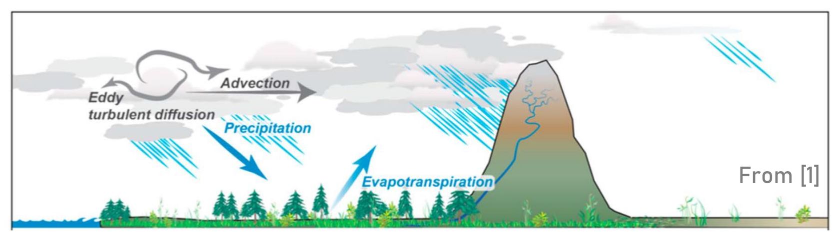
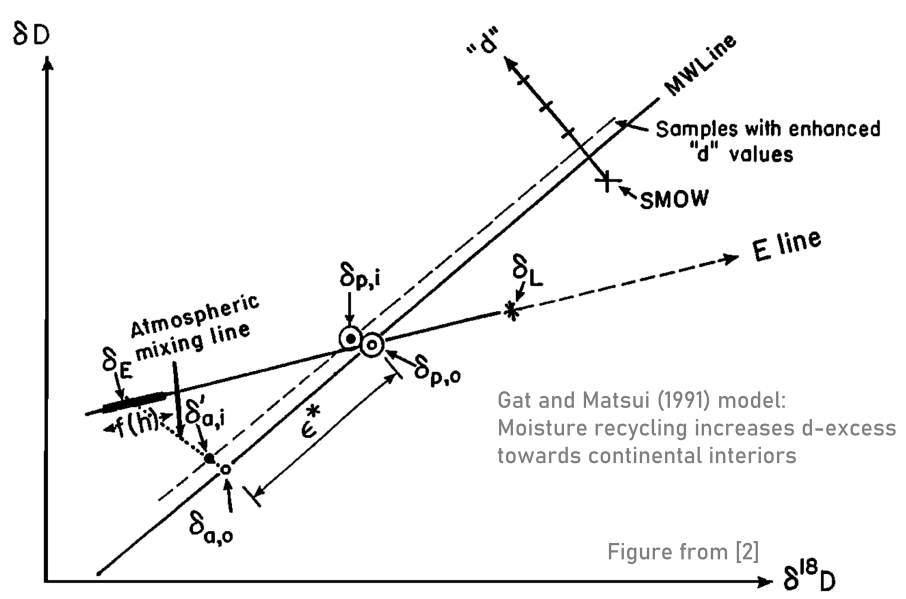
AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

# Seasonal water storage and evapotranspiration partitioning controls on the relationship between continental moisture recycling and precipitation deuterium excess

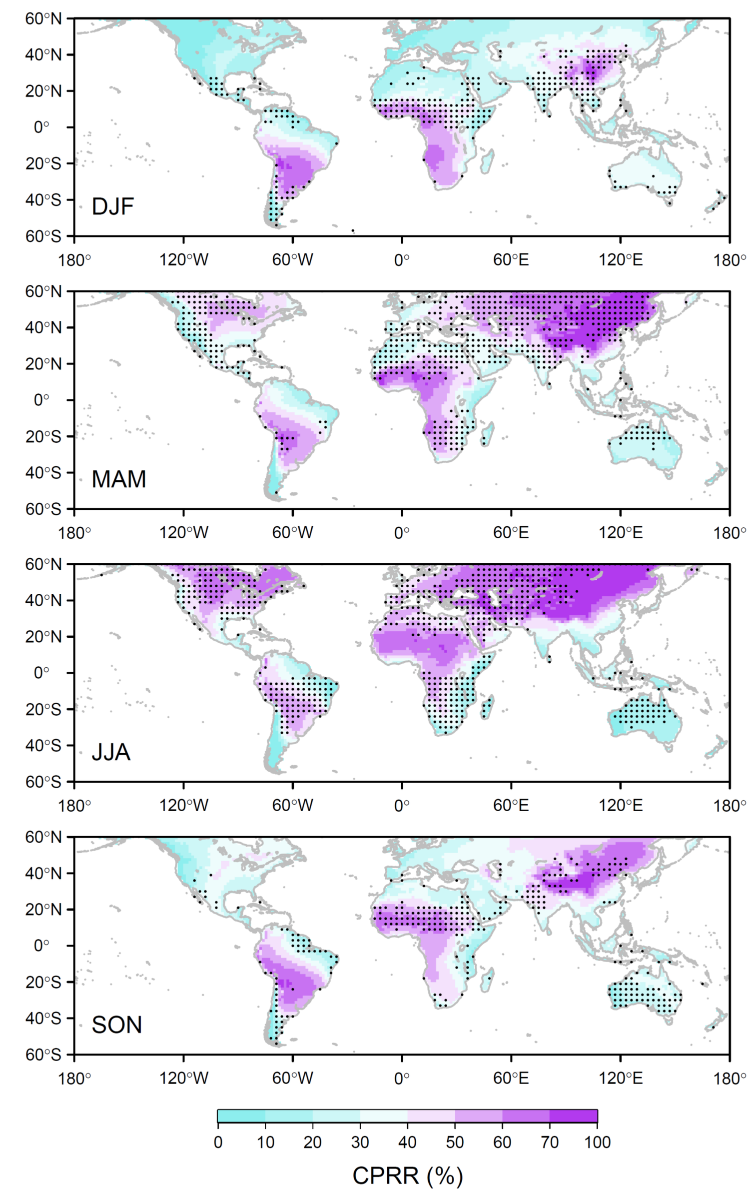
Zhengyu Xia[1*], Matthew J. Winnick[1]
[1] University of Massachusetts Amherst
* zhyxia@hotmail.com

## 1. Traditional paradigm



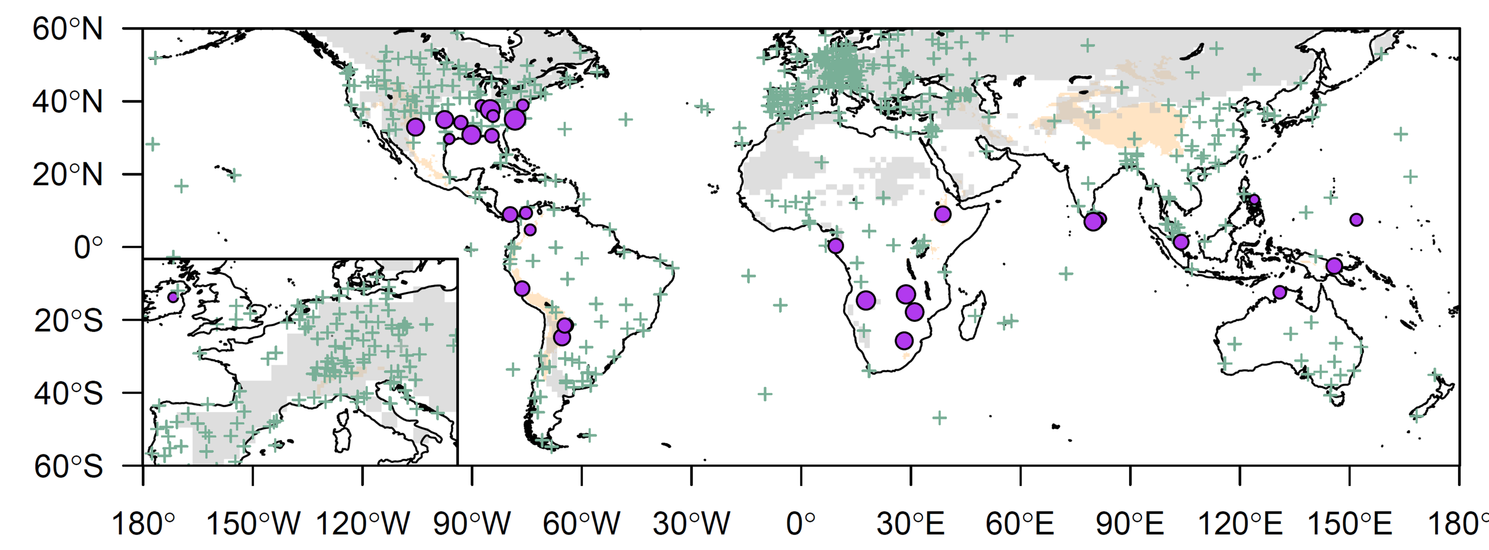




Limitations:
1) The model is based on steady-state mean annual conditions
2) May only apply to regions with high P/ET and weak seasonality




Dot pattern indicates P < ET

## 2. Seasonal swings in moisture recycling



local CPRR vs. site CV d-excess (MC)
- Significant (median R = 0.9)
- Significant (median R = 0.6)
- Insignificant
- CPRR seasonality > 40%

CV d-excess: "converted vapor" d-excess after correcting the fractionation in local condensation (data from GNIP and USNIP)

CPRR (Continental Precipitation Recycling Ratio): the fraction of precipitation at a given location that originates from terrestrial moisture sources

Based on moisture tracking model WAM-2layers (from [3])

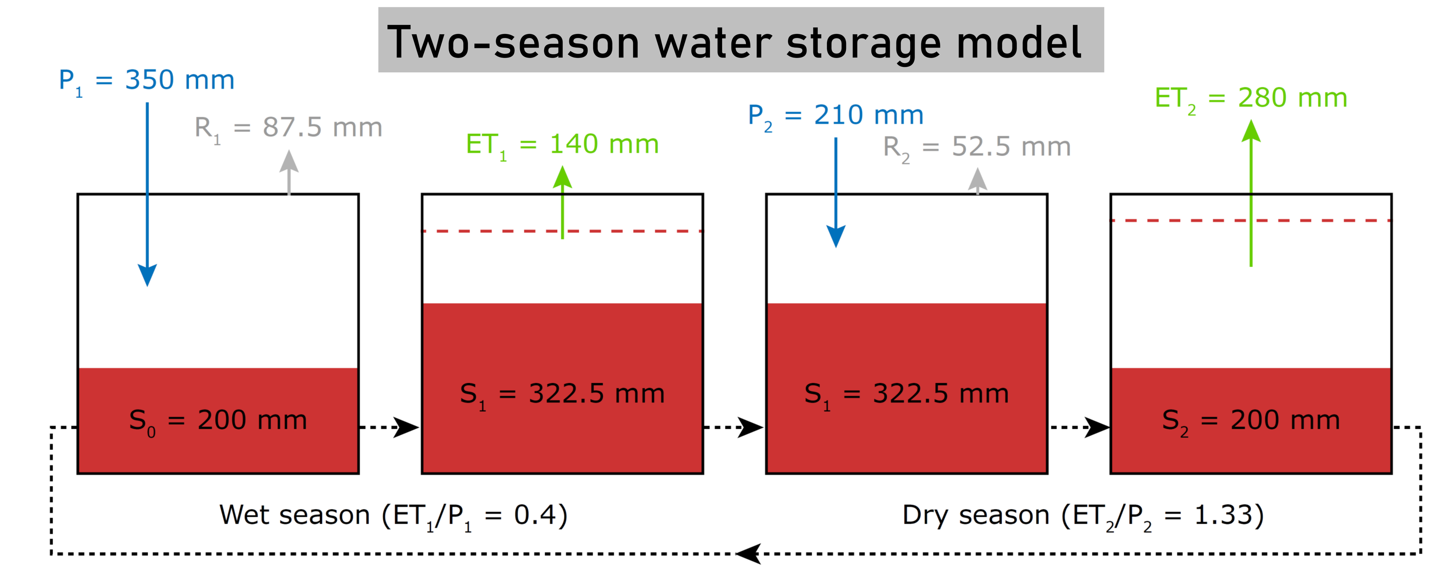
1) There are large seasonal changes in moisture recycling regime in North America and Eurasia, with CPRR increasing from 10% in winter to 60% in summer
2) However, precipitation d-excess does not increase in response to the seasonal swings in moisture recycling as shown by spatial correlation patterns
3) Widespread conditions of P < ET indicate that residual water storage is supplying ET flux

## 3. Hypothesis and model design

The d-excess in ET flux is likely not increased during the dry season in highly seasonal climate areas due to:

1) contributions from isotopically-evolved residual water storage (lower d-excess) to supply ET flux
2) higher transpiration fractions (T/ET)

### Two-season water storage model




### The isotopic composition of ET flux

assuming ET removal as a Rayleigh-type process with "closure assumption", from [4]

$$\delta_{ET} = \left(\frac{E}{ET}\right)\frac{\int_1^F[\alpha_{ET}(\delta_I+1000)F^{\alpha_{ET}-1}-1000]dF}{F-1} + \left(\frac{T}{ET}\right)\delta_I \quad \text{with} \quad \alpha_{ET} = \left(\frac{E}{ET}\right)\left[k\frac{\alpha_{eq}^{v-l}}{(1-h)\left(1+k\frac{E}{ET}\frac{h}{1-h}\right)}\right] + \left(\frac{T}{ET}\right)\left(\frac{1}{1+k\frac{E}{ET}\frac{h}{1-h}}\right)$$

### Water flux relationship

The residual water storage size:

$$S_1 = S_0 + P_1 - R_1 - ET_1 \text{ and } S_2 = S_1 + P_2 - R_2 - ET_2$$

The fraction of residual liquid water remaining after ET loss:

$$F_1 = \frac{S_1}{S_1+ET_1} \text{ and } F_2 = \frac{S_2}{S_2+ET_2}$$

The fraction of residual water storage in the source water pool for ET:

$$X_1 = \frac{S_0}{S_0+P_1-R_1} \text{ and } X_2 = \frac{S_1}{S_1+P_2-R_2}$$

### Isotopic flux relationship

The isotopic composition of "modified source water" mixing the new precipitation input (after runoff loss) with the old residual water storage:

$$\delta_{I_1} = X_1\delta_{S_0} + (1-X_1)\delta_{P_1} \text{ and } \delta_{I_2} = X_2\delta_{S_1} + (1-X_2)\delta_{P_2}$$

The isotopic composition of residual water storage after ET loss using isotope mass balance:

$$\delta_{S_1} = \frac{\delta_{I_1}-(1-F_1)\delta_{ET_1}}{F_1} \text{ and } \delta_{S_2} = \frac{\delta_{I_2}-(1-F_2)\delta_{ET_2}}{F_2}$$

### The boundary condition constraint

$$S_2 = S_0 \text{ and } \delta_{S_2} = \delta_{S_0}$$

## 4. Simple model test

| | Wet season | Dry season |
|---|---|---|
| **Model inputs** | | |
| Water flux | | |
| Precipitation (mm) | 350 ($P_1$) | 210 ($P_2$) |
| Runoff (mm) | 87.5 ($R_1$) | 52.5 ($R_2$) |
| ET (mm) | 140 ($ET_1$) | 280 ($ET_2$) |
| Physical climate | | |
| Temperature (°C) | 5 | 15 |
| RH (%) | 80 | 65 |
| Aerodynamic exponent | 0.8 | 0.8 |
| Ecosystem condition | | |
| $T/ET$ | 0.6 | 0.6 |
| Relative water storage size ($S_0/P_1$) | 0.57 | - |
| Isotope flux | | |
| Precipitation δ18O (‰) | –10 | –6 |
| Precipitation d-excess (‰) | 10 | 10 |
| **Model results** | | |
| "Modified" source water δ18O (‰) | –6.0 ($\delta_{I_1}$) | –4.9 ($\delta_{I_2}$) |
| ET δ18O (‰) | –9.9 ($\delta_{ET_1}$) | –7.8 ($\delta_{ET_2}$) |
| Residual water storage δ18O (‰) | –4.3 ($\delta_{S_1}$) | –0.8 ($\delta_{S_0}$ or $\delta_{S_2}$) |
| "Modified" source water d-excess (‰) | 1.1 | 1.9 |
| ET d-excess (‰) | 8.4 | 10.8 |
| Residual water storage d-excess (‰) | –2.1 | –10.6 |

Kinetic fractionation factor of evaporation $k = (D'/D)^m$

Determine the relative importance of seasonal residual water storage

### How large is the available subsurface water storage?

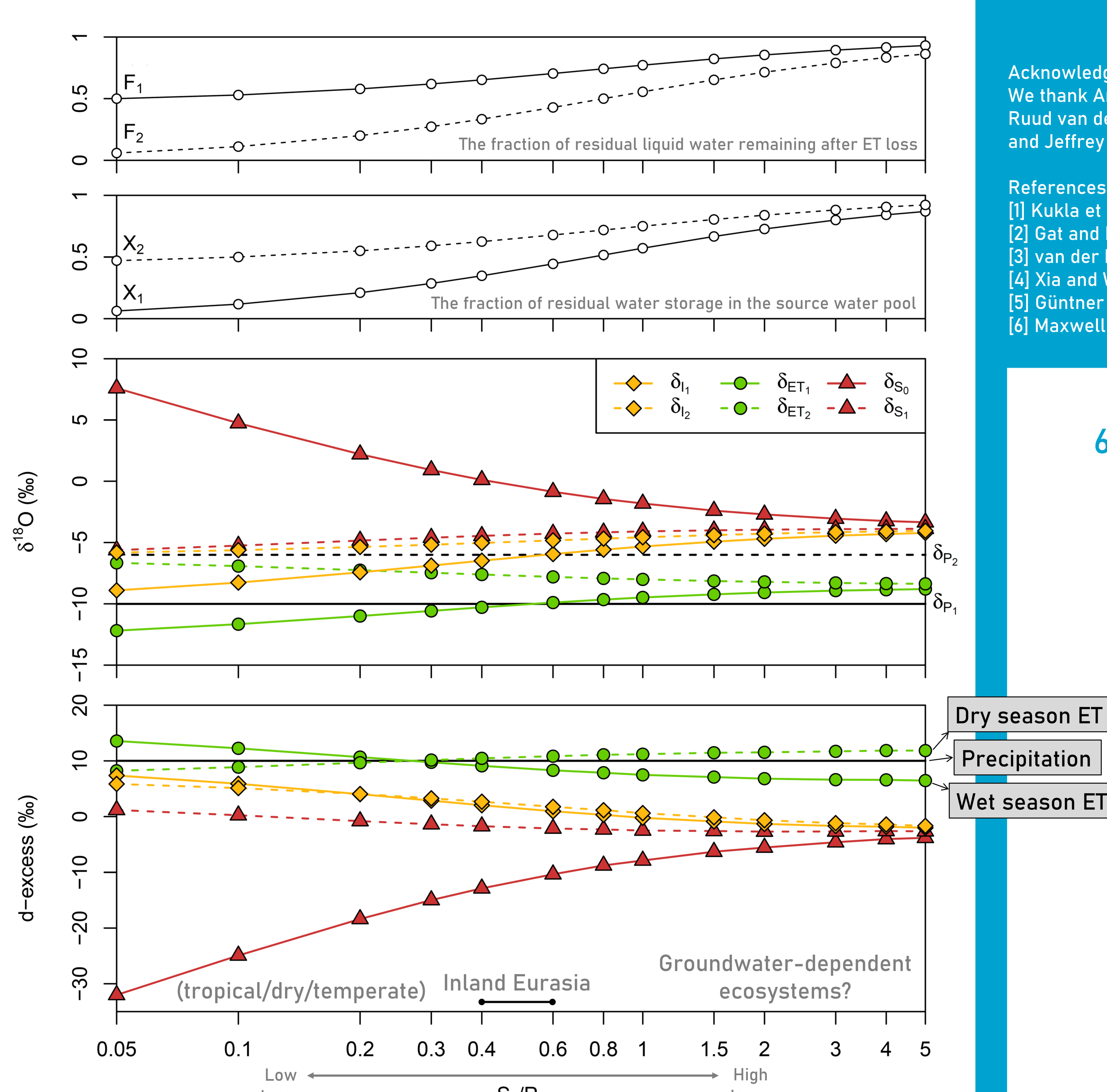
| Koeppen Climate Zone | Mean annual precipitation (MAP) (mm) | Total water storage (TWS) (mm) | TWS/MAP |
|---|---|---|---|
| A, tropical | 1859 | 337 | 0.18 |
| Af, no dry season | 2806 | 607 | 0.22 |
| Am, short dry season | 2294 | 426 | 0.19 |
| Aw, distinct dry season | 1408 | 217 | 0.15 |
| B, dry | 270 | 30 | 0.11 |
| BS, steppe | 441 | 51 | 0.12 |
| BW, desert | 144 | 14 | 0.10 |
| C, temperate | 1146 | 180 | 0.16 |
| Cf, no dry season | 1364 | 266 | 0.20 |
| Cw, dry winter | 1203 | 143 | 0.12 |
| Cs, dry summer | 616 | 77 | 0.13 |
| D, cold | 561 | 258 | 0.46 |
| Df, no dry season | 948 | 478 | 0.50 |
| Dw, dry winter | 478 | 125 | 0.26 |
| E, polar | 452 | 160 | 0.35 |
| ET, tundra | 460 | 148 | 0.32 |
| EF, arctic | 375 | 278 | 0.74 |
| Global | 818 | 179 | 0.22 |

Güntner et al. (2007) model-based estimates on the continental total water storage in different climate zones (from [5])

1) Water storage size is climate-dependent, but highly heterogeneous locally due to many biotic and abiotic factors
2) Overall, the total water storage is less than half of the mean annual precipitation

Inland Eurasia

## 5. The effects of water storage size




Assuming T/ET = 60% for both wet and dry seasons:

1) The dry season ET d-excess is lower than the wet season ET d-excess when the relative water storage size is small (low $S_0/P_1$), driven by high contributions of residual water storage to dry season ET fluxes, and vice versa
2) The ET d-excess is likely lower than precipitation d-excess, challenging the simple view that admixture of recycled moisture increases d-excess towards continental interiors

## Get the poster PDF!

SCAN ME

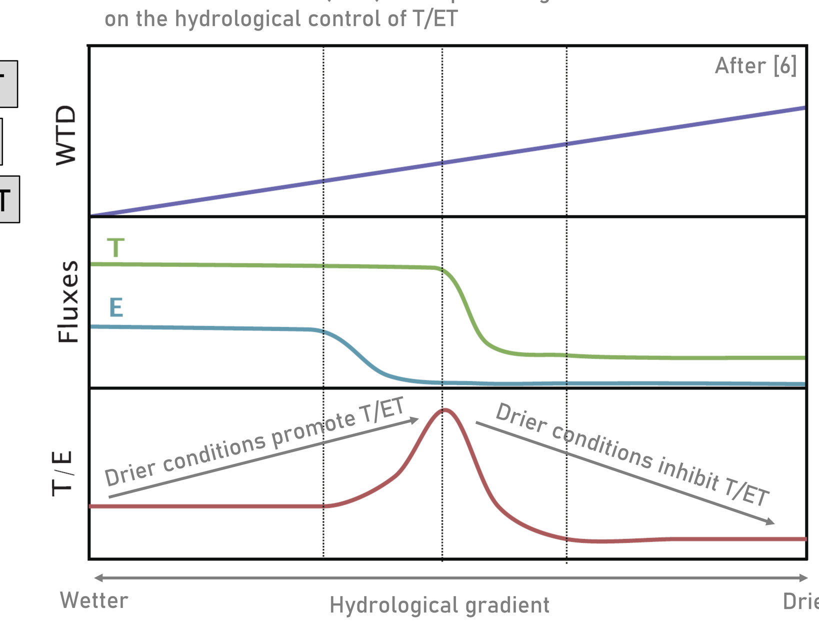
Acknowledgements:
We thank Angela Ampuero Grández, Andreas Link, and Ruud van der Ent for help on running the WAM-2layers, and Jeffrey Welker for providing USNIP data.

References:
[1] Kukla et al., 2019. J. Geophys. Res. Atmo., 124, 563–582.
[2] Gat and Matsui, 1991. J. Geophys. Res., 96, 13179–13188.
[3] van der Ent et al., 2014. Earth Syst. Dynam., 5, 471–489.
[4] Xia and Winnick, 2021. Earth Planet. Sci. Lett., 572, 117120
[5] Güntner et al., 2007. Water Resour. Res., 43, W05416.
[6] Maxwell and Condon, 2016. Science, 353, 377–380.

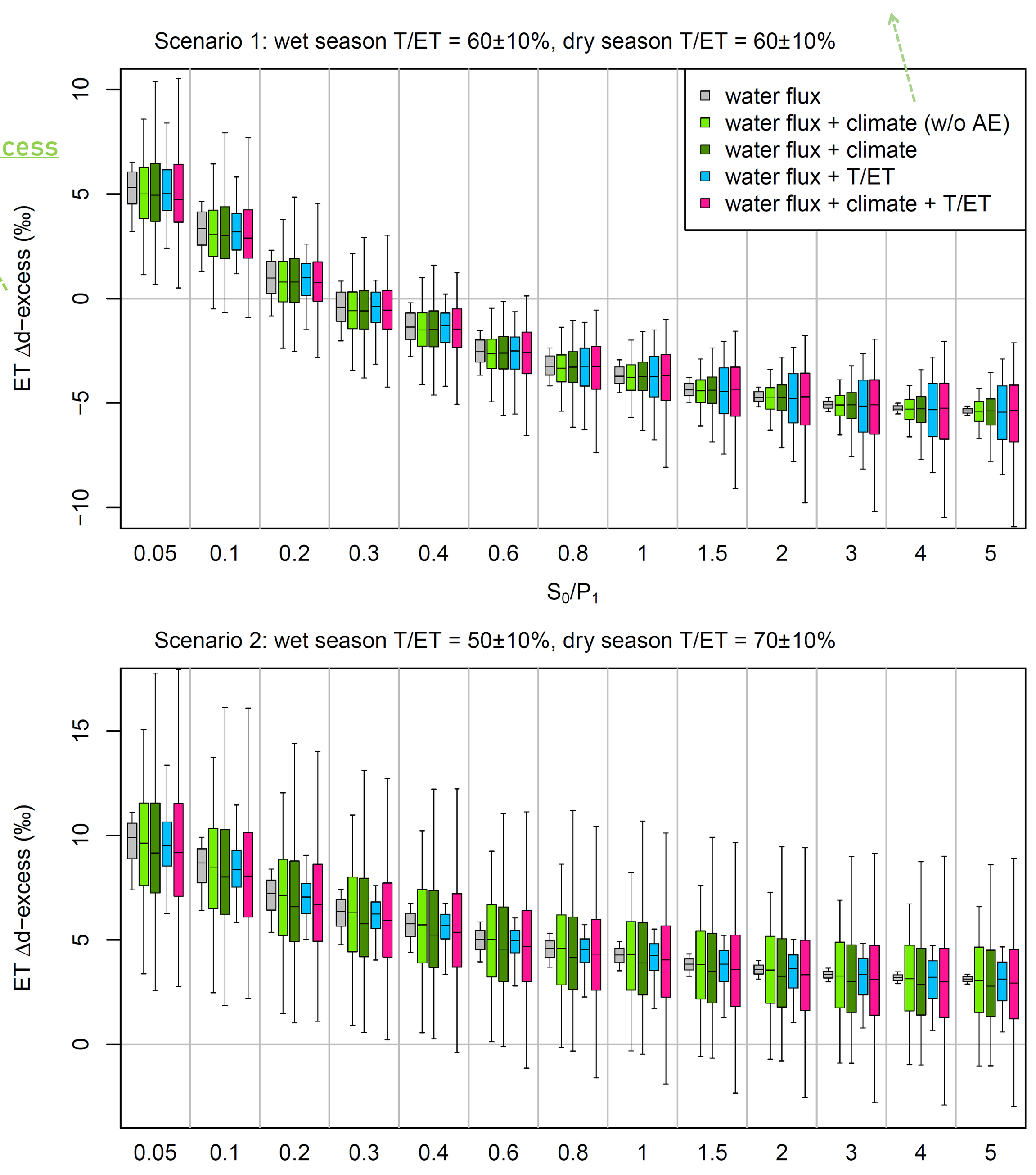
## 6. The effects of ET partitioning and sensitivity to model parameters

ET Δd-excess = wet season ET d-excess – dry season ET d-excess

Maxwell and Condon (2016) conceptual diagram on the hydrological control of T/ET




Monte Carlo simulations using randomized model parameters




1) Seasonal ET partitioning is dependent on macroclimates and ecosystem types that are in part related to the water storage size
2) If T/ET is higher in the dry season, the dry season ET d-excess remains lower than the wet season ET d-excess even at high water storage
3) Randomized water fluxes and other model parameters (within certain ranges) do not affect the results