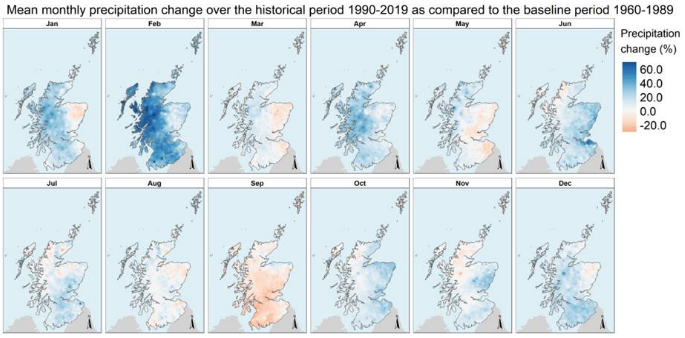
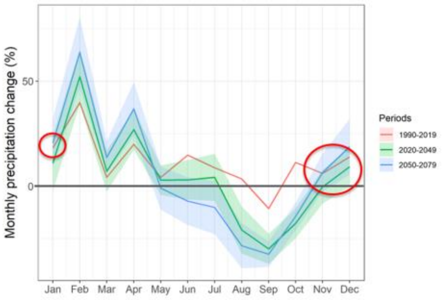
Summary of the Climate Trends, Future Projections and Extremes in Scotland.

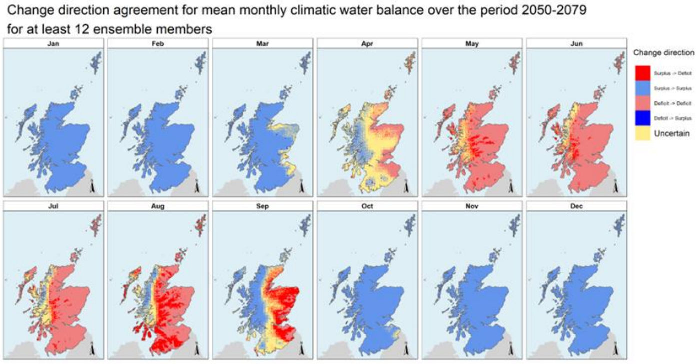
(Project D5-2 Climate Change Impacts on Natural Capital)

10th July 2023

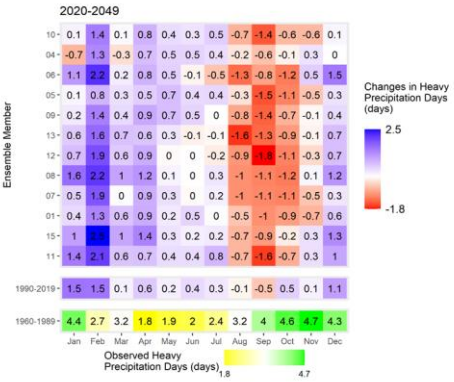


Mean monthly precipitation change over the historical period 1990-2019 as compared to the baseline period 1960-1989





Change direction agreement for mean monthly climatic water balance over the period 2050-2079 for at least 12 ensemble members



2020-2049

Ensemble Member	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	0.1	1.4	0.1	0.8	0.4	0.3	0.5	-0.7	-1.4	-0.6	-0.6	0.1
04	-0.7	1.3	-0.3	0.7	0.5	0.5	0.4	-0.2	-0.6	-0.1	0.3	0
06	1.1	2.2	0.2	0.8	0.5	-0.1	-0.5	-1.3	-0.8	-1.2	0.5	1.5
05	0.1	0.8	0.3	0.5	0.7	0.4	0.4	-0.3	-1.5	-1.1	-0.5	0.3
09	0.2	1.4	0.4	0.9	0.7	0.5	0	-0.8	-1.4	-0.7	-0.1	0.4
13	0.6	1.6	0.7	0.6	0.3	-0.1	-0.1	-1.6	-1.3	-0.9	-0.1	0.7
12	0.7	1.9	0.6	0.9	0	0	-0.2	-0.9	-1.8	-1.1	-0.3	0.7
08	1.6	2.2	1	1.2	0.1	0	0.3	-1	-1.1	-1.2	0.1	1.2
07	0.5	1.9	0	0.9	0.3	0	0.2	-1	-1.1	-1.1	-0.5	0.3
01	0.4	1.3	0.6	0.9	0.2	0.5	0	-0.5	-1	-0.9	-0.7	0.6
15	1	2.5	1	1.4	0.3	0.2	0.2	-0.7	-0.9	-0.2	0.3	1.3
11	1.4	2.1	0.6	0.7	0.4	0.4	0.8	-0.7	-1.6	-0.7	0.3	1
1990-2019	1.5	1.5	0.1	0.6	0.2	0.4	0.3	-0.1	-0.5	0.5	0.1	1.1
1960-1989	4.4	2.7	3.2	1.8	1.9	2	2.4	3.2	4	4.6	4.7	4.3

Summary

This report is a product of the Scottish Government Strategic Research Programme project JHI-D5-2 'Climate Change Impacts on Natural Capital'. **The purpose** of this report is to update and summarise two detailed reports on how Scotland's climate has changed and what the future projections may mean for our Natural Capital and their ability to provide ecosystem services and add researcher perspectives on placing these within a policy implication context. See these two reports for full details:

- Climate Trends and Future Projections in Scotland
- Climate Extremes in Scotland

These reports and maps present high-resolution spatial (1km) and temporal (daily, presented as monthly means) information on how the climate has changed in Scotland since 1960 and is projected to change in the future and what changes in extremes may occur. **The aim** is to present mapped evidence of observed trends in the spatial and temporal distribution of precipitation and temperature across Scotland between 1960 – 1989 and 1990 – 2019 and then using data for 12 future projections (UKCP18), illustrate how these trends may continue in the future. We illustrate a range of visualisation methods to establish the underpinning capabilities to support assessments of the impacts of climate change on Natural Capital assets.

The objective of the research is to inform policy development so that future land management and care for the environment considers likely climate change impacts on Natural Capital and help us understand what the consequences are for the opportunities for Nature Based Solutions.

Key Findings:

The effects of climate change are already here: Scotland's climate has experienced substantial change since the 1960-1989 baseline period. This has serious consequences for Scotland's Natural Capital, society and our economy. We have already experienced some changes in the climate that are comparable in magnitude to those projected for the future (2020 and 2049, and in the case of January an November precipitation, the 2050 -2079 period) by climate models. Observed changes and future projections include:

- At the national level, January, November and December's mean monthly precipitation totals **have already increased since the 1960-1989 baseline period to amounts greater** than those projected for the 2020-2049 period. [Fig.6]
    - February observed temperatures **have already increased** to be at the lower end of the 12 climate projections used for the 2020-2049 period. [Fig. 8]
- Future projections indicate the summer, particularly August, September and the autumn are likely to become drier in the future, but the winter is likely to become wetter. Spring shows large spatial and temporal variation.
    - Lower precipitation and higher rates of evapotranspiration associated with higher temperatures in this period are likely to reduce water availability [Fig. 12].
    - Large upland areas of central and eastern Scotland are projected to shift from climatic water surplus to deficit (evapotranspiration > precipitation). [Fig 12]
        - These seasonal variations and changes in precipitation and temperature amounts will impact ecological functions and Natural Capital's ability to provide ecosystem services.
- Climate extremes have already changed and are projected to increase.
    - The median number of Consecutive Dry Days has decreased in February (-2.1 days) since 1960 but increased in September (1.3 days). [Figs 13, 15]. There is good agreement between projections that this trend will increase in the future. [Fig. 14]

  - The observed median number of Dry Days has decreased by 3.2 in February (becoming wetter). This is already larger than all of the 12 climate projection estimates for the 2020 – 2049 period [Fig 18]. There is good agreement between the 12 projections that there will be an increase in number of Dry Days in the summer, but less agreement about the winter. [Fig. 17]
  - There is strong agreement that August to October is likely to experience a decrease in the number of Heavy Rain Days in upland areas, and good agreement on increases in January and February [Figs. 20, 21]
  - There is a clear observed trend and continued future projection that the number of the largest precipitation events, the number of Very Wet Days (VWD), is likely to increase in the winter but decrease in the summer.
    - There is good agreement that upland areas are likely to experience a decrease in VWD in the summer. There is medium agreement between projections that lowland eastern Scotland may experience an increase in VWD. [Fig. 23]
    - Note: This analysis uses the number of Very Wet Days, not the actual precipitation amount of individual events, which may increase in the summer.
  - Highest temperatures have increased by up to 2.0°C in places and by 1.3°C nationally [Fig. 25]. For the future period 2020-2049, all months are estimated to experience an increase in Highest Temperature, in the order of 2-3°C. There is near complete agreement between all climate projections used that the highest maximum temperature will increase for all months. [Fig. 26]
    - At the national scale, in the most extreme years, March has seen the largest observed increase in Highest Temperature from 16.9°C (1960-1989) to 19.4°C (1990-2019), **which is already larger than the projected changes for the period to 2050**.
  - The number of Very Warm Days increased in all months except June, with February (9 days) and March (5 days) having the largest increase, particularly in the south and east of Scotland. [Fig. 27]
    - All months in the future are likely to have an increase in Ver Wet Days. [Fig. 28]
  - There has been an overall increase (warming) of the Coldest Temperature per month since 1960 [Fig. 29], a trend that is likely to continue in the future. [Fig. 30]

For all of the summaries and indicators presented here, there is a complex spatial and temporal pattern of observed and future projected changes. The research and mapped outputs help identify where and when these changes have already occurred and what changes may occur in the future.

Implications of climate change on Natural Capital

Climate change impacts will vary across different types of Natural Capital and ecosystem service flows. Likely impacts will include:

- Increased water stress for multiple species and habitats, affecting ecosystem function and the provision of ecosystem services.
- Reduced water flow in streams, and higher soil and water temperatures. This can have negative effects on several invertebrate and fish species adapted to cold waters, including Salmon.
- There is a mixed range of impacts for peatlands:
  - A longer growing season may increase primary production and a longer access and working conditions period (i.e., if less snow cover) would benefit efforts to restore as there are more workdays available to deliver restoration activities.
  - A lack of available water in the summer and autumn will increase respiration, and if a severe drought period, decrease some of the primary production.

        - All peatlands can currently have a summer and autumn water deficit, and a longer period of this will not immediately result in impediment to restore. However, a key future consideration is the frequency of prolonged droughts periods and whether these occur in back-to-back years and whether peatlands and their vegetation can recovery sufficiently.
        - Spring droughts are far more damaging than autumn droughts, but near natural and rewetted systems are currently still recovering between drought years and functioning as net sinks for CO_2.
- Drier and more flammable vegetation increasing fire danger, requiring investment in ignition prevention and mitigation measures.
    - More peatland restoration can help prevent drier vegetation and drier surface peat reducing the risks of severe fire. Rewetted peat also makes a very good fire break.
- Changes to crop yields, with potential increases when there are favourable weather conditions (e.g., adequate precipitation in the spring), but with overall reductions, especially where soils have lower water holding capacity and / or on degraded topsoil (e.g., due to erosion, compaction) with low Carbon and hence low water retention.
    - This may be mitigated with appropriate uptake of Enhanced Conditionality measures proposed within the Agricultural (Scotland) Bill, if these are used to enhance soil organic matter and applied appropriately to the conditions at each location.
- Increased species competition for water and nutrients, favouring those with broader tolerance ranges (i.e., pioneer and invasive species), and risking species loss and habitat alteration.
- Mismatches in the growth and development of species that rely on one another (e.g., pollinators and plant species) due to different responses to changed seasonal weather patterns.
- Flooding events increase the risk of the spread of invasive species, as well as increased erosion and concentrated diffuse pollution flushes.

Implications for Policy

Climate change impacts will likely have implications across a broad range of policy areas. The findings presented here have relevance to, but not exclusively:

Climate Change Plan:

- Combined changes in precipitation, temperature and evapotranspiration will affect land use management decisions, with implications for land use transformations to achieve Net Zero.
    - See also: Land Use Transformation story map (SRP Land Use Transformations project JHI-C3-1).
- Our research helps set the context within which adaptation within land use and approaches to Natural Capital management will likely need to operate, and how this relates to mitigation potential utilising Nature Based Solutions, land use transformations and adapted land use management practices.
- **Peatlands:** The aim of restoration is to safeguard the remaining carbon stock from further degradation to limit the large current emissions that occur due to various forms of drainage. Rewetting restores peatlands but may no longer result in a strong carbon sink under current and future climates at our latitude. Crucially however it will help to limit further carbon losses from a very large carbon stock. Restoration is an emissions, flood risk and water quality improvement mitigation strategy, and a biodiversity net gain opportunity. Restoration is not about creating carbon sinks, but if peatlands degrade further risk increasing GHG emissions. Restoration is achieved through re-wetting, hence relies on the availability of water.

- The already experienced and future climate change projections indicate risks of change water availability hence the imperative is to restore peatlands sooner and at a larger scale of effort: the 2026 target of 110,000 ha of restored peatlands may need revision.
- Our findings imply a risk that the anticipated emissions abatement goals from restored peatland may be at risk due to future climate change impacts.
- New restoration approaches and greater scale of effort may be required to cope with future climate conditions and variations in water availability.
    - Additional and more intense winter rainfall could result in increased surplus surface water which raises the potential for impacting maintenance costs through risks to breakage of dams / barriers. There is no current evidence that there have been any major failure rates of drain blocking, reprofiling, or flow management in gullies, or peat slides of bog bursts. There may be value however in ensuring restoration efforts take into consideration potential additional winter precipitation.
    - Snow cover serves as an armour and insulator: it can protect exposed peat from heavy winter rainfall (kinetic energy) and effects of frost heave, helping to prevent erosion and further degradation. Climate change is likely to reduce snow cover hence increasing risks of erosion and changes to surface thermodynamics (black-body albedo effect). Vegetation cover also serve to protect peat. Conversely, less snow cover permits more restoration working days.
    - Fire risk: Longer dry periods increase the risk of peatland (and other habitats) wildfires, so consideration is needed on how to reduce the fuel load (e.g., by peatland rewetting) and reducing the probability of fires being started.
- Future drier conditions imply that peatlands that are currently in good condition risk deterioration. This implies the need for pro-active intervention now to ensure heathy peatlands remain wet under future climatic conditions.
    - The research presented here on climatic water balance indicates where peatlands may be at greater risk. **Note:** the Climatic Water Balance indicator uses estimated potential evapotranspiration rather than actual, hence whilst a useful indicator of potential water deficit, it does not take into account peatland's resilience mechanism of 'bog breathing' which temporarily increases bulk density and maintains proximity of plant roots and mosses to the water table and thereby limits plant water stress.
    - Current evidence suggests that peatlands may become net emitting in more years than at present (which is roughly 1 year in every 10), but they are still currently statistically net zero in terms of emissions. The point at which they switch to a small source is unknown.
- New peatland mapping (produced by the Land Use Transformations and CentrePeat projects) will help illustrate current condition and relate to Peatland Payments analysis (due for publication w.c. 3/7/23). Ongoing research is currently aligning peatland extend and condition maps with locations where Climatic Water Balance shifts from water surplus to deficits.
- The spatial and temporal variation in climate impacts makes estimating the consequences on peatland condition and GHG emissions problematic. UK GHG measurement, modelling[1] and accounting will need to develop rapidly to facilitate emission and sequestration forecasting at an appropriate level of accuracy to enable targeted investment in preventative and restoration efforts.

---

[1] For example the NERC MOTHERSHIP project: About the project | UKRI NERC funded Peat Mothership project and EU Wet Horizons Wet Horizons - Improving wetland knowledge and developing tools to enhance protection and restoration of Europe's wetlands. Focused on biodiversity. - Wethorizons

- Forestry: our results indicate the potential for reduced Yield Class attainment and risks of tree establishment failure due to water scarcity and changes in soil processes in some years and locations because of climate change. Existing values of future carbon sequestration potential through tree planting and growth (e.g., by Forest Research, Aberdeen University and Hutton) may be over-estimated if they have not appropriately factored in reduced growth.
    - Our findings indicate where there may be opportunities for woodland creation considering the spatially varied climate impacts.
    - Note: projections indicate more storms with greater energy, meaning increased risks of high wind speeds and damage due to windthrow.

Agriculture (Scotland) Bill and new payment support schemes:

- The proposed land use Enhanced Conditionality (EC) measures need to be screened to ensure they will remain viable and effective under future climates ('climate proofing'), particularly those that require significant capital investment and or are hard to reverse measures (i.e. new wetlands created now need to be viable in the future, or where land use change occurs such removal of trees for farmland) Consideration of adding new EC measures explicitly intended to increase resilience and adaptive capacity of farming and rural areas to cope with future climates may also be wise. Particular attention may need to be given to water quantity for maintaining ecological flows and (private) water supplies. This will improve the chances of EC measures both reducing emissions and building resilience to climate change impacts.
    - The 'Synthesis Report: Screening Enhanced Conditionality Measures' produced by the Land Use Transformations project (due for publication in July 2023) provides further details.

National Planning Framework 4:

- Regional land use planning needs to incorporate Climate Change risk into Natural Capital approaches. Policies should promote and emphasise the delivery role of stakeholders and communities through a bottom-up approach. It is vital to understand perceived risks, opportunities and mitigating measures under climate change scenarios. This can be done by eliciting preferences for land use management and mitigation solutions under climate change impacts.
- In respect of planning zonation, application of the National Planning Framework 4 needs to take into consideration the potential changes in Land Capability for Agriculture and where land identified as Prime Agricultural may change.
- There is an increasing need for using of Nature Based Solutions now (due to establishment time lags) to counter future warming urban heat islands, such as tree planting, wetlands and larger greenspace for cooling purposes.

Land Use and Land Reform:

- The Land Reform Bill presents opportunities for improved landowner and community involvement in climate mitigation. Our findings here indicate that climate impacts will likely vary spatially, hence there may be a requirement for additional support for regional variations on policy implementation where climate goals are concerned.
- A revised Land Use Strategy will need to take into consideration the spatial and temporal variation in climate change impacts, to facilitate local context solutions.
- The development of land use plans within catchments and by Regional Land Use Partnerships will need to consider the range of plausible future climate conditions.

  - Currently there is insufficient financial support to enable RLUPS to engage with research teams to utilise the climate projections and other aspects of land use transformations for Net Zero and biodiversity targets.
- Longer dry periods increase the risk of wildfires, so consideration is needed on reducing the fuel load and reducing the probability of fires being started accidently. This may have implications for education campaigns (e.g., by Emergency Services and Local Authorities) and strategies for managing outdoor access during at-risk period.
- Policy development to shape and govern private sector investment in land use (as per The Interim Principles for Responsible Investment in Natural Capital) should explicitly require specific initiatives and standards (e.g., codes) to consider the effects of future climatic changes on the characteristics and capability of land, to support investments that are both economically and environmentally viable.
- The British Standards Institute's or other bodies (i.e. the International Sustainability Standards Board) development of standards for the emerging carbon, ecosystem and biodiversity markets need to consider the role of climate change impacts and their influence on the long-term viability of insetting and offsetting (including monitoring, reporting and verification), conservation and ecosystem restoration activities.

Biodiversity:

- Targets for biodiversity enhancement will require consideration of climate change impacts. Use of projections can help identify habitats and species at risk in the future and where and how support may be required now to prevent or alleviate future impacts.
- The use of spatial climate projections enables improved contingency planning though identification of areas at greater or lesser risk of impacts (risk and opportunity mapping, see also Land Use Transformations project, JHI-C3-1).
- Plans for monitoring and reporting of changes in biodiversity will need to take account of climate impacts. These impacts may help to contextualise and explain why biodiversity targets may not be met; but ultimately may also call for reconsideration of what places are designated and how they are managed for nature.
- The need to permit range shifts in response to climate impacts reiterates the importance of natural systems resilience and connectivity. There is a need to go beyond not only measuring it (as per the habitat connectivity index) but also enabling these properties in initiatives such as NatureScot's 30x30 and Nature Networks projects and encouraging nature-friendly land management in wider landscapes.

Water quality and quantity:

- Reduced water availability in dry years will impact the potential to abstract water for irrigation or other purposes, such as energy generation, industry (i.e. distilling).
- Lower flows in rivers will result in reduced dilution of diffuse pollutants (therefore more concentrated) increasing the risk of eutrophication in receiving standing waters, especially in agricultural areas.
- Households and businesses dependent on private water supplies may require additional support.
- Reduced snow cover will impact water flow rates, whilst warmer air temperatures and altered albedo (darker surfaces) will increase water temperature. This will have impacts on the ecology of rivers, e.g., spawning fish populations.
- Reduced instream flows and increased temperatures will jeopardise ability to reach binding targets for Good Ecological Status as set under The Water Framework Directive (WFD).
- The increased risk of winter flooding highlights the need to resource and implement interventions to improve flood resilience in Priority Vulnerable Areas, as designated under the Floods Directive. Upstream measures to

restore hydrological connectivity (slow the flow) through the catchment may provide benefits with respect to both flood and drought risks.
  - Our findings may inform the SEPA guidance on flood risk assessments considering climate change.

Tourism and Access:

- Local and visitor recreational use of Scotland's landscapes may be limited by issues such as wildfire risk, or lack of water for activities such as kayaking; additionally, pressures from tourism may exacerbate climatic pressures (e.g. by adding demand for potable water from rural or private water supplies). This should be taken into account by plans to develop the tourism industry in Scotland.

Food and Drink:

- Our findings, here and elsewhere[2], imply likely changes in agricultural productivity, which may both benefit from and be impacted by climate change.
  - Crop yields are likely to become more variable, with a long-term trend toward decreases due to reduced water availability. There is likely to be increased annual variability, with potentially favourable years resulting in higher yields, but more years with less favourable conditions.
  - Improving soil water holding capacity through more soil organic matter will help buffer against dry periods. This has the benefit of storing more carbon in soils and increases biodiversity.
  - Uncertainty remains on crop and animal disease responses to future climates.
- The spatial variation in climate change impacts will affect the potential for localised food systems.
- The Scottish food system will need to adapt to increased annual variation in productivity, whilst also adapting to the impacts of climate change on food production elsewhere.

Advances in research capabilities

- These results are underpinned by a unique climate data set created by the James Hutton Institute.
  - Note: data coverage is the whole UK but presented here just for Scotland.
- The spatial data resolution is at 1km, meaning that it is now possible to generate the same analyses and visualisations in this report for every 1km climate grid cell in Scotland. This means we can generate results for any spatial unit of interest, e.g., farm, sites with protected designations (SSSI, National Parks), Local Authorities, catchments etc.
- The results presented utilise daily time step data, meaning it is possible to present high temporal resolution time series outputs.
- This dataset and research capability complements parallel research efforts, particularly a new Land Capability for Agriculture classification research platform, spatial crop modelling, and spatial Agrometeorological Indicators.

Note: To better understand the impacts of climate change on Natural Capital and water issues in general, there is an urgent need to greatly improve our research capabilities to monitor and estimate spatially actual evapotranspiration. Currently estimates of future impacts are based on potential evapotranspiration only, leading to large uncertainties in estimates of water availability.

---

[2] See: changes in Land Capability of Scotland and Barley Responses to Climate Change

Contents

This report should be cited as: Rivington M, Jabloun M, Aitkenhead M, Gimona A, Martino S, Gagkas Z, Matthews KB, Waylen K (2023) Summary of the Climate Trends, Future Projections and Extremes in Scotland. (Project D5-2 Climate Change Impacts on Natural Capital). The James Hutton Institute, Aberdeen, Scotland. DOI: 10.5281/zenodo.8132272

Contact: Mike Rivington, Project Lead: mike.rivington@hutton.ac.uk

Acknowledgements This report has been produced by the D5-2 Climate Change Impacts on Natural Capital Project funded by the Scottish Government Rural and Environment Science and Analytical Services Strategic Research Programme (2022-2027). We also thank and acknowledge the UK Meteorological Office for use of the 1km gridded observed climate data and UKCP18 climate projections.

Introduction

This report summarises two larger, more extensive reports produced by D5-2 Climate Change Impacts on Natural Capital Project funded by the Scottish Government Rural and Environment Science and Analytical Services Strategic Research Programme (2022-2027). The full reports are available here:

1. Climate Trends and Future Projections in Scotland
2. Climate Extremes in Scotland

Maps within these reports are also available on a prototype visualisation tool: https://mjabloun.shinyapps.io/agmet-app/ This is a prototype site and will undergo further development during the project, with the aim of making the visualisation tool publicly available.

Approach: In the first report we mapped historical observed trends using observed precipitation, maximum and minimum temperature data from 1990 – 2019 with those from a 1960 – 1989 baseline period. Data from the UKCP18 climate projections (12 individual simulations) for two time periods, 2020 – 2049 and 2050 – 2079, were compared with the observed 1960 – 1989 baseline to identify potential future trends and changes. The 12 projections are based on the high emissions scenario (RCP8.5) but consist of a range of possible climate change from 1°C increase in temperature and an increase in precipitation total, to 3.7°C and a reduction in precipitation.

In the second report we produced and mapped a range of extreme climate Indicators that are derived using the observed and climate model projection data.

Observed changes:

The observed trends in precipitation, maximum and minimum temperature are derived by comparing data from 1990 – 2019 with a 1960 – 1989 baseline period. Observed trends can be summarised as:

Precipitation:

- There has been an overall increase in precipitation, with the area of Scotland experiencing higher precipitation being larger than that of decreases.
- There is a wide variation in spatial and temporal change.
    - In the west precipitation increased in December to May, but either remained similar or decreased in July, August and October.
    - Eastern Scotland became drier in January, March, May, August, September and December, but wetter in February, June, July, October and November.
- The largest increases in precipitation occurred in February.
- There has been mixed response in terms of variability in temporal and spatial patterns of change in precipitation.
    - January, April, July and November (and to a lesser extent August) have seen a decrease in variability in the west.

Temperature:

- For all months there has been an overall increase in temperature, except for the maximum in June and to a lesser extent October and December for the minimum.
- February and March show the largest amount of warming, up to 2°C, whilst other months show an approximate average increase of 1°C.

- The rise in temperature is relatively uniform across the country, and does not reflect the topographical influence, though for some locations there has been little or no change from the 1960 – 1989 baseline period.
- There has been a mixed response on terms of variability of how much change there has been and where this has occurred.
    - January, February and August have seen an almost nationwide shift towards reduced standard deviation, whilst March, April (except the Lochaber and northern Argyll areas), September, October and November have seen a widespread increase.
- All months, with the exception of June and to a lesser extent April and August, show a general national trend of a positive increase (warming) in diurnal temperature range.

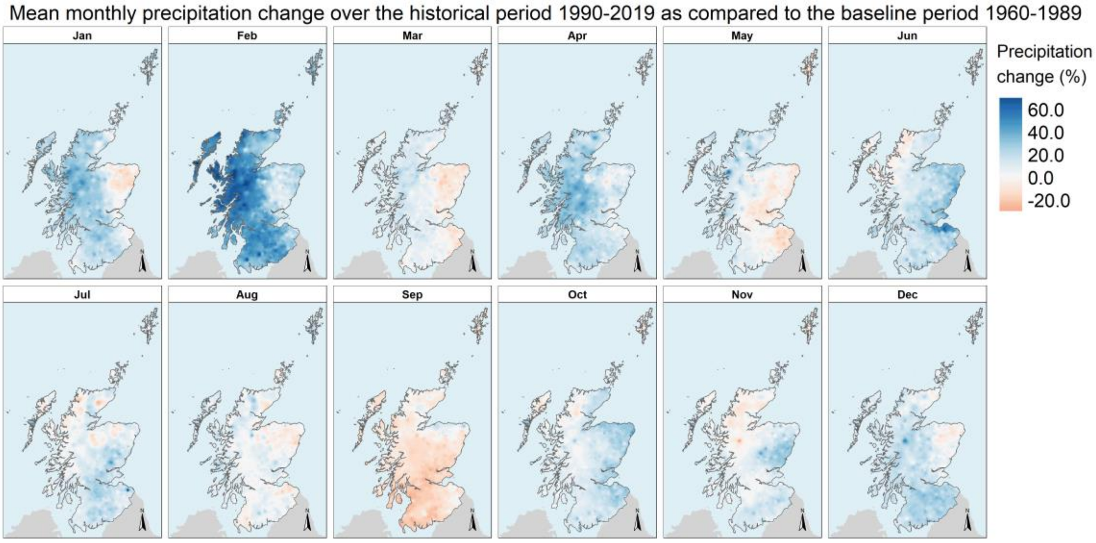


Figure 1. Relative change (%) in mean monthly precipitation between the 1960 – 1989 baseline period and 1990 – 2019 period.

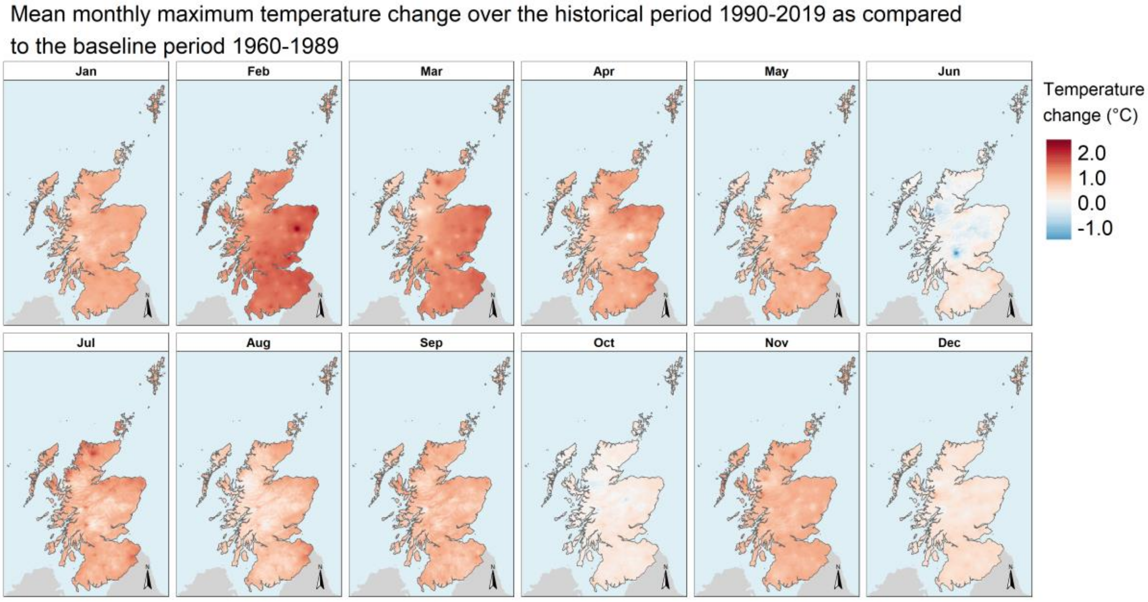


Figure 2. Change in mean monthly maximum temperature change between the 1960 – 1989 baseline period and 1990 – 2019.

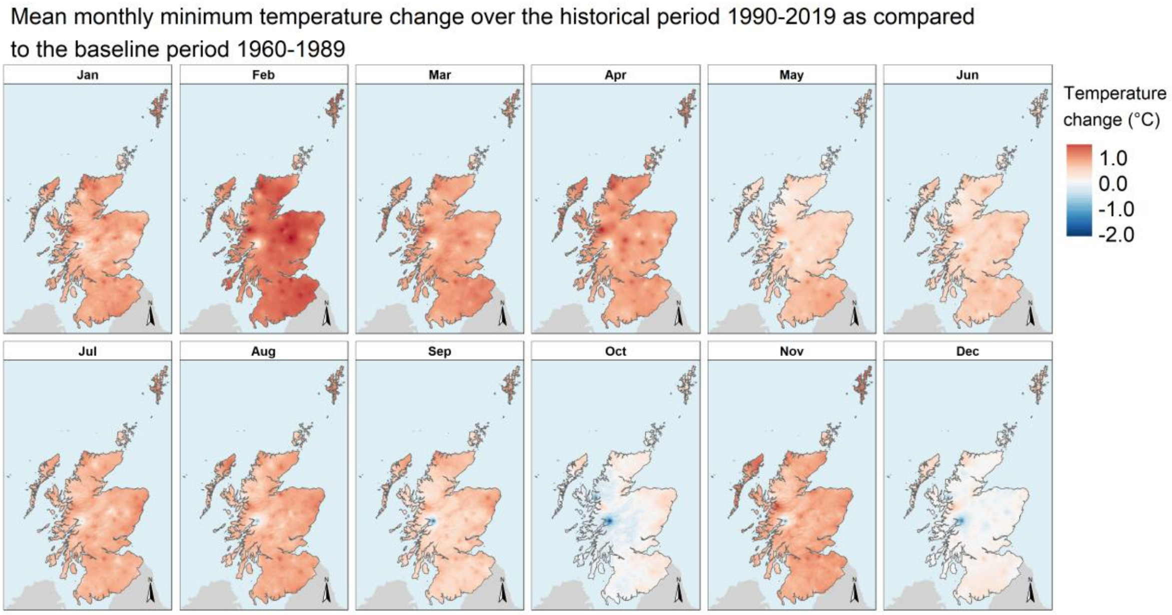


Figure 3. Change in mean monthly minimum temperature change between the 1960 – 1989 baseline period and 1990 – 2019.

Diurnal Temperature Range

The diurnal temperature range is the difference between minimum and maximum temperature per day. It is a useful indication of warming or cooling trends and reflects the total energy input into an ecosystem, affecting phenology. All months, with the exception of June and to a lesser extent April and August, show a general national trend of a positive increase (warming) in diurnal temperature range. Whilst maximum and minimum temperature have increased, this result indicates that the difference between the two has also increased. June has experienced a decrease in diurnal range, which also aligns with the observed decreases in maximum and minimum temperature. The overall increases in temperature and diurnal range aligns with observed changes in plant and insect phenology (through more rapid thermal time accumulation).

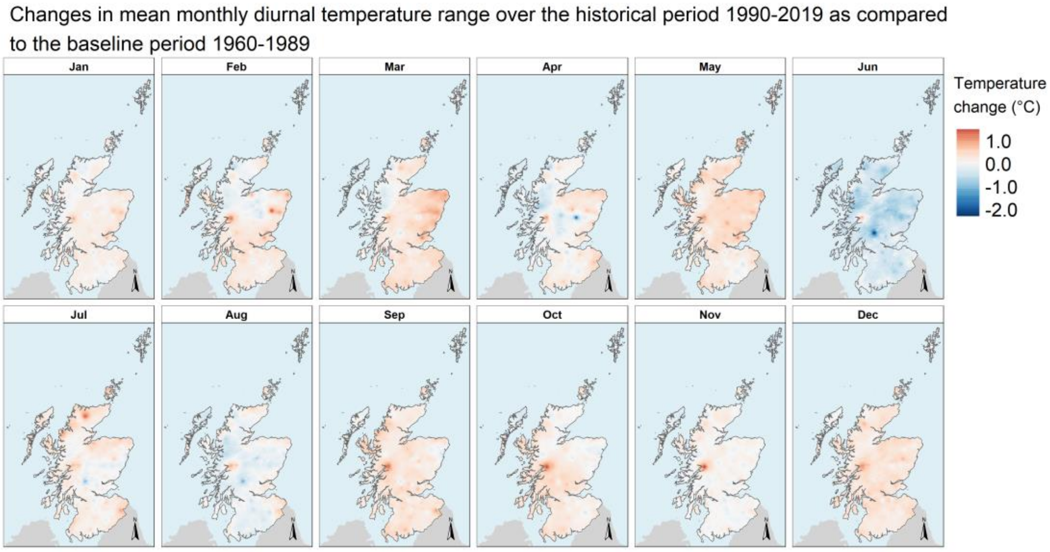


Figure 4. Change in mean monthly diurnal temperature range change between the 1960 – 1989 baseline period and 1990 – 2019.

Climate Change Projections for Scotland

The results presented here use data from the UKCP18 climate projections (12 individual model simulations) for two time periods, 2020 – 2049 and 2050 – 2079. These were compared with the observed 1960 – 1989 baseline to identify potential future changes. The 12 projections are based on the high emissions scenario (RCP8.5) but consist of a range of possible climate change from 1°C increase in temperature and an increase in precipitation total, to 3.7°C and a reduction in precipitation.

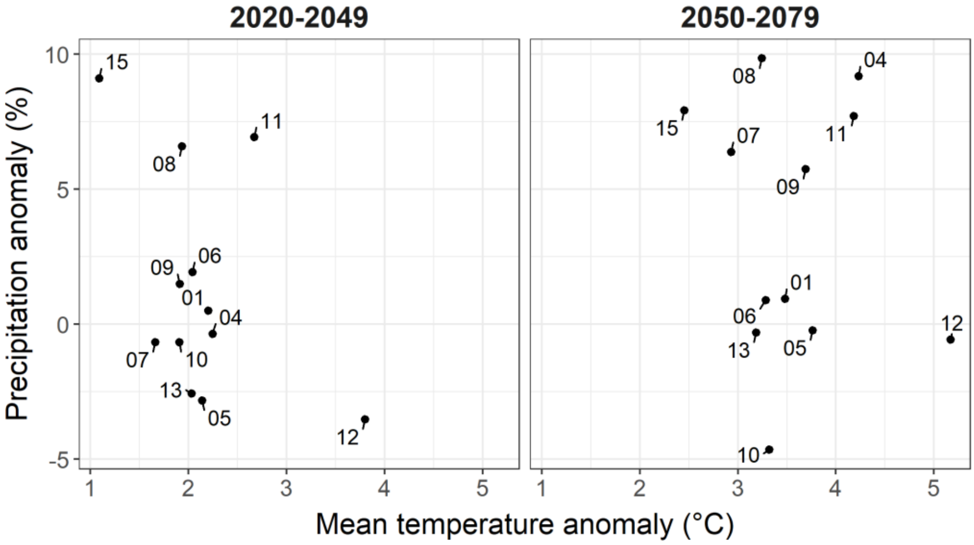


Figure 5. Climate change precipitation and temperature anomaly for 12 projections used under RCP8.5 for 2020-2049 ('2040') and 2050-2079 ('2070') with respect to 1994-2015 baseline.

Projected changes in Precipitation:

Key Finding: the amount of change in mean monthly precipitation between November and January since 1960 is already greater than the mean of the 12 projections used for the 2020 – 2049 future period (Figure 6).

- Projections for the period 2020 to 2049 indicate Scotland's climate to be wetter in December, January (both c.10%), February (45 – 55%) and April (25%) but less so in March (c. 5%).
    - These projected changes align with the observed changes already seen.
- For the 2020 to 2049 period, August, September and October are projected to become drier.
- These patterns continue in the 2050 – 2079 period with increases in the magnitude of change.
- There is a high level of agreement between projections that February and April precipitation will increase, whilst August, September and October will decrease.
- There is large spatial variation in changes to the monthly mean precipitation between projections: eastern areas may become wetter in some months (February, April, May, November and December); mean precipitation in upland areas is likely to decrease in May, August, September and October, and November in the north.

The national monthly precipitation anomaly (Figure 6) shows there has been an overall increase in precipitation between 1990 – 2019 compared to the 1960 - 1989 baseline, except in September, which has become drier. **The observed change is already greater than that of the mean of the 12 climate projections used for November, December and January**. The mean of the projections for next few decades to 2050 indicate Scotland's climate to be wetter in December (c10%), January (c. 10%), February (45 – 55%) and April (25%) but less so in March (c. 5%).

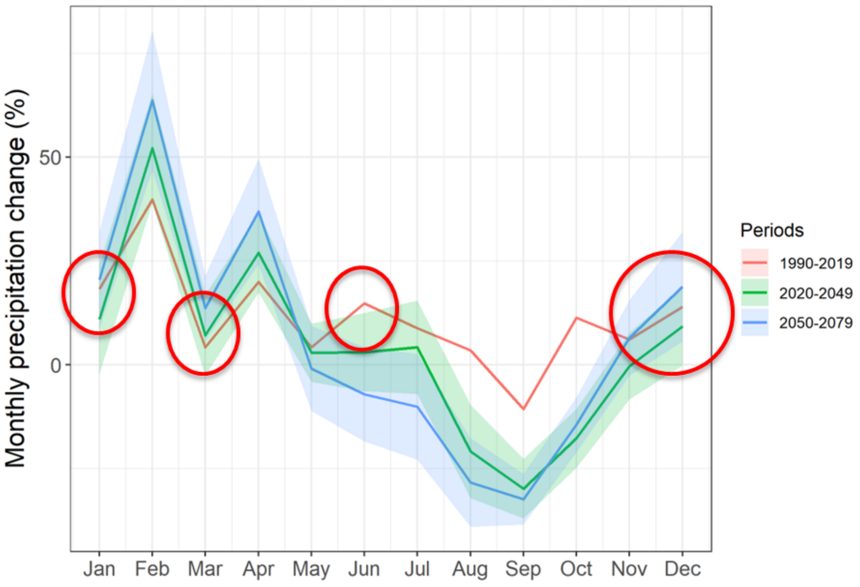


Figure 6. Percent change in the national mean monthly precipitation compared to the 1960-1989 baseline for three time periods. Solid lines: 1990 – 2019 (red, observed data); 2020 – 2049 (green) and 2050 – 2079 (blue) mean of the 12 climate projections. Shaded areas represent the variation between the 12 projections. Note: the 0 line represents the baseline.

These projected changes align with the observed changes already seen. May to July show little signs of future change but do not align well to the observed changes. August, September and October are projected to be drier. These change patterns continue into the 2070's period, except the June – August period is projected to become drier.

Agreement between projections

Rather than provide here maps for all 12 projections, we have instead produced 'agreement maps' showing where the projections produce the same results for the change in direction (i.e., increase or decrease in mean monthly precipitation).

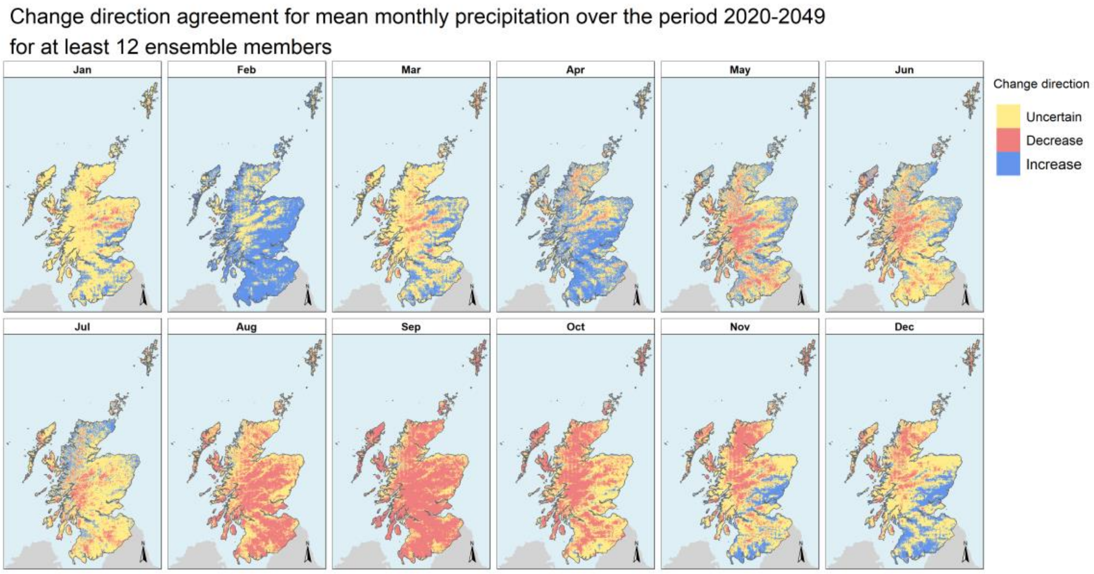


Figure 7. Agreement maps for all 12 projections on the direction of change in mean monthly precipitation for the 2020 – 2049 (top) and 2050 – 2079 (bottom) periods.

Figure 7 shows the agreement in either having an increase or decrease in precipitation for all 12 projections (Note: we have agreement maps for 12 to 7 projections and have the potential to select combinations based on overall projected anomaly and or model skill). This approach gives us more confidence in the probabilities of estimated future climates. From Figure 7, there is general agreement for most of Scotland that September may experience a decrease in precipitation. Similarly, February is likely to see an increase. Yellow areas in Figure 19 represent locations where there is no agreement between the projections (e.g., some indicate increases, other decreases). For January, there are few areas where there is agreement for the 2020 – 2049 period, but this shifts towards agreement that southern Scotland is likely to see an increase in precipitation.

It is worth noting that the level of agreement between projections increases in the 2050 – 2049 period for some months, e.g., the 'uncertain' (yellow) areas in August and September in Figure 7 are less than for the 2020 – 2049 period, but decreases for others (e.g., June).

Projected Changes in Temperature

The national mean monthly observed and projected maximum and minimum temperature changes are shown in Figure 8. Observed temperatures have increased from the 1960 – 1989 baseline in all months except June and October for the maximum temperature and October for the minimum. February has seen the largest observed increase. Future projections indicate a continued warming, particularly in the summer months.

- The observed warming trends in maximum and minimum temperature are projected to continue through the 2020 – 2049 and 2050 – 2079 periods.
    - There is high agreement between all 12 projections on there being continued warming, with all exceeding 2°C by the 2070s.
- There is a greater amount of warming between May and November (up to 4°C per month between 2020 – 2049), but also with substantial warming in the winter (variable by projection, approximately 2-3°C).
- The spatial distribution of change is relatively uniform across Scotland, e.g., does not reflect topographical differences.

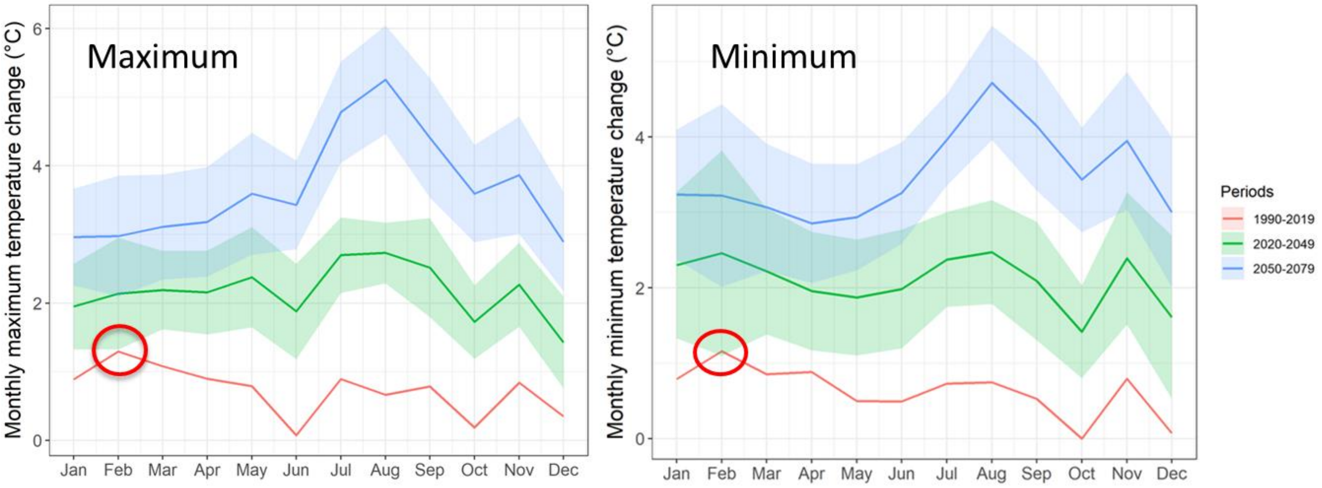


Figure 8. Change in the national mean monthly maximum (top) and minimum temperature (bottom) compared to the 1960-1989 baseline for three time periods. Solid lines: 1990 – 2019 (red, observed data); 2020 – 2049 (green) and 2050 – 2079 (blue) mean of the 12 climate projections). Shaded areas represent the variation between the 12 projections. Red circles highlights when temperatures have already reached the lower future estimates. Note: the 0 line represents the baseline.

Maximum Temperature

The observed trend in maximum temperature is projected to continue through the 2020 – 2049 and 2050 – 2079 periods (Figure 8). All 12 projections agree that there will be an increase in maximum temperature and that this will be uniform across Scotland, but variable per month and between projections. Figure 9 provides an example from on projection (01). For the initial future period to 2050 the ensemble mean increase is approximately 2°C, but higher especially in February, July, August and November. October and December are estimated to have less of an increase. The overall projection mean increase, particularly in the summer months may increase to in excess of 4°C warmer.

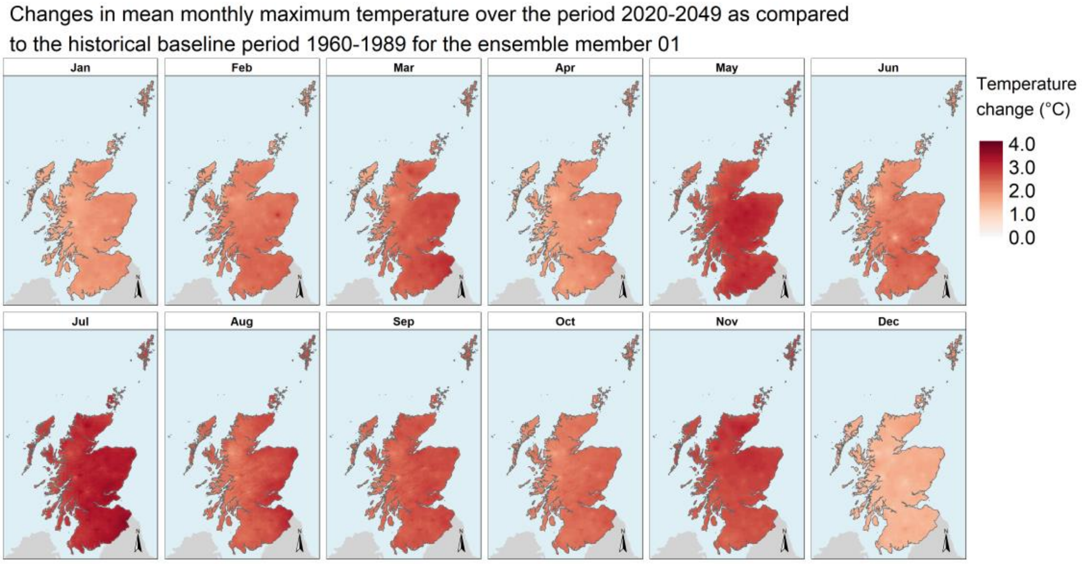


Figure 9. Projection example (01) of change in mean monthly maximum temperature (°C) for 2020 – 2049

Minimum Temperature

The minimum temperature increase is estimated to be relatively uniform across Scotland but unlike maximum temperature does show some relationship with topography and elevation amongst some of the 12 projections. An example (Projection 01) is given in Figure 10.

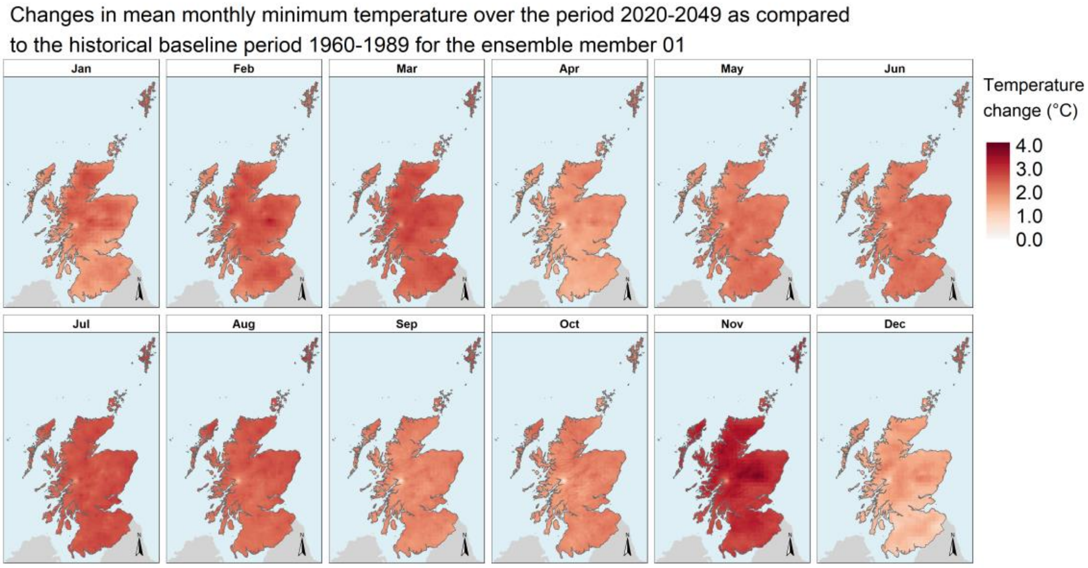


Figure 10. Projection example (01) of change in mean monthly minimum temperature (°C) for 2020 – 2049.

Note: we have not presented the agreement maps for the 12 projections of maximum and minimum temperature, as there is a high level of agreement between them.

Water availability:

Changes in the Climatic Water Balance (precipitation – evapotranspiration) indicate potential differences in water availability. Observed trends and future projections in warming indicate an increased rate of evapotranspiration.

Observed trends:

There has been an observed change in Climatic Water Balance, which is variable both spatially and temporally.

- West coast areas have become wetter (increased surplus water) between December to April.
- March to May have experienced a decrease in Climatic Water Balance (reduced water) in the east as has the whole of Scotland in September.
- June to August have experienced an increase in Climatic Water Balance (precipitation > evapotranspiration).

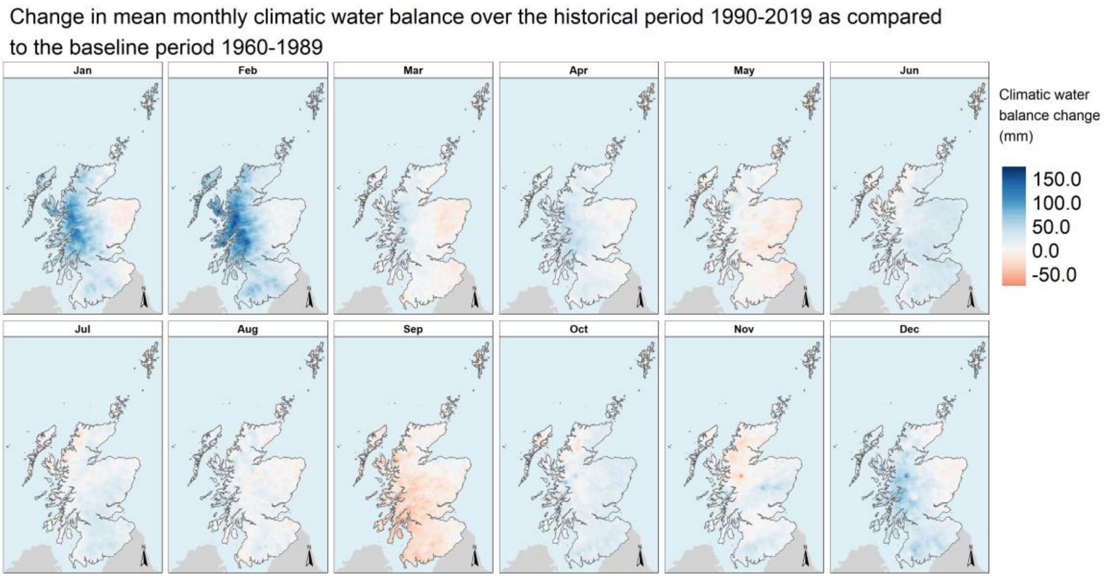


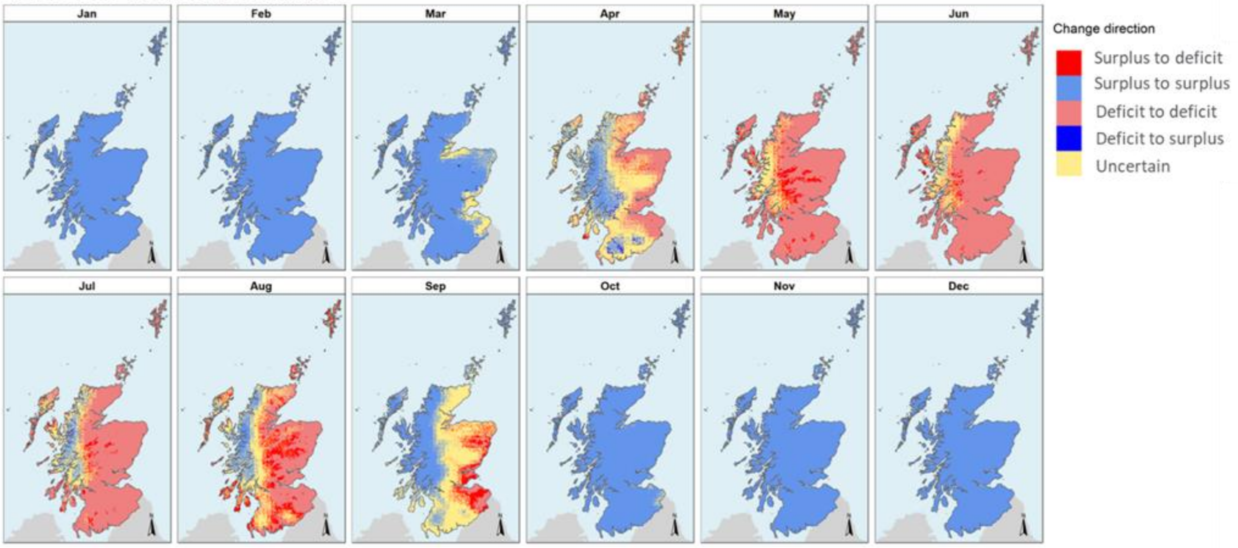
Figure 11. Change in the Climatic Water Balance (precipitation – evapotranspiration) per month between the 1960 – 1989 baseline and 1990 – 2019 current climate period.

Projected changes:

- Projections show a shift in where and when parts of Scotland have a surplus or deficit of water.
- **A key finding** is that some upland areas of central Scotland are projected to shift from water surplus to deficit. Most notably this is seen in May for the central Highlands and in August in the eastern and southern upland areas plus southern Argyll, Islay and Jura and parts of the Outer Hebrides. By 2050 – 2079 for August there is a large increase in this upland area shifting from surplus water to a deficit. Large parts of eastern Scotland in September are projected to see a shift to Climatic Water Balance deficit.
  - Such changes may have substantial impacts on the ecological and hydrological functions of peatlands, as well as other Natural Capital asset types.
- For both the 2020 – 2049 and 2050 – 2079 periods there is good agreement between the 12 projections that October through to March will remain in Climatic Water Balance surplus (precipitation is greater than evapotranspiration.

- For both periods April shows large uncertainty in the direction of change.

Change direction agreement for mean monthly climatic water balance over the period 2020-2049 for at least 12 ensemble members



Change direction agreement for mean monthly climatic water balance over the period 2050-2079 for at least 12 ensemble members

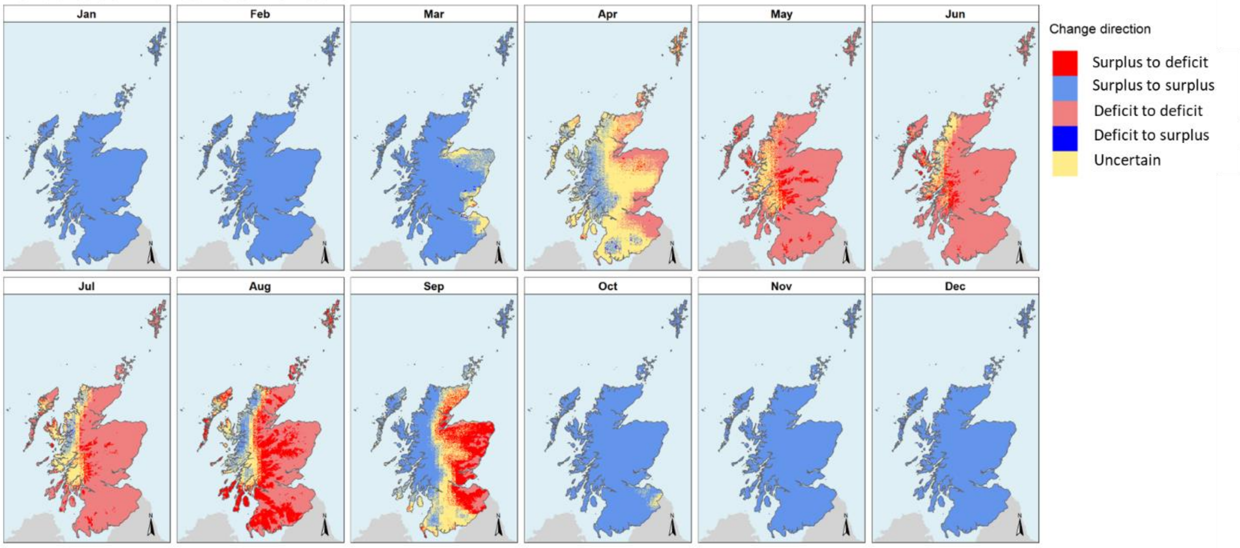


Figure 12. Agreement maps for the change direction (increase: blue, or decrease: red) of the Climatic Water Balance for the period 2020 – 2049 (top) and 2050-2079 (bottom) for all 12 climate projections (ensemble members). Yellow areas indicate no agreement between projections.

Note: Of concern if this shift from surplus to deficit occurs in peatland areas, as seen in Figures 31 and 32 for several of the summer months (and Figures 35 – 36 for the 2050 – 2079 period), is that there may be an increased probability of peat becoming a source of carbon due to drying (reduction in anaerobic conditions), rather than a sink (if remaining wet and maintaining ecological functions), whilst also impacting on restoration efforts. The implication of the projections of CWB is a reduced amount of water available, however the impact on peatlands will also depend on broader hydrological process such as the water table height and seasonal fluctuations (also see report: Moderating extremes in water availability: a review of the role of functioning wetlands | CREW | Scotland's Centre of Expertise for Waters). This important aspect will be a focal issue to assess further within the Climate Change Impacts on Natural Capital project.

Climatic Extremes

See full report: Climate Extremes in Scotland. We mapped values for seven extreme climate indices.

Precipitation Extremes

Consecutive Dry Days

The count of the number of Consecutive Dry Days (CDD) is an indication of when water may become limited and drought conditions occur. It is the maximum length of a dry spell in any one month (when precipitation is less than 1mm per day).

- Since 1960 there has been a small shift in the number of CDD per month (median is < +/- 2), with more increases occurring in March, May, September and, for the western half of Scotland, October. With April experiencing an increase in the east as well, the main parts of the growing season for the arable areas of Scotland have experienced longer dry periods. Conversely, February, April (except the east), June to August, October (in the east only) and November have seen a decrease in Consecutive Dry Days per month.
- There is good agreement between the 12 climate projections that from now until 2050 the winter months may experience a decrease in the number of CDD (change in median of approximately 1 – 3 days), but May through to October are likely to see an increase (approx. 1 – 3 days). For the 2050 – 2079 period these seasonal changes become more pronounced, with the median changes ranging from 1 – 4 days.
- Historically (1960-1989) at the national scale April has had the most Consecutive Dry Days (23) in the most extreme year, but this may decrease by c. 5-6 days between now and 2050, whilst June (16 days) may increase by 1-6 days and September (14) by 2-8 days.

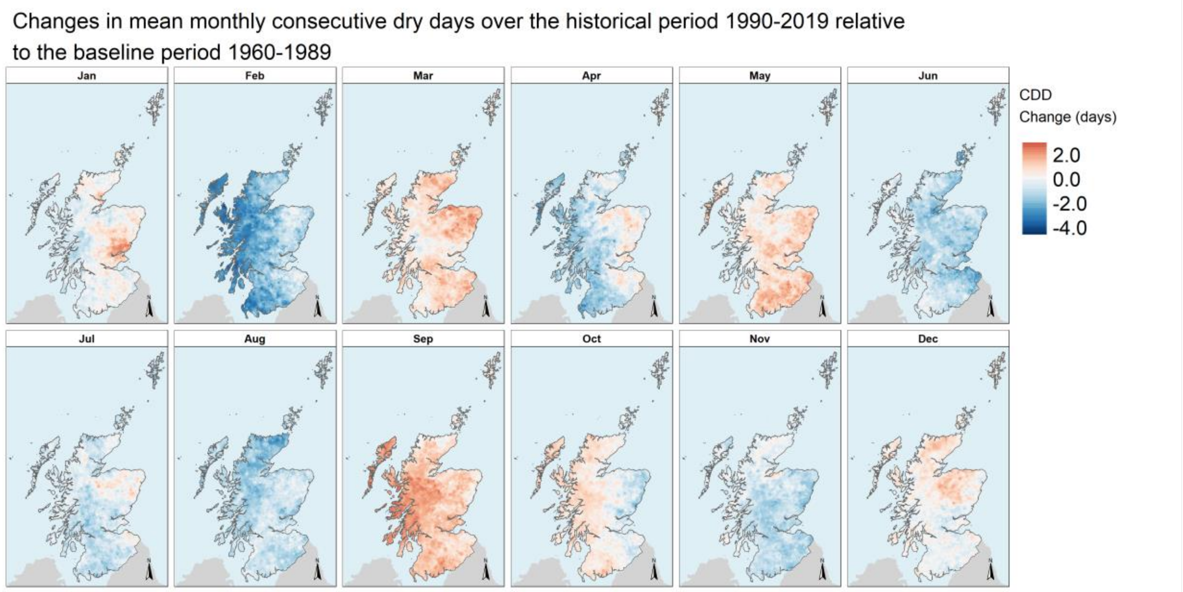
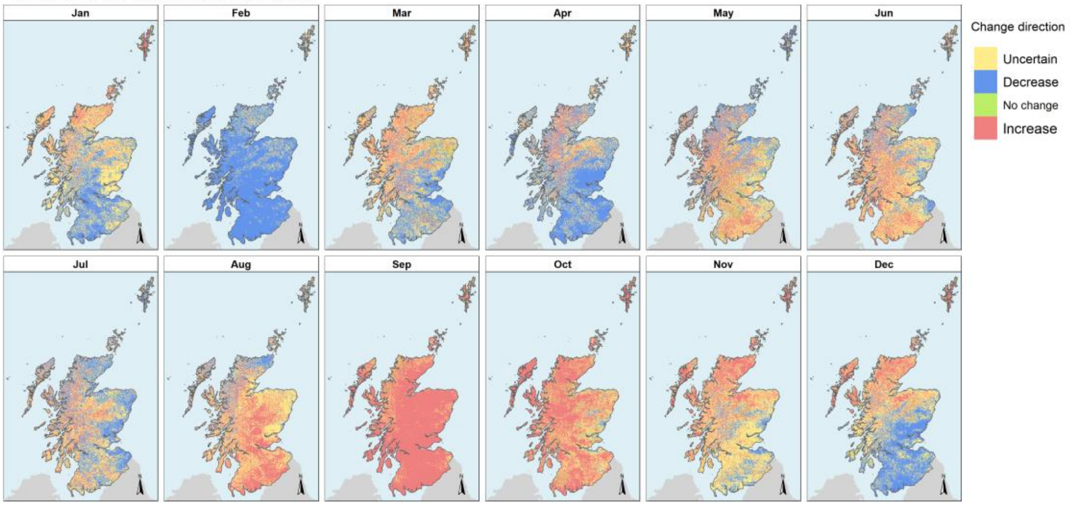

Changes in mean monthly consecutive dry days over the historical period 1990-2019 relative to the baseline period 1960-1989

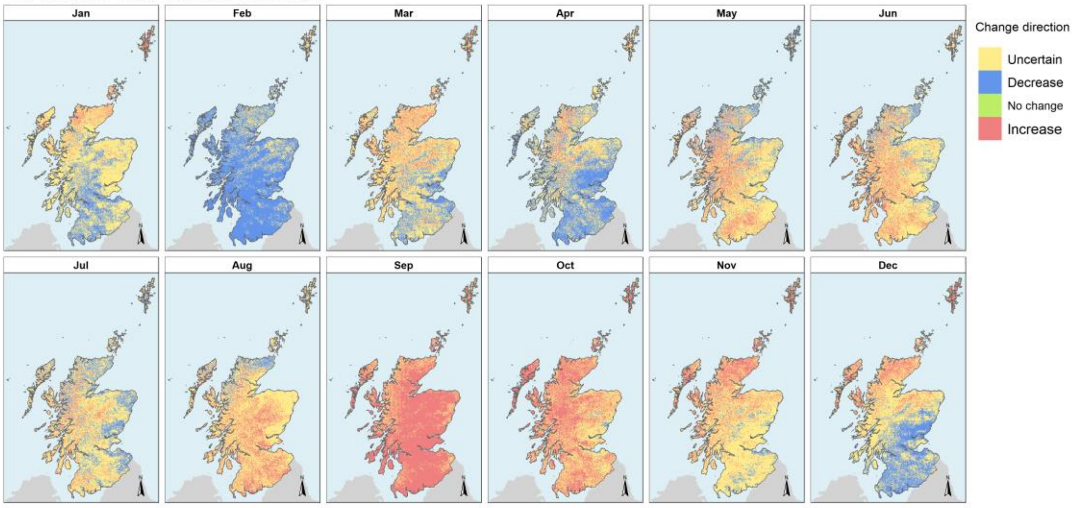
Figure 13. Observed changes in mean monthly Consecutive Dry Days (defined as precipitation <1mm/day) between 1960 – 1989 and 1990 – 2019.

Figure 14 shows the level of agreement as to where the is an increase (red), decrease, (blue), no change (green) or no agreement (yellow) in Consecutive Dry Days between 8, 10 and 12 climate projections. **Note:** Precipitation, unlike temperature, is a highly spatially and temporally variable weather feature, hence challenging for climate models to represent. This is reflected in the amount of uncertainty (yellow) in the agreement maps. Precipitation's spatial and temporal variability helps emphasise the value of the agreement maps, particularly when all 12 agree the direction of change.

Change direction agreement for mean monthly consecutive dry days over the period 2020-2049
for at least 8 ensemble members



Change direction agreement for mean monthly consecutive dry days over the period 2020-2049
for at least 10 ensemble members



Change direction agreement for mean monthly consecutive dry days over the period 2020-2049
for at least 12 ensemble members

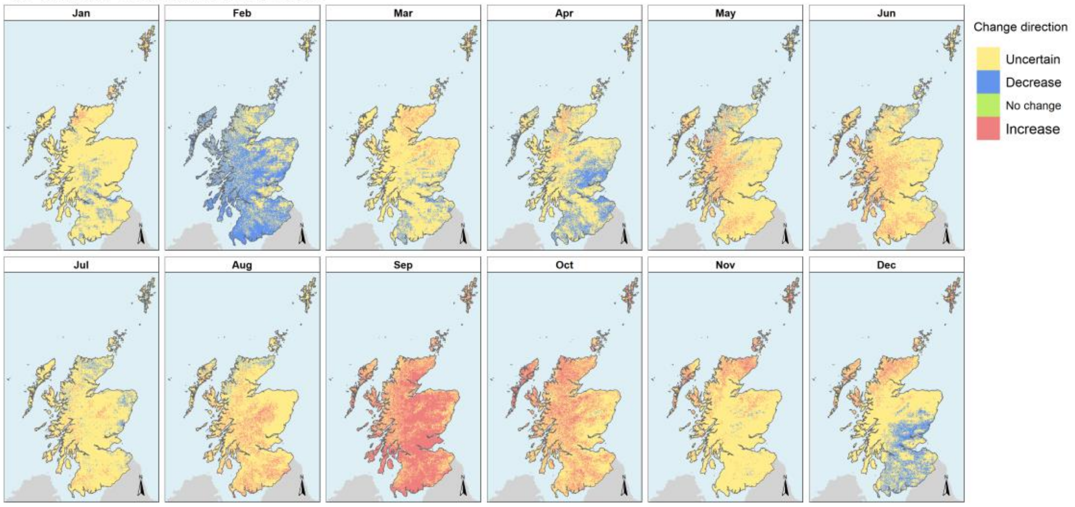
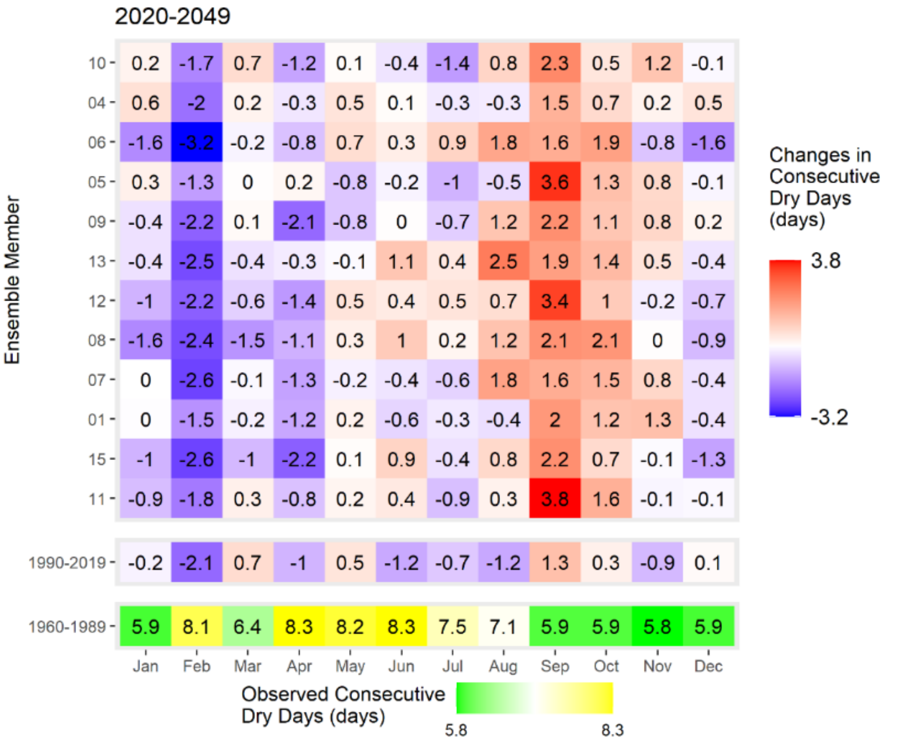


Figure 14. Change direction agreement for 8 (top), 10 (middle) and 12 (bottom) climate projections (ensemble members) in the number of Consecutive Dry Days for the period 2020 – 2049.



Ensemble Member	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	0.2	-1.7	0.7	-1.2	0.1	-0.4	-1.4	0.8	2.3	0.5	1.2	-0.1
04	0.6	-2	0.2	-0.3	0.5	0.1	-0.3	-0.3	1.5	0.7	0.2	0.5
06	-1.6	-3.2	-0.2	-0.8	0.7	0.3	0.9	1.8	1.6	1.9	-0.8	-1.6
05	0.3	-1.3	0	0.2	-0.8	-0.2	-1	-0.5	3.6	1.3	0.8	-0.1
09	-0.4	-2.2	0.1	-2.1	-0.8	0	-0.7	1.2	2.2	1.1	0.8	0.2
13	-0.4	-2.5	-0.4	-0.3	-0.1	1.1	0.4	2.5	1.9	1.4	0.5	-0.4
12	-1	-2.2	-0.6	-1.4	0.5	0.4	0.5	0.7	3.4	1	-0.2	-0.7
08	-1.6	-2.4	-1.5	-1.1	0.3	1	0.2	1.2	2.1	2.1	0	-0.9
07	0	-2.6	-0.1	-1.3	-0.2	-0.4	-0.6	1.8	1.6	1.5	0.8	-0.4
01	0	-1.5	-0.2	-1.2	0.2	-0.6	-0.3	-0.4	2	1.2	1.3	-0.4
15	-1	-2.6	-1	-2.2	0.1	0.9	-0.4	0.8	2.2	0.7	-0.1	-1.3
11	-0.9	-1.8	0.3	-0.8	0.2	0.4	-0.9	0.3	3.8	1.6	-0.1	-0.1
1990-2019	-0.2	-2.1	0.7	-1	0.5	-1.2	-0.7	-1.2	1.3	0.3	-0.9	0.1
1960-1989	5.9	8.1	6.4	8.3	8.2	8.3	7.5	7.1	5.9	5.9	5.8	5.9

Figure 15. National scale changes in the number of ***median*** *monthly Consecutive Dry Days for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049*

Key Finding: Figure 15 shows the median monthly CDD for the 1960-1989 baseline (bottom row) and how this has changed in the period 1990 – 2019 (second row), and the 12 projections (main block, values are the change from the 1960 – 1989 baseline, so add these to the baseline value to get the projected total change). Projections are ranked by highest model skill in estimating precipitation in the bottom row of the main block, to the lowest model skill (top row). This highlights that February has already seen an observed decrease in the number of CDD (-2.1 days) and this is already comparable with what the climate projections estimate as a change from the 1960-1989 baseline for the 2020 – 2049 period. Similarly, September has seen an observed increase in CDD (1.3 days) and this trend is projected to increase.

Implications of changes in Consecutive Dry Days

In respect of impacts on Natural Capital, of concern is the trend for March and May (and April in the east) having more Consecutive Dry Days, as this is a key biotic growth period, but also there is greater fuel load (dead vegetation matter) and when muirburn may get out of control. To assess the full impact of these changes it is also necessary to understand the changes in temperature, precipitation amount and evapotranspiration rates.

Observed precipitation amount changes in the west have increased in December to May, but either remained similar or decreased in July, August and October. Eastern Scotland became drier in January, March, May, August, September and December, but wetter in February, June, July, October and November. Projections for the period 2020 to 2049 indicate Scotland's climate to be wetter in December, January (both c.10%), February (45 – 55%) and April (25%) but less so in March (c. 5%). For the 2020 to 2049 period, August, September and October are projected to become drier.

Based on these changes in precipitation amount, an increase in CDD implies a higher likelihood of water stress occurring. The consequences of this will be variable depending on soil hydrological characteristics and tolerance ranges of species, with some plants potentially benefitting (e.g., due to changed competitive advantage) or being more at risk (e.g., due to low desiccation tolerance). Longer dry periods increase the risk of fire occurrence[3] and soil erosion by wind and heavy precipitation, and place additional pressures on irrigation demand. The overall picture of wetter winters and drier summers implies an increased pressure on ecosystems to cope with changes in the amount of water available.

Number of Dry Days. This is a count of the number of Dry Days (DD) per month (when precipitation is < 1mm). As with Consecutive Dry Days, this indicator provides information on the potential for increased dry conditions and risks of drought and heat stress. DD should be seen in the context of other variables, such as temperature and the related evapotranspiration, and soil hydrology.

- Observed: there has been both a geographical and temporal change in the number of Dry Days since 1960, with a decrease in winter in west and central Scotland, and increase in east. February has seen a decrease and September an increase across most of the country.
- Future: there is a mixed range of uncertainty in the geographical distribution of the number of Dry Days. There is good agreement between the 12 projections that there will be an increase in number of Dry Days in the summer, but less agreement about the winter. Spatially estimates show an increase in Dry Days in the central and southern uplands in August, most of Scotland in September and uplands in October and in the north in November and December.
- Historically (1960-1989) at the national scale April has the most observed Dry Days (28) in the most extreme year, but this has already decreased by four days hence matching the projected decrease by 1-4 days.

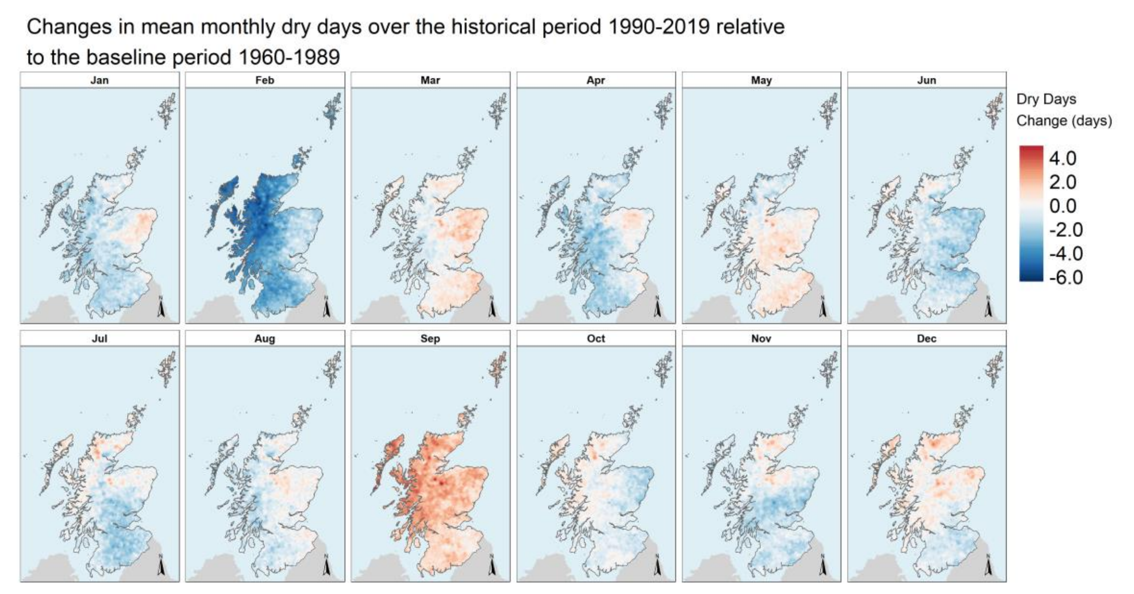
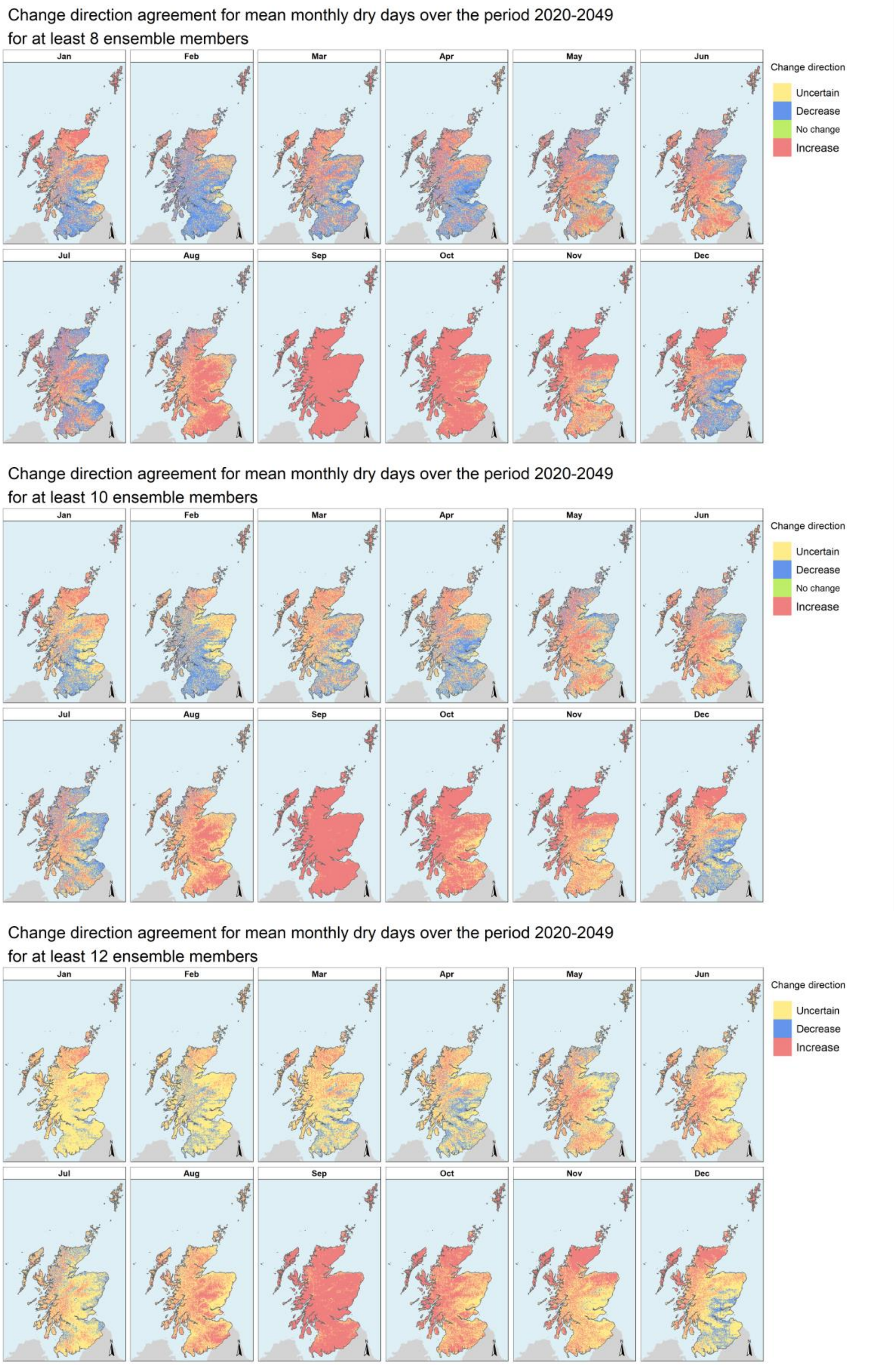

Changes in mean monthly dry days over the historical period 1990-2019 relative to the baseline period 1960-1989

Figure 16. Changes in the number of Dry Days between the 1960 – 1989 baseline and 1990 – 2019 period.

There has been a nationwide increase in the number of Dry Days in September, and most of the east and south in March and May (Figure 16). Conversely February has experienced a nationwide decrease in the number of Dry Days, with more land area having a decrease overall across the year.

---

[3] See D5-2 Deliverable D2.3b Fire Danger Assessment of Scottish Habitat Types (Gagkas et al 2023), available on the project website: [Climate Change Impacts on Natural Capital | The James Hutton Institute]()



Change direction agreement for mean monthly dry days over the period 2020-2049 for at least 8 ensemble members

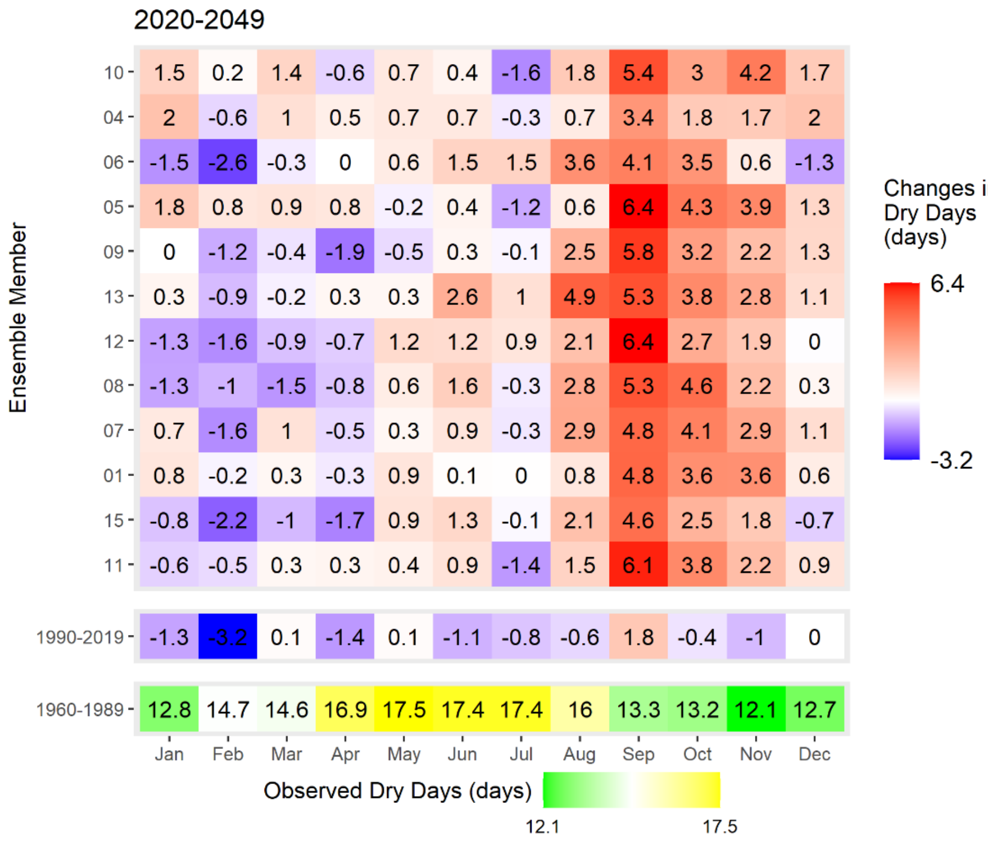
Change direction agreement for mean monthly dry days over the period 2020-2049 for at least 10 ensemble members

Change direction agreement for mean monthly dry days over the period 2020-2049 for at least 12 ensemble members

Figure 17. Change direction agreement for 8 (top), 10 (middle) and 12 (bottom) climate projections (ensemble members) for the number of Dry Days in the period 2020 - 2049.

There has been an observed change in the number of dry days since the 1960-1989 baseline period. For the period 2020-2049 there is some uncertainty, with different model runs projecting different patterns of DD in most areas of the country, which lowers the confidence in the projection for a given area (Figure 17).

When all 12 ensemble members are considered, there is moderate evidence for a split pattern, with more DD in winter in all areas except the N and NE of the country. Projections are more consistent in the second part of the year, with DD projected to increase virtually in all areas except in December. September is consistently expected to experience a decrease in the number of Dry Days across the whole of Scotland (all 12 ensemble members).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	1.5	0.2	1.4	-0.6	0.7	0.4	-1.6	1.8	5.4	3	4.2	1.7
04	2	-0.6	1	0.5	0.7	0.7	-0.3	0.7	3.4	1.8	1.7	2
06	-1.5	-2.6	-0.3	0	0.6	1.5	1.5	3.6	4.1	3.5	0.6	-1.3
05	1.8	0.8	0.9	0.8	-0.2	0.4	-1.2	0.6	6.4	4.3	3.9	1.3
09	0	-1.2	-0.4	-1.9	-0.5	0.3	-0.1	2.5	5.8	3.2	2.2	1.3
13	0.3	-0.9	-0.2	0.3	0.3	2.6	1	4.9	5.3	3.8	2.8	1.1
12	-1.3	-1.6	-0.9	-0.7	1.2	1.2	0.9	2.1	6.4	2.7	1.9	0
08	-1.3	-1	-1.5	-0.8	0.6	1.6	-0.3	2.8	5.3	4.6	2.2	0.3
07	0.7	-1.6	1	-0.5	0.3	0.9	-0.3	2.9	4.8	4.1	2.9	1.1
01	0.8	-0.2	0.3	-0.3	0.9	0.1	0	0.8	4.8	3.6	3.6	0.6
15	-0.8	-2.2	-1	-1.7	0.9	1.3	-0.1	2.1	4.6	2.5	1.8	-0.7
11	-0.6	-0.5	0.3	0.3	0.4	0.9	-1.4	1.5	6.1	3.8	2.2	0.9
1990-2019	-1.3	-3.2	0.1	-1.4	0.1	-1.1	-0.8	-0.6	1.8	-0.4	-1	0
1960-1989	12.8	14.7	14.6	16.9	17.5	17.4	17.4	16	13.3	13.2	12.1	12.7

*Figure 18. National scale changes in the **median** monthly number of Dry Days for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049*

Key Finding: The observed median number of Dry Days has decreased by -3.2 in February. This is already larger than all of the 12 climate projections estimate for the 2020 – 2049 period.

The change in other months is less, being c. 1 day, except September when Dry Days increased by 1.8 days and is projected to continue increasing to c. 4-5 days. The colour shading in Figure 18 emphasises that the summer, particularly September and the autumn and likely to become drier in the future, but the winter is likely to become wetter.

Implications of changes in Dry Days

- Where Dry Days are projected to increase in winter, these could experience both negative and positive consequences for agriculture.
- In winters with several dry days, soil moisture deficit can build up and partially limit the water available for crops when they begin to grow again in the spring.

- In well-drained areas that are projected to experience more dry days in spring and summer, there is a risk of a decrease in average crop yields, while poorly drained soils could see improved crop growth conditions.
- Pests and diseases could increase due to dry and warm conditions.
- Semi-natural vegetation and drier peat soil are more exposed to the risk of fire occurrence.
- Drier conditions could affect the ability to irrigate which can also lead to yield decreases in some areas.

Number of Heavy Rain Days. This indicator represents days when precipitation may be considered as 'heavy rainfall' – here we consider the threshold as days when precipitation is ≥ 10mm.

- Since 1960 there has been a shift in the number of heavy rain days (0 to +3 in the 1990-2019 period compared to the 1960-1989 period) with the highest value reported in winter and little variation in summer and autumn (Figure 19).
- Future projections (both 2020-2049 and 2050-2079 periods) show that the HRD changes in the winter season with an increase up to 4 days, compared to the 1960-1989 period. There is a reduction in summer (from -2 to -4 days). The projections thus seem to affect mainly summer HRD variations with a risk of an increased drought and winter flooding.
- Historically (1960-1989) at the national scale the most Heavy Rain Days in the most extreme year have occurred between October and January (11 days for each month). February has already increased by 3 days (1990-2019) and hence matching the projected decrease by 1-4 days.

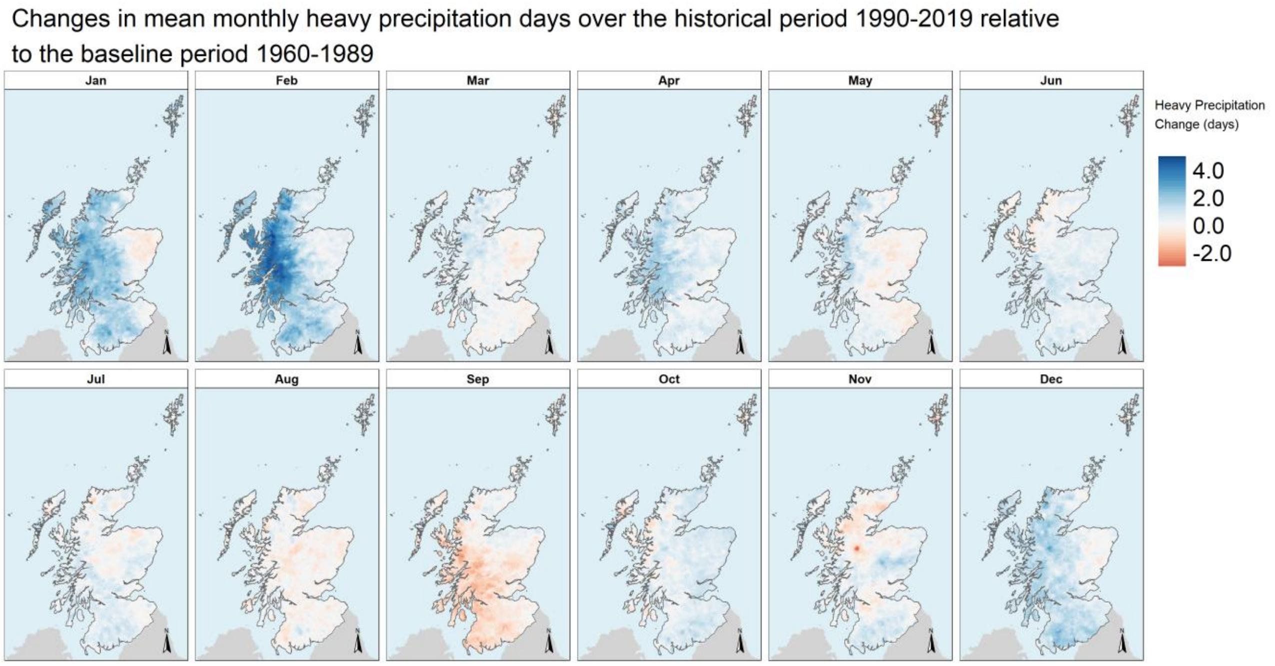
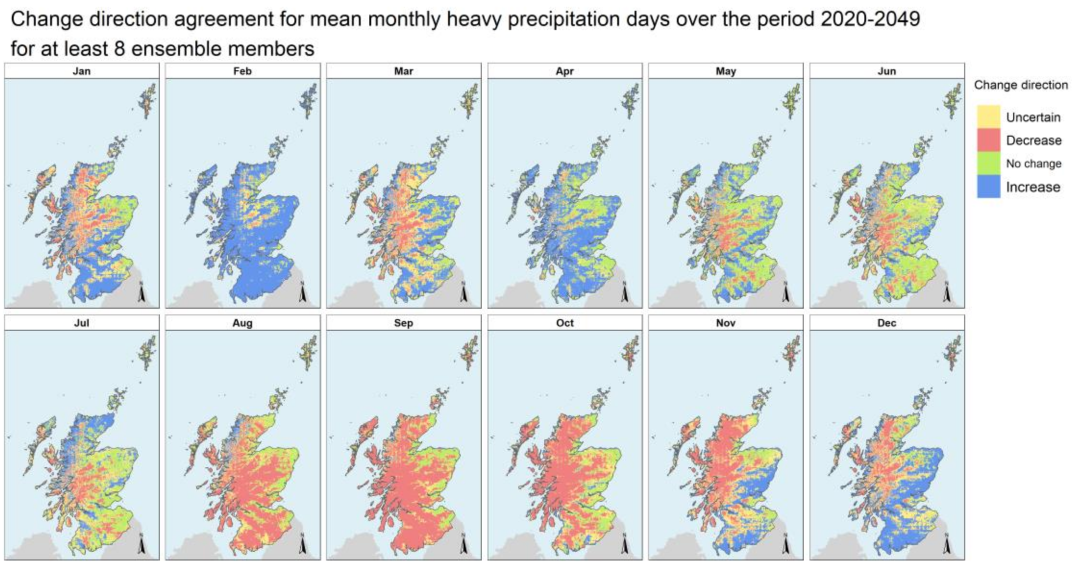
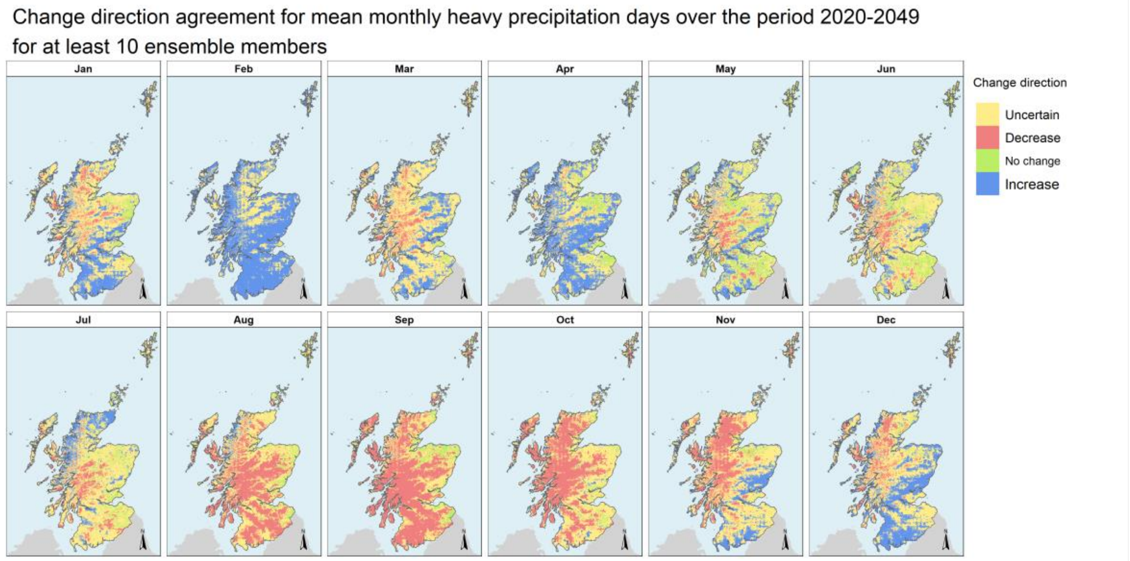


Figure 19. Changes in the number of Heavy Rain Days (≥ 10mm) between the 1960 – 1989 baseline and 1990 – 2019 period.

There is strong agreement (Figure 20) that August to October is likely to experience a decrease in the number of Heavy Rain Days in upland areas, however this does not reflect the quantity of water and potential intensity of the events that do occur, which may be more intense (as warmer air can hold more moisture).





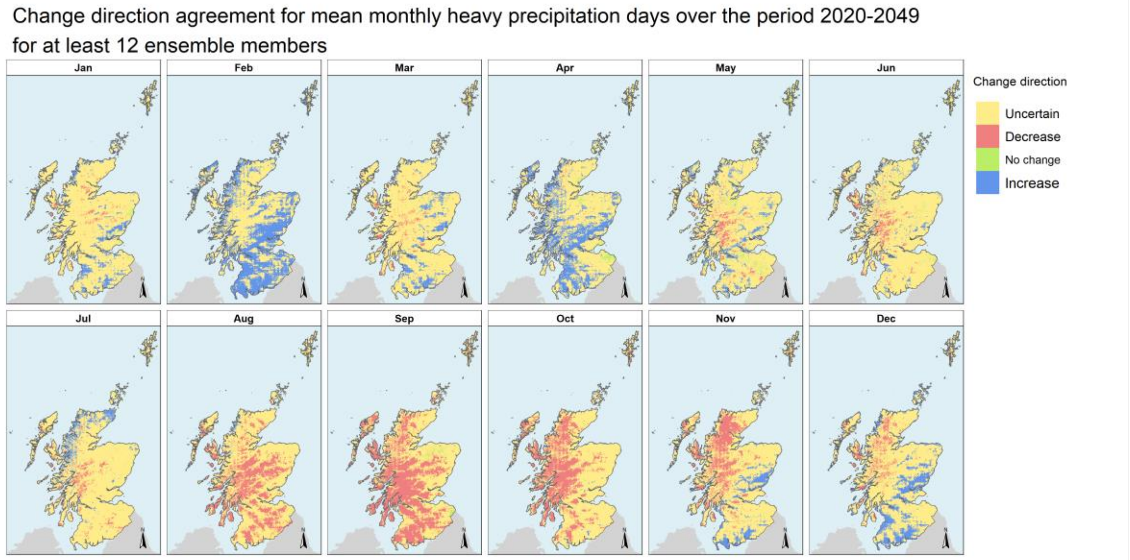
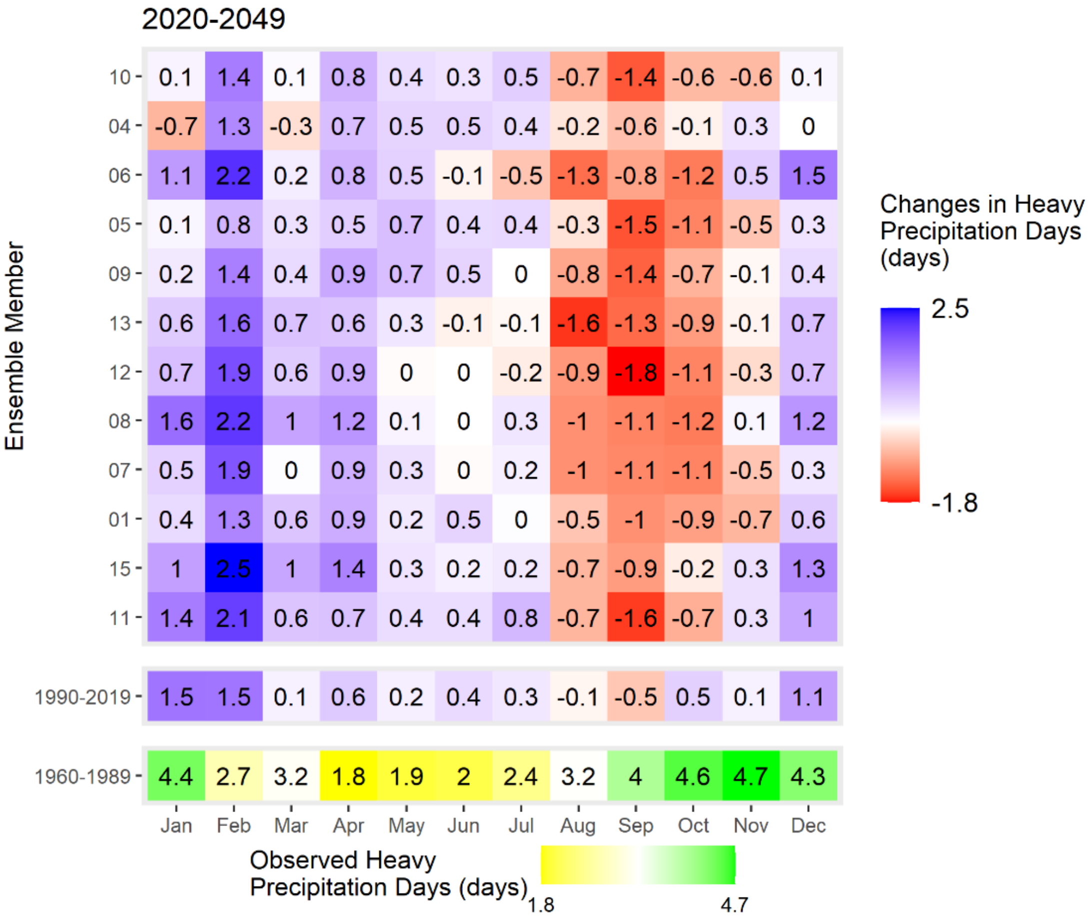


Figure 20. Change direction agreement for 8 (top), 10 (middle) and 12 (bottom) climate projections (ensemble members) for the number of Heavy Rain Days in the period 2020 - 2049.

There is a mixed level of agreement between multiple climate projections on the direction of change in the number of Heavy Rain Days (Figure 20), being good agreement that September is likely to experience decrease and February an increase.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	0.1	1.4	0.1	0.8	0.4	0.3	0.5	-0.7	-1.4	-0.6	-0.6	0.1
04	-0.7	1.3	-0.3	0.7	0.5	0.5	0.4	-0.2	-0.6	-0.1	0.3	0
06	1.1	2.2	0.2	0.8	0.5	-0.1	-0.5	-1.3	-0.8	-1.2	0.5	1.5
05	0.1	0.8	0.3	0.5	0.7	0.4	0.4	-0.3	-1.5	-1.1	-0.5	0.3
09	0.2	1.4	0.4	0.9	0.7	0.5	0	-0.8	-1.4	-0.7	-0.1	0.4
13	0.6	1.6	0.7	0.6	0.3	-0.1	-0.1	-1.6	-1.3	-0.9	-0.1	0.7
12	0.7	1.9	0.6	0.9	0	0	-0.2	-0.9	-1.8	-1.1	-0.3	0.7
08	1.6	2.2	1	1.2	0.1	0	0.3	-1	-1.1	-1.2	0.1	1.2
07	0.5	1.9	0	0.9	0.3	0	0.2	-1	-1.1	-1.1	-0.5	0.3
01	0.4	1.3	0.6	0.9	0.2	0.5	0	-0.5	-1	-0.9	-0.7	0.6
15	1	2.5	1	1.4	0.3	0.2	0.2	-0.7	-0.9	-0.2	0.3	1.3
11	1.4	2.1	0.6	0.7	0.4	0.4	0.8	-0.7	-1.6	-0.7	0.3	1
1990-2019	1.5	1.5	0.1	0.6	0.2	0.4	0.3	-0.1	-0.5	0.5	0.1	1.1
1960-1989	4.4	2.7	3.2	1.8	1.9	2	2.4	3.2	4	4.6	4.7	4.3

*Figure 21. National scale changes in the **median** monthly number of Heavy Rain Days for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049.*

Projections in Figure 21 show a reduction in HRD mainly in August and September (from -0.6 to -1.8 days) and the maximum increase in January and February (up to 3), reinforcing the current pattern of heavy rain changes observed in 1990-2019 compared to the period 1960-1989.

Implications of changes in Heavy Rain Days

The expected increase in Heavy Rain Days in winter can be associated with a higher risk of flooding and conversely with fewer HRD in summer leading to a higher risk of reduced water availability and higher stress. A slight increase in the impact for manufactured infrastructures and human lives and health can be expected in winter. There may be major negative effects on Natural Capital assets represented by soil, vegetation, river and ground waters in the summertime when it is expected that there may be a reduced level of ecological functionality and a potential loss of biodiversity because of the important increase in drought. Also, in summer, higher levels of stress is expected to impact crop production, highly water-intense industries and human consumption.

Number of Very Wet Days.

This indicator provides information on the mean monthly number of Very Wet Days (VWD). A Very Wet Day is classified as a precipitation amount that is greater or equal to the 95th

Percentile. It is the count of these events and represents the top 5% largest precipitation events per month. It hence represents the changes in the number of extremely large precipitation events.

- There is a clear observed trend and continued future projection that the number of the largest precipitation events, the number of Very Wet Days, is likely to increase in the winter but decrease in the summer. The 1960-1989 baseline shows that the number of Very Wet Days was consistent throughout the year (5-6), but the more recent 1990-2019 period shows there were more in the winter, particularly February (3)
- There is good agreement between the climate projections that the upland areas of Scotland are likely to experience a decrease in the number of Very Wet Days in the summer months. There is medium level of agreement between projections that the lowland eastern parts of Scotland may experience an increase in the number of Very Wet Days.
- At a national level for the most extreme years, the winter is projected to have an increase in Very Wet Days and in August – October a decrease. February has already seen an increase from 5 (1960-1989) to 8 (1990-2019).

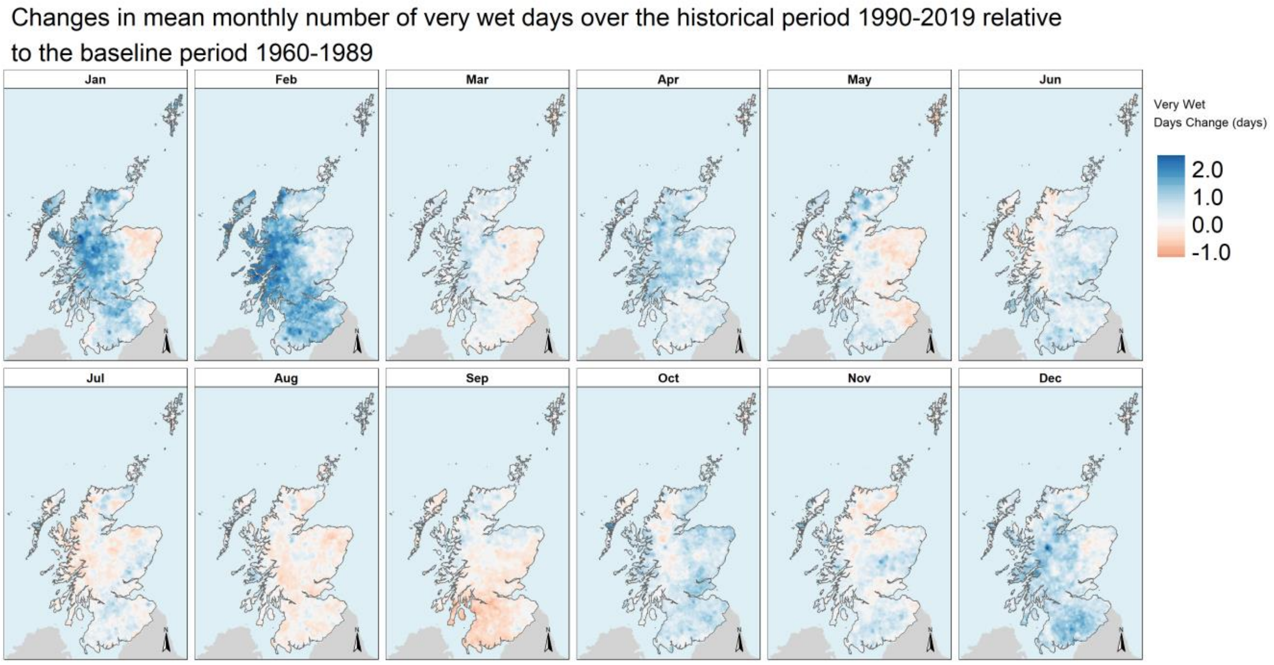
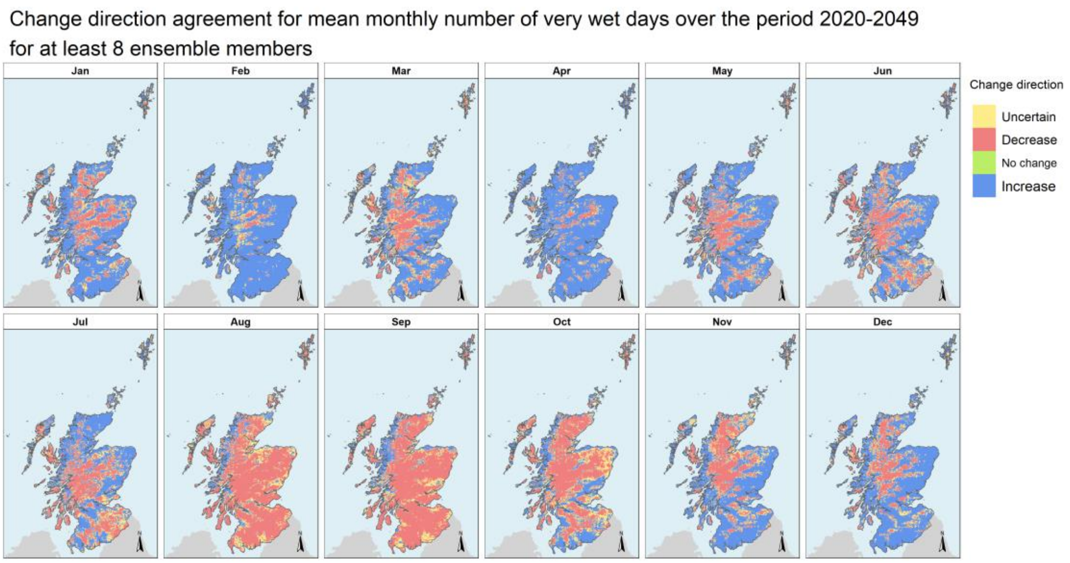
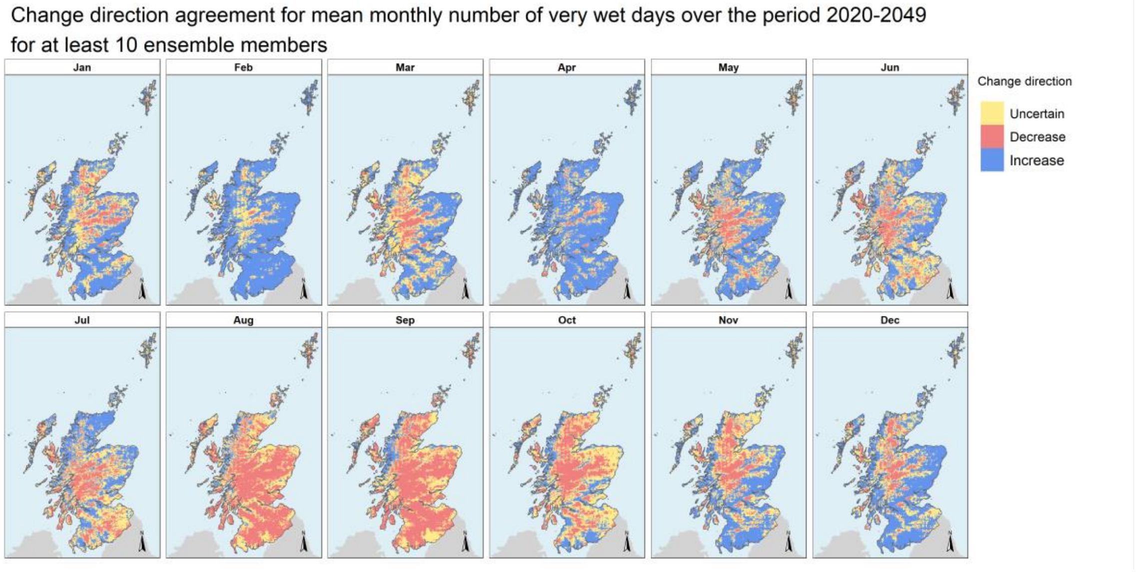


Figure 22. Changes in the number of Very Wet Days between the 1960 – 1989 baseline and 1990 – 2019 period.

There is good agreement between the 12 climate projections that there may be a decrease in VWD in August to October in the uplands, but an increase in February and April in lowland areas (Figure 23).





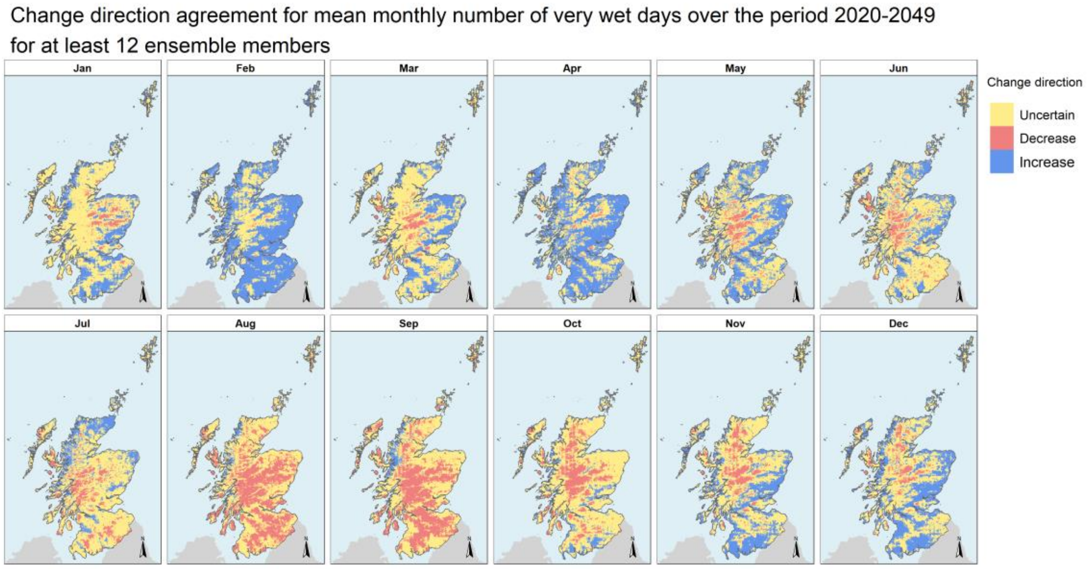
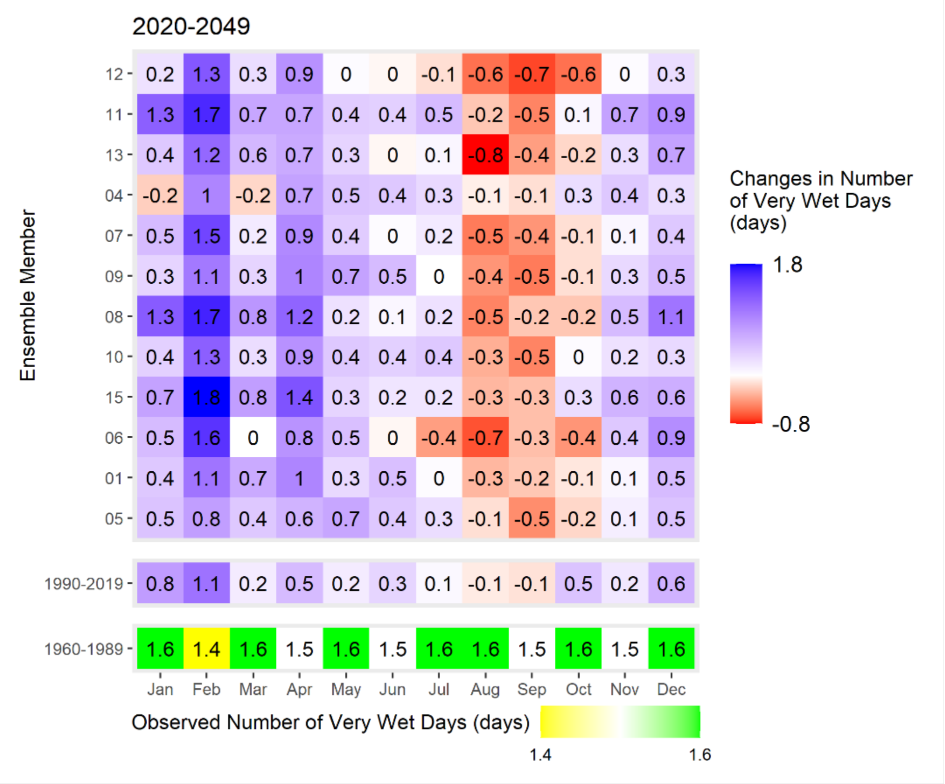


Figure 23. Change direction agreement for 8 (top), 10 (middle) and 12 (bottom) climate projections (ensemble members) for the number of Very Wet Days in the period 2020 - 2049.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12	0.2	1.3	0.3	0.9	0	0	-0.1	-0.6	-0.7	-0.6	0	0.3
11	1.3	1.7	0.7	0.7	0.4	0.4	0.5	-0.2	-0.5	0.1	0.7	0.9
13	0.4	1.2	0.6	0.7	0.3	0	0.1	-0.8	-0.4	-0.2	0.3	0.7
04	-0.2	1	-0.2	0.7	0.5	0.4	0.3	-0.1	-0.1	0.3	0.4	0.3
07	0.5	1.5	0.2	0.9	0.4	0	0.2	-0.5	-0.4	-0.1	0.1	0.4
09	0.3	1.1	0.3	1	0.7	0.5	0	-0.4	-0.5	-0.1	0.3	0.5
08	1.3	1.7	0.8	1.2	0.2	0.1	0.2	-0.5	-0.2	-0.2	0.5	1.1
10	0.4	1.3	0.3	0.9	0.4	0.4	0.4	-0.3	-0.5	0	0.2	0.3
15	0.7	1.8	0.8	1.4	0.3	0.2	0.2	-0.3	-0.3	0.3	0.6	0.6
06	0.5	1.6	0	0.8	0.5	0	-0.4	-0.7	-0.3	-0.4	0.4	0.9
01	0.4	1.1	0.7	1	0.3	0.5	0	-0.3	-0.2	-0.1	0.1	0.5
05	0.5	0.8	0.4	0.6	0.7	0.4	0.3	-0.1	-0.5	-0.2	0.1	0.5
1990-2019	0.8	1.1	0.2	0.5	0.2	0.3	0.1	-0.1	-0.1	0.5	0.2	0.6
1960-1989	1.6	1.4	1.6	1.5	1.6	1.5	1.6	1.6	1.5	1.6	1.5	1.6

*Figure 24. National scale changes in the **median** monthly number of Very Wet Days for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049.*

There is a clear pattern of increases in winter months and decreases in summer months for VWD which is a continuation of the observed trend over time, with more VWD per month in winter and fewer in summer. (Figure 24).

Implications of changes in Very Wet Days

An increase in the number of the largest precipitation events per month in the winter implies an increased risk of flooding and soil erosion. Conversely the reduced number of Very Wet Days in the summer implies an increased risk of dry soil and habitat conditions, but this may be associated with reduced risks of flooding. However, large precipitation events occurring when soils are dry will likely result in soil erosion and nutrient flushes. Fewer Very Wet Days in summer might reduce the amount of cereal crop yield losses due to lodging[4].

There may however be a benefit from the overall wetter conditions in the winter and more Very Wet Days, in that it increases the potential for recharge of ground water to maintain water table levels. This may be important as a buffer against reduced water availability in the summer and help to maintain ecological functions, i.e., peatlands through remaining wet.

Note: A recent Centre of Expertise on Water (CREW) report ‘Assessing climate change impacts on the water quality of Scottish standing waters’ highlighted key impacts of climate change on wetlands. The full report is available here: [Assessing climate change impacts on the water quality of Scottish standing waters] | CREW | Scotland's Centre of Expertise for Waters

---

[4] Lodging is the physical damage such as flattening caused to cereal crops, for example when combined with wet soils and strong winds. It can account for 20% losses to winter wheat every 3-4 years. An introduction to lodging in cereals | AHDB

Temperature Extremes

Highest Temperature. The Highest Temperature indicator represents the highest daily maximum temperature per month. Increases in HT means that the hottest days per month become even hotter.

- There has been an observed increase in the highest maximum temperature from 1960-1989 to 1990-2019 for all months except June and in some western upland areas in August and October. February, March, May, July (primarily the west) and September have experienced the largest increase, by up to 2.0°C and across the whole of Scotland by 1.3°C.
- The observed trend is projected to continue and increase. For the future period 2020-2049, all months are estimated to experience an increase in Highest Temperature, in the order of 2-3°C. There is near complete agreement between all climate projections used that the highest maximum temperature will increase for all months.
- **Key Finding:** At the national scale, in the most extreme years, March has seen the largest observed increase in Highest temperature from 16.9°C (1960-1989) to 19.4°C (1990-2019), which is larger than the projected changes. July and August (27.7°C each between 1960-1989) have changed little (-0.3 and 0.1°C, respectively), but are projected to increase by 1.9 to 8.8°C during the period 2020-2049. For the 2050-2079 period for July and August, the Highest Temperature is projected to increase by 3.0 to 11.8°C.

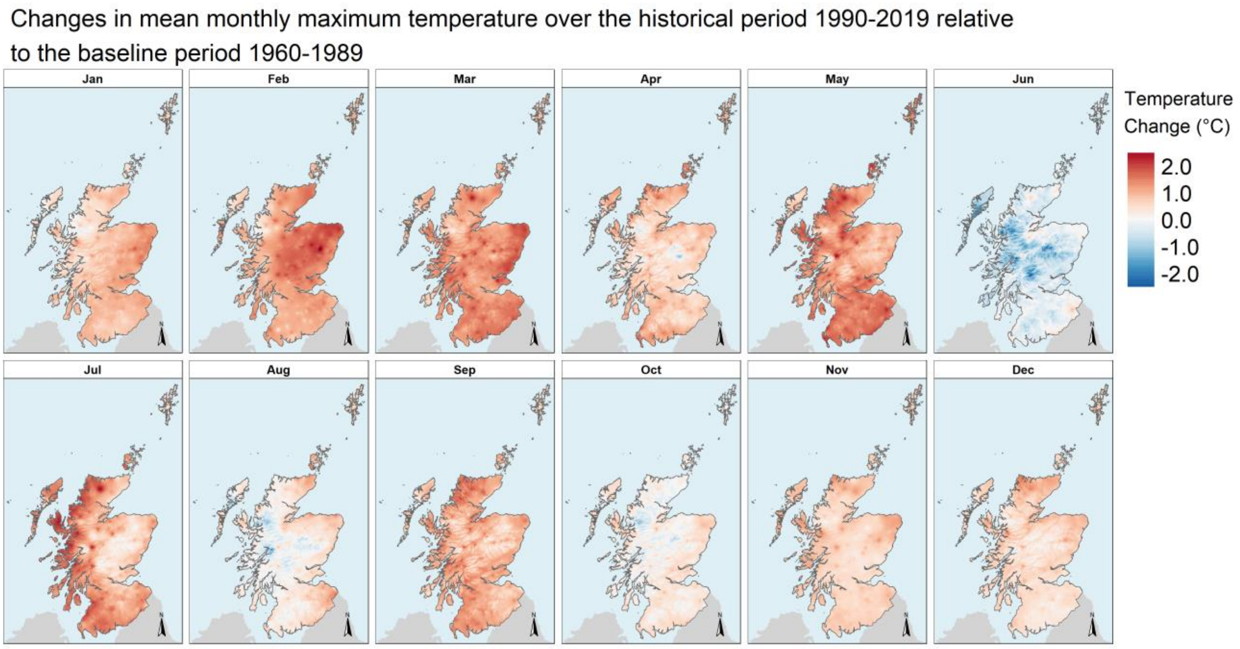
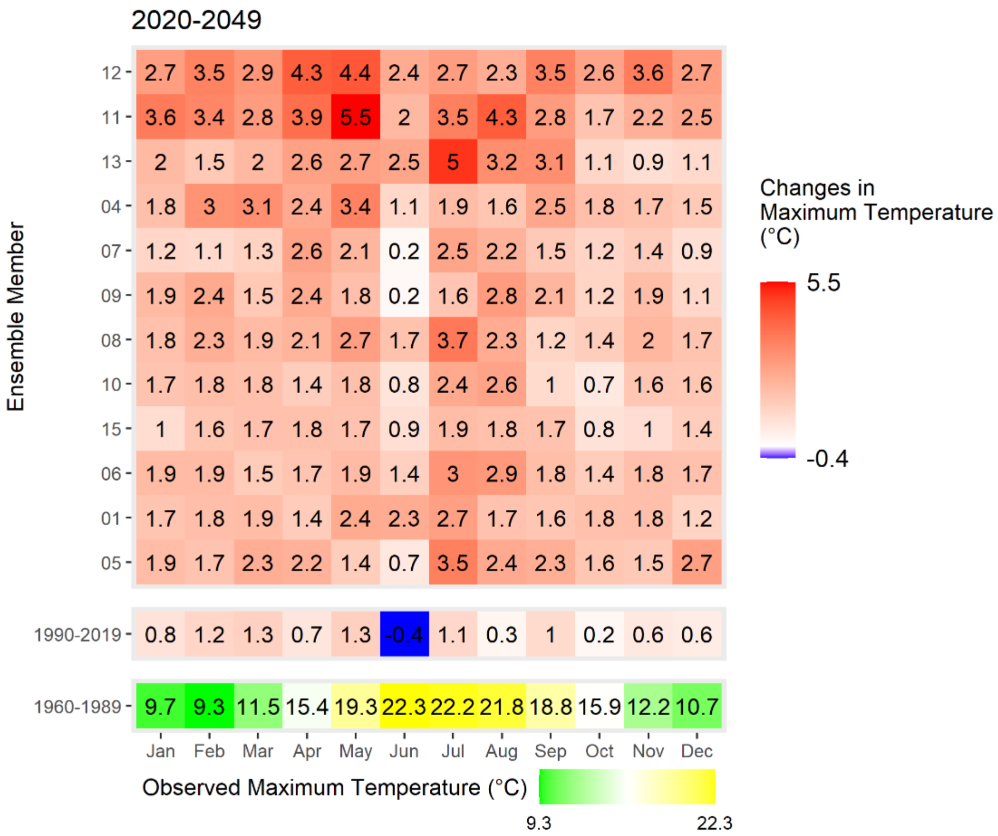


Figure 25. Changes the Highest Temperatures between the 1960 – 1989 baseline and 1990 – 2019 period.

Key Finding: There has been an observed increase in HT from 1960-1989 to 1990-2019 (Figure 25) for all months except June and in some western upland areas in August and October. February, March, May, July (primarily the west) and September have experienced the largest increase, by up to 2.0°C and across the whole of Scotland by 1.3°C. June has experienced a slight decrease in Highest Temperature in upland areas by up to 2.0°C, and on average by up to 0.4°C nationally.

Note: We have not included the agreement maps for Highest Temperature, as there is very good agreement between all 12 climate projections that the highest daily maximum temperatures per month will increase. This is also illustrated in Figure 26.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12	2.7	3.5	2.9	4.3	4.4	2.4	2.7	2.3	3.5	2.6	3.6	2.7
11	3.6	3.4	2.8	3.9	5.5	2	3.5	4.3	2.8	1.7	2.2	2.5
13	2	1.5	2	2.6	2.7	2.5	5	3.2	3.1	1.1	0.9	1.1
04	1.8	3	3.1	2.4	3.4	1.1	1.9	1.6	2.5	1.8	1.7	1.5
07	1.2	1.1	1.3	2.6	2.1	0.2	2.5	2.2	1.5	1.2	1.4	0.9
09	1.9	2.4	1.5	2.4	1.8	0.2	1.6	2.8	2.1	1.2	1.9	1.1
08	1.8	2.3	1.9	2.1	2.7	1.7	3.7	2.3	1.2	1.4	2	1.7
10	1.7	1.8	1.8	1.4	1.8	0.8	2.4	2.6	1	0.7	1.6	1.6
15	1	1.6	1.7	1.8	1.7	0.9	1.9	1.8	1.7	0.8	1	1.4
06	1.9	1.9	1.5	1.7	1.9	1.4	3	2.9	1.8	1.4	1.8	1.7
01	1.7	1.8	1.9	1.4	2.4	2.3	2.7	1.7	1.6	1.8	1.8	1.2
05	1.9	1.7	2.3	2.2	1.4	0.7	3.5	2.4	2.3	1.6	1.5	2.7
1990-2019	0.8	1.2	1.3	0.7	1.3	-0.4	1.1	0.3	1	0.2	0.6	0.6
1960-1989	9.7	9.3	11.5	15.4	19.3	22.3	22.2	21.8	18.8	15.9	12.2	10.7

Figure 26. National scale changes in the Median monthly Highest Temperature for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049.

Key Finding: There has been an increase in the median monthly Highest Temperature from 1960-1989 to 1990-2019 for all months except June (Figure 26), most notably February (+1.2°C), March and May (+1.3°C). This trend is projected to continue in the future throughout the year (including June becoming warmer). In the period 2020-2049 the different projections indicate a relatively even spread in the increase across the year, but by 2050-2079, there is a larger increase in the late spring and summer months. We know from assessments of skill of the climate model to estimate observed temperature (Appendix D, see Figure 69 in Climate Extremes in Scotland) that projection 05 performs the best. The observed change for May is an increase of 1.3°C, which is only 0.1°C less than the estimate made by projection 05 for the 2020-2049 period, hence the observed change is already of the same magnitude as the future projections.

By the 2050-2079 period projection 05 produces estimated increases in Highest Temperatures of 11.1°C in July, giving a potential total of 38.8°C. To put this into perspective and illustrate how much the already experienced changes fit with future projections, the Highest Temperature in Scotland during the 2022 heatwave was 34.8°C (at Charterhall in Berwickshire).

Implications of changes in Highest Temperature

The increase in Highest Temperature already observed and projected to occur even more in the future have implications on many aspects of Nature and society. Increases in the extremes of maximum temperature will likely increase heat and water stresses on plants, animals and habitats, potentially damaging ecological function and delivery of ecosystem services. As the observed and projected increases occur throughout the year, the implications vary.

In the winter, there is likely to be an increase in rapid snow melt and loss of snow cover (Rivington et al 2019). Higher temperatures in spring will affect plant and insect phenology and timing on behaviour, with risks of earlier emergence from hibernation, leaf and bud formation, but when threats of damage by frost remain. High temperatures during anthesis (flowering) in summer reduces crop yield. High temperatures are also associated with increased rates of evapotranspiration and hence more rapid and severe drying of soils and vegetation, which may also increase the amount of combustible material increase the risks of fire occurrence.

Higher maximum temperatures also pose threats to people and infrastructure due to heat stress.

Very Warm Days. The Vary Warm Days indicator is a count of the number of days when the maximum temperature is greater than the 95th percentile of monthly maximum temperature. It represents changes in how long the warmest periods last.

- There has been an observed change in the number of very warm days between the 1960-1989 and 1990-2019 periods, with all months except June (and August in upland areas) seeing an increase. February (9 days) and March (5 days) have had the largest increase, particularly in the south and east of Scotland.
- There is almost complete agreement between climate projections that the number of Very Warm Days will increase in the future for the whole land area of Scotland. February, March and September are projected to have substantial increases, e.g., September, which had 6 days in the 1960-1989 period, but increasing by between 17 to 22 days for the 12 projections, giving a total of 23 to 28 days by 2050.
- Historically (1960-1989) at the national scale the highest number of Very Warm Days in the most extreme year was in August (11 days), which has increased by 1 day (1990-2019), but is projected to increase by 2-11 days up to 2050, and by 9-17 days by 2070. September is projected to see the largest increases of 8-22 and 17-24 days between up to 2050 and 2070, respectively.

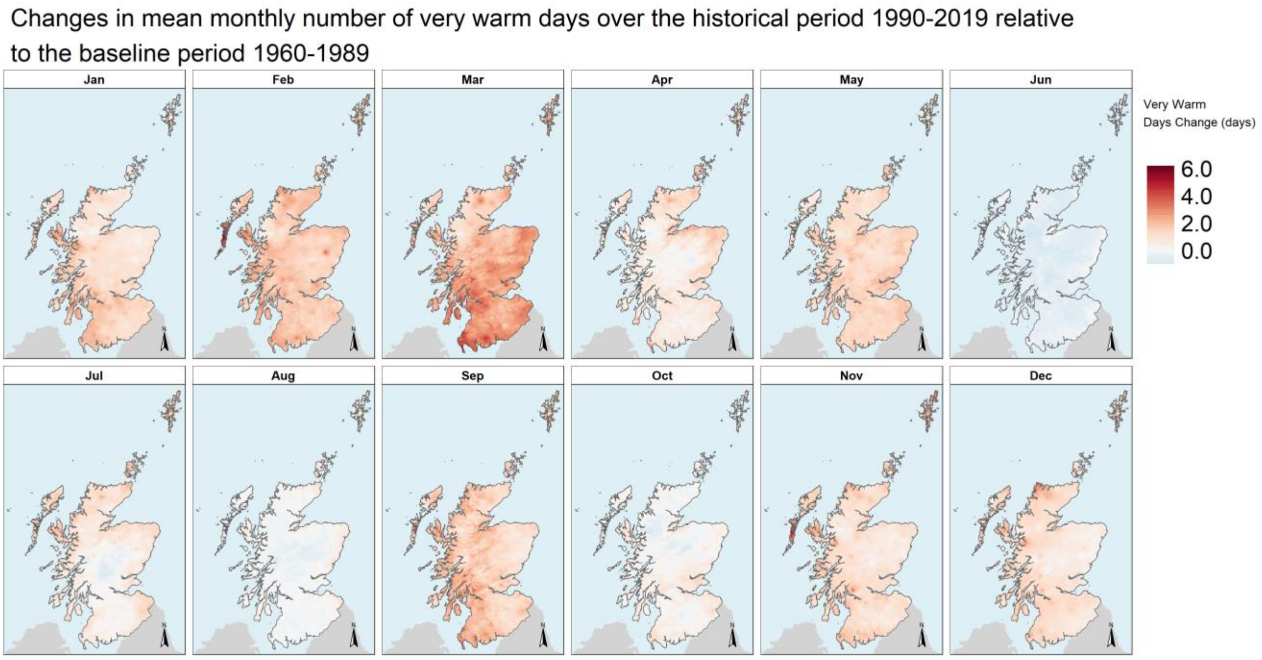
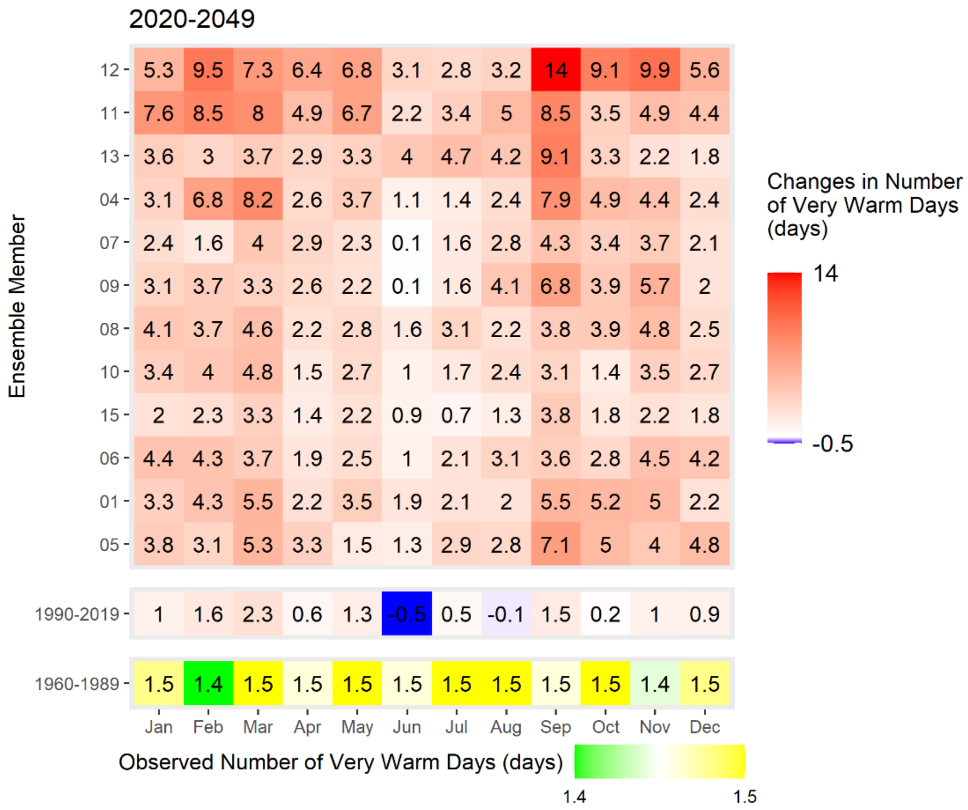


Figure 27. Changes in the number of mean monthly Very Warm Days between the 1960 – 1989 baseline and 1990 – 2019 period.

All months except June and August have experienced a general increase in the number of Very Warm Days, but most notably March.

Note: We have not presented the agreement maps for mean monthly number of Very Warm Days as all projections show an increase, i.e., all maps per month are red meaning all 12 projections agree that the number of Very Warm Days will increase across the whole of Scotland for all months.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12	5.3	9.5	7.3	6.4	6.8	3.1	2.8	3.2	14	9.1	9.9	5.6
11	7.6	8.5	8	4.9	6.7	2.2	3.4	5	8.5	3.5	4.9	4.4
13	3.6	3	3.7	2.9	3.3	4	4.7	4.2	9.1	3.3	2.2	1.8
04	3.1	6.8	8.2	2.6	3.7	1.1	1.4	2.4	7.9	4.9	4.4	2.4
07	2.4	1.6	4	2.9	2.3	0.1	1.6	2.8	4.3	3.4	3.7	2.1
09	3.1	3.7	3.3	2.6	2.2	0.1	1.6	4.1	6.8	3.9	5.7	2
08	4.1	3.7	4.6	2.2	2.8	1.6	3.1	2.2	3.8	3.9	4.8	2.5
10	3.4	4	4.8	1.5	2.7	1	1.7	2.4	3.1	1.4	3.5	2.7
15	2	2.3	3.3	1.4	2.2	0.9	0.7	1.3	3.8	1.8	2.2	1.8
06	4.4	4.3	3.7	1.9	2.5	1	2.1	3.1	3.6	2.8	4.5	4.2
01	3.3	4.3	5.5	2.2	3.5	1.9	2.1	2	5.5	5.2	5	2.2
05	3.8	3.1	5.3	3.3	1.5	1.3	2.9	2.8	7.1	5	4	4.8
1990-2019	1	1.6	2.3	0.6	1.3	-0.5	0.5	-0.1	1.5	0.2	1	0.9
1960-1989	1.5	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5

Figure 28. National scale changes in the median monthly number of Very Warm Days for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049.

Key Finding: There has been an increase in the median number of Very Warm Days since per month 1960 (Figure 28), by as much as 2.3 days in March, but also decreasing slightly (0.5 days) in June. The Projections with the better skill at simulating observed temperature (05, 01, 06) estimate increase in VWD by up to 7.1 days (05 in September) for the period 2020-2049, increasing to 16.6 days (01) in the 2050-2079 period, but may be more at +20 days (see Figure 53b in Climate Extremes in Scotland).

Implications of changes in Very Warm Days

The increase in the number of Very Warm Days already observed and projected to occur even more in the future have implications on many aspects of Nature and society. Increases in the duration of the warmest temperatures per spring, summer and autumn months will likely increase heat stresses on plants and animals, testing the thermal range tolerance of species and habitats. This may potentially alter inter-species competition, damage ecological function and delivery of ecosystem services.

Longer warm periods in the winter are likely to increase snow melt and loss of snow cover[5] and increase stream temperature affecting aquatic biodiversity. High temperatures lasting for longer will result in more rapid thermal time accumulation driver more rapid phenological development which will affect the timing of plant and insect development, with risks of earlier emergence from hibernation, leaf and bud formation, but when threats of damage by frost remain. The longer duration of high temperatures increases the risk that heat stress will occur during anthesis (flowering) in summer which can reduce crop yield. High temperatures are

---

[5] Rivington et al (2019) Snow Cover and Climate Change in the Cairngorms National Park: Summary Assessment. https://www.climatexchange.org.uk/media/3900/cxc-snow-cover-and-climate-change-in-the-cairngorms-national-park_1.pdf

also associated with increased rates of evapotranspiration (see Climatic Water Balance estimates above) and hence more rapid and severe drying of soils and vegetation. This, combined with longer duration warm periods are likely to increase the amount of combustible material increasing the probability of wildfire occurence.

Higher maximum temperatures pose threats to people and infrastructure due to heat stress.

Coldest Temperature. The Coldest Temperature indicator provides information about how the lowest temperatures per month have changed and are projected to in the future. CT is the lowest temperature achieved per month. Changes in minimum temperature are important in terms of its influence on crop and insect phenology, crop requirement for chilling (vernalisation), snow formation, cover and melt, stream temperature etc.

- There has been an overall increase (warming) of the Coldest Temperature per month since 1960. There is some spatial and temporal variation, with the largest increases (warming) in November, January and February, most noticeably in the Cairngorms area and southern uplands. May, October and December have experienced decreases (colder) in Coldest Temperatures in some parts of the north and west whilst experiencing increases (warmer) elsewhere. January has seen the largest increase (warming) of 2.1°C.
- There is good agreement between the 12 future climate projections that there will likely be a continuation of the historical trend of further increases (warming) in Coldest Temperature in all months across the whole of Scotland.
- Historically (1960-1989) at the national scale in the most extreme year, January and February had the Coldest temperatures (-15.6 and -13.1°C respectively), but these have decreased (warmed) by 4.3 and 3.5°C respectively in the 1990-2019 period. The projections to 2050 indicate decreases (warming) ranging from 1.1 to 8.2°C in January, and 5.3 to 10.6°C by 2070.

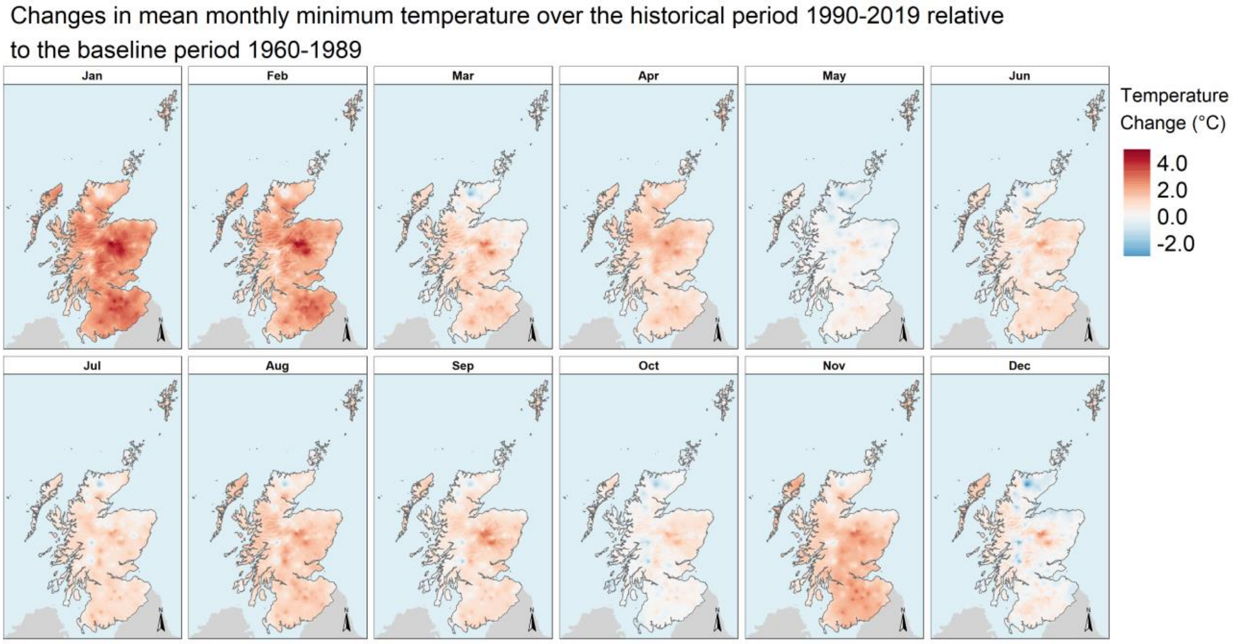
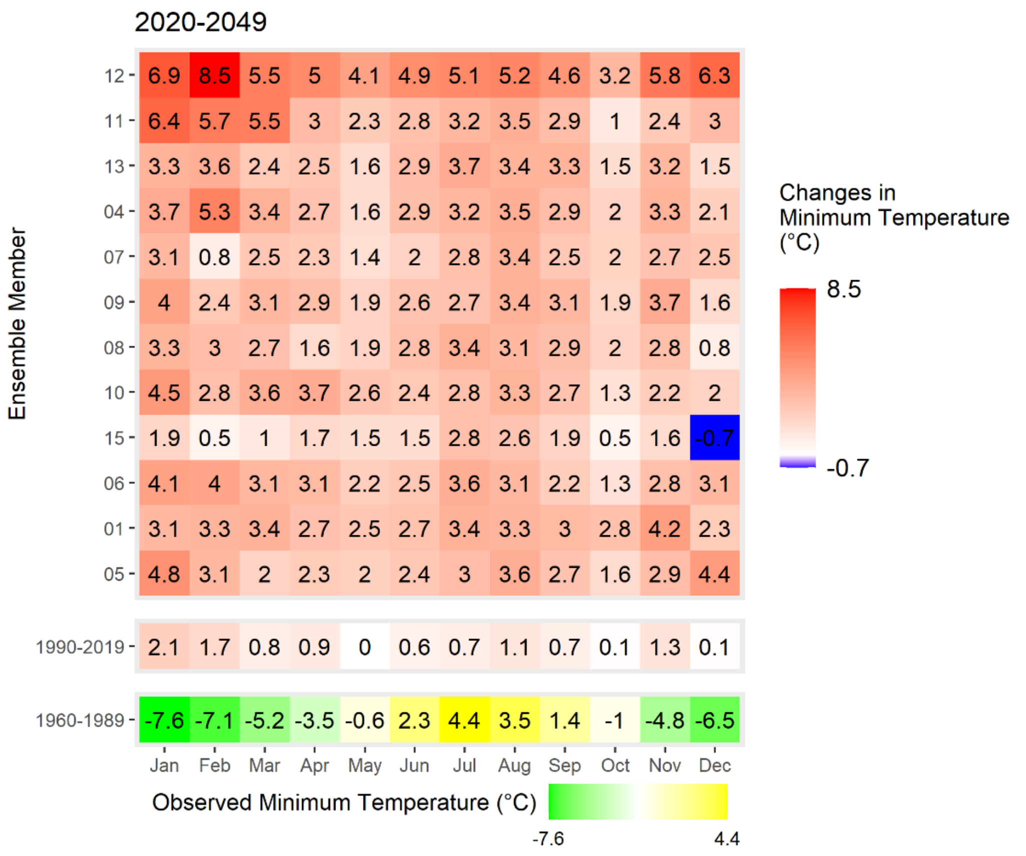


Figure 29. Changes in the lowest monthly Coldest Temperatures between the 1960 – 1989 baseline and 1990 – 2019 period.

Key Finding: There has generally been an increase (warmer) in the Coldest Temperature in all months since the 1960-1989 period (red shading in Figure 29), with the largest increases occurring November, January and February, most noticeably in the Cairngorms area and southern uplands. May, October and December have experienced decreases (colder) in Coldest Temperatures in some parts of the north and west (blue shading), whilst experiencing increases (warmer) elsewhere. These trends align with the overall decreases in minimum temperature (warming) detailed earlier in this report.

We have not presented the agreement maps for mean monthly Coldest Temperature as all projections show an increase (warming).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12	6.9	8.5	5.5	5	4.1	4.9	5.1	5.2	4.6	3.2	5.8	6.3
11	6.4	5.7	5.5	3	2.3	2.8	3.2	3.5	2.9	1	2.4	3
13	3.3	3.6	2.4	2.5	1.6	2.9	3.7	3.4	3.3	1.5	3.2	1.5
04	3.7	5.3	3.4	2.7	1.6	2.9	3.2	3.5	2.9	2	3.3	2.1
07	3.1	0.8	2.5	2.3	1.4	2	2.8	3.4	2.5	2	2.7	2.5
09	4	2.4	3.1	2.9	1.9	2.6	2.7	3.4	3.1	1.9	3.7	1.6
08	3.3	3	2.7	1.6	1.9	2.8	3.4	3.1	2.9	2	2.8	0.8
10	4.5	2.8	3.6	3.7	2.6	2.4	2.8	3.3	2.7	1.3	2.2	2
15	1.9	0.5	1	1.7	1.5	1.5	2.8	2.6	1.9	0.5	1.6	-0.7
06	4.1	4	3.1	3.1	2.2	2.5	3.6	3.1	2.2	1.3	2.8	3.1
01	3.1	3.3	3.4	2.7	2.5	2.7	3.4	3.3	3	2.8	4.2	2.3
05	4.8	3.1	2	2.3	2	2.4	3	3.6	2.7	1.6	2.9	4.4
1990-2019	2.1	1.7	0.8	0.9	0	0.6	0.7	1.1	0.7	0.1	1.3	0.1
1960-1989	-7.6	-7.1	-5.2	-3.5	-0.6	2.3	4.4	3.5	1.4	-1	-4.8	-6.5

Figure 30. National scale changes in the median monthly Coldest Temperature for the two observed periods (1960 – 1989, 1990 – 2019) and per climate projection for 2020 – 2049

Key Finding: At the national level, there has been a warming shift in the median Coldest Temperature since 1960 in all months except May, October and December (Figure 30). January has seen the largest observed increase (warming) of 2.1°C. For all future projections there is an estimation of continued warming (except projection 15 in December) for the 2020-2049 period. There is greater warming estimated for the winter months than for the summer Coldest Temperatures. This warming trend increases in the 2050-2079 period.

Implications of changes in Coldest Temperature

The increase (warming) in the Coldest Temperature reflects a higher probability of fewer days of less intense frosts. This may have benefits in some respects of crop cultivation, especially for horticulture. However, there is a trade-off in that many crops require vernalisation (also called chilling, the cooling of seed during germination in order to accelerate flowering when it is planted). In the summer, potato tuber formation may be impacted if minimum temperature is above 20°C.

Warmer Coldest Temperature may result in less open and ground surface water freezing, which may produce a positive feedback loop of additional warming associated with changes in albedo, where ice may previously have reflected solar radiation, whereas darker unfrozen water will absorb more heat energy. Similarly, less intense cold may reduce the consolidation of snow into ice, meaning snow cover may be more likely to melt, again changing the surface albedo white to dark and so increasing the probability of additional heat energy absorption. A benefit may be reduced frost heave and loosening of soil surfaces which in some circumstances may reduce risks of erosion.

Changes in the Coldest Temperature, coupled with overall warming in the winter and fewer frosts may have implications in respect of cold temperature control of crop and livestock pests and diseases and their vectors. There may also be disruption to hibernation patterns, potentially resulting in emergence of species too early, leaving them exposed to later frosts. Conversely, a potential benefit is that less intense cold may help improve the over-winter survivorship of some species and potentially reduce the risk of winter moorland fires due less creation of fuel.

Implications for Natural Capital

The purpose for the D5-2 Climate Change Impacts on Natural Capital project is to better understand how changes in the climate impact Natural Capital and their ability to provide ecosystem services and form the basis for Nature Based Solutions. This improved understanding will develop as the project progresses. Here we provide a summary of our interpretations of the implications based on our current knowledge. However, it should be noticed that species' climate niche and tolerances are multidimensional, so while individual factors are treated separately, they are likely to act in combination in limiting or promoting different species and associated consequences for ecosystem services:

Table 1. Summary of implications of changes in extreme climate Indices

Indices	**Summary of implications**
Consecutive Dry Days	Prolonged periods of drought will have implications for water resources and water quality. Coupled with reduced precipitation, the increased number of dry days in March and April may have negative impacts during a key time of plant growth. Longer dry periods increase the wildfire danger and soil erosion by wind and heavy precipitation.
Number of Dry Days	The impacts of changes in the number of Dry Days in respect of crops, semi- and natural vegetation is likely to vary depending on soil hydrology, with potentially both positive and negative effects, also variable depending on the timing of when dry periods occur. Drier spring and summers on well drained soils are at risk of reduced crop yields and vegetation biomass production (variable depending on species). There is an increased risk of fire danger.
Heavy Rain Days	Increases in Heavy Rain Days in winter are associated with a higher risk of flooding, while fewer HRD in summer may lead to a reduced water availability and higher water stress. In summer, it is expected for many Natural Capital assets: soil, vegetation, waters to face a reduced level of ecological functionality and a potential loss of biodiversity because of the increase in drought and threats from fewer but heavier precipitation events. Floodplains can reduce the assimilative capacity of containing floods and high soil erosion of arable land and uplands can reduce the carbon stock. Summertime water stress can reduce tree and peatland carbon sequestration.
Very Wet Days	The increase in the number of largest precipitation events per month in the winter implies an increased risk of flooding and soil erosion, but the reduced number of Very Wet Days in the summer implies an increased risk of dry soil and habitat conditions and increased fire danger. Large precipitation events occurring when soils are dry will likely result in soil erosion and nutrients lost to surface waters. Potential benefit from wetter conditions in the winter and more Very Wet Days by increasing the potential for recharge of ground water to maintain water table levels.

Indices	Summary of implications
Highest Temperature	Increases in the extremes of maximum temperature will likely increase heat and water stresses on plants, animals and habitats, potentially damaging ecological function and delivery of ecosystem services. Higher temperatures in spring will drive earlier plant and insect phenological development. Higher maximum temperatures pose threats to people and infrastructure due to heat stress.
Very Warm Days	Increases in the duration of the warmest temperatures per spring, summer and autumn months will likely increase heat stresses on plants and animals, and alongside high maximum temperatures test the thermal range tolerance of species, whilst altering inter-species competition, driving more rapid phenological development, damaging ecological function and delivery of ecosystem services. Aquatic biodiversity could be particularly at risk. Among such species there is Salmon, also of considerable economic value. Longer warm periods in the winter are likely to increase snow melt and loss of snow cover
Coldest Temperature	The increase (warming) in the Coldest Temperature reflects a higher probability of fewer days of less intense frosts and amount of freezing of open water and in soils. Less intense cold may help improve the over-winter survivorship of some species. There is likely to be less snow consolidation into ice and more snow melt leading to changes in surface albedo resulting in more heat absorption. More snowmelt can lead to higher runoff, potentially increasing the risk of winter and spring flooding.

Caveats and uncertainties

In interpreting the results presented here it is important to understand the caveats and uncertainties associated with the projections and baseline data used.

- The observed baseline data at a 1km resolution (HadUK-Grid dataset[6]) used in this study is produced using a spatial interpolation of data between UK Meteorological Office observation stations. This ‘creates a continuous data surface between observation stations to produce a 1km grid surface. The interpolation process does include steps to adjust for distance from the sea and topography, but we recognise that given the diversity of Scotland’s topography and density of observation stations in lowland areas, there are concerns on how representative the interpolated data is in 1km cells covering remote and or higher mountain areas.
    - Cells with an observation station can be considered as highly reliable.
    - Data utility in grid cells without an observation station is best in areas with a sufficiently high density of observation stations and uniform topography.
    - Data utility is lower in mountain areas with few stations.
    - Future projections assessment is based on change from the observed baseline, hence any errors in the baseline will impact the utility of the analyses.
- The climate projection data used represent one set of 12 plausible future climates. The estimates are derived from a sequence of Global (HadGEMN3) and Regional Climate Model (HadRM-3-PPE) dynamic downscaling and a bias correction method[7]. Other climate models produce different projections, hence we highlight that caution is required in the interpretation of the results, in that there are other plausible possible futures not represented in this analysis.

---

[6] HadUK-Grid Overview - Met Office

[7] A refined version of Rivington et al 2008. Climate Research 35:181 (ed.ac.uk)

- Whilst we are confident in the value of the climate trends analysis, we recommend some caution when interpreting results for higher elevation and remote areas.

Recommendations

- For increasing the utility of future projection data, improve the spatial interpolation method and therefor utility of the interpolated observed baseline data in terms of its quality, especially of precipitation in upland locations.
- Improve the capacity to model habitat condition as a function of climate or to find significant correlations over space and time with expected changes in the climate.
- Increase our understanding of how key species are likely to respond to projected changes in the climate, particularly those with essential roles in ecosystem function (e.g., *Sphagnum* spp., soil microbes, fungi).
- Improve our understanding of how climate change will affect micro-climates, i.e., probability of occurrence of occult precipitation.
- Increase understanding of how climate change is likely to interacts with other stressors, such as pollution, land use change, and invasive species. Improve understanding of how climate change is likely to impact directly on key ecosystem services or indirectly through the mediation of habitat condition changes and ecosystem function.
- Improve the analysis of expected social and economic changes caused by loss of Natural Capital.
- Use information on climate change and expected changes in ecosystem function and ecosystem services provision to model individual and societal perception to CC risk as well as responses in terms of land use mitigation strategies and importance of different science communication approaches to risk reduction.

For References, please refer to the primary reports this summary is based on:

- Climate Trends and Future Projections in Scotland
- Climate Extremes in Scotland

The James Hutton Institute:

Craigiebuckler, Aberdeen. AB15 8QH. Scotland

Invergowrie, Dundee. DD2 5DA. Scotland

Phone: +44 (0)344 928 5428

Email: info@hutton.ac.uk