An overview on Convection-Permitting Climate Modeling

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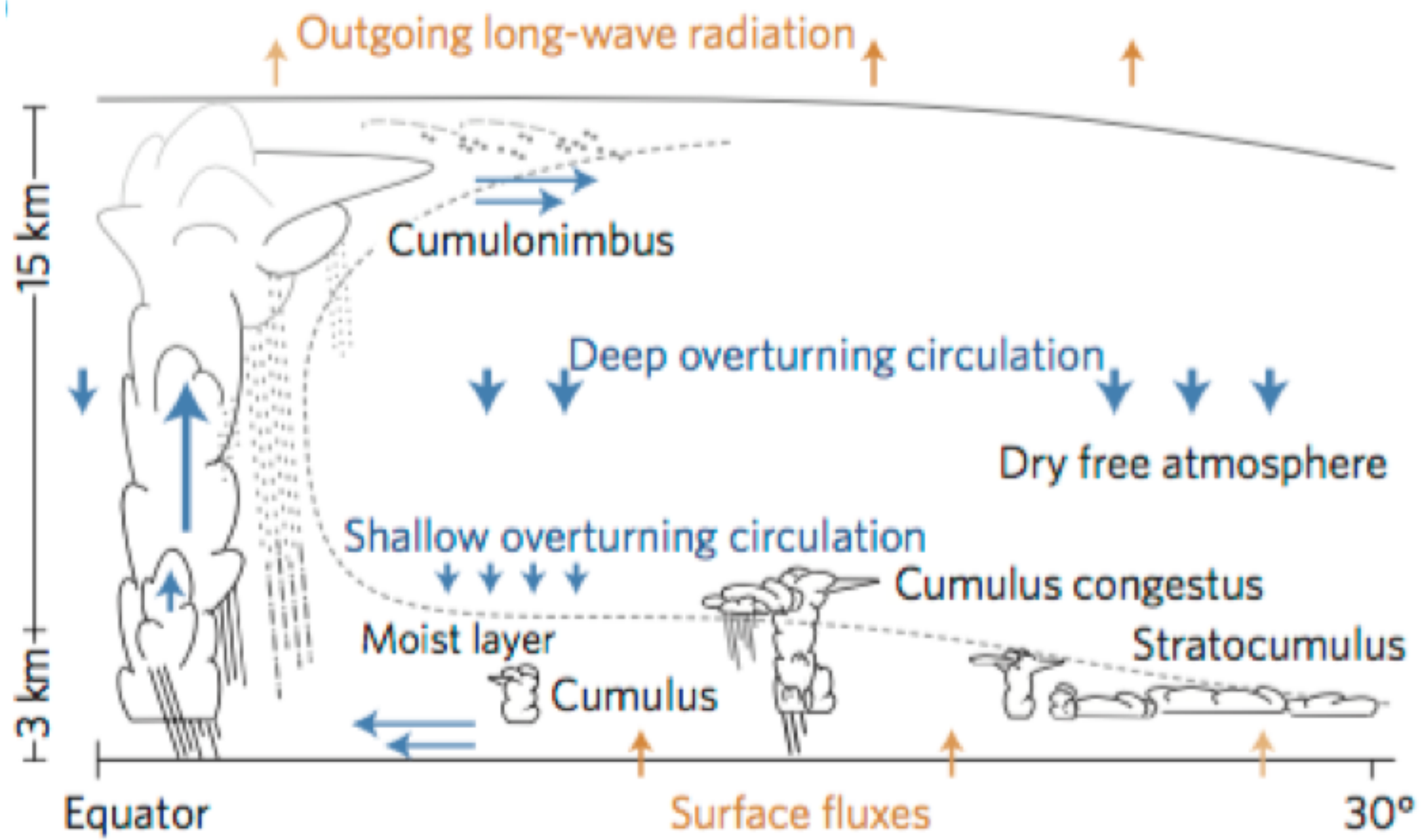
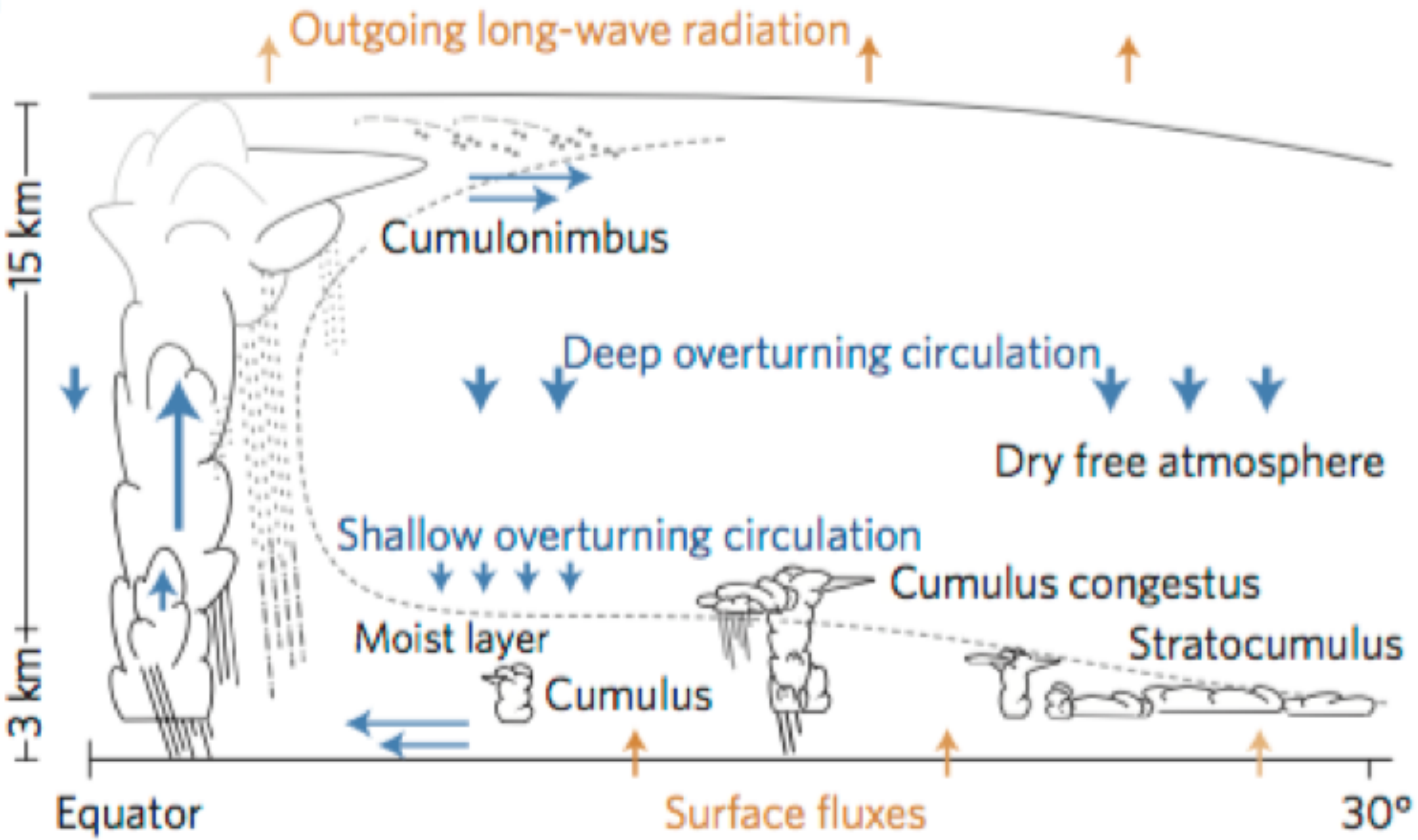
Convection is the rising of plumes of moist air in response to instability in the atmosphere



In the tropics most of the rainfall is convective, while in the mid-latitudes about 40 per cent of precipitation occurs in areas with convective instability

MODELLING CONVECTION

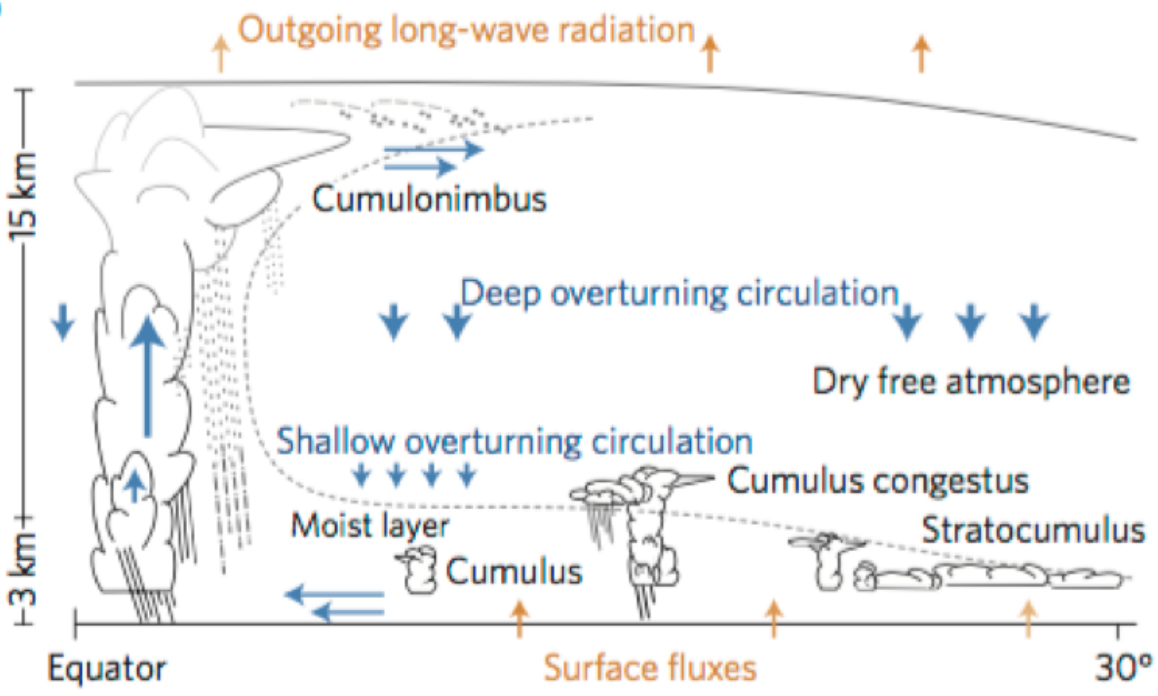


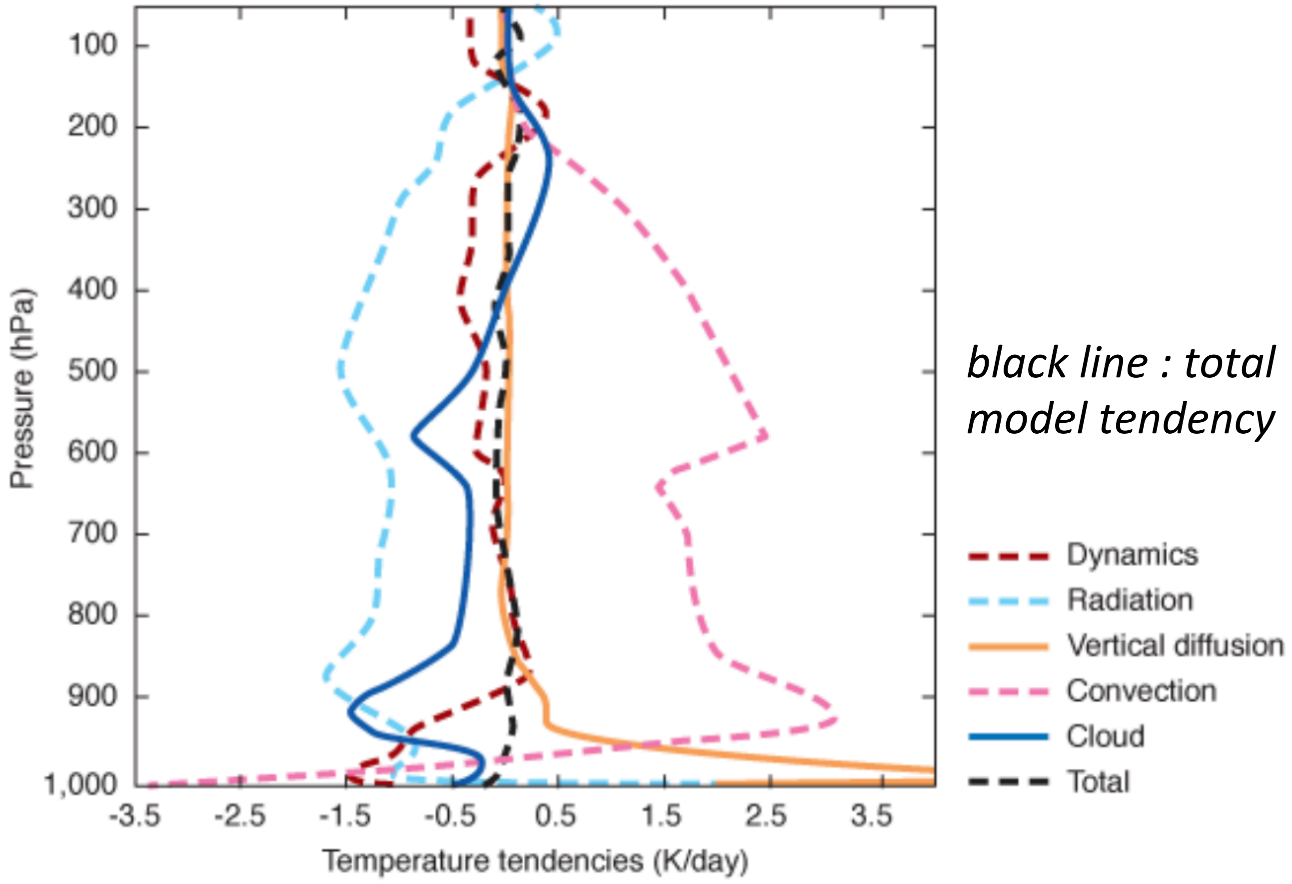
Convection takes place on scales which cannot be simulated with grid spacings of climate models (**RCM > 10** km and **GCM > 100 km**). It is therefore modelled in separate **parameterization schemes**

Parameterization are considerated as a major source for errors and uncertanty in future climate projections.

Convection is the main process of vertical exchange between the lower and the upper troposphere, in particular of water vapour, heat and chemical species

Contribution of the different physical parametrization schemes for temperature in the IFS (averaged over the tropics)

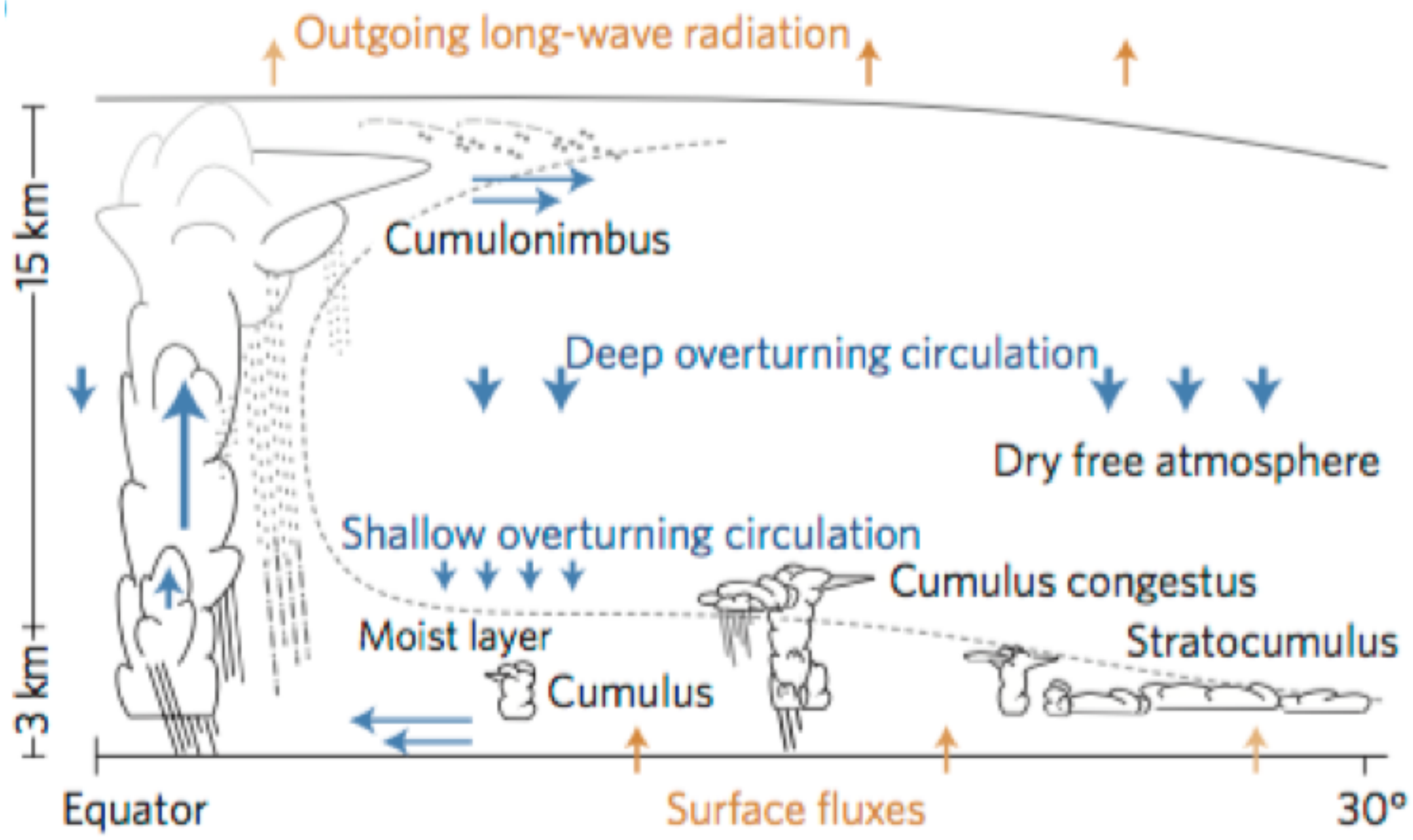




black line : total model tendency

In ECMWF's Integrated Forecasting System (IFS), convection accounts for about **50 per cent** of the total forecast tendencies above the boundary-layer

Interaction with other parameterization schemes:



RCM (> 10 km)
Convection parameterized

Clouds, Aerosols (Microphysics)

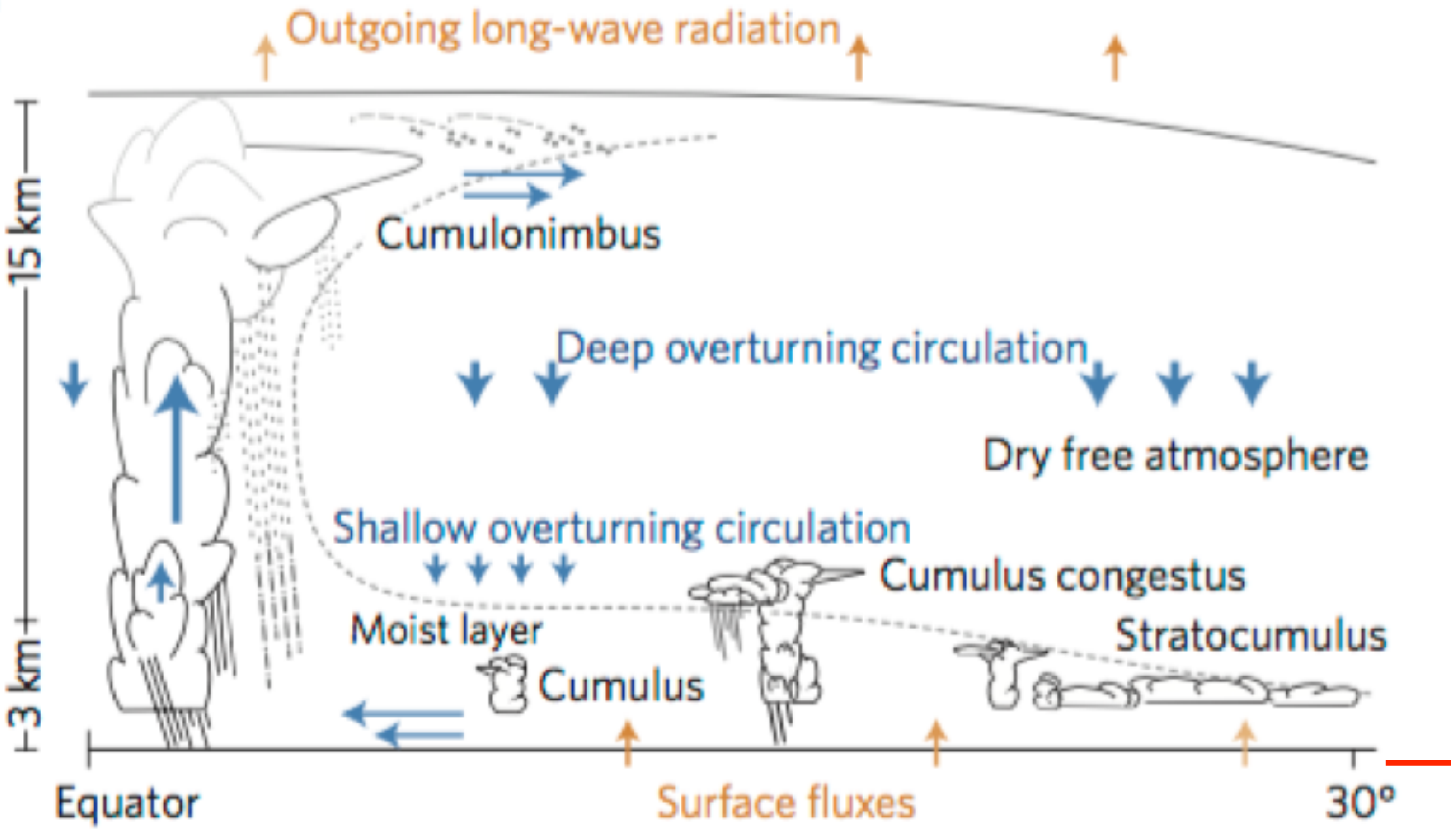
Radiation

PBL (Turbolence)

Soil-Vegetation-Atmosphere Coupling

Weaknesses in convection parameterization schemes can imply far-reaching consequences through nonlinearities

Coarse resolution and Convective parameterization lead to :



Defincies in **diurnal cycle** and inability to represent hourly precipitation extrems [*Dai et al., 1999 Brockhaus et al., 2008*]

Tendency for too much **persistent light rain** and understimation intensity of heavy rain (Berthou et al., 2018)

Understimation of **hourly precipitation intensities** [*Prain et al, 2013*]

The grey zone of convection

The drive towards higher resolution in global weather models complicates matters a little.

"The equations used in convection schemes assume that there is a state of quasi-equilibrium in every grid box, in other words there is an approximate balance between rising and sinking movements of air," Peter says.

This does not hold any more at a grid spacing of 5 km or less.

"This is referred to as the grey zone since we don't yet know how best to represent certain processes at these resolutions. We won't be able to do this correctly if we just continue as before." (https://www.ecmwf.int/en/about/media-centre/news/2017/how-model-convection-and-its-impact-weather)

The upper bound on the horizontal grid spacing of convection-permitting simulations was investigated by *Weisman et al.* [1997] using idealized squall line simulations. Their findings demonstrated the inability to represent accurately nonhydrostatic dynamics with horizontal grid spacings larger than 4 km. The convective mass flux was overestimated once this threshold was exceeded and resulted in "grid-scale storms." The latter emerge as convective instability is forced onto an unrealistically coarse scale, hence overestimating the convective mass flux and precipitation. Thus, CPM at 4 km or coarser grid spacings may not always yield improvements over LSMs. Applying convection parameterization schemes at such grid spacings may overcome the aforementioned issues of underresolved convection [*Deng and Stauffer*, 2006; *Lean et al.*, 2008; *Roberts and Lean*, 2008] (Prein et al 2014)

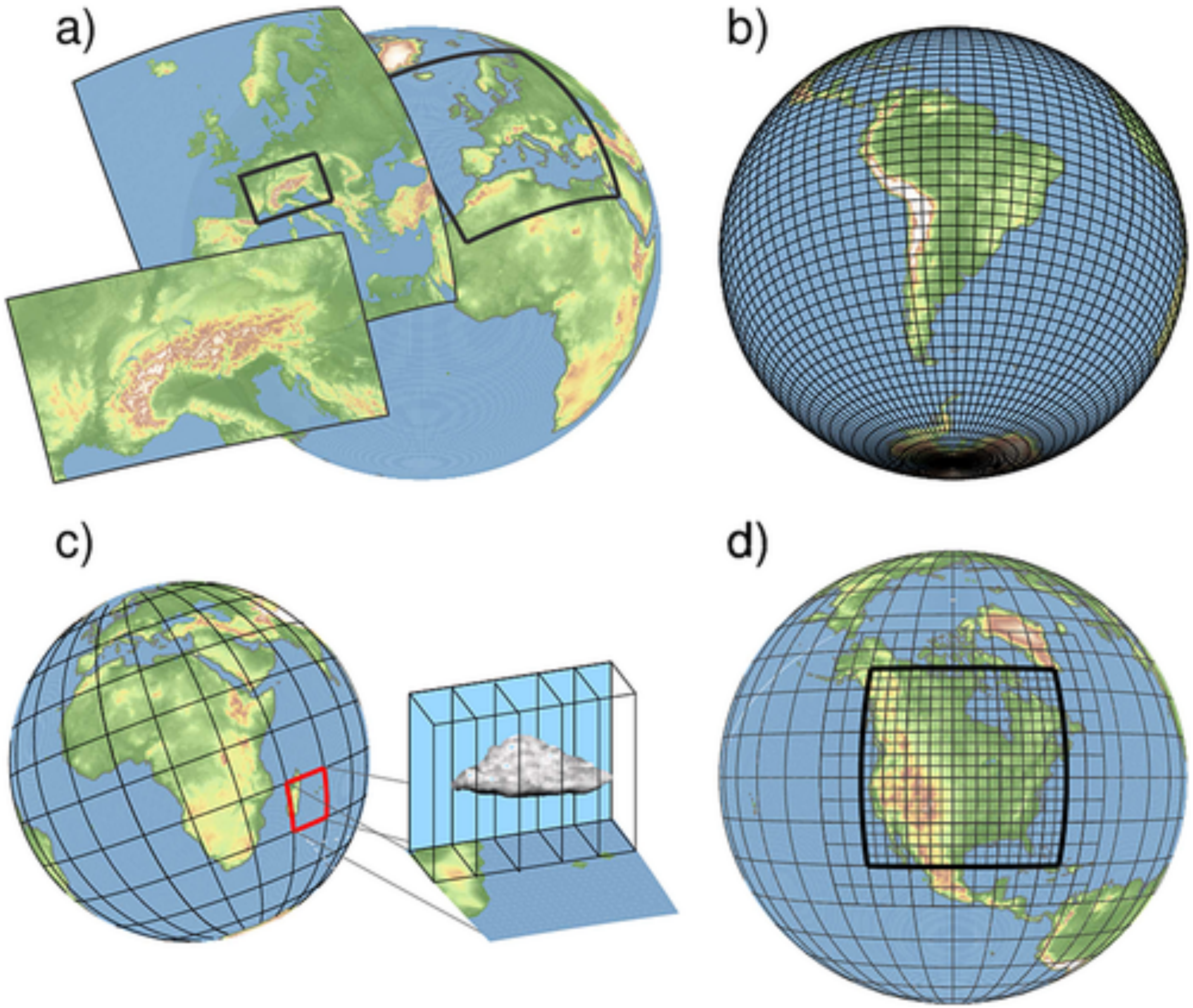
CONVECTION PERMITTING MODELING (CPM)

Since the beginning of the 21st century, advances in high-performance computing allowed steady refinement of the numerical grids of climate models well beyond 10 km

CPM (<= 4 km)

At these scales, convection parameterization schemes may eventually be switched off as deep convection starts to be resolved explicitly

A promising remedy to the error-prone climate simulations using convective parameterizations is the use of convection-permitting model (CPM) (horizontal grid spacing <4 km) that operates on the kilometer scale..


a)
b)
c)
d)

Pioneering work toward CPM climate simulations was provided by [*Grell et al.*, 2000] who performed 14 month long simulations with Δx = 1 km and showed drastic changes in the seasonal average precipitation patterns compared to LSM simulations. More recent studies have performed CPM simulations on time scales longer than 1 year to investigate climatological features in CPM simulations [e.g., *Brisson et al.*, 2015; *Chan et al.*, 2013; *Ban et al.*, 2014; *Fosser et al.*, 2014; *Kendon et al.*, 2014; *Junk et al.*, 2014; *Tölle et al.*, 2014; *Prein et al.*, 2013b; *Rasmussen et al.*, 2011; *Ikeda et al.*, 2010; *Gensini and Mote*, 2014; *Chan et al.*, 2013; *Kendon et al.*, 2012; *Knote et al.*, 2010; *Rasmussen et al.*, 2014, Berthou et al., 2018].

Since the beginning of the 21st century more and more studies have focused on CPM climate simulations and there is now a strong need to synthesize these studies and to build the foundation and common basis for future advances in climate modeling. Furthermore, impact researchers and stakeholders should be informed of what to expect from CPM climate simulations. This review paper aims to provide this kind of scientific basis by summarizing the **knowledge acquired up to now and by highlighting existing challenges and important research questions in this field**. In particular, we review the following: (1) What grid spacing is needed for CPM climate simulations (section 3)? (2) What is the best downscaling strategy to convection-permitting scales (section 4)? (3) What are the most important model components that require further development (section 5)? (4) What are, in theory, the added values of CPM climate simulations compared to LSM simulations (section 6.1)? (5) What added values could actually be demonstrated in practical applications (section 6)? (6) And what can we learn from CPM about future climate change that is not assessable from LSM (section 7)?

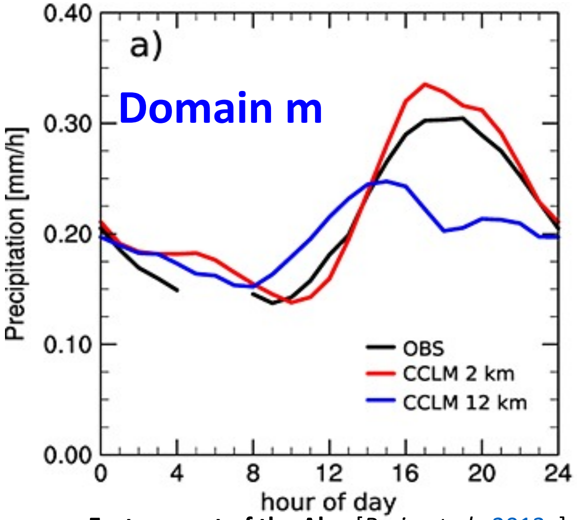
knowledge acquired up to now

Studies to date show that convection-permitting models do not necessarily better represent daily mean precipitation [*e.g., Chan et al. 2013, Berthou et al., 2018*] but have significantly better sub-daily rainfall characteristics with improved representation of the:

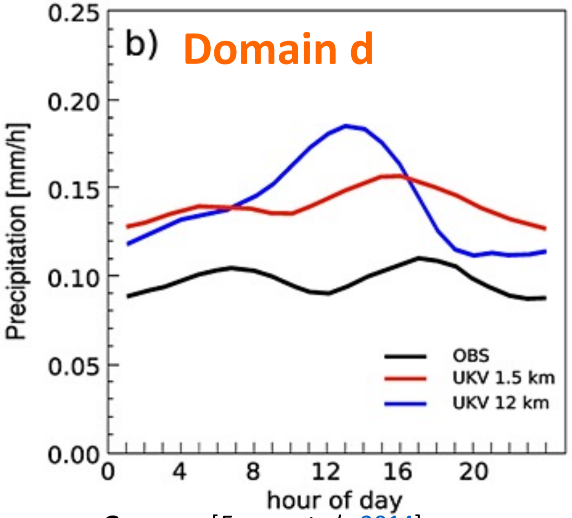
- **Diurnal cycle** of the amount, intensity and frequency of precipitation (*Ban et al. 2014, Kenond et al. 2012, Langhans et al. 2013, Prein et al., 2013, Fosser et al., 2014, Berthou et al., 2018*)
- **The spatial structure** of rainfall and its **duration-intensity** characteristics (*Kendon et al, 2012, Berthou et al., 2018*)
- **Intensity of hourly preciptiation extremes** (*Chan et al. 2014 Ban et.al 2014 Fosser et al. 2015*)
- **Orographic precipitation** (*Liu et al 2016*)

DIURNAL CYCLE

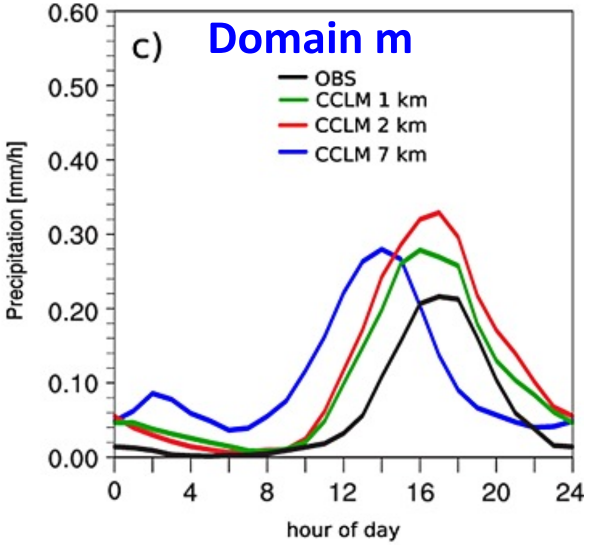
Switzerland [*Ban et al.*, 2014]



Southern UK [*Kendon et al.*, 2012]



Switzerland [*Langhans et al.*, 2013]



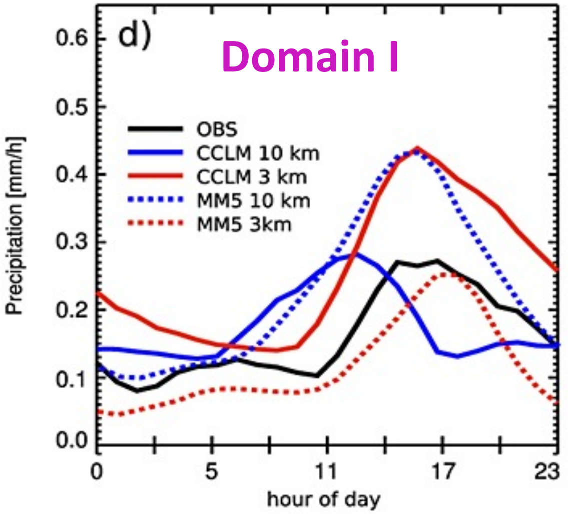
Domain m : JJA mean 1998-2007

Domain d : Annual mean 1989-2008

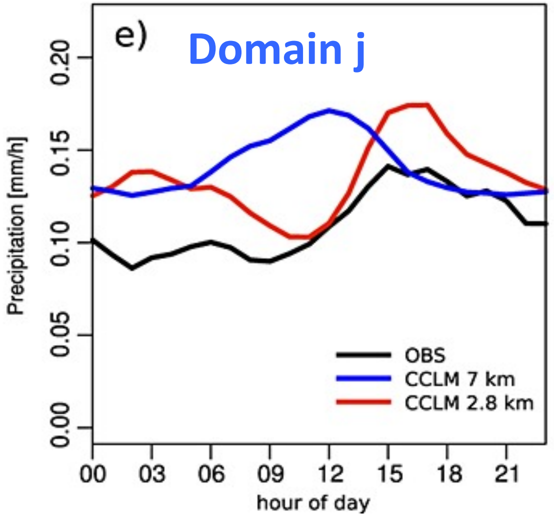
Domain l : JJA 2007-2008

Domain j : JJA 1968-1999

Eastern part of the Alps [*Prein et al.*, 2013a]



Germany [*Fosser et al.*, 2014].



Domains

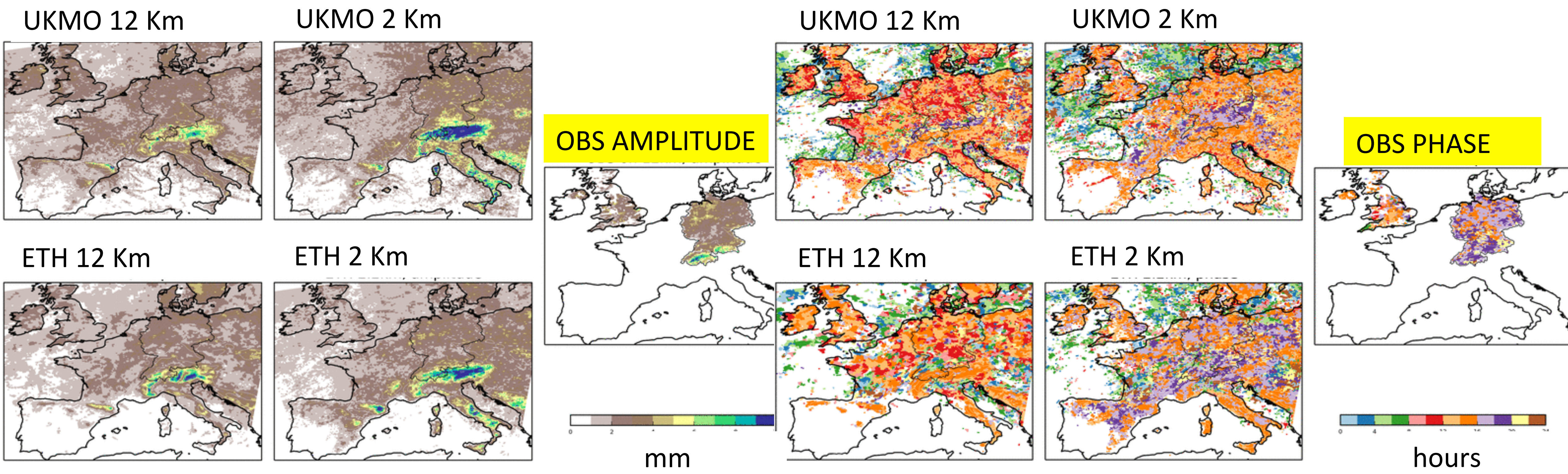
[Prein et al. 2014]

All CPMs climate simulations show improvements in the shape (onset and peak) of the precipitation diurnal cycle compared to their corresponding LSM simulations

[Ban et al. 2014, Kenond et al. 2012, Langhans et al. 2013, Prein et al., 2013, Fosser et al., 2014, Berthou et al., 2018]

DIURNAL CYCLE

Amplitude and the **Phase** (hour of the maximum precipitation in local time) of the mean diurnal cycle at each grid-point



Berthou et al. 2018

Amplitude : CPMs show **stronger amplitudes** in the 2.2 km models over high orography (> 1500 m) compared to the 12 km models

Phase : CPMs show **better timing** of the peak precipitation in the 2.2 km models, the peak being shifted from late morning-early afternoon in parameterised models to mid-late afternoon in the convection-permitting models

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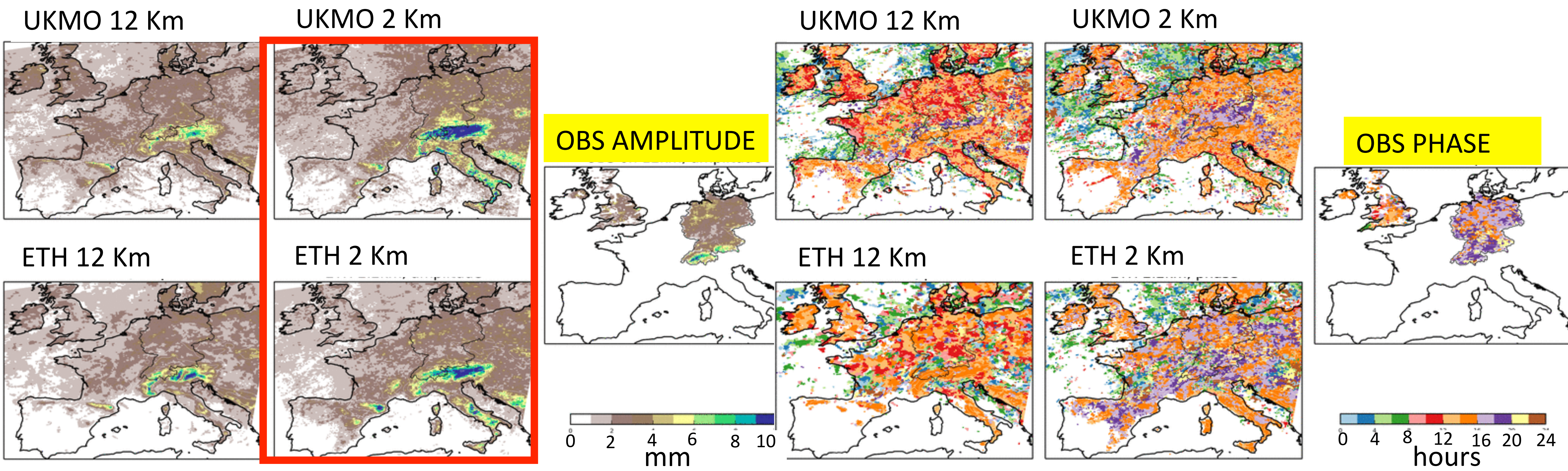

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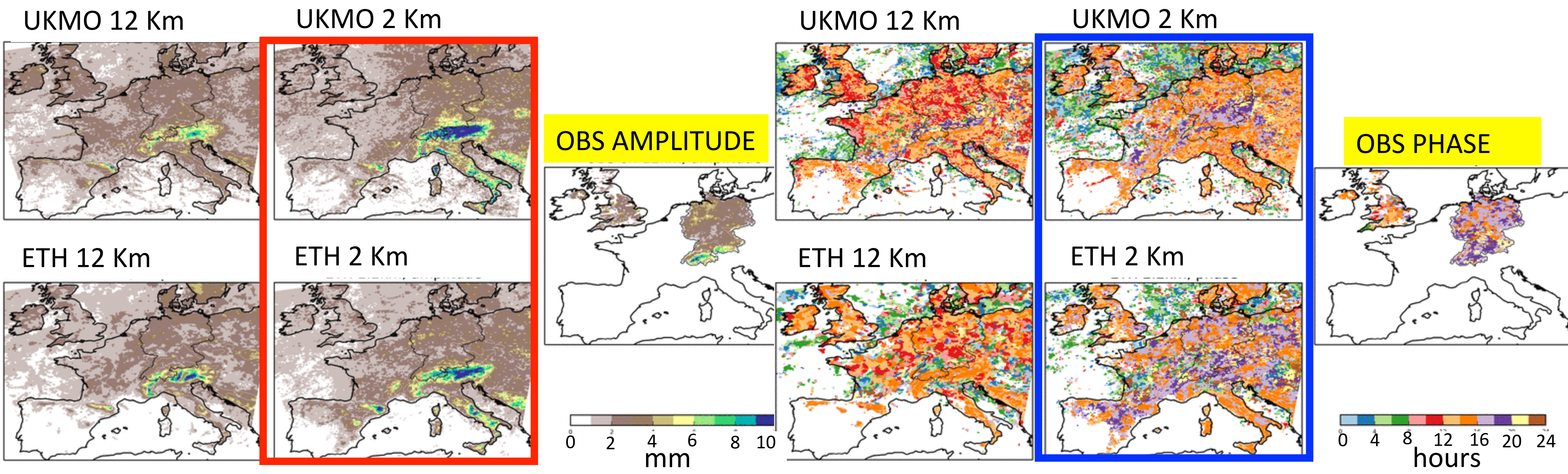

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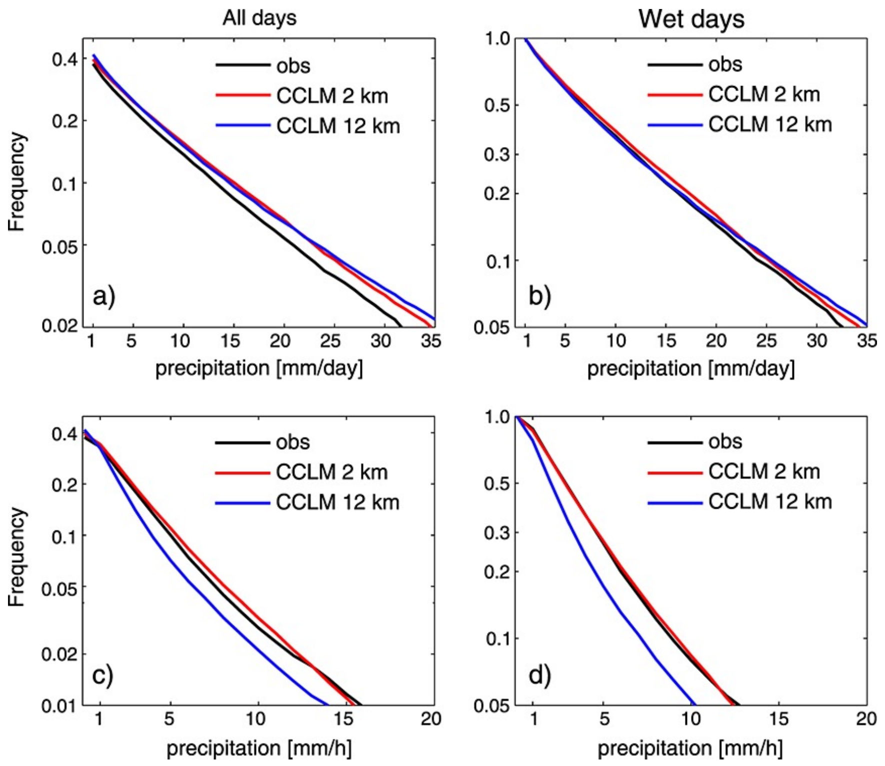
Extreme Precipitation

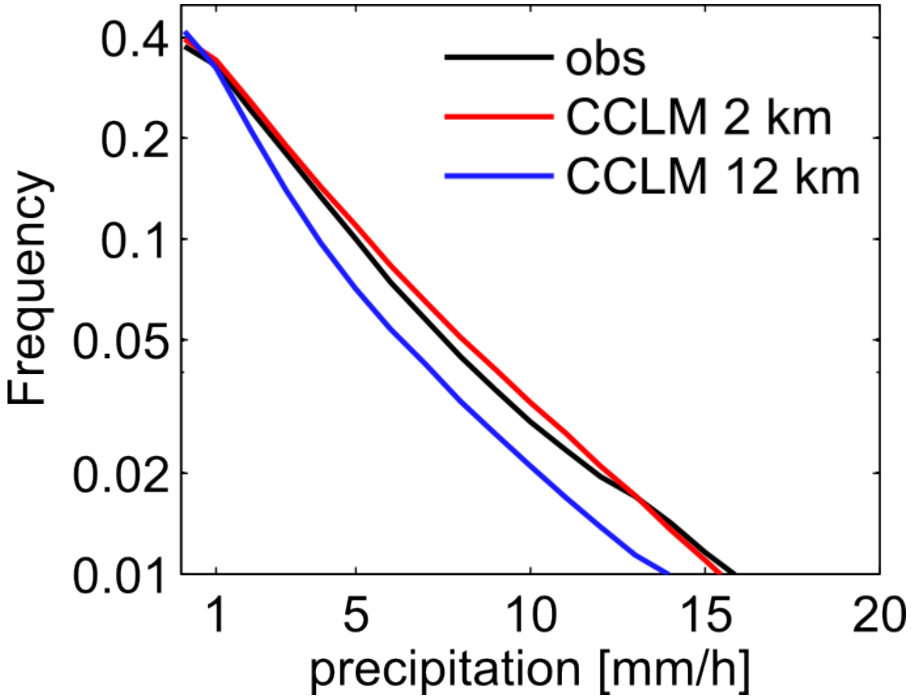
The largest differences between LSM and CPM climate simulations occur on short (subdaily) time scale and for summertime high-precipitation intensities. Heavy hourly precipitation is typically underestimated in LSM, while large improvements were found in CPM climate simulations [*Ban et al.*, 2014; *Fosser et al.*, 2014; *Chan et al.*, 2013, 2014b] (see Figure 9, for an example). *Gensini and Mote* [2014] (see Table 1, domain c) show that CPM climate simulations can reproduce proxies for hazardous convective weather (tornadoes, thunderstorm, and large hail) in the USA



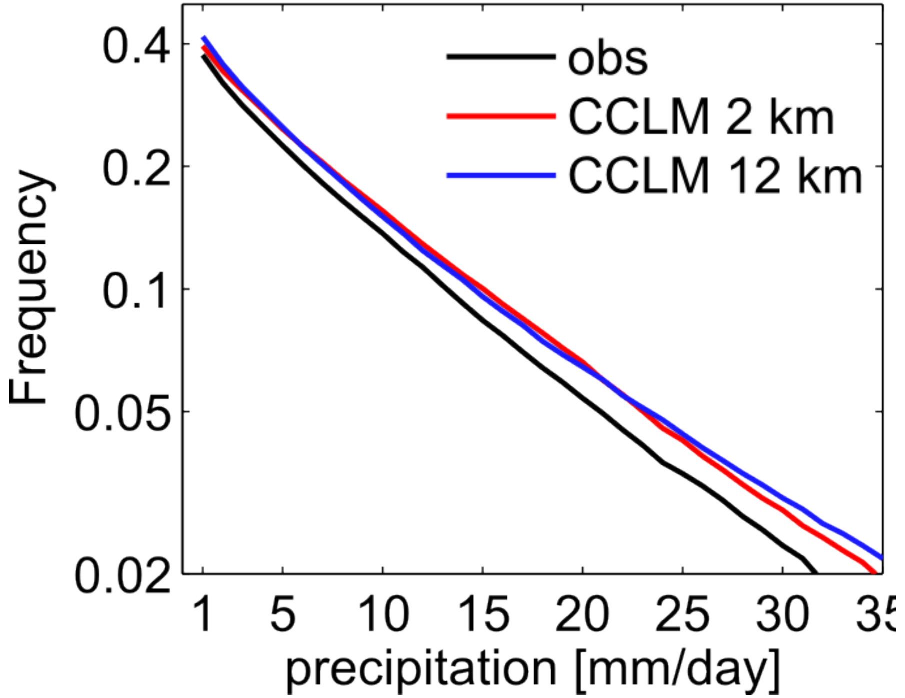
Cumulative distributions of (a, b) daily precipitation and (c, d) daily maximum 1 h precipitation as a function of threshold, expressed relative to the total number of days shown in Figures 9a and 9c and relative to the number of wet days shown in Figures 9b and 9d for the data at 24 Swiss stations. The distributions have been calculated for June, July, and August (JJA) in the period 1998–2007 [*Ban et al.*, 2014]. The CPM simulation with Δx = 2 km reproduces the observations very well, while the LSM simulation with Δx = 12 km underestimates the frequency of daily maximum 1 h precipitation.

EXTREME PRECIPITATION

Hourly JJA extremes



Daily JJA extremes



[Ban et al. 2013]

CPM climate simulations add value to hourly precipitation extremes but not to daily extremes

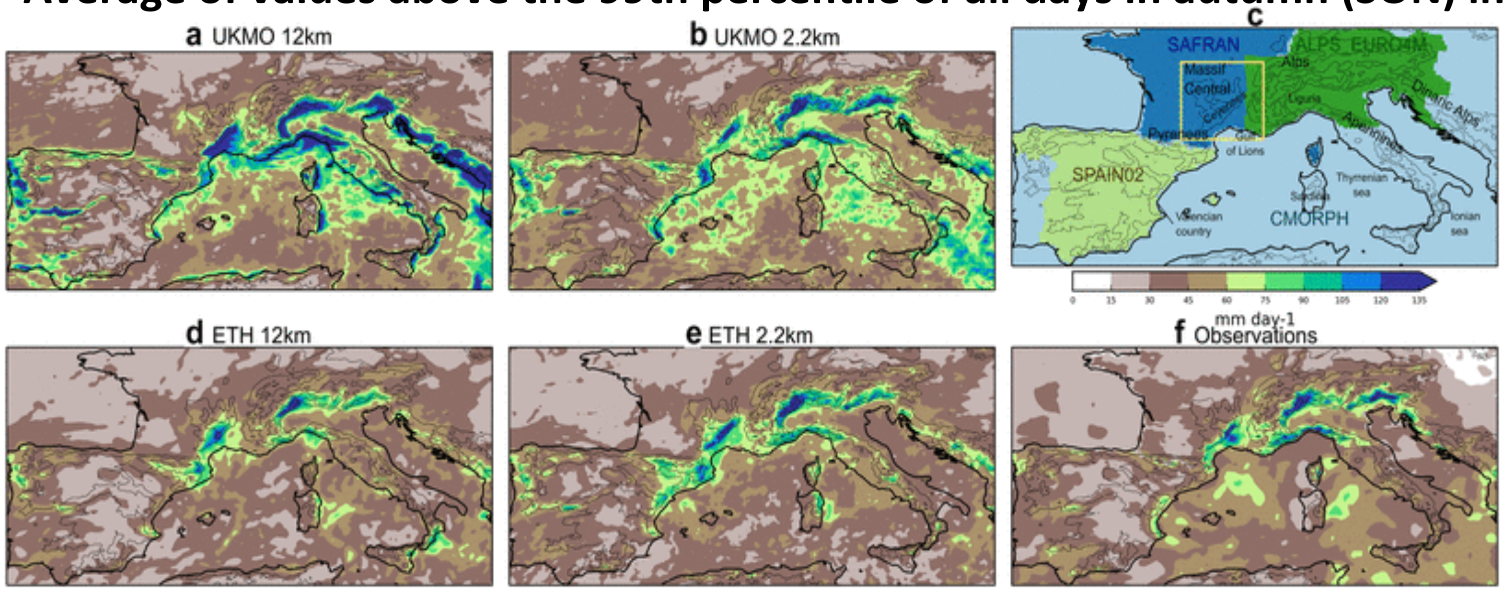
→

Improvement in simulation daily precip intensity seem to be dependent on the region and models

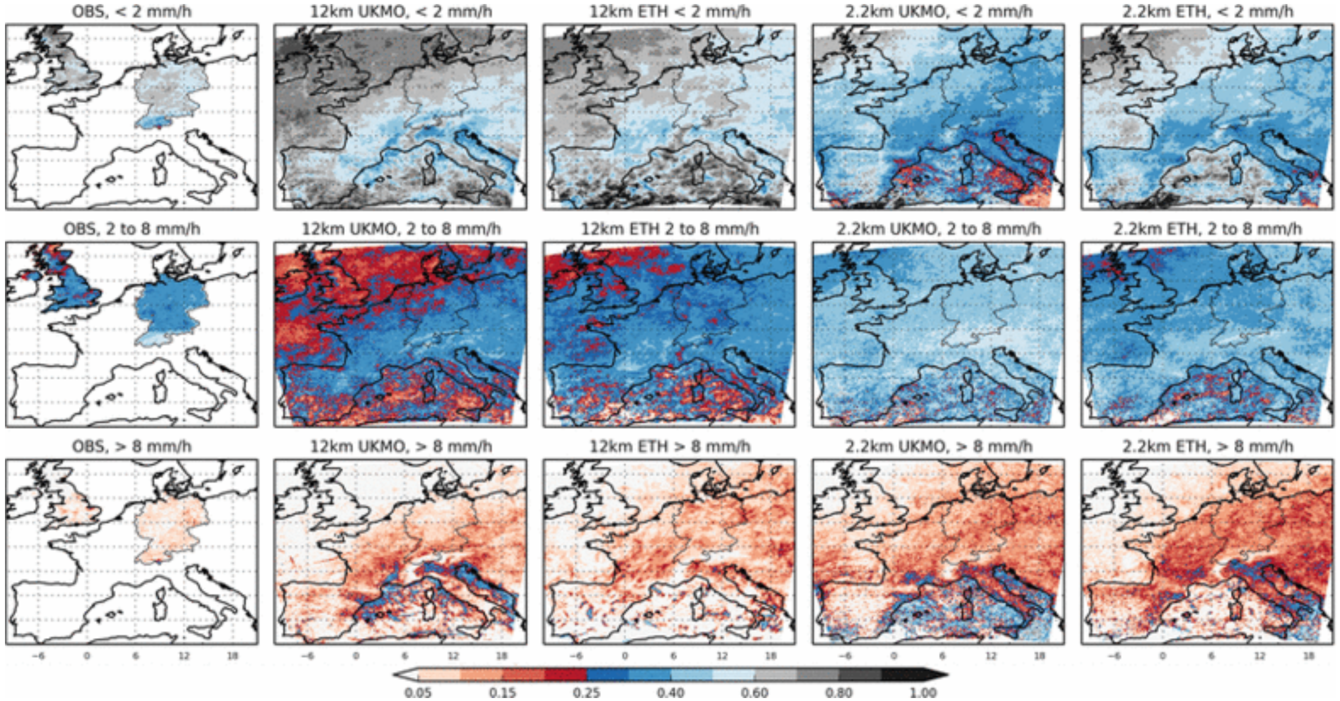
Ban et al. 2014, Kenond et al. 2012, Langhans et al. 2013, Prein et al., 2013, Fosser et al., 2014, Berthou et al., 2018

EXTREME PRECIPITATION

Average of values above the 99th percentile of all days in autumn (SON) in mm/day



Mediterranean intense events in autumn at the daily scale are better repesented by 2.2 km models in terms of location and intensity.



shift in contribution of precipitation from low (< 2mm/h) to moderate (2-8 mm/h) and intense precipitation (>8 mm/h) in both 2.2 Km model

Berthou et al. 2018

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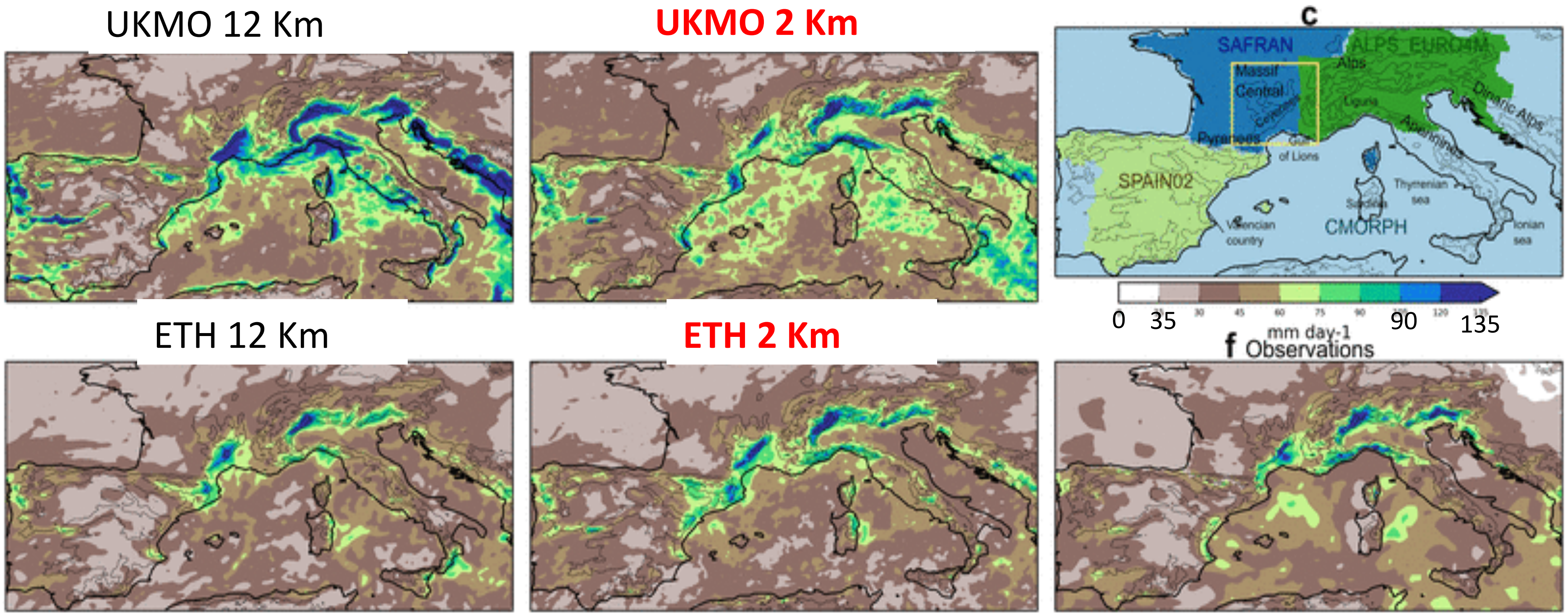

OBS mm/day

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Berthou et al. 2018

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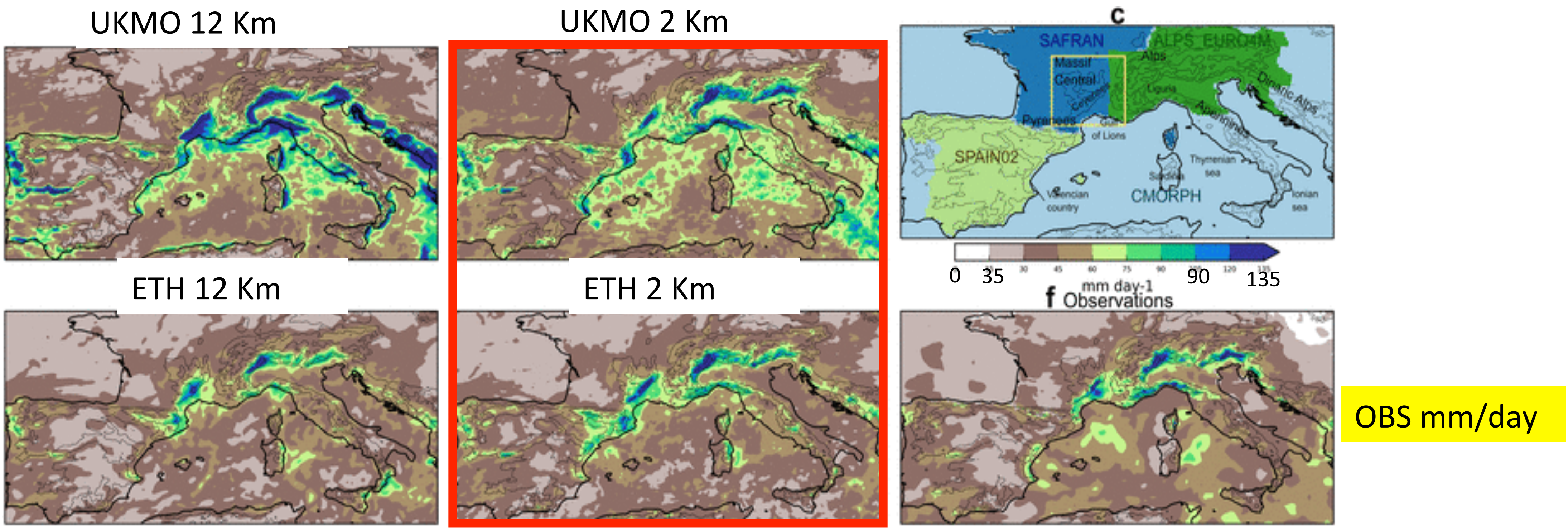

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Berthou et al. 2018

EXTREME PRECIPITATION

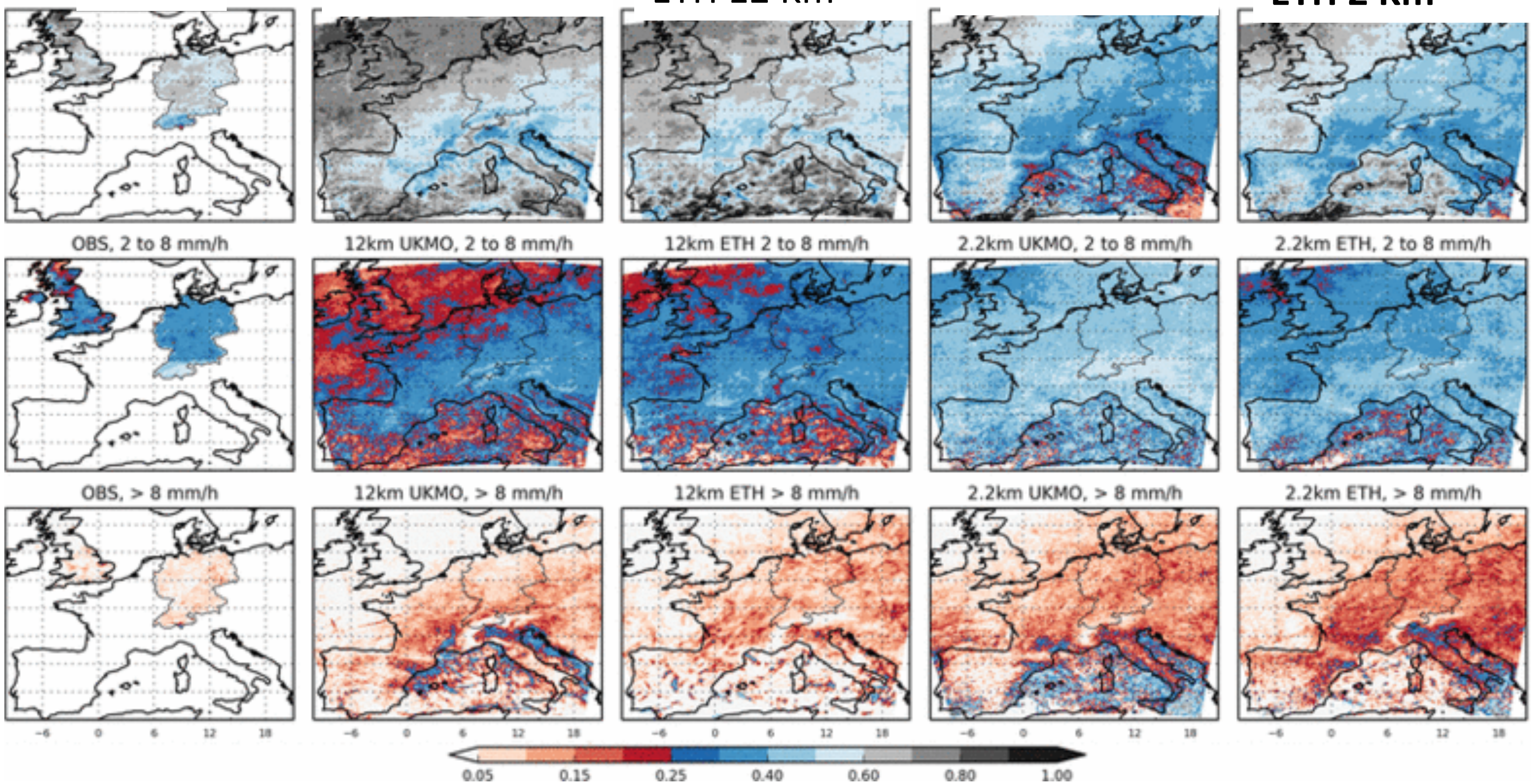
Map of the The fractional contribution to total rainfall from low intensity (< 2mm/h), moderate events (2-8 mm/h) and intense events (>8 mm/h)

OBS | UKMO 12 Km | ETH 12 Km | **UKMO 2 Km** | **ETH 2 Km**

Low < 2 mm/h

Moderate < 8 mm/h

Intensee > 8 mm/h



0.05 0.15 0.25 0.40 0.60 0.80 1.00

Shift in contribution of precipitation from low (< 2mm/h) to moderate (2-8 mm/h) and intense precipitation (>8 mm/h) in both 2.2 Km model in both 2.2 Km model is present everywhere on land

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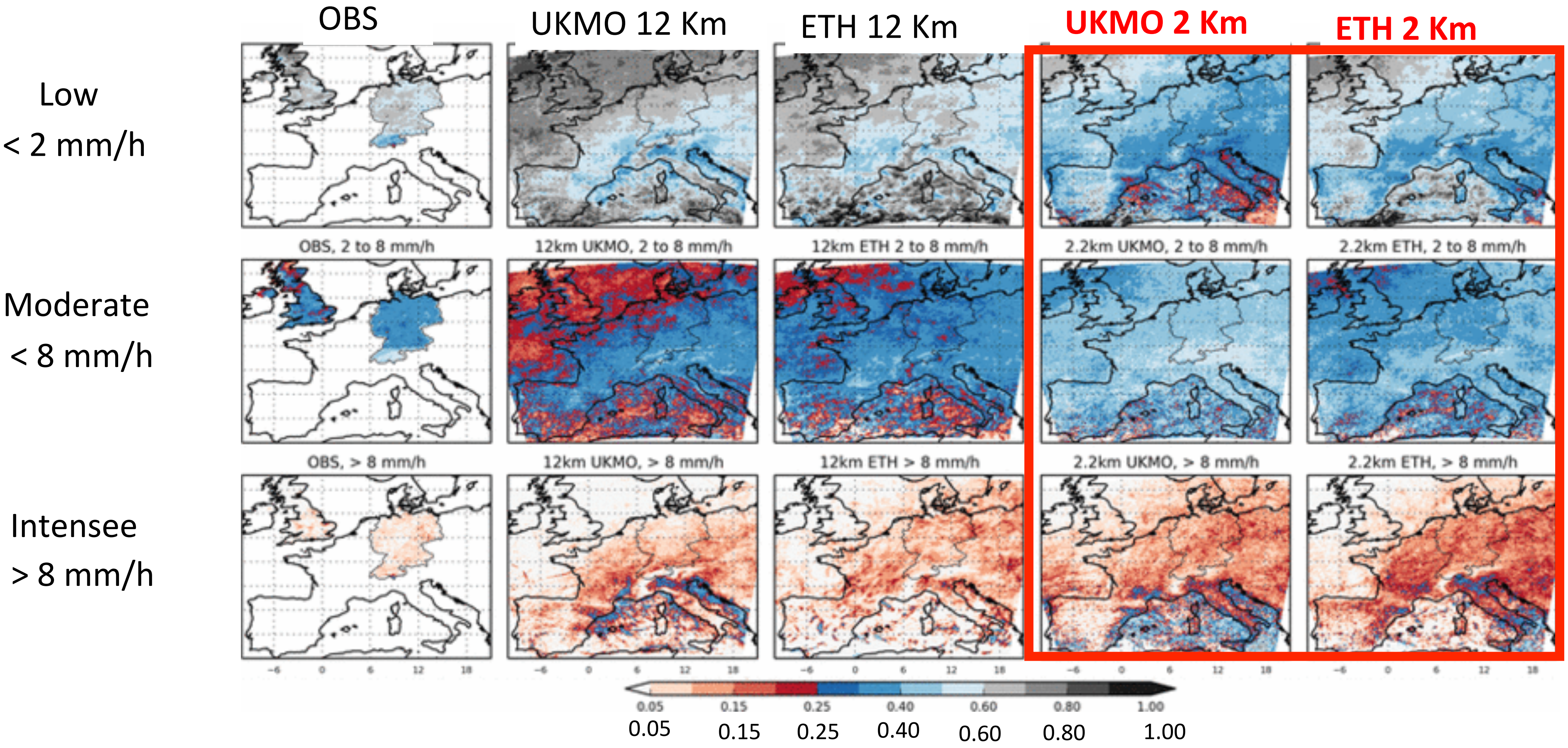

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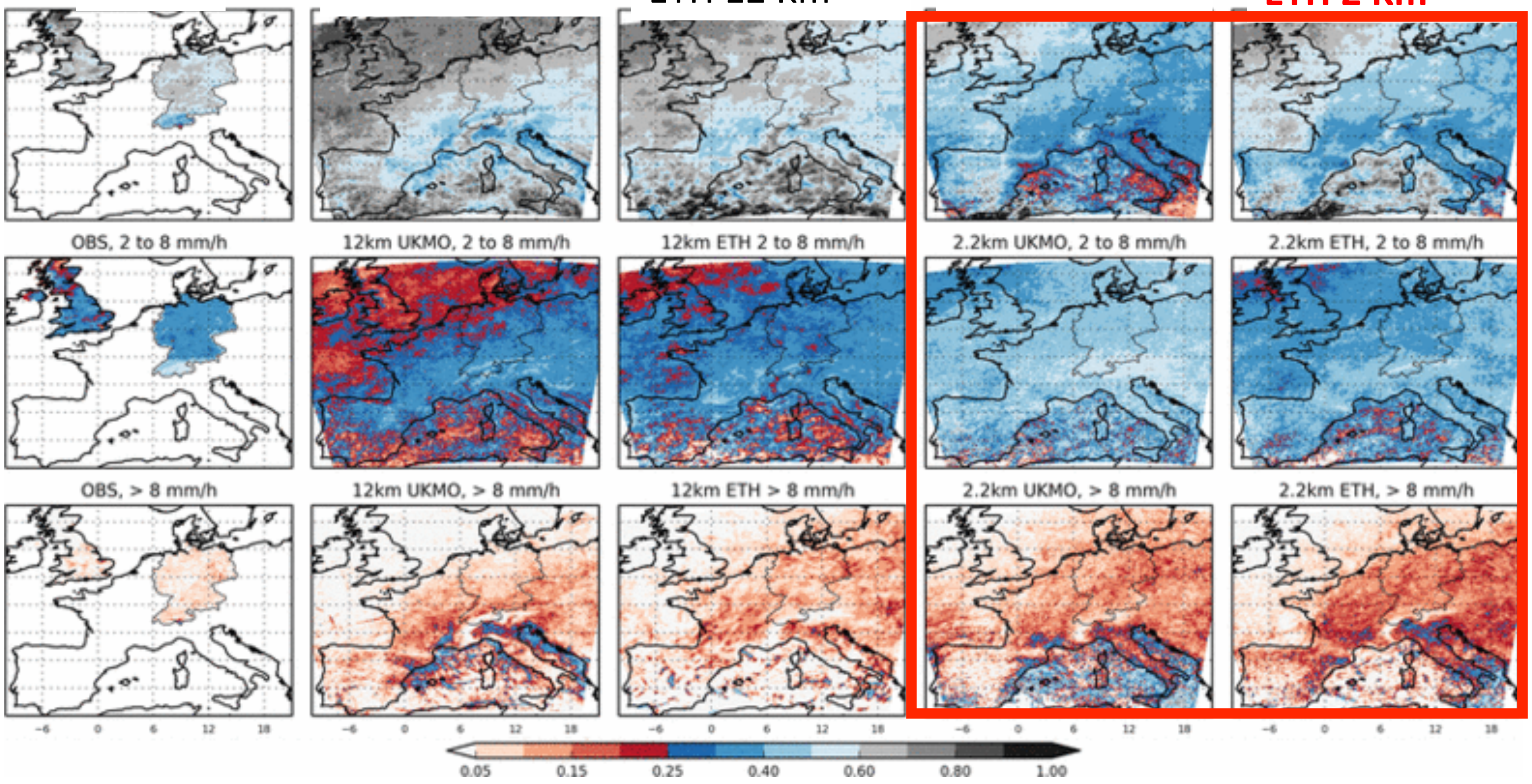
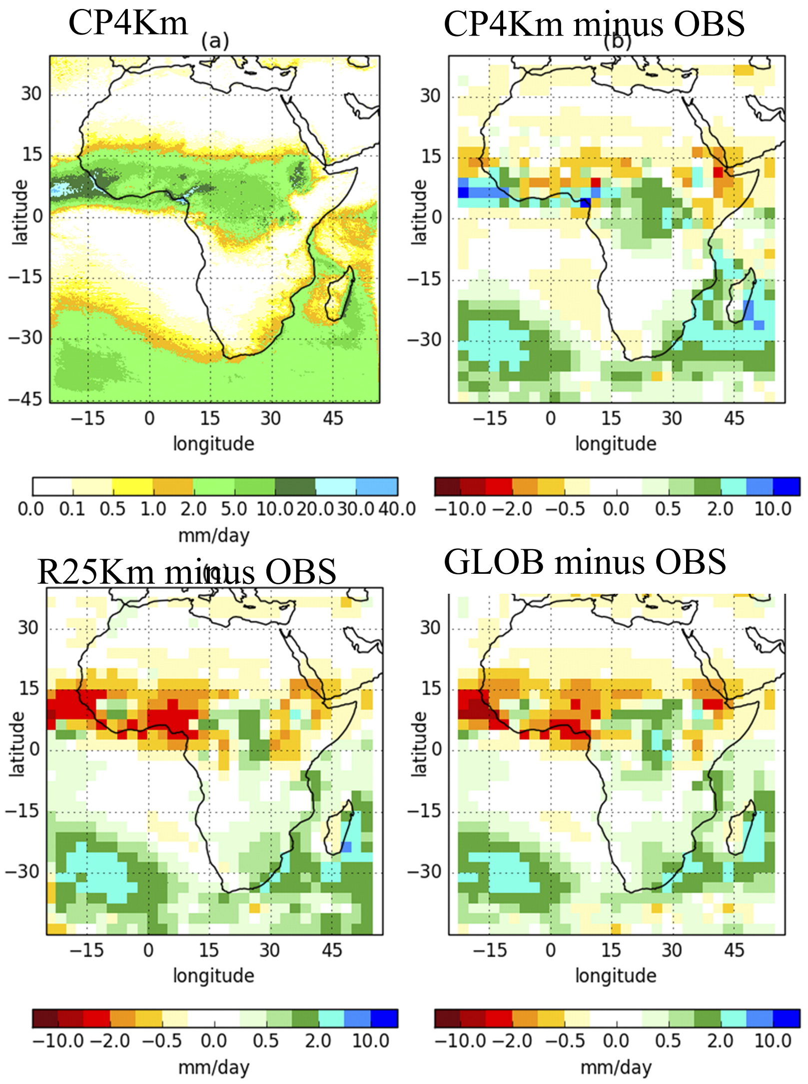


0.05 0.15 0.25 0.40 0.60 0.80 1.00

moderate to intense wet spell tend to be overestimated by the 2.2 km model even if The 2.2 km models yield better results for these events in all countries fot the ETH2.2 and only in Switzerland for UKMO

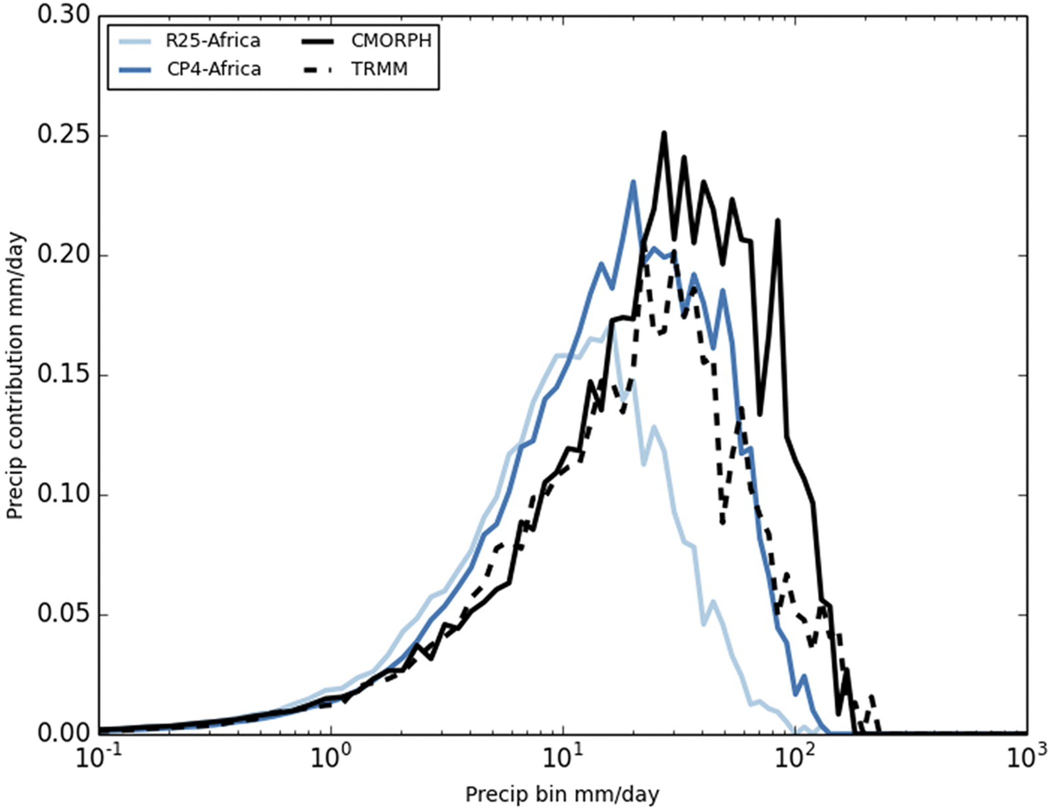
A Pan-African Convection Permitting Climate Simulation: Initial results 5 yr of simualtions [Stratton et al., 2018]

JJA seasonal mean precipitation for 1997–2001



CP4-Africa (4 km) substantially reducing the dry biases

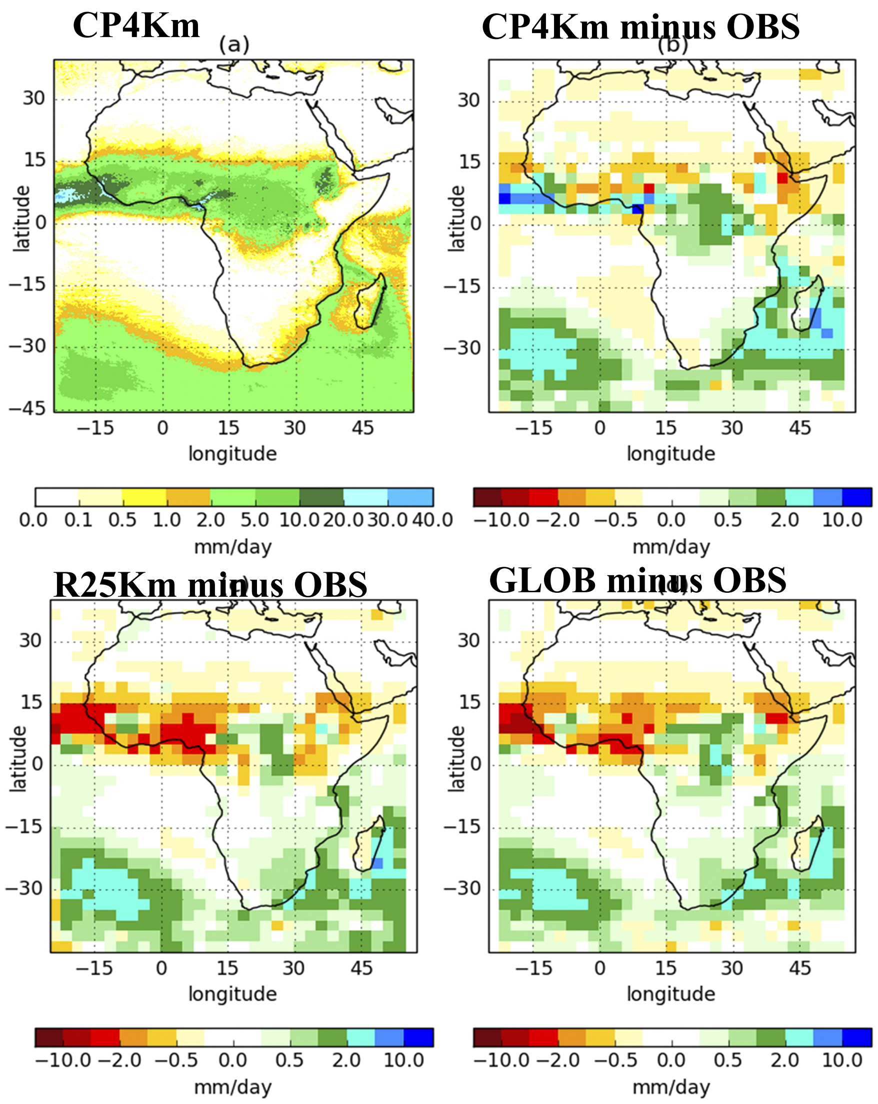
Contribution of 3h (mm day^{-1}) prec to the daily precipitation rate across the West African monsoon (WAM)



CP4-Africa (4 km) compares well with observational data from TRMM and CMORPH, and is a significant improvement over the results with parameterized convection (R25-Africa)

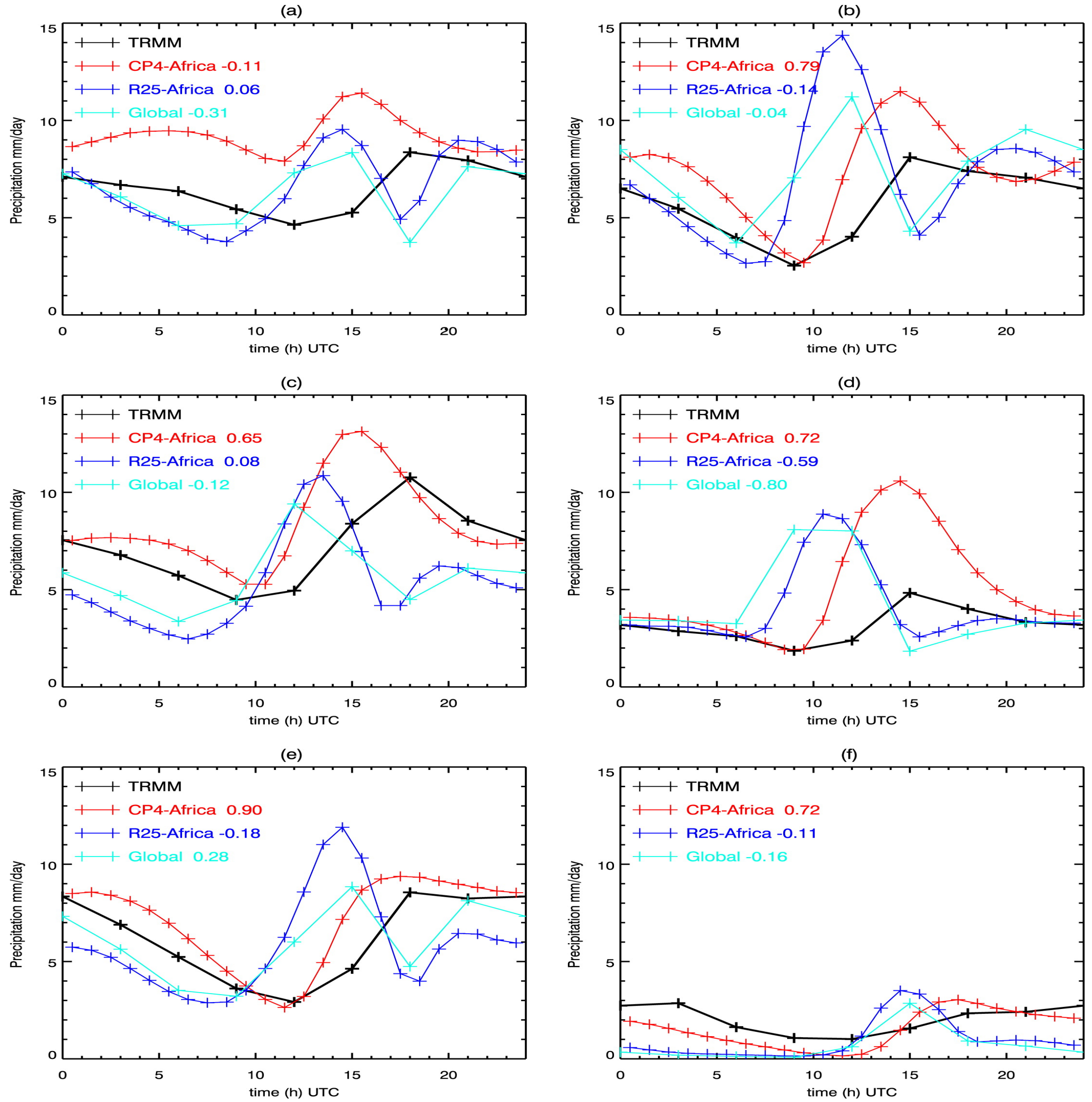
A Pan-African Convection Permitting Climate Simulation: Initial results 5 yr of simualtions [Stratton et al., 2018]

JJA seasonal mean precipitation for 1997–2001



CP4-Africa (4 km) substantially reducing the dry biases

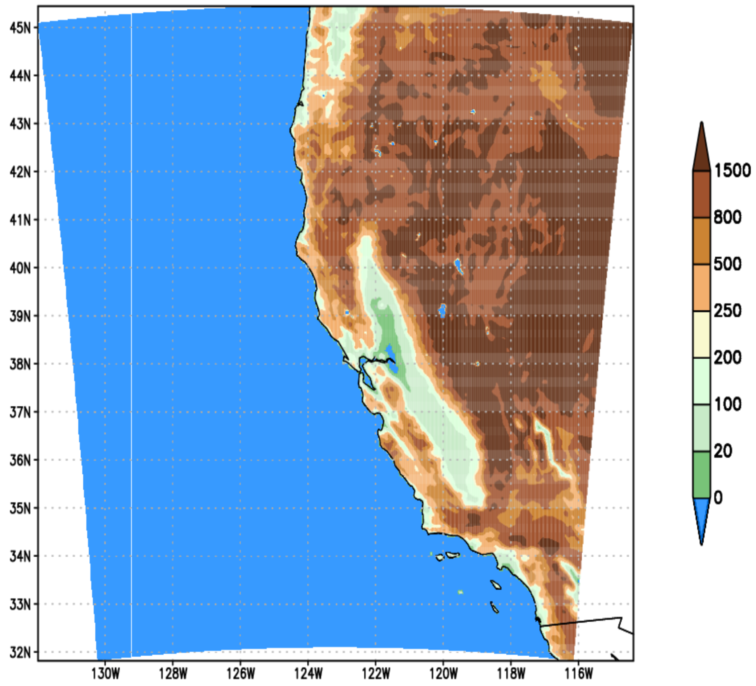
The mean diurnal cycle of precipitation for JJA



In all regions (the diurnal cycle of CP4-Africa is improved with a later peak in rainfall

RegCM V4.7.0: Convection permitting

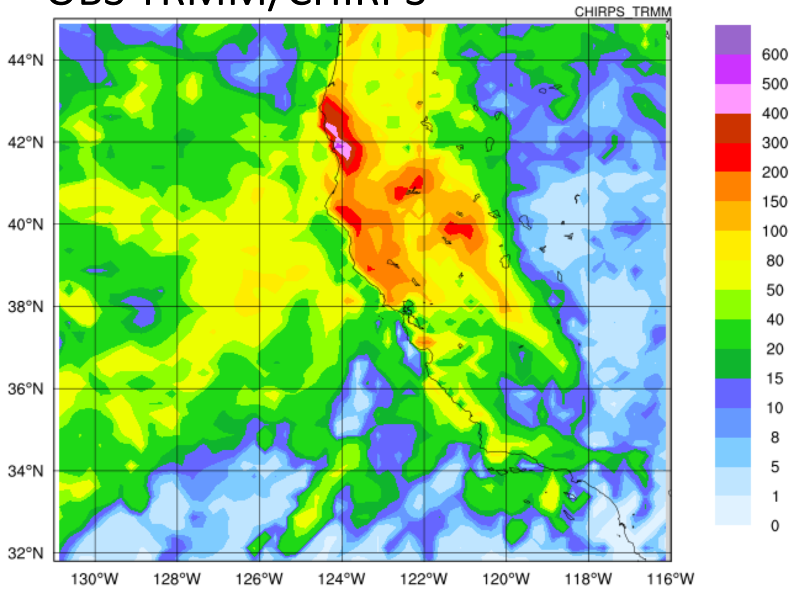
CASE STUDY 1 : Norther California on 16-18 February 2004 (*Ralph et al., 2006*)



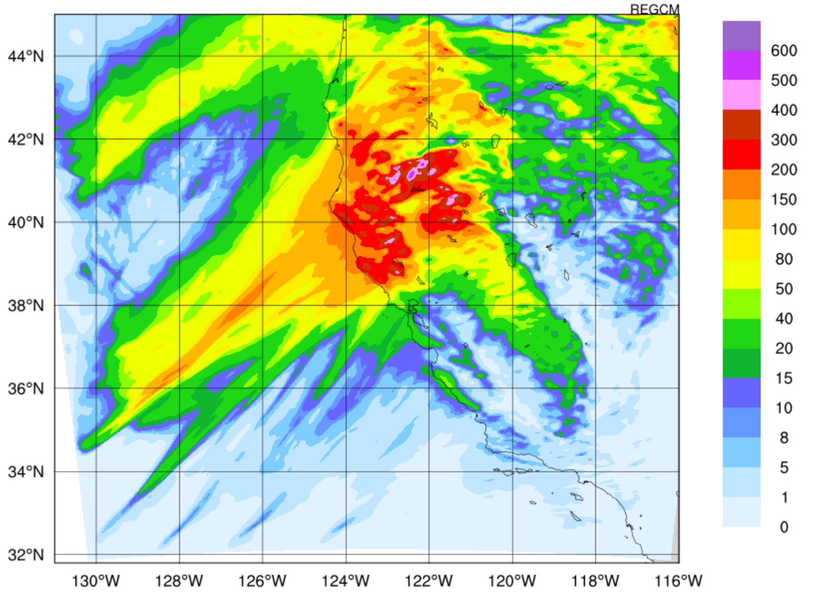
RegCM Domain 3 km

OBS TRMM/CHIRPS

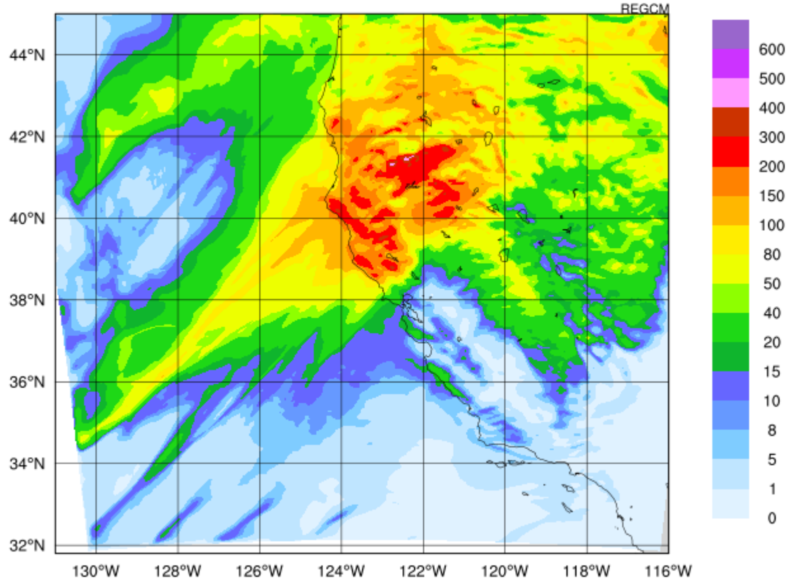
Accumulated prec (mm)



RegCM 3km WSM5



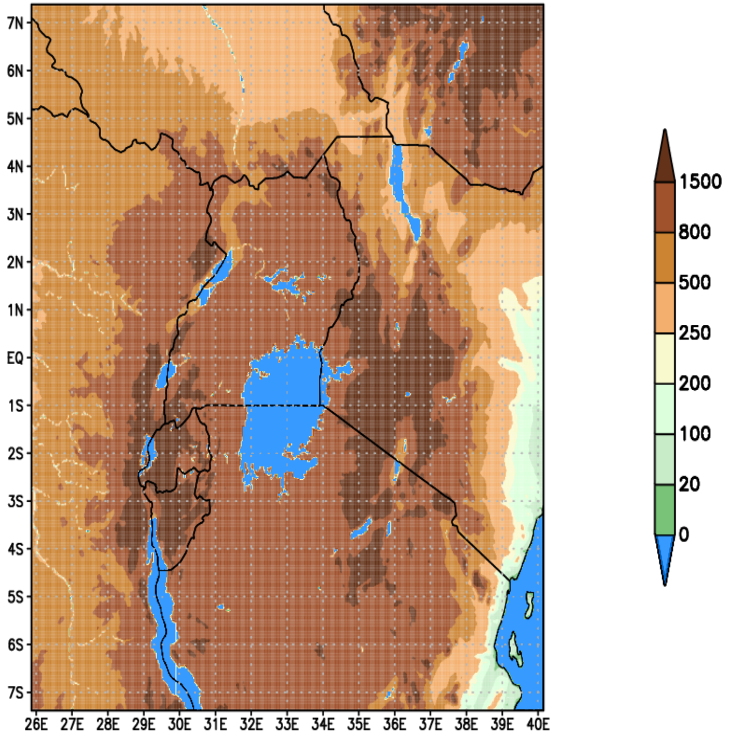
RegCM 3km NOGHE



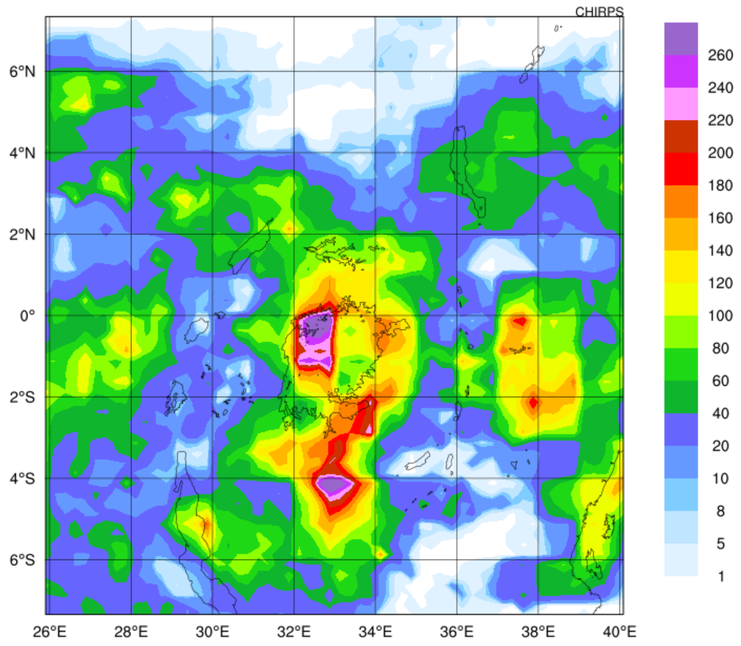
The model reproduces well the precipitation field and localization of the maximum in particular with nogherotto microphysics parameterization

RegCM V4.7.0: Convection permitting

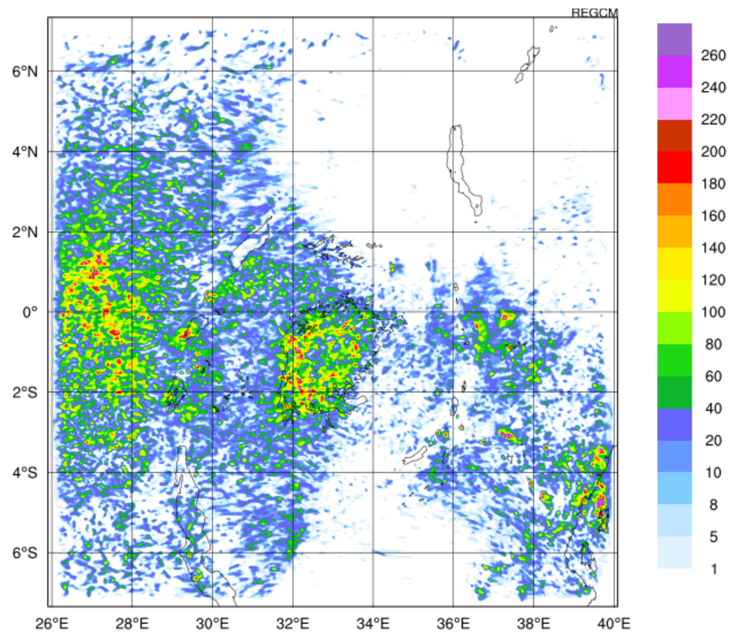
CASE STUDY 3 : Lake Victoria on 26 Nov-1 Dec 1999 (*Ralph et al., 2006*)



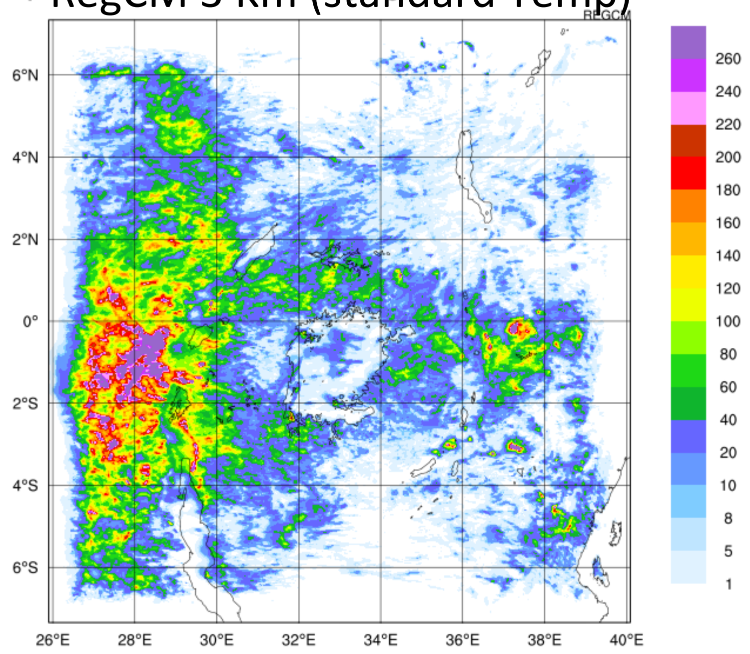
OBS TRMM 60 h acc. Prec (mm)



RegCM 3 Km (T° change)



RegCM 3 Km (standard Temp)



RegCM V4.7.0: Convection permitting

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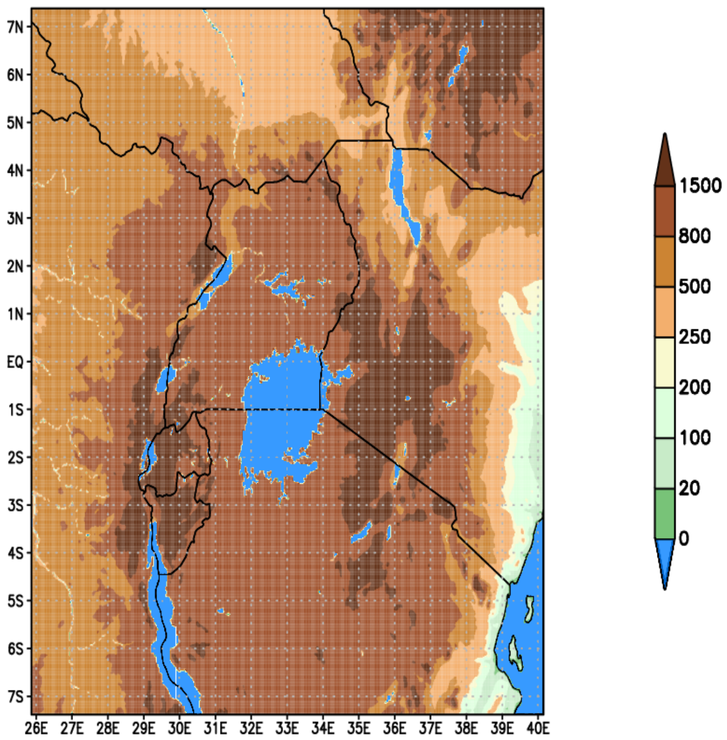

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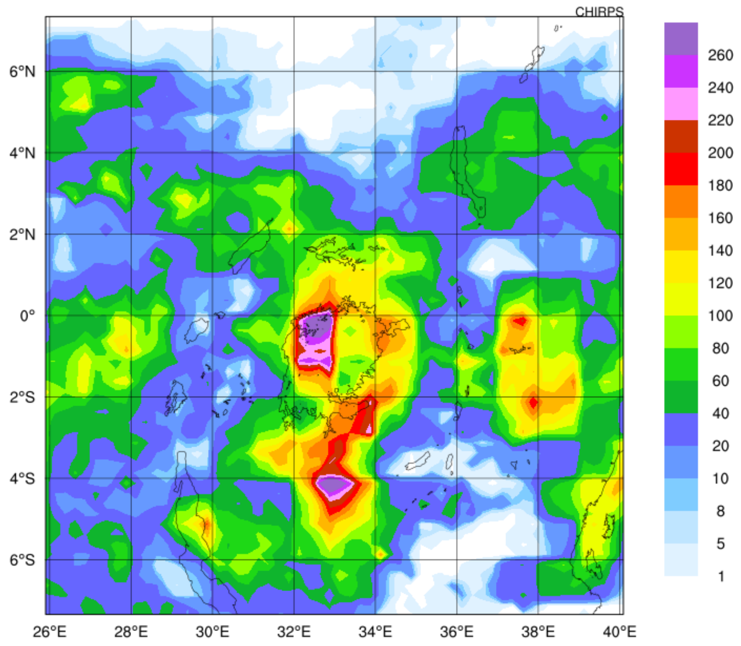
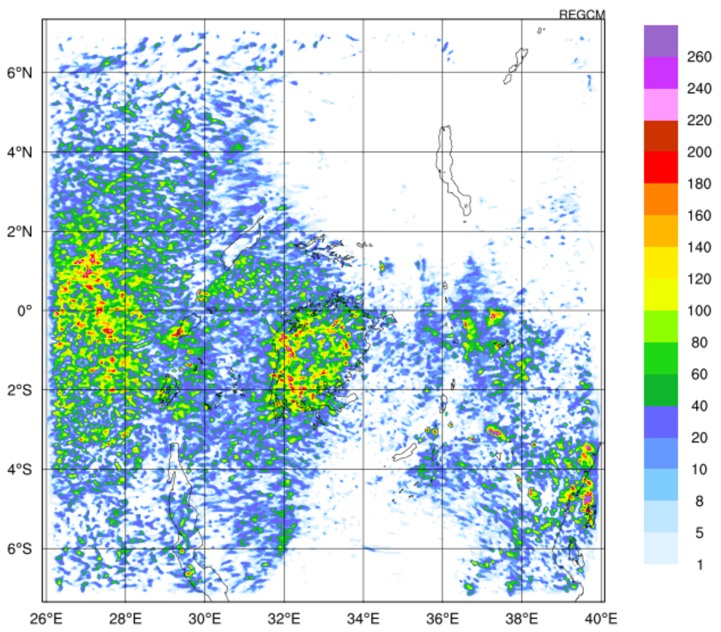
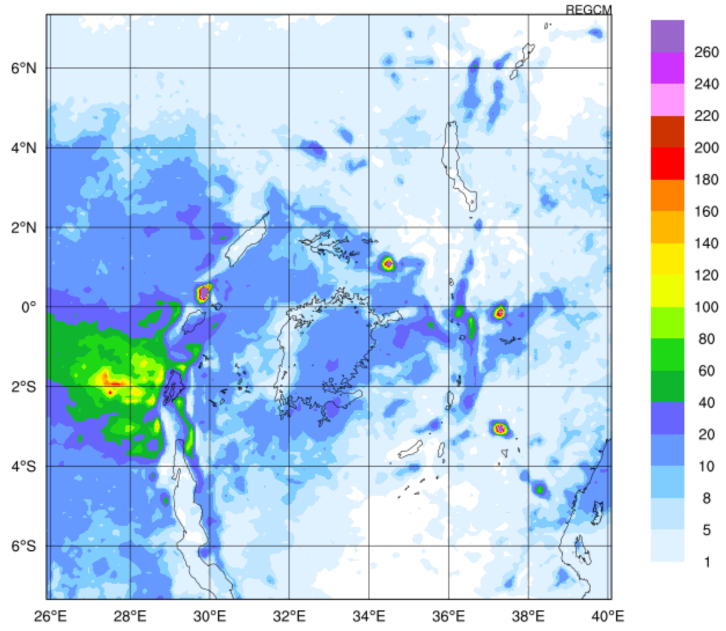


RegCM 3 Km

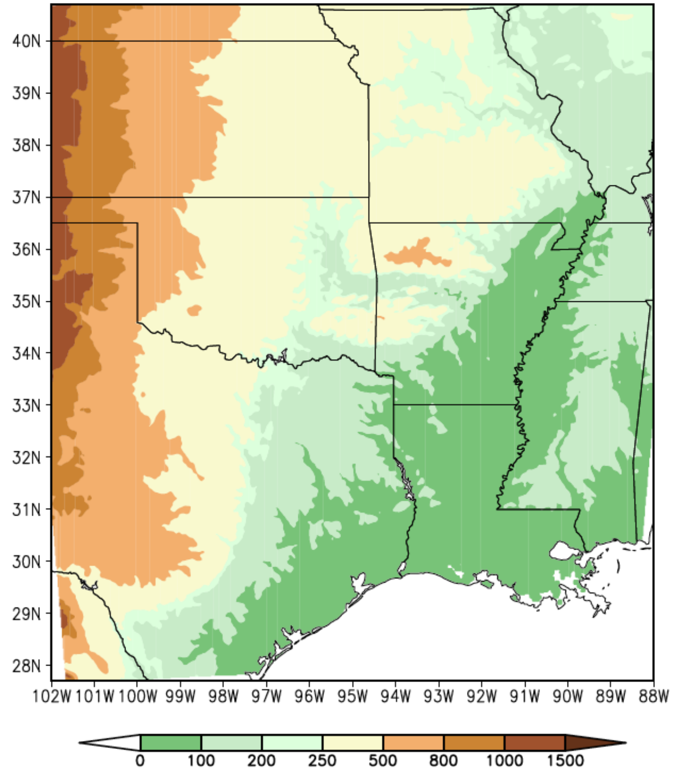


RegCM 12 km

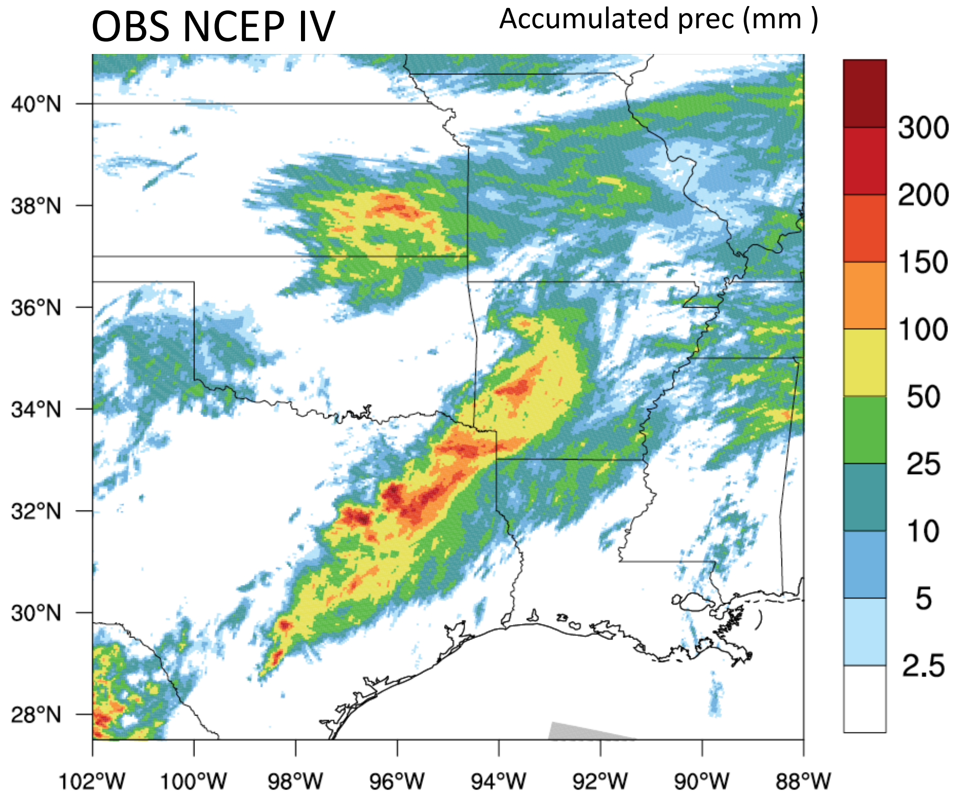


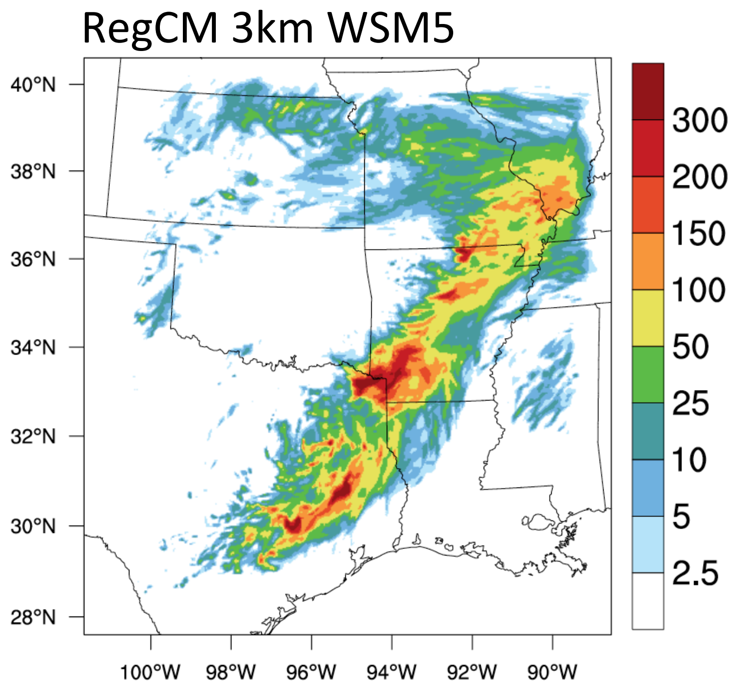
RegCM V4.7.0: Convection permitting

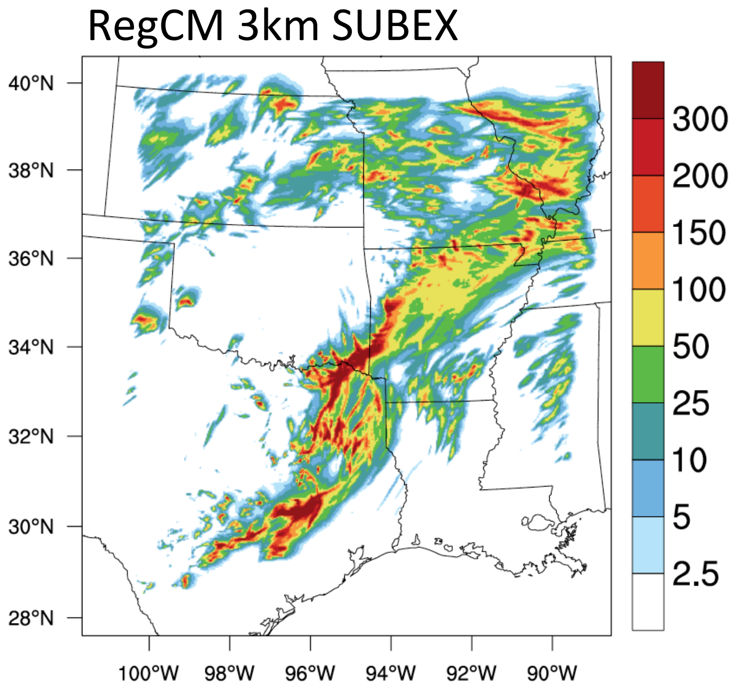
CASE STUDY 2 : Great Plains on 9-11 June 2010 (*Higgins, 2011*)



RegCM Domain 3 km







The model reproduces well the precipitation field and localization of the maximum in particular with WSM5 microphysics parameterization

SPECIAL THANKS TO : J.Abraham Torres Alavez

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THANK YOU FOR YOUR ATTENTION