Summer-time Mediterranean amplification to different climate drivers

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The Mediterranean has been identified as one of the most responsive regions to global climate change[1]. In the last decades (1980-2023), the Mediterranean is warming at a rate of roughly 0.48 °C/decade and 0.30 °C/decade in the summer (JJA) and winter (DJF) season, respectively (see **Figure 1**). In summer, is almost 3 times faster than the globally averaged warming trend (see **Figure 2**).

Emission changes and transport pathways of short-lived climate drivers, make it necessary to understand the influence of each climate driver on the Mediterranean. Here we investigate the contribution of different climate drivers to regional warming trends, focusing in the summer (JJA) season. We are analyzing surface and atmospheric temperature trends in simulations from nine climate models participating in the Precipitation Driver and Response Model intercomparison project (PDRMIP)[2]. The PDRMIP model simulations assume idealized and abrupt forcing applied in global scale, specifically: doubling the CO_2 (**co2x2**), 10 times the present-day black carbon (**bcx10**), 5 times the SO_4 (**sulx5**), 3 times the CH_4 (**ch4x3**) and 2% increase in total solar irradiance (**solar**).

The objective is to determine if distinct differences are present in the ways various climate drivers affect the Mediterranean. We achieve this by offering a detailed description of how surface and air temperature in the Mediterranean amplification (mediterranean trend/anomalies divided by the global mean counterpart) differs between the forcers. First, we analyse trends in the ERA-5 reanalysis and we compare ERA-5 results to individual forcing runs in the PDRMIP.

1 Cos et al. (2022), "The Mediterranean Climate Change Hotspot in the Cmip5 and Cmip6 Projections." *Earth Syst. Dynam.*
2 Myhre *et al. (2016),* "Pdrmip: A Precipitation Driver and Response Model Intercomparison Project—Protocol and Preliminary Results." *Bulletin of the American Meteorological Society.*

Mediterranean trends in ERA-5

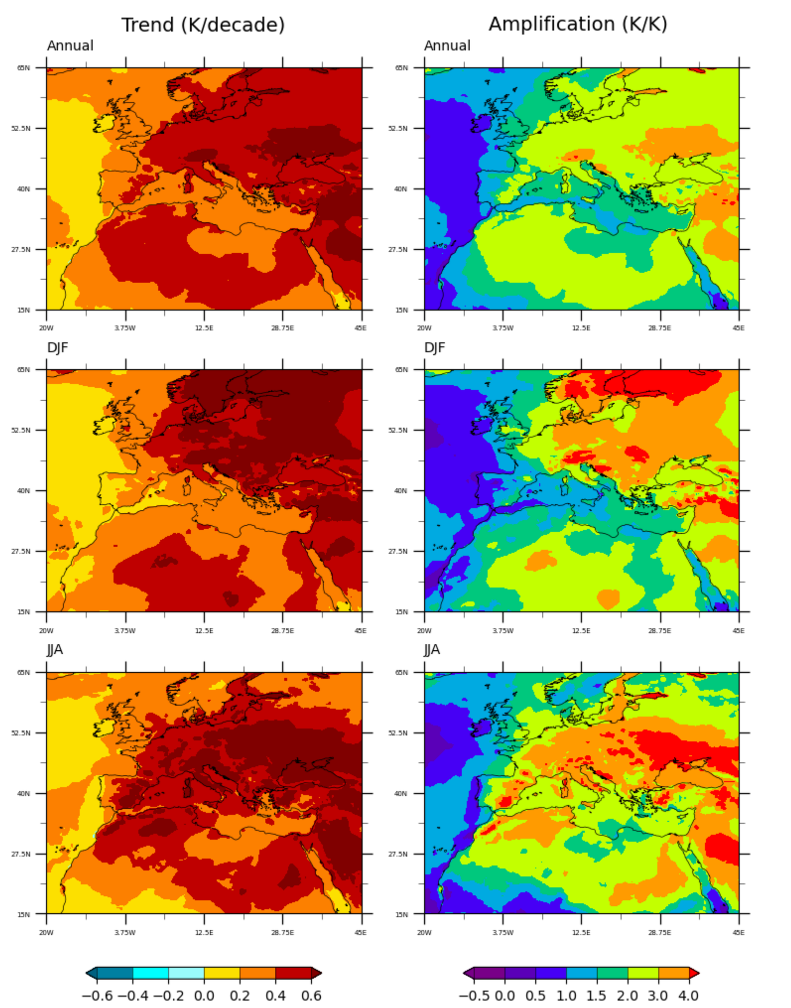

Figure 2 Surface temperature warming trends (left) and amplification (right) in ERA-5 over the period 1980-2023. Top, middle and bottom panels for the annual, winter and summer trends respectively. Units in °C/decade (left panel).

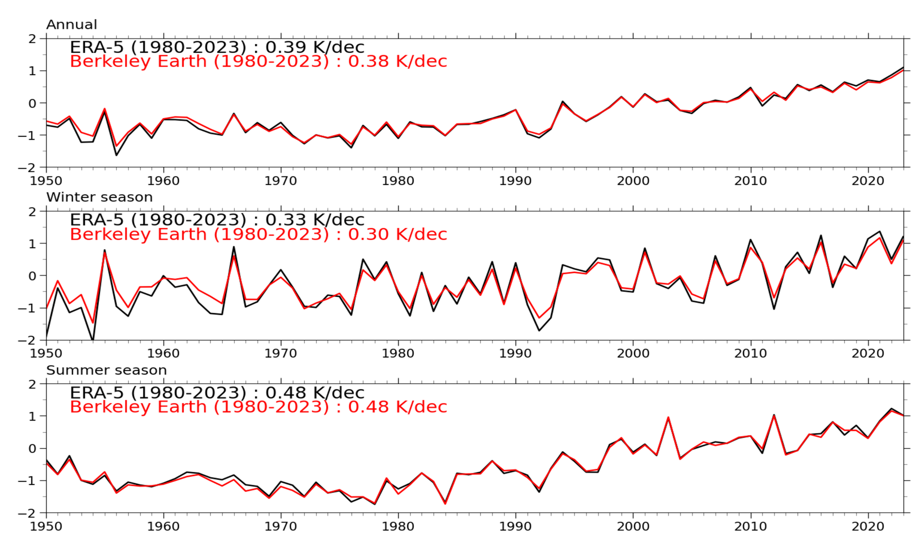

Figure 1 Time series of surface temperature, averaged over the Mediterranean. (top) annual mean, (middle) DJF mean, (bottom) JJA mean. Trends (K per decade) over the period 1980-2023 are mentioned.

Stronger air temperature amplification in July and August.

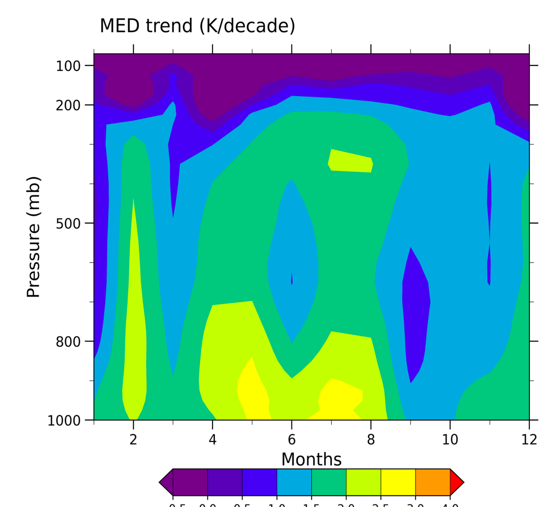

Figure 3 Pressure-time cross sections of the air temperature amplification averaged over the Mediterranean. Stronger amplification is observed in July and August. Negative trends above 200 hPa in all months.

Surface amplification in the PDRMIP simulations

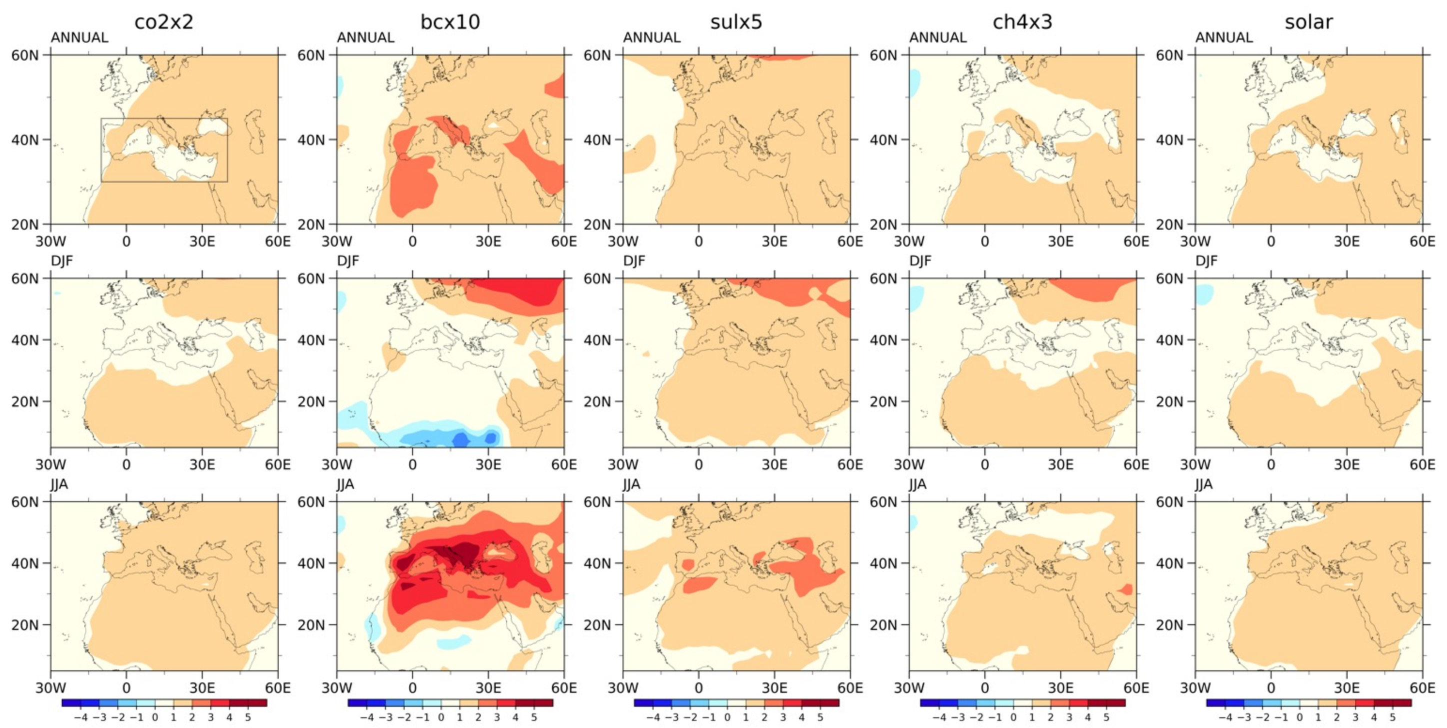

Figure 4 Amplification of surface warming in the ensemble mean PDRMIP models. (top) annual, (middle) DJF, (bottom) JJA for the 5 single forcing simulations. Units in K/K. Note the positive values in sulx5 experiment is due to normalization (increasing sulphates cool the surface).

Stronger MED amplification in summer for Black Carbon

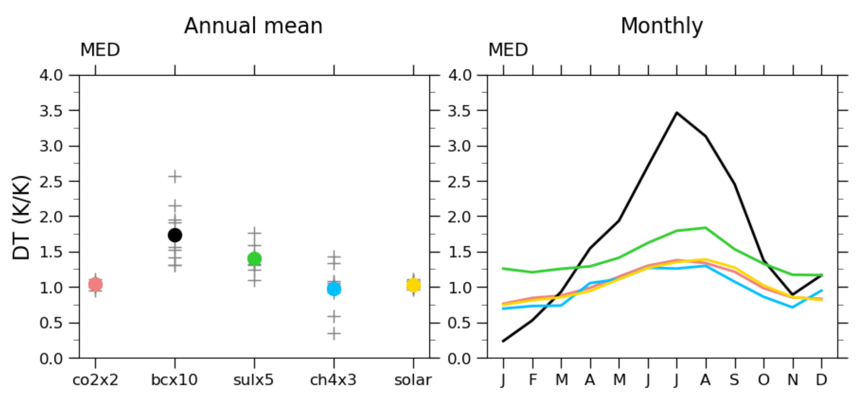

Figure 5 (left) Inter-model spread of the annual amplification in the Mediterranean. Circles for the ensemble mean, crosses for individual models. BC and CH4 show the highest spread. (right) Monthly change of the amplification. Surface warming is stronger in the summer months independently of the forcing. Stronger amplification for Black Carbon. Units in K/K.

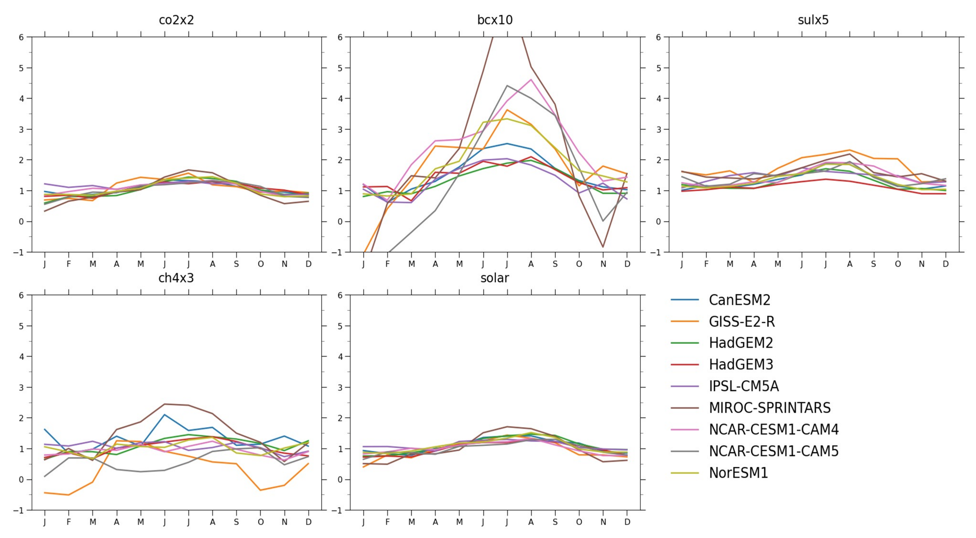

Figure 6 Inter-model spread of the monthly Mediterranean amplification (units K/K) for different forcings. MIROC-SPRINTAS is an outlier.

Air temperature amplification in the PDRMIP simulations

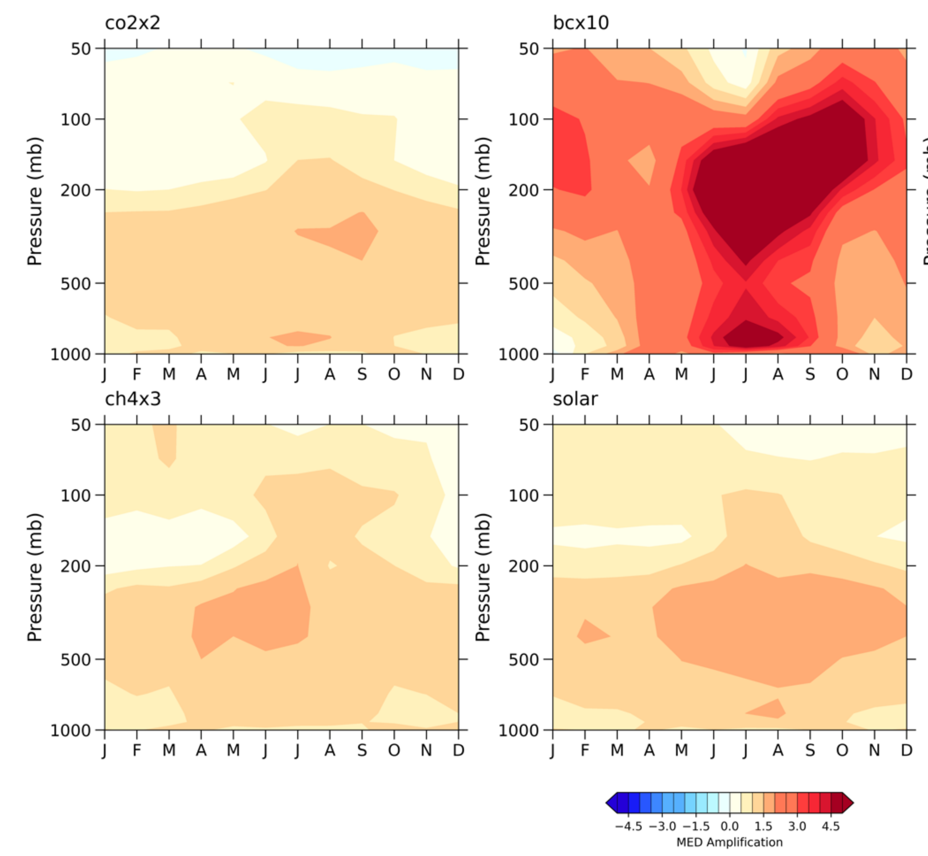

Figure 7 Pressure-time cross sections of the air temperature amplification (units K/K) averaged over the Mediterranean for the different drivers. Note the positive values in sulx5 experiment is due to normalization. Compare with **Figure 3**. Stronger amplification for Black Carbon.

Air temperature amplification: model spread

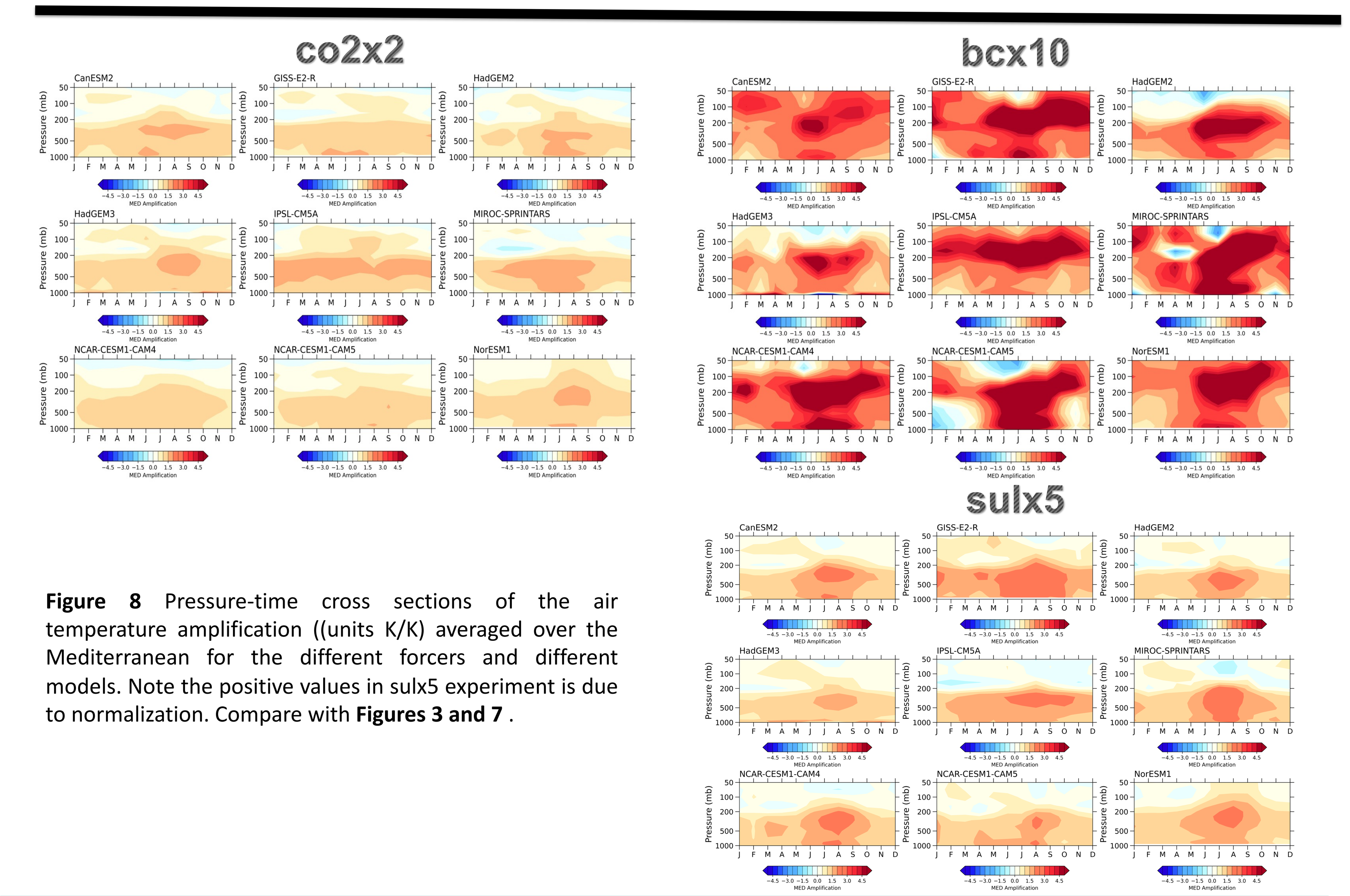

Figure 8 Pressure-time cross sections of the air temperature amplification ((units K/K) averaged over the Mediterranean for the different forcers and different models. Note the positive values in sulx5 experiment is due to normalization. Compare with **Figures 3 and 7** .

Summary

- ✓ The Mediterranean is warming at a rate of roughly 0.48 °C/decade and 0.30 °C/decade in the summer (JJA) and winter (DJF) season, respectively (see **Figure 1**).
- ✓ The stronger air temperature amplification over the period 1980-2023 is found in July and August. Negative trends are found above 200 hPa in all months (see **Figure 3**)
- ✓ The PDRMIP simulations provide evidence for an amplified summer-time warming.
- ✓ Increases in all forcers cause a similar seasonal variation of the temperature amplification, with the highest values during the warm period. Consistent to the surface amplification, the strongest warming in the upper troposphere is found in the June-July-August (JJA) season (see **Figures 4, 5 and 7**).
- ✓ Black Carbon aerosols cause a considerably stronger surface amplification in the JJA season. The air temperature response shows a double peak structure in the lower and upper troposphere and the response spreads to the upper troposphere in September and October (see **Figures 5, 6 and 7**).
- ✓ The spread among the PDRMIP models is low and all show an amplified summer-time warming (see **Figures 6 and 8**).

Models, reanalysis and Methods

We analyse ensemble mean surface and air temperature in coupled simulations from nine climate models the participated to the Precipitation Driver Response Model Intercomparison Project (PDRMIP): CanESM2, GISS-E2-R, HadGEM2, HadGEM3, IPSL-CM5A, MIROC-SPRINTARS, MPI-ESM, NCAR-CESM1-CAM5, and NorESM1. The individual forcings considered by the PDRMIP are: doubling of CO2 concentrations (co2x2), a tripling of CH4 concentrations, (ch4x3), a 2% increase in the solar constant (solar), a 10-fold increase in black carbon concentrations or emissions (bcx10), and a fivefold increase in SO4 concentrations or emissions (sulx5), respectively. All perturbations are instantaneous, and the coupled simulations run for 100 years. We are calculating differences in the last 30 years of the coupled simulations compared to unforced control simulations. Regional anomalies are scaled to global mean anomalies to normalize signals and compare among different forcings and models. We also consider trends in surface and air temperatures in the ERA-5 reanalysis over the 1980-2023 period.

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3) Navarino Environmental Observatory (N.E.O.), Costa Navarino, Greece
4) Mariolopoulos-Kanaginis Foundation for the Environmental Sciences, Greece

The work has been funded by the Public Investment Program of the Greek Ministry of Education, Religious Affairs and Sports.

- PDRMIP -
Precipitation Driver Response Model Intercomparison Project

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