Analyzing Oceanographic Trends: Temperature and Salinity Variability in the Pacific

Vincent Weng

Introduction

This memo examines the variability of temperature and salinity in the Pacific Ocean, leveraging observational data to identify large-scale patterns and trends. The Argo program provides a global network of autonomous floats that collect high-resolution measurements of temperature, salinity, and pressure throughout the world's oceans. These floats periodically dive to several thousand meters, transmitting their data via satellite to offer valuable insights into oceanic conditions. In this study, we analyze daily temperature and salinity observations collected throughout 2020 in the Pacific Ocean, examining how these properties change with depth, time, and location. By quantifying these variations, we aim to enhance our understanding of large-scale oceanographic processes and their implications for climate and circulation dynamics. Temperature and salinity are key indicators of oceanic processes, influencing water density, currents, and climate interactions. Understanding oceanographic variability is essential for studying climate dynamics, ocean circulation, and marine ecosystems.

Methods

We preprocess the data by interpolating for consistency, excluding shallow-depth measurements due to surface variability, and using pressure as a proxy for depth to examine vertical oceanographic structures. To ensure efficiency while maintaining representativeness, we randomly subsample the data and remove incomplete profiles. We then analyze temperature and salinity distributions across latitude, longitude, and time to identify spatial and seasonal trends, further exploring their relationship by plotting profiles and computing the Pearson correlation coefficient. Depth variation is assessed through mean temperature and salinity profiles and their gradients relative to pressure.

To quantify the representativeness of temperature and salinity profiles, we classify them using spatial depth, where values closer to 1 indicate typical profiles and values near 0 denote outliers. Statistical depth is analyzed across latitude, longitude, and time, followed by a log transformation to enhance contrast, spreading out less representative profiles. This analysis is conducted separately for the Northern and Southern Hemispheres to highlight hemispheric differences driven by seasonal and large-scale oceanographic processes.

To capture large-scale patterns while reducing data complexity, we apply quantization using support points, discretizing temperature and salinity into 10 representative levels. This method preserves key statistical properties, facilitating structured comparisons across locations and depths while enhancing the interpretability of dominant temperature-salinity profiles. Finally, for dimensionality reduction, we apply Principal Component Analysis to extract primary modes of variation to explore temperature-salinity relationships across depth and location. To visualize spatial patterns, we map the top 10% and bottom 10% of PCA scores onto geographic locations, highlighting regions with the most extreme temperature variations.

Results

Analysis of temperature and salinity across Pacific oceanic profiles reveals a moderate positive correlation, with a Pearson correlation coefficient of 0.6157. The p-value (9.3251e-12) indicates that this correlation is statistically significant, suggesting that as ocean temperature increases, salinity tends to increase as well. Figures 1 and 2 illustrate this relationship, along with temperature and salinity variations across depth and pressure.

The coefficients of variation of uncertainty for temperature depth are 0.1275 across latitude, 0.0596 across longitude, and 0.0379 across time, as shown in Figure 3. For salinity depth, the corresponding values are 0.3333 across latitude, 0.2518 across longitude, and 0.0214 across time, with graphical representation in Figure 4. When analyzed separately by hemisphere, the Northern Hemisphere temperature depth uncertainty is 0.1274 across latitude, 0.0597 across longitude, and 0.0599 across time, while the Southern Hemisphere values are 0.4787 across latitude, 0.0562 across longitude, and 0.0283 across time (Figure 5). Similarly, for salinity depth, the Northern Hemisphere shows 0.4997 across latitude, 0.2063 across longitude, and 0.0153 across time, while the Southern Hemisphere values are 0.2859 across latitude, 0.2110 across longitude, and 0.0354 across time (Figure 6).

The quantized temperature and salinity profiles (Figure 7) are grouped into 10 discrete levels, capturing variations across the Pacific Ocean. Both temperature and salinity exhibit a strong horizontal (latitudinal) structure, with quantized levels forming bands that follow latitude rather than longitude. This suggests that variations in these properties are more structured along latitudinal gradients than longitudinal differences.

Figure 8 presents the spatial distribution of the top 10% and bottom 10% of PCA scores for temperature. In PC1, the highest scores are concentrated in the western and equatorial Pacific, while the lowest scores are found in the southern Pacific. For PC2, the highest scores are primarily located in the southwestern Pacific, while the lowest scores cluster in the central and northern Pacific. In PC3, the highest and lowest scores form band-like structures, with high scores appearing in the western and central Pacific, and low scores primarily in the southern Pacific. Similarly, Figure 9 presents the same analysis for salinity. In PC1, the highest scores are concentrated in the western Pacific, while the lowest scores are in the northern Pacific. For PC2, the highest scores appear in the northern Pacific and southern latitudes, while the lowest scores cluster in the central Pacific. In PC3, the highest and lowest scores form structured clusters, with high scores in the western Pacific and low scores distributed across the northern and central Pacific.

Interpretation

The results reveal key insights into temperature and salinity variability across the Pacific Ocean in 2020. The moderate positive correlation between temperature and salinity suggests a linked relationship likely influenced by ocean circulation, evaporation, and mixing dynamics. This finding aligns with known oceanographic principles, where regions of higher temperature often coincide with higher salinity due to increased evaporation and reduced freshwater input. The quantization results further demonstrate that temperature and salinity variations exhibit strong latitudinal structuring rather than longitudinal, suggesting that large-scale climatic and oceanic forces, such as equatorial currents and polar water masses, play a critical role in shaping ocean conditions. Additionally, hemispheric differences in uncertainty coefficients highlight distinct seasonal and climatic influences, with higher variability in the Southern Hemisphere potentially linked to stronger ocean mixing and current-driven processes.

The PCA findings reveal dominant spatial patterns in temperature and salinity variability. PC1 captures broad-scale oceanographic differences, with high scores in the western and equatorial Pacific and low scores in the southern Pacific, potentially reflecting major current systems such as the North and South Pacific Gyres. PC2 and PC3 highlight additional structures that align with regional and seasonal influences, such as upwelling zones and thermocline shifts. Moreover, the coefficients of variation of uncertainty across time indicate that temperature and salinity variability remains relatively stable over short-term periods, with lower uncertainty across time compared to latitude and longitude. This suggests that seasonal fluctuations and spatial differences contribute more significantly to variability than day-to-day changes in 2020.

In conclusion, these findings suggest that temperature and salinity are closely linked and that their variability follows strong latitudinal trends. Some factors can include major oceanic processes such as gyres, upwelling, and mixing drive spatial differences. The uncertainty analysis further suggests that spatial and seasonal factors contribute more significantly to oceanographic variability than short-term fluctuations. Overall, this memo provides a statistical and spatially structured view of temperature and salinity patterns, contributing to a deeper understanding of large-scale oceanographic processes in the Pacific Ocean.

Figures

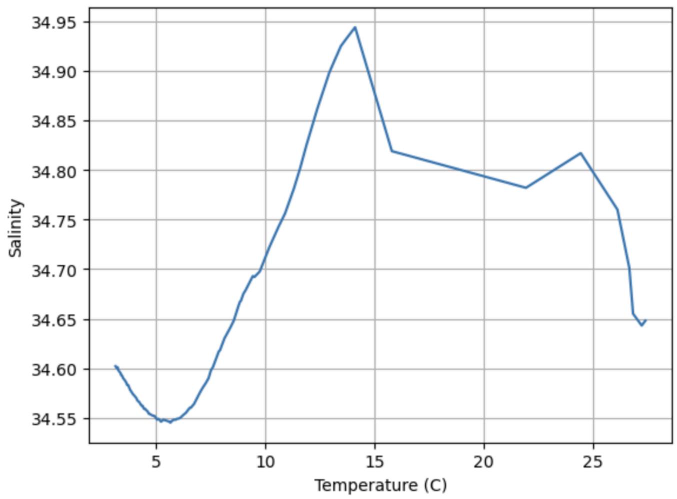


Figure 1: Salinity & Temperature (C)

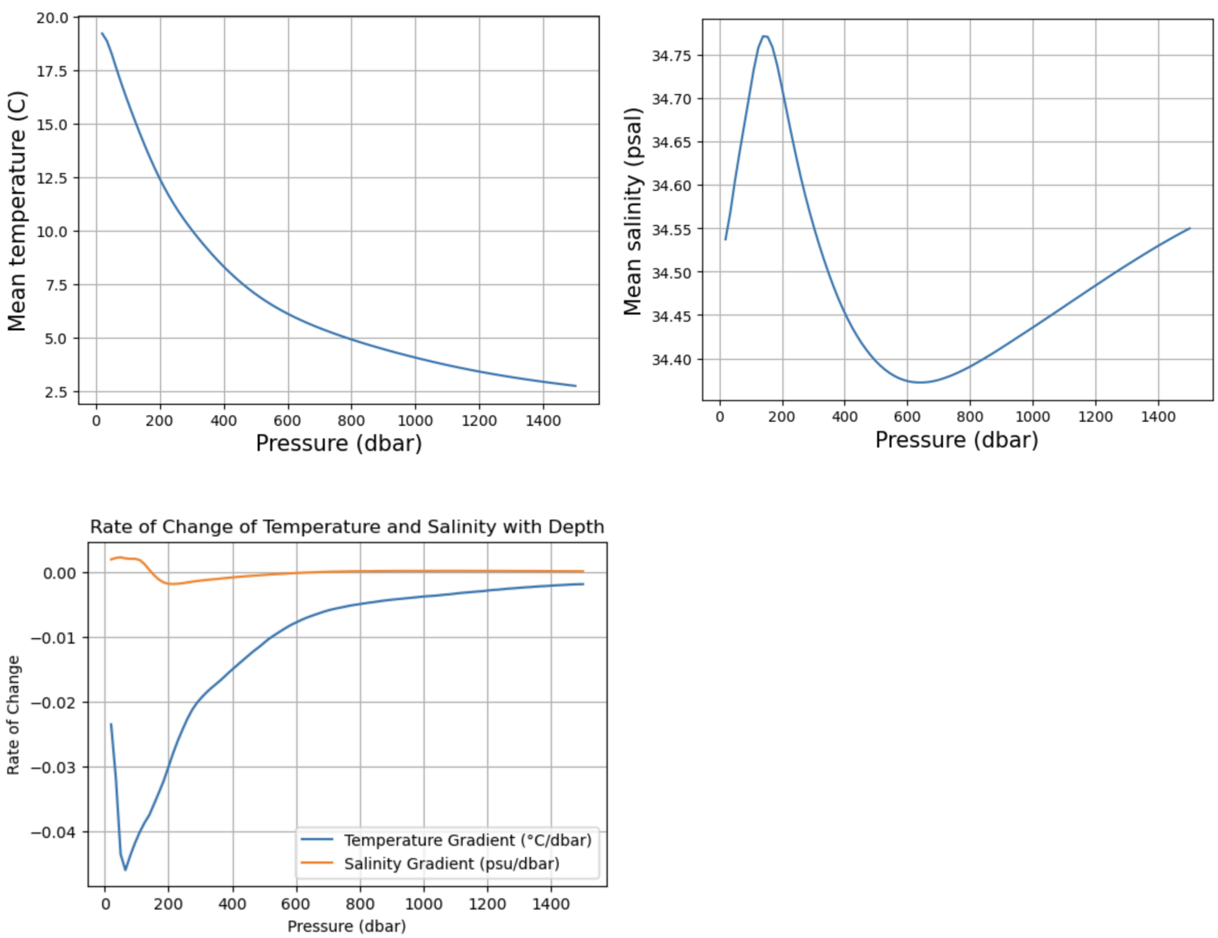
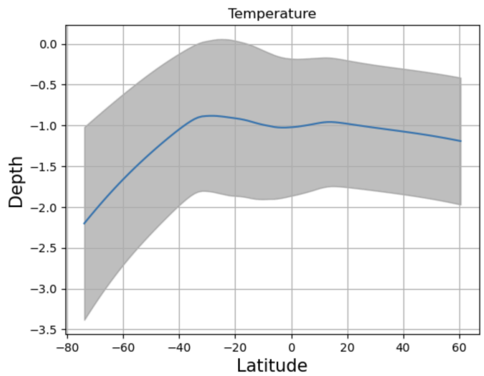
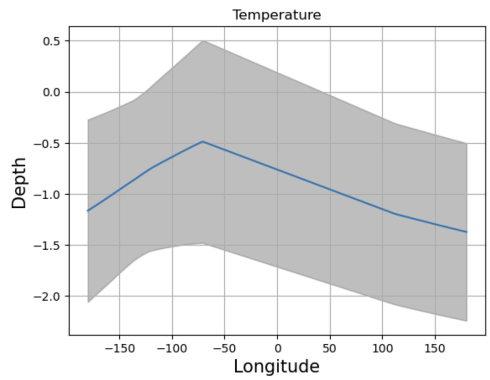


Figure 2: Mean Temperature and Salinity vs. Pressure (dbar)



Coefficient of Variation (CV) of Uncertainty: 0.12752290987345452



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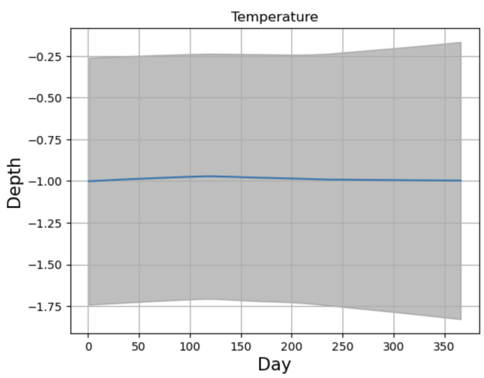
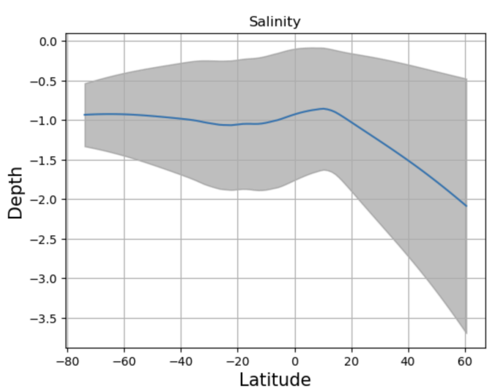


Coefficient of Variation (CV) of Uncertainty: 0.037963625078890284

Figure 3: Temperature Depth Uncertainty Across Latitude, Longitude, and Time



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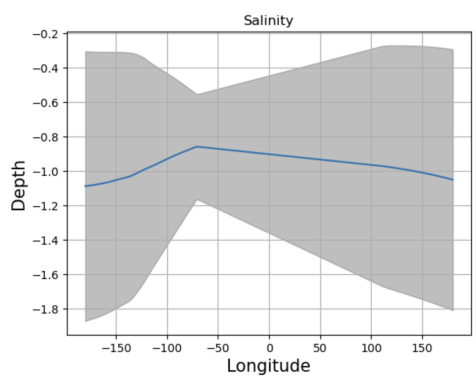

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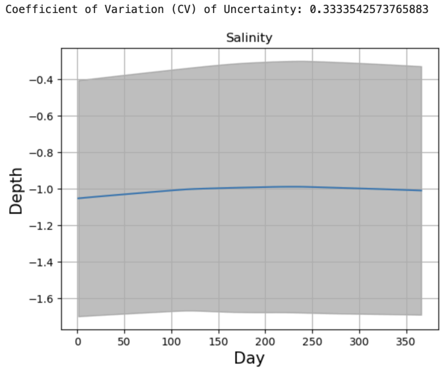
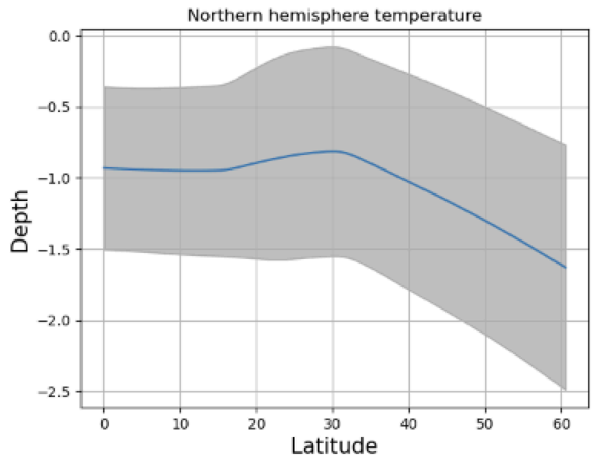
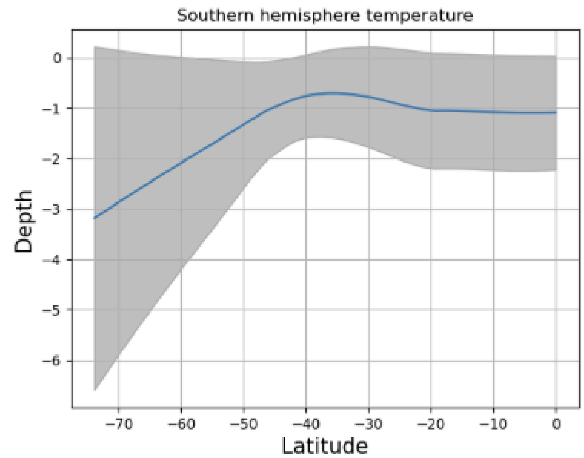


Coefficient of Variation (CV) of Uncertainty: 0.021402373599087025

Figure 4: Salinity Depth Uncertainty Across Latitude, Longitude, and Time





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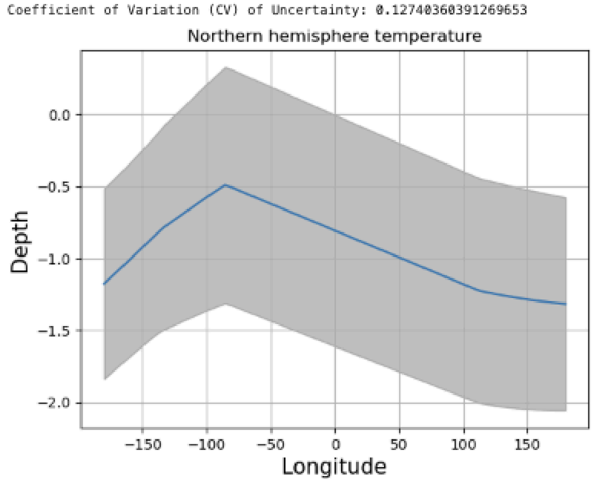

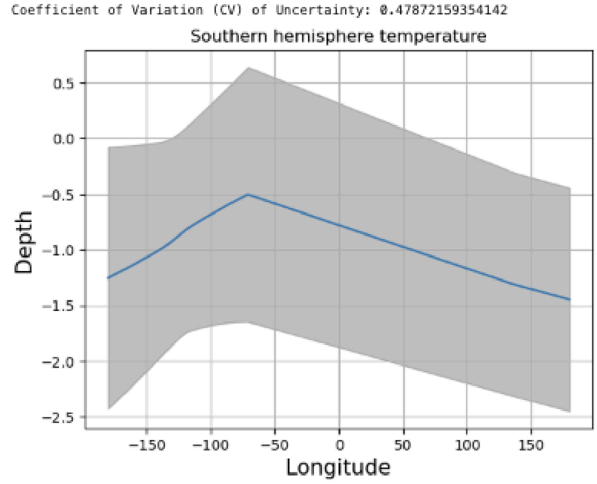

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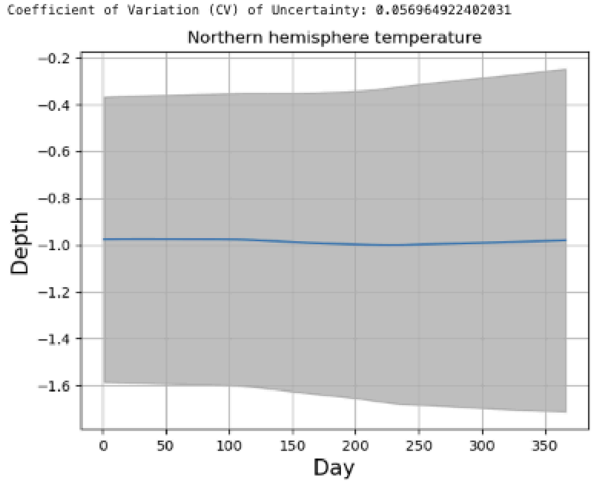
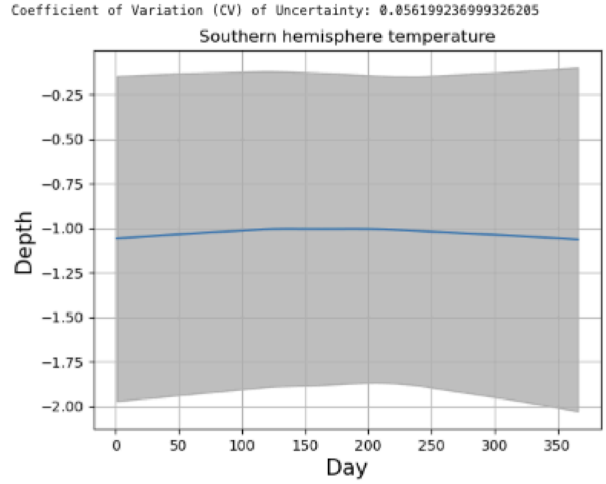
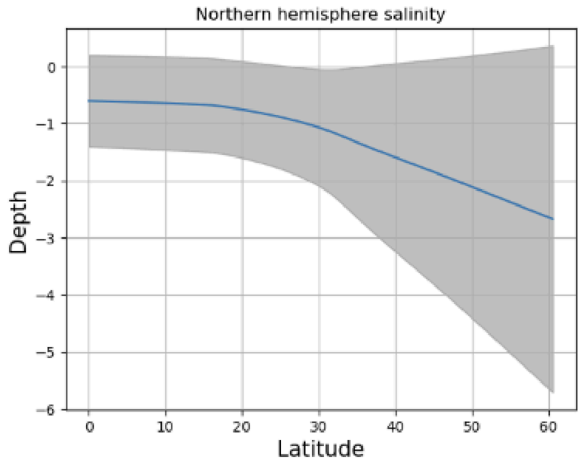




Coefficient of Variation (CV) of Uncertainty: 0.05959180040759956

Coefficient of Variation (CV) of Uncertainty: 0.028250945948814016

Figure 5: Temperature Depth Uncertainty in Southern Hemisphere



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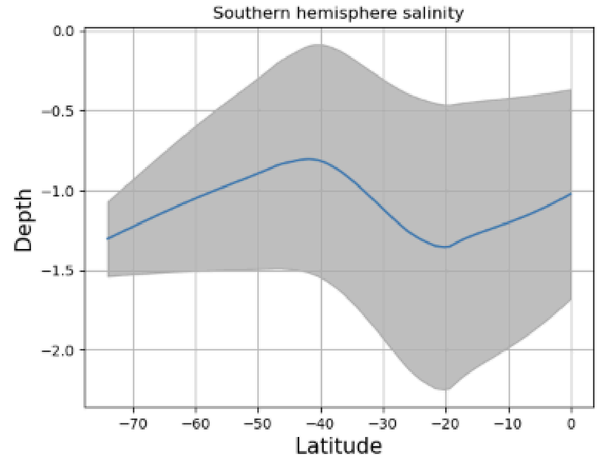

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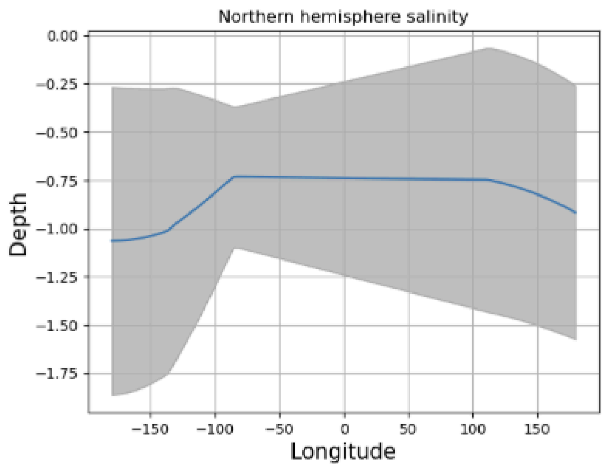

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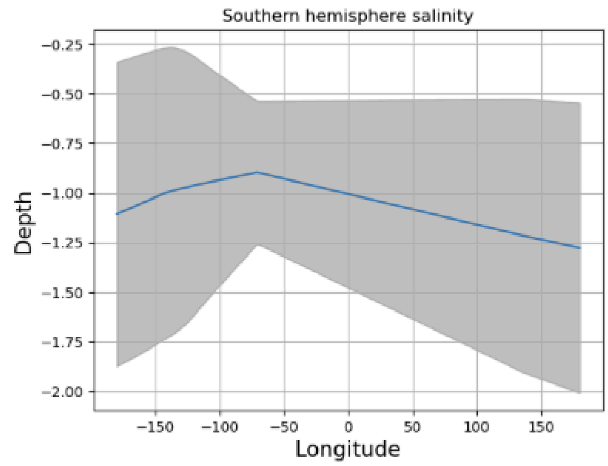

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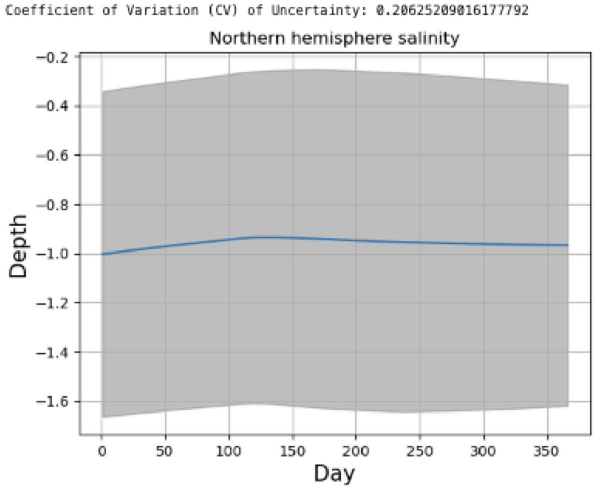

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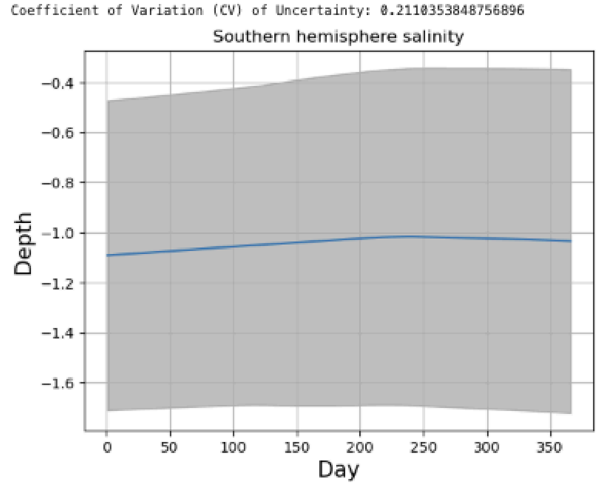

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Figure 6: Salinity Depth Uncertainty in Southern Hemisphere

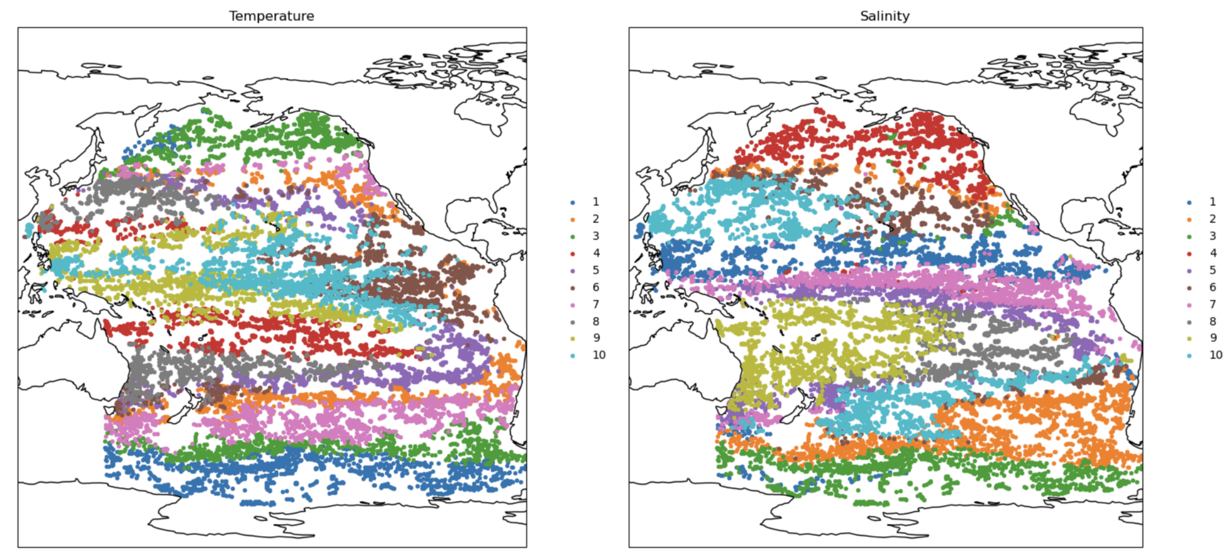

Figure 7: Spatial Distribution of Quantized Temperature and Salinity Profiles

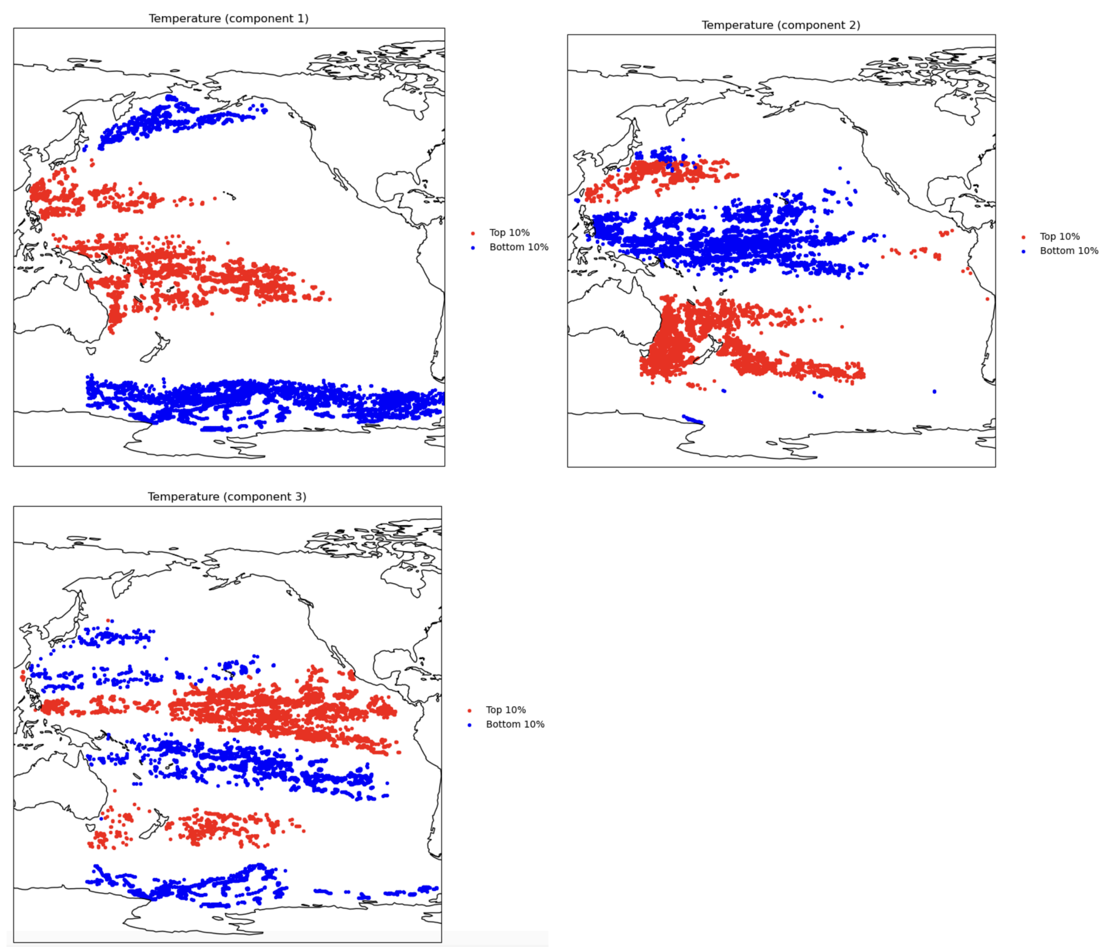

Figure 8: Spatial Distribution of the Top and Bottom 10% of PC Scores for Temperature

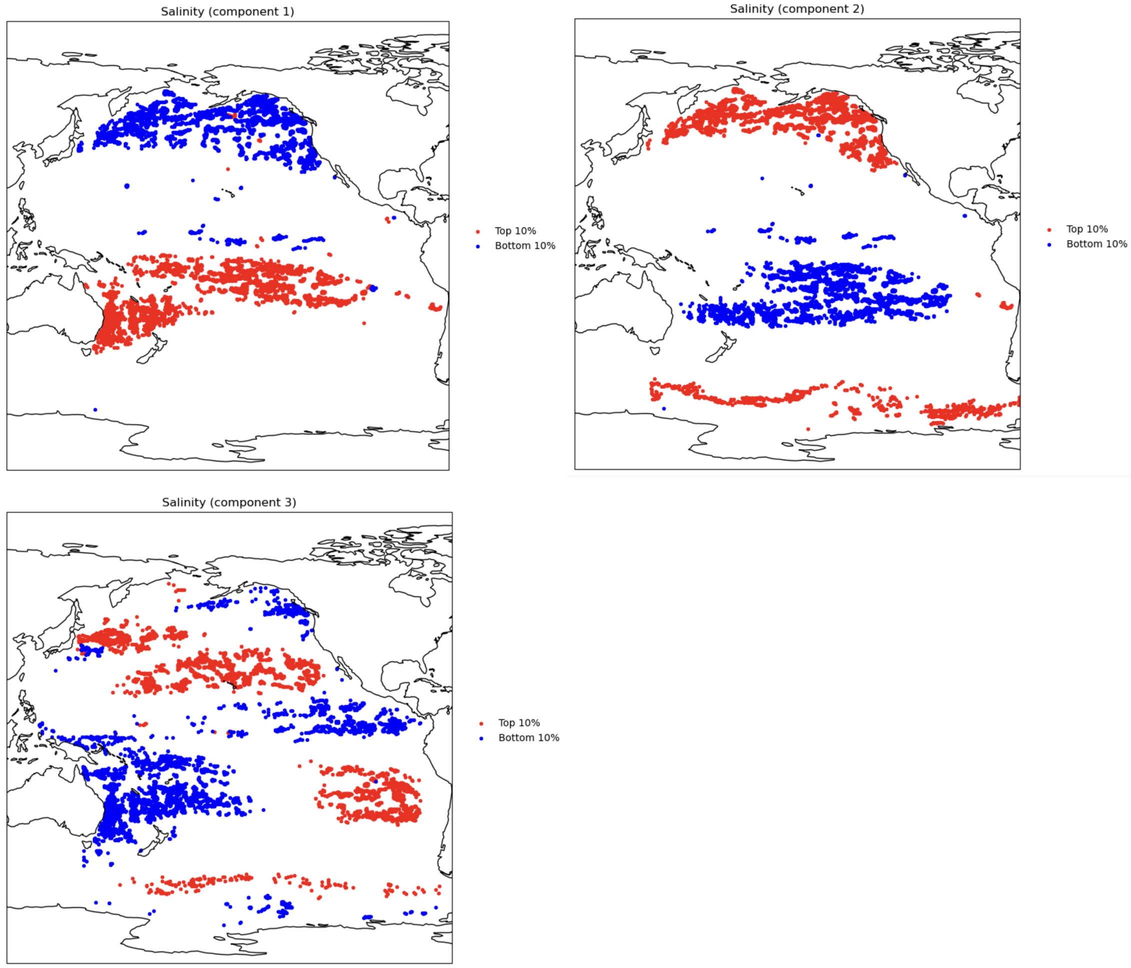

Figure 9: Spatial Distribution of the Top and Bottom 10% of PC Scores for Salinity

Focus	
Methods	
Writing	
Findings	