Types of the evolution and dynamics of marine heatwaves in the East Sea (Japan Sea)

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Abstract

- Marine heatwaves (MHWs) are extreme events in the ocean and adversely affect the marine ecosystem and human society. The East Sea (Japan Sea) is a semi-enclosed deep basin, experiencing the world's most rapid upper ocean warming over recent decades. In this study, characteristics of MHWs extracted from different datasets was first validated against those from a long-term (2000–2014) time-series observations near the east coast of Korea. Then, using the ocean data, a rising frequency of annual mean and summer (JJA) MHWs from 1982 to 2019 over the whole East Sea, were investigated with a maximum increasing rate of 0.45 events per decade. Six sub-regions (three in the west and three in the east) were chosen to investigate three types of MHW evolutions: 1) Type-A, 2) Type-B, and 3) Type-C. Here, possible explanations for these types of MHW evolution in the selected sub-regions are discussed and provides first comprehensive understandings on surface and subsurface MHWs.

1. Introduction

- Marine heatwaves (MHWs) are extremely warm sea surface temperature events in the ocean (above the 90th percentile threshold) (Hobday et al., 2016).
- Surface MHWs and their drivers are studied extensively in the East Sea (Japan Sea) (Oh et al.,2022, Choi et al., 2022, Lee et al., 2022), but none of these studies has not looked into the subsurface evolution even though East Sea experiences the most rapid upper ocean warming.

2. Data and Methods

- NOAA optimum interpolated Sea surface temperature (OISST) (0.25° X 0.25°) is used to detect MHWs (1982-2019).
- Simple Ocean Data Assimilation (SODA) reanalysis, Estimating the Circulation and Climate of the Ocean (ECCOv4r4) (0.5° X 0.5°), Global Ocean Reanalysis product (GLORYS) (0.08° X 0.08°), HYbrid Coordinate Ocean Model (HYCOM) (0.08° X 0.08°):investigate the subsurface evolution of MHWs during June-July-August (JJA).
- Further investigated using in-situ ocean temperature data obtained by East Sea Real-Time Observation Buoy (ESROB) in the East Sea from 2000-2015. The observational data simultaneously collected with a time interval of 10 min using different conductivity-temperature-depth (CTD) sensor up to 110 m depth.
- Classified the subsurface evolution of MHWs using 1.∼K mean clustering (aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean (cluster centres or cluster centroid)) and 2.∼Hierarchical Clustering techniques (Hierarchical clustering requires us to decide on a distance method. Use the euclidean distance method to minimize the variance between clusters).
- Heat budget is calculated

$$\underbrace{\frac{\partial T_m}{\partial t}}_{\text{Local mixed layer temperature tendancy}} = \underbrace{\frac{Q_{net} - Q_z}{\rho_O c_p h}}_{\text{Surface net heat flux}} - \underbrace{\mathrm{u}_m \cdot \nabla T_m}_{\text{Horizontal advection}} - \underbrace{\frac{1}{h}(T_m - T_{-h}) w_E}_{\text{Entrainment and detrainment}} - \underbrace{\frac{1}{h} K_v \frac{\partial T}{\partial z}\Big|_{z=-h}}_{\text{Ocean vertical mixing at mixed layerl}}$$

3. Results and Discussion

3.1 Trend of MHW Metrics and classifications of MHWs in the East Sea (Japan Sea) according to their subsurface evolution using HYCOM dataset

- Selected 6 regions **wES1** [36° N-38.5° N, 128° E–131° E], **wES2** [38.5° N-41° N, 128° E–131° E], **wES3**[41° N-43.5° N, 129.5° E–132.5° E],**eES1** [37° N-39.5° N, 136.6° E–139.6° E], **eES2** [42.5° N-45° N, 137° E–140° E] and **eES3** [45.7° N-48.2° N, 139° E–142° E] with maximum JJA MHW frequency trend (0.45 events per decade).

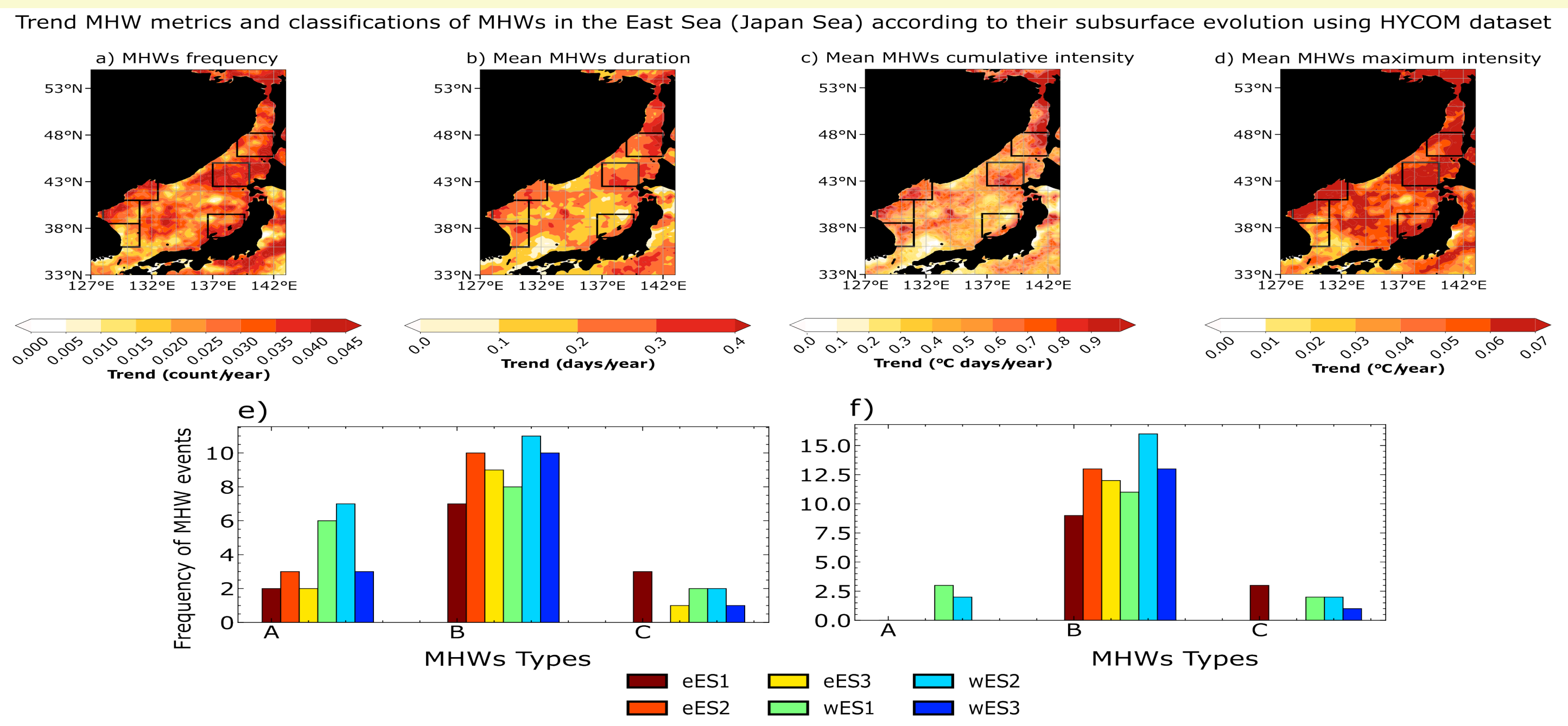

Figure 1. Trend of MHWs a) frequency b) duration c) cumulative intensity d) maximum intensity over the East Sea (Japan Sea). Distribution of MHW clusters in the six regions of the East Sea (Japan Sea) using e) K-means clustering and f) Hierarchical clustering.

3.2 Vertical profiles of hydrographic features of MHW clusters

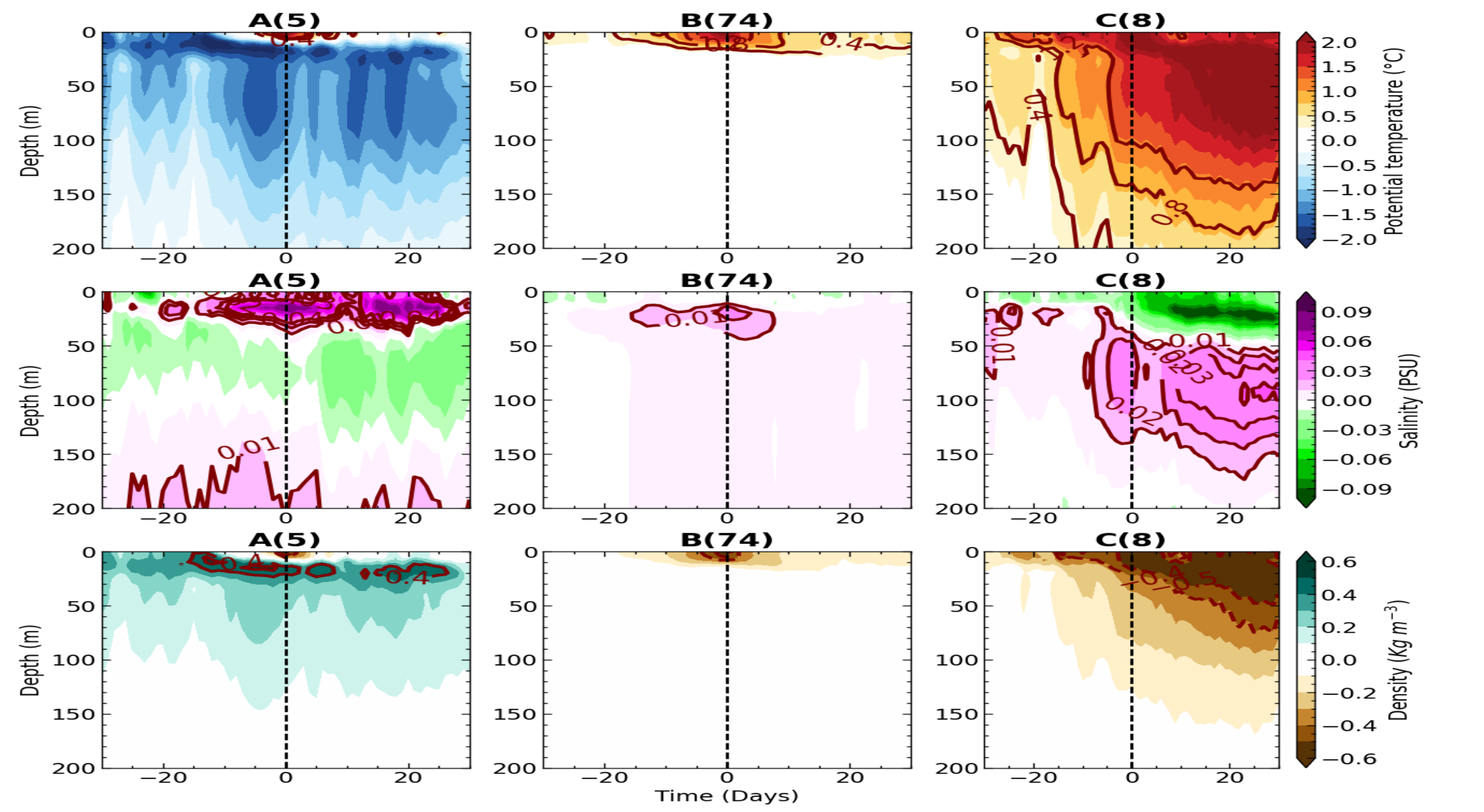

Figure 2. Hierarchical clusters (types A,B,C) of MHWs using the composite of potential temperature (°C), salinity (PSU), density ($Kg\ m^{-3}$) 30 days before and after the MHW peak date.

3.3 Time evolution of average heat budget terms before and after MHW peak date

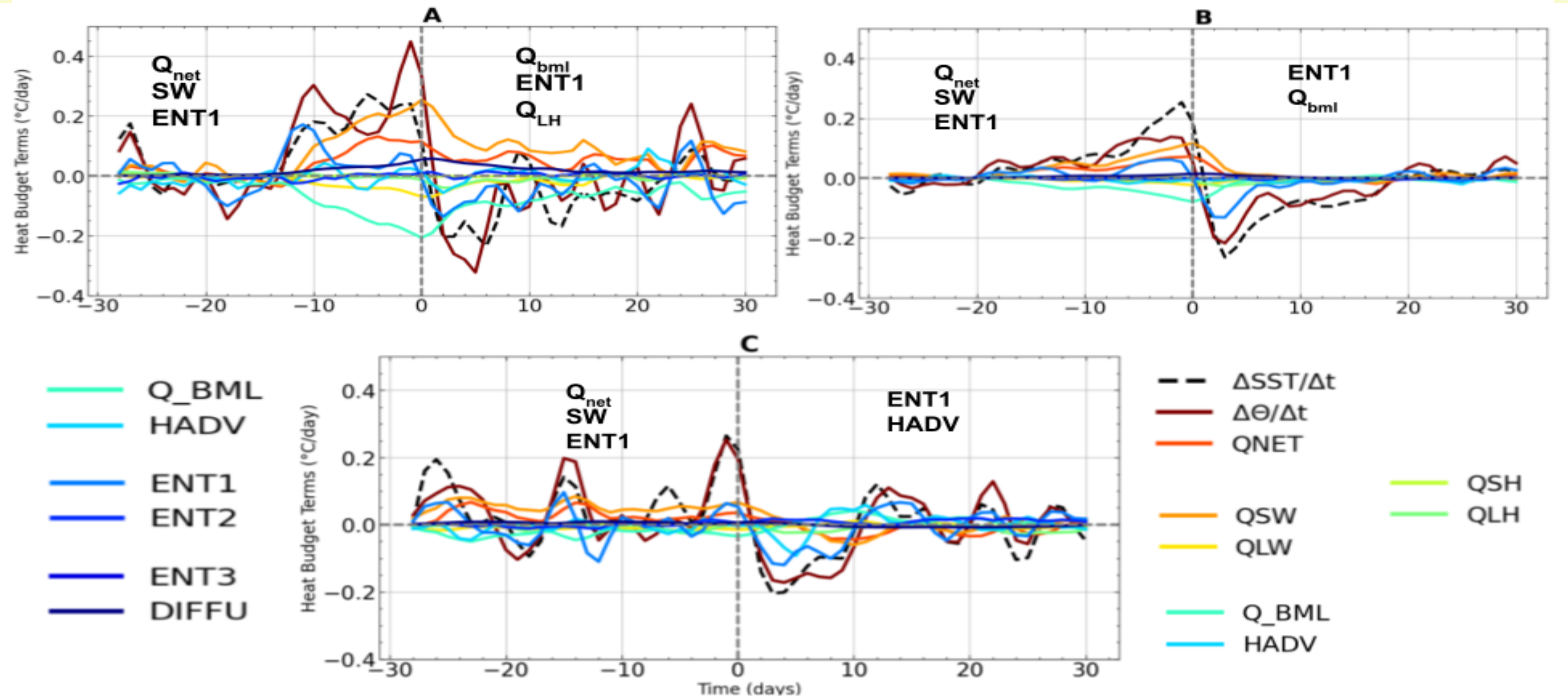

Figure 3. Time Evolution of Average Heat budget terms before and after MHW peak date (using HYCOM during the period 1994-2015).

3.4 The mean vertical profiles and time evolution of different variables of 3 MHW clusters

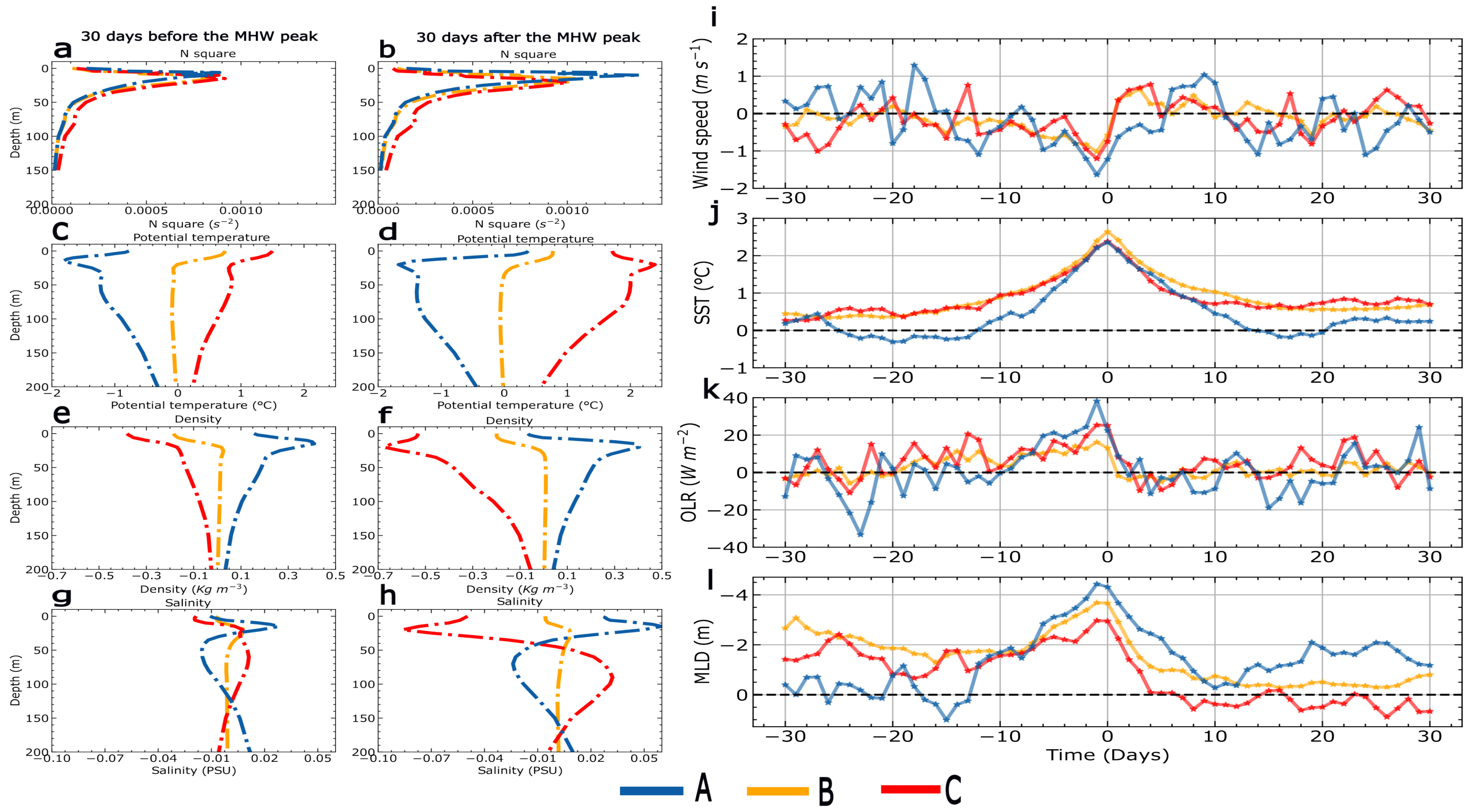

Figure 4. The mean vertical profiles (N square (s^{-2}), potential temperature (°C), density ($Kg\ m^{-3}$), salinity (PSU)) and time evolution of different i) wind speed ($m\ s^{-1}$), j) sea surface temperature (°C), k) Outgoing Longwave Radiation (OLR) ($W\ m^{-2}$), l) Mixed Layer Depth (MLD) (m) of 3 types (using Hierarchical clustering).

3.5 Discussion

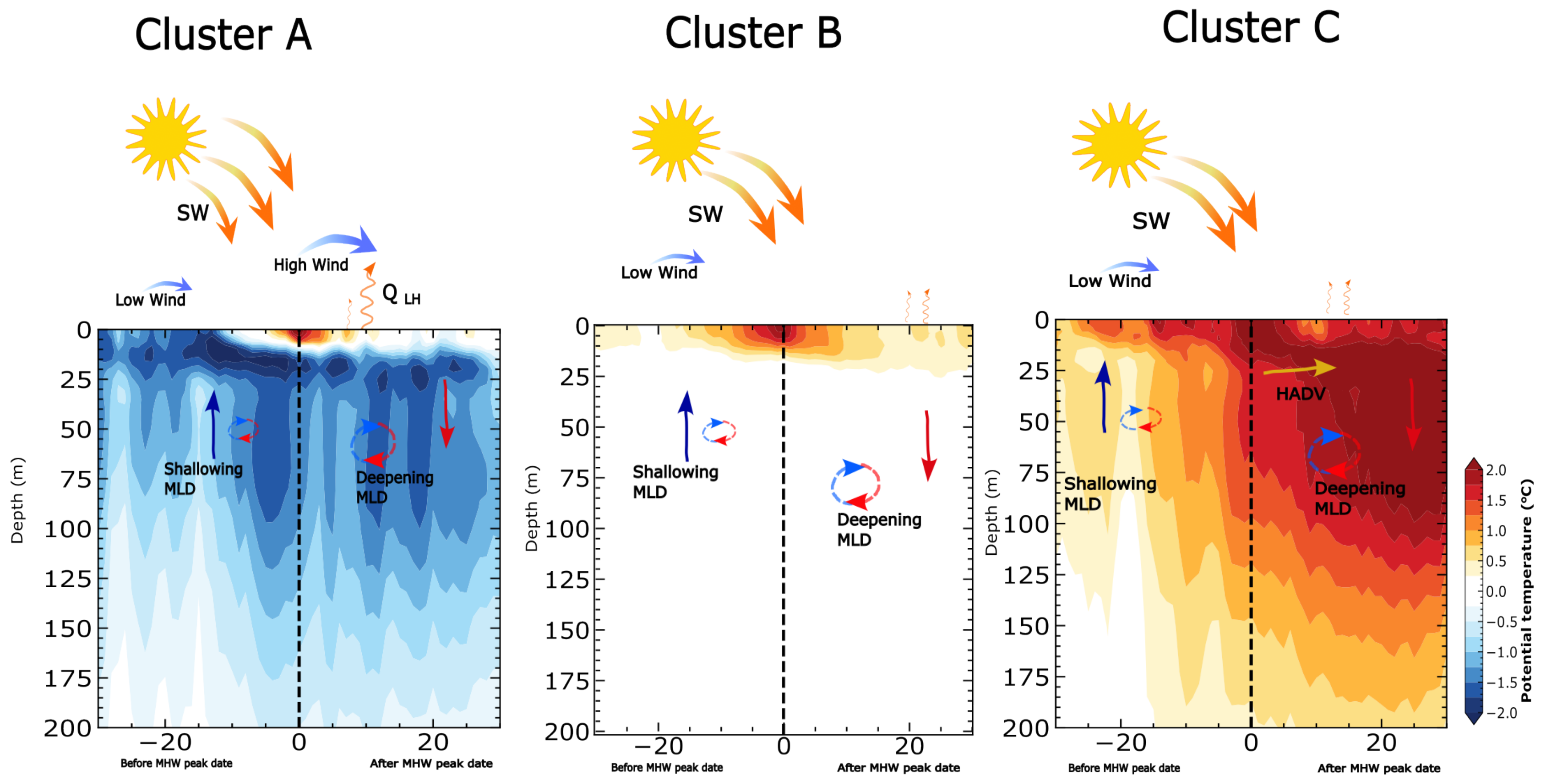

Figure 5. The schematic of the causes of the evolution of the MHW clusters types A, B, C, 30 days before and after the MHW peak date.

4. Conclusion

- In the East sea region, 3 classes of subsurface (Types A, B, C) evolution of MHWs were identified using 4 different model/reanalysis datasets and observations (ESROB).
- The net short wave flux, and Mixed Layer Depth (MLD) shallowing contribute to forming all three clusters. Cluster A is dissipated by MLD deepening, latent heat flux release, and changes in heat release from the below ML while B has the role of only first two factors. The MLD deepening, heat advection play a role in the dissipation of heat in cluster C.