Amplification or dampening of hot extreme temperatures by climate zone

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While global warming is mostly conceptualized in terms of increases in mean temperature, changes in the most extreme conditions encountered often have disproportionate impacts. Hot extremes pose the highest risk for elevated morbidity and mortality as well as for infrastructure and crop failure.

Here, we study warming in the maximum temperature reached each year ($T_{\max}$) as compared to warming in typical summer temperatures, represented by the 80th percentile of daily maxima (T_{80}). We define the amplification factor A as the change in difference between the two over 1970-2020. $A > 0$ implies that hot extremes are warming faster than the summer average (amplification), while negative A implies that hot extremes are warming more slowly compared to the average warming (dampening).

Temperature data are taken from the ERA5 global reanalysis, which combines unprecedented numbers of observations with quality of numerical model and assimilation. Its representation of both mean and extreme temperatures and their trends generally agrees with station data (not shown).

To better grasp patterns in amplification and motivate hypotheses for their causes, we average A by baseline climate zone. Climate zones are delineated based on 1950-1970 ERA5 temperature and precipitation and the Köppen-Trewartha classification (Figs. 1-2).

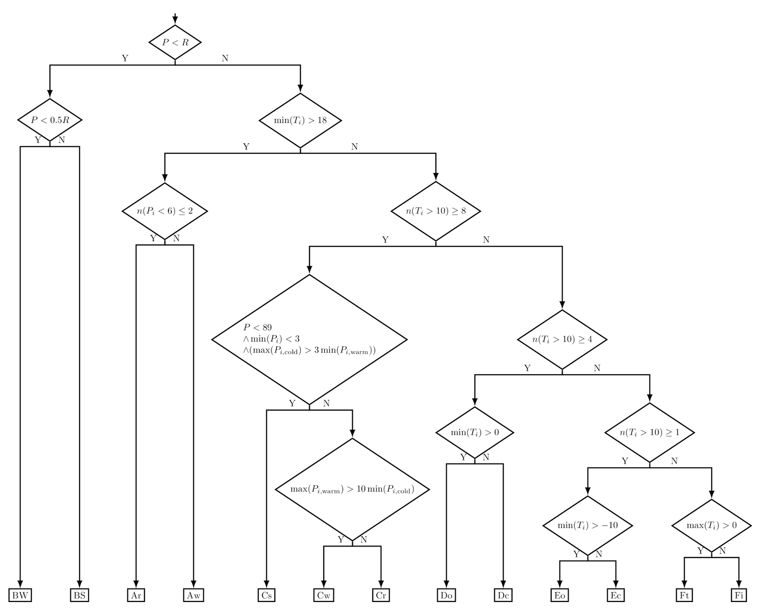

Figure 1. Decision tree for climate zone classification based on 12 monthly mean temperatures T_i (units: °C) and precipitation P_i (units: cm month^{-1}). $P \equiv \sum_1^{12} P_i$ is the annual mean precipitation. R is a precipitation threshold equal to $2.3\bar{T} - 0.64 f_{\text{cold}} + 41$, where $\bar{T}$ is the mean of the monthly temperatures and f_{cold} is the fraction of precipitation occurring during the 6 coldest months. n(criterion) is the number of months per year that meet the criterion. $P_{i,\text{cold}}$ refers to precipitation during the 6 coldest months, while $P_{i,\text{warm}}$ refers to precipitation during the 6 warmest months. Y = yes, N = no. $\wedge$ designates logical "and."

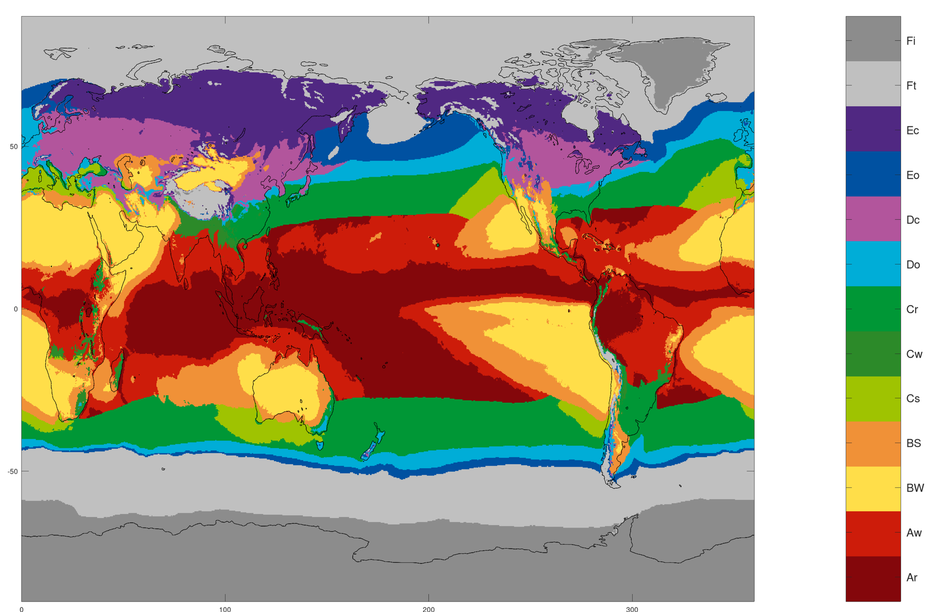

Figure 2. Climate zone classification based on ERA5 temperature and precipitation for 1950-1970.

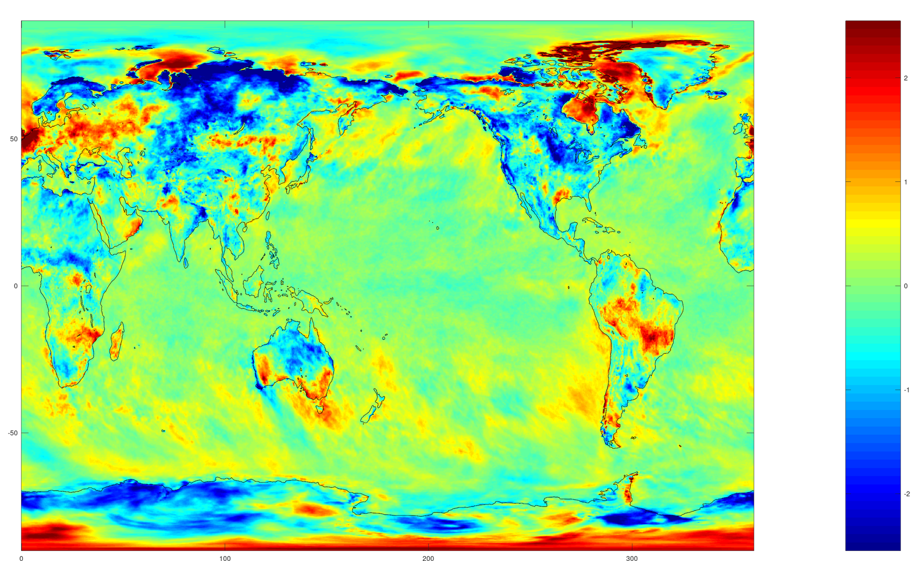

Figure 3. The amplification factor A (warming of $T_{\max}$ minus warming of T_{80}) based on ERA5 for 1970-2020.

	Land	Water
Global mean	−0.23	0.10
Ar	0.14*	0.02
Aw	−0.30	0.04
BW	−0.25	0.07
BS	−0.12	0.04*
Cs	−0.38	0.17
Cw	−0.42	0.15
Cr	−0.30	0.16
Do	0.21*	0.25*
Dc	−0.20	0.04
Eo	−0.41	0.31*
Ec	−0.69	−0.10
Ft	−0.47	0.20*
Fi	−0.38	−0.05

Table. Mean amplification A of extreme temperature over 1970-2020 in ERA5 by climate zone and land/water. Starred differences are significantly different from the respective land/water global mean at the 0.05 level.

Based on the ERA5 reanalysis, over 1970-2020, warming of $T_{\max}$ over land averaged 1.39 K, whereas warming of T_{80} averaged 1.62 K, for a mean A value of -0.23 K (dampening predominates over amplification). However, warming of $T_{\max}$ significantly exceeded warming of T_{80} (implying positive A) in Köppen-Trewartha climate zones Ar (tropical humid) and Do (temperate oceanic) (Fig. 3 and Table). This can be understood in terms of these being zones where abundant water is normally available for evaporation during the hot season, while dry conditions where temperature is more sensitive to radiative forcing are found during rare extremely hot days.

Additional variability in amplification appears to be associated with irrigated areas and possibly also with regional circulation and land use changes. These findings provide a new target for climate model calibration and insight for evaluating the changing risk of temperature extremes.

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