



Supplement of

Contrasting physical drivers of chlorophyll *a* responses to summer marine heatwaves in the South China Sea

Yunlu Fang et al.

Correspondence to: Cong Liu (liucong175@gmail.com) and Yicheng Chen (cyc_dsfirst@foxmail.com)

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Supplement

Supplementary data and methods

Unless otherwise stated, the supplementary analyses used the same MHW definition, study period (1998–2024), and regional definitions as the main analysis.

Daily total precipitation was obtained from the ERA5 post-processed daily statistics on single levels. Precipitation anomalies over the PRE and the nearby Pearl River Delta (PRD) land region were composited across summer MHW events with equal weighting among events. Event-centred composites were aligned to the regional MHW establishment date (day 0), and 95 % confidence intervals were estimated using an event-level bootstrap (Fig. S2).

To assess whether the summer Chl-a anomalies exceeded normal seasonal variability, the observed regional MHW composites were compared with duration- and seasonally matched non-MHW summer pseudo-events. The 5th and 95th percentiles of the matched distributions were used as reference bounds (Fig. S3). The robustness of the VUA high-Chl-a belt was further examined using the summer median and summer means after excluding the upper 5 % and 10 % of daily Chl-a observations at each grid cell (Fig. S4).

Vertically resolved Chl-a for the auxiliary analysis was obtained from the CMEMS Global Ocean Biogeochemistry (BGC) Hindcast product (GLOBAL_MULTIYEAR_BGC_001_029). Daily Chl-a anomalies were calculated relative to the corresponding calendar-day climatology. The anomalies were averaged within each summer MHW event and then equally averaged across events. The vertical Chl-a structures were examined within the VUA and PRE core response regions. To evaluate the potential contribution of vertical redistribution to the observed surface Chl-a responses, BGC surface Chl-a anomalies were compared with the mean BGC Chl-a anomalies over the available water column, while corresponding satellite-derived surface values and anomalies were shown for comparison with the hindcast results (Figs. S5 and S6). These diagnostics were used to assess possible changes in vertical Chl-a structure associated with MHWs and were not interpreted as direct measures of phytoplankton biomass or primary productivity.

The MLD diagnostics used the GLORYS12V1 MLD described in Sect. 2.2 of the main manuscript. Summer MLD climatology was calculated over JJA, and daily anomalies were calculated relative to the corresponding calendar-day climatology. MHW anomalies were averaged within each event and then equally across events. Negative MLD anomalies indicate mixed-layer shoaling (Fig. S7).

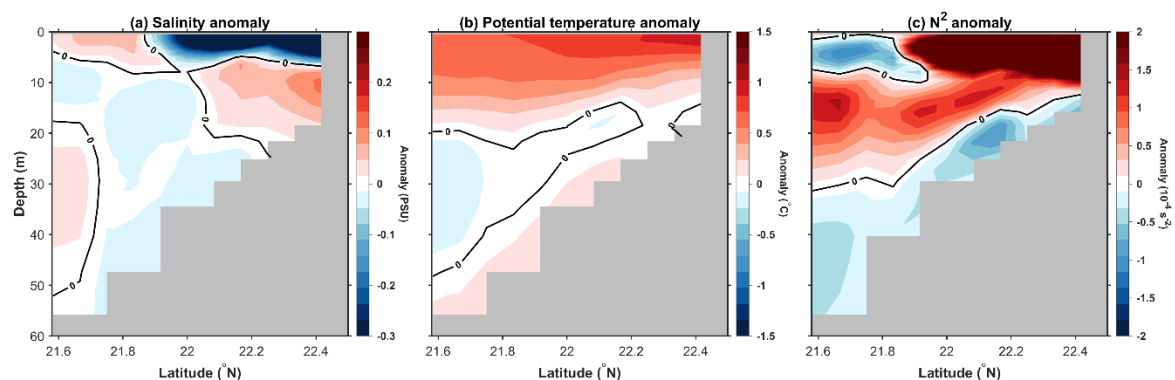


Figure S1. MHW-related summer anomalies along 114.5° E across the PRE shelf. Panels show (a) salinity anomaly, (b) potential temperature anomaly, and (c) N^2 anomaly. Grey shading indicates seafloor bathymetry or masked grid cells.

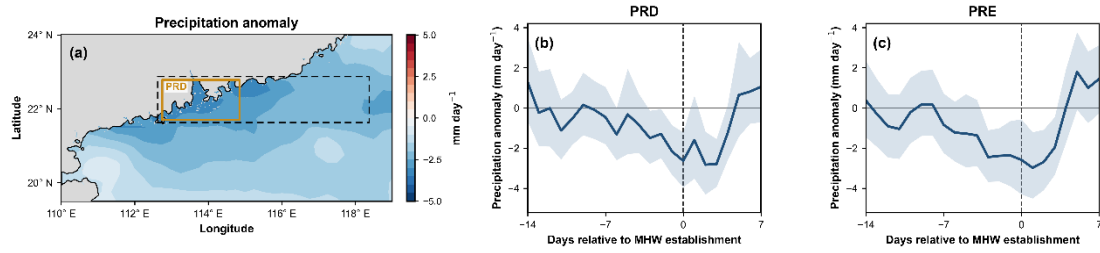


Figure S2. Precipitation anomalies associated with PRE summer MHWs. (a) Spatial composite of precipitation anomalies; the dashed box marks the PRE analysis region, and the orange box marks the PRD land region. (b, c) Composite precipitation anomalies over the PRD land region and PRE ocean region, respectively, relative to the regional MHW establishment date (day 0). Shading denotes the 95 % confidence interval.

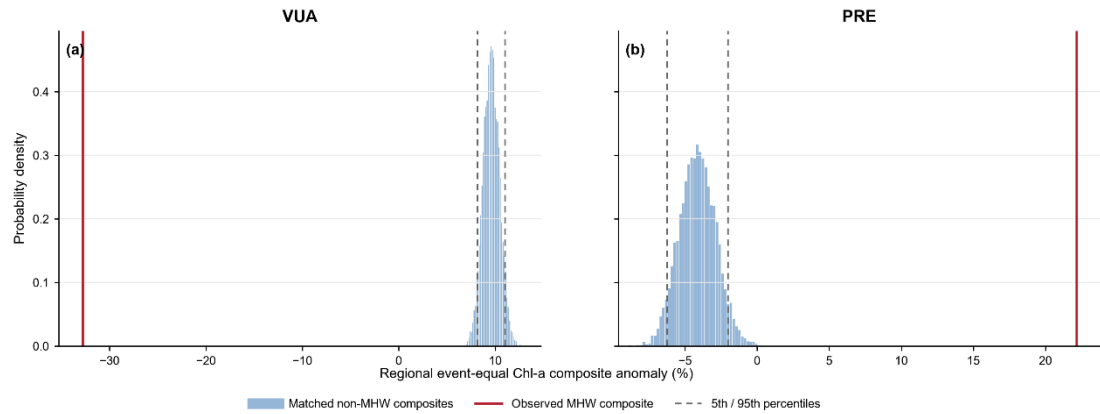


Figure S3. Summer MHW-related Chl-a composite anomalies relative to matched non-MHW summer conditions in the VUA and PRE. Blue histograms show the distributions of matched non-MHW regional composite anomalies in the (a) VUA and (b) PRE. Red vertical lines indicate the observed summer MHW composites, and grey dashed lines denote the 5th and 95th percentiles of the matched distributions.

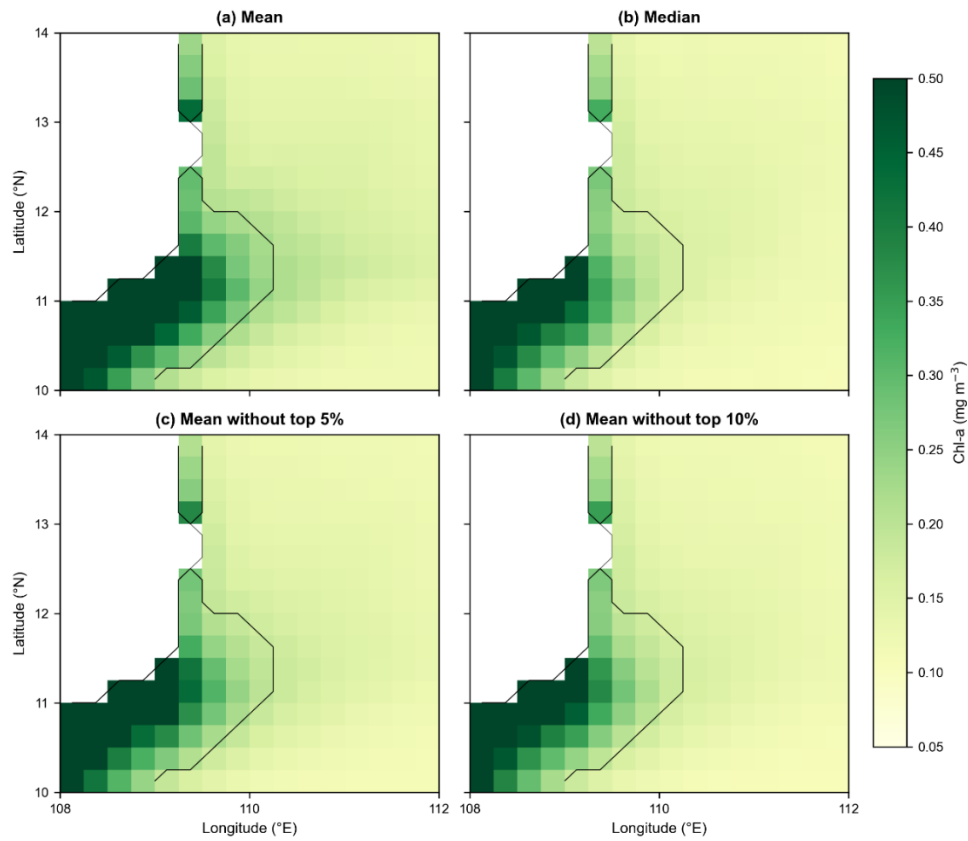


Figure S4. Sensitivity of the VUA summer high-Chl-a belt to alternative representations of the background Chl-a field. Panels show (a) the summer mean Chl-a climatology, (b) the summer median, and the summer mean after excluding the upper (c) 5 % and (d) 10 % of daily Chl-a observations at each grid cell. All panels use the same colour scale to facilitate comparison of the spatial structure and magnitude of the nearshore high-Chl-a belt.

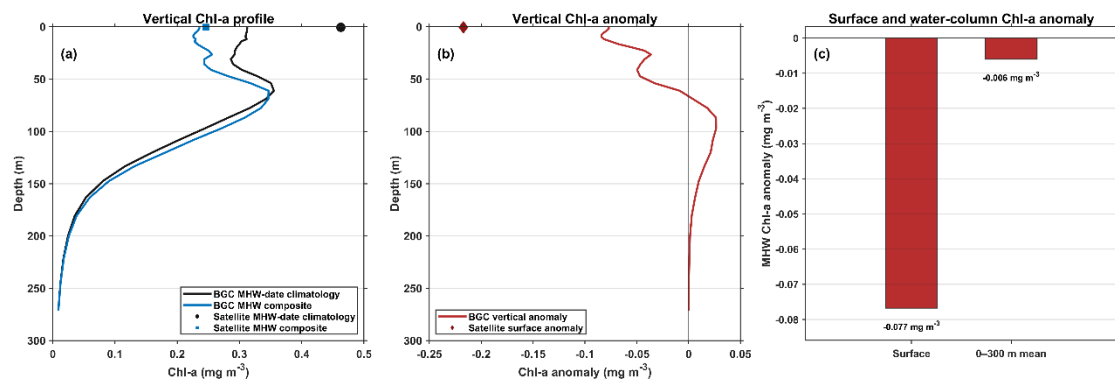


Figure S5. Vertical Chl-a structure in the VUA core response region during summer MHWs. (a) BGC MHW-date climatological profile (black) and MHW composite profile (blue), with satellite surface values shown by the circle and square. (b) BGC vertical Chl-a anomaly, with the satellite surface anomaly shown by the diamond. (c) BGC surface Chl-a anomaly and available water-column mean anomaly.

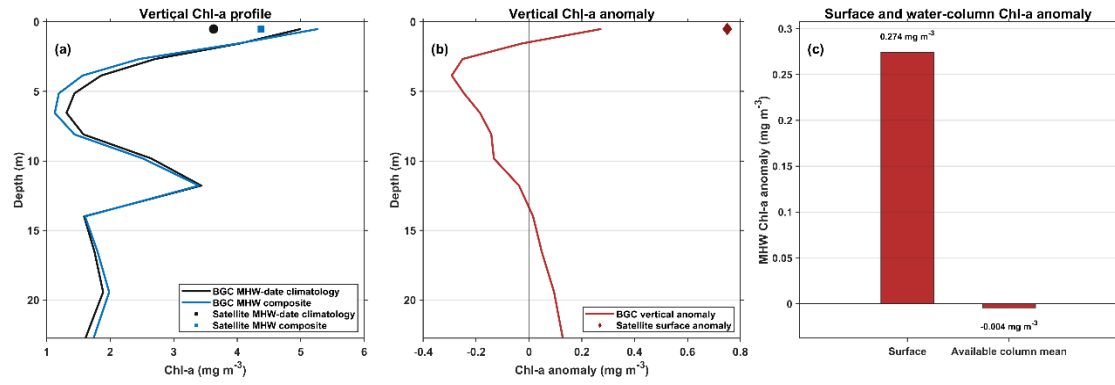


Figure S6. Vertical Chl-a structure in the PRE core response region during summer MHWs. (a) BGC MHW-date climatological profile (black) and MHW composite profile (blue), with satellite surface values shown by the circle and square. (b) BGC vertical Chl-a anomaly, with the satellite surface anomaly shown by the diamond. (c) BGC surface Chl-a anomaly and available water-column mean anomaly.

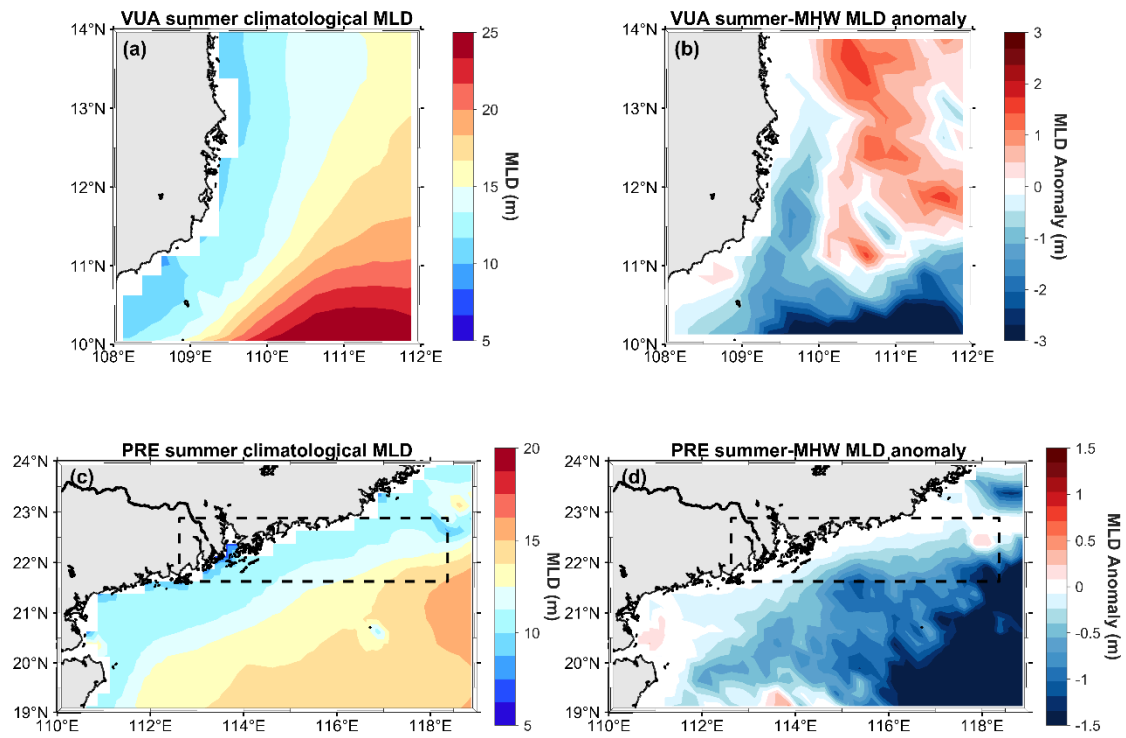


Figure S7. Summer climatological MLD and MHW-related MLD anomalies in the VUA and PRE. Panels show summer climatological MLD in (a) the VUA and (c) the PRE, with the corresponding MHW-related anomalies in (b) and (d), respectively. Negative anomalies indicate mixed-layer shoaling. The dashed box marks the PRE analysis region.

Table S1. Sensitivity of the selected SURD variable subsets to the response lag.

Region	Lag τ (days)	Main-analysis four-variable subset	Rank among candidate subsets
VUA	1	SST_CUM, SSS, SLA, EPV	1
VUA	2	SST_CUM, SSS, SLA, EPV	1
VUA	3	SST_CUM, SSS, SLA, EPV	1
PRE	1	SST_CUM, SSS, SLA, u_wind	1
PRE	2	SST_CUM, SSS, SLA, u_wind	1
PRE	3	SST_CUM, SSS, SLA, u_wind	1

Note: Candidate four-variable subsets were evaluated separately at each response lag using the mean causality leak across bin numbers 2–10. Rank 1 denotes the subset with the lowest mean causality leak at the corresponding lag.