Improving climate hazard information

Simon Brown[1], Rob Shooter[1], Will Keats[1], Daniel Cotterill[1], Freya Garry[1], Elizabeth Kendon[1], Ben Youngman[2], Dan Bernie[1,3], Peter Stott[1],

1. Met Office
2. University of Exeter
3. University of Bristol

UK CLIMATE RESILIENCE PROGRAMME

28th April 2021

Met Office

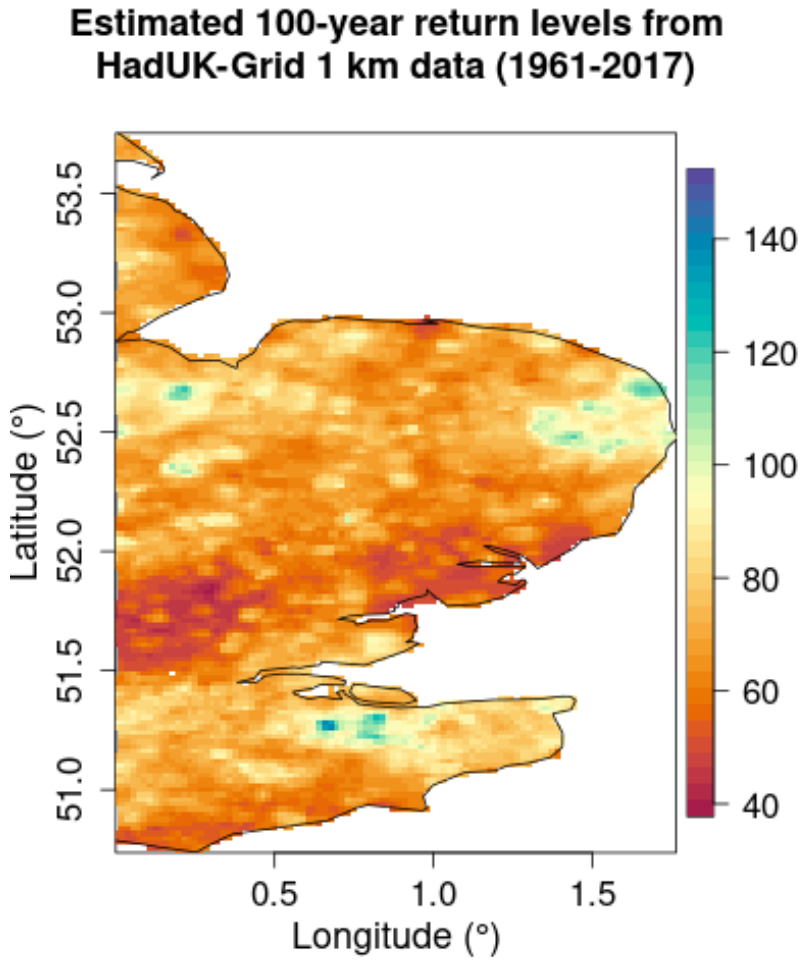
UK Research and Innovation

Improved hazard information

- **Improved representation**
  - km scale gridded climatologies - *Rob shooter, Ben Youngman*
    - Wind gusts, daily rainfall
  - Future changes for observations - *Rob shooter*
- **Improved characterisation**
  - Heatwave frequency-severity-duration – *Simon Brown*
  - Urban environments – *Will Keat*
  - Autumn rainfall – *Daniel Cotterill*
- **Improved relevance**
  - Flooding hazards – *Daniel Cotterill*
  - Multivariate hazards – *Freya Gary*

Improved hazard representation
Wind gusts and daily rainfall – Rob Shooter, Ben Youngman

- **What problems are we trying to solve?**
  - New observations
  - New statistical methods to produce complete spatial fields
  - Odd “features” from traditional gridding approaches
- **How did we achieve improvements?**
  - Generalised additive models (GAMs) for extreme value distributions (Youngman, 2019).
  - Easy to have EV parameters smoothly varying through space and time via multiple covariates, such as: latitude, longitude, orography, distance to coastline, time and even interactions between covariates
  - No need to grid observed events, guessing what happens between stations -> use station data directly and “grid” EV distribution parameters

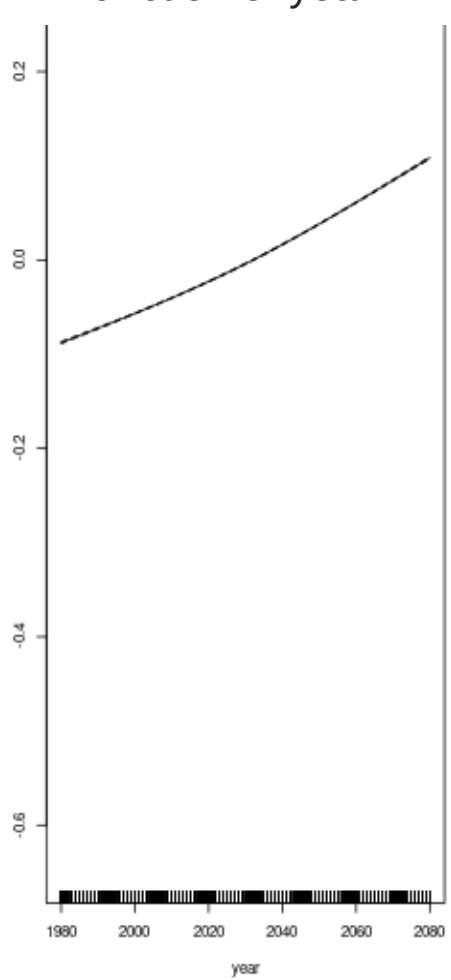


Youngman, B. D. 2018. Generalized additive models for exceedances of high thresholds with an application to return level estimation for US wind gusts. *J. American Stat Association*

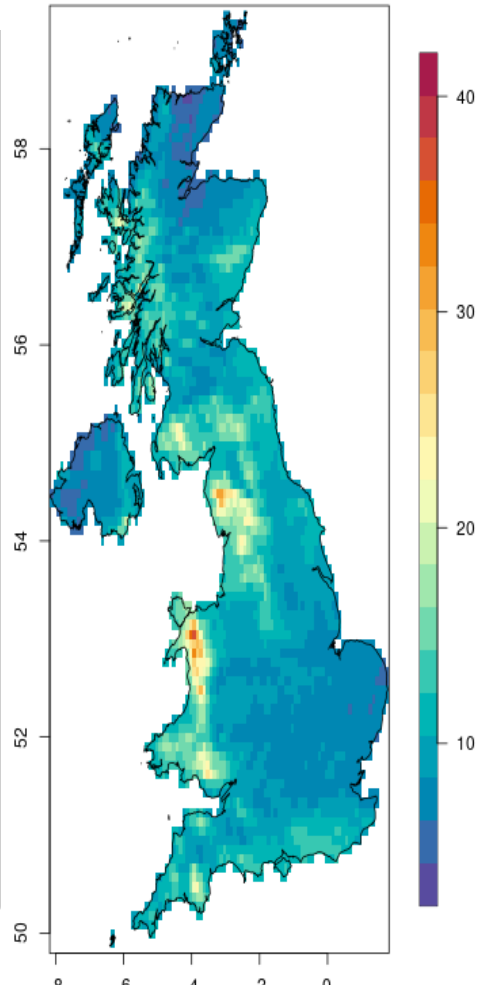
Improved hazard representation
What is a GAM?

- Similar to linear regression/generalised linear models but instead of linear functions of covariates, non-linear smooth functions are used.
  - rather than: $y = \alpha_i x + \beta_i z$,
  - Model: $y = \alpha_i(x) + \beta_i(z)$ for covariates x,z e.g. space, time.
  - For $\alpha()$ and $\beta()$ typically use splines
- Can also model multiple data types simultaneously
  - Station data and climate model data (e.g. CPM UKCP-Local)
  - Joint statistical model – differences between OBS vs CPM in location and scale spatially but time dependent changes and shape parameter are common to both
- An example β function (right) for time for GPD log-scale parameter, controlling heavy-tailedness of data -> future increase heavy rainfall
- Changes in the **observed** daily rainfall easily calculated for any year spanned by either the observations or the climate model (single CPM member)

Log-scale as function of year

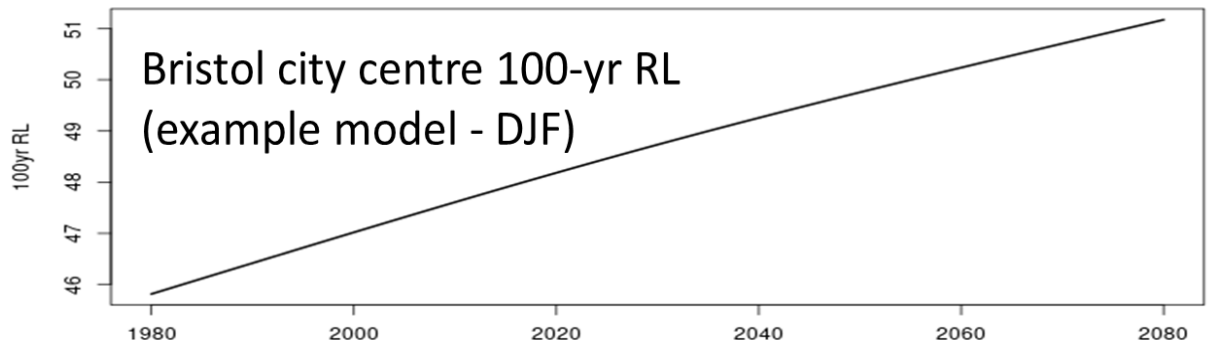


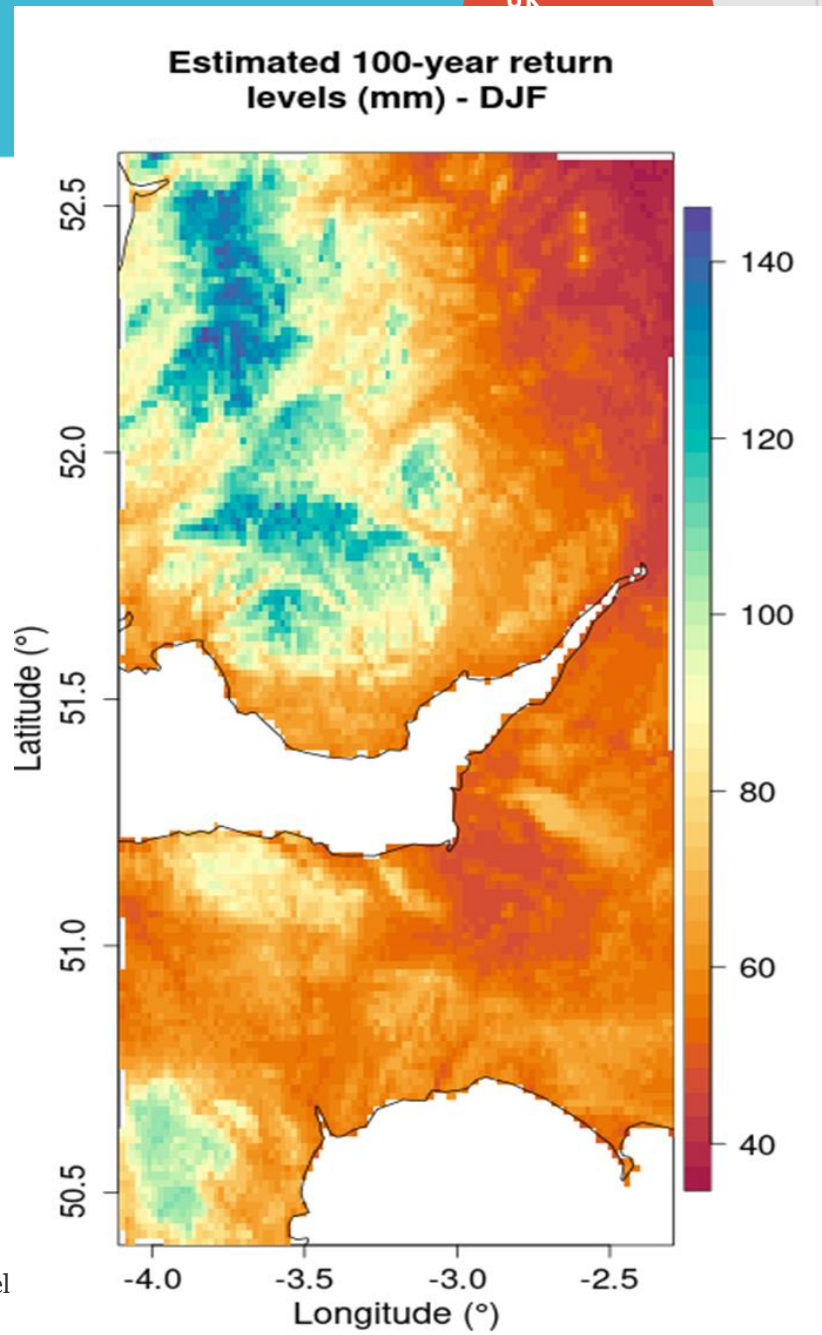
Increase in 100-year daily rainfall return levels between 1990 and 2070



Improved hazard representation
Outputs

- 1st product: Stationary in time present-day return levels of extreme daily rainfall. Spatially complete whole UK at 1 km resolution directly from station data only.
- 2nd product: Future projections for observed data of extreme daily rainfall at 2.2 km resolution for years 1980 to 2080
- Supplementary products:
  - present-day return level estimates of annual wind gust return levels (courtesy Ben Youngman)
  - prototype daily summer temperature maxima (MSc).

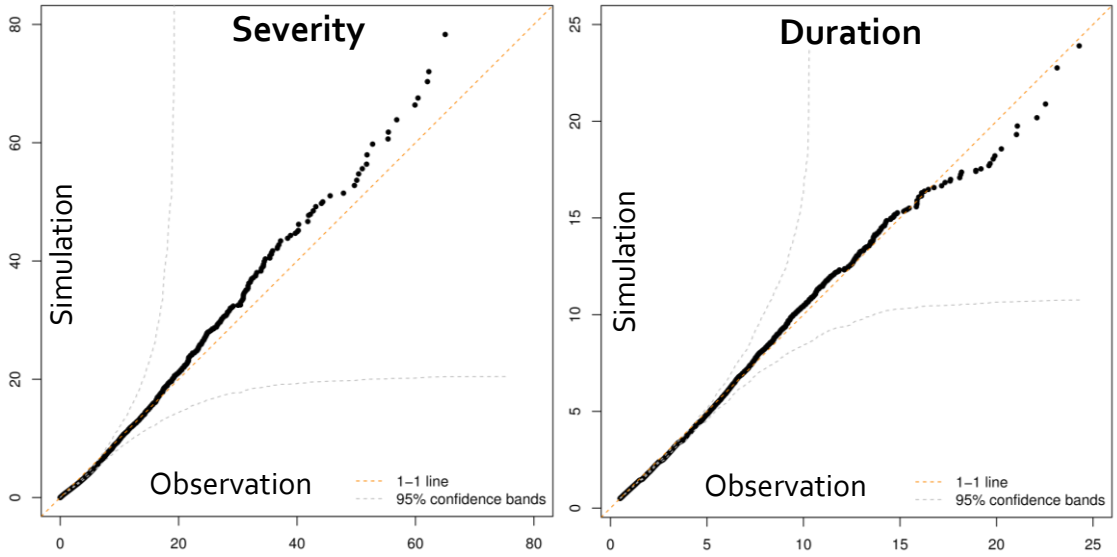


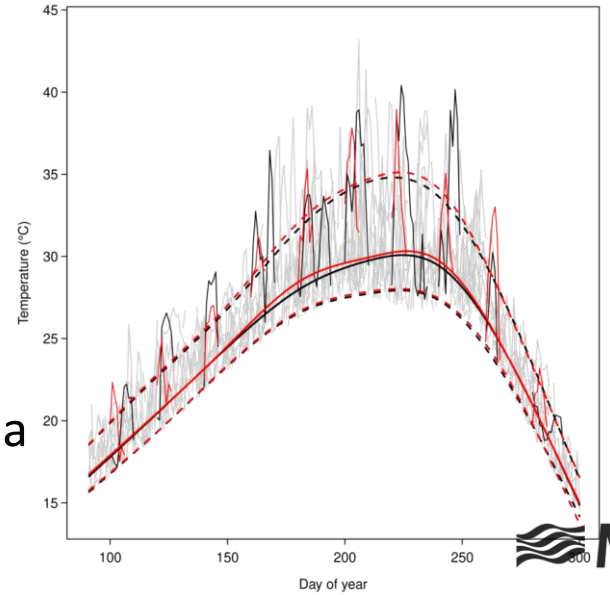


Shooter R and Brown S 2023, High-resolution estimation of daily precipitation extremes in the United Kingdom using a generalised additive model framework Submitted, Weather and Climate Extremes

Improved hazard characterisation
Heatwave frequency-severity-duration

- Definition of a heatwave is often application specific
  - Threshold, duration, time of year, location
- Such stratification makes the paucity of data situation worse
  - Looses useful information from “other” heatwaves
- Development of a method that is agnostic about heatwave definition
- HOTdays tool
  - stochastic simulator of all days above a moderate threshold for the whole year and non-stationary in time
  - Day-to-day extremal dependence during HW is preserved
  - Heatwaves of choice can be extracted from large (10^7 years equivalent)
  - This work is being taken forward by the HCCP to produce a climatology of heatwaves for the UK in the coming year.

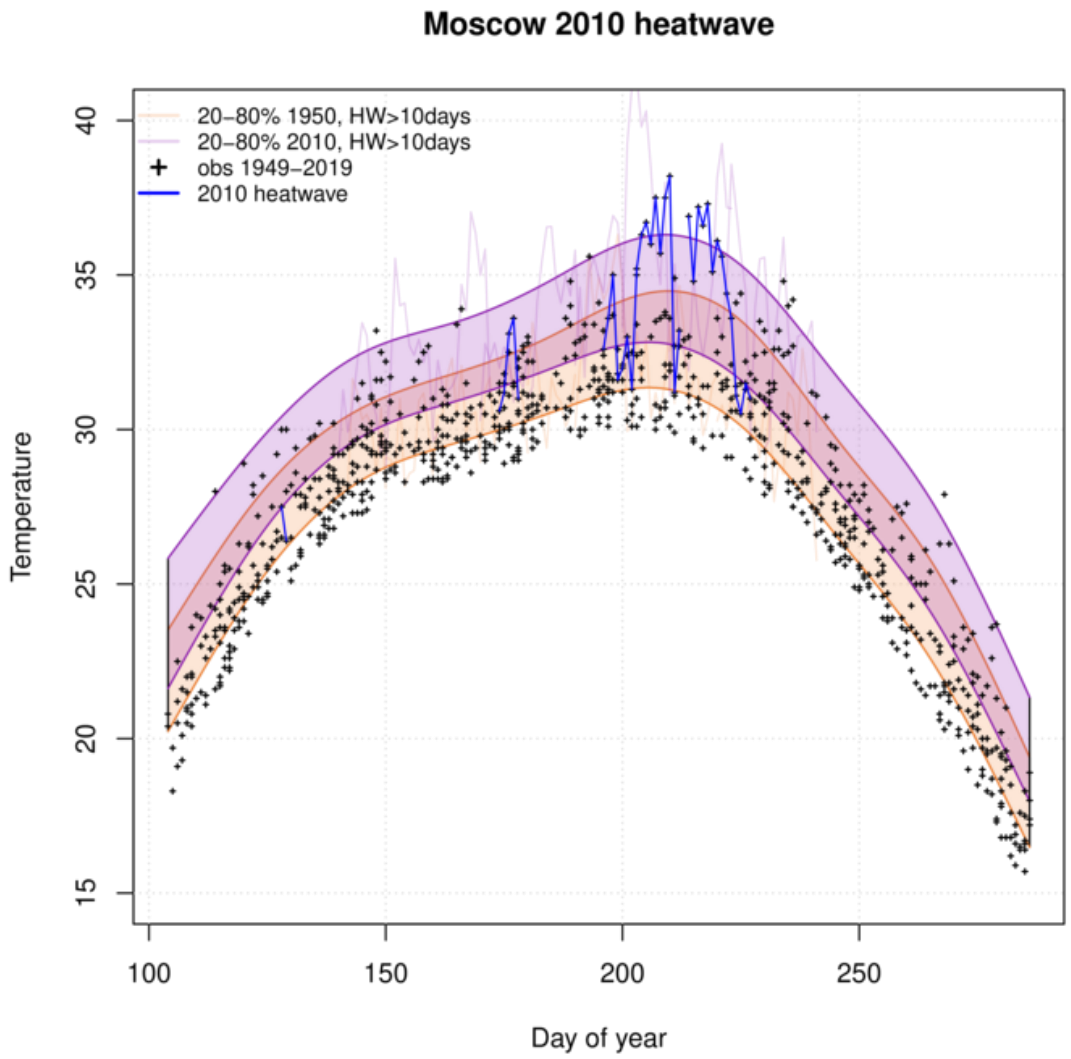


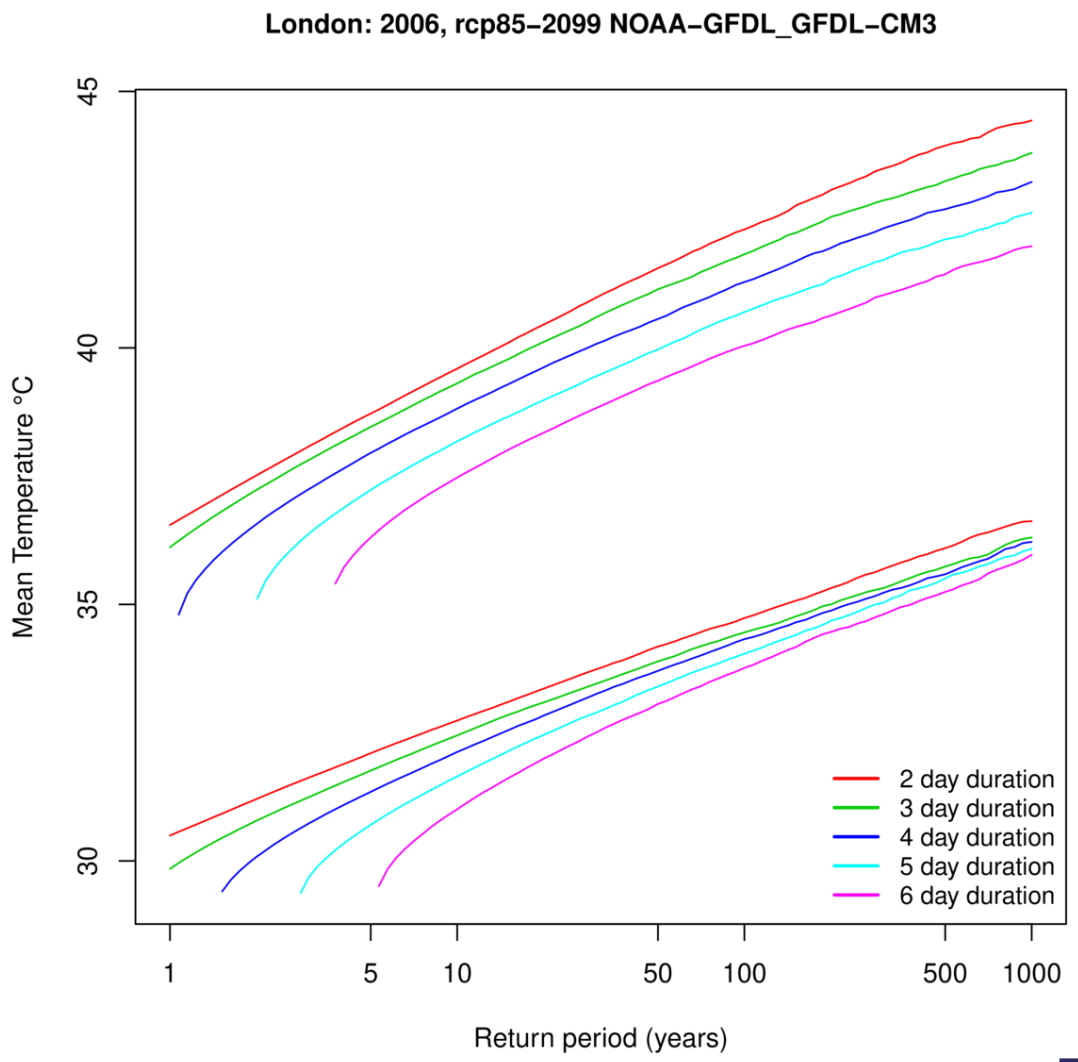


Validation: reproducing a 3500 year pre-industrial climate with an SRES A2 100 year future simulation

Brown S. J. (2020) Future changes in heatwave severity, duration and frequency due to climate change for the most populous cities. Weather and Climate Extremes. 30.

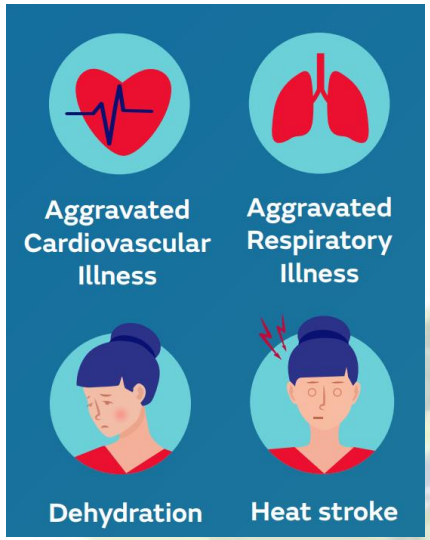
Improved hazard characterisation
Heatwave frequency-severity-duration

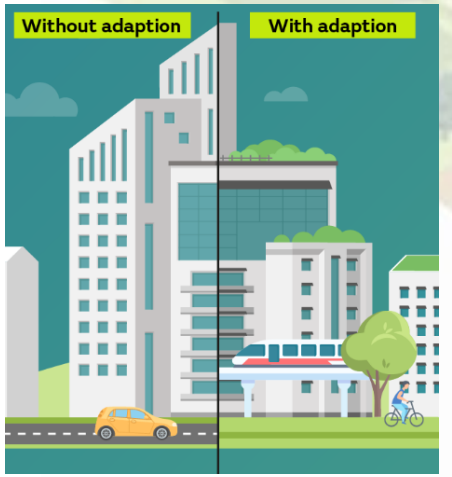




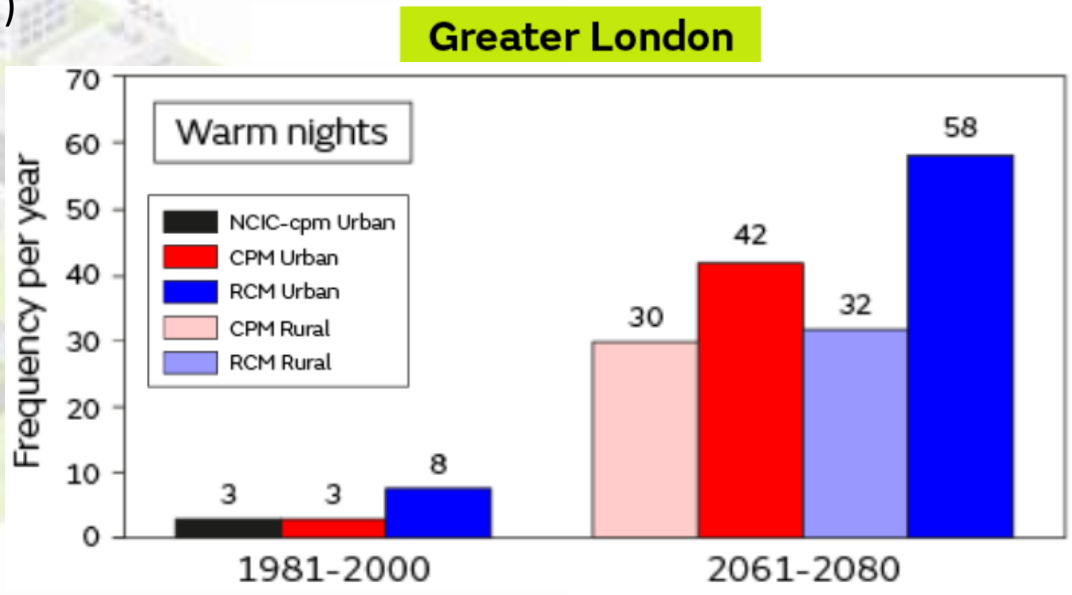
Brown S. J. (2020) Future changes in heatwave severity, duration and frequency due to climate change for the most populous cities. Weather and Climate Extremes. 30.

Improved hazard characterisation in UK cities: Temperature extremes – Will Keat





- UKCP-Local (CPM) has more sophisticated "two-tile" urban scheme that better represents urban processes – street canyons and roofs separately
  → improved diurnal cycle of surface fluxes
- Frequency of hot days and warm nights better captured by CPM compared to UKCP-Regional (RCM)
- Larger future increases in hot days and warm nights over urban areas compared to rural; smaller increases in CPM
- It is important that urban adaptation/mitigation strategies are based on projections with more complex urban schemes than in the RCM

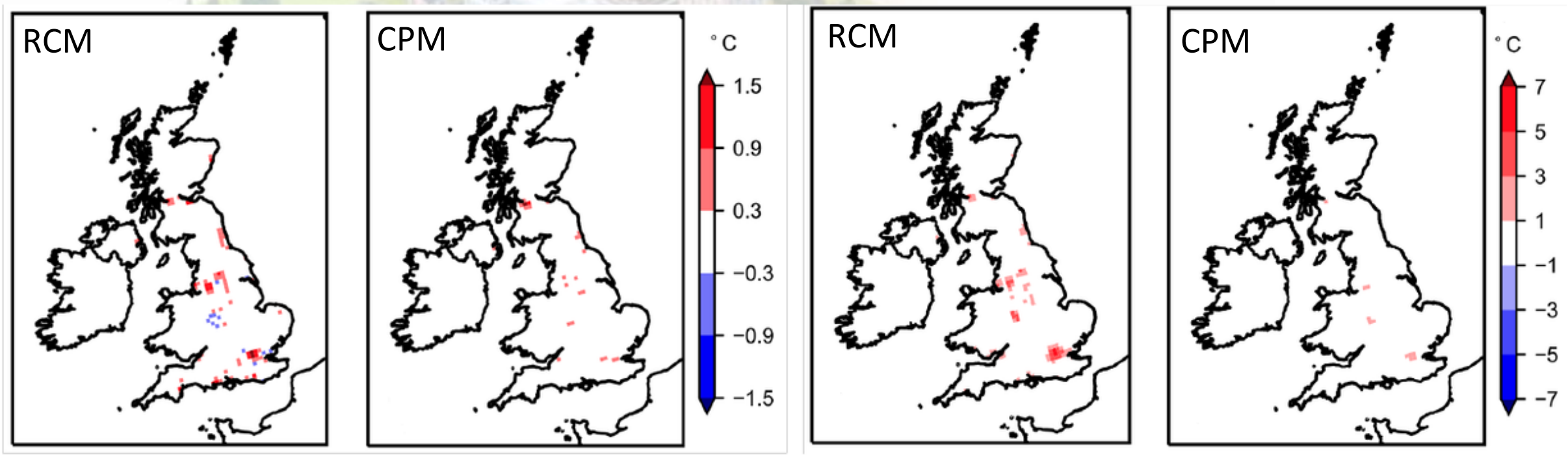


Keat et al., 2021: Climate change over UK cities: the urban influence on extreme temperatures in the UK climate projections, *Clim. Dynamics*

Improved hazard characterisation in UK cities: Temperature extremes

- Urban heat island effect (UHI) for hottest days and warmest nights significantly larger in RCM than CPM (and observations)
- Mostly due to single-tile scheme and larger urban fractions in RCM due to resolution
- In future, daytime CPM absolute temperatures increases are larger than RCM
- Urban areas will warm more than rural areas, but this is more modest in the CPM than the RCM

Day **Urban heat island effect** **Night**



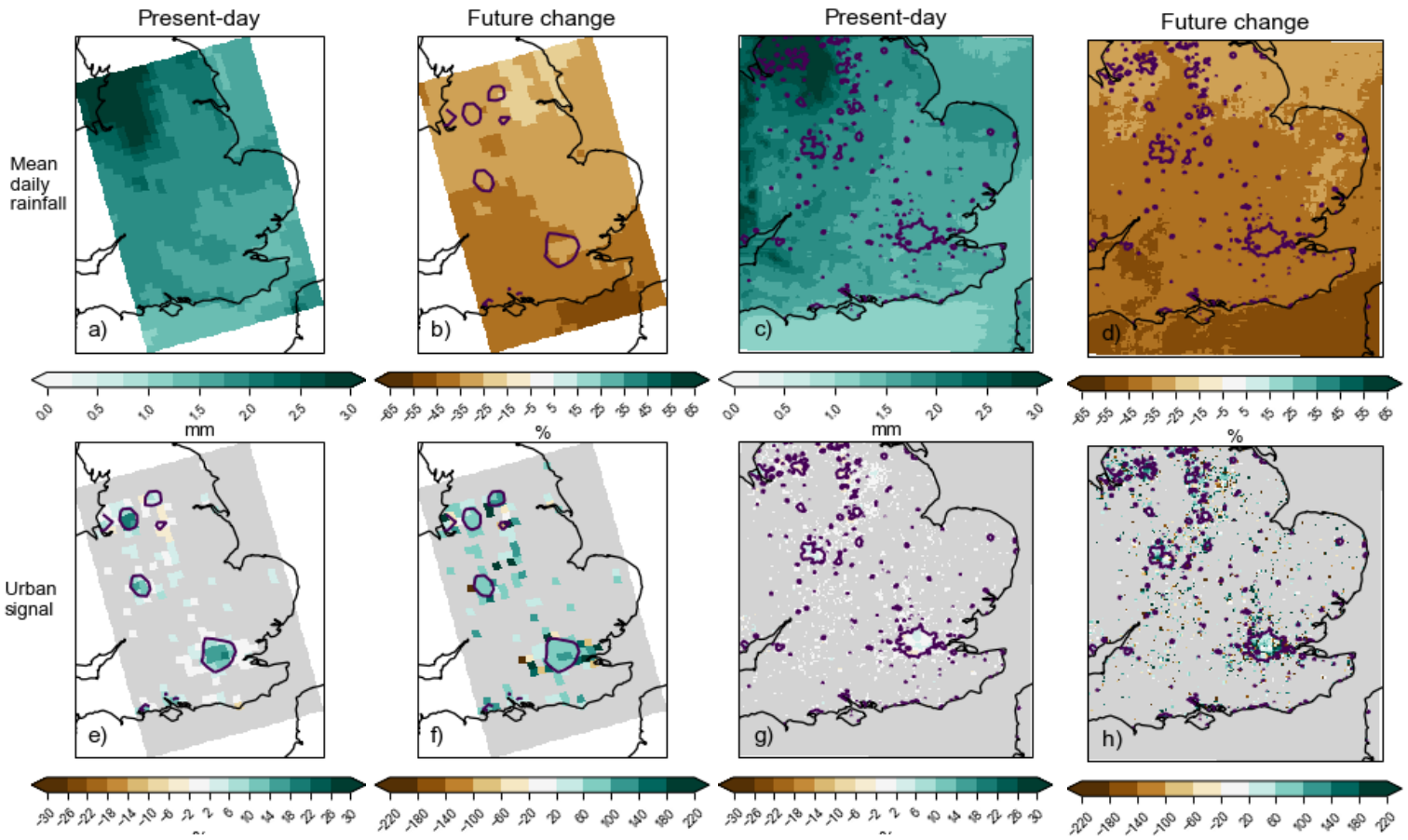
Keat et al., 2021: Climate change over UK cities: the urban influence on extreme temperatures in the UK climate projections, *Clim. Dynamics*

Improved hazard characterisation in UK cities: Rainfall extremes

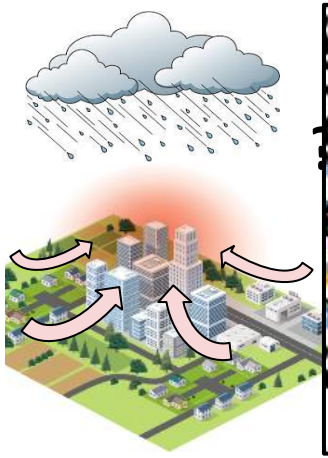
UK CLIMATE RESILIENCE PROGRAMME

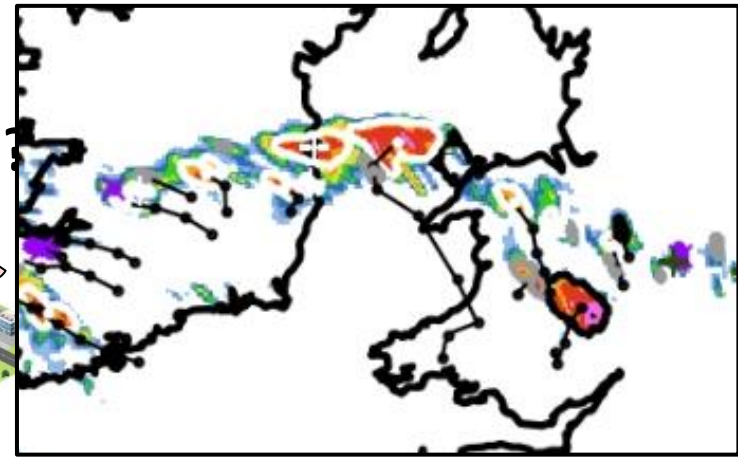
UKCP-Regional (12km)

UKCP-Local (2.2km)



- Too much rainfall occurs over cities in UKCP-Regional - too responsive to surface temperature forcing due to the convection-parameterisation scheme?
- Urban influence (if any) in UKCP-Local is very small
- Research ongoing into the role of the urban heat island in convective initiation/storm morphology
- As part of this work, developed cell tracking code to identify and track convective storms





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Improved hazard characterisation
Using Attribution: rainfall/flooding

(Daniel Cotterill, Peter Stott and Nikos Christidis)

UK CLIMATE RESILIENCE PROGRAMME

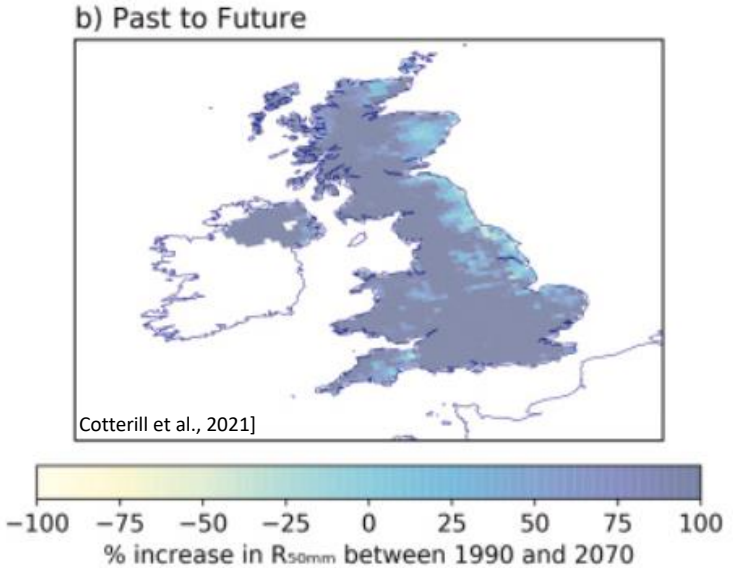
Q1. Can we quantify the influence climate change has already had on the hazard?

- Harder than temperature
- Climate signal smaller for precipitation difficult to see due to high natural variability
- More obs and suitable climate model data becoming available
- Multiple flooding events within first 6 months of project

Approach:

- Examined recent events such as autumn flooding in south Yorkshire in 2019 and many winter storms (such as Dennis/Ciara/Desmond)
- Used number of approaches such as UNSEEN, trend detection and traditional attribution to examine if man-made climate change played a role

Results and Outputs:



- 60% increase in rainfall totals exceeding 50 mm UK-wide in October-December (95% CI: 44–76)
- Under high emissions scenario this is projected to increase by a further 85 % by 2070
- Paper published with results *
- Further work on winter storms soon to be submitted

* Cotterill D, Stott P, Christidis N, Kendon E (2021) Increase in the frequency of extreme daily precipitation in the United Kingdom in autumn. Weather Clim Extrem. https://doi.org/10.1016/j.wace.2021.100340

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Improved hazard characterisation
Using Attribution: Seasonality Changes

(Daniel Cotterill, James Pope and Peter Stott)

UK CLIMATE RESILIENCE PROGRAMME

Q2. Understand how atmospheric circulation is changing and what that means for the hazard?

- UK Rainfall very dependent on circulation
- Understand the drivers of any rainfall changes
- Seasonality changes as a result of circulation changes could impact many industries such as energy, tourism, agriculture and water sectors


England faces longer and drier summers, Met Office research suggests

The Met Office said summer-like conditions were expected to last longer and a 4-12% reduction in rainfall in England was likely in the future during the autumn weeks.

Samuel Osborne
News reporter @samuelosborne98

Tuesday 30 August 2022 19:00, UK

Approach:

- Use 30 weather patterns, defined by sea level pressure anomalies to determine daily circulation type
- Created this data for a number of climate models, along with data from UK climate projections and observations
- Examine changes in frequency of weather types

Results and Outputs:

- UK Summer weather types extending into Autumn
- In England this is projected to result in a 4-12% decrease in autumn rainfall by 2085 due to man-made climate change
- Hotter drier autumns can be expected
- Rainfall extremes expected to increase further despite drying
- Paper** published and results communicated

** Cotterill, D.F., Pope, J.O. & Stott, P.A. Future extension of the UK summer and its impact on autumn precipitation. Clim Dyn (2022). https://doi.org/10.1007/s00382-022-06403-0

Met Office

UK Research and Innovation

Improved relevance

Using Attribution: Hazard to Impacts

(Daniel Cotterill, Dann Mitchell, Peter Stott and Paul Bates)

UK CLIMATE RESILIENCE PROGRAMME

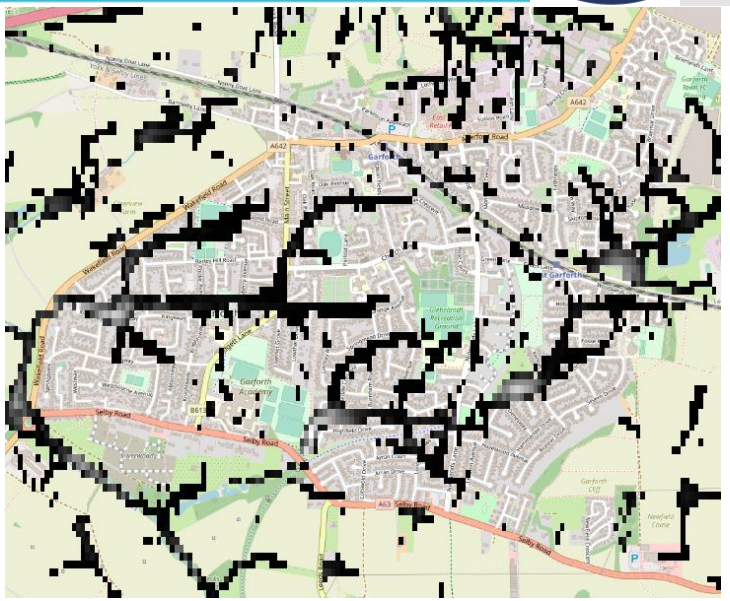
Q3. Can we translate changes in the hazard (rainfall) into impacts (flooding) ?

- Rainfall does not always mean flooding
- Rainfall events vary in spatial/temporal patterns
- Sub-daily rainfall extremes under-studied

Approach:

- Looks at flash flooding in Leeds in August 2014: 80mm falling in 5 hours in some suburbs. 400 properties affected
- Using hydrodynamic flood inundation model LISFLOOD-FP at 30m resolution (Bristol)
- City suburb scale
- Input data from convection permitting UKCP Climate Projections for over 13 000 events

Validation



Simulated flood depth map over Garforth in Leeds for observed event using CEH-GEAR observations and LISFLOOD-FP hydrodynamic model

Achievements:

- First half of project funded by SPF, now under HCCP programme
- Flood model validation complete
- All thirteen thousand UKCP rainfall events over Leeds run through flood model

University of BRISTOL

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Improved relevance
Multi-variate Biases

International Journal of Climatology | RMetS

RESEARCH ARTICLE | Full Access

Characterising temperature and precipitation multi-variate biases in 12 km and 2.2 km UK Climate Projections

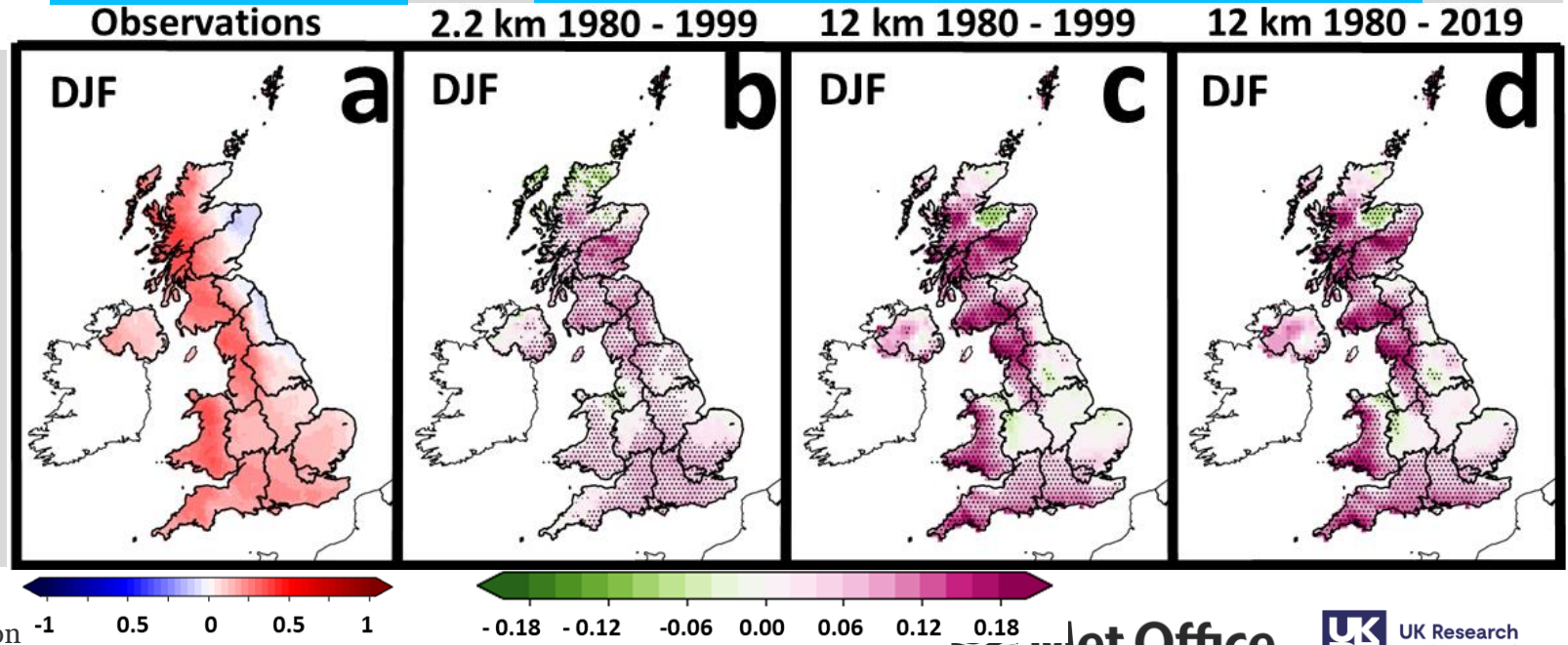
Freya K. Garry, Dan J. Bernie

First published: 13 January 2023 | https://doi.org/10.1002/joc.8006

Underpinning science to improve understanding of multi-variate relationships and biases in models using both correlation and regression methods

Further work has evaluated changes in the multi-variate relationship into the future in both UKCP models and the EuroCORDEX ensemble

Pearson correlation | **Bias in Pearson correlation coefficient in UKCP models**



Contact Freya Garry (freya.garry@metoffice.gov.uk) for more information

Improved relevance
Compound extremes application

Contents lists available at ScienceDirect

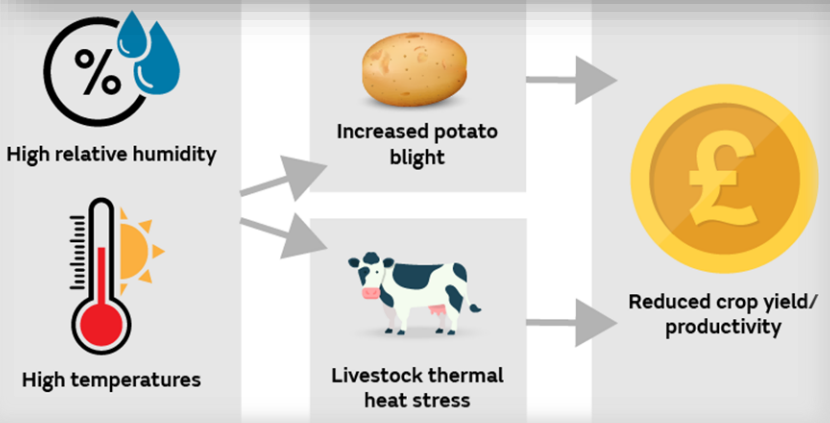
Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

Future climate risk to UK agriculture from compound events

Freya K. Garry *, Dan J. Bernie, Jemma C.S. Davie, Edward C.D. Pope

Met Office, Fitzroy Road, Exeter EX1 3PB, United Kingdom



Weather and Climate Extremes

Volume 38, December 2022, 100522

Probabilistic simulation of big climate data for robust quantification of changes in compound hazard events

Theodoros Economou [a], Freya Garry [b]

Short case study with the **National Trust** with **tenant farmers** in mind including multi-variate hazards and compound events

Contact Freya Garry (freya.garry@metoffice.gov.uk) for more information

Improved relevance
Compound Events: Yorkshire Dales

UK CLIMATE RESILIENCE PROGRAMME

Short case study with the **National Trust** with **tenant farmers** in mind.

Improve understanding of weather and climate hazards of interest to agricultural practitioners in the Yorkshire Dales, and how they may change on climate timescales (30-60 years time).

Clearer visualisation of local changes in a region (which can be hard to interpret from UK wide analysis).

Including compound hazards:

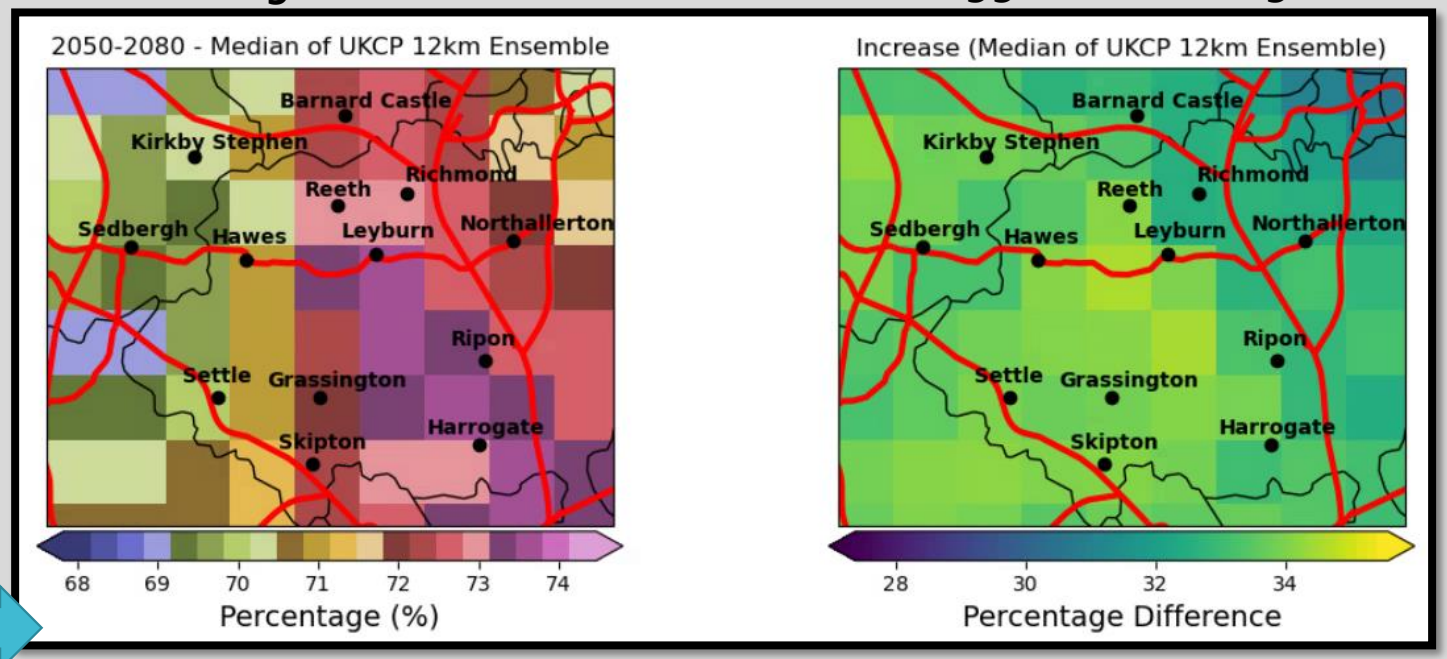
Heatwaves during drought (building on Hanlon et al. 2021)

Temperature humidity index for livestock (Garry et al. 2021)

Fire weather index (from Perry et al. 2022)

Warm dry summers (c.f. 1990-2020 climatology)

2050-2080 **Increase from 1990-2020 to 2050-2080**



Using UK Climate Projections and EuroCORDEX-UK at 12 km

Met Office

UKRI UK Research and Innovation

Improved hazard information

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Much more in the insight paper!

"Improved understanding and characterisation of climate hazards in the UK"