Indian Argo program, Past, Present and Future

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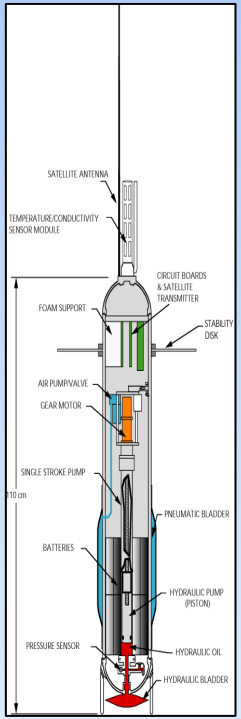
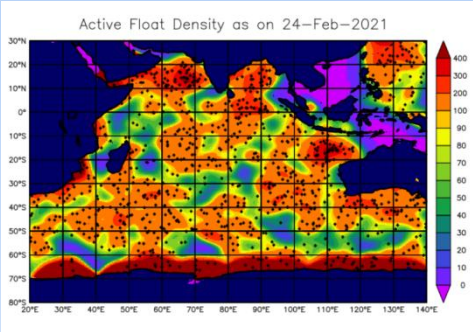
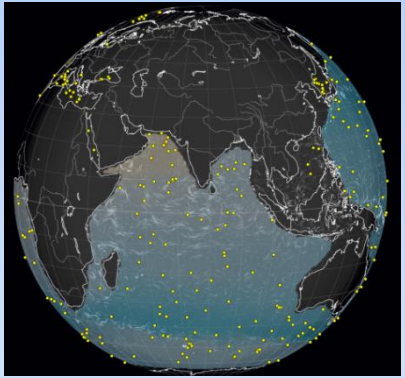
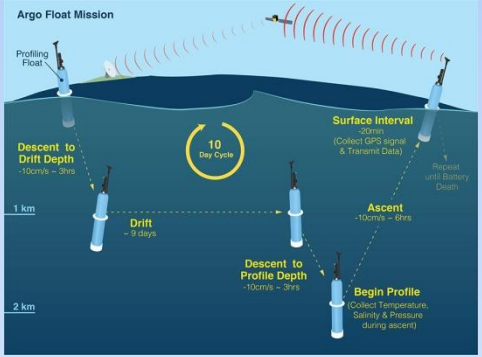








Webinar Series of International Training centre for Operational Oceanography (ITCOOcean)

26 February 2021

ITCOocean, INCOIS, Hyderabad

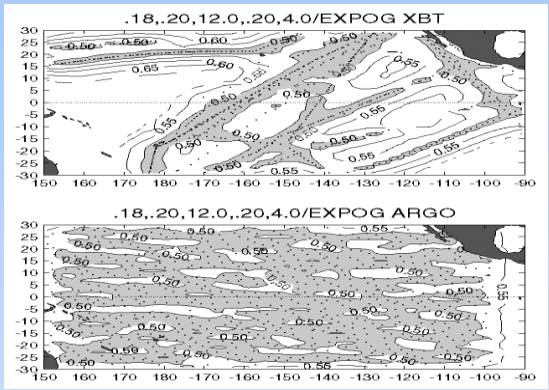
Outline

- 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.
- Data availability (sources ….)
- Summary.

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)

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

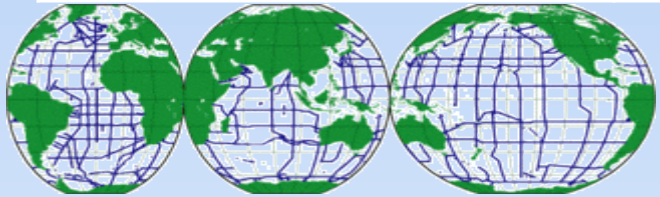
$$u = -\frac{1}{\rho f}\frac{\partial p}{\partial y}, \quad v = \frac{1}{\rho f}\frac{\partial p}{\partial x}$$

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.

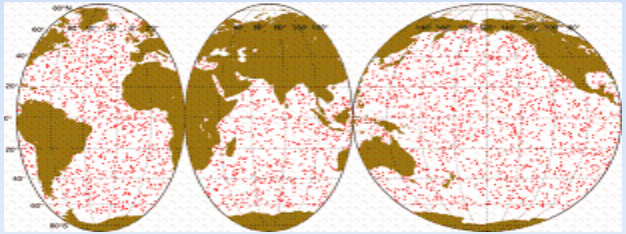
Table summarizing novelty of Argo's data set

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) • 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 (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



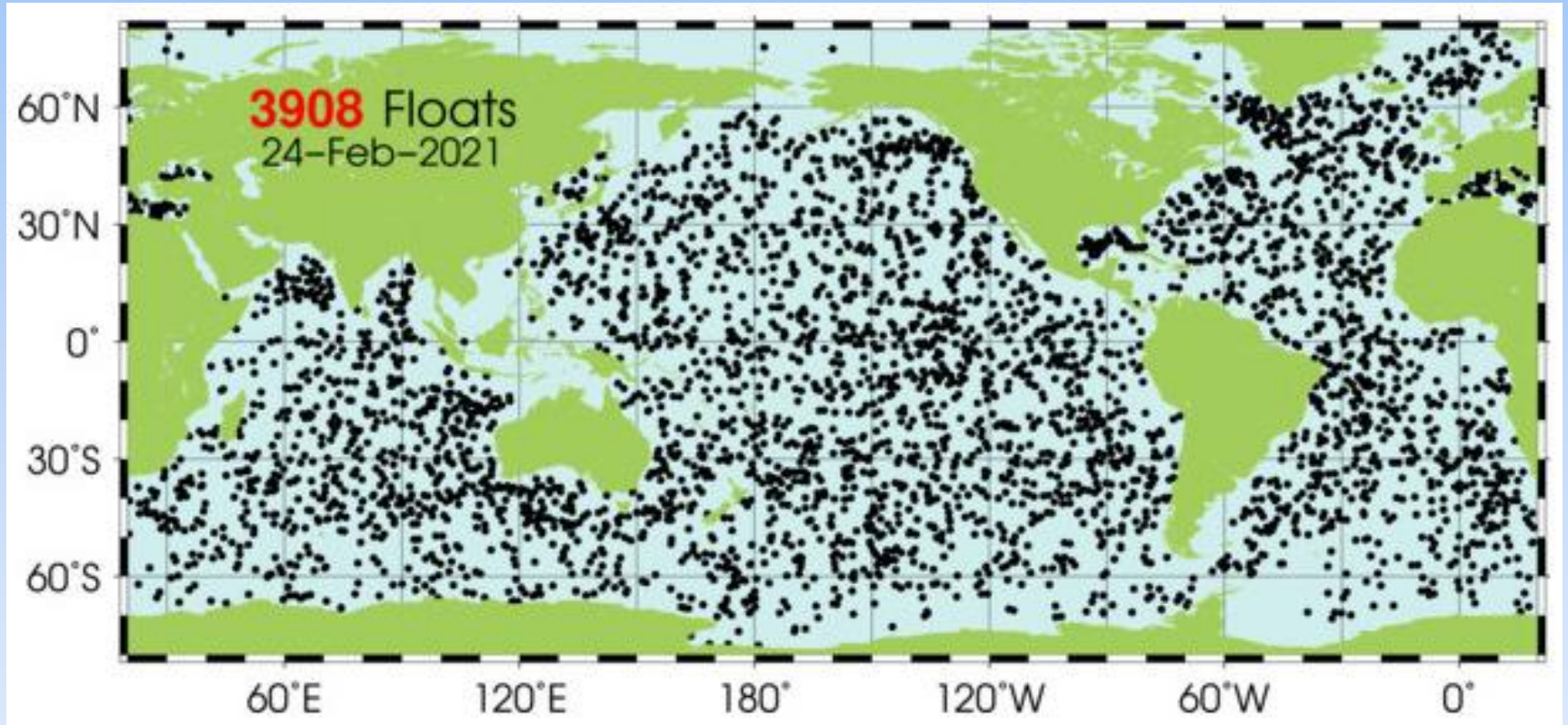
Global coverage at the target of 3° x 3° density achieved near the end of 2007.

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

Argo collaboration and Data Sharing

- **Multi-National Argo**
  - The array is made up of **23** 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.

Latest picture of Argo in the Global Ocean



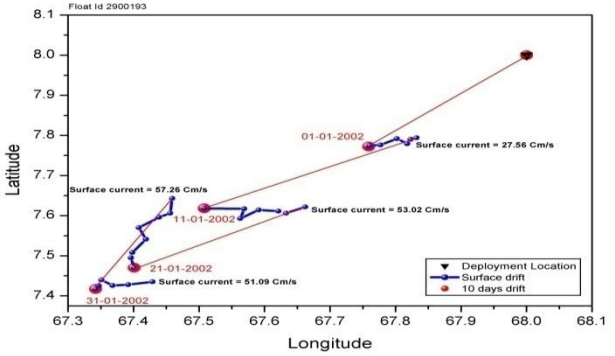
Indian Argo program

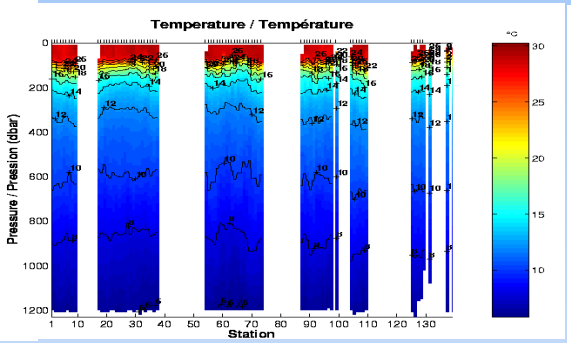
- It started with the deployment of Argo float obtained from MEDS, Canada. The float 2900193 was deployed by INCOIS at 68˚E,8˚N on 22nd Dec, 2001 and obtained valuable insight about deployment, importance of ballasting etc.

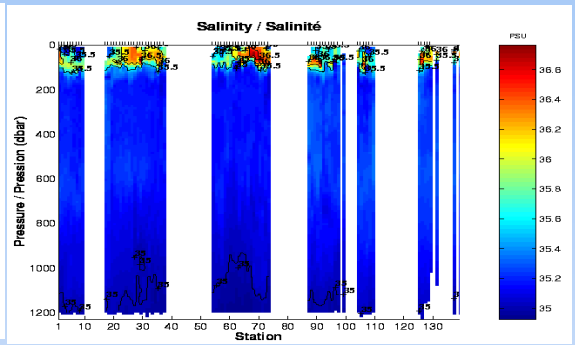
Dr. Howard Freeland giving insights about the Argo float at the “India Argo implementation meeting” held at Hyderabad, July 26 – 27, 2001

Canadian Argo Float deployed by India in Dec. 2001

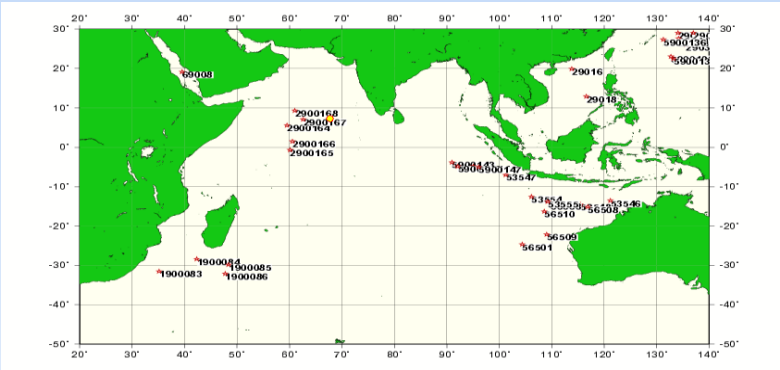
(A Typical Case in South Arabian Sea)







APEX Float with Sea Bird Sensors , Parking Depth of 1200 metre, 180 cc Fluid, 10 day cycle

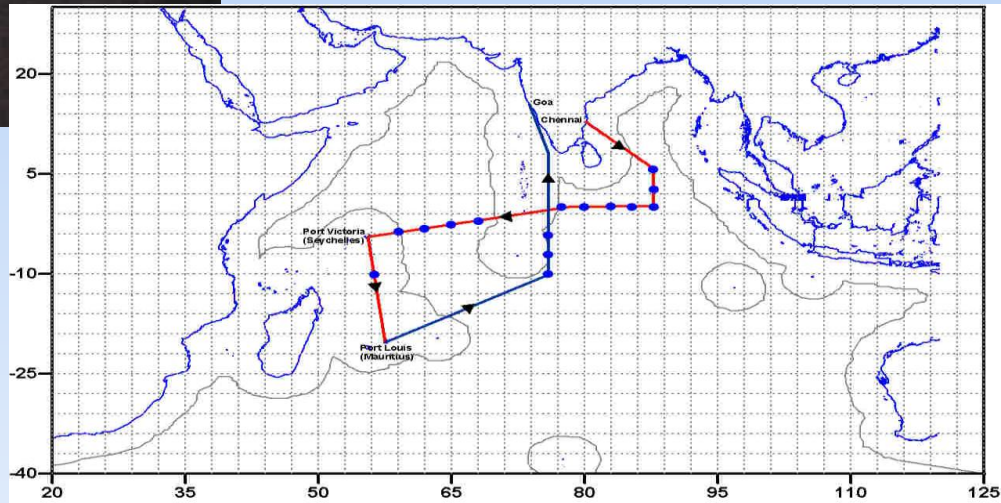


Results from the first Argo float deployed by India, M. Ravichandran, P. N. Vinayachandran, Sudheer Joseph and K. Radhakrishnan. Current Science, Vol 86 (5), 2004.

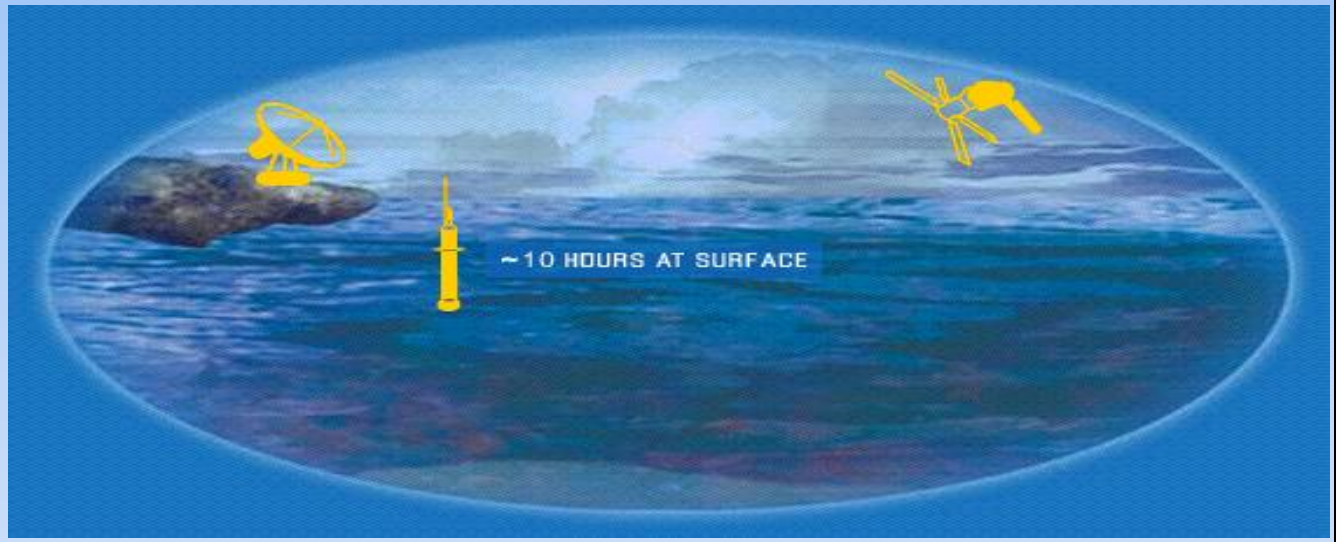
Launching Indian Argo Programme

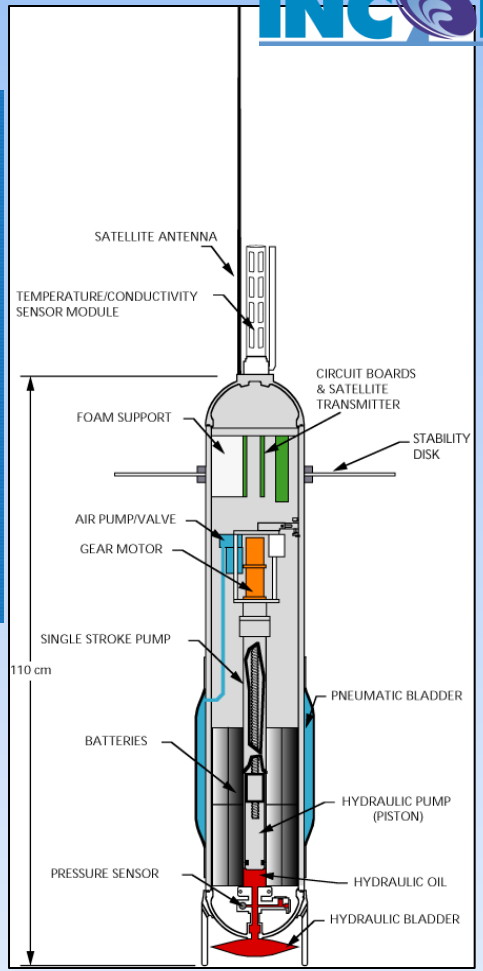
With the insights gained from this the first batch of floats were deployed during Nov – Dec 2002, on the way from Goa to Mauritius.

Subsequently Indian had deployed each year contributing a total of **493** floats (as of today) to the International Argo Program



Argo Cycle and Cross Section

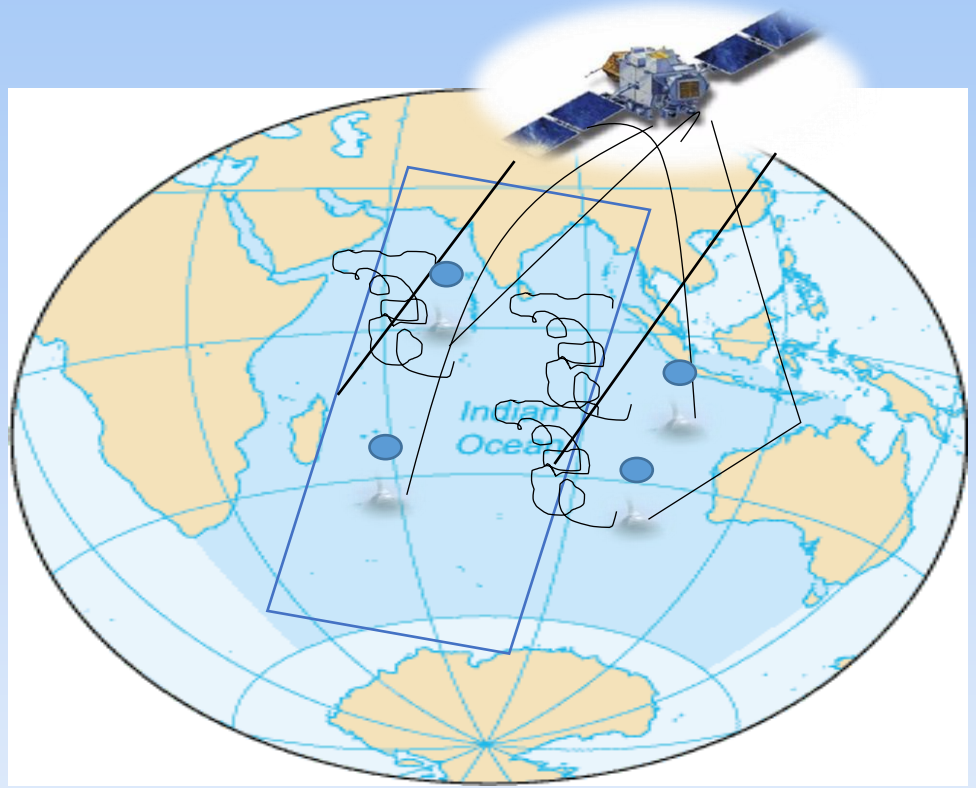


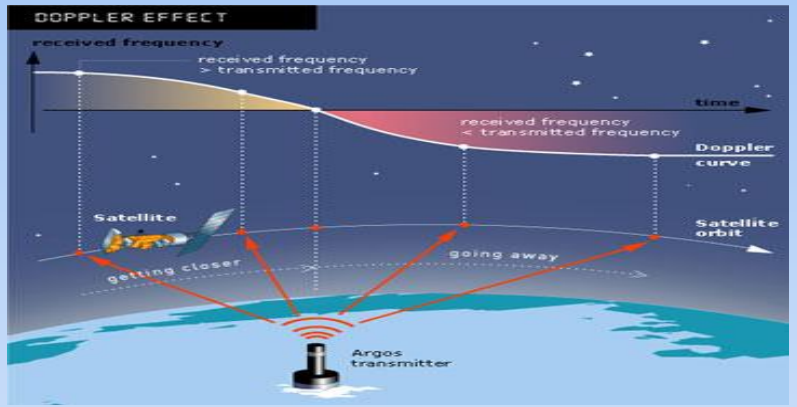


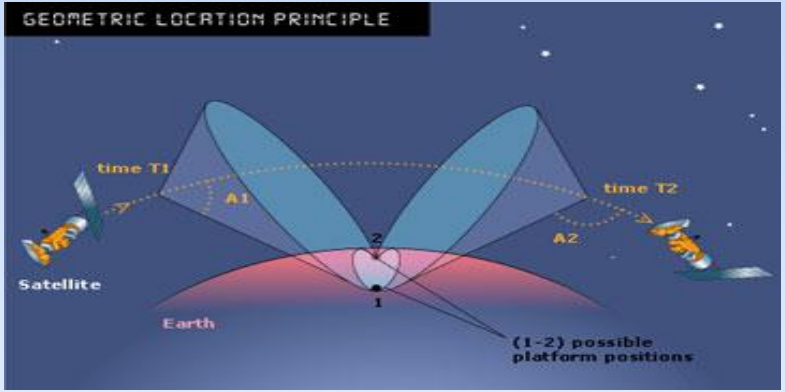
- Drifting Depth: **1000 m**
- Profiling Depth: **2000 m**
- 10 Days/Cycles

www.incois.gov.in

Fixing the location of the float by the satellite

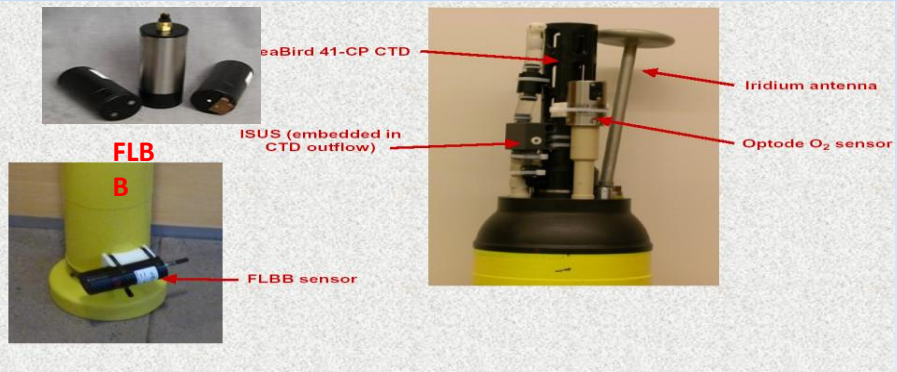






Indian Float Sensors

- 2 FSI
- 393 SBE (both 41 and 41 CP).
  - SBE 41 spot samples, no internal memory, transmits data to float controller. Float controller stores and transmits on the surface.
  - SBD41CP does continuous sampling as float ascends, stores in internal memory. Float controller request and transmits upon reaching surface.
- 14 + 2 (DO [SBE],[Aanderra])
- 15 Near surface temperature mission (NST) sensors
- 67 Bio-Argo (DO,FL,BB)



Accuracy

T: 0.002 ° C

S: 0.005 psu

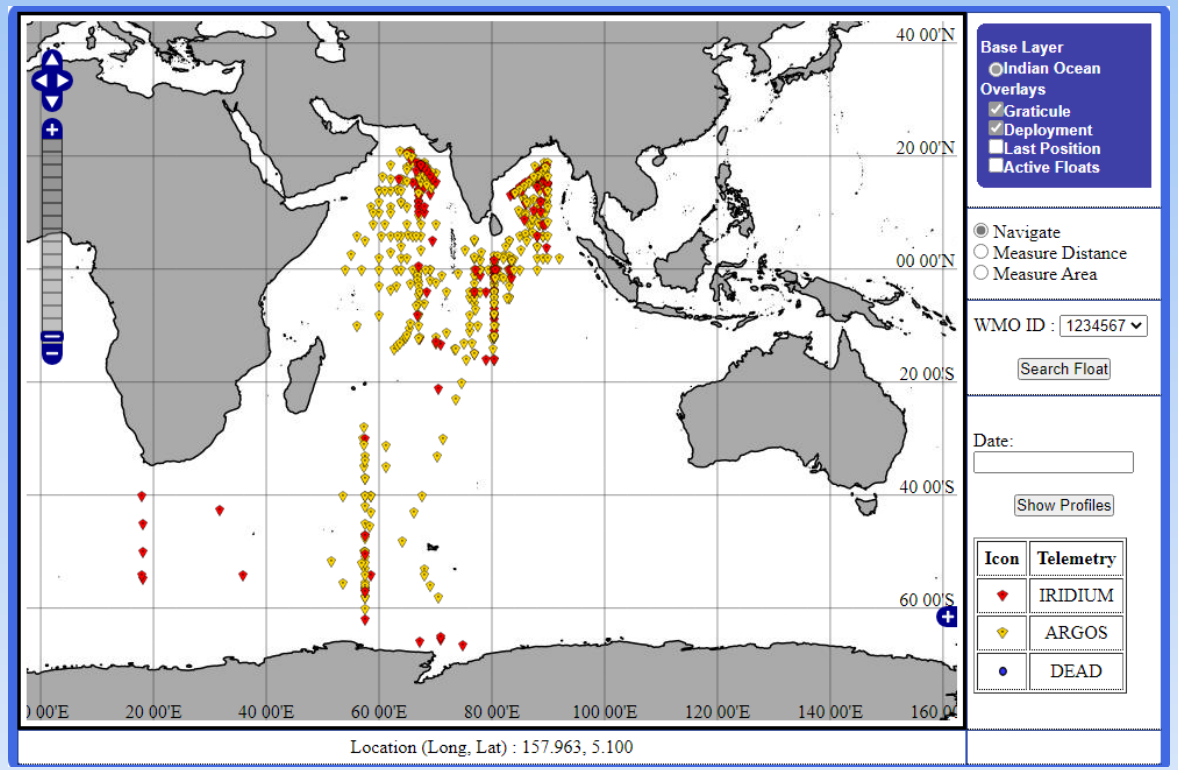
P: 2.0 db

Additional sensors

Oxygen
Chlorophyll
Rain
Nitrate
Light attenuation
.....

Oxygen - Seabird model 43

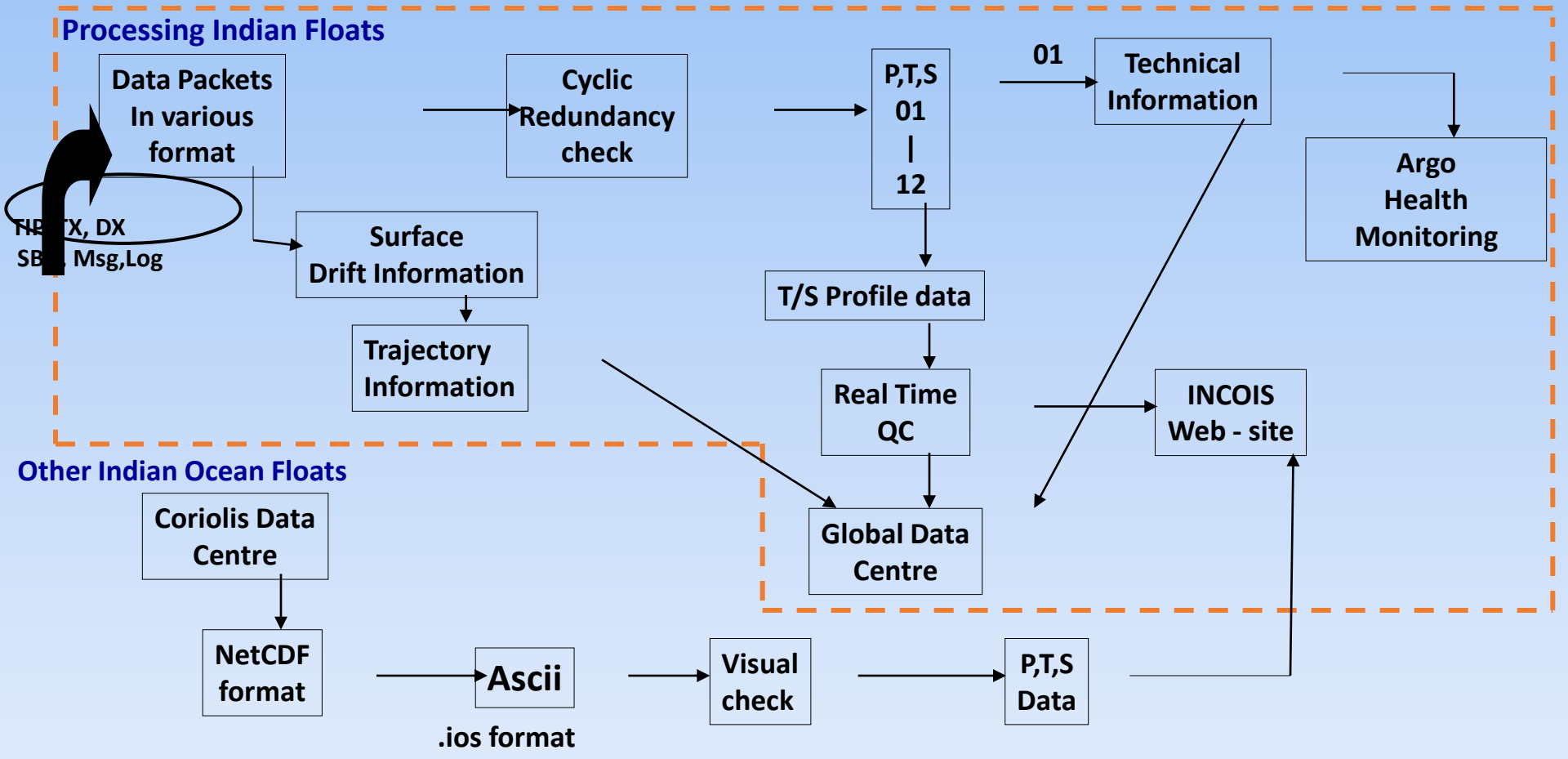
Oxygen - Aanderaa Optode 3830



Type of Sensors	No
CTD alone	395
CTD + Near Surface Temperature Mission	15
CTD + Dissolved Oxygen	16
Bio-Argo (CTD + Chla + DO + FLBB)	67

Type of Satellite	No
ARGOS	386
IRIDIUM (RUDICS)	40
IRIDIUM (SBD)	67

Indian Argo Data Processing



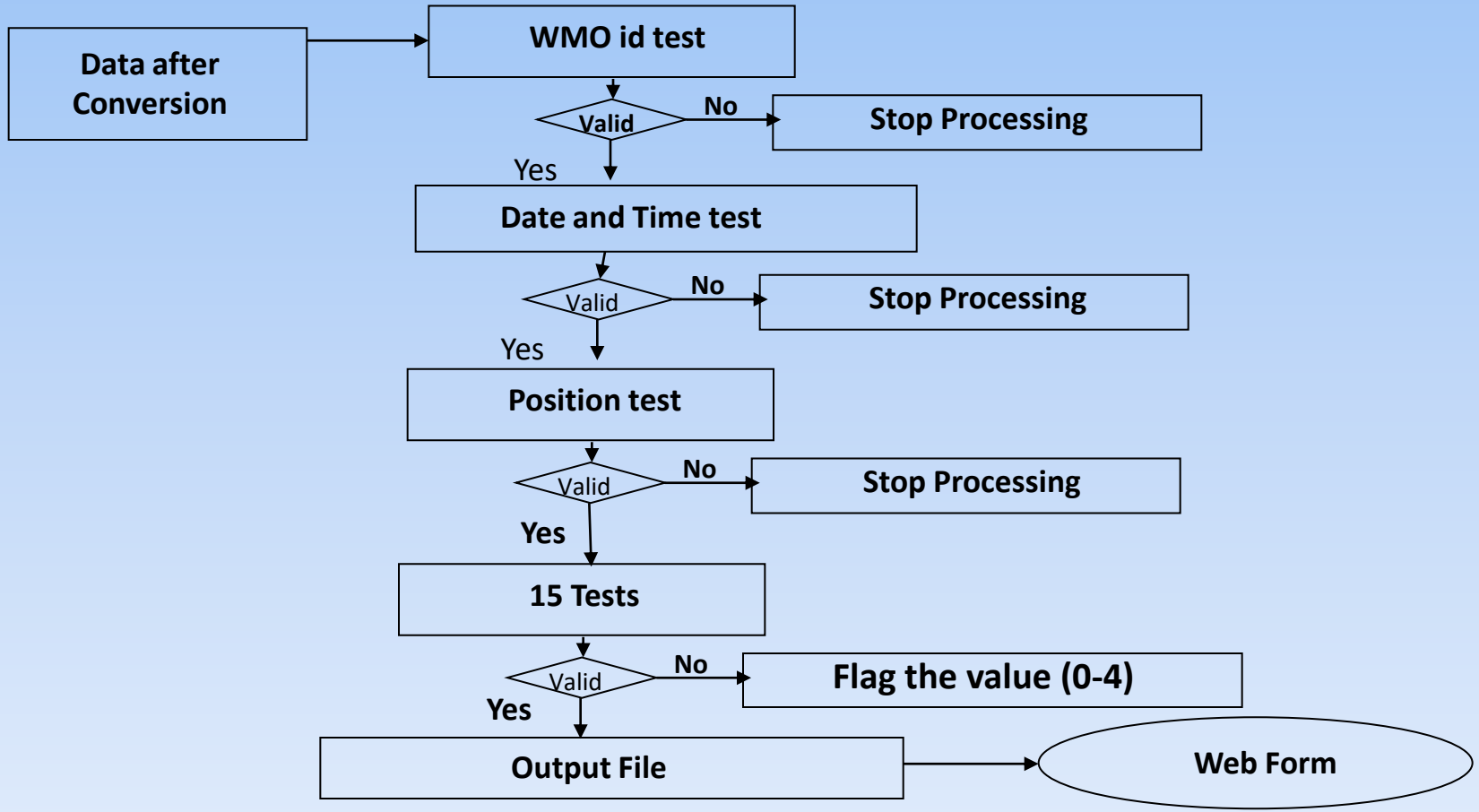
Various types of raw data

Sno	Format	Satellite Type (# of floats)	# (P,T,S) Triplets
1.	TIP, TX format	ARGOS (269)	45 or 75
2.	Msg, Log files	IRIDIUM/Rudics (25)	~ 1000
3.	Short Burst Data	IRIDIUM/NKE PROVORs (11)	~ 1000 (now 145)

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 range of 1 to 12; date must in the expected range for the month; 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.	

Additional Quality Control done by Indian DAC

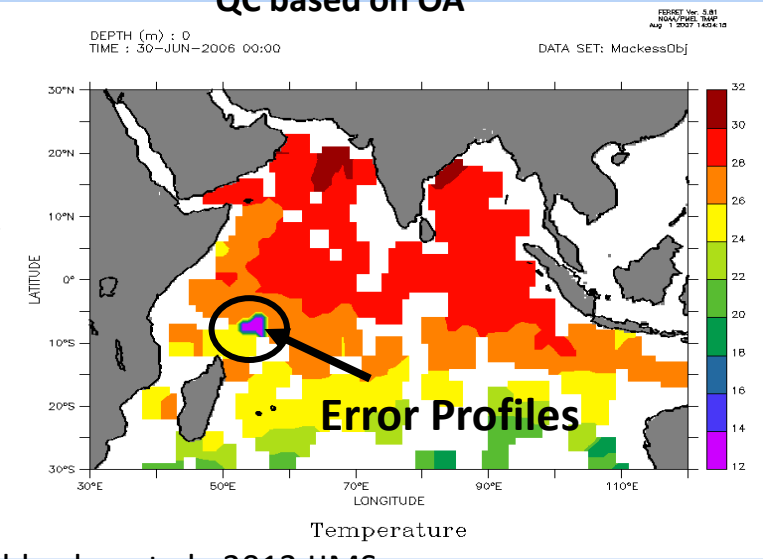
What we do at INCOIS

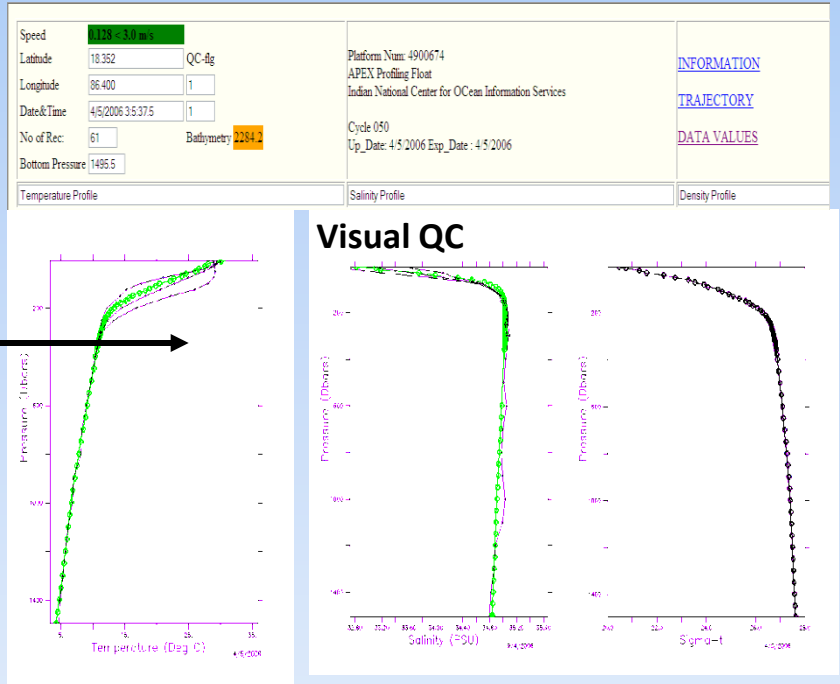
- Visual Quality Control
- Quality control based on Objective Analysis.
- Cluster analysis
- Latitude, longitude patterns
- Delayed quality control

Three way QC of Argo profiles

Automatic QC
(19)

QC based on OA





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

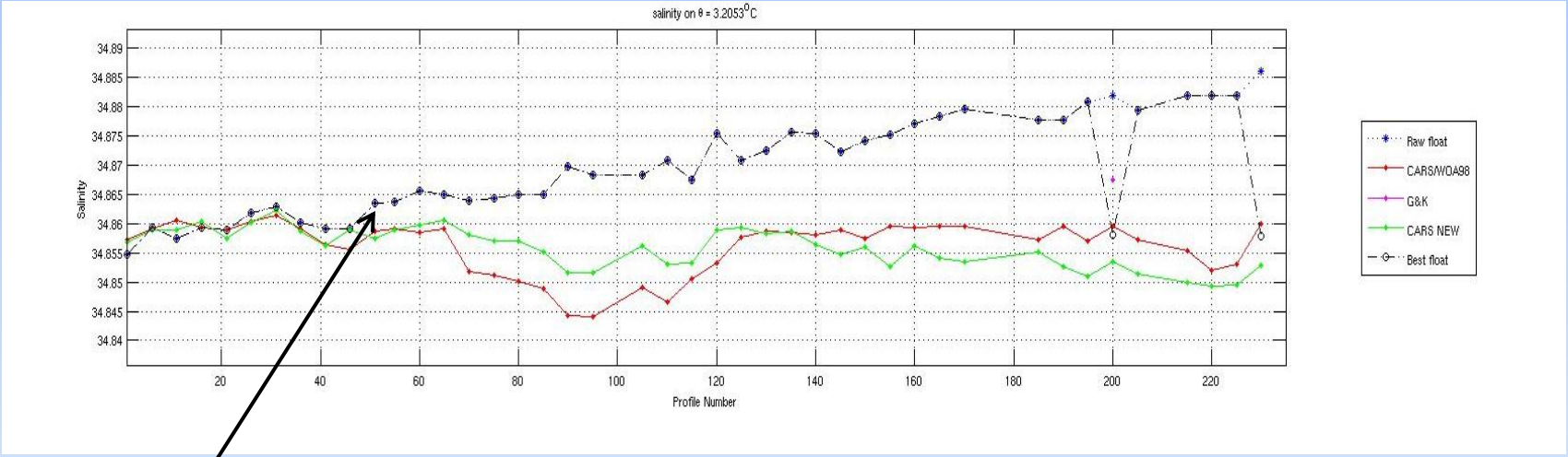
Delayed Mode Quality Control (DMQC)

- 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).

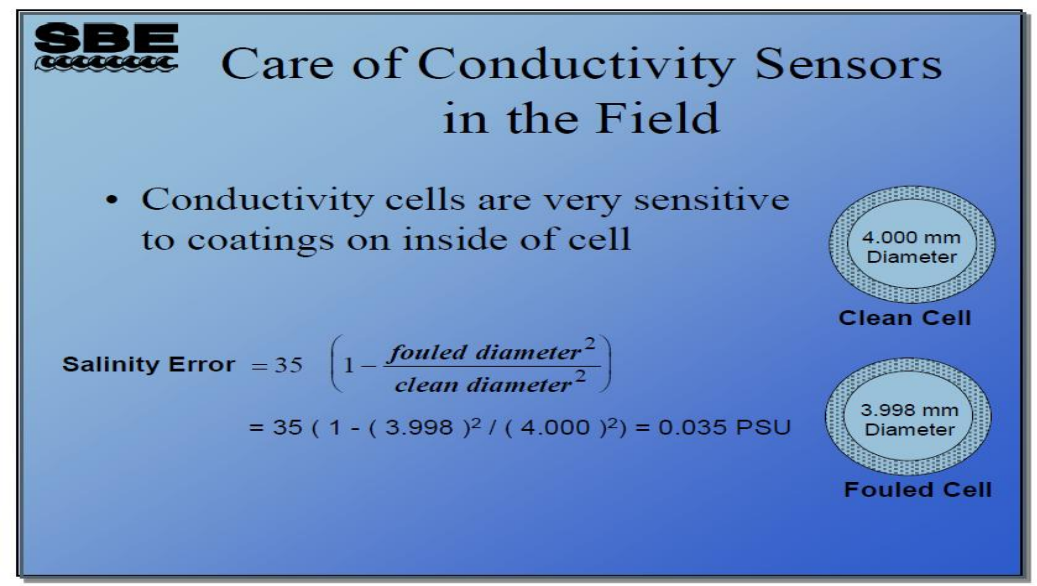
Salinity drifts



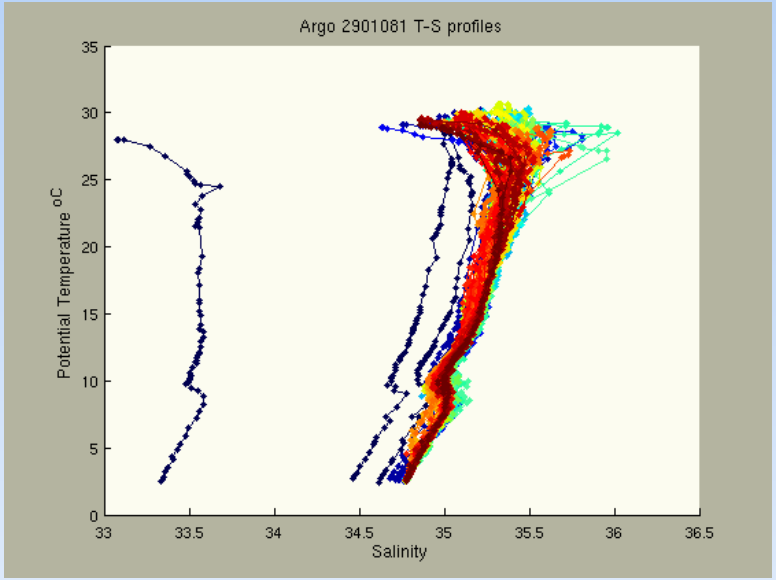
This float is observed to posses drift in salinity starting from cycle 44 onwards

TBTO issues

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

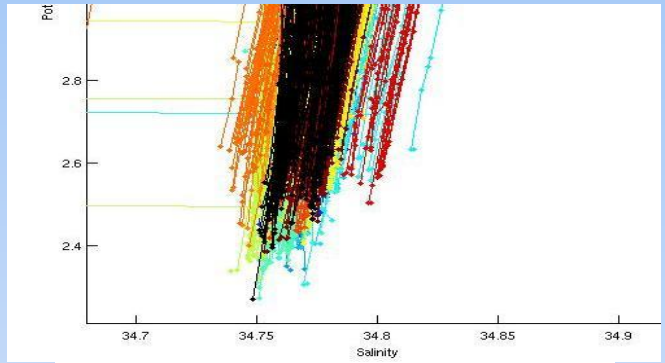


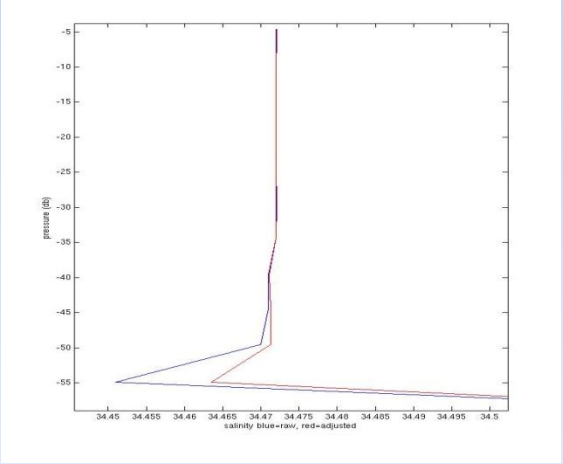
(Courtesy: SBE training manual)



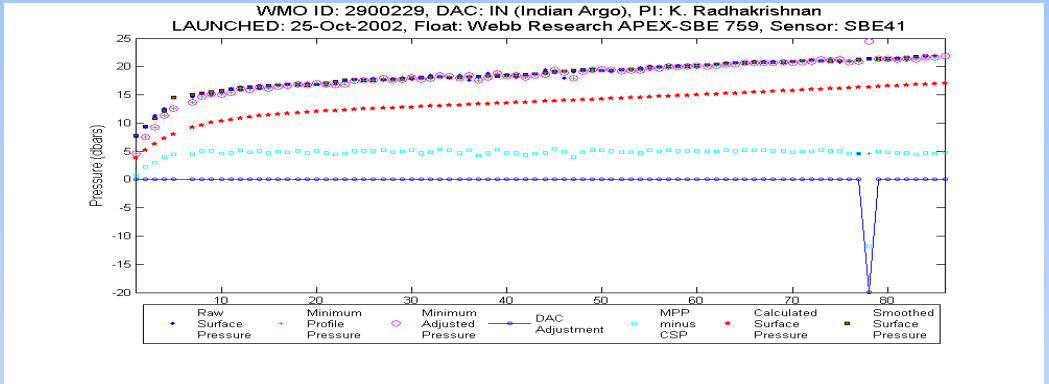
- This happens some times due to trapping and non-flushing of sea water.

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

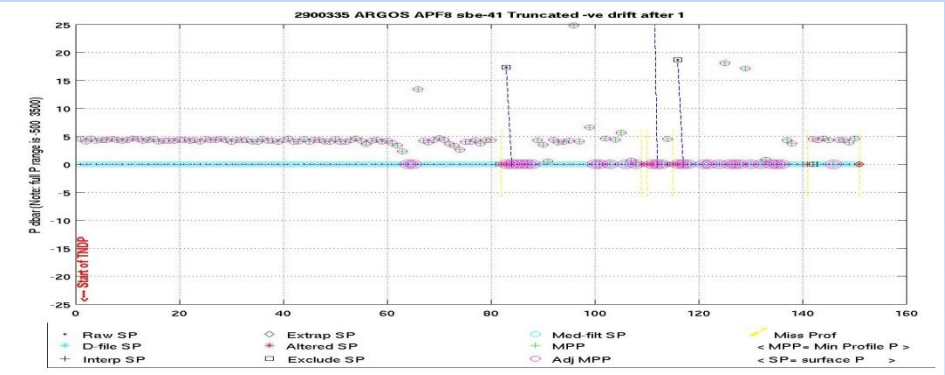




- Pressure sensor offset:

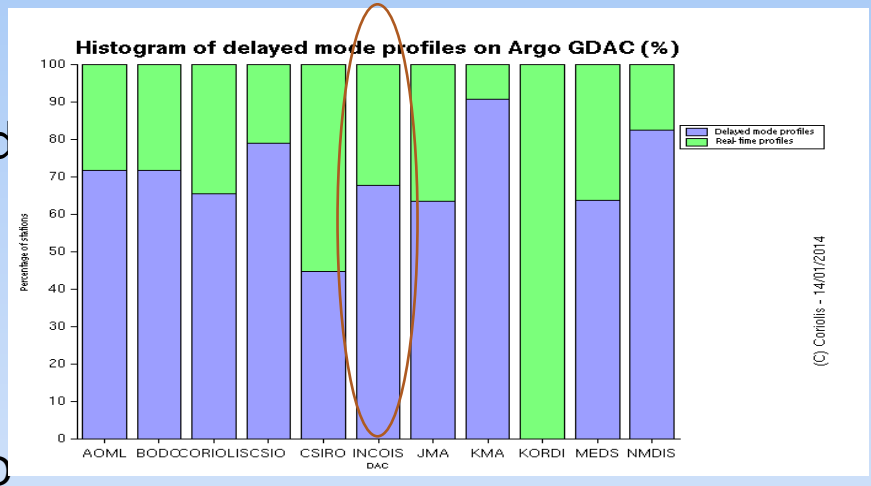


- TNDP issues :



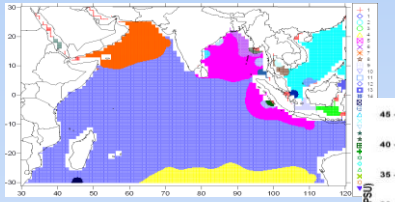
After DMQC

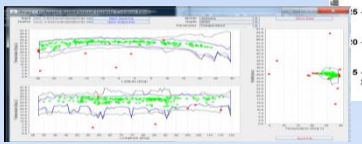
- After all the corrections in delayed mode, the profiles R2900228_xyz.nc will be designated as D2900228_xzy.nc and again uploaded on to GDAC.
- Original parameters are retained and the corrections are given in adjusted fields
  - Eg: Salinity (R files), Salinity_adjusted (D files), Salinity_adjusted_Error (D files).
- Error reported by Objective Analysis and Altimetry based QC will be revisited and corrected if necessary.

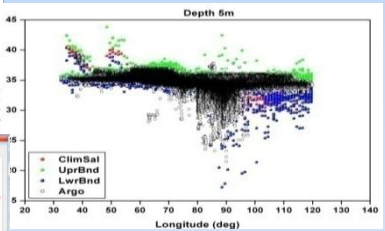


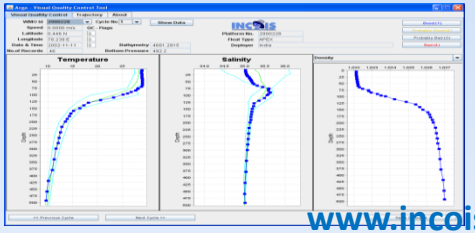
Development of New QC techniques and QC tools

- 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.



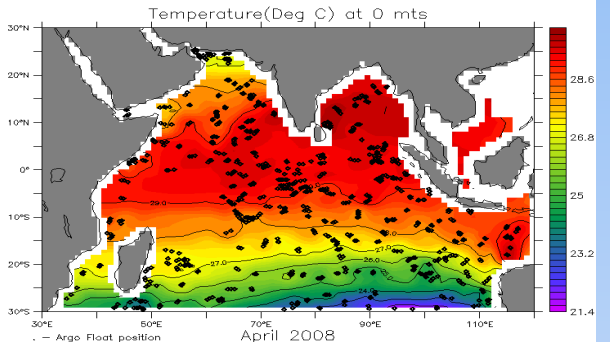


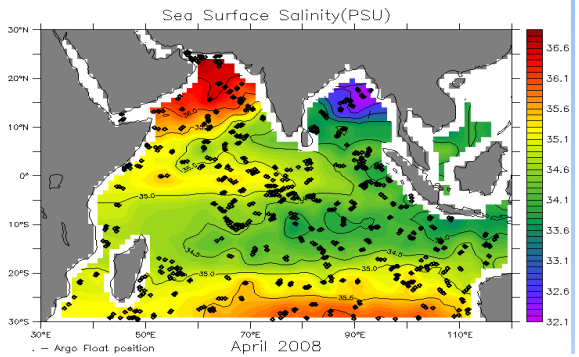


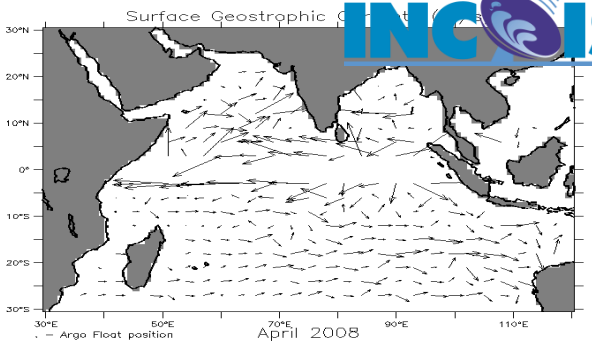


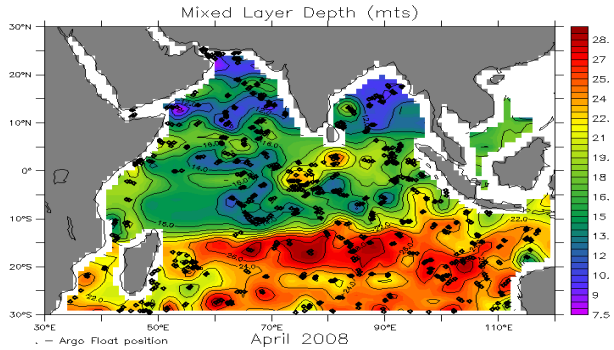
Argo Value added products

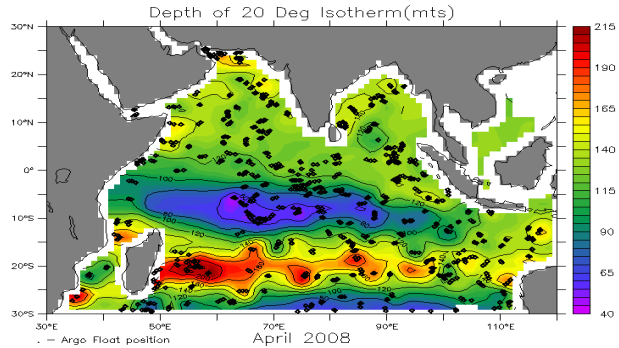
- Using all the quality controlled T/S profiles, gridded products are generated:
  - Objective Analysis and Variational Analysis based.
  - Spatial extent: 30 – 120 E and 30S – 30N.
  - Temporal extent: 10 days and monthly.
- Data delivery:
  - Through Live Access Server (ILAS) – url: las.incois.gov.in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

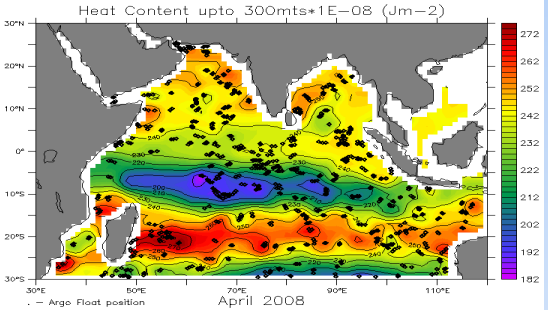


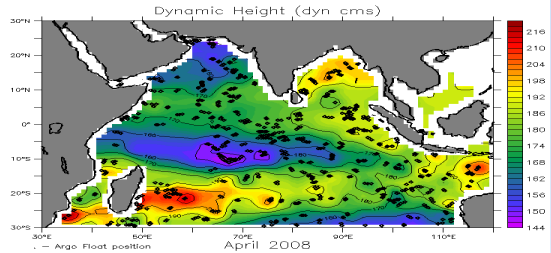








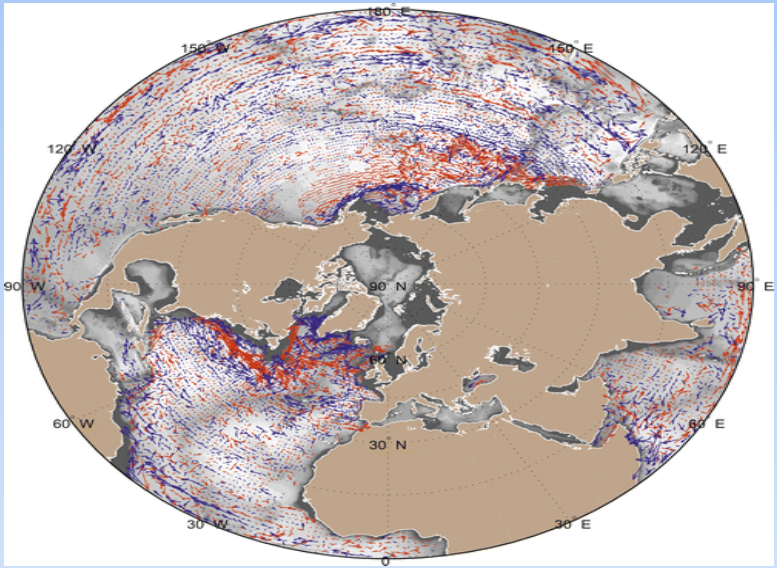


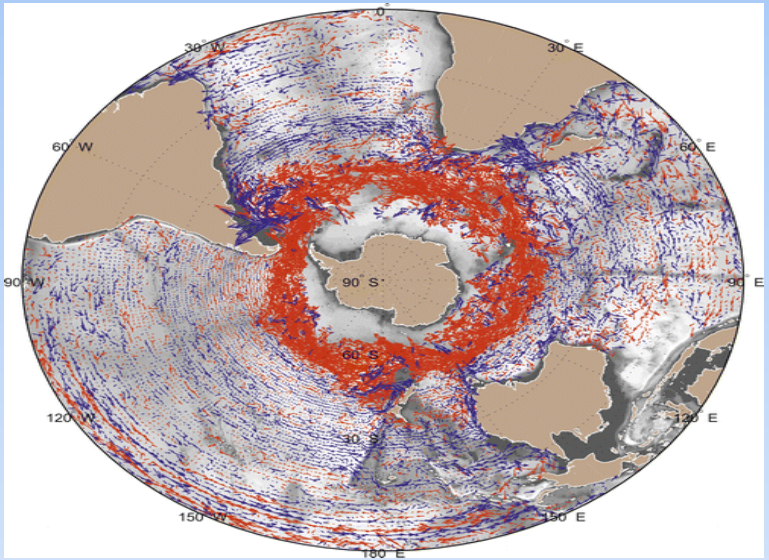


- **Generated Plots using Ferret visualization Software**
- **Plots are made available to users via INCOIS web.**

Udaya bhaskar et al, Technical Report

Currents at 1000 mts depth from Argo profiles





Michel Ollitrault et al., JAOT, 2013

Argo data

Argo data sources

There are many sources of Argo data depending on the desired format, source and application. Browse through the different options below to learn more. Some of the ways listed below are maintained by the Argo Program and Argo Data Management Team, while some are created and hosted by others, but highlighted here.

If you use any Argo data, please cite the Argo DOI.

Argo data files

- Argo profile, trajectory, meta and technical data files
- Real time and delayed mode quality controlled data available
- Maintained by Argo Data Management Team
- Served at Argo GDACs via ftp, http, rsync, DOI, errdap, thredds
- data in NetCDF format
- selection tools available
- Auxiliary directory at GDACs to access experimental data
- Argo Archive at NCEI

GTS data stream

Real time Argo data go out on the GTS for operational centers to gather within 12 hours of the observation for use in their forecasting and prediction models.

- Core Argo profiles only
- Real time quality control only
- BUFR format with QC flags
- Maintained by Argo Data Management Team

Software tools

An array of tools have been developed aimed at both beginners and experts to help users gather, manipulate and quality control Argo data.

- Software tools
- Quick start guide
- Data FAQ
- Developed by both people involved in Argo and those outside of it

Argo data products

- Products using Argo data and sometimes other data sources
- Gridded products of temperature, salinity, mixed layer depth, etc.
- Curated profile collections
- Velocity products

Visualizations and web applications

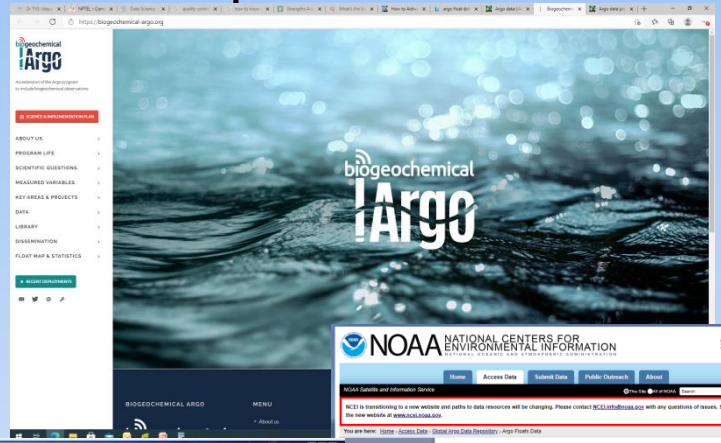
This collection of websites and tools allow non-scientists and scientists alike to quickly look at Argo data plots. Items listed below are not present in all tools.

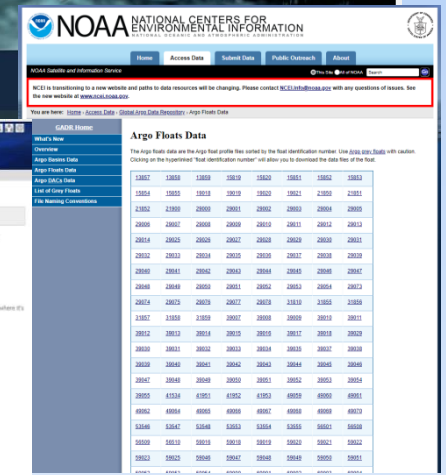
Model outputs and reanalysis products

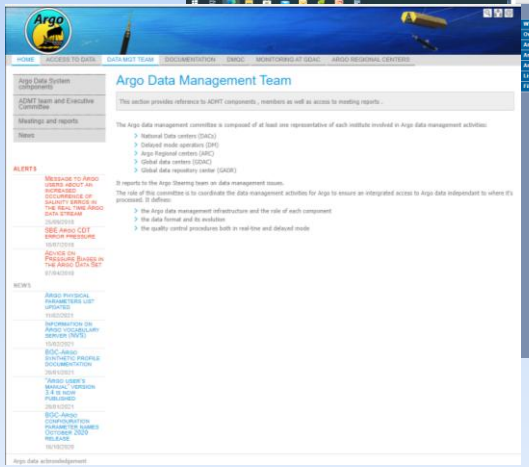
Argo is the primary source of subsurface ocean data at operational centers around the world. Find out which centers assimilate data and what types of data are

Web sites to access data and data products

- https://argo.ucsd.edu
- **Global Argo Data Repository**
- **Biogeochemical Argo | Home**
- Argo Ocean Temperature and Salinity Profiles | NCAR - Climate Data Guide (ucar.edu)
- **Access to data - Argo Data Management**

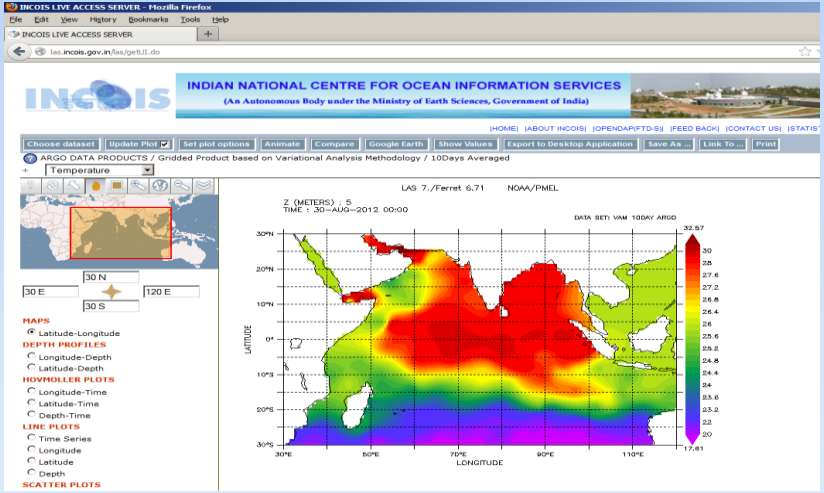






Gridded fields							
Institution	**Documentation & Access**	**Gridded field description**	**Data Source**	**Vertical resolution**	**Temporal coverage**	**Temporal resolution**	**Up fre**
Univ. Brest / Ifremer / CNRS / IRD / LOPS	10.13155/22583 data access	**ISAS15: Global gridded 1/2 degree NetCDF monthly fields and profile data base (2002-2015)**	– Argo only – Argo plus others	152 levels to 2000 m	2002 – 2015	monthly	ev ye
Copernicus Environment Monitoring Marine Service – Coriolis	10.5194/os-9-1-2013 data access	**CORA5: Global gridded 1/2 degree NetCDF dataset produced by optimal interpolation yearly**	Argo plus others	250 levels to 2000 m	1950 – year N-2	monthly	ye
CSIO, MNR	data access	**BOA-Argo: Global gridded 1 degree NetCDF or Matlab dataset produced by the Barnes Method** Includes temperature, salinity, isothermal layer depth, mixed layer depth and composed mixed layer depth	Argo only	58 levels to 1975 dbar	Since 2004-01-01	monthly	ye
CSIRO	http://www.cmar.csiro.au/cars data access via “Access” section of website	**CARS2009: Global gridded 1/2 degree NetCDF dataset produced by LOES filter from all profile data including Argo but excluding bathythermograph. Also seasonal dynamic height and MLD.**	Argo plus others	79 levels to 5500 m	1930 to May 2009	Mean and seasonal sinusoids	ra

- Argo data and products for Indian Ocean consisting of 2 lakhs+ profiles is prepared and being distributed to students and researchers.
- Live Access Server
- https://erddap.incois.gov.in/erddap



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)**
  - BGC data is used for studing the role of eddies on OMZ, OMZ variability in AS and BoB, Chla variability during cyclones, preferential zone of Tuna fish **(Sarma et al., 2018, Sarma et al, 2021, Girish et al., 2019, Nimith et al., 2020)**
- As many as 100+ 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

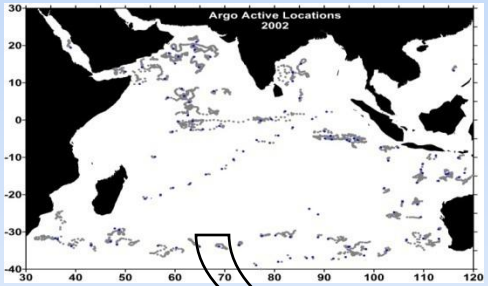
Now

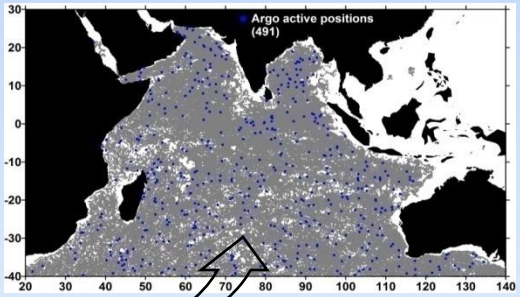
Indigenization efforts successful

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

In between

2006





Beginning

Basic CTD type floats

2002

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

For any question write to uday@incois.gov.in