Argo* Ocean Float System

Part 2

Data Analysis and Results

March 2015

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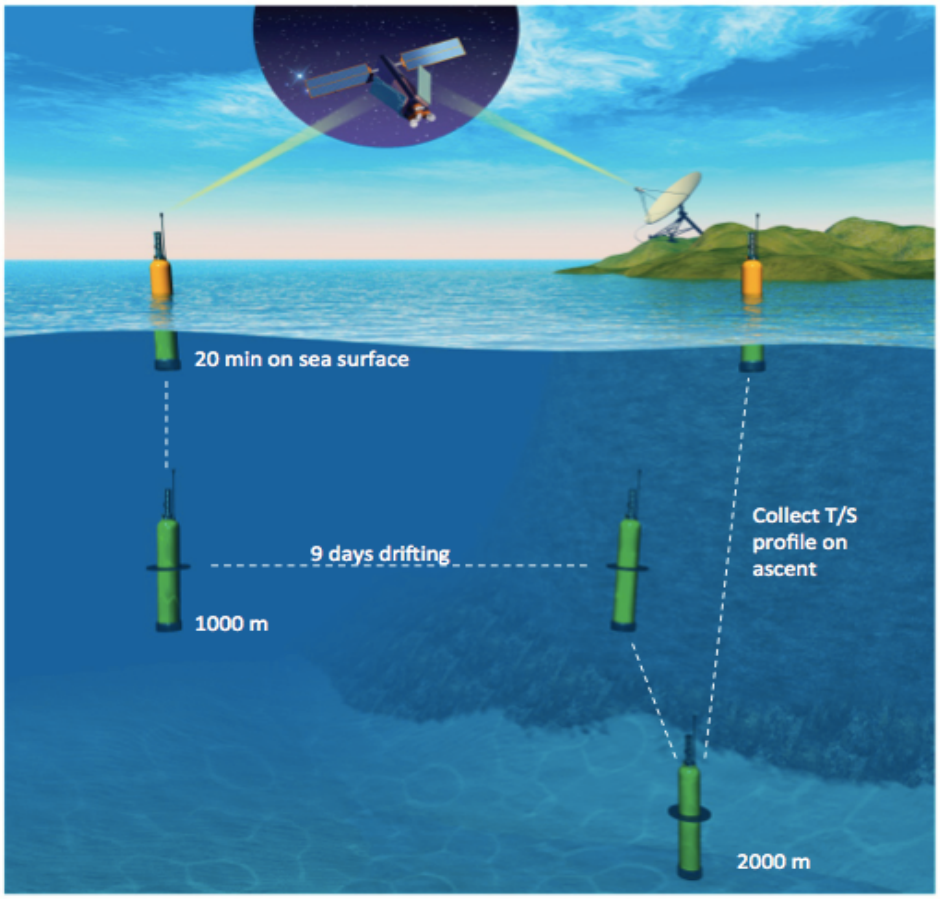
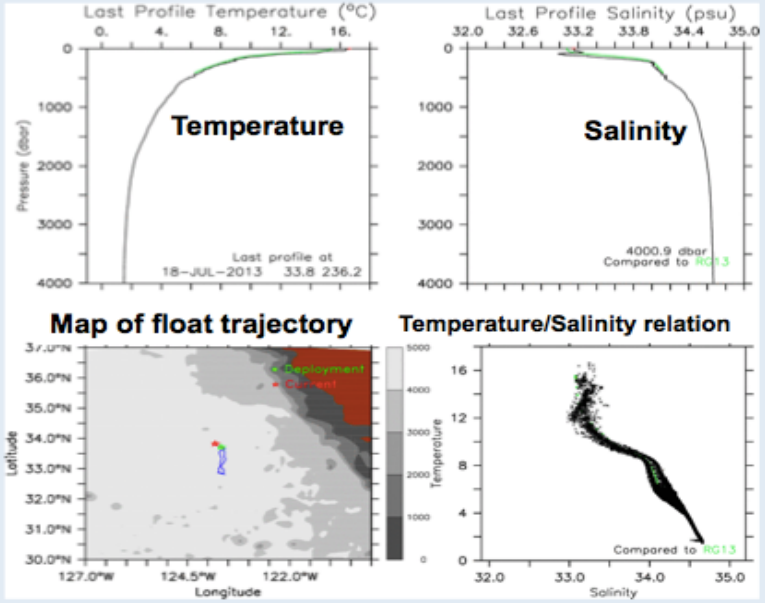
* Array for Realtime Geostropic Oceanography



How do Argo floats work?

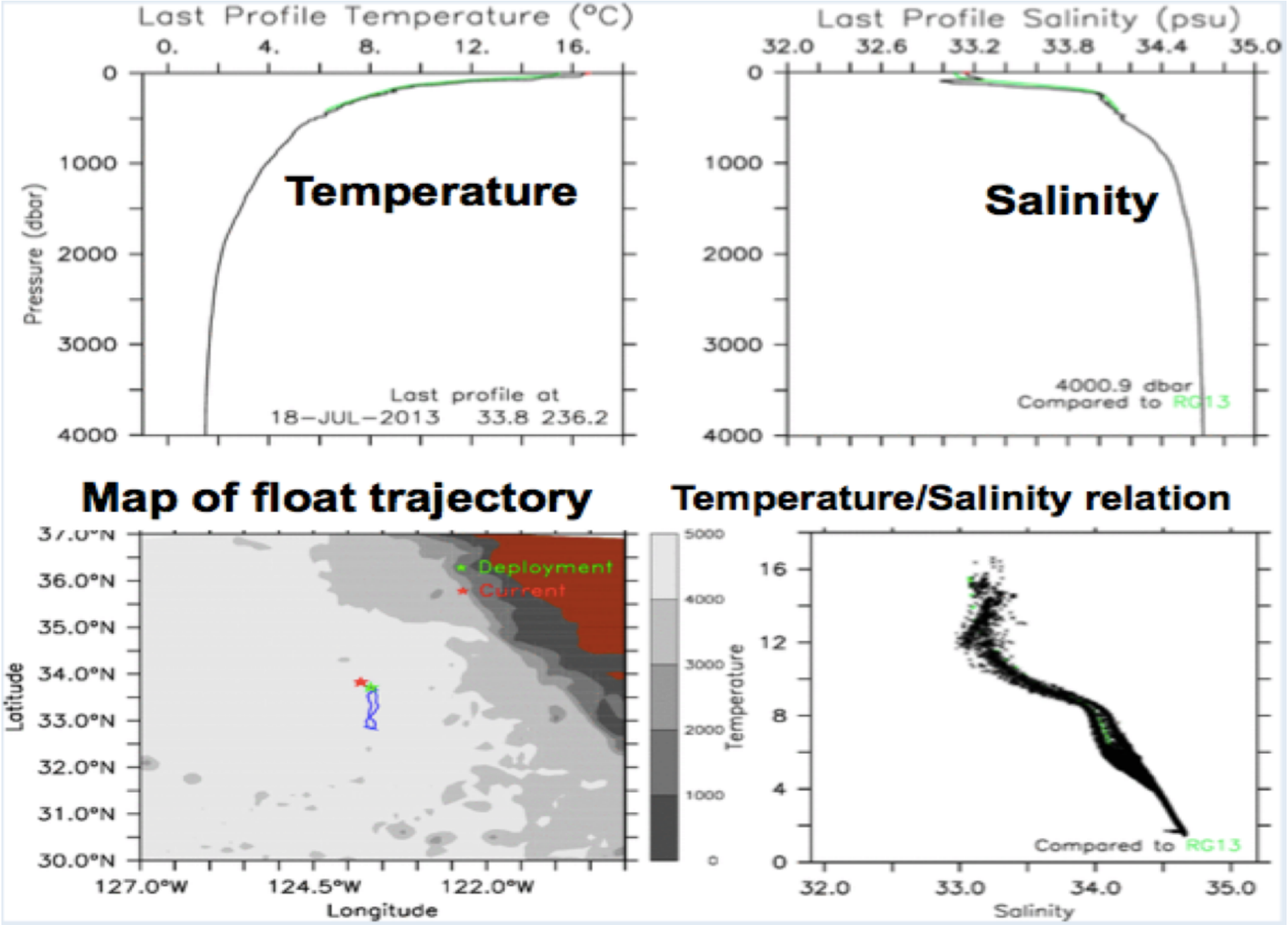
Argo floats collect a temperature and salinity profile and a trajectory every 10 days, with data returned by satellite and made available within 24 hours via the GTS and internet (http://www.argo.net) .



Cost of an Argo T,S profile is ~ $170.

Typical cost of a shipboard CTD profile ~$10,000.

www.argo.ucsd.edu/ and www.argo.net


Last Profile Temperature (°C)
0.
4.
8.
12.
16.
0
1000
2000
3000
4000
Pressure (dbar)
Temperature
Last profile at
18–JUL–2013 33.8 236.2
Last Profile Salinity (psu)
32.0
32.6
33.2
33.8
34.4
35.0
Salinity
4000.9 dbar
Compared to RG13
Map of float trajectory
Deployment
Current
36.0°N
35.0°N
34.0°N
33.0°N
32.0°N
31.0°N
30.0°N
Latitude
127.0°W
124.5°W
122.0°W
Longitude
5000
4000
3000
2000
1000
0
Temperature
Temperature/Salinity relation
16
12
8
4
0
32.0
33.0
34.0
35.0
Salinity
Compared to RG13

Practical Salinity Units (psu)

- Ocean average psu ≈ 35 psu
- River mouth ≈ 15 psu Dead Sea ≈ 40 psu
- Chloride 19 grams Sodium 11 grams

  Sulfate 3 grams Magnesium 1.5 grams

  Calcium .35 grams Potassium .35 grams

Per kg of water = total of 35.2 grams/kg

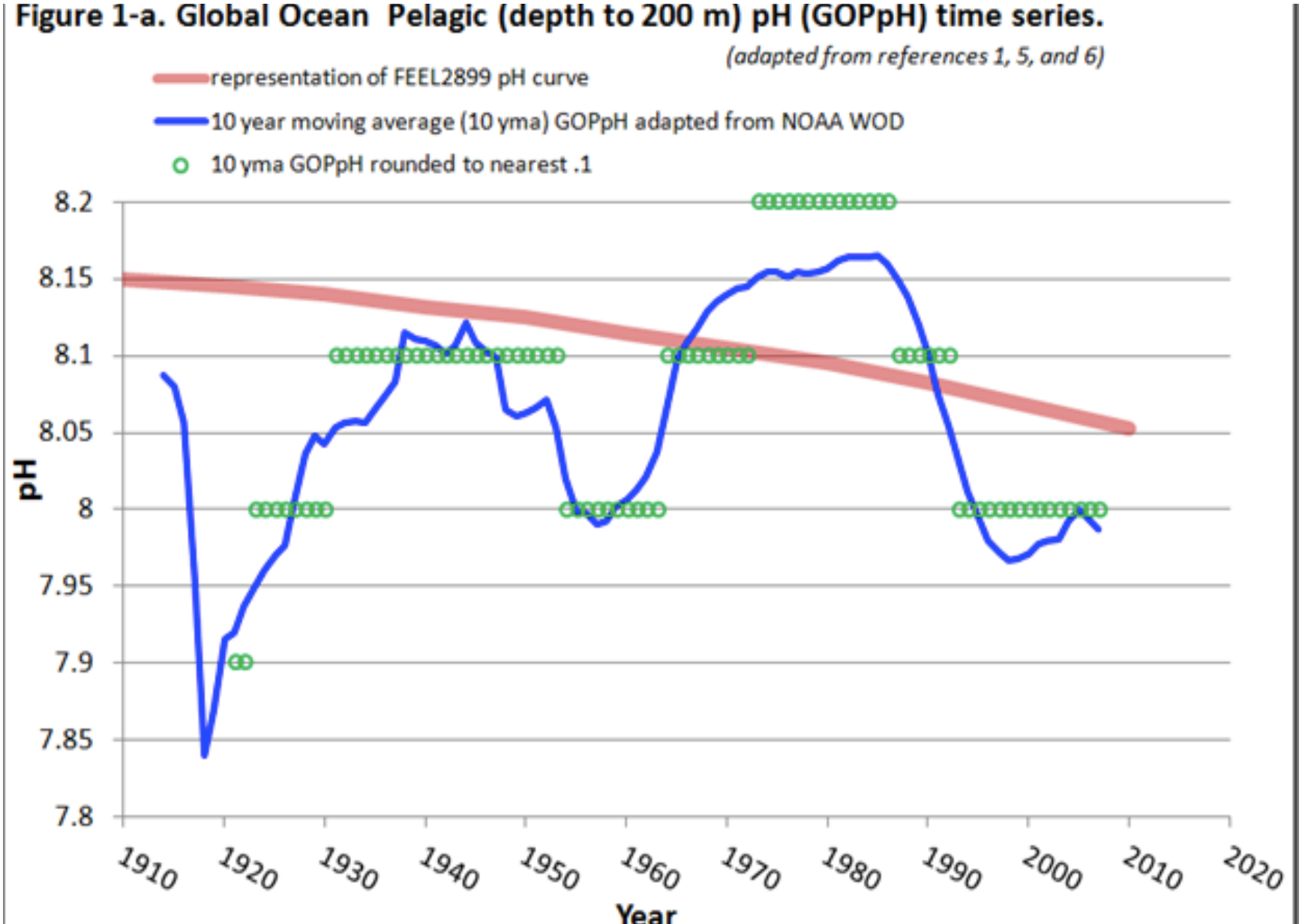
What Ocean Data?

- Temperature, Salinity, Pressure, pH, Oxygen
- Current, direction, Downwelling, Upwelling, Surface height, Patterns
- These are most of the parameters we want
- What Argo gives us:
  - Temperature and Salinity to 2000 meters
  - Dissolved Oxygen expanding capability
  - Pressure and Sea height
  - Accoustic measurements
  - Ocean currents

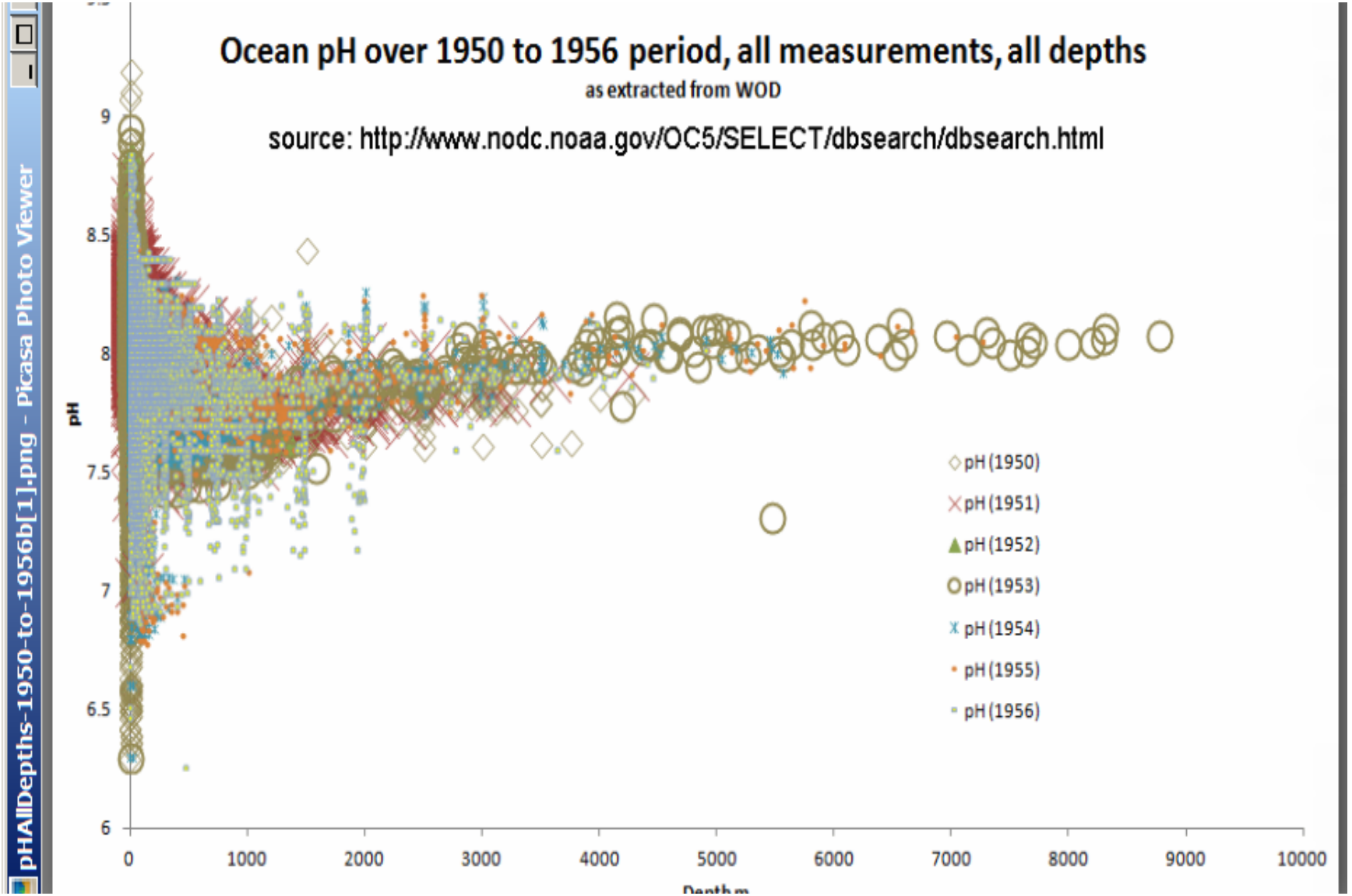
A Big Addition to Argo would be pH measurements

- The main issue seems to be a reliable long term sensor (5 year life)
- Autonomous calibration or a method to uplink sensor drift parameters
- The World Ocean Database has some good but limited pH data that goes back 80 years
- Some of Mike Wallace's work next slide showing Global Ocean pH values (PDO correlation)

Mike Wallace pH Work



Bob's Interesting pH Slide

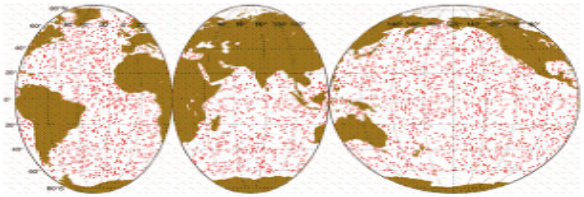


Data pre- and post- Argo

*WOCE World Ocean Circulation Experiment

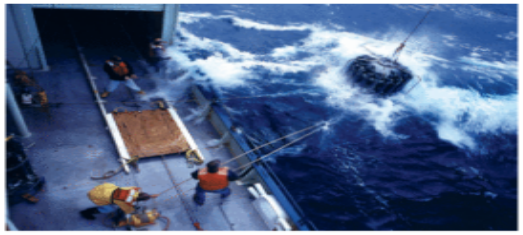
Observation type	T/S	Number per year	Max Depth	Geographical restriction
Ship-based temperature and salinity	T + S	5000 (to 1000m)	Full water depth	• Limited by ship endurance (100 per month) • Few at high latitude in winter • Typically along lines
Expendable XBT from merchant ships	T	25,000	750m	• Along shipping routes • Avoid high latitude in winter • Many areas unsampled
Argo	T + S	42,000 (May 2004) 100,000+ (2013)	2000m	• Ice free areas deeper than 2000m

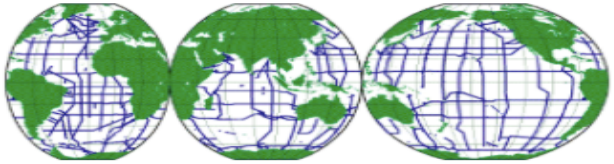
Argo Floats



Global coverage at the target of 3° x 3° density achieved near the end of 2007.

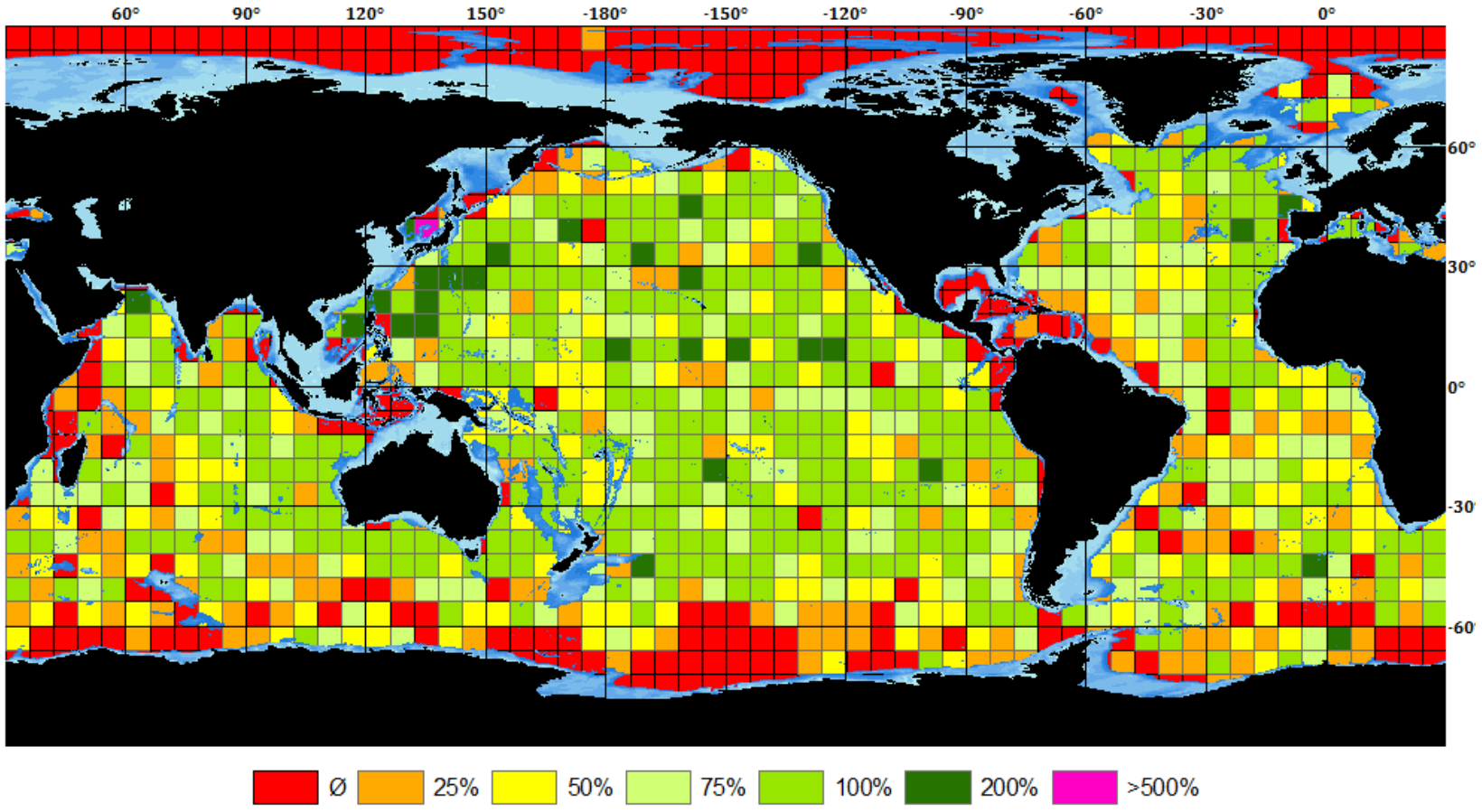
Ship Based CTDs during WOCE





In 8 years the WOCE Hydrographic survey collected data from about 30,000 CTD stations mostly along the sections shown here.

Argo Status: network density
(some analysis indicates southern ocean warming)



Float density (100%=4 floats): good floats only
Challenge in South Indian, and South Atlantic

Data Issues

- Even with the increase in amount and coverage, ARGO data is still limited
- A profile from 1000 M to 2000M then about 100 samples as the float returns to the surface occurs only once every 9 or 10 days
- Most of the time in this profile is spent at 1000 M
- Even if the float population reaches 4000, this sample rate is tiny compared to the vastness of the ocean

Program Design and Planning

- The Argo design for both hardware and data systems was a well planned program
- Issues of early hardware design and data sampling created some bad data in the beginning
- There were many years of discussion and development before the first floats were deployed (2002-3)
- Even today the program is evolving

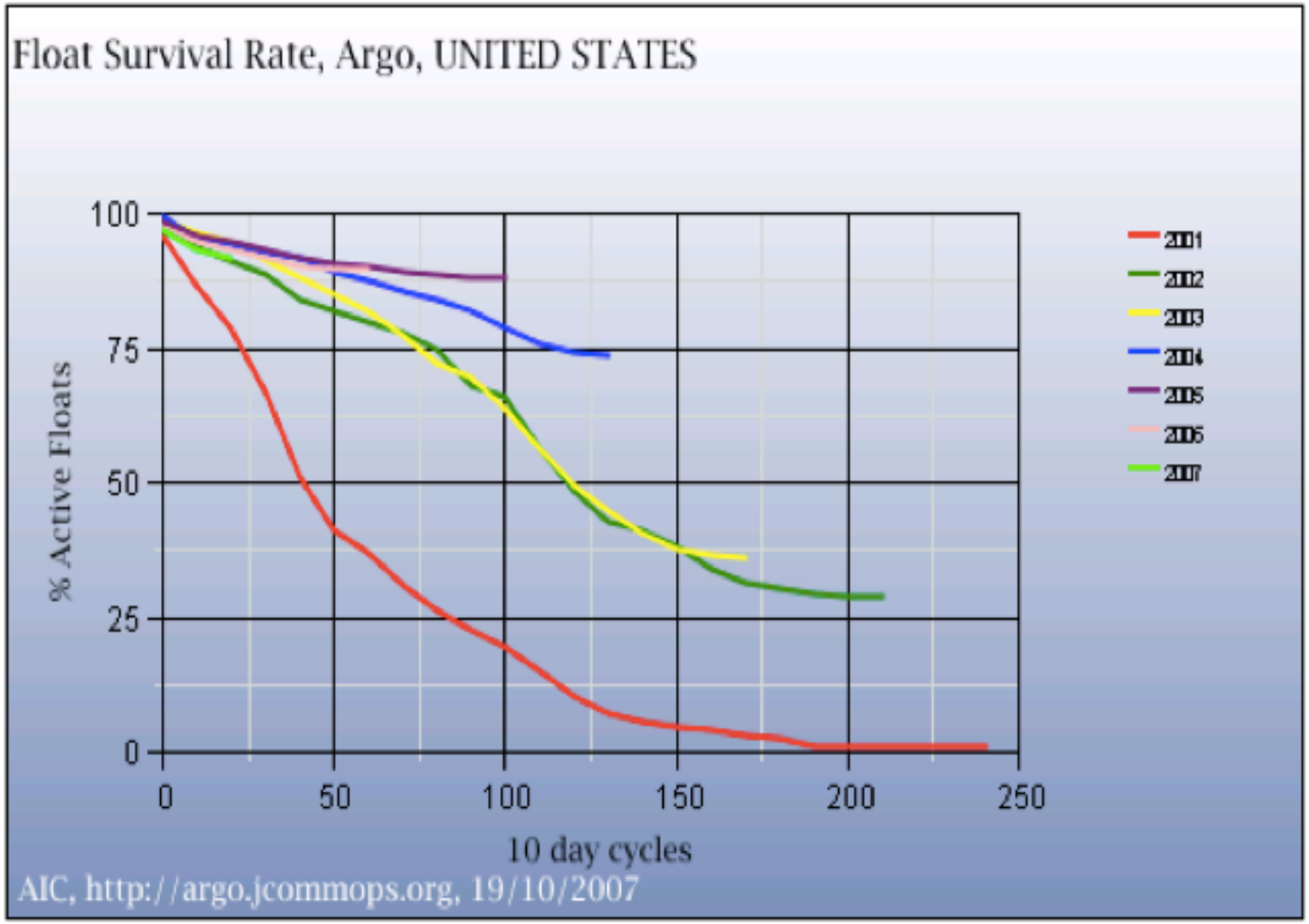


Figure 3: *Float reliability. Note that the percentage of floats surviving for at least 100 cycles increased from about 65% for 2002/03 deployments to about 90% for 2005 deployments.*

Data Handling

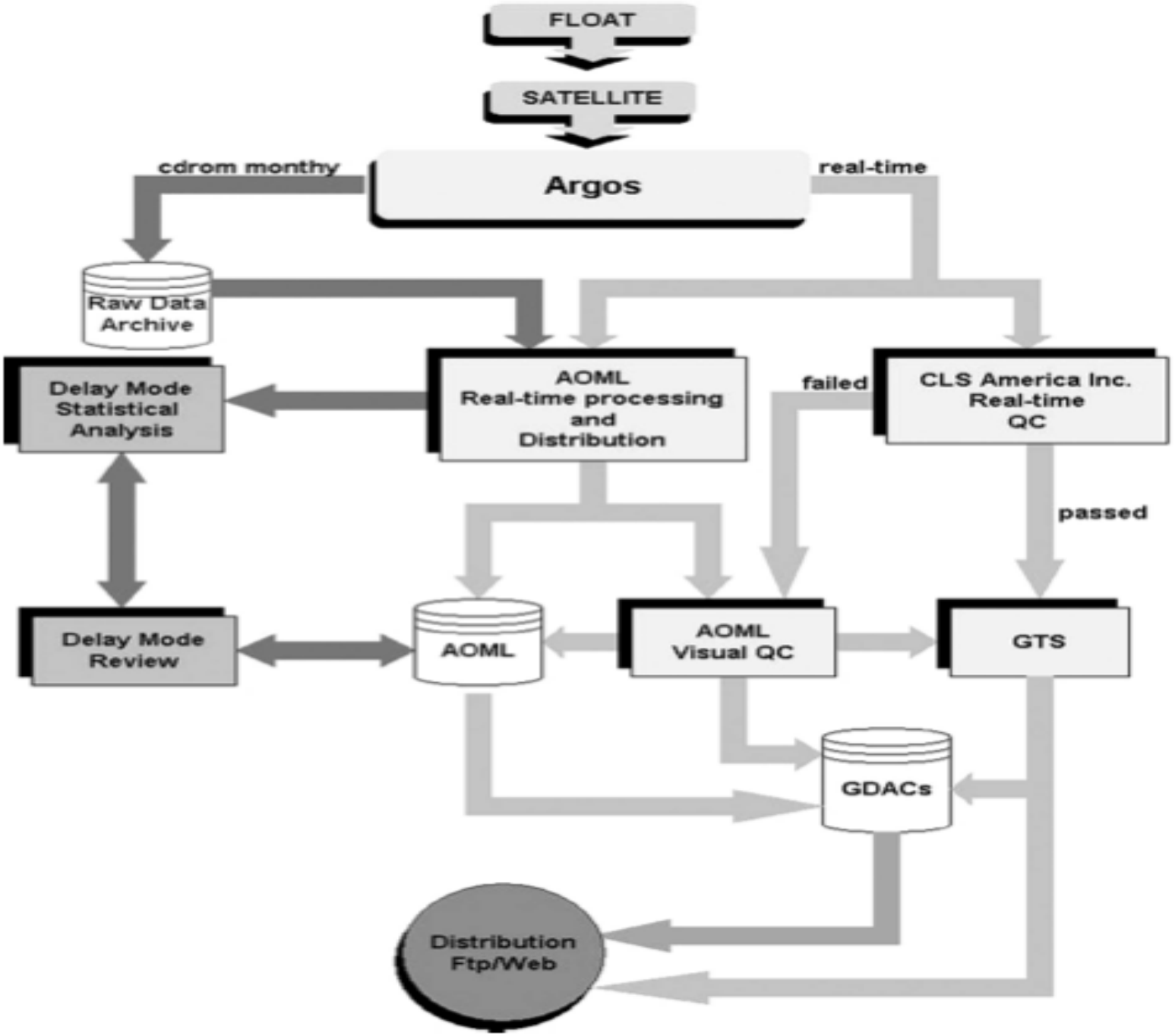
- The data quality and handling plan is good
- In September 2007 a 20 page paper was published in the Journal of Atmospheric and Oceanic Technology entitled “The Real-Time Data Management System for Argo Profiling Float Observations” by Claudia Schmid, Robert Molinari, Reyna Sabina and Yeun-Ho Daneshzadeh of NOAA’s Atlantic Oceanographic and Meteorological Laboratory and Xiangdong Xia, Elizabeth Forteza, Huiqin Yang of U of Miami
- Much of the general discussion of data system that follows is based on this paper
- Anyone with a deeper interest in Argo should read it – find it easily on the net

Argo Data Handling

- There were 9 Data Assembly Centers in the world in 2007 when the paper on the previous slide was written (2489 floats)
- The US DAC will be the example used for the rest of this discussion on data handling and quality
- Data management will be briefly discussed
- Data quality issues will be explored

Argo Data System

- The US part of the construction and deployment of the original 3000 floats encompassed half the fleet (1500 floats)
- Two time scales – a 24 hour processed data stream (with 16 auto QC tests) and a delayed mode stream
- Delayed mode has 2 methods of data checks
- Float providers will provide custom filters for individual floats to correct for drift etc
- Regional DACs collect all data and do analysis on it to locate faulty data and provide error correction techniques
- The DACs from France and the US are responsible for global data distribution


FLOAT
SATELLITE
cdrom monthy
Argos
real-time
Raw Data Archive
Delay Mode Statistical Analysis
AOML Real-time processing and Distribution
failed
CLS America Inc. Real-time QC
passed
Delay Mode Review
AOML
AOML Visual QC
GTS
GDACs
Distribution Ftp/Web

Data Quality

- AOML – Atlantic Oceanographic & Meteorological Laboratory
- GTS – Global Telecommunications System (worldwide distribution)
- GDACs – Global Data Assembly Centers
- For many profiles only a few measurements are bad and are usually spotted by the automatic systems
- Direct intervention by actual operators after an automatic test failure often resolves data quality issues
- Issues with float operation are constantly monitored as well

Data Quality continued

- Quality issues of uplink signals are resolved by a variety of tests and a frame redundancy processes (retransmit, frame check etc)
- Early in the program there were a lot of tests of the tests to verify that the QC test protocols were effective and efficient
- At the publication time of this data paper there were still a list of data quality and control issues being resolved

Specific Data Issues - Baselines

- General expectations based on past measured ocean parameters
- Surface to depth temperature gradients
- General salinity profiles
- Currents and float placements (coastal sampling – 2000 M depth limit)
- Altimetry and satellite calibration
- We have a few ARGO era data snapshots – limitations due to only a decade of data

Temperature and Salinity

- Ocean temperature varies from about 30° C at the surface to around 0° C at the deepest point
- Ocean depths average to about 3600 meters with a few very deep points
- The Mariana trench reaches a depth of almost 11,000 meters
- Salinity in the oceans varies up and down with depth in different regions and drives vertical currents
- Temperature drops with an increase in depth

Some future ARGO development

- pH measurement
- A small set of very deep diving floats
- Specialized “flying” (maneuverable) floats to gather data from shallow coastal zones
- Floats that can operated in polar regions where there is surface ice
- These ice type floats might have very long term storage capability and propulsive drive

Data – from an early float

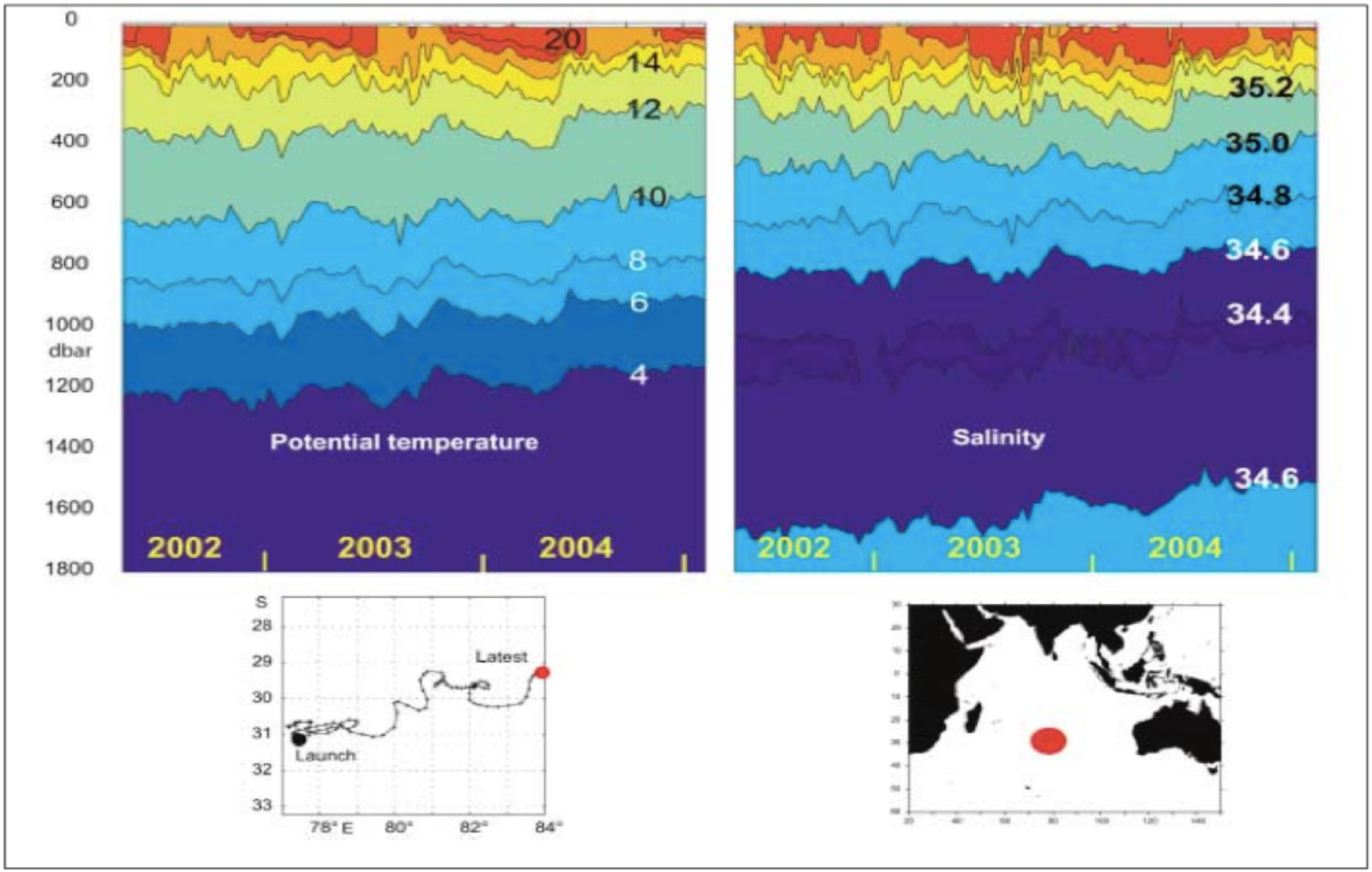
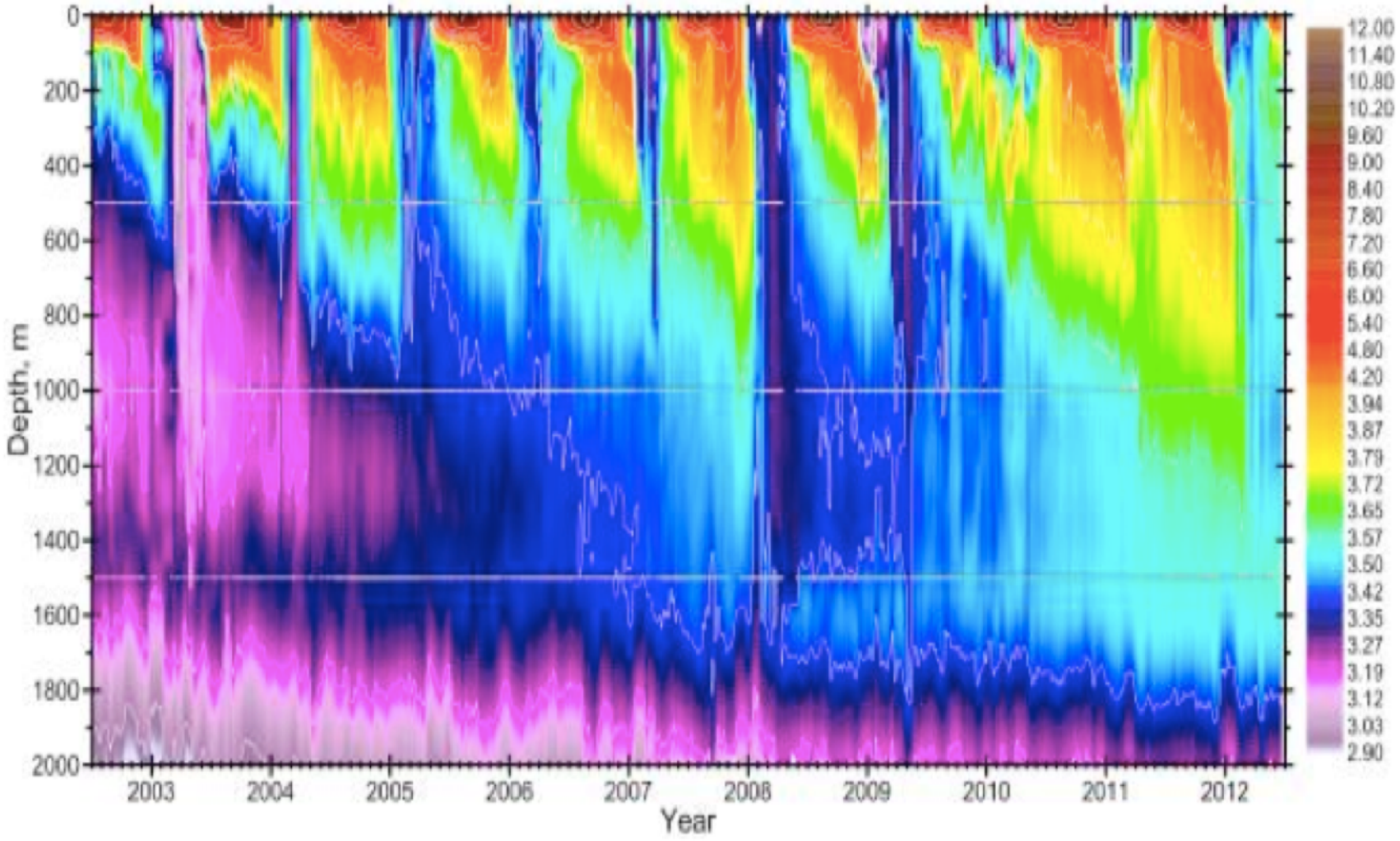
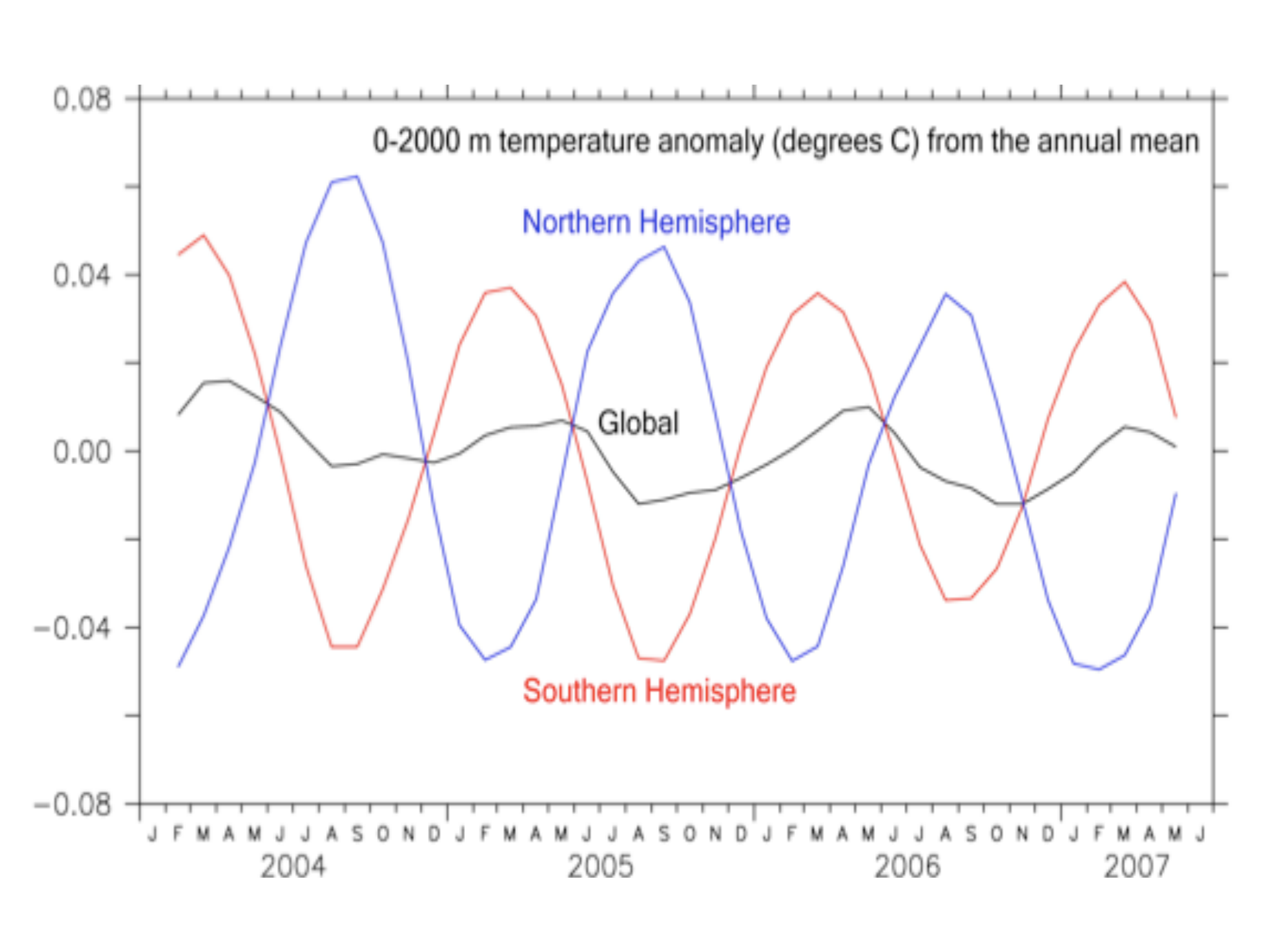
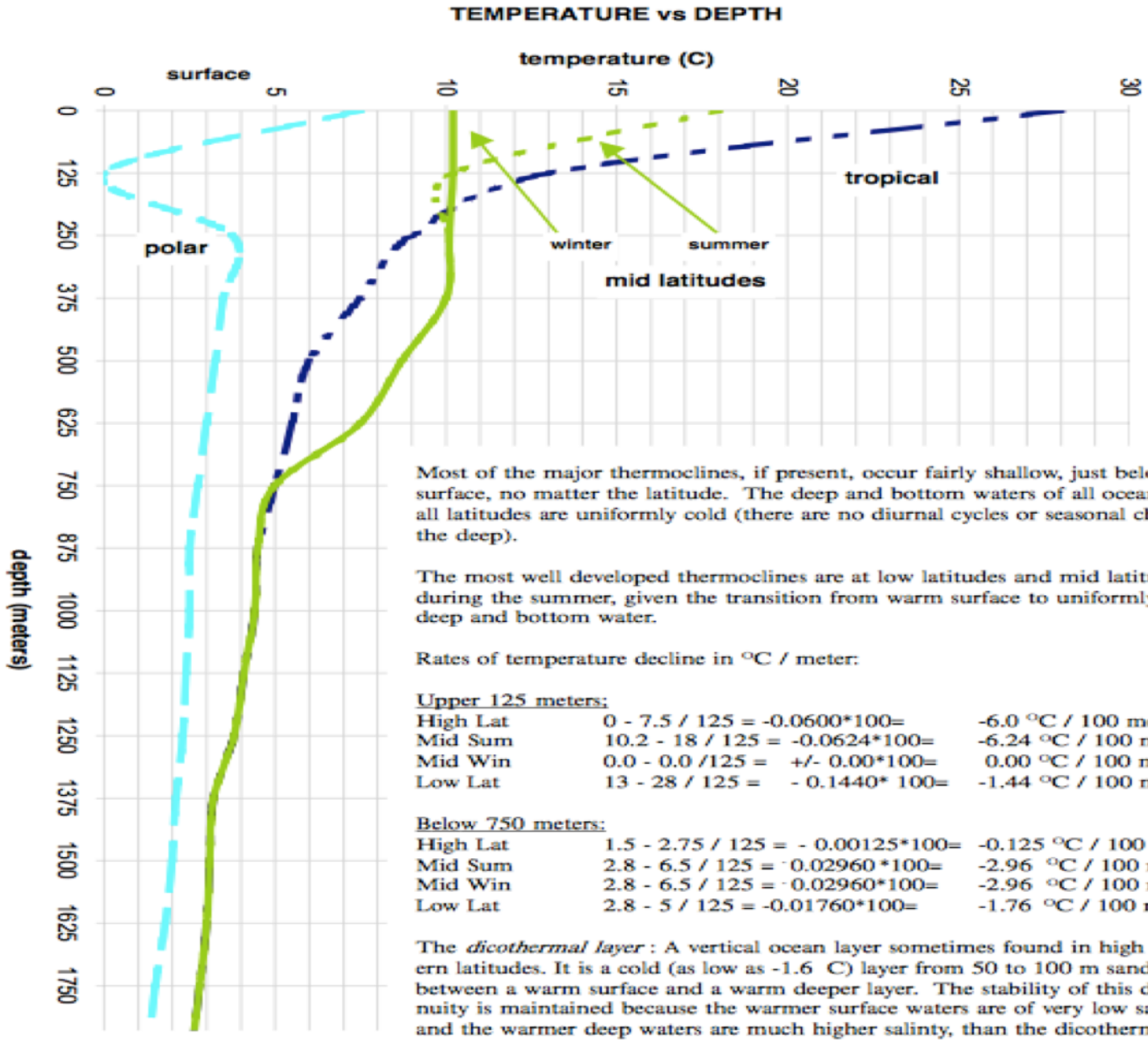


Fig. 3 Time history of temperature/salinity data and the trajectory from an Argo float (WMO ID 1900099) deployed in the south Indian Ocean 28 March 2002. The record shows three seasonal heating and cooling cycles. The trajectory and area of the float operation are shown in the lower panels.

Multi-Year Temp Record in the Labrador Straits




0-2000 m temperature anomaly (degrees C) from the annual mean
Northern Hemisphere
Global
Southern Hemisphere
0.08
0.04
0.00
−0.04
−0.08
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
2004
2005
2006
2007



Most of the major thermoclines, if present, occur fairly shallow, just below the surface, no matter the latitude. The deep and bottom waters of all oceans and all latitudes are uniformly cold (there are no diurnal cycles or seasonal changes in the deep).

The most well developed thermoclines are at low latitudes and mid latitudes during the summer, given the transition from warm surface to uniformly cold deep and bottom water.

Rates of temperature decline in °C / meter:

Upper 125 meters:

High Lat	0 - 7.5 / 125 = -0.0600*100=	-6.0 °C / 100 meters
Mid Sum	10.2 - 18 / 125 = -0.0624*100=	-6.24 °C / 100 meters
Mid Win	0.0 - 0.0 /125 = +/- 0.00*100=	0.00 °C / 100 meters
Low Lat	13 - 28 / 125 = - 0.1440* 100=	-1.44 °C / 100 meters

Below 750 meters:

High Lat	1.5 - 2.75 / 125 = - 0.00125*100=	-0.125 °C / 100 meters
Mid Sum	2.8 - 6.5 / 125 = -0.02960 *100=	-2.96 °C / 100 meters
Mid Win	2.8 - 6.5 / 125 = -0.02960*100=	-2.96 °C / 100 meters
Low Lat	2.8 - 5 / 125 = -0.01760*100=	-1.76 °C / 100 meters

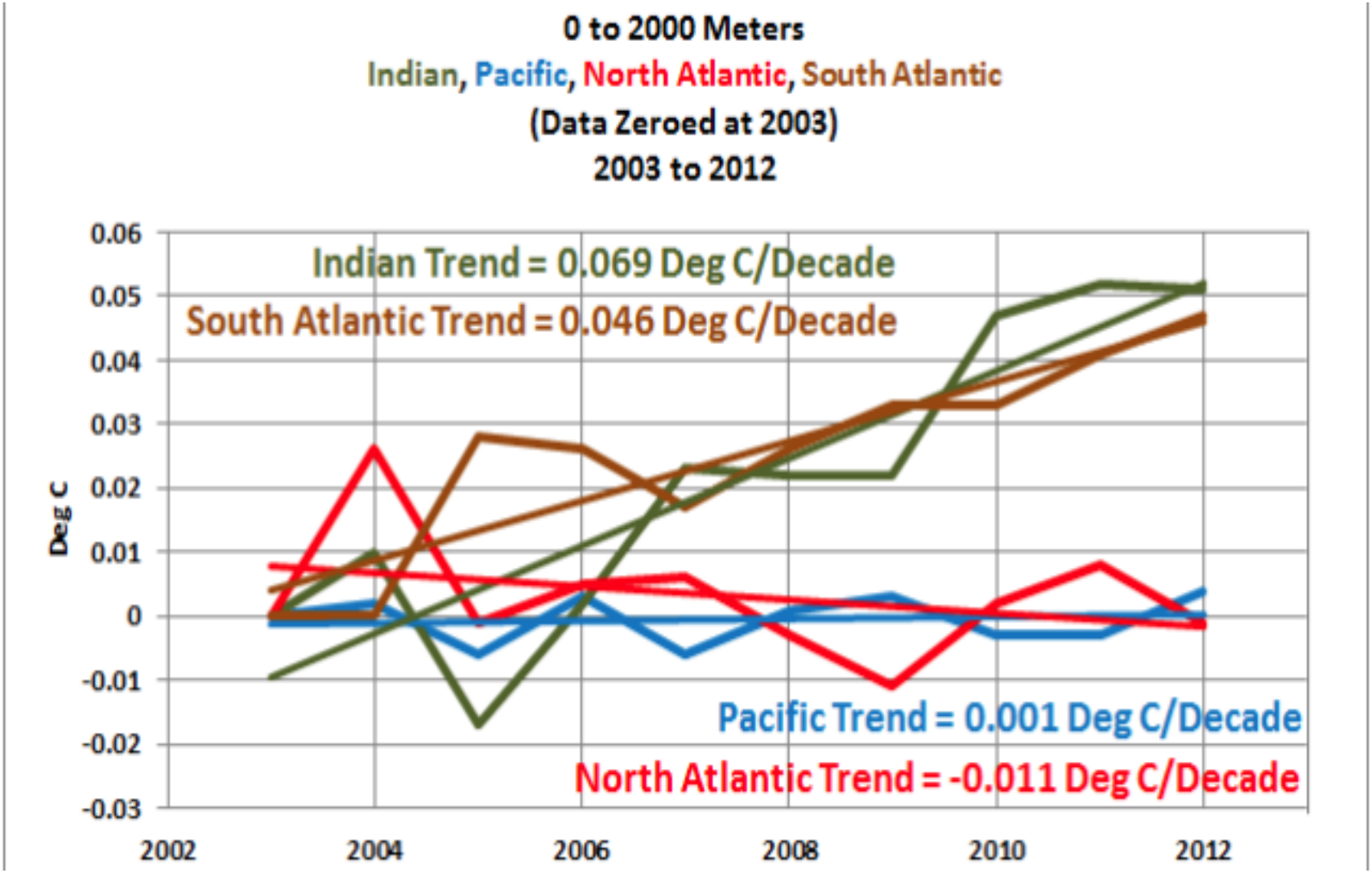
The *dicothermal layer* : A vertical ocean layer sometimes found in high northern latitudes. It is a cold (as low as -1.6 C) layer from 50 to 100 m sandwiched between a warm surface and a warm deeper layer. The stability of this discontinuity is maintained because the warmer surface waters are of very low salinity, and the warmer deep waters are much higher salinty, than the dicothermal layer waters.

Table of Temps – Latitude vs Depth

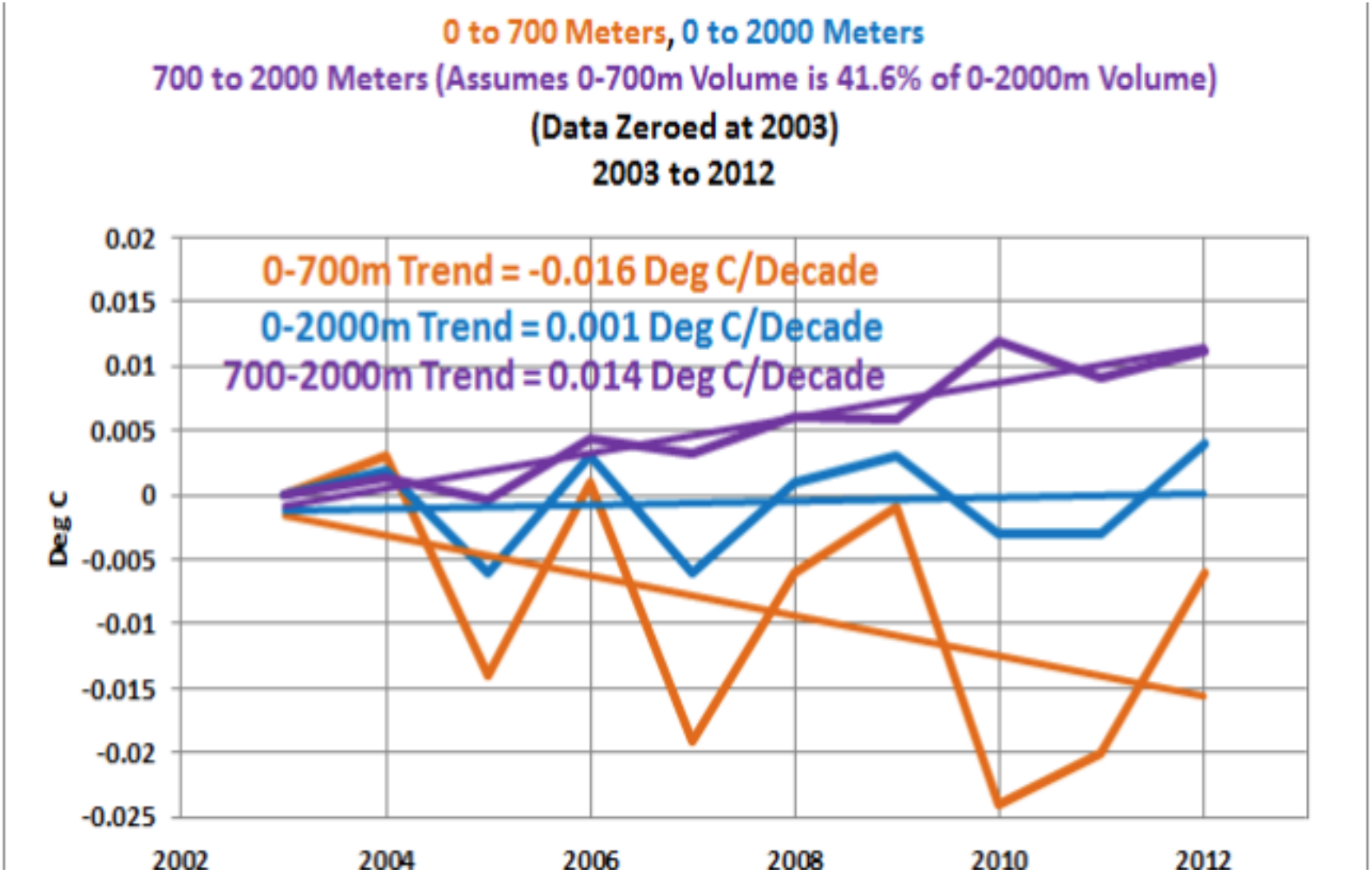
depth		temperature (C)		
in meters	low lat	mid lat summer	mid lat winter	high lat
0	28	18	10.2	7.5
125	13	10.2	10.2	0
250	9	10.1	10.1	3.75
375	7.5	10	10	3.5
500	6	8.7	8.7	3.25
625	5.5	7.5	7.5	3
750	5	6.5	6.5	2.75
875	4.5	5.8	5.8	2.5
1000	4.4	5.1	5.1	2.5
1125	4.1	5	5	2.4
1250	3.8	3.8	3.8	2.3
1375	3.2	3.2	3.2	2.1
1500	3.1	3.1	3.1	2
1625	3	3	3	1.8
1750	2.8	2.8	2.8	1.5
1875	2.6	2.6	2.6	1.3
2000	2.5	2.5	2.5	1.25

Argo Global Temperature Data

All Depths to 2000 meters



Argo – Ocean Temperature @ various depths



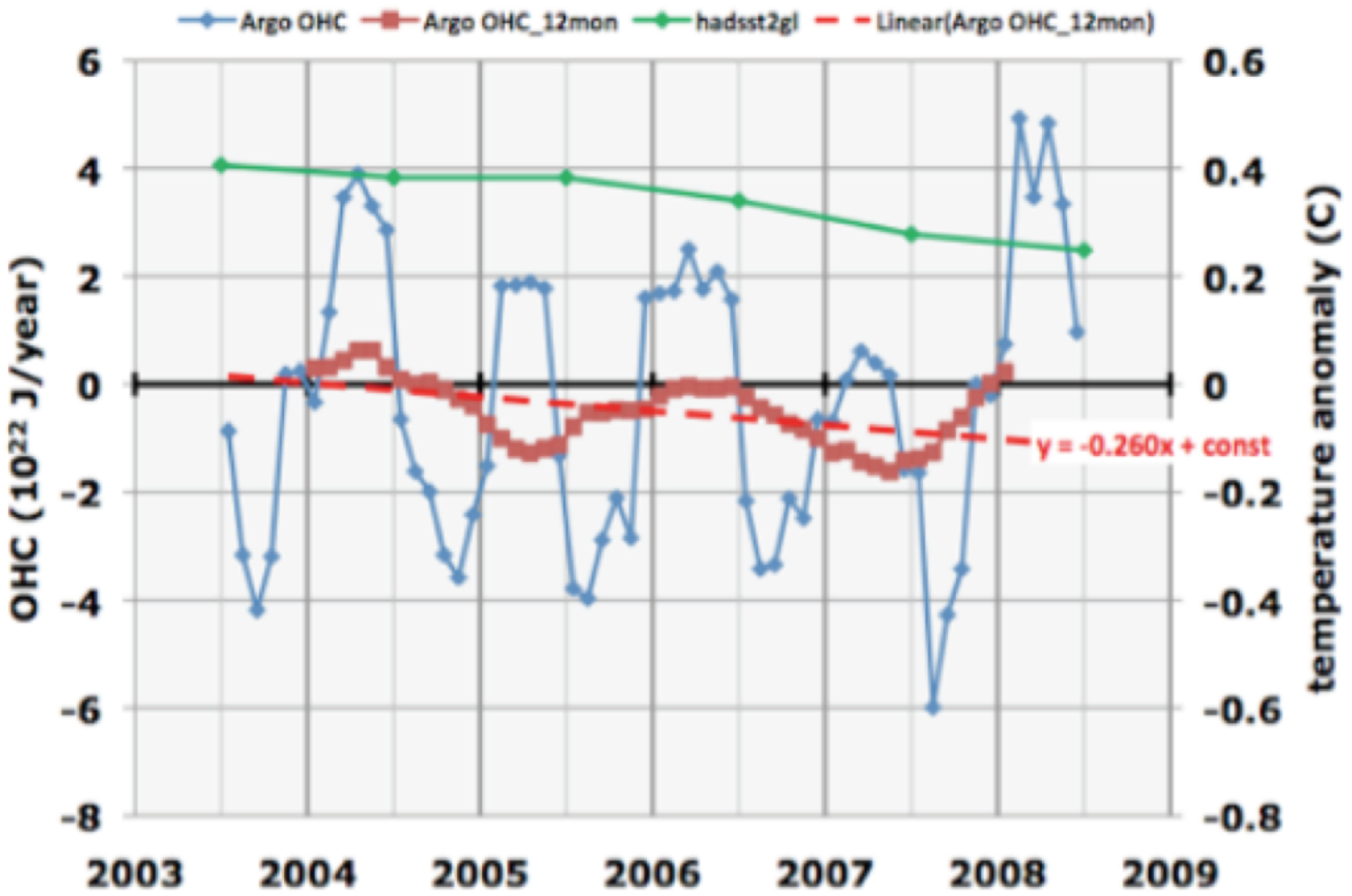


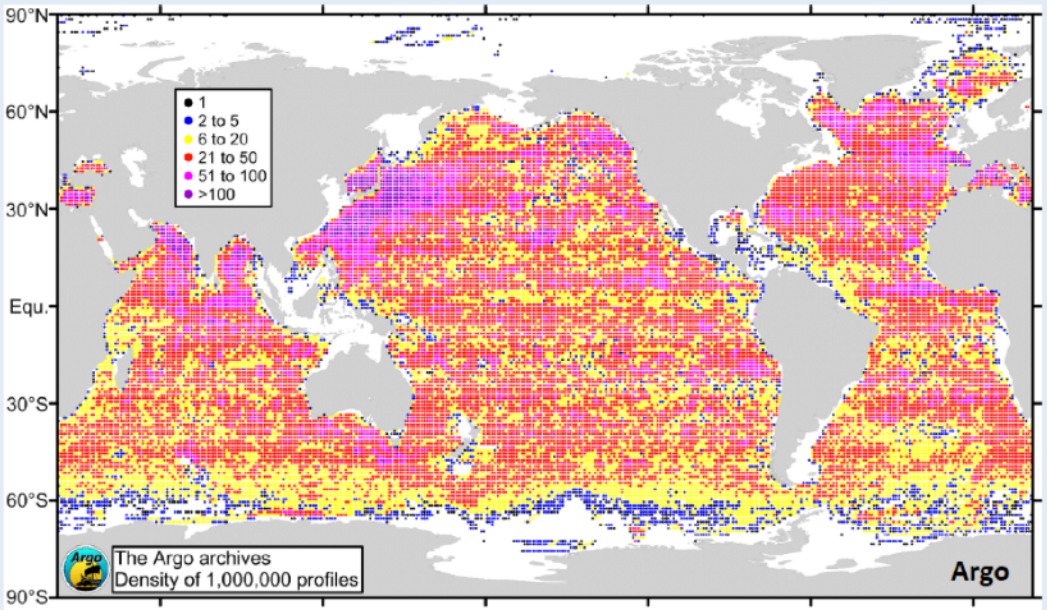
Figure 1. Ocean heat content from Argo (left scale: blue, original data; red, filtered) and ocean surface temperatures (right scale, green). Conversion of the OHC slope to W/m^2 is made by multiplying by 0.62, yielding –0.161 W/m^2.

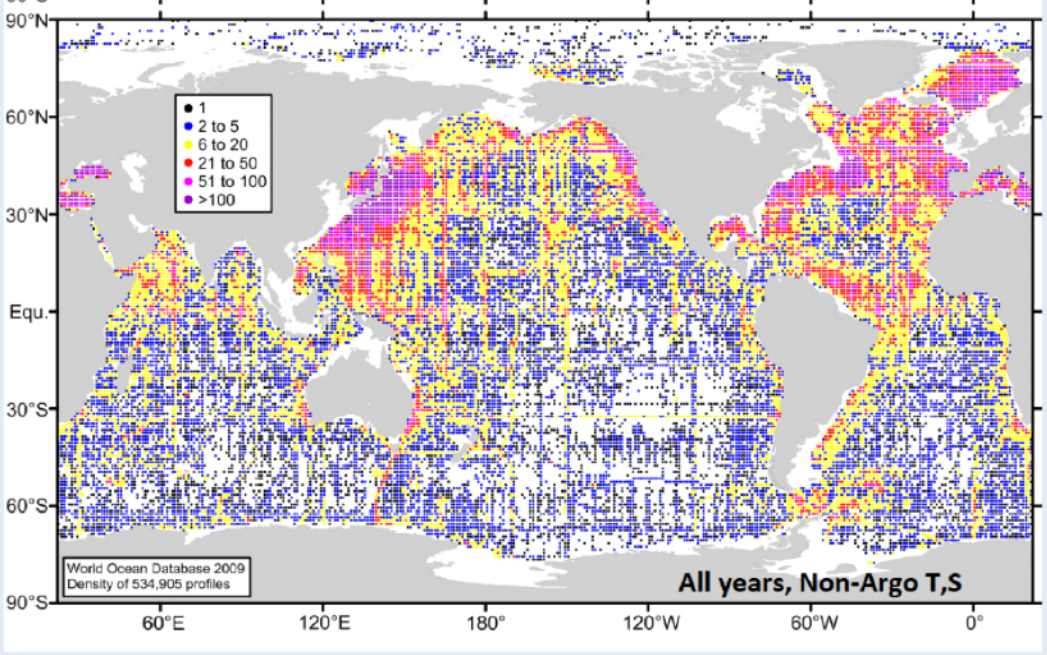
Ocean Temperature – General

- Argo data over the past decade indicates that the average ocean temperature of the top 2000 meters is 6° C
- Average global surface temperature averages about 20° C (to about 50 meters)
- At 2000 meters the average temperature is near 2° C dropping even lower as we go deeper

Ocean Temperatures warm or cool

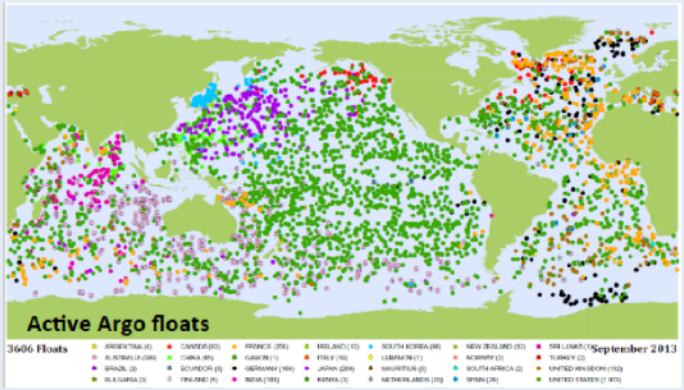
- On average the global oceans are likely to be quite cool
- There is some discussion of the warming of the deep oceans (below 2000 meters) and of the warming of the southern ocean
- Argo for the the next few years may only give brief glimpses of deep ocean temperature
- As far as the southern ocean . . . . .





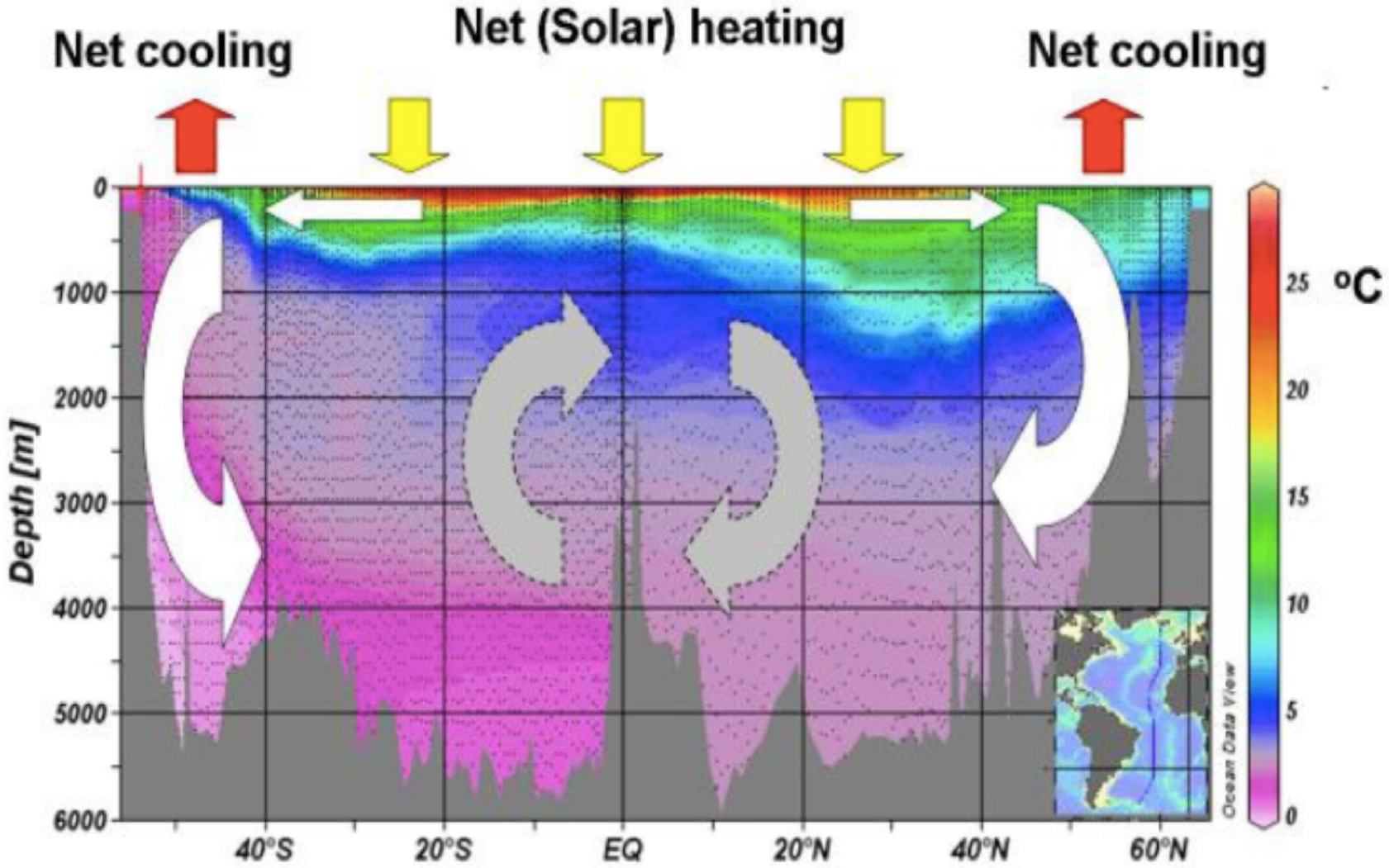
Argo's 1,000,000th profile was collected in late 2012, and 120,000 profiles are being added each year.

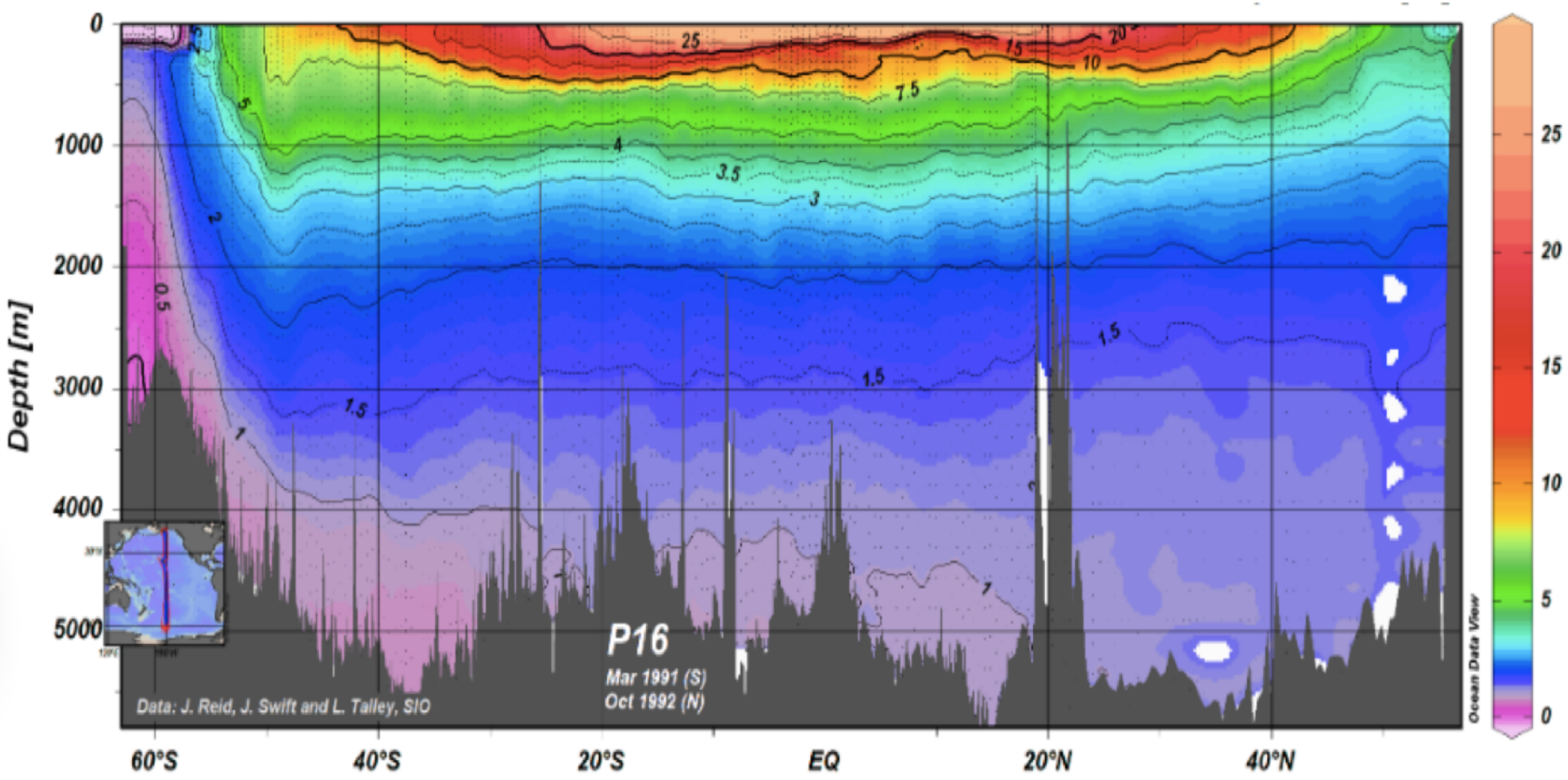
Global Oceanography



Global-*scale* Oceanography

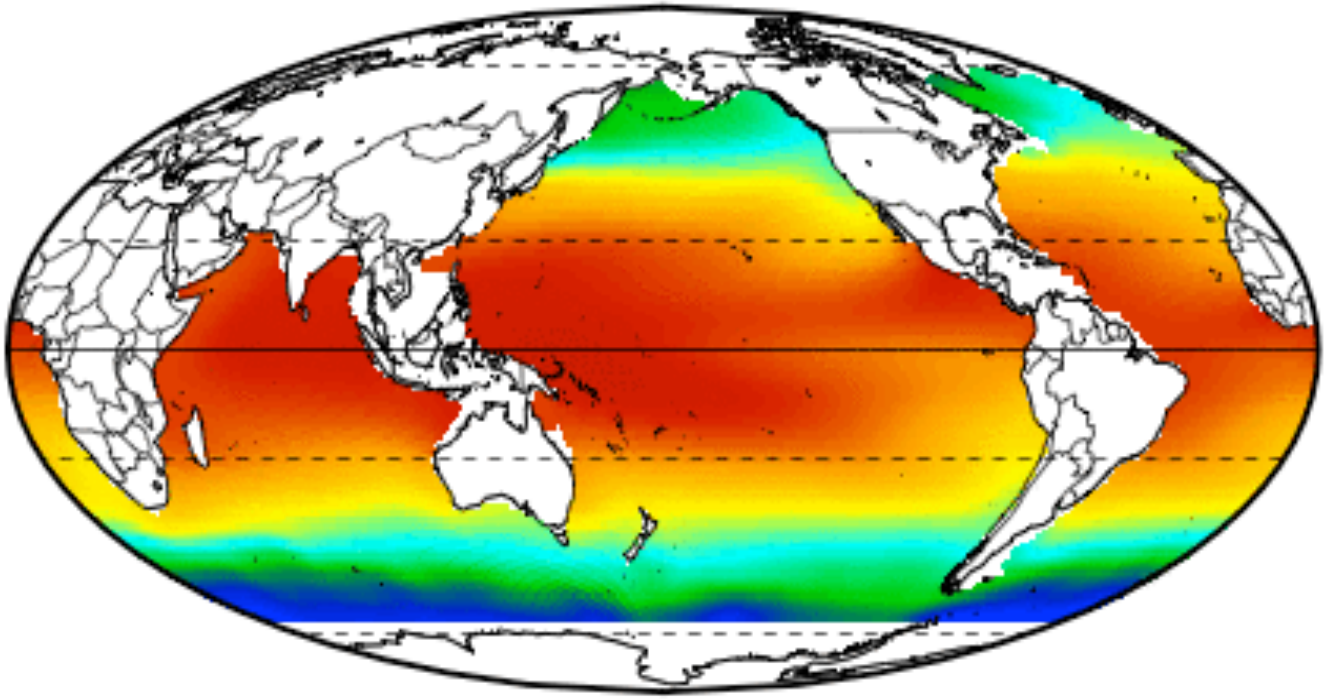
Average Ocean Temperature Distribution with Depth




Depth [m]
0
1000
2000
3000
4000
5000
60°S
40°S
20°S
EQ
20°N
40°N
P16
Mar 1991 (S)
Oct 1992 (N)
Data: J. Reid, J. Swift and L. Talley, SIO
Ocean Data View
25
20
15
10
5
0

Willis' Argo Movie

http://wattsupwiththat.com/2015/01/22/learning-from-the-argonauts/



http://wattsupwiththat.com/2014/03/02/argo-temperature-and-ohc/

Argo Altimetery

- Argo is an in situ complement to satellite altimetry of the sea surface
- The earth elipsoid reference to the gravity field is a geoid that varies up to 100 meters
- The ocean dynamic topography varies up to a meter
- The geoid is now know to a few centimeters
- Distance from the altimetry satellite and the sea surface is also now know to within a few cm

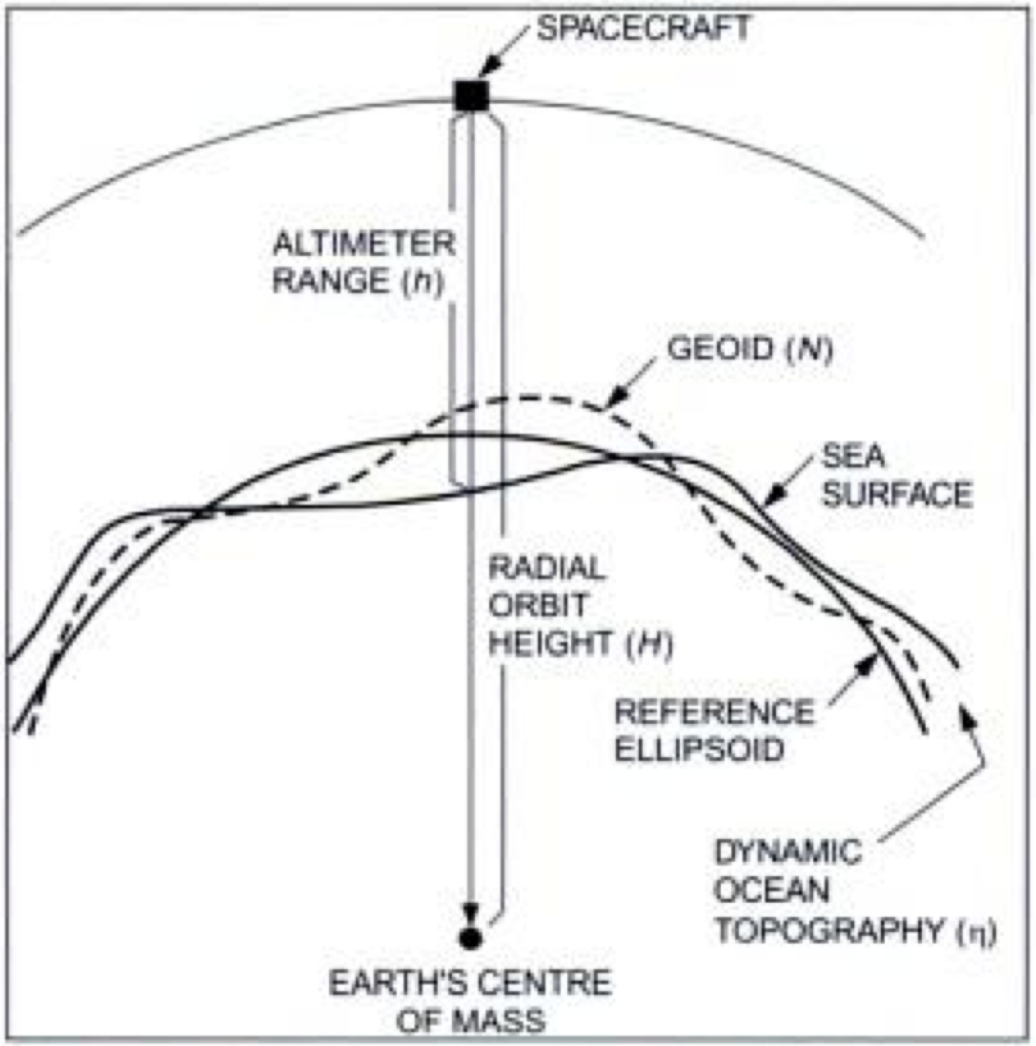
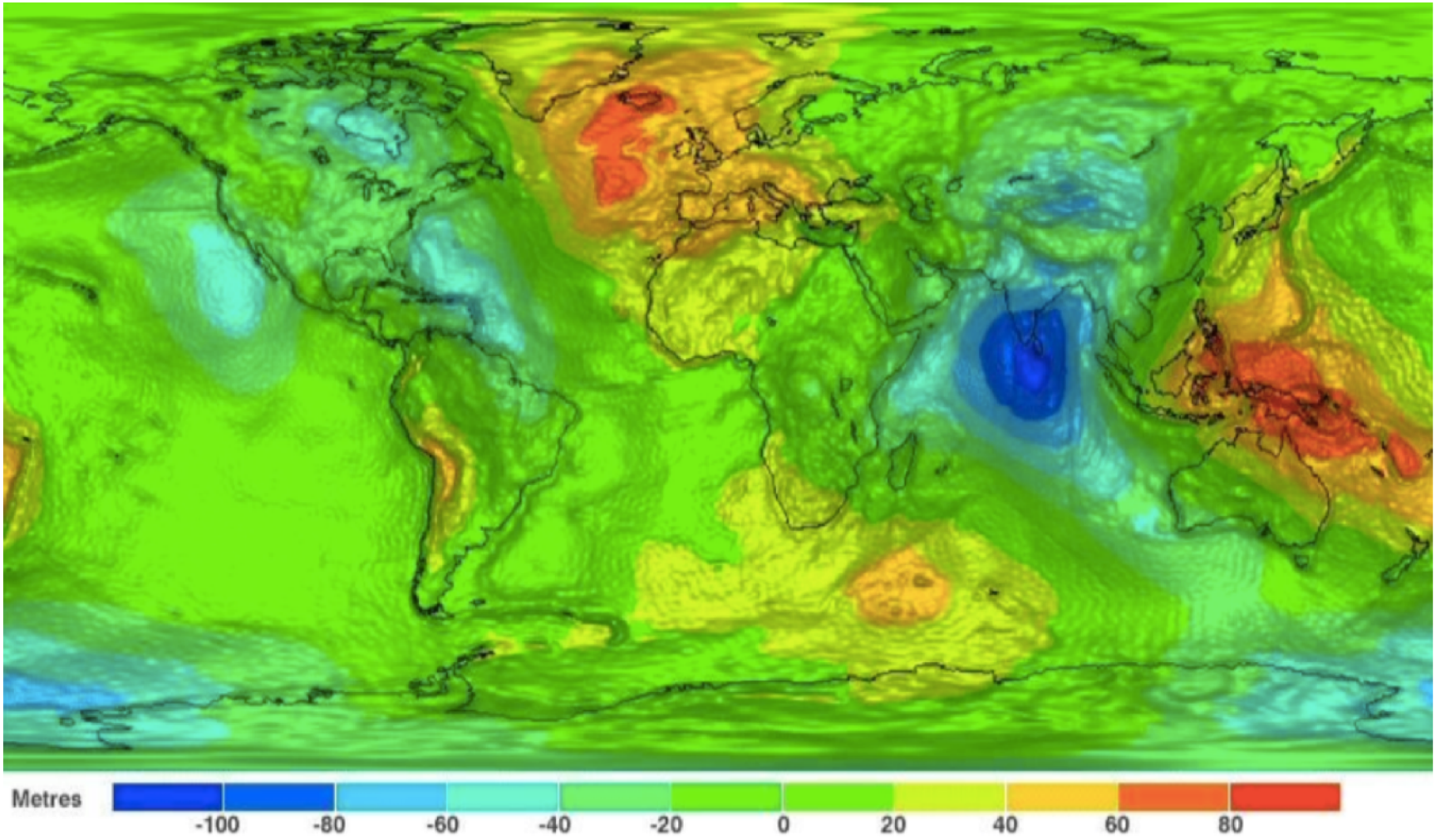


Fig. 3.3.1 Measurement geometry of satellite altimetry.

Satellite Derived Global Geoid Heights



Argo – Heat versus Height

- An interesting data set from the altimetry data

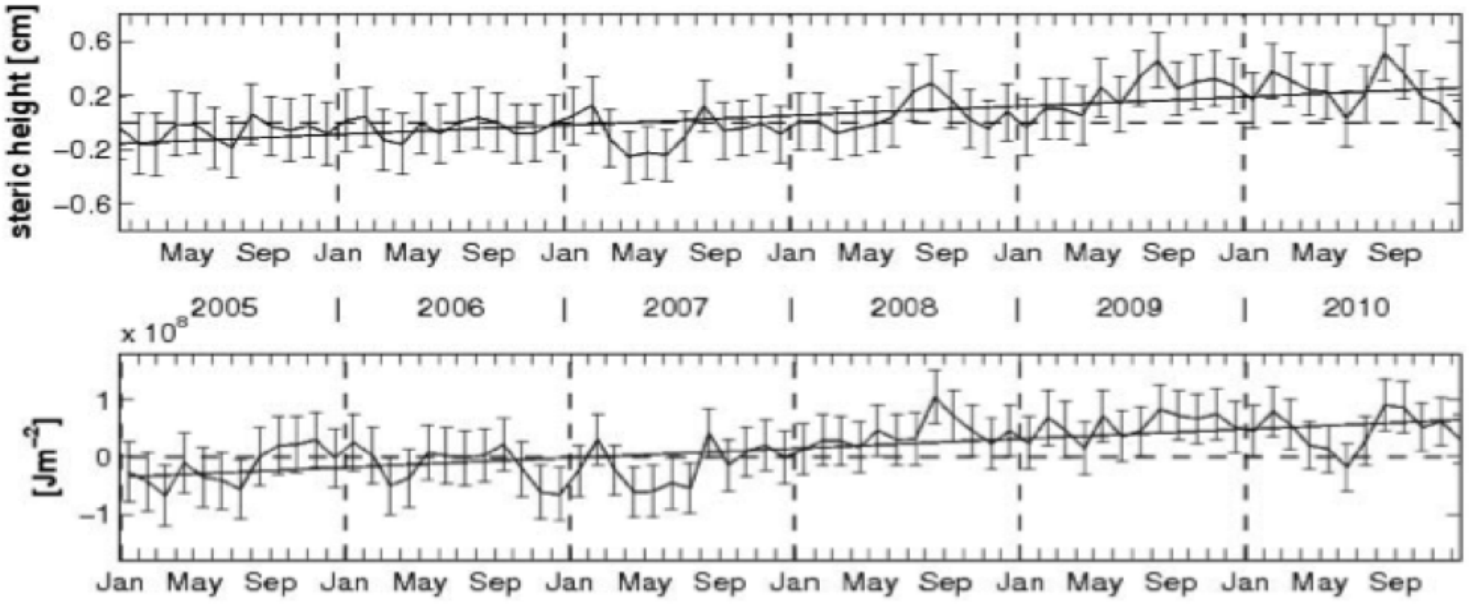


Fig. 7. Global ocean heat content and mean steric sea level variations derived from Argo data (2005–2010) (from von Schuckmann and Le Traon, 2011).

Altimetry and Ocean Circulation

- Regional sea surface changes created by heating or wind driven produce ocean slopes
- El Nino effects on western Pacific warm pools that turn into swift west to east ocean currents are just one example
- Coriolis and tidal effects can now be seen in the data
- It may be too early to understand or even see long term and variable circulation patterns that are set up by these sloping sea surfaces

Argo and Ocean Circulation

- Argo returns position and height data
- Long term position data for an individual float gives data to plot ocean surface flows and gyres
- Original position Systeme Argos (doppler) – now GPS
- Coriolis effects on ocean circulation can be calibrated by Argo and Altimetry data
- Efforts to correlate Argo surface measurements of temperature and salinity to satellite observation are now in analysis

Argo Analysis

- There is a lot of discussion in the literature about the uses of Argo floats for circulation analysis
- It is hard to find good results
- Altimetry data sometimes shows sea height changes that are in the error noise
- It is well know that there are some significant sea height differences in El Nino and storm events (these are transient events)

More Analysis

- There are some very dynamic speeds and heights for circulation patterns in the Indonesian Throughflow (ITF)
- Both Argo and satellite altimetry have produced data from this phenomenon with good analytical results
- When it comes to showing salinity and temperature effects measured in situ by Argo and correlated by altimetry – results are fuzzy
- Measuring and observing wind driven ocean circulation patterns with Argo/Sat is much more successful

Salinity and Circulation Patterns

- Some of the larger northern hemispheric circulation flows such as the Gulf Stream and Kuroshio have both temperature and salinity signatures
- Rainfall and glacial melt in some regions of the ocean show strong freshwater signatures on the ocean surface

Acoustic Measurements

- Ambient sound levels
  - Geophysical interpretations (wind/rain) - Whale detection
  - Shipping detection (submarines?)
- Two-way communication to Passive Aquatic Listeners (PAL)
  - Change sampling strategies
  - Update classification and quantification algorithms

Acoustic Final Thoughts

- 70 enhanced STS/PAL Argo floats to be deployed in the next 2 years
- Worldwide deployments – where do you want one? We are listening.
- Spectral level time series
- Geophysical products: wind and rain
  - accumulation (water budget inputs)
- Whale detection (high frequency clicking)
- Adaptive sampling – changes allowed!

Exploring Ocean Parameters

- Limited data and techniques of the past have given way to Argo and other modern oceanographic research tools
- Implications of this short data set
- Attempts to hijack these new programs by the alarmists can already be seen in the literature
- While at the same time there are some interesting un-foreseen results that are beginning to emerge