5 Supplements

5.1 Detailed model descriptions

WRF

The non-hydrostatic WRF model (Weather Research and Forecast model, Skamarock et al, 2008) is applied in its version V3.9.1.1. A two-step nesting approach is used to realize a 10-year simulation (2006 – 2015) at the convection-permitting grid scale (3.1 km or 0.0275° grid spacing, referred to as WRF-3.1) over the Lake Victoria region. The year 2005 is neglected because of model spin-up and not used for analysis. In a first step, ERA-Interim data (Dee et al, 2011) is used as initial and boundary conditions to simulate the African Great Lake region with a grid spacing of 0.11° (12 km, referred to as WRF-12) and with 35 vertical levels. This simulation in turn provides the initial and boundary data for WRF-3.1 with an increased number of 69 vertical levels. Convection in WRF-12 is parameterized based on the new Tiedke scheme (Zhang and Wang, 2017), while no cumulus parametrization is used in WRF-3.1. Parametrizations for cloud microphysics (WRF Single-Moment 5-class scheme, Hong et al, 2004), shortwave and longwave radiation (RRTMG scheme, Iacono et al, 2008), planetary boundary layer physics (Yonsei University Scheme, Hong et al, 2006) and land surface / soil processes (Unified Noah Land Surface Model, Tewari et al, 2004) are used in both simulations. To account for lake-atmosphere interaction, because of the great water body of Lake Victoria, a one-dimensional mass and energy balance lake model is considered in both simulations (Subin et al, 2012).

ALADIN and AROME

ALADIN and AROME are part of the HARMONIE-Climate (HCLIM) regional climate modelling system designed for a range of horizontal resolutions from tens of kilometres to convection-permitting scales of 1-3 km (Lindstedt et al, 2015; Lind et al, 2016; Belušić et al, 2020; Lind et al, 2020). AROME uses an atmospheric physics package for the convection-permitting scales and ALADIN incorporates a package for resolutions coarser than 10 km. ALADIN is the intermediate model to downscale the ERA-Interim reanalysis first to 12.5 km resolution and then AROME downscales the ALADIN simulation to 2.5 km. Both configurations use the same number of vertical levels (65). AROME employs a shallow convection parameterization based on the eddy diffusivity mass-flux framework (De Rooy and Siebesma, 2008) while ALADIN uses the Kain-Fritch-Bechtold (KFB) scheme (Bazile et al, 2011). The deep convection in ALADIN is represented by an updated version of the mass-flux scheme based on a moisture convergence closure (Bougeault, 1985). Both ALADIN and AROME share the same surface modelling system – SURFEX (Masson et al, 2013) and the one-dimensional Freshwater Lake (FLake) model (Mironov et al, 2010). The 12.5 km ALADIN simulation uses the ERA-Interim data to initialize soil parameters and a climatology of lake profiles which vary over time and space (Kourzeneva et al, 2012) to initialize lake parameters. The subsequent AROME simulation is initialised by data from the ALADIN simulation. All ten-year (2006-2015) simulations are conducted with one year spinup (2005). A comprehensive and full description of the HCLIM modelling system and its applications over different regions is presented in Belušić et al (2020).

Met Office Model

The United Kingdom Met Office (UKMO) Unified Model is non-hydrostatic with a semi-implicit, semi-Lagrangian dynamical core (Clark et al, 2016; Walters et al, 2019). A pan-Africa domain (significantly larger than the domain of the other models used) is simulated for the years 1997-2006. Stratton et al (2018) provides full details on this simulation, which is often referred to as CP4-Africa or CP4A. UKMO4.5 has a 4.5 km horizontal grid at the equator with 80 vertical levels, and explicitly represents convection, including stochastic perturbations in the sub-cloud boundary layer (no shallow convection scheme). UKMO-25 has a 25 km grid with 63 vertical levels, and parameterised convection based on the Gregory and Rowntree (1990) mass flux scheme, with developments in the representation of down-draughts, entrainment rates, momentum transport, and closure (Walters et al, 2019). Cloud microphysical processes use an extensively modified version of Wilson and Ballard (1999) scheme, with only UKMO-25 including sub-grid turbulent production of mixed-phase clouds. Lakes are uncoupled, with their climatological seasonal surface temperatures forced by version 3 of the Along Track Scanning Radiometer (ATSR) Reprocessing for Climate (ARC) Lake Surface Water Temperature and Ice Cover (ARC-Lake) dataset (Hook et al, 2012). Sea surface temperatures are interpolated from the Reynolds et al (2007) daily blended analyses. The land surface scheme is that of the Joint UK Land Environment Simulator (JULES; Best et al, 2011; Clark et al, 2011), with soil moisture initialised from an offline reanalysis-forced JULES simulation. Lateral boundary conditions were provided by a global 25 km atmospheric simulation driven by observed sea surface temperatures (Reynolds et al, 2007). This combination of lateral boundary conditions from a parent global model, not reanalysis, combined with a pan-African CP domain, allows significant upscale impacts of the convection on the continental scale (e.g. Stratton et al, 2018; Jackson et al, 2020) and has the effect that some deviations of the regional model from analyses are caused by the parent global model, but this setup was used to allow the same global model to drive a future-climate regional simulation (Kendon et al, 2019).

RegCM

The RegCM version 4.7.1, developed at the International Centre for Theoretical Physics (ICTP, Giorgi et al, 2012), has a version which utilizes the MM5 (Grell et al, 1994) non-hydrostatic dynamical core, and has been developed for simulations at convection permitting grid-scales (Coppola et al, 2020;Coppola et al, 2021). Simulations, conducted at 3 km grid-spacing and with 41 vertical levels (RegCM-3.0), have been performed, in which the model is directly forced by a Pan-Africa CORDEX (Coordinated Regional Downscaling Experiment) simulation at 0.22° grid-spacing (RegCM-25) with ERA-Interim boundary conditions (Dee et al, 2011). The coarser resolution RegCM-25 simulations are conducted with the hydrostatic dynamical core version of RegCM 4.7.1 Giorgi et al, 2012. Both the RegCM-25 and RegCM-3.0 simulations utilize the planetary boundary layer scheme of Holtslag et al (1990), and the radiation scheme of CCM3 (Kiehl et al, 1996). A 1-dimensional lake model in the vertical following Hostetler et al (1993) and Bennington et al (2014) thermodynamically couples the lake points to the RegCM. This lake model configuration is only utilized in the RegCM-3.0 simulation for this study. Additionally, both the RegCM-25 and RegCM3.0 simulations use the Community Land Model (CLM) version 4.5 (Oleson et al, 2013) for land surface processes. Soil moisture is initialized in the CLM based on a climatological soil moisture average (Giorgi and Bates, 1989).

COSMO-CLM

The regional climate model COSMO-CLM version 5 (Rockel et al, 2008) numerically solves the set of nonlinear primitive equations on an Arakawa C-grid. Besides this dynamical model core (Doms and Baldauf, 2015), physical parameterization schemes are activated for radiation (Ritter and Geleyn, 1992), turbulence (Mironov and Raschendorfer, 2001), land (Schulz et al, 2016; Schulz and Vogel, 2020), two-moment microphysics (Seifert and Beheng, 2001, 2006) and deep or shallow convection (Tiedtke, 1989). Two simulations are launched: one parameterized (12 km, COSMO-CLM-12) and one convection-permitting (2.8 km, COSMO-CLM-2.8), both directly forced by ERA5 (Copernicus Climate Change Services, 2017) lateral boundary conditions. The coarse resolution domain is bounded at 22° to 44° longitude and -12° to 5.5° latitude. The high-resolution domain is slightly larger than the evaluation domain, centered on Lake Victoria and encompassing both branches of the East African rift. For a shorter period, this convection-permitting simulation was evaluated by Van de Walle et al (2020), describing that adaptations to the default model setup are based on the COSMO-CLM tropical configuration (Panitz et al, 2014), further adjusted for the African Great Lakes (Thiery et al, 2015) by its online coupling to the one-dimensional Freshwater Lake (FLake) model (Mironov et al, 2010). As recommended by Thiery et al (2014b), the lake temperature profile is initialised with stratified conditions, 25°C surface temperature and 4°C lake bottom temperature. The simulation period is 2006-2015, with one year spin-up (2005) that let the lake water surface temperatures as well as the soil moisture evolve to normal climatological values.

1026 ## 5.2 Additional figures

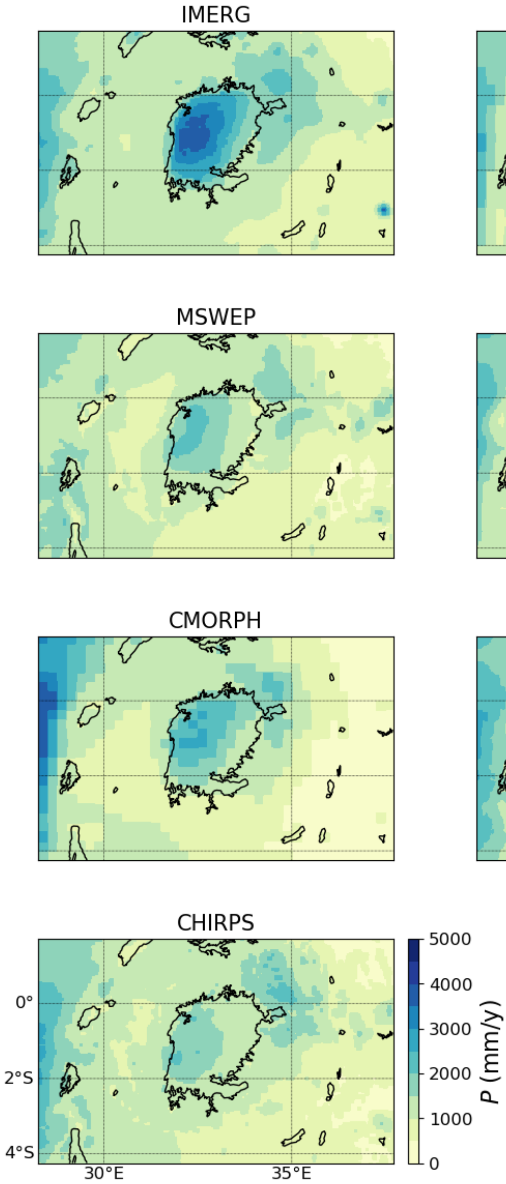

Fig. S1 Absolute rainfall amount per year for all observational products for the period 2006-2015.

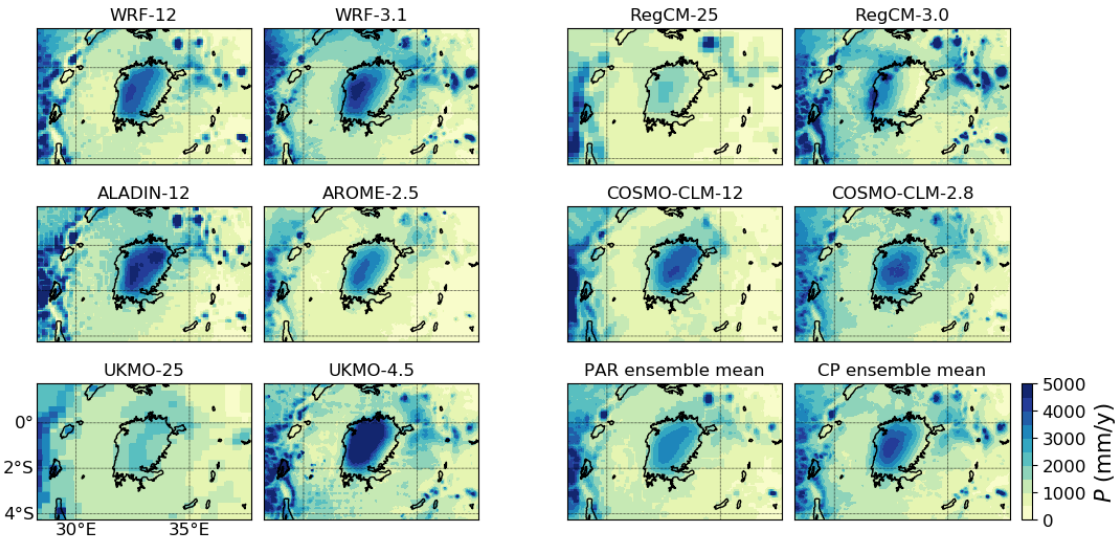

Fig. S2 Absolute rainfall amount per year for all parametrised and convection-permitting models as well as the ensemble mean.

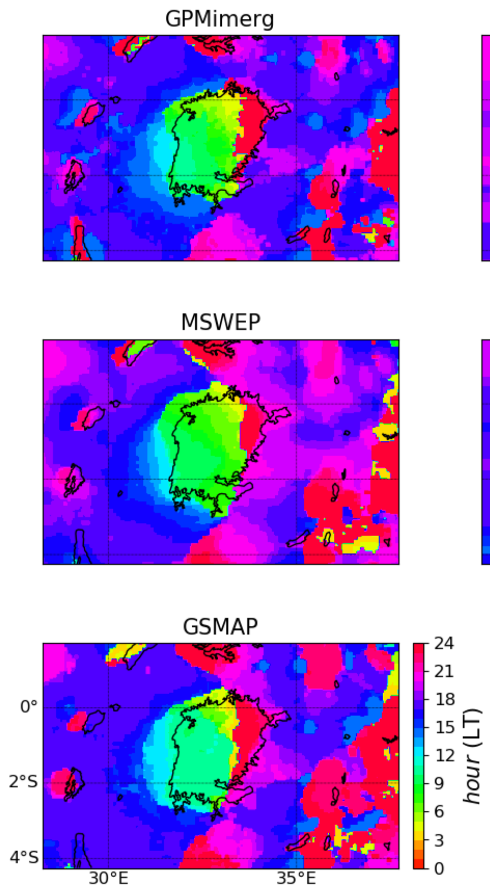

Fig. S3 Peak local time of precipitation for the different observational products with ≤3h temporal resolution for the period 2006-2015.

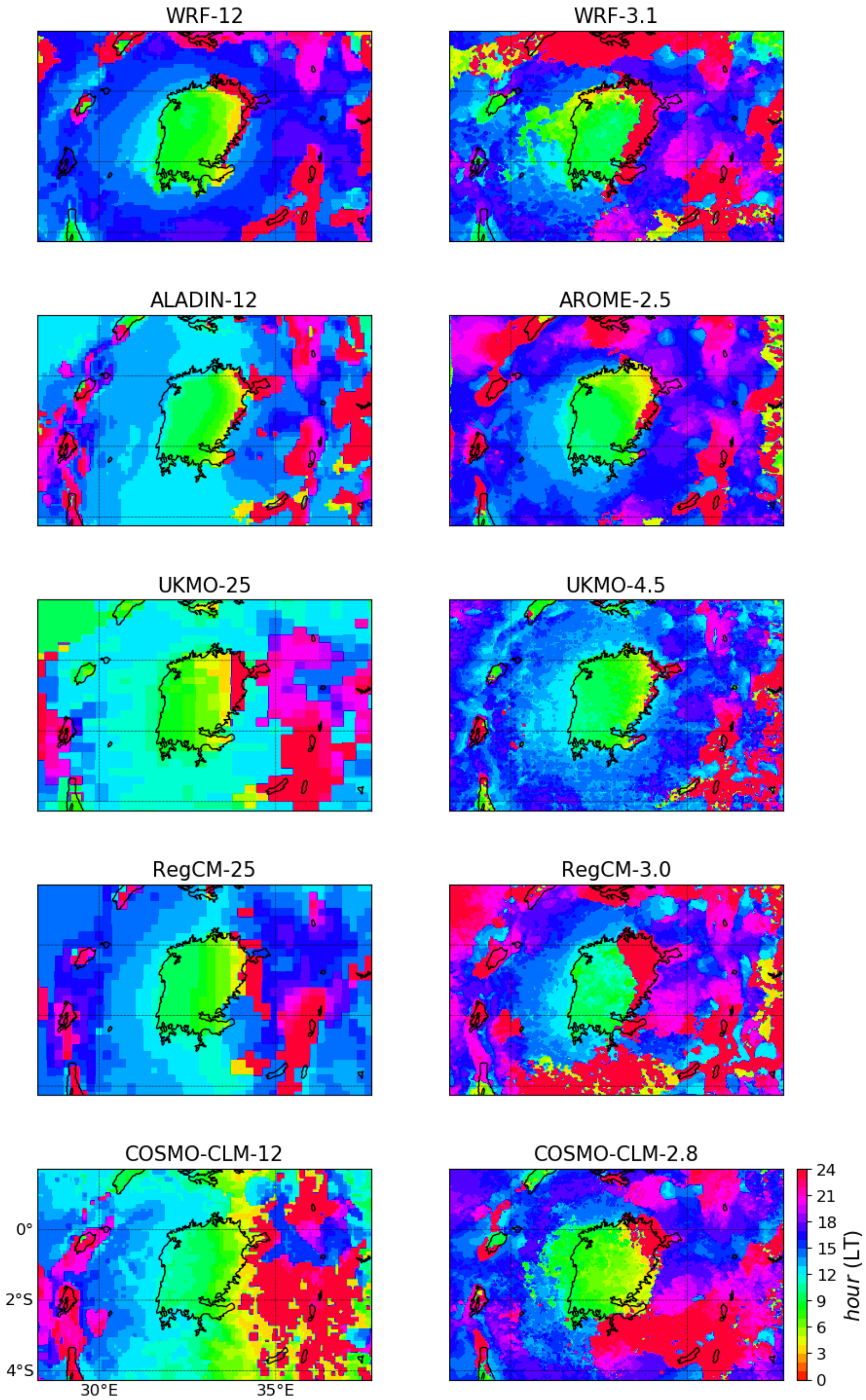

Fig. S4 Peak local time of precipitation for all parametrised and convection-permitting models.

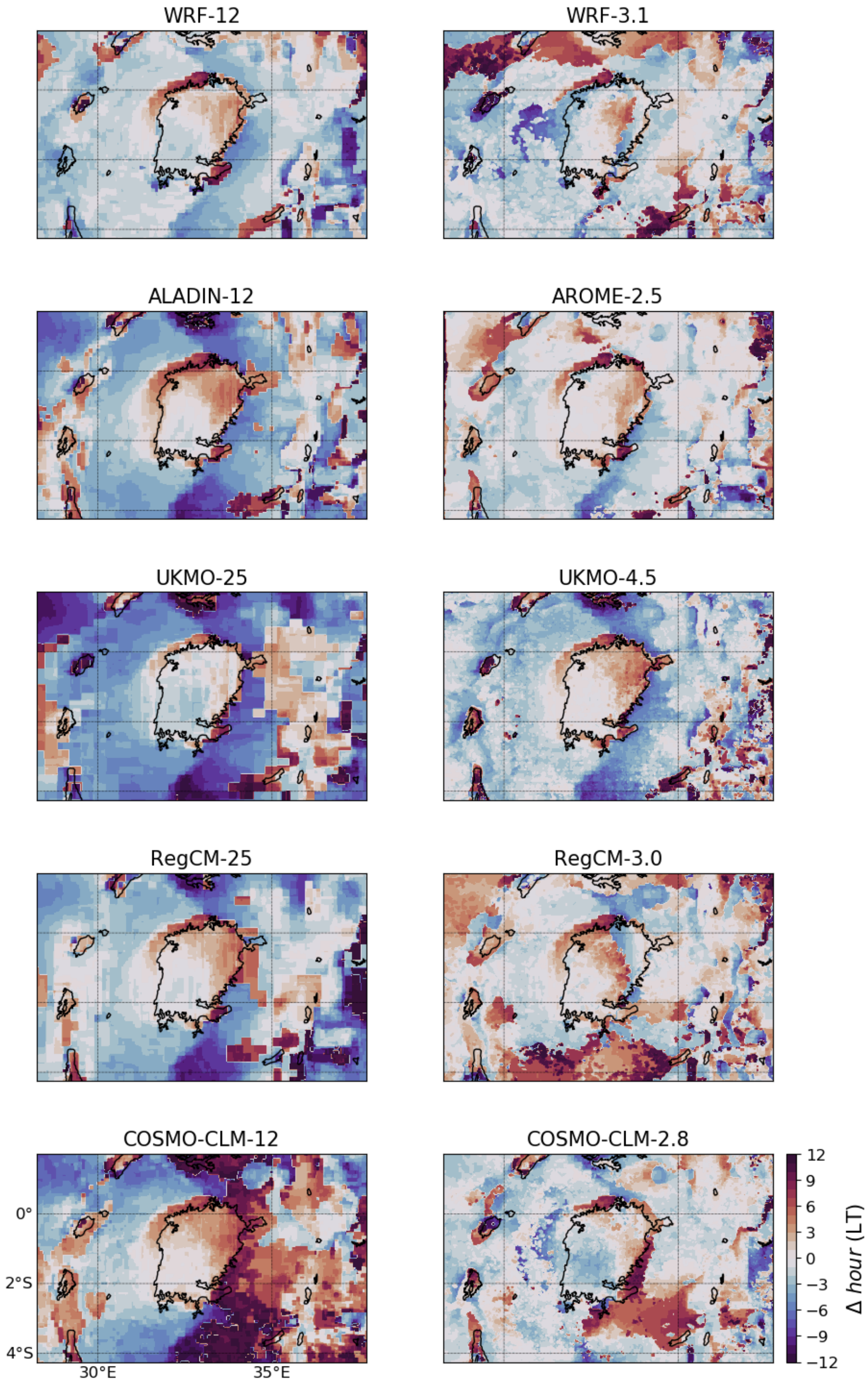

Fig. S5 Peak local time bias of precipitation for all parametrised and convection-permitting models against the observational mean.

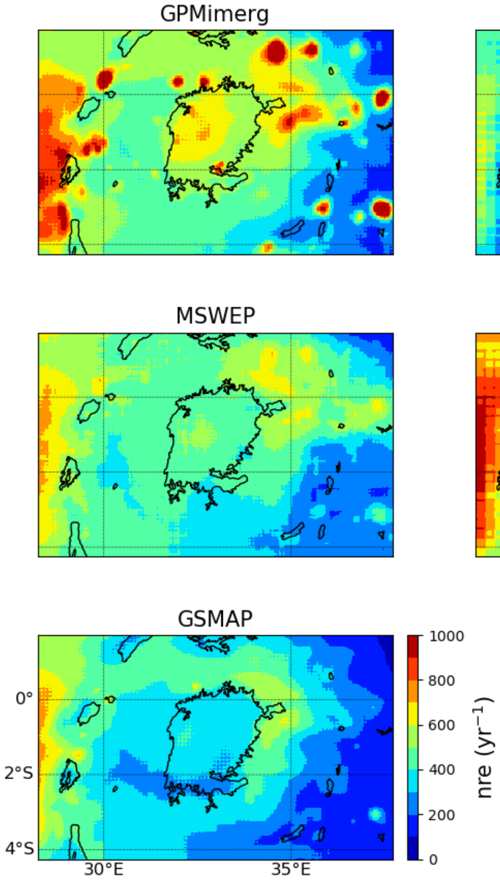

Fig. S6 Total number of rainy events (*nre*) per year for all observational products with ≤3h temporal resolution. The *nre* metric counts the number of three-hourly precipitation events exceeding 0.125 mm/3h.

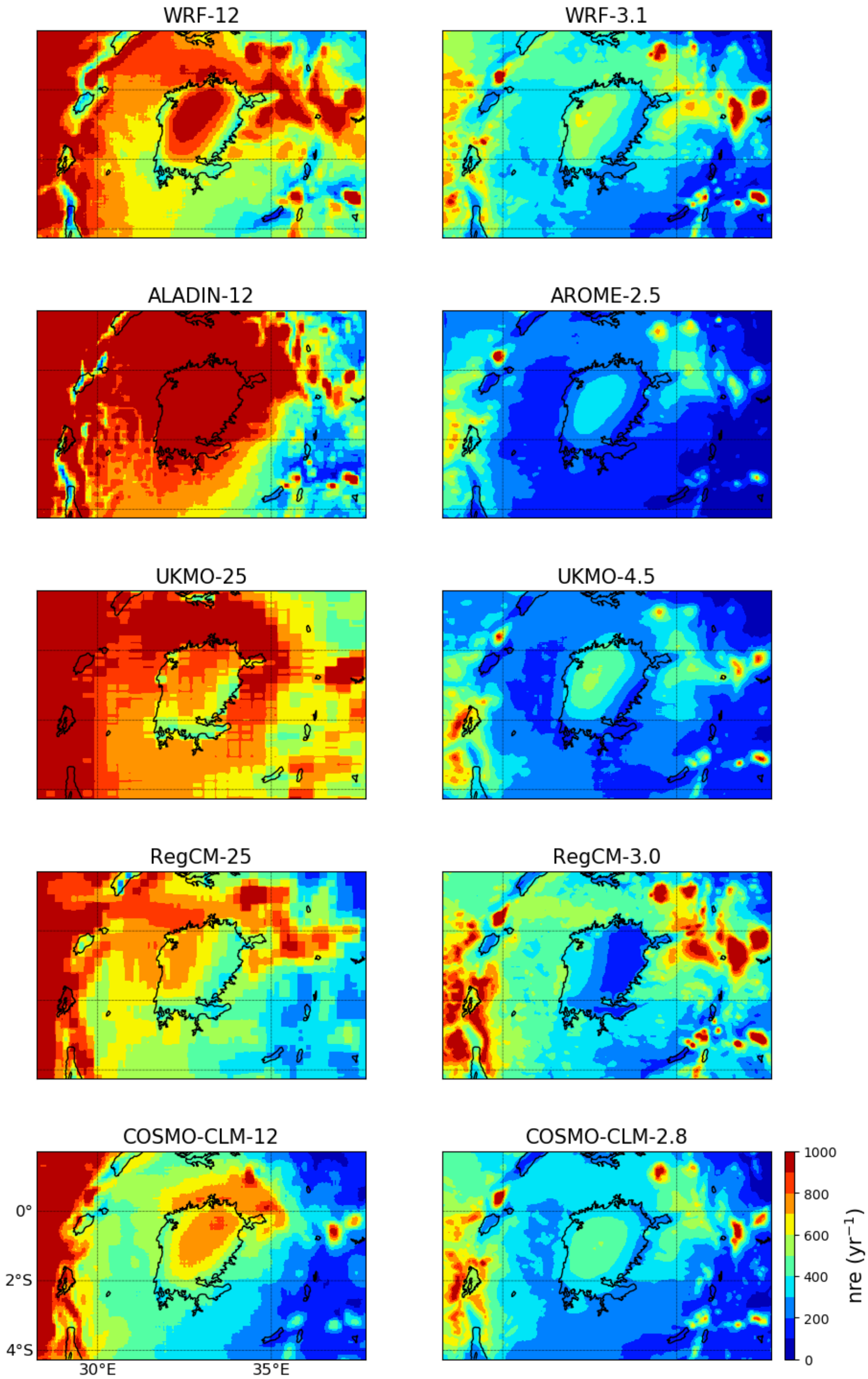

Fig. S7 Total number of rainy events (*nre*) per year for all parametrised and convection-permitting models.

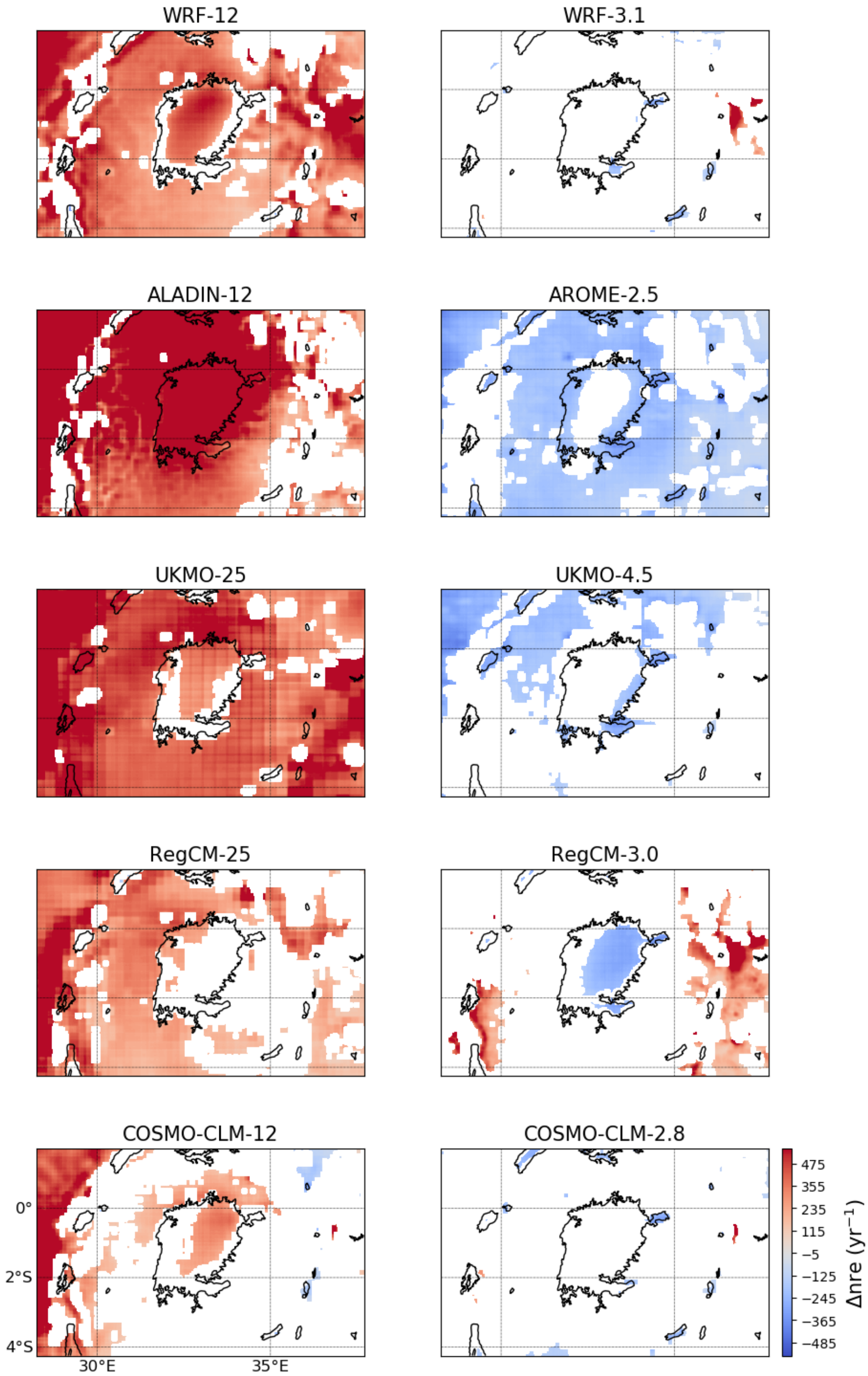

Fig. S8 Bias of total number of rainy events (*nre*) per year for all parametrised and convection-permitting models against the observational mean. Values within the observational range are masked white.

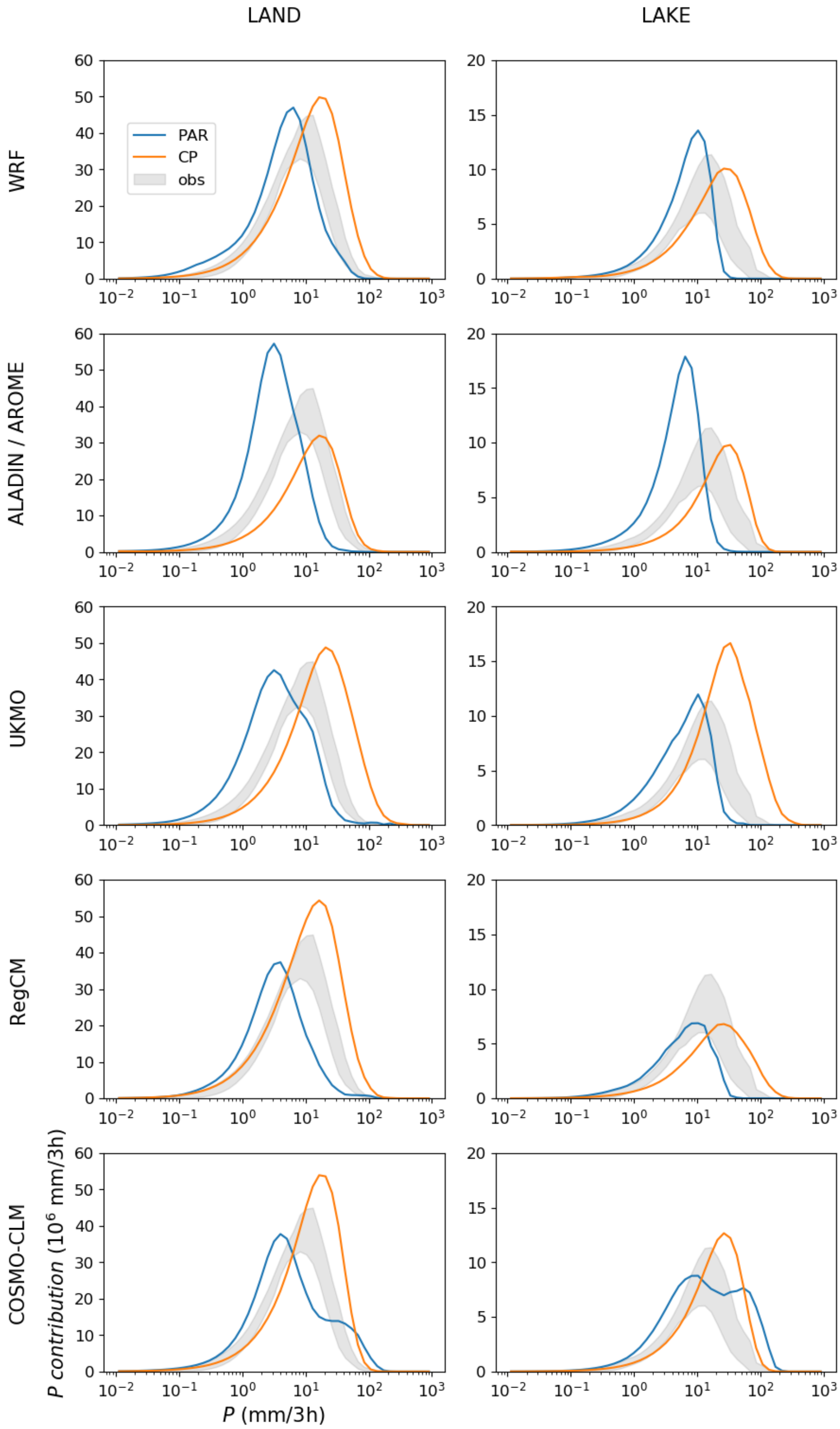

Fig. S9 Separate land and lake rainfall contributions of three-hourly intensity bins for all parametrised and convection-permitting models compared to the observational band.

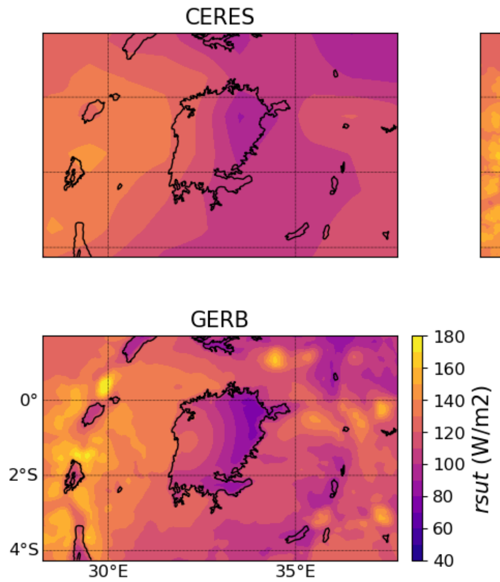

Fig. S10 Averaged upward shortwave radiation at the top-of-the-atmosphere for the observational products for the period 2006-2015.

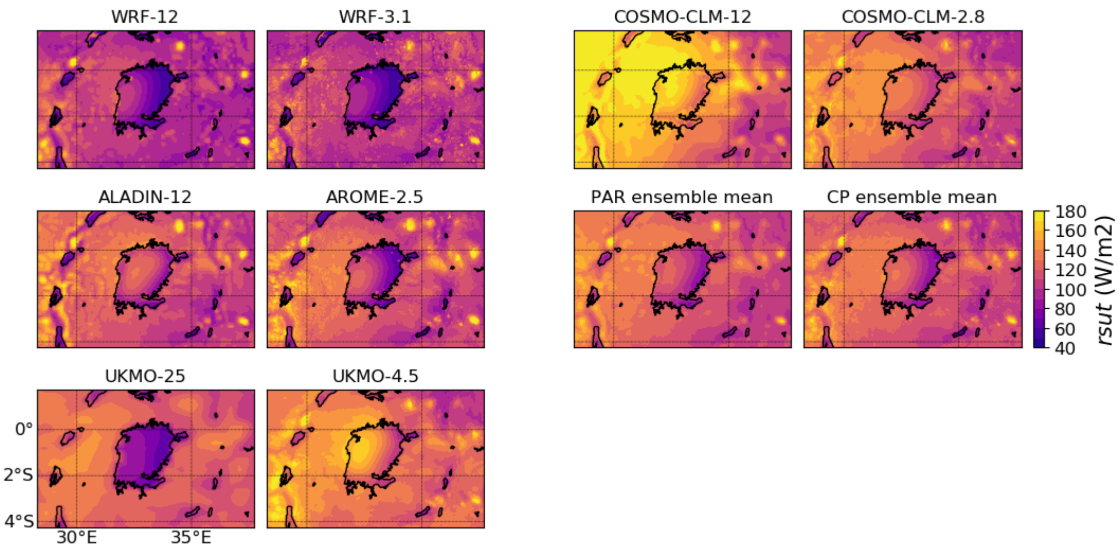

Fig. S11 Averaged upward shortwave radiation at the top-of-the-atmosphere for all parametrised and convection-permitting models except RegCM, as well as the ensemble mean.

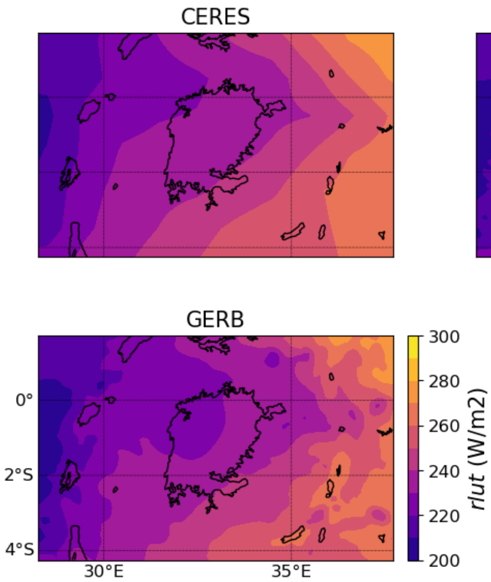

Fig. S12 Averaged upward longwave radiation at the top-of-the-atmosphere for the observational products for the period 2006-2015.

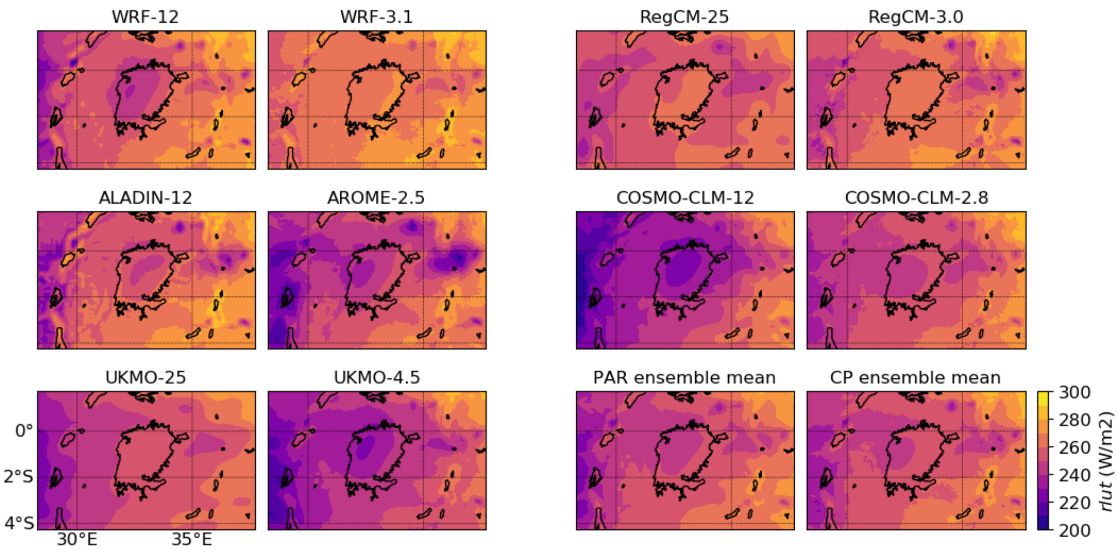

Fig. S13 Averaged upward longwave radiation at the top-of-the-atmosphere for all parametrised and convection-permitting models, as well as the ensemble mean.

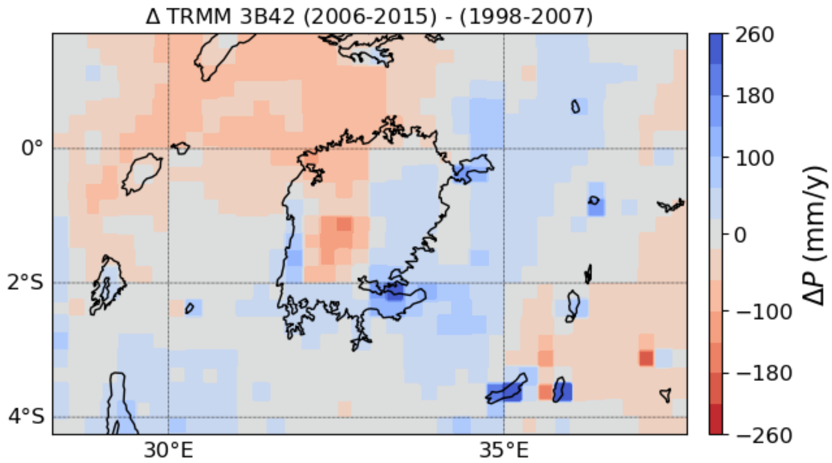

Fig. S14 Difference of averaged total rainfall per year for two TRMM-3B42 periods 2006-2015 and 1998-2007.