

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

European and Alpine Snow Cover in a Changing Climate

Observations Processes Projections

Sven Kotlarski
MeteoSwiss



***Future
Scenarios***

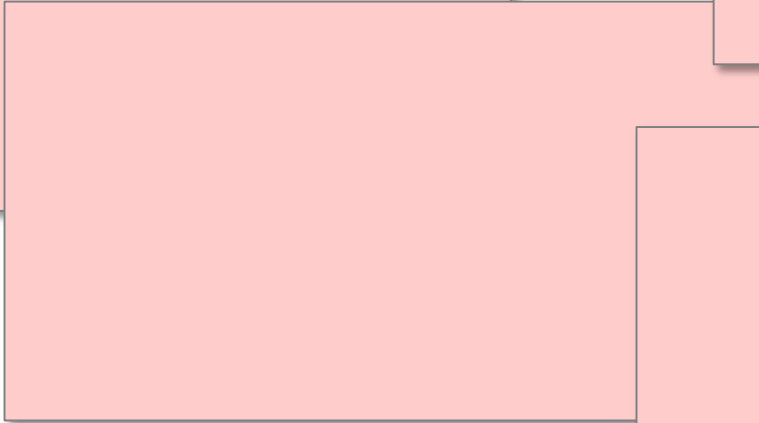
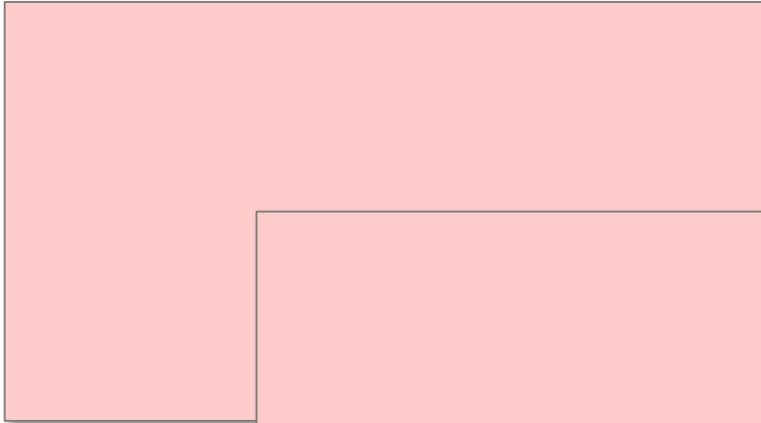


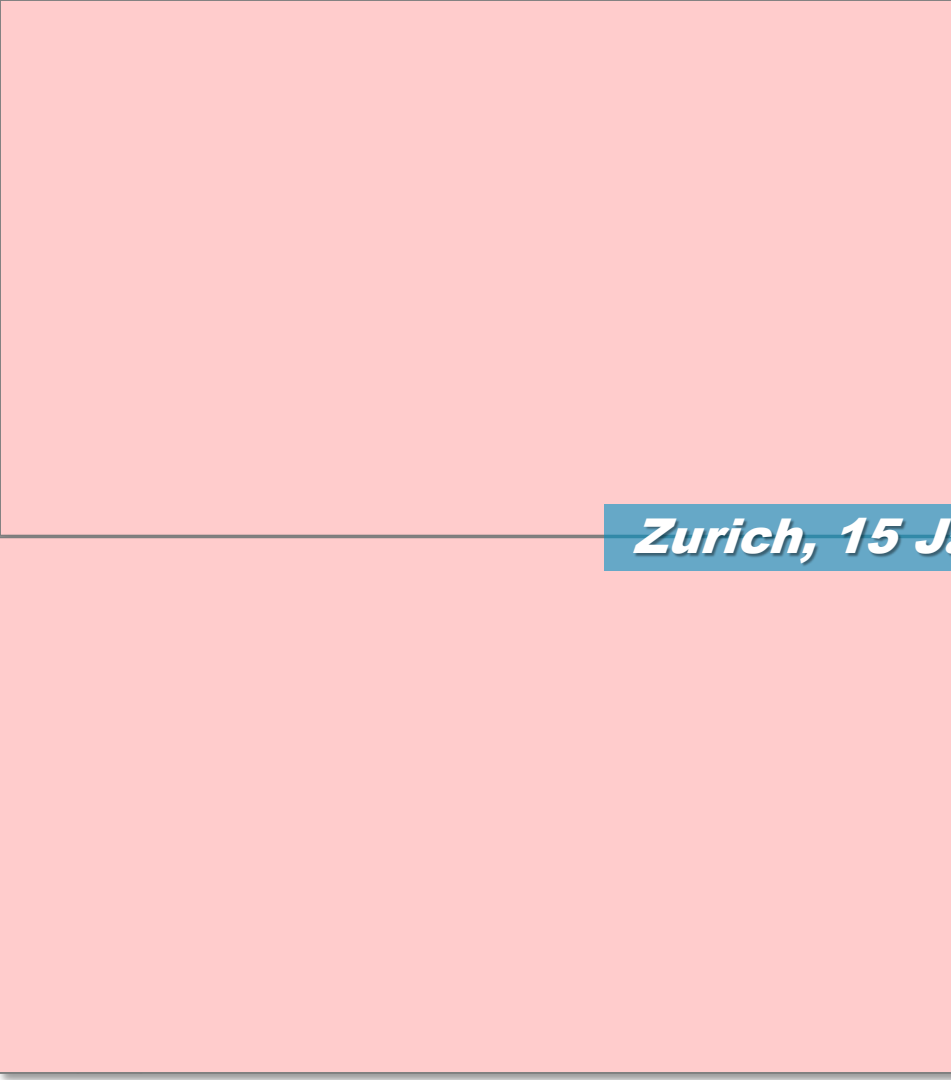
***Past
Evolution***

***Snow Cover
and Climate***



Northern Germany this week ...





Zurich, 15 January 2021

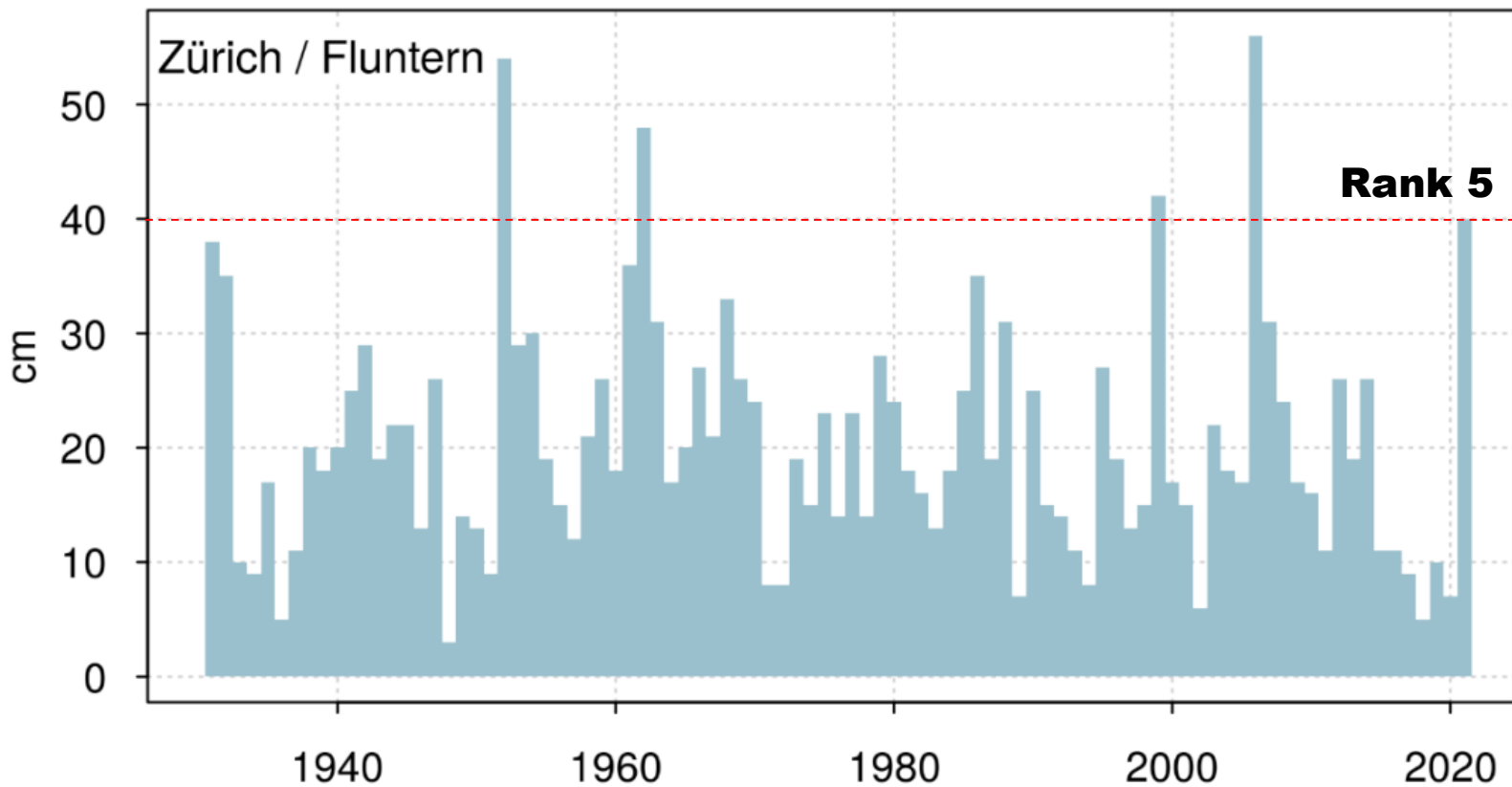
Photo: Sven Kotlarski



Photo: Sven Kotlarski



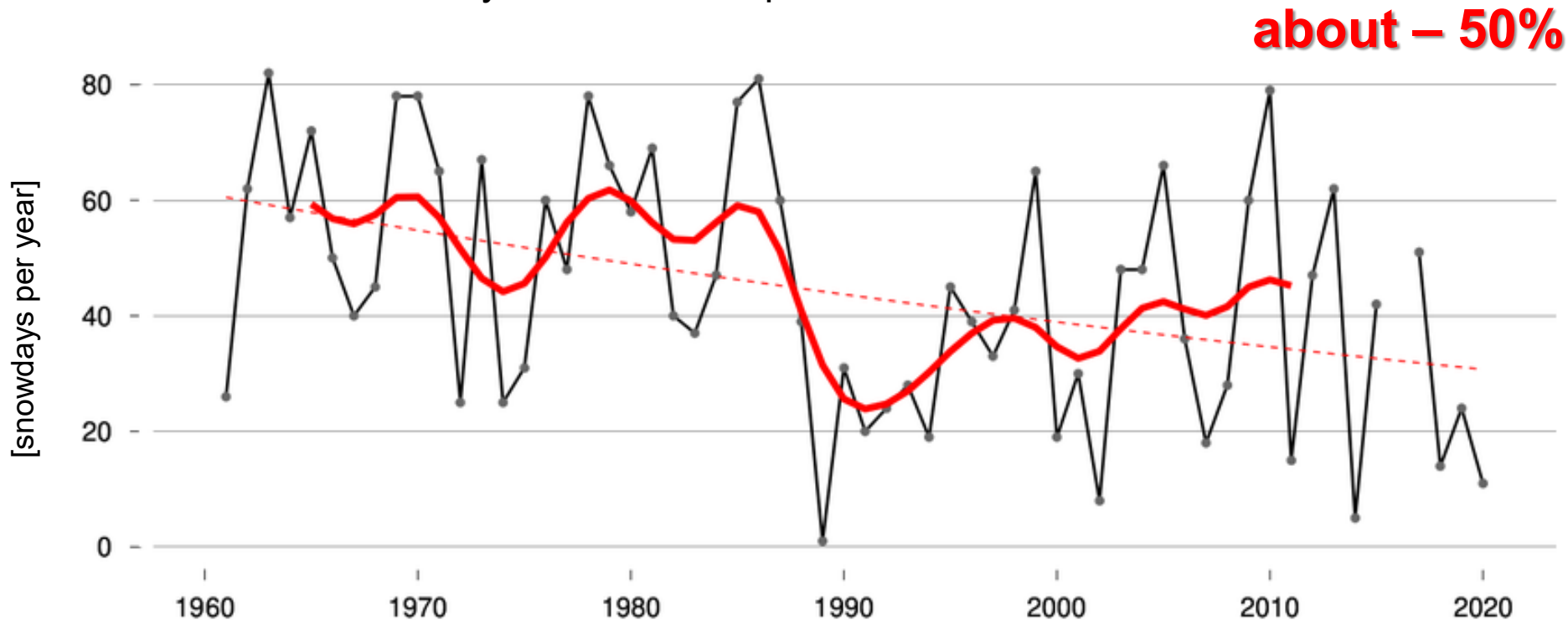
Annual max. 2-day new snow sum in Zurich





Snow days in Zurich

Annual number of days with snow depth > 1 cm

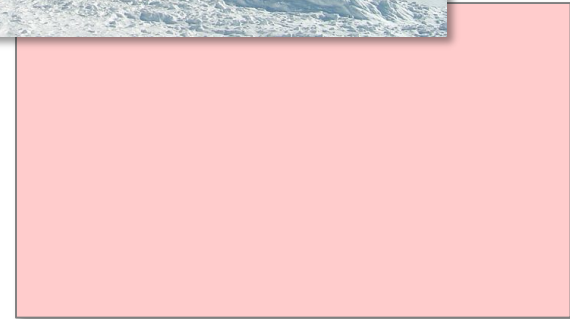


Relation can be complex...

large number of indicators, extremes vs. means, local vs. regional scale, ...

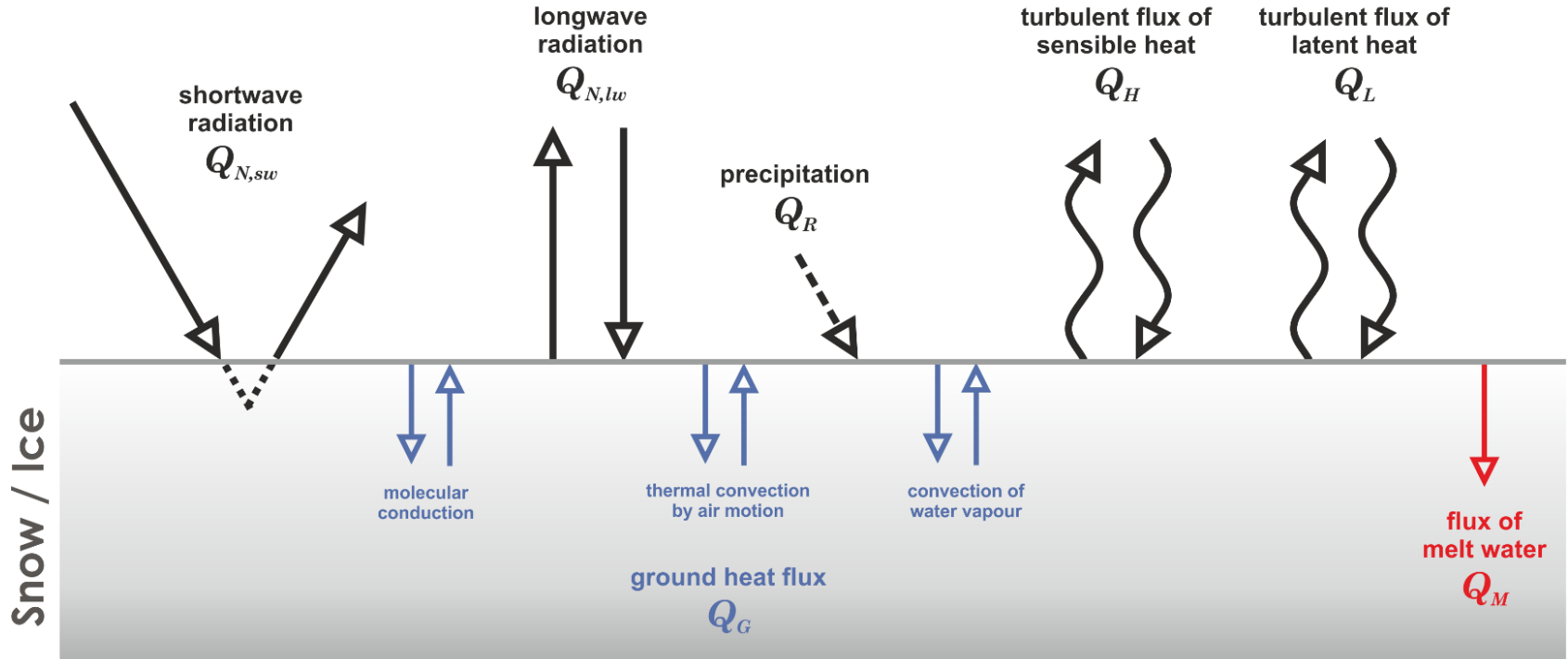
Snow cover is relevant ...

- Important **natural water resource**
(CH: **30%** of annual precipitation, **40%** of annual discharge, **60%** of electricity by hydropower)
- High importance for **tourism and recreation** in many regions
- **Natural hazards** (snow avalanches, spring meltwater, ...)
- **Ecology, Agriculture, ...**
- **Interactive component of global and regional weather and climate systems**



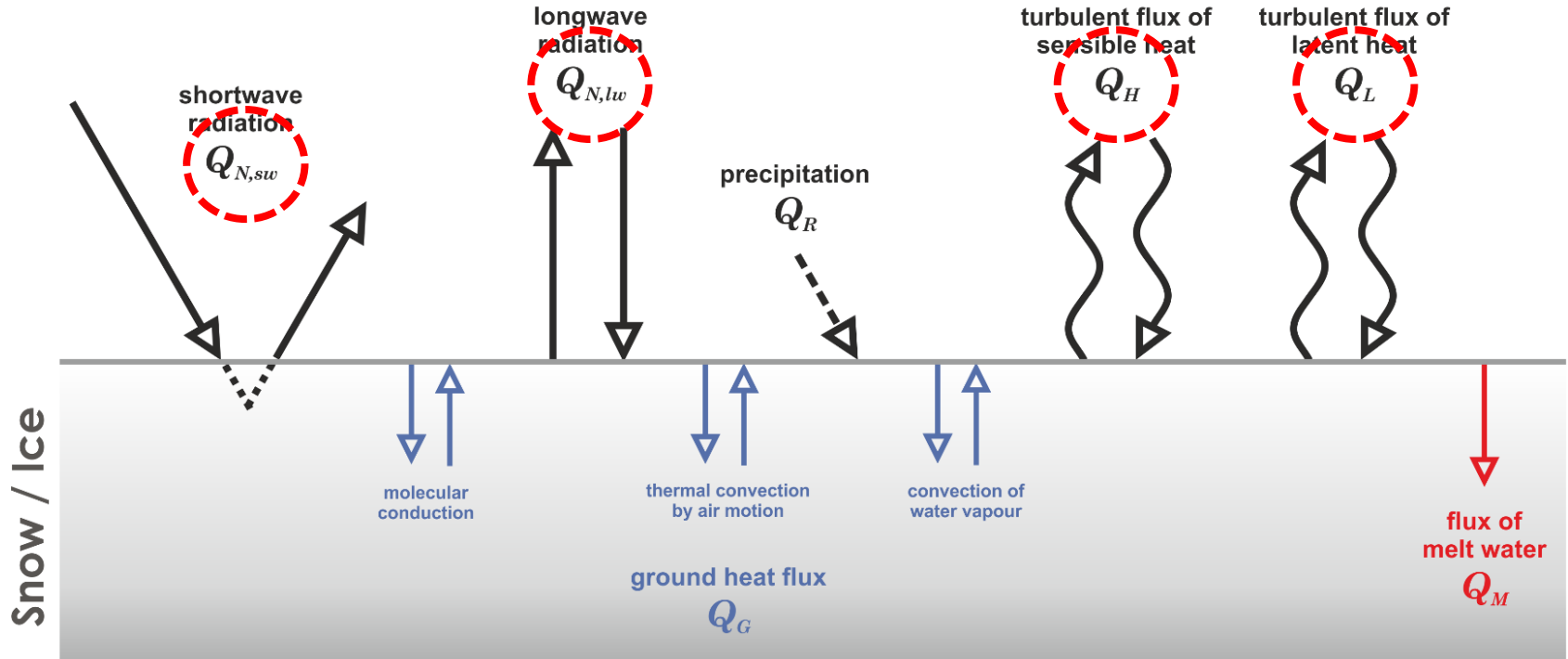


Surface energy balance of the snow pack





Surface energy balance of the snow pack



Kottarski 2007 (modified after Oerlemans 2001)

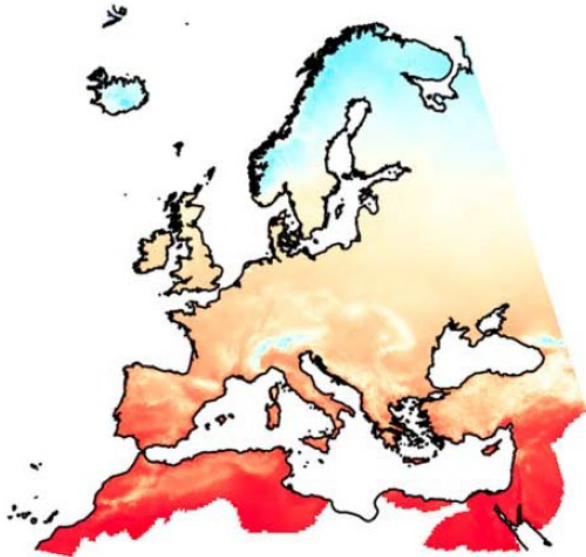
Air temperature as a primary driver (or at least a good proxy)



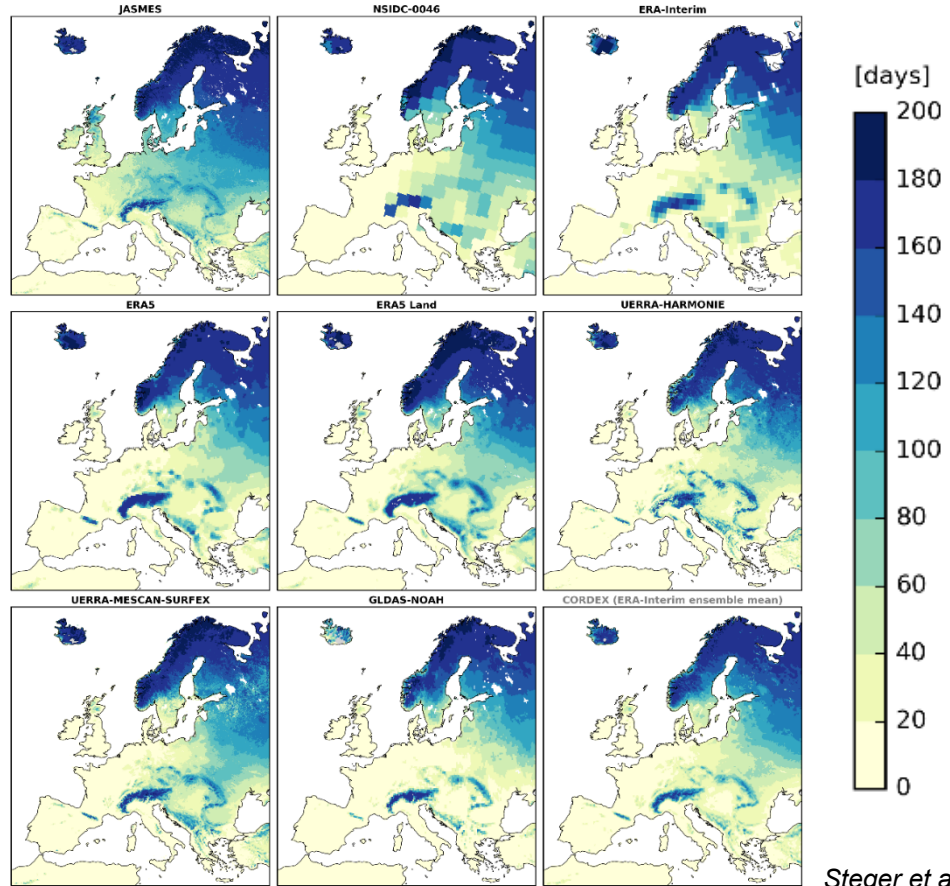
European snow coverage

Mean number of
snow-covered days
per year (1989 – 2007)

Annual mean temperature 1981-2010 (E-OBS)



Cornes et al. 2018



Steger et al., in prep.



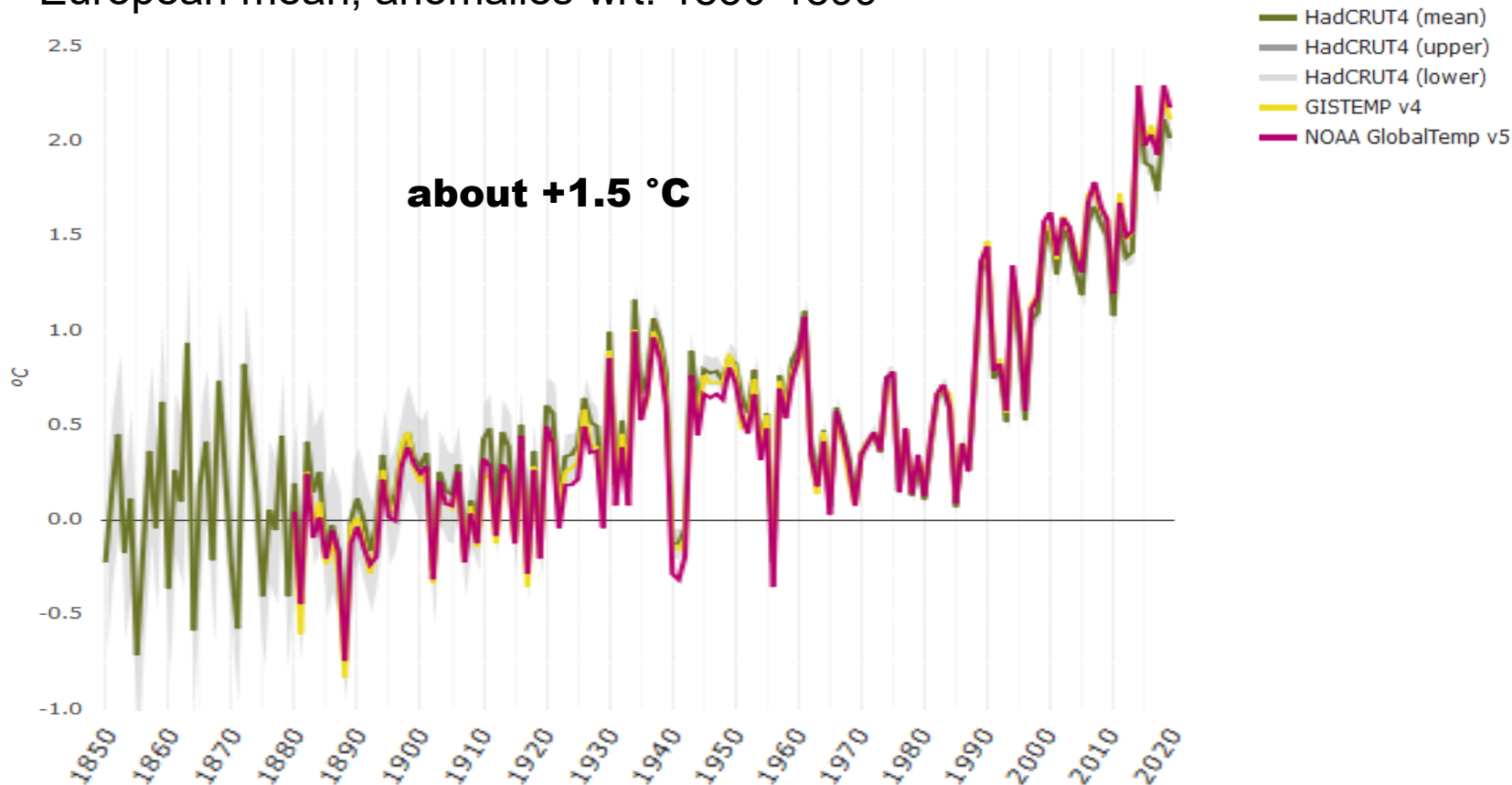
*Snow Cover
and Climate*

*Past
Evolution*



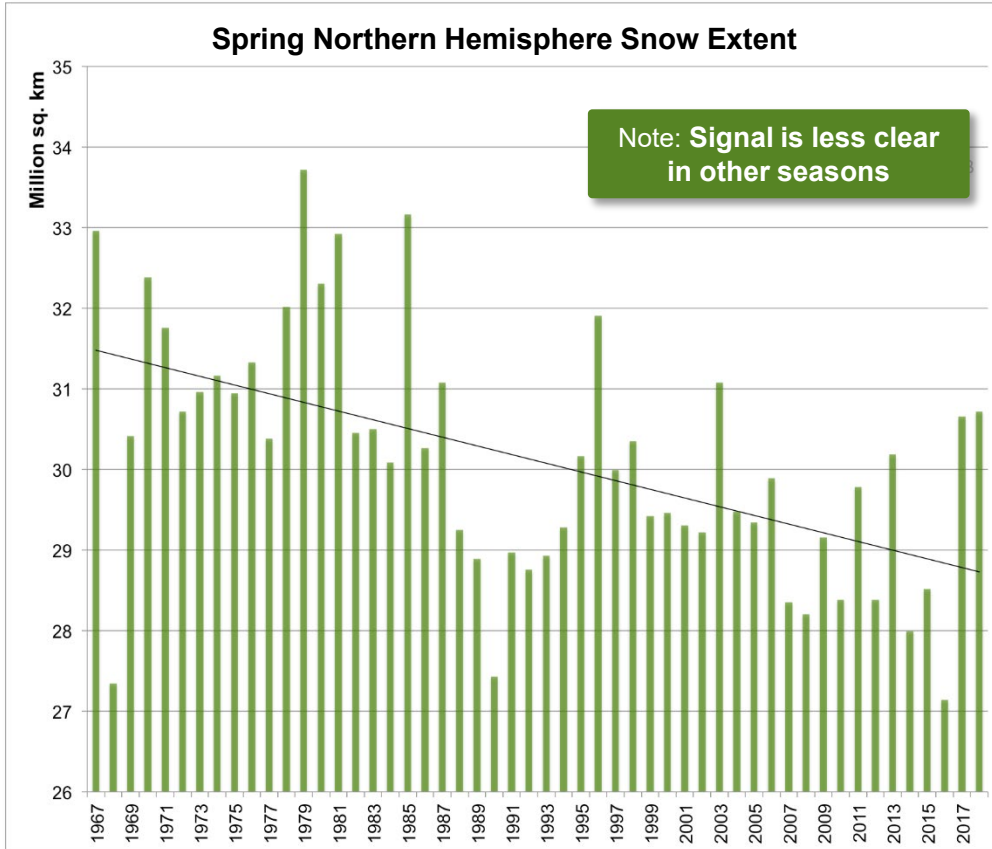
Evolution of annual mean temperature

European mean, anomalies wrt. 1850-1899

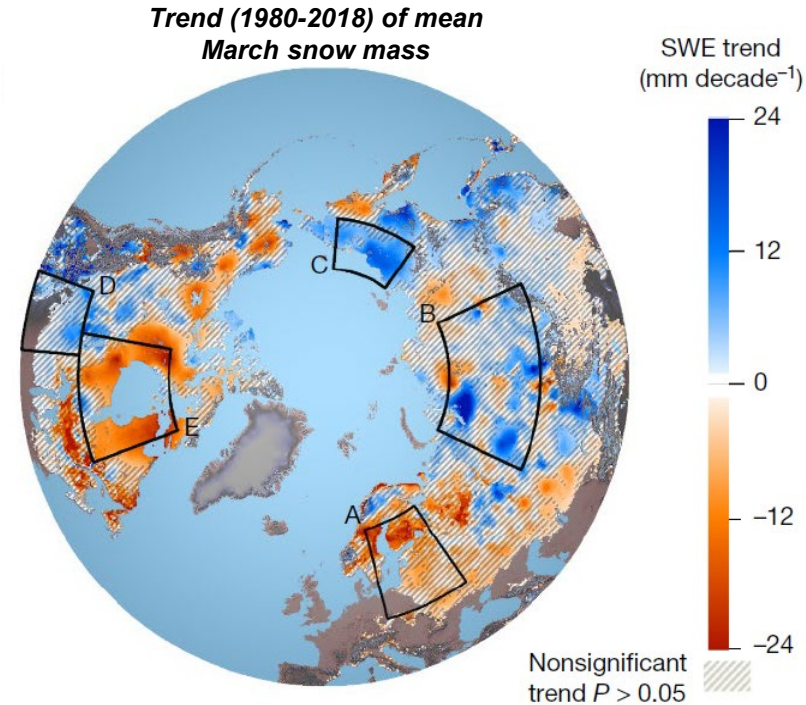




Northern Hemisphere Snow Cover Change



Source: <https://climate.rutgers.edu>




Pulliainen, Nature 2020

“Our analysis shows **that the maximum continental-scale snow mass for Eurasia is not declining, but instead showing, on average, consistent values even though regional trends are strong.**”

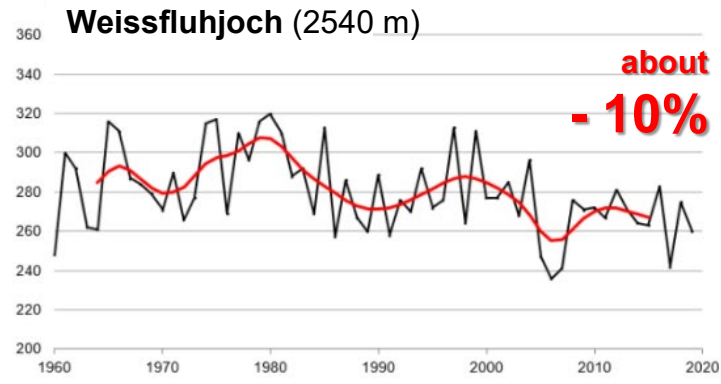
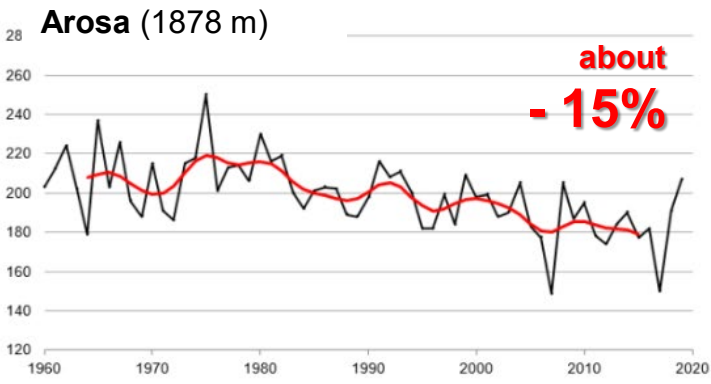
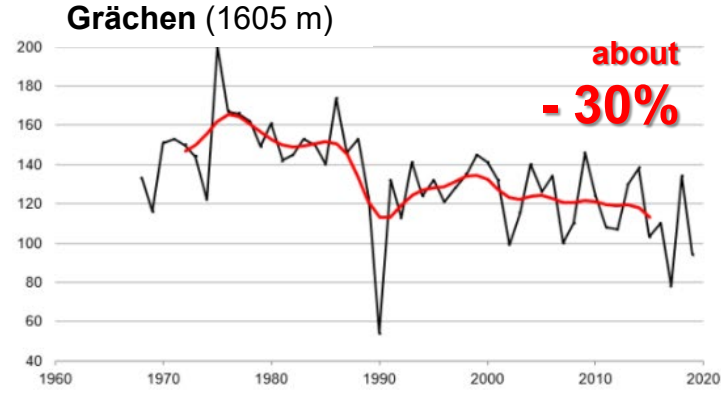
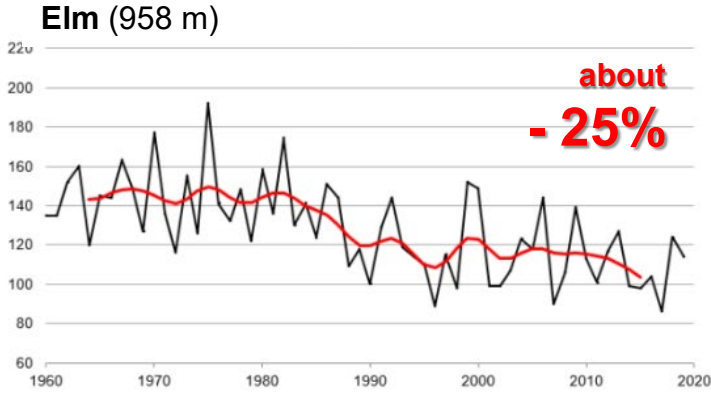


Observed Snow Cover Change Switzerland

Number of days per year > 1 cm snow depth



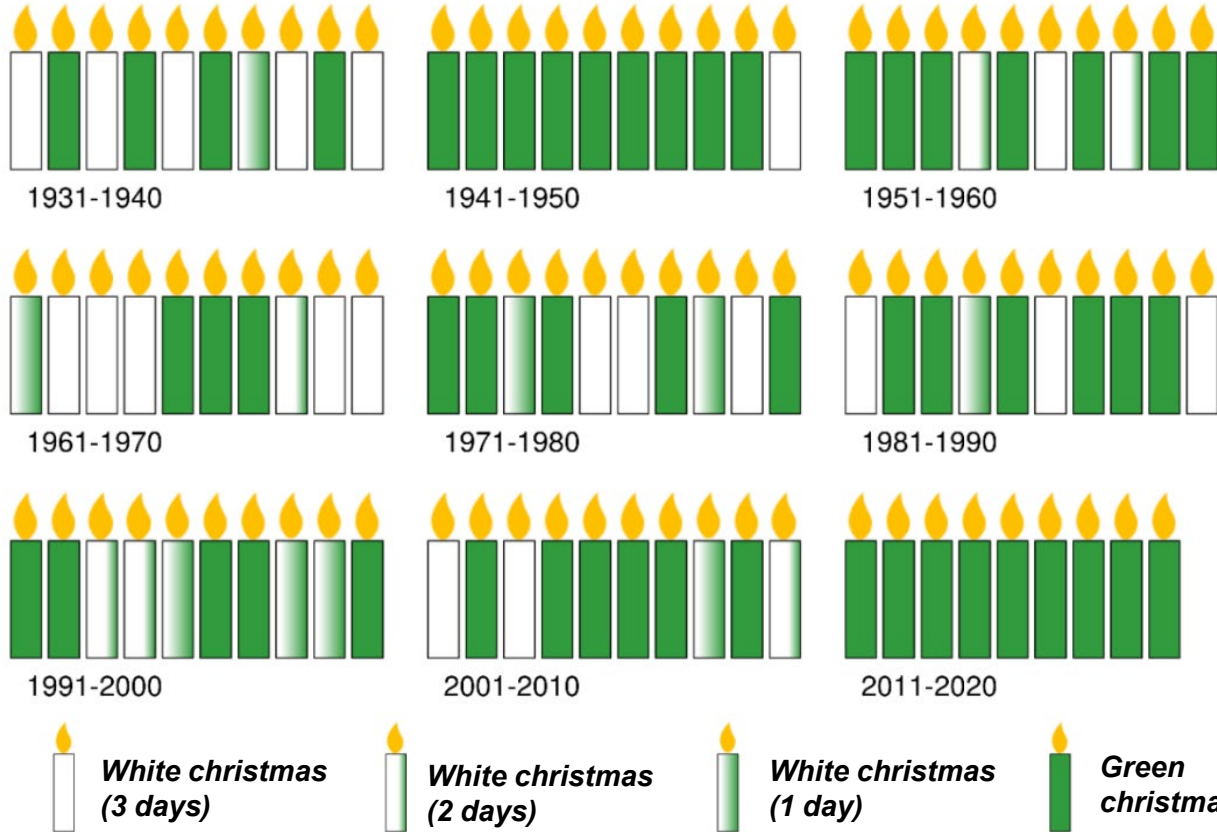
+2°C
since 1864





White Christmas in Zurich?

Snow cover on 24th December to 26th December



***Future
Scenarios***



***Past
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Climate projections and impact modelling

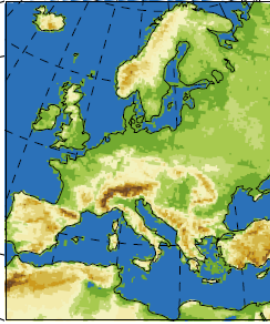
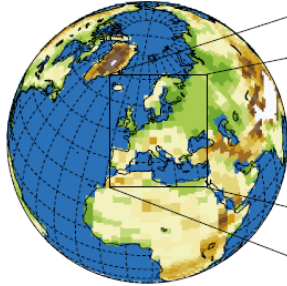
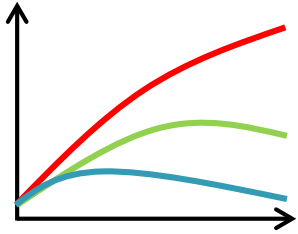
Greenhouse
gas scenario

GCM

~ 150 km

RCM

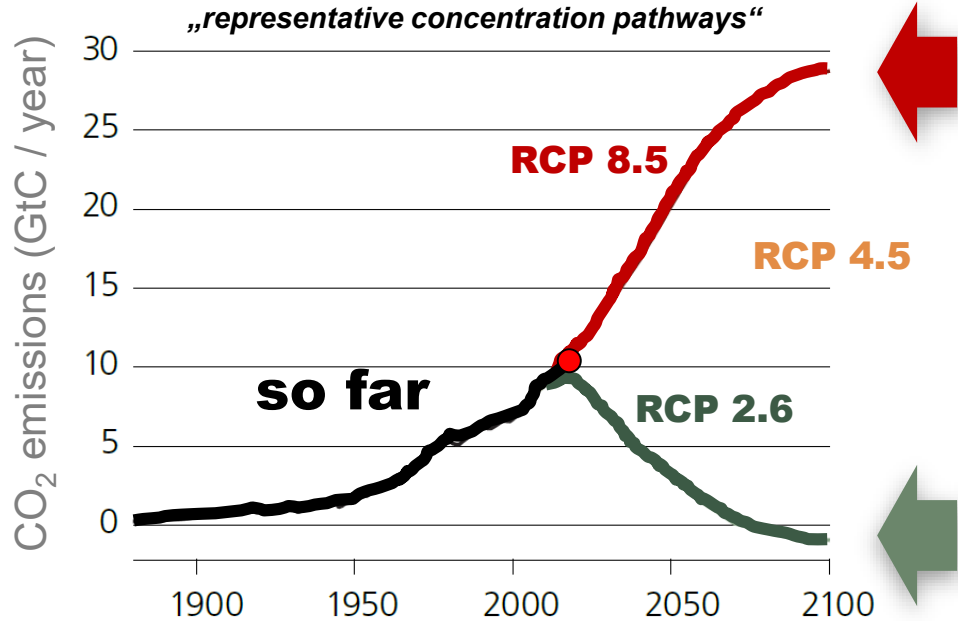
~ 10-50 km





Greenhouse gas scenarios: **What if?**

Are prescribed to climate model simulations



**A fossil world
without climate mitigation**

**Strong mitigation
«Paris»**



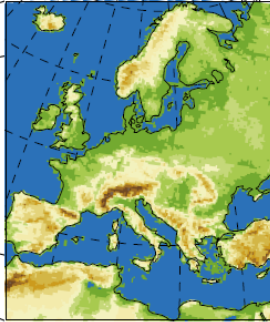
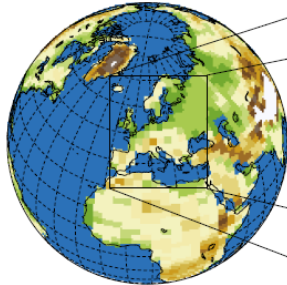
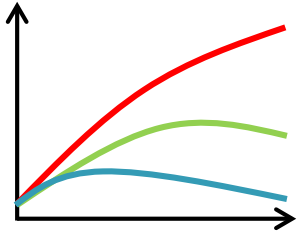
Climate projections and impact modelling

Greenhouse gas scenario

GCM
~ 150 km

RCM
~ 10-50 km

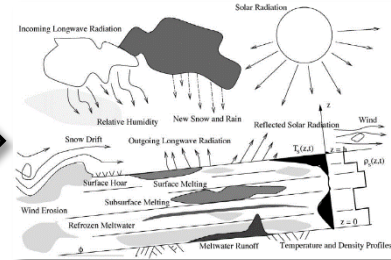
Impact
Local to regional scale



Spatial scale

Translation

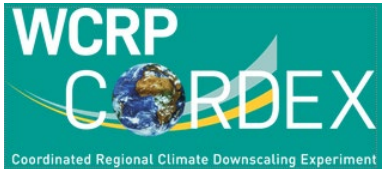
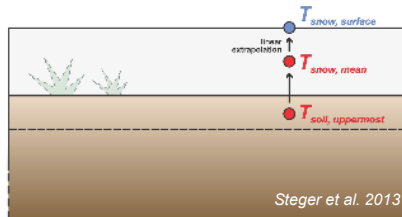
Climate model biases



Bartelt and Lehning 2002

- Time-dependent snow albedo (e.g. 0.4 - 0.7)
- Prognostic snow density (50 - 400 kg m⁻³)

surface energy fluxes



Use ensembles to quantify uncertainties



EURO-CORDEX Climate Projections

RCP 8.5, with respect to 1981-2010

Winter (DJF) temperature change [°C]

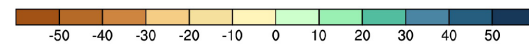
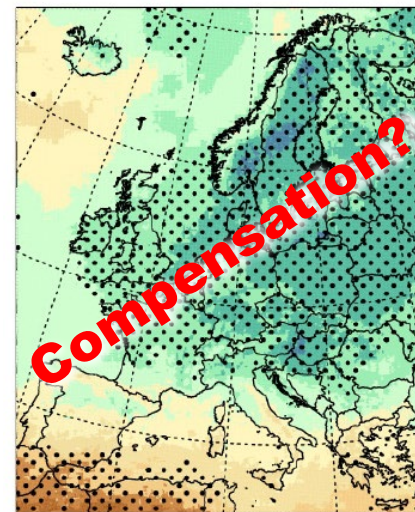
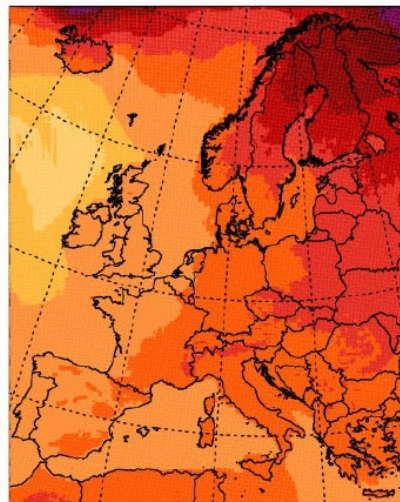
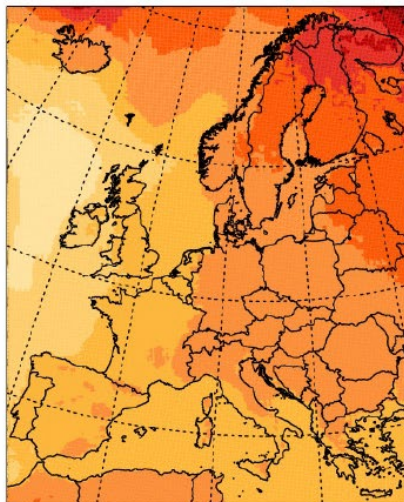
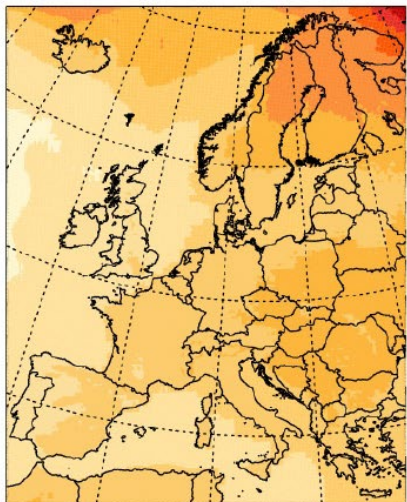
Winter (DJF)
precipitation change [%]

2035

2060

2085

2085





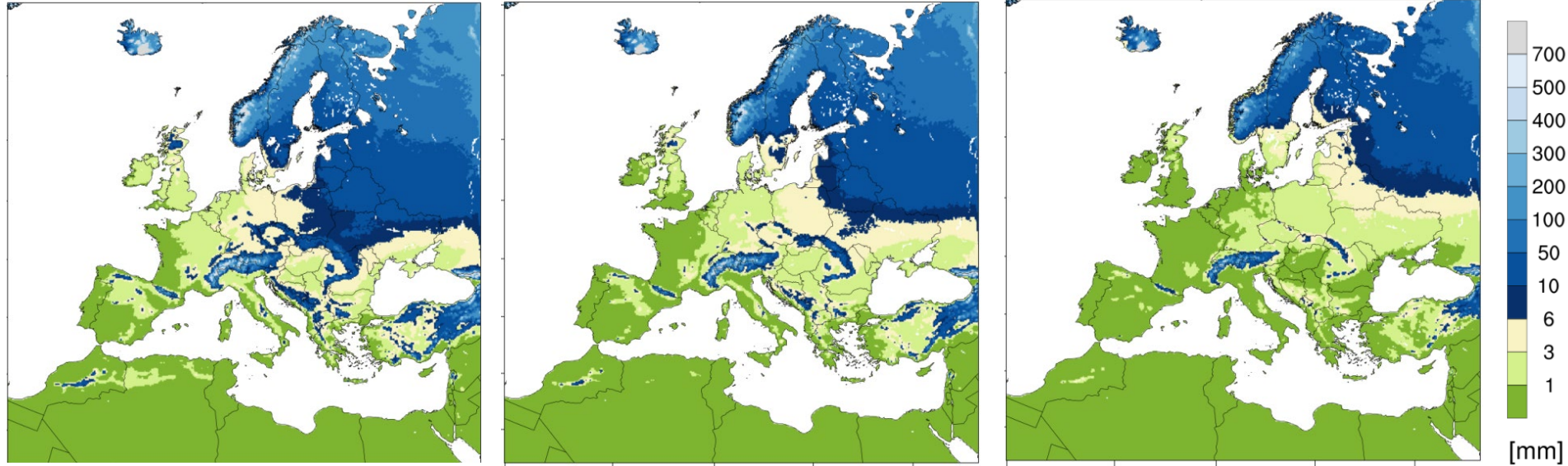
Mean Winter (Nov-Apr) SWE Change

EURO-CORDEX Ensemble Mean, RCP 8.5

1971 - 2000

2021 - 2050

2070 - 2099



The projected increase in winter precipitation does not offset the warming effect.



Mean winter SWE change Alps

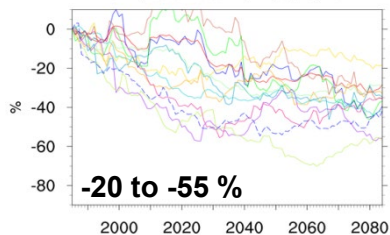
numbers:
Relative change wrt. 1971-2000



RCP2.6

500 – 1000 m

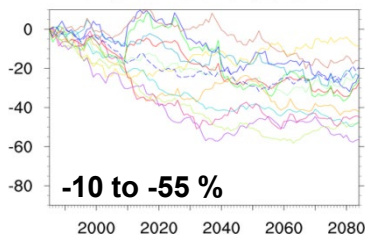
snw, 500-1000 m, Alps, rcp26



-20 to -55 %

1000 – 1500 m

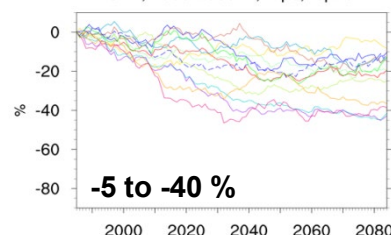
snw, 1000-1500 m, Alps, rcp26



-10 to -55 %

1500 – 2000 m

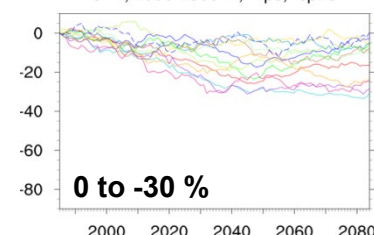
snw, 1500-2000 m, Alps, rcp26



-5 to -40 %

2000 – 2500 m

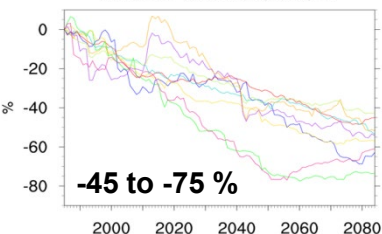
snw, 2000-2500 m, Alps, rcp26



0 to -30 %

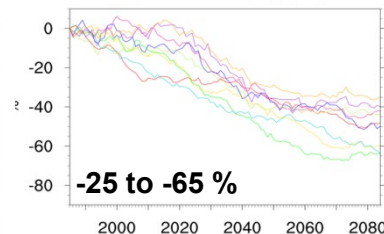
RCP4.5

snw, 500-1000 m, Alps, rcp45



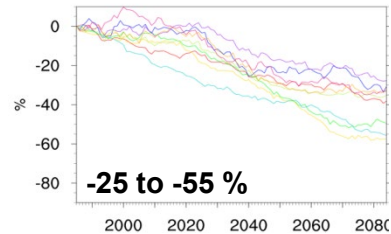
-45 to -75 %

snw, 1000-1500 m, Alps, rcp45



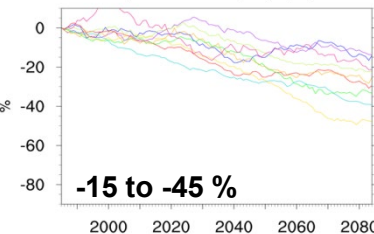
-25 to -65 %

snw, 1500-2000 m, Alps, rcp45



-25 to -55 %

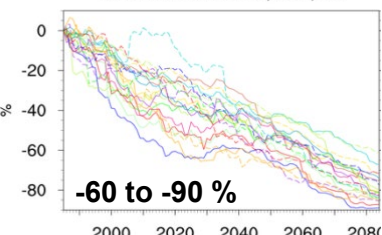
snw, 2000-2500 m, Alps, rcp45



-15 to -45 %

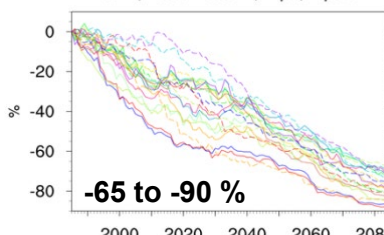
RCP8.5

snw, 500-1000 m, Alps, rcp85



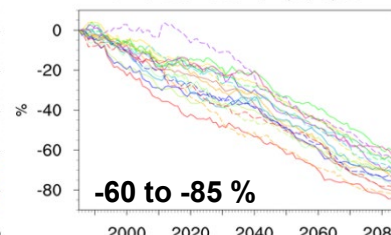
-60 to -90 %

snw, 1000-1500 m, Alps, rcp85



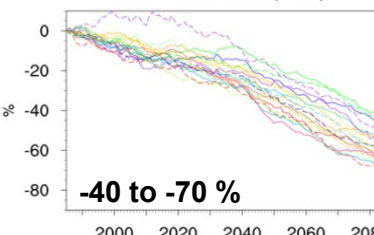
-65 to -90 %

snw, 1500-2000 m, Alps, rcp85



-60 to -85 %

snw, 2000-2500 m, Alps, rcp85



-40 to -70 %



Mean winter SWE change Alps

numbers:
Relative change wrt. 1971-2000



500 – 1000 m

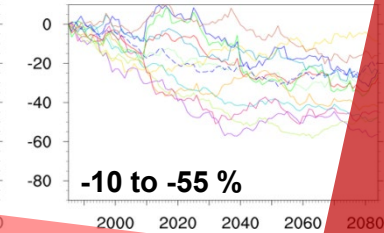
snw, 500-1000 m, Alps, rcp26



Percentage loss

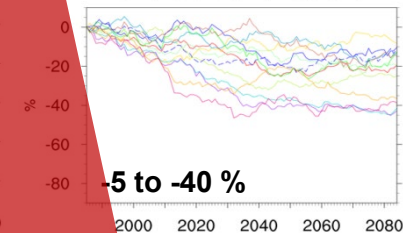
1000 – 1500 m

snw, 1000-1500 m, Alps, rcp26



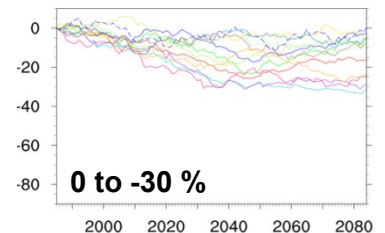
1500 – 2000 m

snw, 1500-2000 m, Alps, rcp26



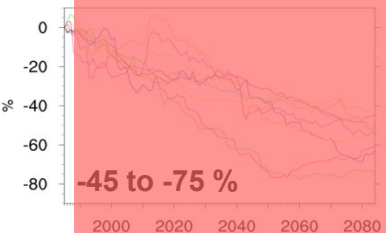
2000 – 2500 m

snw, 2000-2500 m, Alps, rcp26

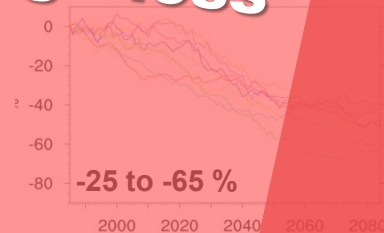


RCP2.6

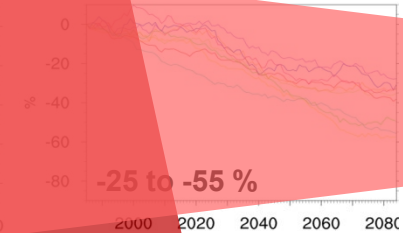
snw, 500-1000 m, Alps, rcp45



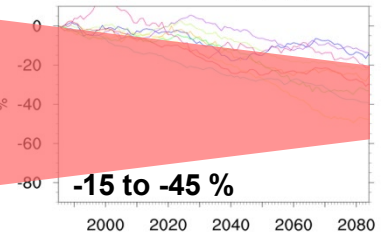
snw, 1000-1500 m, Alps, rcp45



snw, 1500-2000 m, Alps, rcp45

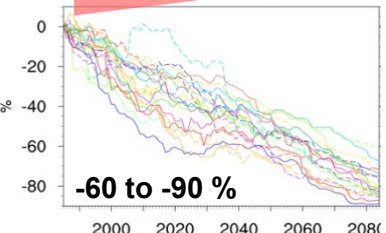


snw, 2000-2500 m, Alps, rcp45

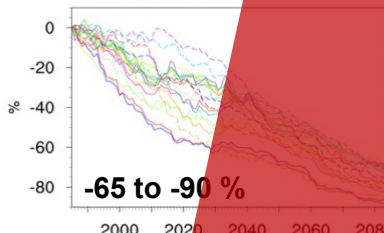


RCP4.5

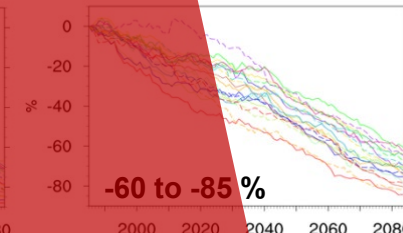
snw, 500-1000 m, Alps, rcp85



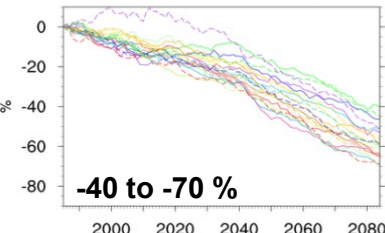
snw, 1000-1500 m, Alps, rcp85



snw, 1500-2000 m, Alps, rcp85



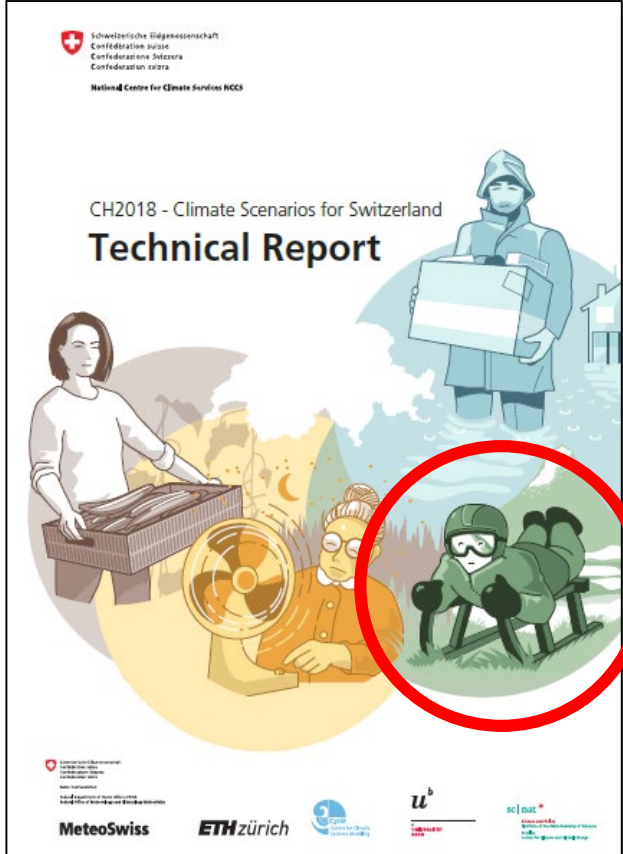
snw, 2000-2500 m, Alps, rcp85



RCP8.5



The CH2018 Climate Scenarios for Switzerland






www.climate-scenarios.ch

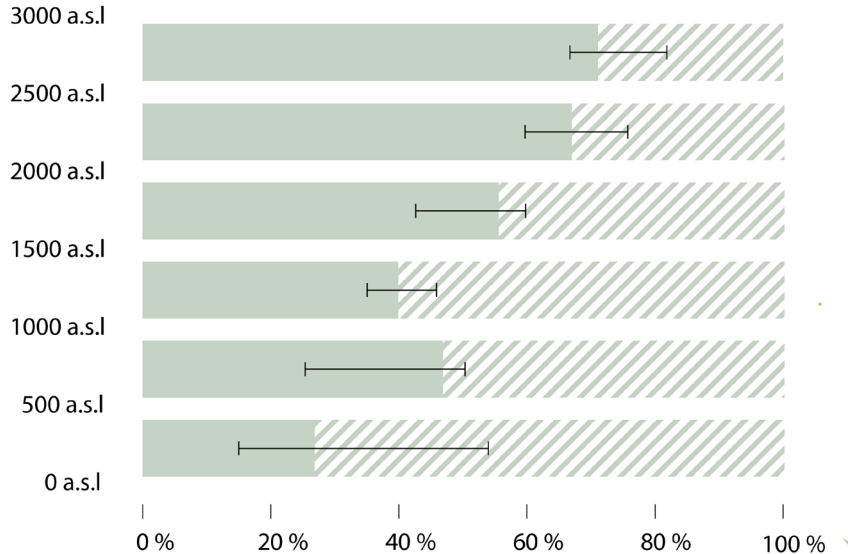


Snow cover

Snow cover around 2060 without climate change mitigation as a percentage of today's norm, in terms of average snow water equivalent from September to May at different altitudes (30-year averages).

RCP 8.5 by mid-century

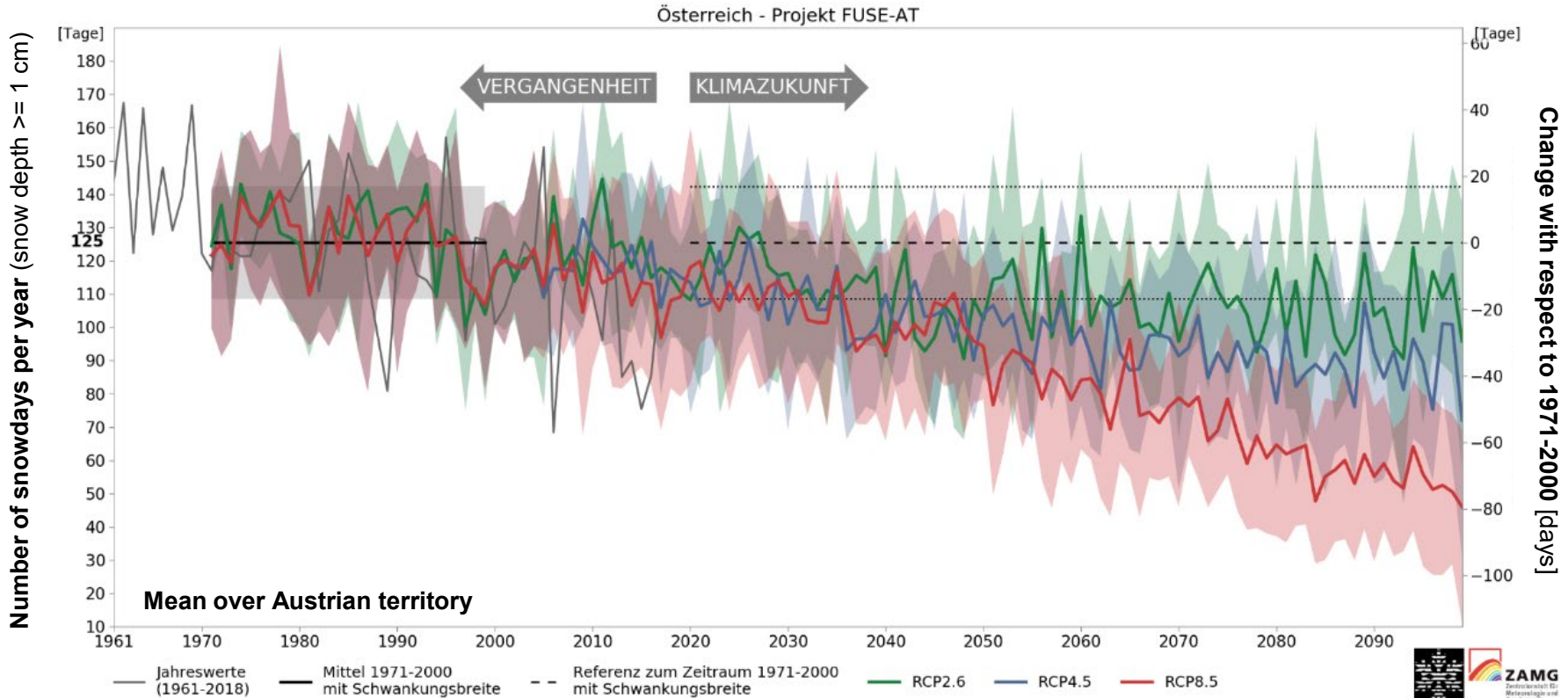
 Loss (today = 100%)
  Expected around mid-century (median of all simulations)
  Possible (range of simulations).





FUSE-AT: Snow projections for Austria

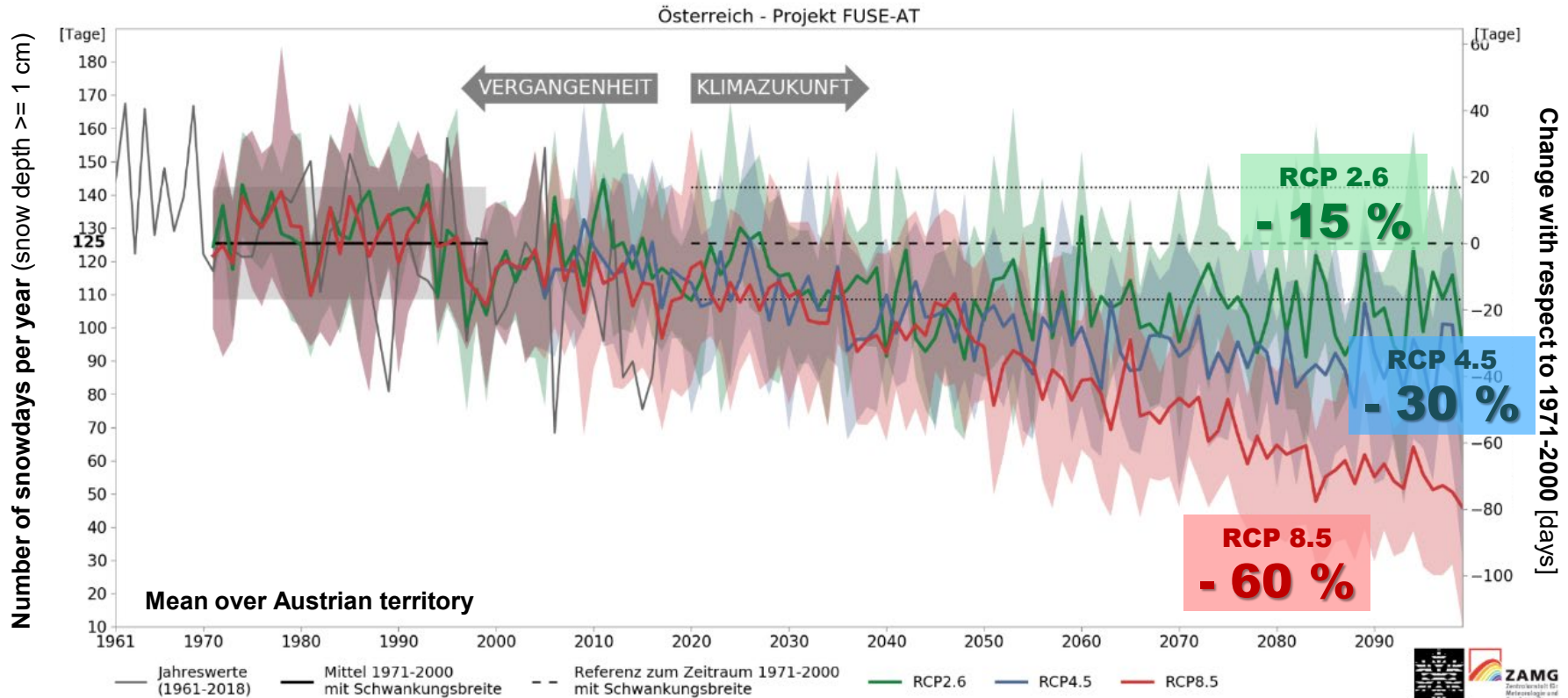
Offline snowpack model driven by bias-adjusted EURO-CORDEX data





FUSE-AT: Snow projections for Austria

Offline snowpack model driven by bias-adjusted EURO-CORDEX data



***Future
Scenarios***

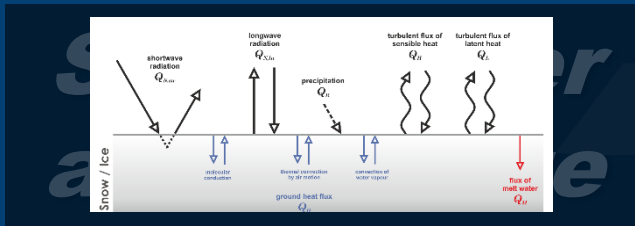
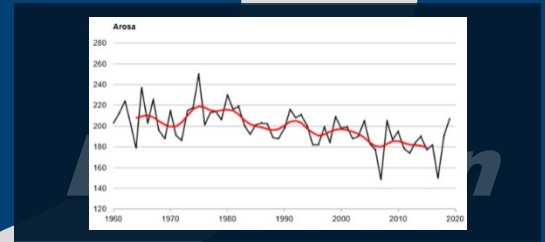
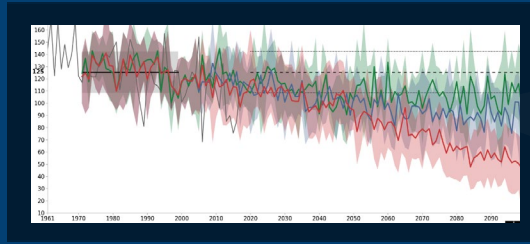


***Past
Evolution***

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➔ Michael Rothleitner



Thank you!