Using Earth Observation Data of Vegetation to improve global hydrological Simulations

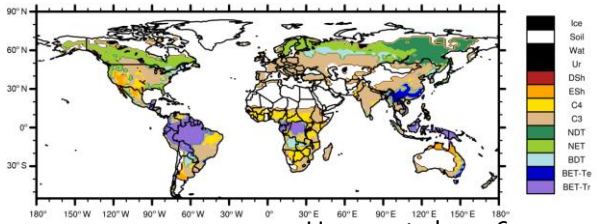
Tina Trautmann[1,2,3]

Sujan Koirala[1], Nuno Carvalhais[1,4], Andreas Güntner[3,5] , Hyungjun Kim[6] & Martin Jung[1]

[1]*Max-Planck-Institute for Biogeochemistry, Jena, Germany*
[2]*International Max Planck Research School for Biogeochemical Cycles, Jena, Germany*
[3]*Potsdam University, Potsdam, Germany*
[4]*Universidade Nova de Lisboa, Caparica, Portugal*
[5]*German Research Center for Geoscience, Potsdam, Germany*
[6]*University of Tokyo, Tokyo, Japan*

Background

Despite the important role of vegetation, vegetation properties in global Hydrological Models

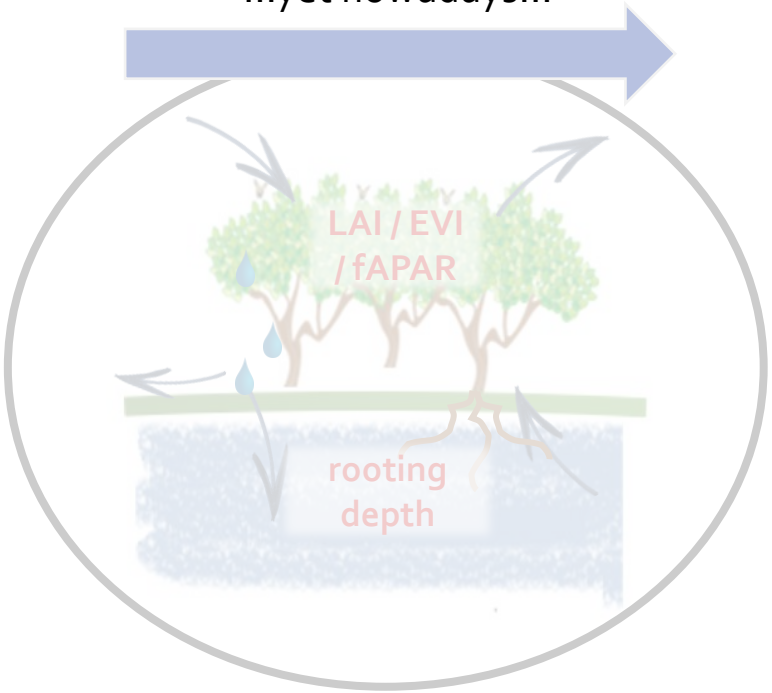


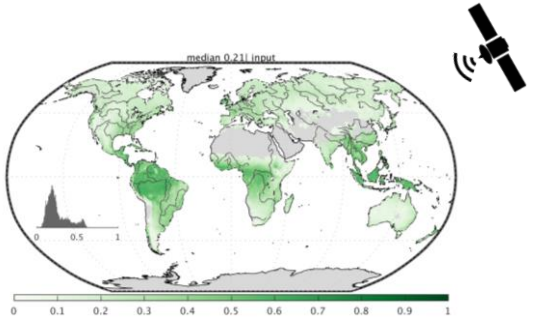
Harper et al. 2016

are **traditionally** defined as…

- uniform values
- Look-Up-Tables for PFT / land cover classes

…yet nowadays…





can be **continuously described based on Earth Observation data,** such as

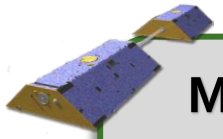
- LAI / fPAR / EVI time series
- treecover
- rooting depth

.. so the question is:

What is the value of including additional, observation based information on vegetation?

Tina Trautmann | MPI-BGC Jena | ttraut@bgc-jena.mpg.de

Methods



Multi-Criteria Calibration

of each experiment

Hydrological Model

with vegetation dependent parameters

Comparison

of optimized experiments at different scales

- Terrestrial Water Storage TWS (GRACE)
- Evapotranspiration ET (FLUXCOM)
- gridcell Runoff Q (GRUN)
- Soil Moisture SM (ESA CCI)

Experiments

different ways to paramterize vegetation using EO based data

Focus on 3 aspects

1) transpiration demand by vegetation
2) soil water supply for transpiration via roots
3) influence of vegetation on infiltration & runoff generation

What is the value of including additional, observation based information on vegetation?

Tina Trautmann | MPI-BGC Jena | ttraut@bgc-jena.mpg.de

Experiments

Focus on 3 aspects = **3 vegetation dependent parameters**

1) transpiration demand by vegetation
   → defined by the grid's vegetation fraction (p.vegFr)
   = function of **EVI** (daily mean seasonal cycle)

2) soil water supply for transpiration via roots
   → plant available soil water (p.smax)
   = function of **rooting depth / soil water capacity data**
   - maximum rooting depth (Fan et al. 2017)
   - effective rooting depth (Yang et al. 2016)
   - soil water capacity (Wang-Erlandsson et al. 2016)
   - available water capacity (Tian et al. 2019)

3) influence of vegetation on infiltration & runoff generation
   → runoff/infiltration coefficient (p.berg)
   = linear function of vegetation fraction

→ iteratively increase spatial information

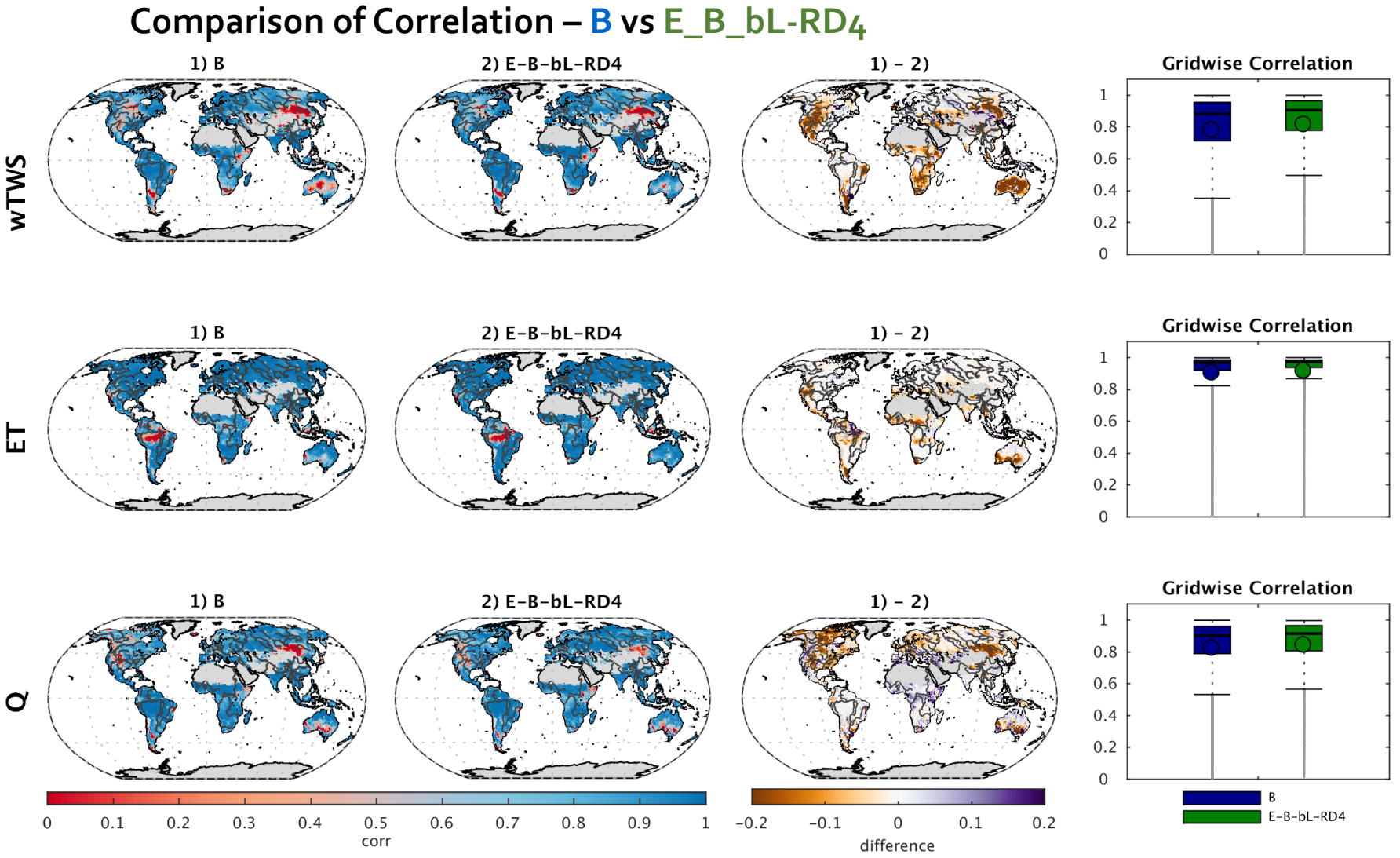
→ compare the optimized **baseline experiment (B)** against the **vegetation experiment (E-B-bL-RD4)**

- **no** spatial information
- parameters are optimized as global uniform values

- parameters are defined as function of **spatially varying data**
- optimization of (constant) scaling factors

Tina Trautmann | MPI-BGC Jena | ttraut@bgc-jena.mpg.de

Results



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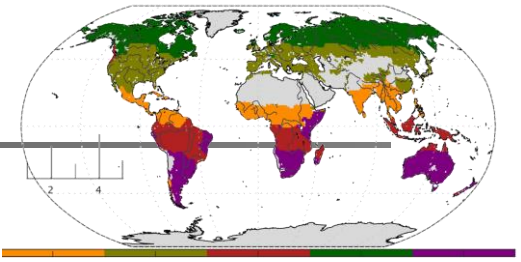
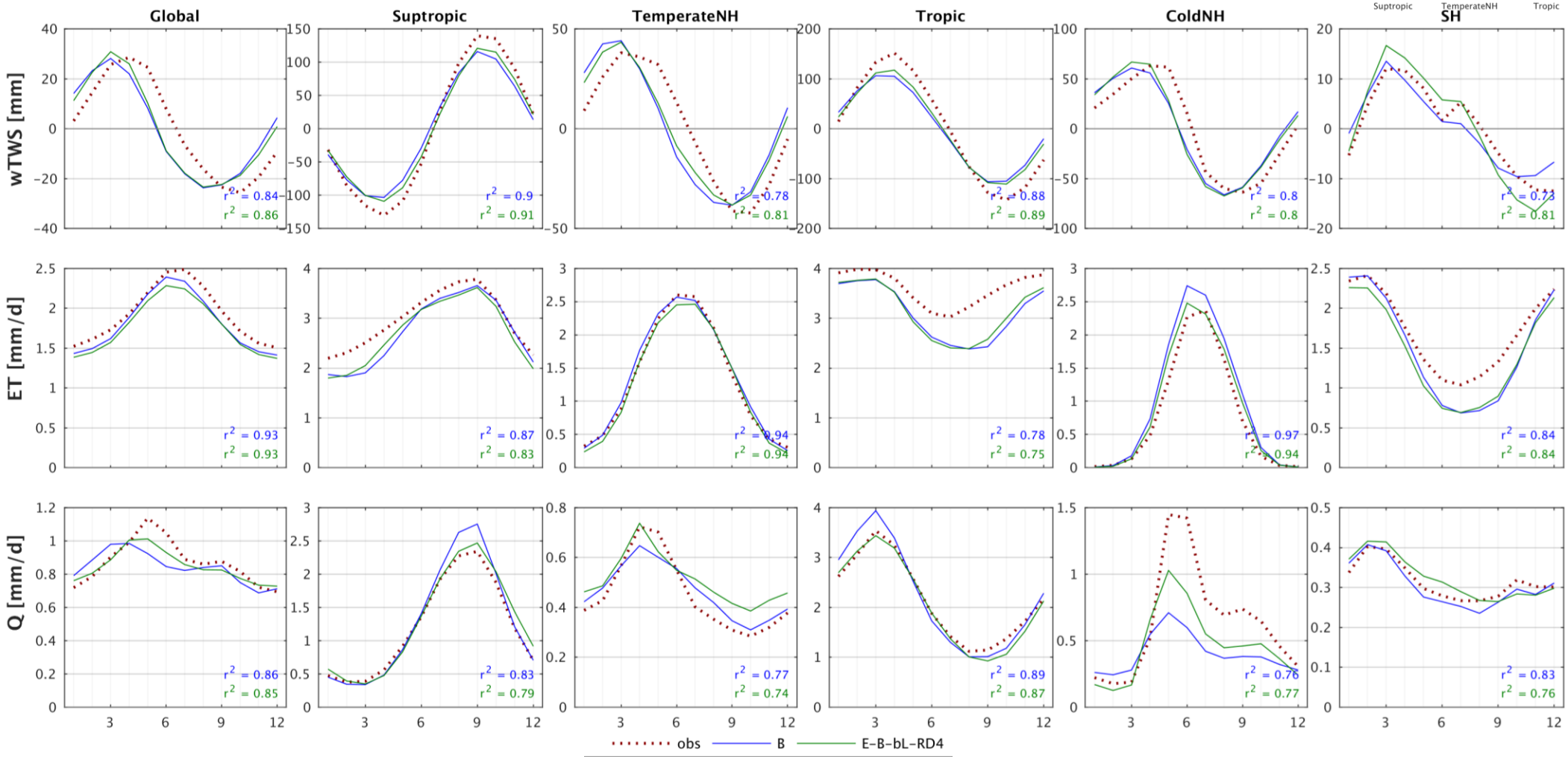
Results



Comparison of the Mean Seasonal Cycle – observations vs B vs E-B-bL-RD4



Tina Trautmann | MPI-BGC Jena | ttraut@bgc-jena.mpg.de

Summary

- already the baseline model **B** with calibrated, yet global uniform parameters can reproduce observed pattern reasonable well
- including vegetation related information further improves model results
  - TWS in (semi-)arid regions
  - ET in tropics & semi-arid regions
  - Q in temperate and cold regions
  - esp. rooting depth/soil water capacity showed high potential to improve TWS & Q simulations

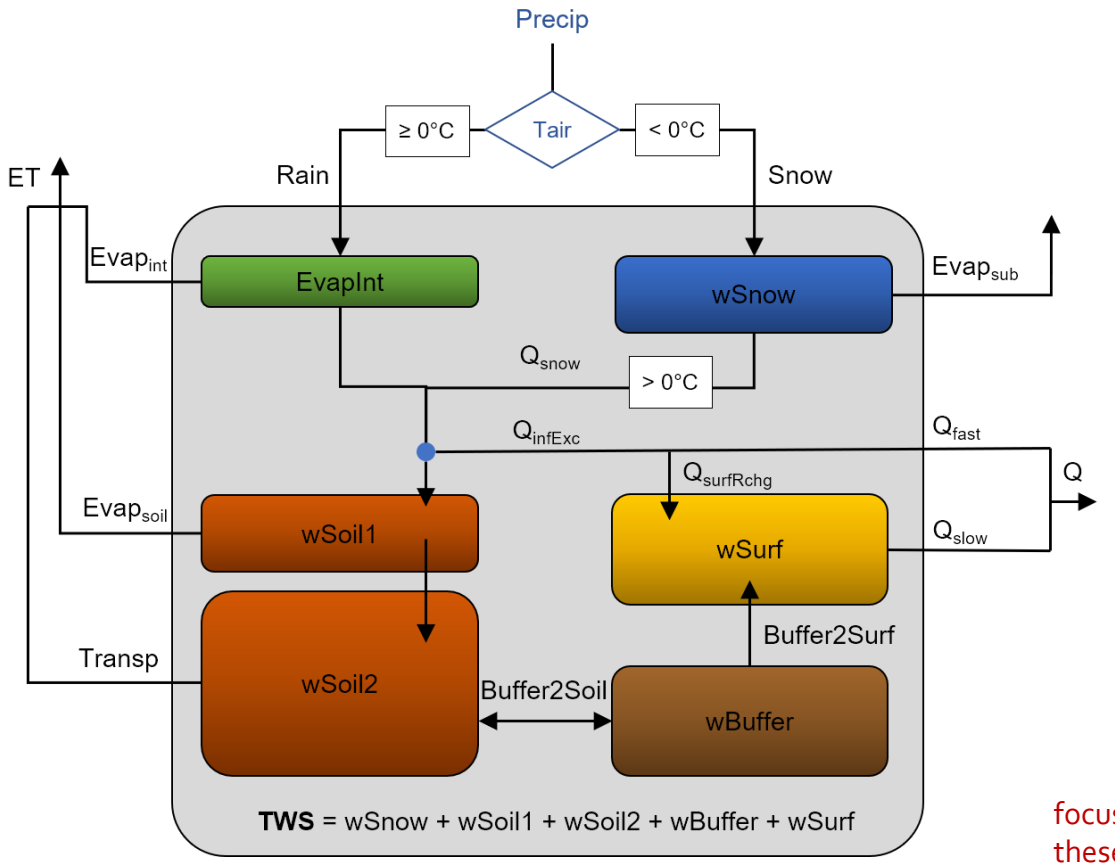
Outlook

- evaluation against independent discharge measurements of large catchments

Tina Trautmann | MPI-BGC Jena | ttraut@bgc-jena.mpg.de

more Details…

Methods – Hydrological Model



- 12 calibration parameter (+5 snow)

- snow component
- 2-layer soil storage
- infiltration & runoff generation depending on soil moisture (Bergström 1995)
- buffer storage
- linear ‚surface' water storage
- evapotranspiration (ET) depending on soil moisture and potential ET, partitioned into bare soil evaporation and plant transpiration

focus on these parameter

parameter	description
transpiration	
p.vegFr	vegetation fraction of the grid cell
p.pInt	interception coefficient
p.alphaVeg	transpiration coefficient (α in Priestley-Taylor formula)
p.k2	fraction of lower soil layer available for transpiration
infiltration / runoff generation	
p.smaxVeg	maximum plant available water content
p.berg	shape parameter of runoff-infiltration curve

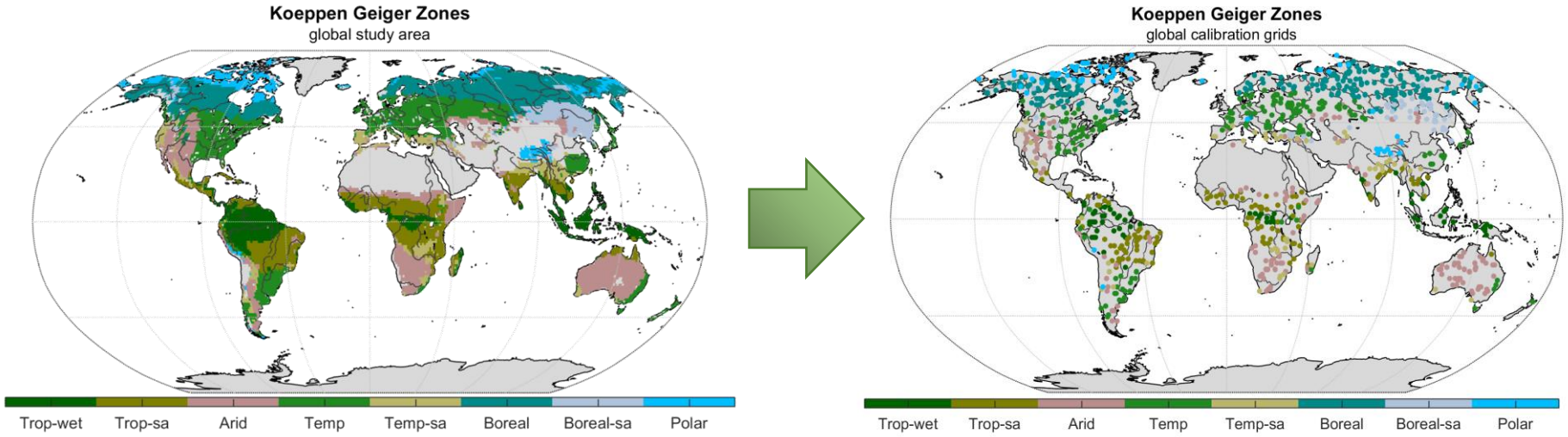
Data

	Product	Space	Time	Data Uncertainty	Reference
Calibration					
TWS	GRACE mascon RL06	global	monthly	with product	Wiese et al. 2018
wSnow	GlobSnow v2	Northern Hemisphere	daily	~35 mm, uncertain > 100mm	Takala et al, 2011
wSoil	ESA CCI SM v4.04	~global	daily	with product	Dorigo et al. 2017
Evap	FLUXCOM ensemble	global	daily	with product	Jung et al. 2018
Q	GRUN v1	global	monthly	~ 50 %	Ghiggi et al. 2019
Forcing					
Precip	GPCP 1dd v1.2	global	daily		Huffmann et al. 2000
Tair	CRUNCEP v6	global	daily		Vivoy et al. 2015
Rn	CERES Ed4A	global	daily		Wielicki et al. 1996

Tina Trautmann | MPI-BGC Jena | ttraut@bgc-jena.mpg.de

Methods – Multi-Criteria Calibration

- **Calibration for a spatial subset**
  - 8 % of total area
  - stratified random sampling among Koeppen-Geiger zones



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Methods – Multi-Criteria Calibration

- **Constraining multiple variables of the water balance**

GlobSnow ESA CCI

$$\frac{d}{dt}\underbrace{\text{wSnow} + \text{wSoil} + (\text{wGW} + \text{wSurf})}_{\text{TWS}} = (\text{Rain} + \text{Snow}) - \underbrace{\text{EvapSub} - \text{EvapInt} - \text{EvapSoil} - \text{Transp}}_{\text{ET}} - \underbrace{\text{Qfast} - \text{Qslow}}_{\text{Q}}$$

optimized snow parameter from Trautmann et al. 2018

TWS ← GRACE

ET ← FLUXCOM

Q ← GRUN

- algorithm: Covariance Matrix Evolution Strategy (CMAES) (Hansen & Kern 2004)
- aim: find parameter set with minimum total costs

based on Pearson correlation

based on uncertainty weighted Nash-Sutcliff Efficency

$$\text{total cost} = \underbrace{\text{SMcost}}_{\text{monthly timeseries}} + \underbrace{\text{TWScost} + \text{SWEcost} + \text{ETcost}}_{\text{monthly timeseries}} + \underbrace{\text{Qcost}}_{\text{mean seasonal cycle}}$$

$$\text{cost} = \frac{\sum \frac{(x_{obs} - x_{mod})^2}{\sigma^2}}{\sum \frac{(x_{obs} - \bar{x}_{obs})^2}{\sigma^2}}$$

x_{obs} … observed variable
x_{mod} … modelled variable
σ … uncertainty of x_{obs}

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