National report of India (2022)

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1. The status of implementation

1.1a Floats deployment

During the year 2021-22, India has deployed one core Argo float in the Indian Ocean, thus taking the total contribution to 494 floats. All the active floats data are processed and sent to GDAC.

1.1b Performance Analysis of Floats deployed

Of the 494 floats deployed so far, 83 are presently active and transmitting data

1.2 Technical problems encountered and solved

None

1.3 Status of contributions to Argo data management

- **Data acquired from floats**

  India had deployed 494 floats so far (till Jan 31, 2022). Out of these 83 floats are active. All the active floats data are processed and sent to GDAC.

- **Data issued to GTS**

  BUFR format messages from these floats are being sent to GTS via RTH New Delhi.

- **Data issued to GDACs after real-time QC**

  All the active floats (83) data are subject to real time quality control and are being sent to GDAC.

- **Web pages**

  INCOIS is maintaining Web-GIS based site for Indian Argo Program. It contains entire Indian Ocean floats data along with trajectories. Further details can be obtained by following the link: https://incois.gov.in/argo/argo.jsp

- **Statistics of Argo data usage**

  There is a wide array of users in India for the Argo data, both profile data as well as value added products. These userbase include students and researchers from Academia, research centres, operational centres etc. Indian Meteorological Department (IMD), the nodal agency for monsoon forecast in India, is using Argo data for their operational purpose. Scientists, Students and Researchers from INCOIS, NIO, SAC, C-MMACS, NRSA, IITM, NCMRWF, IISc etc are using Argo data in various analysis and published several peer reviewed scientific papers utilizing this data. Increased availability of biogeochemical variables from the Argo floats are used for the validation of Biogeochemical model outputs like ROMS with Fennel module, and for the basic research on biogeochemical aspects.

  INCOIS Argo web page statistics during the year 2021-22 are as shown below:

Page	Number
Argo Web Page Views	24654
Argo Data Download	1810
Argo Products	3520

Products generated from Argo data

- Value added product generation from the Argo profile data were continued during the reporting period. The Argo T/S data are first objectively analysed, and the gridded output is used in deriving value added products. Value added products developed and provided for scientific use include Depth of 20º isotherm, depth of 25º isotherm, dynamic height, geostrophic currents, heat content, isothermal layer depth, mixed layer depth and geostrophic currents. All these data are available for free download through INCOIS LAS. For further details visit http://las.incois.gov.in.

1.4 Status of Delayed Mode Quality Control process

- INCOIS started generating and uploading D files to GDAC from July 2006, and as of today, profiles belonging to all eligible floats have been subjected to DMQC.
- Enhanced Delayed Mode Quality Control software OWC is being used successfully for QC purpose. Using this software all the eligible floats are reprocessed to tackle pressure sensor offset problems, salinity hooks, thermal lag corrections, salinity drifts etc
- About 55% of the eligible profiles are subjected to DMQC and the delayed mode profiles are uploaded on to GDAC. Majority of the old dead float which are passed through DMQC are converted to Ver 3.1 and uploaded to GDAC

1.5 Trajectory files status:

INCOIS Ver 3.1 trajectory files for all APEX Argo and Iridium floats are still found to be having issues and are being rejected. The problem is still being worked out.

2. Present level of and future prospects for national funding for Argo including a summary of the level of human resources devoted to Argo.

Indian Argo Project is fully funded by Ministry of Earth Sciences, (MoES), Govt. of India. Funding is requested for the procurement of 30/40 Argo floats per year including (3:2 Normal and Bio), Data management activities, Data analysis, etc. for the period 2021-2026. India plans to deploy these floats in the Bay of Bengal, Arabian Sea, Equatorial Indian Ocean and Southern Ocean sector of Indian Ocean

Three Permanent and one temporary scientific/technical personnel are working under Indian Argo project, which include personal for deployment of Argo floats, Data system, Analysis of Data, etc.

3. Summary of deployment plans (level of commitment, areas of float deployment) and other commitments to Argo (data management) for the upcoming year and beyond where possible.

India is committed to deploy floats in the Indian Ocean wherever gap exists. India will be deploying 30-40 floats per year during 2021-2026period. Generally, a 3:1 ratio will be maintained between core Argo floats (CTD only) and BGC floats. After ascertaining the gap region, cruise plan of MoES research vessels and availability of funds, these floats will be procured and deployed.

4. Summary of national research and operational uses of Argo data as well as contributions to Argo Regional Centers.

Operational: All Argo data are being routinely assimilated in Ocean Model for providing Global ocean analysis. This analysis is being used by Indian MET department for initialization of coupled ocean-atmosphere forecast of the Monsoon. From the year 2011, India is providing seasonal forecast of monsoon using dynamical model wherein Ocean analysis (with assimilation of Argo) is an important contribution. The analysis products are being made available through INCOIS live access server (las.incois.gov.in).

Research: Argo data are being widely used for many applications to understand the Indian Ocean dynamics, cyclone and monsoon system in relation to heat content, thermosteric component of sea level and validation of OGCM by various Indian institutions and university students.

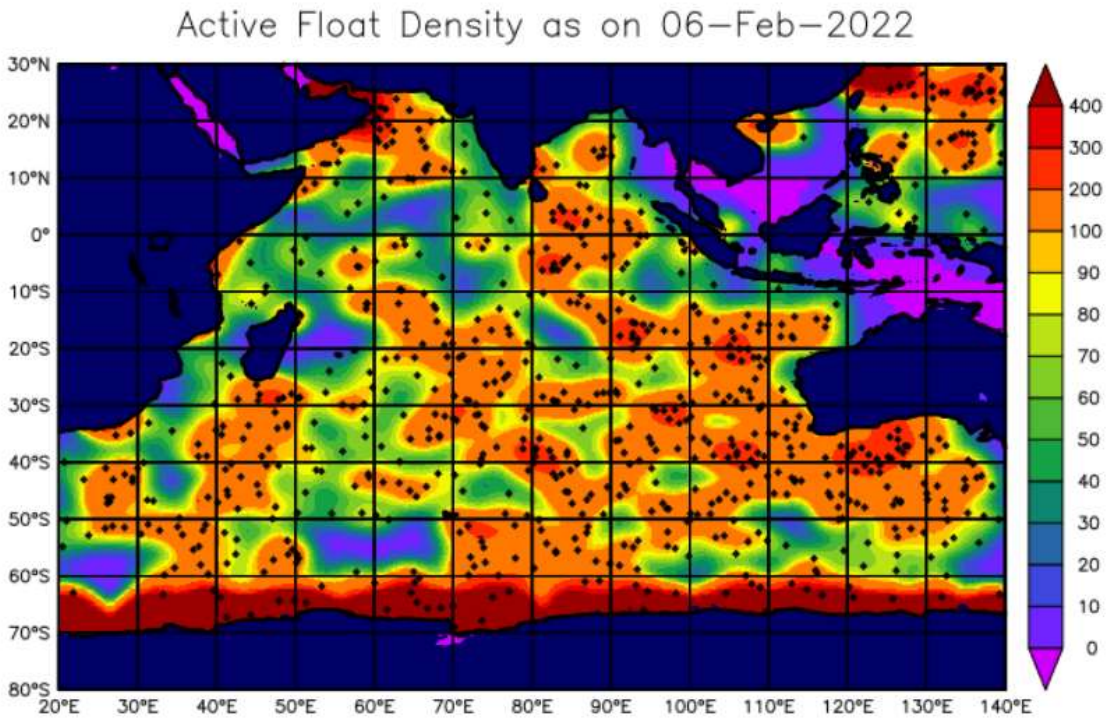
Argo Regional Centre (ARC) - Indian Ocean

(http://www.incois.gov.in/argo/ARDCenter.jsp)

- Acquisition of Argo data from GDAC corresponding to floats other than deployed by India and made them available on INCOIS web site.
- All these data sets are made available to the user through a s/w developed with all GUI facilities. This s/w is made available through FTP at INCOIS and UCSC web sites.
- Delayed Mode Quality Control (Refer 2.0 above)
- Data from the Indian Ocean regions are gridded into 1x1 box for monthly and 10 days and monthly intervals. These gridded data sets are made available through INCOIS Live Access Server (ILAS). Users can view and download data/images in their desired format.
- ERDDAP site was set up for the data and data products derived from Argo floats (http://erddap.incois.gov.in/erddap/index.html)
- Data Sets (CTD, XBT, Subsurface Moorings) are being acquired from many principle investigators. These data are being utilized for quality control of Argo profiles.
- Value added products: Two types of products are currently being made available to various user from INCOIS web site. They are:
  (i) Time series plots corresponding to each float (only for Indian floats).
  (ii) Spatial plots using the objectively analysed from all the Argo floats data deployed in the Indian Ocean.

  These valued added products can be obtained from the following link https://incois.gov.in/argo/ANDCProducts.jsp

  float density in Indian Ocean as of February, 2022 is shown below.



5. Issues that your country wishes to be considered and resolved by the Argo Steering Team regarding the international operation of Argo. These might include tasks performed by the AIC, the coordination of activities at an international level and the performance of the Argo data system. If you have specific comments, please include them in your national report.

None

6. To continue improving the quality and quantity of CTD cruise data being added to the reference database by Argo PIs, it is requested that you include any CTD station data that was taken at the time of float deployments this year. Additionally, please list CTD data (calibrated with bottle data) taken by your country in the past year that may be added to the reference database. These cruises could be ones designated for Argo calibration purposes only or could be cruises that are open to the public. To help CCHDO track down this data, please list the dates of the cruise and the PI to contact about the data.

Data Sets (CTD, XBT, Subsurface Moorings) are being acquired from many principle investigators. These data are being utilized for quality control of Argo profiles.

7. Argo bibliography

INCOIS is actively involved in utilization of Argo data in various studies pertaining to Indian Ocean. Also INCOIS is encouraging utilization of Argo data by various universities by funding them. Some of the publications resulted from Argo data which includes scientists from INCOIS are given below:

1) Banik, T., V. Thandlam, B. K. De, S. S. Kundu, R. B. Gogoi, P. L. N. Raju, and A. Guha (2021), Understanding dynamics of tropical cyclones in the Bay of Bengal using lightning data, *Meteorology and Atmospheric Physics*, *133*(5), 1505-1522, doi: https://doi.org/10.1007/s00703-021-00824-y
2) Chandra, A., and S. Kumar (2021), Sea surface temperature and ocean heat content during tropical cyclones Pam (2015) and Winston (2016) in the Southwest Pacific region, *Mon. Weather Rev.*, *149*(4), 1173-1187, doi: https://doi.org/10.1175/MWR-D-20-0025.1
3) Chowdhury, K. M. A., W. Jiang, G. Liu, M. K. Ahmed, and S. Akhter (2021), Dominant physical-biogeochemical drivers for the seasonal variations in the surface chlorophyll-a and subsurface chlorophyll-a maximum in the Bay of Bengal, *Regional Studies in Marine Science*, *48*, 102022, doi: https://doi.org/10.1016/j.rsma.2021.102022
4) Dandapat, S., A. Chakraborty, J. Kuttippurath, C. Bhagawati, and R. Sen (2021), A numerical study on the role of atmospheric forcing on mixed layer depth variability in the Bay of Bengal using a regional ocean model, *Ocean Dyn.*, *71*(10), 963-979, doi: https://doi.org/10.1007/s10236-021-01475-8
5) Gadi, R., P. N. Vinayachandran, and D. N. Subramani (2021), Data-driven feature-oriented modeling of Southwest Monsoon Current, *Ocean Model.*, *168*, 101912, doi: https://doi.org/10.1016/j.ocemod.2021.101912
6) Ganguly, D., K. Suryanarayana, and M. Raman (2021), Cyclone Ockhi Induced Upwelling and Associated Changes in Biological Productivity in Arabian Sea, *Mar. Geod.*, *44*(1), 70-89, doi: https://doi.org/10.1080/01490419.2020.183867
7) Girishkumar, M. S., J. Joseph, M. J. McPhaden, and E. Pattabhi Ram Rao (2021), Atmospheric Cold Pools and Their Influence on Sea Surface Temperature in the Bay of Bengal, *Journal of Geophysical Research: Oceans*, *126*(9), e2021JC017297, doi: https://doi.org/10.1029/2021JC017297
8) Jain, V., D. Shankar, P. N. Vinayachandran, A. Mukherjee, and P. Amol (2021), Role of ocean dynamics in the evolution of mixed-layer temperature in the Bay of Bengal during the summer monsoon, *Ocean Model.*, *168*, 101895, doi: https://doi.org/10.1016/j.ocemod.2021.101895
9) Jayaram, C., T. V. S. U. Bhaskar, N. Chacko, S. Prakash, and K. H. Rao (2021), Spatio-temporal variability of chlorophyll in the northern Indian Ocean: A biogeochemical argo data perspective, *Deep Sea Research Part II: Topical Studies in Oceanography*, *183*, 104928, doi: https://doi.org/10.1016/j.dsr2.2021.104928
10) Jayaram, C., J. Pavan Kumar, T. V. S. Udaya Bhaskar, I. V. G. Bhavani, T. D. V. Prasad Rao, and P. V. Nagamani (2021), Reconstruction of Gap-Free OCM-2 Chlorophyll-a Concentration Using DINEOF, *Journal of the Indian Society of Remote Sensing*, doi: https://doi.org/10.1007/s12524-021-01317-6
11) Jha, R. K., and T. V. S. Udaya Bhaskar (2021), Optimal parameters for generation of gridded product of Argo temperature and salinity using DIVA, *Journal of Earth System Science*, *130*(3), 170, doi: https://doi.org/10.1007/s12040-021-01675-2

12) Jithin, A. K., and P. A. Francis (2021), Formation of an Intrathermocline Eddy Triggered by the Coastal-Trapped Wave in the Northern Bay of Bengal, *Journal of Geophysical Research: Oceans*, *126*(12), e2021JC017725, doi: https://doi.org/10.1029/2021JC017725

13) Kuttippurath, J., N. Sunanda, M. V. Martin, and K. Chakraborty (2021), Tropical storms trigger phytoplankton blooms in the deserts of north Indian Ocean, *npj Climate and Atmospheric Science*, *4*(1), 11, doi: https://doi.org/10.1038/s41612-021-00166-x

14) Mandal, A. K., A. Chaudhary, N. Agarwal, and R. Sharma (2021), Sub-Surface Ocean Structure from Satellite Surface Observations in the North Indian Ocean, *Mar. Geod.*, *44*(6), 573-592, doi: https://doi.org/10.1080/01490419.2021.1974132

15) Maneesha, K., D. H. Prasad, and K. V. K. R. K. Patnaik (2021), Biophysical responses to tropical cyclone Hudhud over the Bay of Bengal, *J. Oper. Oceanogr.*, *14*(2), 87-97, doi: https://doi.org/10.1080/1755876X.2019.1684135

16) Maneesha, K., V. S. Prasad, and K. Venkateswararao (2021), Ocean impact on the intensification of cyclone Titli, *Journal of Earth System Science*, *130*(3), 164, doi: https://doi.org/10.1007/s12040-021-01660-9

17) Mathew, T., S. Prakash, L. Shenoy, A. Chatterjee, T. V. S. Udaya Bhaskar, and B. Wojtasiewicz (2021), Observed variability of monsoon blooms in the north-central Arabian Sea and its implication on oxygen concentration: A bio-argo study, *Deep Sea Research Part II: Topical Studies in Oceanography*, *184-185*, 104935, doi: https://doi.org/10.1016/j.dsr2.2021.104935

18) Mohapatra, S., and C. Gnanaseelan (2021), A new mode of decadal variability in the Tropical Indian Ocean subsurface temperature and its association with shallow meridional overturning circulation, *Glob. Planet. Change*, *207*, 103656, doi: https://doi.org/10.1016/j.gloplacha.2021.103656

19) Pradhan, M., A. Srivastava, S. A. Rao, D. S. Banerjee, A. Chatterjee, P. A. Francis, O. P. Sreejith, M. Das Gupta, and V. S. Prasad (2021), Are ocean-moored buoys redundant for prediction of Indian monsoon?, *Meteorology and Atmospheric Physics*, *133*(4), 1075-1088, doi: https://doi.org/10.1007/s00703-021-00792-3

20) Prakash, K. R., T. Nigam, V. Pant, and N. Chandra (2021), On the interaction of mesoscale eddies and a tropical cyclone in the Bay of Bengal, *Nat Hazards*, doi: https://doi.org/10.1007/s11069-021-04524-z

21) Pramanik, S., and S. Sil (2021), Assessment of SCATSat-1 Scatterometer Winds on the Upper Ocean Simulations in the North Indian Ocean, *Journal of Geophysical Research: Oceans*, *126*(6), e2020JC016677, doi: https://doi.org/10.1029/2020JC016677

22) Prasanth, R., V. Vijith, V. Thushara, J. V. George, and P. N. Vinayachandran (2021), Processes governing the seasonality of vertical chlorophyll-a distribution in the central Arabian Sea: Bio-Argo observations and ecosystem model simulation, *Deep Sea Research Part II: Topical Studies in Oceanography*, *183*, 104926, doi: https://doi.org/10.1016/j.dsr2.2021.104926

23) Sabu, P., M. P. Subeesh, J. V. George, N. P. Anilkumar, and M. Ravichandran (2021), Enhanced subsurface mixing due to near-inertial waves: observation from Seychelles-Chagos Thermocline Ridge, *Ocean Dyn.*, doi: https://doi.org/10.1007/s10236-020-01430-z

24) Seelanki, V., T. Nigam, and V. Pant (2021), Upper-ocean physical and biological features associated with Hudhud cyclone: A bio-physical modelling study, *J. Mar. Syst.*, *215*, 103499, doi: https://doi.org/10.1016/j.jmarsys.2020.103499

25) Thoppil, P. G., et al. (2021), Ensemble forecasting greatly expands the prediction horizon for ocean mesoscale variability, *Communications Earth & Environment*, *2*(1), 89, doi: https://doi.org/10.1038/s43247-021-00151-5

26) Udaya Bhaskar, T. V. S., V. V. S. S. Sarma, and J. Pavan Kumar (2021), Potential Mechanisms Responsible for Spatial Variability in Intensity and Thickness of Oxygen Minimum Zone in the Bay of Bengal, *Journal of Geophysical Research: Biogeosciences*, *126*(6), e2021JG006341, doi: https://doi.org/10.1029/2021JG006341

27) Valsala, V., M. G. Sreeush, M. Anju, P. Sreenivas, Y. K. Tiwari, K. Chakraborty, and S. Sijikumar (2021), An observing system simulation experiment for Indian Ocean surface pCO2 measurements, *Prog. Oceanogr.*, *194*, 102570, doi: https://doi.org/10.1016/j.pocean.2021.102570

28) Vidya, P. J., M. Balaji, and R. Mani Murali (2021), Cyclone Hudhud-eddy induced phytoplankton bloom in the northern Bay of Bengal using a coupled model, *Prog. Oceanogr.*, *197*, 102631, doi: https://doi.org/10.1016/j.pocean.2021.102631

29) Vijay, A., K. Munnooru, G. Reghu, A. Gera, R. R. Vinjamuri, and M. V. Ramanamurthy (2021), Nutrient dynamics and budgeting in a semi-enclosed coastal hypersaline lagoon, *Environmental Science and Pollution Research*, doi: https://doi.org/10.1007/s11356-021-15334-y

30) Vissa, N. K., P. C. Anandh, V. S. Gulakaram, and G. Konda (2021), Role and response of ocean–atmosphere interactions during Amphan (2020) super cyclone, *Acta Geophysica*, *69*(5), 1997-2010, doi: https://doi.org/10.1007/s11600-021-00671-w

31) Yajnik, K. S., and C. K. Devasana (2021), Changing variability of sea surface temperature in the post-WWII era, *Journal of Earth System Science*, *130*(3), 144, doi: https://doi.org/10.1007/s12040-021-01637-8

8. How has COVID-19 impacted your National Program's ability to implement Argo in the past year? This can include impacts on deployments, procurements, data processing, budgets, etc.

COVID-19 has severe impact on the Argo Programme on budget, procurement and deployments. India deployed one float during the year 2021. However, data processing is not affected by COVID.

9. Argo is still interested in piloting the RBR CTD. Does your National Program have any deployment plans for RBR floats in the next couple years? If so, please indicate how many floats will you be buying in 2022 and 2023 (if known) and where they might be deployed.

India plans to procure and deploy 15 floats each in 2022 and 2023. We do not have provision for procurement of specific brand. The procurement process is through the open / global tender with general technical specifications.