Future amplification of hot extremes due to land-atmosphere interactions – understanding and reducing the model uncertainties

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CMIP5 projected changes in hot extremes

Regional changes in TXx (hottest day temperature) per degree of global warming:

**Goal:** Understand the different warming rates:

- Regional differences
- Model differences
- Reduce inter-model uncertainties?
Accelerated warming of hot extremes relative to mean temperatures

**Approach:** local *mean warming* rates account for some differences, local processes may *amplify extreme over mean* warming

ΔTXx / ΔTmean CMIP5 ensemble mean (2070-2099) – (1951-1980)

Stippling = spatial patterns of change robust across most models

[Donat et al. 2017, GRL]
What drives the regional amplification of hot extremes?

At each grid cell, record the date of the hottest day to investigate relationship to other variables on that hottest day.

For example, Evaporative Fraction (partitioning of surface heat fluxes (latent $Q_e$ and sensible $Q_h$) as proxy for soil moisture)

$$EF = \frac{Q_e}{Q_e + Q_h}$$

[also checked changes in cloud cover (radiation), atmospheric circulation (advection) related to hottest day]
Comparing the relationships between models and observations to evaluate the land-atmosphere feedbacks related to hot extremes

😊 very sparse (if any) long-term observations of soil moisture, heat fluxes, evaporation or related variables at daily resolution

😊 soil moisture in summer is strongly related to seasonal precipitation during spring/summer; long-term observations of monthly precipitation exist with good coverage of global land area, in particular Northern Hemisphere

→ to compare models vs observations: use precipitation in preceding 3 months (SPI) as proxy for moisture / EF on the days when heat extremes occur
ΔTXx/ ΔTmean and ΔEF (on hottest day), CMIP5 mean

→ Regions with strongest ΔTXx/ ΔTmean amplification characterised by reduction in EF on the day of the hot extreme

→ Land-atmosphere feedbacks explain much of the global pattern of amplified warming of hot extremes over mean warming
Inter-model uncertainties: Relationship between $\Delta EF$ (on hottest day) and $\Delta TXx/\Delta Tmean$

In the regional ‘hot spots’ of largest $\Delta TXx/\Delta Tmean$: Models with stronger EF reduction have stronger accelerated warming of TXx
Relationship between TXx changes and preceding precipitation

James Alex Ferguson 2023

→ Significant relationships between ΔSPI3 (preceding the hot extreme) and ΔTXx: models with stronger reduction in seasonal P simulate stronger amplification of ΔTXx/ΔTmean

→ Effects of internal variability small compared to inter-model differences (*coloured dots = different runs of same model*)
TXx response to moisture variability

→ In Europe and North America: Models with stronger TXx response to precipitation variability in the past climate simulate stronger amplification of ΔTXx/ΔTmean in the future
TXx changes related to strength of SPI-TXx response

Most models tend to show stronger SPI-TXx response than observed
CMIP5 ensemble constrained by observed SPI-TXx relationship

Using only models in which the SPI-TXx relationship is similar to observations

→ reduces the probability of strongest ΔTXx/ΔTmean amplification

→ reduces the uncertainty of future projected TXx changes
Summary

- Climate model simulations show distinct ‘hot spots’, robust across most CMIP5 models, where daily hot extremes warm faster than mean temperatures.

- These ‘hot spots’ are related to changes in surface energy fluxes, consistent with drying soils, leading to accelerated warming on the days hot extremes occur.

- Uncertainty of future simulated changes in hot extremes is controlled by (1) future changes in seasonal precipitation, and (2) strength of the SPI-TXx relationship in the models.

- Constraining (2) based on observations reduces the probability of strongest amplification of hot extremes, and reduces range of future projections.

Thank you for listening. Email: m.donat@unsw.edu.au
Thank you.

More details for part 1 (EF-TXx relationship):

More details for part 2 (constraining based on observed SPI-TXx relationship):
On request, currently under review.

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dTXx/dTmean spatial pattern robust across most models

[Donat et al. 2017, GRL]
[amplification TXx over seasonal mean]

[Donat et al. 2017, GRL]
Models passing the observational constraint (white)
In the $\Delta TXx/\Delta T\text{mean}$ regional ‘hot spots’:
Models in which $TXx$ is more strongly related to $EF$ in past climate show stronger future amplification $\Delta TXx/\Delta T\text{mean}$

$\rightarrow$ can we determine if some simulations are more realistic than others?
TXx changes related to strength of SPI-TXx response

→ In Europe and North America: Models with stronger TXx response to precipitation variability in the past climate simulate stronger amplification of $\Delta TXx/\Delta Tmean$ in the future.

→ Most models tend to show stronger SPI-TXx response than observed.
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