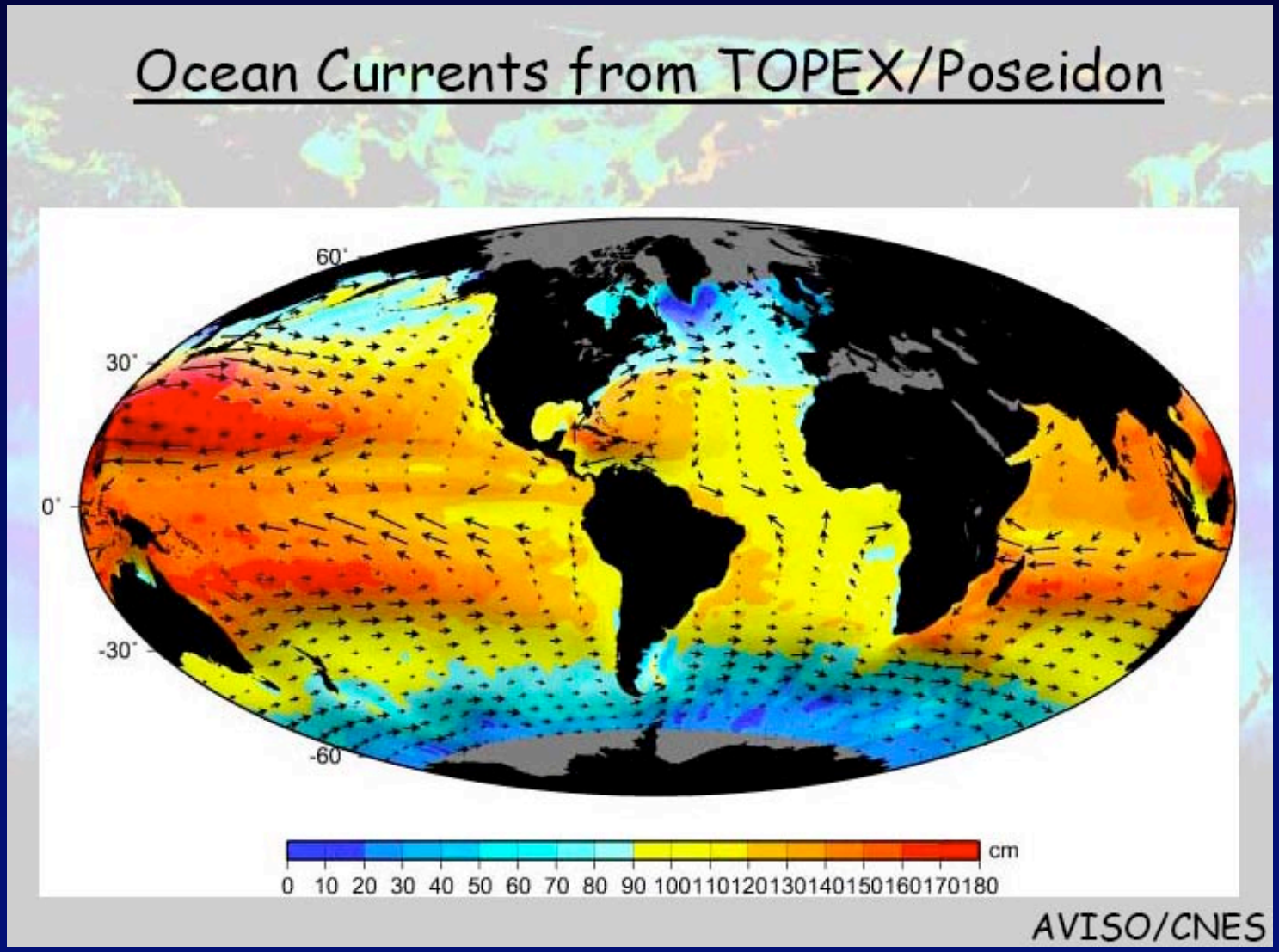




http://www.angliacampus.com/public/sec/geog/coastln/page09.php

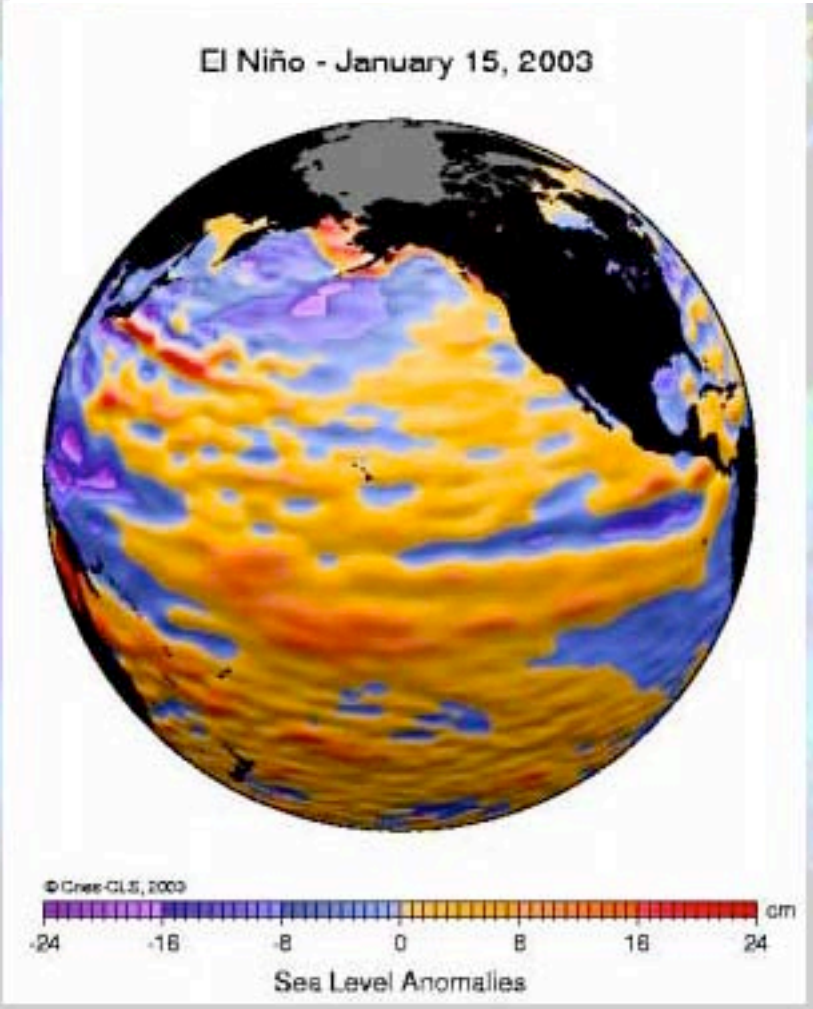
NASA/GSFC

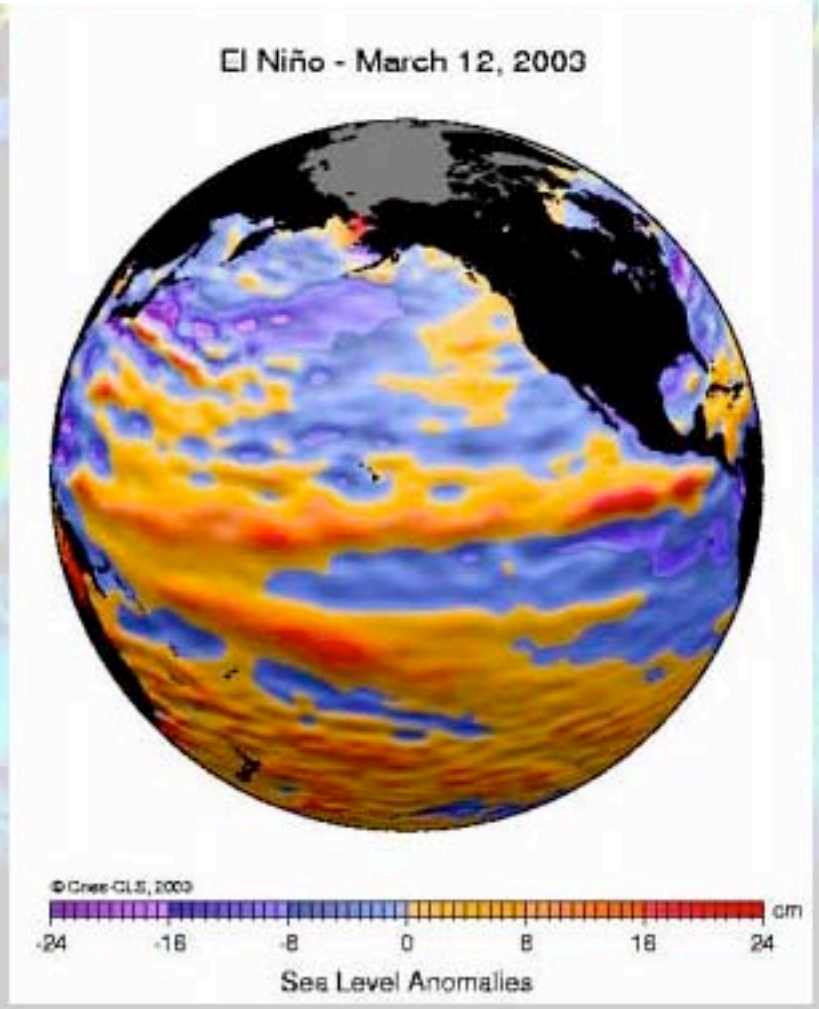
Capabilities are Awesome



From a presentation by Mark Abbott

Results are Important!



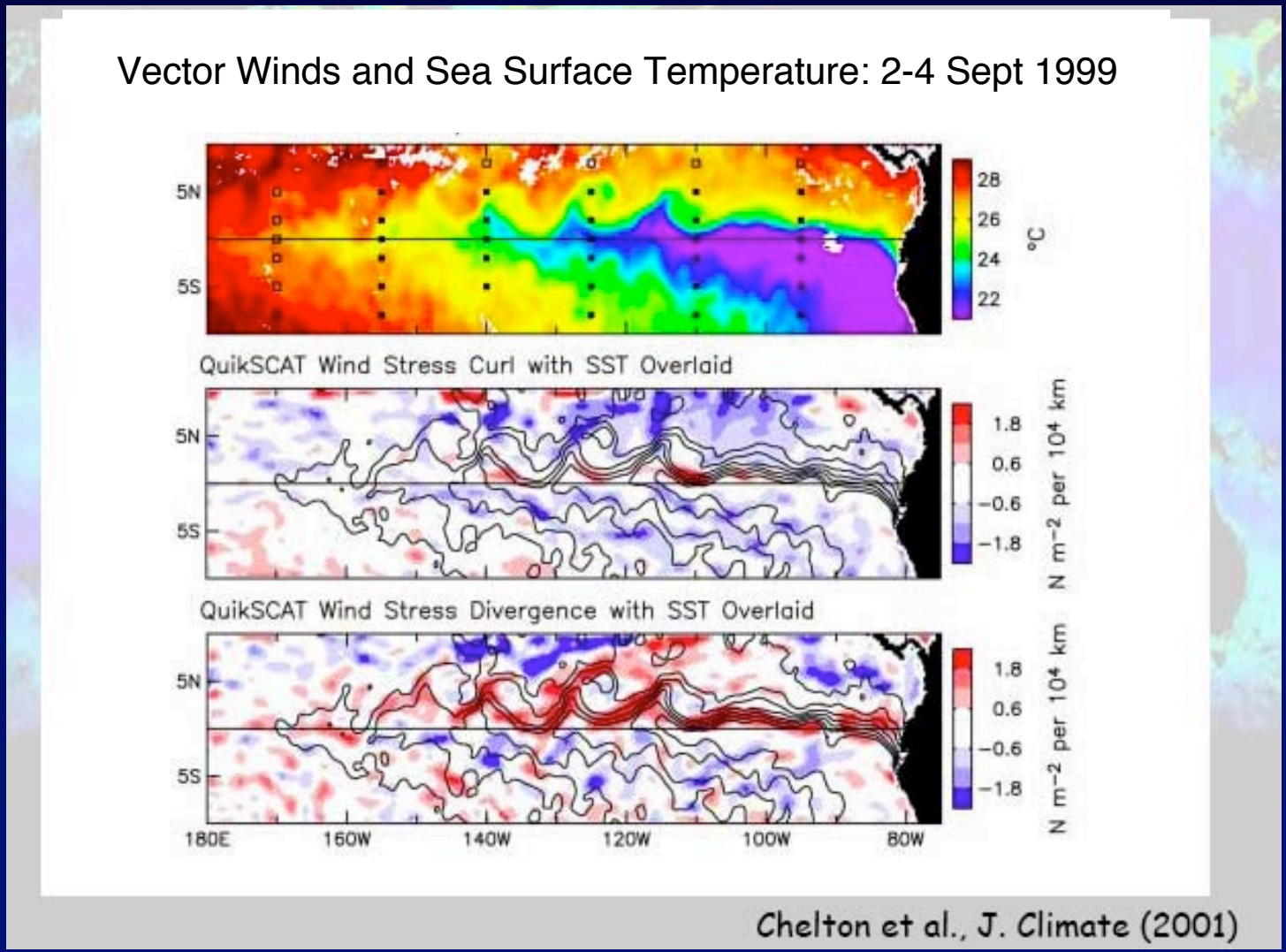


Decline of the 2002 - 2003 El Niño

AVISO/CNES

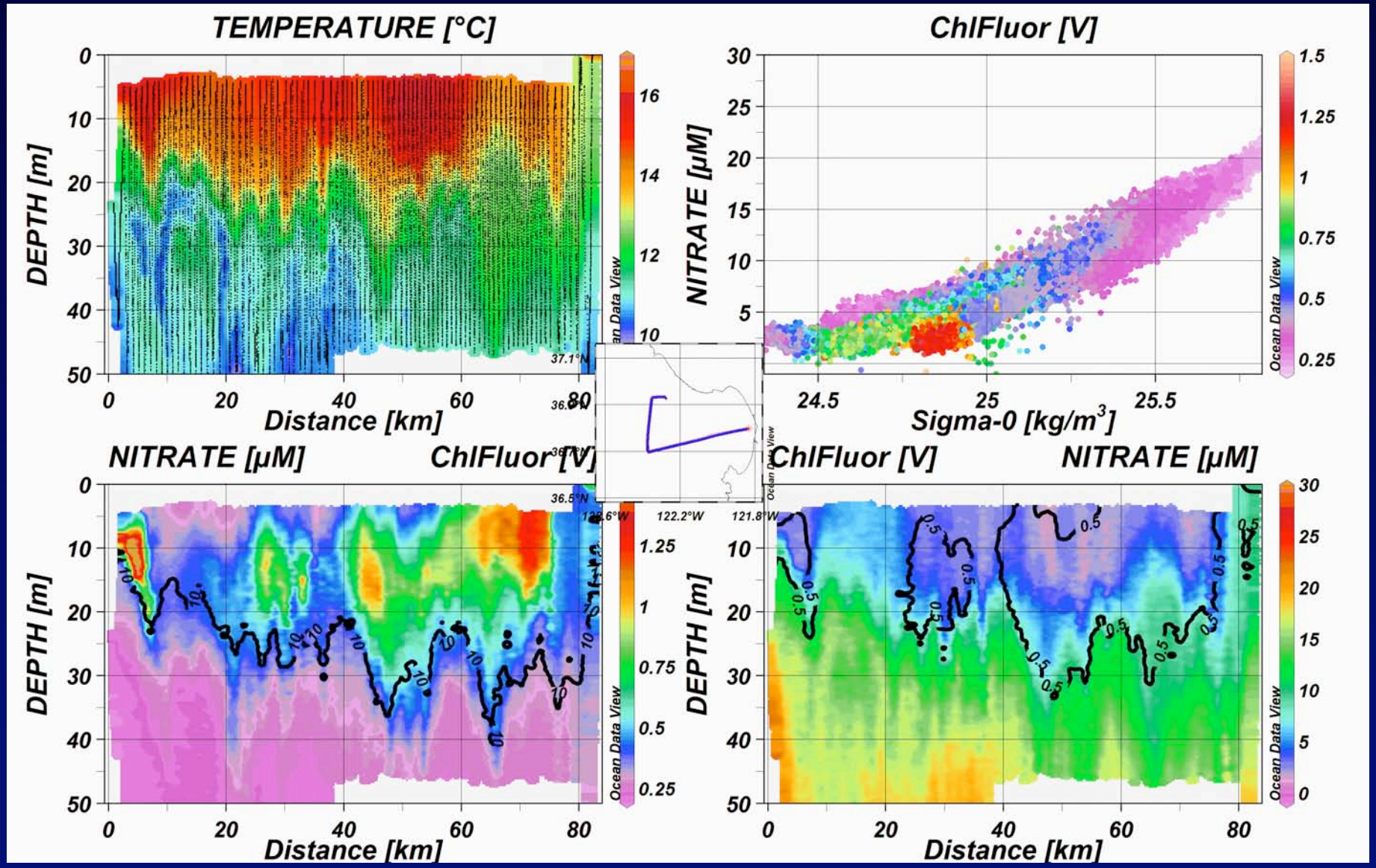
From a presentation by Mark Abbott

Remote sensing permits integrated, interdisciplinary analyses on the scales that matter



From a presentation by Mark Abbott

New technology describes mesoscale variability in the ocean interior



Ken Johnson MBARI

John Cullen: Agouron Symposium 2008

Years of records now possible

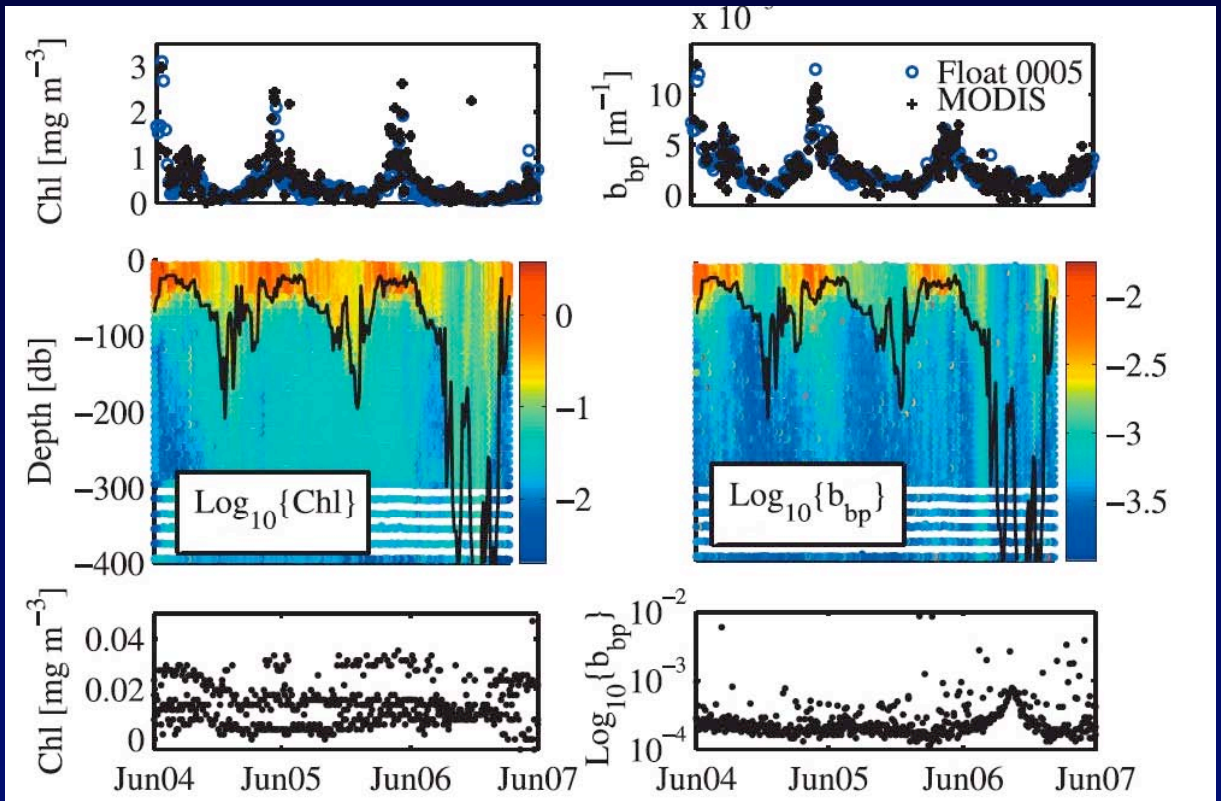
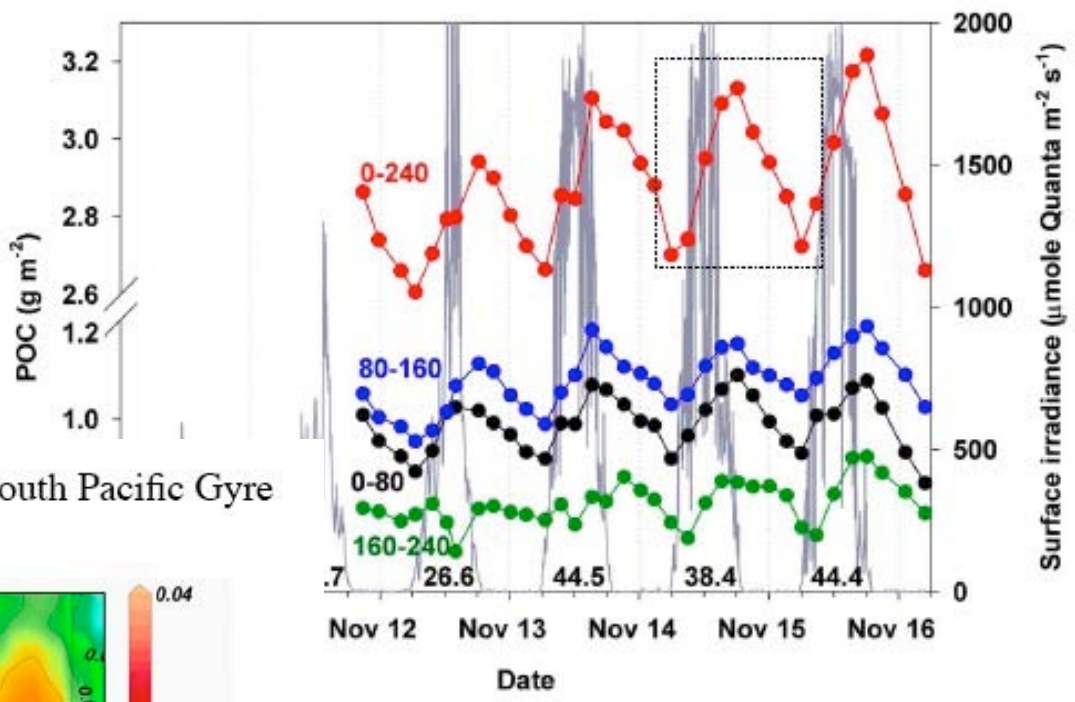


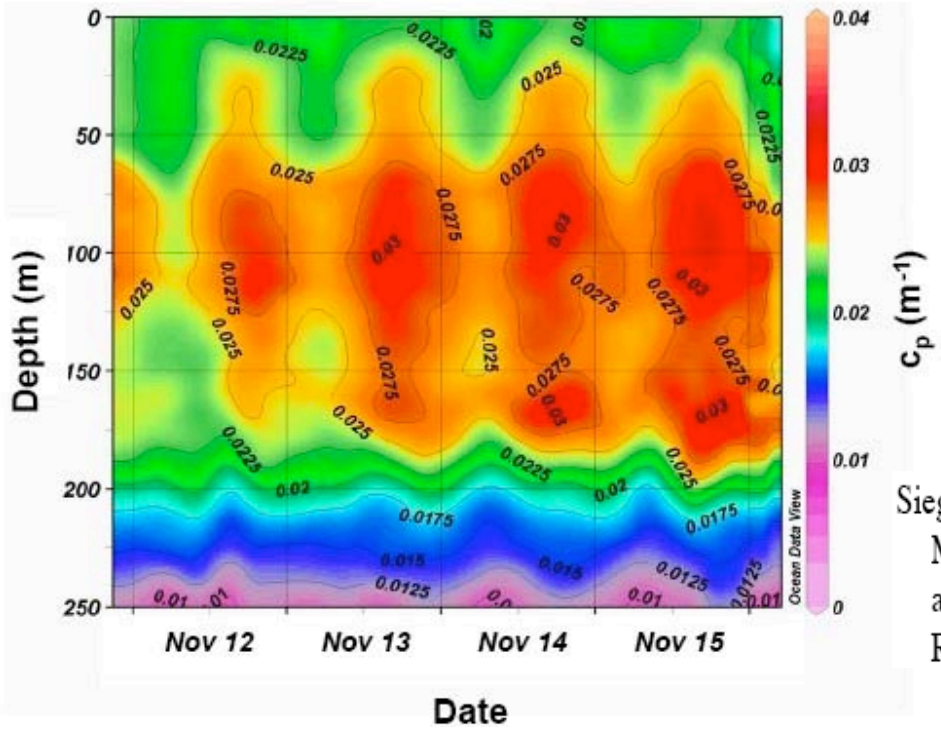
Fig. 2. Time series of (left) chlorophyll concentration and (right) particulate backscattering coefficient. (top panels) Near-surface float and Moderate Resolution Imaging Spectroradiometer Aqua satellite data, (middle panels) midwater column float data, and (bottom panels) float data below 950 meters (note log scale for particle backscattering). For satellite chlorophyll concentration and backscattering coefficient, we use NASA's inversion products OC3 and GSM, respectively (http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/MSI12_prod.html).

Boss et al., EOS 2008

Continuous measures of optics reveal rates



H. Claustre et al.: Metabolic balance in the South Pacific Gyre



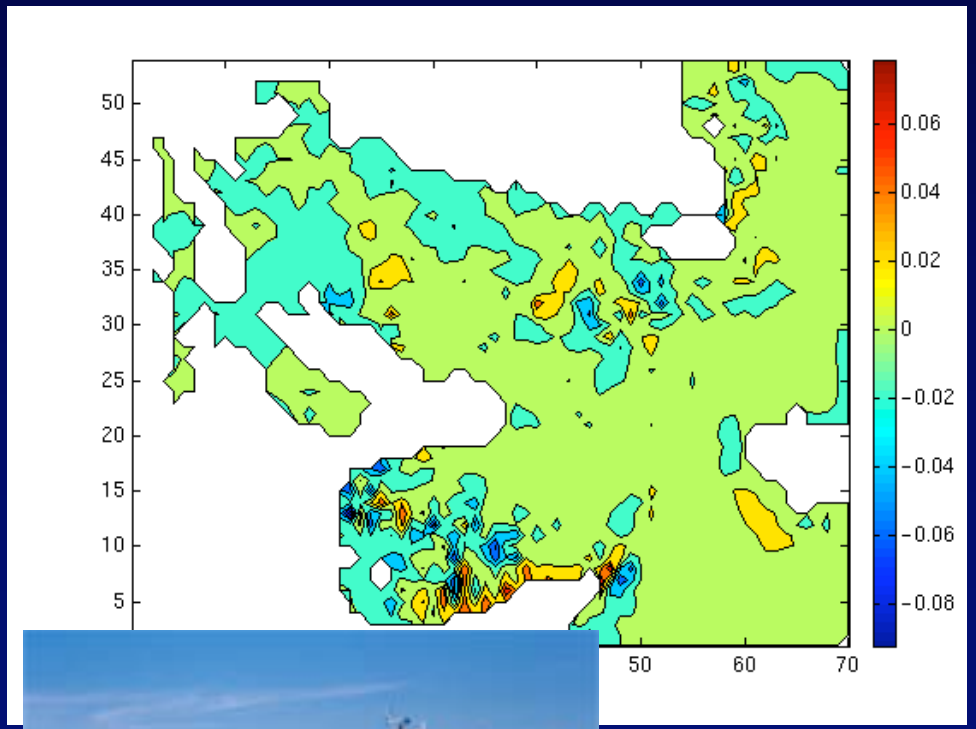
Biogeosciences, 5, 463–474, 2008

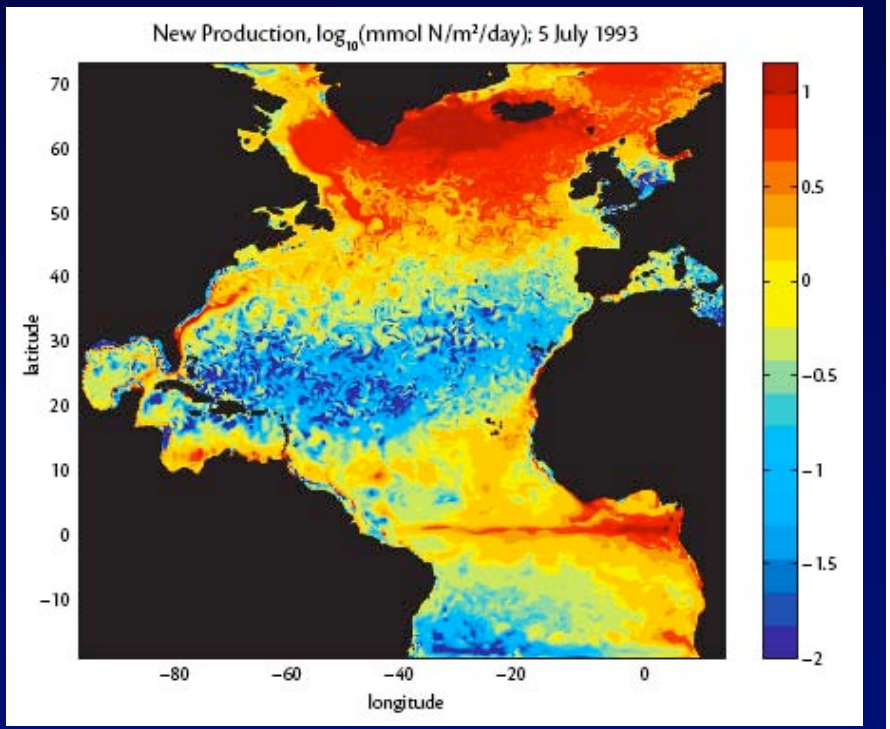
see

Siegel, D. A., Dickey, T. D., Washburn, L., Hamilton, M. K., and Mitchell, B. G.: Optical determination of particulate abundance and production variations in the oligotrophic ocean, Deep-Sea Res., 36, 211–222, 1989.

Ultimate Goal:

An Interdisciplinary, Coupled, and Data Assimilating Observation and Modeling System





cmep

Bays to Basins

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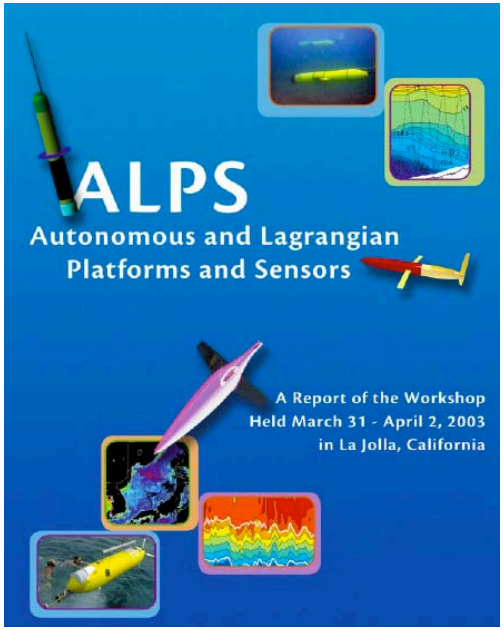
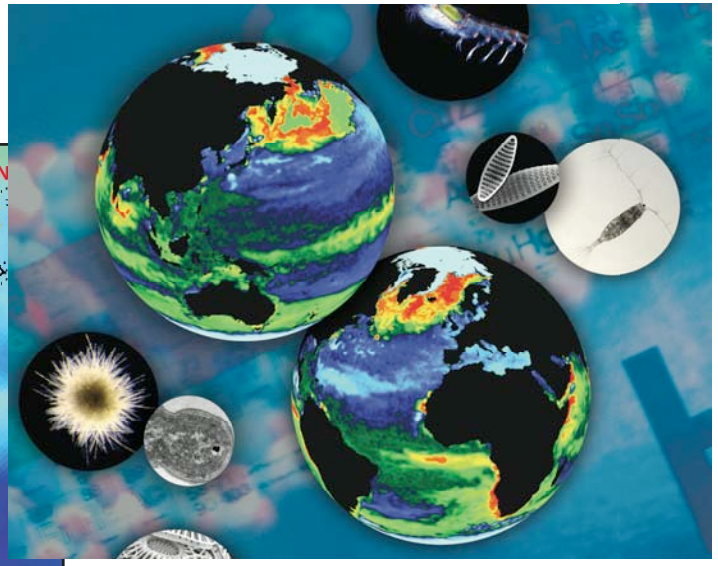
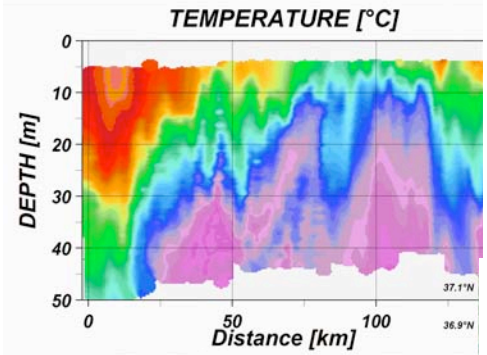
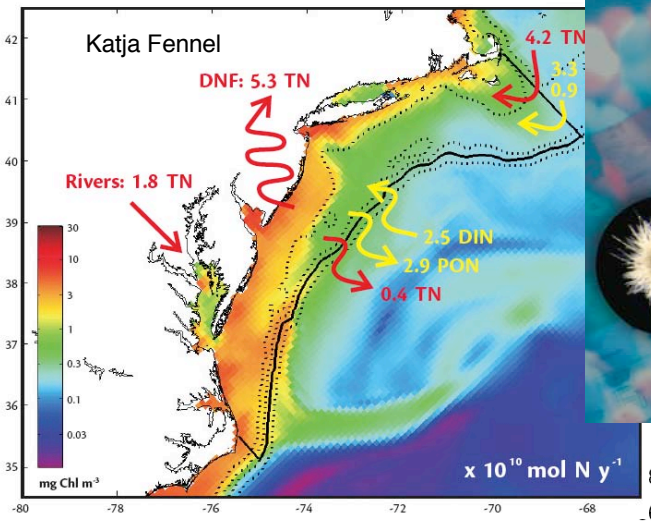


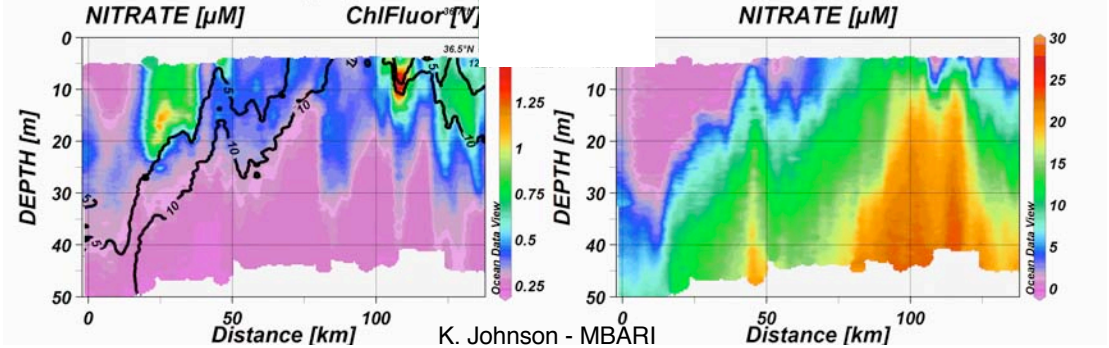
And also:

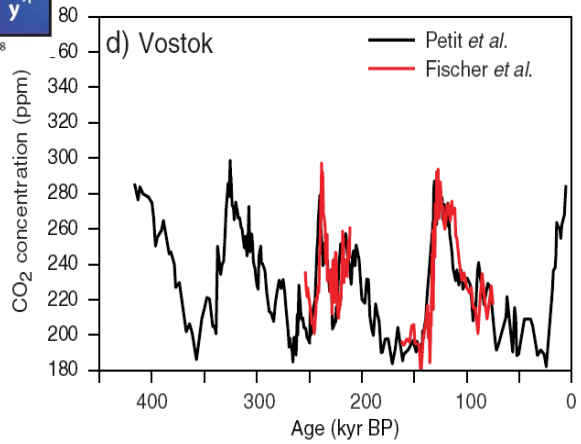
To understand how physically forced oceanographic variability is integrated by marine ecosystems in space and time to result in the biogeochemical state of the ocean.





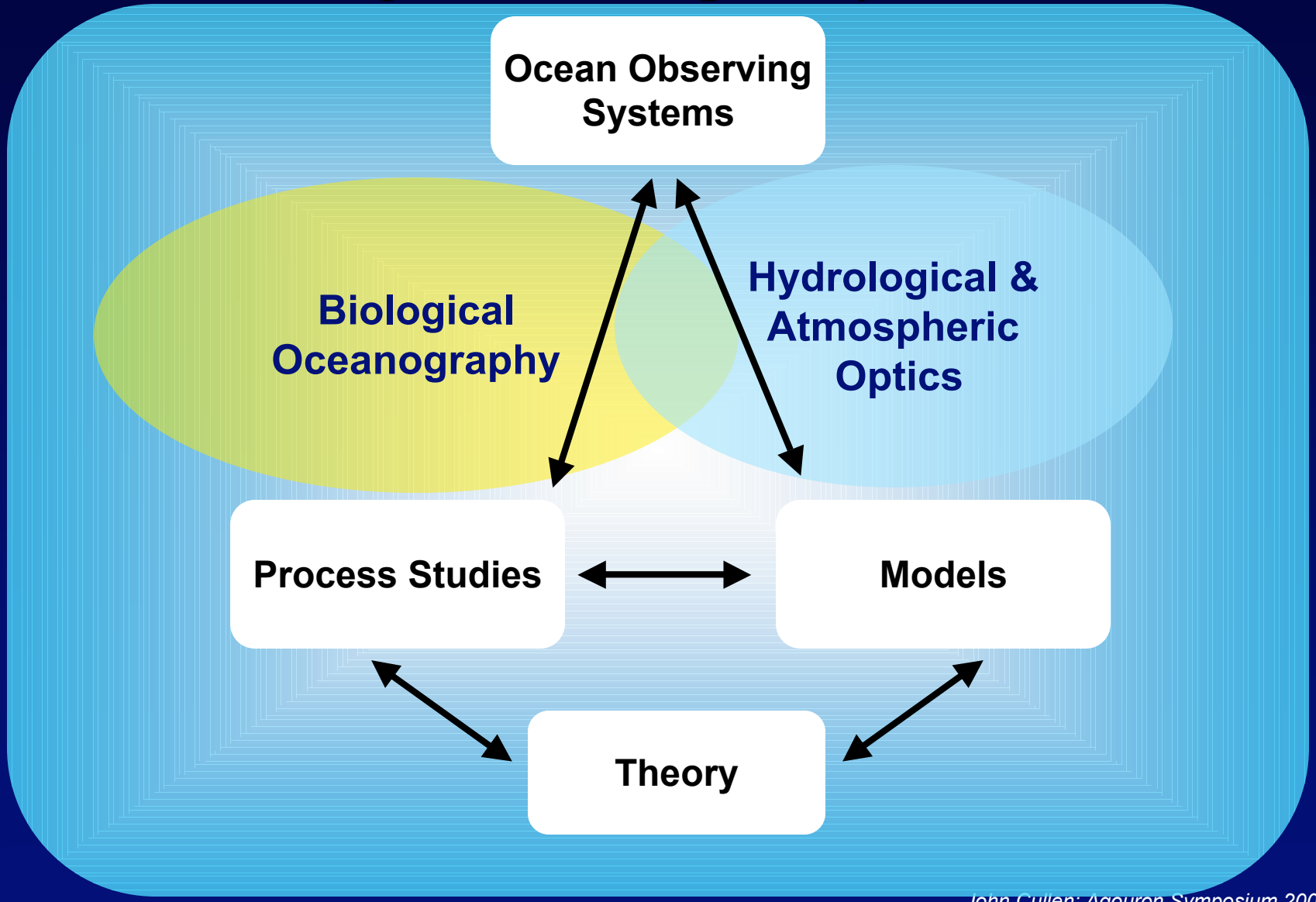




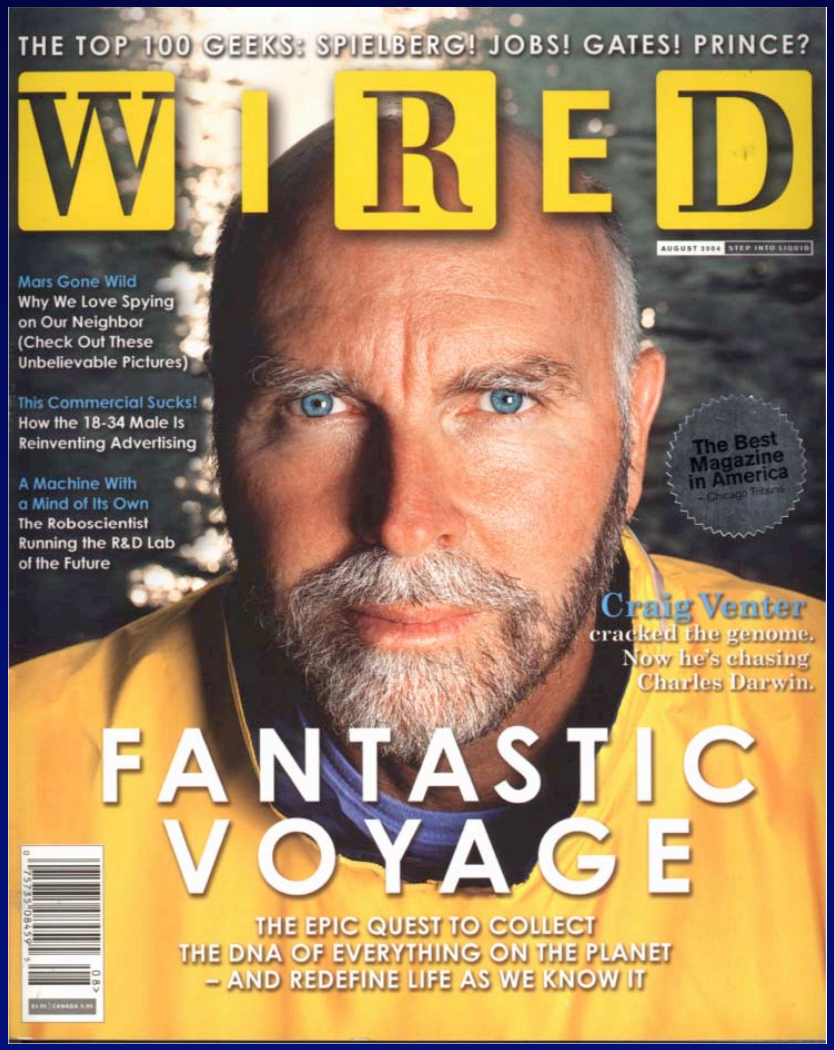


K. Johnson - MBARI

New capabilities were developed through interdisciplinary research



Where does molecular ecology and genomics fit in?



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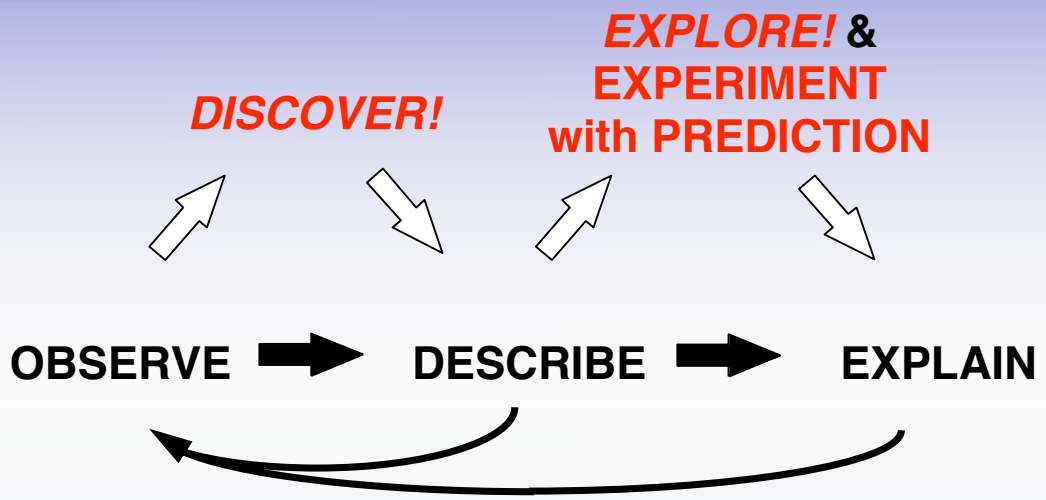
What have advances in molecular ecology and genomics contributed? What can be contributed?



GOAL: PREDICTION WITH MEASURABLE SKILL

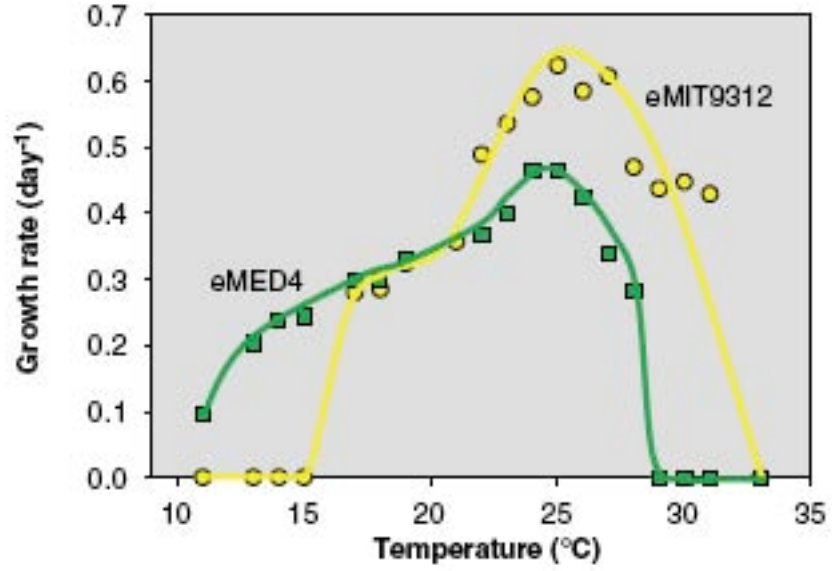
Needs: **Technology for observations**
Integration of knowledge → Insight
(opportunity to think)

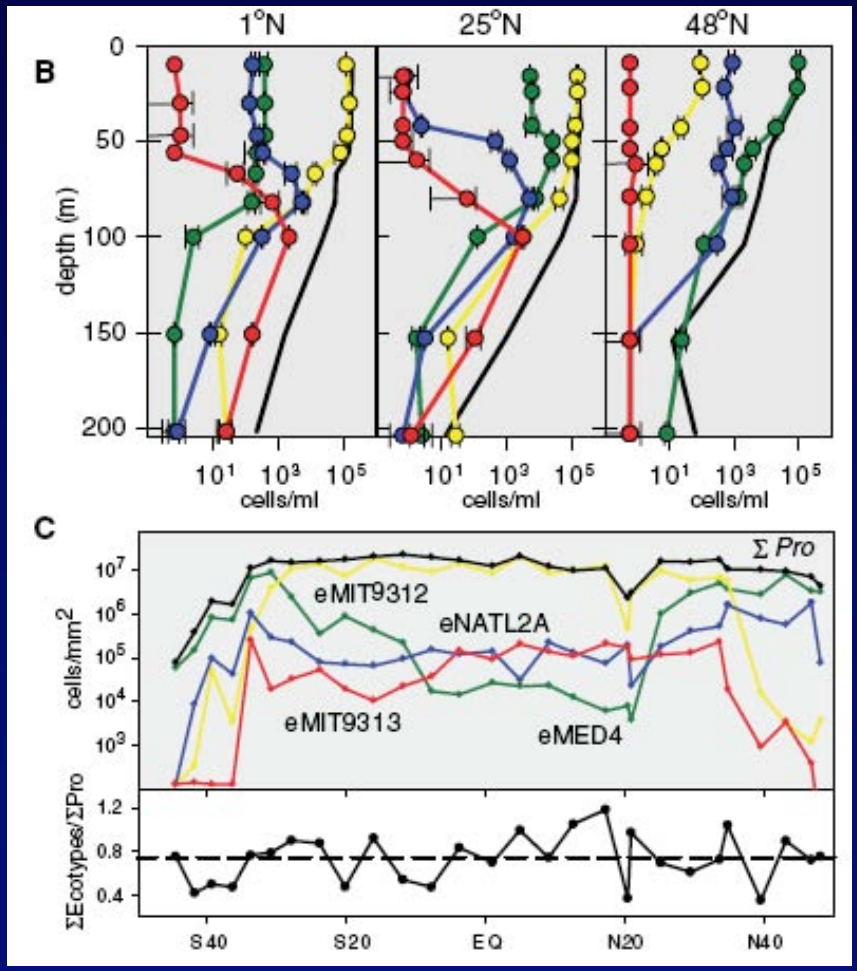
Answers: a) Lots. b) Lots more!

Distributions of functional groups distinguishable no other way

Niche Partitioning Among *Prochlorococcus* Ecotypes Along Ocean-Scale Environmental Gradients

Zackary I. Johnson,[1,2]* Erik R. Zinser,[1,3]* Allison Coe,[1] Nathan P. McNulty,[1] E. Malcolm S. Woodward,[4] Sallie W. Chisholm[1]†





SCIENCE VOL 311 24 MARCH 2006

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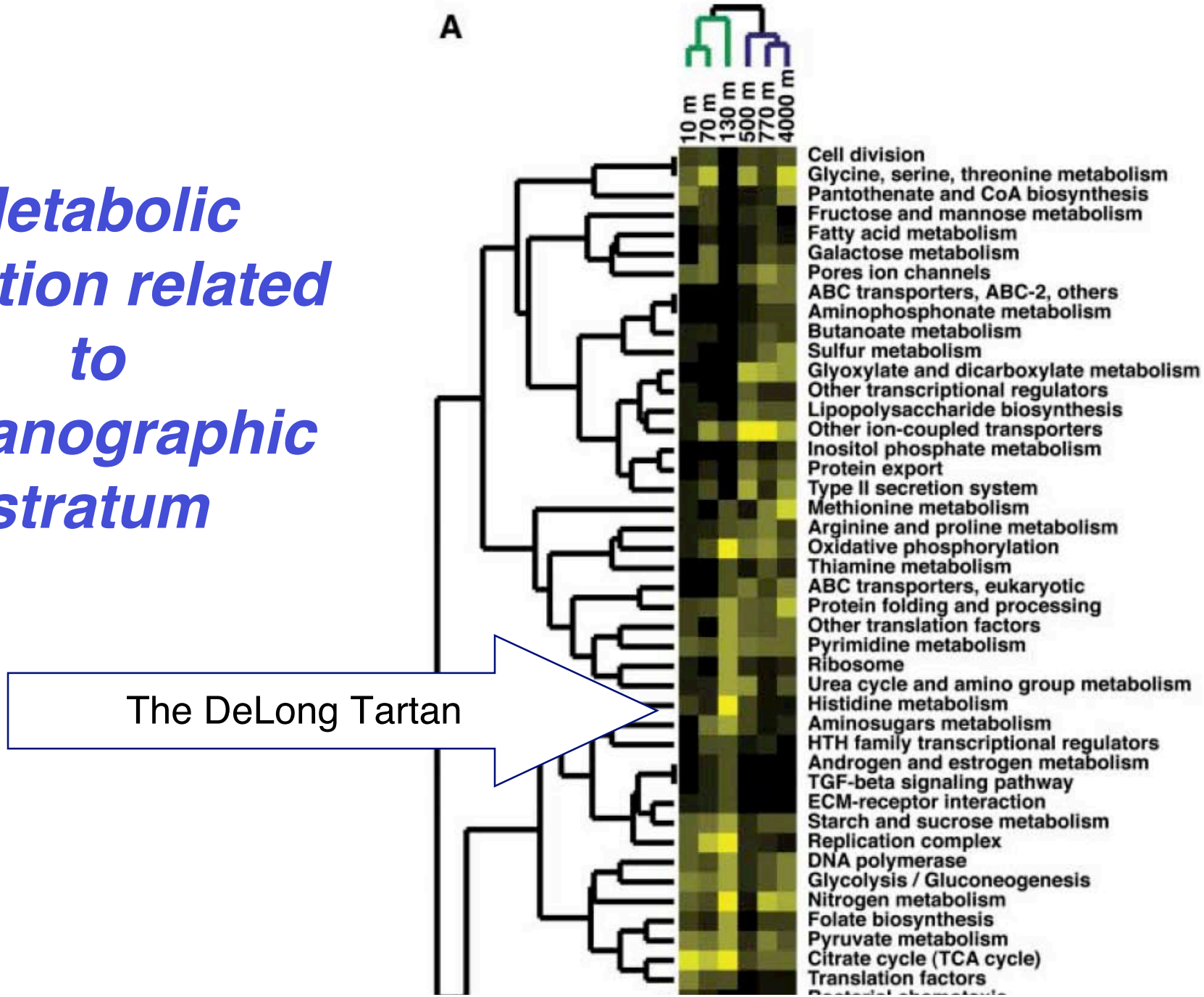
Metabolic function related to oceanographic stratum

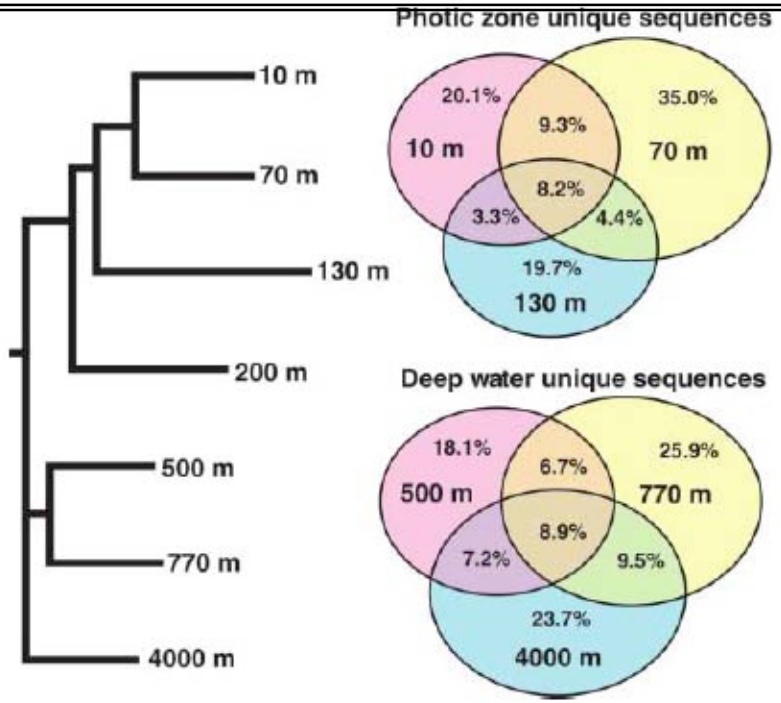


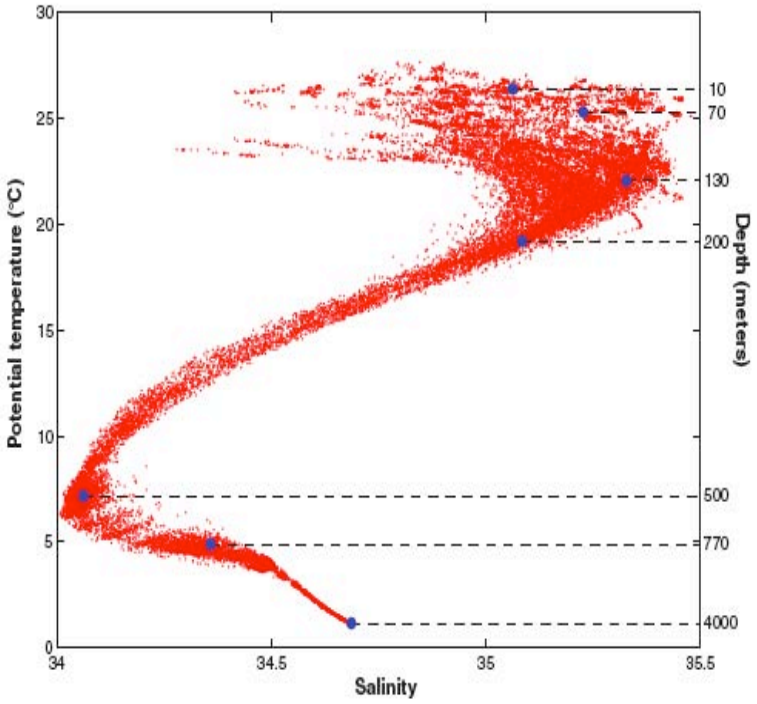
The critical ingredient: ENVIRONMENTAL CONTEXT

SCIENCE VOL 311 27 JANUARY 2006

Community Genomics Among Stratified Microbial Assemblages in the Ocean's Interior

Edward F. DeLong,[1*] Christina M. Preston,[2] Tracy Mincer,[1] Virginia Rich,[1] Steven J. Hallam,[1] Niels-Ulrik Frigaard,[1] Asuncion Martinez,[1] Matthew B. Sullivan,[1] Robert Edwards,[3] Beltran Rodriguez Brito,[3] Sallie W. Chisholm,[1] David M. Karl[4]





Genetic variability related quantitatively to well defined ecological regimes

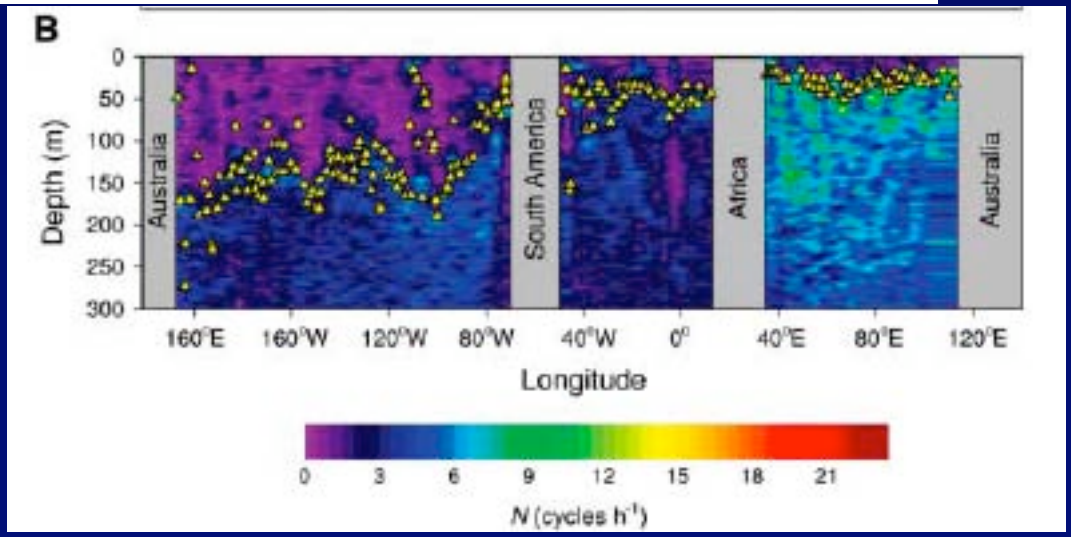
Science, 2006

Explicit consideration of oceanographic processes and measurements

Oceanographic Basis of the Global Surface Distribution of *Prochlorococcus* Ecotypes

Heather A. Bouman,[1*] Osvaldo Ulloa,[1] David J. Scanlan,[3] Katrin Zwirglmaier,[3] William K. W. Li,[4] Trevor Platt,[4] Venetia Stuart,[5] Ray Barlow,[6] Ole Leth,[2] Lesley Clementson,[7] Vivian Lutz,[8] Masao Fukasawa,[9] Shuichi Watanabe,[9] Shubha Sathyendranath[5]

12 MAY 2006 VOL 312 SCIENCE www.sciencemag.org



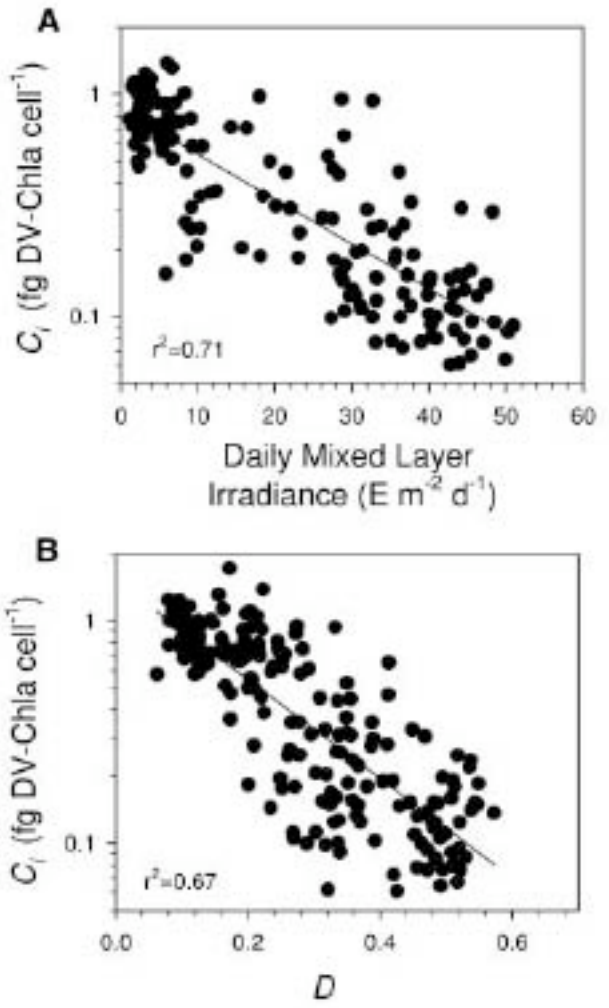
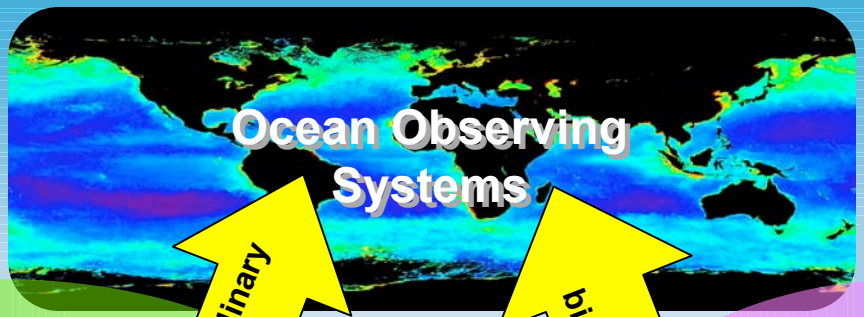


Fig. 3. Relationship between the intracellular concentration of divinyl chlorophyll a (C_i) for *Prochlorococcus*. (**A**) The average daily irradiance within the mixed layer ($\bar{I}_m$) and (**B**) the ratio of the sum of the concentration of photoprotective pigments to the total pigment concentration (D) for samples collected during the BEAGLE expedition.

The challenge: Get to **this** sooner rather than later



Genomics & the other 'omics

Physical Chemical & Biological Oceanography

Hydrological & Atmospheric Optics [+Acoustics]

Integrated interdisciplinary sensor systems

Assimilative biogeochemical models

Process Studies

Theory / Models

Physiological Ecology Including Gene Expression

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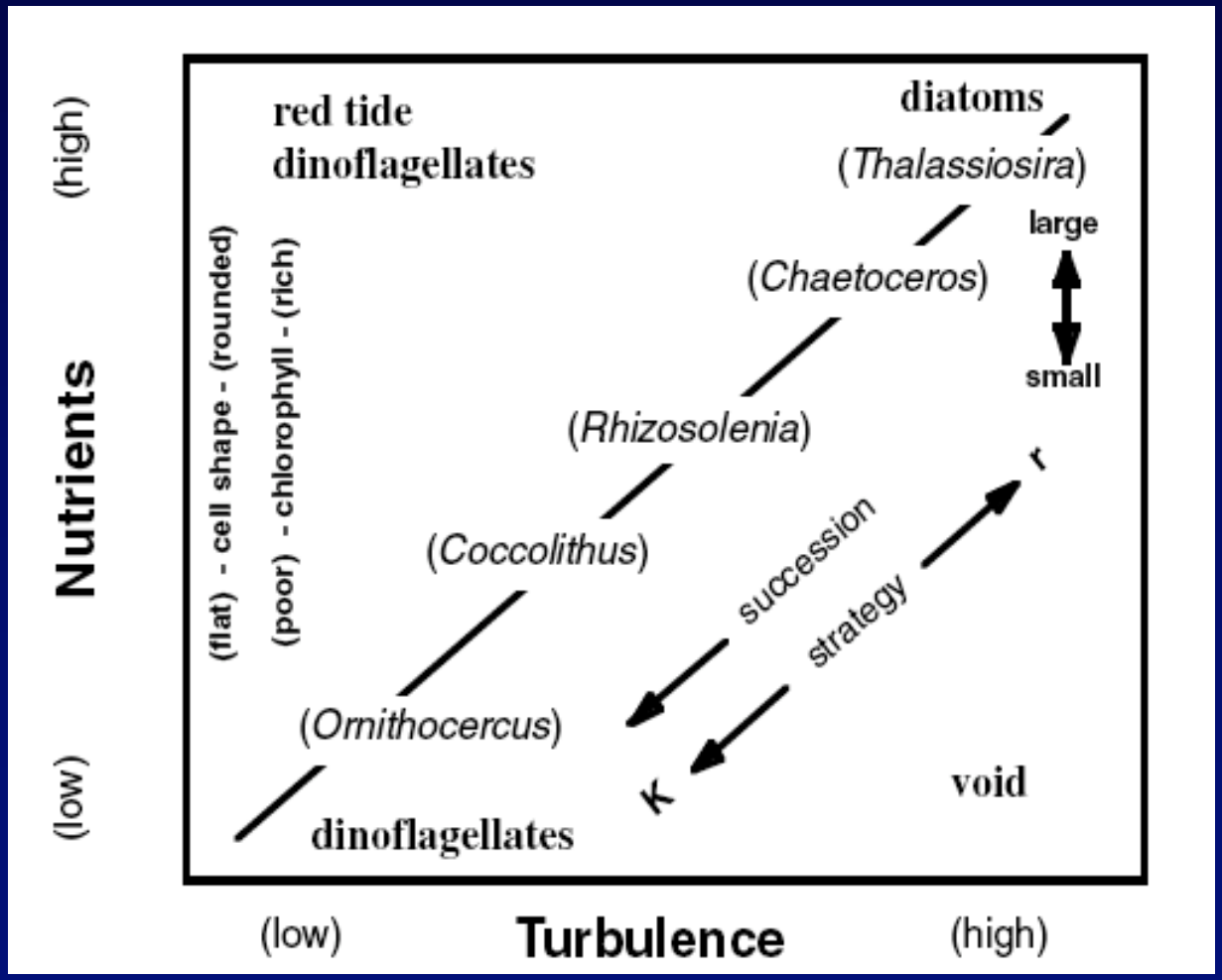
A Tool for Making Sense of Microbial Diversity in the Marine Environment:

Margalef's Mandala



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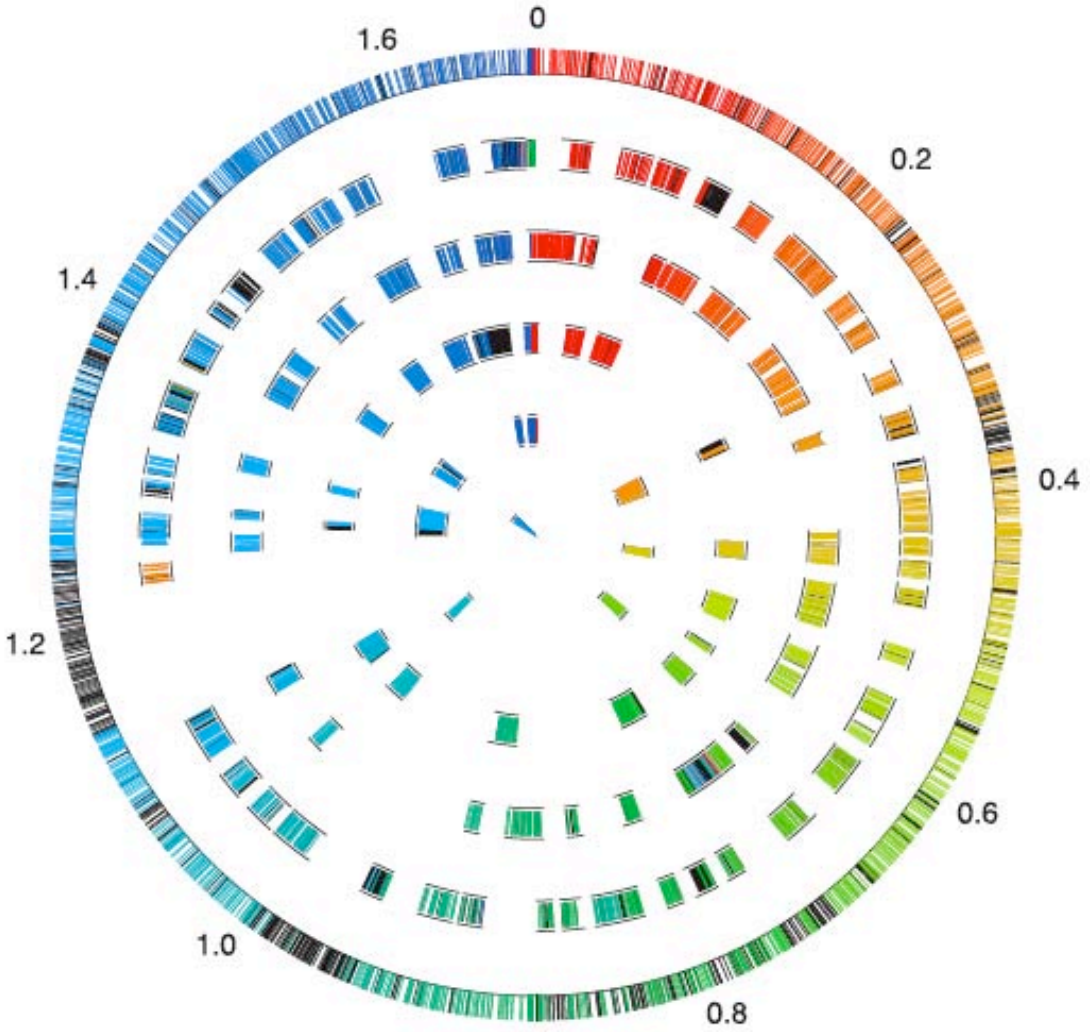
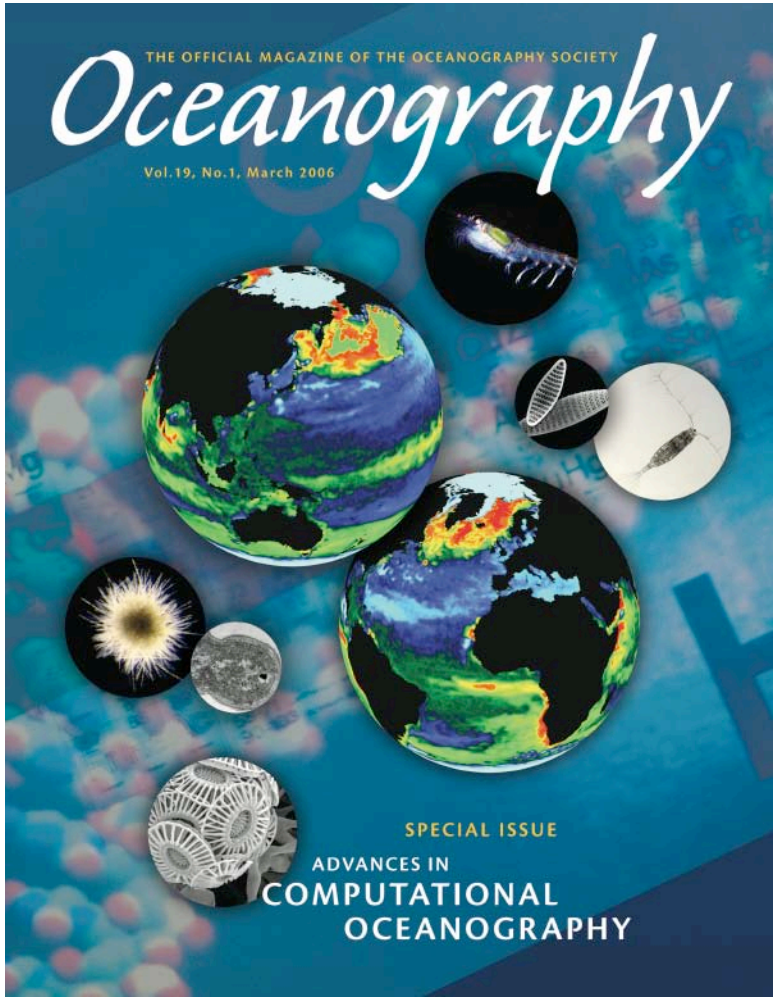
The Genomics Mandala?

Fig. 2. Gene conservation among closely related *Prochlorococcus*. The outermost concentric circle of the diagram depicts the competed genomic sequence of *Prochlorococcus marinus* MED4 (*11*). Fragments from environmental sequencing were compared to this completed *Prochlorococcus* genome and are shown in the inner concentric circles and were given boxed outlines.



Venter et al., Science, 2004

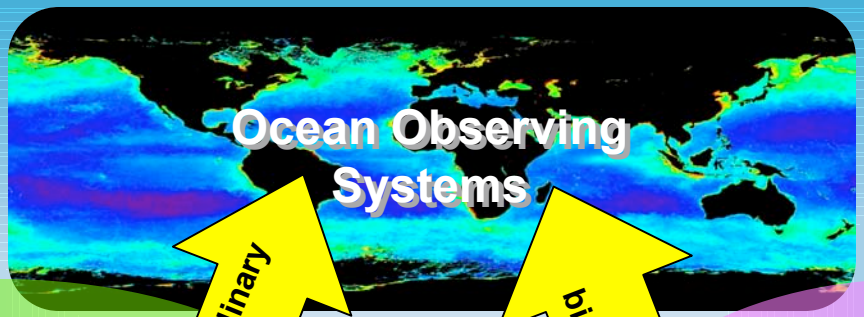


in fact, it may not be premature to state that for marine microbes, the species concept is "road kill" on the genomics highway.

Jargon of vocabulary?

Oceanography	Bio-Optics	Genomics
Turbulence Closure Scheme	Apparent Optical Properties	Fosmids
Shear Instability	Volume Scattering Function	TBLASTX high-scoring sequence pair bitscores
N-star	Packaging effect	KEGG and COG annotated bins
Hydrostatic model	Inelastic scatter	ORFs
Net westward intensification	Normalized water leaving radiance	BAC
PDO	Average cosine of downwelling irradiance	contigs
Mode water eddy	Semi-analytic model	synteny
Rossby wave	Hyperspectral absorption - attenuation	distinctly nonpunctate
Triple isotope oxygen	Nonphotochemical quenching	scaffold

The challenge: Get to **this** sooner rather than later



Genomics & the other 'omics

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Integrated interdisciplinary sensor systems

Assimilative biogeochemical models

Process Studies

Theory / Models

Physiological Ecology Including Gene Expression

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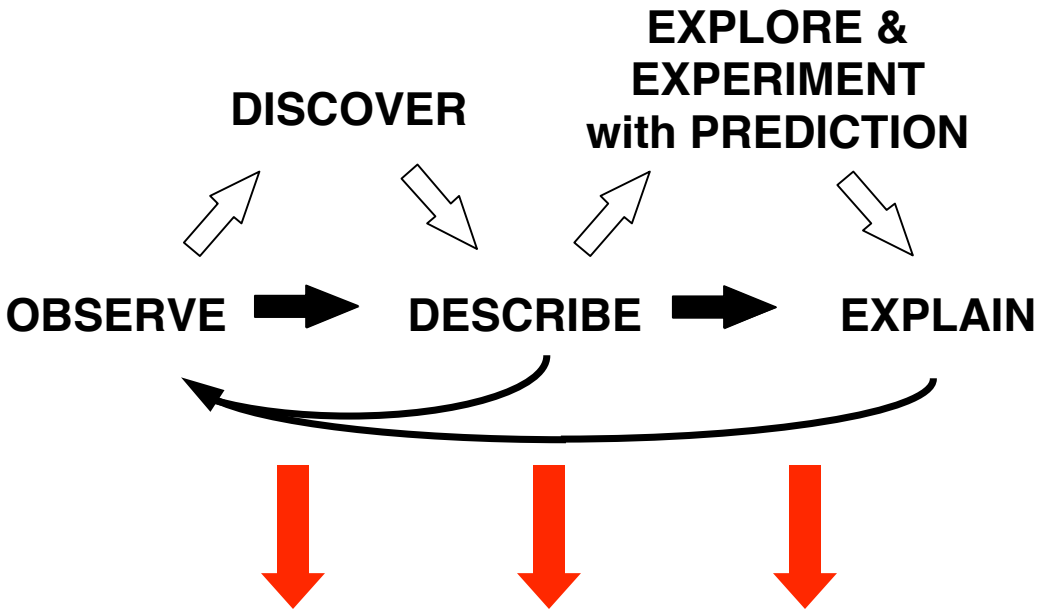
We will need "Sense-Making Tools" in a world of Too Much Information

after Paul Saffo
Institute for the Future



Knowledge – Insight

for

Research – Education – Outreach – Management

The "VISION" Portal

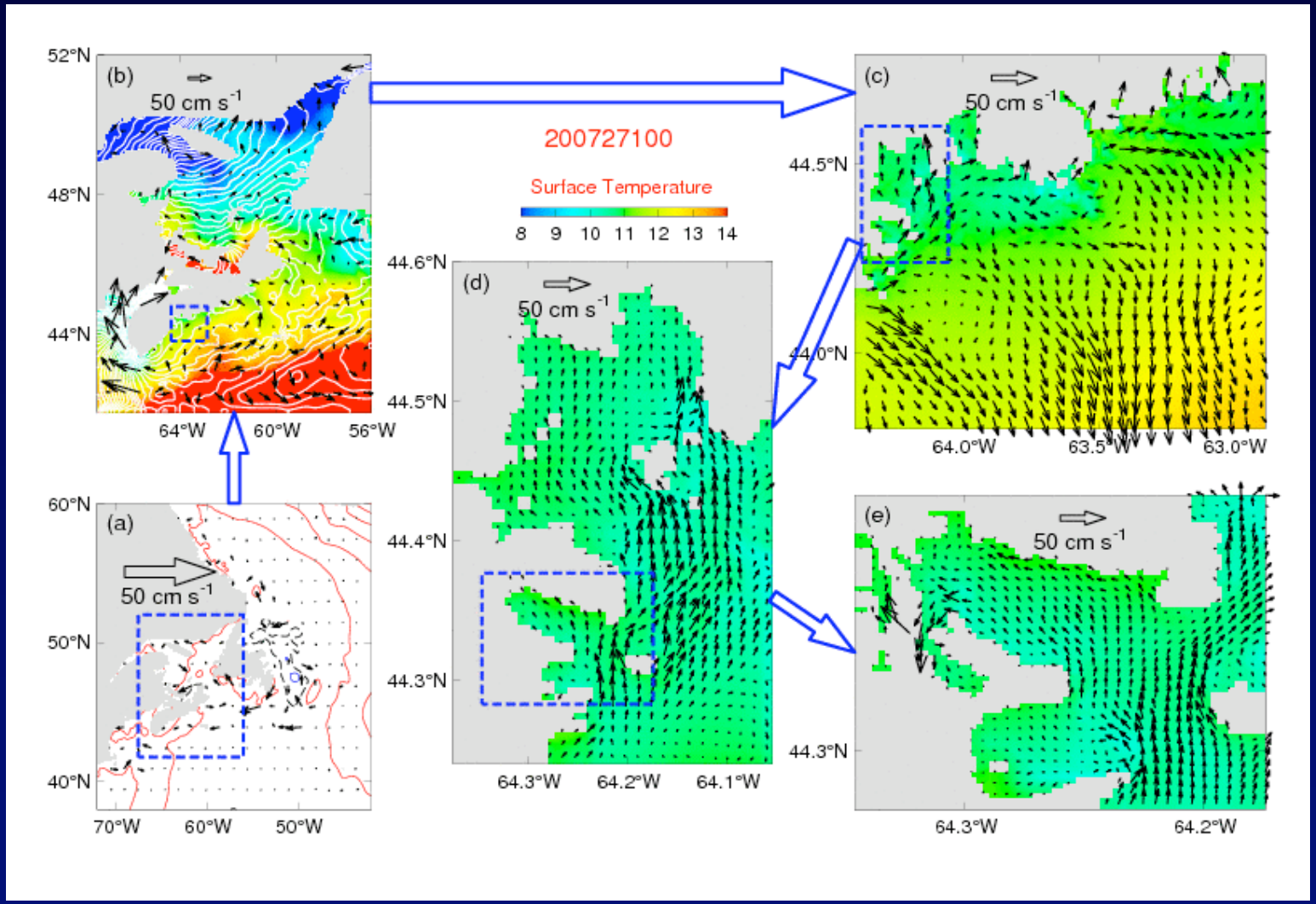
Virtual-reality Information System and Integrated Ocean-observing Network

- Virtual reality access to all ocean environments
  - Fully 4-dimensional
  - Scalable from global to mm and smaller
  - Physical, chemical, biological
- Direct access to oceanographic data
  - Integrated with the Global Ocean Observing System
    - DATA
    - MODELS
- Contextual hyperlinks to scientific literature and databases
- Multiple levels of interaction
  - Entertainment, education, exploration, research, prediction

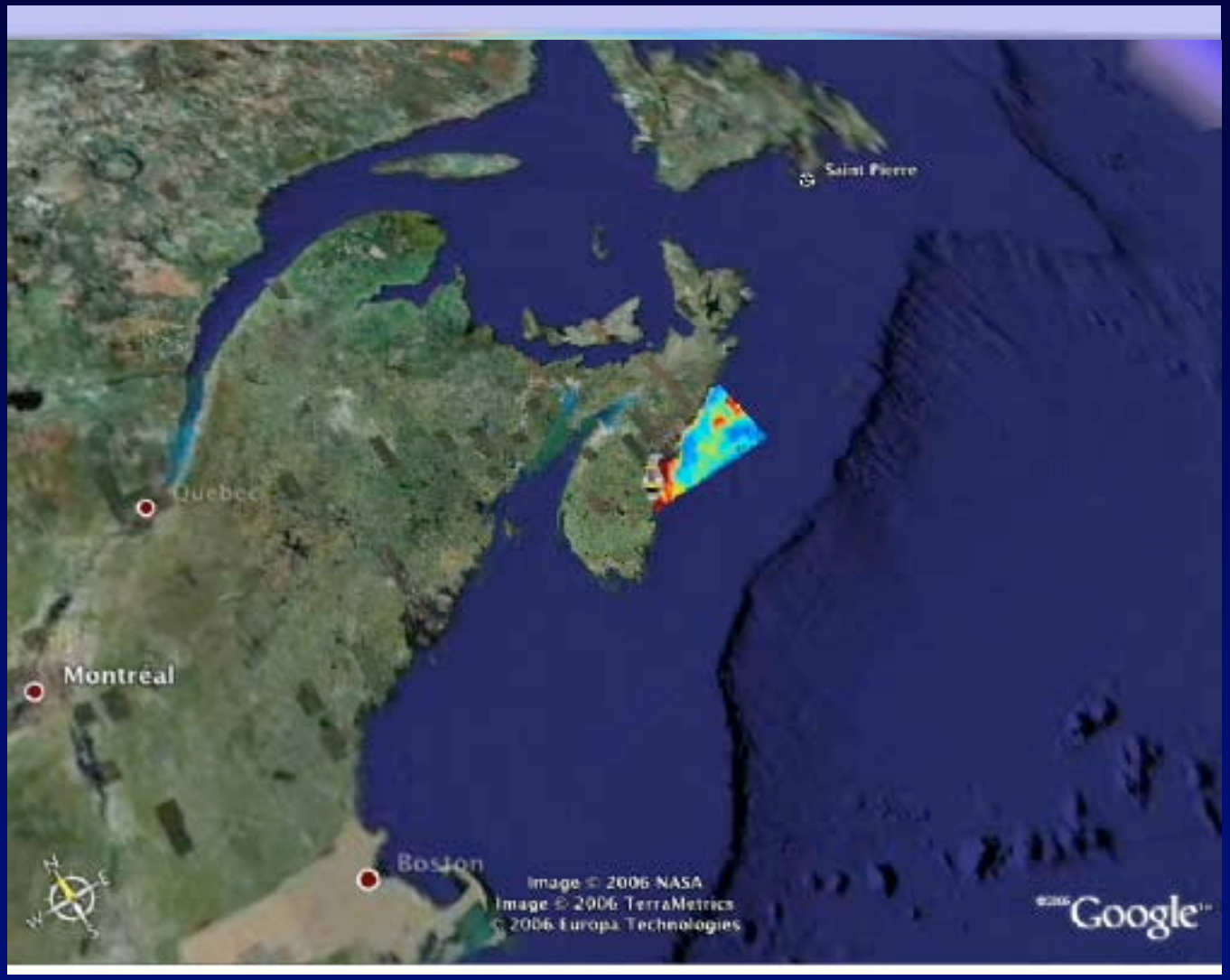
The "Lunenburg Project":

Interdisciplinary Marine Environmental Prediction in the Atlantic Coastal Region

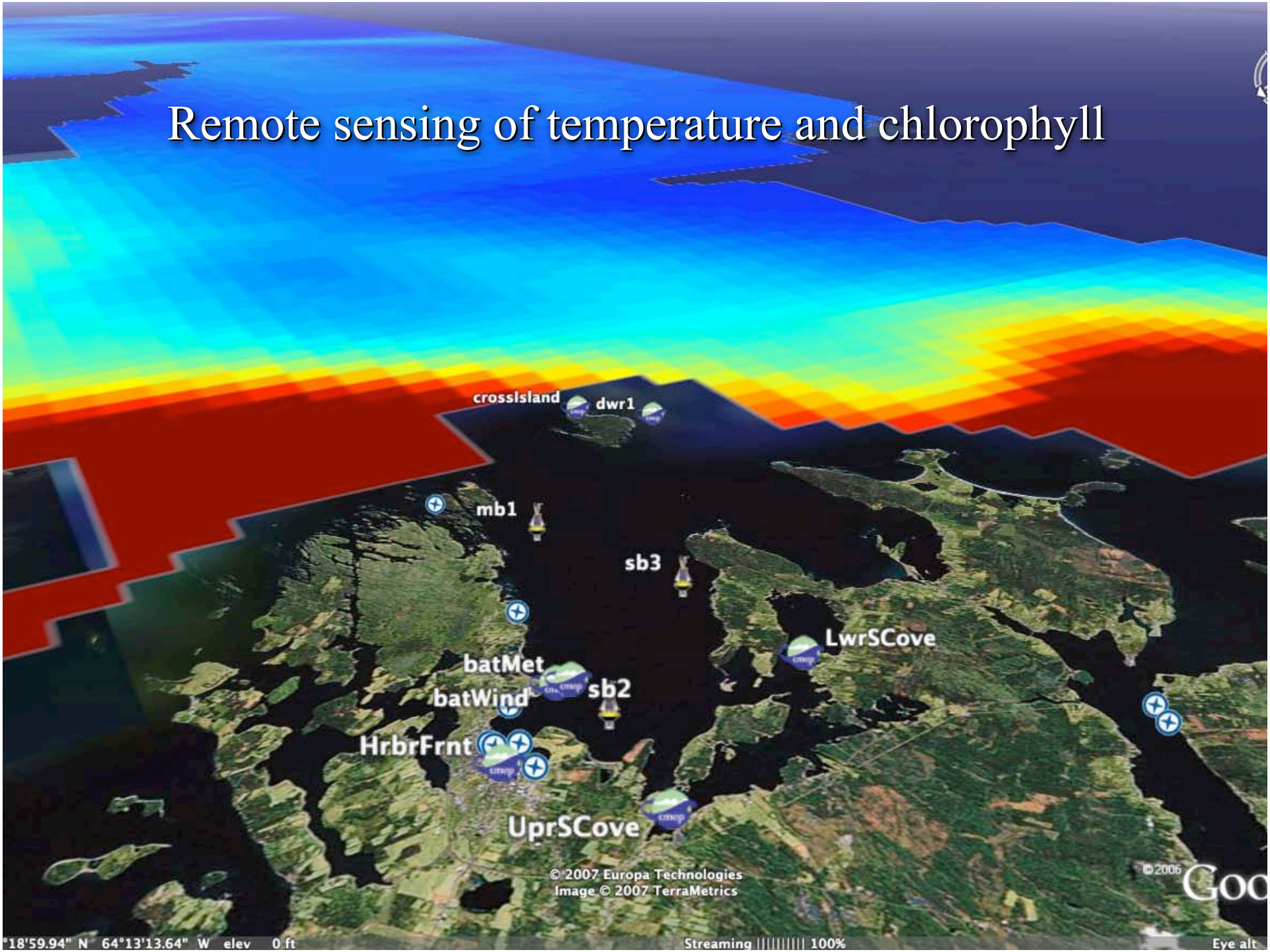
Models within models within models



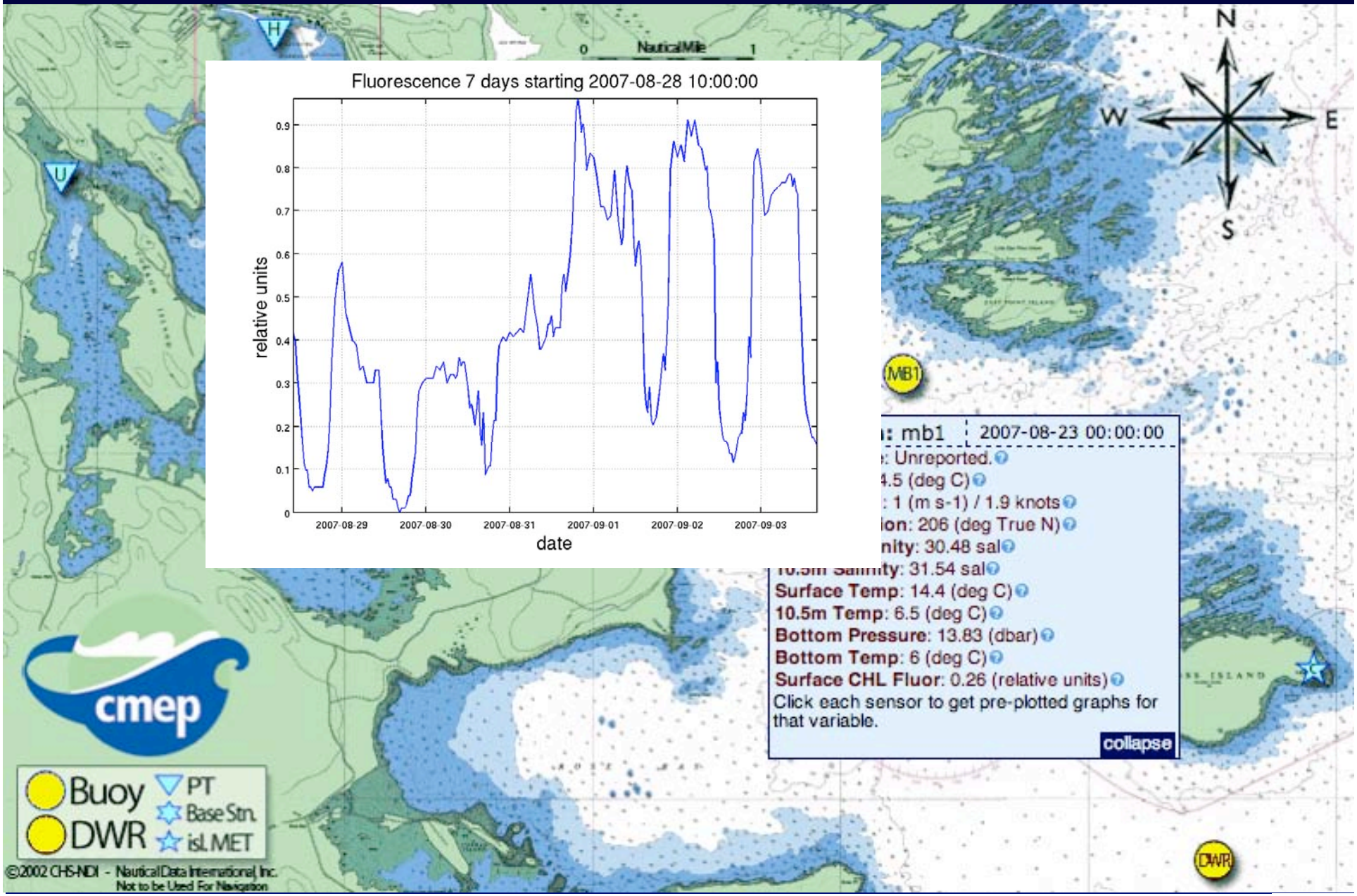
Google Earth Access



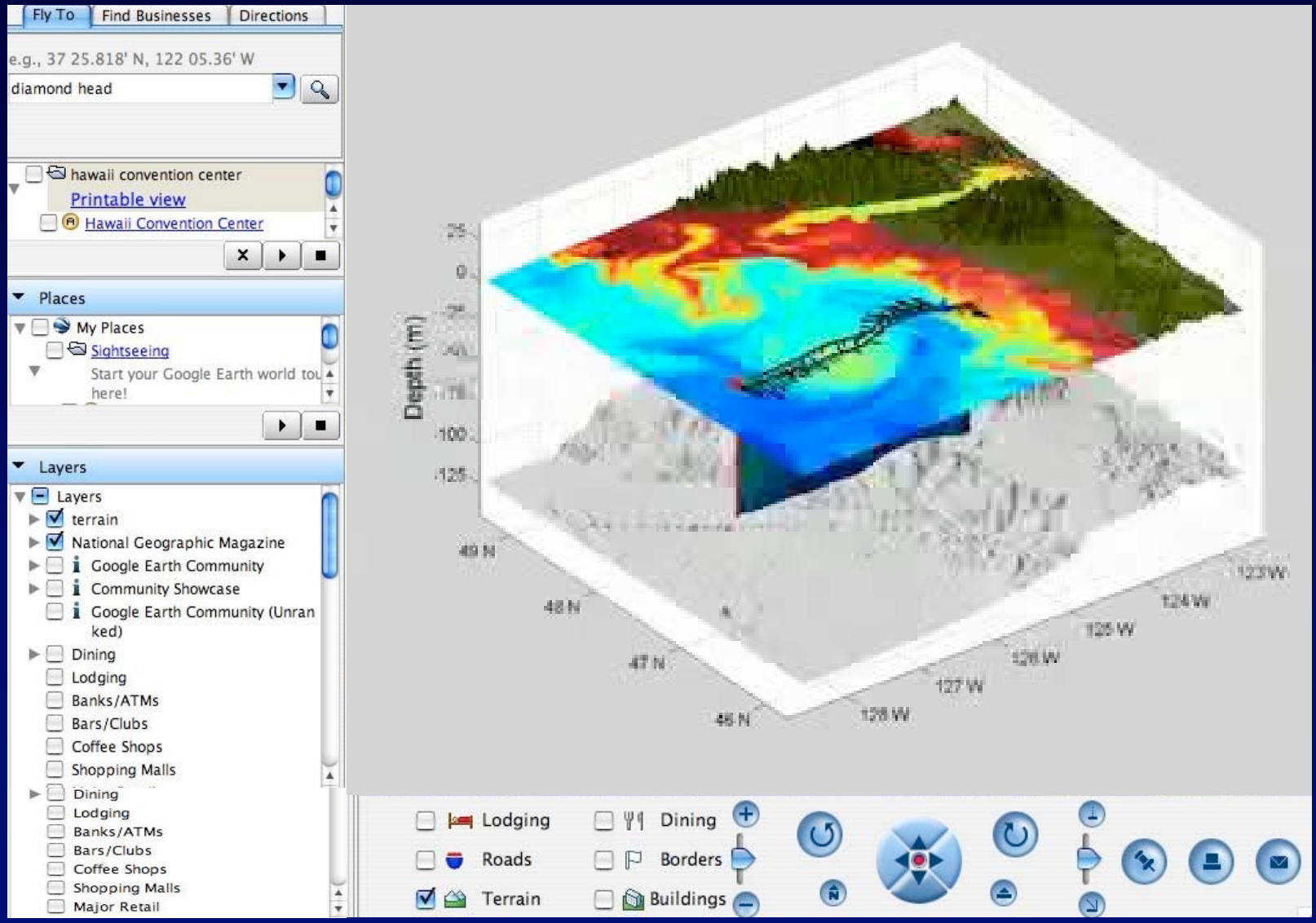
Remote sensing of temperature and chlorophyll



Easy access to real-time and archived data

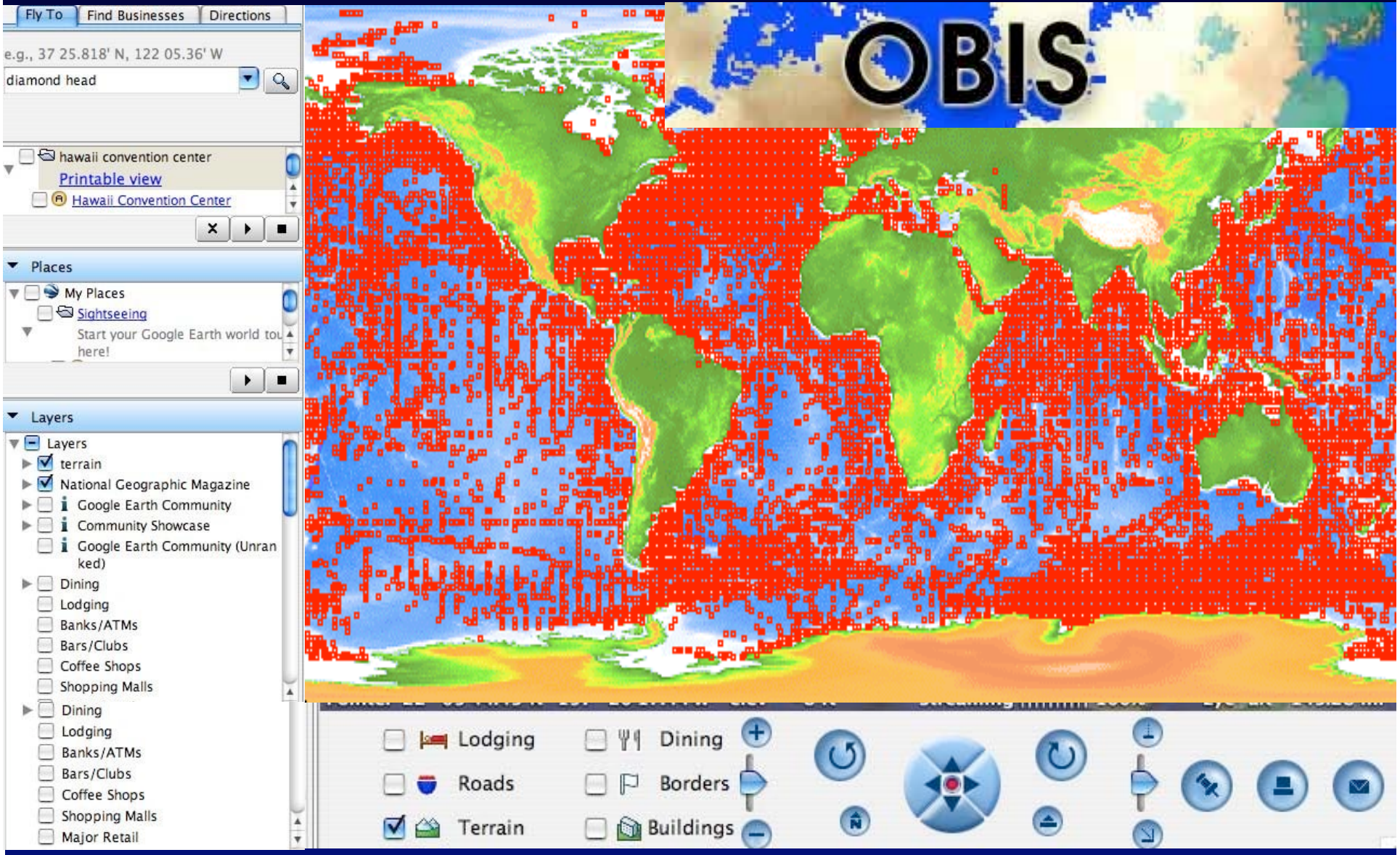


Probe the Ocean Depths



Brandon Sackmann, University of Maine
http://optics.dmc.maine.edu/sackmann/wash_coast/WashCoastAnim.avi

Switch to layers for all ocean information systems



Layers for All Ocean Knowledge

- Weather
- Hazards
- History
- Currents
- Shipwrecks
- Surf Report
- Minerals
- Ecosystems
- Pollution
- Forecasts
- Climate models
- Bottom type
- Genomics
- Sea Life

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Information to Knowledge through Thinking