Climate Modeling in the Alps

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Thanks to:
Nikolina Ban, Roman Brogli, Oliver Fuhrer, Laureline Hentgen, David Leutwyler, Samuel Lüthi, and others

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Wir bauen Brücken. Seit 1669

International Mountain Conference 2019, Innsbruck,8-12 September 2019

Flash floods

Role of climate change?

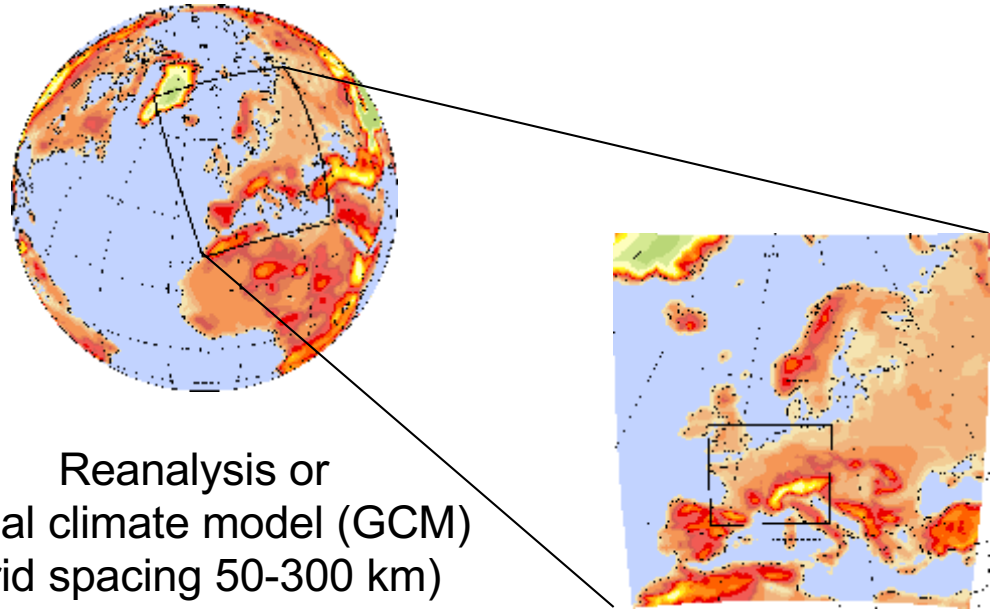
Flash flood
Zürich, Haldenegg

Hail
Zürich, Winterthurerstrasse, June 1, 2012

Convection over Lake Millstätter, Austria

June 10, 2018 (Peter Maier, Facebook)

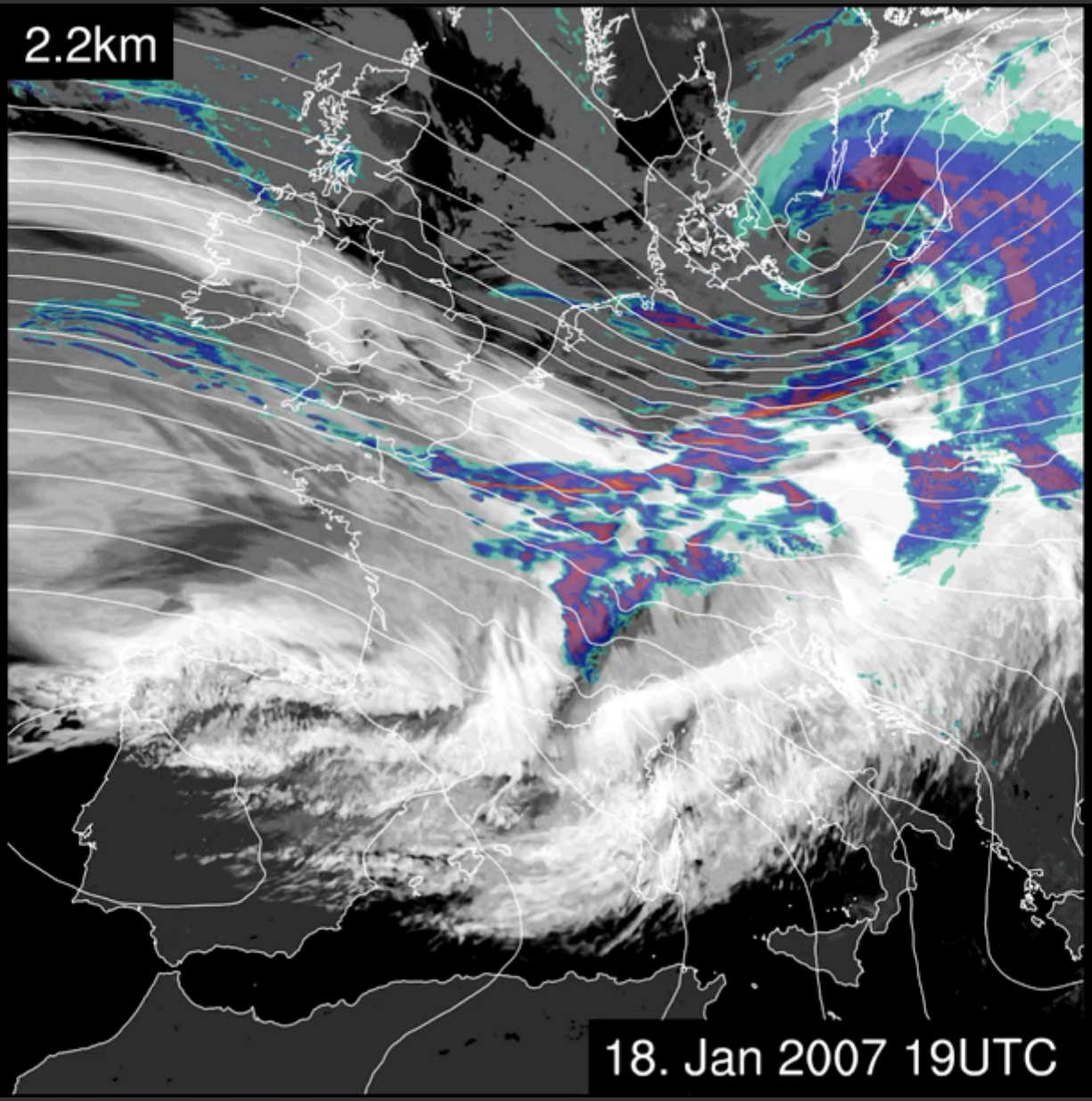
GCM and RCM simulations



Reanalysis or
global climate model (GCM)
(grid spacing 50-300 km)

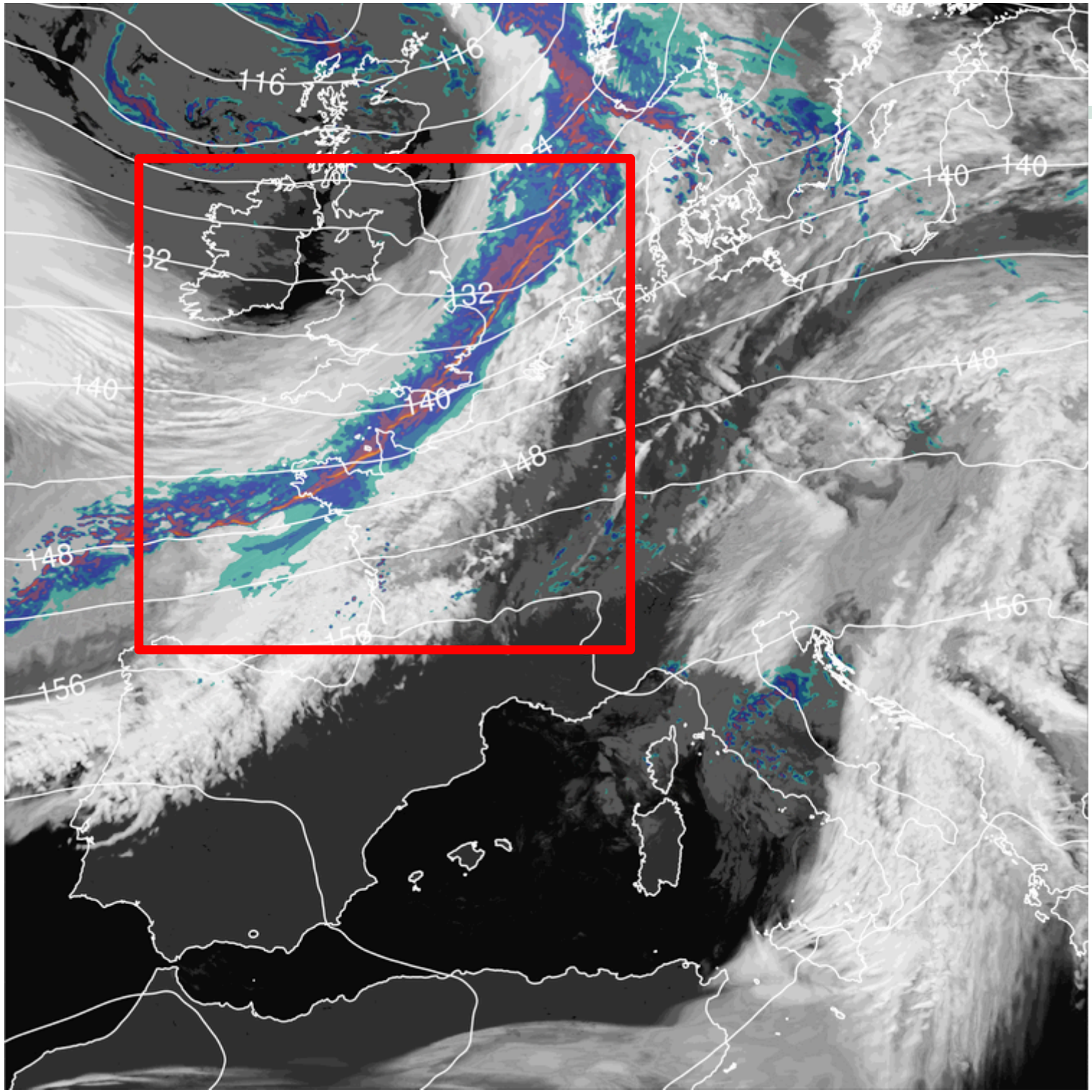
Regional climate model (RCM)
(grid spacing 2-50 km)

2 km simulation driven by ERA



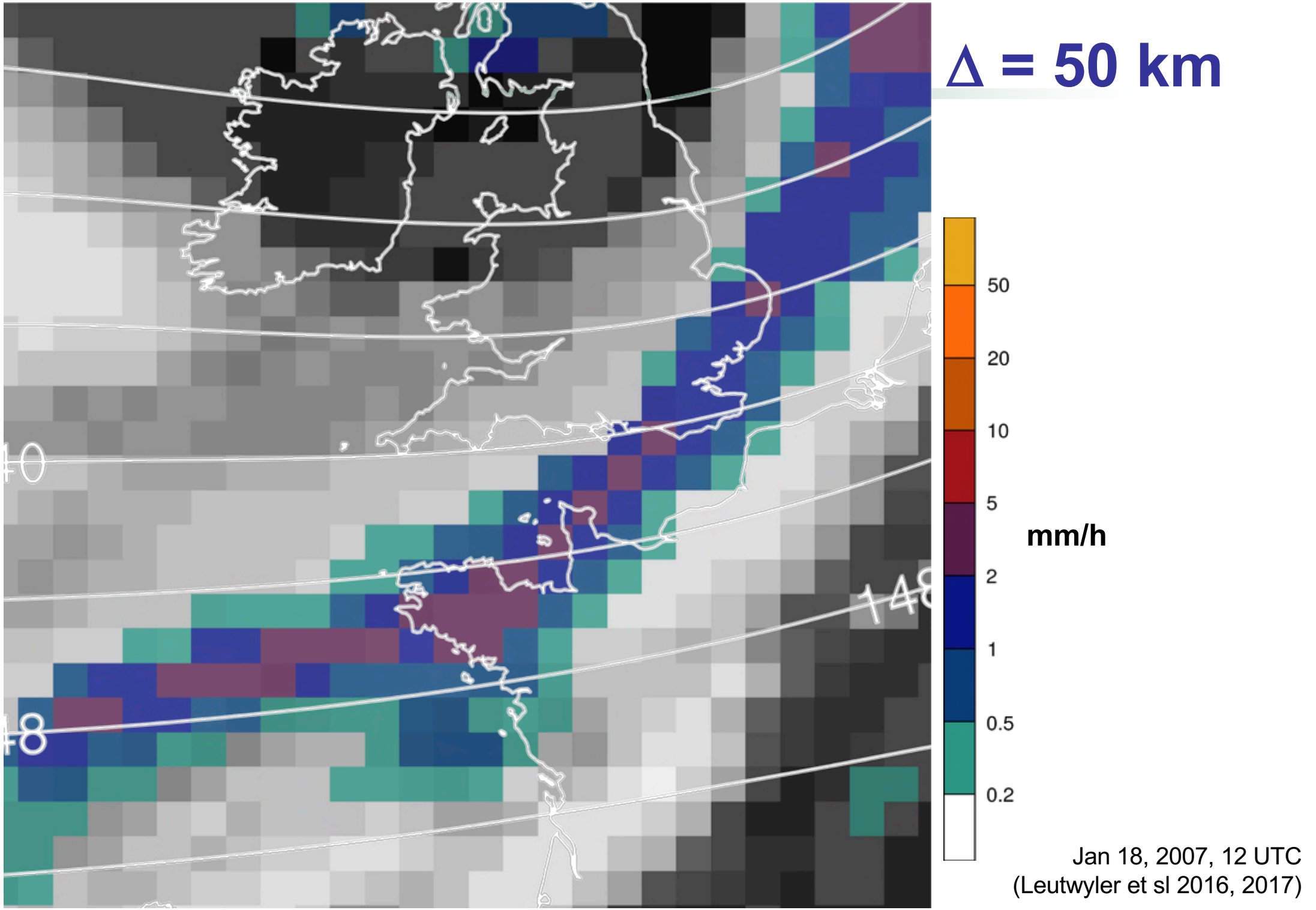
David Leutwyler, ETH Zurich, animations via crCLIM: http://www.c2sm.ethz.ch/research/crCLIM

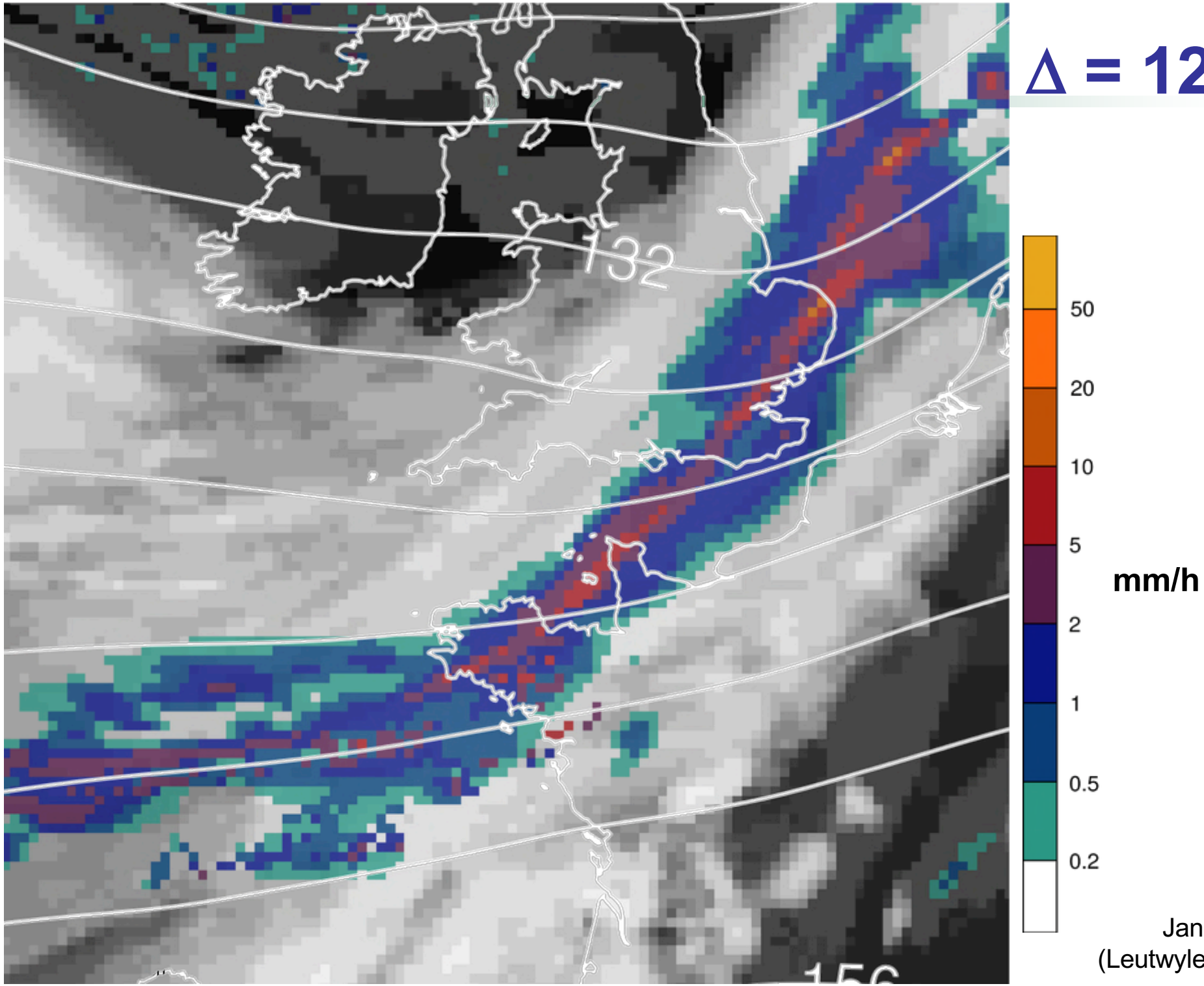
Multiscale challenge

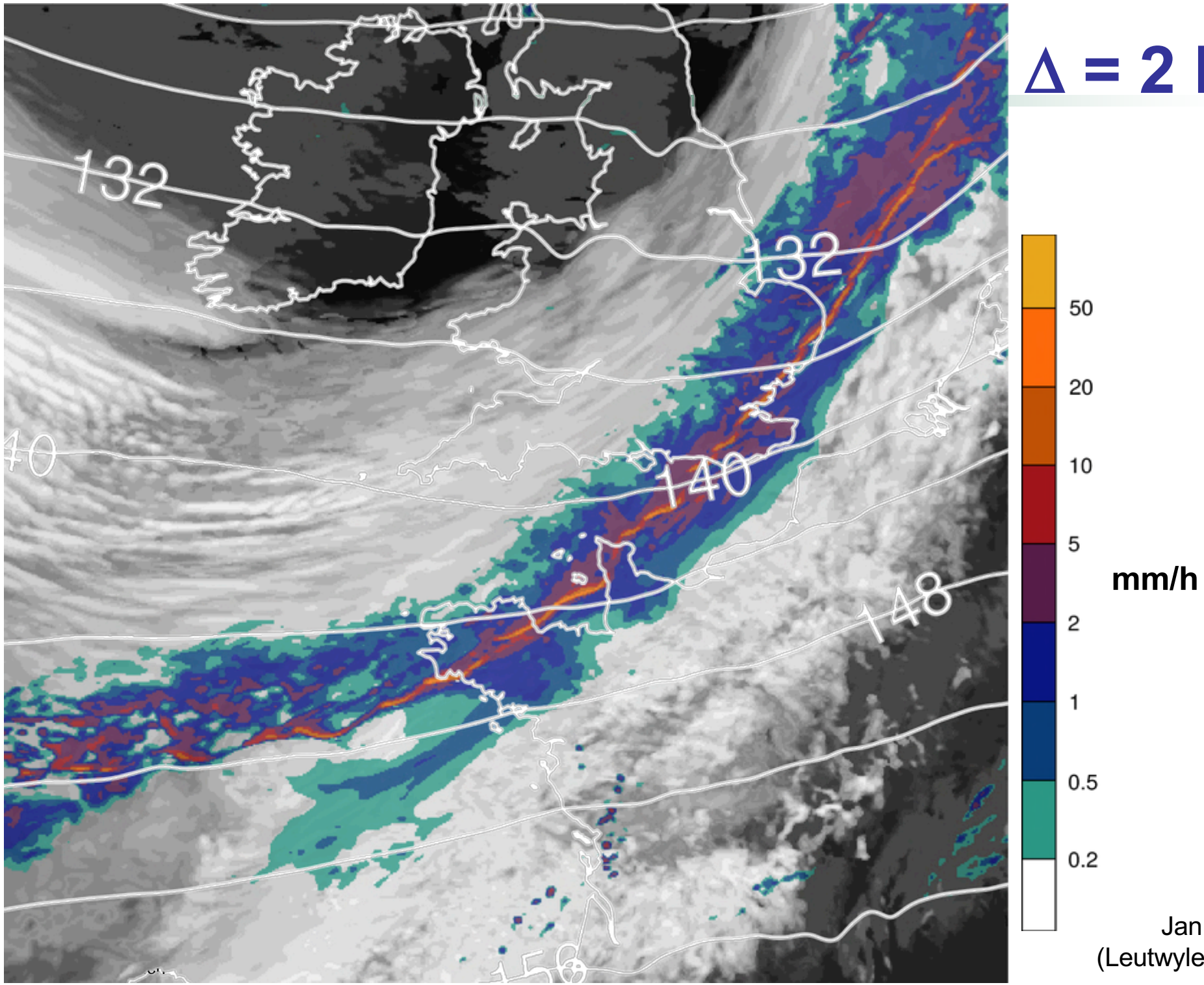


Δ = 2 km

Jan 18, 2007, 12 UTC
(Leutwyler et sl 2016, 2017)


Δ = 50 km
50
20
10
5
2
1
0.5
0.2
mm/h
Jan 18, 2007, 12 UTC
(Leutwyler et sl 2016, 2017)


Δ = 12 km
132
50
20
10
5
2
1
0.5
0.2
mm/h
Jan 18, 2007, 12 UTC
(Leutwyler et sl 2016, 2017)

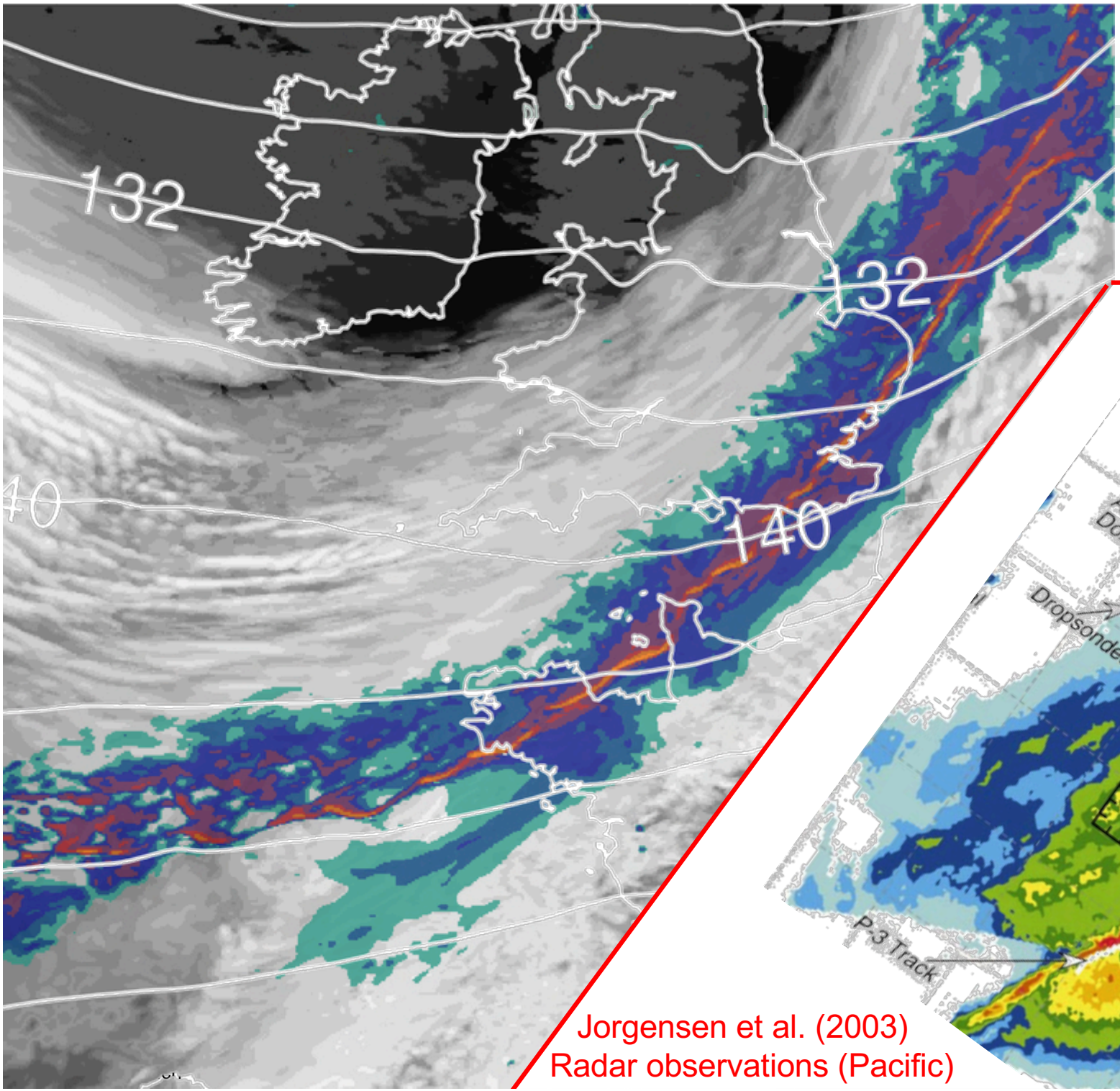


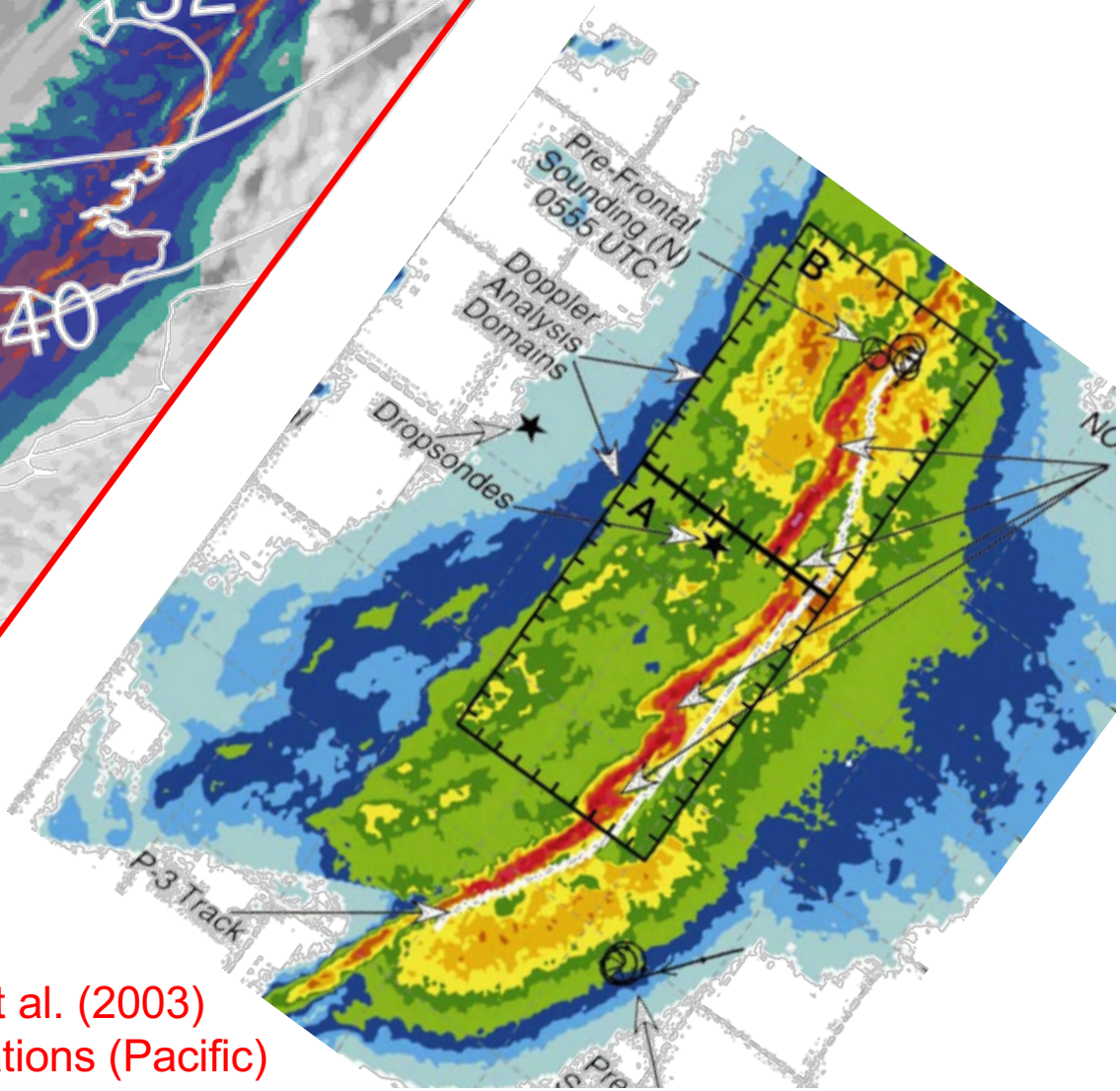
Δ = 2 km

Jan 18, 2007, 12 UTC
(Leutwyler et sl 2016, 2017)

Δ = 2 km

Break-up of cold-frontal rain band





Jorgensen et al. (2003)
Radar observations (Pacific)

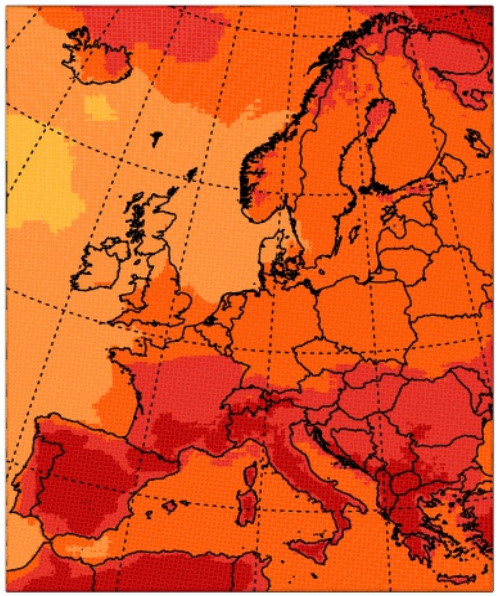

Sommer drought?
(Keystone / Anthony Anex)

Mediterranean amplifcation

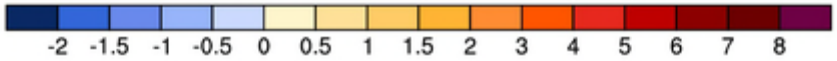
RCP8.5, 2070-2099 versus 1981-2010

Median of 21 CORDEX Simulationen

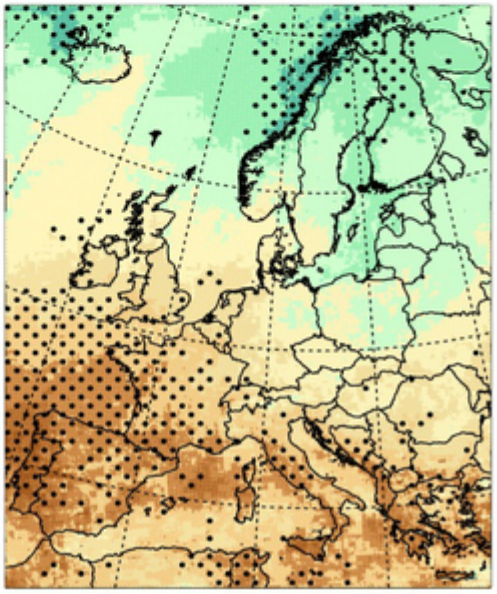
JJA



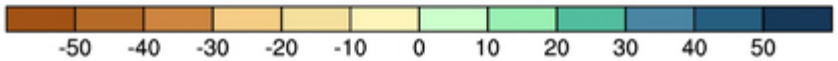
Change in near-surface air temperature [ºC]



JJA



Change in precipitation [%]



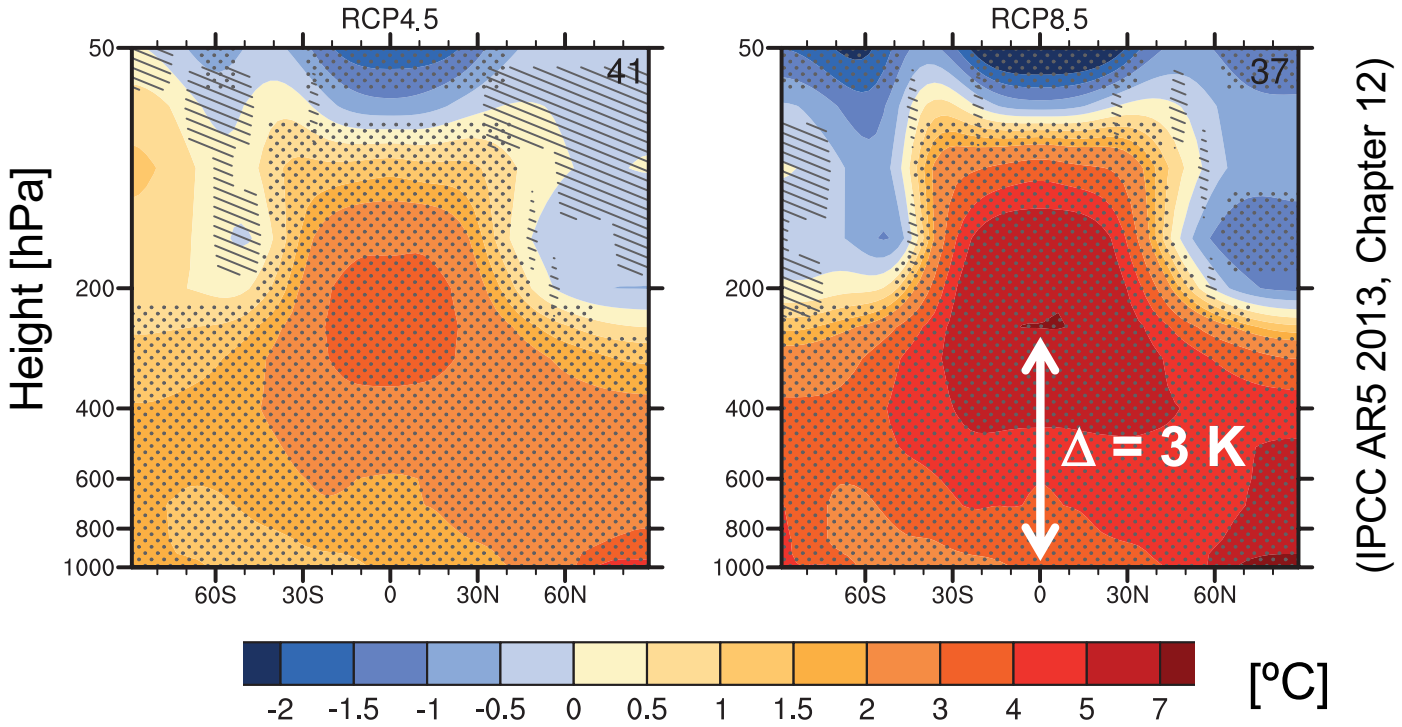
(stippled where 90% of models agree on sign)

Mediterranean Amplification (summer):
enhanced warming and drying at low latitudes

(CH2018)

Causes of Mediterranean Amplification

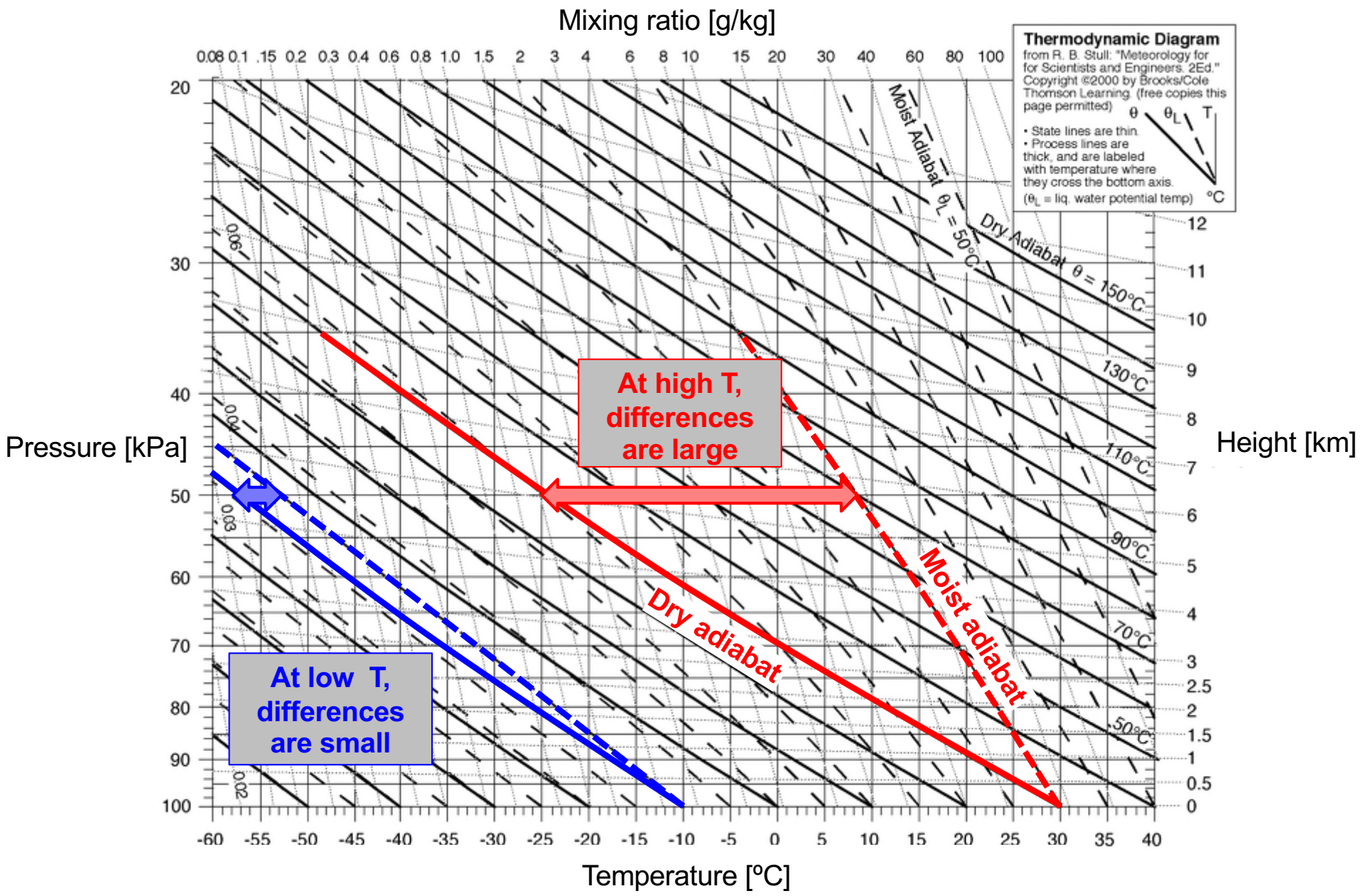
Projected zonal mean temperature changes (2081-2100 versus 1986-2005)



- Mechanism behind stratification changes: moist adiabat
- Hypothesis: stratification changes cause changes in convective activity, precipitation and lower-tropospheric temperature
- Tested with separation of climate-change signal

(Kröner et al. 2017, Brogli et al. 2019)

Differences between dry and moist adiabat



(Brogli et al. 2019; Brogli et al., submitted)

Large-scale precipitation extremes?

Flood August 2005
(Zirlinn, A)

Daylong precipitation extremes

Theory: Clausius-Clapeyron scaling

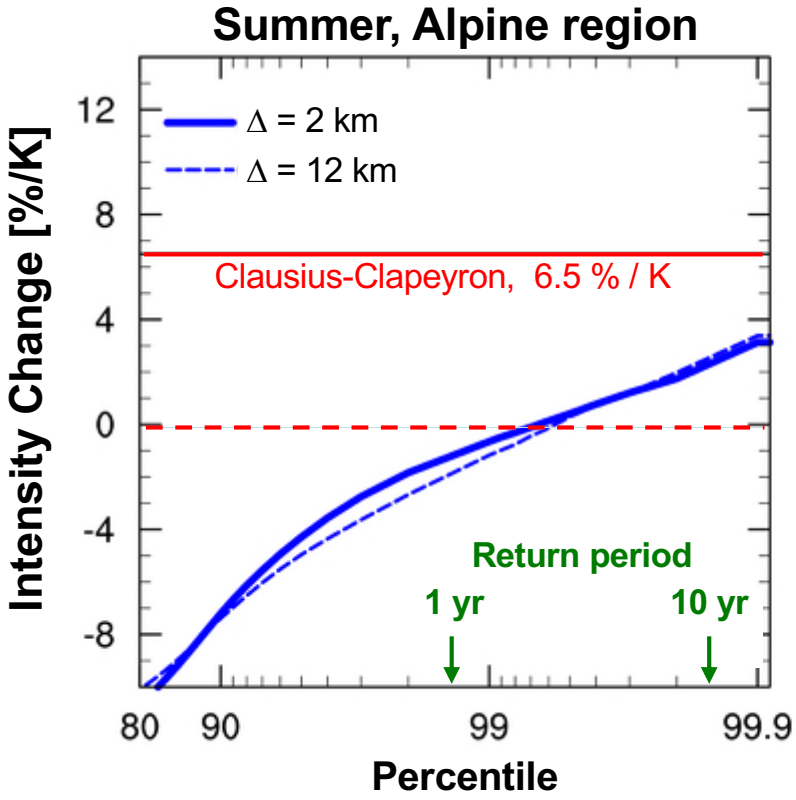
- Increase of heavy precipitation controlled by availability of water vapor.
- Warm air can hold 6.5% more water vapor per ºC.
- **Climate change: Increase in precipitation intensity by up to 6.5% per ºC warming**

II. *Ueber die bewegende Kraft der Wärme und die Gesetze, welche sich daraus für die Wärmelehre selbst ableiten lassen; von* R. Clausius [1]).

(Clausius 1850)

Climate models

- Models largely confirm Clausius-Clapeyron scaling (many studies, many different models)



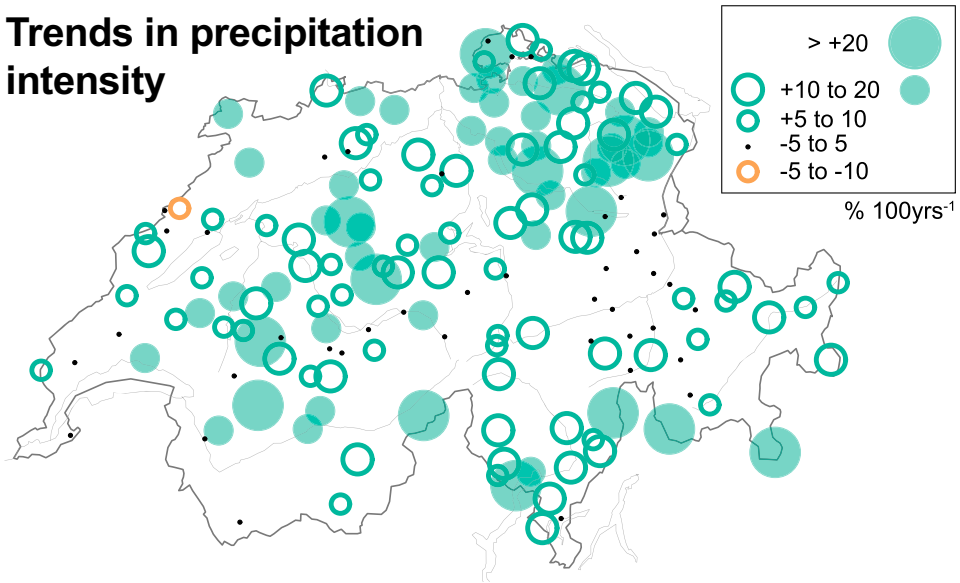
(Ban et al 2015)

Daylong precipitation extremes

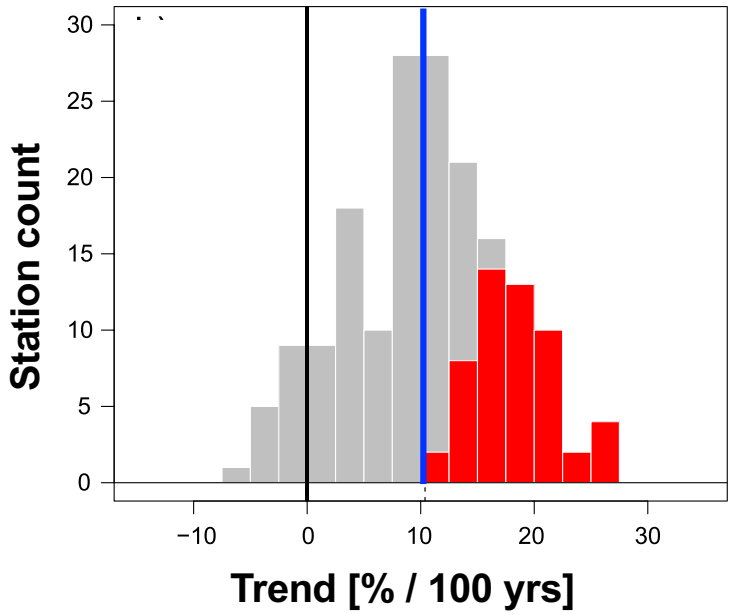
Observations

- Analysis requires long-term daily observations at many stations
  => Here: 185 stations in Switzerland since 1900

- Trends in very rare events are difficult to detect
  => Here: return periods of 1 year, annual maximum of daylong precipitation (Rx1d)



31% of stations have statistic significant increase
(no significant negative trends)



Average increase corresponds to 7.4 % / ºC.
Consistent with Clausius-Clapeyron scaling

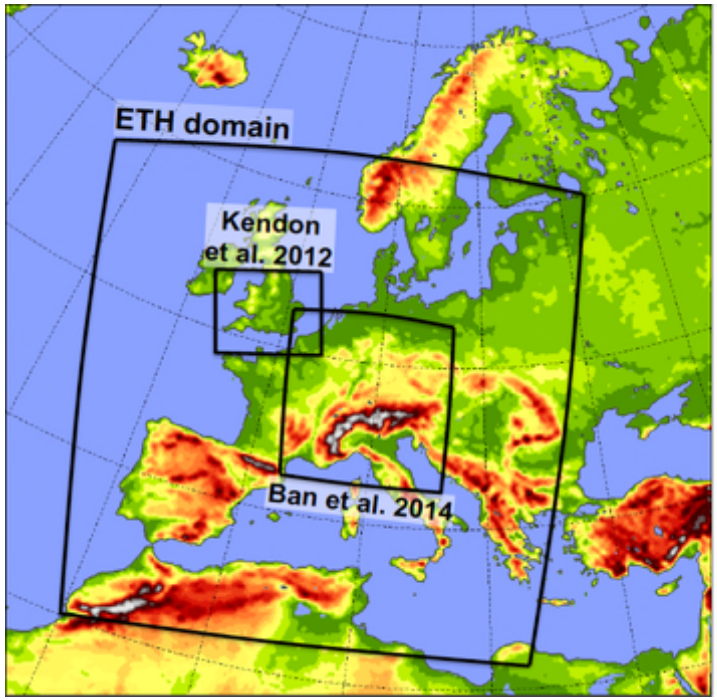
(Scherrer et al 2016)

Short-term precipitation extremes?

Flash flood
Lausanne railway station, June 11, 2018

Short-term (hourly) precipitation extremes

- Can the Clausius-Clapeyron scaling also be applied?
  => Conflicting results in literature
- Over the Alps, published results consistent with CC-scaling
- But other regions (e.g. UK, NL) appear to exhibit super-CC scaling



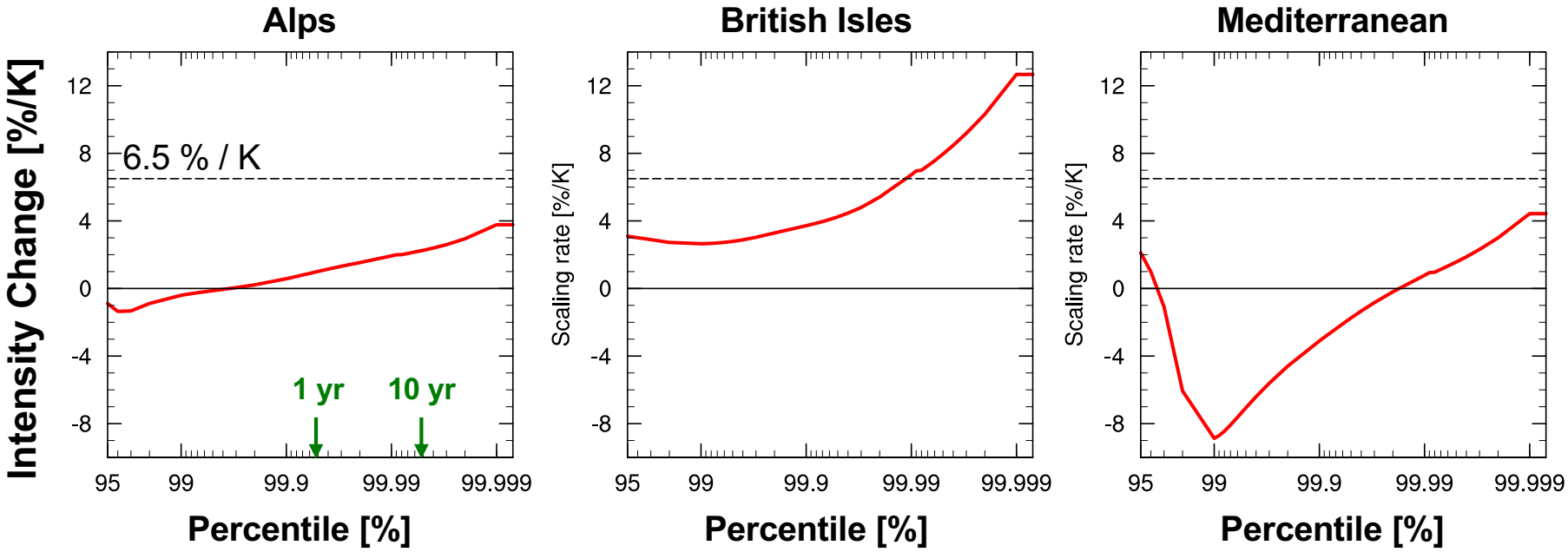
Continental-scale simulations

- 2 km resolution, 10 years long
- Current climate (driven by ERA-reanalysis)
- Future climate (PGW approach)
  - climate change information from MPI-ESM-LR (CMIP5 simulation)
  - end of century, RCP 8.5

Leutwyler et al. 2016, 2017; Hentgen et al. 2019; Ban et al. 2019, submitted

Hourly precipitation extremes

JJA, RCP8.5, 2081-2090 versus 1991-2000



Consistent with CC scaling, similar as Ban et al. (2015)

Inconsistent with CC scaling! similar as Kendon et al (2014)

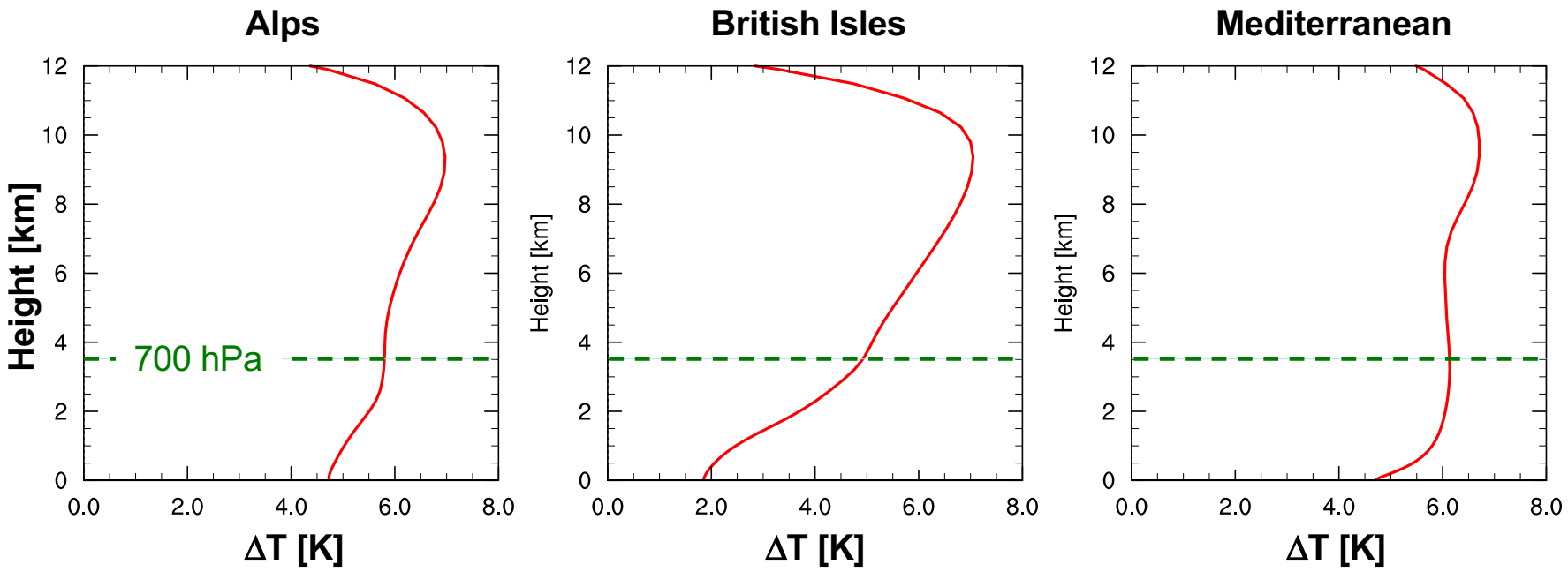
Consistent with CC scaling, reduction at low percentiles, increases at high percentiles

(Ban et al. 2019 submitted)

Changes with height

Hourly events, JJA, RCP8.5, 2081-2090 versus 1991-2000

Consider projected temperature change as a function of height

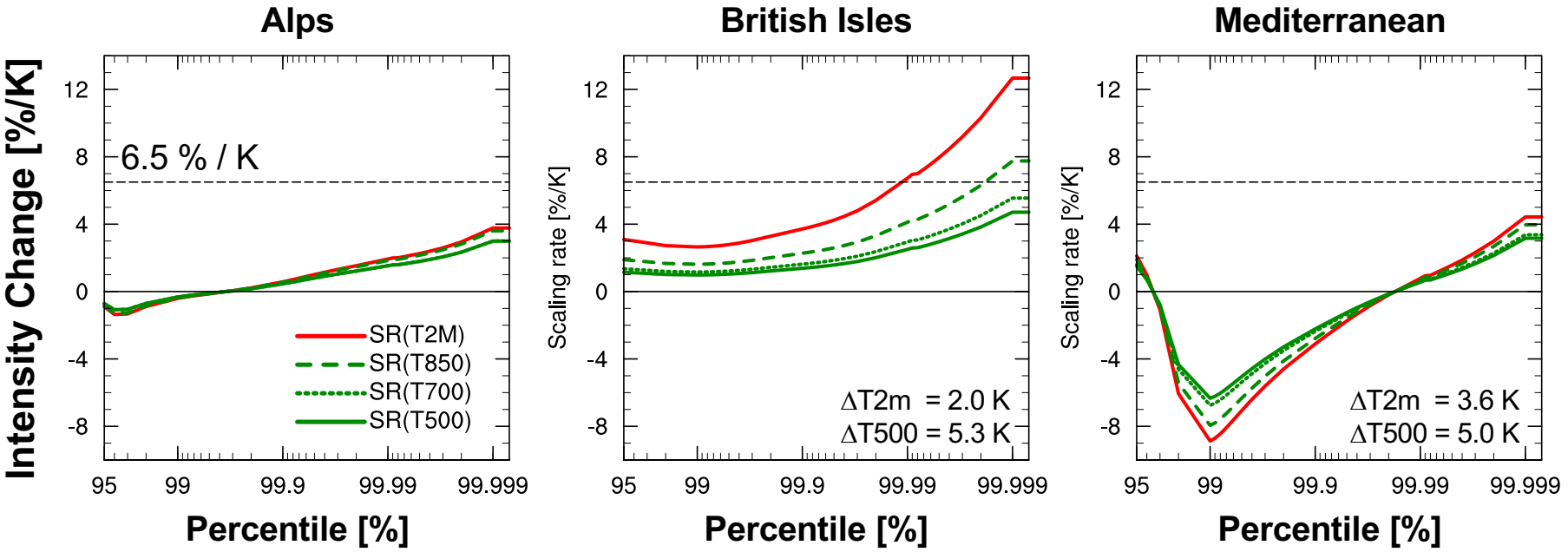


- Warming depends upon height (related to moist adiabatic lapse rate)
- Effect depends strongly upon region, most pronounced over British Isles

(Ban et al. 2019 submitted)

Hourly precipitation extremes

JJA, RCP8.5, 2081-2090 versus 1991-2000



Consideration of warming at representative height is important

- Projected changes become consistent with Clausius-Clapeyron (increases ≤ 6-7%/K)
- Beware of wet-day percentiles!
- Significant differences between 12 and 2km resolution

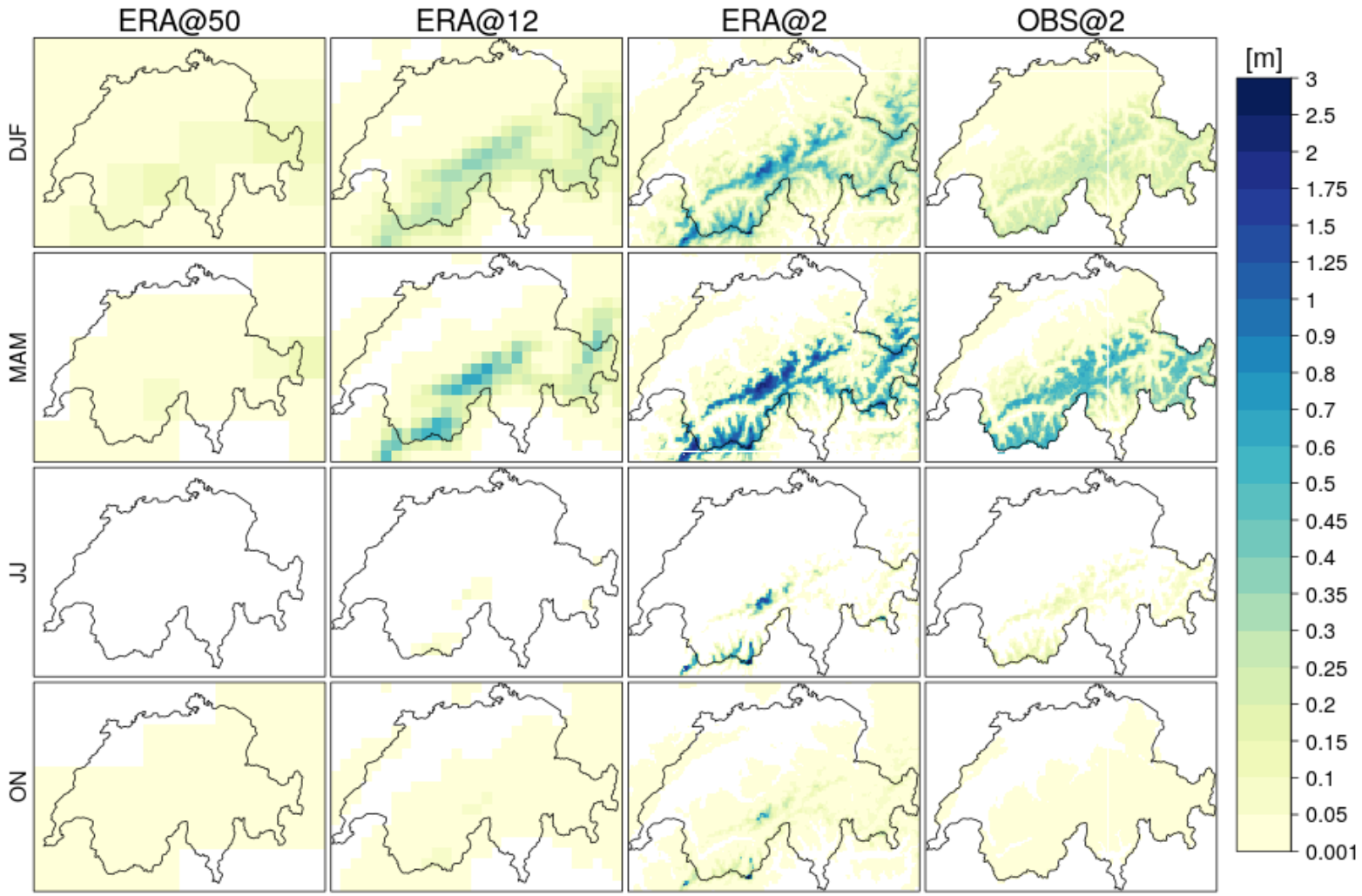
(Ban et al. 2019 submitted; Ban et al. 2015; Schär et al. 2016)

Snow fall and snow cover?

Oliver Stebler, 10. Oktober 2016

Validation of CTRL over Switzerland

Annual cycle of SWE in CTRL versus OBS



(Lüthi et al. 2019)

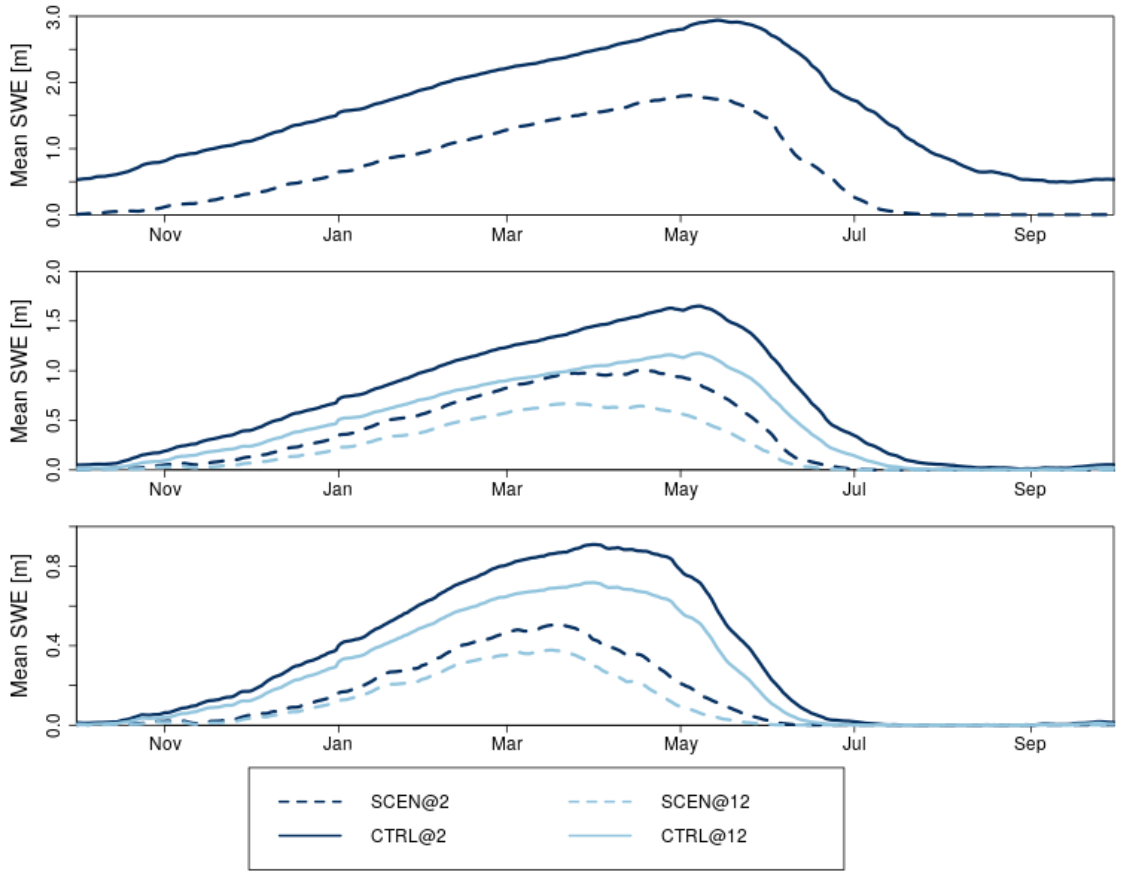
Snow projections

Annual cycle of SWE in CTRL and SCEN simulations

Altitude range 3000-3500 m

2500-3000 m

2000-2500 m



- Large decreases in all seasons by the end of the 21st century
- Heights above 3000m represented only by 2 km model
- At high altitude, transition from permanent to seasonal snow cover

(Lüthi et al. 2019)

Summary

- Kilometer-resolution climate models provide exciting prospects over complex topography
- Main advance is explicit treatment of convection
- Improved and more physical representation of climate change
- Enables new collaborations with impact sciences and mountain research

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