Recent Changes in Dissolved Oxygen Concentrations in the Arabian Sea using BGC-Argo Data

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❖ Introduction:

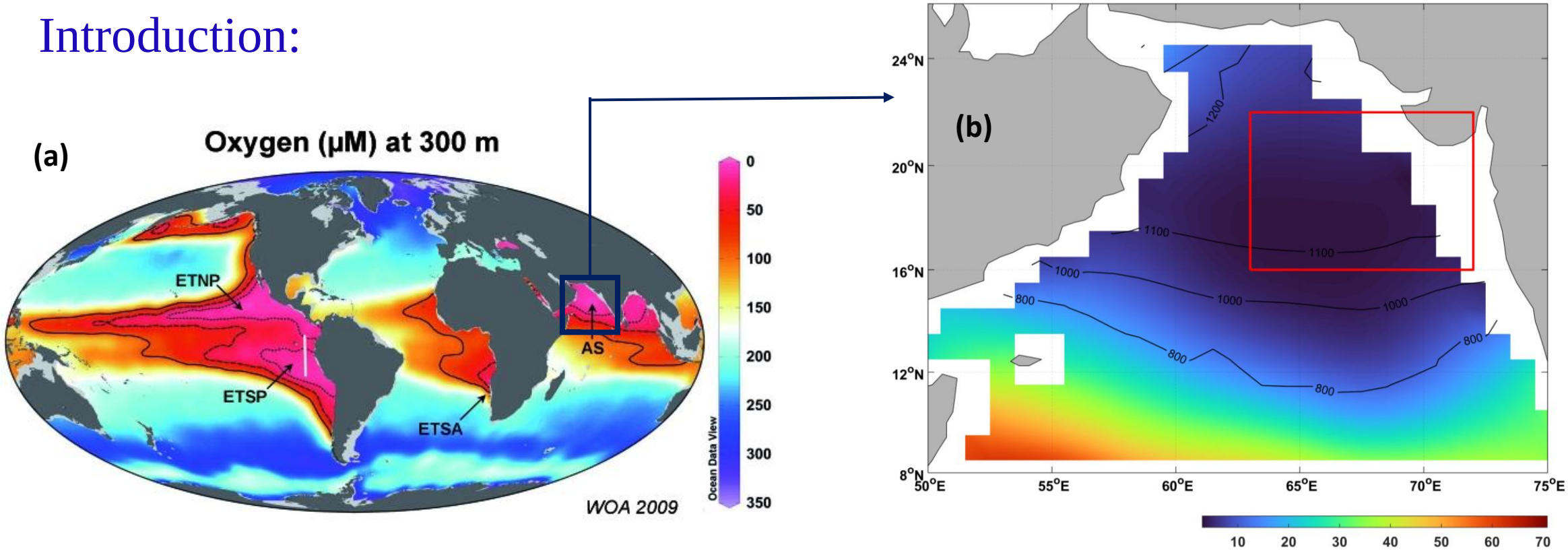


Fig. 1: (a) Dissolved oxygen (DO) concentration at 300 m water depth. Source: https://www.mpi-bremen.de/en/How-the-Ocean-loses-nitrogen.html. (b) Annual climatology of DO at 300 m from WOA 2023 data. Black contour lines indicates the thickness of oxygen minimum zone (OMZ, DO ≤ 20 μmol.kg-1). Red box represents the study region.

Salient features of the Arabian Sea (AS):

- Semi-enclosed basin with a complex water mass distribution.
- More saline subsurface than any other part of the Indian Ocean.
- One of the world's most intense and thickest perennial oxygen minimum zone (OMZ). (Paulmier et al., 2009)
- A rich marine biodiversity.

❖ Data: BGC Argo

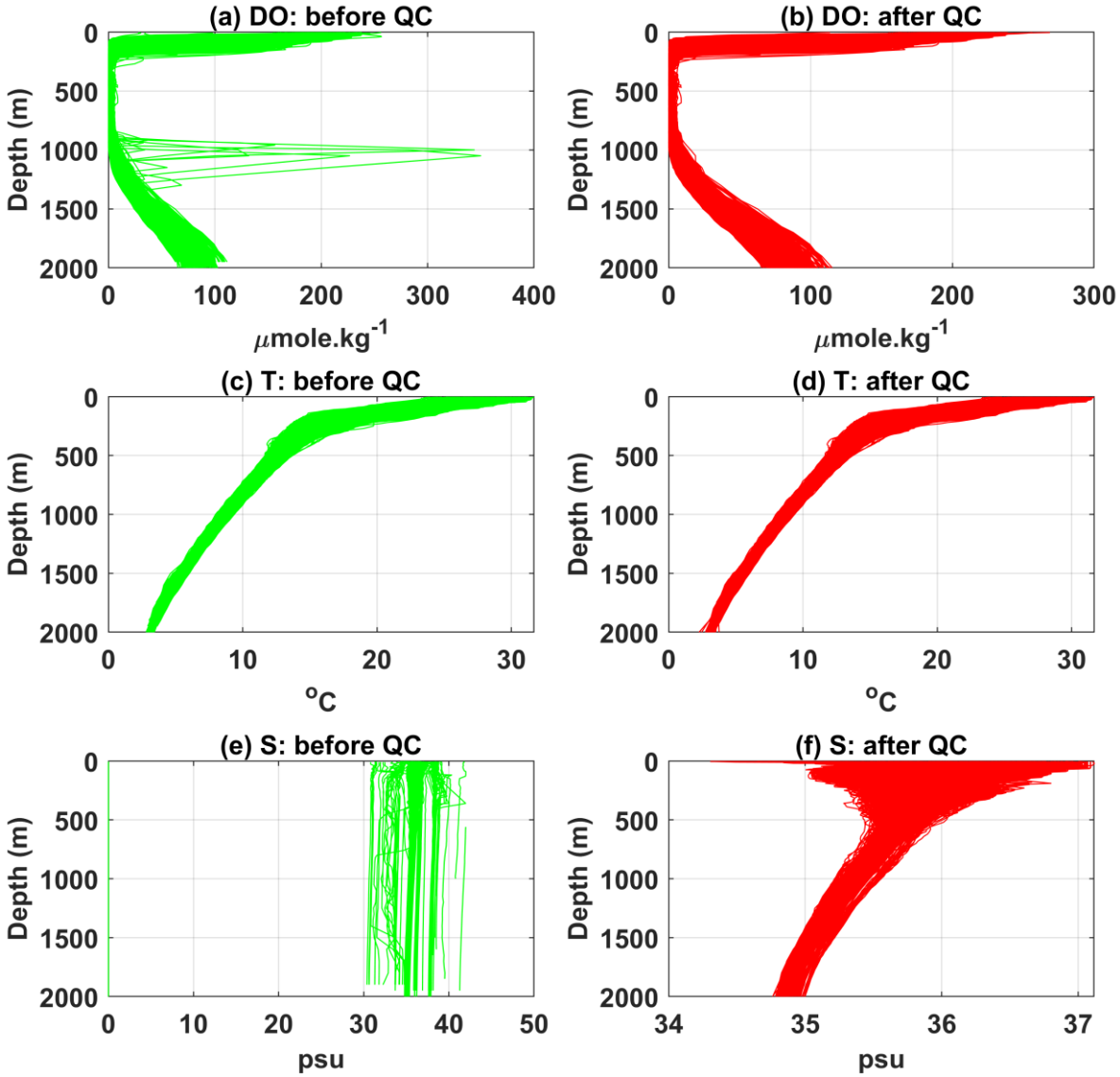


Fig. 2: BGC-Argo profiles of dissolved oxygen (DO), temperature (T) and salinity (S) before (left column) and after (right column) quality control (QC).

- Profile data: Dissolved Oxygen (DO), Temperature (T), Salinity (S)
- Maximum depth: 2000 m
- Source: Euro-Argo ERIC (https://dataselection.euro-argo.eu/)
- No. of profiles: 5378 (before QC), 2518 (after QC)
- Time period: 2013 – 2023

(BGC-Argo QC Manual: Thierry et. al., 2021)

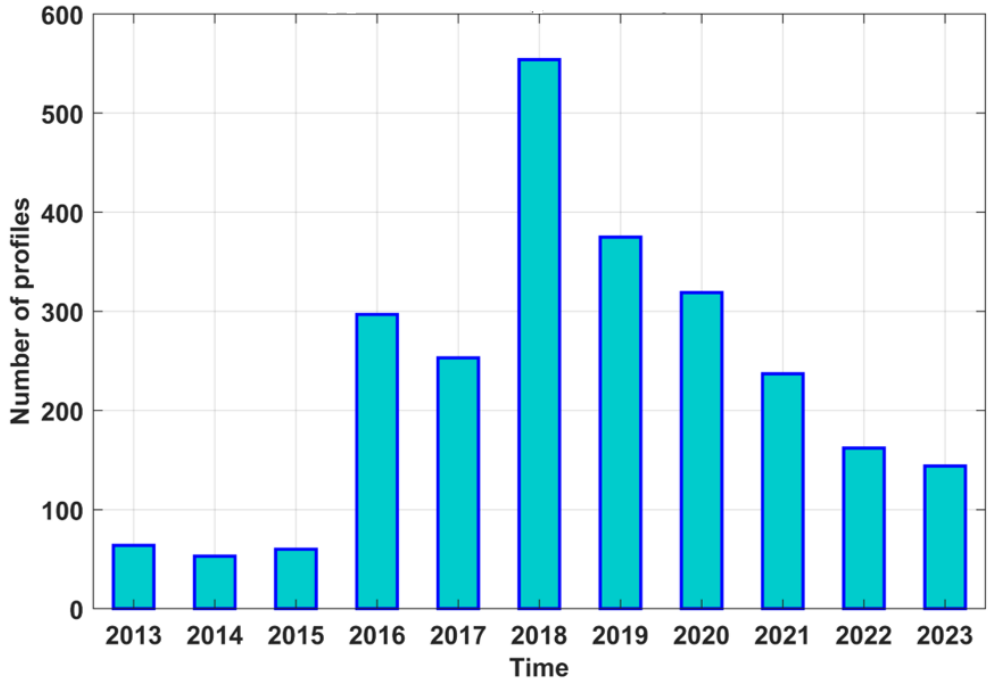


Fig. 3: Number of quality controlled Argo-DO profiles in the study regions.

Results

❑ Variation of dissolved oxygen (DO):

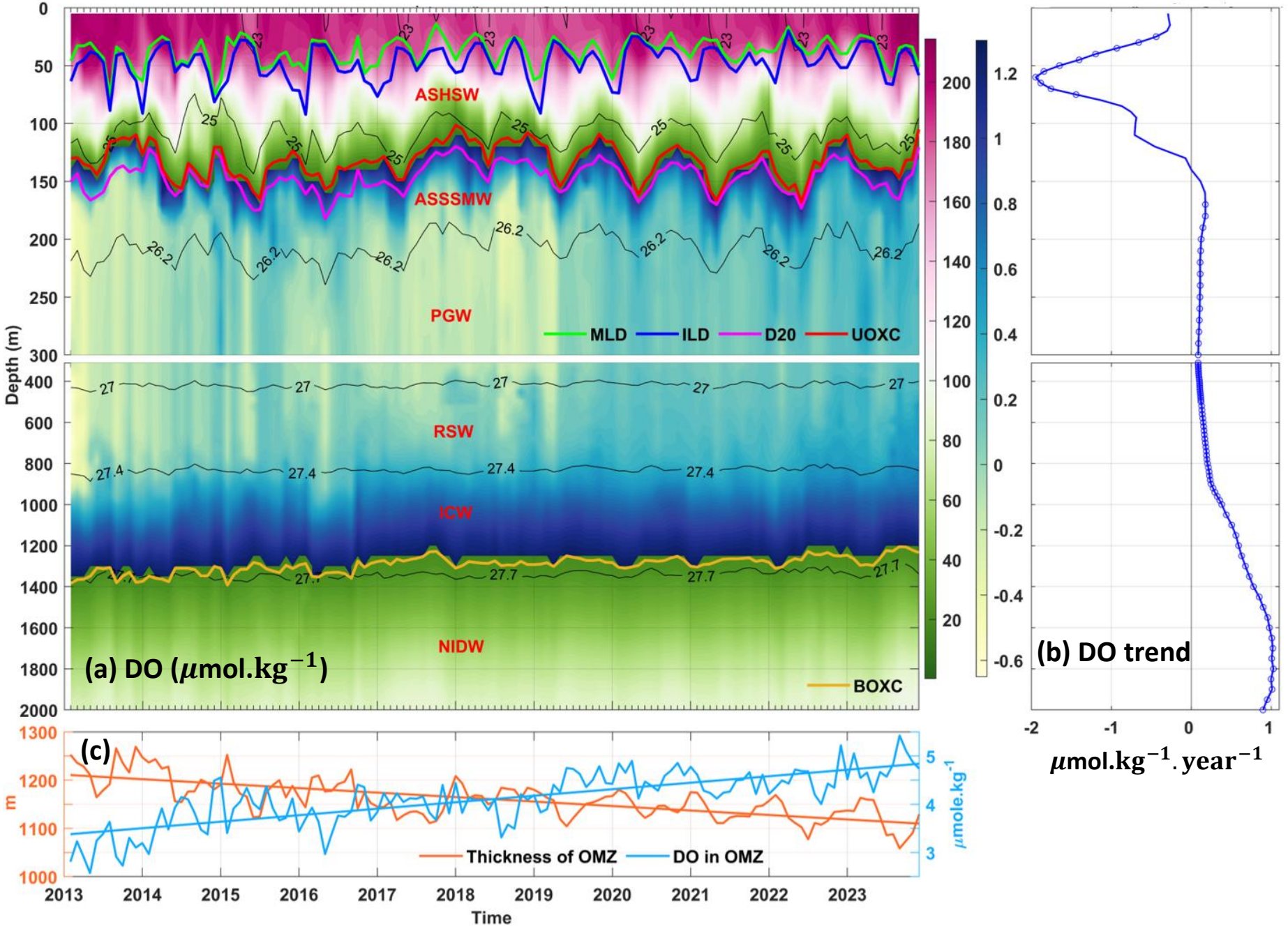


Fig. 4: (a) Time-depth section of DO with time series of mixed layer depth (MLD, green line), isothermal layer depth (ILD, blue line), 20℃ isotherm (D20, magenta line), and upper (UOXC, red line) and bottom oxycline (BOXC, yellow line). (b) Trends of DO concentration along depths. (c) Time series of thickness (orange line) and depth-averaged DO concentration (sky-blue line) of OMZ.

Water Masses

ASHSW	AS High Salinity Water
ASSSMW	AS Subsurface Salinity Minimum Water
PGW	Persian Gulf Water
RSW	Red Sea Water
ICW	Indian Central Water
NIDW	North Indian Deep Water

❑ Underlying mechanisms:

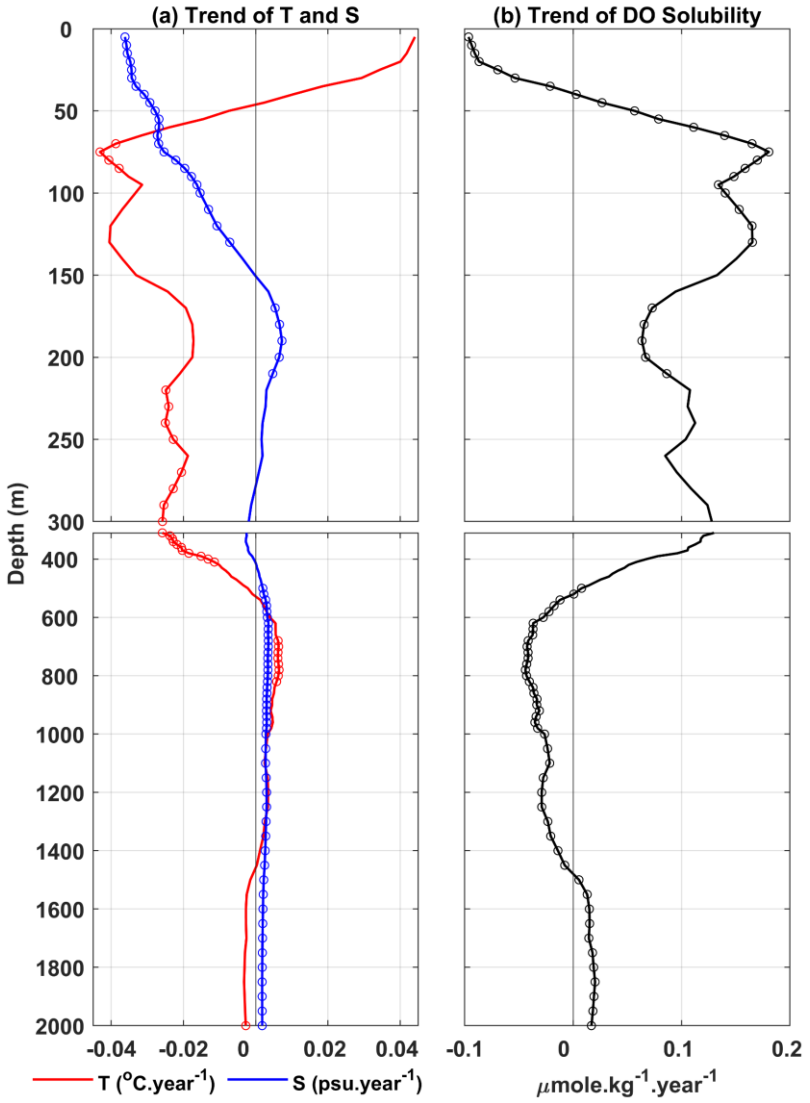


Fig. 5: Temporal trends of (a) temperature (T, red line) and salinity (S, blue line), and (b) DO solubility.

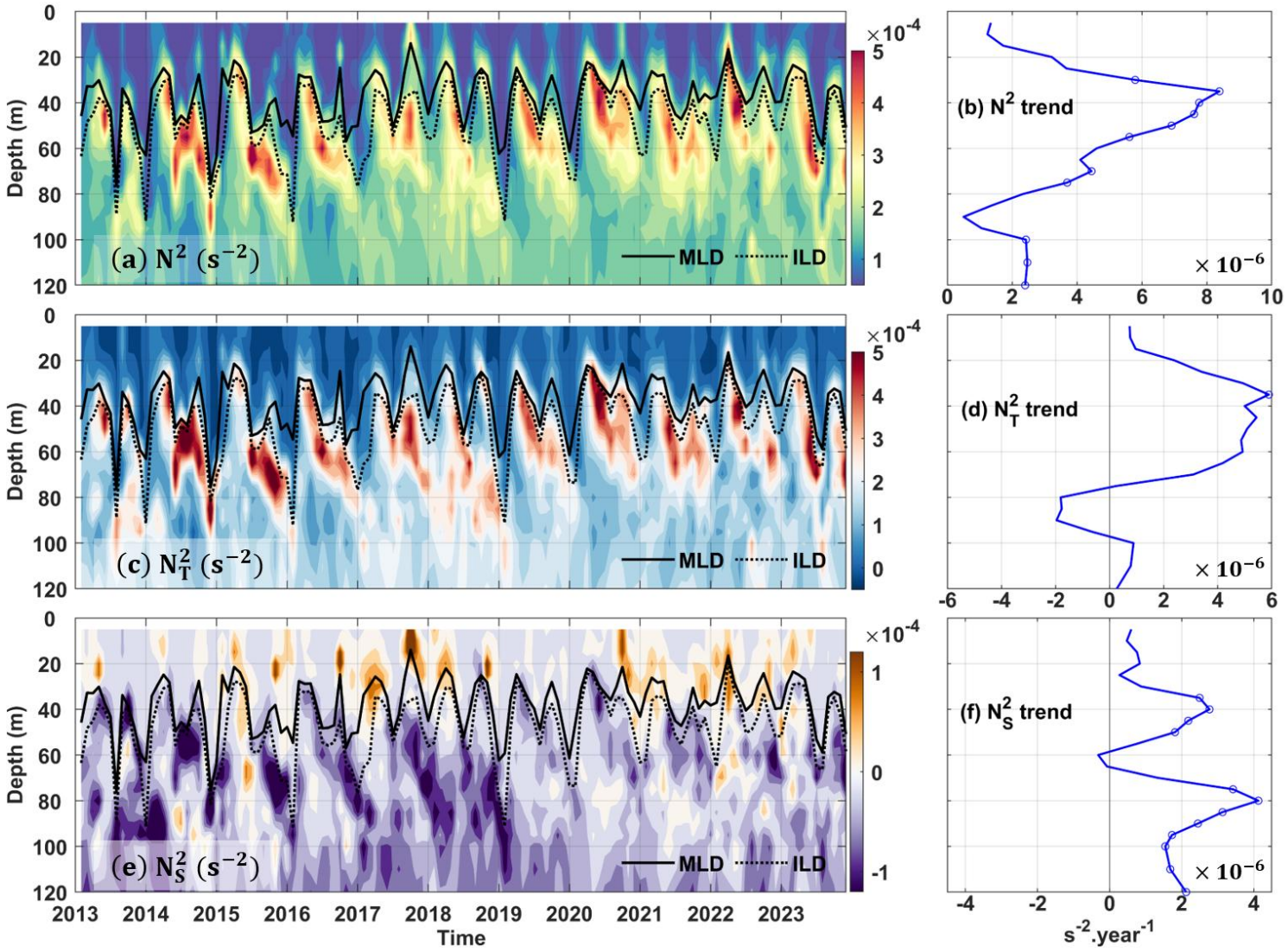


Fig. 6: Time-depth section of (a) density (N^2), (c) thermal (N_T^2) and (e) haline (N_S^2) stratification and their trends (right column) in upper water column..

❑ Decomposition of DO concentration:

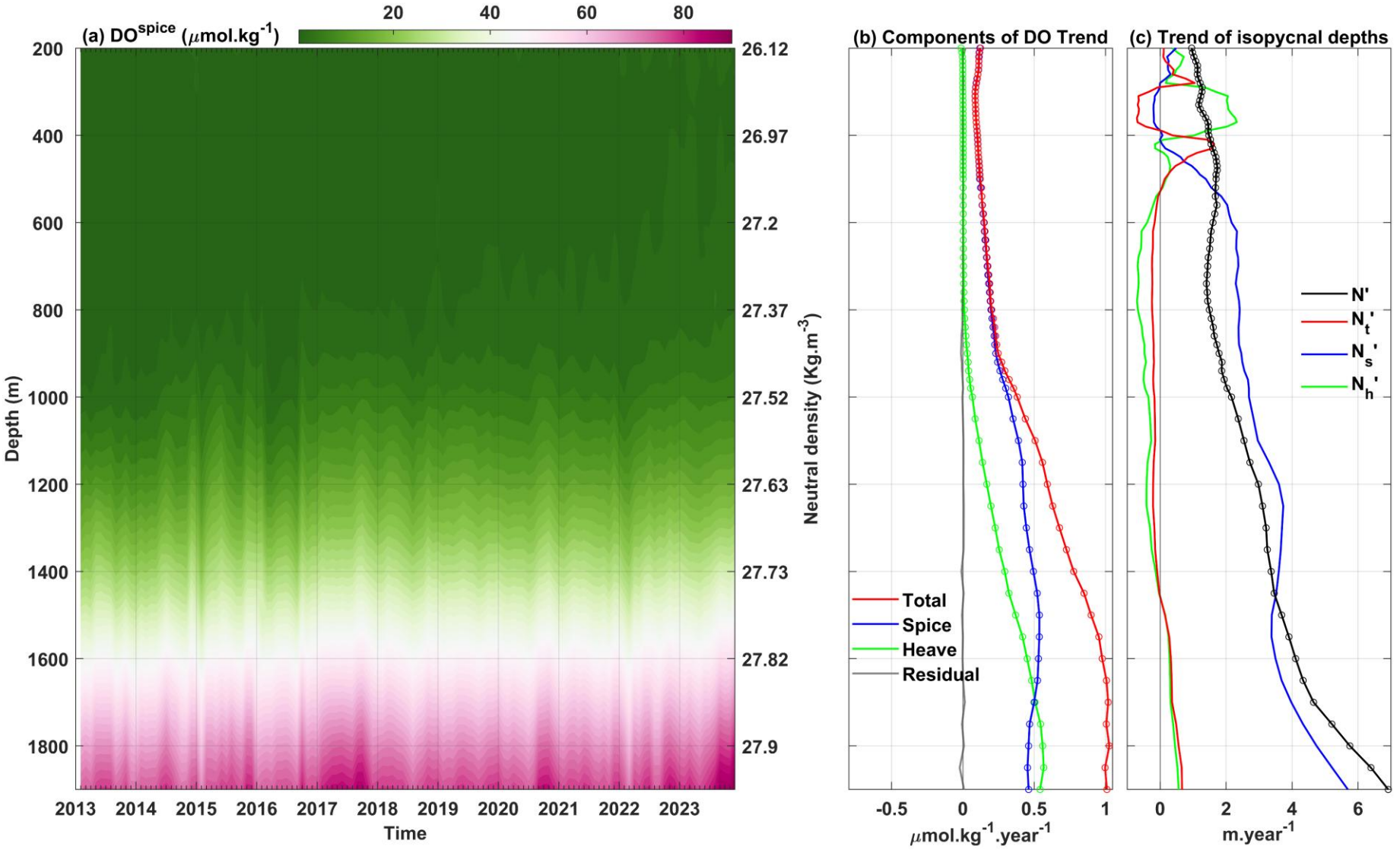


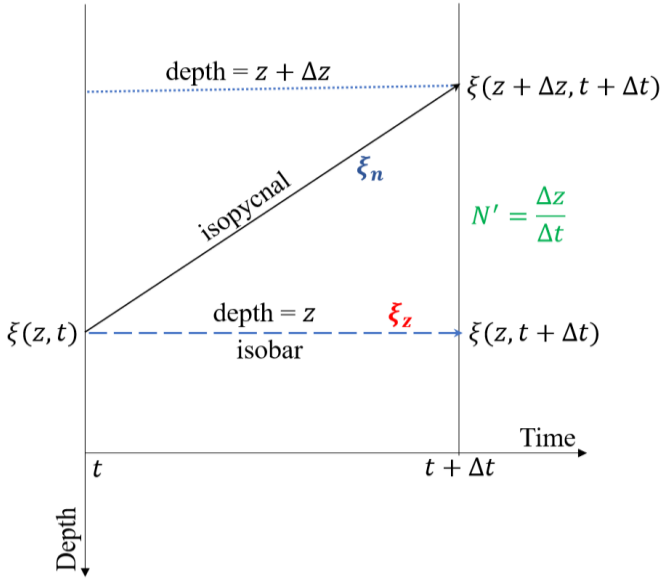
Fig. 7: (a) Vertical structure of the spice component of DO; (b) Total (red), spice (blue) and heave (green) components of DO trend; (c) Trend of true isopycnal depth (N') and ispopycnal depth due to pure temperarure (N_t'), pure salinity (N_s') and pure heave (N_h').

- Decomposition equation for a tracer $\xi = \xi(z, t)$,

$$\underbrace{\left.\frac{\partial \xi}{\partial t}\right|_z}_{Total} = \underbrace{\left.\frac{\partial \xi}{\partial t}\right|_n}_{Spice} - \underbrace{N' \frac{\partial \bar{\xi}}{\partial z}}_{Heave}$$

- Time rate of change of isopycnal depth,

$$N' = \frac{\Delta z}{\Delta t} = N_t' + N_s' + N_h'$$



(Shee et al. 2023, *Scientific Reports*)

❑ Assessing of vertical stability:

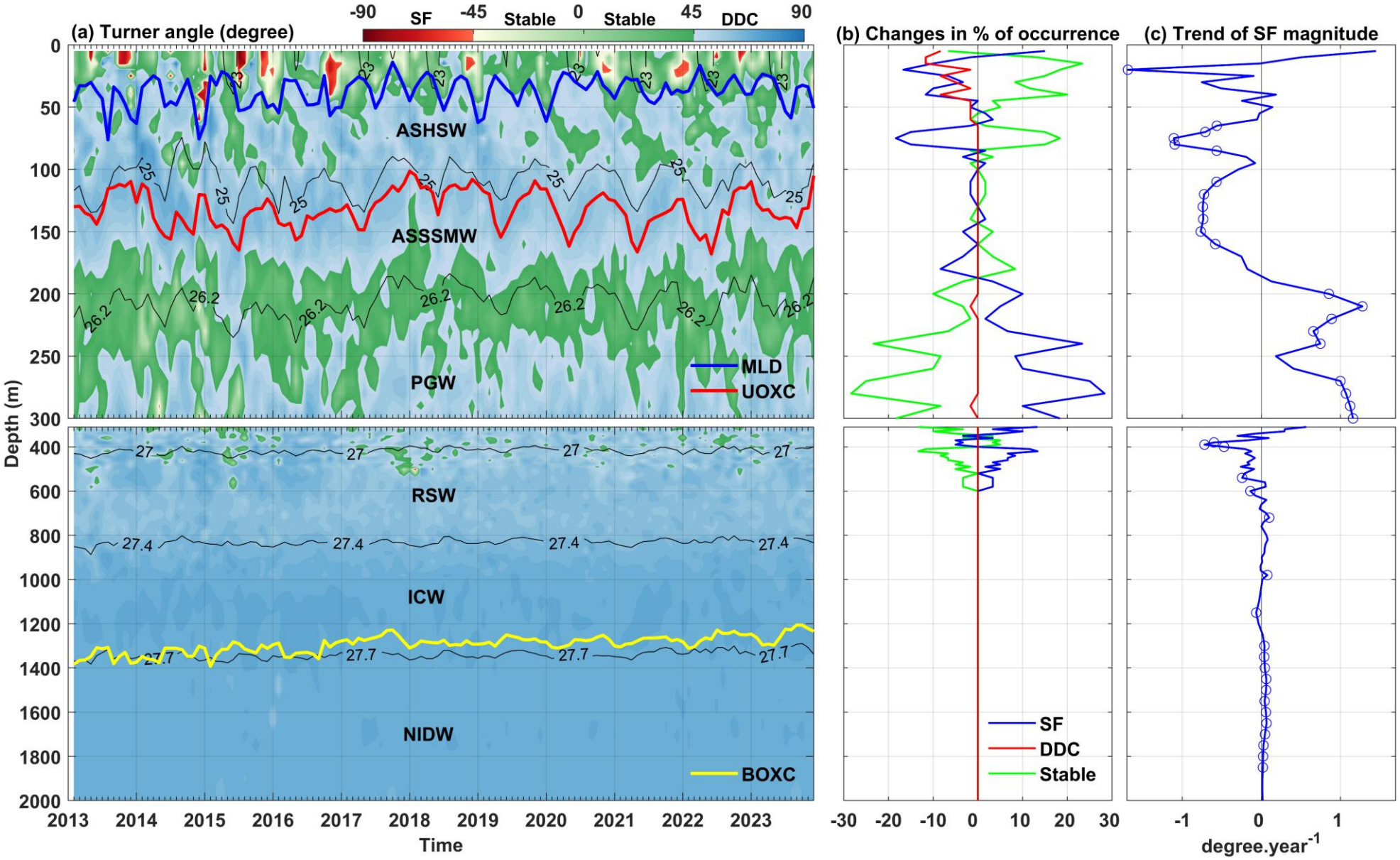


Fig. 8: Time-depth section (a) Turner angle illustrating salt fingering (SF), doubly stable and double-diffusive convection (DDC). (b) Change in percentage of occurrence of the SF (blue), DDC (red) and doubly stable (green) states between last (2019 – 2023) and initial lustrum (2013 – 2017). (c) Temporal trends of the SF magnitude.

Turner angle, $Tu = \tan^{-1}\left(\frac{A+B}{A-B}\right)$ where $A = \alpha\frac{\partial T}{\partial z}$, $B = \beta\frac{\partial S}{\partial z}$

❖ Conclusion:

- Widespread decrease of DO in top layer is due to reduced mixing and ventilation caused by enhance stratification.
- Upper oxycline has an annual cycle and highly correlated to the 20℃ isotherm. However, it has no notable trend in this region.
- Shallowing trend of bottom oxycline leads the shrinkage of OMZ by ~200 m. Additionally, the DO concentration in OMZ increases by ~140% due to improved mixing along isopycnals and salt finger instabilities.
- Positive trends of DO between 200 – 900 m is solely dominated by its spice component. Oxygenation below 900 m depth is controlled both by isopycnal upheaving and mixings.
- Salinification triggered by intense salt-finger instability at intermediate and deeper water masses is predominantly responsible for the upward displacement of isopycnals.
- This work show the ability of BGC-Argo profile dataset to explore the DO variation in ocean water column made up of different water masses.

❖ Limitations:

- Absence of continuous subsurface current measurements limited our ability to distinctly quantify isopycnal advective and diffusive mixings.

- In addition, biochemical processes were not comprehensively considered in this analysis.

❖ Societal benefits:

- Provides better understanding about the recent shifts in oceanic ecosystem of the Arabian Sea, including implications for biological production and fisheries.

- Helps to guide future models predicting the distribution of biochemical tracers and for focused quantitative studies on fisheries.

References

- Paulmier, A., & Ruiz-Pino, D. (2009). Oxygen minimum zones (OMZs) in the modern ocean. Progress in oceanography, 80(3-4), 113-128.
- Ravichandran, M., Girishkumar, M. S., & Riser, S. (2012). Observed variability of chlorophyll-a using Argo profiling floats in the southeastern Arabian Sea. Deep Sea Research Part I: Oceanographic Research Papers, 65, 15-25.
- Thierry, V., Bittig, H., & the Argo-BGC team (2021). Argo Quality Control Manual for Dissolved Oxygen Concentration, v2.1.
- Shee, A., Sil, S., & Gangopadhyay, A. (2023). Recent changes in the upper oceanic water masses over the Indian Ocean using Argo data. *Scientific Reports* (Journal quartile rank: Q1), *13*(1), 20252.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