Modification of global precipitation data for enhanced hydrologic modeling of tropical montane watersheds

Michael Strauch, Rohini Kumar, Stephanie Eisner, Mark Mulligan, Julia Reinhardt, William Santini, Tobias Vetter, Jan Friesen

http://cdn.phys.org/newman/gfx/news/hires/2013/tropicalclou.jpg

INTERNATIONAL SOIL AND WATER ASSESSMENT TOOL CONFERENCE

SWAT 2017

June 28 – 30 | Warsaw, Poland

SESSION B4:
SWAT REVIEW PAPERS AND
LARGE SCALE APPLICATIONS

HELMHOLTZ
CENTRE FOR
ENVIRONMENTAL
RESEARCH – UFZ

coordinated by

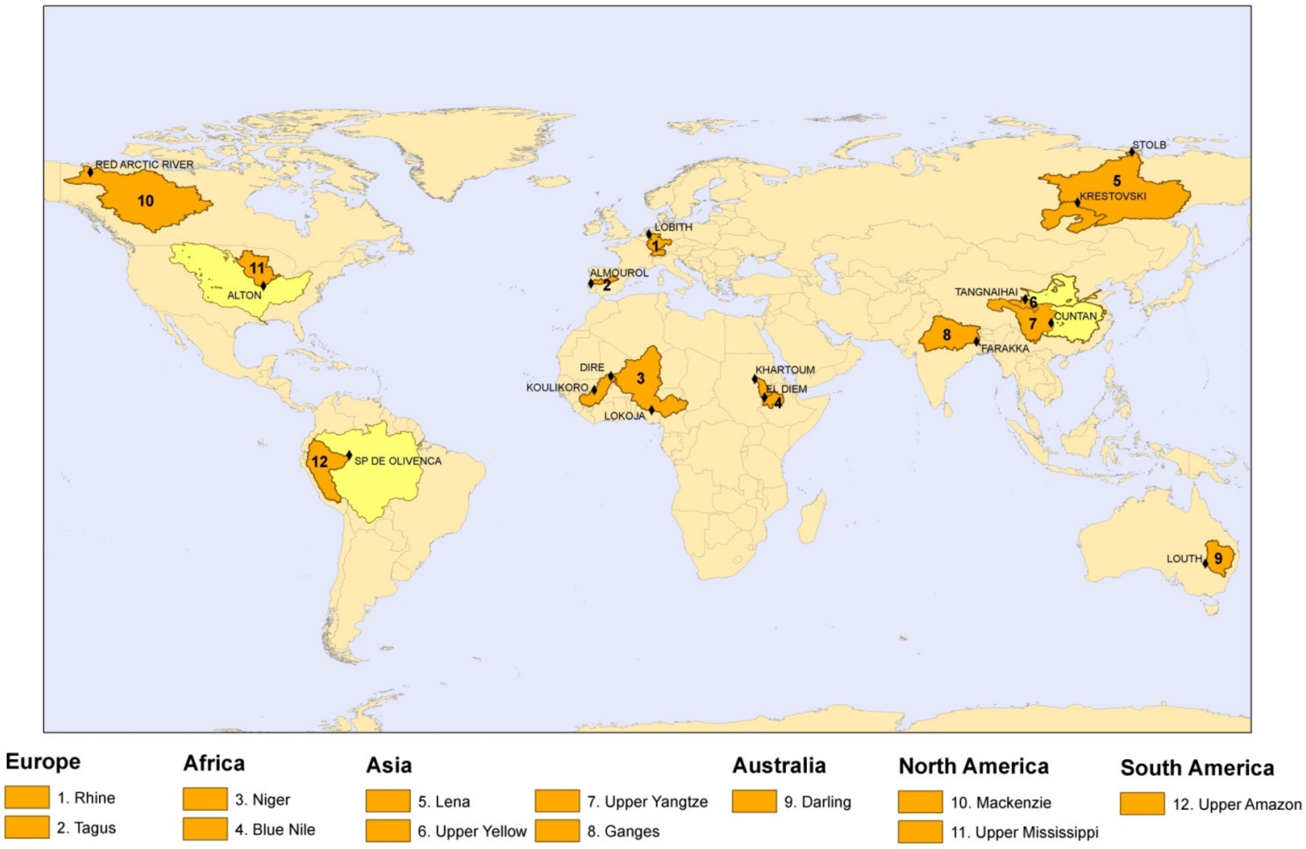
MOTIVATION

ISI-MIP

Inter-Sectoral Impact Model Integration and Intercomparison Project (Phase 2a)

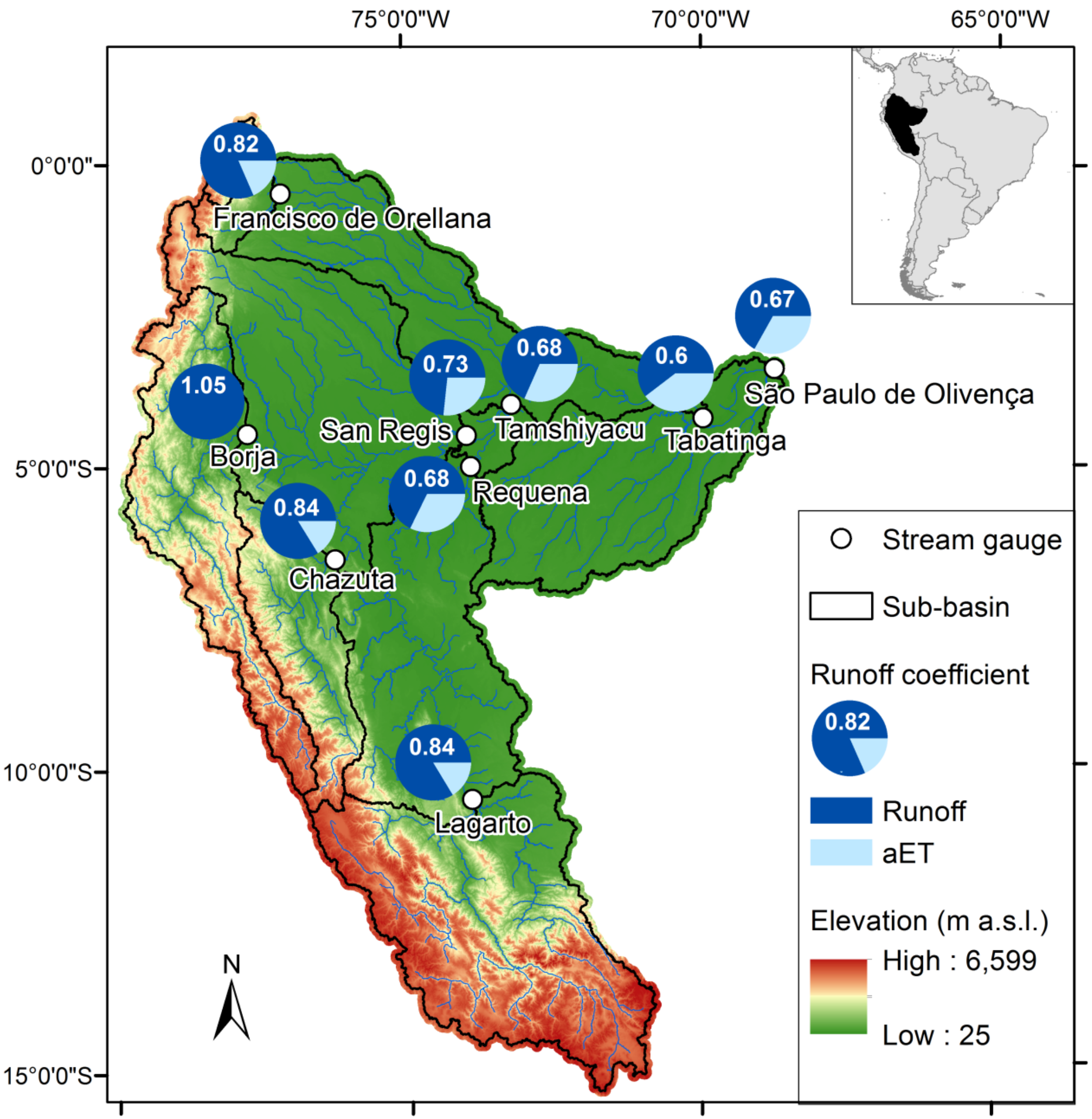
- **community-driven** modelling effort
- bringing together **impact models** across sectors and scales
- to create consistent and comprehensive projections of the impacts of **different levels of global warming**

Focus regions for catchment-scale hydrological modelling



MOTIVATION

Upper Amazon Basin



- $1.02\ 10^6$ km²
- large elevation range
- Amazonian lowlands: tropical rain forest
- Andean region: montane forests, shrubland, grassland
- unreasonably high runoff coefficients (R / P) for montane subbasins

➢ errors in the data?

R: 5-10% (Filizola et al., 2009)

P: (WFDEI*) huge uncertainty!

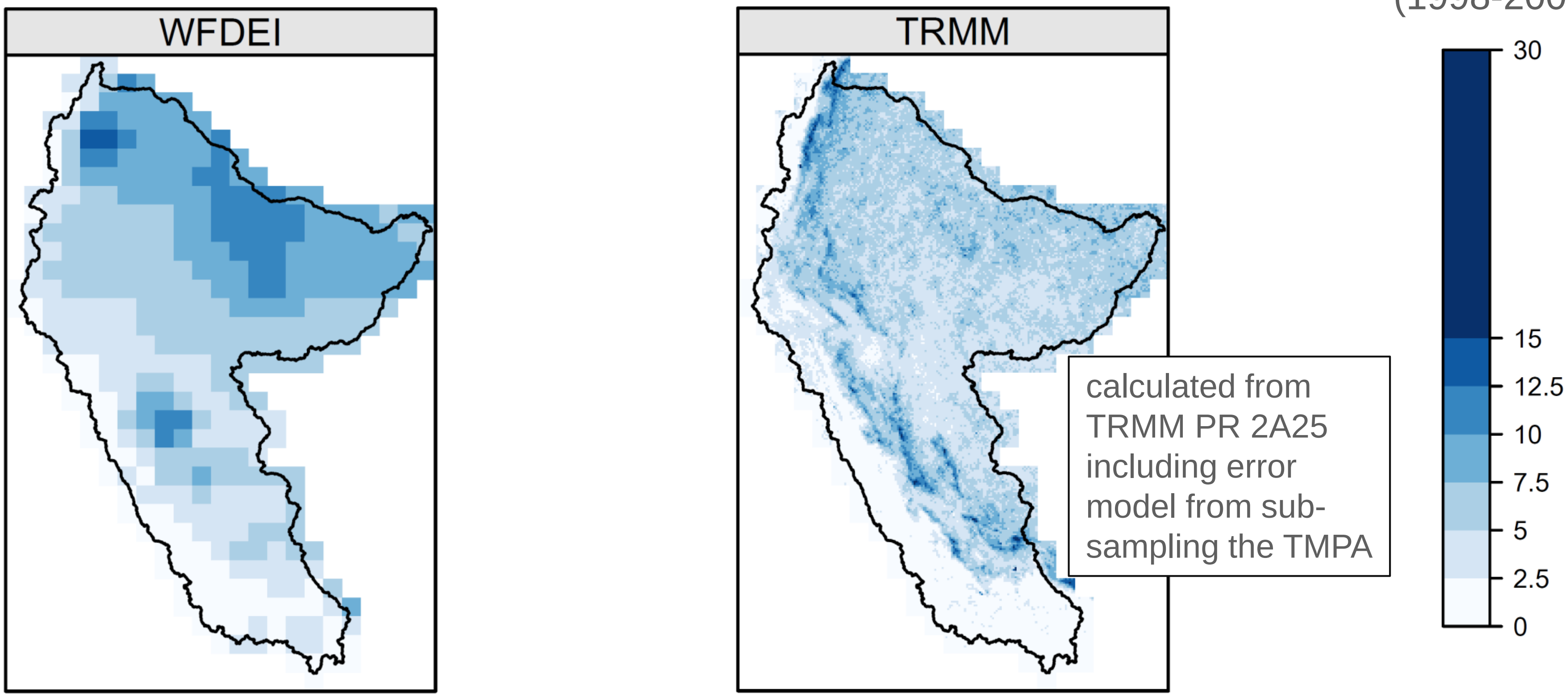
⇒ (1) complex terrain

⇒ (2) cloudwater interception

* WFDEI: WATCH Forcing Data methodology applied to ERA-Interim data (Weedon et al., 2014)

Problem 1: Complex terrain

Average daily precipitation (mm)
(1998-2008)



- Weedon et al. (2014)
- global 0.5° grid (used in ISIMIP2)
- daily resolution
- basin-wide annual mean (2132 mm) is close to ground-based HYBAM product (2143 mm)

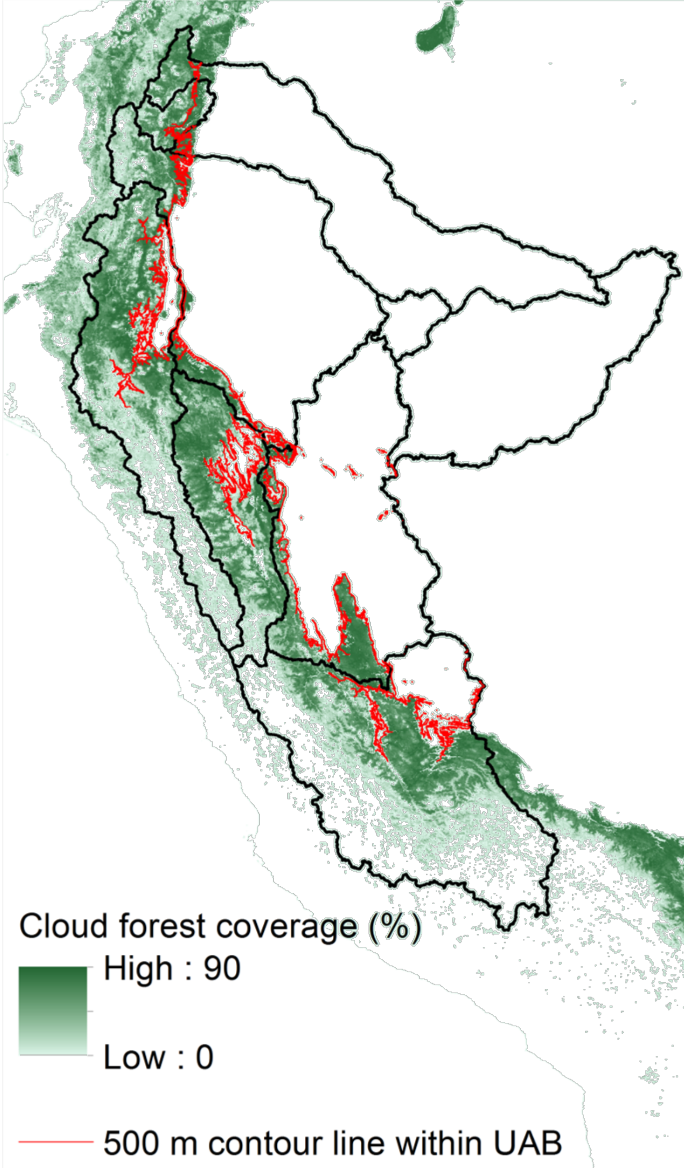
- Nesbitt and Anders (2009)
- 0.05° grid between 36° N/S
- climatology (only average rates!)
- annual mean too low (1707 mm), but gradients are resolved more reasonably

Problem 2: Cloud water interception in tropical montane cloud forests

Cloud water interception (CWI) is an unaccounted source of water

CWI varies strongly and can reach values of more than 1000 mm yr^{-1} (e.g. Bruijnzeel et al., 2011)

Clark et al. (2014) calculated a cloud water contribution of 316 ± 116 mm (or 11 ± 4%) to annual streamflow for the Kosñipata catchment in the eastern Peruvian Andes using an isotopic mixing model

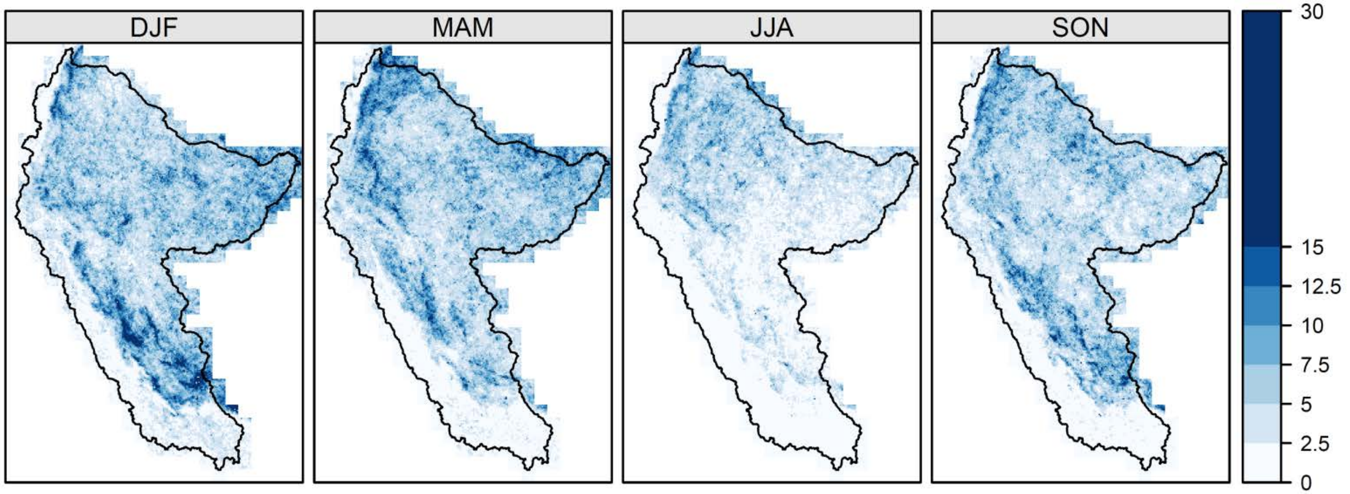


Source: Mulligan (2010)

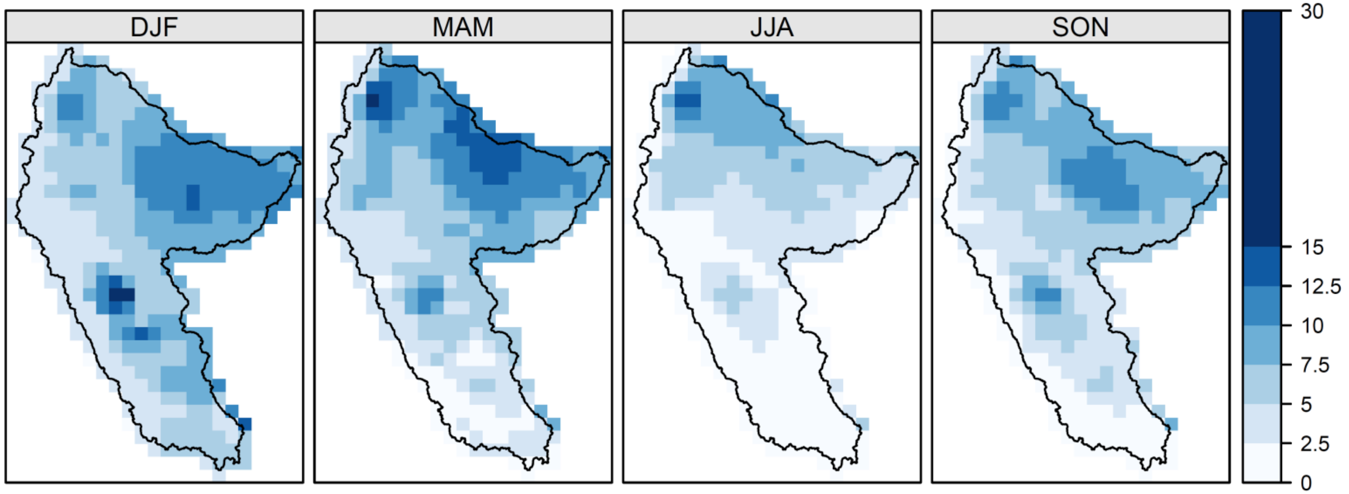
METHODS Adjustment of WFDEI data

(1) TRMM correction

TRMM average precipitation rate (mm/day in 1998-2008), 0.05° grid



WFDEI average precipitation rate (mm/day in 1998-2008), 0.5° grid



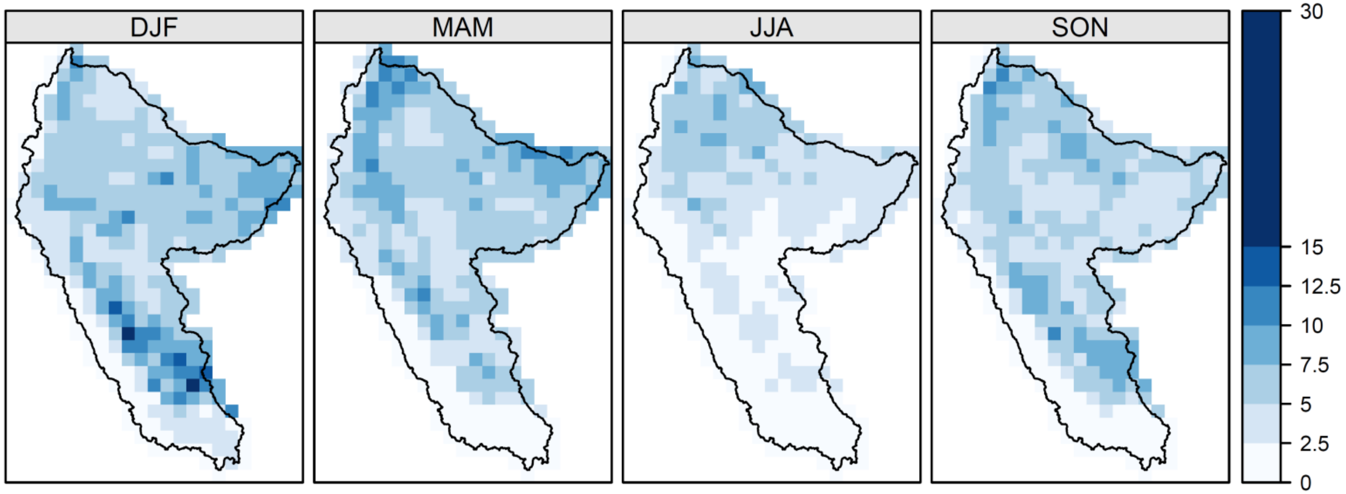
METHODS

Adjustment of WFDEI data

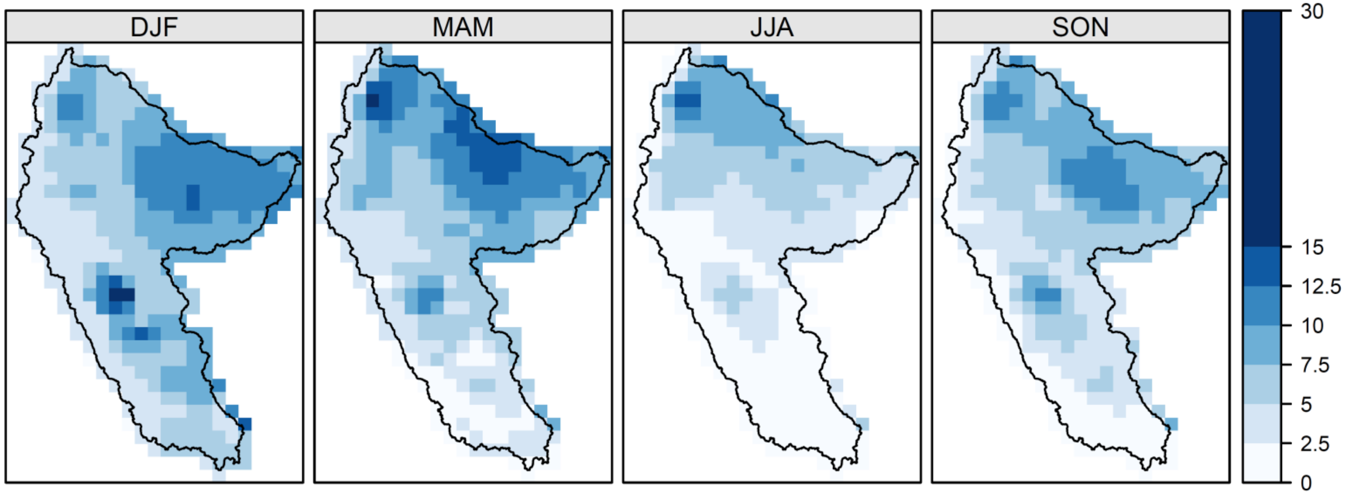
(1) TRMM correction

Step 1:
Aggregate TRMM to 0.5°

TRMM average precipitation rate (mm/day in 1998-2008), 0.5° grid



WFDEI average precipitation rate (mm/day in 1998-2008), 0.5° grid



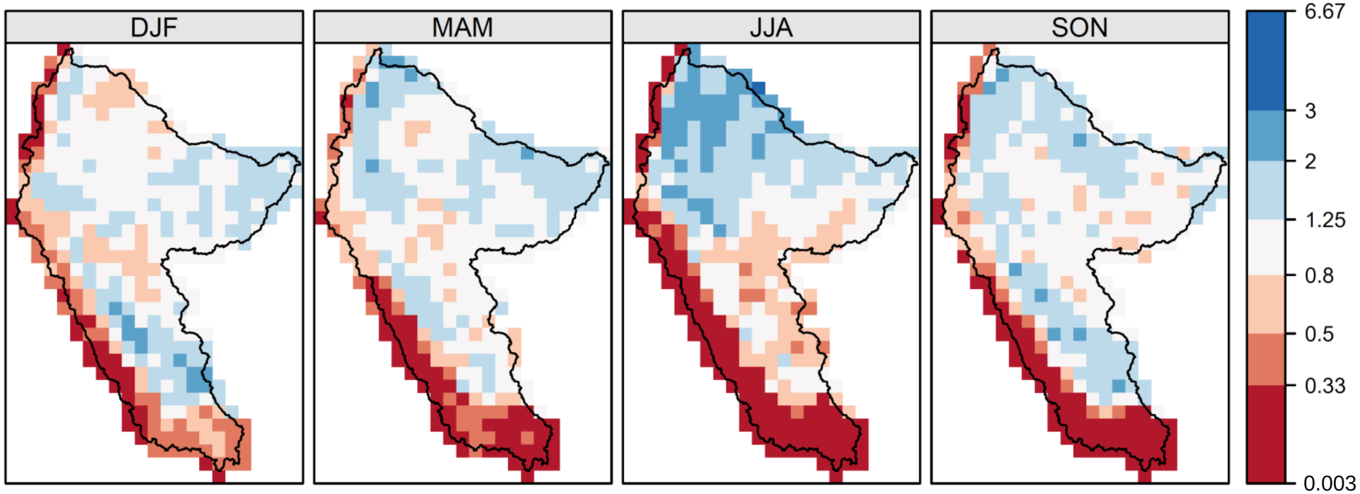
METHODS

Adjustment of WFDEI data

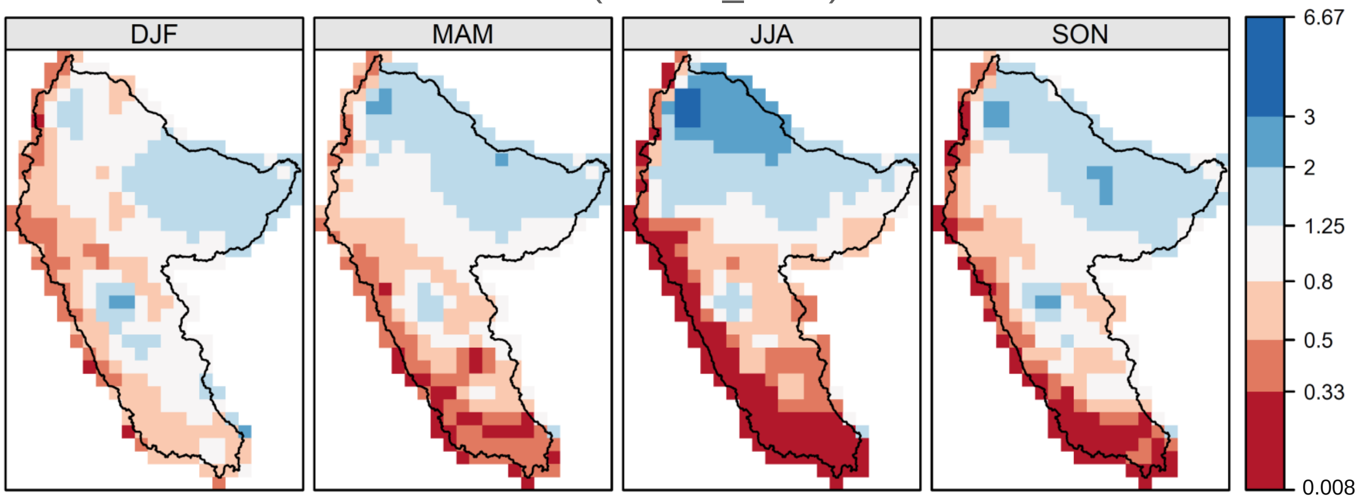
(1) TRMM correction

Step 2:
Divide grid cell values by basin average

TRMM normalized (TRMM_norm)



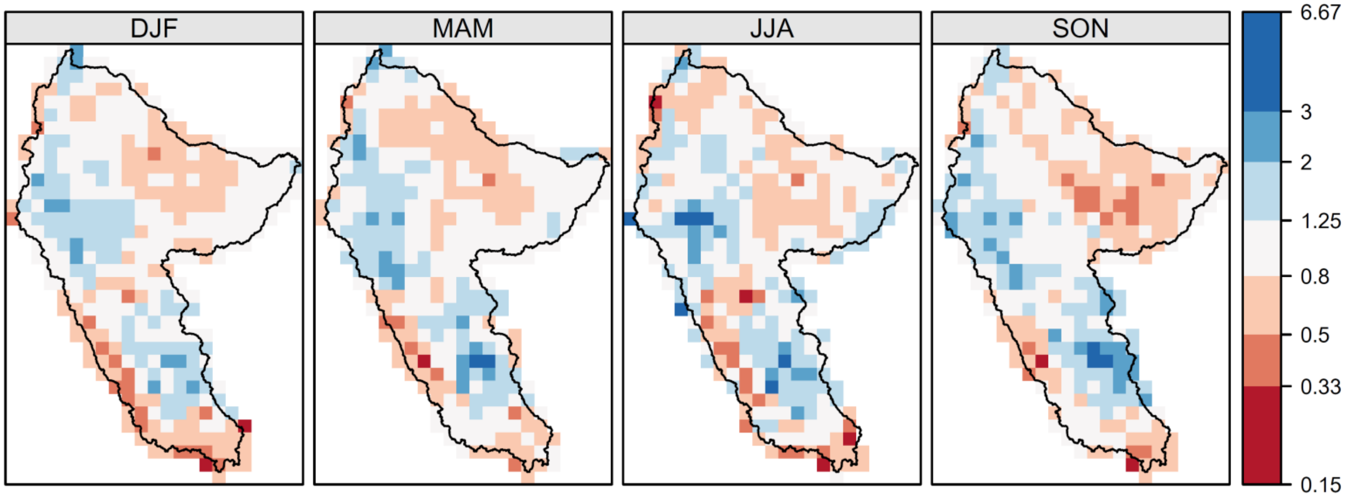
WFDEI normalized (WFDEI_norm)



METHODS Adjustment of WFDEI data

(1) TRMM correction

TRMM correction factors (α)



Step 3: $\alpha_{i,s} = \dfrac{\text{TRMM\_norm}_{i,s}}{\text{WFDEI\_norm}_{i,s}}$

i: individual 0.5° grid cell

s: season

t: day

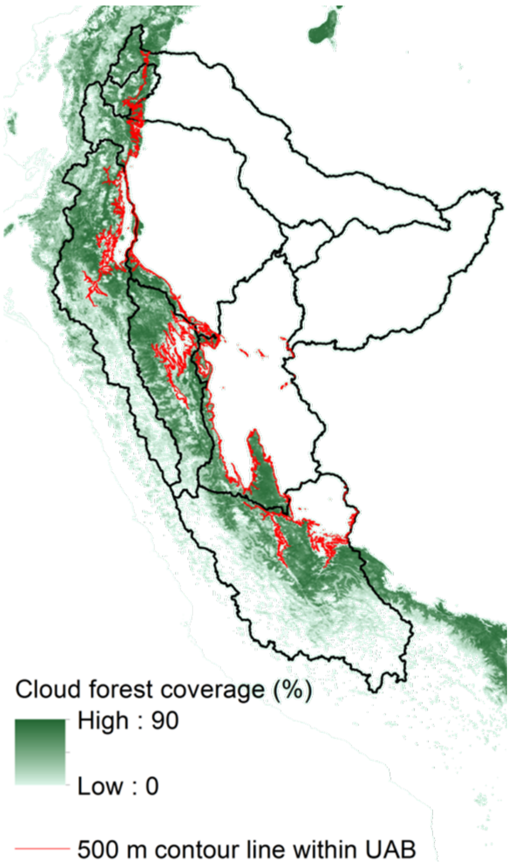
Step 4: $\text{WFDEI\_TRMM}_{i,s,t} = \alpha_{i,s}\text{WFDEI}_{i,s,t}$

METHODS

Adjustment of WFDEI data

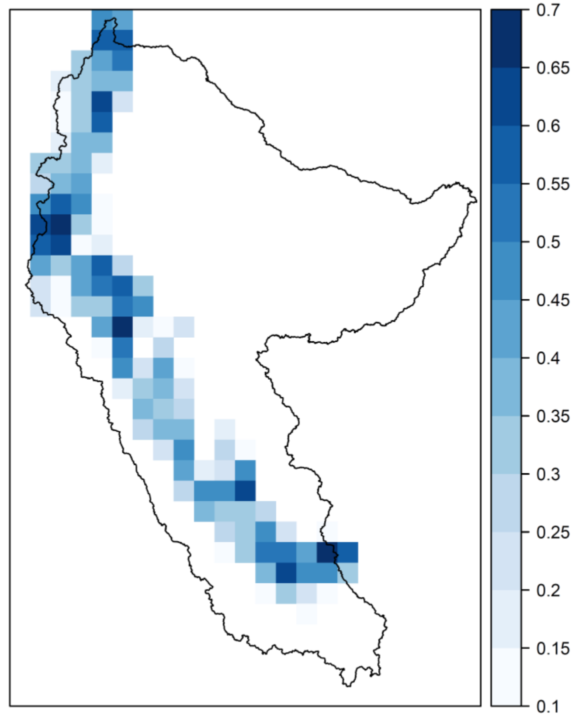
(2) CWI correction

Cloud forest coverage



Source: Mulligan (2010)

CWI correction factor 1: β



β = aggregated (0.5°) coverage as fraction between 0 and 1

CWI correction factor 2:

γ = fraction of CWI on precipitation (constant)

Two scenarios:

γ = 0.15, γ = 0.5

$$\text{WFDEI\_CWI}_{i,t} = (1 + \gamma\, \beta_i)\text{WFDEI}_{i,t}$$

$$\text{WFDEI\_TRMM\_CWI}_{i,t} = (1 + \gamma\, \beta_i)\text{WFDEI\_TRMM}_{i,t}$$

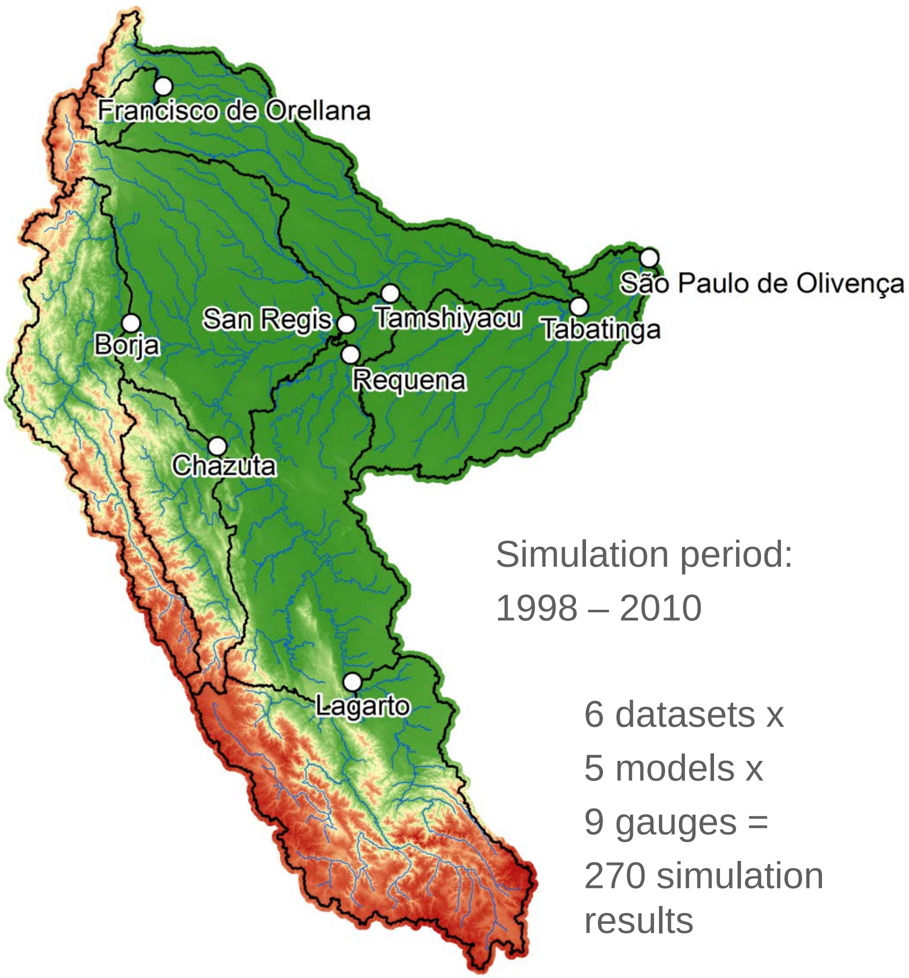
METHODS Test with hydrologic model ensemble

Input precipitation datasets:

- WFDEI
- WFDEI_CWI15
- WFDEI_CWI50
- WFDEI_TRMM
- WFDEI_TRMM_CWI15
- WFDEI_TRMM_CWI50

Hydrologic models (uncalibrated):

- HBV model (Bergström, 1995)
- mHM (Kumar et al., 2013; Samaniego et al., 2010)
- SWAT (Arnold et al., 1998; modified for tropical plant growth: Strauch and Volk, 2013)
- SWIM (Krysanova et al., 1998)
- WaterGAP3 (Verzano, 2009)



Simulation period:
1998 – 2010

6 datasets x
5 models x
9 gauges =
270 simulation results

Can we achieve better model performance with adjusted precipitation?

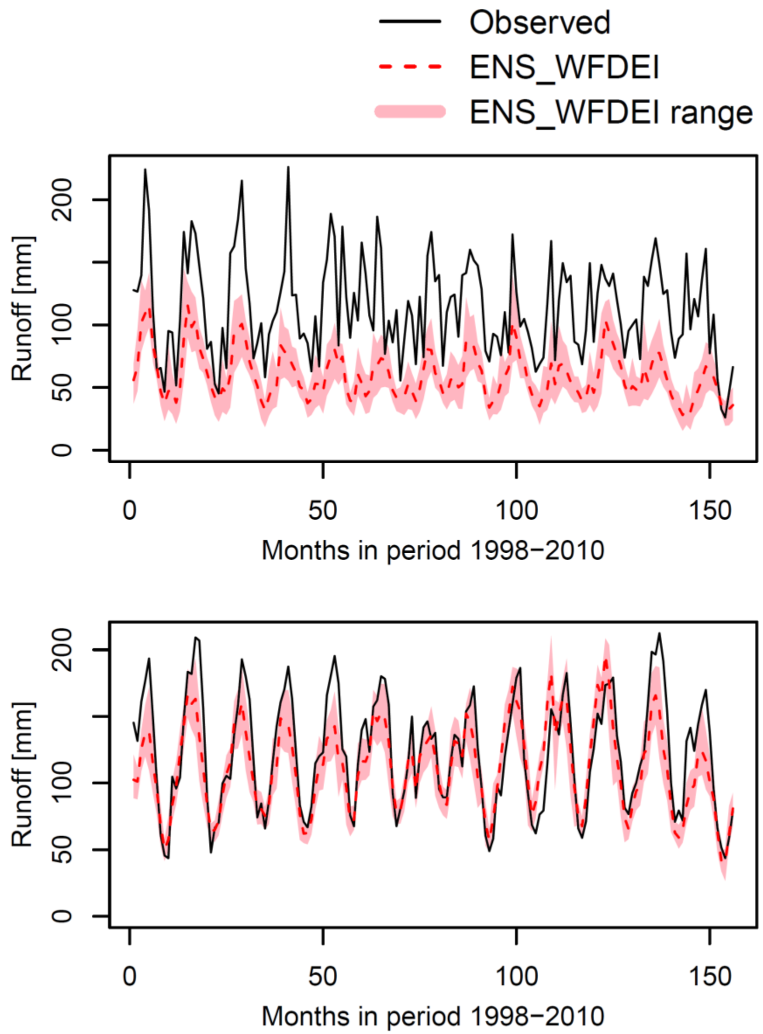
RESULTS

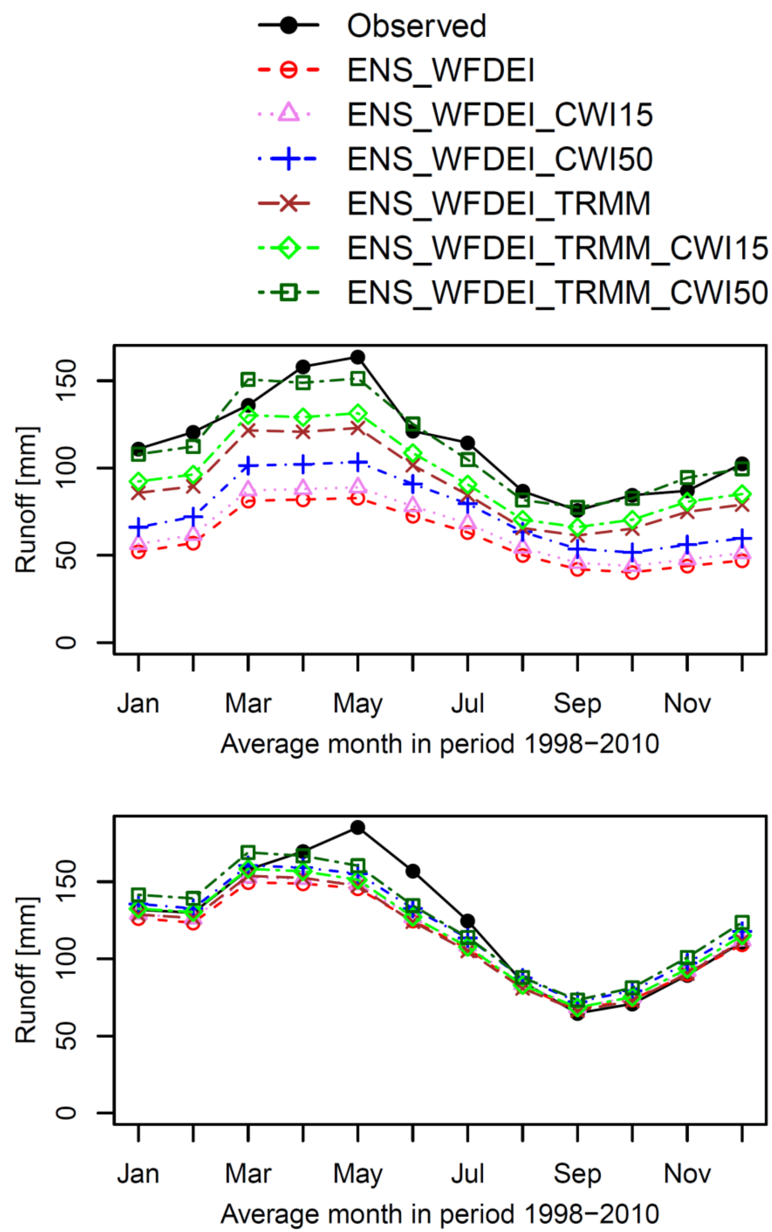
Simulations using adjusted precipitation

Simulations using WFDEI precipitation

Borja

São Paulo de Olivença





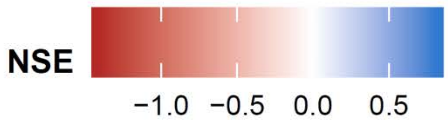
RESULTS

Nash-Sutcliffe efficiency (NSE) for the ensemble mean

	WFDEI	WFDEI_CWI15	WFDEI_CWI50	WFDEI_TRMM	WFDEI_TRMM_CWI15	WFDEI_TRMM_CWI50
Average (all gauges)	0.11	0.26	0.50	0.45	0.53	0.55
São Paulo de Olivença	0.67	0.70	0.74	0.71	0.74	0.76
Tabatinga	0.73	0.72	0.65	0.72	0.66	0.41
Tamshiyacu	0.58	0.65	0.77	0.80	0.79	0.66
San Regis	0.32	0.45	0.66	0.75	0.77	0.65
Requena	0.62	0.68	0.78	0.84	0.84	0.76
Lagarto	0.06	0.12	0.29	0.55	0.61	0.72
Borja	−1.43	−1.10	−0.46	0.16	0.34	0.53
Chazuta	0.10	0.29	0.59	0.66	0.64	0.32
Francisco de Orellana	−0.64	−0.14	0.45	−1.17	−0.62	0.13

Amazonian lowland

Andean region



CONCLUSIONS

Unrealistically high R/P coefficients point to errors in the data

…assuming stationarity of long-term water storages, e.g. glaciers!

Our approach to adjust daily precipitation data…

…is simple but plausible, accounting for complex terrain gradients and/or cloud water interception (but not for temporal dynamics!)

…is based on freely available tropics-wide data

…generally **increased model performance** in the UAB (but differently across gauges)

…should be transferable to other tropical montane regions

Climatic Change (2017) 141:547–560
DOI 10.1007/s10584-016-1706-1

CrossMark

Adjustment of global precipitation data for enhanced hydrologic modeling of tropical Andean watersheds

Michael Strauch[1] · Rohini Kumar[2] · Stephanie Eisner[3] · Mark Mulligan[4] · Julia Reinhardt[5] · William Santini[6,7] · Tobias Vetter[5] · Jan Friesen[8]

REFERENCES

Arnold, J.G., Srinivasan, R., Muttiah, R., Williams, J., 1998. Large area hydrologic modeling and assessment part I: Model development. Journal of the American Water Resources Association, 34: 73-89.

Bergström, S., 1995. The HBV model. In: Singh, V.P. (Ed.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO., pp. 443-476.

Bruijnzeel, L.A., Mulligan, M., Scatena, F.N., 2011. Hydrometeorology of tropical montane cloud forests: emerging patterns. Hydrological Processes, 25(3): 465-498.

Clark, K.E. et al., 2014. The hydrological regime of a forested tropical Andean catchment. Hydrol. Earth Syst. Sci., 18(12): 5377-5397.

Kumar, R., Samaniego, L., Attinger, S., 2013. Implications of distributed hydrologic model parameterization on water fluxes at multiple scales and locations. Water Resources Research, 49(1): 360-379.

Krysanova, V., Müller-Wohlfeil, D.-I., Becker, A., 1998. Development and test of a spatially distributed hydrological/water quality model for mesoscale watersheds. Ecological Modelling, 106(2–3): 261-289.

Mulligan, M., 2010. Modelling the tropics-wide extent and distribution of cloud forests and cloud forest loss with implications for their conservation priority. In: Hamilton, L.S. (Ed.), Tropical Montane Cloud Forests. International hydrology series. Cambridge University Press, Cambridge and New York, pp. 14-38.

Nesbitt, S.W., Anders, A.M., 2009. Very high resolution precipitation climatologies from the Tropical Rainfall Measuring Mission precipitation radar. Geophysical Research Letters, 36(15): L15815.

Samaniego, L., Kumar, R., Attinger, S., 2010. Multiscale parameter regionalization of a grid-based hydrologic model at the mesoscale. Water Resources Research, 46(5): W05523.

Strauch, M., Volk, M., 2013. SWAT plant growth modification for improved modeling of perennial vegetation in the tropics. Ecological Modelling, 269: 98-112.

Verzano, K., 2009. Climate change impacts on flood related hydrological processes: Further development and application of a global scale hydrological model. PhD Thesis, University of Kassel, Kassel.

Weedon, G.P. et al., 2014. The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. Water Resources Research, 50(9): 7505-7514.

APPENDIX

EQUATIONS

- TRMM corrected precipitation

$$W_{T_{i,s,t}} = \alpha_{i,s} W_{i,s,t} \qquad \frac{\bar{T}_{i,s}}{\frac{1}{N}\sum_{i=1}^{N}\bar{T}_{i,s}} = \alpha_{i,s}\frac{\bar{W}_{i,s}}{\frac{1}{N}\sum_{i=1}^{N}\bar{W}_{i,s}}$$

- CWI corrected precipitation

$$W'_{i,t} = (1 + \gamma\,\beta_i) W_{i,t}$$

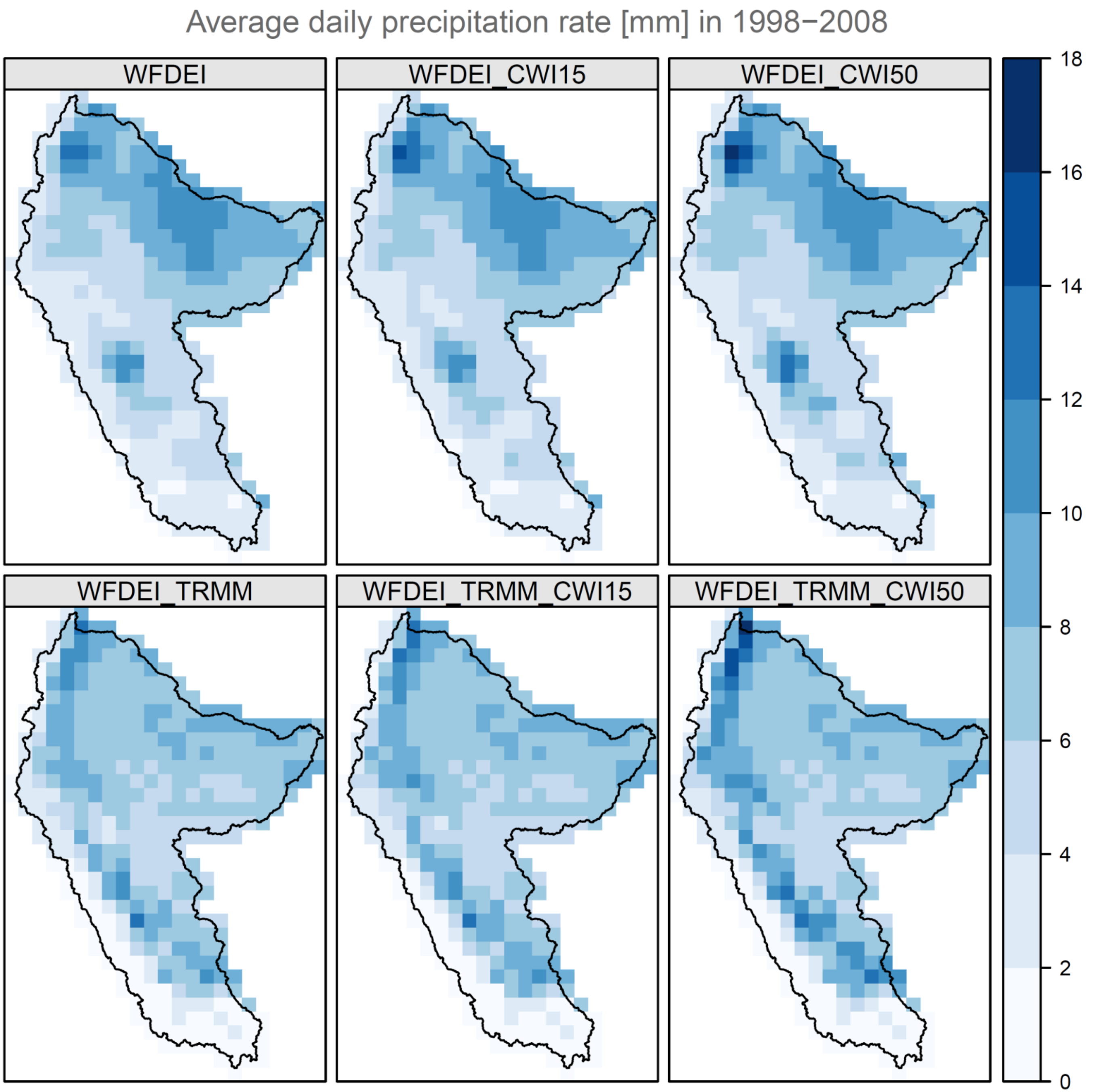
- TRMM and CWI corrected precipitation

$$W_{T\,i,t}' = (1 + \gamma\,\beta_i)\, W_{T\,i,t}$$

i: individual 0.5° grid cell
s: season (DJF, MAM, JJA, or SON)
t: day
α: TRMM correction factor
W: WFDEI precipitation
$\bar{T}$: average daily precipitation rate (mm) of TRMM
$\bar{W}$: average daily precipitation rate (mm) of WFDEI
N: total number of all grid cells in the UAB (405)
γ: CWI correction factor 2 (CWI fraction on P, 0.15 or 0.5)
β: CWI correction factor 1 (cloud forest coverage)

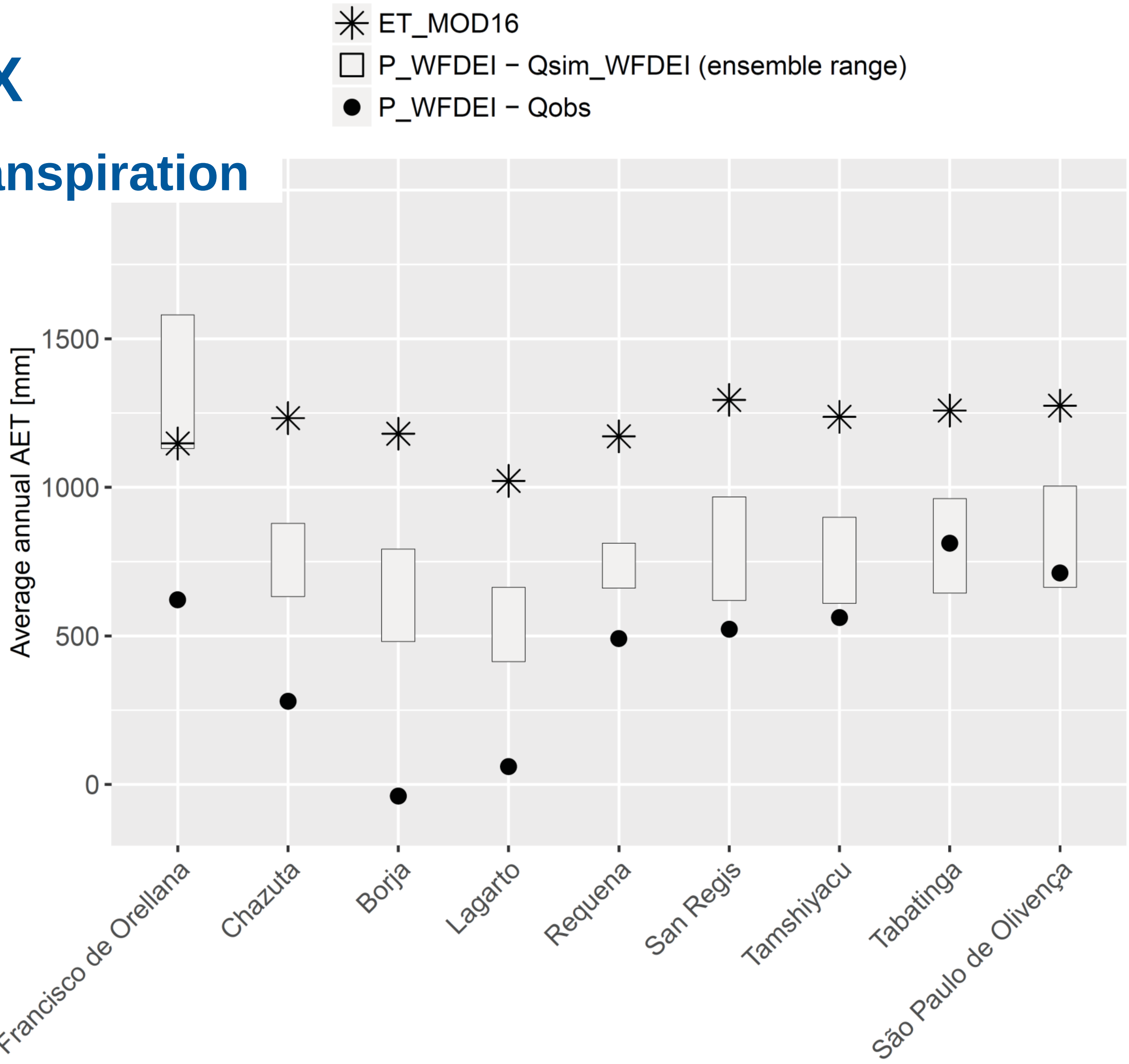
APPENDIX

Spatial distribution of adjusted precipitation (mean)



APPENDIX

Evapotranspiration



APPENDIX

Evapotranspiration