Long-lasting marine heatwaves in the East Korea Bay, East/Japan Sea: Characteristics and mechanisms

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Introduction

- Marine heatwaves (MHWs) have become more intense, frequent, and prolonged in recent decades, devastatingly affecting marine ecosystems and subsequent socio-economic consequences.
- In the East Korea Bay (EKB), located in the northwestern East/Japan Sea (EJS), the duration of MHWs is 32% longer (16.8±24.0 days/event) than in the entire EJS. Notably, the EKB has experienced two exceptionally prolonged MHWs lasting over four months each.
- In this study, we investigated the distinct characteristics of the long-lasting MHWs in the EKB and their possible driving mechanism using satellite and reanalysis data. During the long-lasting MHWs, enhanced ocean surface cooling mainly driven by a latent cooling and a negligible solar radiation anomaly suggest a predominant influence of oceanic processes.

Data and Methods

- Study area: Range: East Korea Bay
- Period: 1982.01.01~2018.12.31
- Spatial resolution: 1° × 1° (bilinear interpolation)

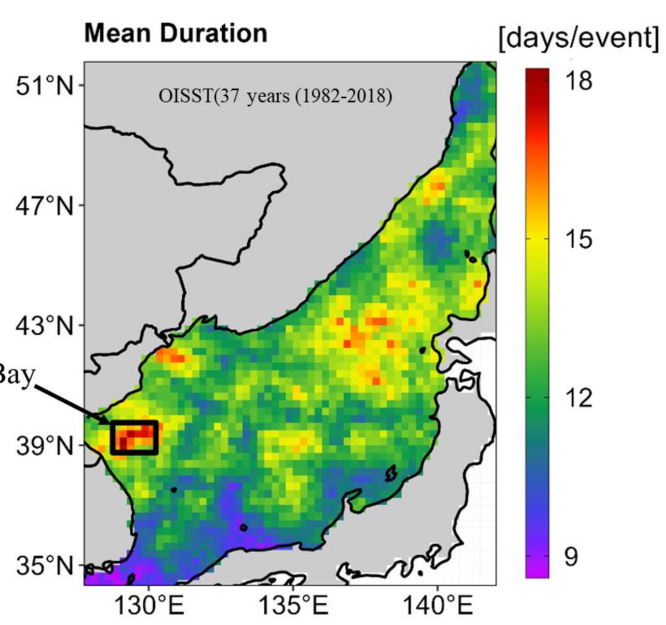

Fig 1. Spatial distribution of MHWs duration climate mean in the East/Japan Sea. Black box indicates East Korea Bay.

Table 1.Model and observation data lists

Source	Temporal coverage	Resolution		Input variables	remarks
		Spatial	Temporal		
OISST	1982.01.01~2018.12.31 (37 years)	0.25°	daily	Sea surface temperature	Detecting marine heat waves
KHOA	1993.01.01~2018.12.31 (26 years)	0.25°	daily	Ocean current velocity, Sea surface height	Eddy impacts
AVISO	1993.01.01~2018.12.31 (26 years)	0.25°	daily	Eddies	
ERA5	1982.01.01~2018.12.31 (37 years)	0.25°	daily	Heat flux	Heat budget analysis
HYCOM	1995.01.01~2018.12.31 (24 years)	0.083°	daily	Vertical T/S profiles, Ocean current velocity	

Long-lasting MHWs in EKB

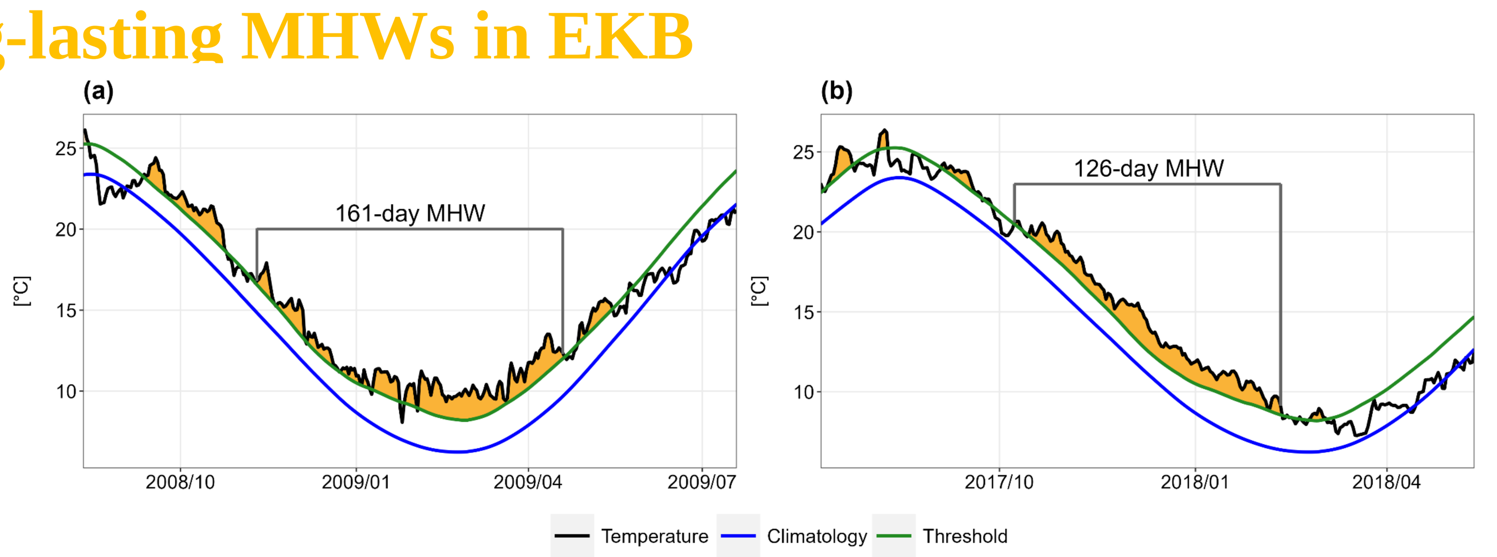

Fig 2. The two extremely long-lasting MHWs in the EKB: (a) 161 days (10 Nov 2008–19 Apr 2009) and (b) 121 days (8 Oct 2017–10 Feb 2018). The black is SST; blue, climatological seasonal cycle; green, MHWs threshold; orange, MHWs.

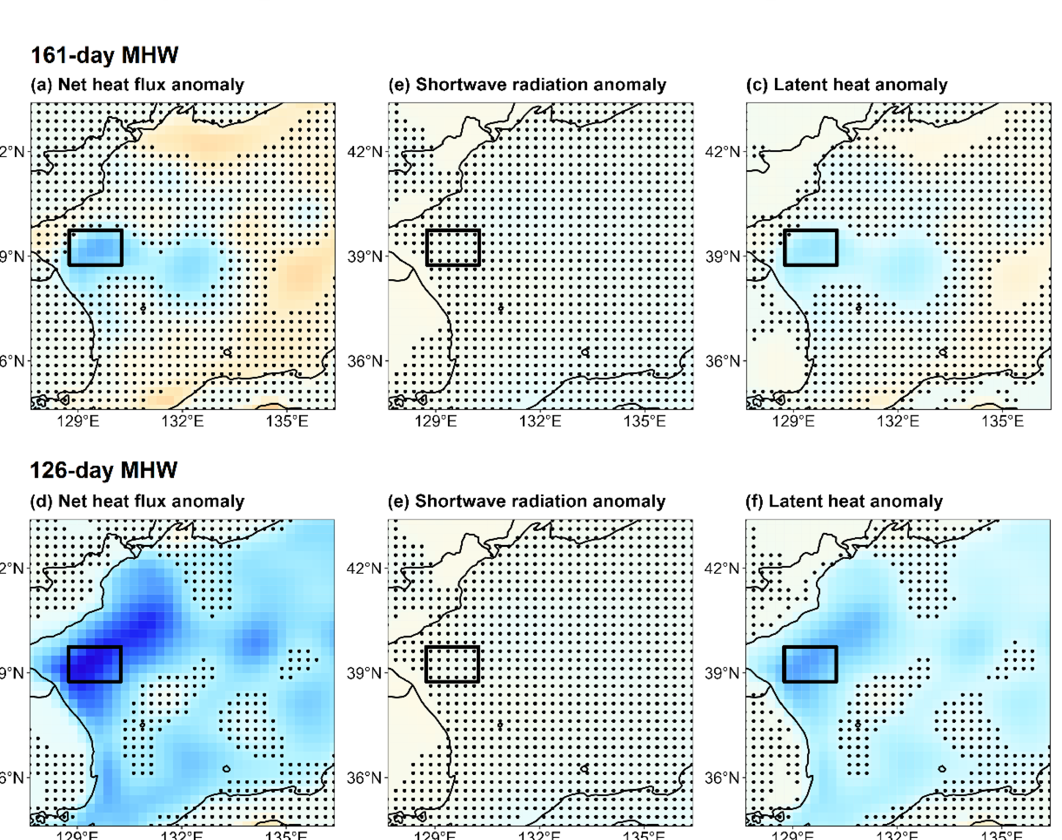

Fig 3. Anomalies of the (a) net heat flux, (b) shortwave radiation, (c) latent heat flux during 161 day MHWs case, (d) net heat flux, (e) shortwave radiation and (f) latent heat flux during 126 day MHWs with respect to the climatological period 1982–2011 (30 years). The dots indicate insignificant difference at the 99% confidence level.

- Based on the spatial distribution of MHW characteristics, the longer duration of MHWs in the EKB compared to the EJS may be due to either the generally longer MHWs or a few exceptionally long MHWs in the EKB.
- During 37 years (1982-2018), the two longest MHW in the EKB persisted for 161 days (10/Nov/2008–19/Apr/2009; Fig. 2a), and 126 days (08/Oct/2017–10/Feb/2018; Fig. 2b). The both long-lasting MHWs onset in the cooling season including fall.
- Significant cooling of the ocean surface with a negligible shortwave radiation anomaly(Fig 3)

East Korea Bay Eddies in Fall (OND)

- The East Korean Warm Current moves relatively northward during the extremely long-lasting MHWs (Fig 4)
- The MHWs in the EKB occur mostly along the boundary of the eddies (Fig 5)

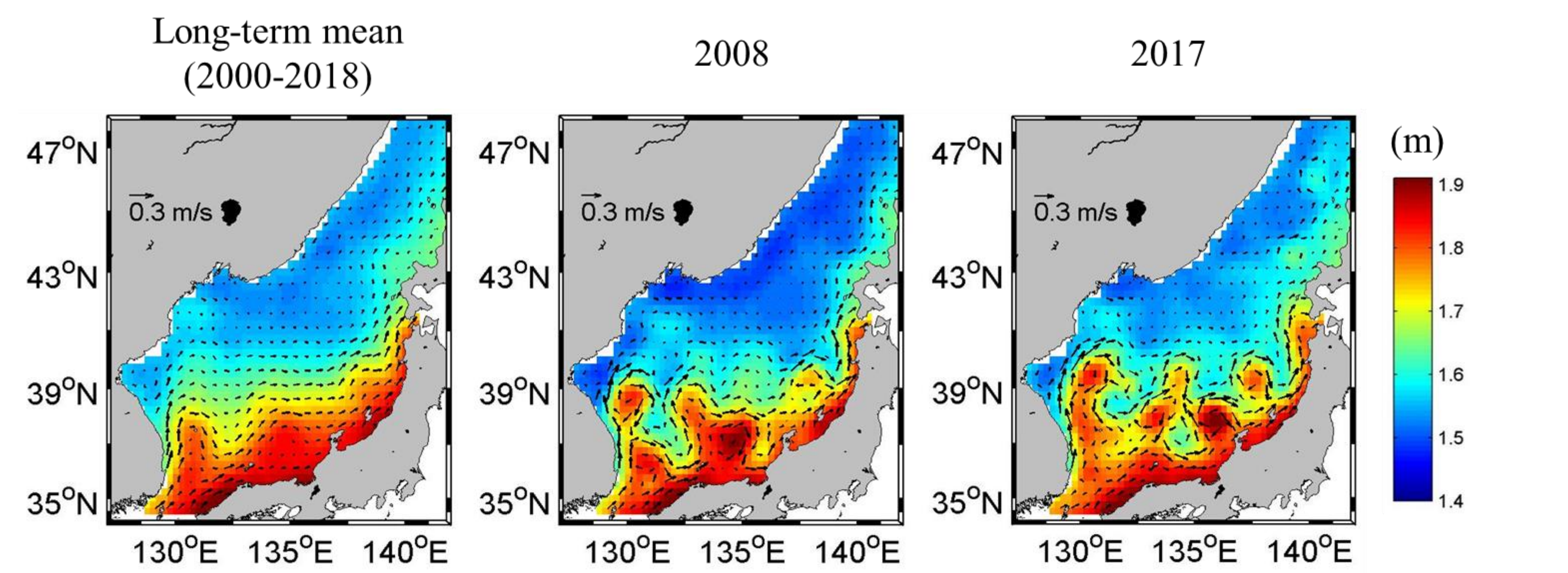

Fig 4. Spatial distribution of Fall (OND) SSH in the East/Japan Sea. (a) long-term mean (2000-2018), (b) 2008 and (c) 2017 in KHOA SSH based on AVISO

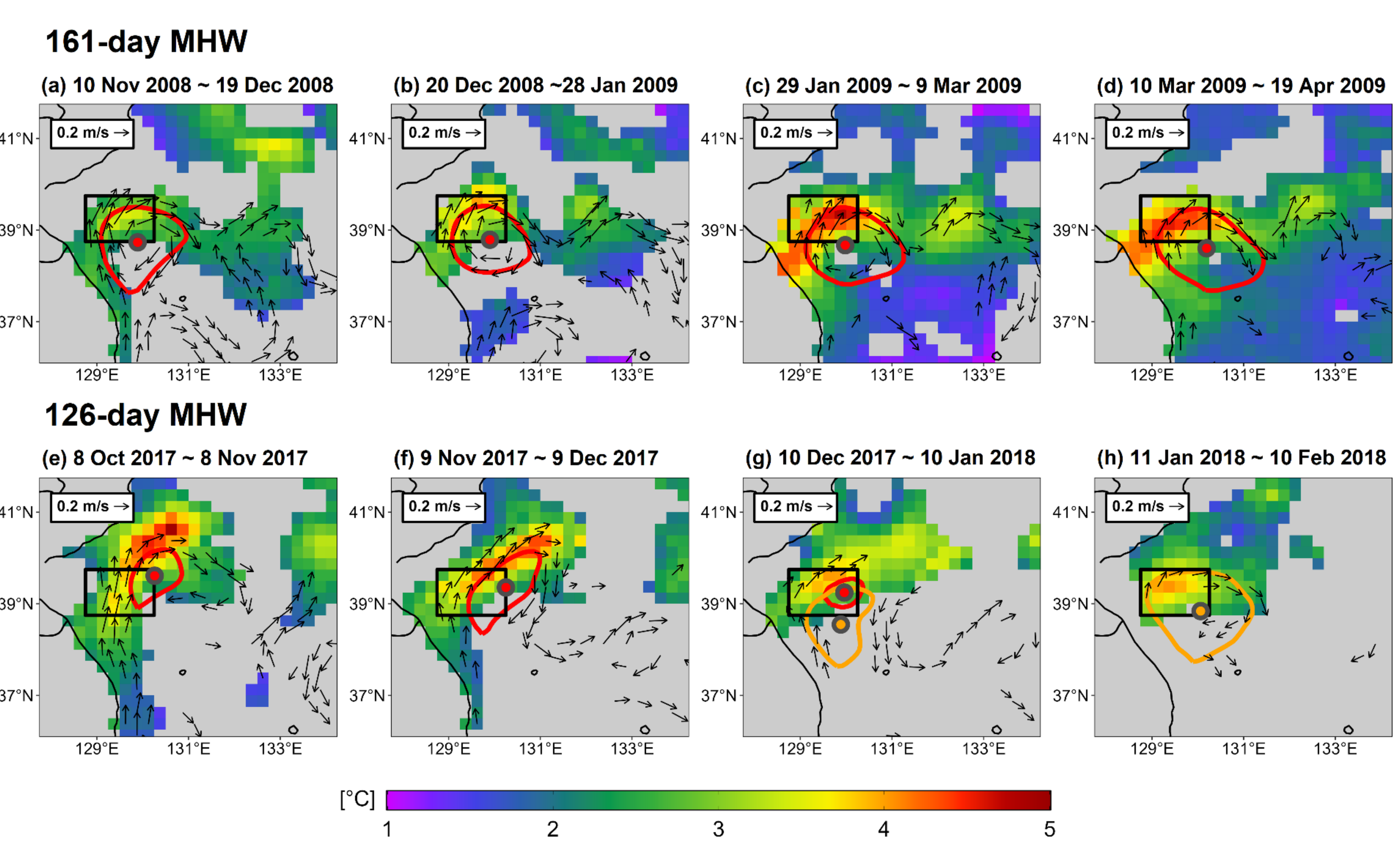

Fig 5. Spatial distribution of the mean sea surface heights (shade, m), ocean currents (vectors, > 0.2 m/s), eddy boundary (red and orange contours) and eddy center (red and orange dots) during the extremely long-lasting MHWs: 161-day MHW (averages of 40-day, 40-day, 40-day, 41-day; a–d): (a) 10 Nov–19 Dec, 2008, (b) 20 Dec 2008–28 Jan 2009, (c) 29 Jan–9 Mar, 2009, (d) 10 Mar–19 Apr, 2009, 126-day MHW (averages of 32-day, 31-day, 32-day, 31-day; e–h): (e) 8 Oct–8 Nov, 2017, (f) 9 Nov–9 Dec, 2017, (g) 10 Dec 2017–10 Jan 2018, (h) 11 Jan–11 Feb, 2018.

Heat budget analysis

- **Mixed Layer Heat budget equation** (Pak et al., 2022)

$$\underbrace{\frac{\partial T_m}{\partial t}}_{\text{Volume-averaged temperature tendency}} = \overbrace{\frac{Q_{net}}{\rho c_p h}}^{\text{Surface heat flux}} \underbrace{- \overrightarrow{u_m} \cdot \nabla T_m}_{\text{Horizontal advection}} \overbrace{- \frac{1}{h}(T_m - T_{-h})\left(\frac{\partial h}{\partial t} + \vec{u}_{-h} \cdot \nabla h + w_{-h}\right)}^{\text{Entrainment}} + Residual$$

- Vertical T/S profiles: HYCOM
- Mixed layer depth: variable density criterion (de Boyer Montégut et al., 2004)
- Ocean temperature and horizontal advection are volume averaged over MLD

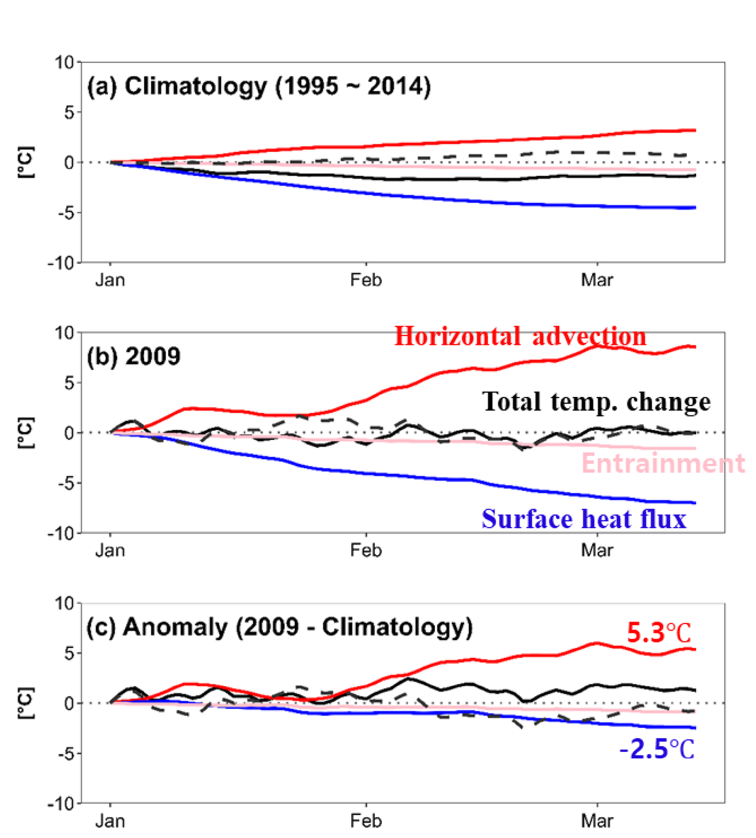

Fig 6. Comparison of heat budget between climatological period and the longest MHW period in the EKB: (a) climatological period (1995–2014), (b) the longest MHW period in the EKB (1 Jan 2009–13 Mar 2009), and (c) the anomalous heat budget in the longest MHW period with respect to the climatological period. Black line indicates volume-averaged temperature; red line, horizontal advection; blue line, air-sea heat flux at the surface; pink line, entrainment; gray dashed line, residuals.

- Ocean temperature increases primarily due to horizontal advection during long-lasting MHW in the EKB

Summary

- The long-lasting MHWs in the EKB (161 days(2008), 126 days(2017))
- Onset in fall and Occurs mostly in the northwest area of the EKB eddies
- Ocean (anticyclonic eddies) rather than atmosphere is the main driver → The long-lasting MHWs in the EKB have been associated mainly with ocean processes (eddies) rather than atmospheric processes.