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sui Cambiamenti Climatici

Seasonal forecasting of surface and sub-surface marine heat waves: a global validation and comparison

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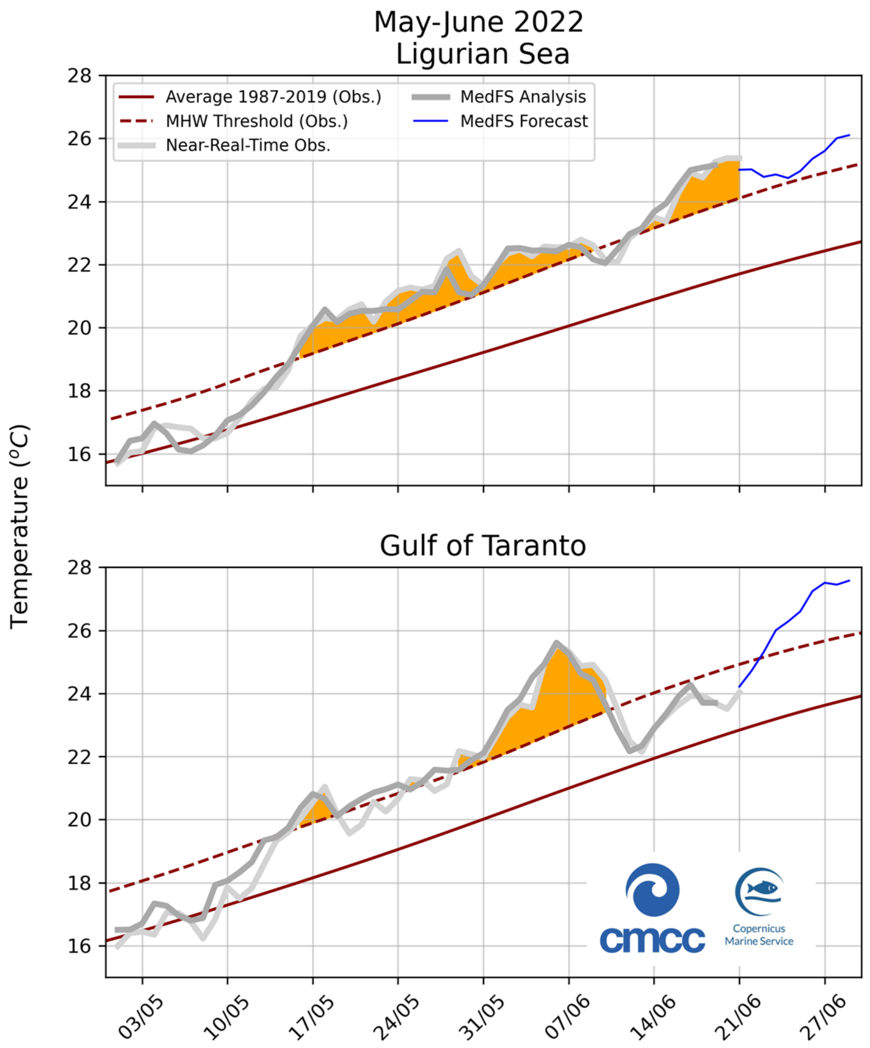
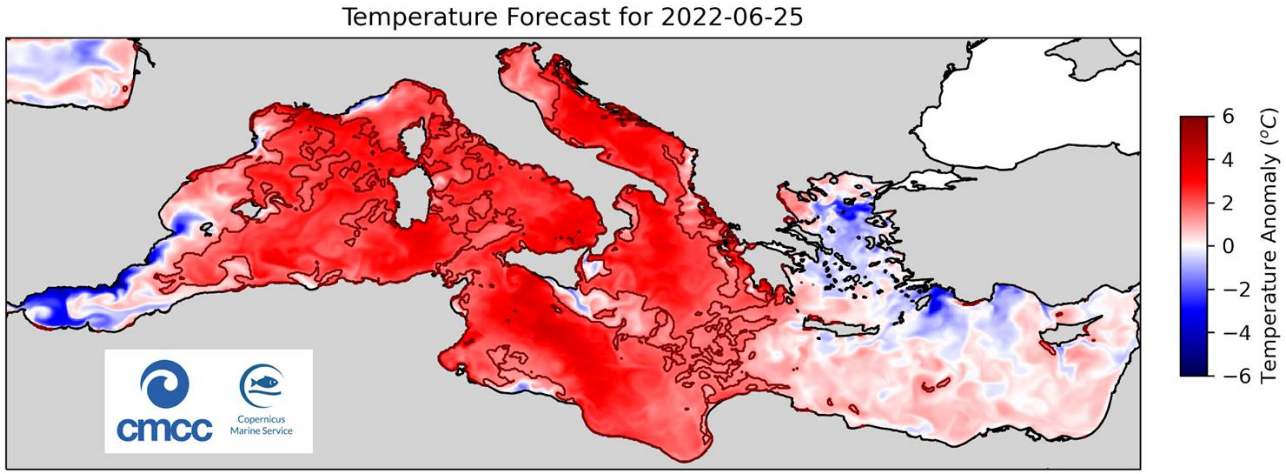
EuroSea

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862626

But first…the news





MHW currently taking place in the Med

- Two tropical-African anticyclones
- Initiated in May
- 5°C anomalies
- Spreading eastward

https://www.cmcc.it/article/marine-heat-wave-in-the-mediterranean-observations-and-predictions

Overview of our EuroSea work

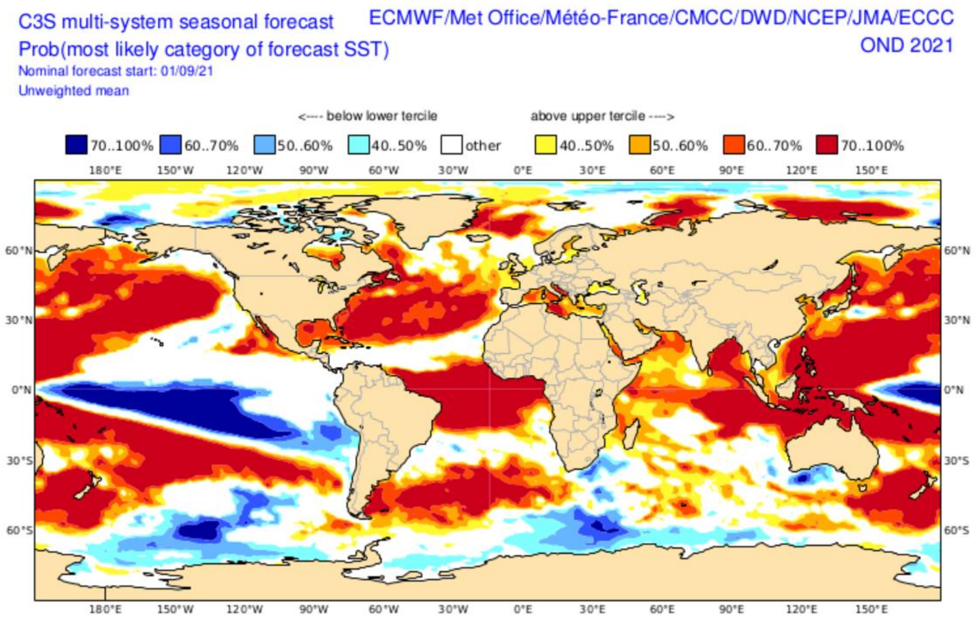
Climate Change Service

CMCC & ECMWF work in EuroSea:

- Validate essential ocean variables in seasonal forecasts systems
- Define and produce user-relevant indicators e.g. Marine Heat Waves (MHWs)
- Move towards operational marine seasonal forecasting!

Parameters

- [ ] MSLP (9)
- [ ] SST (18)
- [ ] T2m (9)
- [ ] T850 (9)
- [ ] geopotential height 500hPa (9)
- [ ] precipitation (9)
- [ ] zonal wind 10hPa (6)



❑ Sub-surface T

❑ OHC

❑ SLA

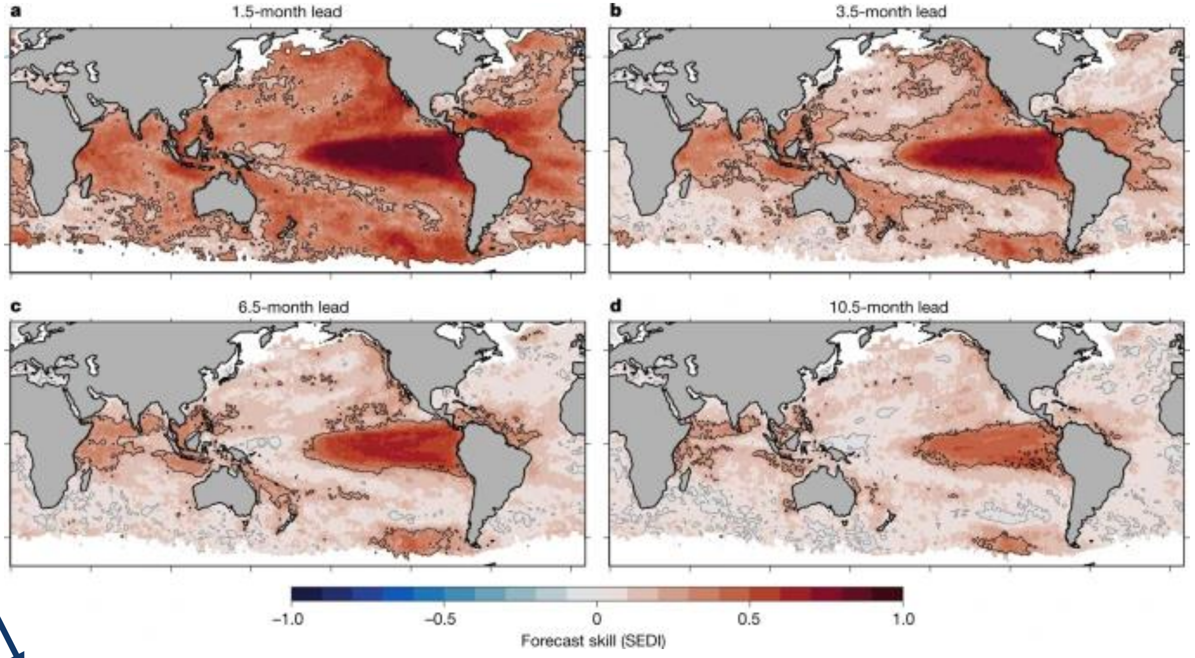
❑ MHWs

Aims: Seasonal Forecasting of MHWs

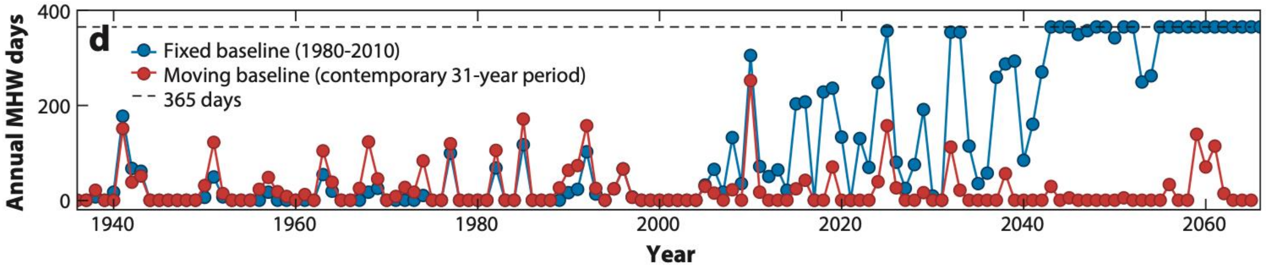
Questions to answer:

- Are MHWs well predicted?
- Focus on precision or propensity?
- Climatology: do we use fixed or moving?
- How much forecast skill comes from the warming trend?
- Are subsurface MHWs more useful and more predictable?

(Jacox et al, 2022):
Global forecast skill of surface MHW occurrence



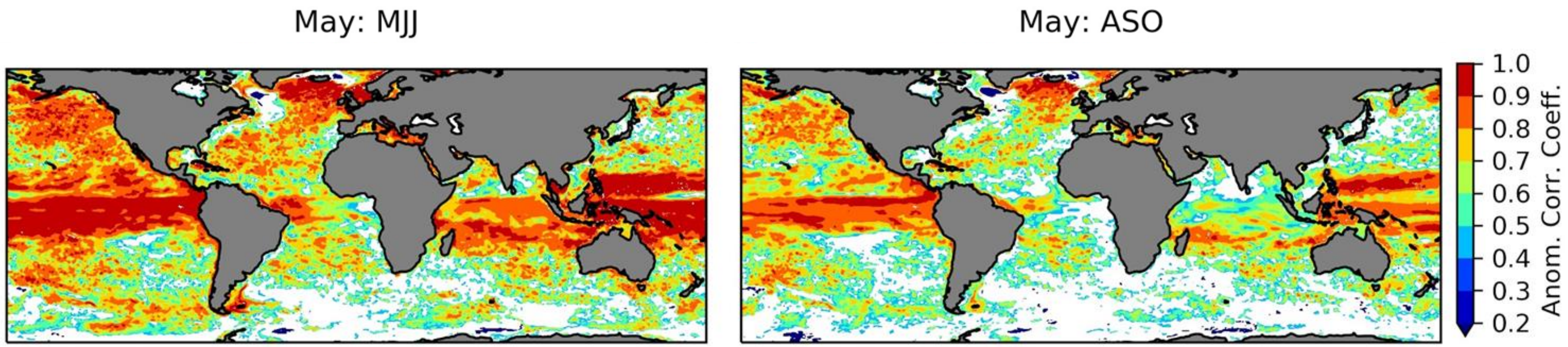
(Oliver et al, 2021): Long-term simulations in N. Pacific



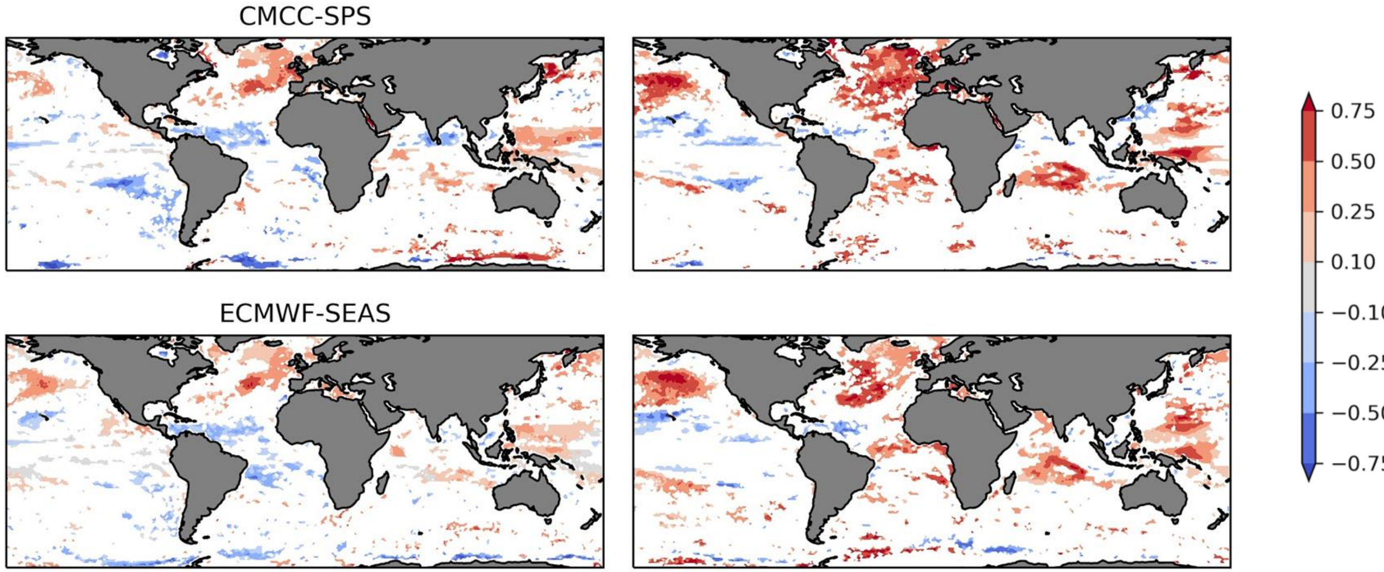
Work done so far: OHC anomaly forecasts

Seasonal forecast skill of upper-ocean heat content in coupled high-res systems
McAdam, Masina, Balmaseda, Gualdi, Senan, Mayer. Jan 2022, Climate Dynamics

OHC 0-300m validated against global reanalysis (top): skill late into forecast period in a range of dynamical environments.



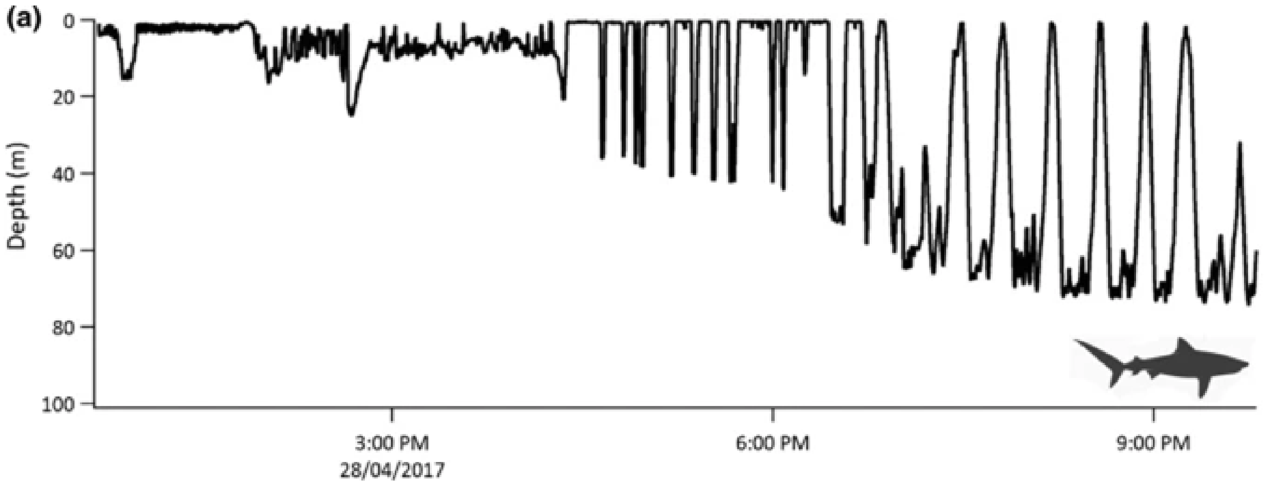
Difference between OHC and SST forecast skill (bottom):
OHC forecasts are more skillful than SST in many regions, typically because OHC anomalies are more persistent.
White=not statistically significant.



Method: Defining subsurface MHWs

To define MHWs, let's start using ocean heat content (OHC) alongside SST:

- Upper-1cm of the ocean may not be so practically useful
- Daily cycle of many species covers a range of depths: resting, foraging, escaping heat…
- *Caveats: coverage of subsurface observations, quality of reanalysis, non-existent forecast data*

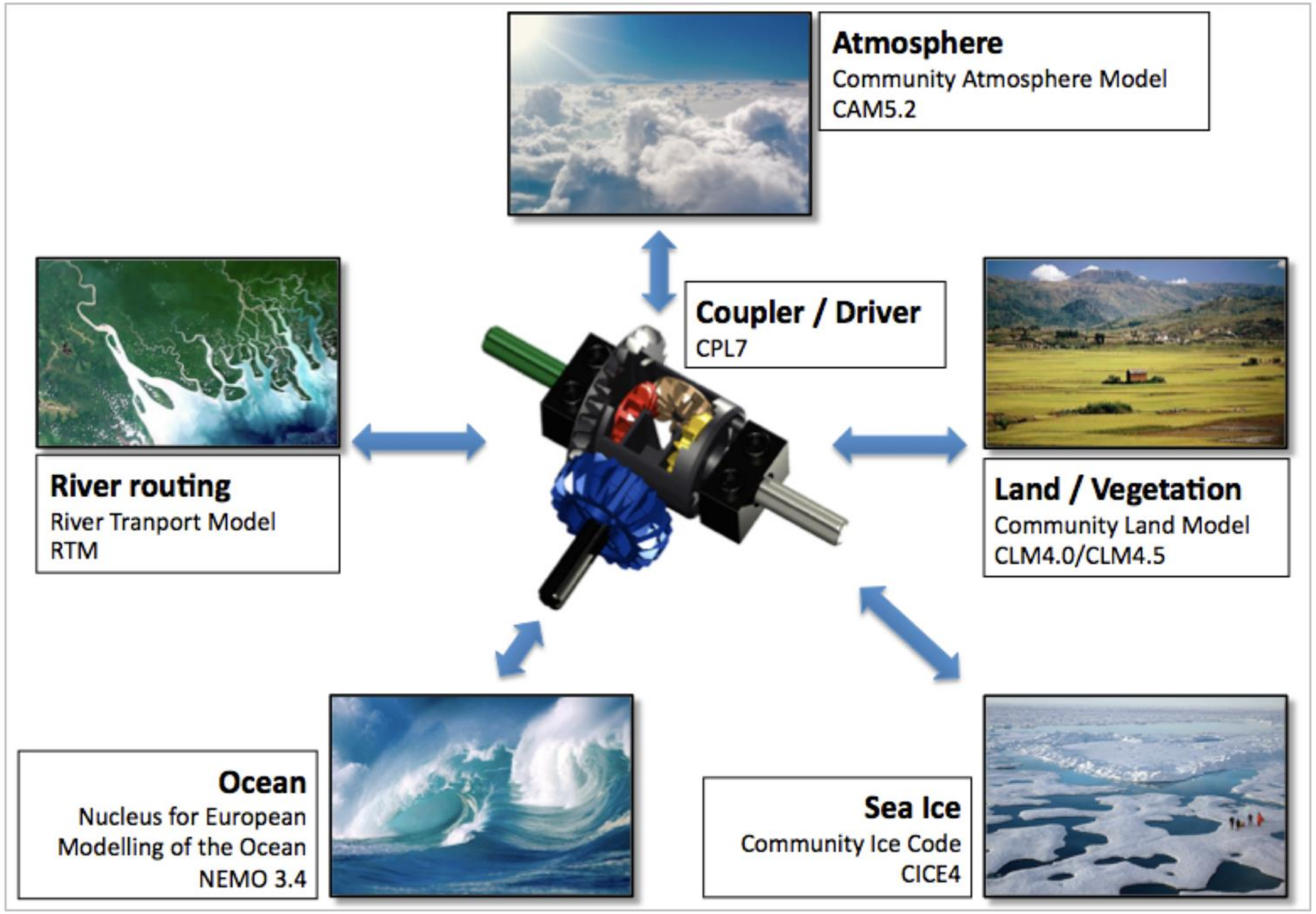


(Andrzejaczek et al, 2019): Daily vertical motion of a tiger shark in the Ningaloo Reef, Western Australia.

In this work, we:

1. Define subsurface MHWs using OHC 0-40m
2. Validate forecast systems against reanalysis
3. Compare prediction skill of subsurface and surface MHWs

Re-forecasts from CMCC-SPS3.5



	CMCC-SPS3.5
Re-forecast period	1993-2016 (for OHC)
Ensemble	40
Forecast period	6 months
Coupler	CPL7
Atmosphere	
Model	CAM
Horizontal Resolution	0.5°
Vertical Resolution (top)	45 levels (0.3 hPa)
Initialisation	ERA-Interim
Ocean	
Model	NEMO v3.4
Horizontal Resolution	0.25° tripolar grid
Vertical Resolution	50 levels
Initialisation	C-GLORS v6

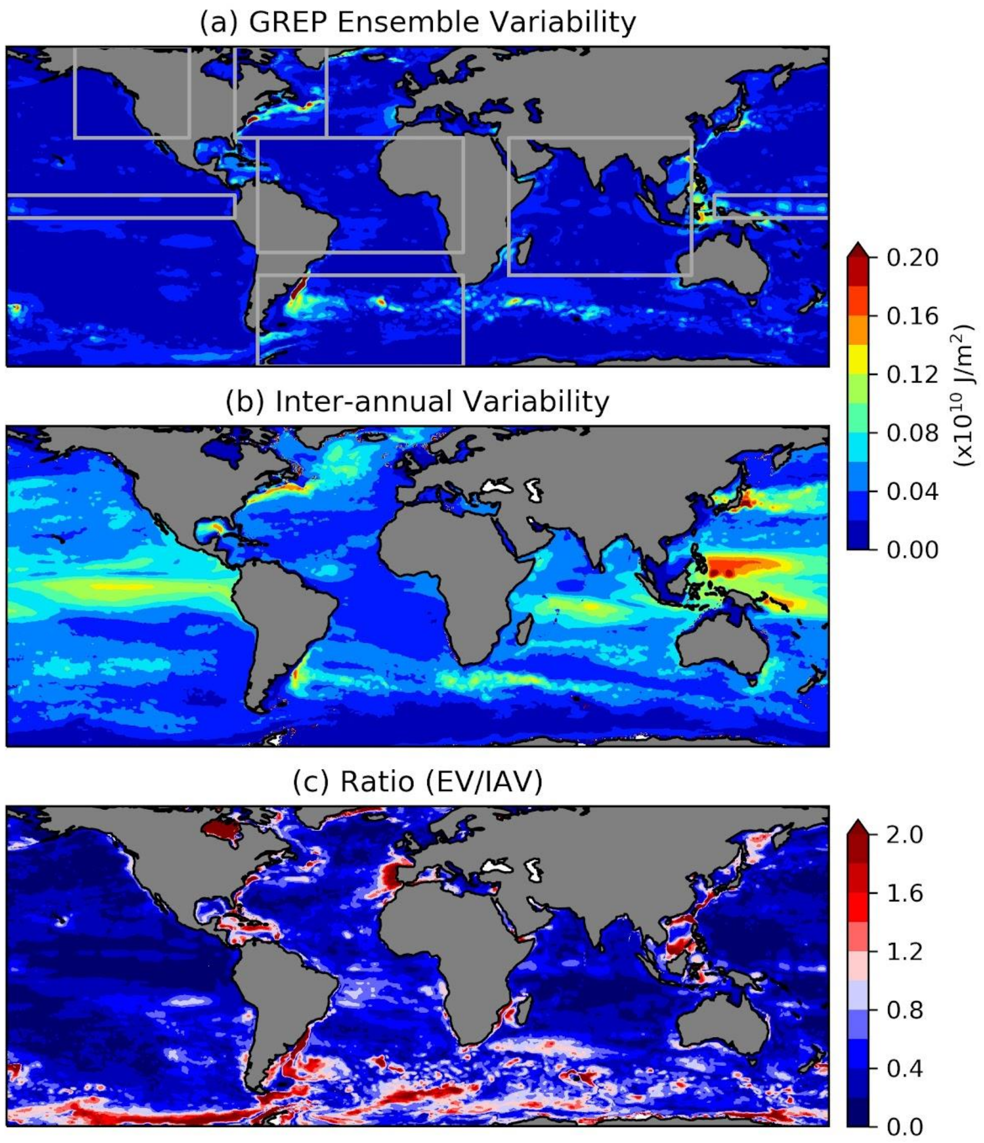
Validation: GREP

Global Reanalysis Ensemble Product (GREP) details

Name	C-GLORSv7	FOAM	GLORYS2V4	ORAS5
Institution	CMCC	UK MetOffice	CMEMS	ECMWF
Horizontal resolution	0.25°	0.25°	0.25°	0.25°
Vertical resolution	75 z-levels	75 z-levels	75 z-levels	50 z-levels
Surface fluxes	CORE	CORE	CORE	CORE + wave forcing
Atmospheric forcing	ERA-Interim	ERA-Interim	ERA-Interim	ERA-Interim until 2014 ECMWF NWP after 2014
Ocean–sea ice model	NEMO3.2-LIM2	NEMO3.2-CICE	NEMO3.1-LIM2	NEMO3.2-LIM2
DA variables	SIC, Arctic SIT, T, S, SSH, SST	SIC, T, S, SST, SSH	SIC, T, S, SST, SSH, runoff	SIC, T, S, SST, SSH
DA sources	OIv2d, PIOMAS, EN4, AVISO	OSISAFv2, EN4, ICOADS, AVHRR, ATSR, AMSRE, AVISOv3	CERSAT, CMEMS, AVHRR	OSTIA, OIv2d, EN4, AVISO

Right: Ensemble spread of OHC0-300m compared to physical variability

Ocean reanalyses agree amongst themselves across most of the ocean (see EV/IAV), exceptions in red!



Method: Defining MHW Indicators

Climatology: Daily Averaging
Climatology/thresholds determined with an 11-day moving window (Hobday et al, 2016).

Climatology: Smoothing
Polynomial regression (Prodhomme et al, 2021; Mahlstein et al, 2015)

(Hobday et al, 2016)

Adapted methodology

MHW Detection Algorithm
90^{th} percentile threshold
MHWs >= 5 days, short gaps included (<2 days)

MHW Characteristics
For each event: Duration, Intensity, Strength/Category

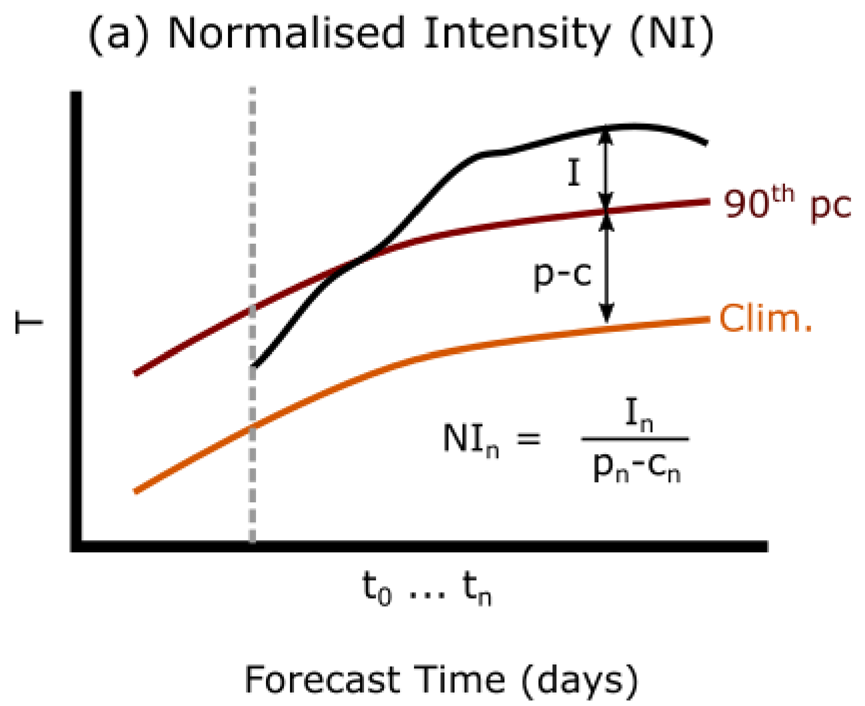
MHW Forecast Indicators
For each target season: number of MHW days & strongest intensity

Summer MHWs only, over 3.5 month period
Northern Hemisphere: from mid-May to Feb
Southern Hemisphere: from mid-Nov to Feb

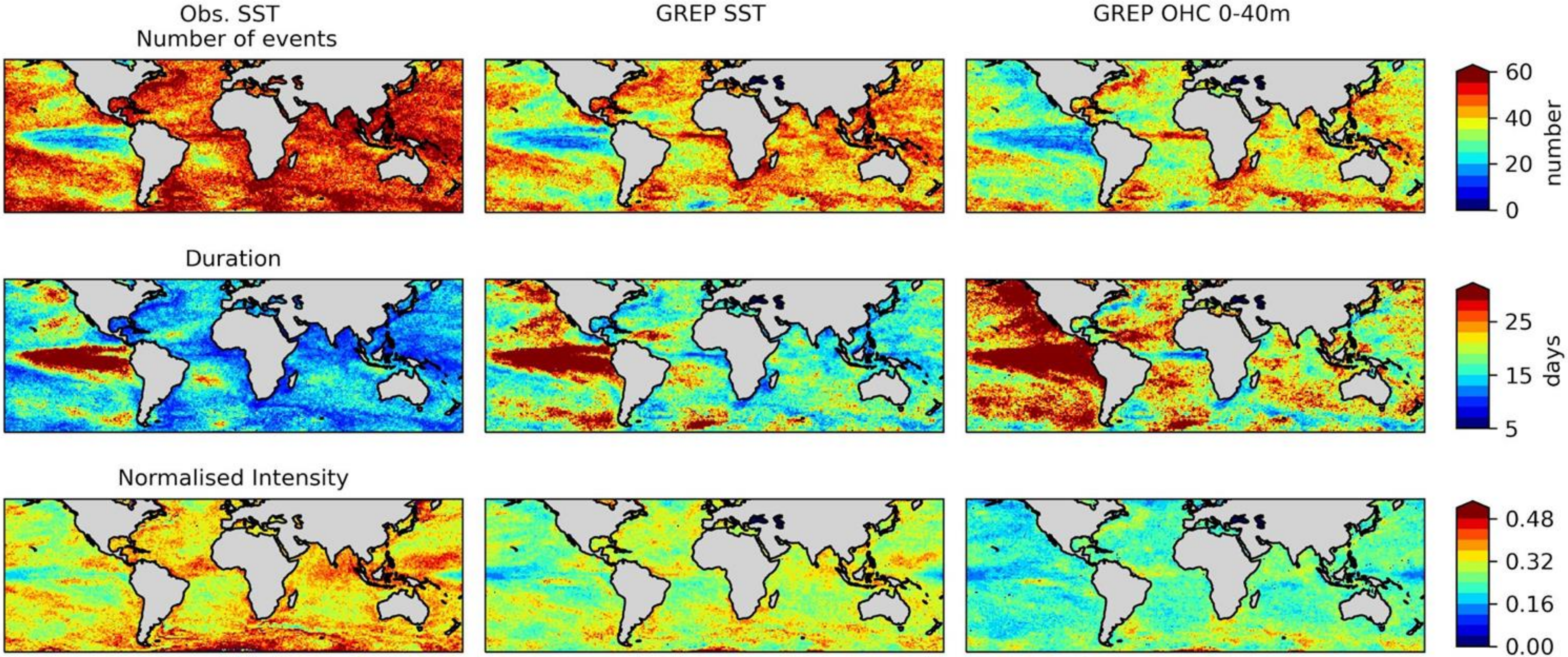
Method: Defining MHW Indicators

Using a normalised intensity (sometimes called “strength” or, in it’s discretised form, “category”:

- Highlights exceptionality of an event (i.e. a 2°C intensity may be considered a different category depending on the area).
- Allows us to compare MHWs defined by SST and MHW



Results: Mean MHW characteristics (1993-2016)

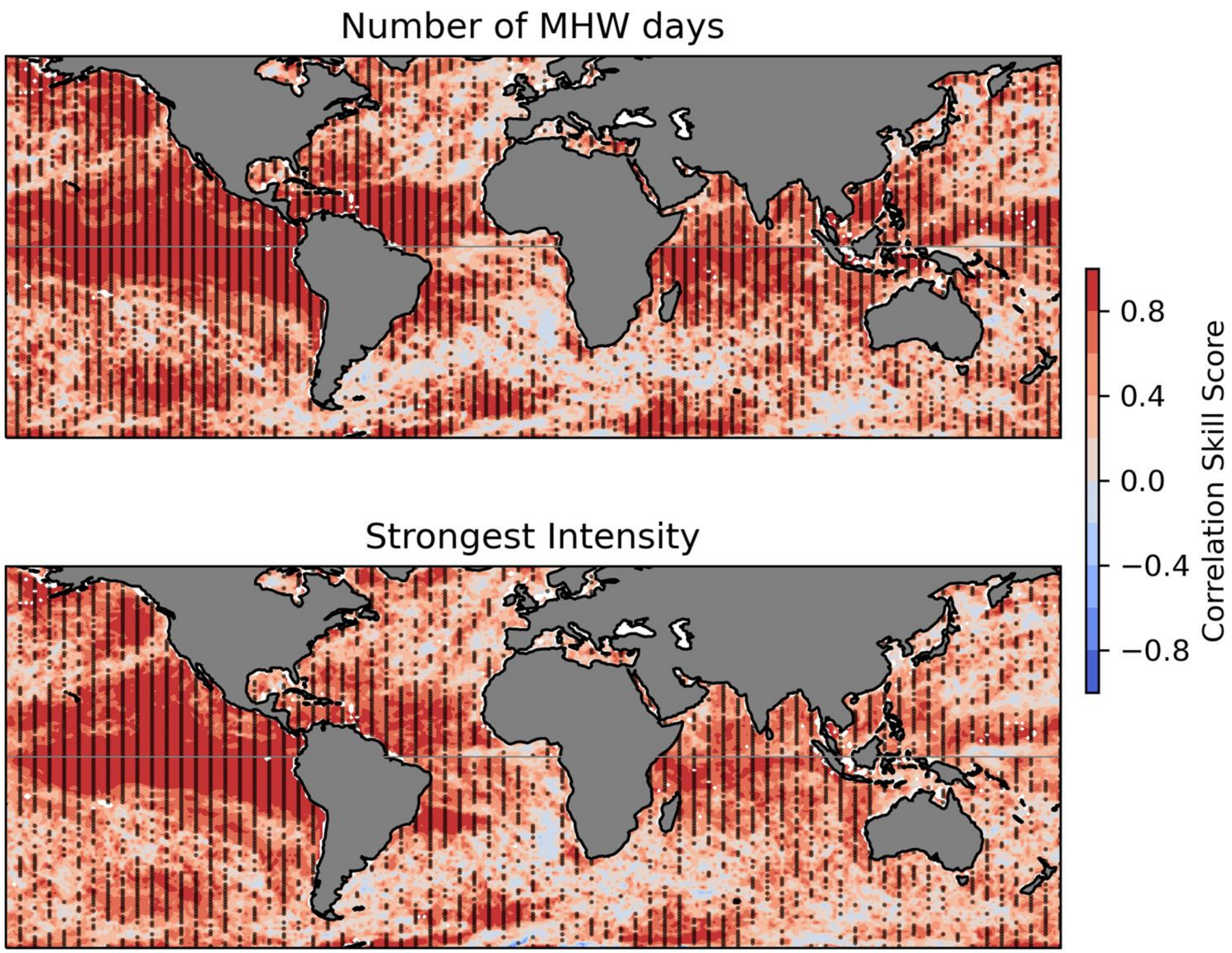


Results: Skill of subsurface MHW forecasts

Correlation between number of MHW days/strongest intensity MHW in the summer season for SPS3.5 and GREP.

Black stippling: statistical significance.

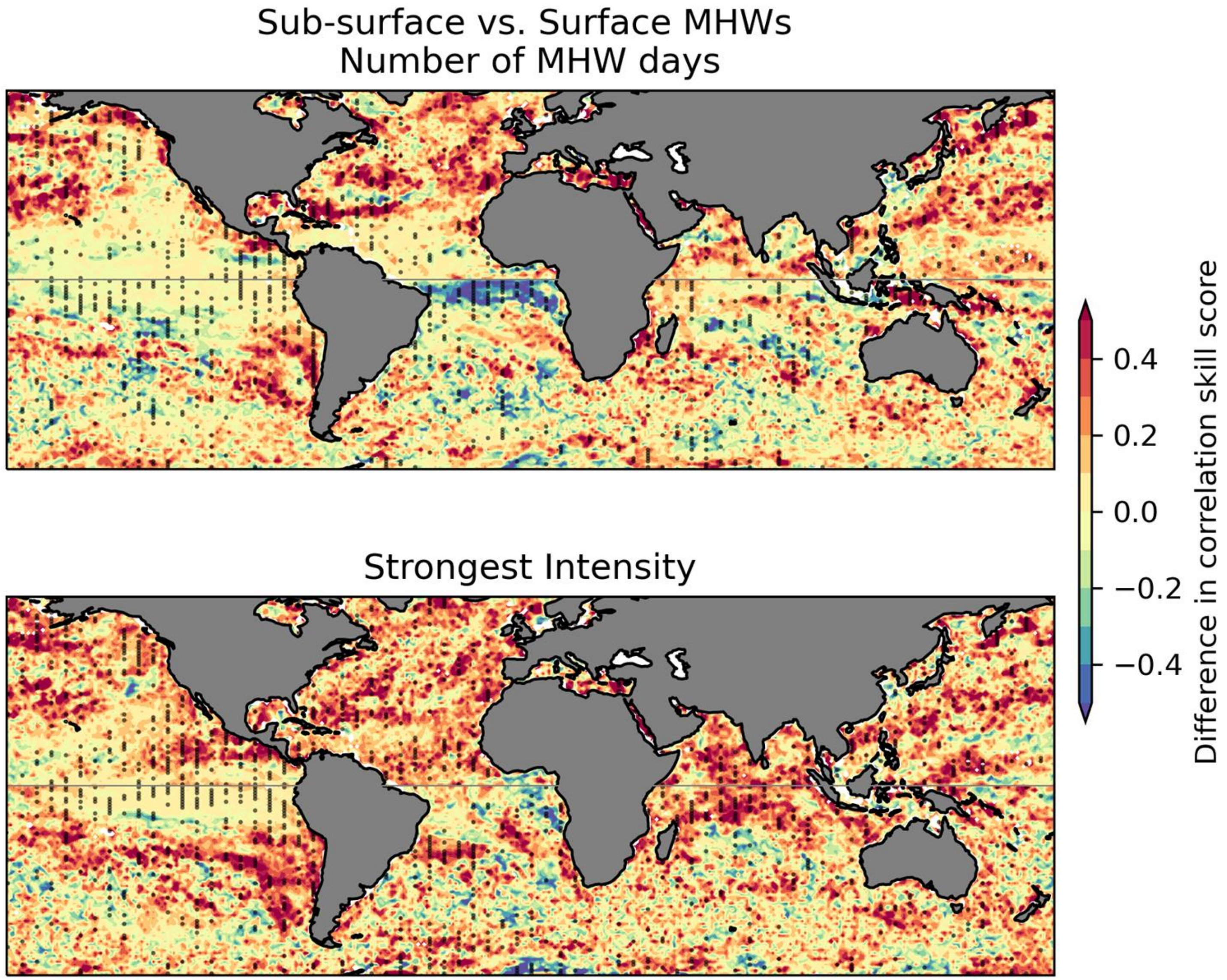
- Widespread skill in two seasonal MHW indicators.
- Where the duration is well captured, so is the intensity.
- Regions of poor skill linked to forcings?



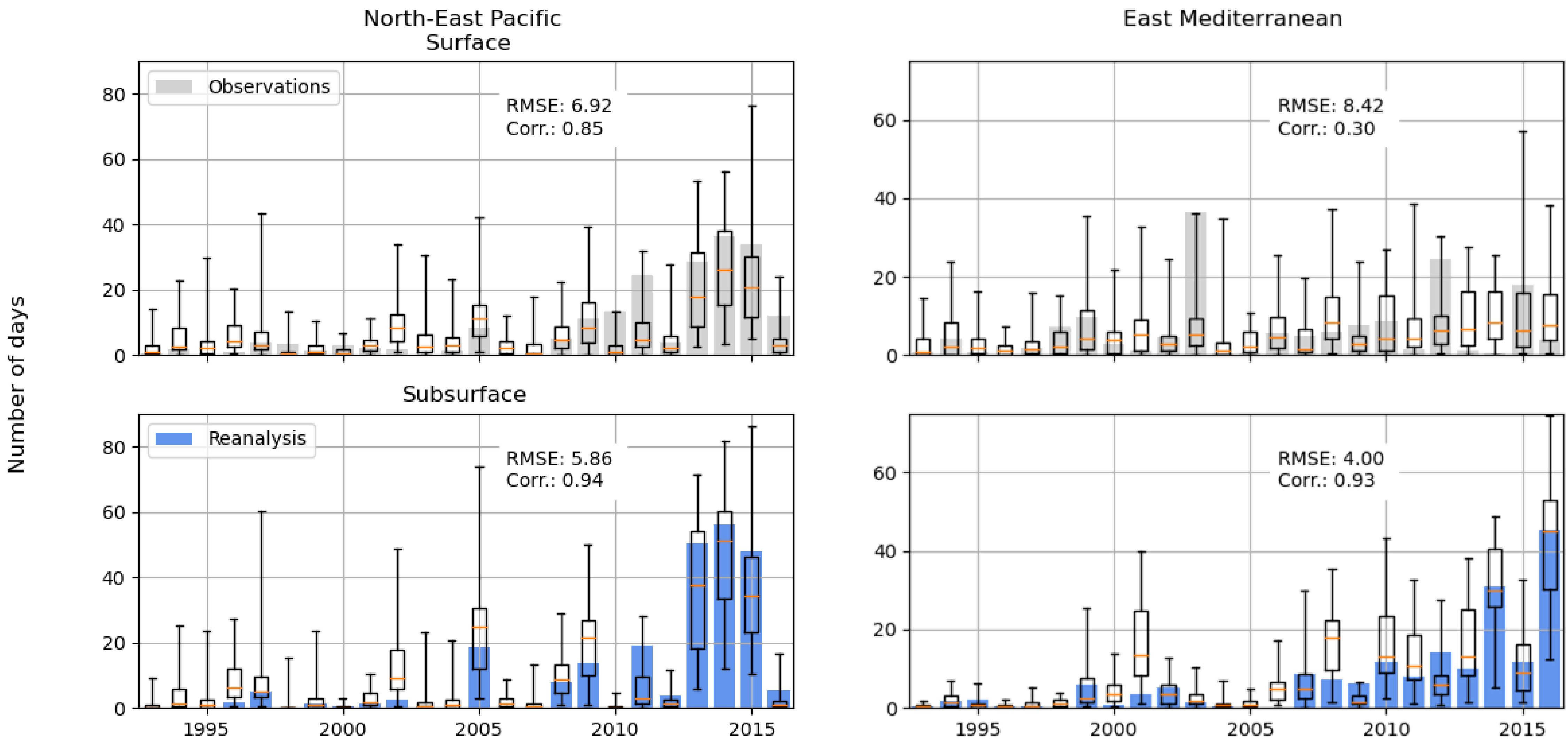
Results: Comparison to surface MHW forecasts

Black stippling: statistical significance in difference.

- Subsurface skill is generally higher.
- Regions of similarity are those where skill is high.
- Increase in skill is more widespread in intensity.
- Where the duration is well captured, so is the intensity.



Results: Subsurface MHW Predictions in Practice



Take-home messages

(1)
OHC should be considered as a complementary MHW indicator to SST

(2)

The historical MHW record looks quite different for subsurface events - are we missing big events by focusing on SST?

(3)

Seasonal forecasts predict subsurface events with greater skill than surface events.
The longer-duration and slow-changing nature of subsurface MHWs is easier to predict.

(4)

More subsurface monitoring would help event tracking and, in the long run, boost validation reliability.
Extending seasonal forecast record of “unused” marine variables would help too!

References

https://www.cmcc.it/article/marine-heat-wave-in-the-mediterranean-observations-and-predictions

Andrzejaczek, S., Gleiss, A.C., Pattiaratchi, C.B. and Meekan, M.G., 2019. Patterns and drivers of vertical movements of the large fishes of the epipelagic. *Reviews in Fish Biology and Fisheries*, *29*(2), pp.335-354.

Hobday, A.J., Alexander, L.V., Perkins, S.E., Smale, D.A., Straub, S.C., Oliver, E.C., Benthuysen, J.A., Burrows, M.T., Donat, M.G., Feng, M. and Holbrook, N.J., 2016. A hierarchical approach to defining marine heatwaves. *Progress in Oceanography*, *141*, pp.227-238.

Jacox, M.G., Alexander, M.A., Amaya, D., Becker, E., Bograd, S.J., Brodie, S., Hazen, E.L., Pozo Buil, M. and Tommasi, D., 2022. Global seasonal forecasts of marine heatwaves. *Nature*, *604*(7906), pp.486-490.

McAdam, R., Masina, S., Balmaseda, M., Gualdi, S., Senan, R. and Mayer, M., 2022. Seasonal forecast skill of upper-ocean heat content in coupled high-resolution systems. *Climate Dynamics*, *58*(11), pp.3335-3350.

Oliver, E.C., Benthuysen, J.A., Darmaraki, S., Donat, M.G., Hobday, A.J., Holbrook, N.J., Schlegel, R.W. and Sen Gupta, A., 2020. Marine heatwaves. *Annual Review of Marine Science*, *13*, pp.1-30.

Sanna et al, 2017, RP0285 – CMCC-SPS3: The CMCC Seasonal Prediction System 3

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