Is there a universal calibration-free continuous hydrological model? Testing a dynamic Budyko model in two continents

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Key Points:
- Dryness state of a basin is a dynamic or time-varying phenomenon
- This study introduces a “decay function” that allows us to determine the dryness index of a basin at an instant of time
- The concept of dryness index helps in constructing a timescale-independent zero-parameter hydrological model

Supporting Information:
- Supporting Information S1

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Dynamic hydrologic modeling using the zero-parameter Budyko model with instantaneous dryness index

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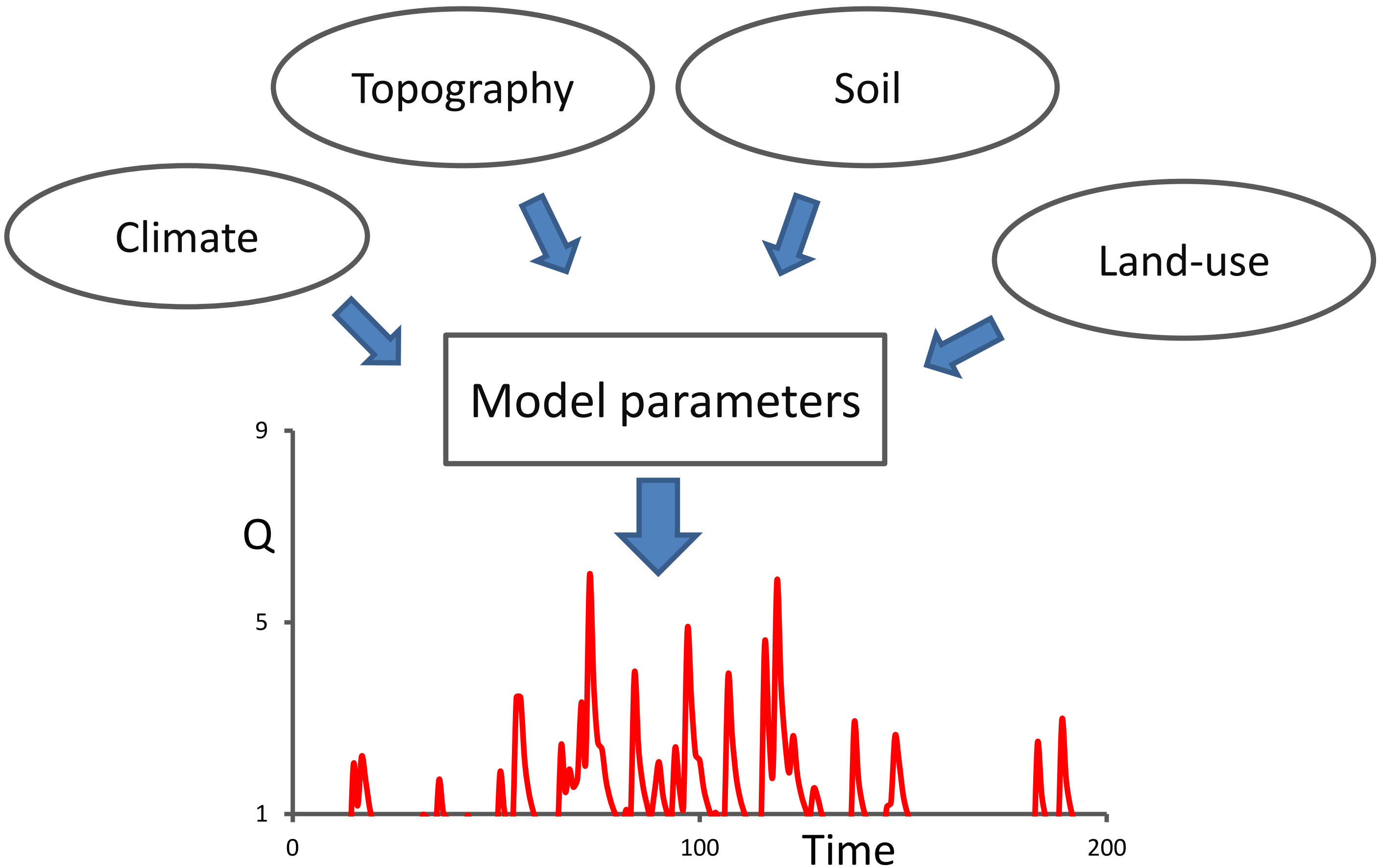
Abstract Long-term partitioning of hydrologic quantities is achieved by using the zero-parameter Budyko model which defines a dryness index. However, this approach is not suitable for dynamic partitioning particularly at diminishing timescales, and therefore, a universally applicable zero-parameter model remains elusive. Here an instantaneous dryness index is proposed which enables dynamic hydrologic modeling using the Budyko model. By introducing a “decay function” that characterizes the effects of antecedent rainfall and solar energy on the dryness state of a basin at a time, I propose the concept of *instantaneous dryness index* and use the Budyko function to perform continuous hydrologic partitioning. Using the same decay function, I then obtain discharge time series from the effective rainfall time series. The model is evaluated by considering data form 63 U.S. Geological Survey basins. Results indicate the possibility of using the proposed framework as an alternative platform for prediction in ungagued basins.

Regionalization methods are generally followed for prediction in ungauged basins



However, the limitation of regionalization methods is that it is hard to assign physical meanings to a model's parameters

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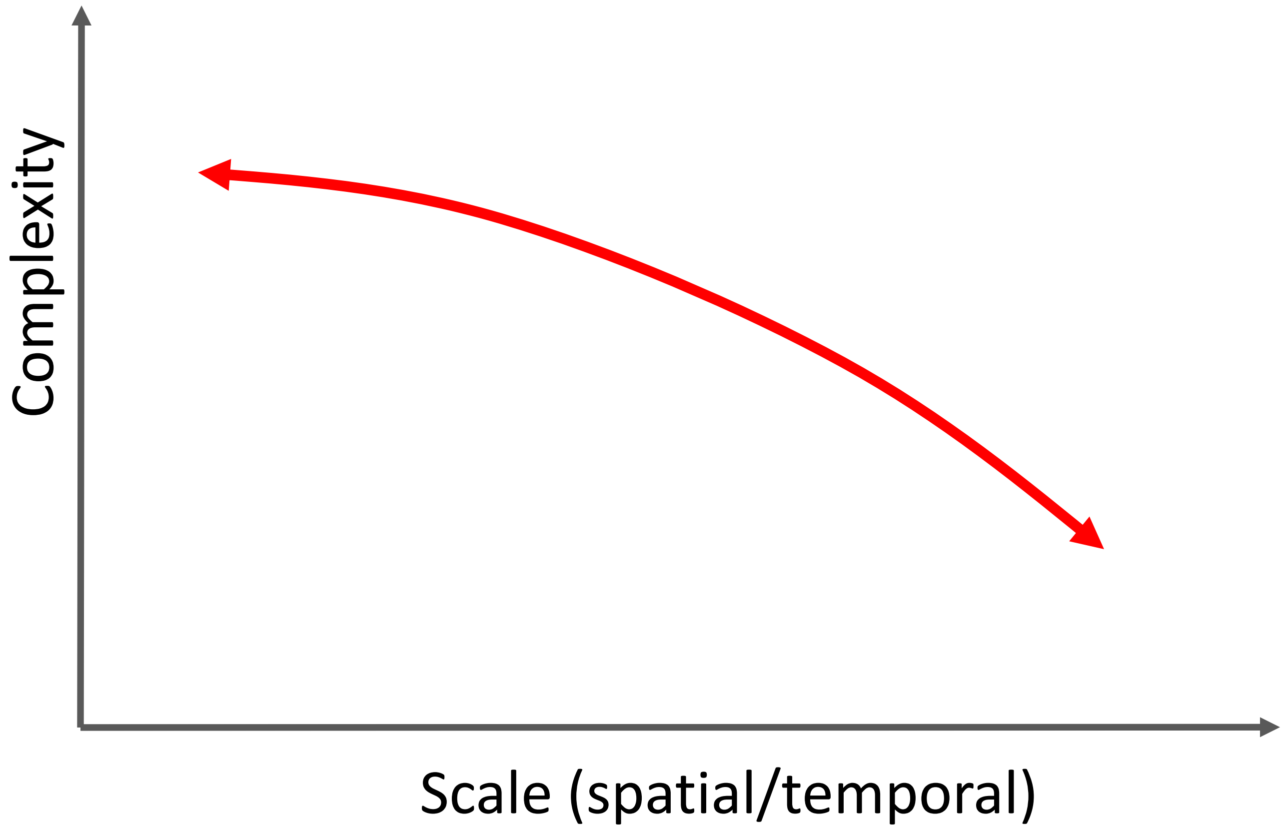
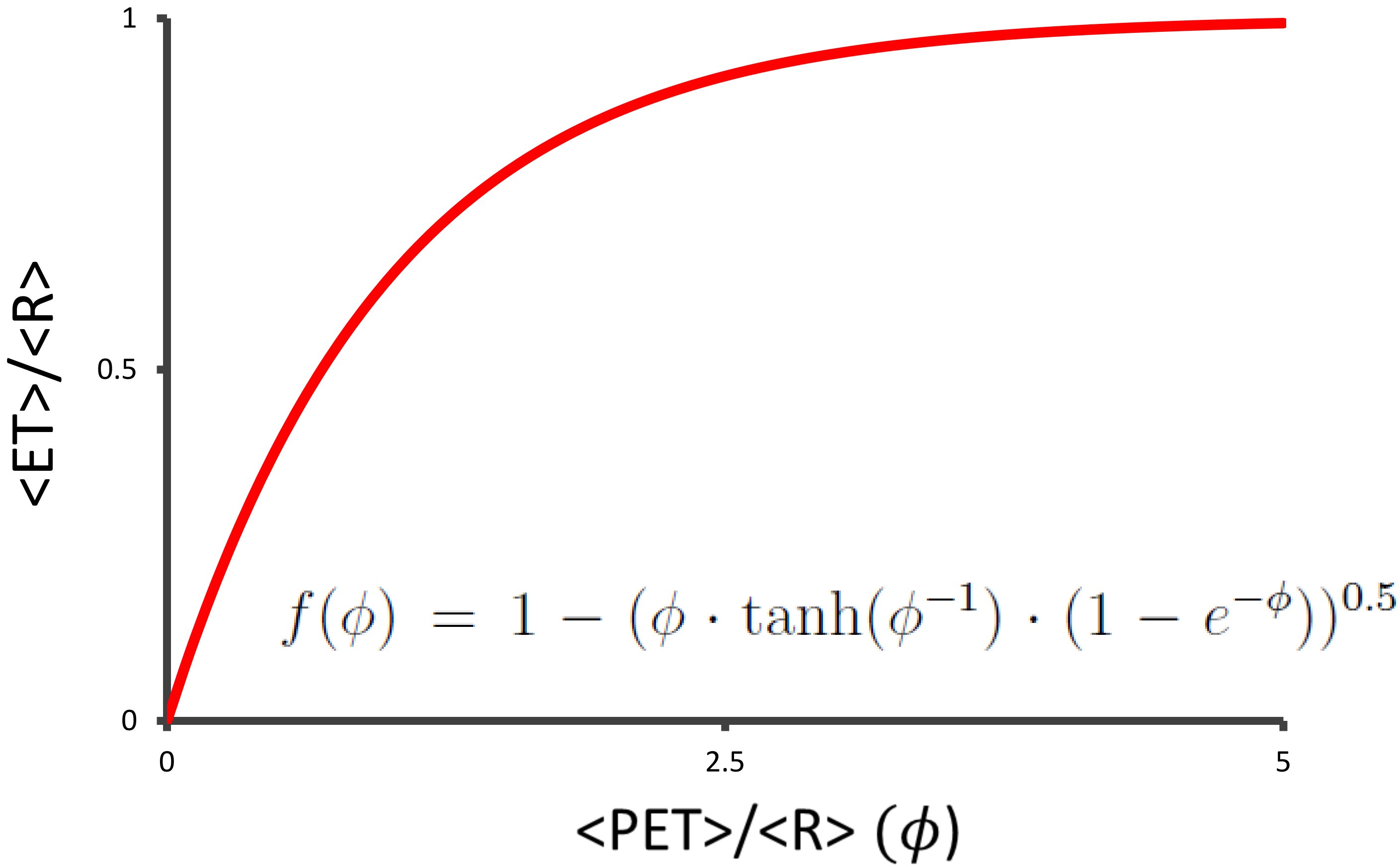
Hydrologic complexity decreases with scale



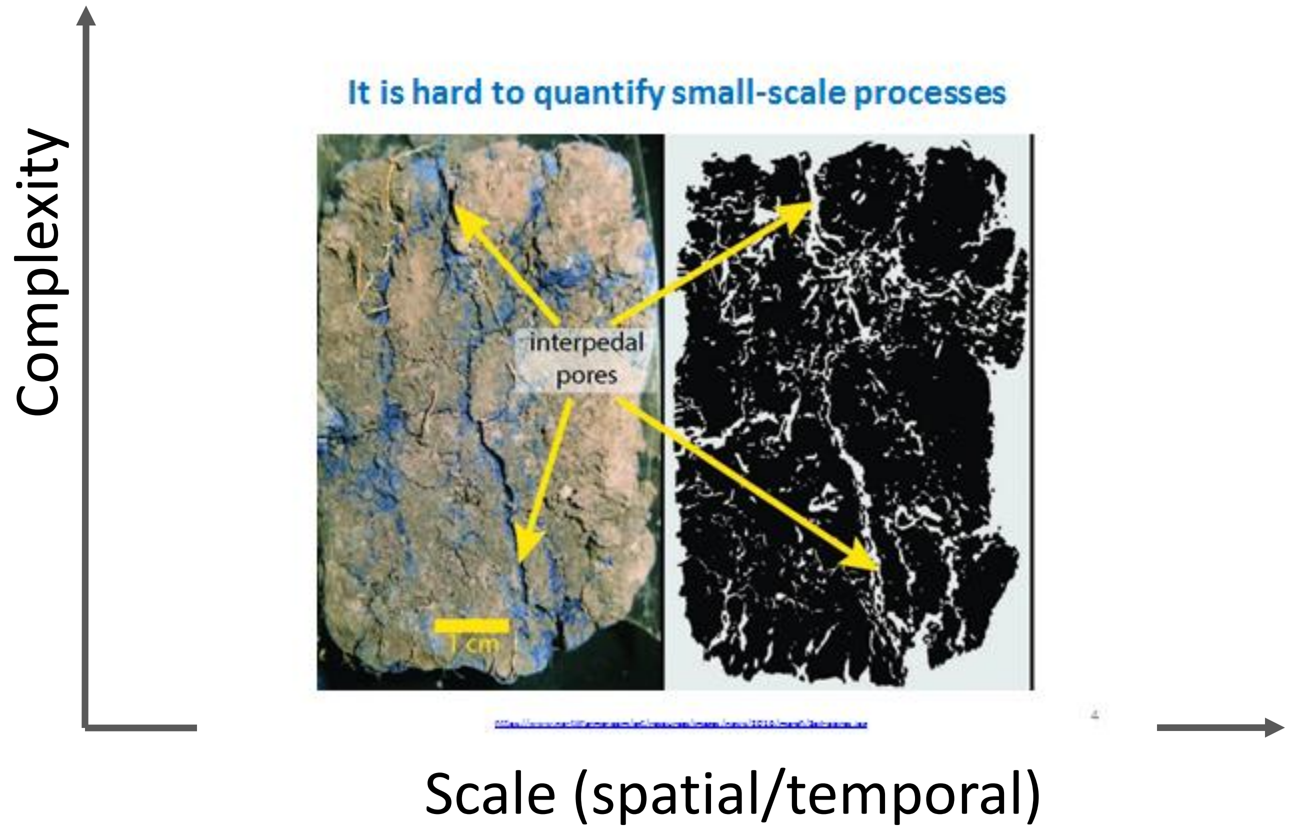
(e.g., **Klemes, JoH, 1983; Sivapalan, HP, 2003**)

Long-term hydrologic partitioning follows the Budyko curve



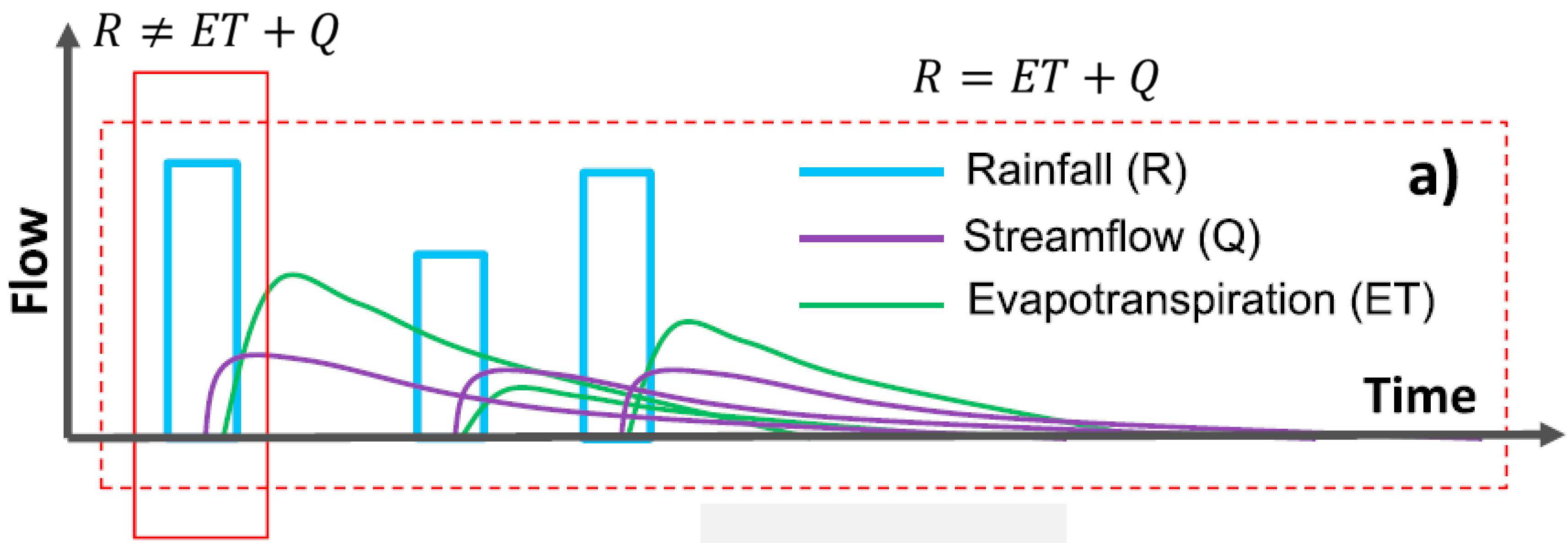
It is generally assumed that $< \boldsymbol{R} > = < \boldsymbol{Q} > + < \boldsymbol{ET} >$ (storage fluctuation is neglected)

Hydrologic complexity decreases with scale: is there a downward approach?



(Klemes, JoH, 1983; Sivapalan et al., HP, 2003)

Why hydrology is complex for a small timescale



For a small timescale, we cannot neglect storage fluctuation:

$R = dS/dt + ET + Q$

Hydrologists therefore use the term effective rainfall (ER). If we similarly define rainfall loss (RL), the mass balance equation at any instant of time is $R(t) = ER(t) + RL(t)$

(e.g., **Biswal, GRL, 2016**)

http://www.telegraphindia.com/1111213/images/13bhrGraphic.jpg; http://www.krisweb.com/hydrol/Salmon_River.jpg

Dryness state of a catchment needs to be considered as a dynamic phenomenon

It is hypothesized here that *instantaneous dryness index* (φ) is a function of *antecedent rainfall and solar energy inputs*

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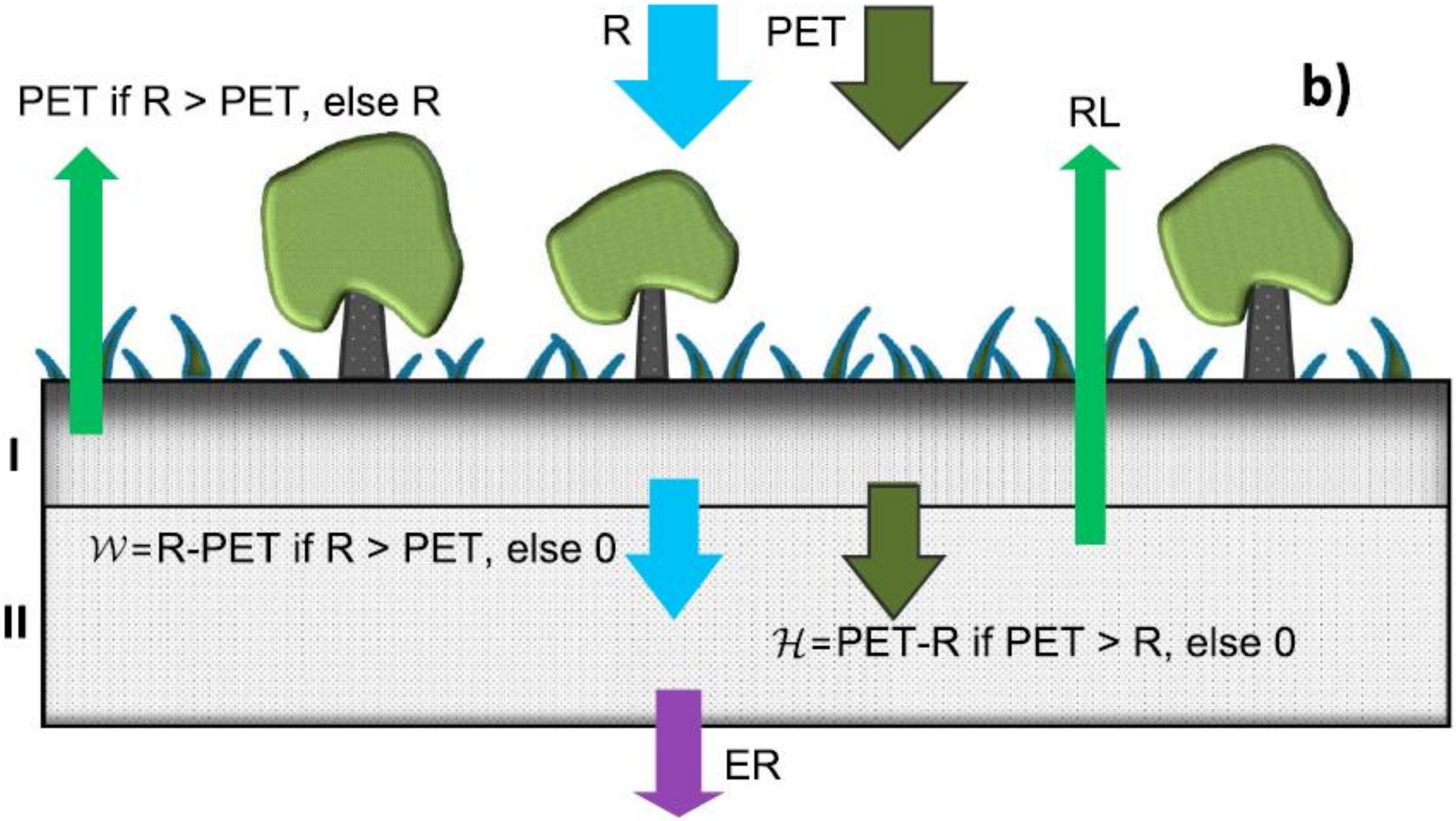
A conceptual diagram of the proposed model



Available water (W) and solar energy (H) determine the dryness state of the catchment

(**Biswal, GRL, 2016**)

An instantaneous dryness-index for zero-parameter/ calibration-free hydrological modelling

$$FW(t) = \int_{t-N}^{t} W(\tau) \cdot \boldsymbol{x(t-\tau)} \cdot d\tau$$

$$FH(t) = \int_{t-N}^{t} H(\tau) \cdot \boldsymbol{x(t-\tau)} \cdot d\tau$$

$$(W(t) = Max(R - PET, 0))$$

$$(H(t) = Max(PETT - R, 0))$$

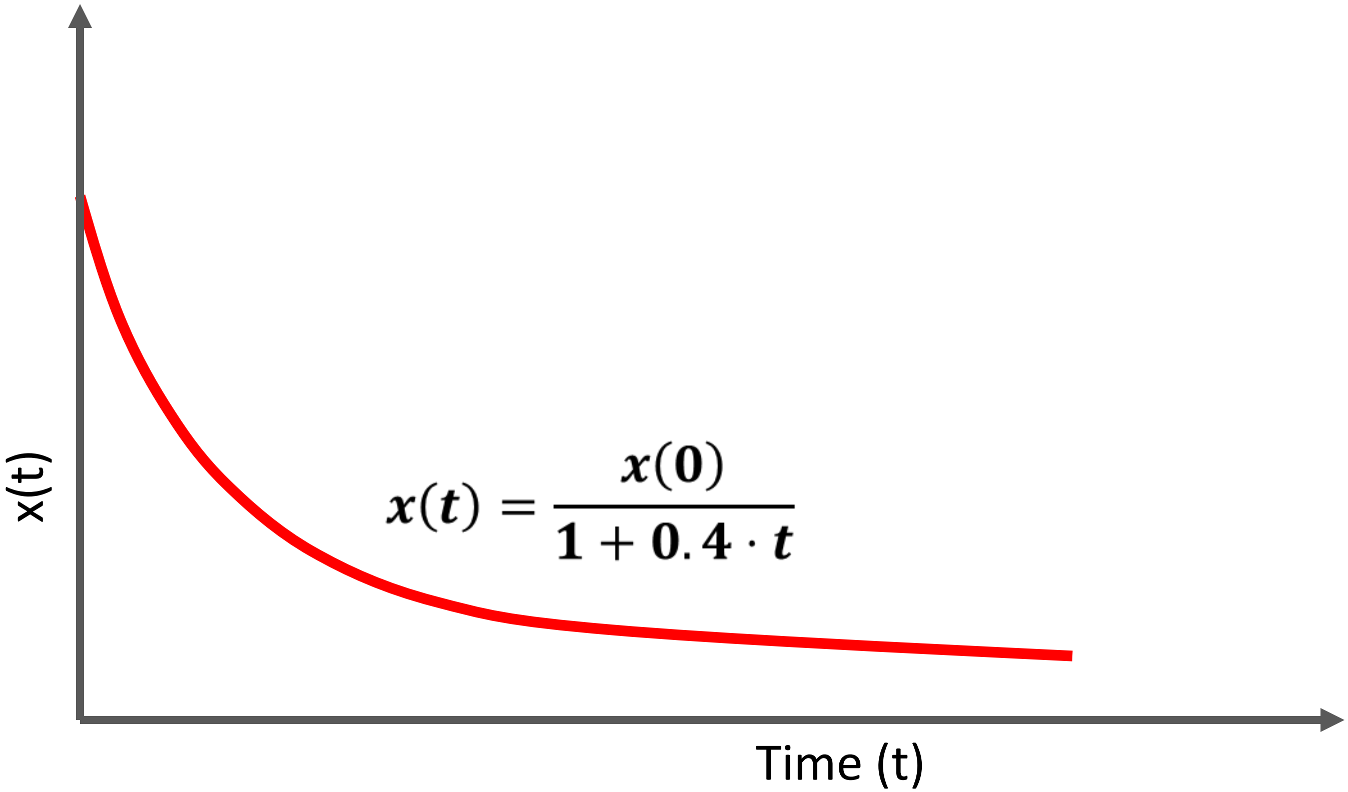
$$\boxed{\boldsymbol{\varphi(t)} = \frac{\boldsymbol{FH(t)}}{\boldsymbol{FW(t)}}}$$

$$ER(t) = W(t) \cdot f(\varphi)$$

$$R = ET + Q$$

(**Biswal, GLR, 2016**)

The proposed 'universal' decay function

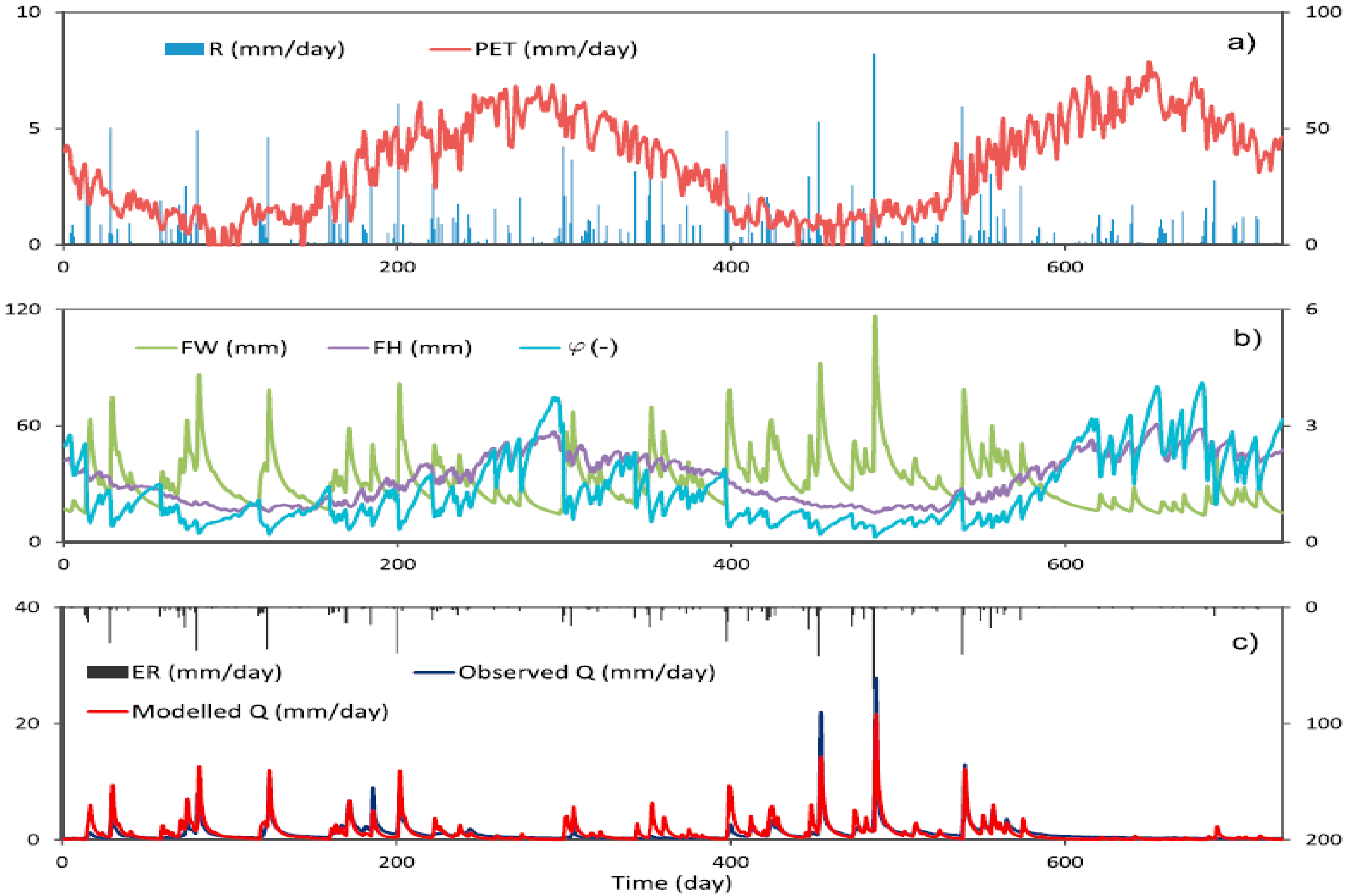


$$x(t) = \frac{x(0)}{1 + 0.4 \cdot t}$$

The universal decay-function (assumed to be valid in every real world catchment) was derived by performing recession flow analysis and imposing the mass balance condition considering data from 15 MOPEX catchments

(**Biswal, GLR, 2016**)

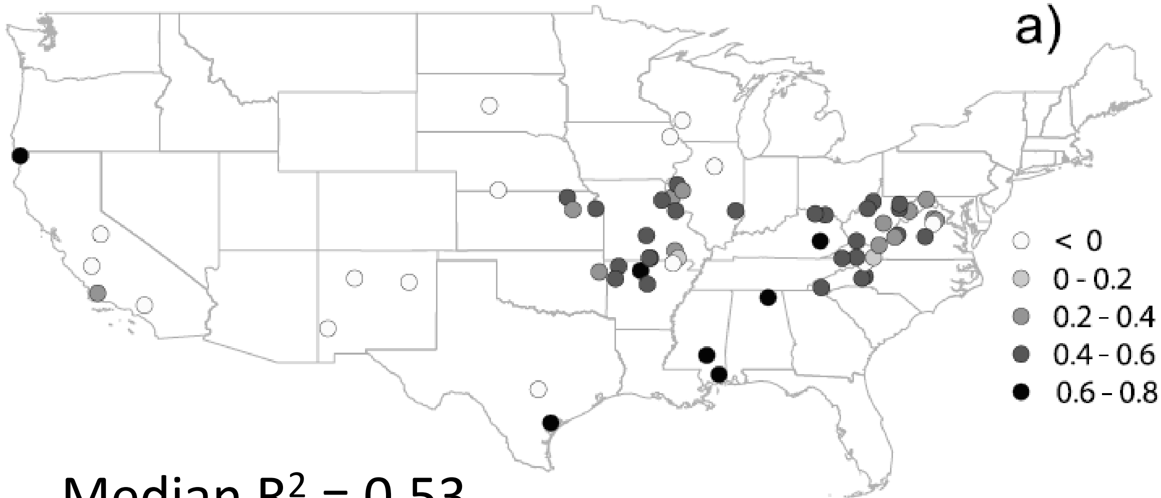
A sample simulation (USGS ID: 7058000; duration: 2 yrs)



(Biswal, GLR, 2016)

Performance of the model in 63 MOPEX catchments

Median NSE = 0.41



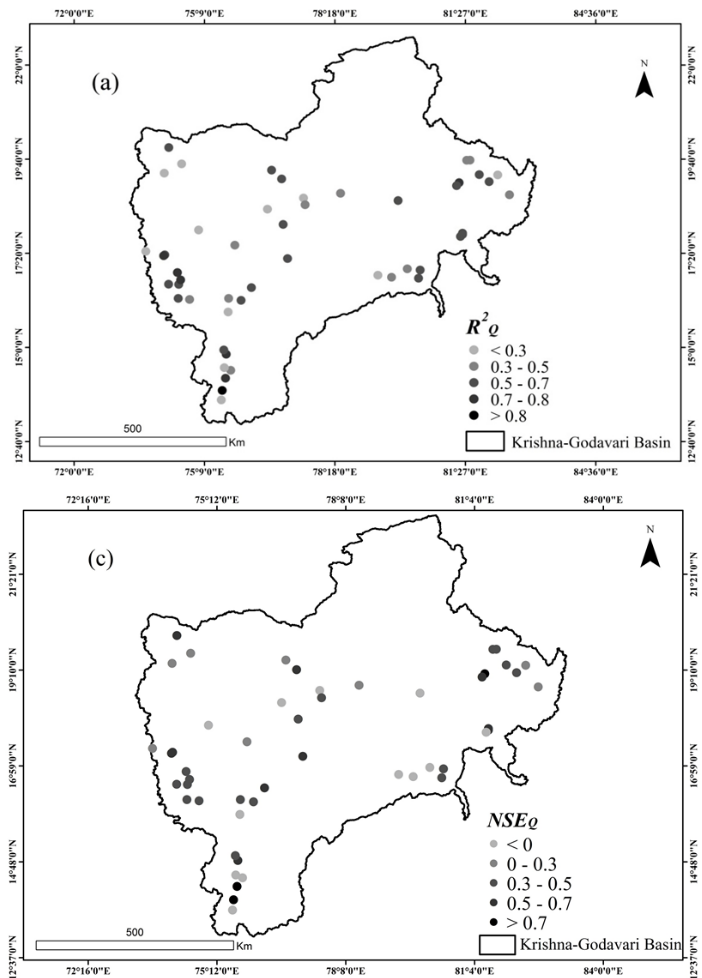
Median R^2 = 0.53

(Biswal, GLR, 2016)

Performance of the model in 50 south Indian catchments

Median NSE = 0.39

Median R^2 = 0.51



Note that most of the catchments are heavily influenced by human activities.

(**Patnaik et al., manuscript in review**)

Concluding remarks

1. The dryness state of a catchment is a dynamic phenomenon.

2. A single decay function is used to develop a zero-parameter/calibration-free hydrological model by following a downward approach.

3. The proposed zero-parameter model can be used as an alternative platform for ungauged basin prediction.

4. We need to properly utilize catchment similarities to develop simple hydrological models and avoid the issue of model over-parameterization.

Thank You