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Are dependencies of extreme rainfall on humidity more reliable in convection-permitting climate models?

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Model simulations

Table S1. List of RCM model simulations. All RCM simulations have been performed with 12 km grid spacing

Short name	Long name	Time stamp in files	Institute	Tas	Humidity
COSMO-CLM	CLMcom-ETH-COSMO-crCLIM-v1-1	2019-09-02	ETH Zurich, Zurich, Switzerland in collaboration with the CLM-Community	3hr	hurs, 3hr
HadRM3	MOHC-HadREM3-GA7-05	2020-01-31	MetOffice, Hadley Centre, UK	3hr	hurs, 3hr
RACMO	KNMI-RACMO22E (v1)	2017-05-09	Royal Netherlands Meteorological Institute, De Bilt, The Netherlands	3hr	hurs, 3hr
RCA4	SMHI-RCA4 (v1)	2018-12-27	Swedish Meteorological and Hydrological Institute, Rossby Centre, Sweden	3hr	hurs, 3hr
HIRHAM5	DMI-HIRHAM5 (v1)	2014-02-19	Danish Meteorological Institute, Danmark	3hr	hurs, 3hr
REMO	REMO2015_v2	NA	GERICS, Germany	3hr	tdps, 3hr
ALADIN	CNRM-ALADIN63 (v1)	2018-09-29	CNRM (Centre National de Recherches Meteorologiques, Toulouse 31057, France)	3hr	hurs, 3hr

Table S2. List of CPM simulations. Domain "ALP" stands for the Alpine domain as used in the CORDEX FPS study (Ban et al. 2021). Only runs have been considered where the domain also covers The Netherlands. Domain "NWE" stands for the European North Western domain as defined within the European EUCP project.

Short name	Long name	period	Institute	Domain	Humidity
COSMO-CLM	COSMO-pompa_5.0_2019.1	2000-2009	ETH Zurich, Zurich, Switzerland in collaboration with the CLM-Community	ALP	Huss, 3hr
UKMO-UM	UKMO-UM10p1_v01	2000-2011	MetOffice, Hadley Centre, UK	ALP	hurs, 3hr
HCLIM-ALP	HCLIM38h1_KNMI	1999-2009	Royal Netherlands Meteorological Institute, De Bilt, The Netherlands	ALP	hurs, 3hr
HCLIM-NWE	HCLIM38h1_KNMI	2008-2018		NWE	hurs
AROME41	CNRM-AROME41t1	2000-2009	CNRM	NWE	

Supplemenary Information Figures

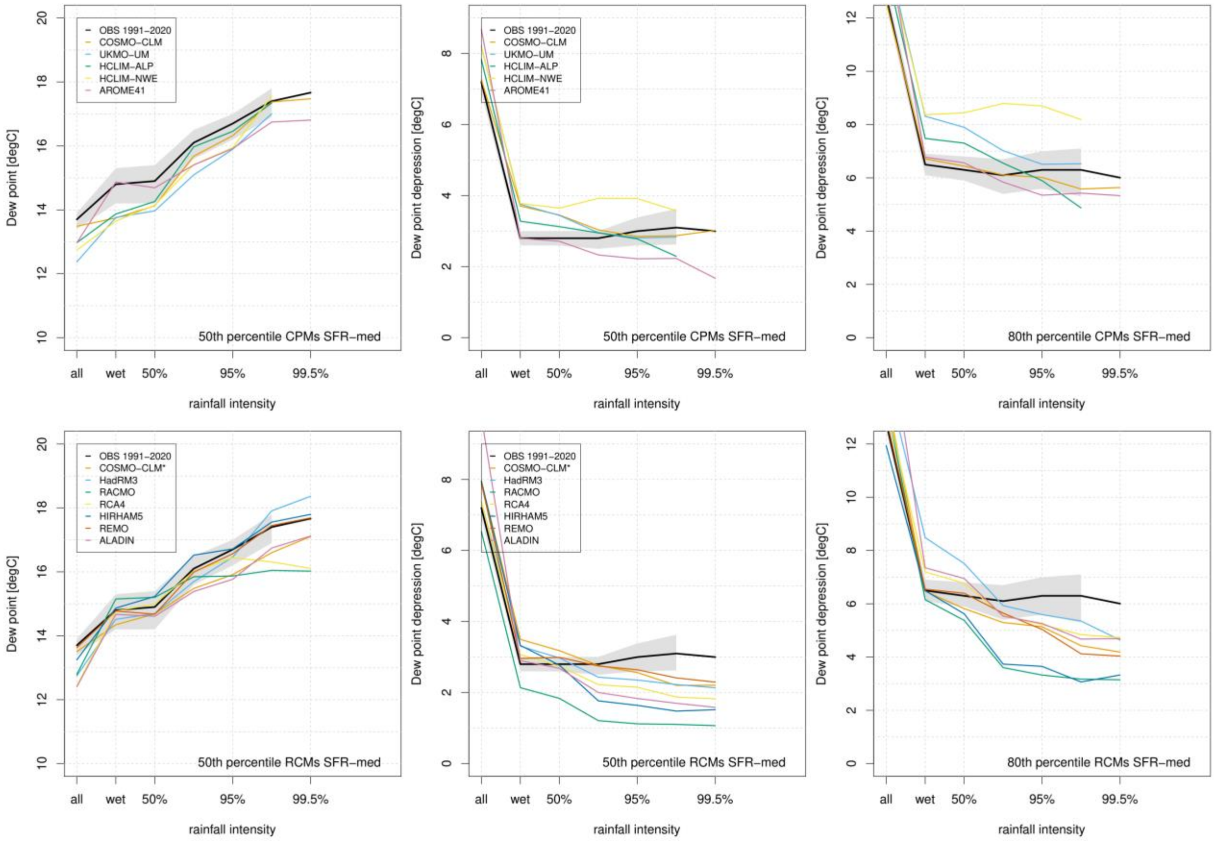
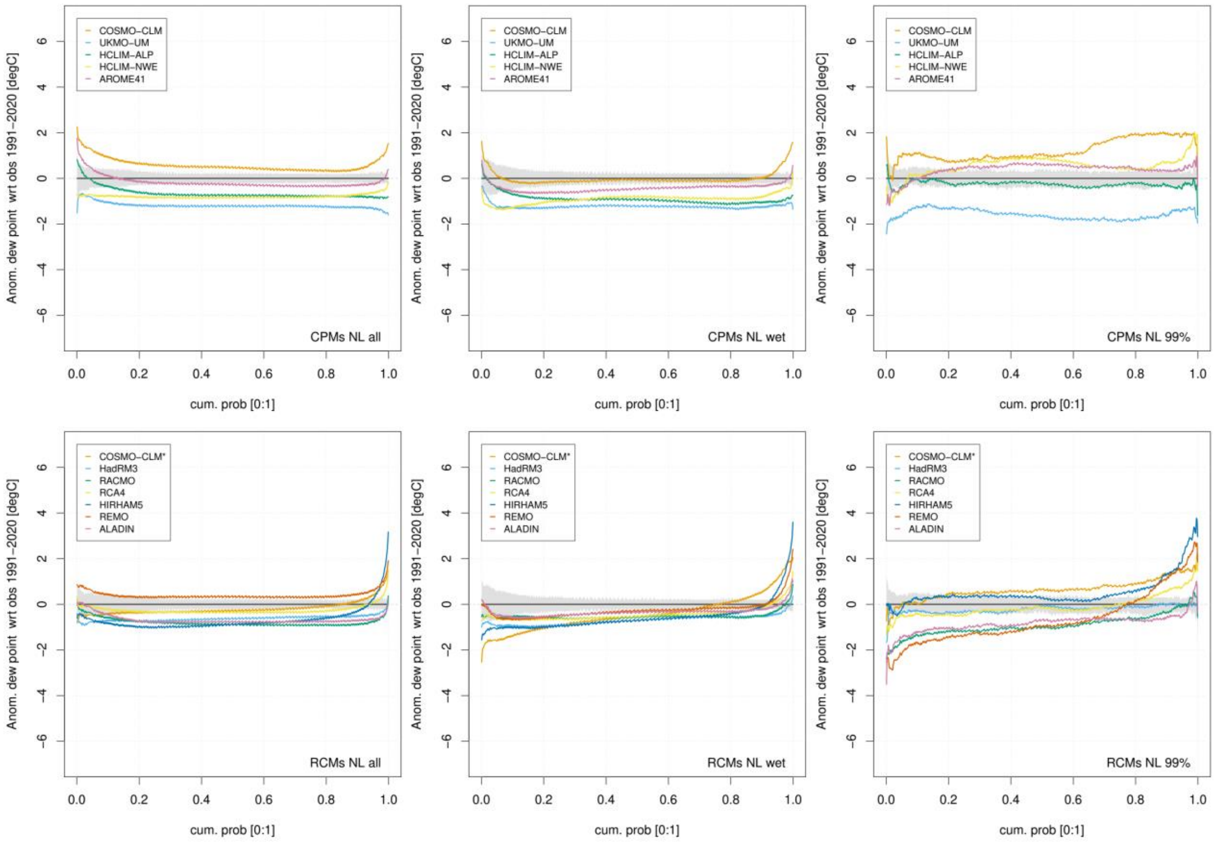
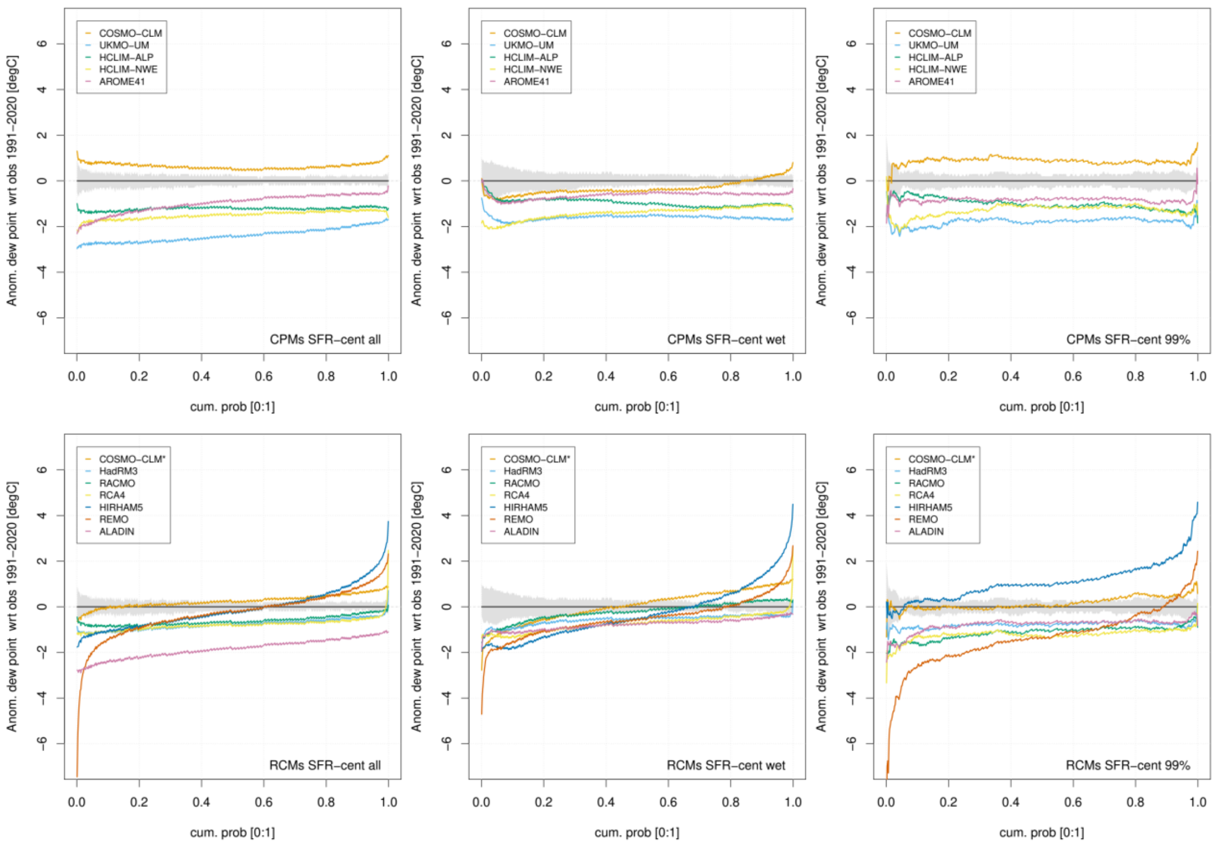


Figure S1. As Figure 3 from main paper, but now for SFR-med.


COSMO−CLM
UKMO−UM
HCLIM−ALP
HCLIM−NWE
AROME41
COSMO−CLM*
HadRM3
RACMO
RCA4
HIRHAM5
REMO
ALADIN
Anom. dew point wrt obs 1991−2020 [degC]
cum. prob [0:1]
CPMs NL all
CPMs NL wet
CPMs NL 99%
RCMs NL all
RCMs NL wet
RCMs NL 99%


COSMO−CLM
UKMO−UM
HCLIM−ALP
HCLIM−NWE
AROME41
COSMO−CLM*
HadRM3
RACMO
RCA4
HIRHAM5
REMO
ALADIN
Anom. dew point wrt obs 1991−2020 [degC]
cum. prob [0:1]
CPMs SFR−cent all
CPMs SFR−cent wet
CPMs SFR−cent 99%
RCMs SFR−cent all
RCMs SFR−cent wet
RCMs SFR−cent 99%

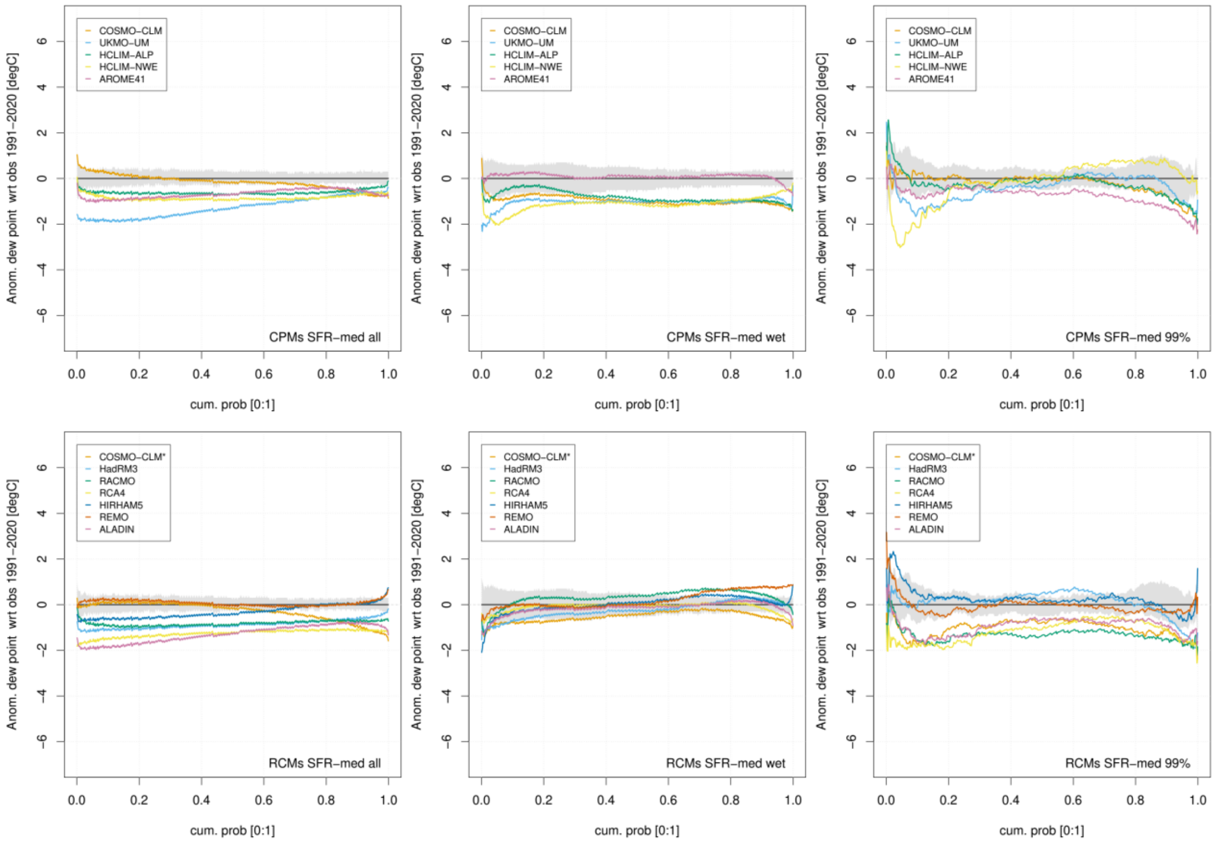
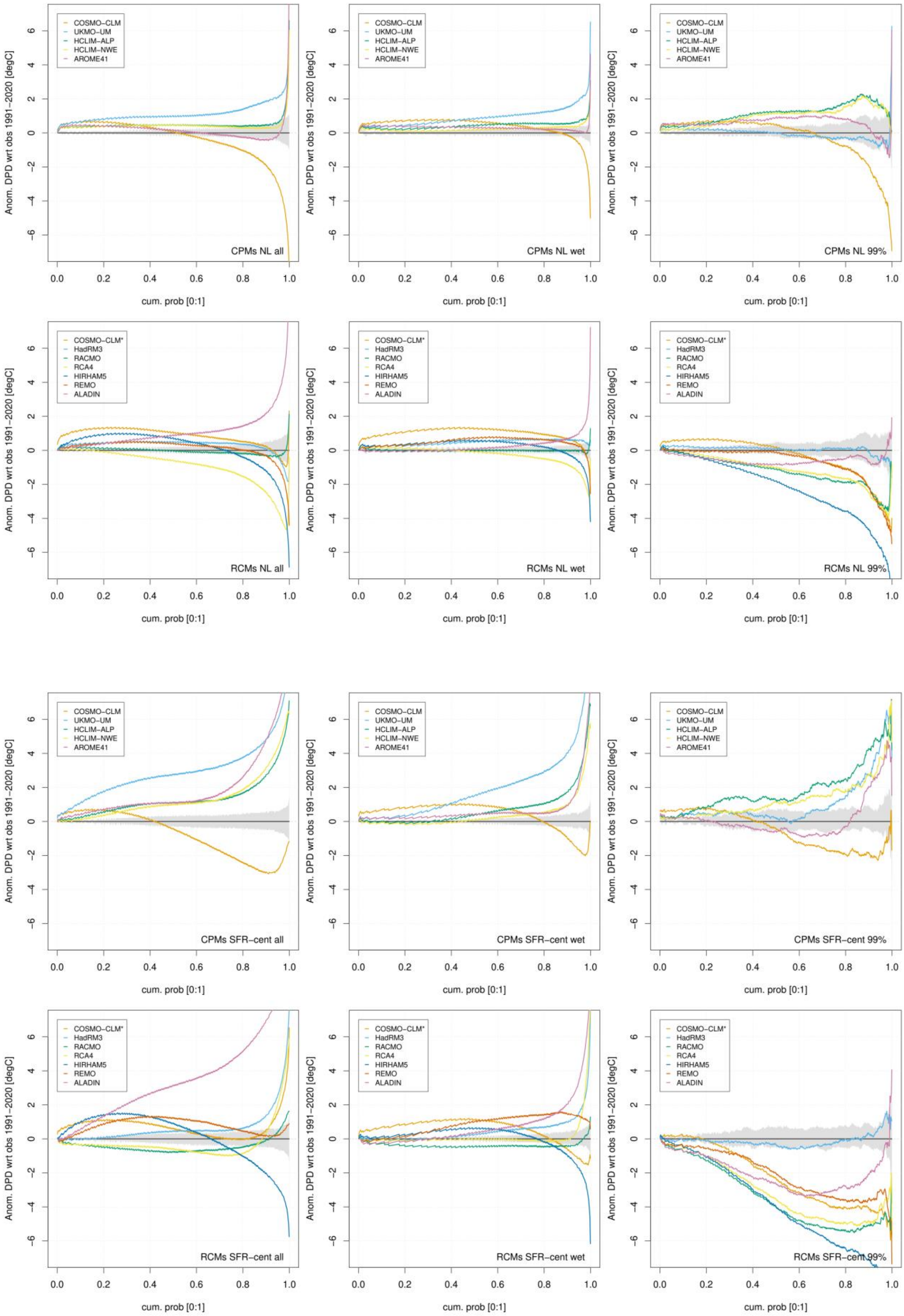


Figure S2 (two pages). Dew point anomaly of the CPMs and RCMs compared to observations, for all hours (left) and wet hours (middle) and hours with rain exceeding the 99th percentile (right). Each panels shows the anomaly in the distribution from low dew points (left) to high dew points (right). Results are shown for NL (first two rows on previous page), SFR-cent (last two rows on previous page and SFR-med (this page). Comparing panels from left to right one can easily see how the anomaly depends on the rainfall intensity class. Note also that some models, for example, HIRHAM5 shows wider distribution of the dew point than the observations, in particular overestimating high dew point values (positive biases of 2-4 degree in left plots for NL and SFR-cent).


CPMs NL all
CPMs NL wet
CPMs NL 99%
RCMs NL all
RCMs NL wet
RCMs NL 99%
CPMs SFR−cent all
CPMs SFR−cent wet
CPMs SFR−cent 99%
RCMs SFR−cent all
RCMs SFR−cent wet
RCMs SFR−cent 99%
COSMO−CLM
UKMO−UM
HCLIM−ALP
HCLIM−NWE
AROME41
COSMO−CLM*
HadRM3
RACMO
RCA4
HIRHAM5
REMO
ALADIN
Anom. DPD wrt obs 1991−2020 [degC]
cum. prob [0:1]

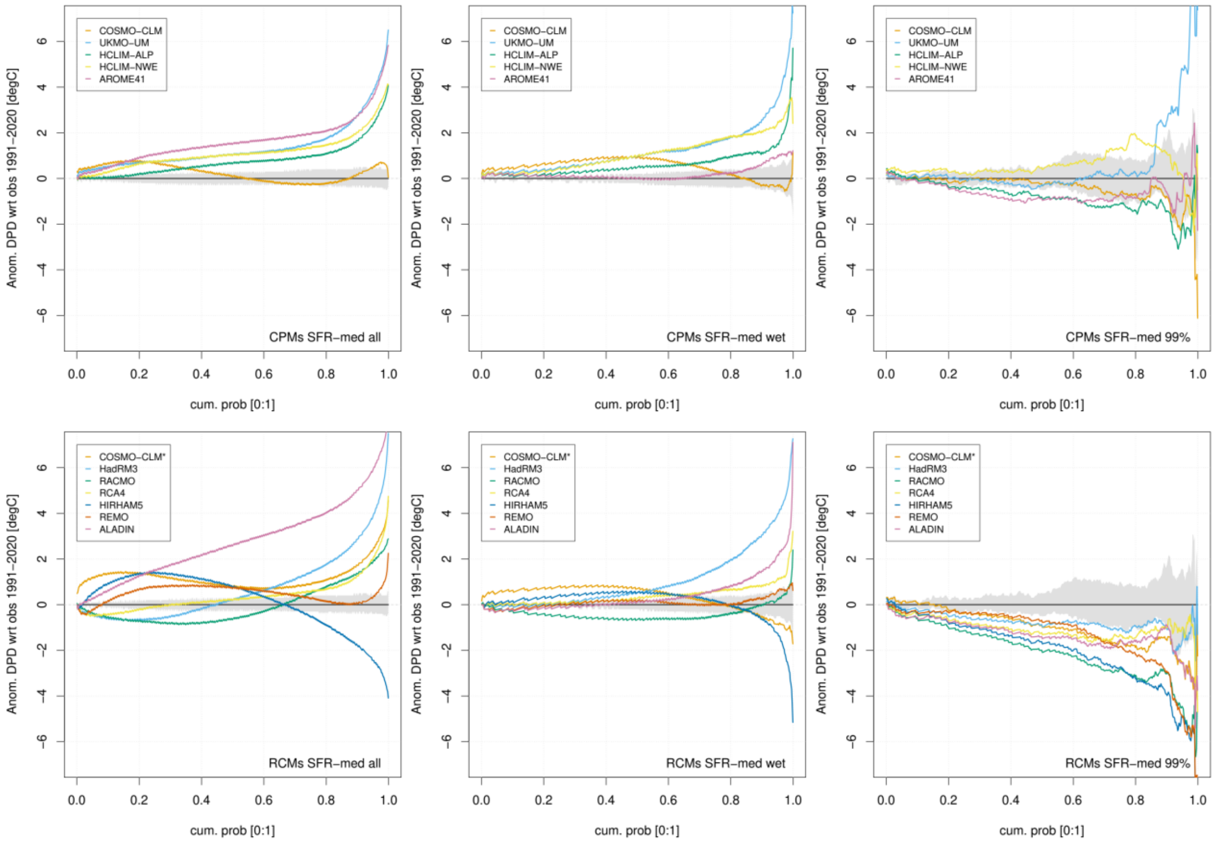


Figure S3. Same as previous plot, but now for anomaly in dew point depression. For all areas, the RCMs show a very substantial shift to low DPD (that is, high relative humidity) for the most extreme rainfall – a shift not visible in the CPM results.

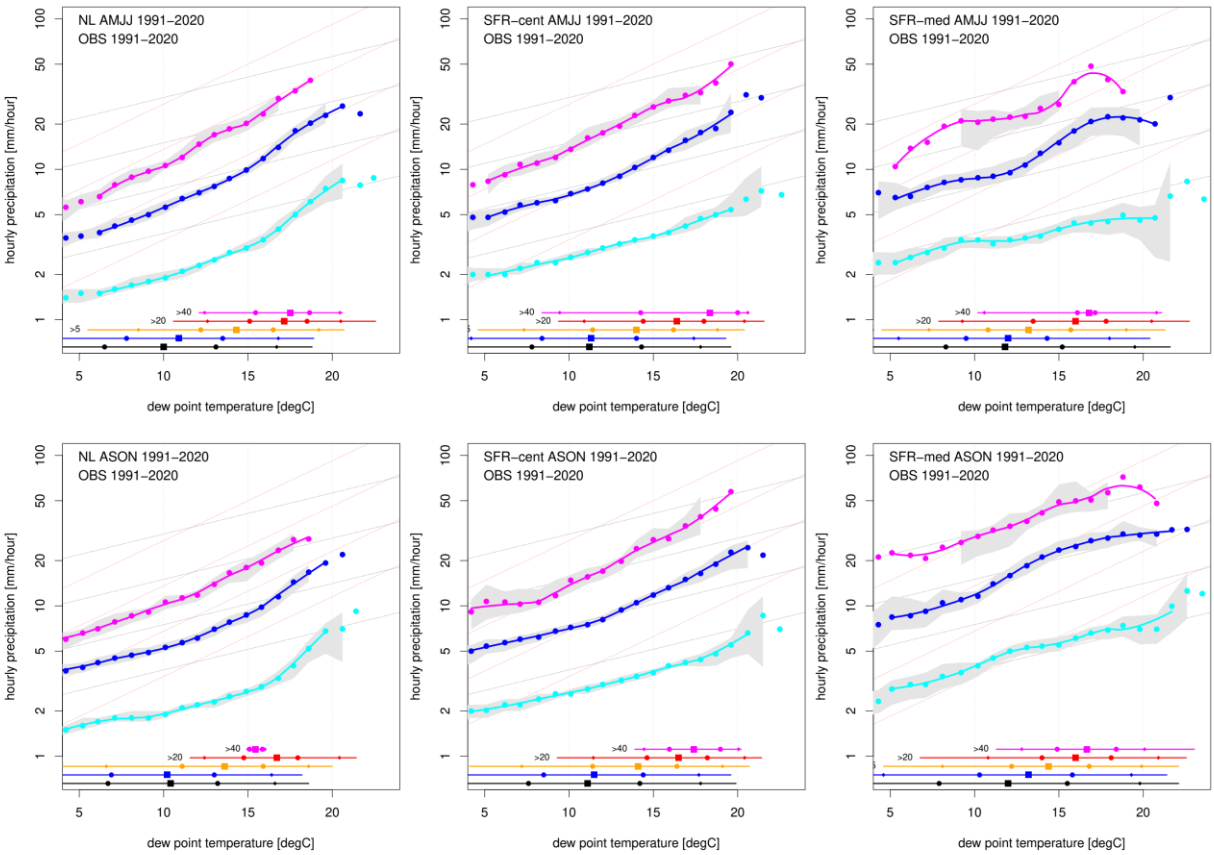


Figure S4. As Figure 5 of main text, but now for AMJJ (upper panels) and ASON (lower panels)

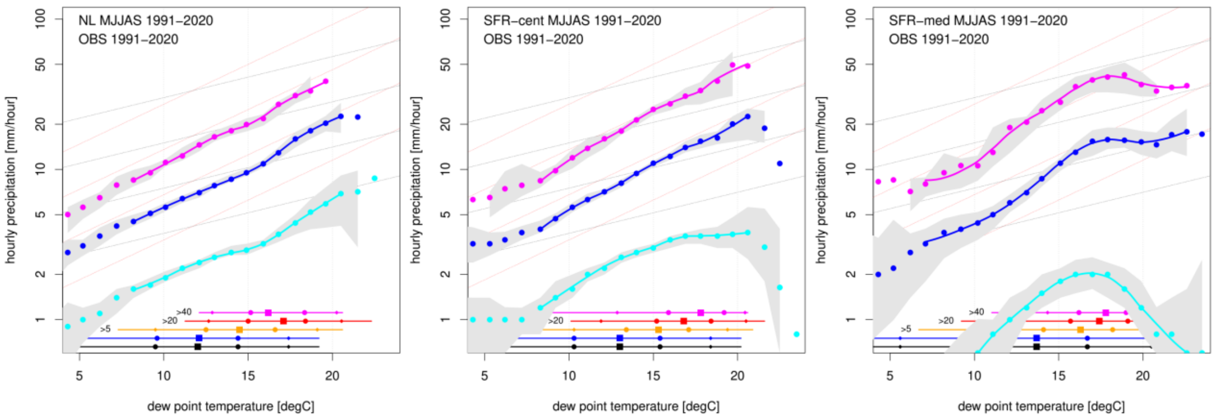


Figure S5. As Figure 5 of main text, but now absolute percentiles, 99th (cyan), 99.9th (blue) and 99.99th (magenta). Note, rather similar behavior, yet larger uncertainty estimates in particular for the lower percentiles. This could be related to strong influence of large-scale circulation on the frequency of rainfall, which is sampled with the bootstrap. Note also that the blue horizontal line at the bottom gives the distribution of all days (and not exceeding 0.1 mm as in the main text) and is therefore the same as the black line below.

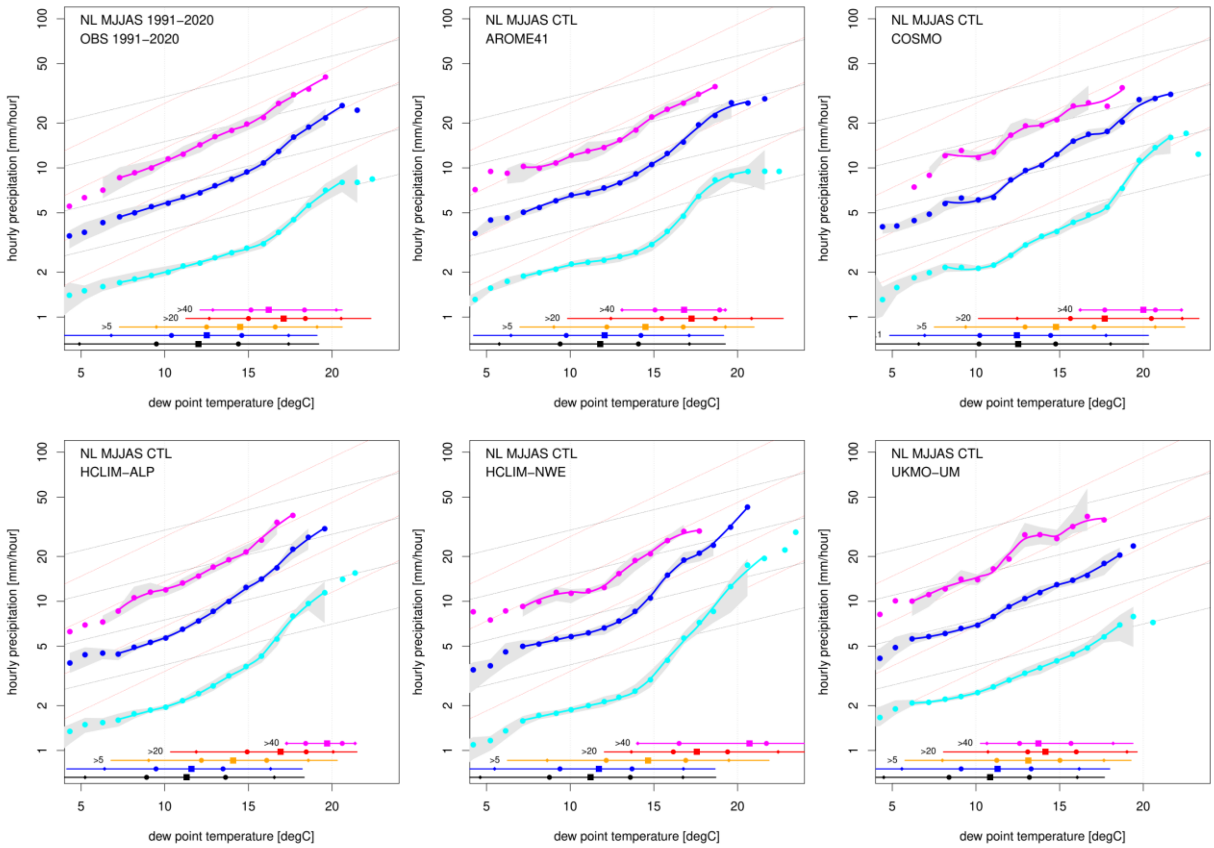


Figure S6. Scaling of hourly extremes on dew point temperature, CPM results compared to observations (left-top) for NL. Lines and symbols similar to Figure 6 of the main document.

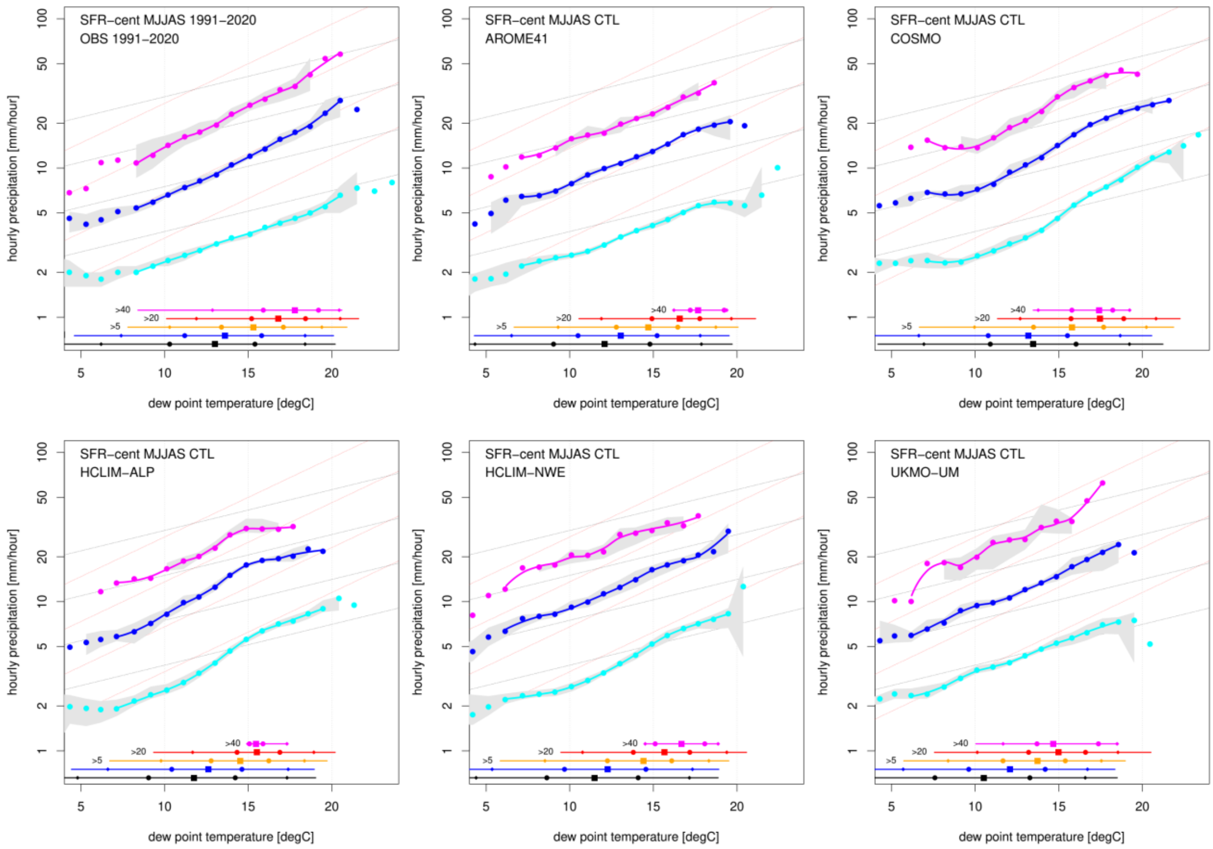


Figure S7. Scaling of hourly extremes on dew point temperature, CPM results compared to observations (left-top) for SFR-cent

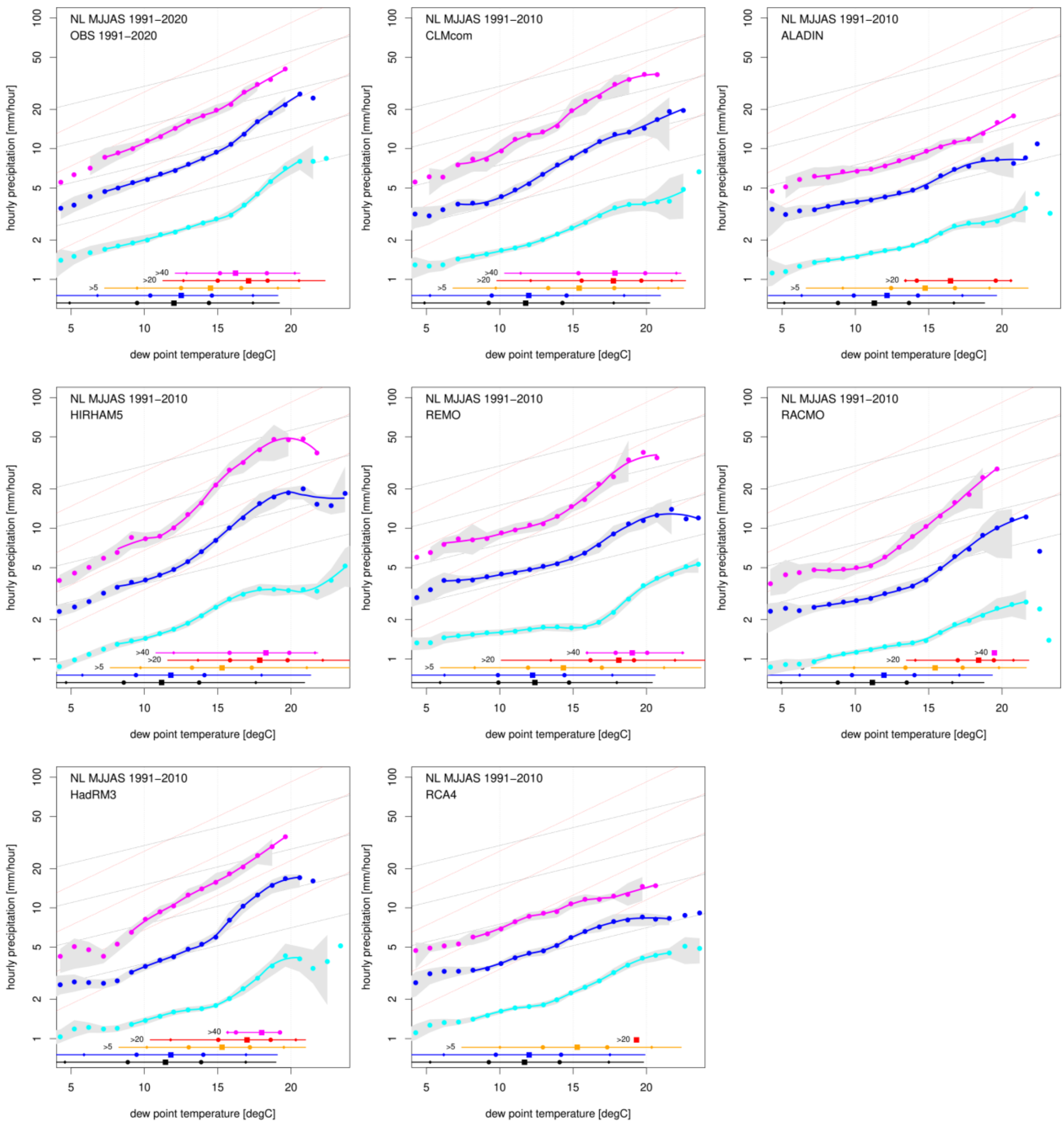


Figure S8. Scaling of hourly extremes on dew point temperature, RCM results compared to observations (left-top) for NL. We note that the scale break, switching from (sub)CC rates to rates beyond 2CC, in RACMO around 12 °C dewpoint is caused by the development of resolved convective systems – with an up and an downdraft – that are too persistent and long lived.

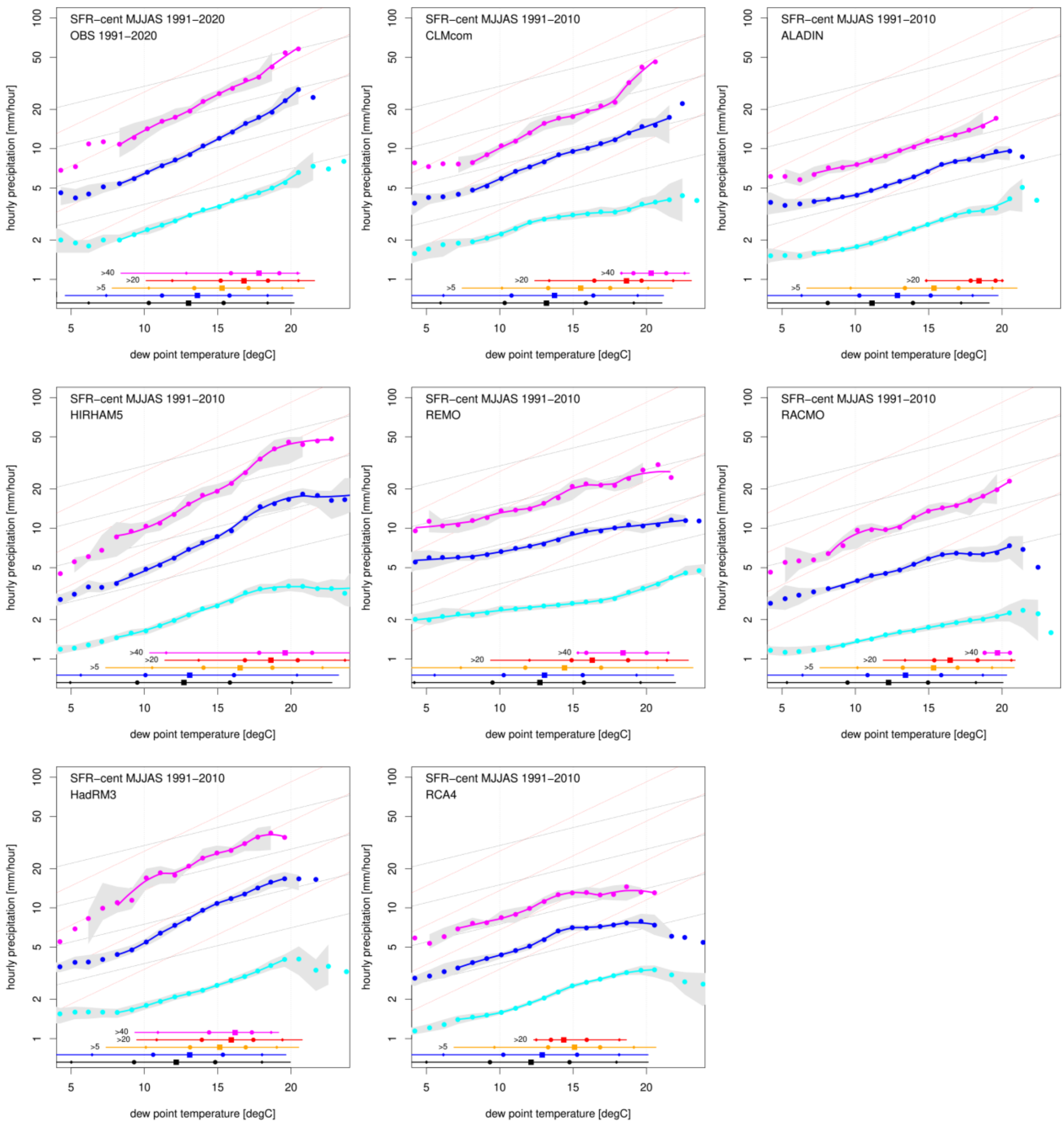


Figure S9. Scaling of hourly extremes on dew point temperature, RCM results compared to observations (left-top) for SFR-cent

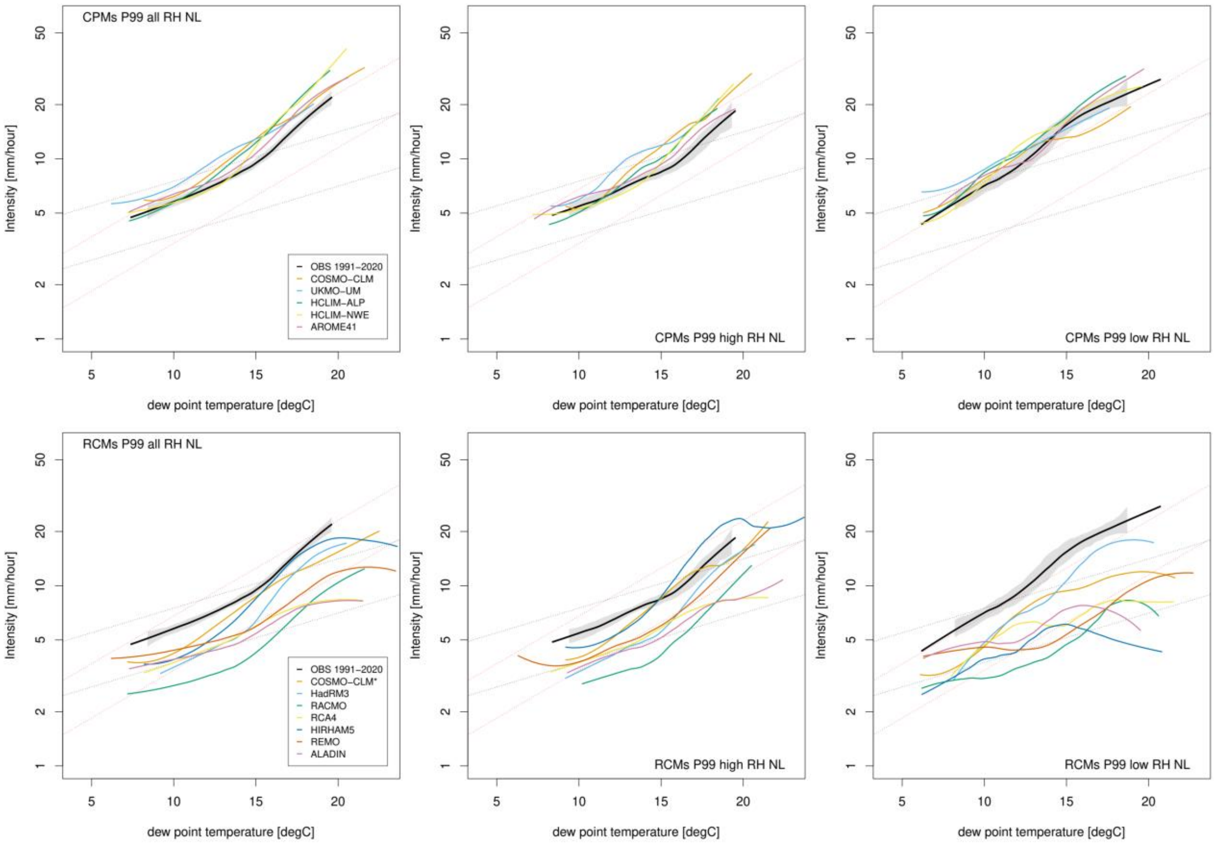


Figure S10. As Figure 6 of the main text, but now for NL.

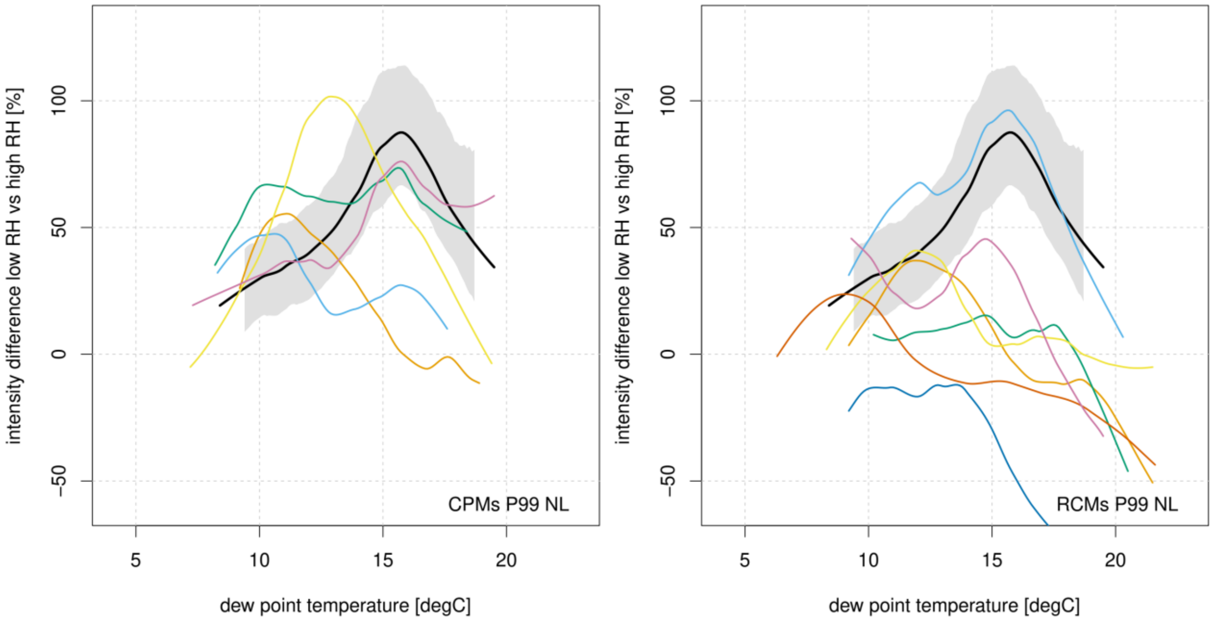


Figure S11. As Figure 8 of main text, but now for NL.

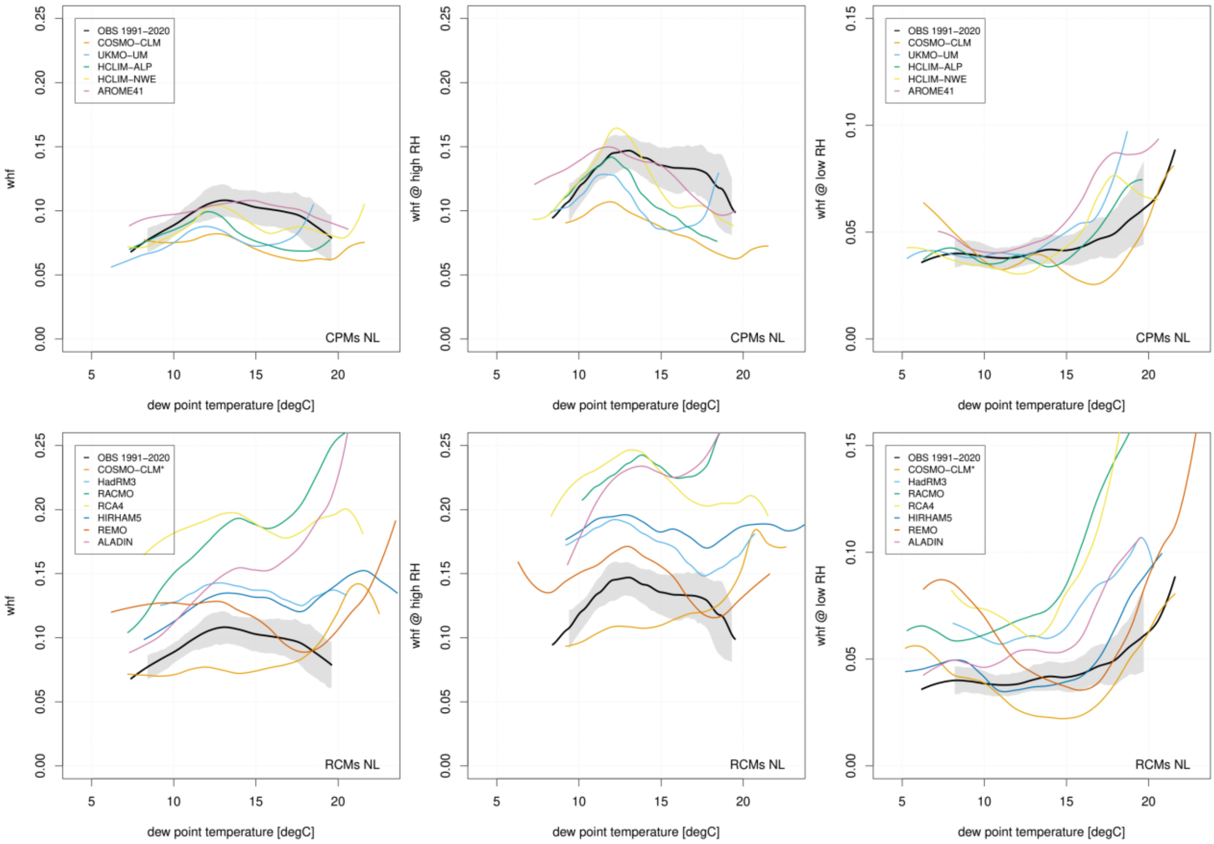


Figure S12. As Figure 9 from main text, but now for NL.

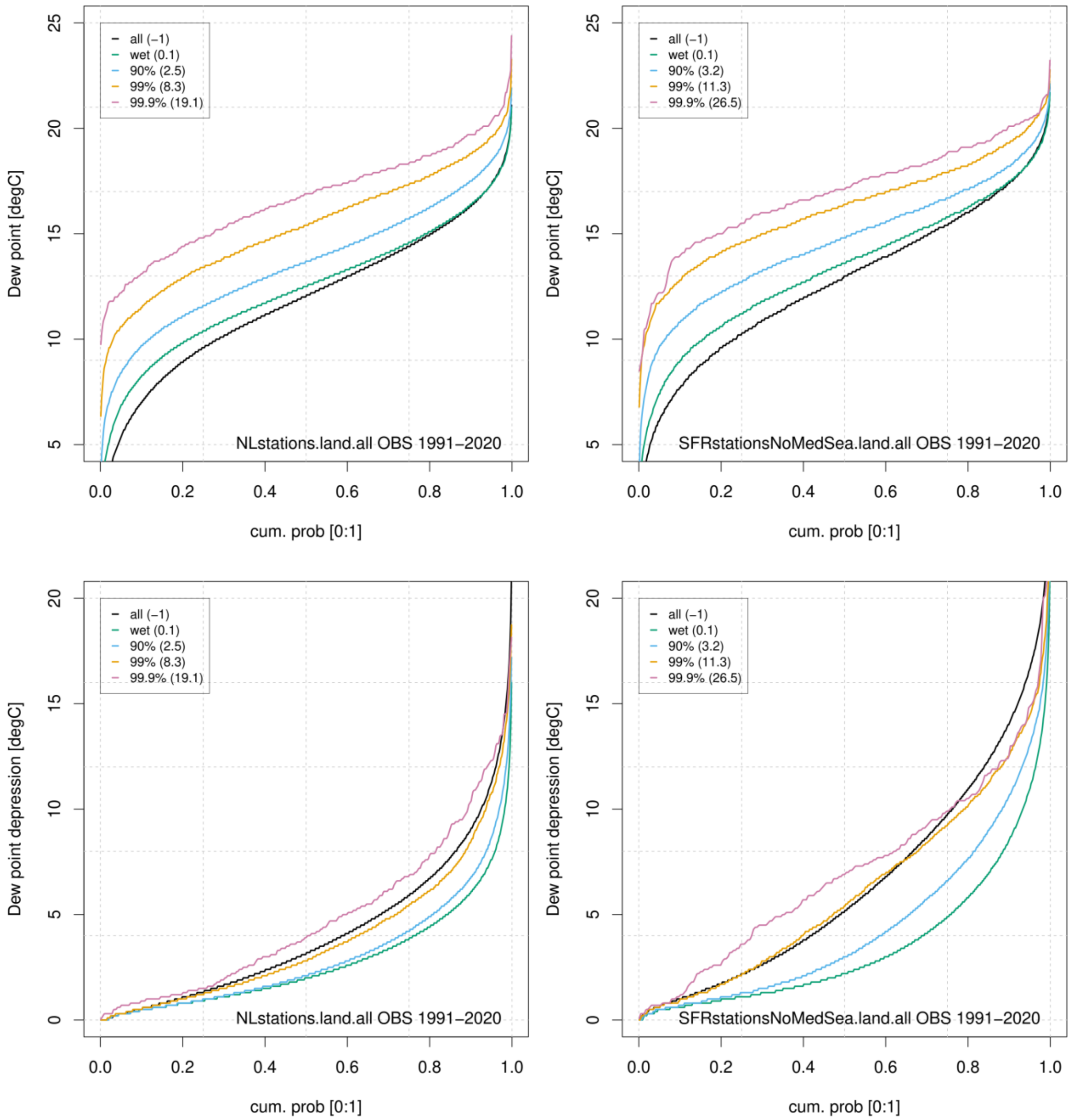


Figure S13. Distribution of dew point and dew point DP (upper panels) and dew point depression DPD for different selections of data based rainfall intensity, classified into all hours, wet hours, and hours with rain exceeding the 90, 99, 99.9th percentile of rain (wet conditioned); the rainfall threshold are mentioned in the legend. Left are results for NL, and right for SFR-cent. More extreme rainfall occurs at higher DP (higher absolute humidity) and higher DPD (lower relative humidity).

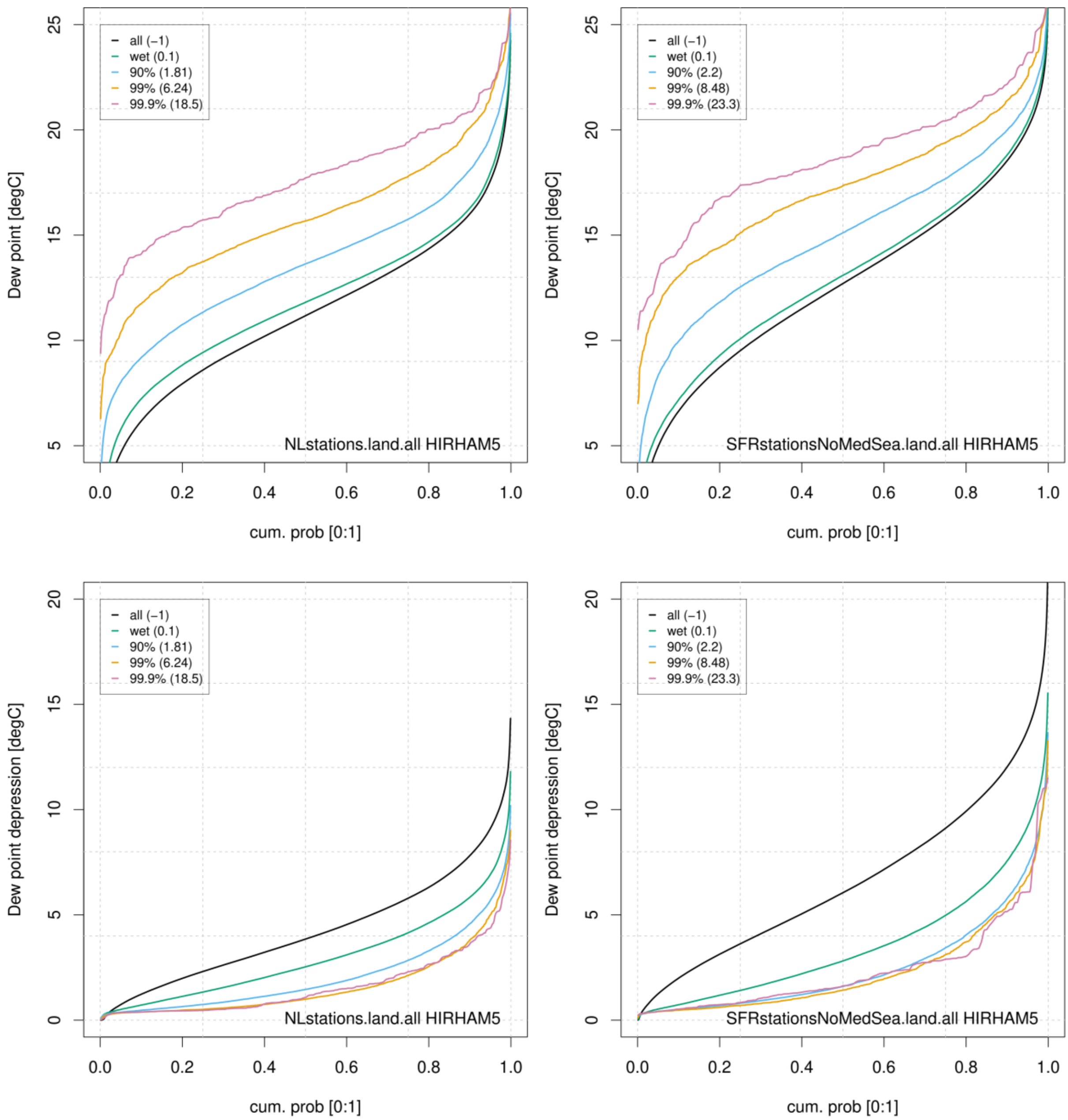


Figure S14. Same as previous Figure, but now for an RCM (HIRHAM5). The model slightly overestimates absolute humidity for extreme events, but strongly overestimates the relative humidity (too small DPD).

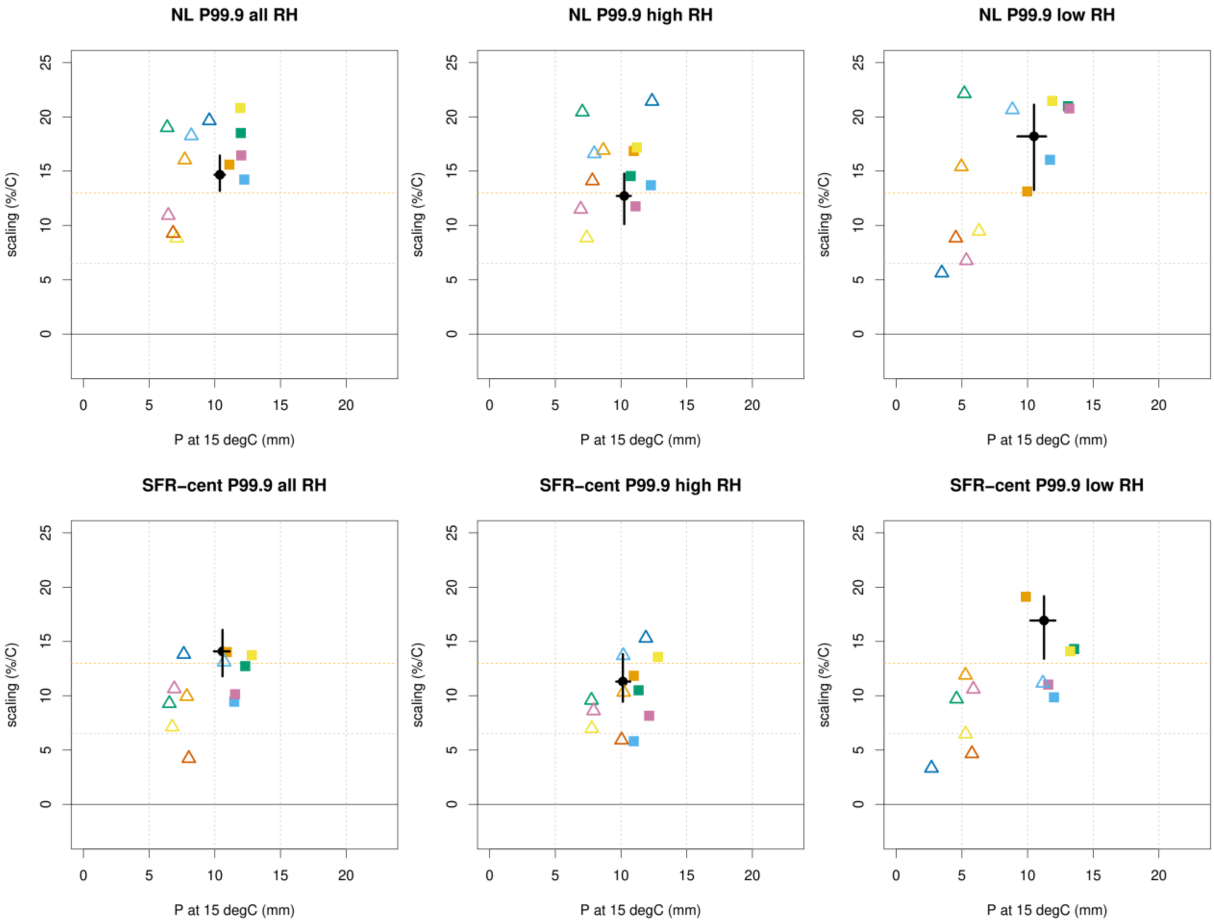


Figure S15. As Figure 7 of the main text, but now for the 99.9th percentile of all hours (absolute percentile). Note the slightly higher values of precipitation for low relative humidity (11-12 mm, on the right) as compared to high relative humidity (10 mm, middle). Note also that observed scaling coefficients have larger uncertainty estimates and vary more for the different selections on relative humidity, but are again surprisingly similar in NL and SFR-cent.

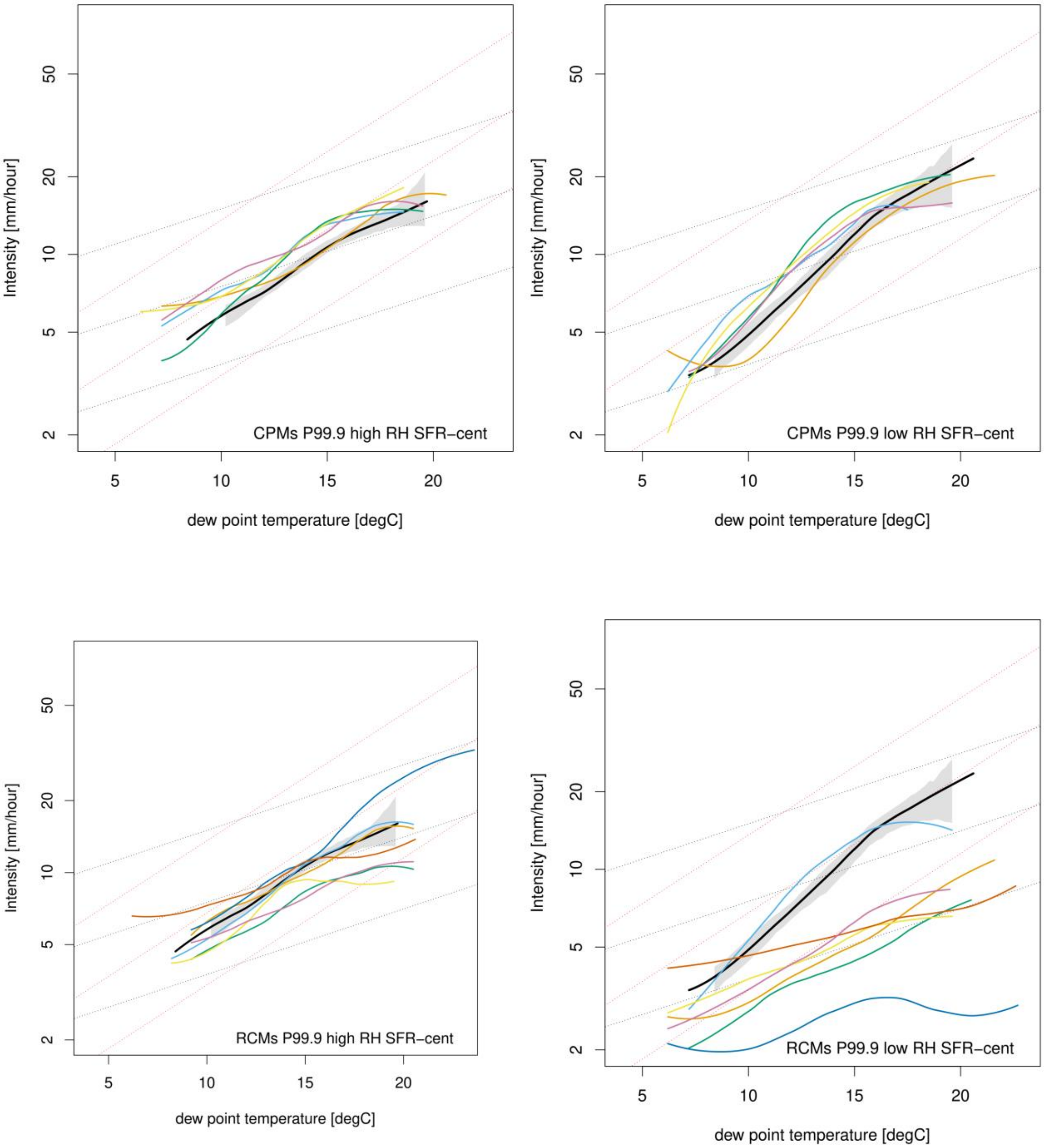


Figure S16. Scaling of hourly rainfall for cases with high relative humidity (left) and low relative humidity (right). Percentiles are now based on all hours, including dry hours. Shown is the 99.9th percentile (~ once every 1000 hours). Upper panels compare CPMs to the observations, and lower panels the RCMs.

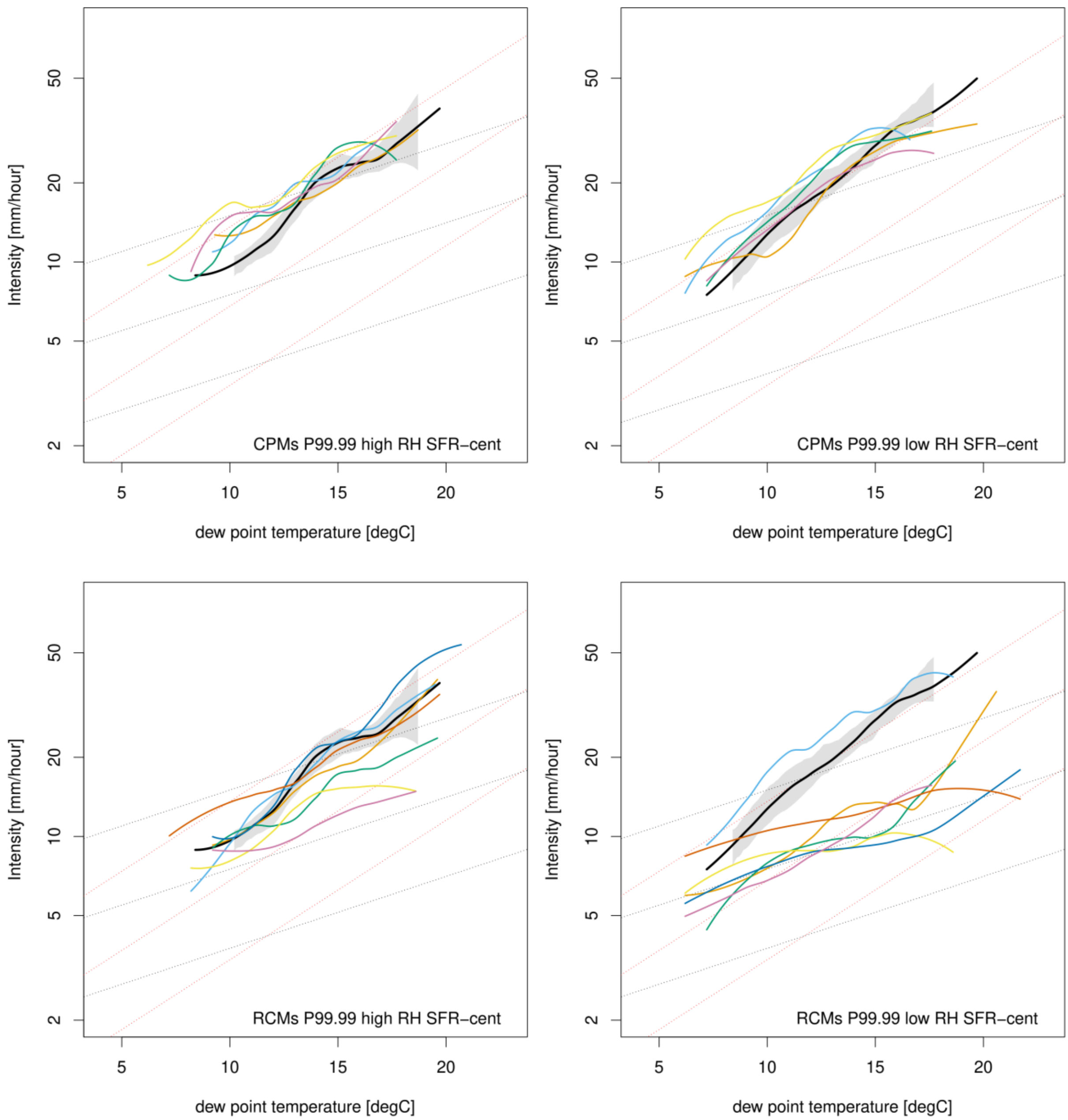


Figure S17. Same as previous Figure, but now the 99.99th percentile of hourly rainfall.

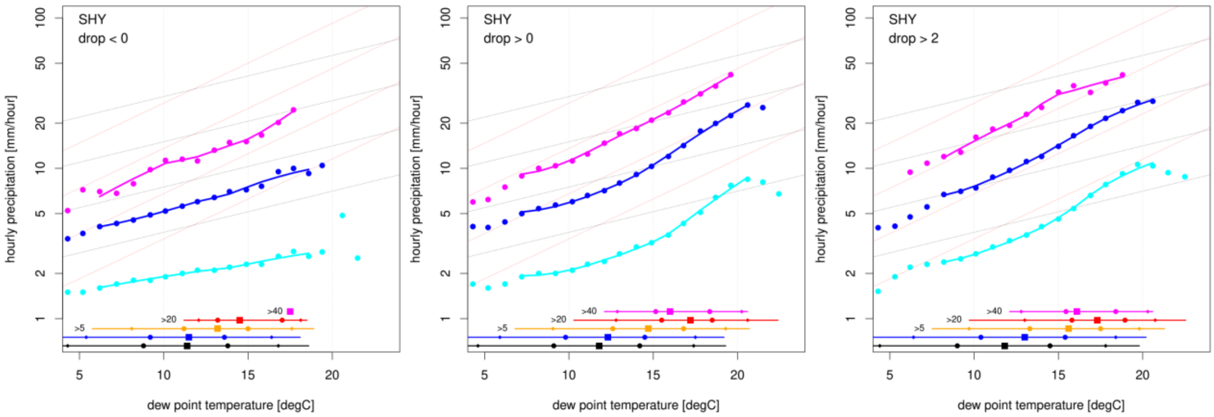


Figure S18. Scaling on sub-selections of data characterized by the temperature drop between two hour before and one hour after the rainfall measurement. From left to right, a temperature rise (negative drop), temperature drop, and temperature drop exceeding 2 degrees.

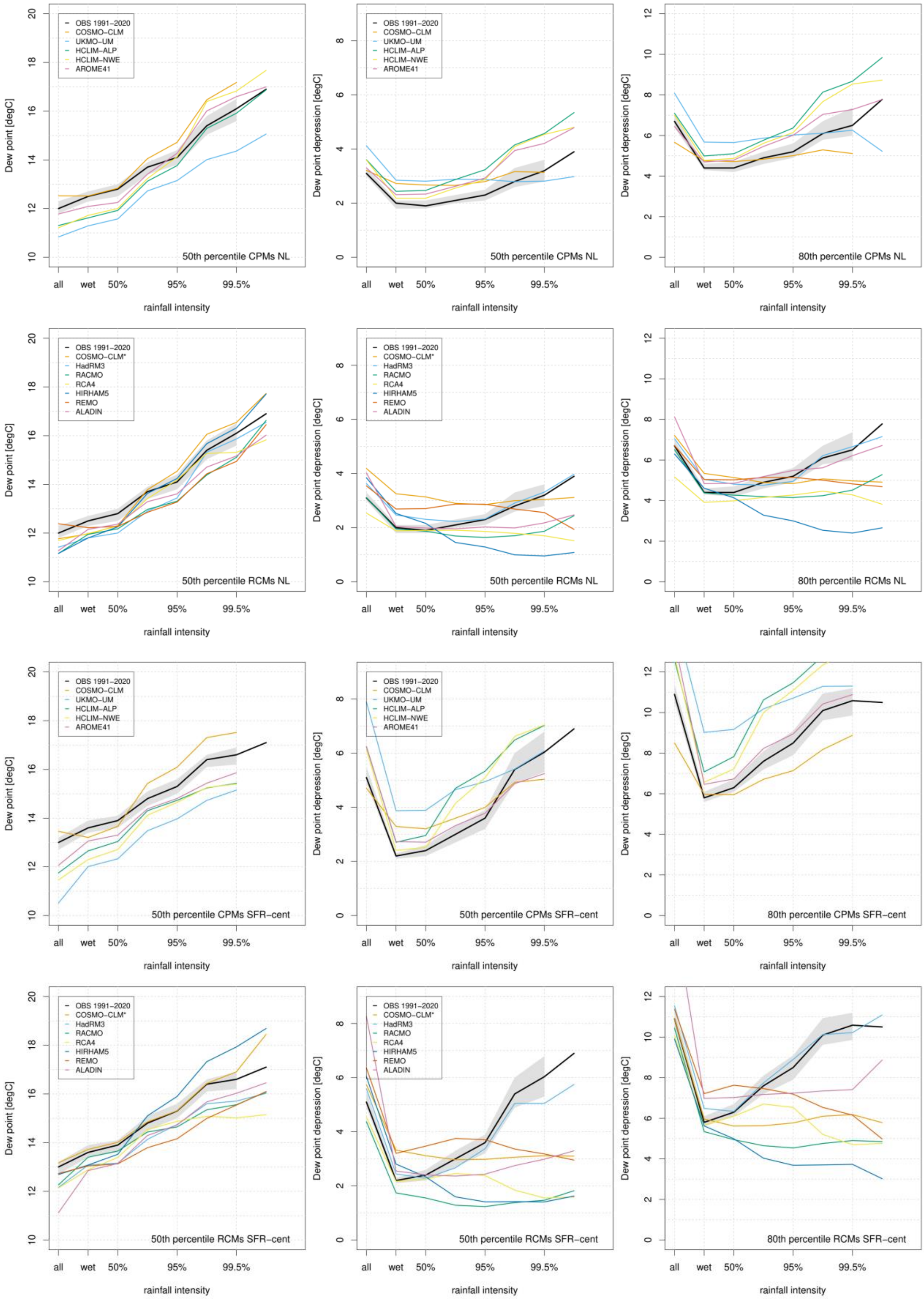


Figure S19. As Figure 3 of paper, but now with the CPM results based on mean precipitation over 5x5 grid points similar to the resolution of the RCMs.

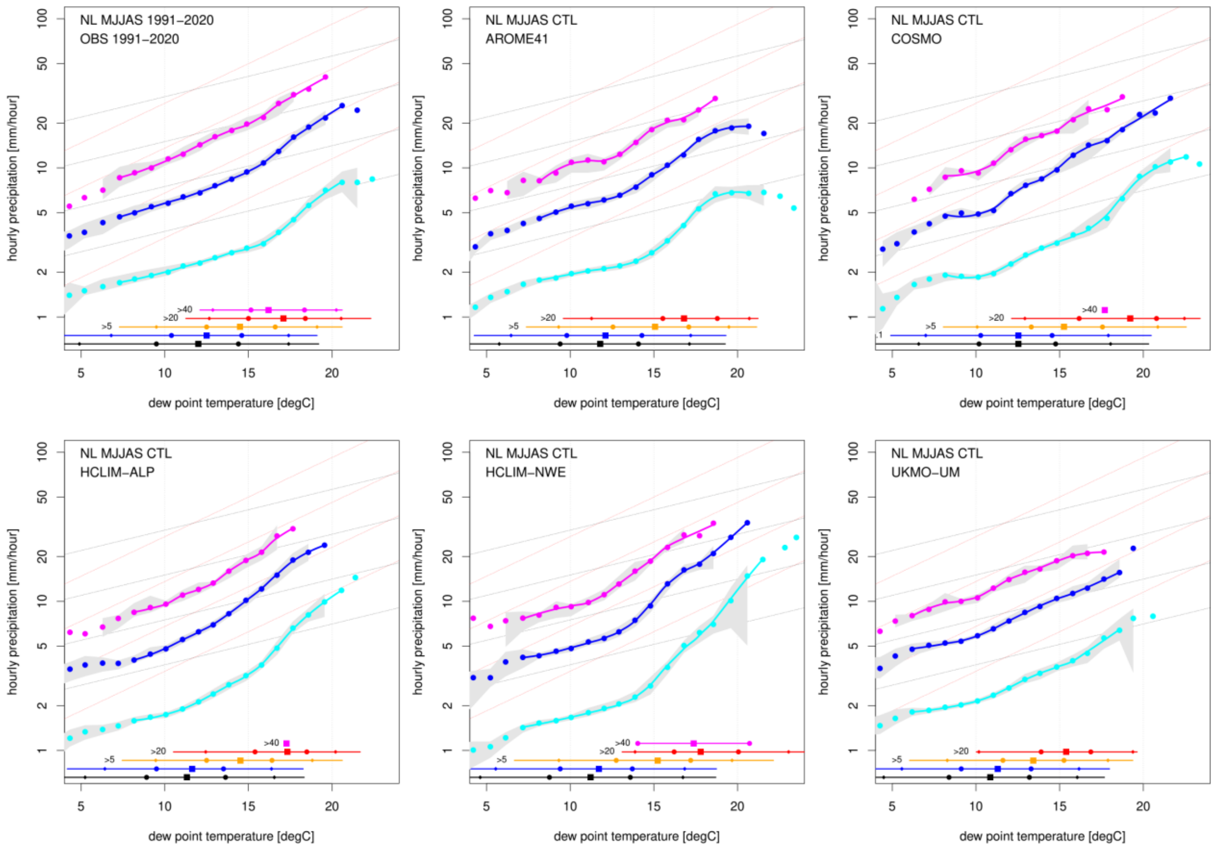


Figure S20. As Figure S6 of supplement, but now with the CPM results based on mean precipitation over 5x5 grid points similar to the resolution of the RCMs.