

HARMONIZATION STRATEGIES FOR MULTI-SCALE SOIL MOISTURE OBSERVATIONS: A COMPARATIVE STUDY

Sadra Emamalizadeh ¹, Tim Howson ²,Riccardo Mazzoleni ¹, Philip Vincent ², Jonathan Evans ², Gabriele Baroni ¹

¹ University of Bologna, Italy | ² UK Centre for Ecology & Hydrology, United Kingdom

Sadra.emamalizadeh2@unibo.it



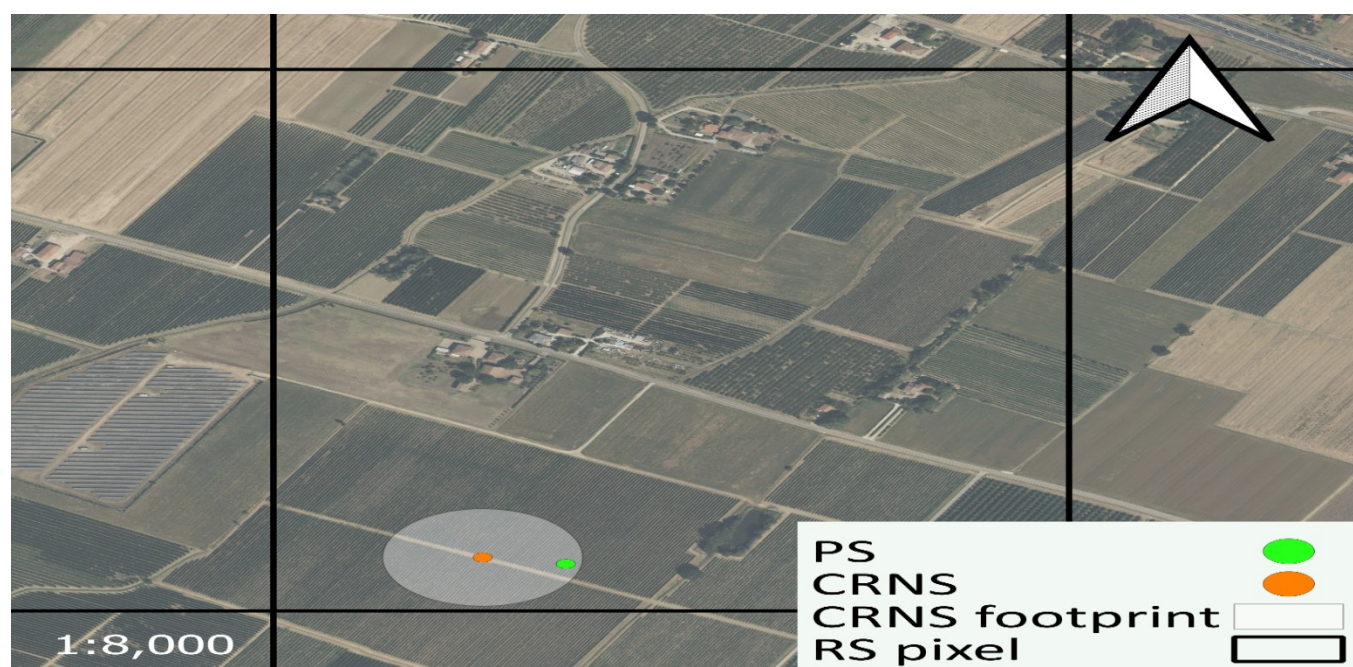
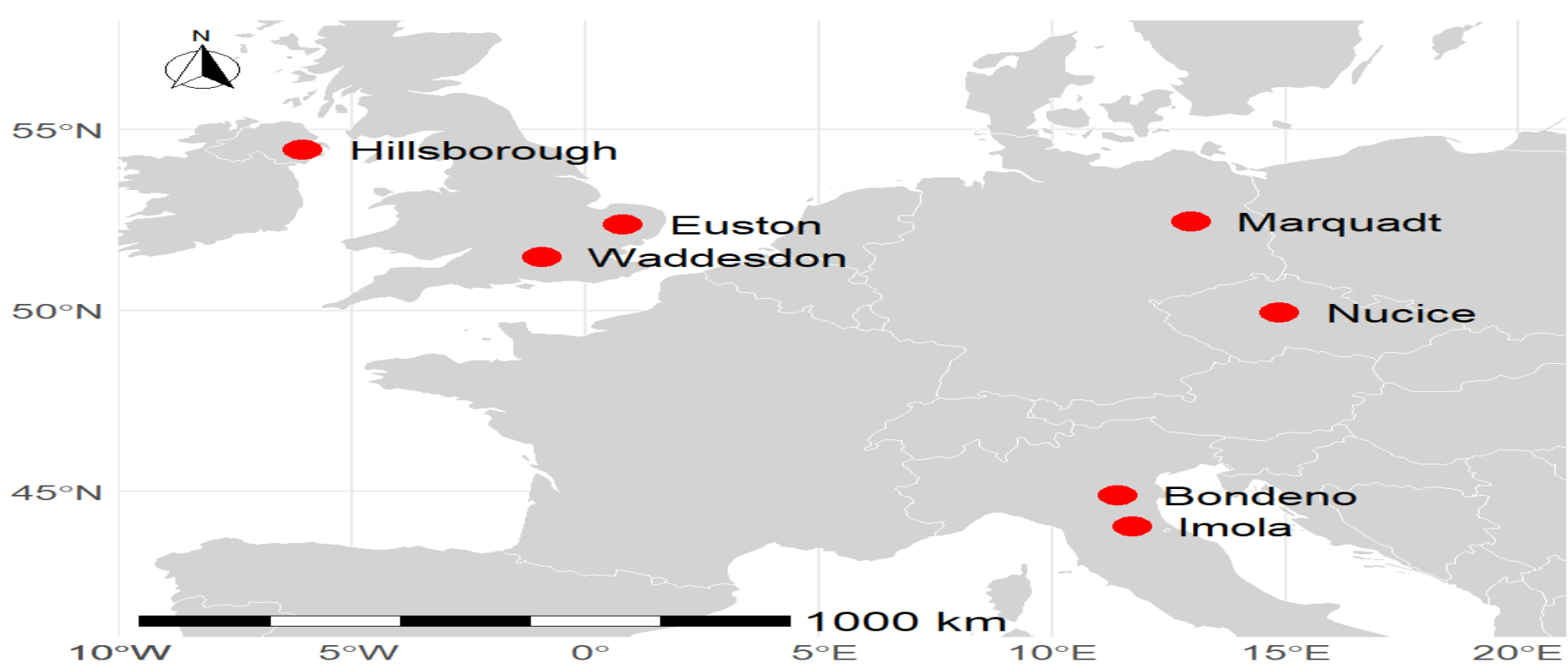
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



1. Introduction and Objectives

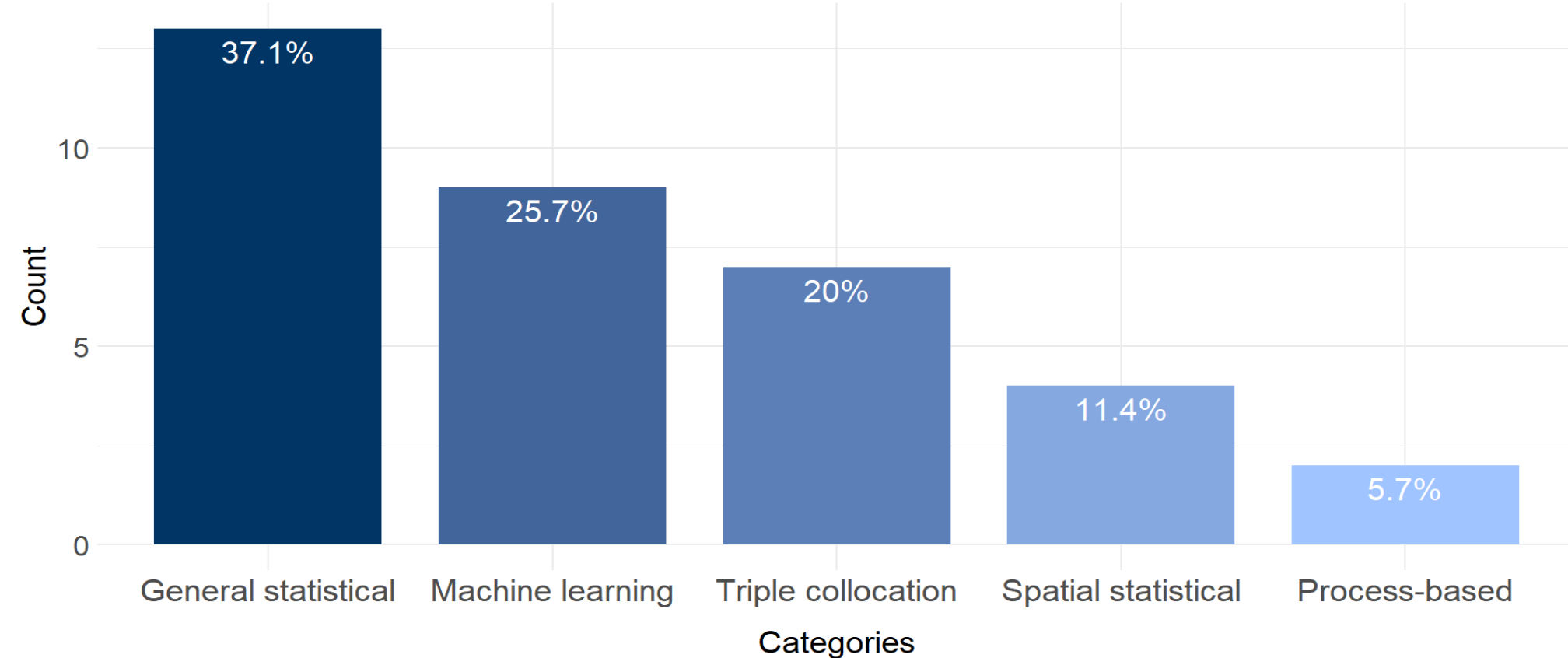
- **Soil Moisture (SM)**, or Soil Water Content (SWC), is a key variable in environmental and hydrological systems. However, comparing observations from diverse sensors—**point-scale (PS)**, **cosmic-ray neutron sensing (CRNS)**, and **remote sensing (RS)**—is difficult due to differences in spatial resolution, depth, units, and timing.
- This study focuses on **harmonization**, not fusion, as a preprocessing approach that enhances comparability across datasets while preserving their unique characteristics.
- We propose a four-step harmonization framework involving adjustments in:
 - Units, Temporal resolution, Depth, and Lateral spatial scale**
- For each step, **at least two widely used methods** from the literature were applied and compared both **quantitatively and qualitatively**.
- Key considerations choosing the approaches are:
 - ☐ Minimizing dependence on field data to ensure broad applicability
 - ☐ Avoiding synthetic data generation
 - ☐ Preserving each dataset's intrinsic nature
 - ☐ Keeping harmonization distinct from data fusion

2. Study Areas and Datasets

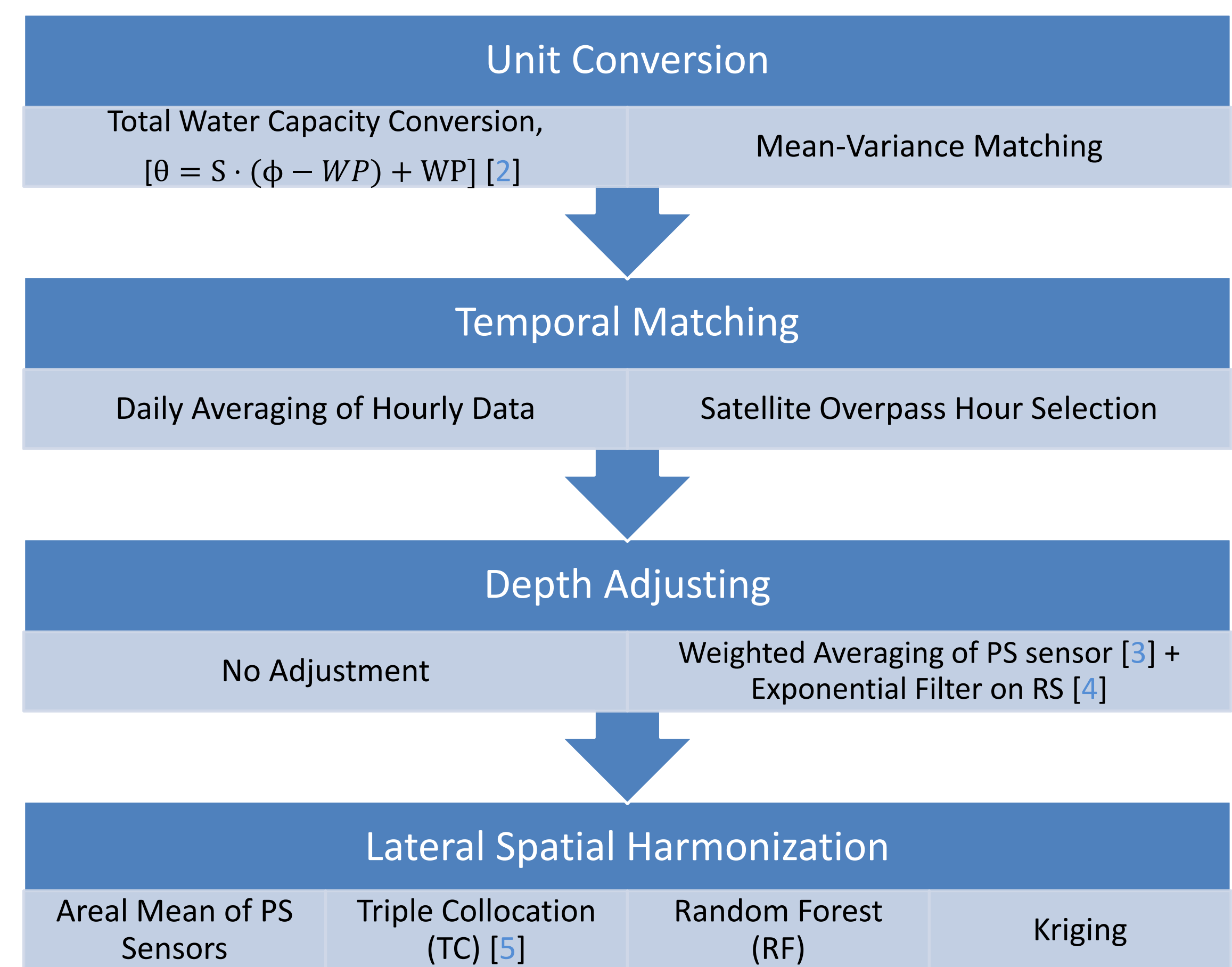


Upper panel shows Geographic locations of the **seven study sites** across Europe and right panel is Example from the Imola site showing the **1 km daily surface soil moisture (SSM)** product from Copernicus Global Land Services [1] in saturation unit (black grid), the **CRNS hourly** sensor location and its footprint (orange point and grey shaded circle, 125 m radius), and the **static hourly PS** location (green point). This illustrates the spatial relationship among the different sensing systems.

Distribution of Lateral Spatial Harmonization Methods

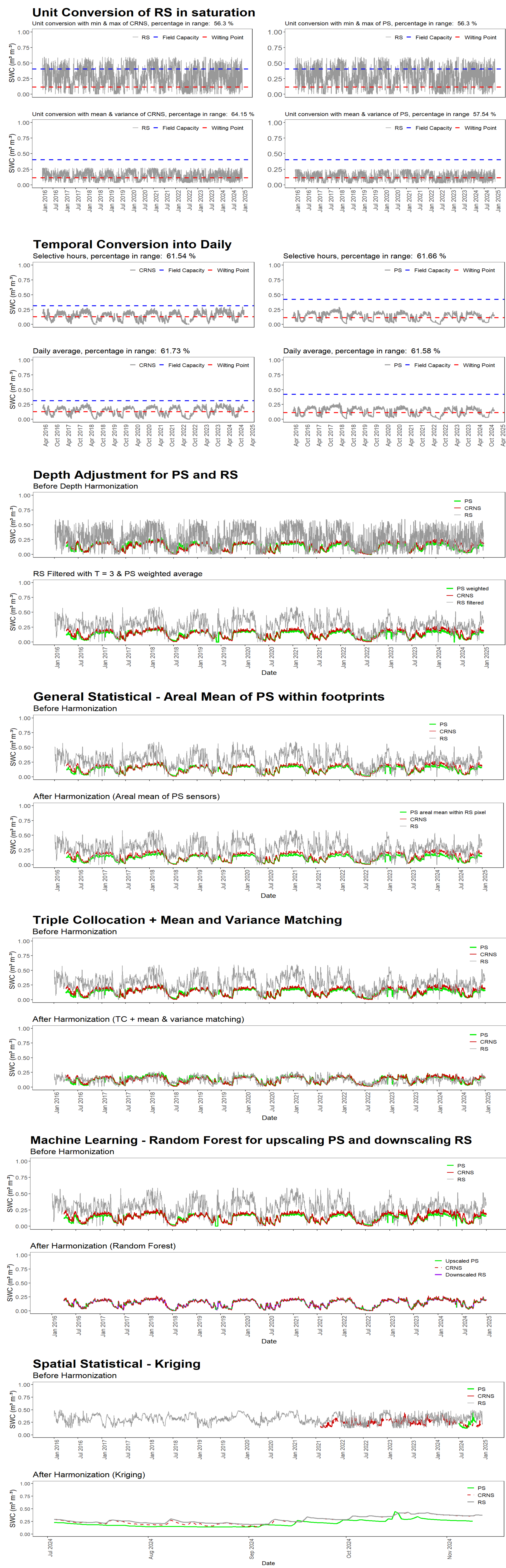


3. Steps, Methods and the Work Flow



To assess methods quantitatively at each step, we used **Field Capacity (FC)** and **Wilting Point (WP)** thresholds derived from **eupfv2** [6] pedotransfer functions, using soil data from **SoilGrids** [7]. We calculated the **percentage of data points within the [WP–FC] range** before and after harmonization. For additional evaluation, we used: **R (correlation coefficient)** for temporal agreement and **ubRMSD** to measure unbiased error.

4. Results



5. Discussions and Conclusions

• Unit Harmonization

- The **porosity-based conversion** (using soil physical limits) outperformed linear scaling with slightly higher improvements in R, ubRMSD and change of percentage of the points within the limits.

- It also holds more **physical interpretability**, making it preferable despite its reliance on soil data.

• Temporal Harmonization

- Both **daily averaging** and **satellite overpass sampling** produced similar results.

- **Daily averaging** was chosen for downstream use as it preserves all available data and avoids discarding valuable non-overpass hours.

• Depth Harmonization

- Applying an **exponential filter** to RS data increased the percentage of values within [WP–FC] by 11%.

- **Weighted averaging** of PS sensors had limited impact.

- Depth harmonization was retained for RS and PS to better match **CRNS's integrated depth sensitivity**.

• Lateral Spatial Harmonization

Method performance is **site-dependent**, especially on PS sensor density:

- **Ordinary Kriging** showed the highest improvement ($\Delta 16\%$ for CRNS; $\Delta 30\%$ for RS footprints), but was only applicable at **2 of 7 sites** due to sensor requirements.

- **Random Forest** tended to **overfit** and resemble **data fusion**, making it less suitable for harmonization purposes.

- **Areal Mean** and **TC + Mean-Variance Matching** offered **modest but consistent improvements**, and those are good choices when **few or even a single PS sensor** is available.

- For TC, harmonization still requires a post-processing step; we recommend **areal mean** over time-series shifting to retain original signal structure.

6. References

1. <https://www.sommet-project.eu/>
2. Saxton, K.E., & Rawls, W.J. (2006). *Soil water characteristic estimates by texture and organic matter for hydrologic solutions*. *Soil Sci. Soc. Am. J.*, 70, 1569–1578.
3. Schrön, M. et al. (2017). *Improving calibration and validation of cosmic-ray neutron sensors in the light of spatial sensitivity*. *Hydrol. Earth Syst. Sci.*, 21, 5009–5030.
4. Wagner, W., Lemoine, G., & Rott, H. (1999). *A method for estimating soil moisture from ERS scatterometer and soil data*. *Remote Sens. Environ.*, 70, 191–207.
5. Stoffelen, A. (1998). *Toward the true near-surface wind speed: Error modeling and calibration using triple collocation*. *J. Geophys. Res. Oceans*, 103(C4), 7755–7766.
6. <https://pftinterface.rissac.hu/>
7. <https://soilgrids.org/>