Cairngorms Climate Conference – Net Zero with Nature

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Snow Cover and Climate Change in the Cairngorms National Park: Summary Assessment

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Objective: To estimate the impacts of climate change on snow cover in the CNP

Key Findings:

Observed

- Decline in:
  - Snow cover (Whitehillocks, 1969-2005)
  - Snow depth (Cairngorm Mountain 1983-2018)
- Warming trend:
  - Balmoral (1918-2018) and Cairngorm Mountain (1983-2018)

Modelled Future

- Up to 2030 likely to have similar snow cover to the past
  - Large annual variation
- From 2040s likely to be a significant decline
- By 2080s likely to be years with very little snow cover

- This is a summary study with large caveats and uncertainties
- Results are consistent with IPCC Reports.

Background: global changes

- Global warming has led to widespread shrinking of the cryosphere:
  - Mass loss from ice sheets and glaciers (very high confidence)
  - **Reductions in snow cover (high confidence)**
  - Arctic sea ice extent and thickness (very high confidence)
  - Increased permafrost temperature (very high confidence).
- Ice sheets and glaciers worldwide have lost mass (very high confidence).
- Arctic June snow cover extent on land declined by 13.4 ± 5.4% per decade from 1967 to 2018, a total loss of approximately 2.5 million km^2, **predominantly due to surface air temperature increase** (high confidence).
- Permafrost temperatures have increased to record high levels (1980s-present) (very high confidence) including the recent increase by 0.29°C ± 0.12°C from 2007 to 2016 averaged across polar and high mountain regions globally.
- Between 1979 - 2018, Arctic sea ice extent has very likely decreased for all months of the year.
  - *[need to consider consequences on high latitude thermodynamics and impacts on weather - MR]*

Source: Intergovernmental Panel on Climate Change Special Report: The Ocean and Cryosphere in a Changing Climate. 24th September 2019.

Background: physical basis

Key assumption, but based on evidence: Snow cover is better correlated to temperature than precipitation

- 1 °C rise in temperature can correspond to a 15-day reduction in snow cover at 130 m and a 33-day reduction at 750 m (Trivedi et al 2007).
- Annual variation influenced by the North Atlantic Oscillation.
- Scotland's snow cover characterised by large variability in the number of days of cover (e.g. repeated accumulation followed by melting) especially at lower altitudes, while at higher altitudes the pattern has been more stable.

- In the Arctic snow-cover extent has decreased by approximately 20% per decade during 1979–2013
- Timing of snowmelt onset has advanced 2 weeks on average across the Arctic area since 1979

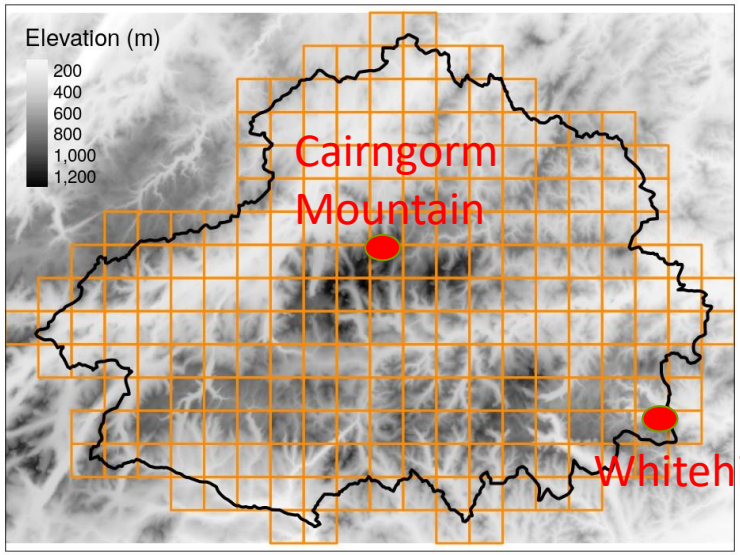
UKCP18 Headline Findings:

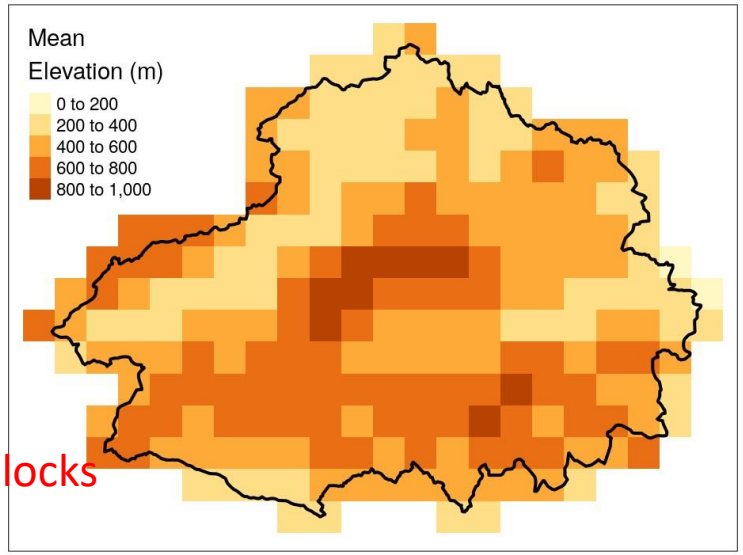
- By the end of the 21 Century, lying snow decreases by almost 100% over much of the UK, although smaller decreases are seen over mountainous regions in the north and west

Data and Methods

- Met Office Observed station weather, 1 and 5km resolution interpolated data
  - Balmoral and Cairngorm Mountain historical analysis
- Snow Survey of Great Britain (1969-2005): Whitehillocks
- UKCP18 Climate Projections (2020-2080)
  - RCP8.5 scenario
  - Downscaled and bias corrected (from 12km to 5km)
- Snow Model (temperature and precipitation) applied at 5km resolution for whole CNP

Note: important to consider the caveats and uncertainties in the data and methods





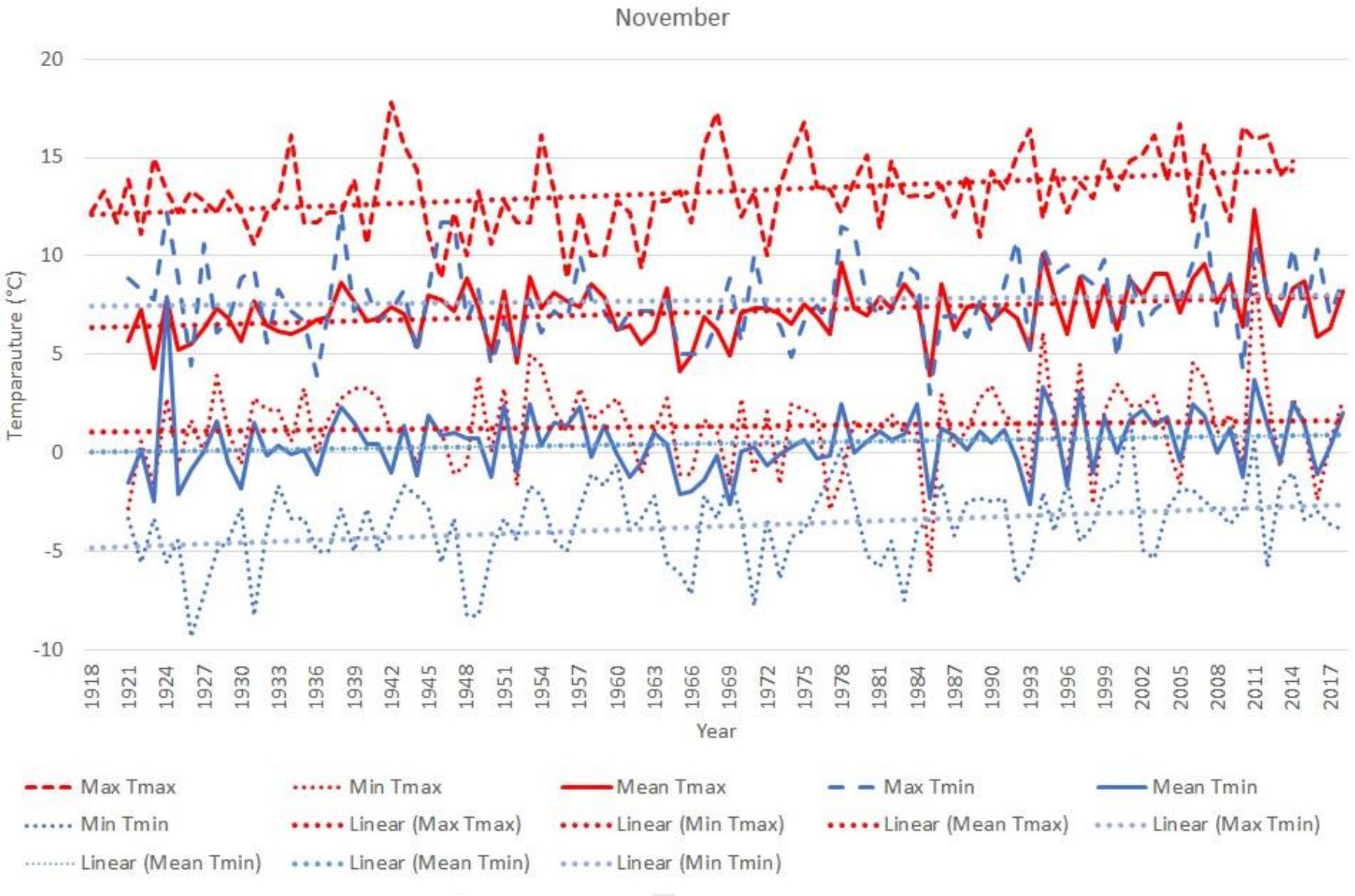
Results: changes in monthly precipitation (total) and temperature (mean) at Balmoral (1928-2018)

	Precipitation (mm)	Maximum Temperature (°C)	Minimum Temperature (°C)
November	↑ 17	↑ 1.64	↑ 0.85
December	↓ -111	↑ 0.64	↓ -0.34*
January	↓ -24	↑ 1.34	↑ 1.20
February	↑ 45	↑ 0.98	↑ 0.37
March	↑ 47	↑ 1.23	↑ 1.28
April	↑ 33	↑ 1.90	↑ 0.82
May	↓ -117	↑ 1.34	↑ 0.81

* Speculation: clearer skies?

- Clear warming trend in all winter months
- Maximum temperature trend greater than minimum temperature
- Variable precipitation response

Balmoral: observed changes in maximum and minimum temperature (1918-2018)

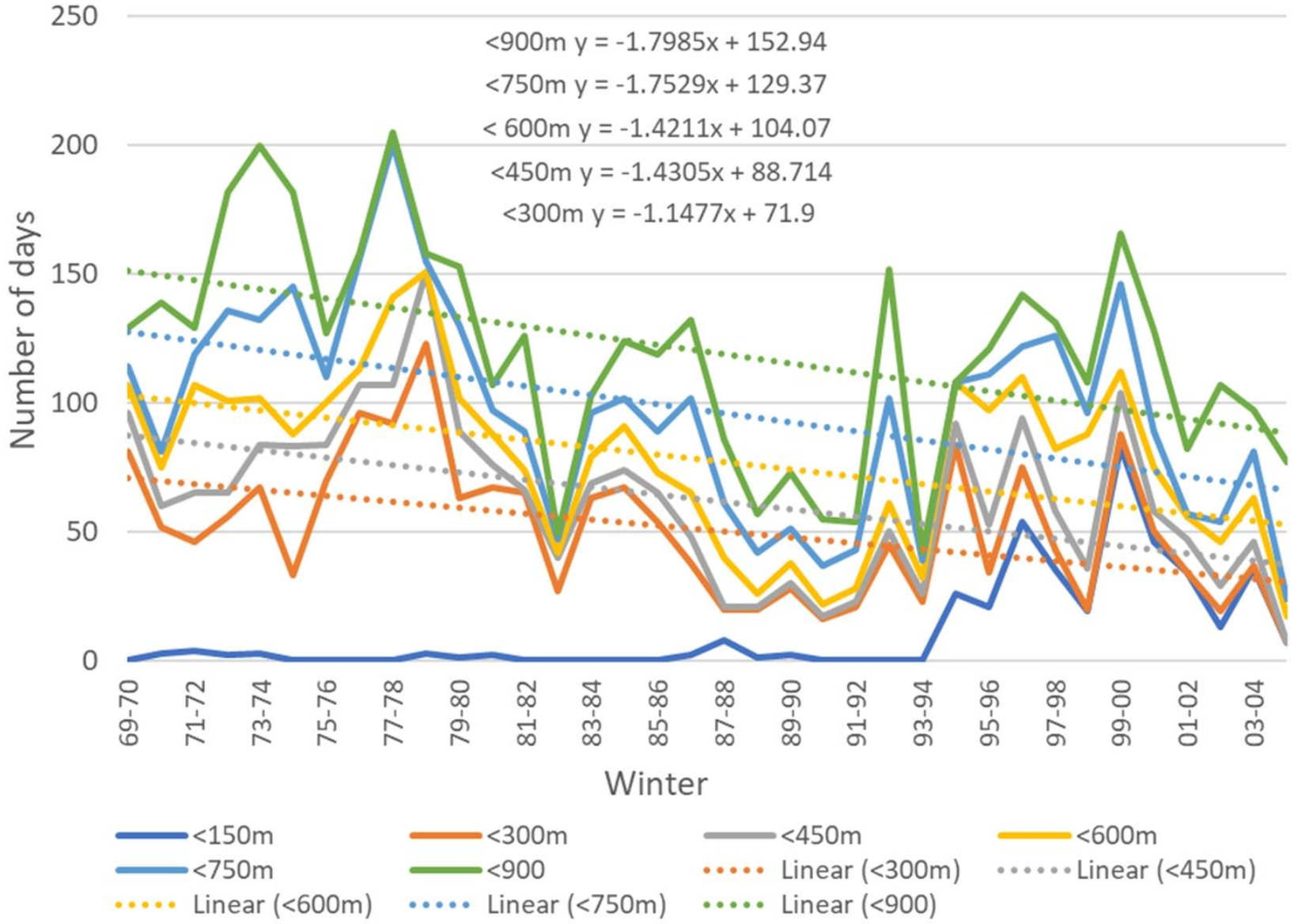


Increases in temperature:

- Highest maximum
- Mean maximum
- Mean minimum
- Lowest minimum

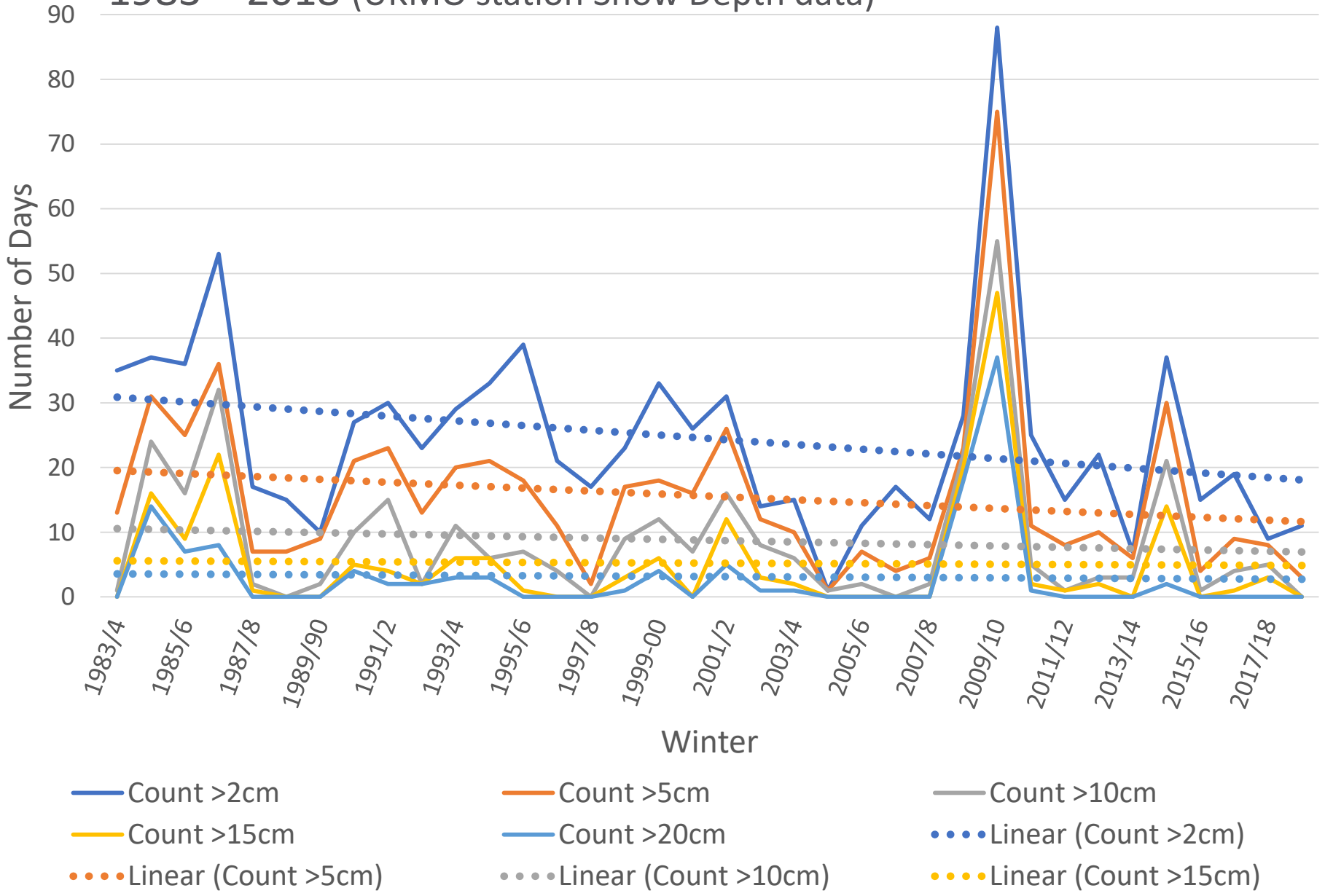
Similar responses seen in other winter months

Observed changes in snow cover: Whitehillocks (1969-2005)



- Substantial year-to-year variability in snow cover
- Mean decrease across all elevations was 52.8 days
- Decrease in snow cover days per year was steeper at higher altitudes
- Distance to Balmoral is 24km

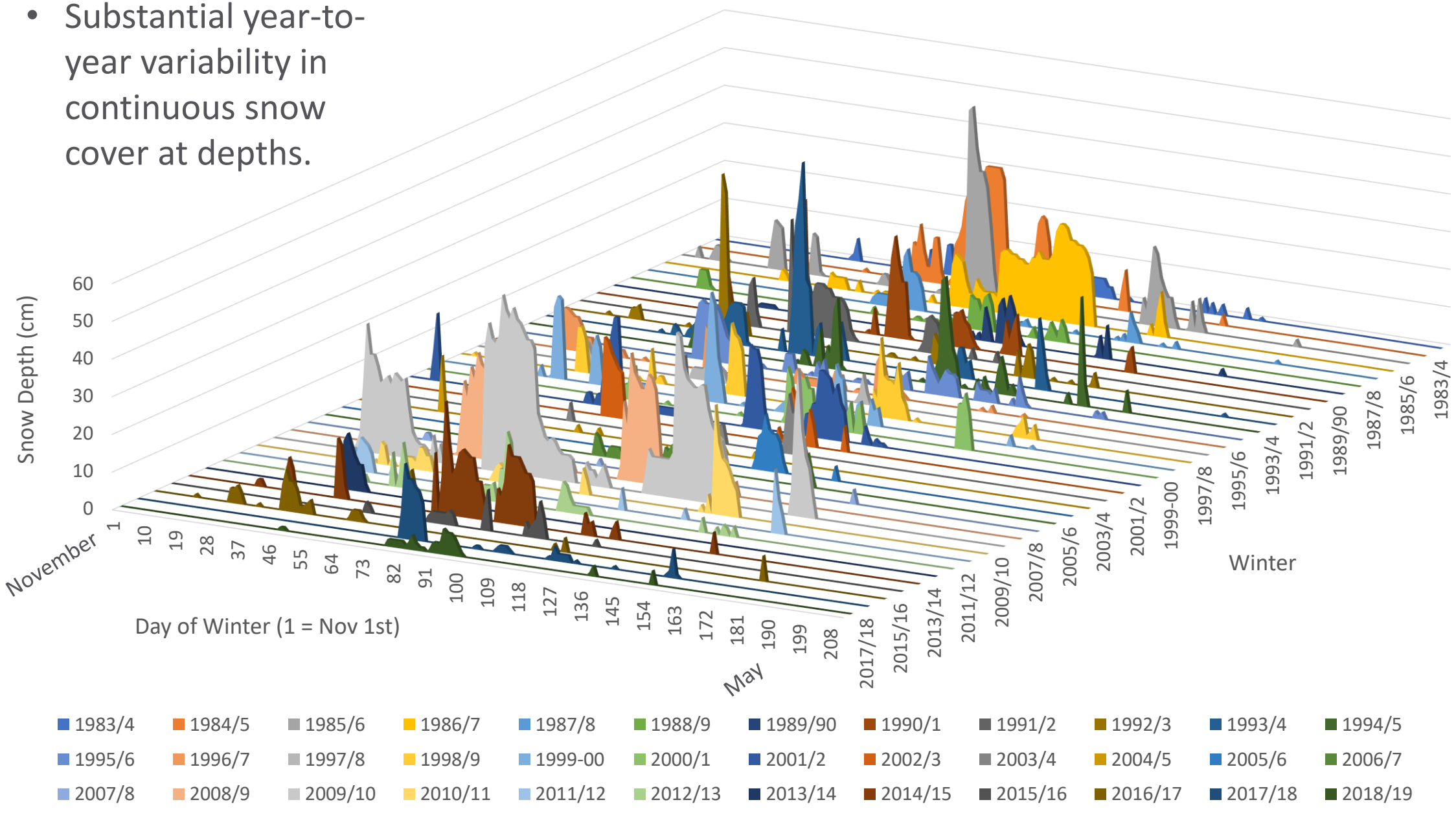
Cairngorm Chairlift: count of days above 2, 5, 10, 15 and 20 cm depths 1983 – 2018 (UKMO station Snow Depth data)



- Substantial year-to-year variability in number of days at a range of snow depths.
- Large decrease over time for 2 and 5 cm depths, less so for >15 and >20 cm

Cairngorm Chairlift Snow Depth (cm) 1983-2018

- Substantial year-to-year variability in continuous snow cover at depths.



Data for future projections: Climate model assessment and bias correction

UKCP18 Climate projections

HadGEM3

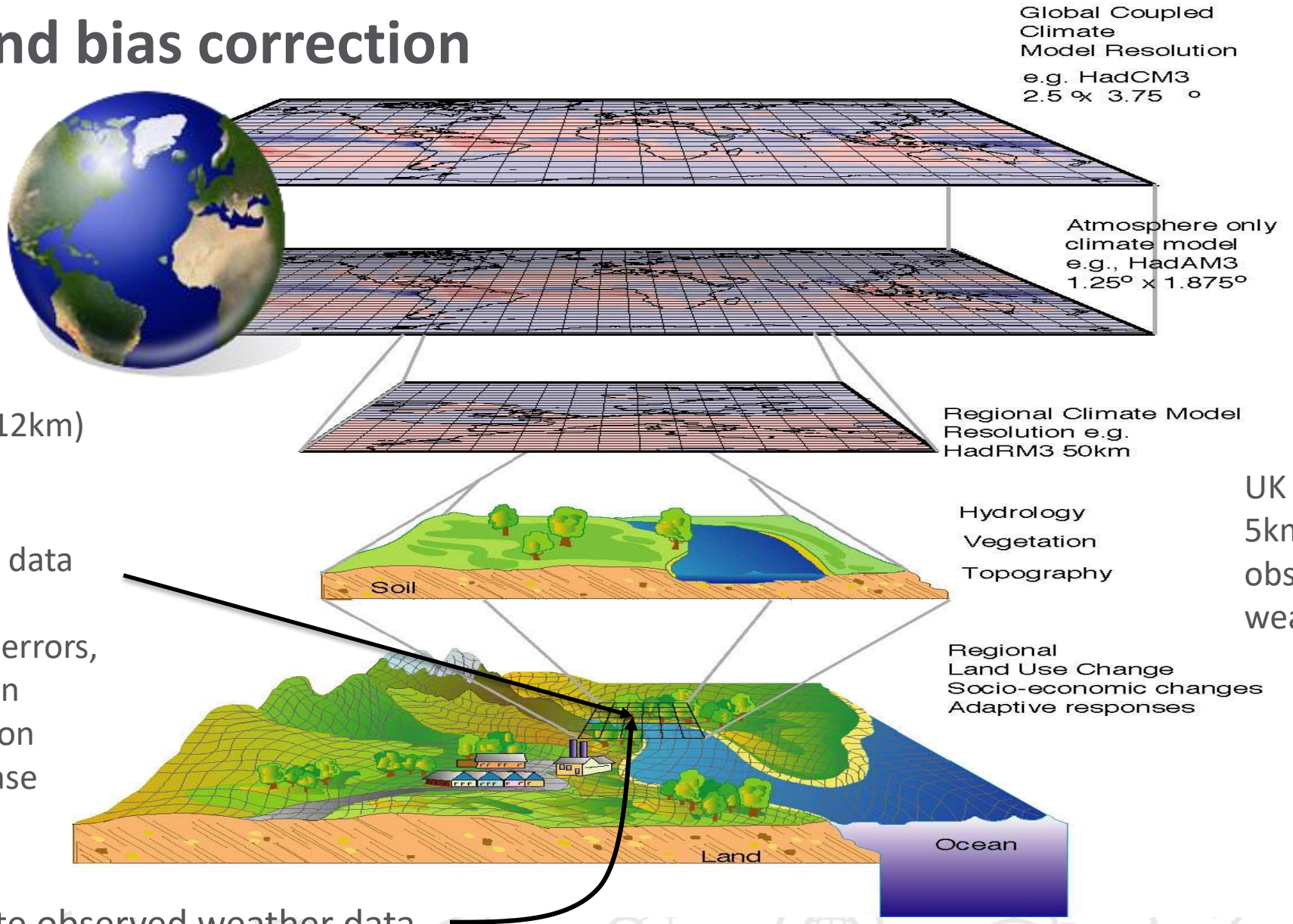
↓

HadRM3

(x12 ensemble members, 12km)

↓

Additional Step:
Comparison of modelled data with historical observed weather data to identify errors, then apply bias correction factors to future projection data. The aim is to increase data utility for future conditions.

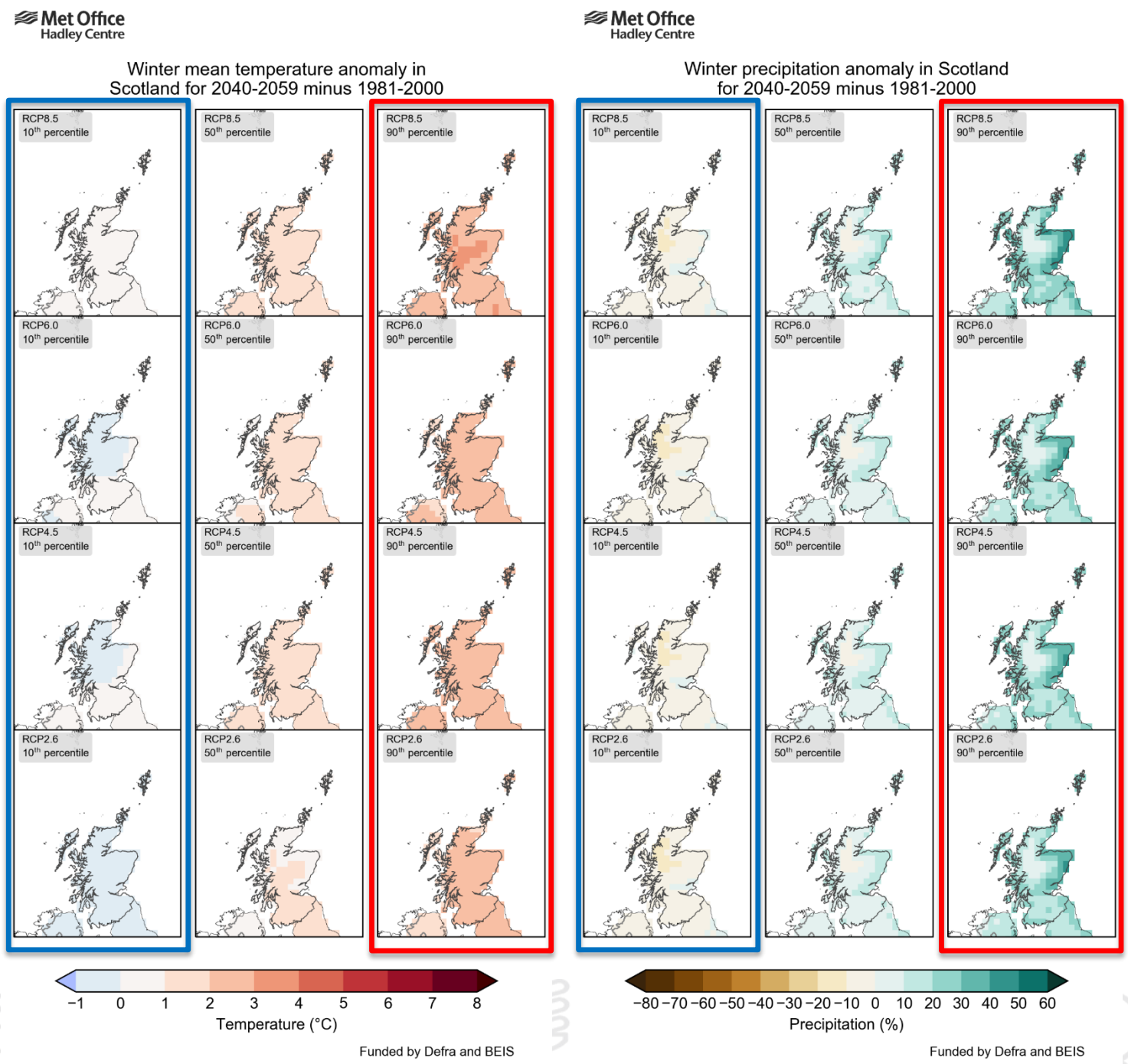


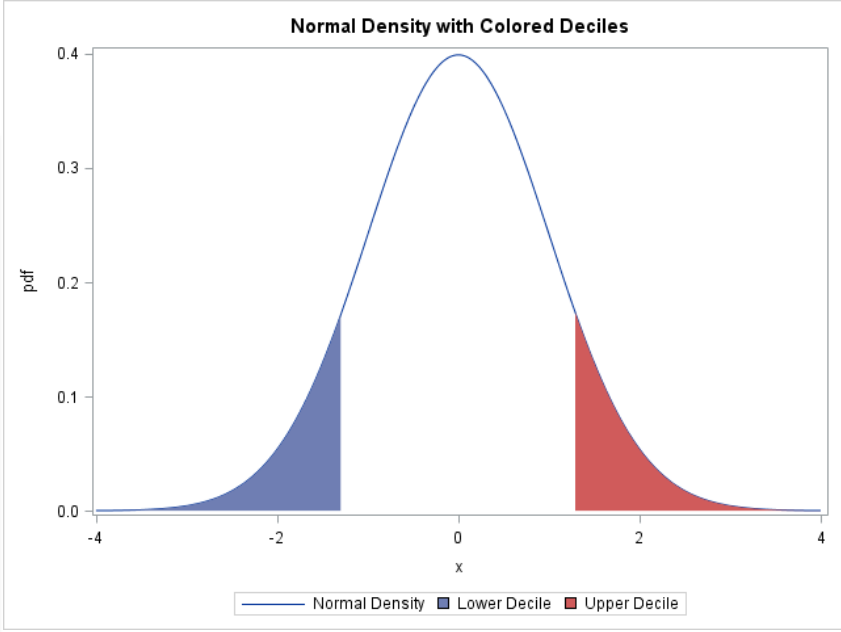
UK Met Office 5km interpolated observed weather data

Site observed weather data

High emissions

Low emissions





Key message: Probabilistic climate projections for 2040-2059

Wide range in the probability distribution:

Scotland likely to have warmer (1-2°C) and wetter winters (+10 to 20%).

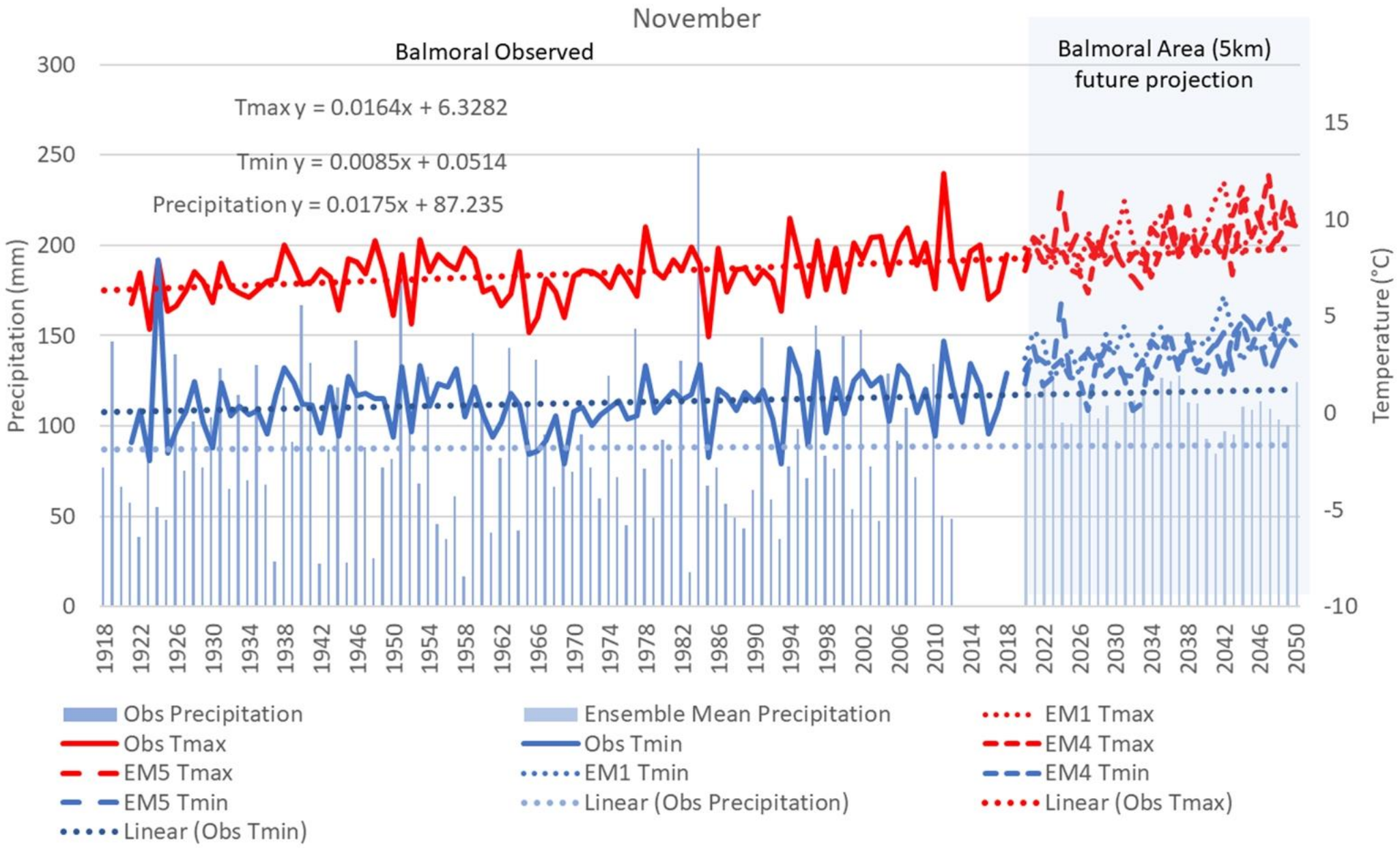
Lower probability of either:

Similar temperatures and precipitation

OR

2-4°C warmer and 20-30% wetter

Observed changes at Balmoral 1918-2018 and projections to 2050



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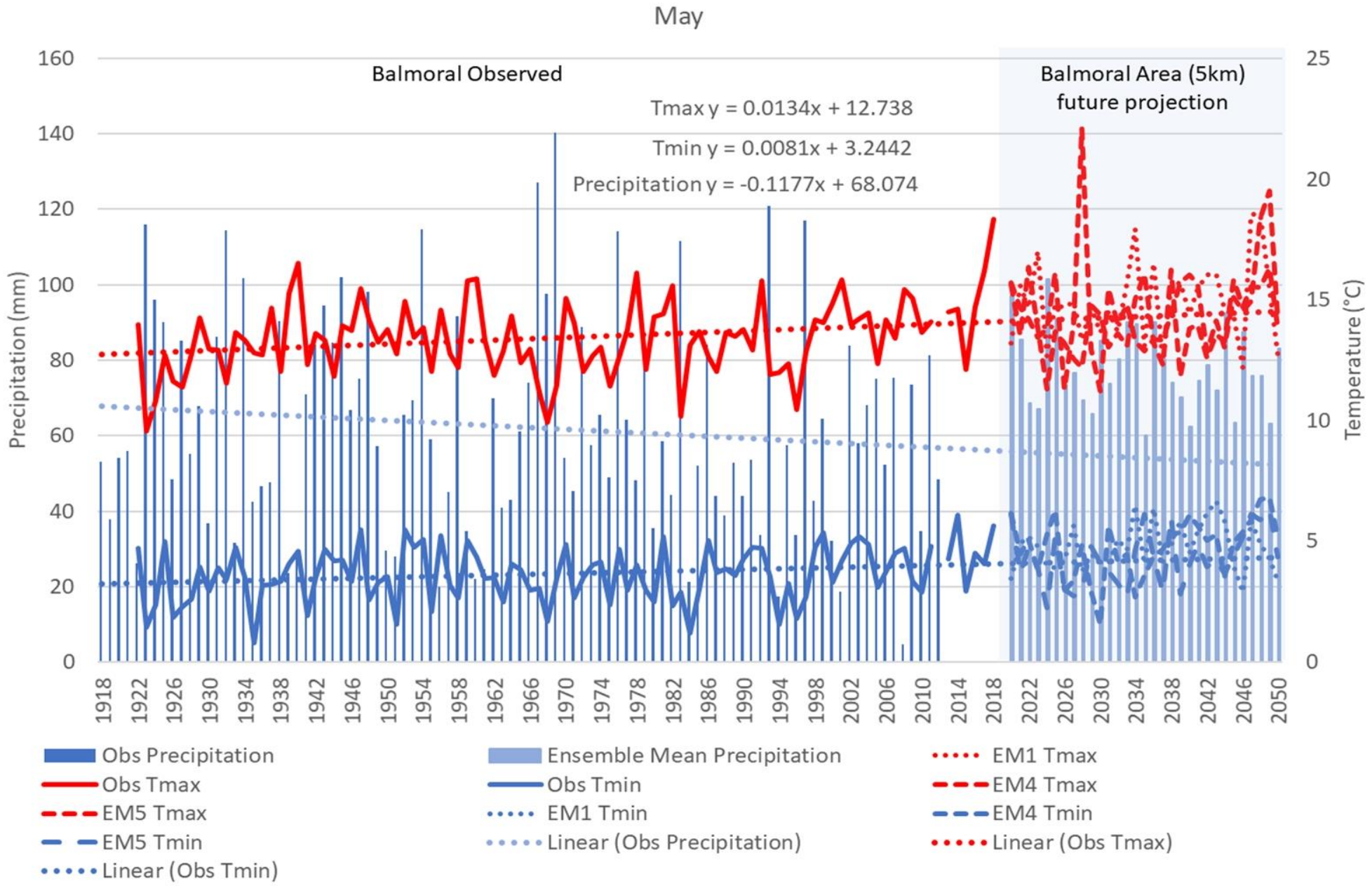
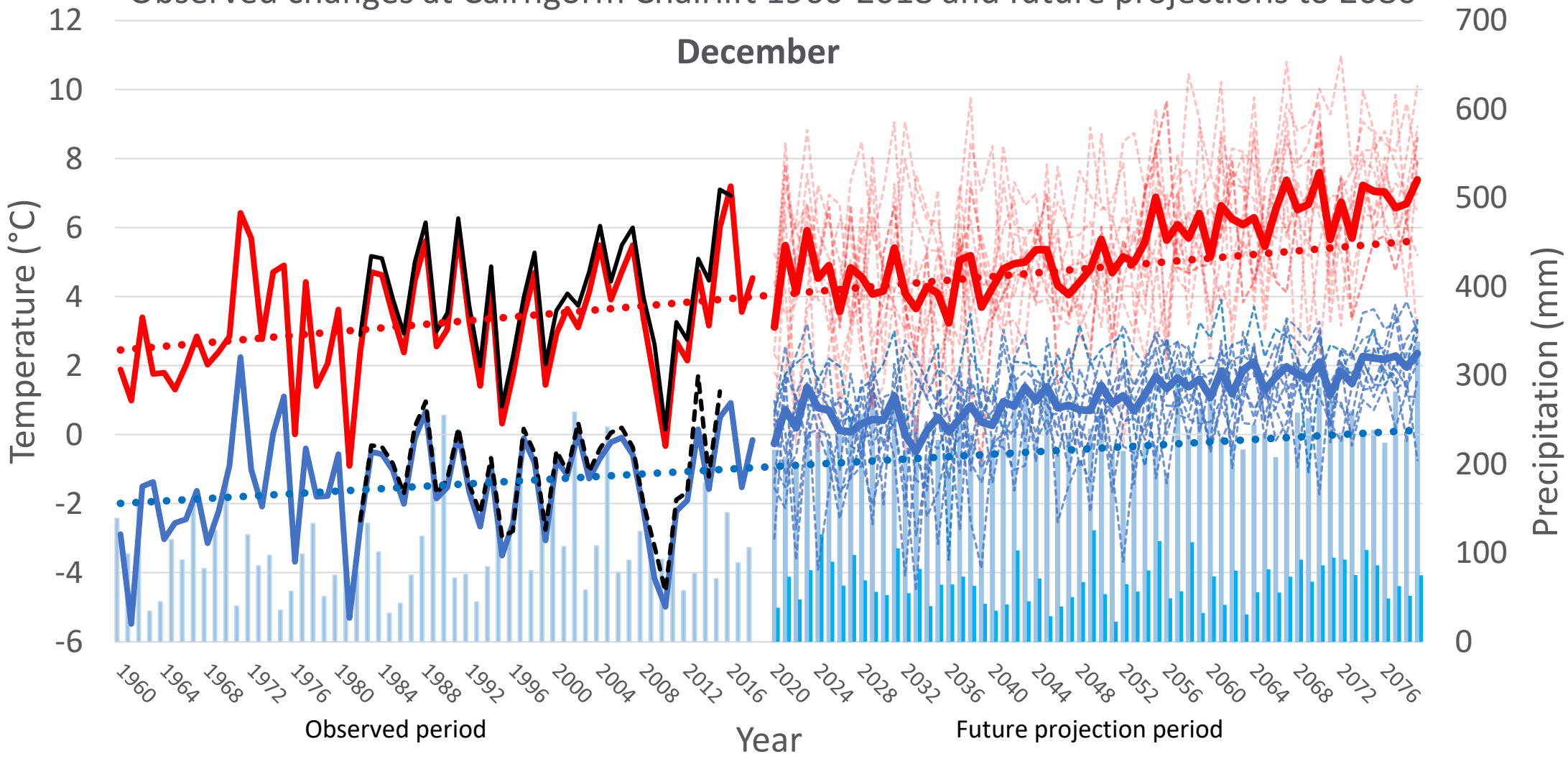


Observed changes at Cairngorm Chairlift 1960-2018 and future projections to 2080



Obs Prec
EM Max Prec
Em Min Prec
Obs Tmax
Obs Tmin
EM1 Tmax
EM2 Tmax
EM3 Tmax
EM4 Tmax
EM5 Tmax
EM6 Tmax
EM7 Tmax
EM8 Tmax
EM9 Tmax
EM10 Tmax
EM11 Tmax
Ens Mean Tmax
EM1 Tmin
EM2 Tmin
EM3 Tmin
EM4 Tmin
EM5 Tmin
EM6 Tmin
EM7 Tmin
EM8 Tmin
EM9 Tmin
EM11 Tmin
Ens Mean Tmin
Obs Stn Tmax
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Linear (Obs Tmax)
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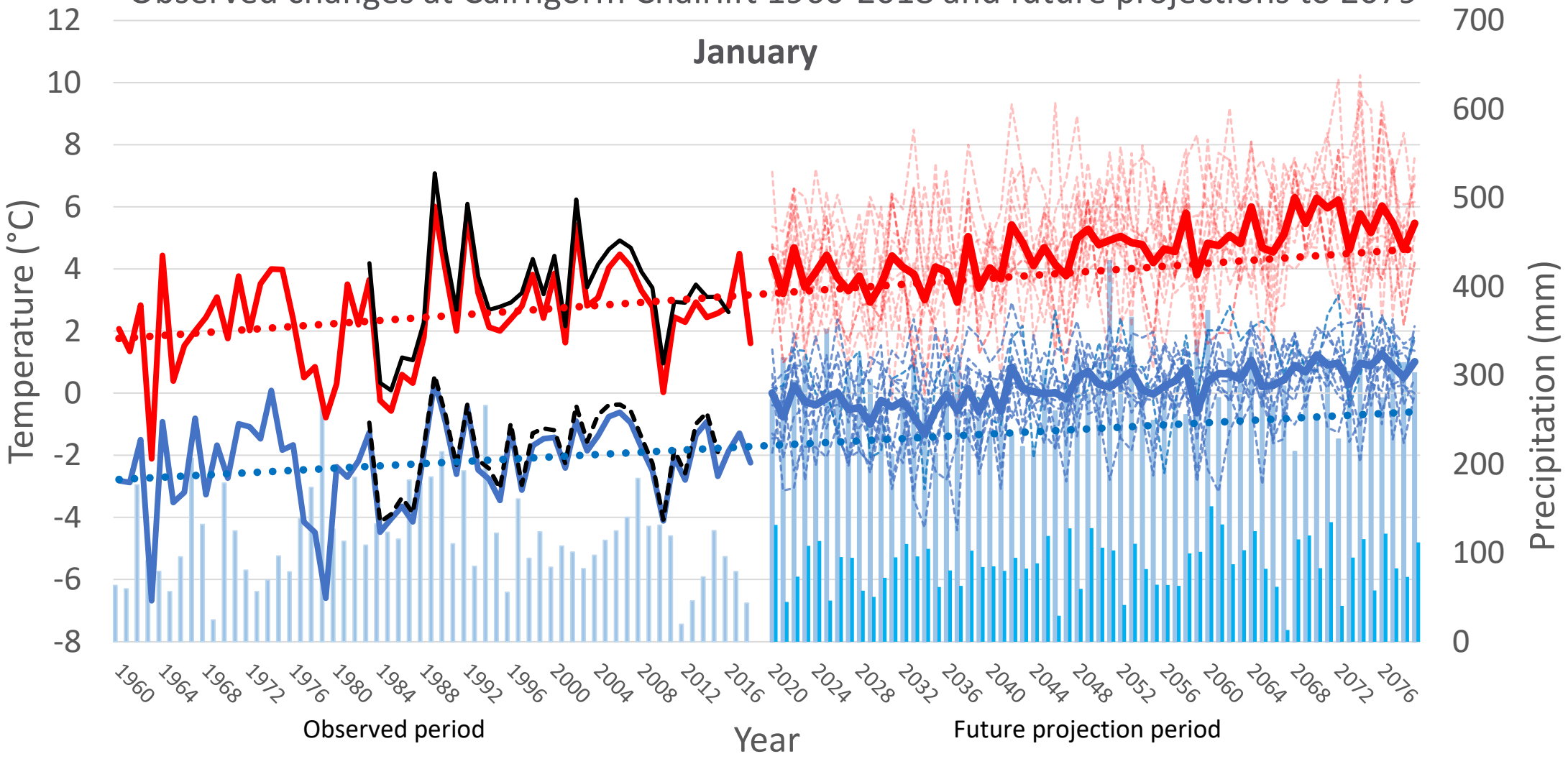
Observed changes at Cairngorm Chairlift 1960-2018 and future projections to 2079



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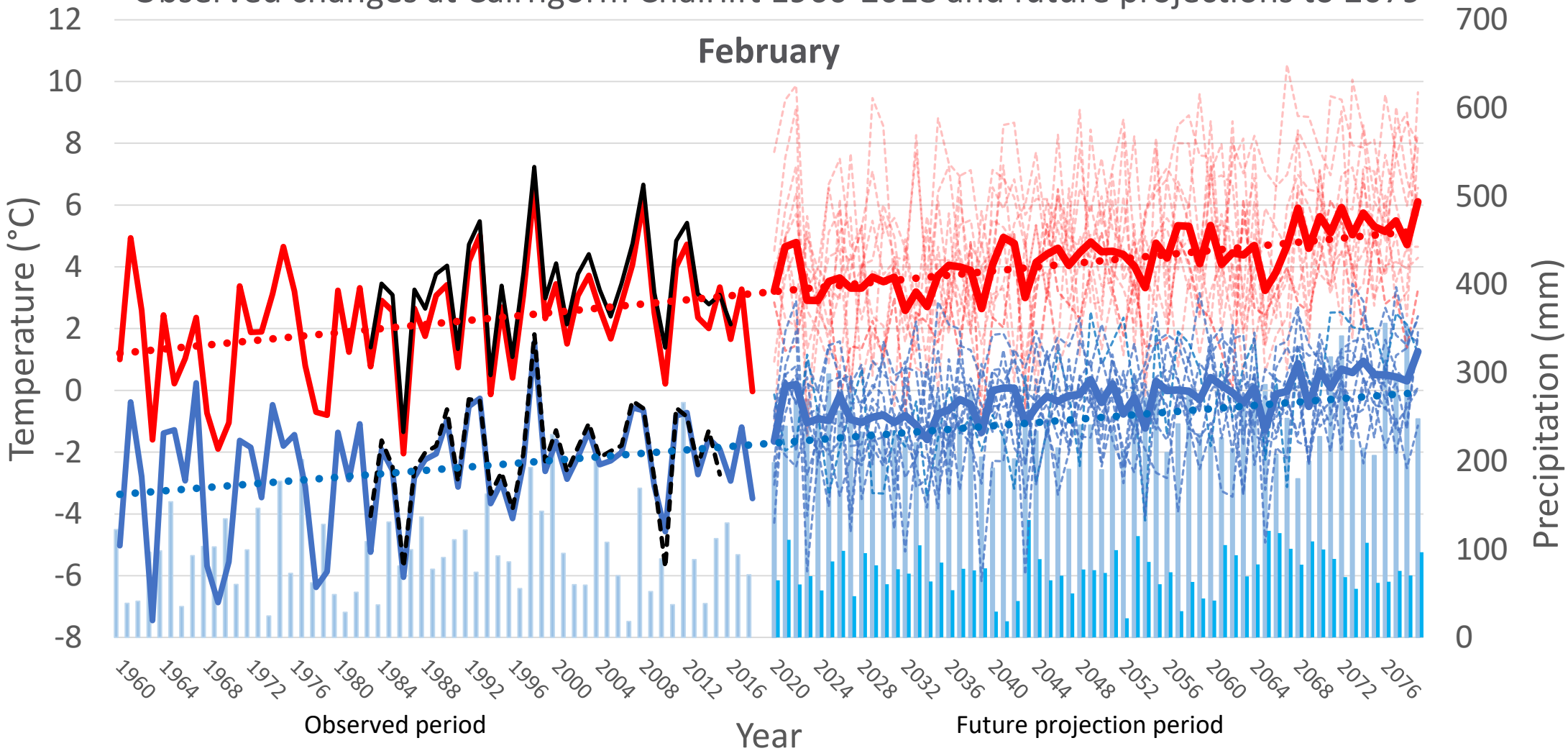

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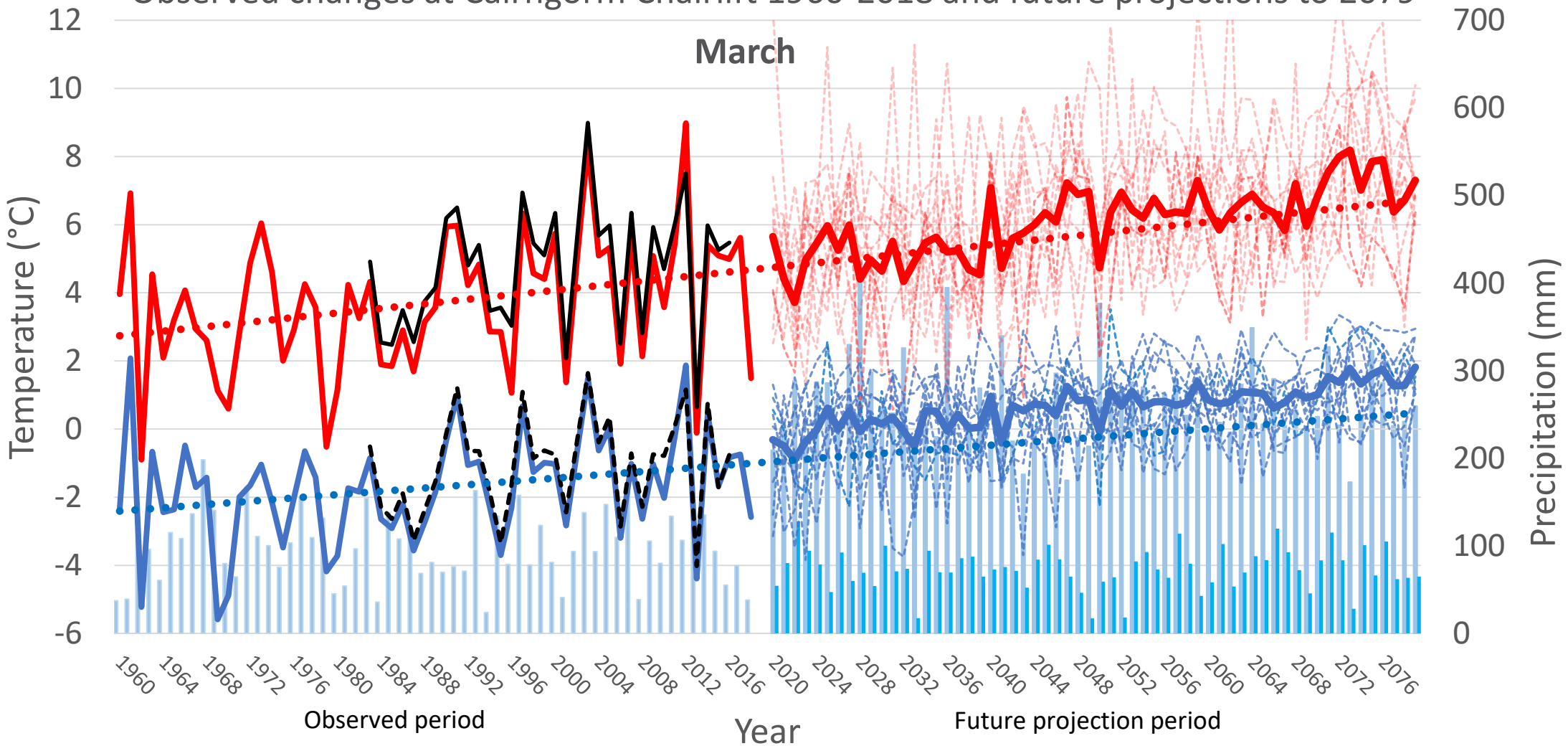

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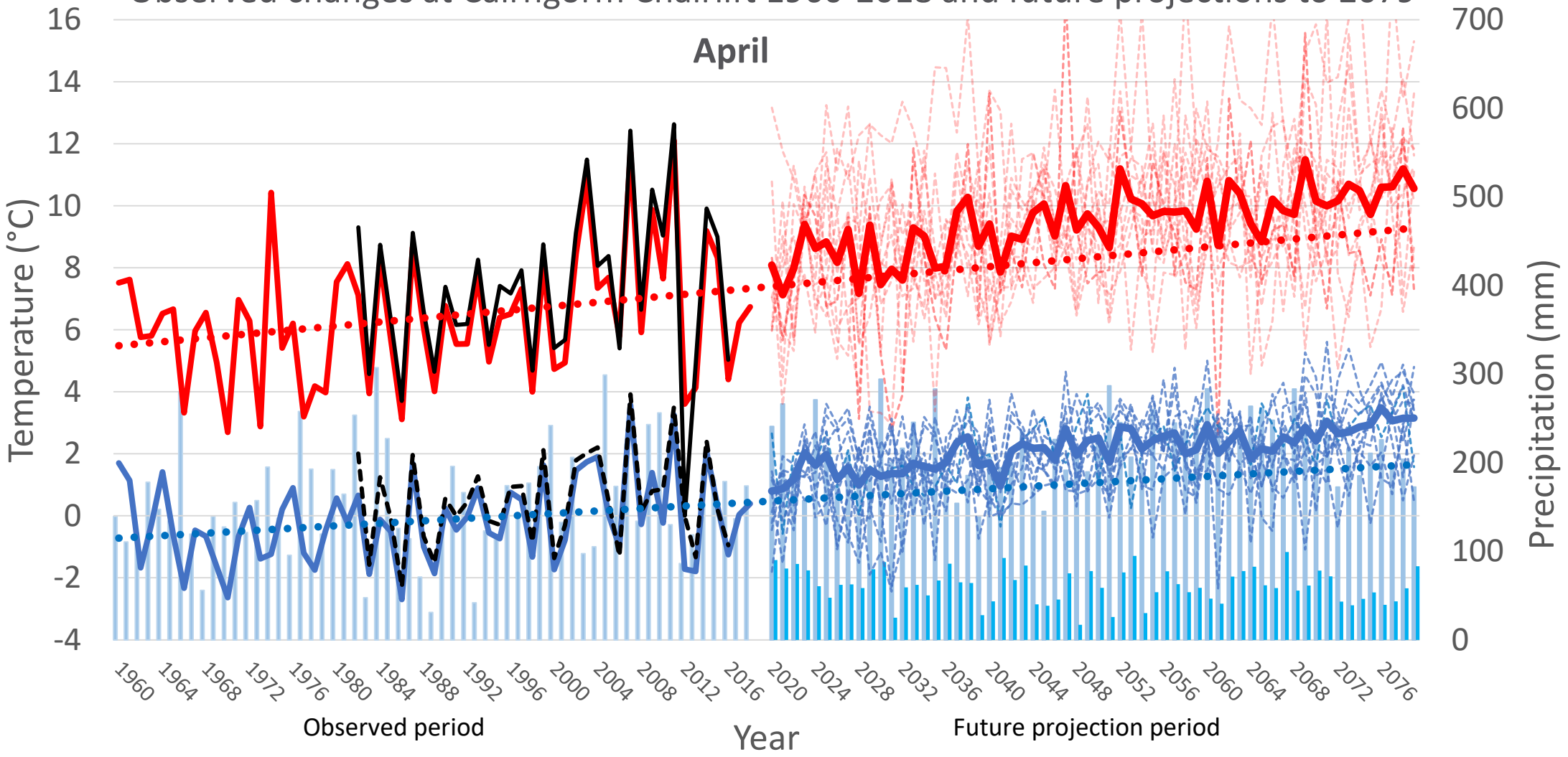

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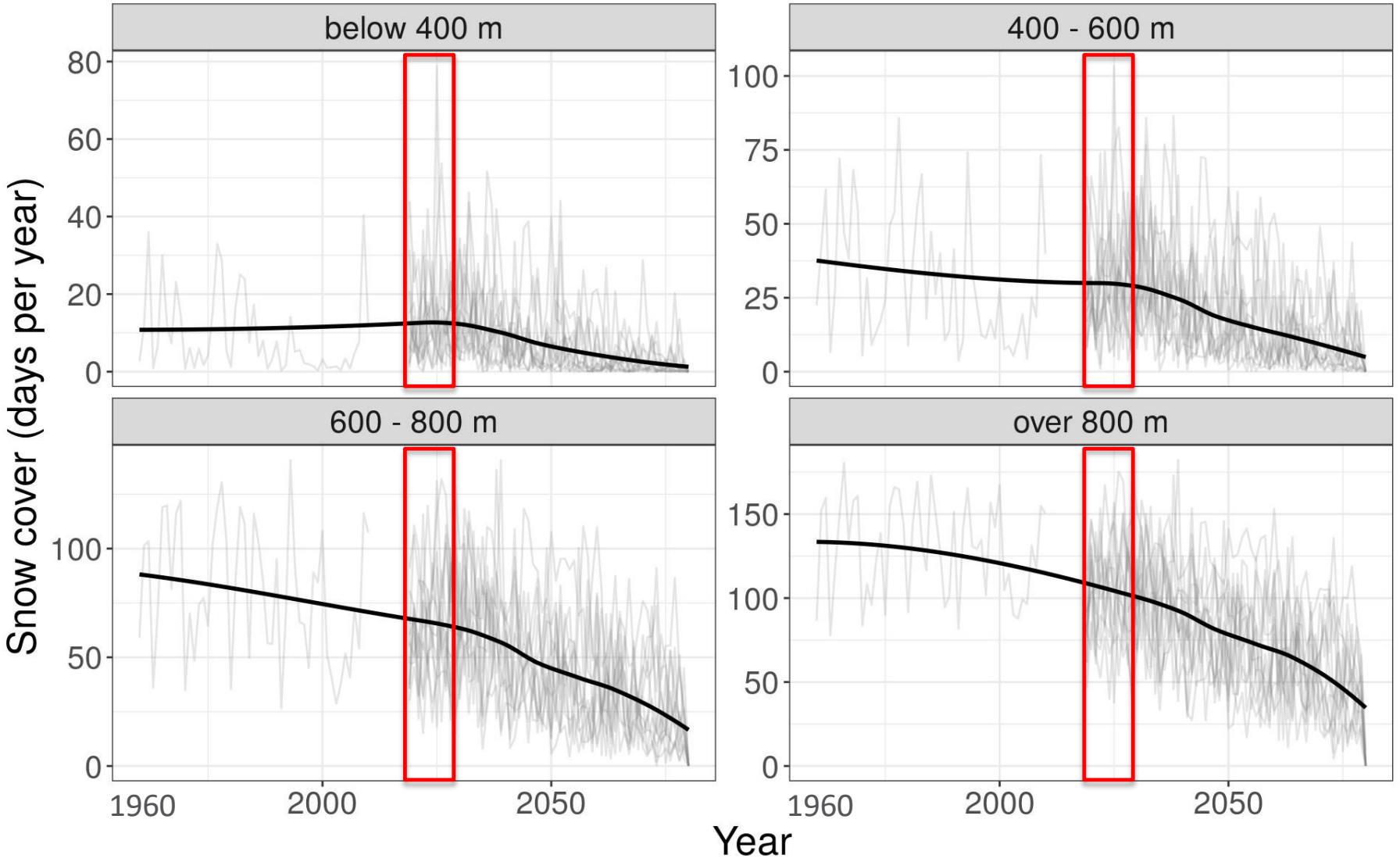
Future snow cover projections: Whole CNP

Annual snow cover (days per year) at four elevation ranges for the Cairngorms National Park. Light grey lines show individual model runs (12) with the heavy black line indicating the smoothed average (1960-2080)

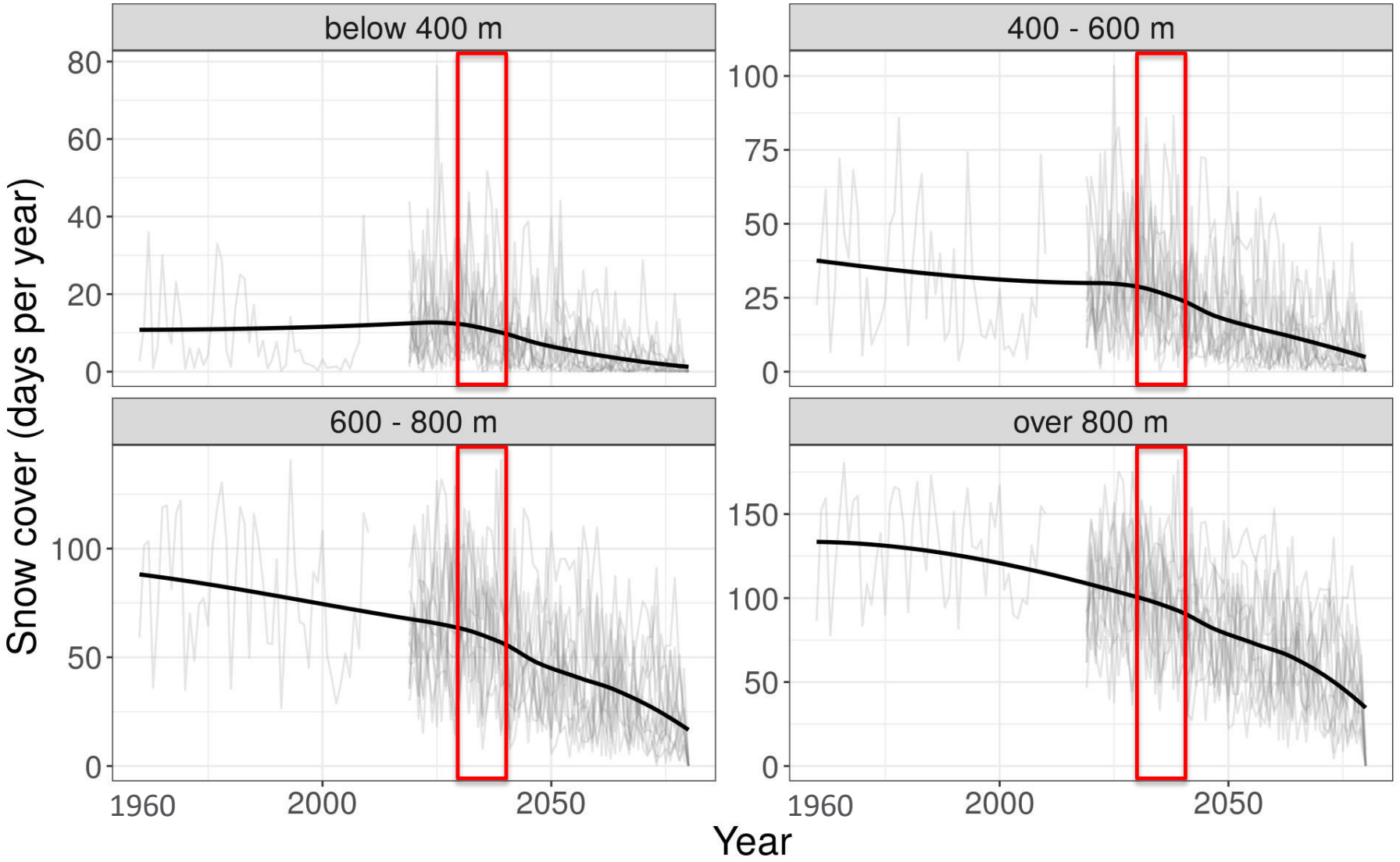


Future timeline

2020-2030: similar amounts and level of annual variation of snow cover to the past at all elevations. Some years likely to be similar or even possibly greater snow cover than in the past.

Future snow cover projections: Whole CNP

Annual snow cover (days per year) at four elevation ranges for the Cairngorms National Park. Light grey lines show individual model runs (12) with the heavy black line indicating the smoothed average (1960-2080)



Future timeline

2030-2040: declining snow cover but with similar levels of annual variation to the past at all elevations. Some years likely to be similar to the past but not achieving the larger quantities or spatial coverage of snow cover, especially at the low- to mid-range elevations.

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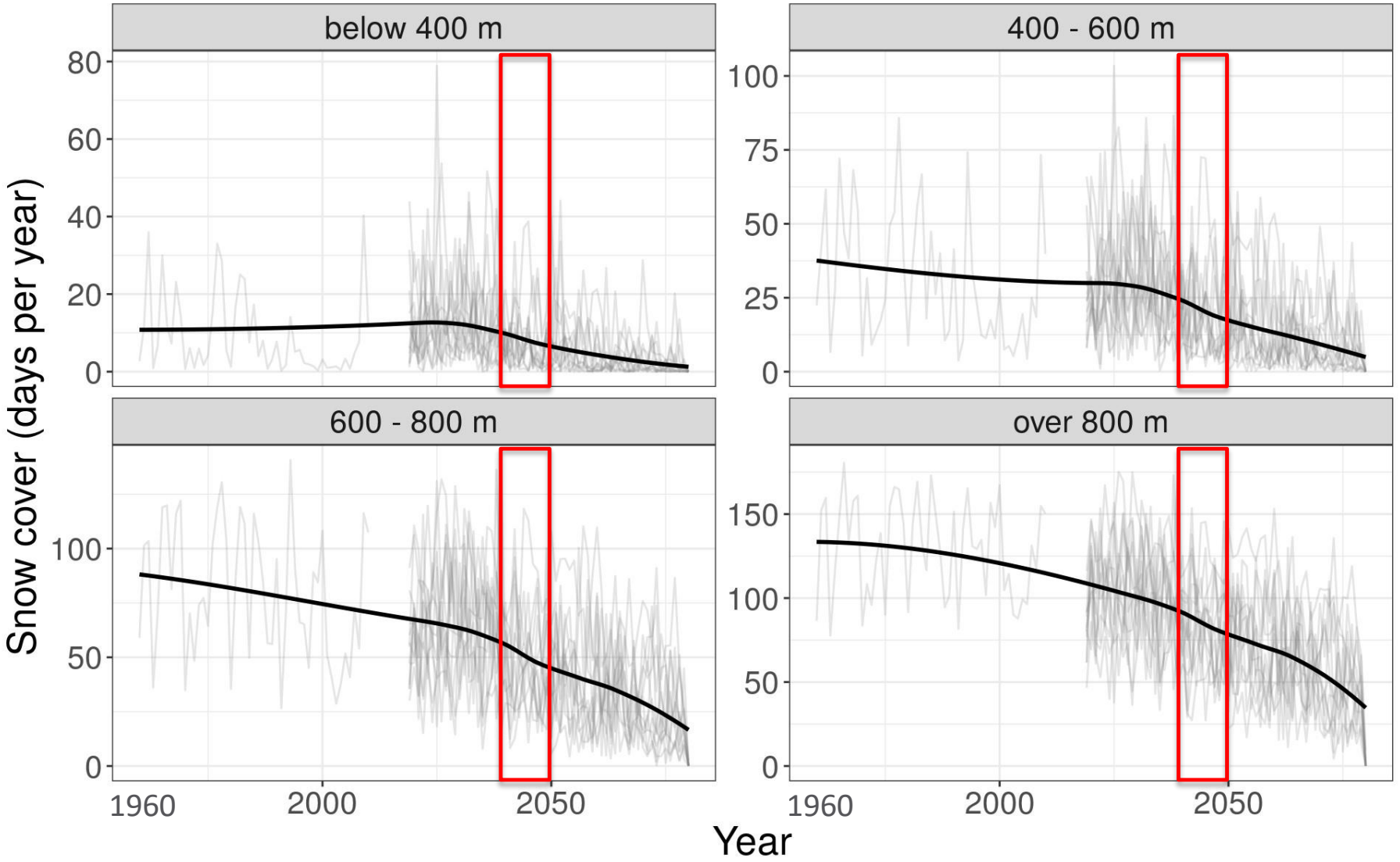

Future timeline

2040-2050: rate of decline increases at all elevations to approximately half of historic long-term average snow cover. Average amounts of snow cover similar to the lowest levels seen in the past.

Future snow cover projections: Whole CNP

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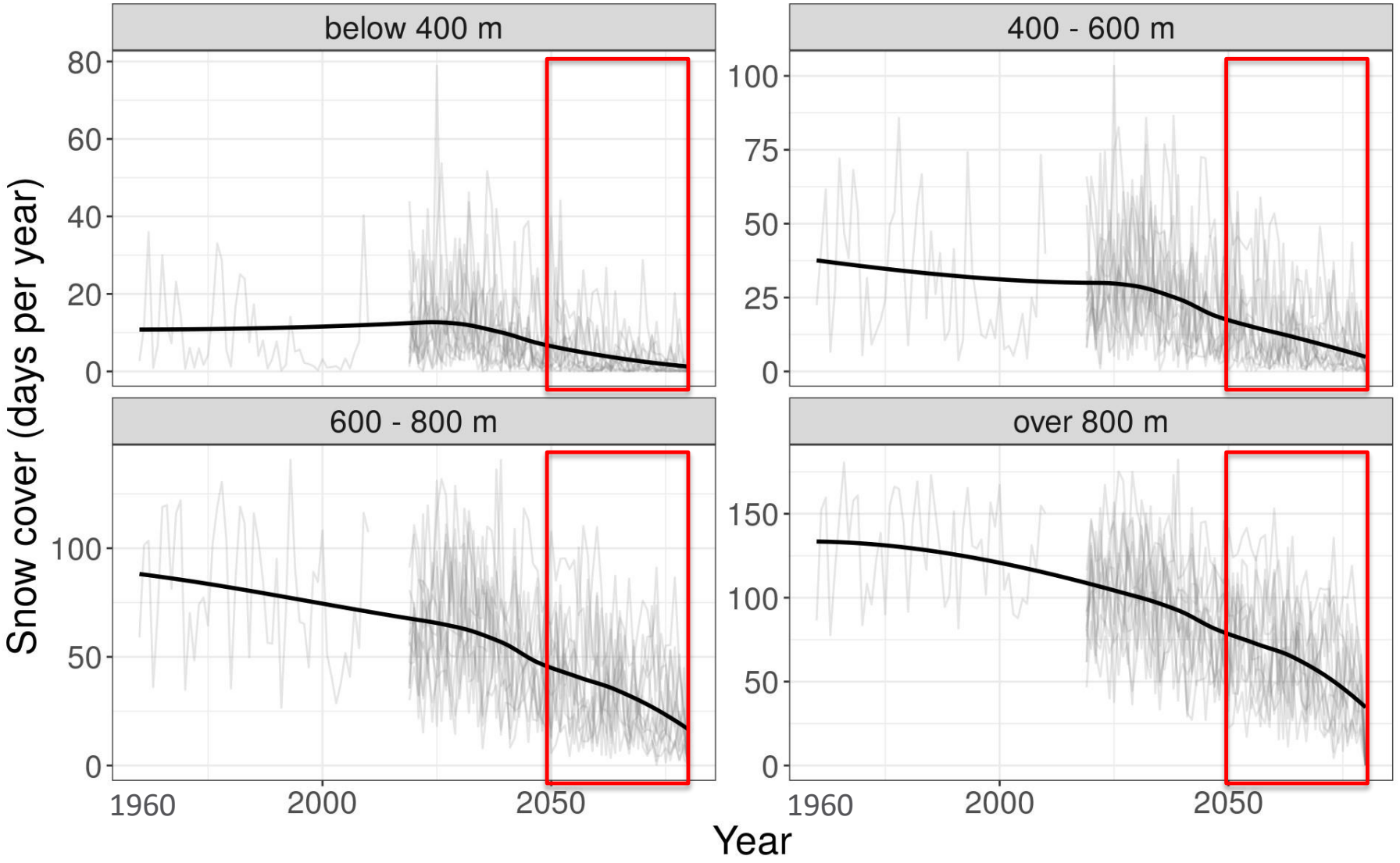
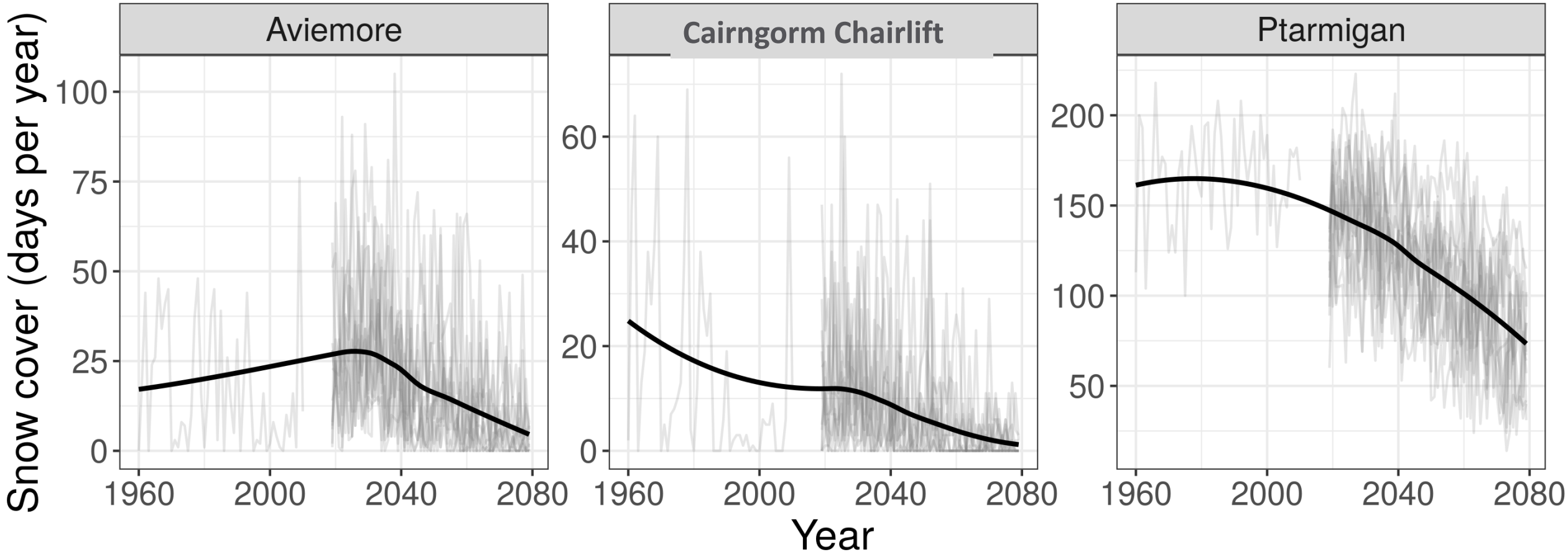


Future timeline

2050-2080: continued increasing rate of decline particularly at higher elevations, approaching <25 days above 600m on average, but with some years where the largest amount of snow cover is similar to the historic low amounts. There is potential for some years to have no snow even at the highest elevations.

Future Snow Cover Projections: Cairngorm Mountain

Annual snow cover (days per year) at four elevation ranges for the Cairngorms National Park. Light grey lines show individual model runs (12) with the heavy black line indicating the smoothed average (1960-2080)



Summary

Key Findings:

- Observed decline in snow cover (Whitehillocks, 1969-2005) and snow depth (Cairngorm 1983-2018)
- Observed warming trend (Balmoral, 1918-2018) and Cairngorm
- Up to year 2030 likely to have similar snow cover to the past
  - Large annual variation
- From 2040s likely to be a significant decline
- By 2080s likely to be years with very little snow cover
- This is a summary study with large caveats and uncertainties
- Results are consistent with IPCC Reports.

Conclusions:

- Observed warming trend seen at Balmoral and Cairngorm is occurring elsewhere in the UK and fit with climate model projections.
- Current rate of emissions will lead to loss of snow cover, but ...
- If emissions ceased now, there will still be warming for next 30-40 years, but…
- Successful global mitigation efforts will help reduce warming hence snow cover loss
- Changes in snow cover will alter the albedo (surface reflectance) and localised thermodynamics
- Need to consider impacts globally – Scotland may be less impacted

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Thanks to:

You for listening

RESAS Strategic Research Programme

UK Meteorological Office for use of observed and climate model projection data.

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SYSTEM CERTIFICATION ISO 9001 SGS

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