[S02, P13]

Long-term sea level rise rates in the southwestern East Sea (Japan Sea) from 1993 to 2023: Focusing on thermosteric and halosteric effects

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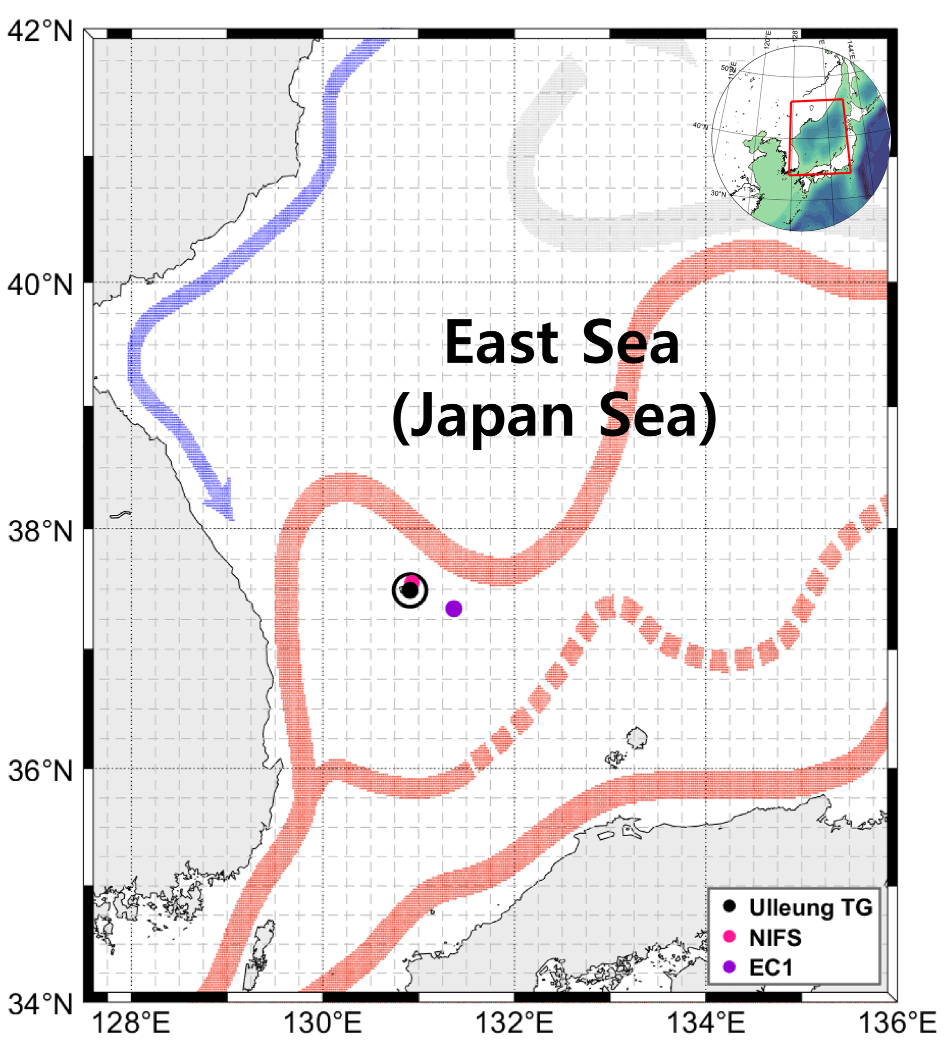
Introduction

- Rapid sea level rise exceeding 7 mm/yr has been observed in the southwestern East Sea (Japan Sea) near Ulleung Island during 1993–2020. (Lee et al., 2022; Lee et al., 2024)
- Sea level of the East Sea (Japan Sea) is strongly affected by volume transport of Korean Strait. The transport is strongly correlated with atmospheric pressure, surface wind stress, and sea level differences between the Pacific and the East Sea (Lyu and Kim, 2005; Han et al. 2020)
- Limited assessment of steric effects on regional sea level rise in the southwestern East Sea (Japan Sea)

Data and Methods



▶ **Fig. 1**. Site map around Ulleung Island. The black solid circle indicates a 15 km radius. The locations of the tide gauge (black) and temperature–salinity observation stations (magenta and purple) are shown as colored circles. Red and blue arrows indicate major currents in the southwestern East Sea (Japan Sea).

▶ **Table 1.** Data used for estimating sea level rise rates and trends. Each dataset undergoes appropriate QA/QC procedures and annually and seasonally averaged to derive the sea level rise rates.

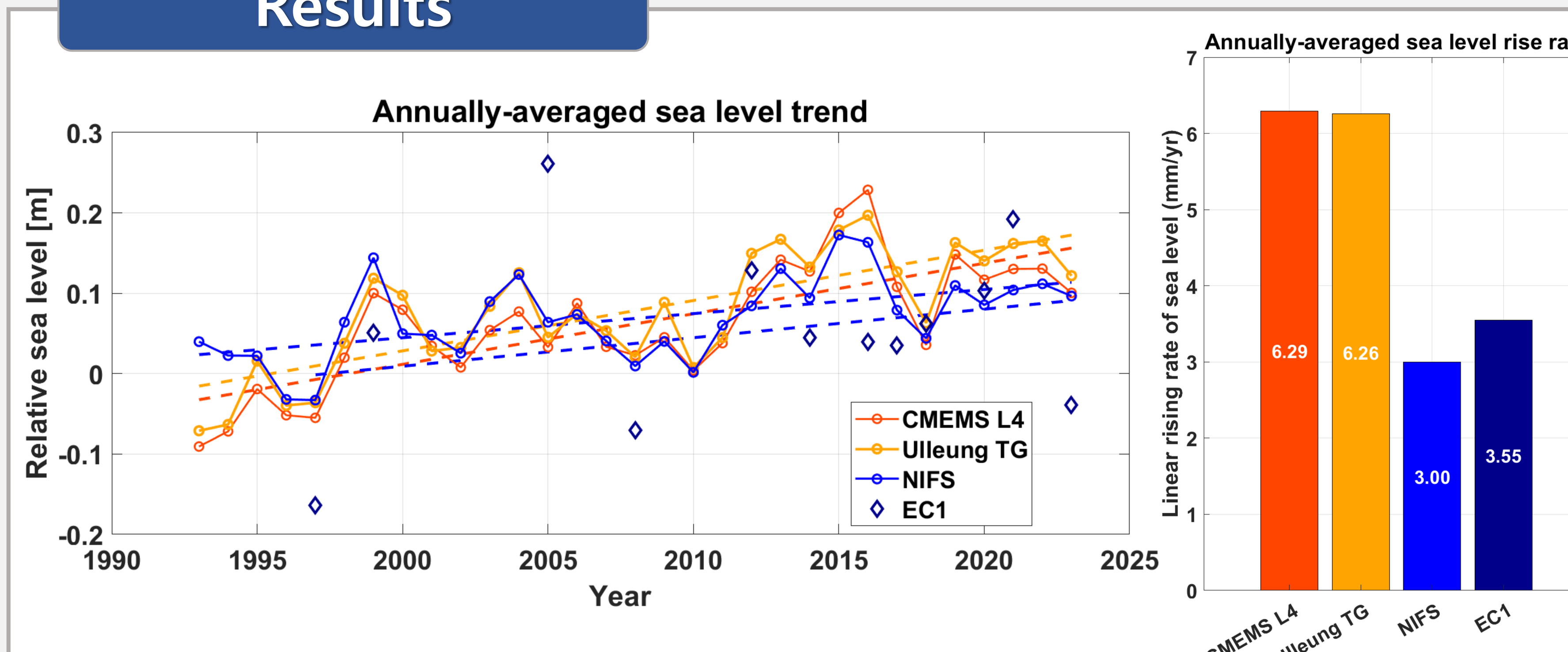
Variables	Data source	Data interval	Period	Resolution
Ulleung Tide gauge (Ulleung TG) [m]	Korea Hydrographic and Oceanographic Agency (KHOA)	Hourly	1993–2023	-
Sea Level Anomaly (SLA) [m]	Copernicus Marine Service (CMEMS)	Daily		0.125°x0.125° Satellite altimeter **Gridded data (L4)**
Temperature [°C], Salinity [PSU]	National Institute of Fisheries Science (NIFS)	Every 2 months		Reference depth: 0-500 m
	Several research cruises (EC1)	Irregular, 13 castings	1997–2023	Full-depth profiling CTD at Ulleung Interplain Gap

➢ **Steric sea level** $= \frac{1}{g}\int_0^{500} \frac{1}{\rho - \rho_0} dP$

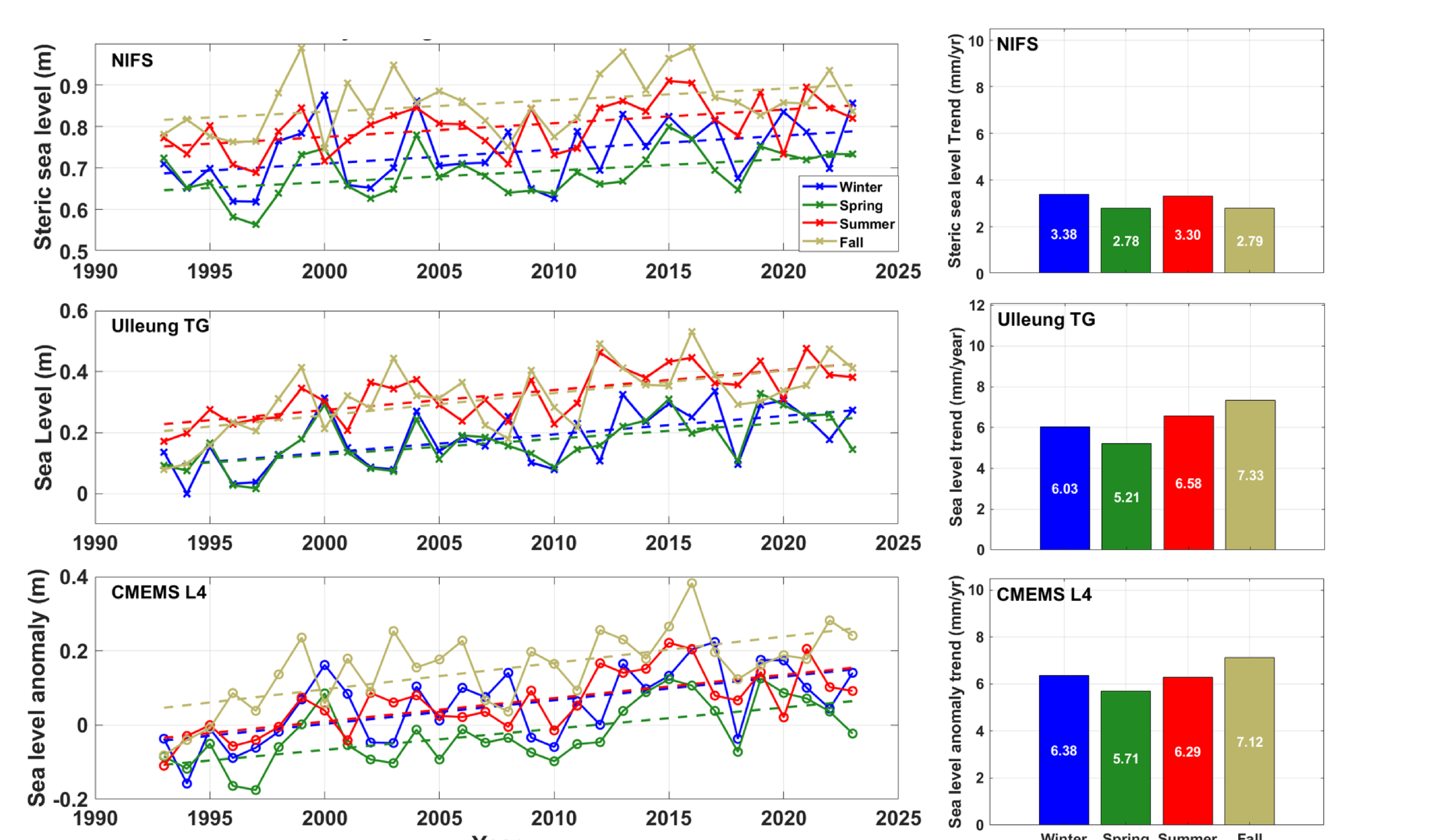
➢ **Rossby radius of deformation** $= \frac{\textit{first baroclinic gravity wave phase speed}}{2\Omega \sin(\theta)}$

- $\rho(Temperature,\ Salinity,\ Pressure)$
- $\rho_{Ther}\ (Temperature,\ 34.5,\ Pressure)$
- $\rho_{Halo}\ (8.98.,\ Salinity,\ Pressure)$

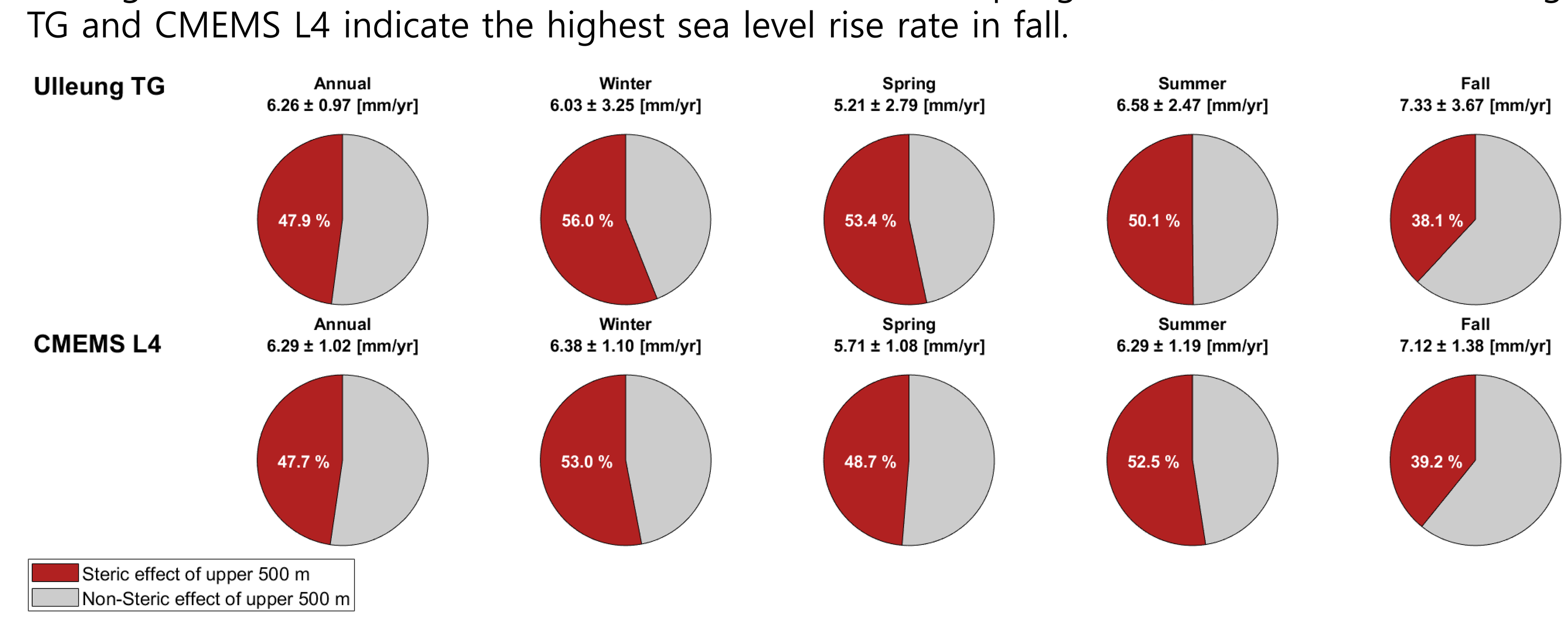
Results



▶ **Fig. 2**. Annually averaged sea level time series and rise rates. Mean sea level was removed from CMEMS L4 and Ulleung TG data. CMEMS L4 and Ulleung TG show similar annually averaged sea level rise. NIFS and EC1 indicate sea level rise rate of 3.00 mm/yr and 3.55 mm/yr.

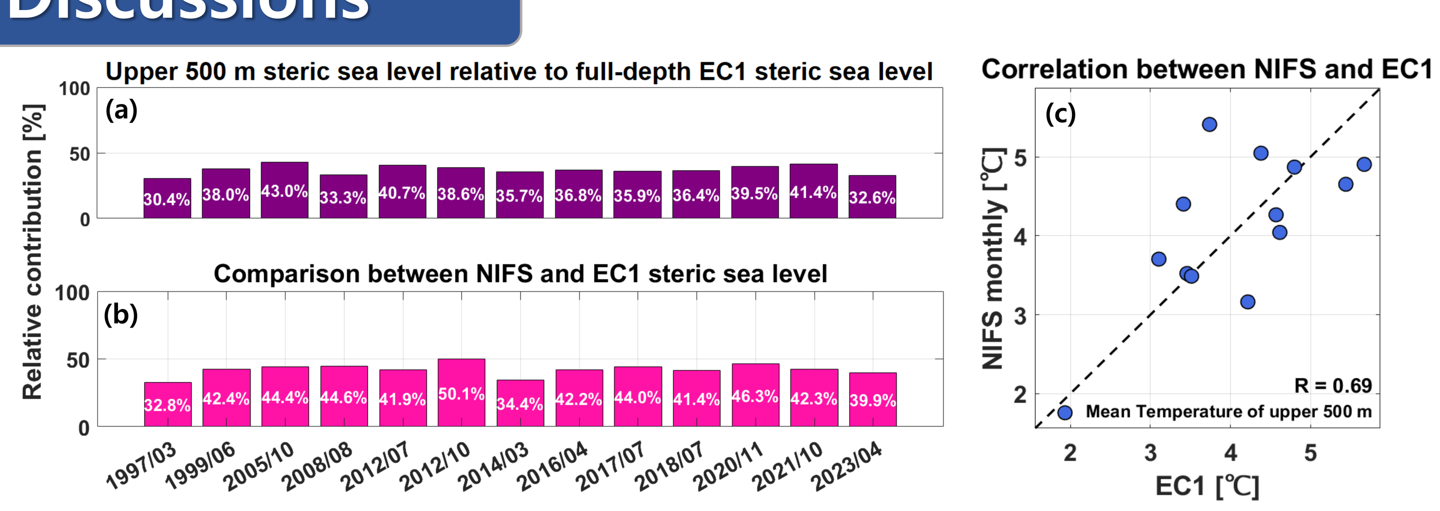


▶ **Fig. 3**. Annually averaged sea level for each season time series and rise rates. The NIFS shows the highest sea level rise rate in winter and lower rates in spring and fall, whereas the Ulleung TG and CMEMS L4 indicate the highest sea level rise rate in fall.

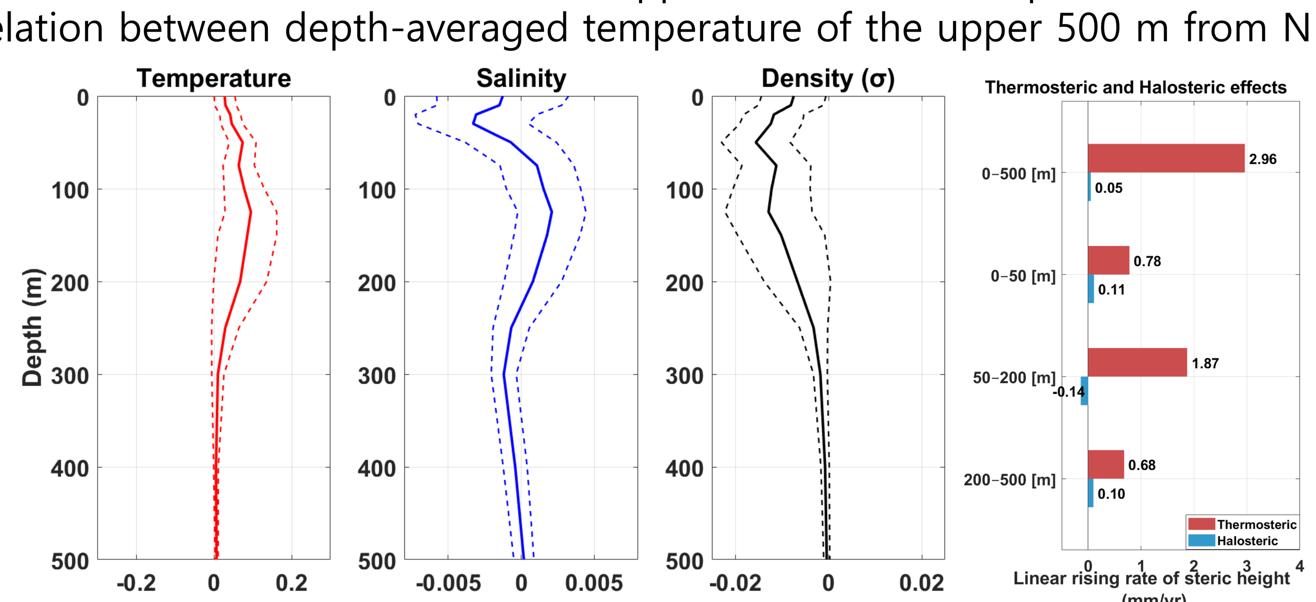


▶ **Fig. 4**. Contribution of steric effect in the upper 500 m sea level rise rate. Among the seasonal sea level rise rates, 48.7–56.0% in winter, spring, and summer can be attributed to steric effects, whereas the contribution in fall is lower at 38.1–39.2%.

Discussions



▶ **Fig. 5**. Contribution and representativeness of upper-500 m steric variability. (a) Relative contribution of the upper-500 m steric component to the full-depth EC1 steric sea level. (b) Relative contribution of NIFS steric sea level of upper 500 m to full-depth steric sea level from EC1. (c) Correlation between depth-averaged temperature of the upper 500 m from NIFS and EC1.



▶ **Fig. 6**. Vertical variation of temperature, salinity, density and linear rising rates of steric effect separated into thermosteric and halosteric. Changes are most significant at depth of 50–200 m, with the thermosteric of sea level rise offsetting the halosteric of sea level fall. Furthermore, thermosteric was dominant across the upper 500 m.

Conclusions

- Approximately 50% of the annually-averaged sea level rise rate is explained by steric effect in the upper 500 m.
- About 50% of the seasonal average sea level rise rates in winter, spring, and summer are driven by the upper 500 m steric effect, and although the sea level rise rate in fall was the highest, the upper 500 m steric effect was the lowest at about 38%.
- Changes water properties in the upper 500 m play a major role in steric sea level variability across the full depth. At 50–200 m, halosteric drive sea level lowering counteracted by thermosteric, producing a net rise. Overall, thermosteric is dominant in the upper 500 m.

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