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Influence of total biomass and rainfall interception on cosmic-ray soil moisture measurements

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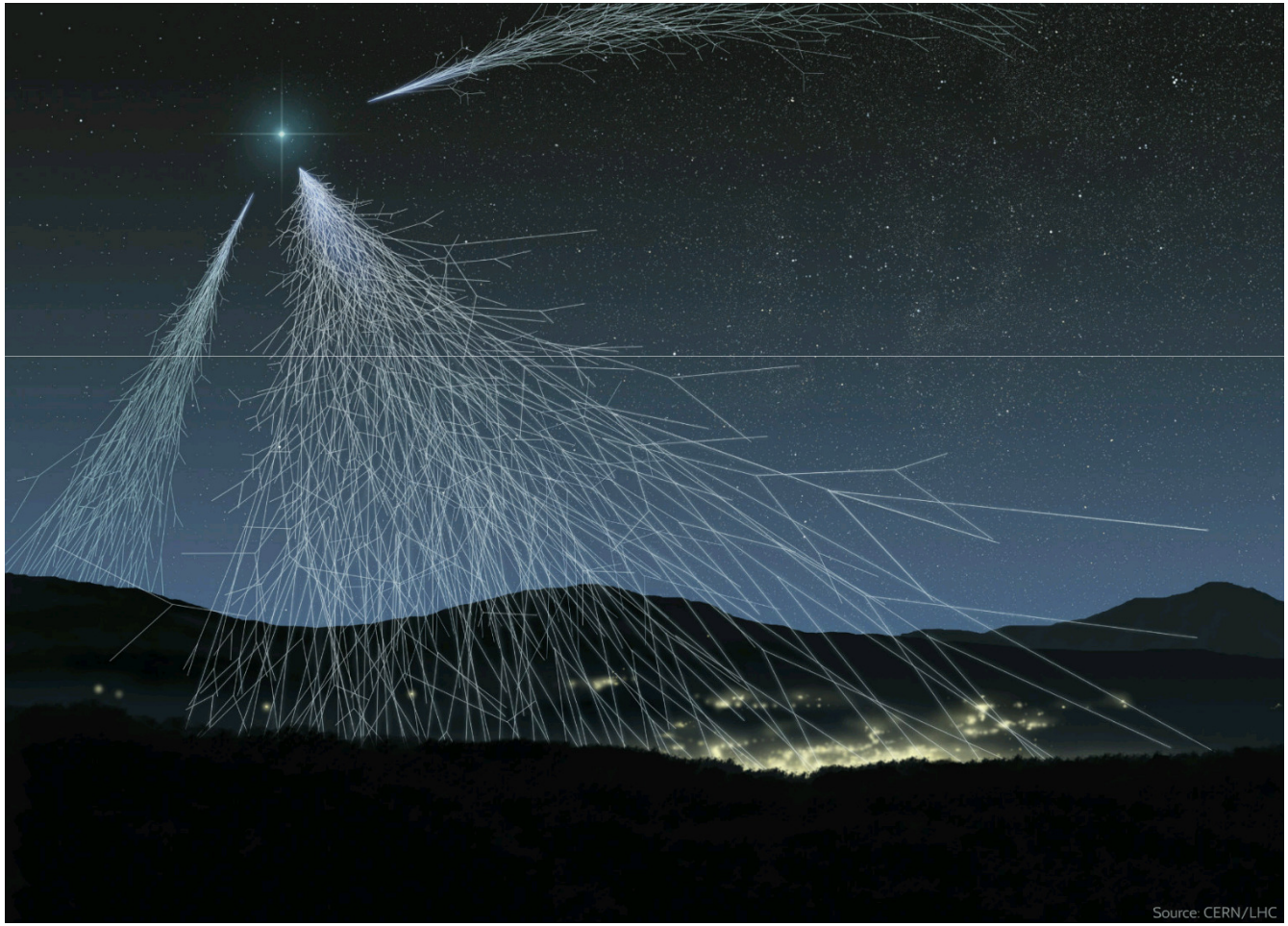
Cosmic-ray soil moisture sensing

- Cosmic rays lead to emission of fast neutrons into the lower atmosphere



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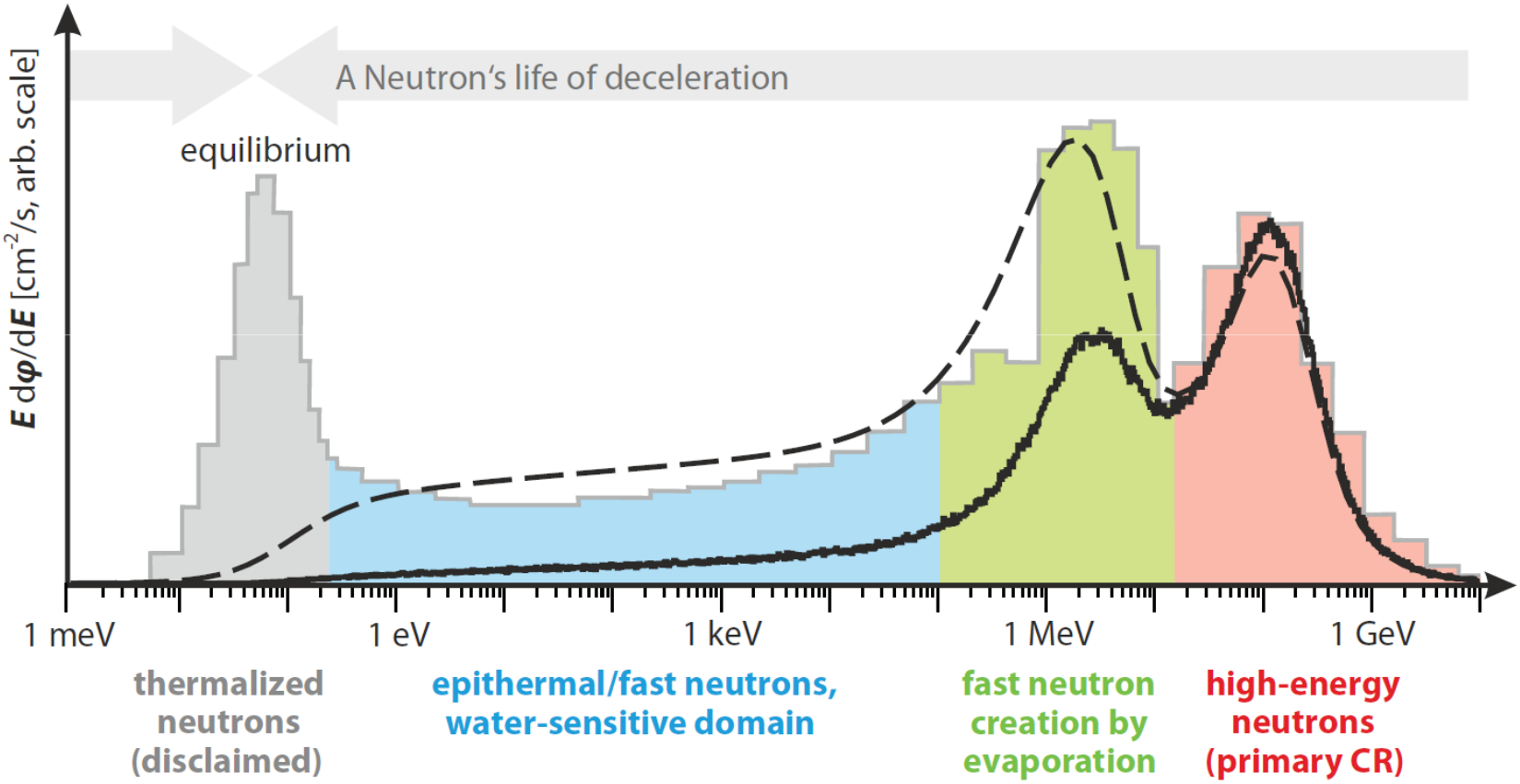
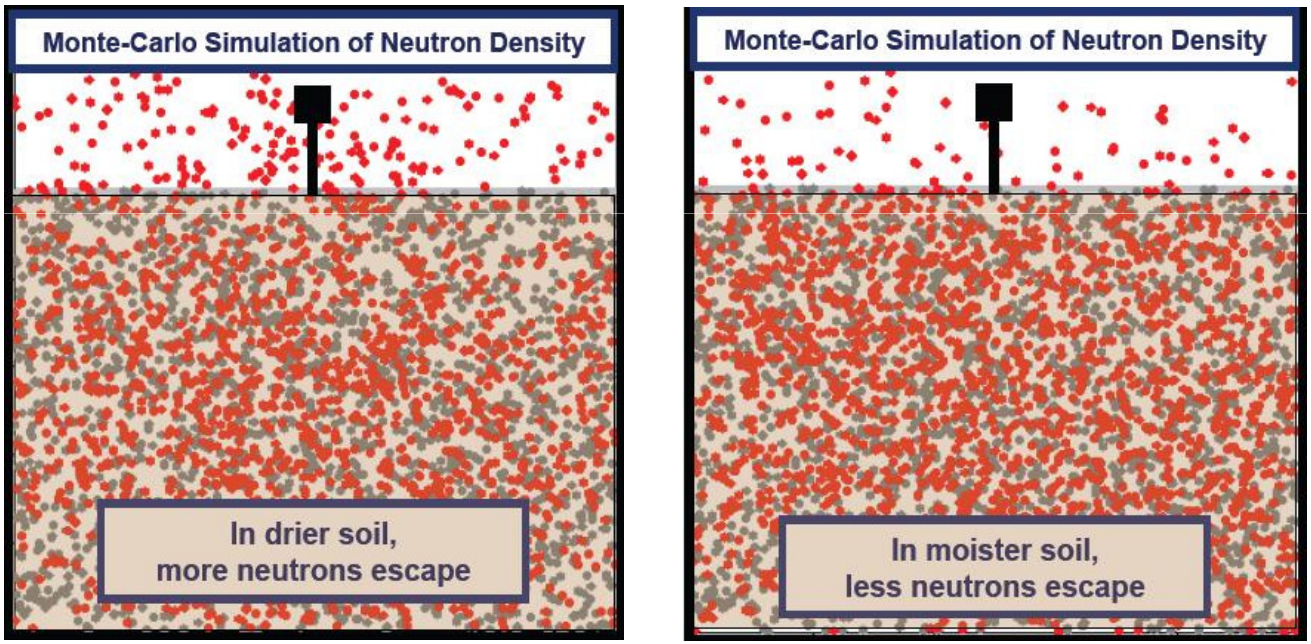


Neutron energy spectra at the surface (Köhli et al., 2015)

Cosmic-ray soil moisture sensing

- Cosmic rays lead to emission of fast neutrons into the lower atmosphere
- Fast neutrons lose energy primarily through collisions with hydrogen mainly located in the soil



Cosmic-ray soil moisture sensing

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- Continuous measurement of neutron flux to estimate soil moisture at hourly resolution

Cosmic ray probe in the field of Rollesbroich (May 2011)

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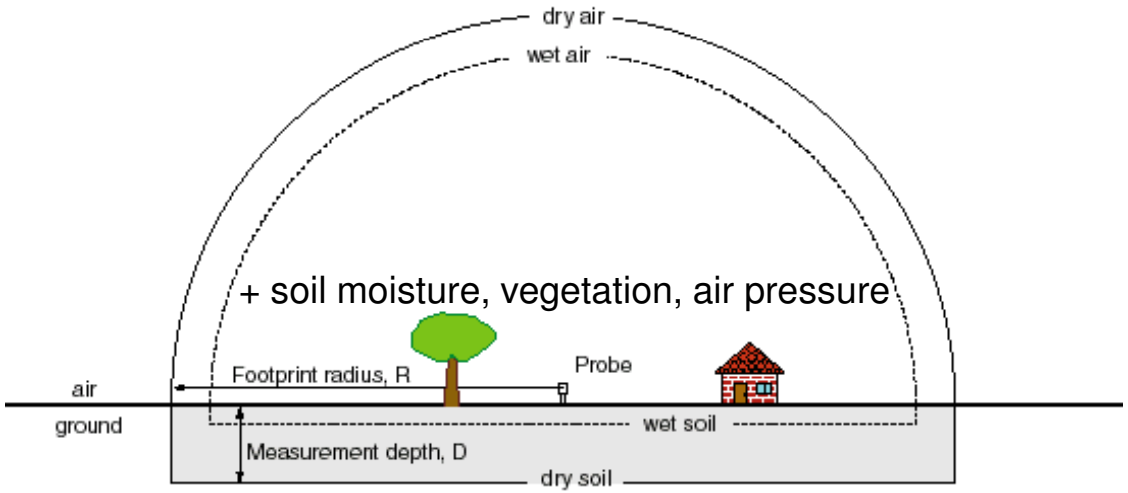
- Large Footprint (~150-250 m radius, ~5-70 cm depth)



Zreda et al., 2012, HESS
Köhli et al., 2015, WRR

Cosmic ray probe in the field of Rollesbroich (May 2011)

Cosmic-ray soil moisture sensing

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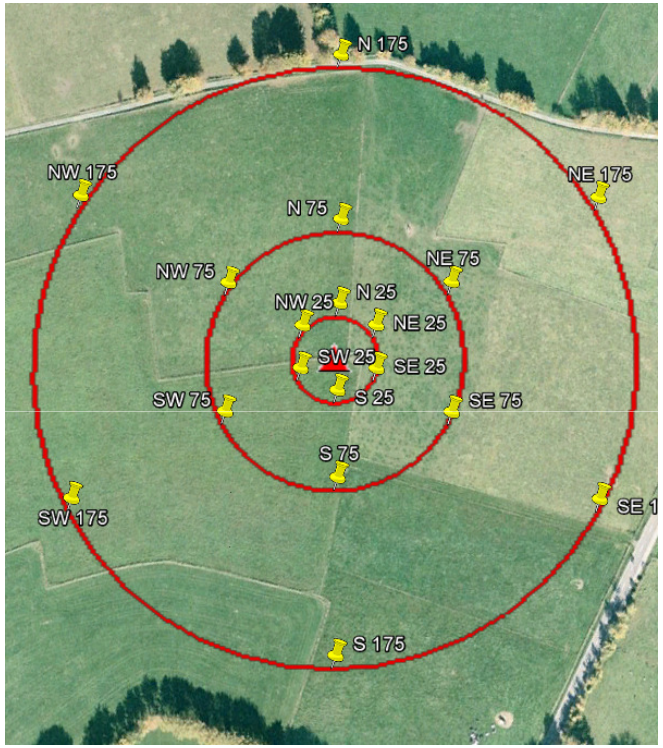
- Fast neutrons lose energy primarily through collisions with hydrogen mainly located in the soil
- Continuous measurement of neutron flux to estimate soil moisture at hourly resolution
- Large Footprint (~150-250 m radius, ~5-70 cm depth)
- Simple calibration with the N0-method:

$$\theta_{tot} = \frac{\rho_{bd} \cdot a_0}{(N_{corr} / N_0) - a_1} - \rho_{bd} \cdot a_2$$

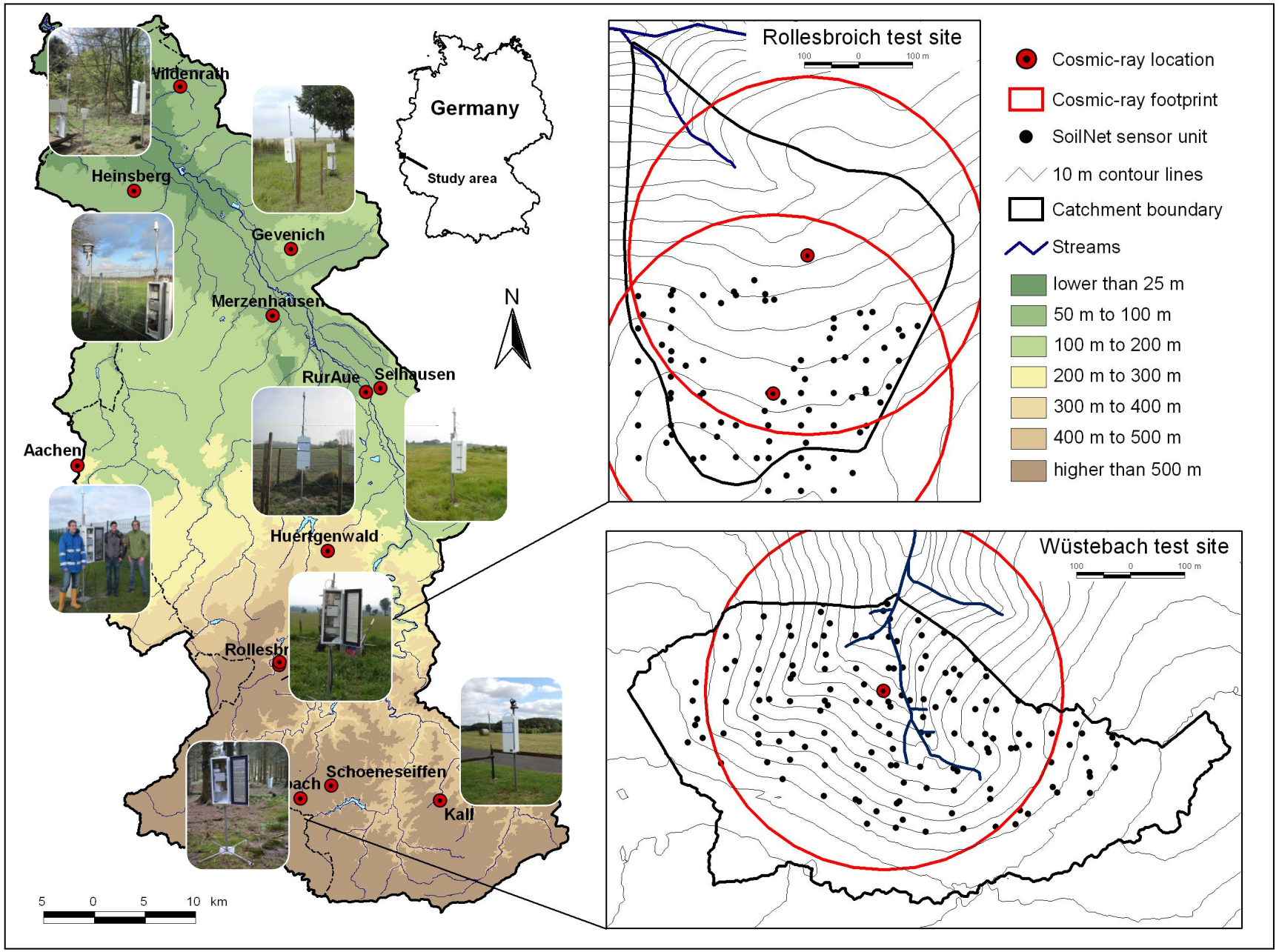
$$\theta_{vol} = \theta_{tot} - \theta_{lat} - \theta_{SOM}$$

Θ_{tot}	Total water content [cm³/cm³]
a_0, a_1, a_2	Constant parameters
ρ_{bd}	Soil density [g/cm³]
N_{corr}	Measured and corrected fast neutrons (counts/h)
N_0	Fast neutron counts for dry soil conditions (counts/h)
Θ_{vol}	Volumetric soil water content [cm³/cm³]
Θ_{lat}	Lattice water content [cm³/cm³]
Θ_{SOM}	Water equivalet of soil organic matter [cm³/cm³]



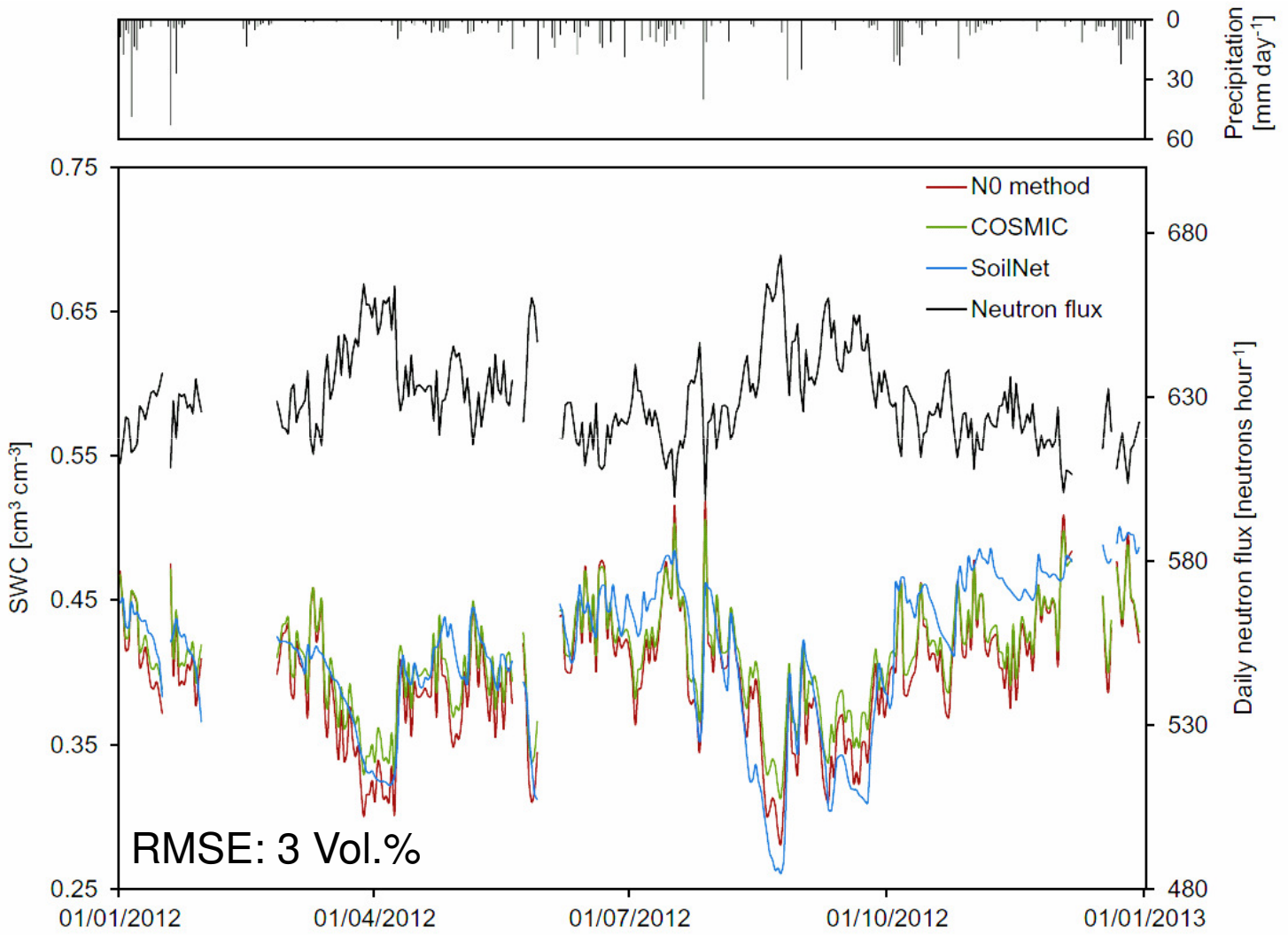
Field calibration in Rollesbroich (May 2011)

Network of 13 cosmic-ray soil moisture probes



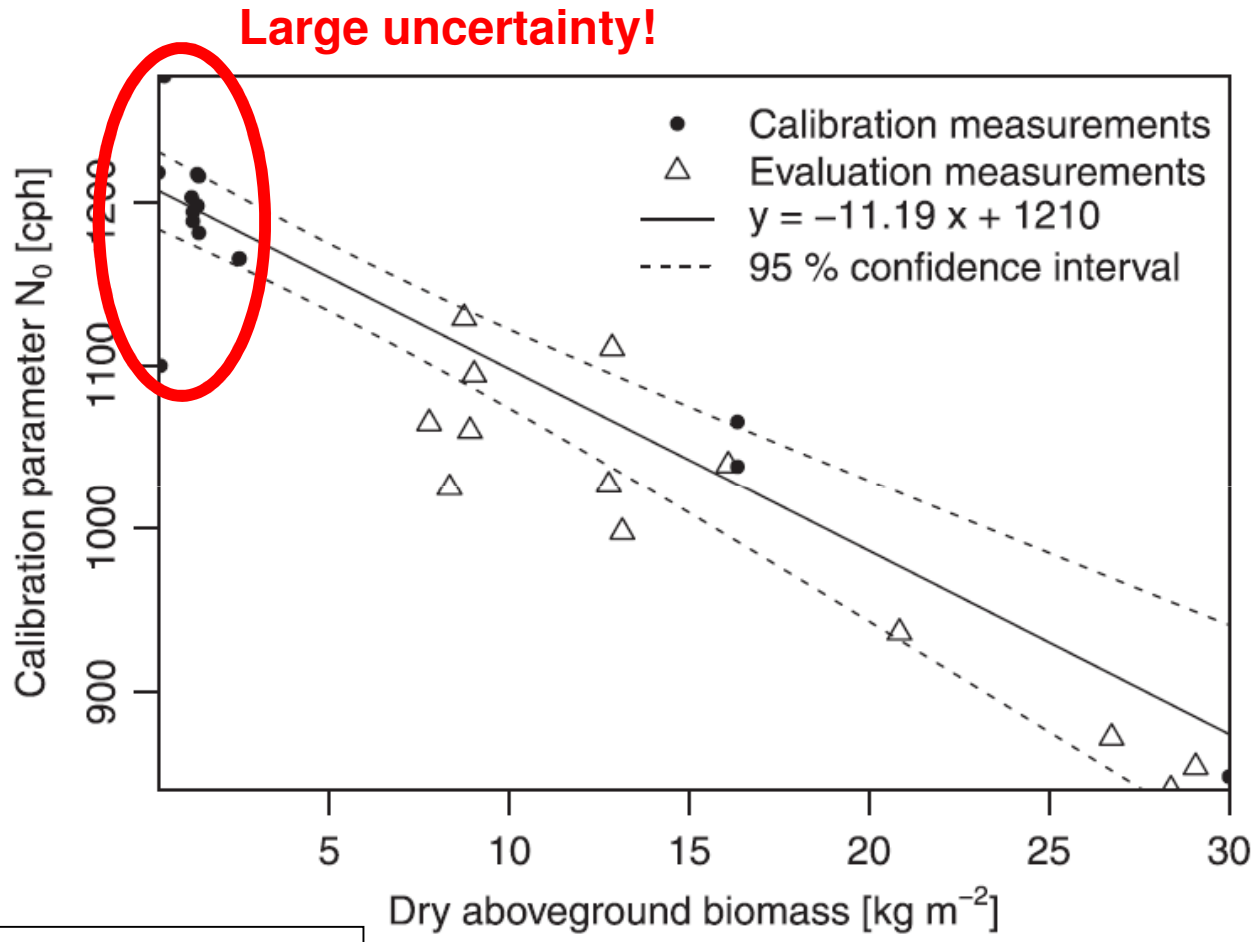
Comparison with in-situ soil moisture data

Example: grassland test site Rollesbroich



Baatz et al. (2014), J. Hydrol.

Cosmic-ray data is influenced by biomass



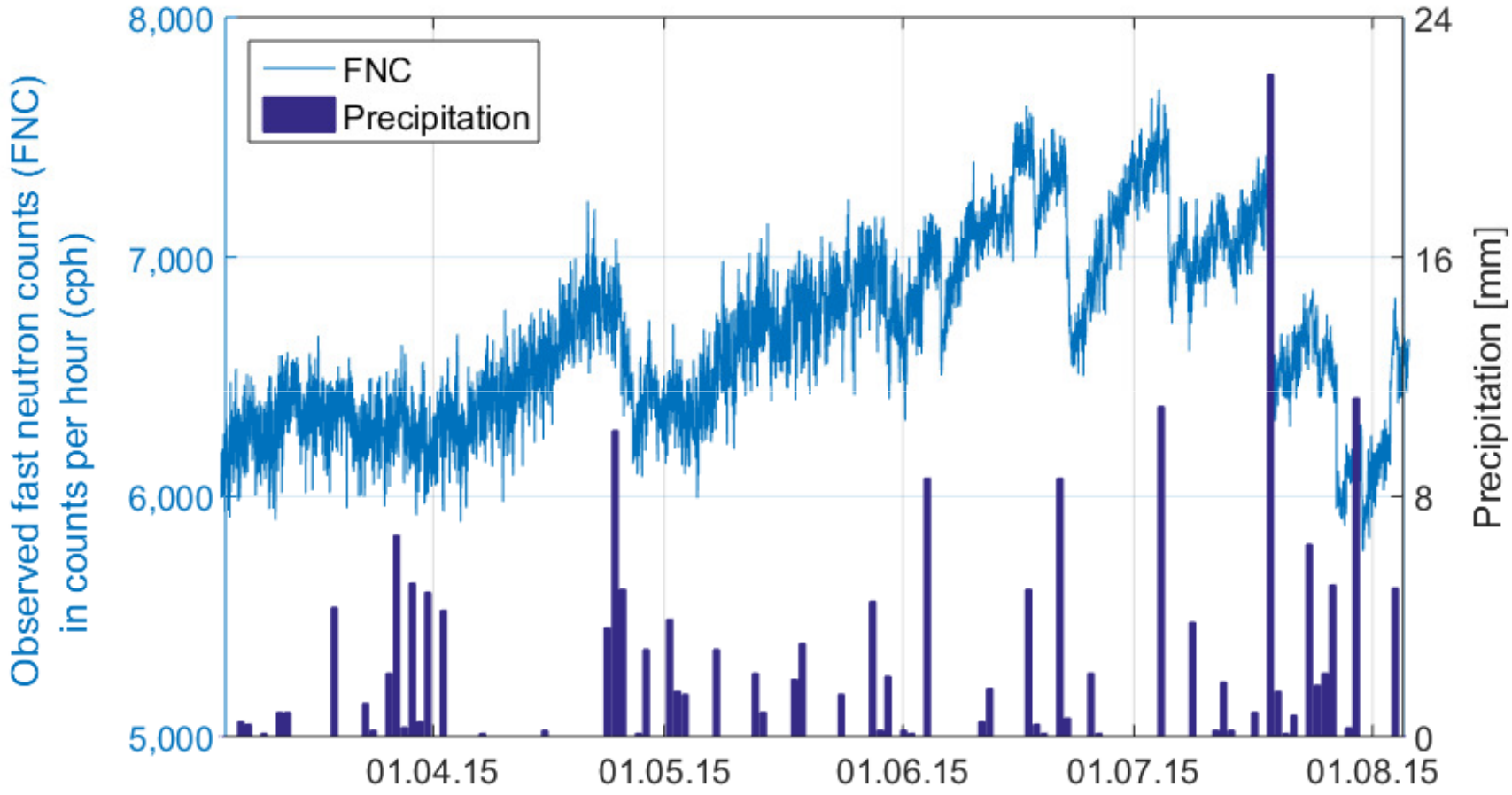
$$\theta_{tot} = \frac{\rho_{bd} \cdot a_0}{(N_{corr} / N_0) - a_1} - \rho_{bd} \cdot a_2$$

Baatz et al. (2015), WRR

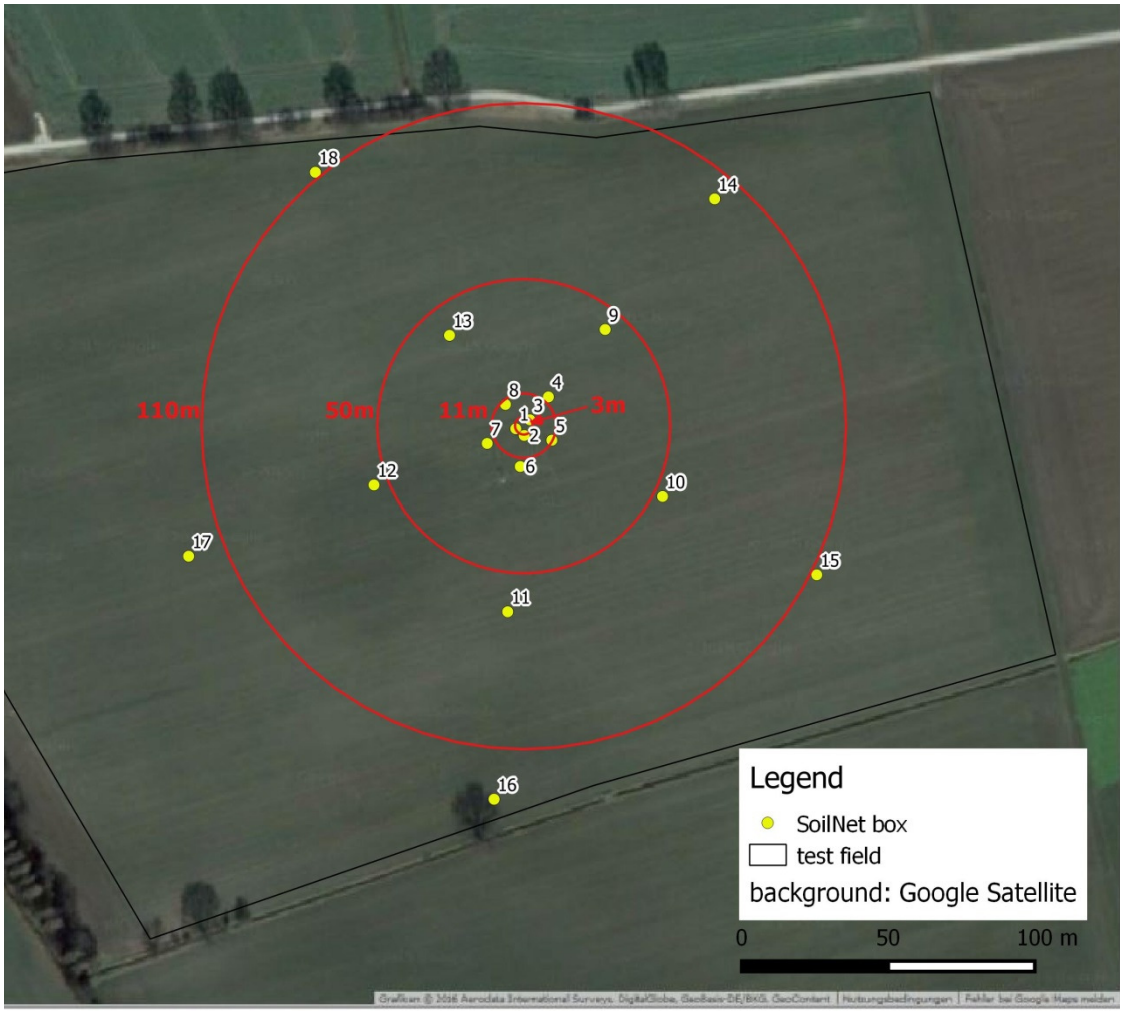
Selhausen test site: Experimental setup

Seven cosmic-ray neutron probes (4 CRS1000, 2 CRS2000/B, 1 cross calibrator)

Measured fast neutron intensities



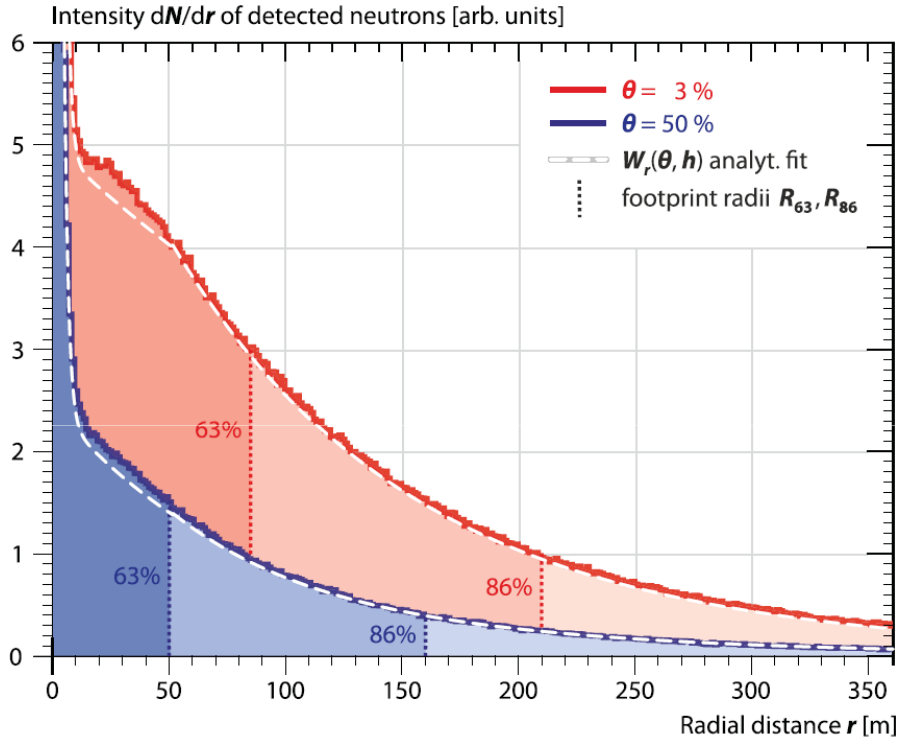
Experimental setup: SoilNet



SoilNet sensor unit

18 SoilNet sensor units each with 2 SMT100 SWC sensors installed at 5, 10 and 20 cm depth

Comparison of Cosmic-ray with SoilNet data



Köhli et al., 2015

→ SWC measured by SoilNet has to be weighted accordingly to be comparable to CRNP

Vertically → depending on penetration depth, and soil water content

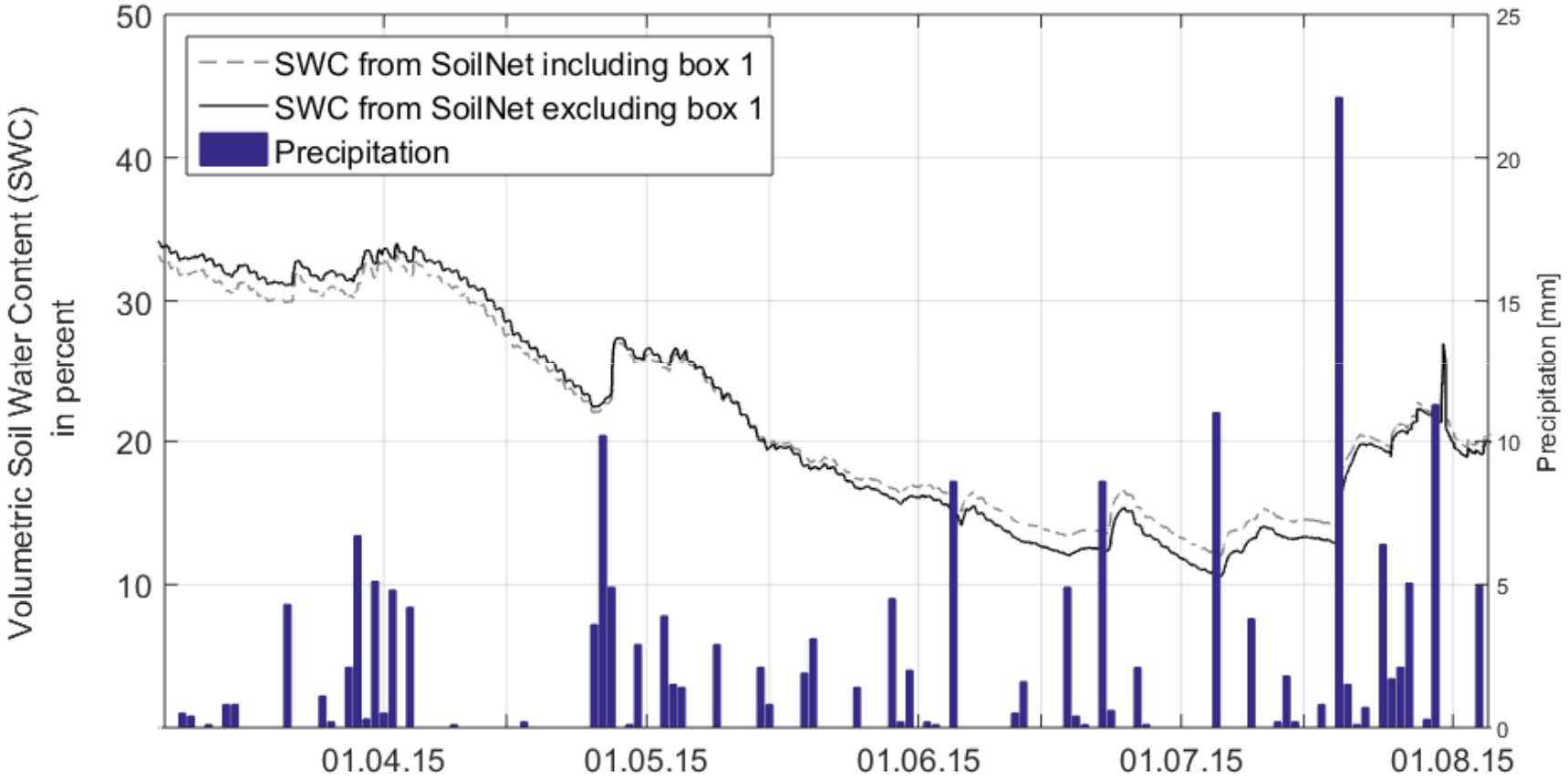
$$D_{86}(r,\theta) = \rho_{bd}^{-1}\left(p_0 + p_1\left(p_2 + e^{-r/100}\right)\frac{p_3+\theta}{p_4+\theta}\right)$$

$$W_d(r,\theta) \propto e^{-2d/D_{86}(r,\theta)}$$

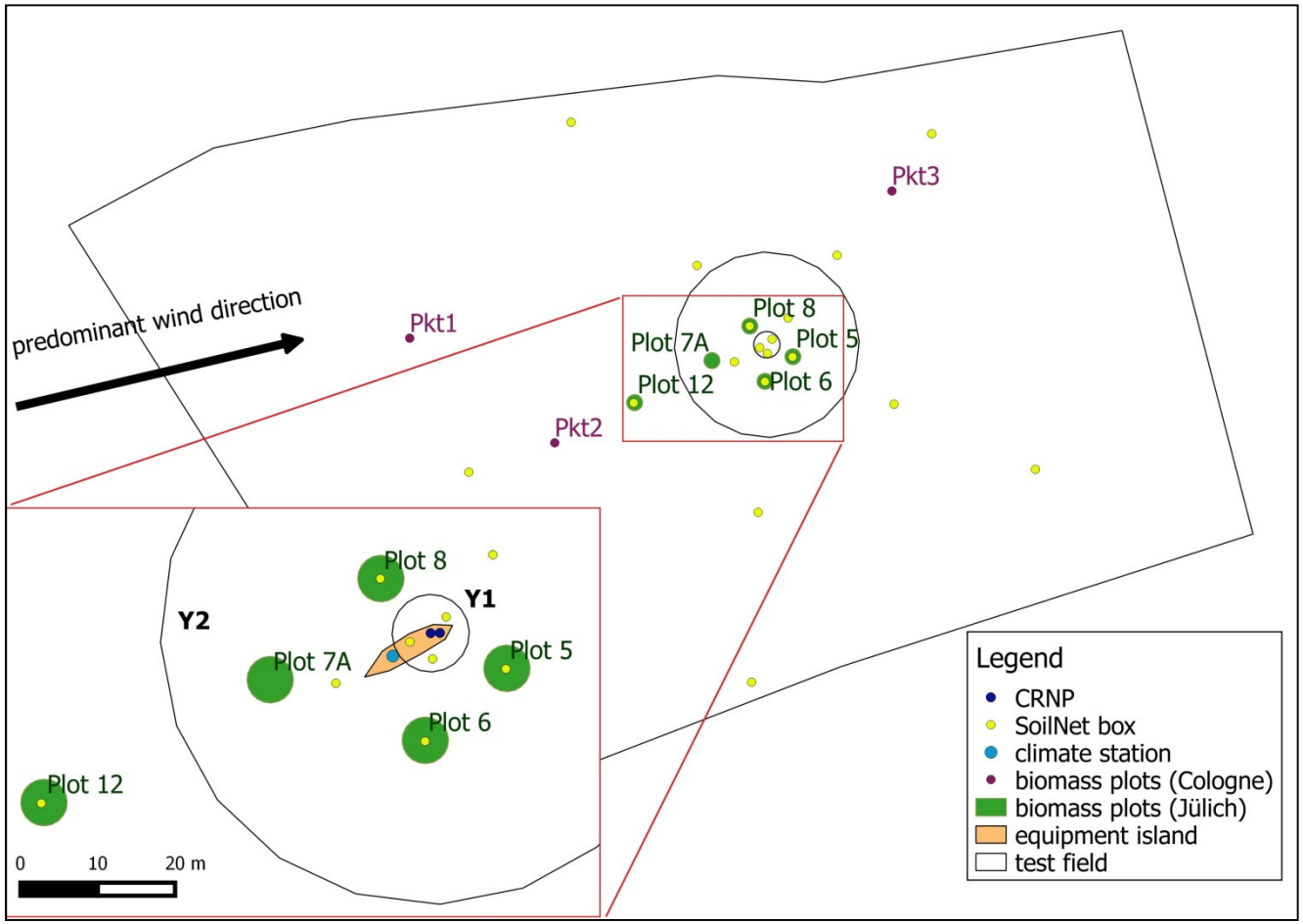
Horizontally → depending on distance, soil water content and air humidity

$$W_r(h,\theta) \approx \begin{cases} F_1\, e^{-F_2 r} + F_3\, e^{-F_4 r}, & 0.5\,\mathrm{m} < r \leq 50\,\mathrm{m} \\ F_5\, e^{-F_6 r} + F_7\, e^{-F_8 r}, & 50\,\mathrm{m} < r < 600\,\mathrm{m} \end{cases}$$

Weighted soil moisture



Biomass, LAI and interception sampling according to ICOS protocols

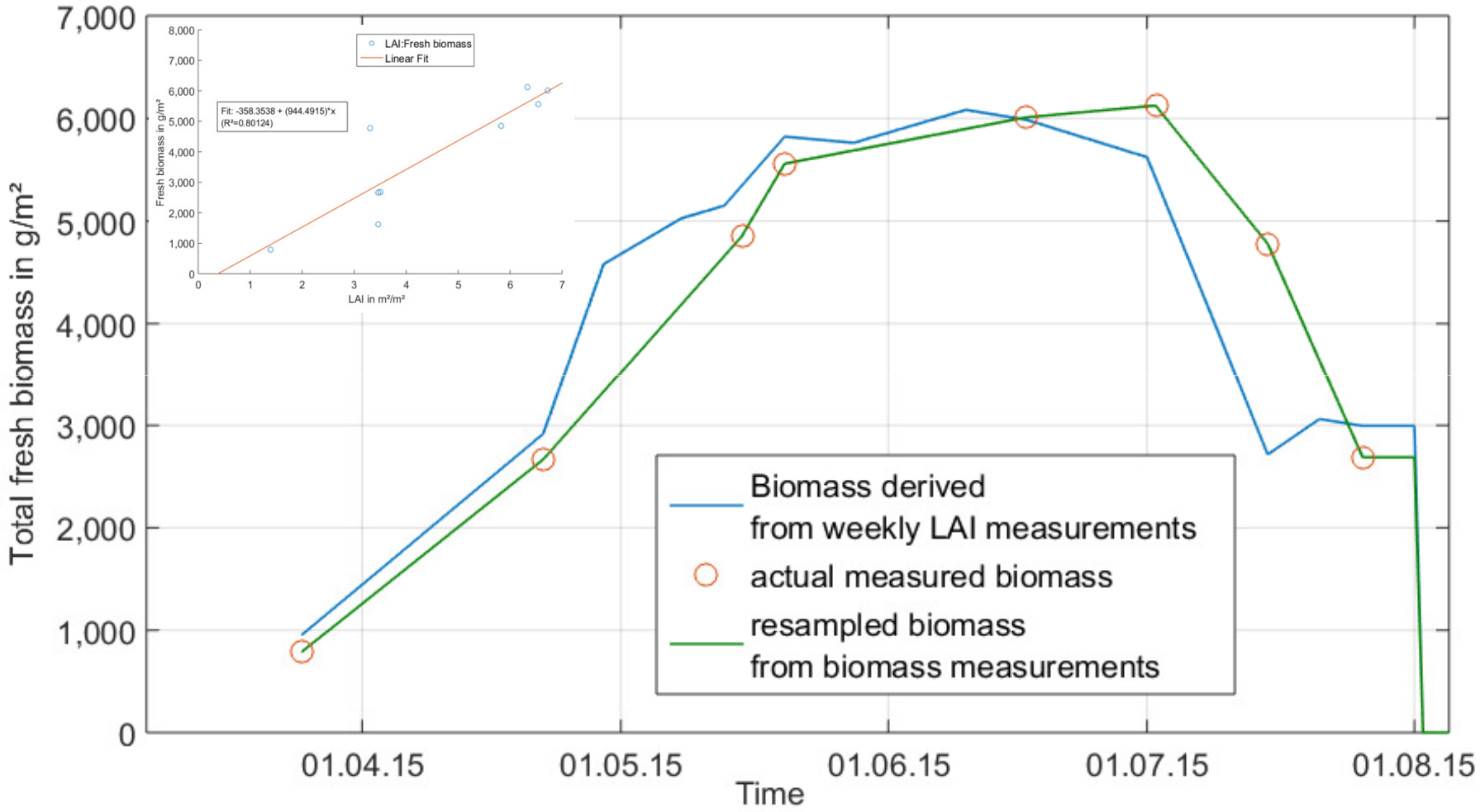


Biomass sampling plots

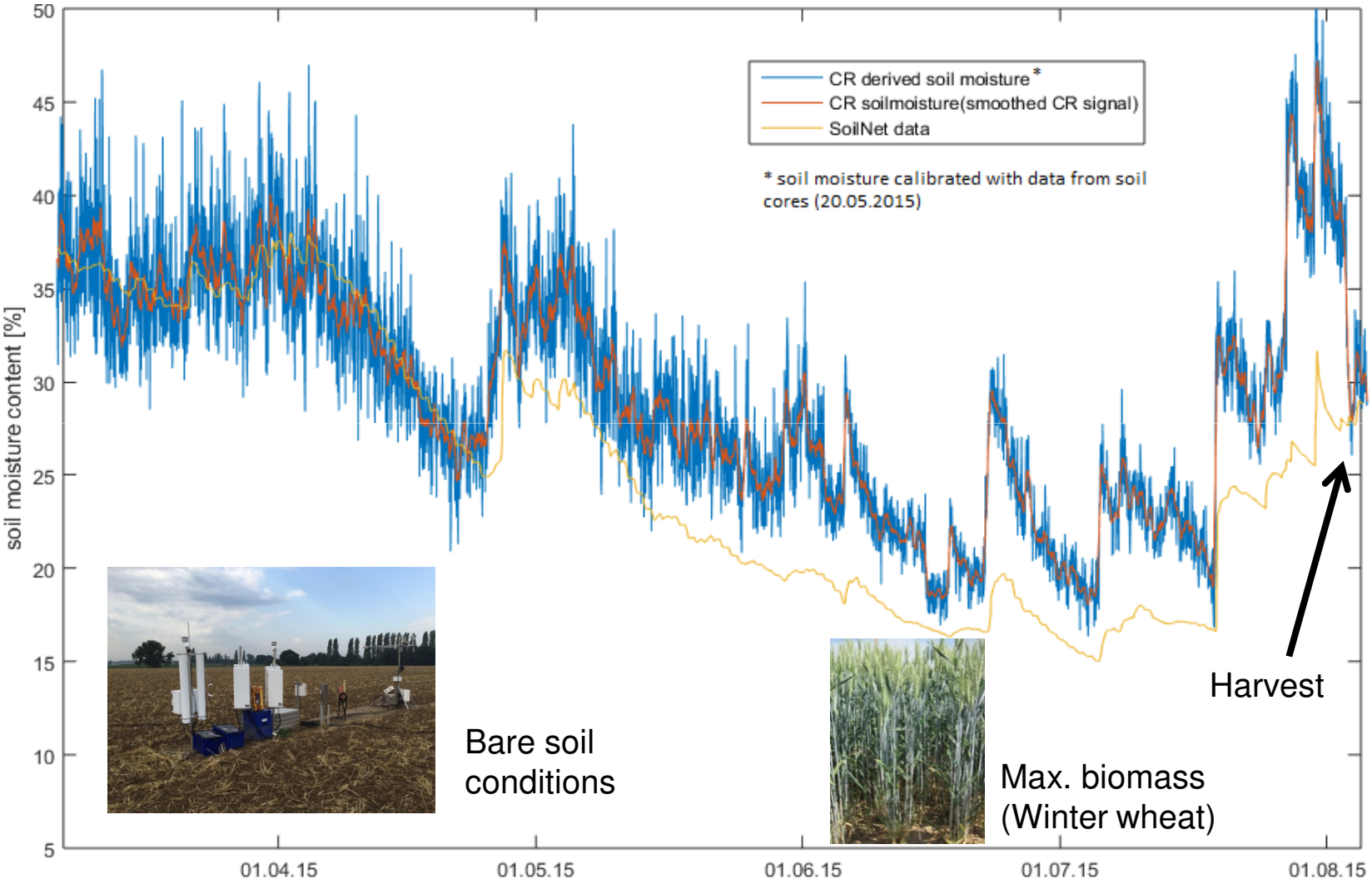
LAI measurements

Interception measurements

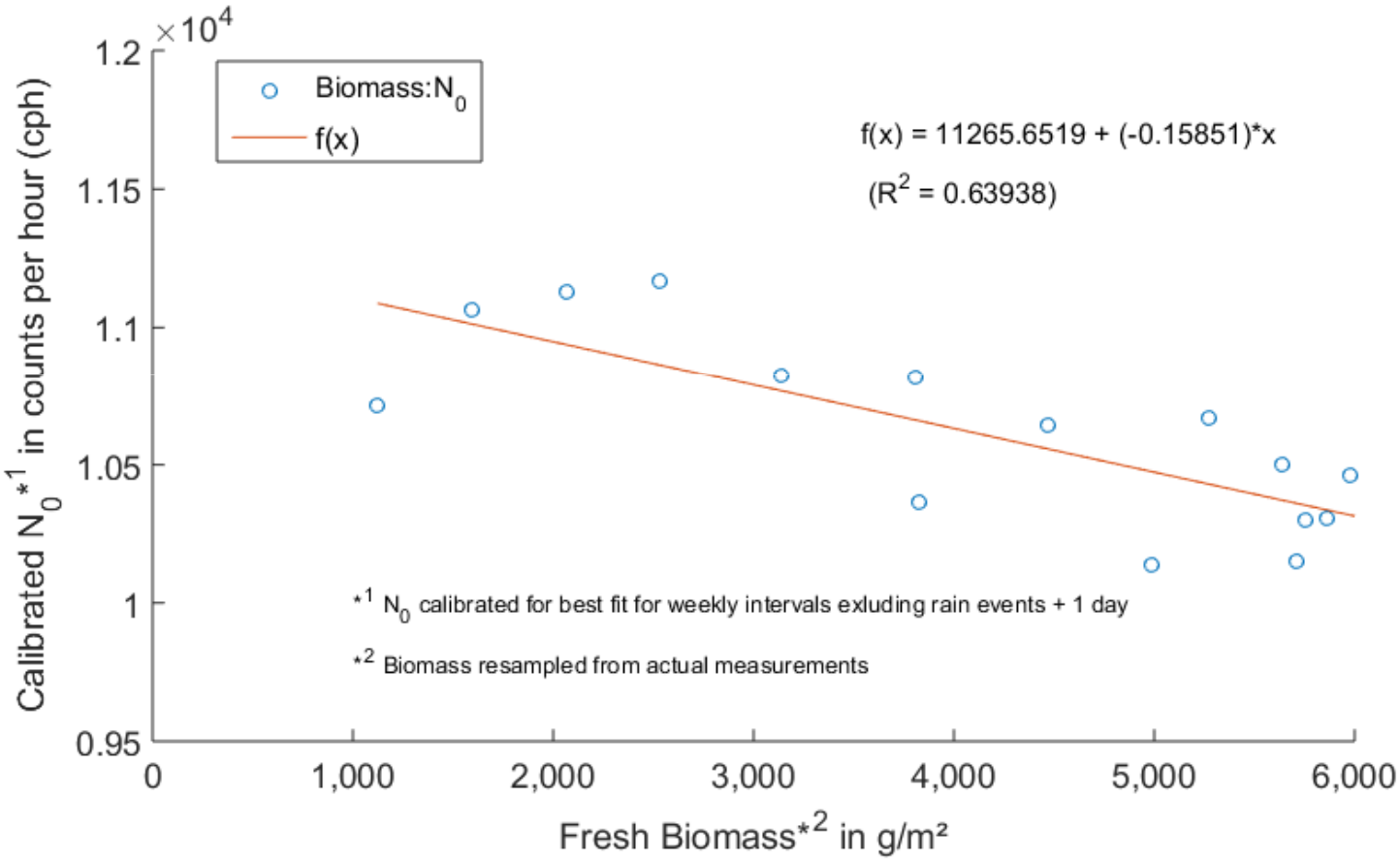
Biomass development



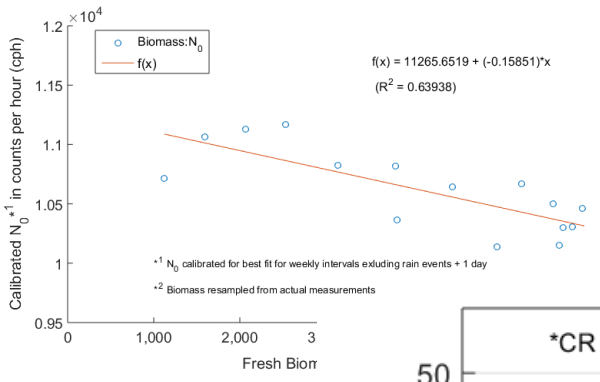
Biomass effects on cosmic-ray soil moisture

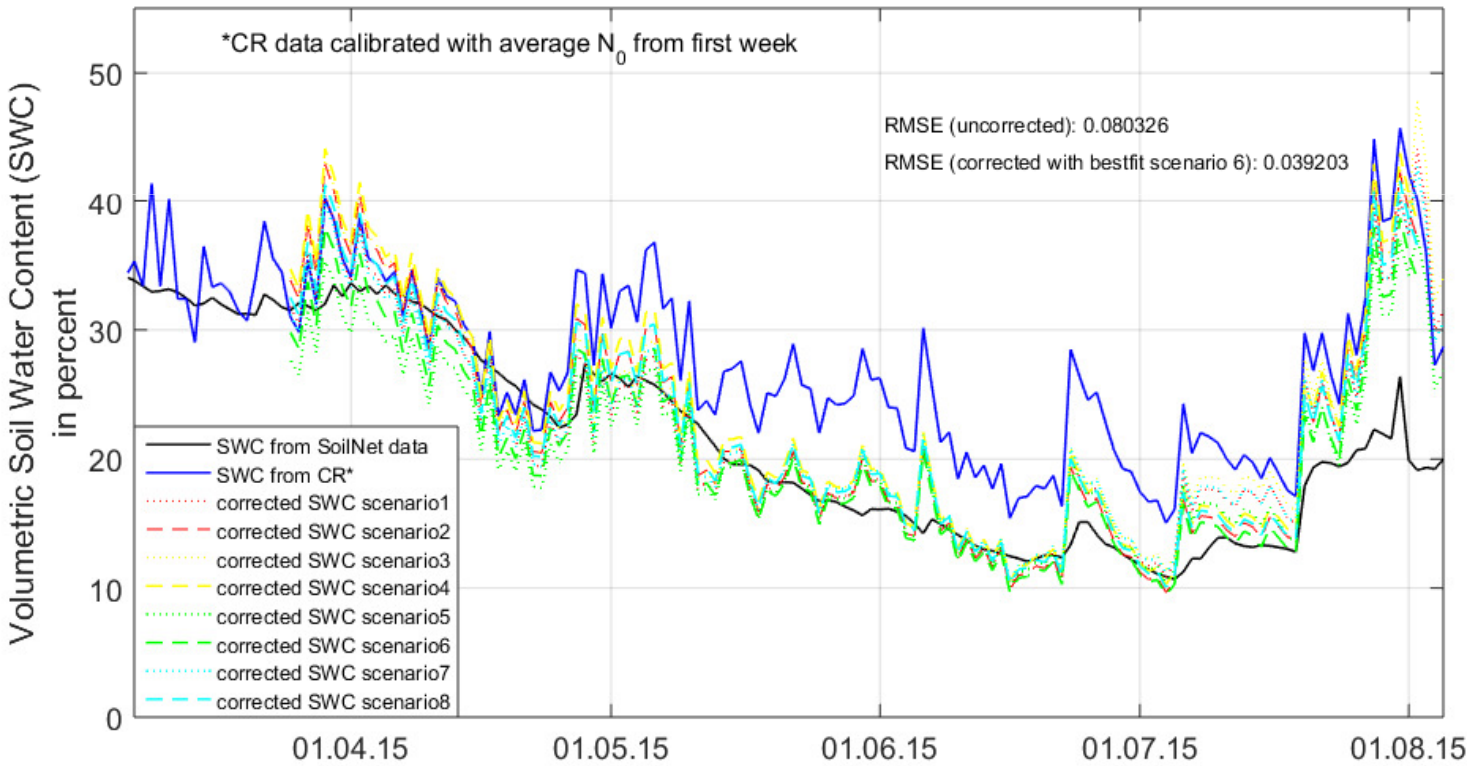


Relationship between N0 and biomass

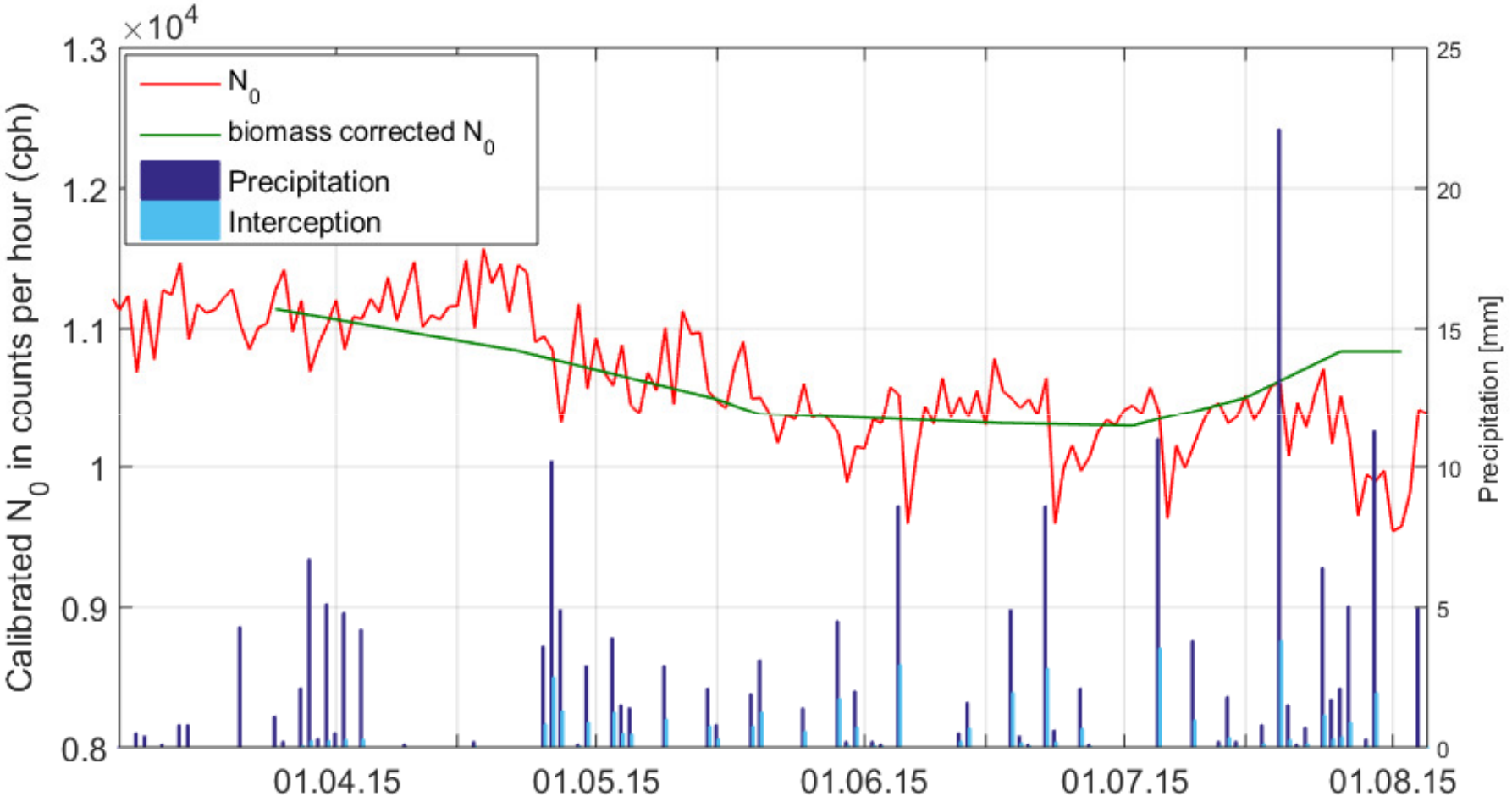


Correction of biomass effects





Influence of interception effects on N0



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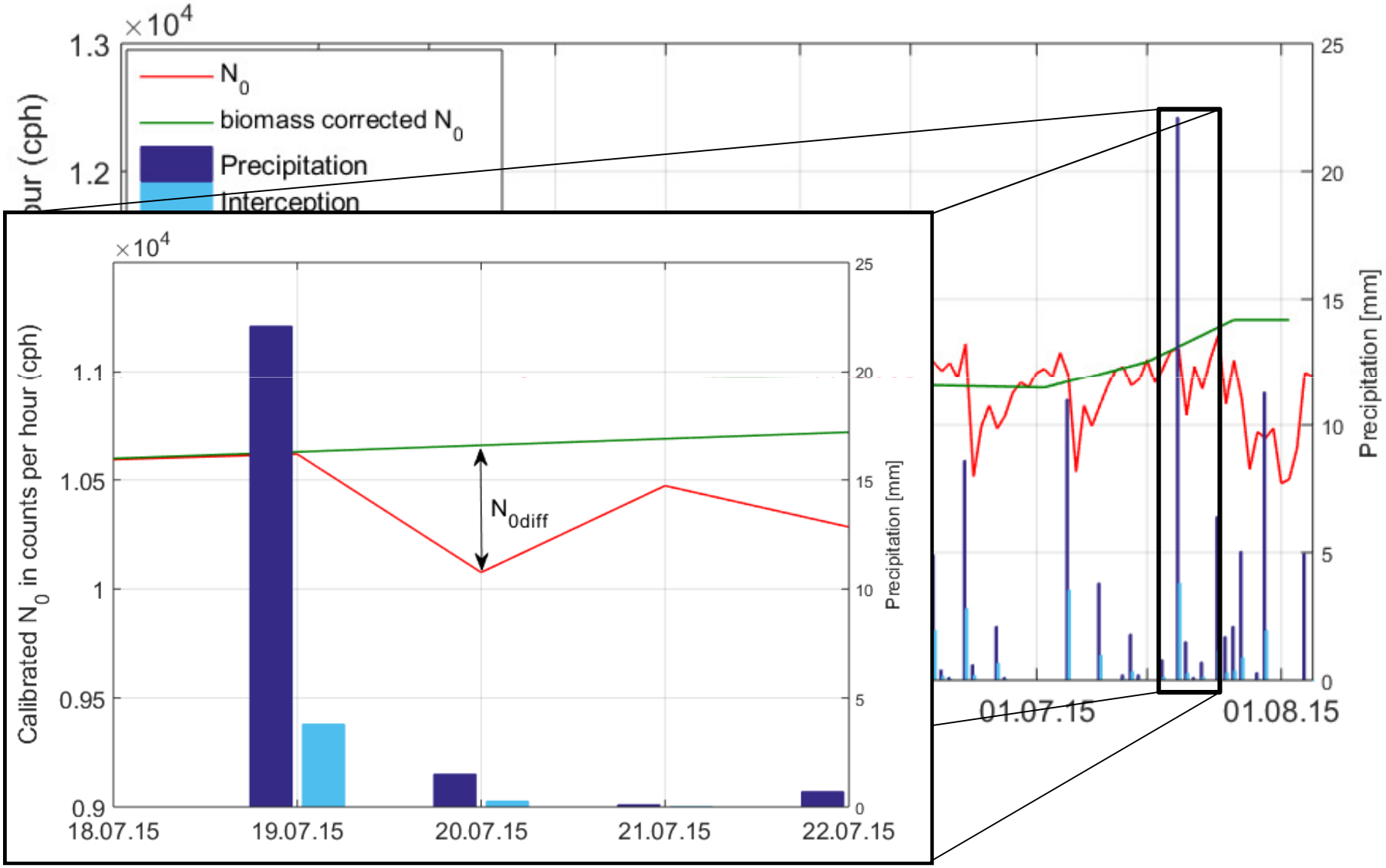

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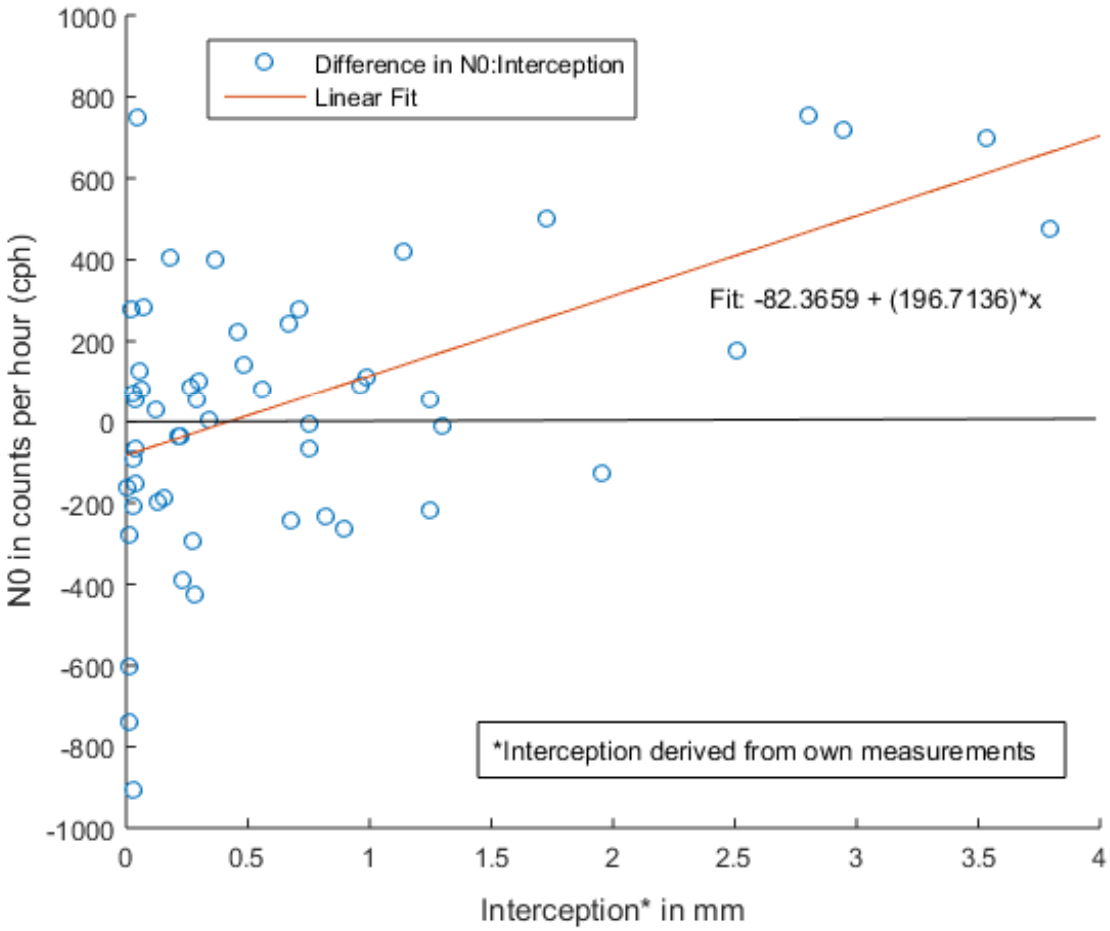

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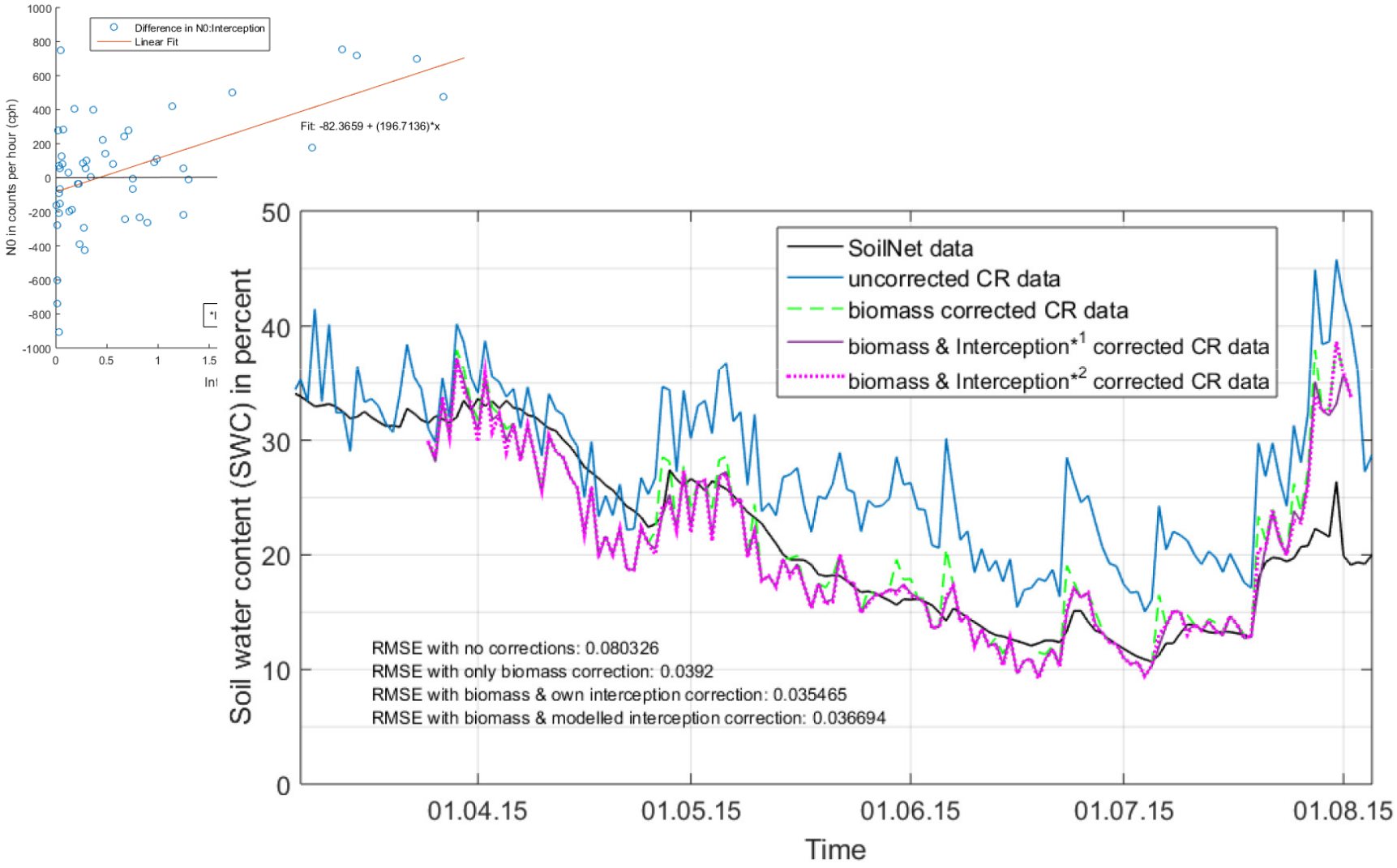
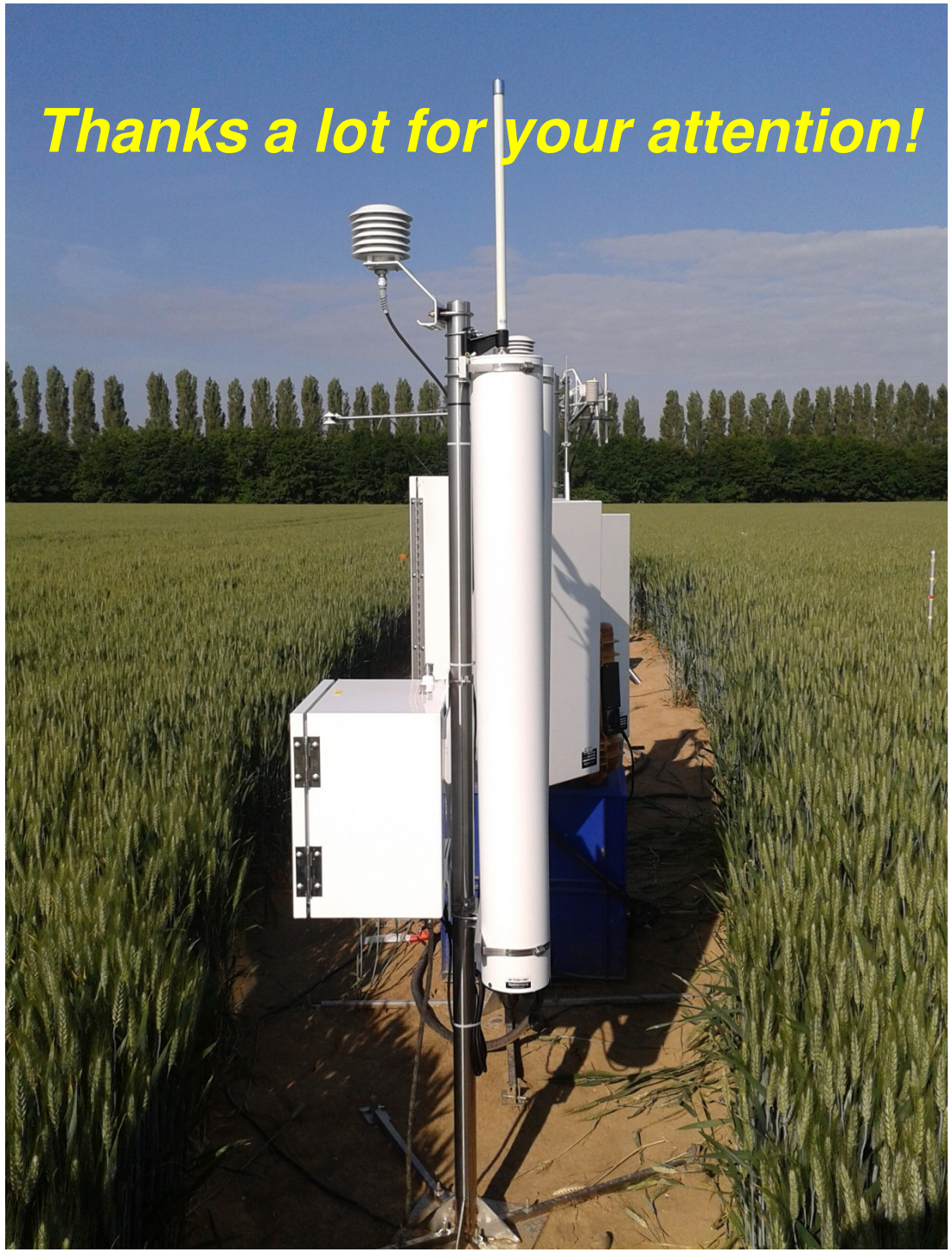


Conclusions

- This study stressed the importance of biomass and interception effects on cosmic-ray soil moisture measurements in agricultural environments
- The RMSE could be reduced from 0.08 m^3/m^3 to 0.035 m^3/m^3 by applying corrections for biomass and interception effects
- Remaining deviations are likely due for strong soil moisture gradients in the top 5 cm of the soil
- Further experiments with different crops have started this year (e.g. sugar beet)



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