Estimating the Contribution of Local and Advective parcels to Mixed Layer Dynamics in the Indian Sector of the Southern Ocean through a Box Model approach.

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Southern ocean dynamics are essential for understanding climate change and its consequences. However, the mechanisms of vertical transport of salt and density remain a missing link between surface and deep water variation. In order to understand the importance of each phenomena in the upper layer variability we constructed a box model aggregating data from a M-Triton type mooring (temperature, salinity and current speed) released in 2012 at 60°S 140°E (inertial period = 13.81 hours) as part of the KARE-17 expedition, CTD casts from the same expedition and ERA5 reanalysis data (Sea surface temperature, evaporation, total precipitation). Mooring data was filtered two times using a 4th order, 13hour, low-pass Butterworth filter, forward and then backwards in time in order to minimize phase shifting. Data was then interpolated into a regular 20m grid and subsampled hourly.

Taking the law of conservation of a scalar quantity applied for density as a basis, assuming compression to be negligible and a 3 dimensionally independent diffusivity tensor K (m^2 s^{-1}) we approximated the total density variation as Eq.1

$$\frac{\partial \rho}{\partial t} + X = K_\rho \frac{\partial^2 \rho}{\partial z^2} \tag{1}$$

Where $X = \vec{u}\nabla\rho$ is the advection of density ρ (Kg·m^{-3}) according to current speed vector $\vec{u}$ (m s^{-1}). The box model is build considering only vertical diffusivity, ocean-atmosphere net heat flux and the balance between evaporation and precipitation so that the difference between the model and the sampled data is assumed to be caused by the horizontal advection factor *X*. Diffusivity coefficients for temperature and salt are estimated using the parametrization proposed by Zhang (1998). Using this framework, fluxes of a property *P* (temperature and salinity) between each box can be discretized as

$$\frac{P_i^{t+1} - P_i^{t+1}}{dt} = \frac{1}{dz}\left[K_{p,i}\frac{P_{i+1}^t - P_i^t}{dz} - K_{p,i-1}\frac{P_i^t - P_{i-1}^t}{dz}\right] \tag{2}$$

Where *i* and *t* are the depth and time indexes respectively and δ denotes their discretized step.

The model results (Fig.1) could explain 97.07% of the long period surface temperature variability, but its accuracy falls with depth. A significant factor of non-local variability was identified to be near inertial period internal waves at 75 and 100m, which extended mixed layer depth to these depths at Feb 13th and May 7th , respectively, which is almost 2 months earlier than the mixing time for the model experiment, on Apr 2nd and July 21st. During internal wave propagation K_ρ was found to increase up to two orders of magnitude, reaching as high as 10^{-3} m^2 s^{-1} (usual values for the series fall between 10^{-6} and 10^{-5}).

The increase in both temperature and salinity found between 141 and 200m deep could not be explained using only local sources and vertical diffusivity, therefore most of the variation was thought to be from the horizontal variation (factor X). The main sources of this difference were then investigated by analyzing the absolute dynamic topography and deriving geostrophic current velocity fields from the merged SSALTO/DUACS altimetry dataset available at the Copernicus Marine Service and cross referencing them to sea surface temperature data. The main events of horizontal advection impacting these layers (between March 27th and April 12th, and at May 21st) were then mapped to frontal shifts and temporal variation of nearby meanders, while events smaller in temporal scale could be mapped to the passing and/or intensification of eddies.

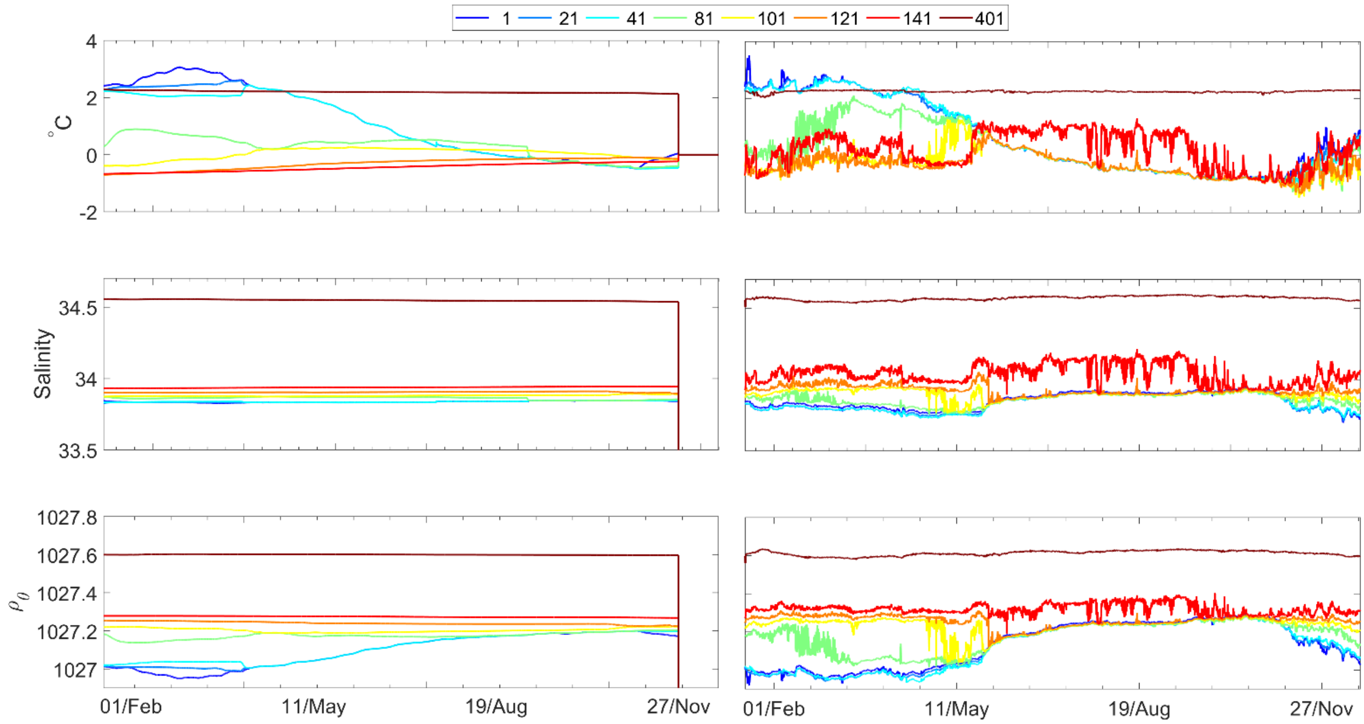

Figure 1: Comparison between the model and sampled time-series of temperature, salinity and potential density, on the left and right panels respectively.

At intermediate depths of around 400m, although variations were on a smaller scale model and mooring data presented significant differences: The model indicates a lightening tendency of -2.468 $Kg \cdot m^{-3}$ per day, caused by a salinity freshening trend of -7.512·10^{-5} psu per day, starting from Feb 26th. Sampled data from the mooring, on the other hand, had the inverse trend of becoming heavier and saltier at the same depth, with rates of +7.222·10^{-5} and +8.746·10^{-5} density and salinity per day, respectively. This implies a mean 1.626·10^{-4} salinity per day being provided by lateral advection to maintain the observed values. Mooring data was also distinct in that salinity signal was periodic, containing significant amplitude on the seasonal band (85.3days, RMS amplitude = 0.2512), 56.9-13 days (RMS amplitude = 0.0038) and also on the near-inertial band (RMS amplitude =0.0021). Variation of salinity in the near inertial band was deemed significative, being one order of magnitude higher than the estimated salinity variation due to sensor depth changes.

It was generally understood from looking at altimetry and surface temperature data that whenever observation did not match the model results, a warm water vortex structure was found to be propagating through the studied area.

References

Zhang J., R. W. Schmitt and R. X. Huang. The sensitivity of the GFDL modular ocean model to parameterization of double -diffusive processes. J. Phys. Oceanogr., 28: 589-605, 1998.