Harmonising CRNS and point-scale soil moisture data using Hydrus-1D

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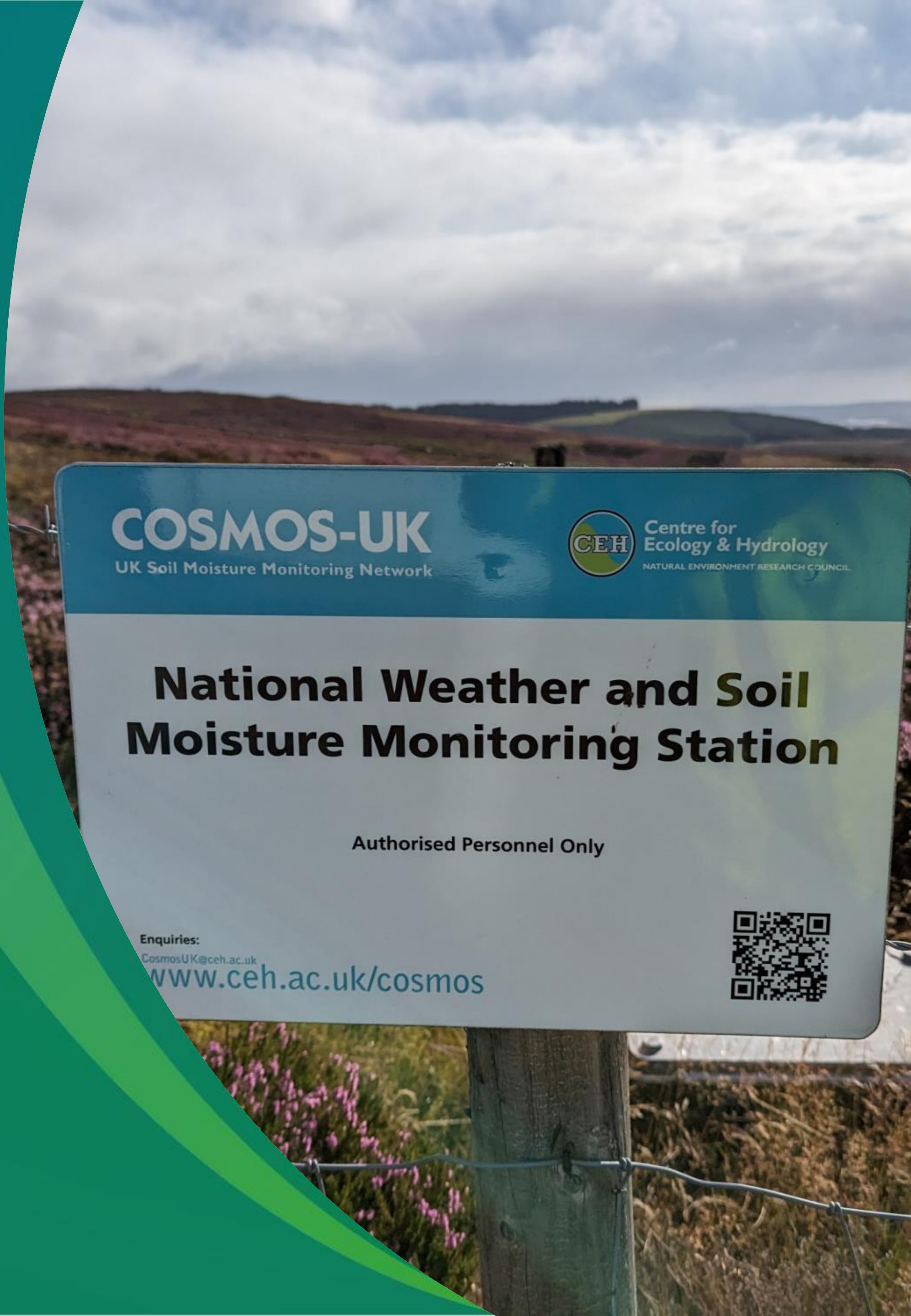


Aims and Objectives

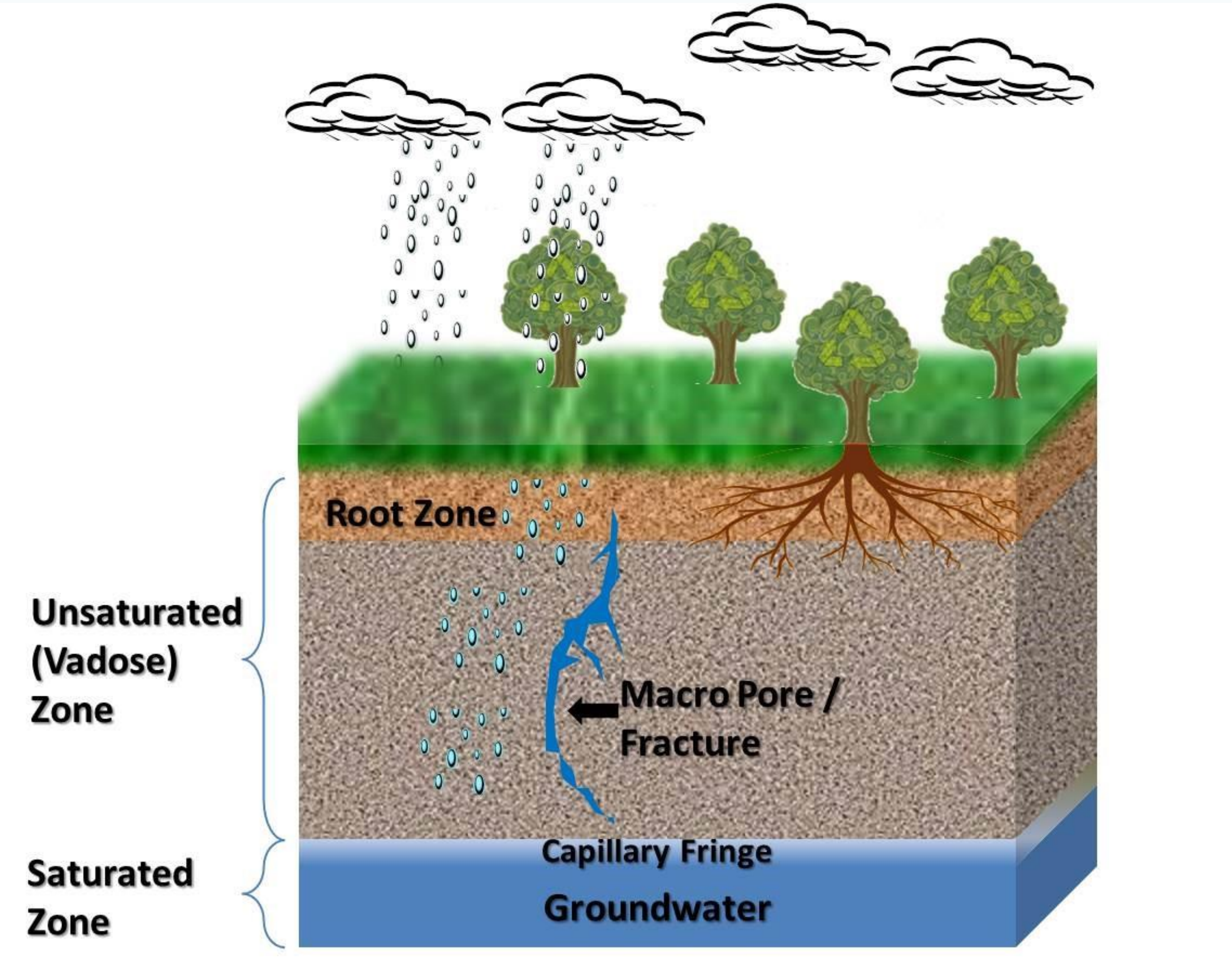
SoMMet (Soil Moisture Metrology) – need for soil moisture observation systems at multiple scales to be harmonised

This work aims to:

a) Make CRNS and point-scale measurements more comparable
b) Improve QA of CRNS data
c) Investigate methods of bias correcting implausible point-scale sensor data
d) Estimate soil moisture profiles beyond the CRNS penetration depth

Simulating water flow

- Hydrus-1D model – process model that simulates water flow through unsaturated (vadose) zone
- The standard HYDRUS-1D module numerically solves the Richards equation for variably-saturated water flow and advection-dispersion type equations for heat and solute transport



Basic model

- Classes developed by Michael Tso (UK-CEH)
- Select a COSMOS-UK site and pull driving data from the COSMOS-UK API and MODIS LAI satellite data
- **Precipitation**
- **PE (Potential Evapotranspiration)**
- **MODIS LAI (Leaf Area Index) -** the amount of leaf surface area relative to the ground area – taken from Google Earth Engine: [MCD15A3H.061 MODIS Leaf Area Index/FPAR 4-Day Global 500m | Earth Engine Data Catalog | Google for Developers]
- Root water uptake distribution representative of permanent grassland

$$T_p = ET_p(1 - e^{-0.463LAI})$$

$$E_p = ET_p e^{-0.463LAI}$$

where T_p = Potential Transpiration,

E_p = Potential Evaporation and

ET_p = Potential Evapotranspiration

We develop the linear function of potential root water uptake distribution $S_p^*(z)$ vs depth, following Hoffman and van Genuchten.

$$S_p^* = \begin{cases} 1 & \text{for} \quad z > L - r_1 \\ \frac{z - [L - (r_1 + r_2)]}{r_2} & \text{for} \quad L - r_1 \geq z \geq L - (r_1 + r_2) \\ 0 & \text{for} \quad L - r_1 z < L - (r_1 + r_2) \end{cases} \tag{1}$$

```
# Define loop for potential root water uptake distribution proposed by Hoffman and Van Genuchten
def z_loop(z, r1 = 10, r2 = 20):
    if z > -r1:
        return 1
    elif z < -(r1 + r2):
        return 0
    else:
        return(z+(r1+r2))/r2
```

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Processes and materials

- Originally taken from LANDIS Horizon Hydraulics Data (now not publicly available)
- van Genuchten-Mualem model parameters
- Possible to estimate these from bulk density and soil texture information (UK-CEH - soil sampling CRNS calibrations)
- Quasi-saturation – between saturated and field capacity
- Residual – amount left after drainage

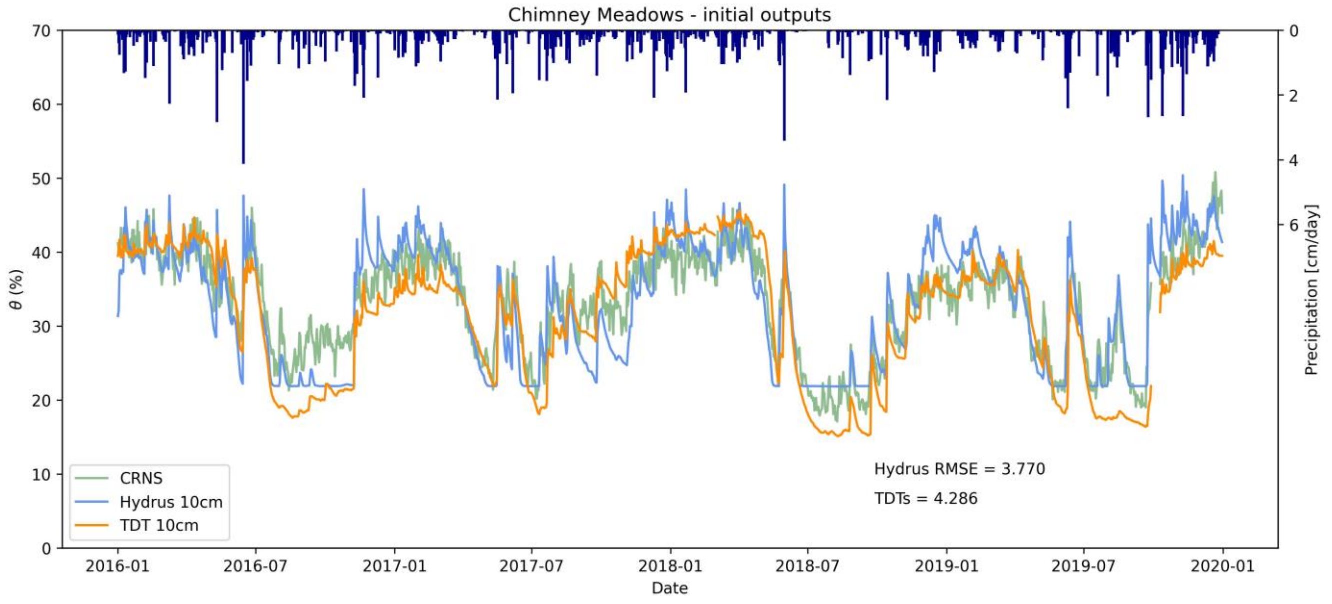
Water Content at Quasi-Saturation (θ_S), Residual Water Content (θ_R), Saturated Hydraulic Conductivity (K_s), and Model Fitting Parameters (n, α)

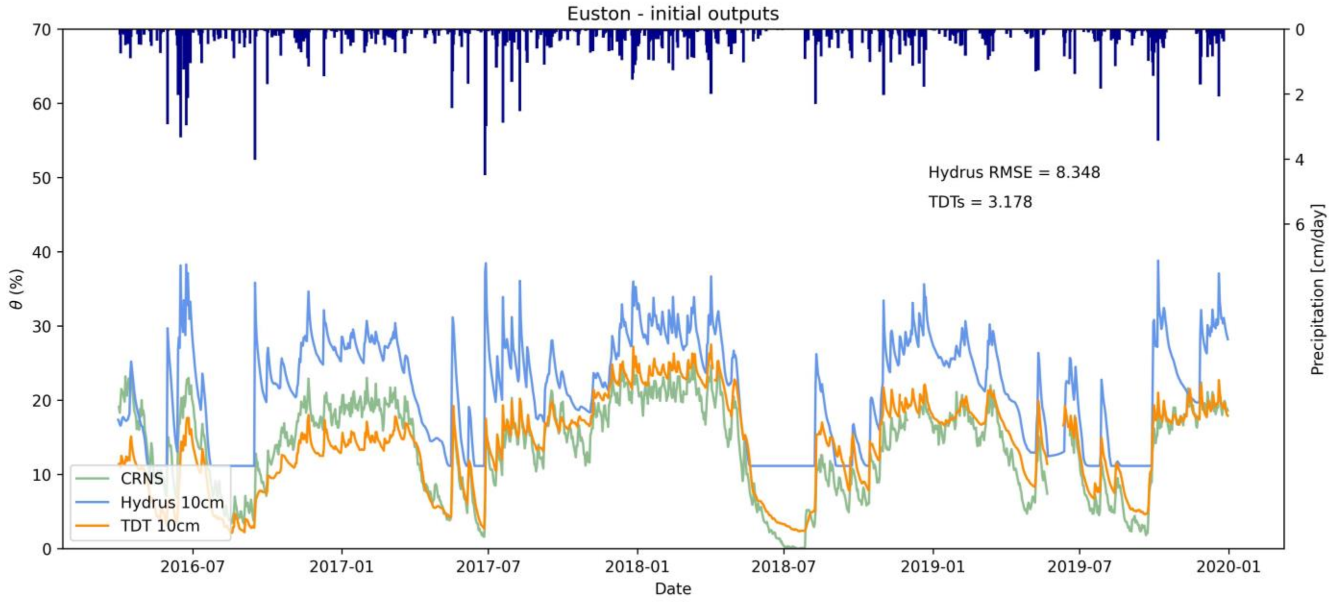
Site identifier	Soil hydraulic parameters				
	$\theta_S(vol.\%)$	$\theta_R(vol.\%)$	α	n	K_s
CARDT	48.36	9.59	0.0492	1.2438	109.3
CGARW	90.0	9.0	0.1158	1.383	6540.5
CHIMN	54.56	11.36	0.054	1.2326	101.4
ELMST	32.5	7.32	0.0591	1.2488	76.4
EUSTN	45.21	7.31	0.0908	1.348	115.5
FINCH	36.98	7.71	0.0784	1.2984	92.05
HADLW	57.47	12.22	0.0441	1.2229	105.3
HYBRY	69.09	13.47	0.0406	1.2321	117.6
LODTN	44.09	11.35	0.0384	1.2131	71.5
RISEH	72.3	14.59	0.0468	1.2247	107.3
ROTHD	33.9	7.46	0.0406	1.2385	107.3
SPENF	40.33	9.34	0.051	1.2387	76.4
WRTTL	35.38	7.65	0.0489	1.2483	76.4

(Beale *et al.*, 2021)

Initial outputs

- Dry periods not modelled well (flatlining)
- Model input parameters needed refining particularly for Euston





Five grassland sites chosen

- CARDT
- CHIMN
- EUSTN
- HADLW
- WADDN
- Time series expanded up until 2024 (full years)

Refining inputs and CRNS comparisons

- Soil texture parameters taken from Harmonized World Soil Database
- Bulk density from field measurements
- Fitting parameters optimised using Rosetta and least squares minimization from CRNS soil moisture and predicted Hydrus values
- Initial pressure head calculated from:

$$h_i = \frac{\left[\left(\frac{\vartheta_s - \vartheta_r}{\vartheta_i - \vartheta_r}\right)^{\frac{1}{m}} - 1\right]^{\frac{1}{n}}}{\alpha} \quad \text{(van Genuchten, 1980)}$$

h_i = Initial pressure head, Initial water content (θ_i), Water Content at Quasi-Saturation (θ_s), Residual Water Content (θ_r), Saturated Hydraulic Conductivity (K_s), and Model Fitting Parameters (n, α); m = 1-1/n

Depth weighted means for Hydrus and TDT comparisons:

$$W_d = e^{-2d/D}$$ (Köhli *et al.*, 2015)

where W_d= weight for given depth, D = D86 depth in which 86% of neutrons penetrate the soil, d = depth (5, 10, 15, 25 and 50cm depths used to coincide with TDT depths)

$$\vartheta_w = \frac{\sum \vartheta_d W_d}{\sum W_d}$$ (Köhli *et al.*, 2015)

ϑ_w = depth weighted mean, ϑ_d= water content at given depth

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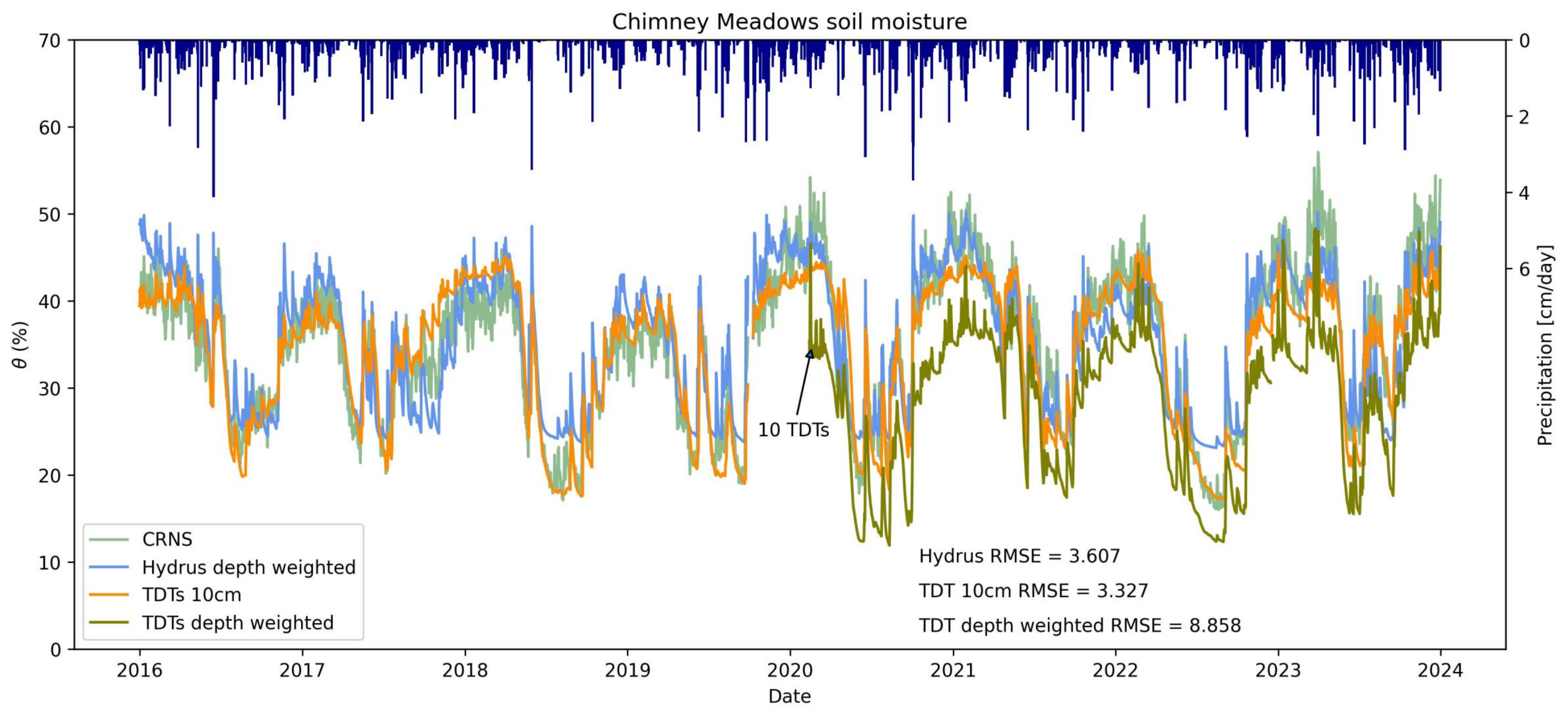
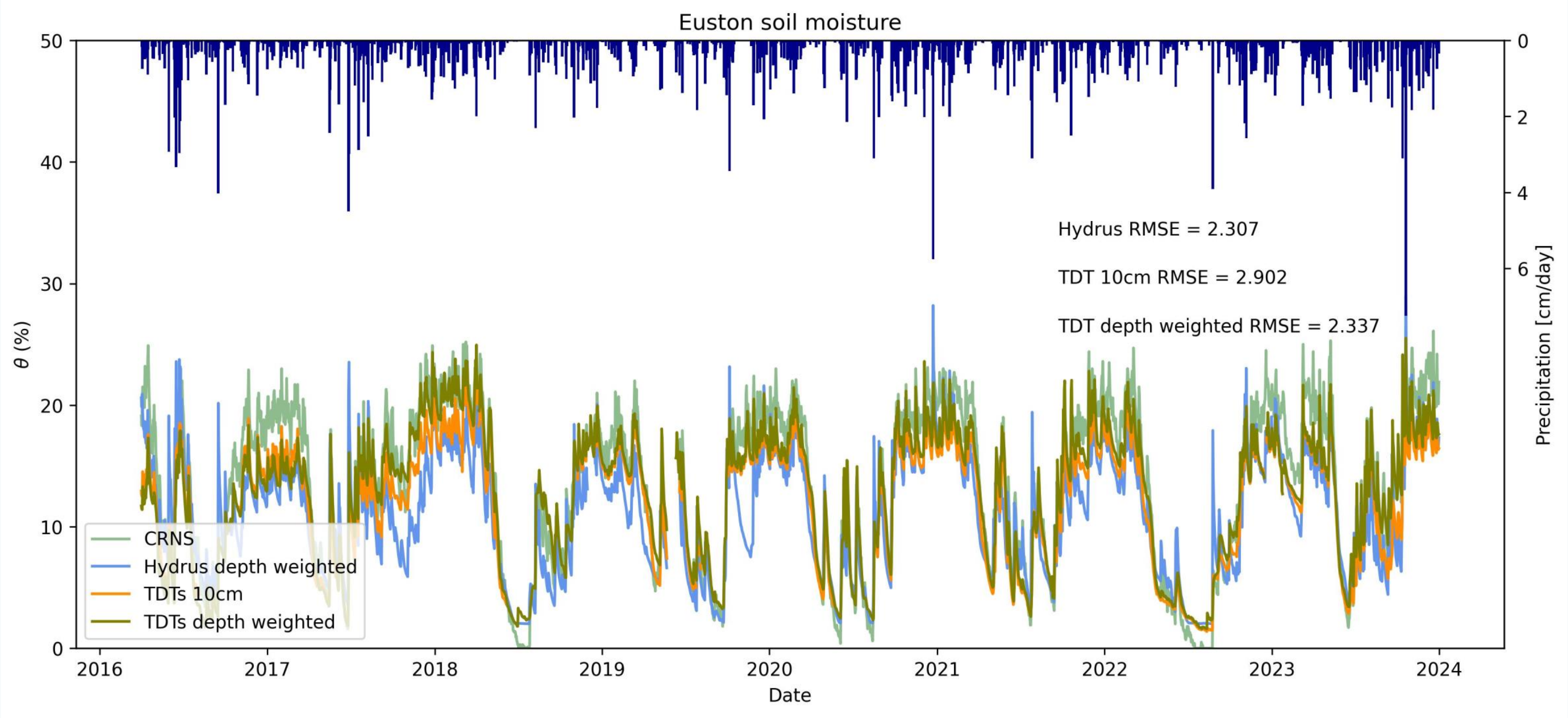
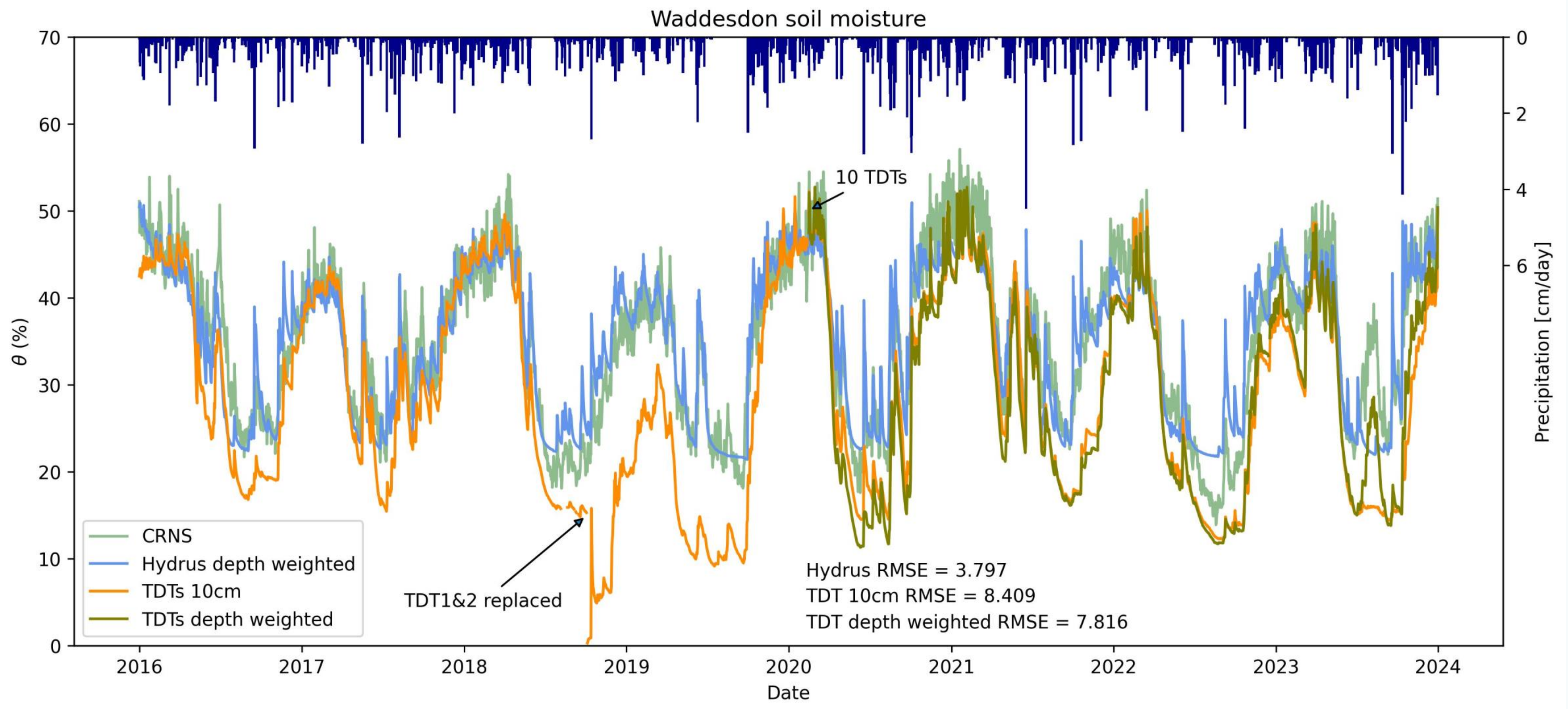


Reasonable agreement between Hydrus and CRNS – depth weighted mean of TDT measurements not as good agreement as 10cm TDTs. The average can be biased by TDT installation issues.



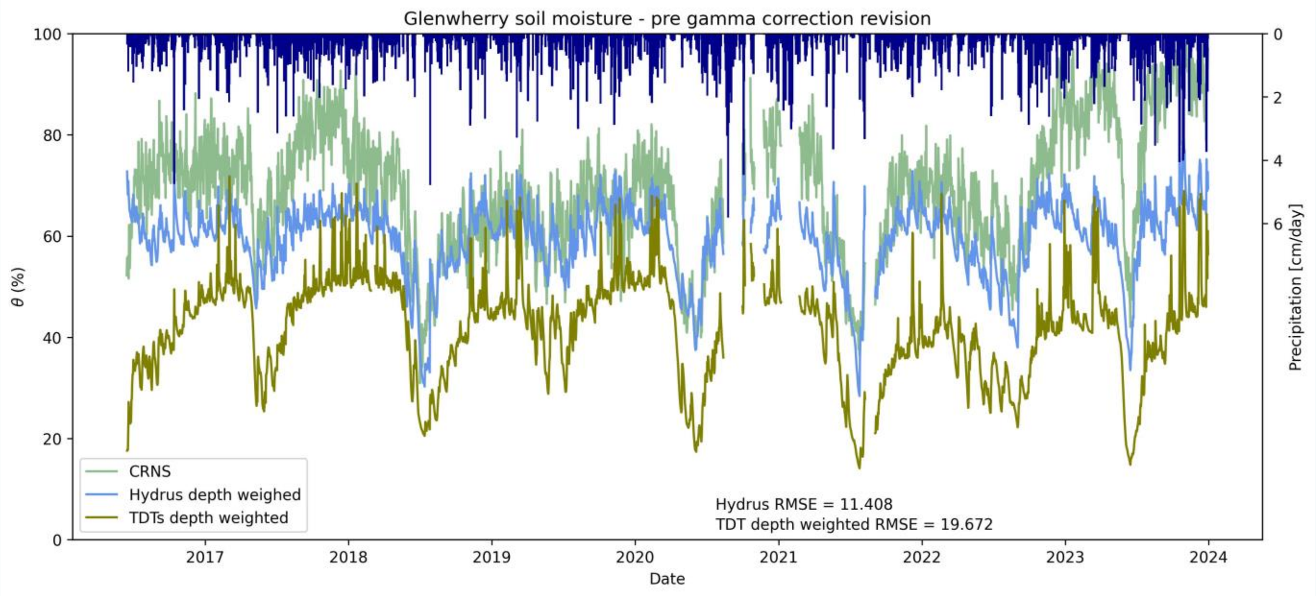
Reasonable agreement between Hydrus, CRNS and TDTs – missing rainfall adversely affects model outputs

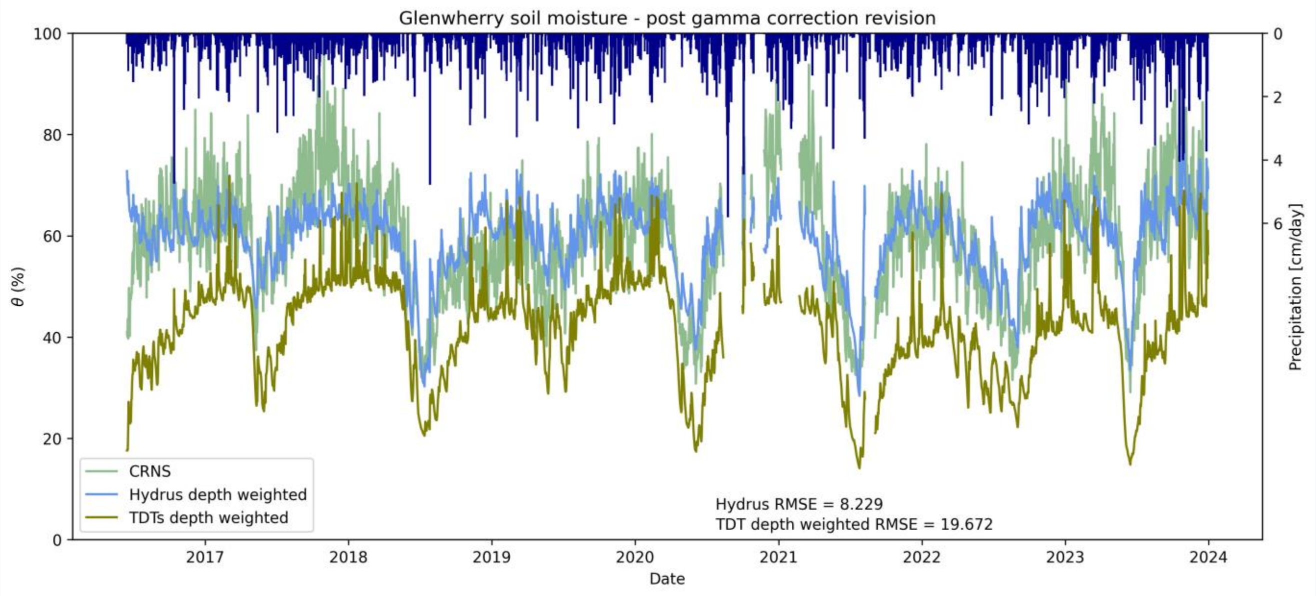


Reasonable agreement between Hydrus and CRNS – TDTs capture lower moisture conditions better, Hydrus still has a tendency to bottom out before TDTs and CRNS. We still have soil samples for WADDN, which we hope to get more accurate laser diffraction soil texture estimates in the lab – currently underestimating clay.

Quality Assurance

- Glenwherry in Northern Ireland showed rising trend in soil moisture as a new solar maximum approached
- The Hydrus-1D does not show the same trends
- Revised neutron intensity corrections (gamma value) appear to have improved VWC estimates for this and other sites
- It could be a useful tool to improve quality of CRNS soil moisture estimates





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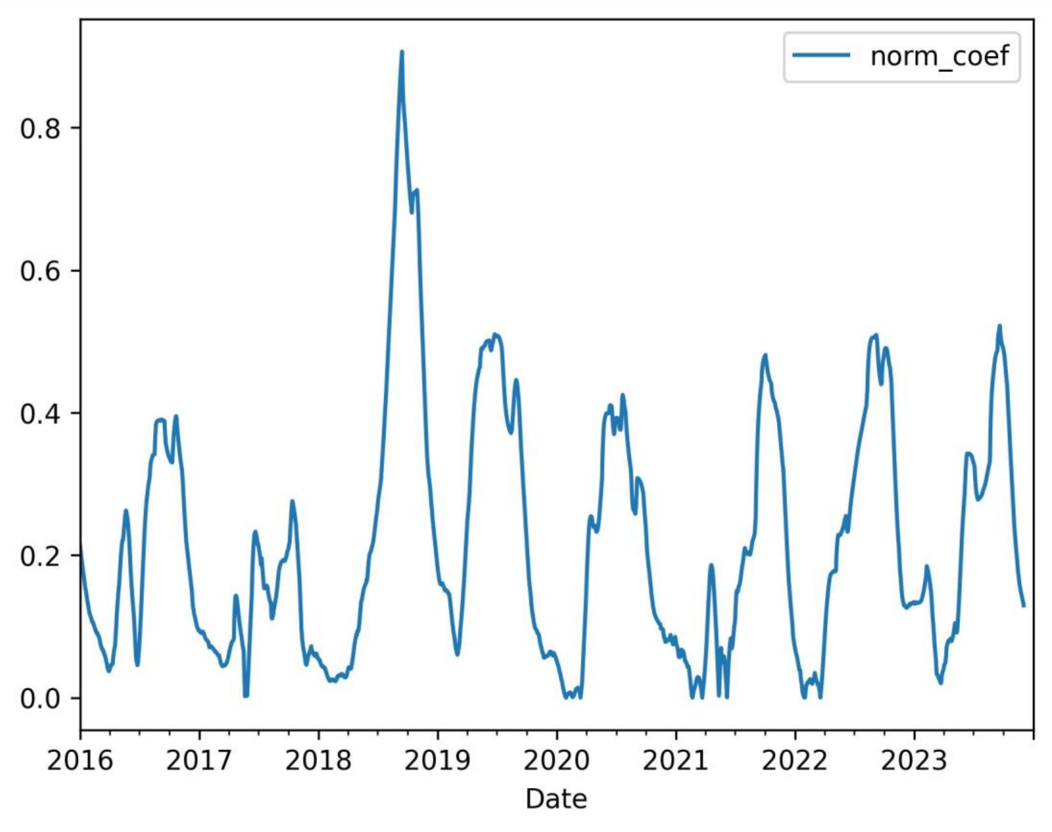
Bias correcting implausible point-scale sensor data

Rolling regressions

1. Deviations of point-scale TDT sensors from the Hydrus model are monitored using 30-day window linear regressions
2. Where TDT=Hydrus 1:1 slope
3. The slope is used to bias correct periods where a given threshold is exceeded
4. Bias = $\vartheta_{pred} - \vartheta_{hydrus}$
5. $\vartheta_{corr} = \vartheta_{pred}$ - (Bias * norm_coef)
6. Implausible TDT data re-estimated using Hydrus predictions which have been calibrated from the COSMOS data



Normalized deviation from 1:1 slope for WADDN TDT1 and Hydrus at the same depth (10 cm)

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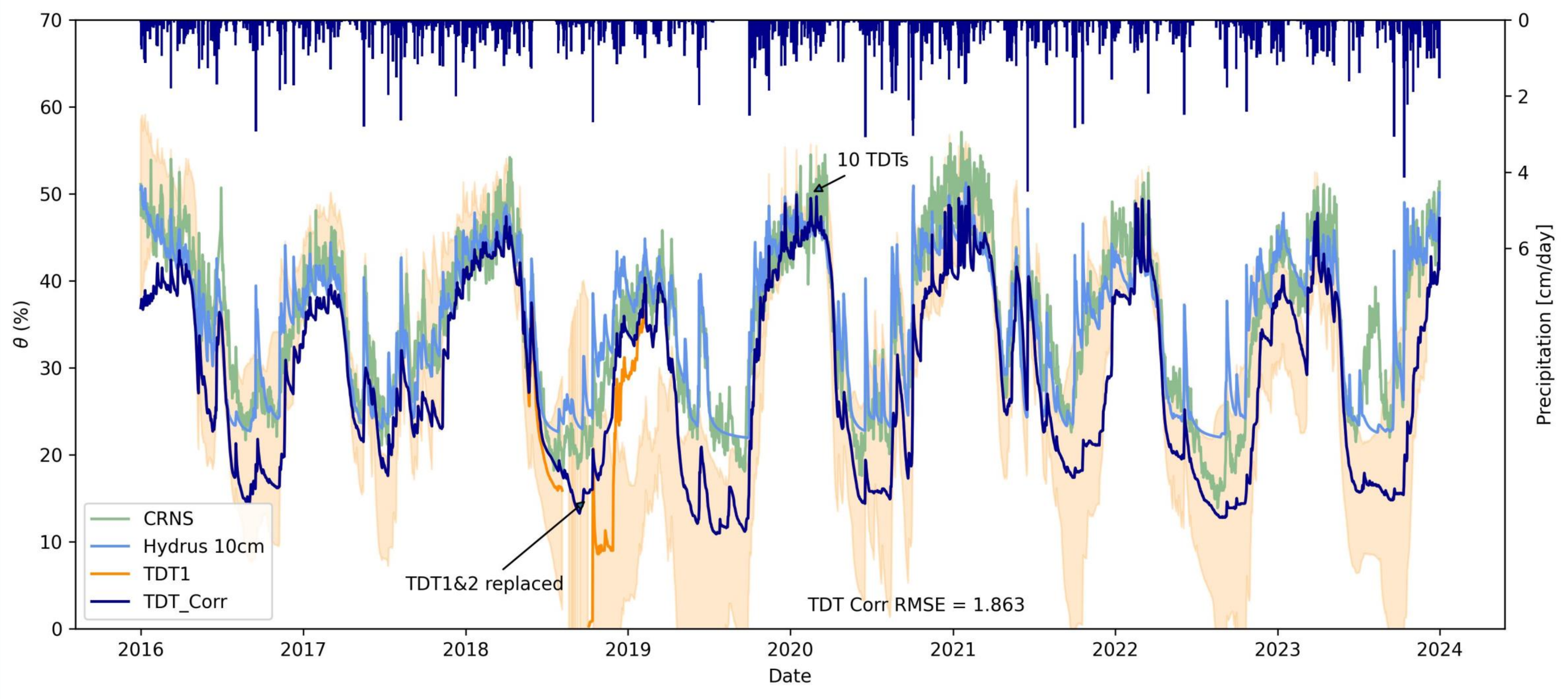
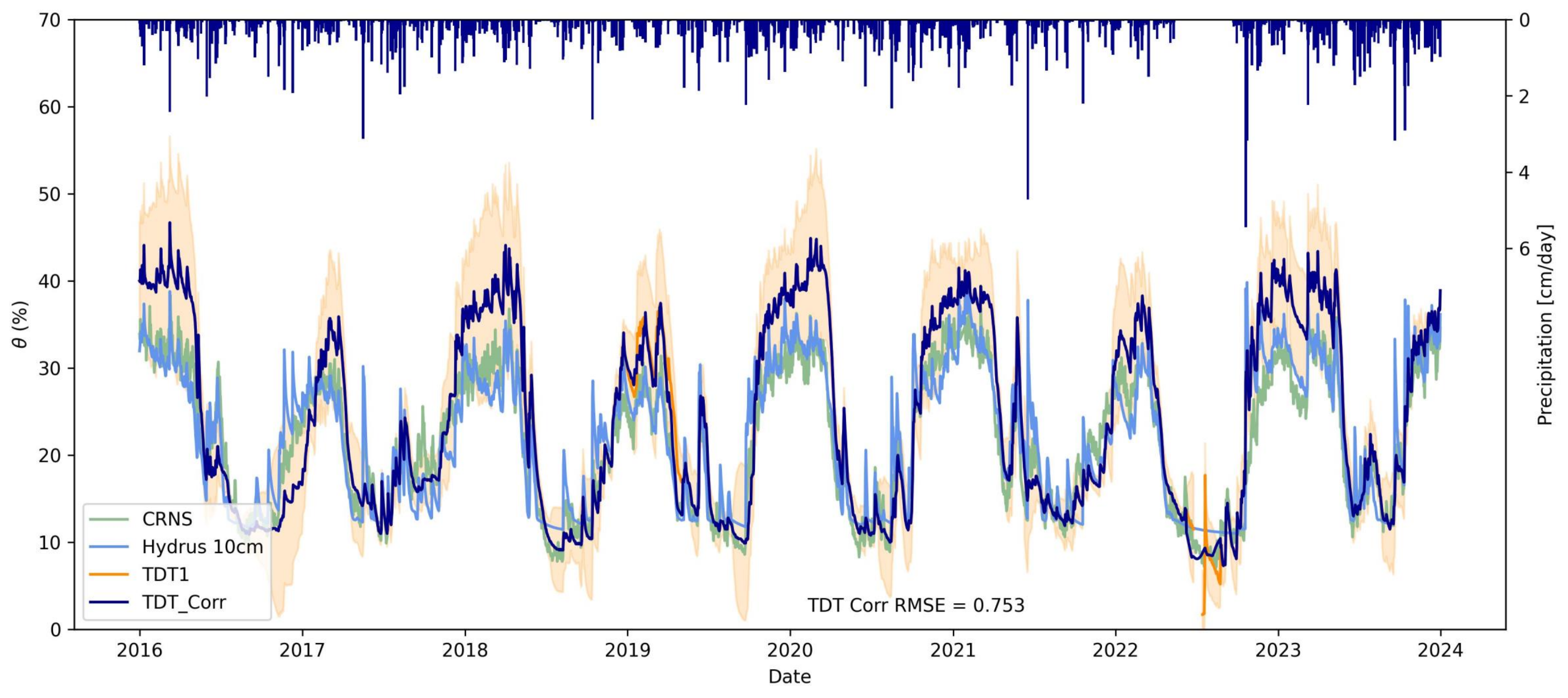
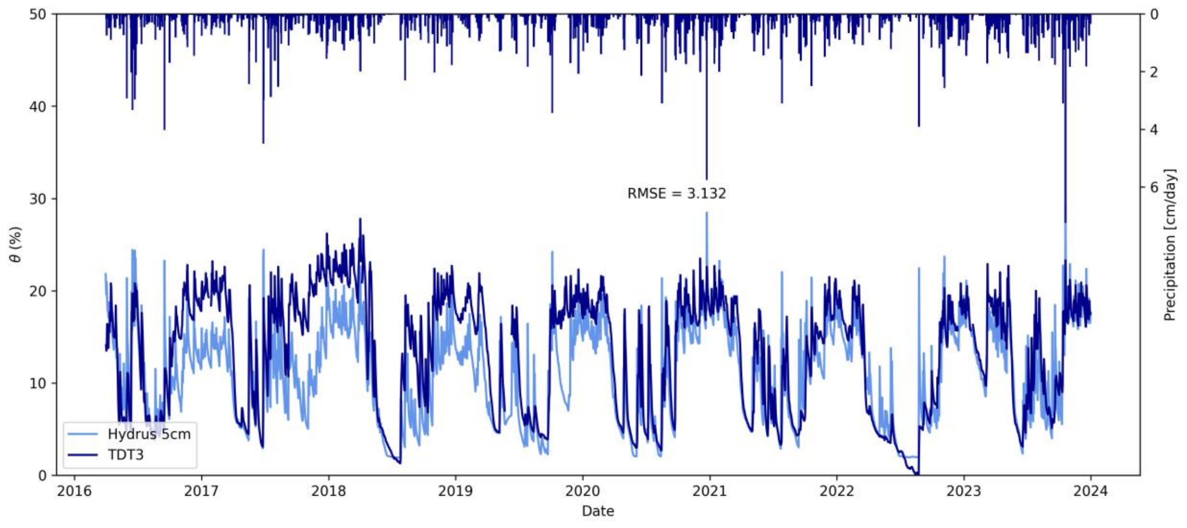


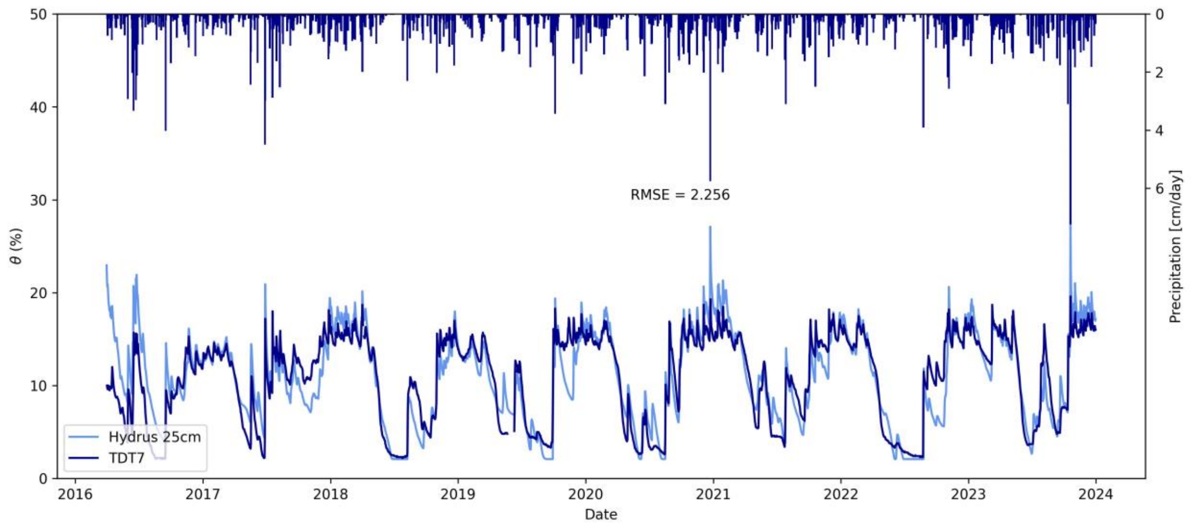
Where TDT1 and TDT2 needed replacing TDT1 data is bias corrected based on the Hydrus model (WADDN)



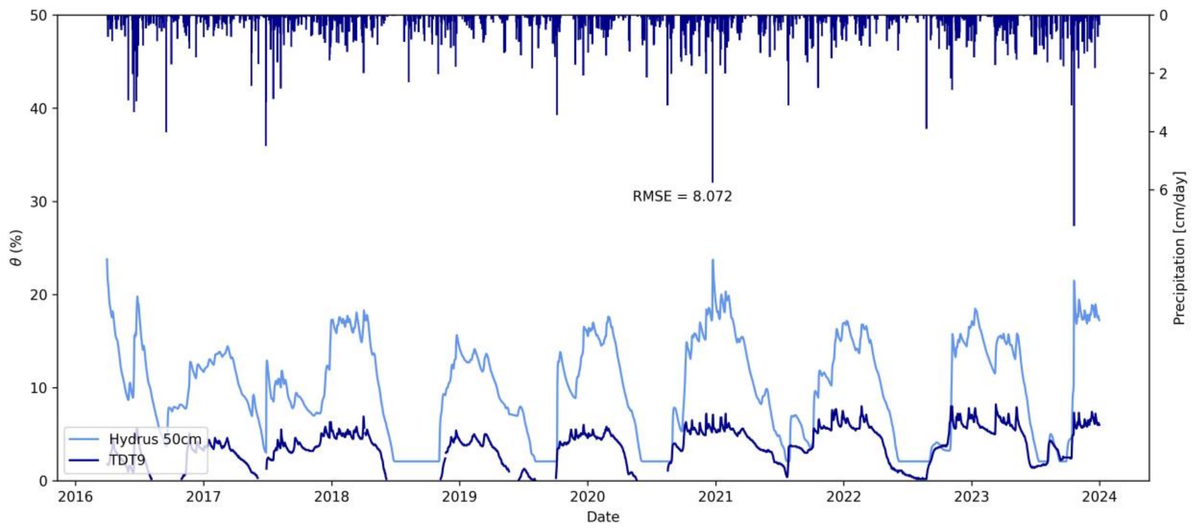
Where TDT1 was replaced TDT data is bias corrected based on the Hydrus model (CARDT)

Estimating soil moisture profiles beyond CRNS probe - EUSTN





- Poor agreement with depths > 25 cm
- Best agreement at 25 cm
- Method may not be appropriate to estimate depths beyond 25cm
- Soil hydraulic properties may need to be revised throughout the profile



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Summary and Further work

1. Good comparability between CRNS measurements, Hydrus and 10cm TDT data
2. Depth weighted means based on 5,10,15,25 and 50cm TDTs less comparable at CHIMN, more comparable at other sites – TDT issues
3. Significant uncertainties remain e.g. how best to calibrate Hydrus
4. Depth profiles beyond 25cm were not modelled well
5. Investigate Hydrus 2D for taking horizontal neutron probe footprint into account

For additional information please contact timhow@ceh.ac.uk

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