Marine heatwaves below the surface, a challenge to observe

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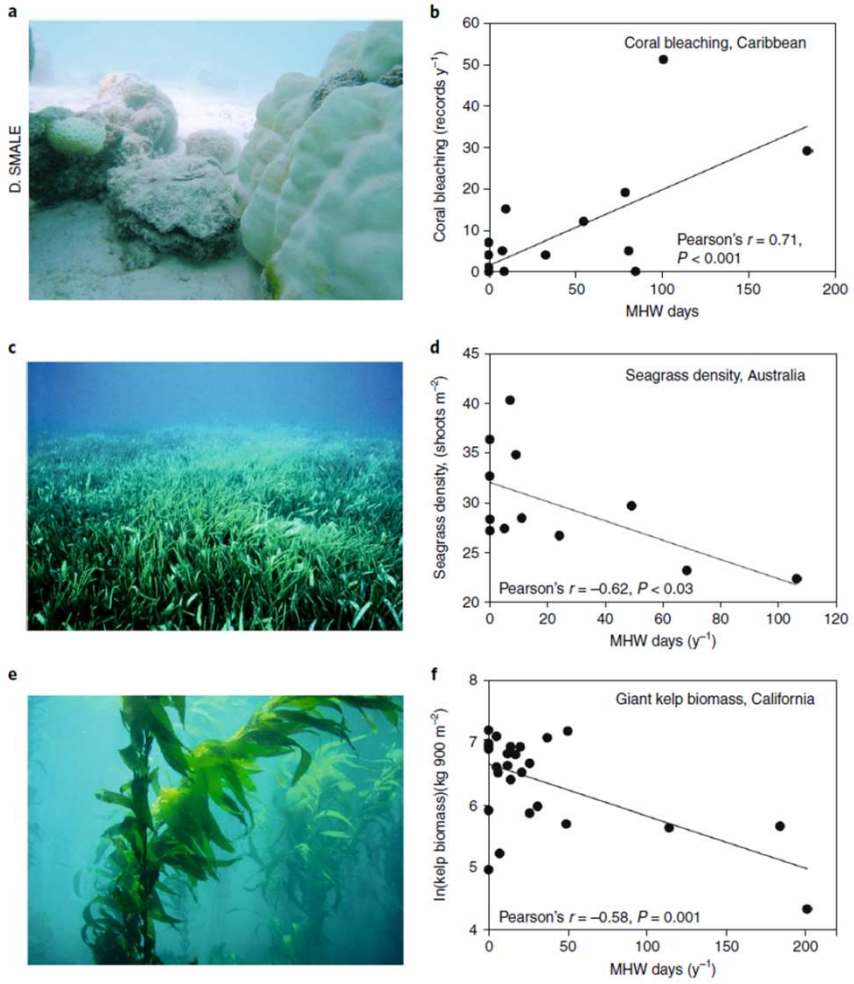
Ouline

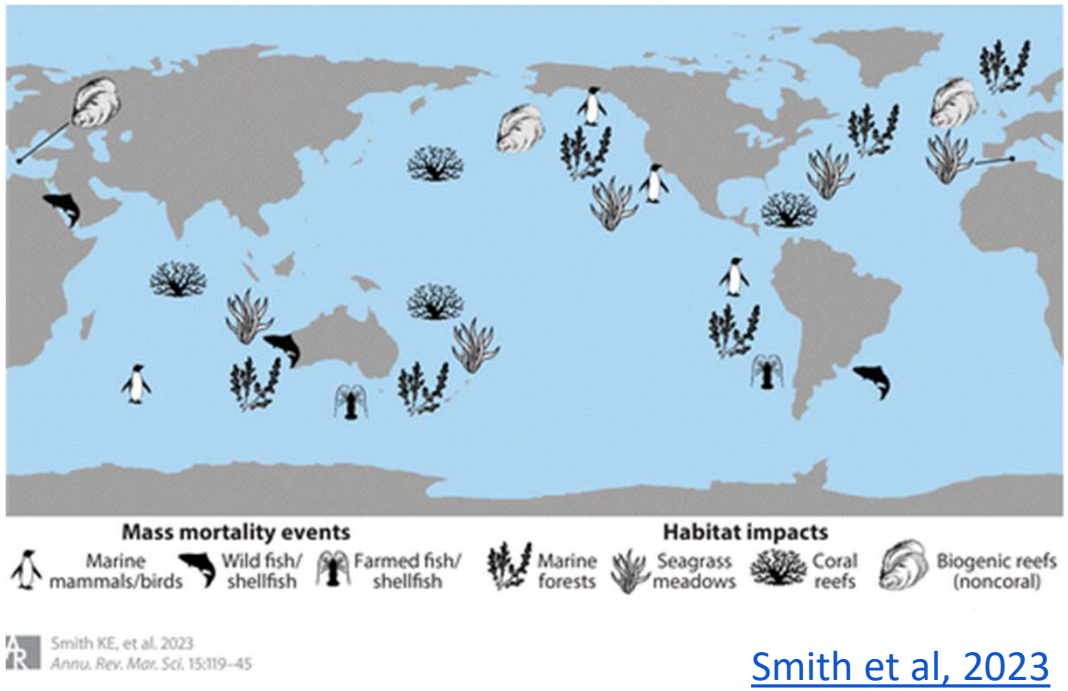
The vast vajority ofobservational studies of marine heatwaves (MHWs) used satellite Sea Surface Temperature (SST), thanks to the great satellite dataset (gap free, hourly, over 40 years).

- **Why do we need sub-surface observations of MHWs?**
- **Why are they sparse? Many challenges.**
- **Where are we at?**

Conclusions.

Why do we need sub-surface information?





Smith et al, 2023

"Biological Impacts of Marine Heatwaves"

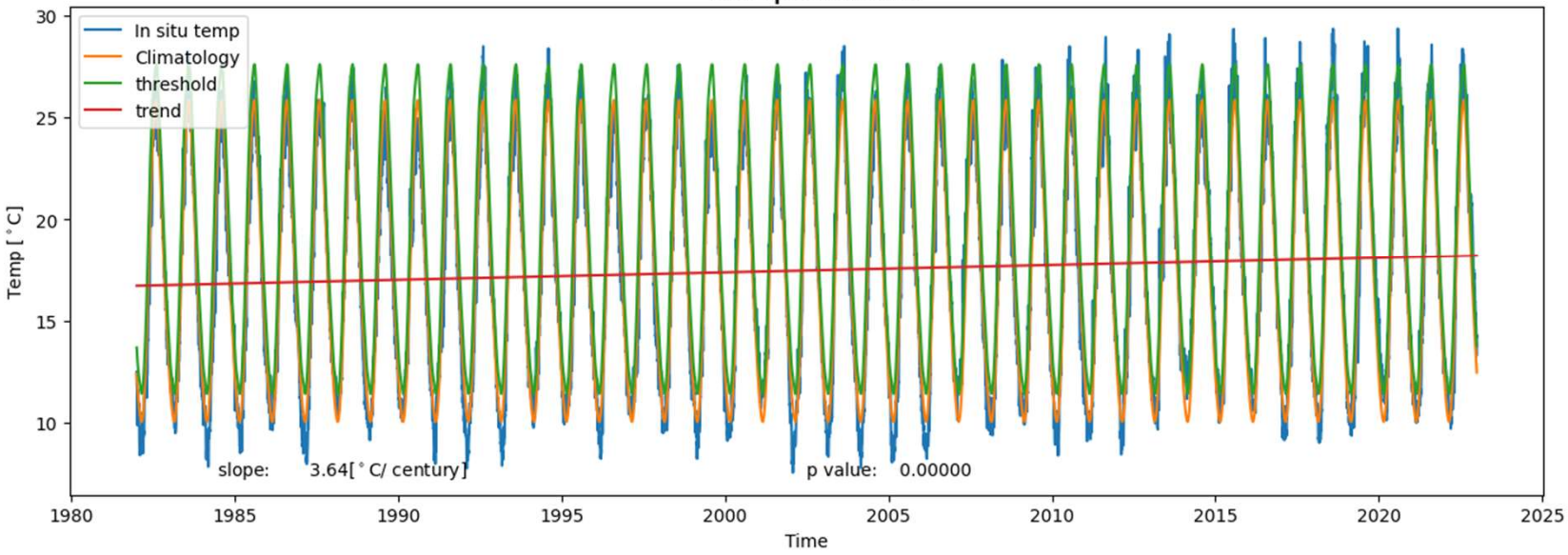
Smale et al., 2019 "Marine heatwaves threaten global biodiversity and the provision of ecosystem services"

Why are sub-surface observations of MHWs sparse?

MHW are extreme events!

Detecting extreme events

1. Pick a time series
2. Set the baseline period
3. Chose a threshold value
4. Detect consecutive days
5. Calculate metrics

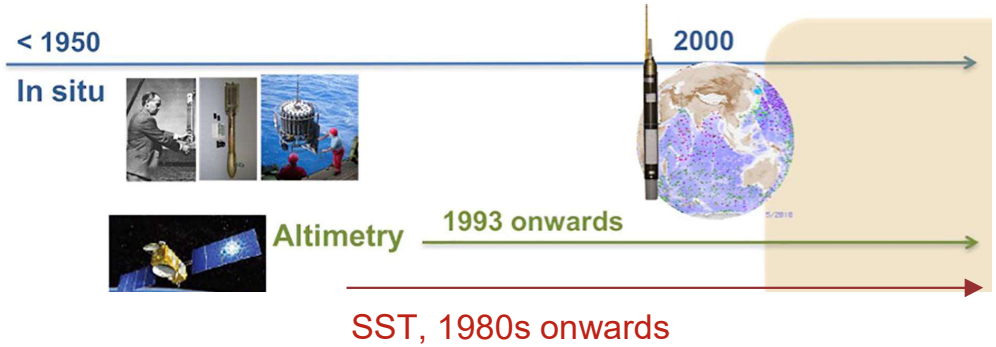


Why are sub-surface observations of MHWs sparse?

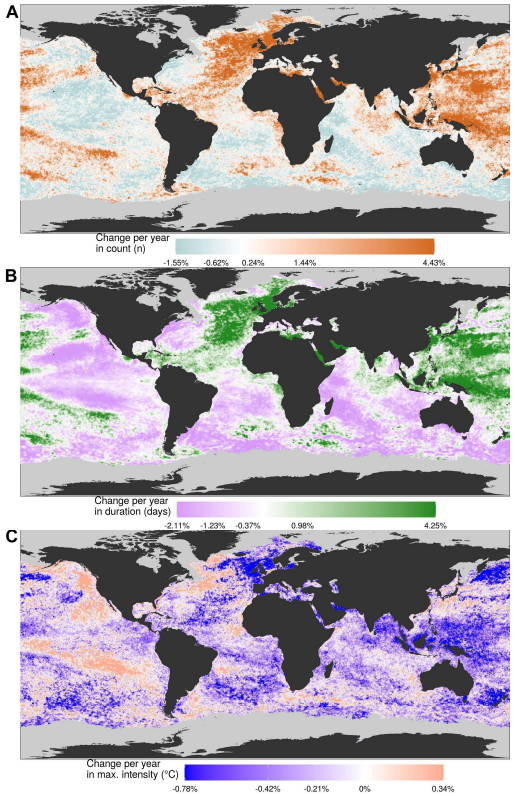
Challenge 1:

- Long time-series for the baseline
- Considering the seasonal variability

-> need decade(s) of daily observations.



Adapted from Meyssignac et al, 2019



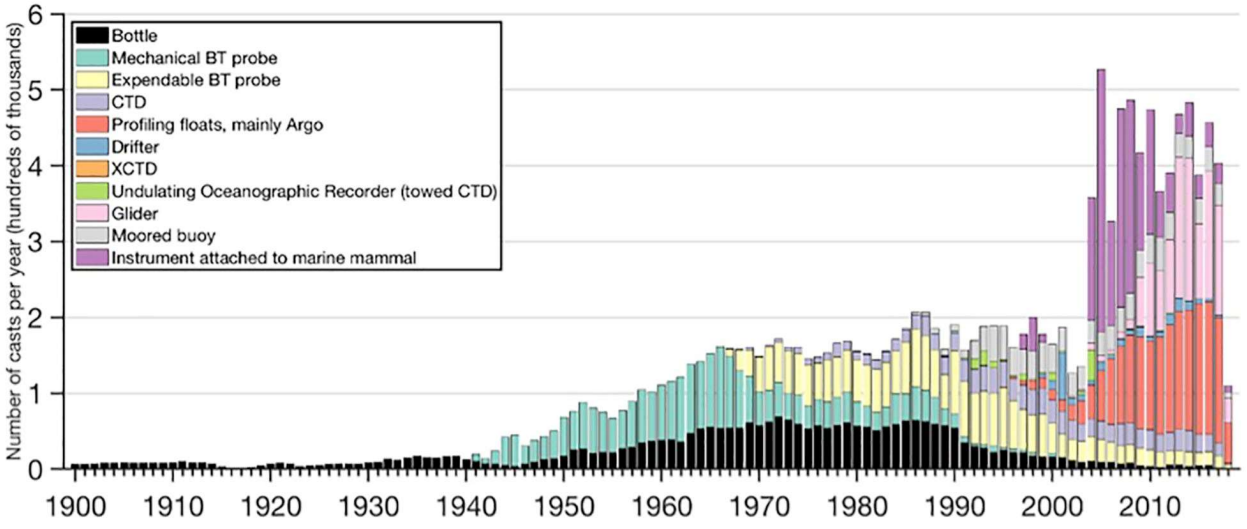
Schlegel et al., 2019 Global map showing changes in MHW detection as the time series at each pixel is shortened from 30 to 10 years.

Why are sub-surface observations of MHWs sparse?

Challenge 2:

- Observations are discrete, have QC issues, instrument failures, turnaround times etc…
- Need to consider varying number of observations over decades because of underlying ocean warming.
- Need to consider the differences between observation platforms

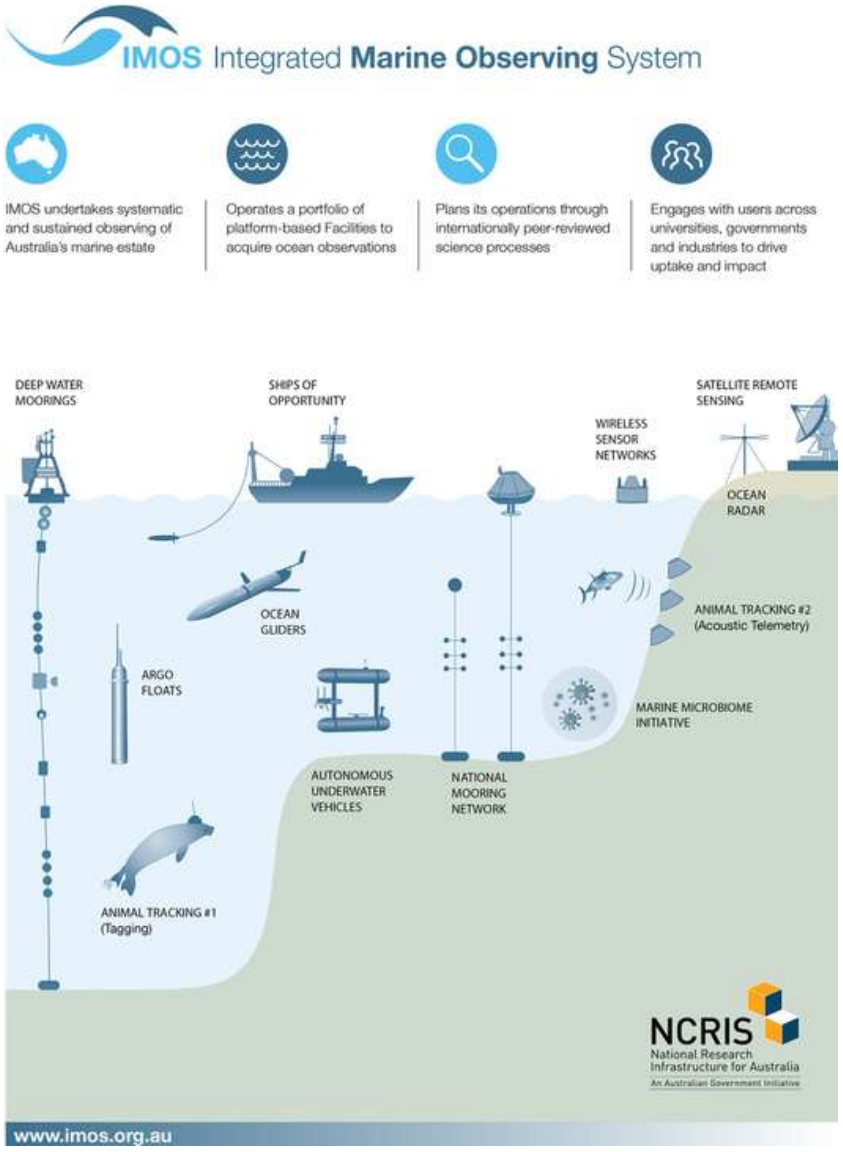
-> remove linear trend, sub-sample.



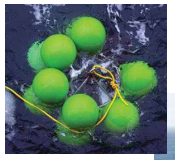
Meyssignac et al, 2019

Platform-specific pros and cons

Platform type	Variables measured	Horizontal resolution & coverage	Vertical resolution & coverage	Temporal resolution & coverage
Remote-sensed Altimetry	SSH, geostrophic **V**	~0.25º, global	/	Days, 3 decades
Remote-sensed SST, ocean colour	T, chl-a	km, global	/	Hours/day, 4 decades



Platform-specific pros and cons



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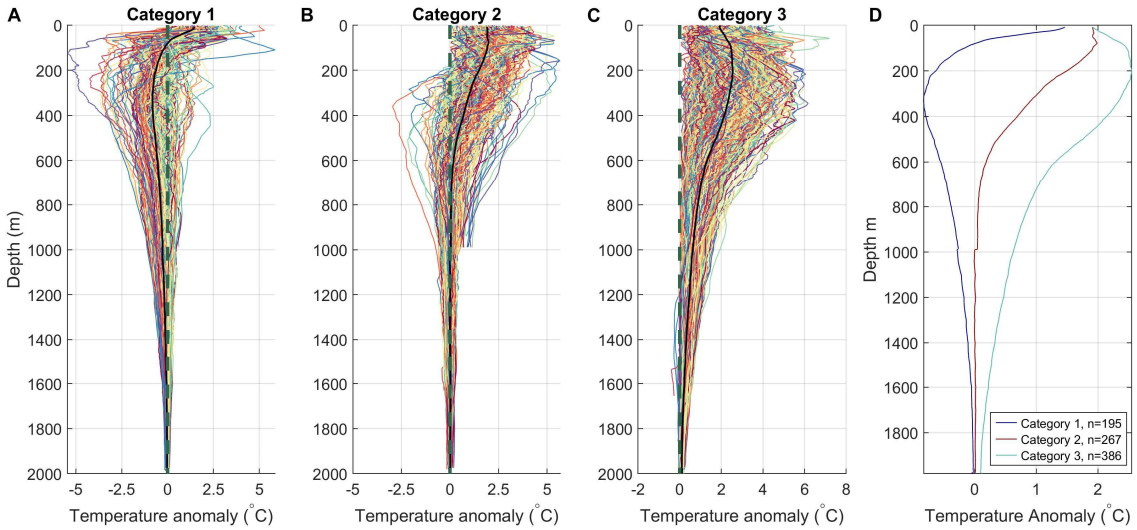
Remote-sensed • Altimetry	SSH, geostrophic **V**	~0.25°, global	/	Days, 3 decades
Remote-sensed • SST, ocean colour	T, chl-a	km, global	/	Hours/day, 4 decades
Moorings	T, S, **V**…	/	m, 100s m	Minutes, years
CTDs, bottle samples	T, S, chl-a, DO, CDOM, (nutrients)…	/ (or arrays)	m, 100s m	/ (or sampling strategy)
ARGO floats	T, S, (bio: chl-a, DO, CDOM, pH, Nitrate)	100s km, global-ish	m, 2 km	Weeks (10-day cycle), years
Animal tagging (CTD)	T, S, chl-a, DO, CDOM	10s km, regional	m, 100s m	Weeks, years
Gliders AUV (triaxus)	T, S, chl-a, DO, CDOM (**V**)	km*, 10s kms	m, max 1km	Hours*, Weeks (or sampling strategy)

* Gliders move in space and time

Where are we at?
Vertical anomalies associated to surface MHWs

Example (Elzahaby et al. (2019)):

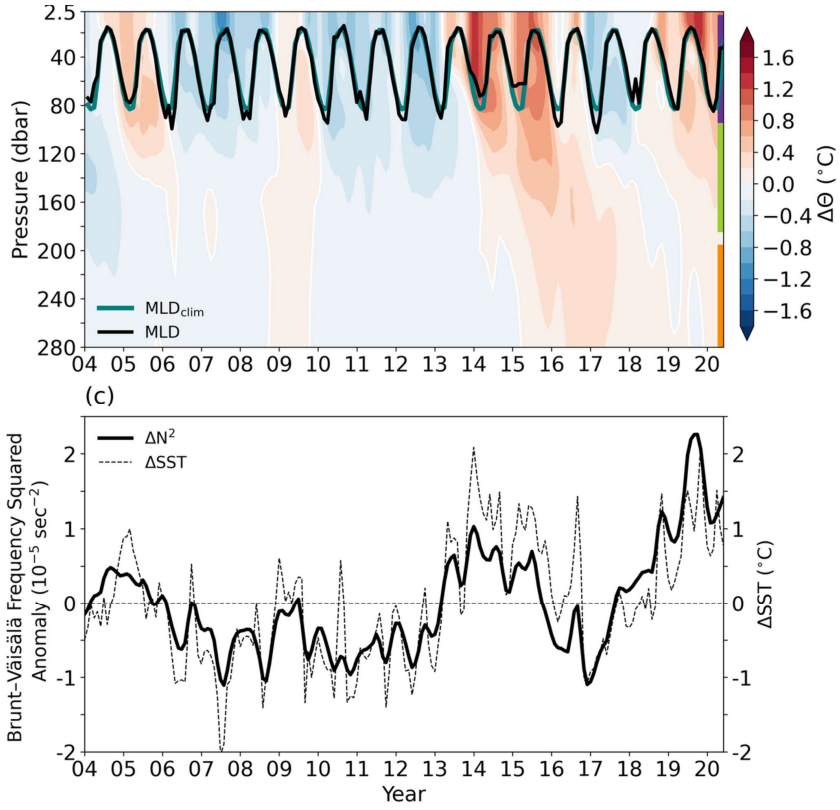
ARGO floats (anomalies from the mean)
-> temperature anomalies during SST MHWs
shallow events [0–150 m],
intermediate events [150–800 m],
deep events [>800 m]: more than expected (>45%), dominating MHWs in winter in warm core eddies.



Where are we at?
Vertical anomalies associated to surface MHWs

Example (Scannel et al., 2020):

ARGO gridded monthly 1º -> temperature anomalies after SST MHWs
-> Propagation of heat downward, and persistence of subsurface heat (possible seasonal reemergence).

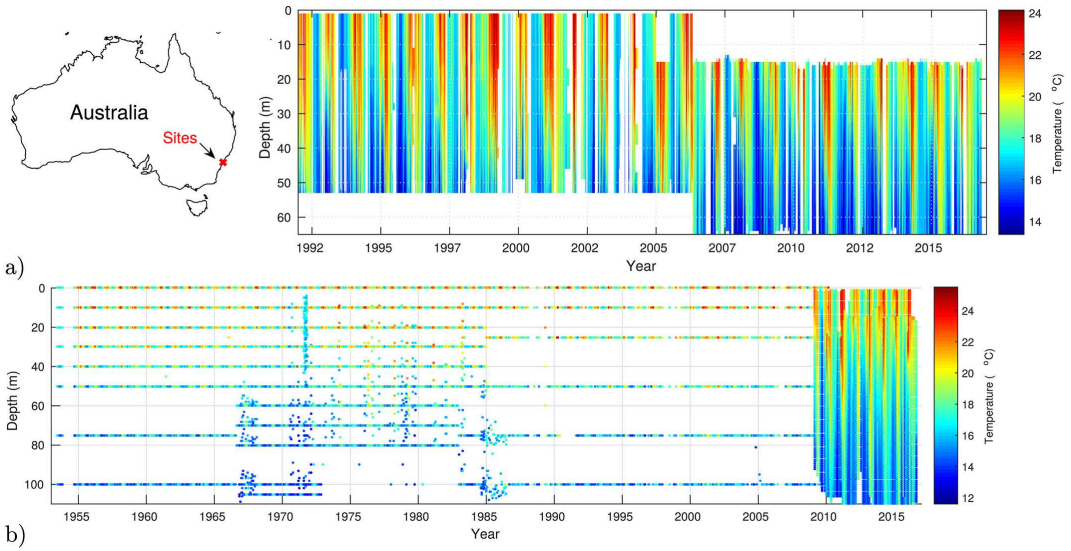


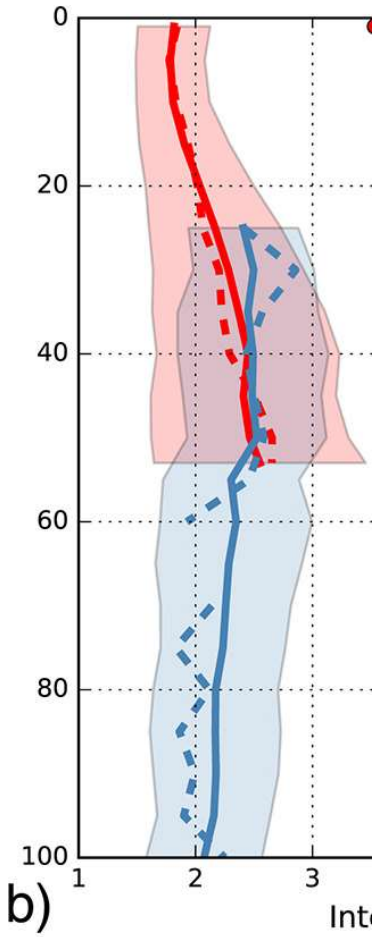
Where are we at?
MHWs independently from the surface

Example (Schaeffer et al. (2017)):

Coastal moorings off Sydney

Maximum intensity sub-surface ~50 m depth at both sites, linked to thermocline depth.
Sub-surface MHWs usually during weak stratification and downwelling winds.





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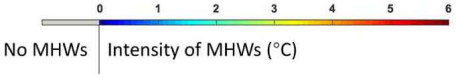
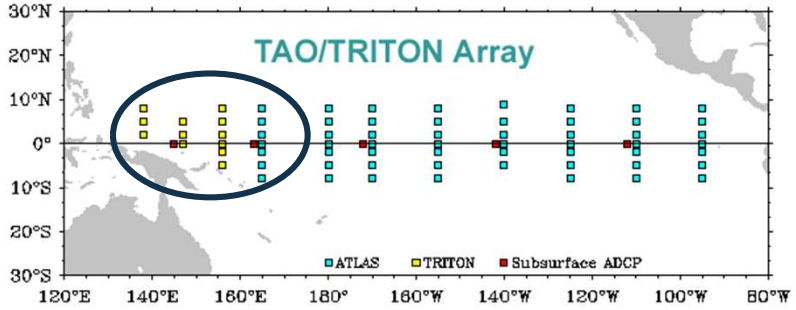
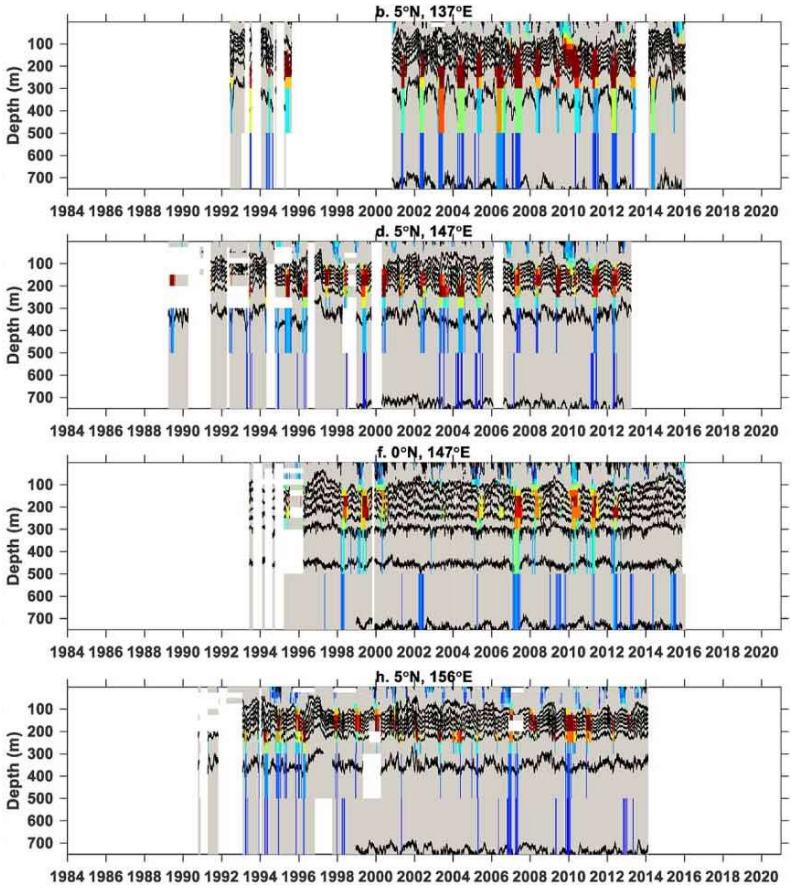
MHWs independently from the surface



Example (Hu et al., 2021):

Tropical western Pacific Ocean 19 moorings (50–300 m depth)
The ensemble mean intensity of these subsurface MHWs reaches a maximum of about 5.2 °C at 150 m, and the ensemble mean duration of the subsurface MHWs is about 13–22 days with a mean of about 17 days.





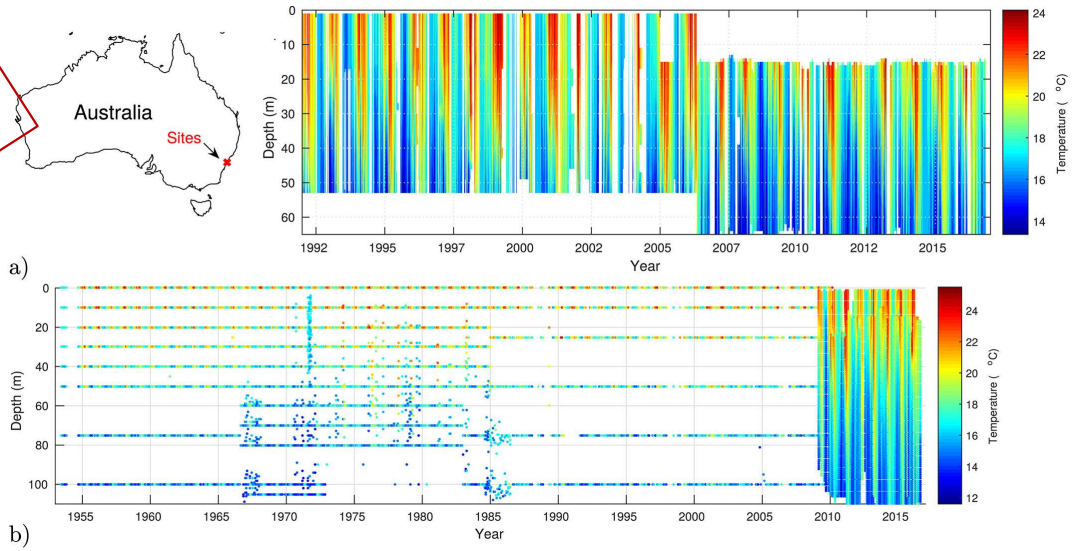
Where are we at?
MHWs independently from the surface

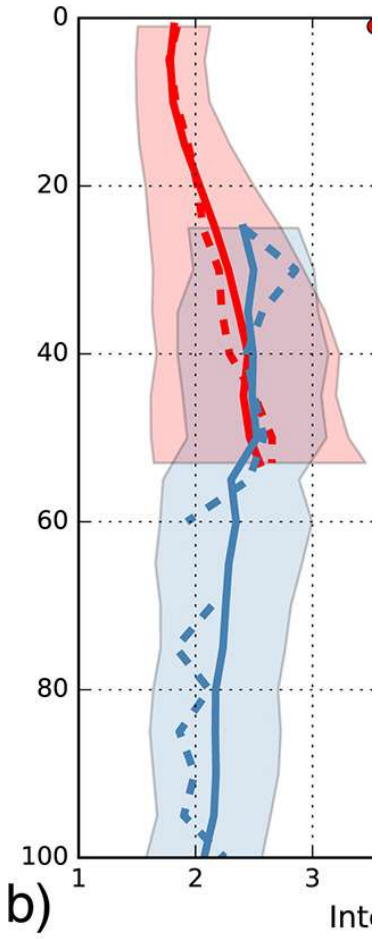
Example (Schaeffer et al. (2017)

Coastal moorings

Maximum intensity sub-surface ~50 m depth at both sites, linked to thermocline depth.

Note:
Port Hacking climatology 1953 – 2016
MHWs: 2010-2016
(we can do better!)





Where are we at?
Creating unbiased climatology

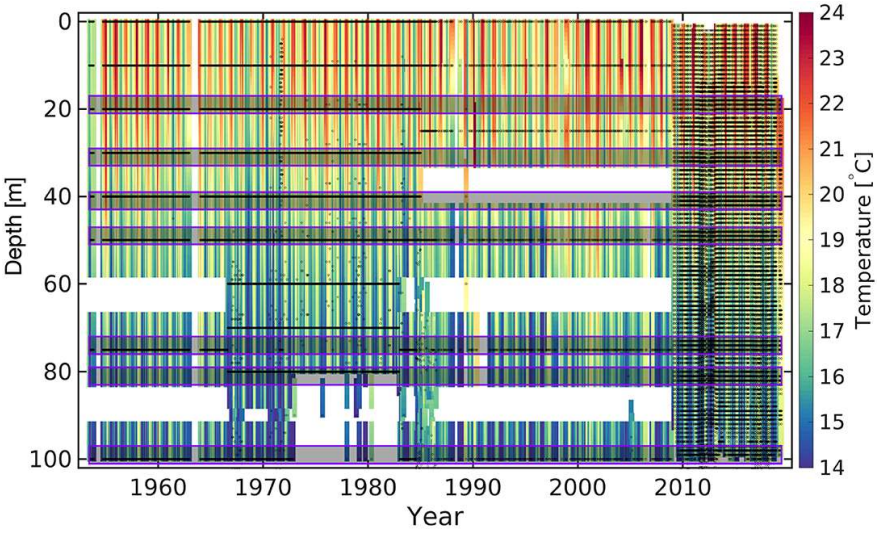
Example (Hemming et al., 2020**):**

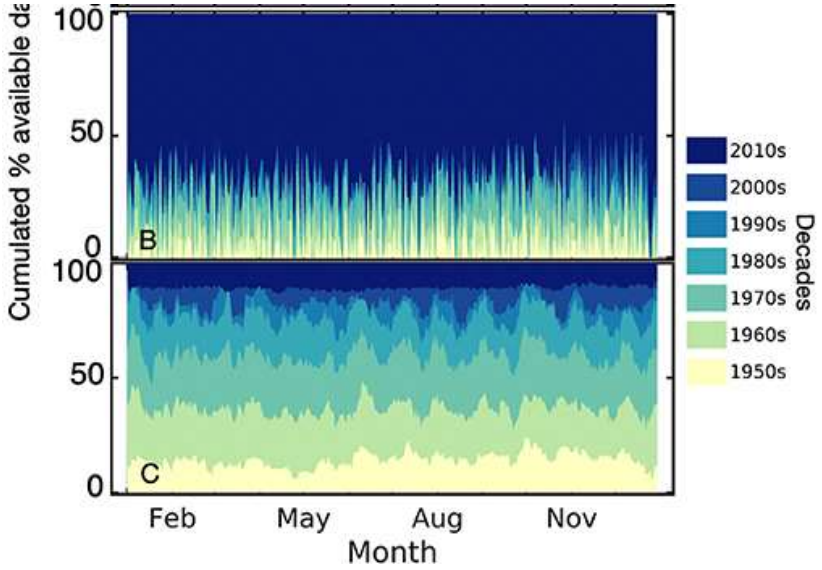
The Port Hacking National Reference Station off South East Australia:

- bottle data collected typically every 1 to 4 weeks at discrete depths between 1953 and 2010
- since 2009 near-monthly vertical profiling CTD profiles and 5 min moored data at various depths

-> 70% of data for a given day of the year but ~ 1/7 of the 66 year record.

Solution: ratio of 6:1 between bottle and mooring years.

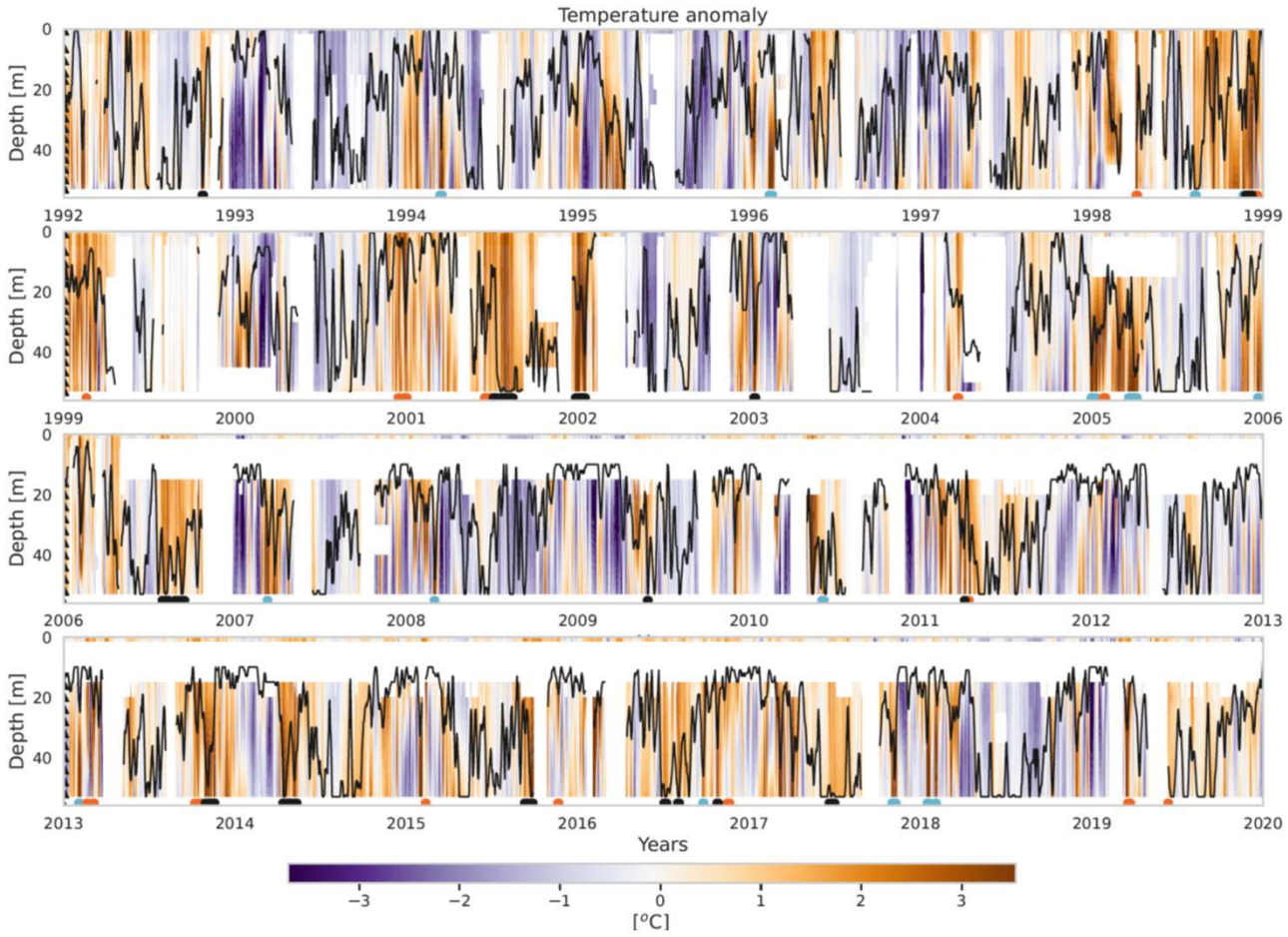




Where are we at?
Sub-surface MHWs

Example (Schaeffer et al., in review**): coastal mooring ORS065**

Temperature anomaly measurements ORS065, SST, with Mixed Layer Depth



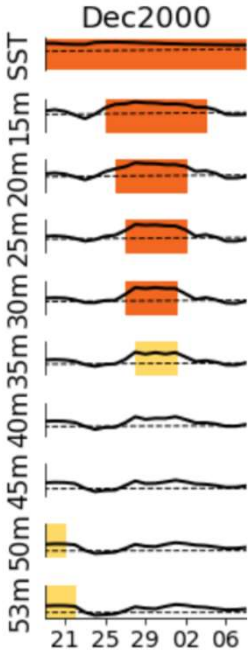
Where are we at?
Sub-surface MHWs


Strong MHW

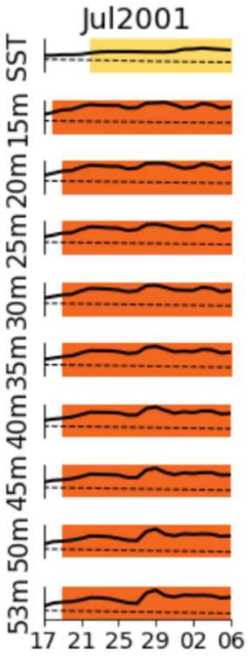

Moderate MHW

Example (Schaeffer et al., in review)**: coastal mooring ORS065**

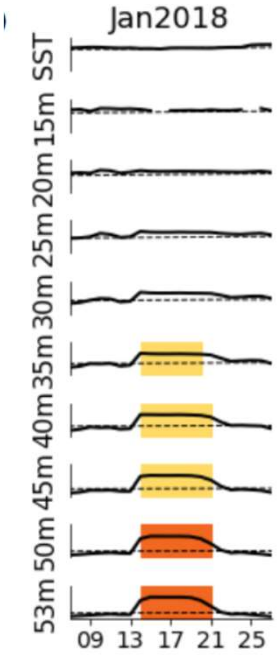
Shallow MHW



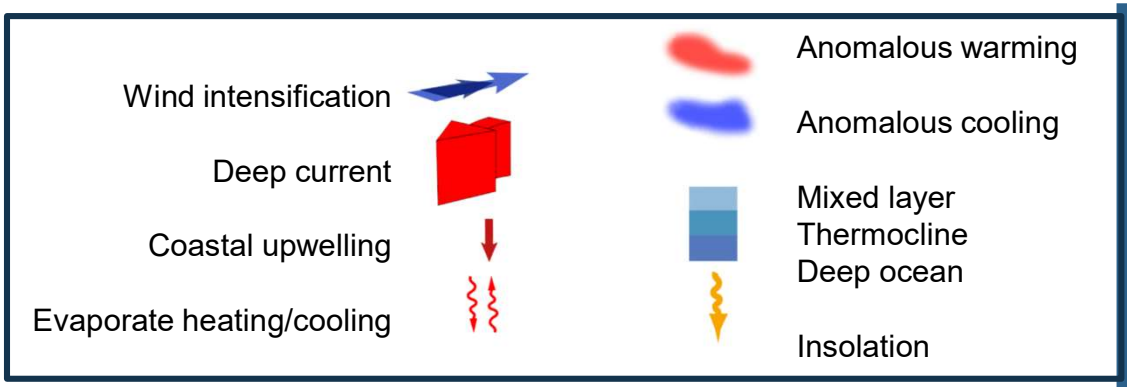
Extended MHW



Sub-surface MHW (no surface signature!)



Where are we at?
Sub-surface MHWs



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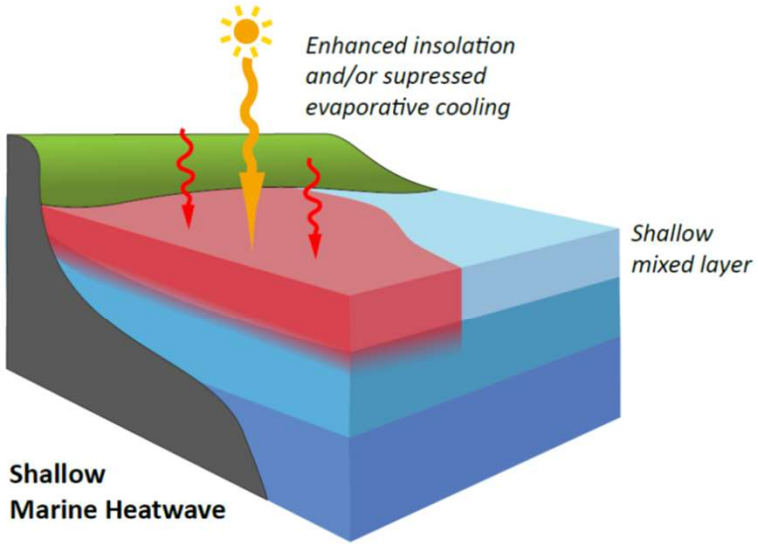
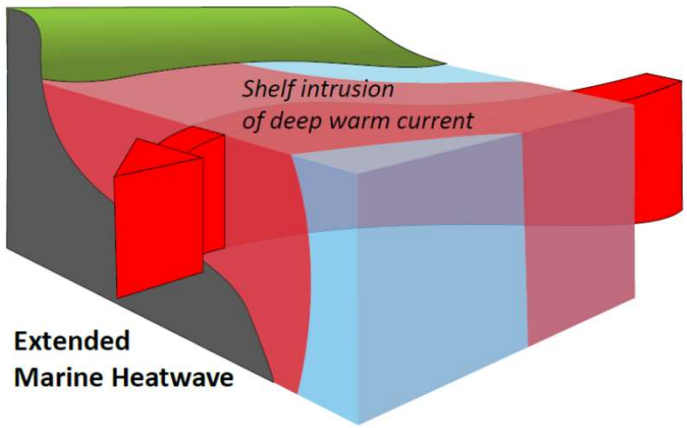


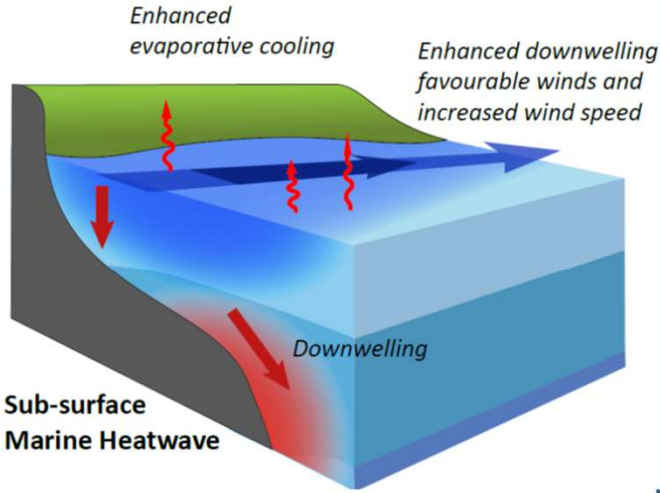
STRONGLY STRATIFIED PERIODS

Extended MHW



WEAKLY STRATIFIED PERIODS

Sub-surface MHW (no surface signature!)



STRONGLY STRATIFIED PERIODS

Conclusion

Don’t ignore the sub-surface because it’s convenient,
It’s all about the thresholds to define extremes
-> we need more long-term sustainable observations in the sub-surface.