

Seasonal contribution to the winter spice generation in the South Indian Salinity maxima

by

Madhu Kaundal

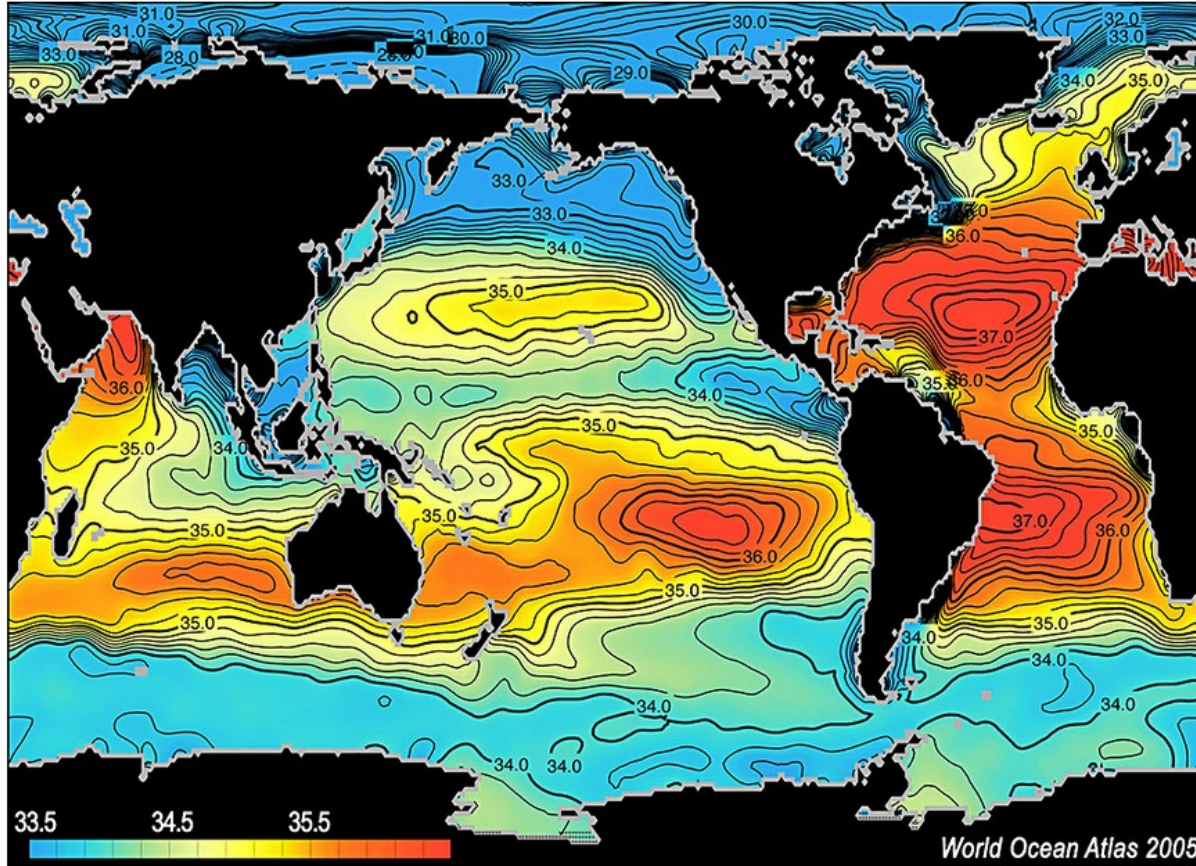
Indian Institute of Technology Kharagpur, India

Contributors: Mihir Kumar Dash, Jithendra Raju N.

April 30, 2021



Introduction

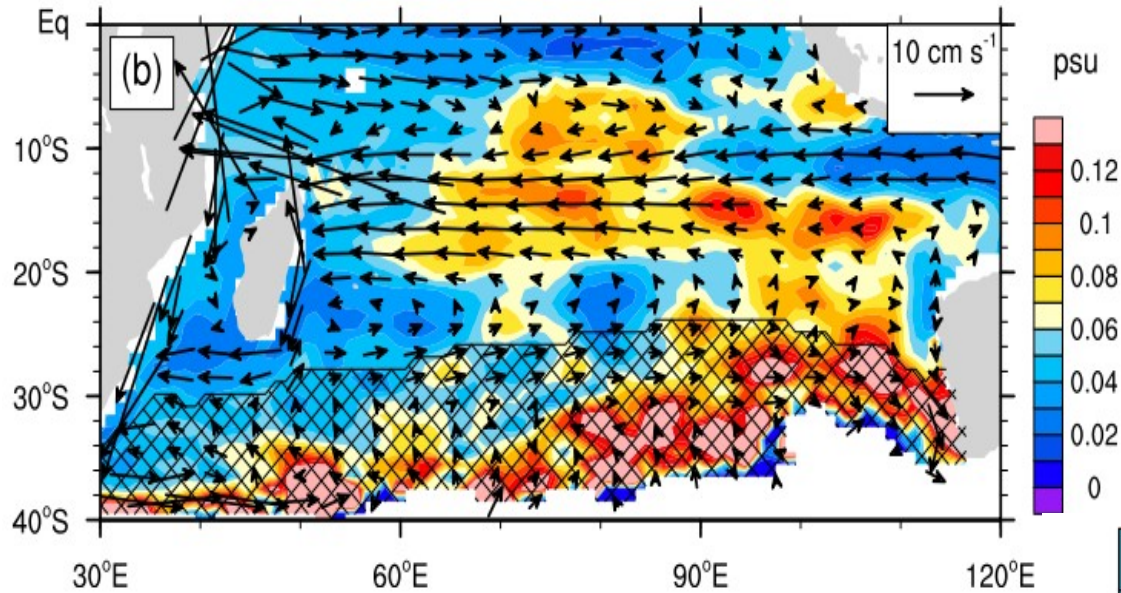


Salinity maxima in the world oceans.
Formation is due to the reasons as follows

- Positive E-P regions.
- Subsidence region (Hadley cell descending branch).

Study region: South indian ocean Salinity maxima.

South Indian Ocean Salinity maxima

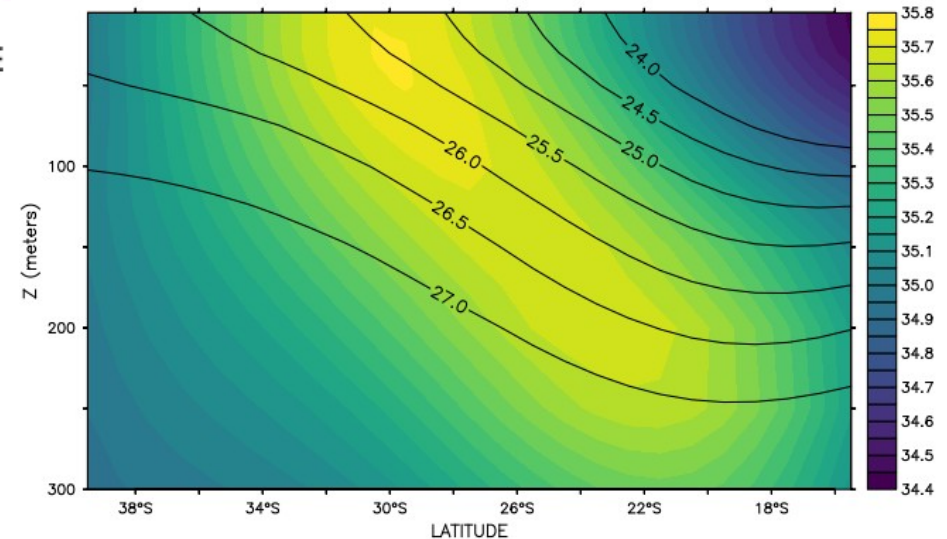


Standard deviation of spiciness anomalies (colors) and velocity vectors for mean current on 25σ_θ (Nagura et.al 2018).

Annual mean of salinity (shaded, psu), averaged for longitudinal section 70E-110E (vertical structure of salinity maxima and its movement towards equator). Isohaline contours are shown with solid black lines(kg/m³) .

SSSmax regions experience temperature and Salinity (T/S) changes .

T/S changes with compensation in density is a Term called as Spiciness (Stommel 1962, Munk 1981).



Equal density and spiciness

S

T



Case-1: Salinity and
Temperature decreases

Density remains constant
in both the cases



S

T



Case-2: Salinity and
Temperature increases

Spiciness processes

Subsurface T/S changes can be formed locally through two main process.

- Suduction process
- Injection process

Subduction: occurs where an isopycnal outcrops and sea surface spiciness (T/S changes) anomalies are found and then they subduct in to the main thermocline along the isopycnal surface.

Injection: When isopycnal is not exposed to the surface but large destabilizing salinity gradients are present in conjunction with the weak stratification(weak temperature gradient) and thus due to convective mixing at the base of mixed layer saline water is injected into the main thermocline.

Background Basis

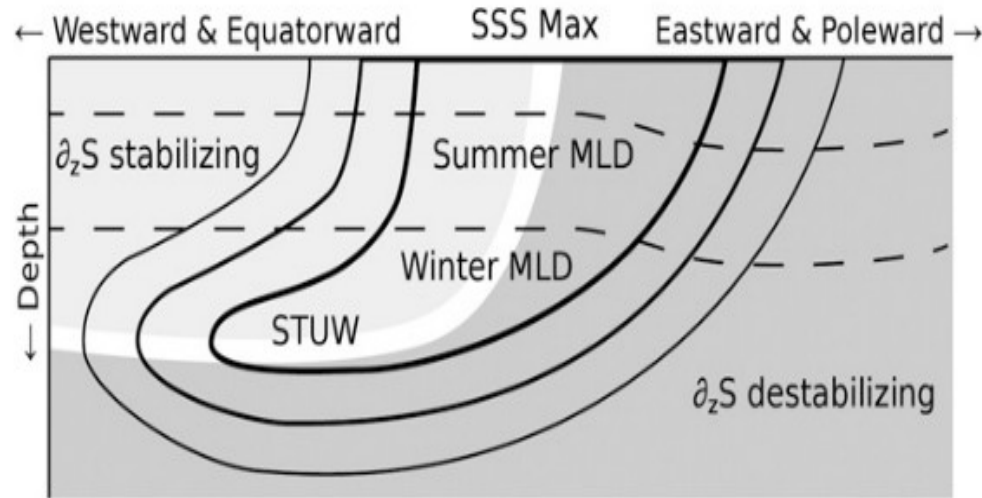
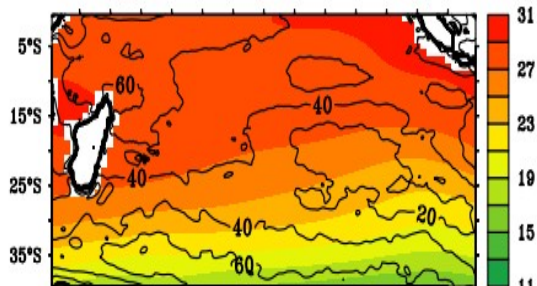


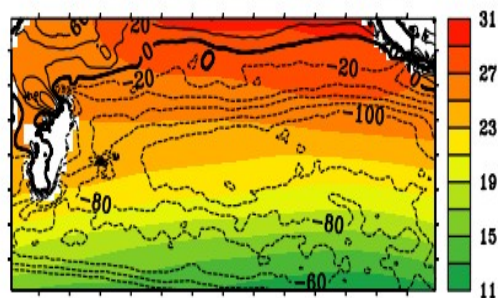
Fig. Vertical structure of salinity maxima and its movement towards equator. Isohaline contours are shown with solid black lines. Dark shaded region illustrate that in mix layer eastward and poleward (westward and equatorward) of the sea surface salinity (SSS_{max}), $\partial_z S$ is stabilizing (destabilizing) because of the equatorward movement of subtropical under water (STUW) with respect to sea surface salinity maxima. (Johnson et. al., 2016)

1. S_{max} has subsurface salinity maxima present, Known as Subtropical underwater.
2. Subtropical water movement towards west-Ward and equator-ward along geostrophic pathway.
3. Contrasting regions of $\partial_z S$ along S_{max} edges.
4. Along eastward edge, Salinity is decreasing with depth , $\partial_z S$ is destabilizing with heavy top water.
5. Water parcel lose heat much faster than salt and become negatively buoyant, suseptible for finger convective plumes.

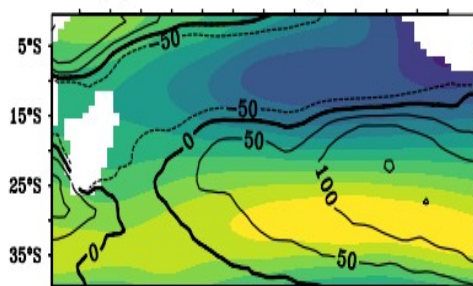
(a) MLT and Heat flux (JFM)



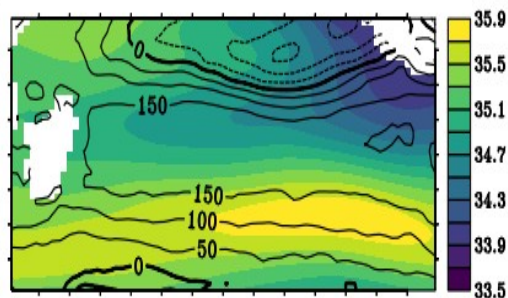
(d) MLT and Heat flux (JAS)



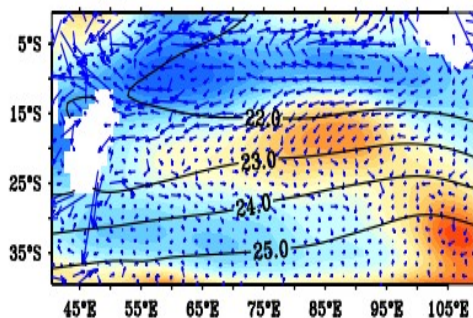
(b) MLS and E-P (JFM)



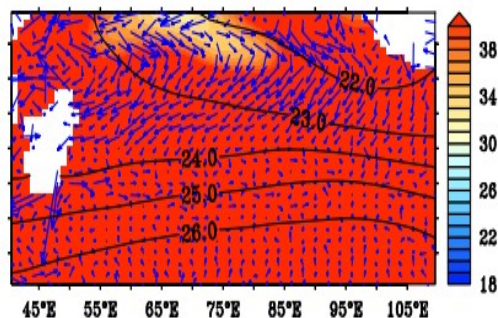
(e) MLS and E-P (JAS)



(c) MLD and currents (JFM)



(f) MLD and currents (JAS)



(a), (d) Mixed layer temperature (MLT; color in $^{\circ}\text{C}$) and heat flux ($\text{CI}=20 \text{ W m}^{-2}$) and (b), (e) Mixed layer salinity (MLS; color in psu) and E-P (evaporation minus precipitation; contours, $\text{CI}=50 \text{ cm year}^{-1}$). (c), (f) Mixed layer depth (MLD; color in m) and surface currents (vectors) and surface σ (black contours, $\text{CI}=1 \text{ kg m}^{-3}$) for austral summer (JFM) and austral winter (JAS). The seasonal mean is obtained from ARGO (2005-2018).

Mix layer budget

$$\rho c_p h \frac{\partial \langle T \rangle}{\partial t} = Q_{net} - q_{-h} - \rho c_p h \langle U \rangle \cdot \nabla \langle T \rangle - \rho c_p w_e \cdot (\langle T \rangle - T_{-h}) + \varepsilon_T$$

$$\rho h \frac{\partial \langle S \rangle}{\partial t} = E - P \langle S \rangle - \rho h \langle U \rangle \cdot \nabla \langle S \rangle - \rho w_e \cdot (\langle S \rangle - S_{-h}) + \varepsilon_s$$

$$\varepsilon_T = \rho \cdot C_p \left[-\nabla \int_{-h}^0 U' \cdot T' dz + h A_h \nabla^2 \langle T \rangle - K_T \partial_z T(z=-h) \right] + e_T$$

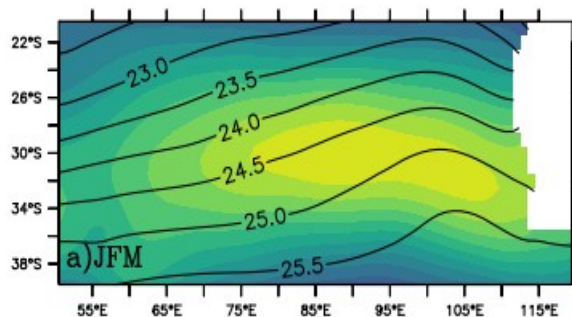
$$\varepsilon_s = \rho \left[-\nabla \int_{-h}^0 U' \cdot S' dz + h A_h \nabla^2 \langle S \rangle - K_s \partial_z S(z=-h) \right] + e_s$$

It is reported by Johnson et., al that during winters the vertical diffusion magnitude peaks for all S_{max} present in the world ocean and eddy advection term nearly doubles its magnitude during winters in south Indian ocean S_{max} region. This is likely related to the south west monsoon intensification during austral winter.

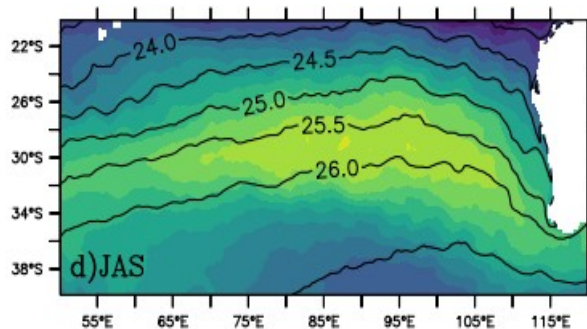
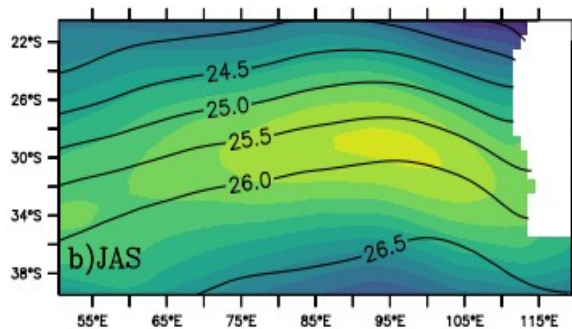
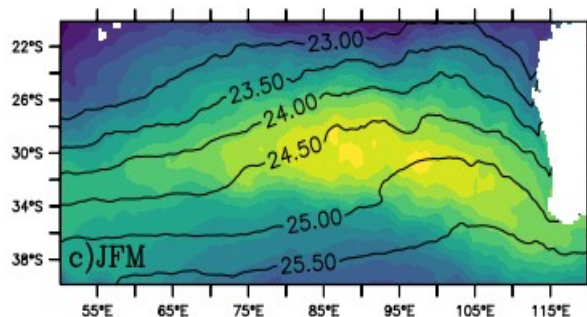
To better understand these terms mix layer budget calculation for the region is computed.

Data validation

ARGO



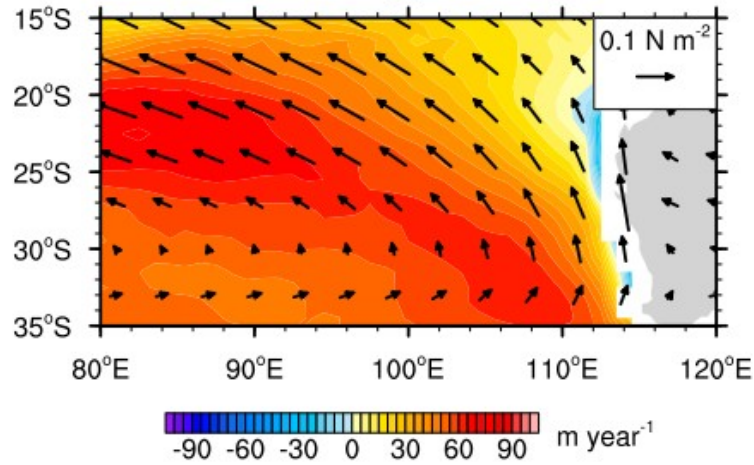
ECCO



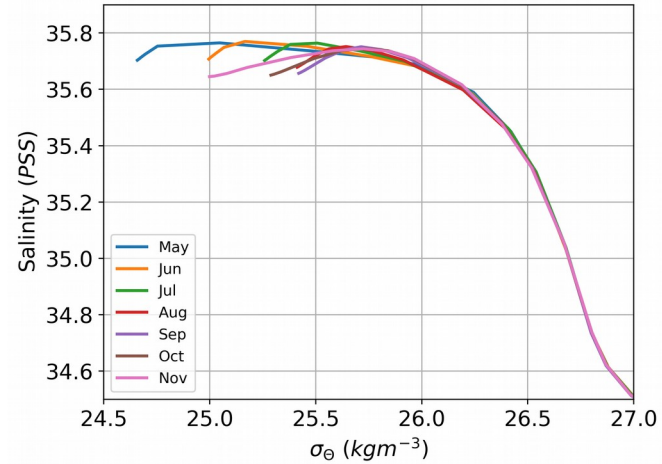
To look for spiciness events which occur within few days, high frequency output of high resolution data is required so ECCO is used and compared with the Observations.

Fig 1. Seasonal mean SSS (sea surface salinity, psu) shaded and density (kg/m³) contours for ARGO (Left column), a) austral summer JFM (Jan-Feb-Mar) and b) austral winter JAS (July-Aug-Sep). Similar for ECCO (Right column), c) JFM d) JAS for climatological years of 2005-2018

North box



Ekman pumping velocity



Winter evolution of $S-\sigma_\theta$ from may to november

No density compensation is observed in northern box in meridional as well as vertical direction

- Positive ekman pumping shows dowelling in region has also subduction rate of about $60\text{-}70 \text{ m yr}^{-1}$.

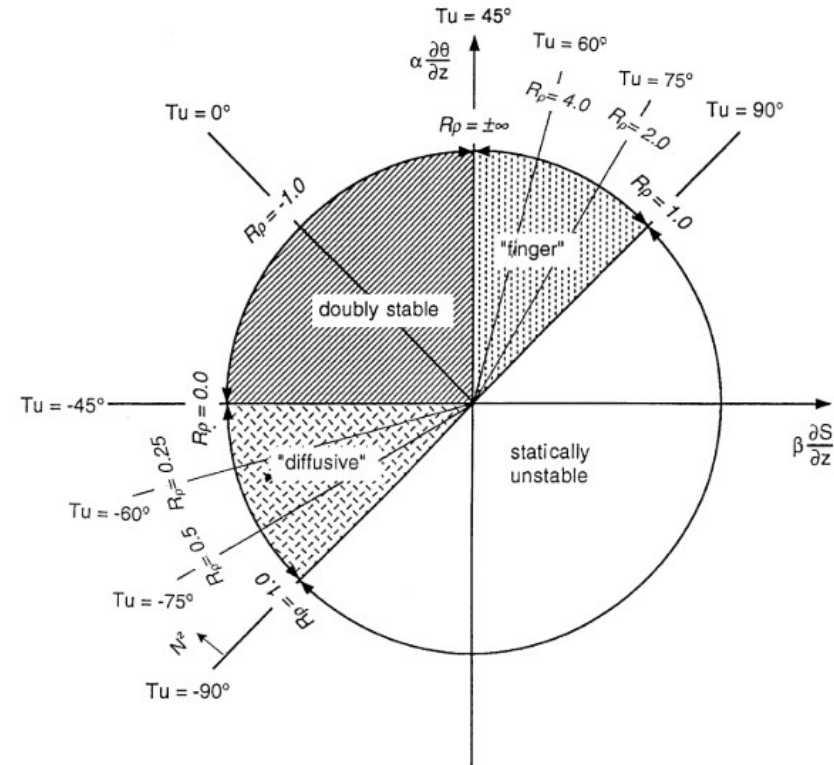
Turner angle

Vertical gradient of temperature and salinity are density compensating that a water column with destabilizing $\partial_z S$ can stabilize by $\partial_z T$. The contribution of vertical gradient of temperature and salinity to the density compensation can be quantified in terms of Turner angle.

$$Tu = \tan^{-1} \left(\frac{\alpha \partial_z T + \beta \partial_z S}{\alpha \partial_z T - \beta \partial_z S} \right)$$

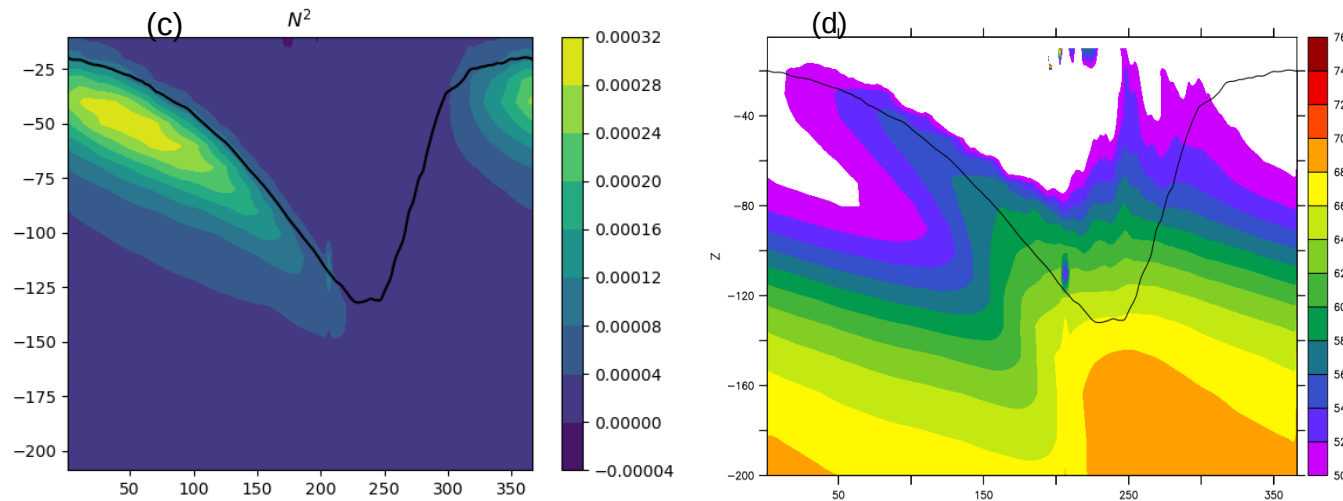
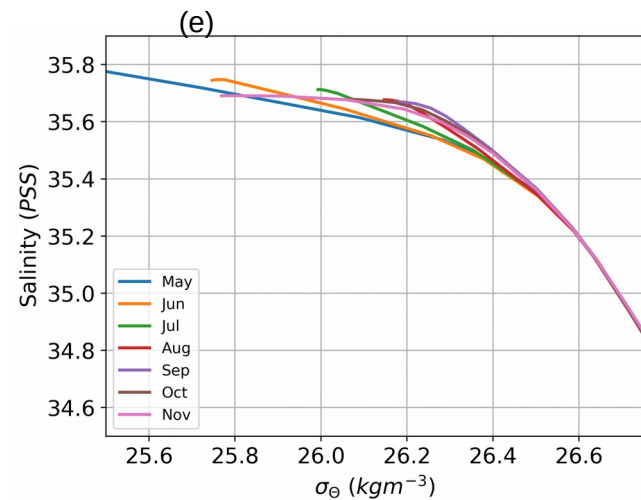
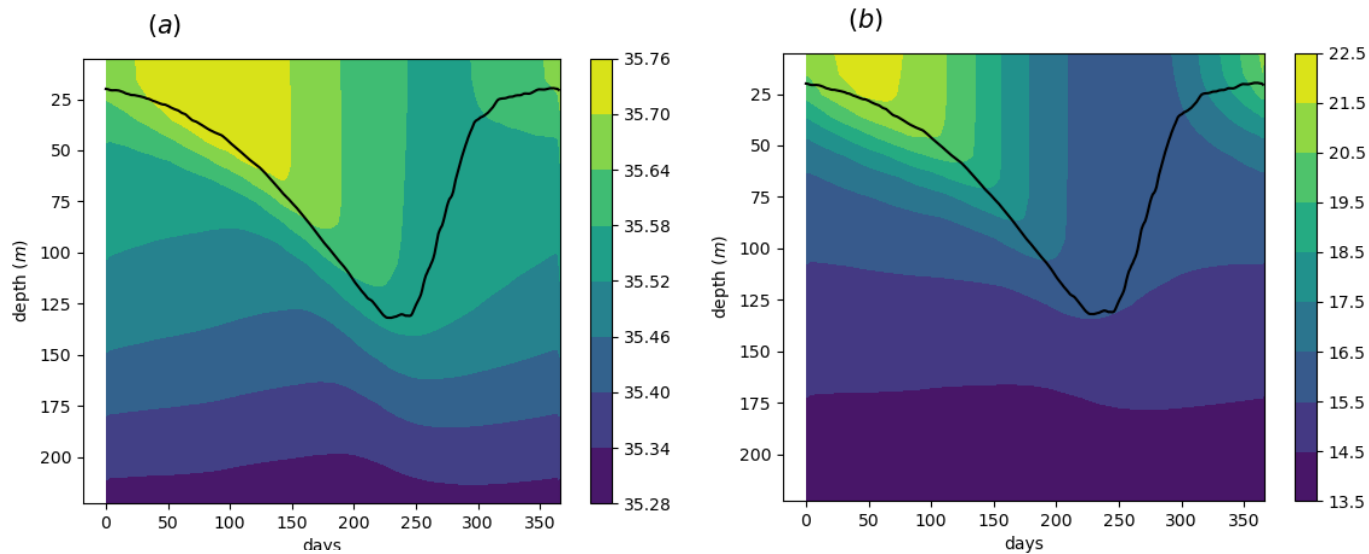
$$\tan^{-1} \left(1 - 2\rho_0 \beta \frac{\partial S}{\partial \rho} \right)$$

Turner angle changes throughout the year because of changes in surface heat and water fluxes.



Turner angle (Tu) and density ratio R_ρ . Y-axis is represented by vertical temperature gradient and X-axis is vertical salinity gradient, scaled in terms of their contribution to the density change. Water column stability is shown as quadrants. $90^\circ > Tu > 45^\circ$ is the region of salt fingering. $Tu \pm 45^\circ$ is stable region.

South box

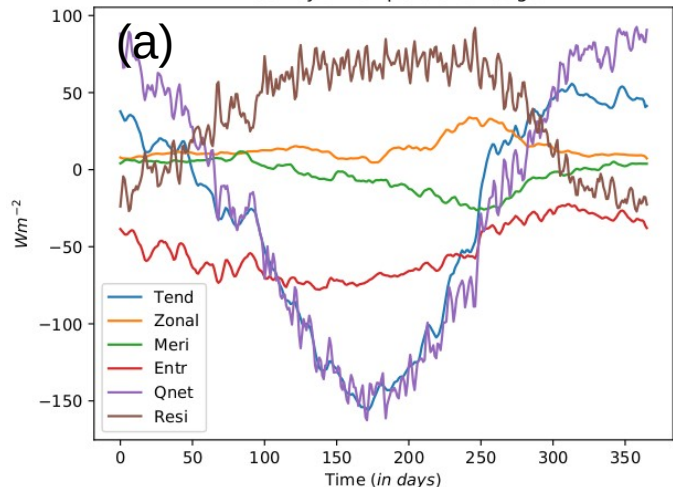


Mean annual cycle of (a) Temperature and (b) salinity with depth, (c) N^2 (d) Turner angle ($^\circ$). Winter evolution (e) of water column S-sigma Theta climatological curve from may to november.

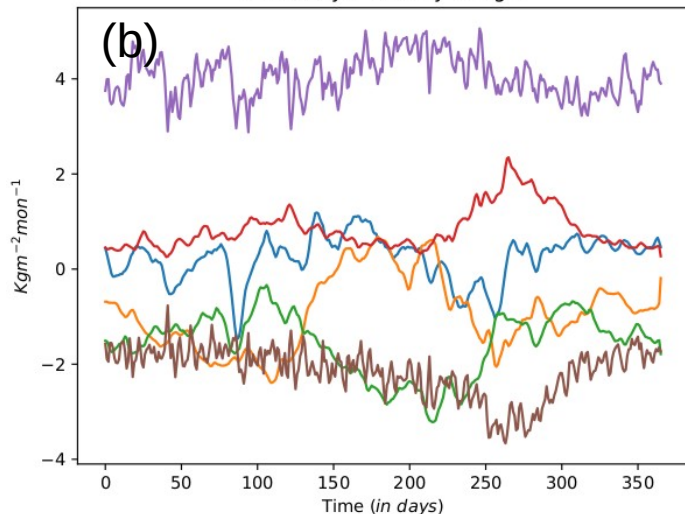
Budget calculation

North box

Mixed Layer Temperature Budget

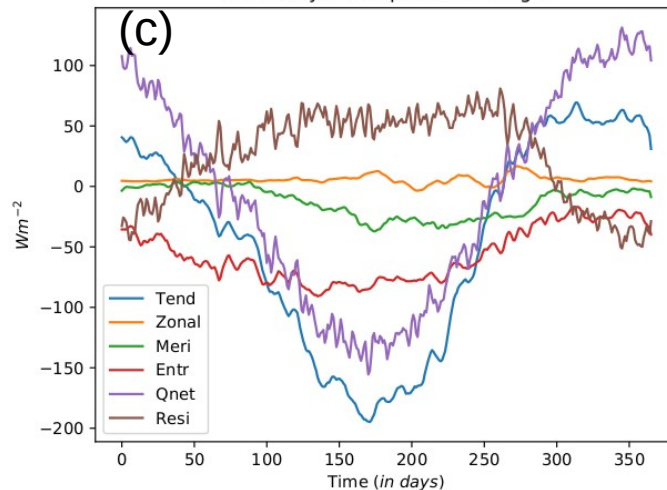


Mixed Layer Salinity Budget

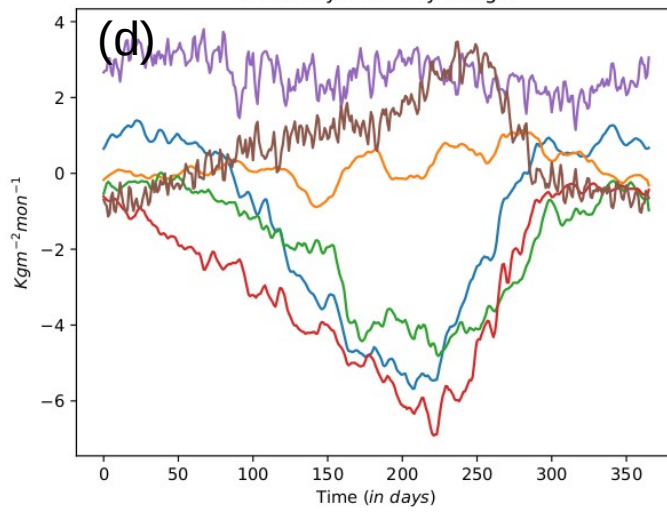


South box

Mixed Layer Temperature Budget



Mixed Layer Salinity Budget



Annual cycle of budget terms for mixed layer heat and salt budget in both boxes. Heat and salt tendency terms (in blue), zonal advection (orange), meridional advection (green), Entrainment (red), Net heat flux (Q_{net}) and Freshwater flux terms (voilet), Residue terms (brown).

North box

- Surface heat flux
- Freshwater Flux controlling spiciness monthly evolution.

South box

- Entrainment
- Meridional advection playing major role for spiciness changes.