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Introduction:

Eddies can impact the biogeochemistry of our oceans in a number of ways. These mesoscale features can transport, trap, and mix biogeochemical properties as they propagate (Please see supplementary material for more details). The Southern Ocean is not only a region that plays an enormous role in global ocean circulation and nutrient transport, but is also a region that is filled with eddy activity (See Figure 1). It is largely assumed that therefore, with the high potential to impact local biogeochemistry, eddies in the Southern Ocean may play a large role in the biogeochemical structure there.

Current studies that explore Southern Ocean biogeochemistry tend to focus on biological impacts, resulting in most of the current knowledge about properties including oxygen and nitrogen being from the spring and summer months as biology is negligible in winter. In addition, there is limited in situ data in the Southern Ocean, resulting in many studies having to used scattered observations coupled with models. The resolution of these models are larger than the size of most mesoscale eddies and therefore do not include eddies or their impacts. A number of physical studies working towards improving models in the Southern Ocean have discussed how moving forward, eddies must be included to create an accurate understanding of the Southern Ocean.

BGC-Argo Floats:

Biogeochemical Argo Floats like those deployed by the SOCCOM Project have begun to narrow the gap in Southern Ocean knowledge by obtaining data in data-limited regions and seasons. They collect profiles of data including temperature, salinity, oxygen, nitrate, and pH at discrete depths as the rise from 2000m to the surface, repeating a profiling cycle once every 10 days (See Figure 2). In the Southern Ocean, these floats frequently encounter eddies, allowing my lab to begin to explore how they may be impacting Southern Ocean biogeochemistry.

In this study, we aim to determine if there are differences between cyclonic (clockwise), anticyclonic (counter-clockwise) and non-eddy biogeochemical profiles in the Southern Ocean. In this presentation, we focus on properties of temperature, salinity, oxygen and nitrate, and will also be examining Dissolved Inorganic Carbon (DIC) as part of the overall study. If there are differences between eddy types, this could have implications on both our current understanding of the biogeochemical structure in the Southern Ocean, as well as have a direct impact on the quality of biogeochemical models from the Southern Ocean.

Eddy Altimetry and Eddy Matchups:

This study uses all available profiles from the SOCCOM network in the Pacific Basin of the Southern Ocean; roughly 10,000 profiles. We use the AVISO eddy database, which identified eddies with satellite altimetry (See Figure 5), to identify which of these profiles were obtained inside an eddy. If a profile at is within 1.5 radius of the center of an eddy at a time given by the AVISO database, we store is as an eddy profile as well as store the eddy type. All profiles outside of 1.5 radius are stored as non-eddy profiles (See figure 4). Many consider 1 radius to be the boundary of an eddy, however, we consider 1.5 radius for this study because when using a Gaussian approximation for an eddy, a radius of 1.5 has velocities that are 25% of the maximum velocity at 1 radius.

Regional and Temporal Segregation of Profiles:

On top of eddy type, we additionally separate all of our profiles by region and season. We separate by region because the Antarctic Circumpolar Current is made up of Fronts and Frontal Zones, with each zone having different distinct biogeochemical properties. In addition, there is large seasonal variability in the Southern Ocean which also directly impacts changes in biogeochemistry (Please see supplementary material for more details). As a result, we have groupings of float profile data organized by eddy type, frontal zone, and season (Figure 5).

Calculating Anomalies, Statistical Mean and Standard Error:

Creating our groupings of profiles helps limit the bias in our results, but variability including large-scale variability may still be present in our profiles. In an effort to remove any additional variability that cannot be removed by geographic and temporal organization, we calculate anomalies using gridded averages from World Ocean Atlas as our mean background state (See Figure 6). Our anomalies highlight the small variations between WOA and the float profiles and we consider the differences away from zero as being caused by eddies.

To compare each of our groupings to one another, we calculate a statistical mean anomaly profile and standard error of the anomaly profiles (See Figure 7). Areas were the standard error between different eddy types with in the same grouping do not overlap are considered areas where the eddies are significantly different from one another.

Comparing Biogeochemical Properties between Eddy Types:

When comparing cyclonic, anticyclonic and non-eddy profiles to one another across all biogeochemical properties, we found many instances where the eddy types were all significantly different from one another. (See Figure 8 as well as Supplementary Material for additional results). Using the mean float profile as a baseline, we also see evidence of potential upwelling and downwelling in our profiles.

For example, Figure 8 shows cyclonic, anticyclonic, and non-eddy profiles in the Subantarctic Zone across all seasons. While cyclonic profiles tend to only be significantly different than non-eddy profiles at specific depths in winter and spring, anticyclonic profiles are consistently statistically different at most depths. We notice differences between seasons where the statistically significant signal is stronger or weaker. For example, in spring the anticyclonic oxygen profile is dampened compared to the same signal in other seasons. Furthermore, the oxygen anomalies take on a shape where there is a more negative oxygen anomaly at the surface than at depth. Altogether, this tells us that there appears to be a downwelling signal across all seasons, which is characteristic of anticyclonic eddies. The dampening of this signal in spring may suggest biological activity where there is less available oxygen near the surface to be down-welled.

When comparing this zone to the other zones of our study (Polar Frontal Zone and Southern ACC Zone), we do not observe the strong downwelling signal in anticyclonic eddies. Instead, cyclonic eddies appear to become more statistically significant across all seasons and even provide evidence of upwelling. However, these signals are not as clear across the rest of the biogeochemical properties we examine (See supplementary material for additional results).

Summary and Next Steps

We found that there are significant differences between eddy-types of different groupings in the Southern Ocean, and are currently in process of finishing up our results and defining when and where the major differences take place.

However, when looking through our results, we found that our non-eddy profiles for oxygen and nitrate, especially in the Polar Frontal Zone and Southern ACC Zone, did not return to zero and instead had an anomaly value. The WOA data of oxygen and nitrate is averaged over 60+ years, while our float data represents less than 10 years. We believe we are seeing interannual variability in the WOA averages that results in bias in our anomalies. Since this signal is likely in all of our anomalies, we will be calculating a double anomaly for oxygen and nitrate where we use the non-eddy profiles as our background state. As a result, we hope to remove any interannual signal and be left solely with small variations that can be interpreted as being caused by eddies.