Marine Heatwaves in the Chesapeake Bay

Piero Mazzini & Cassia Pianca

Virginia Institute of Marine Science - William & Mary

Image by: NASA

VIMS | William & Mary
Virginia Institute of Marine Science

Source:
https://www.worldatlas.com/articles/what-are-the-harmful-effects-of-a-heat-wave.html

Publications about Marine Heat Waves

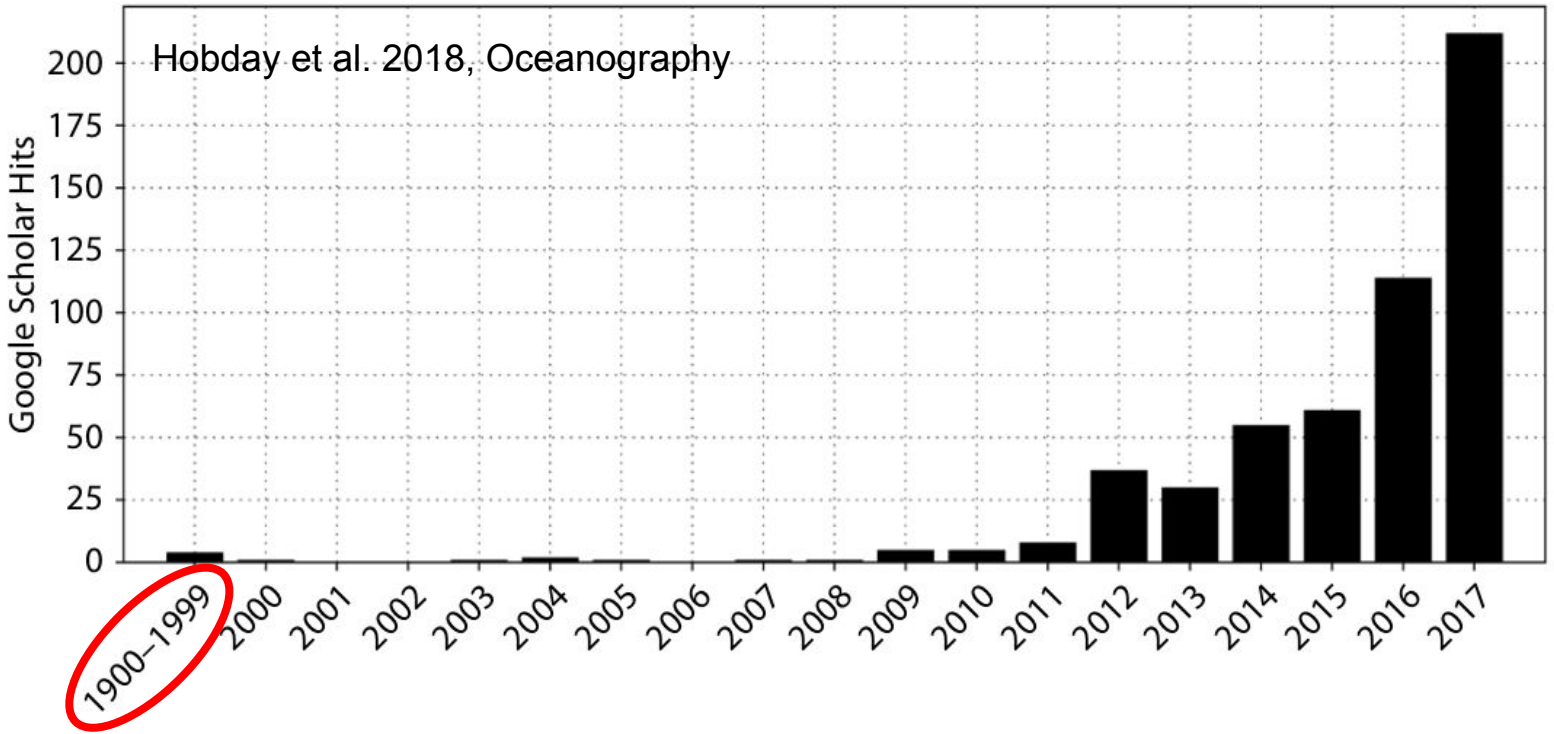


FIGURE 1. Frequency of publications returned from a Google Scholar search based on the search terms "marine heatwave" and "marine heat wave." Note the first bin (1999) contains all records for the period 1900–1999.

- **record-breaking harmful algal blooms**

  (McCabe et al., 2016; Trainer et al., 2020; Gobler, 2020)

- **global-scale coral bleaching**

  (Hughes et al., 2017; Eakin et al., 2019)

- **mortality of kelps, SAVs, invertebrates**

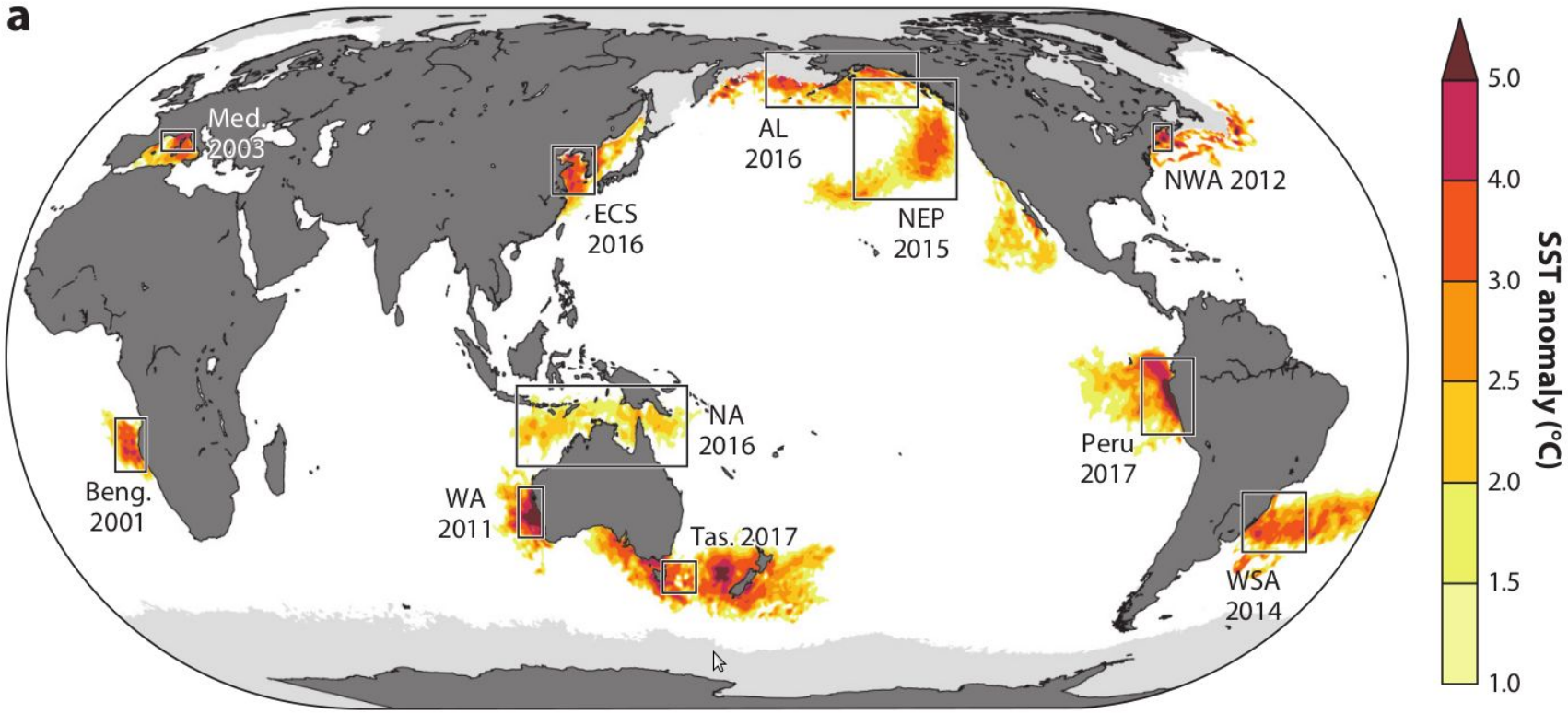
  (Moore and Jarvis, 2008; Garrabou et al., 2009; Marbà and Duarte, 2010; Fraser et al., 2014; Thomson et al., 2015; Wernberg et al., 2016; Shields et al., 2018; Thomsen et al., 2019; Seuront et al., 2019; Shields et al., 2019; Filbee-Dexter et al., 2020; Aoki et al., 2021; Johnson et al., 2021)

- **impacted commercial fisheries and aquaculture**

  (Mills et al., 2013; Caputi et al., 2016; Oliver et al., 2017; Jacox, 2019)

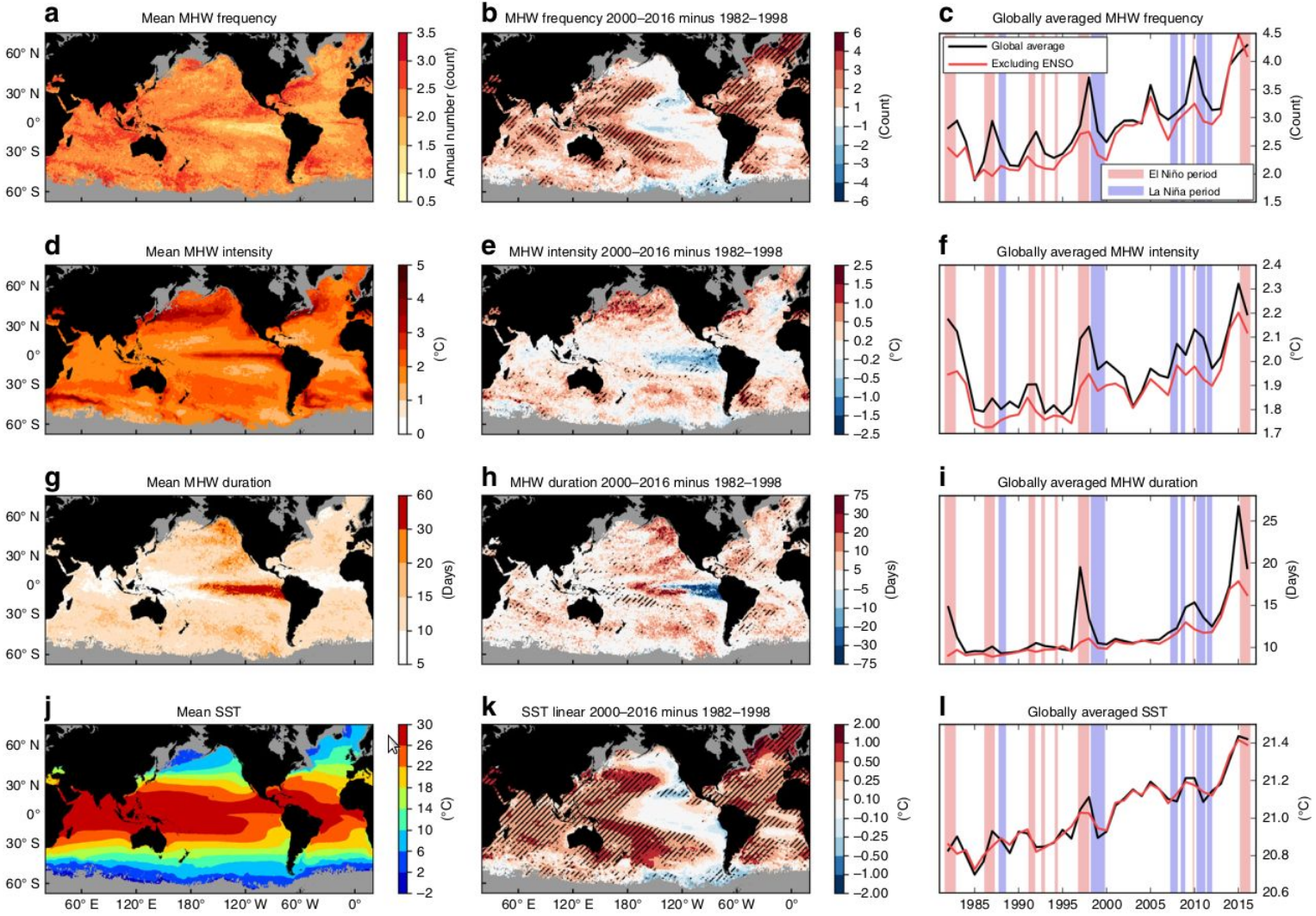
- **geographical species shifts and changes in species composition**

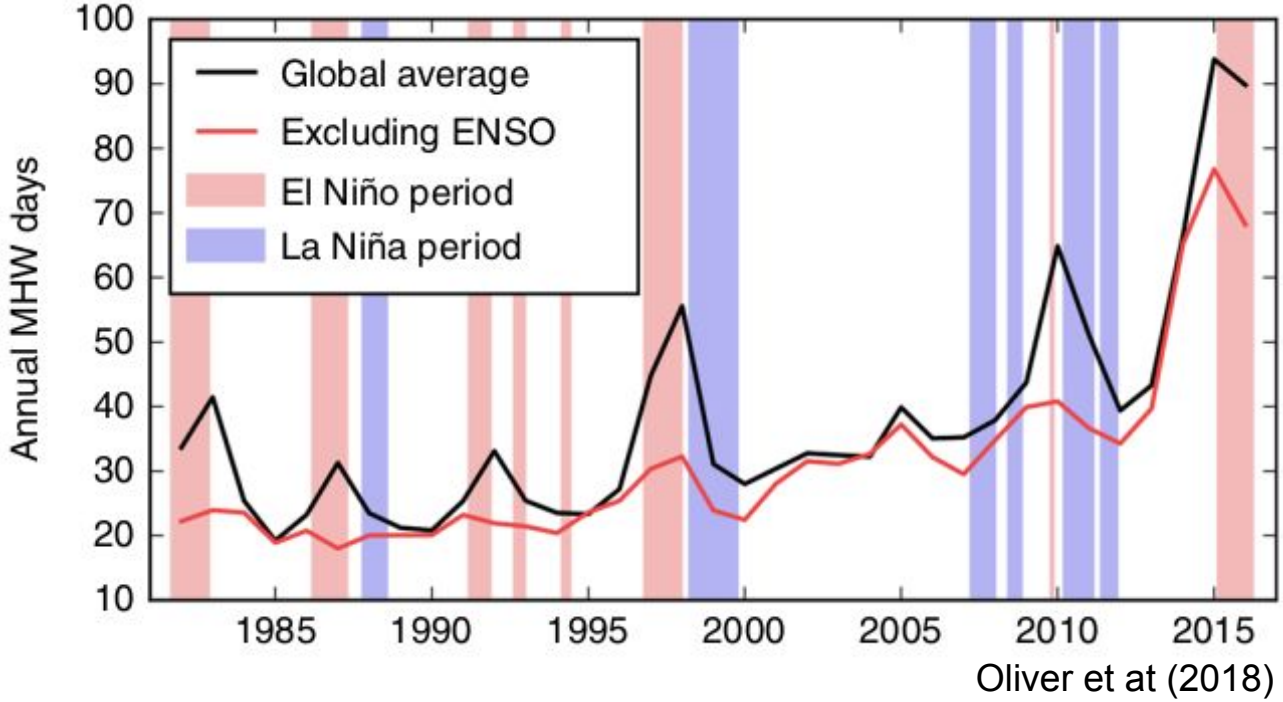
  (Ehlers et al., 2008; Cavole et al., 2016; Sanford et al., 2019)



Oliver et al. 2021, Ann. Rev. Mar. Sci.

Oliver et at. 2018, Nat. Commun.





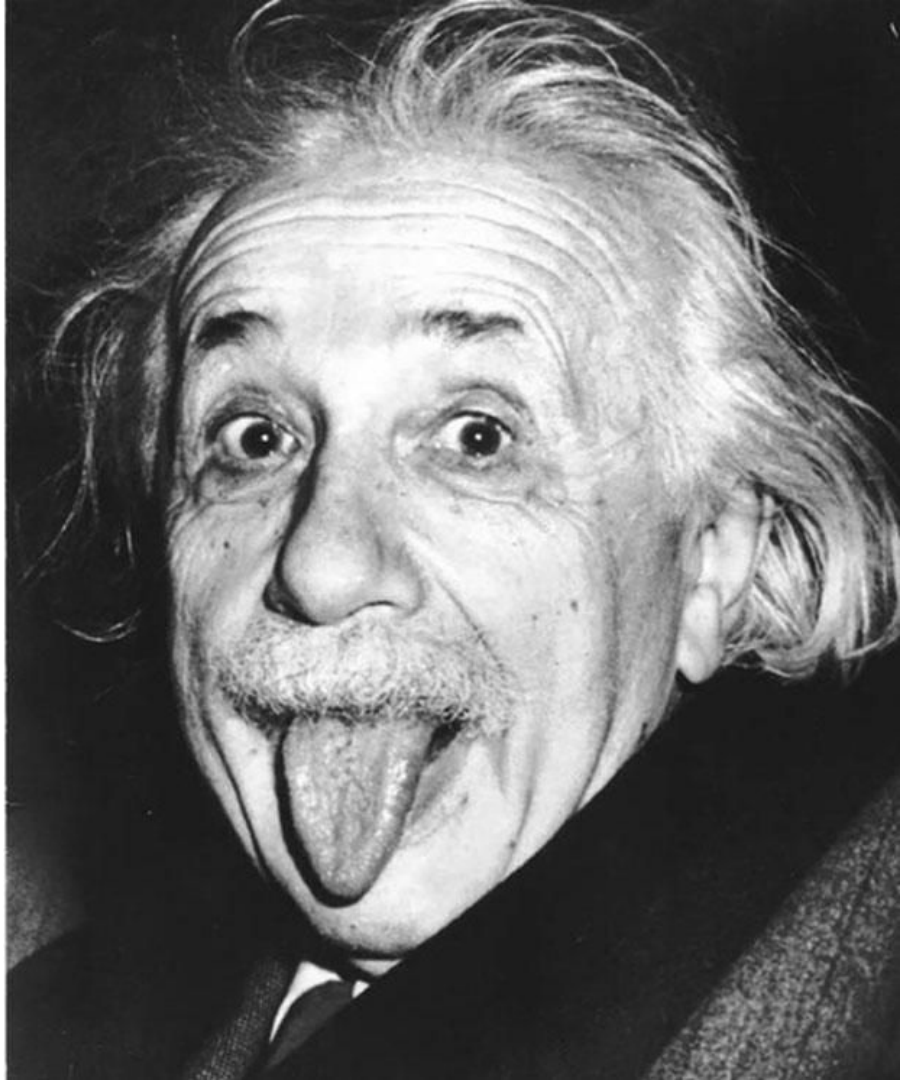
Oliver et at (2018)

From 1925 to 2016, global average MHWs:

- **34%** increase in *frequency*
- **17%** increase in *duration*
- **54%** increase in *MHW days*

https://westwind.org/upcoming-westwind-4/

Time for **SCIENCE**!



Goals:

1. Characterize MHWs in the CB with regard to their frequency, intensity, duration and cumulative intensity;

2. Analyze trends in MHWs characteristics;

3. Evaluate the contribution of long-term trends versus internal variability in SST to observed trends in MHWs characteristics;

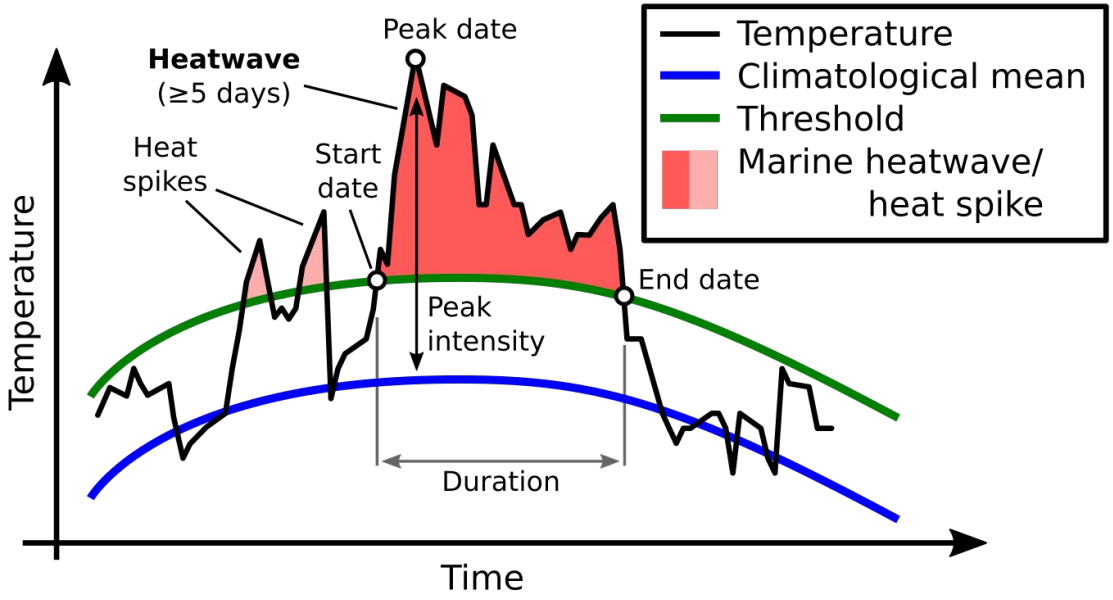
4. Investigate the co-occurrence of MHWs between different regions within the CB, and between CB and the adjacent coastal ocean;

5. Examine the relationship between MHWs and large scale (basin- to global-scale) climate indices: namely the North Atlantic Oscillation (NAO) index, El Niño (Niño 1+2) and Bermuda High Index (BHI).

Objective definition

Hobday et at (2016)

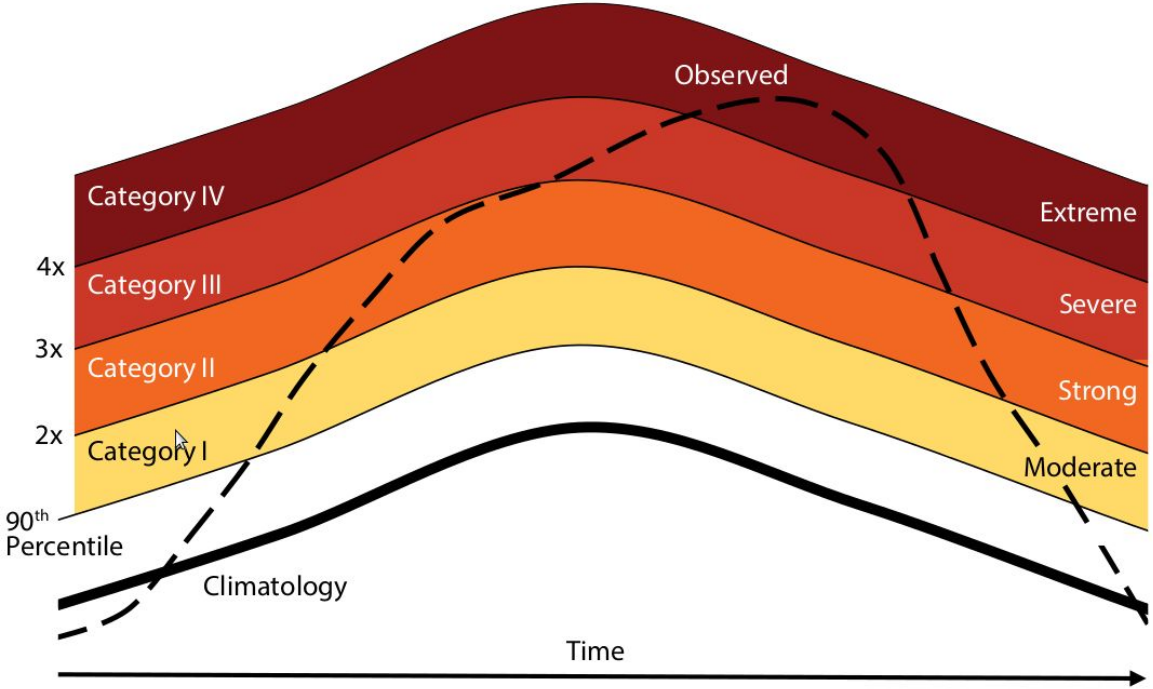
- Minimum record length of 30 years
- Climatology is calculated using an 11-day moving-average window
- SST > 90th percentile (threshold) of seasonal climatology for 5 consecutive days or more
- definition considers MHWs as relative warm deviations from the baseline climatologies, allowing them to exist at any time of the year, and not only during hot summer months.



http://www.marineheatwaves.org/all-about-mhws.html

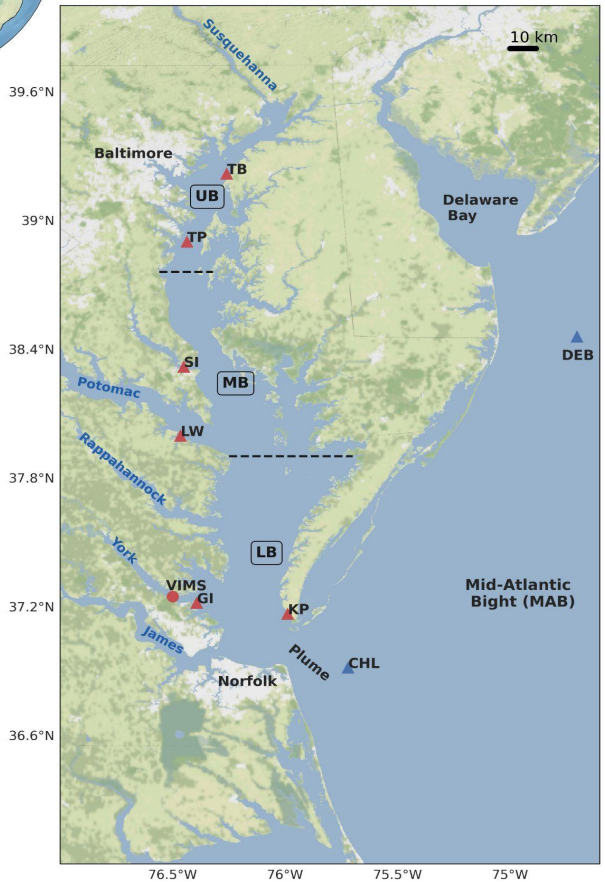
MHW metrics:

- Duration
- Intensity
- Frequency
- MHW days
- Cumulative Intensity
- Categories: Moderate, Strong, Severe, and Extreme
- etc...



Hobday et al (2018)

Chesapeake Bay



- Largest and most productive estuary in the US (Cloern et al., 2014).

- Watershed area 166,319 km^2, encompassing 6 states (NY, PA, DE, MD, VA, WV) + Washington D.C.

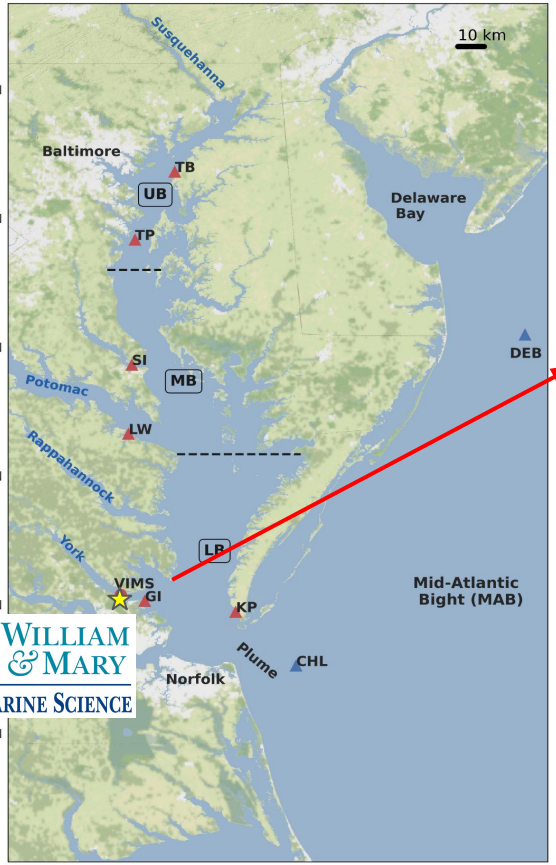
- 18 million people live within the CB watershed

- environmental issues: eutrophication, HABs, hypoxia

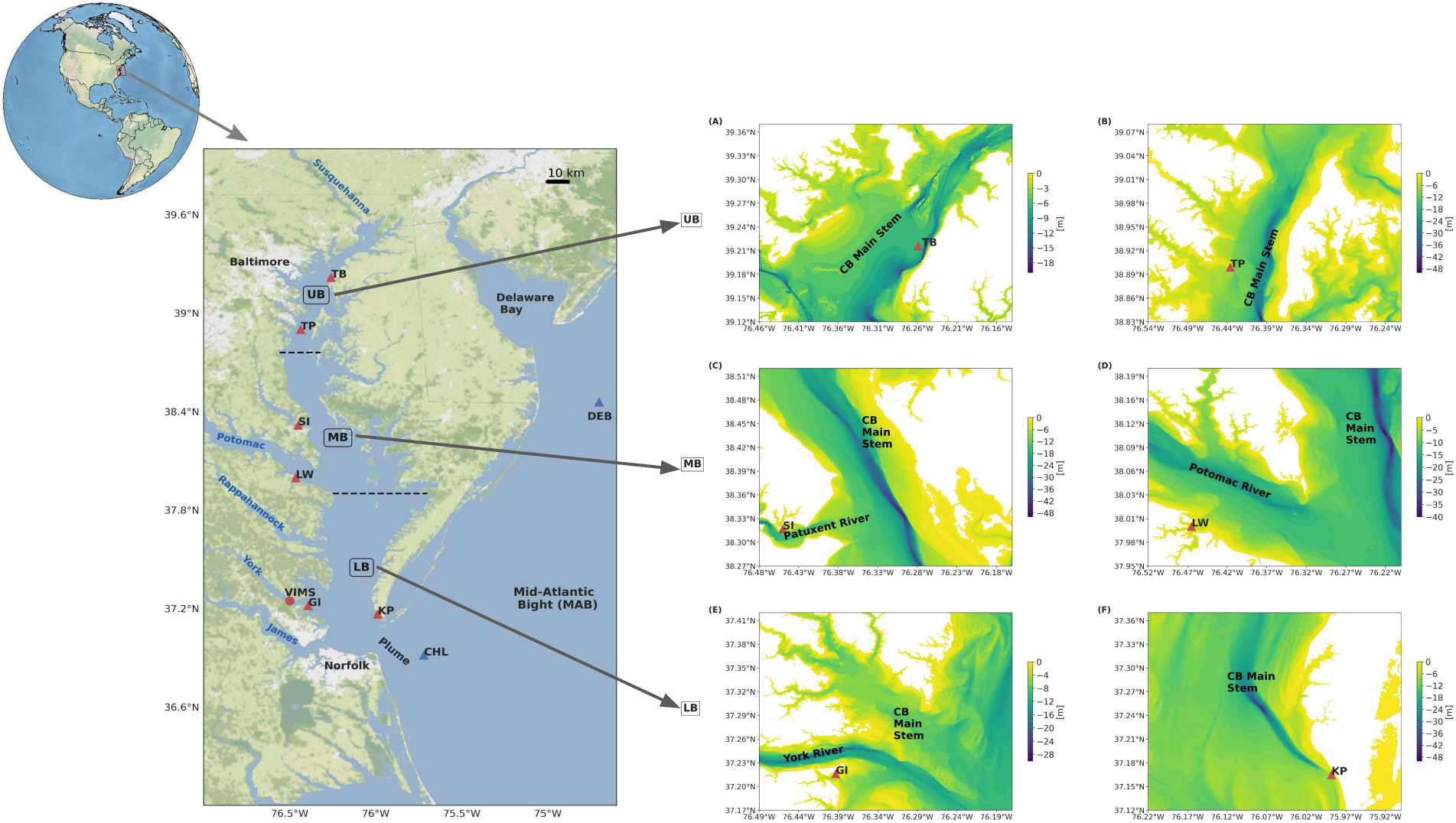
Estuary characteristics:

- 320 km long
- 4.5-48 km wide
- average depth of 6.4 m
- coastal plain, partially mixed estuary
- 50% of its freshwater inflows from Susquehanna River
- Long residence times: ~160 days

Chesapeake Bay



VIMS | William & Mary
Virginia Institute of Marine Science


10 km
Susquehanna
Baltimore
TB
UB
TP
Delaware Bay
DEB
SI
MB
Potomac
LW
Rappahannock
York
LB
VIMS
GI
KP
James
Plume
CHL
Norfolk
Mid-Atlantic Bight (MAB)
39.6°N
39°N
38.4°N
37.8°N
37.2°N
36.6°N
76.5°W
76°W
75.5°W
75°W
(A)
CB Main Stem
(B)
CB Main Stem
(C)
CB Main Stem
Patuxent River
(D)
CB Main Stem
Potomac River
(E)
CB Main Stem
York River
(F)
CB Main Stem
[m]

Information about Stations

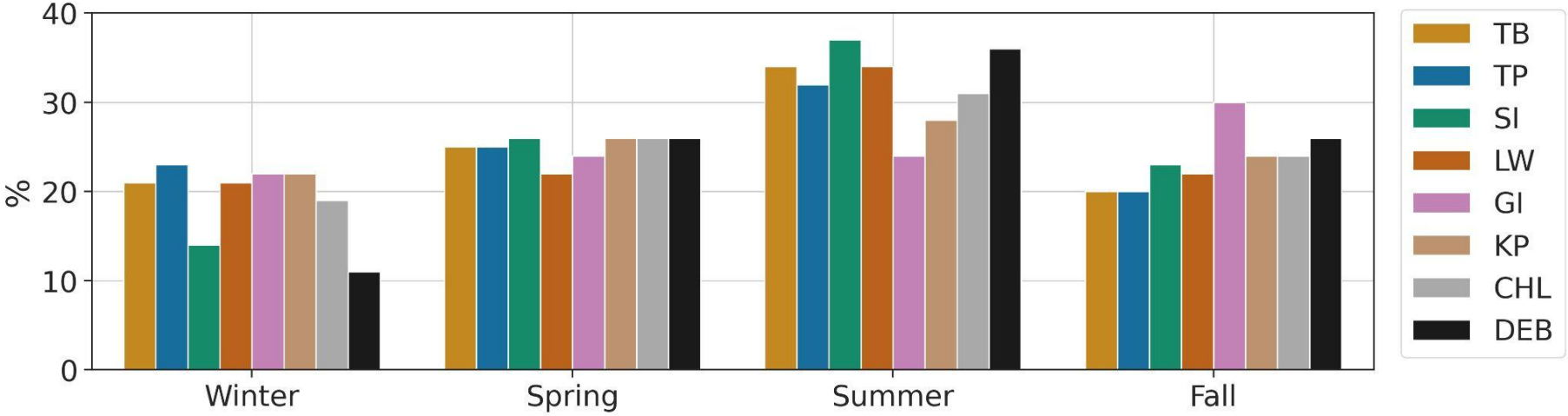
TABLE 1 | Summary of the stations used in this study: TB, Tolchester Beach; TP, Thomas Point; SI, Solomons Island; LW, Lewisetta; GI, Goodwin Island (extended with data from VIMS Ferry Pier between 1986 and 1997, see section 2 Methods); KP, Kiptopeke; CHL, Chesapeake Light Tower; DEB, Delaware Bay buoy.

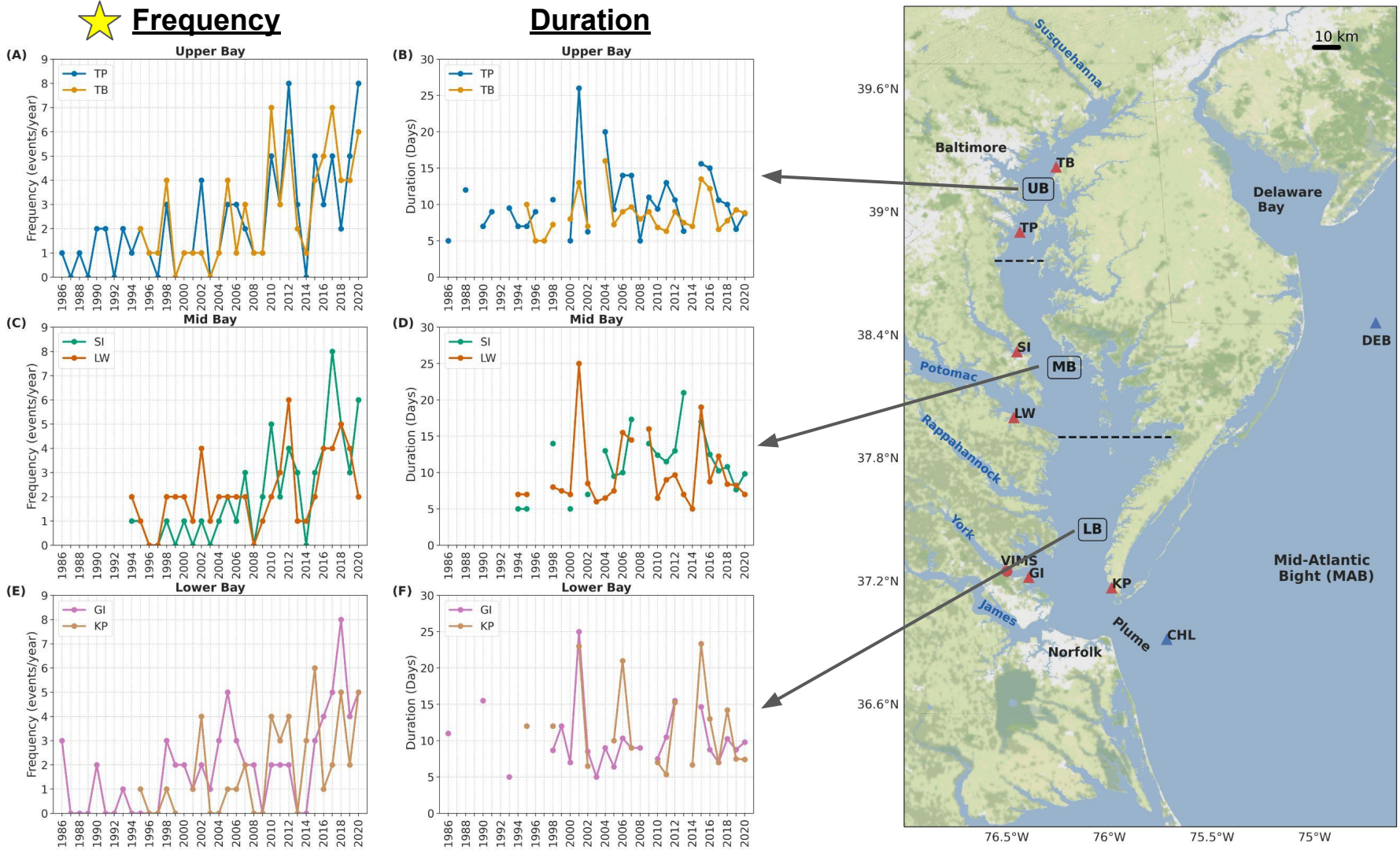
Name	Station ID	Location	Distance (km)	Depth (m)	Start-end	Length (years)	Source
TB	8573364	39.216°N 76.259°W	247.5	0.82	1995–2020	26	CO-OPS
TP	TPLM2	38.899°N 76.436°W	214.7	1.00	1986–2020	35	NDBC
SI	8577330	38.317°N 76.450°W	151.9	0.70	1994-2020	27	CO-OPS
LW	8635750	37.995°N 76.465°W	118.3	1.92	1994–2020	27	CO-OPS
GI	CBVGIWQ	37.216°N 76.393°W	43.0	0.75	1986–2020	35	CBNERR/VIMS
KP	8632200	37.165°N 75.988°W	18.5	1.50	1995–2020	26	CO-OPS
CHL	CHLV2/44099	36.915°N 75.722°W	25.7	0.46	1986–2020	35	NDBC
DEB	44009	38.457°N 74.702°W	197.7	0.60	1986–2020	35	NDBC

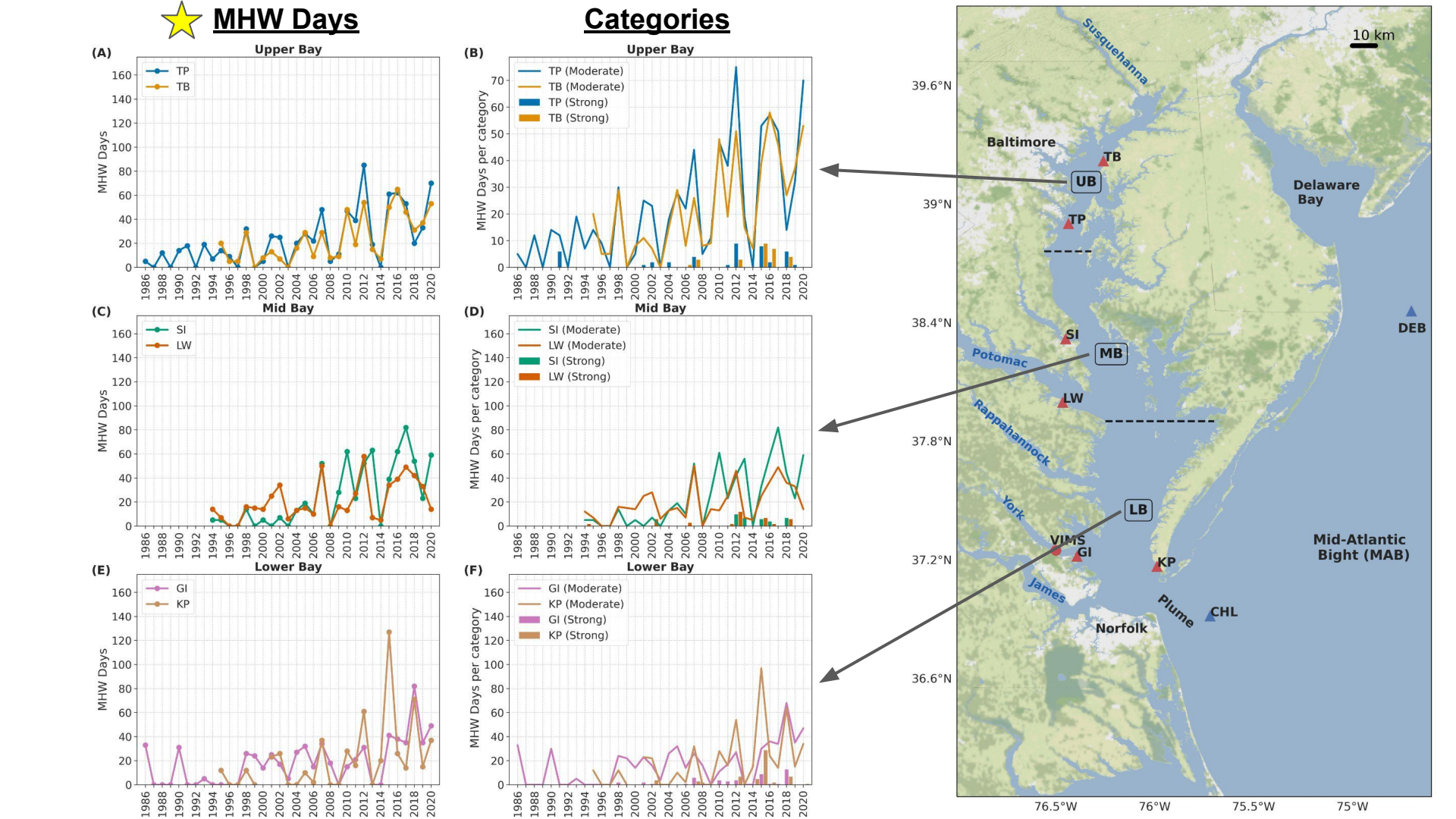
Distance refers to the linear distance from each station to the Chesapeake Bay mouth; Depth refers to the average depth at which the temperature sensors are located.

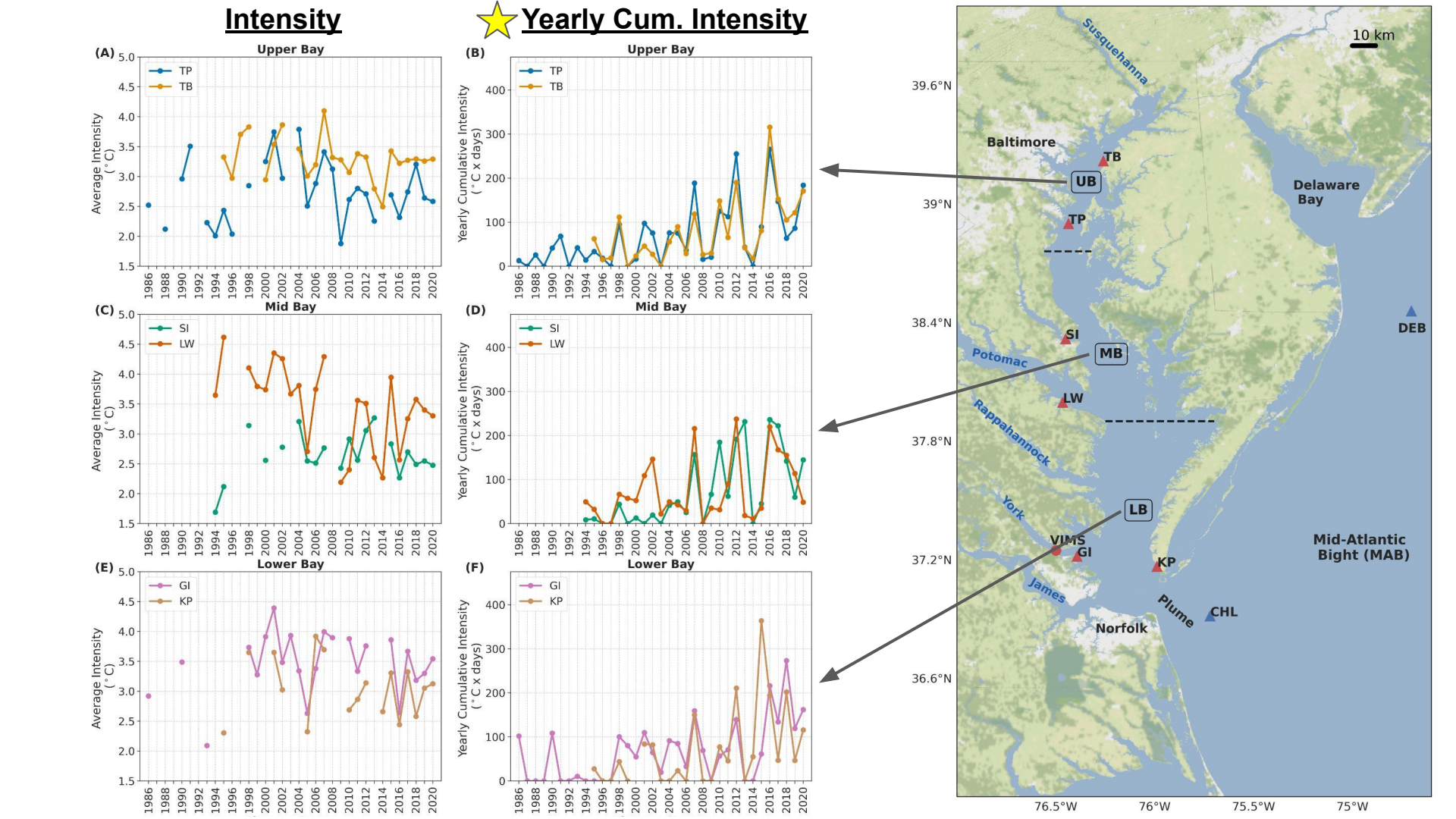
Results

Seasonal Variability in MHW Occurrence




Frequency
Duration
(A)
Upper Bay
TP
TB
Frequency (events/year)
(B)
Upper Bay
TP
TB
Duration (Days)
(C)
Mid Bay
SI
LW
Frequency (events/year)
(D)
Mid Bay
SI
LW
Duration (Days)
(E)
Lower Bay
GI
KP
Frequency (events/year)
(F)
Lower Bay
GI
KP
Duration (Days)
10 km
Susquehanna
Baltimore
TB
UB
Delaware Bay
TP
DEB
SI
MB
Potomac
LW
Rappahannock
York
LB
VIMS
GI
KP
Mid-Atlantic Bight (MAB)
James
Plume
CHL
Norfolk
39.6°N
39°N
38.4°N
37.8°N
37.2°N
36.6°N
76.5°W
76°W
75.5°W
75°W


MHW Days
Categories
(A)
Upper Bay
TP
TB
MHW Days
(B)
Upper Bay
TP (Moderate)
TB (Moderate)
TP (Strong)
TB (Strong)
MHW Days per category
(C)
Mid Bay
SI
LW
MHW Days
(D)
Mid Bay
SI (Moderate)
LW (Moderate)
SI (Strong)
LW (Strong)
MHW Days per category
(E)
Lower Bay
GI
KP
MHW Days
(F)
Lower Bay
GI (Moderate)
KP (Moderate)
GI (Strong)
KP (Strong)
MHW Days per category
10 km
Susquehanna
Baltimore
TB
UB
Delaware Bay
TP
DEB
SI
MB
Potomac
LW
Rappahannock
York
LB
VIMS
GI
KP
Mid-Atlantic Bight (MAB)
James
Plume
CHL
Norfolk
39.6°N
39°N
38.4°N
37.8°N
37.2°N
36.6°N
76.5°W
76°W
75.5°W
75°W

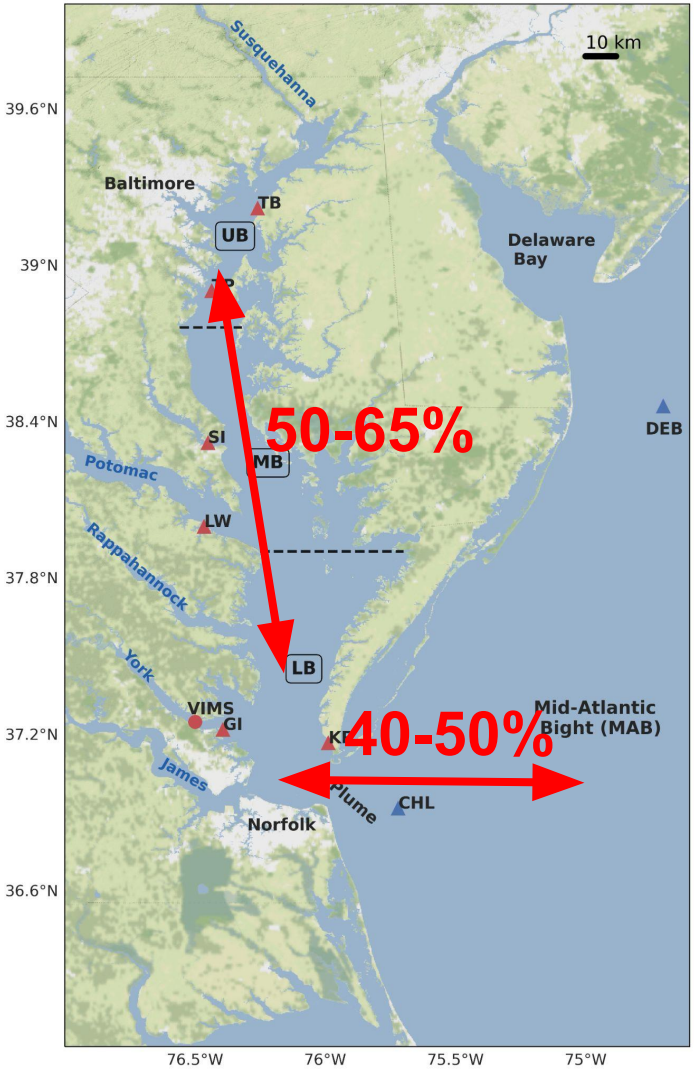

Intensity
Yearly Cum. Intensity
(A)
Upper Bay
TP
TB
Average Intensity (°C)
(B)
Upper Bay
TP
TB
Yearly Cumulative Intensity (°C x days)
(C)
Mid Bay
SI
LW
Average Intensity (°C)
(D)
Mid Bay
SI
LW
Yearly Cumulative Intensity (°C x days)
(E)
Lower Bay
GI
KP
Average Intensity (°C)
(F)
Lower Bay
GI
KP
Yearly Cumulative Intensity (°C x days)
10 km
Susquehanna
Baltimore
TB
UB
Delaware Bay
TP
DEB
SI
MB
Potomac
LW
Rappahannock
York
LB
VIMS
GI
KP
James
Plume
CHL
Norfolk
Mid-Atlantic Bight (MAB)
39.6°N
39°N
38.4°N
37.8°N
37.2°N
36.6°N
76.5°W
76°W
75.5°W
75°W

Co-occurrence

Jaccard Index: $$J(A,B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}$$

UB - MB - LB: 50-65%, lags: <= 2 days

CB - MAB: 40-50%, lags: 2 - 5.5 days



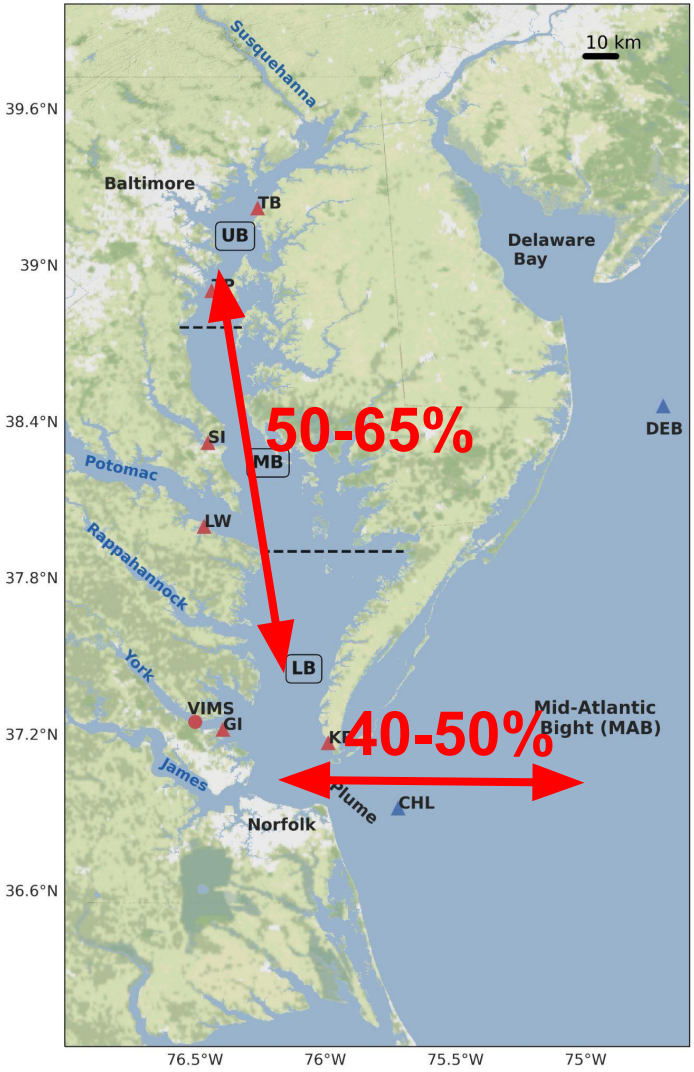
Co-occurrence

Jaccard Index: $$J(A,B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}$$

UB - MB - LB: 50-65%, lags: <= 2 days
CB - MAB: 40-50%, lags: 2 - 5.5 days

Surface mixed layer temperature budget
(Moisan and Niiler, 1998; Oliver, 2021; Schlegel et al., 2021):

$$\underbrace{\frac{\partial T_{\mathrm{mix}}}{\partial t}}_{\text{temperature change}} = \underbrace{\frac{Q_{\mathrm{net}}}{\rho c_{\mathrm{p}} H}}_{\text{air sea heat flux}} \underbrace{- u_{\mathrm{mix}} \cdot \nabla_{\mathrm{h}} T_{\mathrm{mix}}}_{\text{advection}} \underbrace{+ R}_{\text{residual}}$$



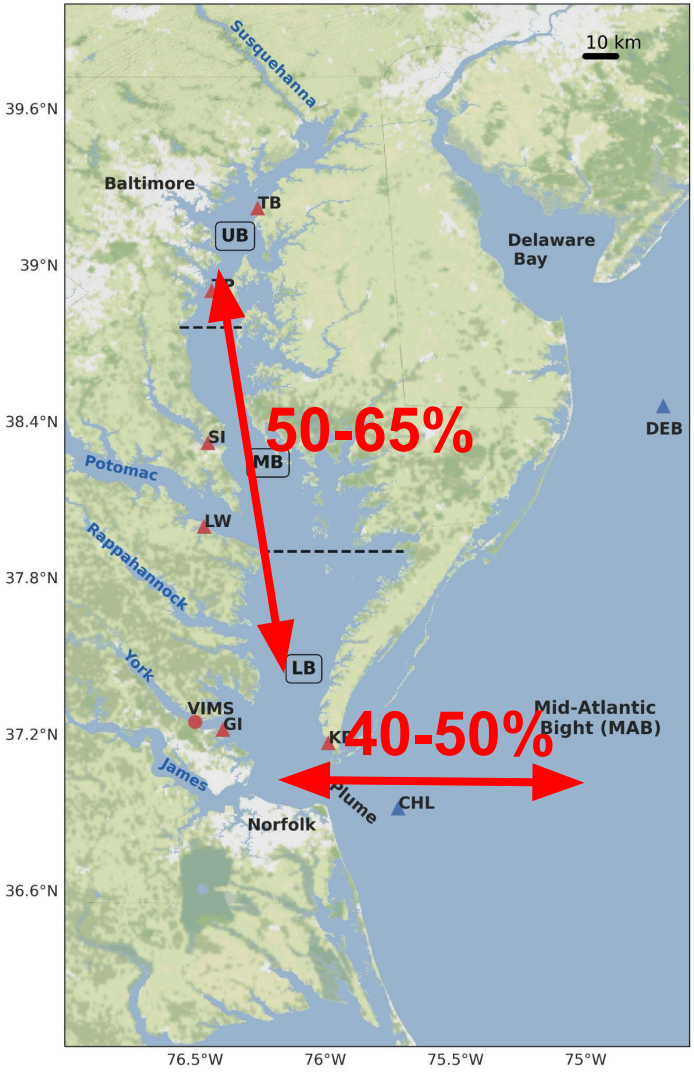
Co-occurrence

Jaccard Index: $$J(A,B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}$$

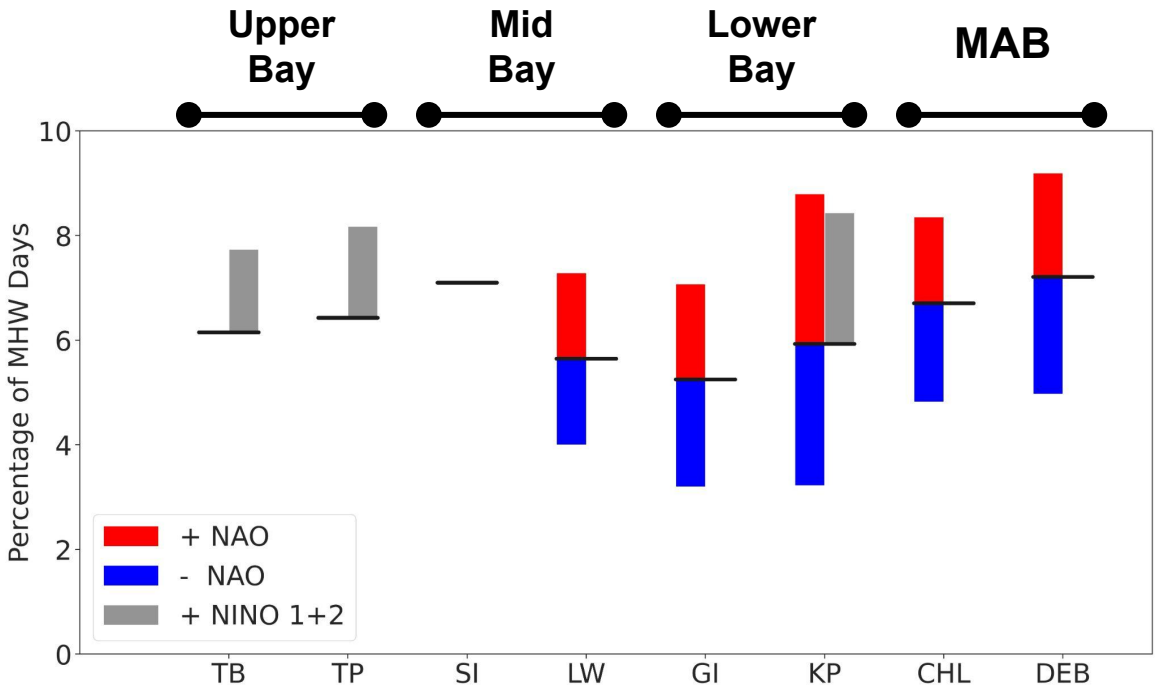
UB - MB - LB: 50-65%, lags: <= 2 days
CB - MAB: 40-50%, lags: 2 - 5.5 days

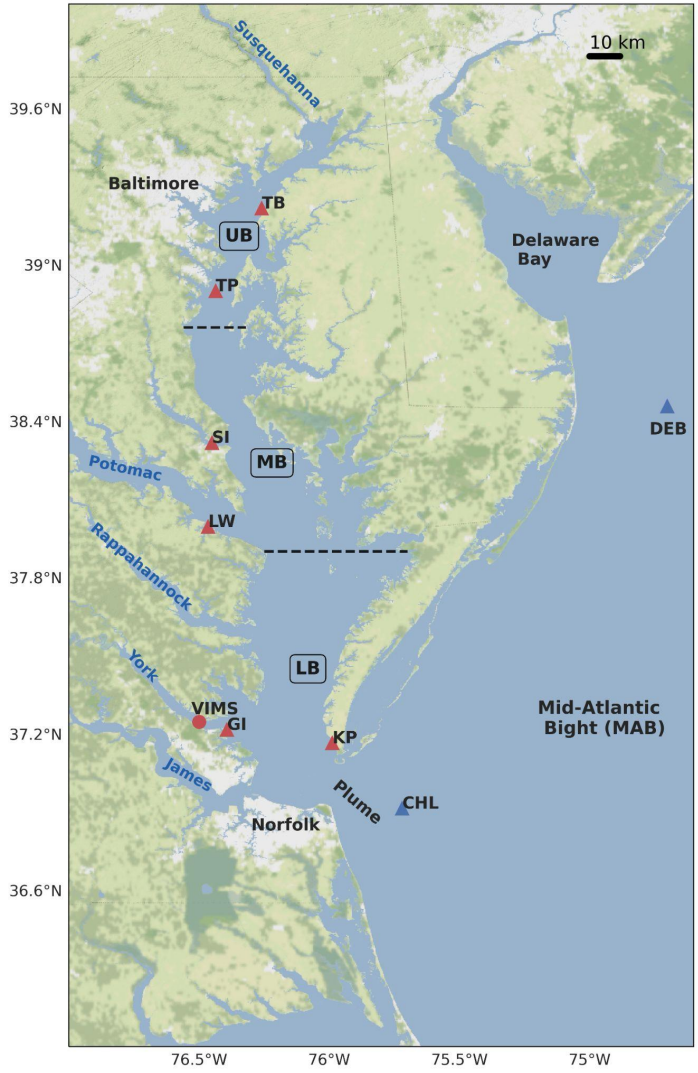
Surface mixed layer temperature budget
(Moisan and Niiler, 1998; Oliver, 2021; Schlegel et al., 2021):

$$\underbrace{\frac{\partial T_{\mathrm{mix}}}{\partial t}}_{\text{temperature change}} = \underbrace{\frac{Q_{\mathrm{net}}}{\rho c_{\mathrm{p}} H}}_{\text{air sea heat flux}} - \underbrace{u_{\mathrm{mix}} \cdot \nabla_{\mathrm{h}} T_{\mathrm{mix}}}_{\text{advection}} + \underbrace{R}_{\text{residual}}$$

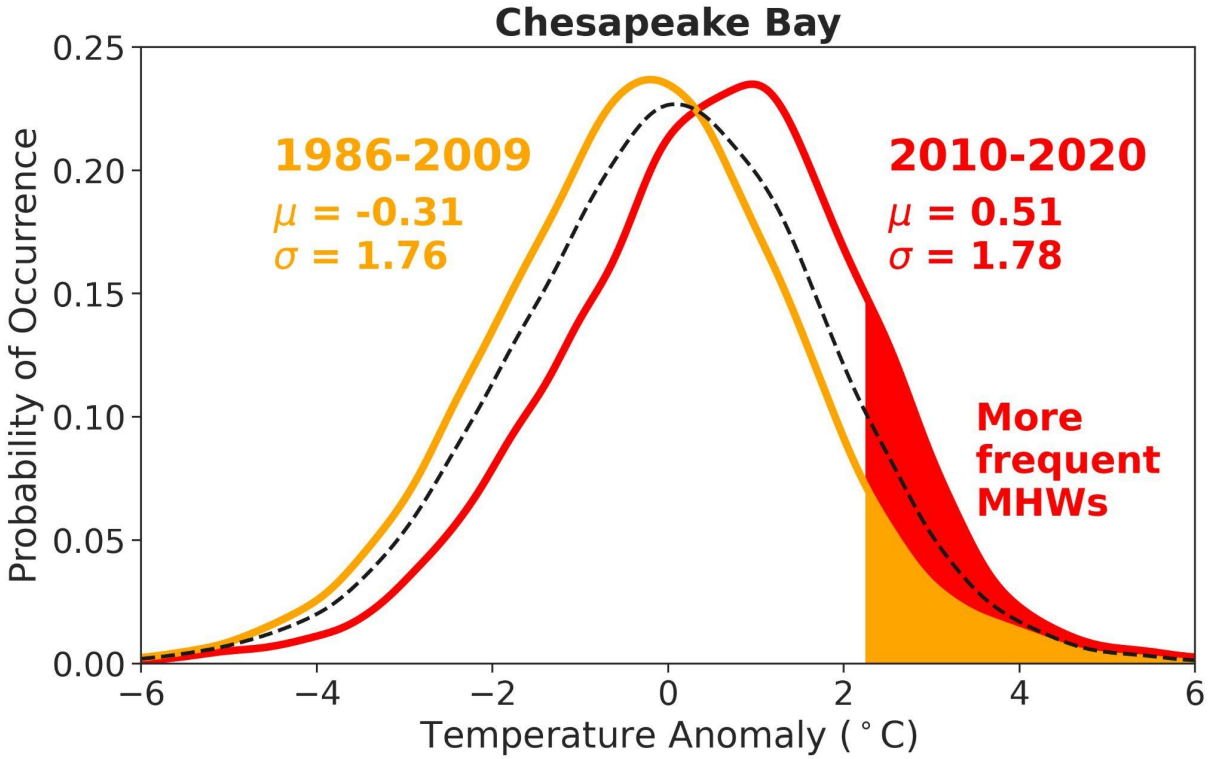


Relation to Climate Indices





What is driving the trends? Temperature Increase



Summary

Average MHW characteristics:

- Frequency: 2x per year
- Intensity: 3 ^{o}C
- Duration: 11 days
- MHW days: 22 days
- Yearly cumulative intensity: 72 ^{o}C x days

Co-occurrence of MHW events:

- UB - MB - LB: 50-65%, <= 2 days
- CB - MAB: 40-50%, 2-5.5 days

Significant trends:

Frequency, MHW days and yearly cum. intensity.

If trends persist,

by 2100 the CB will reach a semi-permanent MHW state

Photo by Stepehn Salpukas.

https://spectrumnews1.com/ky/louisville/weather/2020/07/05/heat-index-explained

Future Work

- MHWs impact on water quality, dissolved oxygen, chlorophyll, HABs, etc
- Subsurface characteristics
- Spatial variability (tributaries, embayments, etc)
- Systematic comparison of MHWs in different estuary types, morphologies, sizes, flushing times, and contrasting coastal ocean regions (e.g., eastern vs. western boundary systems)
- And much more!!!

https://www.goodnewsnetwork.org/oyster-and-seagrass-restoration-in-the-chesapeake-bay/

Thank you

Mazzini, P.L.F. and C. Pianca. 2022. Marine Heatwaves in the Chesapeake Bay. *Frontiers in Marine Science,* 8:750265, doi:10.3389/fmars.2021.750265