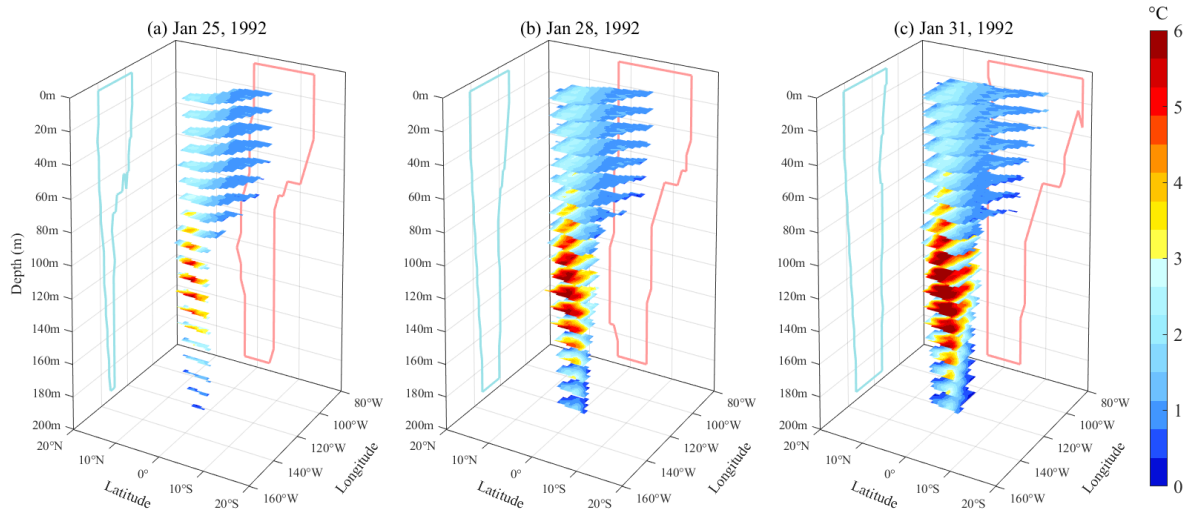
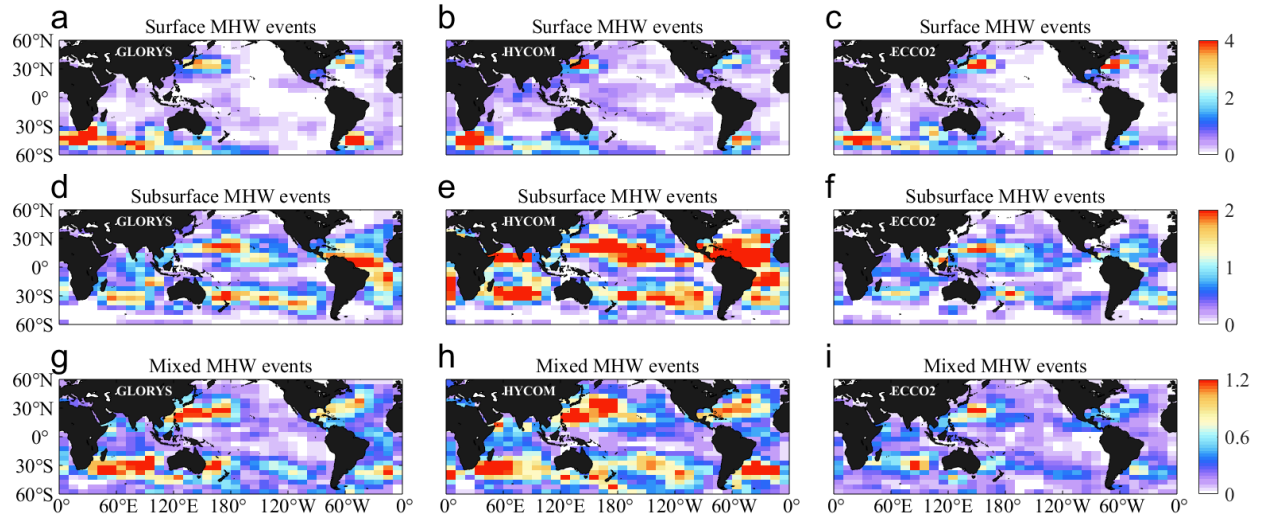


Frequent marine heatwaves hidden below the surface of the global ocean

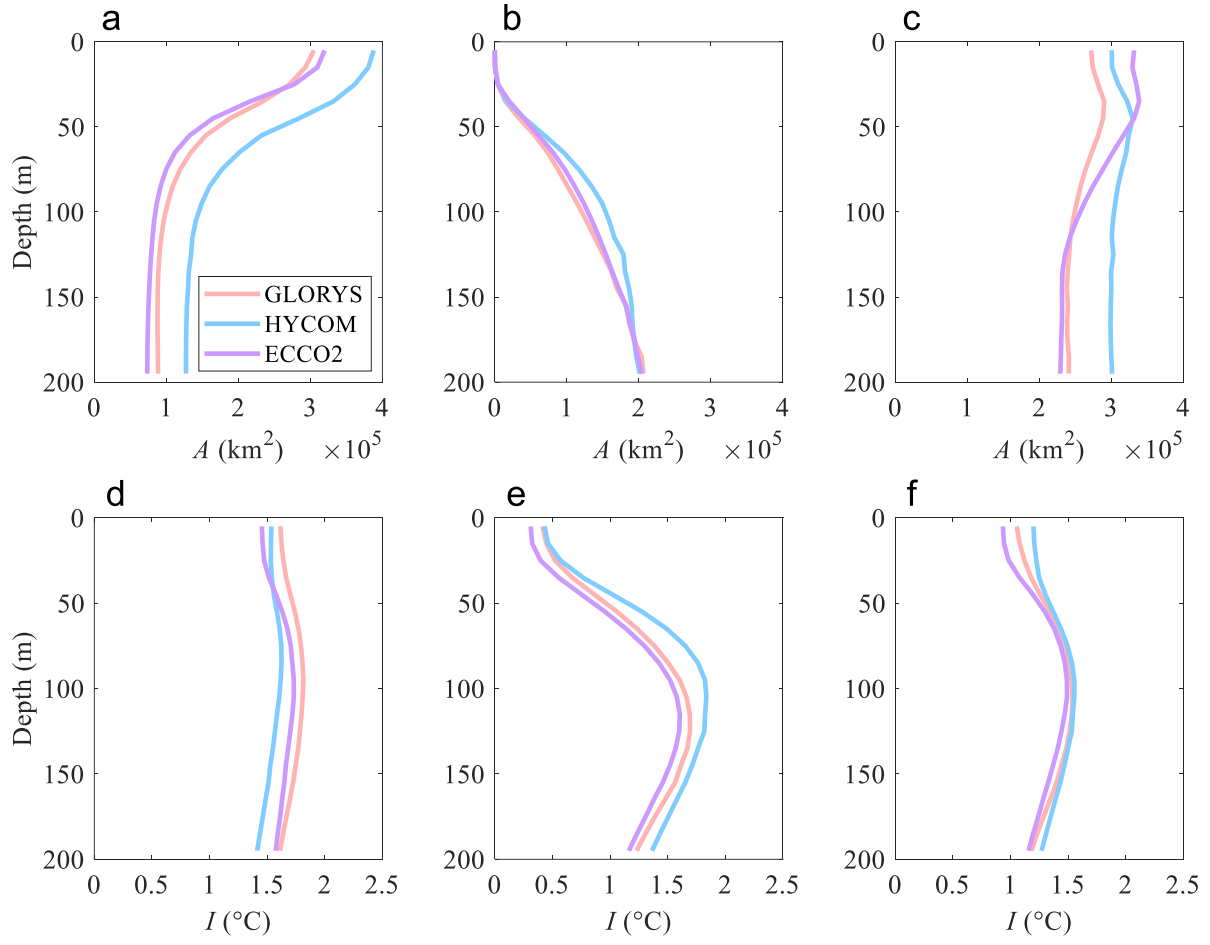
In the format provided by the
authors and unedited



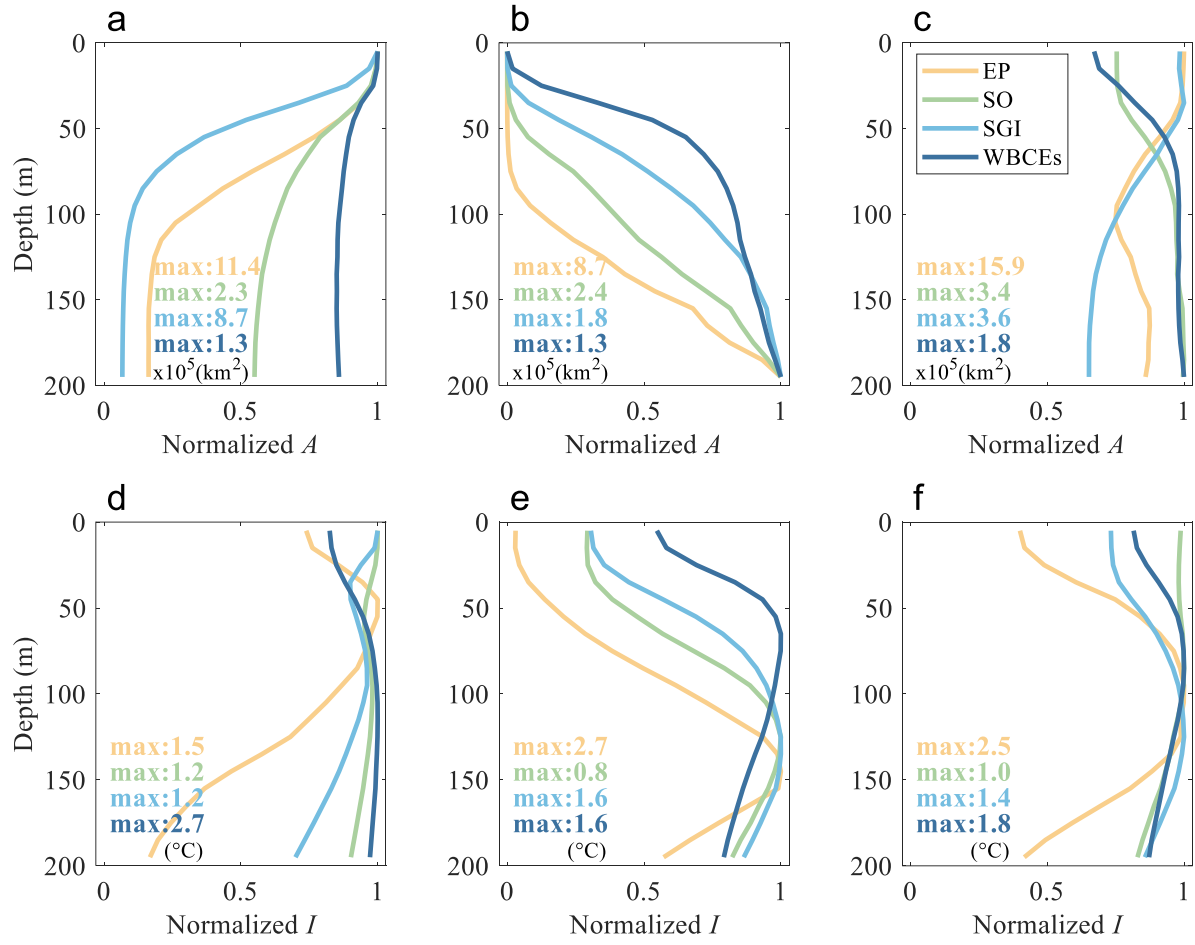
Supplementary Fig. S1 | An MHW event identified under the four-dimensional spatio-temporal framework with evolving spatial structure. Colors show the temperature anomalies relative to the climatological mean seasonal cycle. The contours in blue and red represent the projection of MHW spatial structure in longitude-depth and latitude-depth planes, respectively. Here the result is derived from the ECCO2.



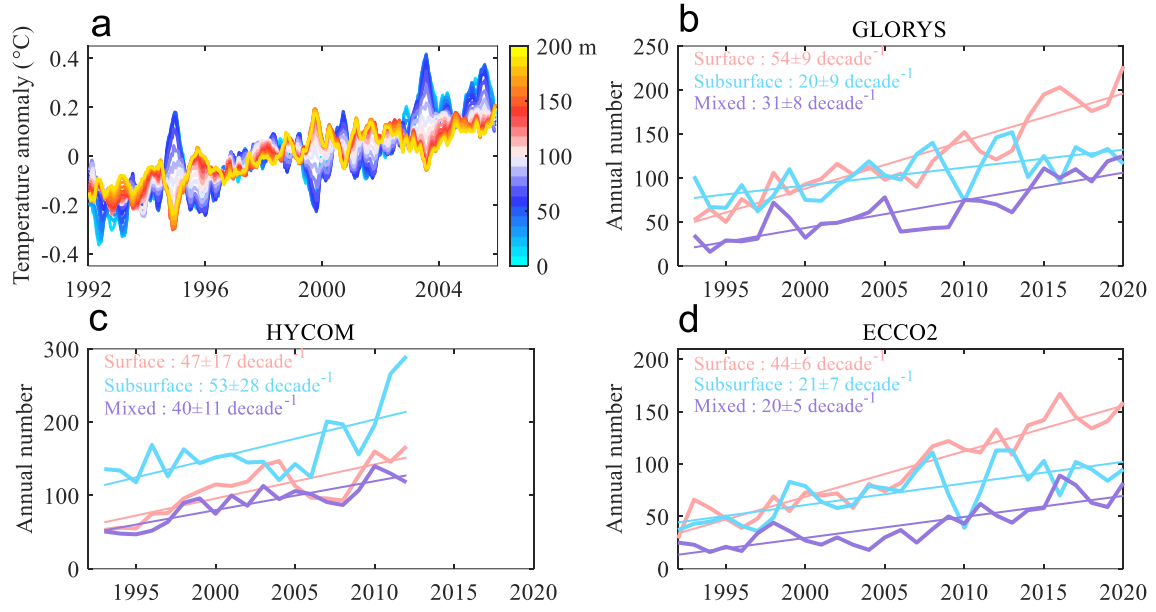
Supplementary Fig. S2 | Same as Fig. 1 except that a fixed grid cell number criterion of 125 is replaced by a fixed volume criterion of $1.3 \times 10^4 \text{ km}^3$.



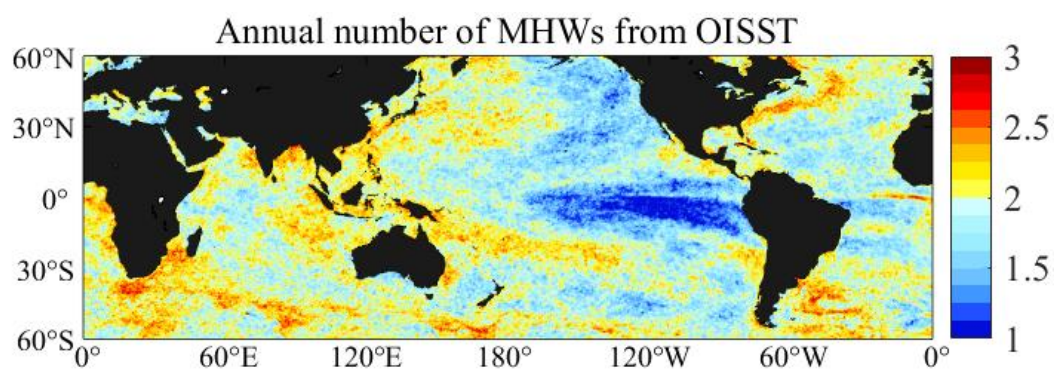
Supplementary Fig. S3 | Same as Fig. 2 except that a fixed grid cell number criterion of 125 is replaced by a fixed volume criterion of $1.3 \times 10^4 \text{ km}^3$.



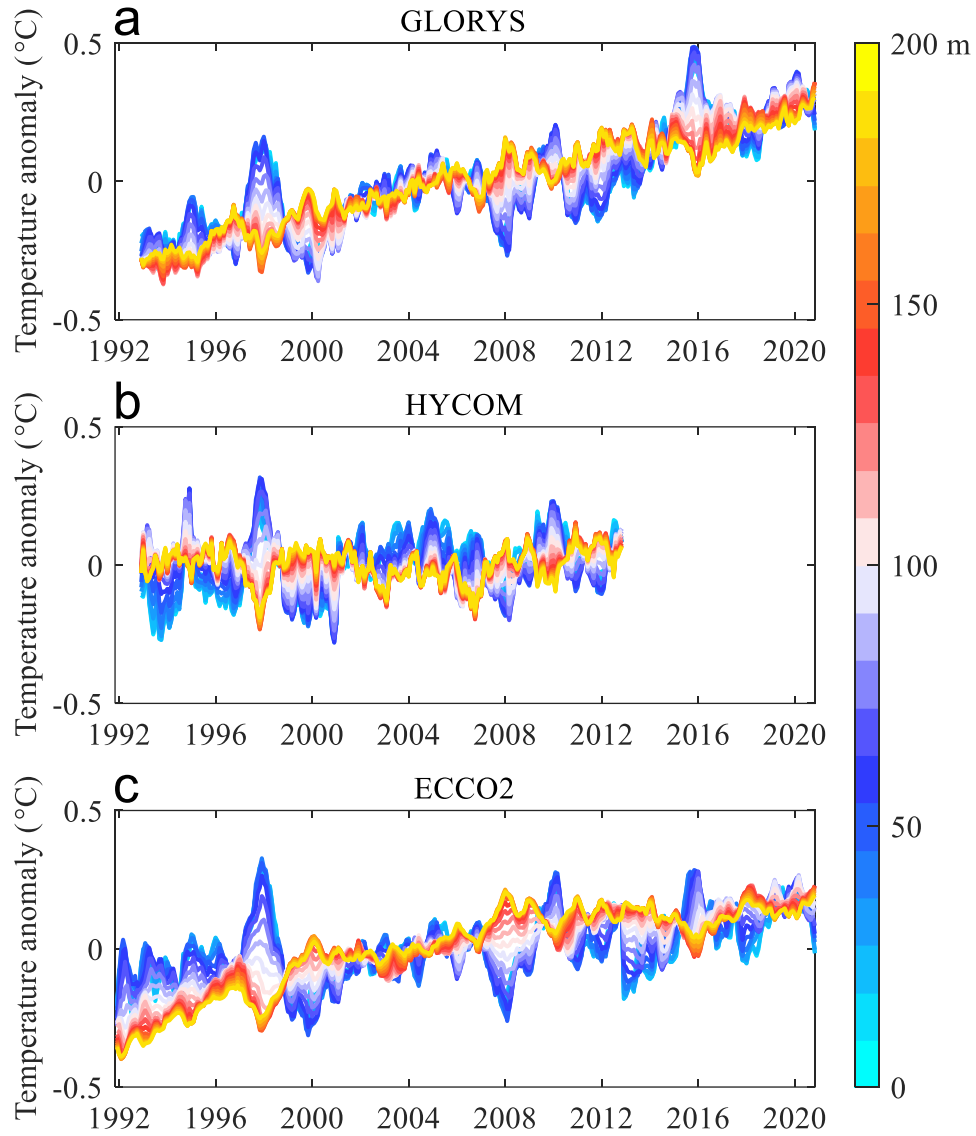
Supplementary Fig. S4 | Same as Fig. 3a-f except that a fixed grid cell number criterion of 125 is replaced by a fixed volume criterion of $1.3 \times 10^4 \text{ km}^3$.



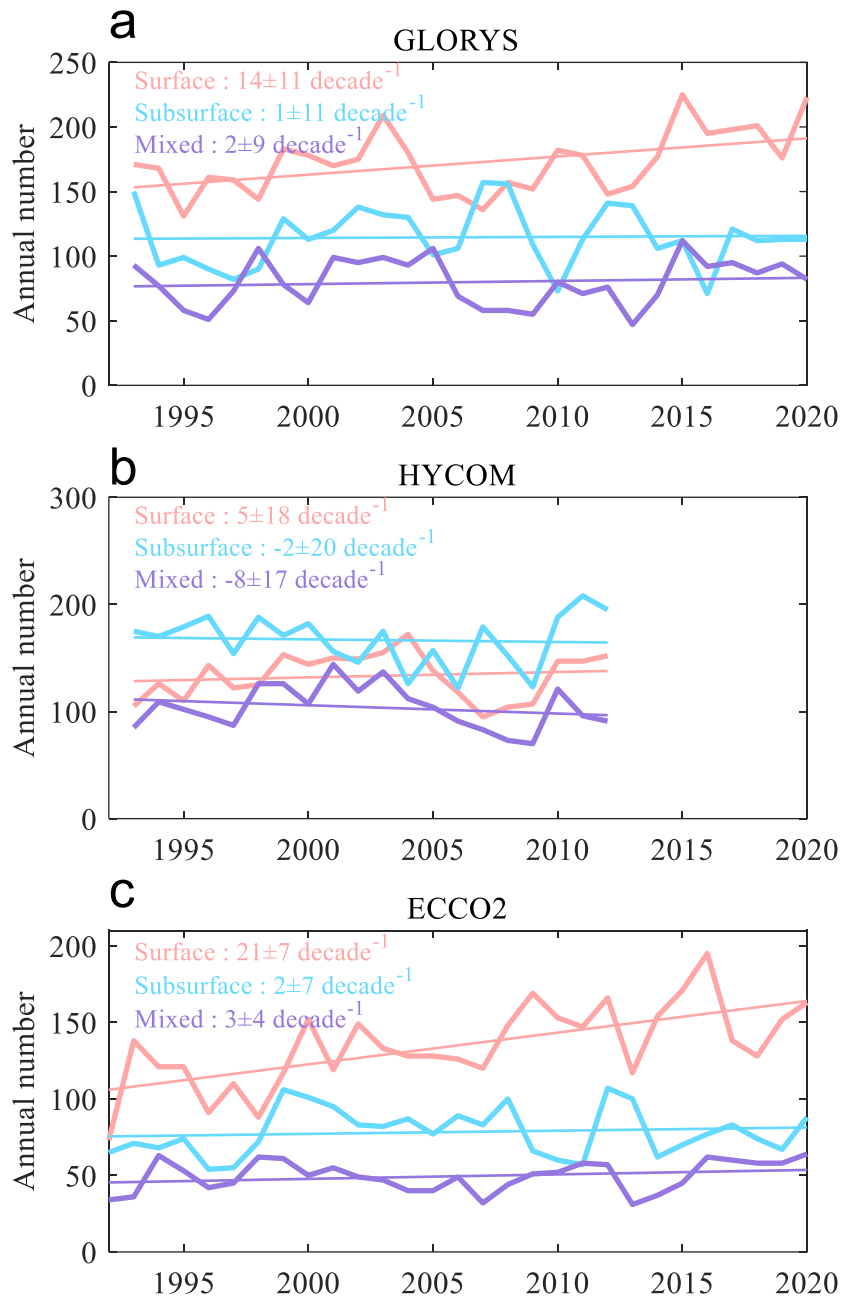
Supplementary Fig. S5 | Same as Fig. 4 except that a fixed grid cell number criterion of 125 is replaced by a fixed volume criterion of $1.3 \times 10^4 \text{ km}^3$.



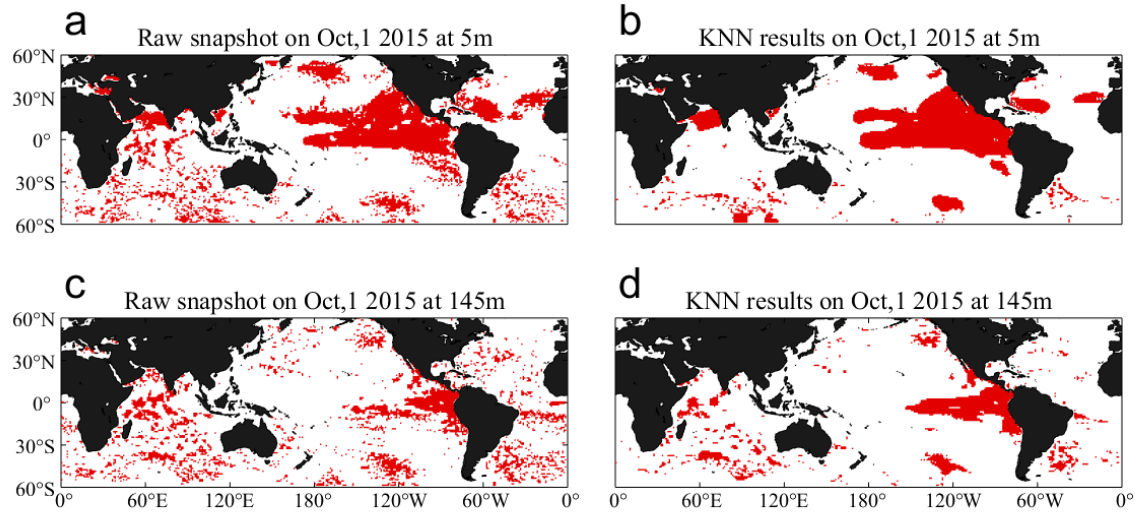
Supplementary Fig. S6 | Climatological mean annual number of MHW events identified in the temporal domain based on the observational SST. Here the data come from the National Oceanic and Atmospheric Administration (NOAA) Optimum Interaction Sea Surface Temperature V2.0 high-resolution (OISST), covering the period 1992-2020.



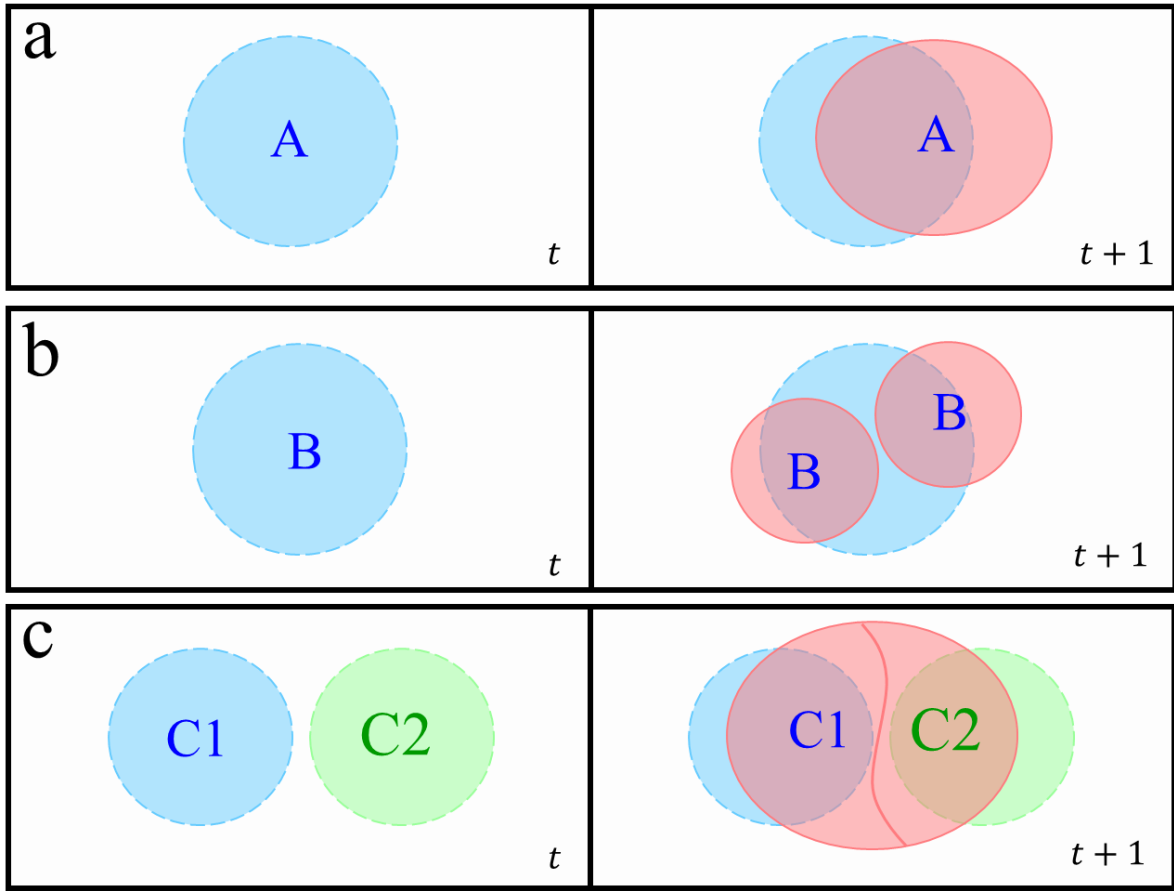
Supplementary Fig. S7 | Mean-state warming of the three reanalysis datasets. Time series of monthly mean temperature averaged with area weight over the global ocean (60°N-60°S) derived from the GLORYS (a), HYCOM (b) and ECCO2 (c). Here the time-mean temperature at each depth is subtracted from the corresponding time series to facilitate the illustration.



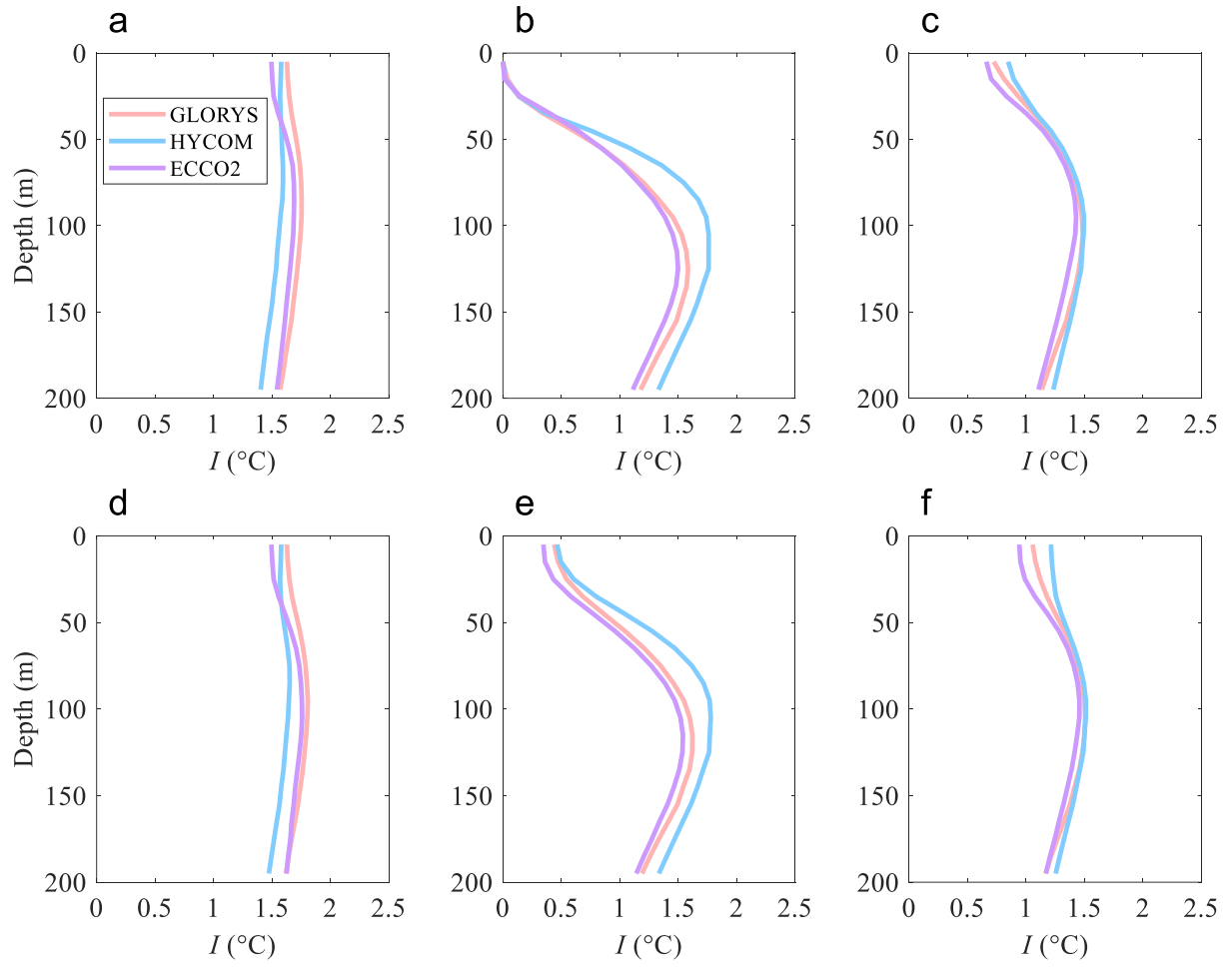
Supplementary Fig. S8 | Long-term changes of MHW events without the effects of mean-state warming. a, Time series of annual number of the global surface, subsurface and mixed MHW events in the GLORYS derived from the linearly detrended temperature data. **b, c,** Same as **a**, but for the HYCOM and ECCO2, respectively. The pink, blue and purple lines correspond to the results for the surface, subsurface and mixed MHW events, respectively.



Supplementary Fig. S9 | An example of MHW snapshots before and after the NN smoothing on October 1, 2015 derived from the ECCO2. **a, and **c**, are the raw MHW snapshots at 5m and 145m, respectively; **b**, and **d**, are their corresponding NN-smoothed results.**



Supplementary Fig. S10 | Schematic of the MHW tracking procedure under different scenarios. a, no MHW splitting or merging, **b**, MHW splitting and **c**, MHW merging. Blue or green filled color with dashed lines represents MHW events at time t while the red filled color with solid lines represents the corresponding successors at time $t+1$. Different MHW events are indexed by different letters. All of the three scenarios occur frequently in the tracking process.



Supplementary Fig. S11 | Global mean $I(z)$ from the three reanalysis datasets. a-c, Using the “zero-padding” method, **d-e**, “extrapolation” method.

Supplementary Table S1 | Numbers and proportions of the surface, subsurface and mixed MHW events in the global ocean (60°S-60°N) derived from the three reanalysis datasets with a fixed volume criterion of $1.3 \times 10^4 \text{ km}^3$. Numbers and proportions here should be compared to their counterparts in Table 1 derived from a fixed grid cell number criterion of 125.

Datasets	Climatological mean annual number	Proportion of surface MHW events	Proportion of subsurface MHW events	Proportion of mixed MHW events
GLORYS	281.4	42.2%	35.0%	22.8%
HYCOM	356.4	30.2%	45.3%	24.5%
ECCO2	198.2	48.9%	31.4%	19.7%

Supplementary Table S2 | Numbers and proportions of the surface, subsurface and mixed MHW events in the global ocean (60°S-60°N) derived from the three reanalysis datasets during their overlapping period 1993-2012. The baseline in identifying MHW events is chosen as 1993-2012. Numbers and proportions here should be compared to their counterparts in Table 1 where MHW events in the three reanalysis datasets are computed during their own respective periods, i.e., 1993-2020 for GLORYS, 1993-2012 for HYCOM and 1992-2020 for ECCO2.

Datasets	Climatological mean annual number	Proportion of surface MHW events	Proportion of subsurface MHW events	Proportion of mixed MHW events
GLORYS	332.3	46.8%	31.1%	22.1%
HYCOM	374.4	32.6%	42.4%	25.0%
ECCO2	248.5	51.1%	29.8%	19.1%

Supplementary Table S3 | Proportions of the mixed MHW events with no surface signals at the beginning, the end or the in-between of their life cycles derived from the three reanalysis datasets.

Datasets	At the beginning	At the end	At the in-between
GLORYS	13.7%	6.5%	1.7%
HYCOM	16.4%	7.5%	1.1%
ECCO2	11.3%	6.6%	1.6%

Supplementary Table S4 | Numbers and proportions of the surface, subsurface and mixed MHW events in upper 200 m (first row) and 400 m (second row) of the global ocean (60°S-60°N) derived from the GLORYS data.

Depth range	Climatological mean	Proportion of surface	Proportion of subsurface	Proportion of mixed
	annual number	MHW events	MHW events	MHW events
0-200 m	308.5	46.9%	31.2%	21.9%
0-400 m	341.4	38.8%	41.8%	19.4%

Supplementary Table S5 | Sensitivity of proportions of the global surface, subsurface and mixed MHW events to the correlation coefficient threshold r_c in defining the neighborhood for the NN smoothing. Here the sensitivity test is performed based on the GLORYS data.

r_c	Surface MHW events	Subsurface MHW events	Mixed MHW events
0.4	44.6%	32.2%	23.2%
0.5	46.9%	31.2%	21.9%
0.6	49.8%	28.6%	21.6%

Supplementary Table S6 | Sensitivity of proportions of the global surface, subsurface and mixed MHW events to the grid cell number threshold N_c . MHWs occupying less than N_c grid cells are discarded from analysis. Here the sensitivity test is performed based on the GLORYS data.

N_c	50	100	125	150	200	250
Surface MHW events	39.7%	45.9%	46.9%	47.8%	49.7%	51.3%
Subsurface MHW events	39.1%	32.9%	31.2%	29.8%	27.5%	25.2%
Mixed MHW events	21.2%	21.2%	21.9%	22.4%	22.8%	23.5%

Supplementary Table S7 | Sensitivity of proportions of the global surface, subsurface and mixed MHW events to the definition of neighborhood for the NN-smoothing, i.e., neighborhood defined as the region with correlation coefficient $r > 0.5$ vs. the $5^\circ \times 5^\circ \times 50\text{m}$ cube. Here the sensitivity test is performed based on the GLORYS data.

Neighborhood	$r > 0.5$	$5^\circ \times 5^\circ \times 50\text{m}$
Surface MHW events	46.9%	34.9%
Subsurface MHW events	31.2%	37.5%
Mixed MHW events	21.9%	27.6%