wege entstehen, indem wir sie gehen
paths emerge in that we walk them

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Regional and Local Climate Modeling Research Group

ReLoClim

Sensitivity of precipitation in a set of convection-permitting simulations in the Alpine region

Marie Piazza [1], Heimo Truhetz [1], Andreas Prein [2], Andras Csaki [1]

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[2] National Center for Atmospheric Research, Boulder, Colorado, USA

March 7th 2017
COSMO/CLM/ICON/ART-User Seminar @ DWD, Offenbach, Germany.

Outline

1. Introduction
    1. The added-value of CPM for precipitation
    2. The project NHCM-2 : goals and methods
    3. High resolution datasets for Austria
2. Evaluation and sensitivity of precipitation
    1. Frequency-intensity distribution
    2. Height-dependency
    3. Summertime mid-afternoon peak
3. Driving data and evaluation strategy
    1. Case study: June 26th 2009
    2. Verification metrics with the WegenerNet
4. Conclusions & outlook

Motivation: Added-value of CPM for precipitation

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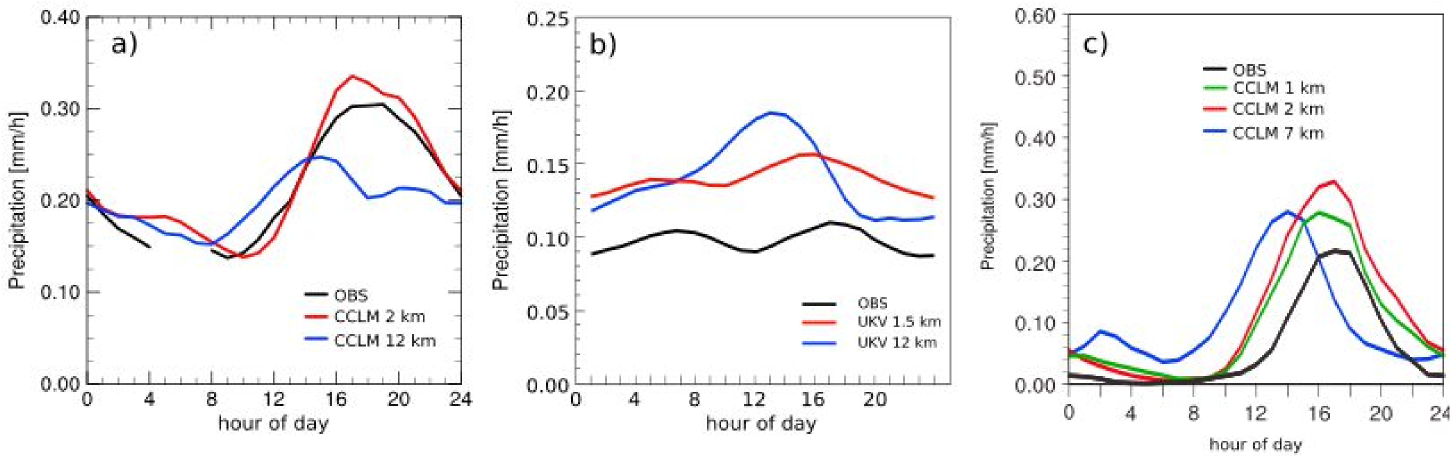
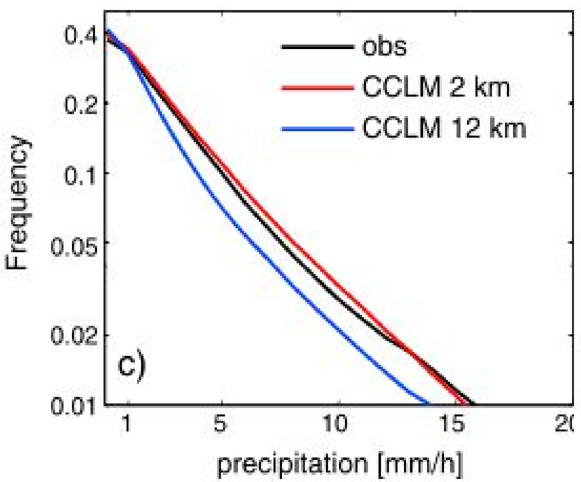


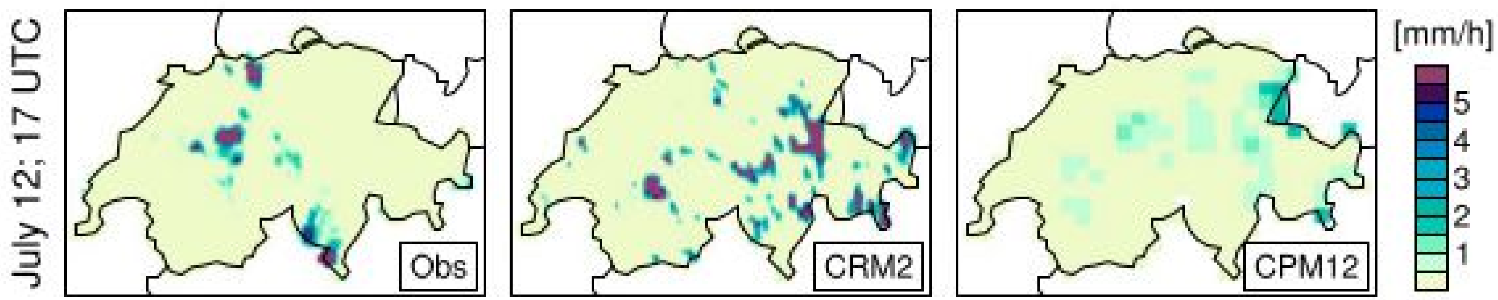
Adapted from Prein et al. 2015

A review on regional convection-permitting climate modeling: Demonstrations, prospects, and challenges (2015)

Andreas F. Prein[1,2], Wolfgang Langhans[3], Giorgia Fosser[4], Andrew Ferrone[5], Nikolina Ban[6], Klaus Goergen[7,8,9], Michael Keller[6,10], Merja Tölle[11], Oliver Gutjahr[12], Frauke Feser[13], Erwan Brisson[14], Stefan Kollet[9,15], Juerg Schmidli[6,10], Nicole P. M. van Lipzig[16], and Ruby Leung[17]

- **extreme precipitation** on hourly time scales
- timing of the **diurnal cycle** of precipitation (summer)
- **spatial structure** of precipitation objects
- **frequency** of wet-day





(left and up) Adapted from Ban et al. 2014

Questions and aims

- Investigate the role of certain parameters in the Alpine region

  → improve model setup for climate simulations

- How sensitive is the representation of precipitation at climate scales?

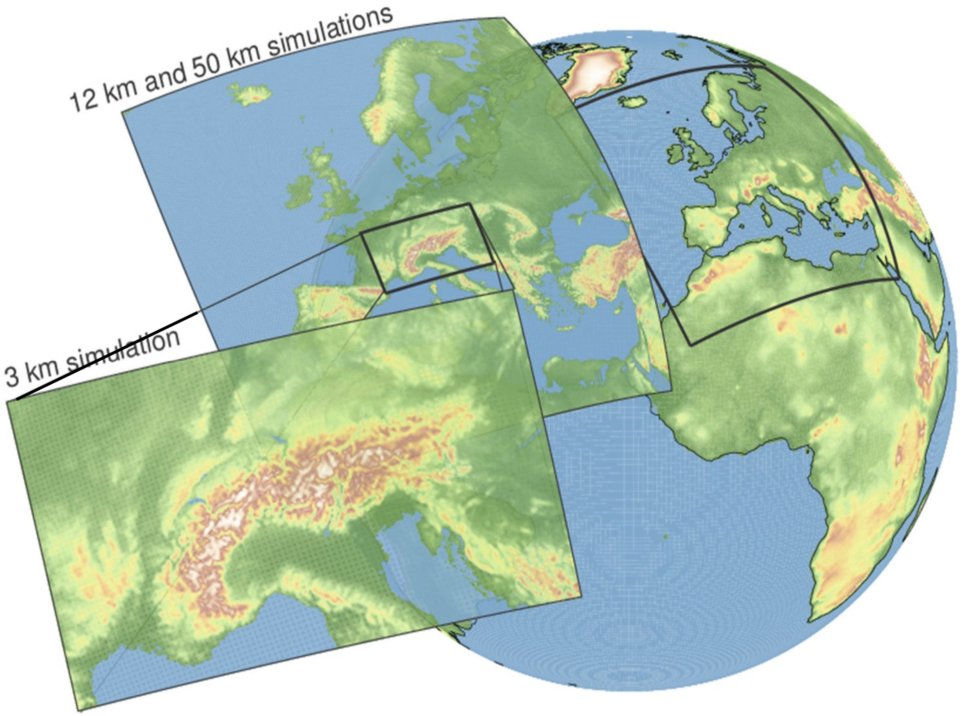
  → improve our current understanding of CPCM

- What is the influence of the LBCs?

  → Develop robust evaluation strategy

Sensitivity experiments

Domain: Greater Alpine Region
Resolution: ~3 km (0.0275°)
Period: 2006 – 2010
Spin-up run (soil): 17 years



Adapted from Prein et al. 2015

8 CCLM experiments

cosmo_131108_5.00_clm1
int2lm_120831_1.20_clm3

- Driving data (**CLM12**): EURO-CORDEX hindcast at 0.11° (K. Keuler, BTU Cottbus); frequency: 3 hours
- Reference run: **REF3**
- Adapted from standard setup for EURO-CORDEX. Main changes: iadv_order=3; q_crit=4; tur_len=500; lconv=True; lexpcor=True; initial snow field (warm start), lforest=True

1 WRF simulation: WRF3

similar setup as for CLM3

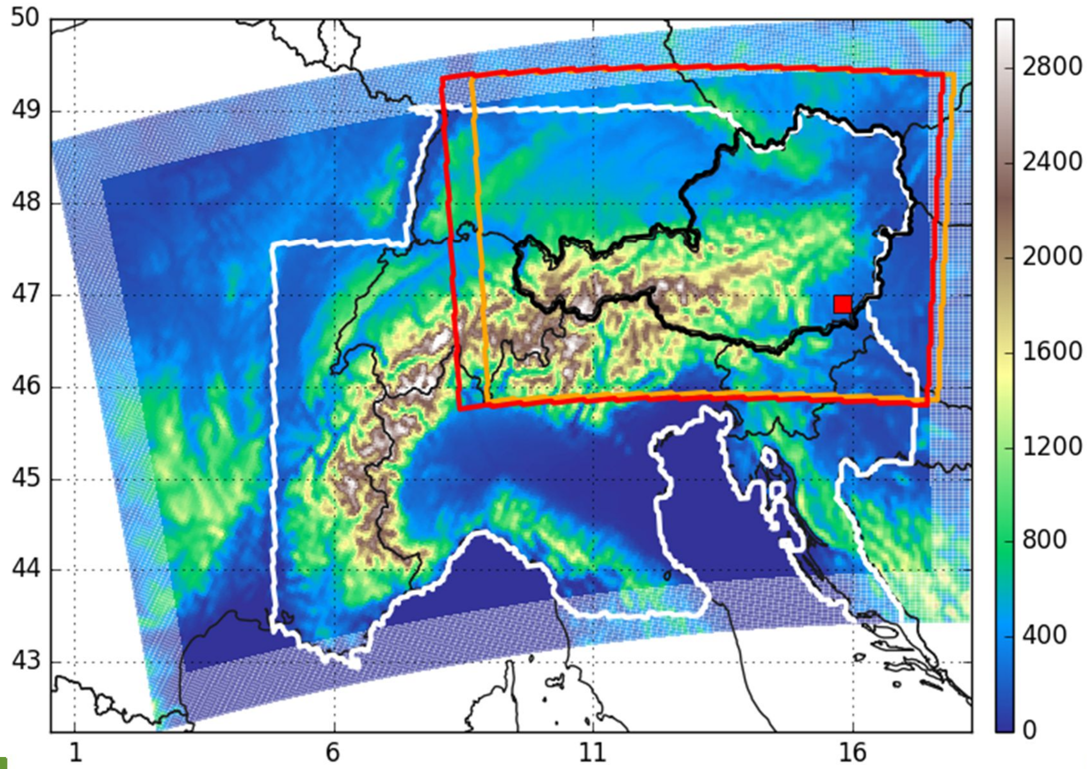
Liste of experiments with COSMO-CLM

Parameters	Description	Name
Lateral boundary conditions	Increase frequency (3h →1h) and include W New driving run: ERAint_011_r2i1p1	**LBC_FW**
	IFS as driving data *(<u>stops in 2009</u>)*	**LBC_IFS**
Turbulence	Unstable summer condition Decrease turbulent length scale: tur_len=150 q_crit=1.6;iadv_order=5	**TURB1**
	Turn off correction of vertical turbulent diffusion (turbulent heat and moisture fluxes due to subgrid-scale condensation) lexpcor=FALSE	**TURB2**
Orography	Smoothed orography at 0.11°	**OROG11**
Microphysics	Tuning microphysics - increase falling speed of snow: v0snow=15 - decrease conversion rate to graupel: qc0=0.0005	**MICROPHYS**

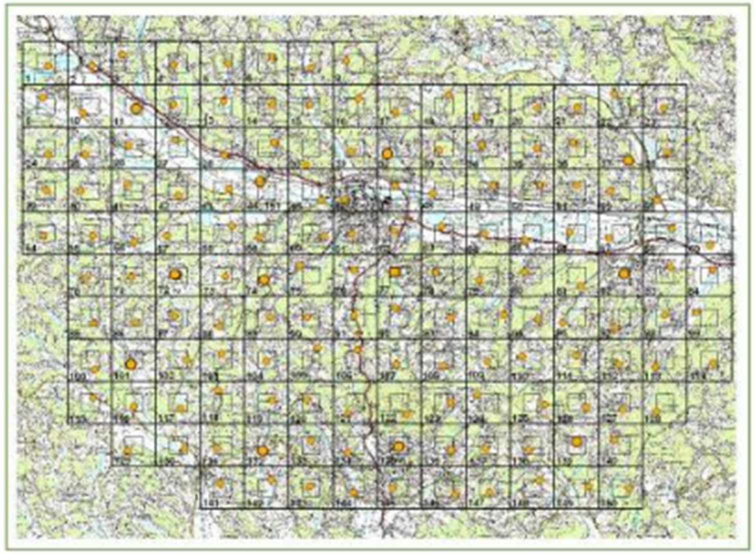
A set of high- resolution gridded datasets

	Type	Domain	Frequency	Resolution	Period
INCA* *Haiden et al. 2011*	Radar + stations	Austria+	hourly	1 km	Since 2006
GPARD-1* *Hofstätter et al. 2015*	Rain gauges	Austria+	daily	1 km	Since 1961
WegenerNet *Kirchengast et al. 2014*	151 stations	Feldbach area 20km*15km	< hourly	1km	Since 2007

*Provided by the Austrian Department for Meteorology and Geodynamics (ZAMG)



The WegenerNet stations network



From Kirchengast et al. 2008

Frequency-Intensity distribution - Winter

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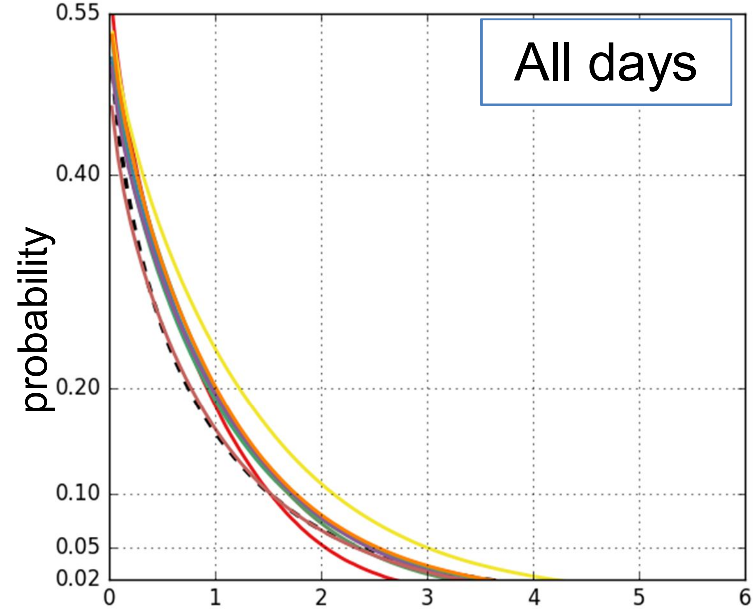
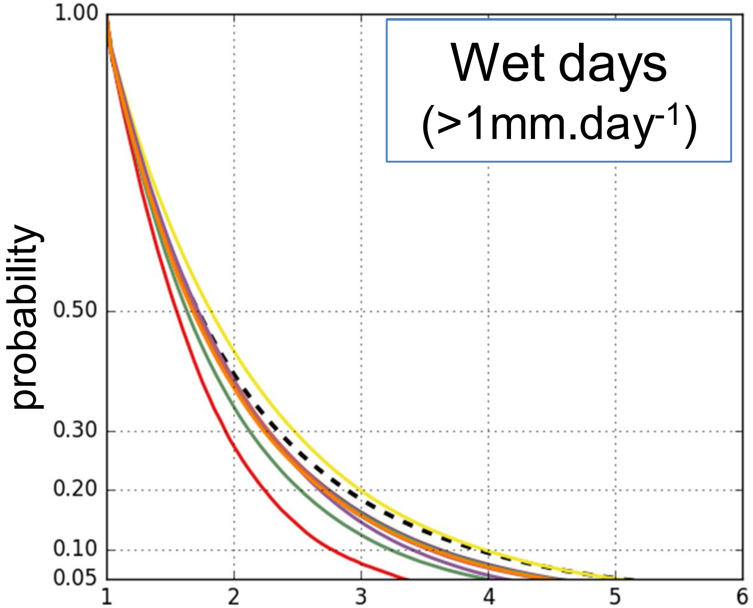
Daily SUM and MAX of hourly total precipitation
2006-2009, Austria, **winter**

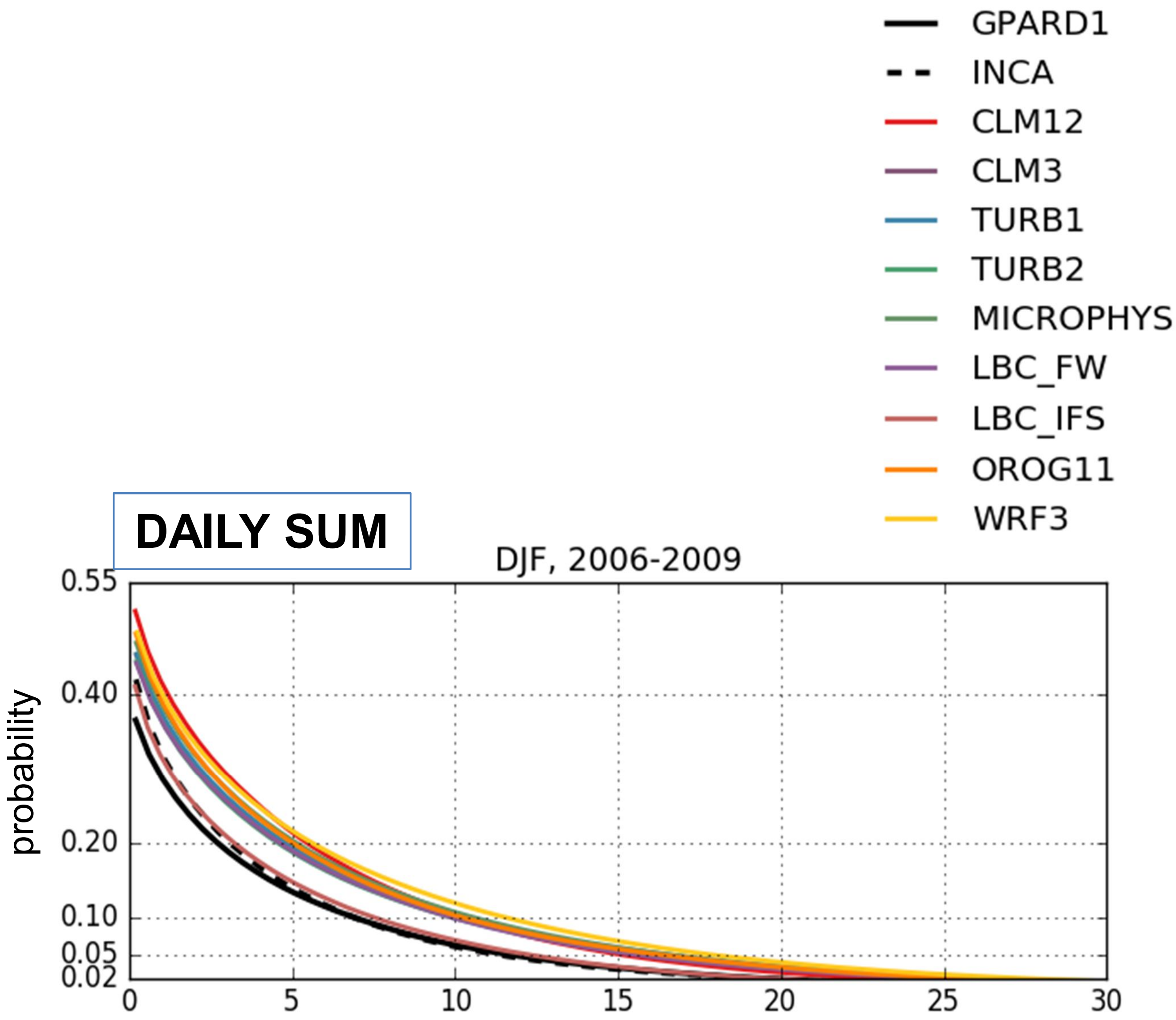
DAILY MAX





mm/hour

DAILY SUM

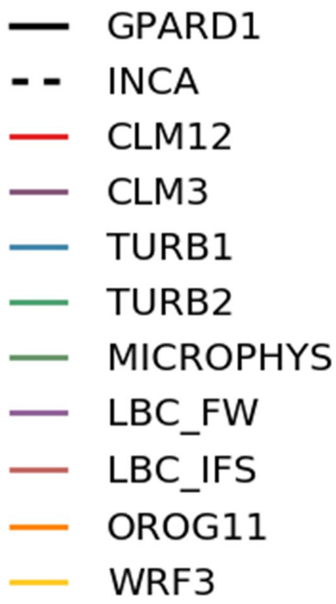


mm/day

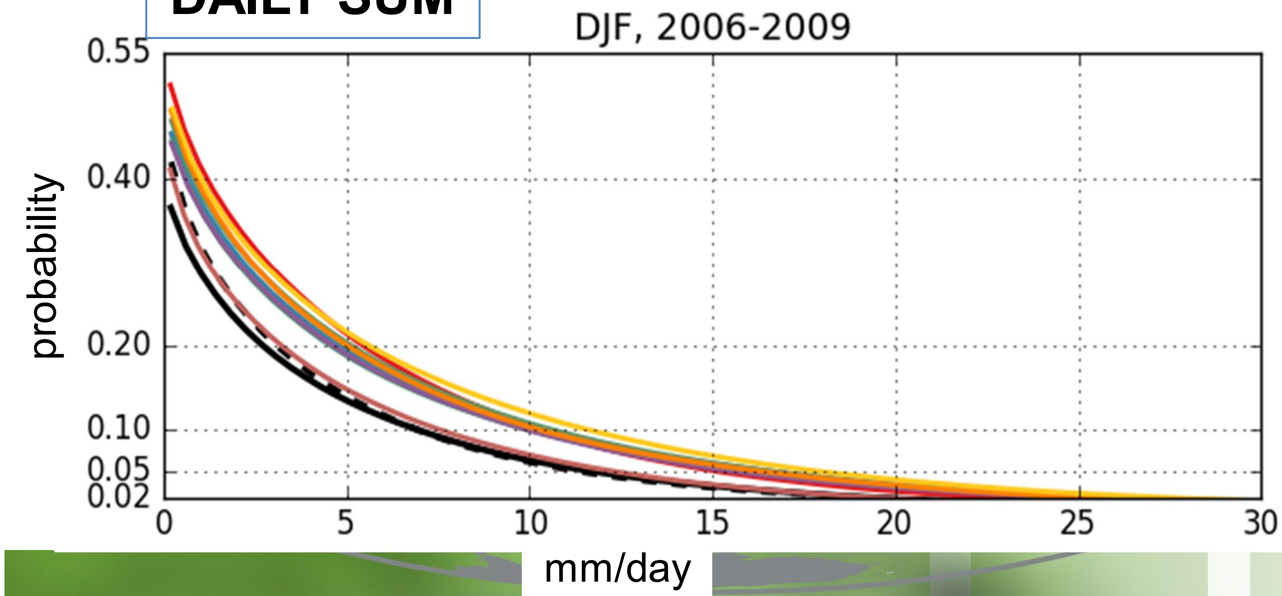
Frequency-Intensity distribution - Winter

Daily SUM and MAX of hourly total precipitation 2006-2009, Austria, **winter**

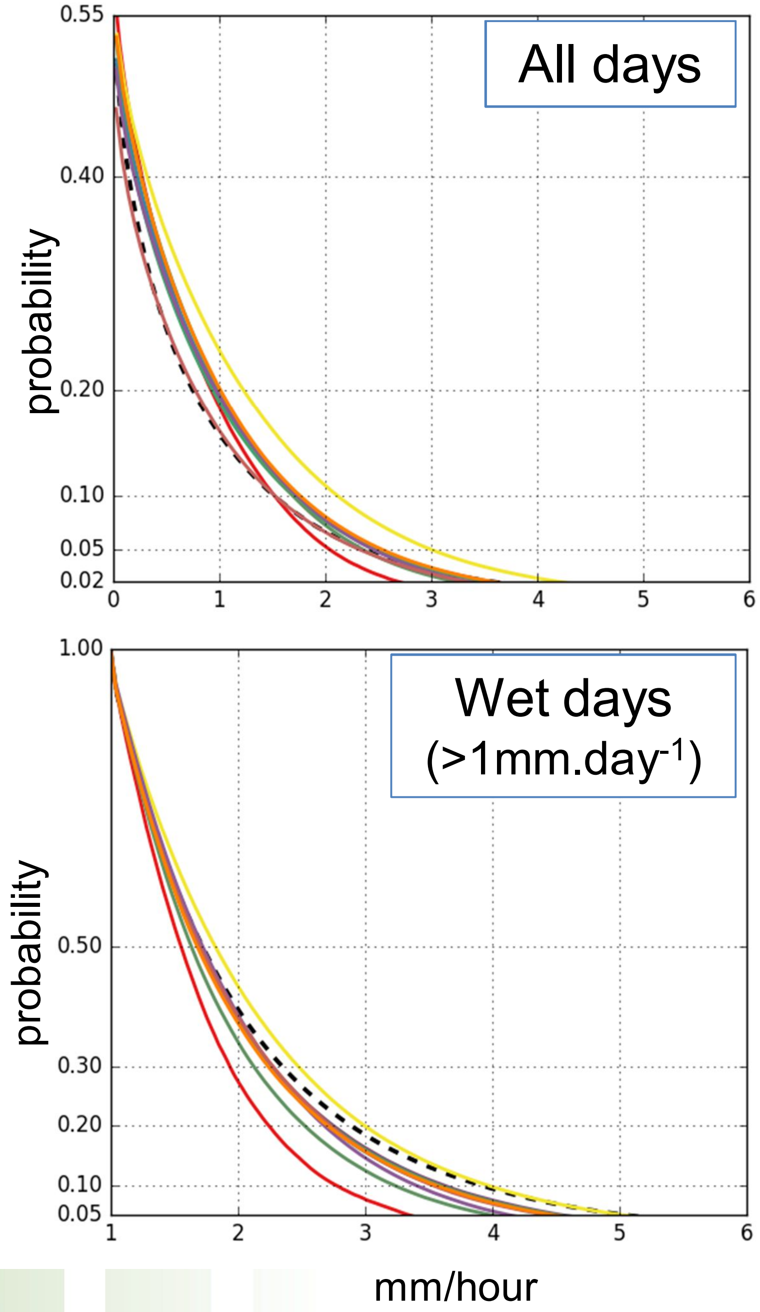
- Small spread among CLM12-driven experiments → few sensitivity of TURB, MICROPHYS, LBC_FW
- LBC_IFS: excellent agreement → role of the driving data *(large-scale forcing, frontal activity in winter)*
- Added-value: daily max, extremes



DAILY SUM

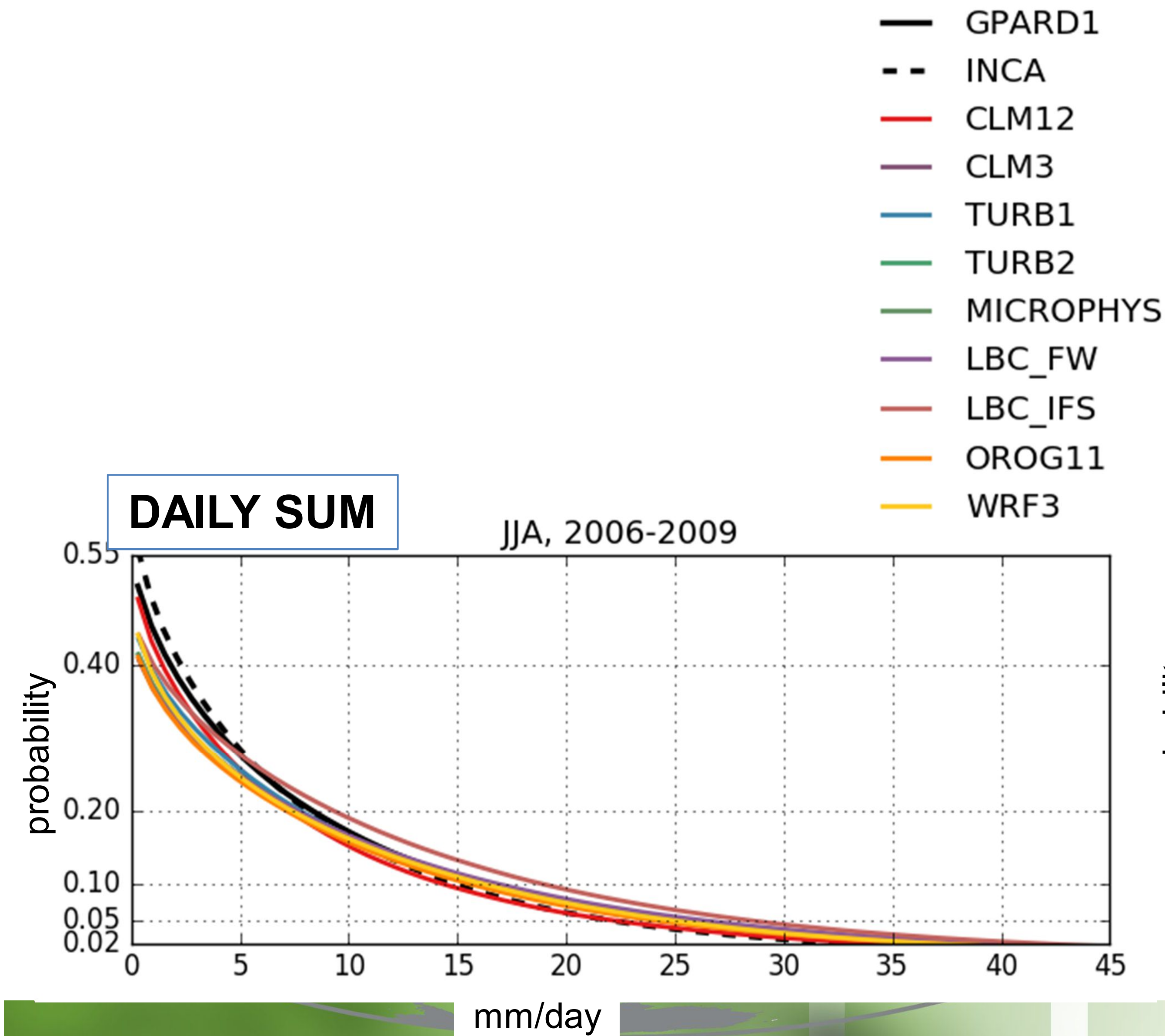


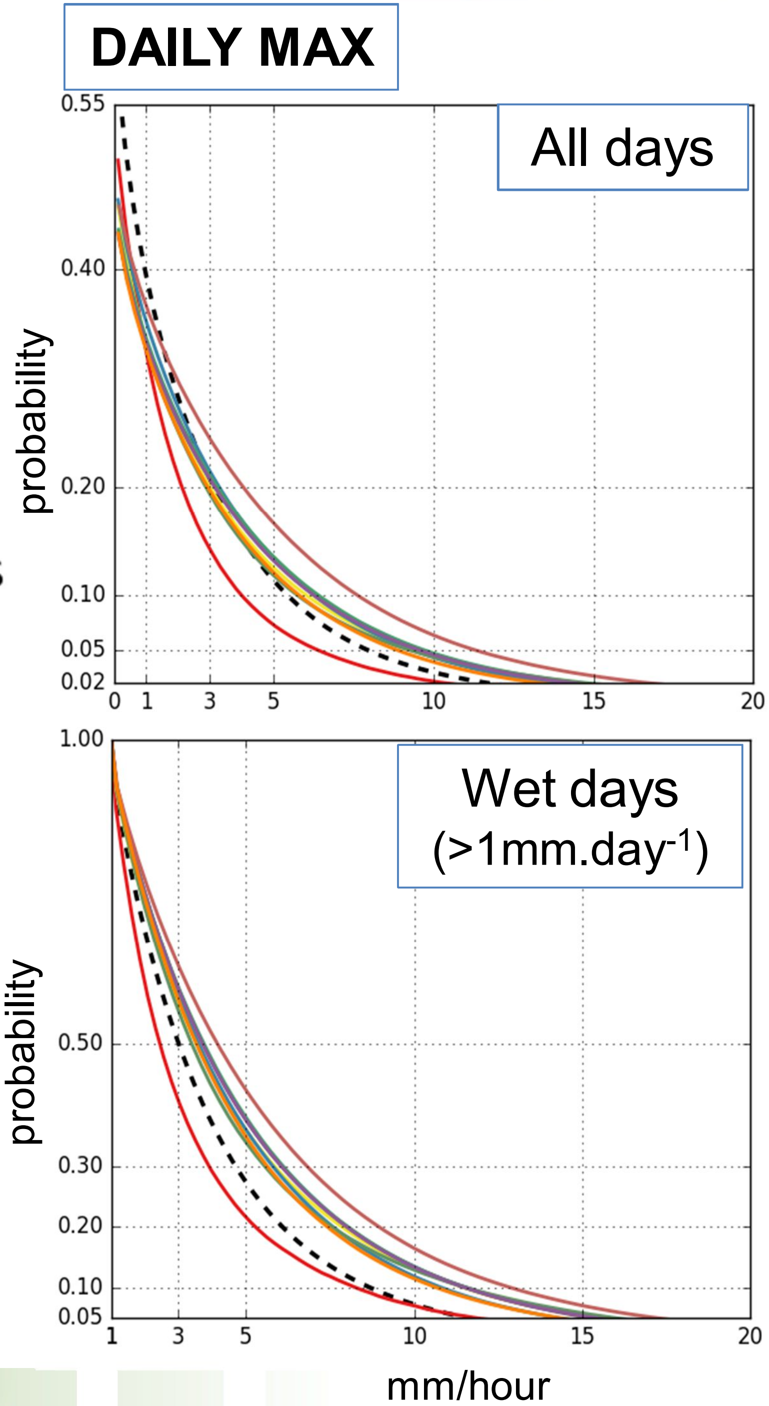
DAILY MAX



Frequency-Intensity distribution - Summer

Daily SUM and MAX of hourly total precipitation 2006-2009, Austria, **summer**

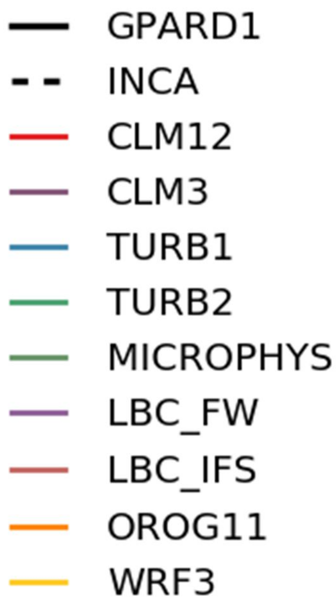


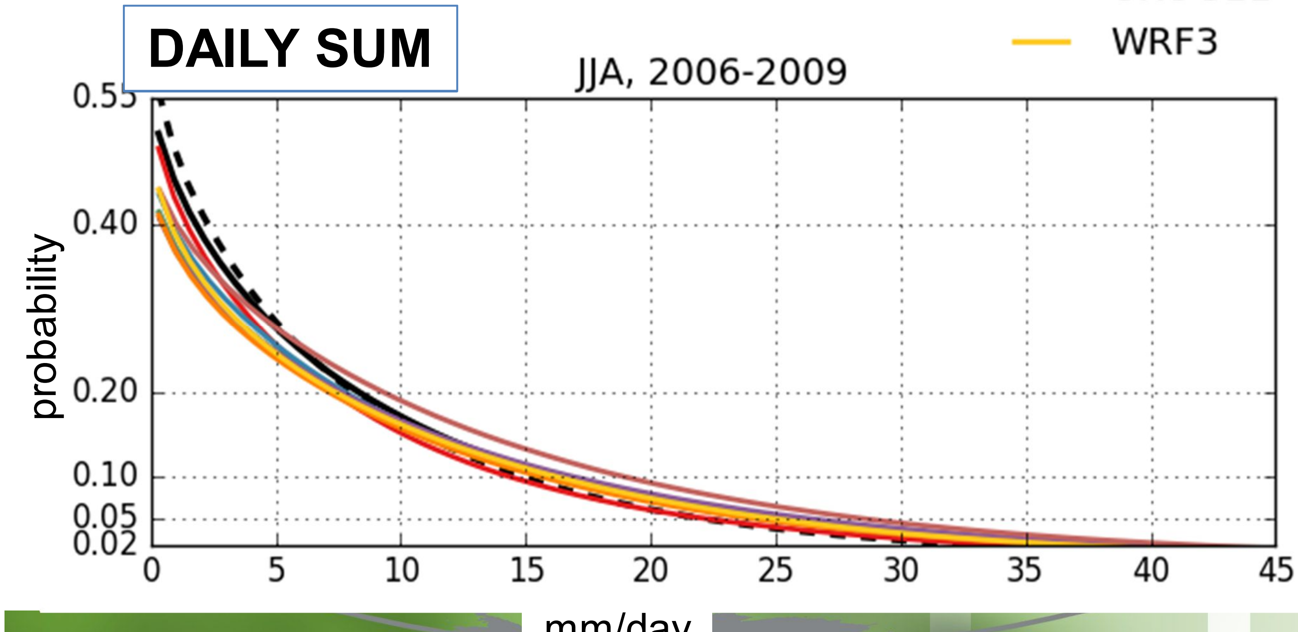


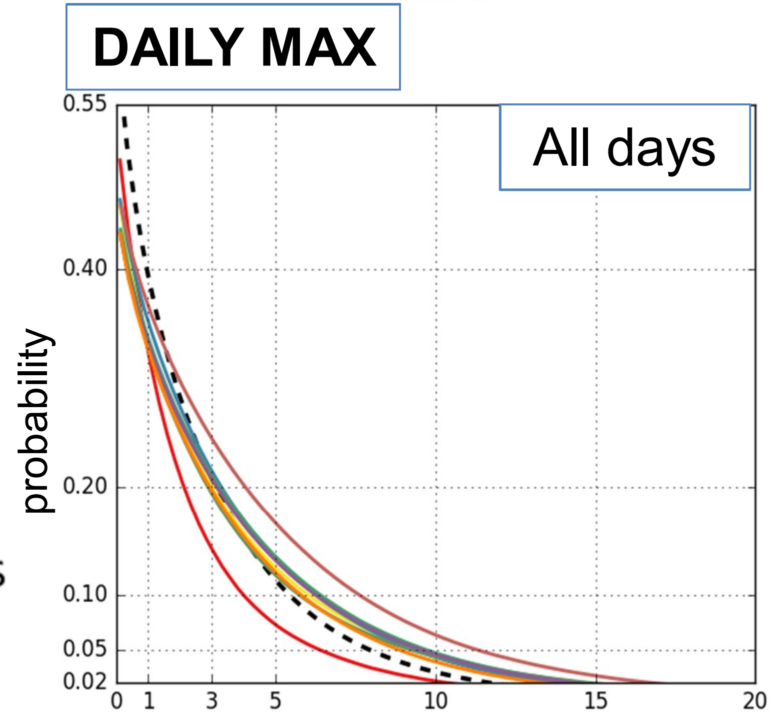
Frequency-Intensity distribution - Summer

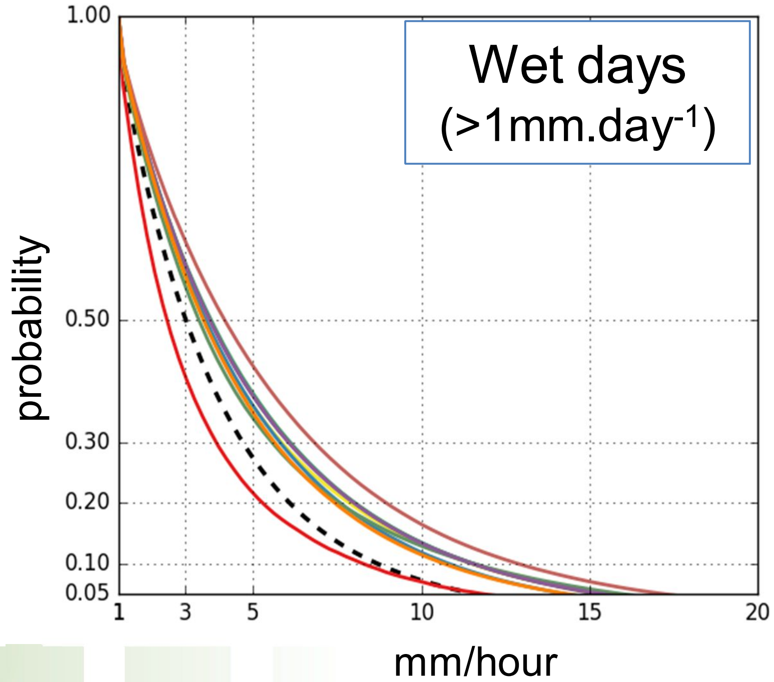
Daily SUM and MAX of hourly total precipitation 2006-2009, Austria, **summer**

- Small spread among CLM12-driven experiments → few sensitivity of TURB, MICROPHYS, LBC_FW
- LBC_IFS: syst. overestimation
  Added-value: daily max, extremes
- CPM: too many dry days

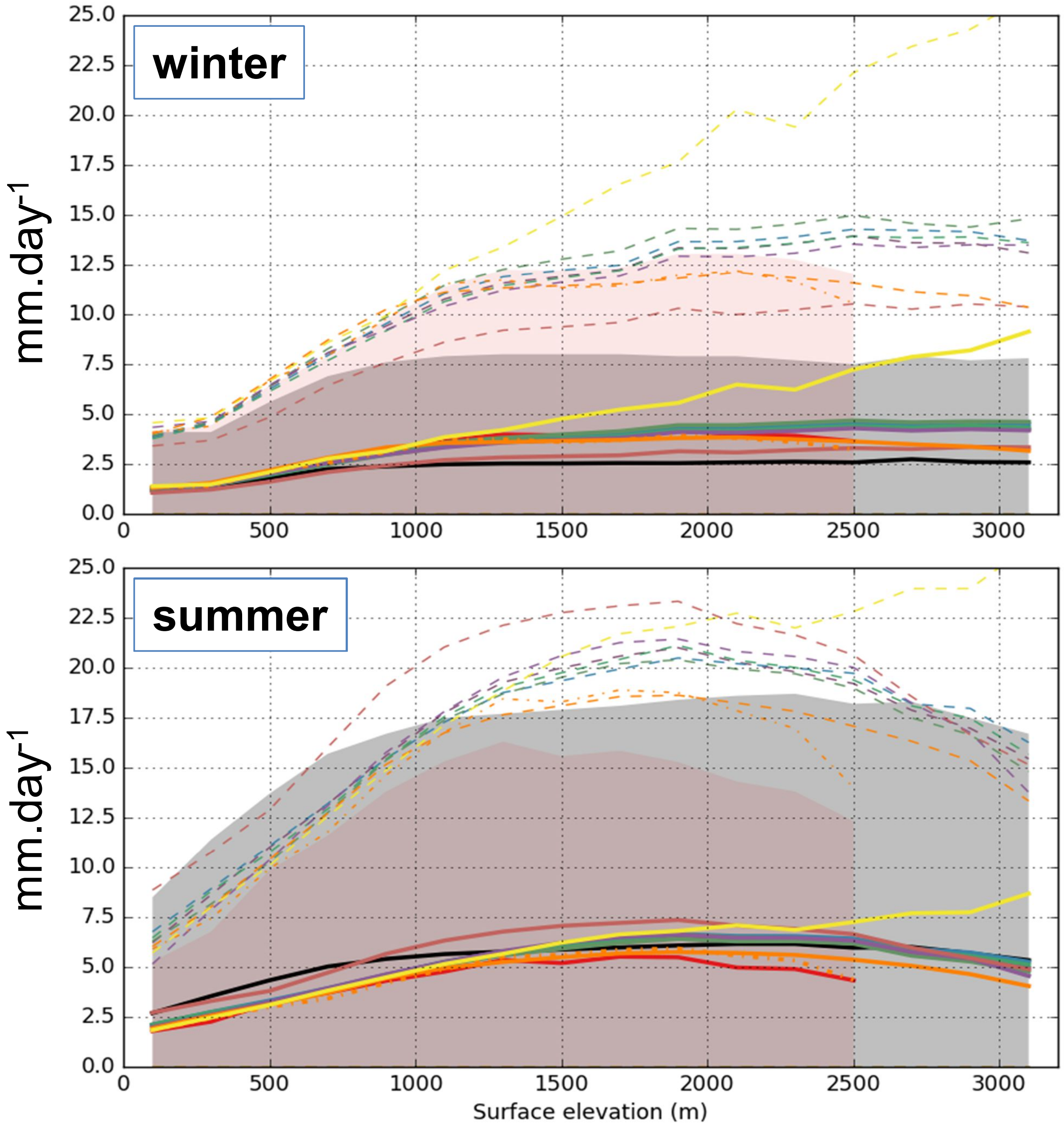






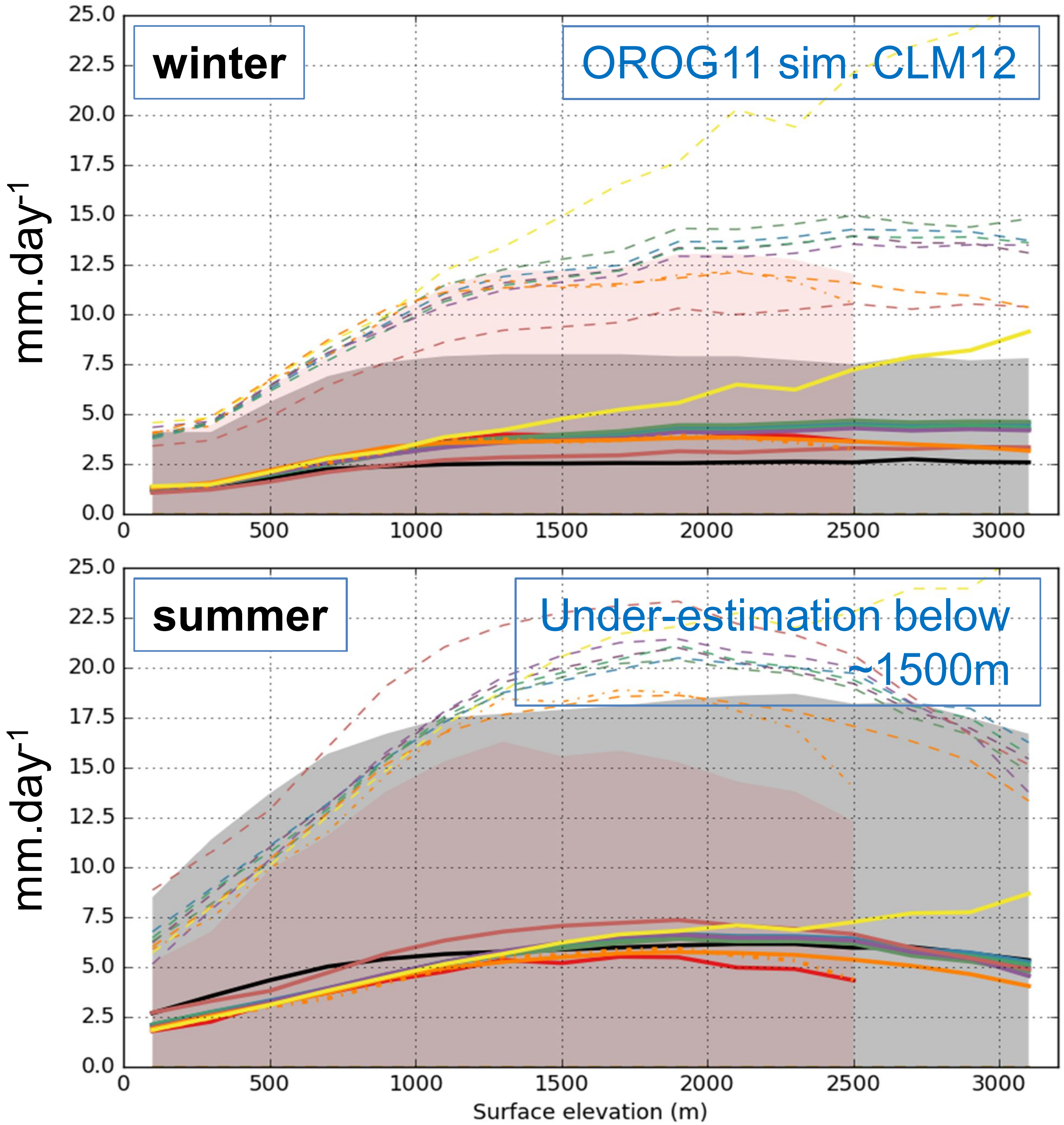


Height dependency of daily precipitation



- Austria, 2006-2009
- 200m elevation ranges
- Daily; spatial mean, q10-90
- threshold for wet days: TOT_PREC > 1 $mm.day^{-1}$

Height dependency of daily precipitation

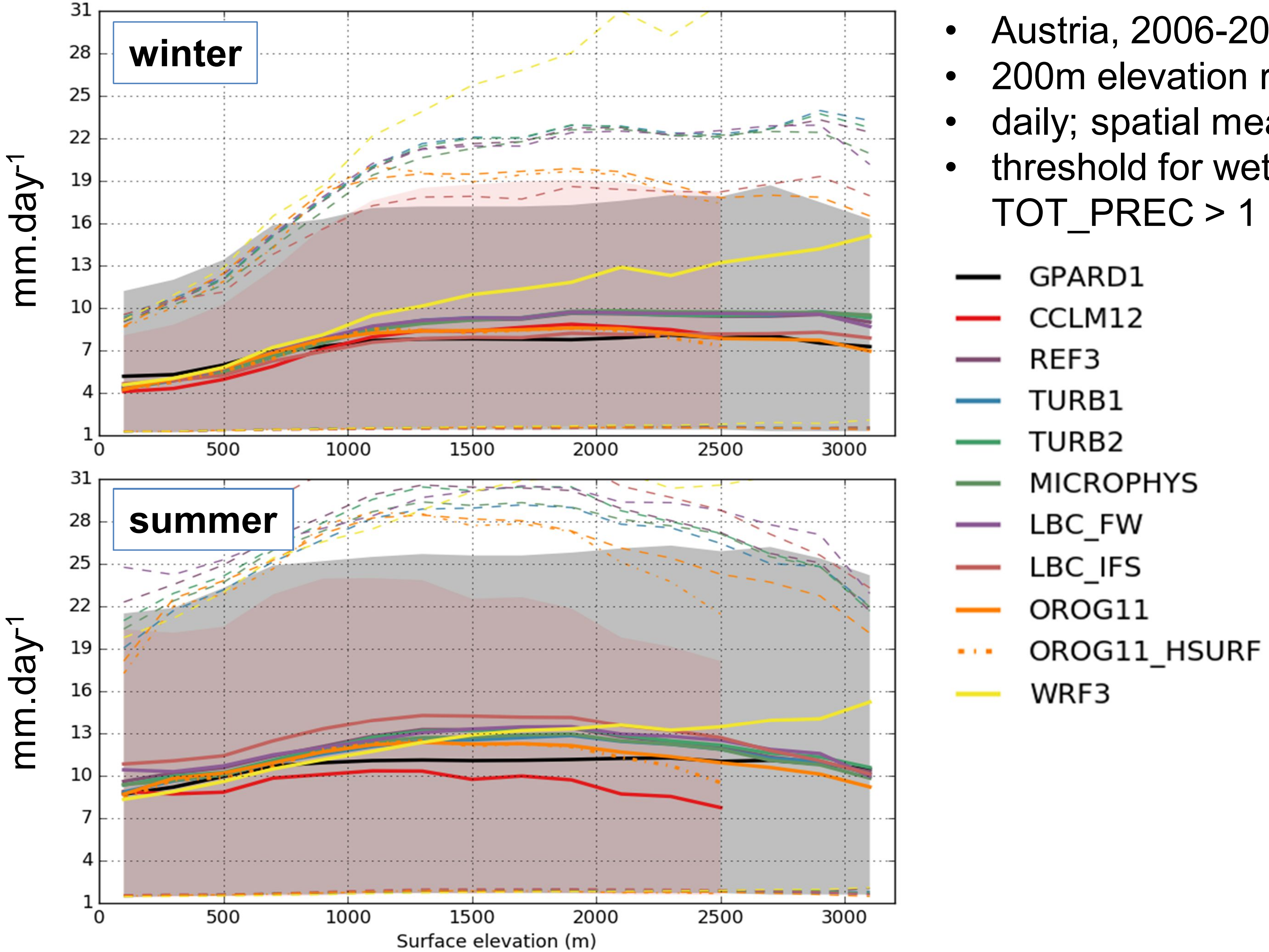


- Austria, 2006-2009
- 200m elevation ranges
- Daily; spatial mean, q10-90
- threshold for wet days: TOT_PREC > 1 $mm.day^{-1}$

GPARD1
CCLM12
REF3
TURB1
TURB2
MICROPHYS
LBC_FW
LBC_IFS
OROG11
OROG11_HSURF
WRF3

- Strong height-dependency for extreme values
- WRF3: monotone increase with atlitude
- LBC_IFS: excellent agreement

Height dependency of daily precipitation



- Austria, 2006-2009
- 200m elevation ranges
- daily; spatial mean, q10-90
- threshold for wet days: TOT_PREC > 1 mm.day^{-1}

Height dependency of daily precipitation

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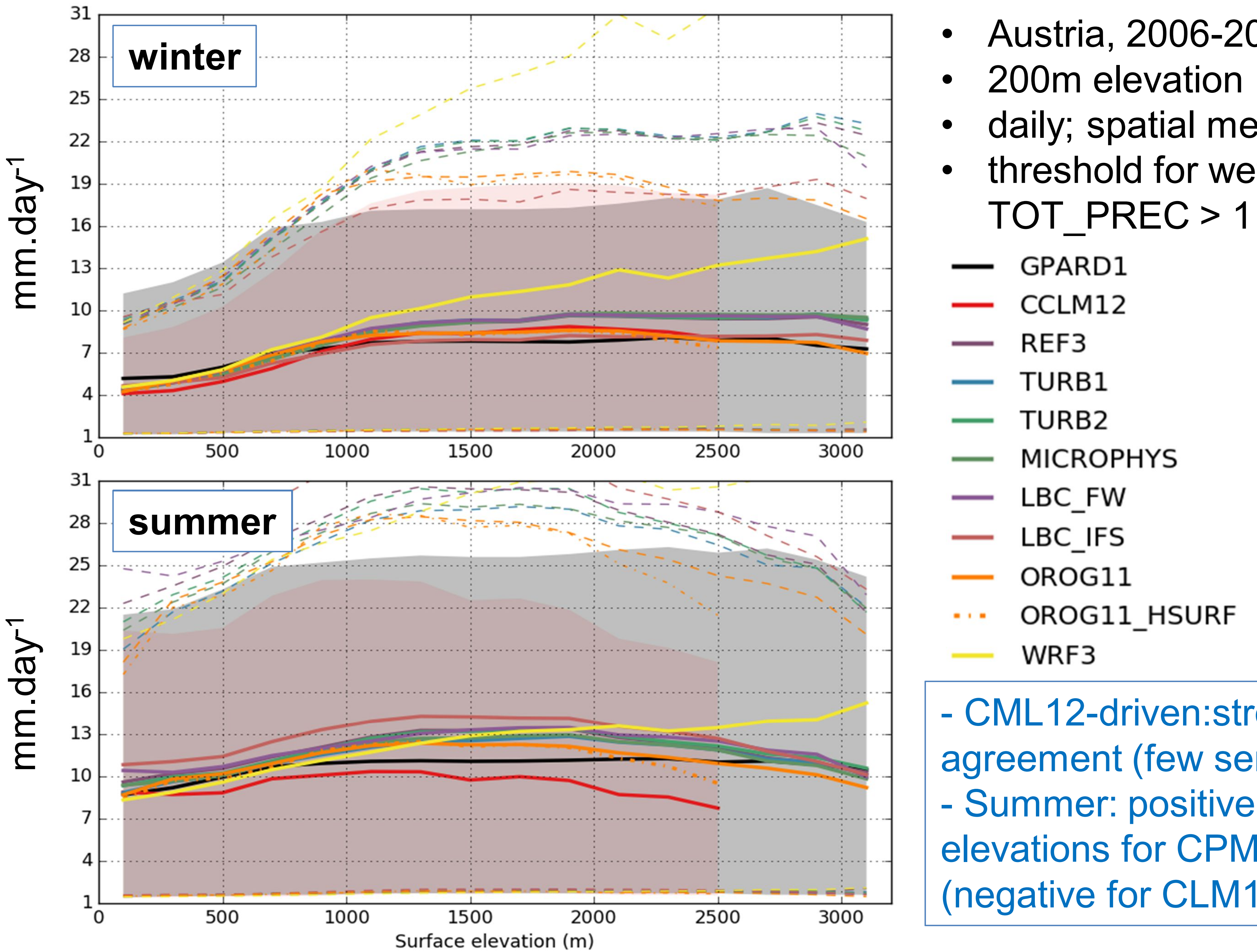
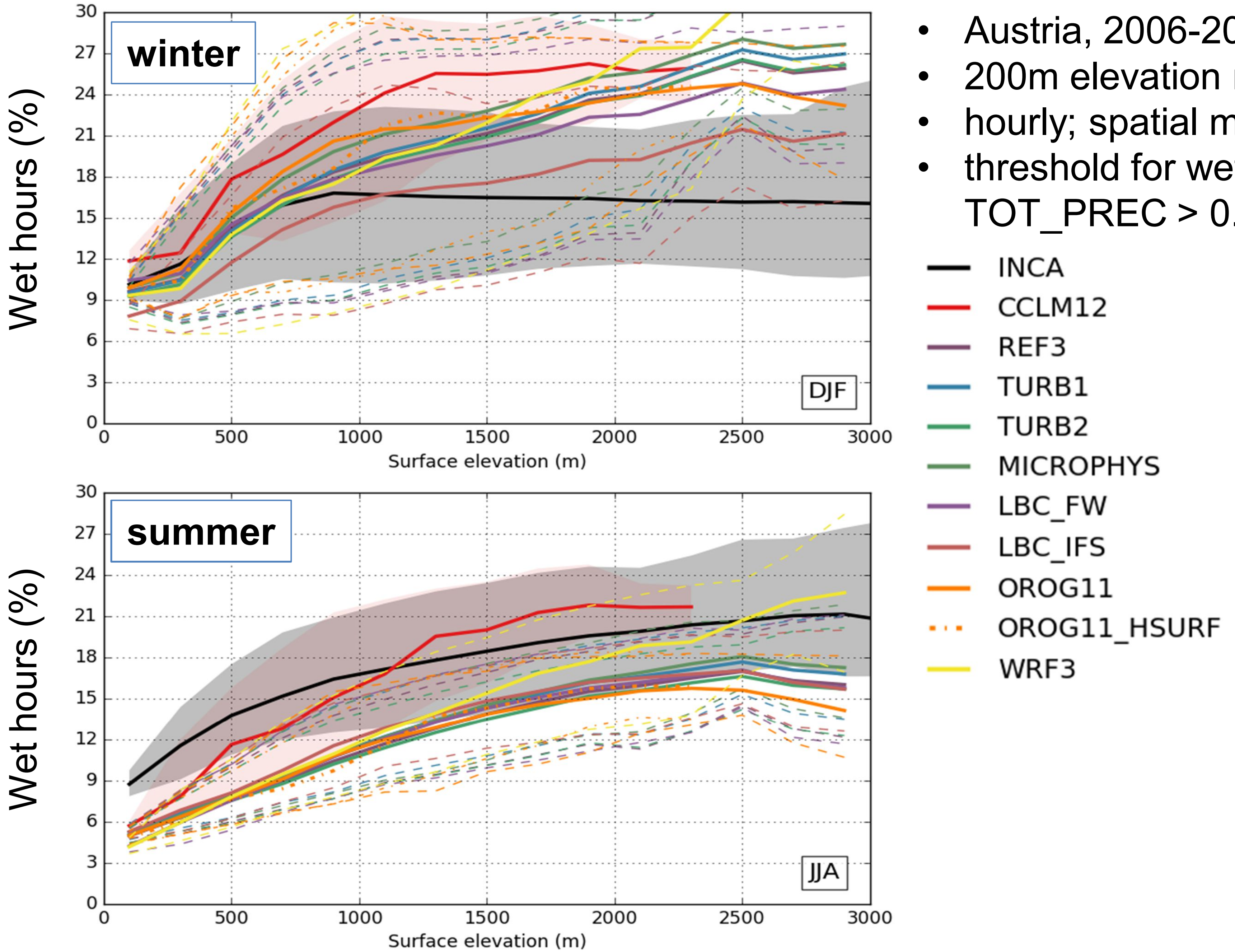


- Austria, 2006-2009
- 200m elevation ranges
- daily; spatial mean, q10-90
- threshold for wet days: TOT_PREC > 1 mm.day^{-1}

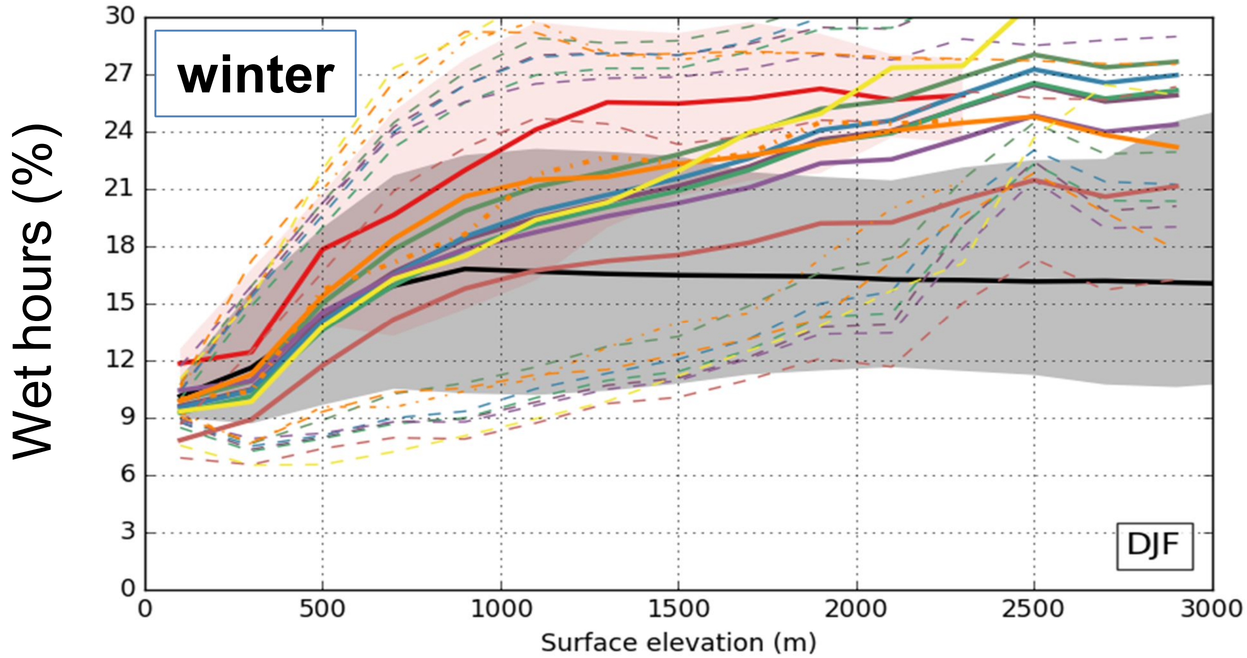
- CML12-driven:strong agreement (few sensitivity)
- Summer: positive bias at all elevations for CPM but WRF3 (negative for CLM12)

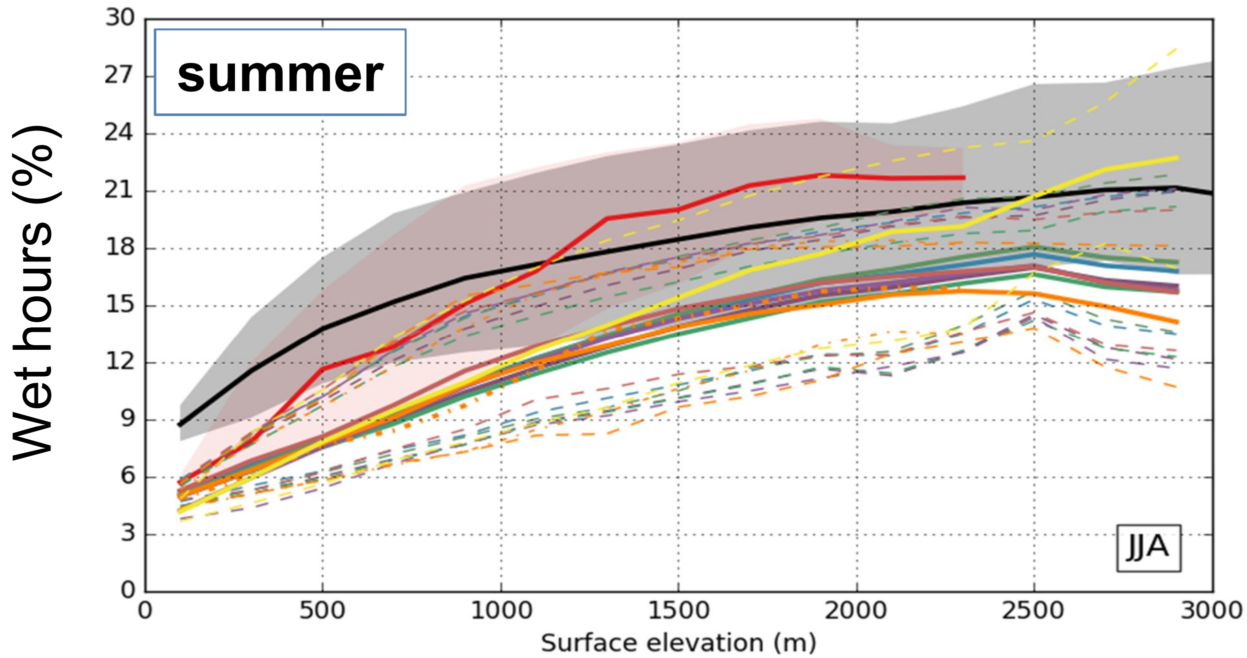
Height dependency of hourly occurence



- Austria, 2006-2009
- 200m elevation ranges
- hourly; spatial mean, q10-90
- threshold for wet days: TOT_PREC > 0.1 $mm.hour^{-1}$

Height dependency of hourly occurence



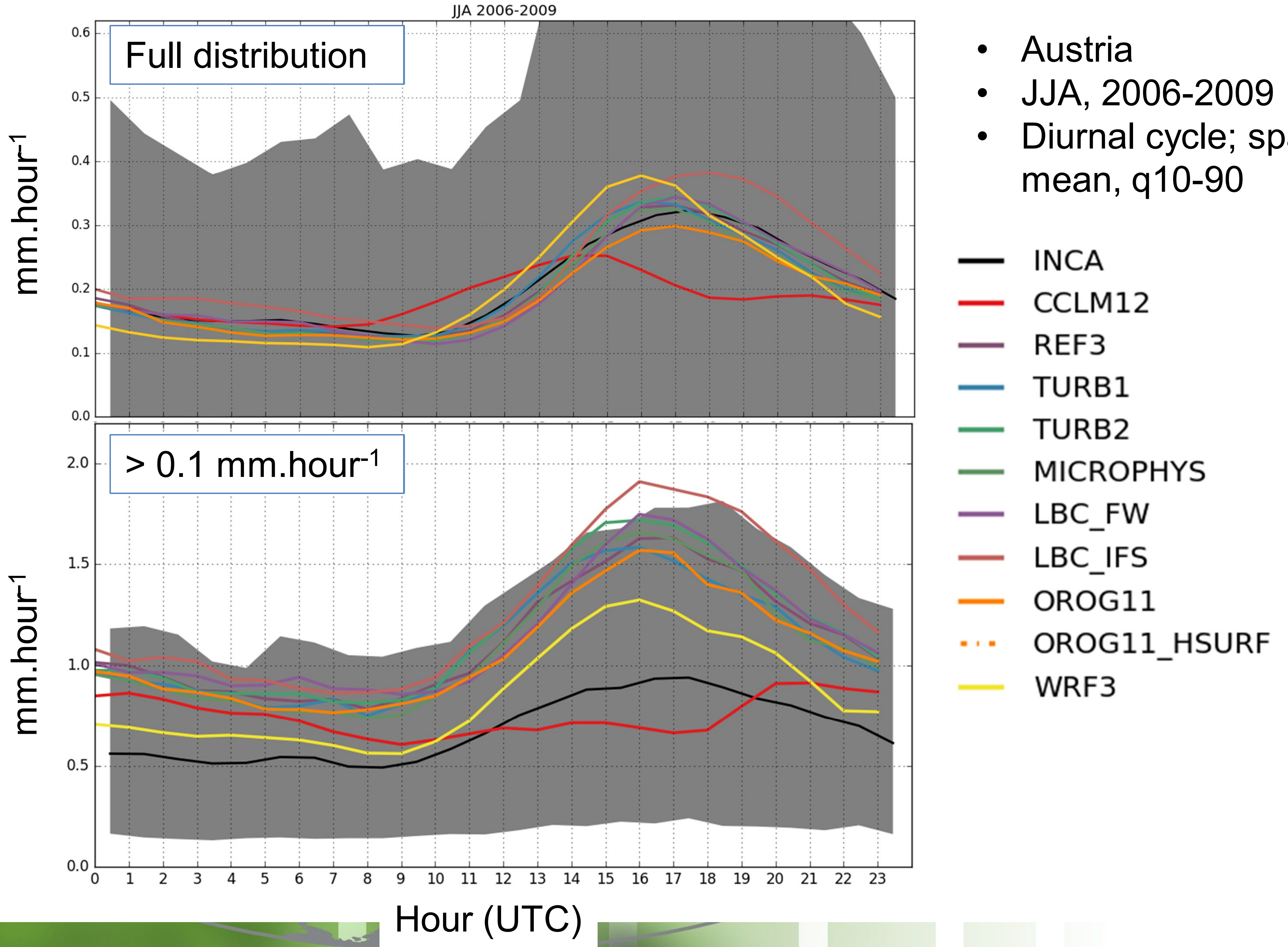


- Austria, 2006-2009
- 200m elevation ranges
- hourly; spatial mean, q10-90
- threshold for wet days: TOT_PREC > 0.1 mm.hour^{-1}

INCA
CCLM12
REF3
TURB1
TURB2
MICROPHYS
LBC_FW
LBC_IFS
OROG11
OROG11_HSURF
WRF3

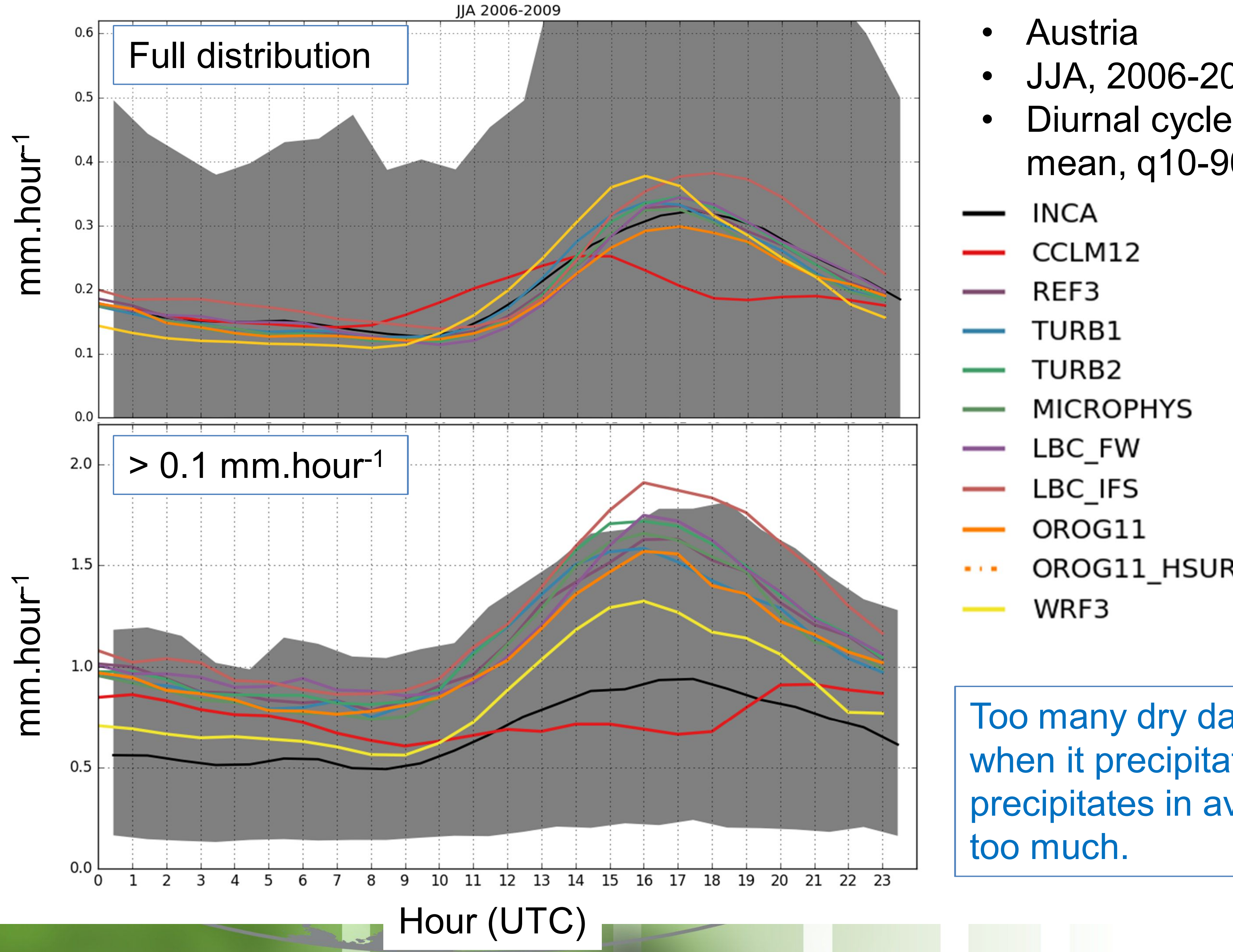
In summer: out of the range of observed variability of occurrence in low-land.

The afternoon peak of precipitation in summer



- Austria
- JJA, 2006-2009
- Diurnal cycle; spatial mean, q10-90

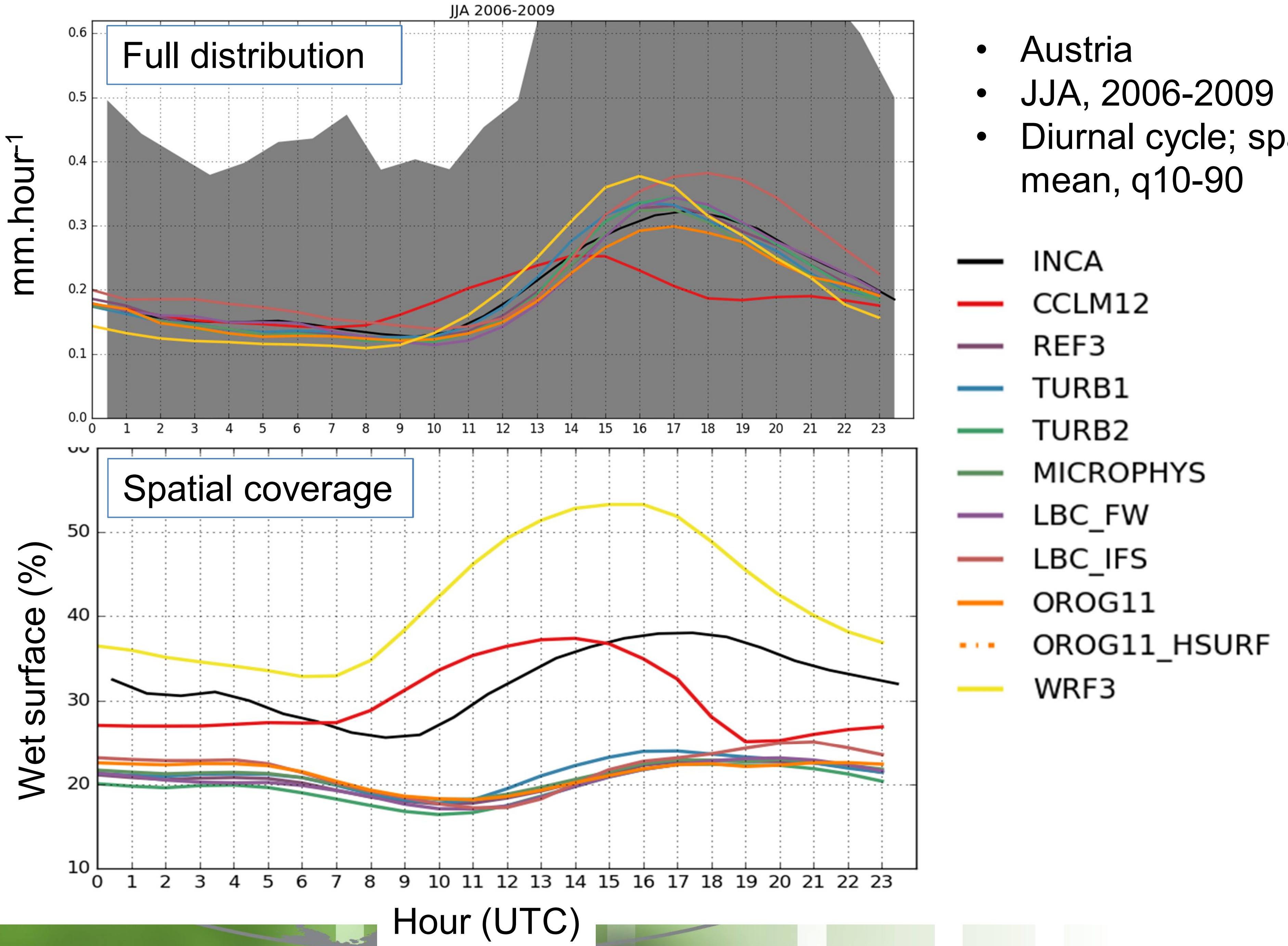
The afternoon peak of precipitation in summer



- Austria
- JJA, 2006-2009
- Diurnal cycle; spatial mean, q10-90

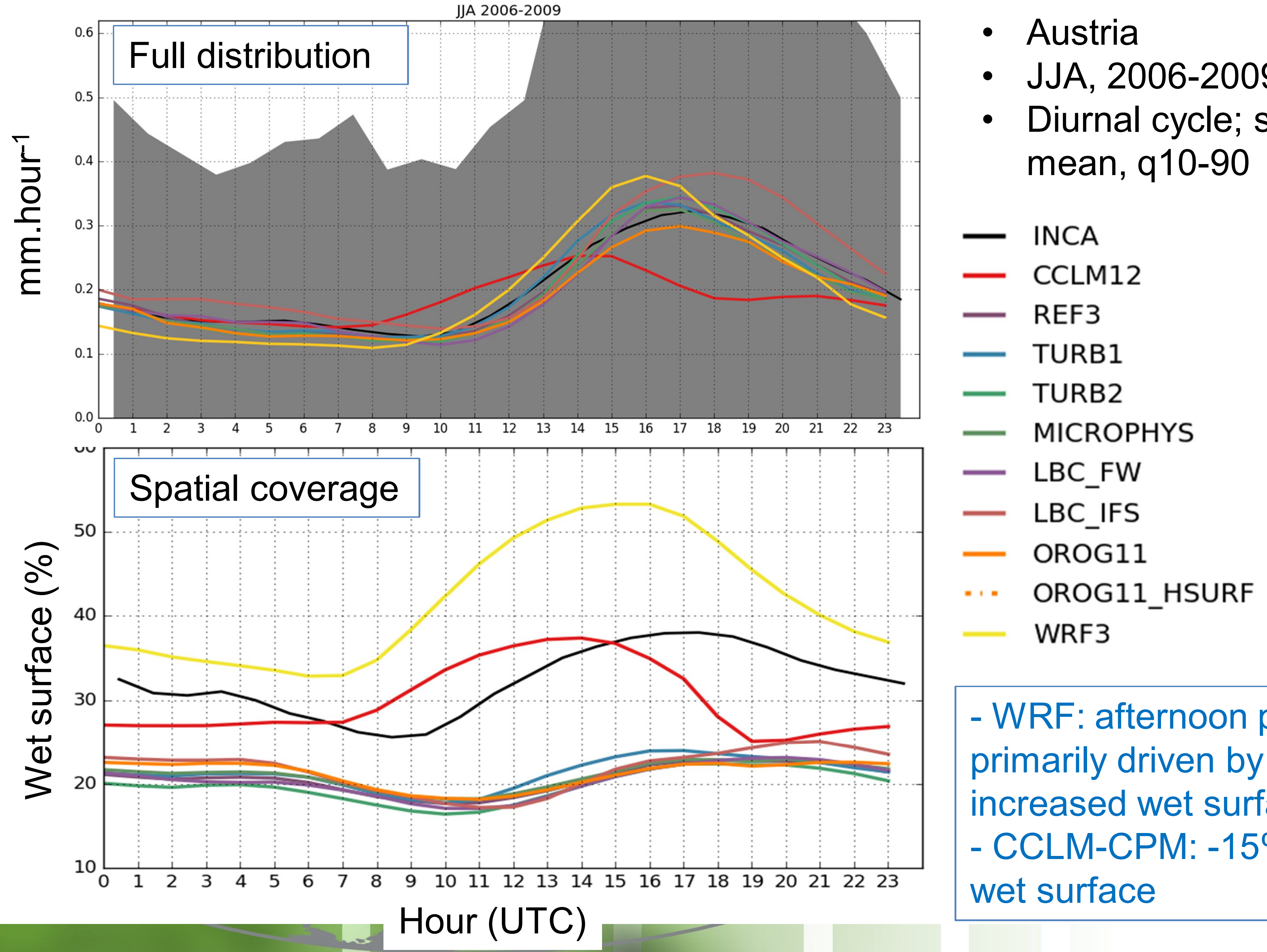
Too many dry days; but when it precipitates, it precipitates in average too much.

The afternoon peak of precipitation in summer



- Austria
- JJA, 2006-2009
- Diurnal cycle; spatial mean, q10-90

The afternoon peak of precipitation in summer



- Austria
- JJA, 2006-2009
- Diurnal cycle; spatial mean, q10-90

- WRF: afternoon peak primarily driven by increased wet surface
- CCLM-CPM: -15% of wet surface

The afternoon peak of precipitation in summer

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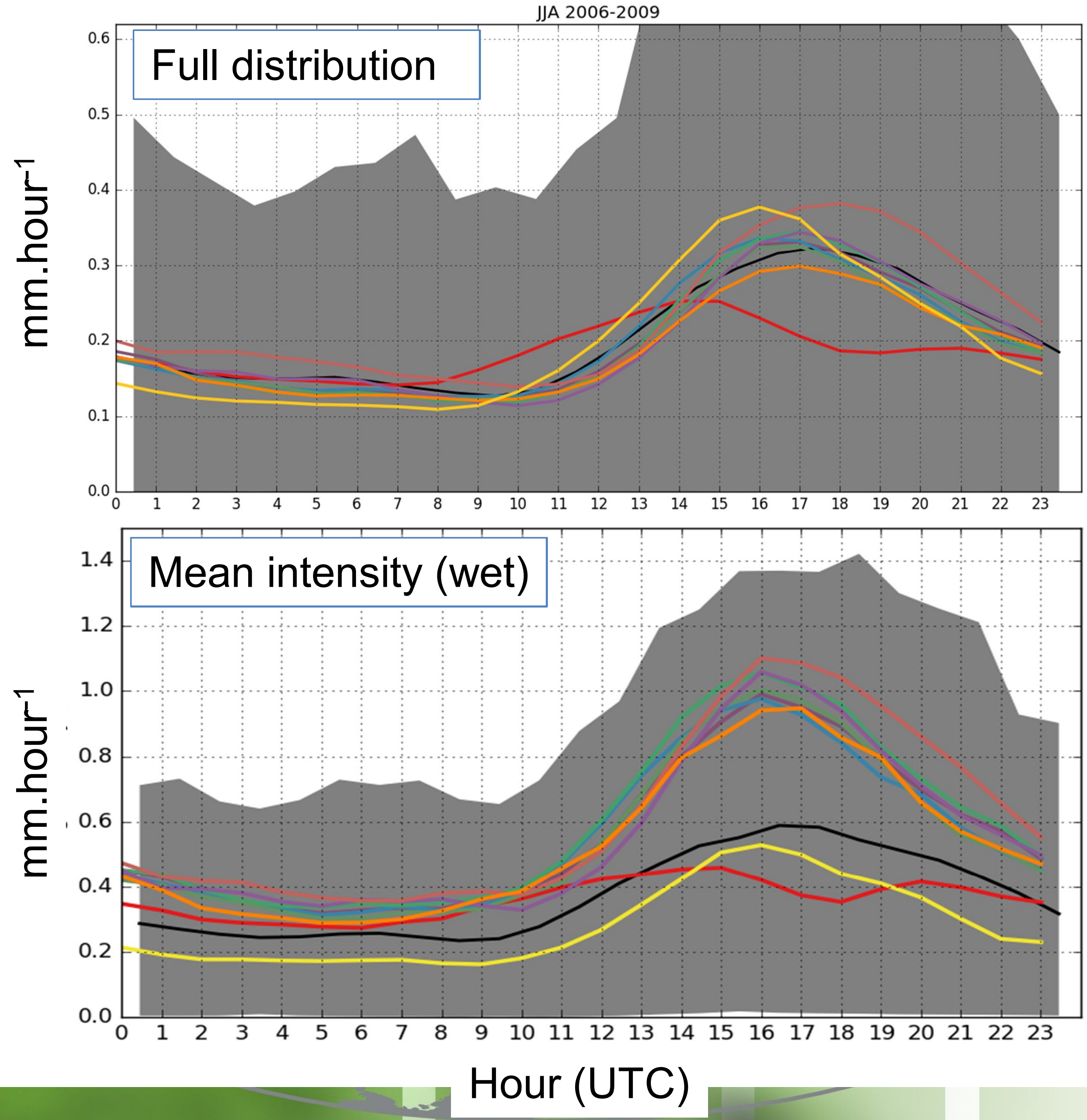
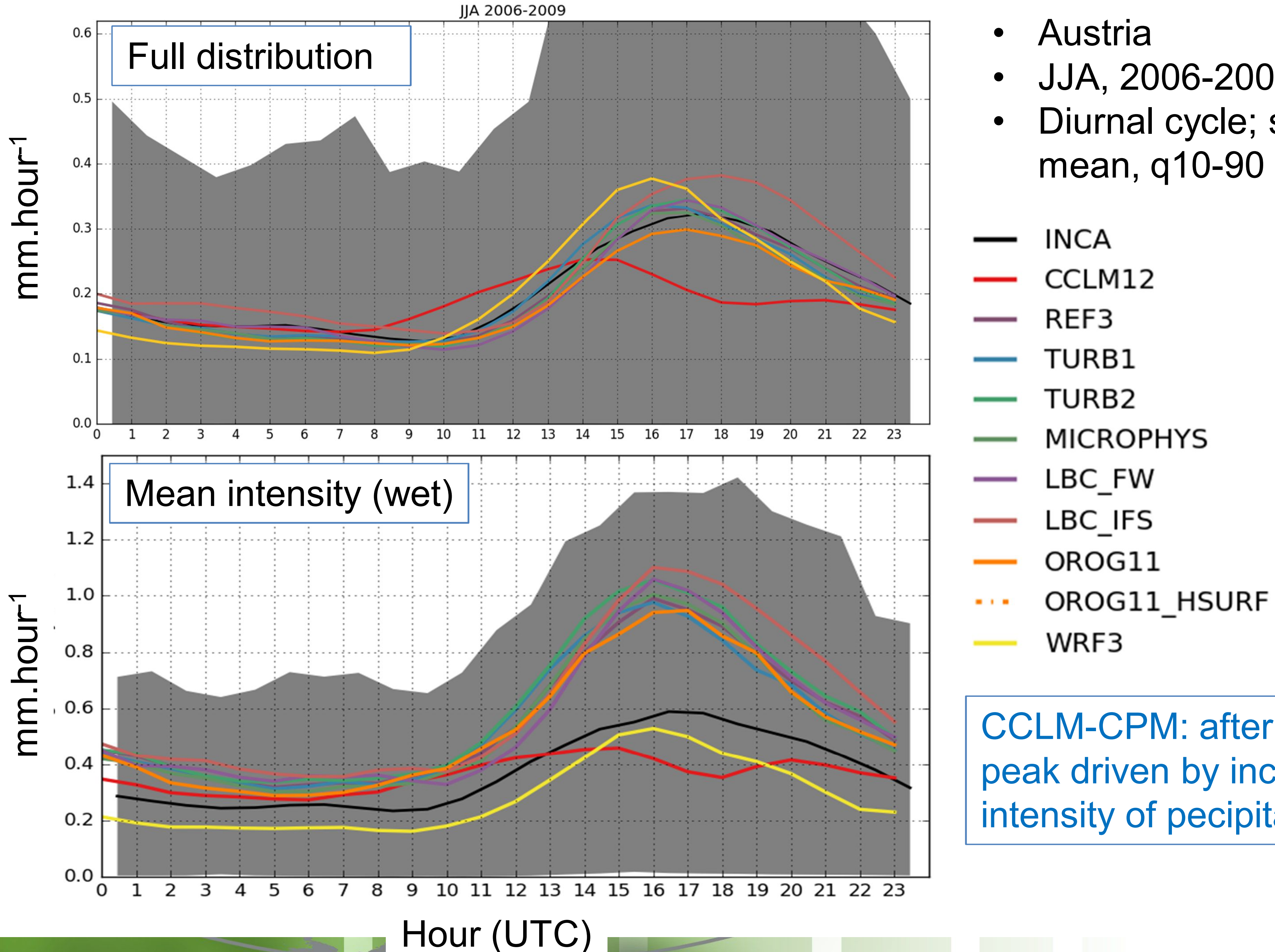
- Austria
- JJA, 2006-2009
- Diurnal cycle; spatial mean, q10-90



The afternoon peak of precipitation in summer



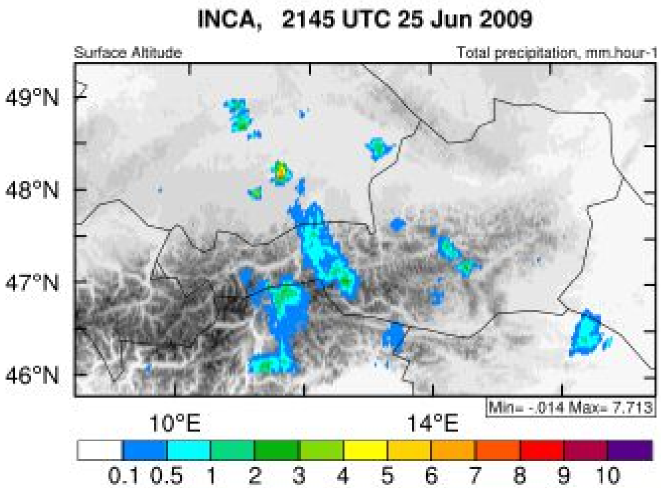
- Austria
- JJA, 2006-2009
- Diurnal cycle; spatial mean, q10-90

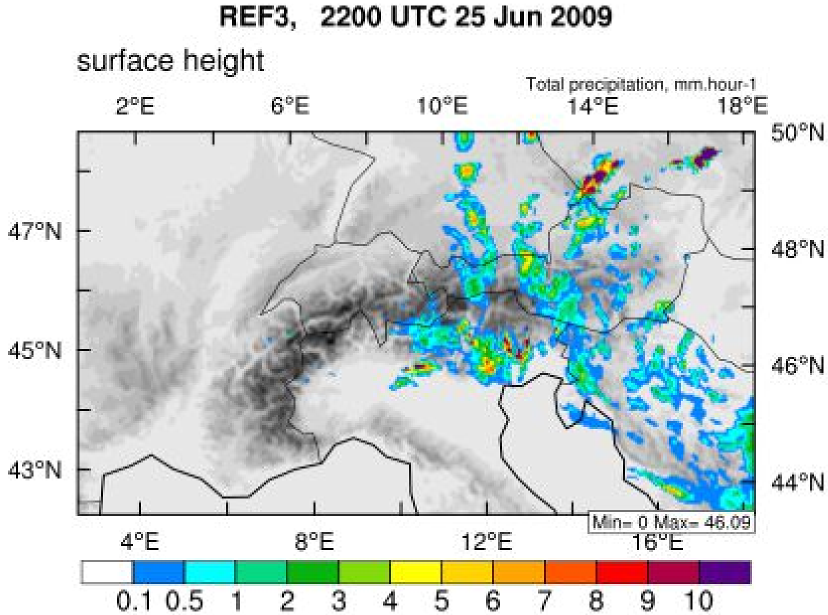
CCLM-CPM: afternoon peak driven by increased intensity of pecipitation

Event-based analysis

- Obs: INCA
- June 26th, 2009
- Intense precipitation event

- Expe: **REF3**
- Model domain

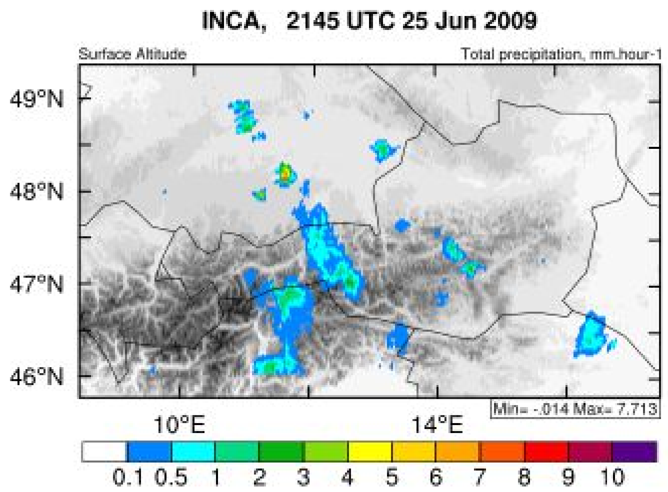


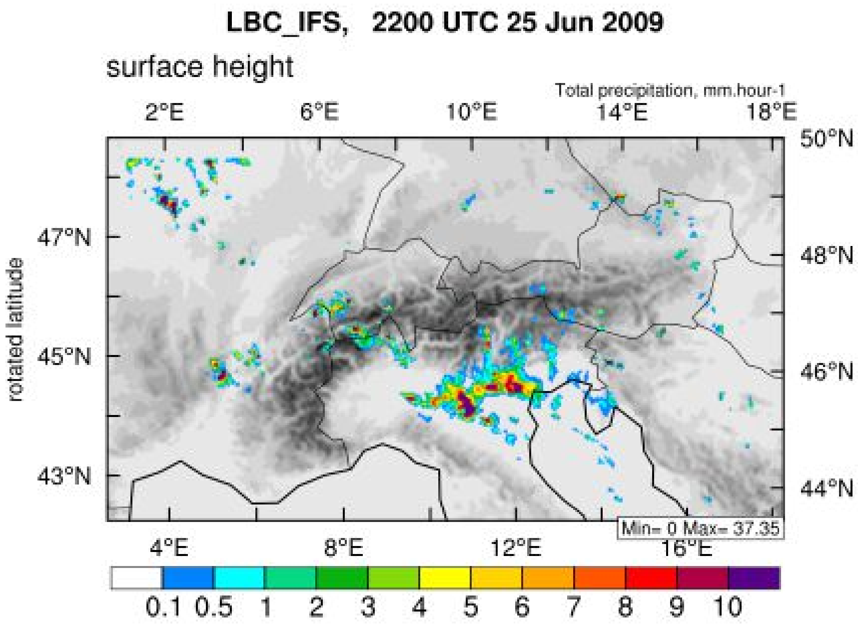


Event-based analysis

- Obs: INCA
- June 26th, 2009
- Intense precipitation event

- Expe: **LBC_IFS**
- Model domain

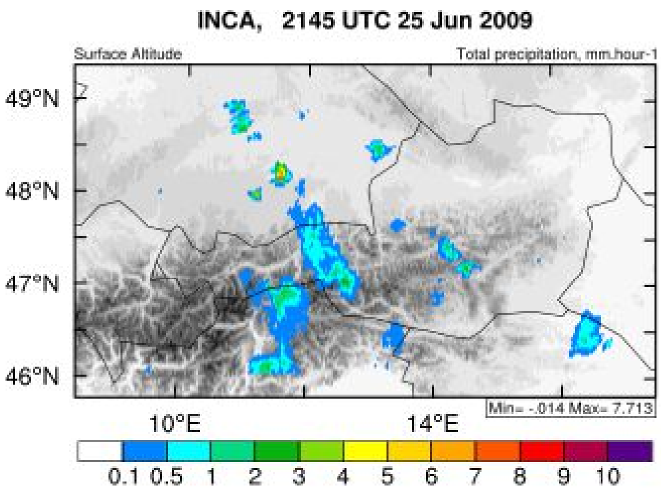


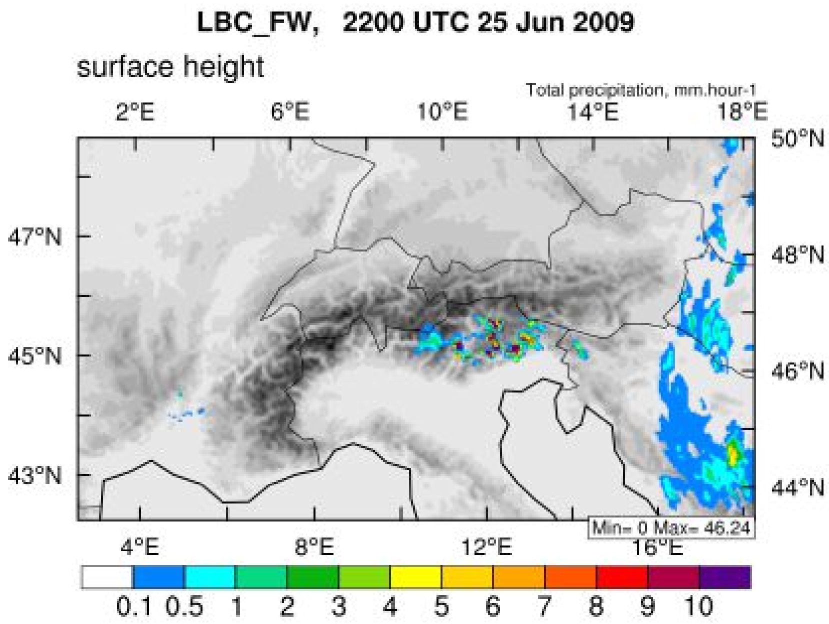


Event-based analysis

- Obs: INCA
- June 26th, 2009
- Intense precipitation event

- Expe: **LBC_FW**
- Model domain

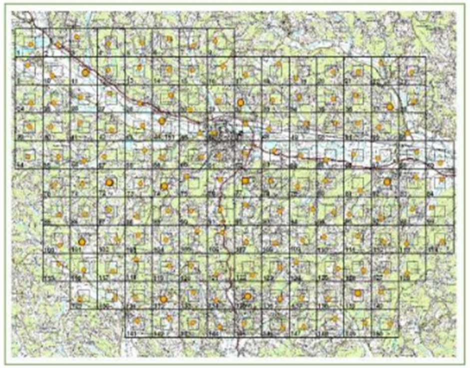




Verification metrics with the WegenerNet

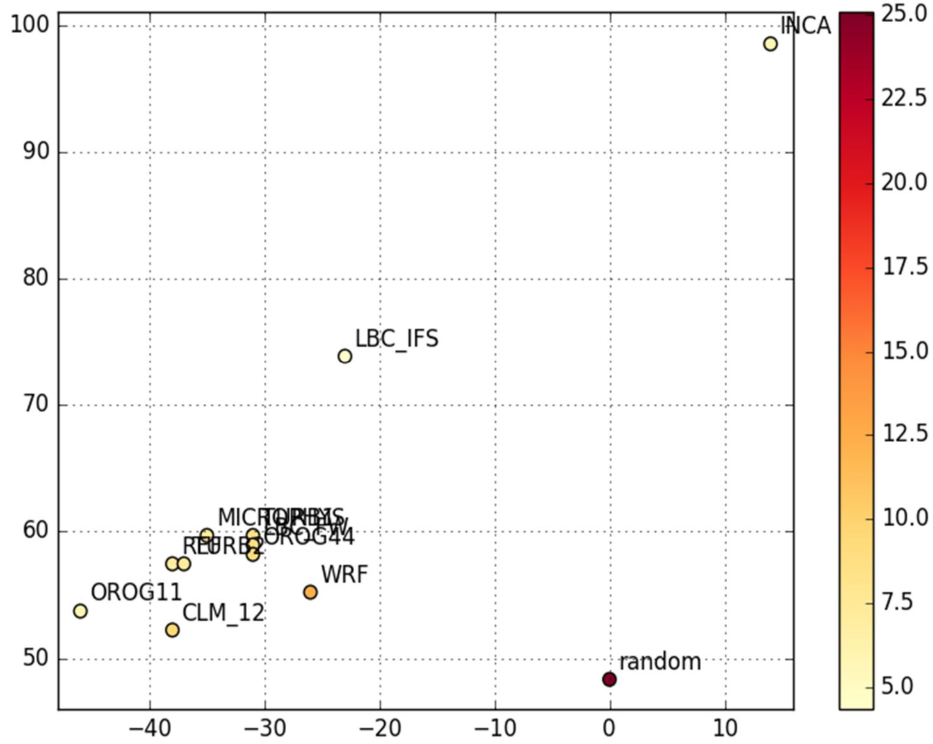
- Indices for verification of occurrence of precipitation
  - Total number of wet days
  - Number of **captured** wet days (observed and simulated)
  - Number of **missed** wet days (observed but not simulated)
  - Number of **false alarm** (simulated but not observed)
- Wet days definition (account for double-penalty problem): at least one wet hour (> 0.1 mm.hour $^{-1}$)

The WegenerNet stations network



From Kirchengast et al. 2008

Captured (% of total observed)



False alarm (% of total wet days)

Difference of the number of wet days simulated and observed

Conclusions

Added-value for CLM3 and CLM12 consistently verified

- for sub-daily scales and strong precipitation

Evaluation for winter and summer

- Winter: (still) too strong interaction of the large-scale flow with the orography
- Summer: CCLM and WRF lead to similarly good representation of the mean diurnal cycle, but with distinct processes:
  - WRF produces larger areas of less intense precipitation
  - CCLM produces smaller but more intense precipitation (more peaked)

Role of the driving data:

- Strong agreement between the simulations driven with CLM12
  - sensitivity to the parameters tested for turbulence and microphysics << sensitivity to the LBCs
- internal variability of the driving simulation (1st nest)
- IFS as driving data improves the event-based comparison
- condition for verification strategy and event-based analyses

References

- Prein , A. F., Rasmussen, R., & Stephens, G. (2017): Challenges and Advances in Convection-Permitting Climate Modeling. BAMS, doi: 10.1175/BAMS-D-16-0263.1.
- Prein, A. F., Langhans, W., Fosser, G., Ferrone, A., Ban, N., Goergen, K., ... & Brisson, E. (2015). A review on regional convection-permitting climate modeling: Demonstrations, prospects, and challenges. Reviews of geophysics, 53(2), 323-361.
- Ban, N., Schmidli, J., & Schär, C. (2014). Evaluation of the convection-resolving regional climate modeling approach in decade-long simulations. Journal of Geophysical Research: Atmospheres, 119(13), 7889-7907.
- Kirchengast, G., T. Kabas, A. Leuprecht, C. Bichler, and H. Truhetz (2014): WegenerNet: A pioneering high-resolution network for monitoring weather and climate. BAMS, 95, 227-242, doi:10.1175/BAMS-D-11-00161.1
- Haiden, T., A. Kann, C. Wittmann, G. Pistotnik, B. Bica, and C. Gruber (2011): The Integrated Nowcasting through Comprehensive Analysis (INCA) System and Its Validation over the Eastern Alpine Region, Wea. Forecasting, 26, 2, 166-183, doi: 10.1175/2010WAF2222451.1

HighEnd:Extremes project powered by klima+energie fonds

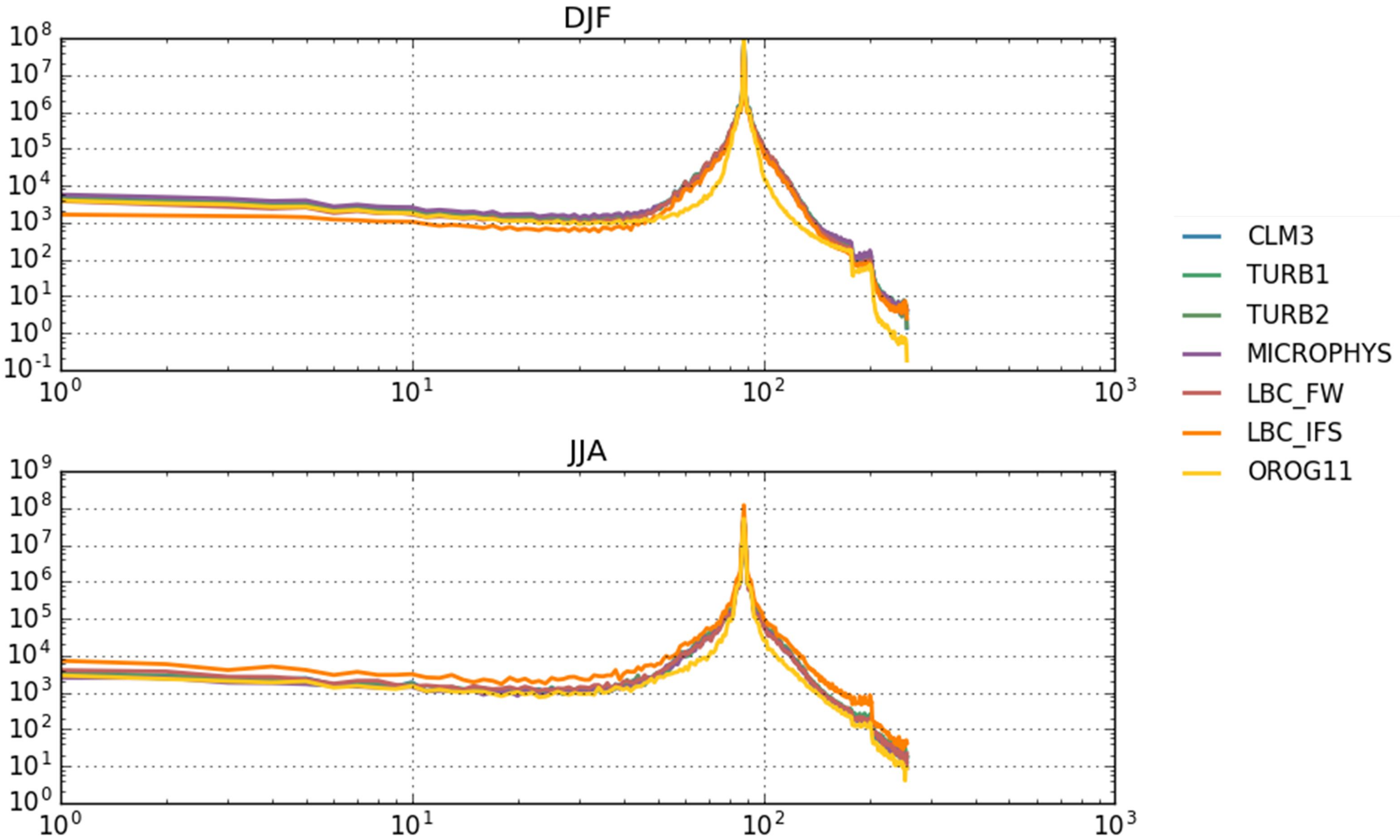
NHCM-2 project FWF Der Wissenschaftsfonds.

Acknowledgments:

The computational results presented have been achieved in part using the Vienna Scientific Cluster (VSC). The authors gratefully acknowledge the computing time granted on the supercomputers JUROPA and JURECA at Jülich Supercomputing Centre (JSC).

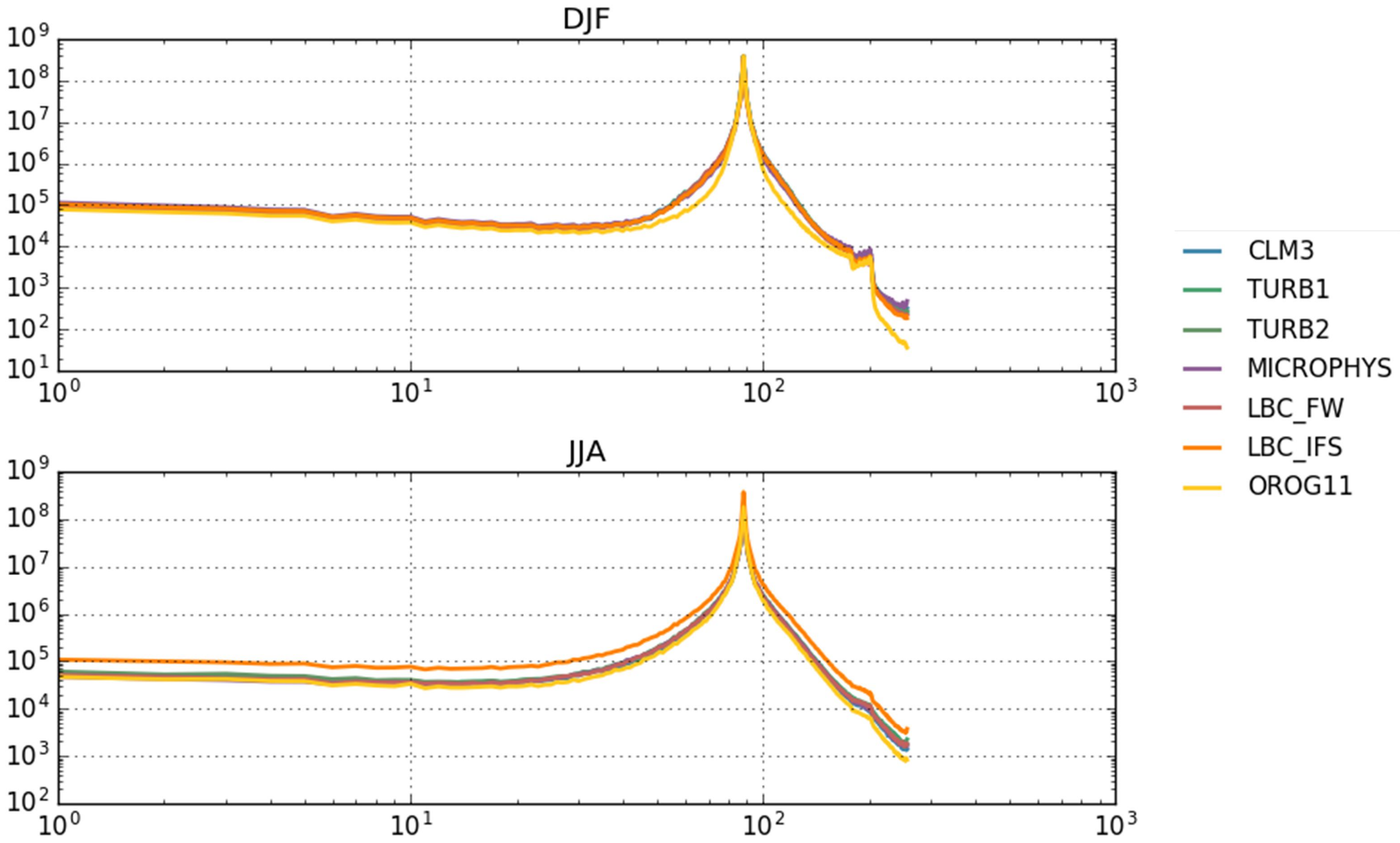
Supplementary materials

Spatial power spectrum of seasonal precipitation



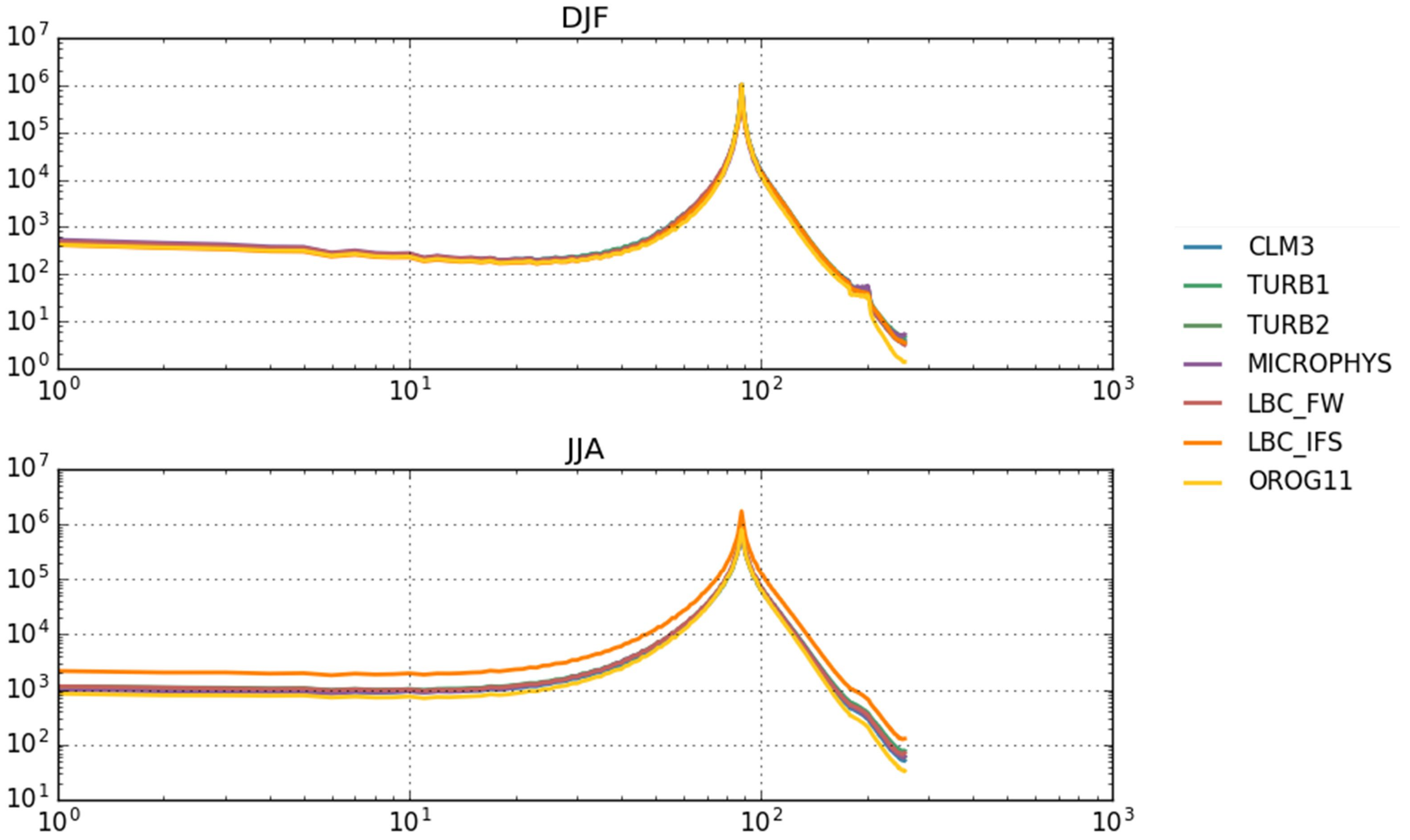
Number of grid points

Spatial power spectrum of daily precipitation



Number of grid points

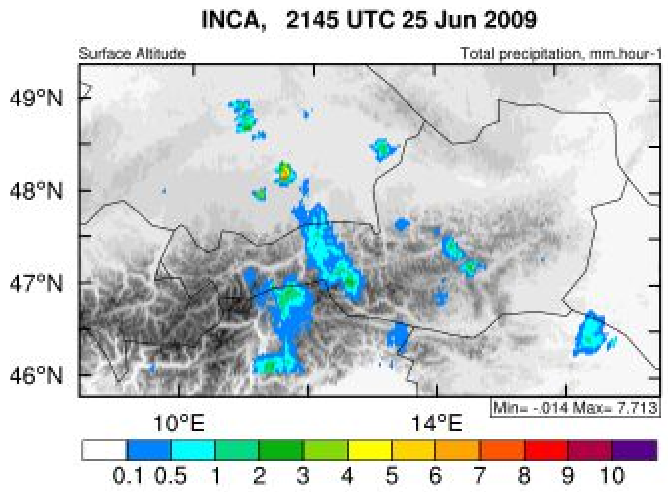
Spatial power spectrum of hourly precipitation



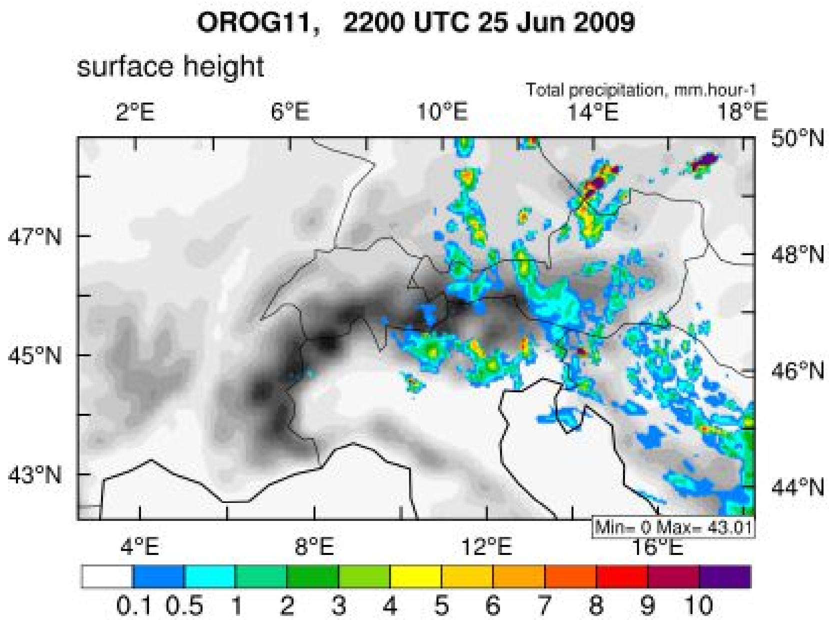
Number of grid points

Event-based analysis

- Obs: INCA
- June 26th, 2009
- Intense precipitation event



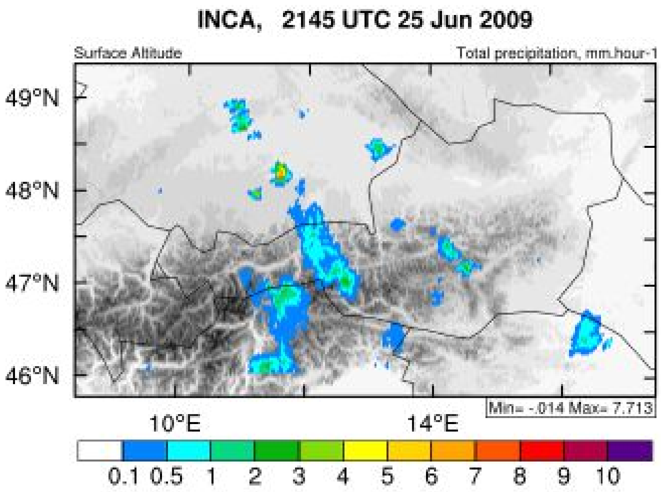
- Expe: **OROG11**
- Model domain

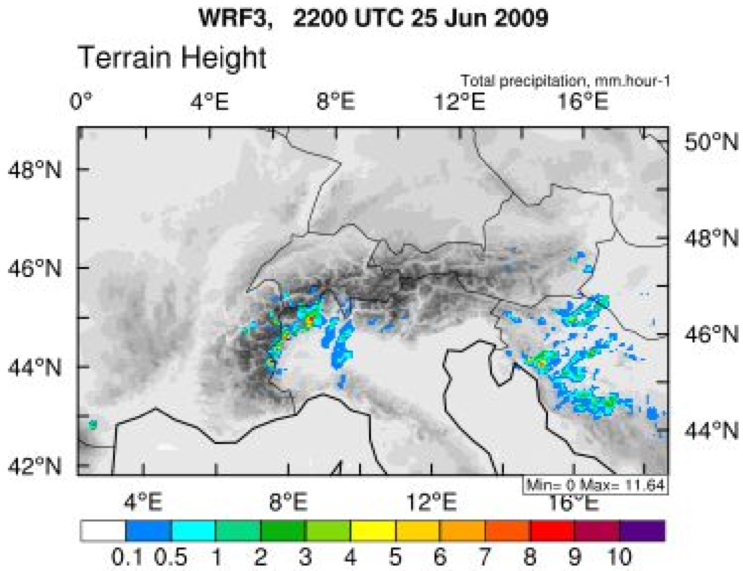


Event-based analysis

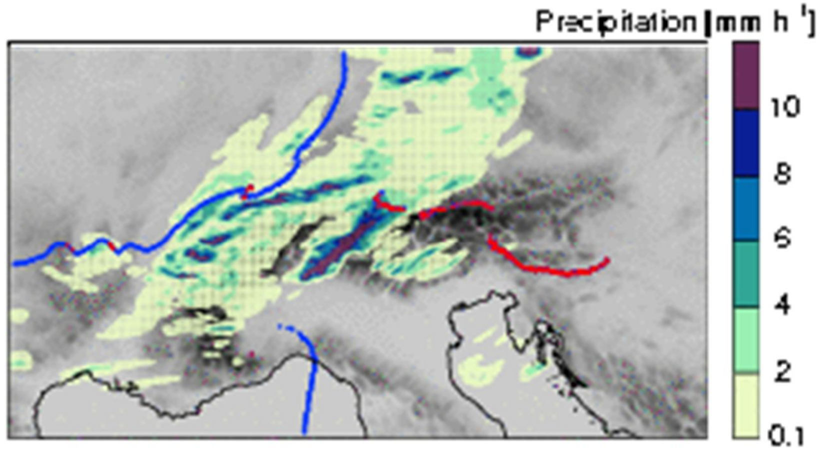
- Obs: INCA
- June 26th, 2009
- Intense precipitation event

- Expe: **WRF3**
- Model domain

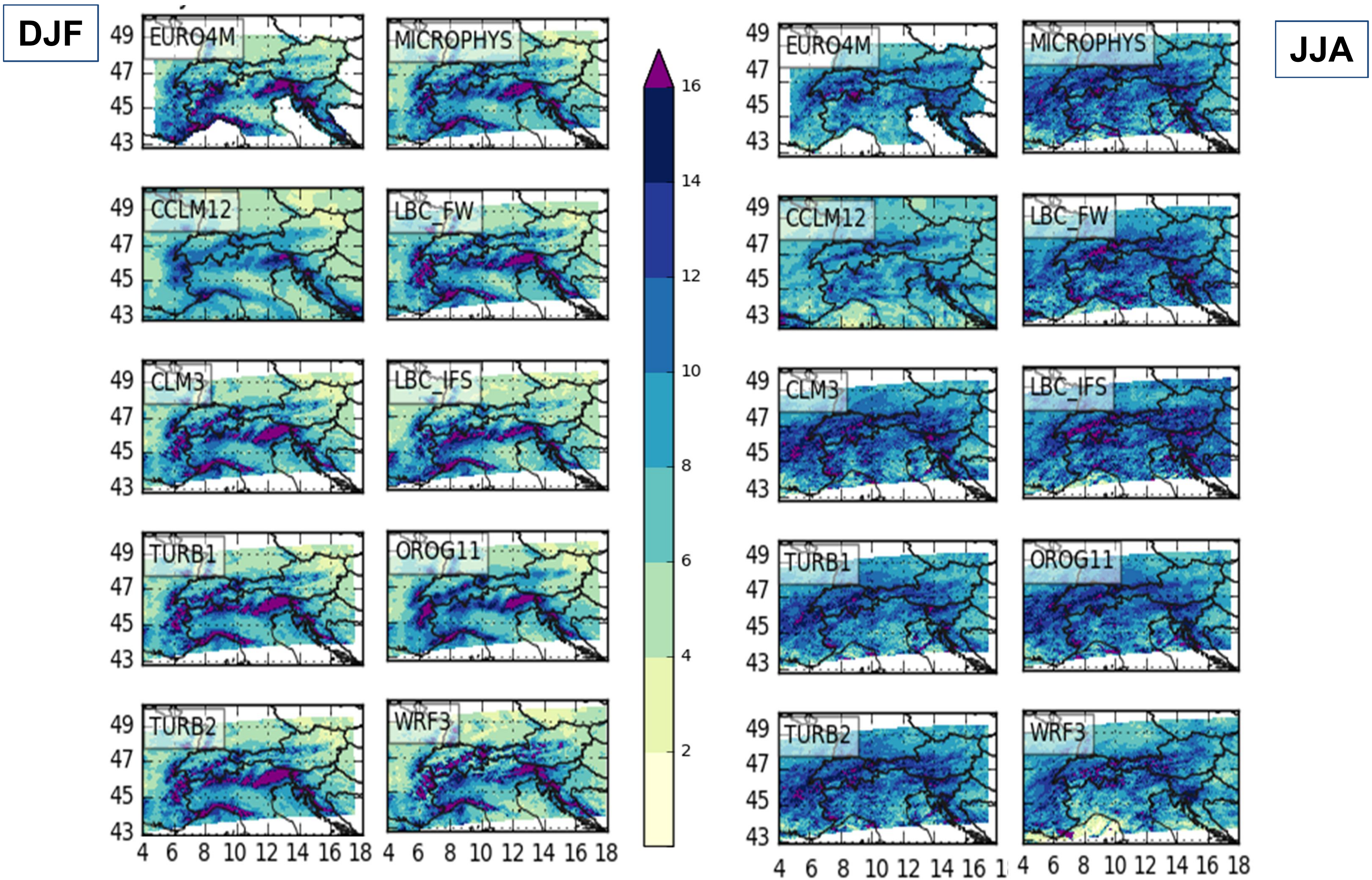




Fronts IFS and IFS-driven
2007 event, Sept. 18th
Front detection algorithm



Spatial distribution of daily sum vs. EURO4M

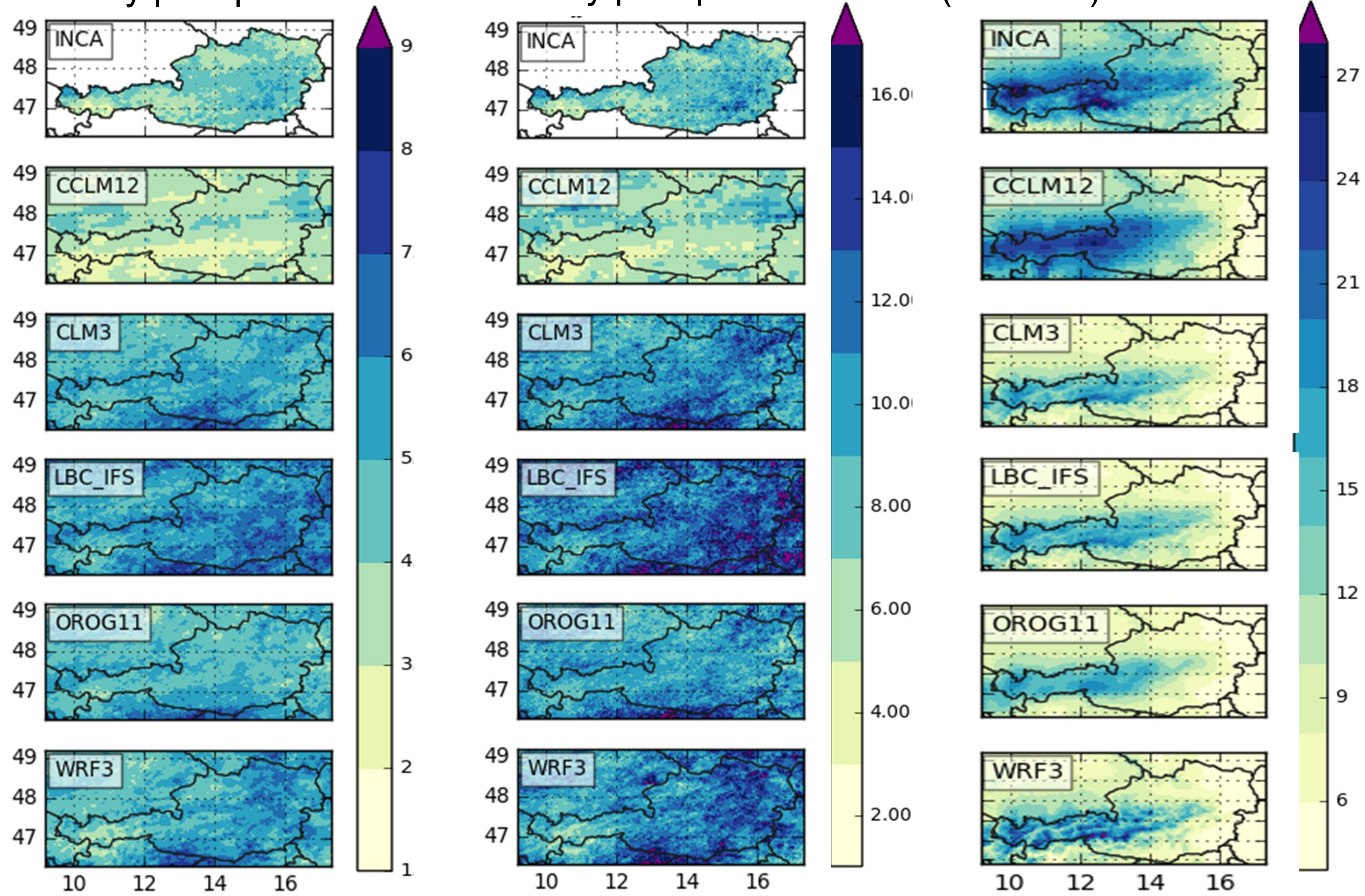


JJA hourly precip vs. INCA

Mean of daily maximum of hourly precipitation

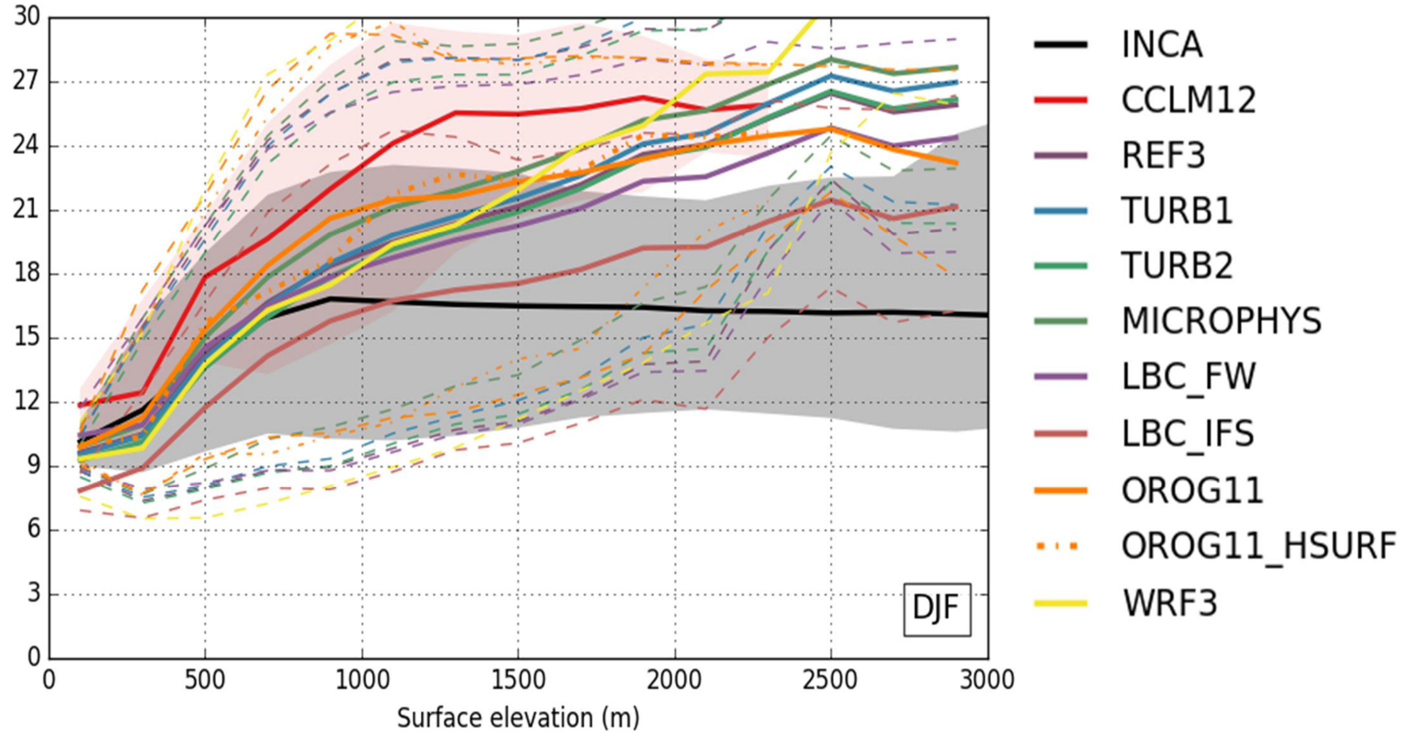
Stddev of daily maximum of hourly precipitation

Freq occ of wet hours (>0.1mm)

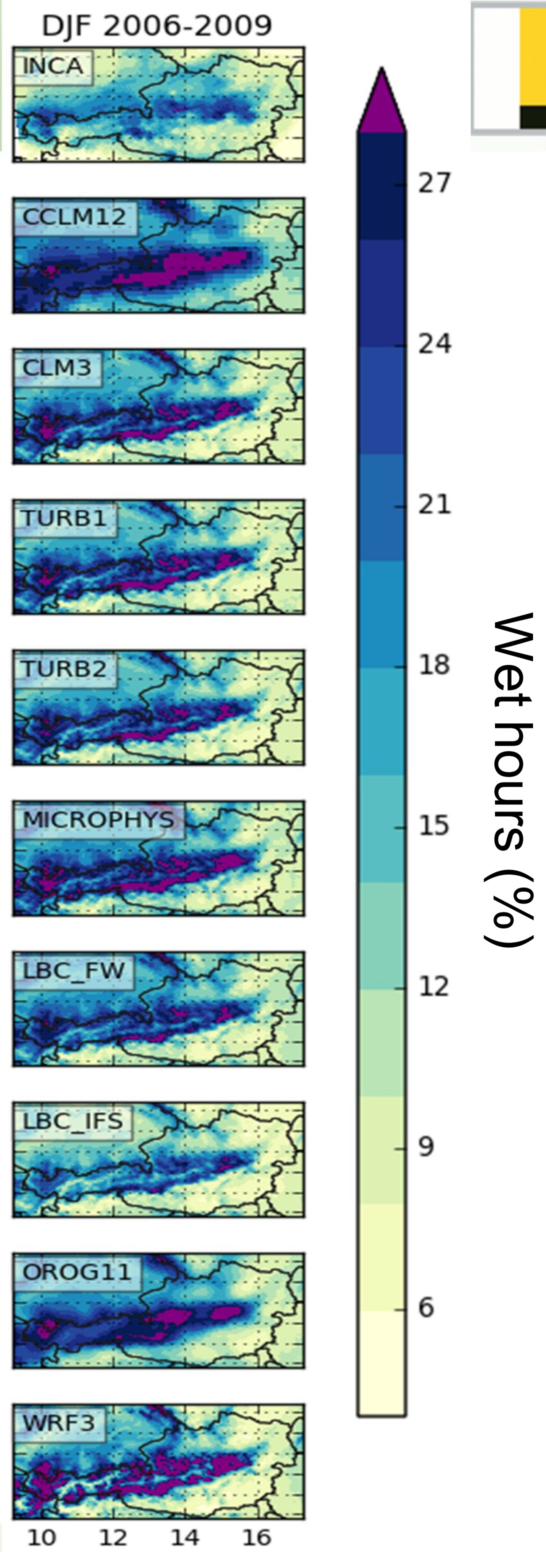


Height dependency Freq. Occ. - Winter

threshold:
TOT_PREC > 0.1 mm.hour^{-1}

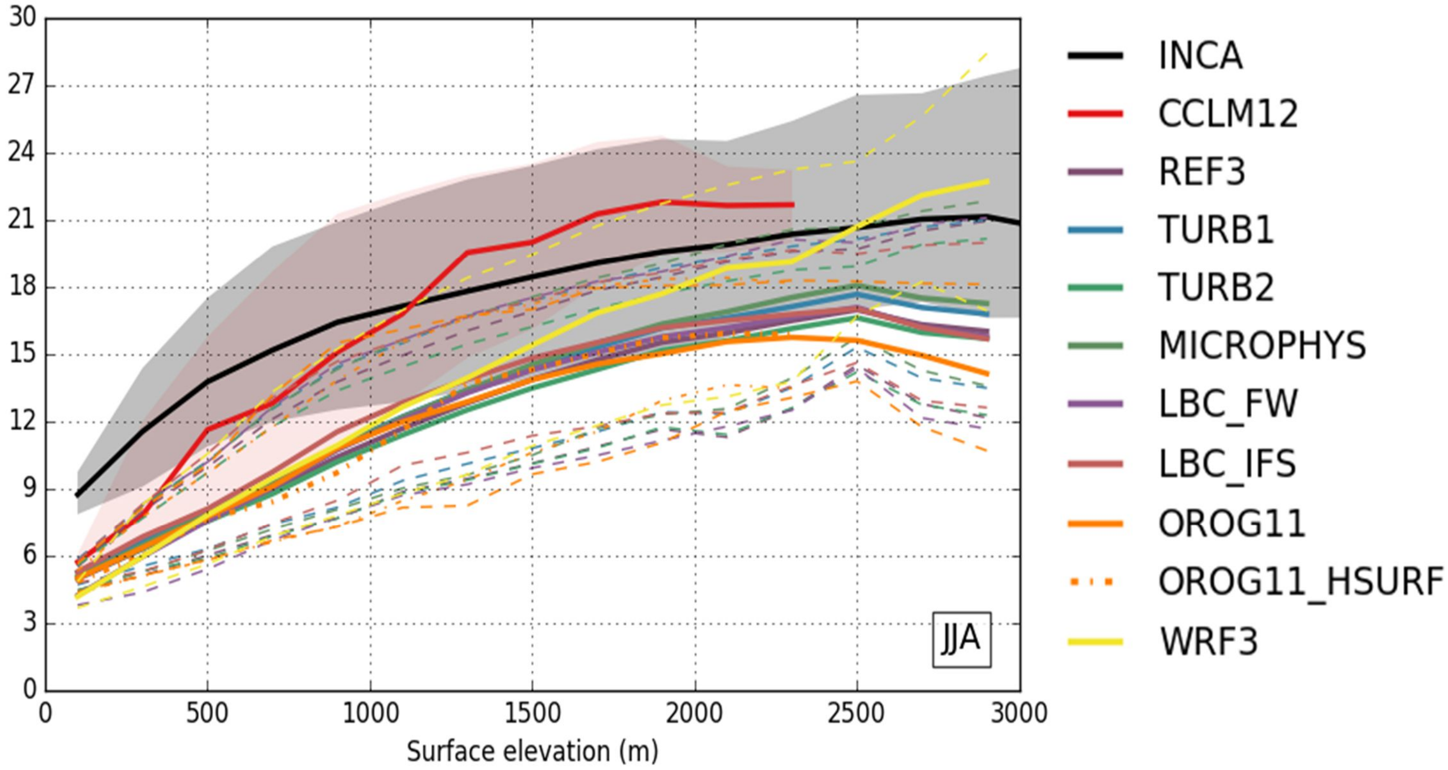


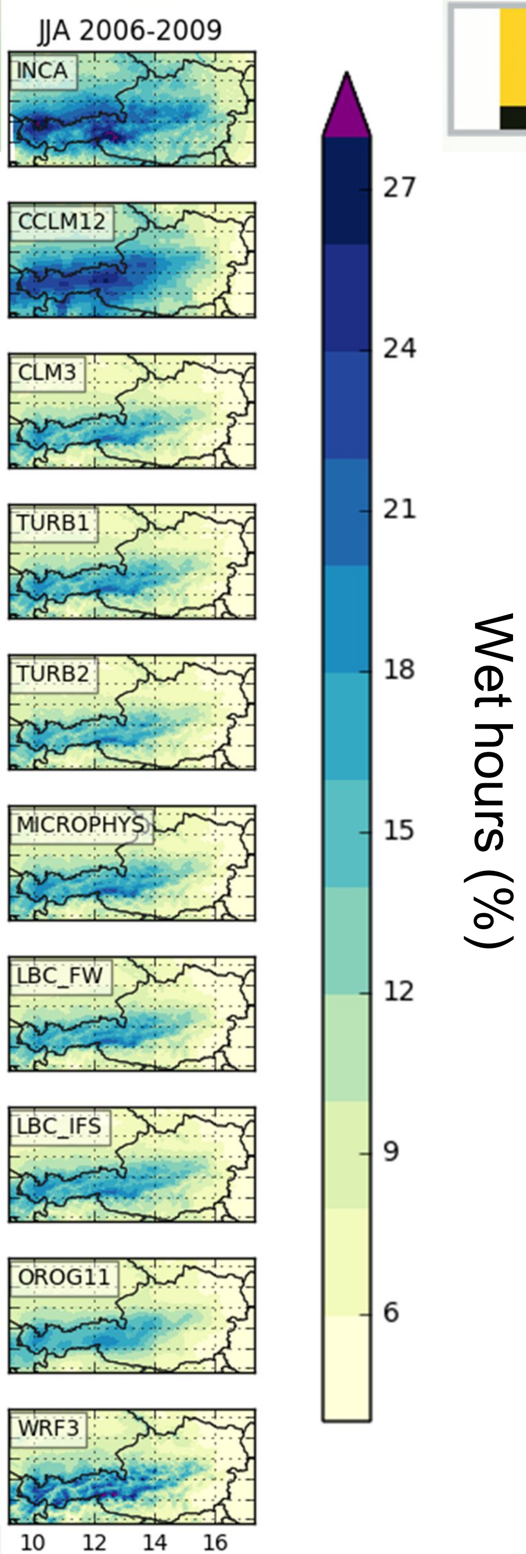
Contrast low-land / mountains



Height dependency Freq. Occ. - Summer

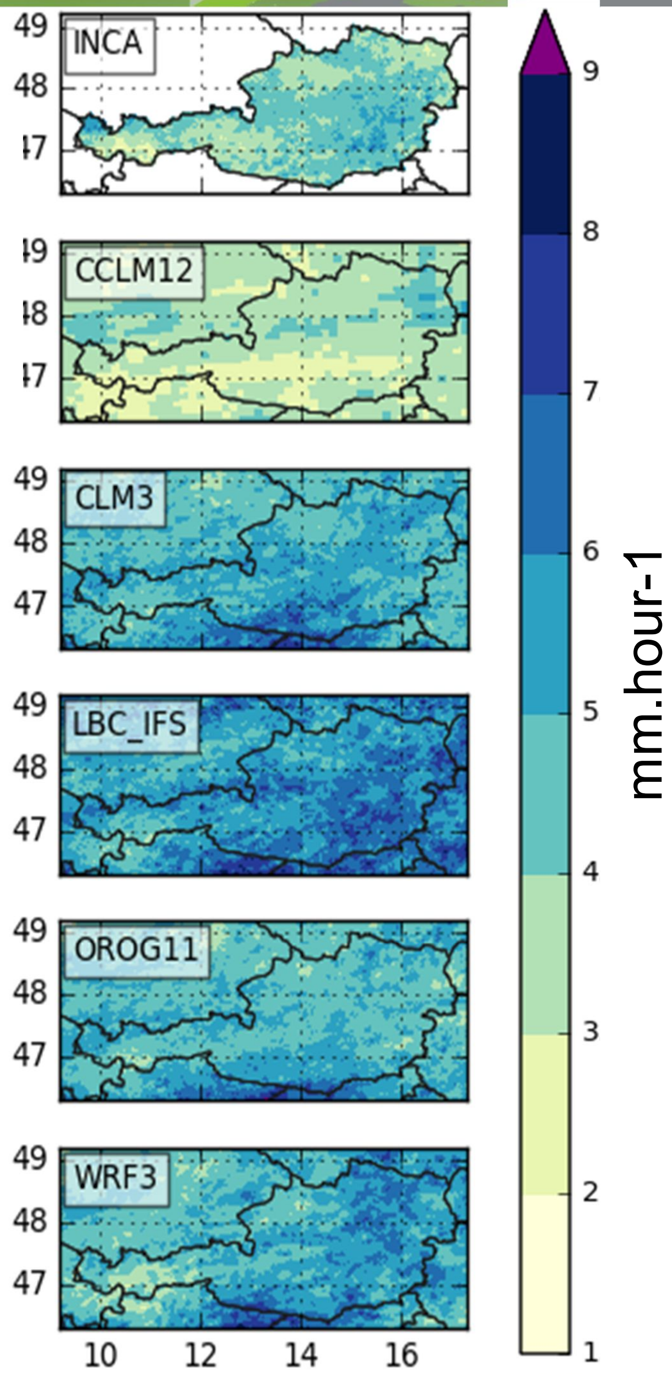
threshold:
TOT_PREC > 0.1 mm.hour^{-1}

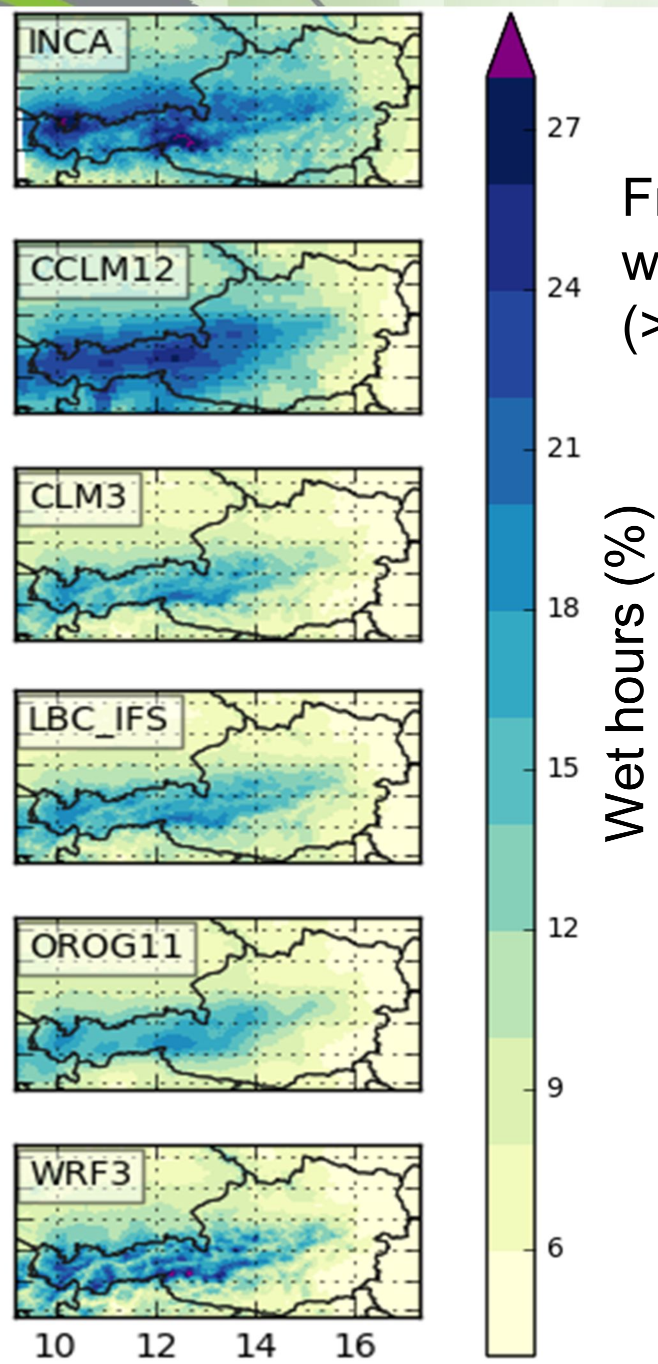




JJA

Mean of daily maximum of hourly precipitation

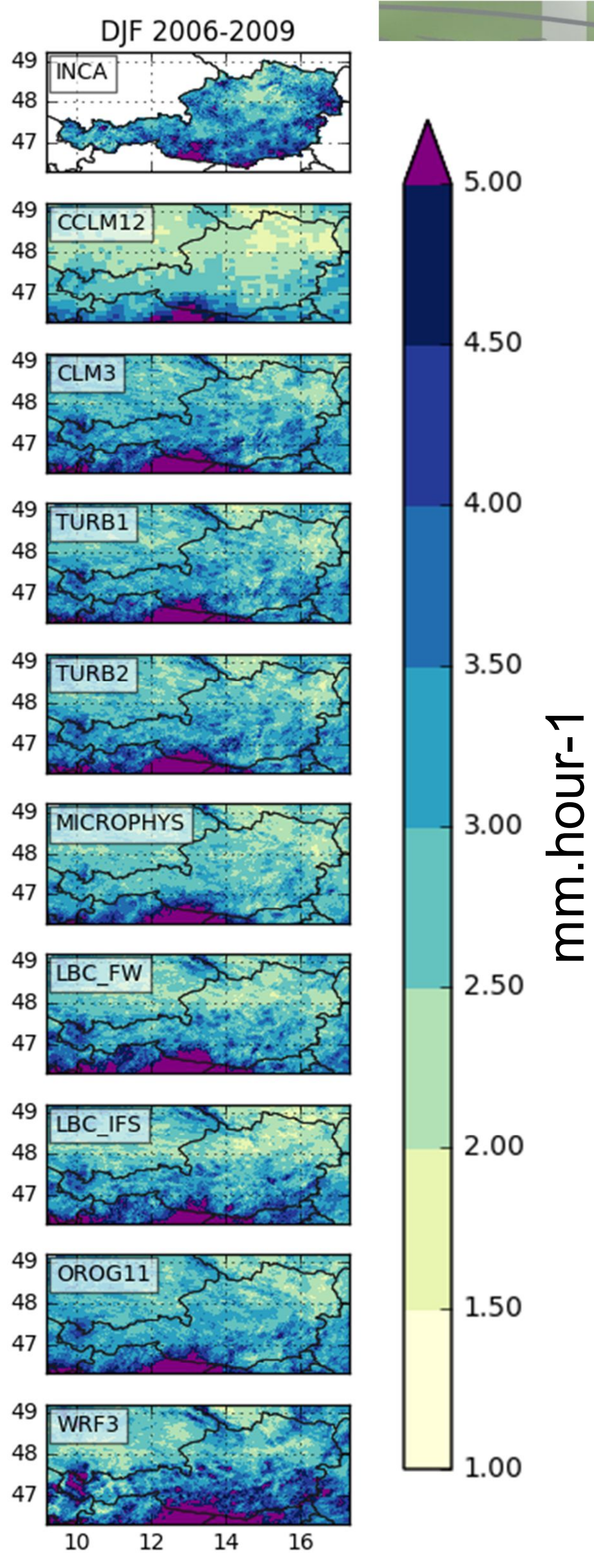


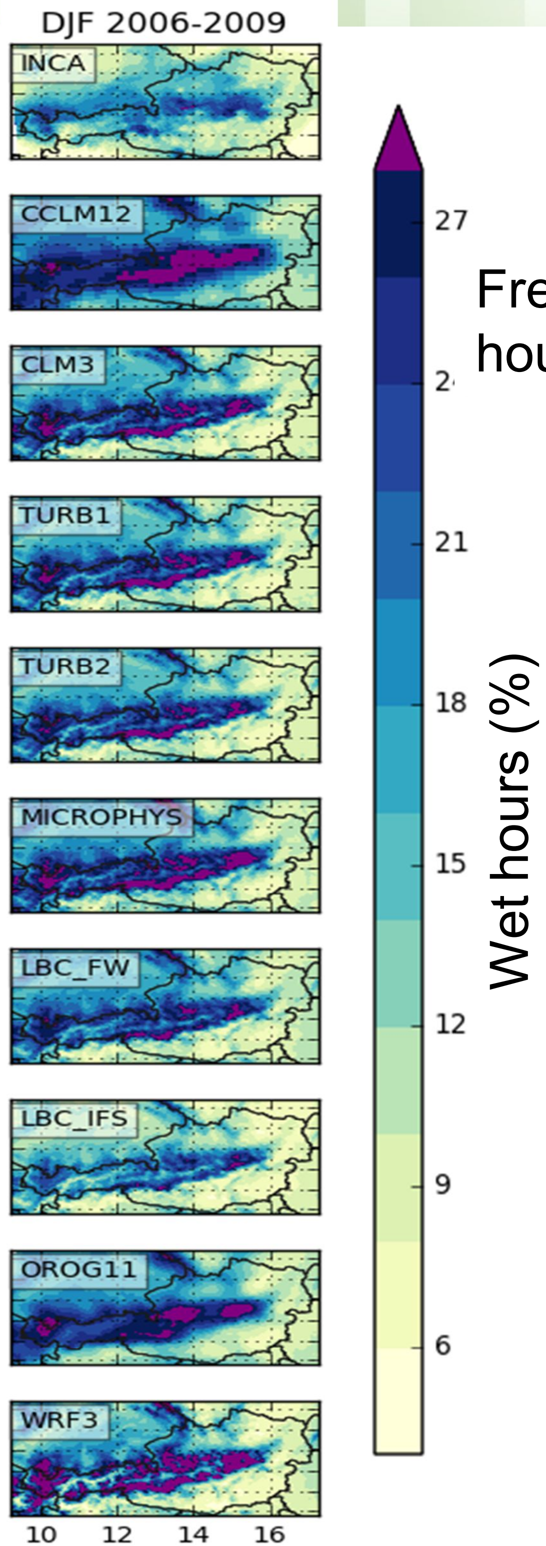


Freq occ of wet hours (>0.1mm)

DJF

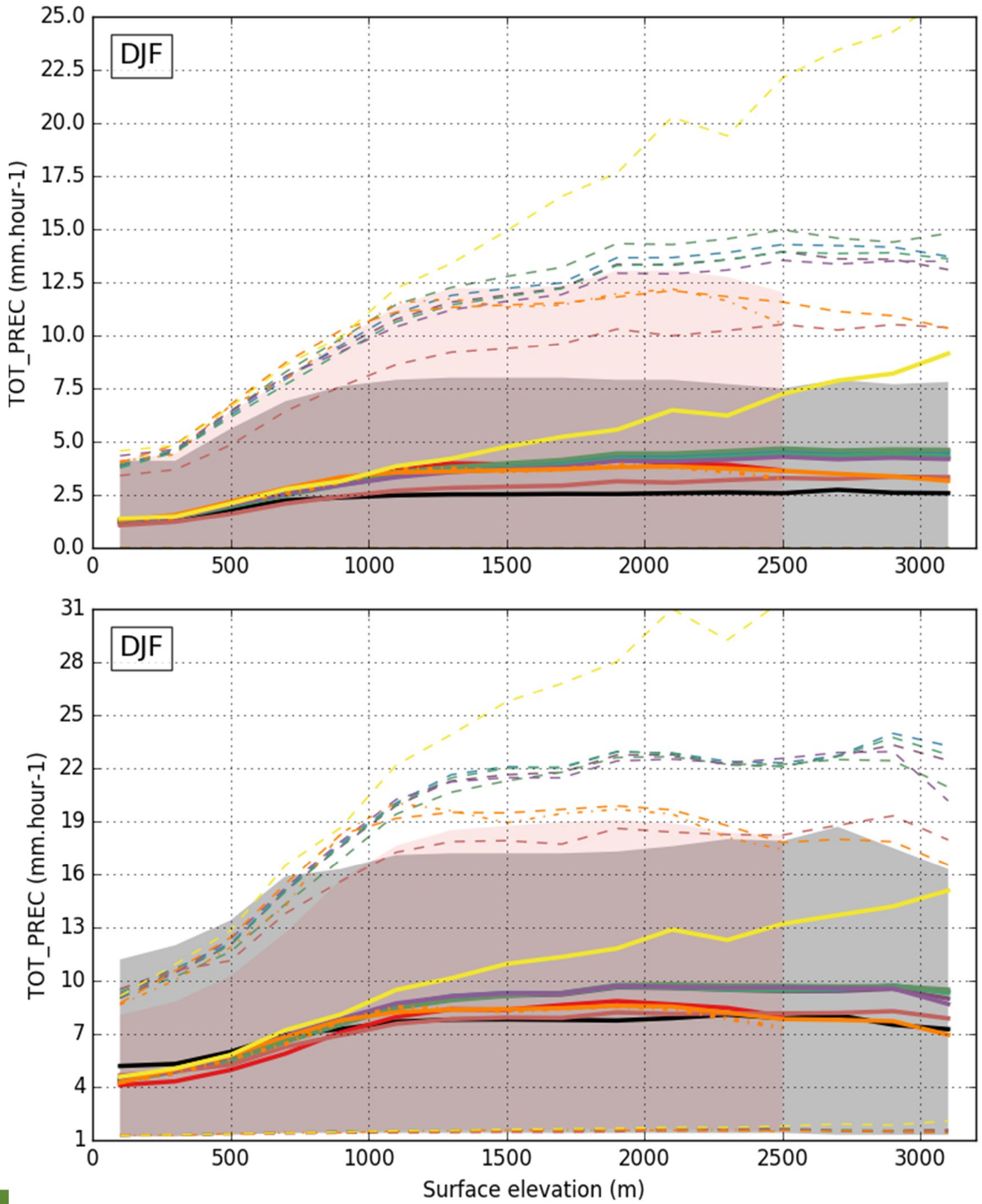
Mean of daily maximum of hourly precipitation





Freq occ of wet hours (>0.1mm)

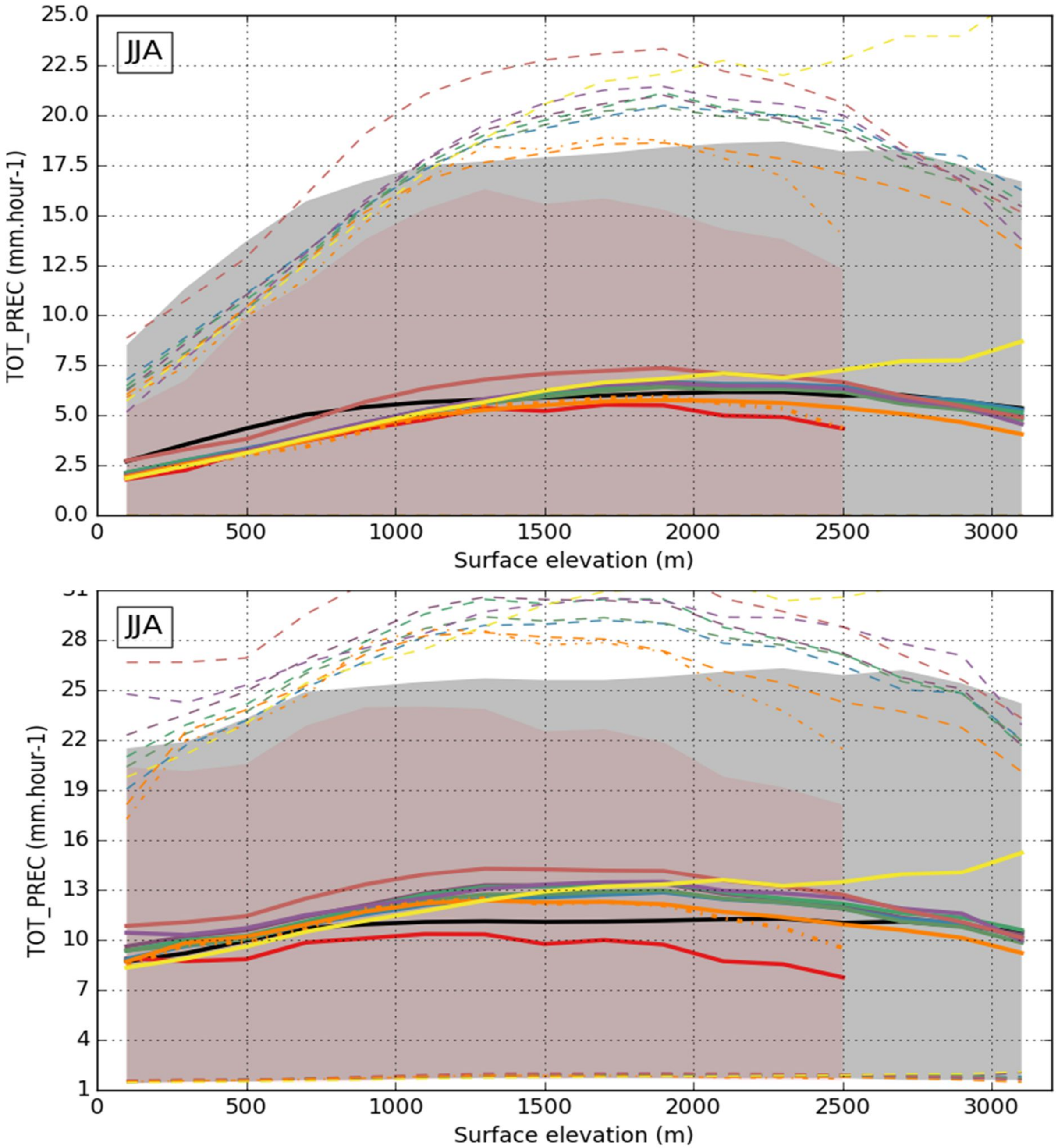
Height dependency of daily precipitation - Winter



Austria
Full distribution of daily precipitation

Austria
Treshold on wet days
TOT_PREC > 1 mm.day-1

Height dependency of daily precipitation - Summer

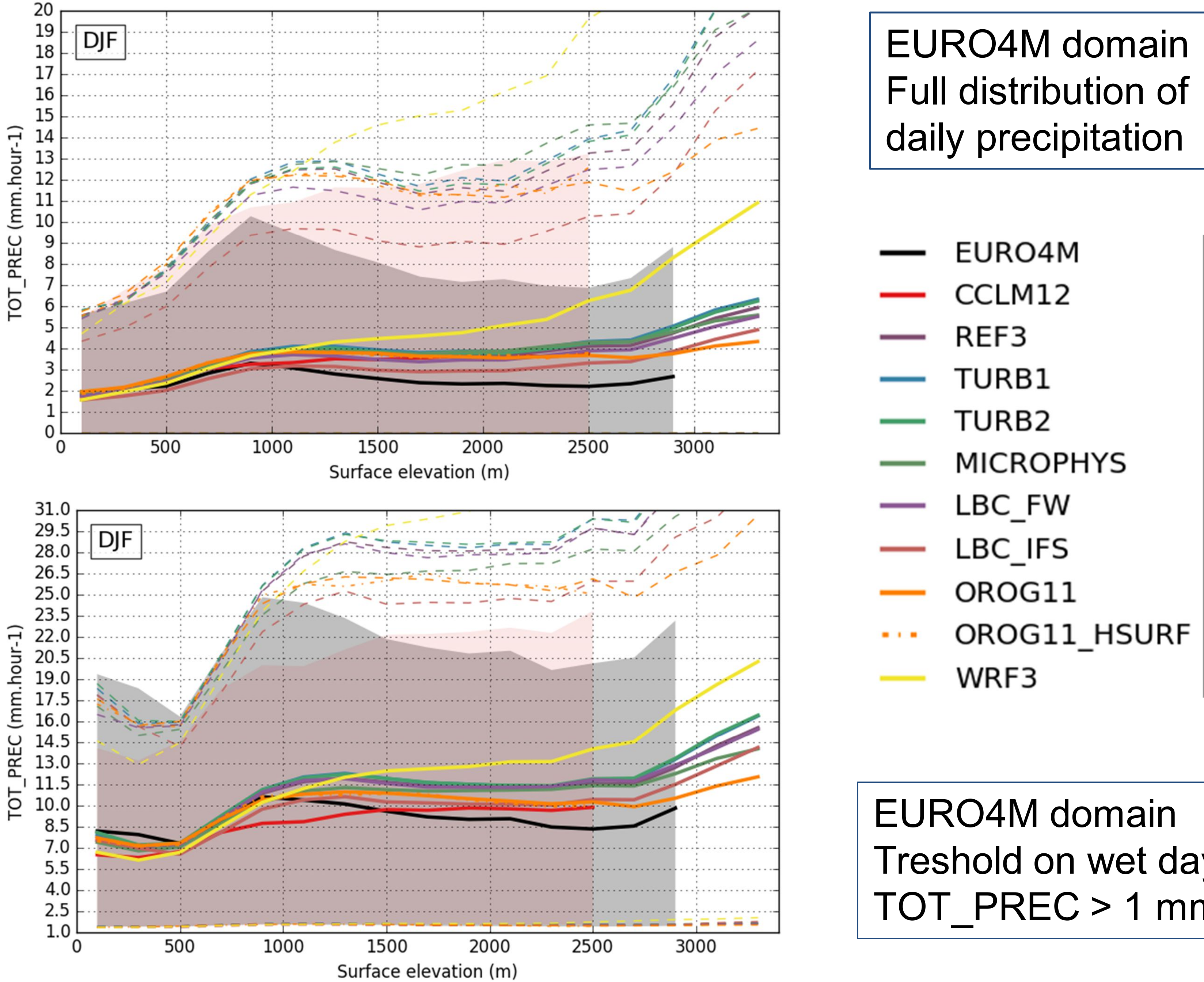


Austria
Full distribution of
daily precipitation

- GPARD1
- CCLM12
- REF3
- TURB1
- TURB2
- MICROPHYS
- LBC_FW
- LBC_IFS
- OROG11
- OROG11_HSURF
- WRF3

Austria
Treshold on wet days
TOT_PREC > 1 mm.day-1

Height-dependency evaluation: EURO4M, winter



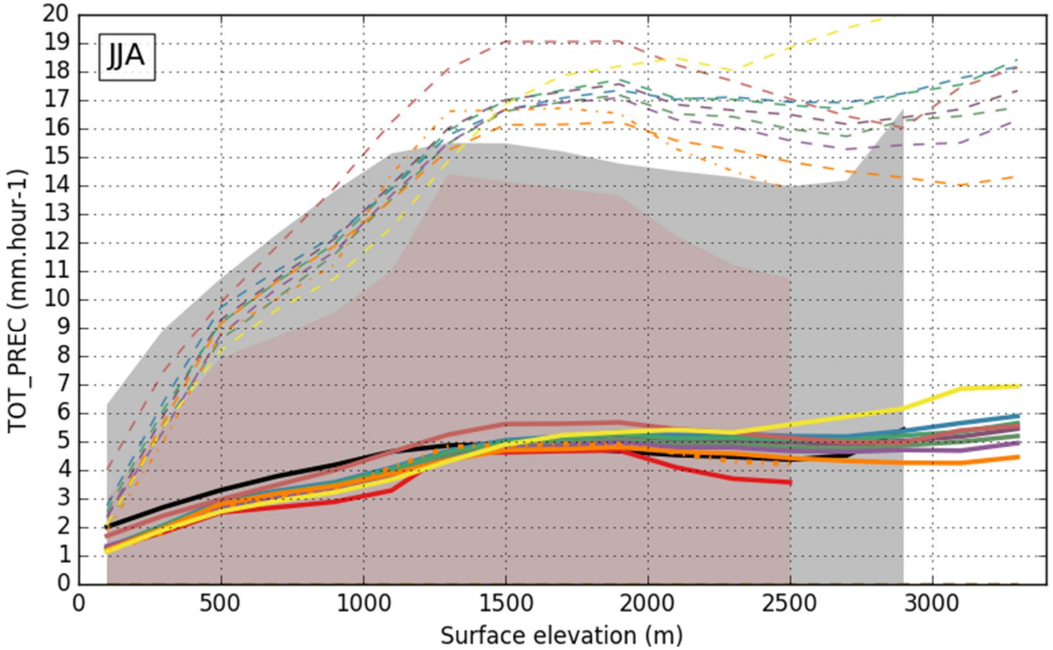
EURO4M domain
Full distribution of
daily precipitation

EURO4M domain
Treshold on wet days
TOT_PREC > 1 mm.day-1

Height-dependency evaluation: EURO4M, summer

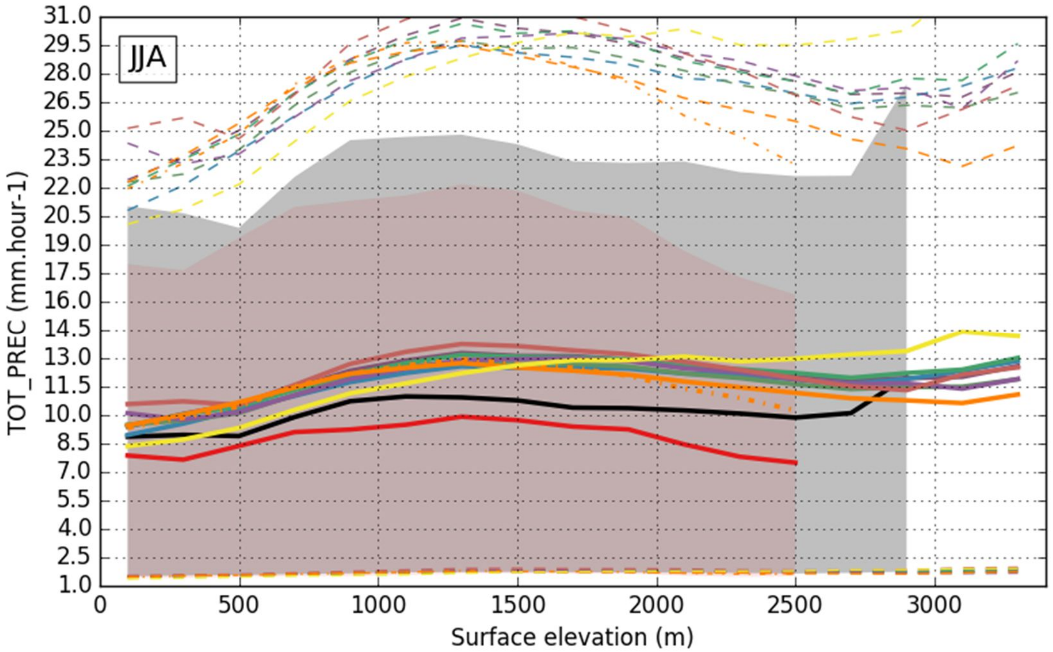
Wegener Center

UNI GRAZ



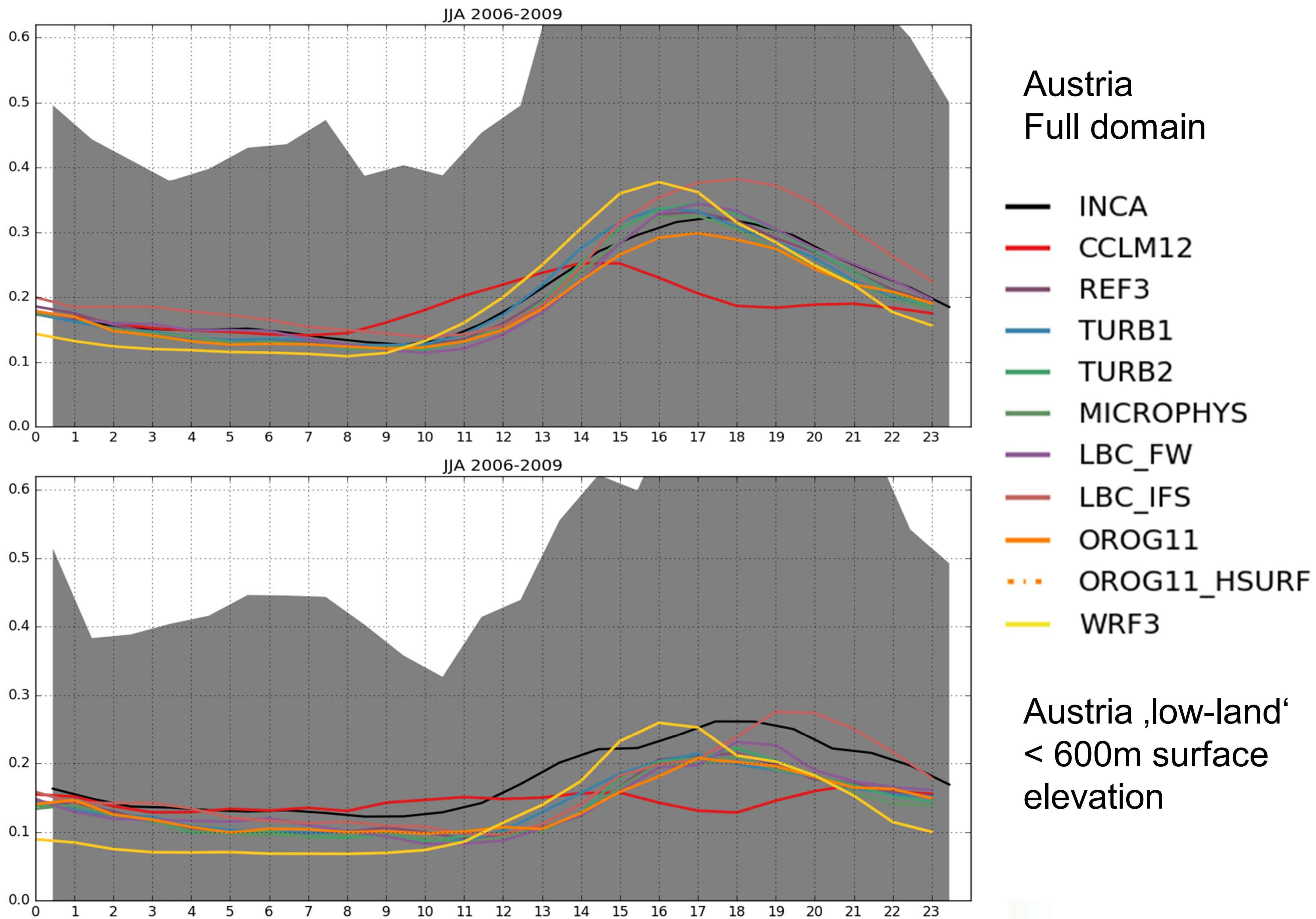
EURO4M domain
Full distribution of
daily precipitation

- EURO4M
- CCLM12
- REF3
- TURB1
- TURB2
- MICROPHYS
- LBC_FW
- LBC_IFS
- OROG11
- OROG11_HSURF
- WRF3



EURO4M domain
Treshold on wet days
TOT_PREC > 1 mm.day-1

The afternoon peak of precipitation in summer



Austria
Full domain

Austria ‚low-land'
< 600m surface elevation

Evaluation of occurrence of precipitation

Set of indices:

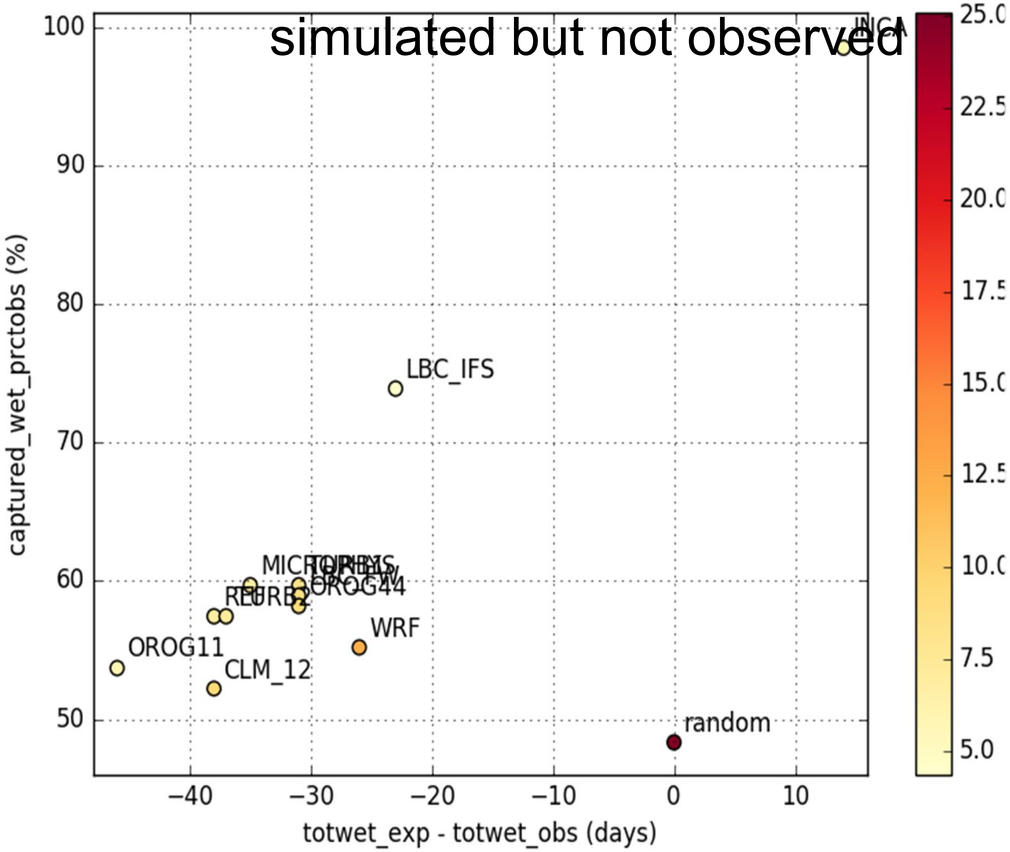
Total number of wet days

Number of captured wet days
observed and simulated

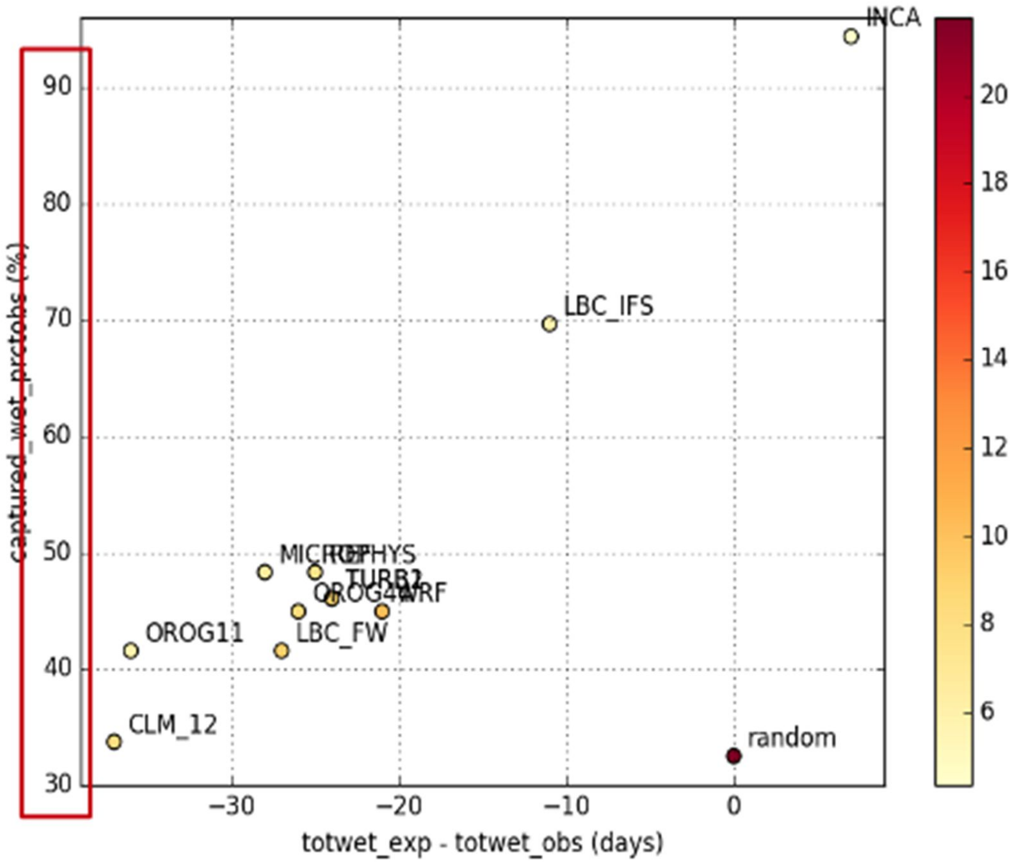
Number of missed wet days
observed but not simulated

Number of false alarm
simulated but not observed

Percentage of observed wet days that are captured



PR_thresh1h = 0.1 mm.hour-1



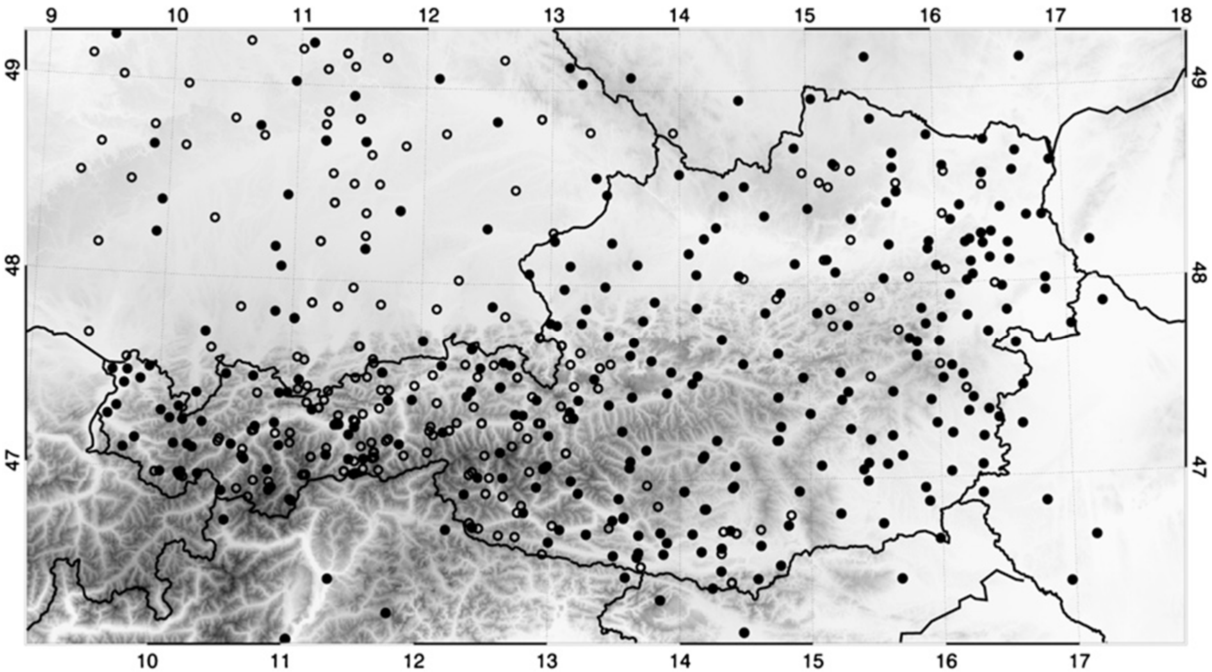
PR_thresh1h = 1.0 mm.hour-1

Observational datasets

- **INCA** (Haiden et al. 2011)

Integrated Nowcasting through Comprehensive Analysis

1 km resolution, Austria
Hourly temperature at 2m and precipitation, since 2006



Stations used operationally in the hourly temperature and precipitation analysis for INCA. From Haiden et al. 2011.

- **GPARD-1** (Hofstätter et al. 2015)

gridded dataset from high density network of in situ measurement stations

1 km resolution, Austria
Daily precipitation, since 1961

Sensitivity experiments

REF	OROGRAPHY			LAT. BOUND. CONDIT.	PARAMETRIZATION OF TURBULENCE		MICRO-PHYSICS TUNING
REFRUN	OROG11	OROG44	SSOOFF	LBC_FW	TURB1	TURB2	MICPHY
Similar to ACQWA, with COSMO 5.0	Smooth orography at 0.11°	Smooth orography at 0.44°	Turn off sub-grid scale orography	Hourly LBC, including vertical wind	Unstable summer condition	Turn off correction of vertical turbulent diffusion	decrease falling speed of snow, increase conversio n rate to graupel
			lsso=FALSE		tur_len=150 q_crit=1.6 iadv_order=5	lexpcor = FALSE	v0snow=15 qc0=0.0005

Conclusions

→ In summer, the statistical distribution of total precipitation and temperature are robust among experiments

- convective processes dominate

→ The representation of the precipitation afternoon peak varies strongly with altitude

- systematic underestimation in low level areas
- OROG11 gives similar results
- overestimation above 1800 m (except OROG44)

→ Precipitating extreme events are systematically underestimated by the model

- positive influence of lateral boundary forcing on 5 days cumulated precipitation

********** New Model version 5.0 with snow **********
N03_r2i3p2:
Same as N03_r2i2p2 but we use additionally the snow fields of the N03_r2i1p1 simulation in the laf file to have a warm start for as much as possible variables.
****

*********** Hourly 0.11° LBC including W **************
ERAint_011_r2i1p1:
Since the BTU 0.11° parent simulation provides only 3 hourly LBC and does not include W in its nesting output a sensitivity expermiment is conducted in which the effect of hourly LBC and as much as possible LB parameters is investigated.
****

********** New Model version 5.0 with hourly LBC **********
N03_r2i4p1:
Same as N03_r2i3p2 but with hourly LBC from ERAint_011_r2i1p1 which also include W!

GOAL:
The goal of this experiment is to find out whow important the update frequency of the LBC is for the model performance.
****

********** New Model version 5.0 with 2-moment scheme **********
!!!!!!!!!!NOT STTARTED JET!!!!!!!!!!
N03_r2i3p4:

Same as N03_r2i3p2 but we use the 2-moment microphysic scheme instead of the one moment scheme. The 2-moment scheme have been schown to be beneficiel in simulating snowpack in the Colorado Headwaters with WRF (Liu et al. 2011) and for simulating high cloud in CCLM (Keller et al. 2014).

****

********** New Model version 5.0 with ~ COSMO-DE; COSMO-2 Setup ***************
N03_r2i3p3:
Same as N03_r2i3p2 but we decrease the Turbulent Length Scale from tur_len=500 m to tur_len=150 m. Additionaly, we change the value of q_crit from 4.0 to 1.6 and use a 5th order advection sceme (iadv_order=5 instead of 3). This is more similar to the setup used in COSMO2 of Meteo Swiss and COSMO-DE of the DWD.

Goal: The goal of this experiment is to find out if the DWD and MeteoSwiss setups have benefits for the NHCM-2 simulations. DWD lowerd tur_len to get more unstable conditions during summer and to easier trigger deep convection. This could potentially resolve the dry bias

convective activity in low pressure-gradient conditions is very sensitive to the application of lexpcor. Langhans found that disabling lexpcor leads to a strong increase of precipitation during situations with intermittent convective precipitation.
****

********** New Model version 5.0 with 0.11° smoothed orography ****************
N03_r2i5p2:
Same as N03_r2i3p2 but we smoothed the HSURF field to mimic a 12 km orography in a 3 km simulation. Also the SSO where modified. All files are taken from the external fields of the 0.11° EURO-CORDEX simulation and then remapped to the 0.0275 grid. The program used for this task can be found here:

/lustre/jhome9/eau00/eau007/projects/NHCM2/programs/OrographySensExp/PrepareExternPara m.sh
****

********** New Model version 5.0 with 0.44° smoothed orography ****************
N03_r2i6p2:
Same as N03_r2i5p2 but the orography is smoothed to a 0.44° model grid. The program used for this task can be found here:

/lustre/jhome9/eau00/eau007/projects/NHCM2/programs/OrographySensExp/PrepareExternPara m.sh
****

********** New Model version 5.0 without SSO parameterization ***************
N03_r2i3p6:
Same as N03_r2i3p2 but lsso=.FALSE.

Goal: The goal of this experiment is to find out which affect the sub surface orography (SSO) scheme in general and the gravity wave dragging in speciffic has on our simulations. This is a common sensitivity experiment that will also be conducted with WRF and REMO.

In CCLM I have swiched on the SSO bei default. It consits of two parts. The first part is the near-surface drag (gkwake), blocking and the second the gravity wave drag (gkdrag). According to Jan-Peter Schultz the genaral setup of the corresponding parameters is:
gkdrag=0.075
gkwake=0.50
To swich both off:
gkdrag=0.0
gkwake=0.0
OR use lsso=.FALSE. (used in this simulation)

****

********** New Model version 5.0 with tuned microphysic ***************
N03_r2i3p7: