Estimating the water balance and uncertainty bounds in a highly-groundwater-dependent and data-scarce areas: An example for the upper Citarum basin

Steven Reinaldo Rusli, Albrecht Weerts, Ahmad Taufiq, and Victor Bense

Rationale: The contrast in groundwater storage assessment

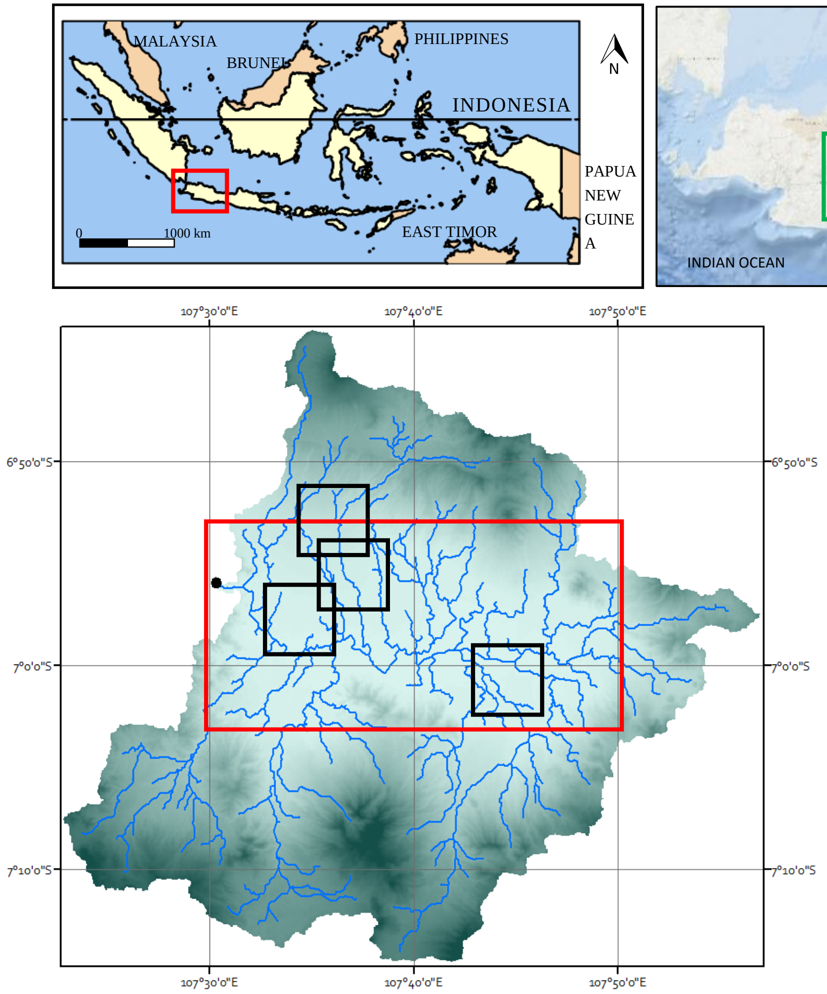

Figure 1. The upper Citarum basin, location, and abstraction area (red and black box)

Approx. 10 million population in 2018: ~150 Mm^3 of annual groundwater abstraction (domestic sector)

The actual groundwater abstraction is estimated to be 14 times higher than the reported one, equivalent to ~255 Mm^3 a year (industrial sector) (Taufiq, et al., 2017)

The groundwater abstraction in the Upper Citarum basin has caused **dwindling groundwater table** (Gumilar, et al., 2015; Asian Development Bank, 2016; Tirtomihardjo, 2016; Taufiq, et al., 2017)

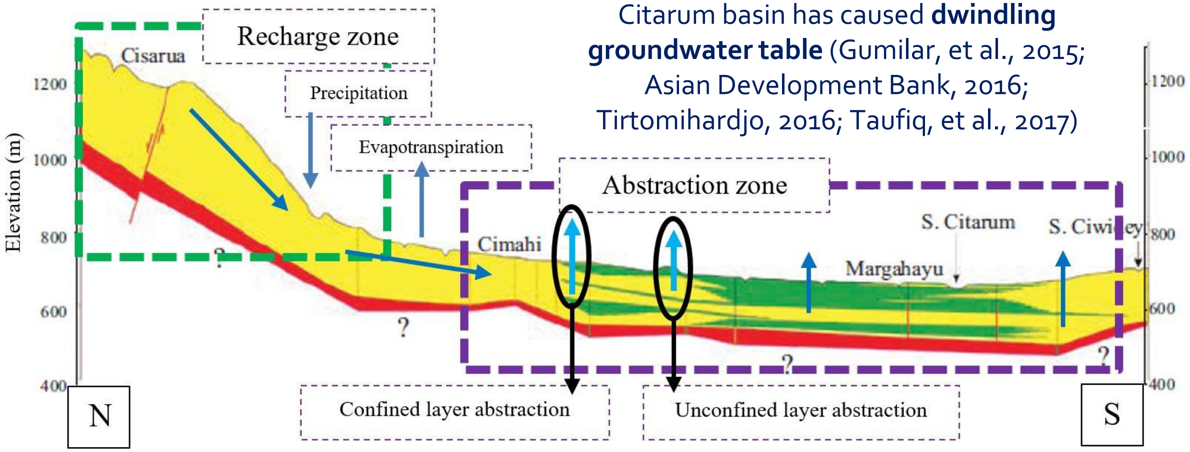

Figure 2. Hydrogeological cross-section and groundwater abstraction point sample in the Upper Citarum basin

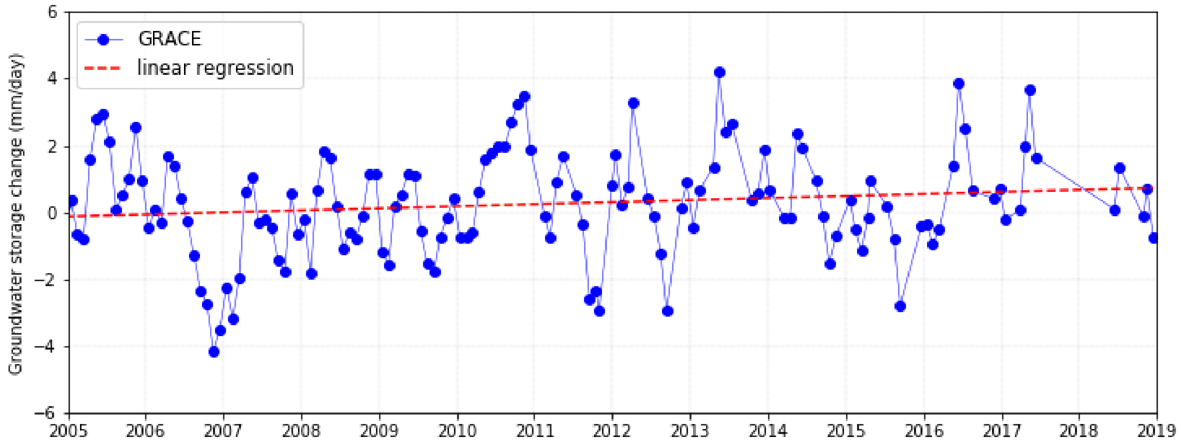

Figure 3. GRACE estimates on groundwater storage changes from 2005 to 2019 in the Upper Citarum basin (mm/day)

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Acknowledgement

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Material and method: Estimates source, hydrological model, and uncertainty quantification

Table 1. Water balance components and estimation method

Precipitation (rainfall)	Rainfall station measurements Interpolated gauge-based of SACA&D Gauge-corrected satellite observation of CHIRPS GPCC-corrected satellite estimate of TRMM3B43
Actual evaporation	Global Land Evaporation Amsterdam Model (GLEAM) Re-analysis product of ERA5 wflow_sbm hydrological model-based estimate
Discharge	Automatic water level recorder measurements ERA5-driven LISFLOOD model (GloFAS-ERA5) wflow_sbm hydrological model-based estimate
Groundwater abstraction	Population-based estimate Literatures of previous studies
Recharge / groundwater storage change	wflow_sbm hydrological model-based estimate ETC-based estimate Satellite-based estimate of GRACE

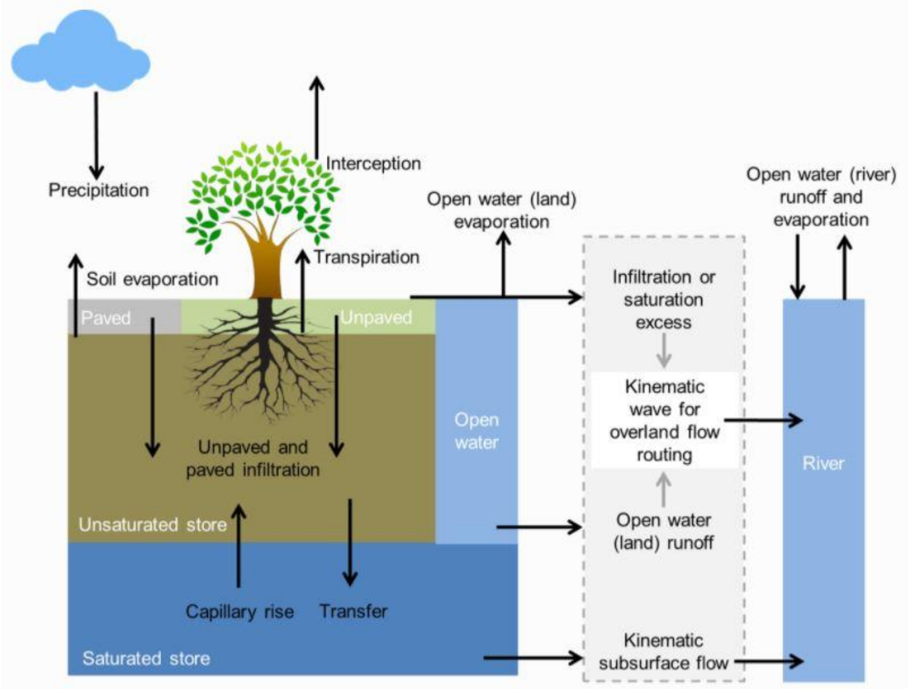

Figure 4. wflow_sbm model overview

Parameterization: point-scale (pedo)transfer functions (PTFs) (Imhoff, et al., 2020) Prevents equifinaliy and **bypass calibration** (Wannasin, et al. 2021)

Extended triple collocation (ETC): evaluates uncertainty by deriving correlation coefficient of each measurement system with respect to an unknown target variable (McColl, et al. 2014) expressed through RMSE and r^2 (Wu, et al. 2019)

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Results: Rainfall estimates

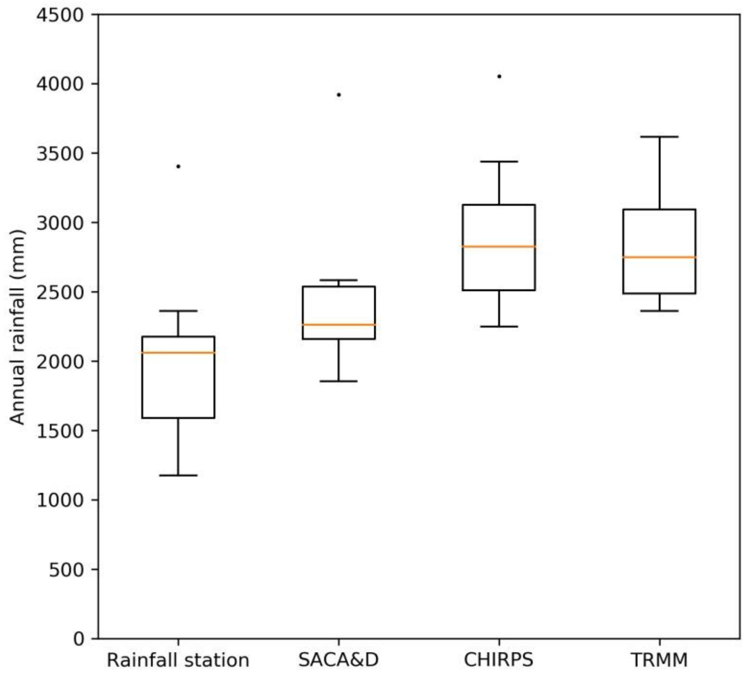

Figure 5. Rainfall estimates boxplot

Table 2. Number of annual non-rainy day from each rainfall estimate

	Rainfall station	SACA&D	**CHIRPS**	TRMM
Rainfall data quality screening	233.17	161.94	133.31	170.93

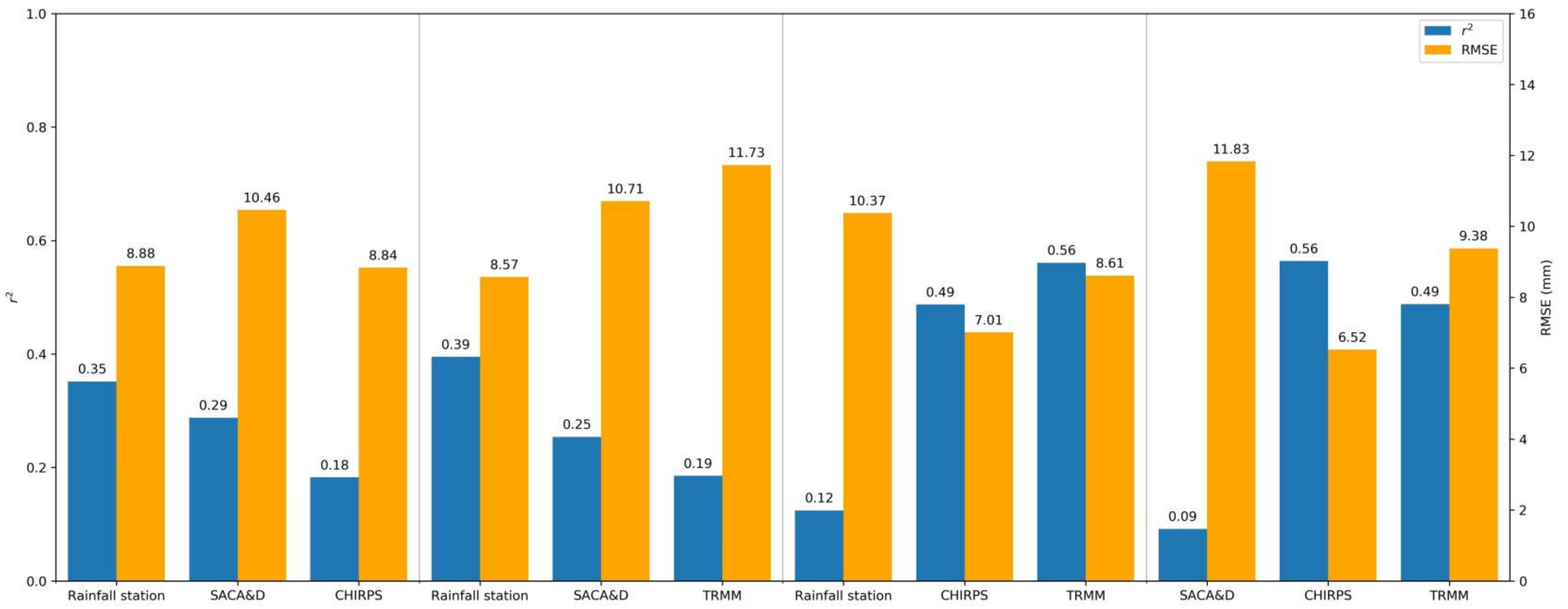

Figure 6. ETC application on rainfall estimates

r^2: satellite-based > rainfall-station-based
RMSE: **CHIRPS** > TRMM

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Results: Actual evaporation estimates

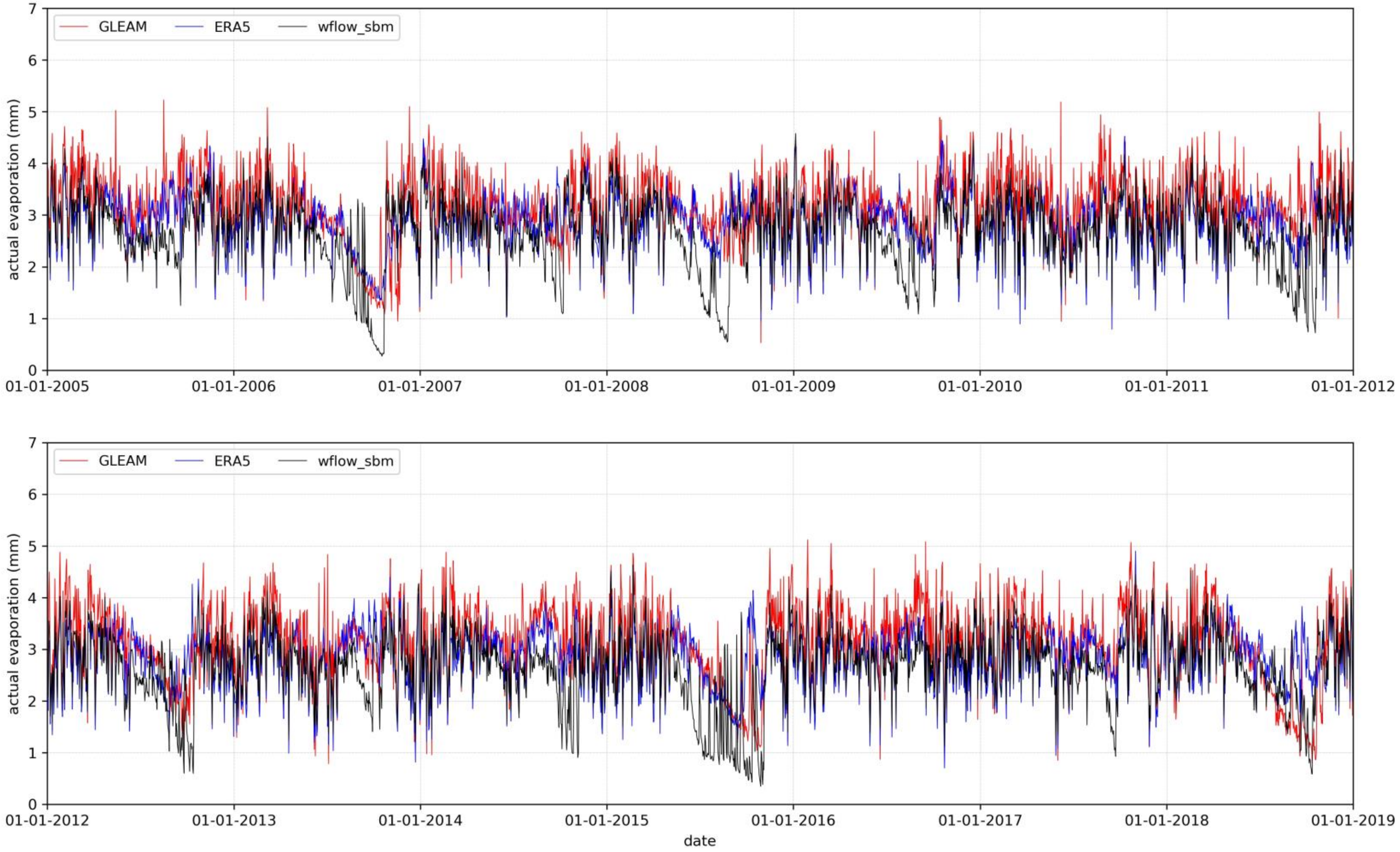

Figure 6. Comparison on actual evaporation estimates

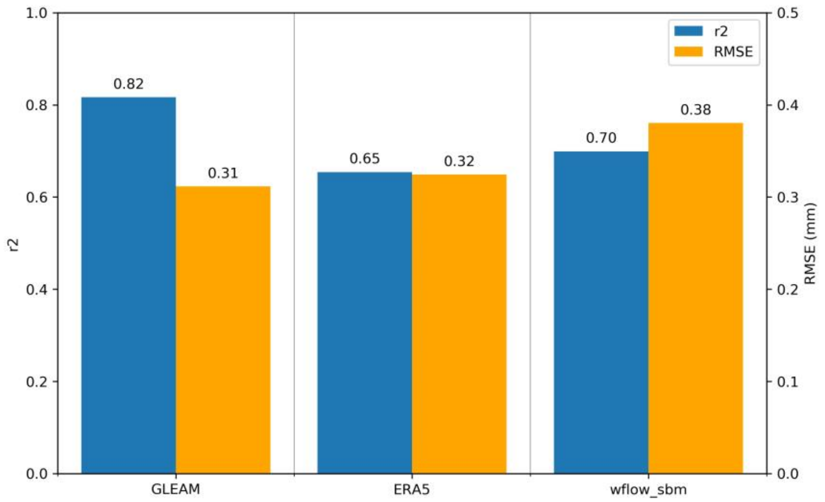

Figure 7. ETC application on actual evaporation estimates

Highest r^2: GLEAM
Lowest RMSE: GLEAM

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Results: Discharge estimates

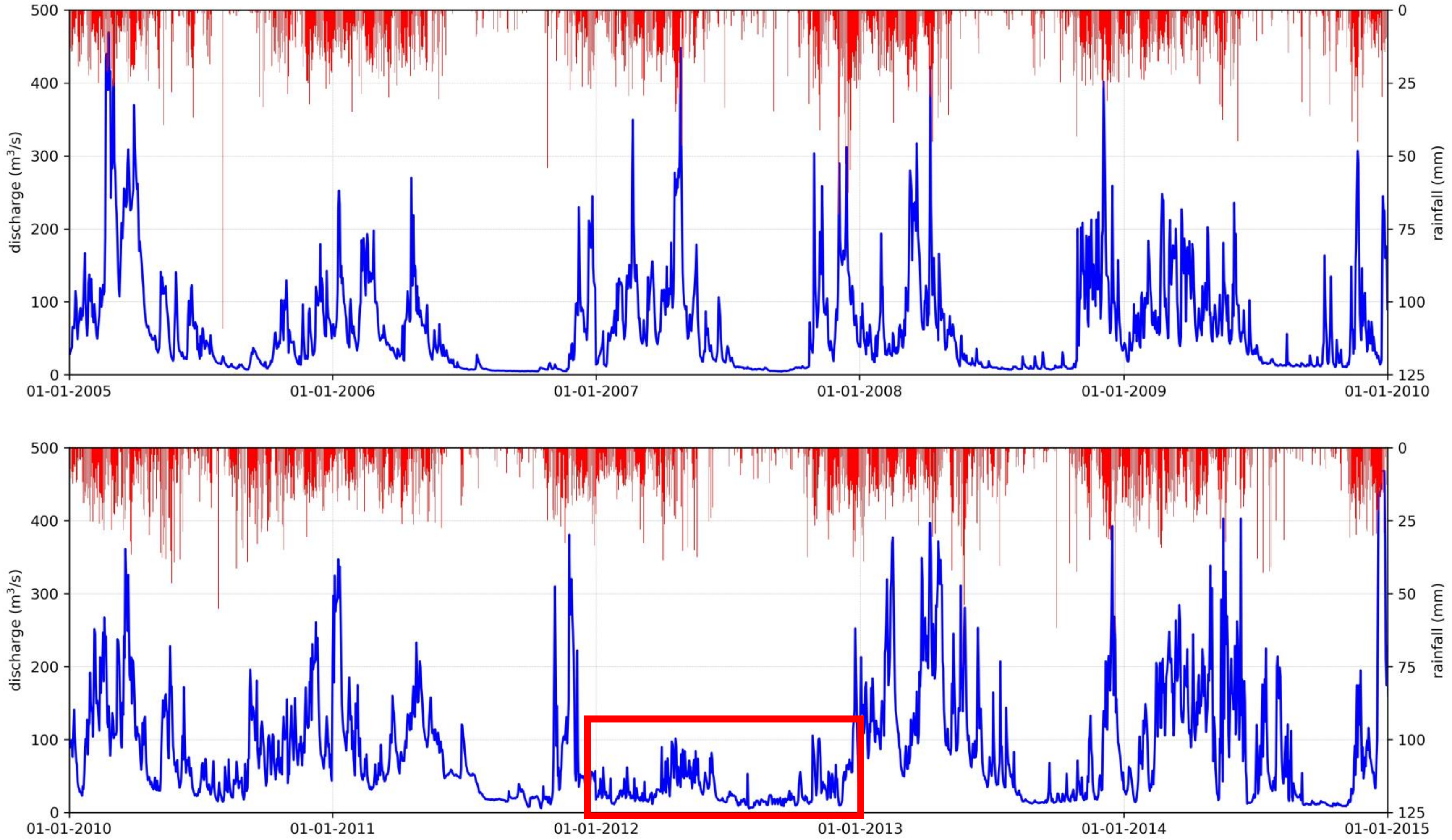

Figure 8. Comparison on actual evaporation estimates

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Results: Discharge estimates

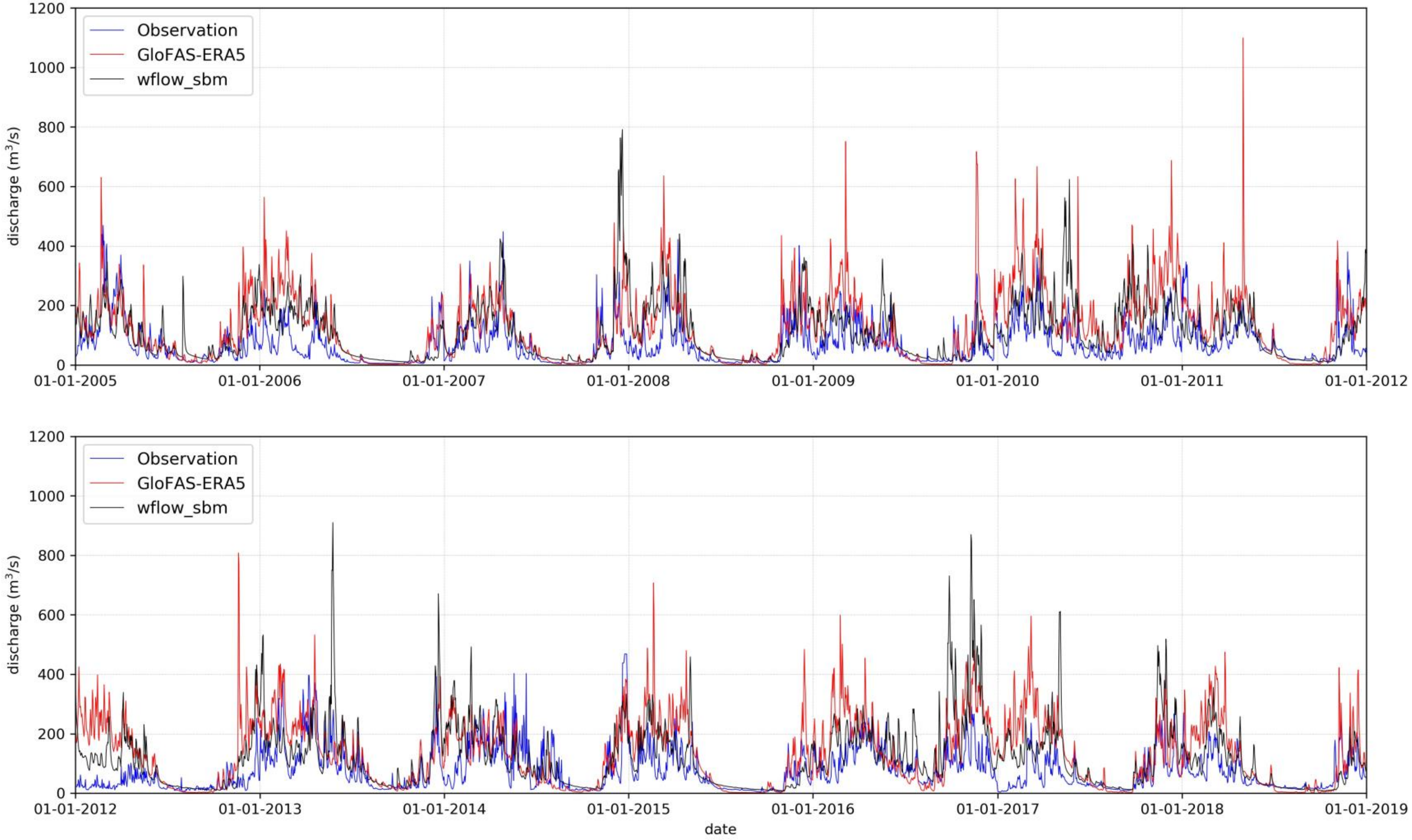

Figure 9. Comparison on actual evaporation estimates

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Results: Recharge estimates

$$R = \frac{\Delta S}{\Delta t} = I - O = P - (AET + Q + Groundwater_{abs})$$

Table 2. Water balance component estimates in the Upper Citarum basin (mm/day)

<table>
<tr><th>Components</th><th>Uncertainty bounds</th><th>wflow_sbm-based estimate</th><th>ETC-based estimate</th></tr>
<tr><td>Precipitation</td><td>4.90 – 7.80</td><td colspan="2">7.80</td></tr>
<tr><td>Actual evaporation</td><td>2.67 – 3.13</td><td>2.67</td><td>3.13</td></tr>
<tr><td>Discharge</td><td>3.65 – 6.12</td><td>5.38</td><td>3.65</td></tr>
<tr><td>Groundwater abstraction</td><td></td><td>0.57</td><td></td></tr>
<tr><td rowspan="2">Total water storage changes</td><td rowspan="2">-0.82 – +0. 45</td><td>-0.82</td><td>+0.45</td></tr>
<tr><td colspan="2">GRACE: +0.25</td></tr>
</table>

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Results: Inter-annual water balance components estimates (mm/day)

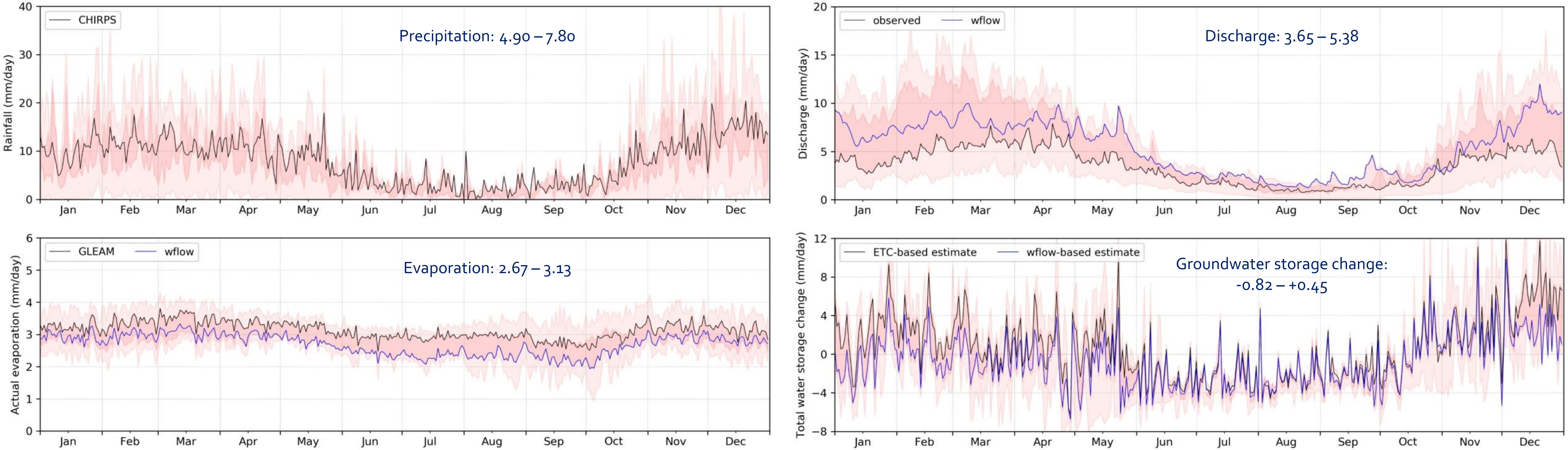

Figure 10. Inter annual water balance components estimates and its uncertainty bounds (mm/day)

The use of satellite-based rainfall estimates even in area with 11 rainfall stations: the importance of data quality screening
Calibration bypass by wflow_sbm PTF-based parameterization results in estimates between the observation and GloFAS-ERA5
Successfull grasp on the hydrological behavior of surface components is shown by narrow range among estimates and their uncertainty bounds
Higher uncertainty on subsurface estimates due to unsimulated hydrogeological fluxes

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