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Effects of univariate and multivariate bias correction on hydrological impact projections in alpine catchments

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1 Results hydrological model calibration and validation: Figures S1–S2

In the Figures S1-S2 results of the model calibration and validation are shown for the Hinterrhein and the Schwarze Lütschine catchment. Due to the availability of glacier volume data in 1973 and 2003, calibration was carried out after a 3-year warm-up period from 1976 to 2003 and the validation of the model from 2003 to 2006, which marks the end of the availability of the meteorological data used as input. The graphs show all evaluated aspects: streamflow, glacier volume, snow cover, and SWE.

2 Results bias correction distributions of temperature and precipitation data: Figures S3–S42

To illustrate differences of the bias correction methods on the climate variables precipitation and air temperature, Figures S3-S42 were added for each GCM–RCM dataset and for the two RCP scenarios. The top and the bottom row of the graph panels show the marginal distributions of the climate variables. These demonstrate that both bias correction methods, QDM and MBCn, correct the individual climate variables similarly well. This is the consequence of both methods being based on the same quantile mapping method. However, their differences lie in the ability to preserve the interdependence of the climate variables. This is shown in the middle two rows of the panels, where the two climate variables are plotted against each other. Local regression lines show the variation of the interdependence and so do the density plots in the third row. As the zero-degree air temperature line lies within the catchments mostly all year around, these differences translate quite prominently into the hydrological processes, as shown in this study.

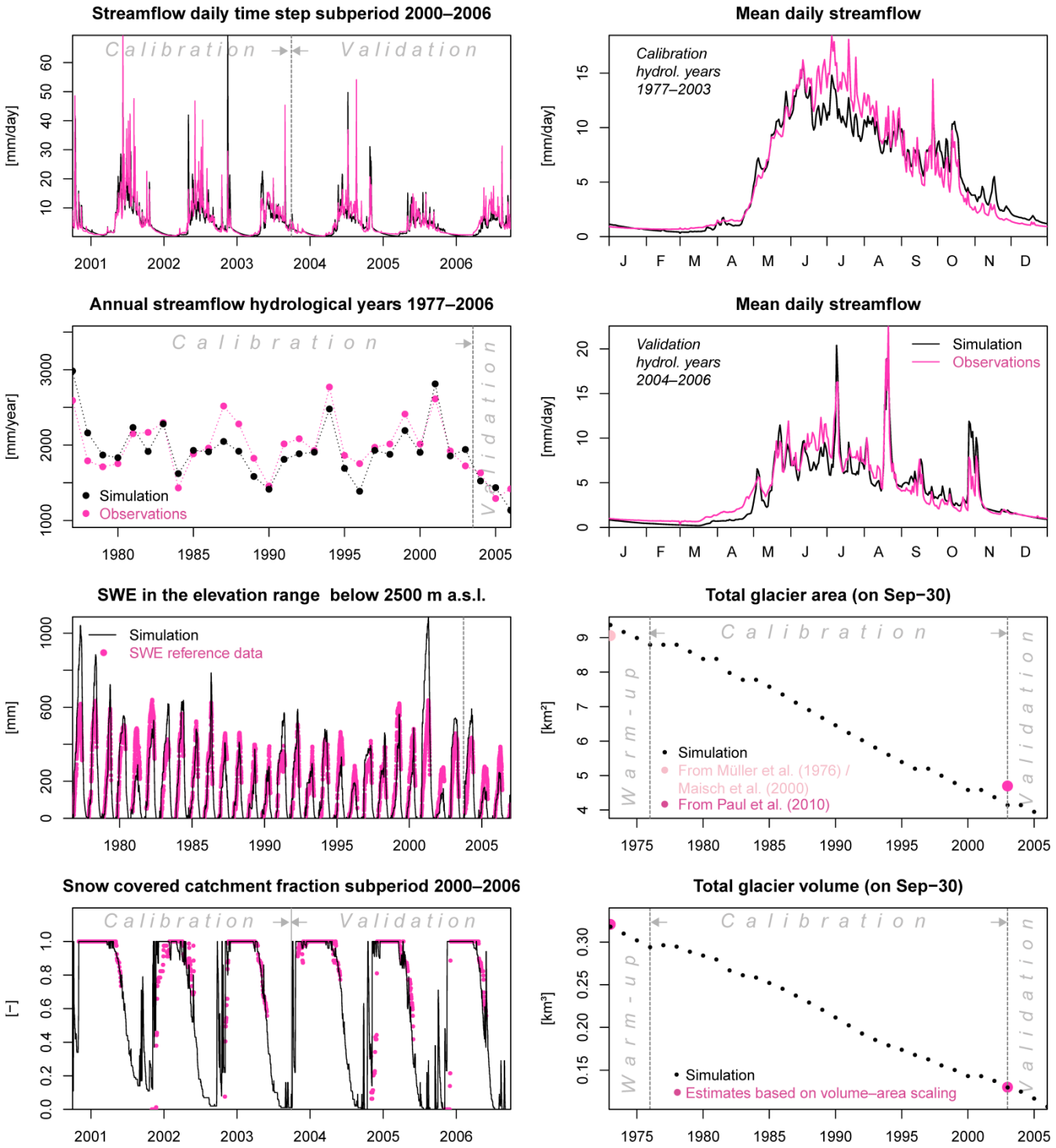

Figure S1: Hinterrhein catchment: Streamflow, area-weighted mean snow water equivalent (SWE) for the catchment's elevation range below 2500 m a.s.l. (1550–2500 m a.s.l.), snow covered catchment area fraction, glacier volume, and glacier area from HBV-light simulations (in black) compared to observation-based reference data (in pink). All shown variables with the exception of glacier area were used in the multi-criteria model calibration. Calibration period: 1976-10-01 until 2003-09-30; validation period: 2003-10-01 until 2006-12-31.

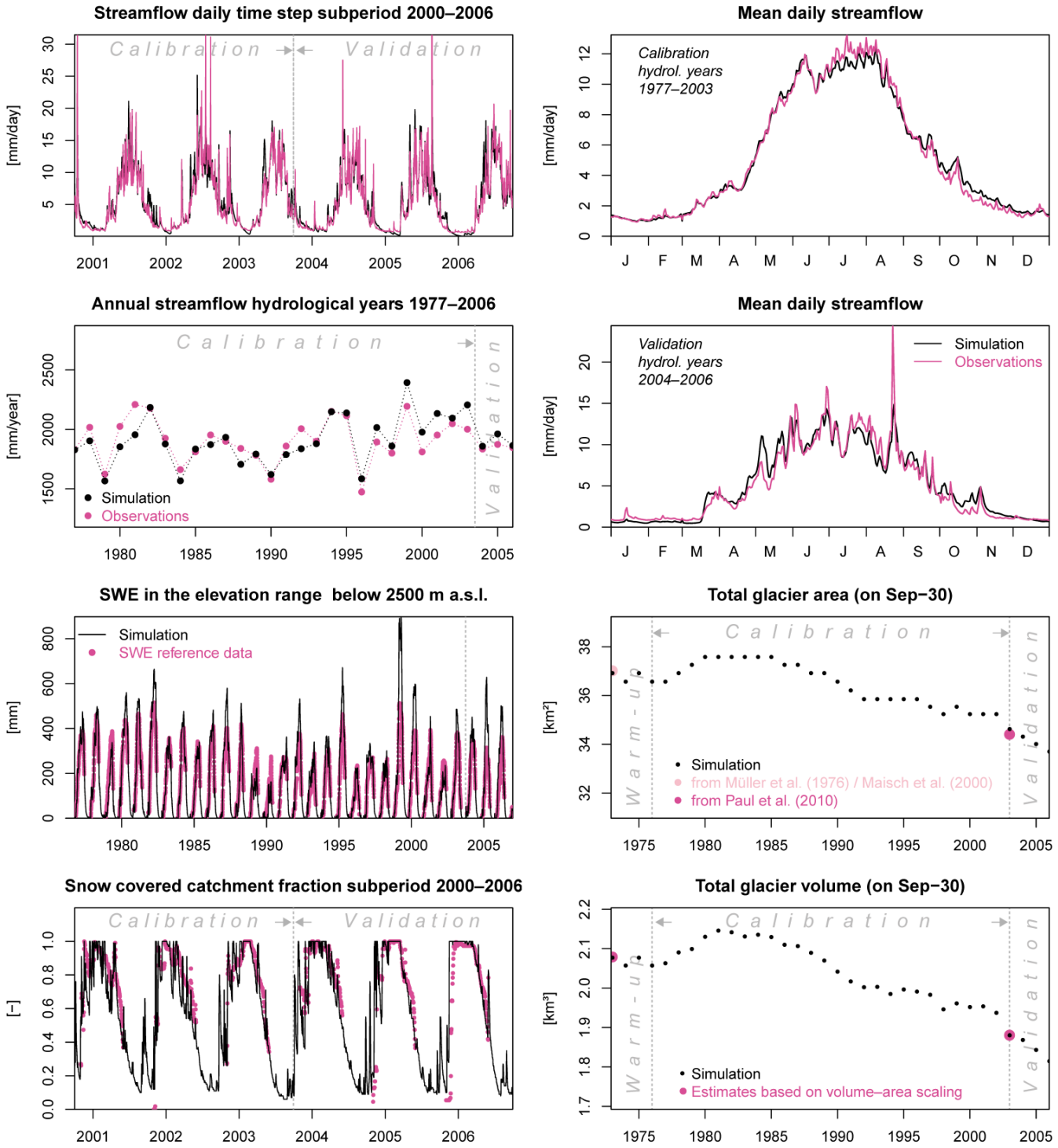

Figure S2: Schwarze Lütschine catchment: Streamflow, area-weighted mean snow water equivalent (SWE) for the catchment's elevation range below 2500 m a.s.l. (650–2500 m a.s.l.), snow covered catchment area fraction, glacier volume, and glacier area from HBV-light simulations (in black) compared to observation-based reference data (in pink). All shown variables with the exception of glacier area were used in the multi-criteria model calibration. Calibration period: 1976-10-01 until 2003-09-30; validation period: 2003-10-01 until 2006-12-31.

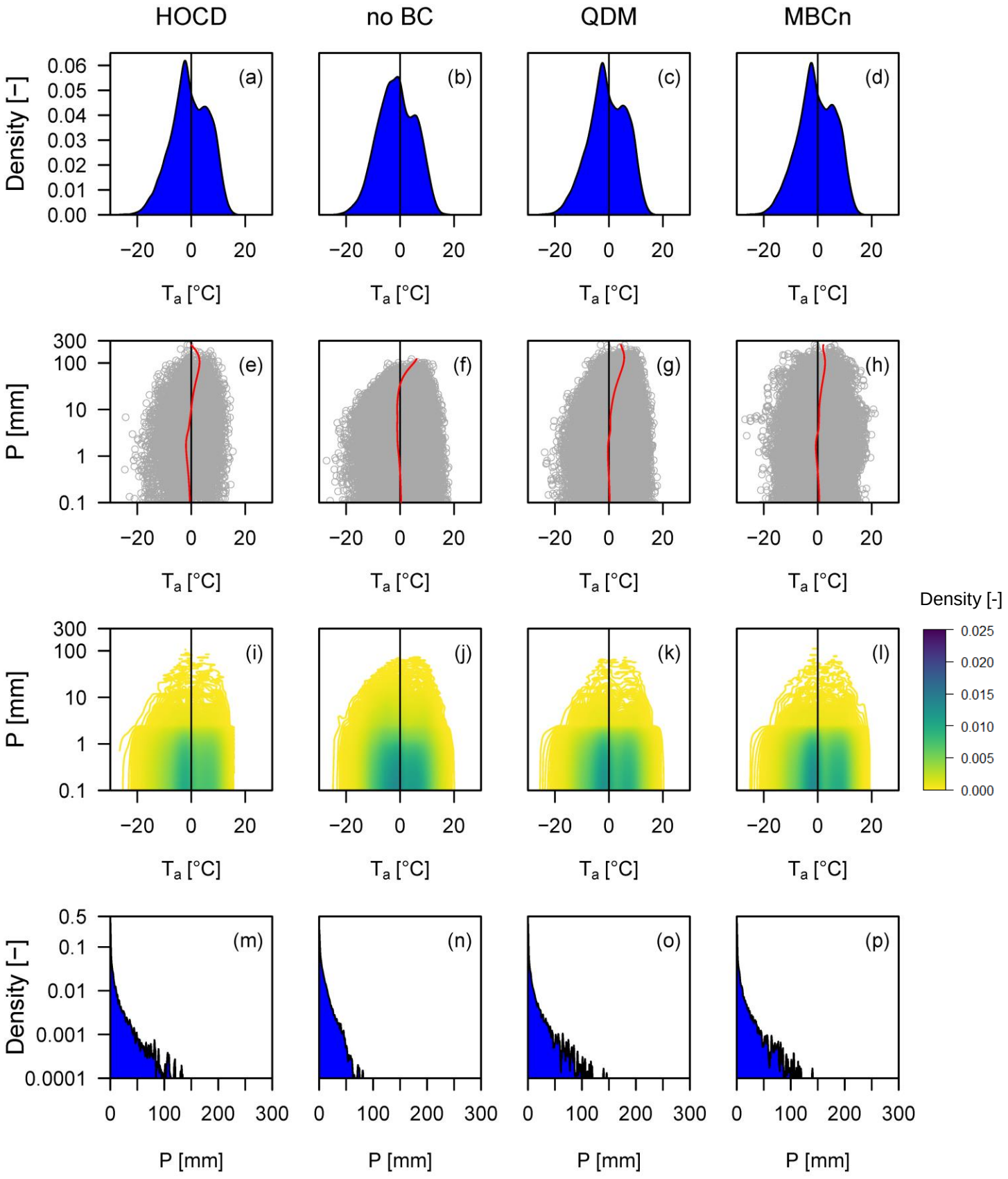

Figure S3: Hinterrhein catchment: Representation of T_a and P over the historical reference period 1977–2006 for the Hinterrhein catchment according to the historically observed climate data (column HOCD) and uncorrected (no BC), univariate-corrected (column QDM), and bivariate-corrected (column MBCn) data from EC-EARTH–CCLM4-8-17 for RCP 4.5. Top and bottom panel show marginal distributions of T_a and P, respectively; centre panels show bivariate plots for T_a and P with local regression lines (plots e–h) and density allocation (plots i–l).

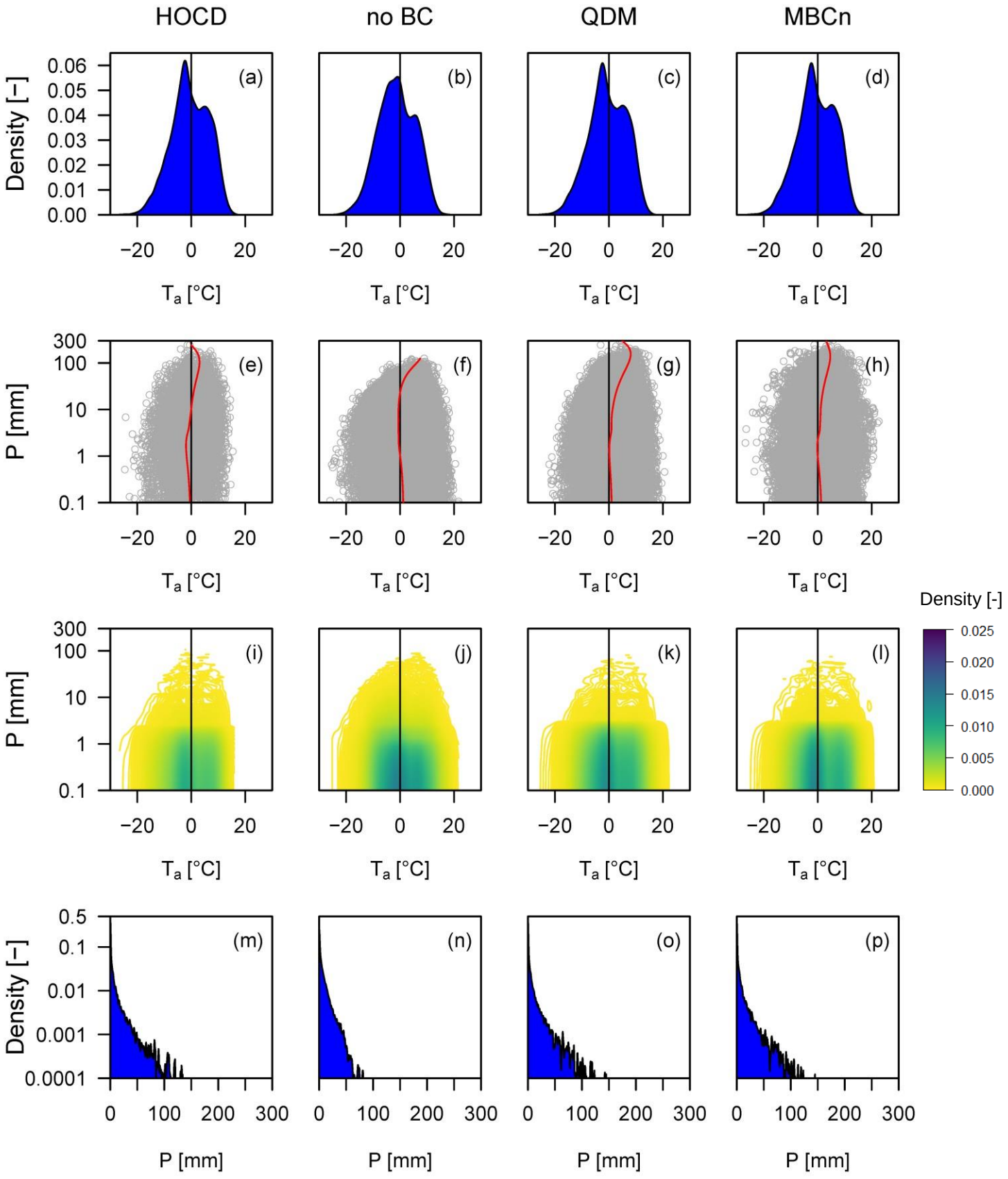

Figure S4: As previous figure (for detailed explanations see Figure S3) but for data from EC-EARTH–CCLM4-8-17 for RCP 8.5 for the Hinterrhein catchment.

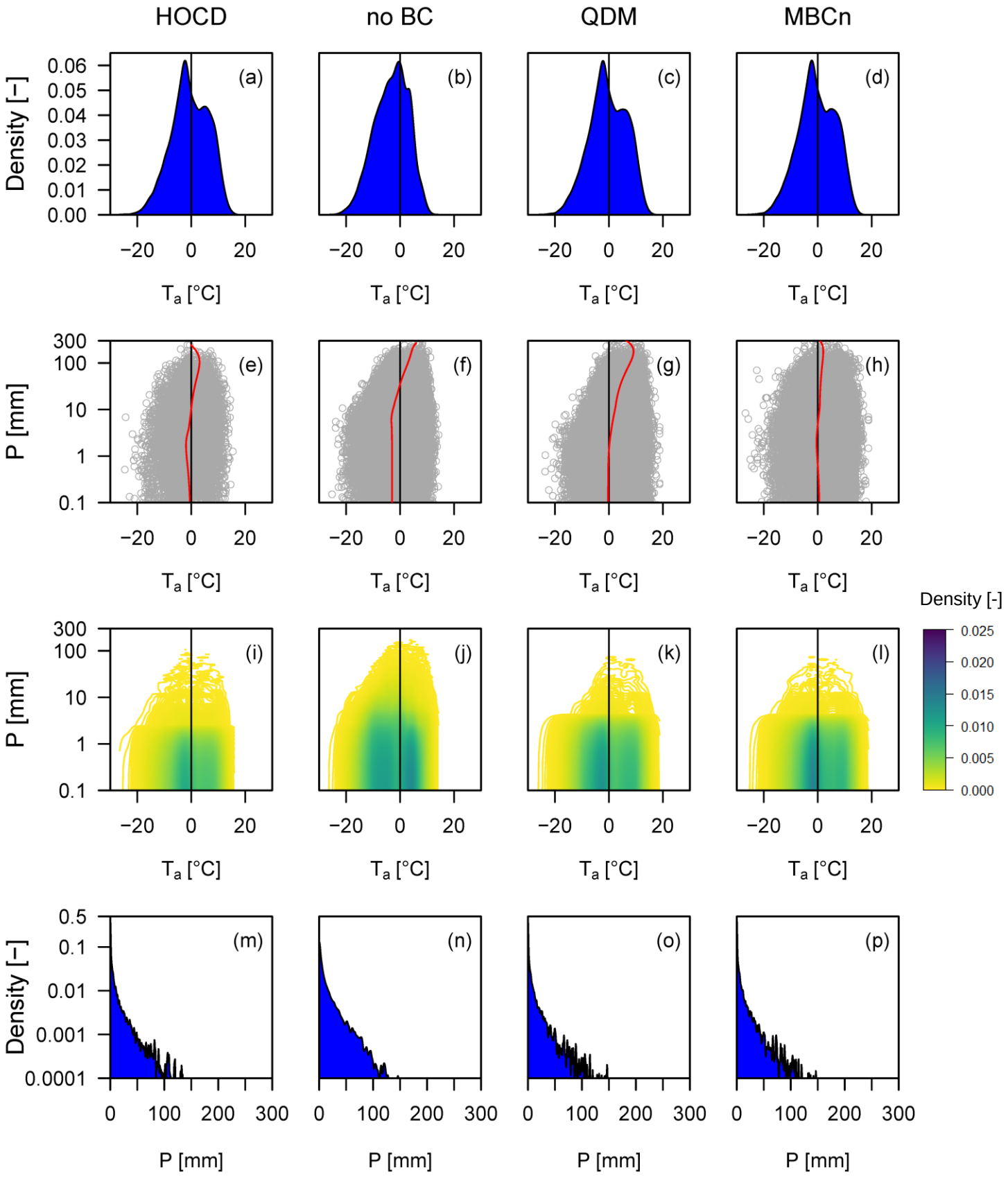

Figure S5: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–HIRHAM5 for RCP 4.5 for the Hinterrhein catchment.

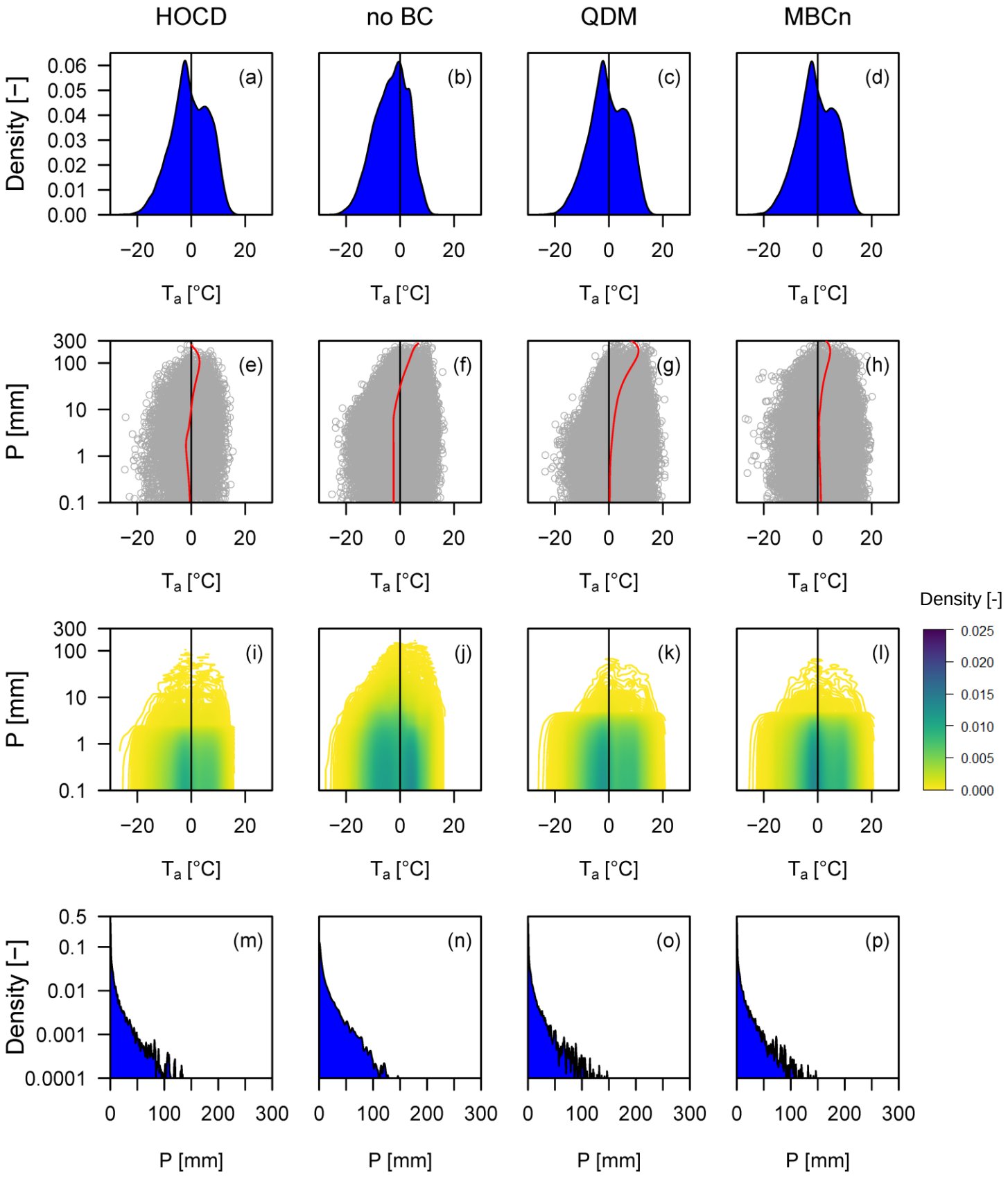

Figure S6: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–HIRHAM5 for RCP 8.5 for the Hinterrhein catchment.

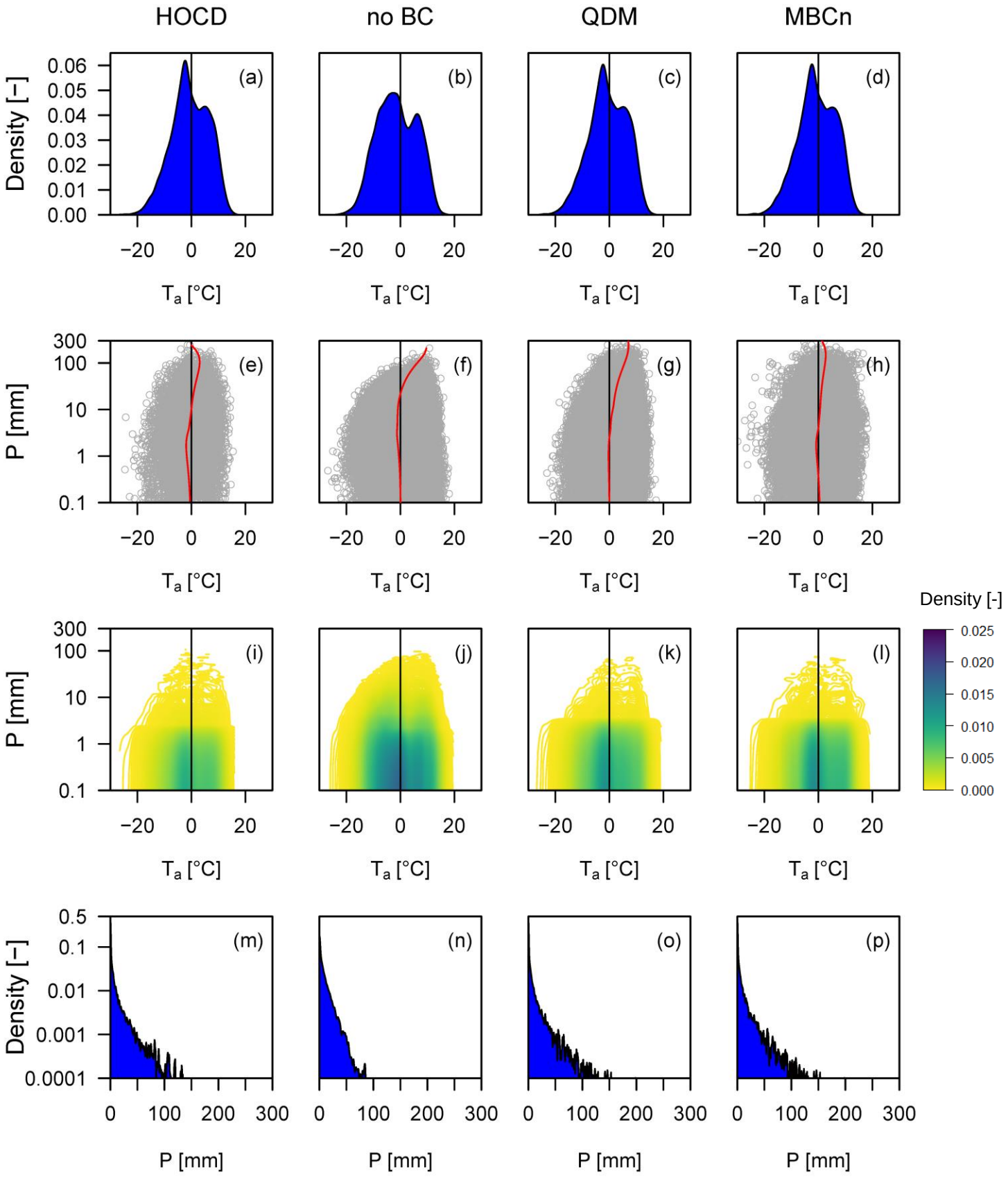

Figure S7: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5-LR–CCLM4-8-17 for RCP 4.5. Note that a warning concerning an inconsistency in the historical run of the GCM CNRM-CM5 has been issued on the CORDEX errata page (https://www.euro-cordex.net/078730/index.php.en) after data had been downloaded and selected for this study.

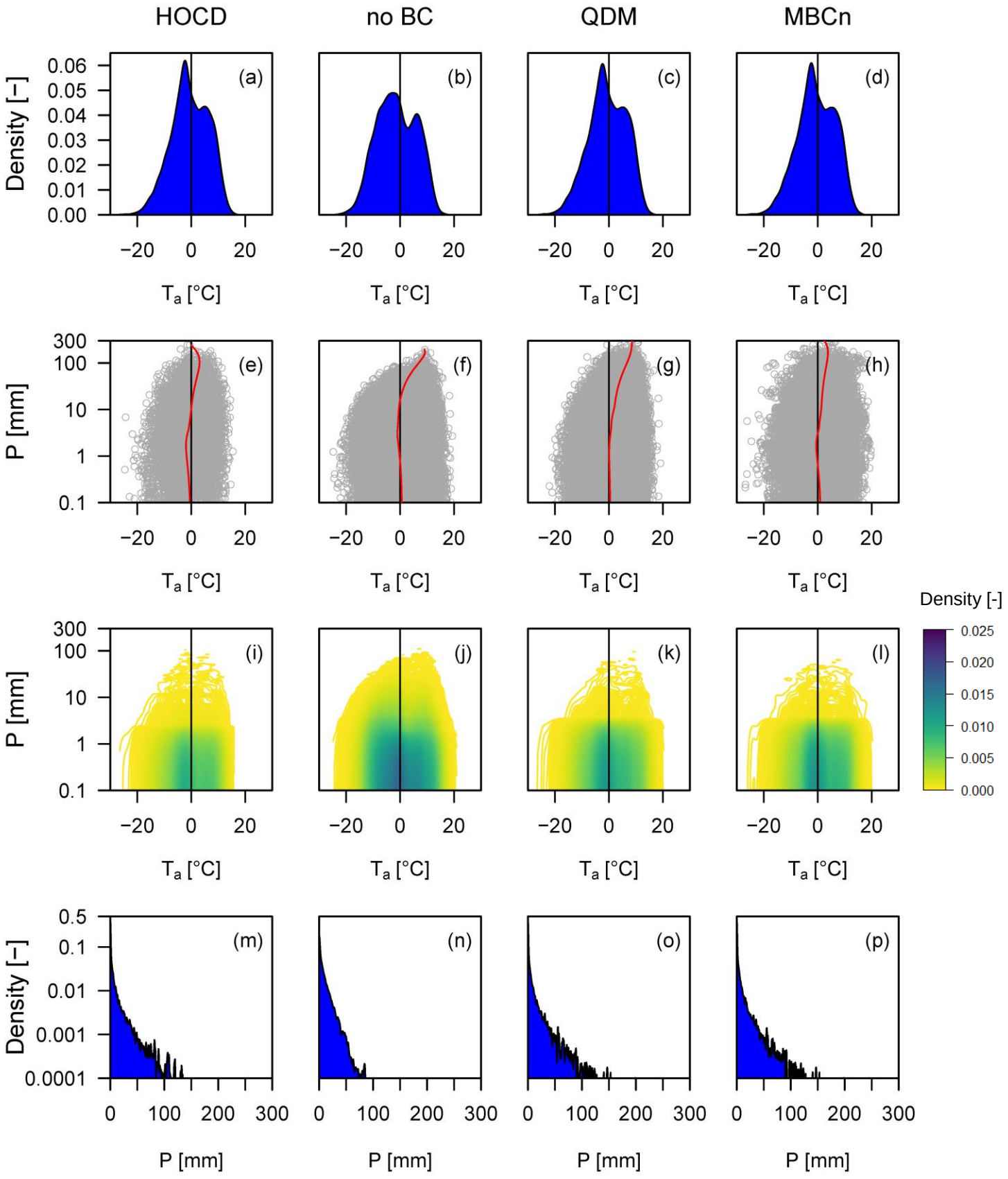

Figure S8: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5-LR–CCLM4-8-17 for RCP 8.5 for the Hinterrhein catchment. Note that a warning concerning an inconsistency in the historical run of the GCM CNRM-CM5 has been issued on the CORDEX errata page (https://www.euro-cordex.net/078730/index.php.en) after data had been downloaded and selected for this study.

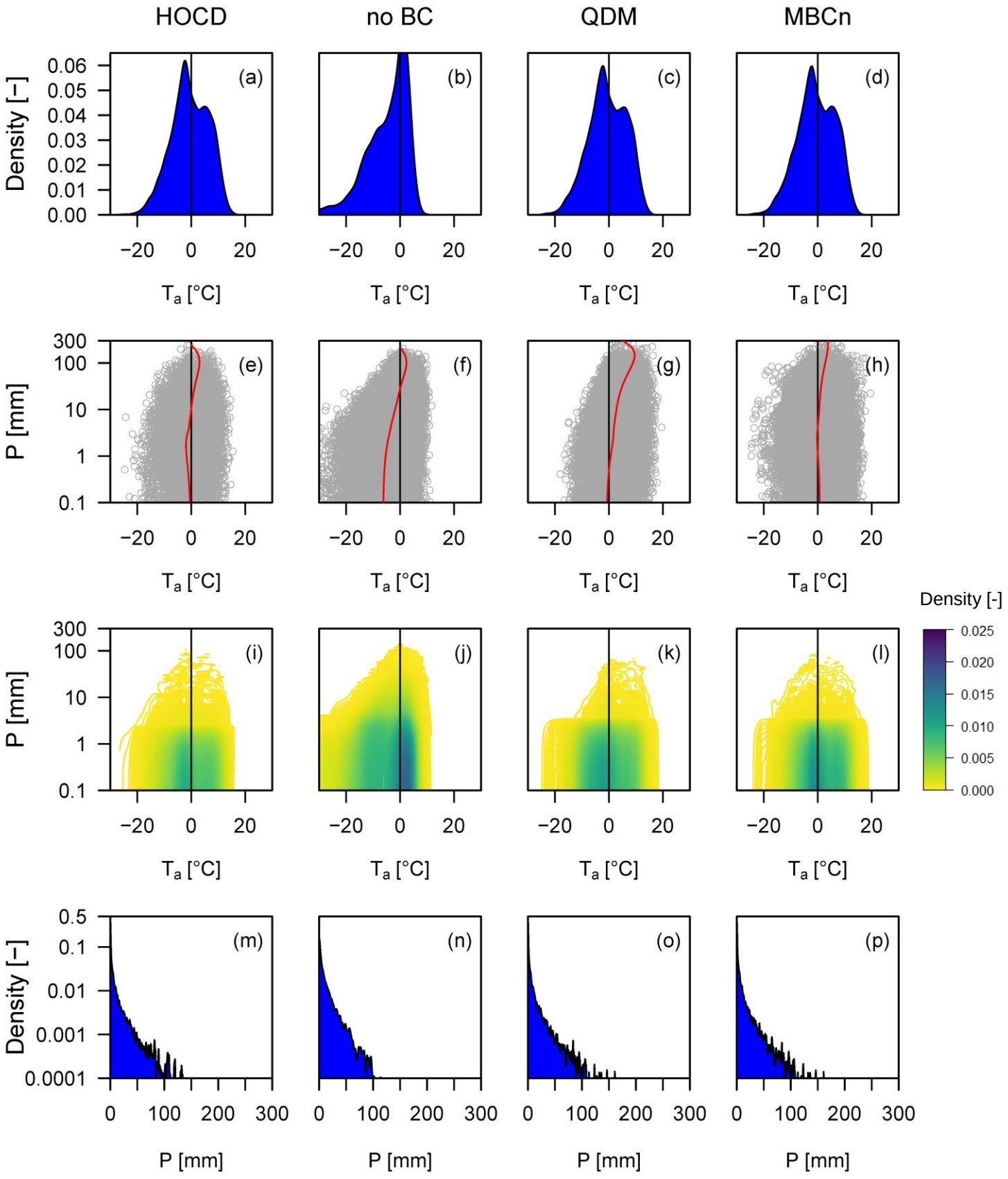

Figure S9: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5–RCA4 for RCP 4.5 for the Hinterrhein catchment.

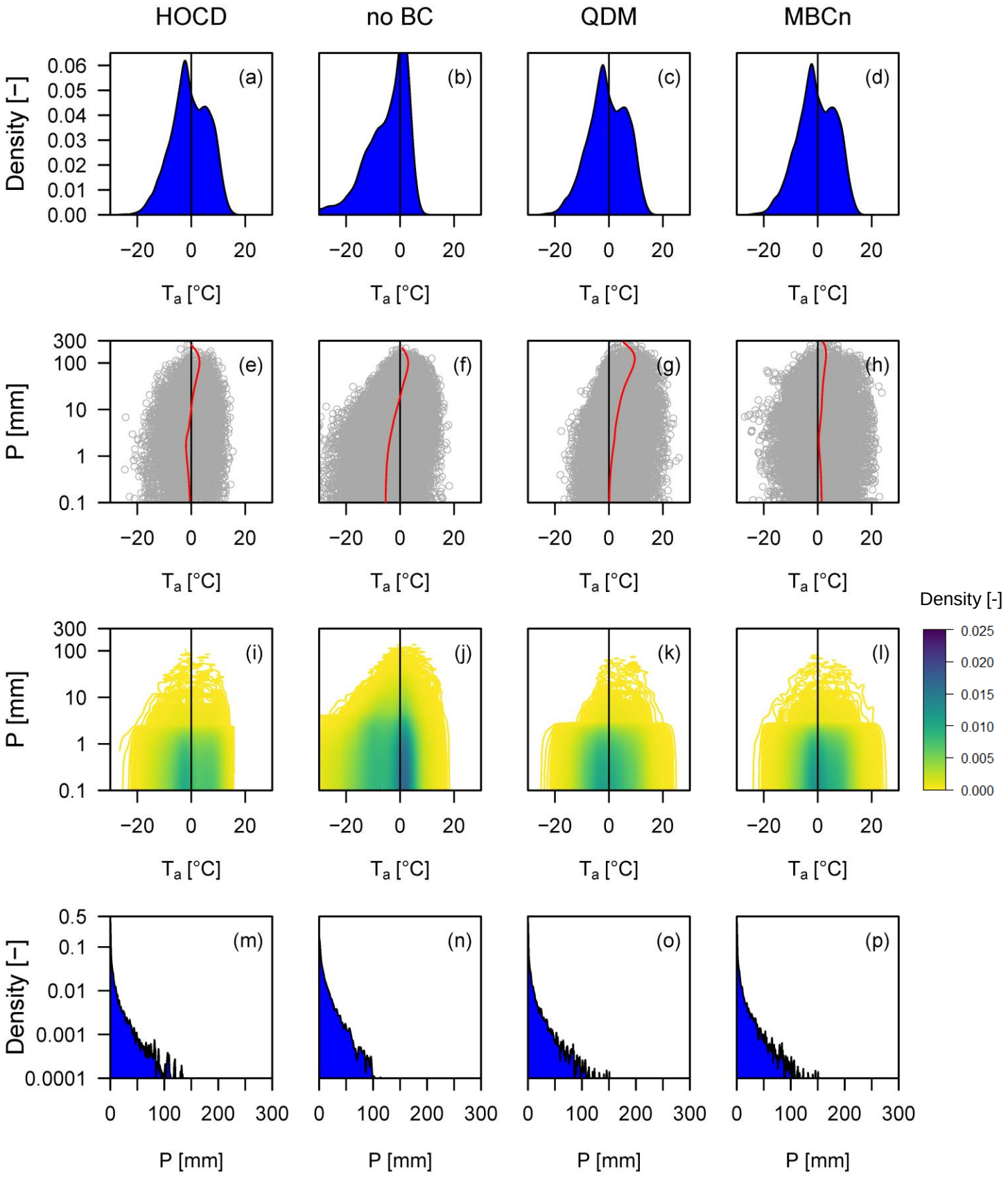

Figure S10: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5–RCA4 for RCP 8.5 for the Hinterrhein catchment.

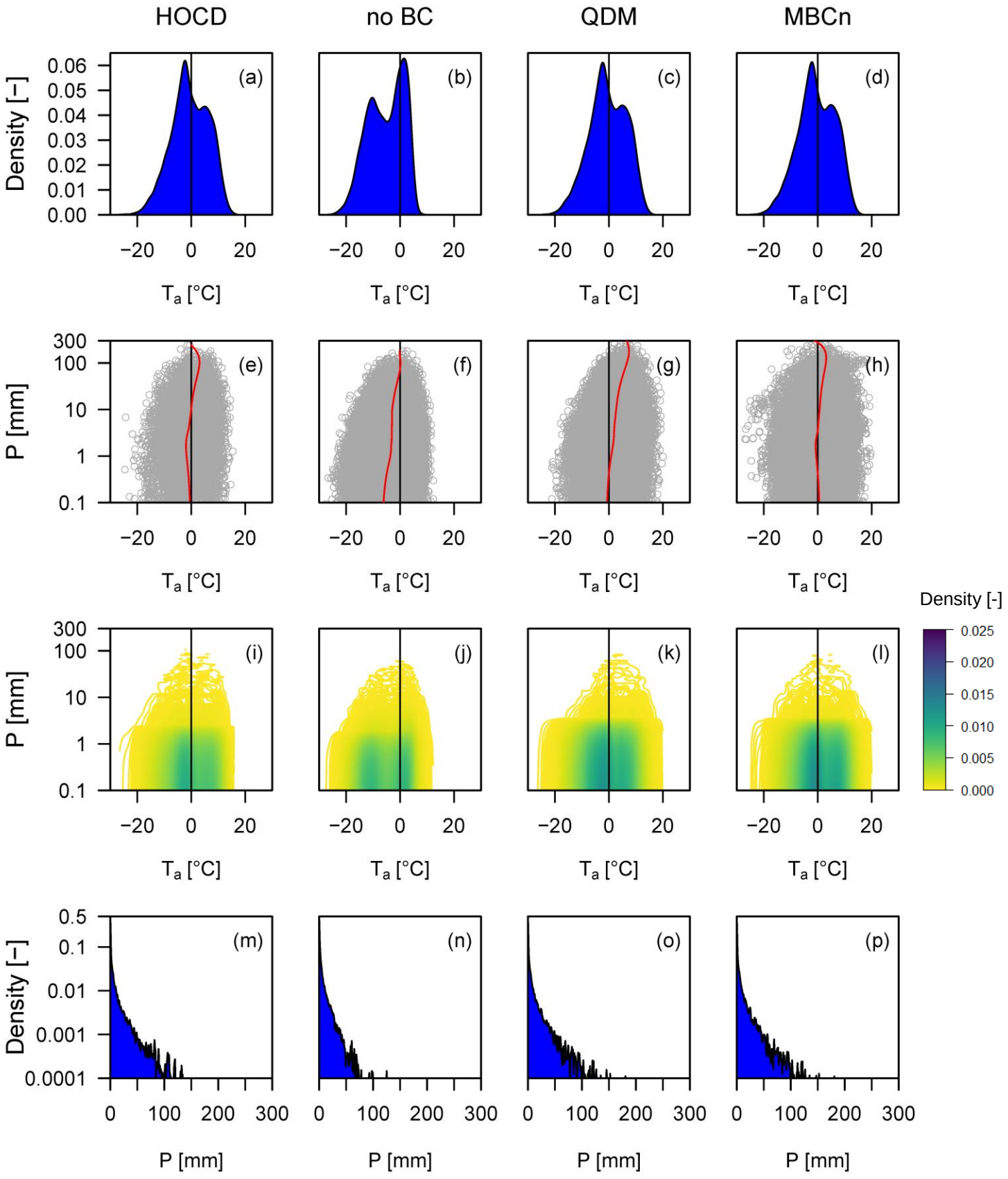

Figure S11: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–RACMO22E for RCP 4.5 for the Hinterrhein catchment.

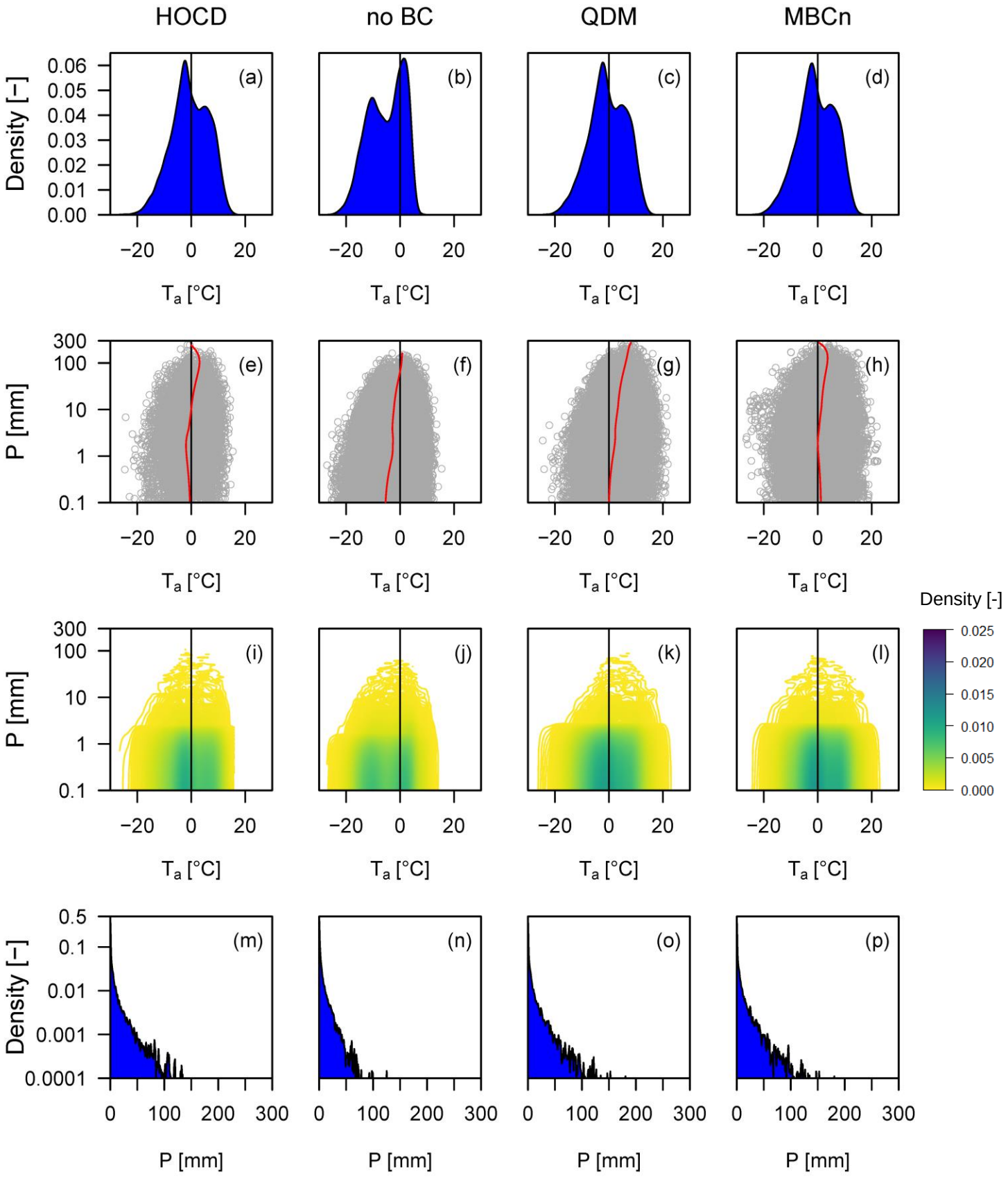

Figure S12: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–RACMO22E for RCP 8.5 for the Hinterrhein catchment.

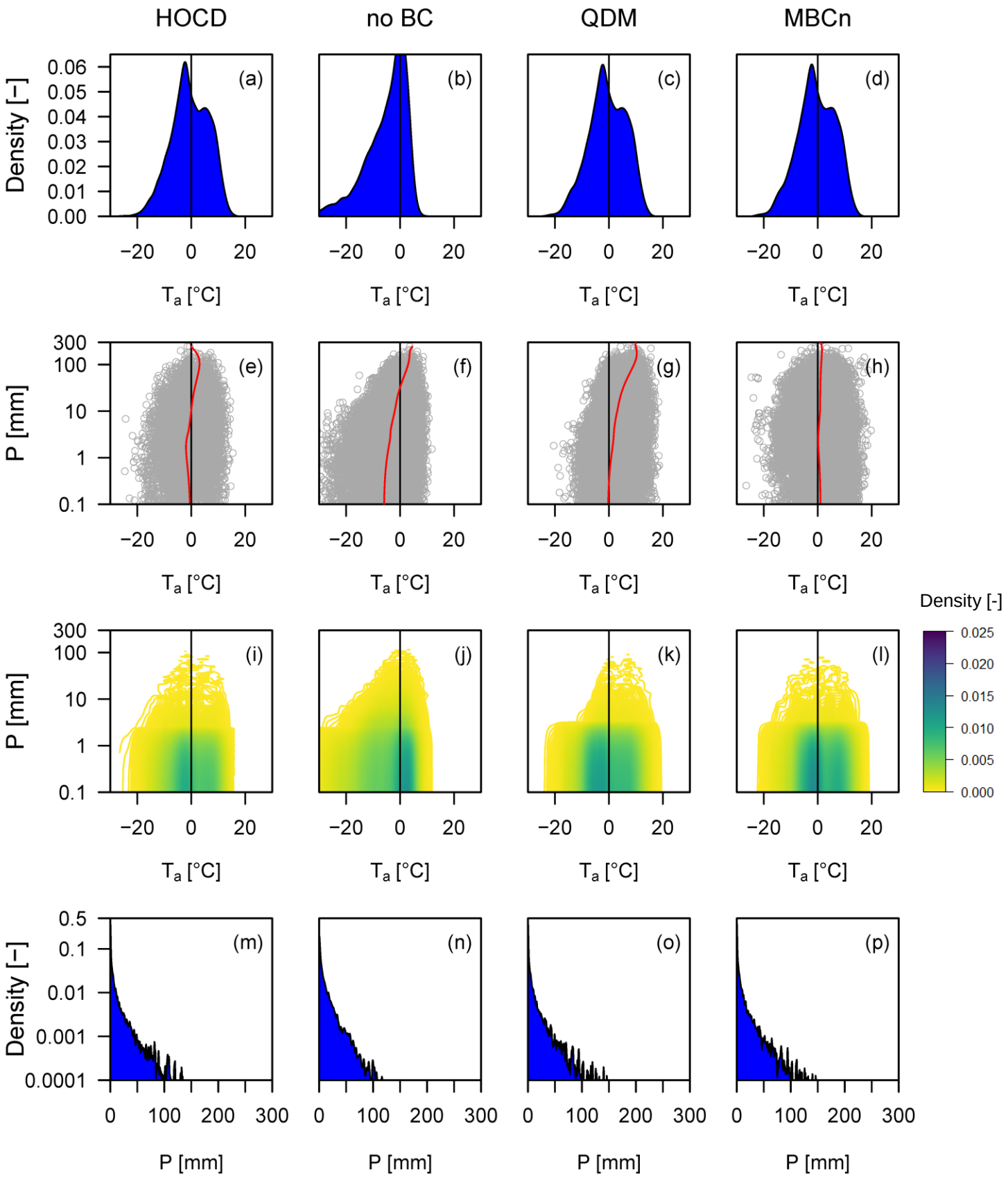

Figure S13: As previous figures (for detailed explanations see Figure S3) for the Hinterrhein catchment but for data from EC-EARTH–RCA4 for RCP 4.5 for the Hinterrhein catchment.

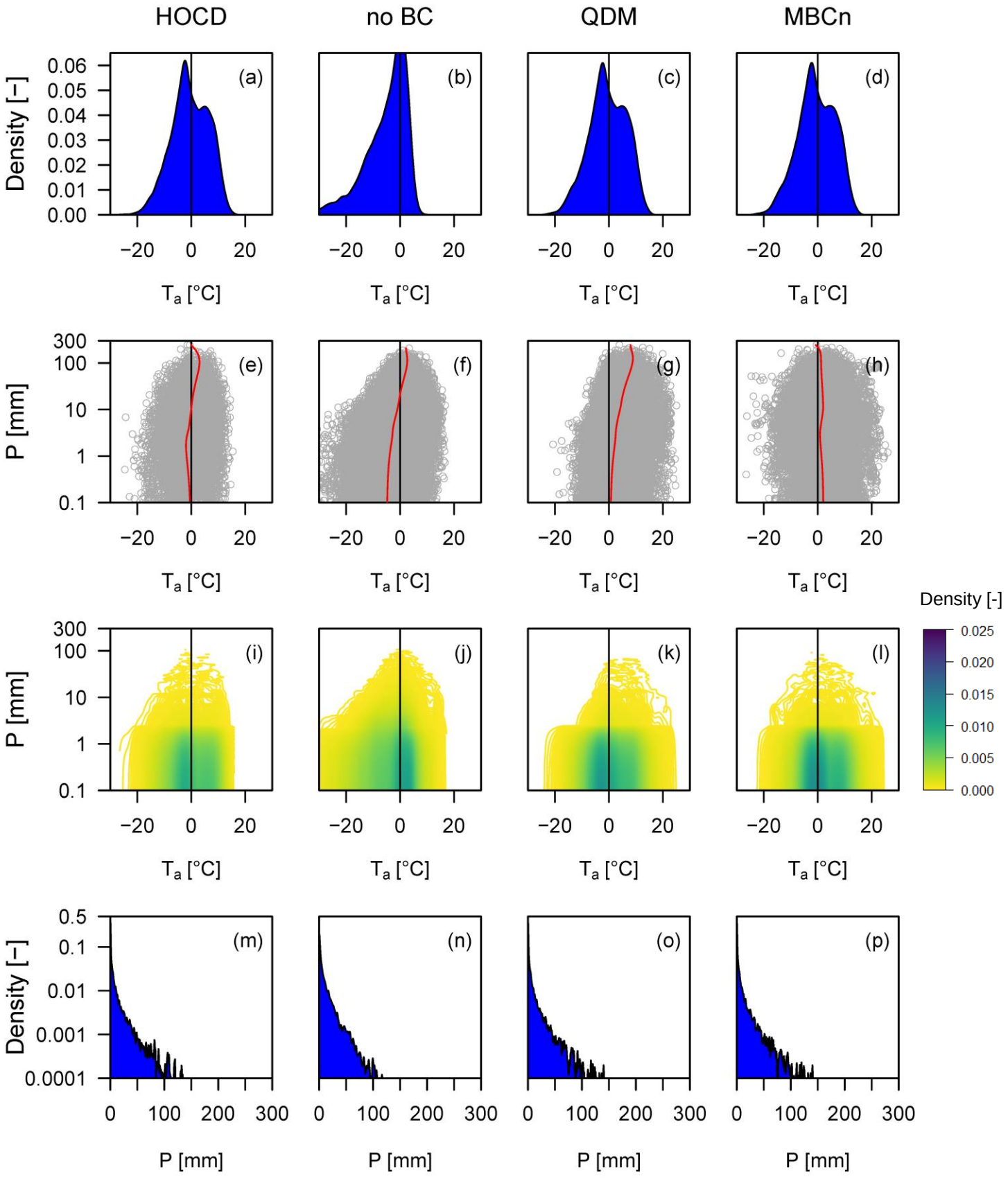

Figure S14: As previous figure (for detailed explanations see Figure S3) but for data from EC-EARTH–RCA4 for RCP 8.5 for the Hinterrhein catchment.

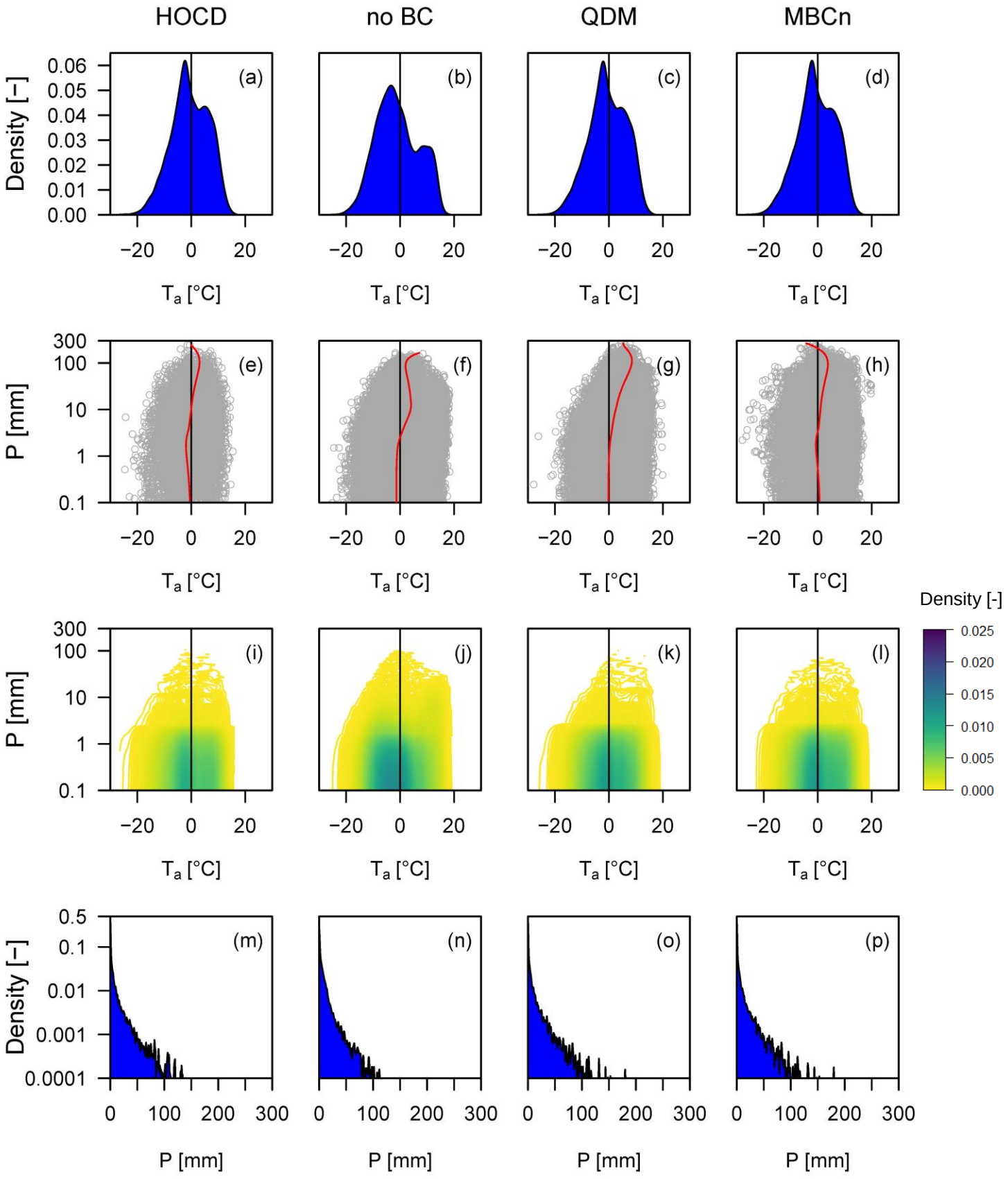

Figure S15: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–WRF331F for RCP 4.5 for the Hinterrhein catchment.

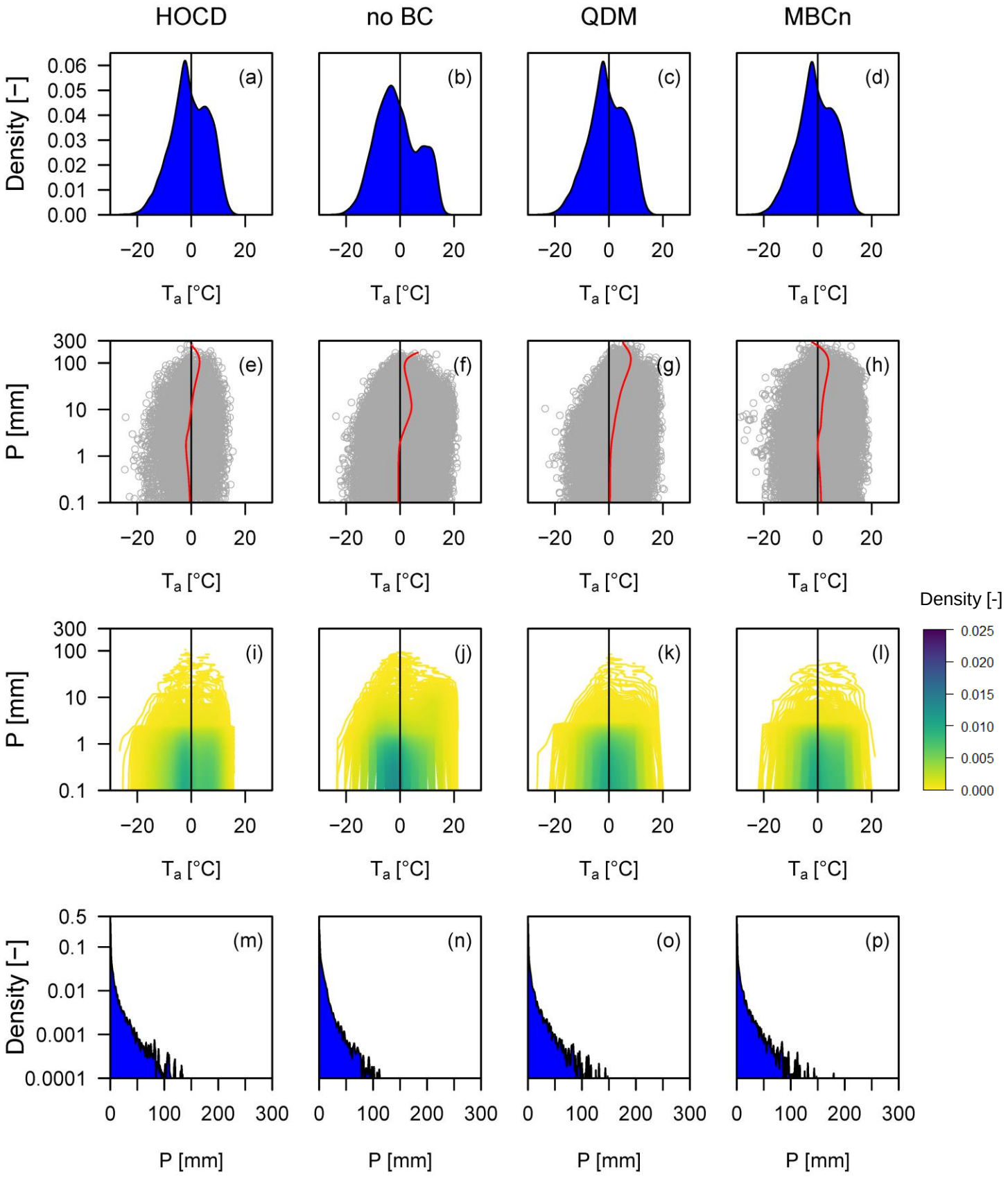

Figure S16: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–WRF331F for RCP 8.5 for the Hinterrhein catchment.

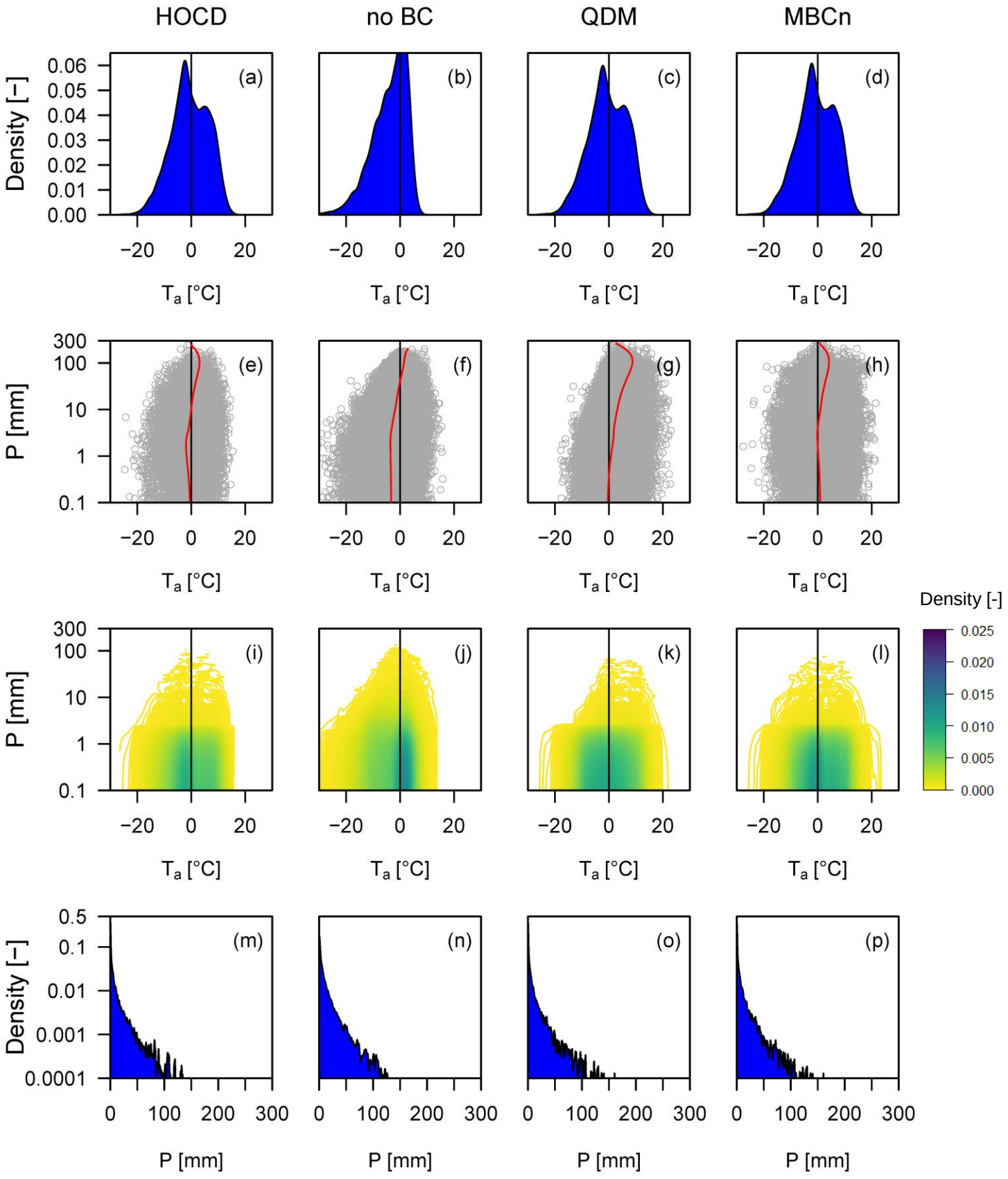

Figure S17: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–RCA4 for RCP 4.5 for the Hinterrhein catchment.

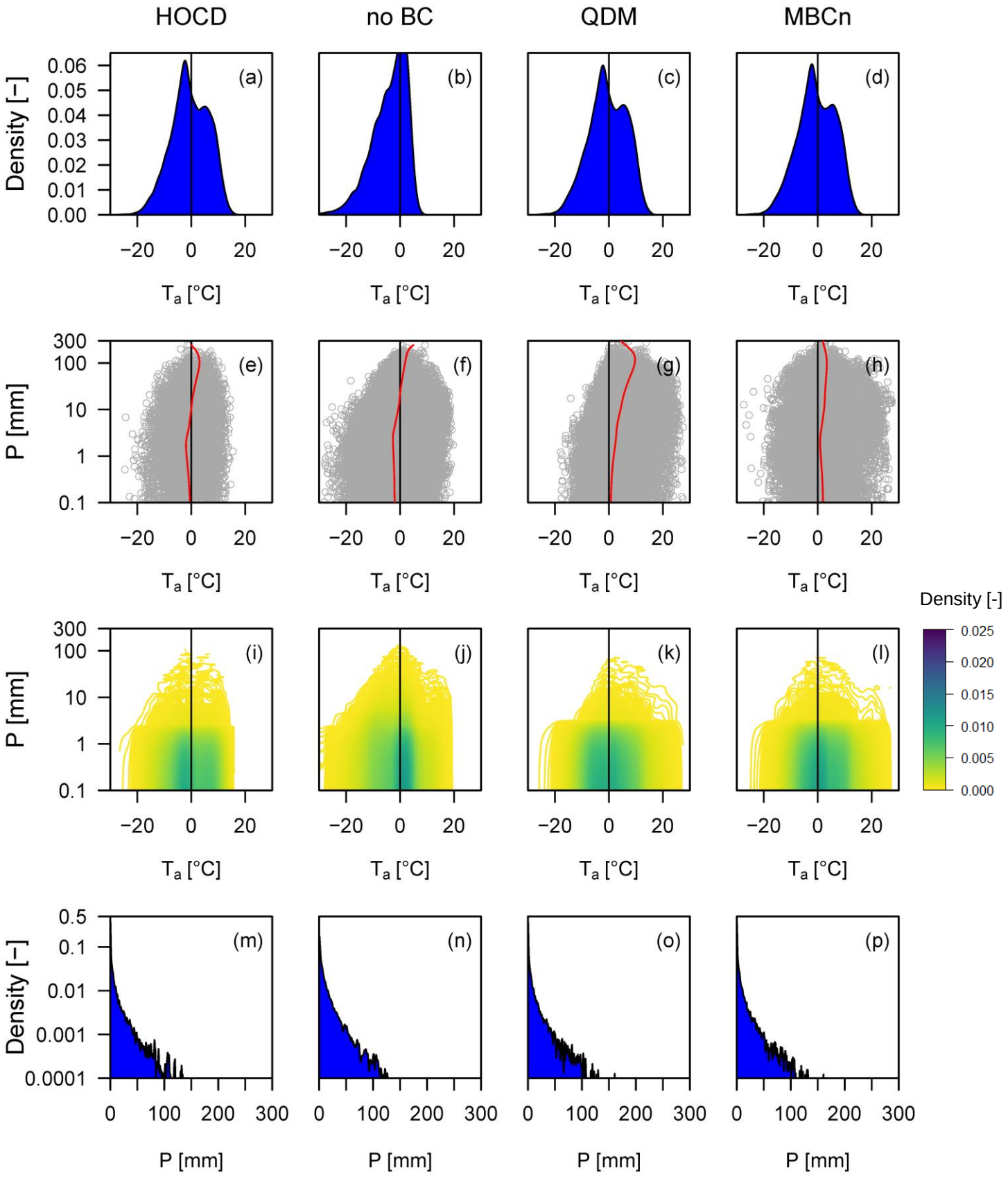

Figure S18: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–RCAC4 for RCP 8.5 for the Hinterrhein catchment.

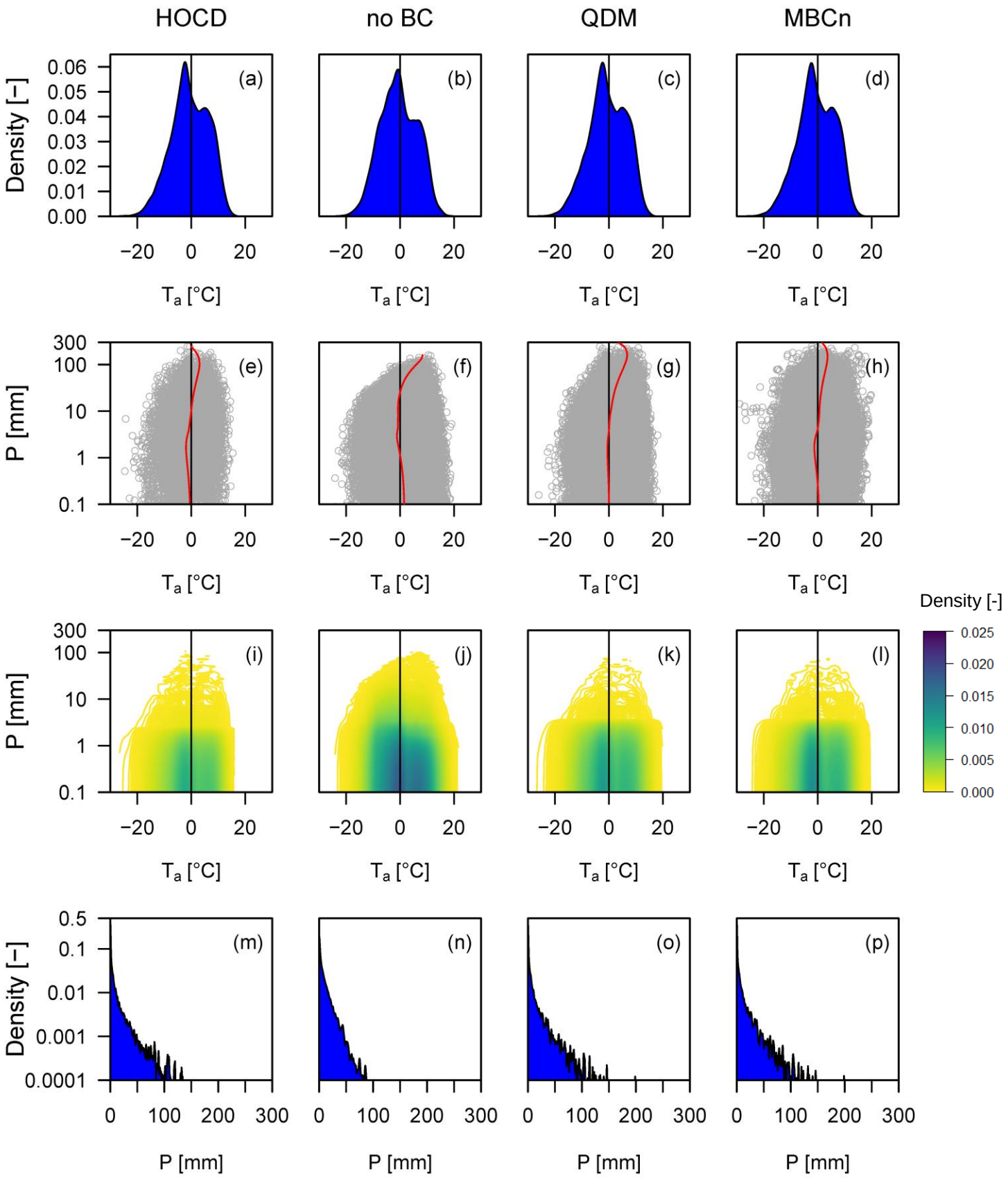

Figure S19: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–CCL4-8-17 for RCP 4.5 for the Hinterrhein catchment.

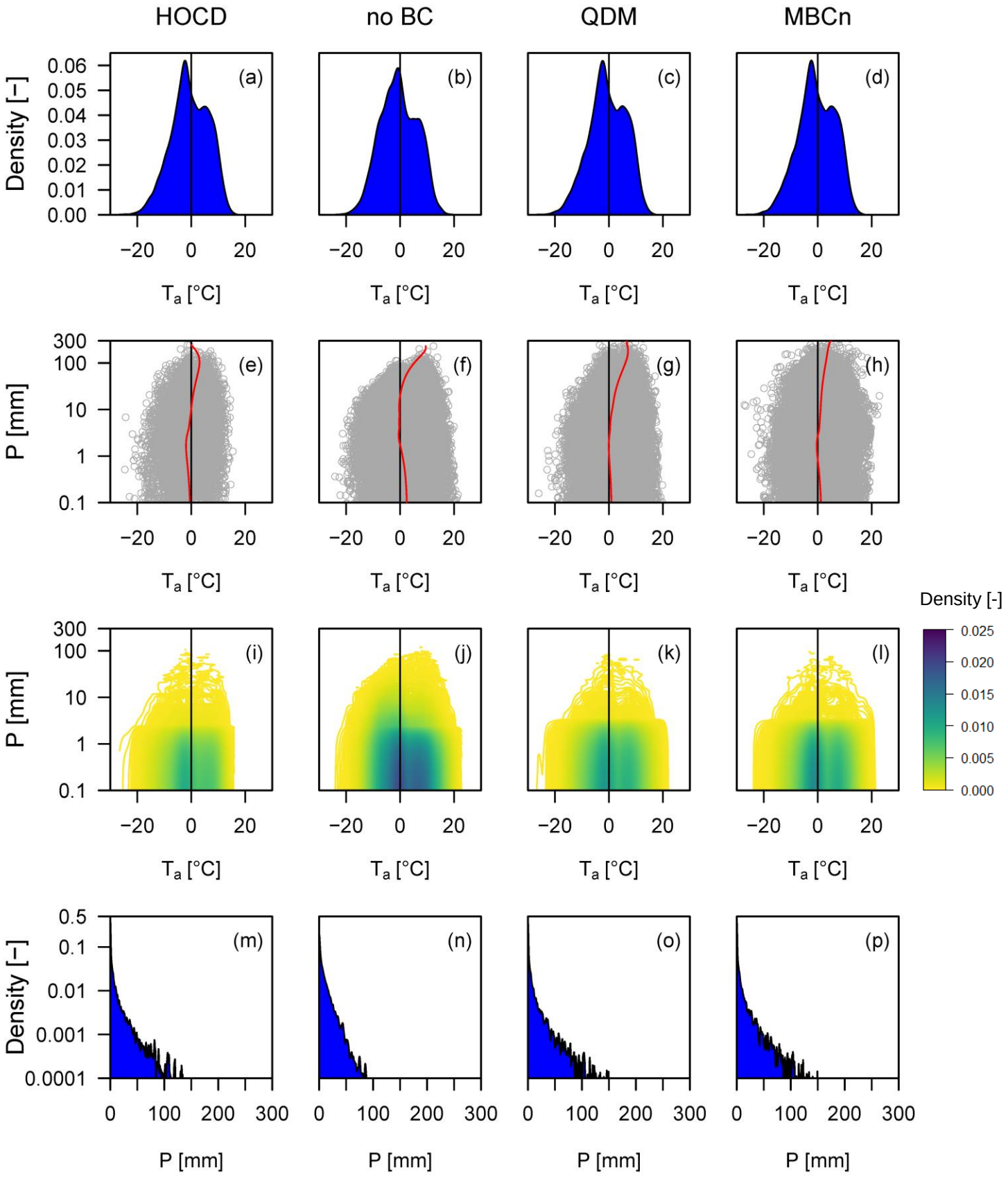

Figure S20: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–CCL4-8-17 for RCP 8.5 for the Hinterrhein catchment.

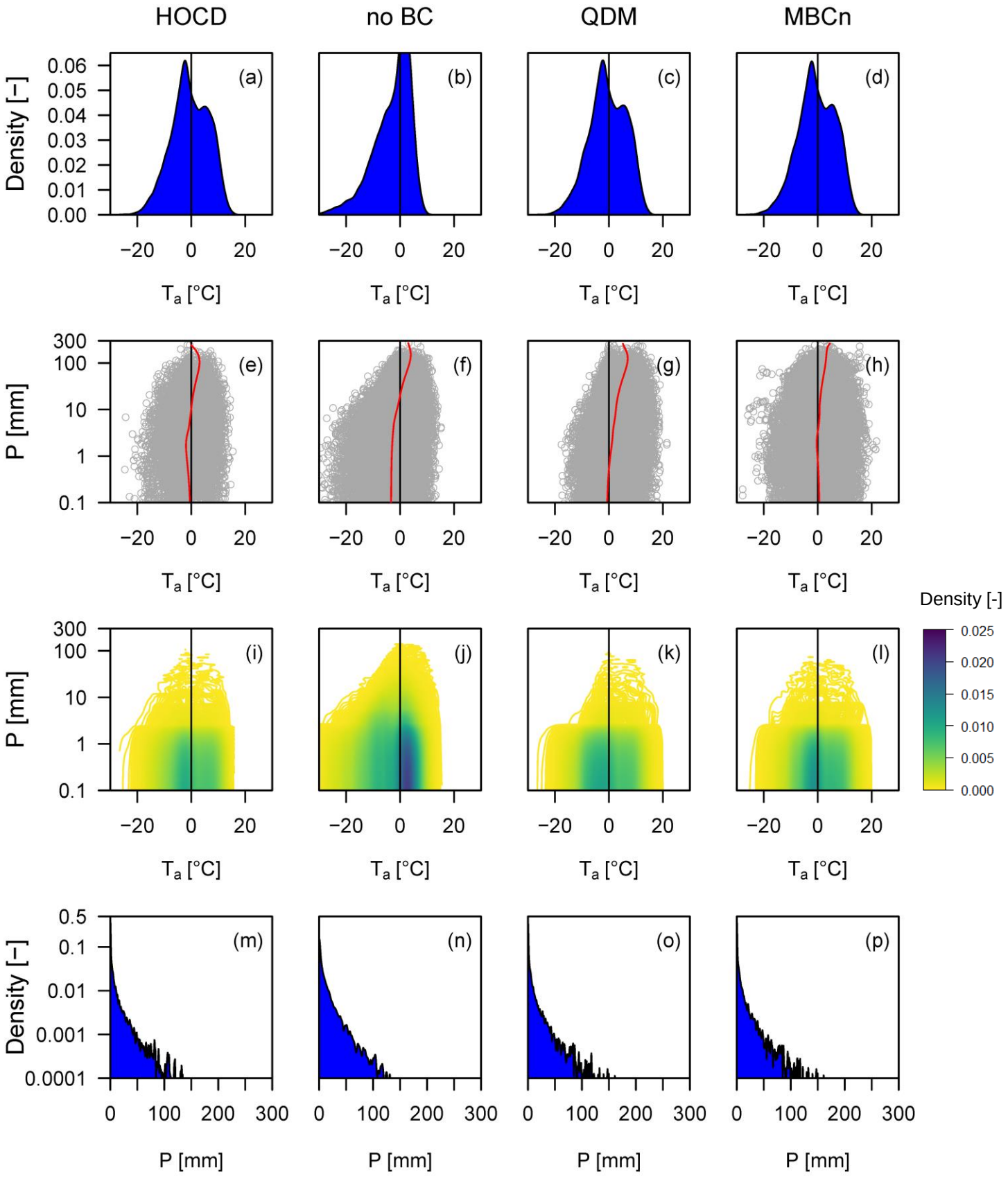

Figure S21: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–RCA4 for RCP 4.5 for the Hinterrhein catchment.

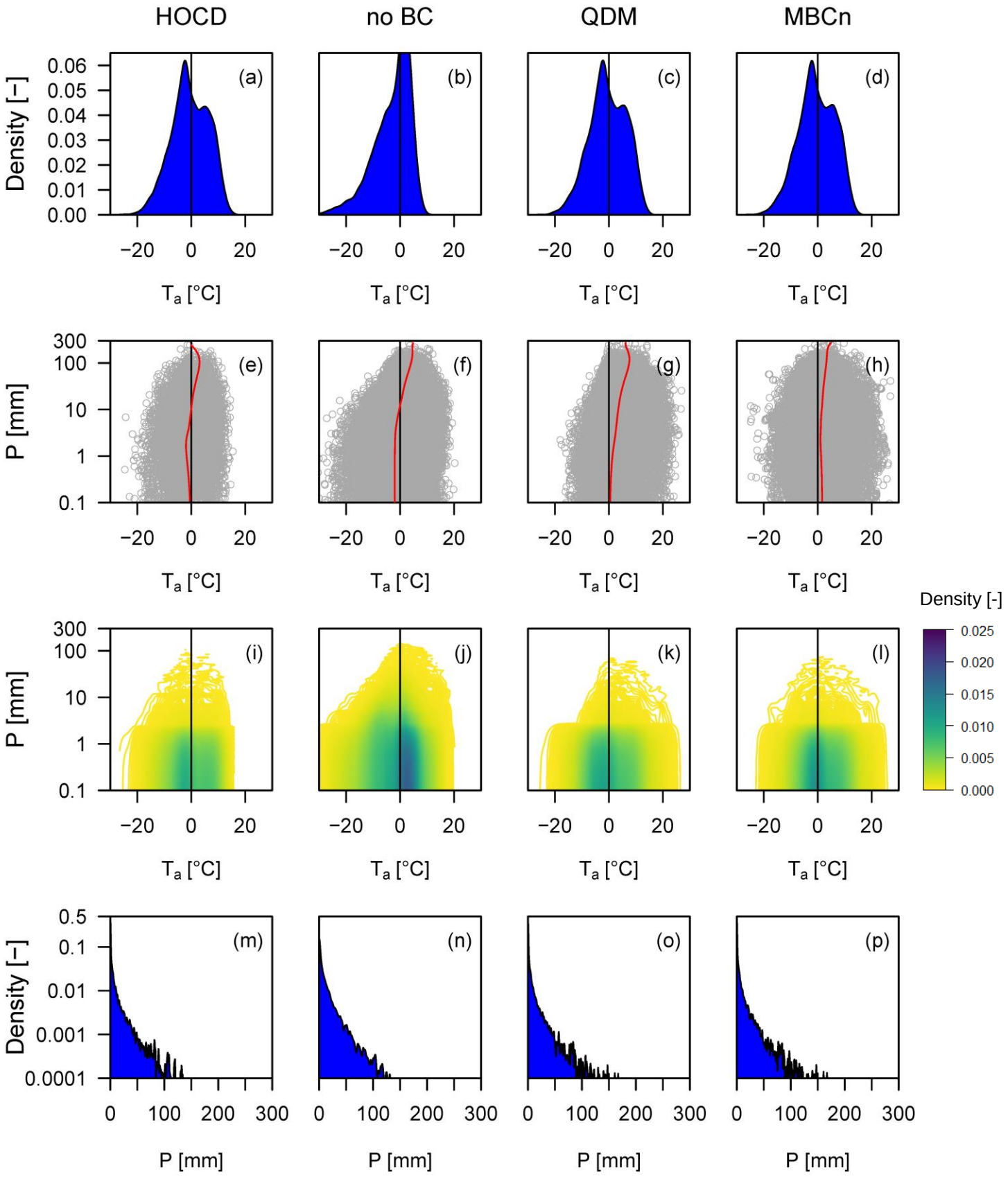

Figure S22: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–RCA4 for RCP 8.5 for the Hinterrhein catchment.

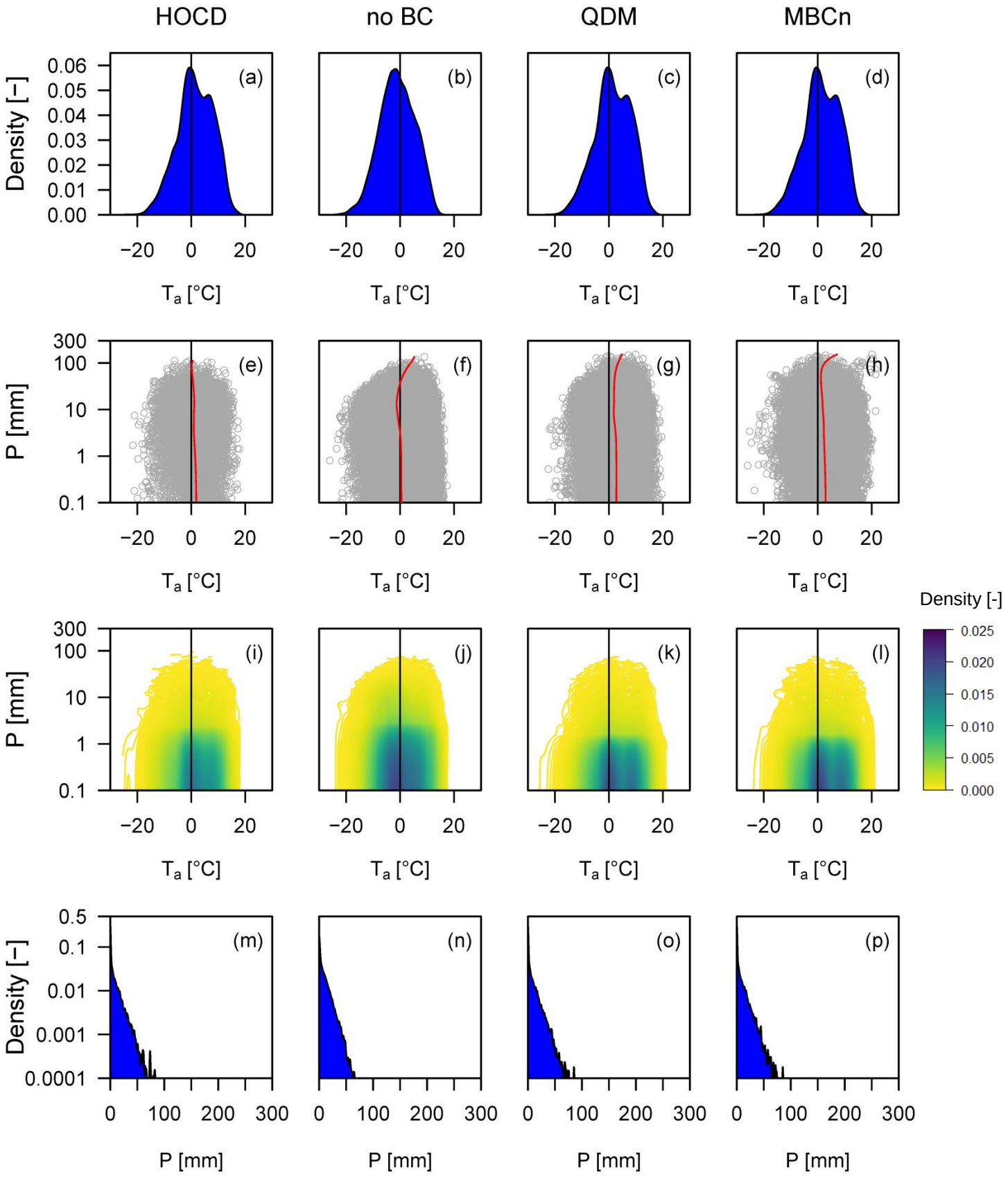

Figure S23: Schwarze Lütschine: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–CCLM4-8-17 for RCP 4.5 for the Schwarze Lütschine catchment.

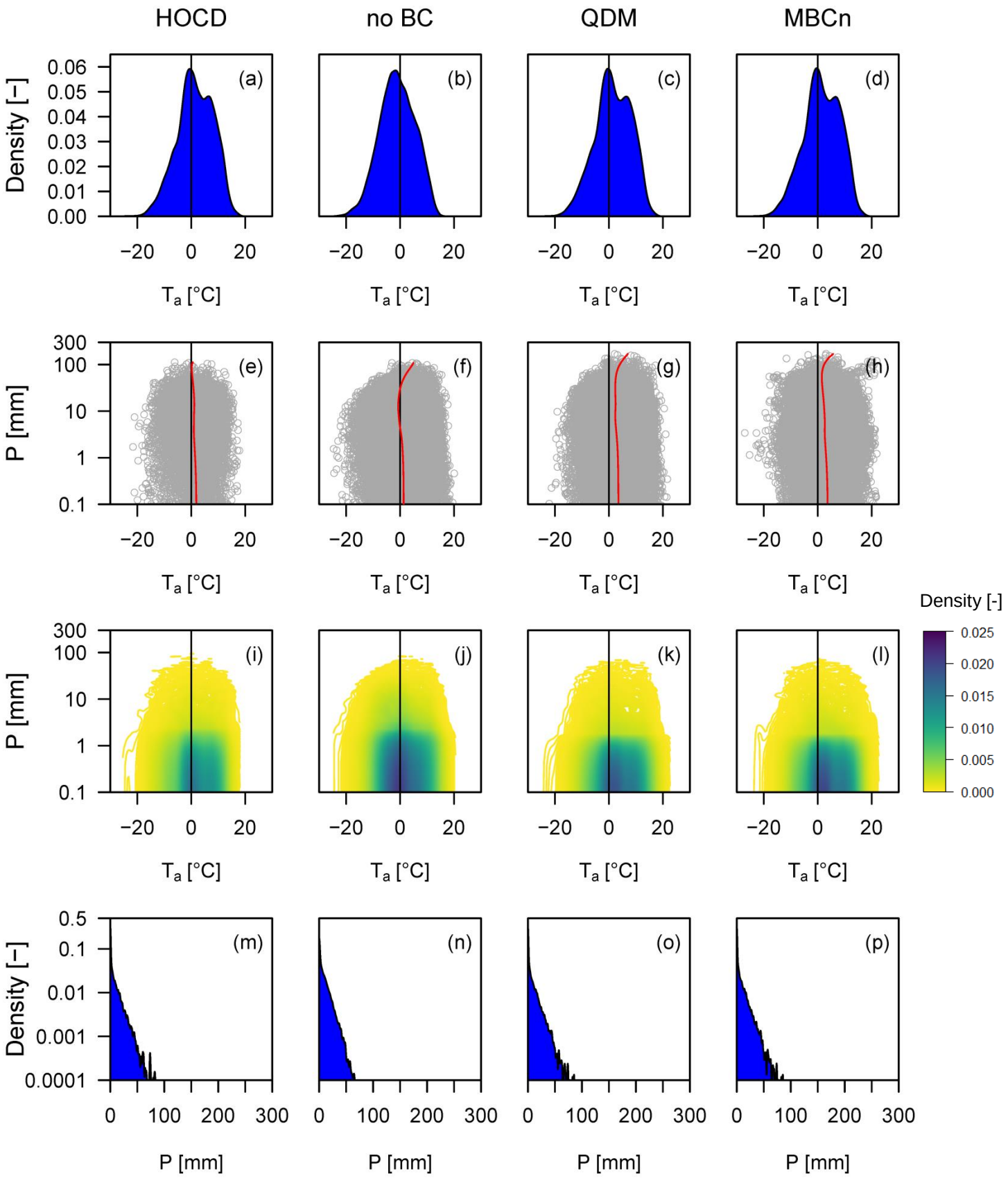

Figure S24: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–CCLM4-8-17 for RCP 8.5 for the Schwarze Lütschine catchment.

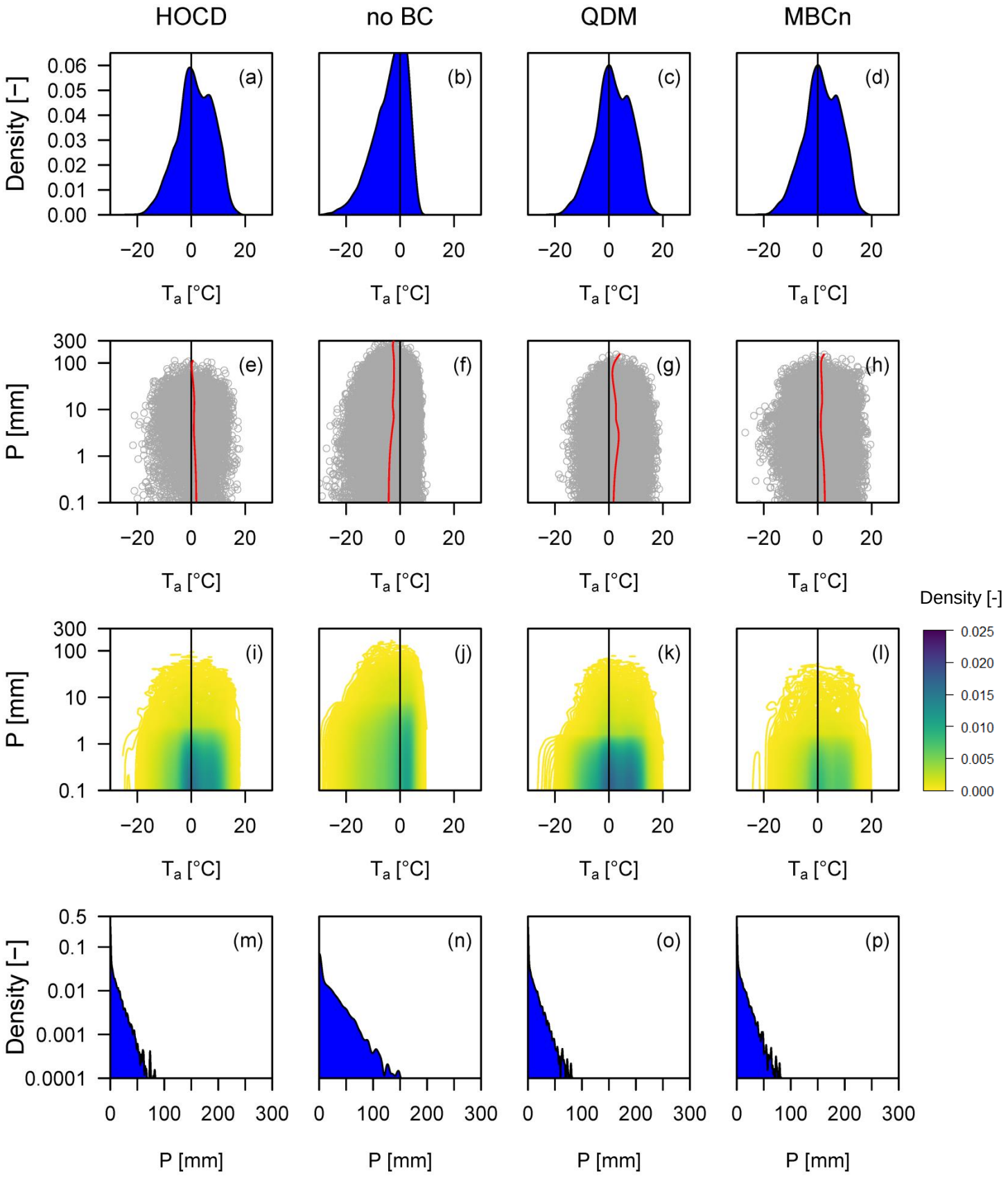

Figure S25: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–HIRHAM5 for RCP 4.5 for the Schwarze Lütschine catchment.

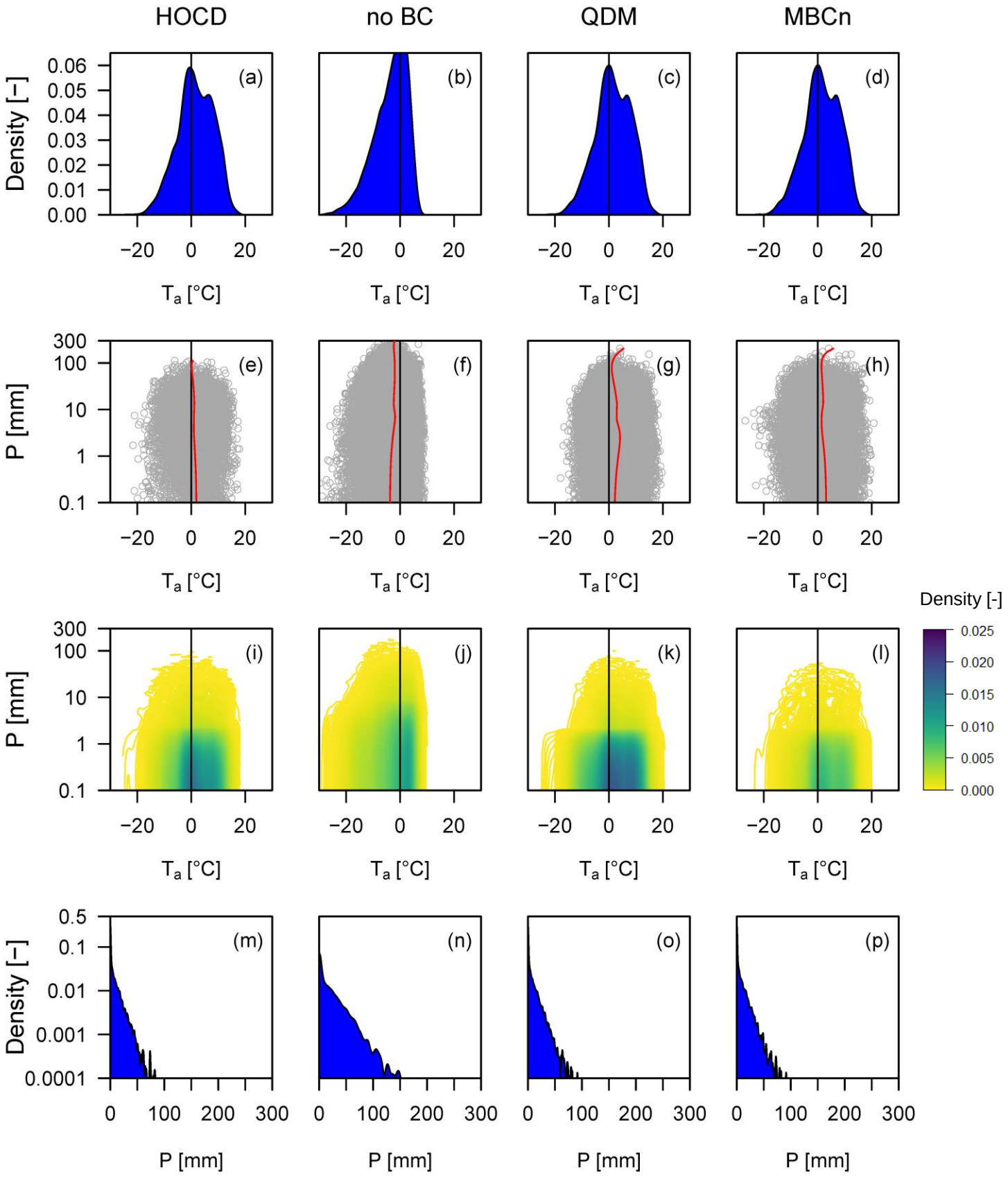

Figure S26: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–HIRHAM5 for RCP 8.5 for the Schwarze Lütschine catchment.

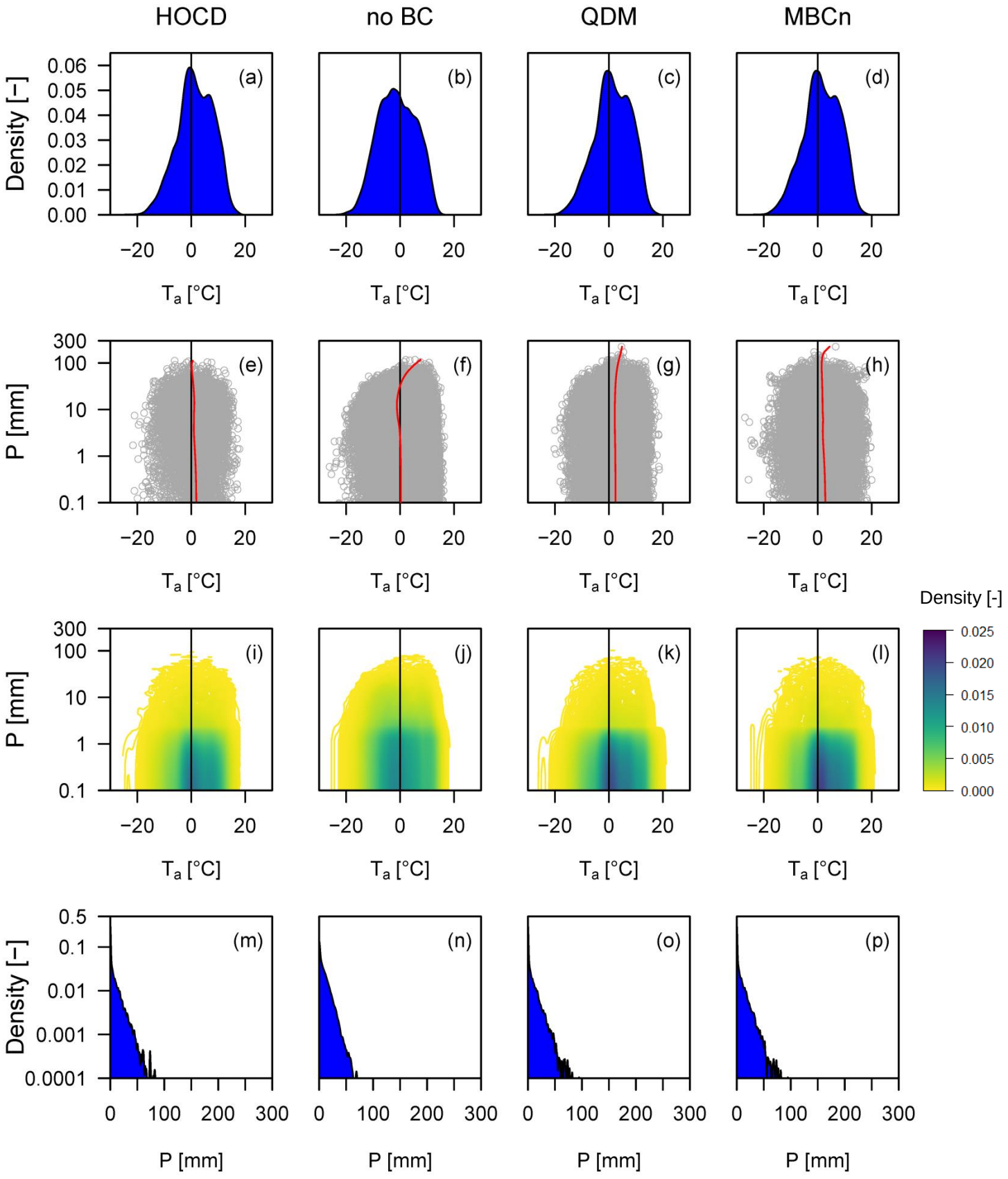

Figure S27: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5-LR–CCLM4-8-17 for RCP 4.5 for the Schwarze Lütschine catchment. Note that a warning cornering an inconsistency in the historical run of the GCM CNRM-CM5 has been issued on the CORDEX errata page (https://www.euro-cordex.net/078730/index.php.en) after data had been downloaded and selected for this study.

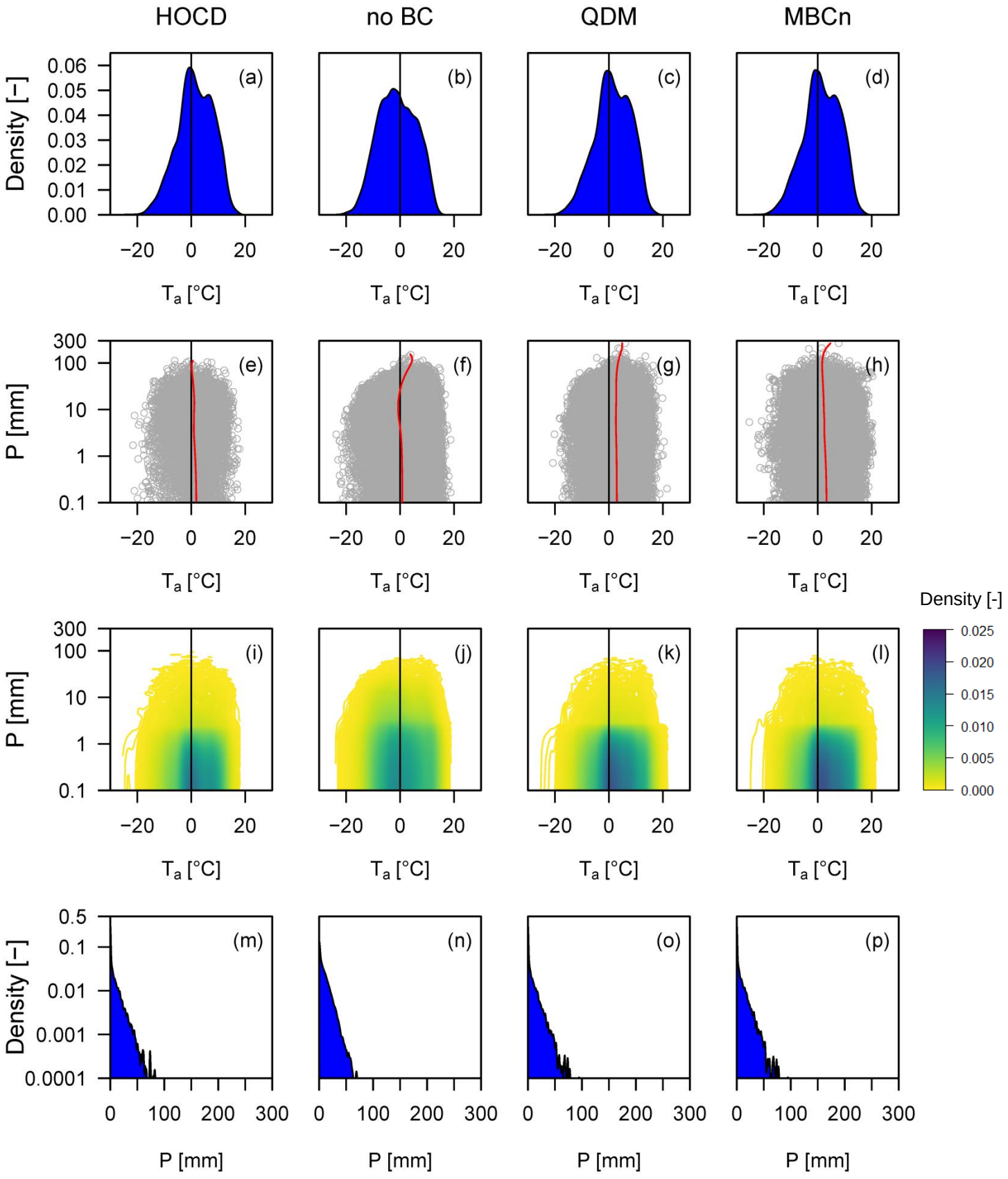

Figure S28: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5-LR–CCLM4-8-17 for RCP 8.5 for the Schwarze Lütschine catchment. Note that a warning cornering an inconsistency in the historical run of the GCM CNRM-CM5 has been issued on the CORDEX errata page (https://www.euro-cordex.net/078730/index.php.en) after data had been downloaded and selected for this study.

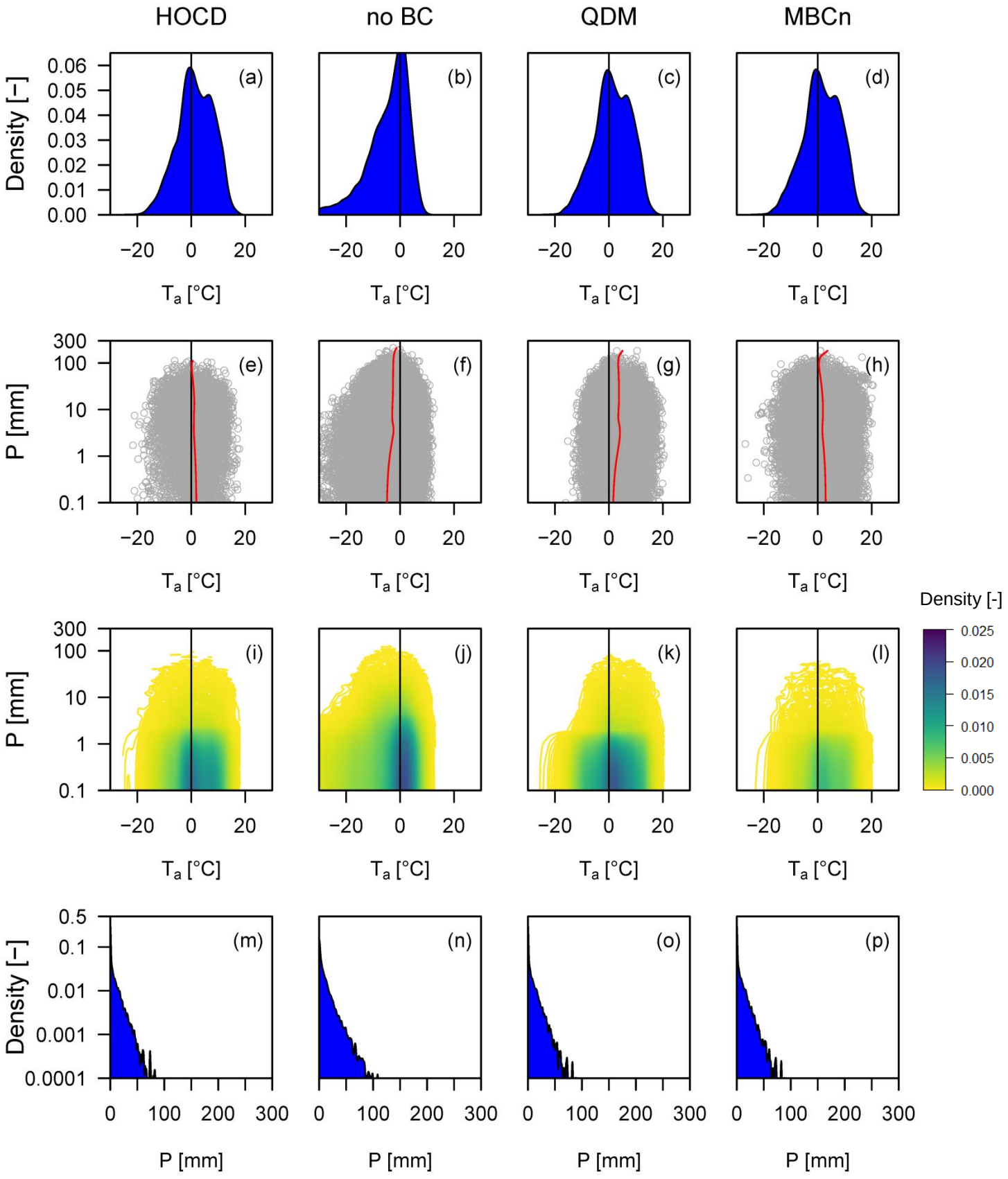

Figure S29: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5–RCA4 for RCP 4.5 for the Schwarze Lütschine catchment. Note that a warning concerning an inconsistency in the historical run of the GCM CNRM-CM5 has been issued on the CORDEX errata page (https://www.euro-cordex.net/078730/index.php.en) after data had been downloaded and selected for this study.

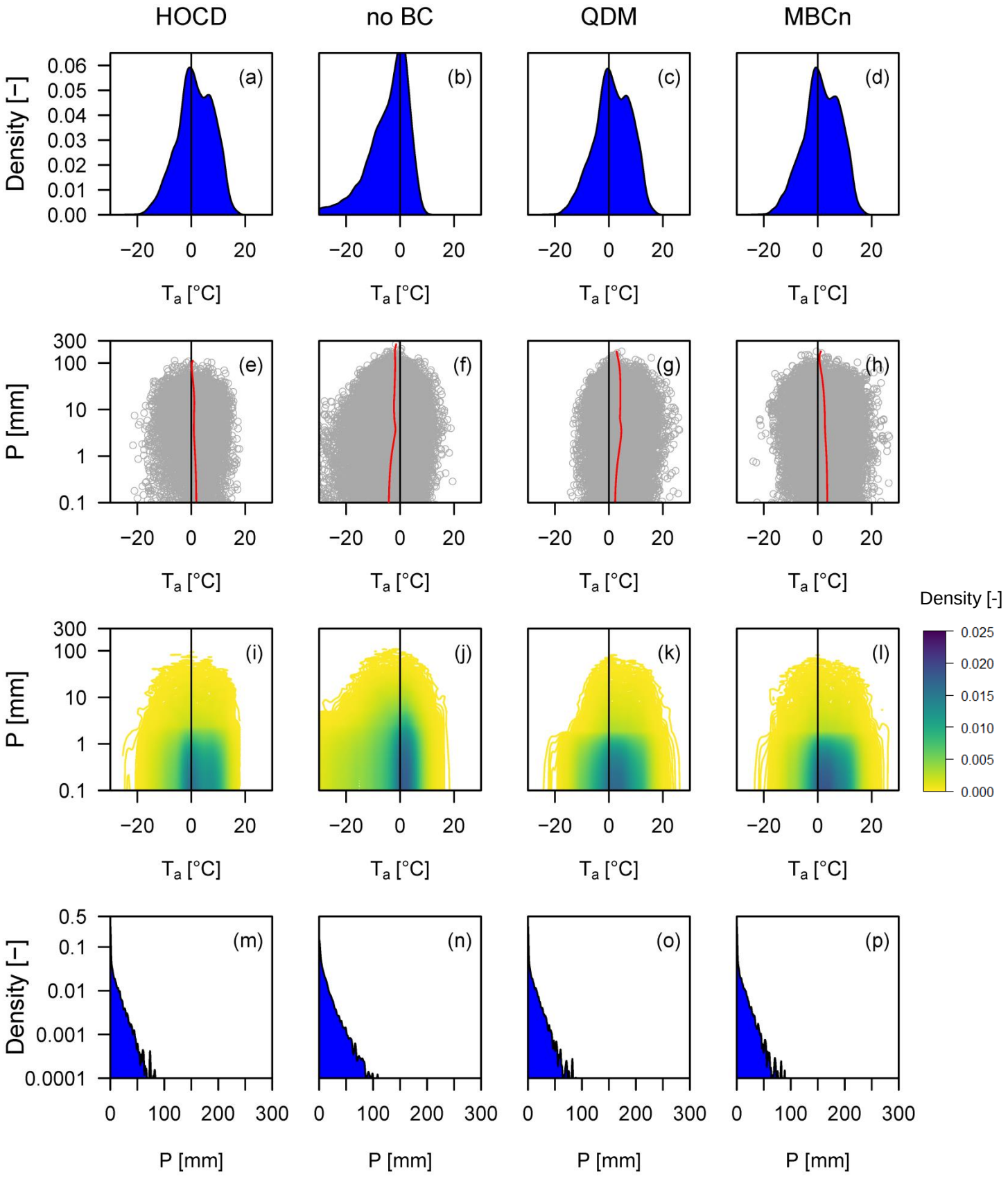

Figure S30: As previous figures (for detailed explanations see Figure S3) but for data from CNRM-CM5–RCA4 for RCP 8.5 for the Schwarze Lütschine catchment. Note that a warning concerning an inconsistency in the historical run of the GCM CNRM-CM5 has been issued on the CORDEX errata page (https://www.euro-cordex.net/078730/index.php.en) after data had been downloaded and selected for this study.

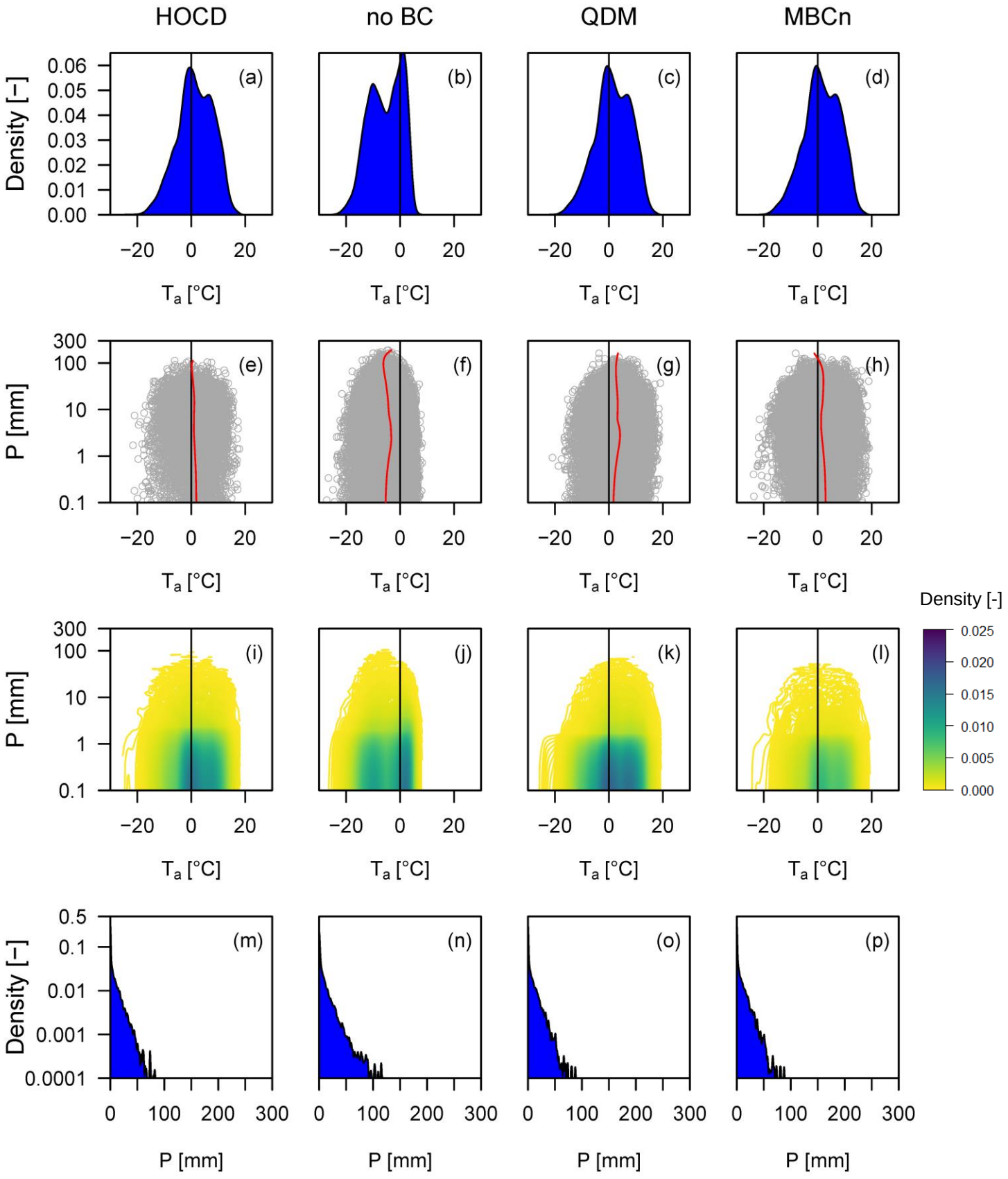

Figure S31: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–RACMO22E for RCP 4.5 for the Schwarze Lütschine catchment.

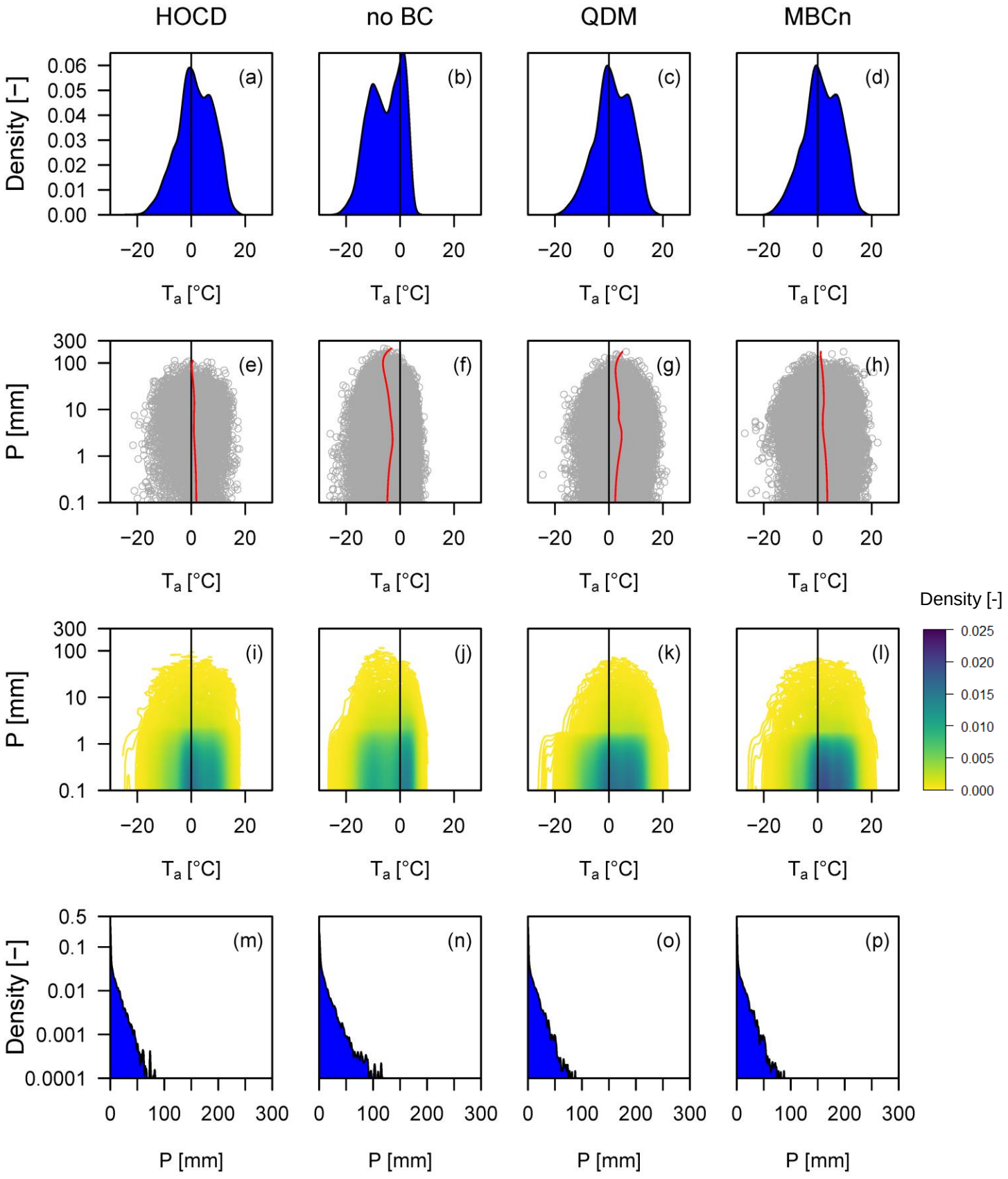

Figure S32: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–RACMO22E for RCP 8.5 for the Schwarze Lütschine catchment.

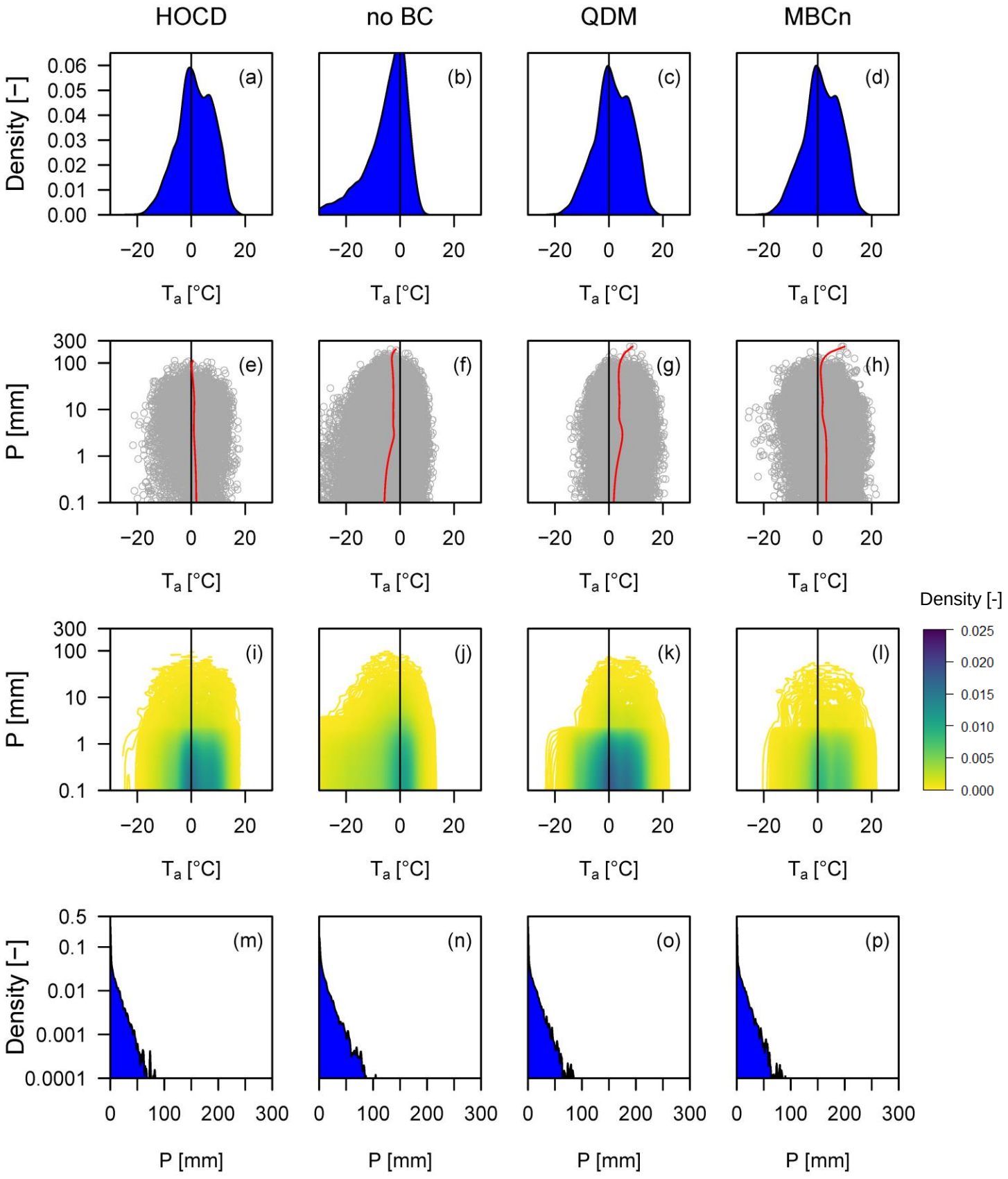

Figure S33: As previous figures (for detailed explanations see Figure S3) but for data from EC-EARTH–RCA4 for RCP 4.5 for the Schwarze Lütschine catchment.

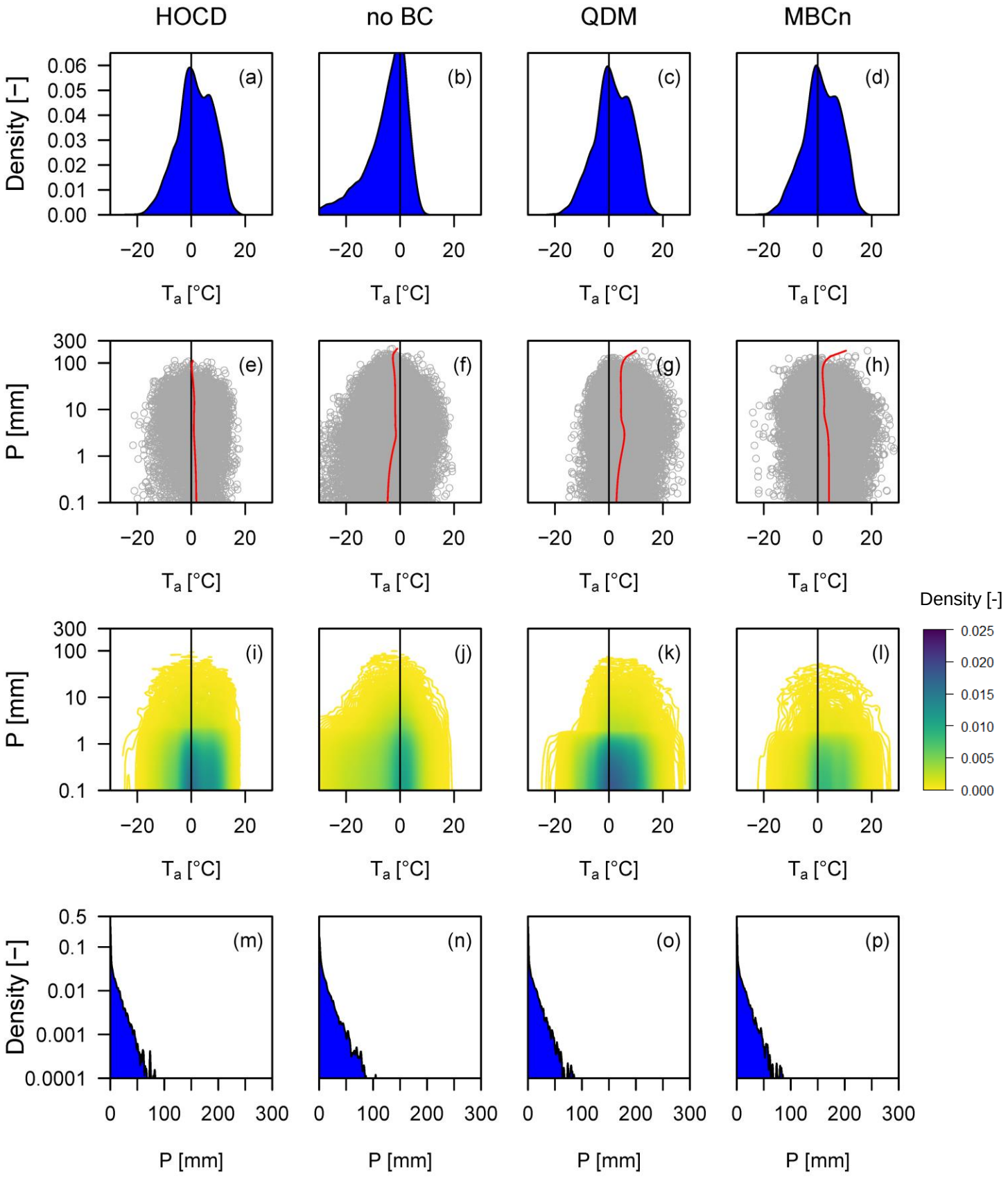

Figure S34: As previous figure (for detailed explanations see Figure S3) but for data from EC-EARTH–RCA4 for RCP 8.5 for the Schwarze Lütschine catchment.

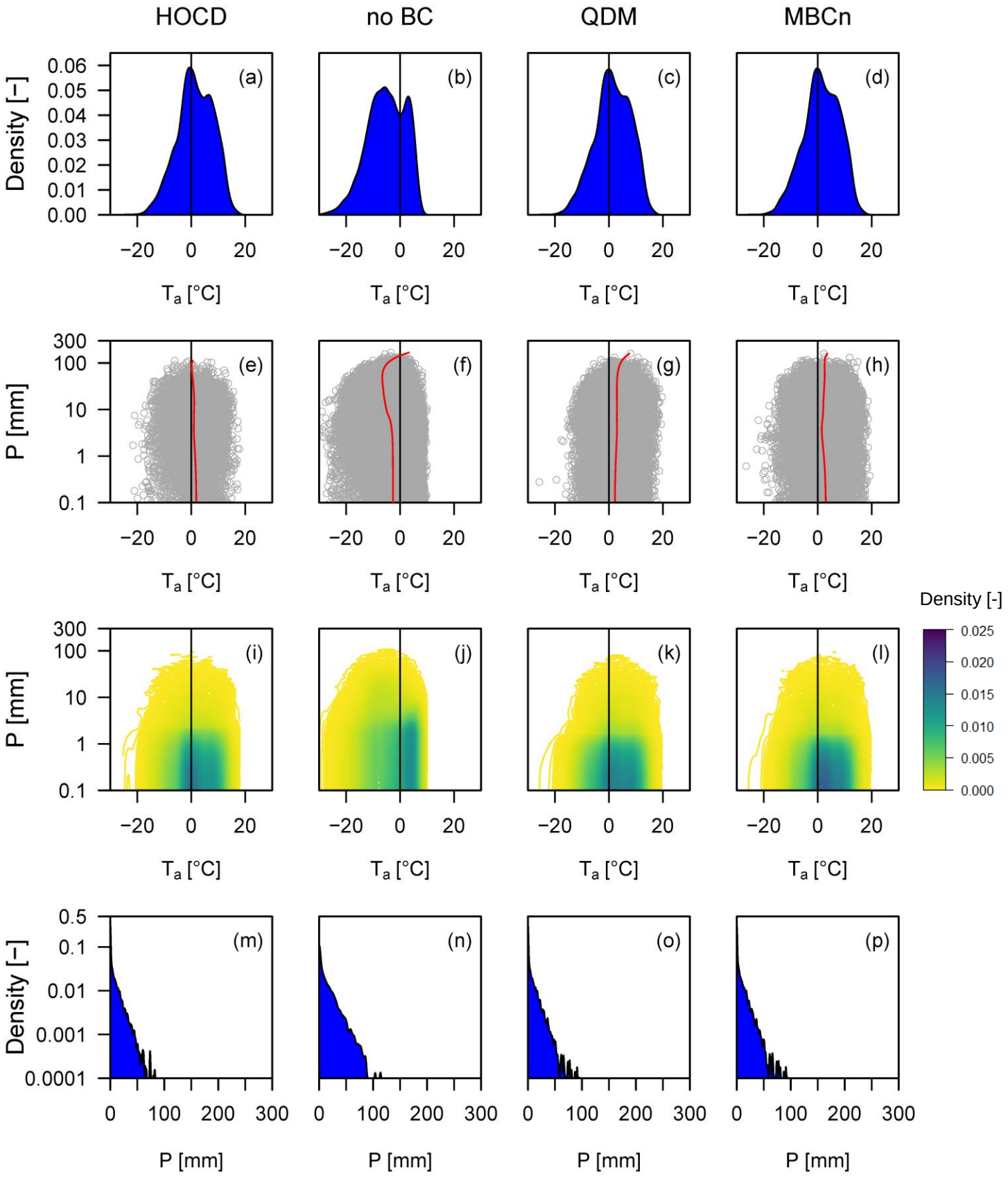

Figure S35: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–WRF331F for RCP 4.5 for the Schwarze Lütschine catchment.

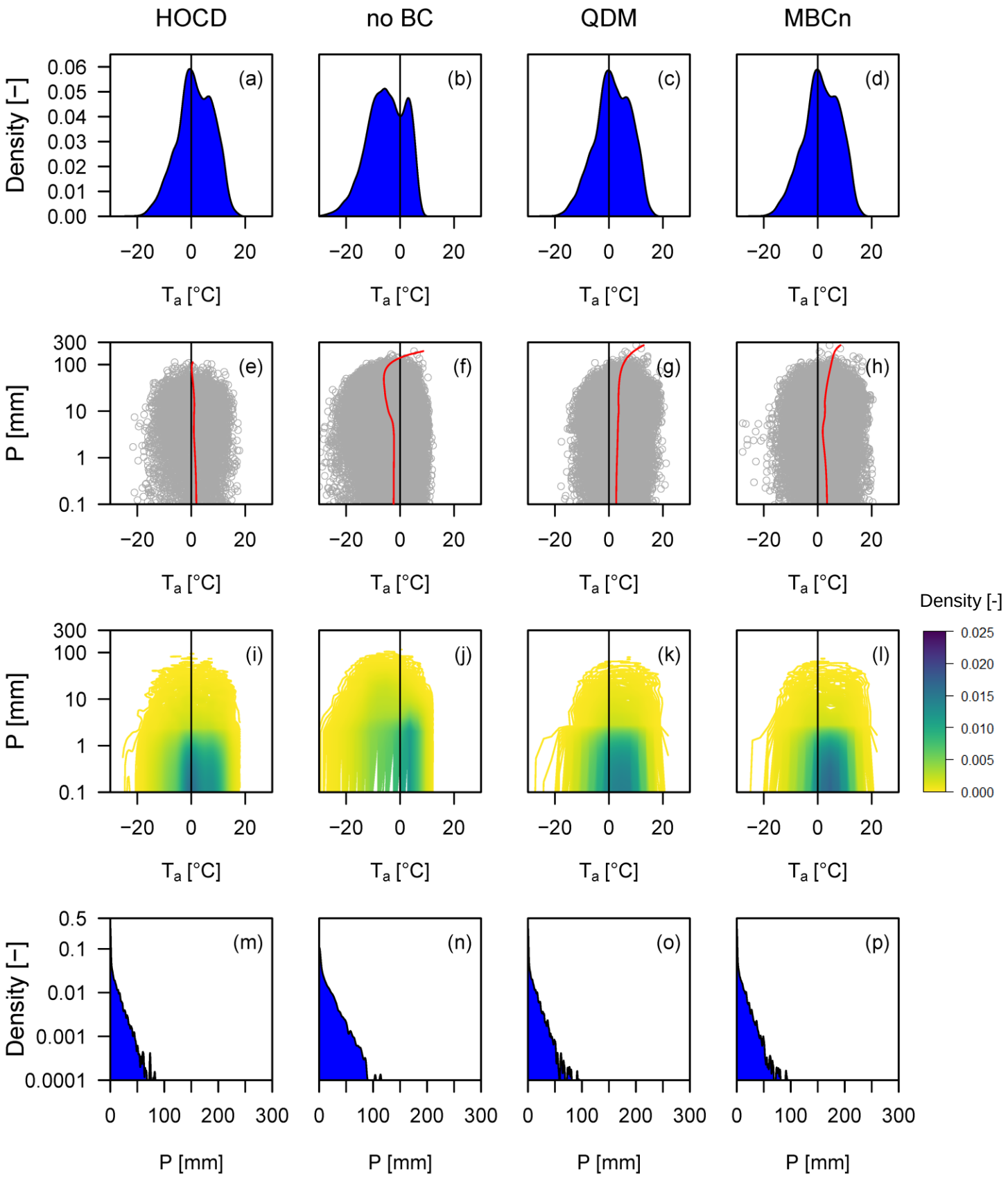

Figure S36: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–WRF331F for RCP 8.5 for the Schwarze Lütschine catchment.

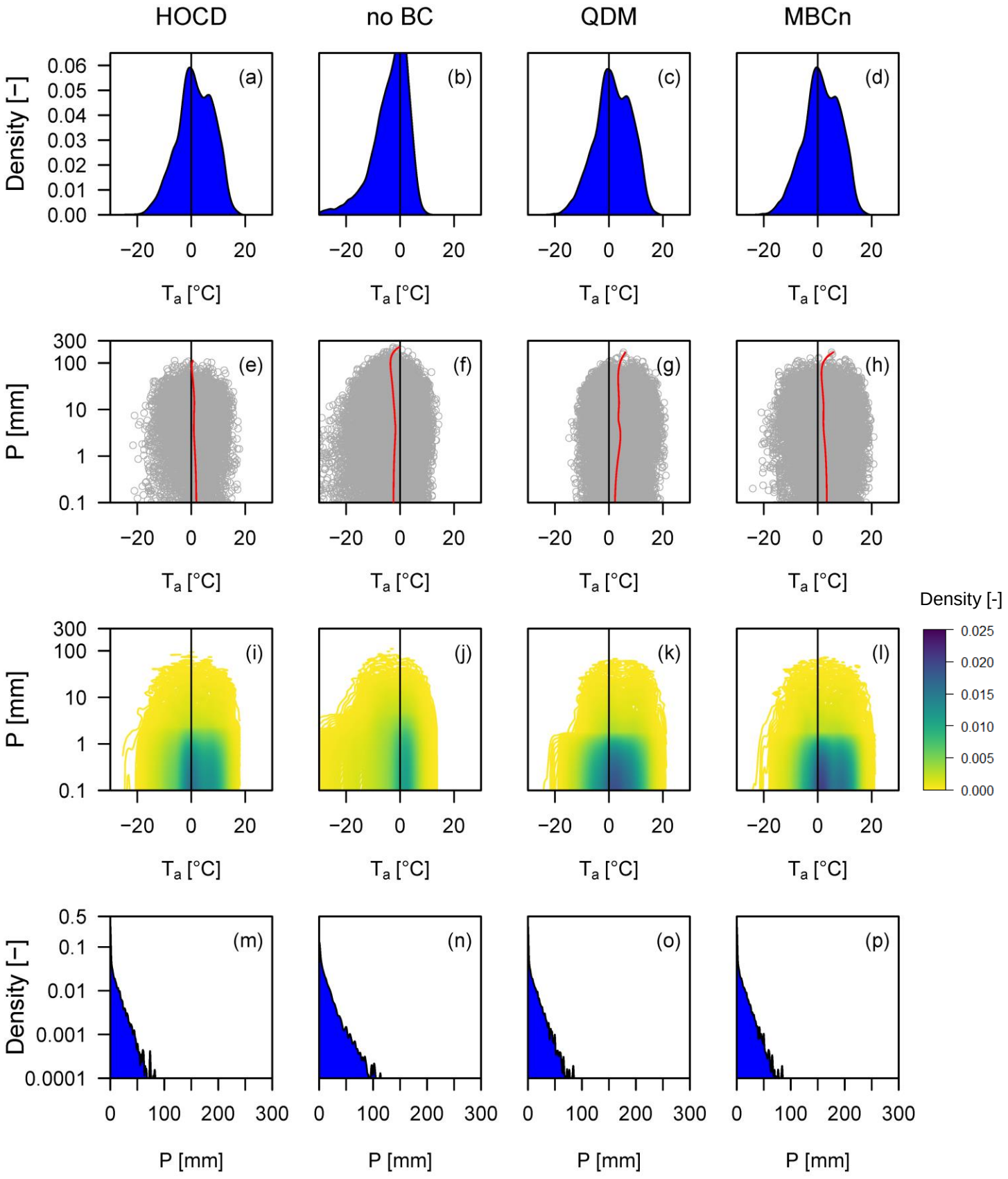

Figure S37: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–RCA4 for RCP 4.5 for the Schwarze Lütschine catchment.

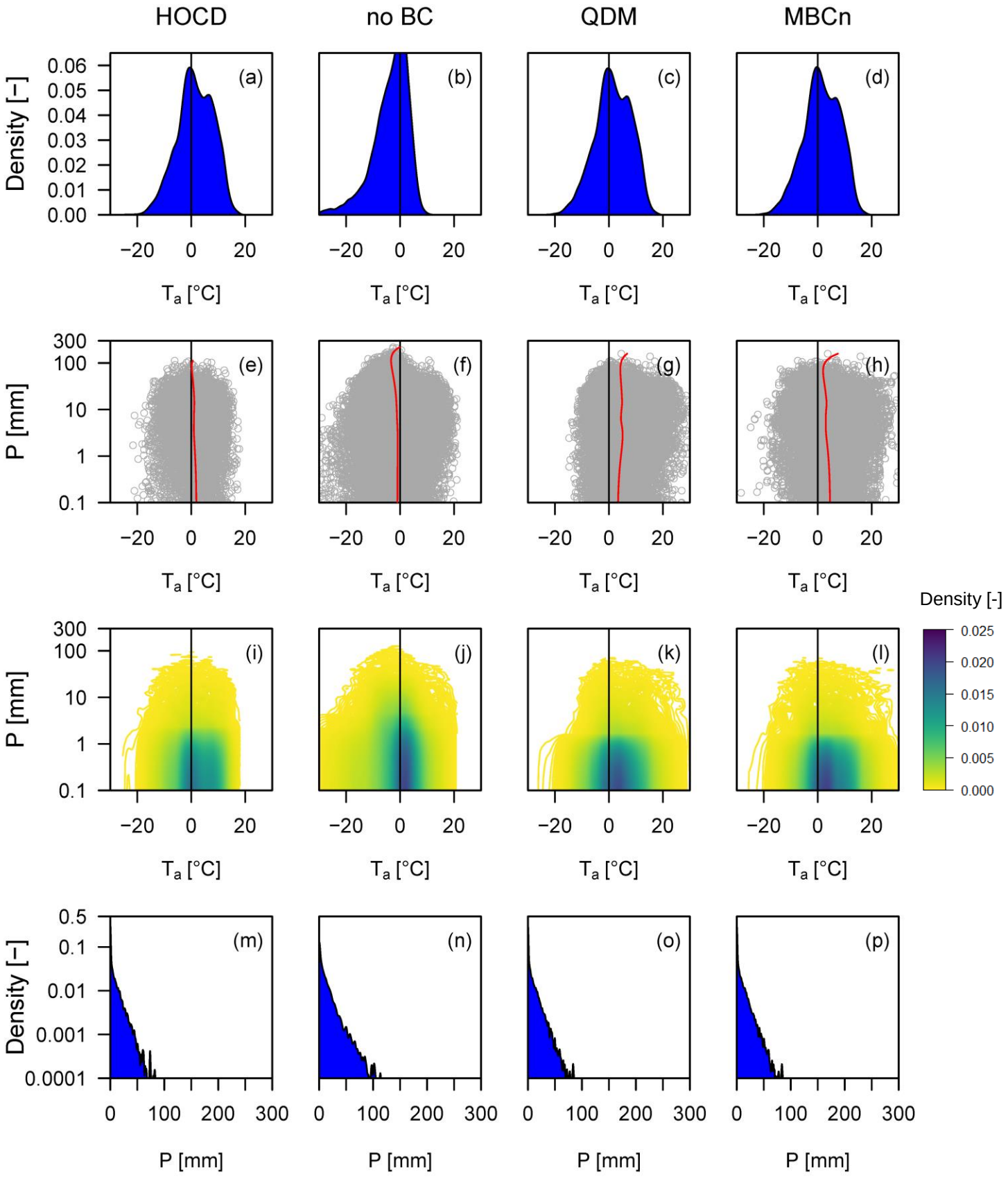

Figure S38: As previous figures (for detailed explanations see Figure S3) but for data from IPSL-CM5A-MR–RCA4 for RCP 8.5 for the Schwarze Lütschine catchment.

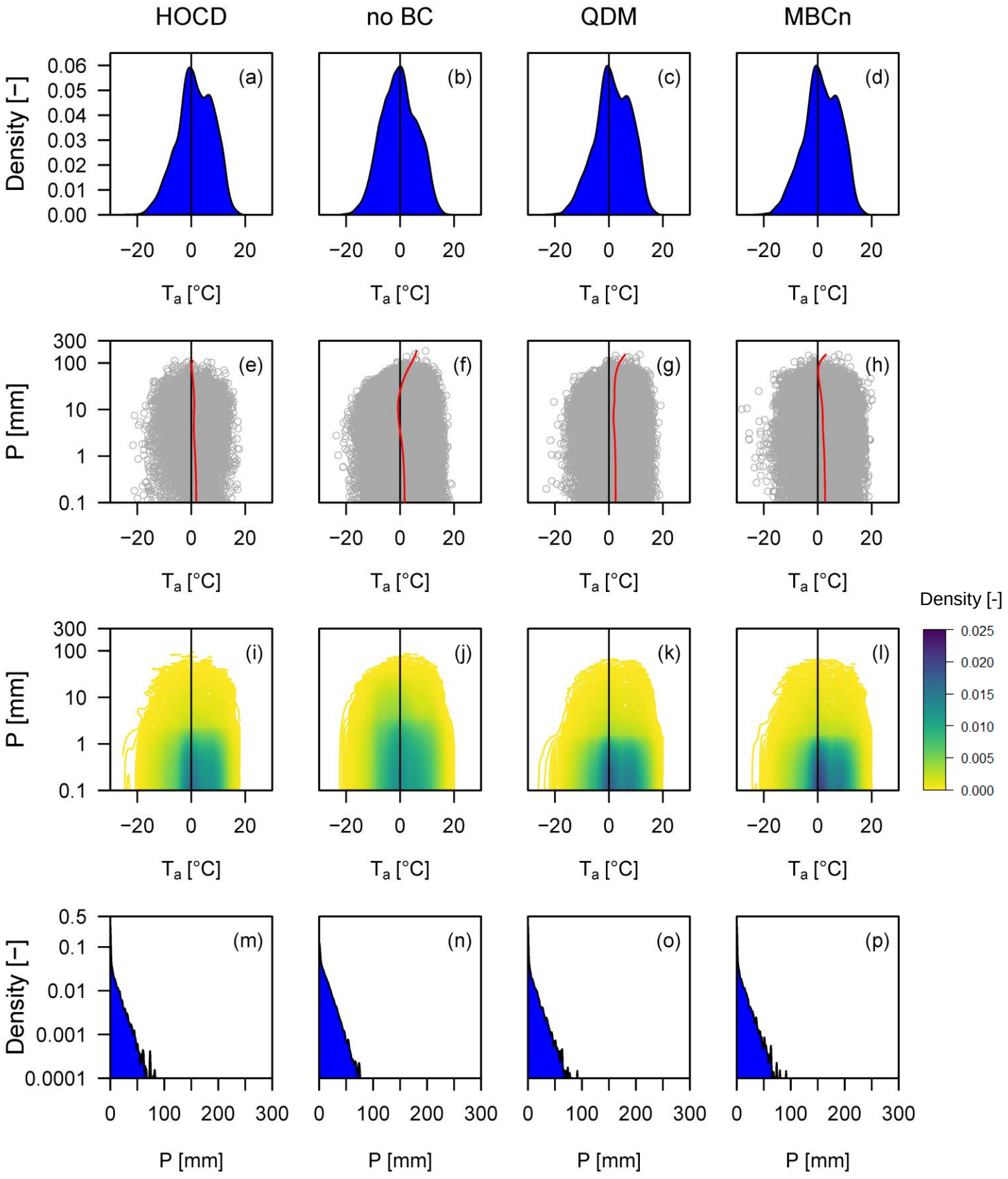

Figure S39: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–CCL4-8-17 for RCP 4.5 for the Schwarze Lütschine catchment.

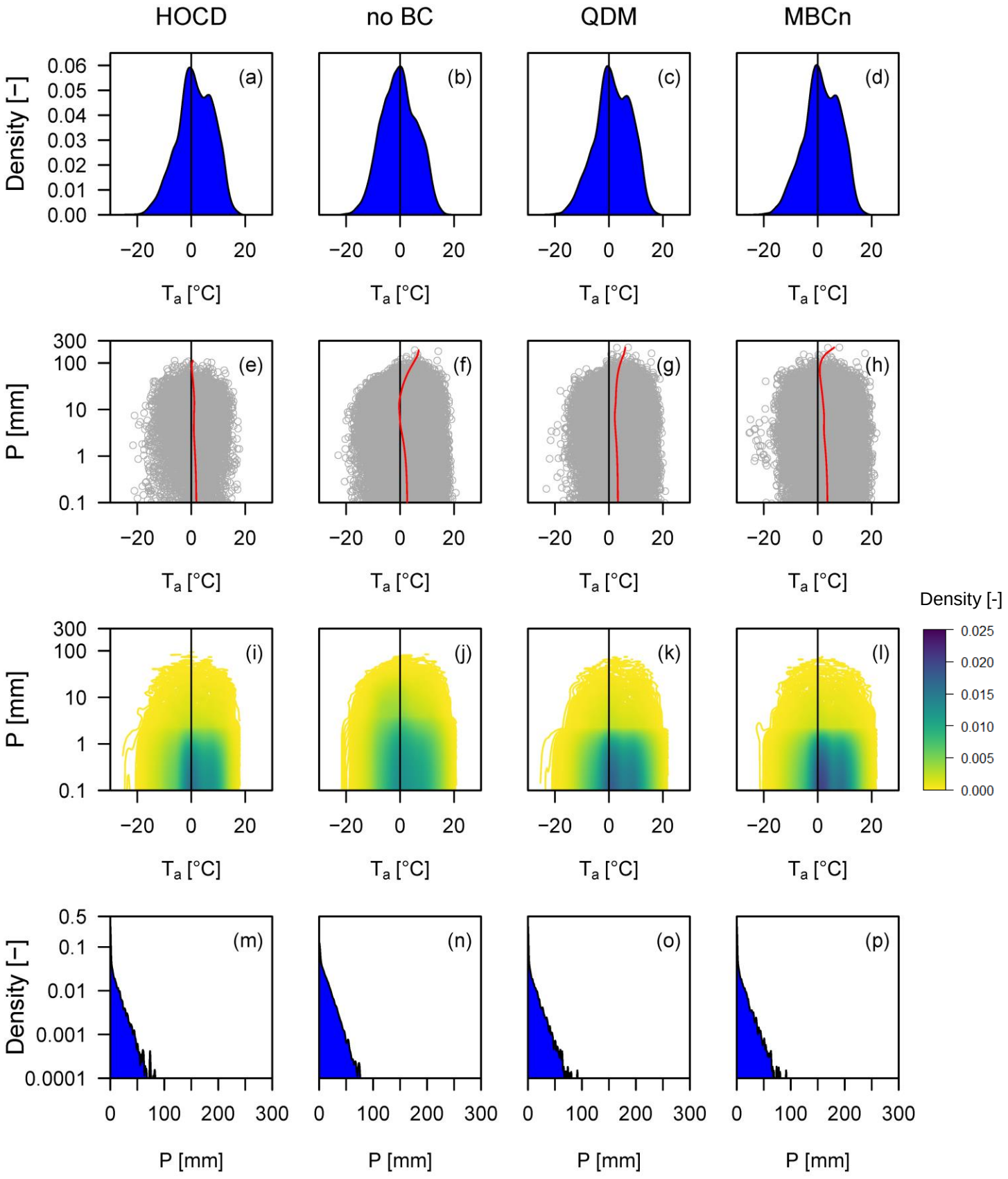

Figure S40: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–CCL4-8-17 for RCP 8.5 for the Schwarze Lütschine catchment.

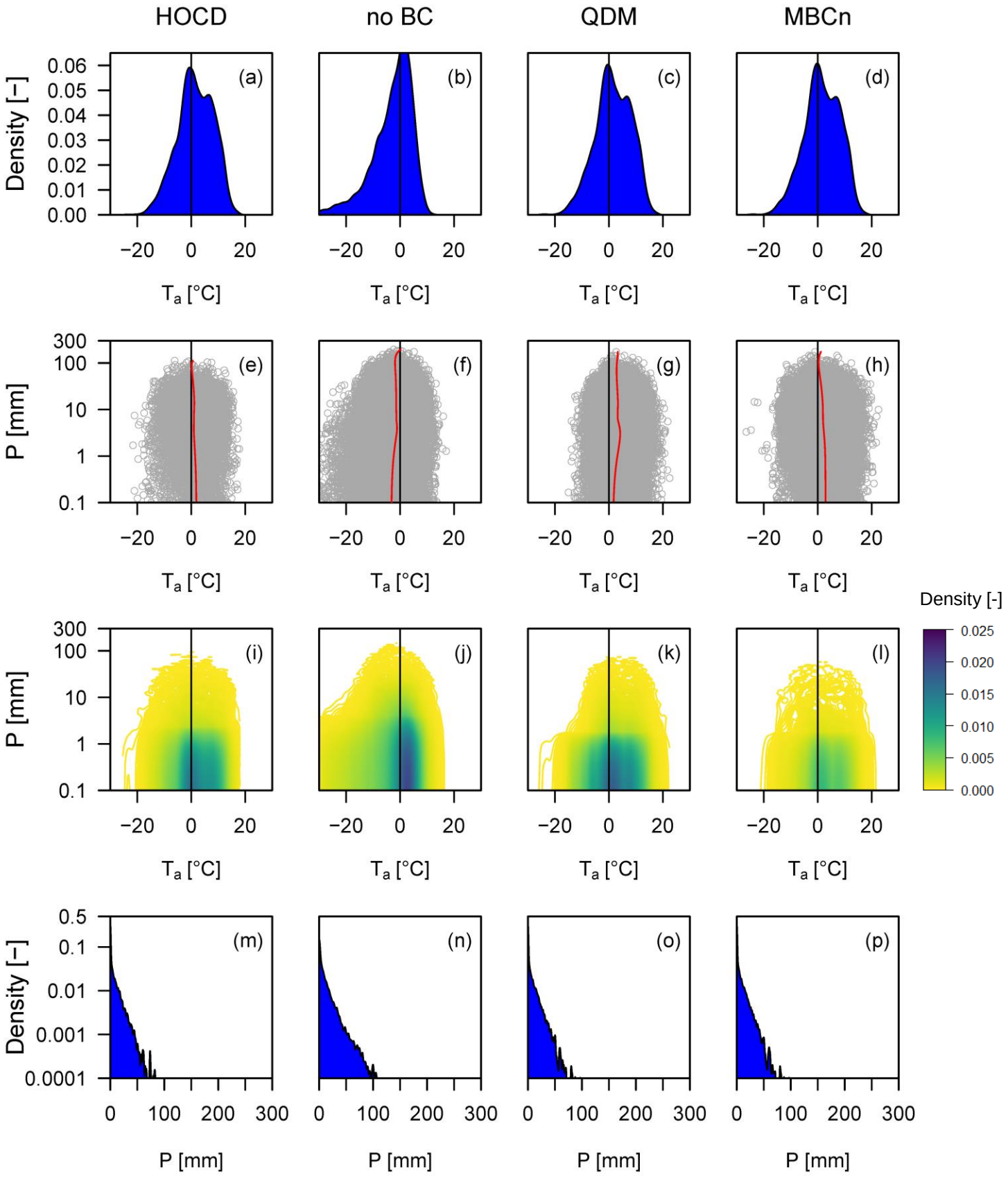

Figure S41: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–RCA4 for RCP 4.5 for the Schwarze Lütschine catchment.

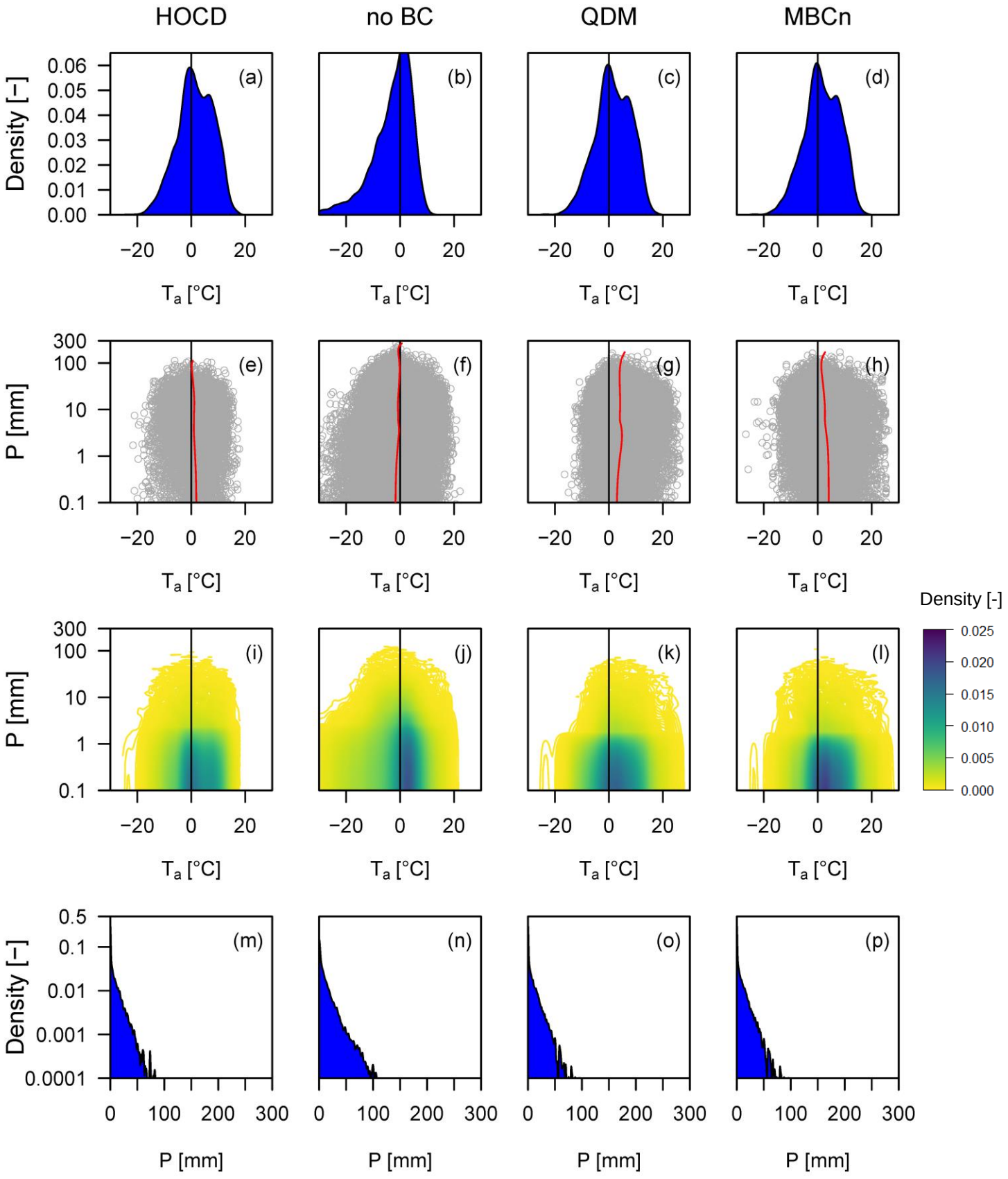

Figure S42: As previous figures (for detailed explanations see Figure S3) but for data from MPI-ESM-LR–RCA4 for RCP 8.5 for the Schwarze Lütschine catchment.