Oscar Schofield
Rutgers University
http://rucool.marine.rutgers.edu

For the next few days here is my plan:

I am an ocean scientist, not an engineers like all of you. So we will talk about a lot of new technologies but will try to focus on what things they can teach about the ocean.

A brief view of big ocean questions facing us. What technology do we need?

A look to where the ocean is going

What are the backbone technologies to ocean observatories

Case example I: Southern Ocean processes and a future observatory

Case example II: Transport of urbanized rivers on broad continental shelves

What are some of the big initiatives in the United States?

My father was a scientist/engineer from Sweden


I grew up surfing, swimming, skin diving, fishing, and scuba diving.
The ocean has always been to central to my life.

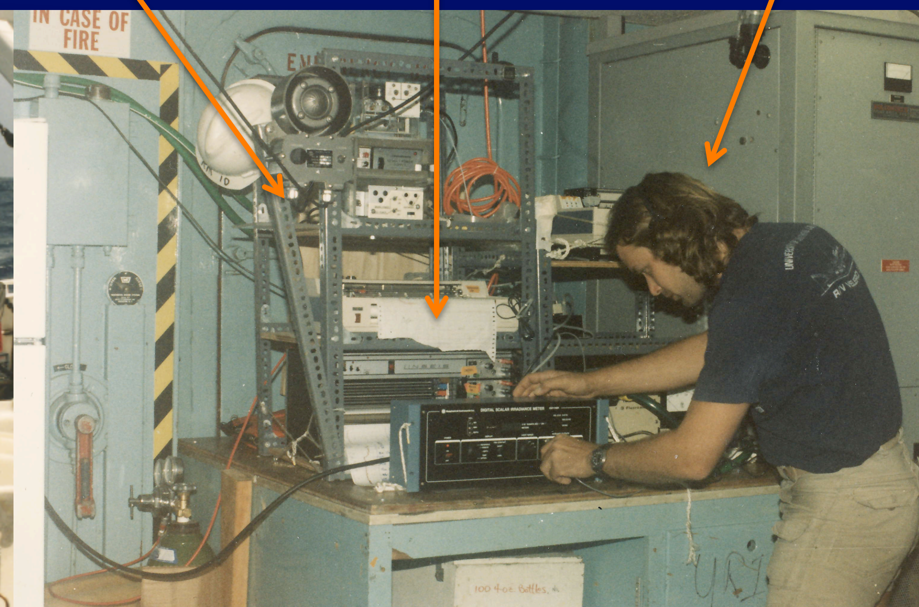
First cruise at 18, once science became an active hands-on experience, I loved it

First cruise, hand lowering instrument at age 18

Hand built instrumentation

Data recorded to paper

Bad 1980's hair

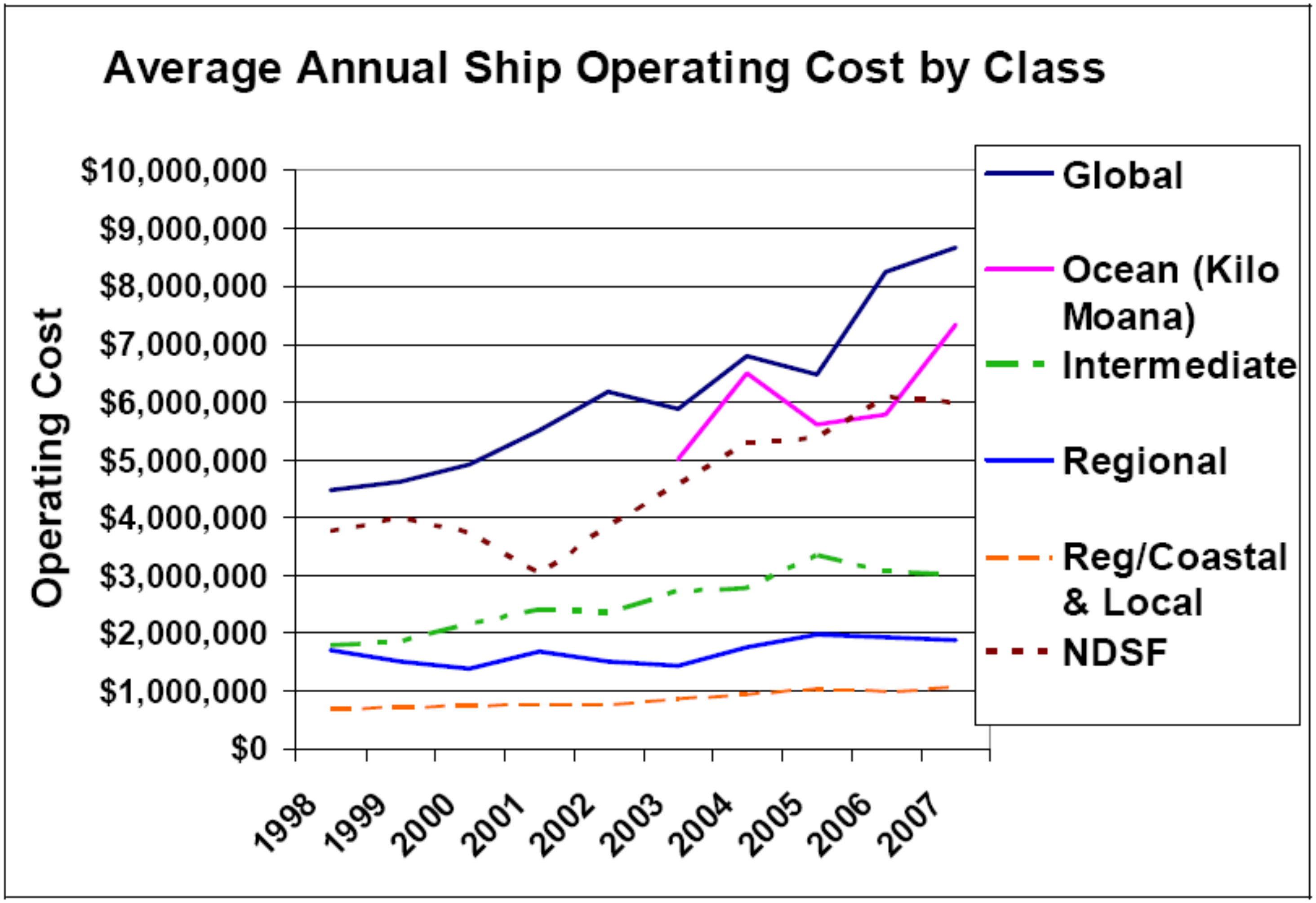


To look to the future it is useful to how far we have come?
Where were we 30 years ago?

[11]

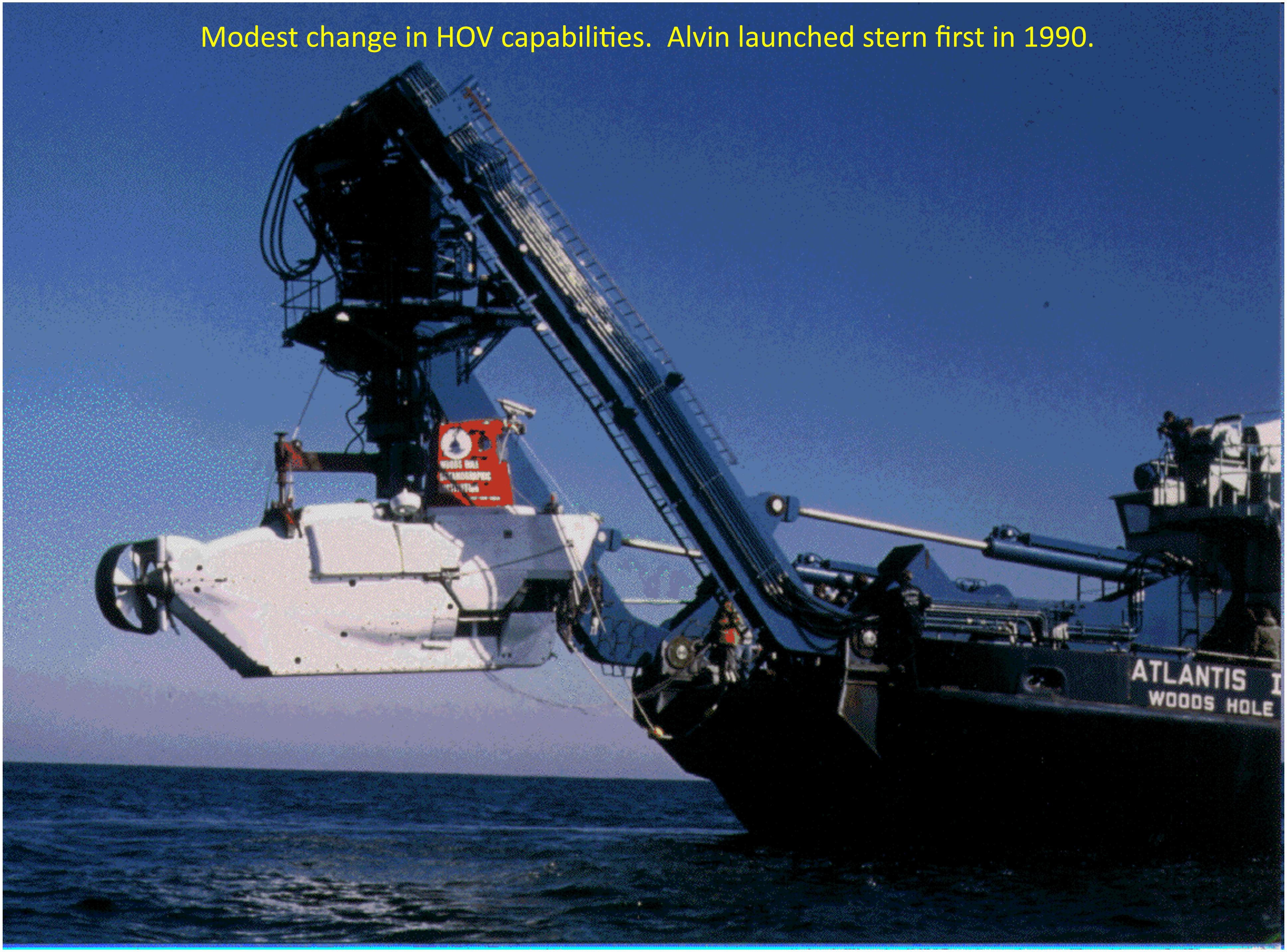
Apple II Introduced
4K of Memory

Viking 1 lands on Mars

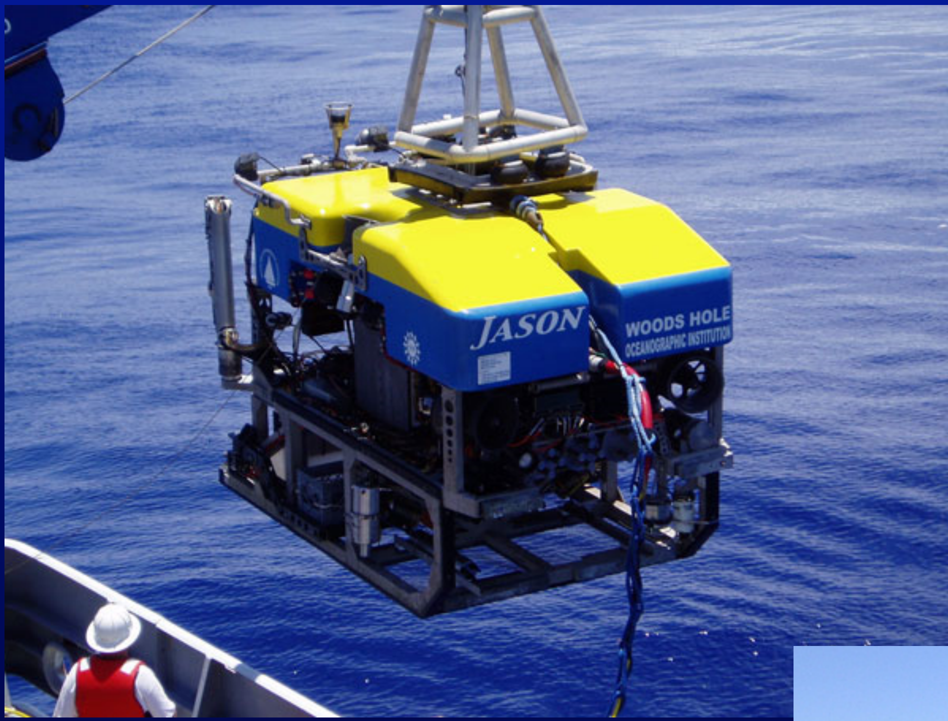


Average Annual Ship Operating Cost by Class
Operating Cost
$10,000,000
$9,000,000
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Global
Ocean (Kilo Moana)
Intermediate
Regional
Reg/Coastal & Local
NDSF

Modest change in HOV capabilities. Alvin launched stern first in 1990.



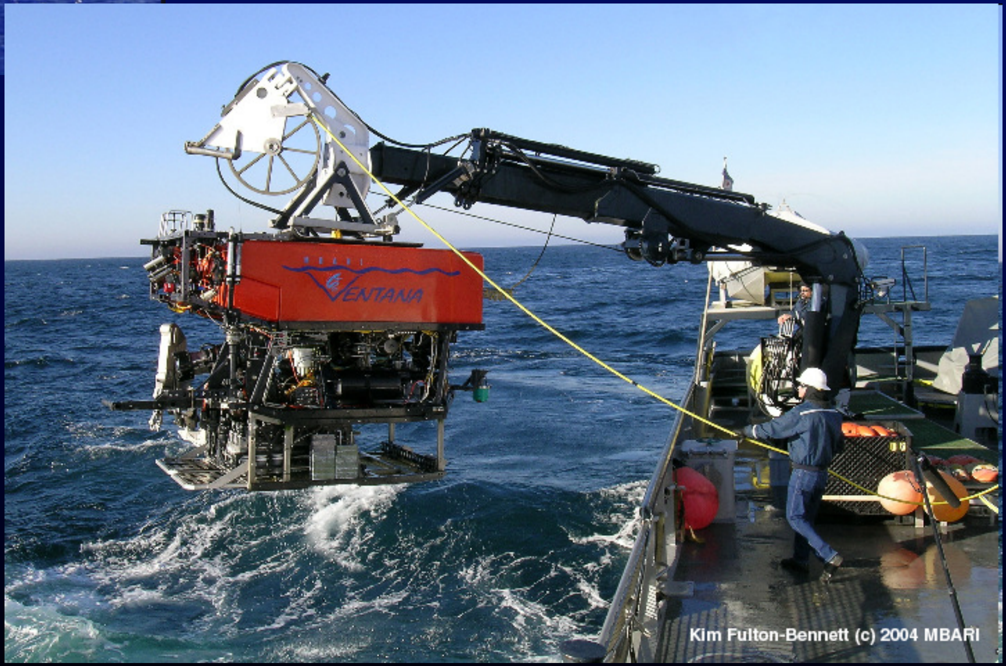
Alvin launched bow first in 2010. Biggest changes are in support ship.



Jason – 1988

Much greater change in capabilities of remotely operated vehicles, but not more vehicles. 1 ROV in National Facility. Several in private facilities.

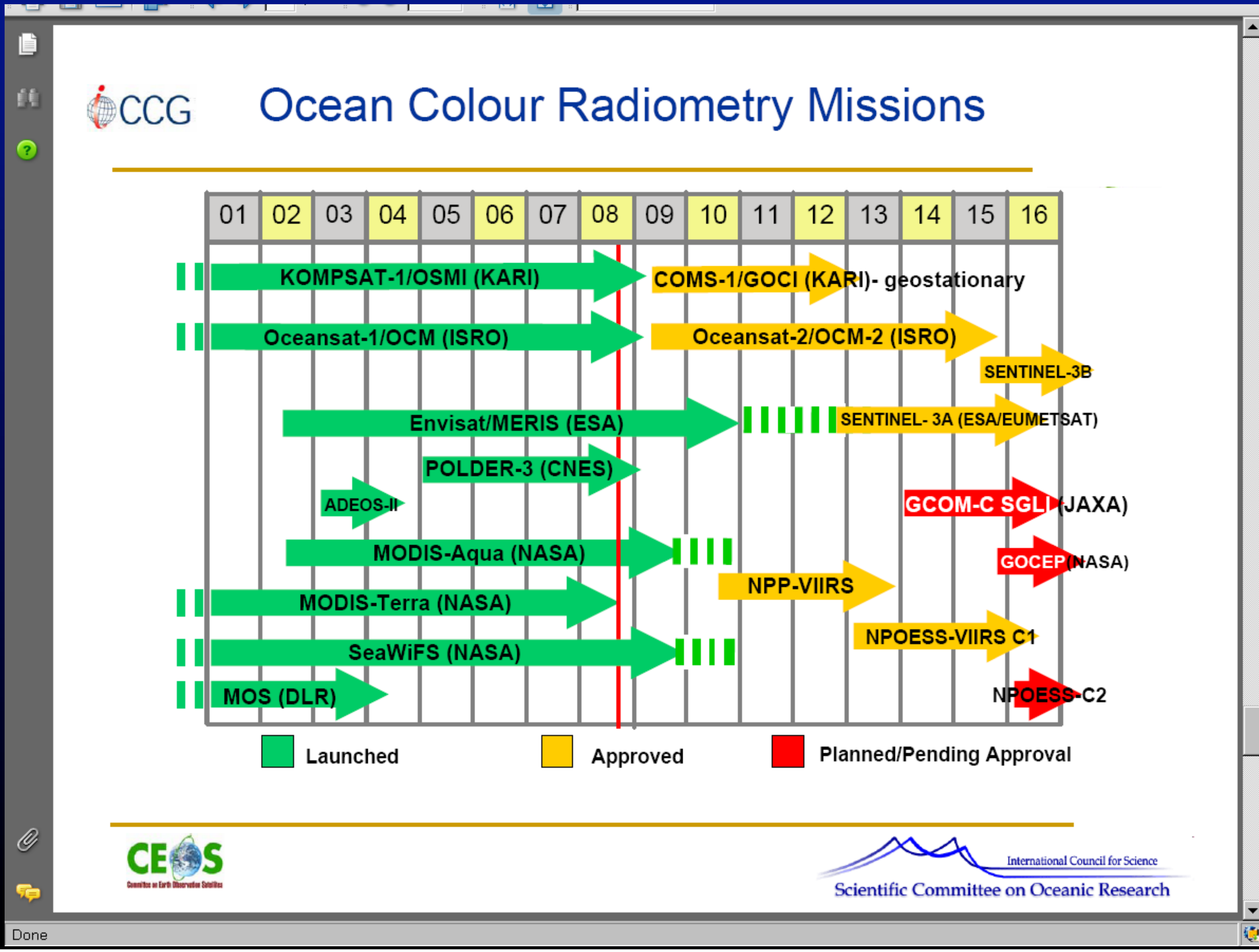
Ventana - 1988

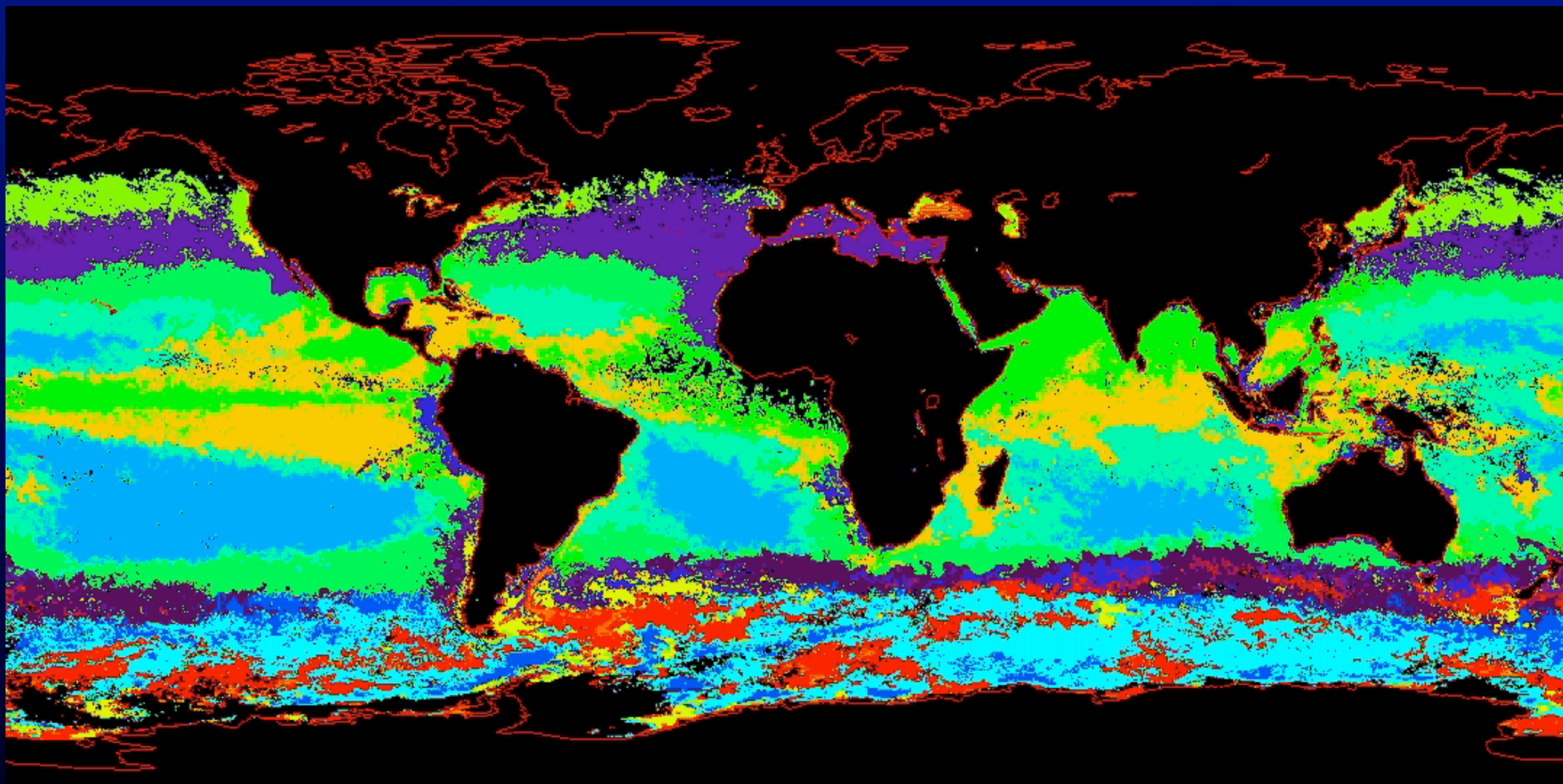


Main satellite sensors used today were operating in 1990’s. Data access and quality is better.

Satellite Altimetry (Walter Munk described TOPEX/Poseidon as "the most successful ocean experiment of all times”) has gone from one platform in 1992 to an array today.

Coastal Zone Color Scanner operated 1978 to 1986 and then a hiatus until 1997. A large array of ocean color missions with different functions:



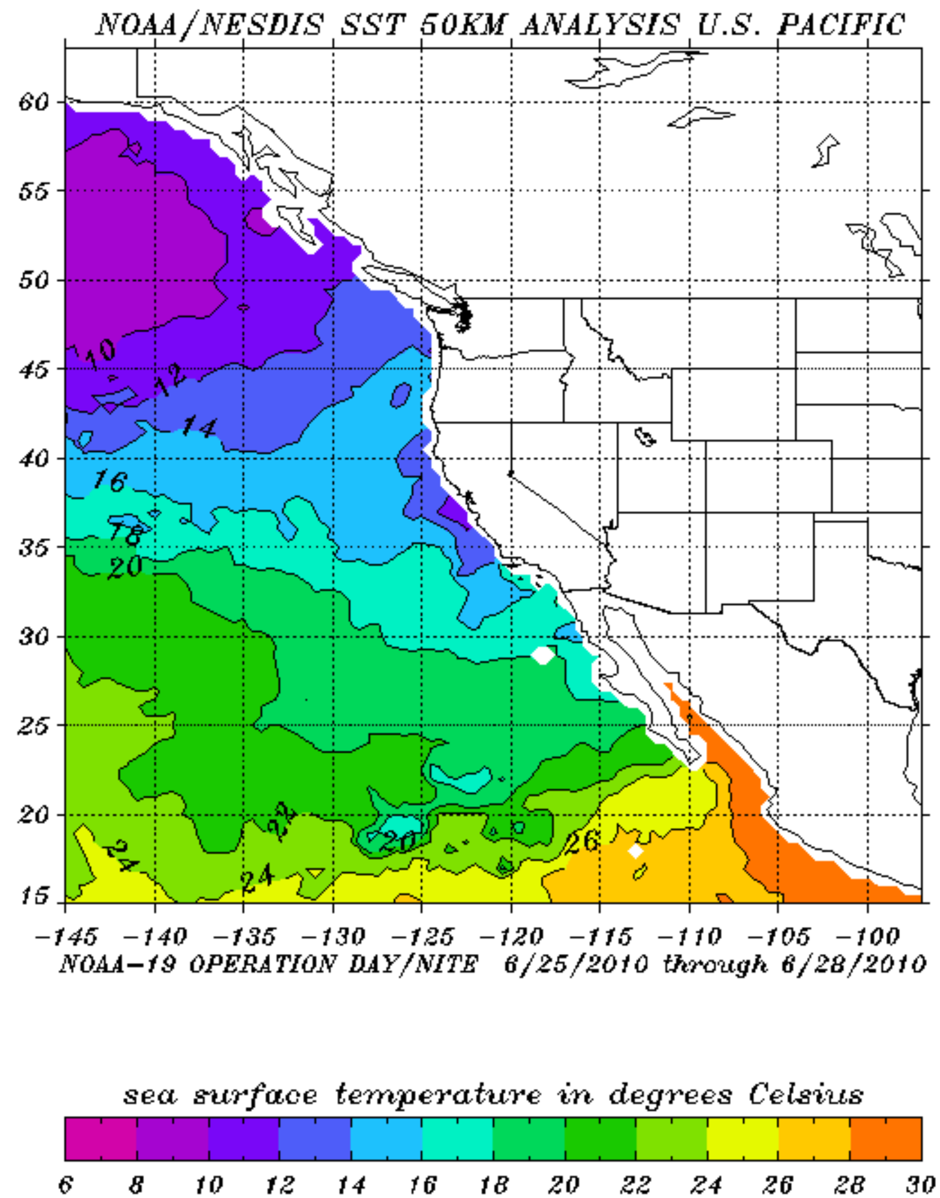


Sea Surface Temperature – "NOAA has been providing research quality SST data continuously since 1981"

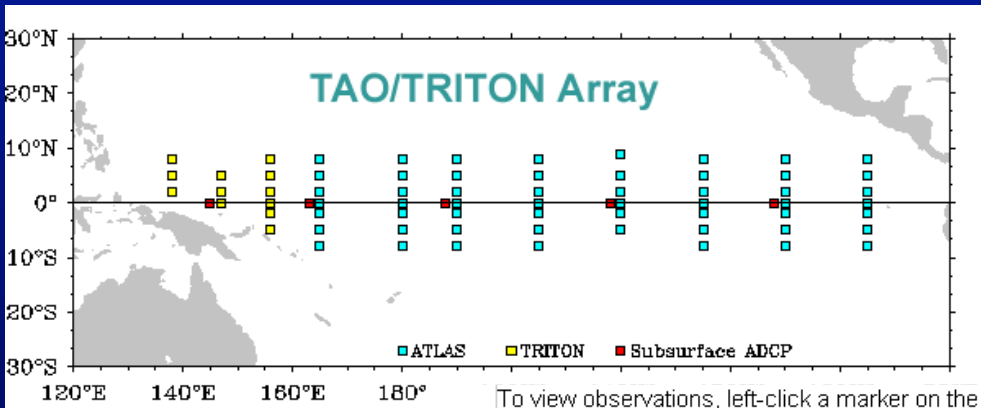
Other ocean relevant missions include winds – (scatterometer – QuikScat), precipitation (TRMM)

OCO/Atmospheric CO_2 – coming

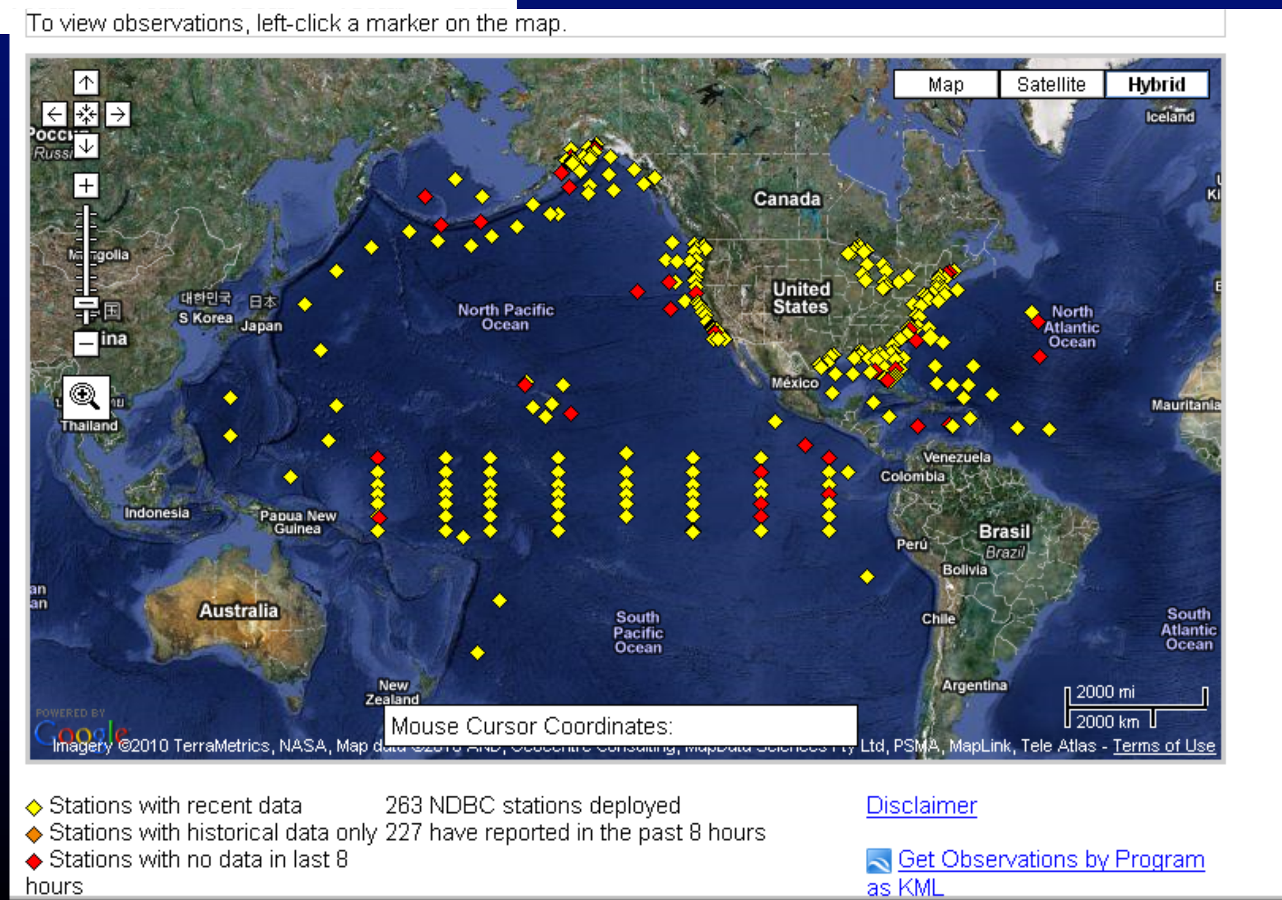
Aquarius/Sea Surface Salinity - coming

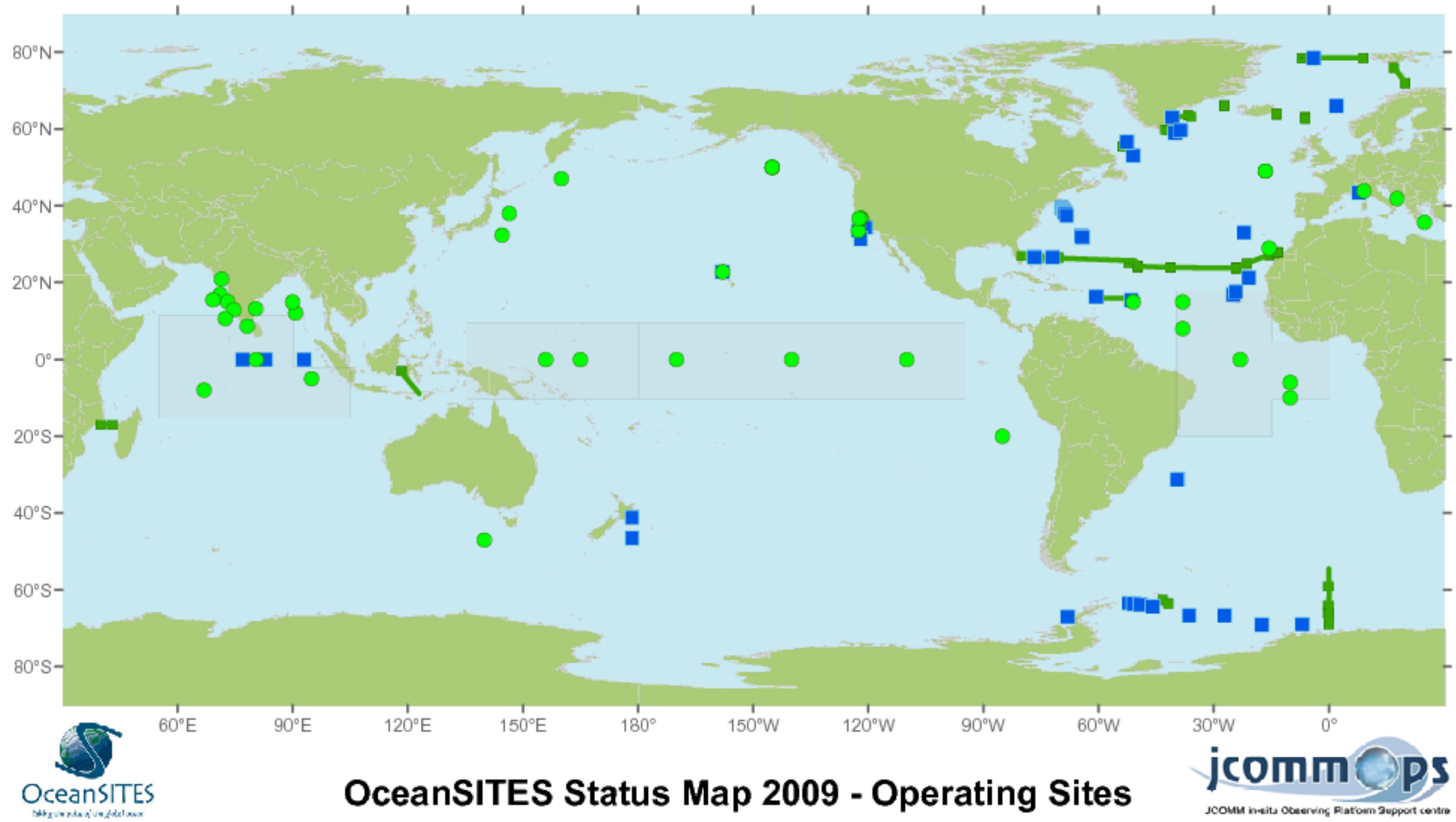


Moorings – TAO array of 70 moorings completed in 1994



Current NDBC buoy array. Mostly for meteorology.



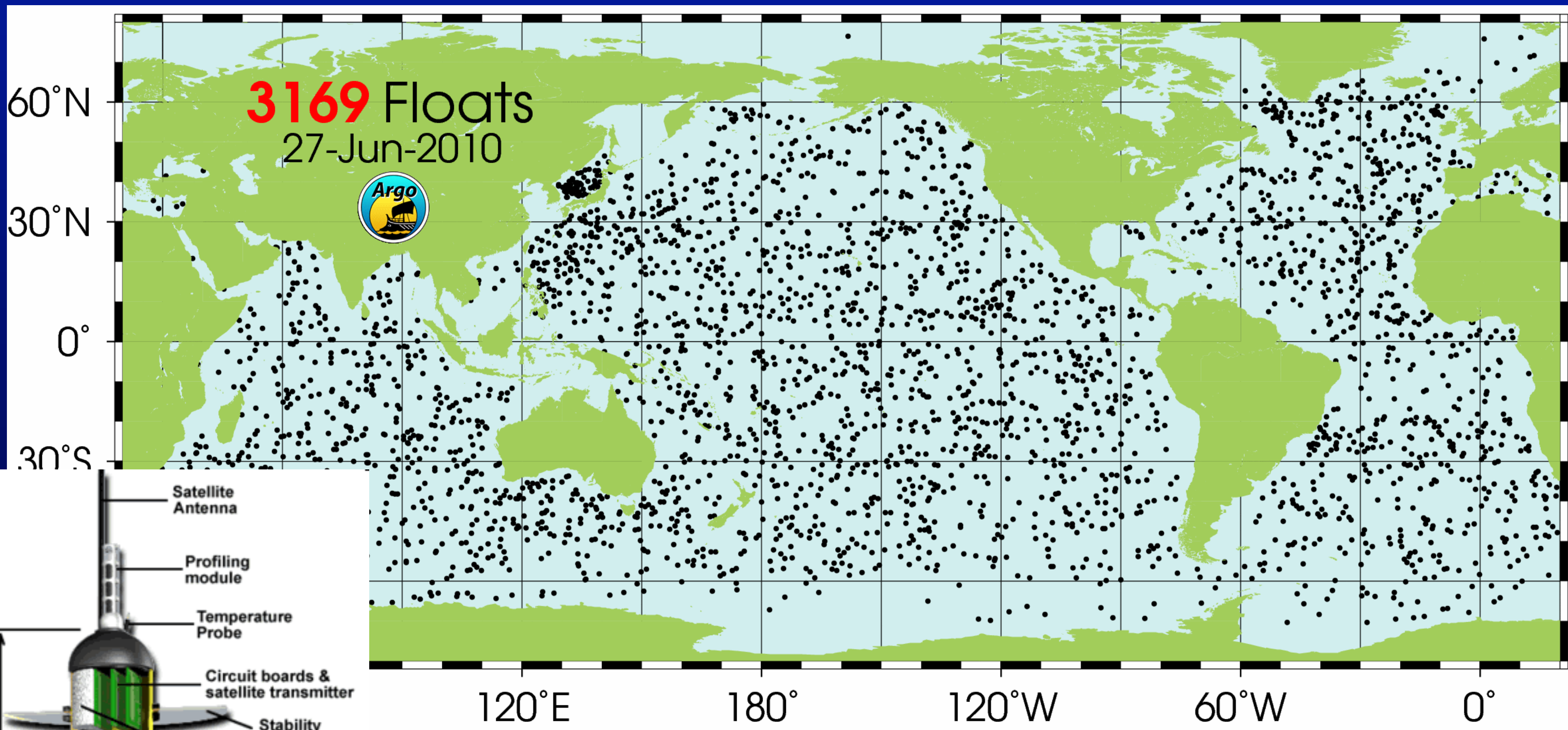


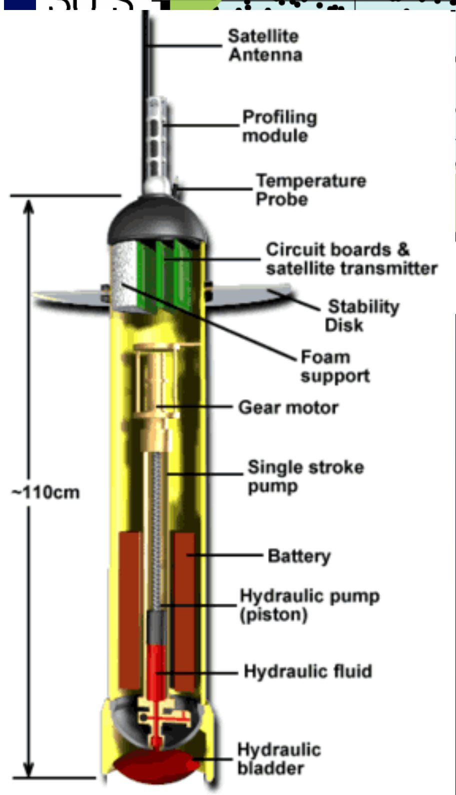
OceanSITES Status Map 2009 - Operating Sites

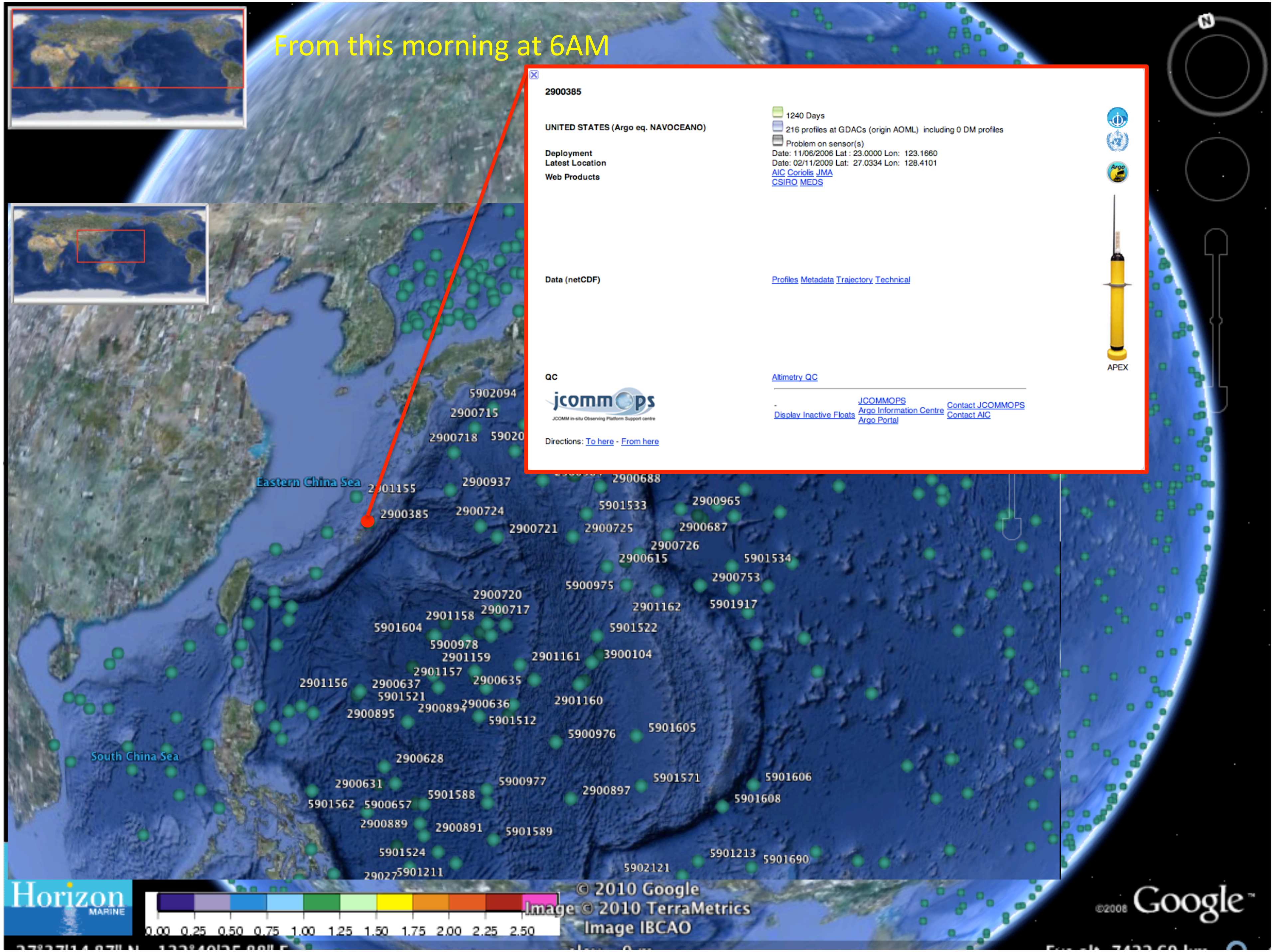
OceanSITES Moorings and Observatories (91) **Transport sites (16)**

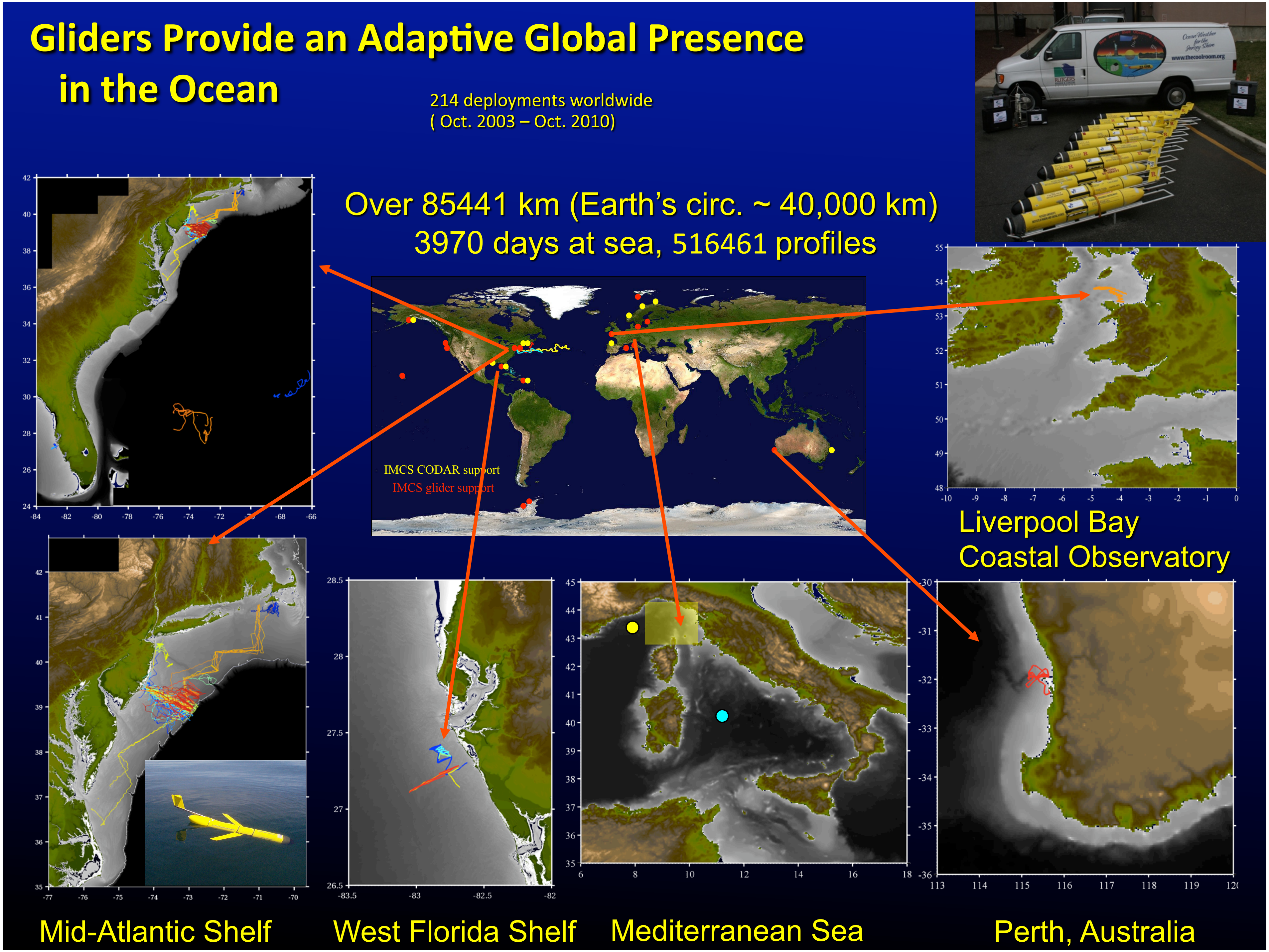
- OPERATING Real time data (44)
- OPERATING Delayed Mode data (47)
- OPERATING
- Transport Stations

Note: This status was based on information provided in 2009.

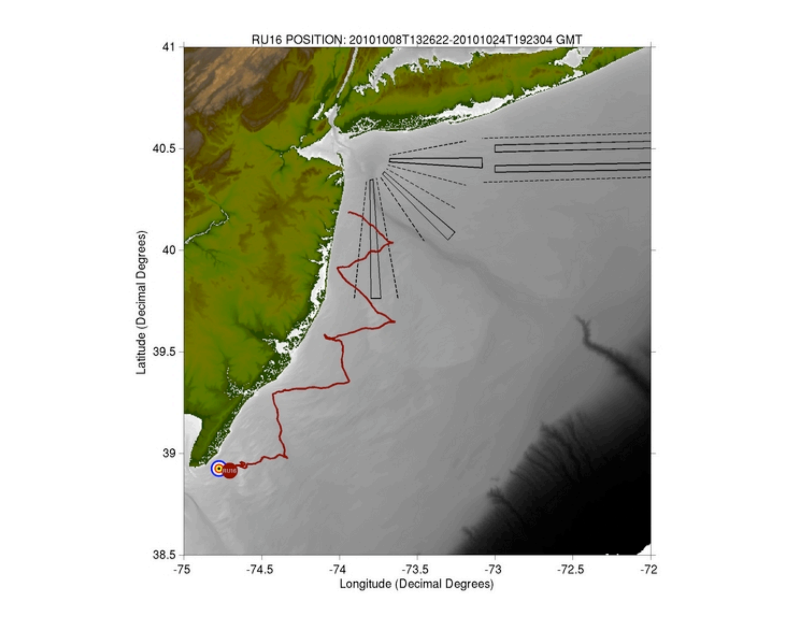

3169 Floats
27-Jun-2010
Argo
60°N
30°N
0°
30°S
120°E
180°
120°W
60°W
0°

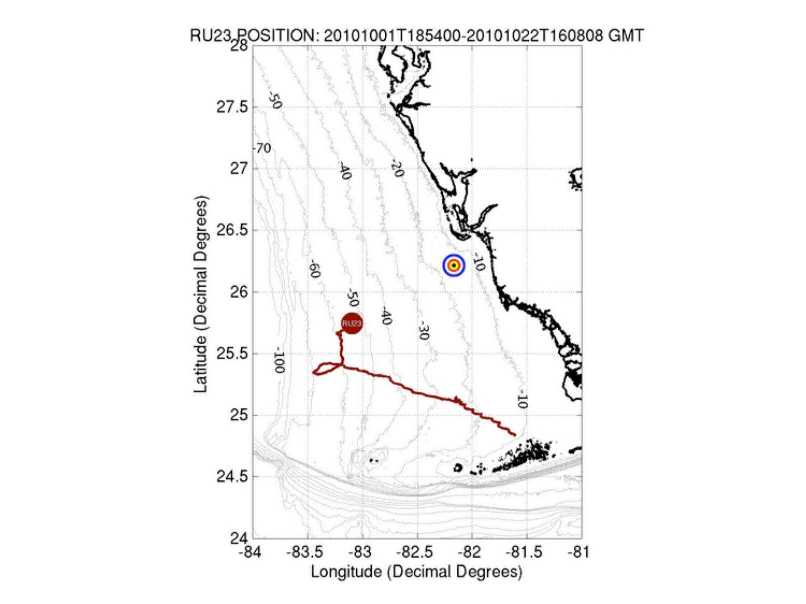

Satellite Antenna
Profiling module
Temperature Probe
Circuit boards & satellite transmitter
Stability Disk
Foam support
Gear motor
Single stroke pump
Battery
Hydraulic pump (piston)
Hydraulic fluid
Hydraulic bladder
~110cm

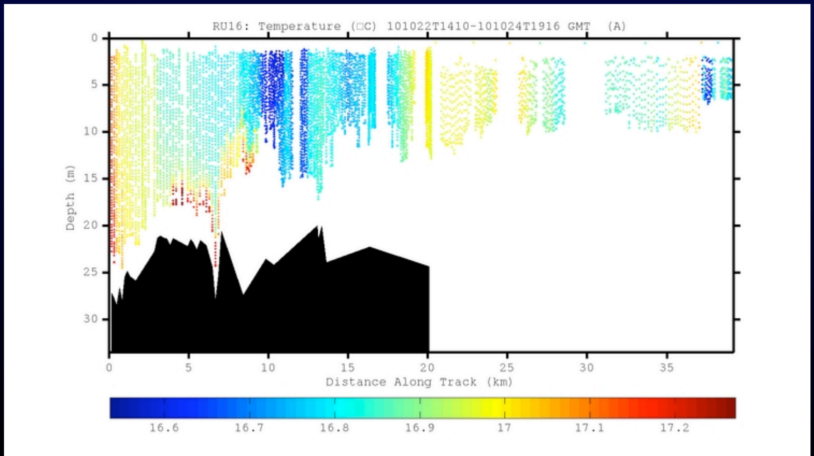

From this morning at 6AM
2900385
UNITED STATES (Argo eq. NAVOCEANO)
1240 Days
216 profiles at GDACs (origin AOML) including 0 DM profiles
Problem on sensor(s)
Deployment
Latest Location
Web Products
Date: 11/06/2006 Lat : 23.0000 Lon: 123.1660
Date: 02/11/2009 Lat: 27.0334 Lon: 128.4101
AIC Coriolis JMA
CSIRO MEDS
Data (netCDF)
Profiles Metadata Trajectory Technical
APEX
QC
Altimetry QC
jcommops
JCOMMOPS
Argo Information Centre
Argo Portal
Display Inactive Floats
Contact JCOMMOPS
Contact AIC
Directions: To here - From here
Eastern China Sea
South China Sea
2900385
2901155
2900937
2900724
2900721
2900725
2900688
5901533
2900965
2900687
2900726
2900615
5901534
2900753
5900975
2900720
2900717
2901158
2901162
5901917
5901604
5901522
5900978
2901159
2901161
3900104
2901157
2901156
2900637
2900635
5901521
2900894
2900636
2901160
2900895
5901512
5900976
5901605
2900628
2900631
5900977
2900897
5901571
5901606
5901588
5901608
5901562
5900657
2900889
2900891
5901589
5901524
5901213
5901690
5901211
5902121
5902094
2900715
2900718
Horizon MARINE
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
© 2010 Google
Image © 2010 TerraMetrics
Image IBCAO
©2008 Google

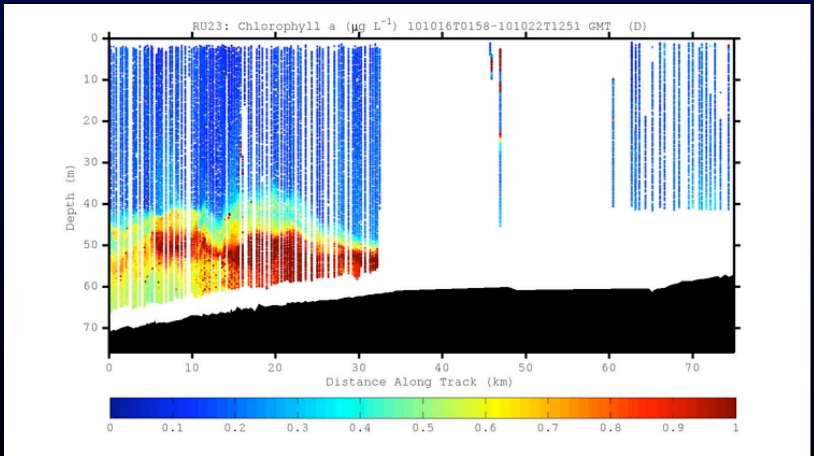

Gliders Provide an Adaptive Global Presence
in the Ocean
214 deployments worldwide
(Oct. 2003 – Oct. 2010)
Over 85441 km (Earth's circ. ~ 40,000 km)
3970 days at sea, 516461 profiles
IMCS CODAR support
IMCS glider support
Liverpool Bay
Coastal Observatory
Mid-Atlantic Shelf
West Florida Shelf
Mediterranean Sea
Perth, Australia

Glider data from this morning









Sensors:

1990 Vector averaging current meters, temperature and salinity (Seacat introduced 1986), data still recorded to magnetic tape in many cases. ADCP's just entering the market.

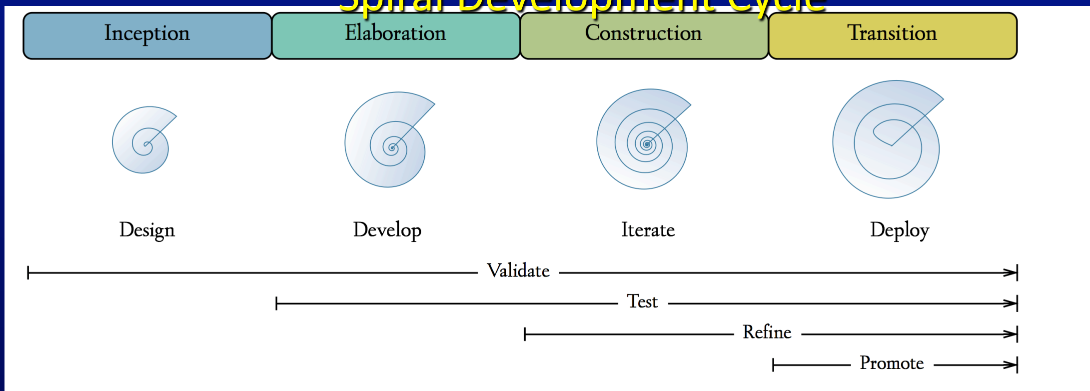
Some biooptics

Sensors – 25 years ago ADCP's were just entering the market and moored CTD's barely available. Now biogeochem. sensors more widely available, an ADCP and CTD in every pot

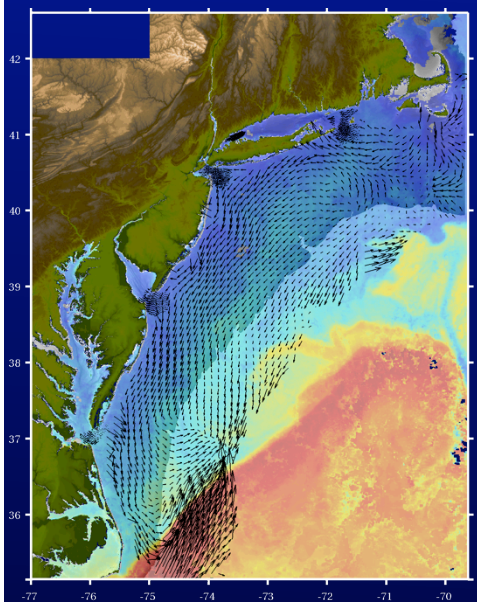
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. C5, PP. 7399-7412, 1992
doi:10.1029/92JC00408
Estimation of Seasonal Primary Production From Moored Optical Sensors in the Sargasso Sea

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

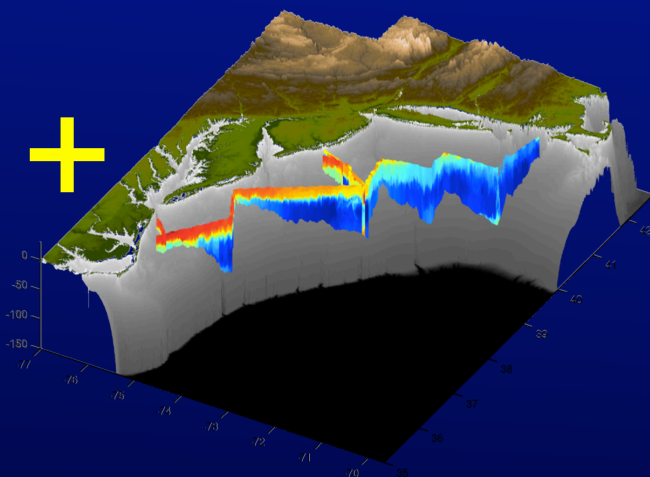
Rutgers, Webb Research, and Instrument Companies Spiral Development Cycle



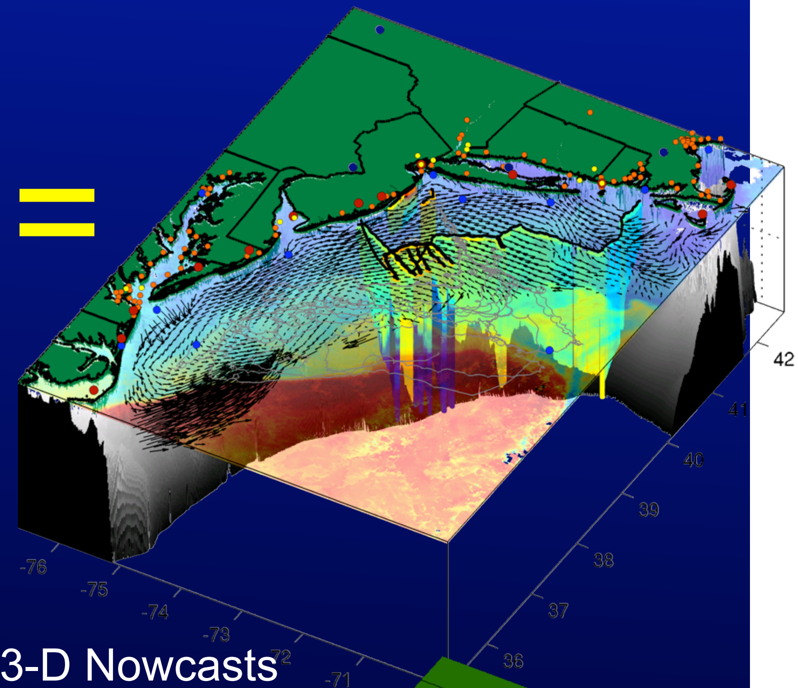
Couple data assimilative models to glider data.



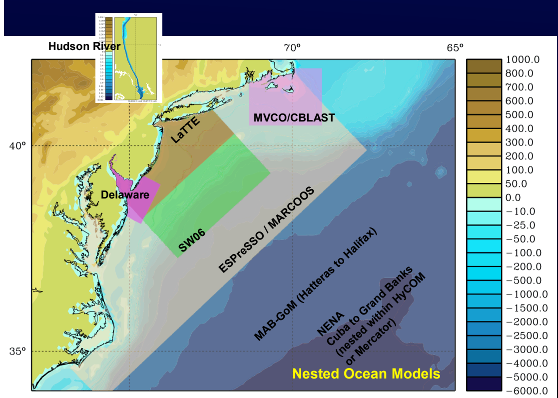
Remote Sensing



Gliders



3-D Nowcasts



Nested Models

S4DVAR procedure

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

Lagrange multiplier $\ddot{\mathbf{e}}_i \equiv \ddot{\mathbf{e}}(t_i) \equiv \ddot{\mathbf{e}}(i\Delta t)$

At extrema of L, we require:

$$\frac{\partial L}{\partial \ddot{\mathbf{e}}_i} = 0 \Rightarrow \frac{d\mathbf{x}_i}{dt} - \mathbf{N}(\mathbf{x}_i) - \mathbf{F}_i = 0 \qquad \textit{NLROMS}$$

$$\frac{\partial L}{\partial \mathbf{x}_i} = 0 \Rightarrow -\frac{d\ddot{\mathbf{e}}_i}{dt} - \left(\frac{\partial \mathbf{N}}{\partial \mathbf{x}}\right)^T \ddot{\mathbf{e}}_i - \delta_{im}\mathbf{H}^T\mathbf{O}^{-1}(\mathbf{H}\mathbf{x}_m - \mathbf{y}_m) = 0 \qquad \textit{ADROMS}$$

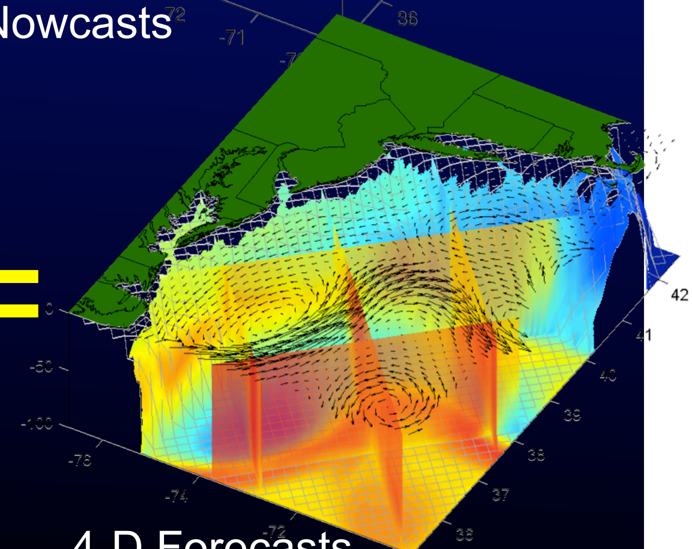
$$\frac{\partial L}{\partial \mathbf{x}(0)} = 0 \Rightarrow \mathbf{B}^{-1}(\mathbf{x}(0) - \mathbf{x}_b) - \ddot{\mathbf{e}}(0) = 0 \qquad \textit{coupling of NL \& ADROMS}$$

$$\frac{\partial L}{\partial \mathbf{x}(\tau)} = 0 \Rightarrow \ddot{\mathbf{e}}(\tau) = 0 \qquad \textit{i.c. of ADROMS}$$

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 $\ddot{\mathbf{e}}(0)$
(4) Compute $\frac{\partial J}{\partial \mathbf{x}(0)} = \mathbf{B}^{-1}(\mathbf{x}(0) - \mathbf{x}_b) - \ddot{\mathbf{e}}(0)$
(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



4-D Forecasts

1990 – end of box models to low resolution (3x3 degree) 3D models for biogeochem.

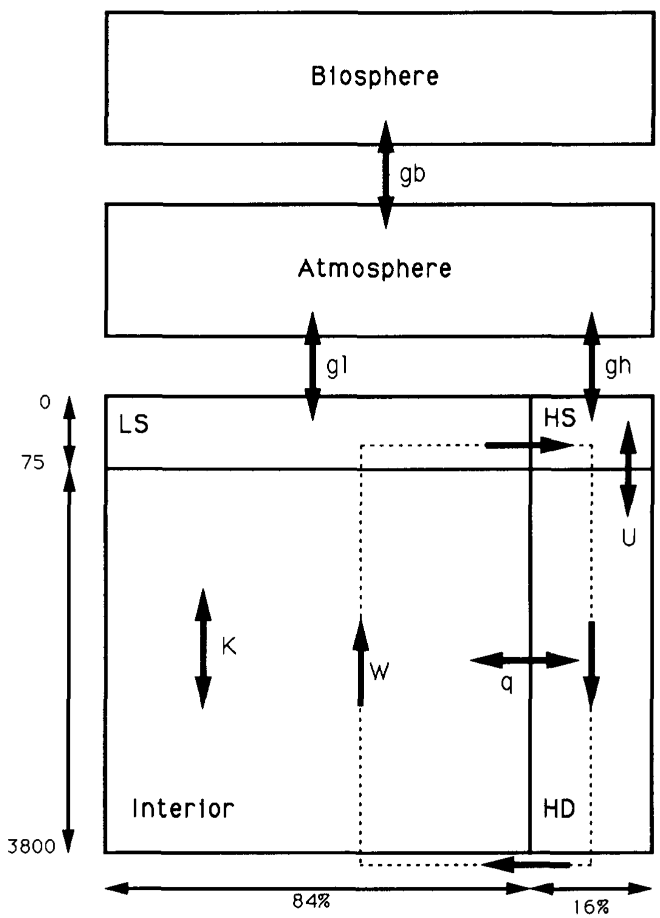


Fig. 1. Structure of the HILDA model. The biosphere box is included only for calculating isotopic perturbations due to the anthropogenic CO_2 emissions, i.e., the Suess effect.

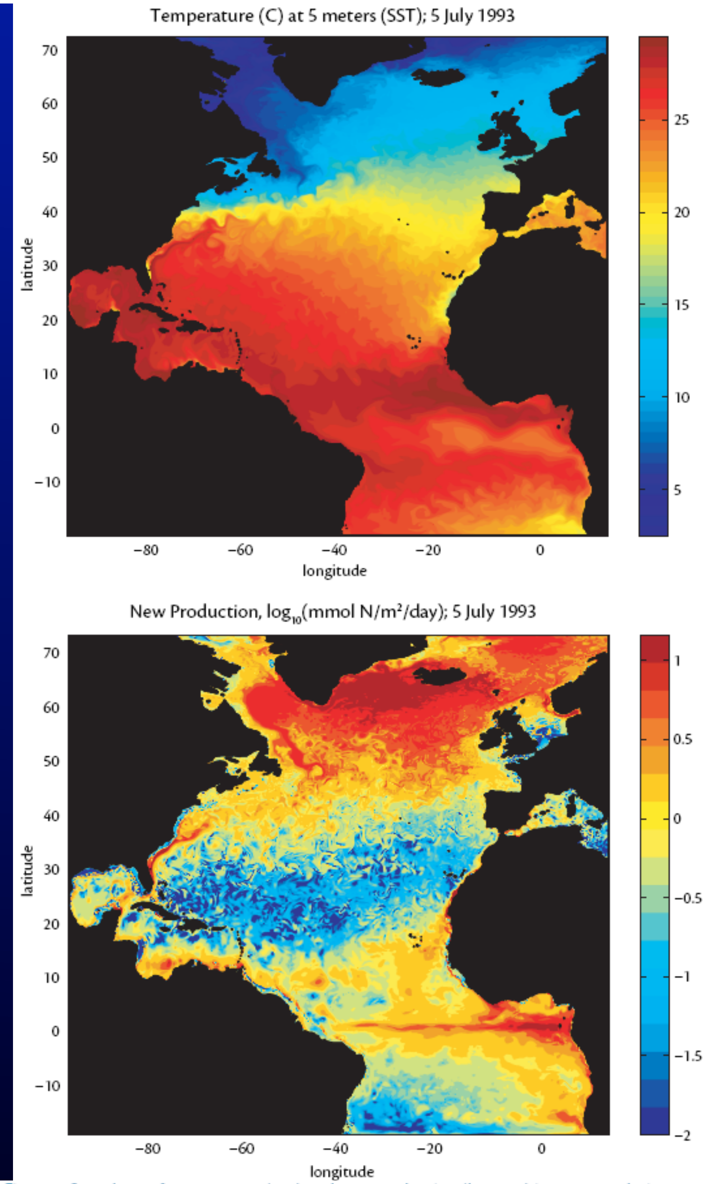


Figure 7. Snapshots of temperature (top) and new production (bottom) in a 0.1° resolution simulation of the North Atlantic. The temperature field reveals active mesoscale processes throughout the basin; biological uptake of nutrients is replete with mesoscale structure in nearly all areas except for the subpolar region, where production is still light limited in early July. Eddies play an important role in determining the mean.

Web – first browser Mosaic developed in 1992.

Circa 1990 - 2400 to 4800 baud

Data communications – 1980 – 300 baud

WiFi 802.11g – 50,000,000 baud

Ship to shore communications – 1990 we used the ATS satellite on Saturday mornings served by a shore-based operator in Malabar, FL or San Diego, CA, who made a collect telephone call. The whole fleet listened in on each conversation:

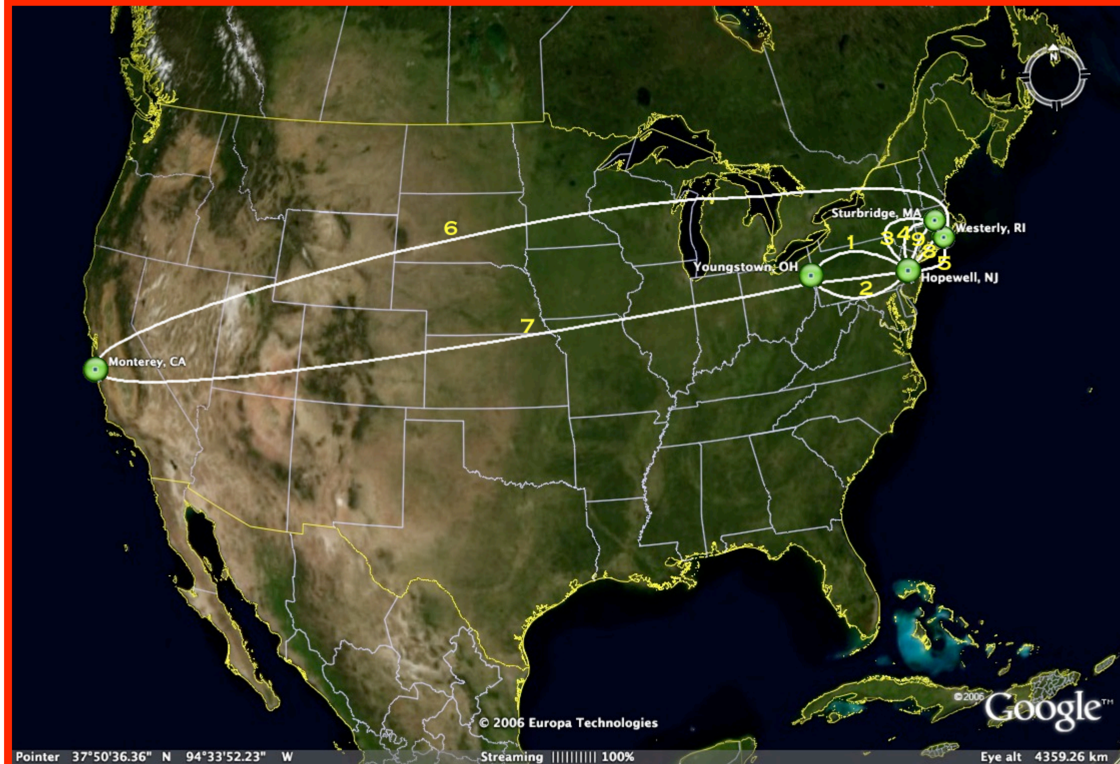
“Hello honey, how are the kids? And you have to say “over”, over.”

2010 http://hiseasnet.ucsd.edu/

HiSeasNet Technology

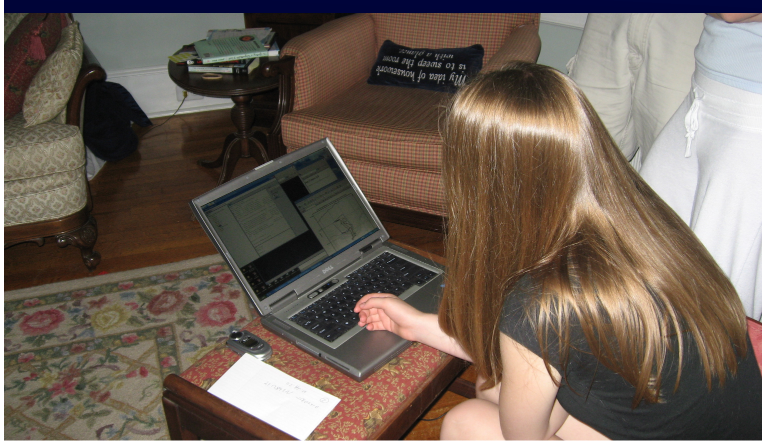
- Uses marine-stabilized antennas
  - 2.4m dishes for larger vessels (C-band)
  - 1m-1.5m dishes for smaller vessels (Ku-band)
- Connectivity is all IP based
  - 64kbps to 96kbps ship-to-shore
  - Shared shore-to-ship links between 192kbps (3 ships) to 256kbps (5 ships)
  - Allows for flexibility of any type of traffic to be sent (e-mail, web, FTP, SSH, IM, VoIP, etc.)

Sustained Observatory Operations from Multiple Locations

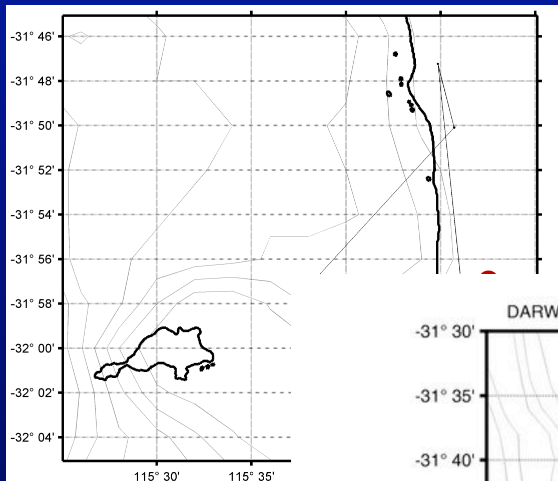


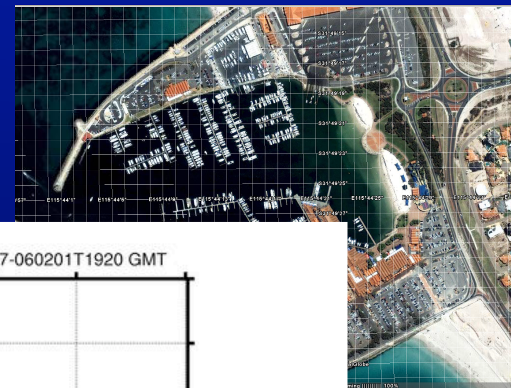
McDonald's WiFi

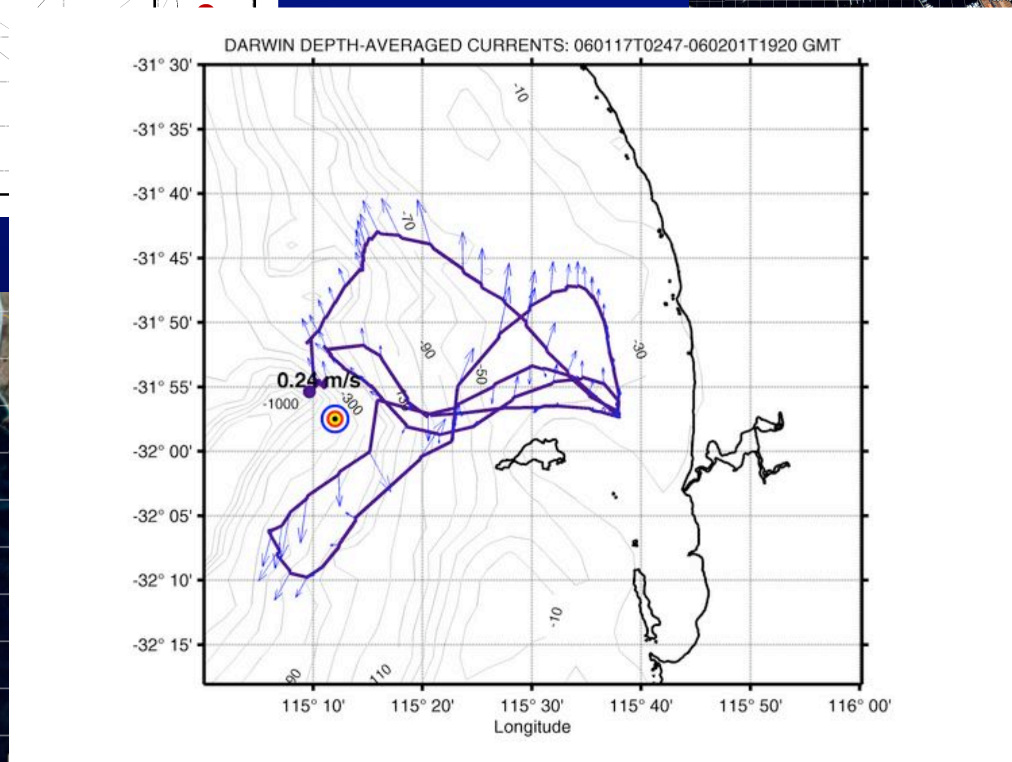
Scott's Living Room – Glider Recovery in Hawaii

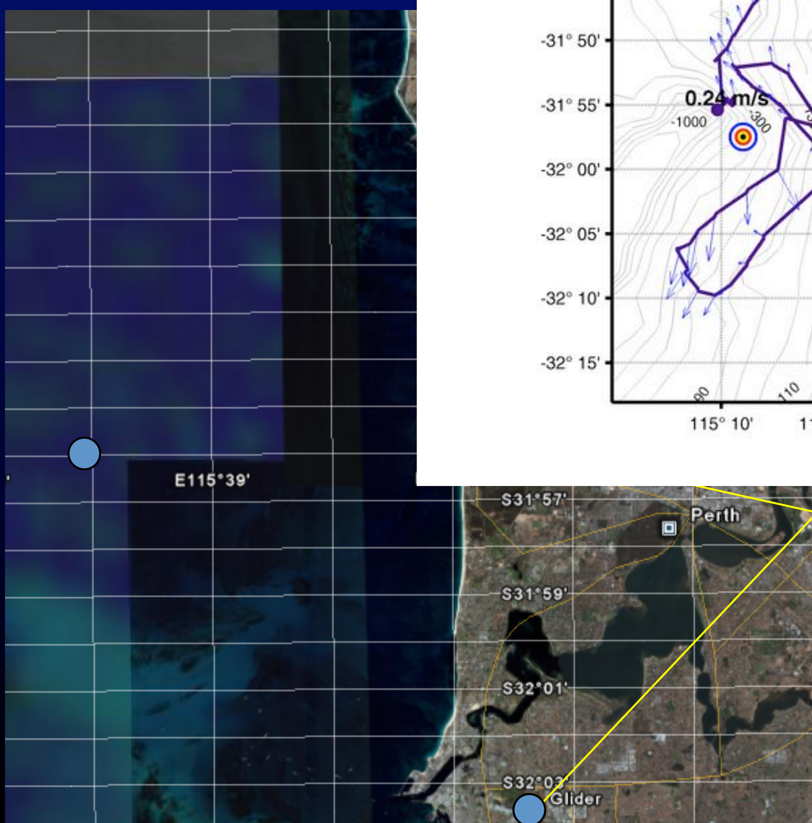


Darwin's Odyssey – January 11, 2006









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?

Batteries – more power

1990 rechargeable Lead acid energy density 0.14 MJ/kg

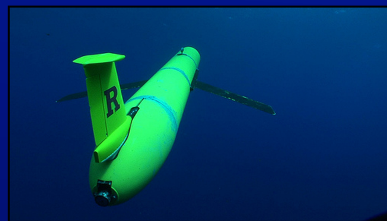
1990 primary alkaline 0.4-0.59 MJ/kg

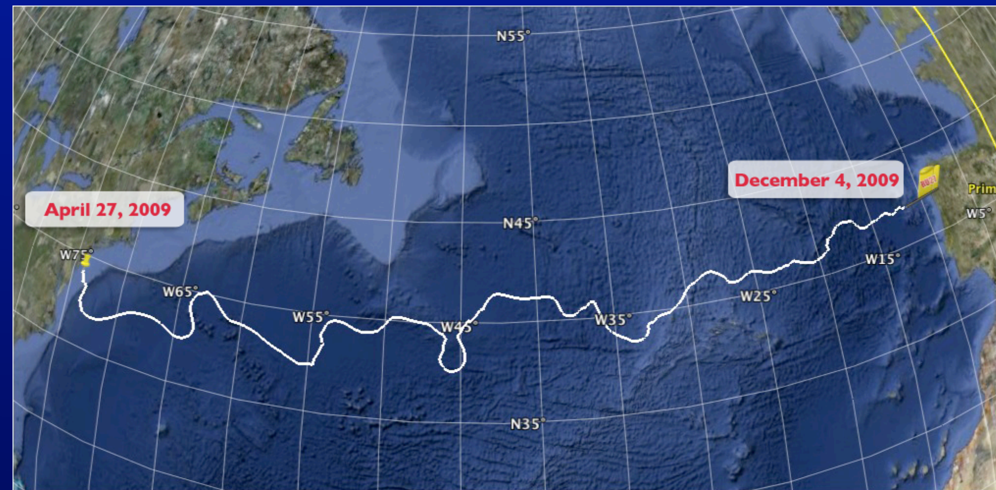
2010 rechargeable Lithium ion 0.5 MJ/kg

2010 primary Lithium 1 MJ/kg

Mission Complete: Scarlet Knight is the first underwater robot to cross an ocean basin

221 Days
7,409 km
11,000 Dives
11,000 Climbs
Energy Equivalent of 8 minutes power for lights on the Rockefeller Center Tree.





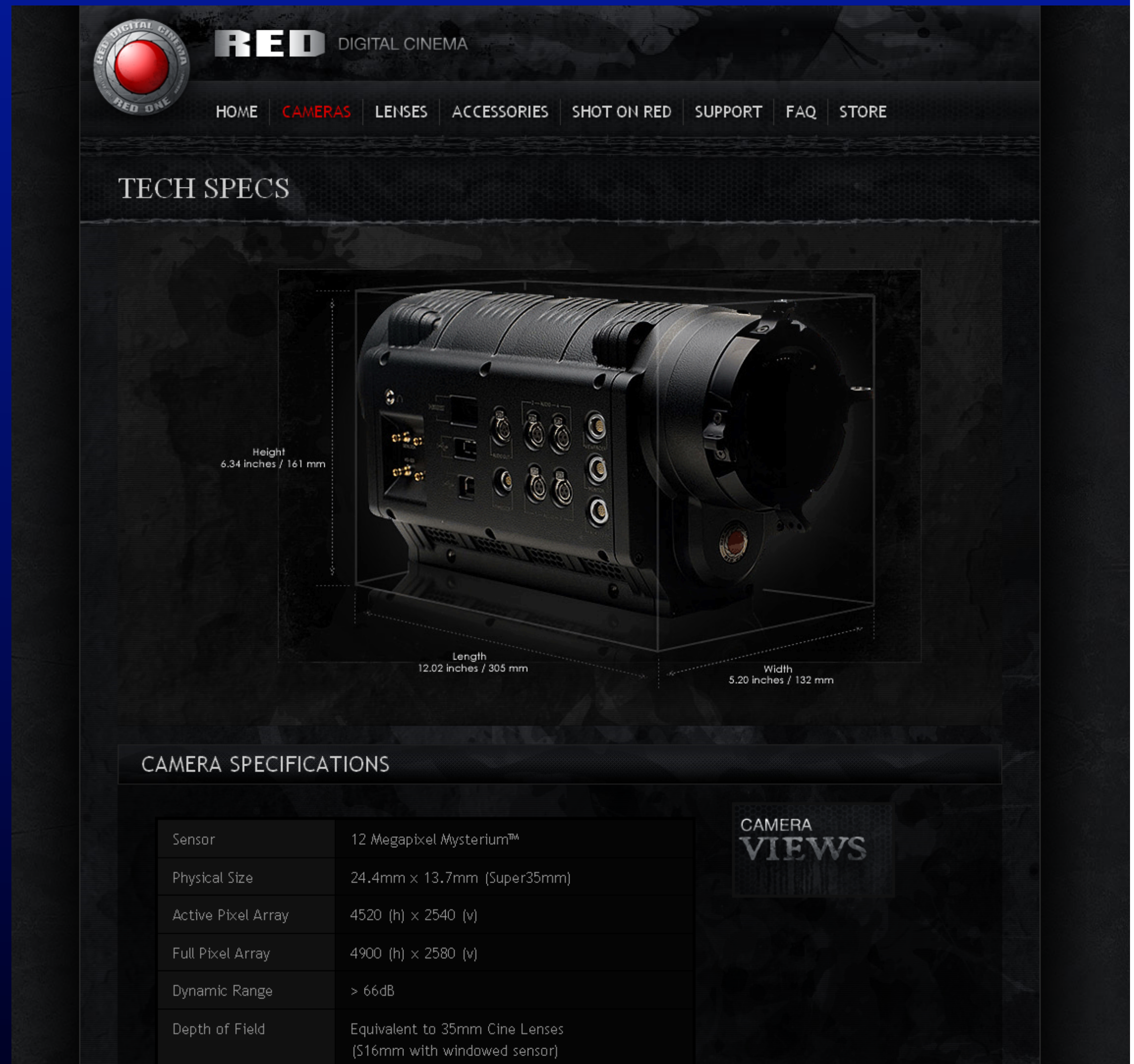
Tuckerton, New Jersey, USA

Baiona, Galicia, Spain

Mission Complete: Scarlet Knight is the first underwater robot to cross an ocean basin

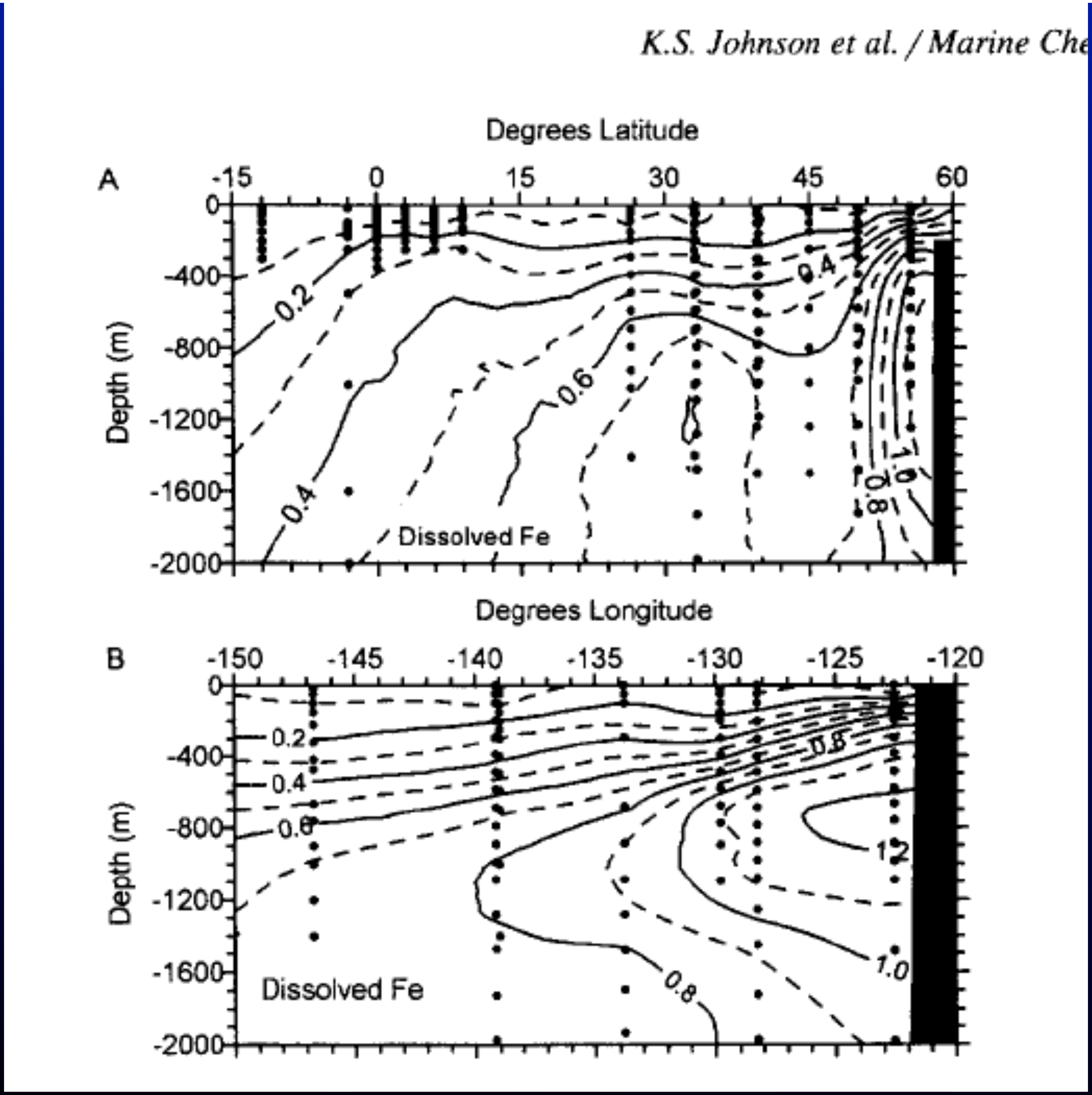
A hero's Welcome, December 9, 2009

Imaging – a scientific CCD with much < 0.5 Mpixel and 10's of $1k was the 1990 standard. Now, high def, stereo..... Red – 14 Mpixel...



Analytical capabilities allowing greater number of samples to be analyzed.

Late 1980's state of the art for Fe – meridional section from Alaska to south of Equator and zonal section from California to Hawaii for iron. About 80 samples each, and each took 2 years in a shore based lab to analyze.



Mid-2000's –
720 Fe samples
analyzed at sea.

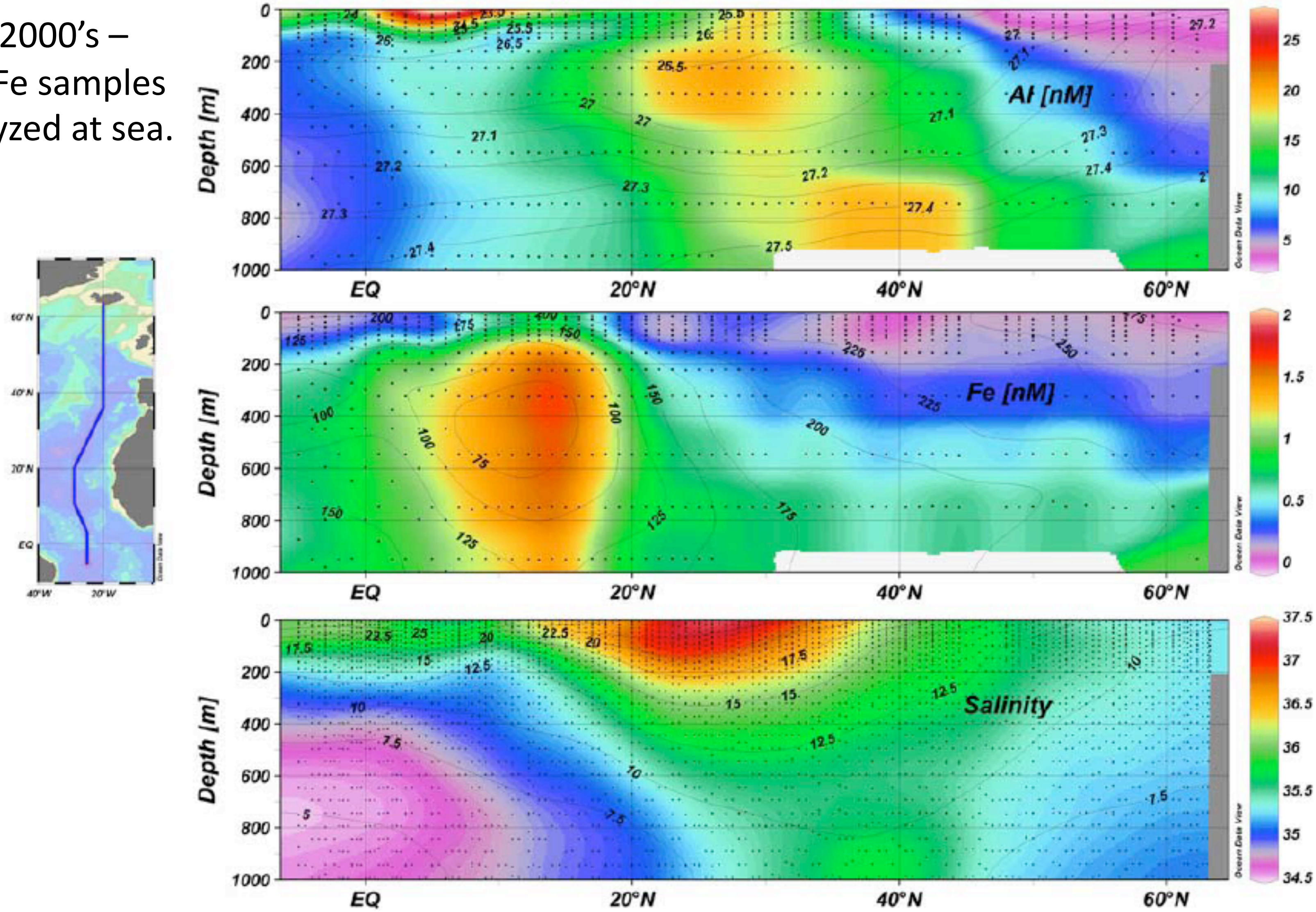
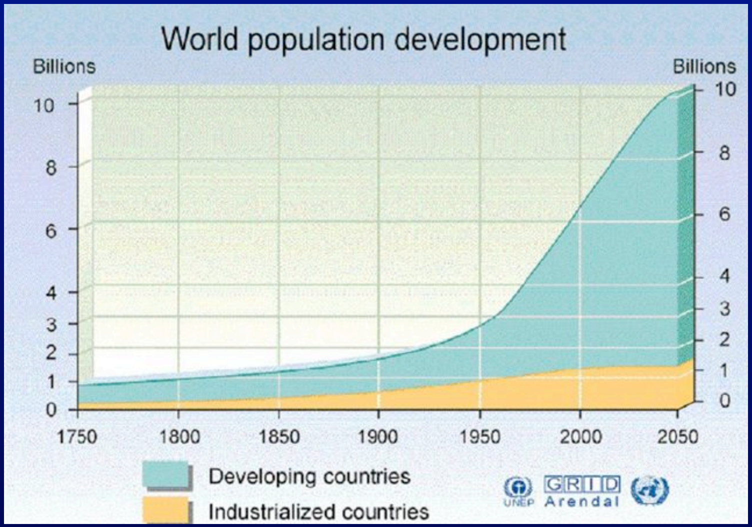
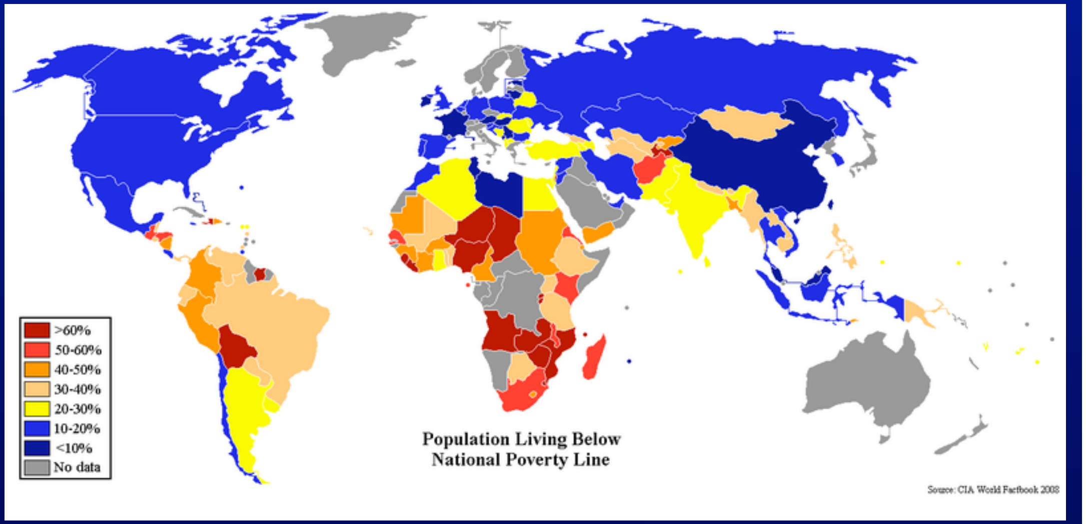


Figure 1. Property distributions between 62°N and 5°S, contoured using Ocean Data View of (top) dissolved Al, (nM) overlain with potential density contours in kg m^{-3}; (middle) Fe, (nM) overlain with oxygen contours in μM; (bottom) salinity, (PSS78) overlain with potential density contours in kg m^{-3}.

Why is this important now?

Growing Human Population – Greatest in Less Developed Countries





Reduced Fish Population – Fishing Displaced to Less Developed Countries