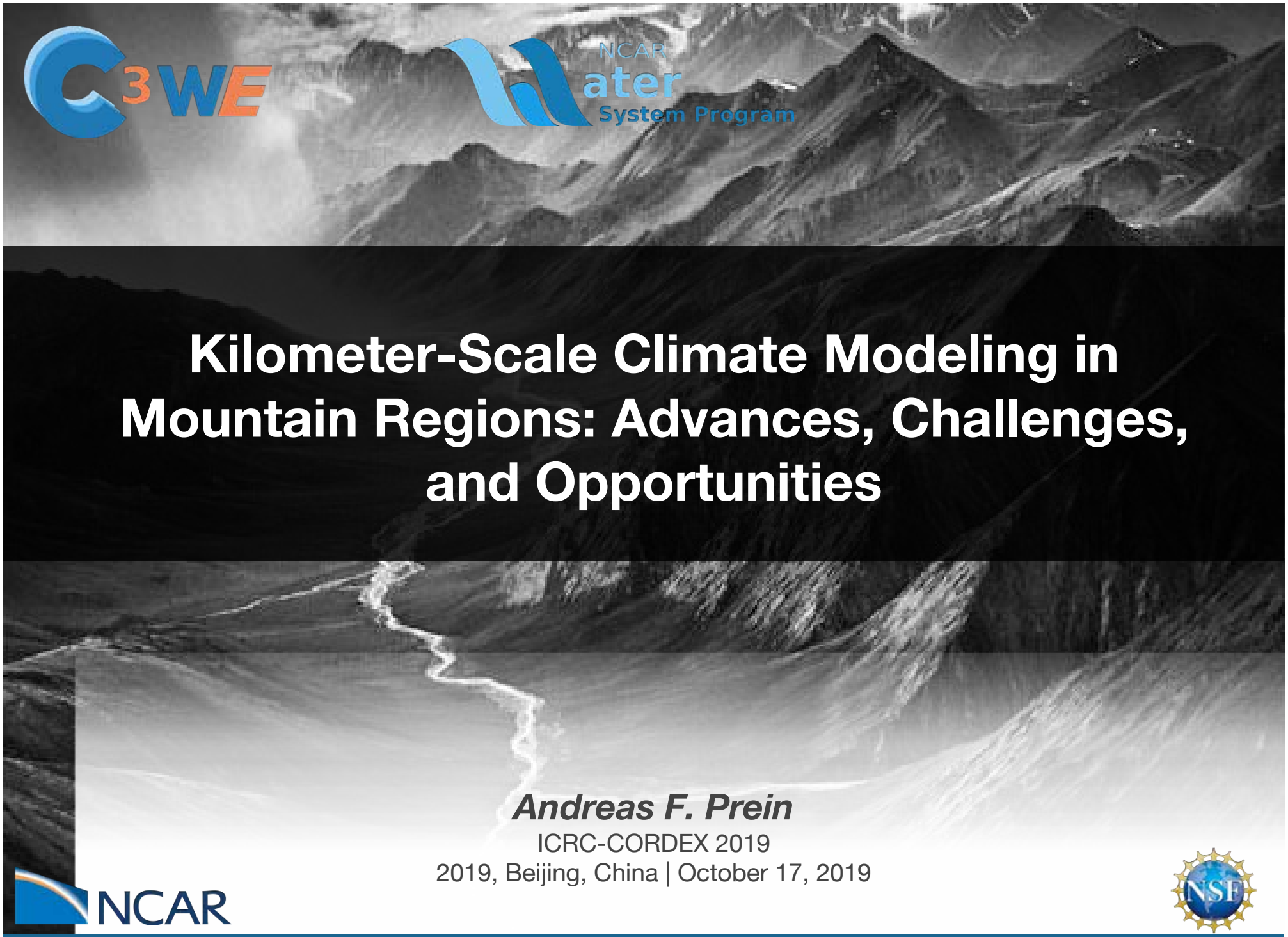


Kilometer-Scale Climate Modeling in Mountain Regions: Advances, Challenges, and Opportunities

Andreas F. Prein

ICRC-CORDEX 2019

2019, Beijing, China | October 17, 2019

NCAR

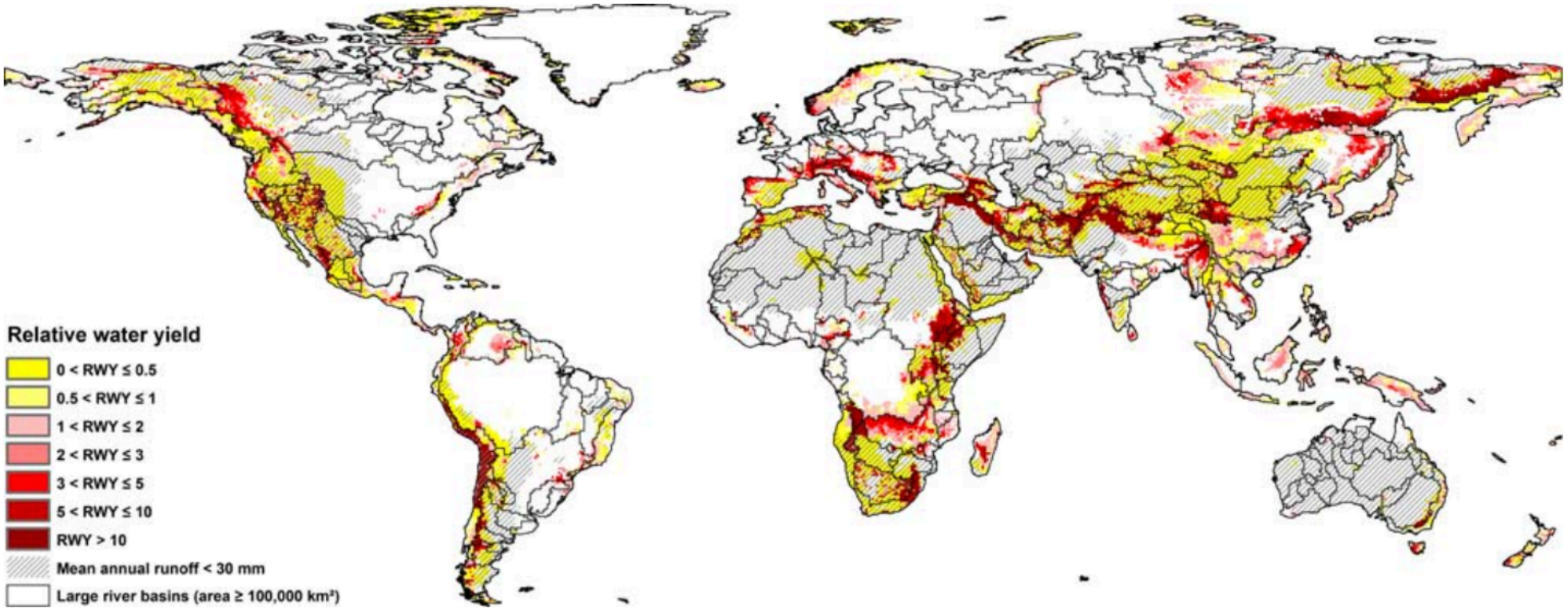
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

“Half of the precipitation used as drinking water and for hydroelectric power has its origin in mountain regions.”

[Viviroli et al. 2007]

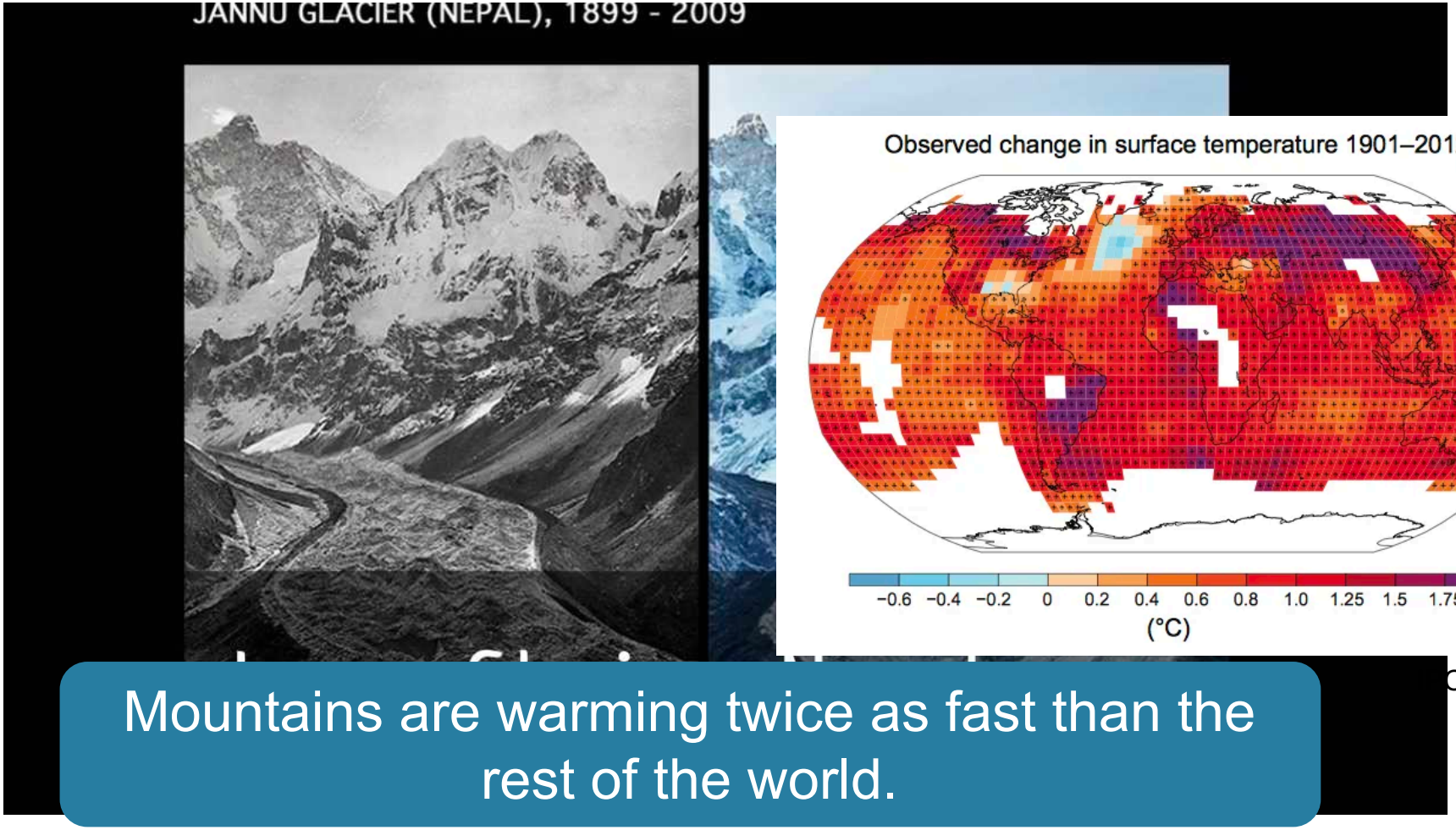
Mountains – The Water Towers of the World

Mountains over-proportionally provide runoff into the earths major rivers



[Viviroli et al. 2007]

Mountain Areas are Changing Rapidly



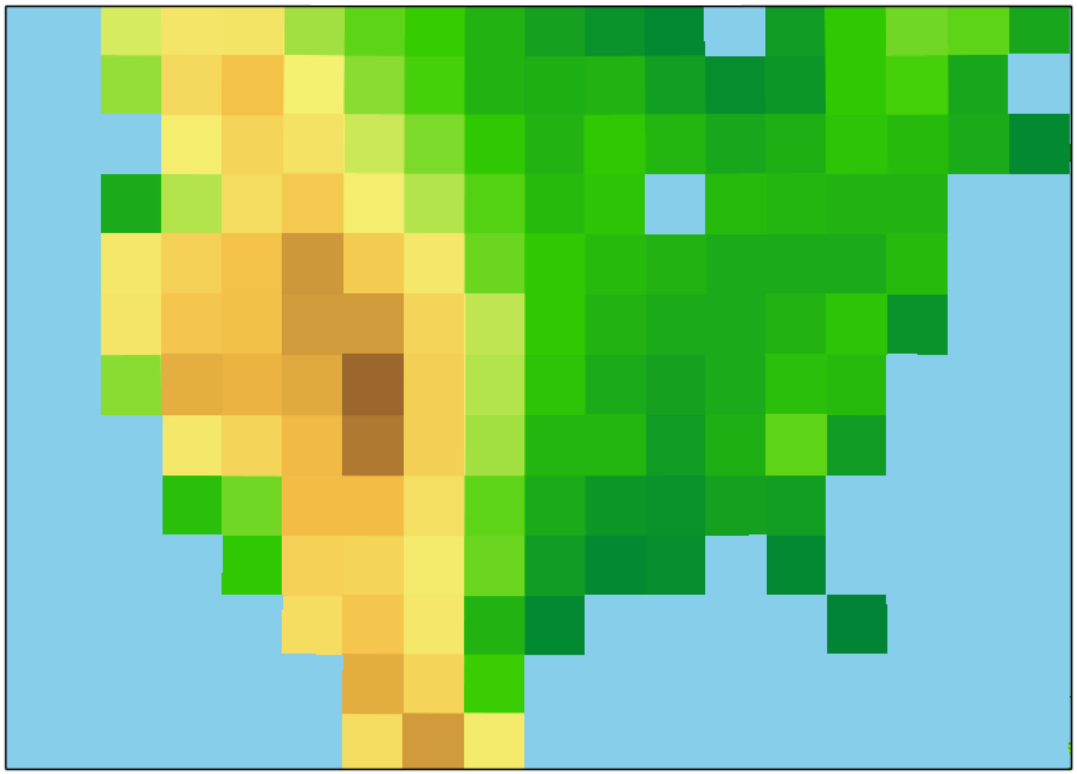
CC 2013

Mountains are warming twice as fast than the rest of the world.

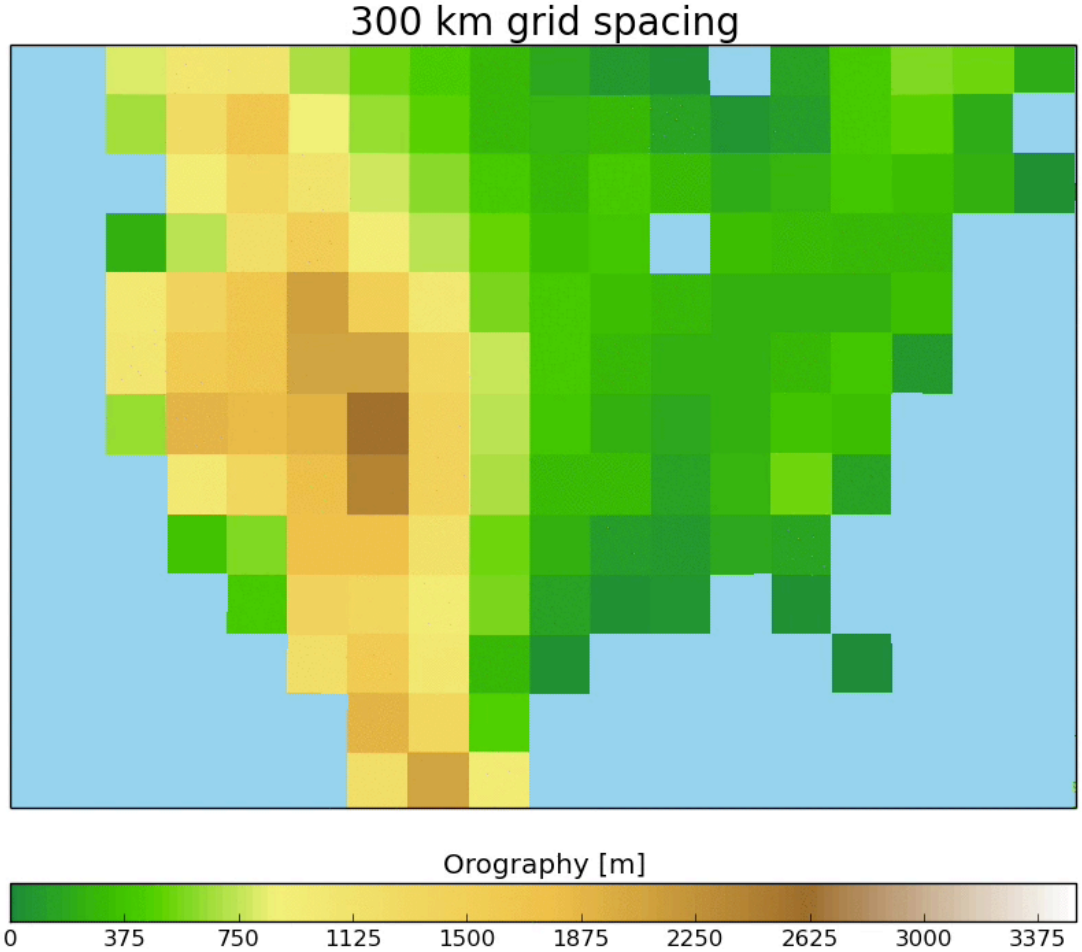
1. Kilometer-scale models are needed to simulate mountainous regions
2. The added value is in the processes
3. Observations can learn from kilometer-scale models

1. Kilometer-scale models are needed to simulate mountainous regions
2. The added value is in the processes
3. Observations can learn from kilometer-scale models

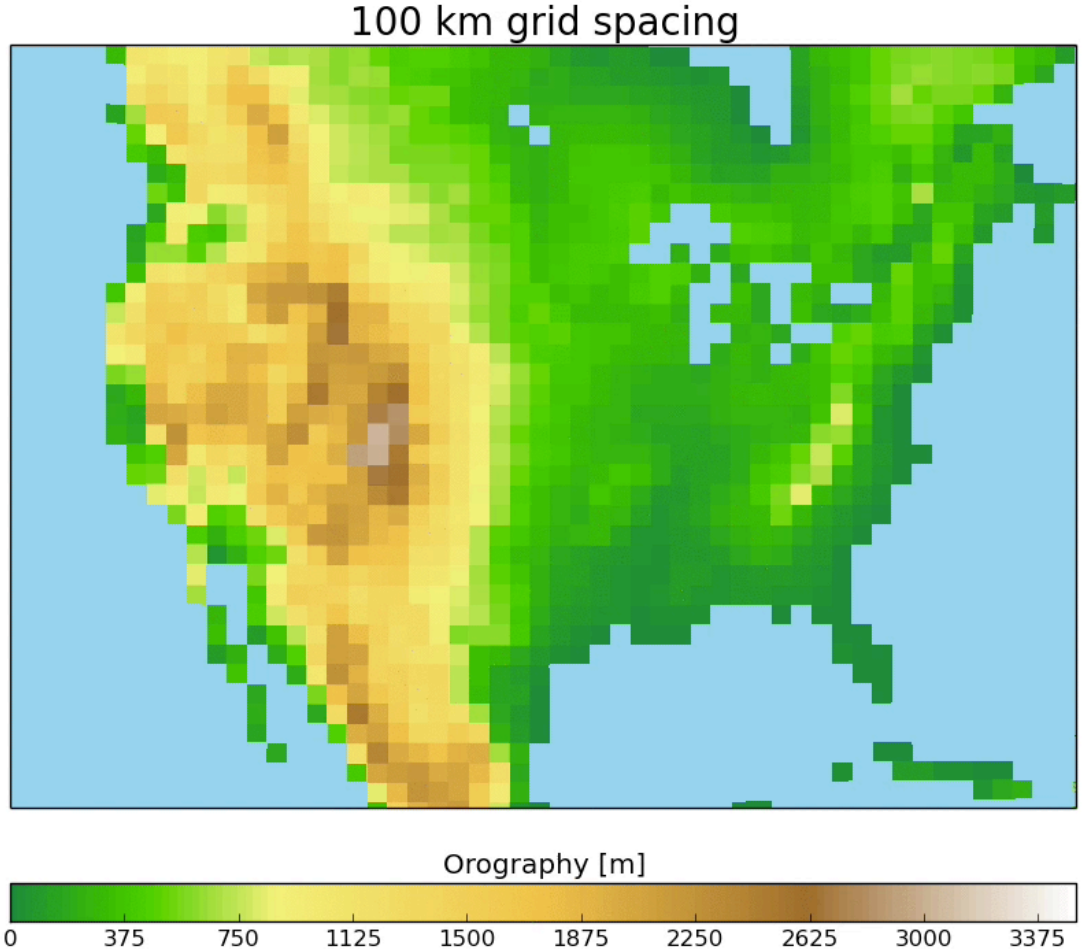
Resolution of State-Of-The-Art Climate Models



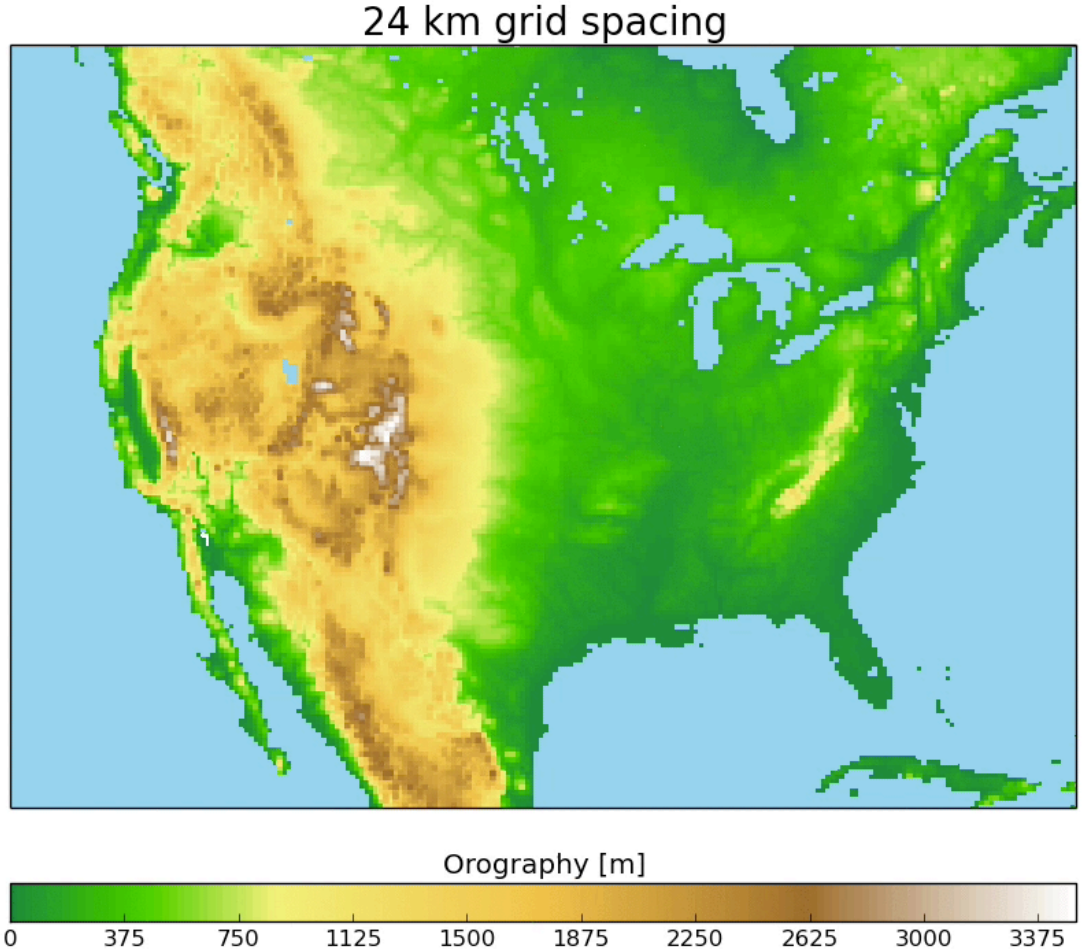
Resolution of State-Of-The-Art Climate Models



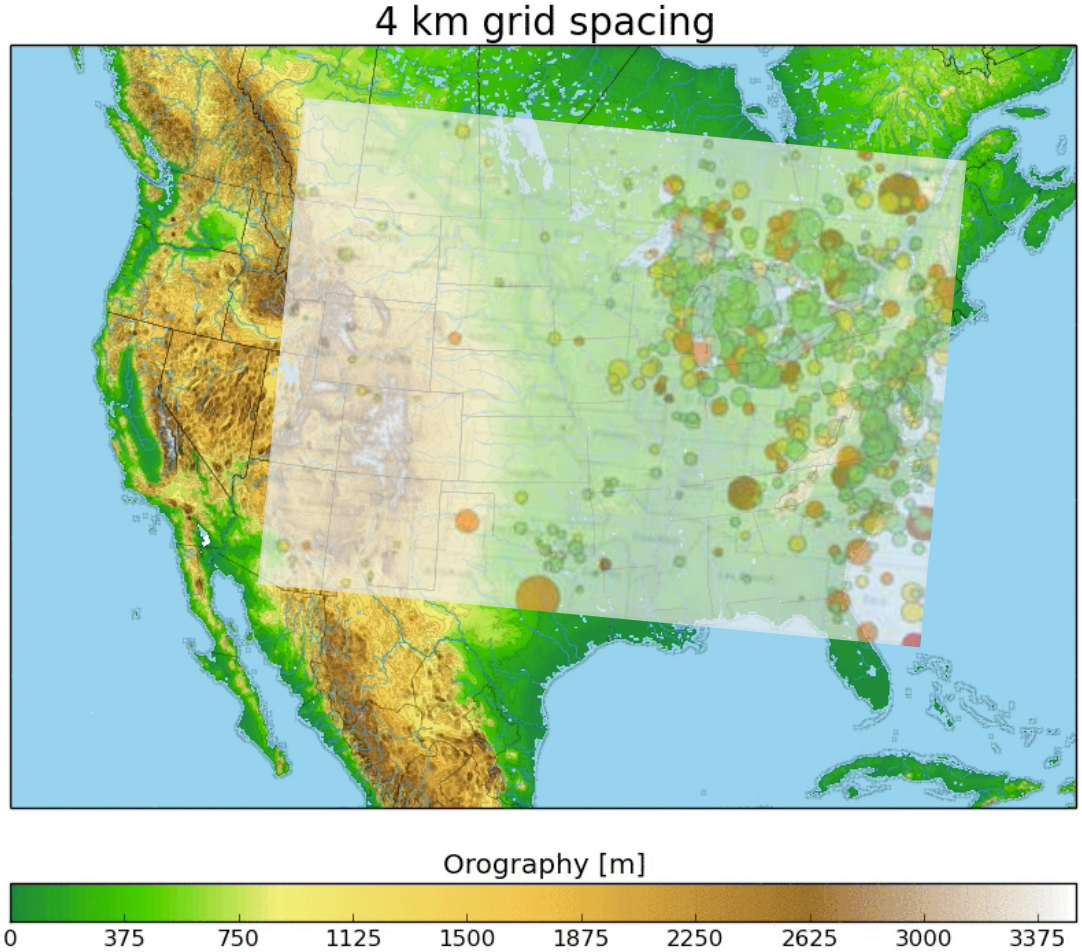
Resolution of State-Of-The-Art Climate Models



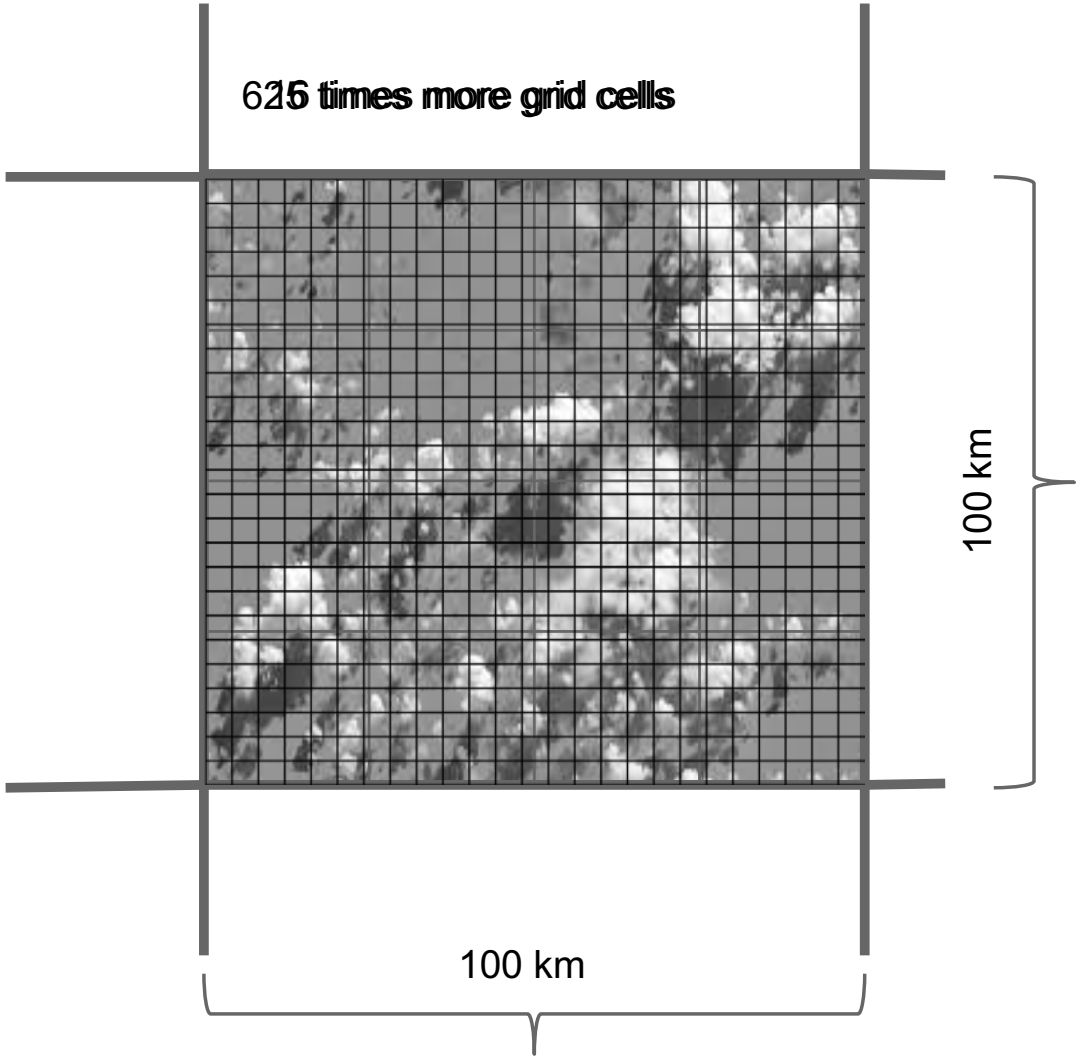
Resolution of State-Of-The-Art Climate Models



Resolution of State-Of-The-Art Climate Models



Deep convection in atmospheric models



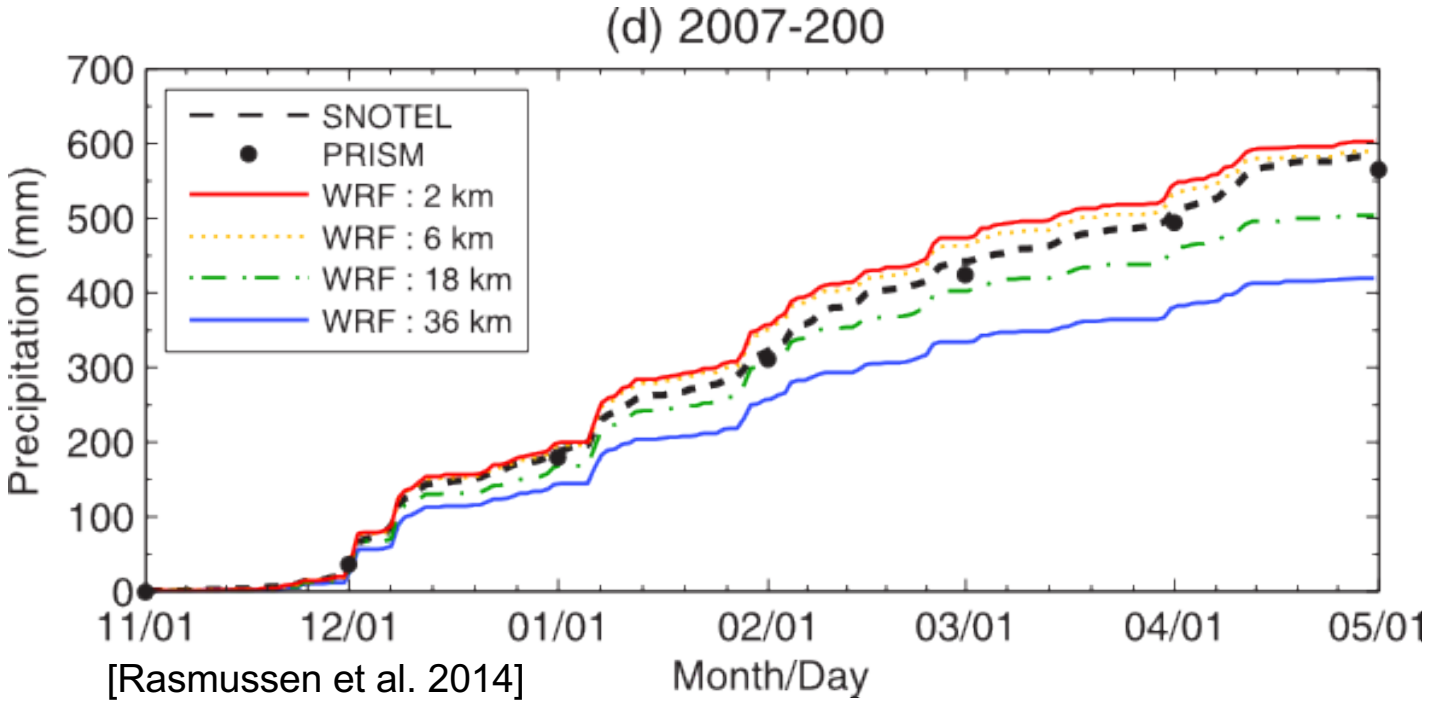
GCM grid spacing (~100 x 100 km)

- Deep convection is sub-gridscale process
- Needs cumulus parameterization

When do we start to resolve deep convection?

- ~4 km horizontal grid spacing (Weisman et al. 1997)

Orographic Cold-Season Precipitation



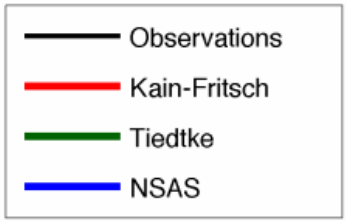
[Rasmussen et al. 2014]

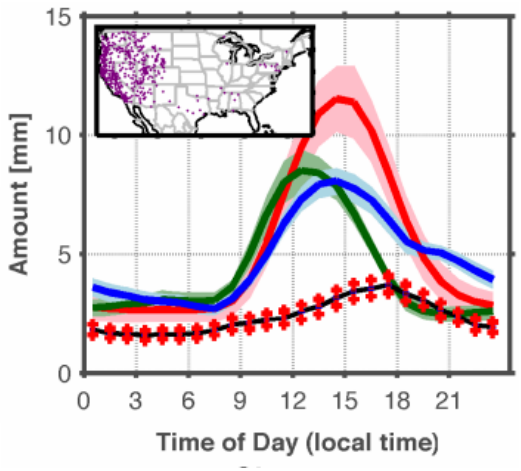
- Improved PR amount/patters in mountains
  [Rasmussen et al. 2014; Prein et al. 2013]
- Better snow pack dynamics (build up and melt)
  [Rasmussen et al. 2014]
- Large benefits for hydrology, snow, glacier modeling
  [Rasmussen et al. 2014; Mölg, T. and G. Kaser 2011]

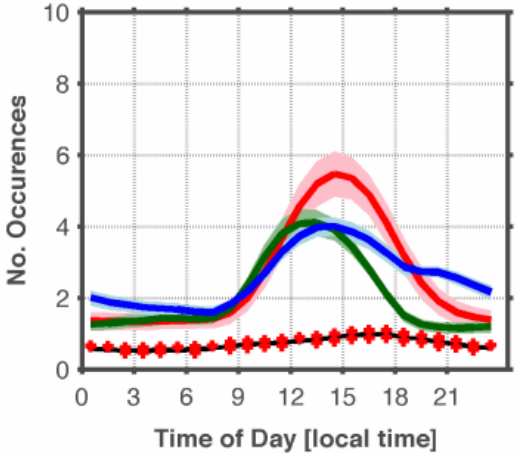
Simulating Convective Rainfall

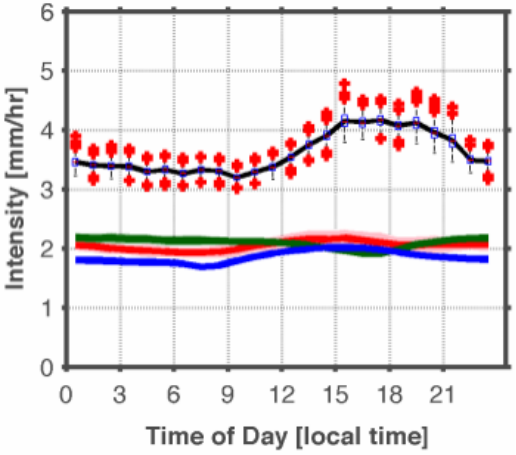
Amount

WRF 36 km



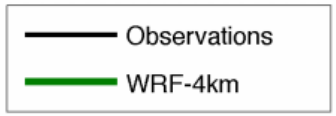


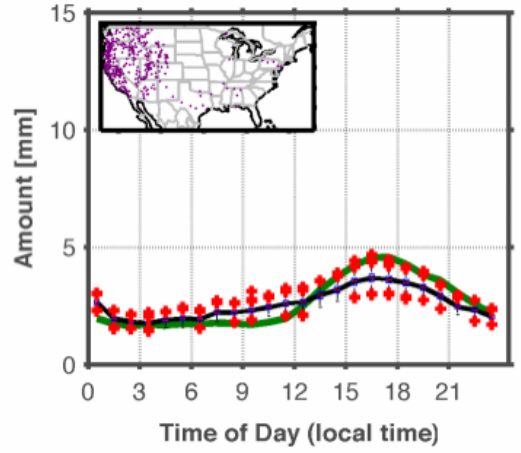


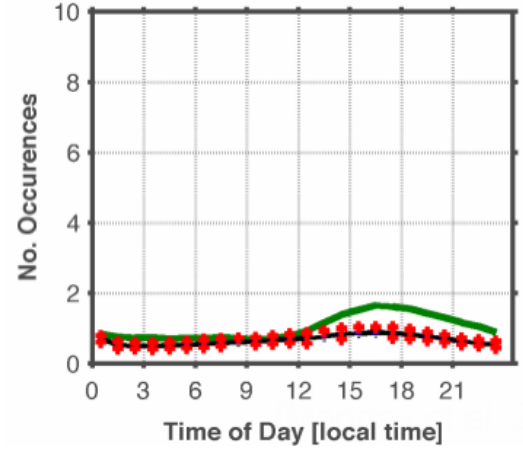


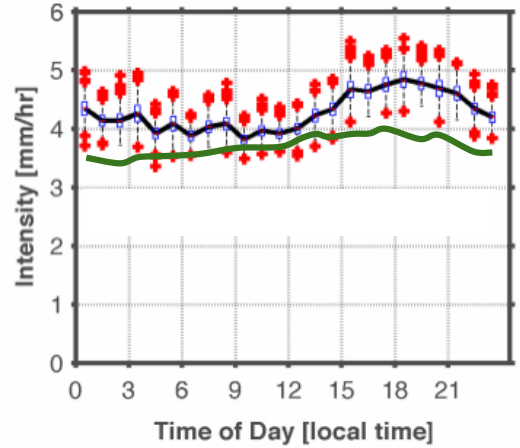
[Mooney et al. 2017]

WRF 4 km





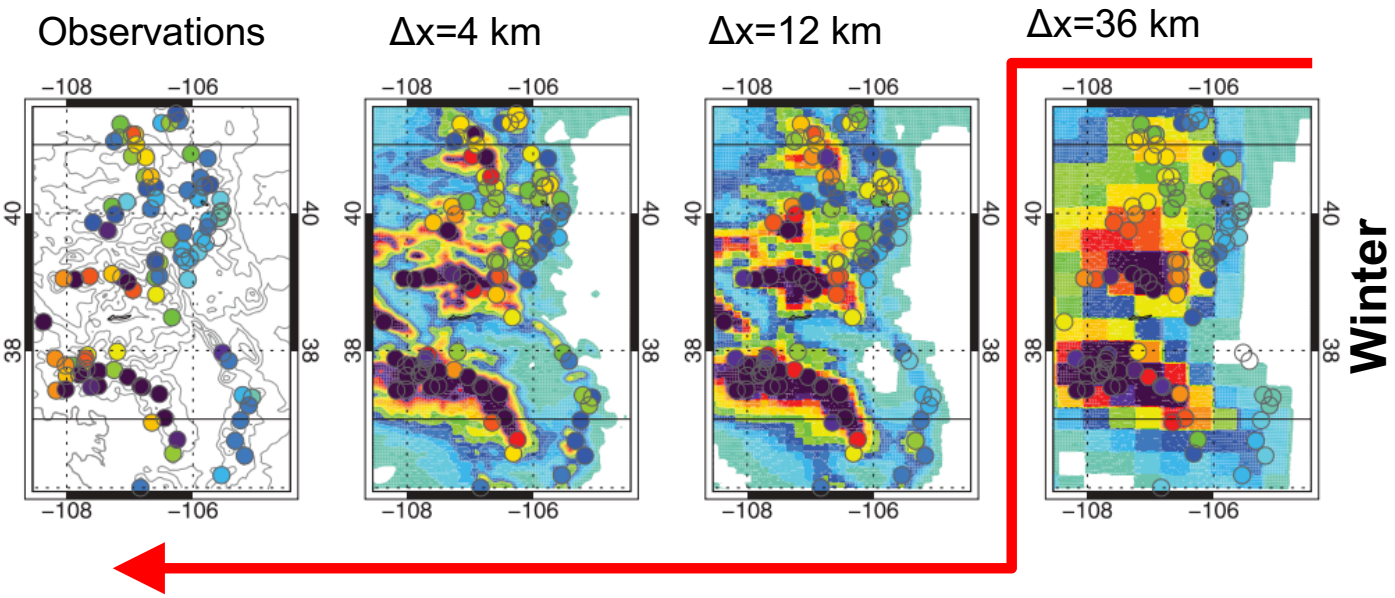




[Mooney et al. 2016; Ban et al. 2015]

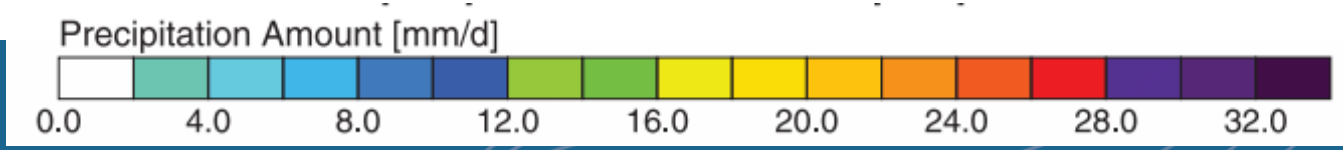
1. Kilometer-scale models are needed to simulate mountainous regions
2. The added value is in the processes
3. Observations can learn from kilometer-scale models

Grid-spacing Sensitivity of Heavy Mountain Precipitation



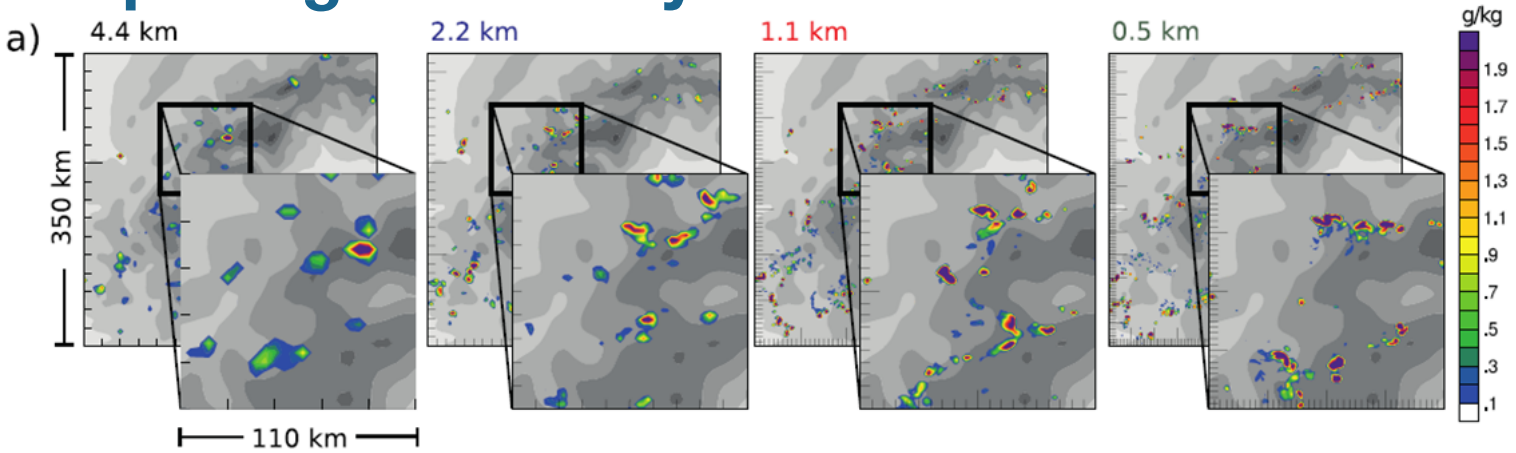
Cold Season
4- and 12-km are similar and outperform 36-km simulation

Warm Season
4-km is necessary to simulate heavy summertime events

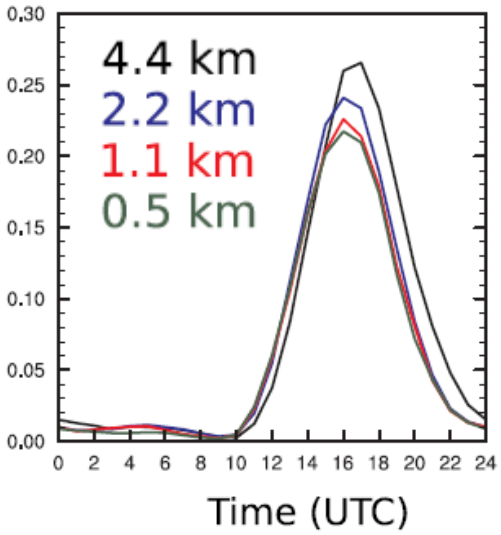


NCAR | UCAR

Grid-spacing Sensitivity of Warm Season Rainfall

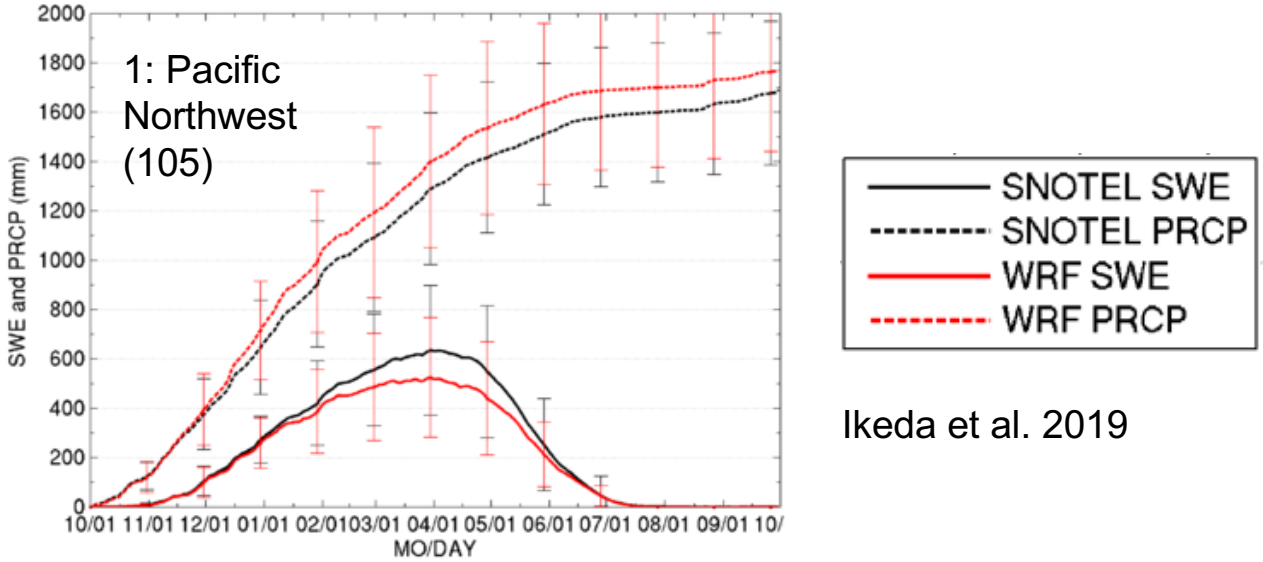


[Langhans et al. 2012]



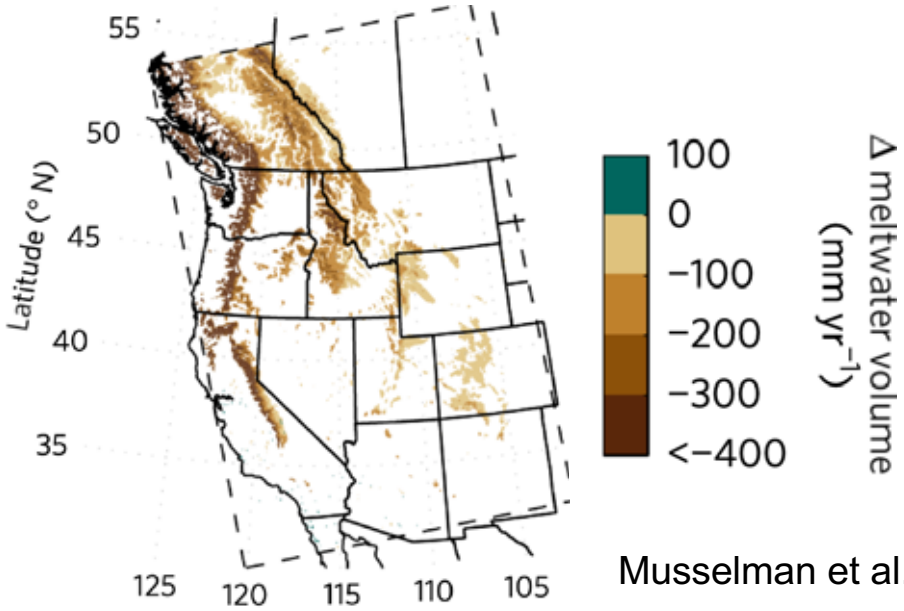
Bulk properties (e.g., precipitation) converged to 0.5 km model
Precipitation structures are did not converge

SNOTEL vs WRF at SNOTEL sites: 13-year climatology



Ikeda et al. 2019

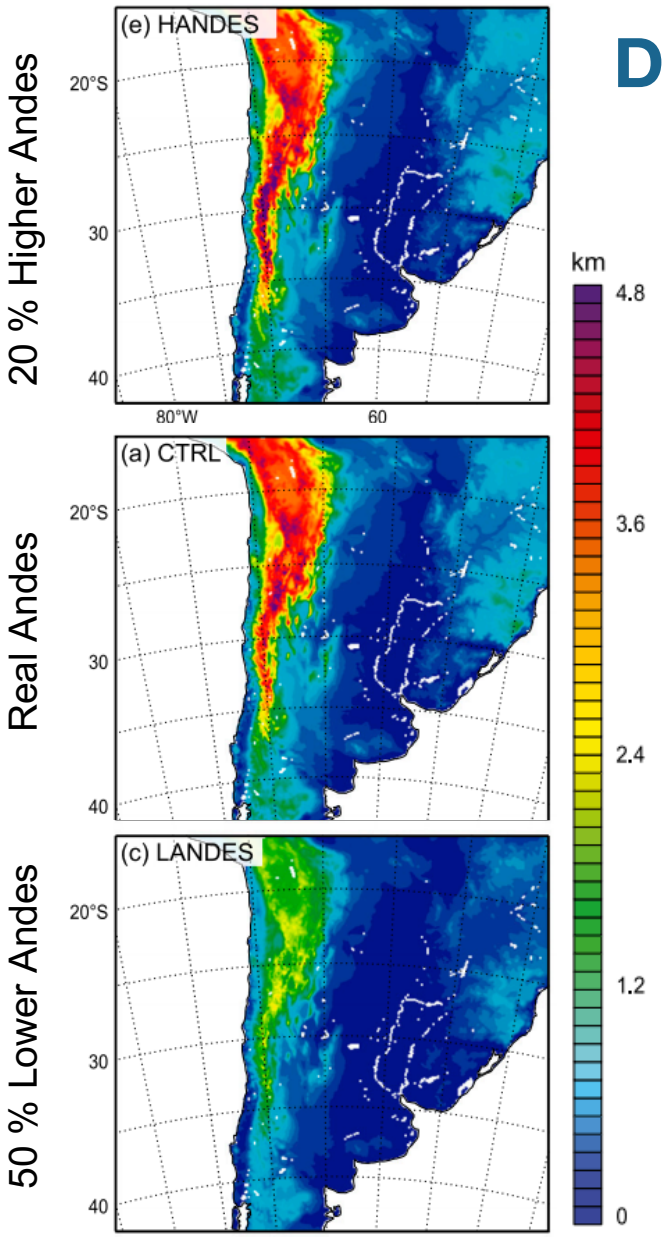
4 km model can realistically simulate snowpack dynamics

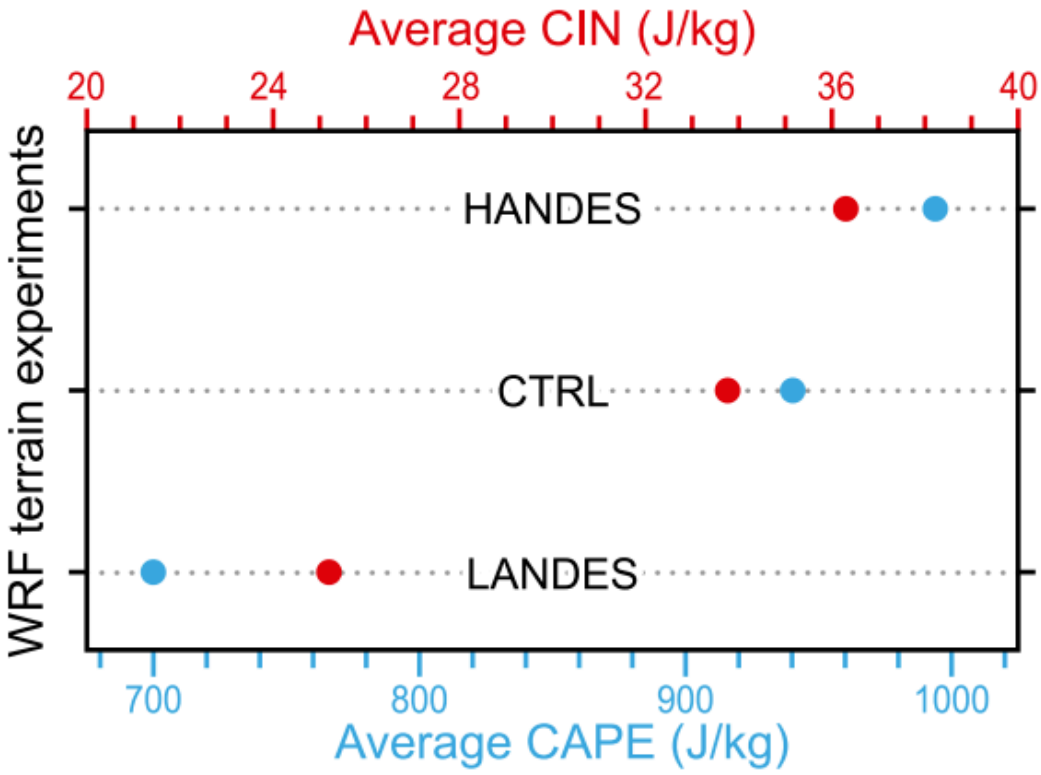


Musselman et al. 2017

Snowpack will melt slower due to climate change

Downstream Effects of Mountains

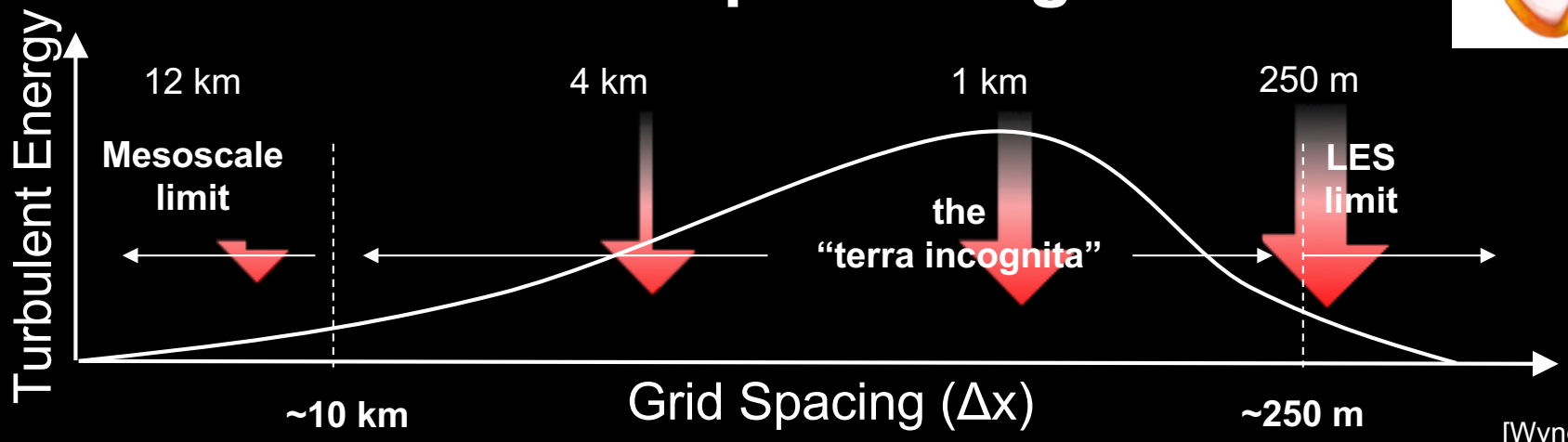




Reduced Andes experiments show more widespread convective initiation, weaker average storm intensity, and more rapid propagation of the MCS to the east.

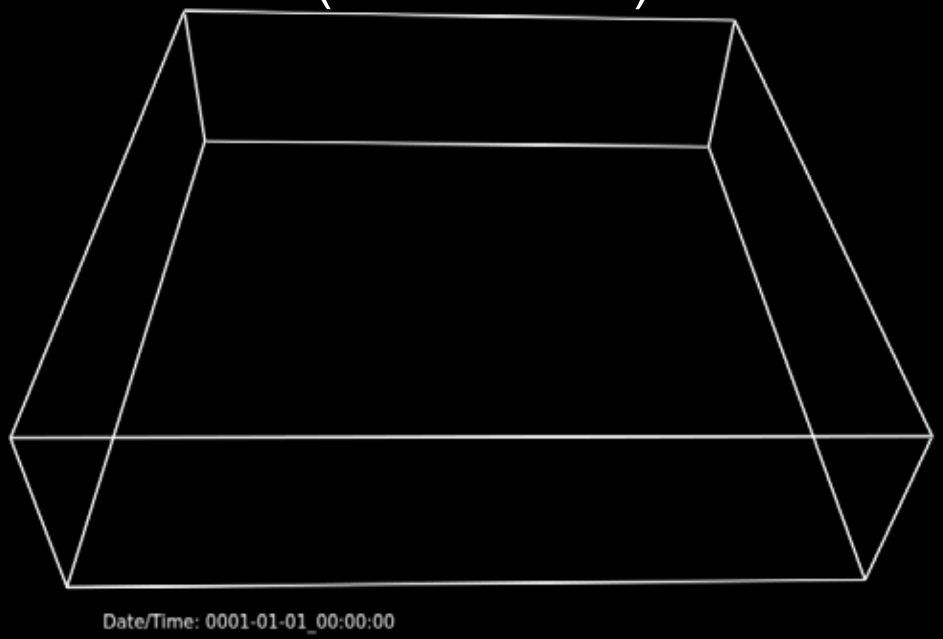
Rasmussen and Houze 2016

MCS in 3 atmospheric regimes

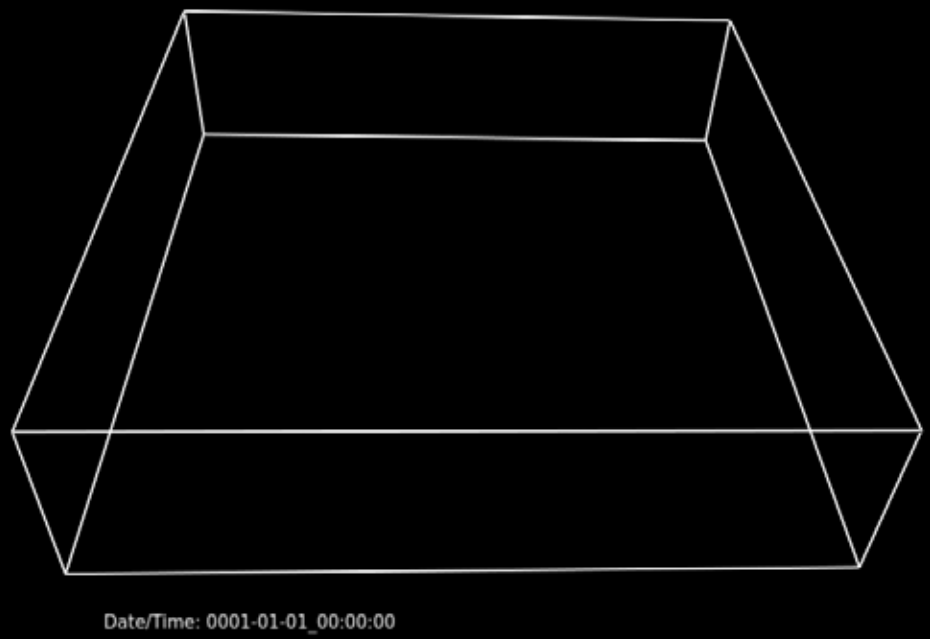


[Wyngaard 2004, JAS]

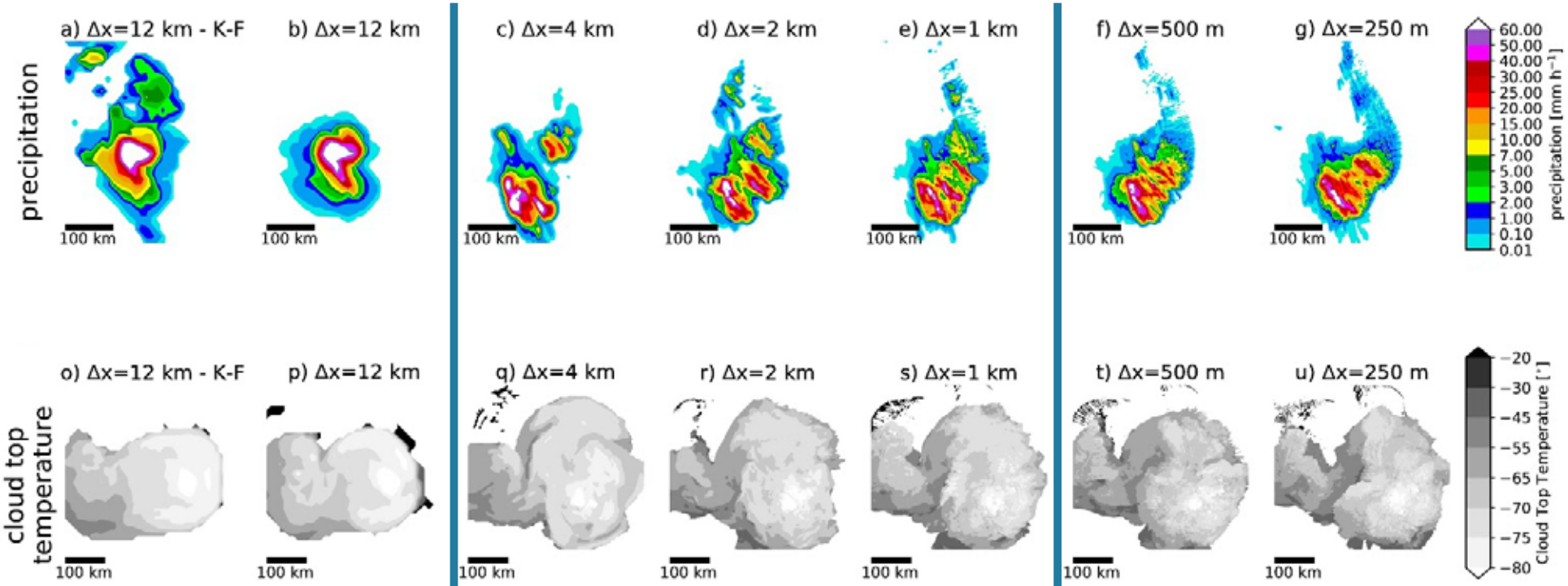
Δx = 12 km
(K-F scheme)



Δx = 4 km



Example MCSs Features



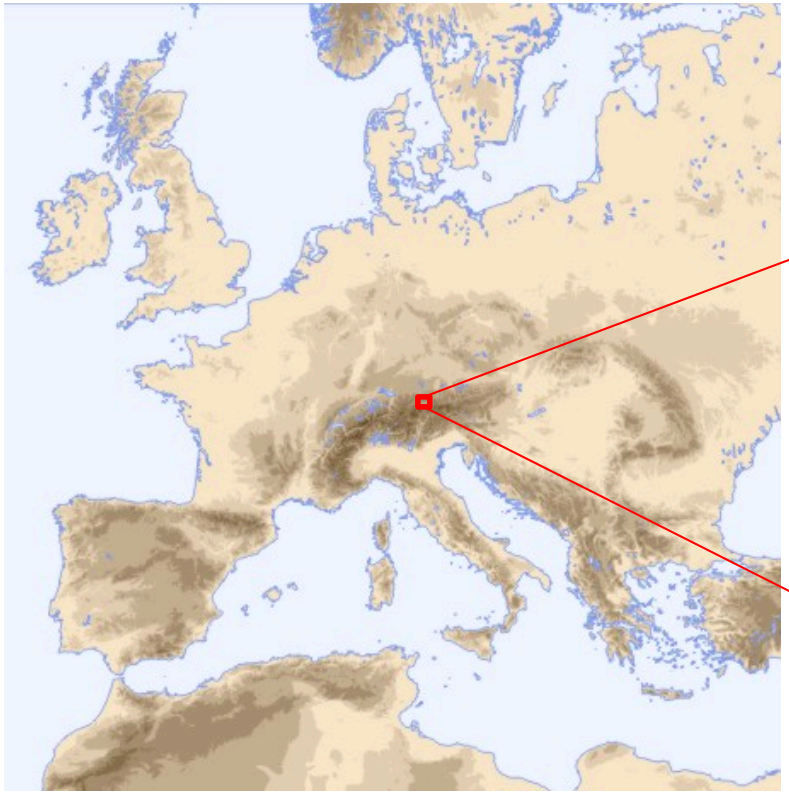
step improvement
from Δx=12 km to Δx=4 km

further structural
improvements from Δx=4 km
to Δx=1 km

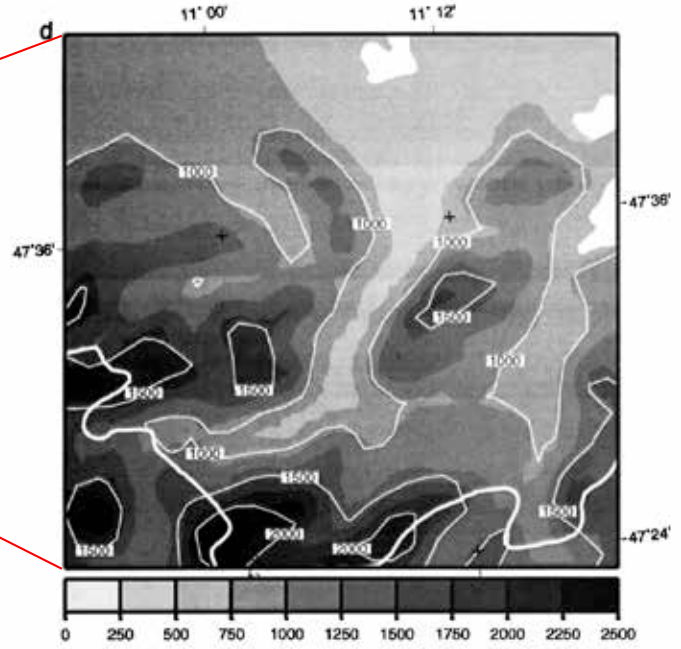
bulk convergence

[Prein et al. in preparation]

CPM for “Climate” Simulations



14 month long integration on a 46x46 km domain at Δx=1 km

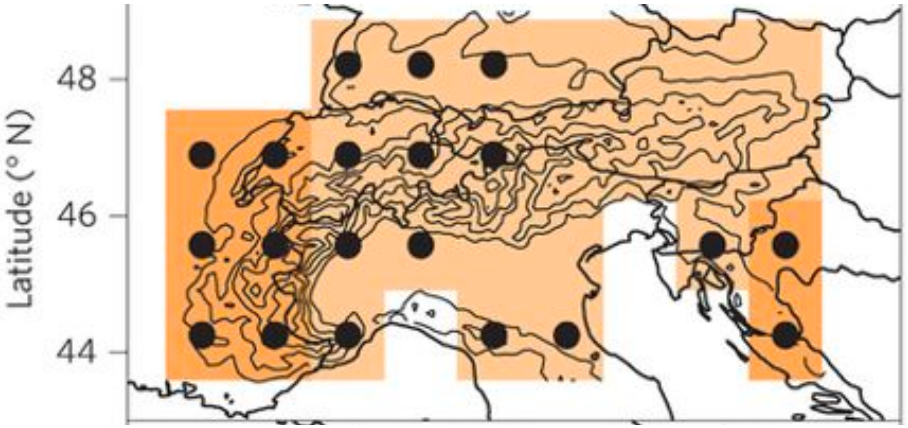


“…convection in the regional model simulation tends to be locked to the mountains, while in the cloud-resolving simulations the convection moves with the upper level flow, producing precipitation maxima away from the mountain tops”

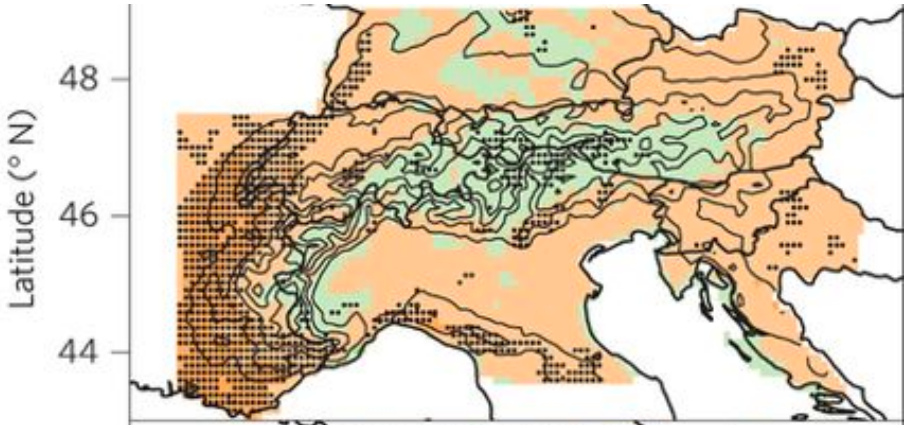
Grell et al. 2000; JGR

Changes in the Climate Change Signal

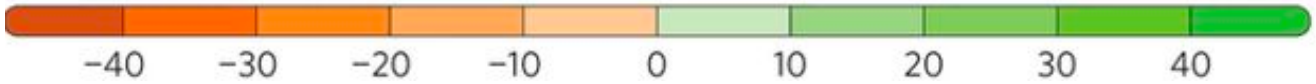
Global Models



12 km EURO-CORDEX Models



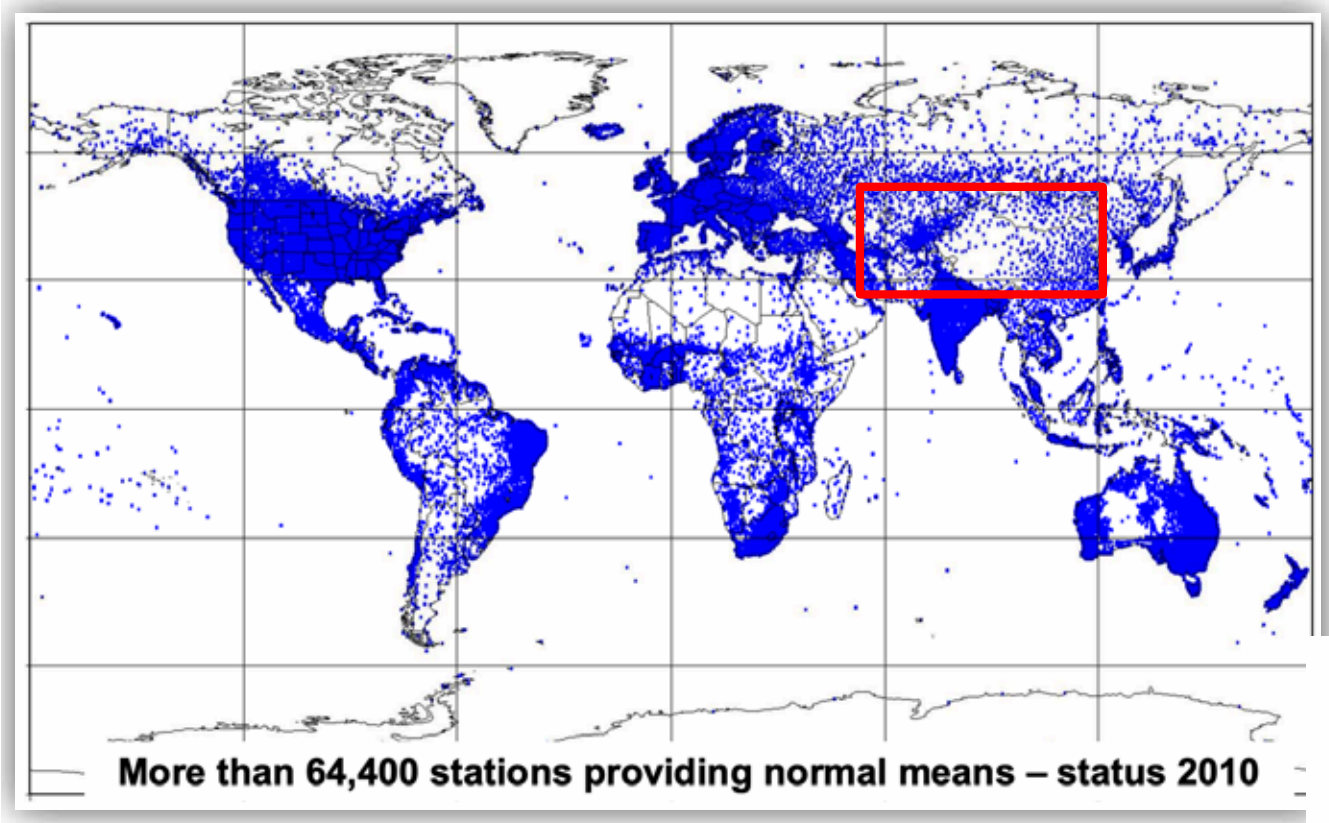
JJA mean precipitation change 1975-2004 vs. 240-269



The regional models simulate an increase in precipitation over the high Alpine elevations that is not present in the global simulations. [Giorgi et al. 2016]

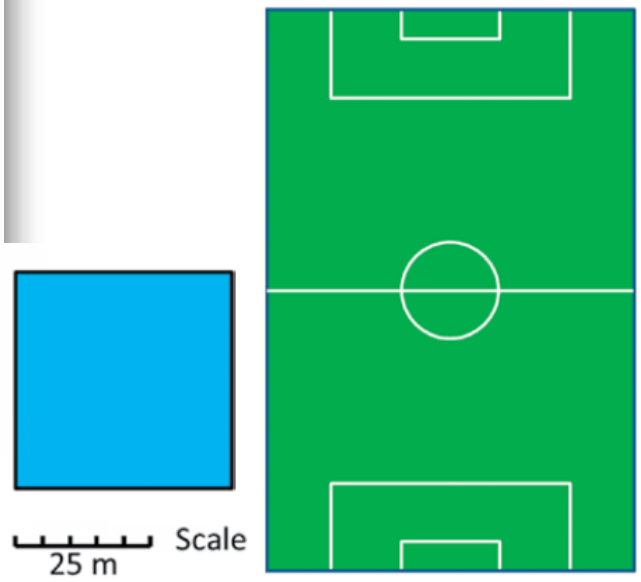
1. Kilometer-scale models are needed to simulate mountainous regions
2. The added value is in the processes
3. Observations can learn from kilometer-scale models

Global Density of Precipitation Gauges

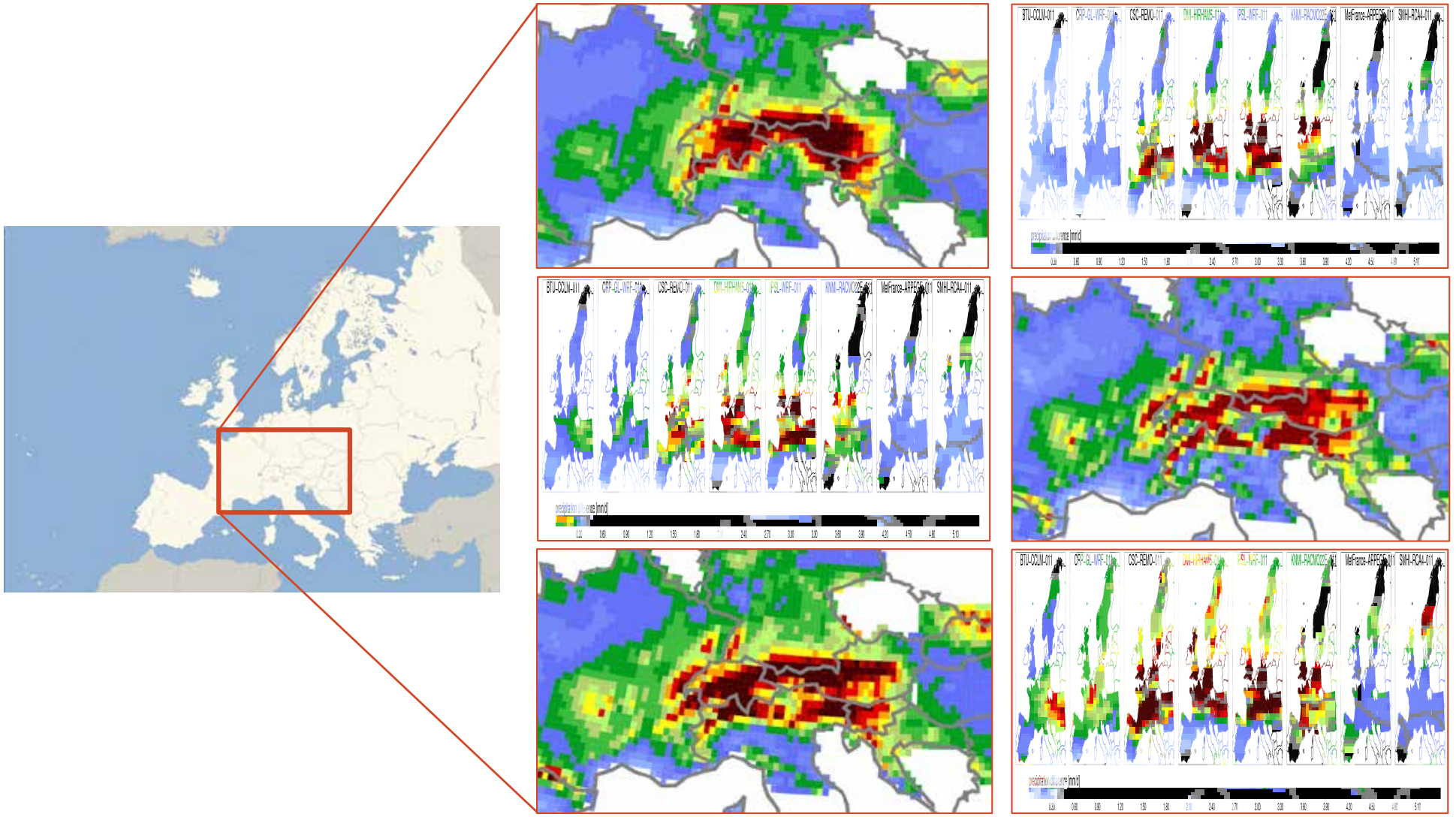


DWD 2011

The total area measured globally by all currently available rain gauges is surprisingly small, equivalent to less than half a football field or soccer pitch.
[Kidd et al. 2017]



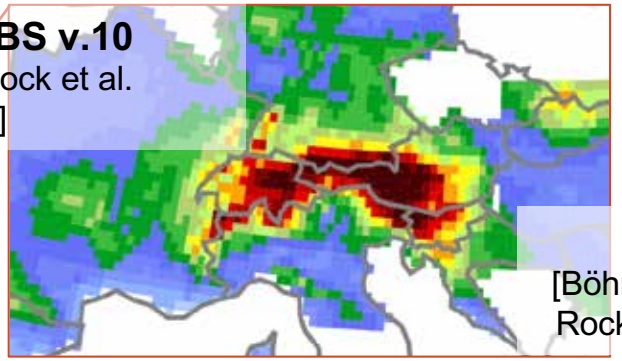
Summer precipitation in the Alps (1989-2008)



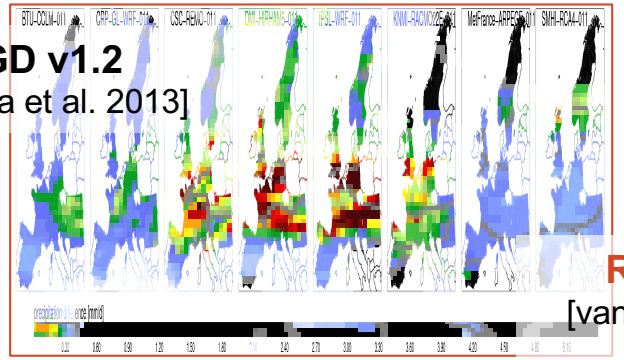
Prein and Gobiet 2017

Summer precipitation in the Alps (1989-2008)

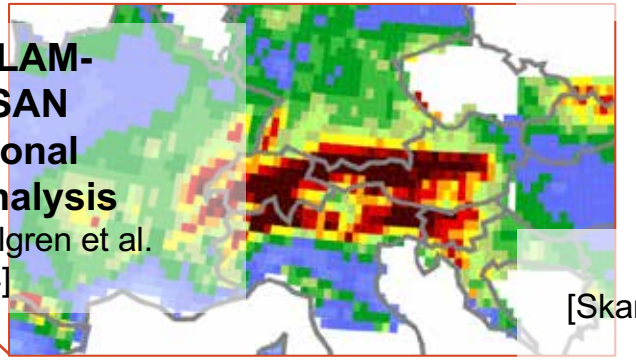
E-OBS v.10
[Haylock et al. 2008]

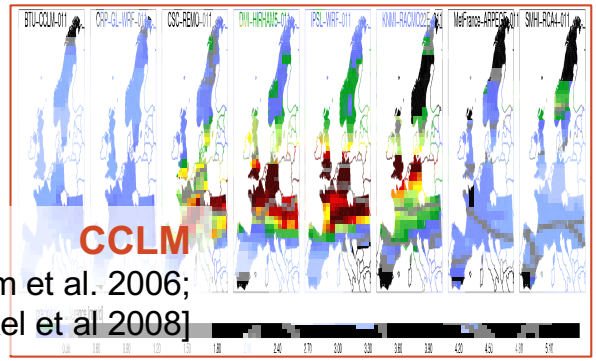


APGD v1.2
[Isotta et al. 2013]

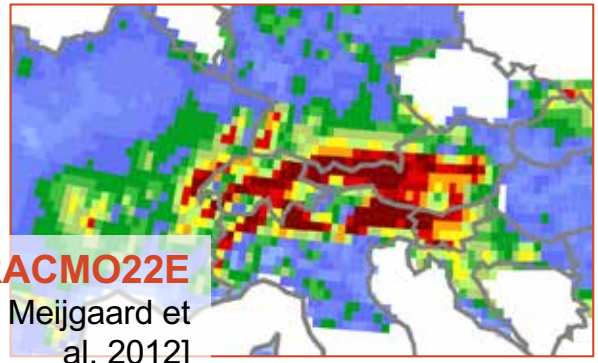


HIRLAM-MESAN regional reanalysis
[Dahlgren et al. 2014]

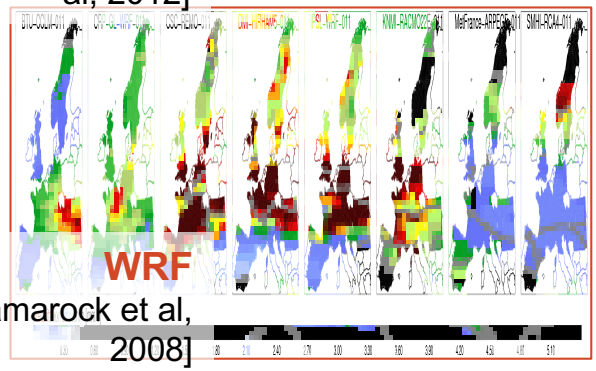




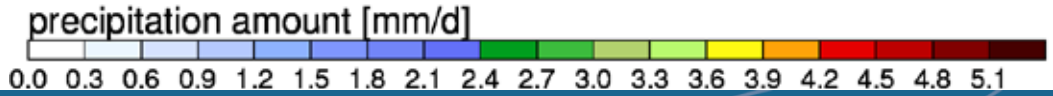
CCLM
[Böhm et al. 2006; Rockel et al 2008]



RACMO22E
[van Meijgaard et al, 2012]

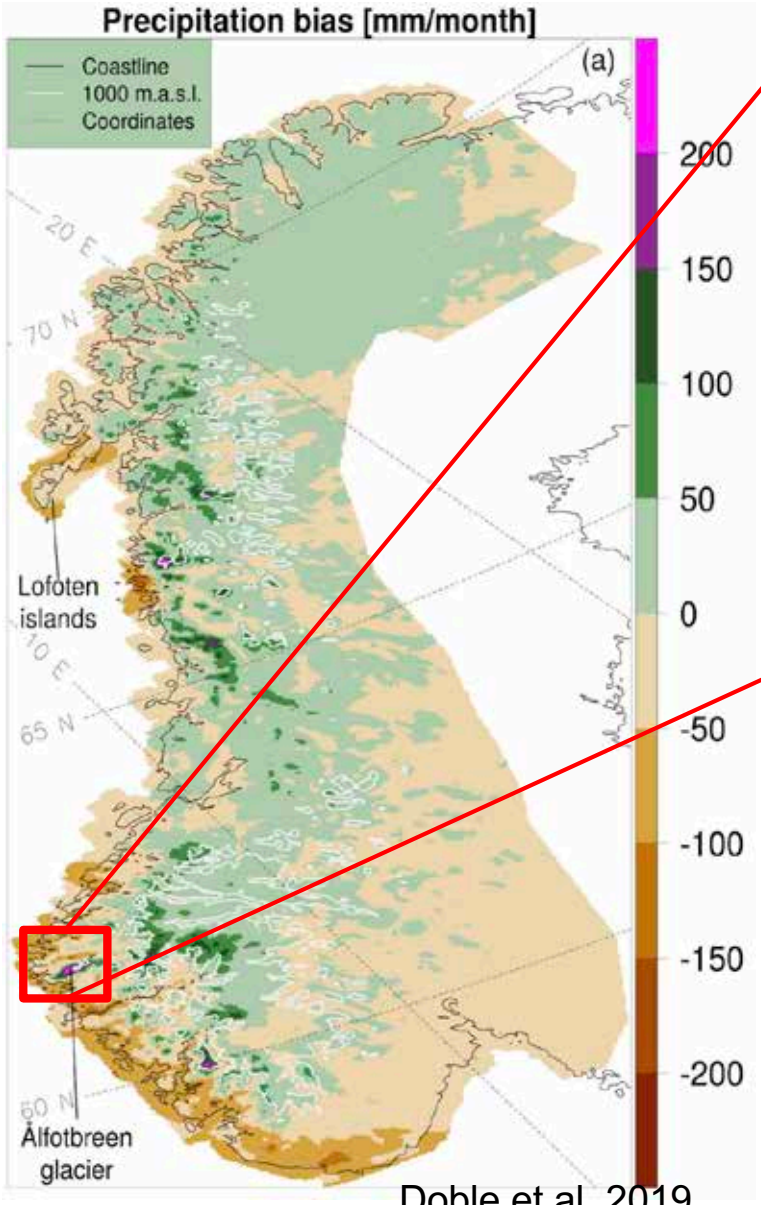


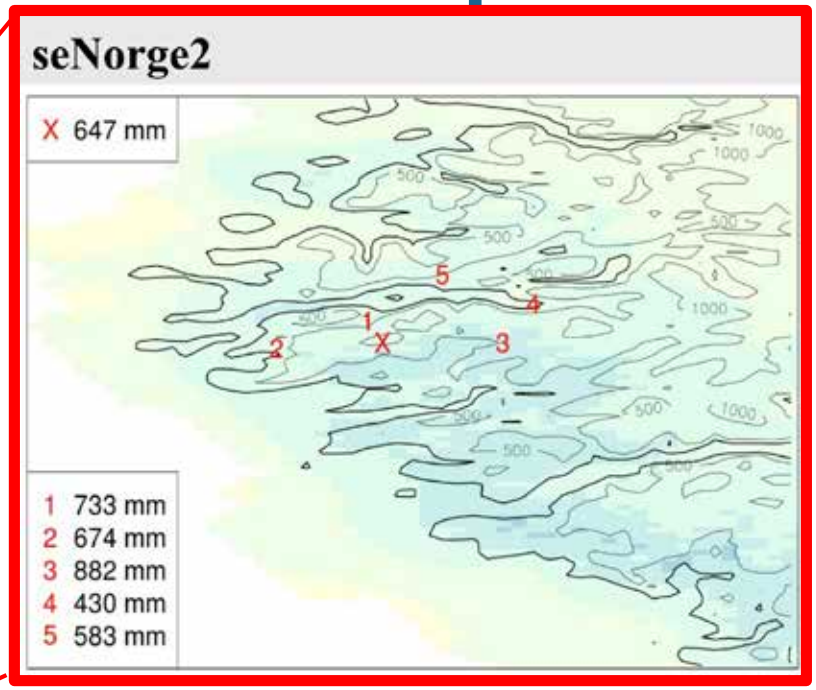
WRF
[Skamarock et al, 2008]

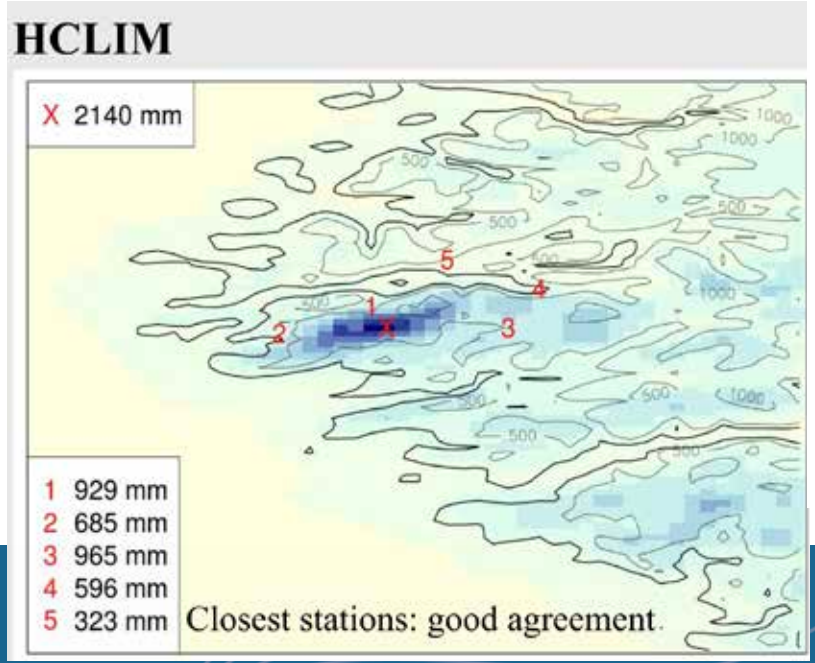


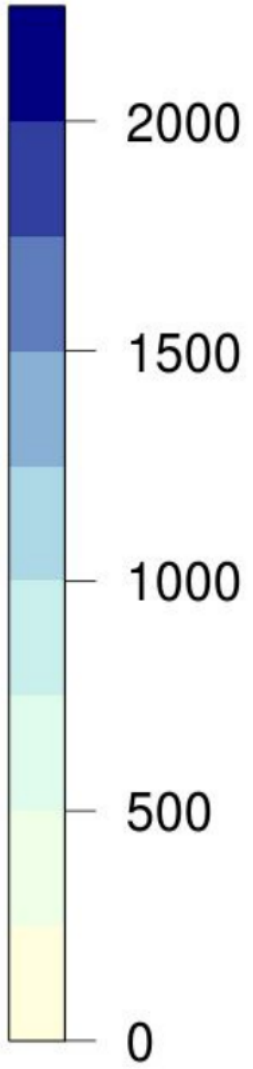
Prein and Gobiet 2017

Evaluating Models in Complex Terrain





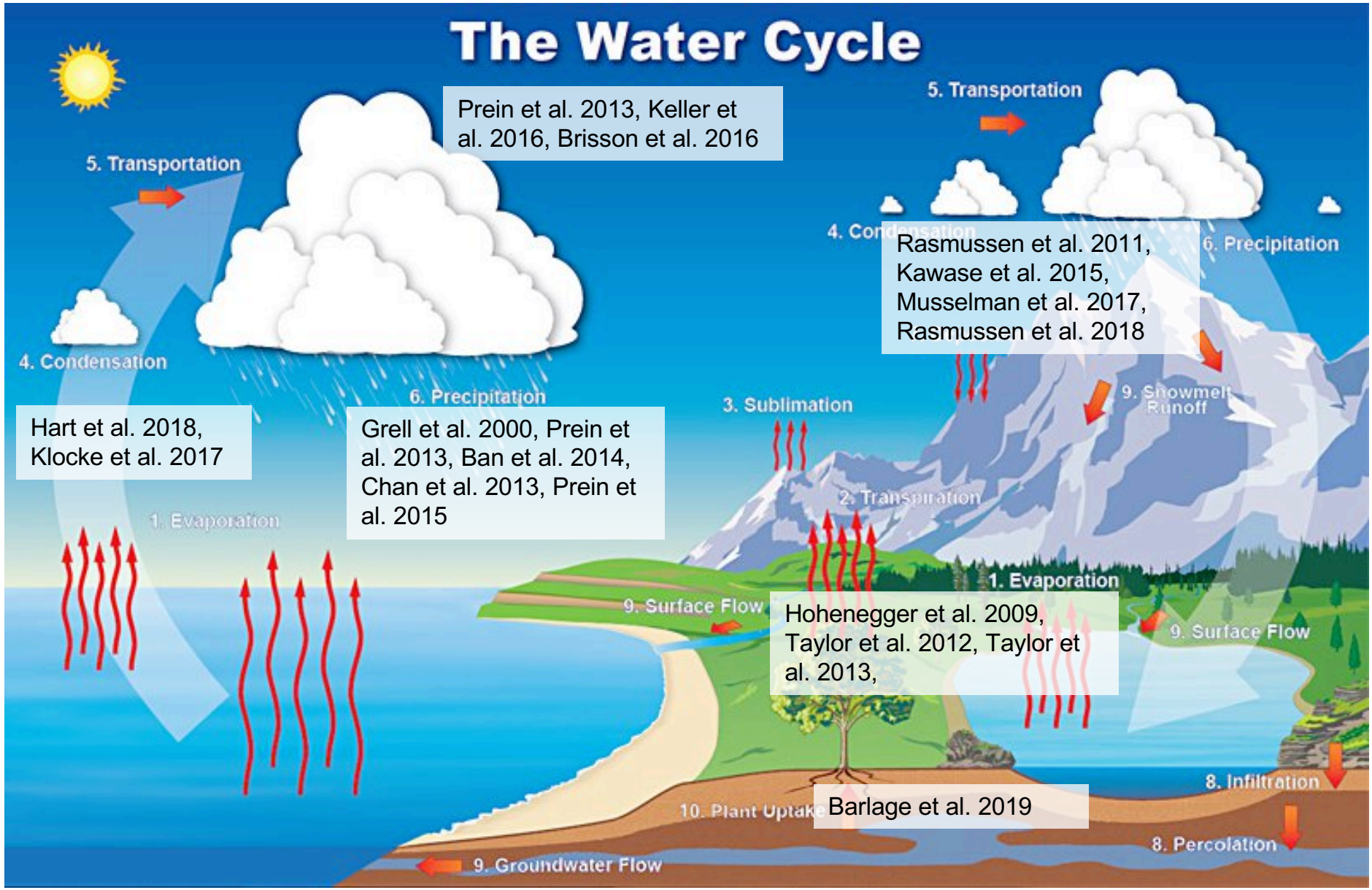




Doble et al. 2019

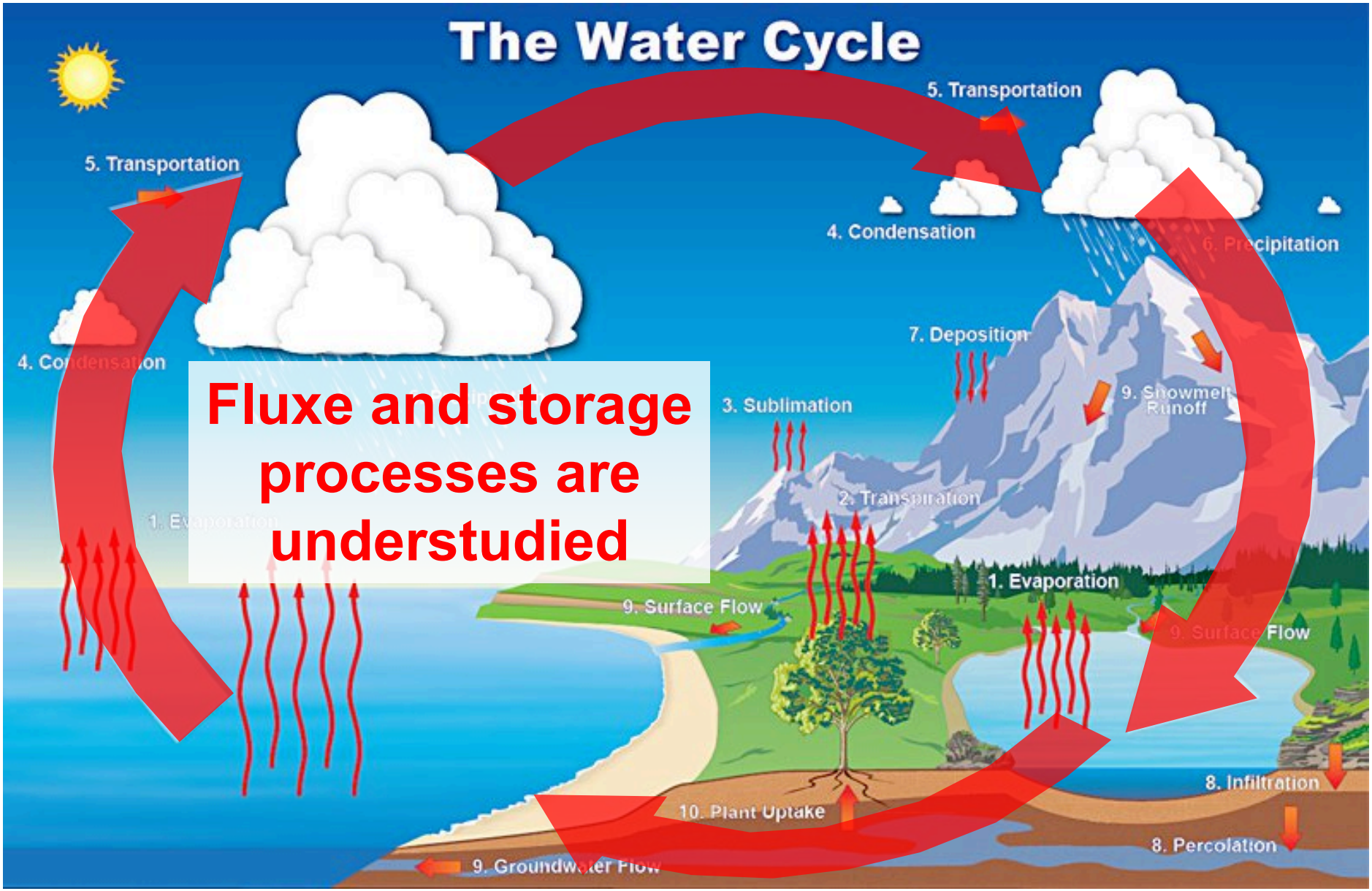
Challenges and Opportunities

Improving the Water Cycle



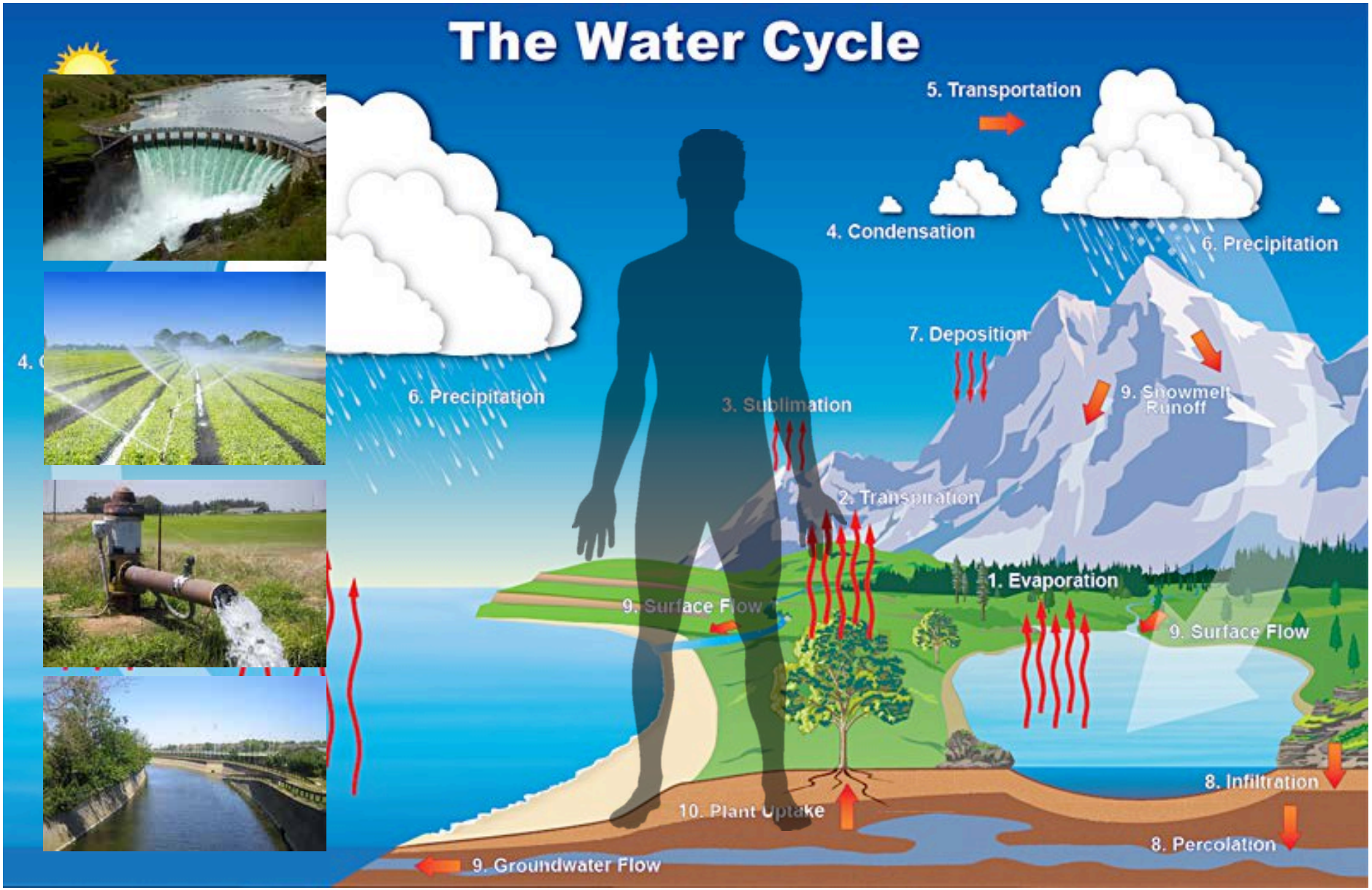
http://www.filtersfast.com

Improving the Water Cycle



http://www.filtersfast.com

Improving the Water Cycle



http://www.filtersfast.com

Thank You

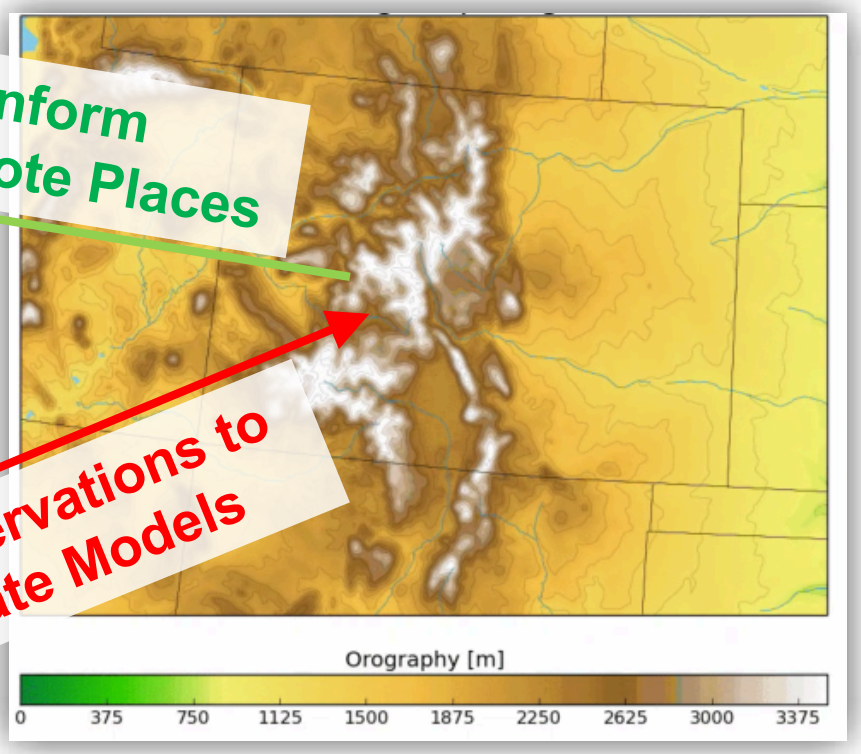
prein@ucar.edu

Sebastião Salgado

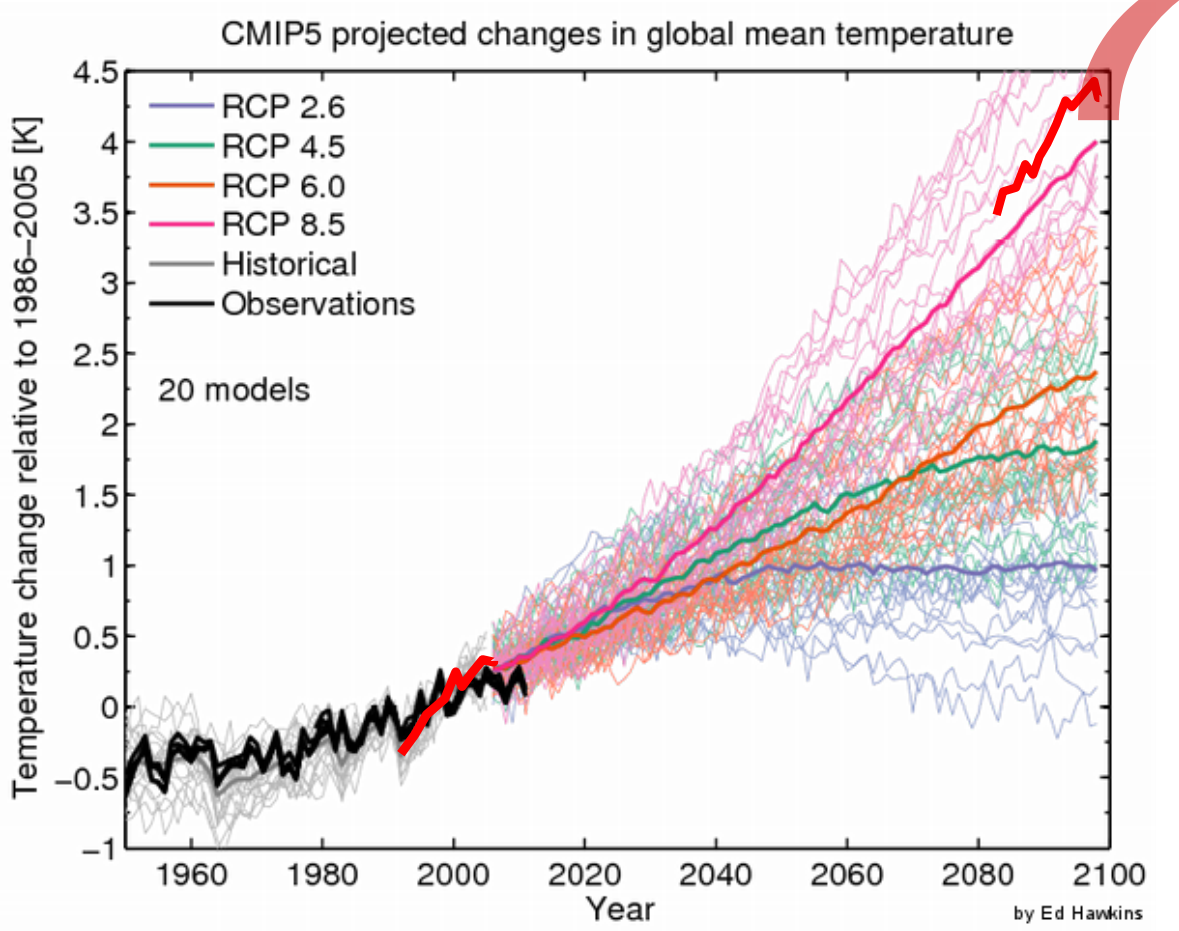
Model Evaluation in Mountainous Regions

Use Models To Inform Observations in Remote Places

Use Observations to Evaluate Models



Assessing Uncertainties

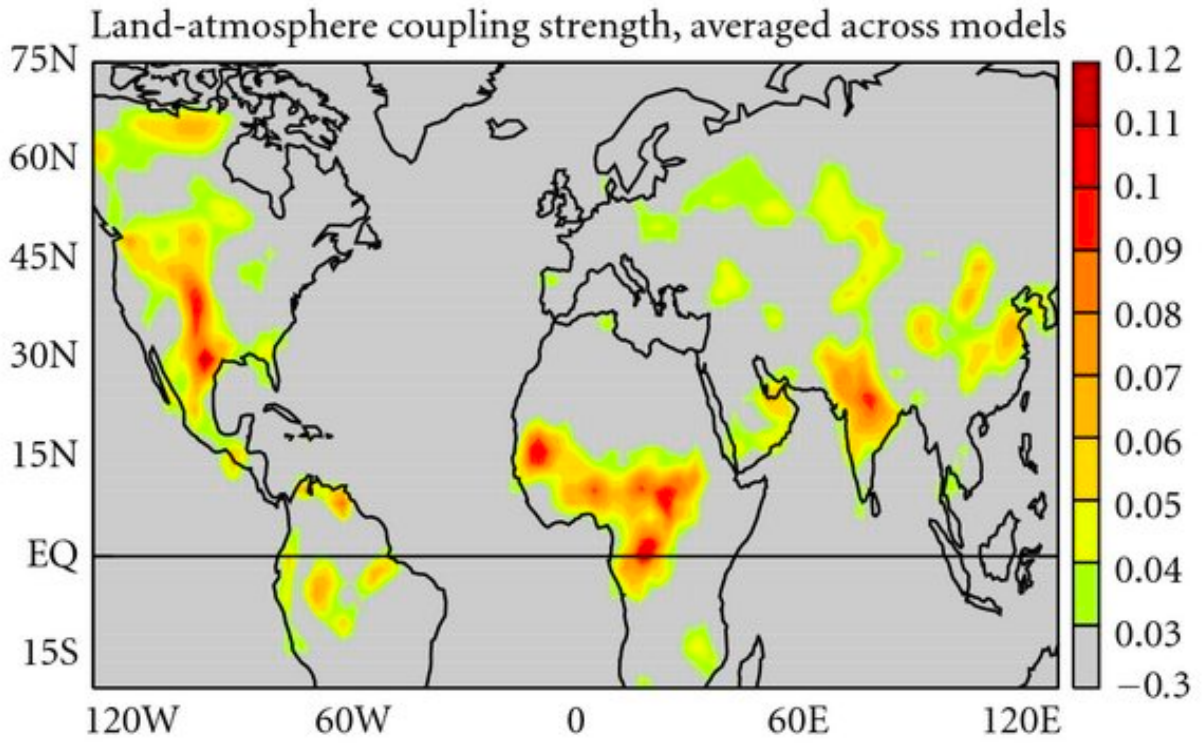


Select 1 GCM & 1 scenario to downscale a region over ~10-year period with one RCM

Assessing uncertainty is community effort and needs a framework

e.g., CORDEX-FPS

Dry & Warm Bias in CMIP5 GCMs



Koster and Sud (2006)

"For boreal summer, such hot spots for precipitation and temperature are found over large regions of Africa, central North America, and India" [Koster and Sud 2006]