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Mediterranean Marine Heatwaves:
On the physical drivers behind the 2003 and 2015 events

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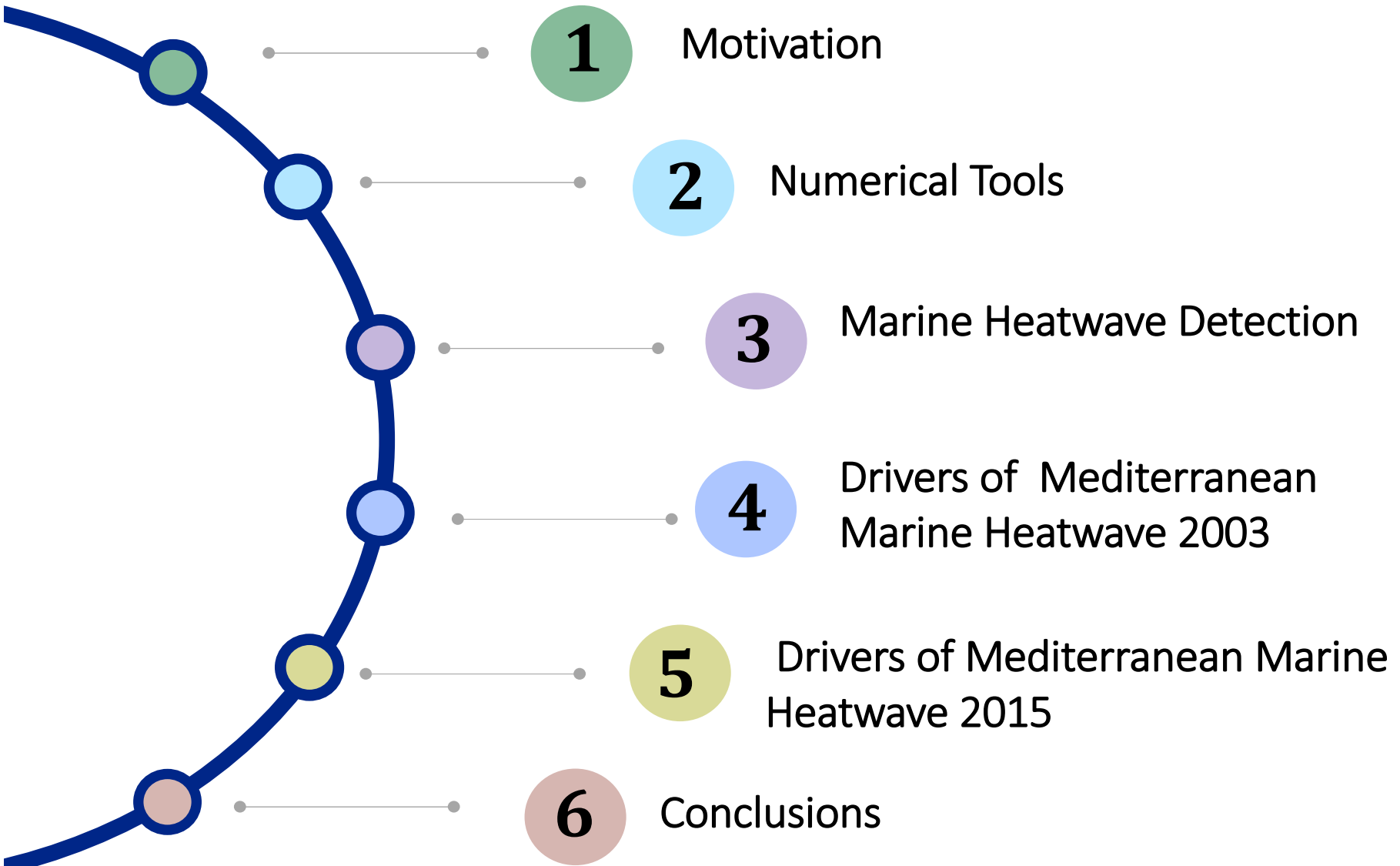
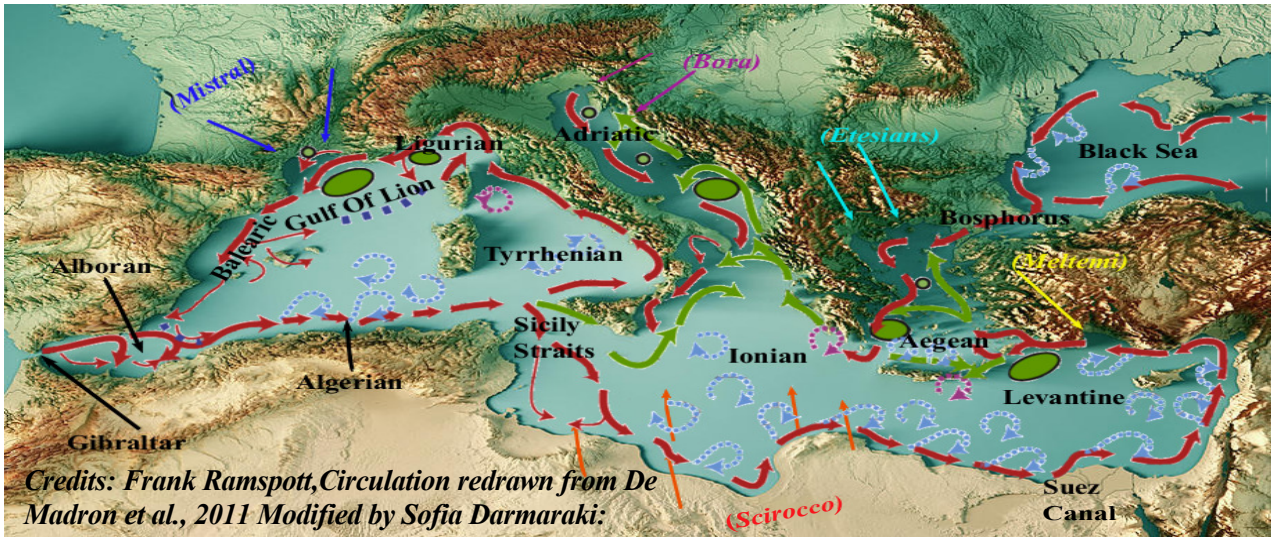
➢ Outline



Mediterranean Sea



- Transitional region
- Large marine biodiversity
- Mediterranean Thermohaline Circulation
- Climate Change Hot Spot *(Giorgi et al 2006)*
- Increasing basin mean SST in 21th century: ~1-4 ℃

Marine Heatwaves (MHWs) in the basin

- *26* events have occurred between 1982-2017, with record-warm sea water temperatures, resulting in:
- ***Mass mortalities*** of benthic invertebrates e.g. sponges gorgonians, red corals ***(e.g.*** *Garrabou et al.2009,2001)*
- **Most intense MHWs: 2003, 2015**

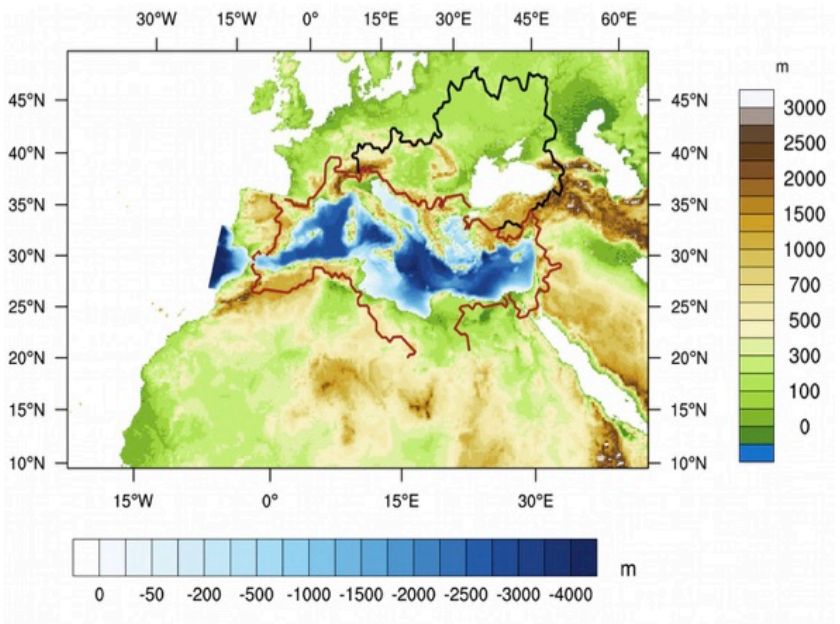
👉 No investigation of their driving mechanisms so far with online model diagnostics !

Numerical & Observational Tools

To study the development of the 2003 & 2015 MHWs we used:

1: Fully Coupled **R**egional **C**limate **S**ystem **M**odel: **CNRM –RCSM6**

Domain covered by CNRM-RCSM6



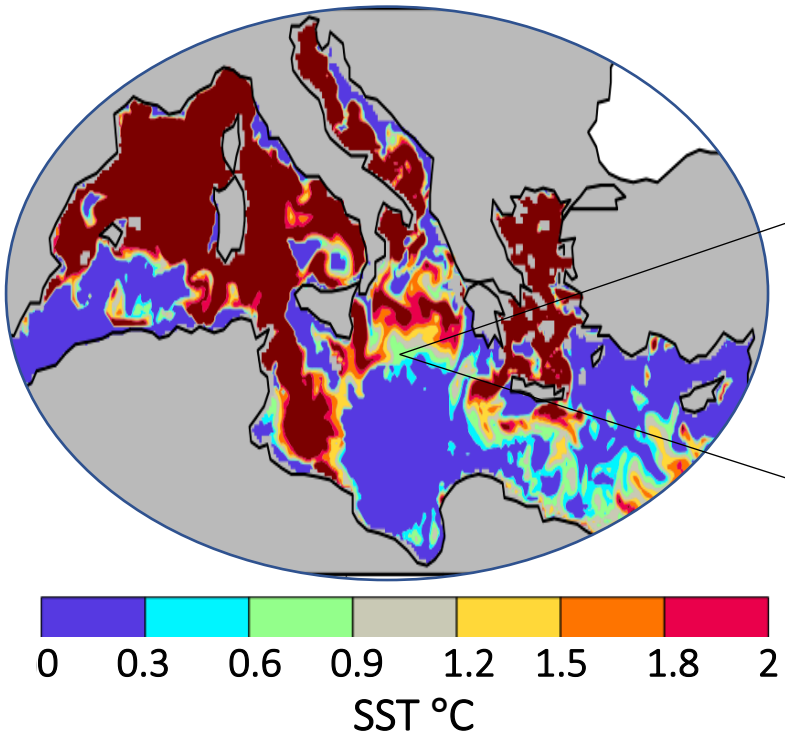
A Mediterranean Sea-dedicated model:

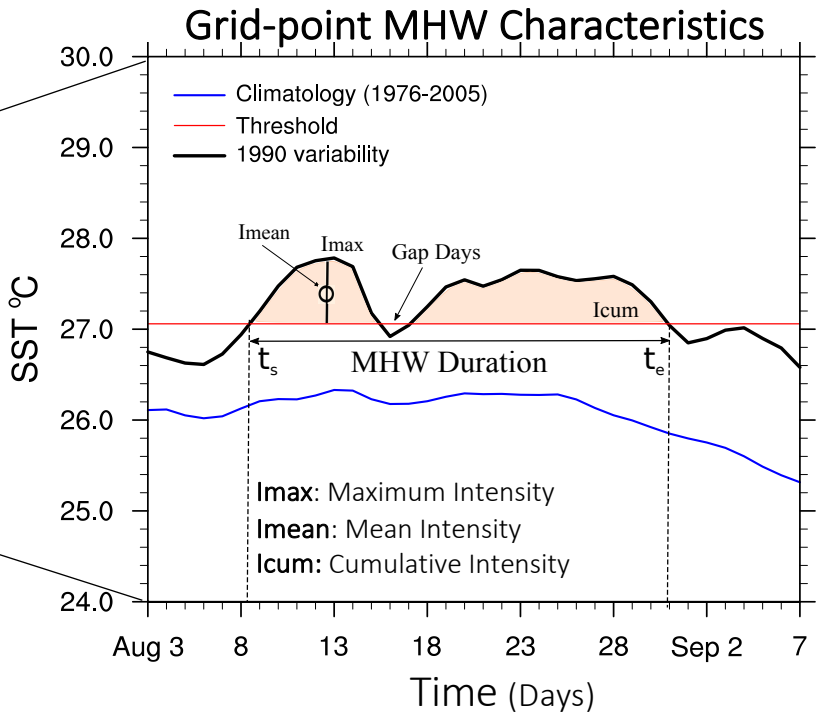
- **6-8km** ocean resolution (NEMOMED12)
- **12km** atmosphere resolution
- Hindcast simulation between 1980-2017
- **High-resolution** & **Frequency of coupling**: Important for representation of Mediterranean Sea features
- **Free Air-Sea fluxes**: Important for MHW atmosphere-ocean interactions
- Part of the **MedCordex** Initiative: (https://www.medcordex.eu, *Ruti et al 2016*)
- More info : https://www.umr-cnrm.fr/spip.php?article1098

We also used:

2: **Observational SST dataset** (**OBS**): Mediterranean Sea High Resolution (0.04 °) L4 SST Reprocessed (1982-2017) by Copernicus Marine Service *(Pisano et al., 2012)*

Marine Heatwave Detection





This is how a MHW looks like on a 2D scale.

"A discrete, prolonged anomalously warm water event at a particular location" *(Hobday et al., 2016)*

And this is how a MHW looks like on a single point.

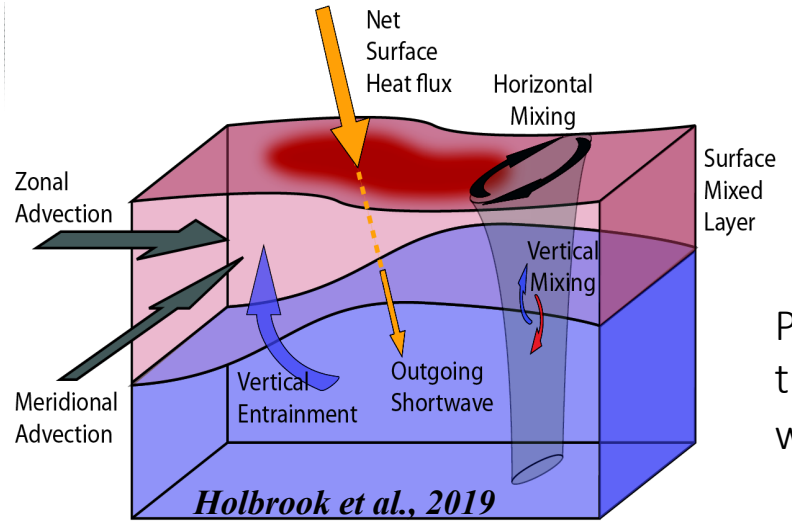
Detection Method

- Using as a threshold the 30-year average (1982-2012) of the 99th quantile of SST (2D map), we identified which & when grid points were above threshold for 5 days in a row, every year ***(Darmaraki et al., 2019)***.
- Every time 20% of basin grid points were found above threshold, a Marine Heatwave was detected!
- This way we targeted:

Mediterranean MHWs

- ✓ Summer
- ✓ Long-Lasting
- ✓ Large-scale

Ocean & Atmosphere Heat Budgets



$$\mathbf{h} \rightarrow \bar{T} = \frac{1}{h}\int_{-h}^{0} T dz$$

Physical processes driving MHWs are explored through the analysis of heat sources and sinks within the surface mixed layer:

For the first time, an online Mixed Layer temperature budget (daily scale) was used to describe changes in Mixed Layer temperature during the MHWs of 2003 and 2015, according to:

- **Mixed Layer Temperature Rate of Change**

$$\underbrace{\frac{\partial \bar{T}}{\partial t}}_{\text{Total Trend}} = -\underbrace{\overline{\boldsymbol{\nabla}(T\boldsymbol{u})}}_{\text{Advection}} + \underbrace{\frac{Qnet - QSW_{(-h)}}{\rho_0 C w h}}_{\text{Forcing}} + \underbrace{\overline{\boldsymbol{\nabla}_H(k_H \boldsymbol{\nabla}_H T)}}_{\text{Lateral Diffusion}} + \underbrace{\frac{(kZ\frac{\partial T}{\partial z})_{(-h)}}{h}}_{\text{Vertical Diffusion}} - \underbrace{\frac{1}{h}\frac{\partial h}{\partial t}(\bar{T} - T_{(-h)})}_{\text{Entrainment}}$$

Further decomposition of atmosphere forcing was also performed according to:

- **Atmosphere Heat Flux decomposition**

$$\underbrace{Q_{net}}_{\text{Net Surface Heat fluxes}} = \underbrace{Q_{LH}}_{\text{Latent}} + \underbrace{Q_{SH}}_{\text{Sensible}} + \underbrace{Q_{SWD}}_{\text{Shortwave down}} + \underbrace{Q_{LWD}}_{\text{Longwave down}} + \underbrace{Q_{SWUP}}_{\text{Shortwave up}} + \underbrace{Q_{LWUP}}_{\text{Longwave up}}$$

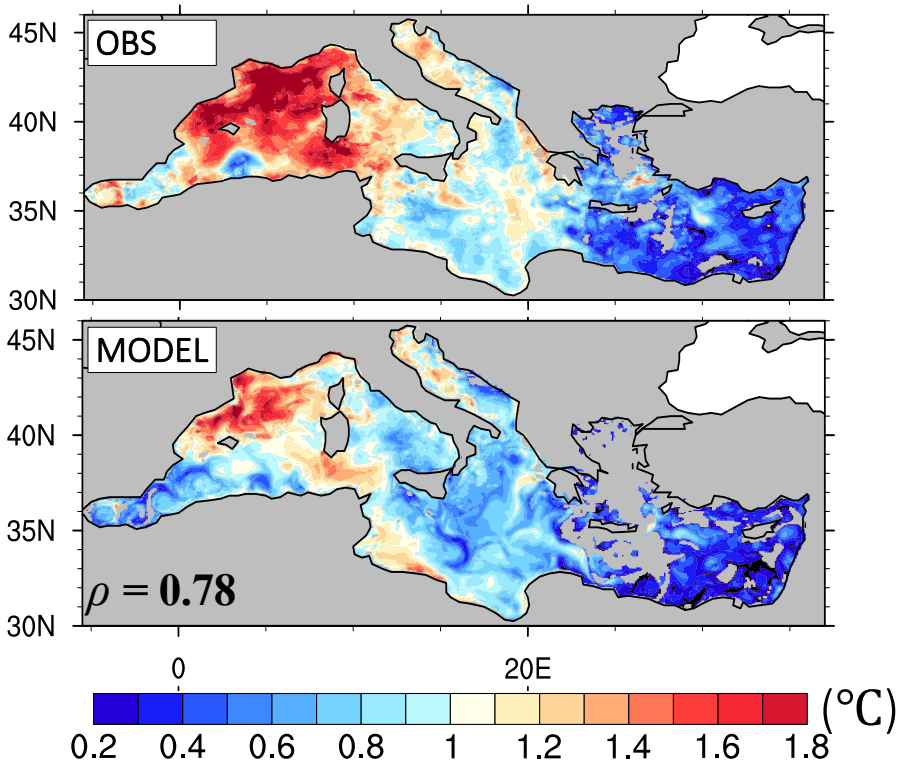
! Heat fluxes warming (cooling) the ocean are considered positive (negative)

Darmaraki et al., in prep

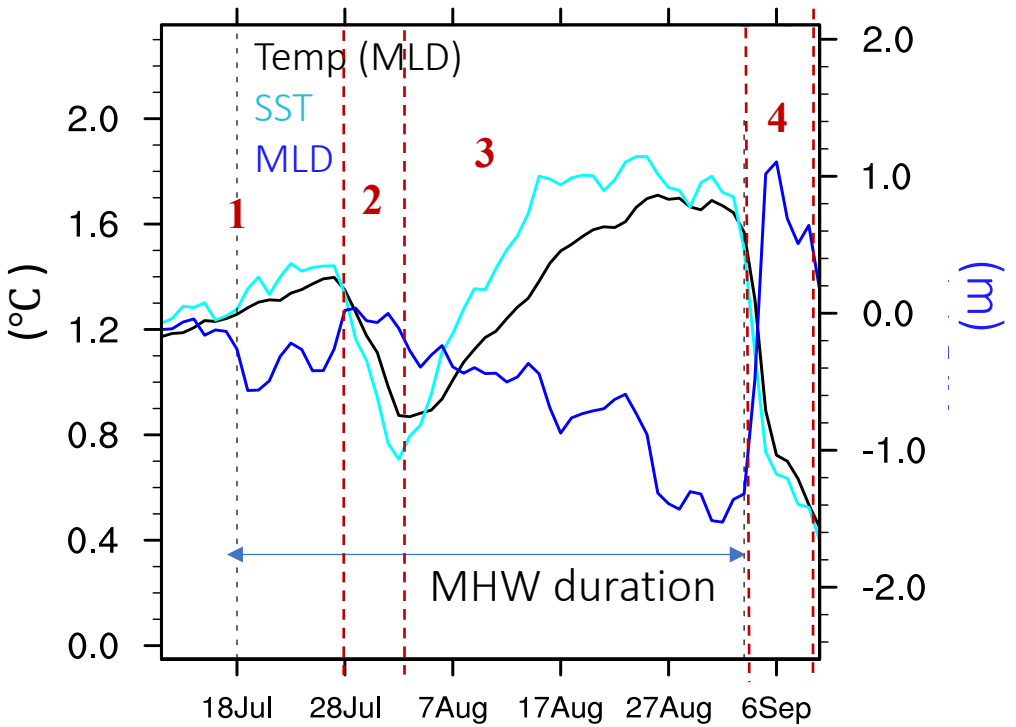
MHW 2003 basin-scale signature

Darmaraki et al., in prep

Mean event intensity



Daily MHW-area averaged anomalies



Characteristics

- Duration: 18 July – 3 Sep (48 days)
- Mean Intensity: 0.8 °C
- Max Coverage: 79 %
- Mostly in NW Mediterranean

! Abnormally high SST, Mixed layer Temperature

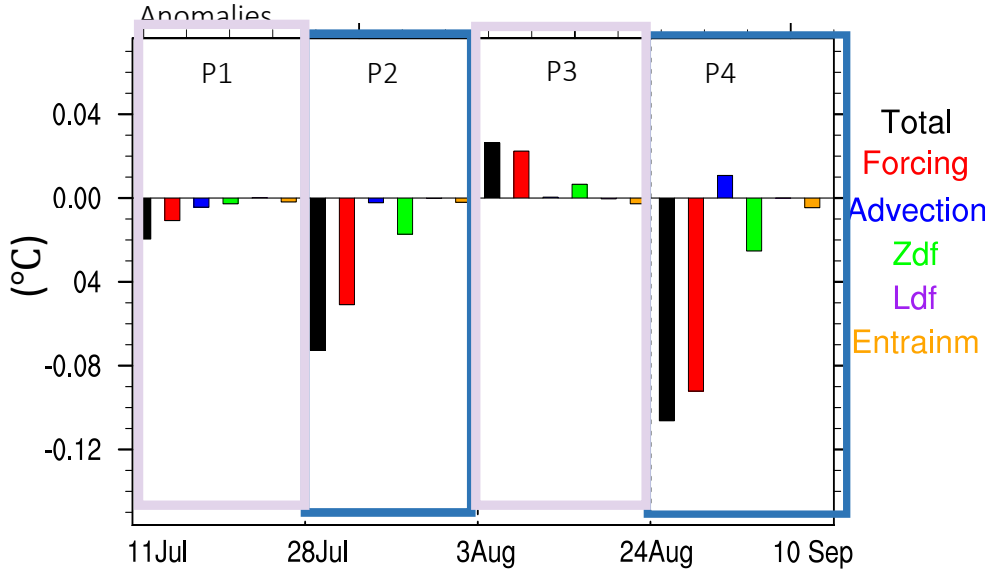
! Shallower than normal Mixed Layer Depth

👉 *Split in 4 phases based on increasing/decreasing SST anomalies to better disentangle driving processes* →

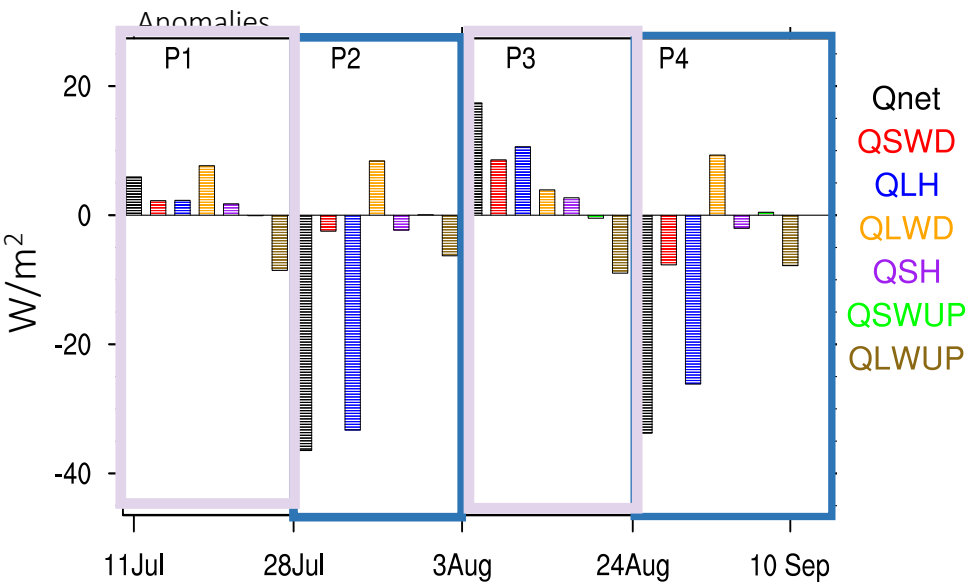
MHW 2003: Atmosphere forcing & wind

Darmaraki et al., in prep

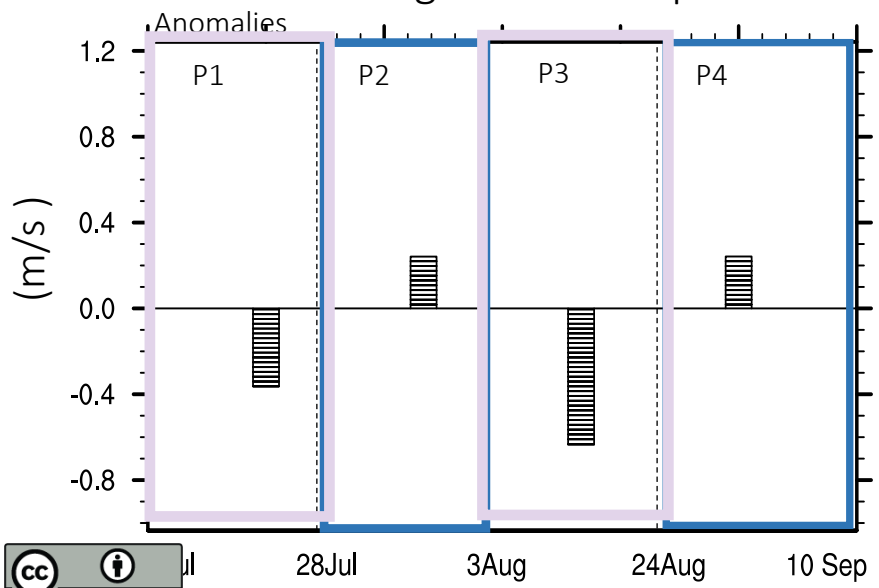
Time-integrated Mixed Layer Heat Budget



Time-integrated Atmosphere Heat flux



Time-integrated Windspeed



P1,P3 (Increasing SST anomalies – MHW development)

- Lower/Higher than normal Forcing, Shortwave (Q_{SWD}),
- Lower than normal: Windspeed, Latent(Q_{LH})
- Higher/Lower than normal Vertical Diffusion (Zdf)

P2-P4 (Decreasing SST anomalies – MHW decay)

- Opposite ocean & atmosphere forcing than P3

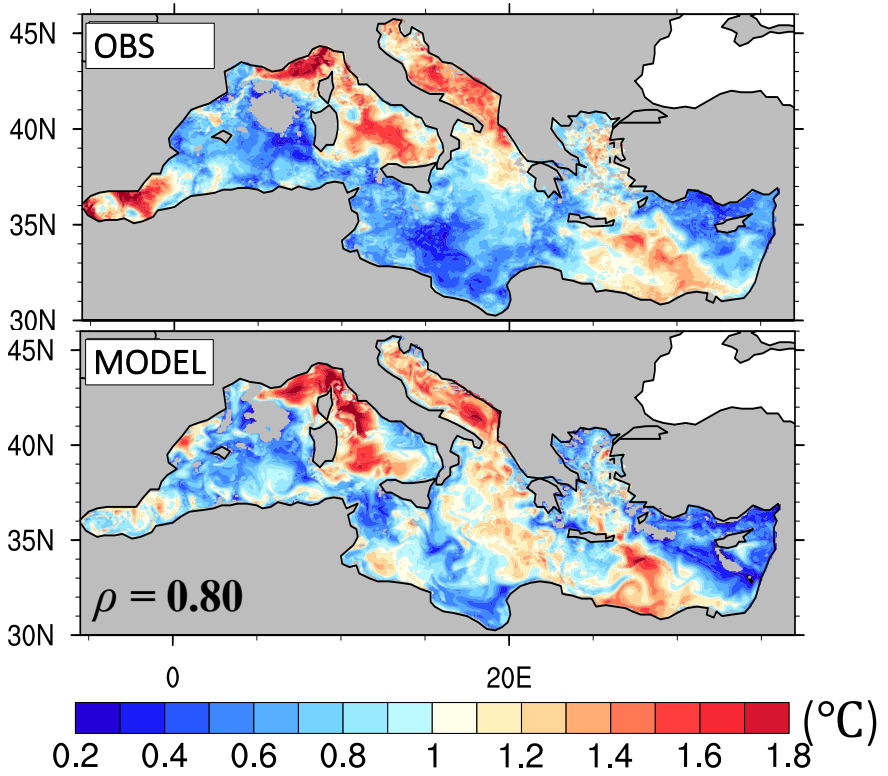
Longwave down (Q_{LWD}) abnormally high at all times

👉 **Span of time-integrated period matters !**

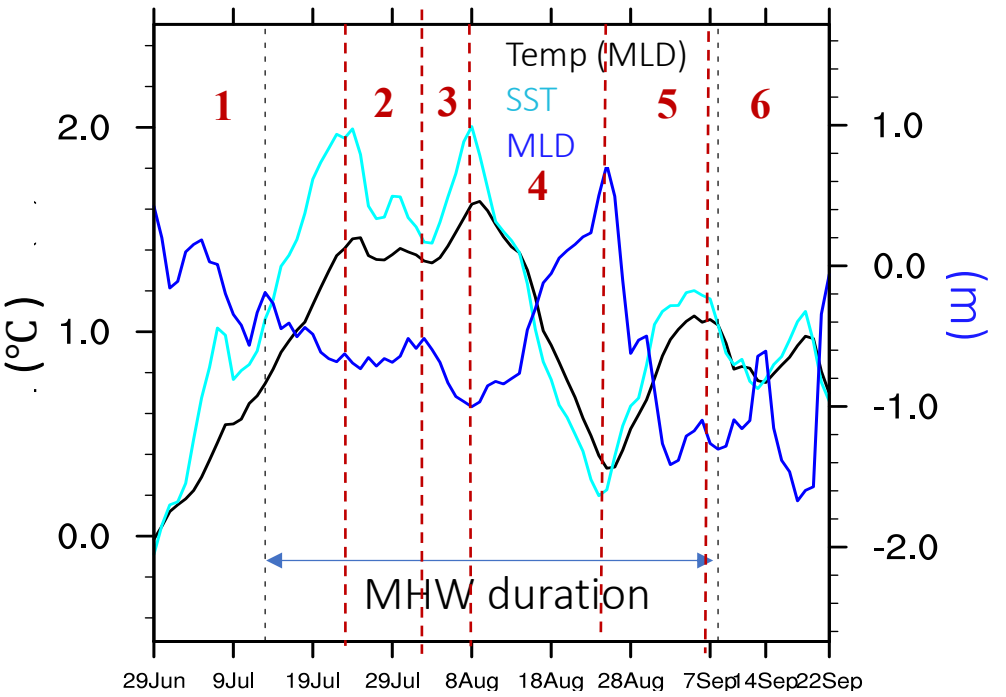
MHW 2015 basin-scale signature

Darmaraki et al., in prep

Mean event intensity



Daily MHW-area averaged anomalies



Characteristics

- Duration: 14 July – 10 Sep (56 days)
- Mean Intensity: 0.9 ℃
- Max Coverage: 82 %
- Covered almost the whole basin

! Abnormally high SST, Mixed layer Temperature

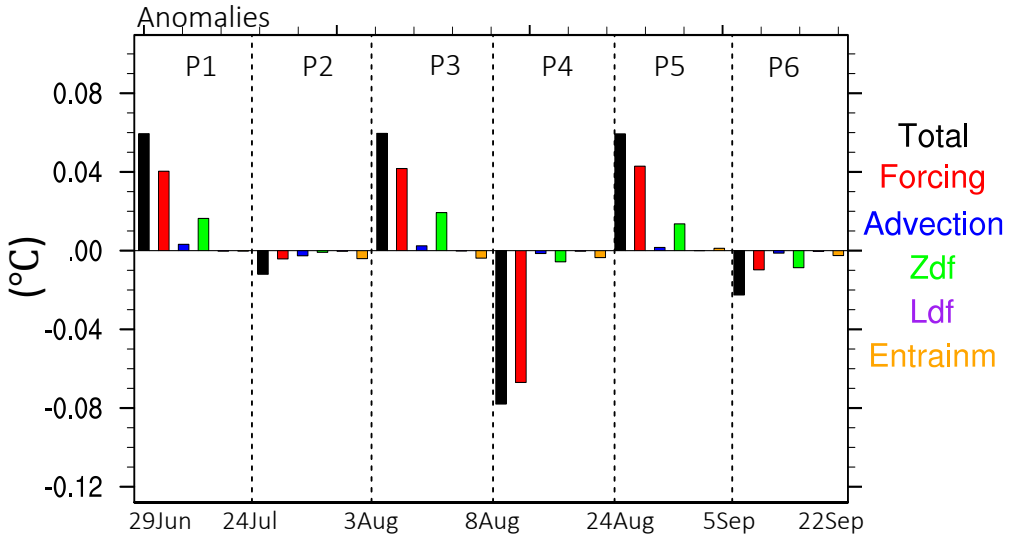
! Shallower than normal Mixed Layer Depth (at most times)

👉 *Split in 6 phases based on increasing/decreasing SST anomalies to better disentangle driving processes* →

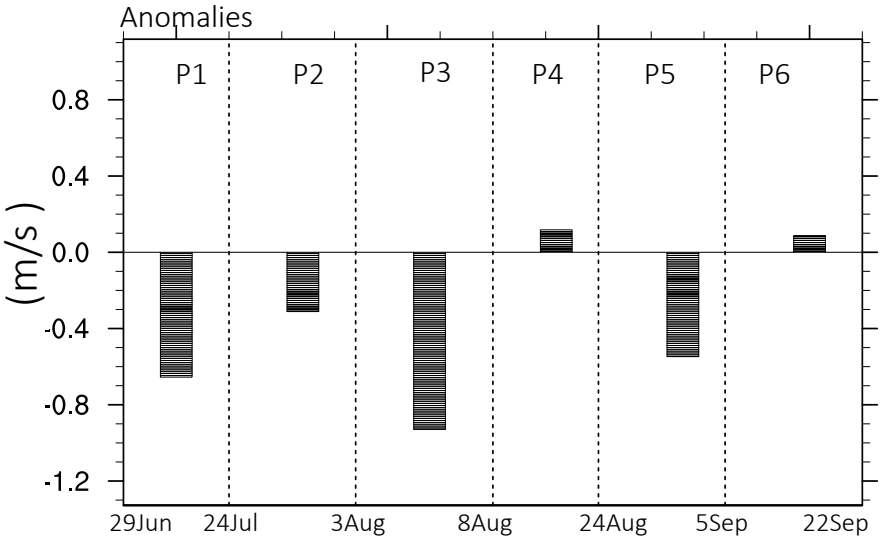
MHW 2015: Atmosphere forcing & wind

Darmaraki et al., in prep

Time-integrated Mixed Layer Heat Budget



Time-integrated Windspeed



P1,P3,P5 (Increasing SST anomalies - MHW development)

- Higher than normal Forcing, Shortwave (Q_{SWD}),Advection
- Lower than normal: Windspeed, Vertical Diffusion (Zdf),Entrainment

P2,P4,P6 (Decreasing SST anomalies – MHW decay)

- Opposite ocean forcing than P2,P4,P6, except Windspeed in P2.

- Atmosphere forcing and windspeed appear to drive this MHW <u>on a basin scale</u>, however:

👉 **The influence of entrainment and advection processes become more important on local scale**

Mediterranean Marine Heatwaves in short

Definition

- Qualitative : *A discrete, prolonged anomalously warm water event at a particular location*
- Quantitative: Long-lasting, large-scale, summer MHWs, Thresholds: 99th quantile of SST, 5 days minimum duration, 20% minimum spatial coverage

Model Representation

- Fully-coupled Regional Climate System Model with high ocean & atmosphere resolution

Key driving mechanisms of MHW 2003

- **Anomalously high** atmospheric forcing (shortwave), **low** Latent Heat Flux, **low** Vertical Diffusion & **weaker** than average winds
- **Time scale of integration** affects the results on the contribution of each budget term to the MHW development/decay: Too long → influence of some factors can be counteracted, Too short → Not representative of the conditions before the MHW

Key driving mechanisms of MHW 2015

- **Anomalously high** atmospheric forcing , **low** Vertical Diffusion & **weaker** than average winds
- Large MHW spatial scale considered can "obscure" the contribution from smaller-scale processes (in the basin) such as, Advection,Entrainment

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Do we choose an appropriate spatiotemporal MHW scale (how?) to investigate or do we adapt our research questions ?

Thank you for watching

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Model capture well past MHW characteristics

➢ **IDF plot**