Supplementary Information

1 Supplementary figures

1.1 Supplementary table to Sect. 1 Introduction

Table S1. Overview of rooting depth or root zone storage capacity estimate methods. See also Sect. 1.1.

	Field observation based	**Look-up table**	**Root distribution modelling**	**Inverse modelling**	**Calibration**	**Mass balance based**
Estimated variable	Actual root depths/profiles	Root zone storage capacity	(Hydrological) active root profiles	(Potential) hydrological active root depth	Hydrological root zone storage capacity	Hydrological root zone storage capacity
Spatial scale	Local, regional, global (scaled up from field observations)	Regional, global	Local (Potential for scaling up)	Global/regional	Catchment (transferable to global scale by regionalisation)	Catchment, regional, global
Type of model or algorithm	Mean biome, regression model	N/A	Analytical, stochastic, genetic algorithm	Vegetation model	Hydrological model	Mass curve technique or cumulative mass balance
Required input data	Regression model requires climate, soil, and vegetation information	Literature rooting depth, soil texture data	Climate, soil, and vegetation information	Climate, soil, and vegetation information	Climate and hydrological data	Runoff and/or evaporation demand, and precipitation
Main merits	- observation based	- grounded in literature - facilitates land cover change experiments	- improves understanding of root distribution development	- Earth observation based	- compensates for model uncertainties	- observation based - no need for soil and vegetation data - model independent
Main limitations	- Limited coverage of observations - possible need to convert to active root zone storage capacity	- assumes that a single rooting depth is valid across a land cover type	- model dependent - detailed input data required	- model and data dependent	- model and data dependent - parameter equifinality	- dependent on hydrological data
References (examples)	(Canadell et al., 1996; Jackson et al., 1996; Schenk and Jackson, 2009)	(Müller Schmied et al., 2014; Wang-Erlandsson et al., 2014)	(Collins and Bras, 2007; Laio et al., 2006; Schenk, 2008; van Wijk and Bouten, 2001)	(Ichii et al., 2007; Kleidon, 2004)	(Fenicia et al., 2009; Winsemius et al., 2009)	(de Boer-Euser et al., n.d.; van Dijk et al., 2014; Gao et al., 2014), this study.

1.2 Supplementary figures to Sect. 2 Methods and Sect. 3 Data

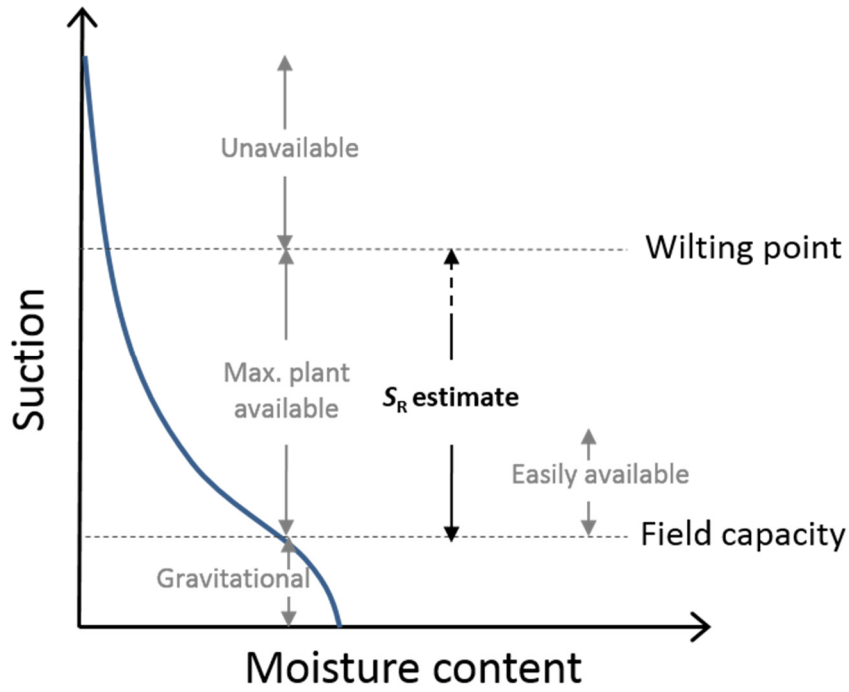

Figure S1. S_R estimate on the soil moisture retention curve. Ideally, the root zone storage capacity S_R correspond to the maximum plant available water. In case of a prolonged drought where all soil moisture is depleted. The estimated S_R is likely larger than the easily available moisture content and close to the maximum plant available moisture content. See also Sect. 2.1.

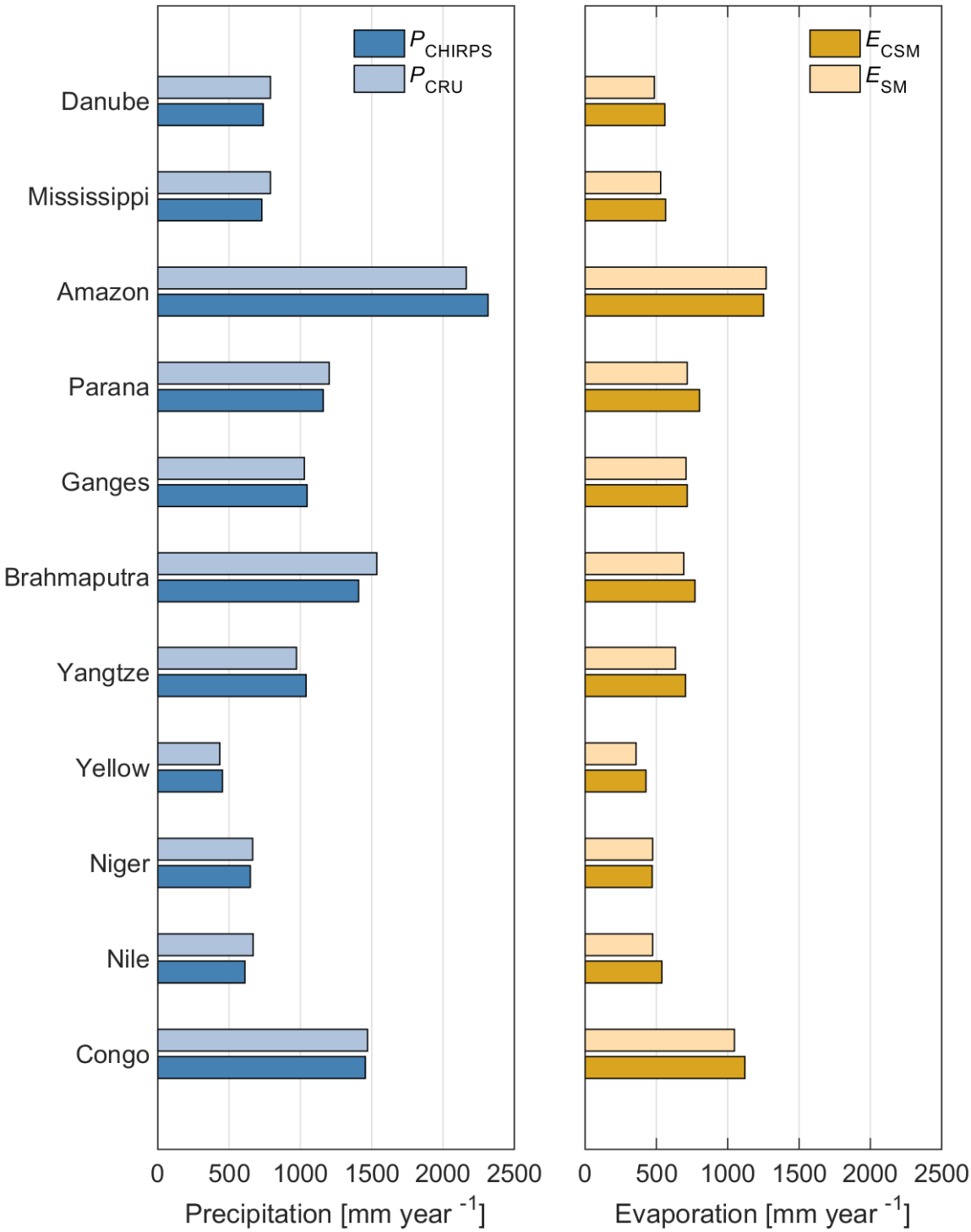

Figure S2. Mean annual precipitation and evaporation by river basins. See also Sect. 3.1.

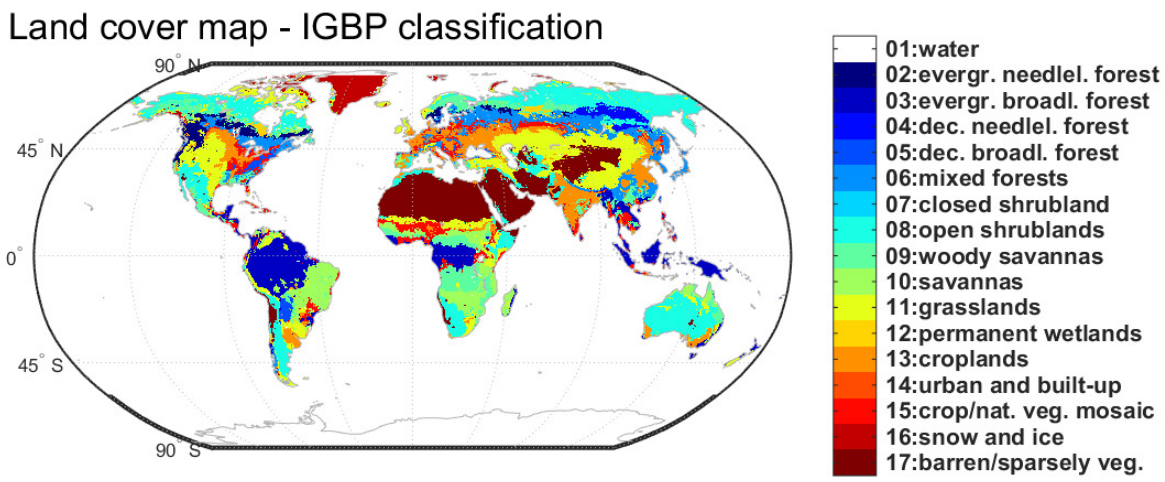

Figure S3. Land cover map (MCD12C1 from MODIS) used in this study showing the dominant land cover type in each grid cell.

1.3 Supplementary figures to Sect. 4 Results and discussion

RMSE improvements in simulated mean annual evaporation (i.e., the increase in similarity between a benchmark evaporation products E_{CSM} or E_{SM} and the simulated E by using $S_{R,CRU\text{-}SM}$ or $S_{R,CHIRPS\text{-}CSM}$ instead of $S_{R,STEAM}$ as input to STEAM) were achieved for most of the world, see Figure S4. In particular, improvements are large in the southern mid-latitudes and in the tropical belt. Only in the northern mid-latitudes is E simulation performance worse independent of the data used. The RMSE improvements in E simulation are generally slightly higher with $S_{R,CRU\text{-}SM}$ than with $S_{R,CHIRPS\text{-}CSM}$.

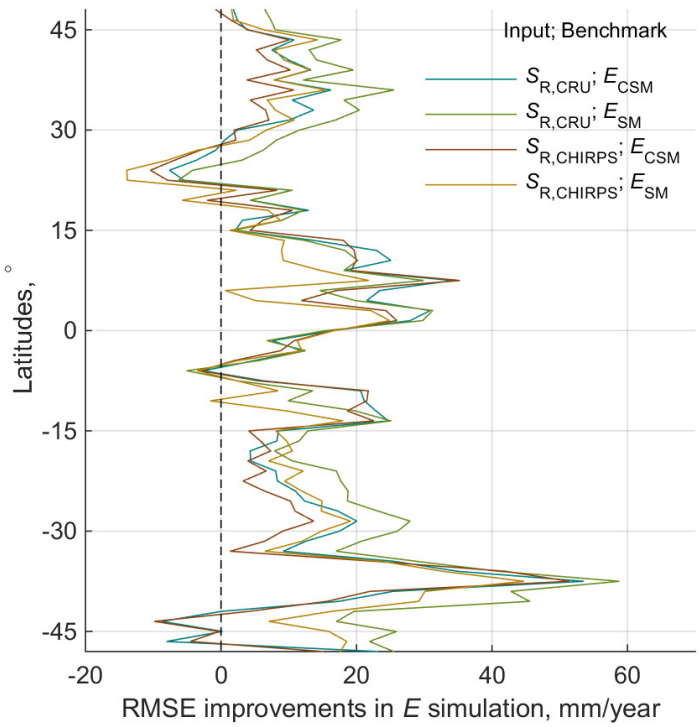

Figure S4. RMSE improvements of E simulation achieved by using $S_{R,CRU}$ and $S_{R,CHIRPS}$ as input to STEAM instead of $S_{R,STEAM}$. E_{CSM} and E_{SM} were used as benchmark for measuring improvements. See also Sect. 4.3.

2 Increasing performance in STEAM by Gumbel normalised S_R

2.1 Methods

As shown in Sect. 4.4, different land cover types seemed to increase E simulation in STEAM by Gumbel normalisation with different drought return years. A drought return period of 2 years ($S_{R,CRU-SM,2yrs}$) offers the best evaporation simulation performance in woody savannahs, savannahs, croplands, grasslands, open shrublands, barren land, and deciduous broadleaf forest, whereas it tends to decrease the model performance in other forest types. Instead, $S_{R,CRU-SM,5yrs}$ offers the highest performance in evergreen needleleaf forest, and $S_{R,CRU-SM,10yrs}$ or $S_{R,CRU-SM,20yrs}$ are best in evergreen broadleaf forests and mixed forest.

Thus, we create a root zone storage capacity map $S_{R,CRU-SM,merged}$ that uses different drought return periods for different land cover types to increase performance in STEAM in principal based on Fig. 8. in Sect. 4.4. For water, urban land, and snow, where root zone storage capacity is not important, no Gumbel normalisation was applied. Table S2 shows the drought return periods matched to the different land cover types.

Table S2. The drought return period applied to the different land cover types.

S_R	Land cover type
$S_{R,CRU-SM,2yrs}$	07:closed shrubland, 08:open shrublands, 09:woody savannas, 10:savannas, 11:grasslands,12:permanent wetlands,13:croplands, 15:cropland/natural veg. mosaic,17:barren or sparsely vegetated
$S_{R,CRU-SM,10yrs}$	02:evergreen needleleaf forest, 03:evergreen broadleaf forest, 06:mixed forests
$S_{R,CRU-SM,60yrs}$	04:deciduous needleleaf forest, 05:deciduous broadleaf forest,
$S_{R,CRU-SM}$	01:water, 14:urban and built-up, 16:snow and ice

2.2 Results and discussion

Figure S5 shows a comparison between $S_{R,CRU-SM}$ (the maximum value of the time series 2003-2013) and $S_{R,CRU-SM,merged}$ (Gumbel normalisation with different drought return periods for different land cover types). The Gumbel normalisation reduces root zone storage capacity particularly in northern Australia, northern India, eastern Brazil, southern Bolivia, and eastern Africa.

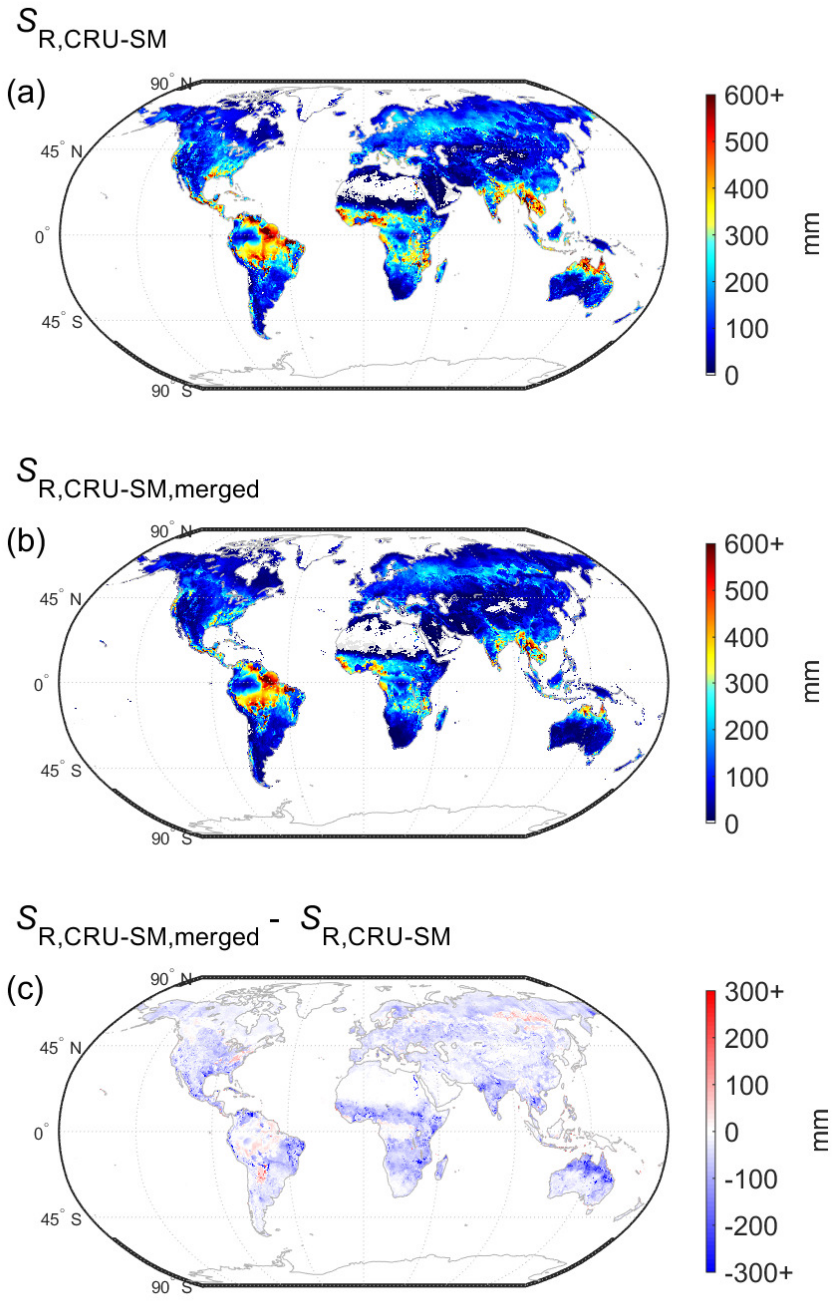

Figure S5. The (a) $S_{R,CRU\text{-}SM}$ (maximum storage deficit over the years 2003-2013), (b) $S_{R,CRU\text{-}SM,merged}$ (merged using the best performing Gumbel normalised S_R for each land cover type), and (c) the difference $S_{R,CRU\text{-}SM}$ and $S_{R,CRU\text{-}SM,merged}$.

Figure S6 compares the STEAM-simulated evaporation when using, on the one hand, $S_{R,CRU\text{-}SM,merged}$ and, on the other, the look-up table based $S_{R,STEAM}$. Similar to $S_{R,CRU\text{-}SM}$ (Fig. 6), $S_{R,CRU\text{-}SM,merged}$ has the greatest potential to influence model simulations for the hot and dry seasons, and for the seasonal tropical forests where the root zone storage capacity varies strongly. Compared to $S_{R,CRU\text{-}SM}$ (Fig. 6), $S_{R,CRU\text{-}SM,merged}$ causes greater reductions in evaporation in January south of Sahara, in April in Argentina, South Africa and Australia, and in July in Northern Hemisphere.

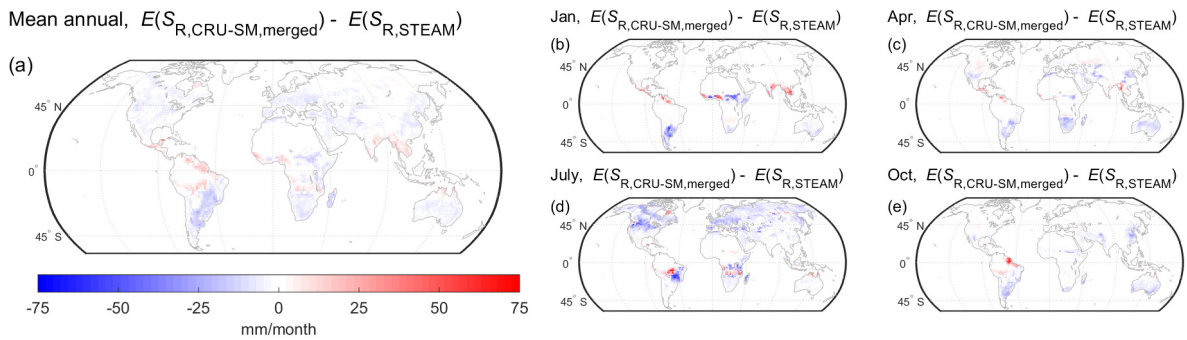

Figure S6. Difference in STEAM-simulated evaporation between using $S_{R,CRU\text{-}SM,merged}$ and $S_{R,STEAM}$ as root zone storage capacity parametrisation at (a) mean annual scale and averages for the months of (b) January, (c) April, (d) July, and (e) October over the time period 2003-2013. See also Sect. 4.3.

Overall, the total mean annual evaporation are not changed significantly by the use of the different root zone storage capacities $S_{R,STEAM}$, $S_{R,CRU\text{-}SM}$, and $S_{R,CRU\text{-}SM,merged}$. $S_{R,CRU\text{-}SM,merged}$ decreases the total evaporation by about 2200-2400 km^3/year and transpiration ration by 2-3 percentage points, see Table S3.

Table S3. Overview of STEAM-simulated mean annual evaporation and transpiration ratio (2003-2013) depending on the input root zone storage capacity $S_{R,STEAM}$, $S_{R,CRU\text{-}SM}$, or $S_{R,CRU\text{-}SM,merged}$.

	E (km^3/yr)	Transpiration ratio (%)
$S_{R,STEAM}$	73,460	58
$S_{R,CRU\text{-}SM}$	73,660	57
$S_{R,CRU\text{-}SM,merged}$	71,190	55

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