How people and ecosystems organize their storage requirements

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Lan Wang-Erlandsson

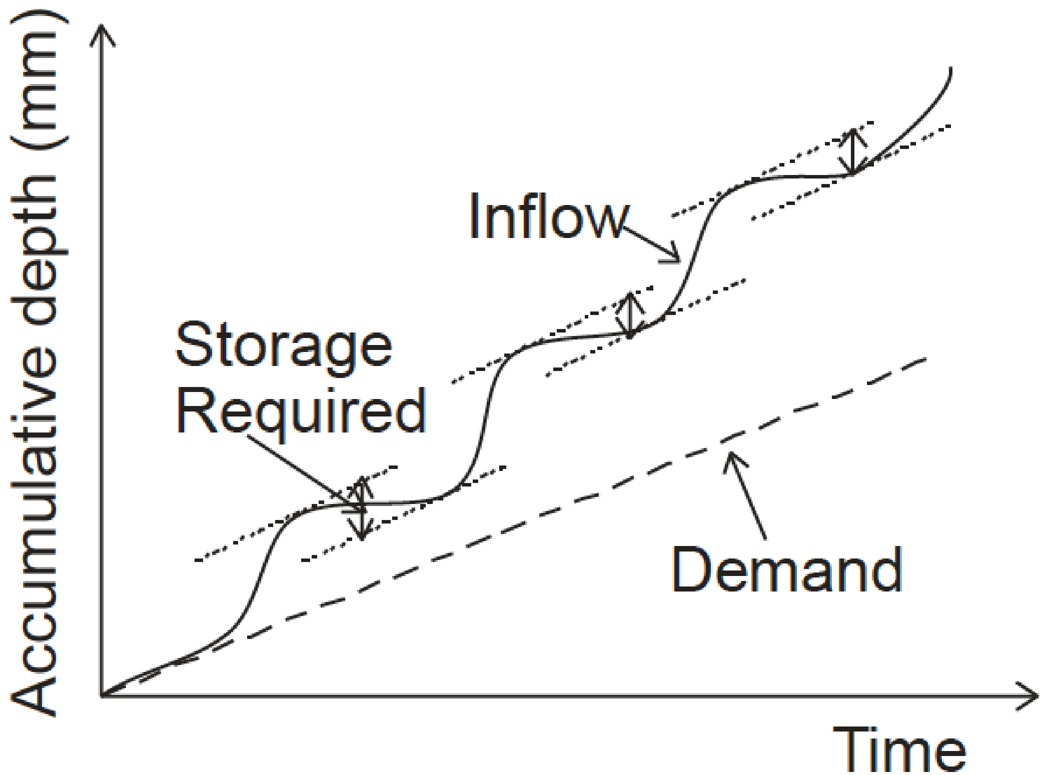
GIFT workshop Addis Ababa, November 2015

Dams in the Anthropocene

Marib dam
Yemen

Dam design

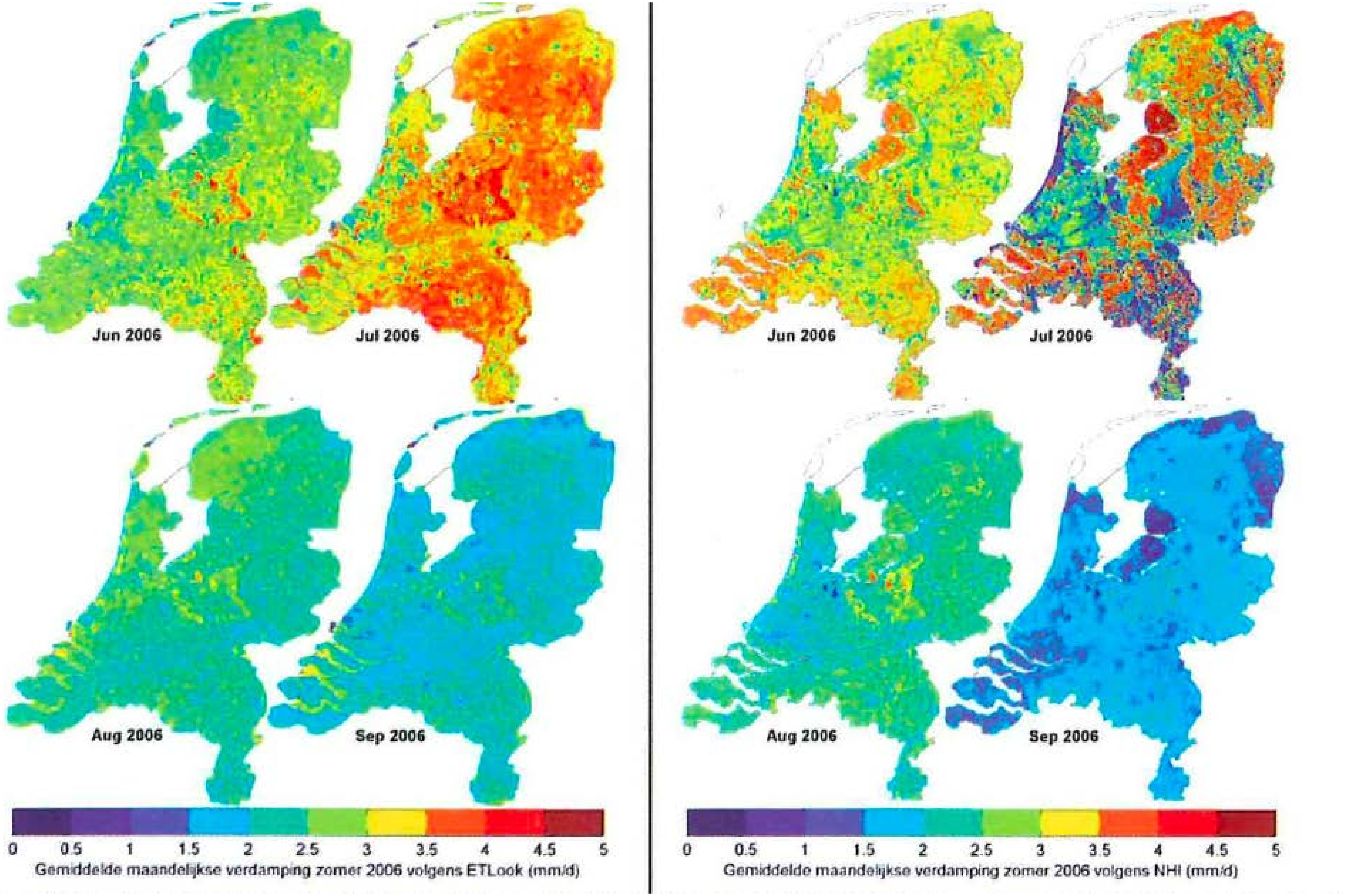
- Mass Curve Technique (Rippl, 1883)



Are People Unique

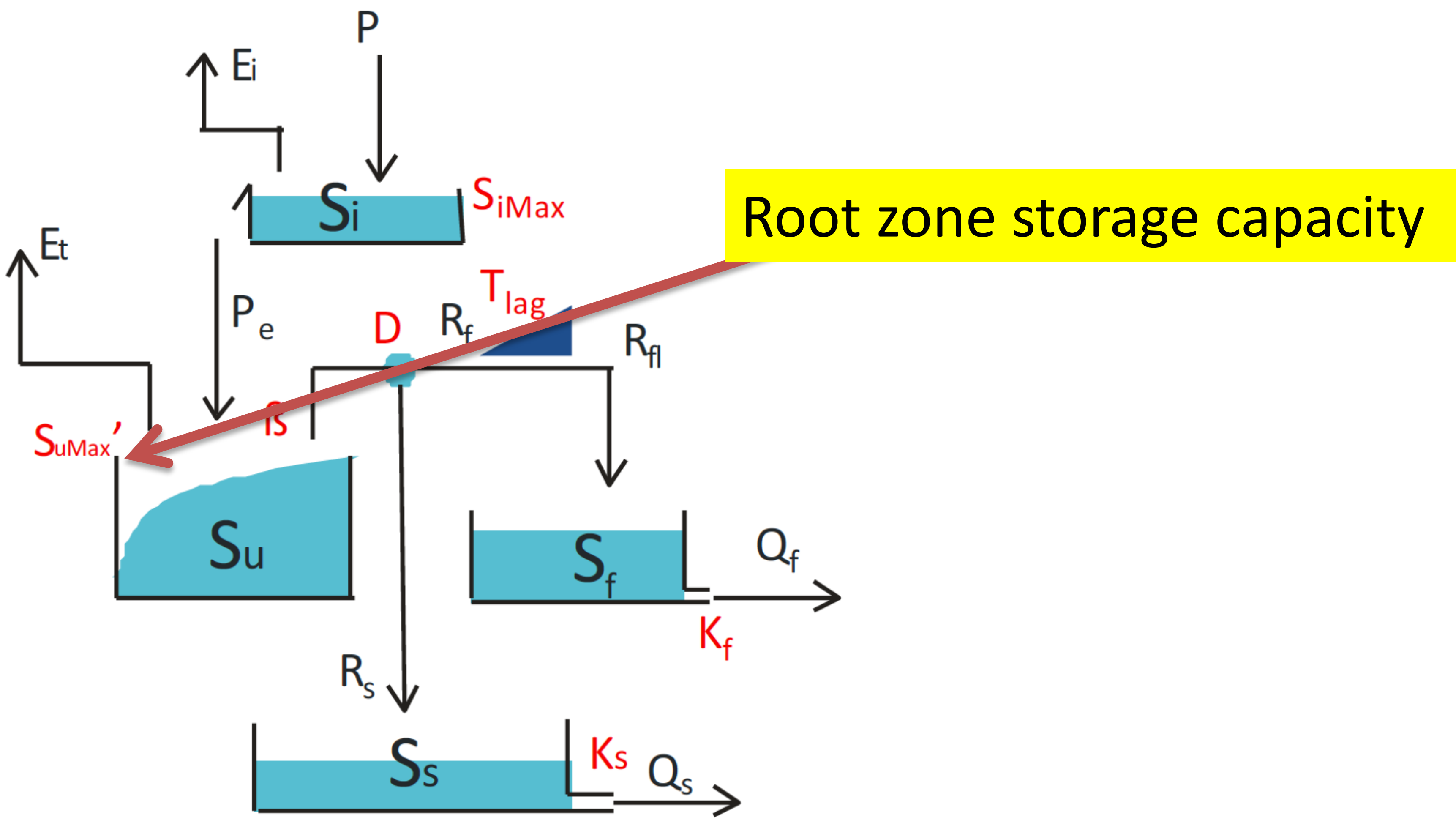
In designing their storage this way?

A problem



Jun 2006
Jul 2006
Aug 2006
Sep 2006
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Gemiddelde maandelijkse verdamping zomer 2006 volgens ETLook (mm/d)
Jun 2006
Jul 2006
Aug 2006
Sep 2006
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Gemiddelde maandelijkse verdamping zomer 2006 volgens NHI (mm/d)

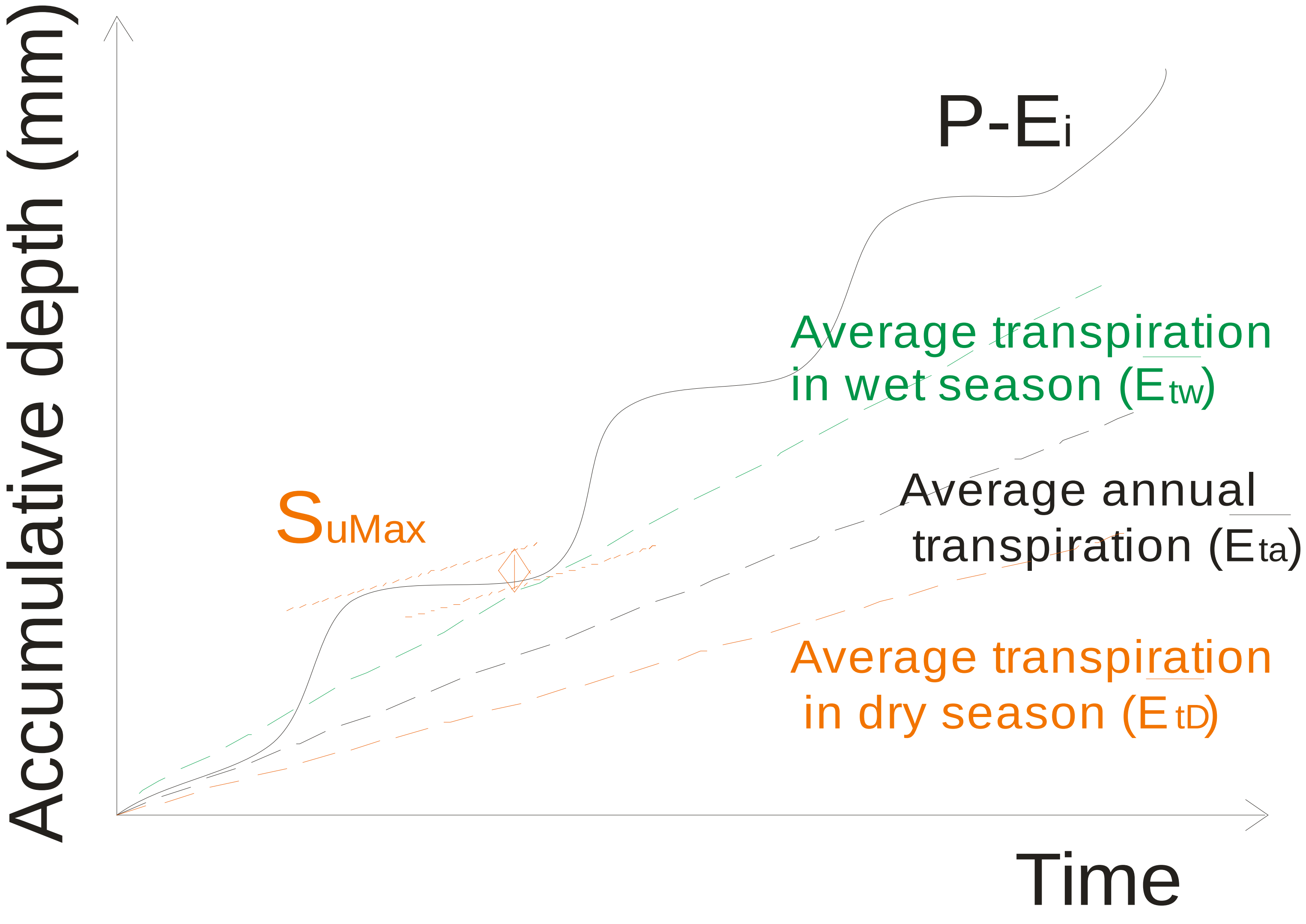
Root storage in Models



State of the Art to determine S_{umax}

1. use a soil map (e.g.:Harmonized World Soil Database of FAO)
2. determine the range between field capacity and wilting point
3. derive the rooting depth from ecosystem maps (e.g: Land Cover Type Climate Modeling Grid created from MODIS data)
4. multiplication of the two gives root zone storage capacity
5. this method is almost universal, e.g.: Federer et al. (1996); van den Hurk et al. (2000); van den Hurk (2003); Zhou et al. (2006); Bastiaanssen et al. (2012), and many others.

New way to determine Root zone storage capacity



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL061668

Climate controls how ecosystems size the root zone storage capacity at catchment scale

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Key Points:
- Root zone storage capacity (SR) can be estimated with mass curve technique
- Ecosystems design SR to bridge droughts with 10–40 years return period
- SR was linked to aridity index, dry spell duration, seasonality, and runoff ratio

Supporting Information:
- Readme
- Figures S1–S4 and Tables S1–S3
- Data set S1

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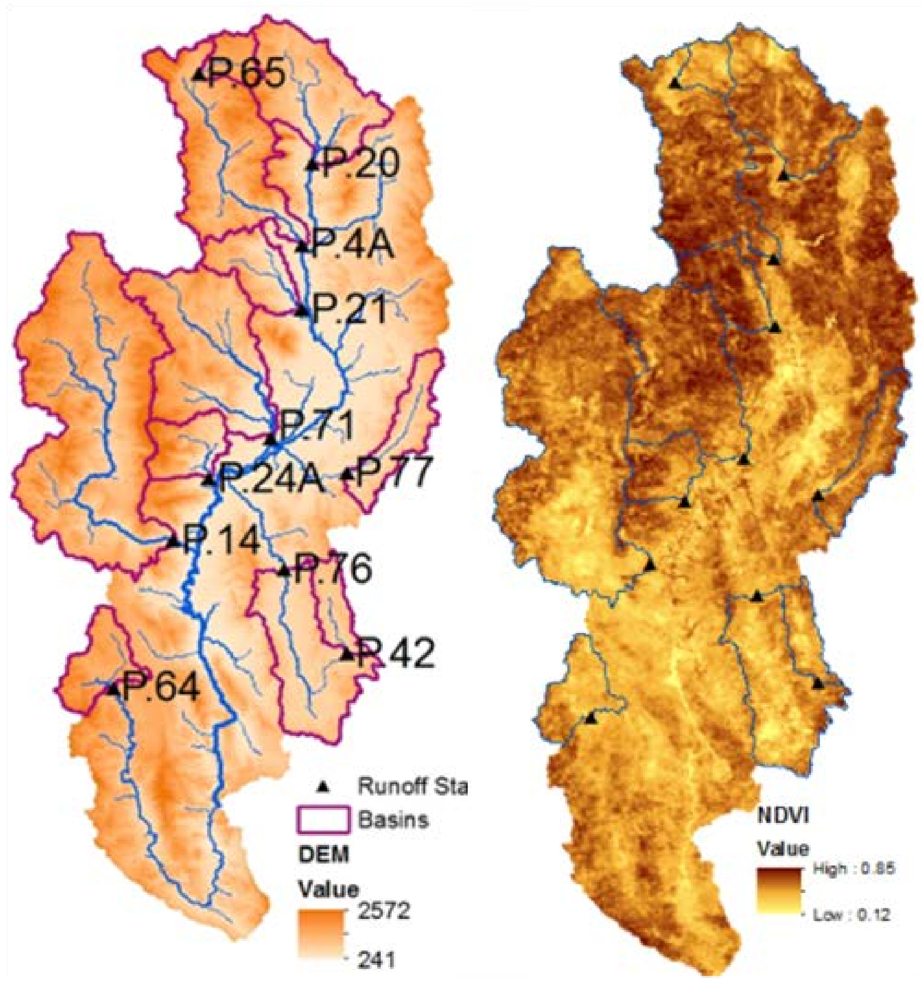
Citation:
Gao, H., M. Hrachowitz, S. J. Schymanski,

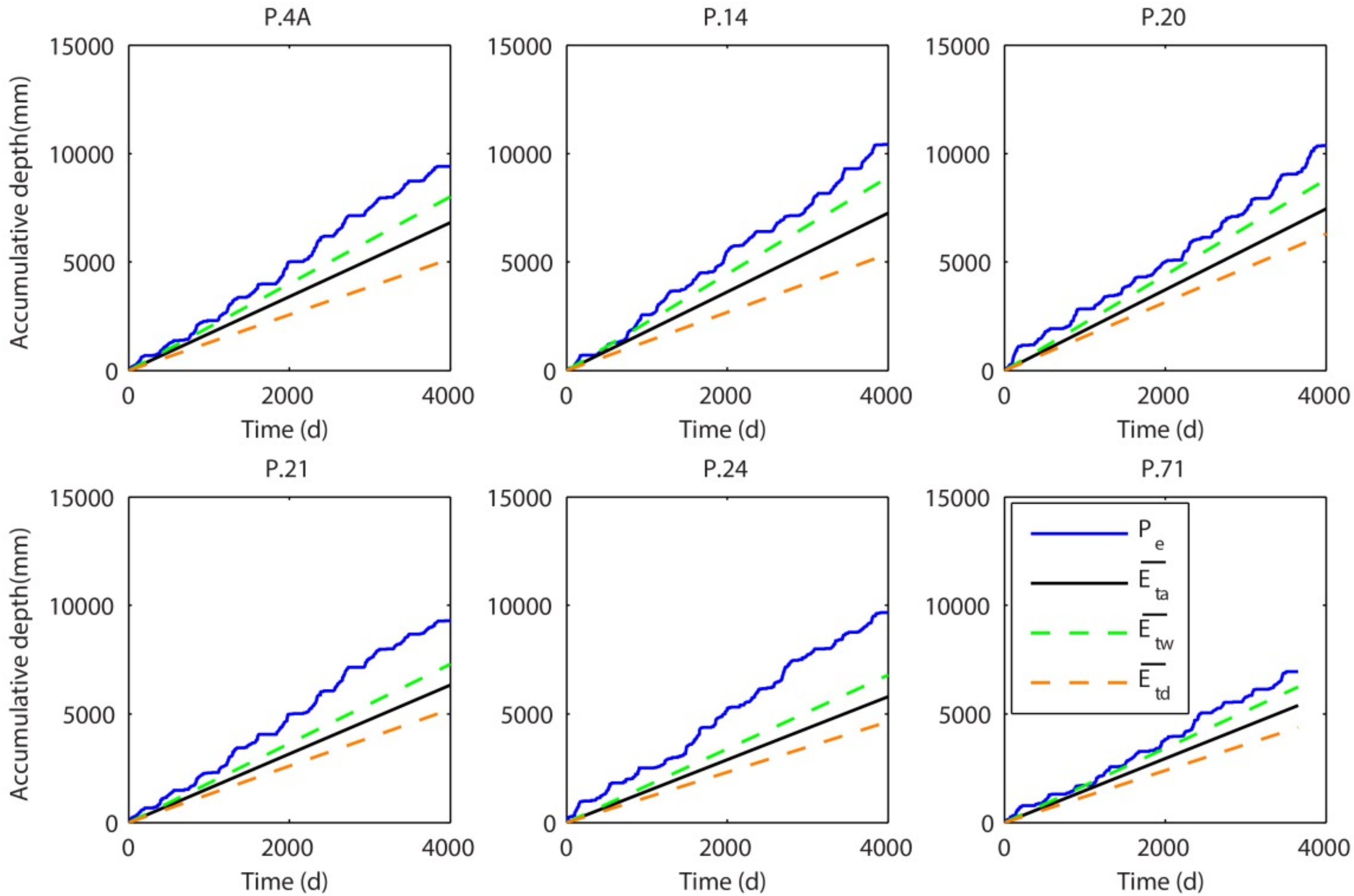
Abstract The root zone moisture storage capacity (S_R) of terrestrial ecosystems is a buffer providing vegetation continuous access to water and a critical factor controlling land-atmospheric moisture exchange, hydrological response, and biogeochemical processes. However, it is impossible to observe directly at catchment scale. Here, using data from 300 diverse catchments, it was tested that, treating the root zone as a reservoir, the mass curve technique (MCT), an engineering method for reservoir design, can be used to estimate catchment-scale S_R from effective rainfall and plant transpiration. Supporting the initial hypothesis, it was found that MCT-derived S_R coincided with model-derived estimates. These estimates of parameter S_R can be used to constrain hydrological, climate, and land surface models. Further, the study provides evidence that ecosystems dynamically design their root systems to bridge droughts with return periods of 10–40 years, controlled by climate and linked to aridity index, inter-storm duration, seasonality, and runoff ratio.

Gao, H., et al., 2014.
Geophysical Research Letters, 41, 7916-7923, doi: 10.1002/2014GL061668

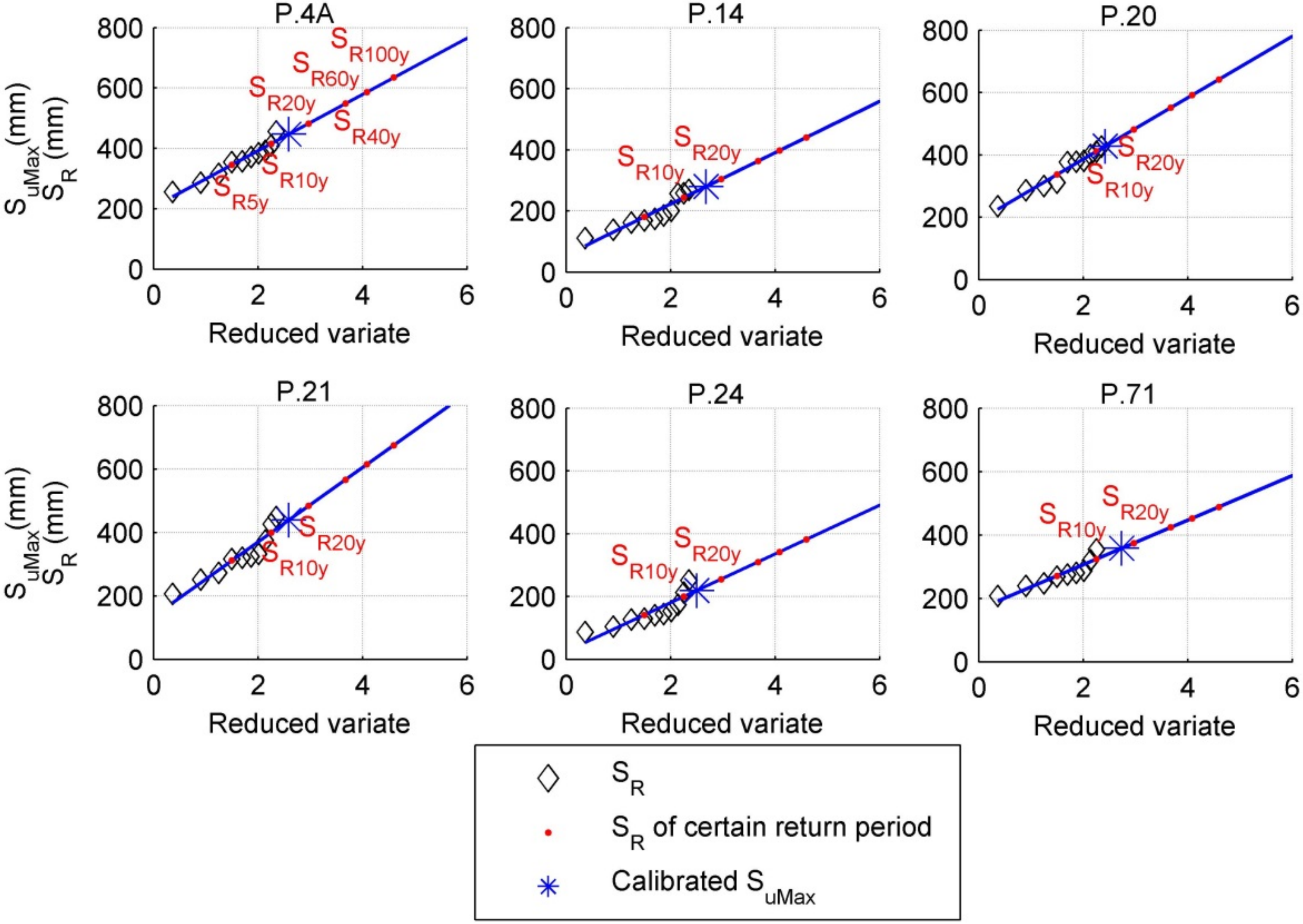
Upper Ping, Thailand



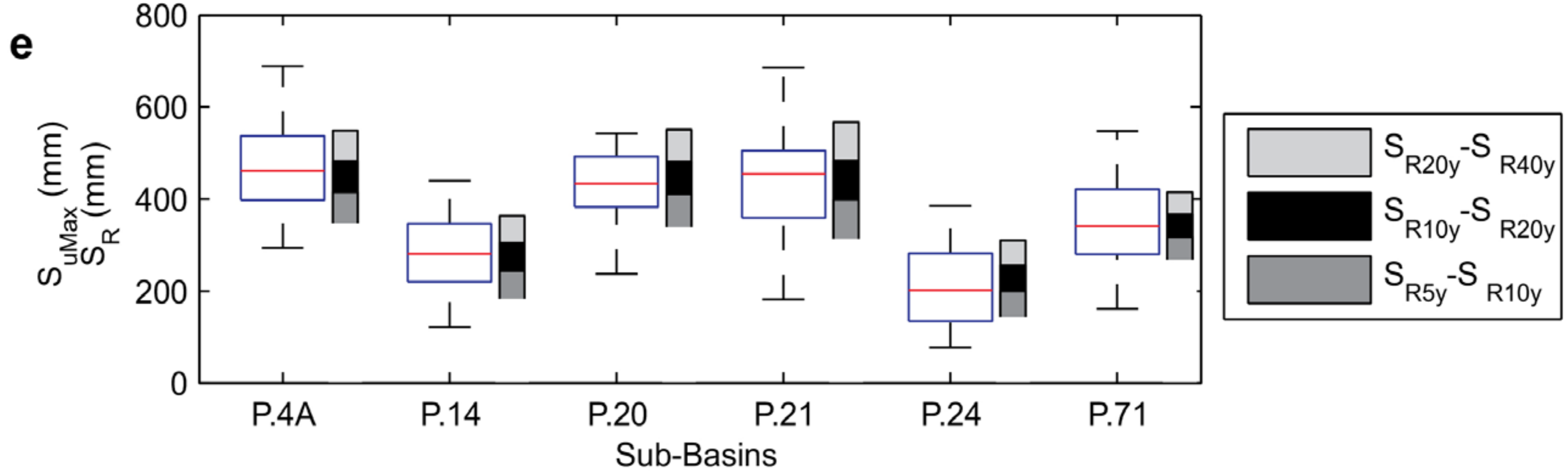
6 sub-catchments



Gumbel extremes

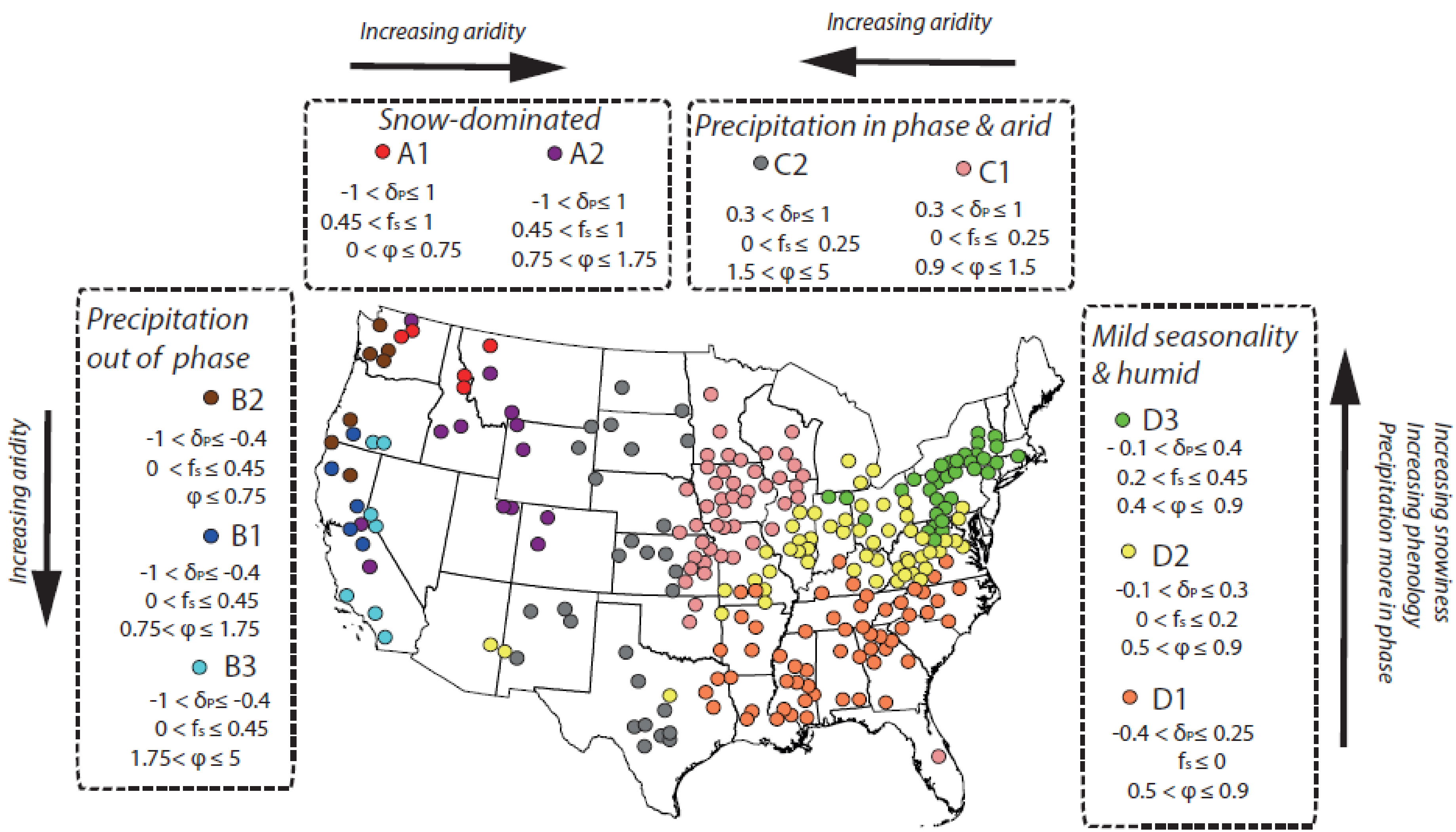


Comparing design storage with calibrated storage

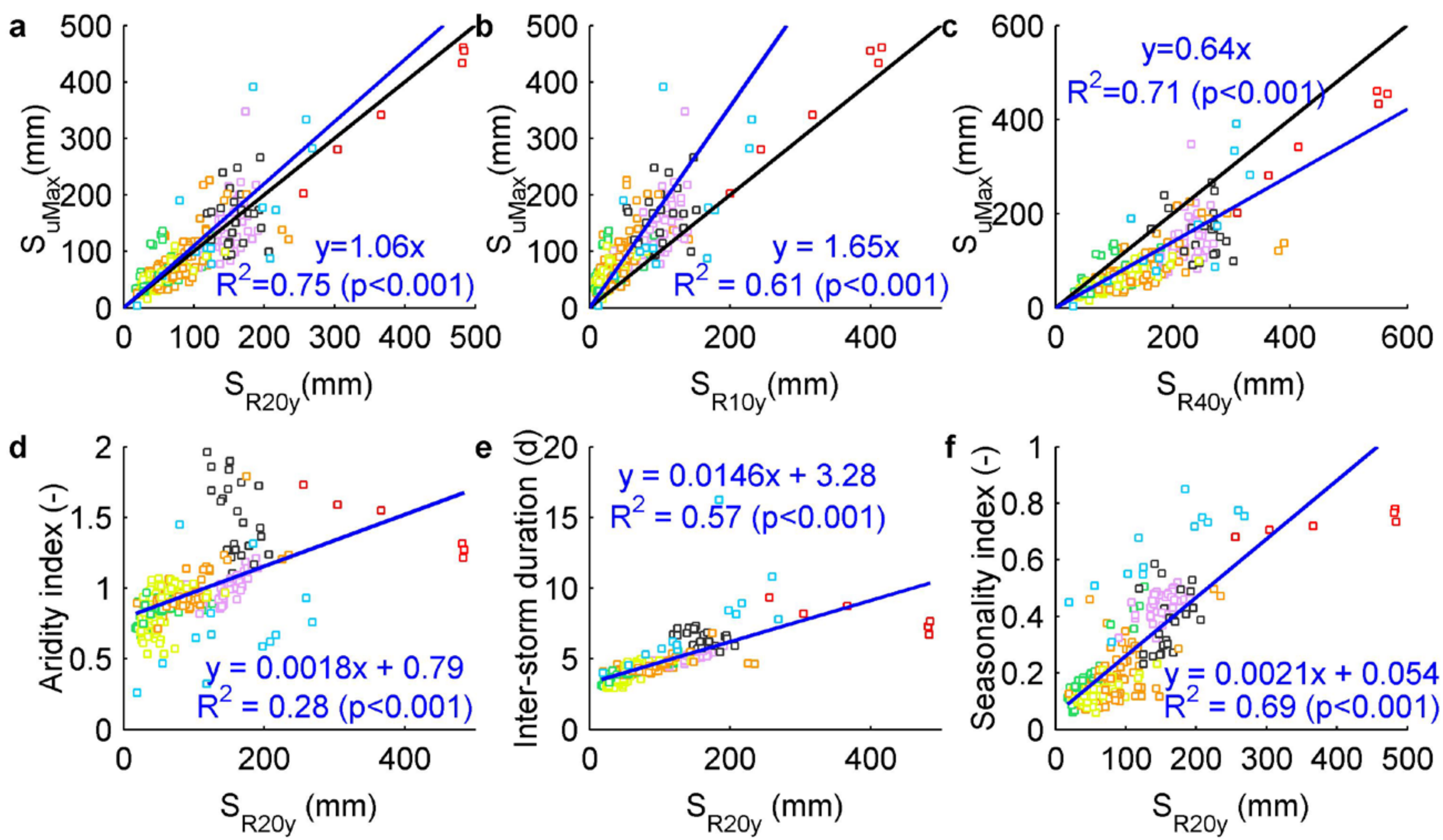


Hongkai Gao, GRL

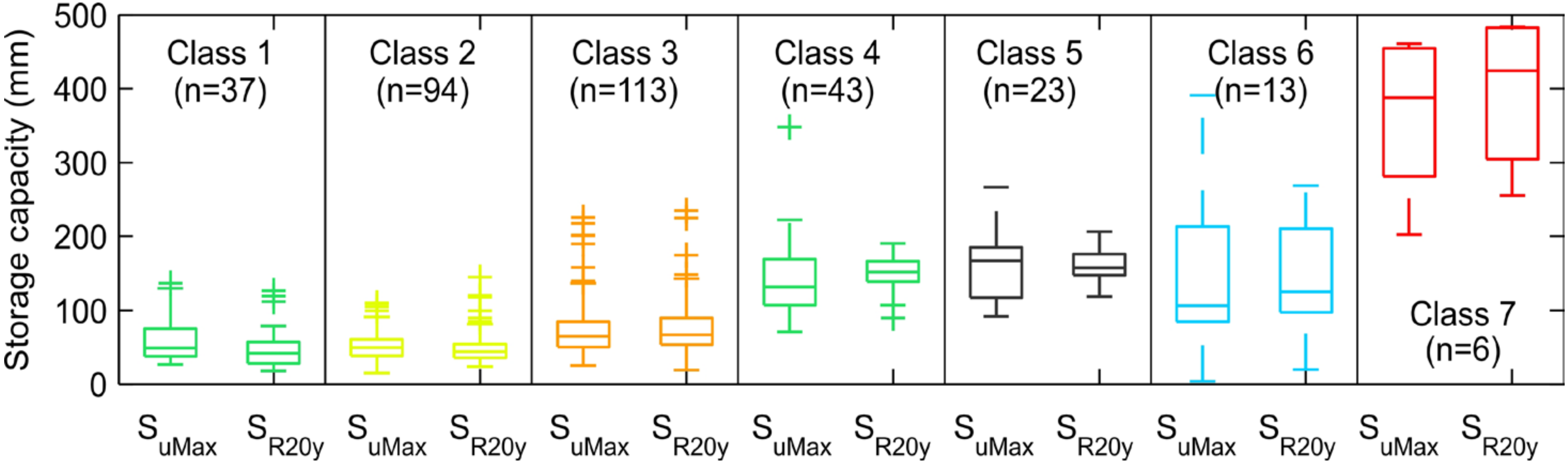
Validation on Mopex Data Set



20 year Return Period



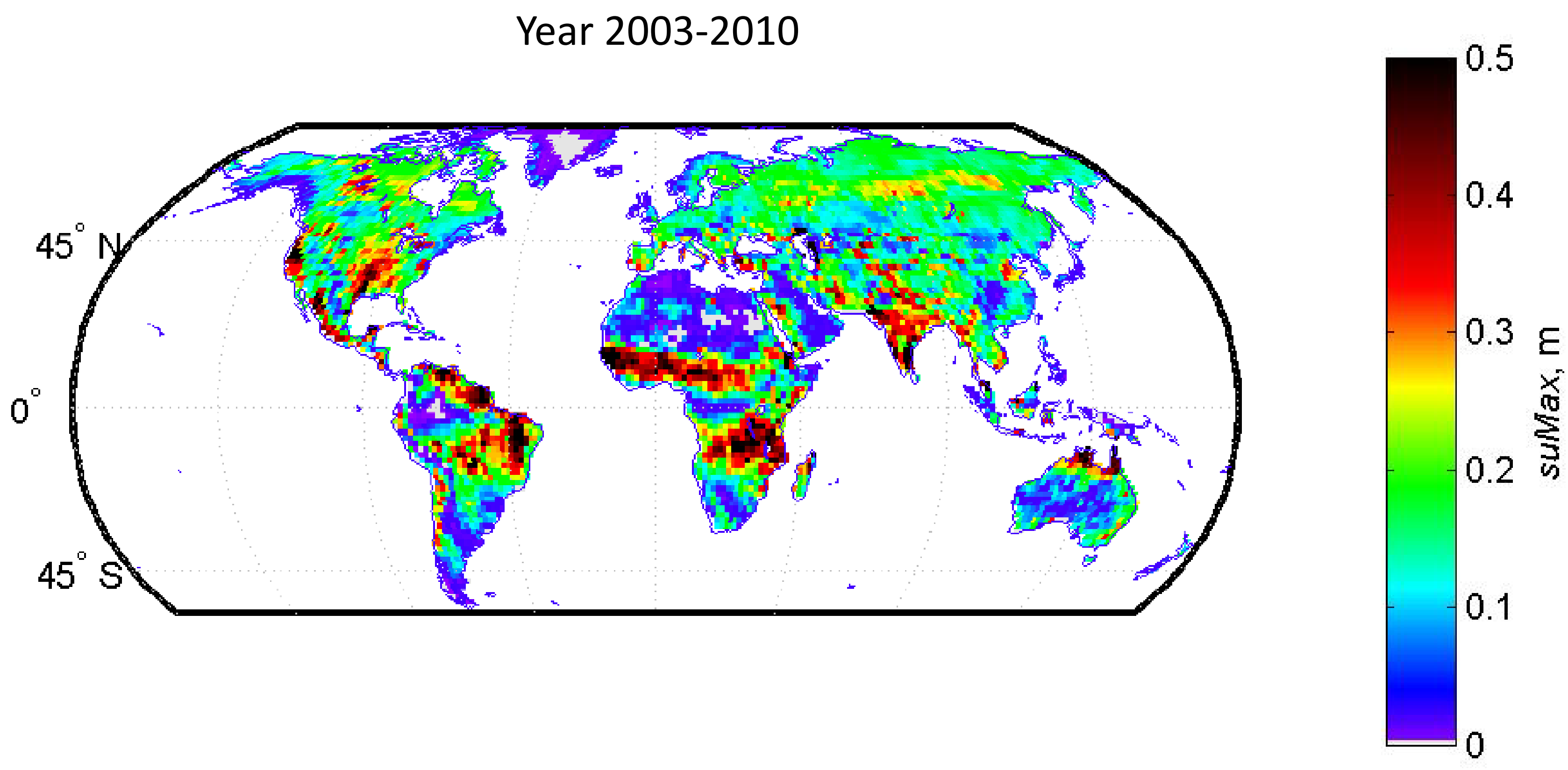
7 Different Eco-regions



Eco-region according to Wiken et al. (2011)

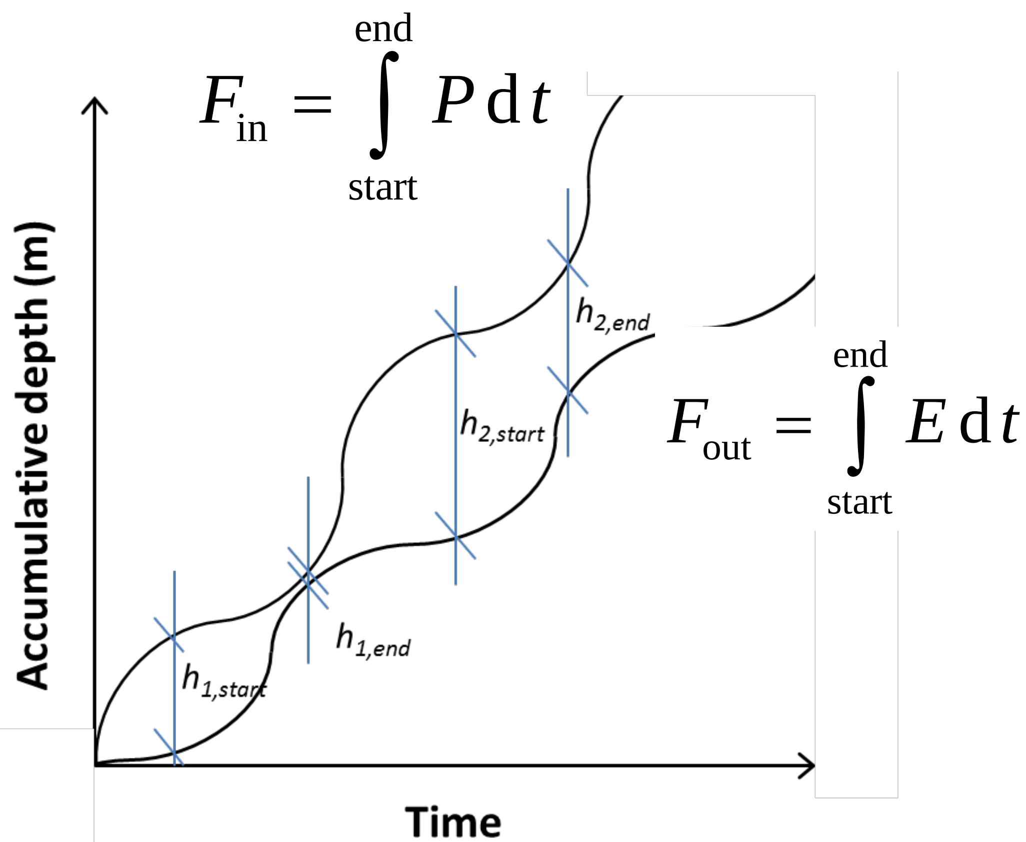
Can this also be done at Global level?

Recalculate Storage on basis of ERA-Interim



Work in progress by Lan Wang-Erlandsson

Rippl with Earth Observation data

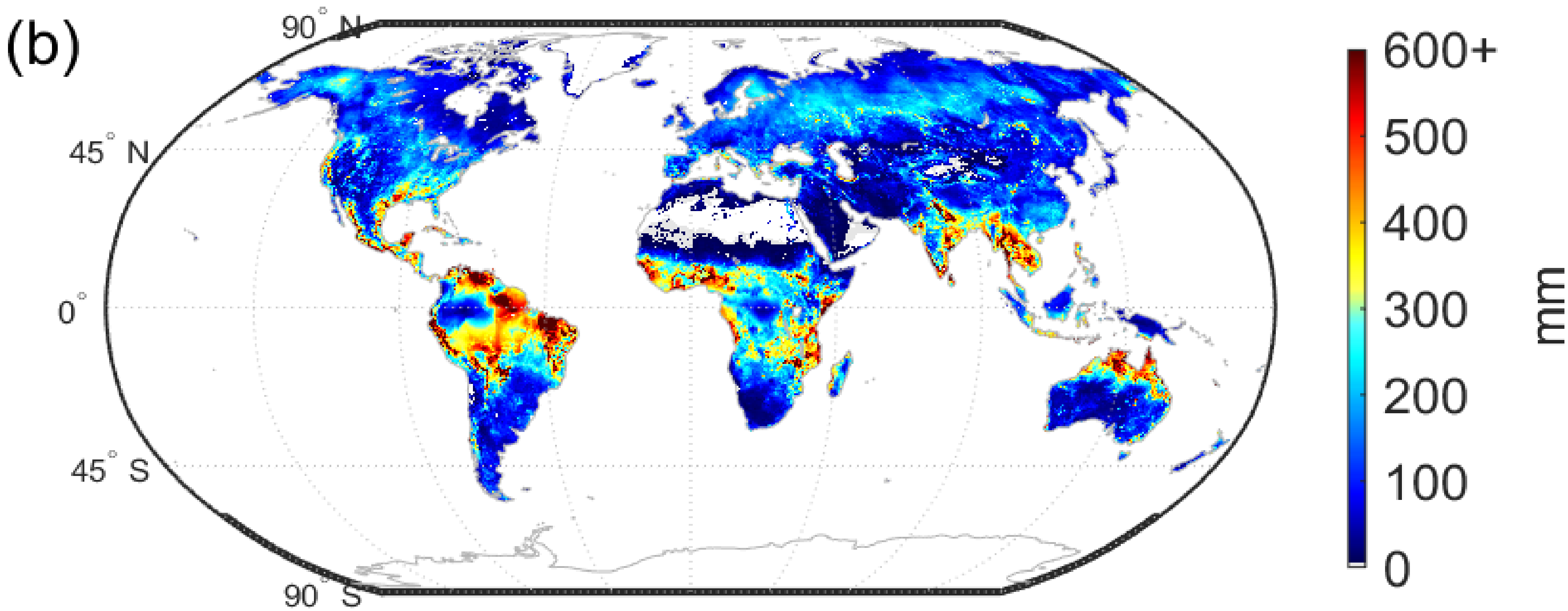


DATA (0.5º resolution)

- *P:* CRU
- *E:* Mean of SSEBop and MODIS 16
- period 2003-2013
- Global coverage

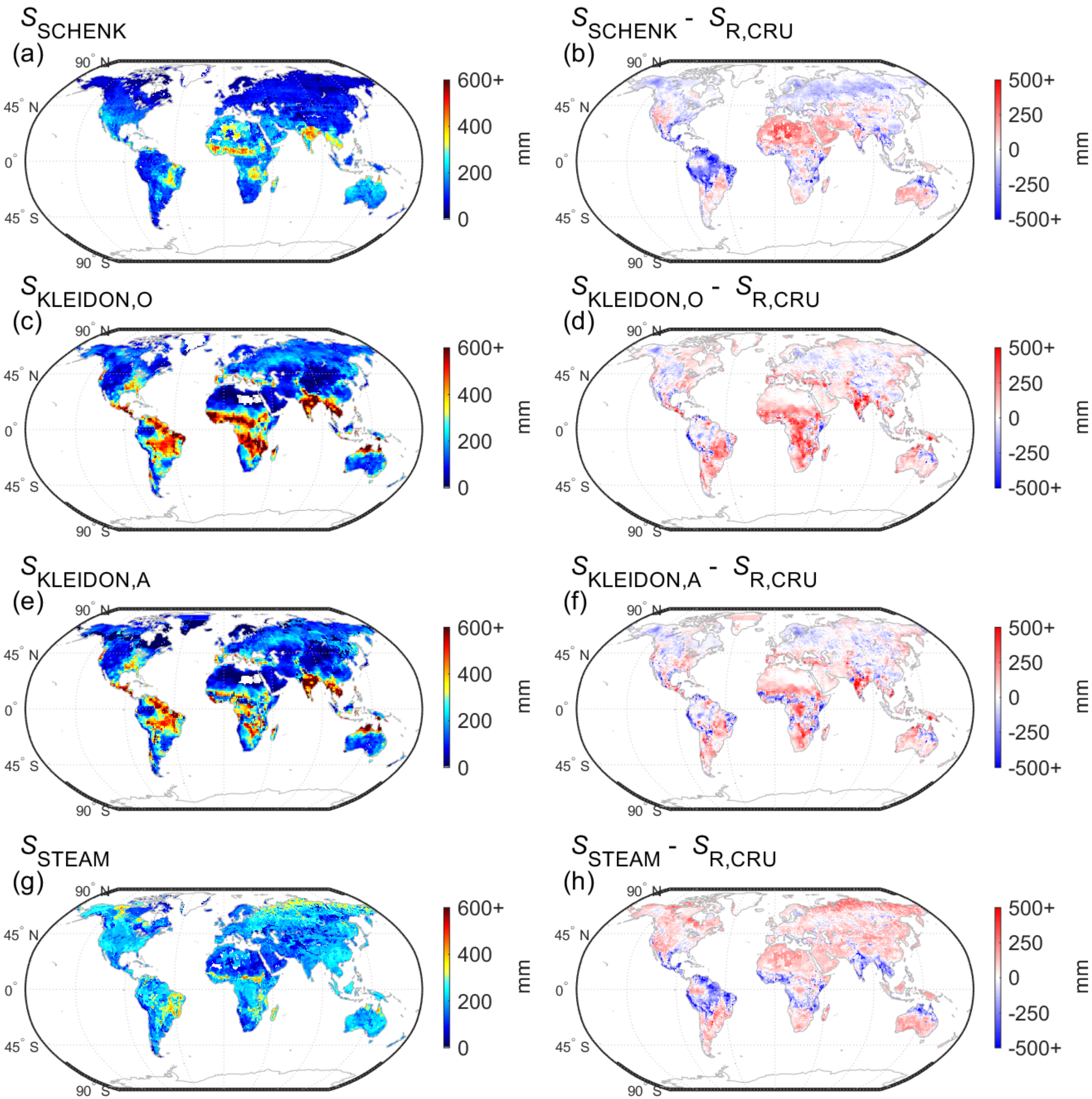
Results

$S_{R,CRU}$, 2003-2013



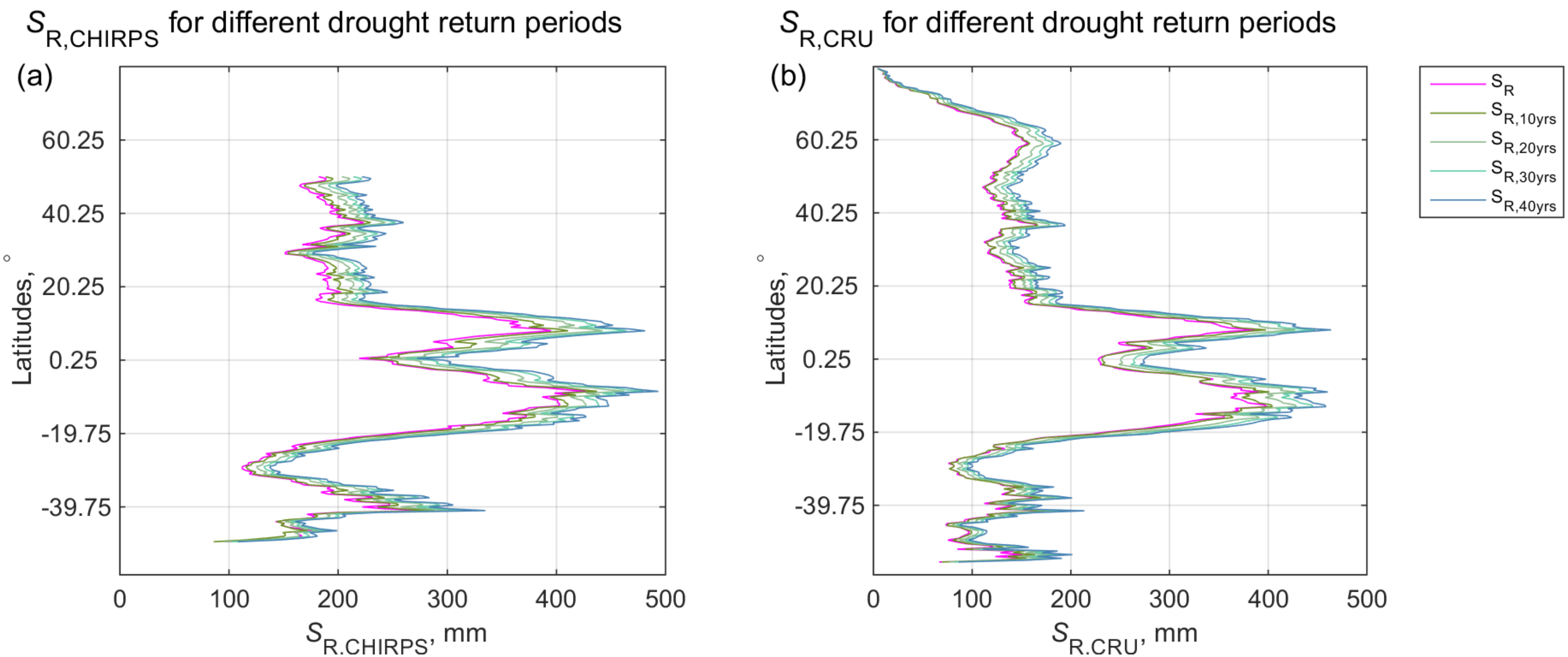
- S_R < 300 mm in most regions
- S_R > 300 mm in equatorial regions marked by seasonality

Comparison

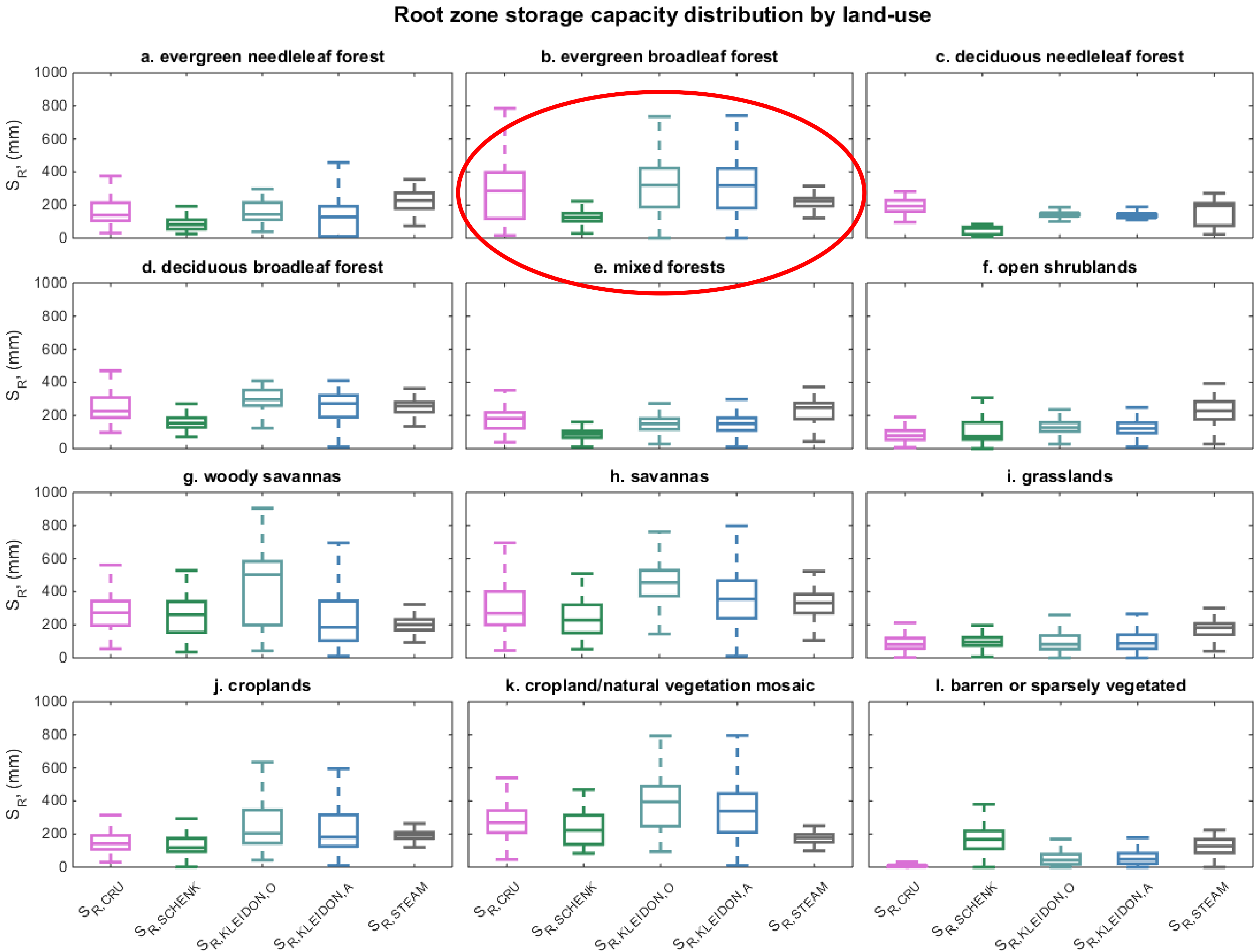


- Less variations in $S_{R,SCHENK}$, and $S_{R,STEAM}$
- $S_{R,SCHENK}$, and $S_{R,STEAM}$ both low in Amazon rainforest
- $S_{R,KLEIDON}$ often larger than $S_{R,CRU}$

Drought frequency analysis

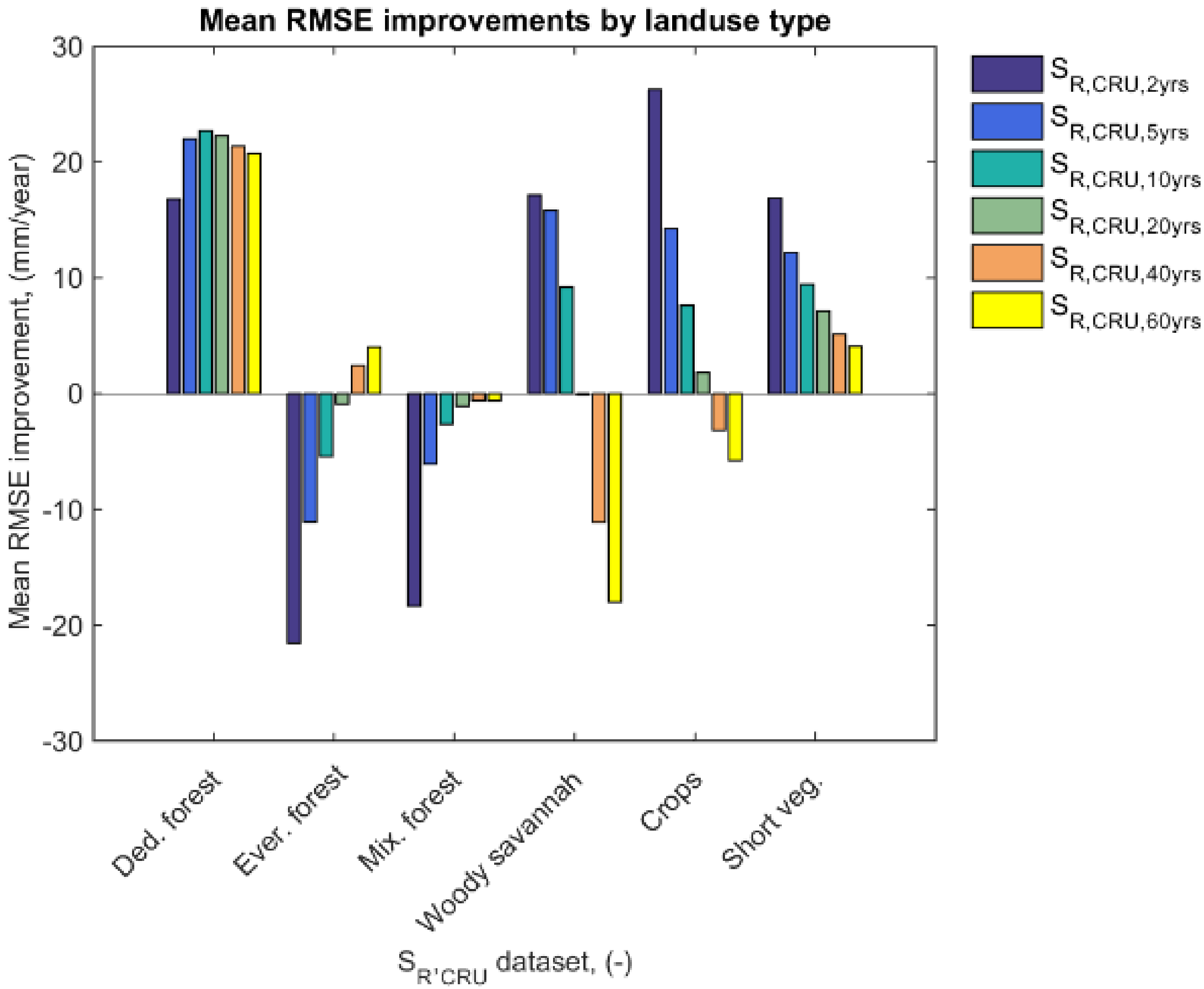


- The S_R:s for 2003-2012/2013 correspond to $S_{R,10yrs}$-$S_{R,20yrs}$

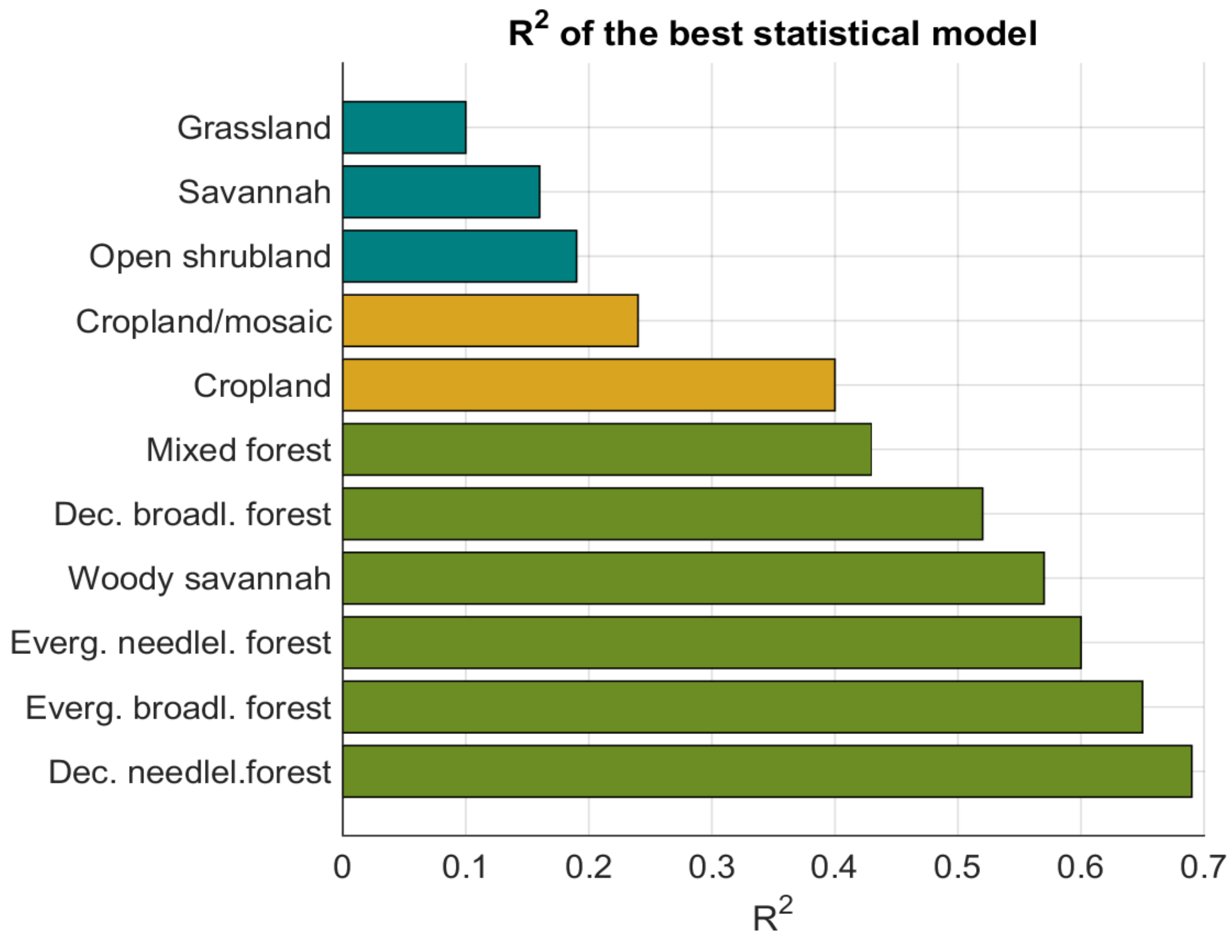


Root zone storage capacity distribution by land-use
a. evergreen needleleaf forest
b. evergreen broadleaf forest
c. deciduous needleleaf forest
d. deciduous broadleaf forest
e. mixed forests
f. open shrublands
g. woody savannas
h. savannas
i. grasslands
j. croplands
k. cropland/natural vegetation mosaic
l. barren or sparsely vegetated
S_R, (mm)
0
200
400
600
800
1000
S_R,CRU
S_R,SCHENK
S_R,KLEIDON,O
S_R,KLEIDON,A
S_R,STEAM

Vegetation takes risks



Correlation to climatic variables



Separating different evaporation fluxes

Earth Syst. Dynam., 5, 441–469, 2014
www.earth-syst-dynam.net/5/441/2014/
doi:10.5194/esd-5-441-2014

Earth System Dynamics
Open Access

Contrasting roles of interception and transpiration in the hydrological cycle – Part 1: Temporal characteristics over land

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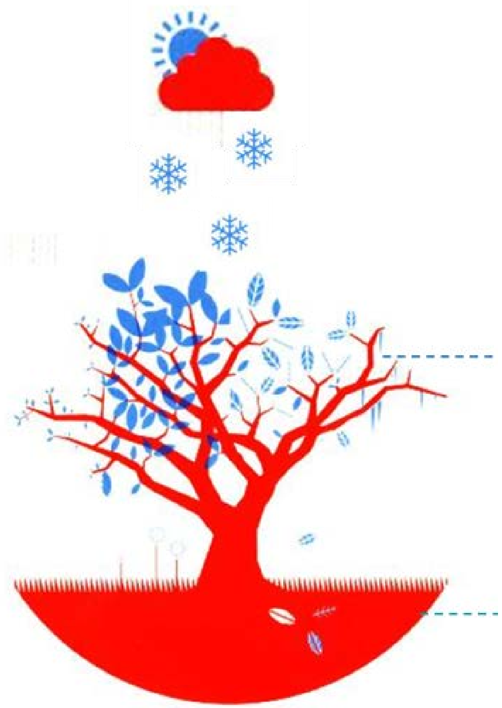
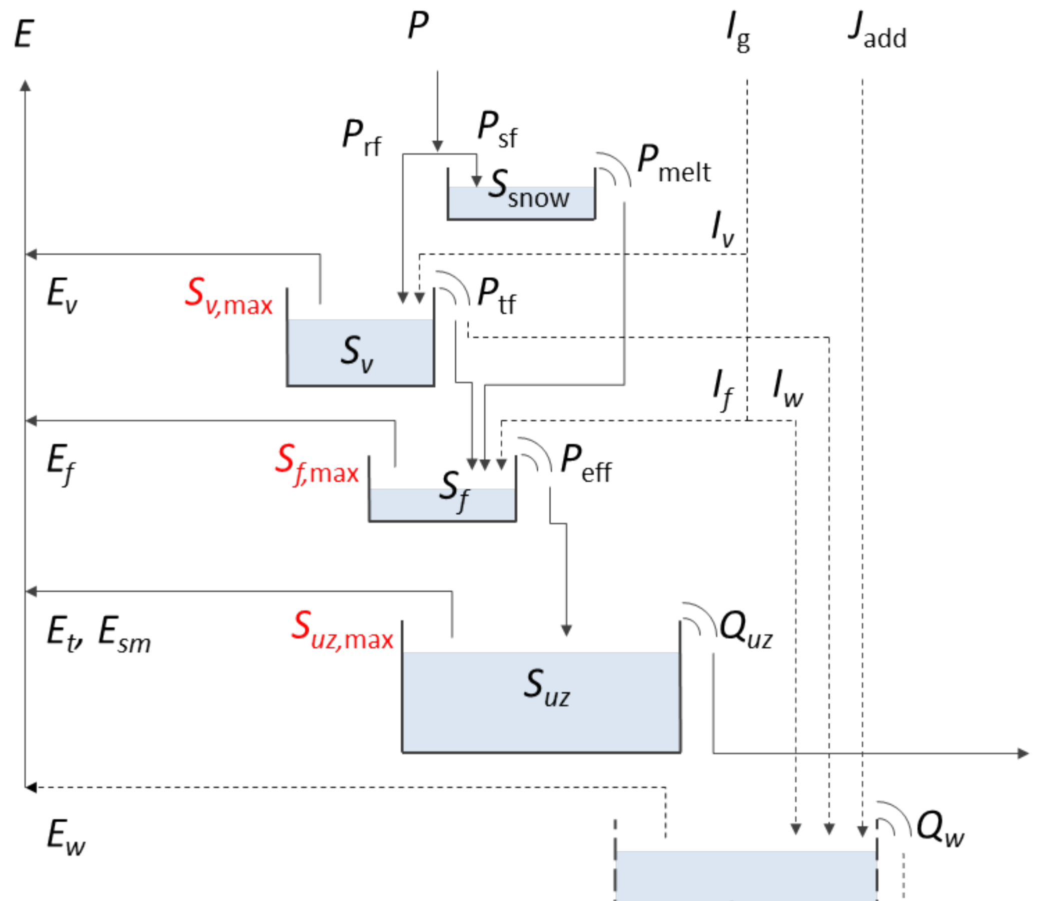
STEAM

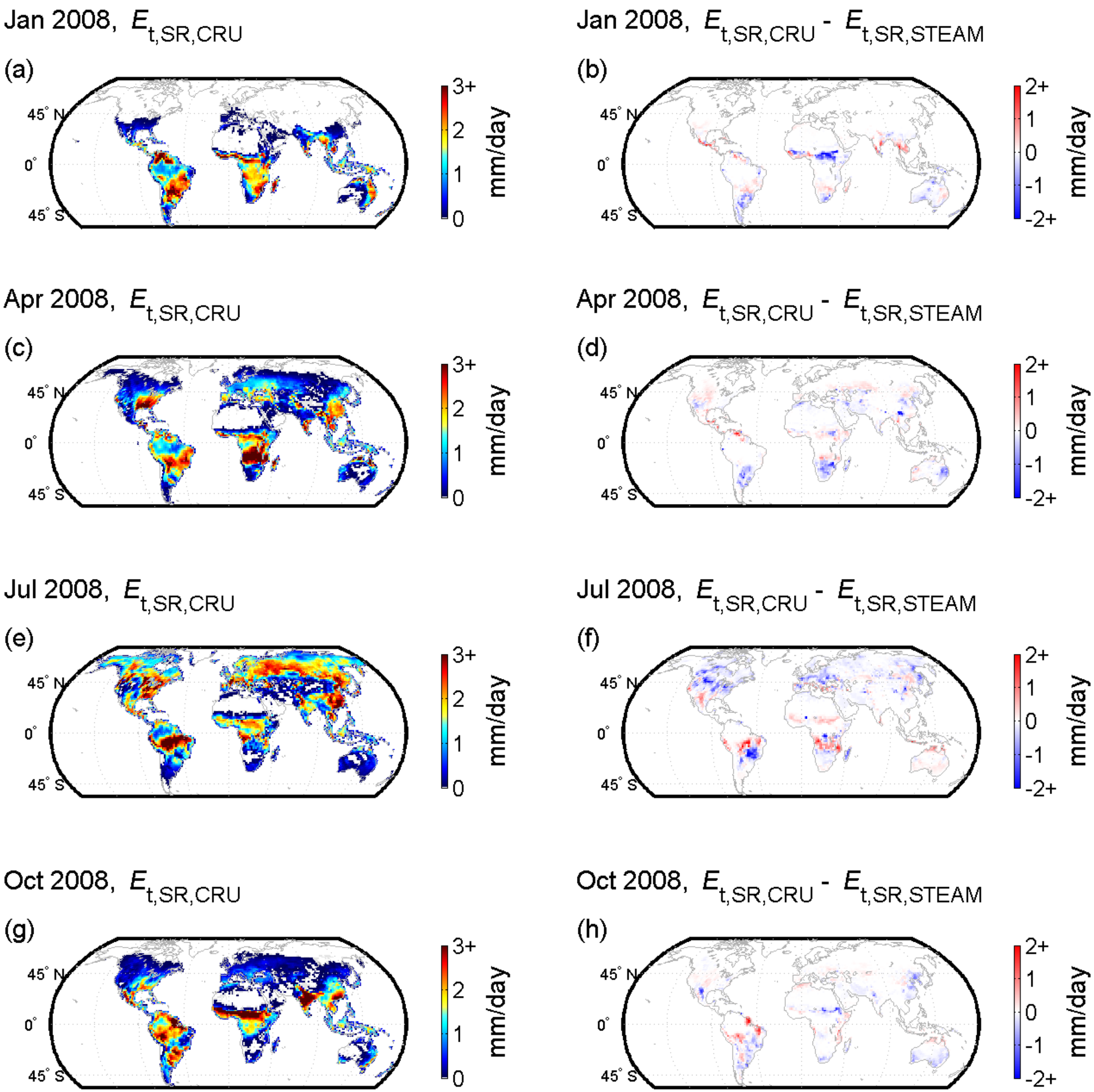




STEAM schematization
including stocks and fluxes

1.5° latitude x 1.5° longitude
3 hours time step
Land-use fraction representation

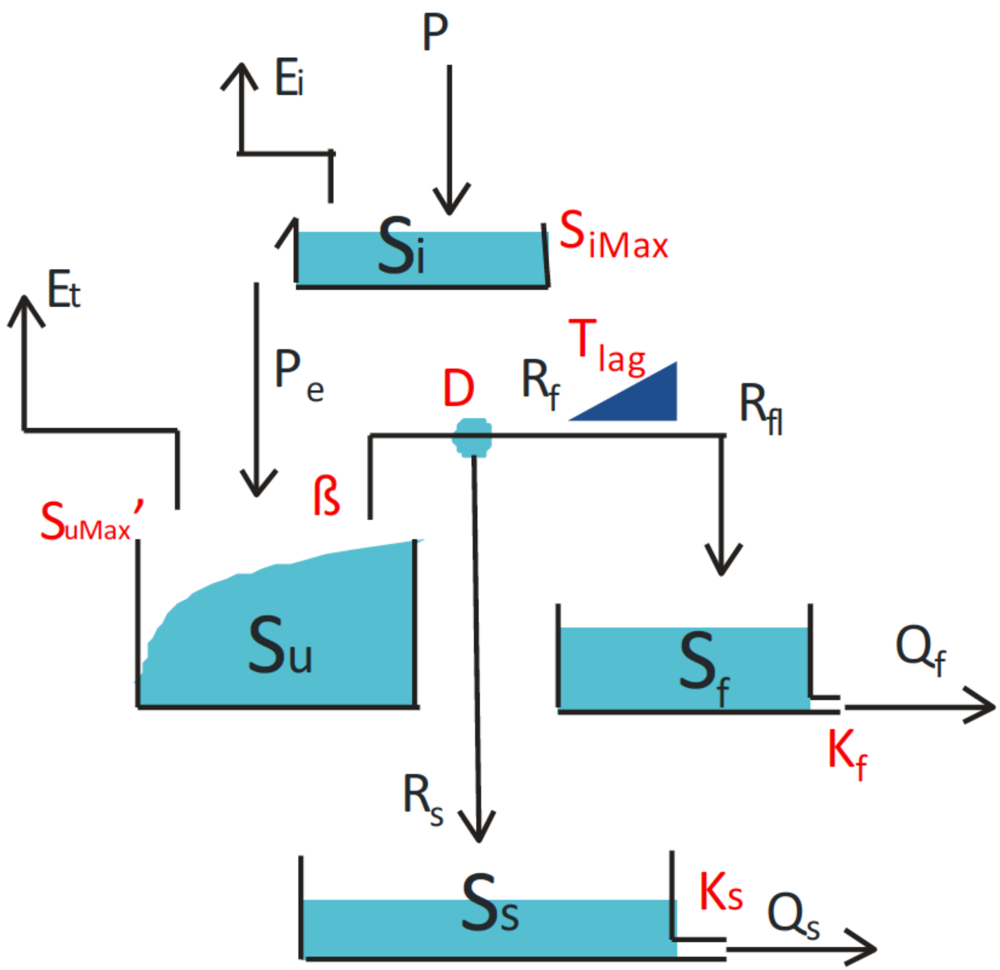
Wang-Erlandsson et al. (2014), ESD.



Input S_R into STEAM

- Largest differences in transpiration during dry periods
- Minor differences in boreal regions in E_T despite S_R differences

Models are alive !



Root zone storage is the result of co-evolution

Root zone storage is essentially the result of an ecosystem interacting with the climate

References:

Gao, H., Hrachowitz, M., Schymanski, S. J., Fenicia, F., Sriwongsitanon, N. and Savenije, H. H. G.: Climate controls how ecosystems size the root zone storage capacity at catchment scale, Geophys. Res. Lett., n/a–n/a, doi:10.1002/2014GL061668, 2014.

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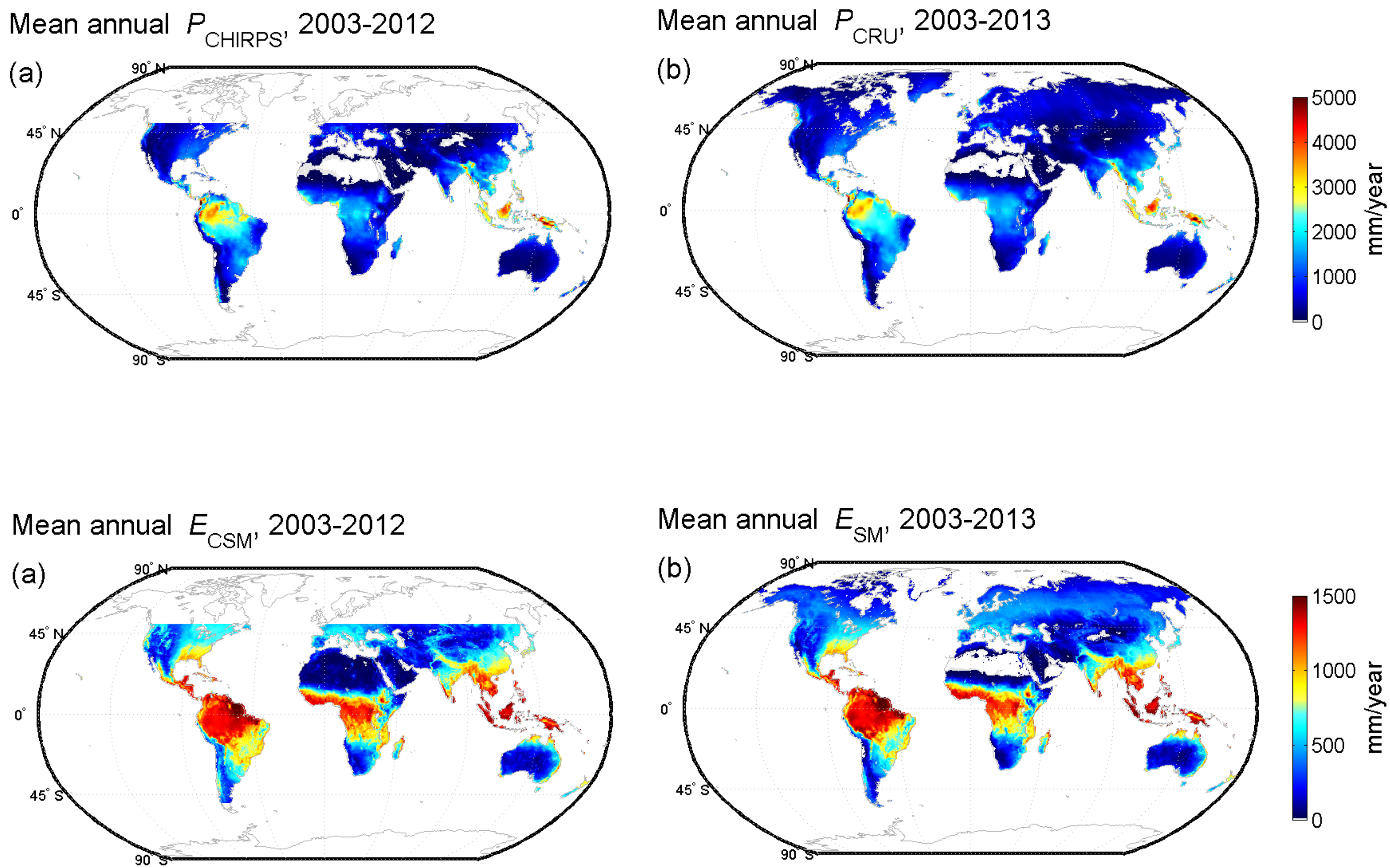
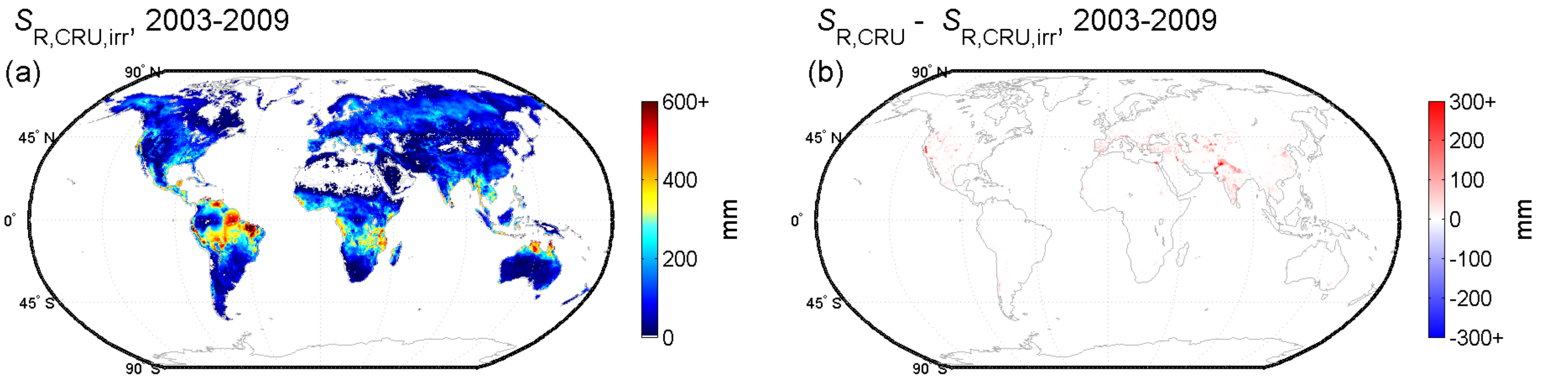


Mean annual P_CHIRPS, 2003-2012
(a)
90° N
45° N
0°
45° S
90° S
Mean annual P_CRU, 2003-2013
(b)
90° N
45° N
0°
45° S
90° S
5000
4000
3000
2000
1000
0
mm/year
Mean annual E_CSM, 2003-2012
(a)
90° N
45° N
0°
45° S
90° S
Mean annual E_SM, 2003-2013
(b)
90° N
45° N
0°
45° S
90° S
1500
1000
500
0
mm/year



$S_{R,CRU,irr}$, 2003-2009
(a)
90° N
45° N
0°
45° S
90° S
600+
400
200
0
mm
$S_{R,CRU}$ - $S_{R,CRU,irr}$, 2003-2009
(b)
90° N
45° N
0°
45° S
90° S
300+
200
100
0
-100
-200
-300+
mm