Pan-European Mountain Tourism Meteorological and Snow Indicators

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

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High climate sensitivity of mountain (winter) tourism
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 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.
Local-scale studies

Marke et al., 2015

Spandre et al., in press
Need for pan-European studies for:
- Large scale sectoral assessments
- Comparisons between local markets

Recent study (Damm et al.) at European scale
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)
Pan-European Mountain Tourism
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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)
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/stddev 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
Time series, example Oberkärnten 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
Time series, example Oberkärnten 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

UERRA+Historical+RCP2.6

Natural snow
Time series, example Oberkärnten 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

UERRA+Historical+RCP2.6+RCP4.5

Natural snow
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

UERRA+Historical+RCP2.6+RCP4.5+RCP8.5

Natural snow
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

Managed snow

UERRA+Historical
Time series, example Oberkärnten 1500 m elevation (Austria)
Number of days with more than 30 cm of snow on the ground, RCP8.5
Time series, example Oberkärnten 1500 m elevation (Austria)
Number of days with more than 30 cm of snow on the ground, RCP8.5

Managed snow

sd_days_30 - Scenario : RCP45 - Configuration : MS - point : Oberkärnten 1500m
Time series, example Oberkärnten 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

Managed snow
Time series, example Oberkärntern 1500 m elevation (Austria)
Number of days with more than 30 cm of snow on the ground, RCP8.5

UERRA+Historical+RCP2.6+RCP4.5+RCP8.5
Managed snow

Reference 1986 – 2005 (HIST)
Mean/stdev & Q10/Q20/Q50/Q80/Q90
Time series, example Oberkärnten 1500 m elevation (Austria)
Number of days with more than 30 cm of snow on the ground, RCP8.5

Managed snow

UERRA+Historical+RCP2.6+RCP4.5+RCP8.5

Reference 1986 – 2005 (HIST)
Mean/stdev & Q10/Q20/Q50/Q80/Q90

2021-2040, 2041-2060, 2081-2100
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
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
Changes with elevation, France « Region Auvergne-Rhône-Alpes FRK » (NUTS-2) : production of machine made snow

2021-2040

2041-2060

2081-2100
Changes with elevation, France « Region Auvergne-Rhône-Alpes FRK » (NUTS-2) : production of machine made snow

2021-2040

2041-2060

2081-2100
Maps for a given elevation (800 m, number of days with more than 30 cm of natural snow)
Maps for a given elevation (800 m, number of days with more than 30 cm of natural snow) RCP2.6
Maps for a given elevation (800 m, number of days with more than 30 cm of natural snow) RCP8.5
Climate Change Maps for a given elevation (800 m, number of days with more than 30 cm of managed snow)
Maps for a given elevation (800 m, number of days with more than 30 cm of managed snow) RCP2.6
Maps for a given elevation (800 m, number of days with more than 30 cm of managed snow) RCP8.5
Snow production amount at 800 m elevation
Climate Change

Snow production amount at 800 m elevation RCP2.6
Snow production amount at 800 m elevation RCP8.5
Number of days with more than 100 kg m\(^{-2}\) at 1400 m elevation (mean)

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

A new Europan-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

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