

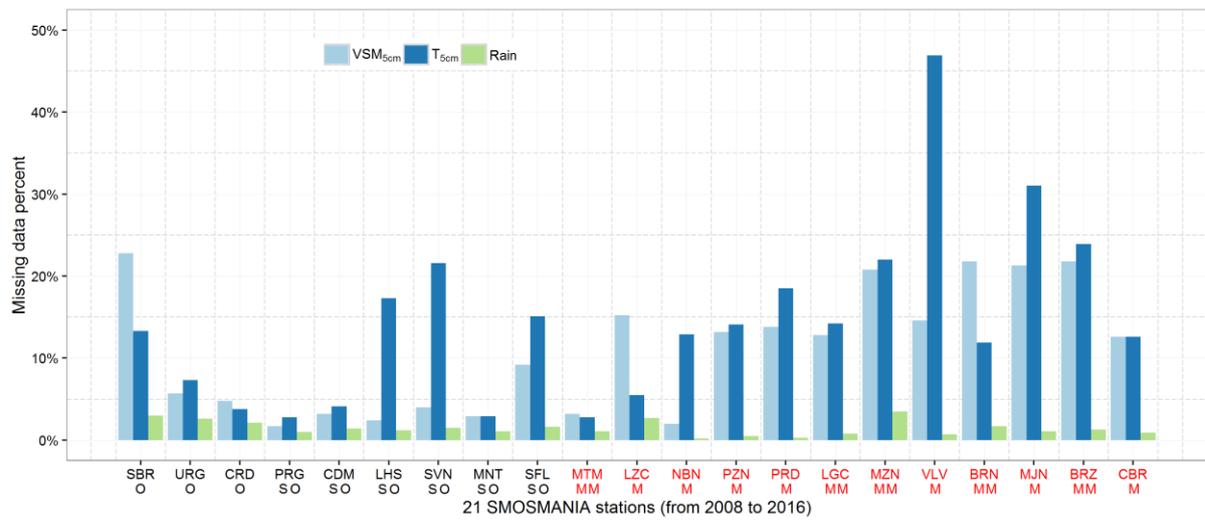
*Supplement of*

**Identification of soil-cooling rains in southern France from soil temperature and soil moisture observations**

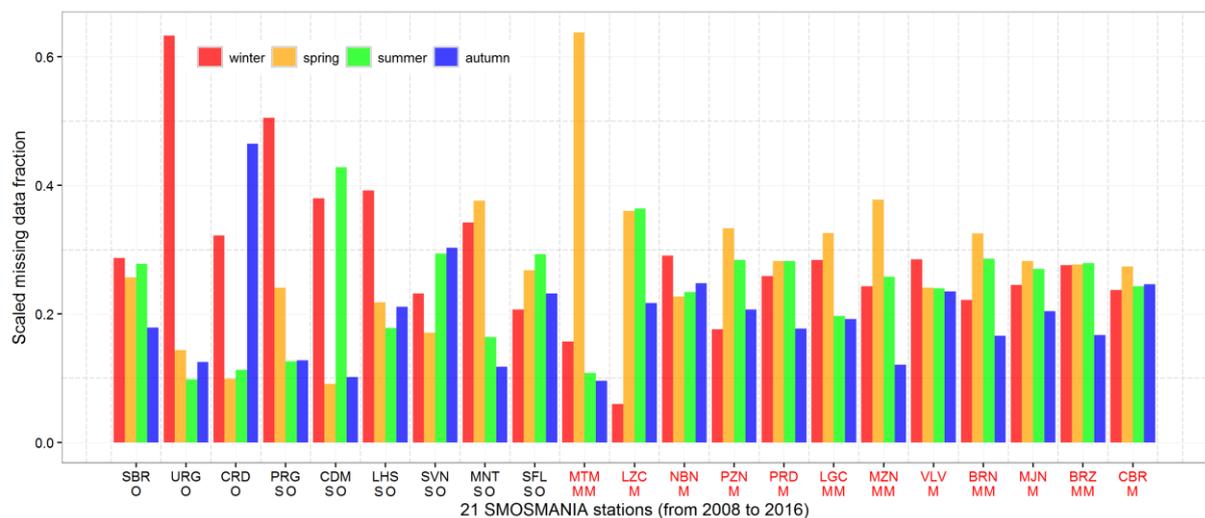
**S. Zhang, C. Meurey, and J.-C. Calvet**

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## Fraction of missing data of in situ observations



**Figure S1.** Fraction of missing data for in situ VSM<sub>5cm</sub> (light blue), T<sub>5cm</sub> (dark blue) and Rain observations measured every 12 min for the 21 SMOSMANIA stations from 2008 to 2016. Stations are sorted from (left) West to (right) East. Symbols “O”, “SO”, “M”, and “MM” indicate Oceanic, Semi-Oceanic, Mediterranean, and Mediterranean/Mountain climates, respectively.



**Figure S2.** Scaled seasonal distribution of the fraction of missing data of either VSM<sub>5cm</sub> or T<sub>5cm</sub> for the 21 SMOSMANIA stations (winter, spring, summer, autumn, corresponding to December-January-February, March-April-May, June-July-August, September-October-November, respectively). Stations are sorted from (left) West to (right) East. Symbols “O”, “SO”, “M”, and “MM” indicate Oceanic, Semi-Oceanic, Mediterranean, and Mediterranean/Mountain climates, respectively.

**Table S1.** Fraction of missing data, from 0 to 1, of either  $VSM_{5cm}$  or  $T_{5cm}$  for the 21 SMOSMANIA stations and its seasonal distribution in % (winter, spring, summer, autumn, corresponding to December-January-February, March-April-May, June-July-August, September-October-November, respectively). Fractions larger than 0.1 are in bold. Seasonal grouping of missing data larger than 40 % is in bold. Stations are sorted from (top) West to (bottom) East.

Station (full name)	Mean fraction of missing data	Winter	Spring	Summer	Autumn
<b>SBR</b> (Sabres)	<b>0.24</b>	29 %	26 %	28 %	18 %
<b>URG</b> (Urgons)	0.07	<b>64 %</b>	15 %	9 %	12 %
<b>CRD</b> (Créon d'Armagnac)	0.06	32 %	11 %	11 %	47 %
<b>PRG</b> (Peyrusse Grande)	0.03	<b>48 %</b>	24 %	14 %	14 %
<b>CDM</b> (Condom)	0.04	38 %	10 %	<b>43 %</b>	10 %
<b>LHS</b> (Lahas)	<b>0.18</b>	39 %	22 %	18 %	21 %
<b>SVN</b> (Savenès)	<b>0.23</b>	23 %	17 %	29 %	30 %
<b>MNT</b> (Montaut)	0.03	34 %	38 %	17 %	10 %
<b>SFL</b> (Saint-Félix-de-Lauragais)	<b>0.19</b>	21 %	27 %	29 %	23 %
<b>MTM</b> (Mouthoumet)	0.05	16 %	<b>64 %</b>	10 %	10 %
<b>LZC</b> (Lézignan-Corbières)	<b>0.16</b>	6 %	36 %	36 %	22 %
<b>NBN</b> (Narbonne)	<b>0.13</b>	29 %	22 %	23 %	25 %
<b>PZN</b> (Pézenas)	<b>0.14</b>	18 %	33 %	28 %	21 %
<b>PRD</b> (Prades-le-Lez)	<b>0.20</b>	26 %	28 %	28 %	18 %
<b>LGC</b> (La-Grand-Combe)	<b>0.15</b>	28 %	33 %	20 %	19 %
<b>MZN</b> (Mazan-L'Abbaye)	<b>0.23</b>	24 %	38 %	26 %	12 %
<b>VLV</b> (Villevieille)	<b>0.48</b>	29 %	24 %	24 %	24 %
<b>BRN</b> (Barnas)	<b>0.22</b>	22 %	32 %	29 %	16 %
<b>MJN</b> (Méjannes-le-Clap)	<b>0.31</b>	24 %	28 %	27 %	20 %
<b>BRZ</b> (Berzème)	<b>0.31</b>	28 %	28 %	28 %	17 %
<b>CBR</b> (Cabrières-d'Avignon)	<b>0.13</b>	24 %	28 %	24 %	24 %
<b>Mean value</b>	<b>0.17</b>	29%	28%	24%	20%

## Soil characteristics

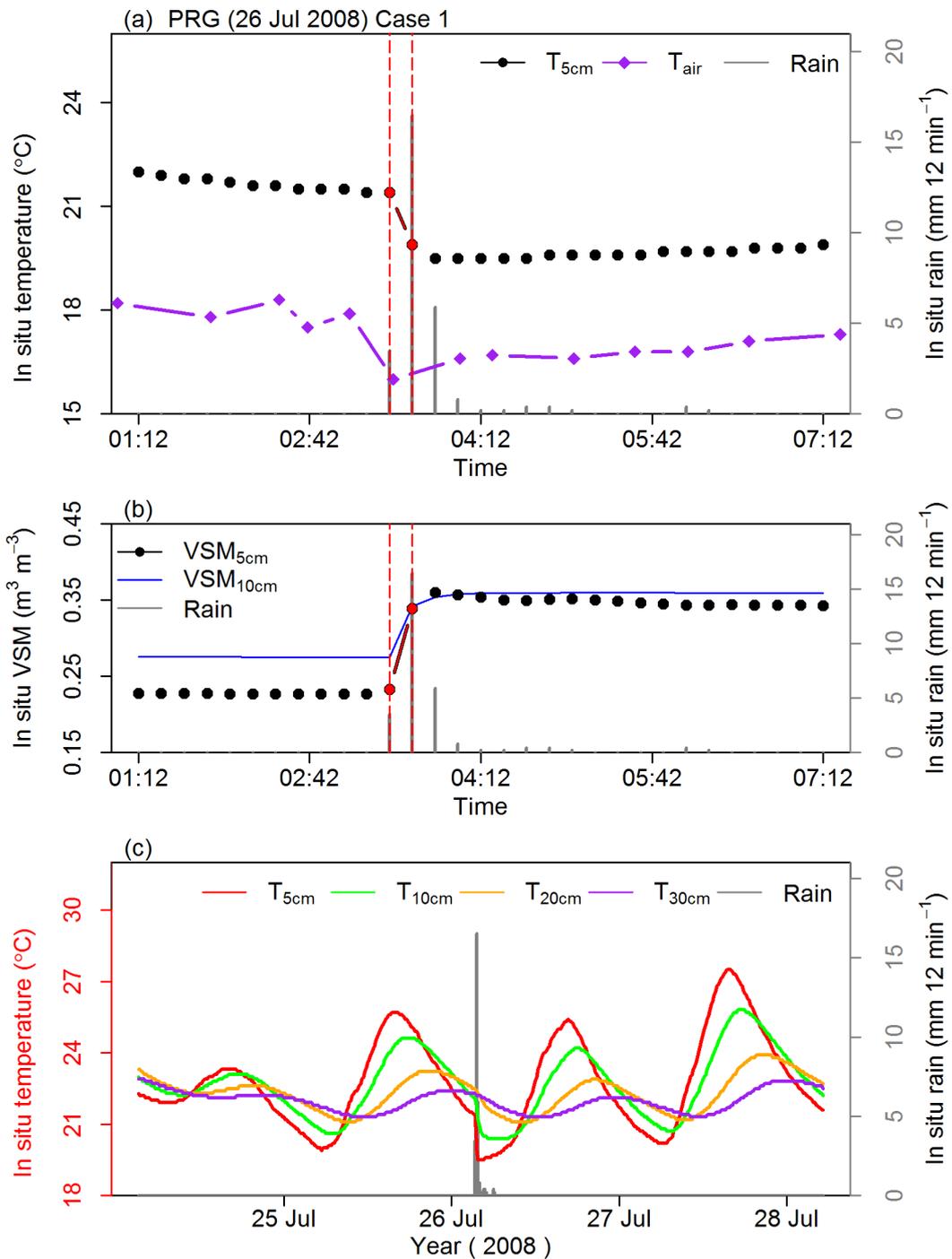
**Table S2.** Reconstructed soil characteristics at a depth of 5 cm for the 21 stations of the SMOSMANIA network, assuming a zero fraction of gravels. Stations are sorted from (top) West to (bottom) East.

Station	$VSM_{sat}$ ( $m^3 m^{-3}$ )	$f_{sand}$ ( $m^3 m^{-3}$ )	$f_{clay}$ ( $m^3 m^{-3}$ )	$f_{silt}$ ( $m^3 m^{-3}$ )	$f_{gravel}$ ( $m^3 m^{-3}$ )	$f_{SOM}$ ( $m^3 m^{-3}$ )
<b>SBR</b>	0.440	0.502	0.021	0.016	0	0.021
<b>URG</b>	0.472	0.079	0.078	0.341	0	0.029
<b>CRD</b>	0.487	0.413	0.027	0.029	0	0.045
<b>PRG</b>	0.497	0.073	0.193	0.197	0	0.039
<b>CDM</b>	0.457	0.078	0.215	0.232	0	0.019
<b>LHS</b>	0.413	0.154	0.196	0.205	0	0.032
<b>SVN</b>	0.457	0.191	0.103	0.235	0	0.014
<b>MNT</b>	0.453	0.145	0.077	0.290	0	0.036
<b>SFL</b>	0.396	0.253	0.132	0.196	0	0.024
<b>MTM</b>	0.419	0.211	0.148	0.144	0	0.079
<b>LZC</b>	0.464	0.222	0.138	0.145	0	0.031
<b>NBN</b>	0.495	0.116	0.206	0.122	0	0.060
<b>PZN</b>	0.510	0.224	0.077	0.141	0	0.047
<b>PRD</b>	0.460	0.130	0.150	0.202	0	0.057
<b>LGC</b>	0.405	0.410	0.072	0.078	0	0.035
<b>MZN</b>	0.600	0.219	0.049	0.056	0	0.075
<b>VLV</b>	0.557	0.261	0.054	0.082	0	0.046
<b>BRN</b>	0.424	0.385	0.047	0.066	0	0.078
<b>MJN</b>	0.460	0.192	0.068	0.161	0	0.119
<b>BRZ</b>	0.572	0.148	0.092	0.155	0	0.032
<b>CBR</b>	0.488	0.222	0.113	0.132	0	0.045

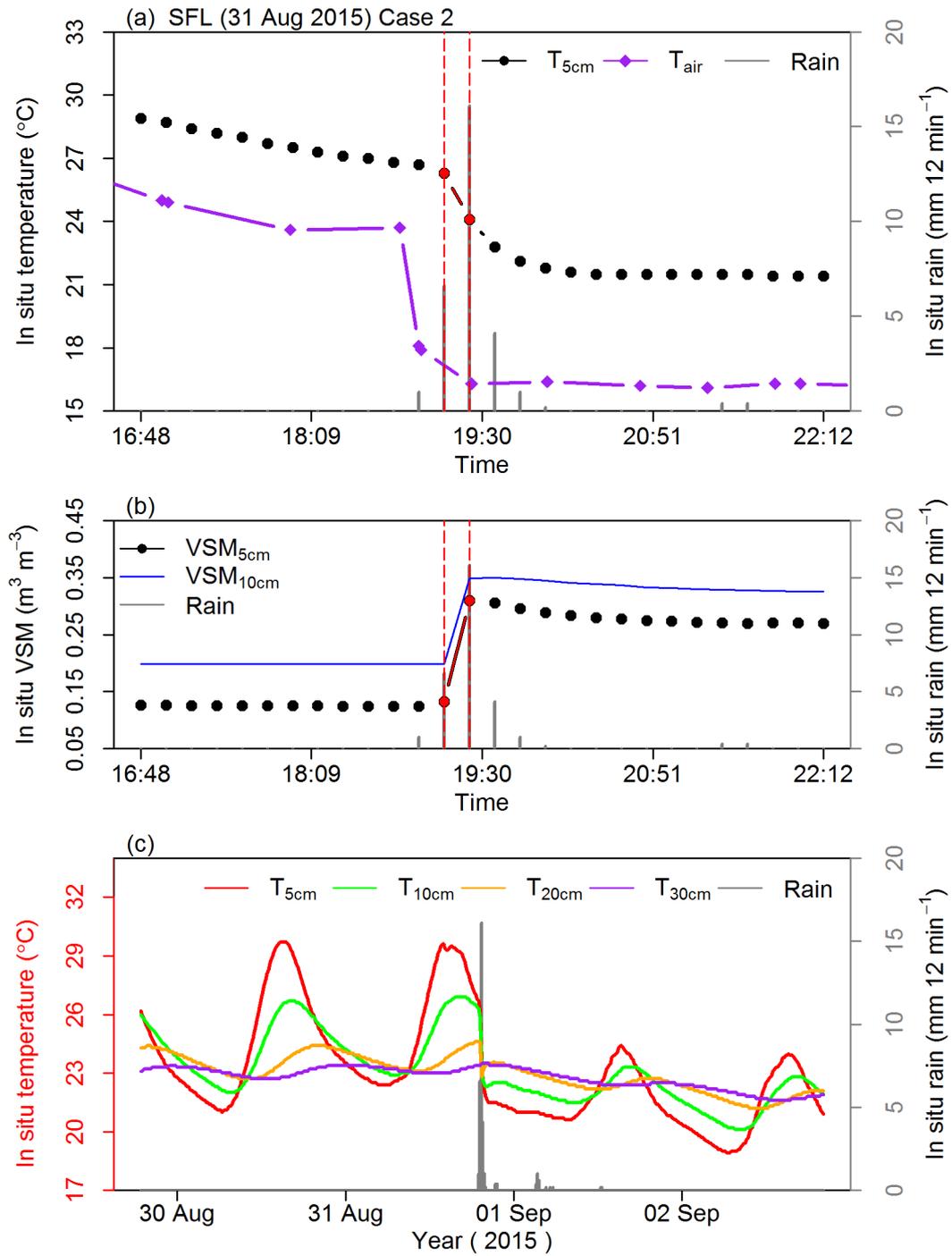
**Table S3.** Observed soil characteristics at a depth of 10 cm for the 21 stations of the SMOSMANIA network. Adapted from Table 1 in Calvet et al. (2016). Stations are sorted from (top) West to (bottom) East.

Station	$VSM_{sat}$ ( $m^3 m^{-3}$ )	$f_{sand}$ ( $m^3 m^{-3}$ )	$f_{clay}$ ( $m^3 m^{-3}$ )	$f_{silt}$ ( $m^3 m^{-3}$ )	$f_{gravel}$ ( $m^3 m^{-3}$ )	$f_{SOM}$ ( $m^3 m^{-3}$ )
<b>SBR</b>	0.352	0.576	0.026	0.013	0.002	0.032
<b>URG</b>	0.474	0.076	0.078	0.341	0.005	0.025
<b>CRD</b>	0.437	0.457	0.027	0.033	0.000	0.045
<b>PRG</b>	0.431	0.051	0.138	0.138	0.214	0.028
<b>CDM</b>	0.413	0.073	0.241	0.231	0.012	0.030
<b>LHS</b>	0.416	0.102	0.202	0.189	0.051	0.039
<b>SVN</b>	0.445	0.128	0.073	0.176	0.162	0.017
<b>MNT</b>	0.447	0.135	0.066	0.230	0.102	0.020
<b>SFL</b>	0.413	0.127	0.071	0.118	0.250	0.021
<b>MTM</b>	0.405	0.110	0.081	0.076	0.297	0.032
<b>LZC</b>	0.429	0.129	0.066	0.068	0.292	0.015
<b>NBN</b>	0.401	0.063	0.135	0.075	0.290	0.036
<b>PZN</b>	0.495	0.222	0.074	0.131	0.055	0.023
<b>PRD</b>	0.494	0.038	0.052	0.069	0.326	0.021
<b>LGC</b>	0.428	0.254	0.044	0.042	0.214	0.019
<b>MZN</b>	0.560	0.212	0.037	0.045	0.097	0.049
<b>VLV</b>	0.506	0.294	0.054	0.086	0.031	0.029
<b>BRN</b>	0.379	0.105	0.009	0.016	0.474	0.016
<b>MJN</b>	0.506	0.064	0.029	0.056	0.317	0.028
<b>BRZ</b>	0.508	0.097	0.074	0.110	0.191	0.020
<b>CBR</b>	0.501	0.120	0.057	0.068	0.241	0.013

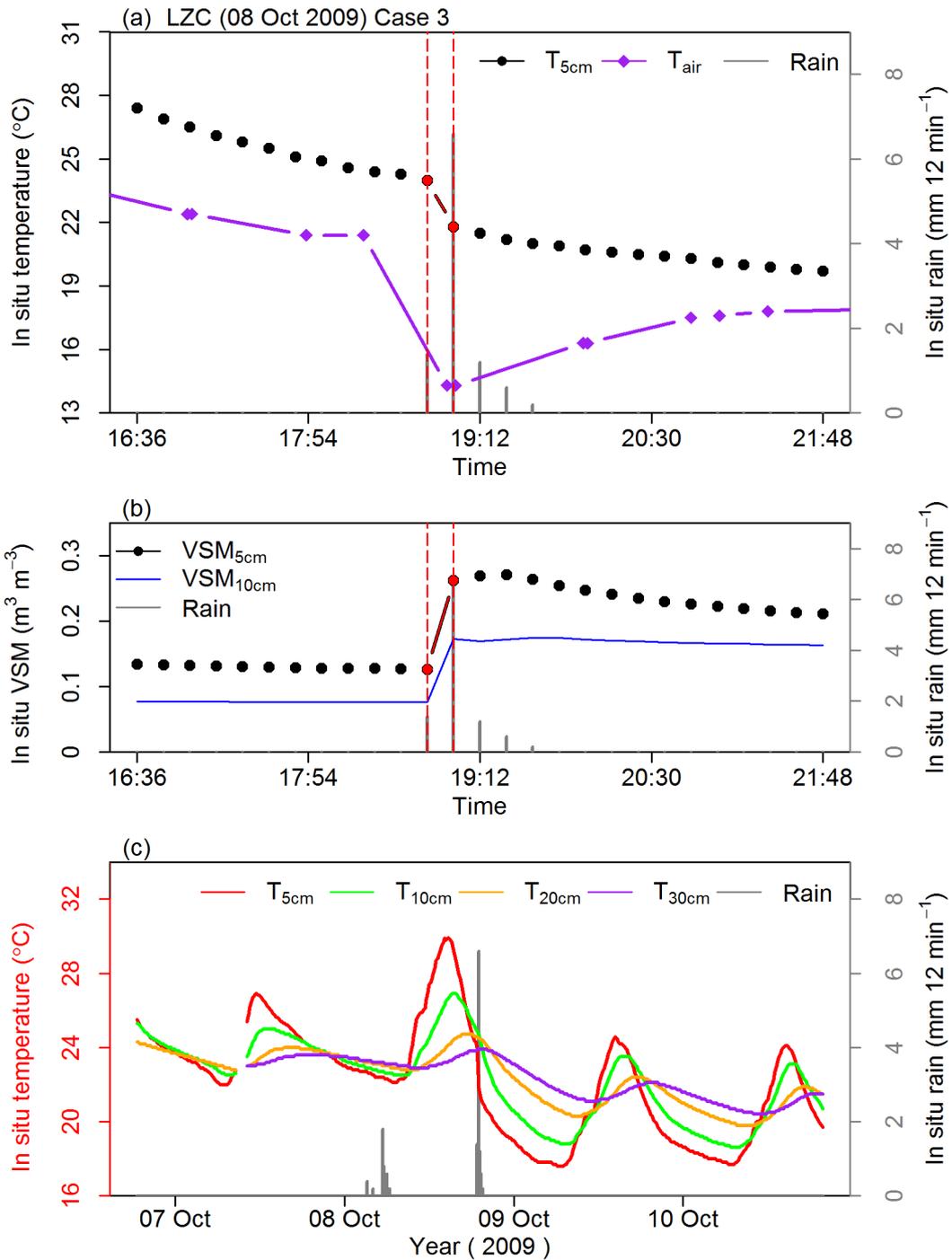
### Examples of significant soil-cooling rains



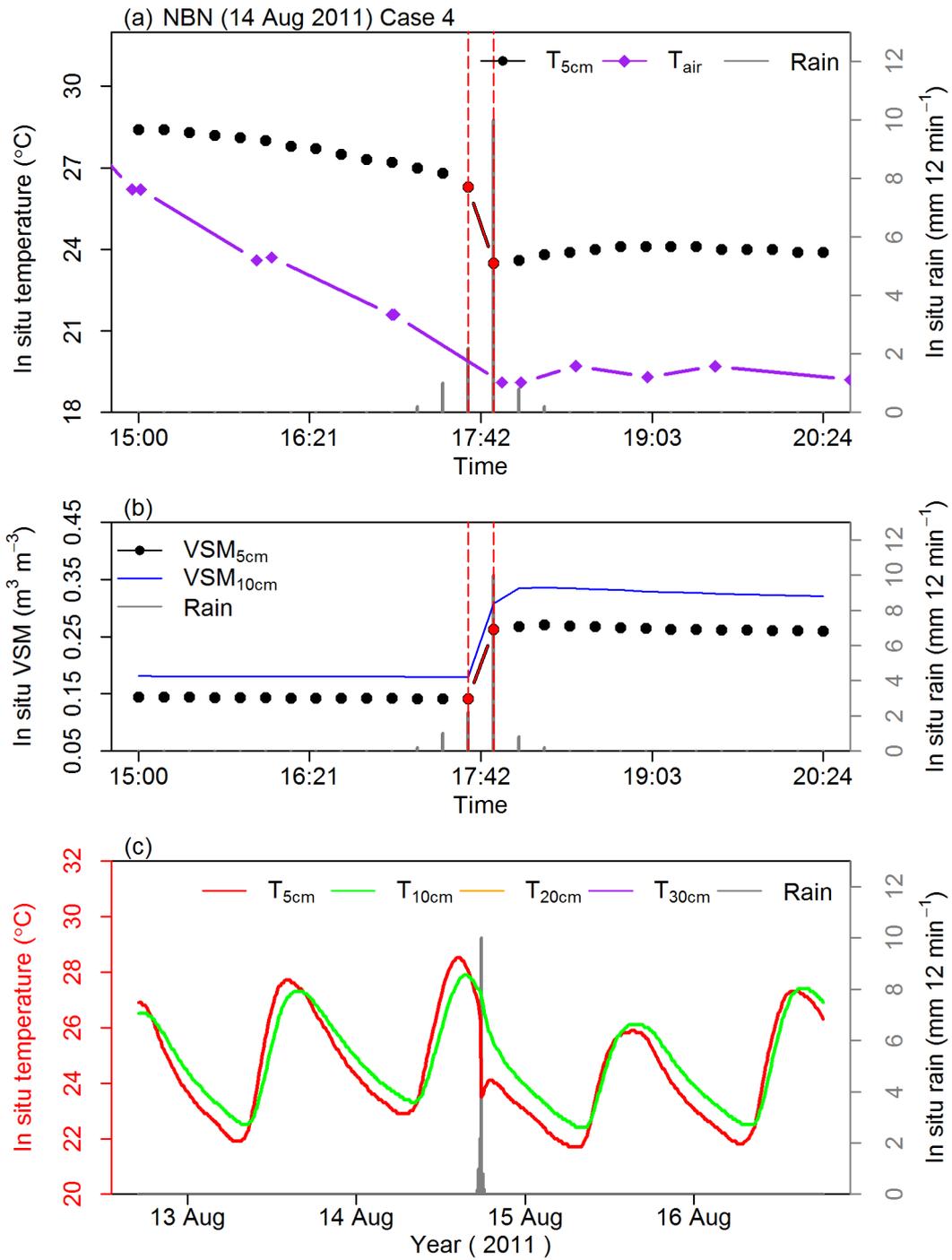
**Figure S3.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 1 (see Table 4) at PRG station on 26 July 2008. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 24 to 28 July 2008 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



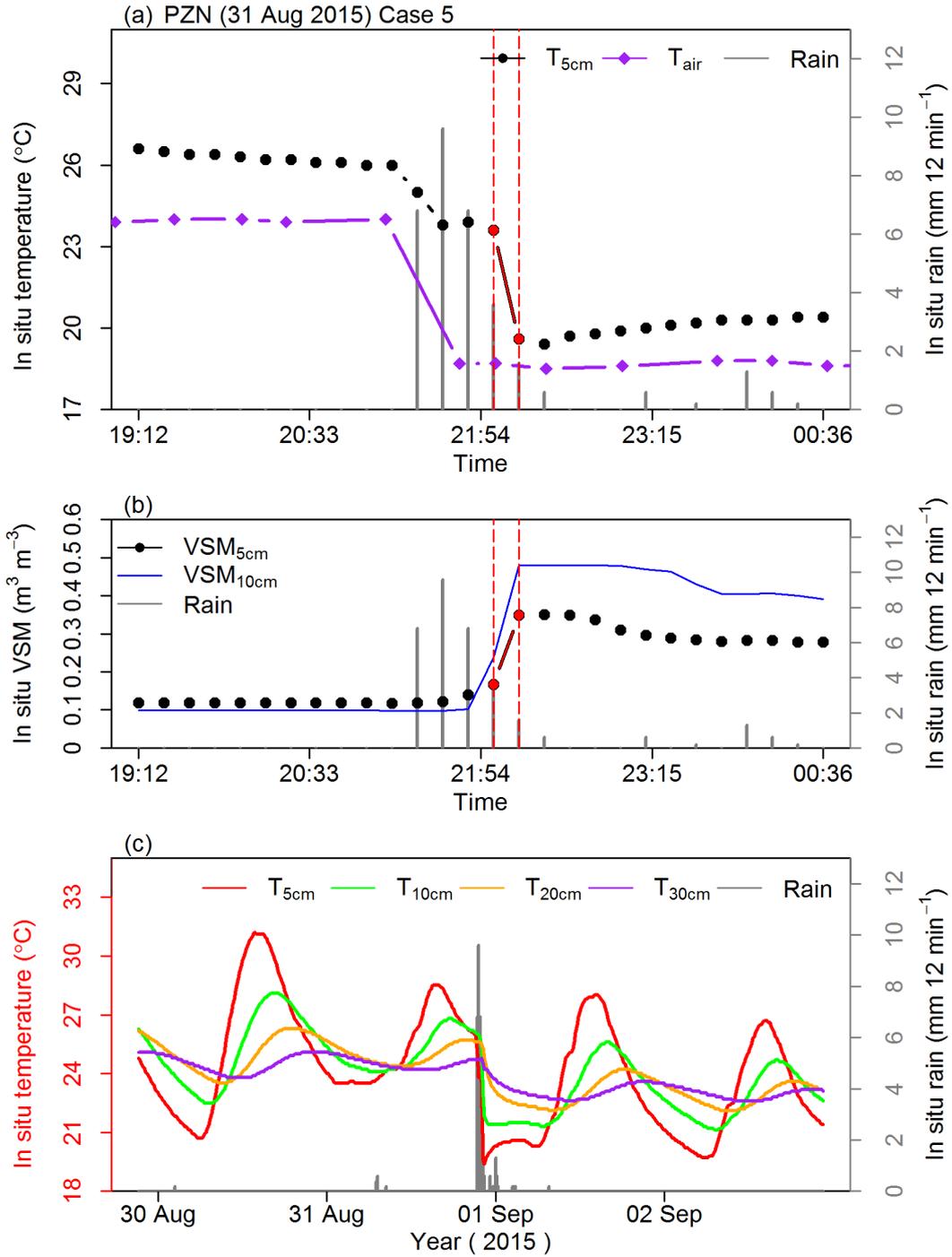
**Figure S4.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 2 (see Table 4) at SFL station on 31 August 2015. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 29 August to 2 September 2015 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



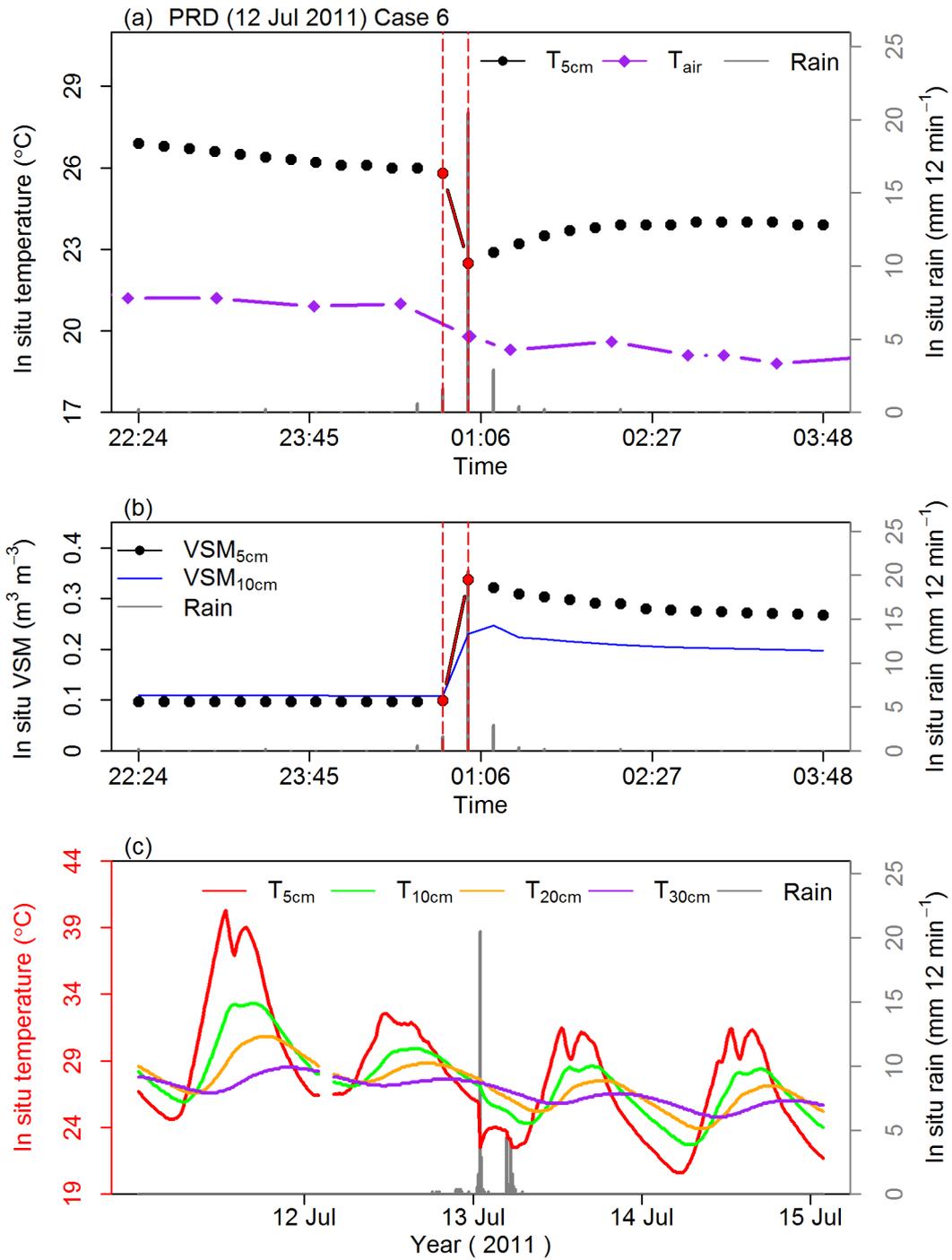
**Figure S5.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 3 (see Table 4) at LZC station on 8 October 2009. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 6 to 10 October 2009 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



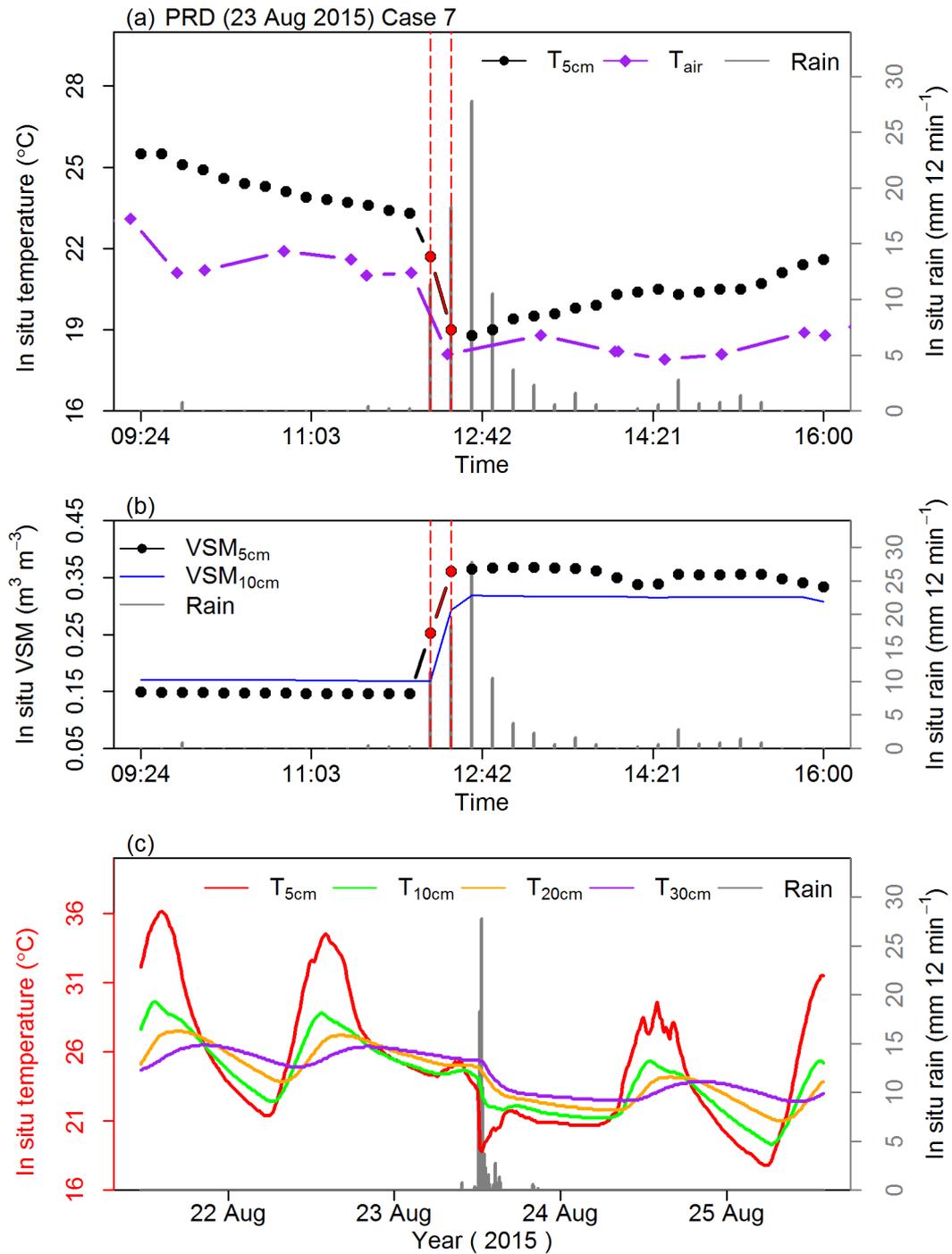
**Figure S6.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 4 (see Table 4) at NBN station on 14 August 2011. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 12 to 16 August 2011 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey. In situ soil temperatures at depths of 20 and 30 cm are missing.



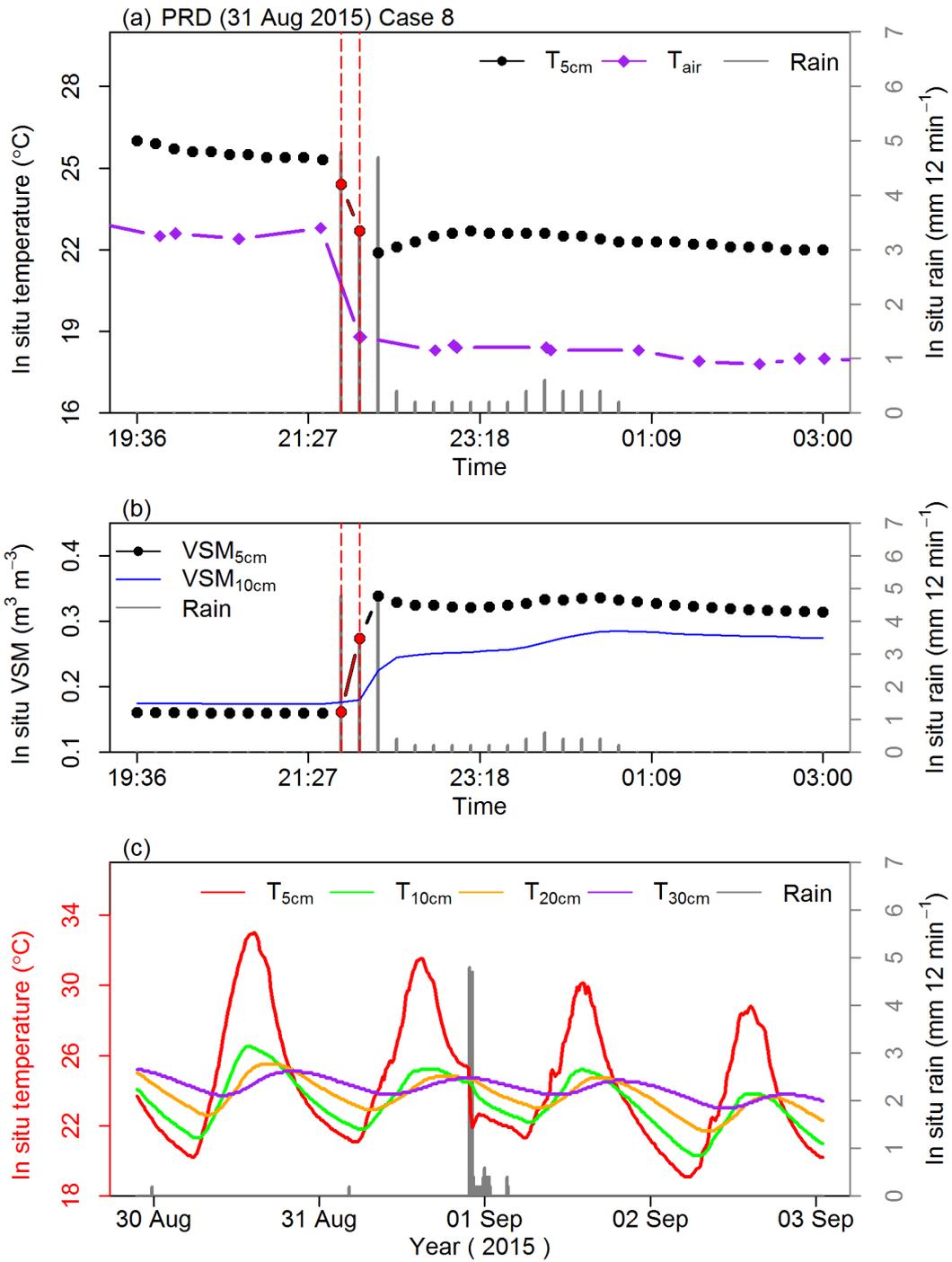
**Figure S7.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 5 (see Table 4) at PZN station on 31 August 2015. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 29 August to 2 September 2015 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



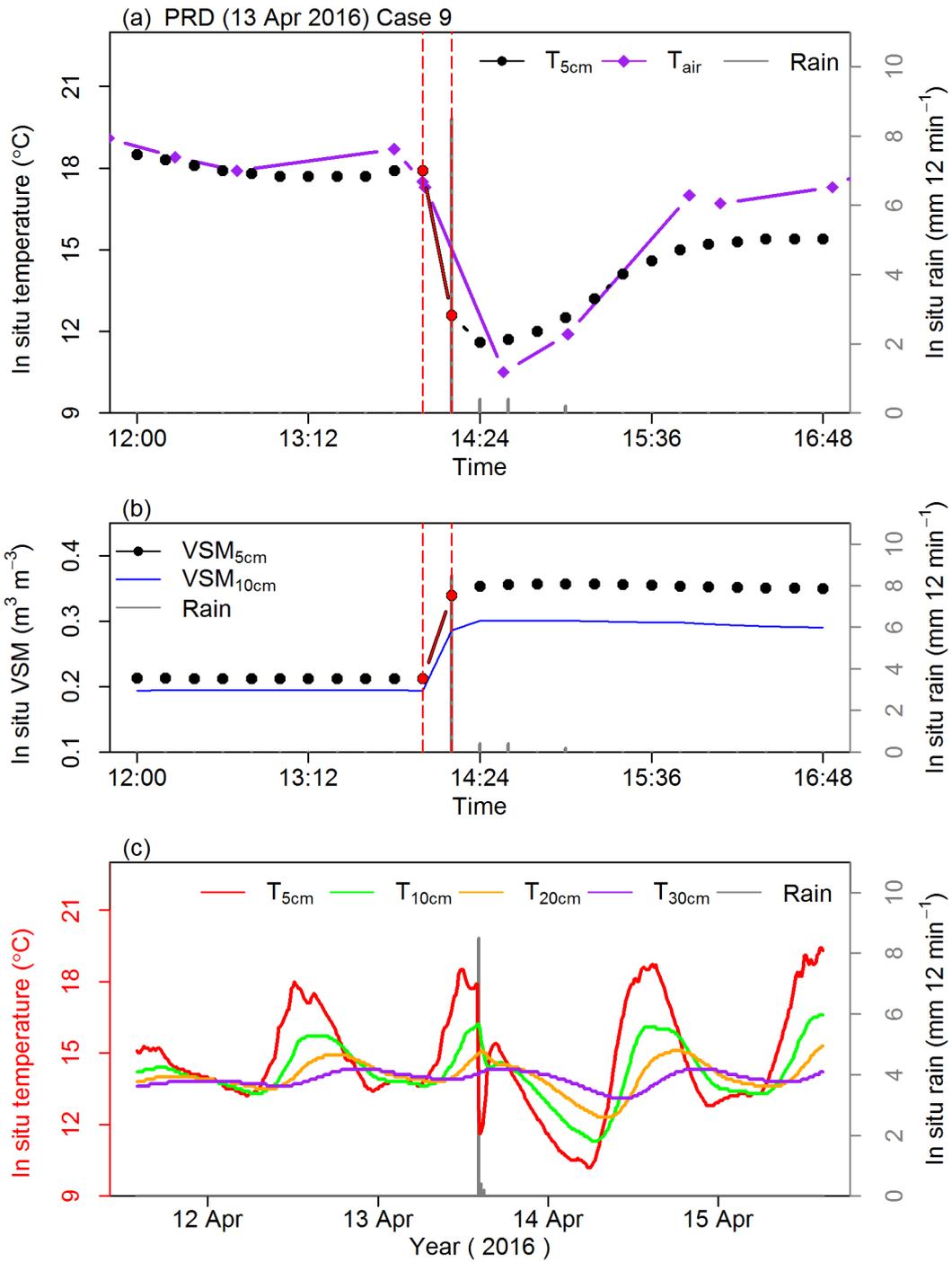
**Figure S8.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 6 (see Table 4) at PRD station on 12 and 13 July 2011. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 11 to 15 July 2011 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



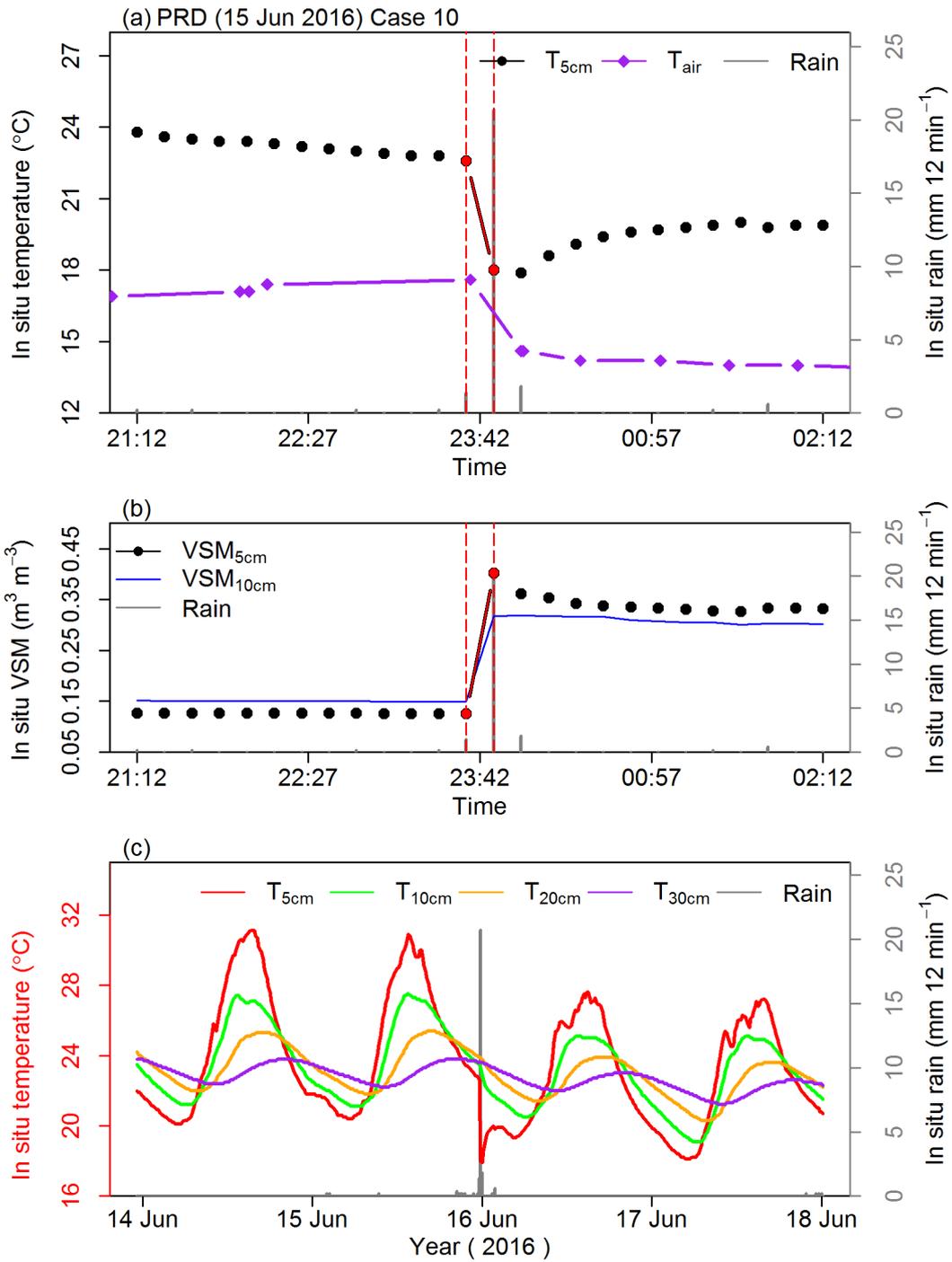
**Figure S9.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 7 (see Table 4) at PRD station on 23 August 2015. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 21 to 25 August 2015 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



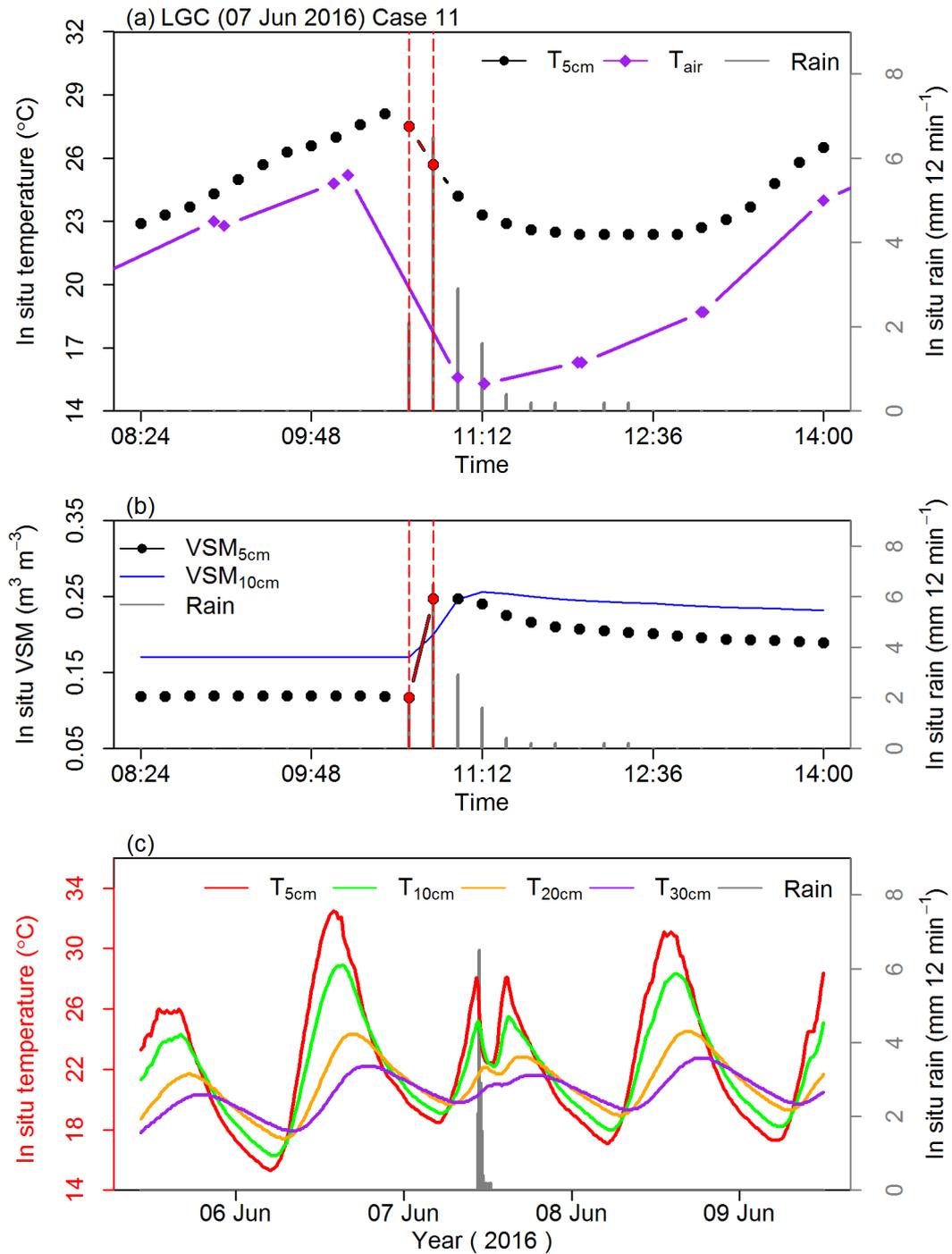
**Figure S10.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 8 (see Table 4) at PRD station on 31 August and 1 September 2015. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 29 August to 3 September 2015 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



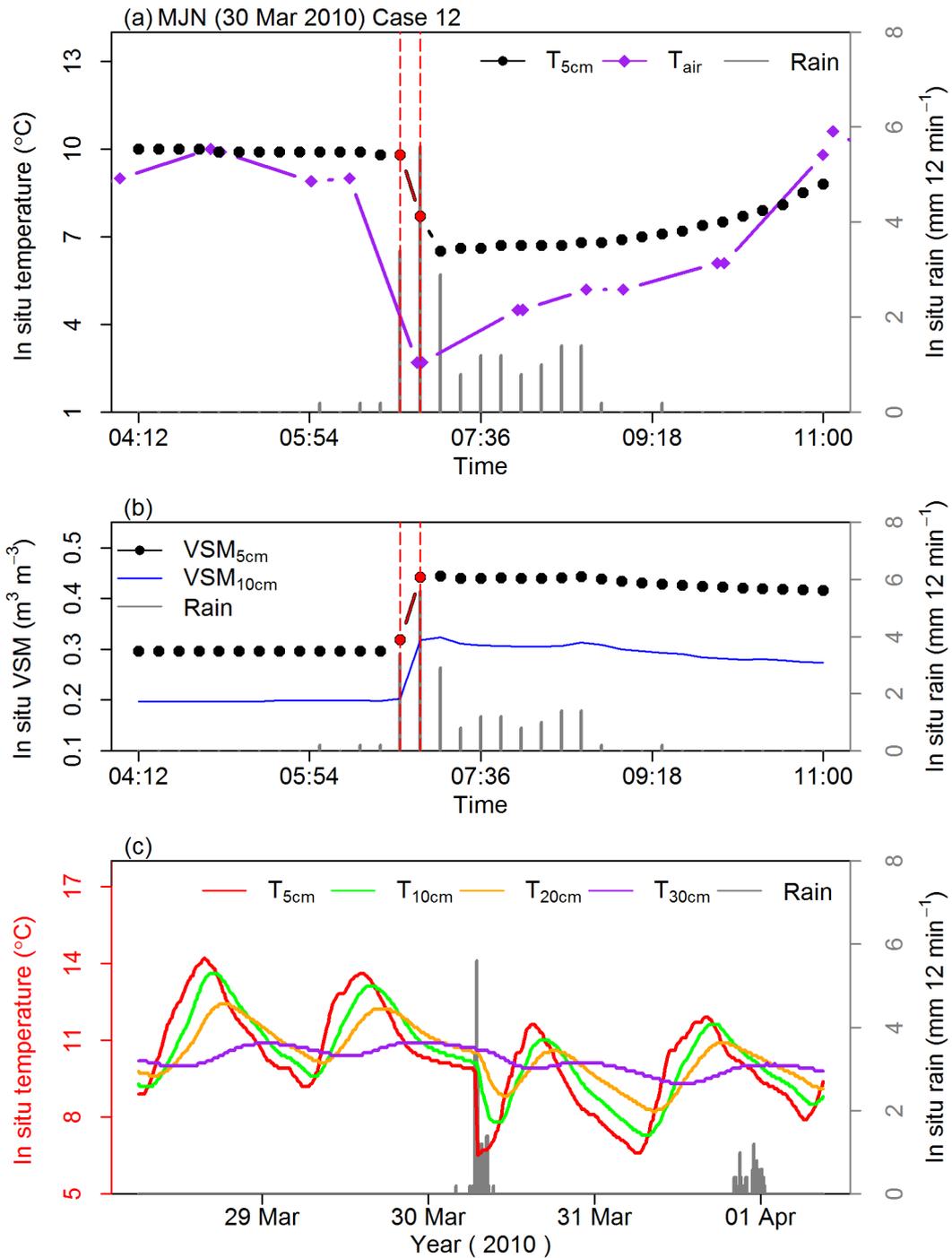
**Figure S11.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 9 (see Table 4) at PRD station on 13 April 2016. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 11 to 15 April 2016 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



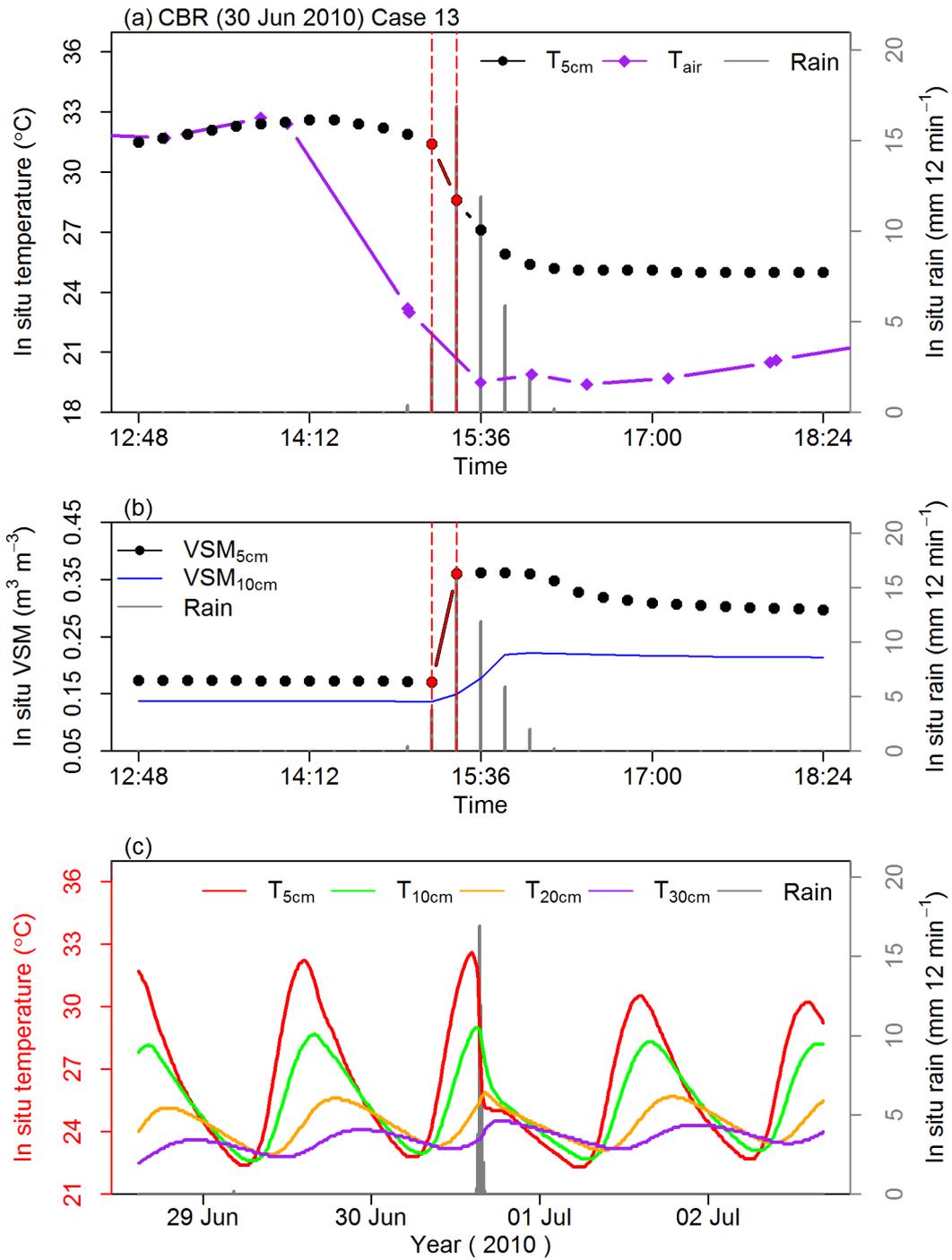
**Figure S12.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 10 (see Table 4) at PRD station on 15 and 16 June 2016. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 13 to 18 June 2016 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.



**Figure S13.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 11 (see Table 4) at LGC station on 7 June 2016. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 5 to 9 June 2016 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.

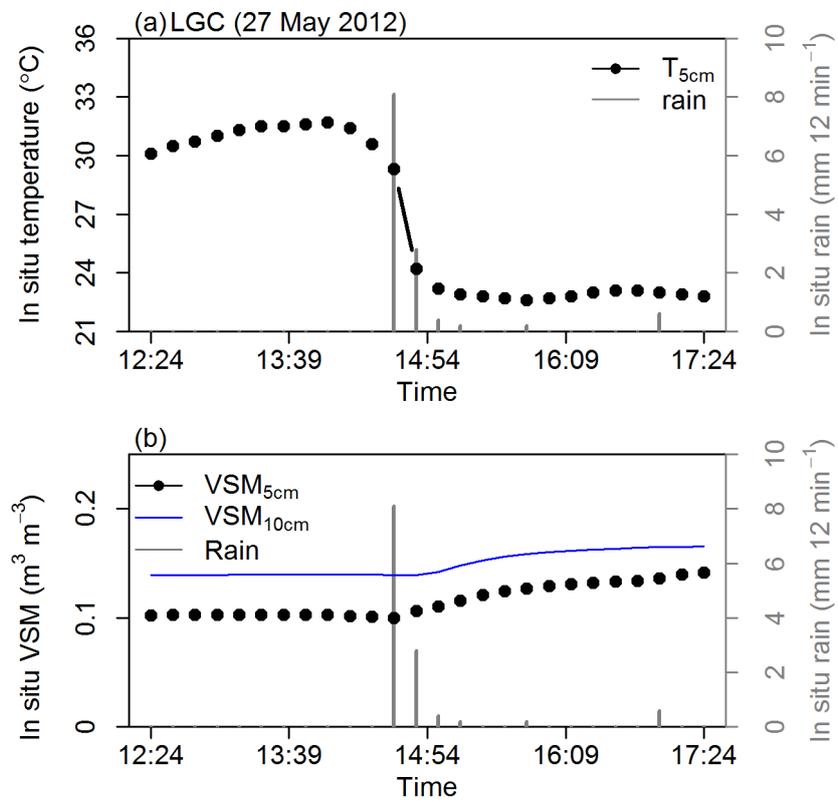


**Figure S14.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 12 (see Table 4) at MJN station on 30 March 2010. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 28 March to 1 April 2010 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.

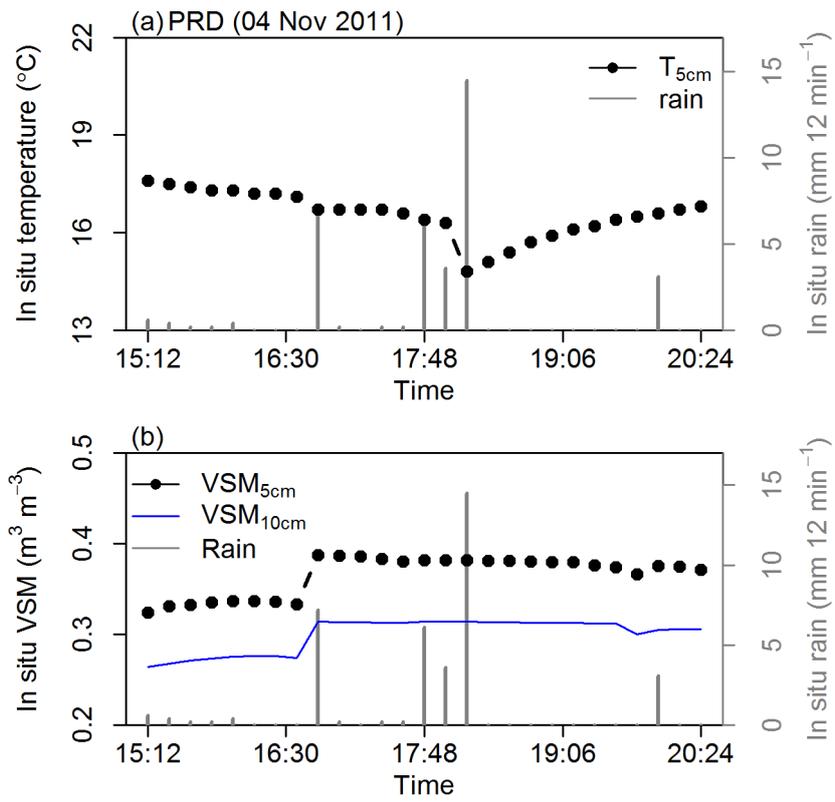


**Figure S15.** (a) In situ  $T_{5\text{cm}}$  (black) and accumulated rainfall (grey) observations measured every 12 min, and the maximum and minimum  $T_{\text{air}}$  values in an hour (purple); (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) observations also measured every 12 min, from case 13 (see Table 4) at CBR station on 30 June 2010. The red dashed lines show the duration from time  $t_1$  to  $t_2$ , and the corresponding  $T_{5\text{cm}}$  and  $VSM_{5\text{cm}}$  are highlighted by red. (c) In situ soil temperature measured from 28 June to 2 July 2010 at depths of 5, 10, 20 and 30 cm, together with the in situ rainfall observations ( $\text{mm } 12 \text{ min}^{-1}$ ) shown in grey.

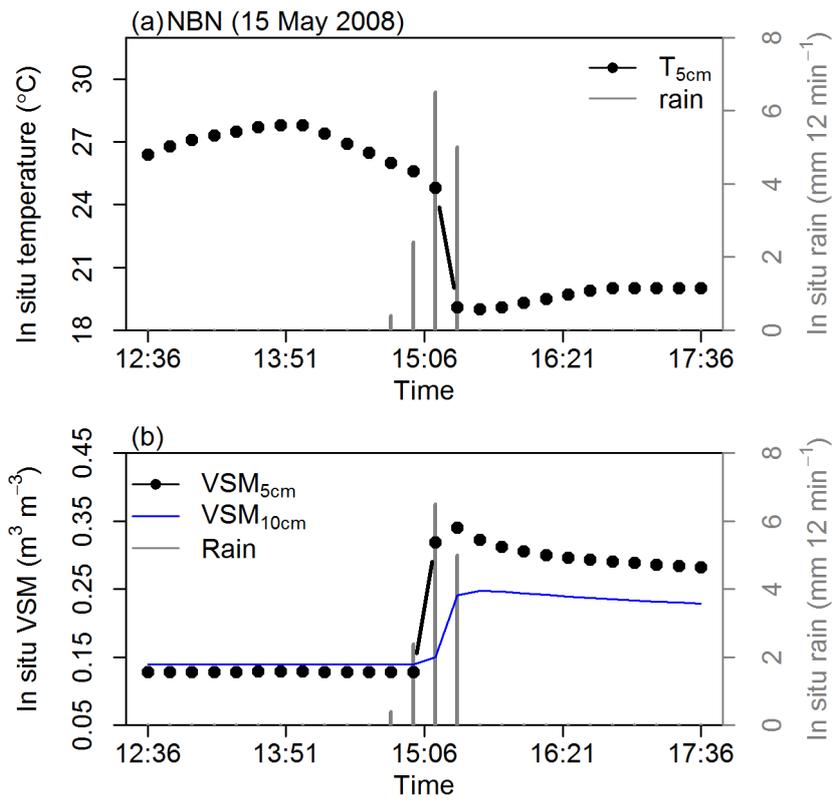
## Examples of $VSM_{5cm}$ response to rain



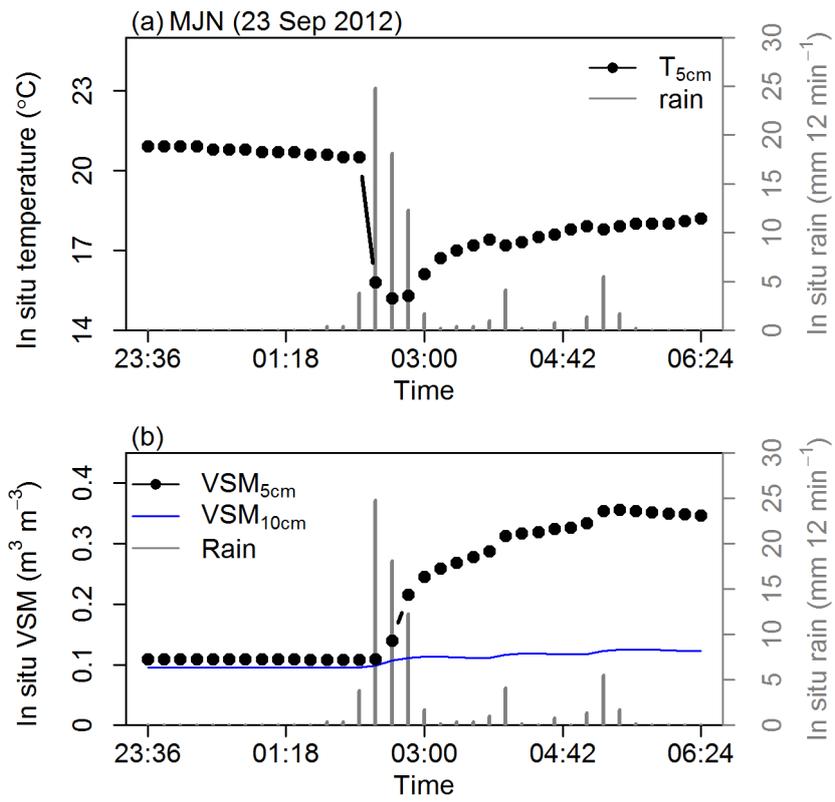
**Figure S16.** (a) In situ  $T_{5cm}$  (black) and rainfall (grey) observations, and (b) in situ  $VSM_{5cm}$  (black),  $VSM_{10cm}$  (blue) and rainfall (grey) observations are measured every 12 min at LGC station on 27 May 2012.



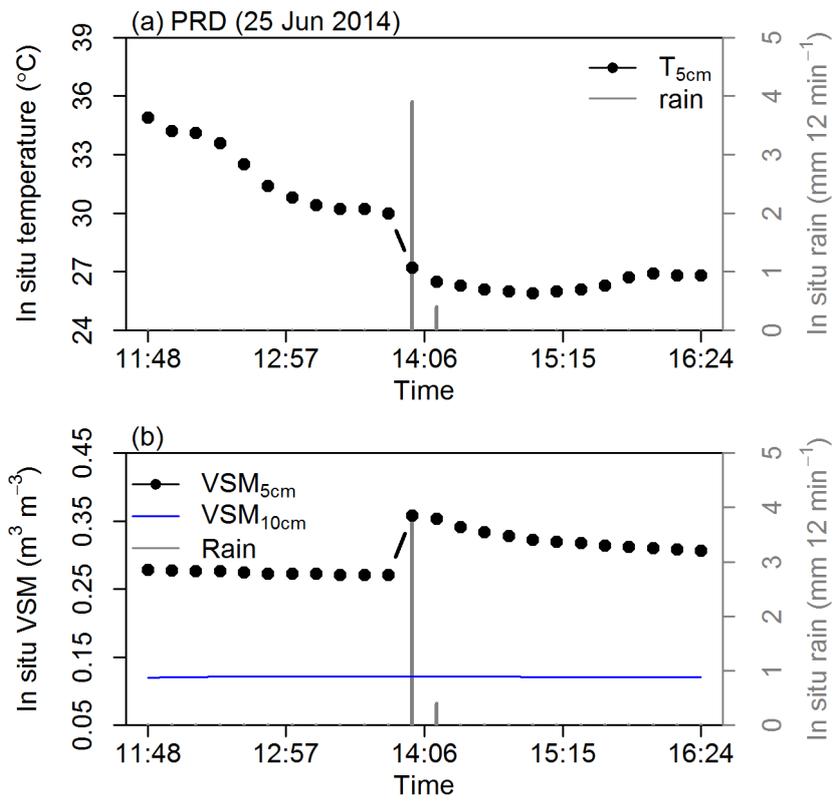
**Figure S17.** (a) In situ  $T_{5\text{cm}}$  (black) and rainfall (grey) observations, and (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) and rainfall (grey) observations are measured every 12 min at PRD station on 4 November 2011.



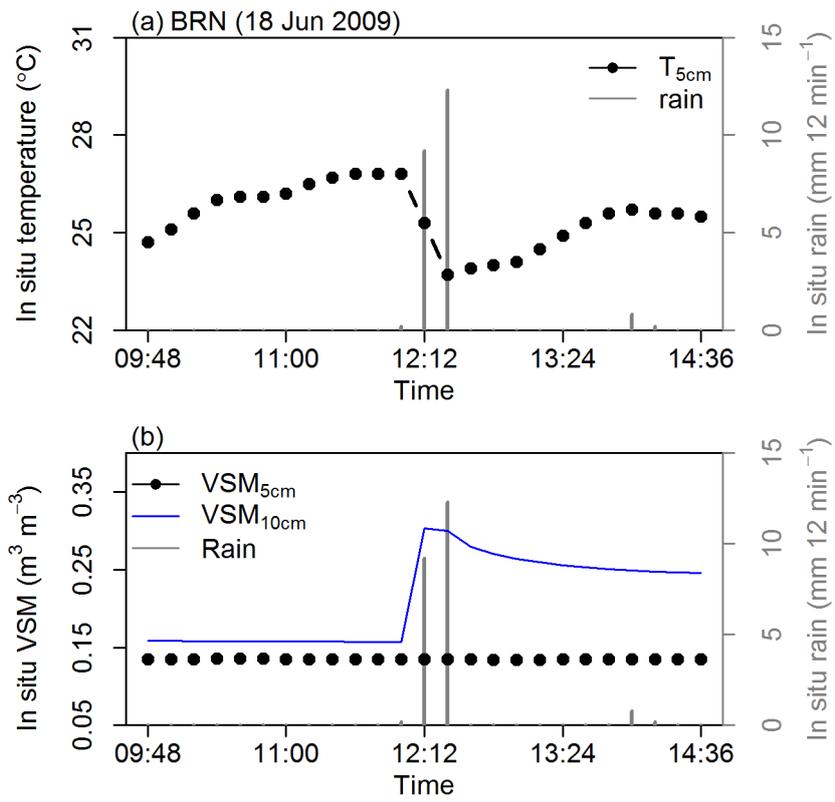
**Figure S18.** (a) In situ  $T_{5\text{cm}}$  (black) and rainfall (grey) observations, and (b) in situ  $\text{VSM}_{5\text{cm}}$  (black),  $\text{VSM}_{10\text{cm}}$  (blue) and rainfall (grey) observations are measured every 12 min at NBN station on 15 May 2008.



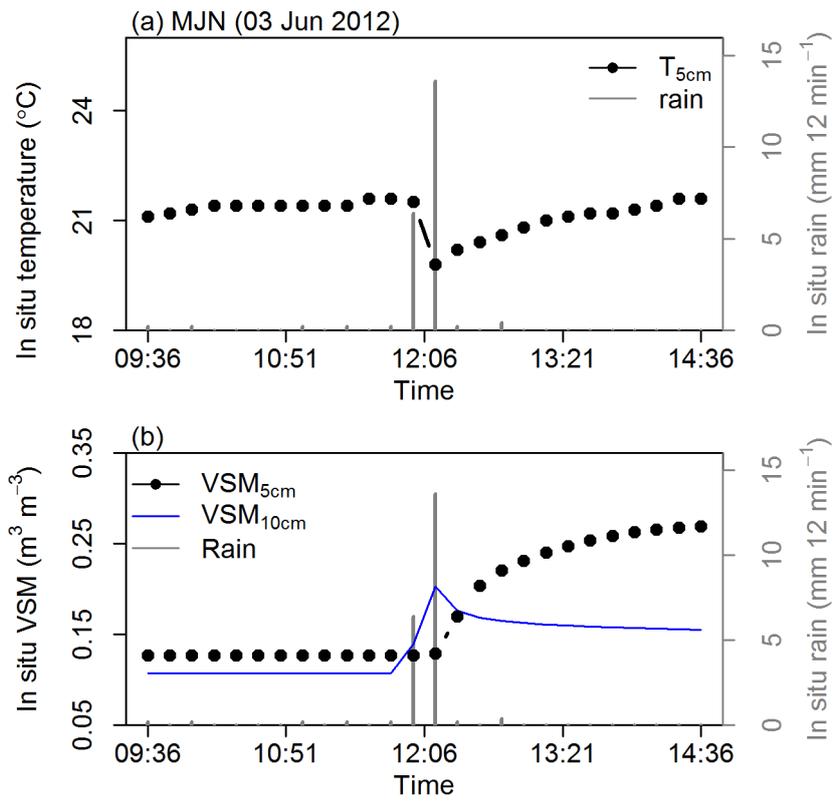
**Figure S19.** (a) In situ  $T_{5\text{cm}}$  (black) and rainfall (grey) observations, and (b) in situ  $\text{VSM}_{5\text{cm}}$  (black),  $\text{VSM}_{10\text{cm}}$  (blue) and rainfall (grey) observations are measured every 12 min at MJN station on 23 and 24 September 2012.



**Figure S20.** (a) In situ  $T_{5cm}$  (black) and rainfall (grey) observations, and (b) in situ  $VSM_{5cm}$  (black),  $VSM_{10cm}$  (blue) and rainfall (grey) observations are measured every 12 min at PRD station on 25 June 2014.  $VSM_{5cm}$  increase is observed together with the  $T_{5cm}$  decrease, but there is no change in  $VSM_{10cm}$ , below  $0.15 \text{ m}^3 \text{ m}^{-3}$ .



**Figure S21.** (a) In situ  $T_{5\text{cm}}$  (black) and rainfall (grey) observations, and (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) and rainfall (grey) observations are measured every 12 min at BRN station on 18 June 2009.  $VSM_{10\text{cm}}$  increase is observed together with the  $T_{5\text{cm}}$  decrease, but there is no change in  $VSM_{5\text{cm}}$ , below  $0.15 \text{ m}^3 \text{ m}^{-3}$ .



**Figure S22.** (a) In situ  $T_{5\text{cm}}$  (black) and rainfall (grey) observations, and (b) in situ  $VSM_{5\text{cm}}$  (black),  $VSM_{10\text{cm}}$  (blue) and rainfall (grey) observations are measured every 12 min at MJN station on 3 June 2012.