Ocean robots reveal the importance of Antarctic Winter Water to the global carbon cycle

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Winter Water and the Southern Ocean

With global climate change continuing to worsen, it is critical that the climate system and all its parts are well understood. The Southern Ocean (~ southern ⅓ of the globe) is known for being a powerful absorber of atmospheric carbon dioxide. To better understand the Southern Ocean's influence on the global climate system, this project examines **how the formation of Antarctic Winter Water connects to the carbon cycle.**

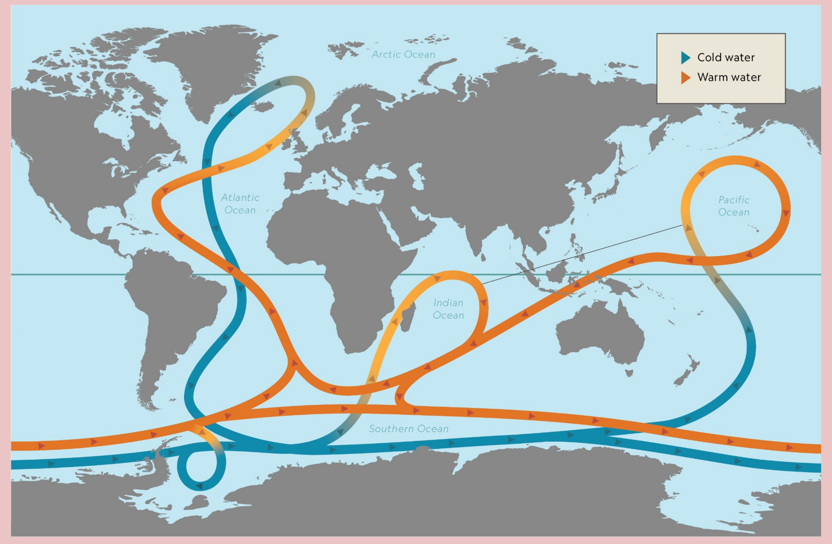


Figure 1: Global conveyor belt map depicting global overturning circulation. From National Geographic.

In the ocean, temperature typically decreases with depth. However, a strange phenomenon occurs in certain parts of the Southern Ocean. **Figure 2** displays a typical Southern Ocean cross section of water masses in the upper 300m. During the winter, the surface Mixed Layer (ML) is colder than the lower Circumpolar Deep Water (CDW) because it is losing heat to the atmosphere. When the ML begins to warm during the summer, it leaves behind some of this cold water, creating a **warm-cold-warm layering effect.** Winter Water is defined as this cold water mass trapped between the relatively warmer ML and CDW. The Polar Front (**Figure 6**) is typically considered the northern boundary of WW.

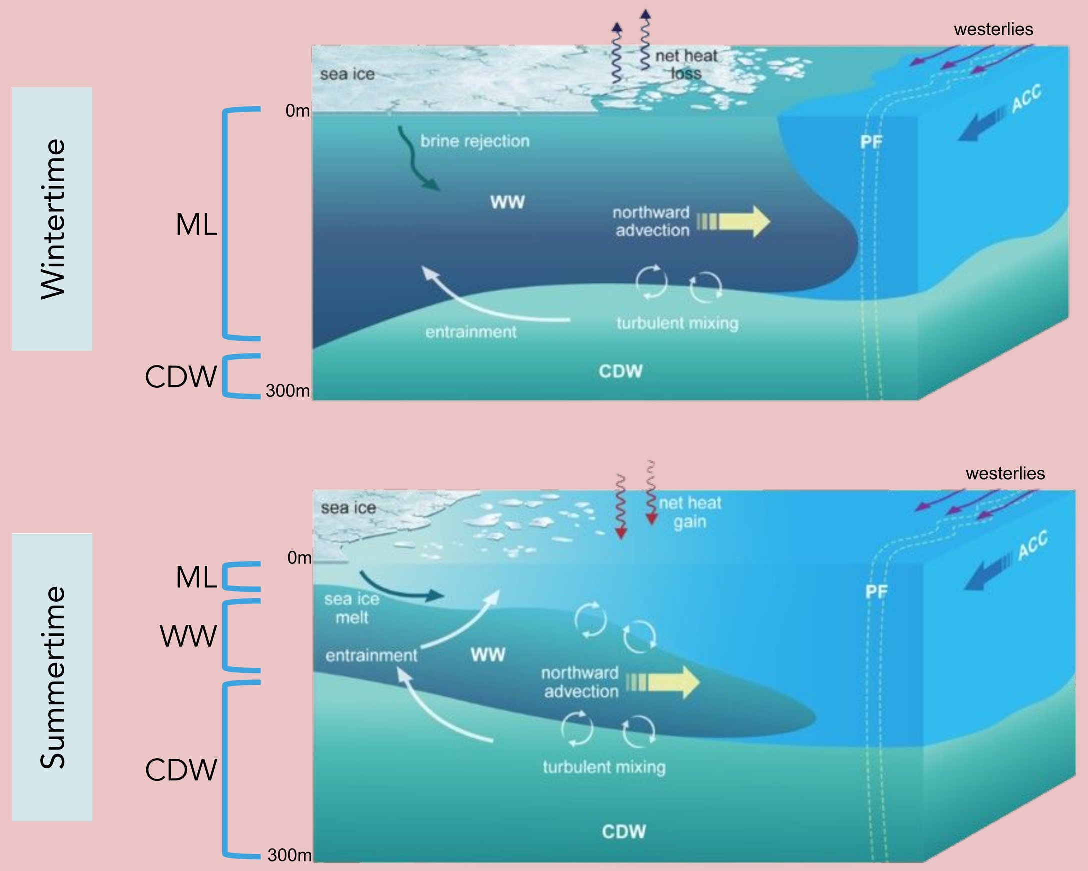
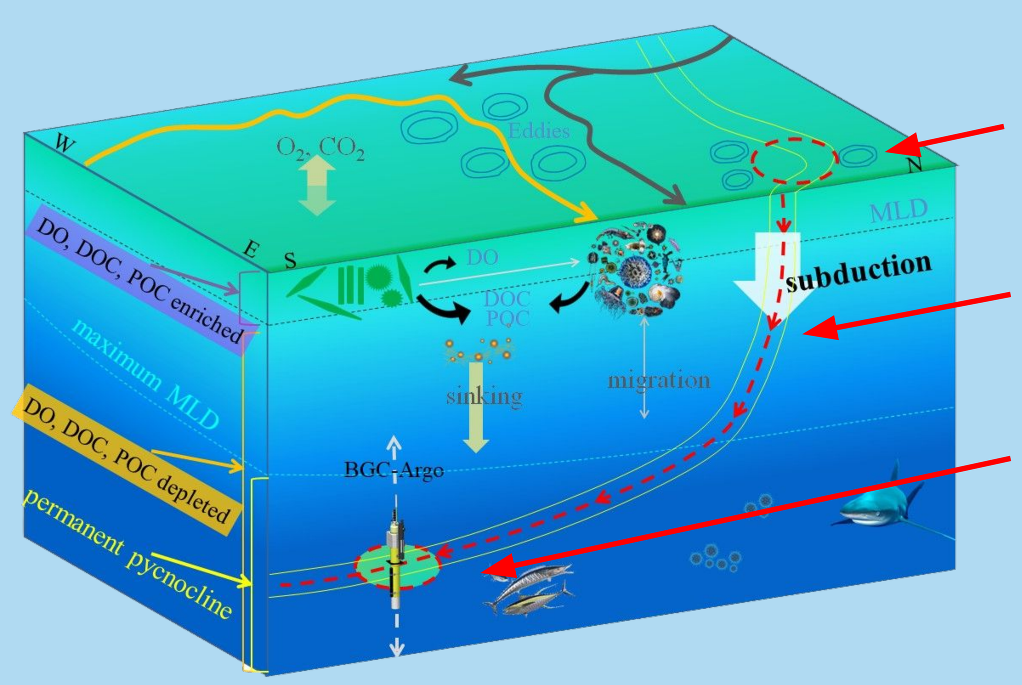


Figure 2: Wintertime and summertime cross sections of Southern Ocean Water. Mixed Layer (ML), Winter Water (WW), and Circumpolar Deep Water (CDW) are marked. Surface water heat gain determines the formation of WW during the summer. From Spira et al. (in review).

How does the formation of Antarctic Winter Water connect to the carbon cycle?

Eddy Subduction Pump (ESP)



Eddies are small, localized circulation events that form as offshoots of larger circulation patterns.

Because of their circular movement, they can pull surface water to lower depths.

An **ESP anomaly** occurs when a sampling device runs into this surface water, detecting a seemingly random change in water characteristics.

Figure 3: Eddy Subduction Pump system. From Chen et al. (2021).

ESP anomalies are detected when there is a **spice anomaly and an AOU anomaly at the same depth**. Spice is a temperature/salinity variable that distinguishes water masses and AOU is used to determine how long it has been since the water in question was at the surface. ESP anomalies may indicate **carbon subduction** (the movement of carbon from the atmosphere to the ocean for storage) because the surface water brings any dissolved particles with it as it travels.

Biogeochemical-Argo Floats

Biogeochemical-Argo floats have been deployed across the Southern Ocean for years and have collected data on temperature, salinity, nitrate, oxygen, and more. The floats descend to a depth of 2,000m, collect data as they rise to the surface, transmit that data, and repeat the process. Referencing Michael Chen's ESP anomaly detection code as well as literature on the subject, a Winter Water detection algorithm was developed. This algorithm required a **temperature decrease** to occur, the water to be **less than 2℃**, and the temperature inversion to occur **below the ML.** **Figure 5** includes examples of profiles with WW, ESP anomalies, and both.

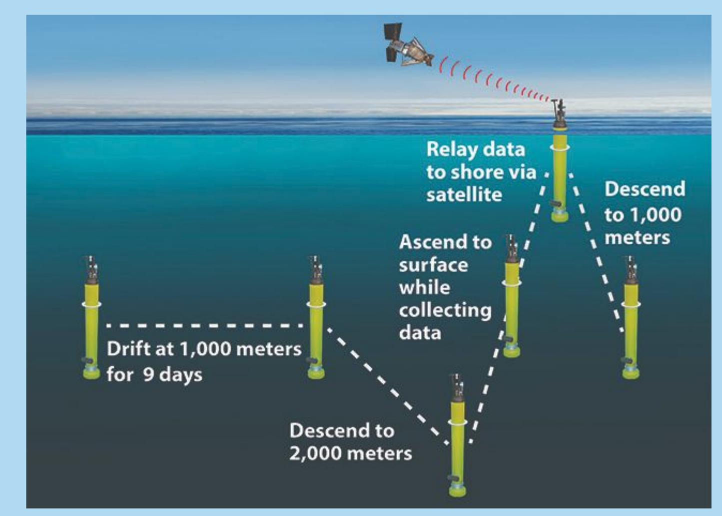


Figure 4: Data collection cycle by BGC-Argo floats. From Kim Fulton-Bennett © 2020 MBARI.

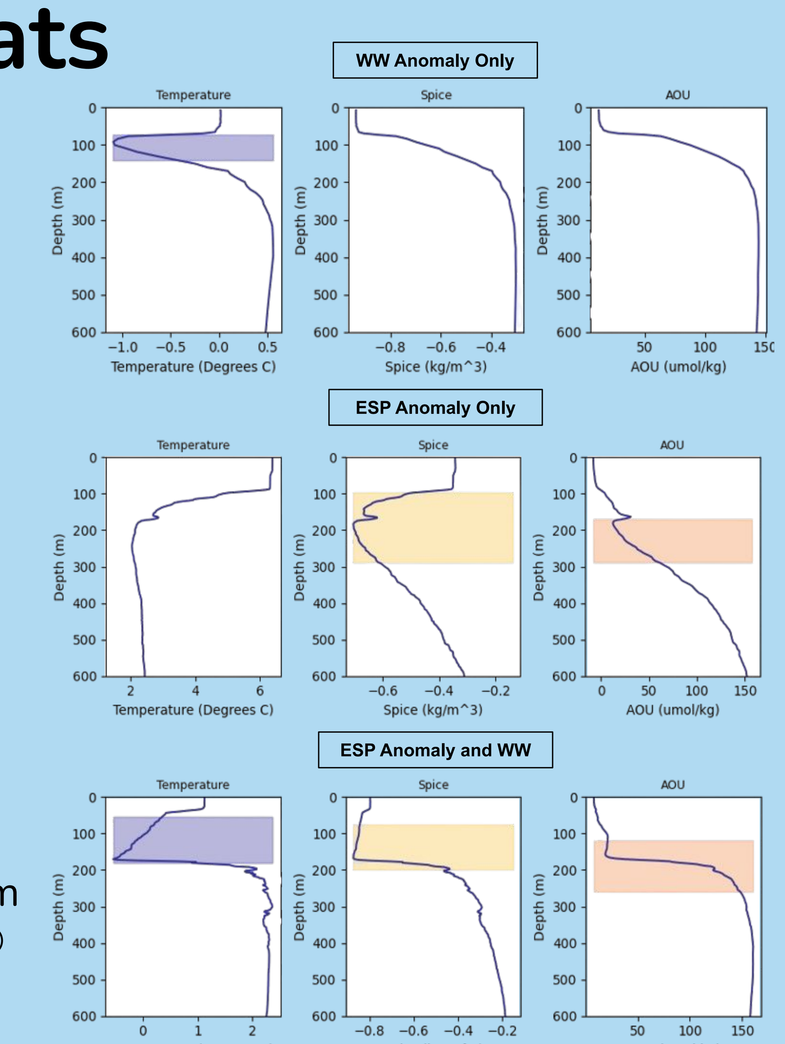


Figure 5: Temperature, spice, and AOU vs depth diagrams for 3 example Southern Ocean profiles. The first is a Winter Water only profile, the second an ESP anomaly only profile, and the third a profile with both.

Results

Figure 6 reveals that Winter Water and ESP anomalies have a strong geographic correlation. There is significant overlap in their locations and both appear to be **bounded by the Polar Front**.

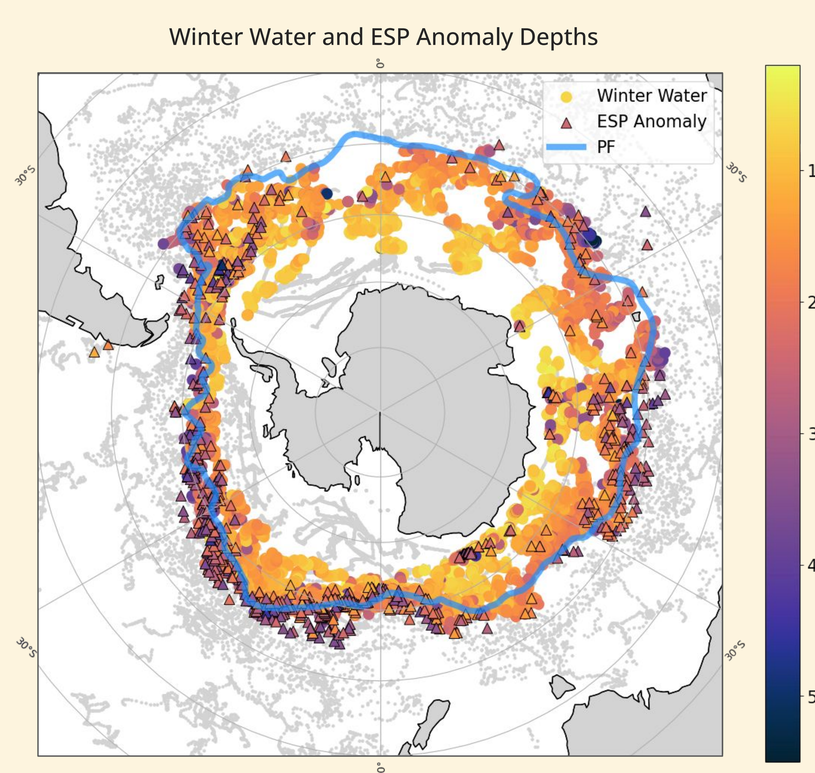


Figure 6: Map of all Southern Ocean profiles collected with Winter Water and ESP anomaly points colored by depth. A strong geographic correlation is depicted by their overlap. The Polar Front is marked in blue.

Not only do these events occur in similar locations but in water of similar characteristics. **Figure 7** displays TS diagrams of ESP anomaly and WW points. The left figure shows a strong overlap in their temperature and salinity (physical) characteristics. The right figure illustrates that **⅔ of ESP anomalies are WW as well**, with 2℃ serving as an apparent division between WW and non-WW ESP anomalies.

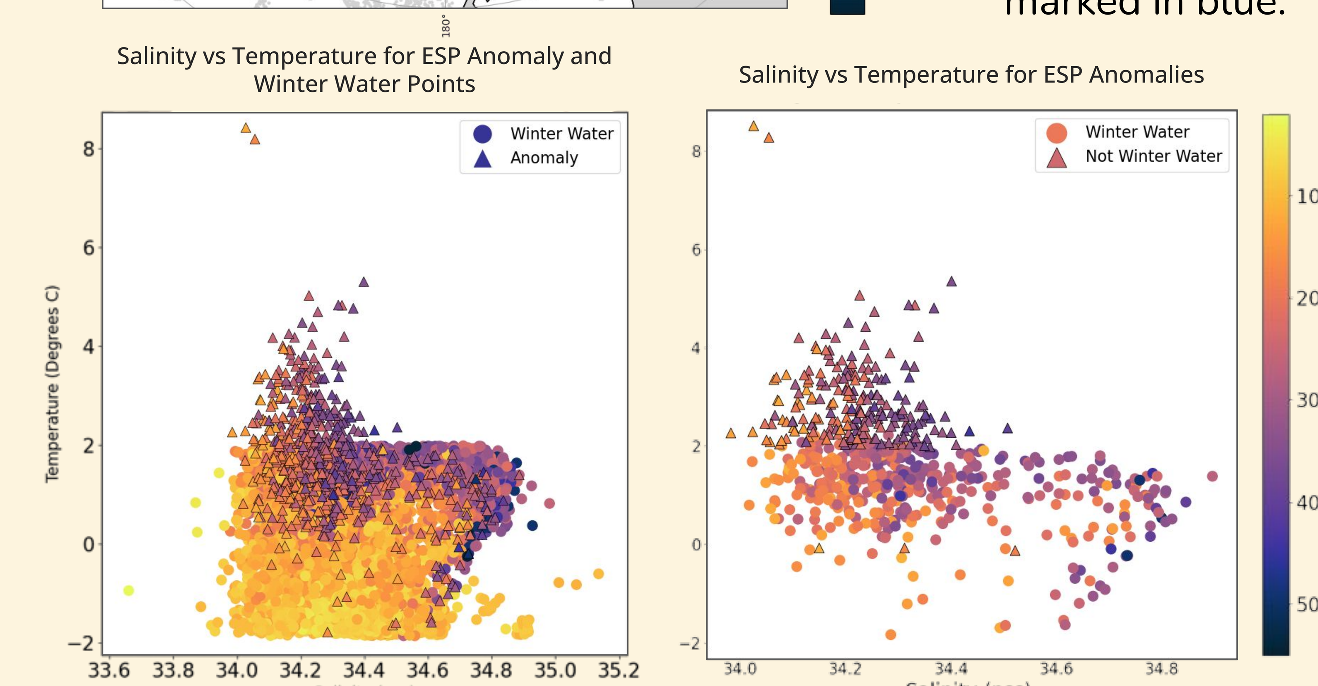


Figure 7: Temperature/Salinity (TS) diagrams for all WW and ESP anomaly points colored by depth (left) and all ESP anomaly points colored by depth and differentiated based on WW status (right). On the left, circles represent WW points while triangles represent ESP anomalies. On the right, circles represent ESP anomalies that are not WW while triangles represent ESP anomalies that are WW.

Given these graphs, there appears to be a **strong correlation** between both the **geographic and physical characteristics** of Winter Water and ESP anomalies.

Discussion

The formation of Antarctic Winter Water is a **critical part of the ESP process**. Because the ESP process is a key part of the global carbon cycle (**Figure 8**), Winter Water must also be important to this carbon flow. Better understanding this biological pump means we **understand the entire system better**. This allows for **better solutions to climate change** that reduce economic burdens, protect human health, and begin to alleviate the disproportionate effects climate change has already inflicted upon traditionally marginalized communities.

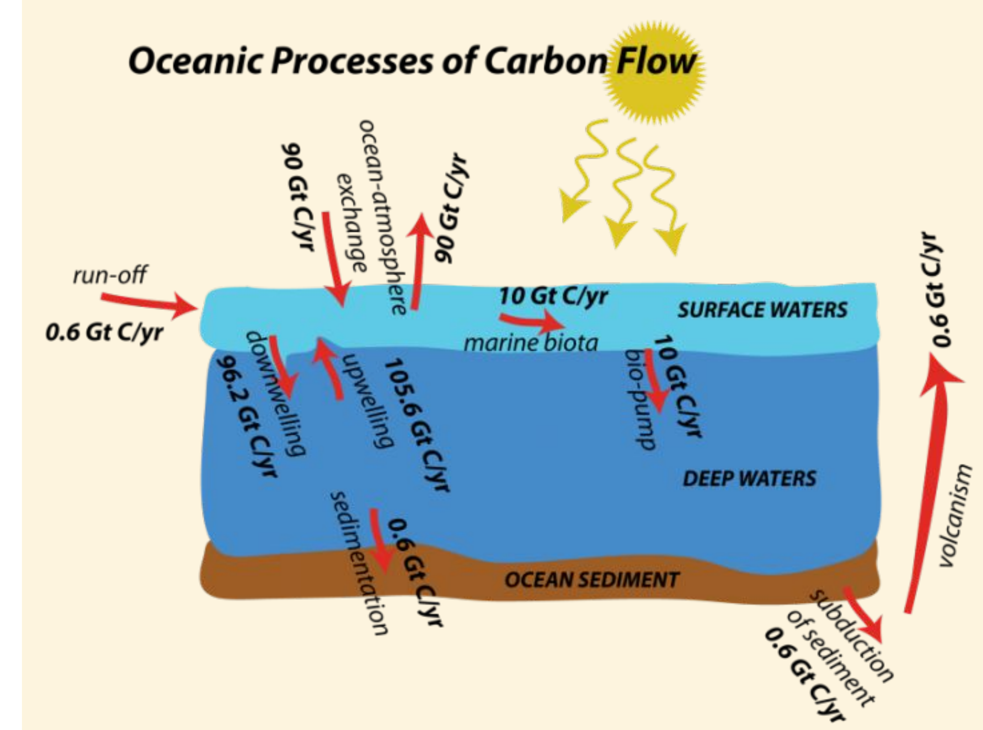


Figure 8: Carbon flow into, out of, and within the ocean. The ESP is part of the bio-pump. From David Bice (Penn State University).

Acknowledgements

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Citations

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