

Pan-European Mountain Tourism Meteorological and Snow Indicators



as part of the C3S Sectoral Information System “European Tourism”

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CNRM UMR 3589





Climate
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High climate sensitivity of mountain (winter) tourism



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Climate
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Need to account for snow management !

One major limitation that has been criticized in many publications of the last decade (e.g. Scott et al., 2003; Scott et al., 2006; Steiger, 2010; Steiger & Stötter, 2013) is the omission of snowmaking. This is akin to modelling the impact of climate change on an irrigated crop, without the irrigation. Where snowmaking is an integral component of contemporary ski

Steiger et al., 2017

variable ski seasons, a contraction in the number of operating ski areas, altered competitiveness among and within regional ski markets, and subsequent impacts on employment and the value of vacation properties (Steiger et al., 2017). Studies that continue to omit snowmaking do not reflect the operating realities of most ski areas and overestimate impacts at 1.5–2°C. In all regional markets, the extent and timing of these impacts depend on the magnitude of climate change and the types of adaptive responses by the ski industry, skiers

IPCC 2018, SR15



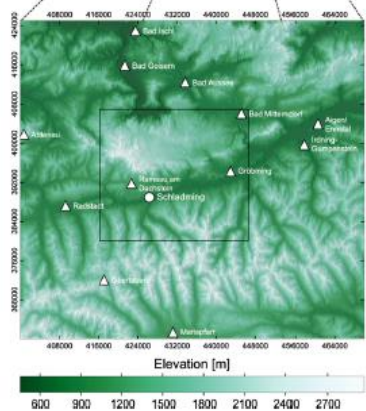
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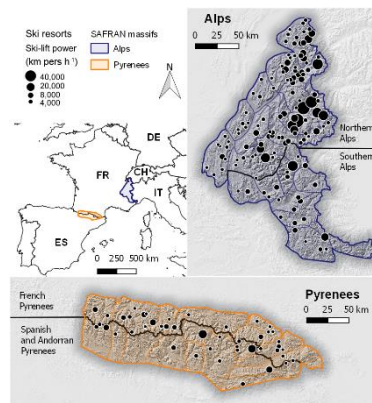
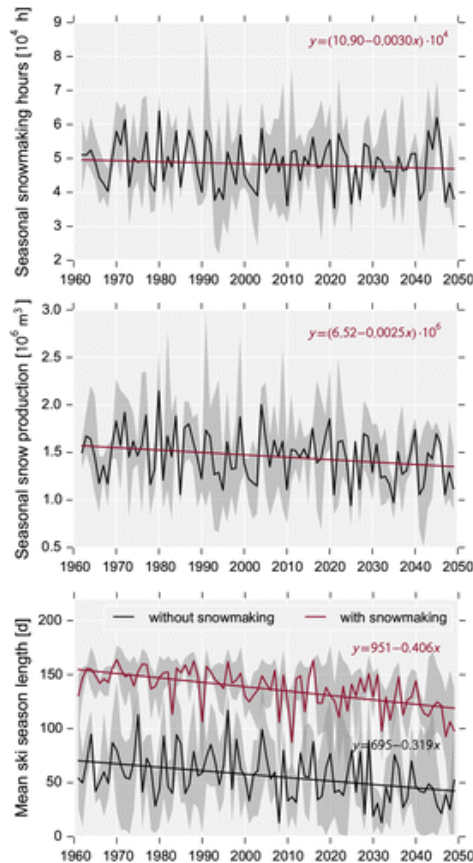


Climate
Change

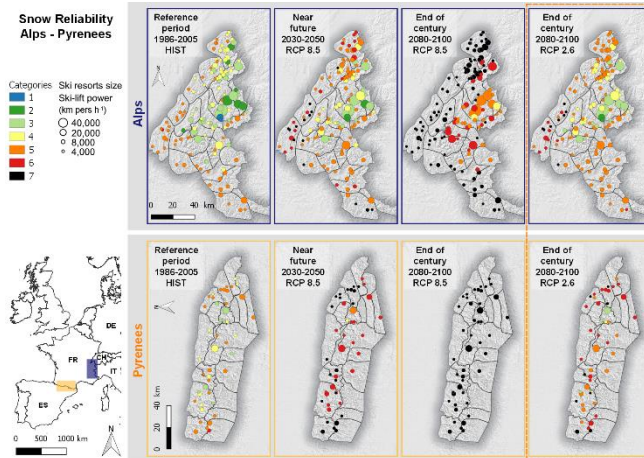
Local-scale studies



Marke et al., 2015



Spandre et al., in press



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- # Need for pan-European studies for:
- Large scale sectoral assessments
 - Comparisons between local markets

Recent study (Damm et al.) at European scale



Contents lists available at ScienceDirect

Climate Services

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



Impacts of +2 °C global warming on winter tourism demand in Europe



Andrea Damm^{a,*}, Wouter Greuell^b, Oskar Landgren^c, Franz Prettenthaler^a

^aJoanneum Research Forschungsgesellschaft mbH, Centre for Climate, Energy and Society, Leonhardstrasse 59, A-8010 Graz, Austria

^bWageningen University and Research Centre, Lumen Building 100, Droevendaalsesteeg 3, NL-6708 PB Wageningen, The Netherlands

^cNorwegian Meteorological Institute, P.O. Box 43, Blindern, N-0313 Oslo, Norway

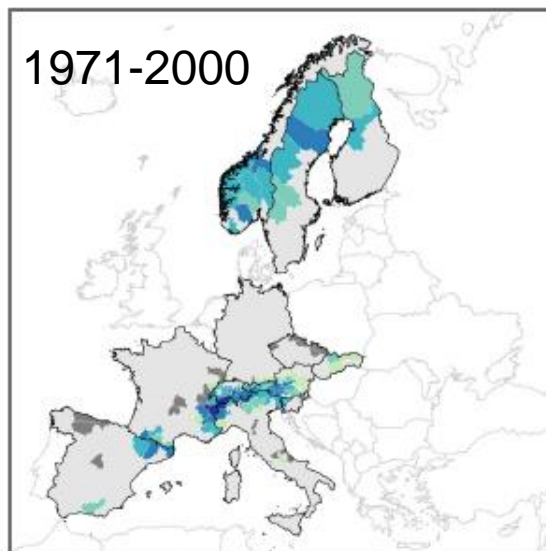


CNRM UMR 3589

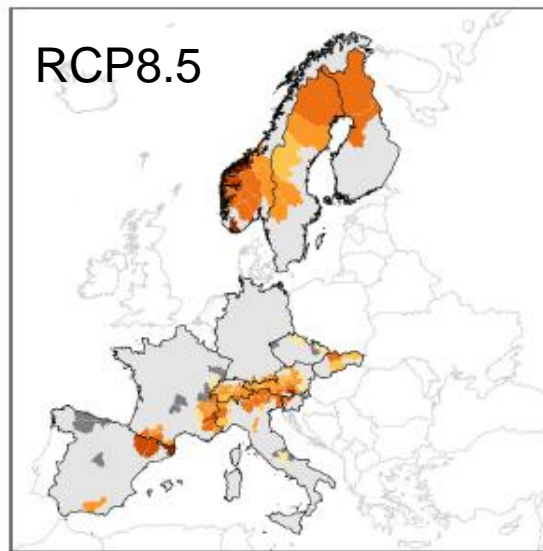
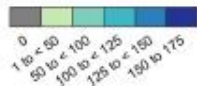


Damm et al. 2017:

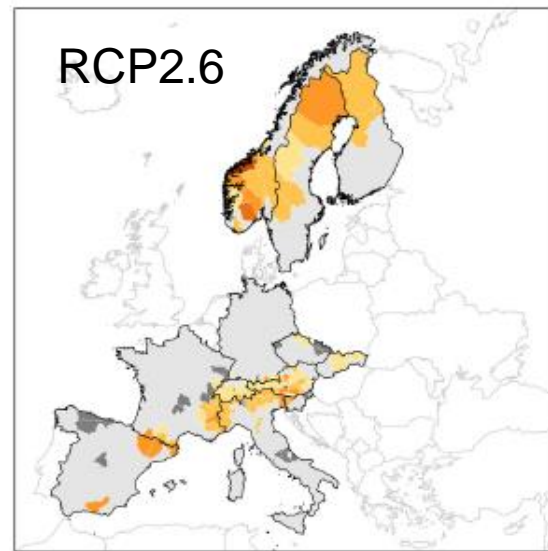
- Only natural snow
- Only partial coverage of European mountain regions
- Use coarse resolution observation data base (E-OBS)
- 4 RCP8.5 GCM/RCM pairs (2 RCP2.6, 5 RCP4.5)



Ski season length (Number of days with SWE > 120 mm)
1971-2000 (median) | SWE measured at mean altitude of ski areas



Change in ski season length [days]
mean over RCP8.5 | 2026-2055 compared to 1971-2000



Change in ski season length [days]
mean over RCP2.6 | 2071-2100 compared to 1971-2000



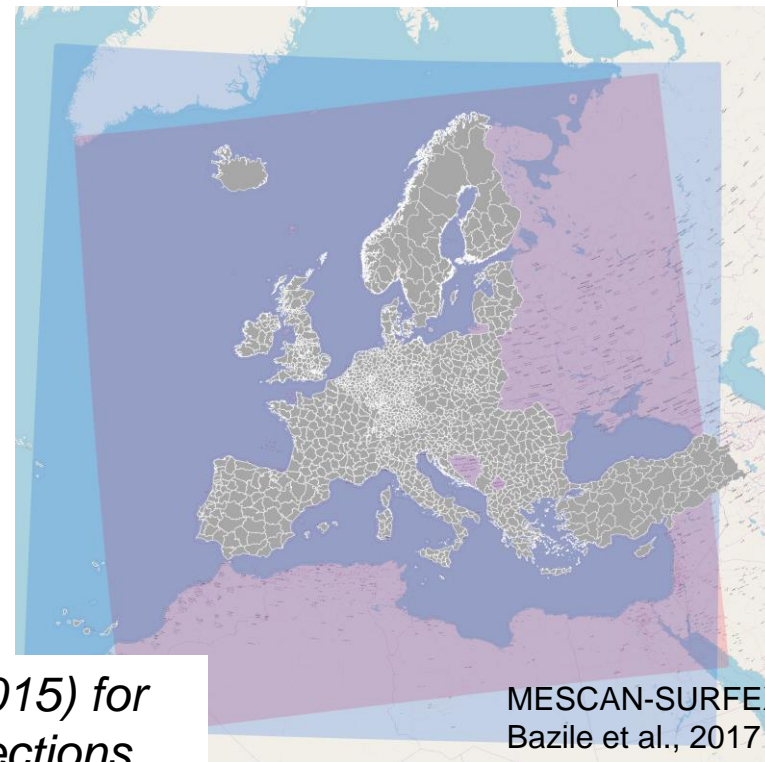
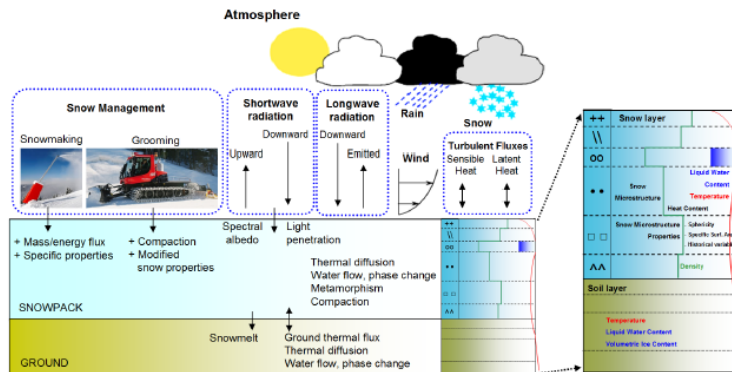


Climate
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Pan-European Mountain Tourism Meteorological and Snow Indicators

Legend

- NUTS3 level
 - UERRA 5.5km grid
 - EUR11 grid
- OpenStreetMap tile
©OpenStreetMap contributors



*Use of a snowpack model accounting for
snow management (Crocus-Resort,
Spandre et al., 2016)*

*Use of UERRA 5.5 km reanalysis (1960-2015) for
adjustment of EUROCORDEX 12 km projections
(ADAMONT method, Verfaillie et al., 2017)*

MESCAN-SURFEX,
Bazile et al., 2017



Climate
Change

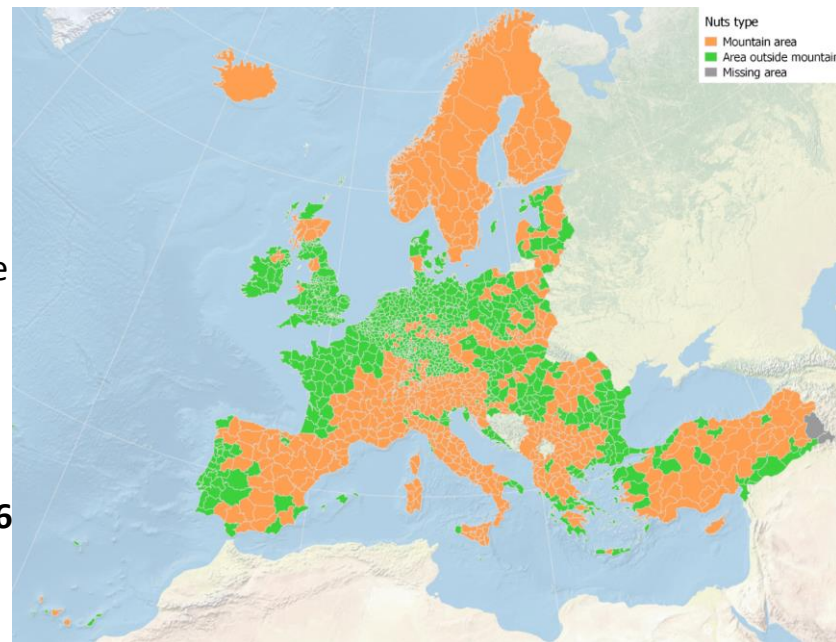
NUTS-3 regions

- Steps of 100 m, flat terrain.
- Case-by-case identification of “mountain” NUTS-3, within which the elevation range needs to be specified (taking into account terrain information, but also climate data availability)
- Selection of **6584** points from the UERRA 5.5 km, corresponding to NUTS-3 areas and elevation levels.

9 GCM/RCM pairs for RCP4.5 and RCP8.5, incl. 2 for RCP2.6

39 annual-scale indicators (snow cover duration, beginning/end of season, peak SWE for natural snow, groomed snow and managed snow, temperature, snowmaking hours, precipitation)

Computation of **aggregated indices** (20-yrs time periods), mean/stdev and quantiles (Q10, Q20, Q50, Q80 and Q90).



5652 mountain points
3 snow model configurations (natural, groomed & managed snow)
2305 model.years (RCM+UERRA)
91065 annual scale indicators
3276 aggregated indicators



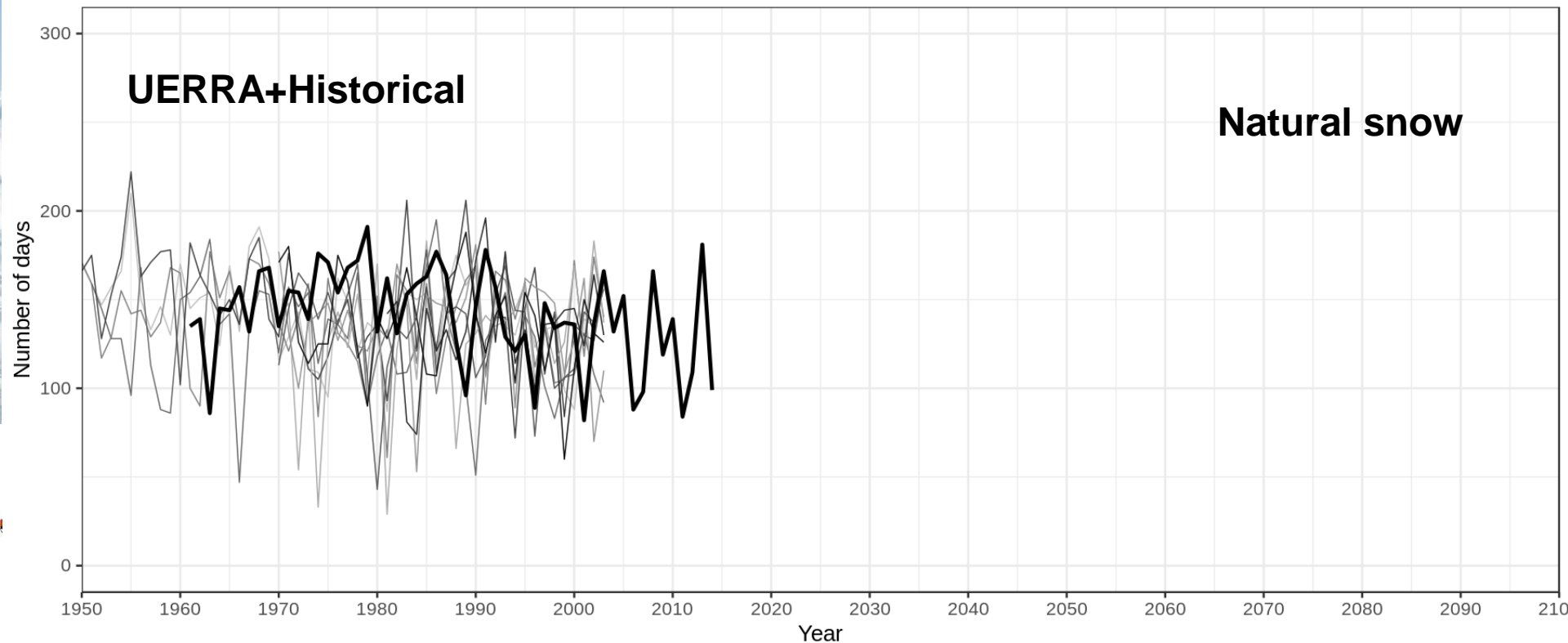


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground

sd_days_30 - Scenario : HISTORICAL - Configuration : NS - point : Oberkärnten 1500m



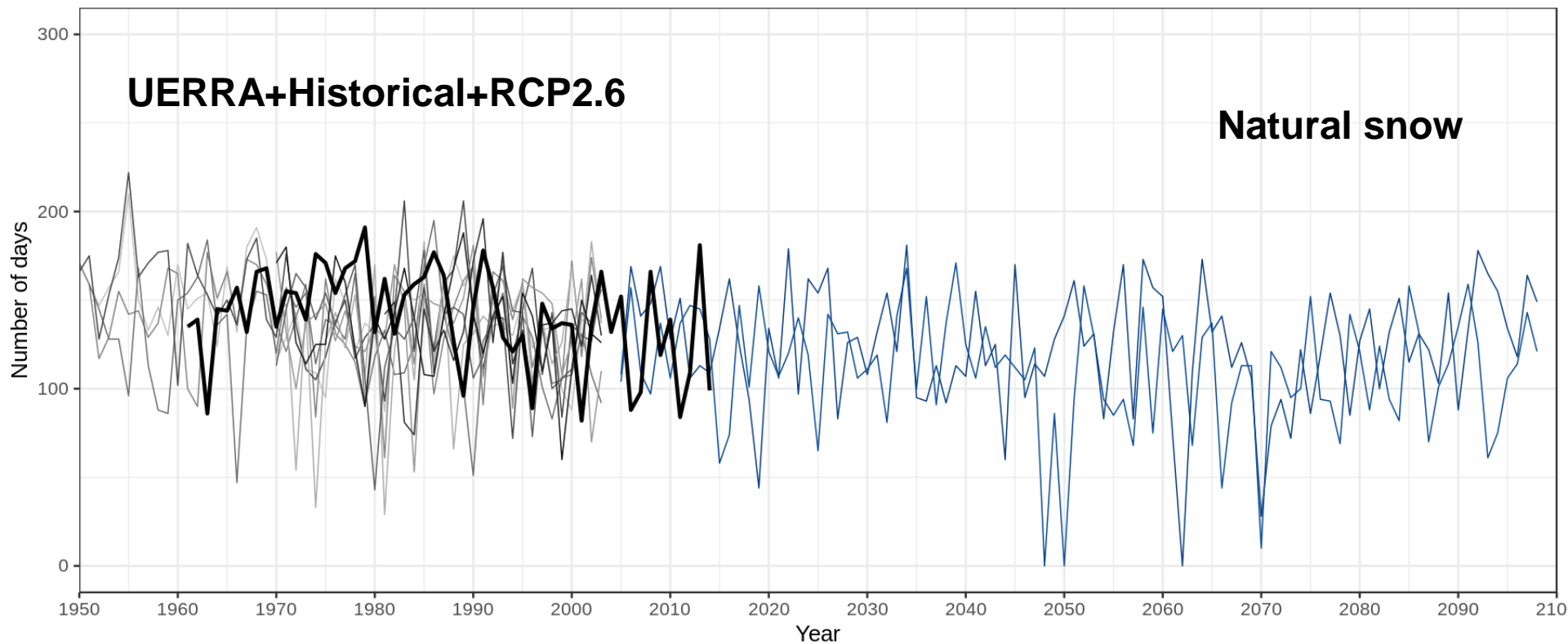


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground

sd_days_30 - Scenario : RCP26 - Configuration : NS - point : Oberkärnten 1500m



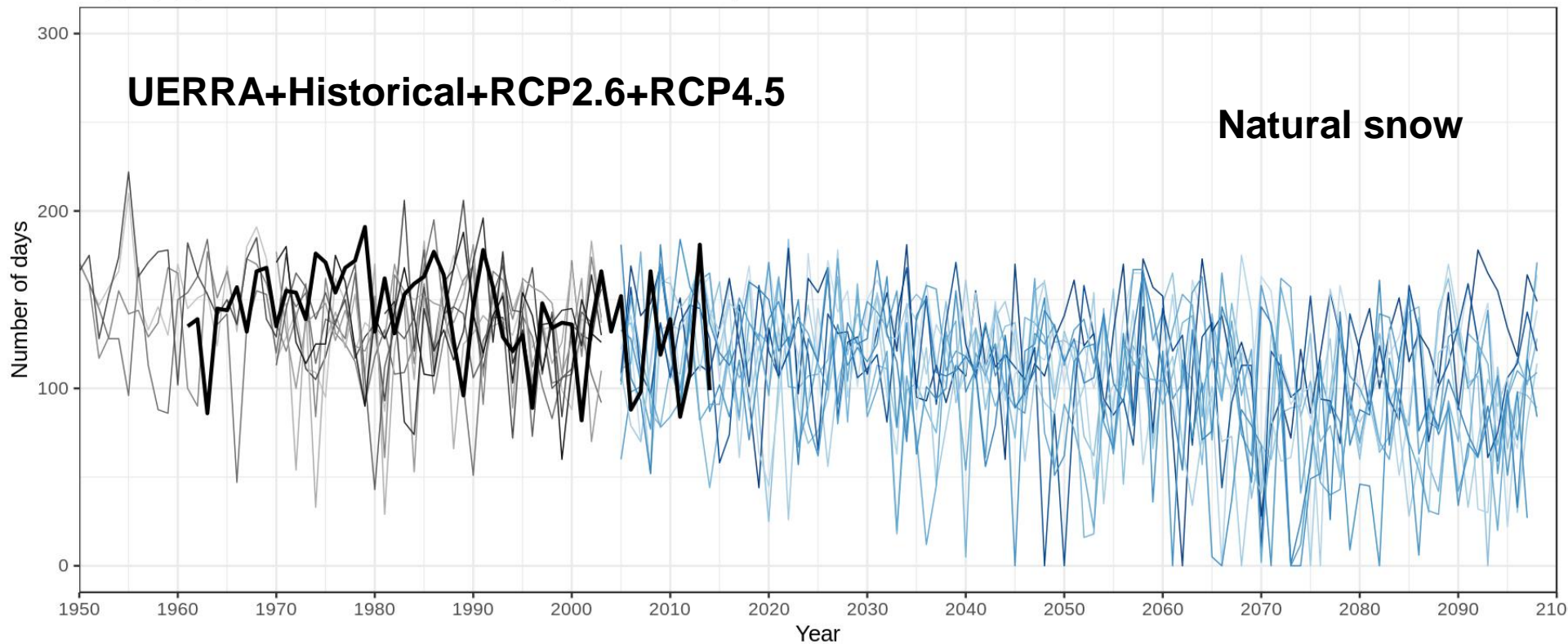


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground

sd_days_30 - Scenario : RCP45 - Configuration : NS - point : Oberkärnten 1500m



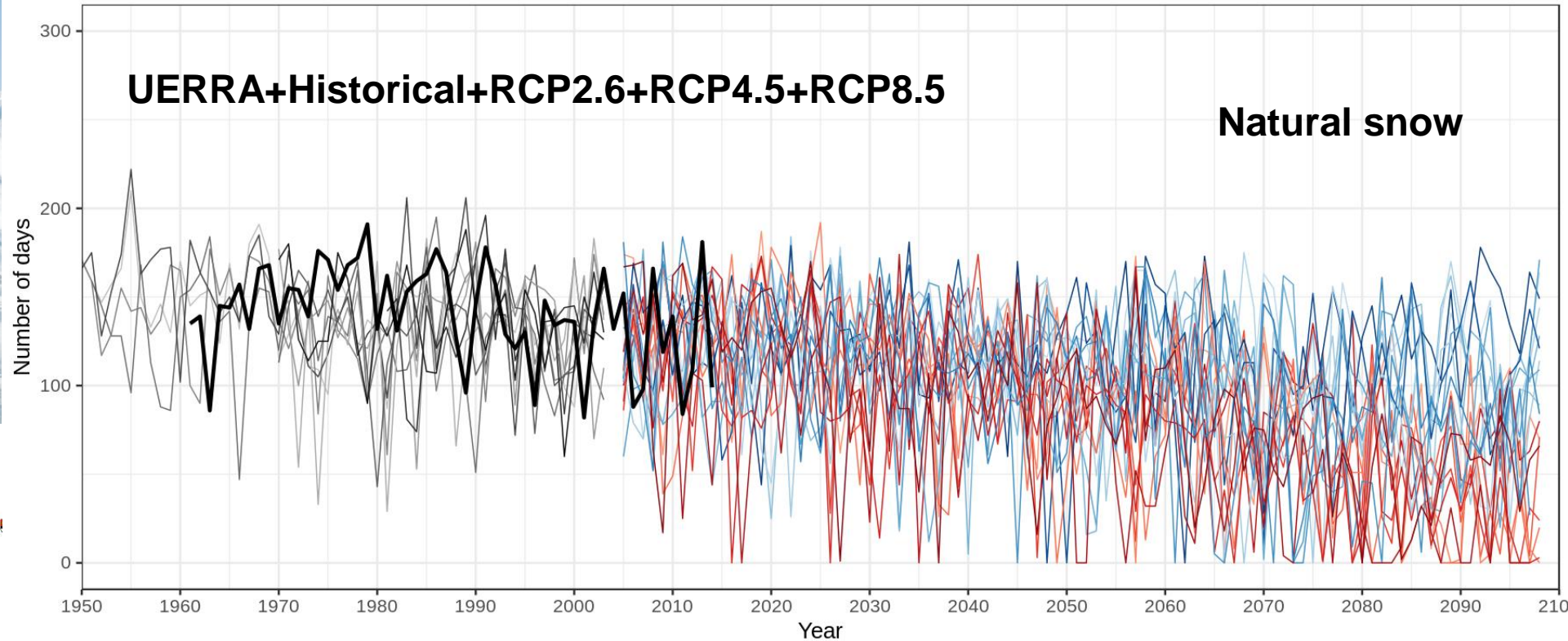


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground

sd_days_30 - Scenario : RCP85 - Configuration : NS - point : Oberkärnten 1500m



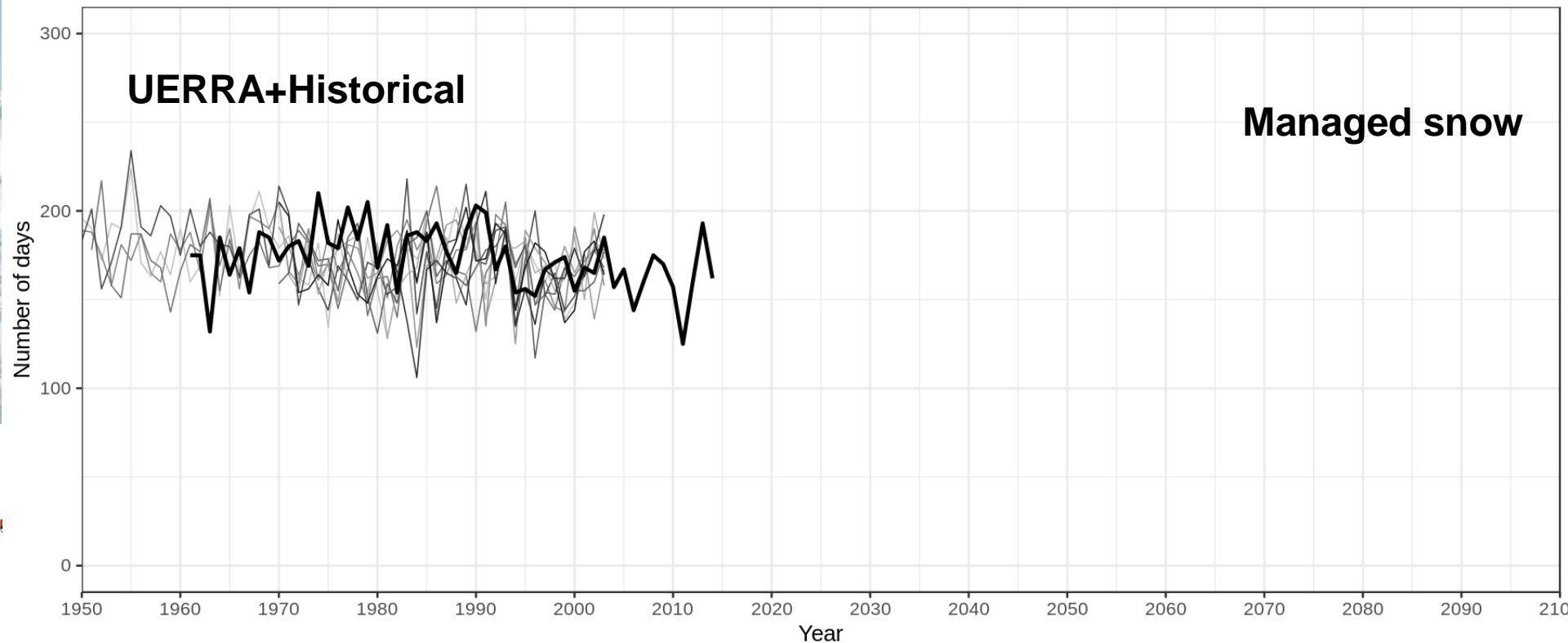


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground, RCP8.5

sd_days_30 - Scenario : HISTORICAL - Configuration : MS - point : Oberkärnten 1500m



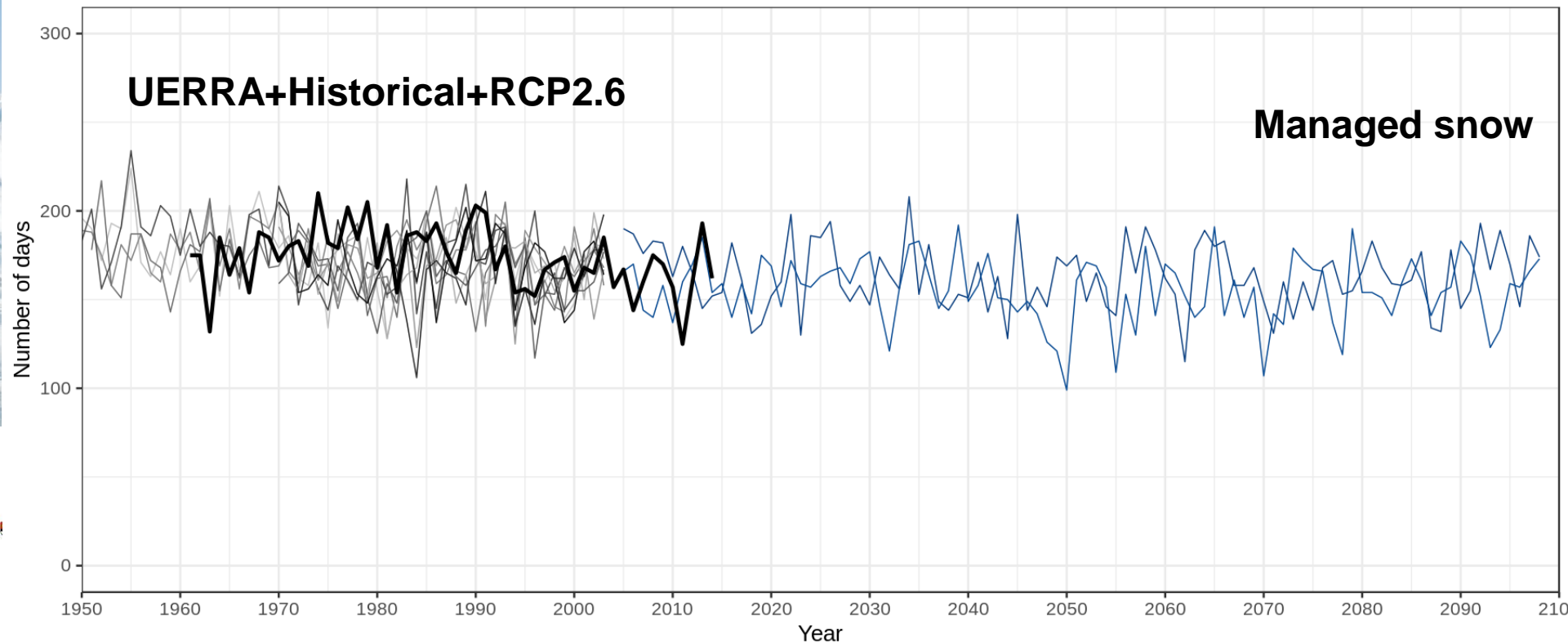


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground, RCP8.5

sd_days_30 - Scenario : RCP26 - Configuration : MS - point : Oberkärnten 1500m



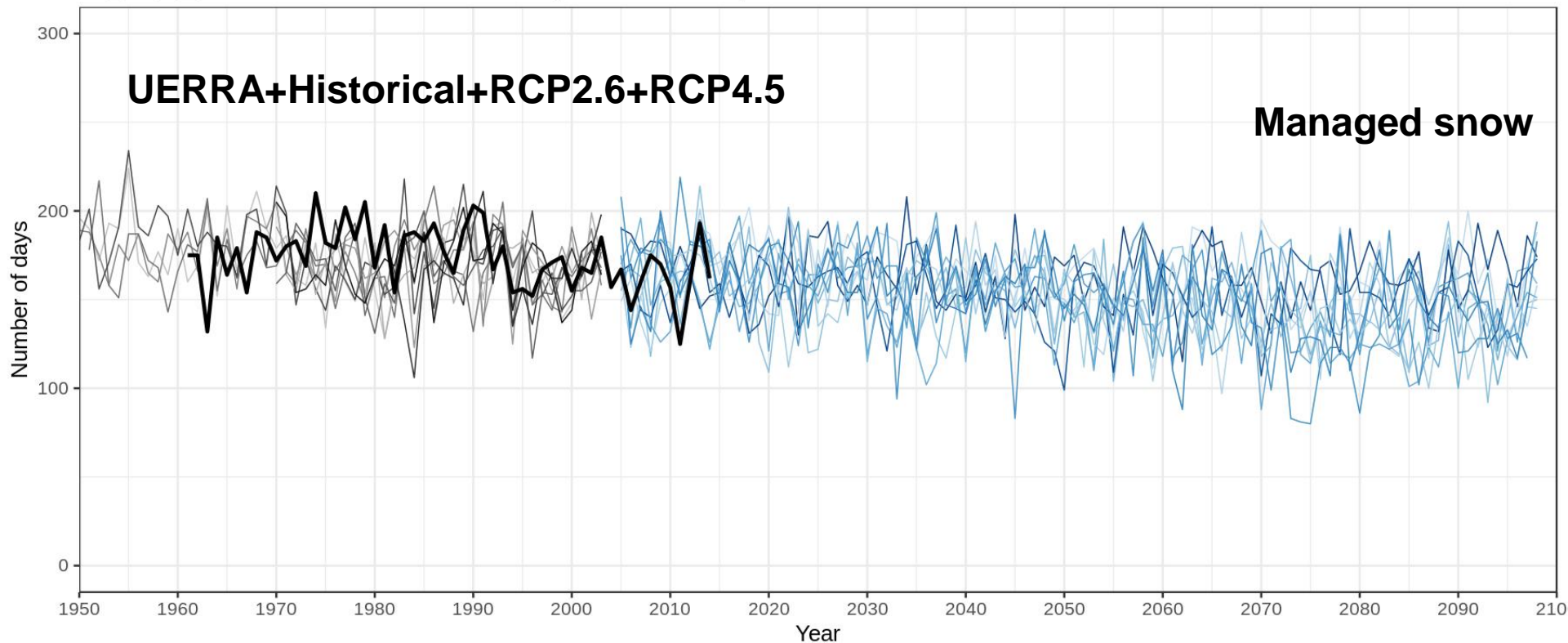


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground, RCP8.5

sd_days_30 - Scenario : RCP45 - Configuration : MS - point : Oberkärnten 1500m



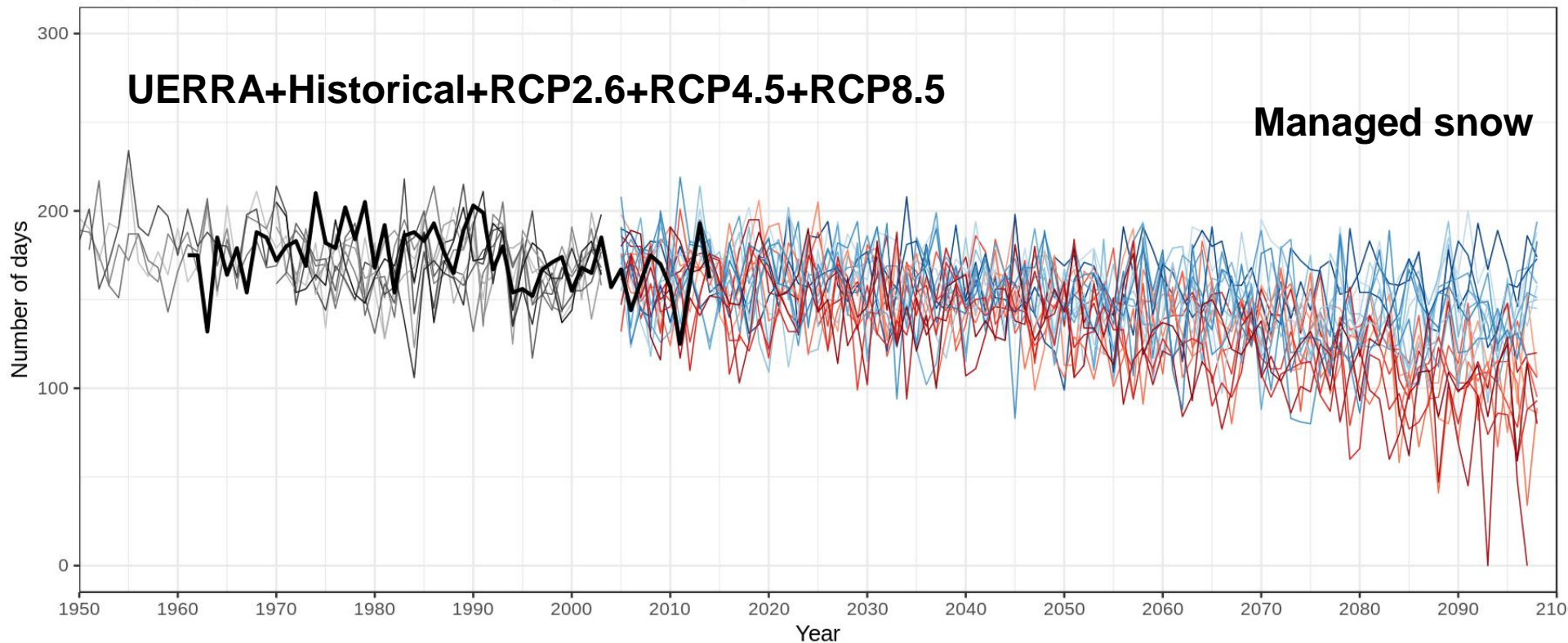


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground, RCP8.5

sd_days_30 - Scenario : RCP85 - Configuration : MS - point : Oberkärnten 1500m



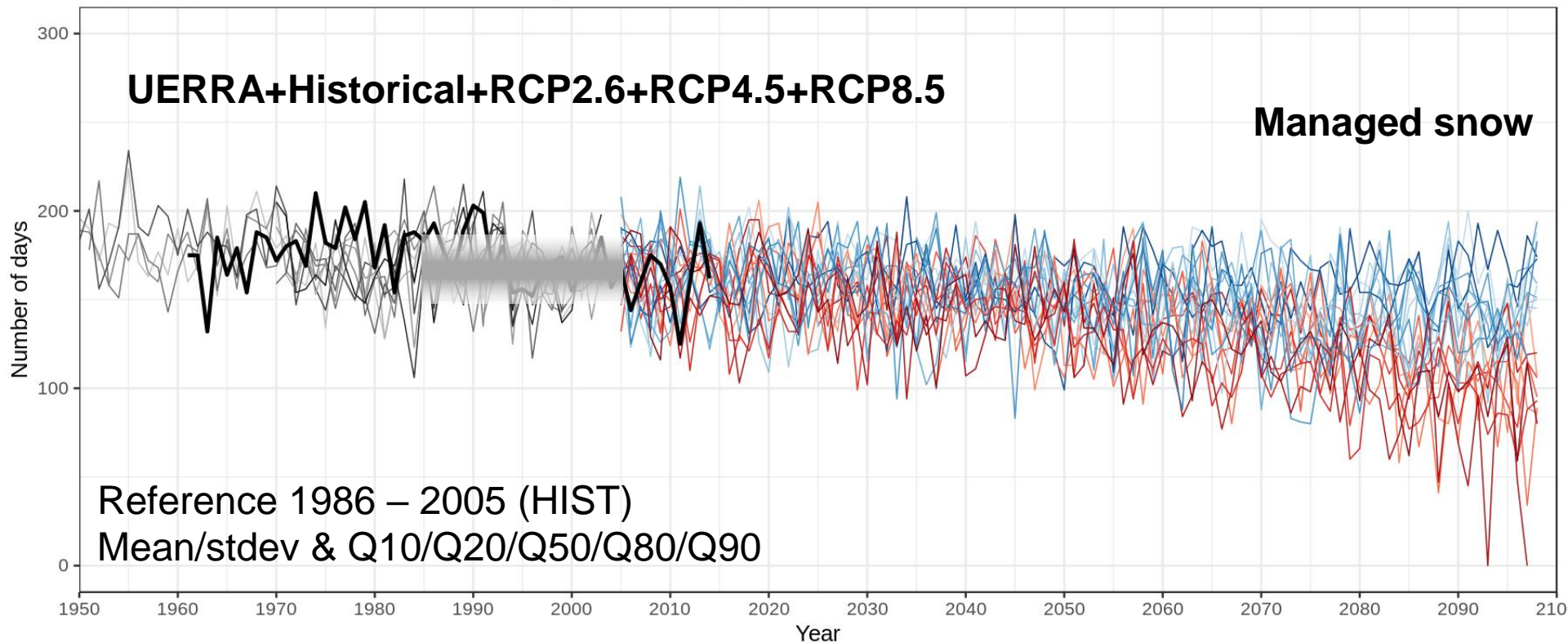


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground, RCP8.5

sd_days_30 - Scenario : RCP85 - Configuration : MS - point : Oberkärnten 1500m



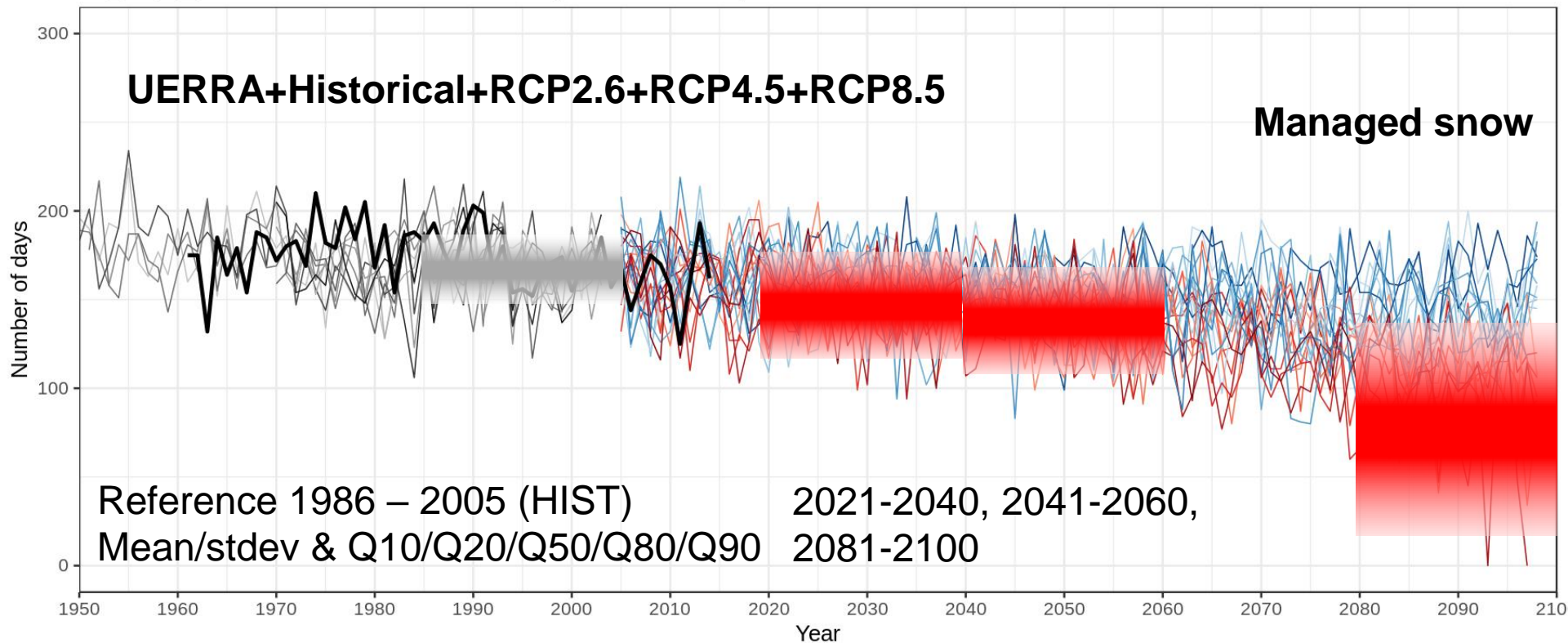


Climate
Change

Time series, example Oberkärntern 1500 m elevation (Austria)

Number of days with more than 30 cm of snow on the ground, RCP8.5

sd_days_30 - Scenario : RCP85 - Configuration : MS - point : Oberkärnten 1500m





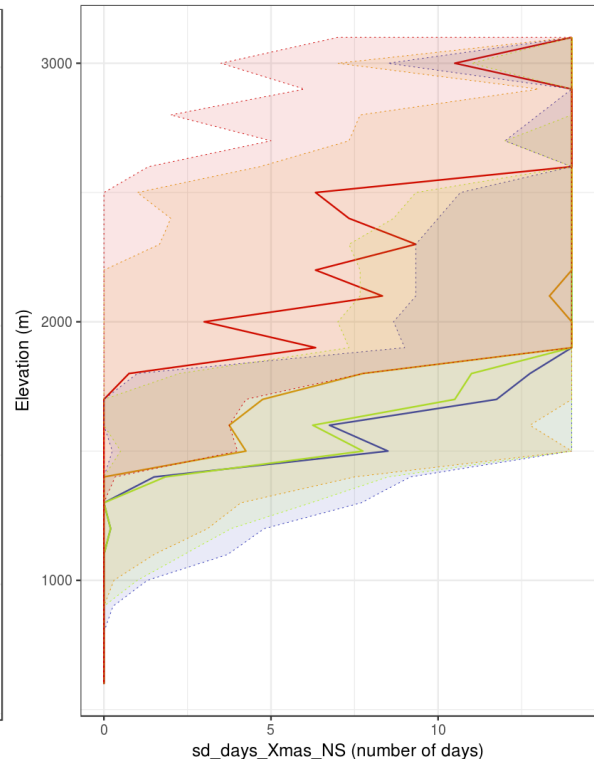
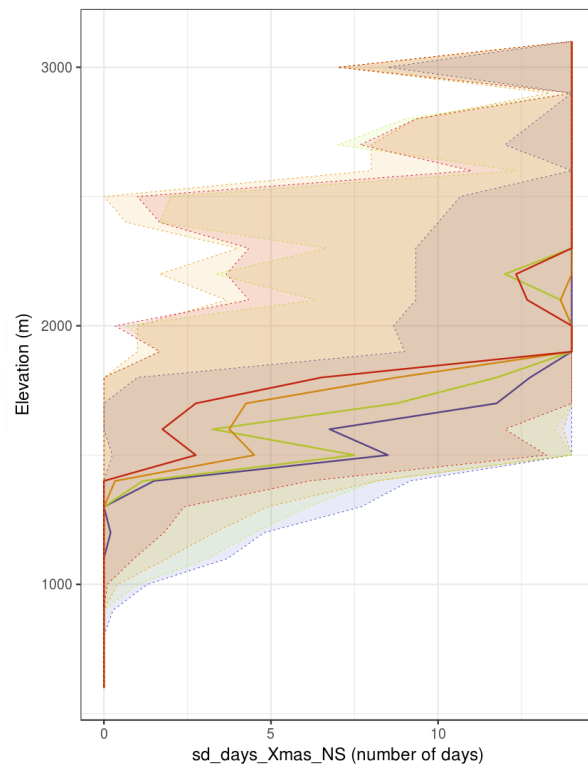
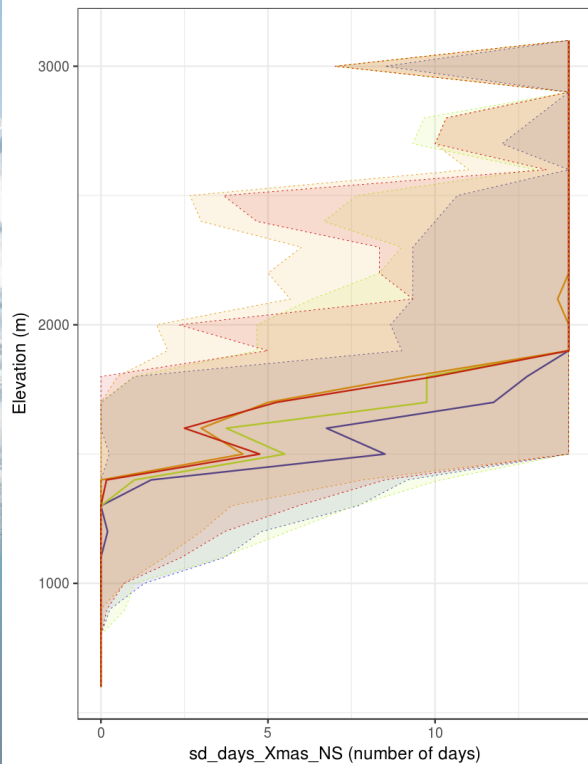
Climate
Change

Changes with elevation, France « Region Auvergne-Rhône-Alpes FRK » (NUTS-2) : number of days with > 30 cm for Xmas, natural snow.

2021-2040

2041-2060

2081-2100



Scenario (Q)

- HISTORIC
- RCP26
- RCP45
- RCP85



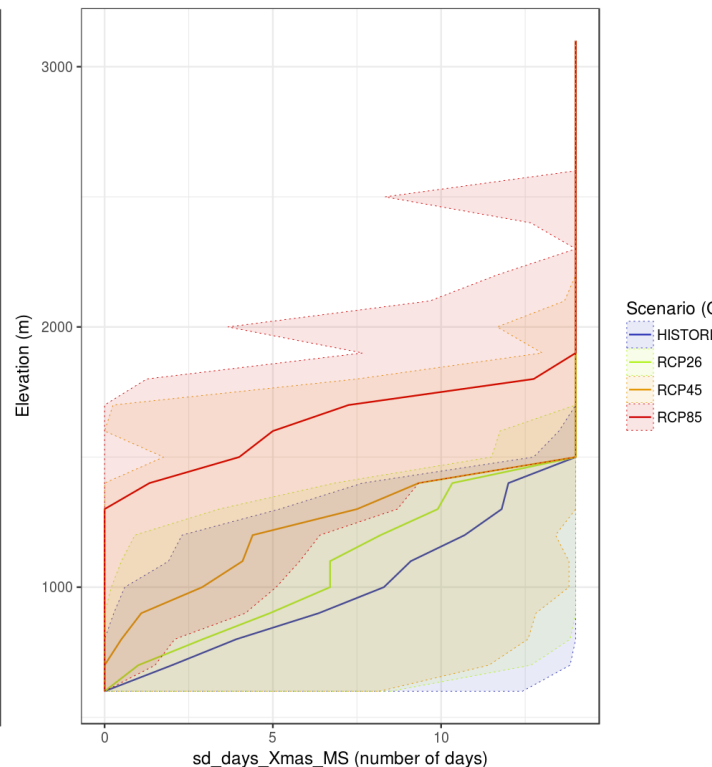
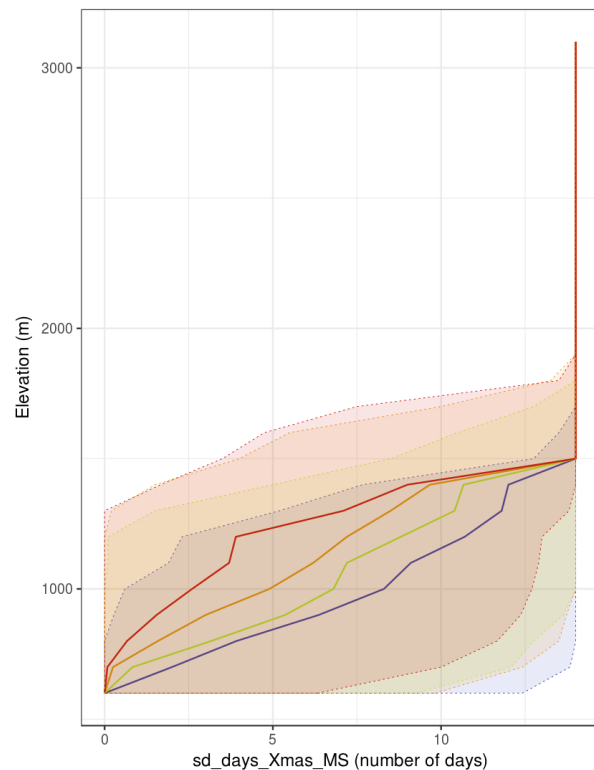
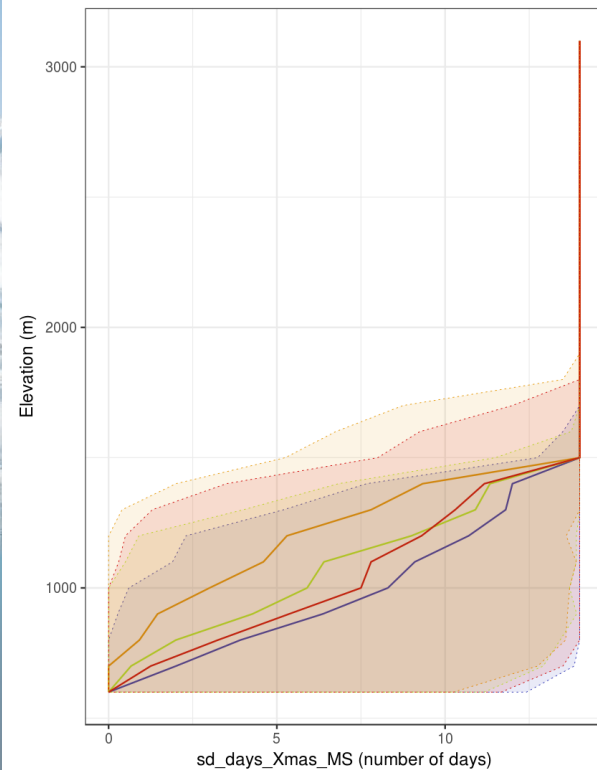
Climate
Change

Changes with elevation, France « Region Auvergne-Rhône-Alpes FRK » (NUTS-2) : number of days with > 30 cm for Xmas, managed snow.

2021-2040

2041-2060

2081-2100





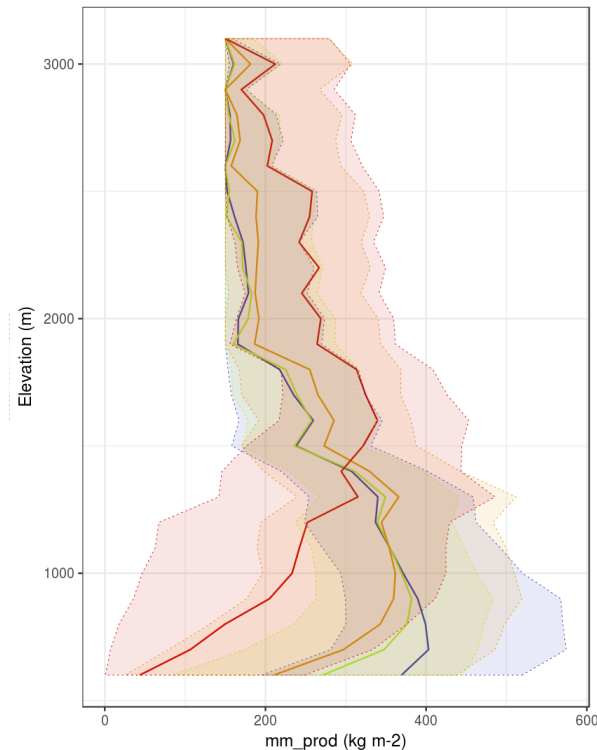
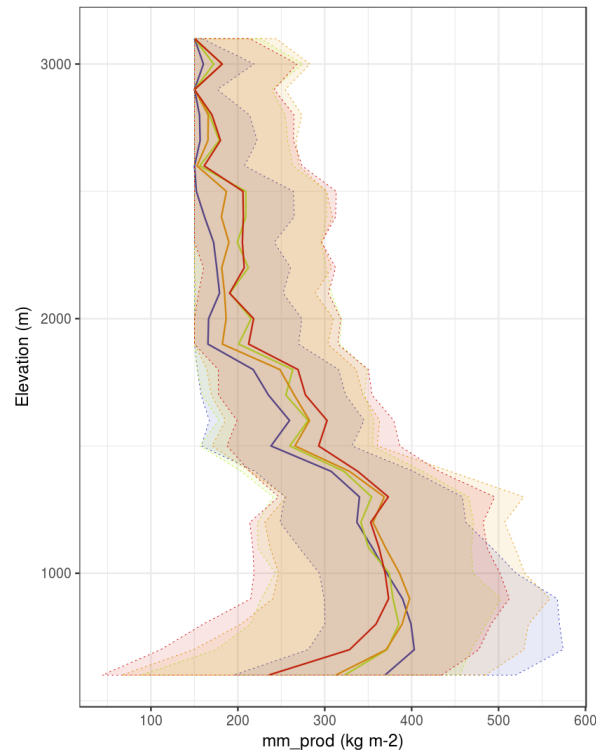
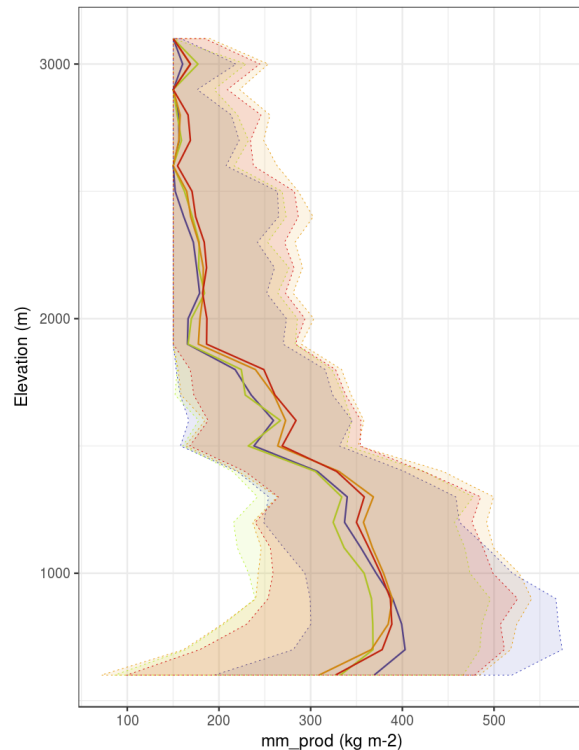
Climate
Change

Changes with elevation, France « Region Auvergne-Rhône-Alpes FRK » (NUTS-2) : production of machine made snow

2021-2040

2041-2060

2081-2100



Scenario (Q)

- HISTORIC
- RCP26
- RCP45
- RCP85



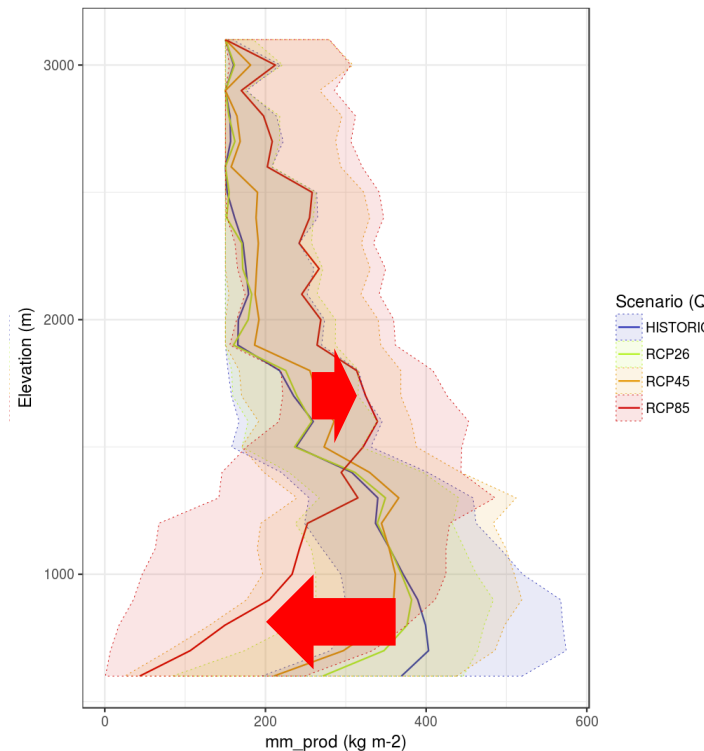
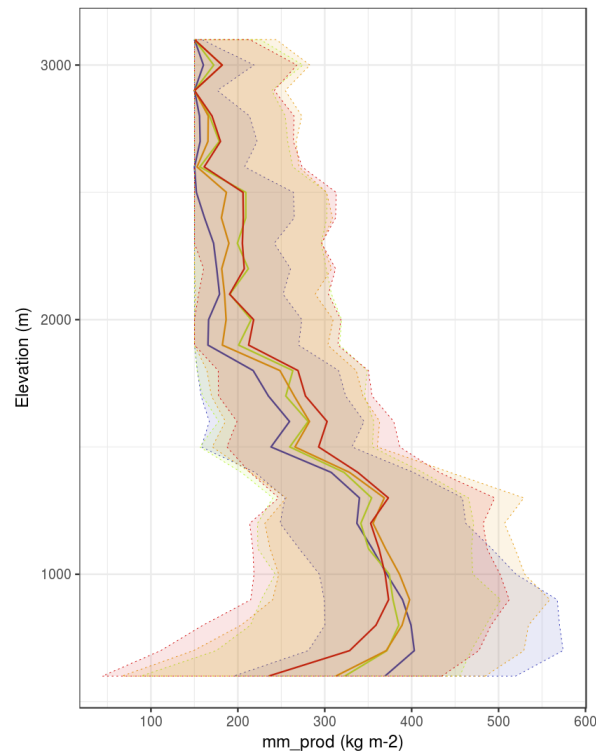
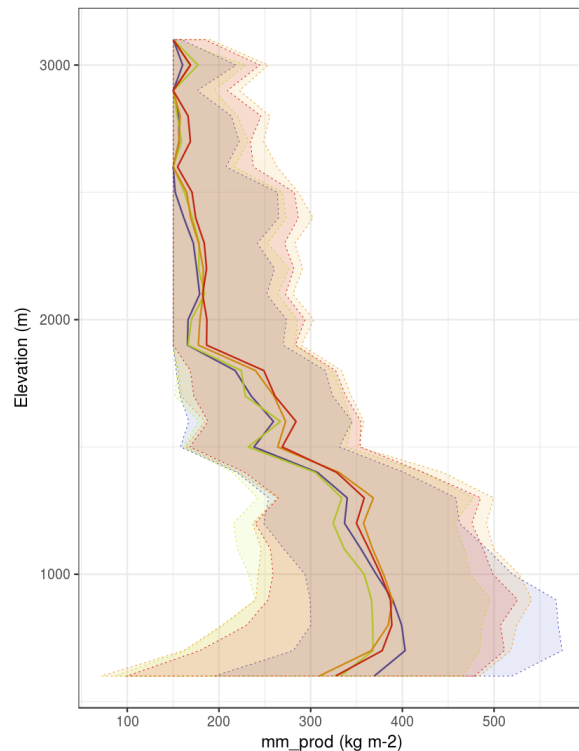
Climate
Change

Changes with elevation, France « Region Auvergne-Rhône-Alpes FRK » (NUTS-2) : production of machine made snow

2021-2040

2041-2060

2081-2100



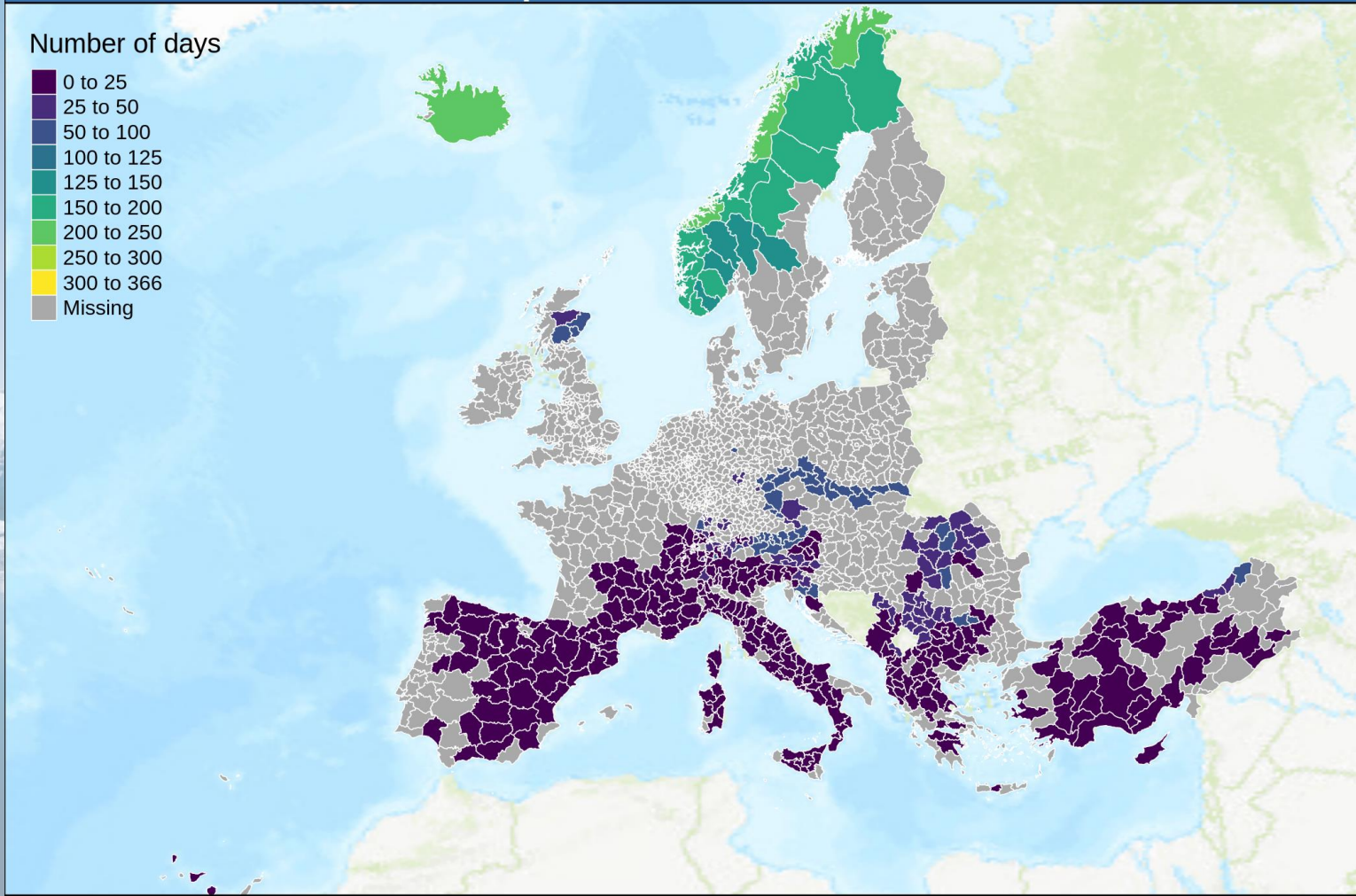


Climate
Change

**Maps for a
given
elevation
(800 m,
number of
days with
more than
30 cm of
natural
snow)**

period : 1986_2005

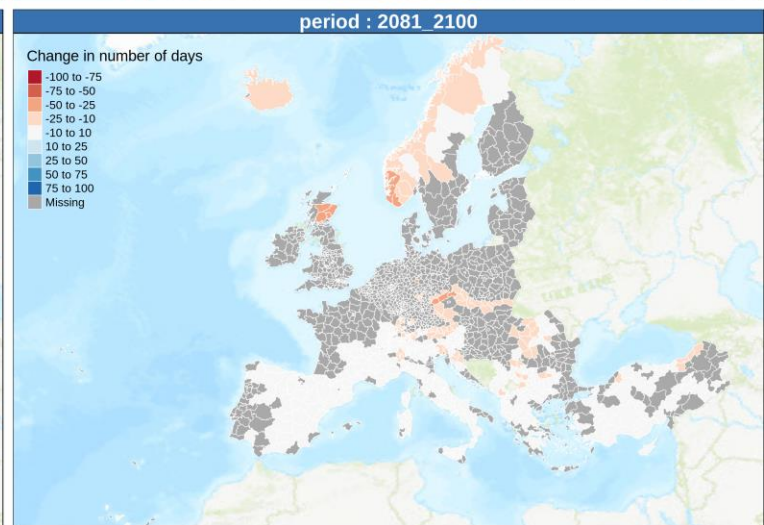
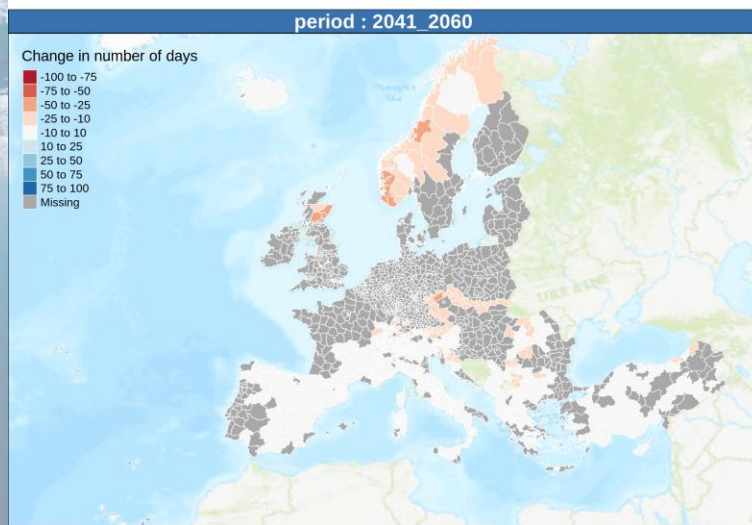
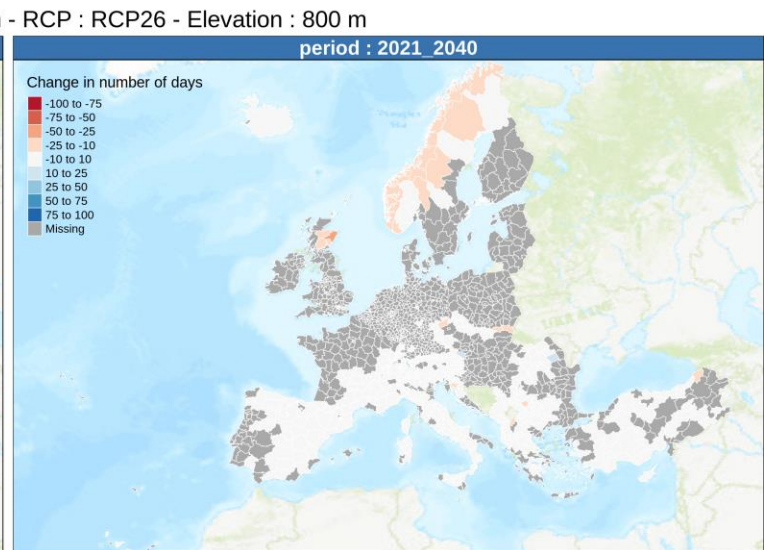
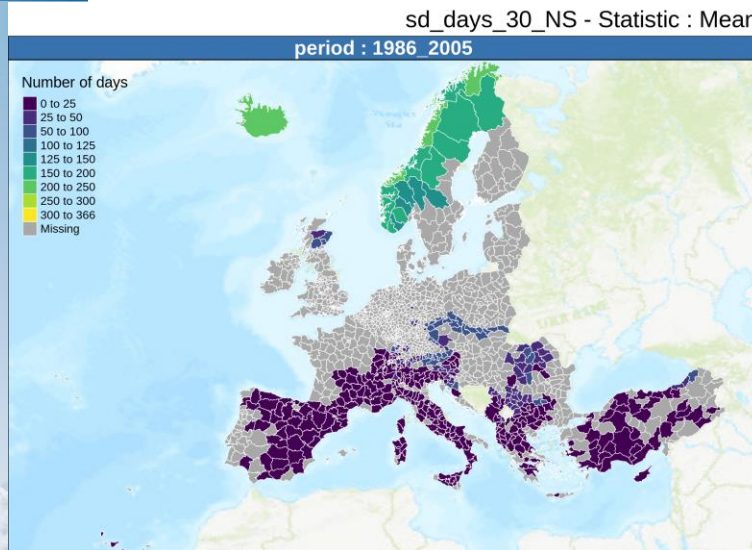
Number of days





Climate
Change

Maps for a
given
elevation
(800 m,
number of
days with
more than
30 cm of
natural
snow)
RCP2.6





Climate
Change

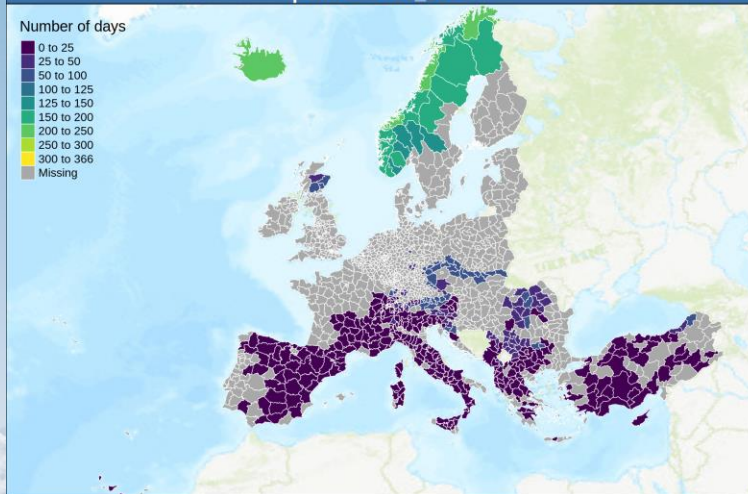
Maps for a
given
elevation
(800 m,
number of
days with
more than
30 cm of
natural
snow)
RCP8.5

sd_days_30_NS - Statistic : Mean - RCP : RCP85 - Elevation : 800 m

period : 1986 2005

Number of days

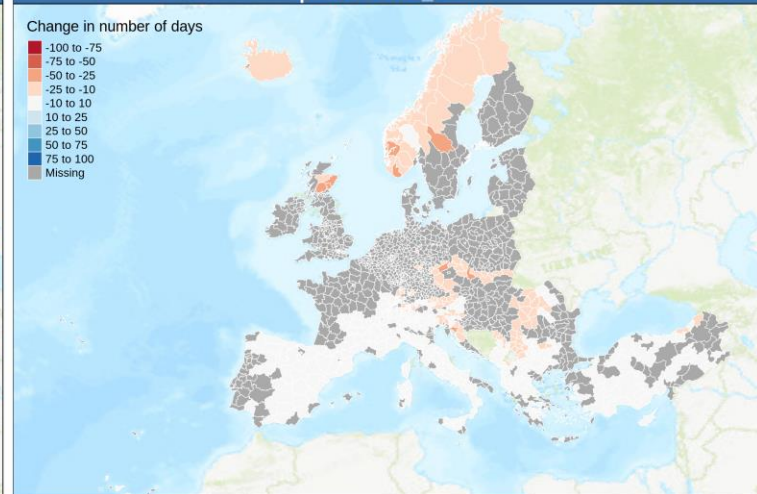
0 to 25
25 to 50
50 to 100
100 to 125
125 to 150
150 to 200
200 to 250
250 to 300
300 to 366
Missing



period : 2021 2040

Change in number of days

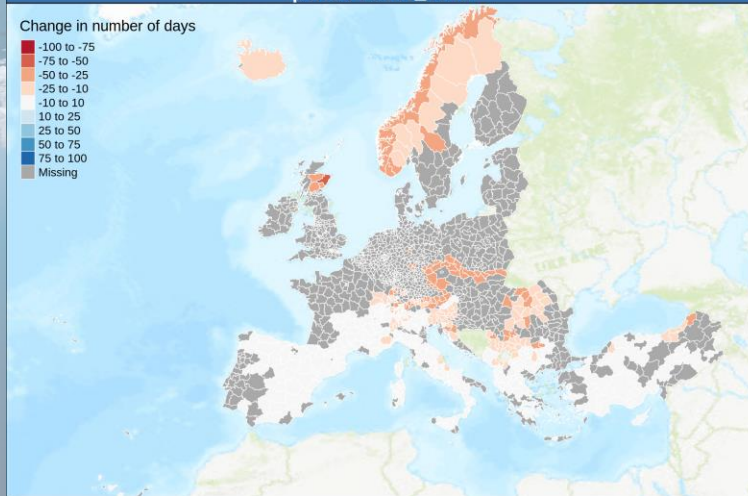
-100 to -75
-75 to -50
-50 to -25
-25 to -10
-10 to 0
0 to 25
25 to 50
50 to 75
75 to 100
Missing



period : 2041 2060

Change in number of days

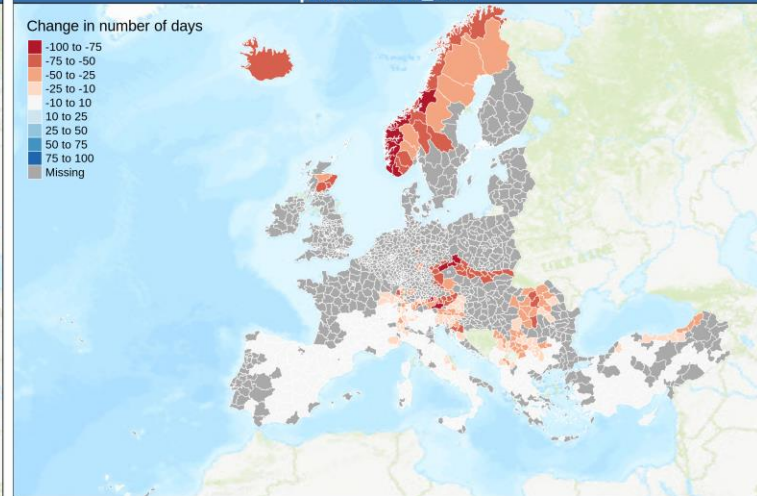
-100 to -75
-75 to -50
-50 to -25
-25 to -10
-10 to 0
0 to 25
25 to 50
50 to 75
75 to 100
Missing



period : 2081 2100

Change in number of days

-100 to -75
-75 to -50
-50 to -25
-25 to -10
-10 to 0
0 to 25
25 to 50
50 to 75
75 to 100
Missing



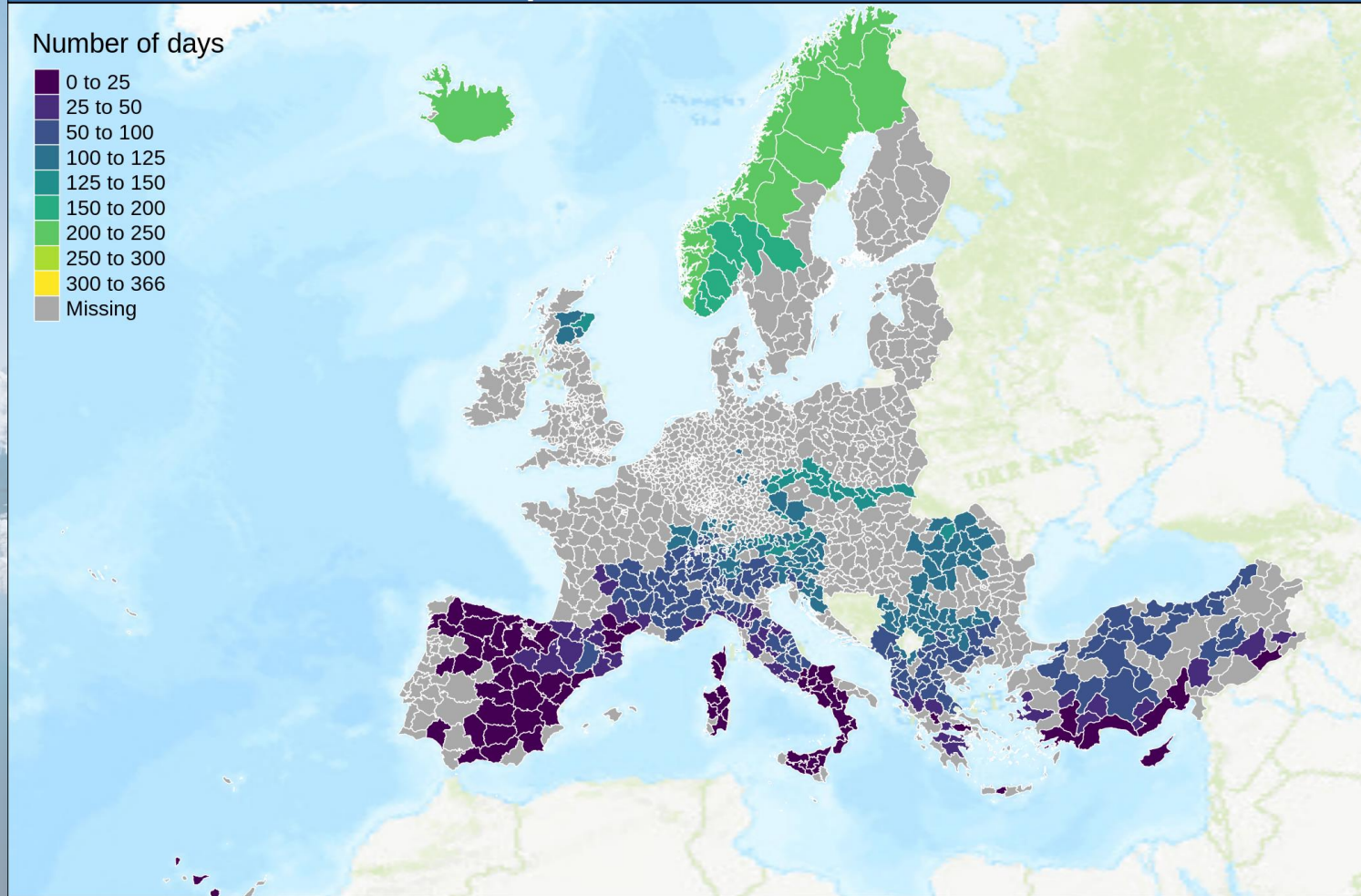
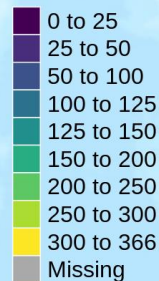


Climate
Change

**Maps for a
given
elevation
(800 m,
number of
days with
more than
30 cm of
managed
snow)**

period : 1986_2005

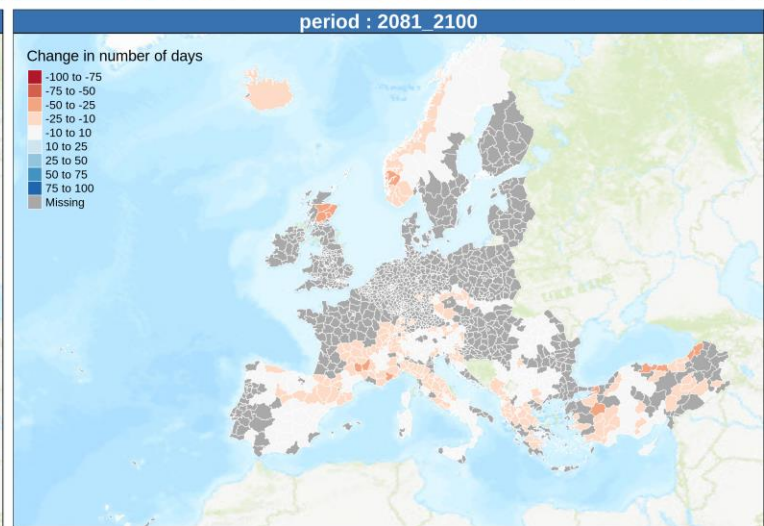
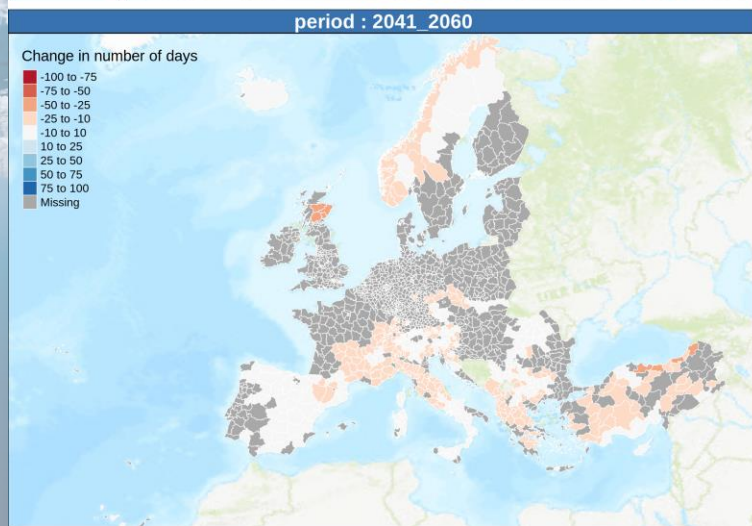
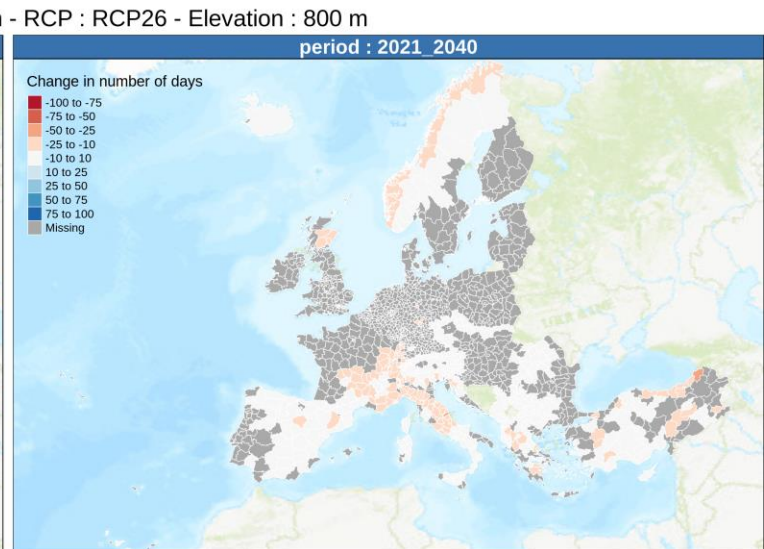
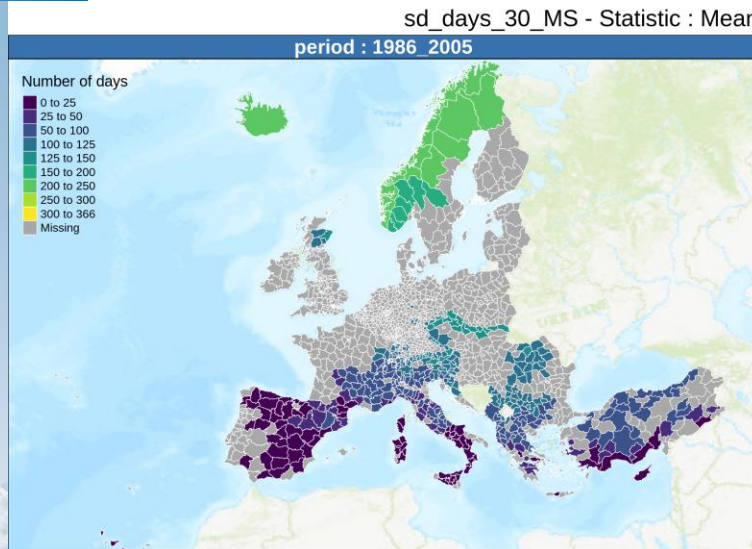
Number of days





Climate
Change

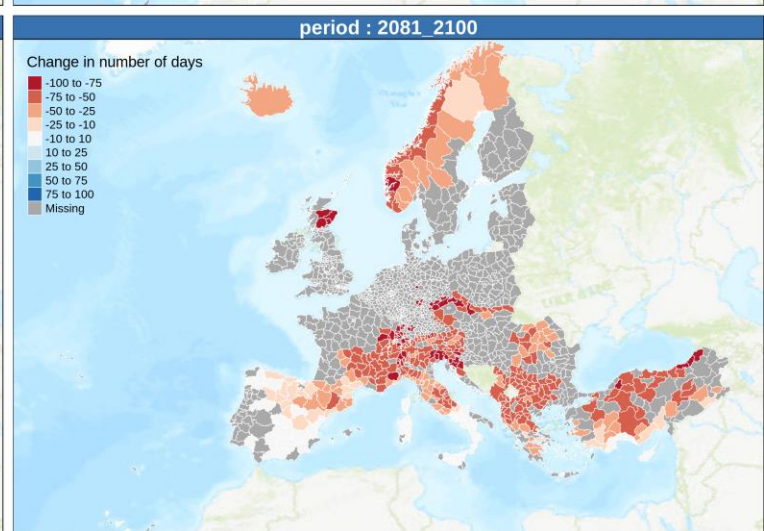
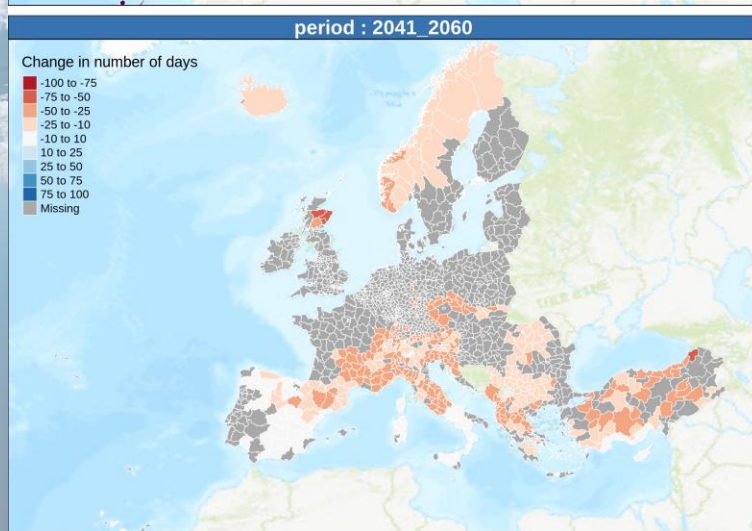
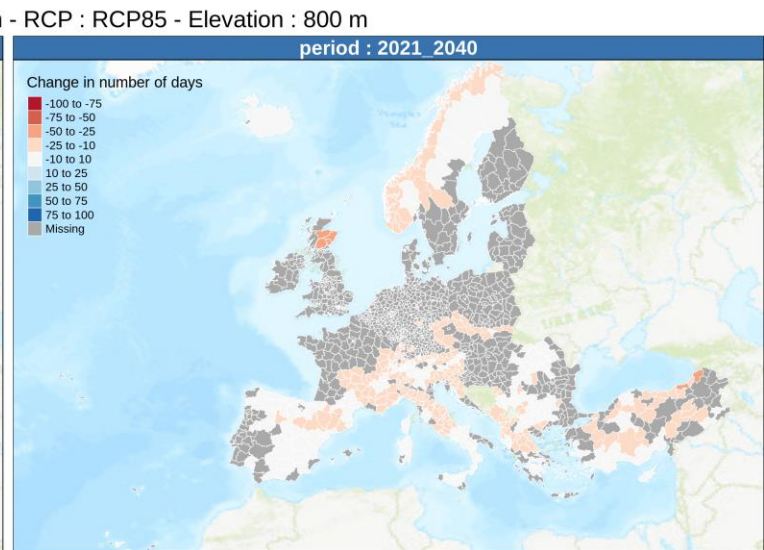
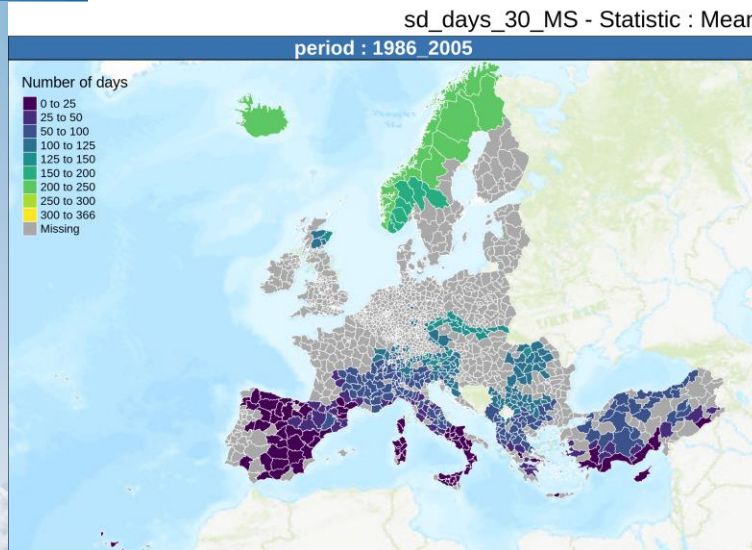
Maps for a
given
elevation
(800 m,
number of
days with
more than
30 cm of
managed
snow)
RCP2.6





Climate
Change

Maps for a
given
elevation
(800 m,
number of
days with
more than
30 cm of
managed
snow)
RCP8.5



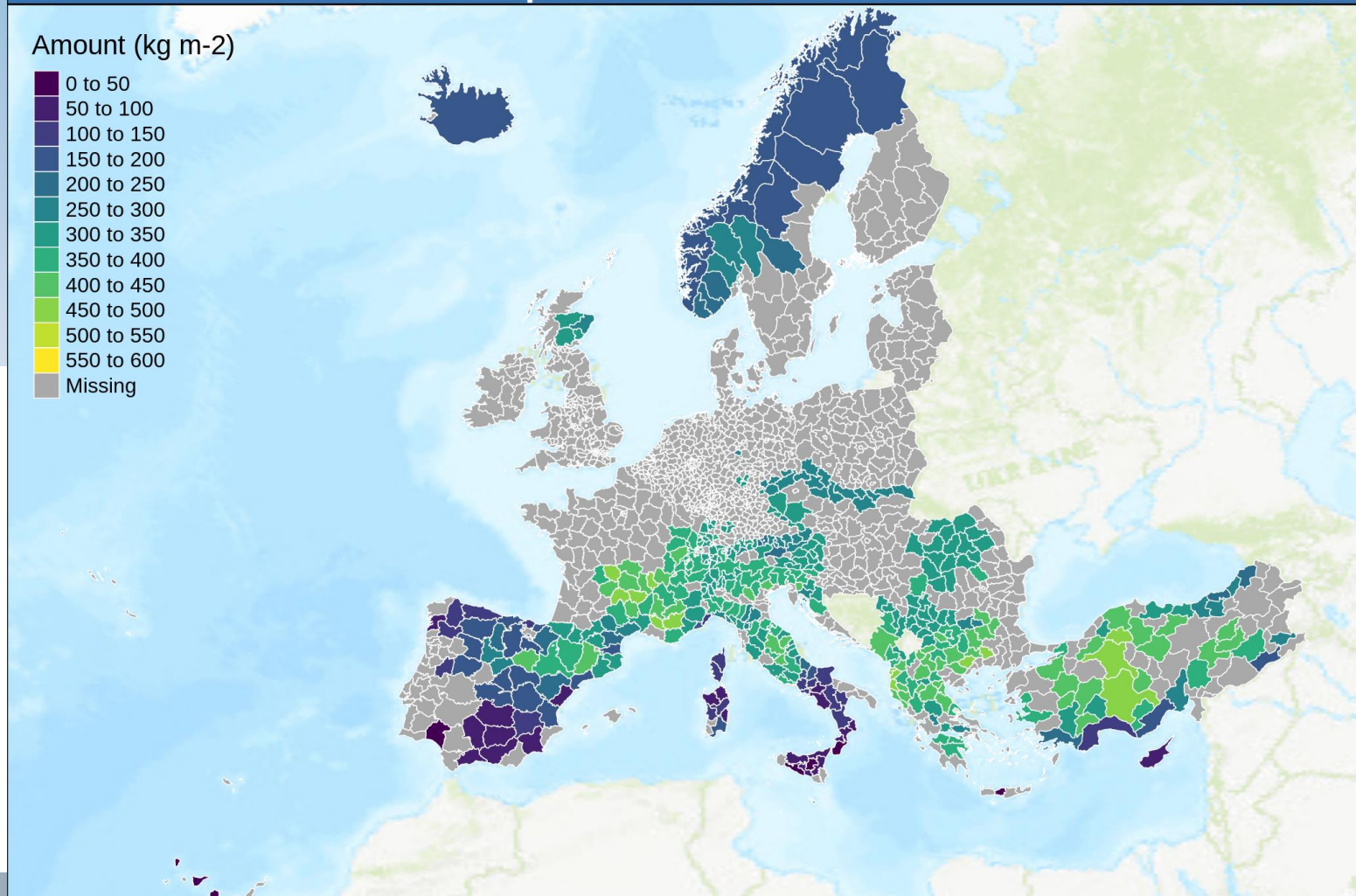


Climate
Change

Snow production amount at 800 m elevation

period : 1986_2005

Amount (kg m⁻²)

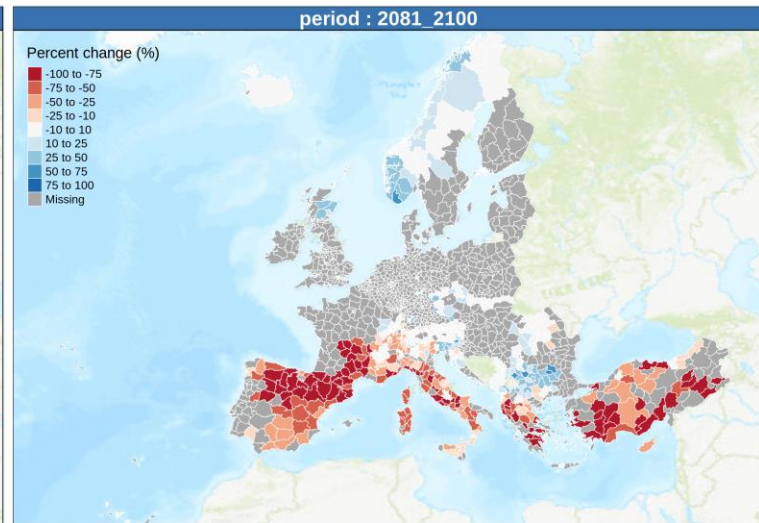
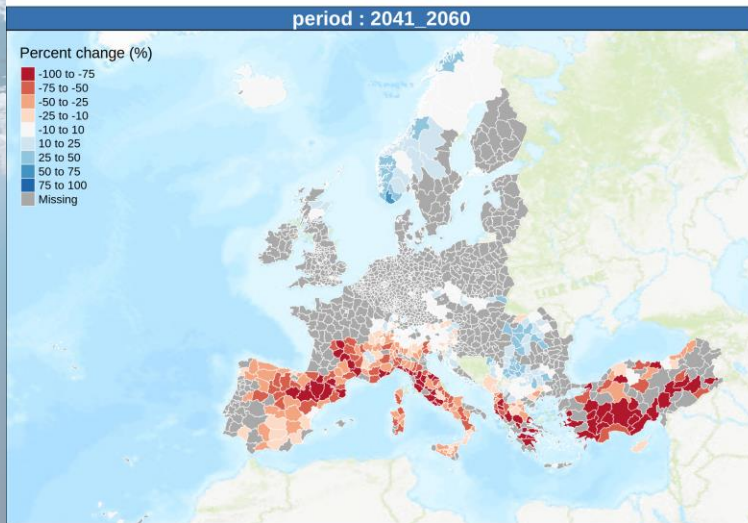
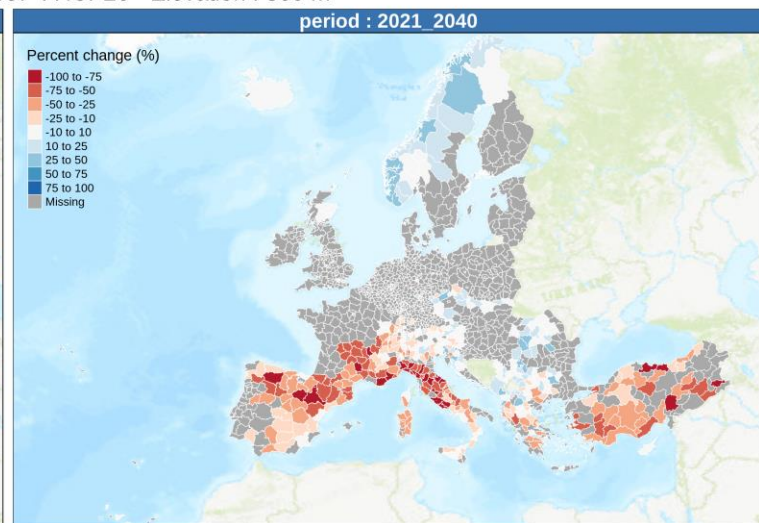
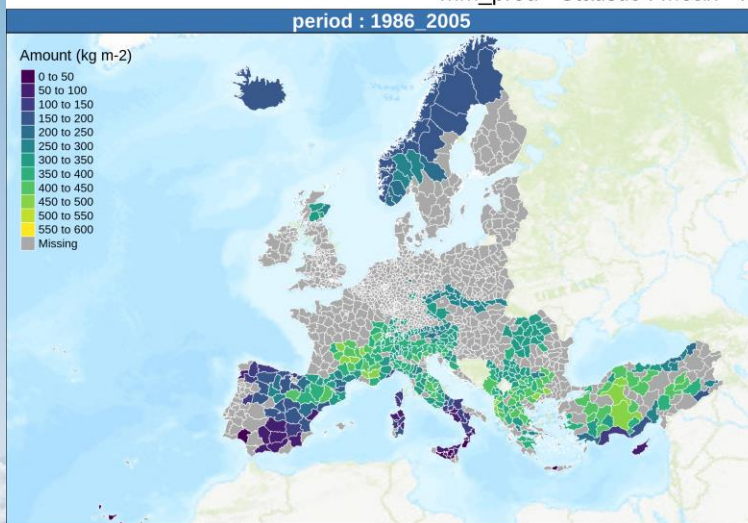




Climate
Change

Snow production amount at 800 m elevation RCP2.6

mm_prod - Statistic : Mean - RCP26 - Elevation : 800 m

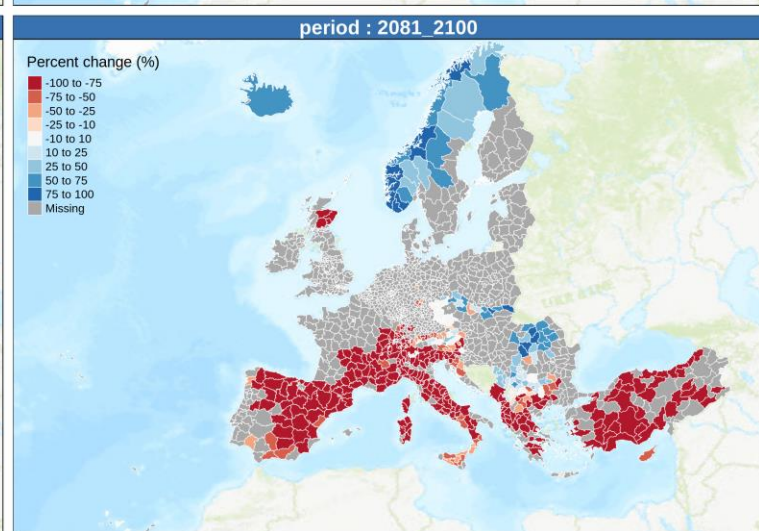
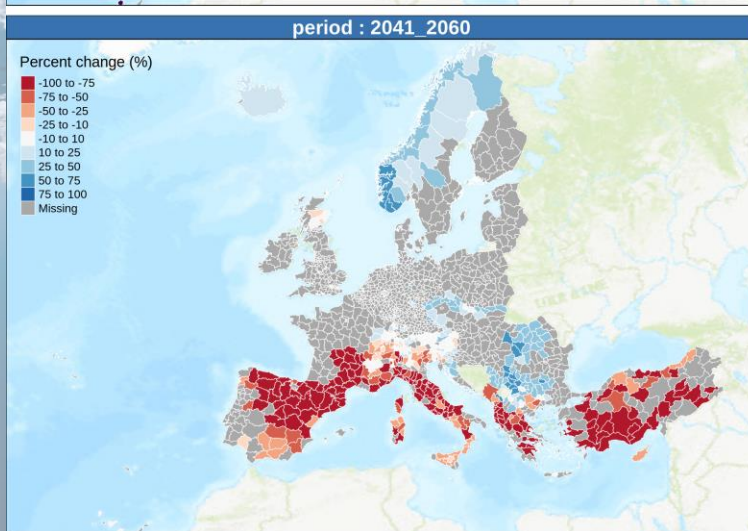
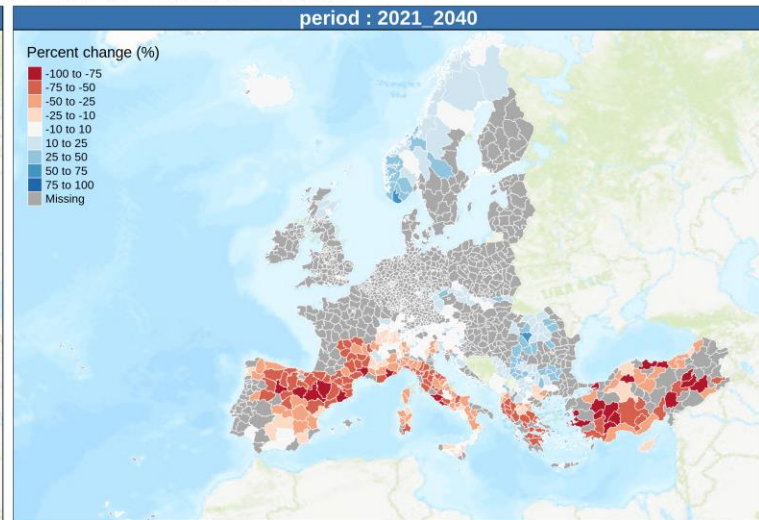
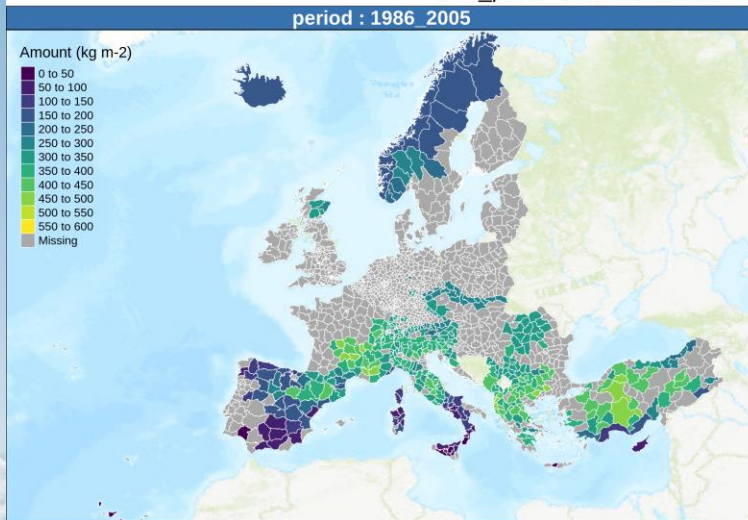




Climate
Change

Snow production amount at 800 m elevation RCP8.5

mm_prod - Statistic : Mean - RCP : RCP85 - Elevation : 800 m





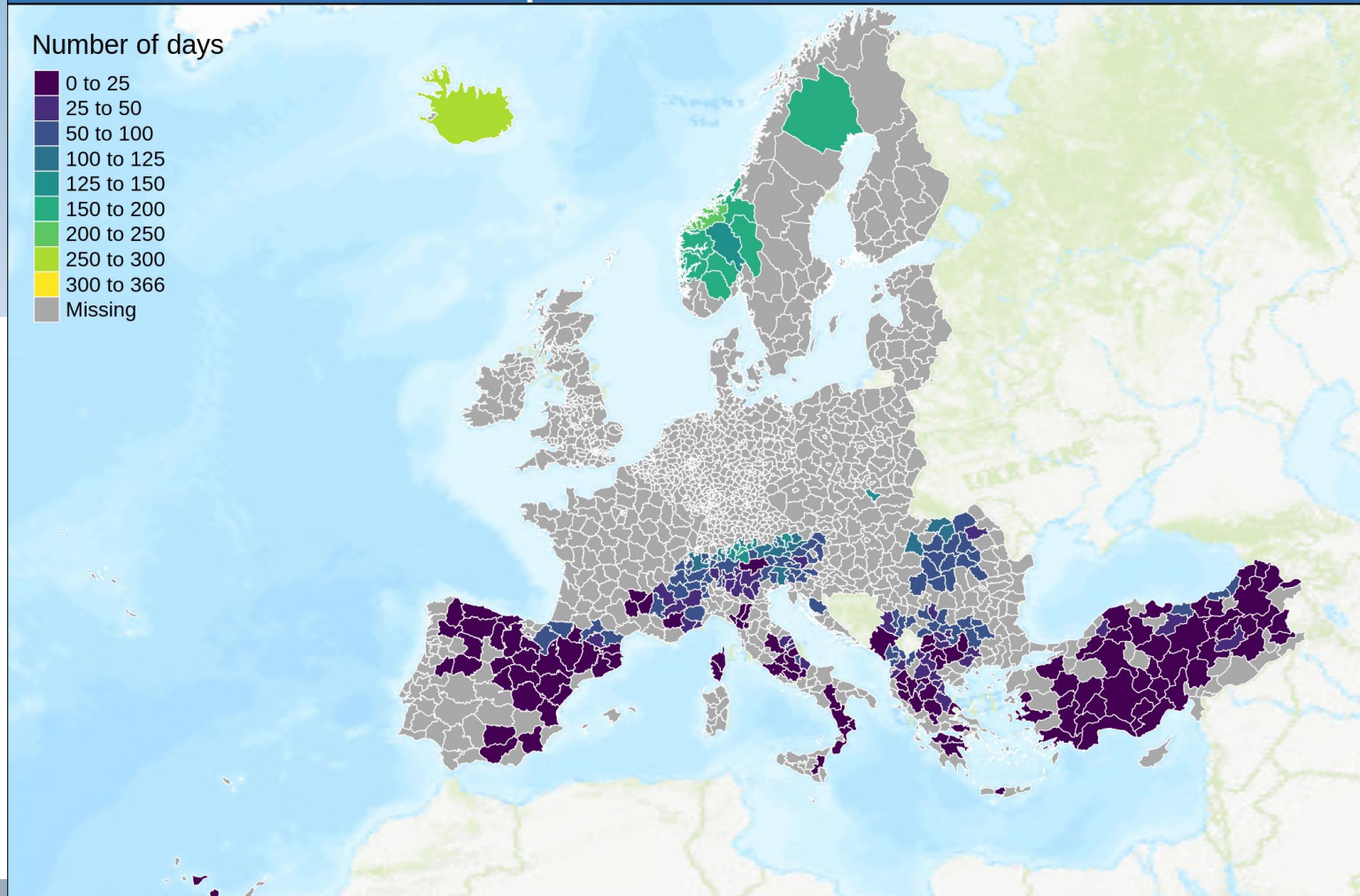
Climate
Change

**Number of
days with
more than
 100 kg m^{-2} at
1400 m
elevation
(mean)**

**(natural
snow)**

period : 1986_2005

Number of days





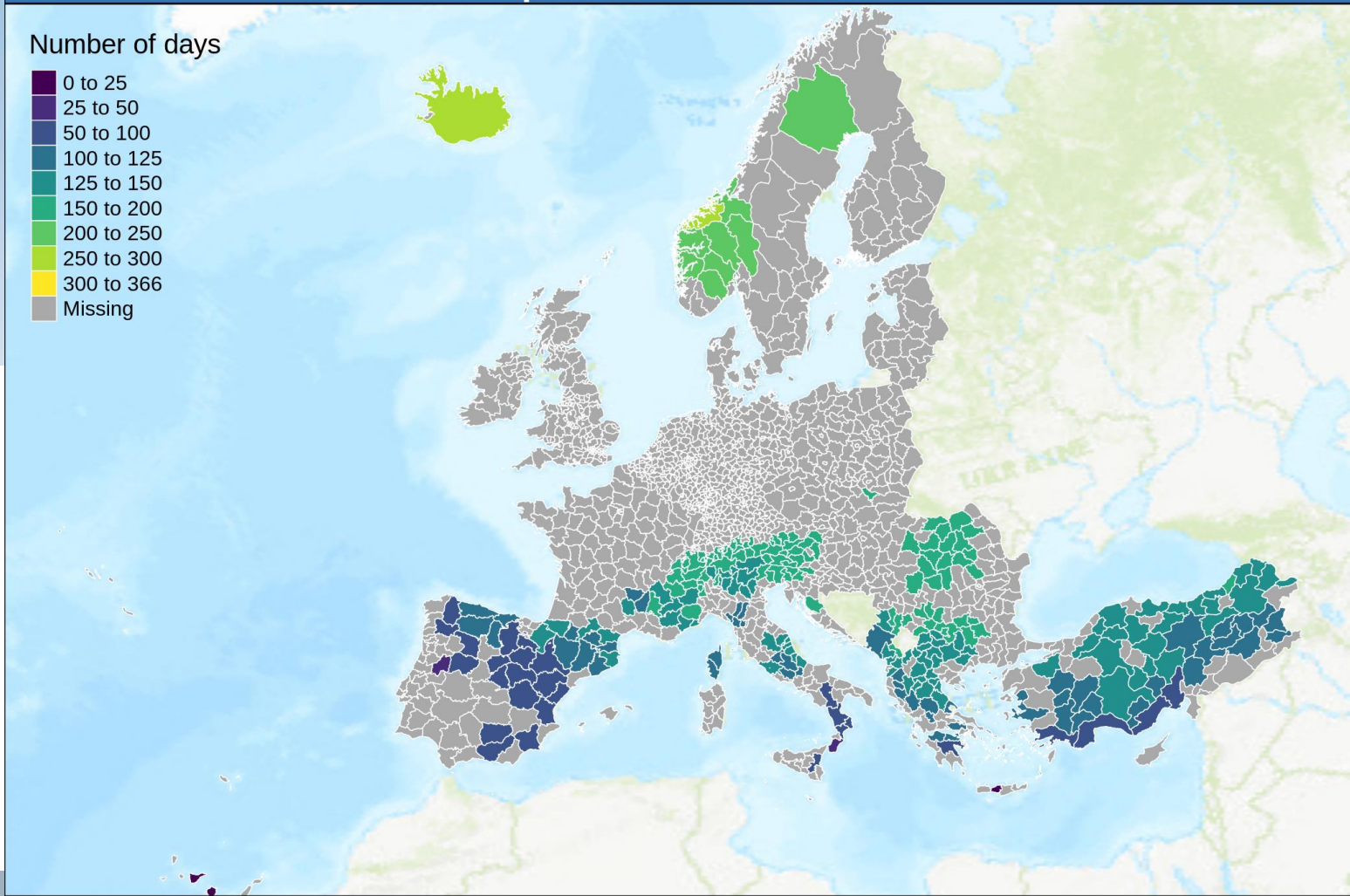
Climate
Change

**Number of
days with
more than
 100 kg m^{-2} at
1400 m
elevation
(mean)**

**(managed
snow)**

period : 1986_2005

Number of days





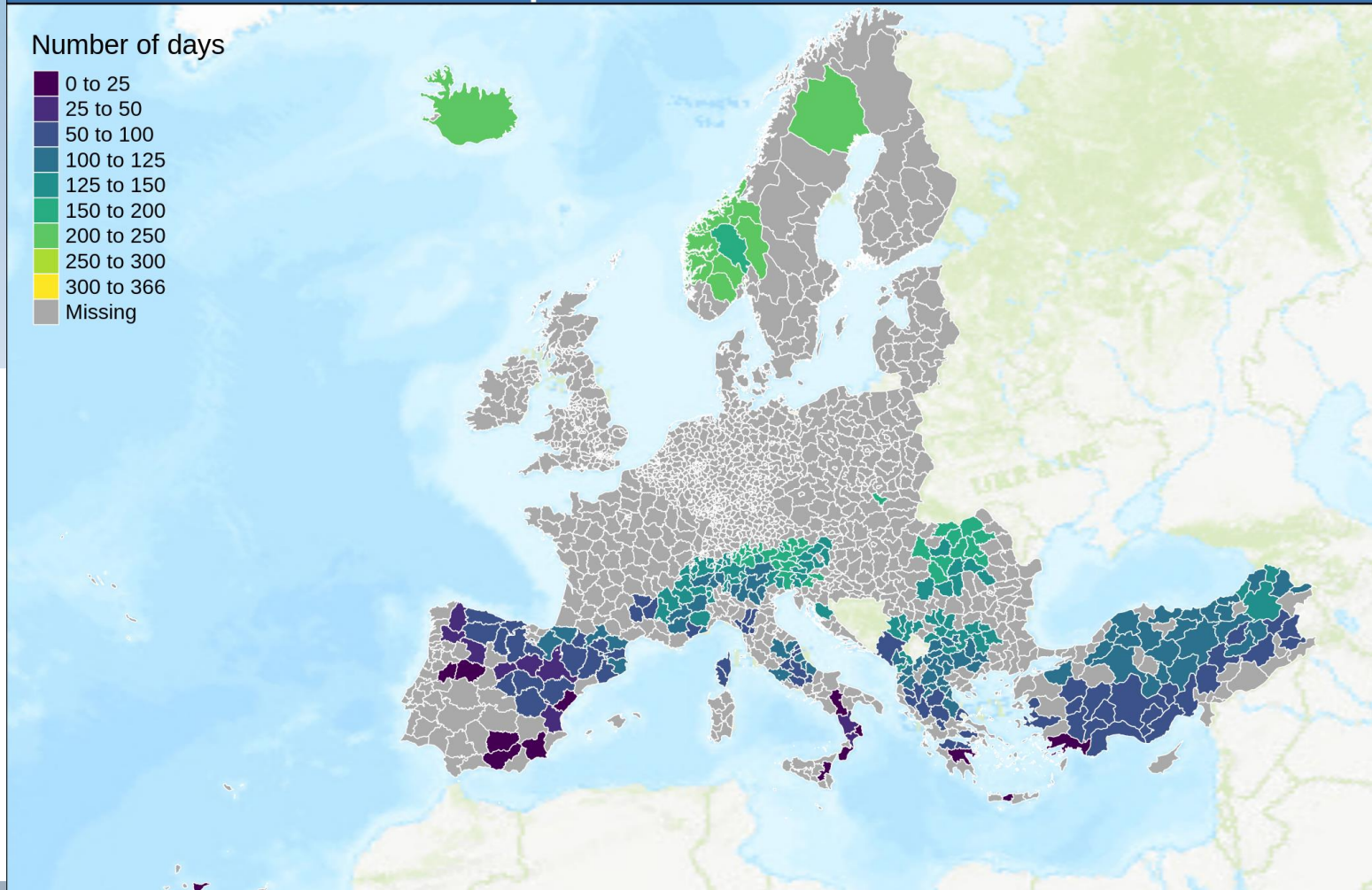
Climate
Change

**Number of
days with
more than
 100 kg m^{-2} at
1400 m
elevation
(Q10)**

**(managed
snow)**

period : 1986_2005

Number of days

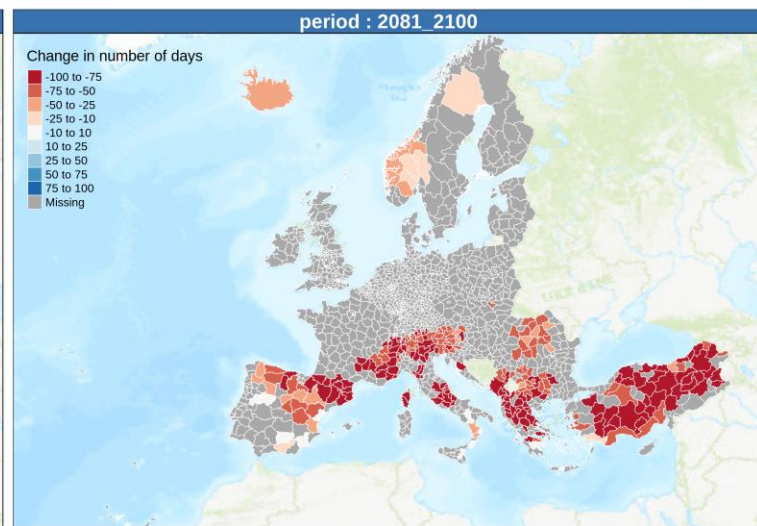
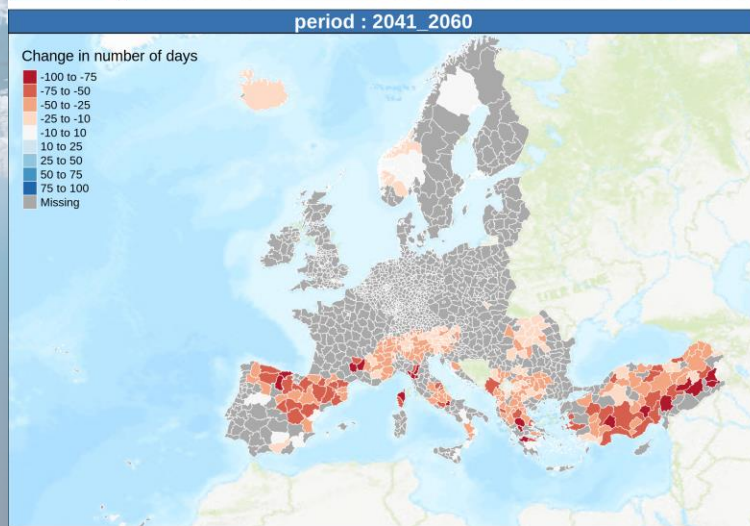
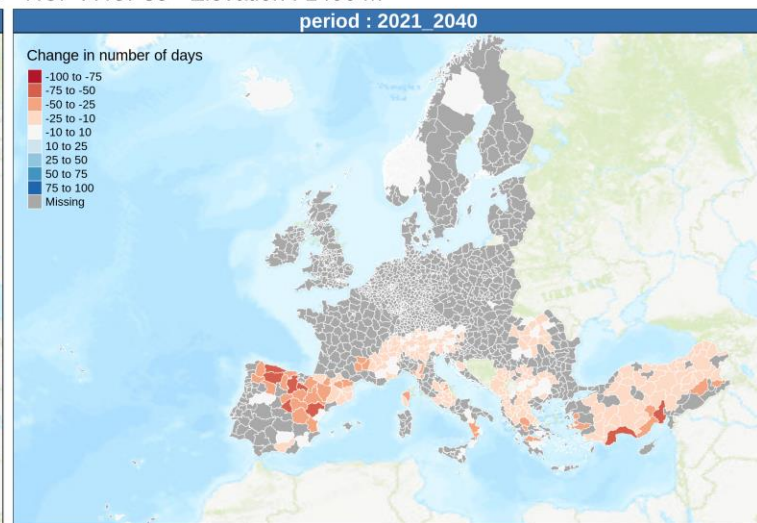
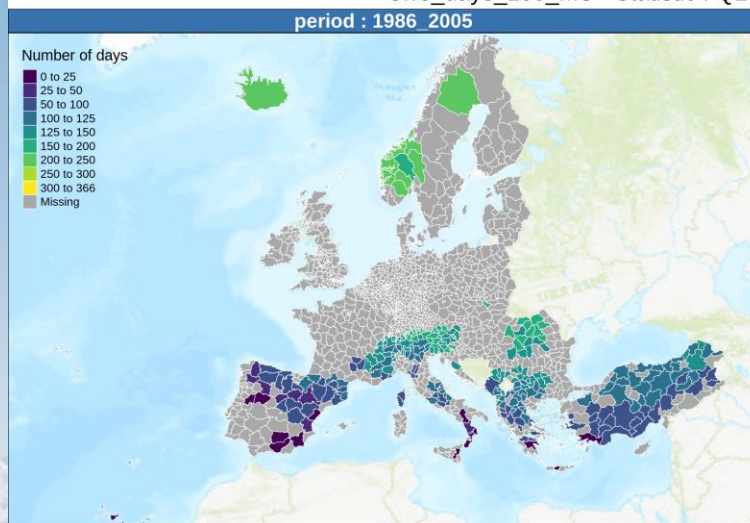




Climate
Change

**Number of
days with
more than
 100 kg m^{-2} at
1400 m
elevation
(Q10)
under
RCP8.5
(managed
snow)**

swe_days_100_MS - Statistic : Q10 - RCP : RCP85 - Elevation : 1400 m





Climate
Change

Conclusions

<https://climate.copernicus.eu/european-tourism>

A new European-wide set of climate change impact indicators for addressing climate change impacts on mountain tourism (and beyond) accounting consistently for natural and managed snow conditions (incl. water requirements).

Projection of major declines in snow reliability in European mountains, depending on time horizon, elevation and emission scenario – and snow management configuration.

Data available within a few weeks/months on the C3S Data Store (CDS) as part of the Sectoral Information System « European Tourism », including online visualization tool, open for broad exploitation (scientific and for consulting/planning studies, see case studies online).

Does not replace local, high resolution studies accounting for fine-scale topography and ski resort characteristics



CNRM UMR 3589

