Met Office

Welsh Water

ANALYSIS OF WASTE WATER FLOODING EVENTS AND RAINFALL

- Welsh Water (WW) have recently sought funding to reduce the incidence of sewer flooding in Wales. WW is intending to use this funding to support activities that are over and above “normal” levels and are therefore commissioning a report to provide further evidence to support their business case for this work.

- WW are particularly concerned with the hydrological overload flooding (HOF) events and they would like to understand where their operational area sits in a national context on a range of hydrological and topographical factors that may influence sewer flooding.

- This report identifies the major meteorological events that have an impact on waste water flooding events in context for the whole regions and sub-divisions (high-level postcodes) historically (Phase 1a)

- Phase 1b, comparing the WW area with the rest of the country is contained in the middle section and Phase 2 concerning climate change is in the final third of the presentation.

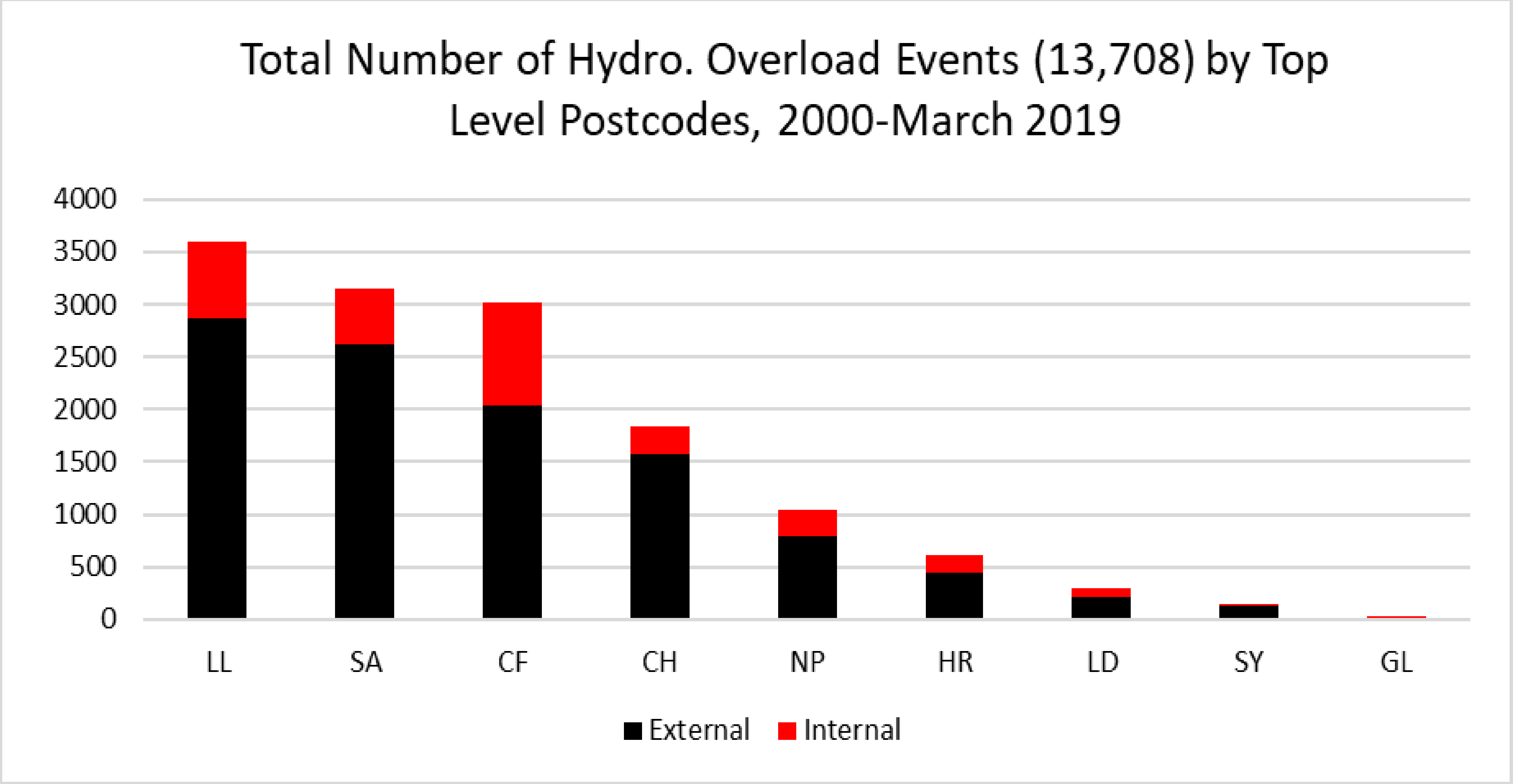
Welsh Water

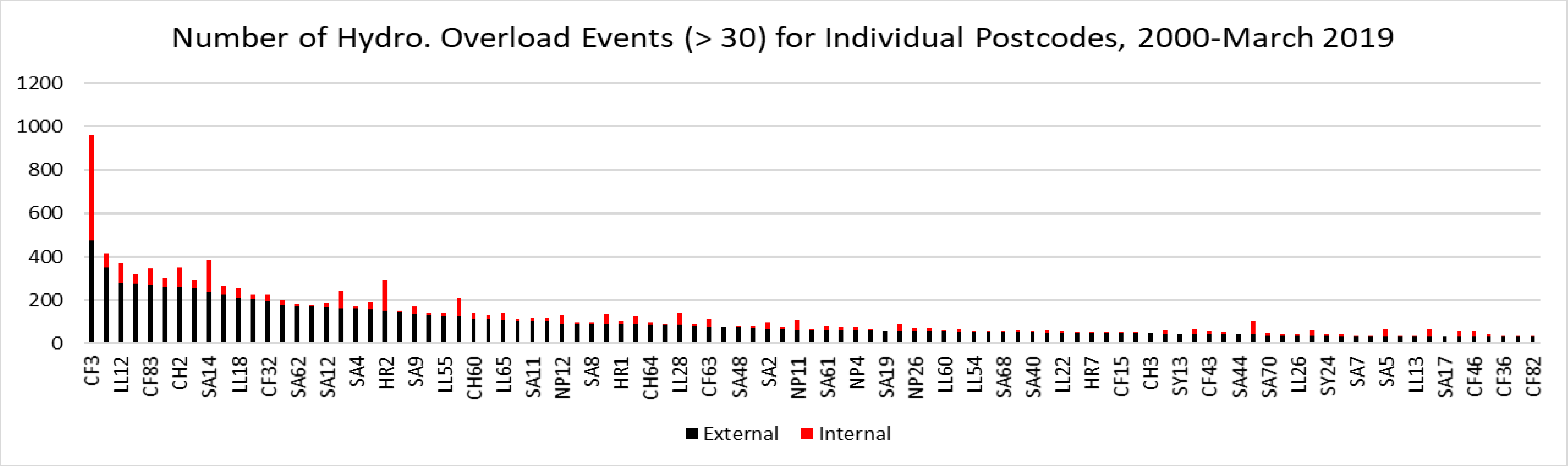
ANALYSIS OF WASTE WATER FLOODING EVENTS AND RAINFALL

PHASE 1A

Met Office

- Analysis of WW sewer-flooding event data (April 2000-March 2019) reveals that 70% of events occurred in the LL, SA and CF postcode areas reflecting the populated areas of NE and south Wales. 20% occurred in CH (Chester) and NP(Newport).
- The majority (78 %) were due to external flooding events.
- Wrexham, Swansea and Cardiff postcodes are the most prone sites.
- The high total for CF3 is discussed on next slide

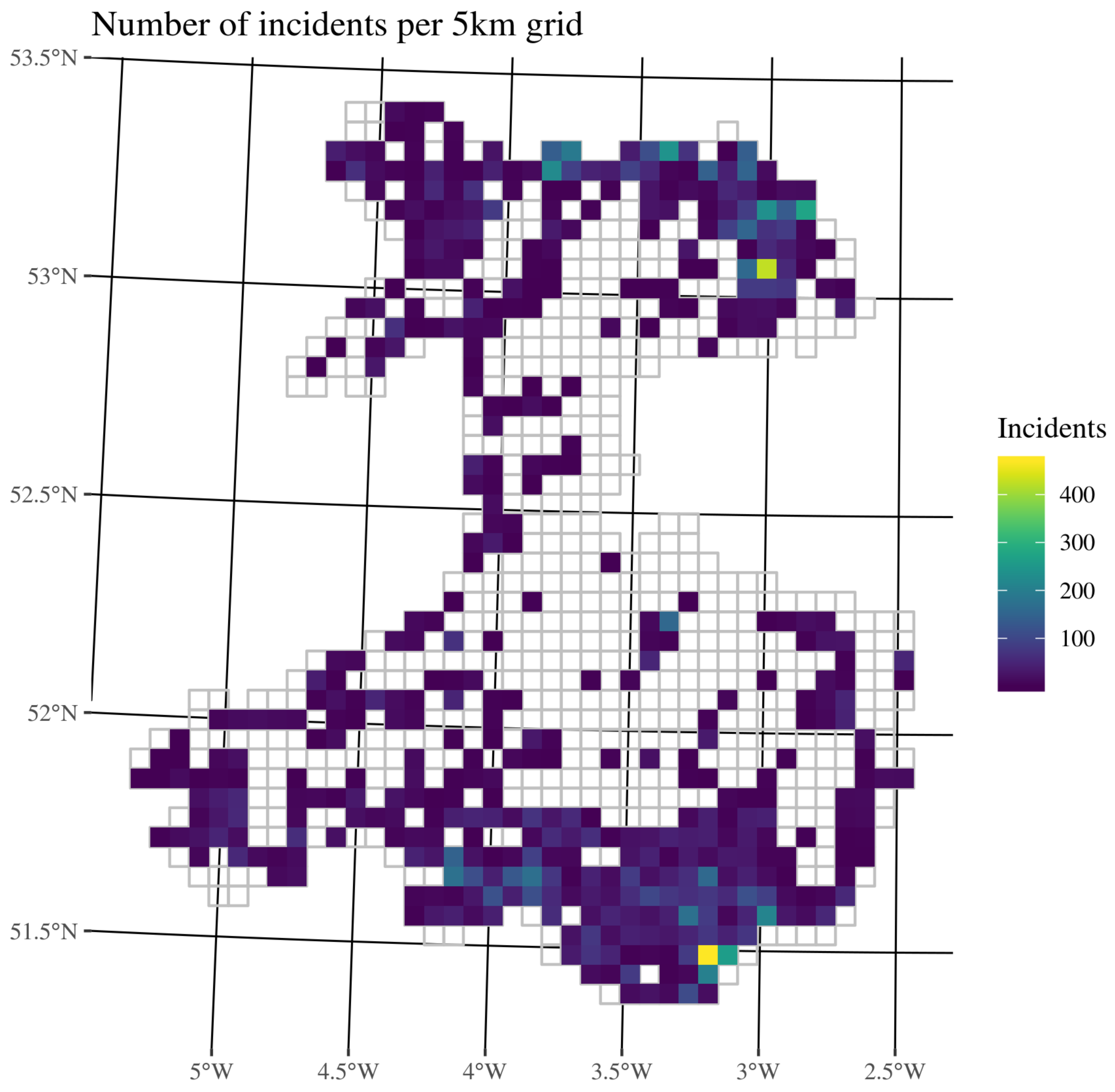




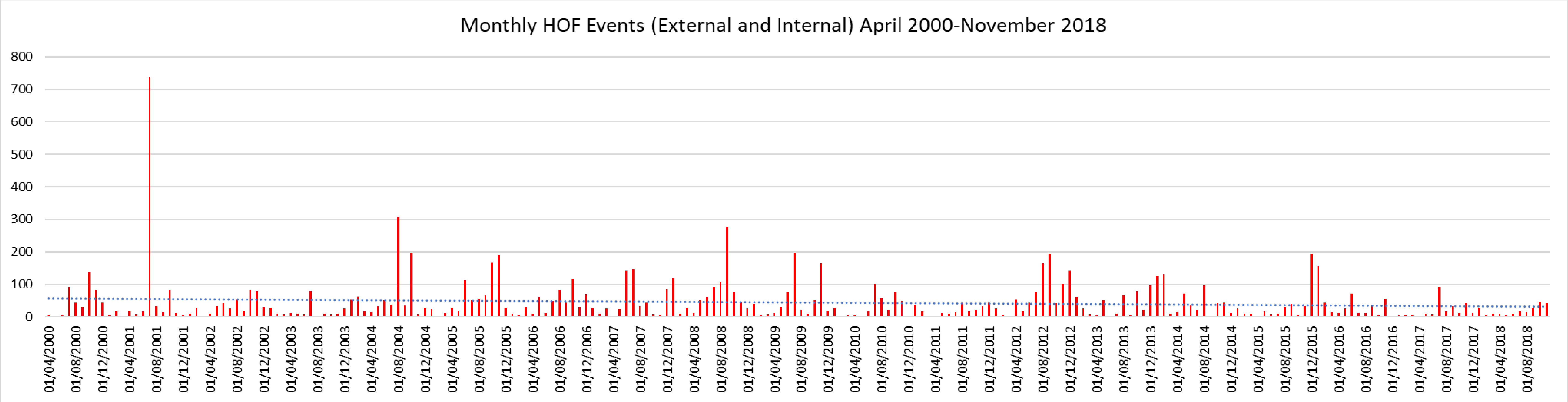
Sewer flooding incidents

Welsh Water’s sewer flooding incidents have been aligned with the National Climatological Information Centre (NCIC) 5km grid. The Figure shows the number of incidents per grid square. White squares have no incidents.

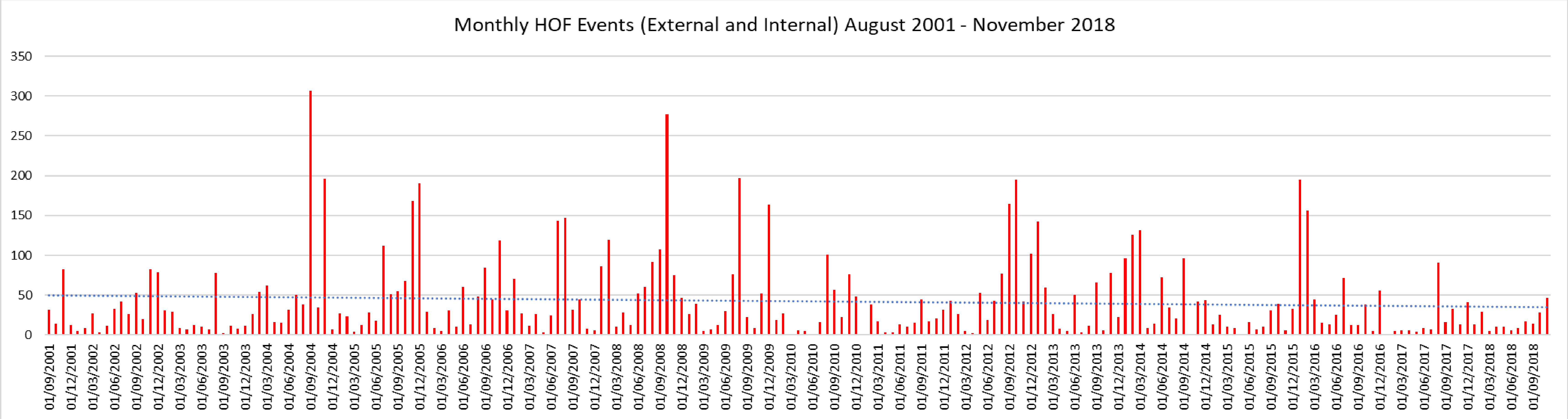
Two locations stand out as having a particularly large number of incidents: Cardiff and Wrexham.



An exceptional event on 3rd/4th July 2011 dominates the record. This was a severe rainfall event but is limited to the CF and NP areas, CF3 (central Cardiff) in particular. Note the dates shown are for the month beginning on that day but not every month is displayed on the x axis and due to space constraints).



There is a general, but very small downward trend in HOF events, even if the period prior to August 2001 is excluded.

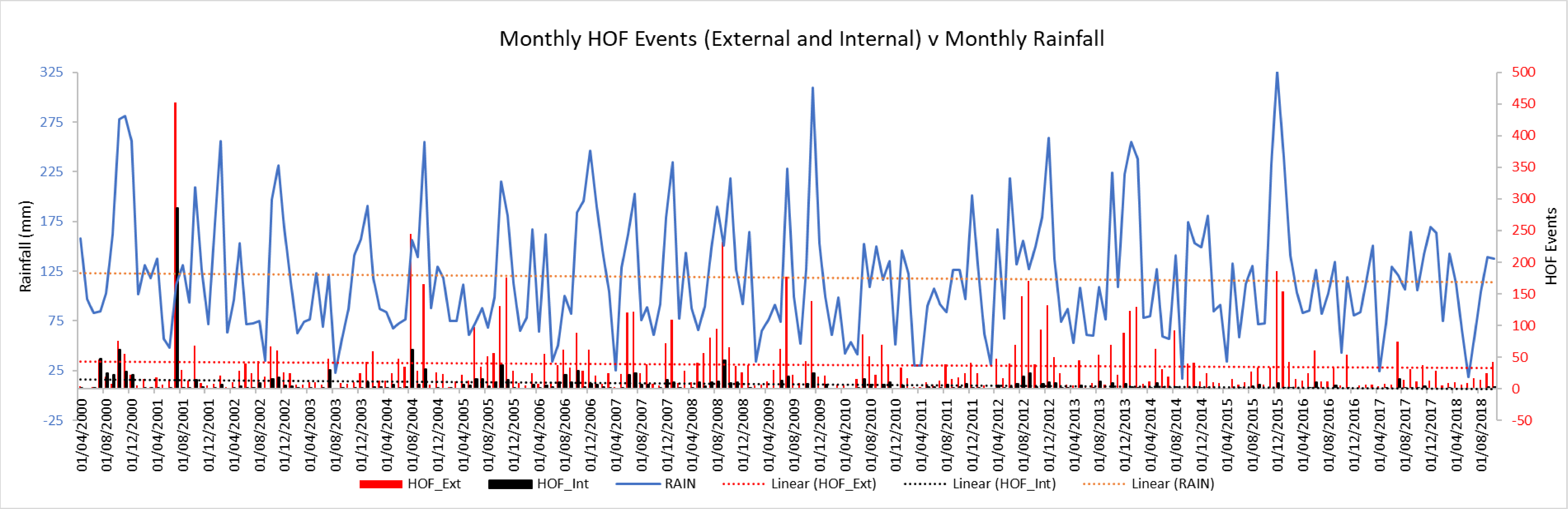


Met Office

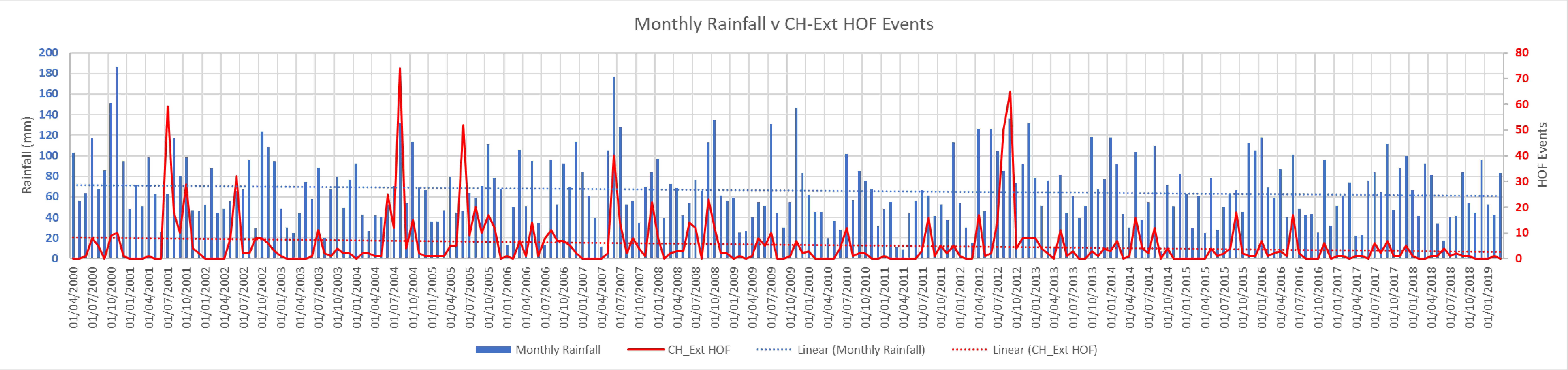
The rainfall data used in this report are based upon 5-km gridded daily rainfall data produced by the National Climate Information Centre (NCIC) and have been selected to coincide with the Welsh Water area and when required, the relevant postcode areas.

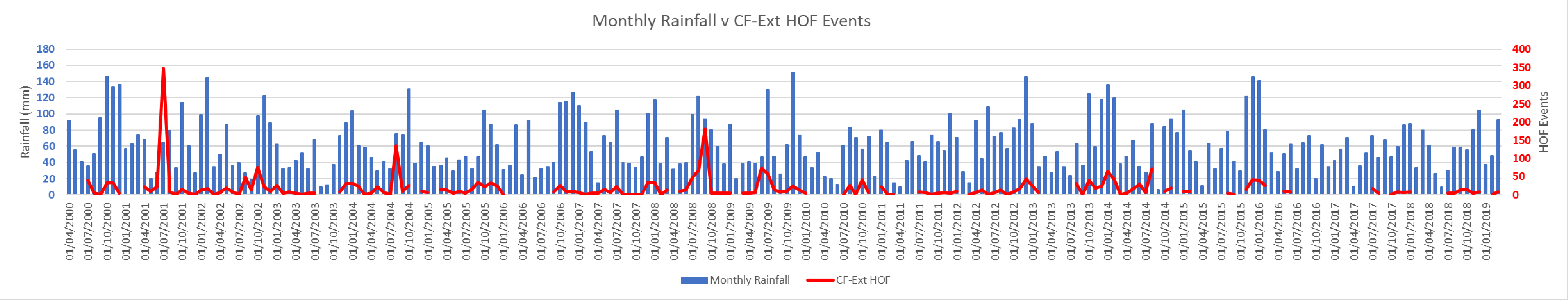
A plot of monthly rainfall v the total number of all HOF events in each month April 2000-November 2018 shows some agreement in some years but not in all. The July 2001 event mentioned in the previous slide particularly stands out with 452 External and 286 Internal HOF events. There is small downward trend in monthly rainfall and both External and Internal events.

For the rest of this report, only external events have been considered as these are more likely to be weather-dependent and internal events are more rare.



Similar patterns were found when the postcode area data are analysed – examples from CH and CF areas (External HOF events)

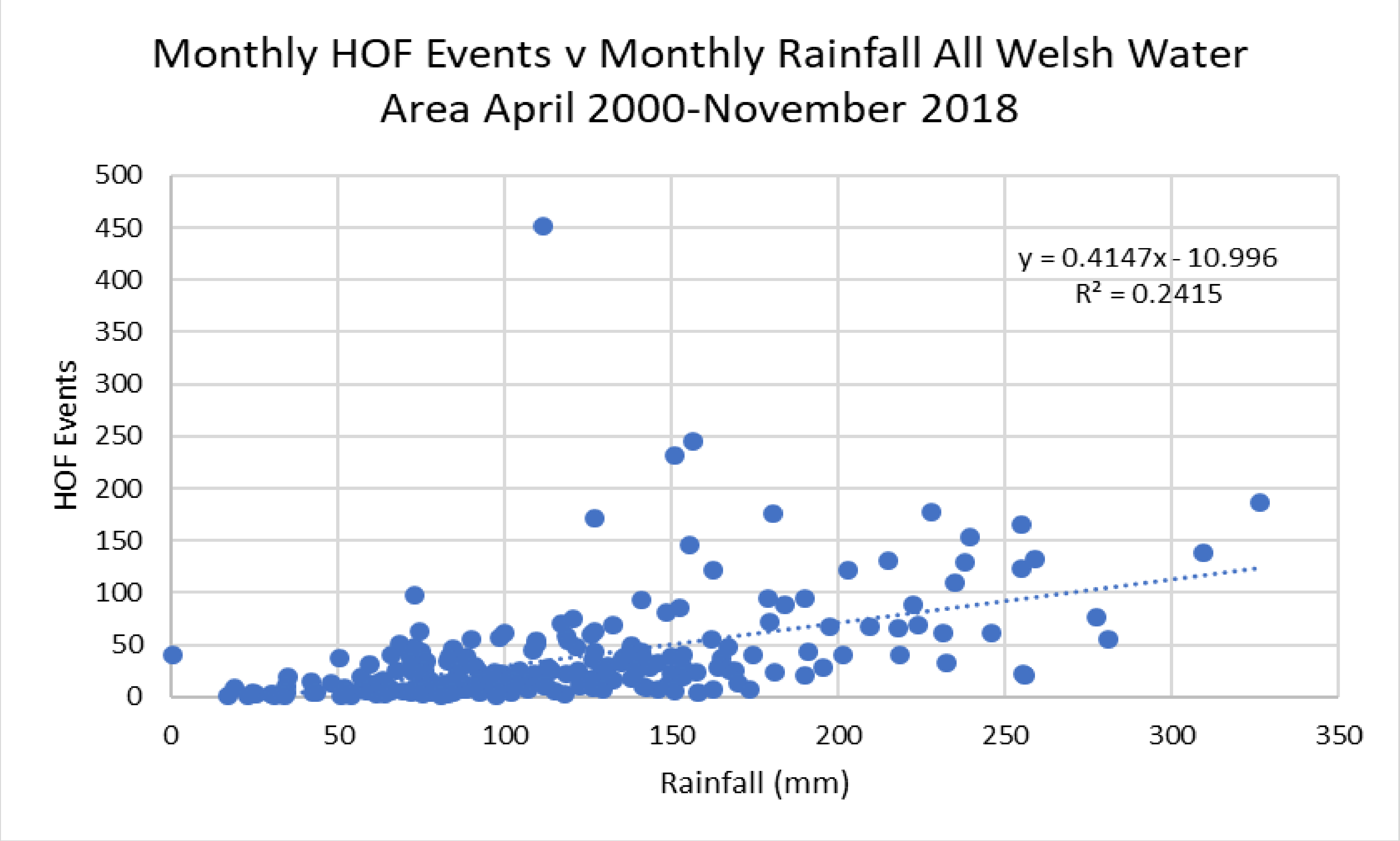


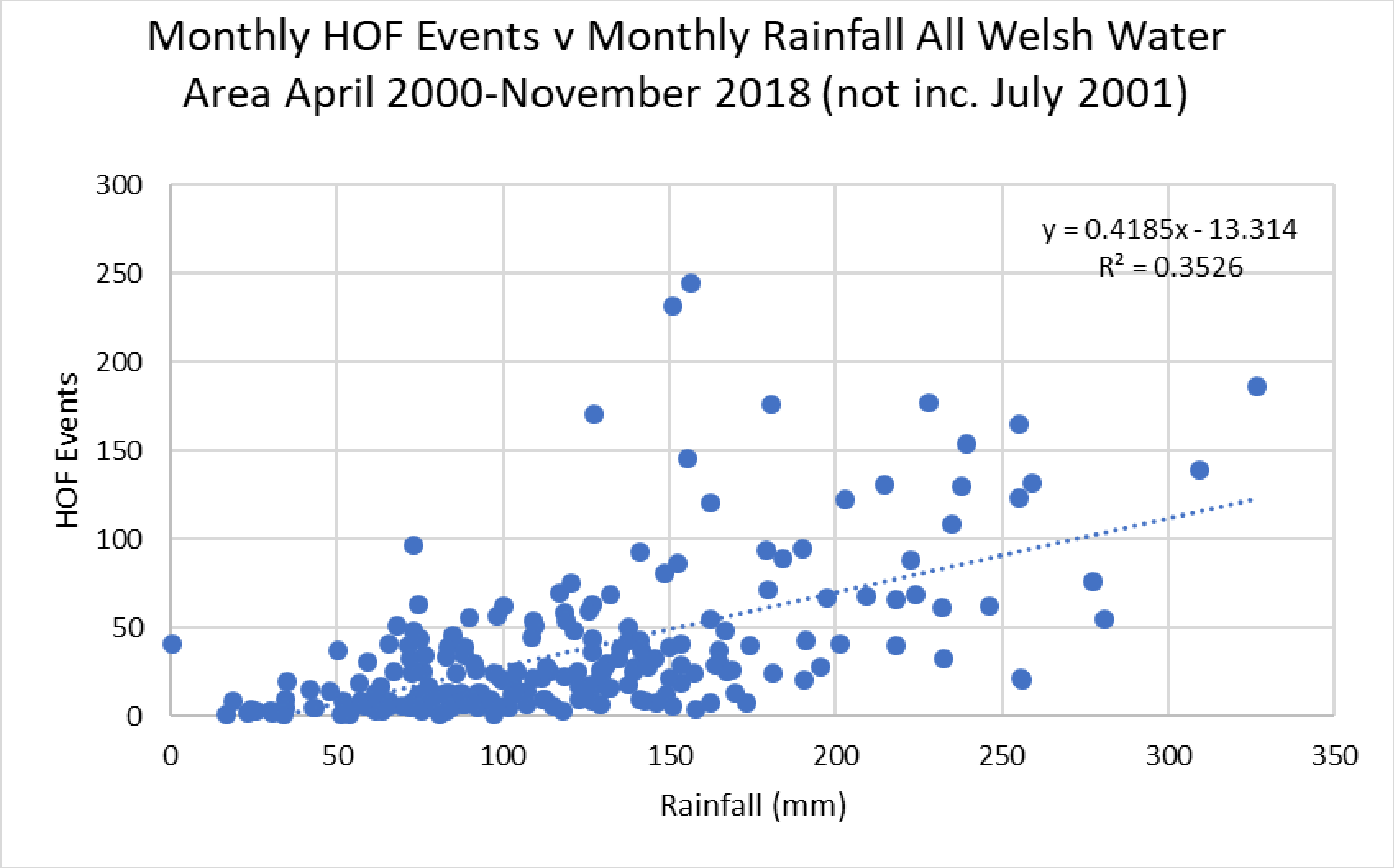


Met Office

A correlation of HOF events versus monthly rainfall for the Welsh Water shows an expected pattern of increasing HOF events with increasing wetter months. However, the R^2 value of 0.24 is modest but it does cover the whole of the Welsh Water region and so may mask some more localised trends.

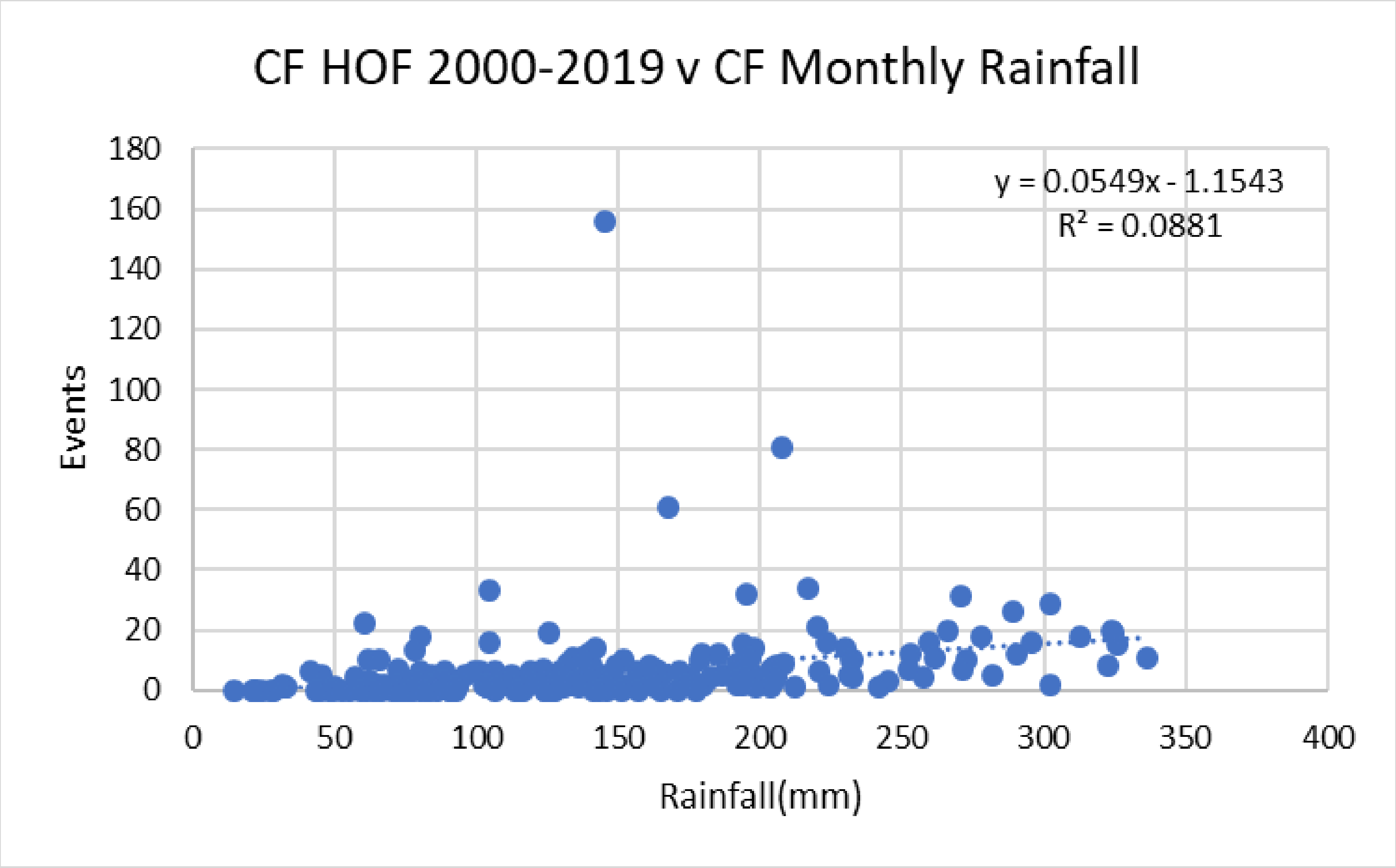
The July 2001 event appears as an outlier with its 456 events which occurred with an unexceptional monthly rainfall total of 111mm.
Removing the July 2001 from the calculation results in a higher correlation of 0.35, shown in the second graph.

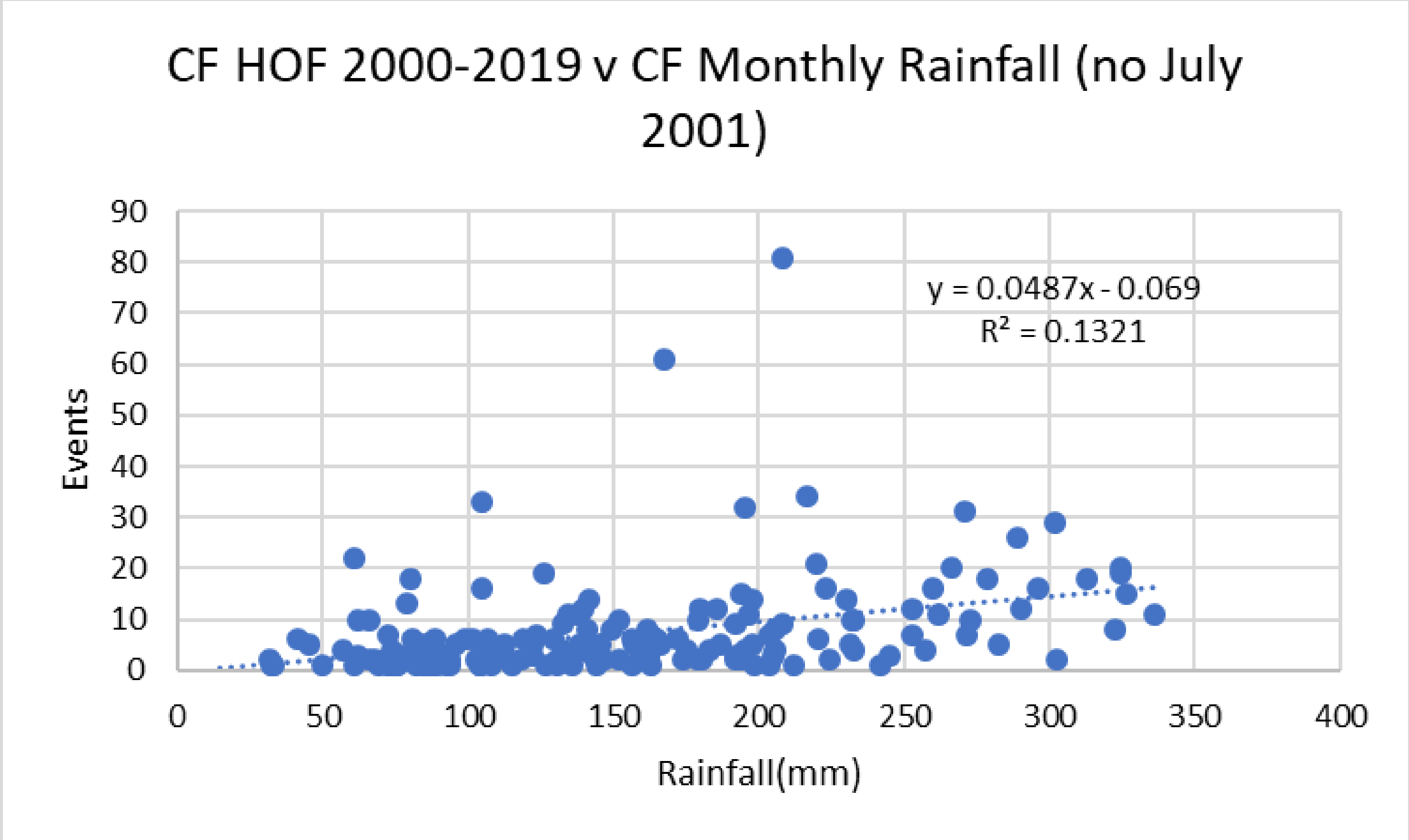


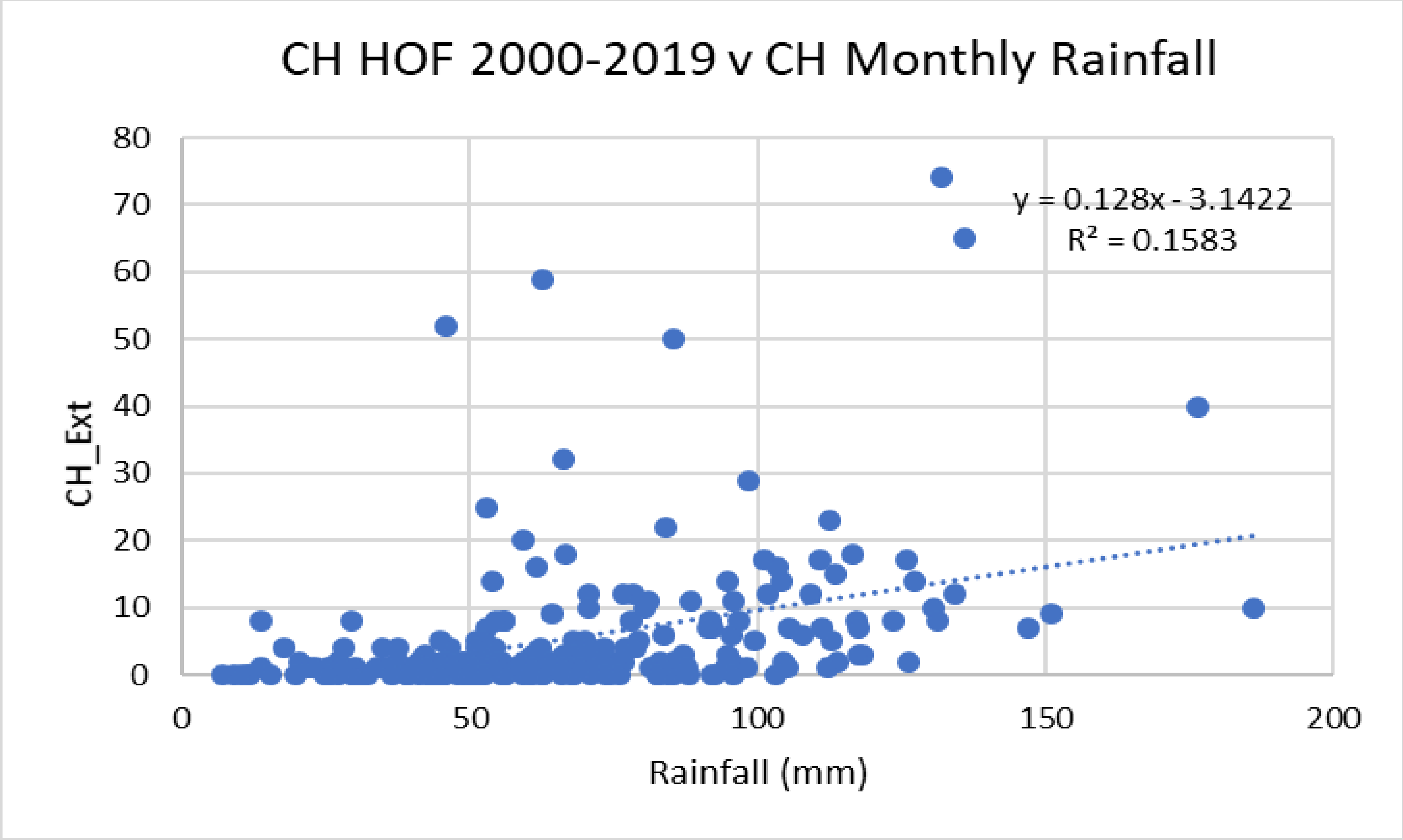


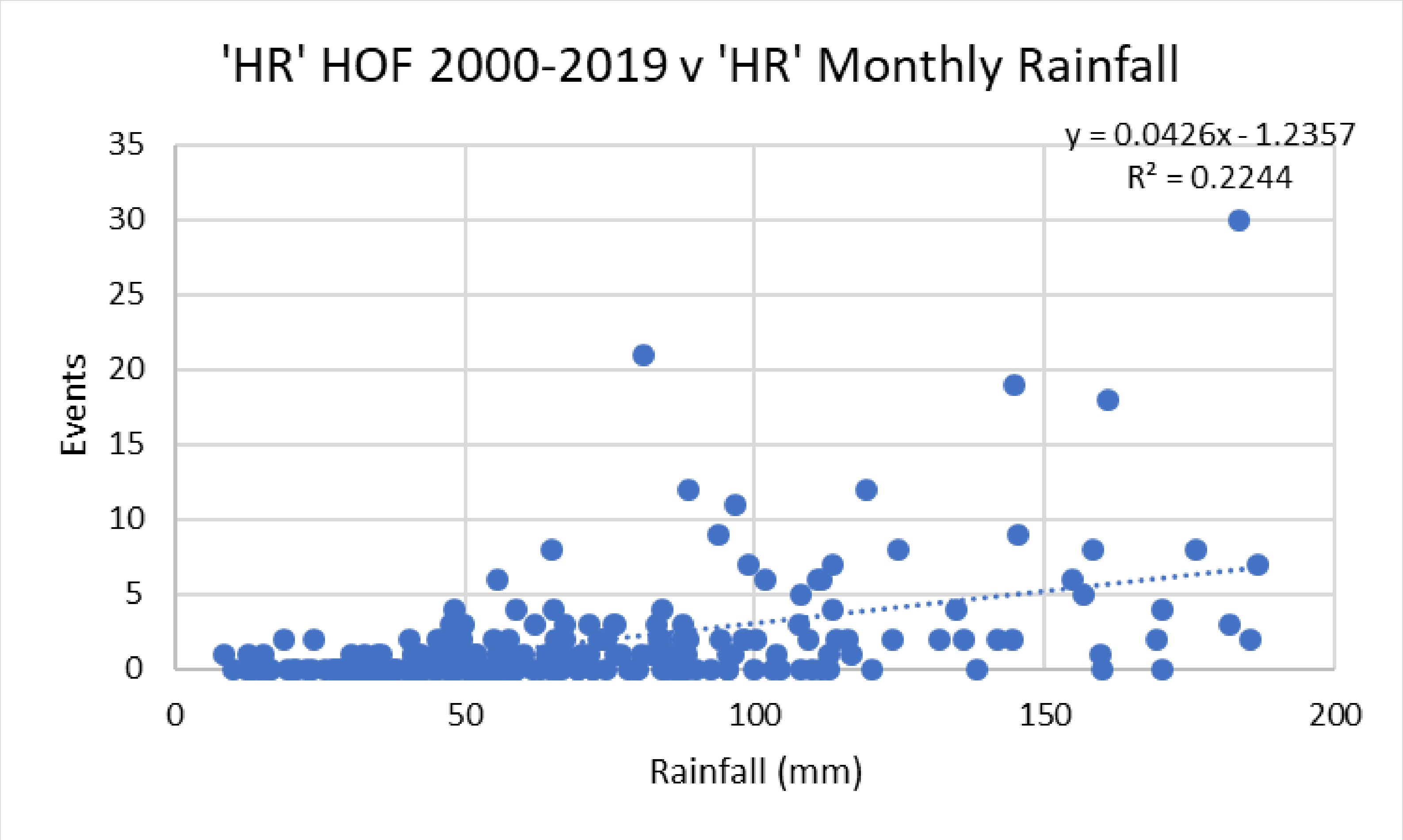
Met Office

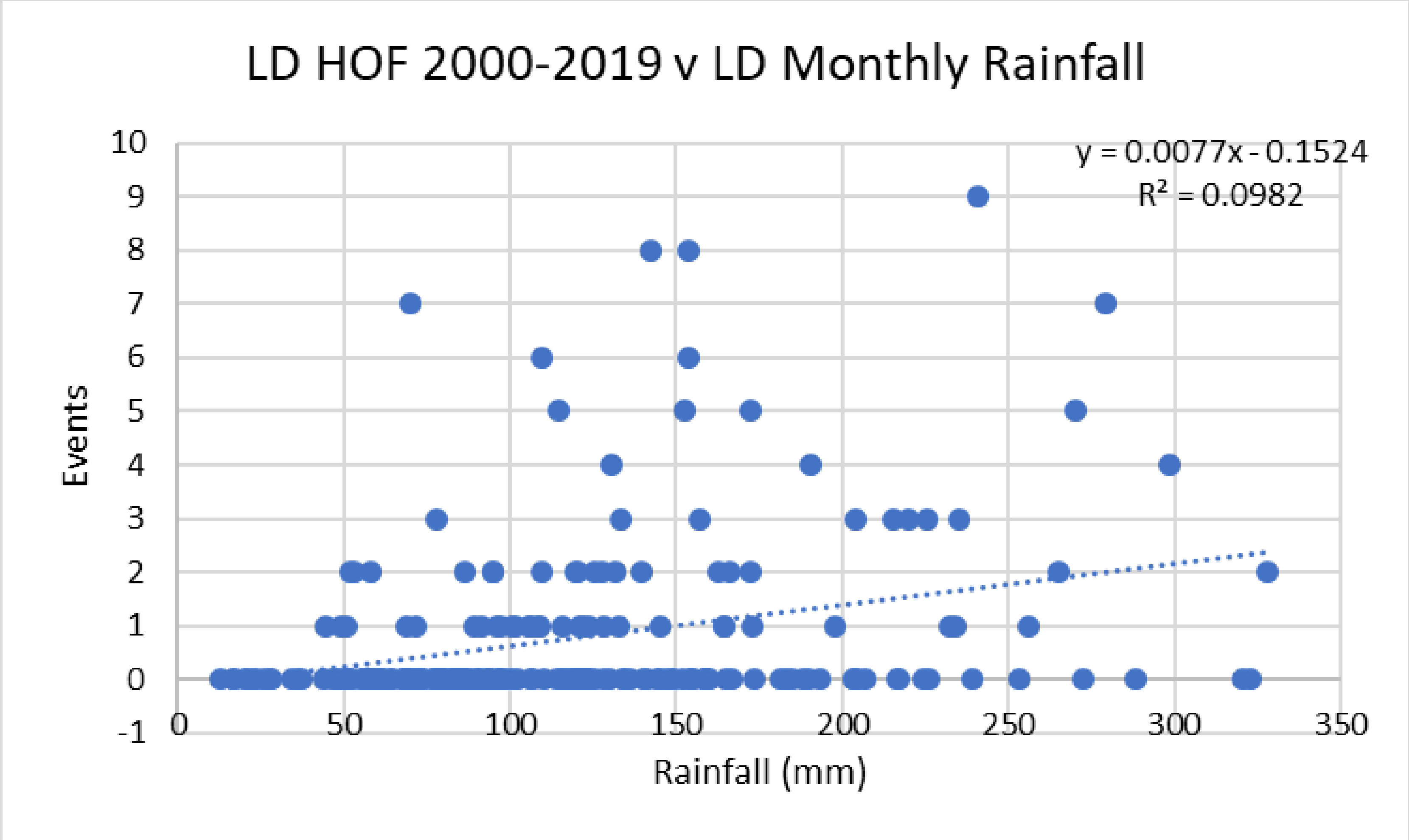
Similar HOF Events v Monthly rainfall correlation plots have been produced for each of the postcode areas. Note CF and NP have two plots, one with and one without the July 2001 event. HR is an amalgamation of the HR,GL and WR postcodes



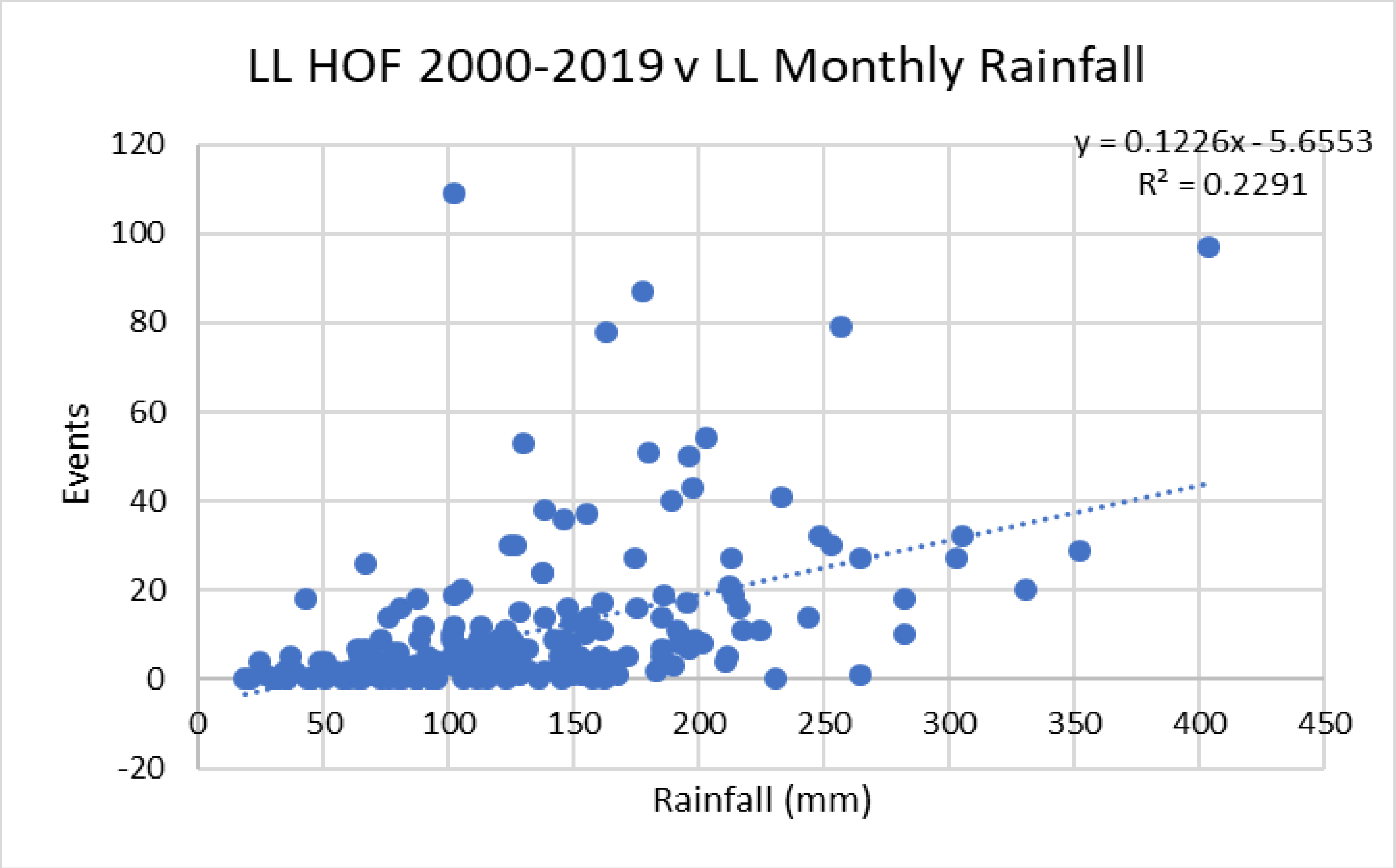




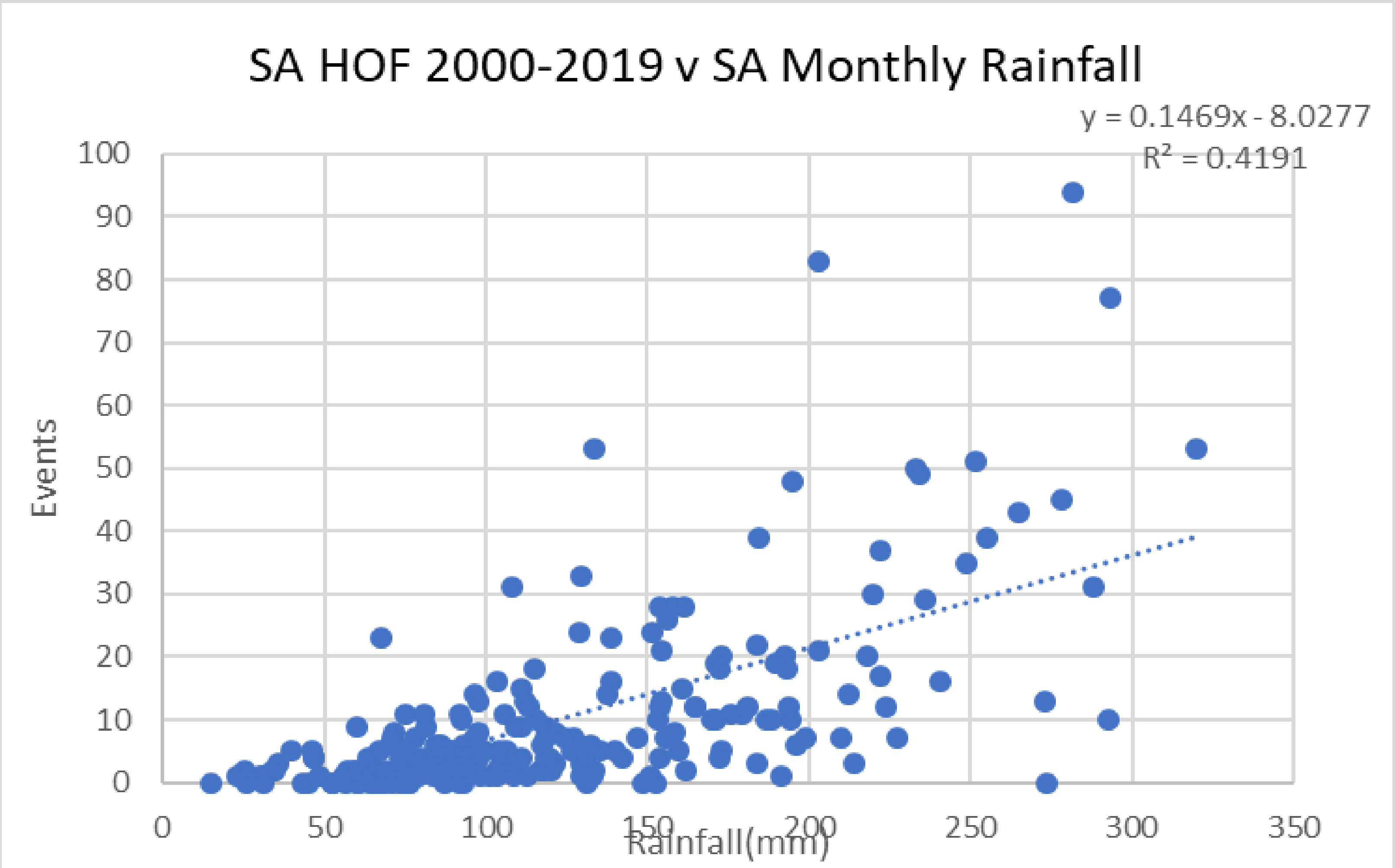




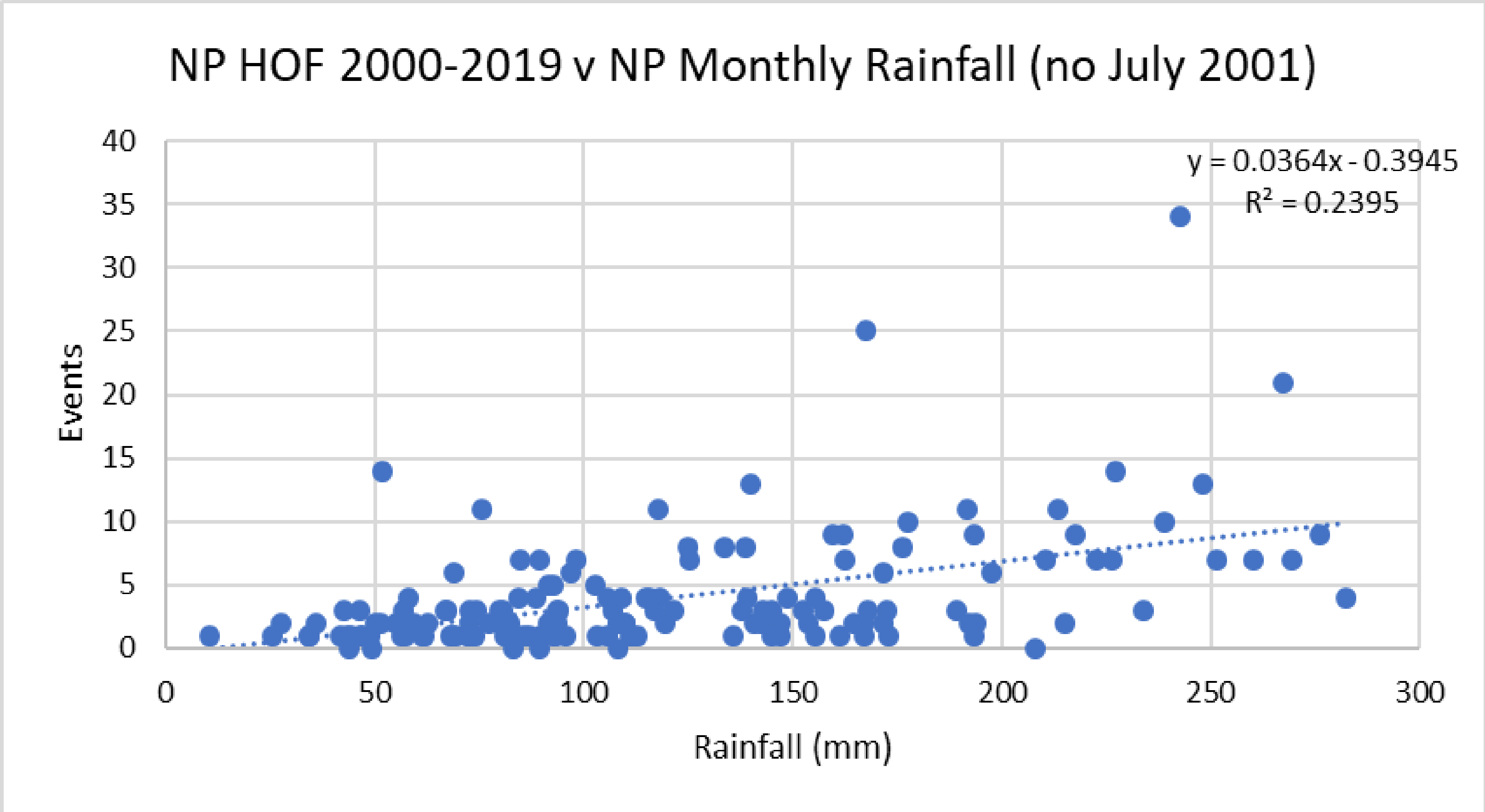
Met Office



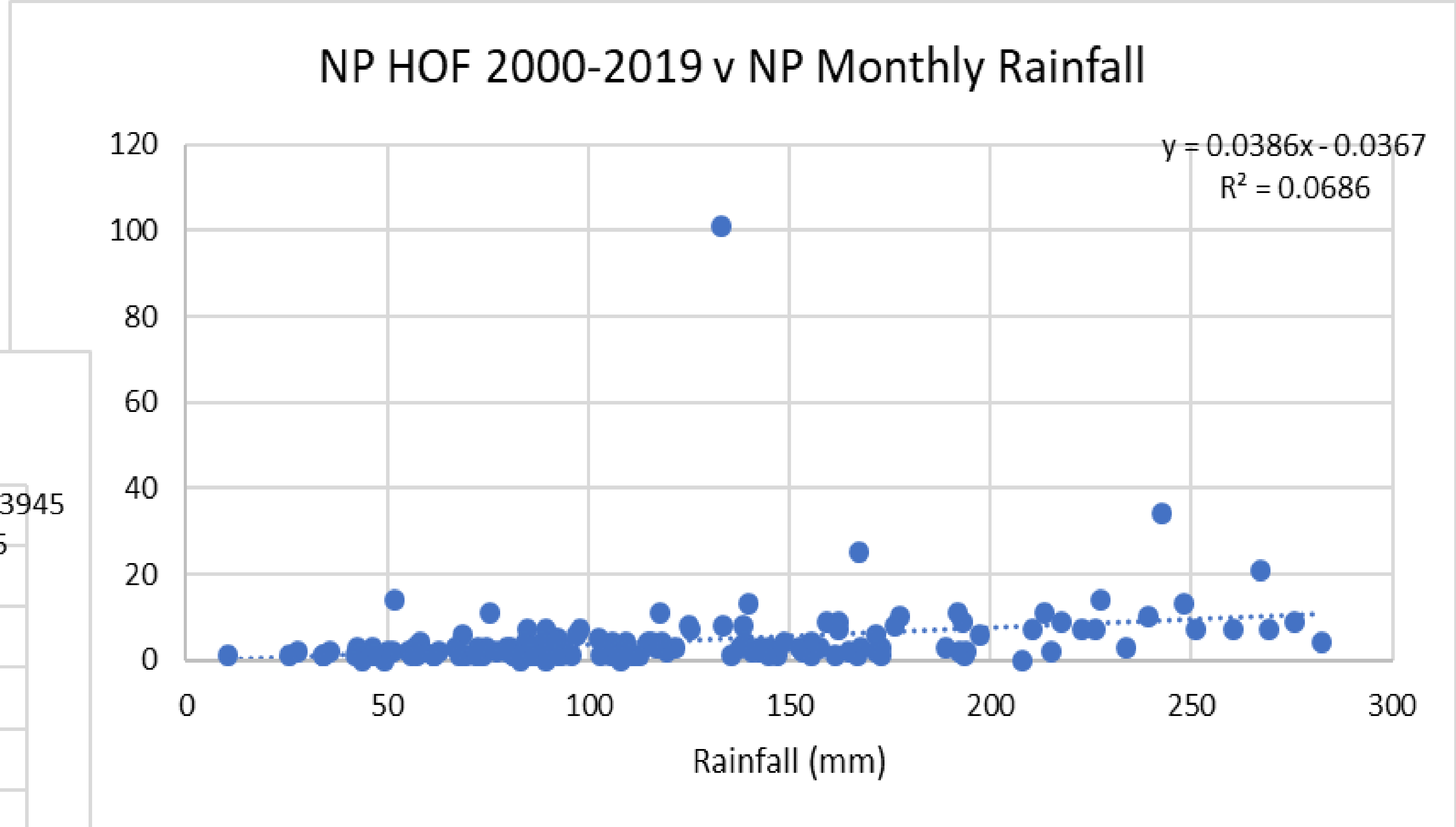
LL HOF 2000-2019 v LL Monthly Rainfall
y = 0.1226x - 5.6553
R² = 0.2291
Events
Rainfall (mm)



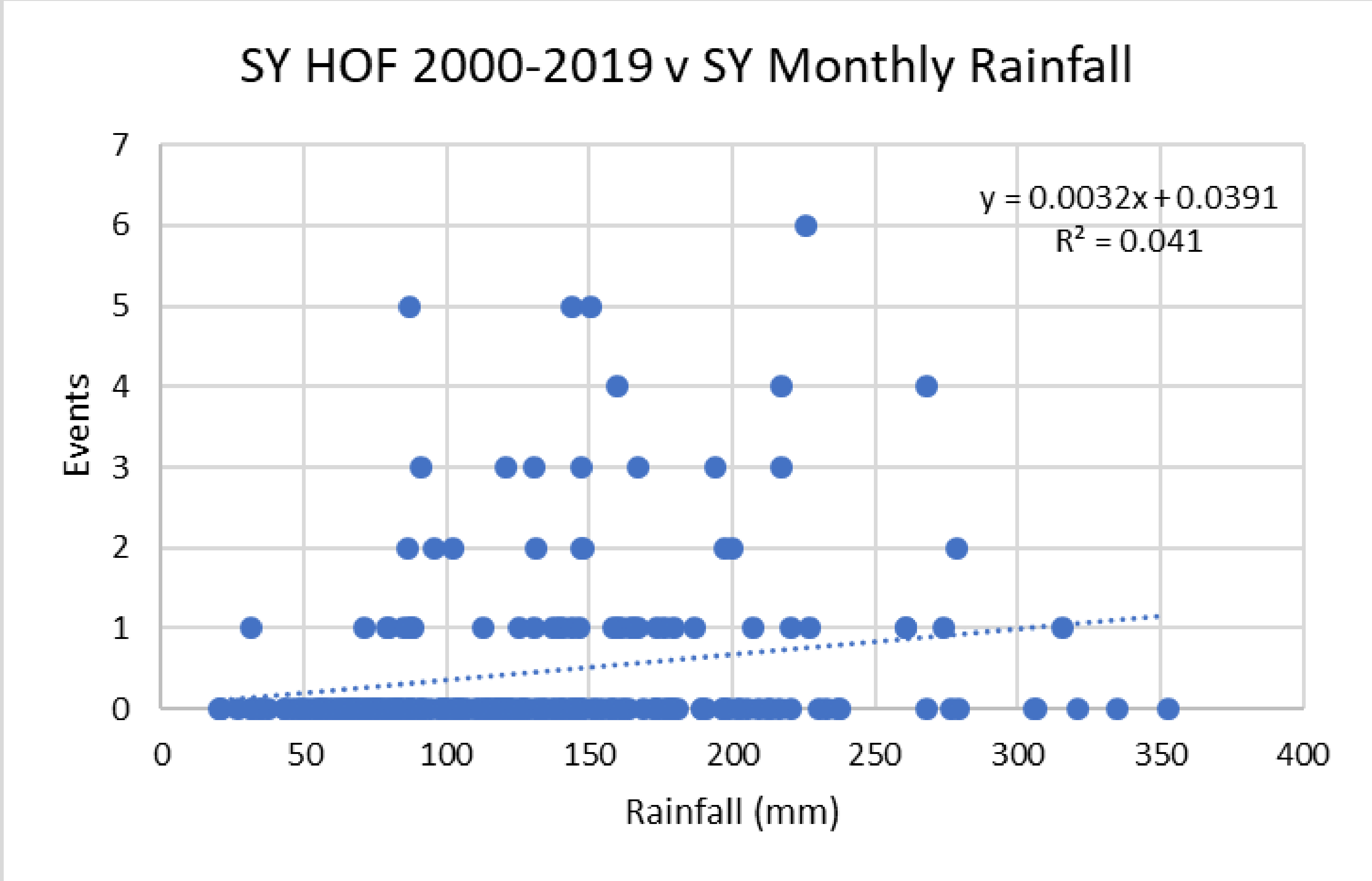
SA HOF 2000-2019 v SA Monthly Rainfall
y = 0.1469x - 8.0277
R² = 0.4191
Events
Rainfall(mm)



NP HOF 2000-2019 v NP Monthly Rainfall (no July 2001)
y = 0.0364x - 0.3945
R² = 0.2395
Events
Rainfall (mm)



NP HOF 2000-2019 v NP Monthly Rainfall
y = 0.0386x - 0.0367
R² = 0.0686
Rainfall (mm)



SY HOF 2000-2019 v SY Monthly Rainfall
y = 0.0032x + 0.0391
R² = 0.041
Events
Rainfall (mm)

- For those areas with very few events, LD and SY, reflecting the fewer number of people living there, the correlations are very low.
- For CF and NP areas, the correlations are improved when the July 2001 values are not included.
- Only the results for the ‘HR’ area has a correlation that is better than that for the whole Welsh Water region analysis. Further investigations would be required to understand why this is.
- Although the increasing trend of events with wetter months is visible at all locations, there is a wide spread of monthly rainfalls associated with the higher number of HOF events.
- Therefore, as the graph in slide 5 indicated, it is difficult to identify the relationship between rainfall and HOF events at a monthly level. More insights might be gained by analysing data measured over a shorter time scale.
- The next few slides relate to the analysis of daily rainfall data.

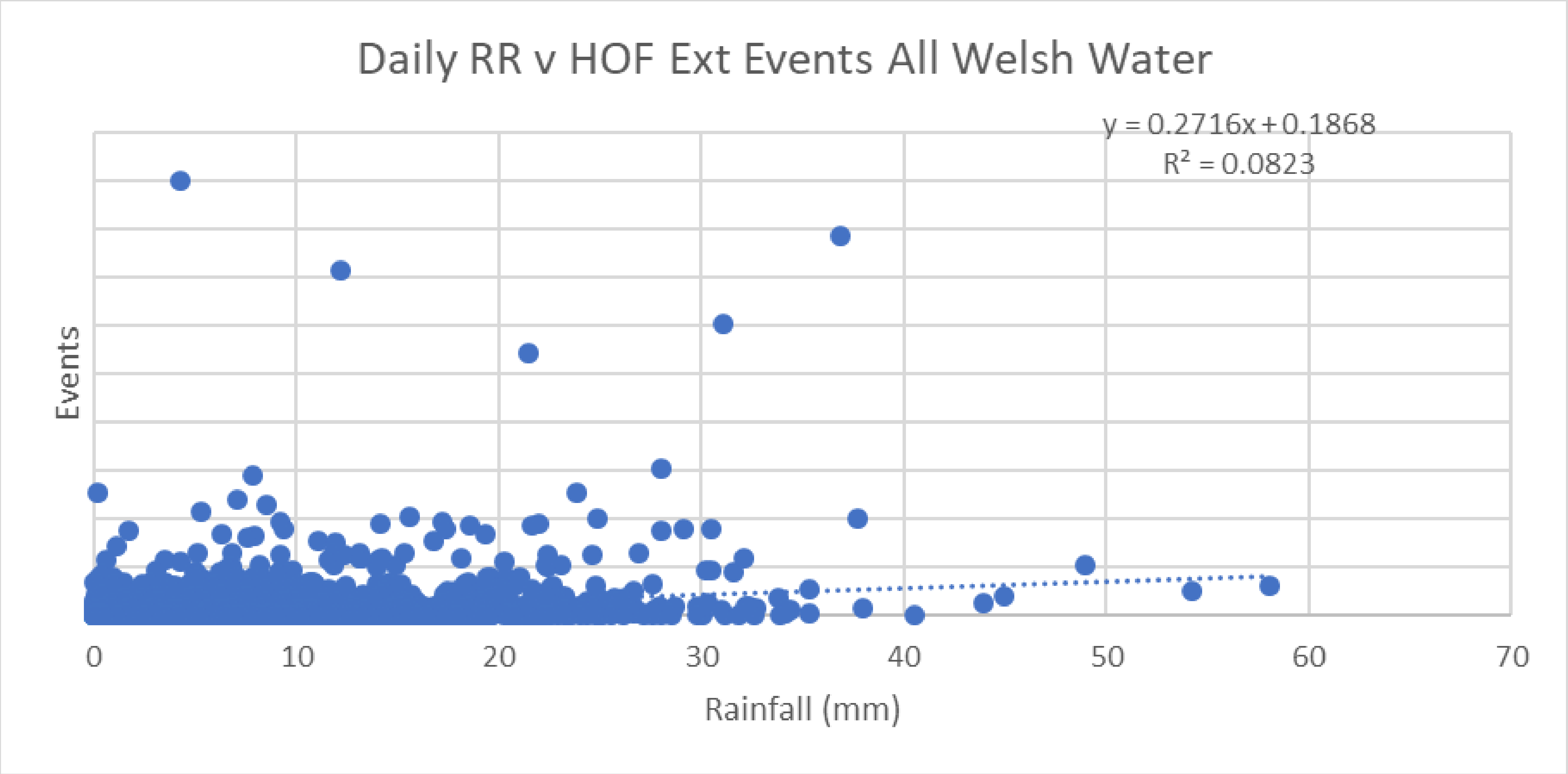
Met Office

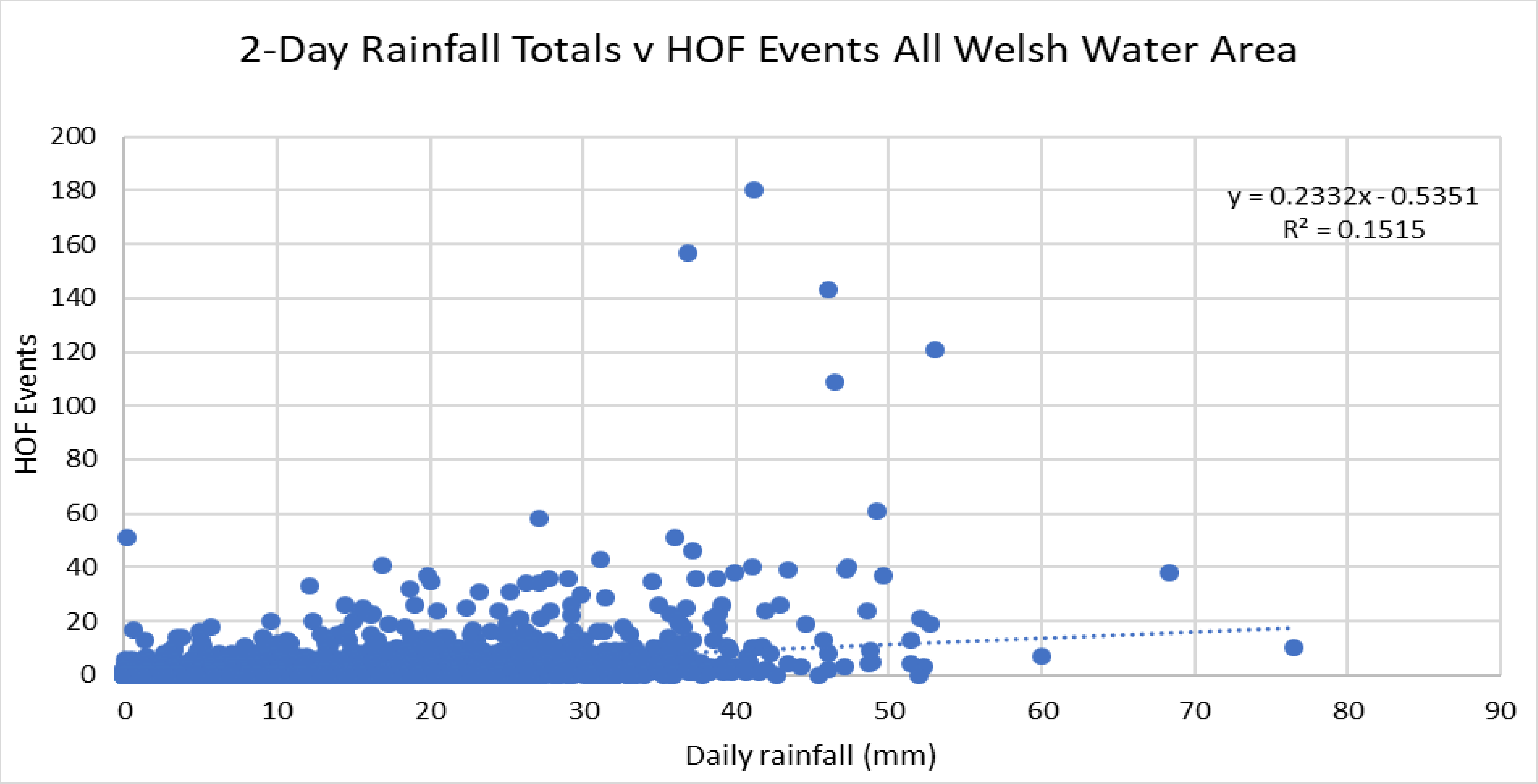
A plot of daily rainfall v daily HOF events (top right) shows a similar pattern to that of the monthly data but a poorer correlation. Very high numbers of events occurring with daily values ranging from < 5mm to > 35mm.

A confounding factor will be that HOF events are recorded on midnight to midnight days whereas the daily rainfall is recorded from 09:00 GMT on one day to 09:00 GMT the next. Therefore, rainfall occurring in the early hours of day dd is allocated to day dd-1 but any associated flooding event will be noted for day dd.

To help account for this, another correlation was carried out using a 2-day rainfall total, for the day that the HOF event occurred (dd) and the previous day (dd-1) - see bottom right plot. The spread of rainfalls for the highest event frequencies now compressed to 35-55mm and the correlation has improved for the WW area. The same results were obtained for all the postcode area analyses (graphs not shown).

Further analysis of daily rainfall is all based upon the 2-day rainfall totals which can be taken to equate roughly to 'event' rainfall (see later).

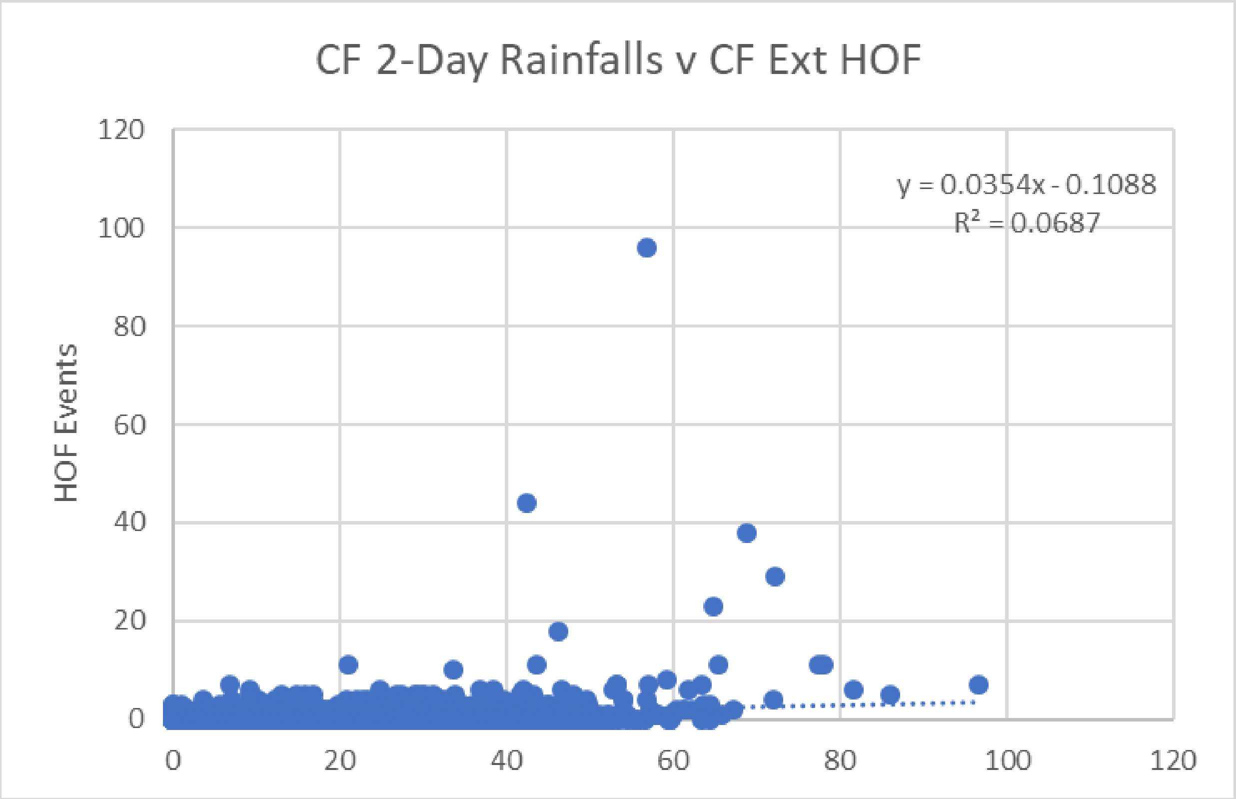


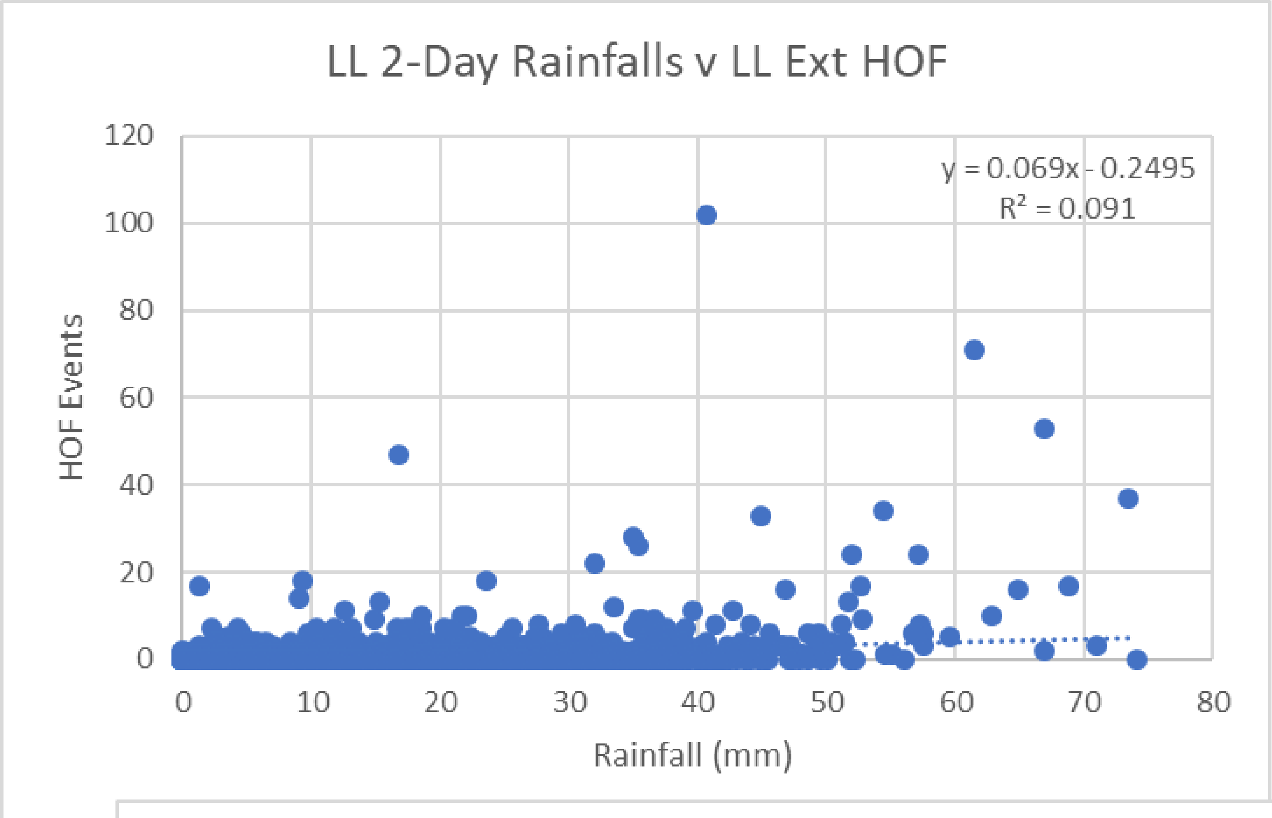


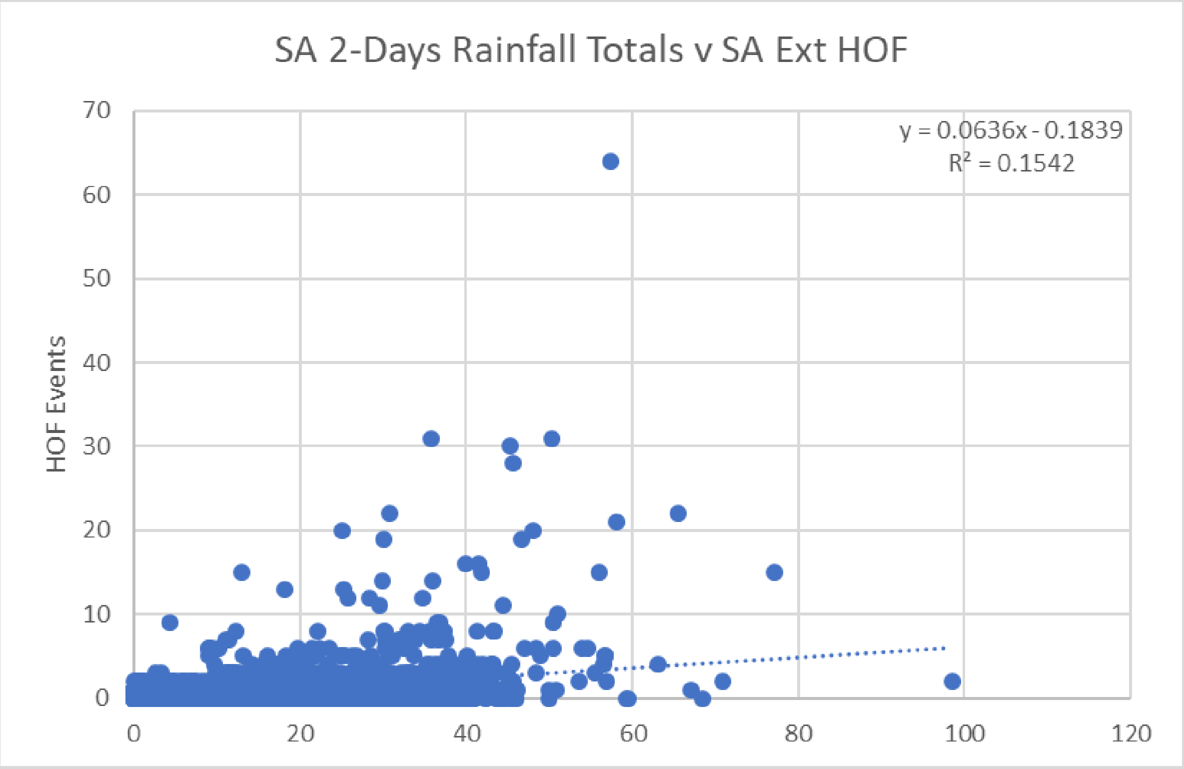
Met Office

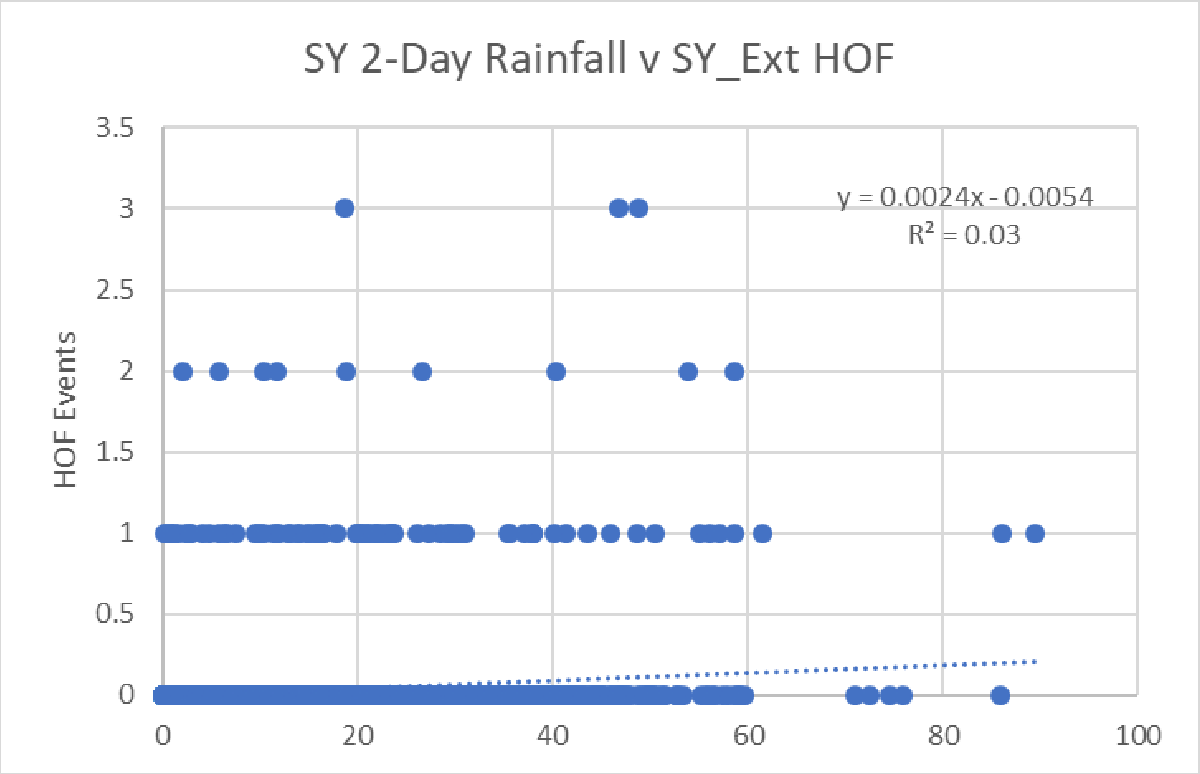
Graphs of 2-day rainfall totals v HOF Events April 2000 – November 2018 for the eight postcode areas are shown. Points to note:

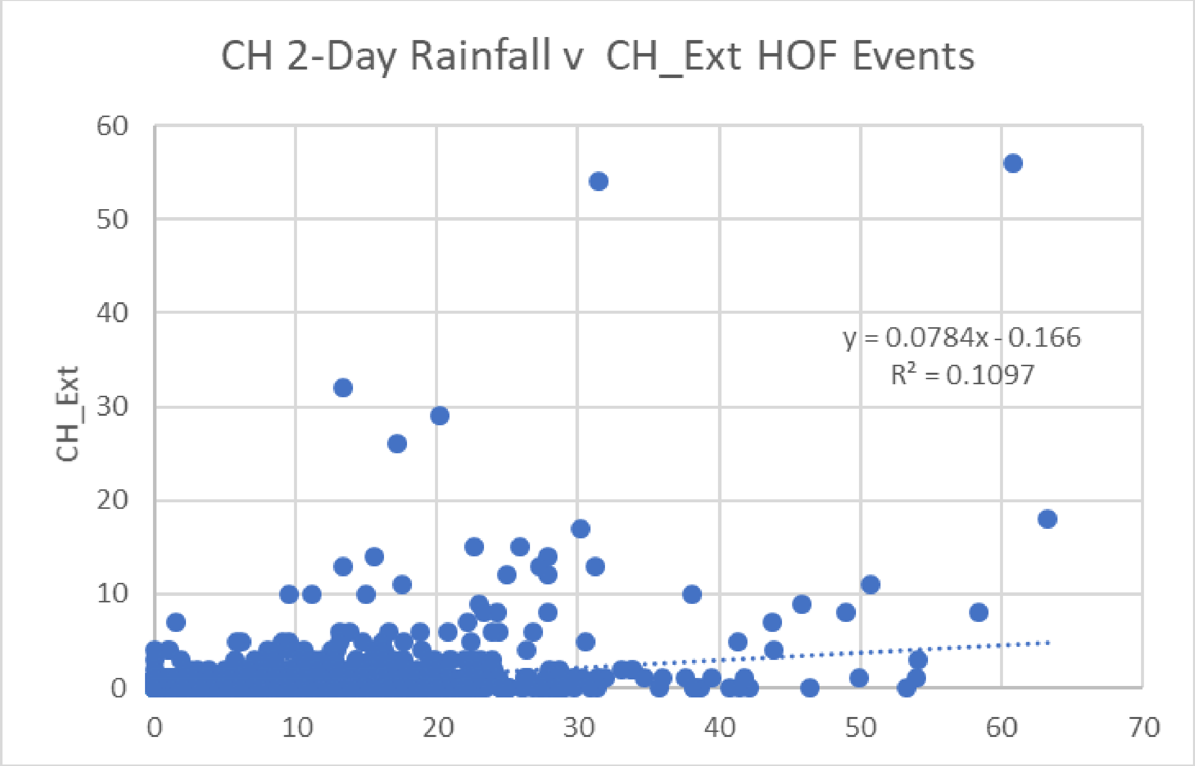
- The different vertical scales
- The plots for SY and LD are poor due to the lack of events
- The plots for CF and NP are adversely affected by the 3/4th July 2001 event.
- More than 10 events in a day have occurred quite frequently in the LL and CH postcode areas but hardly ever or never in the others.

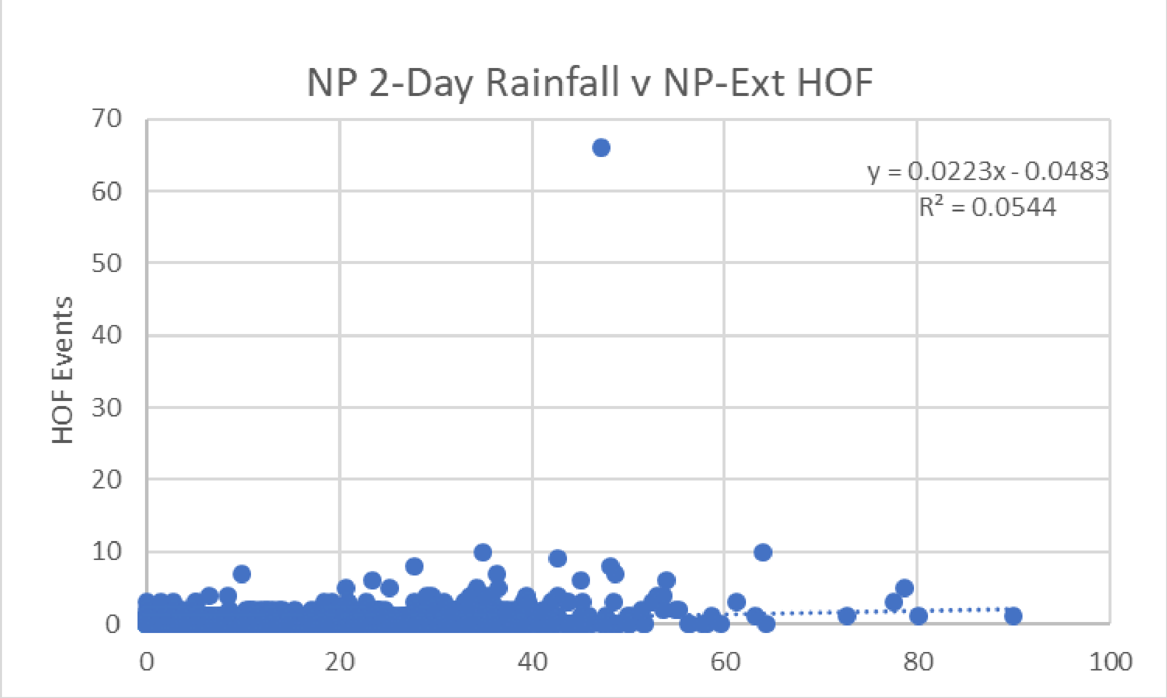


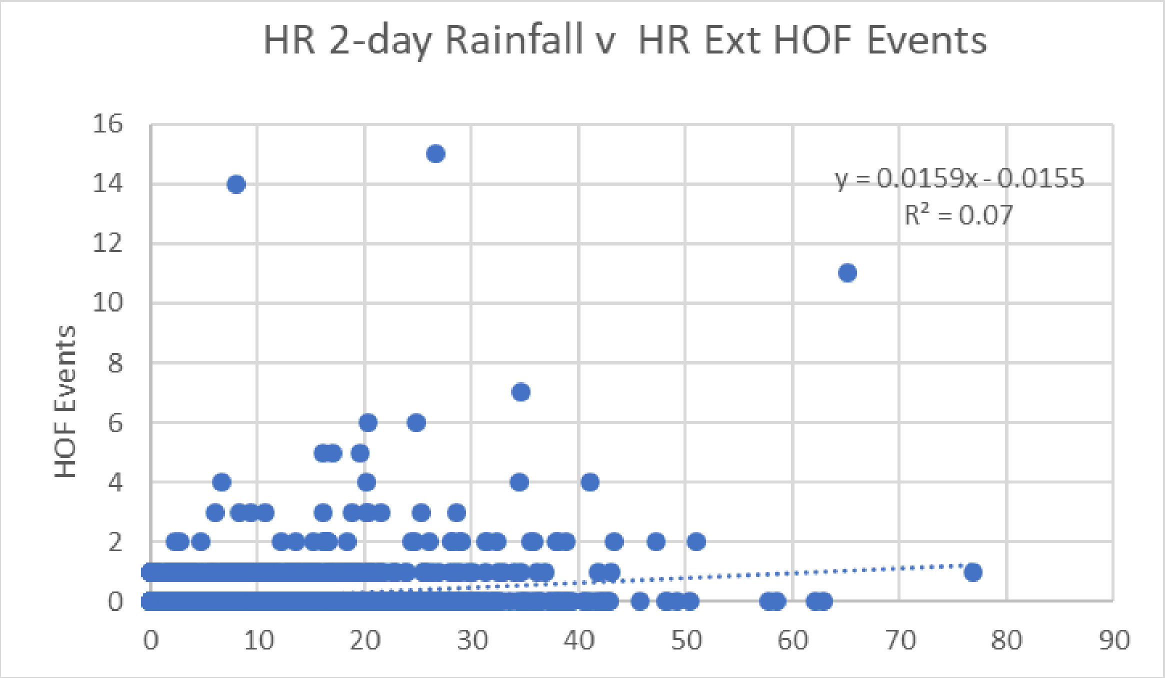


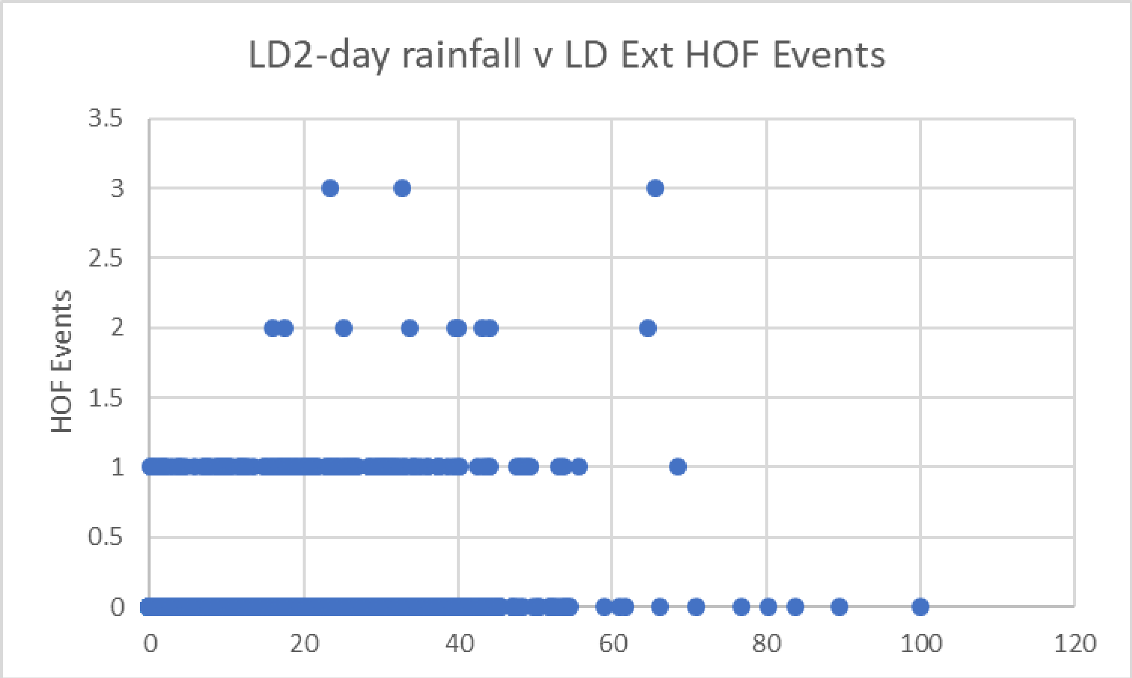




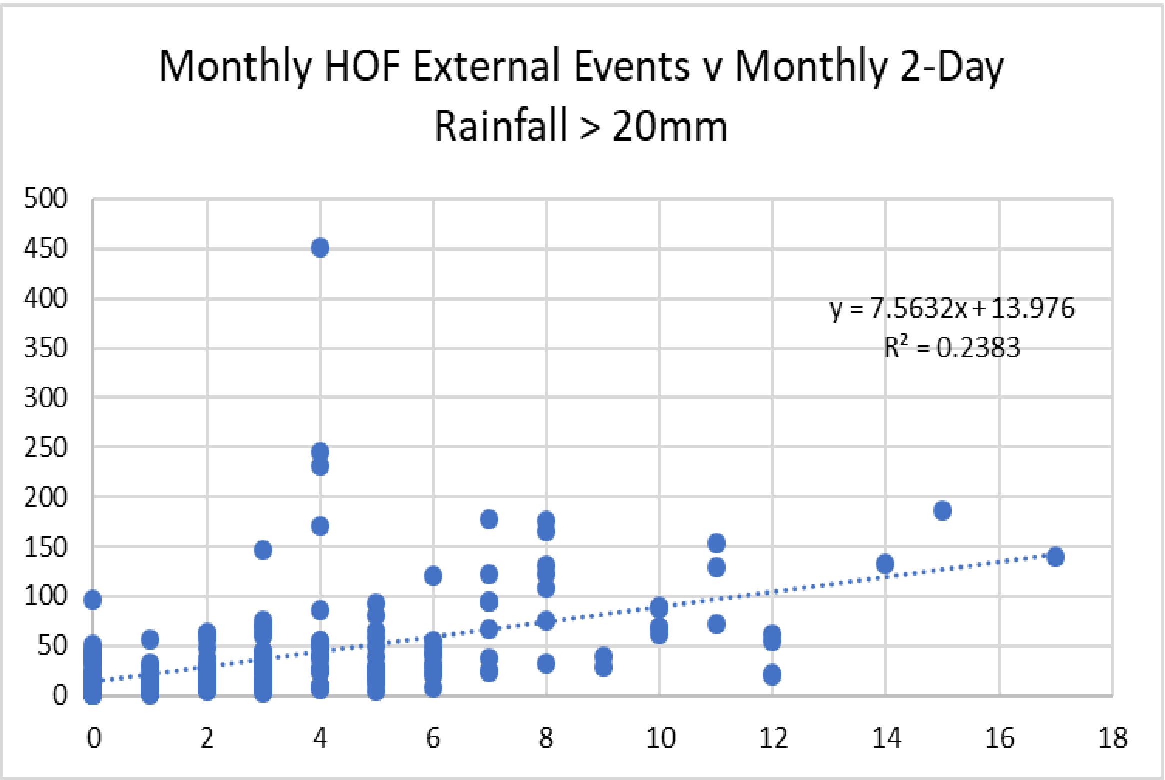


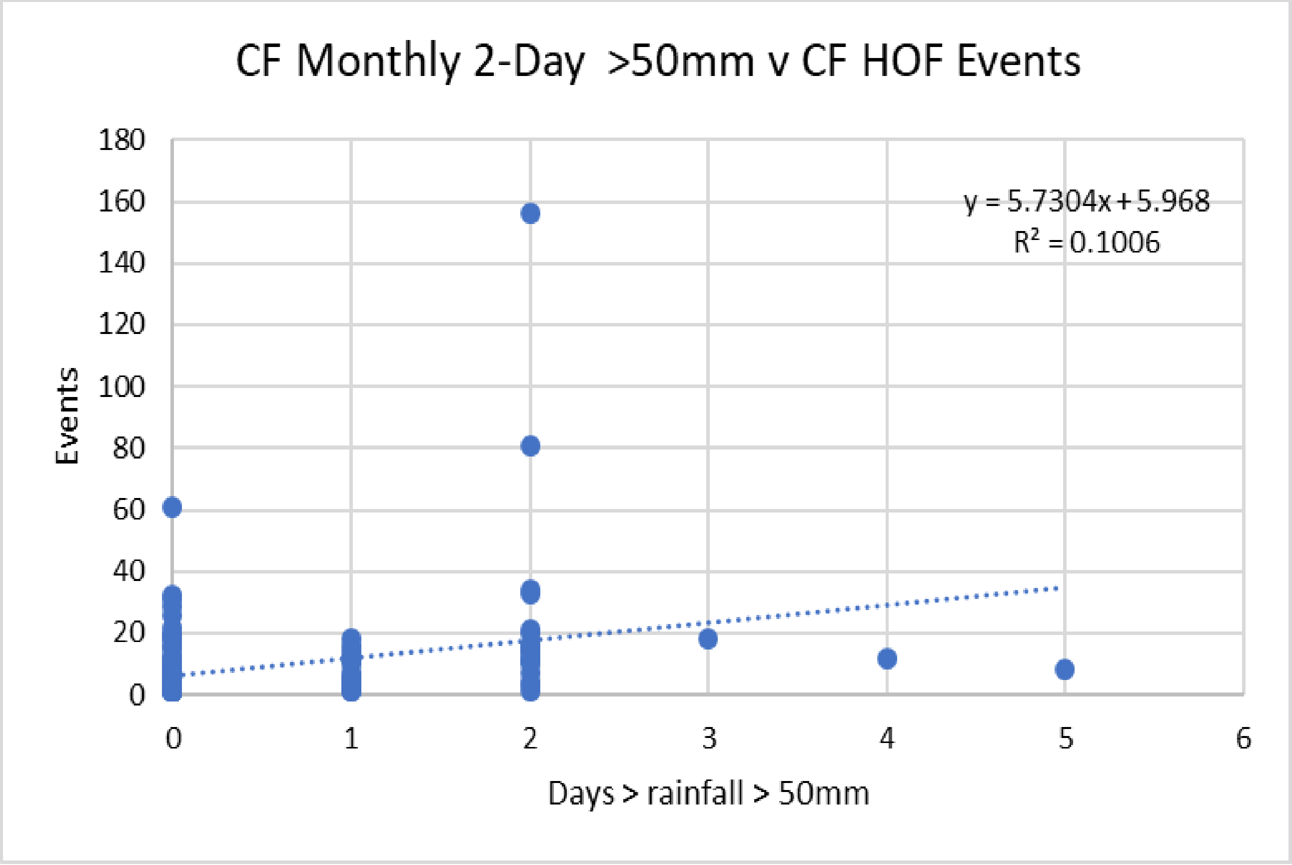


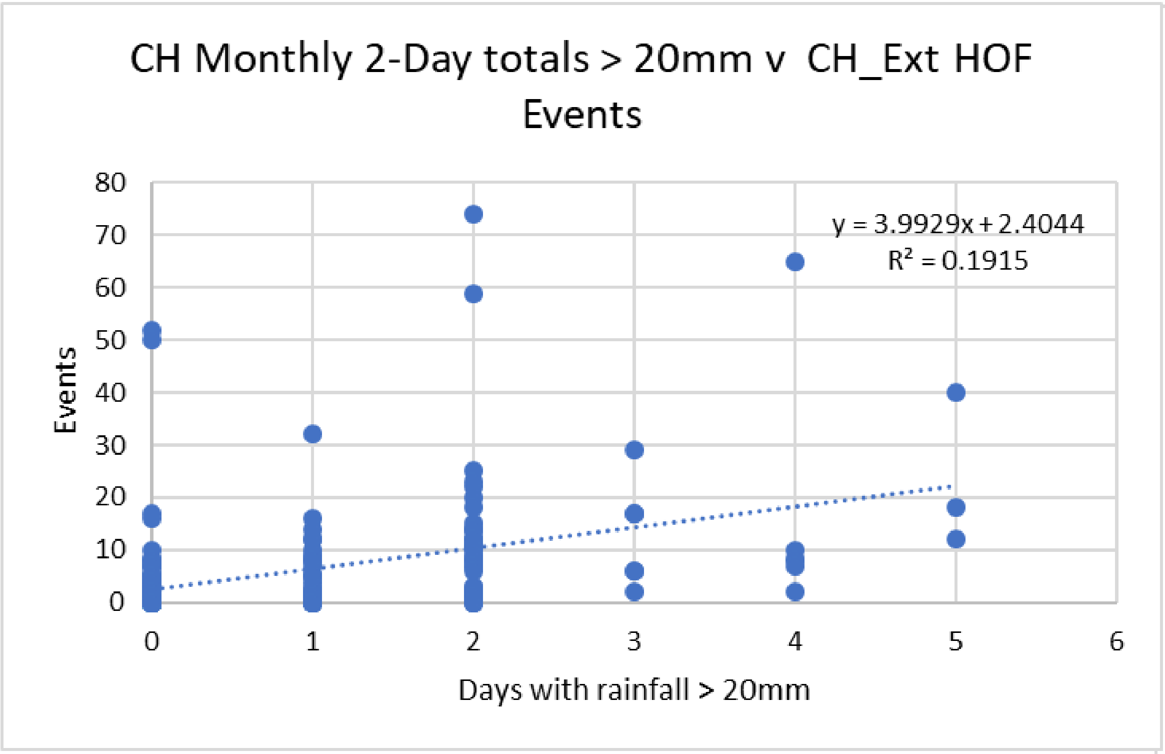


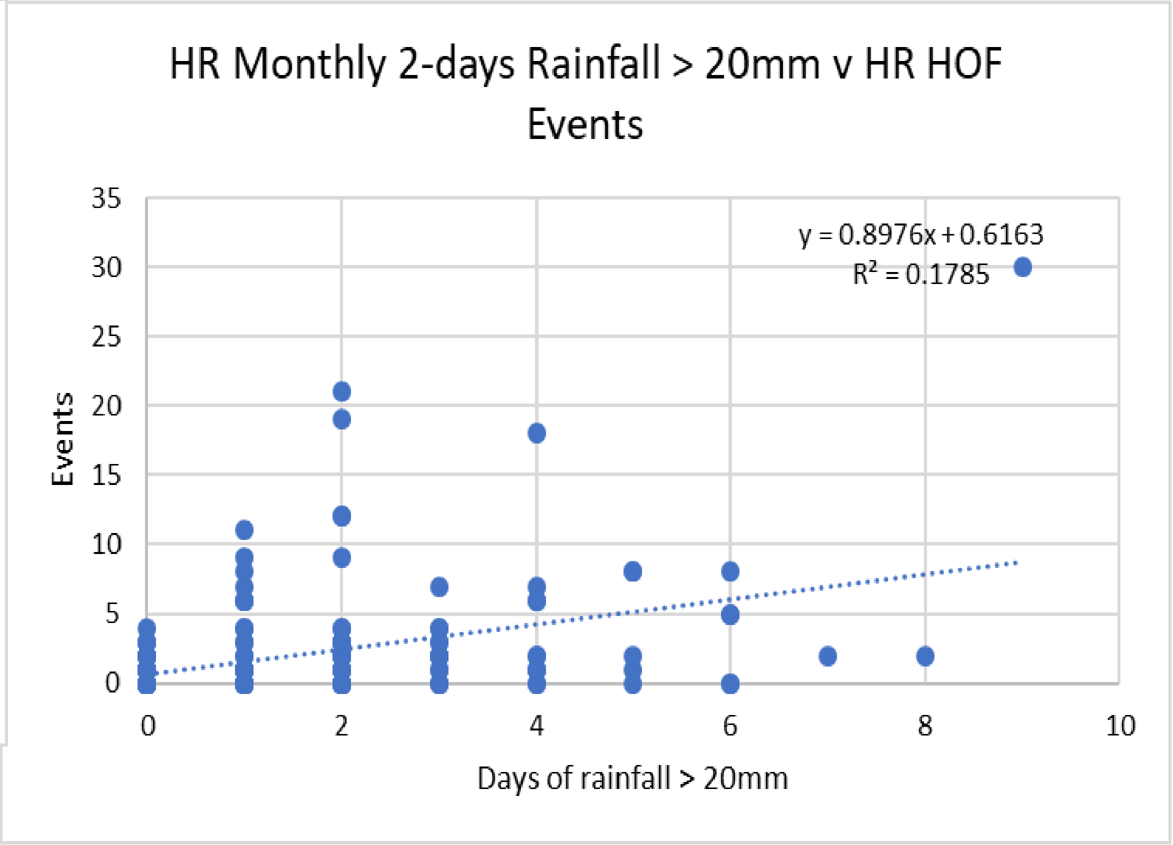


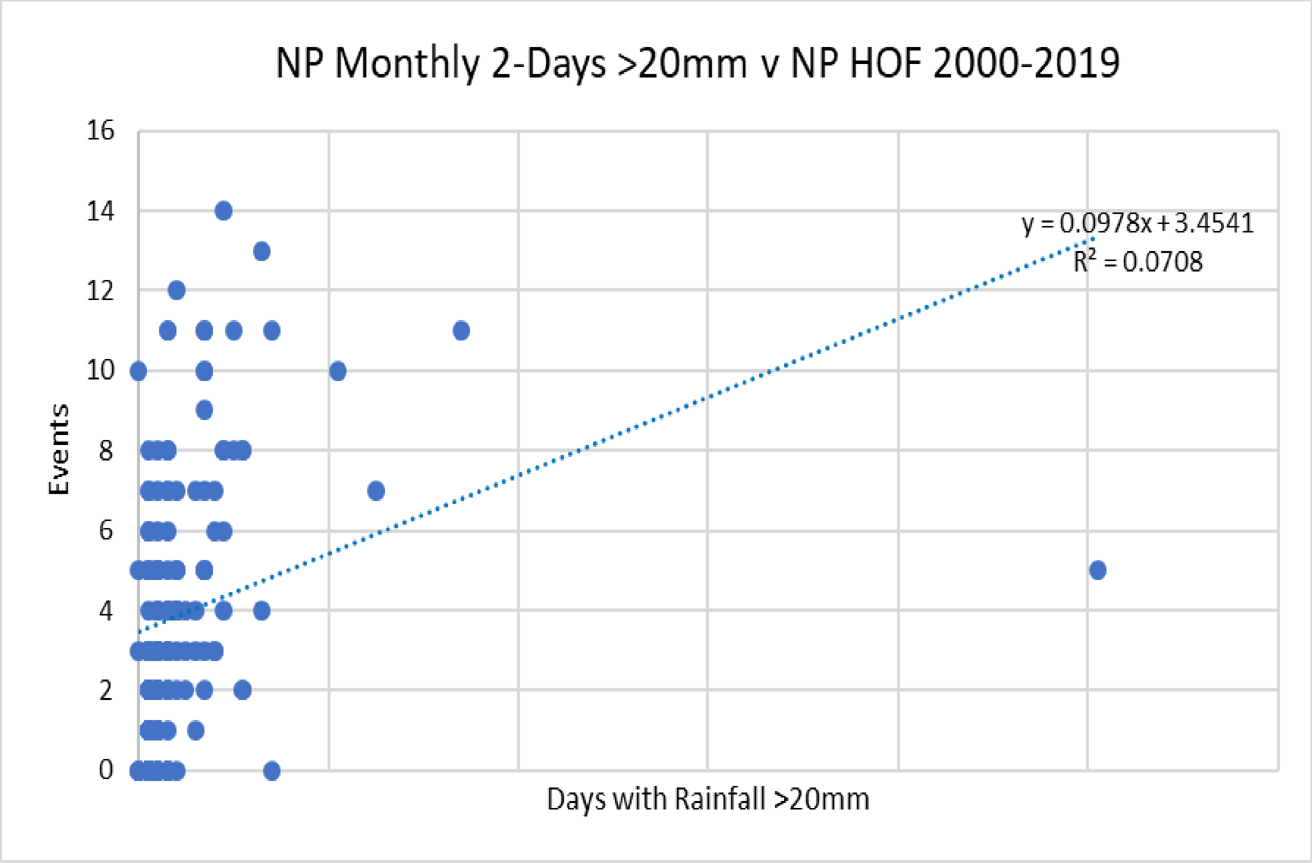
To gain extra insights, the daily rainfall was analysed to isolate the event days (2-day totals) with daily rainfalls > 10, 20, 30, 40 and 50mm. However, there is a balance between trying to isolate 'extreme' days but retaining a suitable number of events to analyse. For most areas, events > 20mm provided the best relationship apart from the LL analysis where 40mm was more significant and for CF, the 50mm provided the best results. These are presented here for WW plus six of the areas and show encouraging results. SY and LD did not have enough events to provide sensible results and so are not included.

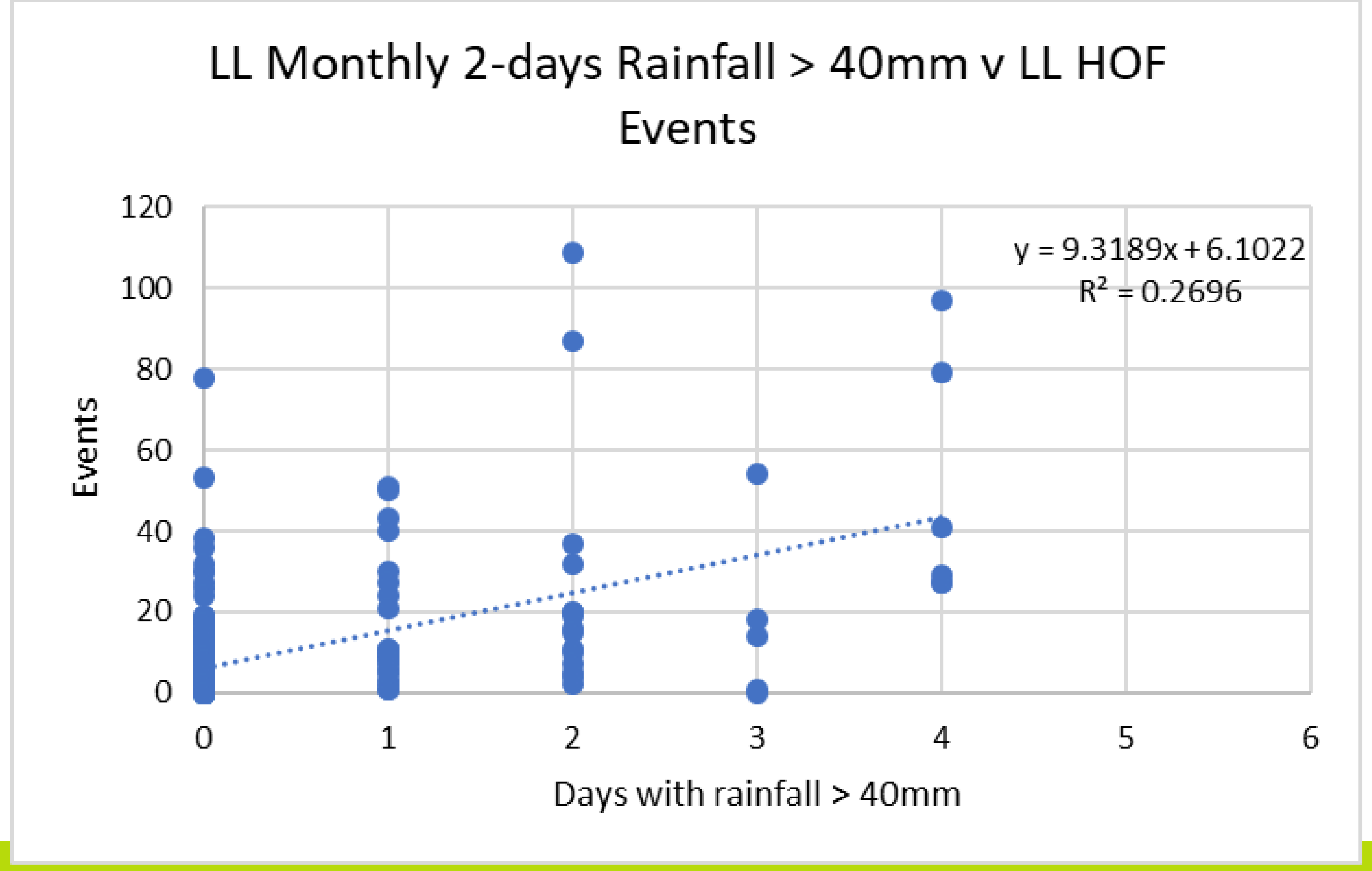


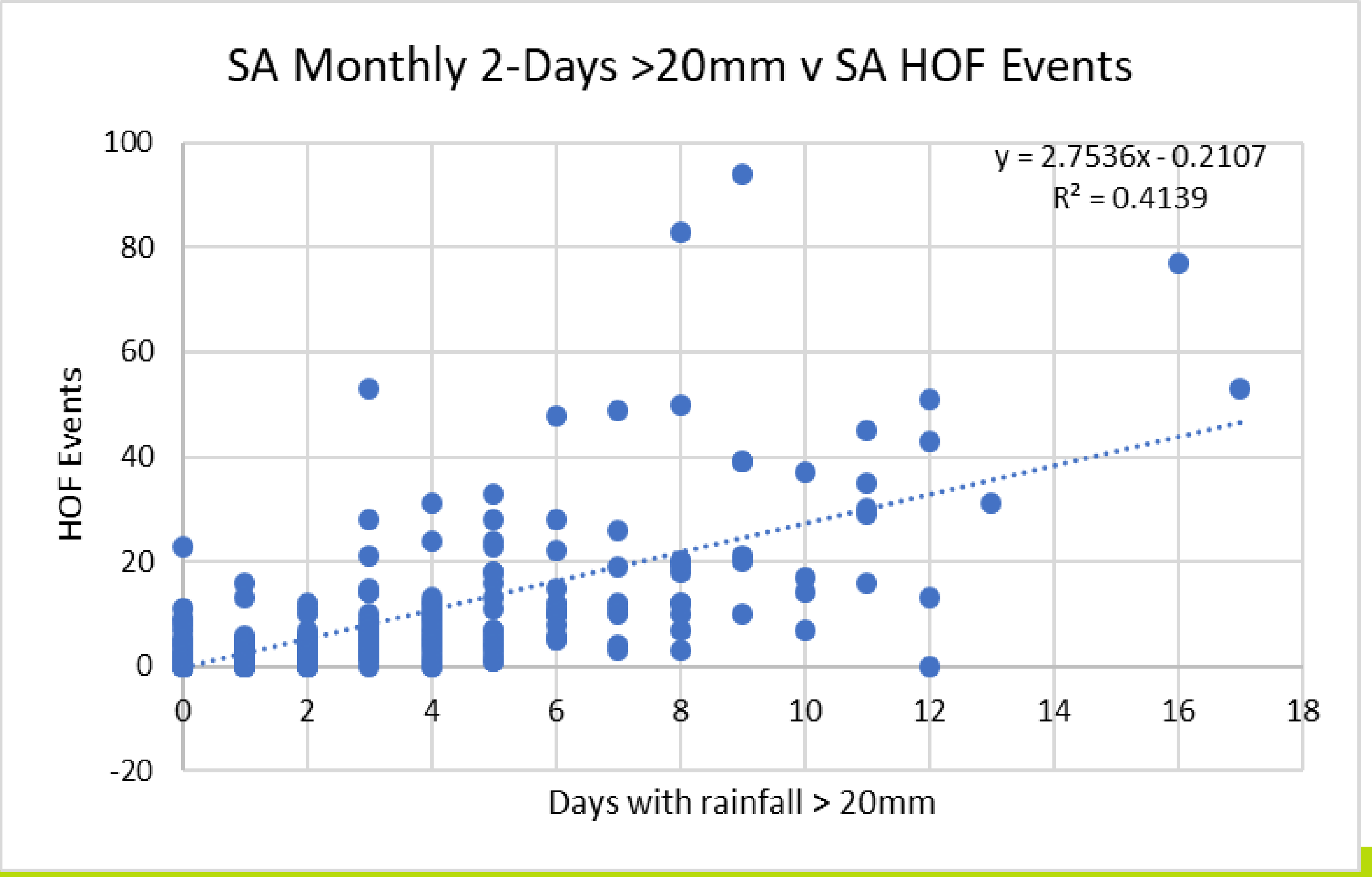




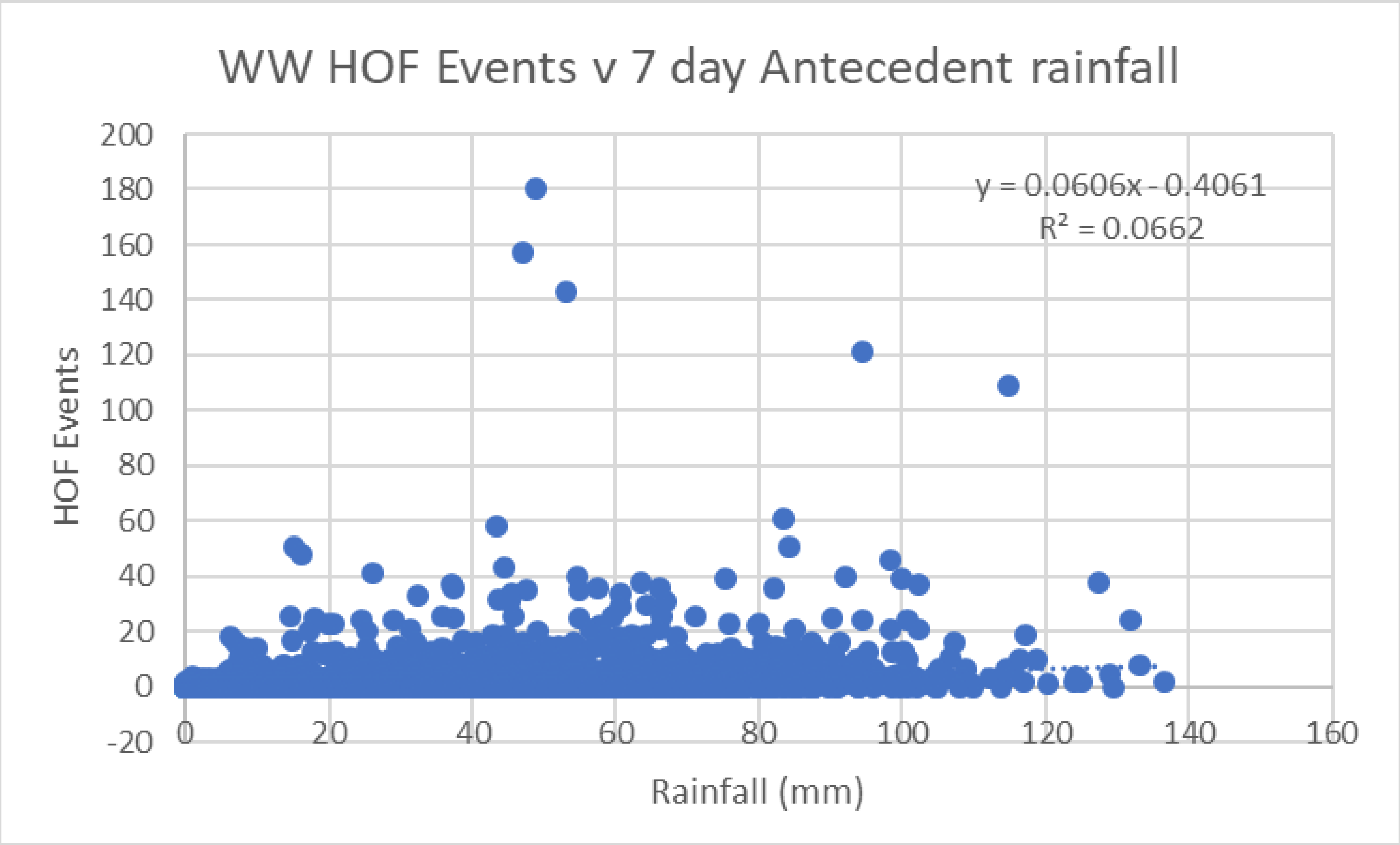


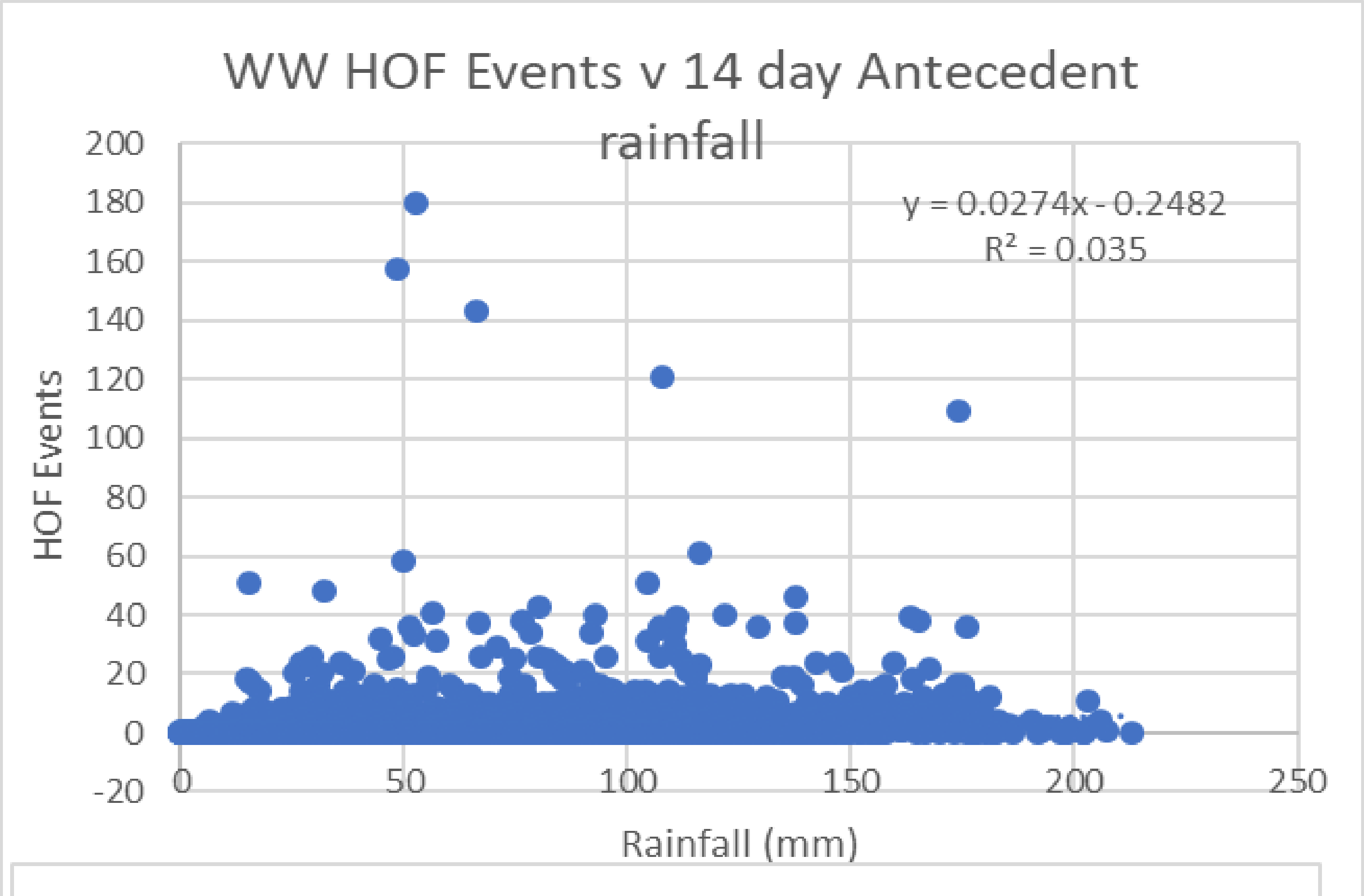


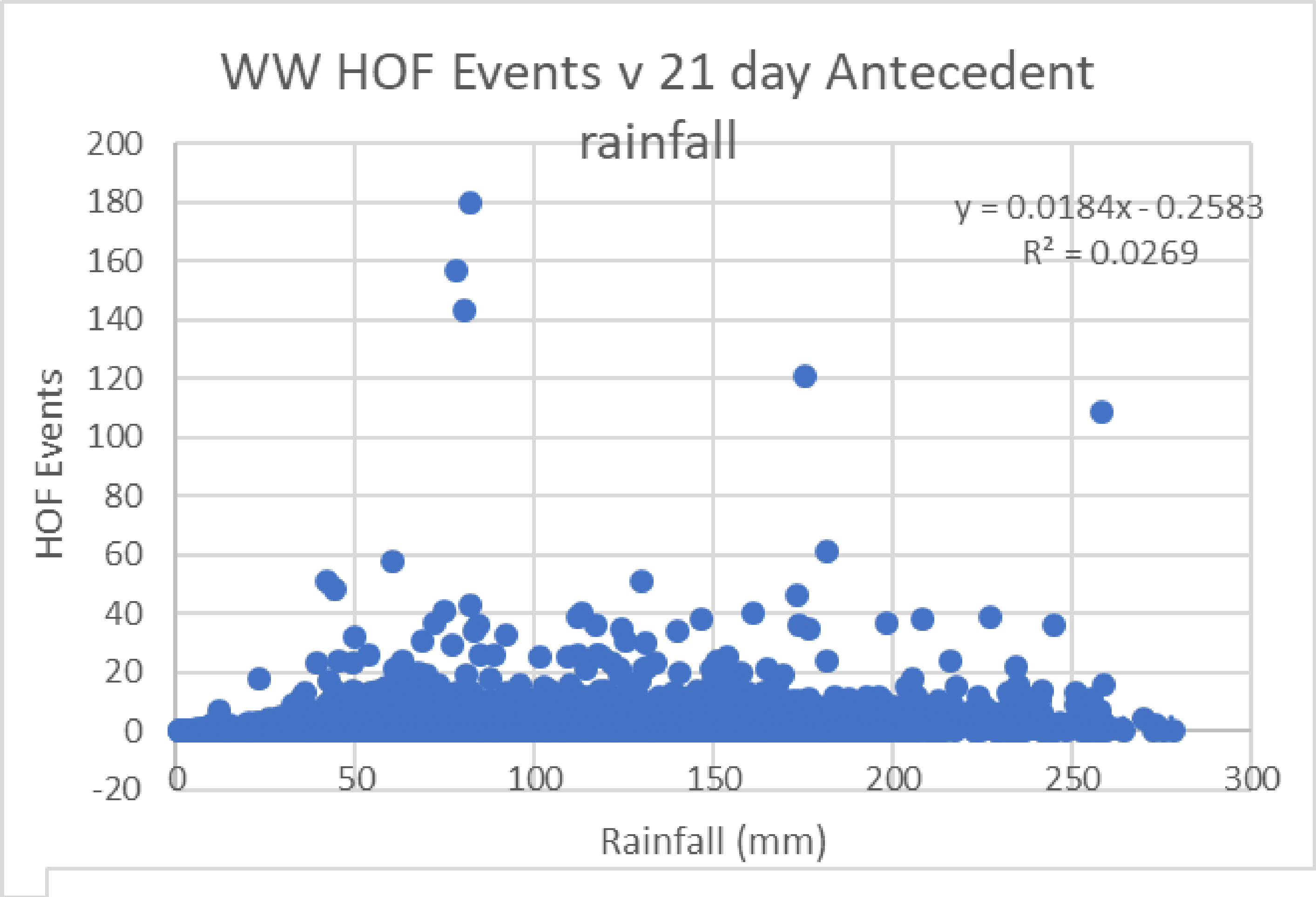


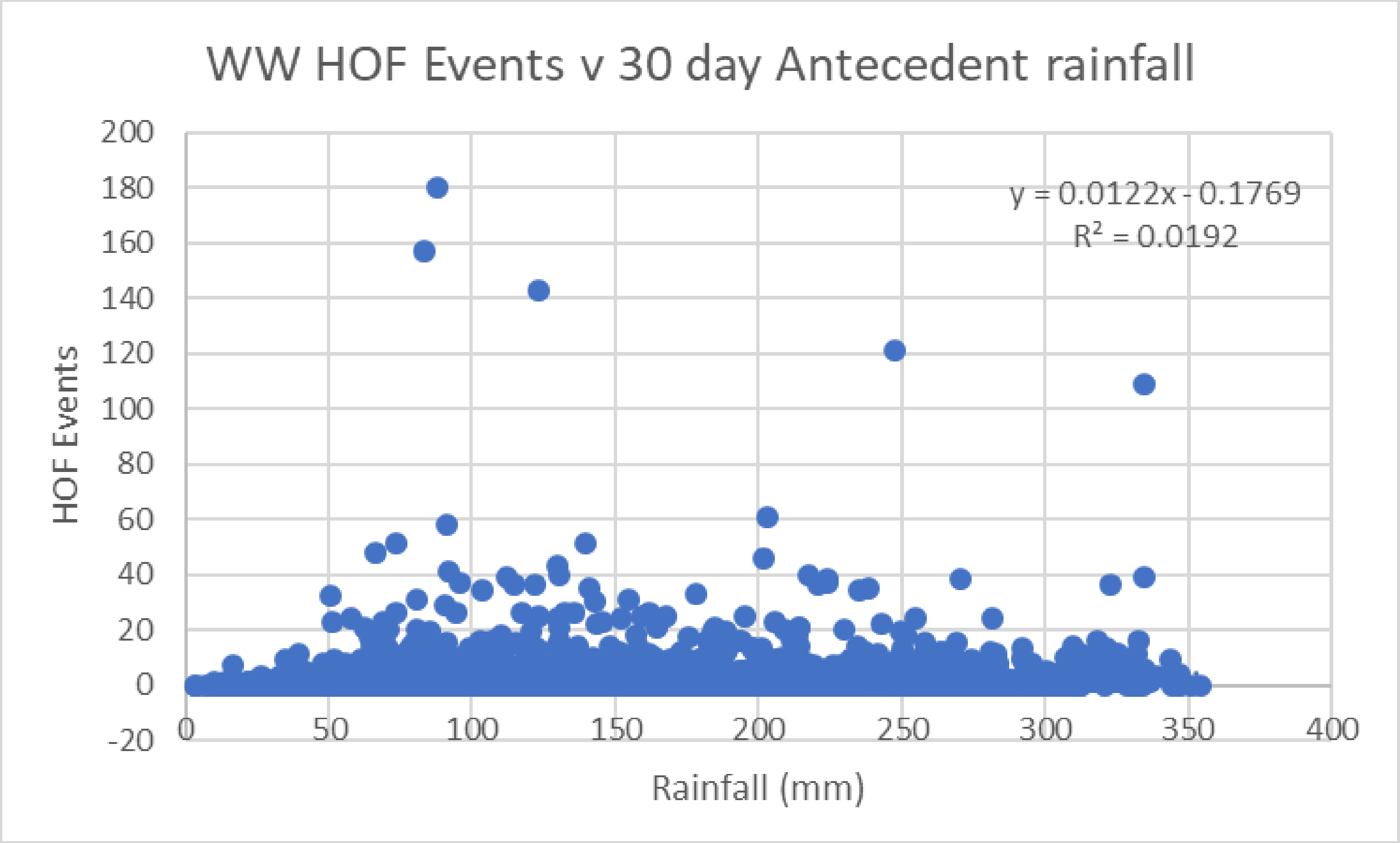


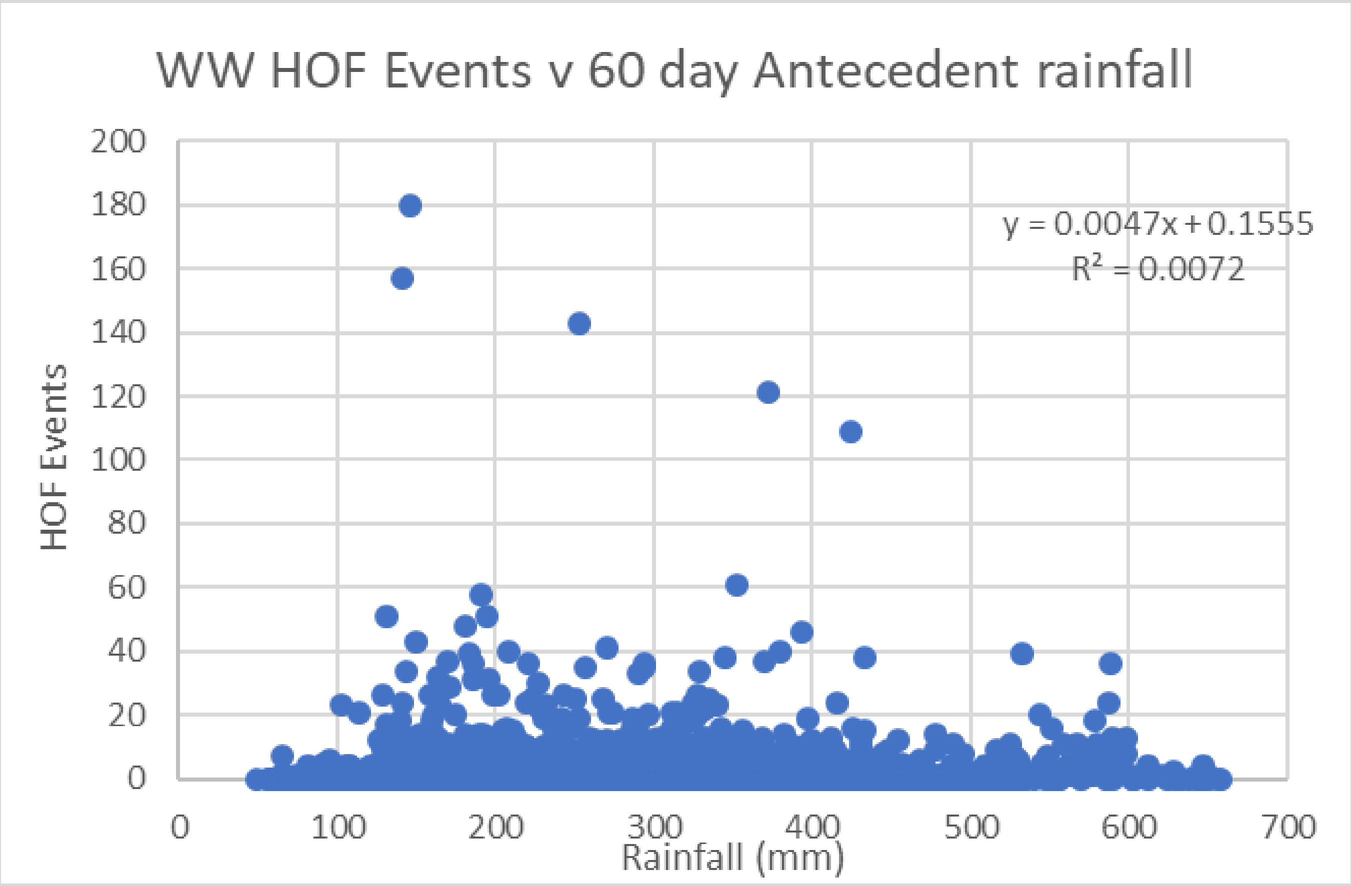
The previous plots show encouraging relationships between “very wet days” and flooding events.
Another area of investigation using the daily data was to consider whether antecedent conditions might also play a significant role. To this end, antecedent rainfalls over periods of 7,14,21,30,60 and 90 days before each event were calculated. However, a visual inspection suggests that the role of antecedent rainfall is small, for WW and all postcode sites. This suggests that it is high event rainfall that triggers sewer flooding events, when considered at the monthly aggregation scale.

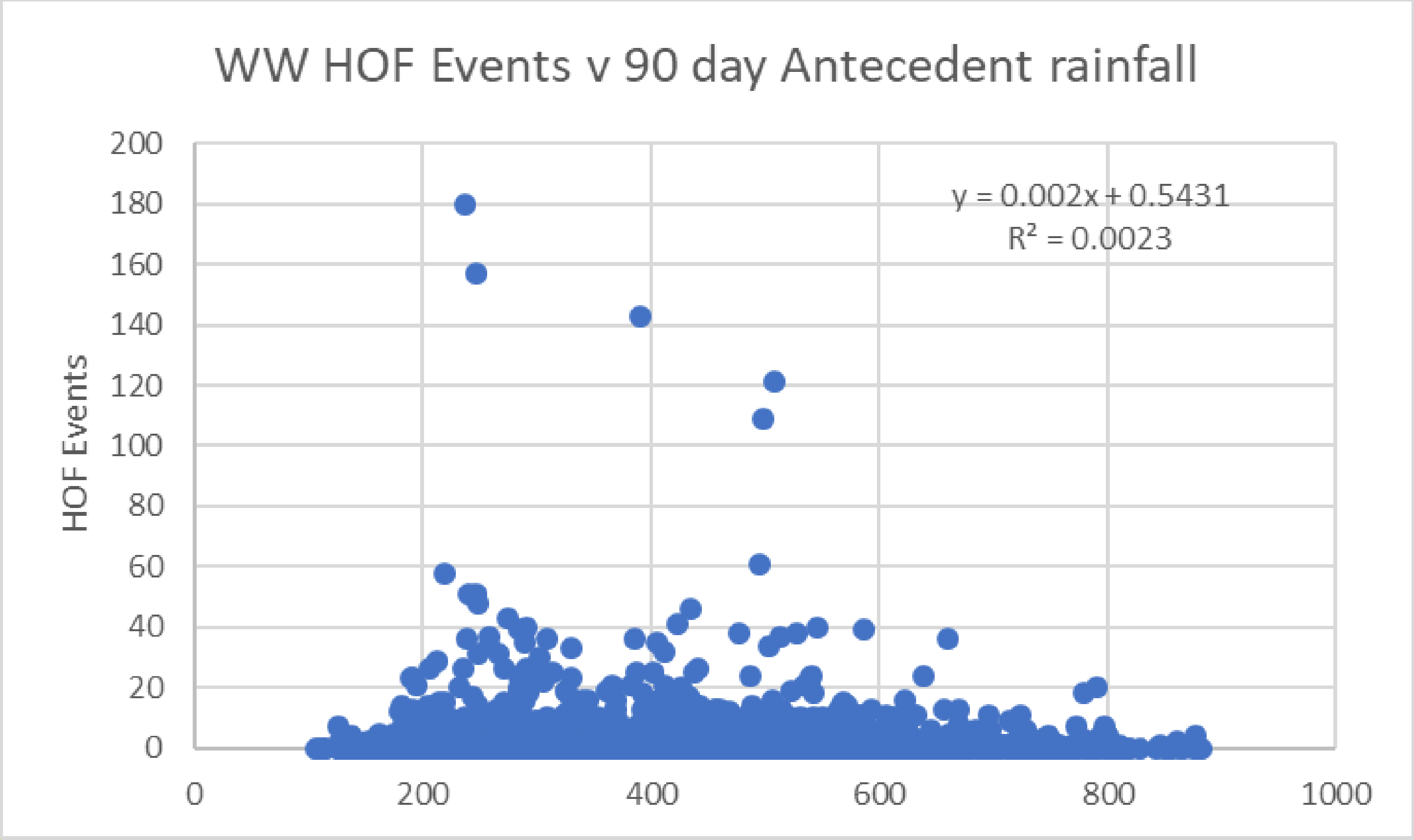












- The previous graphs, showing the relationship between HOF events and "very wet days" (> 20mm) when aggregated on a monthly basis are more encouraging, i.e. the trigger of the event is linked with days with rainfall of the order of 20mm or at higher thresholds in wetter areas. Also, that antecedent conditions do not appear to have a very significant influence.

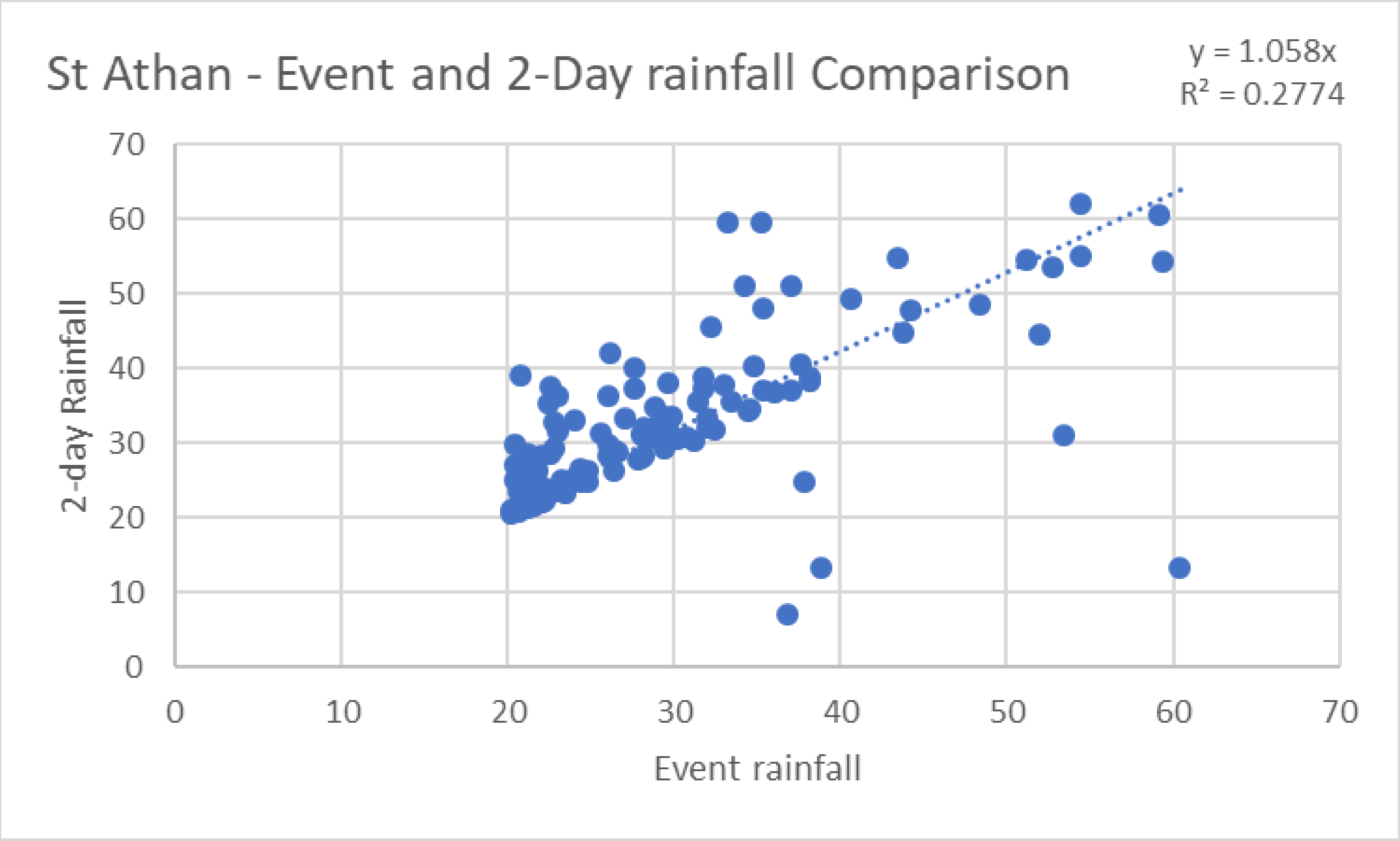
- However, it is likely that flooding events are more likely to occur when these large rainfall totals fall in a few hours, rather than over a 24-hour period. So sub-hourly data are required to determine these extra insights.

- The monthly and daily data previously analysed were available for a 5km gridded data but these are not available on an hourly basis. However, hourly data exists for a selection of individual sites across the UK. A few relevant stations were chosen for further analysis to gain extra insights into the length of time over which the rain falls as well as how much falls. St. Athan's (10 km south-west of Cardiff) was used to represent the south Wales and Hawarden Airport (5km west of Chester) to represent the north-east of Wales, i.e. the two areas with the largest number of events.

Hourly, Event and Daily Rainfall

Hourly – Total rainfall recorded by a rain gauge for a clock hour ending
Event – Cumulative hourly rainfall with at least 2 dry hours demarcation
Daily – Total rainfall from 0900 to 0900 on consecutive days, assigned to the first day

Combinations of hourly and event rainfalls produce the best thresholds for defining sewer flooding events. However, sub-daily data do not exist in climate change datasets. Consequently, for this exercise, thresholds have been set against event rainfalls which roughly equate to 2-day rainfalls (see next slide).
For flooding event analysis and operational forecasting of floods, hourly rainfall data would be utilised.



Although the scatter is quite high, the regression diagnostics show a 1-1 relationship between event rainfall and 2-day rainfall for rainfall amounts that lead to sewer flooding. So 2-day rainfalls can be used as an imperfect surrogate for event rainfalls.

Met Office

Emerging weather criteria that determine whether a day will have above average sewer flooding incidents For Cardiff/St Athan's

General Conditions

An event rainfall of over 50mm (approximating to a 2-day rainfall)

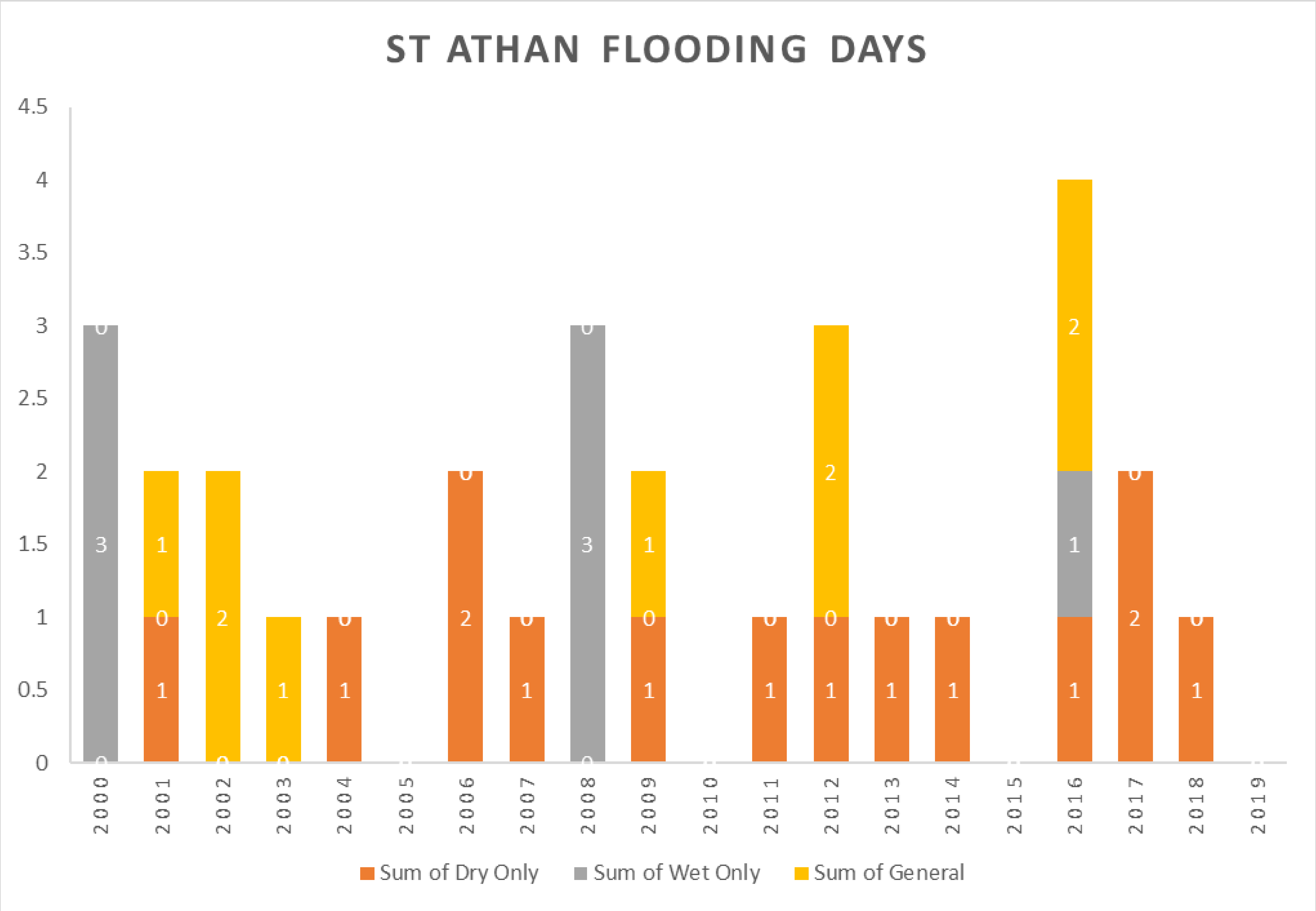
Wet conditions

An antecedent 30-day rainfall of >175mm and an event rainfall of over 20mm

Dry conditions

An antecedent 30-day rainfall of <50mm with an event rainfall of over 20mm

Days per year that have weather which could lead to >10 flooding events in Cardiff postcodes



<u>Days with >10 actual Flooding events</u>
Between April 2000 and March 2019

Hit – 8
Miss – 3
False alarms – 22

Total days - 6939

Emerging weather criteria that determine whether a day will have above average sewer flooding incidents For Chester/Hawarden

General Conditions

An event rainfall of over 40mm (approximating to a 2-day rainfall)

Wet conditions

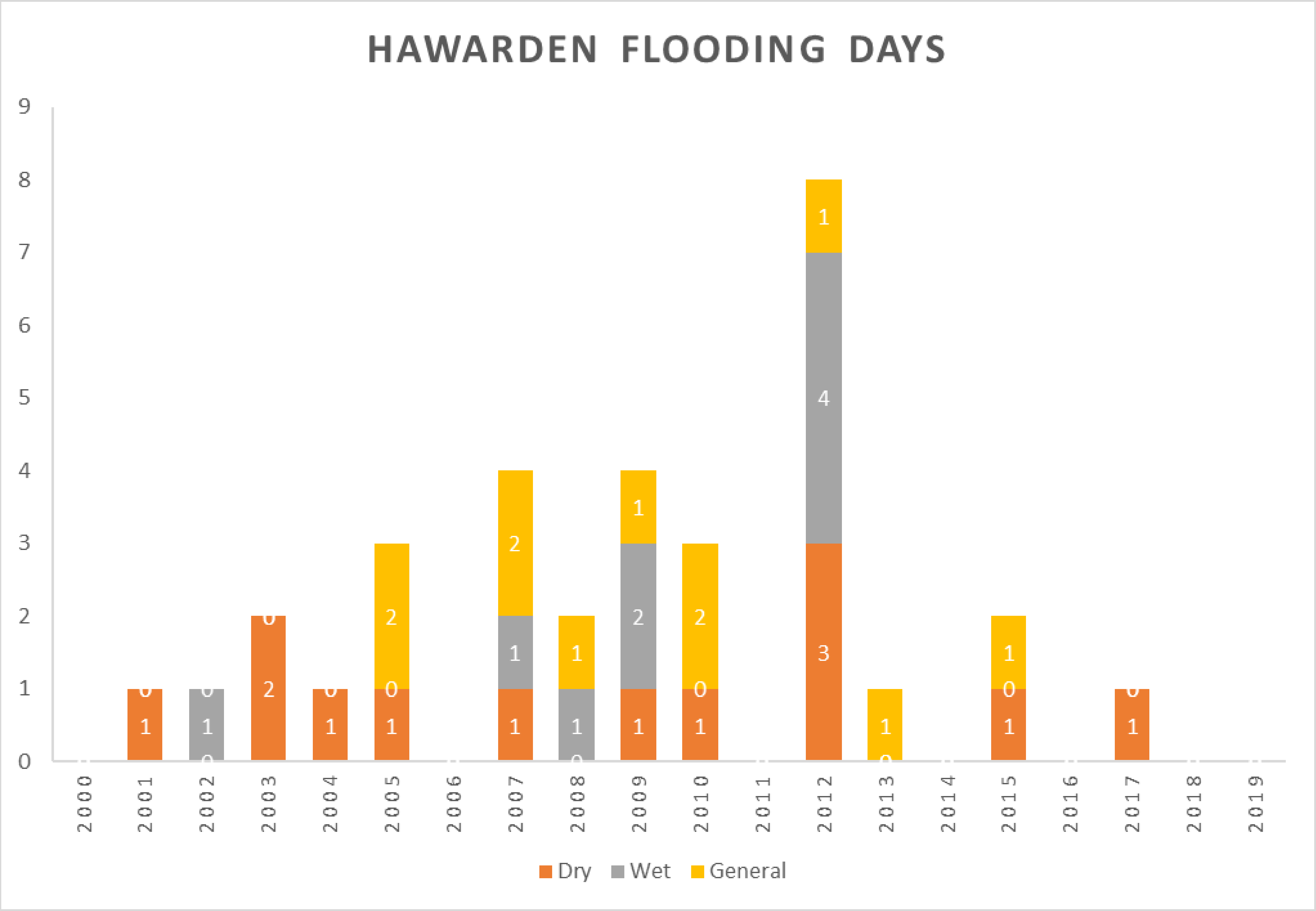
An antecedent 30-day rainfall of >100mm and an event rainfall of over 20mm

Dry conditions

An antecedent 30-day rainfall of <50mm with an event rainfall of over 20mm

Met Office

Days per year that have weather which could lead to >7 flooding events in Chester postcodes



<u>Days with >7 actual Flooding events</u>
Between April 2000 and March 2019

Hit – 12
Miss – 12
False alarms – 21

Total days - 6939

- The difference in the trigger values for the south-east and north-east of Wales reflects the rainfall regimes of the two areas, with St. Athan's being more prone to rain-bearing weather from the Atlantic and Hawarden Airport being in the rain-shadow of Snowdonia and sheltered from the worst of the wet weather from the west.

- Using statistics based upon the Flood Studies Report (FSR - NERC, 1976) and the Flood Estimation Handbook (FEH, 1999), the 'general' conditions event thresholds (assuming 2-day totals) for the two areas of 50mm and 40mm, respectively, are both once a year events for the two locations. However, an 'event' is likely to last for a much shorter than this, perhaps a few hours. Other return periods have been calculated for the two sites with varying 'event' lengths:

St Athan's	**2-days**	**1-day**	**12hours**	**6 hours**	**3 hours**
50mm	1 year	2-5 years	~ 7 years	~18 years	~40 years
Hawarden					
40mm	1 year	2-5 years	10 years	20 years	40 years

- Although the rainfall totals are different at both sites, in terms of the return periods, these trigger events are equally frequent at both sites, regardless of the length of the 'event'.

SUMMARY Phase 1a

An analysis of the WW flooding event data shows that:

- It is difficult to identify a correlation between monthly rainfall and monthly totals of flooding events. There are many flooding events that do not coincide with rainfall events and vice versa.

- An analysis of daily rainfall and flooding incidents shows a poor correlation but amalgamating 2-day totals to give an event total gives better results. However, there are many flooding events that do not coincide with rainfall events and vice versa.

- The best results were obtained by isolating “very wet days” to identify trigger thresholds of at least 20mm.
- More detailed insights were obtained by analysing sub-daily data for south and north-east Wales. This work has identified
- various triggers:
  - ‘general’ conditions (days > 50mm south Wales and >40mm in north-east Wales), different thresholds for the two areas but similar return periods, regardless of ‘event’ length
  - ‘wet’ conditions – 30 antecedent days > 175mm (south Wales) and 30 antecedent days > 100mm (north-east Wales) both followed by a day > 20mm
  - ‘dry’ conditions – 30 antecedent days < 50mm followed by a day > 20mm (both areas)

SUMMARY (cont.)

- The event analysis shows that there are features present in the hourly rainfall which influence the propensity for flooding, that cannot be seen in the daily rainfall. However, as sub-daily data do not exist in the climate change datasets used in Phase 2, for this exercise, thresholds have been set against event rainfalls which roughly equate to 2-day rainfalls.

- This sensitivity to hourly rainfall necessitates a more involved analysis of data for which more time will be required to fully investigate. There is almost certainly a further dependence on sub-daily rainfall to explore.

Welsh Water

ANALYSIS OF WASTE WATER FLOODING EVENTS AND RAINFALL

Phase 1b – National Context

- The 5km gridded daily and monthly rainfall data analysed for WW in Phase 1b are also available for all the water companies in England and Wales.

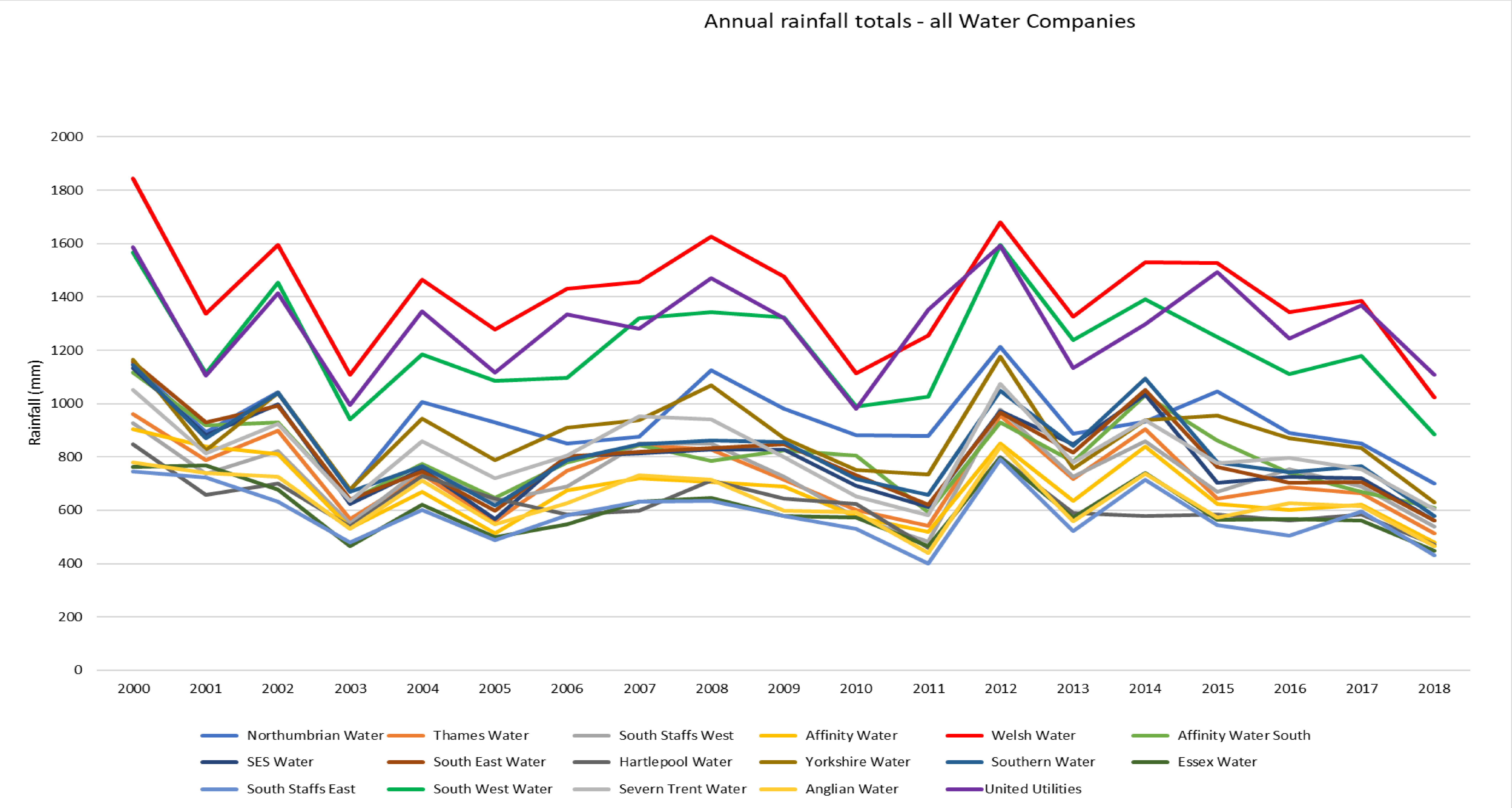
- Phase 1b re-produces some of the analyses presented in Phase 1b for all the other major companies in England to put the WW analyses into a national context.

- Various analyses and plots are presented in the following slides.

Met Office

The annual rainfall totals for 2000-2018 are presented for all the major water companies.

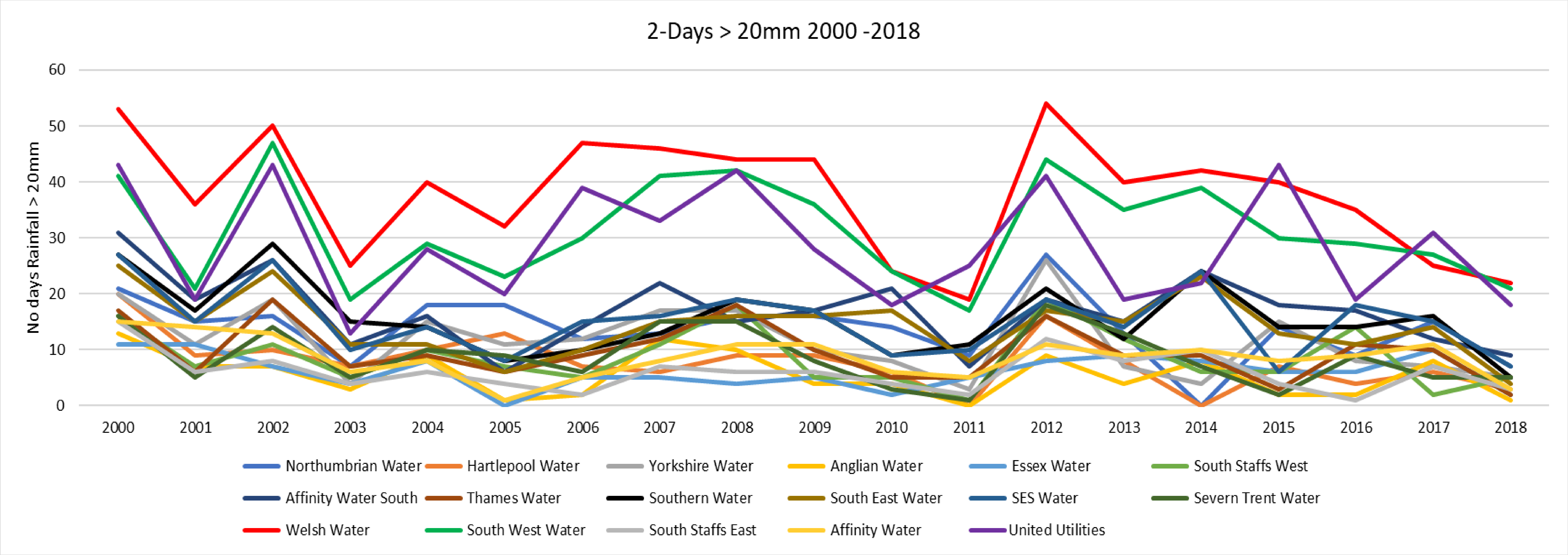
Welsh Water (red) has generally experienced the wettest conditions in England and Wales, closely followed by South-West Water (green) and United Utilities for NW England (purple), the exceptions being the years 2011 and 2018 when UU was slightly wetter.



Areas in the west of the country are the wettest due to their exposure to rain-bearing weather systems from the Atlantic. Note Scottish Water data are not available for this exercise.

Met Office

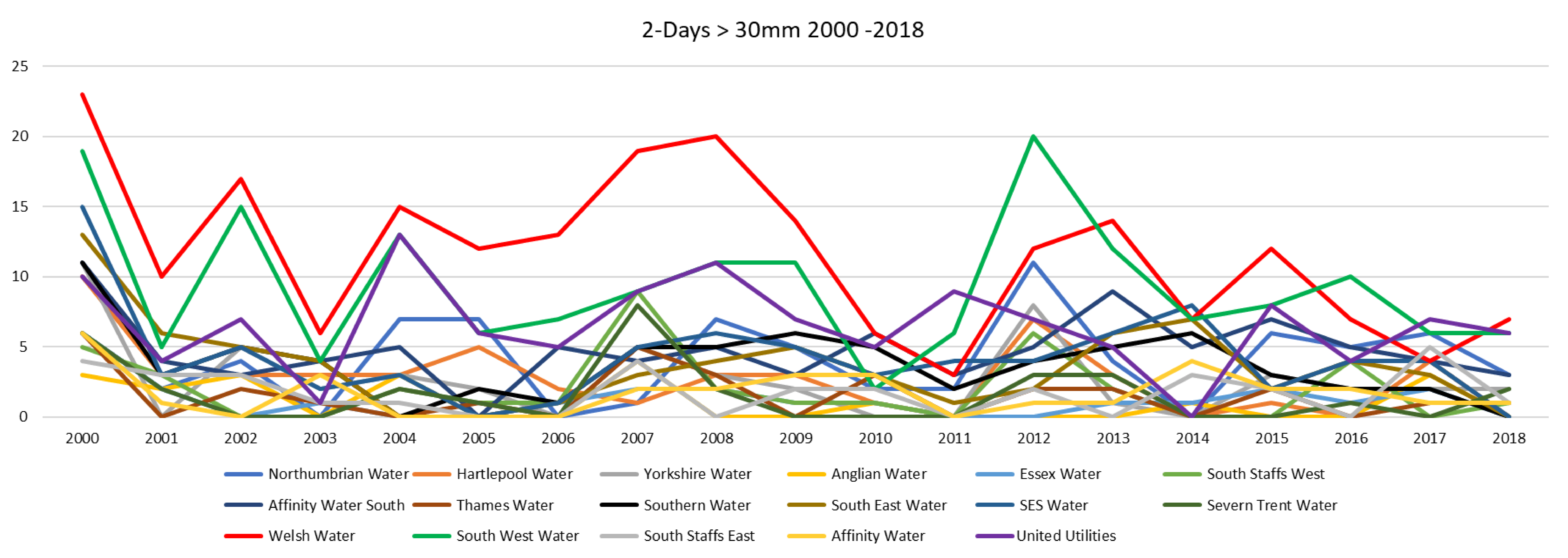
The results in Phase 1a suggest that event rainfalls (2-day totals) exceeding 20mm are likely to be trigger events for WW. The following plot show the frequency of daily rainfall > 20mm (below) and > 30mm and >40mm are shown on the next two slides, for all the water companies in England and Wales.



Welsh Water (red) again stands out as being the most prone to these conditions closely followed by and United Utilities (which was slightly worse in 2011, 2015 and 2017) and South West Water.

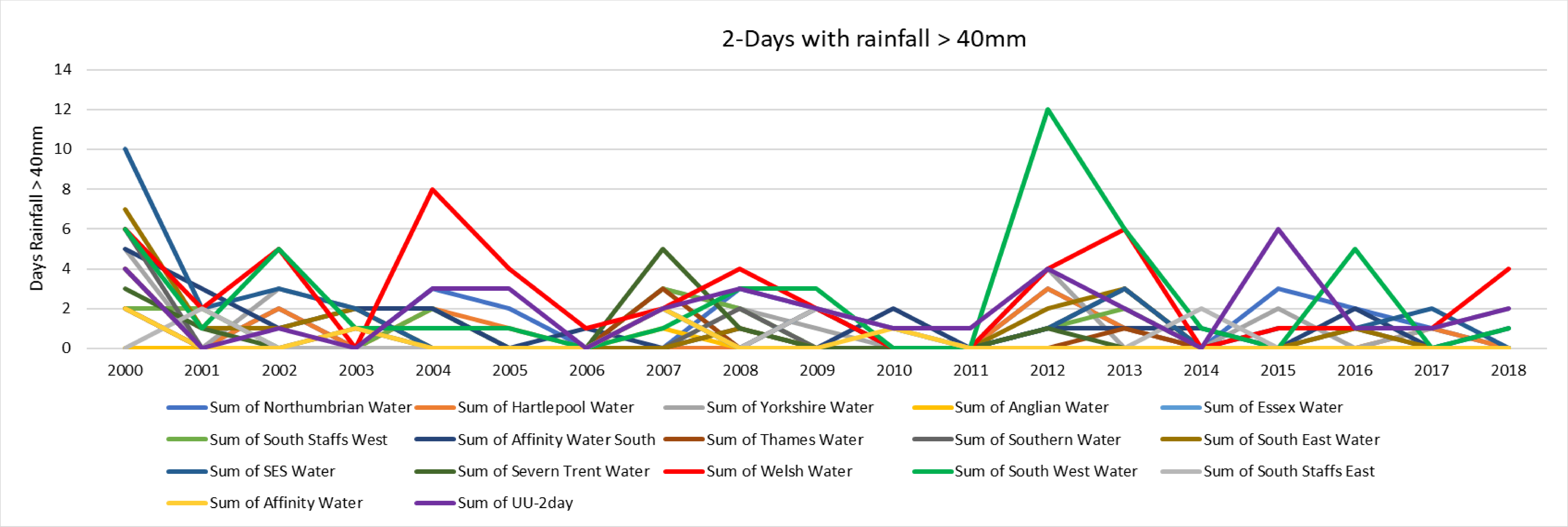
Met Office

Other higher threshold of 30mm and 40 mm (next slide) were tried to see if the results were consistent. For event totals > 30mm Welsh Water has been the most prone area although in 2001, 2012 , 2016 and 2017 South West Water was worse for both thresholds and also United Utilities in 2011 for events > 30mm.



Met Office

At the higher threshold of 40 mm the results are more mixed with Welsh Water and South West Water plus other water companies vying to be the wettest region each year. South West Water experienced many more wet days in 2012. In the years 2014-2017, Welsh Water experiences fewer days than other regions although it was wettest again in 2018.
It should be noted that there are significantly fewer days when 2-day rainfalls exceed 40mm compared with the other lower thresholds (compare the vertical axis here with those in the previous two plots). This is why there is less of a difference between all of the water companies as such rainfalls can occur with isolated, heavy thunderstorms and so are less dependent upon a westerly location. In fact the south-east of the UK tends to be more prone to thunderstorms from the continent.



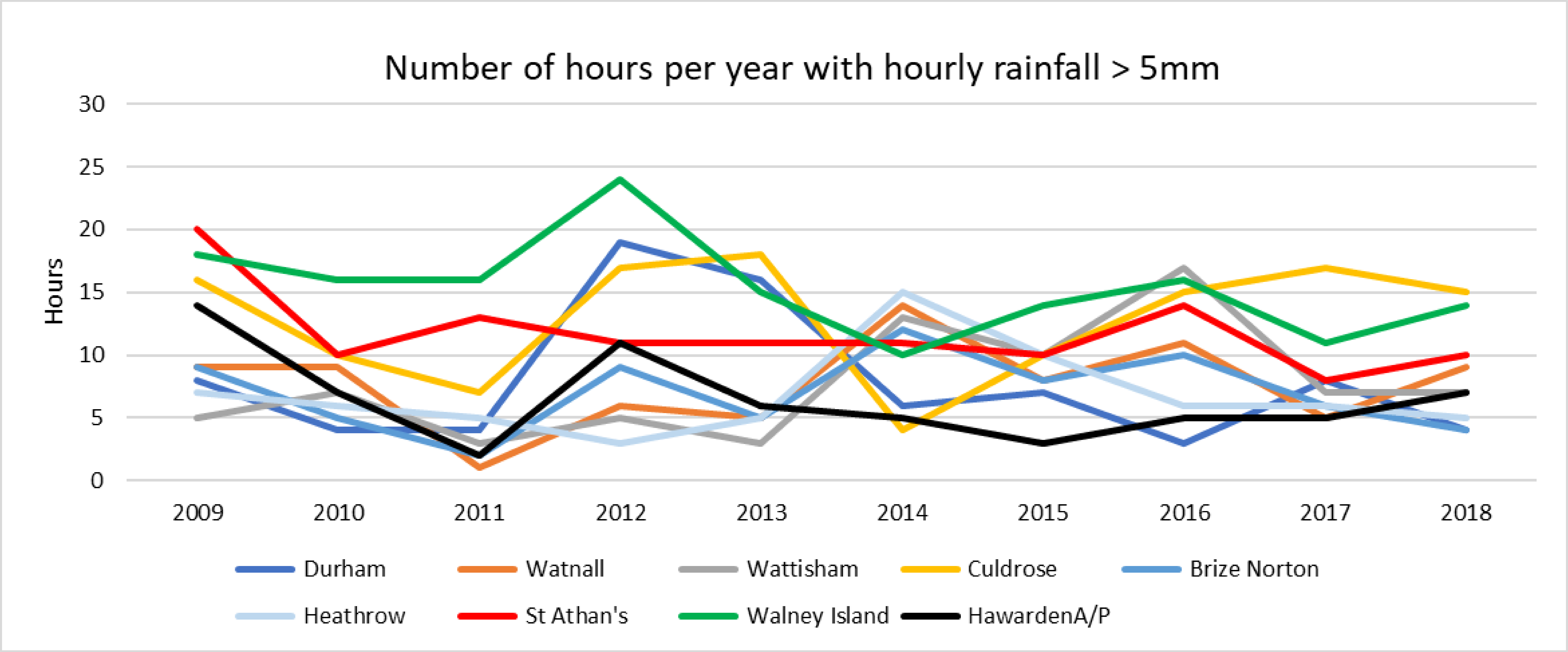
Trends in Hourly Totals

- The previous slides show that in terms of annual rainfall and 2-day totals > 20mm, >30mm and >40mm, the WW area is generally wetter than the rest of England and Wales. This is mainly due to its westerly location and exposure to the wettest conditions.

- However, as discussed, it is often how quickly the rain falls in a day that may be more relevant to sudden flooding events. To investigate this, hourly data have been analysed for St. Athan's, Hawarden Bridge and other locations around the country, in terms of hours with rainfall > 5mm and > 10mm, (arbitrarily chosen thresholds to cover very heavy rainfall events). The other sites in England are :
- Durham, Watnall (Nottingham), Wattisham (Ipswich), Culdrose (Cornwall), Brize Norton (Oxon), Heathrow and Walney Island (Cumbrian coast).

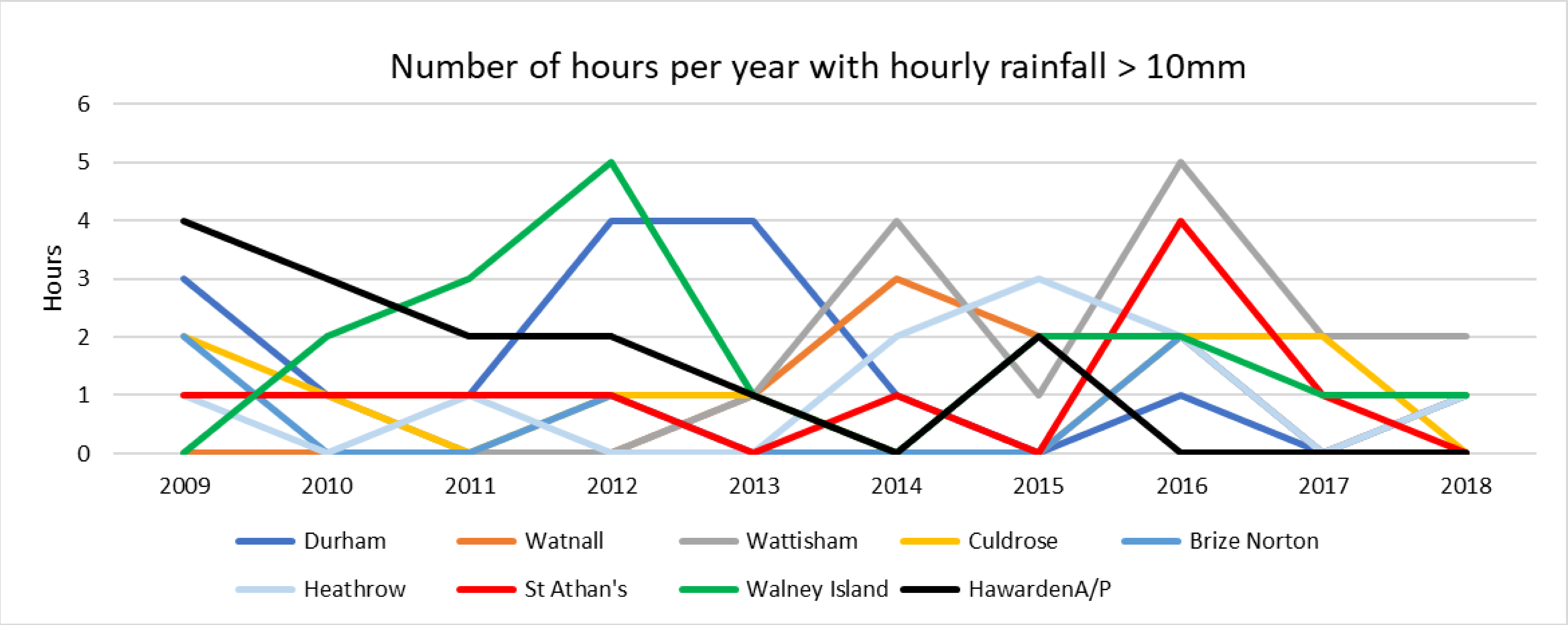
- The following graphs showing the number of hours with rainfall >5mm and > 10mm at these sites for the period 2009-2018.

Met Office



Number of hours per year with hourly rainfall > 5mm
Hours
30
25
20
15
10
5
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Durham
Watnall
Wattisham
Culdrose
Brize Norton
Heathrow
St Athan's
Walney Island
HawardenA/P

Met Office



Number of hours per year with hourly rainfall > 10mm
Hours
6
5
4
3
2
1
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Durham
Watnall
Wattisham
Culdrose
Brize Norton
Heathrow
St Athan's
Walney Island
HawardenA/P

- In terms of hourly rainfalls> 5mm and 10mm, the two Welsh stations are comparable with many of the other chosen sites. The exception is the number of hours with rainfall > 10m in 2009 at Hawarden Bridge and 2016 at St. Athan's.

- Walney Island (Cumbrian Coast) and Culdrose (Cornwall) tend to have more hours with rainfall > 5mm, being the most exposed westerly sites. St. Athan's is more sheltered than these sites hence it does not appear to be particularly unusual. However, the results for Culdrose and Walney island may be more representative of the northern and western parts of Wales. There are generally 5-15 such events each year at all of the sites.

- The picture is more complex for hours with rainfall > 10mm as such rates would be associated with thunderstorms which are more randomly distributed in the UK. However, there are far fewer such events with generally 0 to 4 across all sites but has reached 5.

Met Office

SUMMARY Phase 1b

- In terms of annual rainfall totals, the Welsh Water region is the wettest in England and Wales.

- In terms of the number of days with rainfall above high thresholds of 20mm and 30mm, Welsh Water is generally the wettest region closely followed by South West Water and to a lesser extent United Utilities. This reflects the westerly locations of these regions which are prone to rain-bearing storms from the Atlantic.

- In terms of the number of days with rainfall above the higher threshold of 40mm the situation becomes more complex and patterns are harder to identify. This is because such high totals will be more likely to be associated with thunderstorms which are less dependent upon a westerly location. The south-east of the UK tends to be more prone to thunderstorms from the continent.

- Analysis of hourly rainfall data for various locations in England and Wales shows Cornwall and Cumbrian locations to be the most prone. The St. Athan's site may be more sheltered than these two English sites as the analysis does not indicate it be significantly worse than the other sites. However, Culdrose and Walney Island would be representative of the northern and western part of Wales.

Welsh Water

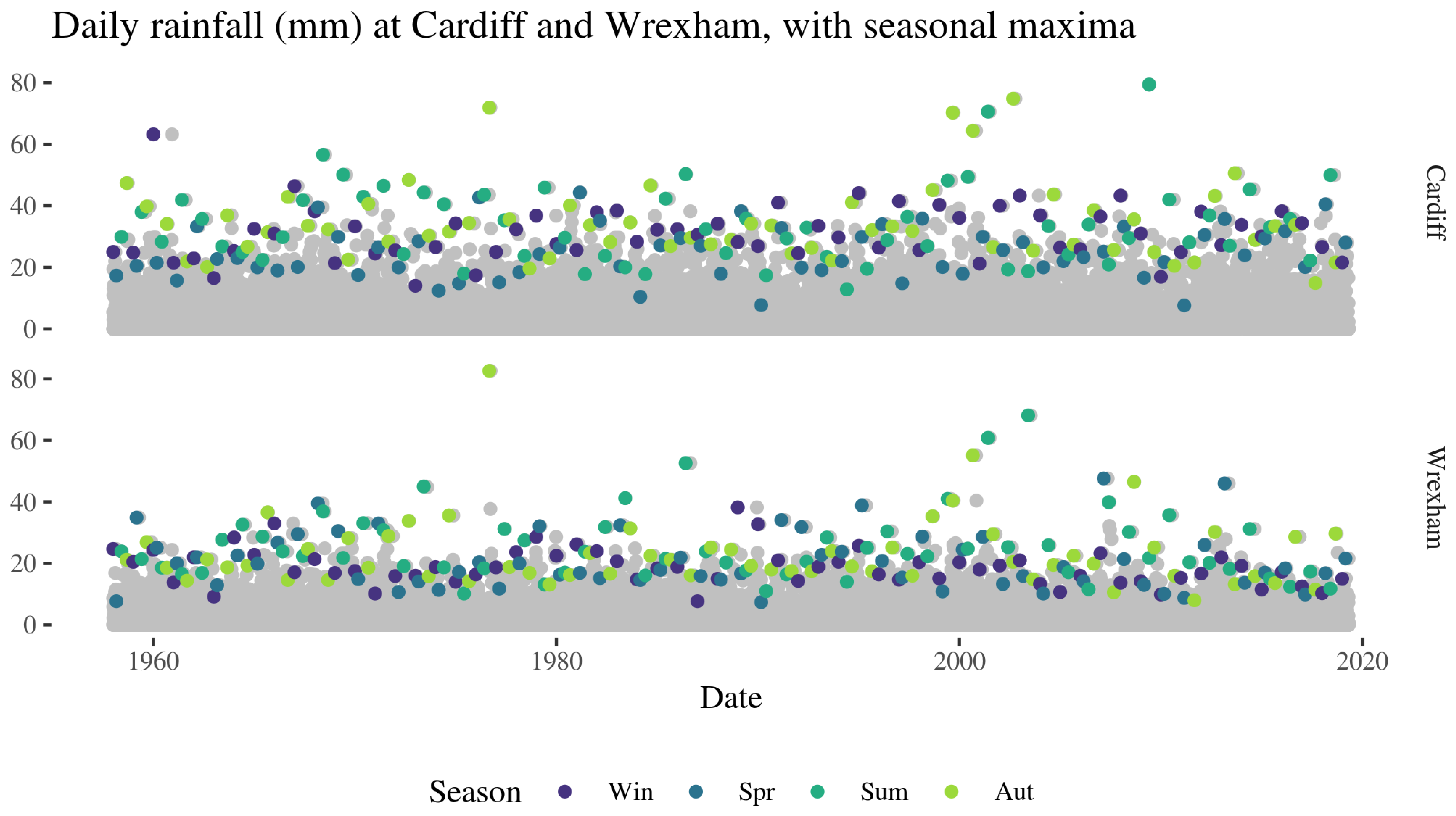
ANALYSIS OF EXTREME DAILY RAINFALL WITH ALLOWANCE FOR CLIMATE CHANGE

PHASE 2

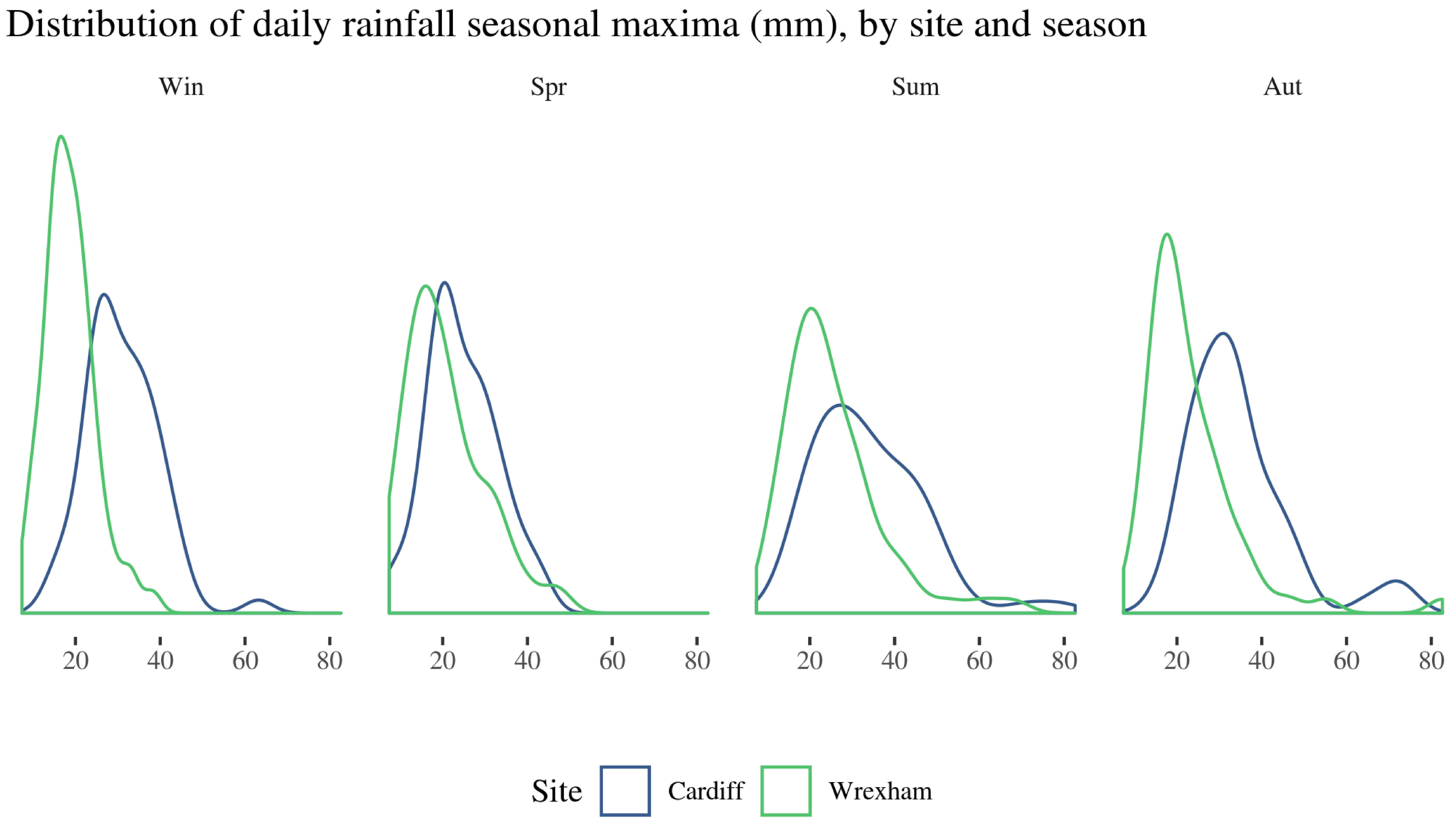
Summary

- In Phase 2 we present an analysis of extreme daily rainfall totals, using NCIC 5km gridded observation data.
- The analysis is carried out for the seasonal maximum value each year, from March 1958 to February 2019 inclusive.
- Climate change is characterised by linking properties of the extremes with global mean temperature, as in Brown et al. (2014).
- We use projections of global mean temperature from the latest Met Office climate projections, UKCP18, to quantify future extreme daily rainfall.

Seasonal maximum daily rainfall totals for high flood event locations



Seasonal maximum daily rainfall totals



Seasonal maximum daily rainfall totals

The seasonal maxima are modelled by Generalised Extreme Value (GEV) distributions (Coles, 2001).

There are differences in the distribution of extremes at each site (Cardiff and Wrexham) and in each season so we assume a different GEV for each site/season.

The GEV distribution allows us to quantify the expected value for a given return period, extrapolating to return periods beyond those already observed.

The following Figures show the GEV parameters – location, scale and shape – for each season on the NCIC 5km grid. There is an apparent altitude effect on the location and scale parameter estimates but there is no obvious structure in shape parameter estimates.

NCIC GEV location parameter

There is evidence of an altitude effect in the location parameter, whereby the parameter value increases with altitude. Parameter values are lower in the spring and summer, indicating lower daily rainfall totals in those seasons

NCIC GEV scale parameter

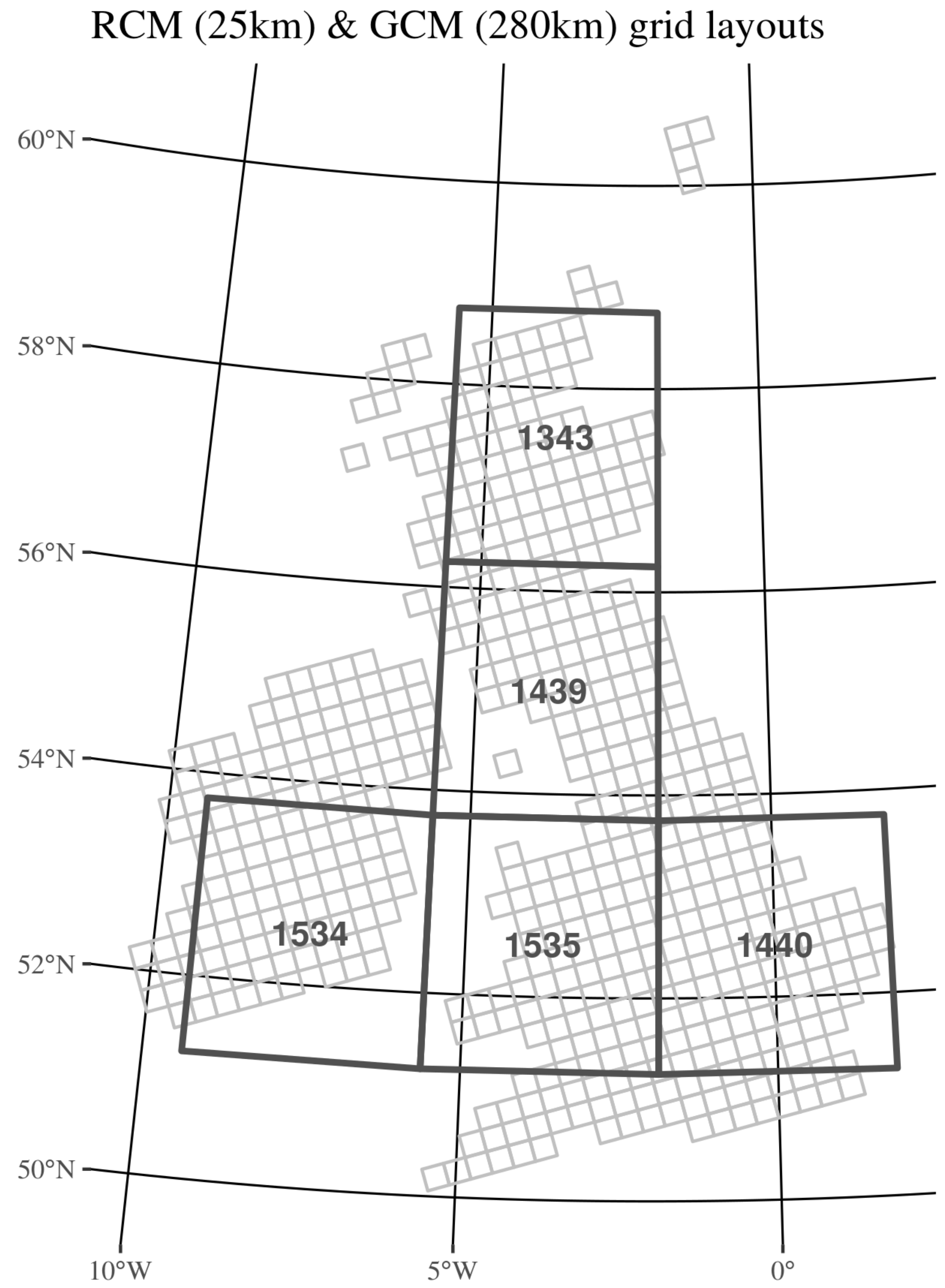
There is evidence of an altitude effect in the scale parameter, whereby the parameter value increases with altitude. Parameter values are greatest in the winter, indicating more variation in daily rainfall totals.

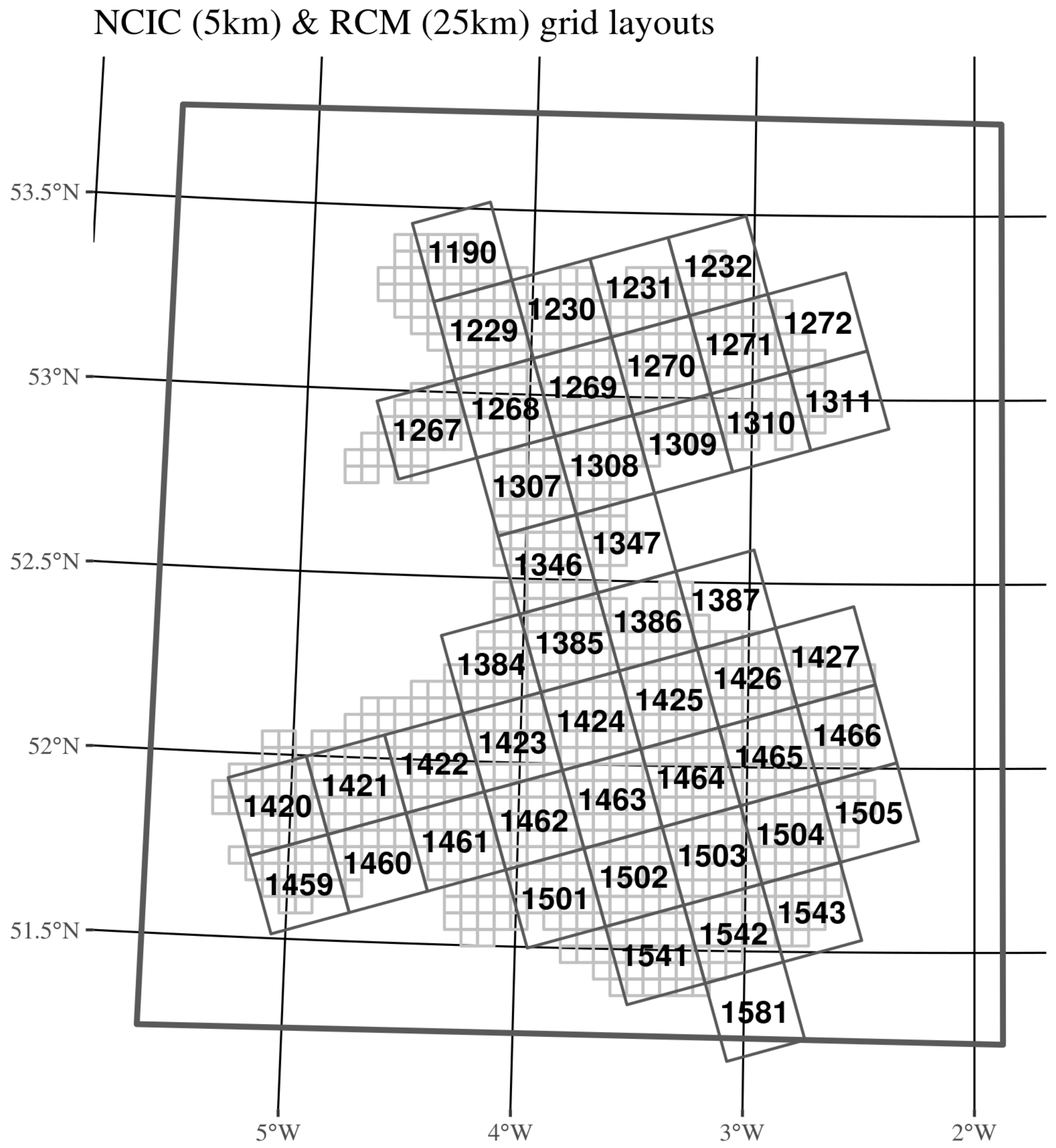
NCIC GEV shape parameter

There is no clear systematic pattern in the shape parameter.

Comparison with Brown et al. (2014)

Brown et al. used seasonal maxima data from a low-resolution (~280km) global model (GCM) with five ‘land’ grids over the UK, a higher-resolution (25km) regional model (RCM), and the NCIC 5km gridded observations dataset.
The Figure shows the relationship between the three grids, over the UK and Wales, with grid IDs for reference.





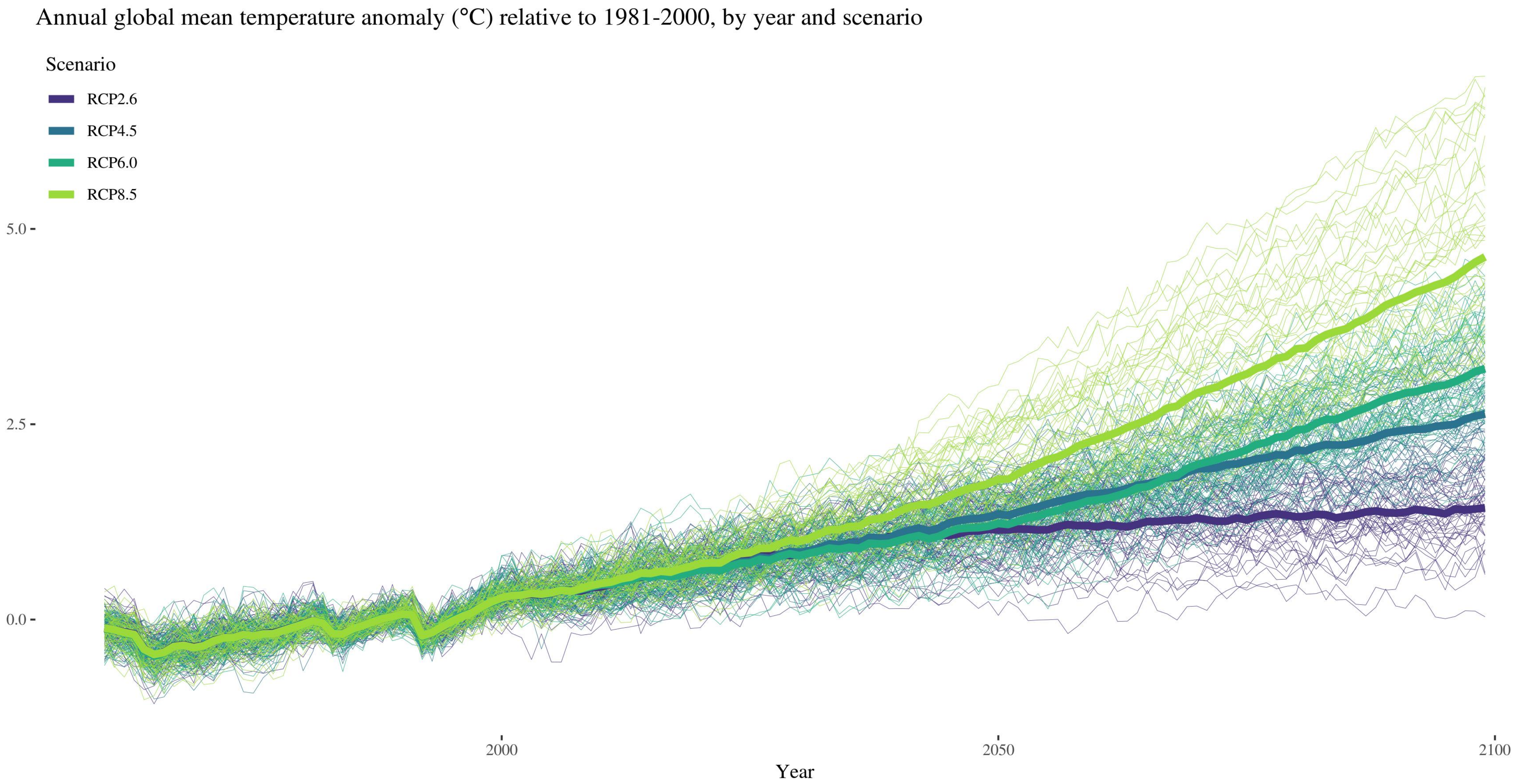
Met Office

Comparison with Brown et al. (2014) – parameter estimates from NCIC (5 km) and RCM (25km) models

Extreme daily rainfall totals are characterised by their relationship with global mean temperature in Brown et al. (2014). We then use projections of global mean temperature to predict future extremes.

Projections are simulated under four carbon emission scenarios: one low, RCP2.6; two medium, RCP4.5 and RCP6.0; and one high, RCP8.5. These relate to the amount of radiative forcing at the end of the century, i.e. 2.6 Wm^{-2}, 4.5 Wm^{-2}, 6 Wm^{-2}, and 8.5 Wm^{-2}, respectively. These are illustrated in the following Figure. The bold line represents the median global mean temperature anomaly from 1958 to 2100, relative to 1981-2000, for each scenario. The lighter lines represent individual simulations.

See explanation on previous page



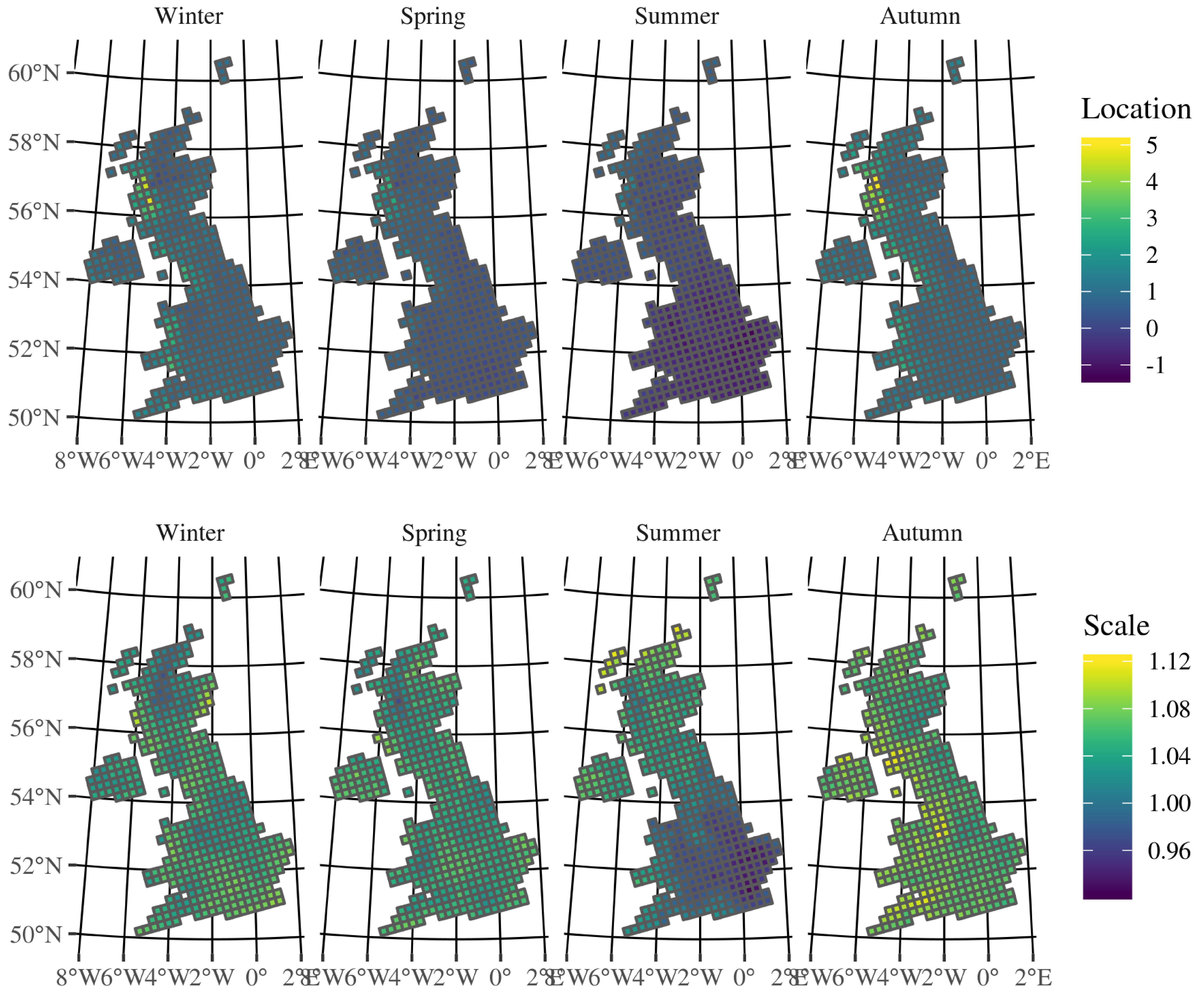
Met Office

Location and scale parameter dependence on global mean temperature

For a 1 degree increase in global mean temperature the plot indicates the corresponding *additive change in location parameter* and *multiplicative change in scale parameter*.

Negative values for the location therefore correspond to a decrease in the location parameter with increasing global mean temperature. There is a clear altitude and east/west effect. The effects are generally greater in the winter and autumn, and tend to be negative in the summer.

Changes in scale parameter lees than 1 correspond to a decrease in the scale parameter with increasing global mean temperature.



Met Office

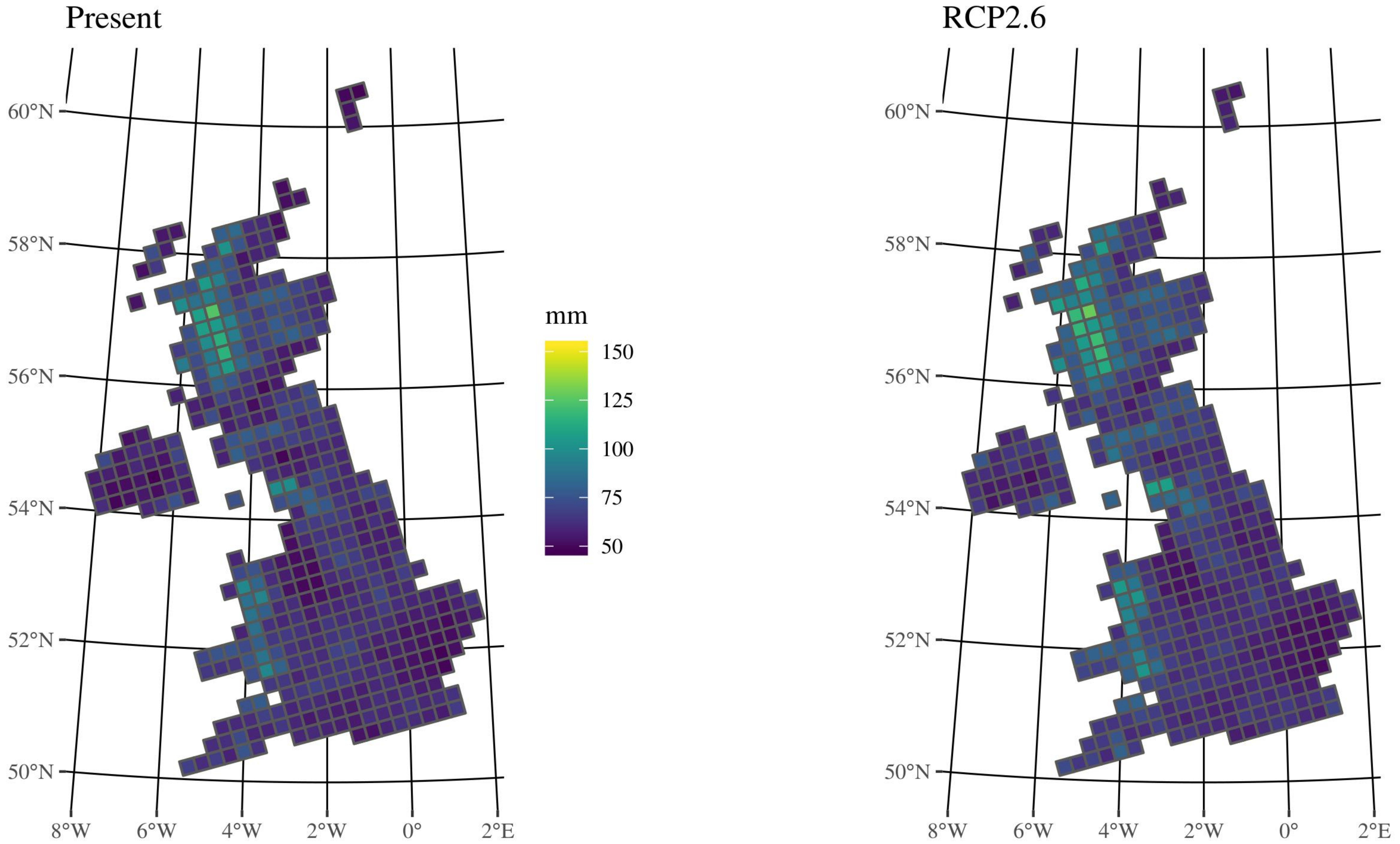
Present and future extreme daily rainfall

The following Figures show:

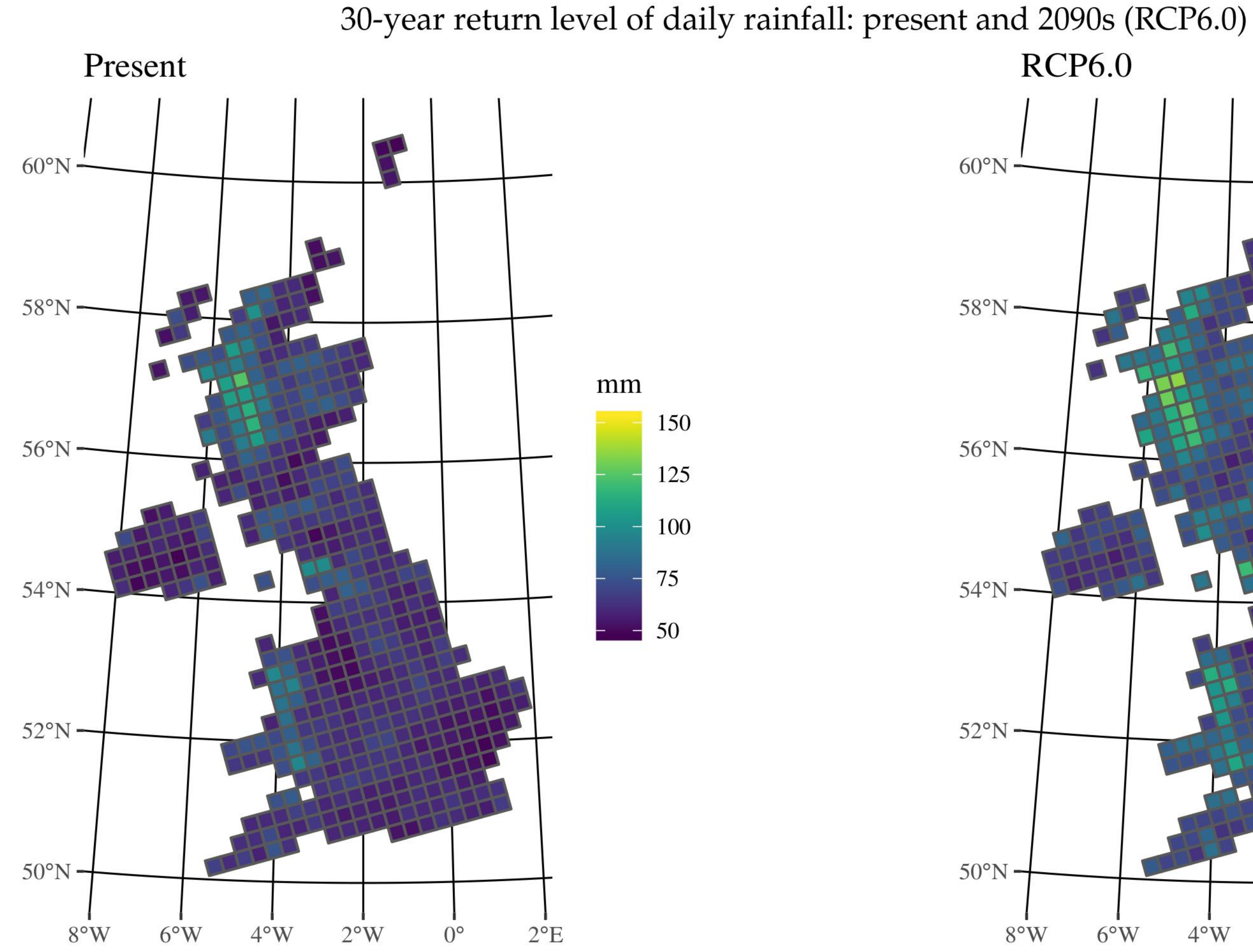
- estimated *return levels* for 30-year and 50-year return frequencies for the 2090s, and absolute and relative change in return level with respect to the present day.
- estimated *return periods* for 20mm and 40mm daily rainfall totals for the 2090s, and relative change in return period compared to the present day.

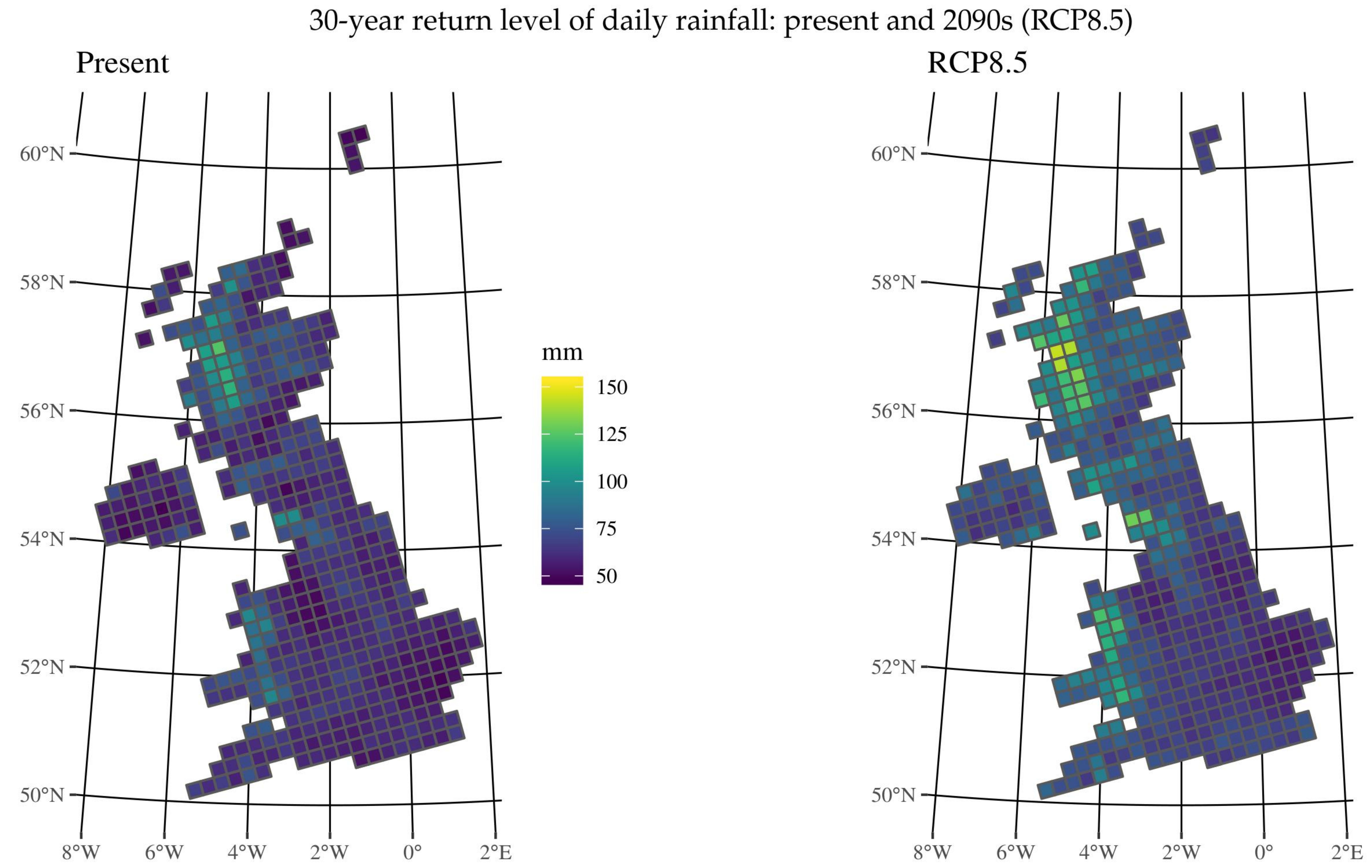
Note that these are point estimates only for each 25km grid over the UK. It is possible to estimate uncertainty due to both projections of global mean temperature anomaly (as shown in the previous slide) and uncertainty in the extreme value distributions for each grid point but these uncertainties are not presented here.

30-year return level of daily rainfall: present and 2090s (RCP2.6)

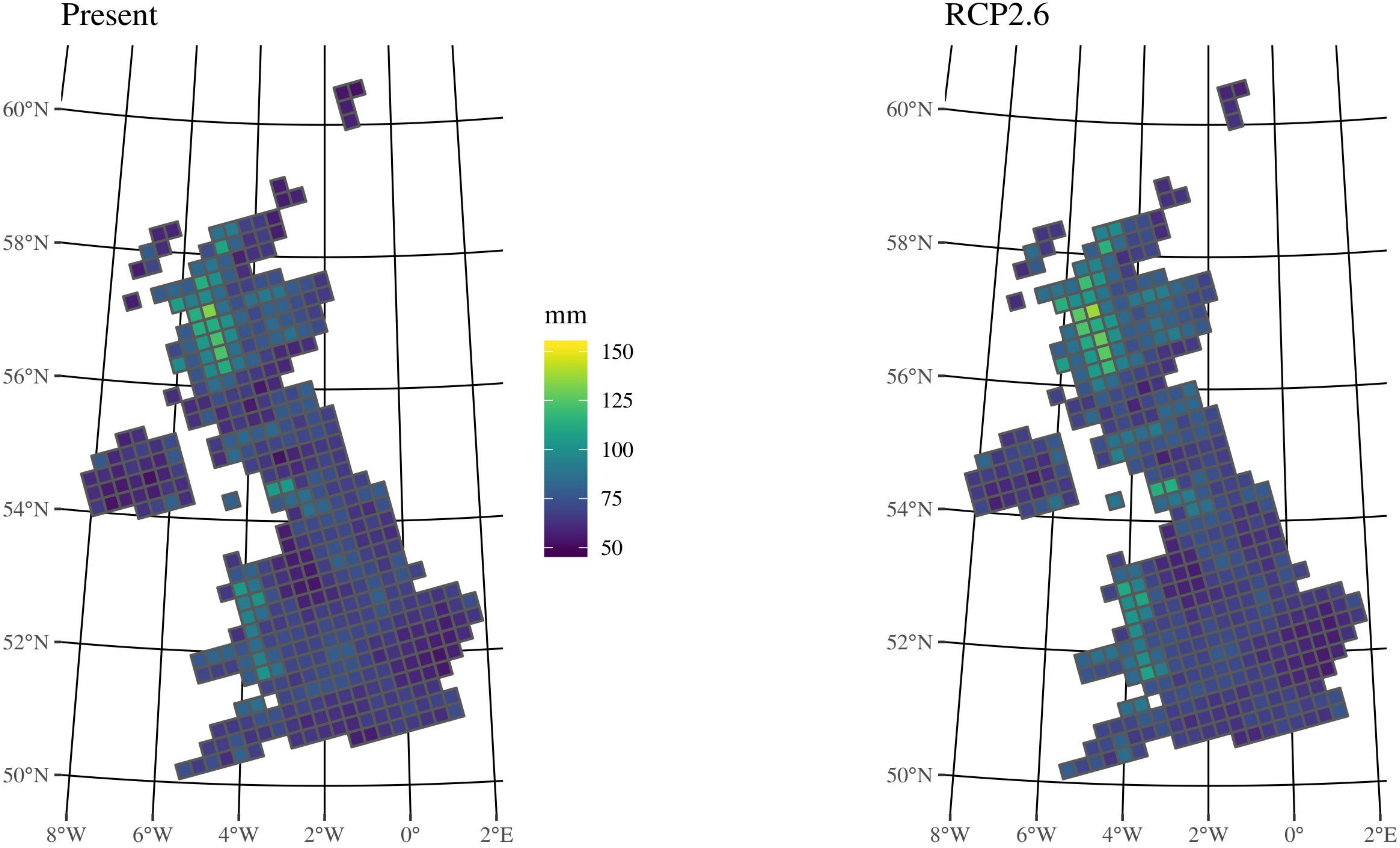


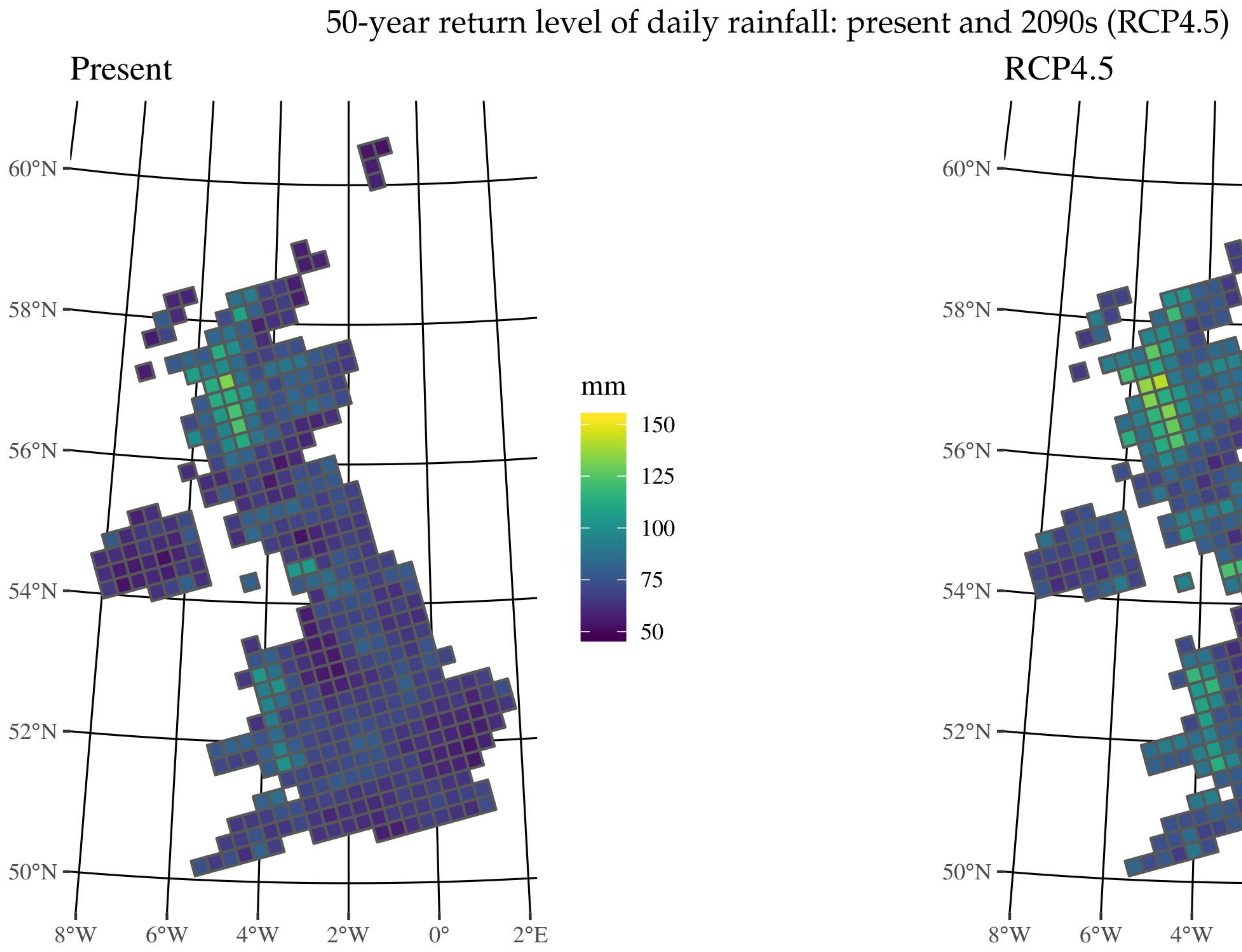

30-year return level of daily rainfall: present and 2090s (RCP4.5)
Present
RCP4.5
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E
mm
150
125
100
75
50


30-year return level of daily rainfall: present and 2090s (RCP6.0)
Present
RCP6.0
mm
150
125
100
75
50
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E

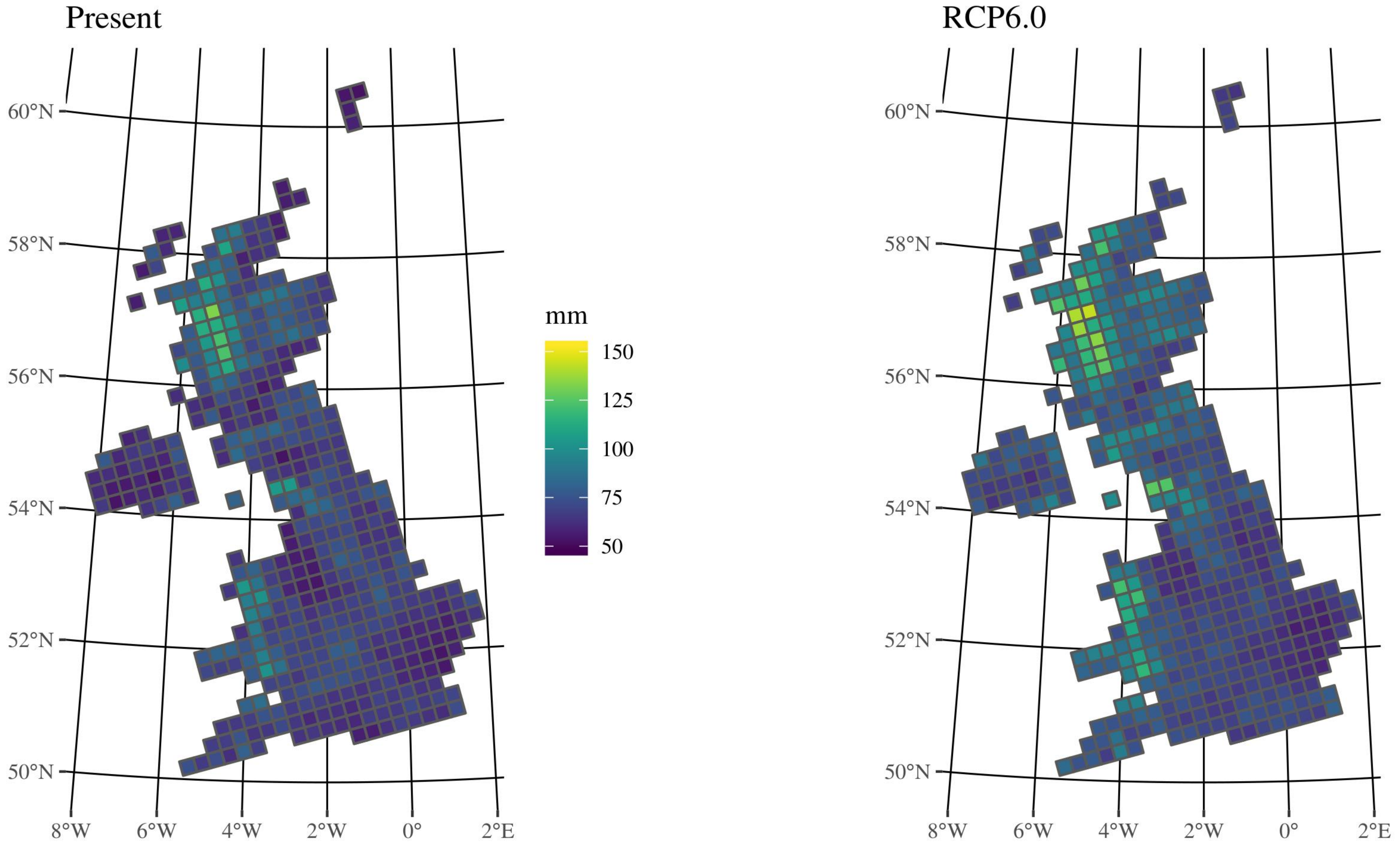

30-year return level of daily rainfall: present and 2090s (RCP8.5)
Present
RCP8.5
mm
150
125
100
75
50
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E

50-year return level of daily rainfall: present and 2090s (RCP2.6)

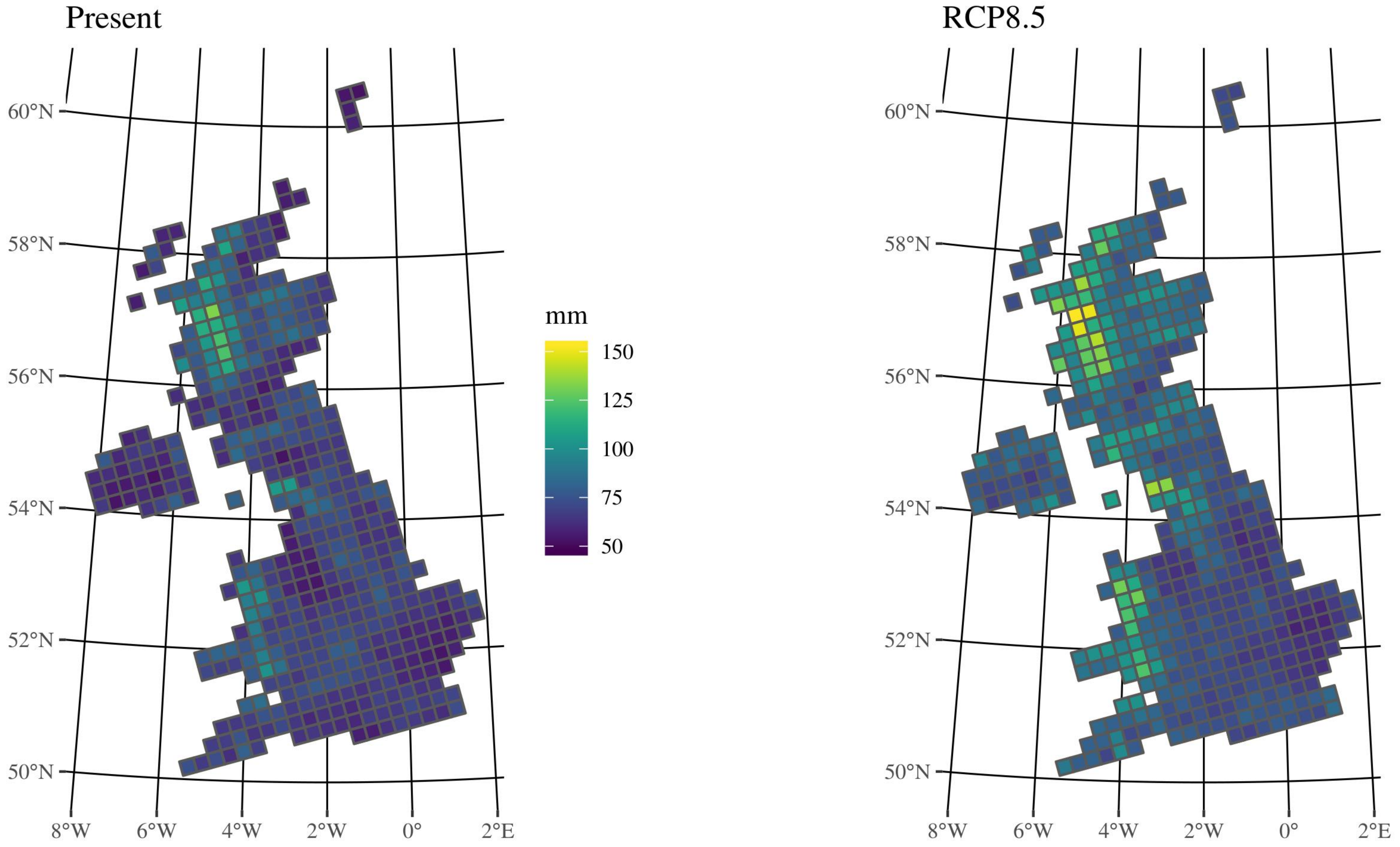



50-year return level of daily rainfall: present and 2090s (RCP4.5)
Present
RCP4.5
mm
150
125
100
75
50
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E

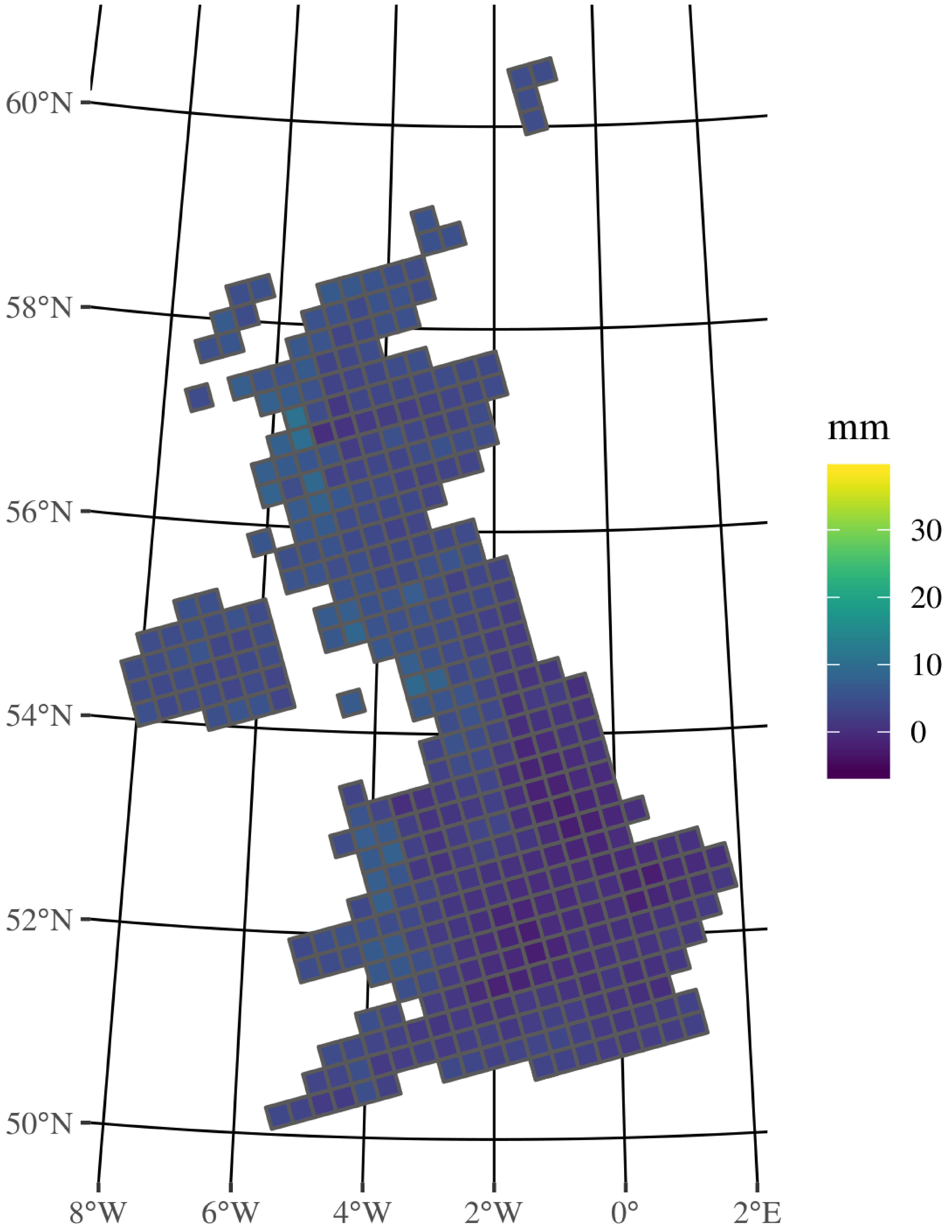
50-year return level of daily rainfall: present and 2090s (RCP6.0)



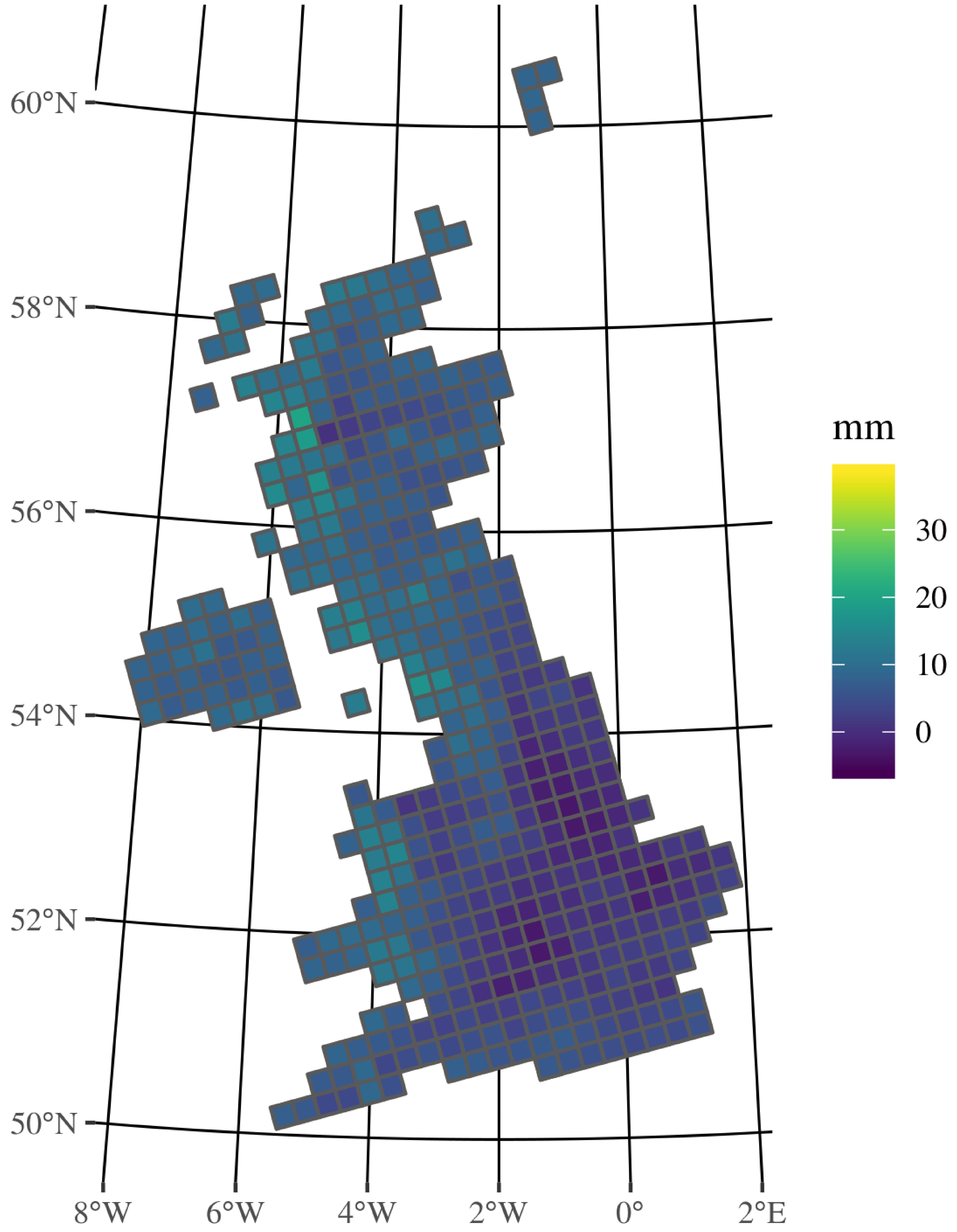
50-year return level of daily rainfall: present and 2090s (RCP8.5)



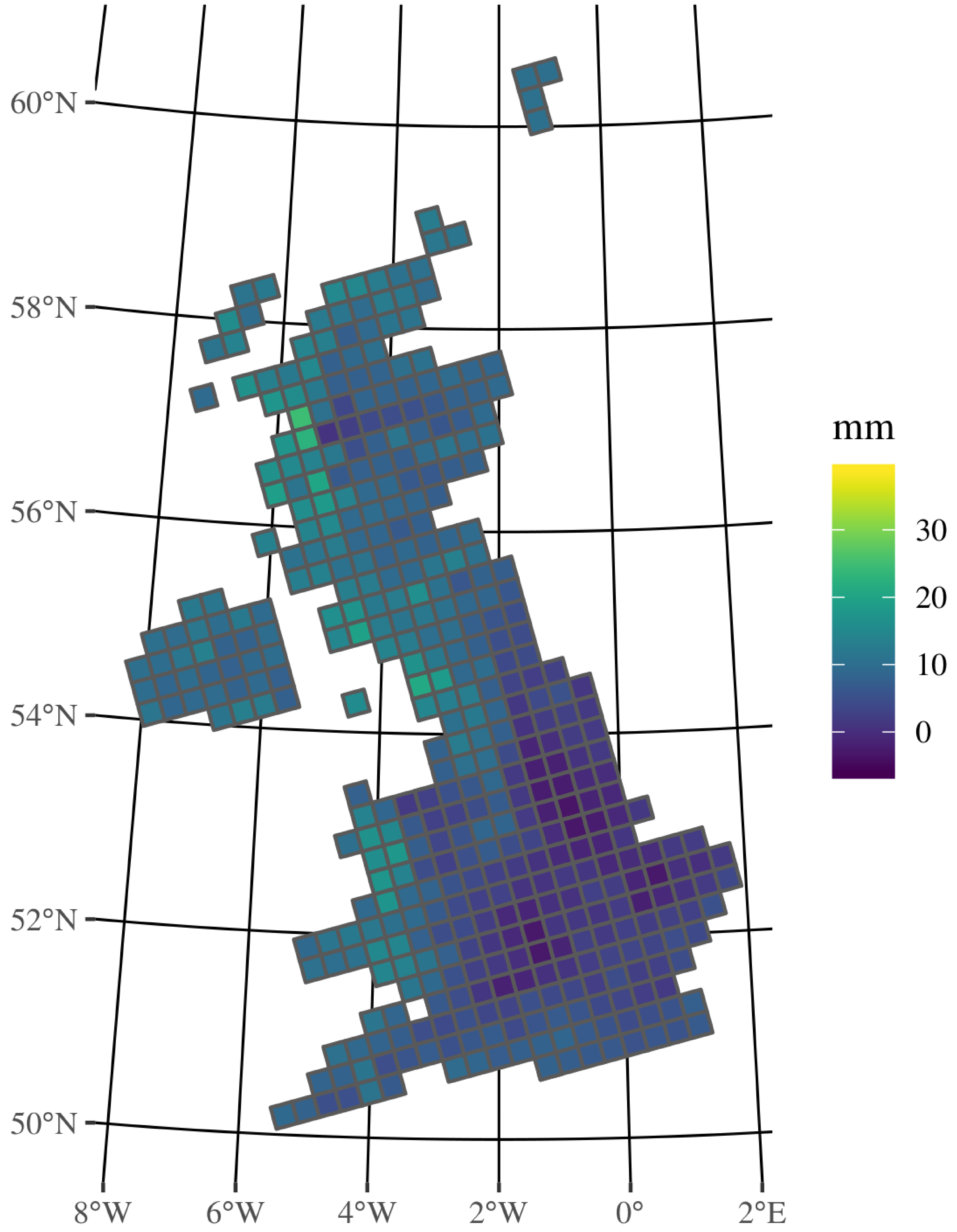
Absolute change in 30-year return level of daily rainfall from present to 2090s (RCP2.6)



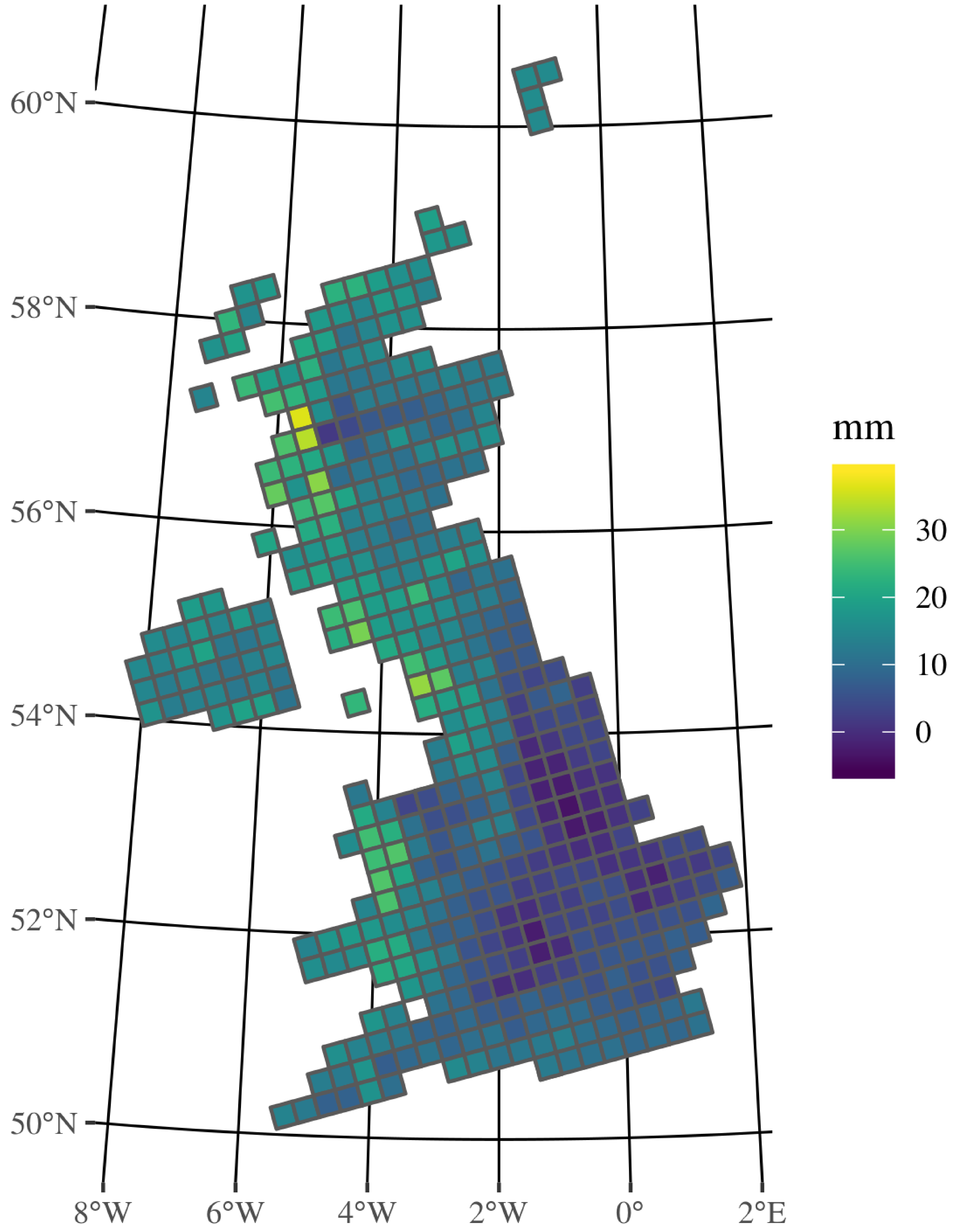
Absolute change in 30-year return level of daily rainfall from present to 2090s (RCP4.5)



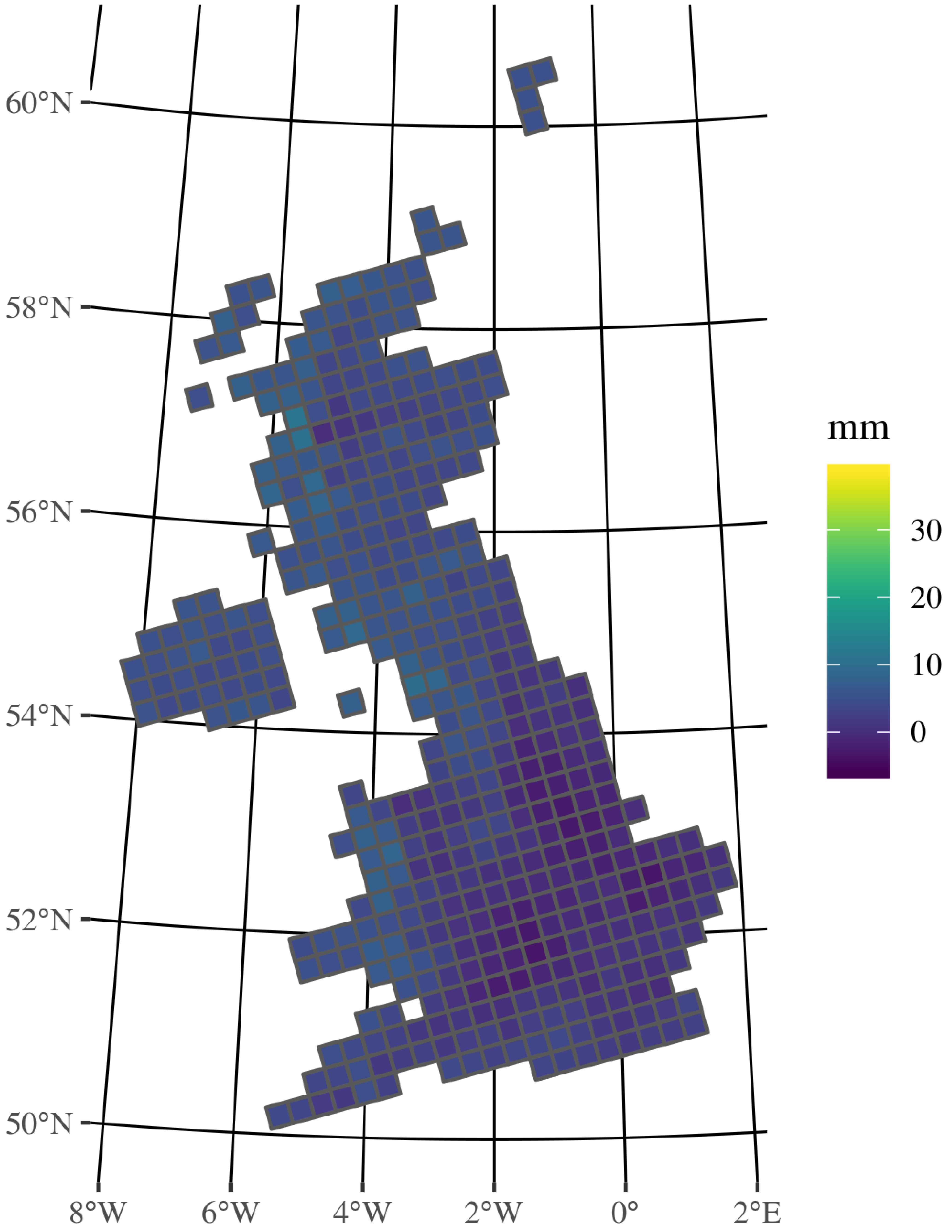
Absolute change in 30-year return level of daily rainfall from present to 2090s (RCP6.0)



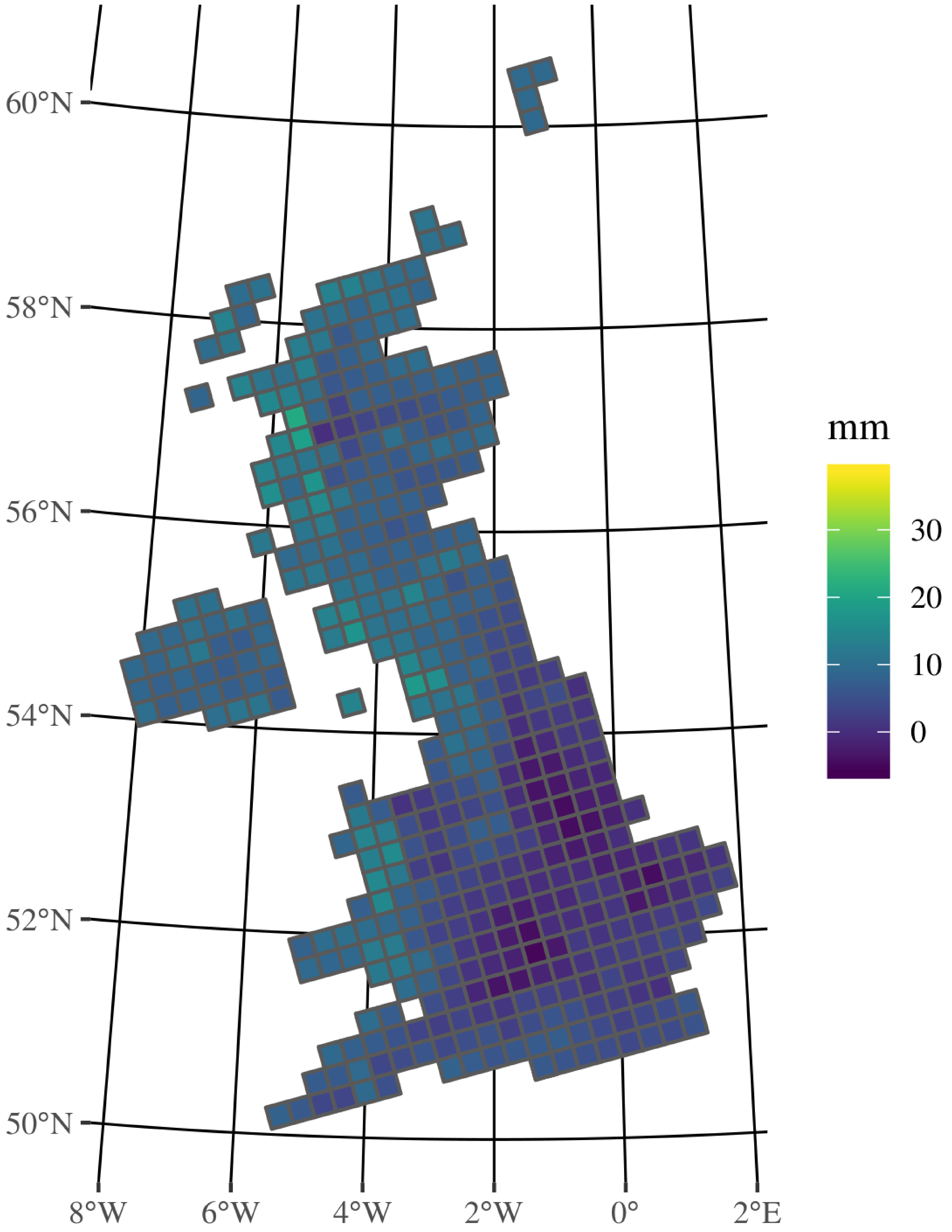
Absolute change in 30-year return level of daily rainfall from present to 2090s (RCP8.5)



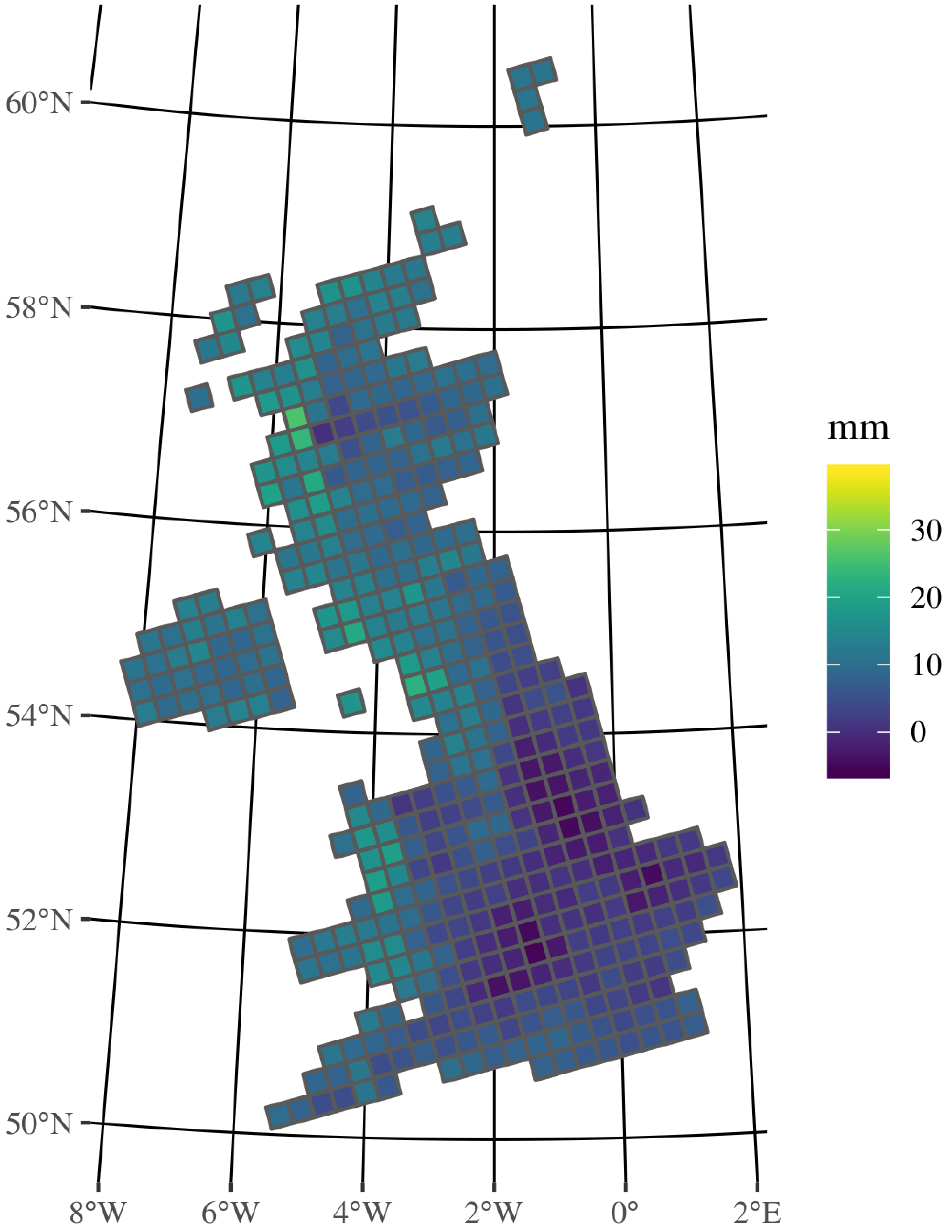
Absolute change in 50-year return level of daily rainfall from present to 2090s (RCP2.6)



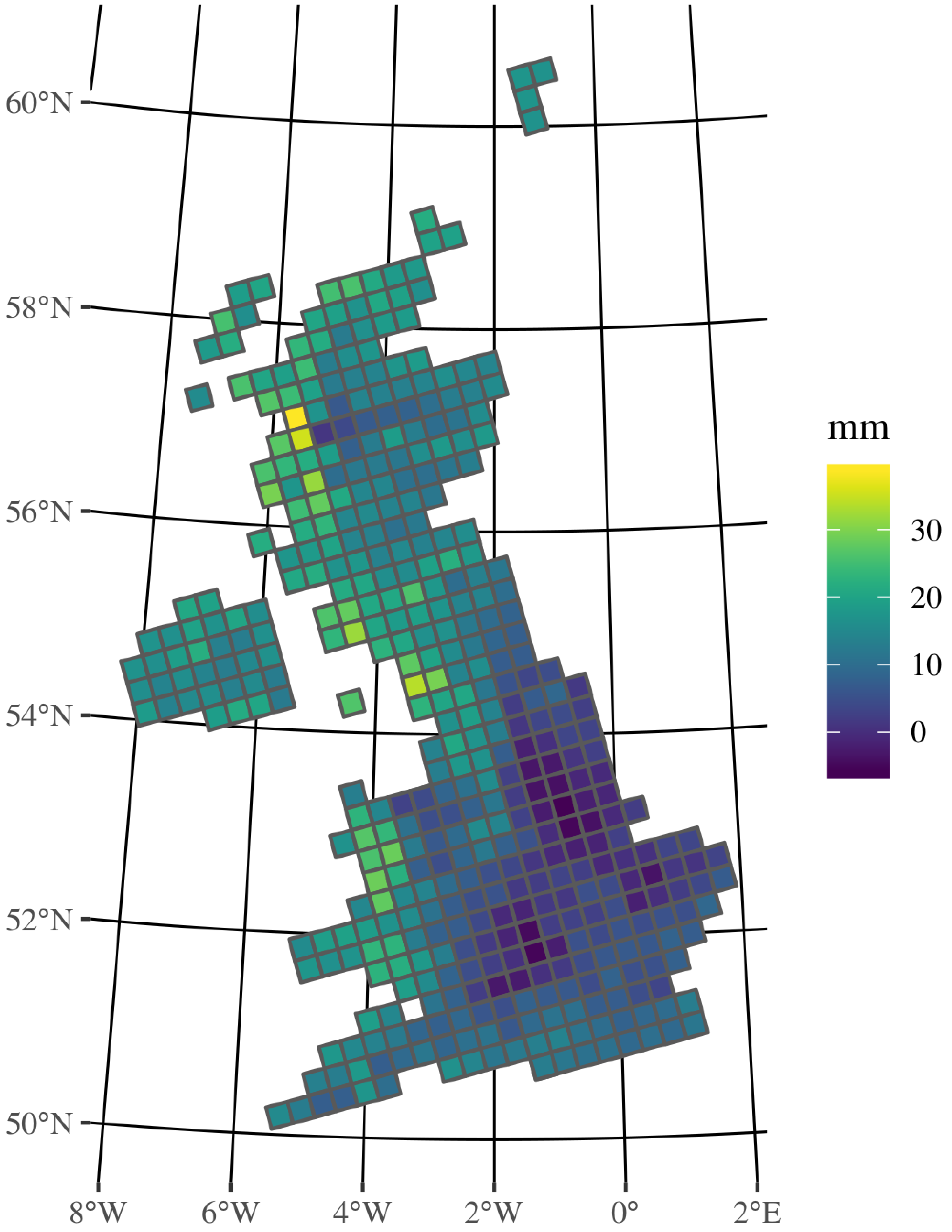
Absolute change in 50-year return level of daily rainfall from present to 2090s (RCP4.5)

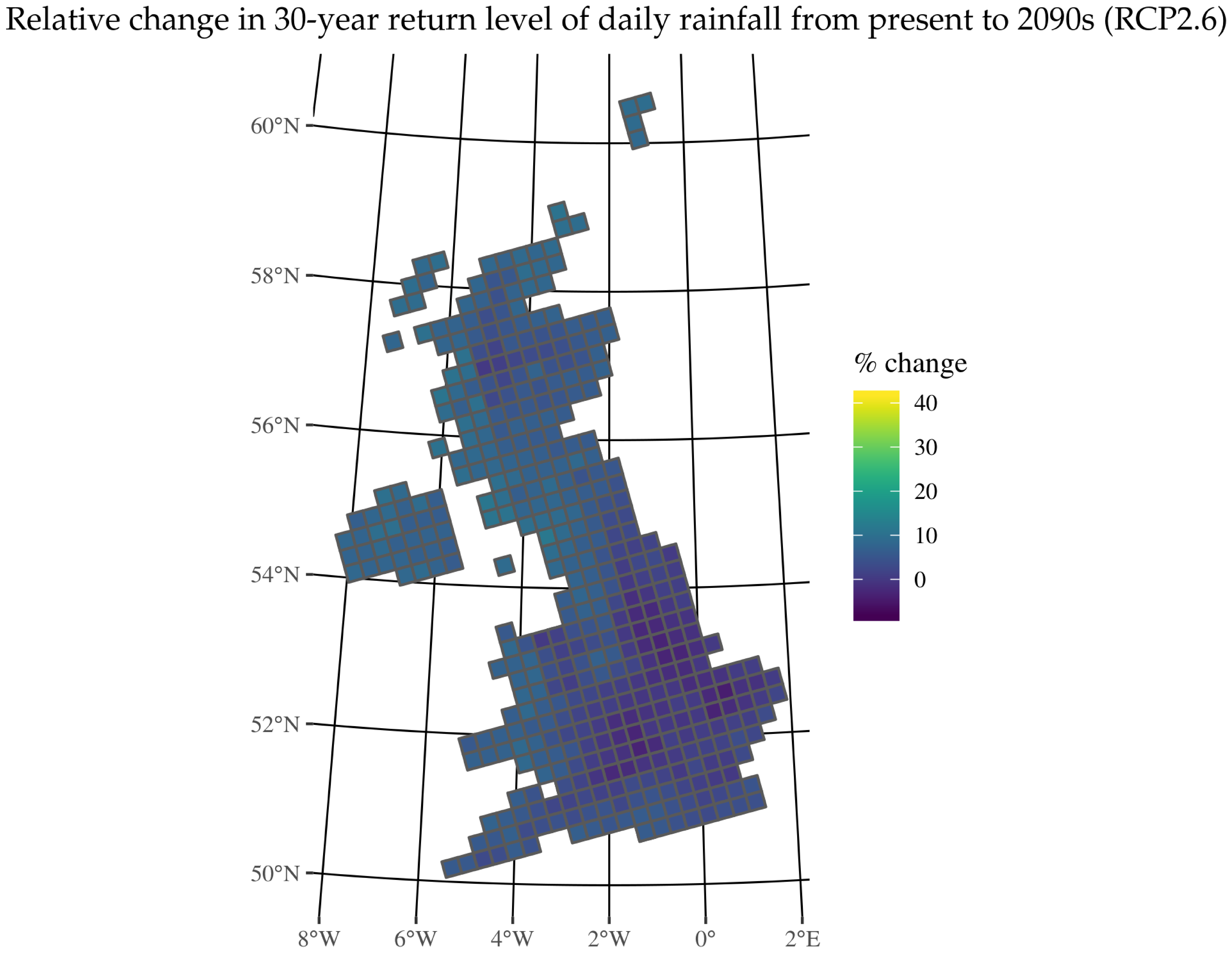


Absolute change in 50-year return level of daily rainfall from present to 2090s (RCP6.0)

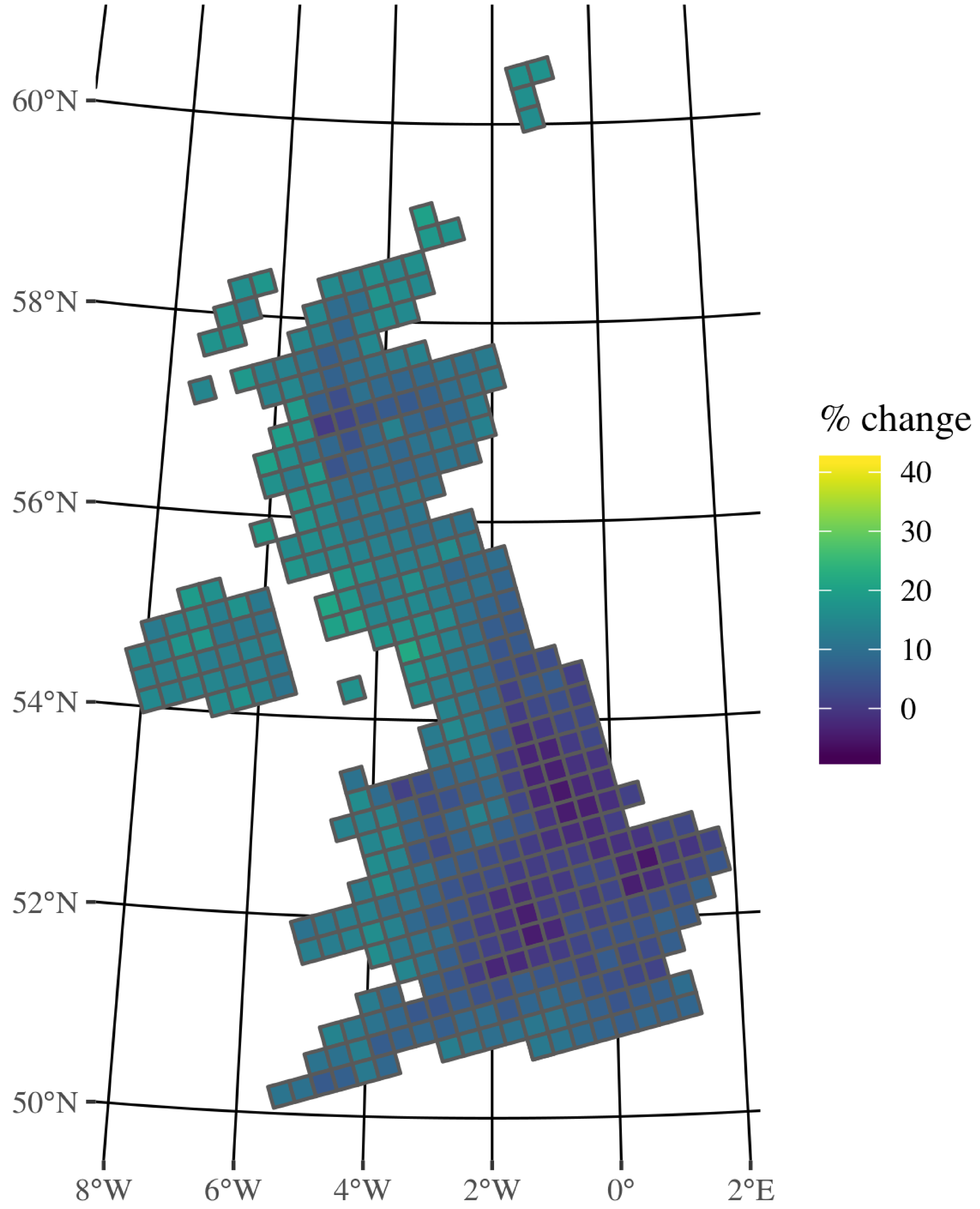


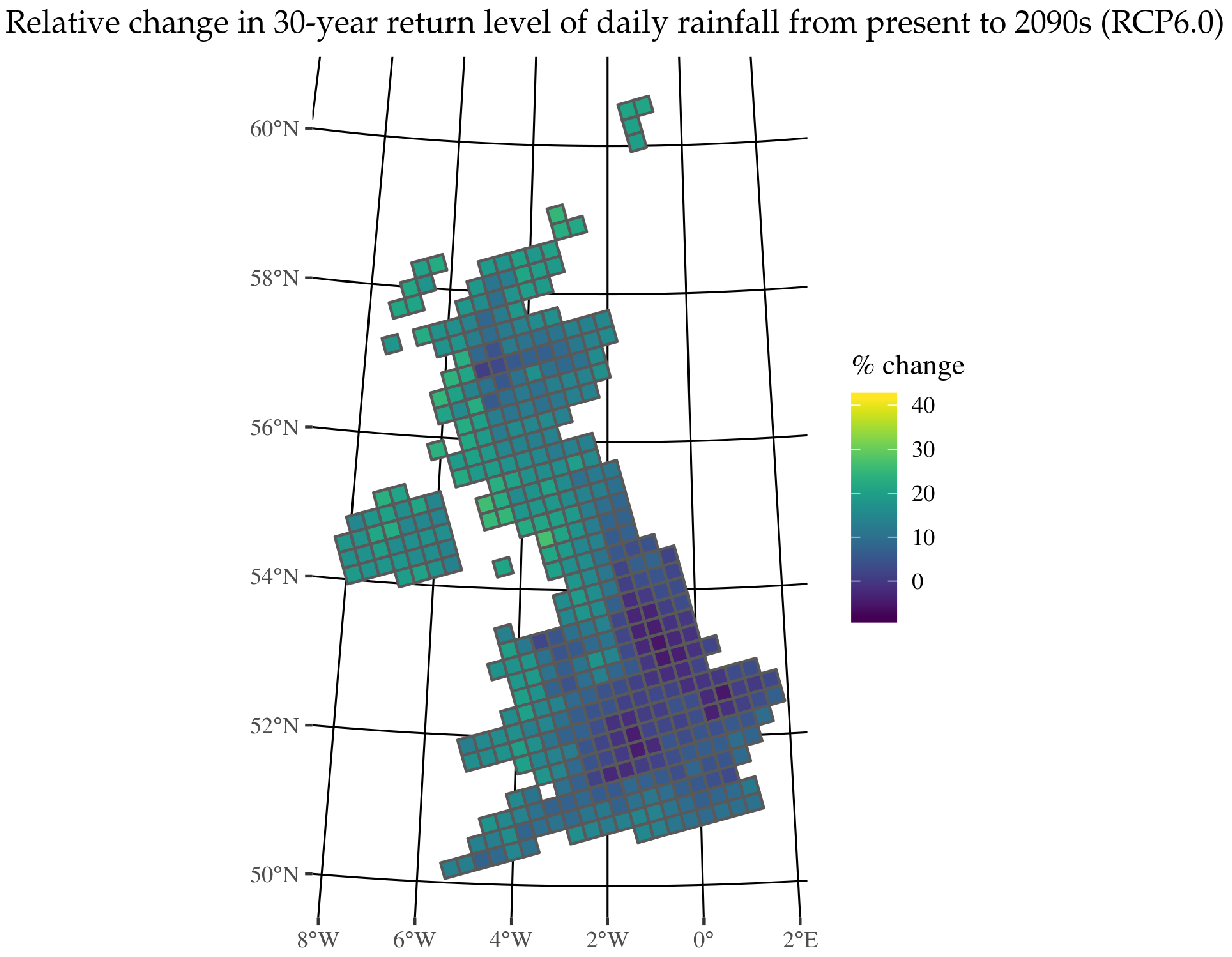
Absolute change in 50-year return level of daily rainfall from present to 2090s (RCP8.5)



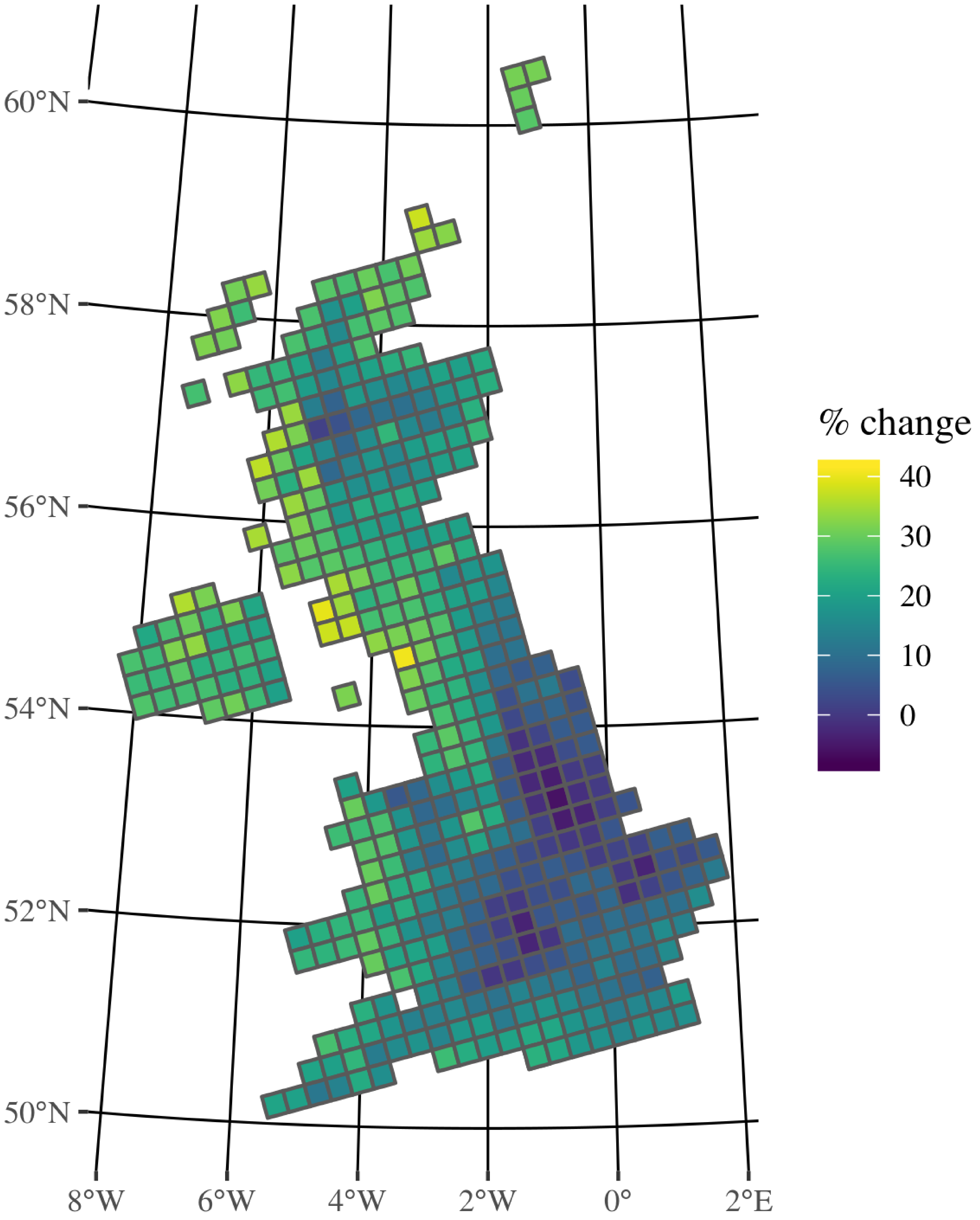

Relative change in 30-year return level of daily rainfall from present to 2090s (RCP2.6)
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E
% change
40
30
20
10
0

Relative change in 30-year return level of daily rainfall from present to 2090s (RCP4.5)

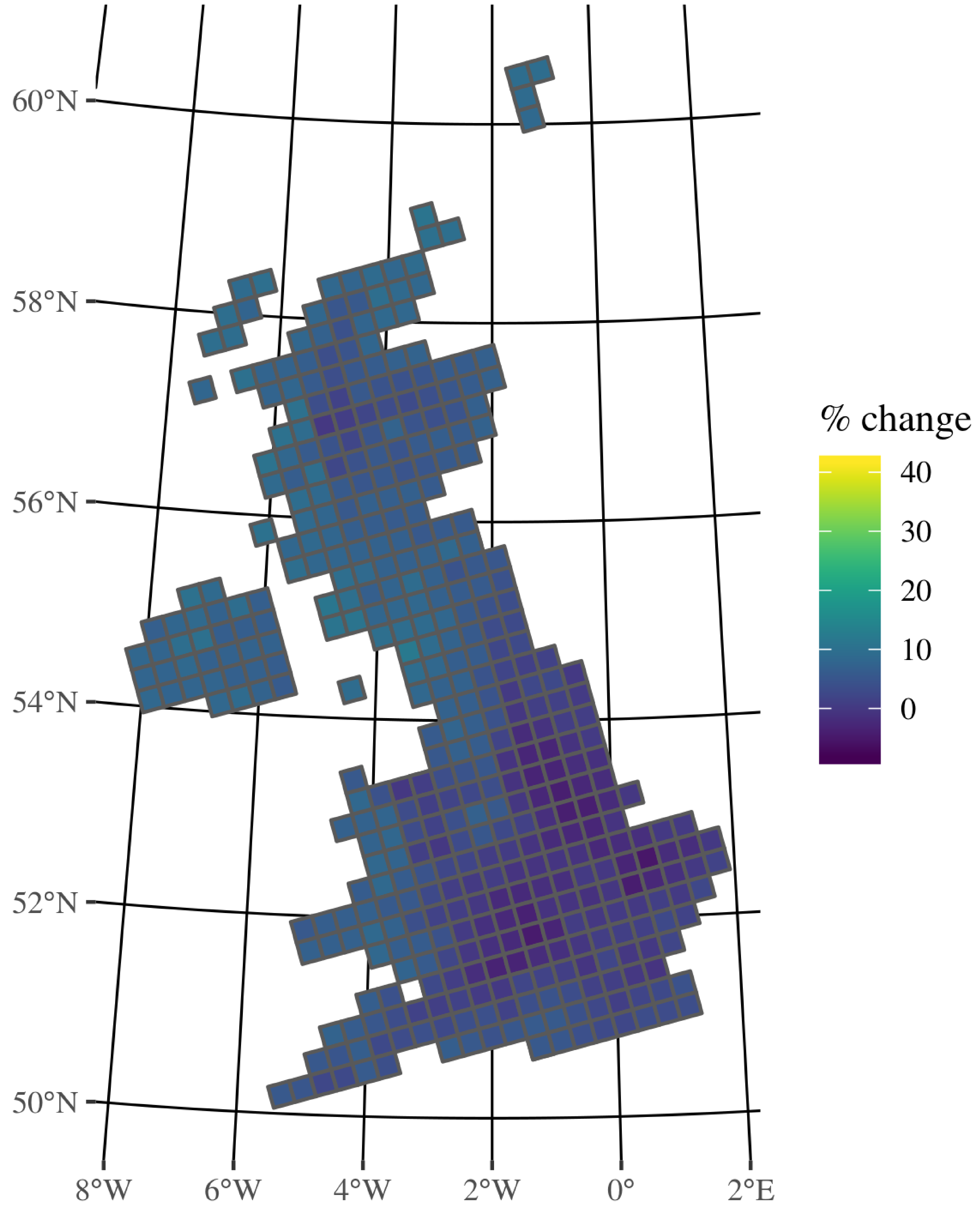



Relative change in 30-year return level of daily rainfall from present to 2090s (RCP6.0)
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E
% change
40
30
20
10
0

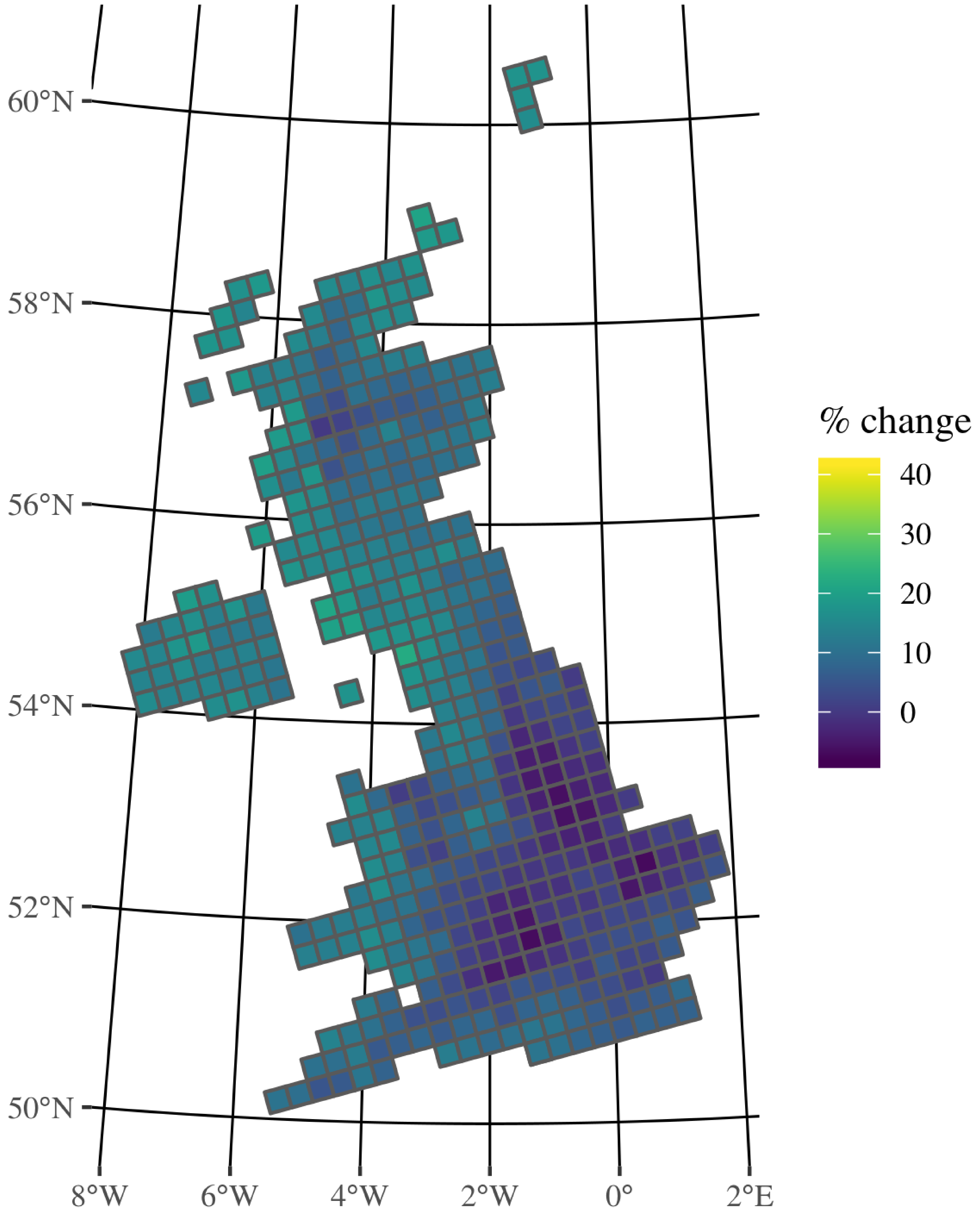
Relative change in 30-year return level of daily rainfall from present to 2090s (RCP8.5)



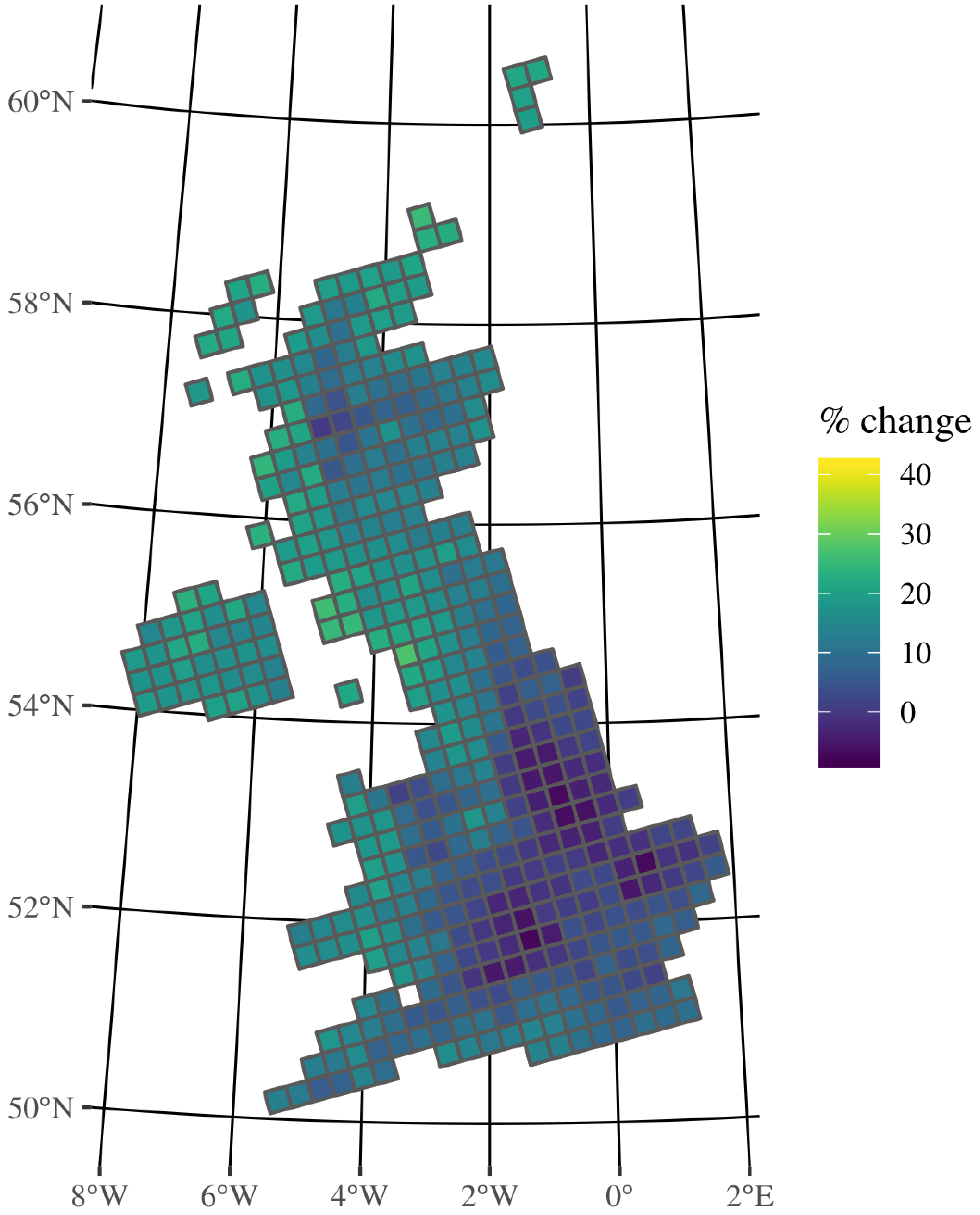
Relative change in 50-year return level of daily rainfall from present to 2090s (RCP2.6)



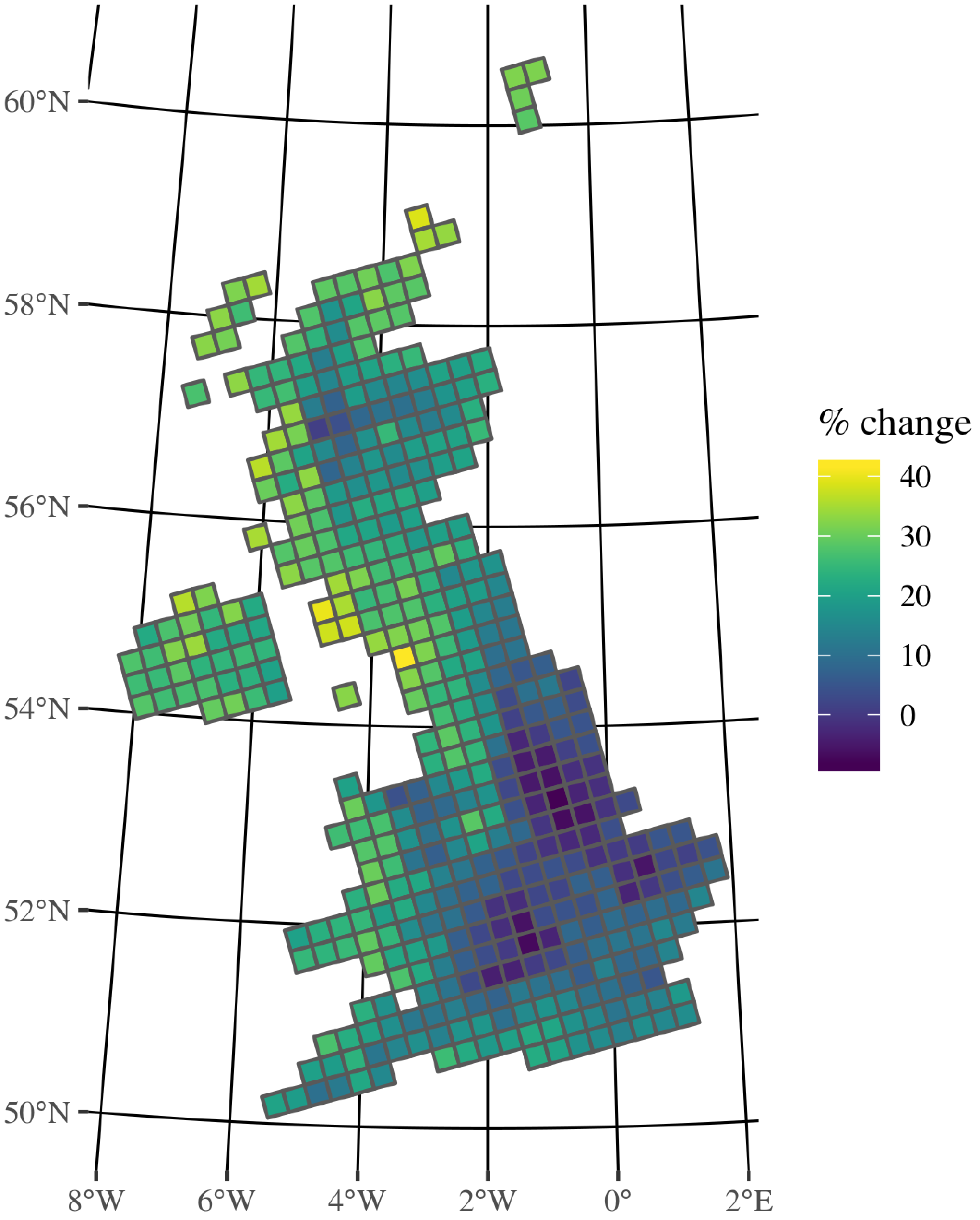
Relative change in 50-year return level of daily rainfall from present to 2090s (RCP4.5)

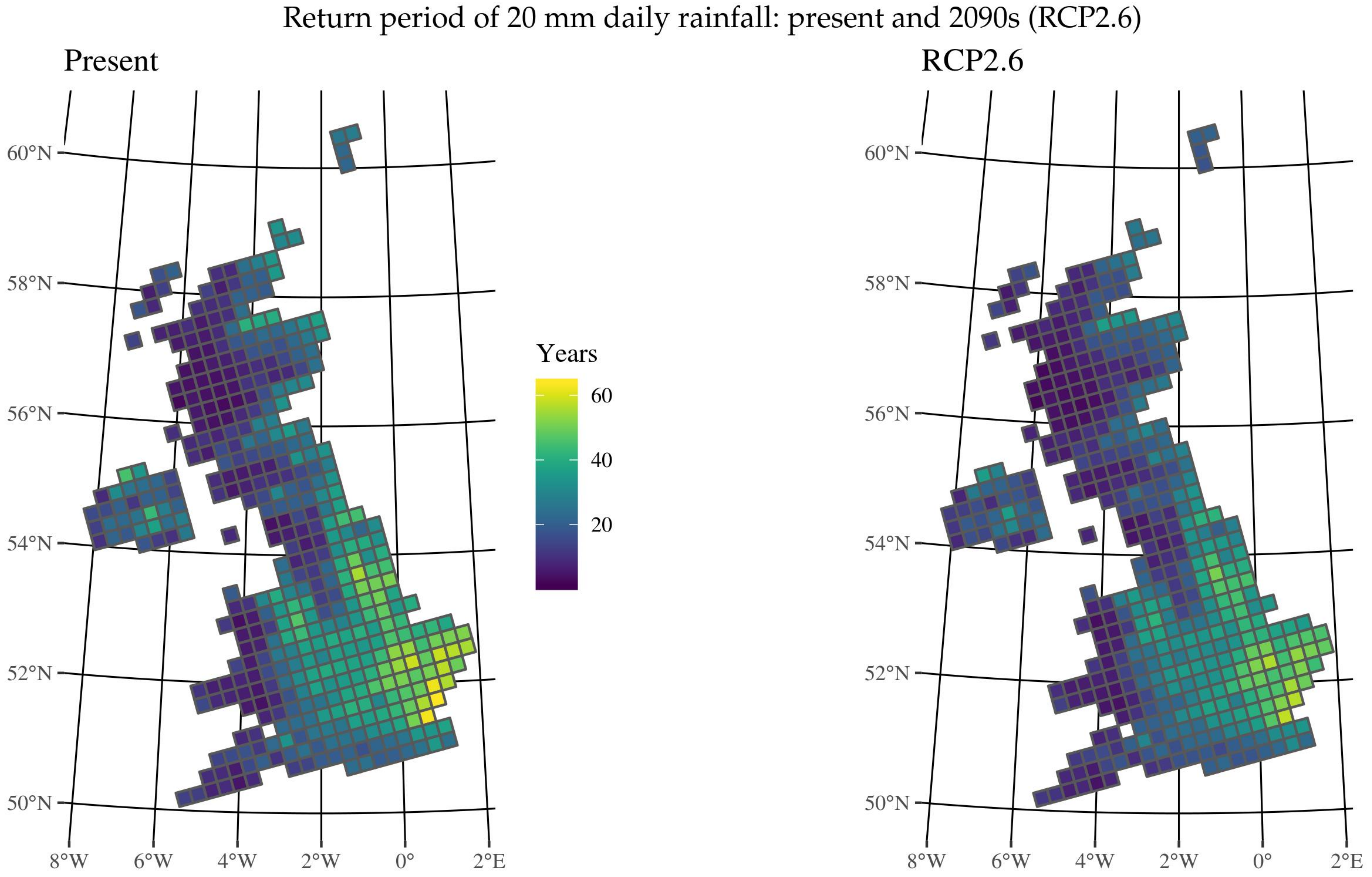


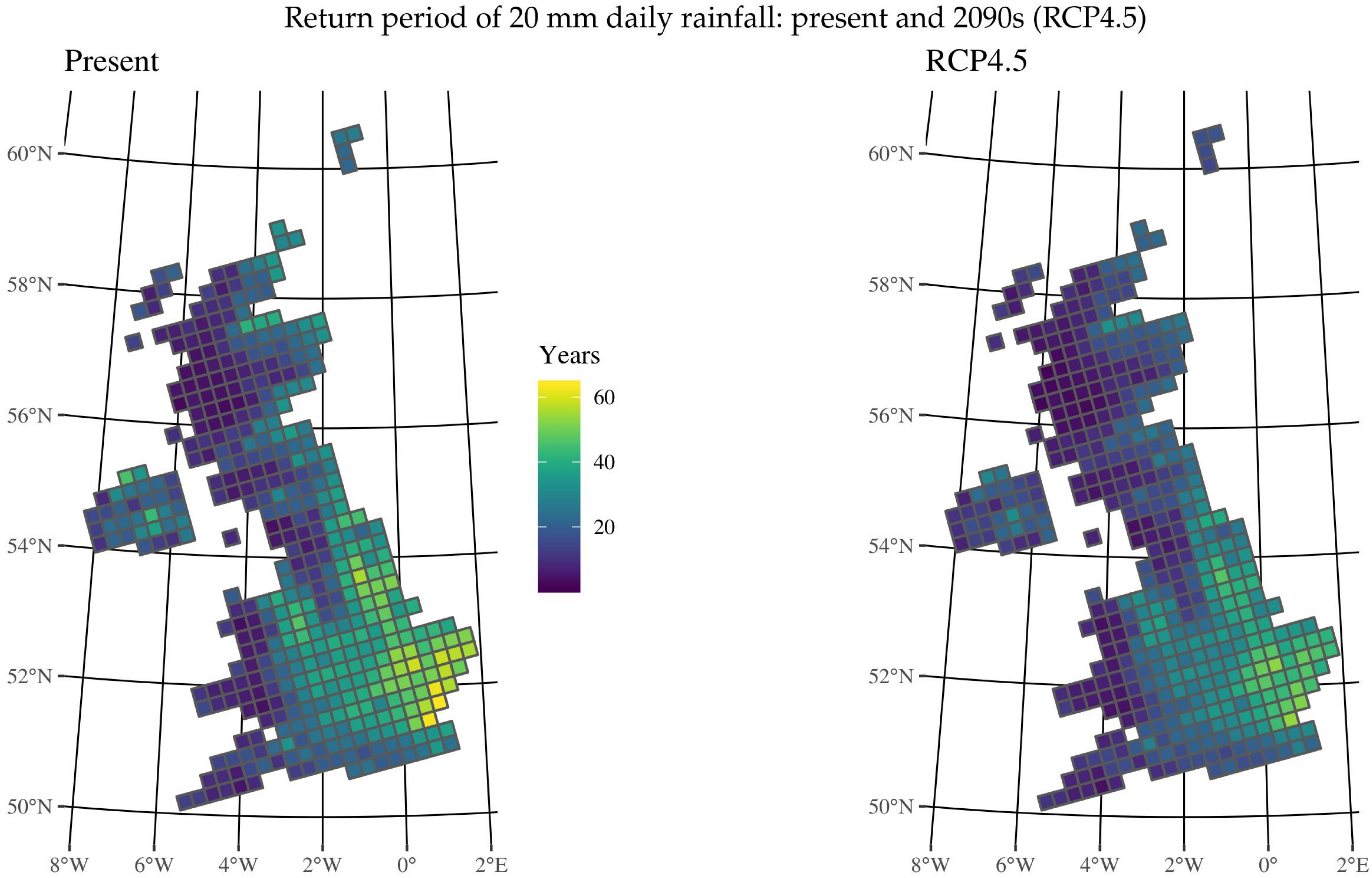
Relative change in 50-year return level of daily rainfall from present to 2090s (RCP6.0)



Relative change in 50-year return level of daily rainfall from present to 2090s (RCP8.5)

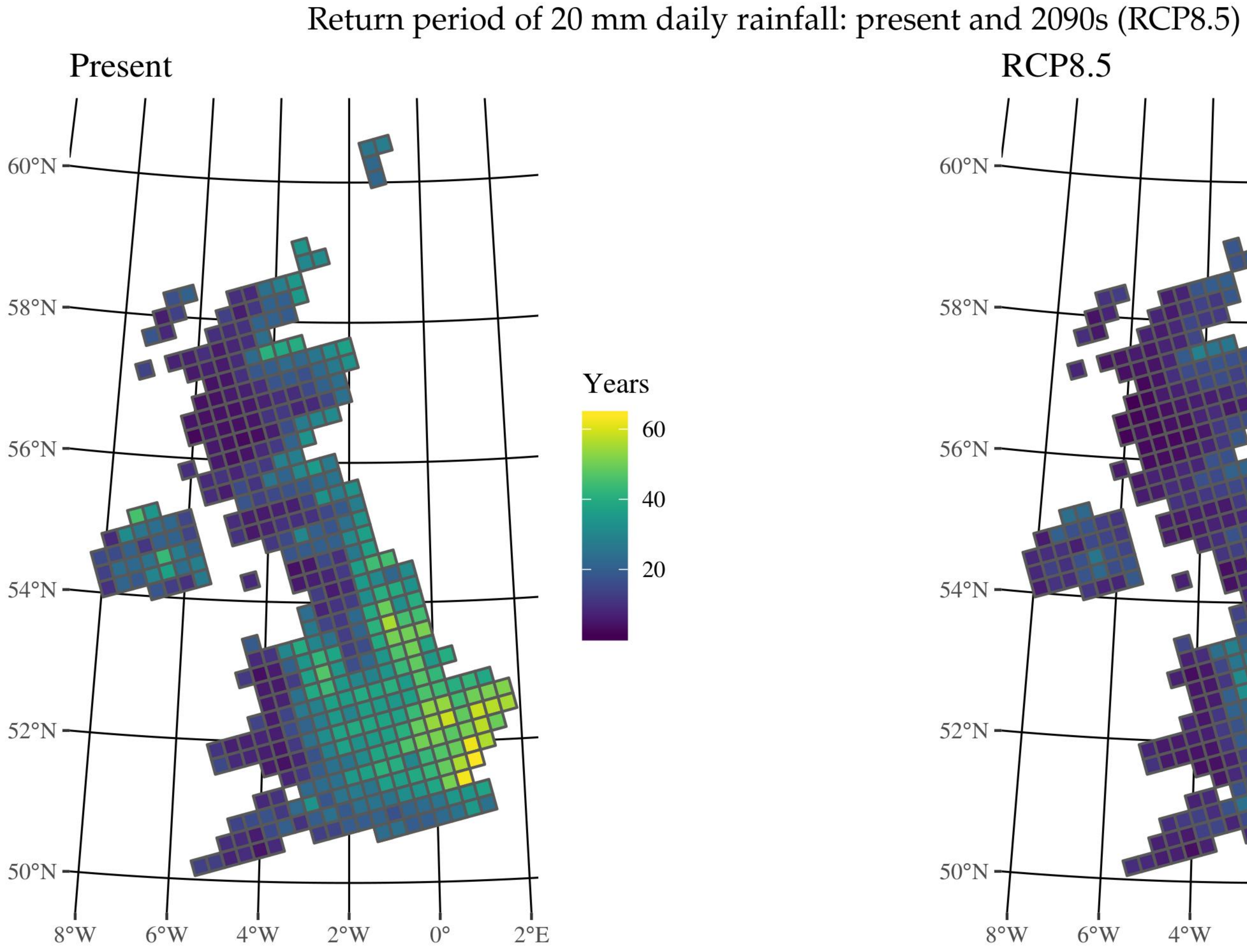



Return period of 20 mm daily rainfall: present and 2090s (RCP2.6)
Present
RCP2.6
Years
60
40
20
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E



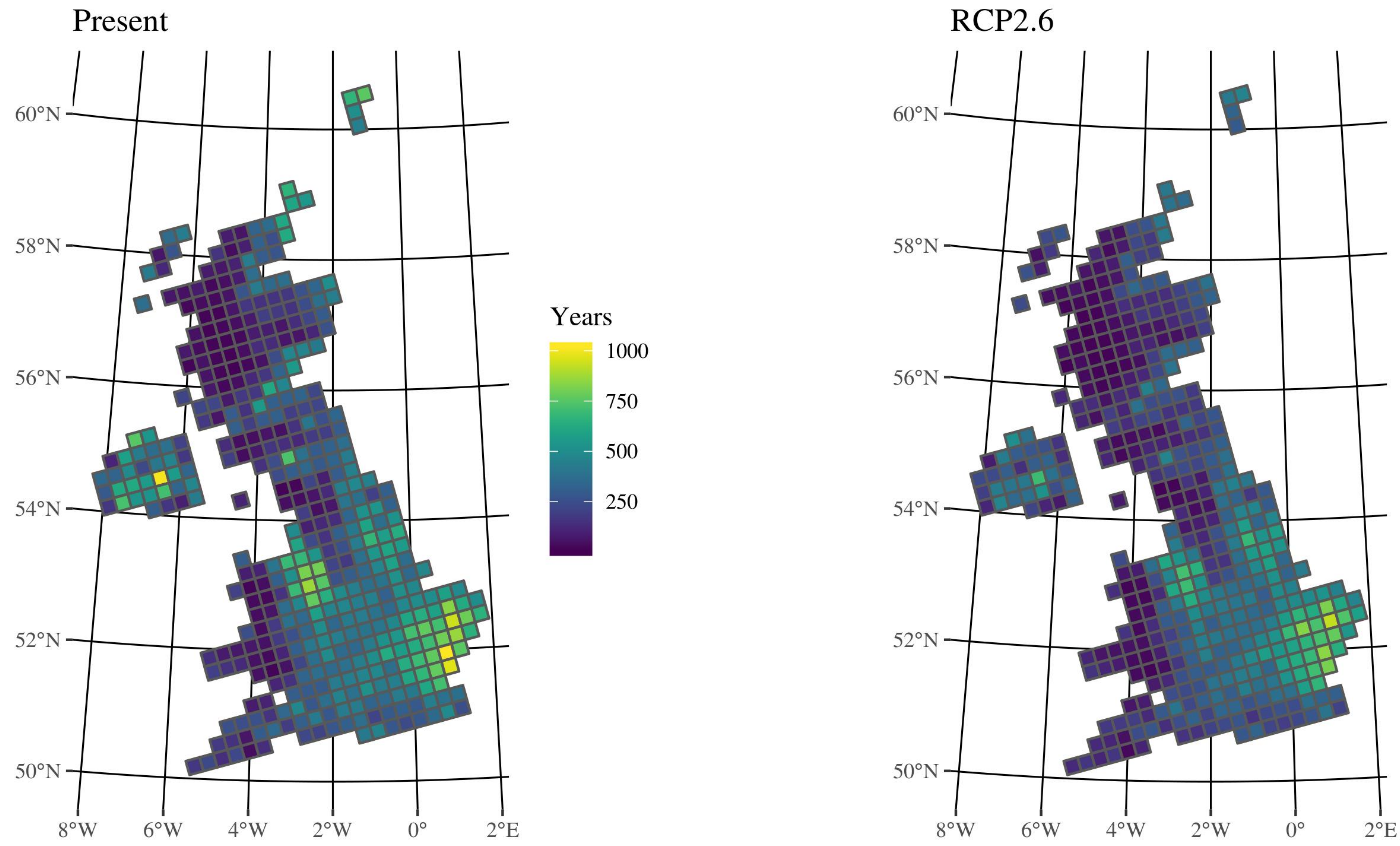
Return period of 20 mm daily rainfall: present and 2090s (RCP4.5)
Present
RCP4.5
Years
60
40
20
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E

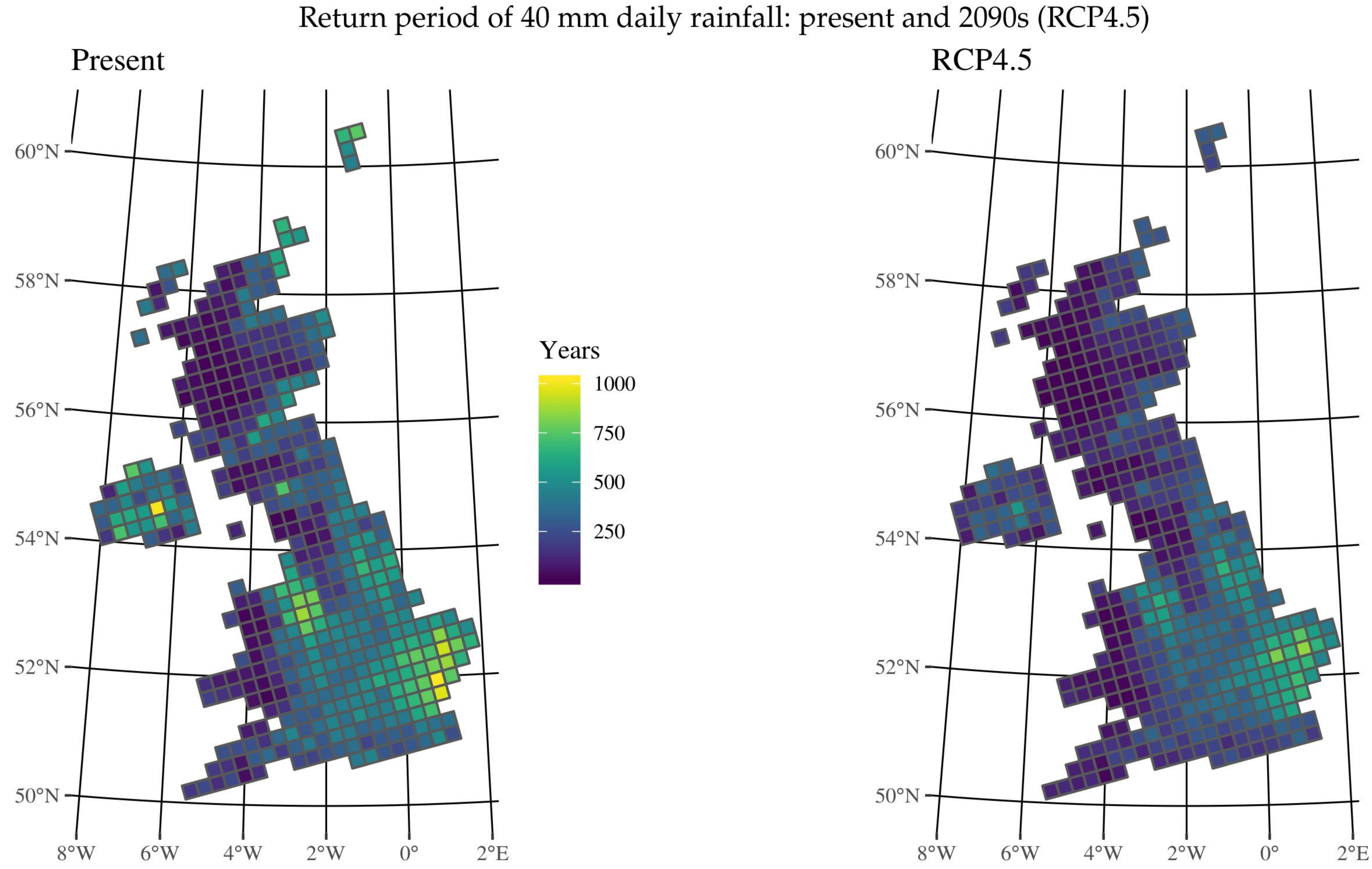

Return period of 20 mm daily rainfall: present and 2090s (RCP6.0)
Present
RCP6.0
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E
Years
60
40
20



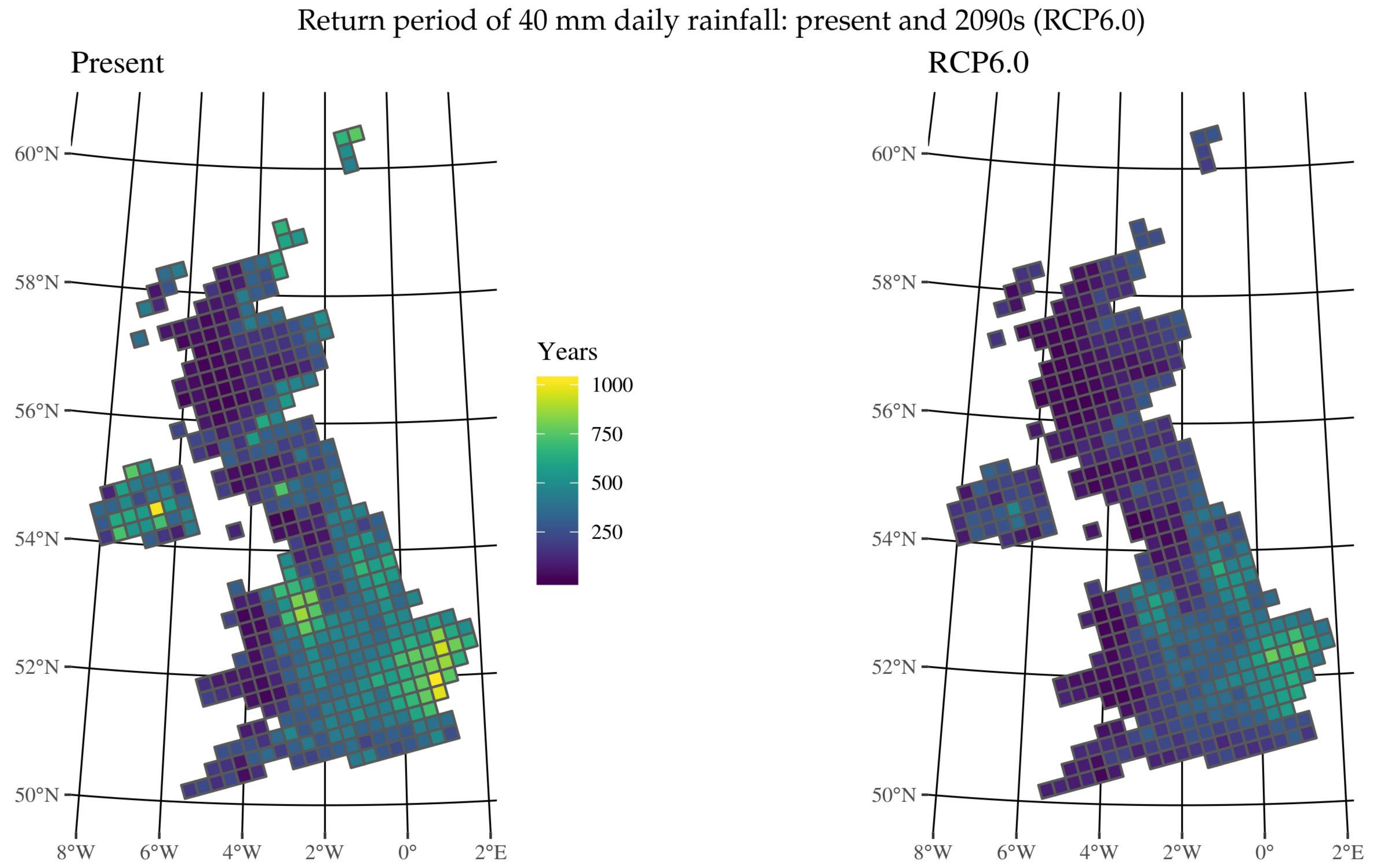
Return period of 20 mm daily rainfall: present and 2090s (RCP8.5)
Present
RCP8.5
Years
60
40
20
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E

Return period of 40 mm daily rainfall: present and 2090s (RCP2.6)

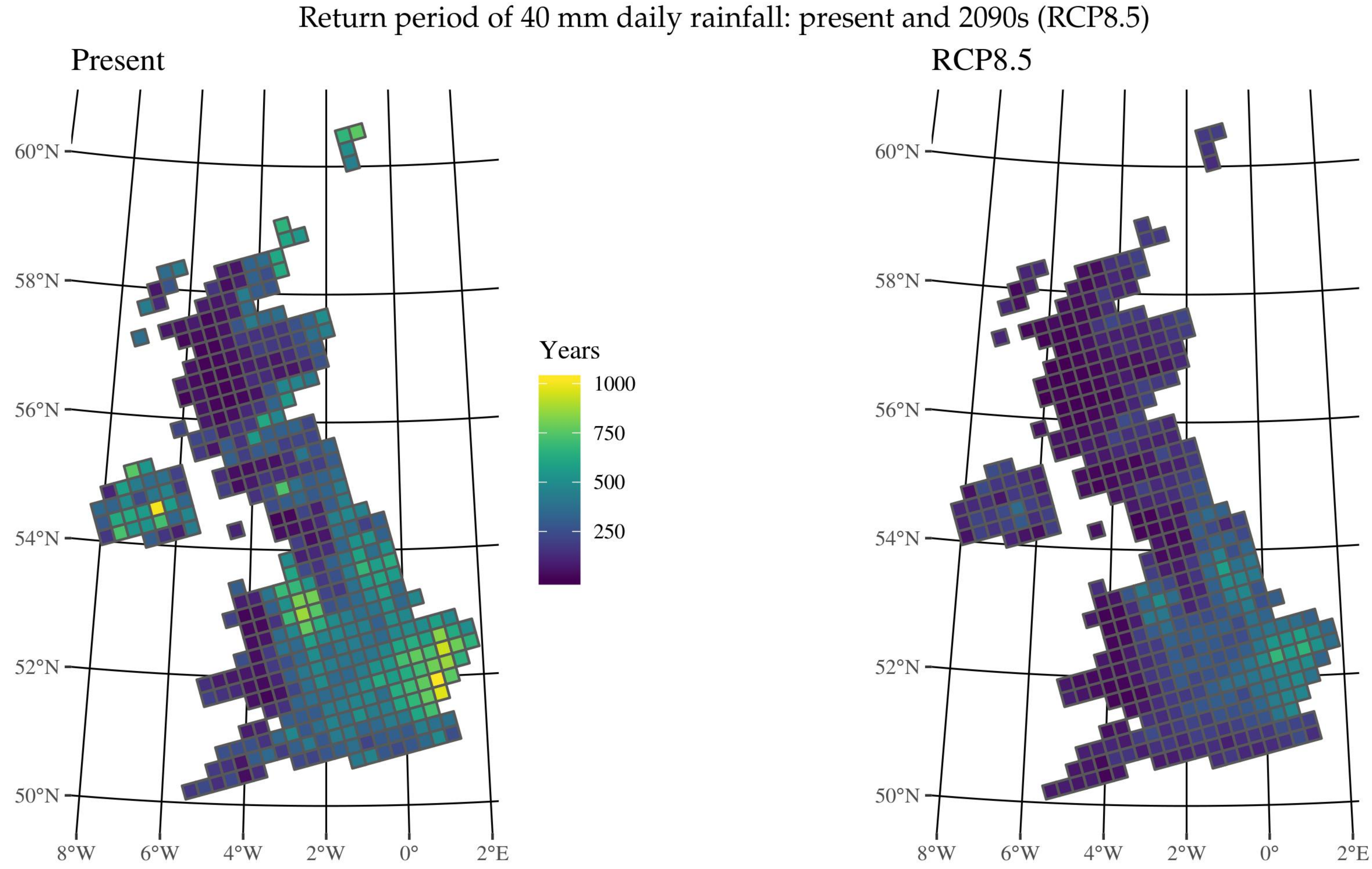




Return period of 40 mm daily rainfall: present and 2090s (RCP4.5)
Present
RCP4.5
Years
1000
750
500
250
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E



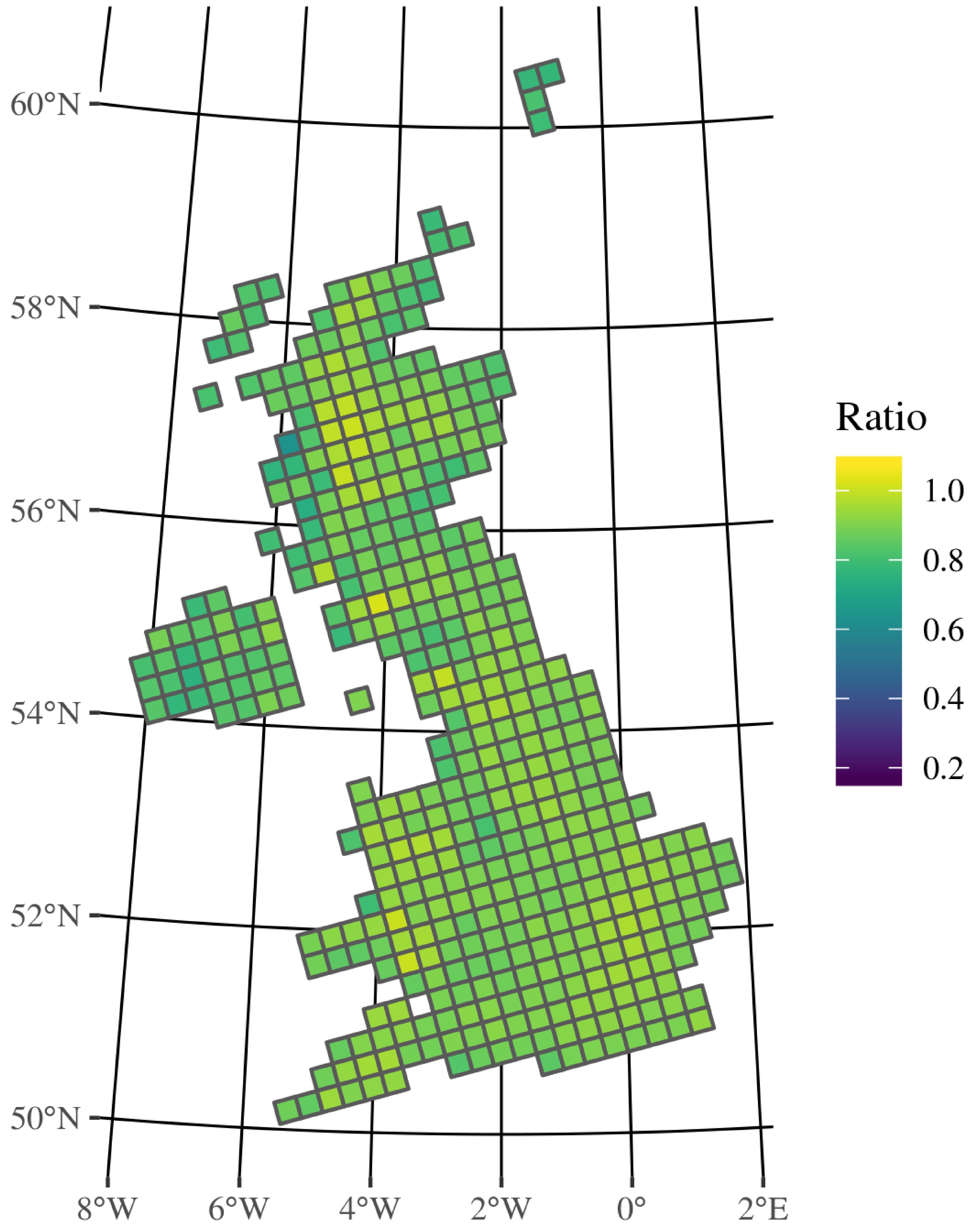
Return period of 40 mm daily rainfall: present and 2090s (RCP6.0)
Present
RCP6.0
Years
1000
750
500
250
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E



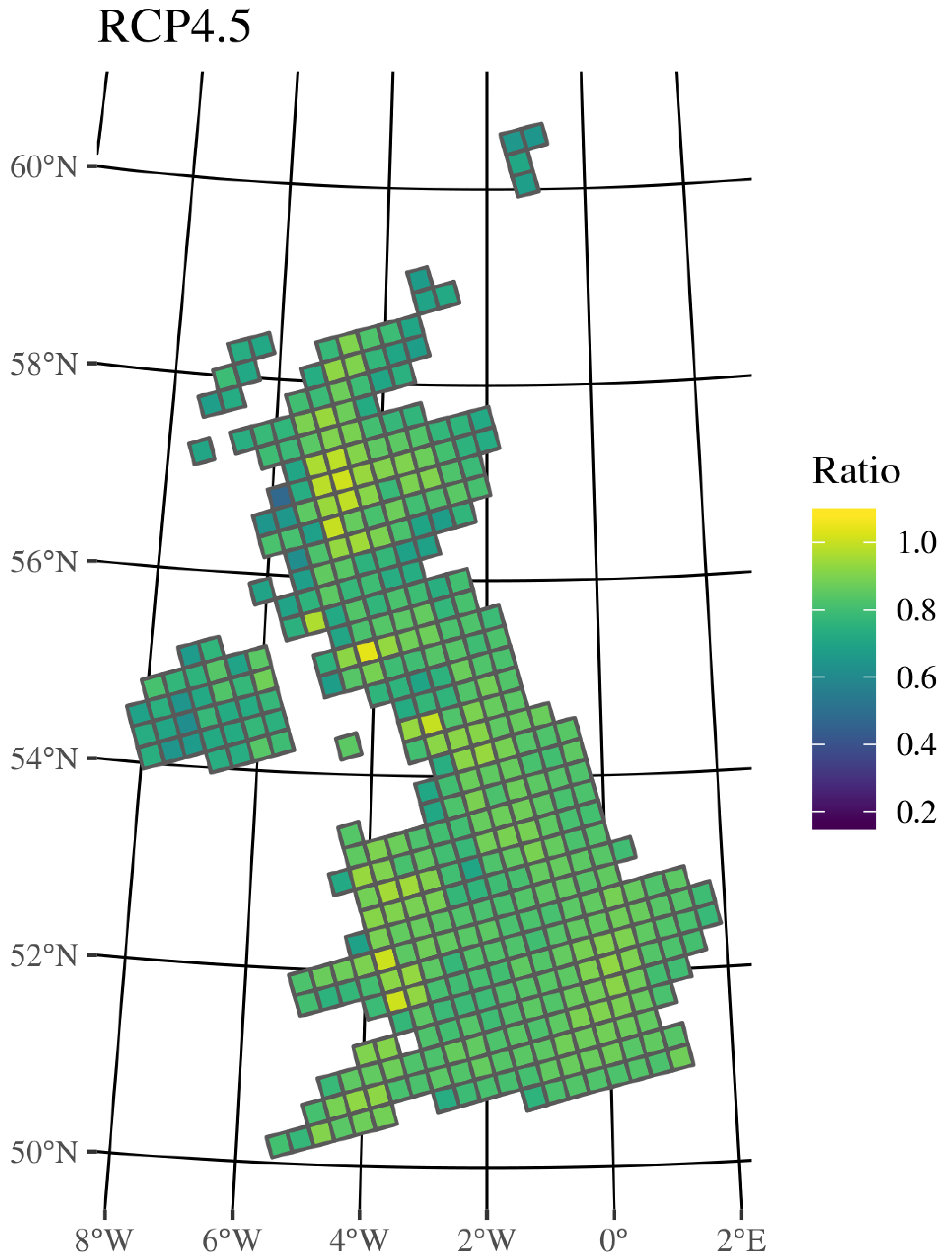
Return period of 40 mm daily rainfall: present and 2090s (RCP8.5)
Present
RCP8.5
Years
1000
750
500
250
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E

Relative return period of 20 mm daily rainfall in 2090s vs present day (RCP2.6)

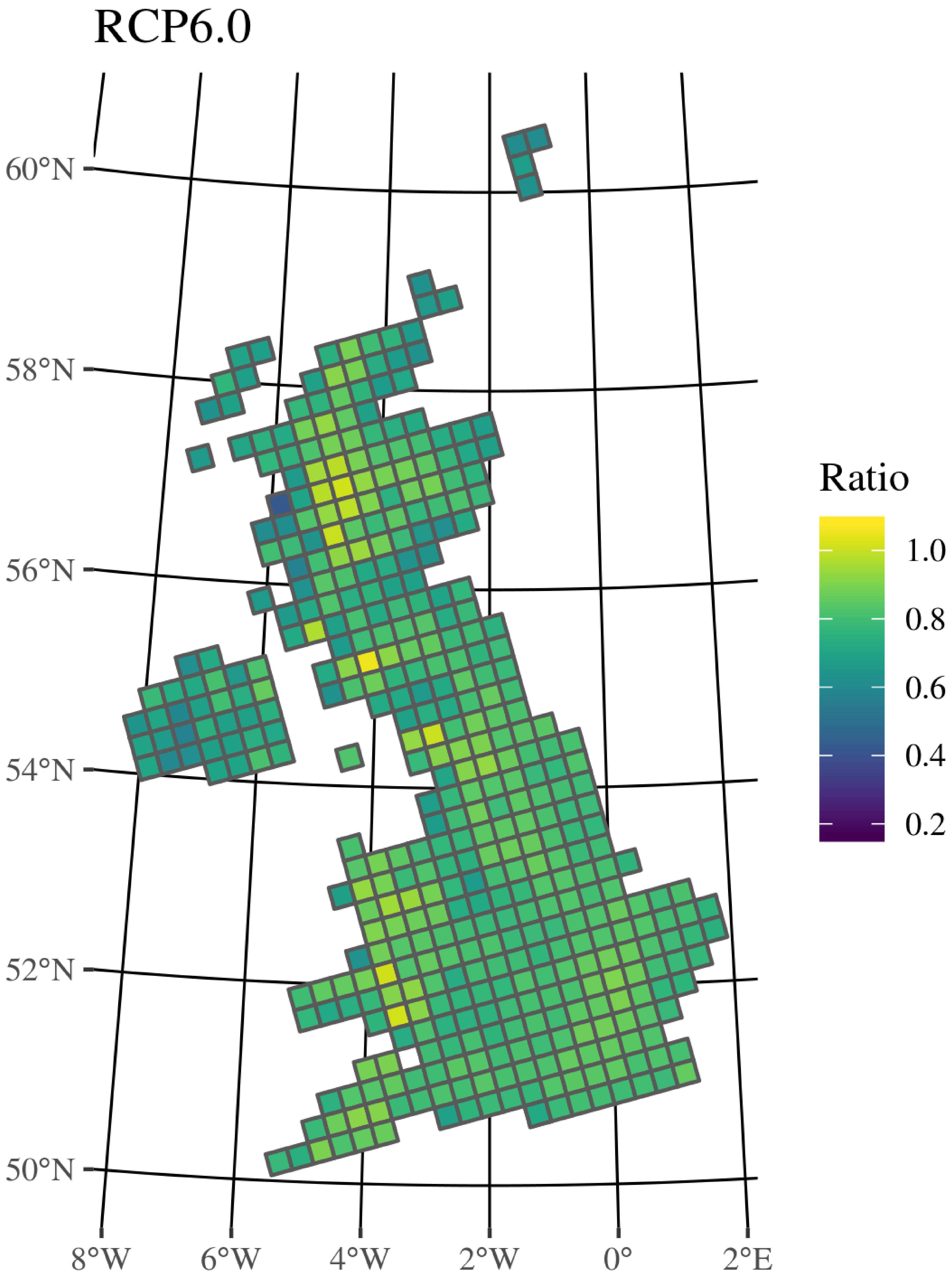
RCP2.6



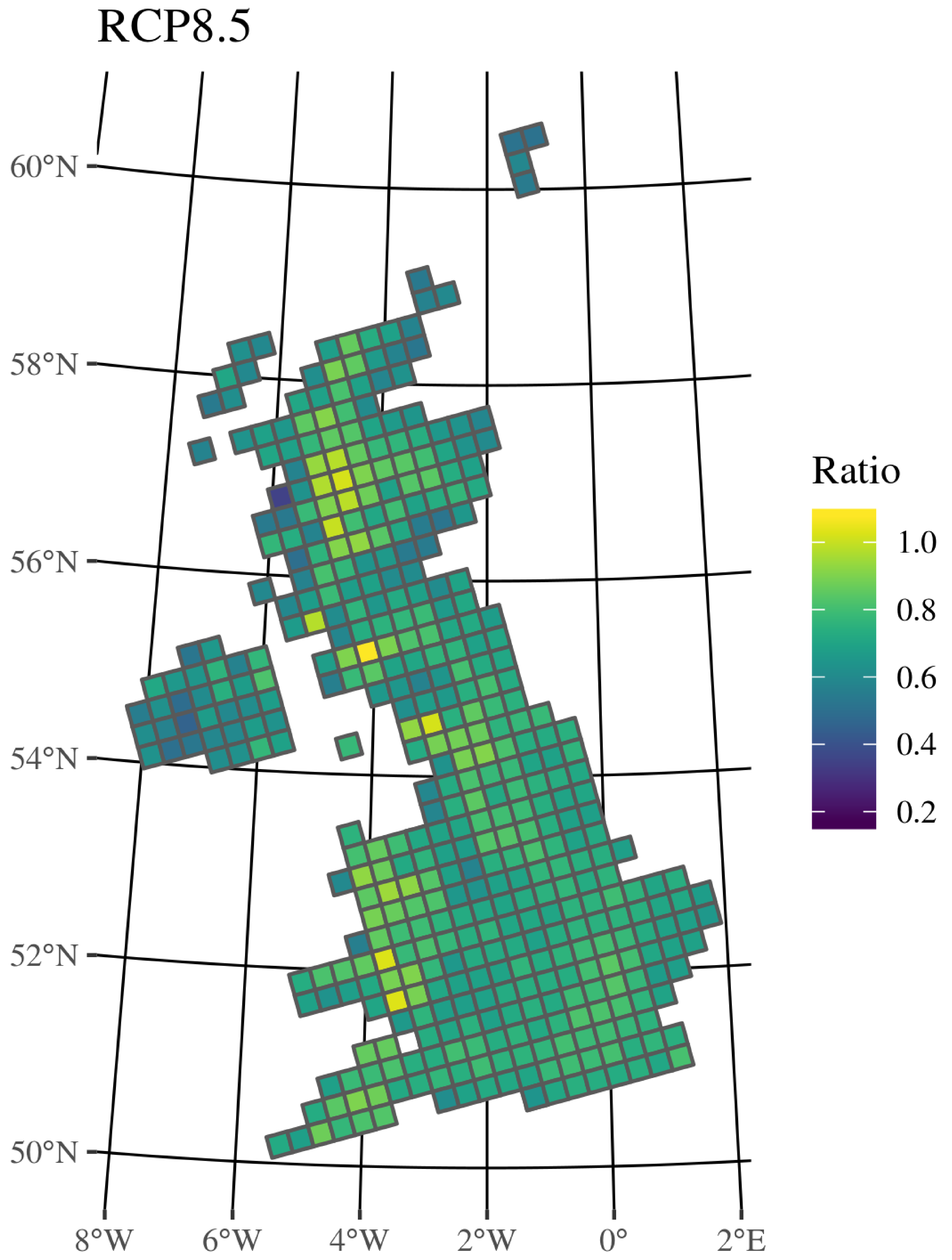
Relative return period of 20 mm daily rainfall in 2090s vs present day (RCP4.5)

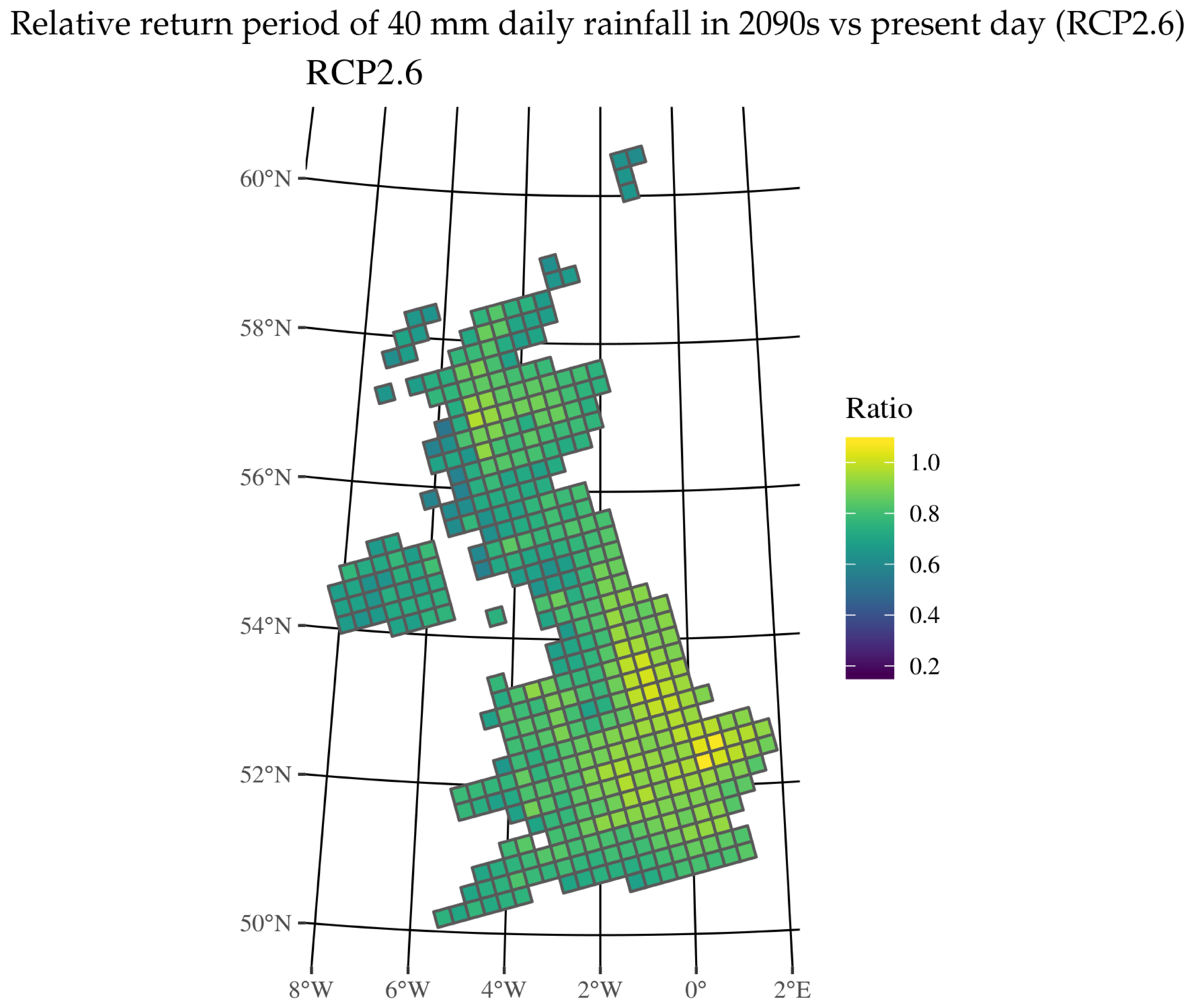


Relative return period of 20 mm daily rainfall in 2090s vs present day (RCP6.0)



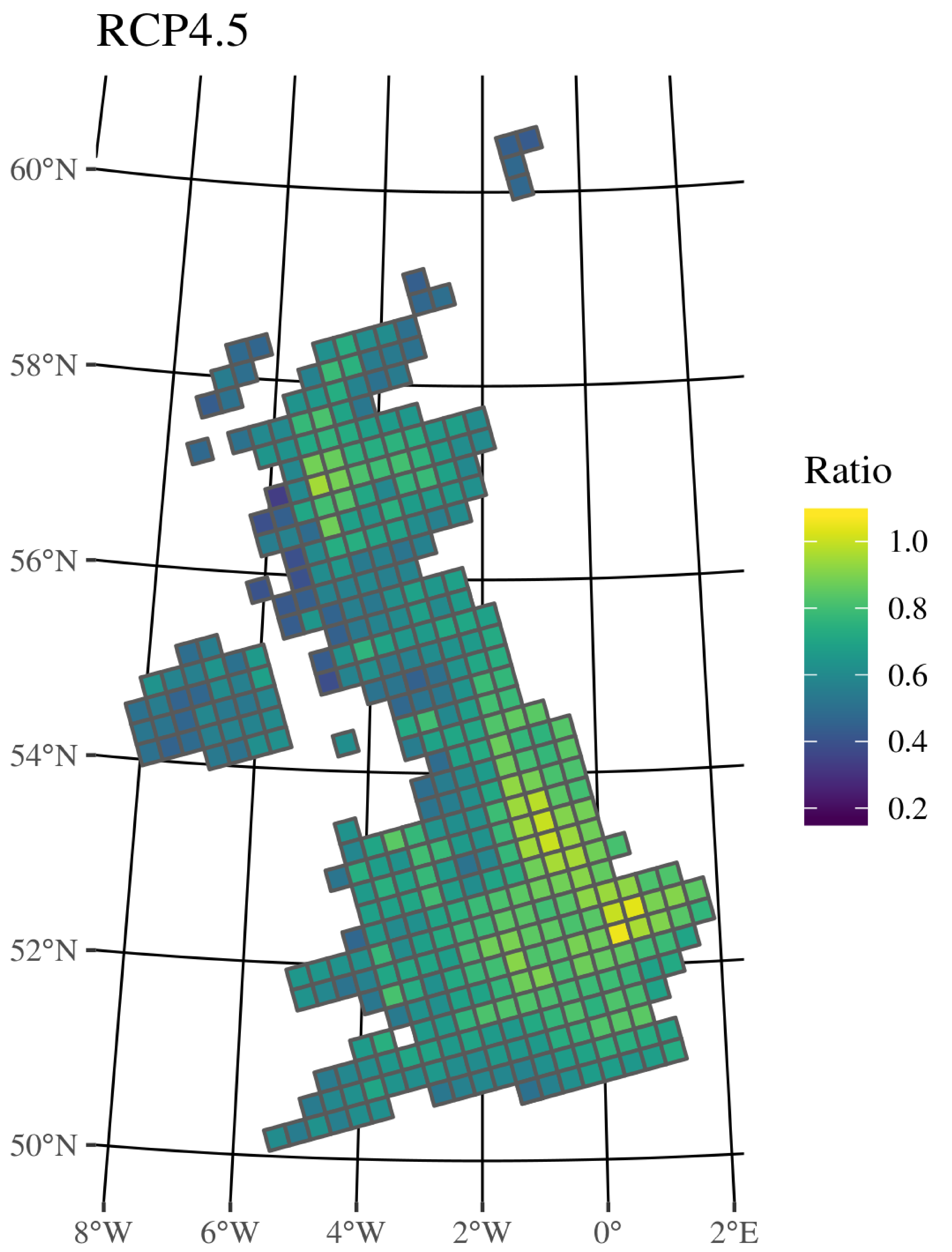
Relative return period of 20 mm daily rainfall in 2090s vs present day (RCP8.5)



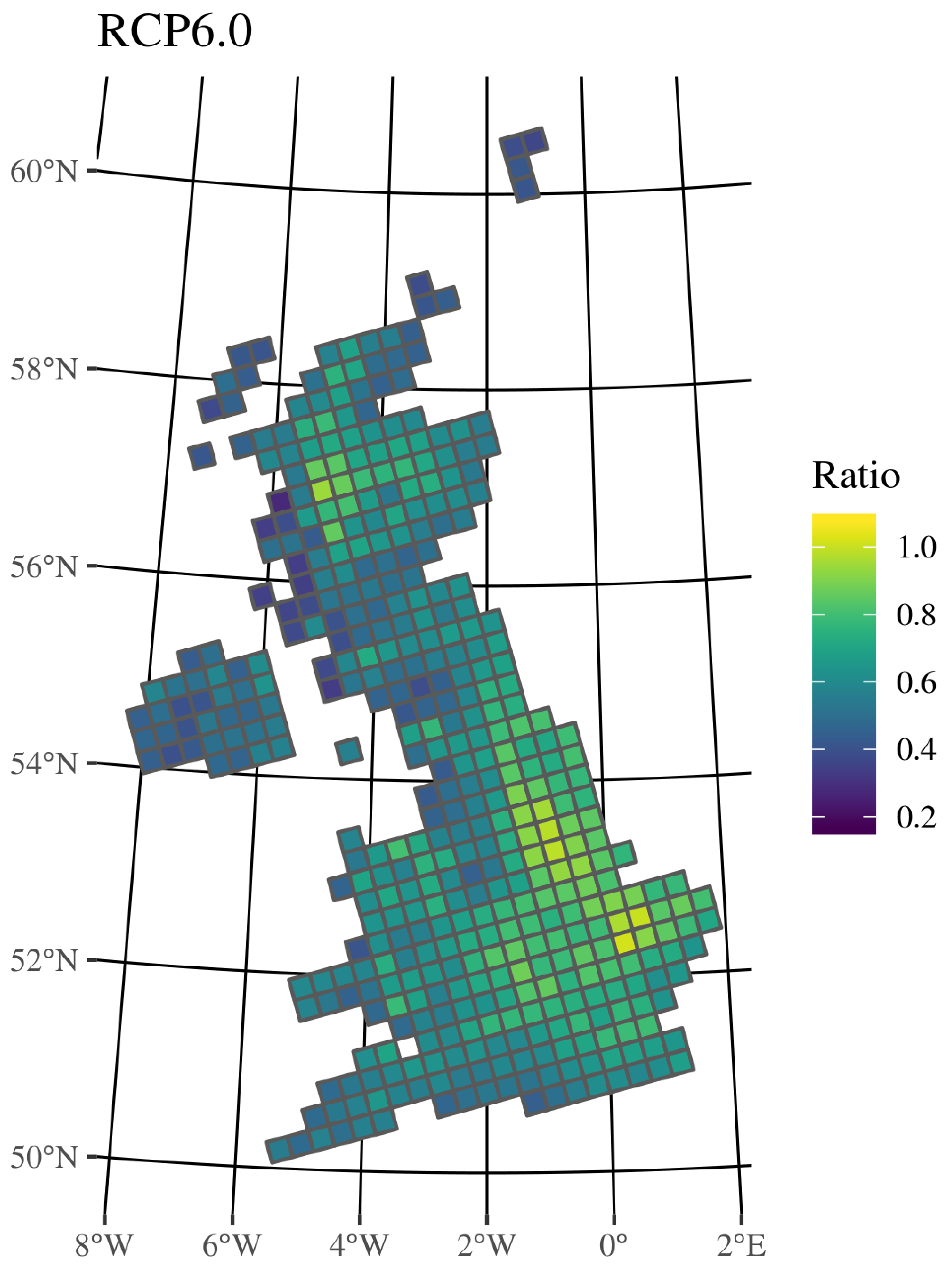


Relative return period of 40 mm daily rainfall in 2090s vs present day (RCP2.6)
RCP2.6
60°N
58°N
56°N
54°N
52°N
50°N
8°W
6°W
4°W
2°W
0°
2°E
Ratio
1.0
0.8
0.6
0.4
0.2

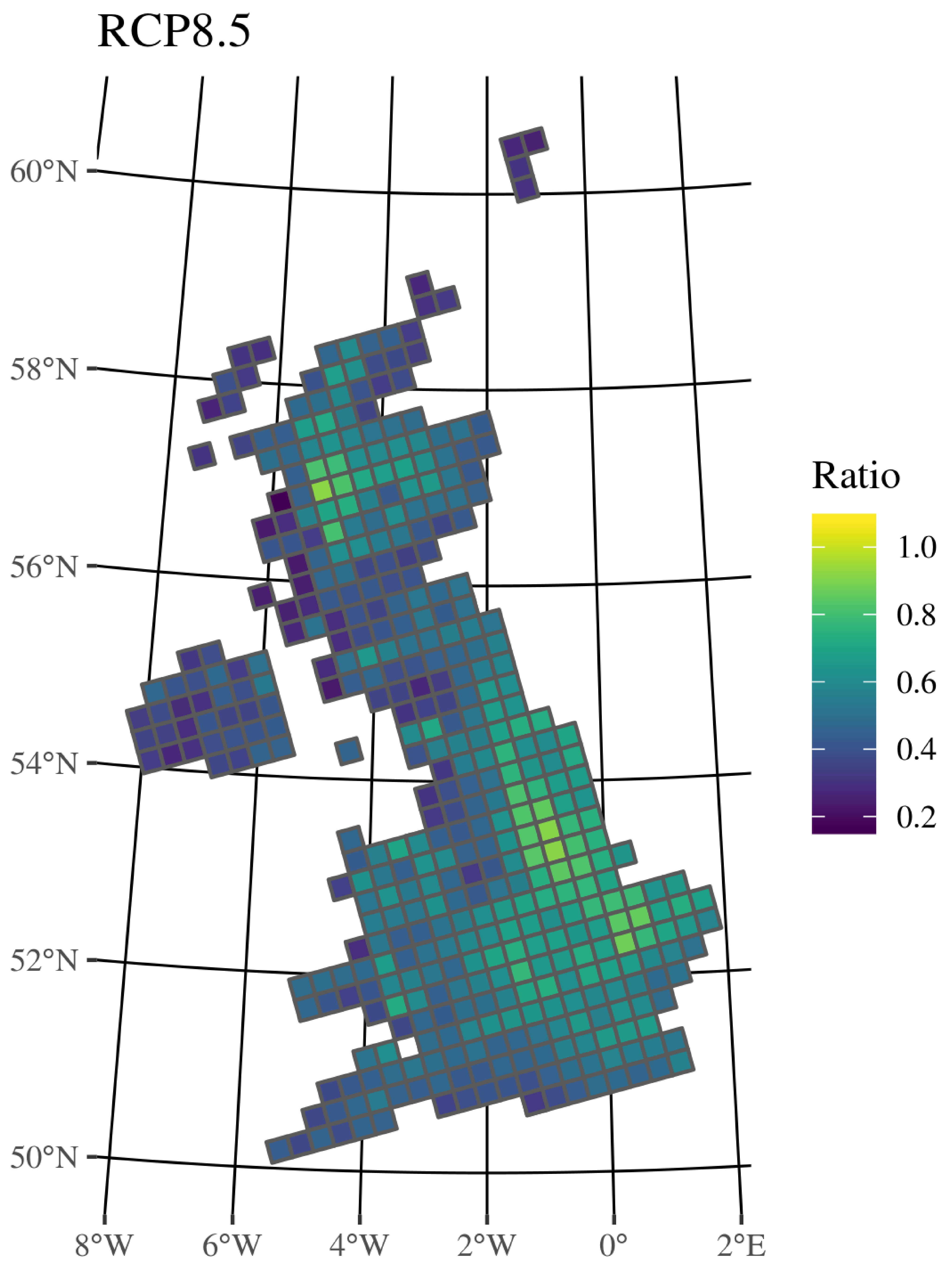
Relative return period of 40 mm daily rainfall in 2090s vs present day (RCP4.5)



Relative return period of 40 mm daily rainfall in 2090s vs present day (RCP6.0)



Relative return period of 40 mm daily rainfall in 2090s vs present day (RCP8.5)



References

Brown, S.J., Murphy, J.M., Sexton, D.M.H. et al. Clim Dyn (2014) 43: 2681. https://doi.org/10.1007/s00382-014-2080-1

Coles, S. (2001) https://doi.org/10.1007/978-1-4471-3675-0

UKCP18: https://www.metoffice.gov.uk/research/collaboration/ukcp

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APPENDIX

A brief description of the Generalised Extreme Value (GEV) Extreme Value Analysis (EVA) Technique

How to estimate the return period of an event from a relatively short data record

- The lowest temperature recorded at Exeter Airport in last 10 years was -16.5 ˚C (26/10/2010) –
- So in terms of frequency, we can say that this temperature has happened once in the last 10 years
- But is this a one in 10 year event?
- This also happens to be the lowest temperature recorded there in the last 50 years so we can say that it has happened once in the last 50 years
- So is this now a 1 in 50 year event?
- If the record length never exceeds 50 years then we cannot have a recurrence of > 50 years based upon its frequency but it is possible that this temperature is even rarer?
- So we need to get outside the confines of the dataset length to be able to try and estimate and describe more extreme events.

How do we estimate return periods that are longer than the data record?

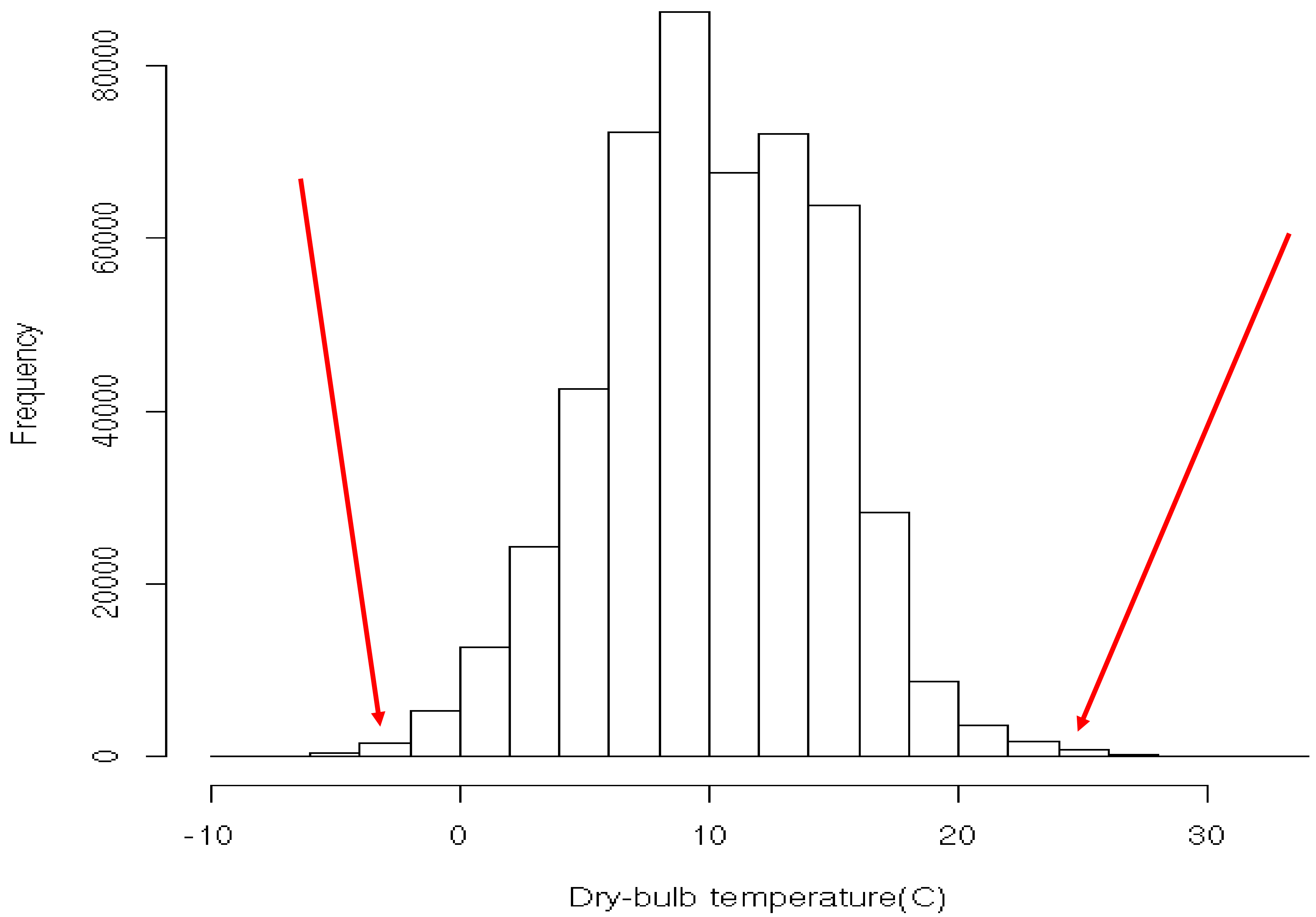
- We do this by trying to fit a theoretical frequency distribution (mathematical expression) to the data series.
- If the theoretical distribution fits the empirical (observed) distribution well then it can be used to interpolate but more importantly, to extrapolate beyond those observed values,
- i.e. to estimate return periods of extreme values that are beyond the length of the relatively short data record.
- This is the essence of the Extreme Value Analysis (EVA).

Extreme Value Analysis - EVA

- Most EVA's only analyse the extremes within a dataset rather than the whole dataset

- Traditionally EVA methods fall into two camps based upon a generalised extreme value (GEV) distribution and the generalised Pareto distribution (GPD).

- For this report, the GEV method has been used.



Generalised Extreme Value (GEV) Method

- Classical GEV is a distribution function based upon independent ‘block’ maxima/minima, i.e. the highest/lowest value in a pre-determined time interval (epoch).
- This is often the annual maxima/minima but for this report seasonal time intervals were chosen.
- Only one value per season is chosen; for this report this value was the highest daily rainfall total in each season. As 30 years’ worth of data were analysed there would be 30 winter values analysed for the winter analysis, 30 spring values for the spring analysis etc.

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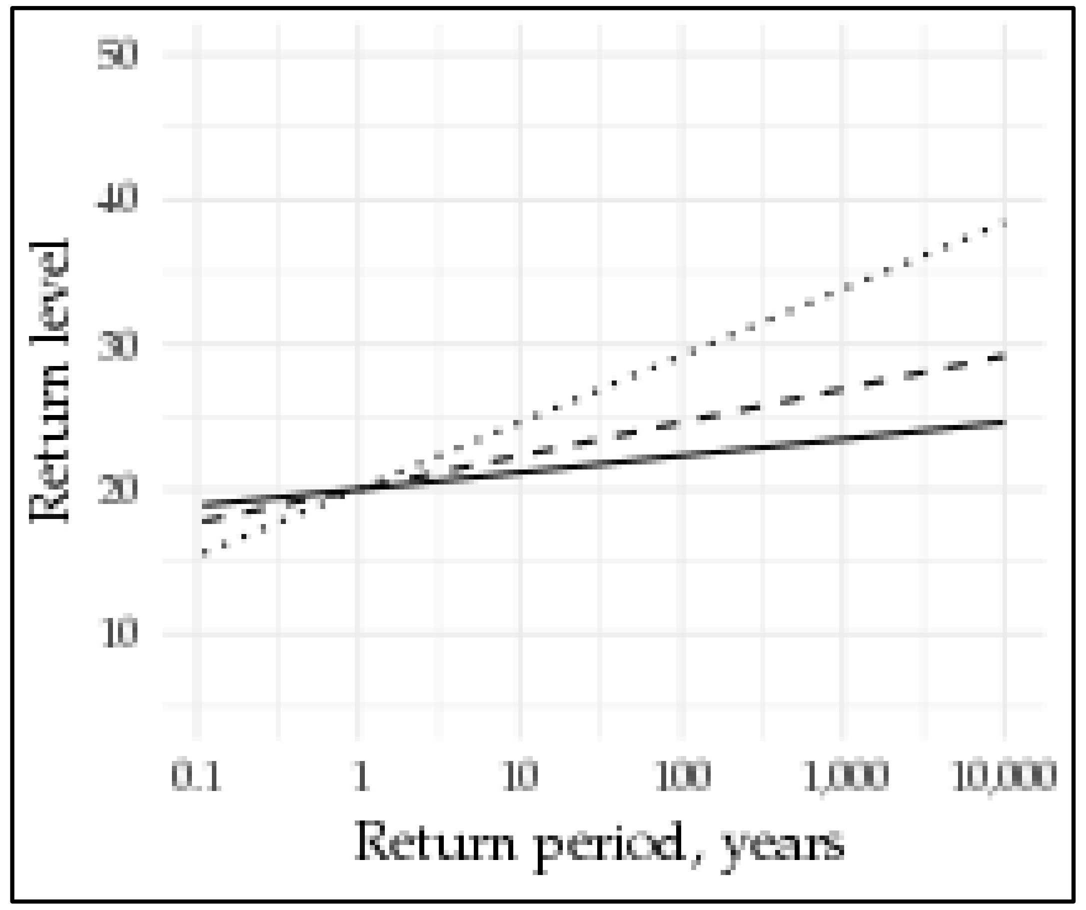
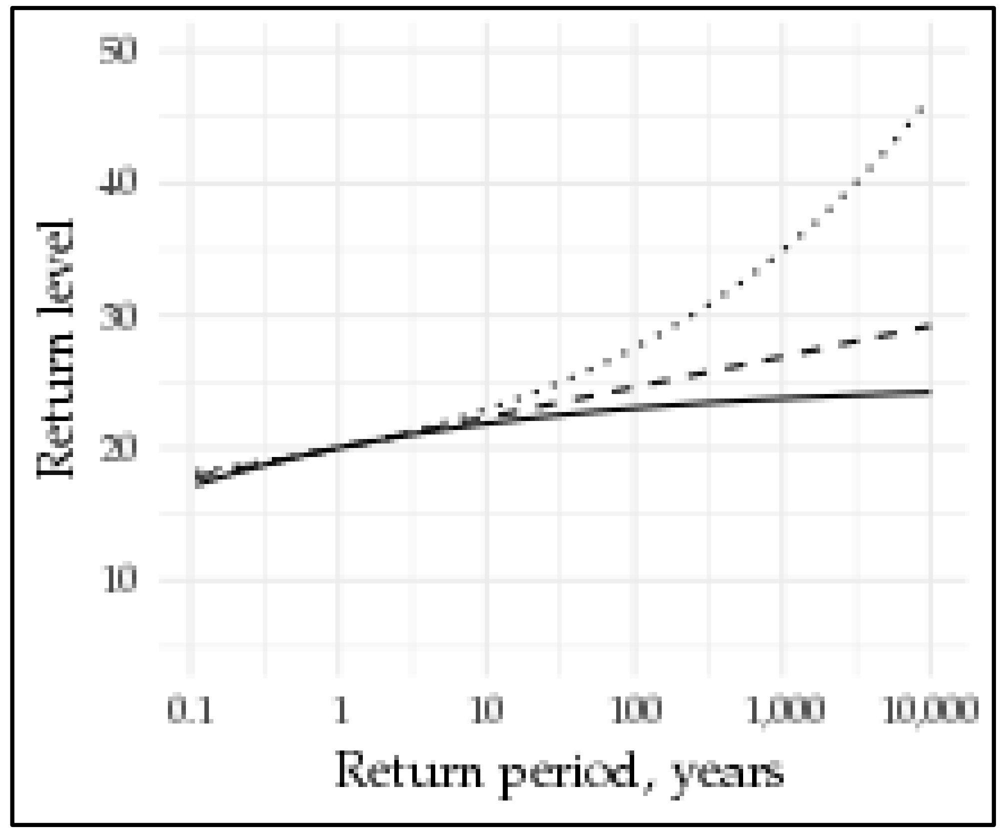
- A GEV distribution would have been fitted to our 30 values and plotted (four plots, one for each season) – an example is shown in the next slide.
- However, there are three common and important parameters that determine the plot of the EVA –
- Scale – which determines the steepness of the gradient of the curve/plot
- Shape – whether this curve turns up (positive), is straight (0) or turns down (negative), resulting in unbounded or bounded results
- Location – where the plot sits on the graph which is determined by the values of the 30 data points , i.e. the higher the values the further up the y-axis the plot will sit
- Note 'return levels' on these graphs simply refer to the values of the inputted data. In these examples, the parameter is temperature (°C)

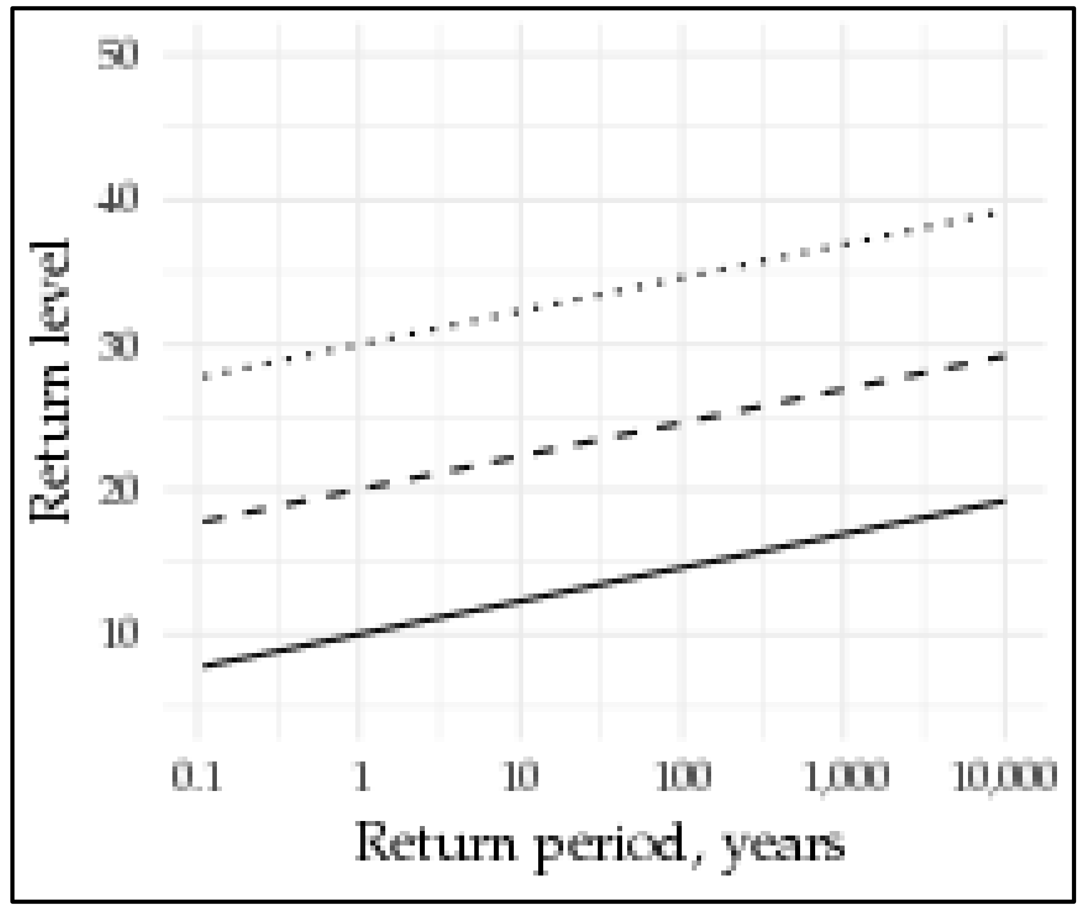
Scale Parameter





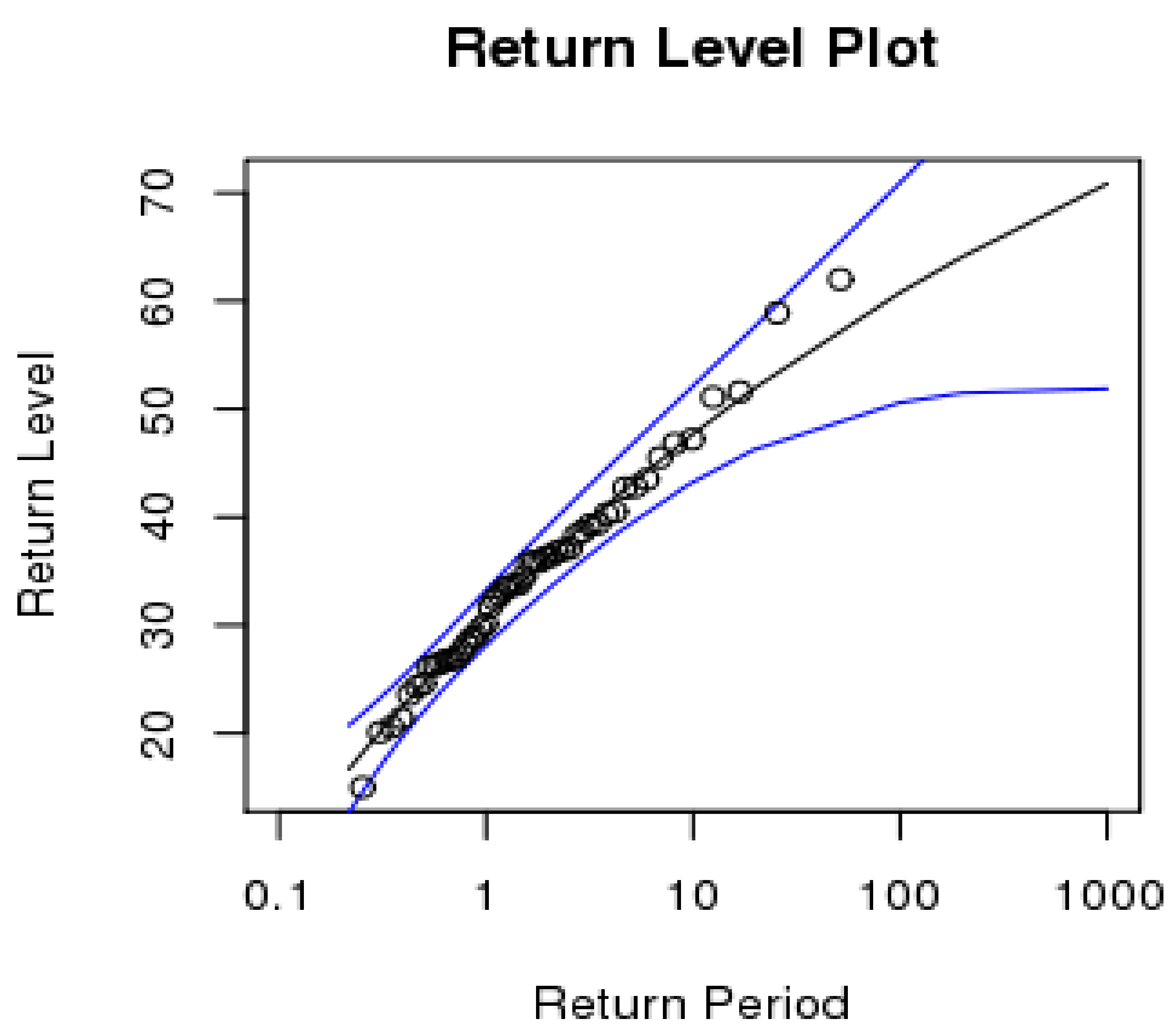
Shape Parameter

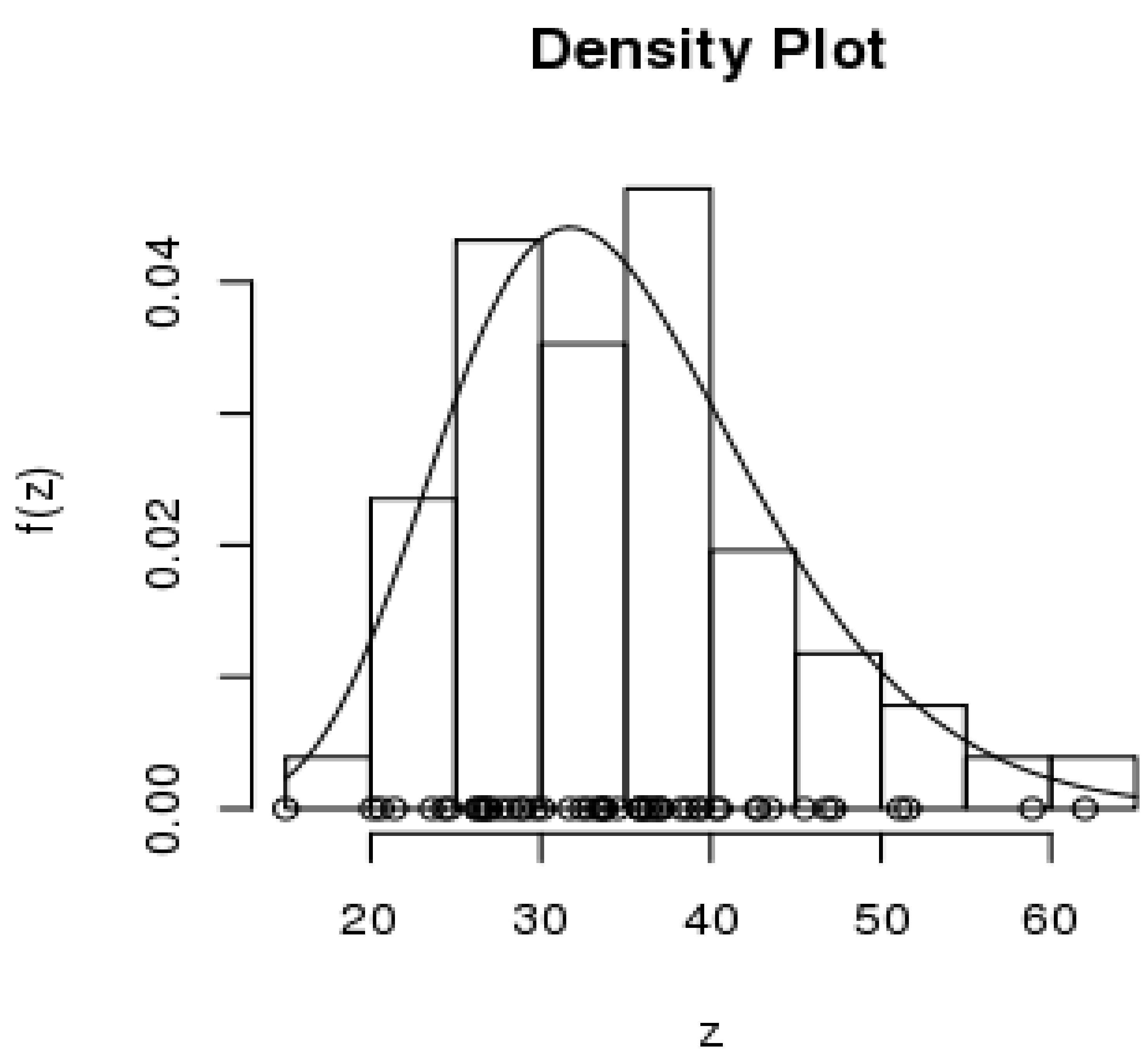
Location Parameter



An example of the GEV Output

This example is based upon annual maximum daily rainfall for a 45 year record.





The right hand graph shows the distribution of the annual maximum daily rainfall values, ranging from ~10 mm to just over 60mm.

The left hand plot is able to determine the return periods of values > 60mm and estimate return periods for lengths of time far greater than the 45 year length of the data record; the underlying statistical formulae are able to calculate return periods for any value and values for any return periods, up to many thousands of years.