Supplementary material
to
“What do moisture recycling estimates tell? Exploring the extreme case of non-evaporating continents”
by

H. F. Goessling and C. H. Reick

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Hydrology and Earth System Sciences (HESS)

Supplement I: Effect of different averaging methods on recycling estimates

Since former studies showing continental recycling ratios used different methods to aggregate (average) recycling ratios over time, we show in Fig. S1 the differences that arise from different averaging methods (compare Sec. 4 in the main paper).

For every time step one has a field of continental recycling ratios (R_c). There are two ways to average them over time, either uniformly:

$$< R_c >_\tau = \sum_{t=t_1}^{t_N} \left(\frac{1}{N} \cdot R_c(t) \right) \tag{1}$$

or weighted according to the precipitation rate $p(t)$:

$$< R_c >_\pi = \sum_{t=t_1}^{t_N} \left(\frac{p(t)}{\sum\limits_{t'=t_1}^{t_N} p(t')} \cdot R_c(t) \right) . \tag{2}$$

Please note that $< R_c >_\pi$ is not defined at locations that do not receive any precipitation in the considered time interval.

While the uniformly weighted mean $< R_c >_\tau$ (Eq. 1) represents the average fraction of recycled (continental) moisture in precipitable water, the precipitation-weighted mean $< R_c >_\pi$ (Eq. 2) corresponds to the fraction of recycled (continental) moisture in precipitation. The resulting difference is large if (and only if) precipitation and R_c covary significantly in time. The difference plots in Fig. S1 reveal that the two methods yield very similar results for monthly means, meaning that precipitation and R_c do not strongly covary at monthly time scale. However, differences are considerably larger for annual means, meaning that precipitation and R_c covary much more at annual time scale.

In the strongly seasonal northern extratropics an interesting aspect can be seen from the differences between the annual means (bottom right): Since R_c is high in northern summer and low in northern winter, regions that receive more precipitation in summer are red in the figure (e.g. eastern/northern Asia and Canada: $< R_c >_\pi$ is larger than $< R_c >_\tau$) and regions that receive more precipitation in winter are blue (e.g. the North Atlantic and the Mediterranean Basin: $< R_c >_\pi$ is smaller than $< R_c >_\tau$).

The patchy white grid cells occuring in the panels showing $< R_c >_\pi$ (middle row) are spots where there is no precipitation in any single time step of the 30 months used for the analysis. Infrequent precipitation events (i.e. low sample sizes) are also one reason why the fields of precipitation-weighted values are less smooth than the fields of the simple uniformly weighted means. Note that in the main paper we show only $< R_c >_\pi$, as Bosilovich et al. (2002), Yoshimura et al. (2004), and van der Ent et al. (2010), while Numaguti (1999) shows $< R_c >_\tau$. (The references can be found in the main paper.)

Supplement II: Simulations with an alternative moist-convection scheme

To address the uncertainty associated with the parameterisation of moist convection, we show in Fig. S2 how precipitation responds to the suppression of continental evaporation when the original Tiedtke mass-flux scheme is used instead of the standard scheme of the MPI-ESM (see Sec. 3.1 and 5 in the main paper).

Supplement III: Results from the standard moist-convection scheme for January

In the main paper we focus on the results for July (Sec. 5, Fig. 4-9), where continental evaporation and, hence, moisture recycling are most pronounced. Figs. S3–S8 show the corresponding situation for January.

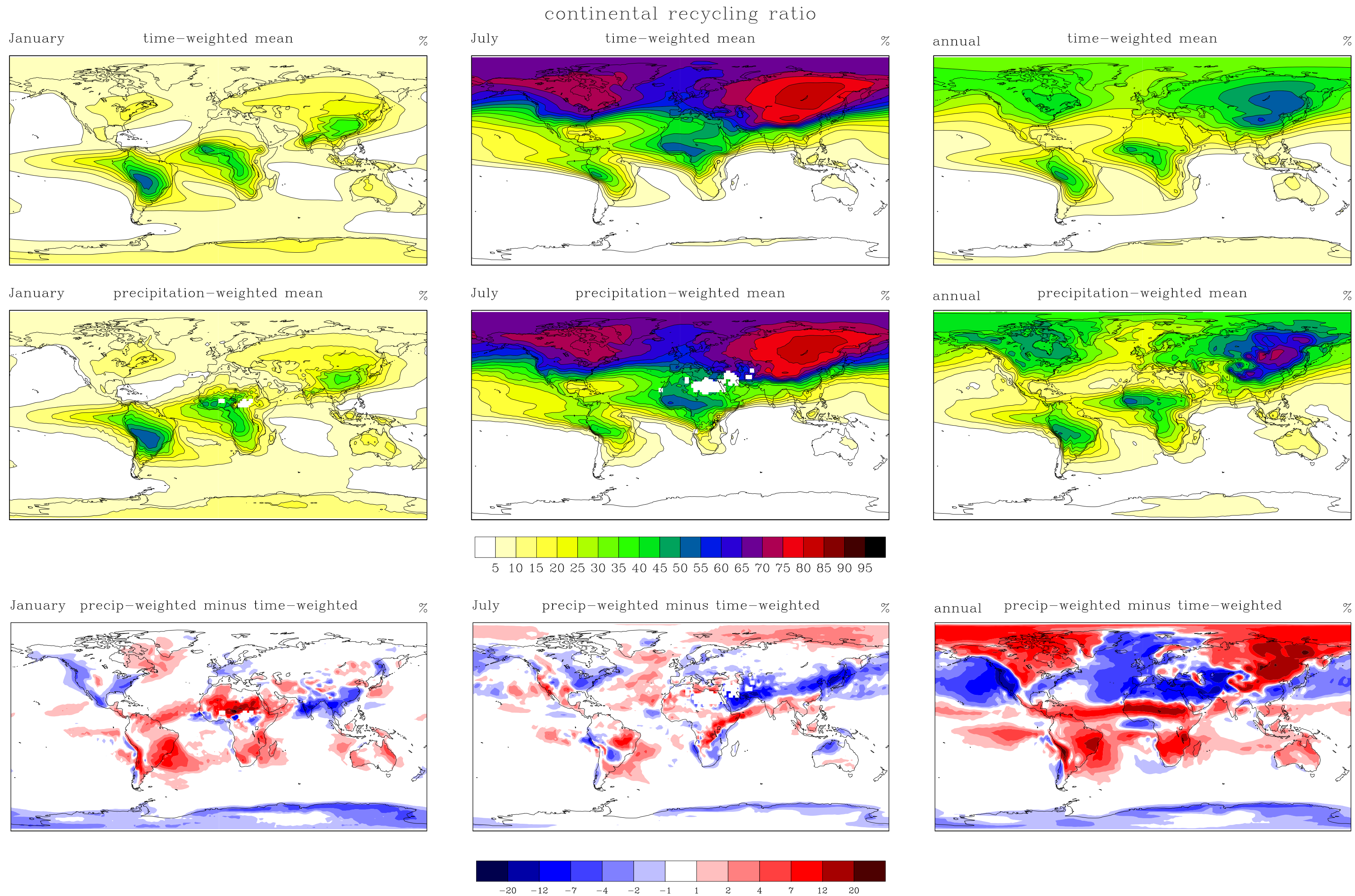

Figure 1: (S1) Comparison of continental recycling ratios (R_c) that have been aggregated differently over time. Left column: January. Middle column: July. Right column: annual. Top row: Uniformly weighted time-means ($< R_c >_\tau$ in Eq. 1). Middle row: Precipitation-weighted time-means ($< R_c >_\pi$ in Eq. 2). Bottom row: Difference between the precipitation-weighted and the uniformly weighted time-means. For more details, please see pp. 1 and 2.

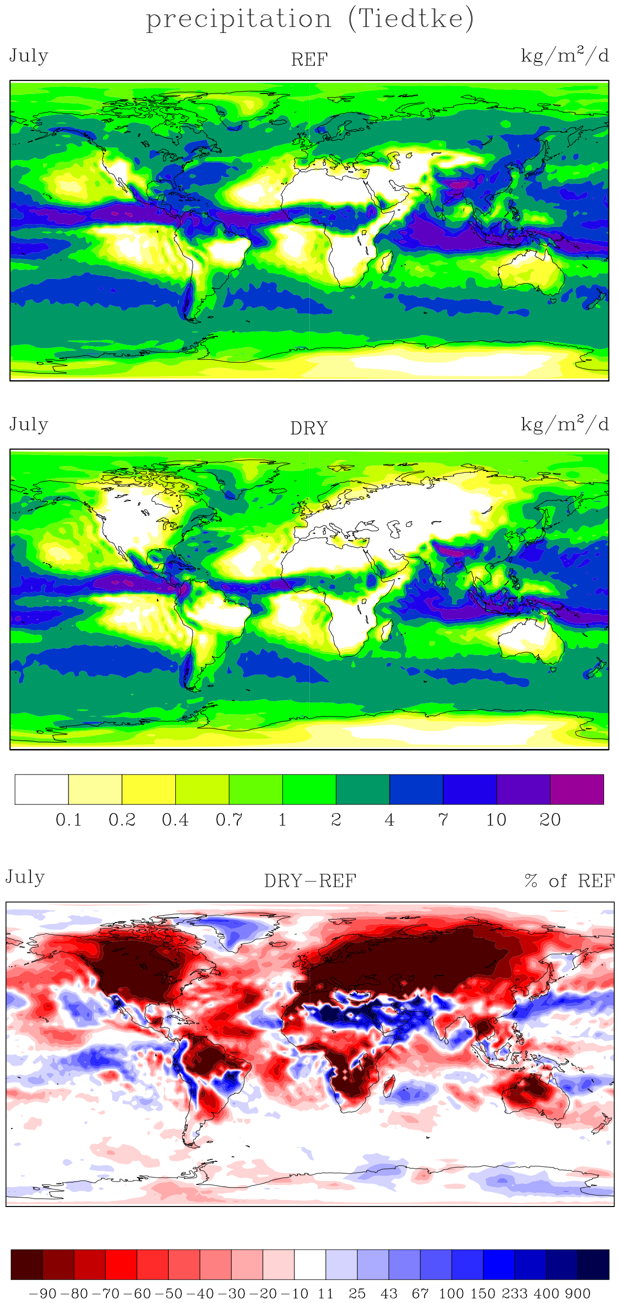

Figure 2: (S2) Precipitation (kg m^{-2} d^{-1}) with the Tiedtke convection scheme in July in the REF experiment (top), in the DRY experiment (middle), and the difference between the two (bottom, %). The values of the blue part of the colour scale of the difference plot equate to (10%, 20%, ..., 90%) in relation to the DRY experiment. The corresponding figure in the main paper showing the results with the standard scheme of the MPI-ESM is Fig. 4.

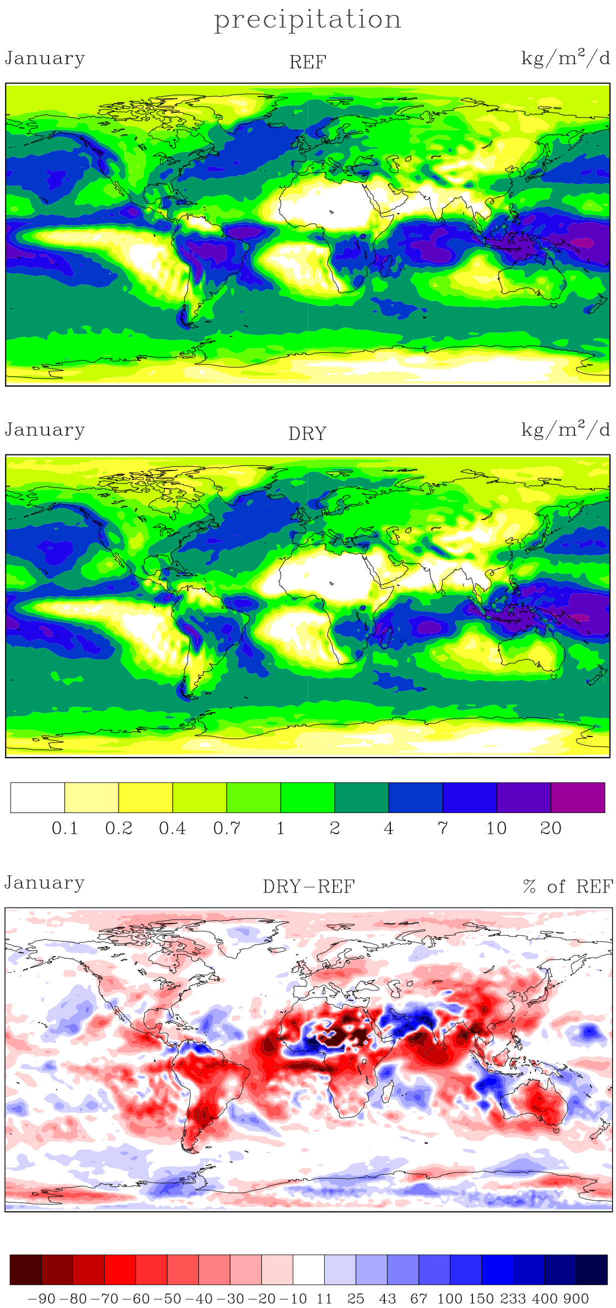

Figure 3: (S3) Precipitation (kg m^{-2} d^{-1}) with the standard convection scheme in January in the REF experiment (top), in the DRY experiment (middle), and the difference between the two (bottom, %). The values of the blue part of the colour scale of the difference plot equate to (10%, 20%, ..., 90%) in relation to the DRY experiment. The corresponding figure in the main paper showing the results for July is Fig. 4.

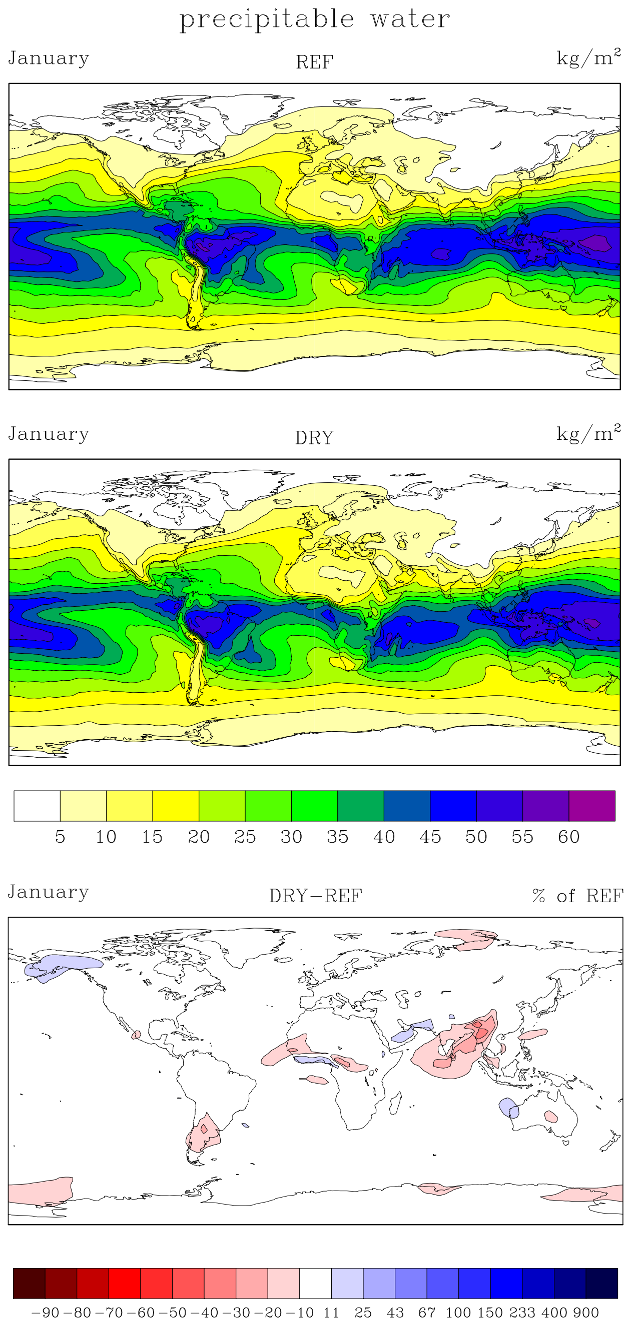

Figure 4: (S4) Precipitable water (kg m^{-2}, vapour + liquid + ice) with the standard convection scheme in January in the REF experiment (top), in the DRY experiment (middle), and the difference between the two (bottom, %). The values of the blue part of the colour scale of the difference plot equate to (10%, 20%, ..., 90%) in relation to the DRY experiment. The corresponding figure in the main paper showing the results for July is Fig. 5.

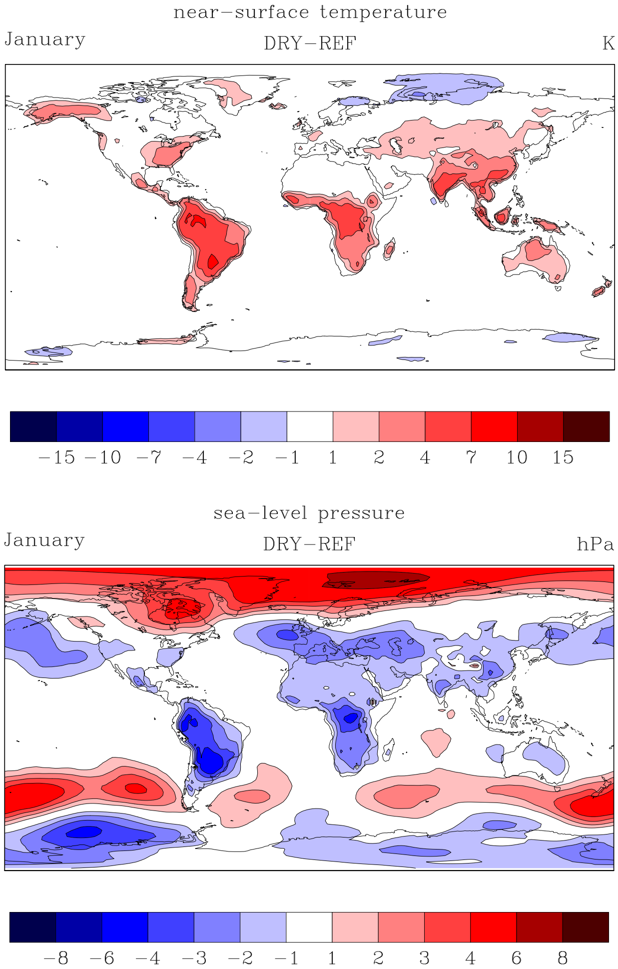

Figure 5: (S5) Top: Difference in near-surface (2m) temperature in January (K, DRY-REF). Bottom: Difference in pressure reduced to sea-level in July (hPa, DRY-REF). Both with the standard convection scheme. The corresponding figure in the main paper showing the results for July is Fig. 6.

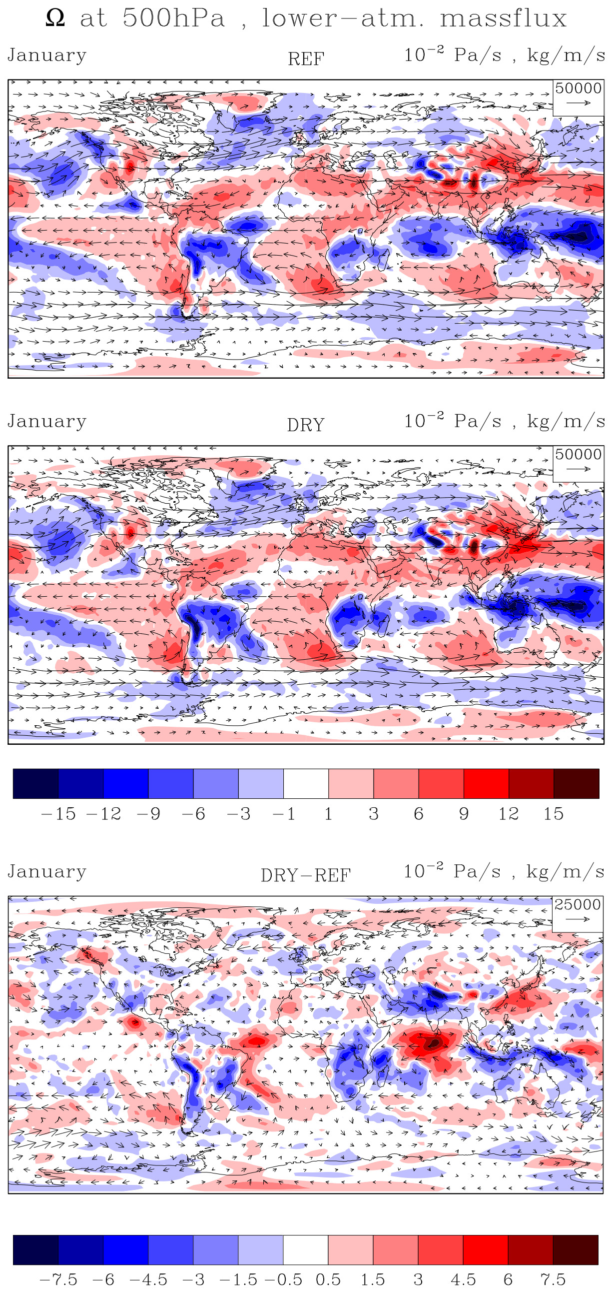

Figure 6: (S6) Vertical velocity (Ω) at 500 hPa (colours, Pa s^{-1}) and horizontal total mass flux in the lowest 13 model levels (arrows, kg m^{-1} s^{-1}) with the standard convection scheme in January in the REF experiment (top), in the DRY experiment (middle), and the difference between the two (bottom). The lowest 13 model levels correspond approximately to the lower half of the atmosphere. Hence, the vertical velocity at 500 hPa approximately corresponds to the divergence of the shown mass flux. Note that the scale for both Ω and the mass flux are changed by a factor 2 in the bottom panel to make the differences better visible. The corresponding figure in the main paper showing the results for July is Fig. 7.

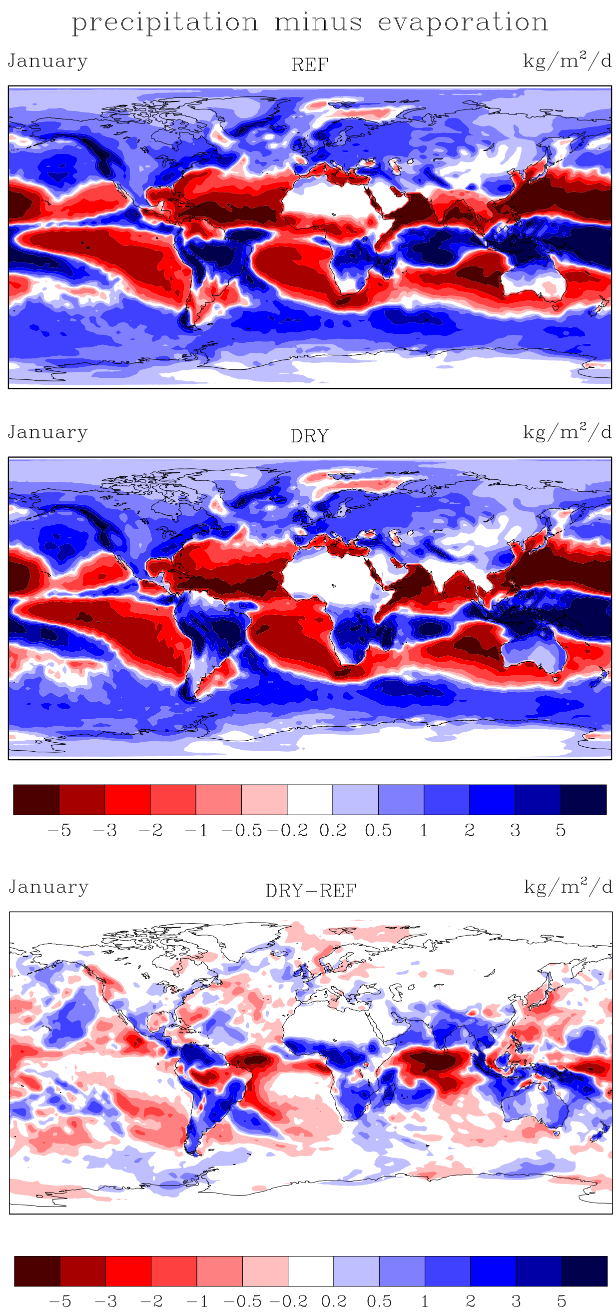

Figure 7: (S7) Precipitation minus evaporation (kg m^{-2} d^{-1}) with the standard convection scheme in January in the REF experiment (top), in the DRY experiment (middle), and the difference between the two (bottom). The corresponding figure in the main paper showing the results for July is Fig. 9.

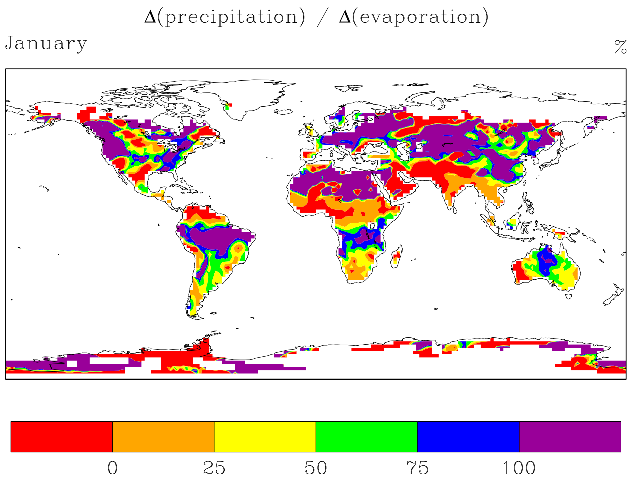

Figure 8: (S8) The response of precipitation in relation to the imposed evaporation decrease ($\frac{P_{REF}-P_{DRY}}{E_{REF}}$, %) with the standard convection scheme in January. Violet indicates over-compensation (the land becomes a weaker moisture sink), blue, green, yellow and orange indicate incomplete compensation (precipitation still decreases, but the land becomes a stronger moisture sink or weaker moisture source), and red indicates amplification (precipitation increases and hence adds to the evaporation decrease). Continental regions with negative evaporation (= dew) in the REF experiment are left white. The corresponding figure in the main paper showing the results for July is Fig. 10.