EGU26-241, updated on 11 May 2026
https://doi.org/10.5194/egusphere-egu26-241
EGU General Assembly 2026

Assessing micro-meteorological flux network data quality: implications for water and energy flux modelling

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Robust climate-impact and (eco)hydrological modelling as well as reproducible research practices rely on (micro)meteorological forcing data that are both physically consistent and stable across dataset versions — conditions that are often difficult to meet within long-term micrometeorological networks. Continuous reprocessing of raw measurements, as implemented in ICOS and FLUXNET, can unintentionally reshape subdaily time series and thereby alter simulations of water and energy balance components. In our research, we identified two major post-processing error sources: dataset versioning and gap-filling. To evaluate how these transformations propagate into process-based modelling, we used the ICOS DE-Tha old-spruce forest site in Saxony (Germany) as a representative case study and applied the subdaily, physically based 1D ecohydrological model BROOK90 to perturbed forcing datasets.

Successive ICOS dataset versions introduced substantial corrections to air temperature, solar radiation, precipitation, wind speed, and vapor pressure, which in turn noticeably altered simulated interception, transpiration, and soil evaporation. Standard ICOS gap-filling procedures (MDS and ERA-I) were also found to generate implausible values, particularly where outputs from different algorithms occurred in close succession, producing artificial spikes such as 10 °C temperature jumps within a 30-minute interval. Artificial gap-filling experiments using ERA-I demonstrated that uncertainties in modeled water and energy balance components increase systematically with both the proportion (1-50%) and the block-length (30 min - 30 days) of substituted subdaily meteorological data. Precipitation and solar radiation replacements induced the strongest single-variate deviations, and multivariate gap-filling resulted in substantially larger uncertainties than single-variable substitutions—approaching 25% overestimation for latent heat (LE) and more than 40% underestimation for sensible heat (H) at 50% substitution using 30-minute blocks. Evapotranspiration partitioning revealed consistent bias patterns under multivariate substitutions, including reduced transpiration and strong overestimation of interception and soil evaporation. Although BROOK90 remained numerically stable across all tested perturbation scenarios, inconsistencies in subdaily forcing propagated into physically implausible process representations.

Importantly, similar inconsistencies and artifacts have been found across many ICOS and FLUXNET sites worldwide, indicating that these issues are systemic rather than site-specific. Our findings

highlight that reproducibility and reliability in long-term flux-network modelling depends critically on transparent dataset versioning, rigorous anomaly detection, and harmonized multivariate gap-filling practices. Strengthening these components will enhance the scientific value of flux networks by ensuring that impact-based ecosystem modelling is grounded in trustworthy subdaily forcing data.