**EVALUATION OF SOIL MOISTURE ESTIMATION TECHNIQUES BASED ON SENTINEL-1 OBSERVATIONS OVER WHEAT FIELDS**

**SUPPLEMENTARY MATERIALS**

1. **Monthly ESA CCI values**

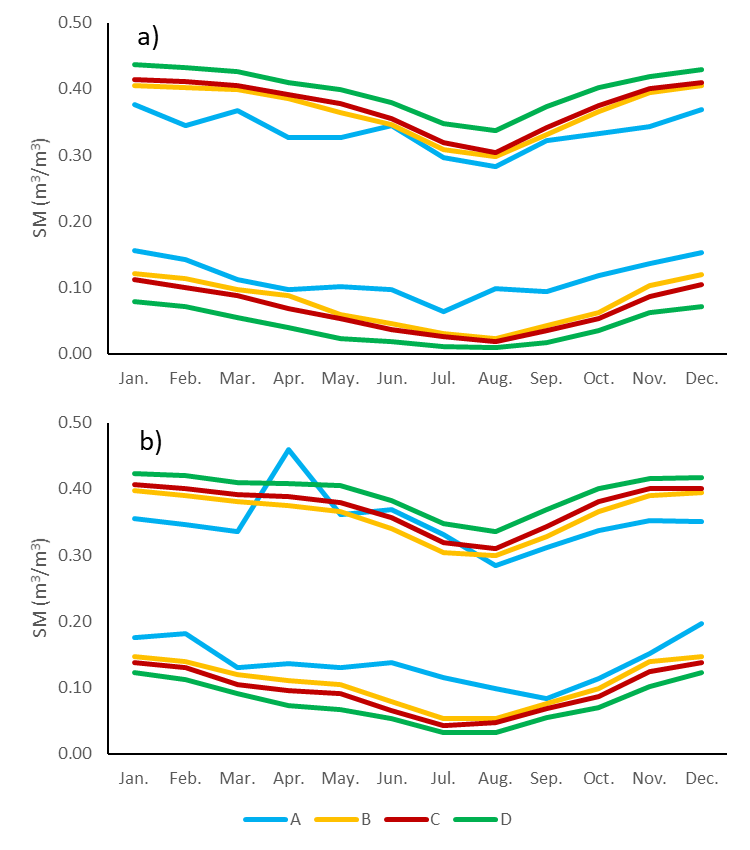
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Figure S1. Monthly ESA CCI SM values for the different schemes considered. a) SM for fields 1, 2, 3, 4, 5 and 6; b) SM for fields 7 and 8.

1. **Calibration results**

In this section, the results for the calibration of the different techniques are presented. The best schemes are selected for further comparison among methodologies.

* 1. **Short Term Change Detection (STCD) approach**

Figure S2 represents the calibration results for the STCD approach. Bars show RMSE and R values obtained after comparing *SMest* with *SMobs* for the different N values tested, different schemes for constraining maximum and minimum SM conditions and for the two backscatter time series: γ0CAN and γ0SOIL. Obtained RMSE values ranged between 0.09 and 0.12, and R values between 0.15 and 0.45. Best results were obtained for short N values (N=4 observations), since for longer values RMSE increased, and R mostly decreased, although the behavior of R was not as consistent. Regarding the schemes tested for constraining maximum and minimum SM conditions, scheme A (max and min values in the ESA CCI SM time series) produced the highest RMSE values and the lowest correlations. Schemes B, C and D provided similar results in terms of RMSE, but in terms of R values better results were obtained as the considered maximum and minimum SM values were more extreme, with best results for scheme D. In most cases, γ0SOIL produces better results than γ0CAN, but differences were not very significant.

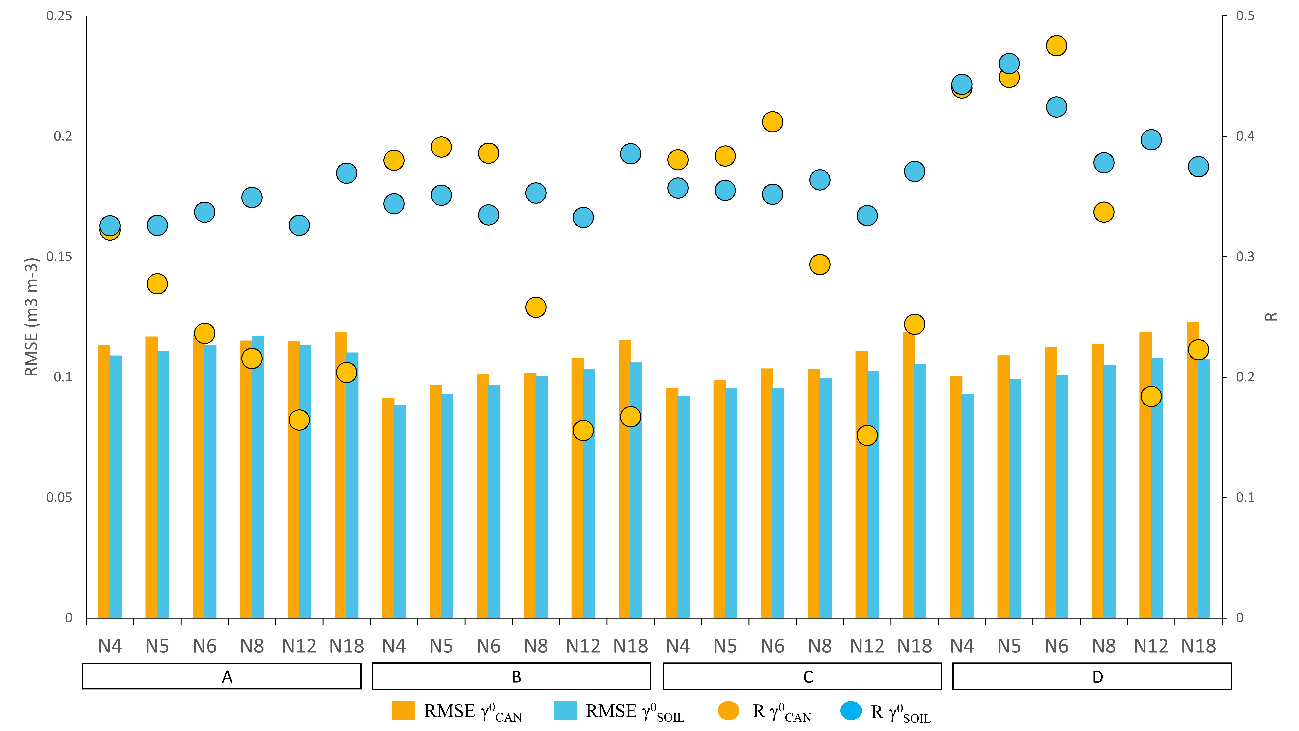


Fig. S2. Median RMSE and Correlation values between *θreal* and *θest* for the STCD approach calibration schemes (A, B, C, D).

Considering both the RMSE and R results, scheme D and N=4 was chosen as the best option with almost the same results for γ0SOIL and γ0CAN.

* 1. **TU Wien Change Detection (TUWCD) Model**

Figure S3 shows the RMSE and R values obtained for the different schemes tested when implementing the TU Wien Change Detection Model. In this case, results improved clearly when applying the method to vegetation corrected γ0SOIL time series, with RMSE values of 0.083-0.189 m3/m3 and R values of ~0.45. With no vegetation correction (γ0CAN), RMSE values increased to 0.101-0.173 m3/m3 and correlation coefficients clearly decreased to ~0.20. Regarding the different schemes tested, optimum results were obtained for scheme 3, where the lower boundary () corresponded to the absolute minimum, and the lower boundary () to the 0.99 percentile. Results worsened when considering narrower higher percentiles for the minimum.

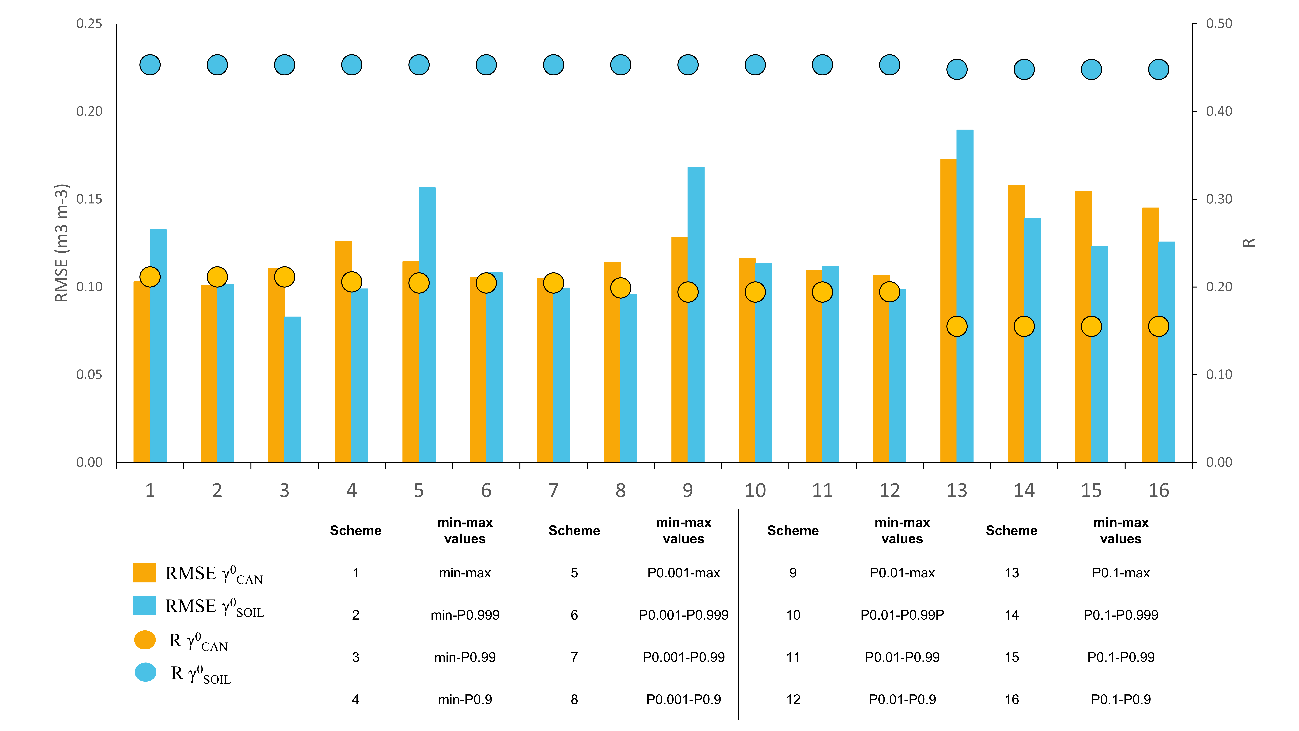


Fig. S3. Median RMSE and Correlation values between *θreal* and *θest* for the Change Detection calibration schemes (1-16).

* 1. **Multitemporal Bayesian change detection (MTBCD) approach**

The optimization results for the roughness parameters *s* and *l* are presented in Figure S4. Low RMSE values (̴ 2dB) were obtained with different combinations of *s* and *l* for γ0SOIL. However, for higher *s* values, the number of (*s,l*) pairs with RMSE below 3 dB decreased. The lowest RMSE (2.17 dB) was achieved with *s=*0.4 and *l*=3, therefore, this set of roughness parameters was used for the implementation of the Multitemporal Bayesian approach, even though it still represents a relevant difference between measured and estimated values. This may have an impact on the retrieved variables. The RMSE values between γ0CAN and the IEM were worse, with higher minimum values (̴ 3dB).

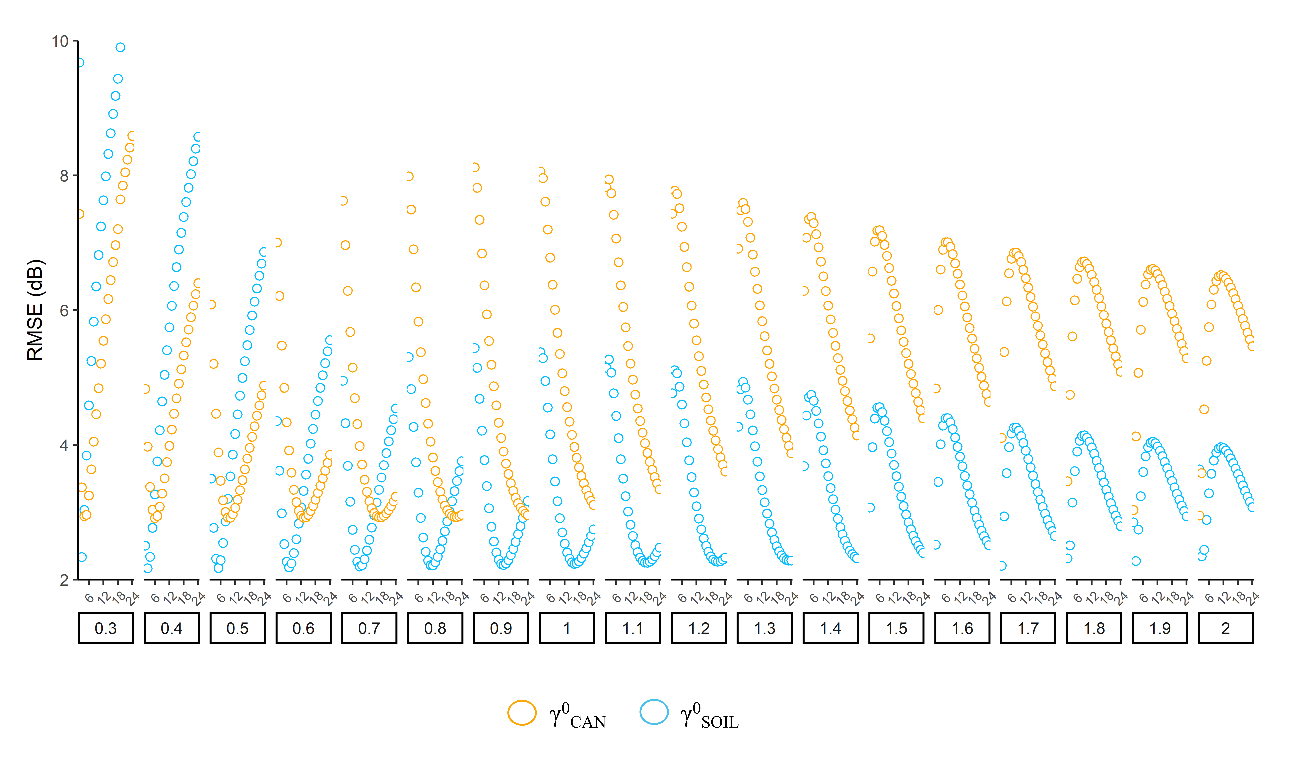
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Fig. S4. RMSE between γ0CAN and γ0SOIL backscatter time series and IEM simulated time series for all wheat fields and every combination of roughness parameters (*s* and *l*).

1. **Comparison between methodologies**

Table S1. RMSE results for the different SM estimation techniques

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Field | Orbit Pass | RMSE (m3/m3) | | | | | | |
| STCD γ0CAN | STCD γ0SOIL | TUWCD γ0CAN | TUWCD γ0SOIL | MTBCD γ0CAN | MTBCD γ0SOIL |
| 1 | 8DESC | 0.116 | 0.114 | 0.154 | 0.165 | 0.119 | 0.115 |
| 1 | 81DESC | 0.116 | 0.113 | 0.119 | 0.134 | 0.129 | 0.123 |
| 1 | 103ASC | 0.098 | 0.106 | 0.121 | 0.134 | 0.109 | 0.114 |
| 2 | 8DESC | 0.095 | 0.091 | 0.141 | 0.104 | 0.159 | 0.096 |
| 2 | 81DESC | 0.091 | 0.084 | 0.128 | 0.113 | 0.136 | 0.119 |
| 2 | 103ASC | 0.103 | 0.092 | 0.143 | 0.100 | 0.151 | 0.120 |
| 3 | 8DESC | 0.064 | 0.063 | 0.055 | 0.056 | 0.106 | 0.103 |
| 3 | 81DESC | 0.070 | 0.069 | 0.055 | 0.052 | 0.072 | 0.078 |
| 3 | 103ASC | 0.085 | 0.076 | 0.065 | 0.060 | 0.099 | 0.052 |
| 4 | 8DESC | 0.078 | 0.079 | 0.133 | 0.075 | 0.178 | 0.146 |
| 4 | 81DESC | 0.067 | 0.072 | 0.137 | 0.066 | 0.124 | 0.088 |
| 4 | 103ASC | 0.122 | 0.073 | 0.147 | 0.075 | 0.147 | 0.115 |
| 5 | 8DESC | 0.122 | 0.122 | 0.073 | 0.050 | 0.085 | 0.122 |
| 5 | 81DESC | 0.118 | 0.118 | 0.077 | 0.065 | 0.077 | 0.074 |
| 5 | 103ASC | 0.123 | 0.125 | 0.077 | 0.054 | 0.094 | 0.088 |
| 6 | 8DESC | 0.107 | 0.108 | 0.059 | 0.062 | 0.063 | 0.119 |
| 6 | 81DESC | 0.096 | 0.093 | 0.062 | 0.069 | 0.073 | 0.081 |
| 6 | 103ASC | 0.104 | 0.103 | 0.074 | 0.059 | 0.077 | 0.089 |
| 7 | 8DESC | 0.131 | 0.144 | 0.112 | 0.154 | 0.117 | 0.105 |
| 7 | 81DESC | 0.134 | 0.147 | 0.109 | 0.165 | 0.125 | 0.165 |
| 7 | 103ASC | 0.128 | 0.141 | 0.106 | 0.137 | 0.128 | 0.142 |
| 8 | 8DESC | 0.081 | 0.081 | 0.120 | 0.137 | 0.132 | 0.097 |
| 8 | 81DESC | 0.084 | 0.090 | 0.115 | 0.132 | 0.138 | 0.140 |
| 8 | 103ASC | 0.092 | 0.092 | 0.100 | 0.091 | 0.130 | 0.091 |

Table S2. BIAS results for the different SM estimation techniques

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Field | Orbit Pass | BIAS (m3/m3) | | | | | | |
| STCD γ0CAN | STCD γ0SOIL | TUWCD γ0CAN | TUWCD γ0SOIL | MTBCD γ0CAN | MTBCD γ0SOIL |
| 1 | 8DESC | 0.045 | 0.041 | 0.099 | 0.119 | 0.049 | 0.033 |
| 1 | 81DESC | 0.034 | 0.034 | 0.054 | 0.095 | 0.089 | 0.092 |
| 1 | 103ASC | 0.017 | 0.013 | 0.059 | 0.070 | 0.057 | 0.018 |
| 2 | 8DESC | -0.028 | -0.026 | 0.001 | 0.044 | -0.048 | -0.028 |
| 2 | 81DESC | -0.020 | -0.018 | -0.026 | 0.054 | 0.004 | 0.062 |
| 2 | 103ASC | -0.035 | -0.033 | -0.063 | 0.004 | -0.077 | -0.057 |
| 3 | 8DESC | -0.020 | -0.016 | 0.013 | 0.031 | -0.089 | -0.090 |
| 3 | 81DESC | -0.028 | -0.025 | -0.002 | 0.012 | -0.018 | -0.057 |
| 3 | 103ASC | -0.058 | -0.045 | -0.003 | 0.038 | -0.042 | -0.023 |
| 4 | 8DESC | -0.014 | -0.023 | -0.095 | -0.041 | -0.157 | -0.133 |
| 4 | 81DESC | -0.051 | -0.047 | -0.118 | -0.042 | -0.104 | -0.077 |
| 4 | 103ASC | -0.072 | -0.056 | -0.101 | -0.050 | -0.102 | -0.104 |
| 5 | 8DESC | -0.107 | -0.108 | 0.022 | 0.006 | -0.022 | -0.108 |
| 5 | 81DESC | -0.101 | -0.100 | 0.023 | 0.021 | 0.014 | -0.044 |
| 5 | 103ASC | -0.106 | -0.108 | -0.004 | 0.015 | -0.020 | -0.070 |
| 6 | 8DESC | -0.091 | -0.092 | -0.030 | -0.046 | -0.016 | -0.109 |
| 6 | 81DESC | -0.077 | -0.075 | -0.015 | -0.038 | 0.038 | -0.058 |
| 6 | 103ASC | -0.089 | -0.090 | -0.040 | -0.035 | 0.004 | -0.073 |
| 7 | 8DESC | 0.066 | 0.079 | 0.058 | 0.107 | 0.068 | 0.011 |
| 7 | 81DESC | 0.051 | 0.065 | 0.059 | 0.110 | 0.094 | 0.117 |
| 7 | 103ASC | 0.050 | 0.063 | 0.062 | 0.073 | 0.100 | 0.097 |
| 8 | 8DESC | 0.014 | 0.018 | 0.032 | 0.103 | 0.031 | 0.017 |
| 8 | 81DESC | 0.002 | 0.011 | 0.036 | 0.093 | 0.064 | 0.102 |
| 8 | 103ASC | 0.022 | 0.031 | 0.041 | 0.043 | 0.072 | 0.047 |

Table S3. ubRMSE results for the different SM estimation techniques

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Field | Orbit Pass | ubRMSE (m3/m3) | | | | | | |
| STCD γ0CAN | STCD γ0SOIL | TUWCD γ0CAN | TUWCD γ0SOIL | MTBCD γ0CAN | MTBCD γ0SOIL |
| 1 | 8DESC | 0.107 | 0.106 | 0.118 | 0.114 | 0.108 | 0.111 |
| 1 | 81DESC | 0.111 | 0.108 | 0.106 | 0.095 | 0.094 | 0.082 |
| 1 | 103ASC | 0.096 | 0.105 | 0.106 | 0.114 | 0.093 | 0.112 |
| 2 | 8DESC | 0.091 | 0.087 | 0.141 | 0.095 | 0.151 | 0.092 |
| 2 | 81DESC | 0.088 | 0.082 | 0.126 | 0.099 | 0.136 | 0.102 |
| 2 | 103ASC | 0.097 | 0.086 | 0.128 | 0.100 | 0.130 | 0.105 |
| 3 | 8DESC | 0.061 | 0.061 | 0.053 | 0.046 | 0.058 | 0.049 |
| 3 | 81DESC | 0.063 | 0.064 | 0.055 | 0.051 | 0.070 | 0.053 |
| 3 | 103ASC | 0.062 | 0.061 | 0.065 | 0.047 | 0.090 | 0.046 |
| 4 | 8DESC | 0.076 | 0.076 | 0.094 | 0.062 | 0.084 | 0.060 |
| 4 | 81DESC | 0.044 | 0.054 | 0.070 | 0.051 | 0.067 | 0.042 |
| 4 | 103ASC | 0.099 | 0.046 | 0.108 | 0.055 | 0.106 | 0.048 |
| 5 | 8DESC | 0.059 | 0.056 | 0.069 | 0.049 | 0.083 | 0.055 |
| 5 | 81DESC | 0.061 | 0.061 | 0.074 | 0.061 | 0.075 | 0.060 |
| 5 | 103ASC | 0.063 | 0.063 | 0.077 | 0.052 | 0.092 | 0.053 |
| 6 | 8DESC | 0.056 | 0.056 | 0.051 | 0.042 | 0.061 | 0.047 |
| 6 | 81DESC | 0.057 | 0.055 | 0.060 | 0.057 | 0.063 | 0.056 |
| 6 | 103ASC | 0.053 | 0.052 | 0.062 | 0.048 | 0.077 | 0.052 |
| 7 | 8DESC | 0.114 | 0.120 | 0.095 | 0.111 | 0.095 | 0.104 |
| 7 | 81DESC | 0.124 | 0.132 | 0.092 | 0.123 | 0.082 | 0.117 |
| 7 | 103ASC | 0.118 | 0.126 | 0.087 | 0.116 | 0.079 | 0.104 |
| 8 | 8DESC | 0.079 | 0.079 | 0.116 | 0.090 | 0.128 | 0.096 |
| 8 | 81DESC | 0.083 | 0.089 | 0.109 | 0.094 | 0.122 | 0.096 |
| 8 | 103ASC | 0.089 | 0.087 | 0.091 | 0.080 | 0.108 | 0.077 |

Table S4. Correlation results for the different SM estimation techniques

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Field | Orbit Pass | R | | | | | | |
| STCD γ0CAN | STCD γ0SOIL | TUWCD γ0CAN | TUWCD γ0SOIL | MTBCD γ0CAN | MTBCD γ0SOIL |
| 1 | 8DESC | 0.618 | 0.639 | 0.468 | 0.539 | 0.591 | 0.630 |
| 1 | 81DESC | 0.675 | 0.748 | 0.665 | 0.797 | 0.752 | 0.843 |
| 1 | 103ASC | 0.764 | 0.712 | 0.606 | 0.660 | 0.718 | 0.718 |
| 2 | 8DESC | 0.658 | 0.719 | -0.291 | 0.645 | -0.432 | 0.665 |
| 2 | 81DESC | 0.779 | 0.826 | 0.135 | 0.623 | 0.030 | 0.553 |
| 2 | 103ASC | 0.594 | 0.735 | 0.055 | 0.734 | 0.035 | 0.604 |
| 3 | 8DESC | 0.183 | 0.197 | 0.140 | 0.350 | 0.039 | 0.215 |
| 3 | 81DESC | 0.160 | 0.100 | 0.303 | 0.304 | 0.114 | 0.223 |
| 3 | 103ASC | -0.128 | 0.024 | -0.078 | 0.121 | -0.077 | 0.310 |
| 4 | 8DESC | 0.178 | 0.182 | -0.065 | 0.348 | -0.171 | 0.291 |
| 4 | 81DESC | 0.671 | 0.534 | 0.175 | 0.404 | 0.236 | 0.784 |
| 4 | 103ASC | 0.039 | 0.484 | 0.019 | -0.053 | 0.007 | 0.423 |
| 5 | 8DESC | 0.417 | 0.429 | 0.063 | 0.470 | -0.016 | 0.358 |
| 5 | 81DESC | 0.310 | 0.315 | 0.090 | 0.156 | 0.188 | 0.273 |
| 5 | 103ASC | 0.281 | 0.259 | -0.081 | 0.437 | -0.107 | 0.362 |
| 6 | 8DESC | 0.615 | 0.603 | 0.497 | 0.693 | 0.425 | 0.594 |
| 6 | 81DESC | 0.589 | 0.605 | 0.440 | 0.477 | 0.441 | 0.521 |
| 6 | 103ASC | 0.624 | 0.634 | 0.323 | 0.718 | 0.197 | 0.576 |
| 7 | 8DESC | 0.367 | 0.251 | 0.631 | 0.488 | 0.671 | 0.580 |
| 7 | 81DESC | 0.345 | 0.225 | 0.716 | 0.367 | 0.784 | 0.489 |
| 7 | 103ASC | 0.360 | 0.168 | 0.760 | 0.496 | 0.779 | 0.603 |
| 8 | 8DESC | 0.473 | 0.457 | 0.127 | 0.099 | 0.147 | 0.049 |
| 8 | 81DESC | 0.463 | 0.381 | 0.248 | 0.117 | 0.254 | 0.119 |
| 8 | 103ASC | 0.223 | 0.257 | 0.325 | 0.407 | 0.324 | 0.510 |