Journal Club March 9th 2021

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machine learning in climate science

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Annual Review of Marine Science

Marine Heatwaves

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What are marine heatwaves (MHW)?

A discrete period of prolonged anomalously warm water at a particular location

American Samoa before, during, and after a coral bleaching event in 2015 [nature.com]

MHW studies examine aspects of sea surface temperature (SST) variability

that affect marine life, e.g. coral bleaching

History of high-impact events

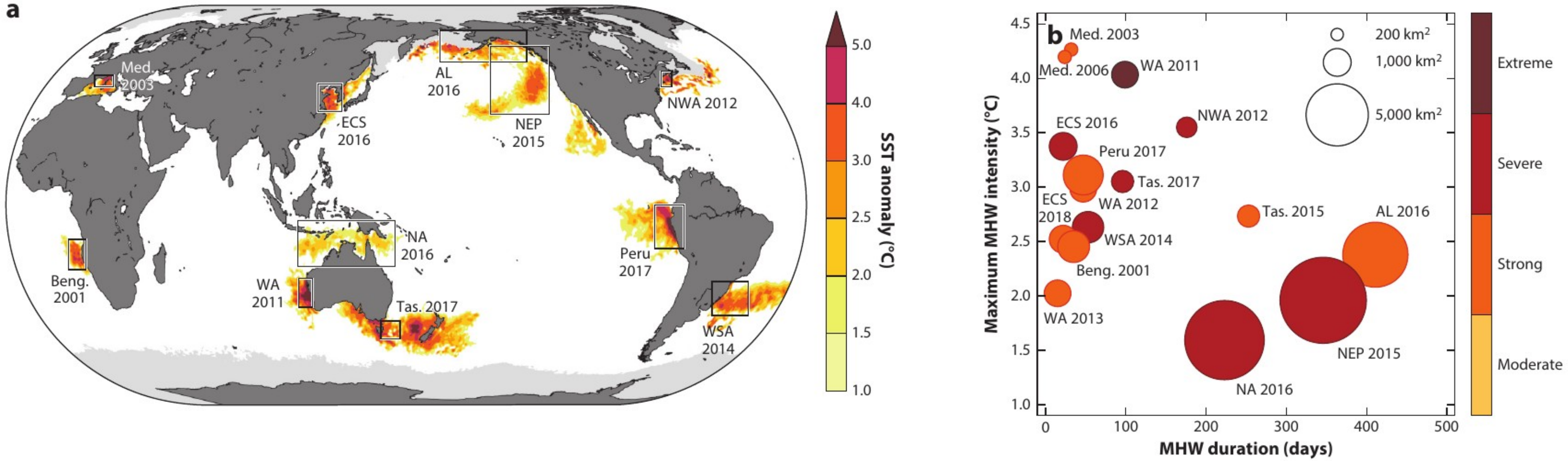
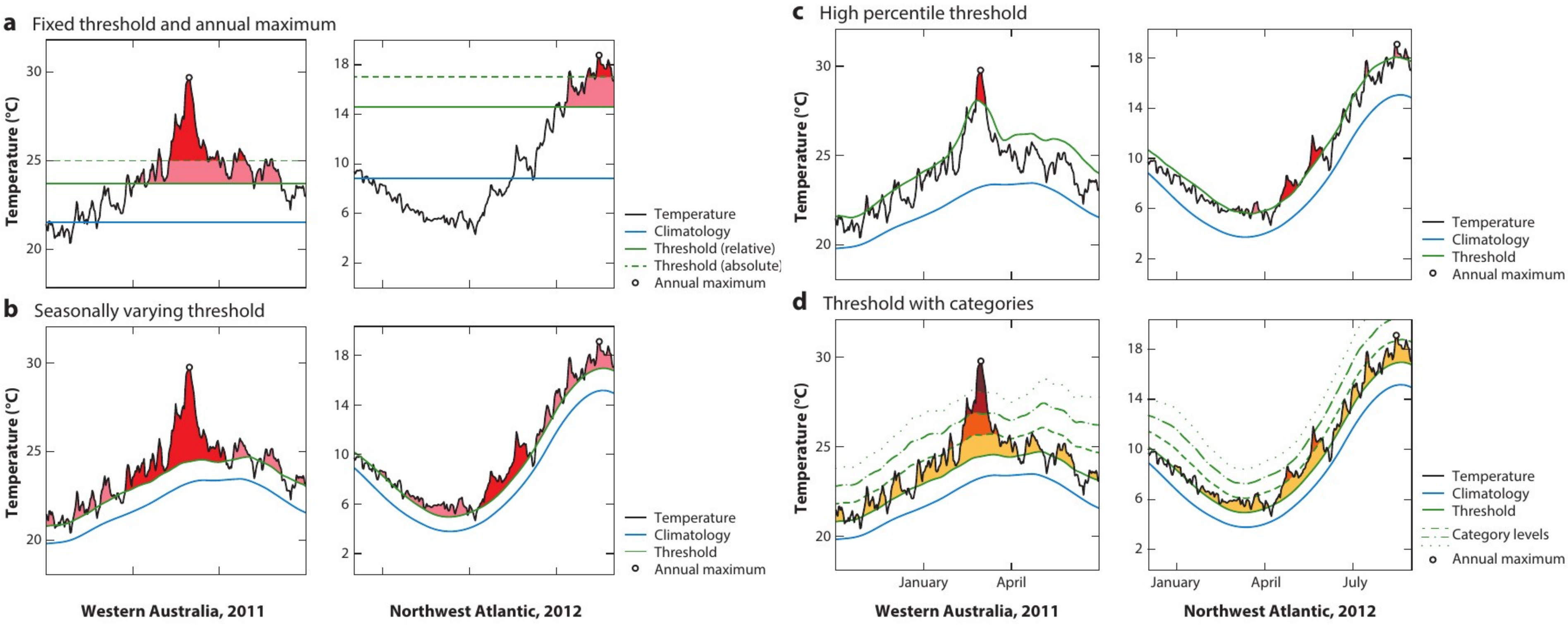


Figure 1

Key historical MHWs. (*a*) SST anomalies (above 1°C) on the day of peak MHW intensity. MHW intensity was defined based on the time series of SST averaged over the regions indicated by the black boxes. Light gray indicates areas of sea ice influence. (*b*) MHW properties for key historical events. The MHW intensity (*y* axis), MHW duration (*x* axis), and category (*color*; see Hobday et al. 2018a) were determined from the spatially averaged time series, as in panel *a*. The MHW area (*circle size*) is the total contiguous area reaching at least category 2 (strong). All events shown in panel *b* are referenced in Section 2. Abbreviations: AL, Gulf of Alaska and Bering Sea; Beng., Benguela; ECS, East China Sea; Med., Mediterranean; NA, northern Australia; MHW, marine heatwave; NEP, northeast Pacific; NWA, northwest Atlantic; SST, sea surface temperature; Tas., Tasman Sea; WA, Western Australia; WSA, western South Atlantic. Panel *a* inspired by a schematic from Frölicher & Laufkötter (2018).

MHW definition

MHW are SST extreme events which are usually based on thresholds.



Datasets

- Sea surface temperature datasets on daily resolution
- Subsurface temperature data is sparce
- Climate models have issues representing eddies, boundary currents and coastal processes which biases SST variability

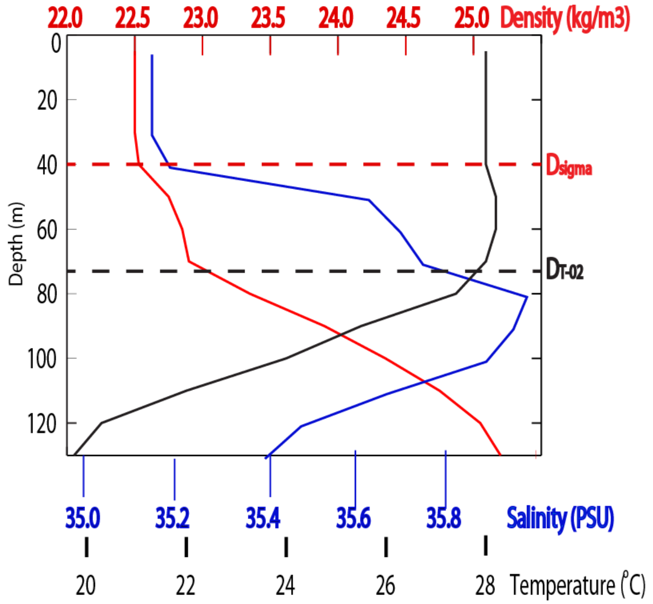
Data set type	Earliest start date	Spatial resolution	Strengths	Weaknesses	Examples
Coarse-scale ocean reanalyses	Around 1900	1/2–1°	Global; continuous; long records; quantification of uncertainty (in some cases); complete three-dimensional ocean state estimated (temperature, salinity, and velocities)	Subgrid-scale physical processes are not resolved; data in the absence of observations, most notably in earlier time periods, are only very weakly constrained by observations	SODA, CERA-20C, GODAS

MHW Mechanisms

Oceanic mixed layer:

Upper layer of ocean with relatively constant temperature, density and salinity due to turbulent motion created by interaction with atmosphere.

- Criteria based on temperature (D_{T-02}) and density (D_{sigma}) exist
- 2.5 m of the ocean holds as much heat as the entire atmosphere above it



https://en.wikipedia.org/wiki/Mixed_layer

MHW Mechanisms

Seawater temperature change in a mixed layer:

$$\underbrace{\frac{\partial \overline{T}}{\partial t}}_{\text{Temperature tendency}} = -\underbrace{\overline{\mathbf{u}} \cdot \nabla \overline{T}}_{\text{Horizontal advection}} + \underbrace{\overline{\nabla \cdot (\kappa_h \nabla T)}}_{\text{Horizontal mixing}} - \underbrace{\frac{1}{h}\kappa_z \left.\frac{\partial T}{\partial z}\right|_{-h}}_{\text{Vertical mixing}} - \underbrace{\left(\frac{\overline{T} - T_{-h}}{h}\right)\left(\underbrace{\frac{\partial h}{\partial t}}_{\text{MLD tendency}} + \underbrace{\mathbf{u}_{-h} \cdot \nabla h}_{\text{Lateral induction}} + \underbrace{w_{-h}}_{\text{Vertical advection}}\right)}_{\text{Entrainment}} + \underbrace{\frac{Q_{SW} - Q_{SW(-h)} + Q_{LW} + Q_{sens} + Q_{lat}}{\rho c_p h}}_{\text{Air–sea heat flux}},$$

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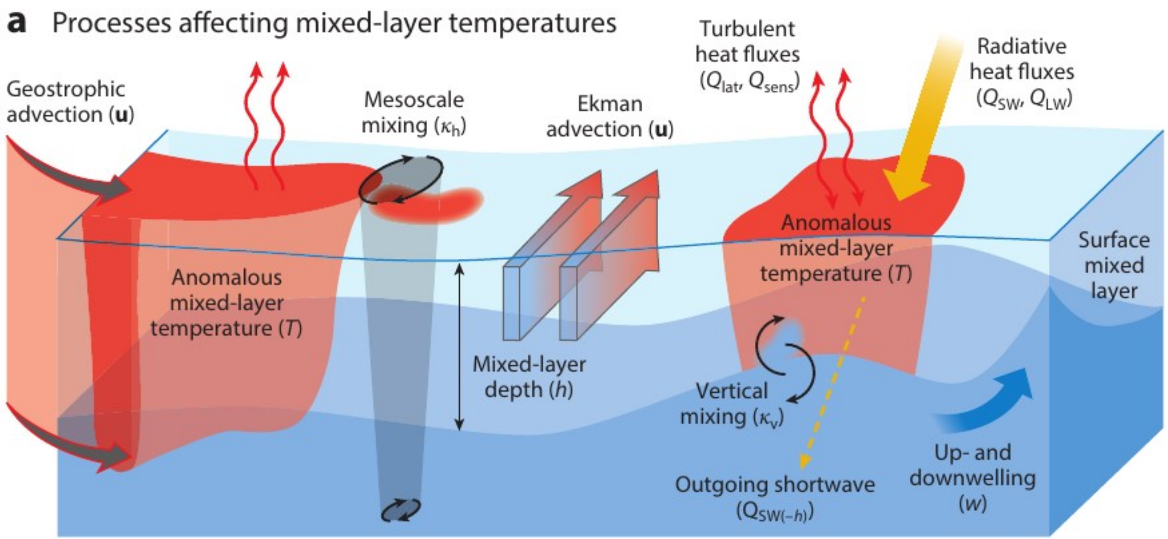

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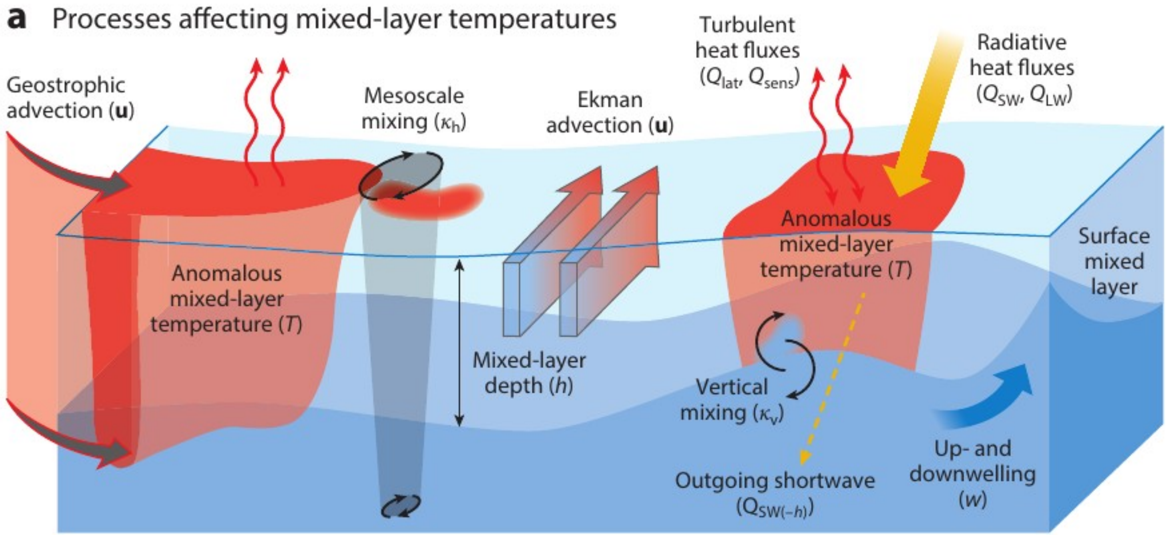
Horizontal advection:

Temperature change by horizontal flows

- geostrophic flows
- Ekman flows (induced by wind stress)
- ocean currents



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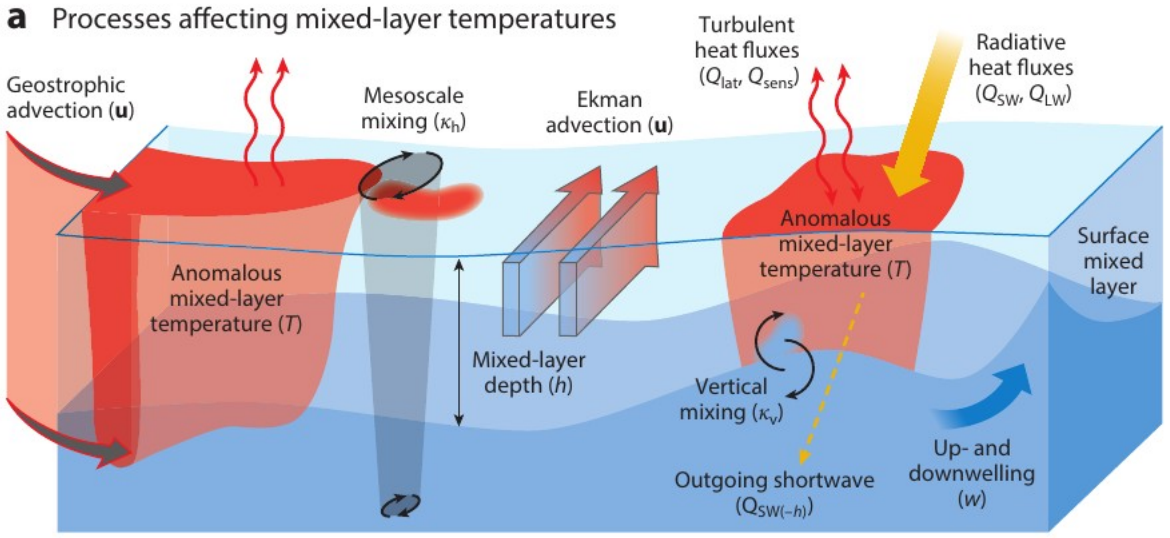
Vertical advection:

Temperatur change by vertical flows

- upwelling and downwelling
- mainly driven by coastal winds



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MHW Mechanisms

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Air-sea heat flux:

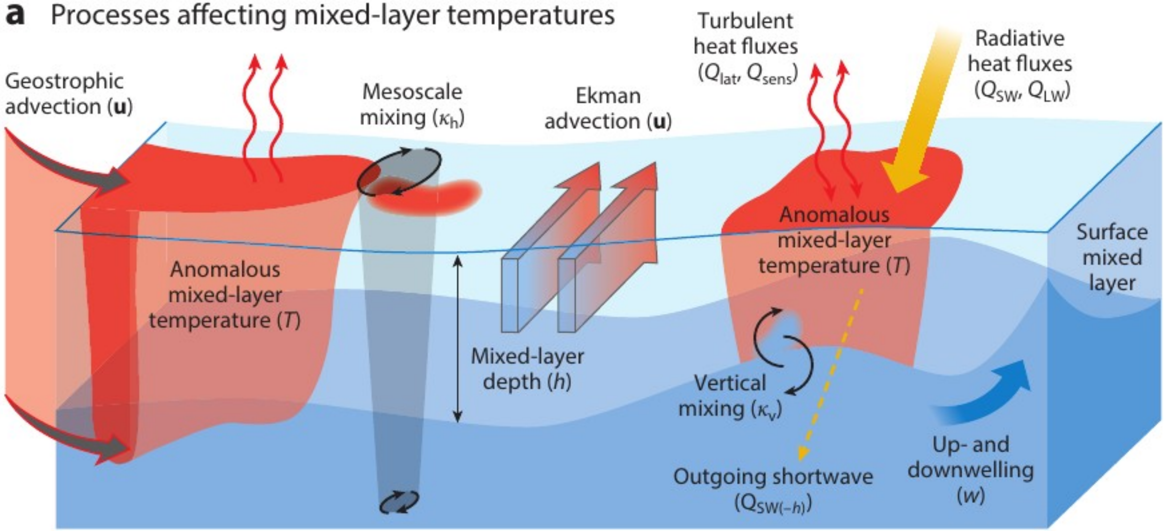
In- and outgoing heat to the ocean

- radiative components:

  shortwave (SW), longwave (LW)
- turbulent components:

  latent (lat) and sensible (sens)

Air-sea flux is large in high pressure regions with little wind



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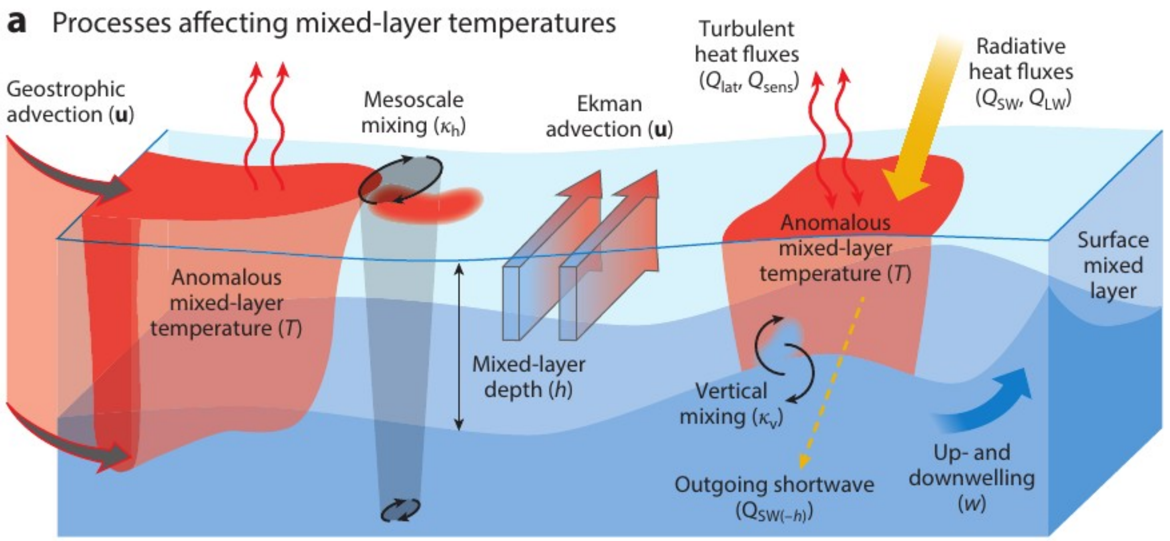
Mixing terms:

Mixing terms have only small contribution to temperature.



Statistical understanding

SST temperature:

$$T_t = T_t^{\mathrm{tr}} + T_t^{\mathrm{S}} + T_t^{\mathrm{NS}},$$

T_t^{tr} : long-term trend

T_t^{S} : seasonal climatological mean

T_t^{NS} : nonseasonal component

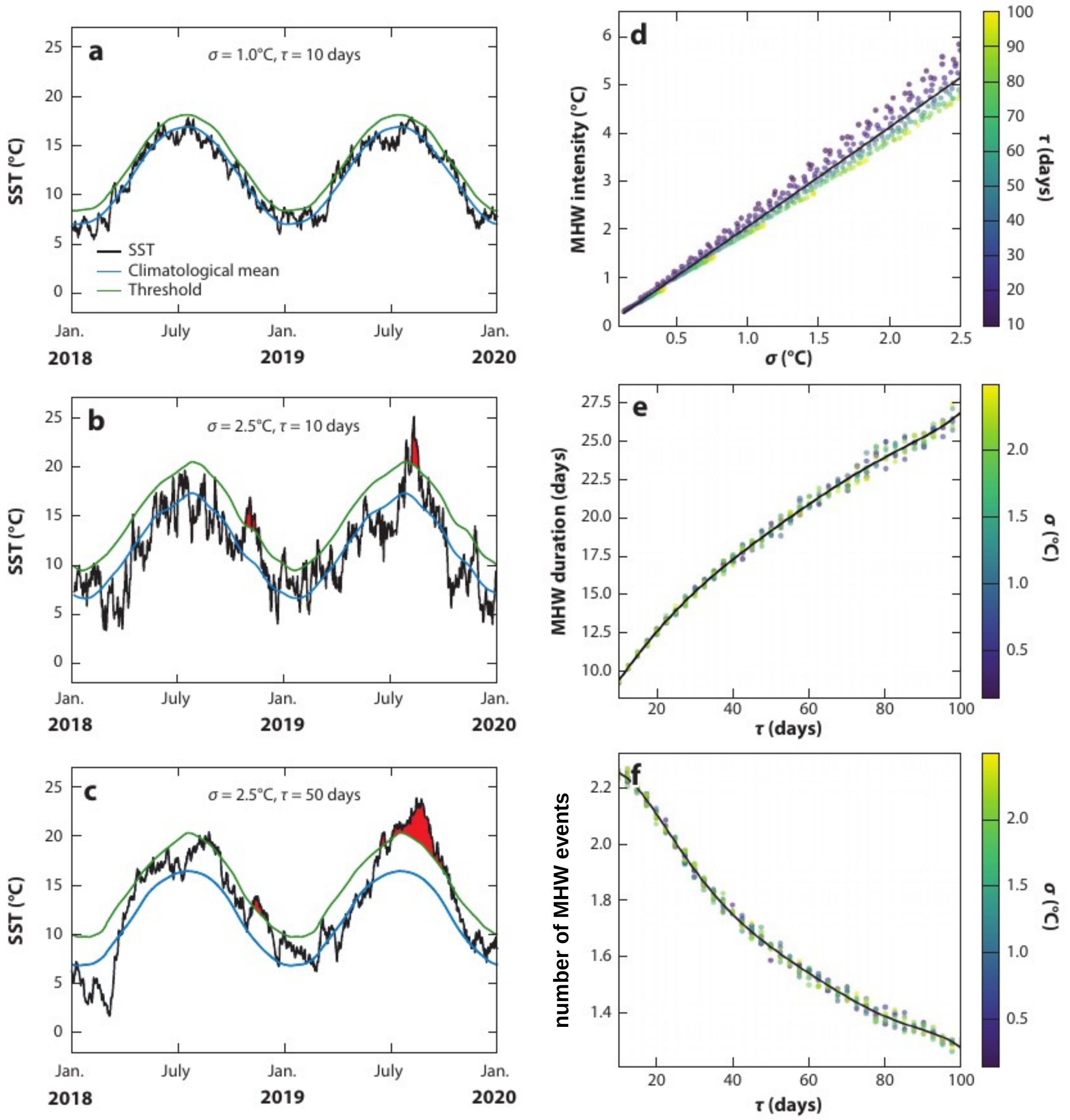
Autoregressive model:

$$T_{t+1}^{\mathrm{NS}} = aT_t^{\mathrm{NS}} + \epsilon_t$$

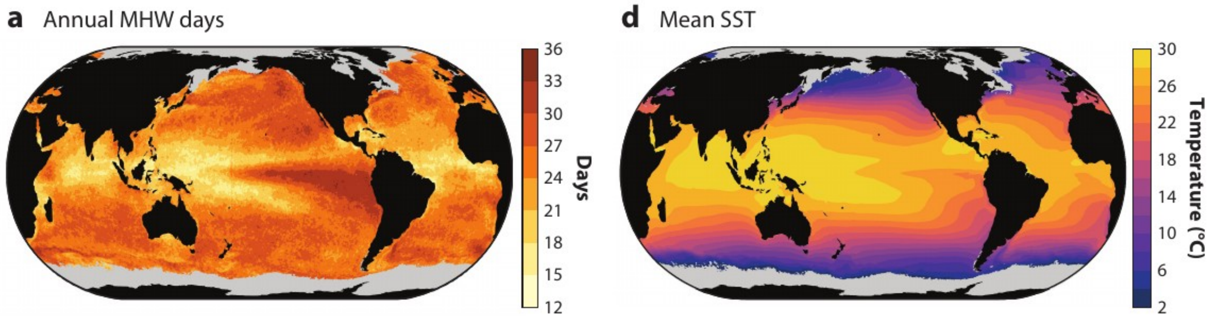
ϵ_t : white noise

$\sigma = \sigma_\epsilon/(1-a^2)$: variance

$\tau = -1/\ln a$: memory time-scale

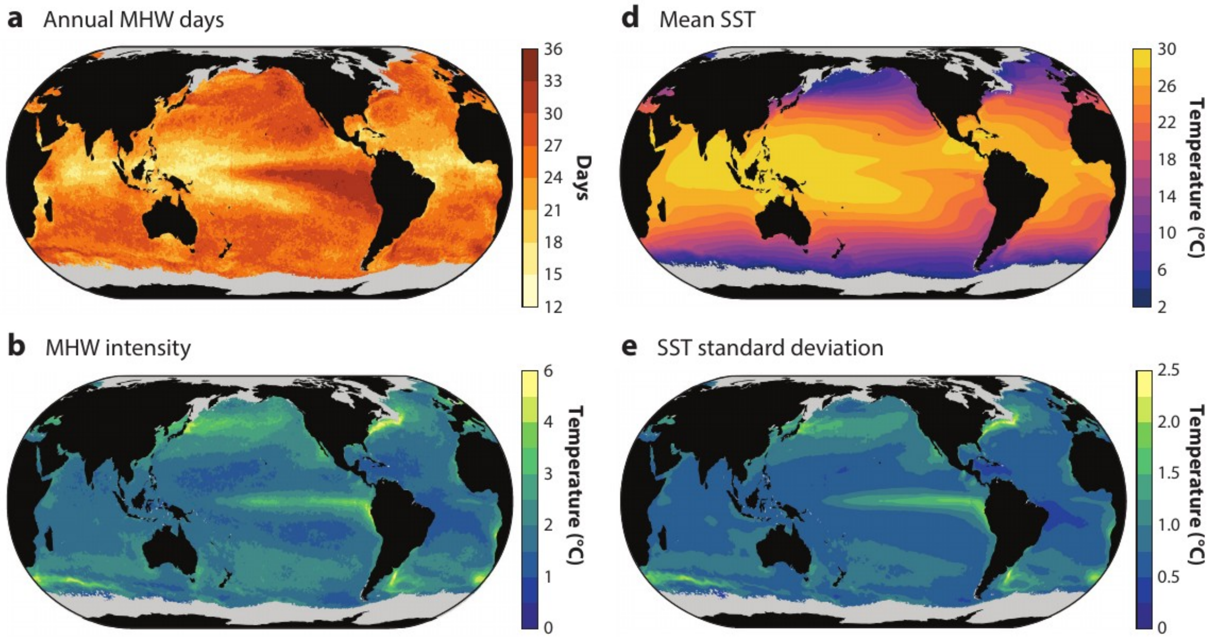


Global distribution



On average: 1-3 MHW events per year

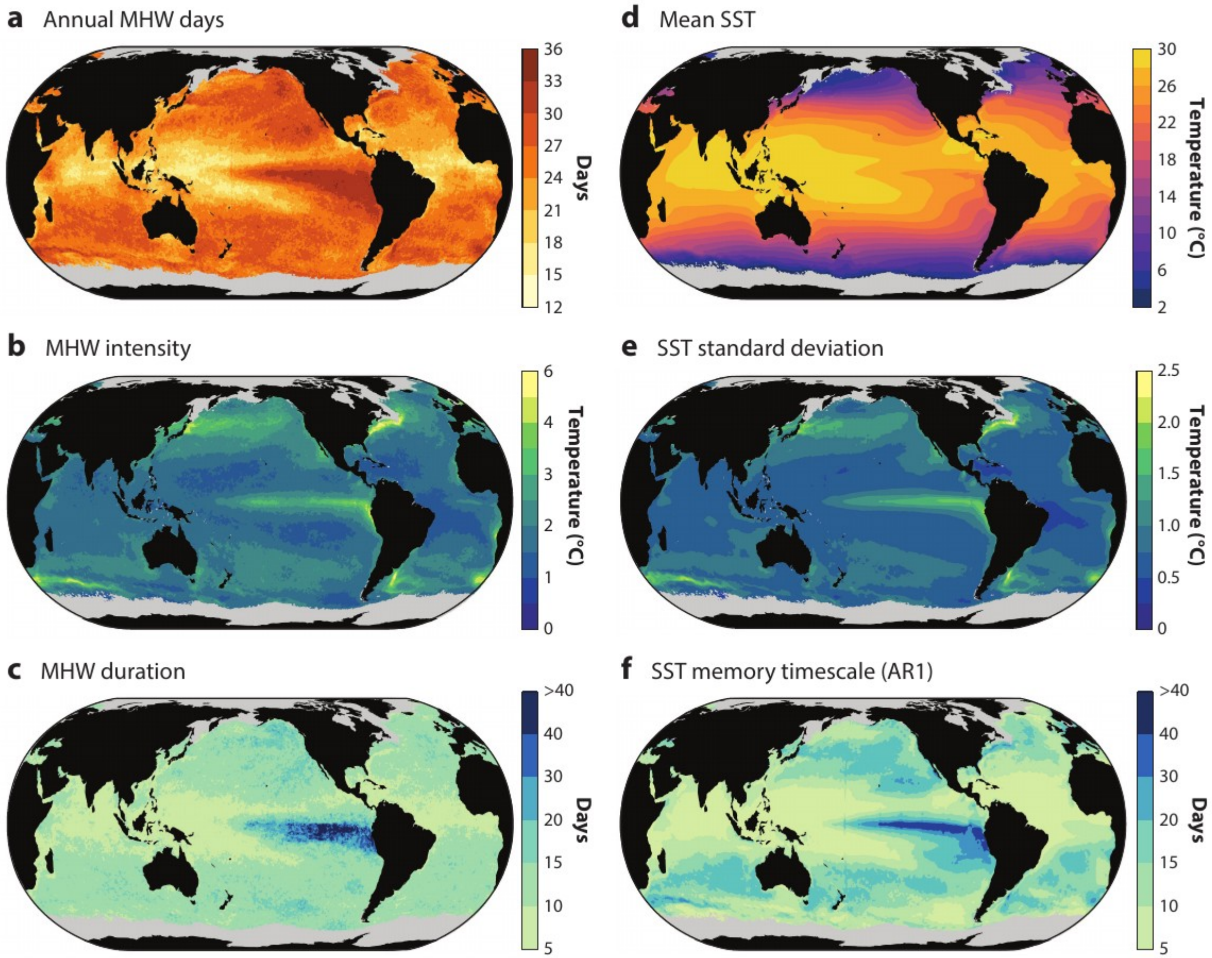
Global distribution



On average: 1-3 MHW events per year

MHW intensity is strongly correlated to SST variance

Global distribution



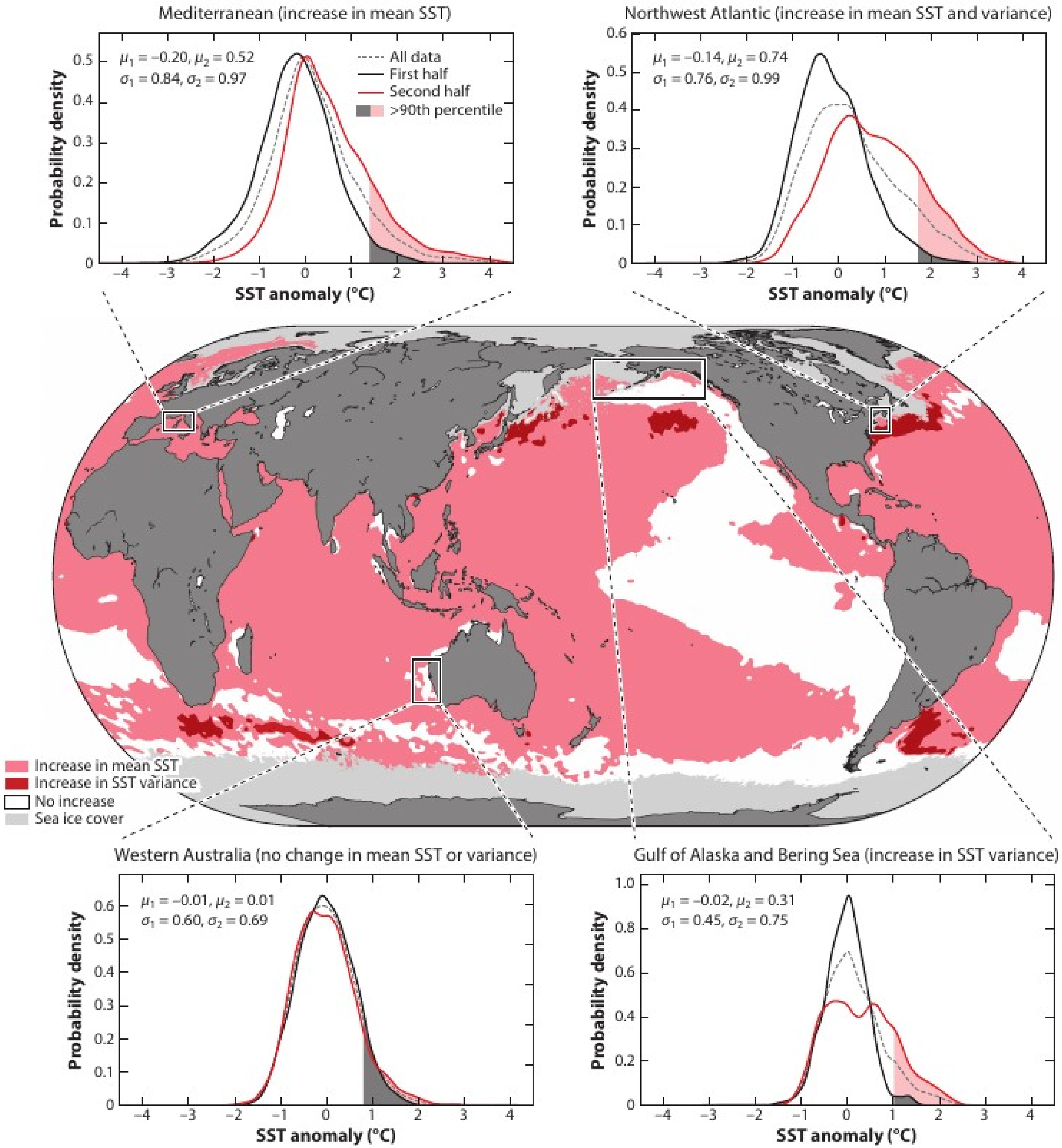
On average: 1-3 MHW events per year

MHW intensity is strongly correlated to SST variance

MHW duration strongly related to SST memory timescale

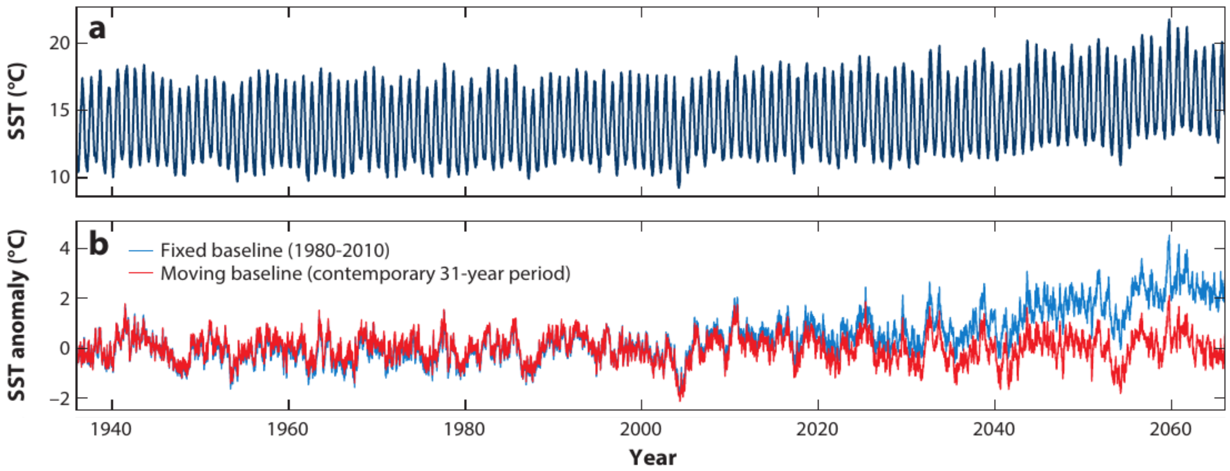
Long-term trends

- MHW frequency increase by 32% since 1925
- MHW duration increase by 17% since 1925
- Further increase in frequency, intensity and duration of MHW is projected



Open questions

- Subsurface temperature observations are needed to understand physical processes and drivers of MHW
- Understanding MHW mechanisms for improving forecast systems
- How can ecosystem adaptation timescales be incorporated into how climatological baseline periods are defined?



Take home message

- Marine heatwaves study SST variability that affects marine life
- Definition of extreme events (threshold) depends on the system of interest
- Nonseasonal SST component can be modeled by an AR(1) process

Thank you for your attention!

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