# Vertical Motion in the Southern Ocean

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## Introduction

- Vertical motions (upwelling/downwelling) are crucial for the transport of oceanic properties like CO2, nutrients, oxygen, heat, and salt.
- Southern Ocean (SO) deep waters upwell, exchanging oceanic properties with the atmosphere, while surface waters sink, carrying them into the deep ocean.
- "Pipe-like" structures in SO are likely to rapidly transmit climate change signals (e.g., temperature anomalies, anthropogenic CO2) into the deep ocean.
- Detailed analyses of special regions in the SO are needed to investigate these structures further.

## Data and Methods

- Analyze vertical velocity estimates in the SO from the ocean synthesis product ECCOv4
- Adjusts initial conditions and parameters instead of adjusting the ocean model’s state to obey the laws of physics and thermodynamics
- Use ECCO to explain underlying ocean physics and dynamics behind ocean changes and motion

## Preliminary Results

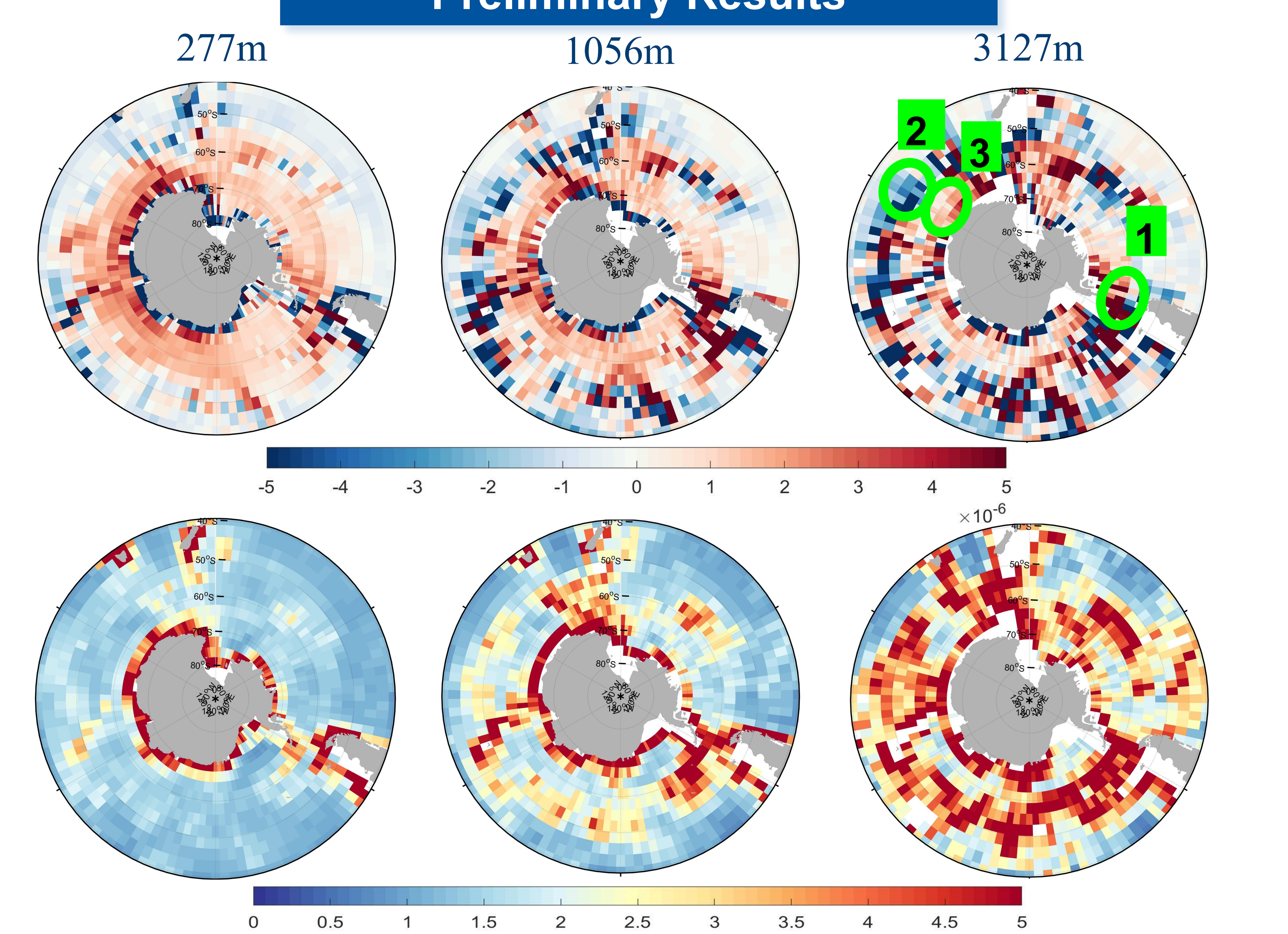


**Figure 1.** Means (top row) and standard deviations (bottom row) of the eulerian vertical velocity at depths of 277m 1056m, and 3127m. The unit is m/s. Red represents upwelling and blue represents downwelling. The labeled circles are the regions studied in Fig.2, Fig. 3, and Fig. 4. There is a downwelling band around Antarctica due to deep water formation. The surface feature (a) is dominated by wind-driven upwelling. The deep ocean feature (c) is more complex, likely due to the impacts of topography. Large temporal variations occur near bathymetric features (e.g., Campbell Plateau).

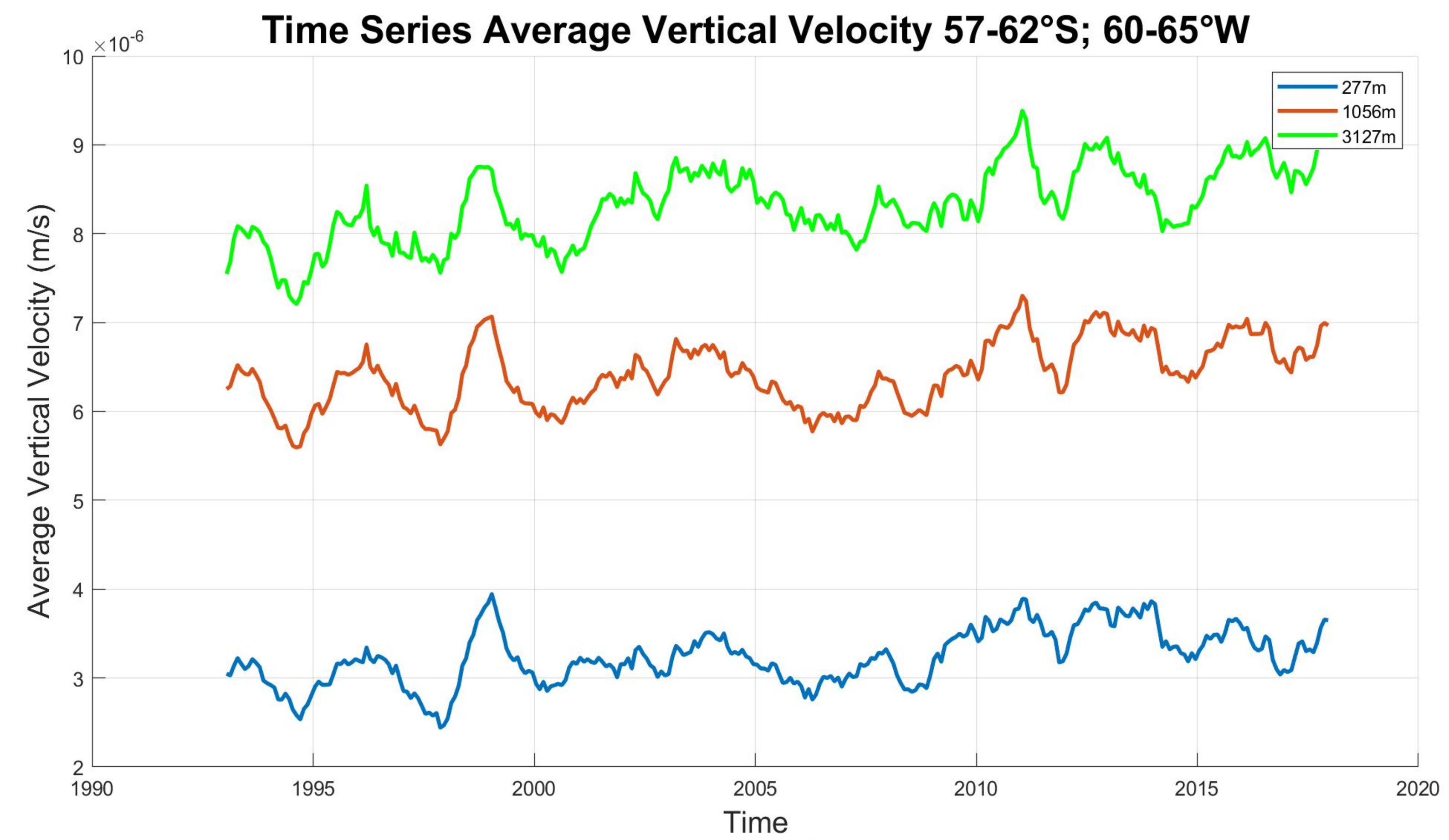


**Figure 2.** Time series of average eulerian vertical velocity at the region labeled 1 in Fig.1 at different depths: 277m (blue), 1056m (red), and 3127m (green). The abyssal layer exhibits the fastest upwelling compared to shallower layers, indicating topographic-related upwelling.

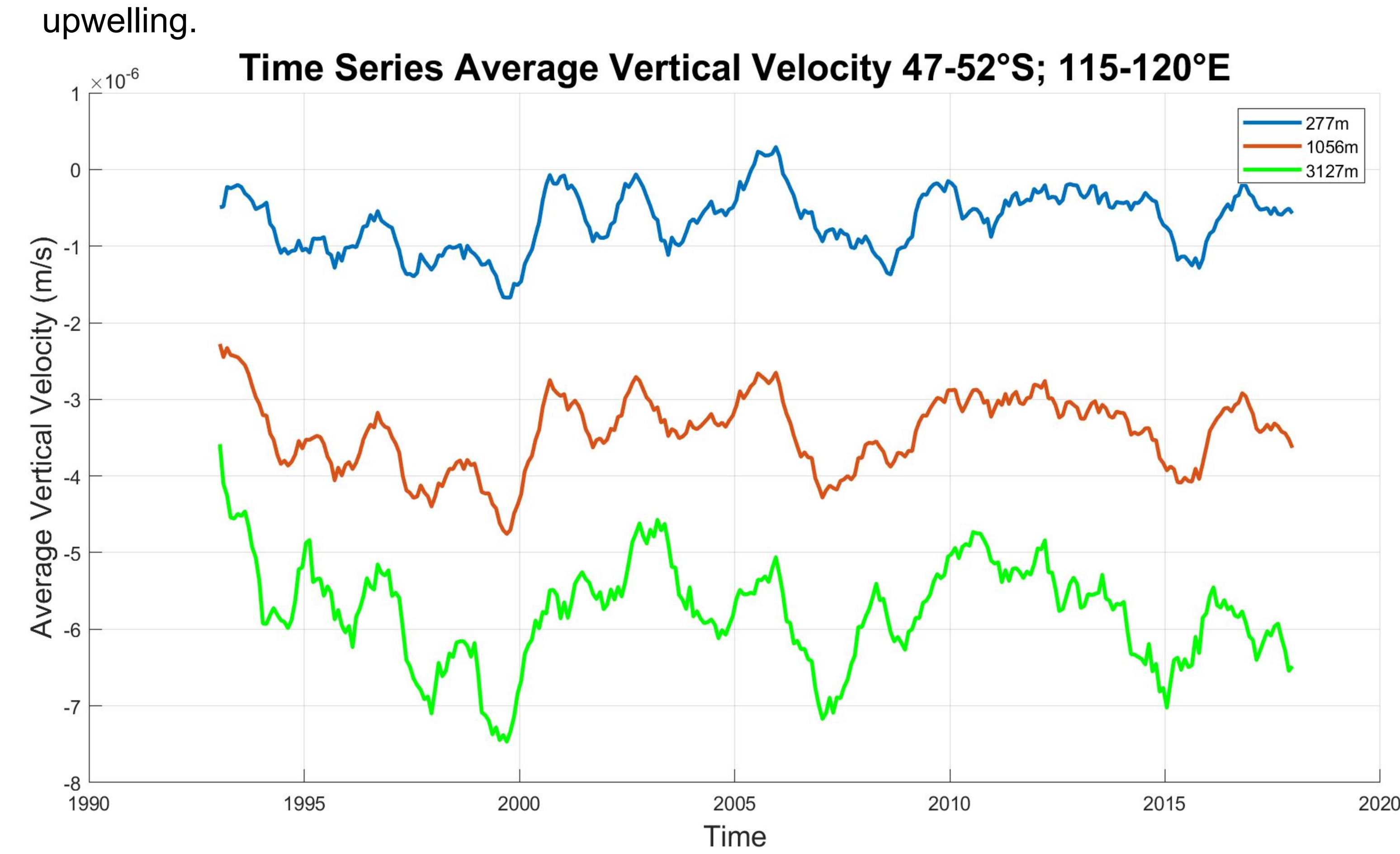


**Figure 3.** Same as Fig.2 but for the region labeled 2 in Fig.1. Between 2000 and 2005, there is a decreasing downwelling speed trend.

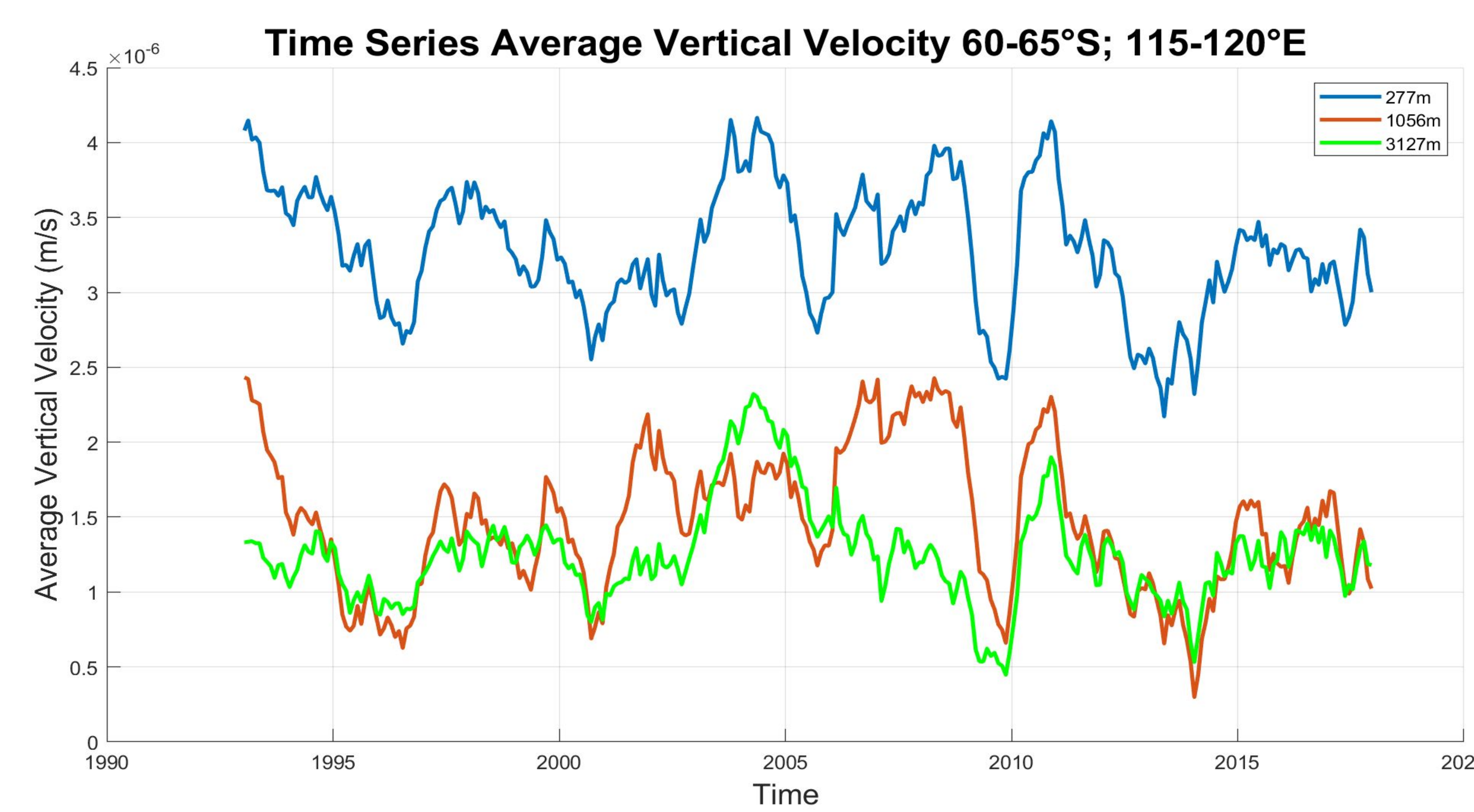


**Figure 4.** Same as Fig. 2 but for the region labeled 3 in Fig.1. The shallower layer’s vertical velocity is about 3 times faster than the deeper layers. There is an increasing upwelling speed trend between 2000 and 2005.

## Conclusions

- Fast abyssal upwelling in figure 2 is the result of the deep currents flowing over large topography. The upwelling is likely mainly along the isopycnal.
- The results reveal strong interannual variations in oceanic vertical motions in the Southern Ocean.
- Large temporal variations are observed near bathymetric features (e.g., Campbell Plateau)
- Significant temporal variations occur around Antarctica due to deep water formation.

## Ongoing Work

- Investigate possible connections between oceanic vertical motions and interannual variability (e.g., Southern Annular Mode), annual variability (e.g., Antarctic ozone hole), and anthropogenic effects (e.g., climate change)
- Produce same figures but for vertical velocity related to eddies, small scale movement, and transport of ocean properties and tracers (e.g., bolus vertical velocity, residual vertical velocity)
- Analyze Lagrangian trajectories of similar regions

## References

1. Rintoul, Stephen R. et al. “Chapter 18 - Dynamics of the Southern Ocean Circulation.” International Geophysics, 2013, vol 103, 2013, Pages 471-492, ISSN 0074-6142, ScienceDirect, https://doi.org/10.1016/B978-0-12-391851-2.00018-0.
2. Liang, Xinfeng et al. "Global Ocean Vertical Velocity From a Dynamically Consistent Ocean State Estimate." Journal of Geophysical Research, 2017, page 8208 - 8224, American Geophysical Union Publications, https://doi.org/10.1002/2017JC012985.