



Rijkswaterstaat  
Ministry of Infrastructure and the  
Environment



# The importance of ecosystem adaptation on hydrological model predictions in response to climate change

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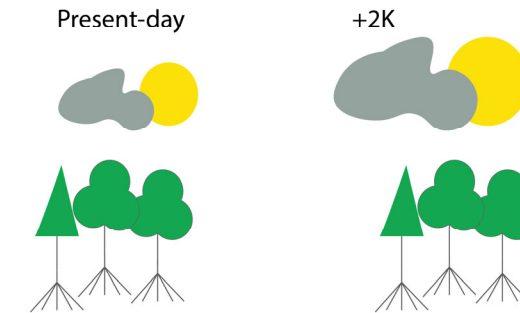
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April 2021

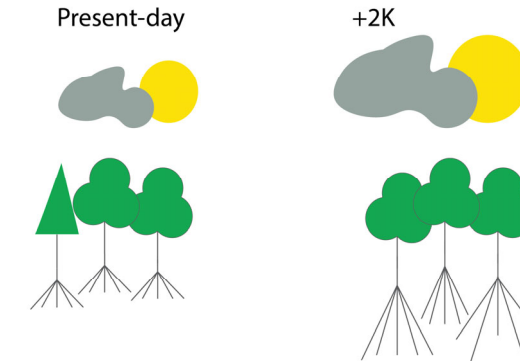
# Unsolved hydrological challenge: consider non-stationarity of hydrological systems

- Models calibrated on past observations are often used to predict the long-term future in a changing world.
- However, land use may change under natural or anthropogenic influence and ecosystems likely adjust their root-zone storage capacity, a key parameter of any hydrological model, in response to climate change.
- *“How can hydrological models be adapted to be able to extrapolate to changing conditions, including changing vegetation dynamics”*  
Blöschl et al., 2019, Hydrol. Sci. J.

Stationarity of hydrological system

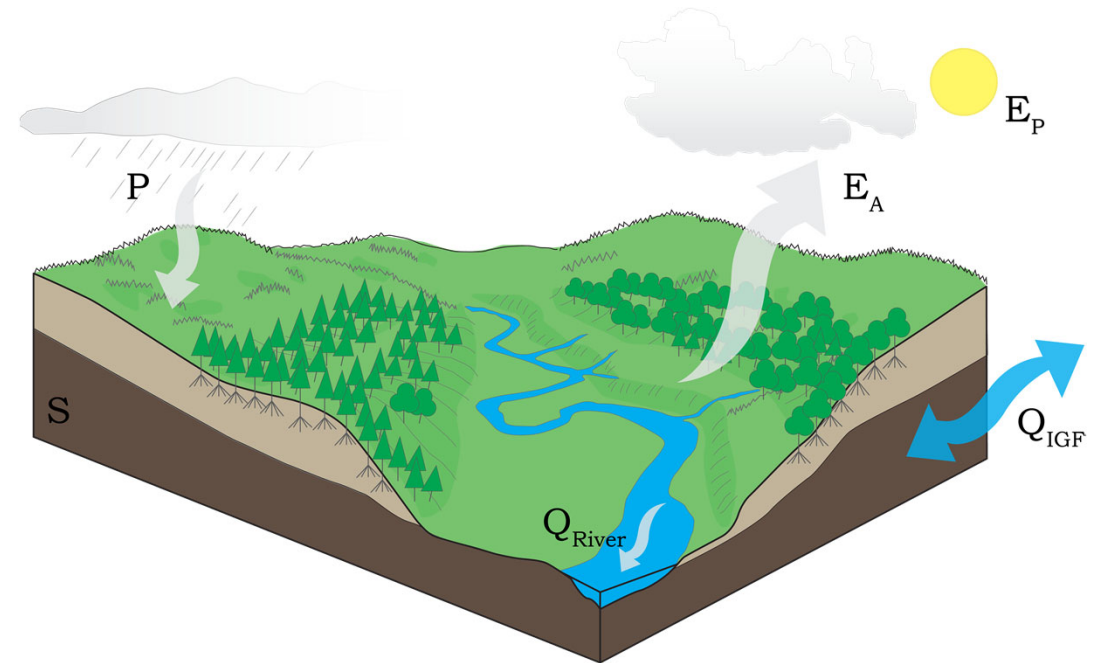


Non-stationarity of hydrological system



# More specifically: changing vegetation dynamics through an adapted root-zone storage capacity

- The root-zone storage capacity is the maximum volume of water in the pores of the unsaturated soil, which is accessible to the roots of vegetation for transpiration.
- Key element controlling the partitioning of precipitation into evaporation and streamflow.
- Can be estimated at the catchment scale from available water-balance data.
- Vegetation likely adapts its root-zone storage capacity in response to changing hydro-climatic variables.



# Hypothesis

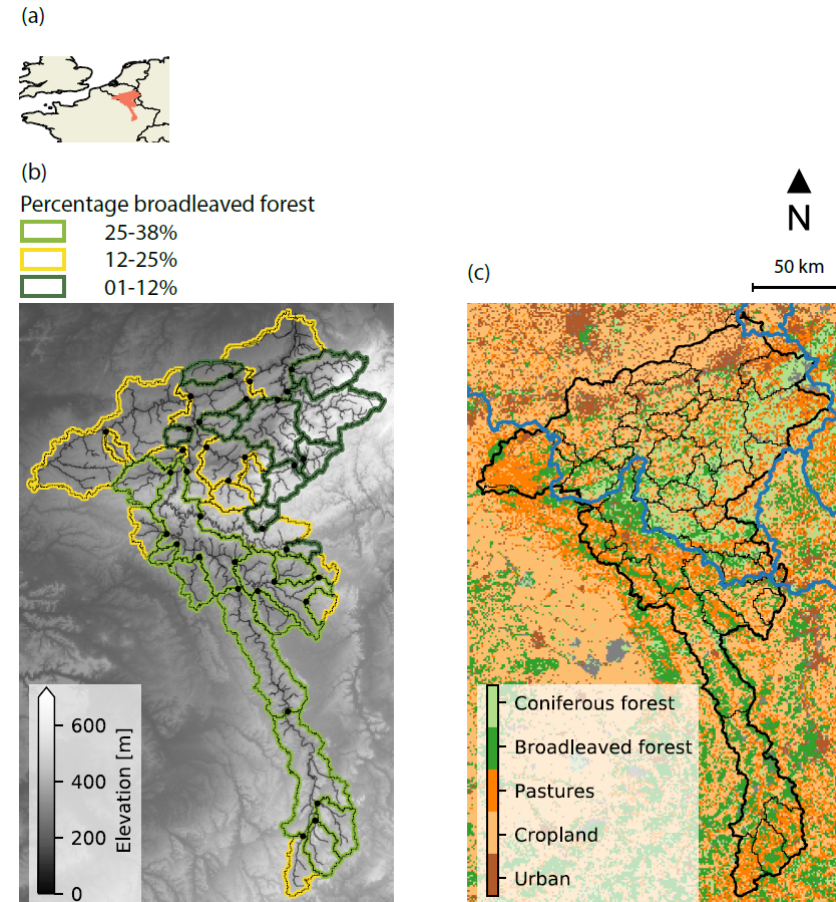
*Changes in the **predicted hydrological response** as a result of **+2K global warming** in comparison to current day conditions are more pronounced when explicitly considering an **adapted root-zone storage capacity** to reflect changes in seasonality and magnitude of hydro-climatic variables as well as potential land-use changes.*

# Study area

The Meuse river basin in northwestern Europe

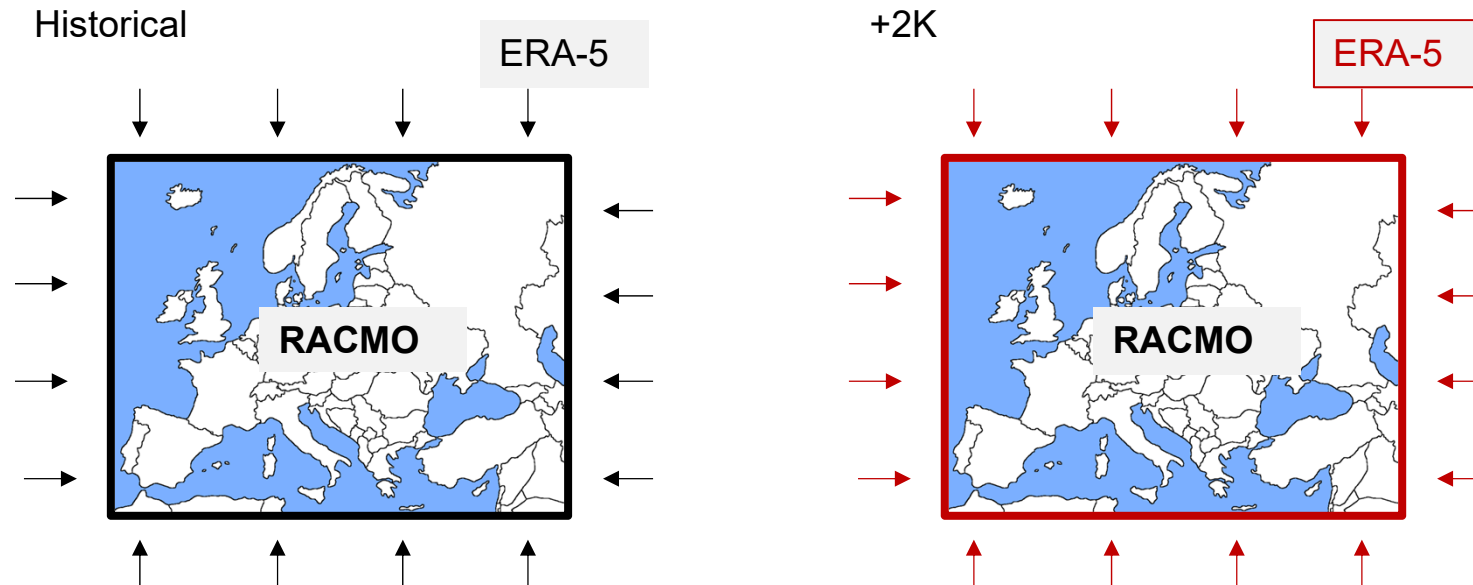
Land-use characteristics:

- Majority of forest in the French part of the basin are relatively old broadleaved forests
- Whereas more than half of the old broadleaved forests in the Walloon part of the basin have been converted to agricultural areas or coniferous plantations



# Observed historical climate data (E-OBS) & Simulated climate data (historical and +2K simulations)

- Observed historical climate data from E-OBS (Cornes et al., 2018, J. Geophys. Res. Atmos.)
- Simulated historical and +2K climate data: pseudo-global warming simulation
  - Historical period is simulated against a warmer climate background by adding perturbations to the ERA-5 initial and boundary conditions

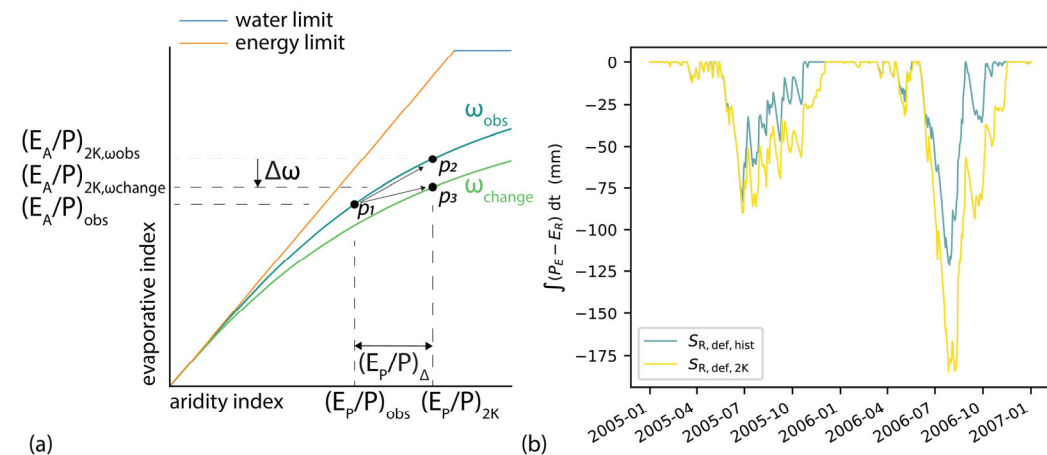


# Approach – estimating the root-zone storage capacity under +2K global warming and potential land-use change

- Estimate the change in long-term runoff coefficient as a result of climate and potential land-use change from vertical and horizontal shifts in the Budyko framework (vertical shifts of  $\omega$  for changes in land-use and horizontal shifts for changes in aridity index)
- Water-balance approach to estimate annual water deficits stored in the root-zone of vegetation to fulfill canopy water demand for transpiration

$$\frac{E_A}{P} = 1 - \frac{Q}{P} = 1 + \frac{E_P}{P} - \left(1 + \left(\frac{E_P}{P}\right)^\omega\right)^{1/\omega}$$

Zhang et al., 2004 (WRR)

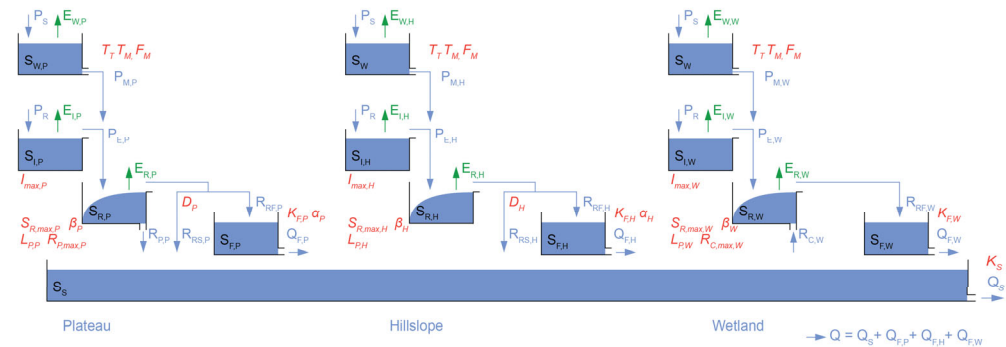


# Hydrological model – wflow\_FLEX-Topo

Distributed process-based wflow\_FLEX-Topo model with three hydrological response units:

- Plateau
- Hillslope
- Wetland

Connected through their groundwater reservoir



# Model scenarios

- Scenario  $2K_A$   
Stationary system: no changes in root-zone storage capacity and historical land use
- Scenario  $2K_B$   
Adapted root-zone storage capacity in response to climate change and historical land use
- Scenario  $2K_C$   
Adapted root-zone storage capacity in response to climate change and land-use conversion from coniferous plantations to broadleaved forest
- Scenario  $2K_D$   
Adapted root-zone storage capacity in response to climate change and land-use conversion from broadleaved forest to coniferous plantation

## Historical climate

Observed historical climate E-OBS

$P_{obs}$  &  $E_{p,obs}$   
 $S_{R,max,A}$

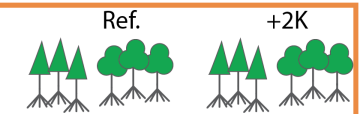
Simulated historical climate data

$P_{hist}$  &  $E_{p,hist}$   
 $S_{R,max,A}$

## Simulated 2K climate ( $P_{2K}$ & $E_{p,2K}$ )

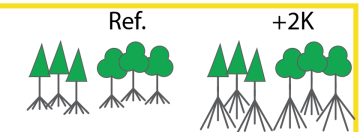
Scenario  $2K_A$   
Stationary system

$S_{R,max,A}$



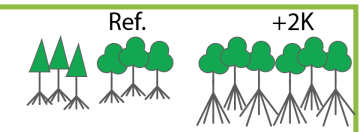
Scenario  $2K_B$   
Adaptive root-zone storage capacity  
historical land use

$S_{R,max,B}$



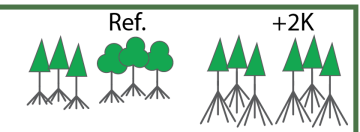
Scenario  $2K_C$   
Adaptive root-zone storage capacity  
broadleaved land use

$S_{R,max,C}$



Scenario  $2K_D$   
Adaptive root-zone storage capacity  
coniferous land use

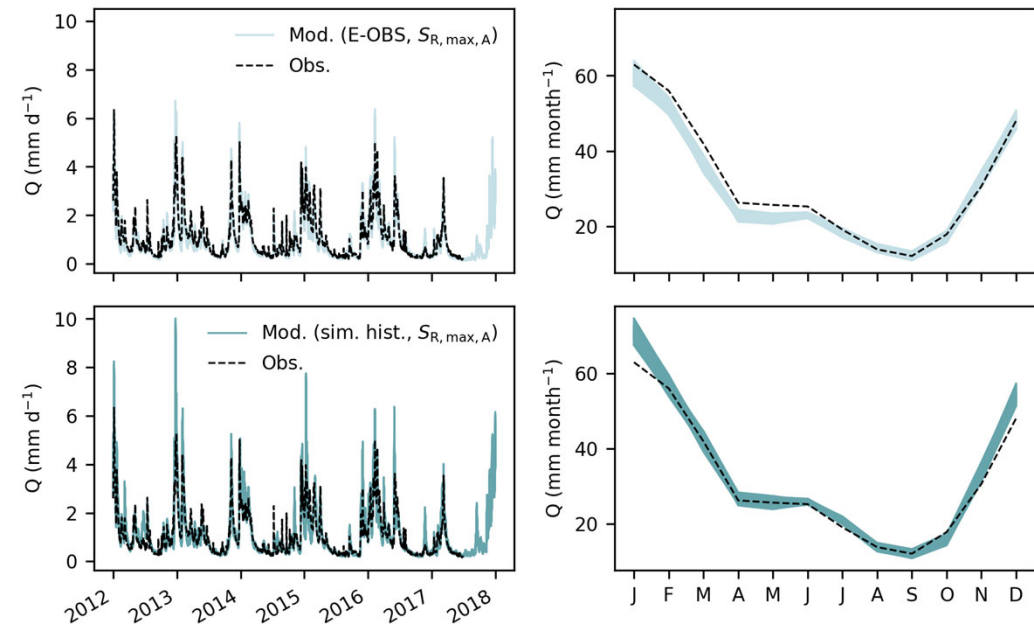
$S_{R,max,D}$



# Model evaluation – observed and simulated historical climate data

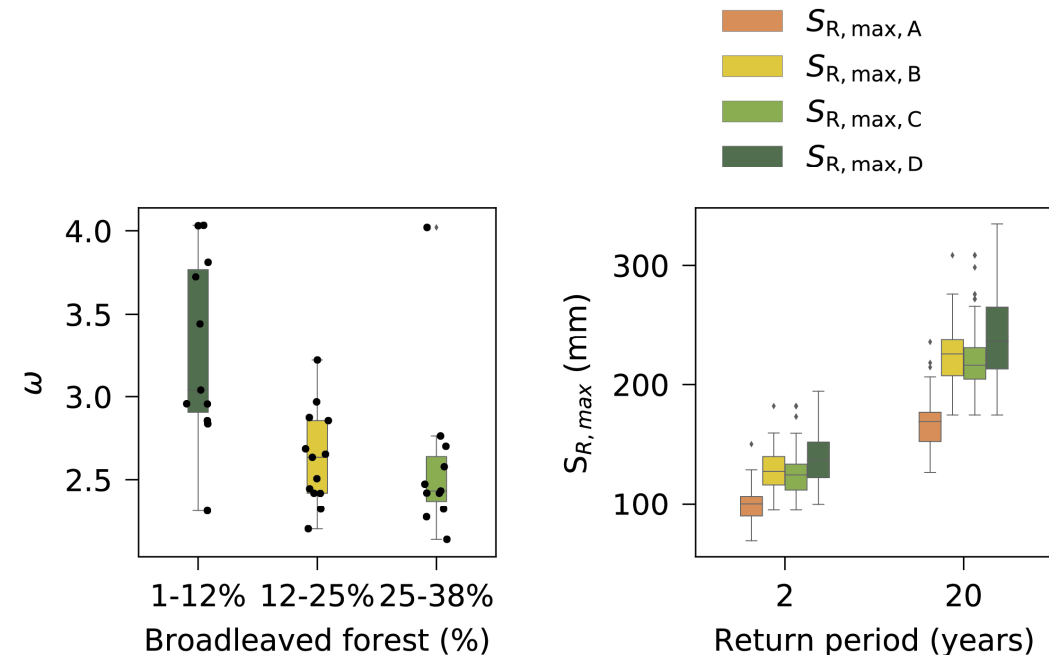
Modeled daily and seasonal streamflow reproduce observations relatively well.

This is the case when the model is forced with the observed historical climate data (E-OBS) and also with the simulated historical climate data



# Hydrological change evaluation – Root-zone storage capacity parameter

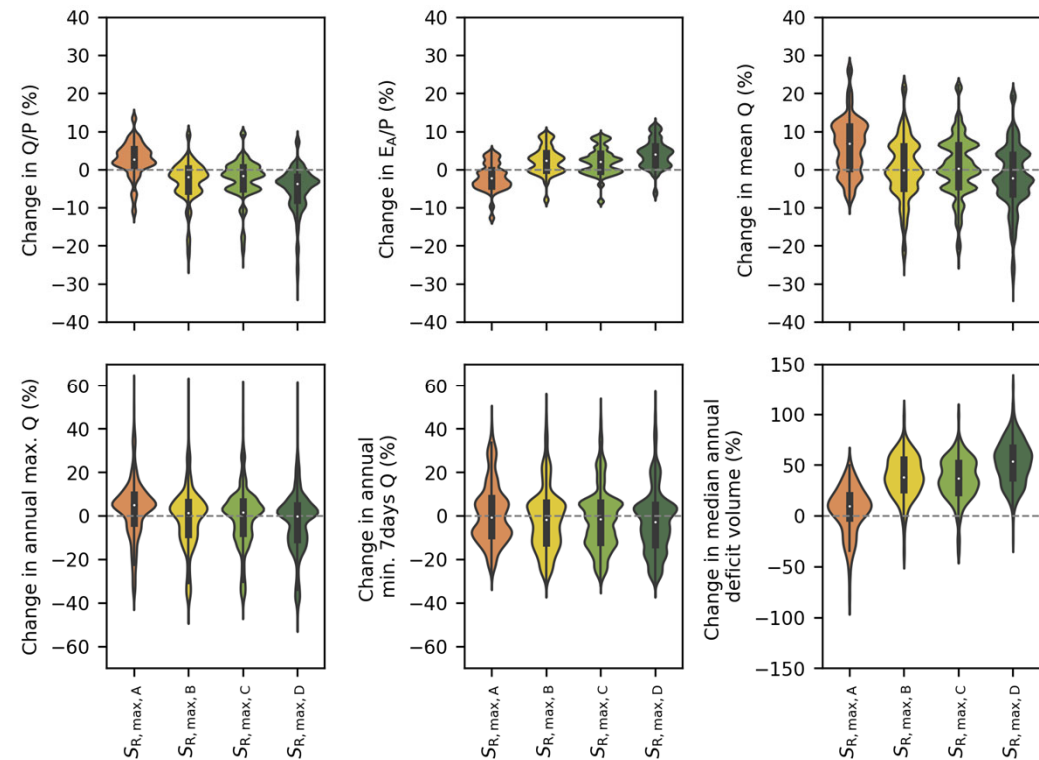
- Catchments with relatively high areal fractions of broadleaved forests tend to have lower  $\omega$  than catchments with relatively low areal fractions of broadleaved forests. These Budyko characteristics are used in a trading space-for-time approach for the potential land-use conversions in scenarios 2K<sub>C</sub> and 2K<sub>D</sub>
- Increase of root-zone storage capacity parameter ( $S_{R,max}$ ) with approx. 34% due to more pronounced seasonality with drier summers under 2K global warming. Increase is exacerbated in scenario 2K<sub>D</sub> which considers land-use conversion from broadleaved forest to coniferous plantations



$$\frac{E_A}{P} = 1 - \frac{Q}{P} = 1 + \frac{E_P}{P} - \left( 1 + \left( \frac{E_P}{P} \right)^\omega \right)^{1/\omega}$$

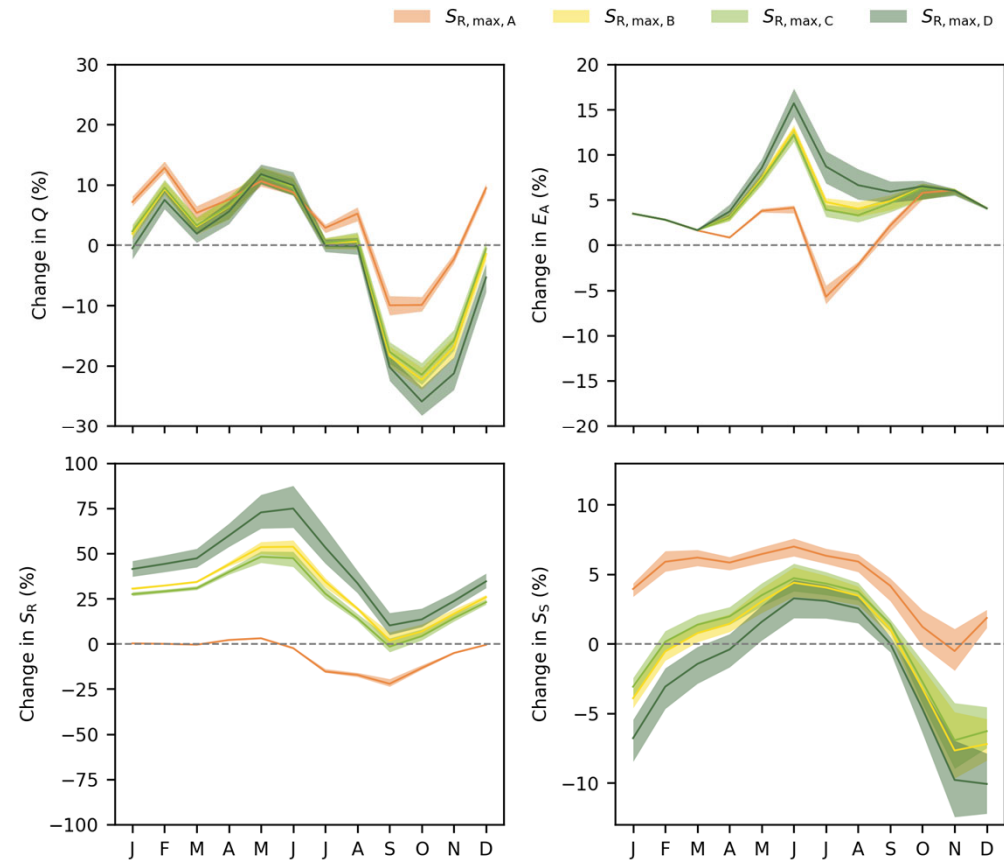
# Hydrological change evaluation under +2K global warming and potential land-use change (4 scenarios)

- Percentage change in annual hydrological response indicators between the +2K and historical model runs for the four scenarios, each with a different assumption for the root-zone storage capacity parameter
  - Runoff coefficients increase (+3%) for the stationary system, while they are projected to decrease (-3%) for the non-stationary systems
  - Stronger increase in median annual volume deficit for the non-stationary systems in comparison to the stationary systems



# Hydrological change evaluation under +2K global warming and potential land-use change (4 scenarios)

- Percentage change in mean monthly hydrological response of several flux and state variables (streamflow, actual evaporation, root-zone storage, groundwater storage) between the +2K and historical model runs for the four scenarios
  - More pronounced decrease in streamflow (-20%) between Sept and Nov for the non-stationary systems in comparison to the stationary system
  - Actual evaporation is no longer reduced as a result of moisture stress in the non-stationary systems
  - Groundwater recharge reduces (-5%) from Oct to Feb in the non-stationary systems, while it increases in the stationary system



# Conclusions

- Hydrological response under +2K global warming is strongly altered if we consider that vegetation adapts its root-zone storage capacity to offset the more pronounced seasonality of hydro-climatic variables under +2K global warming in comparison to a stationary system.
- Through a top-down approach and using regional climate simulations, we introduce a time-dynamic representation of the root-zone storage capacity parameter and contribute to the quest for more plausible representations of catchment properties under change.
  - Apply a space-for-time exchange of Budyko characteristics of dominant land-use types to estimate the long-term runoff coefficient under potential climate and land-use change
  - Estimate the root-zone storage capacity from accumulated water deficits during the dry period
- Main limitations
  - Effects of increased CO<sub>2</sub> levels on productivity and water-use efficiency are not considered
  - Knowledge gap on how ecosystems will adapt their water-use behavior in response to climate change

# Thank you

More details in discussion paper: <https://doi.org/10.5194/hess-2021-204>

