

Autonomous Monitoring of Ocean Carbon Biomass and Sedimentation

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January 16 2005
Antarctic Waters near 60 S 55 W
from NOAA SHIP Ron Brown.

March 16 2005
San Diego, California
Am Chem Soc Meeting

Motivation

Science Questions

?? CO₂ ??

**How does the Ocean's Natural
Carbon Cycle Operate?**

What are the controls?

**How will the controls change in the
future?**

**Monitoring and Verification of
Carbon Management Actions?**

**How much?
Effective?
For how long?**

THANKS TO: DOE-OBER, NOAA-OGP, NOPP, ONR, NSF (for shiptime)
Russ Davis, Jeff Sherman, Todd Wood, Alex Derr, Alexandra Thomposn, Phoebe Lam ...

Menu

- CARBON Cycle
- Robot Carbon Explorer Concept
- Concentration Sensors:
 - Particulate Organic Carbon (POC)
 - Particulate Inorganic Carbon (PIC)
- Optical POC/PIC Sedimentation Recorder (new)
- Vision Forward

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Carbon Math

Emissions - Atmosphere

=

Known

Land + Ocean Sinks

~~Carbon Math~~
~~Emissions - Atmosphere~~

~~=~~

Known

~~Land + Ocean Sinks~~

“We don’t know emissions post 1999”

CD Keeling Jan 17 2005:

AGU Chapman Conference

Proposed New Carbon Math

Atmosphere - Ocean Sink

=

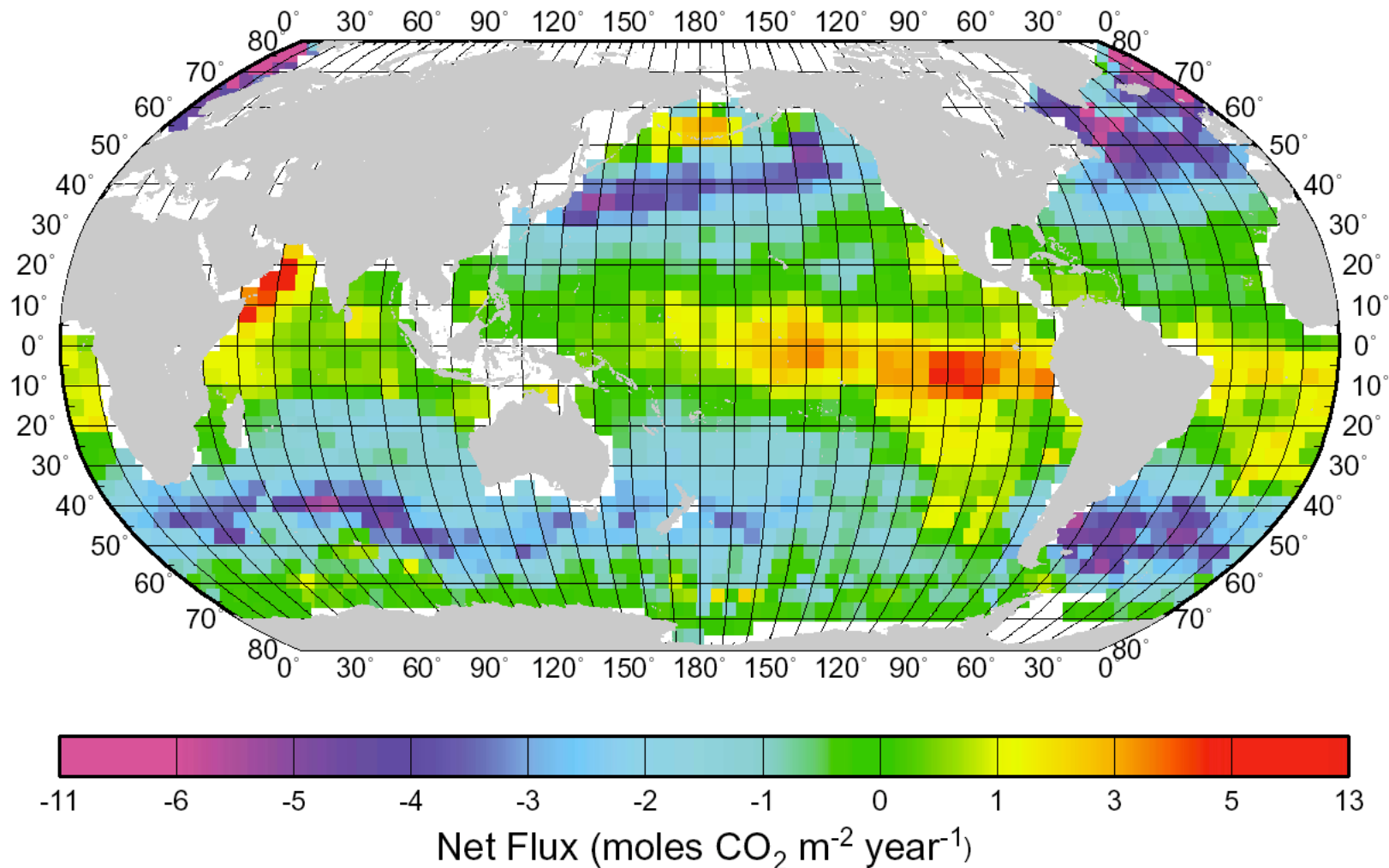
Could be
Known

Land Sink - Emissions

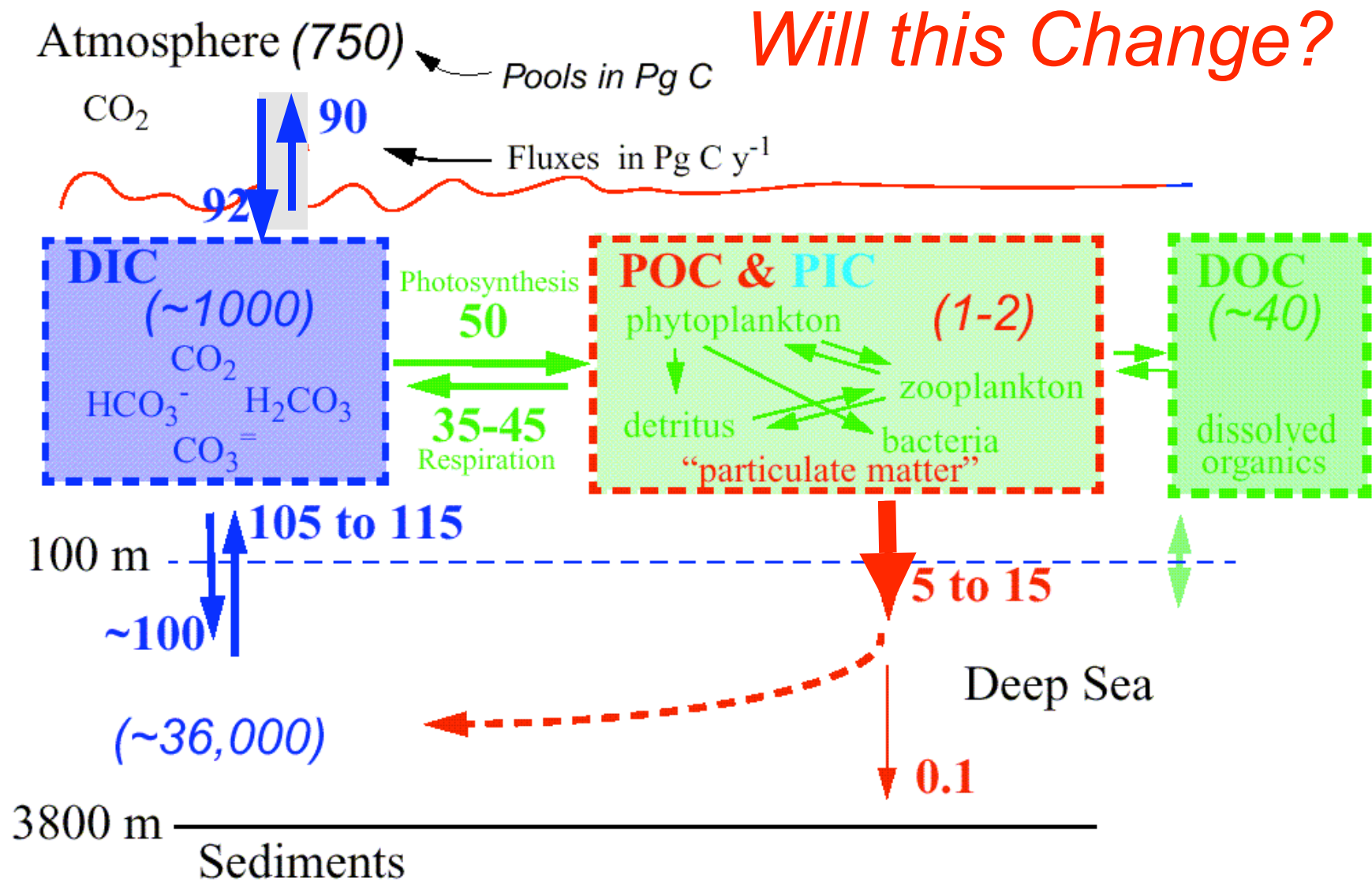
In Real
Time

30 year synthesis: Physical and Biological Processes dictate patterns of ocean CO₂ exchange and net uptake.

Mean Annual Air-Sea Flux for 1995 (NCEP 41-Yr Wind, 940K, W-92)



Takahashi et al. (2002) *Deep Sea Research II*, **49** 1601



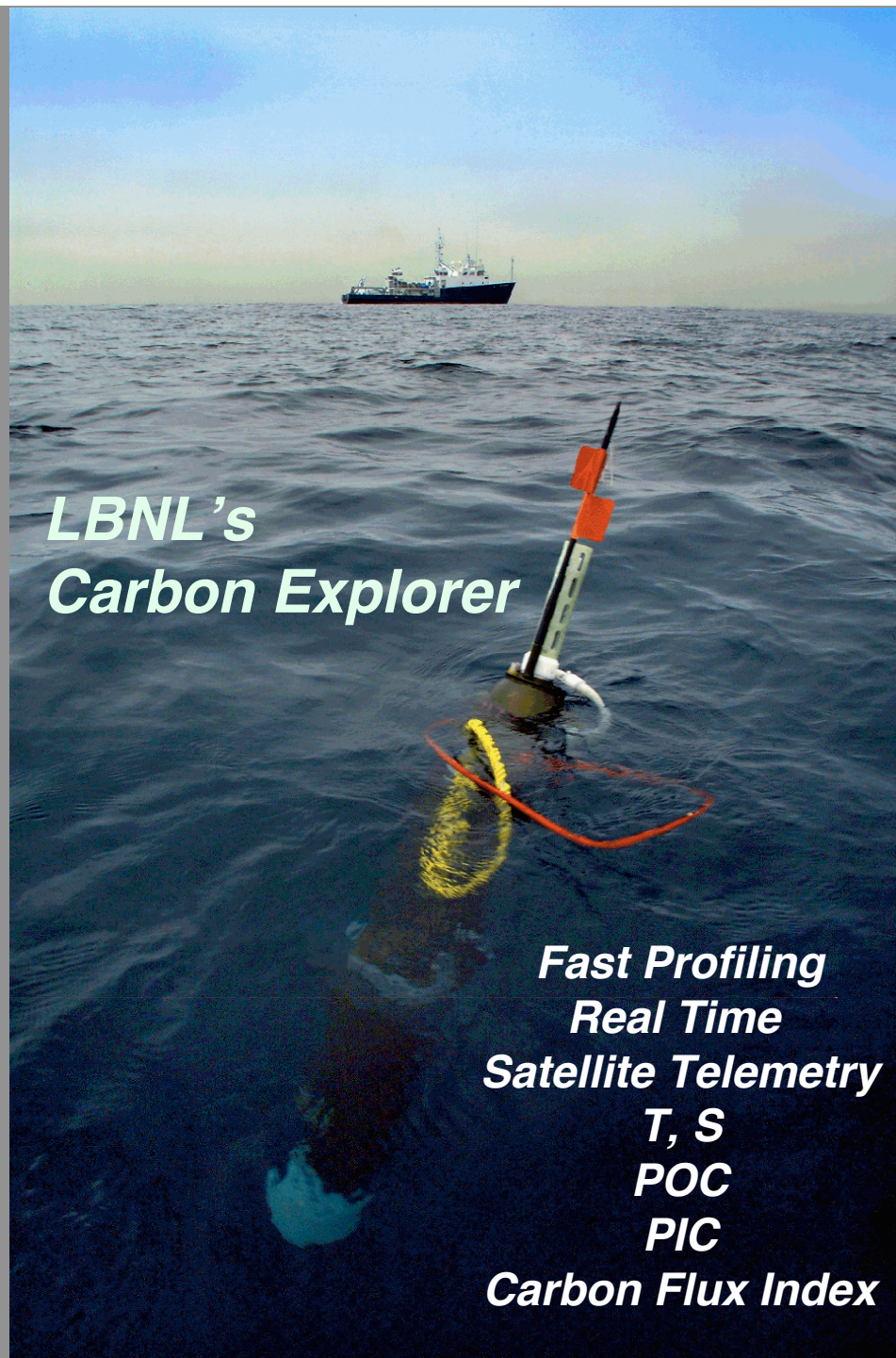
2003 view

How will we know?

New Technology for Ocean Observations

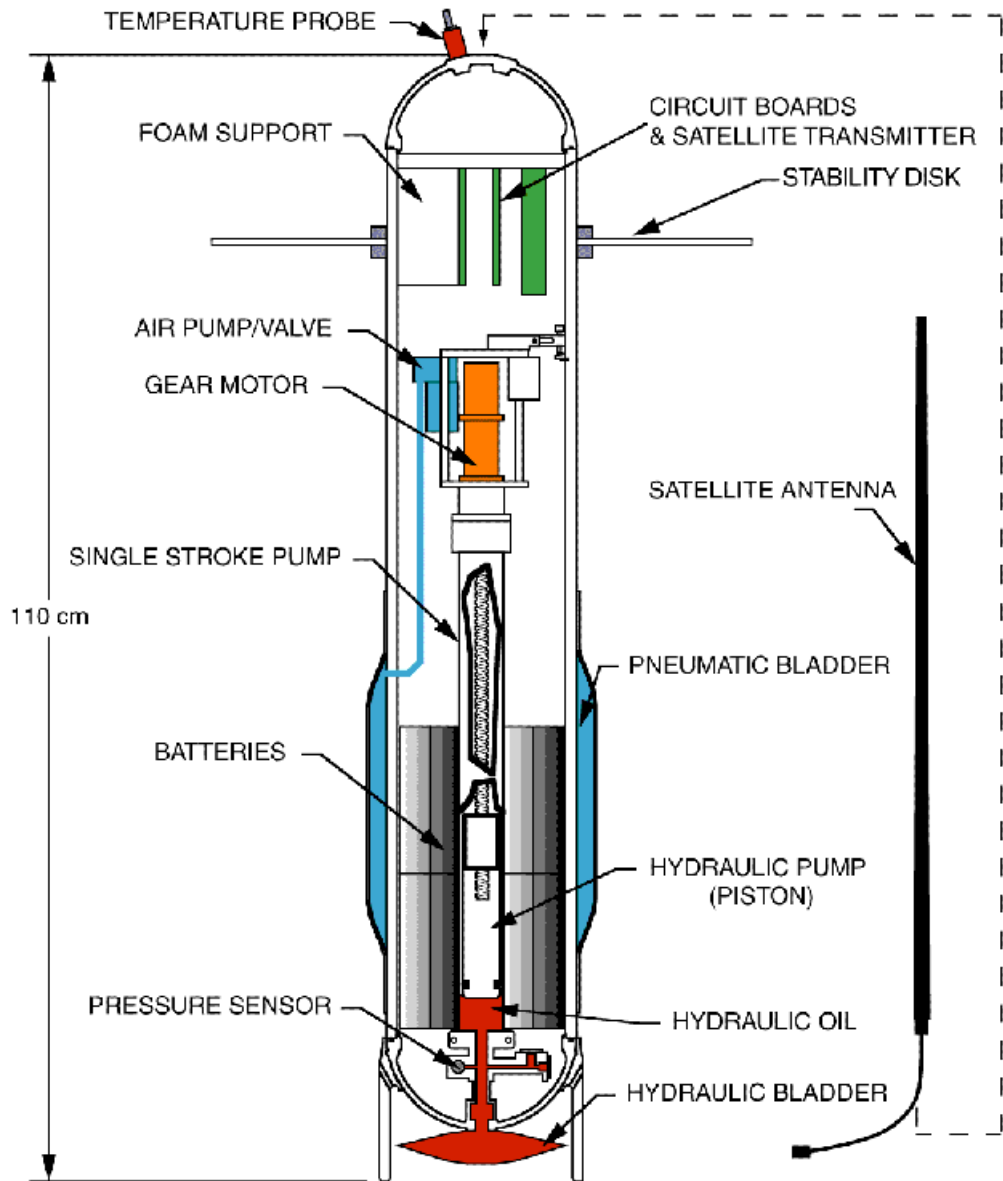


Spray



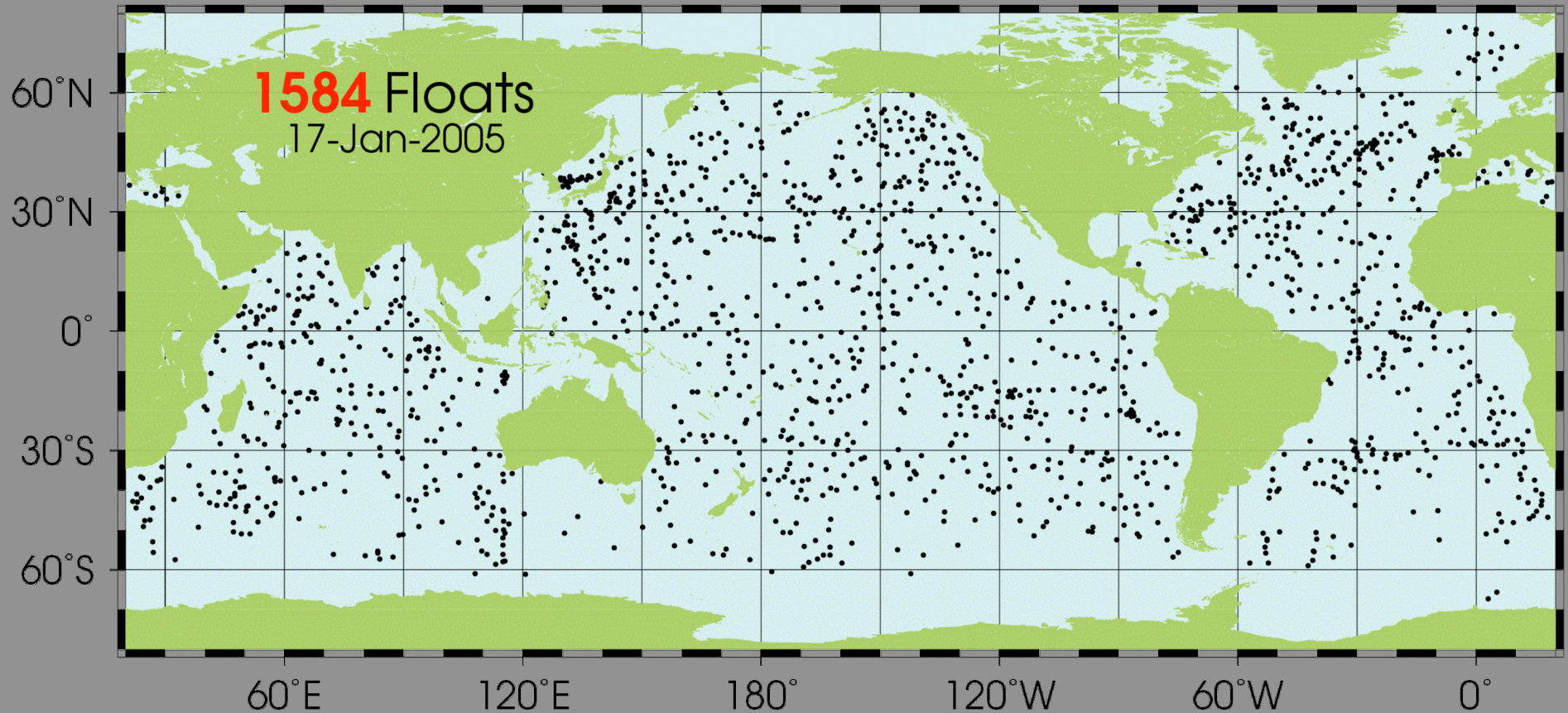
*LBNL's
Carbon Explorer*

*Fast Profiling
Real Time
Satellite Telemetry
T, S
POC
PIC
Carbon Flux Index*



ANIMATION OF FLOAT

ARGO Status Jan 17 2005

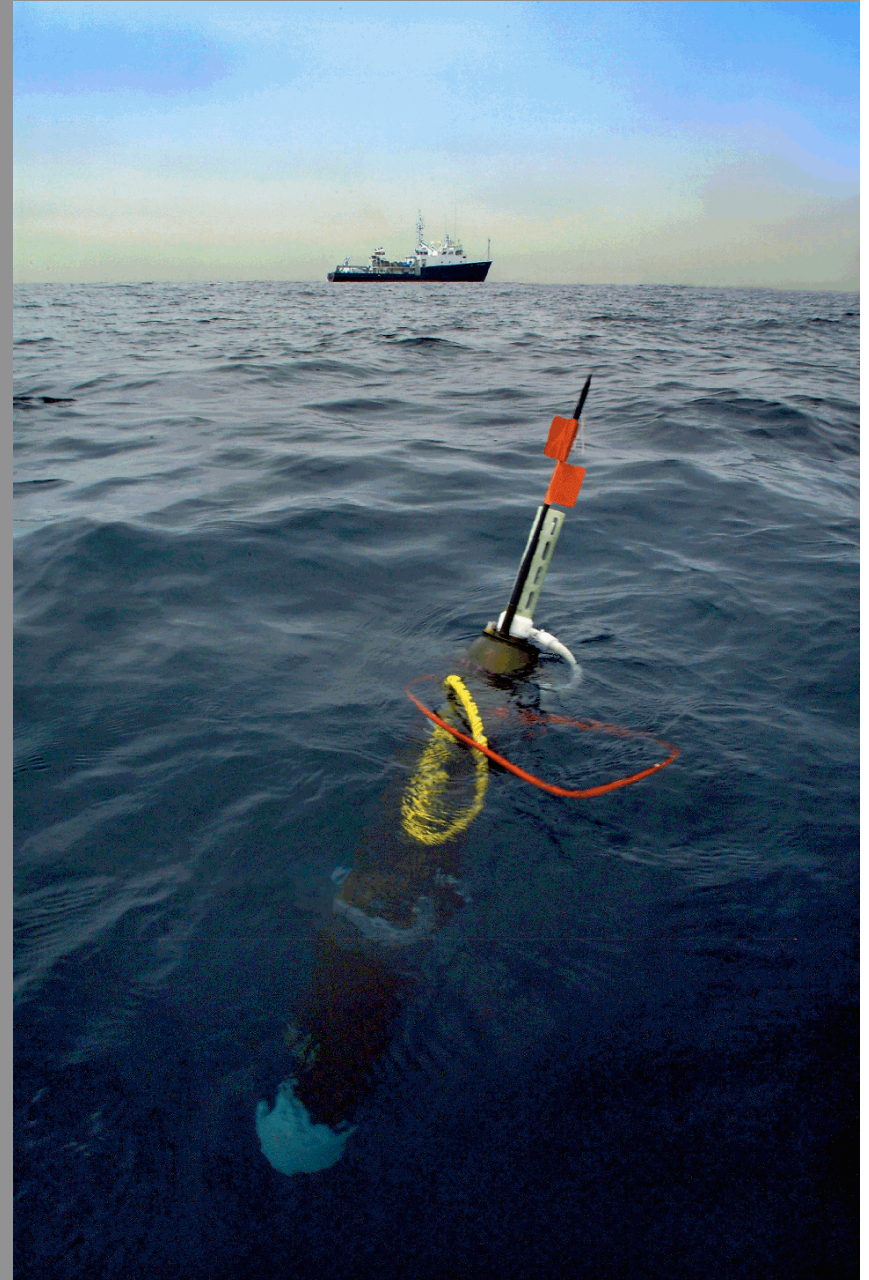


Can we have a Carbon - ARGO?

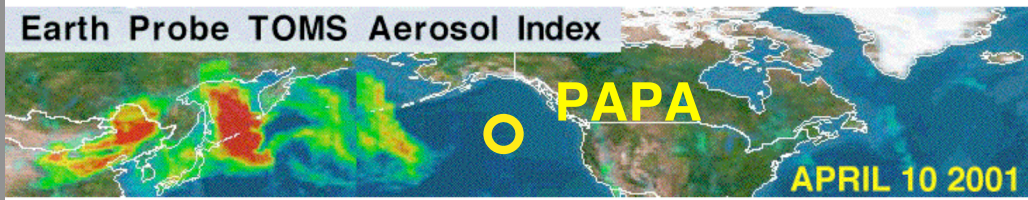
Autonomous Platforms and Optical Sensors

Robot Carbon Explorers

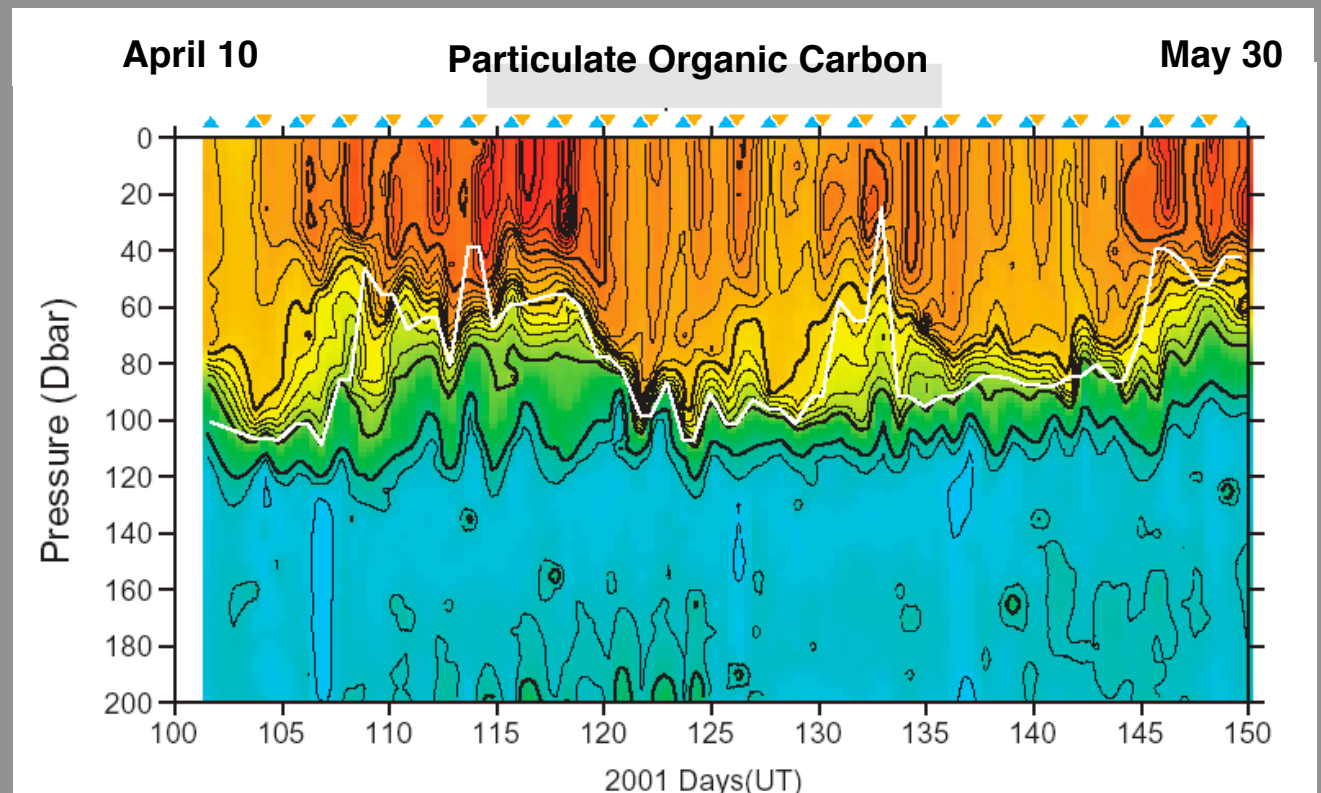
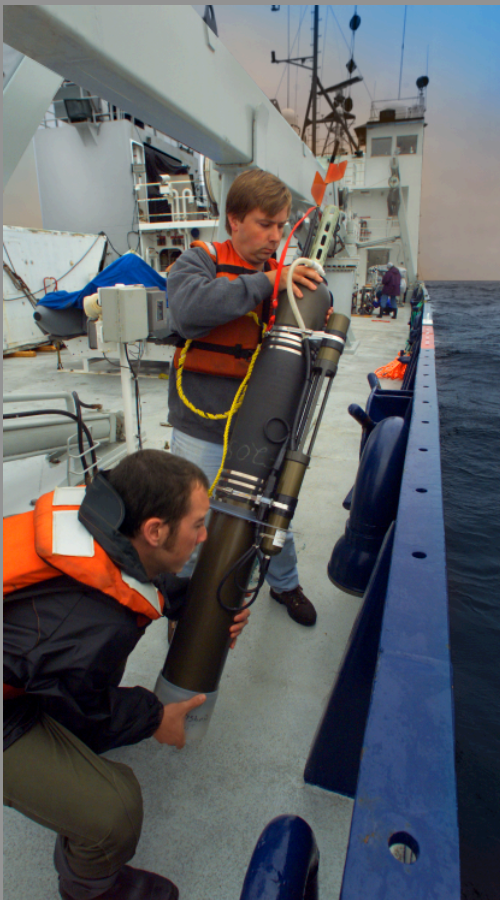
- First obs. of natural iron fertilization of marine biomass by Asian dust (Bishop et al., Science **298**, 817-821, 2002)
- First obs. of purposeful iron-stimulation of carbon biomass and carbon sedimentation in Southern Ocean (Bishop et al. Science, **304**, 417-420, 2004).



Ocean Fertilization by Gobi Dust Observed: First Deployment of Robotic Carbon Explorers



**Gobi Desert Dust Crosses
Pacific April 10-14, 2001**



Bishop, J.K.B., et al. (2002) Science 298, 817-821.

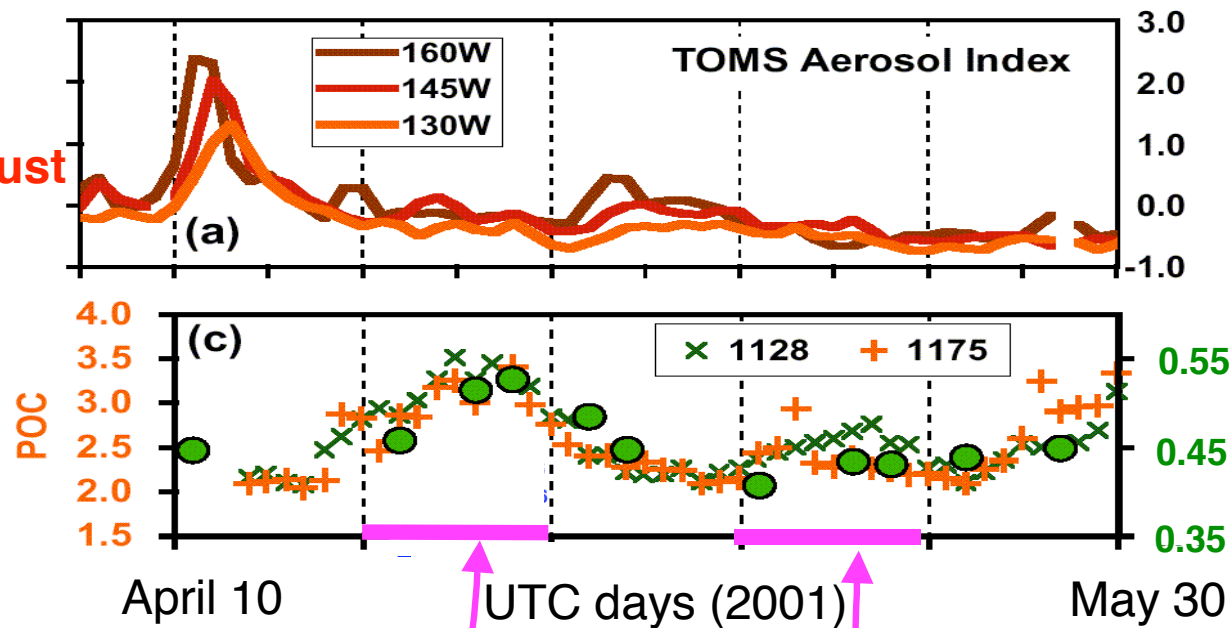
Ocean Fertilization by Gobi Dust Observed: First Deployment of Robotic Carbon Explorers

Earth Probe TOMS Aerosol Index



Gobi Desert Dust Crosses
Pacific April 10-14, 2001

West to East
Decrease in
Aerosol => Dust
Deposition



Surface
Biomass
Doubled

Satellite
Chlorophyll
Increased
by just 20%

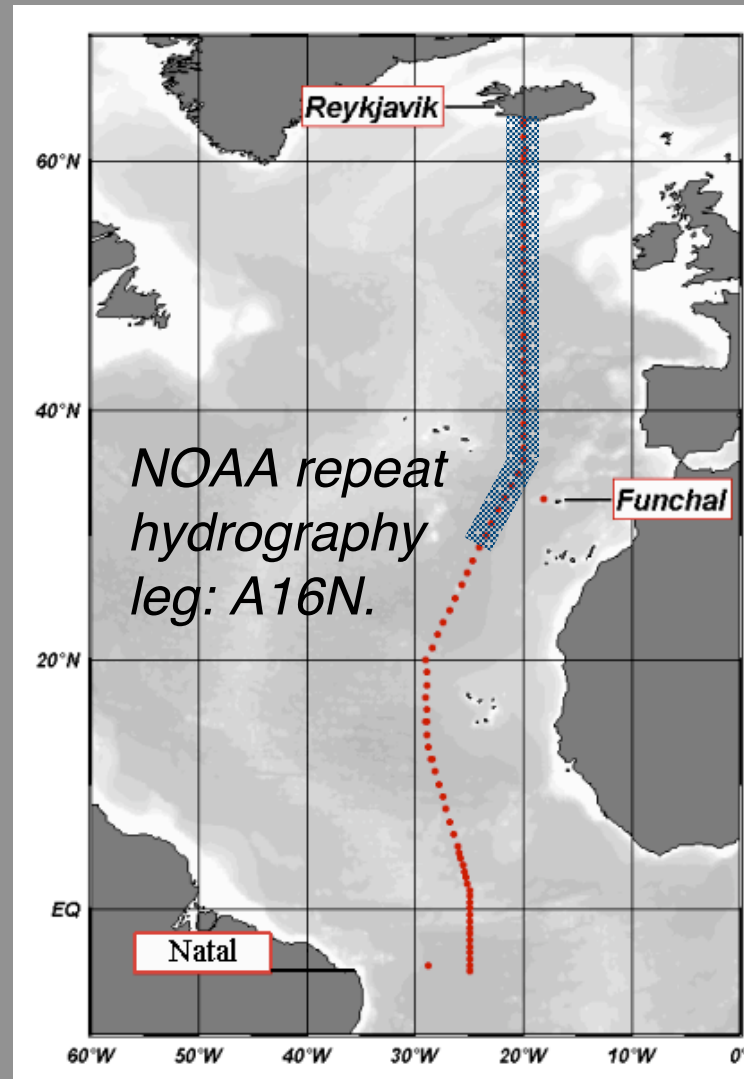
Net POC Growth Rate
and POC/Chl ratio
Increased here

Similar favorable conditions,
but little biomass increase

Bishop, J.K.B., et al. (2002) Science 298, 817-821.

Sensor Development/ Operational Testing

- **POC & PIC concentration**
Ship: CLIVAR Repeat Hydrography
A16N (2003)
A16S (2005)
sensor verification.
small volume sample filtration
- **POC & PIC FLUX (new)**
Buoy and Float Optical Sediment Trap
VERTIGO N Pacific
March 2004, June-July 2004, July 2005).



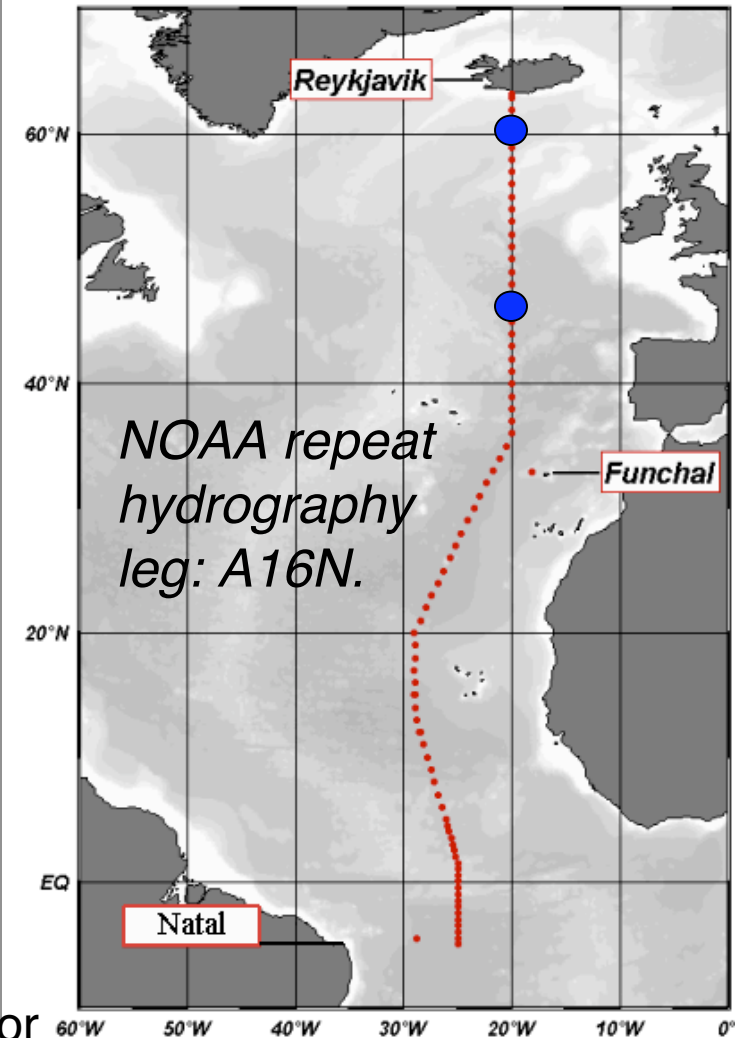
June 2003: Three Carbon Explorers deployed in North Atlantic

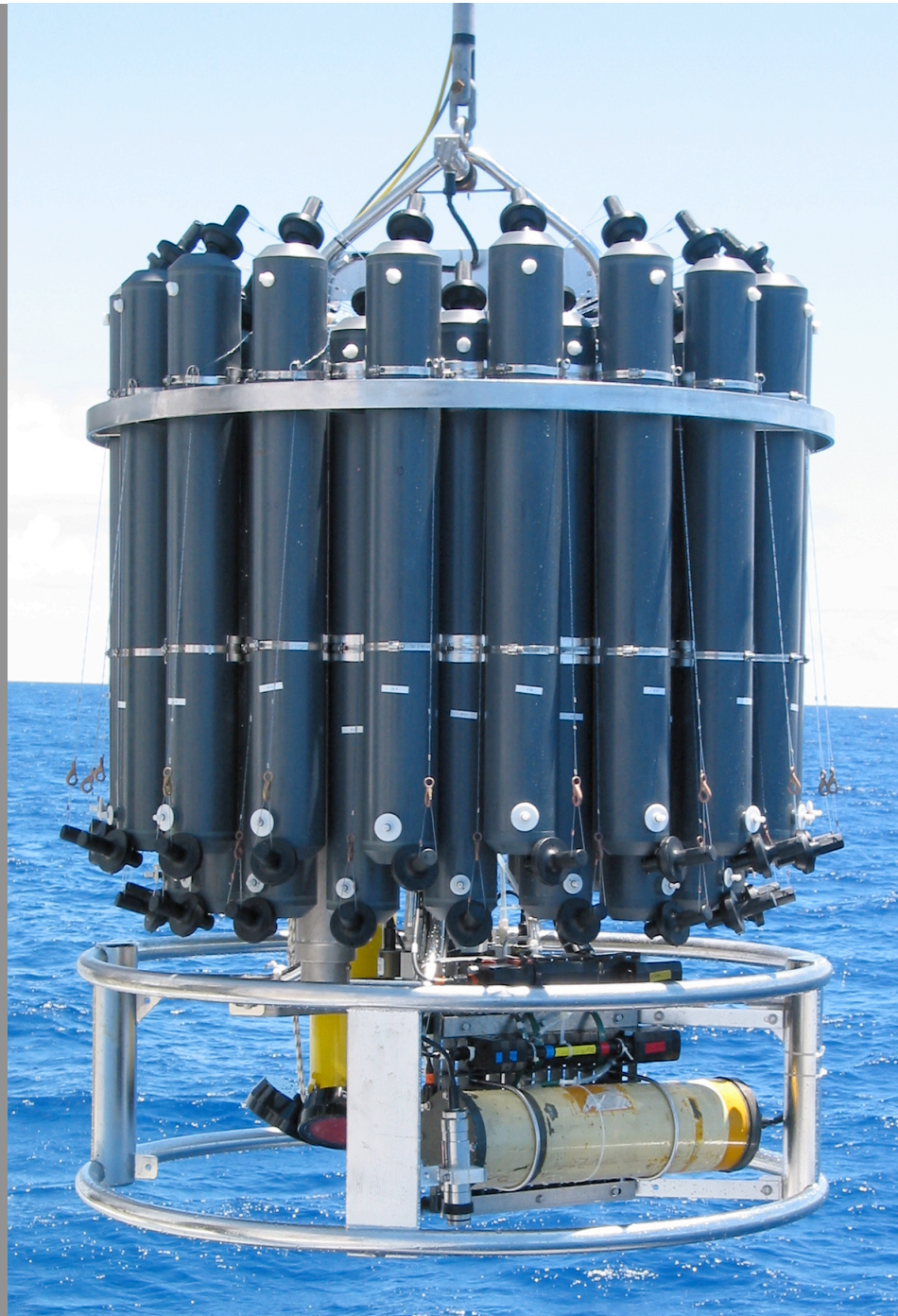
PIC and POC sensors calibrated and operationally proven at stations along the survey track

POC Sensor

Scattering Sensor

PIC sensor





POC sensor vs. Particulate P by ICP-MS.



**Small Volume
(1L - 0.4 µm)
Filtration System**

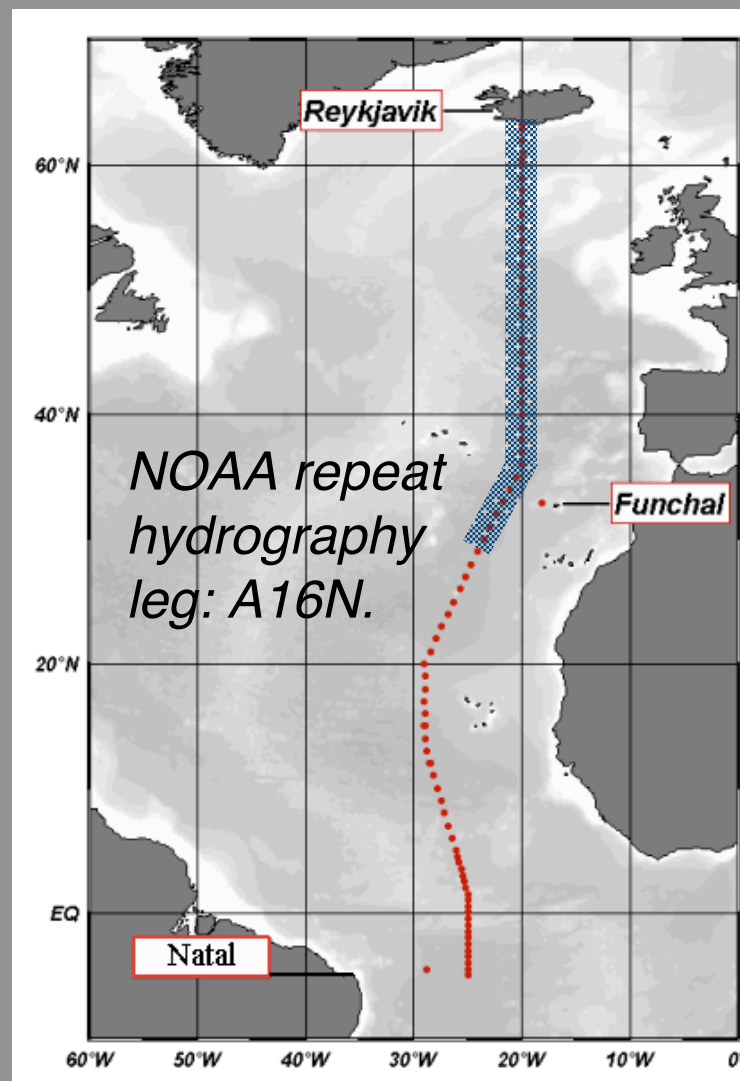
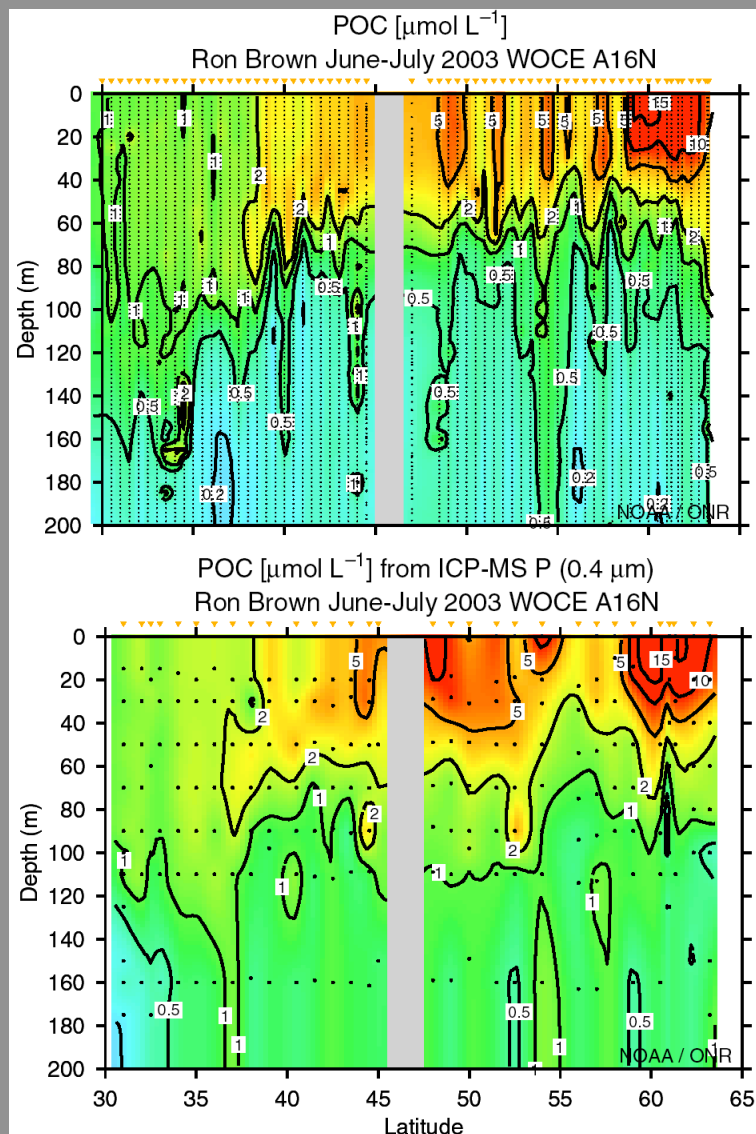
POC = Particulate Organic Carbon

June 2003: *POC sensor* *WOCE A16N*

Transmissometer
POC estimate
April 2004
Using published
Calibration factors

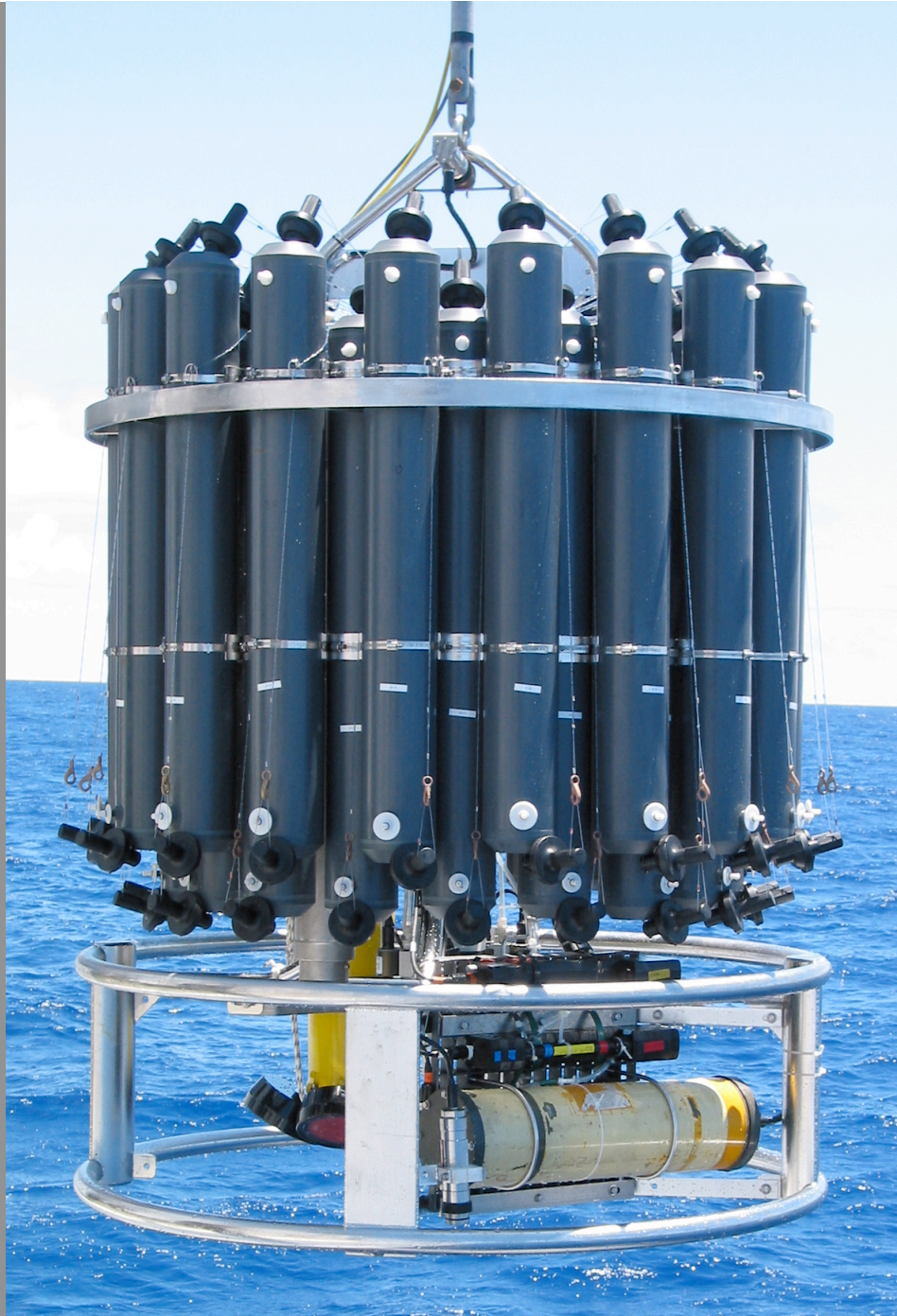
POC
Estimated from
ICP-MS P
Aug - Nov 2004

Results agree!



For the first time, absolute transmissometry is possible to full ocean depth

POC Sensor is stable, reliable and has very consistent response to POC over wide range of ocean conditions.

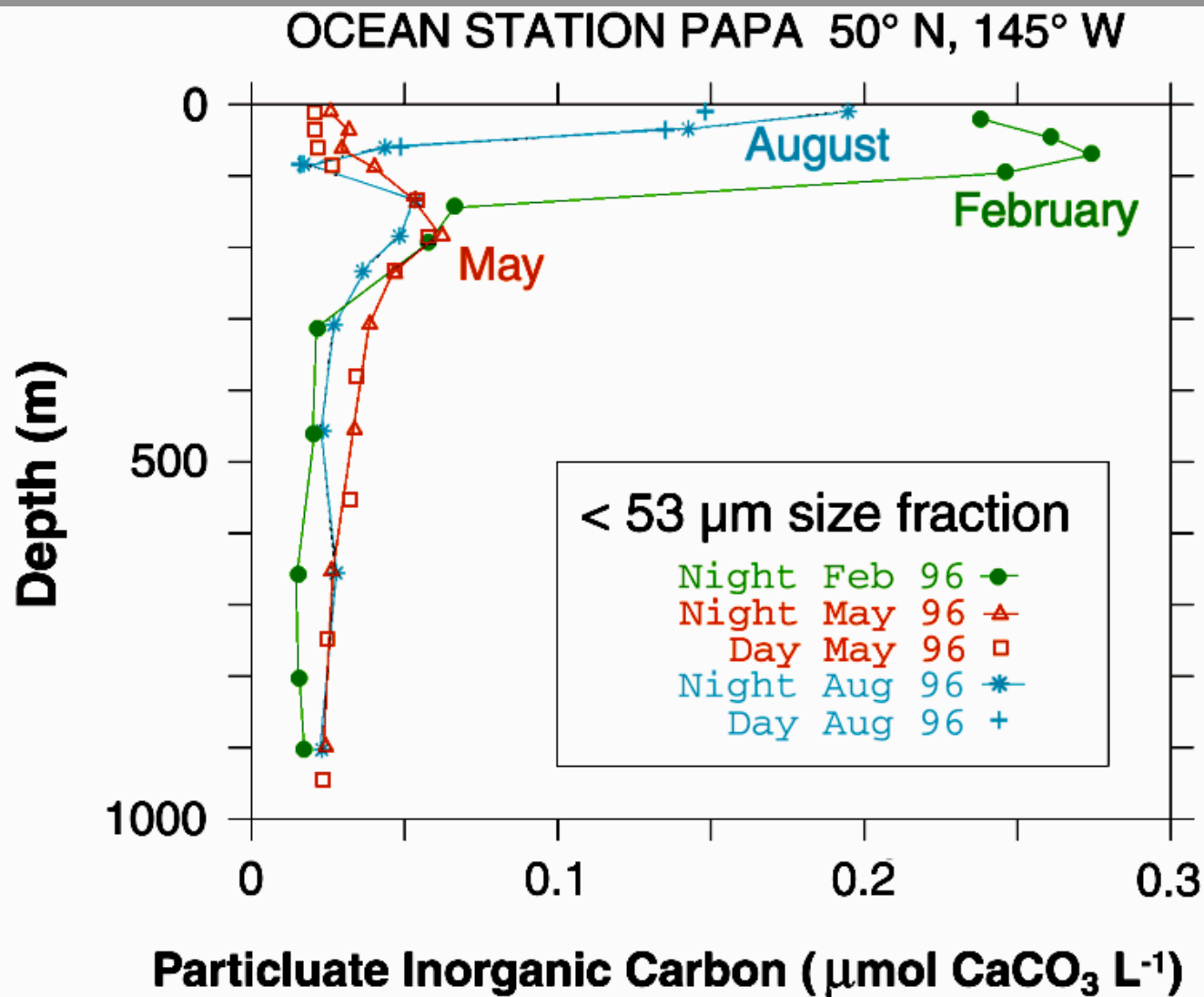


PIC sensor vs. Particulate Ca by ICPMS.

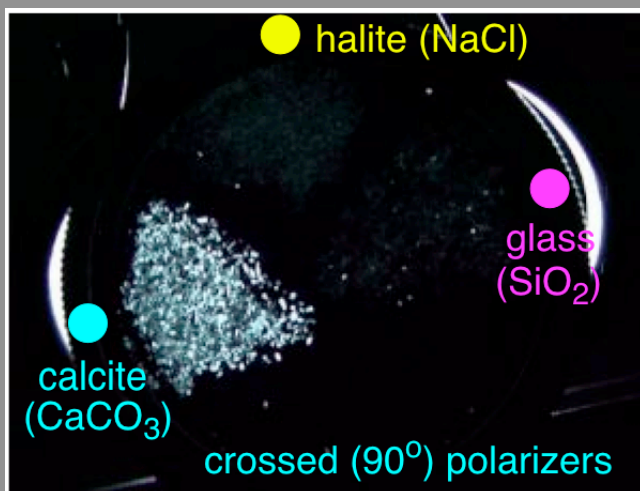
*“PIC is the ballast that helps organic aggregates sink into the deep sea.”
(Armstrong et al. 2003)*

PIC variability is extreme (0.01 to 30 μM)

... and is hard to follow from ships

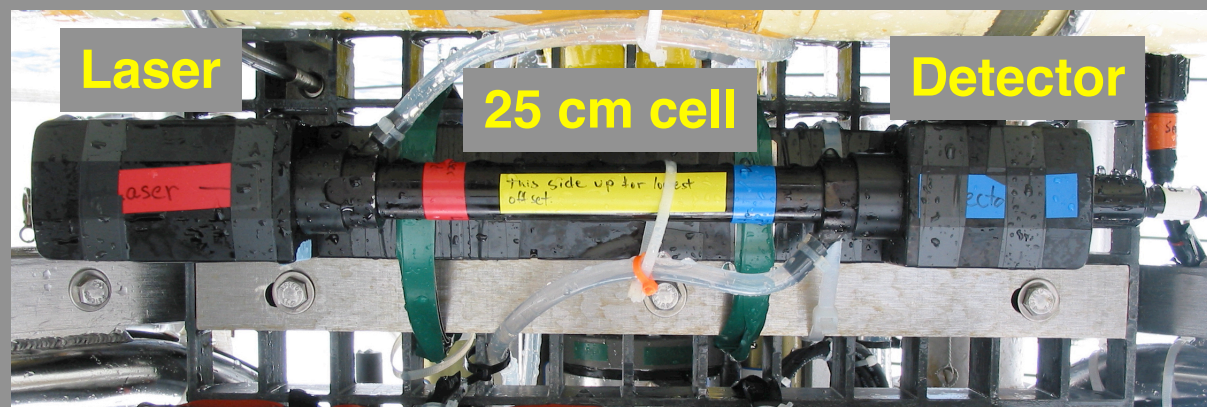


Sensor for particulate inorganic carbon (PIC).



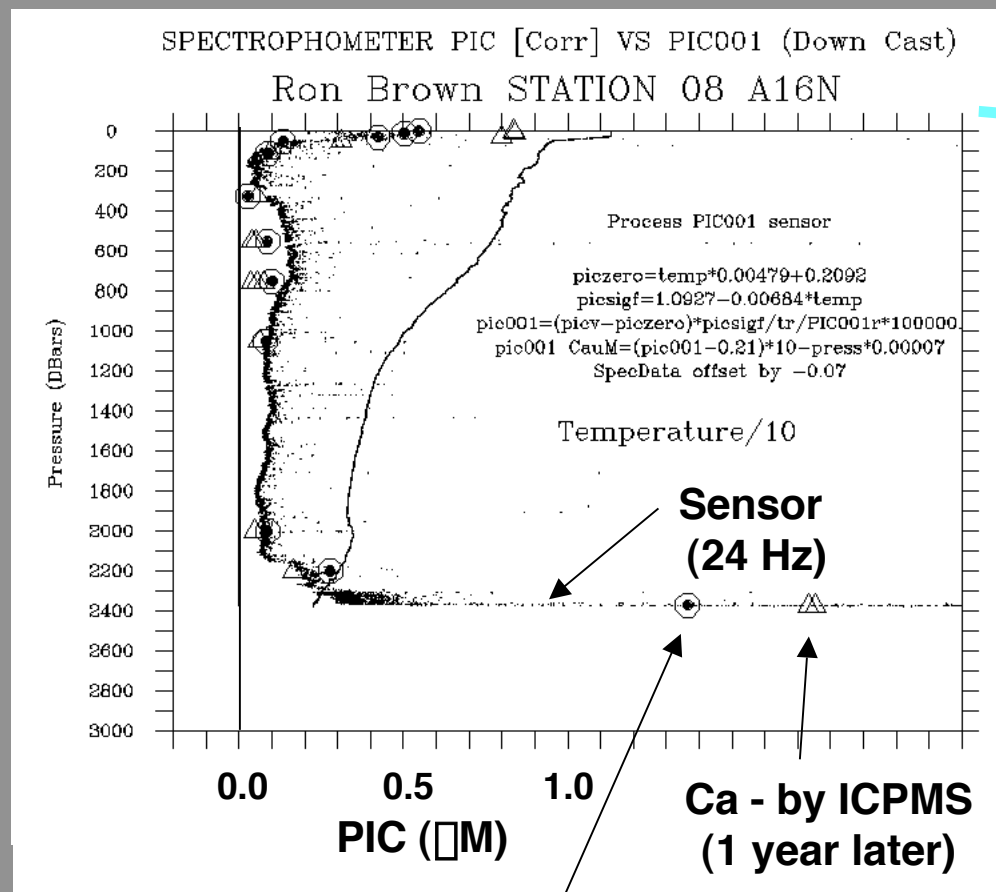
*Concept:
Calcite and Aragonite 'lights up' in
crossed polarized transmitted light*

Three PIC sensors
tested operationally
deployed during
CLIVAR 2003
repeat A16N



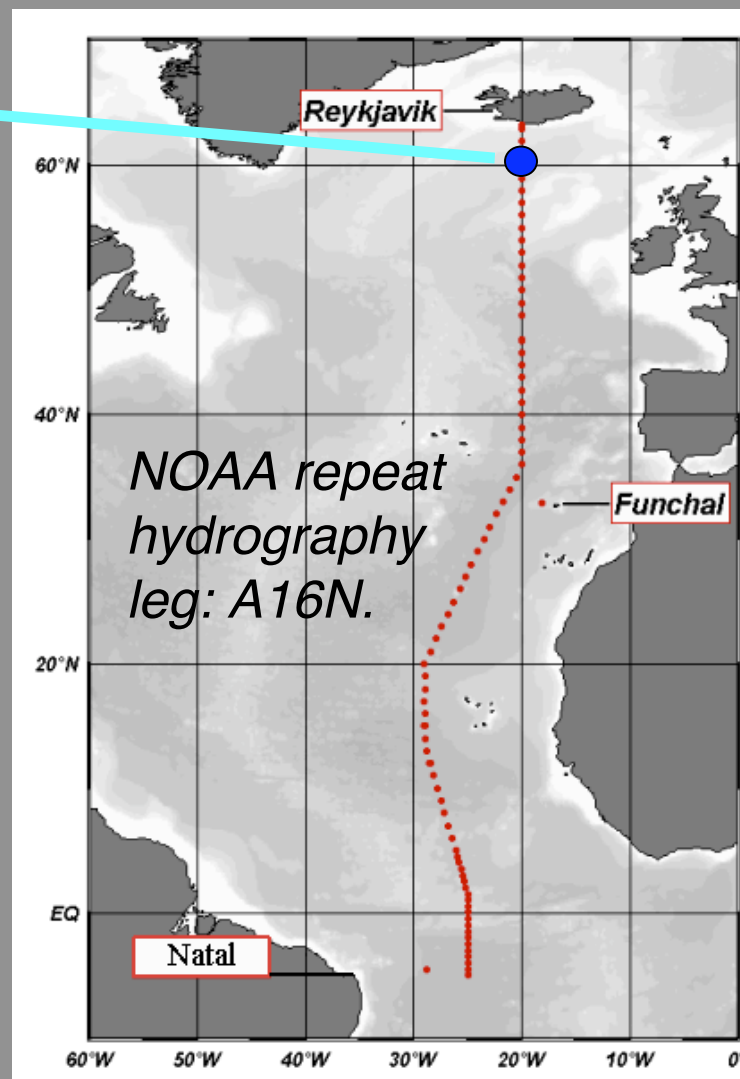
ONR / NOAA/ NOPP / WETLabs, Inc.

June 2003: *PIC* sensors calibrated and operationally tested at stations along the survey track



At sea birefringence measurement
(10 mins/sample)

serial no 001



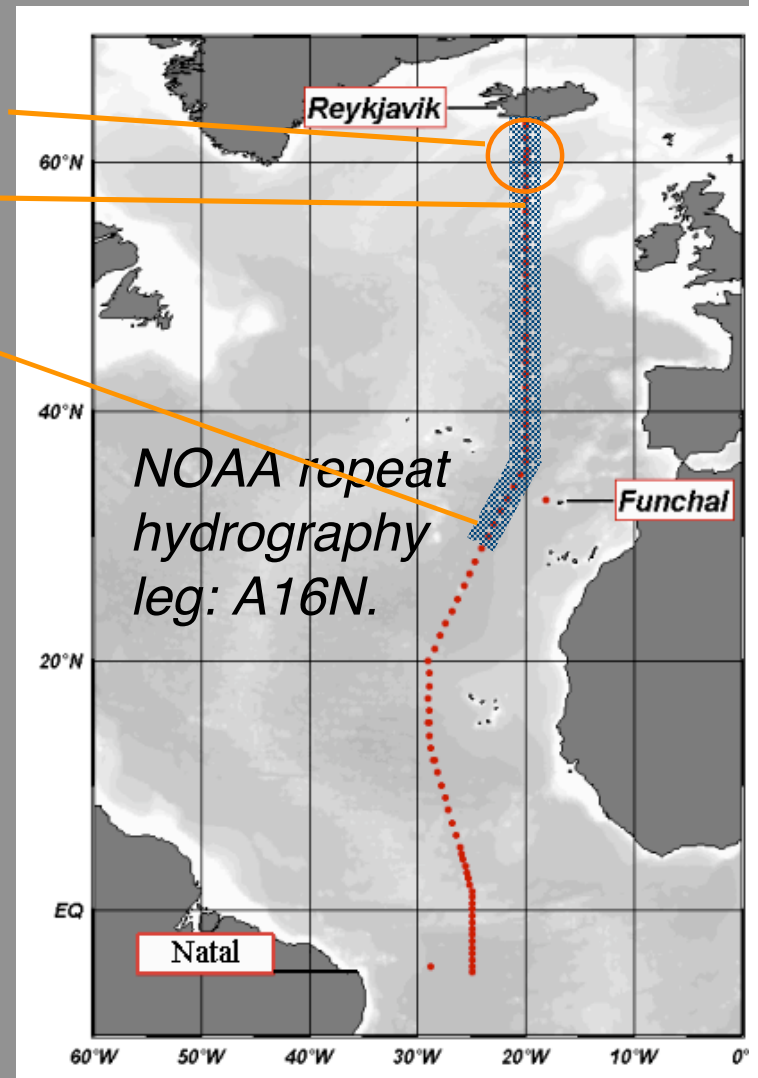
June 2003:A16N science summary

*Iceland Basin euphotic PIC/POC ~0.10
0.01 at 55N
Rises to 0.05 by 30N*

*PIC Concentrations upto
2 μ M south of Iceland
to below 0.1 μ M*

*Signal independent of beam attenuation,
Scattering, and fluorescence*

New data for models of Carbon Export



Sensor Lessons from A16N

3 prototype PIC sensors tested

Open cell (PIC002) best

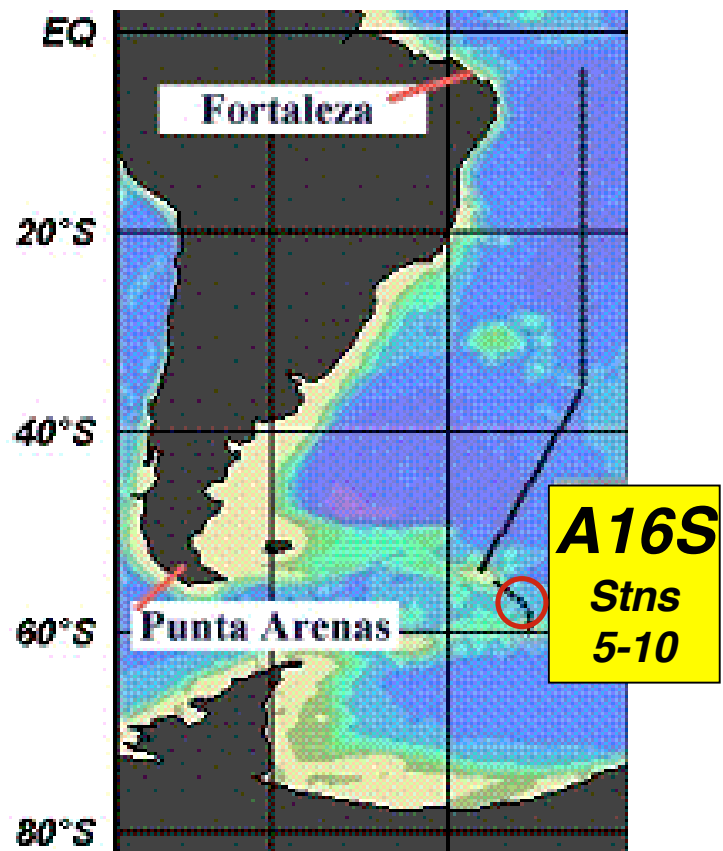
No major interferences

Stability issues in warm water identified

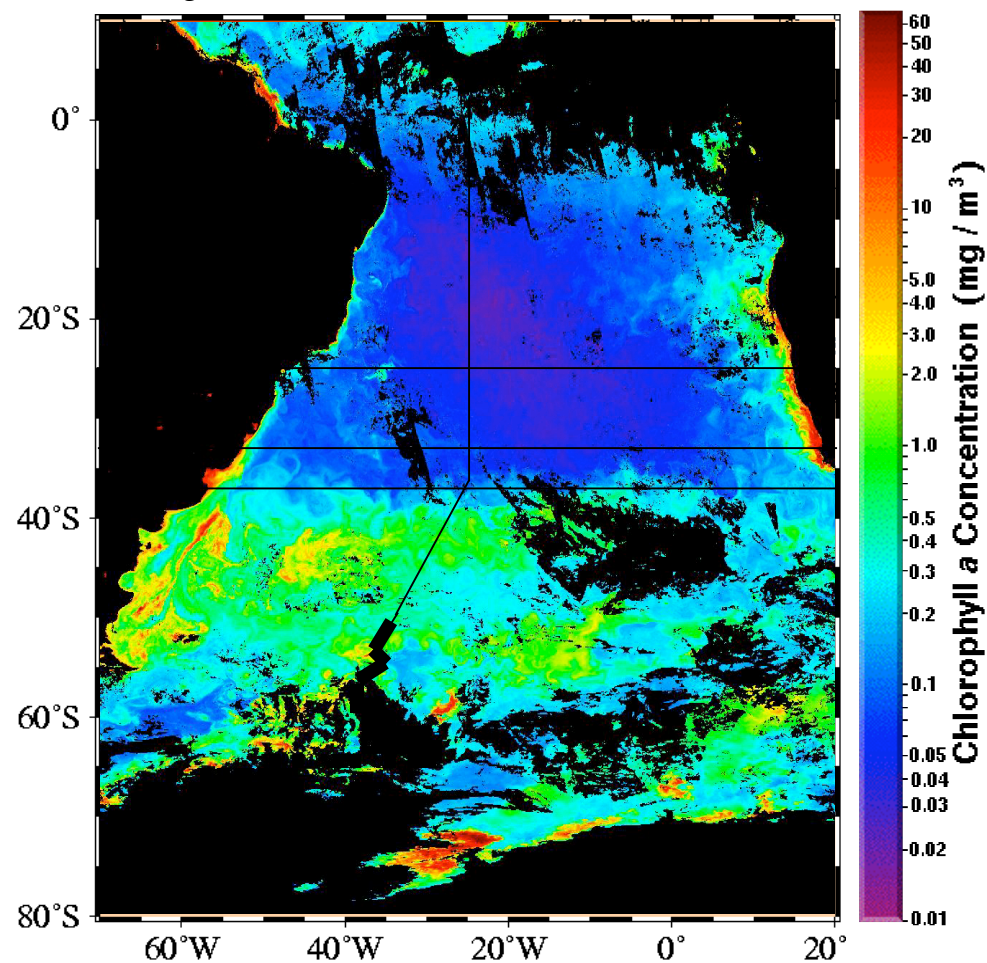


Rebuilt Sensor Jan 3 2005 ready for A16S

January 2005

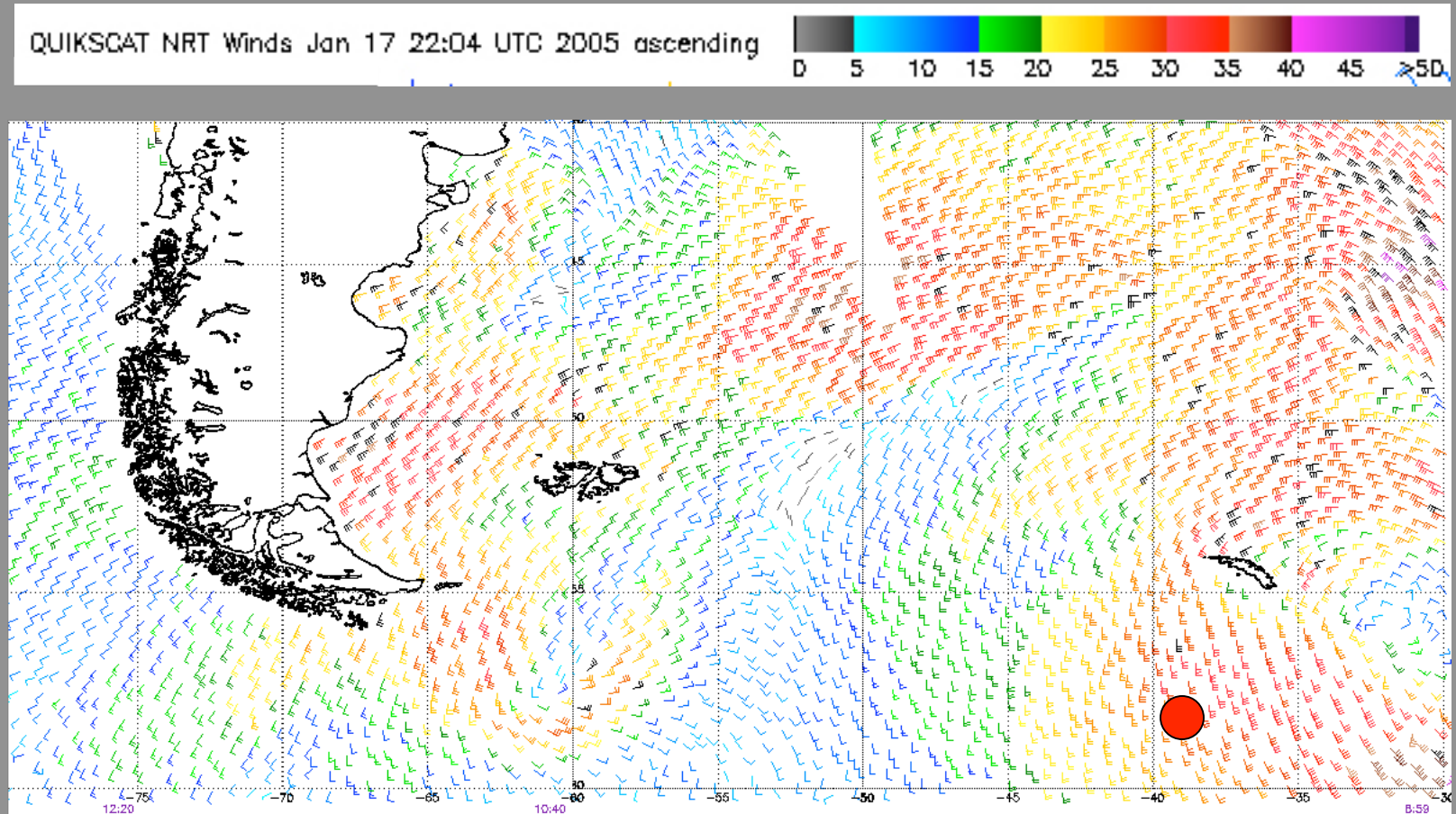


SeaWiFS/MODIS Chlorophyll
Jan 17 - 24 2005



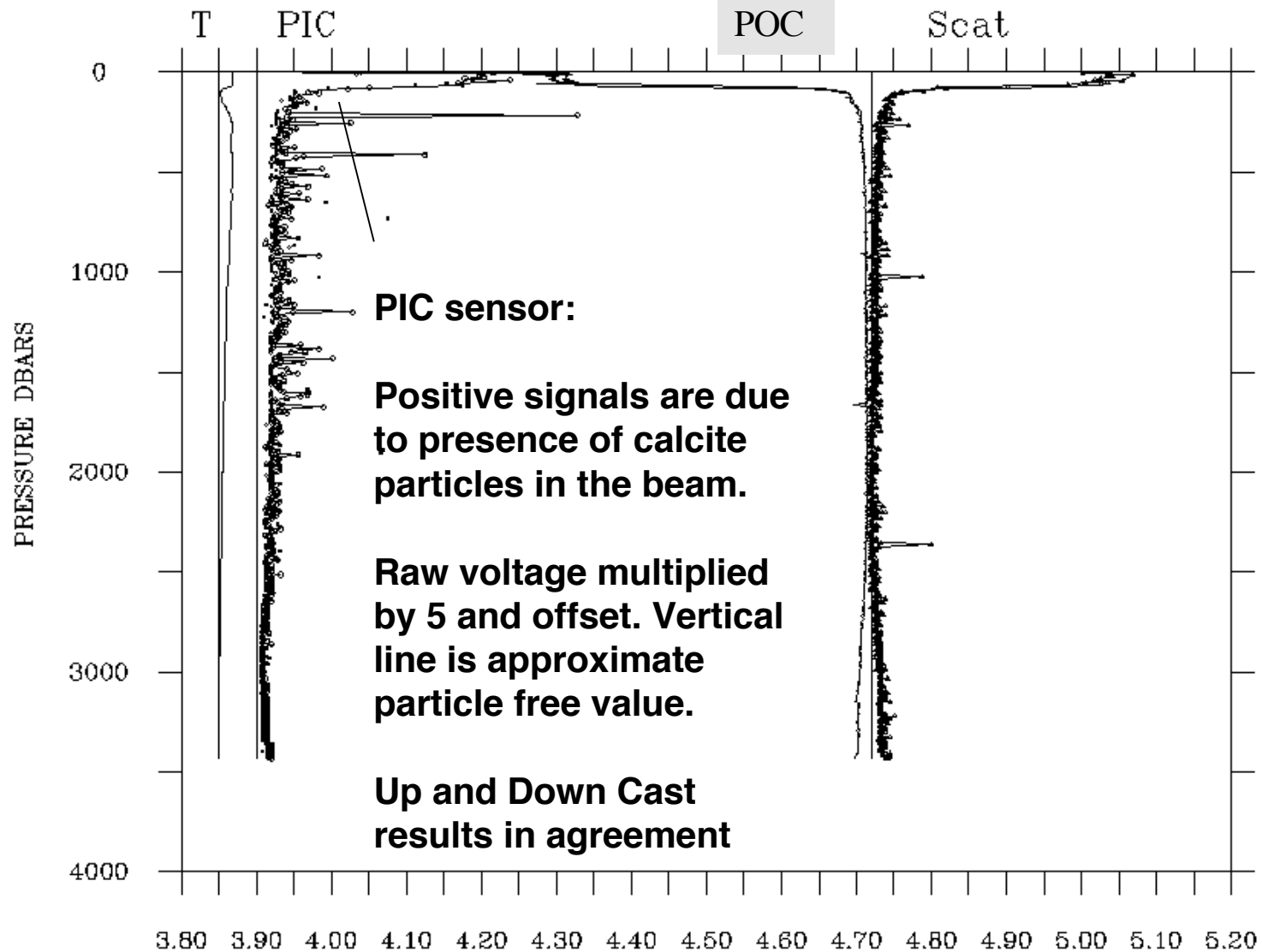
Ron Brown position Jan 17th 2005

Conditions: 25-30 kt winds



Bad weather rosette in use -no sensors

Ron Brown A16S Station 06 cast 1

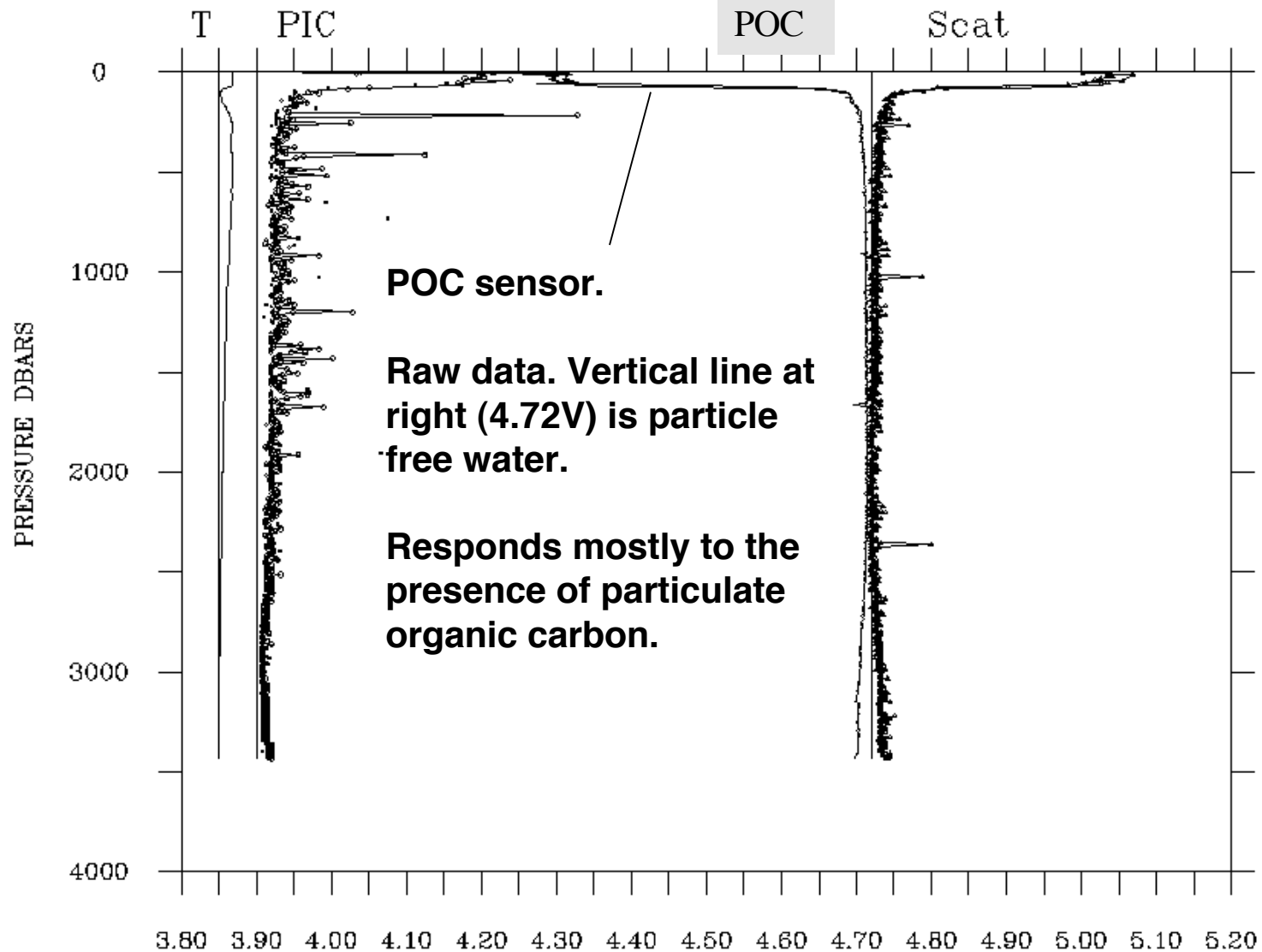


Fri Jan 21 16:20:17 PST 2005

VOLTS

PIC trcorr

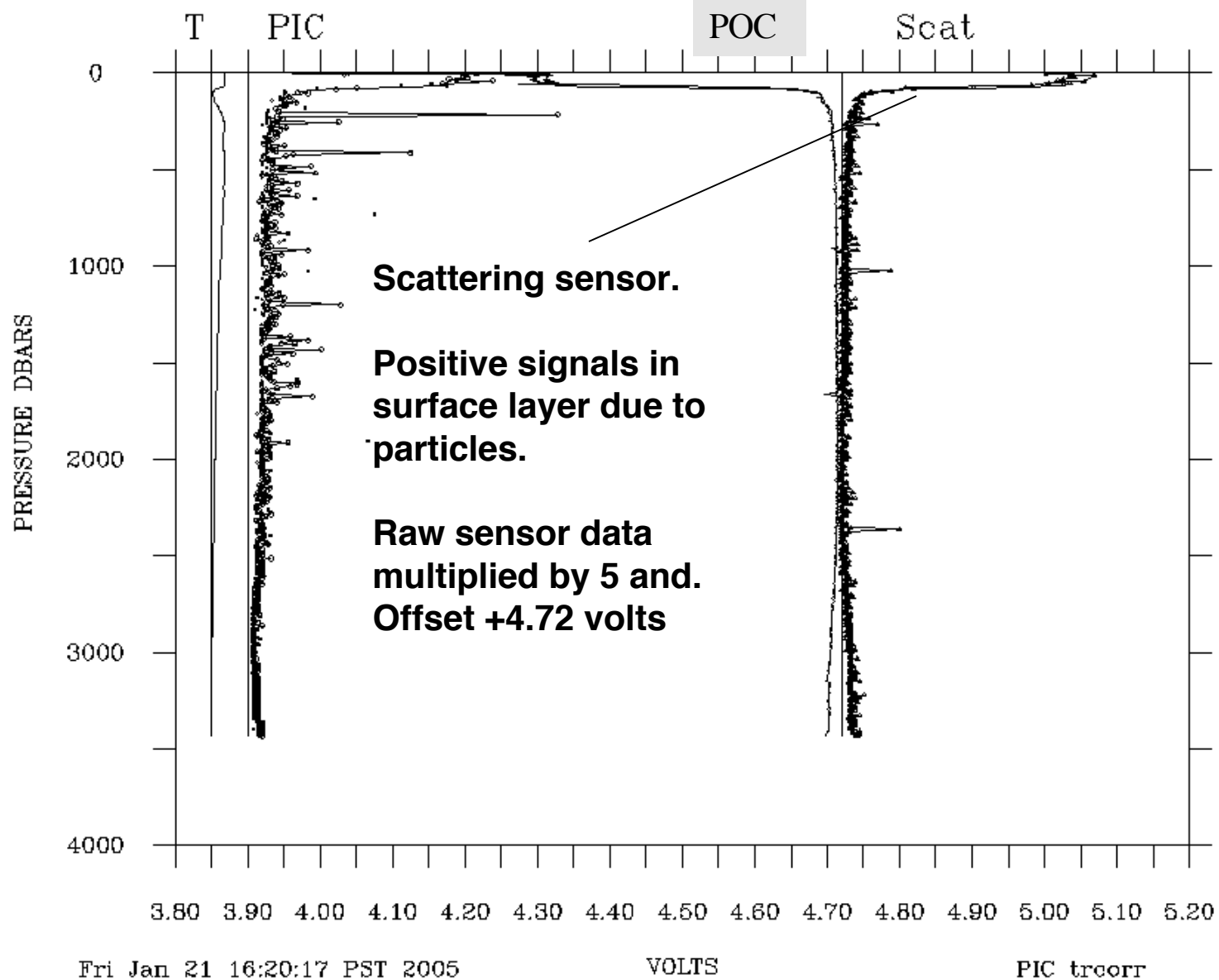
Ron Brown A16S Station 06 cast 1



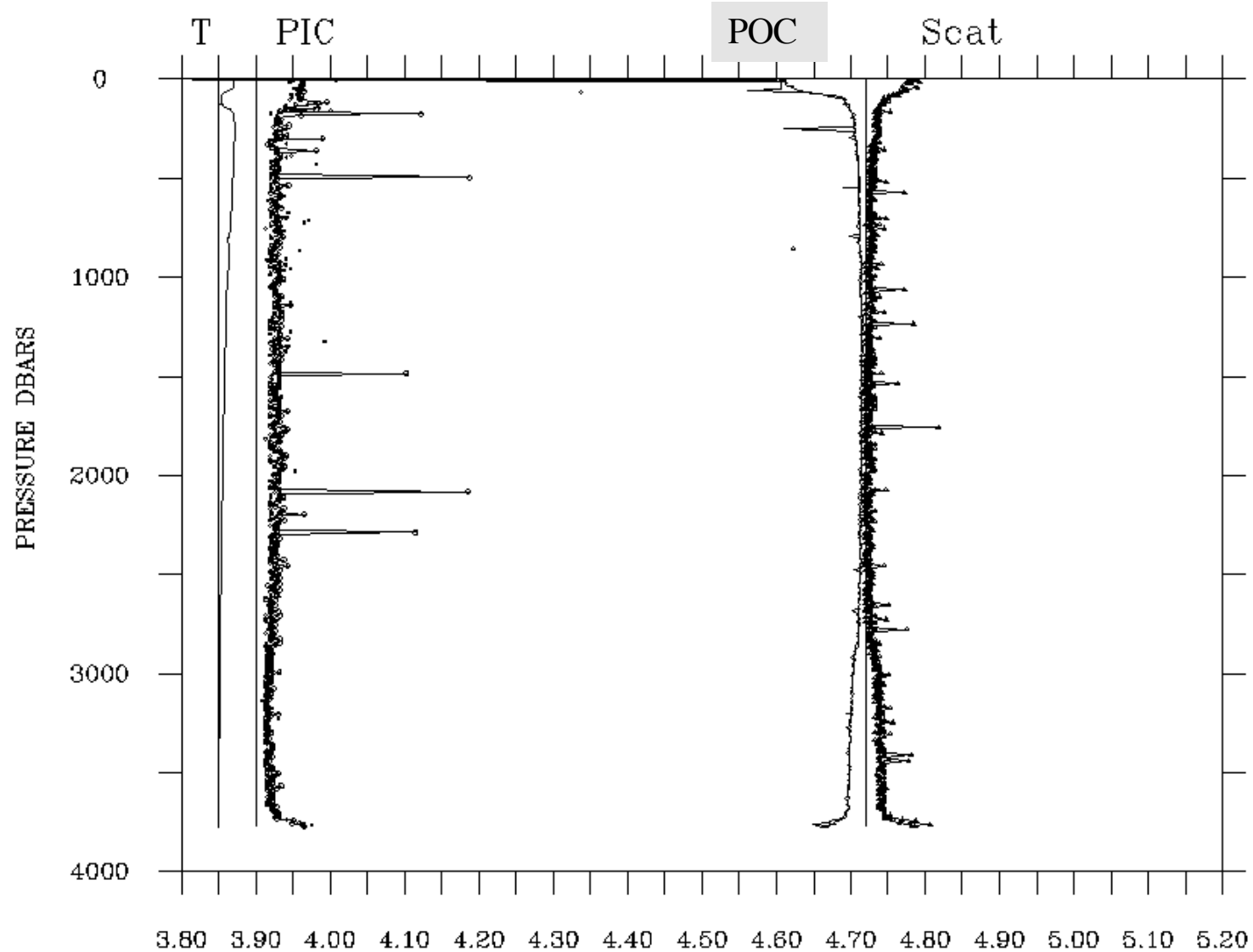
Fri Jan 21 16:20:17 PST 2005

PIC trcorr

Ron Brown A16S Station 06 cast 1



Ron Brown A16S Station 08 cast 1

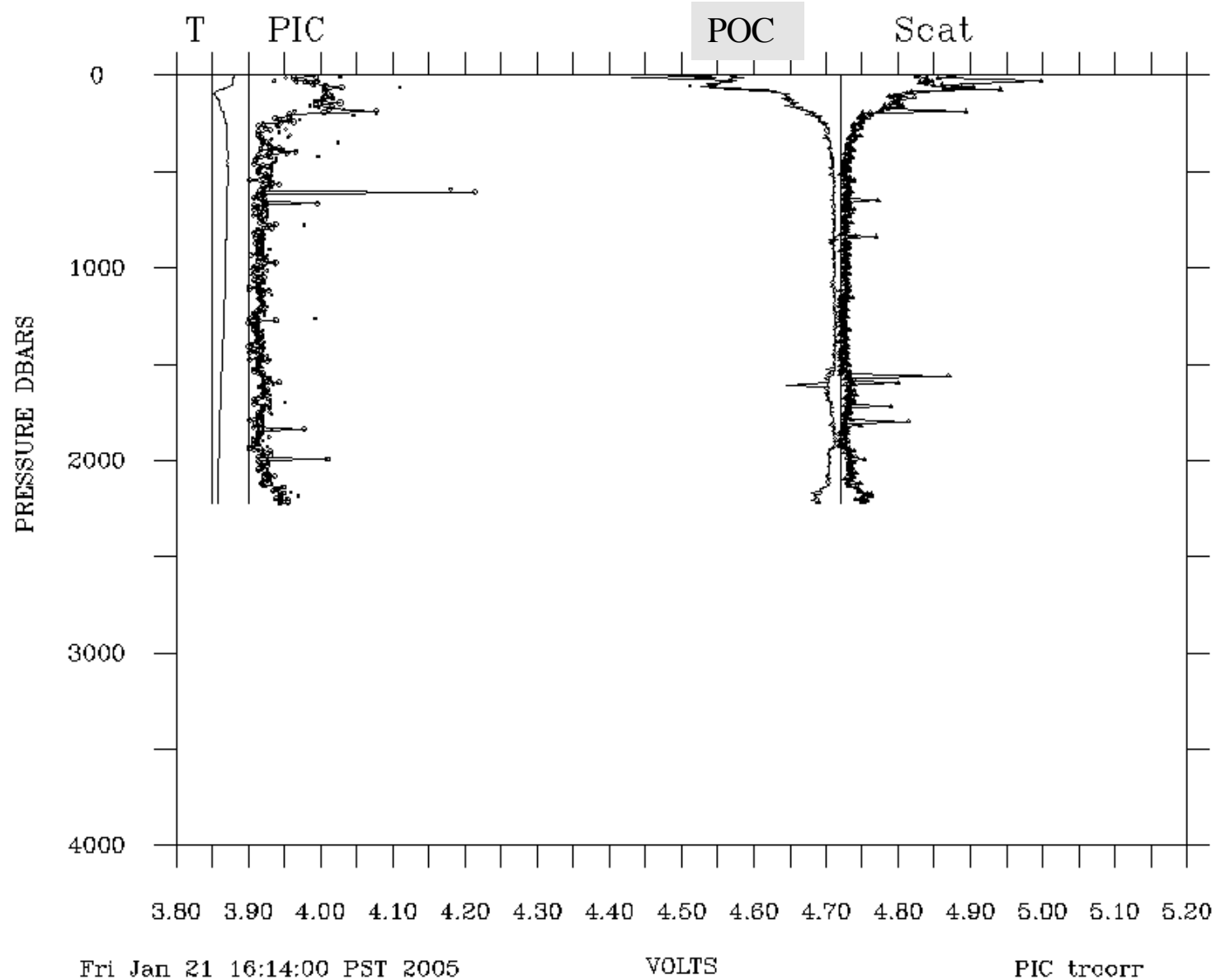


Fri Jan 21 16:17:30 PST 2005

VOLTS

PIC tcorr

Ron Brown A16S Station 10 cast 1

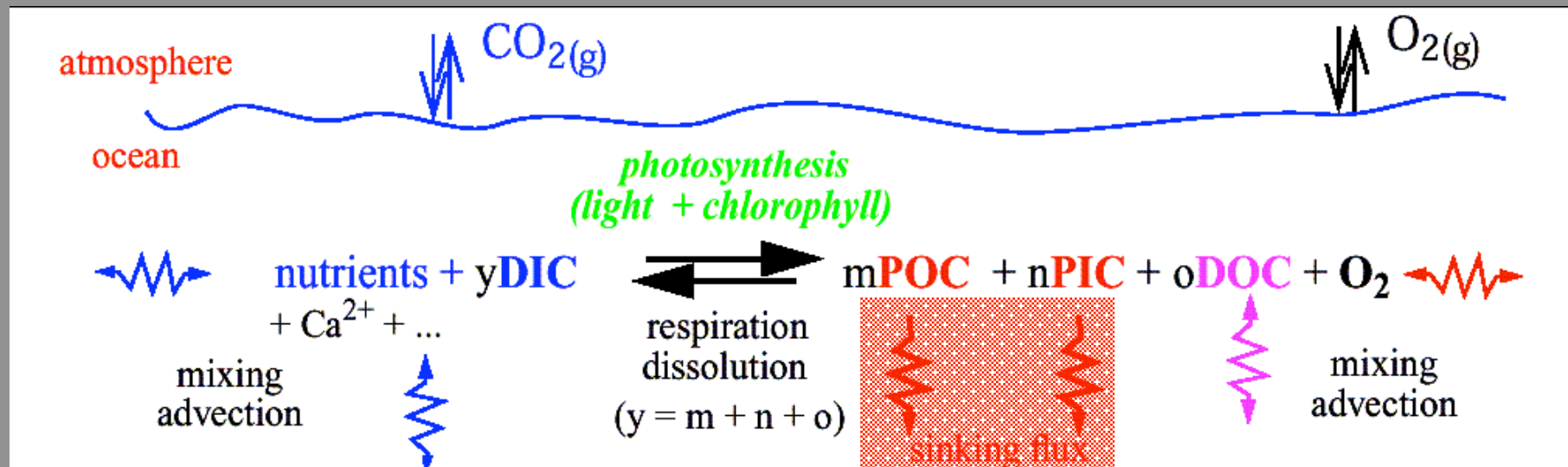


PIC Sensor is ready for operational deployment.

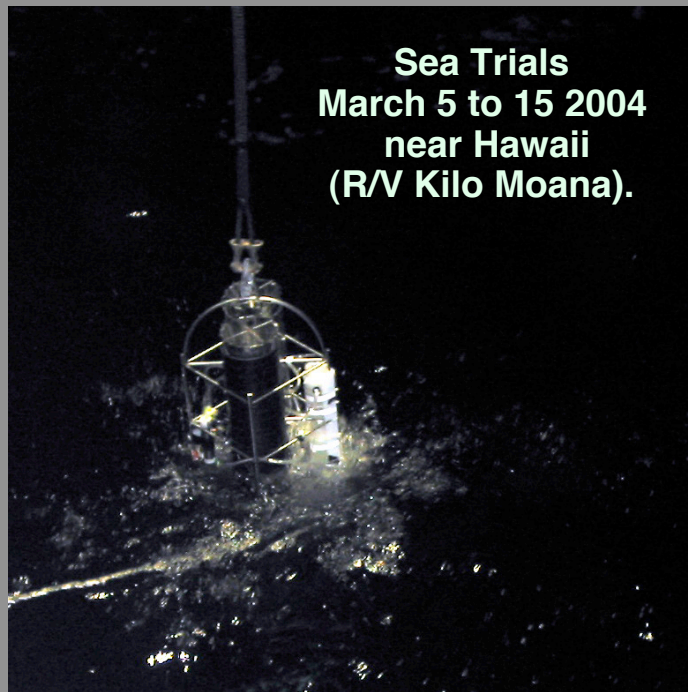
Work in progress to verify sensor calibration response over wide range of ocean conditions.

Results so far look good. May be able to see calcite saturation horizon in real time. A16S results will prove this.

Optical sediment trap for POC and PIC flux.



***~ 5 - 15 Pg of carbon
sinks into the deep sea
each year - we have
very poor
understanding of the
process***



Sea Trials
March 5 to 15 2004
near Hawaii
(R/V Kilo Moana).

*Deployed 9 hrs below
surface buoy at 180 m
with elastomer damping
system*

We aim to put this on a float



Sedimenting
particles fall into
the funnel and
accumulate on a
glass surface
and are
imaged at 15 μ m
resolution by an
upward looking
digital camera.
Periodically, the
surface is
cleaned.

Image Processing: Particles resolved at 15 μ m size

9 Hour Timeseries Analysis

29 Images (once every 20 min)

2 cleaning steps (seq 10 and seq 20)

Detect arriving particles

2 mm

Particles are tracked in three categories and across the entire image

Sequence 12



Sequence 18

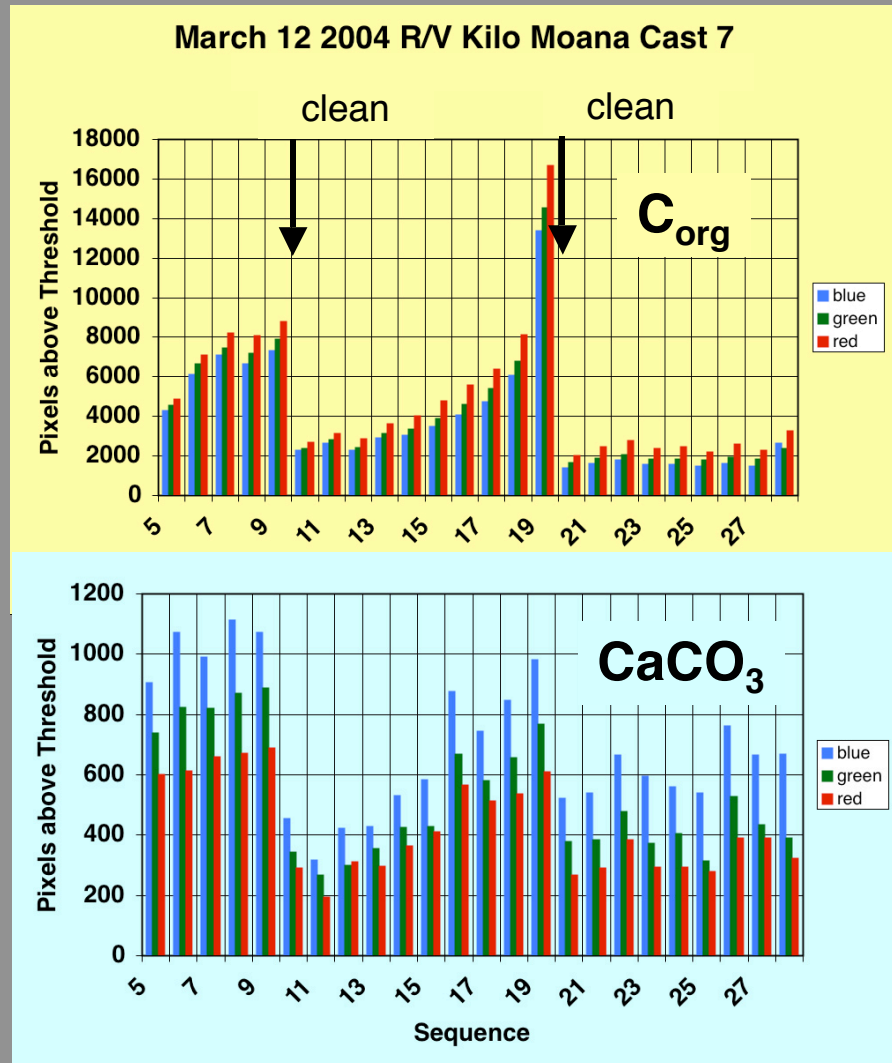


Three Modes of Color (RGB) Imaging:

(1) Non-Polarized transmitted light :
accumulation of particles
containing organic carbon.

(2) Cross-Polarized transmitted light:
accumulation of CaCO_3 particles
containing inorganic carbon.

(3) Reflected Light (not shown):
Definition of particle boundaries

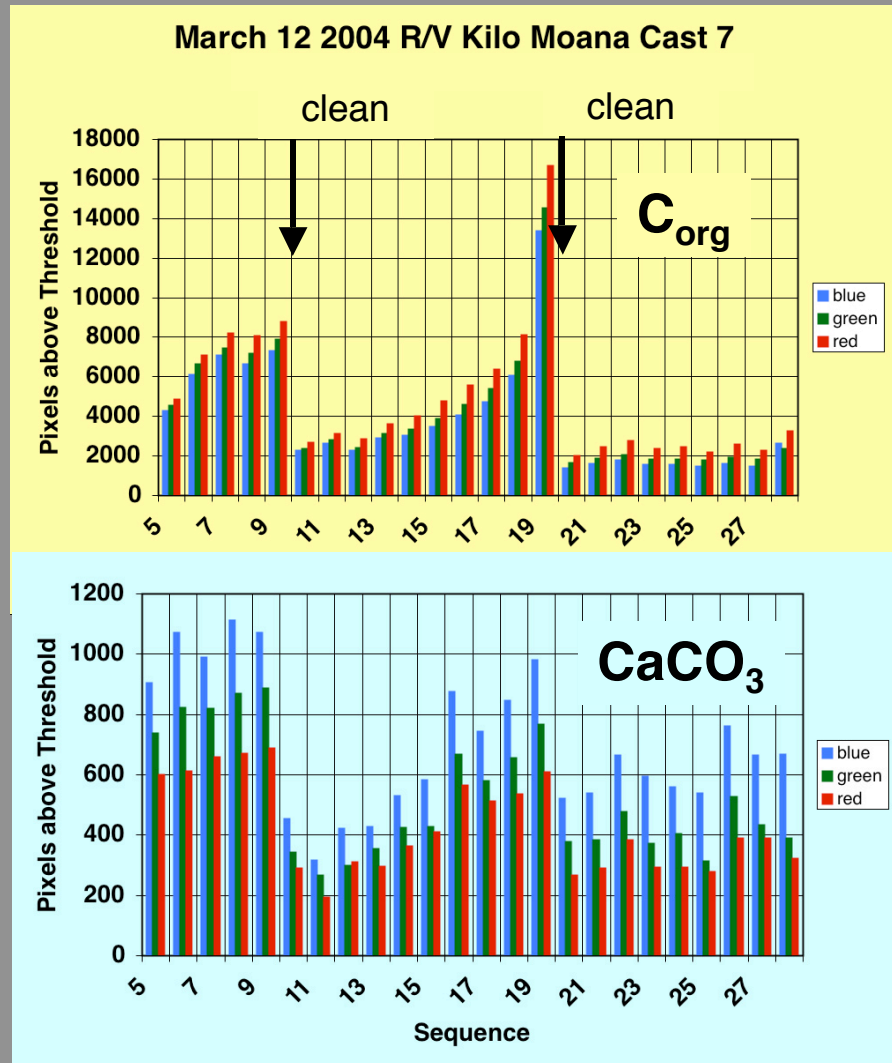


Carbon Sedimentation Flux through
180 m easily detected in a very
low productivity environment.
 $\sim 1.5 \text{ mmol } C_{\text{org}}/\text{m}^2/\text{d}$

First autonomous measure of CaCO_3
sedimentation

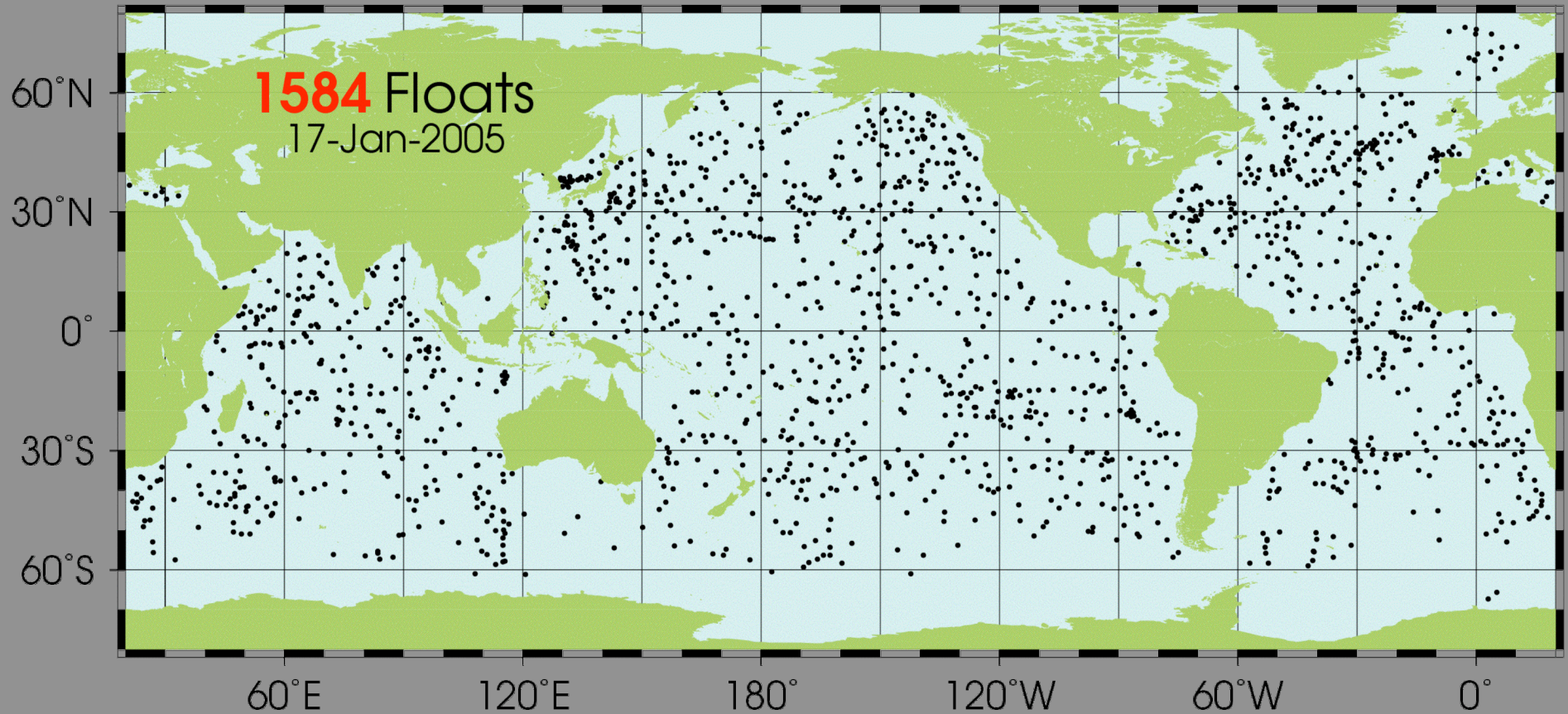
Another 20 days of data
June 20 to July 11 2004
Vertigo Experiment (HOTS)

July-August 2005
North Pacific near Japan



*30 min frequency for weeks
current (2004) capability*

Can we have a Carbon - ARGO?



Prospects for a Carbon ARGO look very good

Carbon Explorer Track record

2 N Pacific OSP	2001
1 Cal current	2001
4 SOFeX	2002 - 1 at 66S
2 N Pacific OSP	2003
3 N Atlantic A16N	2003 - 1 at 60 N
1 HOTS	2004
(lost on launch)	

No major biofouling problems

Transmissometers

~8 float years of data

Includes Carbon Flux Index.

PIC sensor - 1 test

Orbcomm telemetry poor poleward of
55. Iridium will fix that.



Survive all weather

Prospects for a Carbon ARGO look very good

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PIC sensor - 1 test on Carbon Explorer

Orbcomm telemetry poor poleward of
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Sensor STATUS

POC

Sensor is mature.

PIC

Operational testing from
CTD's

POC & PIC flux:

2-3 years for fully
autonomous float ops.

pCO₂, TCO₂, NO₃, O₂...
in progress by others
Needs investment

THANKS TO DOE-OBER, NOAA-OGP,
NOPP/ONR, NSF (for shiptime)

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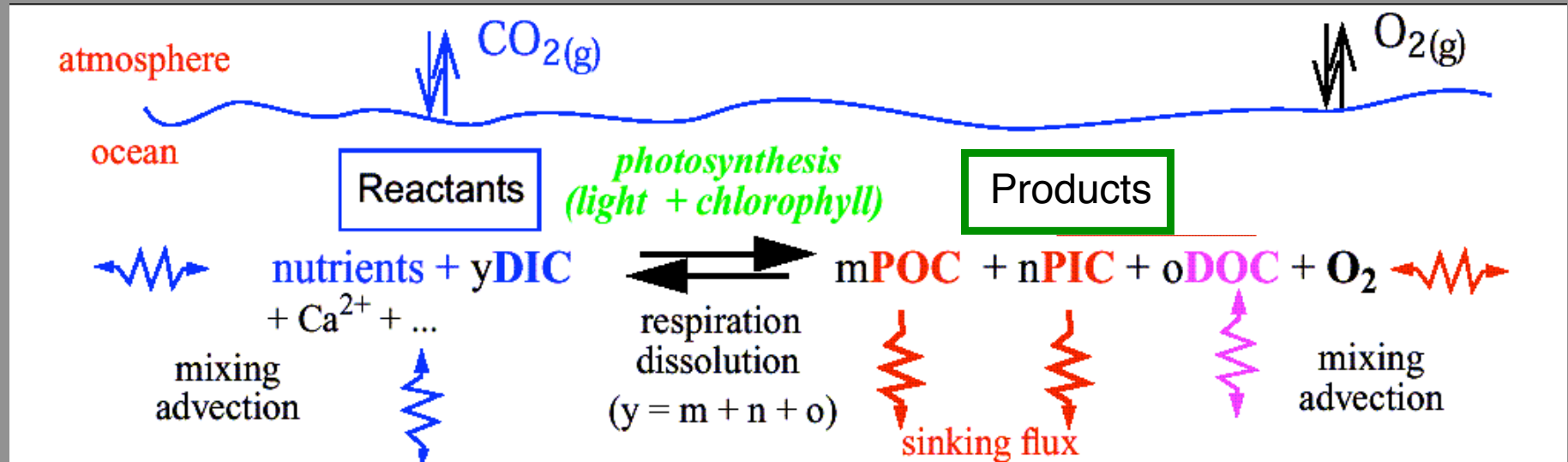
We are now ready
for an ocean
carbon observing
system that is ...

Fast
Real Time
Robotic
High Frequency
Free Ranging
Low Cost

THANKS TO DOE-OBER, NOAA-OGP,
NOPP/ONR, NSF (for shiptime)

Biological Processes in the ocean impact atmospheric CO₂

760 Pg C here **and rising**



38,000 Pg C in the ocean

Our Research focus : sensors for Products

Products of Photosynthesis are the most dynamic and poorly understood Ocean Carbon pools