A REVIEW ON REGIONAL CONVECTION PERMITTING CLIMATE MODELING: DEMONSTRATIONS, PROSPECTS, AND CHALLENGES

Based on the article:
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COSMO / CLM / ART User Seminar, 9 March 2016, Offenbach

Outlook

1. **Introduction** to Convection Permitting Model (CPMs) Simulations
2. **Critical components**
3. **Added value** of CPMs
4. Influences on the **climate change signal & feedback processes**
5. Applications in **impact studies**
6. Major **challenges** and **outlook**

Goal: synthesis of activities on CPMs

Basis for future coordinated projects

What are Convection Permitting Model (CPM) Simulations and which theoretical advantages do they have?

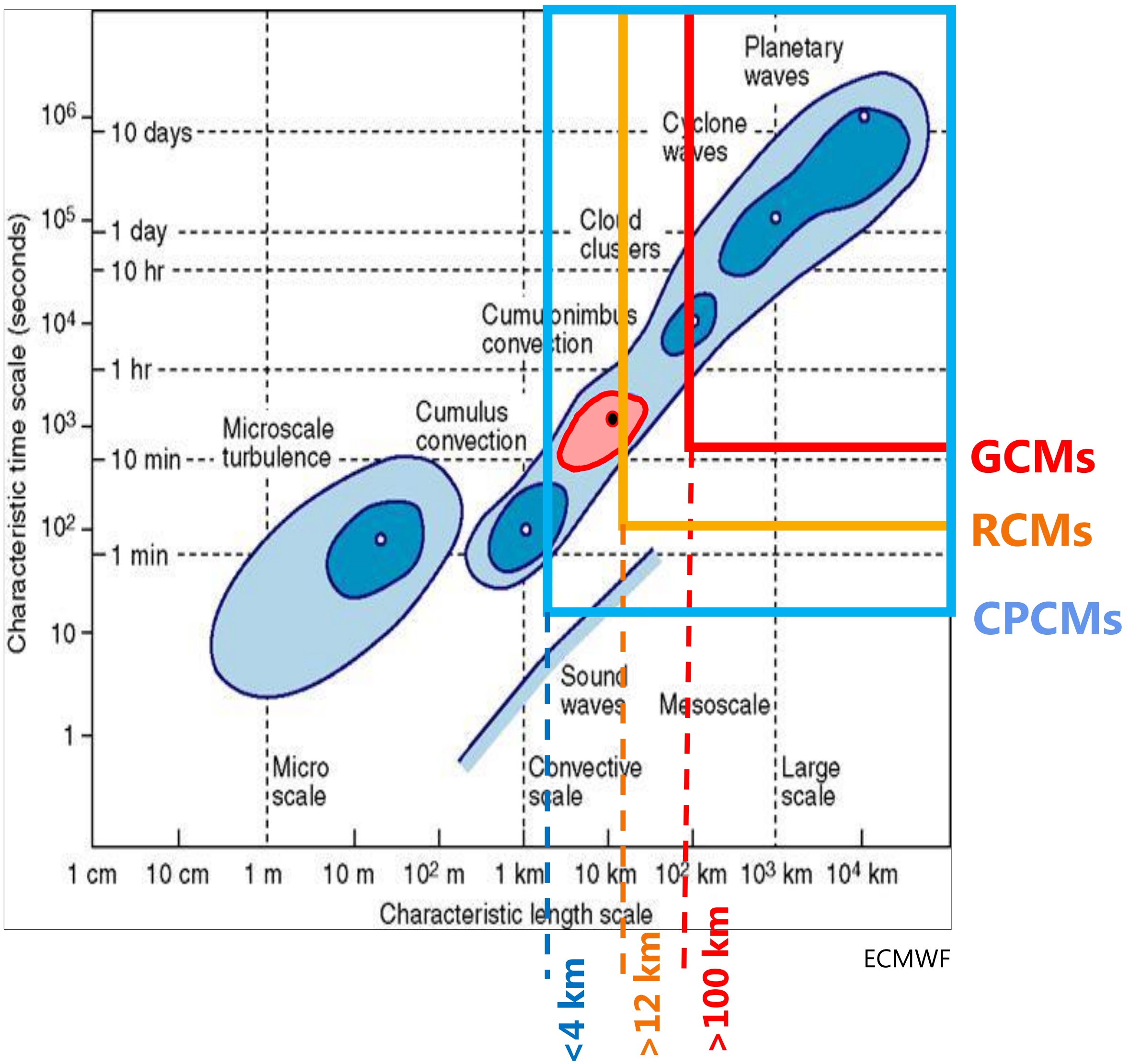
What are Convection Permitting Model (CPM) Simulations and which theoretical advantages do they have?

© Erwan Brisson
Light gray: Ice
Dark gray : Graupel
Red: Snow
Blue: Rain + Cloud water

Surface contours:
Updraft (red); Downdraft (blue)

What are Convection Permitting Model (CPMs) Simulations and which theoretical advantages do they have?

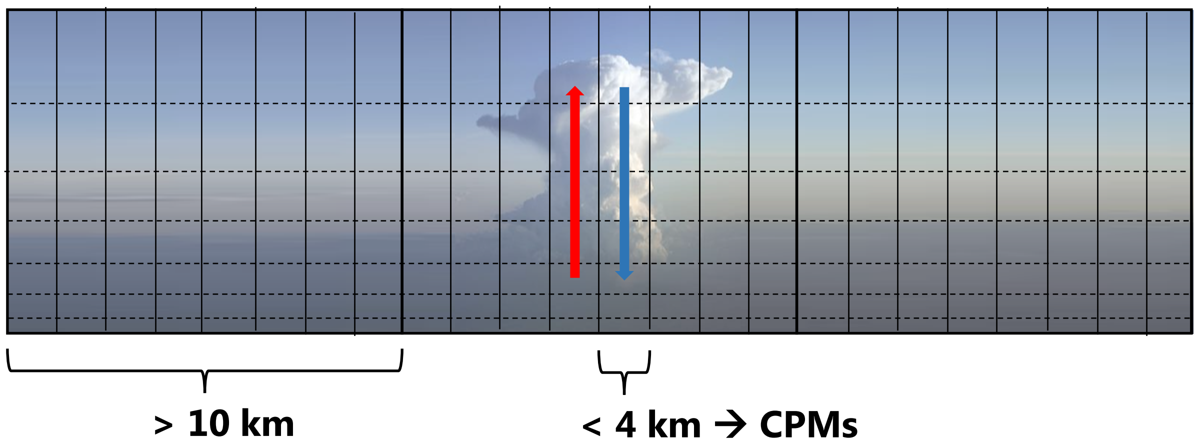
Weisman et al. [1997]: Δx>4km leads to “grid-scale storms” without convection parametrization



ECMWF

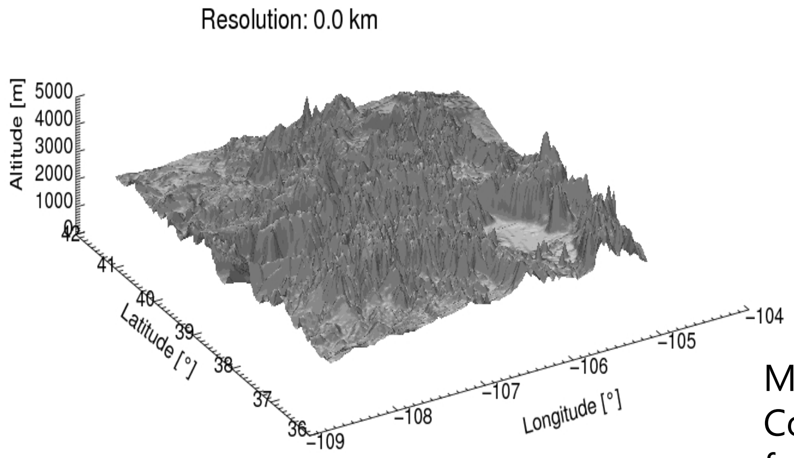
What are Convection Permitting Model (CPM) Simulations and which theoretical advantages do they have?

1.) Omit error prone deep **convection parameterizations**



What are Convection Permitting Model (CPM) Simulations and which theoretical advantages do they have?

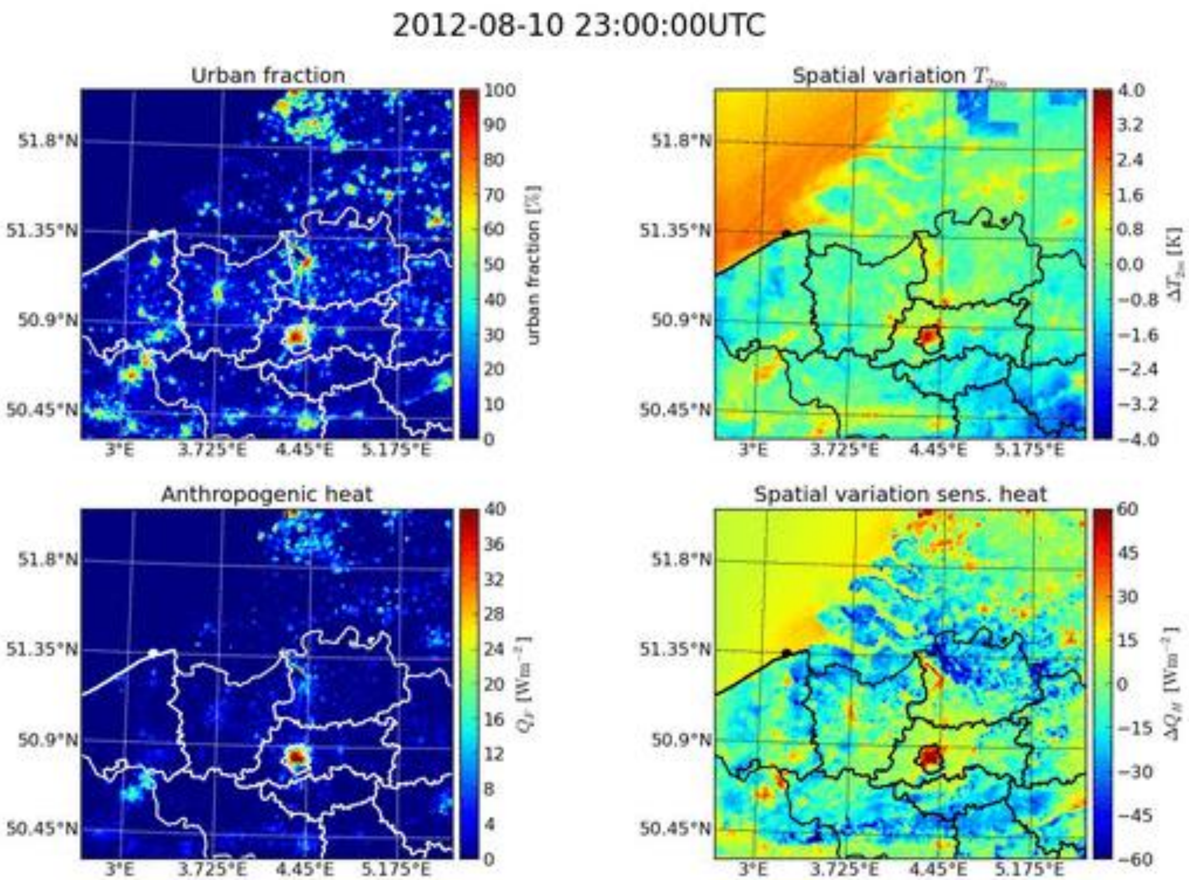
2.) Improved representation of **orography** and surface fields (coastlines, lakes, ...)



Model orography in the Colorado Rocky mountains from Δx=1 km → 100 km

What are Convection Permitting Model (CPM) Simulations and which theoretical advantages do they have?

3.) Improved representation of **land-use change** (urbanization, deforestation,..)



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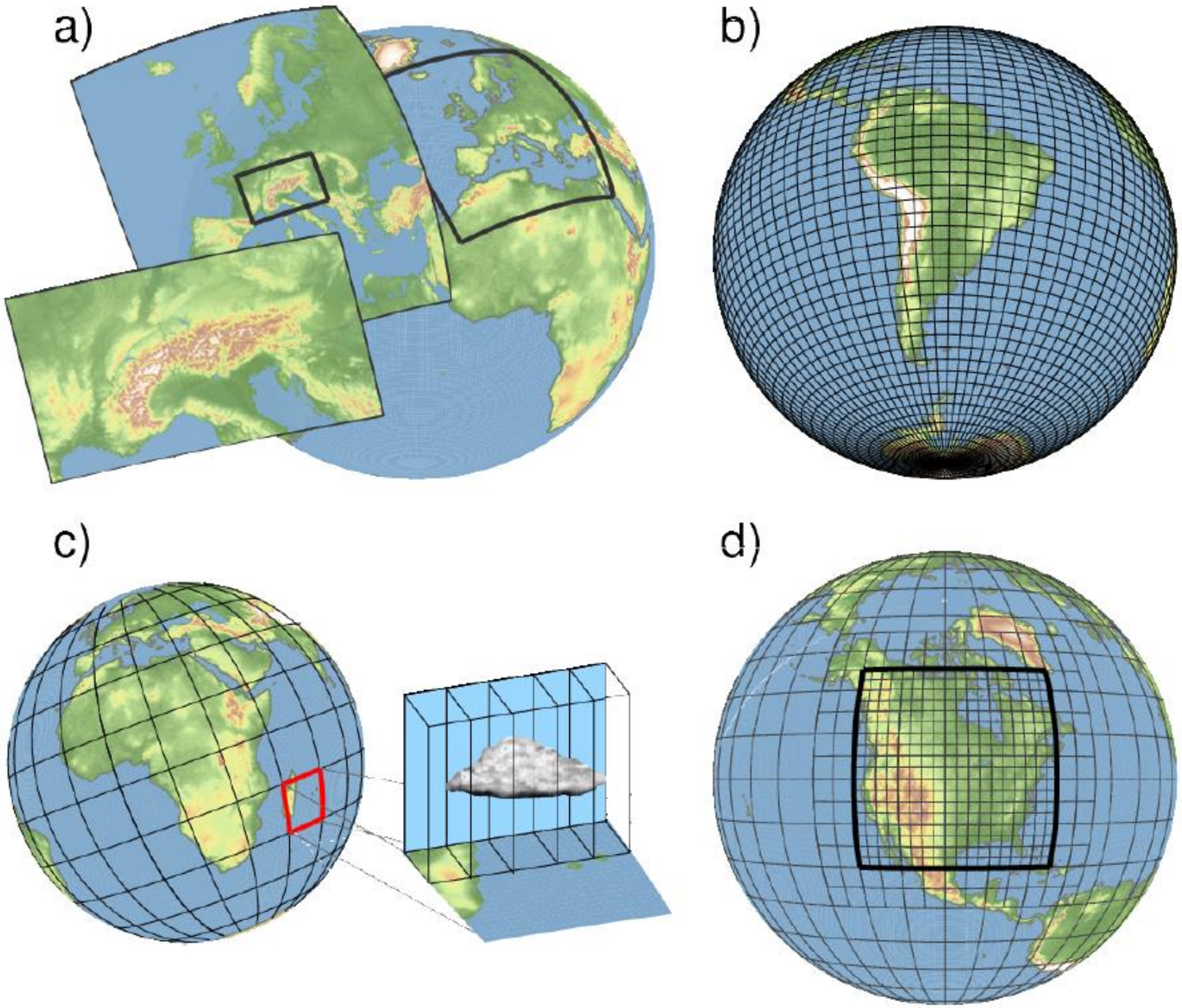
Different modeling approaches for CPM climate simulations



CPM approaches

a) limited-area modeling
b) global CPM climate simulations
c) Superparameterizations
d) Variable resolution global models

Different modeling approaches for CPM climate simulations

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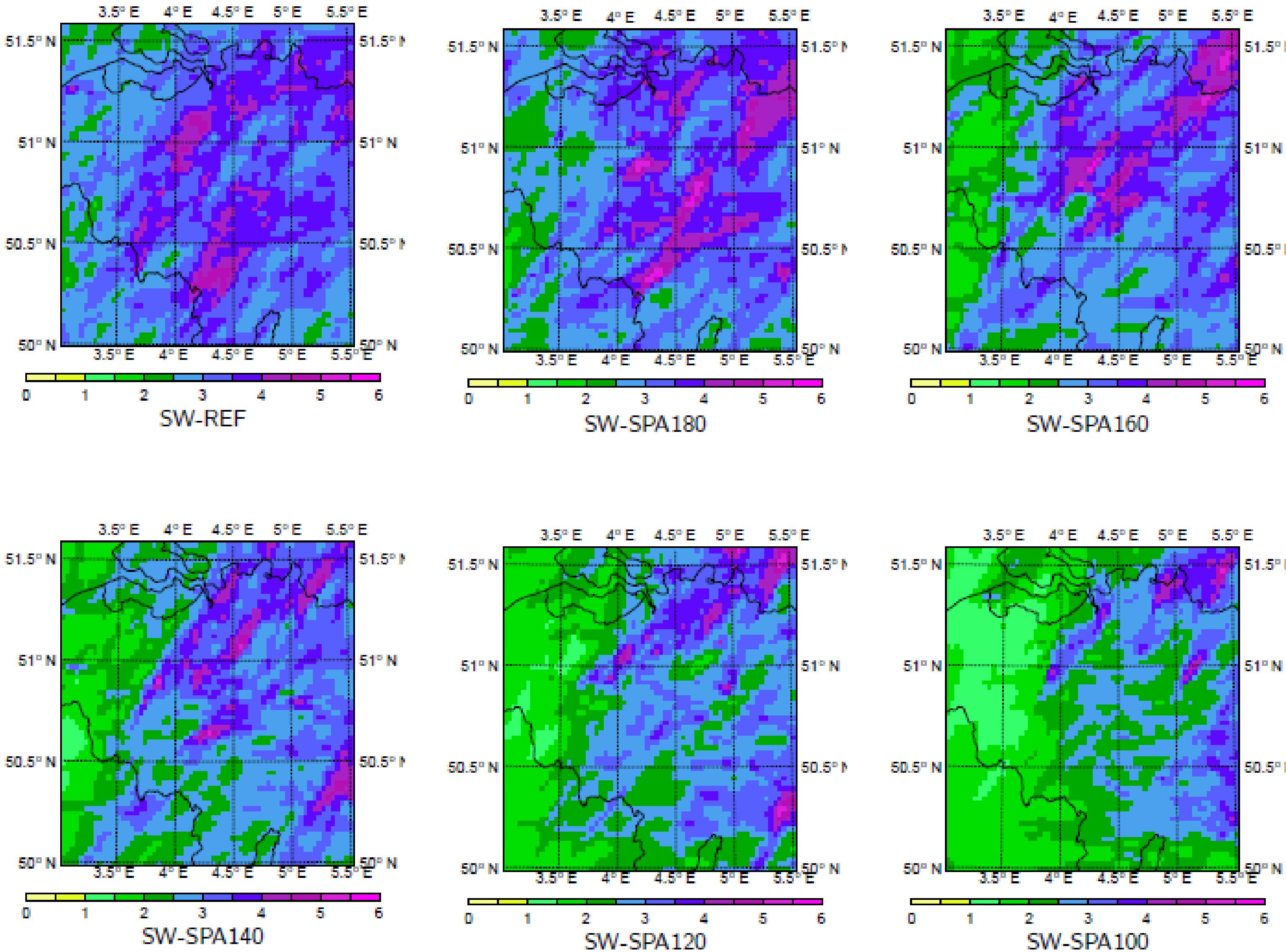
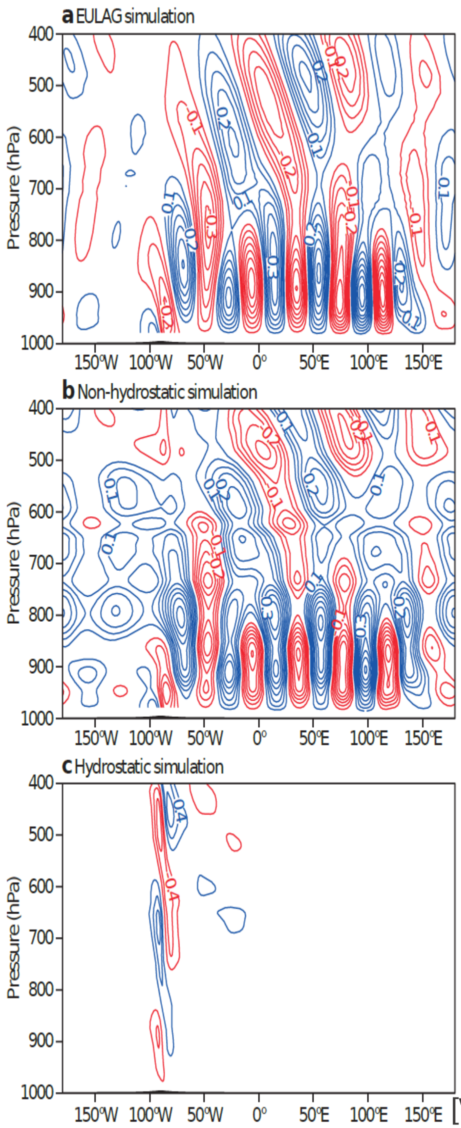
Critical components: Downscaling strategies

JJAS 2007 COSMO-CLM simulation at 2.8 km Brisson et al., 2015]

- 150 km spatial spin-up necessary
- Graupel necessary
- Nesting step < 1:12
- Avoid grey-zone (4-10km)



Critical components: Numerics



Nonhydrostatic EULAG
Analastic reference model

Nonhydrostatic IFS

Hydrostatic IFS

[Wedi and Malardel , 2010]

Hydrostatic approximation

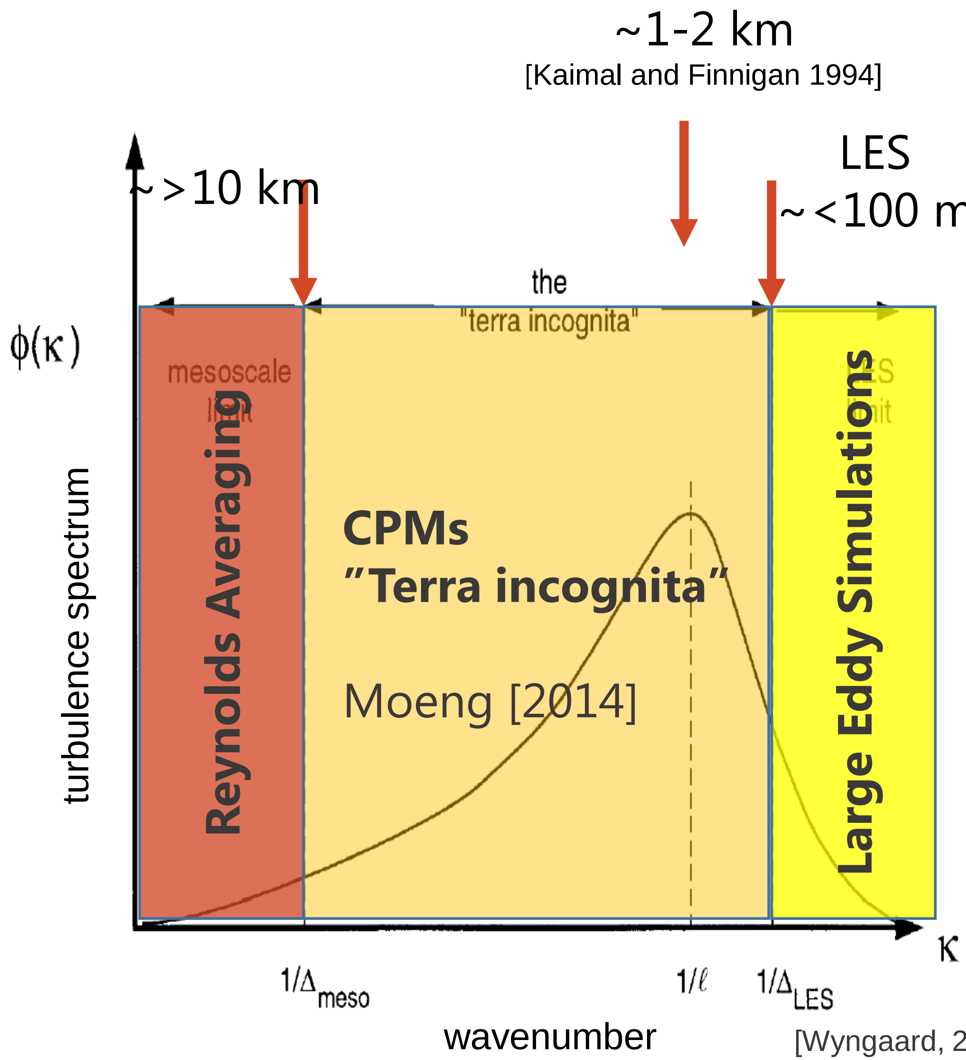
$$\frac{\partial p}{\partial z} = -\rho g$$

p… pressure
ρ… density
g…gravitational acceleration

www.atmos.washington.edu South Sandwhich Islands

Critical components: Turbulence

CPM is too fine to assume all turbulence can be parametrized ($\Delta x > 10km$)



Too coarse to assume energy-producing turbulent motion is resolved ($\Delta x < 100m$)

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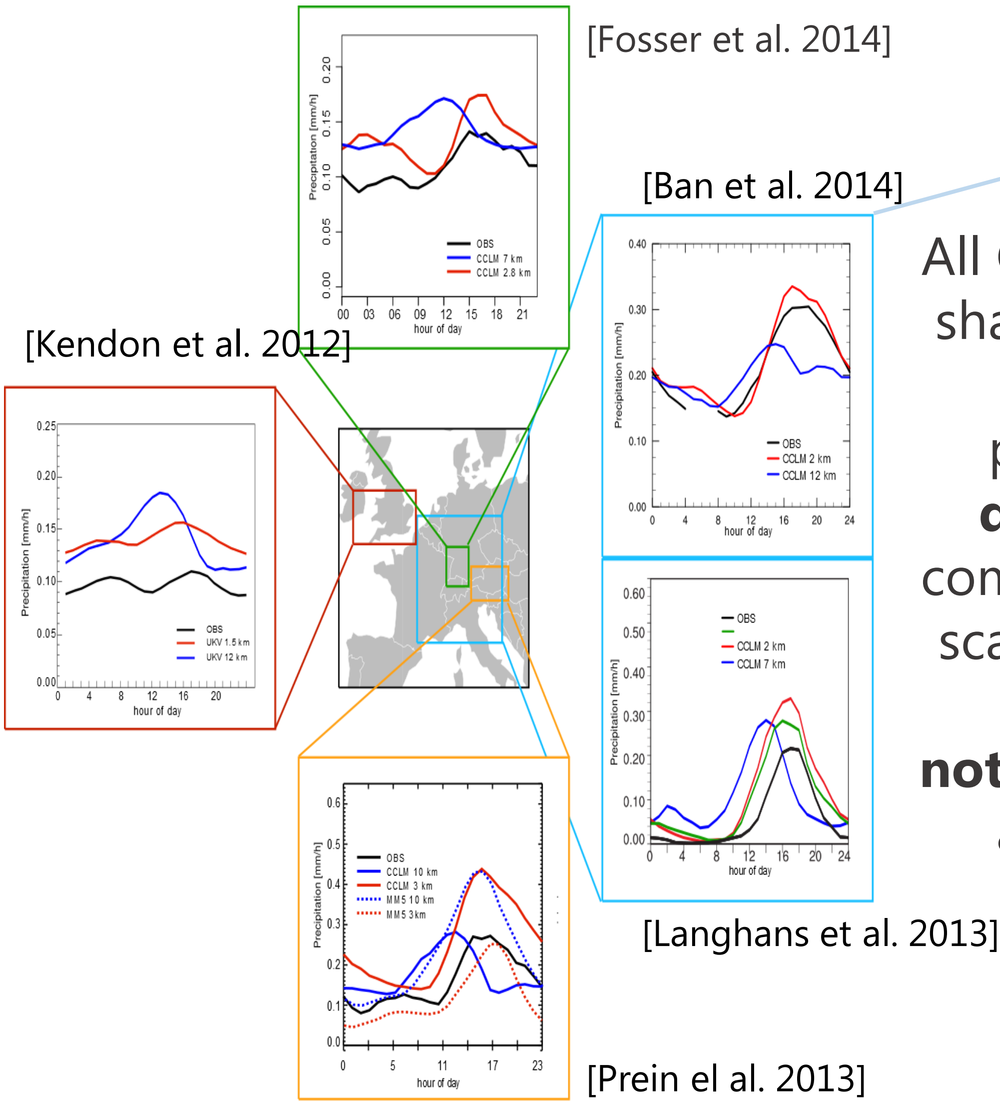
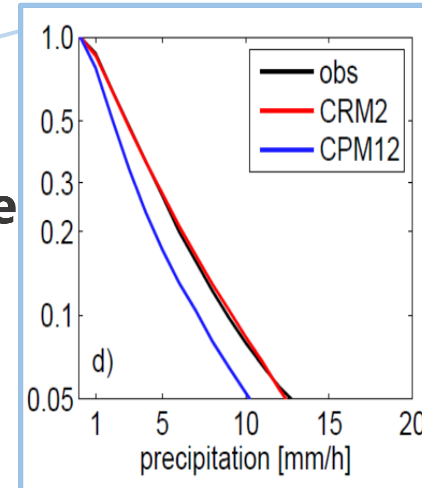
Added value of CPMs
Precipitation diurnal cycle

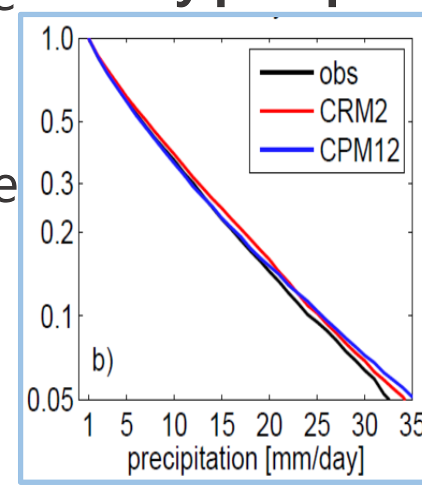


All CPMs **improve** shape (onset and peak) of precipitation **diurnal cycle** compared to large scale simulations but **not necessary** the **amplitudes**

Hourly precipitation



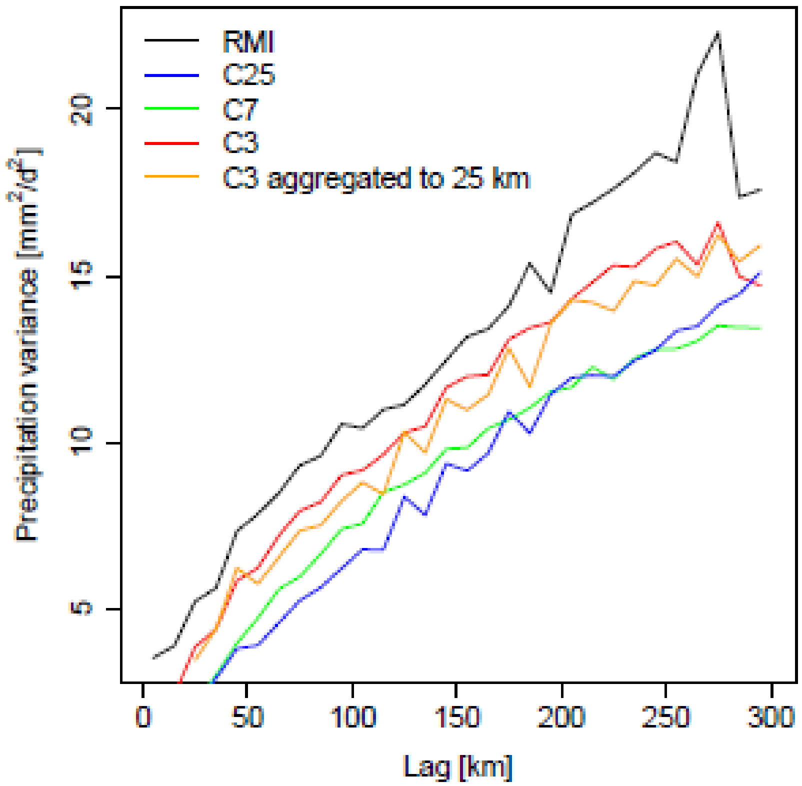
Daily precipitation



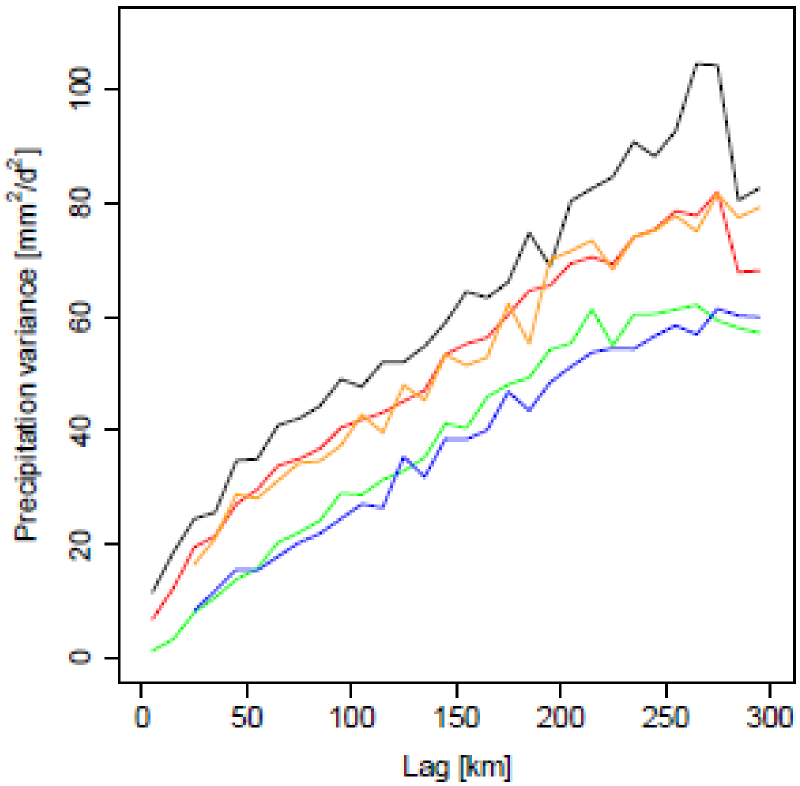
[Ban et al. 2014]

Added value of CPMs
Improved spatial dependency

Decadal COSMO-CLM simulations driven by ERA-Interim for Belgium at 2.8 km [Brisson et al., 2016, Clim. Dyn.]



Average



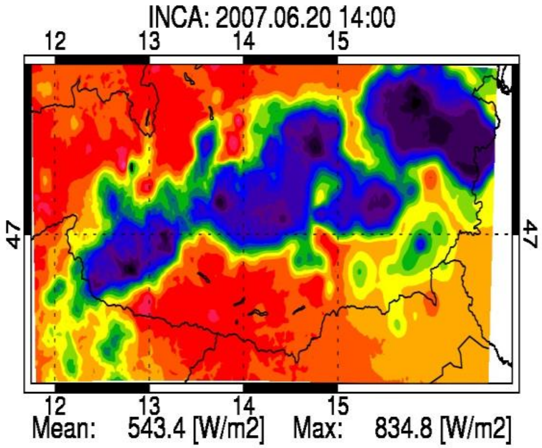
90^{th} quantiles

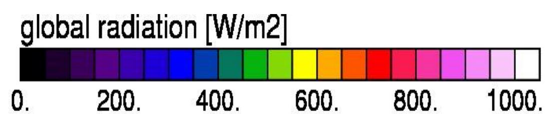
Added value of CPMs
Clouds and global radiation (GL)

CPM: Cloud cover decreases
Smaller denser convective clouds

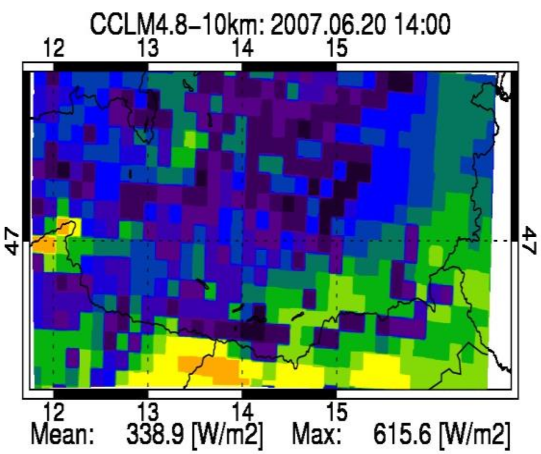
CPCM +14 % in JJA

Reference: 1 km

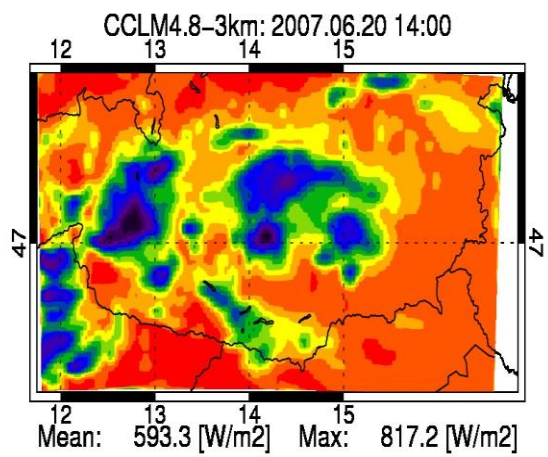


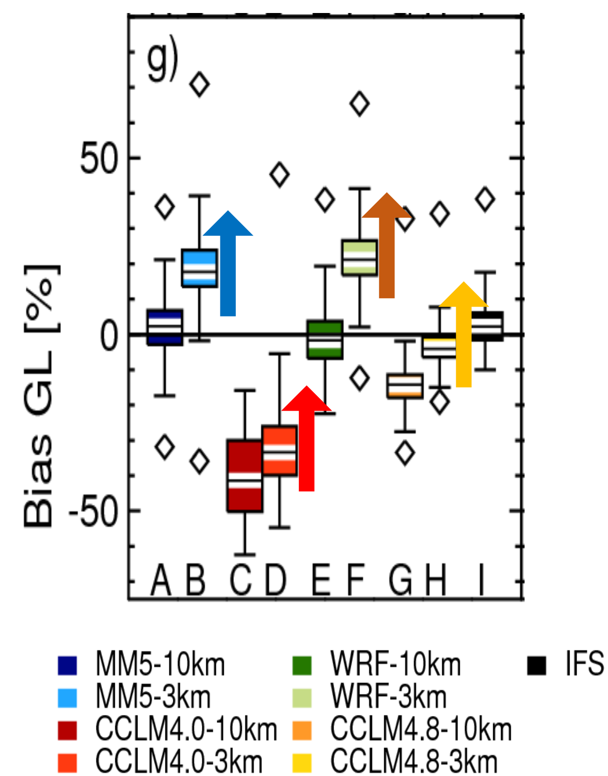


10 km Simulation



3 km Simulation

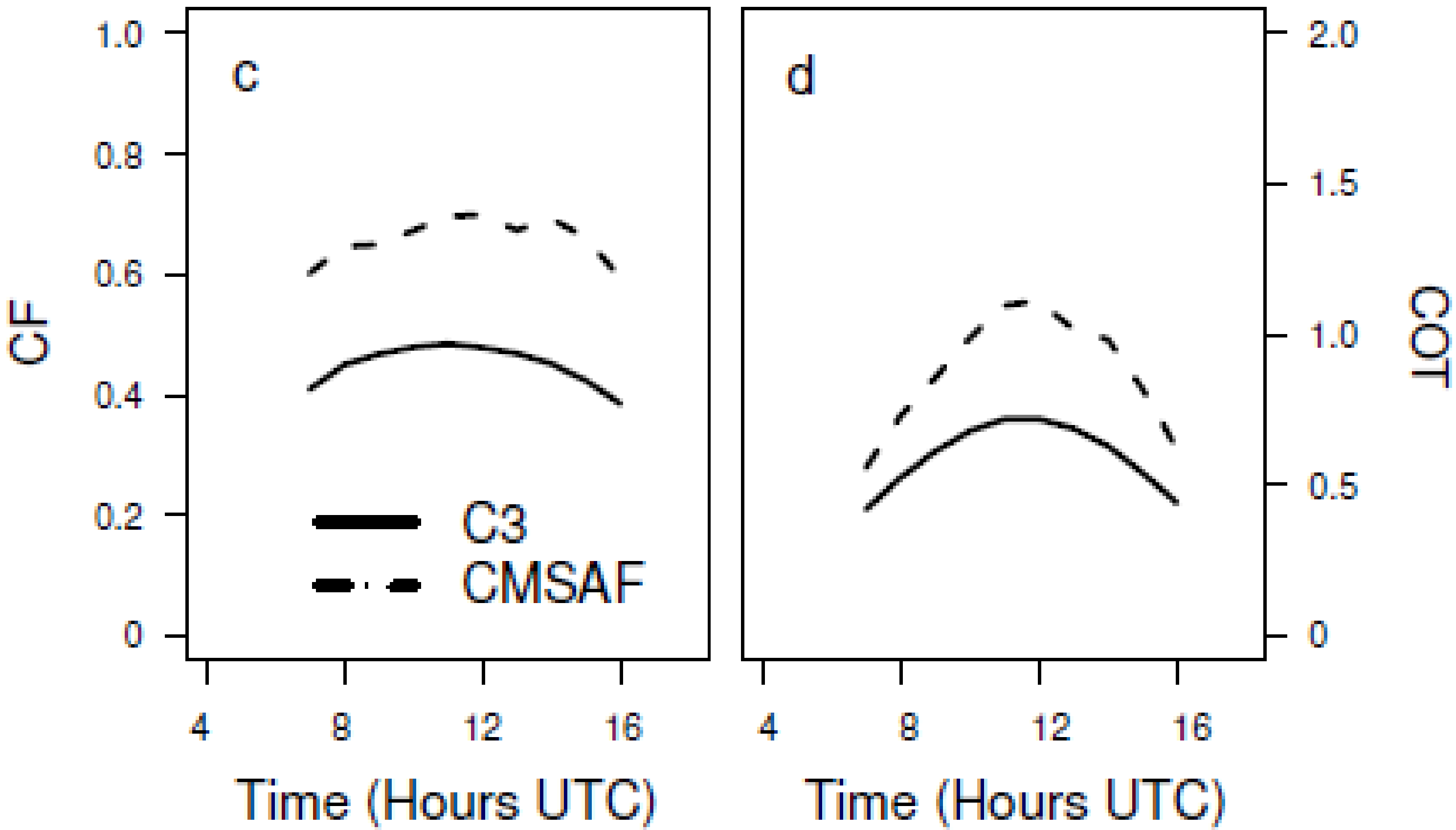




Added value of CPMs
Clouds

Decadal COSMO-CLM simulations driven by ERA-Interim for Belgium at 2.8 km [Brisson et al., 2016, Clim. Dyn.]

- Daily cycle well represented
- Cloud fraction and cloud optical thickness underestimated

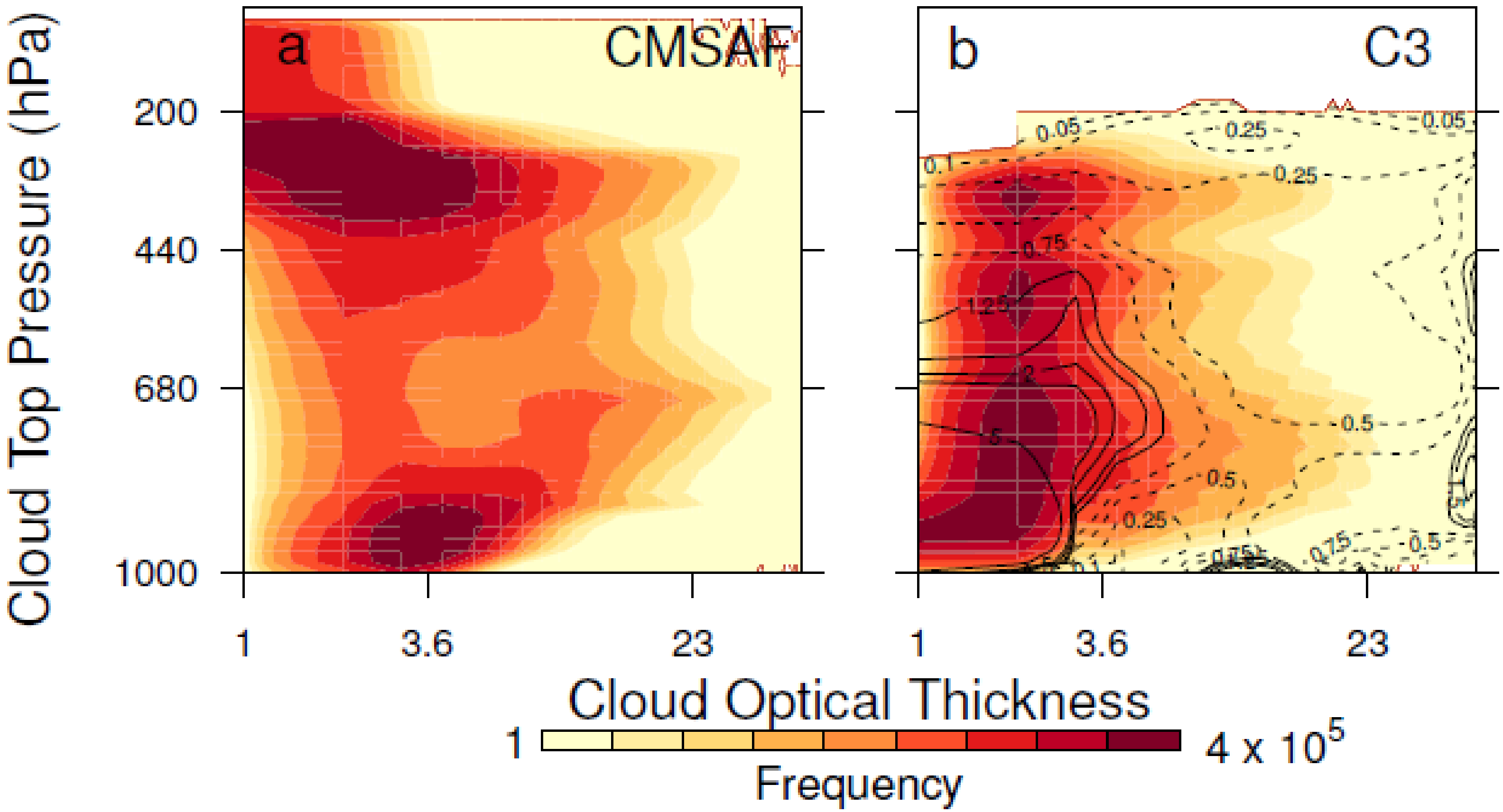


Added value of CPMs
Clouds

[Brisson et al., 2016, Clim. Dyn.]

- Too little high and intermediate, thick clouds
- Too much low, thin clouds

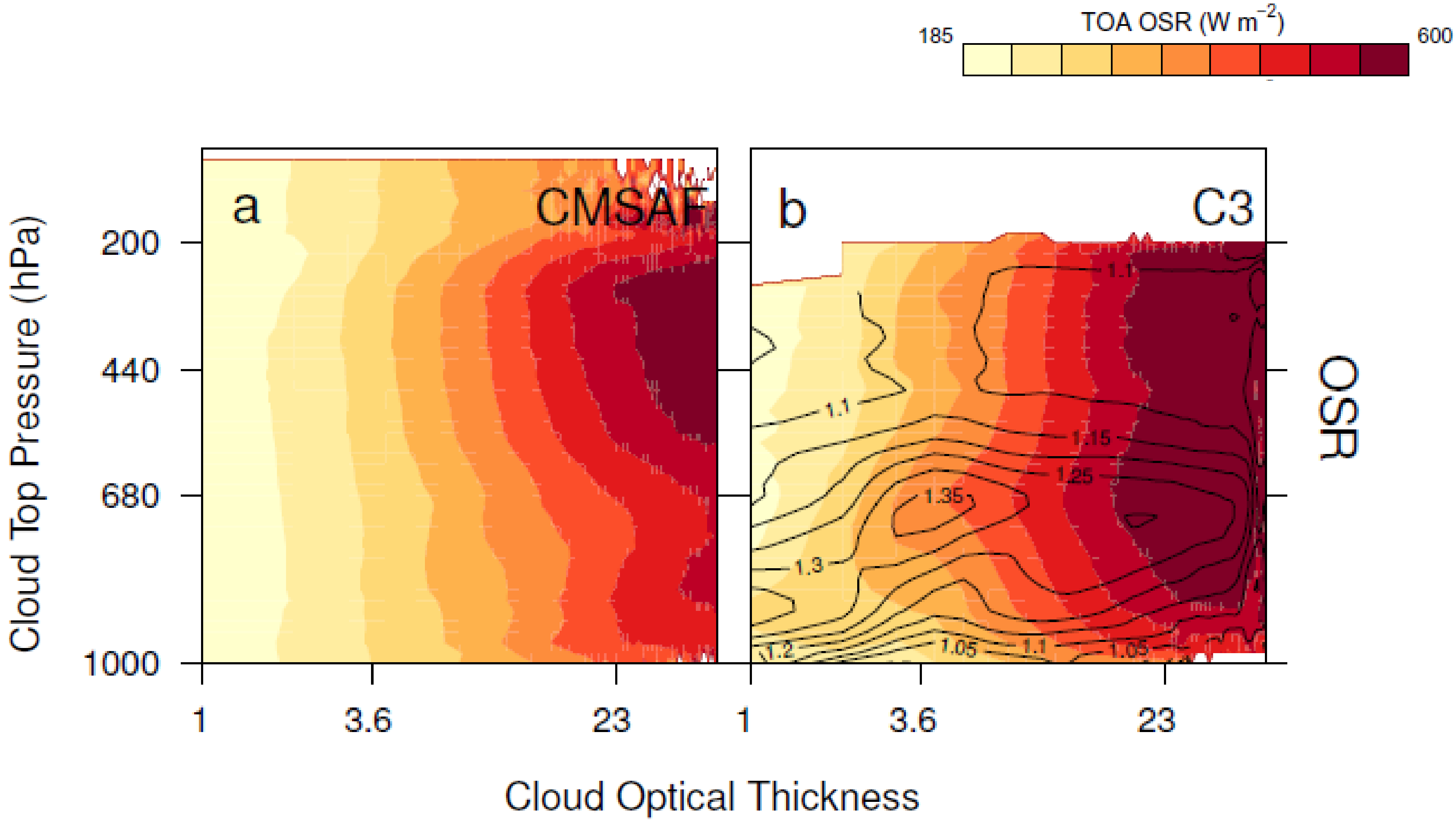
General CPM: overestimated high cloud cover in LSM reduced



Added value of CPMs
Clouds

[Brisson et al., 2016, Clim. Dyn.]

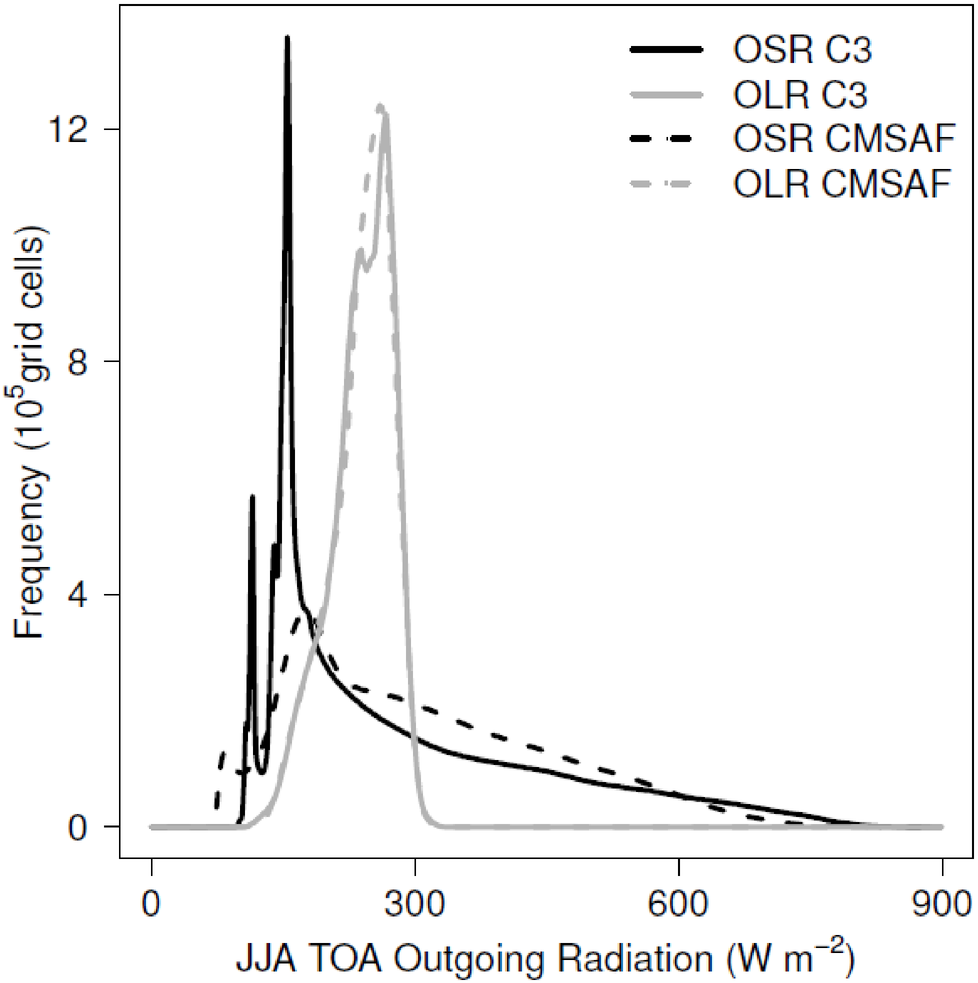
- Underestimation of cloud amount is compensated by too much reflectivity of clouds



Added value of CPMs
Clouds

[Brisson et al., 2016, Clim. Dyn.]

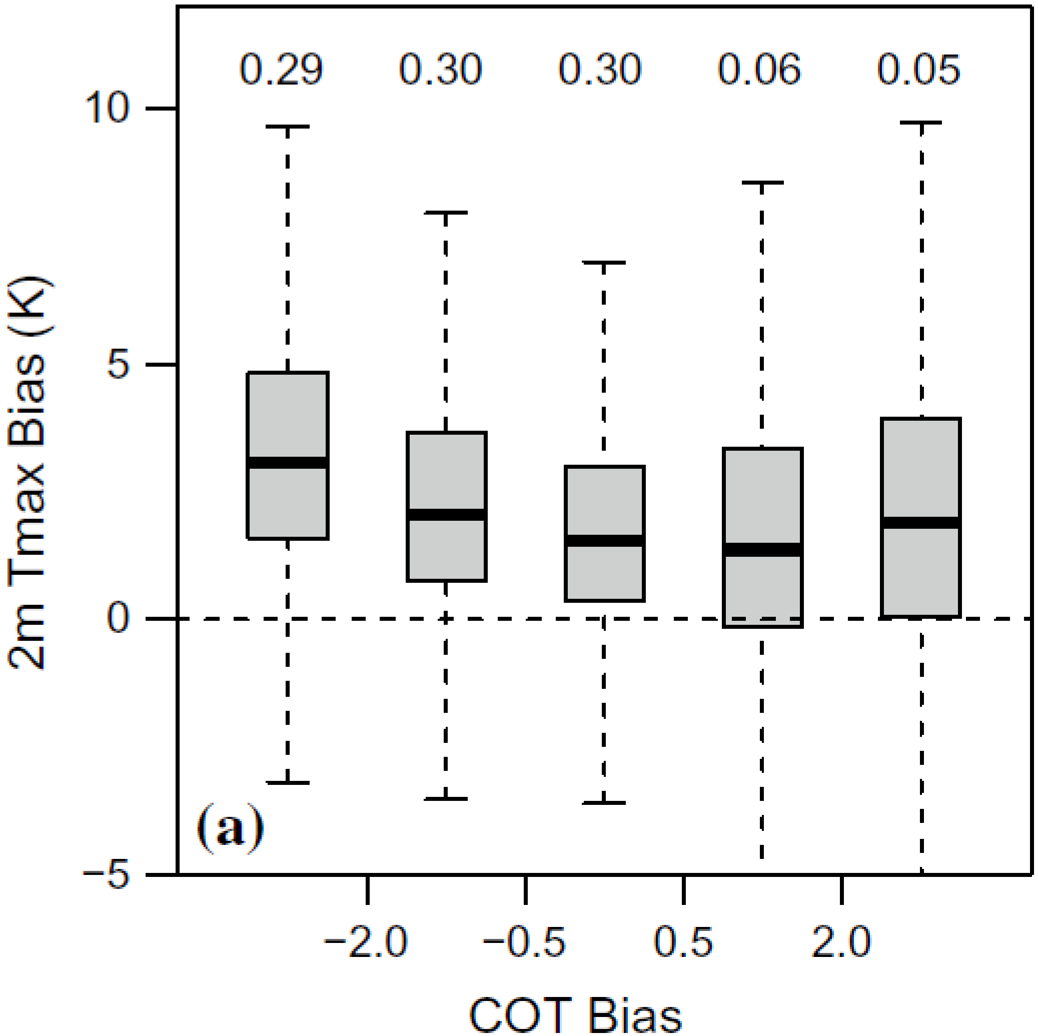
- TOA OSR 6% underestimated (308 W m^{-2} CMSAF; 291 W m^{-2} COSMO-CLM)
- Overestimation clear-sky conditions partly offset by too reflective clouds when they are present



Added value of CPMs
Clouds

[Brisson et al., 2016, Clim. Dyn.]

- Partly explains the overestimation in JJA Tmax



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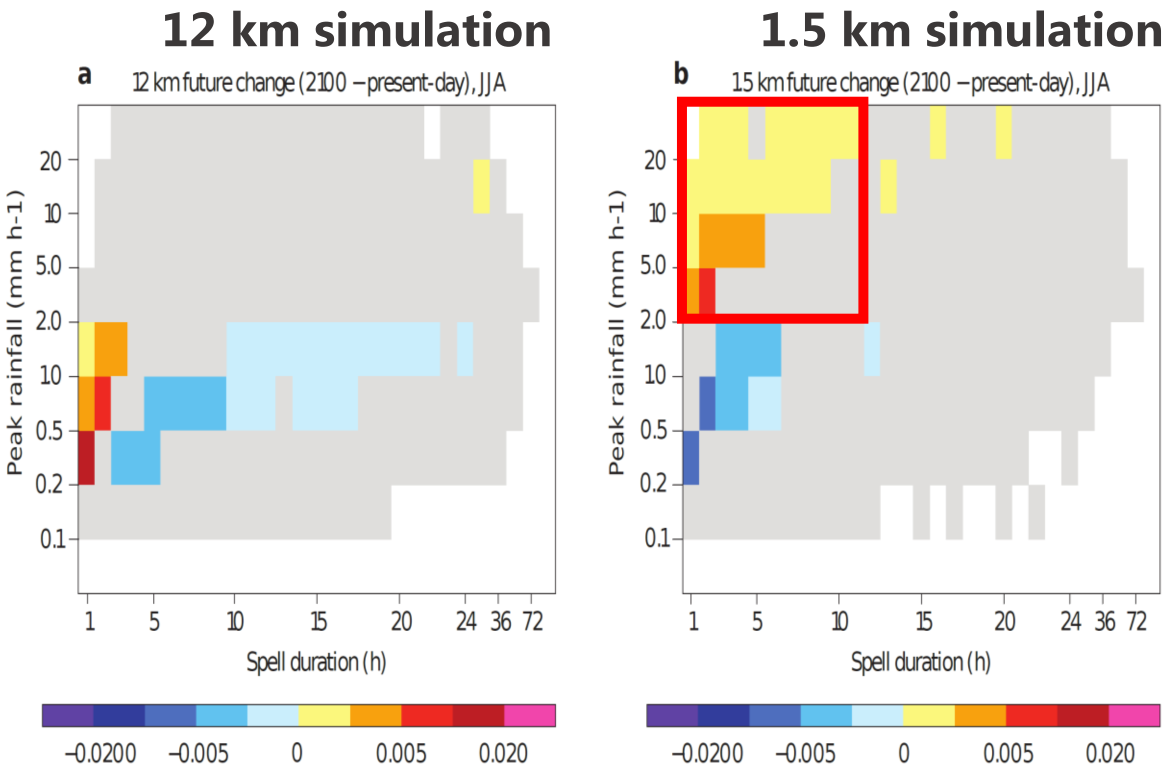
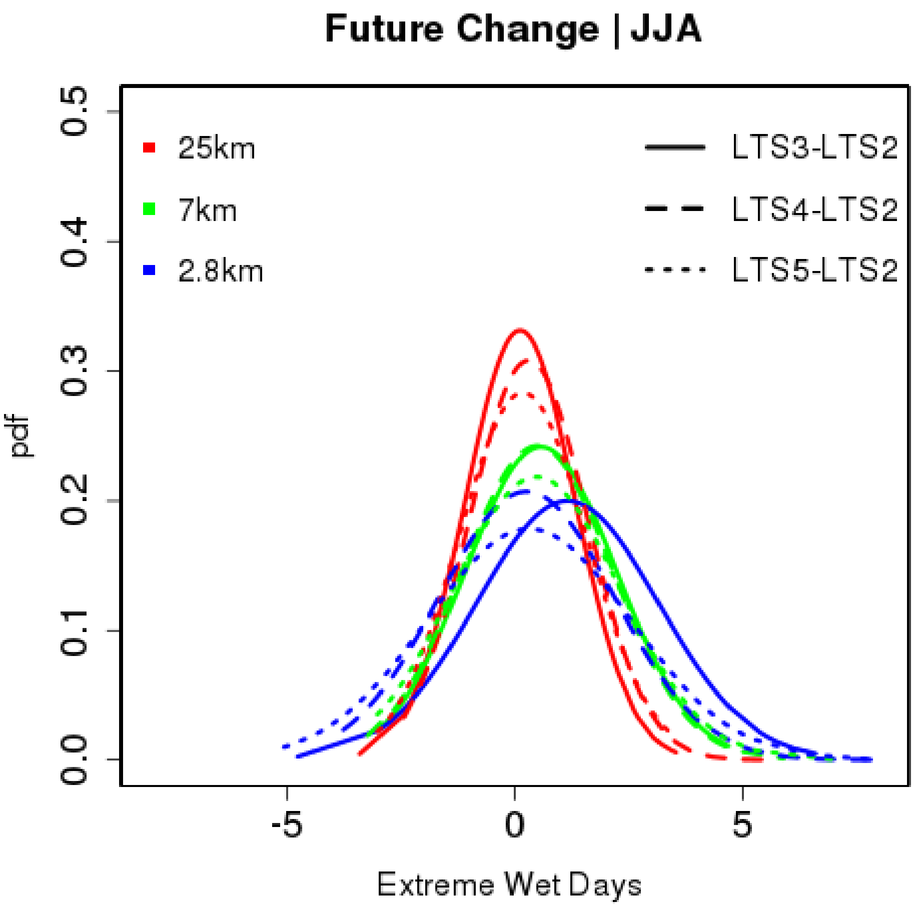
Differences in Climate Change Signal & Feedback Processes Precipitation



[Kendon et al., 2014]

- Increase in short-term future extreme precipitation in the 1.5 km model (flashfloods)
- This is not seen in the 12 km model.

Differences in Climate Change Signal & Feedback Processes Precipitation



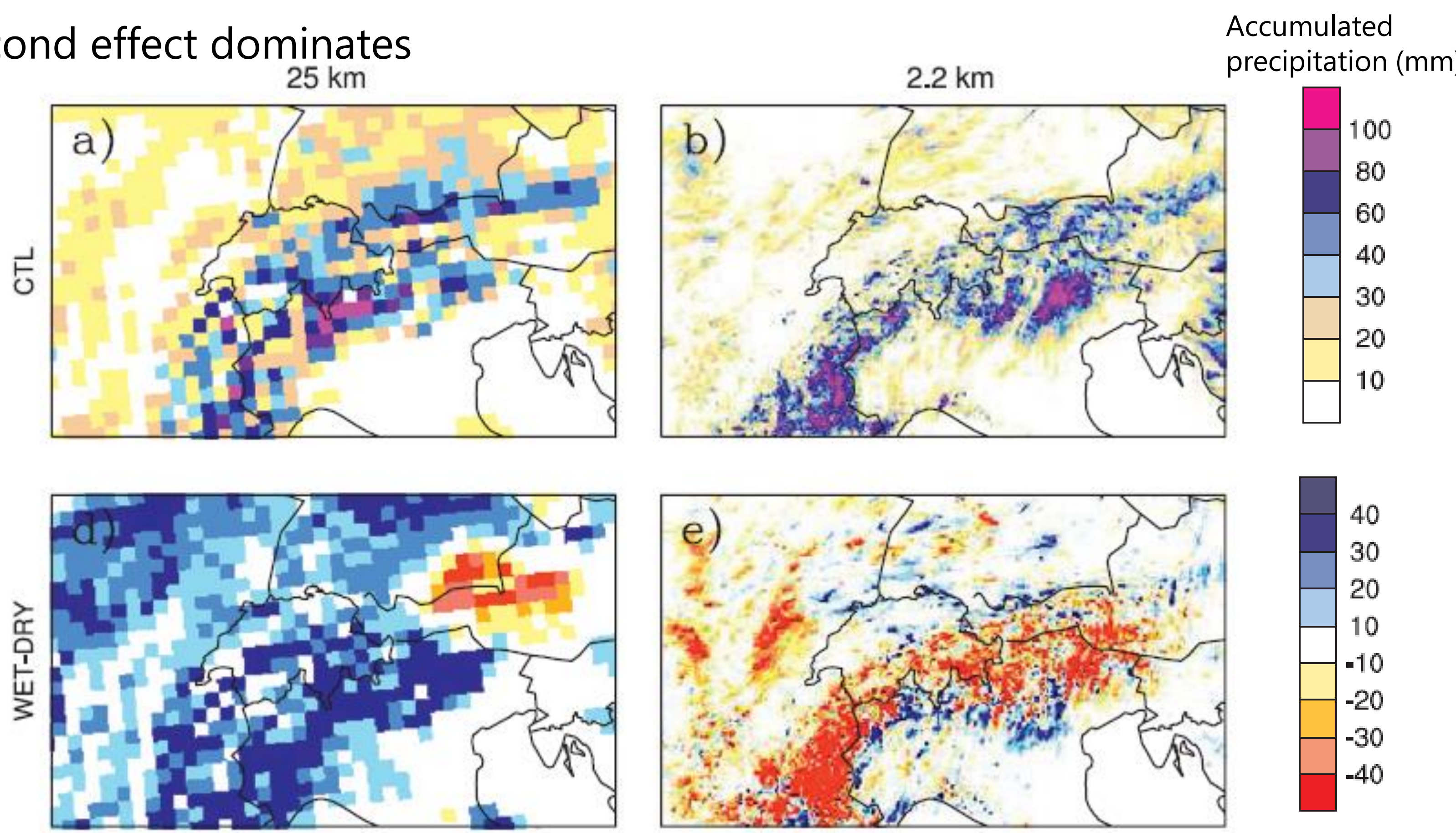
- 99th percentile of the reference period (2001-2010) [Saeed et al., 2016]
- CPS pdf is widened for extreme wet days

Difference in feedback processes Soil moisture precipitation

July 2006 COSMO-CLM simulation [Hohenegger et al., 2009]

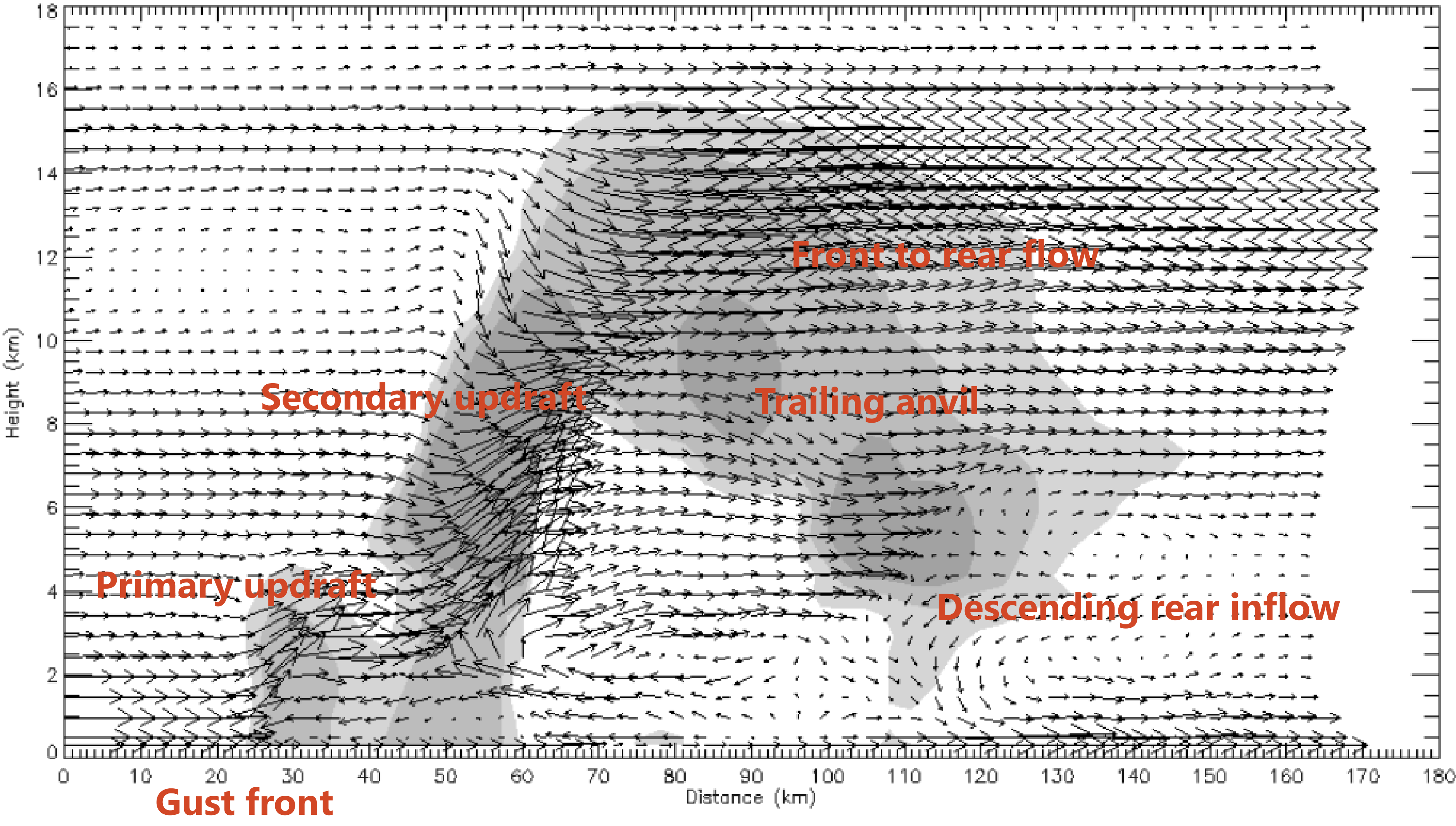
- Wet soil: moister shallower boundary-layer favoring deep convection
- Less vigorous thermals cannot break through the stable air barrier

→ In CPM second effect dominates



Difference in feedback processes
Leaf-area-index precipitation

CPM (3 km) ARPS simulation sub-saharan west africa [Lauwaet et al., 2010]

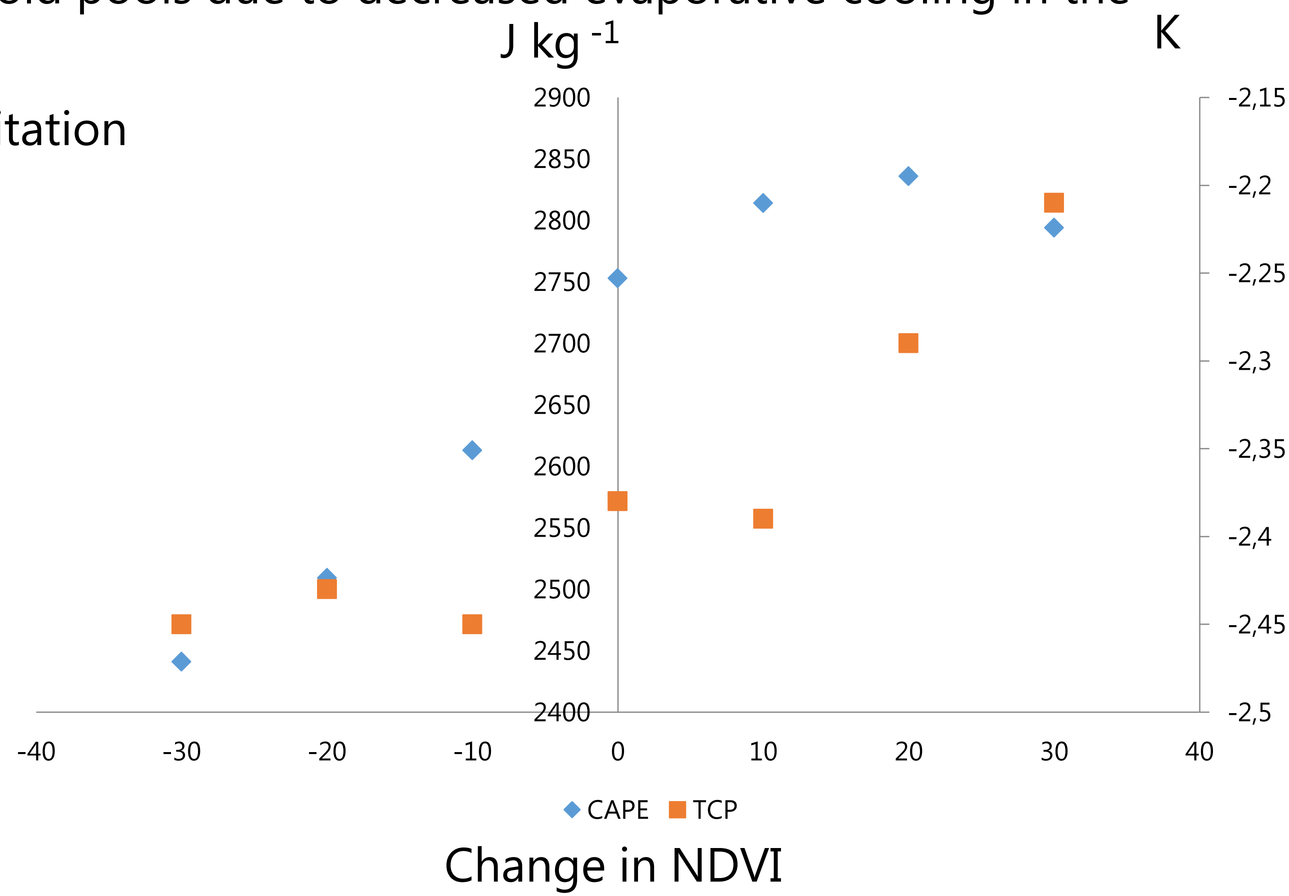


Difference in feedback processes
Leaf-area-index precipitation

CPM (3 km) ARPS simulation sub-saharan west africa [Lauwaet et al., 2010]

- CAPE increases with NDVI due to increase in boundary-layer humidity
- Weaker and smaller cold pools due to decreased evaporative cooling in the boundary layer

→ Little effect on precipitation



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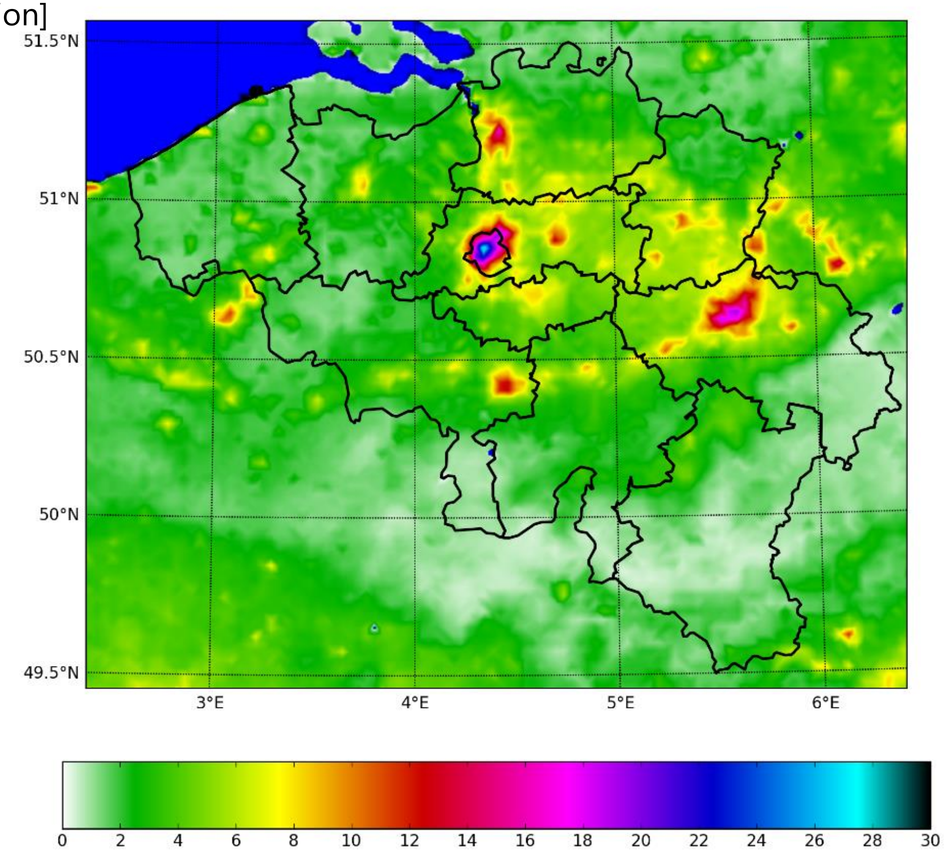
Applications in impact studies
Urban Modelling

Change in the number of days with T_{min}>20˚C in 2060 for a ''middle' climate scenario

[Wouters et al. in preparation]

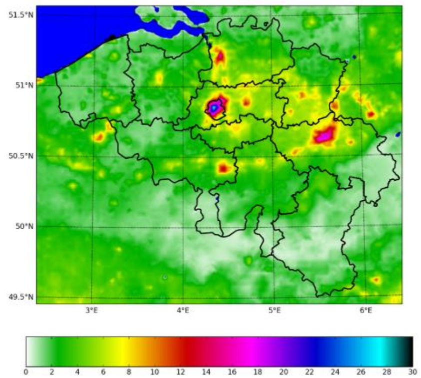


0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

Applications in impact studies
Urban Modelling

Health index: heatwave degree days

1. Heat wave is a period of three days or longer with an average Tmin>18.2˚C and Tmax>29.6˚C



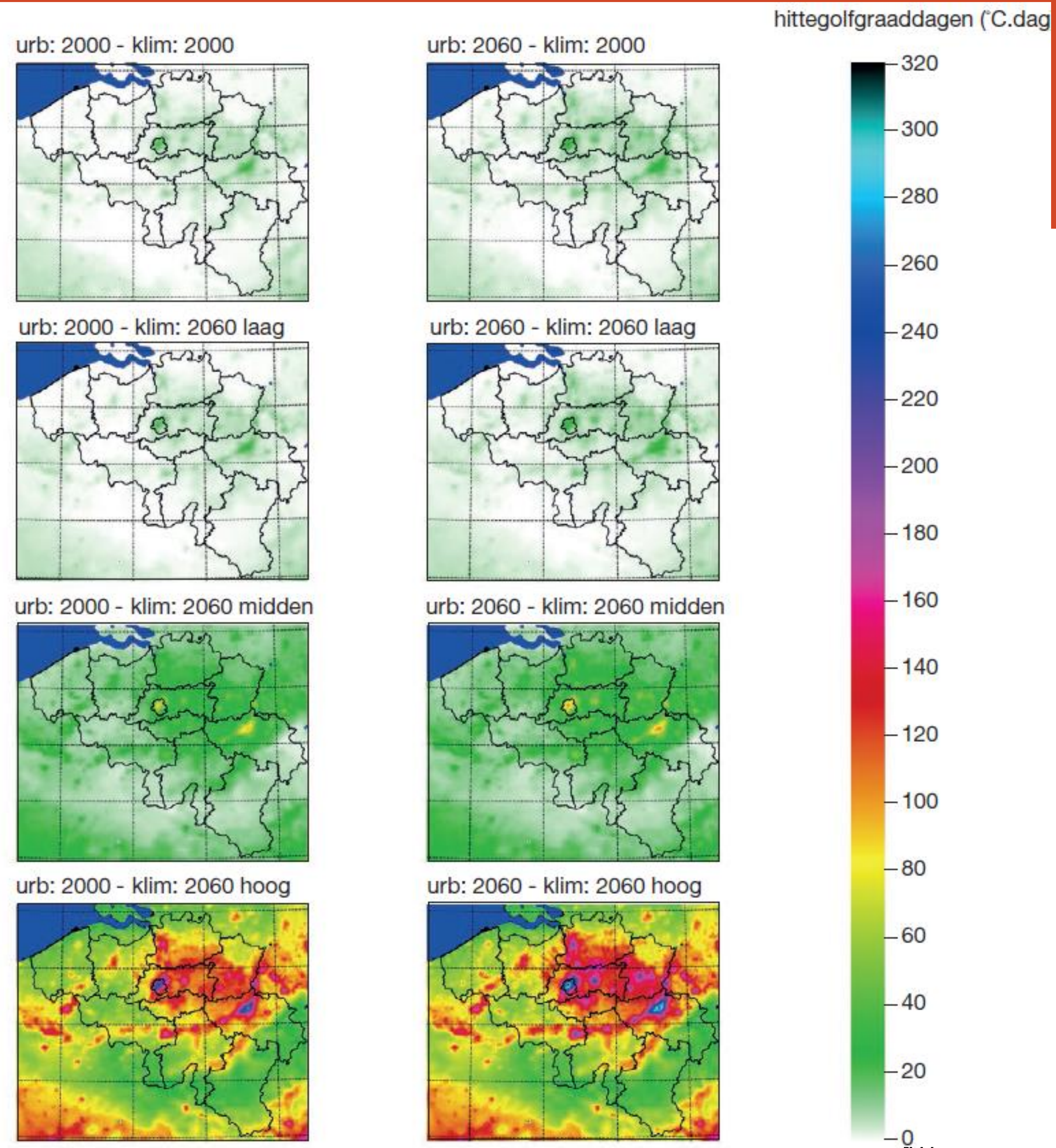
2. For this period an index is calculated:

[

$$HGD = \sum_i \left[\left(T_{\min,i} - 18.2\ °C \right)^+ + \left(T_{\max,i} - 29.6\ °C \right)^+ \right] h_i$$

3. Low, middle and high climate scenario based on the distribution 200 CMIP5 model projections for Uccle (central Belgium) taking 5%, 50% and 95% percentiles

[Wouters et al. in preparation]



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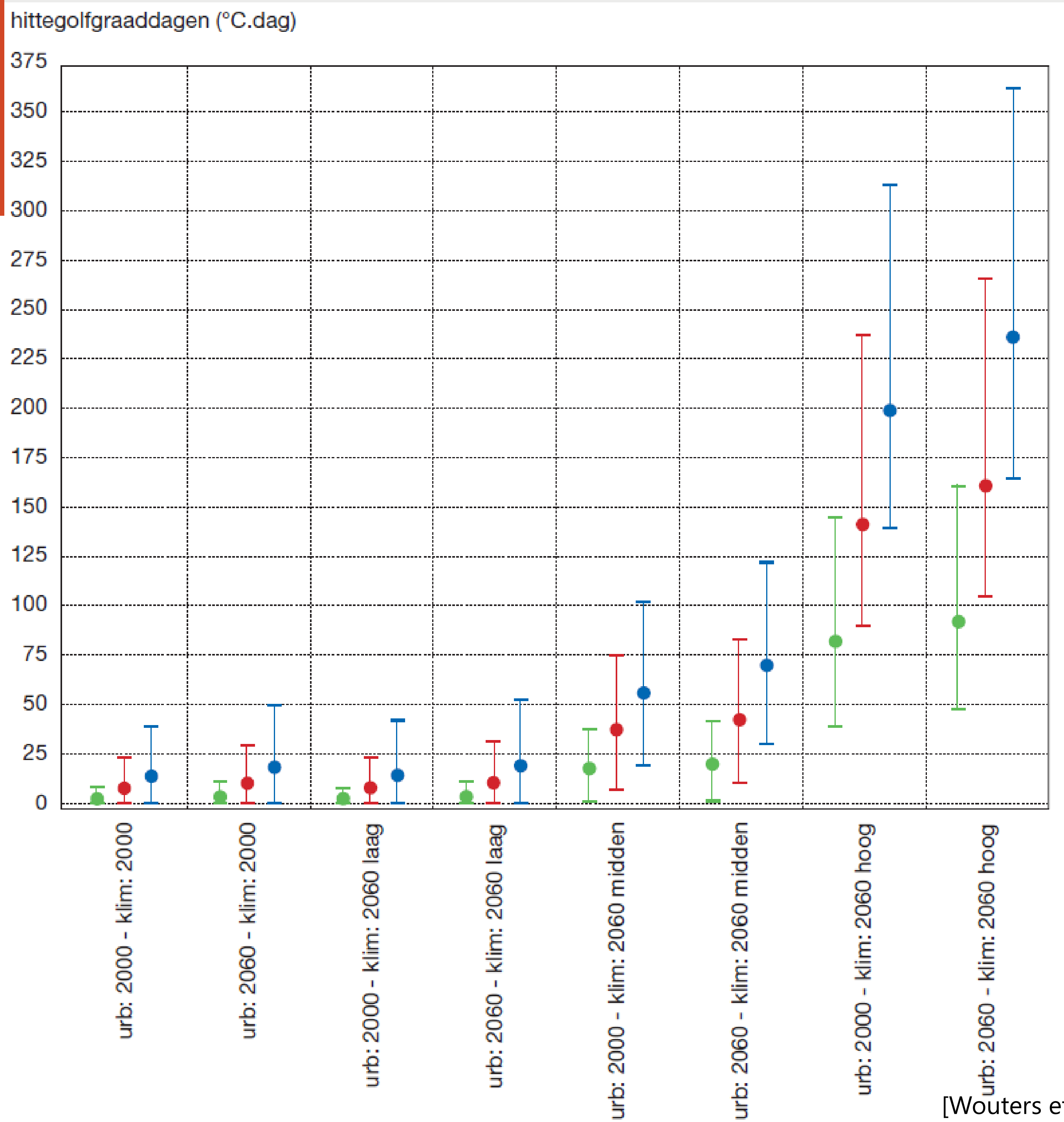

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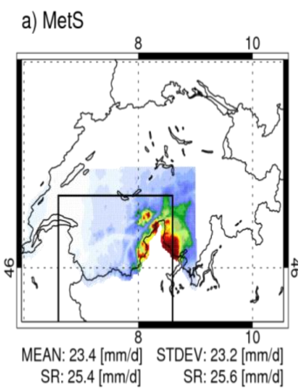
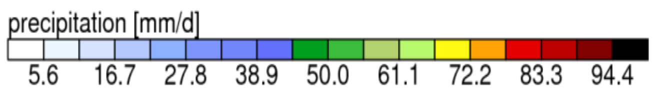
Major challenges

- **Short simulation periods** and large differences between experiments
  → impacts on climate time scales?
- Application of **NWP setup**
  → CPM are not fully tested on climate time scales
- **Observational data** sets
- **Microphysics, aerosols, radiation interactions**
  → missing fundamental understanding
- **Parameterization of turbulence**
- **Higher order numeric scheme**
- **Future computing systems and big data**
- **Coordinated efforts for climate impact studies**

September 19th-21st 1999 Event



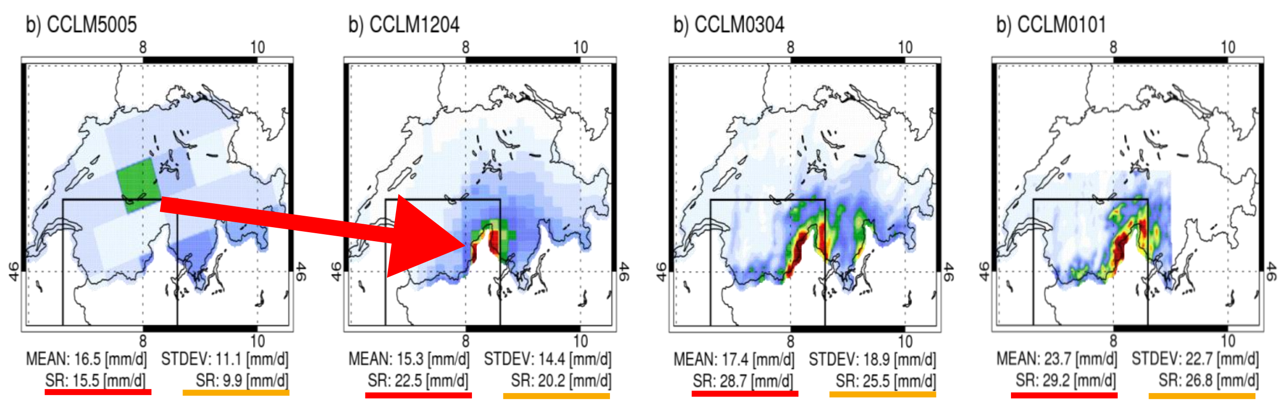
- Finer grids → more precipitation (frontal systems)
- 12 km necessary to get location of maxima
- Finer grids → more spatial variability



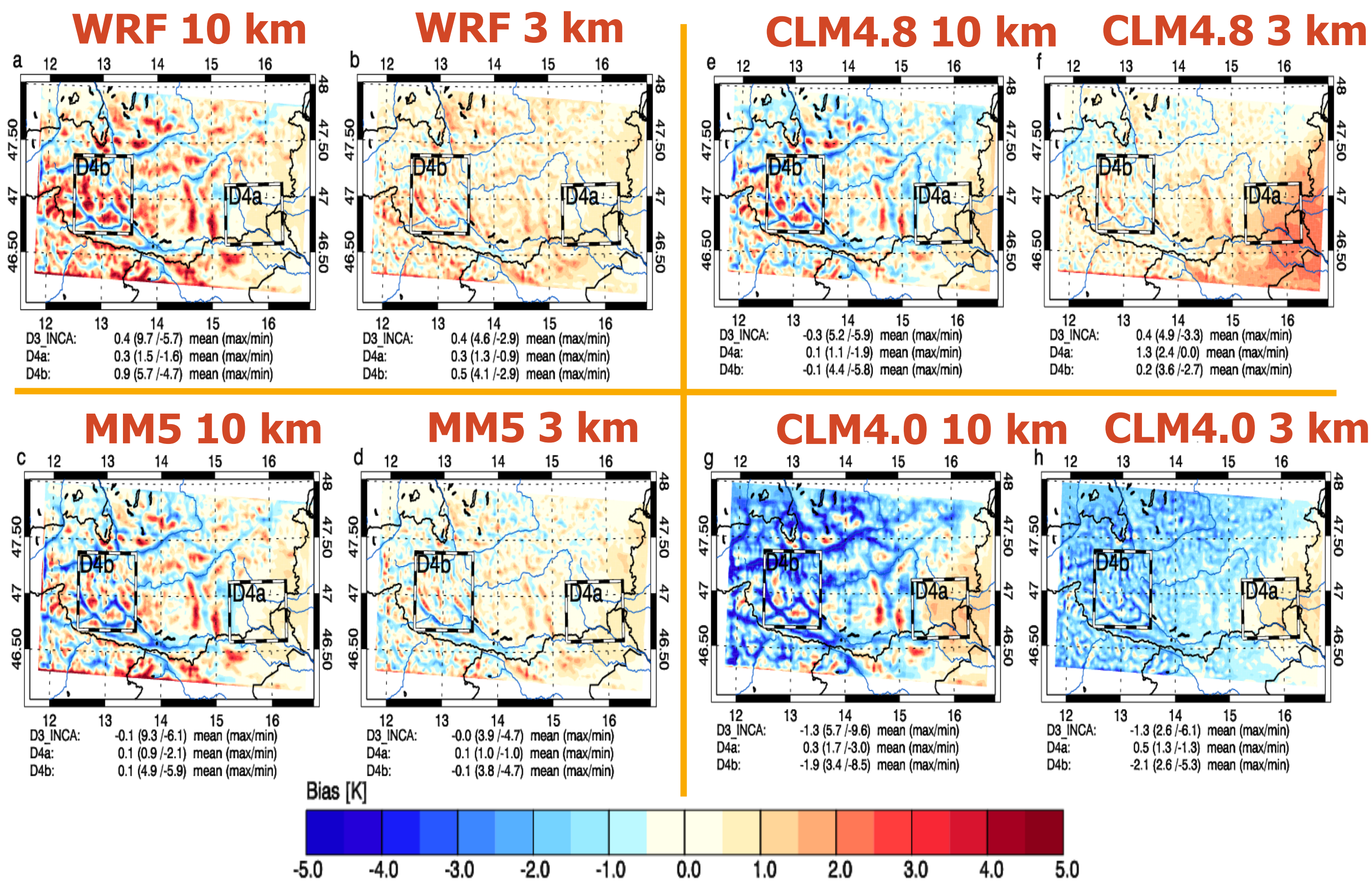
STDDEV: -61 % -11 % 0 % +5 %

Difference: -9.9 mm/d -2.9 mm/d +3.3 mm/d +3.7 mm/d

50 km Model **12 km Model** **3 km Model** **1 km Model**



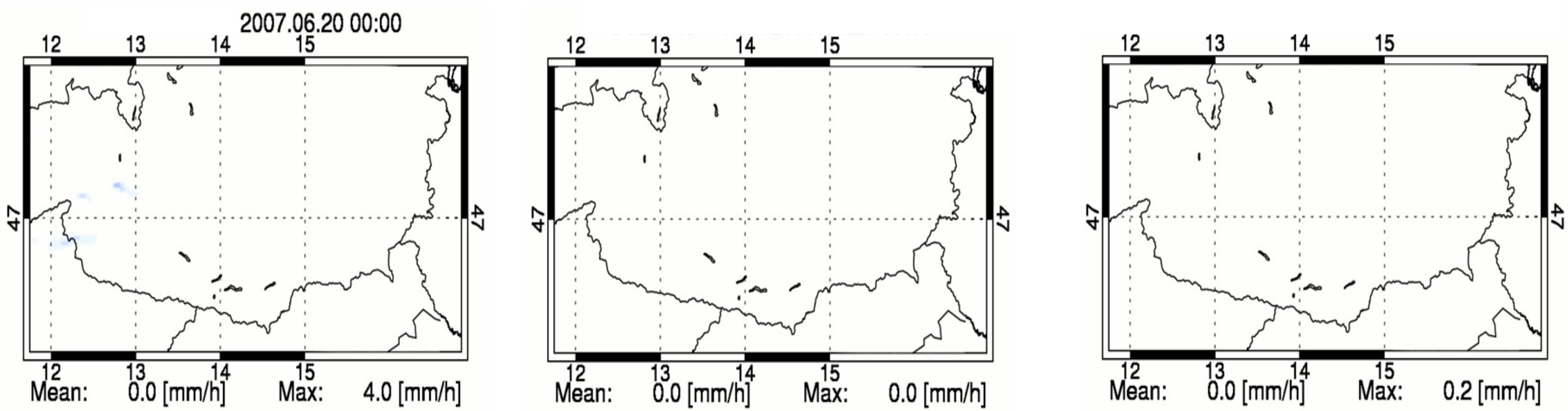
Added value of CPMs
2 m air temperature

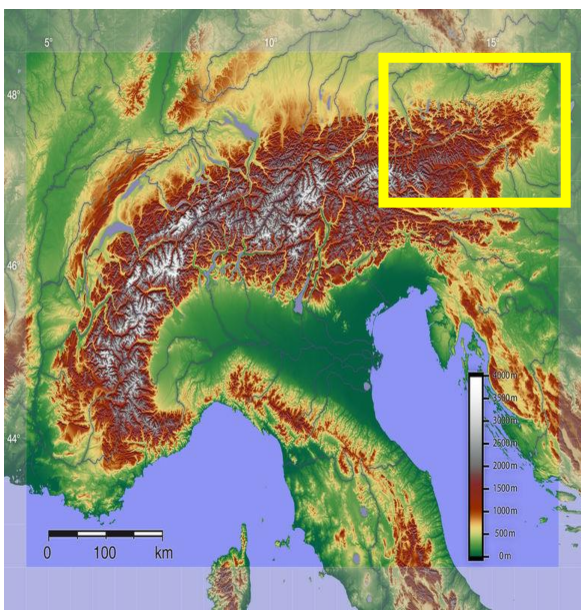


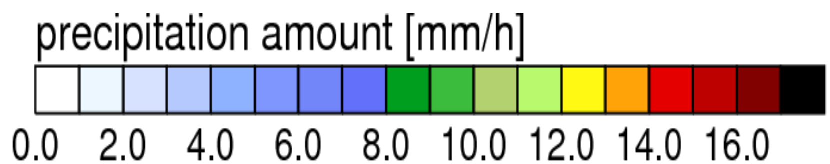
- Improvements in 2 m temperature mainly because of better represented orography
- Similar results with statistical height correction (0.65 °K/100 m)

Precipitation case study: 2007.06.19

m



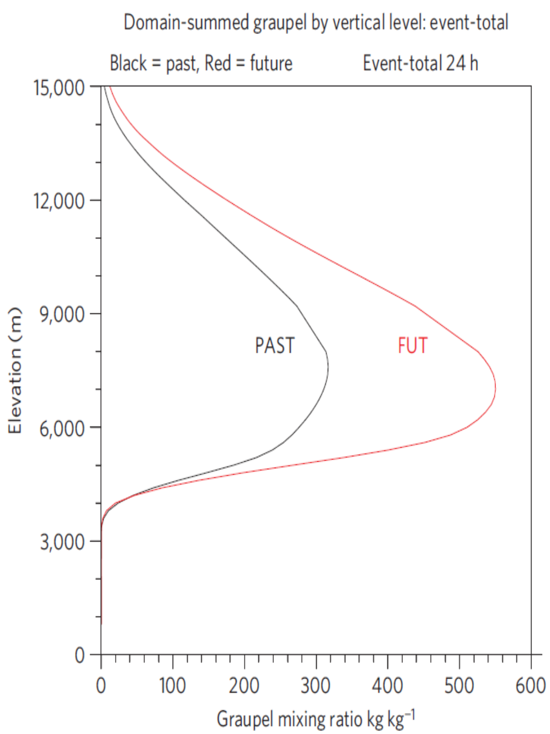


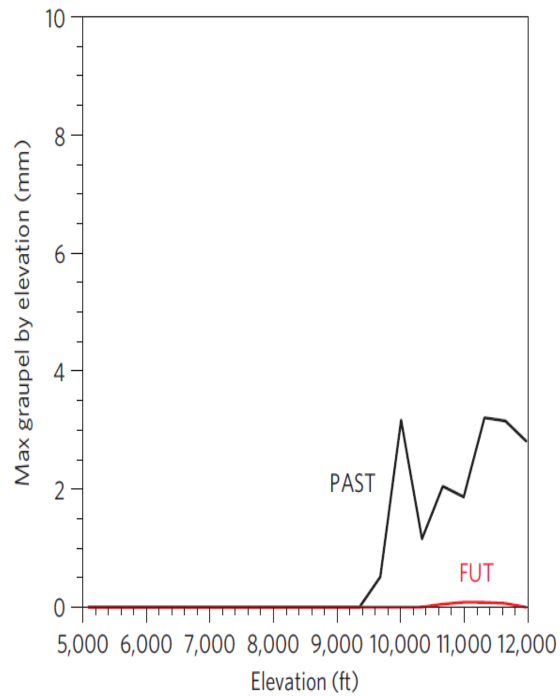


Improvements:

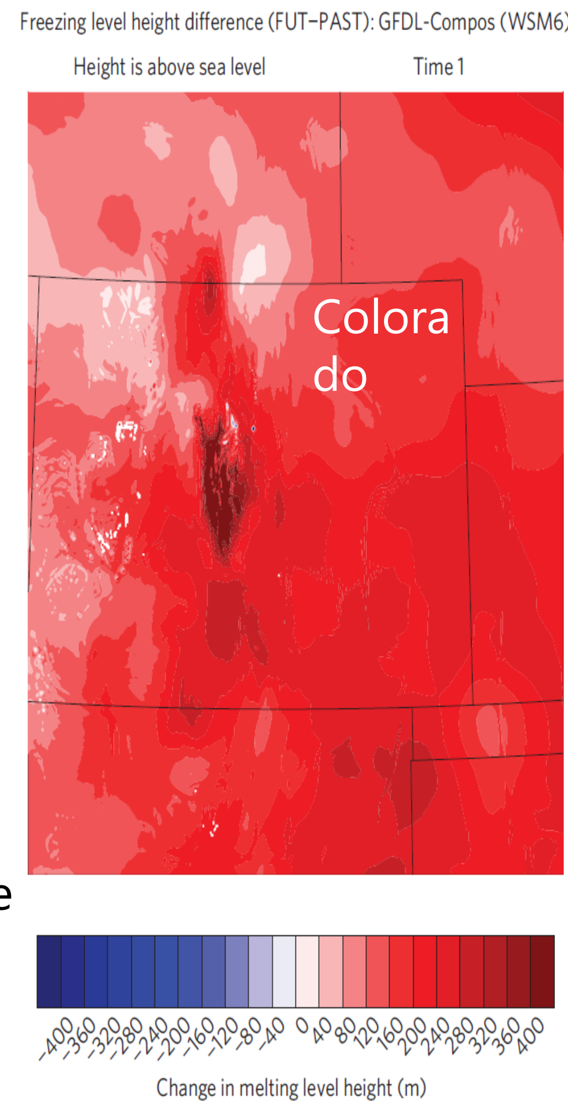
- Timing
- Intensities
- Structures

Differences in the Climate Change Signal Hail



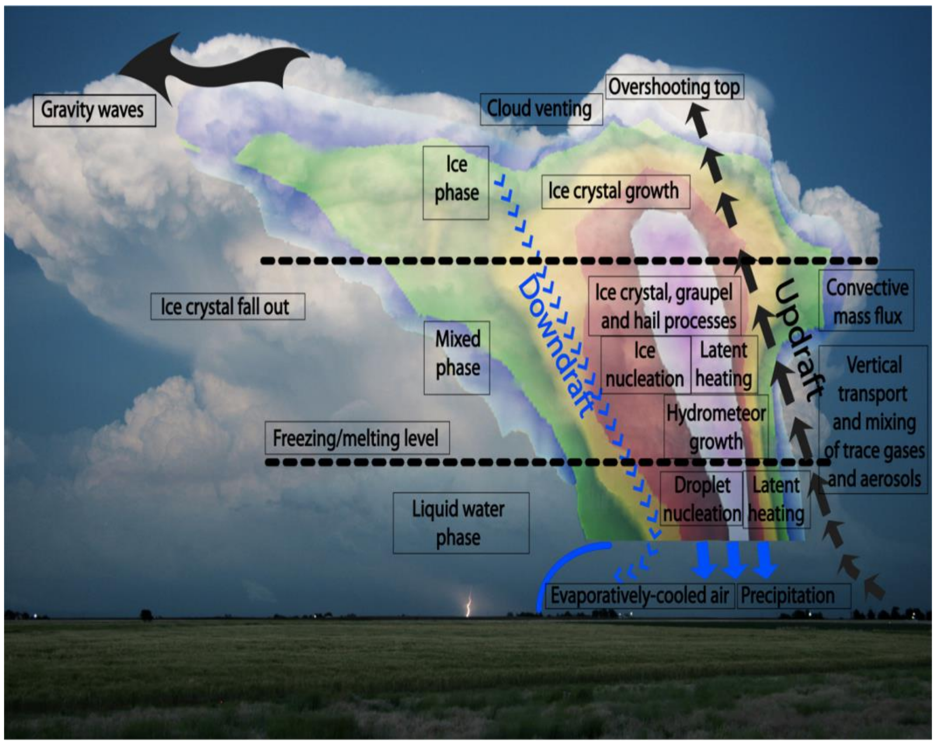


[Mahoney et al. 2012]

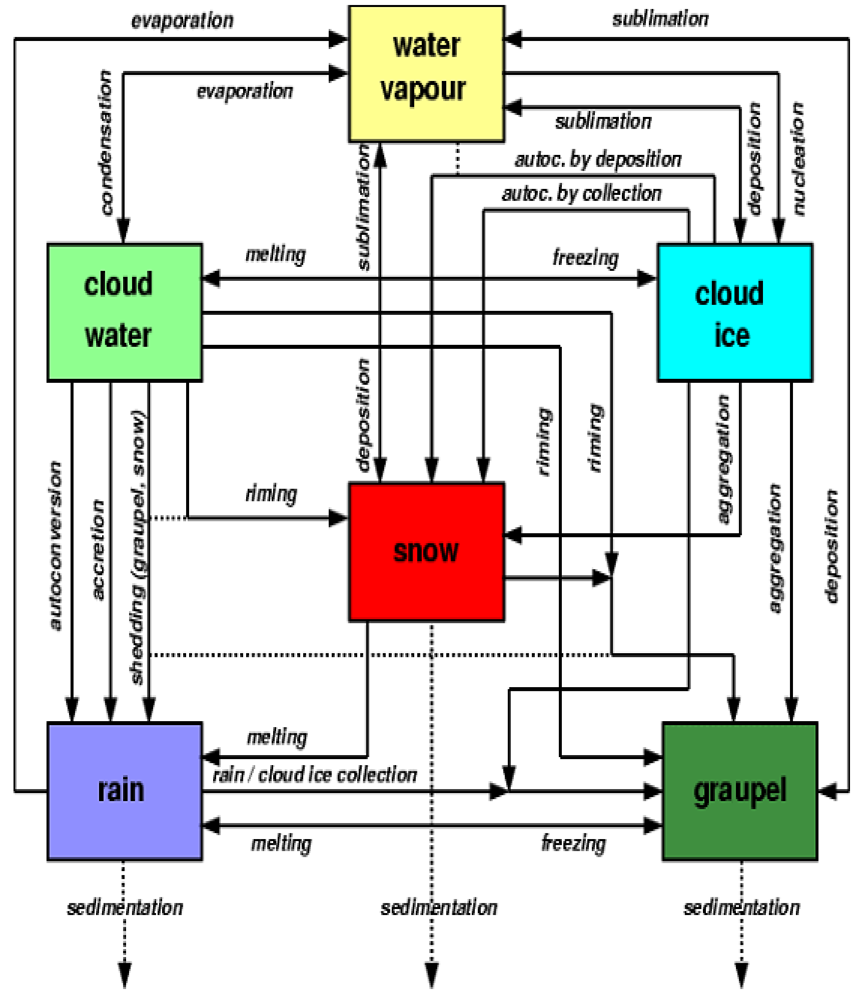


- Graupel and Hail in clouds is increasing in future climate
- Graupel and Hail is nearly vanishing on surface
- Caused by increasing freezing level height
- Potential impacts on flash floods and surface hydrology

Critical components: Microphysics

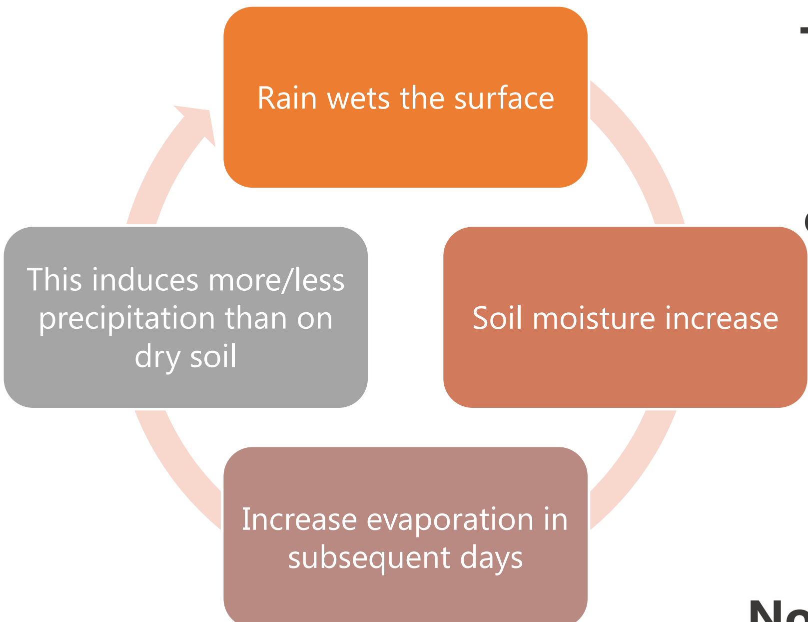


[R. Seigel and S. van den Heever 2011]



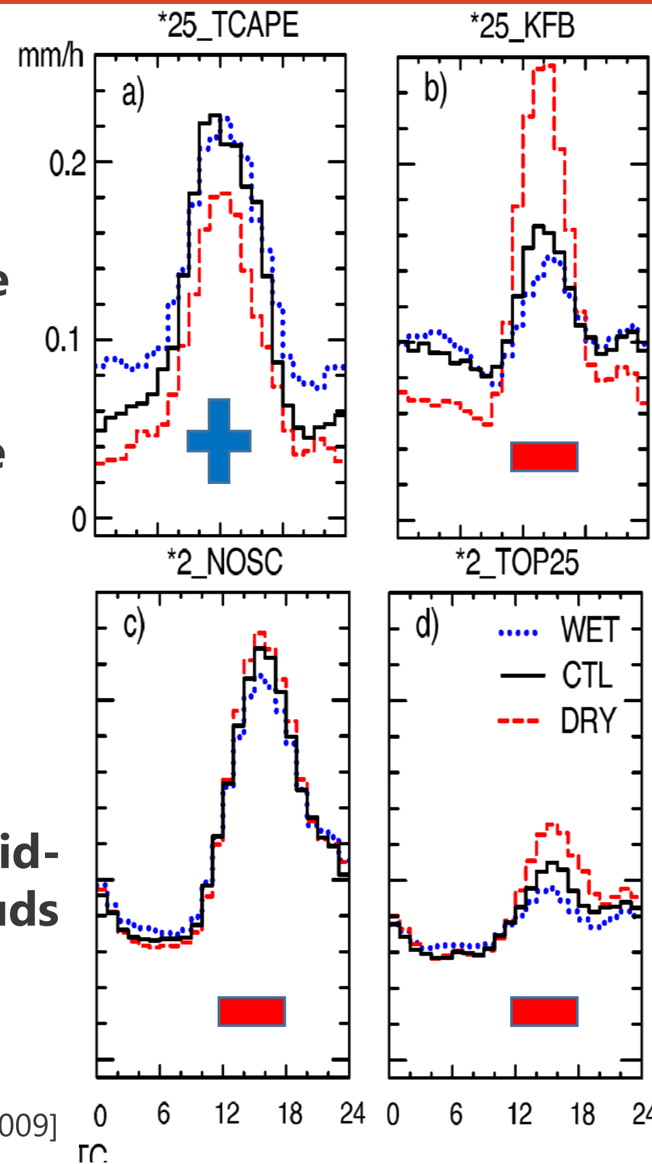
Interactions between the 6 different water phases in COSMO-DE. In GME and COSMO-EU
[http://www.dwd.de]

Difference in feedback processes
Soil moisture precipitation



25 km Tiedtke with CAPE closure

25 km Kain-Fritsch-Bechtold

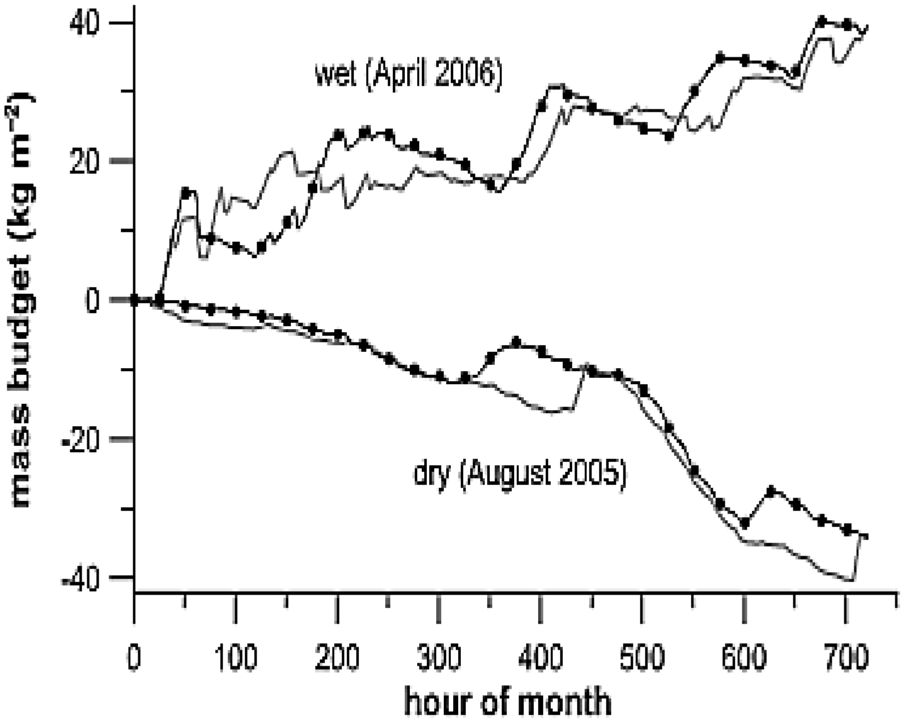


2.2 km No subgrid-scale clouds

2.2 km Smoothed orography

[Hohenegger et al. 2009]

Applications in impact studies
Glacier Modelling



Mass budget on Kersten Glacier (Kilimanjaro) in August 2005 and April 2006 with forcing from:

—— weather station

•–•–• 0.812 km CPCM simulation

CPM simulations allow:

- dynamical interaction between the atmosphere and cryosphere
- to study the influence of the dynamic, thermodynamic, and microphysics phenomena on the mass balance of glaciers
- potential to enhance understanding of processes related to glacier responses to climate forcing

Outlook

- CPM simulations on continental scale
- GPU version of CPMs

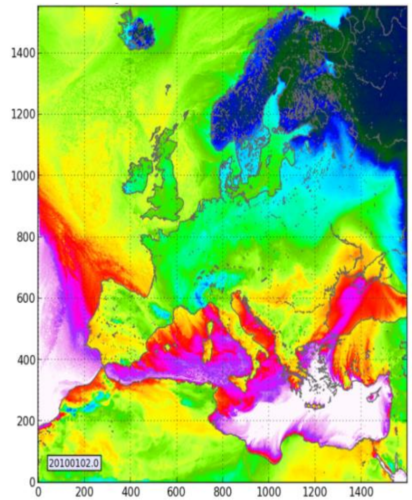
  CCLM: 3 x speedup; 7 x energy consumption

  [Lapillonne and Fuhrer 2014]
- Higher order numeric scheme

  high effective resolution in CCLM

  [Ogaja and Will 2014]
- Turbulence parameterizations for CPMs

  [e.g., *Soares et al.* 2004; *Moeng* 2014]



WRF 3 km [Goergen et al. 2014] WRF 4 km [Rasmussen et al. 2015]