AGU PUBLICATIONS

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Supporting Information (Text) for

Seasonal Evolution of Oceanic Upper Layer Processes in the Northern Bay of Bengal following a Single Argo Float

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Text S1.

Details of data availability and processing steps

The Argo data is obtained from the NOAA National Oceanographic Data Center website (https://www.nodc.noaa.gov/). The sea surface height anomaly (SSHA) data with spatial resolution of $\mathbf{0.25}° \times \mathbf{0.25}°$ are taken from the daily global ocean gridded L4 sea surface heights provided through the Copernicus Marine Environment Monitoring Service (CMEMS) website (http://marine.copernicus.eu/). The SST, latent heat flux (LHF), sensible heat flux (SHF), net shortwave radiation (SWR) and net longwave radiation (LWR), surface net heat flux (NHF), and wind stress are obtained from the TropFlux products (Praveen et al., 2012). The daily TropFlux data with 1° horizontal resolution is processed and provided by ESSO - Indian National Centre for Ocean Information Services through its website (http://www.incois.gov.in/tropflux/data_access.jsp). Daily $\mathbf{0.25}° \times \mathbf{0.25}°$ gridded Tropical Rainfall Measuring Mission (TRMM) 3B42 v7 accumulated (combined microwave-IR) precipitation data are obtained from the Asia-Pacific Data Research Center (APDRC) website (http://apdrc.soest.hawaii.edu/las/v6/dataset?catitem=13062) to estimate surface freshwater buoyancy fluxes.

The above-mentioned data sets are extracted at co-located time and space (averaged over a $\mathbf{0.5}° \times \mathbf{0.5}°$ latitude-longitude box for each position of the float) to derive currents, temperature advection and surface buoyancy fluxes along the Argo float trajectory. Density was calculated at each depth for the profiles using the equation of state (Millero et al., 1980) with temperature and salinity linearly interpolated at regular depth intervals. We have compared our result from observations with general circulation model HYCOM (source: https://www.hycom.org/dataserver/gofs-3pt0/analysis) and ECMWF ocean reanalysis system ORAS4 reanalysis (Balmaseda et al., 2012, source: https://www.ecmwf.int/en/research/climate-reanalysis/ocean-reanalysis).

Text S2.

Criteria and definition of for MLD, ILD and BLT

The MLD is calculated using the following equation,

$$\sigma_{t(z=h)} = \sigma_{t(z=0)} + \Delta T \frac{d\sigma_t}{dt}$$

where ΔT is the desired temperature criterion taken as 1°C (Wyrtki 1971) and $\frac{d\sigma_t}{dt}$ is the coefficient of thermal expansion evaluated using the sea surface temperature and salinity (Kara et al., 2000; Sprintall & Tomczak, 1992). When the salinity stratification in the density profile is negligible, the mixed layer (ML) is the same as the isothermal layer (IL). The isothermal layer depth (ILD) is defined as the depth at which the temperature is decreased by amount ΔT from the SST (Jana et al., 2015). In case of positive and non- negligible salinity stratification, the MLD is shallower than the ILD and the positive difference between the ILD and MLD is known as the barrier layer thickness (BLT).

The occurrence of temperature inversions is defined as when temperature at the subsurface is greater than the surface value by 0.1°C or more (Girishkumar et al., 2013). Accuracy of the temperatures in the Argo profiles is equal to $\pm 0.002°C$ (http://argo.ucsd.edu/), which is much lower than our chosen threshold value (0.1°C) to determine temperature inversions.

Text S3.

Explanation of different terms of MLHB equation

The terms in (Eq. 1) from left to right represent (a) temperature tendency or heat storage rate (HSR), (b) net surface heat flux (NSHF), (c) horizontal advection. The vertical processes are captured by the combination of (d) vertical entrainment and (e) vertical diffusion and can be thought of as the vertical heat redistribution internally within the ML. The remaining value is the residual. Here, h, ρ, C_p and T are MLD, seawater density, specific heat capacity of seawater, and average ML temperature.

In the net surface heat flux term (b), $Q_{net} = (Q_{shortwave} + Q_{longwave} + Q_{latent} + Q_{sensible})$ is the heat flux due to air-sea exchange into the mixed layer (ML) and Q_{pen} is the penetrating shortwave radiation below ML estimated using the empirical formula given by Paulson & Simpson (1977), $Q_{pen} = 0.47 \times Q_{SWR}(R_1 e^{-\frac{h}{\zeta_1}} + R_2 e^{-\frac{h}{\zeta_2}})$. The values of R1, R2, ζ1 and ζ2 are taken as 0.61, 0.38, 1.52, and 18 respectively (Girishkumar et al., 2013). Therefore, (Q_{net}-Q_{pen}) is the effective heat flux that remain within the ML, which affects the changes in the MLT.

In the horizontal advection term, u and v are the horizontal zonal and meridional current components, and the subscript g and ek indicate geostrophic and Ekman components, respectively. The terms $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ are the horizontal temperature gradient in the zonal and meridional direction respectively. In the entrainment term of vertical processes (the term d), the entrainment velocity (W_e) at the base of the ML is sum of vertical velocity below the ML (W_h) and time rate of change of MLD is $\left(\frac{dh}{dt}\right)$. In this study, W_h is computed from the time rate of change of the 23 °C isotherm depth (D23) (Girishkumar et al., 2013) and temperature of water entrained into ML (T_d) is taken as the temperature at 10 m below MLD (Qu, 2003). H is Heaviside step function which is equal to one for $W_e > 0$ and zero otherwise. Here, K_z is the vertical diffusion coefficient and $\frac{\partial T}{\partial z}$ is the average vertical temperature gradient between the base of ML and 10 m below the ML. The value of K_z is taken as 1 $cm^2 s^{-1}$ (Girishkumar et al., 2013; Shenoi et al., 2002).

Text S4.

Explanation of different terms of Net Surface Buoyancy

The terms of Net Surface Buoyancy are explained in this section. Where $F_T(= -\frac{Q_{net}}{\rho C_p})$ is the heat flux arising from the heat input into the ocean from the atmosphere and $F_S(= \frac{(E-P)S}{1-\frac{S}{1000}})$ is the surface salt flux arising from a net excess of precipitation (P) over evaporation (E). Here g is gravitational acceleration, $\alpha\ (= -\frac{1}{\rho}\left[\frac{\partial\rho}{\partial T}\right]_{p,S})$ is thermal expansion coefficient, $\beta\ (= -\frac{1}{\rho}\left[\frac{\partial\rho}{\partial S}\right]_{p,T})$ is the haline contraction coefficients and S is the sea surface salinity. The minus sign in Eq. (3) indicates less buoyancy (i.e. denser) at the upper surface layer when a positive buoyancy flux is out (i.e. upwards) of the ocean surface. $B_0 > 0$ implies destabilizing conditions which may lead to convection. To determine the stability in the water column the Monin-Obukhov length (L) is defined as (Anitha et al., 2008; Sutherland et al., 2013)

$$L = -\frac{u_*^3}{\kappa B_0}$$

Where κ is von Karman's constant and $u_*(= \sqrt{\frac{\tau_0}{\rho}})$ is the friction velocity computed from the surface wind stress (τ_0) and seawater density (ρ).

Description of Movies S1: Trajectory of the Argo float (WMO ID: 5904302) with SSHA map (shaded) and geostrophic current (vectors). Red square indicates the location of the Argo on the day of snapshots. Each frame of this 262-frame visualization is a 5-day average depiction of the SSHA field superimposed with the locations of the ARGO float. This file is uploaded separately as ms01.gif.