# Indian Argo Programme, Data and Applications

TVS Udaya Bhaskar

ODM, INCOIS

uday@incois.gov.in

DBCP workshop, 5th August 2025

ITCOOceann, INCOIS, MoES, Hyderabd - 500090

*Except where otherwise noted, OTGA content is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0.*

With the support of the Government of Flanders, Belgium

# Outline

- Design of International Argo program.
- Novel nature of Argo program.
- Argo collaboration and data sharing.
- Indian Argo program – the journey begins.
- Data Processing, quality control, products.
- Applications of Argo data.
- Indian Indigenization efforts (the success story).
- Summary.

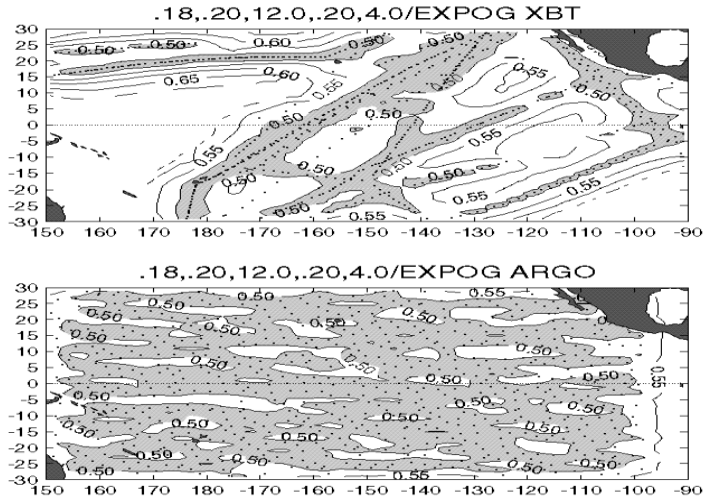
# Origin of Argo

- With the success of ALACEs It was realized that while these floats come up they could also measure
  - the temperature and salinity of the water through which they rose.
  - Towards the end of WOCE most of the ALACEs carried temperature/salinity sensors. They became Profiling ALACE (PALACE) floats. (Davis et al 2001).
- Two proposal were submitted at the end of WOCE program under the chairmanship of Dean Roemmich which formed the basis for the International Argo program. They are:
  - *On the design and Implementation of Argo - An initial Plan for a Global Array of Profiling Floats*
  - *Argo: The Global Array of Profiling Floats*

# Design of Argo program

- The basic idea is to combine altimetry data with Argo data for climate related studies.
  - It is proposed to deploy 1 float in 3° x 3° grid which takes profile upto 2000 dbars once in 10 days.
  - 1 in 3° x 3° is decided based on the error estimates obtained from the mapping obtained with the available XBT data.

    (Uncertainties less than 0.5C are shaded in Fig to represent the achievable accuracy for upper layer temperature estimation. This is equivalent to an accuracy in bimonthly heat content changes of 15 W/m$^2$ for a 50 m thick layer. At that level of accuracy, errors in seasonal changes in heat content are comparable to the errors sought in air-sea heat exchange estimates.)
  - 2000 dbars is chosen as the level of no motion which is used in calculating the dynamic height from the T/S profiles and there by geo-strophic currents.




**(Image courtesy: Roemmich et al., 2001)**

$$h'_{alt} = \frac{\alpha \; p'_{ref}}{g} + \frac{1}{g}\int_{p}^{0} \alpha' \, dp + Errors$$

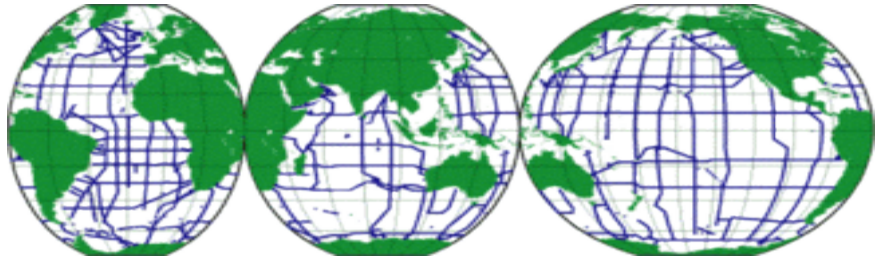
$$u = -\frac{1}{\rho f}\frac{\partial p}{\partial y}, \qquad v = \frac{1}{\rho f}\frac{\partial p}{\partial x}$$

# Novel nature of Argo

- Argo data is unique for several reasons:
  - The distribution of data throughout the oceans is uniform rather than dependent on shipping lines.
  - There is a of lack of seasonal bias since the floats operate year round.
  - The efficient data management network that provides free automatic quality controlled data within 24 hours and scientifically quality controlled, delayed mode data within several months.
  - Multi-national collaboration to deploy, monitor and analyze floats and their data.

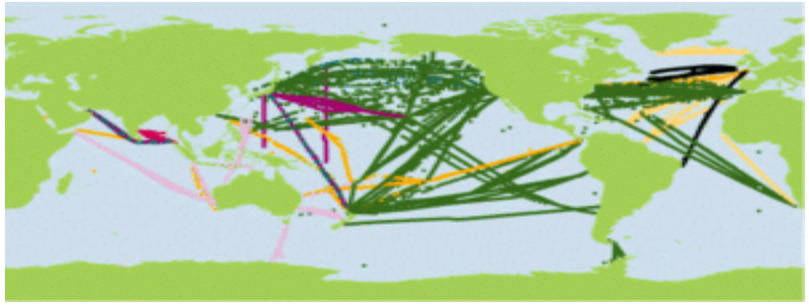
# Table summarizing novelty of Argo's data set

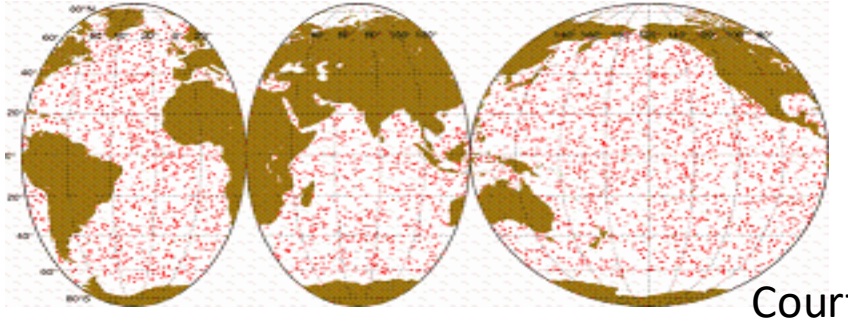
| Observation type | T/S | Number per year | Max Depth | Geographical restriction |
|---|---|---|---|---|
| Ship-based temperature and salinity | T + S | 5000 (to 1000m) | Full water depth | • Limited by ship endurance (100 per month)<br>• Few at high latitude in winter<br>• Typically along lines |
| Expendable XBT from merchant ships | T | 25,000 | 750m | • Along shipping routes<br>• Avoid high latitude in winter<br>• Many areas unsampled |
| Argo | T + S | 42,000 (May 2004)<br>100,000 (2006) | 2000m | • Ice free areas deeper than 2000m |



*In 8 years the WOCE Hydrographic survey collected data from about 30,000 CTD stations*

*Positions of XBT temperature profiles from merchant ships in 2002. Note poor coverage in southern hemisphere*





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

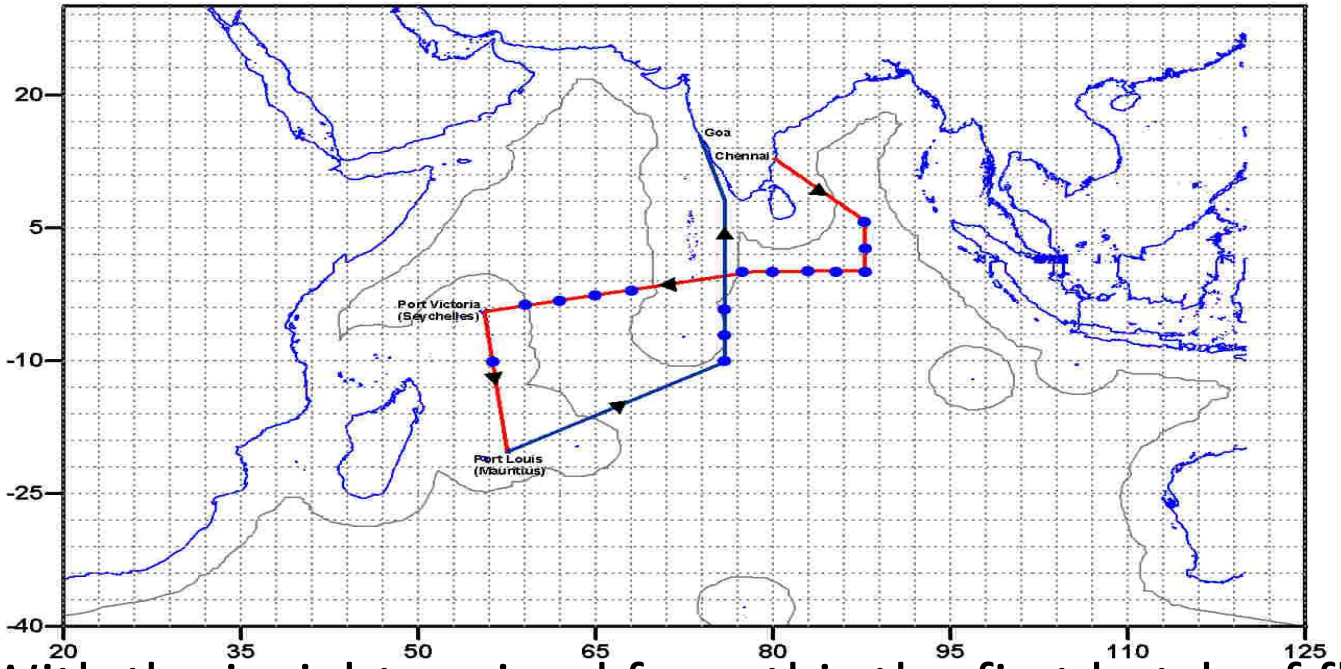
Courtesy: http://www.argo.ucsd.edu

# Argo collaboration and Data Sharing

- **Multi-National Argo**
  - The array is made up of **30** different countries' contributions that range from a single float, to the U.S. contribution, which is roughly 50% of the global array.
- **Management of Argo**
  - The project is overseen by an **International Argo Steering Team (AST)** and a **Data Management Team (ADMT)** that are comprised of representatives of float-providing countries. The array's growth is monitored by the Technical Coordinator at the **Argo Information Center (AIC)** that is located in Toulouse as part of the **JCOMMOPS** monitoring and co-ordinating system for operational ocean observations. There is also an Argo Director.
  - Floats should not be deployed in EEZ and float entering the EEZ to be notified to the respective countries.
  - Real Time quality controlled data to be disseminated with in 24hrs to users and to be made available on GTS.
  - Scientifically quality controlled (delayed mode) data to be distributed with 6months of the float deployment.

# Indian Argo program

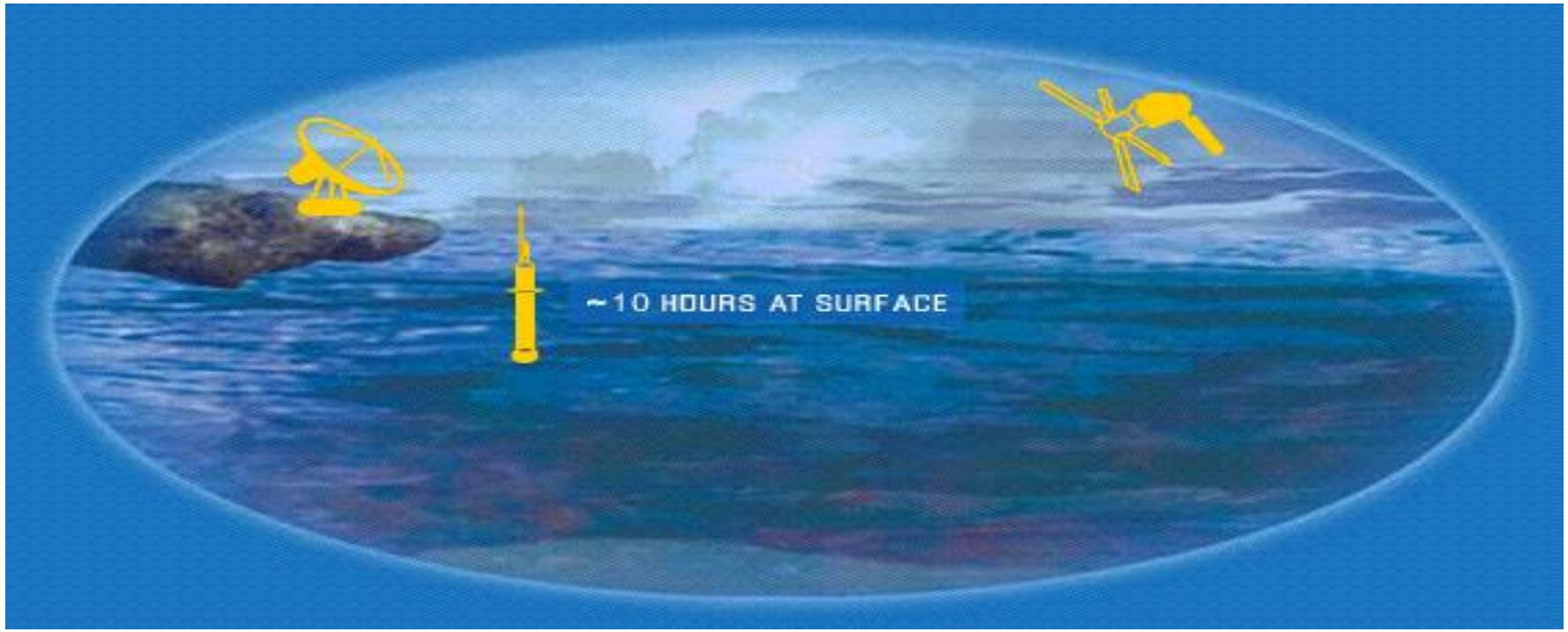
- It started with the deployment of Argo float obtained from MEDS, Canada. The float 2900193 was deployed by INCOIS at 68˚E,8˚N on 22nd Dec, 2001 and obtained valuable insight about deployment, importance of ballasting etc.

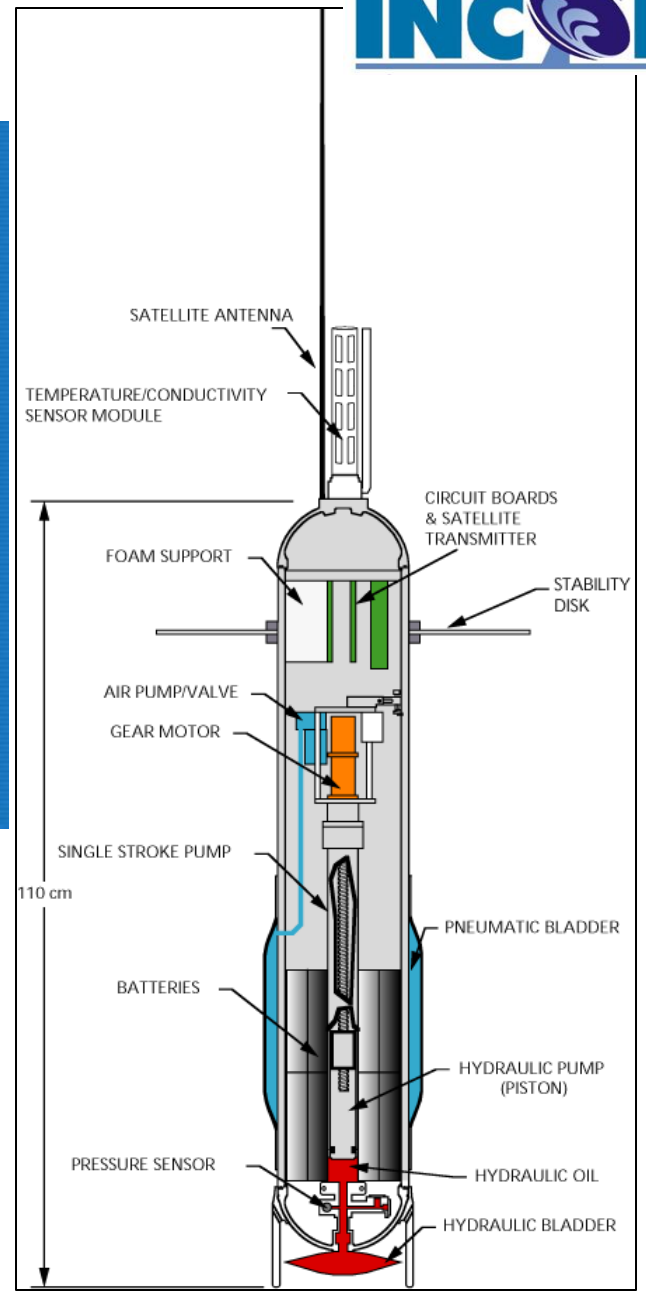


Dr. Howard Freeland giving insights about the Argo float at the "India Argo implementation meeting" held at Hyderabad, July 26 – 27, 2001

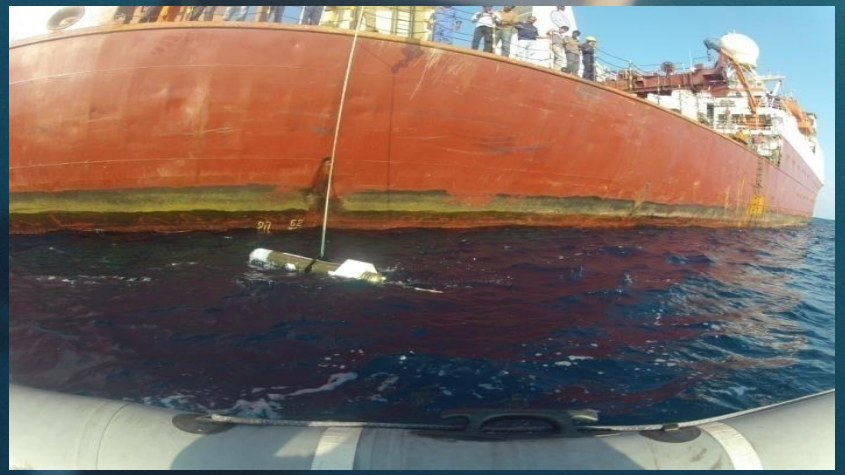
With the insights gained from this the first batch of floats were deployed during Nov – Dec 2002, on the way from Goa to Mauritius.

# Argo Cycle and Cross Section






- Drifting Depth: **1000 m**
- Profiling Depth: **2000 m**
- 10 Days/Cycles



# Different type of floats based on the manufacturer

- Indian had deployed floats of the following type:
  - APEX (8c,9A,9I) from Webb Research Corp. USA. (Now Teledyne).
  - Metocean PROVOR from Canada.
  - PROVOR & AROVOR from NKE, France.
  - PROVOR-Bio from NKE, France.

INCOIS

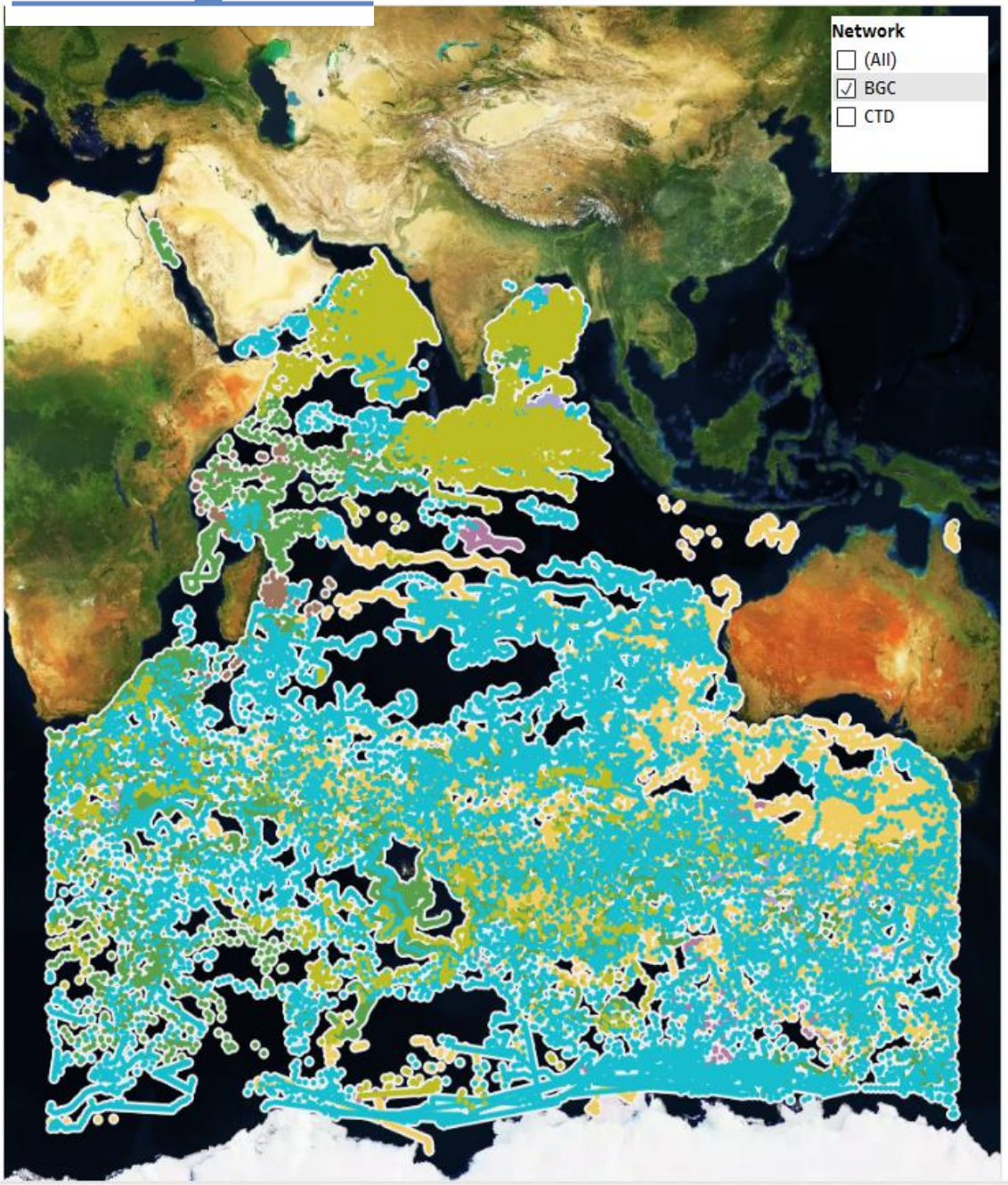
QC Mode: (All)

Communication: (All)

Filter By Date: 10/21/1999 – 4/4/2025

Longitude: 20.0 – 145.0

Latitude: -70.09 – 27.75



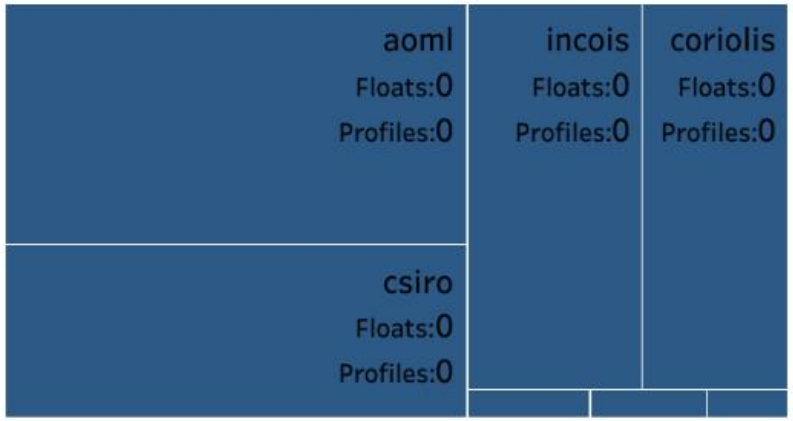
DOXY Profiles: 60,631

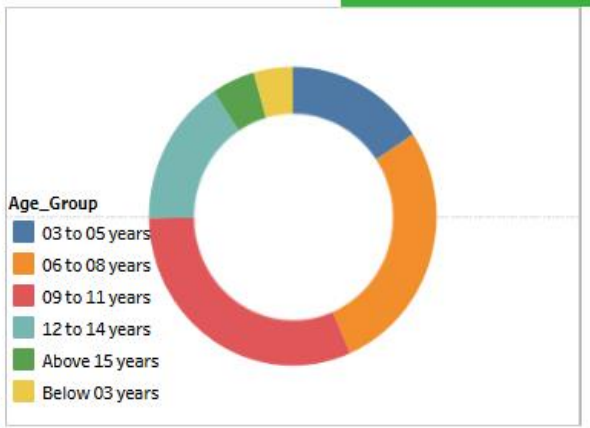
Chla Profiles: 39,606

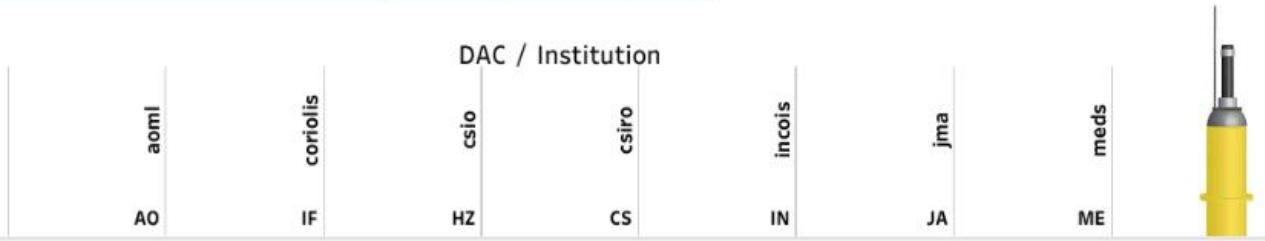
Nitrate Profiles: 14,543

ph Profiles: 12,380

No. Of Daily Active Floats and Profiles



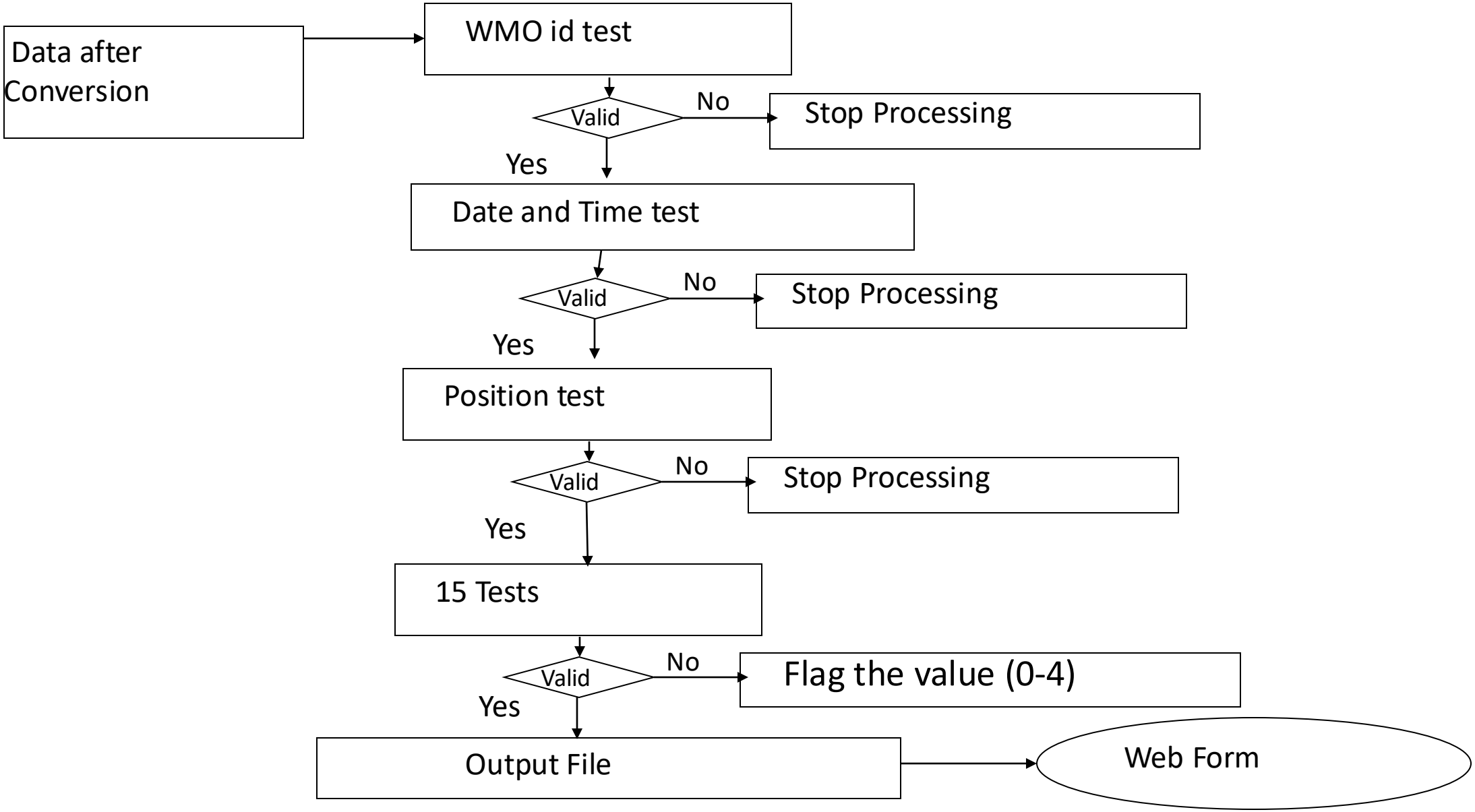



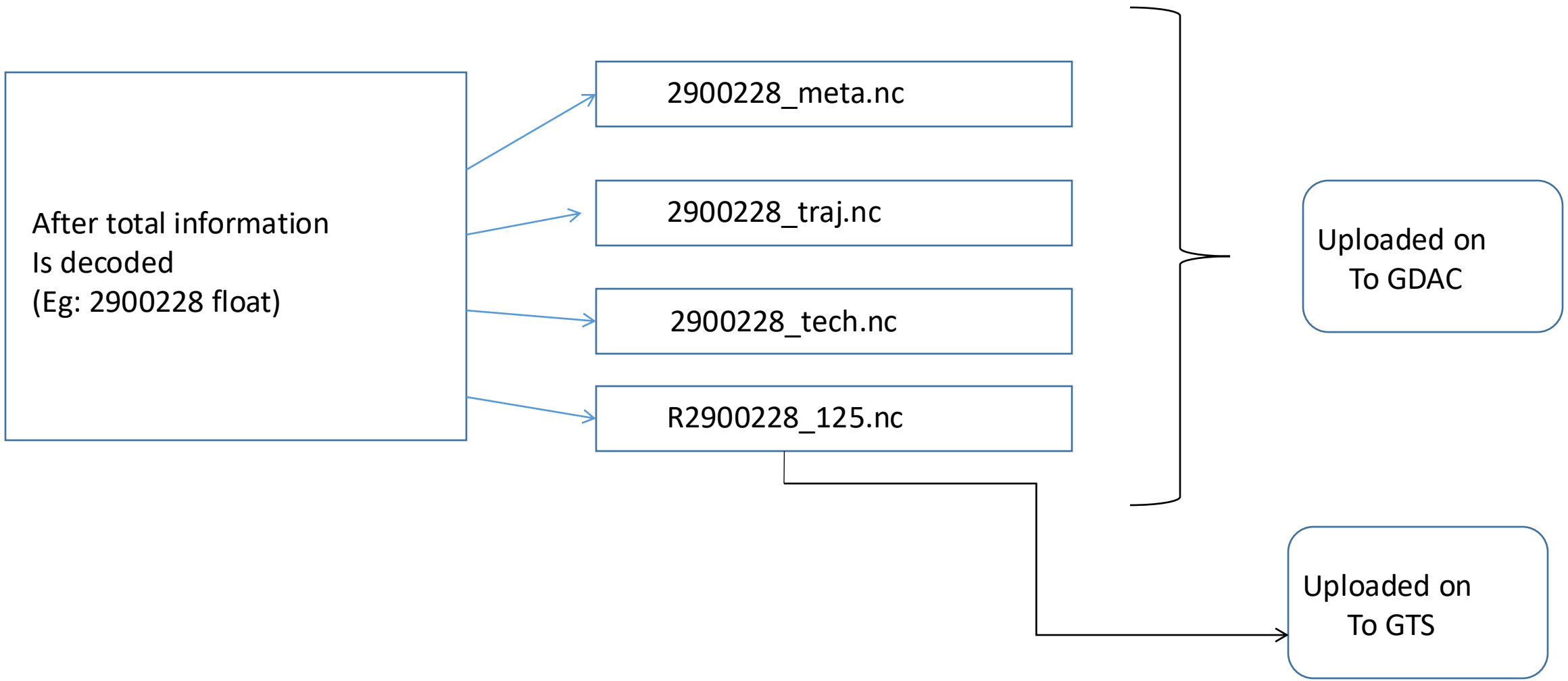
# Quality Control of data

- Two streams of QC are prescribed by the ADMT
  - Real Time Quality Control (RTQC) : to be done immediately after decoding and flagged data to be uploaded on to the GDAC before 24 hrs.
  - Delayed Model Quality Control (DMQC): to be done not less than 6 months after the float deployment.
    - Mainly for checking the sensor degradations

# Argo Data Real Time QC



| | |
|---|---|
| **1. Platform identification:** Each float should have an unique valid identifier provided by World Meteorological Organization (WMO). | **2. Impossible date/time test:** Year must be greater than 1996; month in the range of 1 to 12; date must in the expected range for the month; hours in range 0 – 23; minutes in the range 0 – 59. |
| **3. Impossible location test:** The latitude (longitude) must be in the limits -90 to 90 (0 to 360). | **4. Position on land test:** The floats must be located in the ocean. ETOPO2 bottom topography is used for this test. |
| **5. Impossible speed test:** Surface and subsurface drift speeds must not exceed 3 m $s^{-1}$. | **6. Global range test:** Temperatures must be in the range of -2.5° to 40.0° C and salinity must be from 2 to 41 psu. |
| **7. Regional range test:** Temperatures from floats in the Red Sea (Mediterranean Sea) must range from 21.7° to 40.0° C (10.0° - 40.0° C) and salinity ranges must be from 2.0 to 41.0 (2.0 to 41.0 psu). | **8. Pressure increasing test:** The pressure must increase monotonically. |
| **9. Spike test:** $\|V_2-(V_3+V_1)/2\| - \|(V_3-V_1)/2\|$ for a value $V_2$, where $V_1$ and $V_3$ are the values above and below $V_2$, which may not exceed prescribed limits. Above 500 dbar, the limit for temperature (salinity) is 6°C (0.9) and below 500 dbar the limits are 2°C (0.3). | **10. Top and bottom spike test:** This test is obsolete now. |
| **11. Gradient test:** The test value $\|V_2 - (V_3+V_1)/2\|$ for a value $V_2$ may not exceed prescribed limits. Above 500 dbar, the limit for temperature (salinity) is 9.0°C (1.5) and below 500 dbar the limits are 6.0°C (0.5). | **12. Digit rollover test:** A specific number of bits are allocated for the storage of temperature and salinity values in a float. When the number is exceeded, stored values rollover to the lower end of the range. This rollover when detected is compensated for in the processing algorithm. |
| **13. Stuck value test:** This test checks for constant temperature or salinity values throughout the profile | **14. Density inversion :** This test computes the density at all pressure levels from the observed temperature and salinity values and tests for hydrostatic stability. |
| **15. Grey list:** A list generated based on the history of a float. When a float sensor has systematic problems it is placed on this list. | **16. Gross salinity or temperature sensor drift:** If the average temperature (salinity) from the last 100 dbar of two adjacent profiles exceeds 1°C (0.5), then the profile is considered to be bad. |
| **17. Frozen profile test:** If floats produce five consecutive profiles with very small differences throughout the entire water column (i.e., of the order of 0.001 for salinity and of the order of 0.01°C for temperature) they are candidates for the gray list. | **18. Deepest pressure test :** This test requires that the profile has pressures that are not higher than DEEPEST_PRESSURE plus 10%. DEEPEST_PRESSURE value comes from the meta-data file of the float. |
| **19. Visual Quality Control:** Subjective visual inspection of float values is done by an operator. | |


After total information
Is decoded
(Eg: 2900228 float)
2900228_meta.nc
2900228_traj.nc
2900228_tech.nc
R2900228_125.nc
Uploaded on
To GDAC
Uploaded on
To GTS

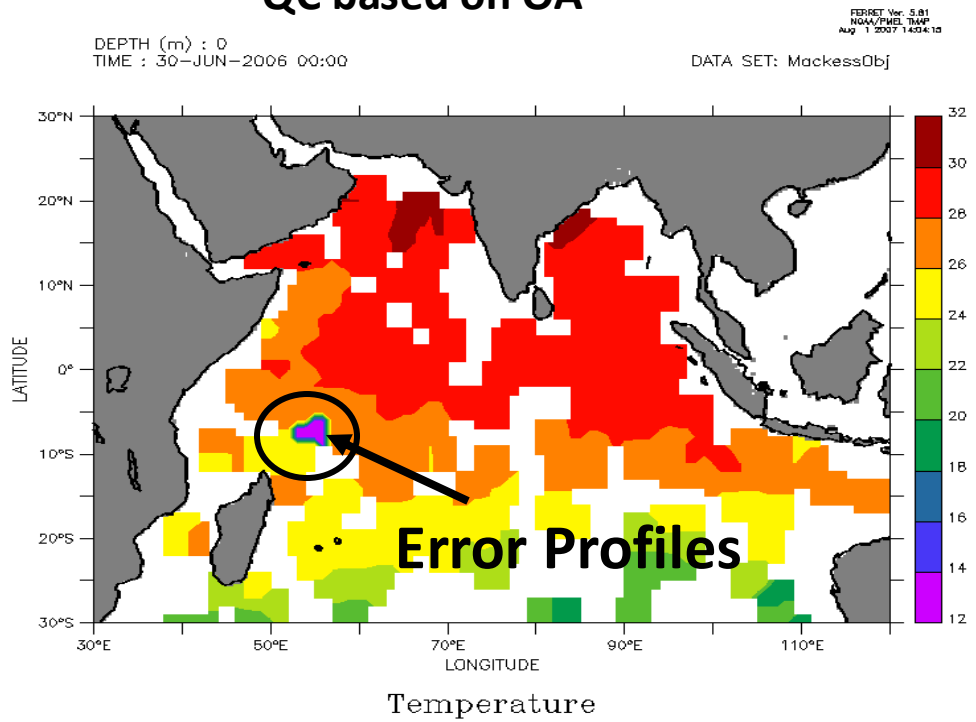
# Quality Control done at INCOIS

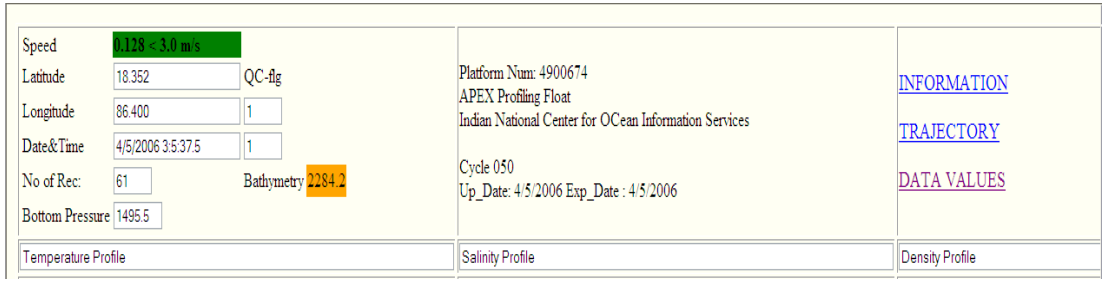
- Visual Quality Control
- Quality control based on Objective Analysis.
- Cluster analysis
- Latitude, longitude patterns
- Delayed quality control

# Three way QC of Argo profiles

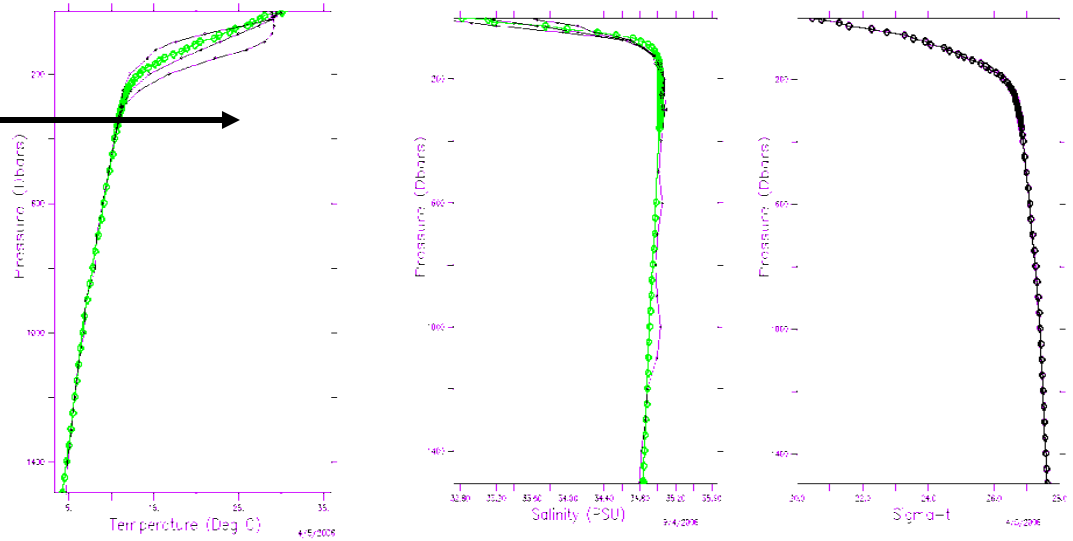
**Automatic QC (19)**

**QC based on OA**




**Visual QC**




Udaya bhaskar et al., 2013 IJMS,
Udaya bhaskar et al., 2012, IJEE

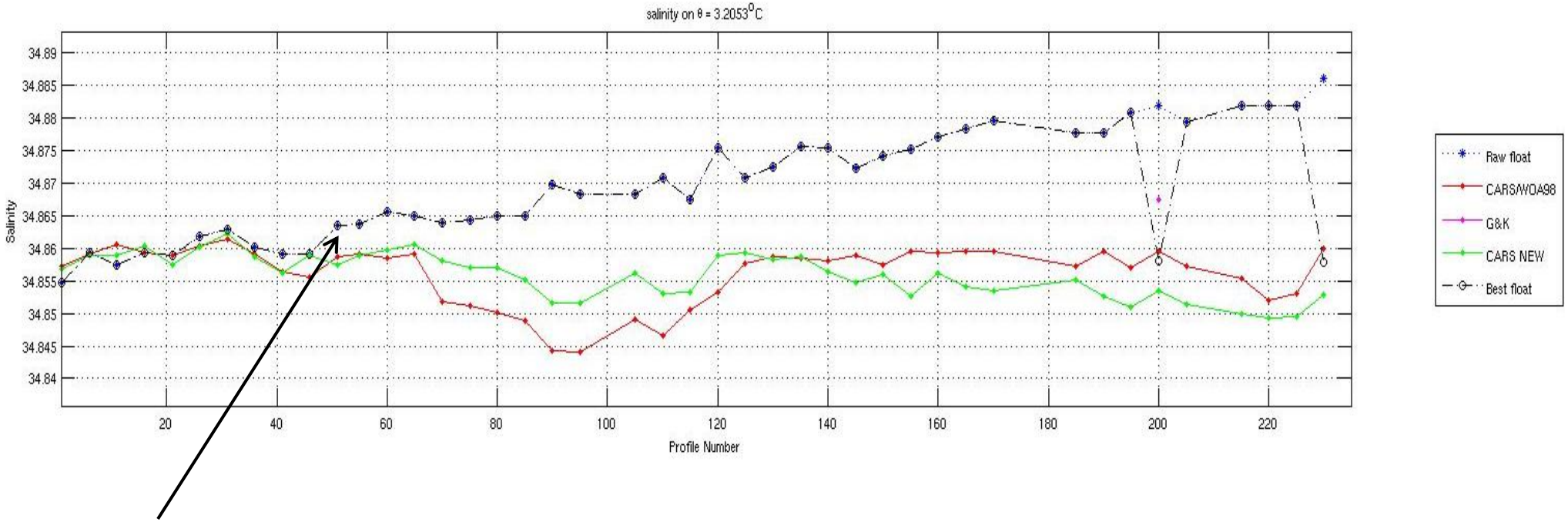
# Delayed Mode Quality Control (DMQC)

- Why DMQC?
  - Once an Argo float is deployed in the ocean, it is very difficult to calibrate its sensors or to monitor its condition under operation.
  - Argo target accuracies for measurement are 5 dbar for pressure, 0.005°C for temperature, and 0.01 for salinity (Argo Science Team, 2000).
  - The former two objectives could be achieved over a four year float life using technology available
  - How ever Salinity measurements were expected to be liable to experience some drift and offset, probably due to bio-fouling.
- Hence DMQC is required…

# What we do in DMQC

- Compare with available ship based CTD and also different climatologies.
- In DMQC we check for:
  - Salinity drifts.
  - Tri-Butyl Tin Oxide (TBTO) problems which causes freshening on salinity in initial profiles.
  - Salinity hooks.
  - Surface pressure Offsets problems.
  - Thermal lags problems.
  - Truncated Negative Drifting Pressure (TNDP).

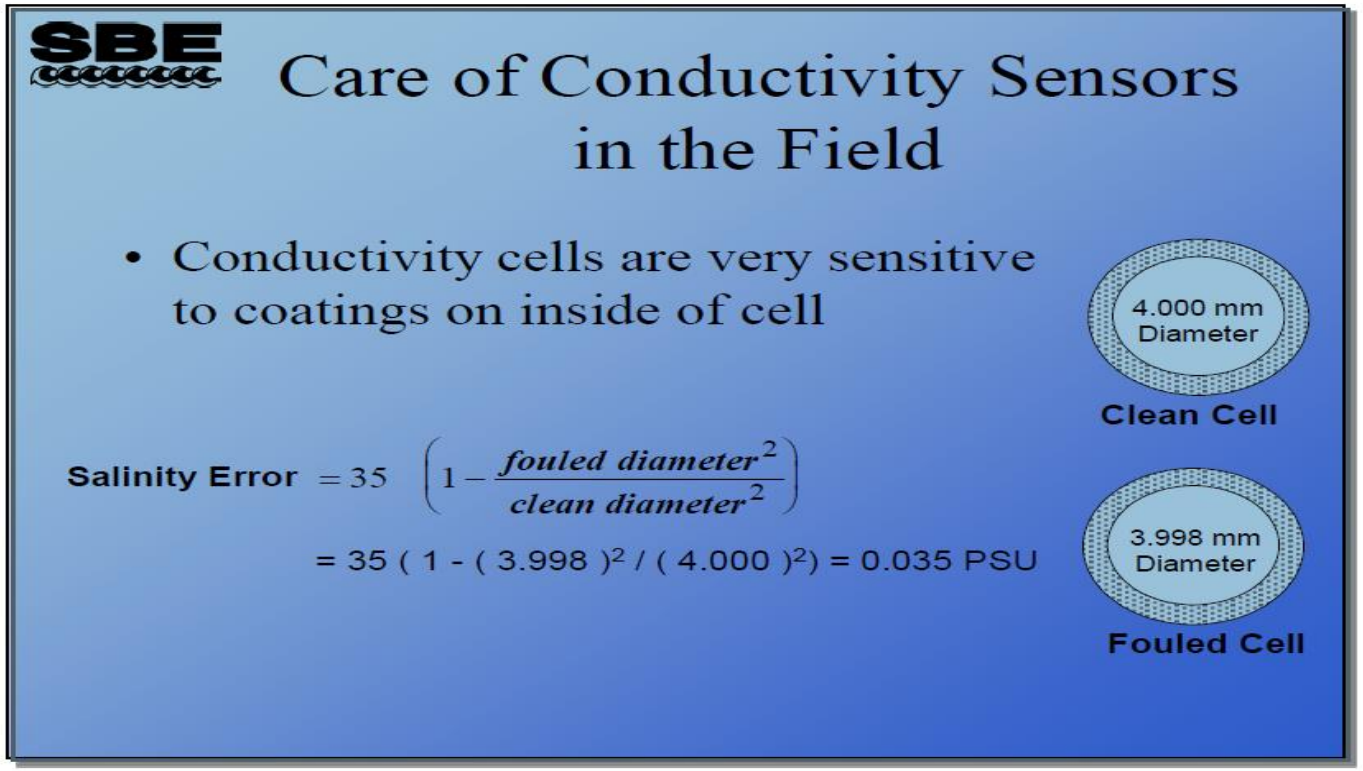
# Salinity drifts



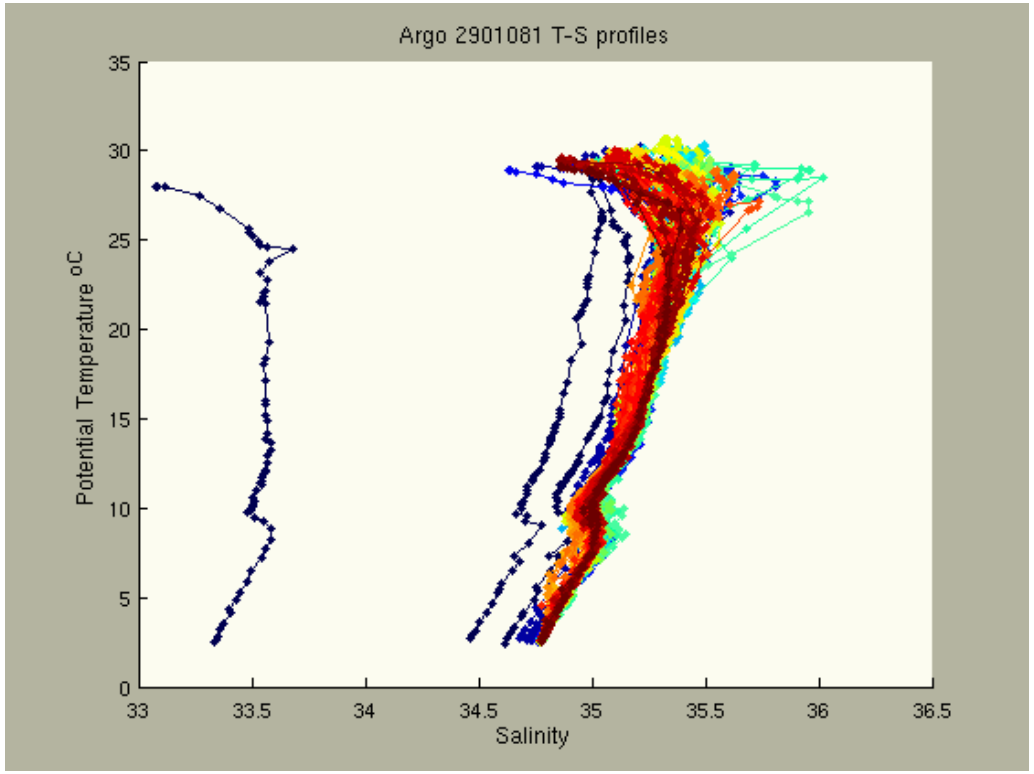

This float is observed to posses drift in salinity starting from cycle 44 onwards

# TBTO issues

- Anti-fouling agents causing the cell dimensions to change there by causing errors in the salinity measurements.

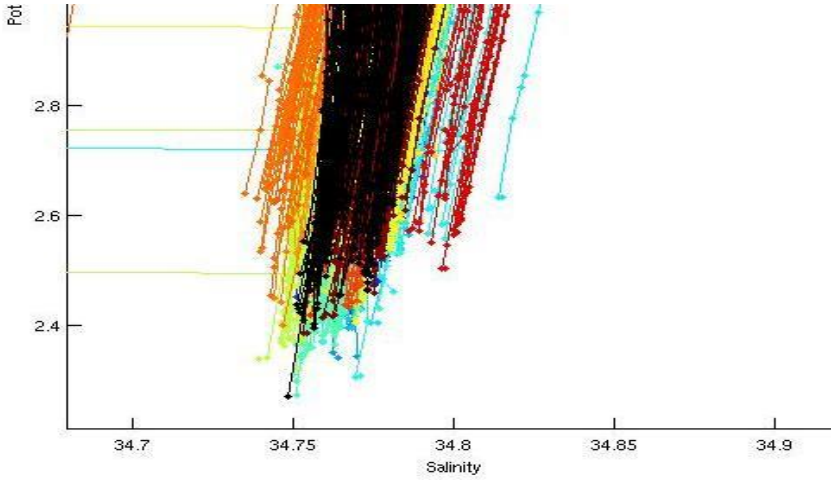


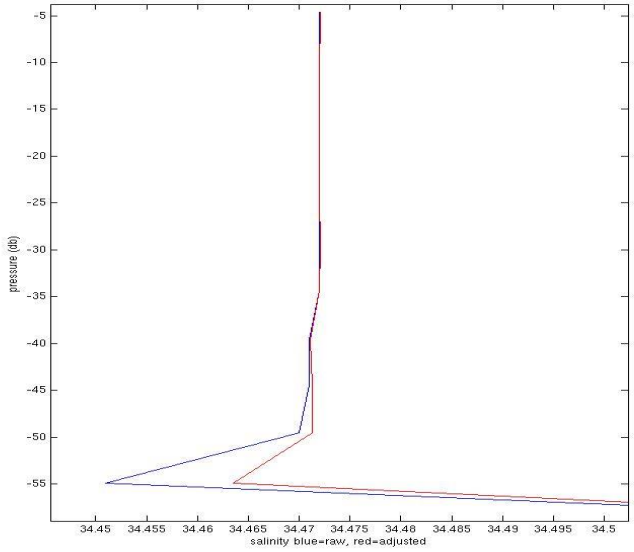

(Courtesy: SBE training manual)



- This happens some times due to trapping and non-flushing of sea water.

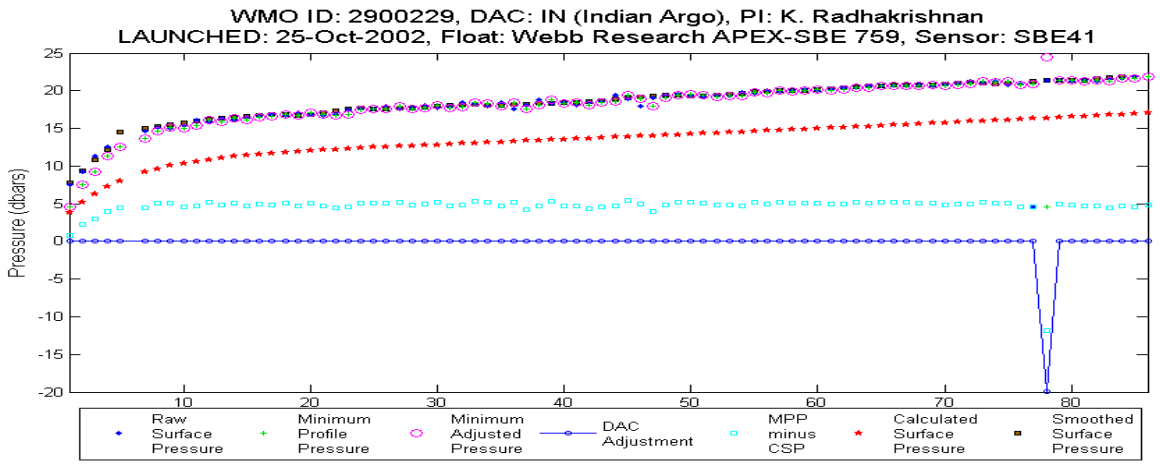
- Thermal lag problems: salinity spiking at the Mixed layer.

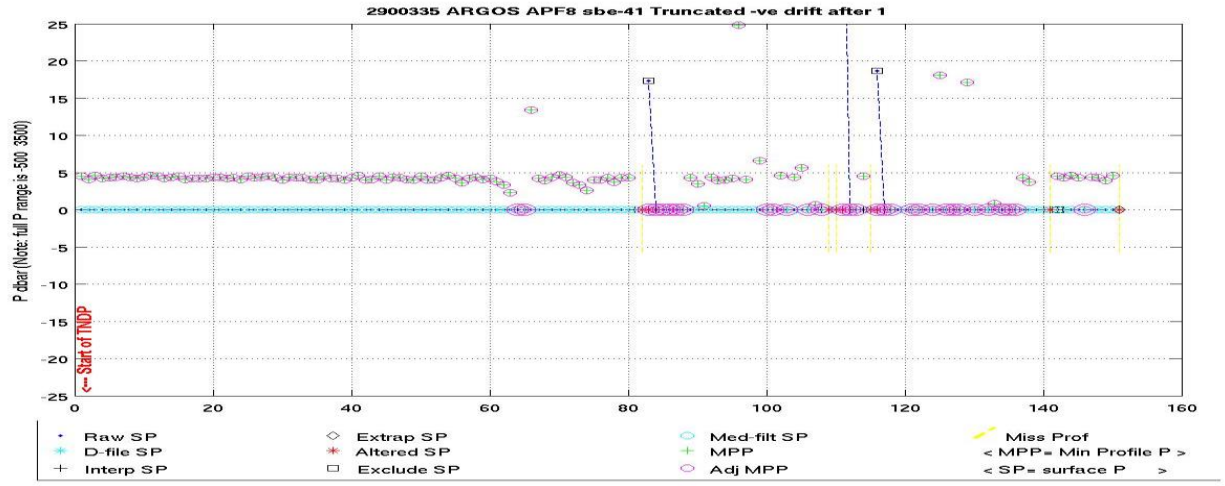


- Pressure sensor offset:

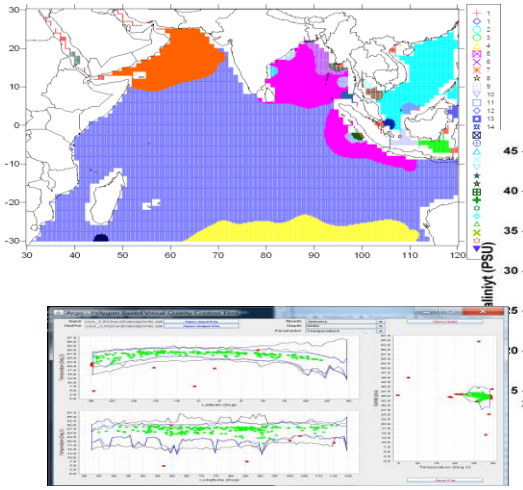
- TNDP issues :

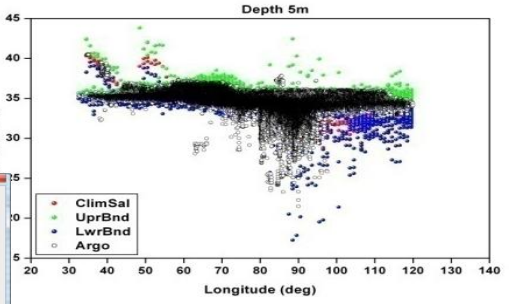


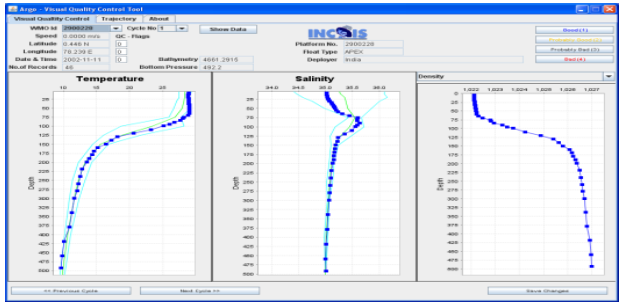



# Development of New QC techniques and QC tools

- Three way Quality Control System is developed and implemented at INCOIS
  - Automatic QC, QC based on Objective Analysis and Visual QC is implemented for quality assessment of CTD data. Flags are assigned/modified accordingly. (udaya bhaskar et.al., Vol 5(1) IJEE, 2013)
- New Quality Control tools for handling bulk data is devised.
  - Cluster based techniques
    - Spatio-temporal clusters are identified.
    - Sensitivity parameters are used to detect outliers.
  - Latitude-Longitude clusters
    - N-sided polygon of Lon/Lat Vs Parameter is generated.
    - Points falling in(out side) polygon is used to detect outliers.
    - GUI for the same is also designed.
  - Visual Quality Control Tool
    - Climatological Mean and Standard deviations as background.
    - Profile is checked against mean and 3 σ.
    - Profile falling outside 3σ envelopes is a suspect profile.
    - Visually flags are modified and changes reflected in the database.





# Role of INCOIS

INCOIS acts as a National Data Centre and Argo Regional Centre (ARC) for India and Indian Ocean respectively

**National Argo Data Centre**

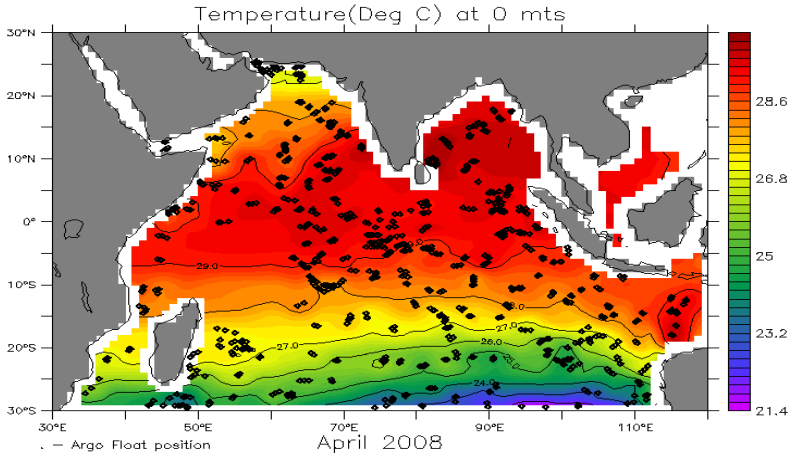
- Deployment of Argo floats.
- Decoding and quality control of Indian floats and transmition to GTS.
- Argo data services.
- Assimilation of Argo data into models.
- Delayed mode QC of Indian Argo floats data.
- Capacity building.

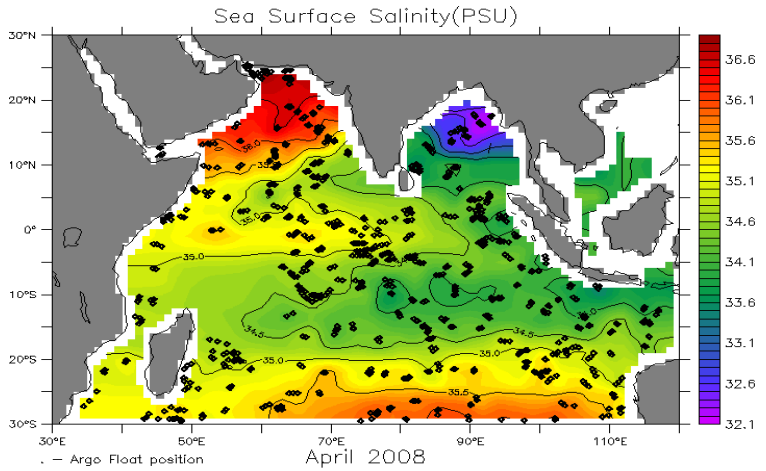
**Argo Regional Centre (ARC)**

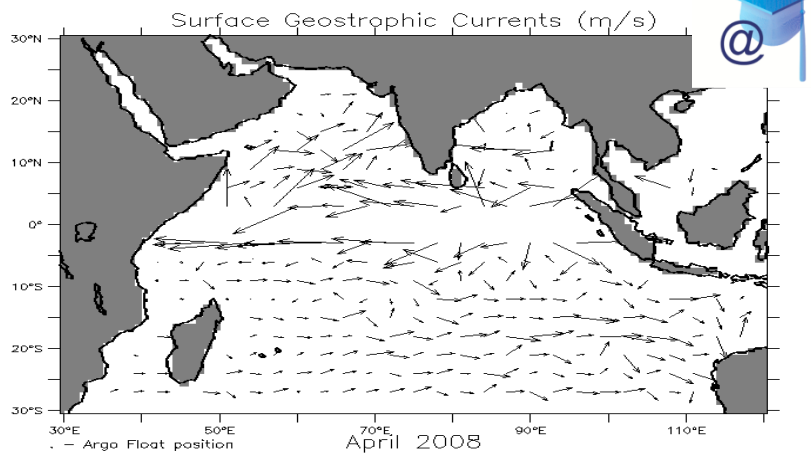
- Coordinating the deployment of Argo floats in Indian Ocean.
- Determine internal consistency by comparing with CTD.
- Comparison with model output and assimilated fields.
- Preparing and distributing the Argo products.
- Assembling high quality CTD for delayed mode QC of Argo data.

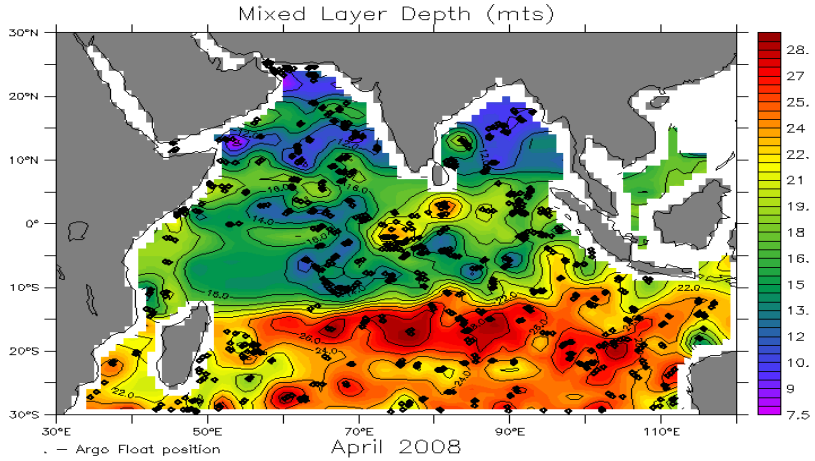
# Argo Value added products

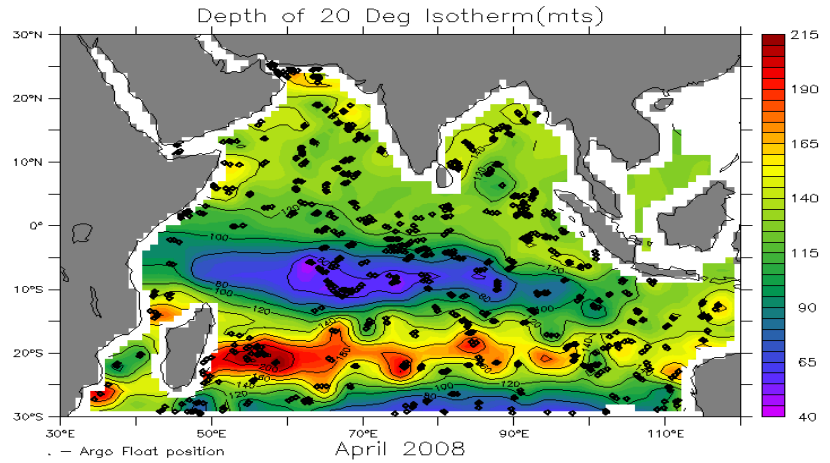
- Using all the quality controlled T/S profiles, gridded products are generated:
  - Objective Analysis and Variational Analysis based.
  - Spatial extent: 30 – 120 E and 30S – 30N.
  - Temporal extent: 10 days and monthly.
- Data delivery:
  - Through Live Access Server (ILAS) – url: las.incois.gov.in
  - Offline through CD (Argo Data Viewer)
  - Secured FTP for Indian Navy.

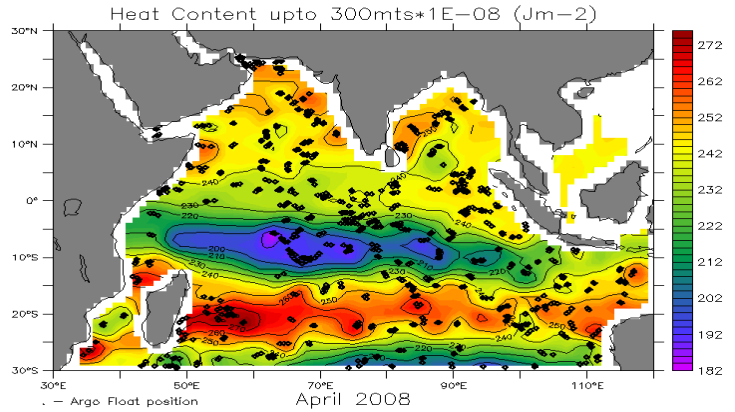


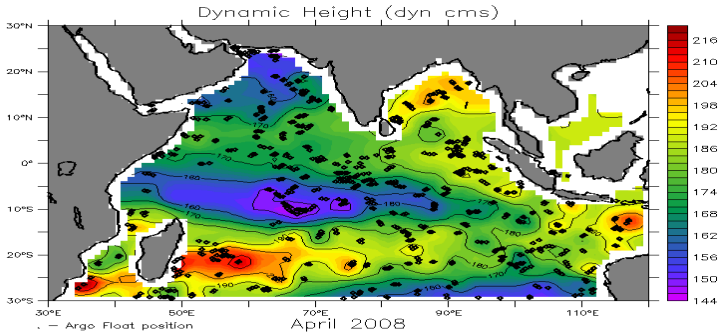




- **Generated Plots using Ferret visualization Software**
- **Plots are made available to users via INCOIS web.**

Udaya bhaskar et al, Technical Report

# Insights with Argo data

- The open nature of the Argo data have helped Indian scientist in studying the long term changes in Indian Ocean which is least understood and a region of sparse in situ data.
- The Argo data was extensively put to use for understanding the:
  - Inter-annual to intra seasonal oscillation studies in IO **(Ravichandran et al)**
  - Mixed layer, Barrier Layer process. **(udayabhaskar et al., Girish et al.,)**
  - Circulation in combination with Sea level data. **(Joseph, S et al)**
  - Up-welling and down-welling process. **(Chiranjivi et al)**
  - Climate change studies (Chla trends, IODE etc) **(prakash et al)**
  - Assimilation into models (INCOIS-GODAS) **(Ravichandran et al)**
  - Validation of satellite data (temperature and salinity). **(Rahman et al, udaya bhaskar et al; satya prakash et al)**
  - Generation of analysis products and many more. **(Ravichandran et al)**
  - Building new climatologies and Atlases. **(Abhishek et al., udaya bhaskar et al)**
- As many as 150+ papers were published in peer reviewed journals by the Indian scientific community.

# Journey

**Floats with additional**
**Bio-sensors, Deep Argo**

***Future***

**2014**

**2013**

**Bio-Argo floats with**
**Chla, Backscattering**

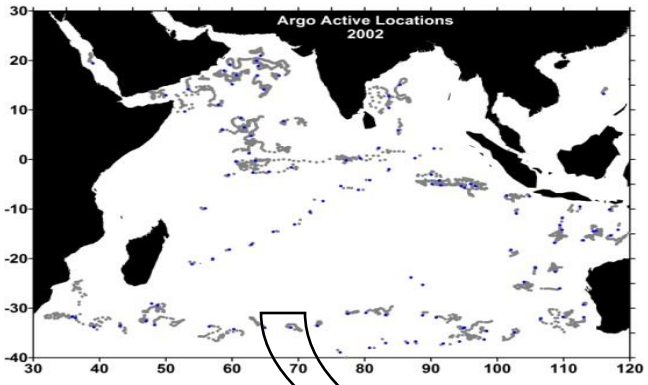
***Now***

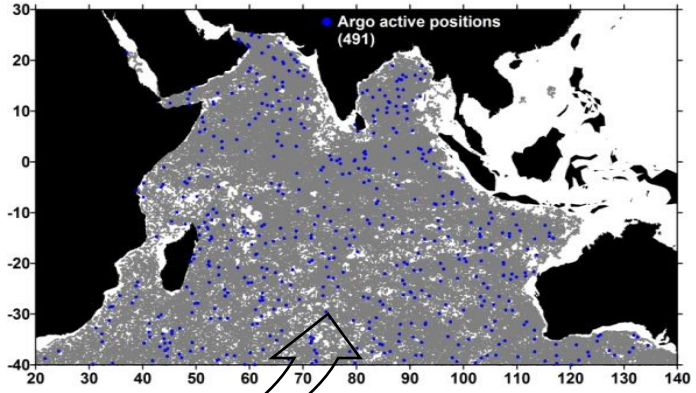
**Indigenization efforts successful**

**Improved CTD type floats**
**+ floats with DO sensors and NST sensors**

***In between***

**2006**



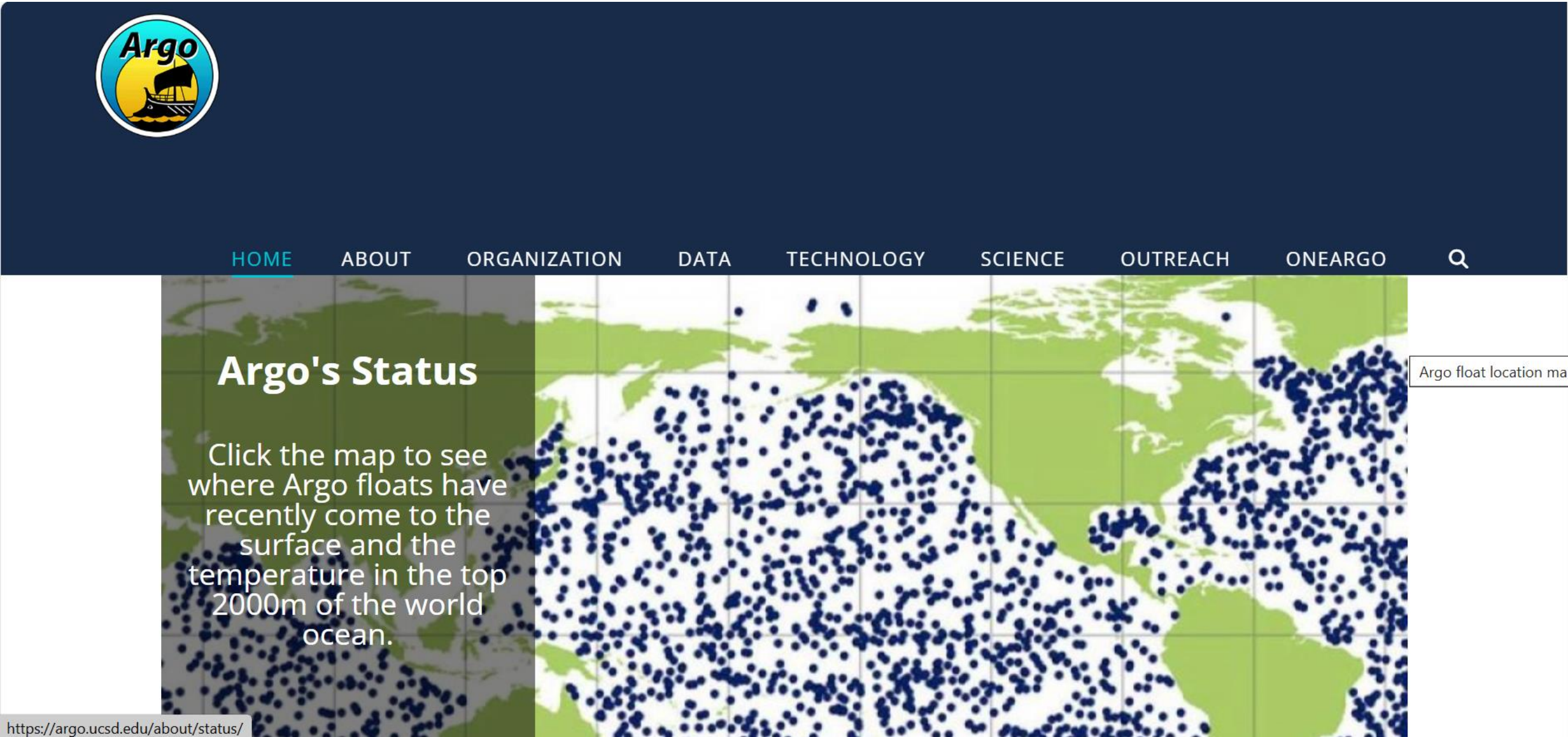




***Beginning***

**Basic CTD type floats**

**2002**

# Website for information: https://argo.ucsd.edu/



# Website for accessing data: http://www.argodatamgt.org/

- **Argo GDAC ftp, https and s3 servers**
- Argo data selection tools
- Argo floats dashboard
- Argo DOI, Digital Object Identifier
- Argo GDAC synchronization service
- ERDDAP data server
- Thredds data server

NEWS

ARGO USER'S MANUAL VERSION 3.43.0
23/06/2025

ARGO DATA DOCUMENTATION IS REPLICATED ON GITHUB
10/08/2022

ARGO NETCDF FILE FORMAT CHECKER UPDATED
18/06/2025

DOCUMENTATION: 4

## Argo GDAC ftp, https and s3 servers

Argo data are freely available from US-Godae and Coriolis GDAC sites with ftp, https or s3 protocols

### GDAC FTP

- ftp://ftp.ifremer.fr/ifremer/argo

### GDAC HTTPS

- https://data-argo.ifremer.fr
- https://usgodae.org/pub/outgoing/argo

### GDAC S3

- Argo data are updated daily on https://registry.opendata.aws/argo-gdac-marinedata

All data files are in NetCDF profile and multi-profile format.

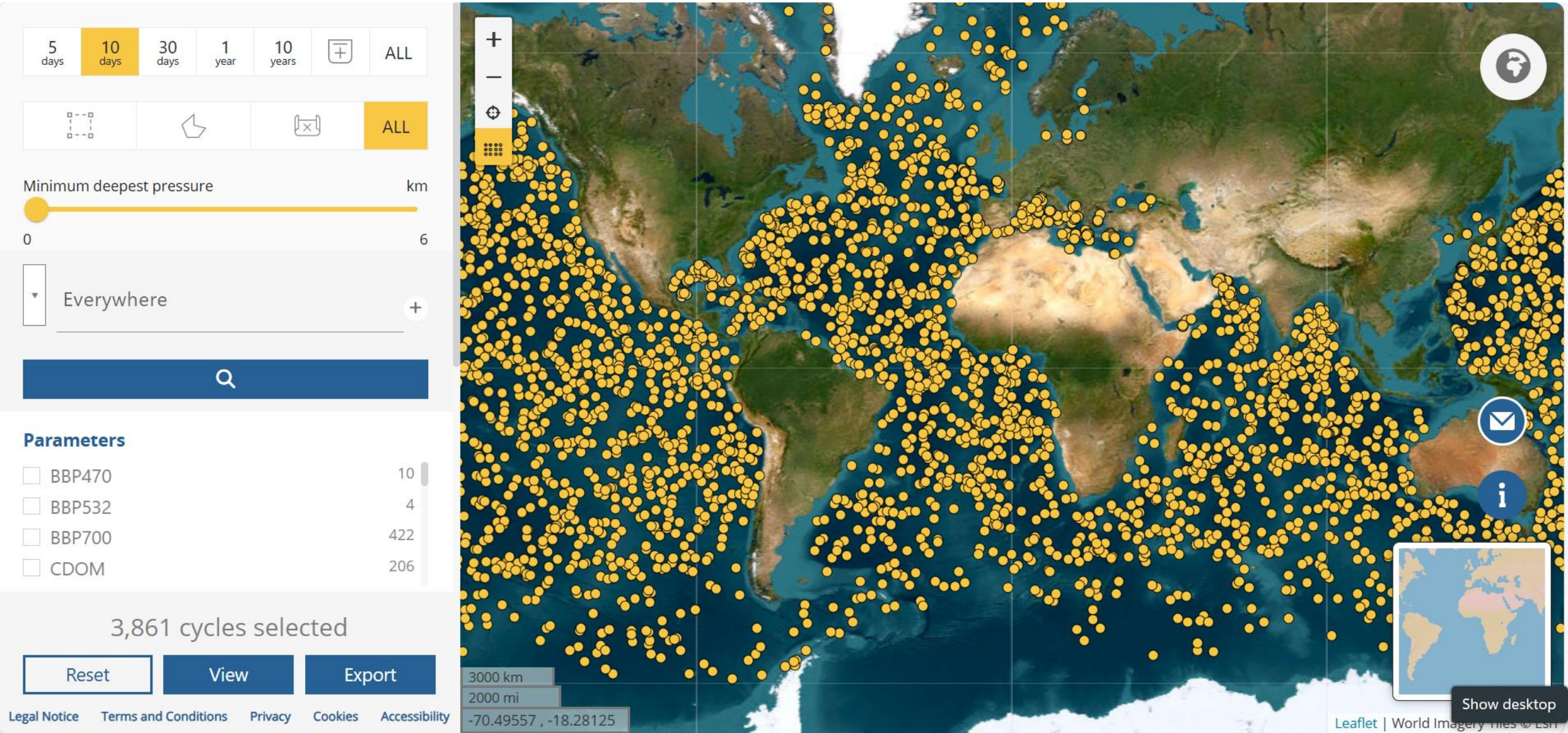
- Description of the data format, Argo user's manual: http://dx.doi.org/10.13155/29825
- US-GODAE GDAC web site

GDACs are updated in real-time and delayed mode with data from Data Assembly Centers (DACs).

The Argo ftp site provides 3 "views" of the data profiles:

- DAC
  - a directory per data assembly center
  - a directory per profiler
  - a file per profile of the profiler
- GEO

# Website for accessing data [https://dataselection.euro-argo.eu/](https://dataselection.euro-argo.eu/)



# Summary

- Argo program has become a indispensible observation system pumping in ~ 1lakhs profiles per year for use by oceanographers.
- It has sustained initial hiccups of battery problems to pressure sensor offsets to micro-leakage problems and now became more and more robust.
- Efforts of all the deploying nations and the ADMT should be given due credits for sustaining this program.

*Thank You*