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# 南大洋の上層における季節変動と力学

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**[課程博士・論文博士共通]**

# 博士学位論文内容要旨
# Abstract

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| 専　攻<br>Major | Applied Marine Environmental Studies | 氏　名<br>Name | Ferreira Azevedo Matheus |
| 論文題目<br>Title | Seasonal variation and governing dynamics of the upper layer in the Southern Ocean | | |

This work presents an investigation of the variability and underlying dynamics of the upper layer of the Southern Ocean. We deployed one of the only open ocean moorings in the Indian sector of the Southern Ocean, providing for the first time the opportunity to observe the upper layer variability on the Southern Ocean throughout a year. This data was then compared to satellite imagery, reanalysis outputs and three different numerical models to find, explain and quantify the drivers of this variability.

The mooring data showed strong seasonal patterns, where the mixed layer lower boundary increases in depth as the ocean surface loses heat to the atmosphere. The diffusivity coefficients of temperature, salinity and density were estimated from approximations and parametrizations of the observed data and used to build a box model for water column response to local surface temperature and salinity forcing. The main result from this approach was that the local forcing could only reliably reproduce the observed variability up to 100 m. Deeper layer variability was observed to be related to shifts in frontal structures, which control if the mooring point receives water from north or south.

Internal waves were observed throughout the year and their occurrence was shown to be related to enhanced mixing at the depth they were detected, as the density diffusivity coefficient increased by about 3 orders of magnitude, to $1.15*10^{-2}$ at 75 m and later, during winter, to $2.96*10^{-3}$ at 100 m. Fourier transforms of the current velocity data indicated the near-inertial period, about 13.8 hours at the mooring position, held most of the energy on the upper layer, but the 24-hour period was also shown to be highly energetic during winter, between the 75 m and 100 m depths, where vertical shear was stronger. A seasonal profile of the vertical energy distribution showed that during Summer, most of the energy was concentrated around 20m deep and decayed with depth, as is expected from wind-generated near-inertial internal waves, but the winter profile showed little energy at the first tens of meters, but a strong diurnal and near-inertial peak between 80 to 100 m deep. The autumn and spring profiles showed an intermediate profile where energy is seen to be progressively leaving the winter peak depth towards the surface.

The winter maximum shear layer presented a diurnal vertical oscillation in phase with the incoming short-wave radiation at the location. A windowed cross-correlation between the vertically integrated shear in the upper layer, wind speed and the net ocean-atmosphere heat flux indicated wind to be a major component of shear throughout the year. Nevertheless, the net heat flux becomes significantly correlated with shear and as highly correlated to it as the wind when the ocean surface lost heat to the atmosphere.

The continuous wavelet transform of the current velocity data indicated kinetic energy at the near-surface was consistently concentrated around the near-inertial period throughout the year. However, at deeper layers below 75 m the energy shifted in frequency towards the diurnal and high frequencies during the winter. Furthermore, both diurnal, inertial, and high-frequency bands seem to respond to the same generation events and thus vanish together, although with different signal dampening. These circumstances lend to the idea of this triad being generated, or at least enhanced by non-linear interaction between the three bands, as $\omega_1 = \omega_2 \pm \omega_3$, and $k_1 = k_2 \pm k_3$.

To explore the non-linear generation hypothesis, we built a 2D nonhydrostatic numerical model to simulate

the effect of diurnal surface cooling as a forcing agent for mixed layer convective instability and internal wave generation. The model included the Coriolis effect and runs with inertial period T=13.8 h and T=19 h were done to test for resonance. In all scenarios the result was consistent: From a starting stratified ocean near-inertial internal waves were generated from surface cooling even though the cooling does not occur in the inertial period. The propagating internal waves could be seen to have significant energy up to 2000 m, and as such, could potentially serve as an energy source for deep ocean mixing. Additionally, we observed a stronger initial stratification at the base of the mixed layer reduces the convection depth even after 4000 hours of model time, indicating that heat dominated systems require a long time to develop, as the mixed layer was still deepening even after a year of simulation time.

The significance of this research is that we could provide valuable data on the Southern Ocean’s upper layer and observe the role of convective adjustment as a driver of shear and internal wave energy, which can propagate over great distances . This mechanism can play an important role at high latitudes and during winter, facilitating mixing across the mixed layer and the deep ocean, so the study of this phenomena might lead to better diurnal cycle parametrizations and more accurate numerical models in the future.