Observational data-driven model to understand onset and decline of marine heatwaves in the Mediterranean

Amélie Simon, Etienne Pauthenet

Pierre Tandeo

Carlos Pires, Ana Russo

Thomas L. Frölicher

Work in progress

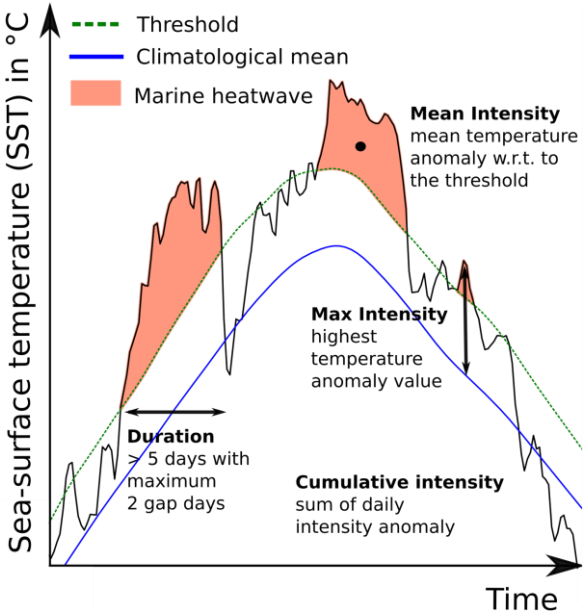
amelie.simon@ifremer.fr

COSS-TT meeting (International Coordination Meeting 10), 17-20 June 2025

Marine heatwaves (MHWs) - Scientific and Societal challenge

Recent common definition

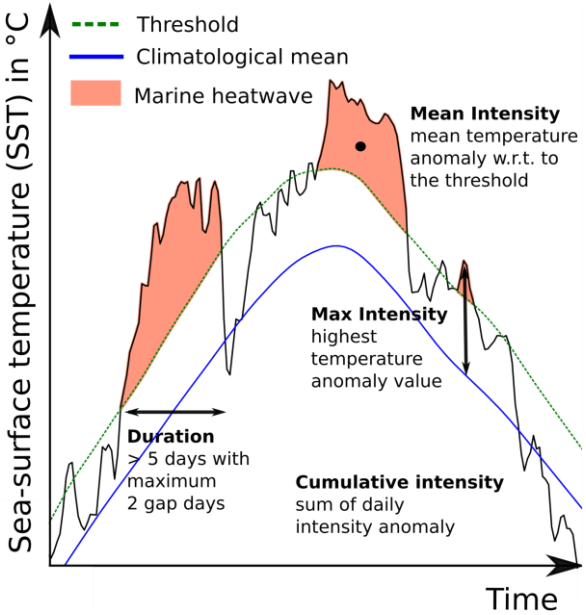
(Hobday et al., 2016, Amaya et al., 2023)



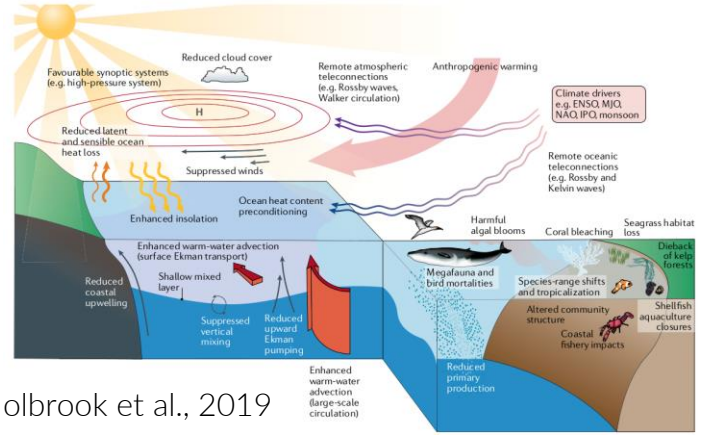
Marine heatwaves (MHWs) - Scientific and Societal challenge

Recent common definition

(Hobday et al., 2016, Amaya et al., 2023)



Physical processes complex and poorly understood

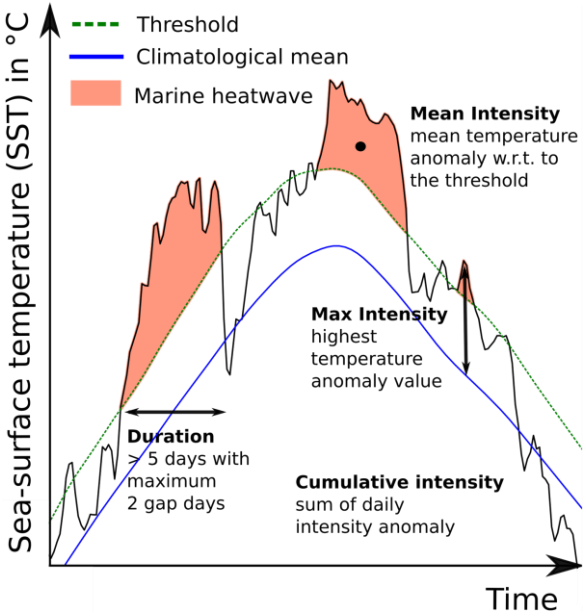


Holbrook et al., 2019

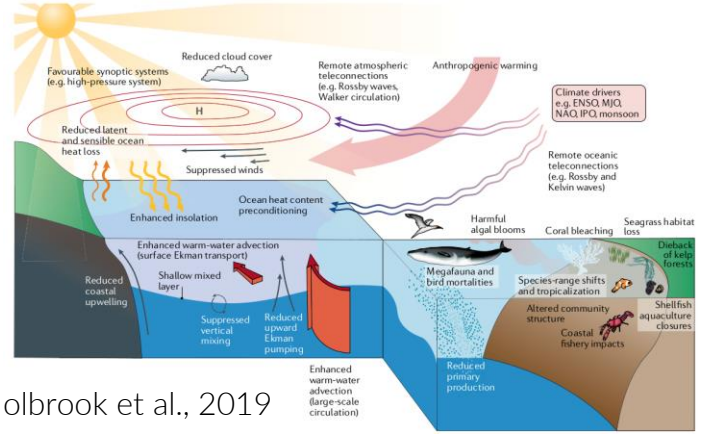
Marine heatwaves (MHWs) - Scientific and Societal challenge

Recent common definition

(Hobday et al., 2016, Amaya et al., 2023)



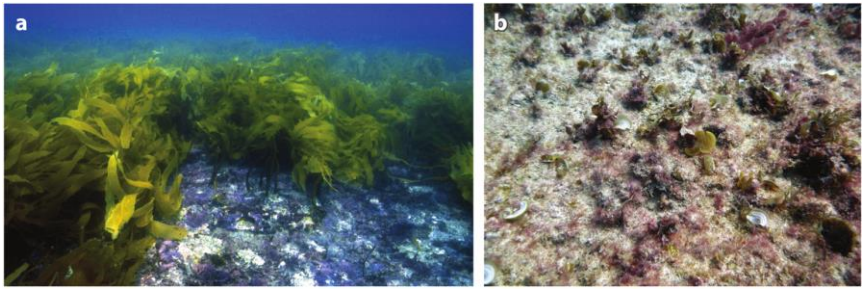
Physical processes complex and poorly understood



Holbrook et al., 2019

Severe ecological impacts

Marine deforestation, mass mortality and species migration…



Kelp forest before (a) and after (b) a MHWs west of Australia *(Wernberg et al., 2024)*

Synoptic drivers of summer MHWs in the Med.

Observation: individual MHWs
(Darmaraki et al., 2024; Murillo et al., 2024)

+

Climate model: all MHWs
(Vogt et al., 2022)

Anticyclonic conditions

Combination of

- increased solar insolation into the sea
- Reduced wind speed
- reduced of latent and sensible heat losses into the atmosphere

Synoptic drivers of summer MHWs in the Med.

Observation: individual MHWs
(Darmaraki et al., 2024; Murillo et al., 2024)

+

Climate model: all MHWs
(Vogt et al., 2022)

Anticyclonic conditions

Combination of

- increased solar insolation into the sea
- Reduced wind speed
- reduced of latent and sensible heat losses into the atmosphere

?

Statistical methods on all observed MHWs

Does all MHWs in the Med have the same drivers ?

Different processes for onset and decline periods ?

1. Linear model

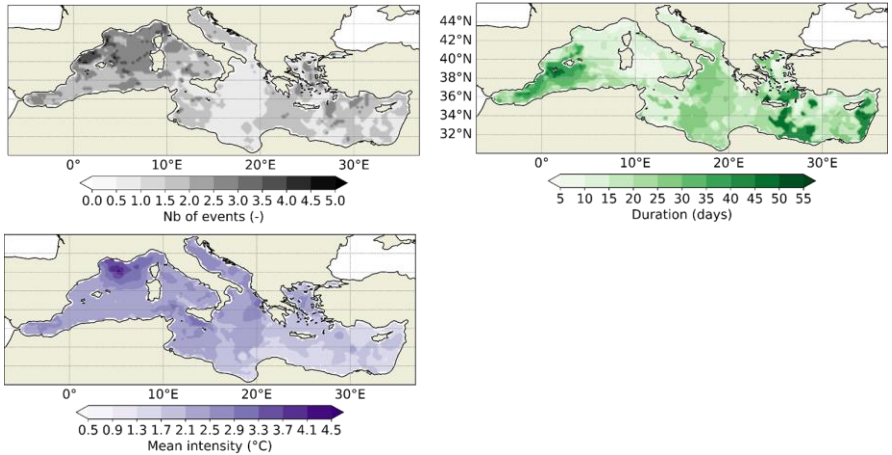
Joint PCA, Simon et al., 2023

1. Nonlinear model

CNN, Work in progress

MHWs in the Med. - Linear model

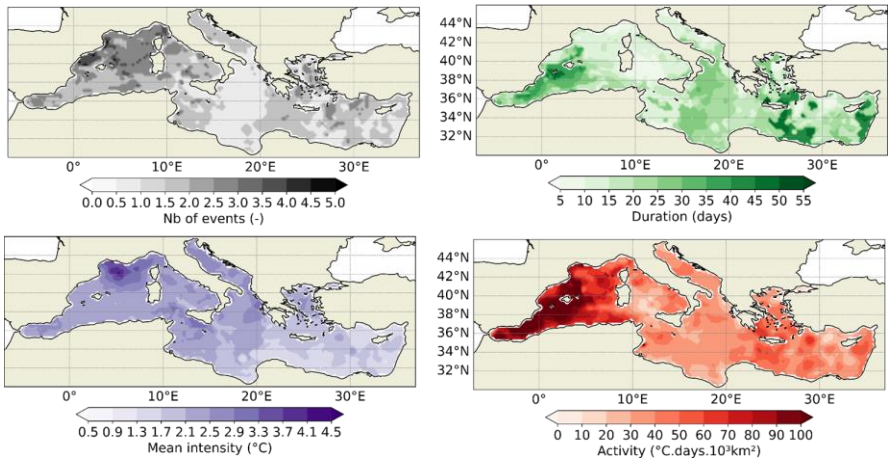
MHWs features of summer 2023



Daily SST (1/4°) from NOAA OISST (blend satellite and in situ data)

MHWs in the Med. - Linear model

MHWs features of summer 2023



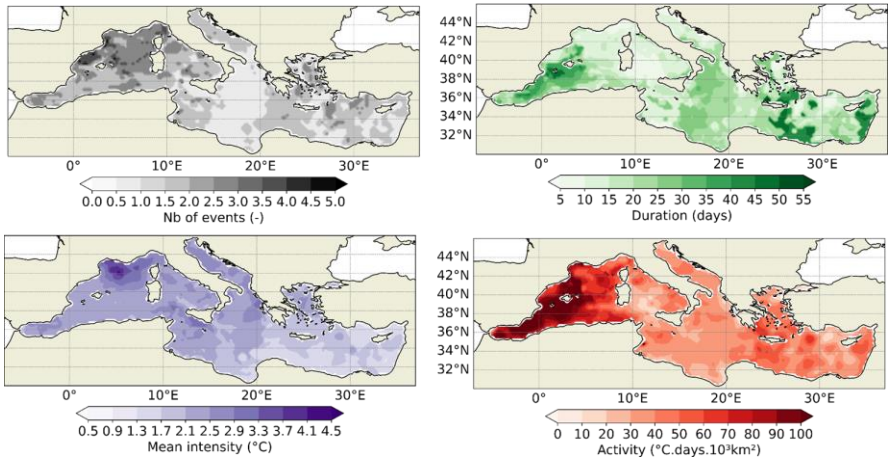
Daily SST (1/4°) from NOAA OISST (blend satellite and in situ data)

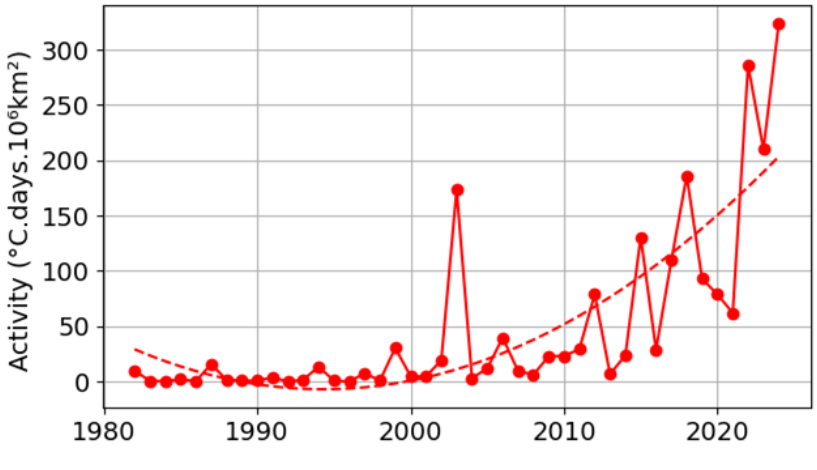
$$Activity = \sum_{EE \in Time\ Range} mean\ intensity_{EE} . duration_{EE \cap Time\ Range} . area_{EE}$$ in °C.days.km²

Simon et al., 2022

MHWs in the Med. - Linear model

MHWs features of summer 2023





Daily SST (1/4°) from NOAA OISST (blend satellite and in situ data)

$$Activity = \sum_{EE \in Time\ Range} mean\ intensity_{EE} . duration_{EE \cap Time\ Range} . area_{EE}$$ in °C.days.km²

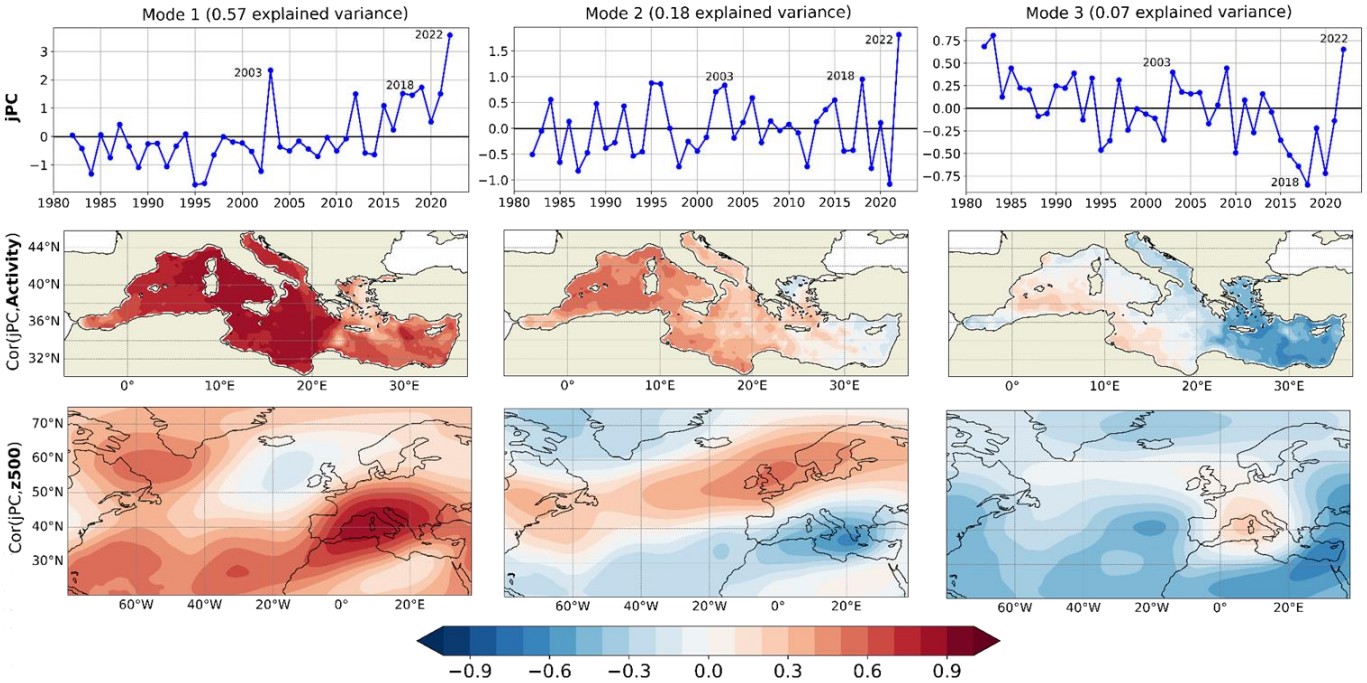
Simon et al., 2022

MHWs in the Med. - Linear model

How spatio-temporal patterns of MHW co-varies with large-scale atmospheric circulations (1982-2022) ?

Joint Principal Component Analysis with:

- MHW activity
- Z500

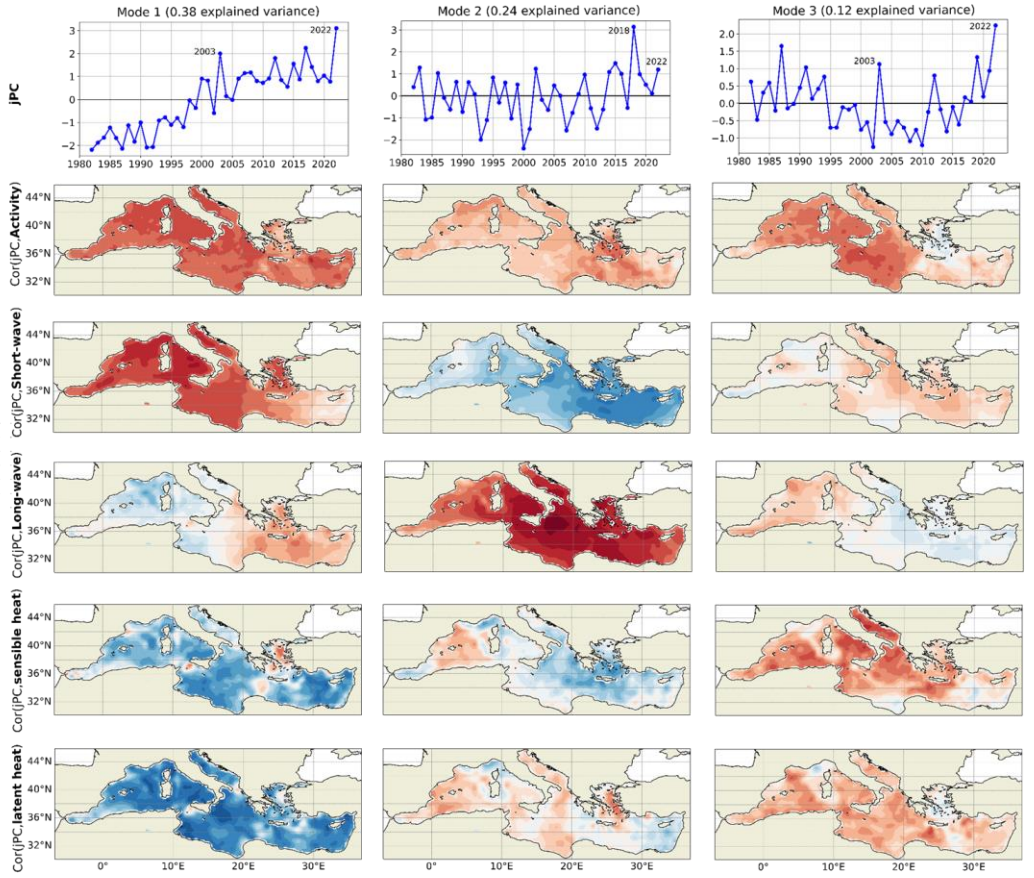


~Positive phase of the summer North Atlantic Oscillation (SNAO)

MHWs in the Med. - Linear model

Joint Principal Component Analysis with:

- MHW activity
- Short-wave radiation
- Long-wave radiation
- Sensible heat flux
- Latent heat flux



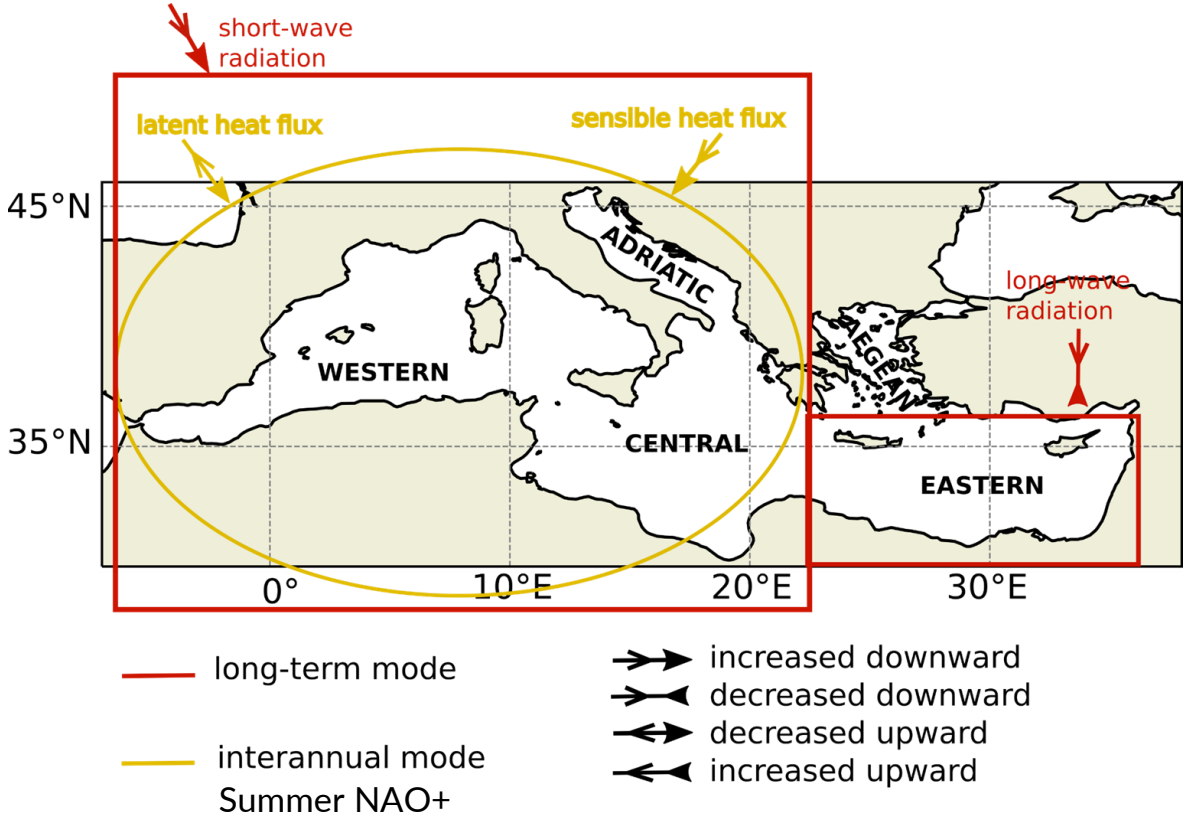
Positive downward

MHWs in the Med. - Linear model

Joint Principal Component Analysis with:

- MHW activity
- Short-wave radiation
- Long-wave radiation
- Sensible heat flux
- Latent heat flux

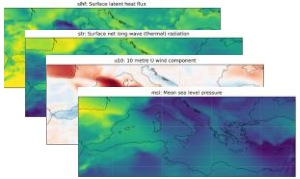
-> Physical processes depend on the region and on the mode of variability



MHWs in the Med. - Nonlinear model

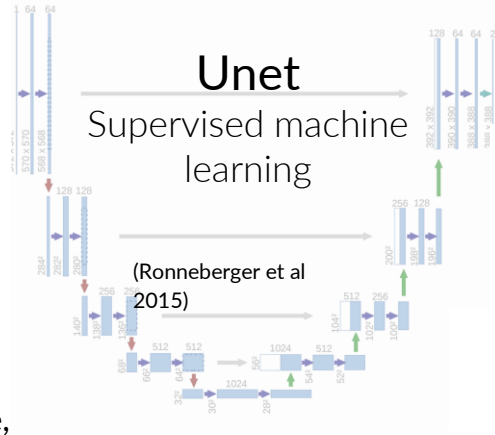
Unet method is skilllful to forecast MHWs in the Med. (Bonino et al. 2023)
Here, Unet is used to understand key physical processes

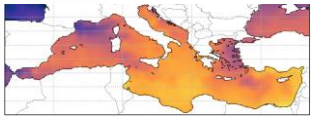
Data: Daily map ¼ degree from 1982-2024 (Detrended)



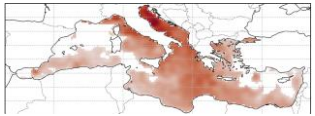
Inputs : 8 atmospheric variables (reanalysis ERA5)

Four air-sea heat fluxes, z500, sea-level pressure, total cloud cover, wind speed





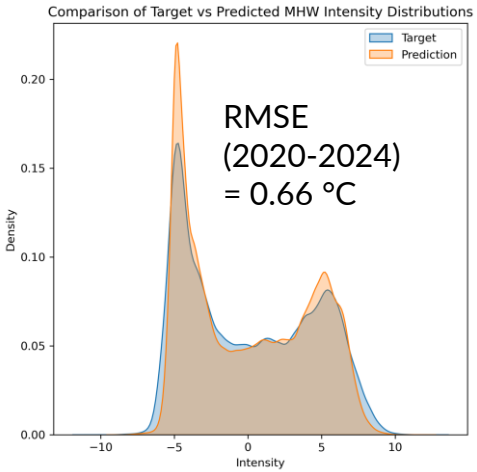
Output : Sea surface temperature (OISST)

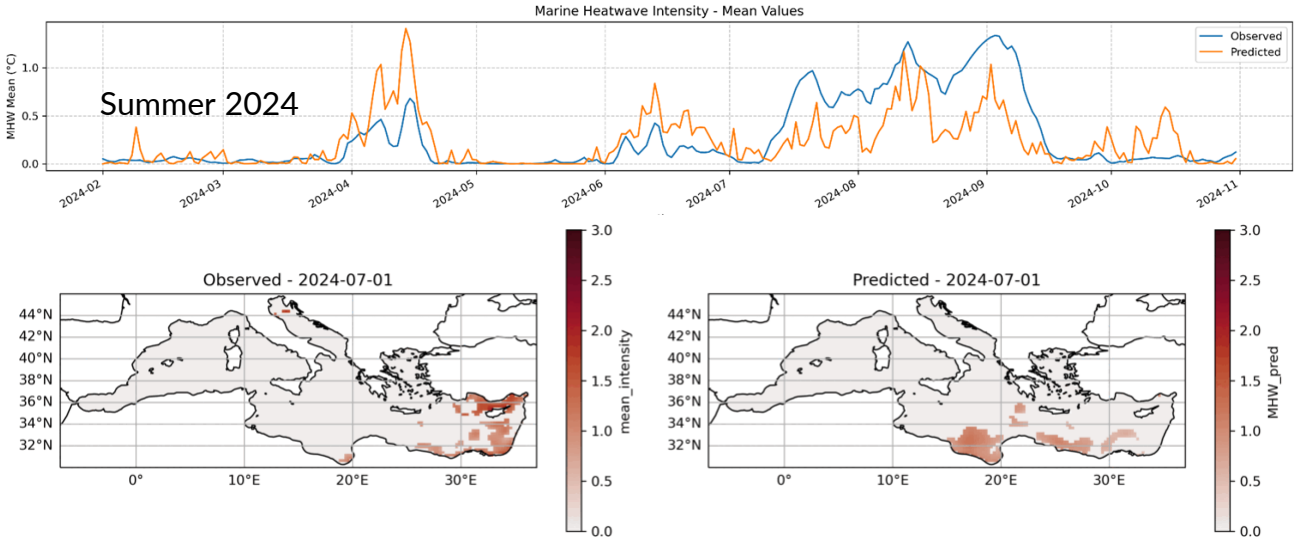


MHW intensity

MHWs in the Med. - Nonlinear model

1. First training over 1982-2019 and testing over 2020-2024

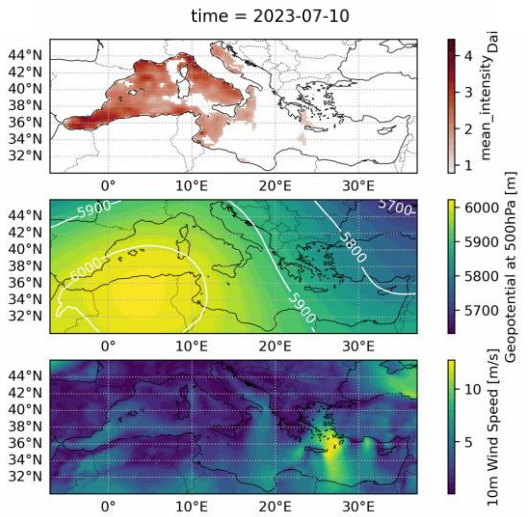


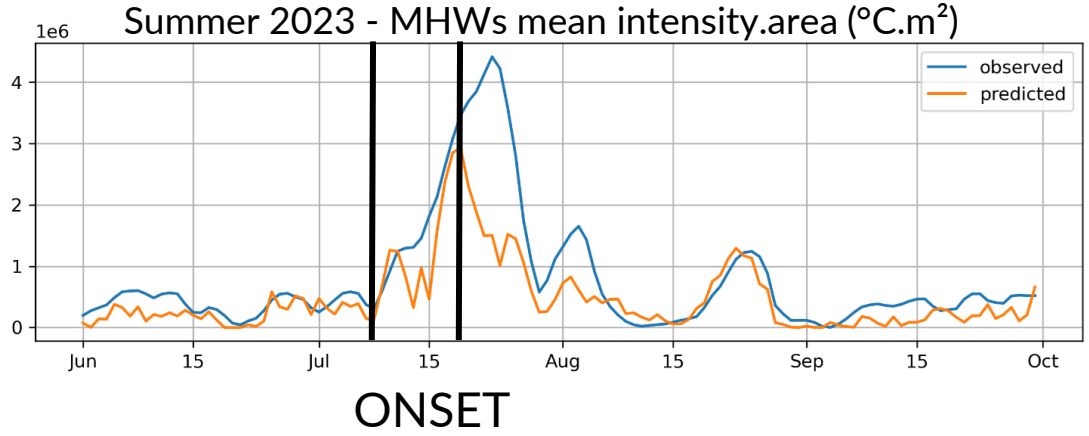


2. Final training is over the whole period (1982-2024) and understand physical processes through permutation feature importance

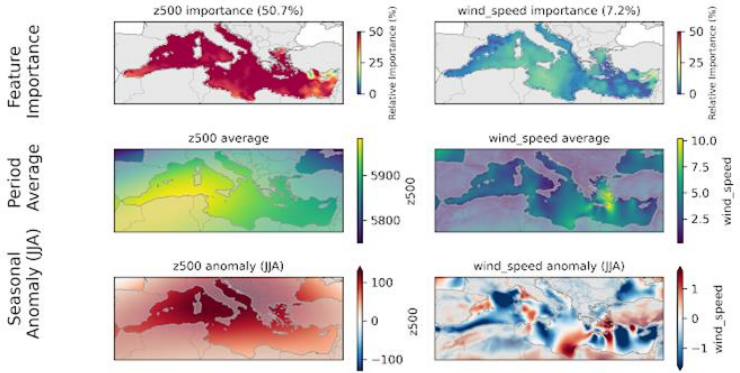
MHWs in the Med. - Nonlinear model

Permutation feature importance

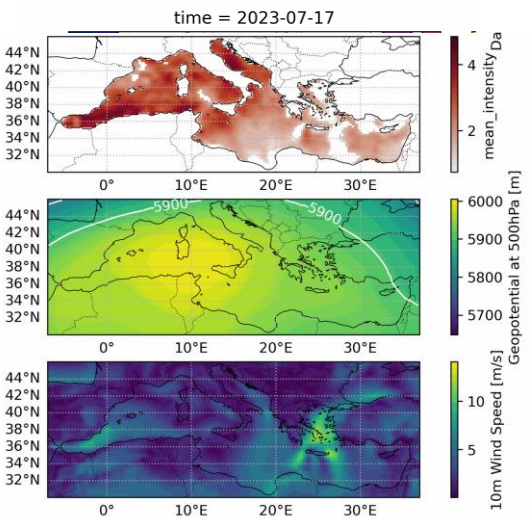


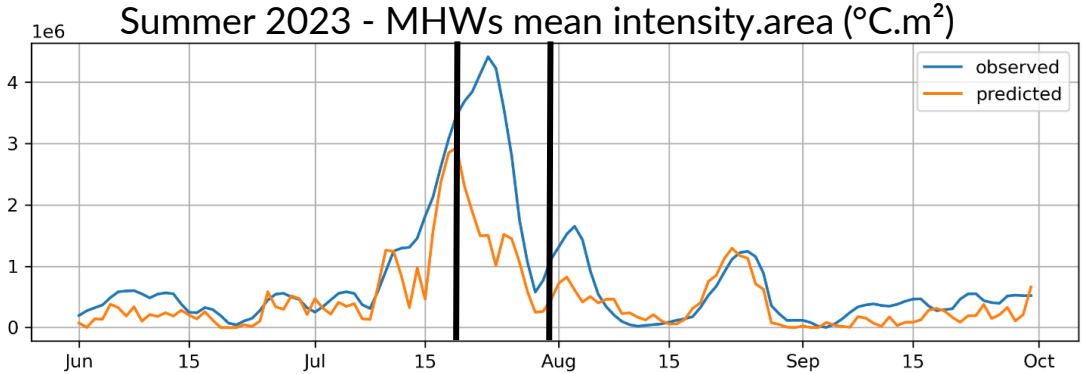


ONSET

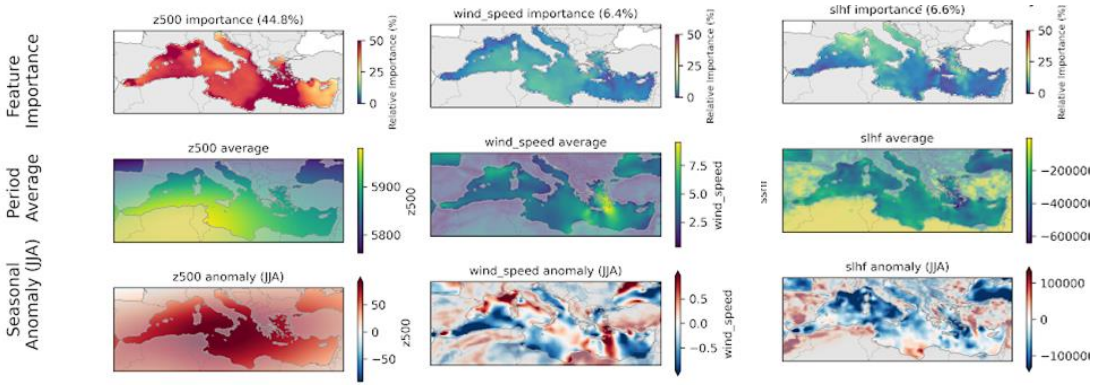


MHWs in the Med. - Nonlinear model

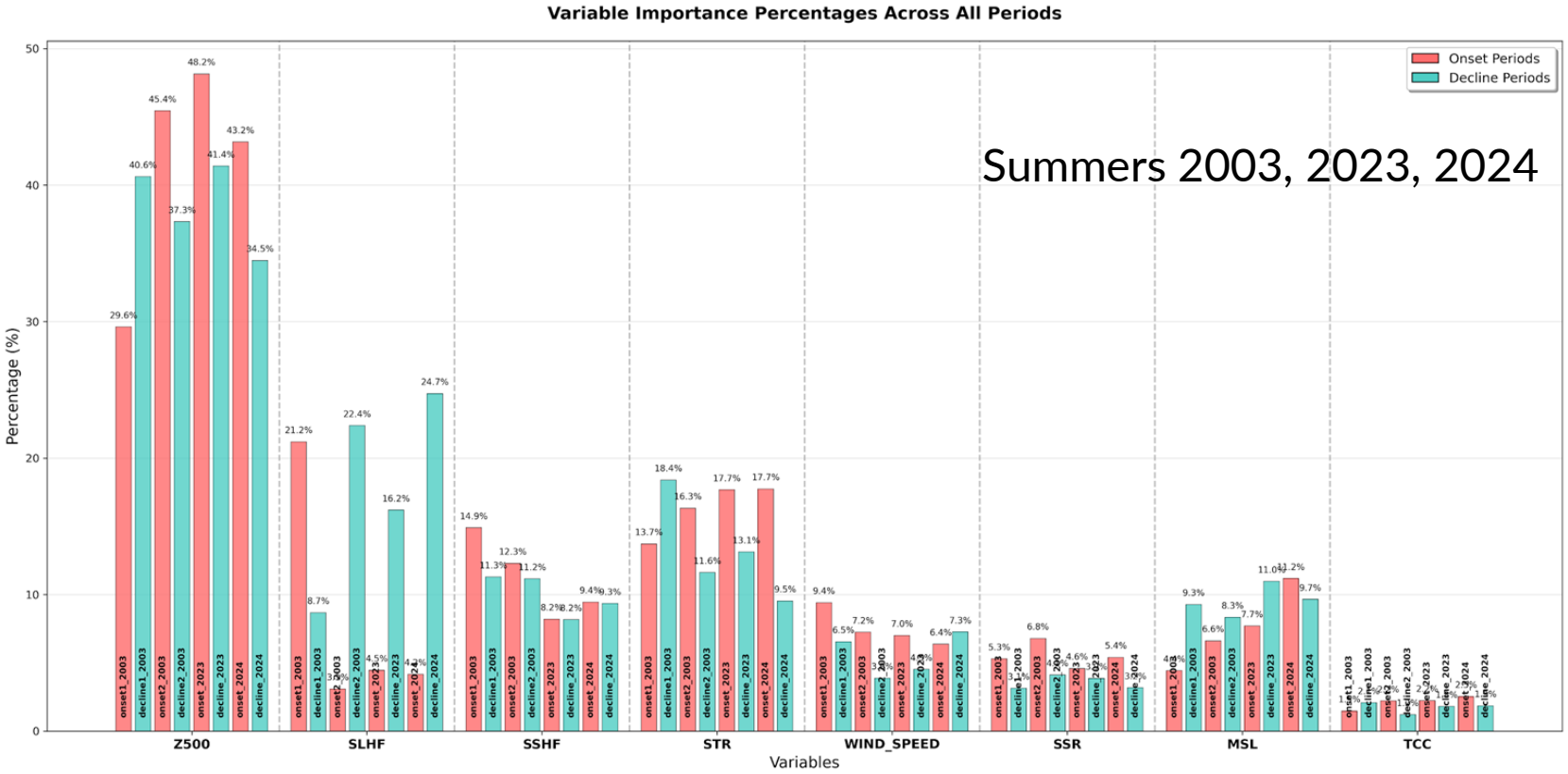




DECLINE



MHWs in the Med. - Nonlinear model



MHWs in the Med. - Conclusions

Linear Model:
MHWs in the western Mediterranean are associated to anticylonic conditions together with advection of warm and moist air (summer NAO+). (Simon et al., 2023)

Nonlinear Model (Preliminary interpretation):

- Z500 has the main importance of the 8 variables (~40%) -> anticyclonic conditions
- Latent heat fluxes is important during most declines -> importance of evaporation processes
- Low wind speed during onset and high wind speed during decline.

Next:
Role of the oceanic variables ?
Coastal and large-scale processes ?
Other regions Bay of Biscay, English Channel ?

MHWs in the Med. - Conclusions

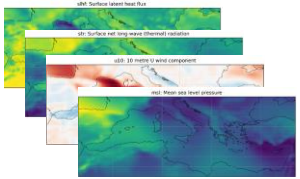
Linear Model:
At interannual time-scale, MHWs in the western Mediterranean are associated to anticylonic conditions with advection of warm and moist air (summer NAO+). (Simon et al., 2023)

Nonlinear Model (Preliminary interpretation):

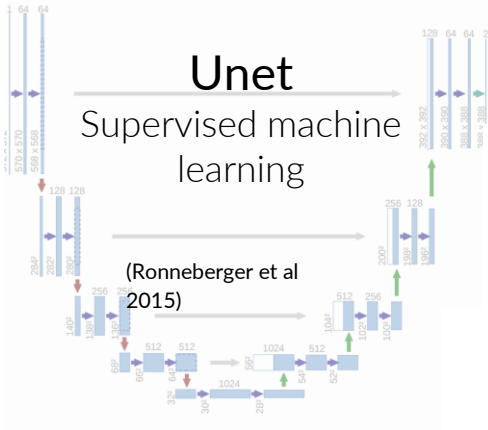
- Z500 has the main importance of the 8 variables (~40%) -> anticyclonic conditions
- Latent heat fluxes is important during most declines and not during onsets -> importance of evaporation processes
- Low speed during onset and high wind speed during decline.

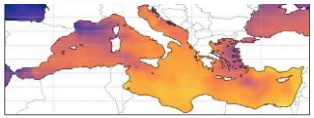
Next:
Role of the oceanic variables ?
Physical processes varies depending on the season ?
Other regions Bay of Biscay, English Channel ?

Thank you !
amelie.simon@
ifremer.fr

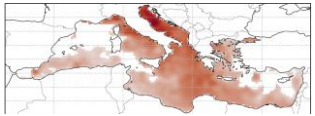


Inputs : local, synoptic and remote variables





Output : Oceanic temperature



Post-processed: MHW intensity