Analysis of 2023 Ocean Temperature Field Anomalies using Argo Data

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Introduction

The year **2023 was the warmest in the modern record**; mean ocean temperatures hit 1°C higher than pre-industrial temperatures for the first time. Higher ocean temperatures are an important ingredient for severe weather formation, as well as increasing ocean stratification, raising sea-levels, and impacting marine ecosystems. In this project, we analyze and compare 2023's **global** and **regional** ocean temperature fields with those of the previous 30 years, identifying **key features** of and **contributors** to 2023's unusual temperature field.

Background

The Argo program, a decades-long international collaboration to maintain a comprehensive ocean observation network, has revolutionized understanding of temperature structure in the world ocean. Argo's core floats allow the structure of the world ocean's temperature field to be spatiotemporally compared, providing a valuable resource for analyzing Earth's climate system.

This project used **Random Forest Regression Ocean Maps** (RFROM: Johnson and Lyman, 2023). These are **1° × 1° × 1-month** ocean temperature maps constructed using machine learning techniques. This random forest regression utilizes satellite data as predictors and ocean temperature from Argo floats and other sources as training data to resolve temperature data on a smaller scale, allowing for the mapping of mesoscale features like eddies.

Methodology

We built a model (e.g. **Figure 1**) of the global temperature field based on 30 years of temperature data (1993-2022). The model contains **a mean** (computed for 2008, mean time in the series), **a linear trend** over the record, and **a seasonal cycle**, consisting of sine and cosine harmonics at 1-6 cycles per year. We then subtracted modeled data from each year's temperature field to examine the residual temperature field.

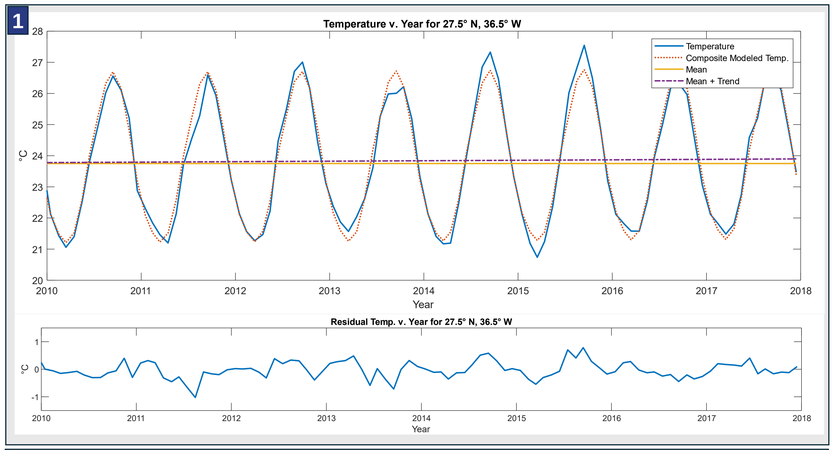


Fig. 1: Example breakdown of the modeling process and residual temperature calculation for the 2.5 dbar pressure at 27.5°N 36.5°W.

Results

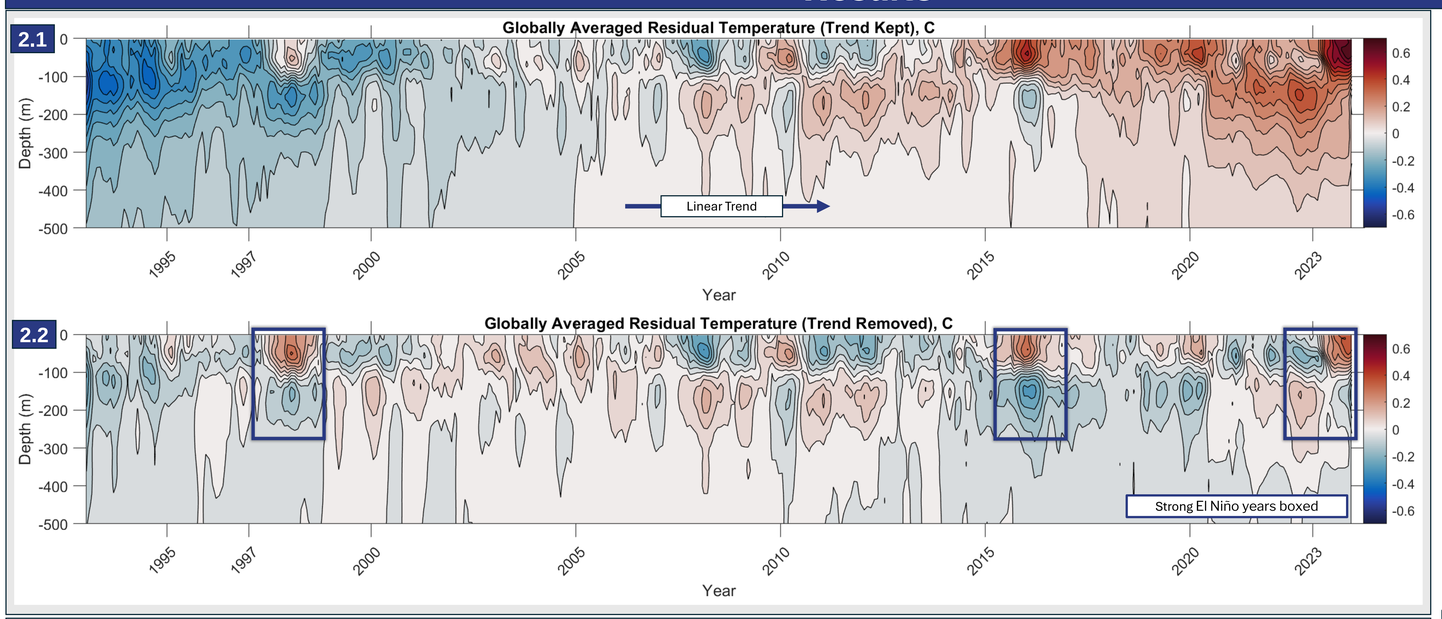


Fig. 2: Globally averaged residual temperature fields from the surface to 500 m over the last 31 years (1993-2023). **2.1** Temperature anomalies with the trend included, highlighting overall warming. **2.2** Anomalies without the linear trend. Strong El Niño and La Niña signals are visible in 2.2; strong El Niño years (1997/98, 2015/16, and 2023/24) are boxed.

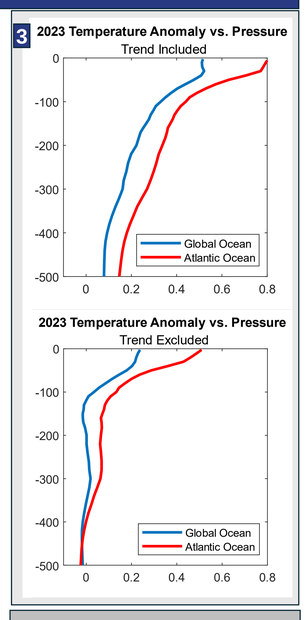


Fig. 3: Temperature anomalies in the global ocean compared to the Atlantic in 2023, with and without trend (as in **Fig. 2**). The North Atlantic at 2.5 dbar was 0.3°C warmer than the global ocean average.

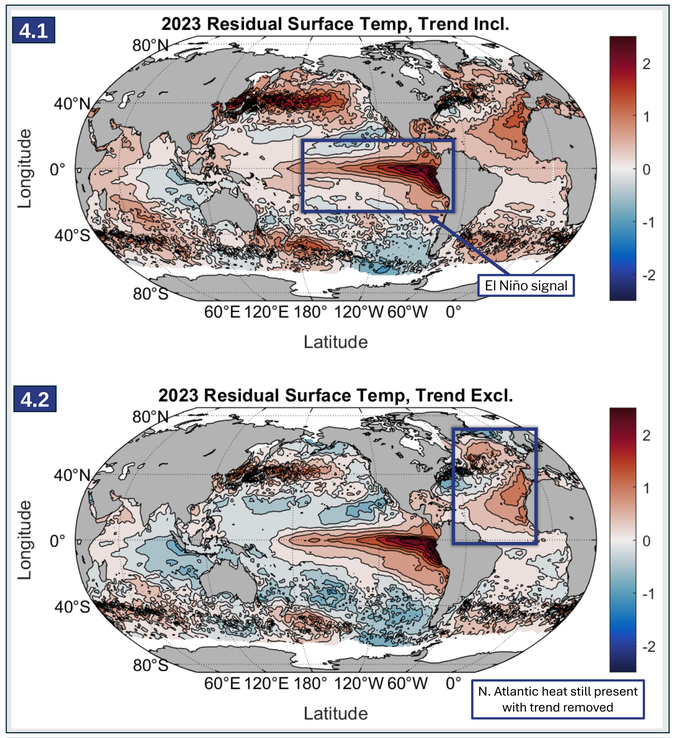


Fig. 4: Residual 2.5 dbar temperature plots for 2023. **4.1** Residual temperature with the trend included; **4.2** Residual temperature field without the linear warming trend. Strong surface warming is present in the North Atlantic.

North Atlantic surface warming in 2023 exceeded the linear trend rates (**Figures 3 and 4**), suggesting an accelerating trend or marine heatwave. Extreme surface warming gives way to **marine stratification**; we found a 7.7% **rise in stratification** in the North Atlantic, compared to 4.9% globally.

Conclusions & Future Work

We found that the global **linear warming trend**, the build-up of a **strong El Niño**, and unprecedented **marine heatwaves**, particularly in the North Atlantic, contributed to 2023's record ocean temperatures. We also found evidence that accelerated rates of surface warming in 2023 resulted in **increased stratification**, with particularly large increases in the tropical North Atlantic.

Implications of stratification on severe weather will be explored in future work.

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