Supplement

S1 Spatial Pattern of scaled parameters in VEG

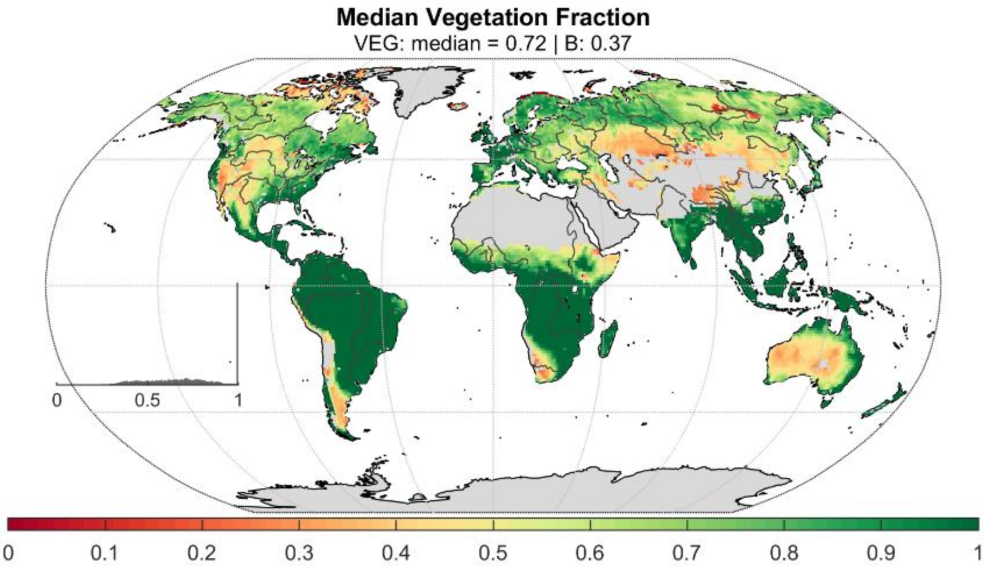

Figure S1 Global distribution of the median vegetation fraction p_{Veg} after calibration of the VEG experiment.

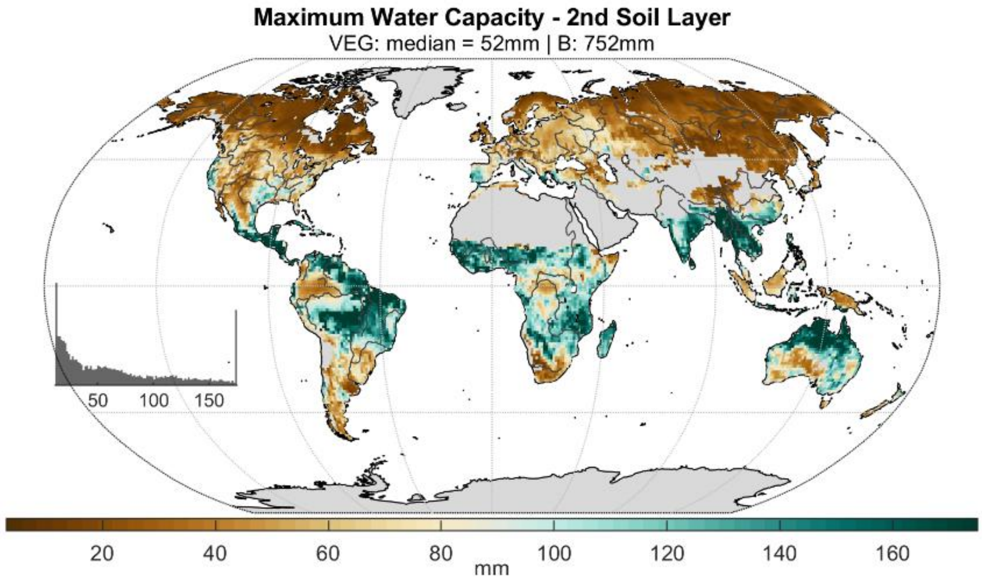

Figure S2 Global distribution of the maximum water capacity of the 2nd soil layer $wSoil_{max(2)}$ after calibration of the VEG experiment.

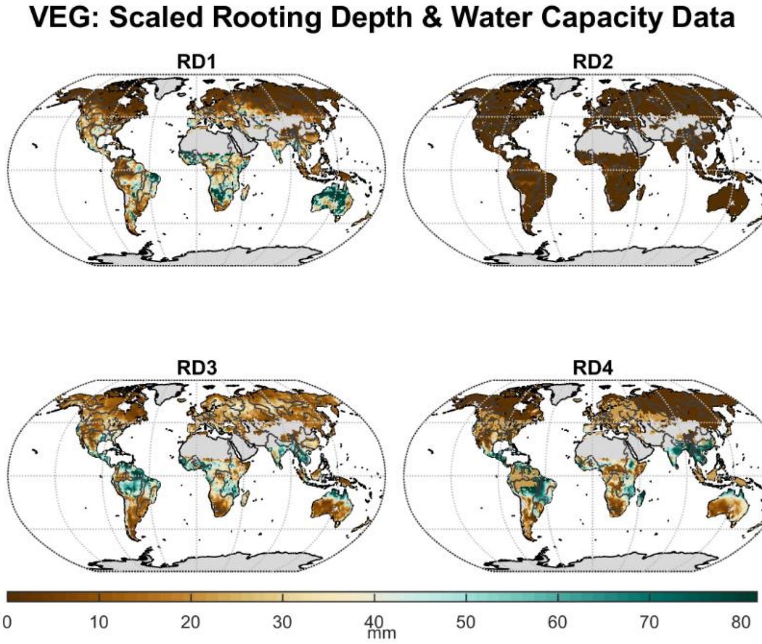

Figure S3 Global distribution of the maximum water capacity of the 2nd soil layer contributed by each data stream after calibration of their scaling parameters in the VEG experiment. RD1 = maximum rooting depth by Fan et al. 2017; RD2 = effective rooting depth by Yang et al. 2016; RD3 = maximum soil water capacity by Wang-Erlandsson et al. 2016; RD4 = plant available water capacity by Tian et al. 2019.

S2 Effective Alpha Coefficient

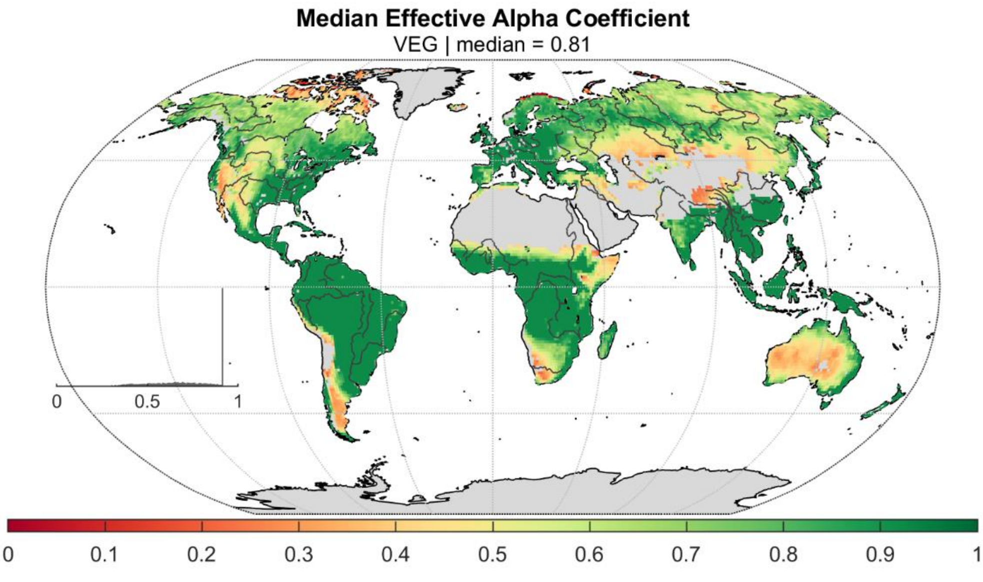

Figure S4 Global distribution of the median effective alpha coefficient (α_{Veg} * p_{Veg}) in the Priestley-Taylor formula after calibration of the VEG experiment.

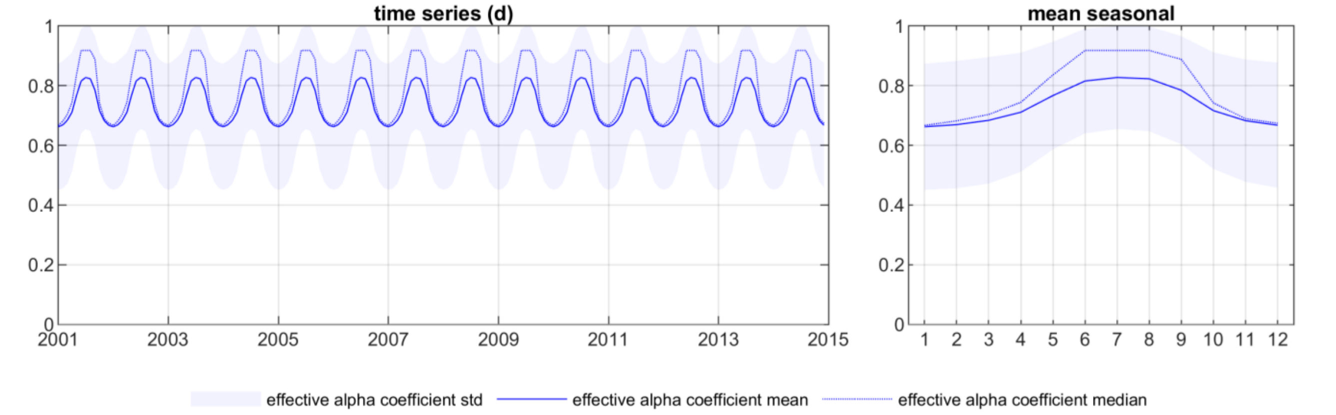

Figure S5 Daily time series and mean seasonal dynamics of the area weighted average, median and standard deviation of the grid-wise effective alpha coefficient in the Priestley-Taylor formula of the calibrated VEG experiment.

S3 Parameter Correlation

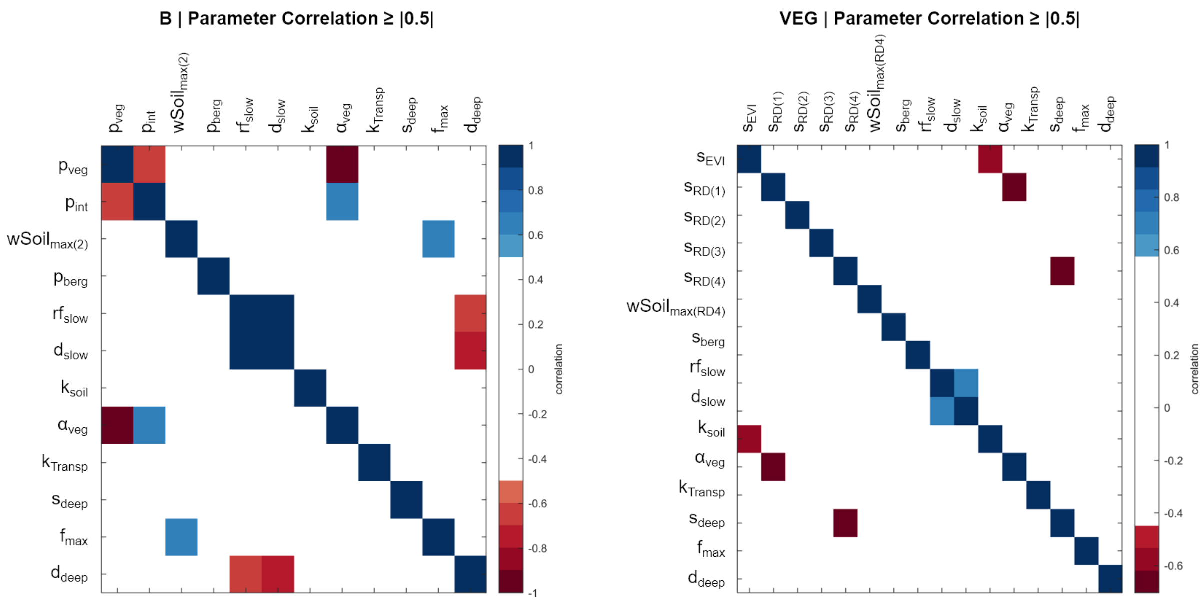

Figure S6 Correlation (≥ |0.5|) between model parameters for the B and VEG experiment.

S4 Regional IAV TWS Composition

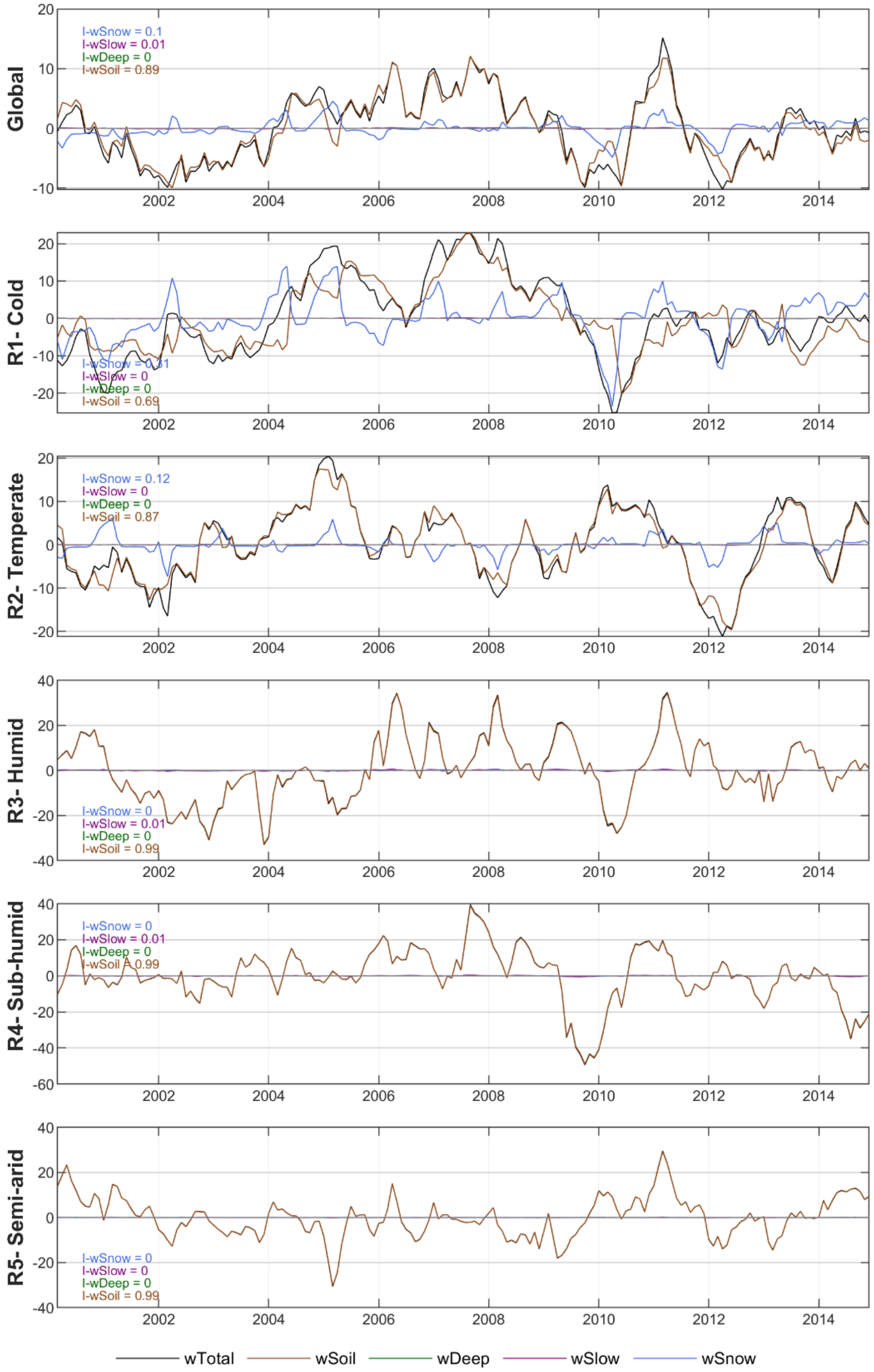

Figure S7 Global and regional average inter-annual variability of simulated total water storage (*wTotal*) and its components (*wSoil*, *wDeep*, *wSlow*, *wSnow*) for B, including the regional Impact Index *I* for each storage.

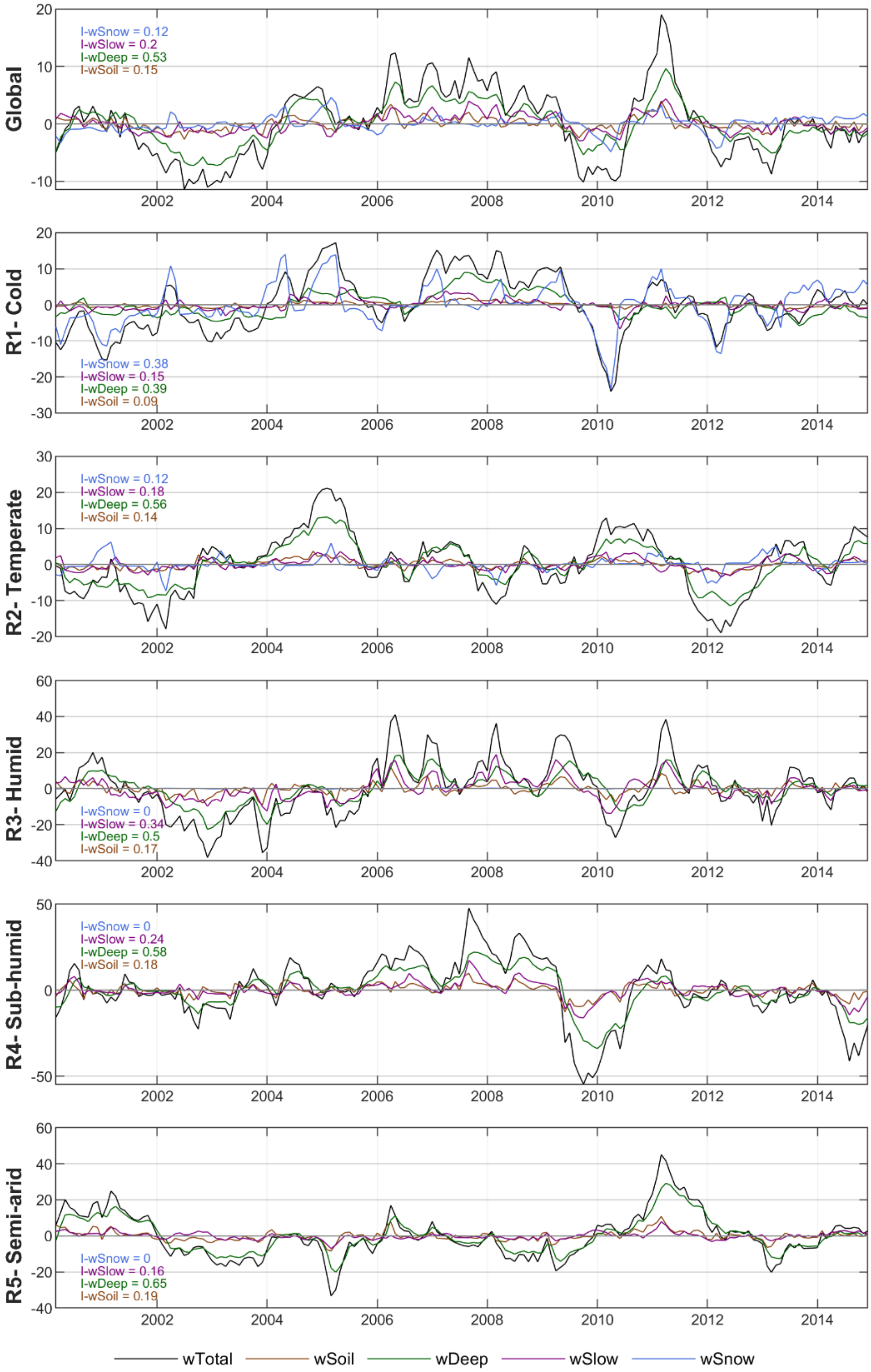

Figure S8 Global and regional average inter-annual variability of simulated total water storage (*wTotal*) and its components (*wSoil*, *wDeep*, *wSlow*, *wSnow*) for VEG, including the regional Impact Index *I* for each storage.

S5 T over ET

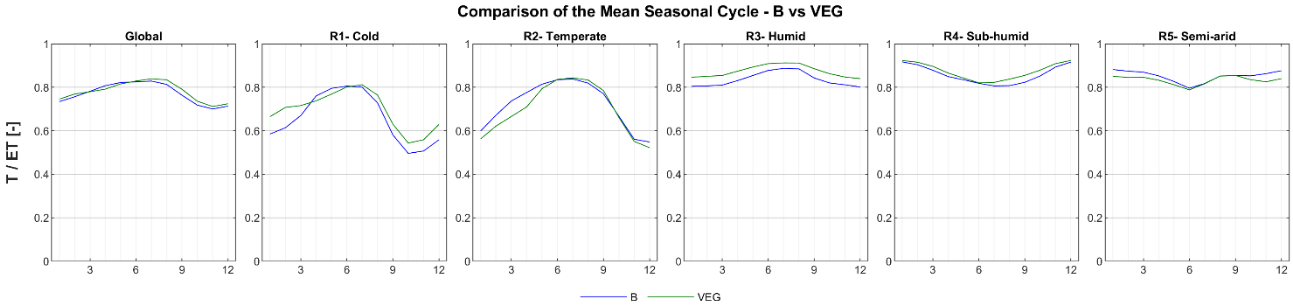

Figure S9 Global and regional average mean seasonal cycles of modelled transpiration (*T*) over evapotranspiration (*ET*) for B and VEG experiments.

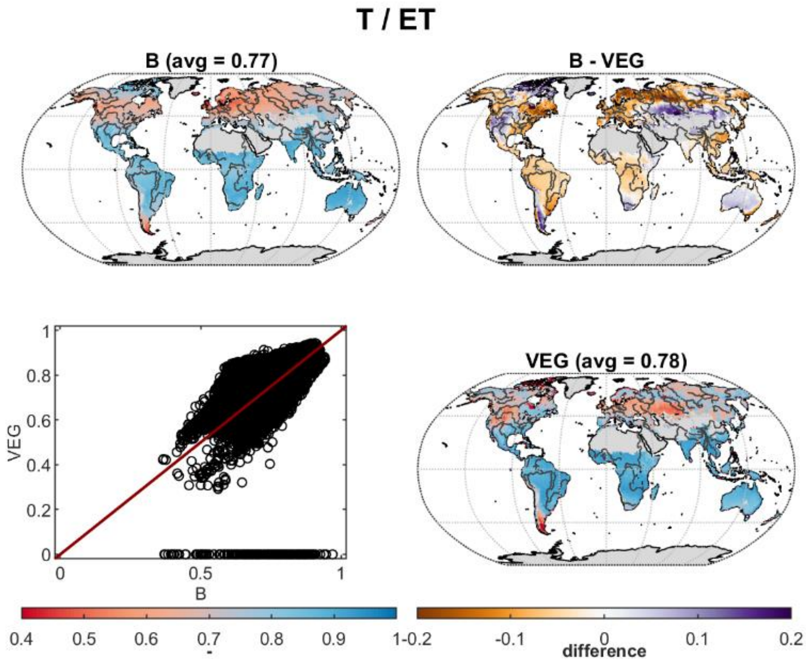

Figure S10 Global distribution of modelled transpiration (*T*) over evapotranspiration (*ET*) for B and VEG experiments, as well as the difference between both (lower right).

S6 Q Components

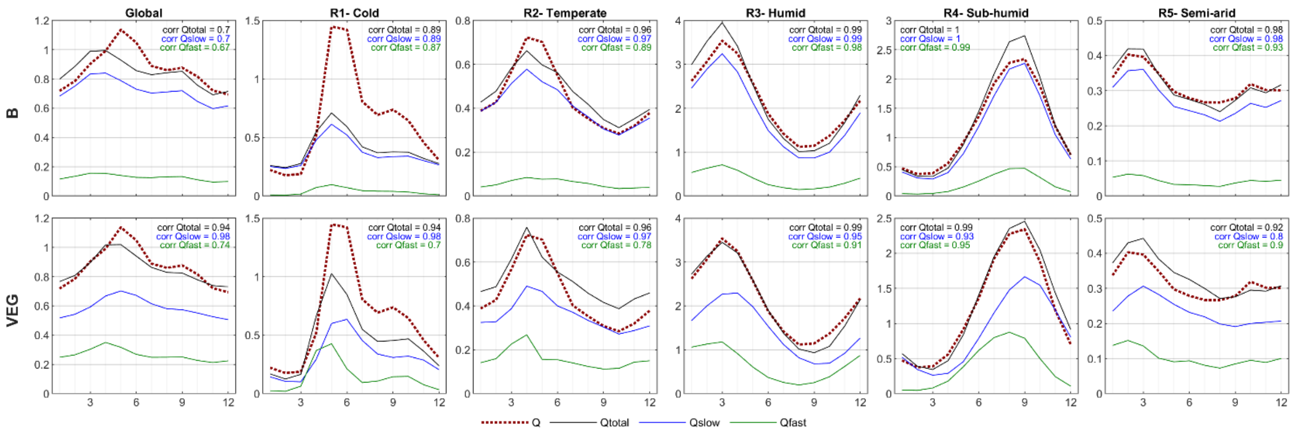

Figure S11 Global and regional average mean seasonal cycle of observed grid-wise runoff from GRUN (*Q*) and simulated total runoff (*Qtotal*), as well as its components *Qslow* and *Qfast*, for the B and VEG experiments. corr is the Pearson correlation coefficient of the respective simulation with observed *Q*.

S7 Comparison of VEG & VEG without capillary rise

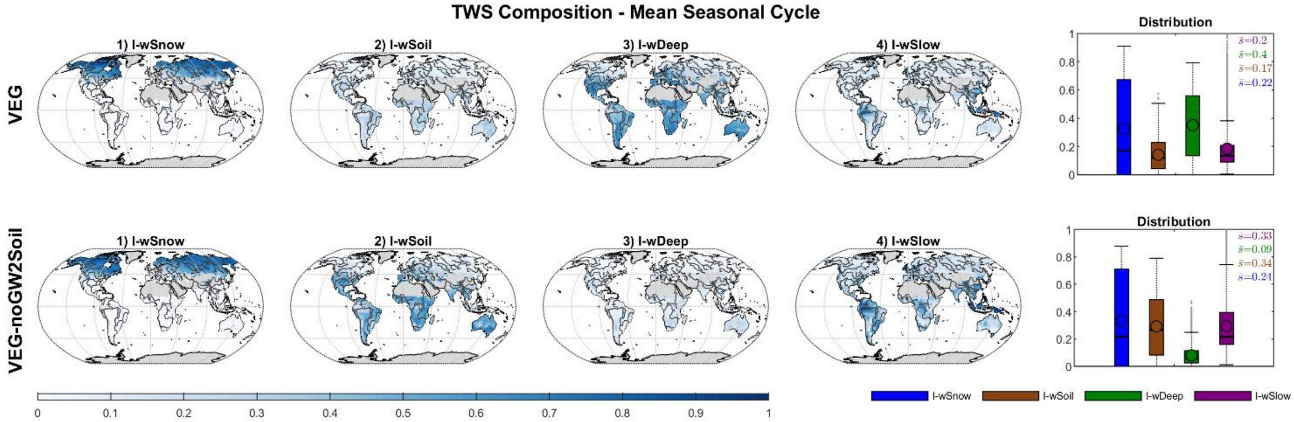

Figure S12 Global distribution of the Impact Index, *I*, for the contribution of simulated snow (*wSnow*), soil (*wSoil*), deep water storage (*wDeep*) and delayed water storage (*wSlow*) to the mean seasonal cycle of total water storage, for VEG and VEG-noGW2Soil, which is a variant of the VEG experiment, in with the capillary rise from *wDeep* to *wSoil* is turned off prior to model calibration.

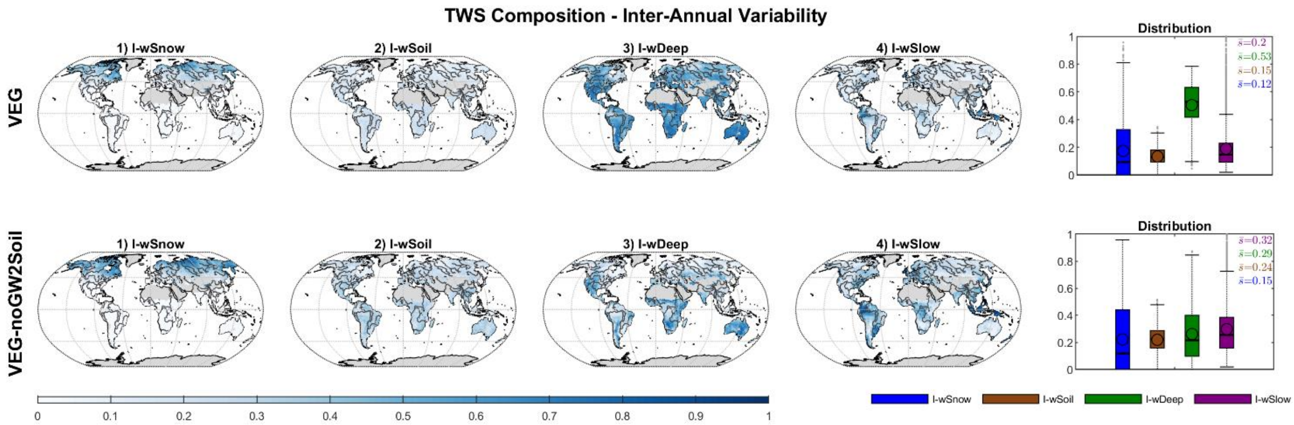

Figure S13 Global distribution of the Impact Index, *I*, for the contribution of simulated snow (*wSnow*), soil (*wSoil*), deep water storage (*wDeep*) and delayed water storage (*wSlow*) to the inter-annual anomalies of total water storage, for VEG and VEG-noGW2Soil, which is a variant of the VEG experiment, in with the capillary rise from *wDeep* to *wSoil* is turned off prior to model calibration.

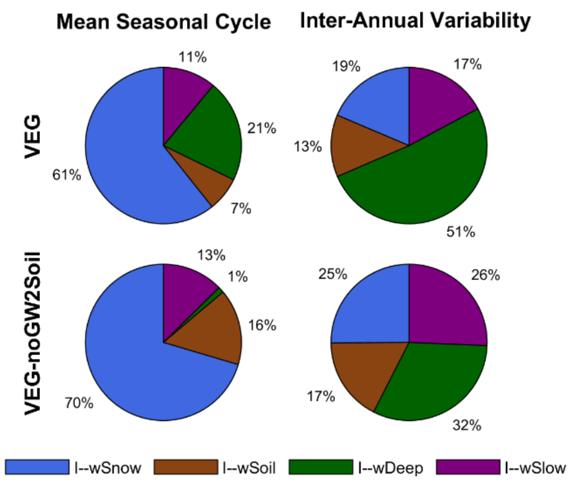

Figure S14 Impact Index *I* for the contribution of simulated snow (*wSnow*), soil (*wSoil*), deep water storage (*wDeep*) and delayed water storage (*wSlow*) to the global average mean seasonal cycle and inter-annual variability of total water storage, for VEG and VEG-noGW2Soil, which is a variant of the VEG experiment, in with the capillary rise from *wDeep* to *wSoil* is turned off prior to model calibration.

S8 Comparison of VEG & VEG with fixed k_{Transp} at 0.05

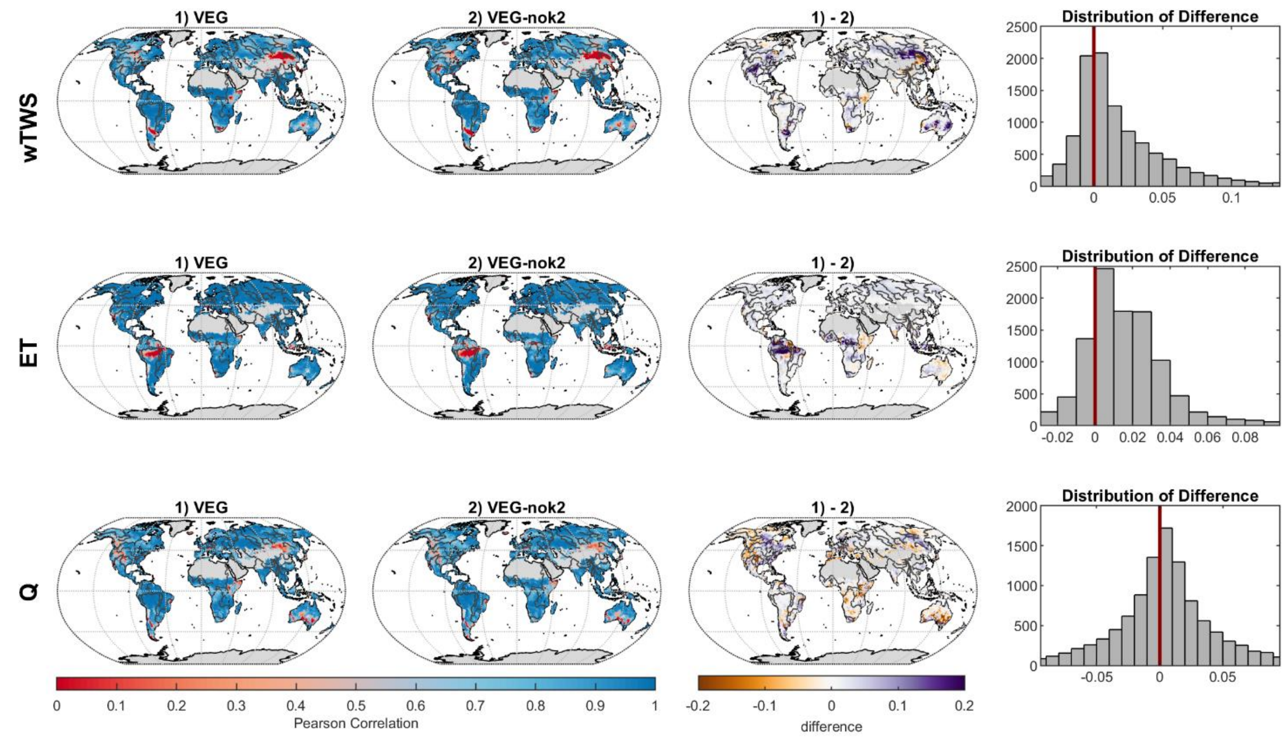

Figure S15 Grid-wise Pearson's correlation coefficient for total water storage (wTWS), evapotranspiration (ET) and runoff (Q) between 1) observations and VEG, and 2) observations and VEG-nok2, as well as differences between 1) and 2) (brown color, i.e., negative values indicate higher correlations for VEG-nok2, while purple color, i.e., positive values indicate better correlation values for VEG). VEG-nok2 is a variant of the VEG experiment, in which the k_{Transp} parameter is not calibrated but fixed at a low value of 0.05.

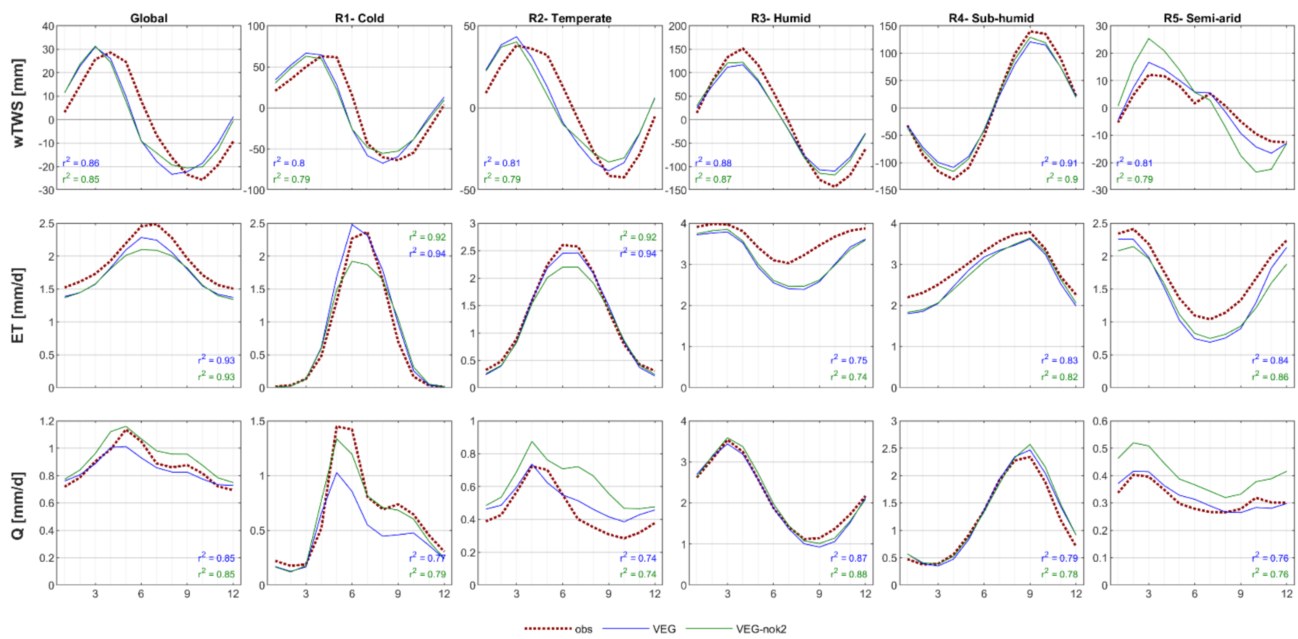

Figure S16 Global and regional mean seasonal cycles of total water storage (*wTWS*), evapotranspiration (*ET*) and runoff (*Q*) for VEG and VEG-nok2, which is a variant of the VEG experiment, in which the k_{Transp} parameter is not calibrated but fixed at a low value of 0.05, compared to the observational constraints by GRACE (*wTWS*), FLUXCOM (*ET*) and GRUN (*Q*).

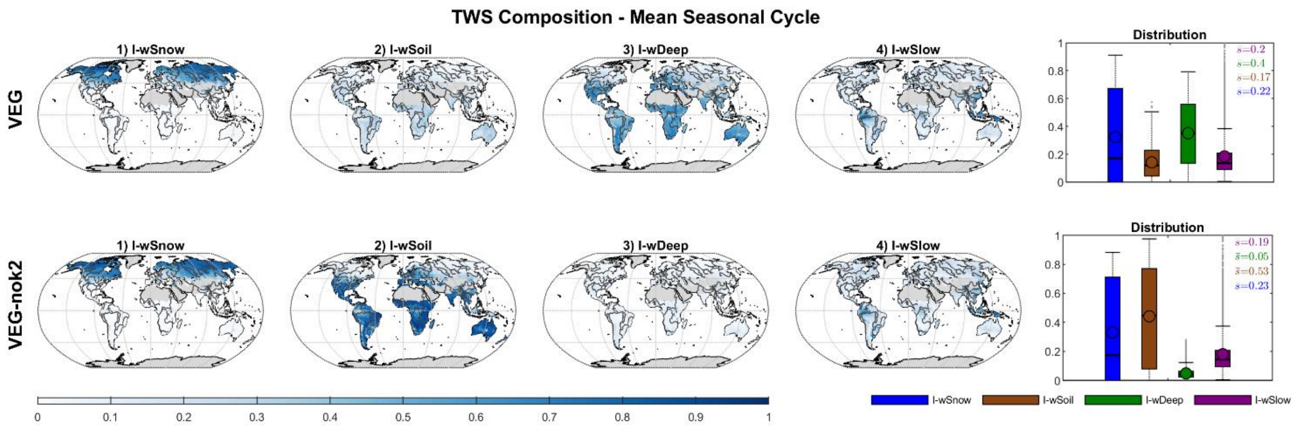

Figure S17 Global distribution of the Impact Index, *I*, for the contribution of simulated snow (*wSnow*), soil (*wSoil*), deep water storage (*wDeep*) and delayed water storage (*wSlow*) to the mean seasonal cycle of total water storage, for VEG and VEG-nok2, which is a variant of the VEG experiment, in which the k_{Transp} parameter is not calibrated but fixed at a low value of 0.05.

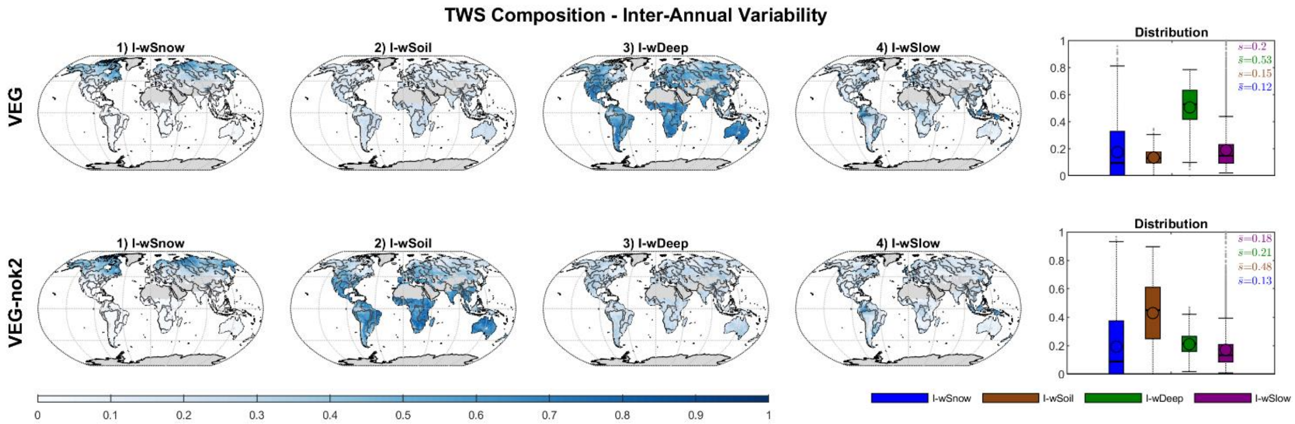

Figure S18 Global distribution of the Impact Index, *I*, for the contribution of simulated snow (*wSnow*), soil (*wSoil*), deep water storage (*wDeep*) and delayed water storage (*wSlow*) to the inter-annual anomalies of total water storage, for VEG and VEG-VEG-nok2, which is a variant of the VEG experiment, in which the k_{Transp} parameter is not calibrated but fixed at a low value of 0.05.

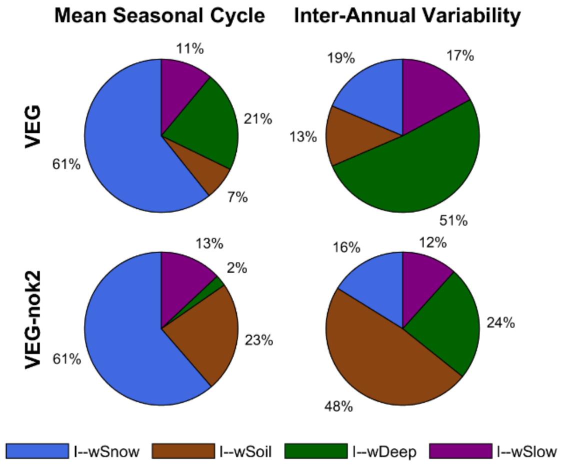

Figure S19 Impact Index *I* for the contribution of simulated snow (*wSnow*), soil (*wSoil*), deep water storage (*wDeep*) and delayed water storage (*wSlow*) to the global average mean seasonal cycle and inter-annual variability of total water storage, for VEG and VEG-nok2, which is a variant of the VEG experiment, in which the k_{Transp} parameter is not calibrated but fixed at a low value of 0.05.