Optimal Temporal Filtering of the Cosmic-Ray Neutron Signal to Reduce Soil Moisture Uncertainty

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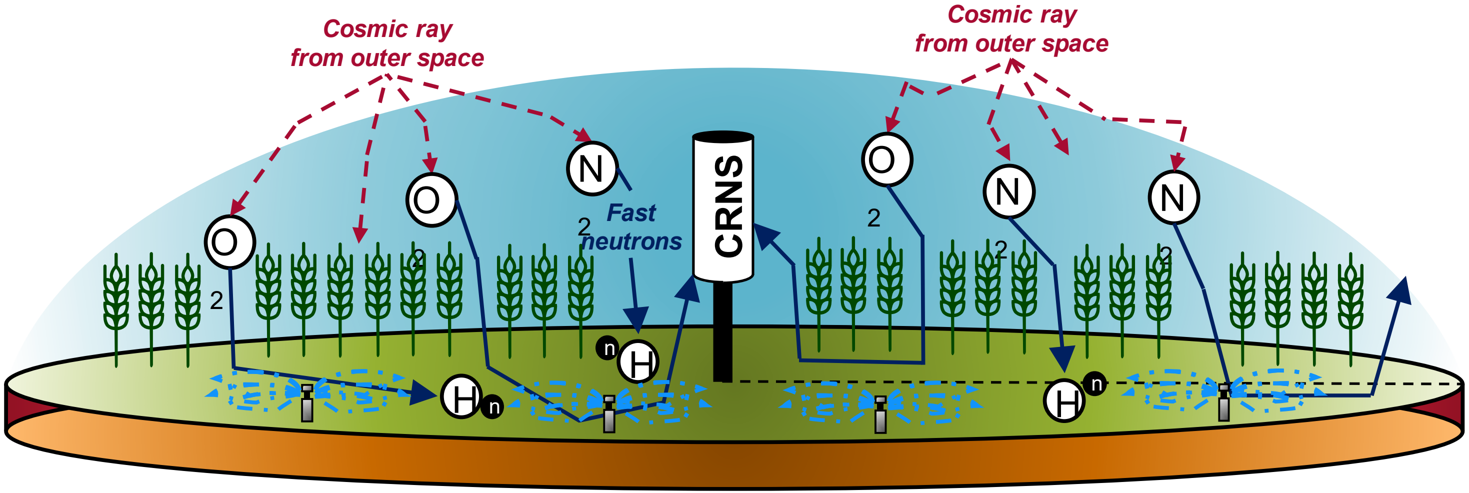
Introduction

- Soil moisture accounts for an estimated 0.001% of earth's volume of water, yet plays a key role in the hydrological cycle (McColl et al. 2017).
    - rainfall into infiltration and runoff.



- Incoming cosmic ray radiation produces fast neutrons that can penetrate the soil and scatter back into the air (eventually hit the CRNS)
- Hydrogen strongly slows these neutrons down, thus:

Fewer detected neutrons = higher soil moisture

Why filter neutron counts?

- Additional hydrogen sources must be accounted for, especially if their contributions change significantly over time to reduce error.

- Uncertainty of the CRNS-derived soil moisture strongly depends on the CRNS count rate subject to Poisson distribution.

- Although averaging neutron count reduce uncertainty by removing spikes, the optimal approach is important. Especially retaining sub-daily scale events such as:
    - Rainfall
    - Irrigation

Fig. 2: Farm irrigation adopted from MacBean and Peylin, 2014.

Study sites

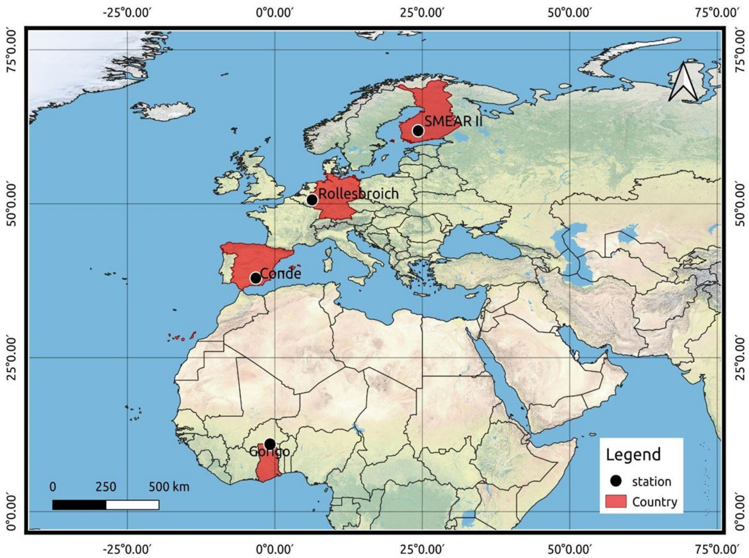


Fig. 3: Geographical distribution of test sites.

Key variable:

- Soil moisture (0-5 cm)
- Temperature
- Relative humidity
- Surface pressure
- Incoming neutron intensity (ref)

Table 1: Summary of the site characteristics

Site name	Bulk Density	Cut-off Rigidity	Other site information
SMEAR II	0.85	1.11	Homogenous Scots pine trees. Silty sand.
Gorigo	1.54	14.68	Highly degraded grassland. Loamy sand soil
Rollesbroich	1.09	3.27	Managed Grassland. Silty clay loam
Conde	1.37	8.33	Evergreen trees and shrubs. Clayey loam.

Analysis

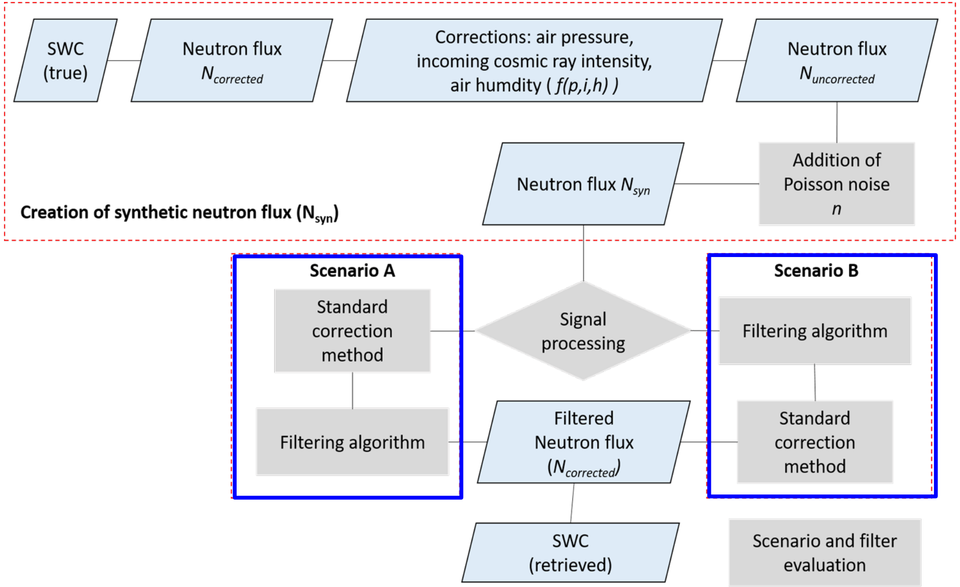


Fig. 4: Flow chart for study analysis

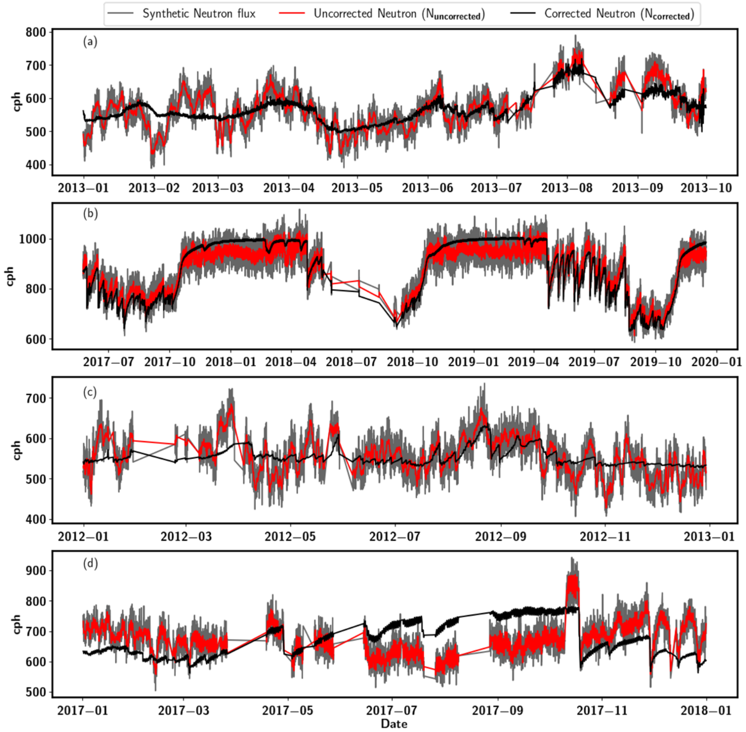


Fig. 5: Generated synthetic neutron flux for SMEAR II (a), Gorigo (b), Rollesbroich (c) and Conde (d).

Evaluation method

- Correlation
- RMSE
- Bias
- Standard deviation

SM - Neutron relation

$$N_{corrected} = \left(\frac{0.0808}{\frac{SWC}{\rho_{bd}} - 0.115} + 0.372 \right) \times N_0$$

Results: Evaluation of filter performance

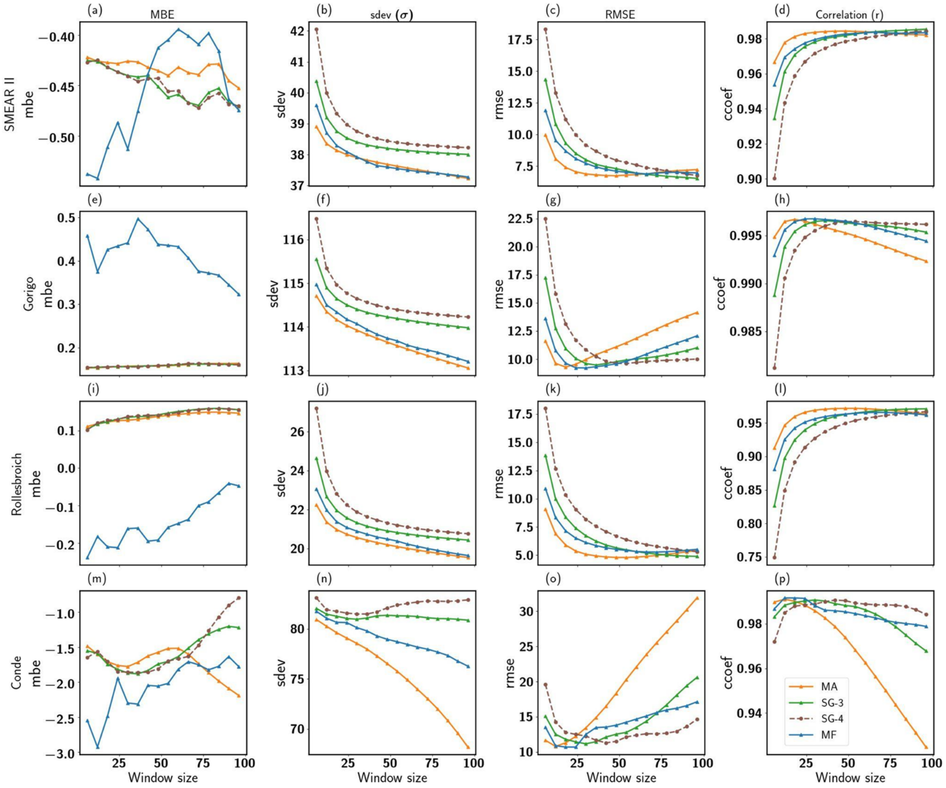


Fig. 6: Performance of MA, MF and SG filter with different window sizes.

- Performance of MA, MF and SG filters improved with increasing window size.
- MA and MF filters converge quickly compared to the Savitzky-Golay filters.
- KF showed great reduction with any optimal window.

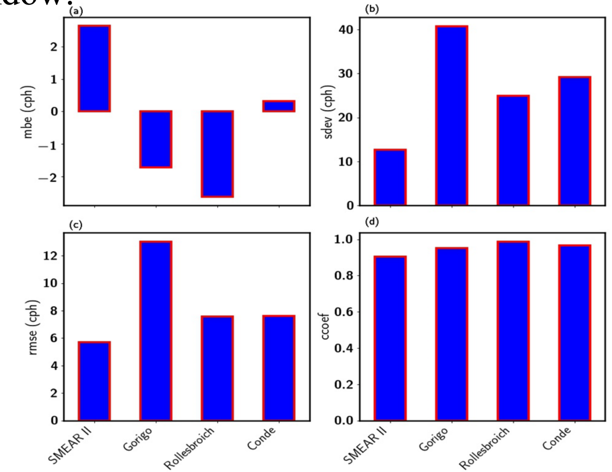


Fig. 7: Performance of MA, MF and SG filter with different window sizes.

Results: Optimal window size and filter

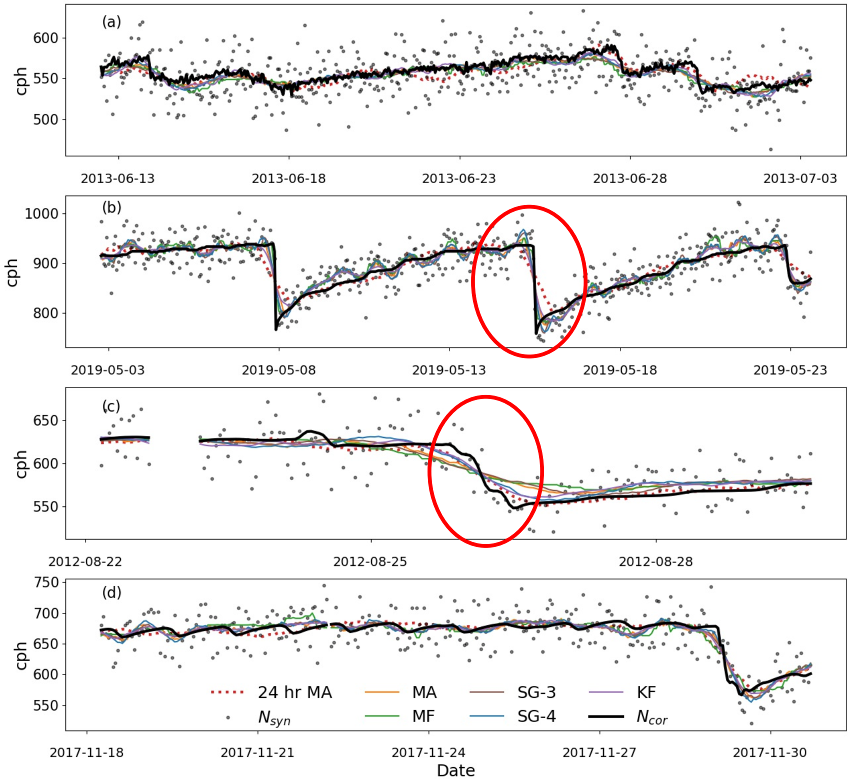


Fig .8: Time series of reconstructed neutron counts by various filters at SMEAR II (a), Gorigo (b), Rollesbroich (c) and Conde (d).

- Overall, the seasonal pattern was captured by the filtered synthetic neutron count.

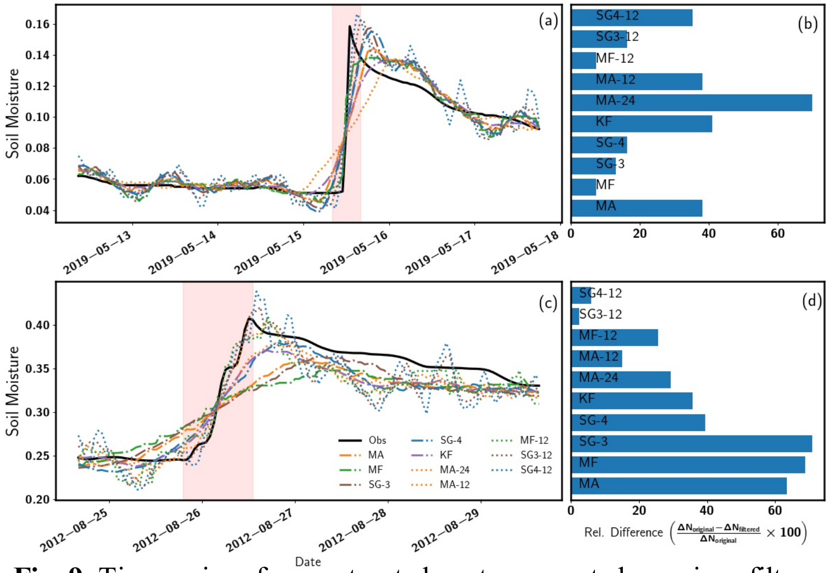


Fig. 9: Time series of reconstructed neutron counts by various filters at SMEAR II (a), Gorigo (b), Rollesbroich (c) and Conde (d).

Smaller window size captured sharp changes well

Results: Optimal window size and filter

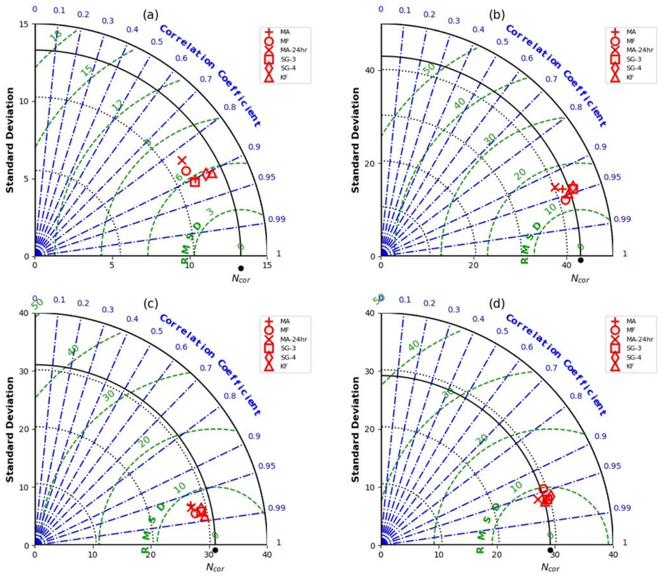


Fig. 10: Performance of filters at SMEAR II (a), Gorigo (b), Rollesbroich (c) and Conde (d).

- KF showed robustness in reducing uncertainty at three sites.

- Uncertainty from correction parameters are also propagated to soil moisture.

Filter (window size)	**Scenario A (cm^3/cm^3)**	**Scenario B (cm^3/cm^3)**
KF	0.006	0.008
MA (30 hr)	0.006	0.009
MA (24 hr)	0.007	0.009
MF (36 hr)	0.007	0.009
SG3 (78 hr)	0.007	0.009
SG4 (84 hr)	0.007	0.008

Conclusion and Recommendation

- All filters showed significant reduction in the uncertainty add to the synthetic neutron counts. A robust performance was shown by the Kalman filtering technique.

- Short and long window size of filters are able to capture closely relevant short and long-term changes respectively (MA, SG and MF).
    - The application of soil moisture data should inform window size

- Also, applying filter after standard atmospheric correction improved the CRNS-estimated soil moisture.

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