SMAPVEX12 Hydra and Theta Probe Calibration

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Hydra Probe Calibration

For the calibration of the Hydra probes used in the SMAPVEX-12 campaign, all measurements were used to determine the relationship between the volumetric water content determined from the core samples (using their measured bulk density) and the corresponding average real dielectric constant from three measurements, determined from the probes. The form of the relationship was similar to others previously-reported (Alharthi and Lange 1987, Seyfried and Murdock 2004, Seyfried et al. 2005) but included some real dielectric constant values greater than 40 which are higher than commonly reported.

Figure 1 indicates that the normal convention for the relationship between the volumetric water content of the sample cores (θv) and the square root of the real dielectric ($(\epsilon_r)^{0.5}$), was appropriate and had a linear form (equation 1) (Ledieu et al 1986, Huang et al 2004, Seyfried et al 2005).

$$\theta v = a(\epsilon_r)^{0.5} + b \qquad \text{(equation 1)}$$

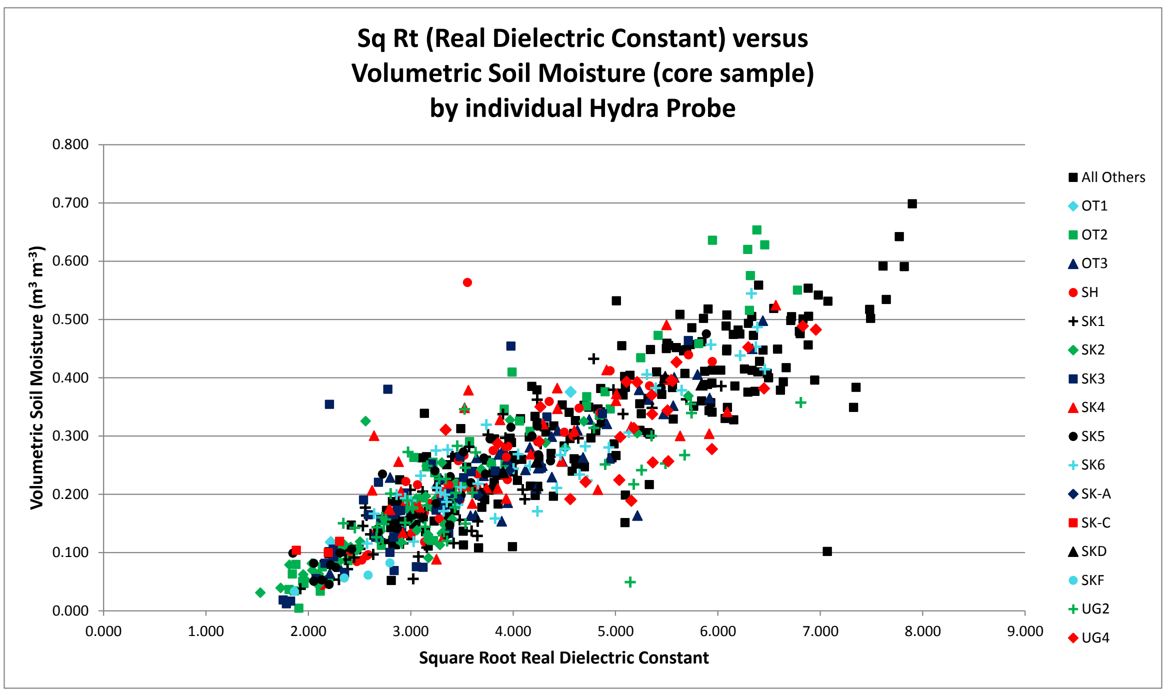


Figure 1. Relationship of volumetric soil moisture content to square root (real dielectric constant) for 16 individual Hydra Probe sensors.

A linear regression was performed between the soil core determined water content and the square root of the real dielectric, as indicated by the probes. This analysis used the entire dataset, all 702 points obtained throughout the sampling period, on all 55 fields. The regression equation established was:

$$\theta v = 0.0838(\epsilon_r)^{0.5} - 0.0846, \qquad \text{(equation 2)}$$

resulting in an r^2 value of 0.7663, and an overall RMSE of 0.0623m^3 m^{-3}.

Outliers were determined to be points that fell beyond the range of two times the standard deviation of the regression residuals. This analysis indicated that there were 30 points classified as outliers. The dates and associated fields of these outliers are shown in Table 1. A linear regression was repeated between the core volumetric water content and the square root of the real dielectric constant form the probes with the outliers removed (Figure 2). The following regression equation was determined:

$$\theta v = 0.0862(\epsilon_r)^{0.5} - 0.0962, \qquad \text{(equation 3)}$$

which resulted in an increase in the r^2 to 0.8523, and a reduction in the RMSE to $0.0475 m^3 m^{-3}$.

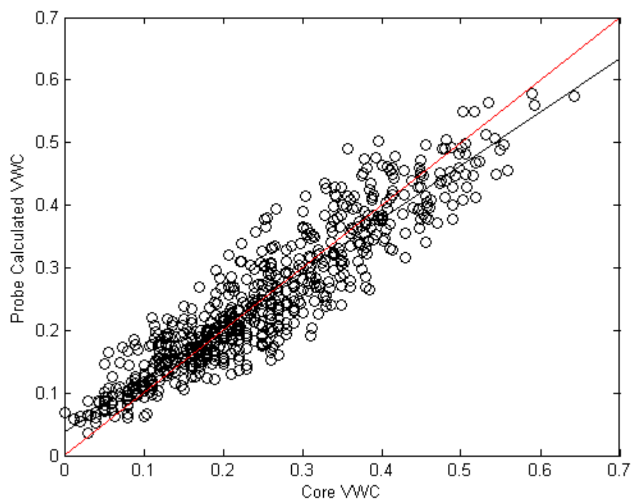


Figure 2: Plot of the core measured volumetric water content and the calculated volumetric water content as calculated from the square root real dielectric constant using equation 3. The black line is the fitted regression, and the red line is the 1:1 line.

A calibration of each field individually, using only the data from that field was conducted. This approach is similar to the calibration used by Cosh et al. (2005). In this calibration technique, the 30 outliers were removed from the dataset. A linear regression was conducted for each field between the core volumetric water content and the square root of the real dielectric constant using data for all sampling dates (Figure 3). The measured volumetric moisture contents as provided in Figures 2 and 3 were derived from a field average bulk density. This resulted in the establishment of 55 calibration equations. The calibration equation for each field is presented in Table 2. There were 5 fields where the field regression analysis was not significant. For fields 11, 12, and 13, this was likely due to too few degrees of freedom. For fields 73 and 122, it can be noted that these two fields had 2nd and 3rd lowest r^2 values, respectively. For these fields, the general equation (equation 3) was used for calibration.

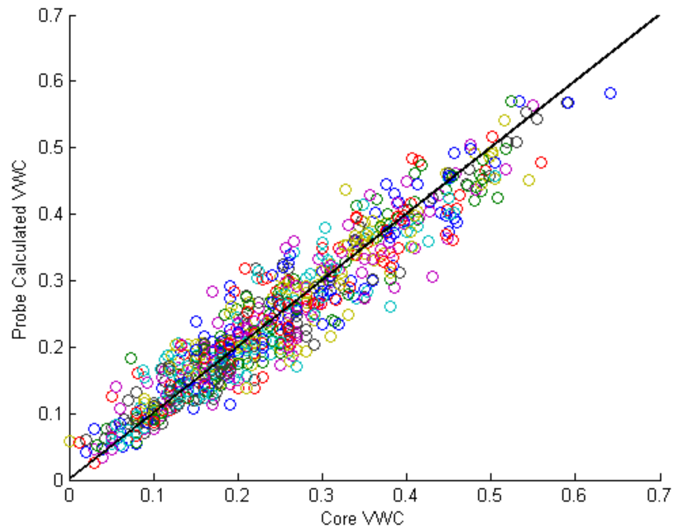


Figure 3: Plot of the core volumetric water content, and the calculated volumetric water content using the individual field equations presented in Table 2. The black line is the 1:1 line.

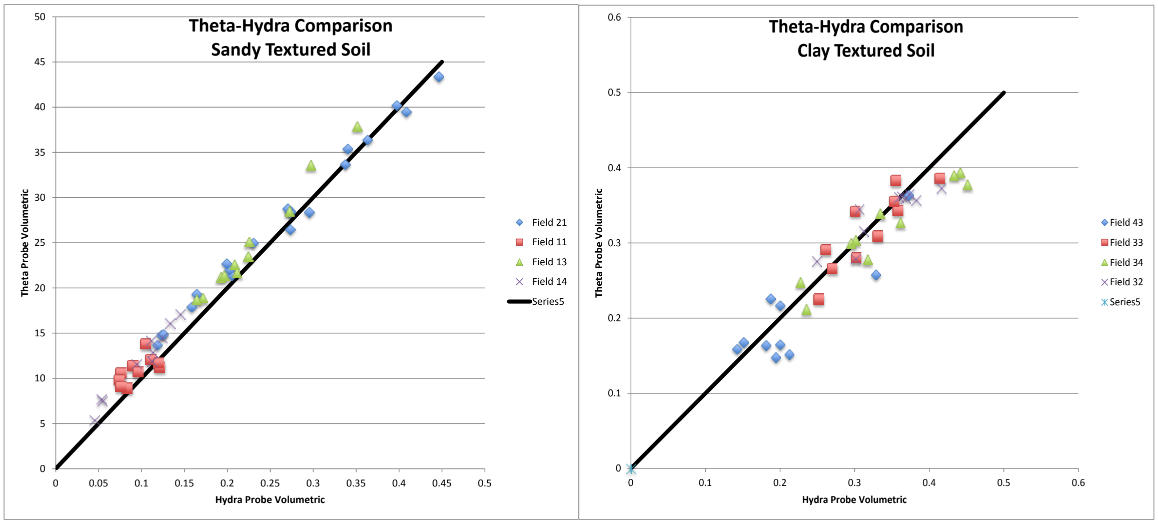
Theta Probe Calibration

Surface soil moisture at pre-determined locations of some sampling fields was measured using Delta-T Theta Probes rather than Hydra Probe sensors because of a shortage of the latter on some sampling dates.

A Theta to Hydra probe comparison was undertaken whereby a series of surface measurements were acquired at the same location with both sensors on several different fields. The comparisons for readings on sandy textured and clay textured soils are shown in Figure 4a and 4b, respectively. Although there is more scatter in the clay soil comparison, the agreement between probes is very good. The equivalent Hydra probe moisture content for a Theta probe measurement can be estimated using regression equations are shown below.

Sand: Hydra probe equivalent θv =1.0408 (Theta θv) – 0.0236, R^2 = 0.987 (equation 4)

Clay: Hydra probe equivalent θv = 0.9983 (Theta θv) + 0.0111, R^2 = 0.864 (equation 5)



a) b)

Figure 4a,b. Theta – Hydra probe comparison for sand (a) and clay soils (b).

Note, that the Hydra probe volumetric content shown in Figure 4 is the value output with the default loam calibration. Thus, the relationship between the two probes can be used to convert the Theta probe volumetric moisture content to equivalent value the Hydra probe, which can then be converted to a real dielectric constant using the loam calibration for the Hydra probe.

$$RDC = ((\text{Hydra probe equivalent } \theta v + 0.179) / 0.109)^2 \qquad \text{(equation 6)}$$

The calibration of the Theta probe data began with the sensor output soil moisture value. The calculation of the soil moisture from the Theta probe was conducted within the sensor software on the basis of a mineral soil setting. The soil moisture output from the theta probe was converted to a Hydra probe equivalent value using either equation 4 or 5, depending on the soil texture. The texture used for each field in determining which equation was used is indicated in Table 3. The Hydra probe equivalent soil moisture was converted to a real dielectric constant value, using equation 6. The square root value of the real dielectric constant was then used in the field appropriate calibration equation, as shown in Table 2.

Table 1: Determined outliers of the total dataset.

Sample Date	Field ID	Core VWC	Calc. VWC
June 23	11	0.339	0.178
June 25	21	0.62	0.443
June 29	21	0.64	0.414
June 25	22	0.628	0.456
July 5	22	0.58	0.445
June 7	23	0.654	0.450
June 29	61	0.33	0.130
June 29	72	0.35	0.100
June 23	73	0.11	0.250
July 13	74	0.38	0.148
June 27	83	0.563	0.213
June 23	94	0.198	0.342
July 10	121	0.41	0.250
July 3	122	0.30	0.137
July 5	122	0.38	0.214
July 5	124	0.35	0.211
July 14	32	0.45	0.249
July 17	32	0.53	0.335
June 27	33	0.163	0.352
June 22	64	0.217	0.362
June 23	65	0.151	0.342
June 25	101	0.188	0.347
July 5	103	0.35	0.211
June 25	104	0.277	0.413
June 22	104	0.102	0.508
June 17	104	0.349	0.529
June 22	105	0.383	0.531
June 25	112	0.357	0.486
June 29	112	0.22	0.349
June 27	113	0.049	0.346

Table 2: Calibration equations used for each field, r^2, RMSE, and number of data points used in establishment of equation. The fields with an * are the fields where the general equation was applied.

Field ID	**Calibration Equation**	**r^2**	**RMSE**	**N**
11*	$0.0862(\epsilon_r)^{0.5}-0.0962$	0.7962	0.3772	672
12*	$0.0862(\epsilon_r)^{0.5}-0.0962$	0.5759	0.0562	672
13*	$0.0862(\epsilon_r)^{0.5}-0.0962$	0.8635	0.0560	672
14	$0.1027(\epsilon_r)^{0.5}-0.1252$	0.8977	0.0121	6
21	$0.1054(\epsilon_r)^{0.5}-0.1505$	0.9657	0.0121	10
22	$0.1097(\epsilon_r)^{0.5}-0.1519$	0.9557	0.0467	9
23	$0.1152(\epsilon_r)^{0.5}-0.1795$	0.9716	0.0190	11
24	$0.1003(\epsilon_r)^{0.5}-0.1349$	0.7159	0.0121	10
31	$0.0804(\epsilon_r)^{0.5}-0.0530$	0.8580	0.0355	15
32	$0.0975(\epsilon_r)^{0.5}-0.1489$	0.8821	0.0491	11
33	$0.0801(\epsilon_r)^{0.5}-0.0735$	0.7799	0.0471	8
34	$0.0735(\epsilon_r)^{0.5}-0.0287$	0.7521	0.0522	10
41	$0.0856(\epsilon_r)^{0.5}-0.0894$	0.8176	0.0503	13
42	$0.1025(\epsilon_r)^{0.5}-0.1628$	0.9206	0.0365	11
43	$0.0846(\epsilon_r)^{0.5}-0.0906$	0.8286	0.0512	13
44	$0.0753(\epsilon_r)^{0.5}-0.0343$	0.7772	0.0406	12
45	$0.0873(\epsilon_r)^{0.5}-0.0807$	0.7553	0.0546	11
51	$0.0753(\epsilon_r)^{0.5}-0.0699$	0.6820	0.0474	16
52	$0.0967(\epsilon_r)^{0.5}-0.1518$	0.7304	0.0391	17
53	$0.0912(\epsilon_r)^{0.5}-0.1297$	0.9128	0.0227	15
54	$0.0859(\epsilon_r)^{0.5}-0.1195$	0.8683	0.0220	14
55	$0.0691(\epsilon_r)^{0.5}+0.0078$	0.7162	0.0473	13
61	$0.0762(\epsilon_r)^{0.5}-0.0829$	0.8370	0.0241	13
62	$0.0828(\epsilon_r)^{0.5}-0.1013$	0.9131	0.0205	13
63	$0.0829(\epsilon_r)^{0.5}-0.1095$	0.7066	0.034	14
64	$0.0788(\epsilon_r)^{0.5}-0.0934$	0.8500	0.0269	13
65	$0.0757(\epsilon_r)^{0.5}-0.0525$	0.7678	0.0446	9
71	$0.0577(\epsilon_r)^{0.5}-0.0450$	0.3784	0.0335	17
72	$0.0907(\epsilon_r)^{0.5}-0.1165$	0.7484	0.0269	12
73*	$0.0862(\epsilon_r)^{0.5}-0.0962$	0.4419	0.0445	672
74	$0.0918(\epsilon_r)^{0.5}-0.1082$	0.7470	0.0443	11
81	$0.0863(\epsilon_r)^{0.5}-0.1043$	0.8503	0.0170	12
82	$0.0898(\epsilon_r)^{0.5}-0.0952$	0.5627	0.0398	16
83	$0.1057(\epsilon_r)^{0.5}-0.1504$	0.8352	0.0302	14
84	$0.1078(\epsilon_r)^{0.5}-0.1679$	0.8387	0.0329	15
85	$0.0770(\epsilon_r)^{0.5}-0.0390$	0.8367	0.0356	12
91	$0.0890(\epsilon_r)^{0.5}-0.1147$	0.7893	0.0307	14
92	$0.0775(\epsilon_r)^{0.5}-0.0571$	0.7896	0.0447	14
93	$0.0979(\epsilon_r)^{0.5}-0.1477$	0.8903	0.0391	15
94	$0.1153(\epsilon_r)^{0.5}-0.1905$	0.8339	0.0337	13
101	$0.0576(\epsilon_r)^{0.5}+0.0236$	0.7249	0.0458	15
102	$0.0809(\epsilon_r)^{0.5}-0.0634$	0.8968	0.0493	15
103	$0.0864(\epsilon_r)^{0.5}-0.0896$	0.9330	0.0382	14
104	$0.0707(\epsilon_r)^{0.5}+0.0028$	0.8492	0.0560	9
105	$0.0529(\epsilon_r)^{0.5}+0.0401$	0.9648	0.0155	10
111	$0.0833(\epsilon_r)^{0.5}-0.1062$	0.7504	0.0425	15
112	$0.0603(\epsilon_r)^{0.5}+0.0171$	0.6351	0.0534	16
113	$0.0727(\epsilon_r)^{0.5}-0.0508$	0.8463	0.0399	14
114	$0.0774(\epsilon_r)^{0.5}-0.0921$	0.6717	0.0441	15
115	$0.0486(\epsilon_r)^{0.5}+0.0526$	0.6142	0.0493	14
121	$0.1079(\epsilon_r)^{0.5}-0.1392$	0.9223	0.0380	12
122*	$0.0862(\epsilon_r)^{0.5}-0.0962$	0.5171	0.0631	672
123	$0.0806(\epsilon_r)^{0.5}-0.0973$	0.7623	0.0544	13
124	$0.0717(\epsilon_r)^{0.5}-0.0069$	0.7589	0.0396	12
125	$0.0936(\epsilon_r)^{0.5}-0.1073$	0.8031	0.0400	11

Table 3: Individual field texture based calibration equation to convert from theta probe soil moisture to hydra probe soil moisture equivalent.

Field ID	Theta Probe Calibration Equation
11	Sand
12	Sand
13	Sand
14	Sand
21	Sand
22	Sand
23	Sand
24	Sand
31	Clay
33	Clay
34	Clay
41	Clay
42	Clay
43	Clay
44	Clay
45	Clay
61	Sand
62	Sand
63	Sand
64	Clay
65	Clay
72	Sand
73	Sand
74	Sand
91	Sand
92	Sand
93	Sand
94	Sand
111	Clay
112	Clay
113	Clay
114	Clay
115	Clay
121	Clay
122	Clay
123	Clay
124	Clay
125	Clay

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