Wind forced near-inertial period internal waves and their contribution to the mixed layer at the Antarctic Circumpolar current

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The role played by turbulent mixing has been observed to be of fundamental importance to the circulation of the Southern ocean, as it provides the dominant contribution to the downward buoyancy flux required to balance the upward dyapicnal transport of deepwaters implicated in the overturning circulation across the region (e.g., Lumpkin and Speer, 2007; Zika et al., 2009; Naveira-Garabato et al., 2013).

A major contributor to this balance is the work on upper-ocean inertial motions associated with variable wind forcing (Alford, 2001,2003; Watanabe and Hibiya, 2002; Furuichi et al. 2008). This research aims to investigate the importance of internal wave motions in the energy transfer between wind and the surface of the antarctic ocean and how it affects the mixed layer. For this purpose data from CTD casts,ERA Interim reanalysis data and satellite imagery from the GHRSST project were juxtaposed to ADCP and CT recorder data from the m-TRITON mooring, deployed between January 15^{th} and December 19^{th} of 2012,centered at 60°S 139°58'E, a point marked by the dynamics of the Antarctic Circumpolar Current (ACC).

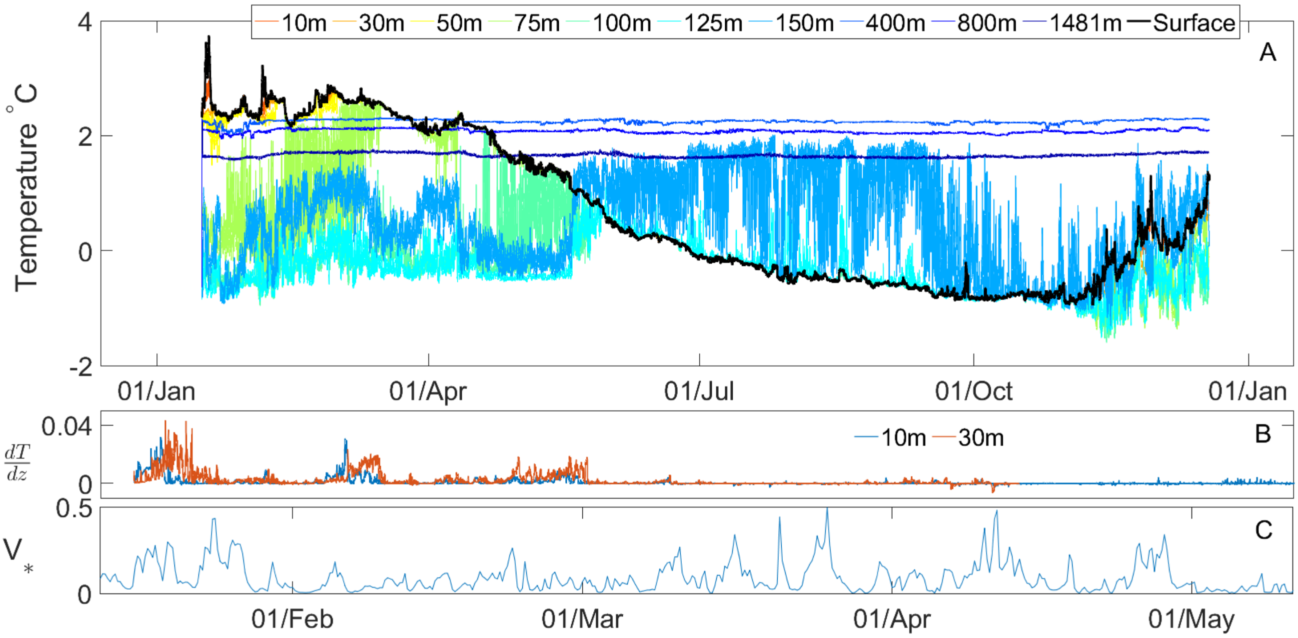

Figure 1: Profile of temperature by depth (A), compared against dT/dz (B) and $V_{\star}$ (C)

Data from the mooring point to two periods of contrasting behavior(Illustrated by figure 1): From November to April stratification was maintained and near-inertial waves were observed. During winter, however, from June to October, convection induced by surface cooling breaks stability and acts as the dominant mixing force in the period. Between those two periods a transition occurs where a cold intrusion centered around the 50 meter depth can be observed. Taking the differential of the temperature with depth (dT/dz) a clear relation between it and friction velocity $V_{\star}$ emerged. High values of $V_{\star}$ being followed by a sharp decrease in dT/dz at shallow layers while causing a spike at a deeper layer (not shown in the figure). This relation persists until May 21^{st}, when surface cooling takes over.

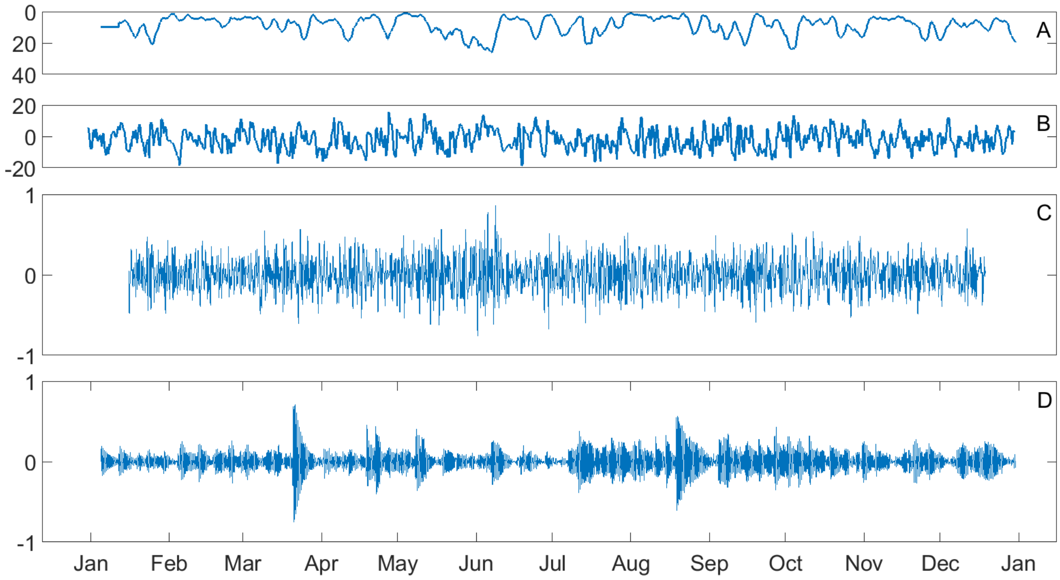

Figure 2: Comparison between mooring and model data where A is the model influence depth estimation, B is the wind northward velocity (v), C is the mooring observed current v speed and D is the model predicted v. Northward component is shown as representative of the time series and units are in m and $m \cdot s^{-1}$.

To understand the influence of inertial oscillations and the wind forcing which presumably causes it, a damped slab model of mixed layer currents was made following the works of Pollard and Millard (1970) and D'Asaro (1985) as an approximation of wind forcing upon the mixed layer as shown in Eq. 1.

$$\frac{dZ}{dt} + \omega Z = \frac{\tau}{H} \tag{1}$$

$$\frac{dZ_I}{dt} + \omega Z_I = -\frac{dT}{dt}\frac{1}{\omega H} - \frac{1/H}{dt}\frac{\tau}{\omega} \tag{2}$$

From the governing equations for such model the inertial component velocity Z_I can be related to inertial frequency (f), wind stress (τ), and depth of the mixed layer (H) by Eq.2. Variables are represented as the complex quantities $Z = u + iv$ and $\tau = (\tau_x + i\tau_y)/\rho$ and $\omega = r + if$, r being a dampening constant which parametrizes the flow of energy from the mixed layer to the deeper ocean(empirically tested to be $1/r = 3$ days for a best fit). Z_I then, , can be calculated at a time step t_2 by Eq. 3 from Z_I at t_1 and derivative of wind stress discretized as $\tau_t = \Delta\tau/\Delta t$. A Root Mean Square Error (RMSE) matrix was done, taking advantage of the processing speed of the slab model, to estimate the best values for r and h, also indicating a correction factor of 1.2 for T to compensate for the reduction caused by the ERA Interim dataset 6 hour averaging.

$$Z_{I2} = Z_{I1} \cdot e^{-\omega\Delta t} - \frac{\tau_t}{H\omega^2}(1 - e^{-\omega\Delta t}) \tag{3}$$

A major difference from previous works was the estimation and application of a turbulent boundary layer of variable thickness as the friction dependent variable $h = 0.22(V_\star/f)$, following Rossby and Montgomery (1935) and Csanady and Shaw (1980). This formulation implies response scale of f so h was calculated using the 14 hour moving average of $V_\star$. Also from $V_\star$ the turbulent dissipation rate ε was estimated as $\varepsilon = \frac{u_\star^3}{kz}$ where k is the Von Kármán's constant ~ 0.4 and z is depth bellow the surface (adapted from Perlin et al., 2005).

In the model current iteration, showcased in figure 2 periods of good phase coherence are followed by wave interference patterns presumably from waves traveling from other locations or which are independent of wind stress. The spike on the first week of June is present on the model, but with lesser intensity.