Supporting material to EGU 2022 presentation 5694 Session OS1.7

Extremely Warm European Summers driven by Sub-Decadal North Atlantic Heat Inertia

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Link to presentation and additional material:

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International Max Planck Research School on Earth System Modelling

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MAX-PLANCK-INSTITUT FÜR METEOROLOGIE

Sub-Decadal Variability & Heat Extremes
Introduction

- summer temperatures increased by ~1.5°C, largely associated with anthropogenic GHG-concentrations, but overlaid by internal variability of 3-3.5°C [Suarez-Gutierrez et al., 2020]
- mechanisms explaining the internal variability of mean summer temperatures have been found on seasonal to sub- and multi-decadal timescales [e.g. Müller et al., 2020, Ghosh et al., 2016]
- their contribution to **extremes variability** is not fully established

- we investigate the **sub-decadal** (5-10yr) variability of European summer heat extremes and their potential drivers
- Max-Planck-Institute Grand Ensemble (**MPI-GE**)
- **summer means** (JJA) from 1950-2022 (GE Hist + RCP4.5)

Sub-Decadal Variability & Heat Extremes

- calculation of **dominant time frequencies** with cross-spectral analysis based on the multi-taper method [Årthun et al., 2016]
- to link the previous finding to heat extremes, we calculate the ratio between all heat extremes and heat extremes on **sub-decadal time scales**

strong agreements between model and reanalysis, but Central Europe stands out in particular

—> this defines region of interest for further analysis

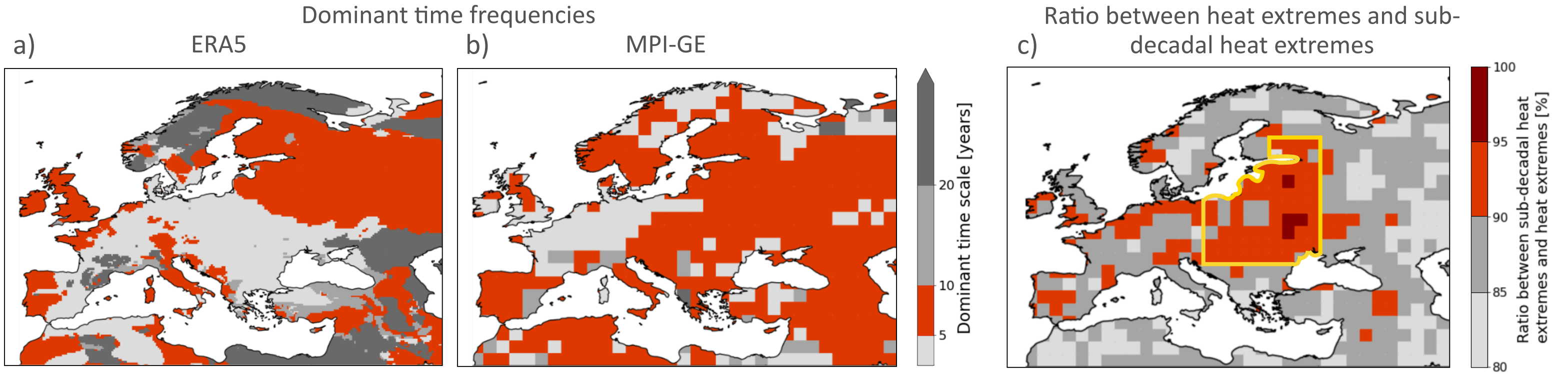


Fig. 1: Dominant time frequencies and their relation to heat extremes. (a),(b) Cross-spectral analysis, performed using the multi-taper method, showing the dominant time scales of European temperature variability in (a) ERA5 and (b) MPI-GE. Color shading in [years]. (c) Ratio between heat extremes (T>90th perc.) and heat extremes on sub-decadal time scales (T>90th perc. and $T_{bandpass}$>0). This means we define 720 heat extremes as the maximum number of extremes, this number is given by the 90th percentile of our used time series (72 years x 100 ensemble member), and calculate the ratio with heat extremes which exceed the 90th percentile and are in a positive bandpass-filtered phase. Color shading in [%]. Period 1950-2020.

Sub-Decadal Variability & Heat Extremes

- North Atlantic has high impact on weather/climate conditions over Europe
- especially for sub-decadal processes the memory for several years cannot reside from the atmosphere, whereas oceans can show such a memory

high anomalies between the 5-10y bandpass-filtered heat flux and heat extremes especially in the western and northern part of the North Atlantic —> warming of the atmosphere

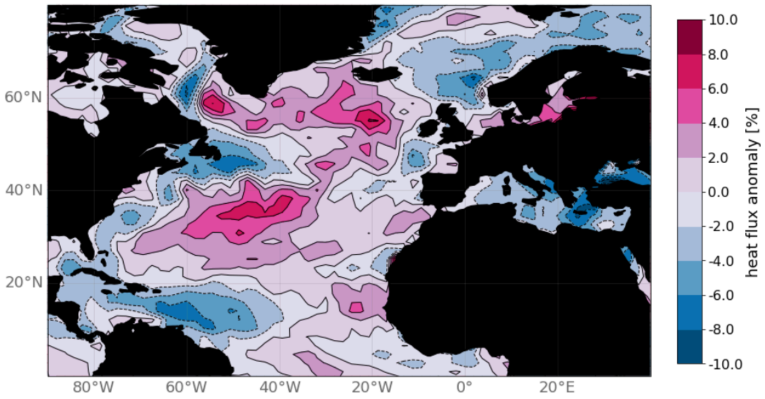


Fig. 2: Composites as fraction of variability between 5-10yr bandpass-filtered Atlantic heat flux (latent + sensible) variability and total Atlantic heat flux variability in MPI-GE for different lags prior to heat extremes. Positive values indicate heat flux into the atmosphere. Values in percent. Dots denote significance at a 95% confidence level. Period 1950-2022.

Contribution of the North Atlantic

Barotropic Stream Function

… transition from a weak to a strong **barotropic stream function**.

… at lag 0 an intensification and northward shift of **North Atlantic current**.

Ocean Heat Content

… positive anomalies along **North Atlantic current** around 40°N —> accumulation of **ocean heat content**.

… spatial location of **ocean heat content** anomalies matches with **heat flux** anomalies

Ocean Heat Transport

… **MOC ocean heat transport** intensifies around 20°N around two years prior heat extremes.

… accumulated heat is released at lag 0, mainly by the **sub-polar gyre heat transport**.

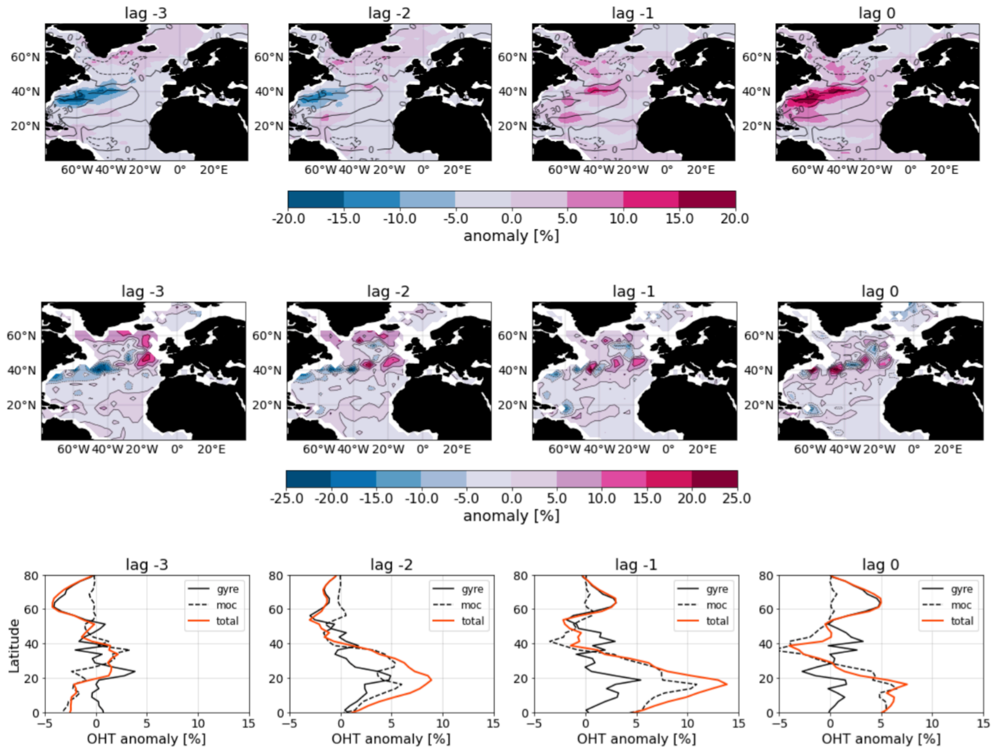


Fig 3: Heat extremes and their relation to ocean quantities. Barotropic Stream Function, Ocean Heat Content, and Ocean Heat Transport. Composites as fraction of variability between 5-10yr bandpass-filtered variability and total variability in MPI-GE for different lags prior to heat extremes. Period 1950-2022.

Atmospheric Pathway
- Vertical Temperature, Sea Level Pressure, and Jet Stream

- warming of tropospheric high latitudes and cooling of lower latitudes leads to **reduction in wind shear**
- **northerly position** as well as a **weakening of the jet stream**, favoring **stationary weather conditions** and the advance of **subtropical air masses**

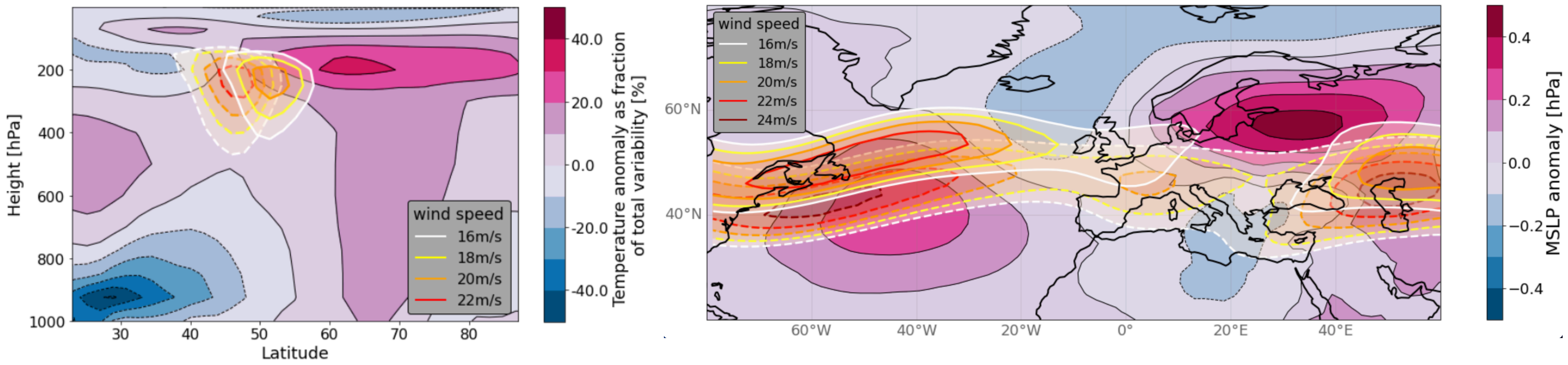


Fig 4: Heat extremes and their atmospheric pathway. a) Composites as fraction of variability between 5-10yr bandpass-filtered temperature variability and total temperature variability in MPI-GE for different lags prior to heat extremes. b) Composite means between 5-10yr bandpass-filtered mean sea level pressure in years showing European heat extremes subtracted by mean sea level pressure mean of all other years in MPI-GE, values given in hPa. The orange contour lines indicate the position of the jet stream (given by the mean zonal wind speed over 200-300hPa) averaged over years showing European heat extremes (solid line) and years showing no heat extremes (dashed line), values given in m/s. Period 1950-2022.

Sub-Decadal Variability & Heat Extremes
Summary & Outlook

- **We show that anomalies in North Atlantic heat inertia lead to heat extremes over Europe.**
- The spatial location of these **heat flux** anomalies can be linked to anomalies in **barotropic stream function, ocean heat content**, as well as **ocean heat transport** with a certain lag prior heat extremes
- We were able to link **heat extremes** over Central Europe with **atmospheric pathways**, such as **SLP** anomalies and the position of the **jet stream**, with anomalies in the **heat flux** in the North Atlantic.
- The described mechanism is attached to a **full coupled atmosphere-ocean cycle** with 7-10yr period [Martin et al., 2019]

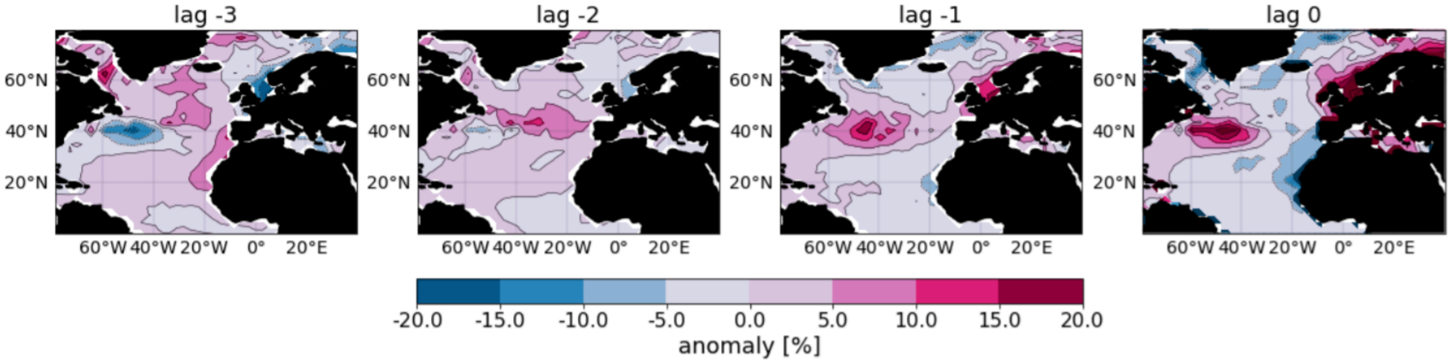
—> Hellmich et al. (in prep.): Extremely Warm European Summers driven by Sub-Decadal North Atlantic Heat Inertia

—> Now predictions: investigate whether these mechanisms in the ocean can also be used to predict heat extremes and thus possibly improve the predictability of European summer temperatures.

Appendix

Sub-Decadal Variability & Heat Extremes
Summary

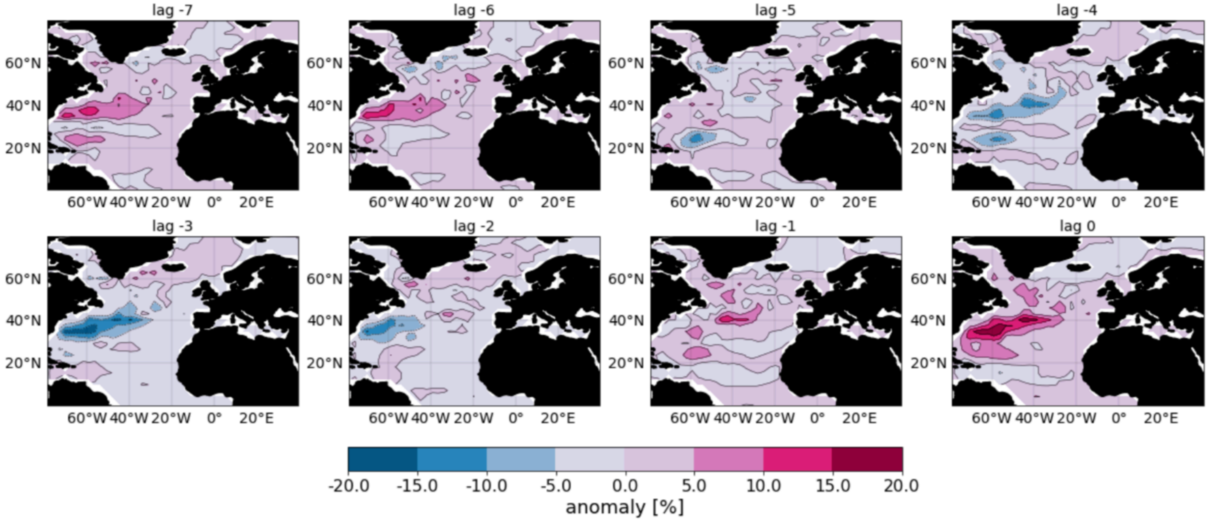
Sea Surface Temperature



Sup. fig. 1: Sea surface temperature. Composites as fraction of variability between 5-10yr bandpass-filtered sea surface temperature variability and total sea surface temperature variability in MPI-GE for different lags prior to heat extremes. Period 1950-2022.

Sub-Decadal Variability & Heat Extremes Summary

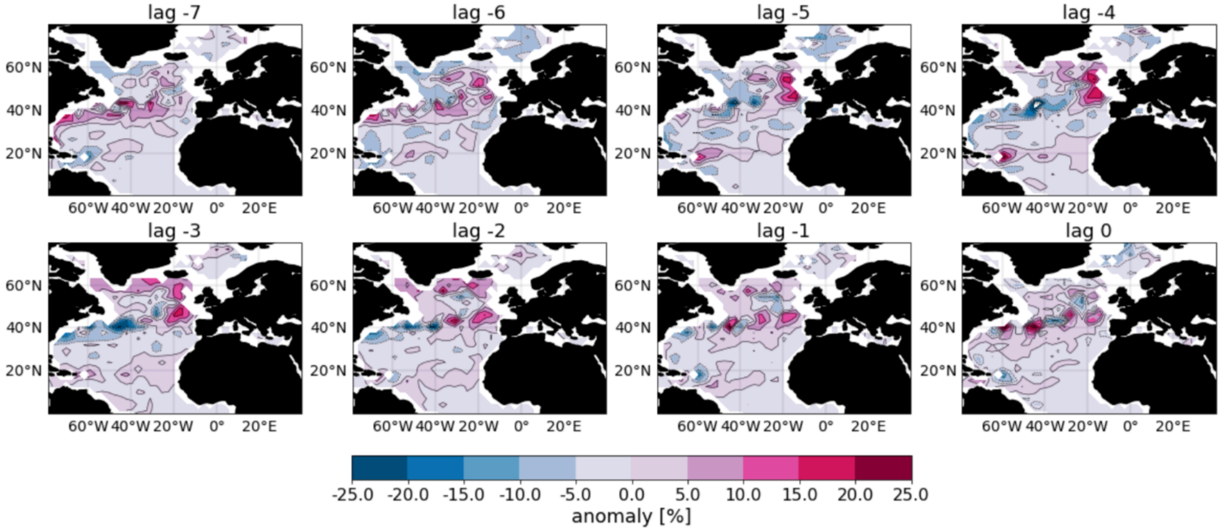
Barotropic Stream Function



Sup. fig. 2: Shift of the barotropic stream function signal. Composites as fraction of variability between 5-10yr bandpass-filtered barotropic stream function variability and total barotropic stream function variability in MPI-GE for different lags prior to heat extremes. Period 1950-2022.

Sub-Decadal Variability & Heat Extremes
Summary

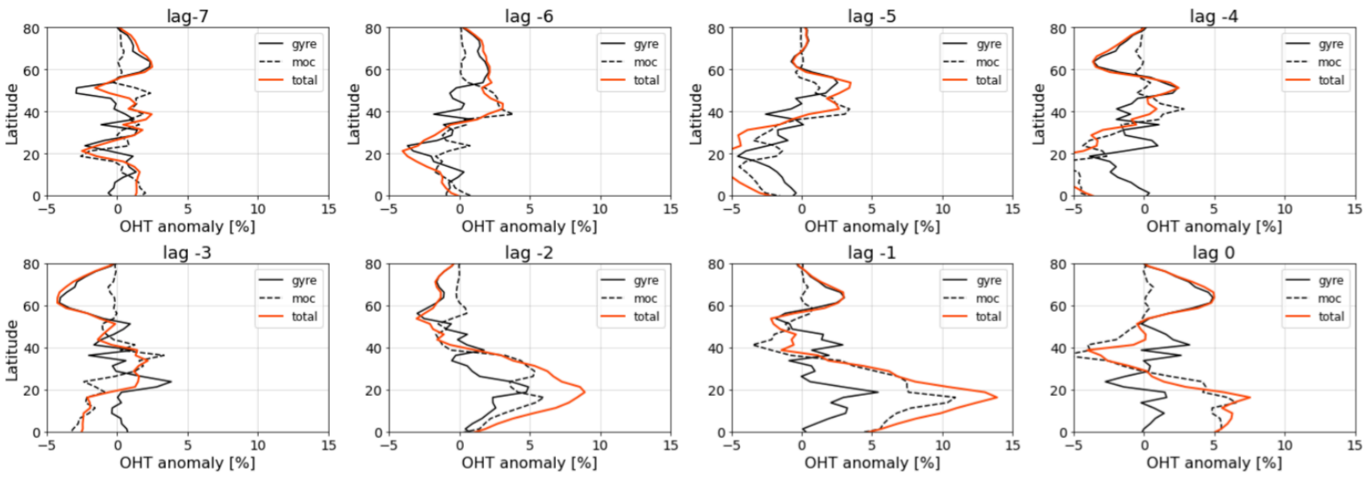
Ocean Heat Content



Sup. fig. 3: Shift of the ocean heat content signal. Composites as fraction of variability between 5-10yr bandpass-filtered ocean heat content variability and total ocean heat content variability in MPI-GE for different lags prior to heat extremes. Period 1950-2022.

Sub-Decadal Variability & Heat Extremes Summary

Ocean Heat Transport



Sup. fig.4: Shift of the ocean heat transport signal. Composites as fraction of variability between 5-10yr bandpass-filtered ocean heat transport variability and total ocean heat transport variability in MPI-GE for different lags prior to heat extremes. Period 1950-2022.