Diving Deeper: Exploring Subsurface Marine Heatwaves in the Global Ocean

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BACKGROUND

- **A growing number** of studies have examined subsurface marine heatwaves (MHWs) at both regional and global scales.
- A recent study on **coastal subsurface MHWs** off Sydney revealed that different vertical structures of MHWs correspond to distinct **local ocean processes** (Schaeffer et al., 2023).
- Another recent study highlighted that **global subsurface MHWs** make the species more sensitive to **thermal stress** (Fragkopoulou et al., 2023).
- Building on these findings, our research focuses on global subsurface MHWs, investigating their vertical structures, drivers and ecological impacts.

DATA & METHODS

Roemmich-Gilson (R-G) gridded Argo data

- To identify global subsurface MHWs, we used monthly ocean temperature & salinity data from R-G gridded (1°× 1°) Argo data (Roemmich and Gilson 2009).

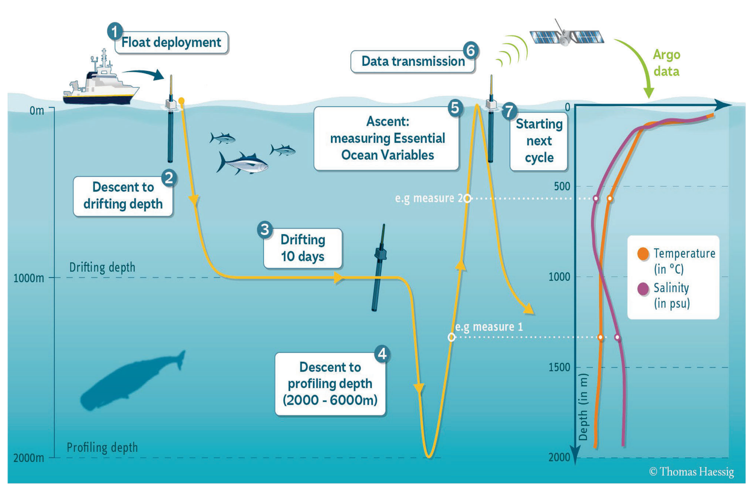


Figure 1. Schematic of Argo work (image from https://argo.ucsd.edu/)

Normalized subsurface MHW definition

- To identify subsurface MHWs in the upper 2000dbar ocean, we normalized the monthly temperature (T) anomaly and defined MHWs as local normalized T anomaly above 1 (Eq.1).

$$norm.\ T\ anomaly = \frac{T - \bar{T}_{climatology}}{T_{90pc} - \bar{T}_{climatology}} \quad (1)$$

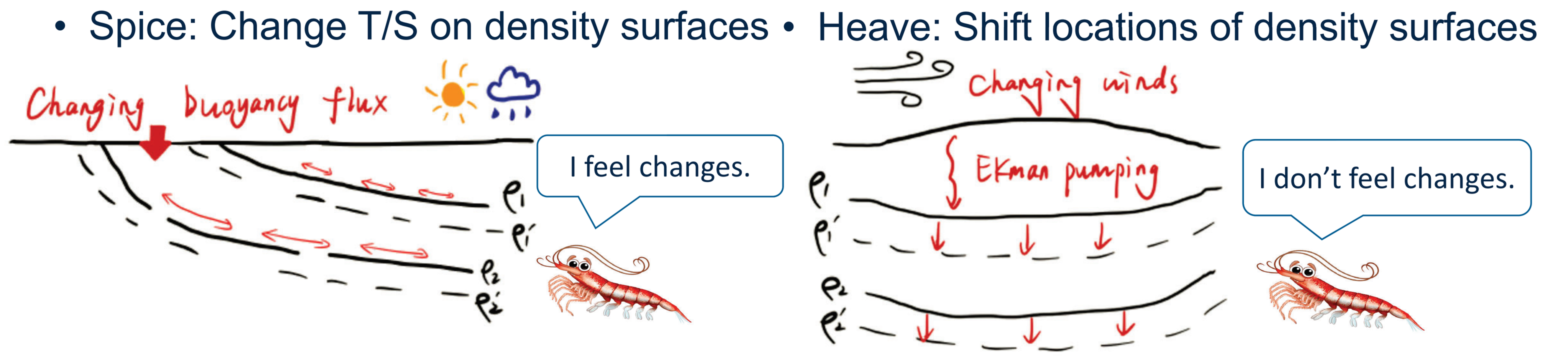
Bindoff & McDougall spice and heave decomposition approach

- To identify the physical processes that caused subsurface MHWs, we will adopt the spice and heave decomposition approach developed by Bindoff & McDougall (1994).
- This approach decomposes the observational temporal changes in temperature (T) and salinity (S) along isobars ("total") into the changes along isopycnals ("spice") and the changes due to isopycnal displacements ("heave") (Bindoff & McDougall 1994) (Eq.2).

total spice heave

$$\begin{matrix} T'|_z = T'|_n - Z'T_z + residual \\ S'|_z = S'|_n - Z'S_z + residual \end{matrix} \quad (2)$$

- The "spice" changes are related to water-mass property changes, while the "heave" changes are related to the isopycnal movements (see the schematic below).
- Plankton, the species that are carried by currents and cannot swim well (e.g., krills), are more affected by the "spice" T changes than "heave" T changes (see the schematic below).



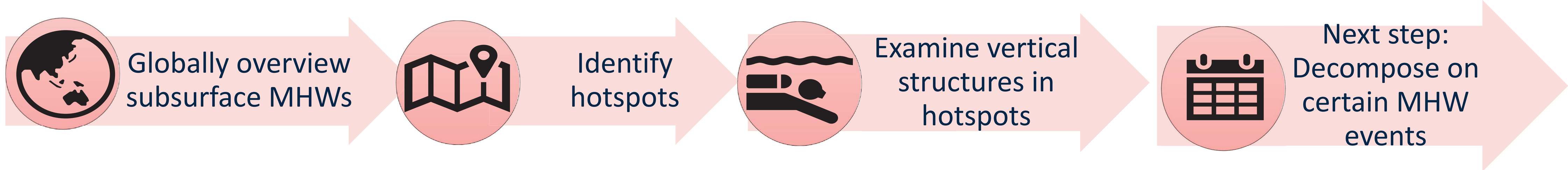
Key messages:

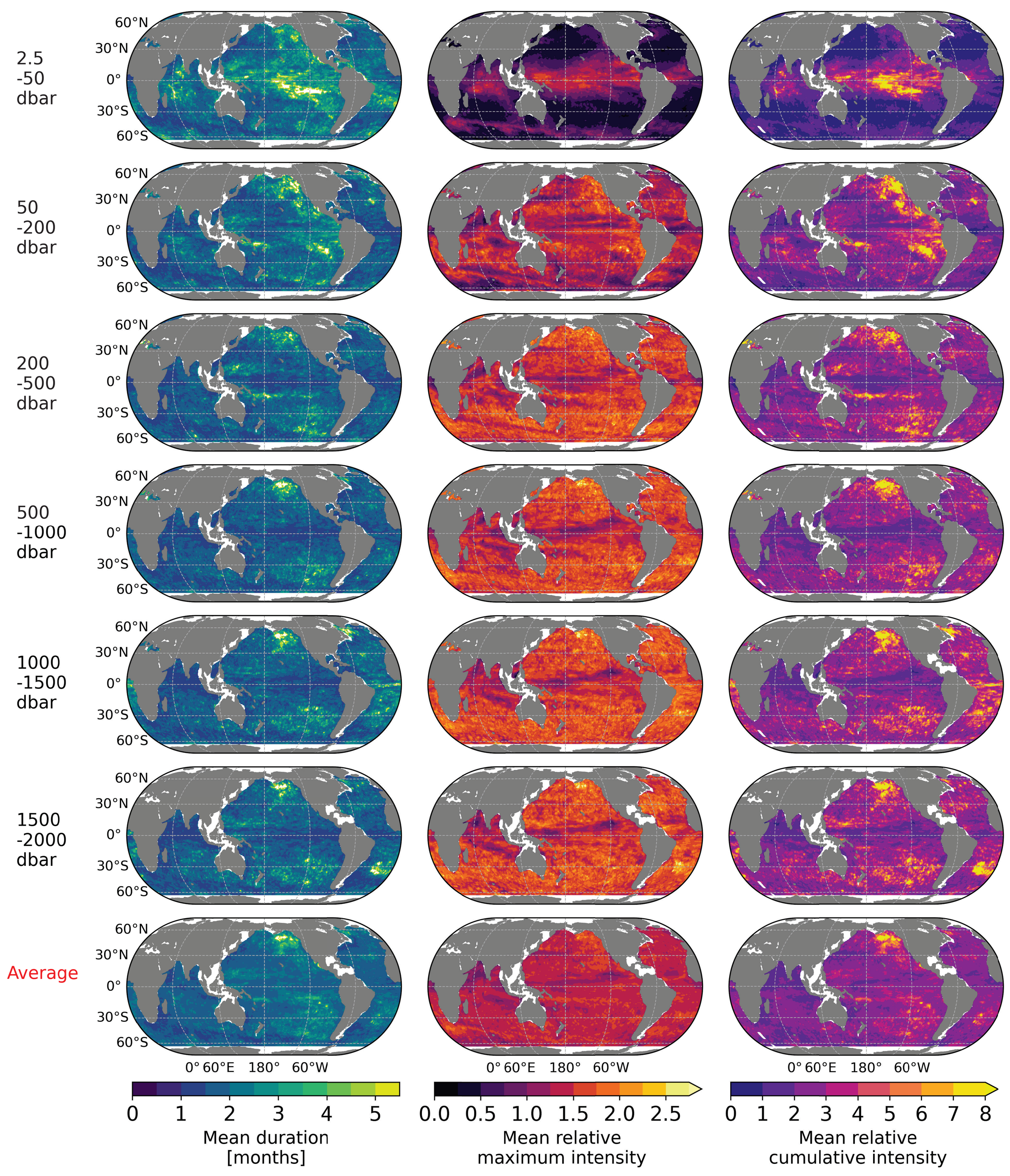
1. From 0-2000 dbar, **subsurface marine heatwaves** (MHWs) can occur **deeply** and **independently**.

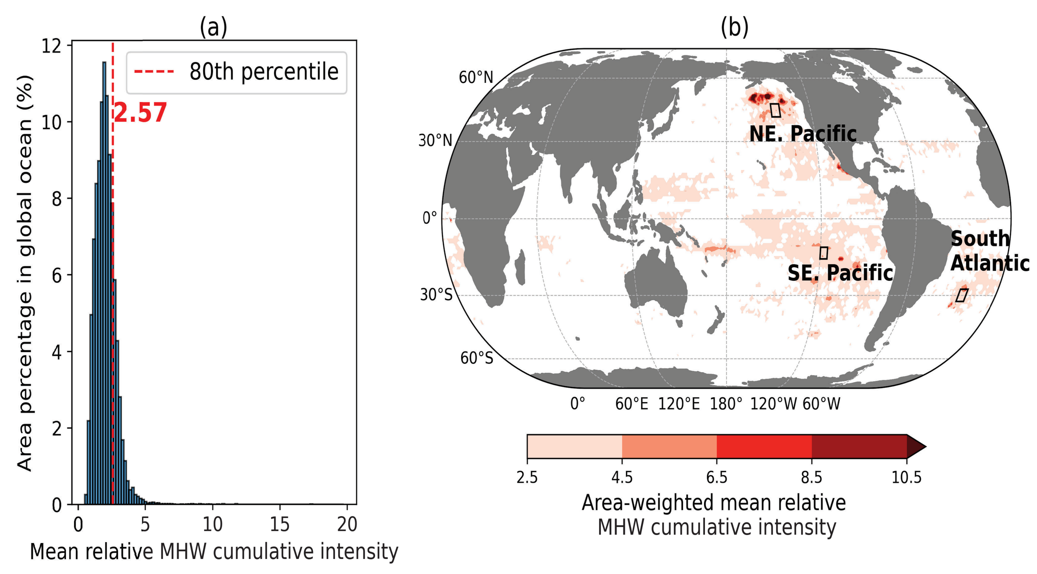
2. **Hotspots** are identified here in areas with the highest ecological exposure to subsurface MHWs in the recent 20 yrs.

3. **A classical decomposition method** is presented to explore the drivers and impacts of subsurface MHWs.

RESULTS







(top) **Figure 3**. Criteria for selecting subsurface MHW hotspots in the global upper ocean. The selected subsurface MHW hotspots are indicated in equal-area boxes.

(left) **Figure 2**. Global distributions of key subsurface MHW metrics in upper 2000m ocean over 2004-2021. The relative intensity is derived by normalizing the MHW intensity against the local temperature standard deviation.

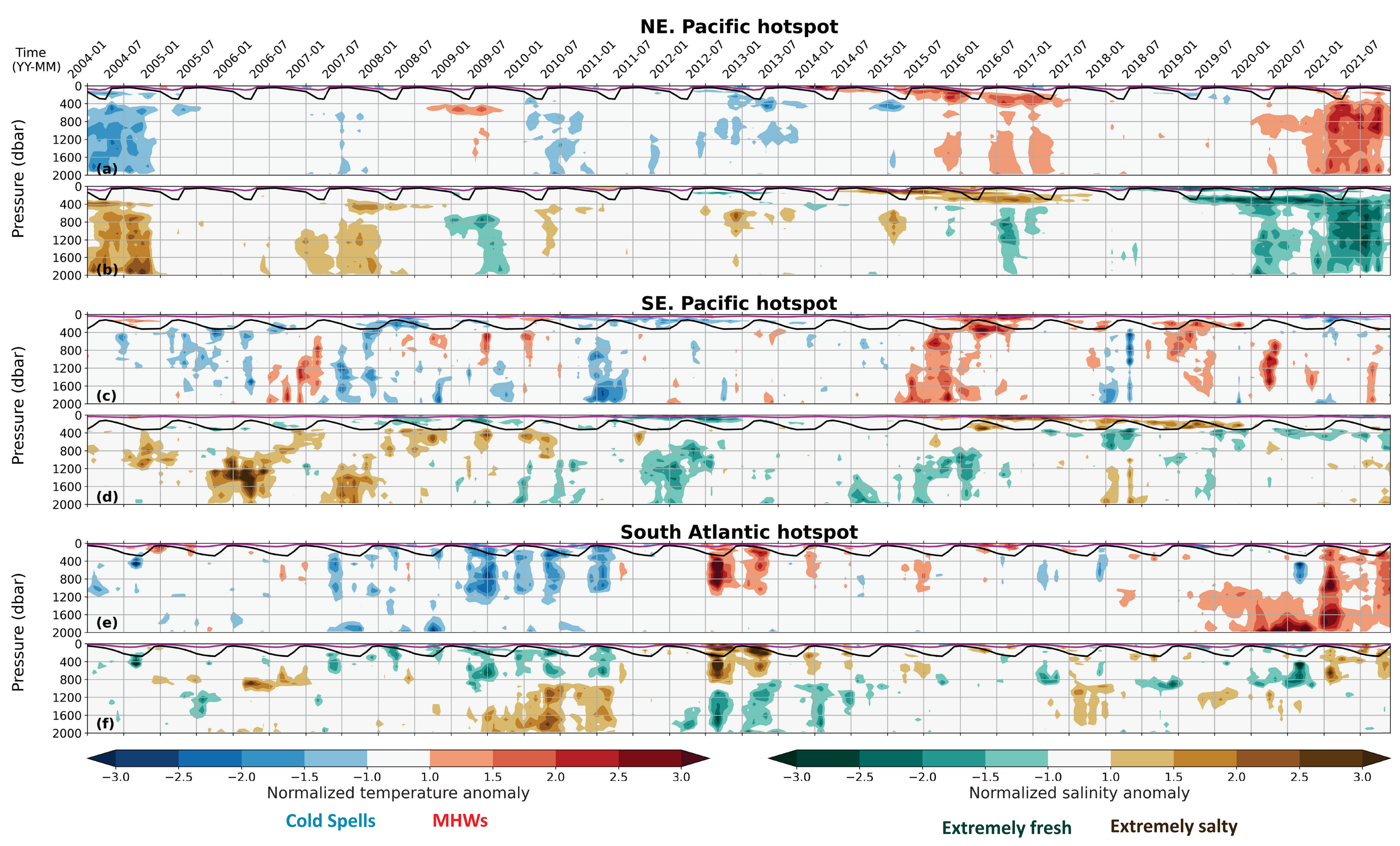


Figure 4. Hovmoller plots of subsurface extreme temperature **(a,c,e)** and subsurface extreme salinity **(b,d,f)** in the selected MHW hotspots over 2004-2021. The mixed layer depth and thermocline maximum depth are shown in pink and black lines, respectively.

References:

1. Bindoff, N. L., & Mcdougall, T. J. (1994). Diagnosing Climate Change and Ocean Ventilation Using Hydrographic Data. *Journal of Physical Oceanography*, *24*(6), 1137-1152. 2. Fragkopoulou, E., Sen Gupta, A., Costello, M. J., Wernberg, T., Araújo, M. B., Serrão, E. A., De Clerck, O., & Assis, J. (2023). Marine biodiversity exposed to prolonged and intense subsurface heatwaves. *Nature Climate Change*. https://doi.org/10.1038/s41558-023-01790-6
3. Roemmich, D., & Gilson, J. (2009). The 2004–2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. *Progress in Oceanography*, *82*(2), 81-100. 4. Scannell, H. A., Johnson, G. C., Thompson, L., Lyman, J. M., & Riser, S. C. (2020). Subsurface Evolution and Persistence of Marine Heatwaves in the Northeast Pacific. *Geophysical Research Letters*, *47*(23).
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