APPENDIX 1

Weather parameters for NSRI-modified MOSES

An example of UKMO weather data that are required to run MOSES is given in Table 1. Data were supplied for Cardington, Bedfordshire in this format for a 6-month period (January to June) 2001 by UKMO.

Table 1 First 24 time steps (6 hours) in Cardington data

Surface downward shortwave radiation **SW**	Surface downward longwave radiation **LW**	Precipitation rain **RAIN**	Precipitation snow **SNOW**	Air temperature **TA**	Westerly wind component **U**	Southerly wind component **V**	Surface pressure **PSTAR**	Specific humidity **QA**
12.8	263.7	0.00E+00	0.00E+00	279.843	-0.403	6.617	97421.1	6.10E-03
15.8	267.9	0.00E+00	0.00E+00	279.939	0.325	5.68	98769.7	6.10E-03
17.5	267.6	0.00E+00	0.00E+00	280.11	0.462	4.535	98172.8	6.22E-03
16.5	269.7	0.00E+00	0.00E+00	280.362	0.148	4.246	98336.4	6.31E-03
12.2	270.9	0.00E+00	0.00E+00	280.589	0.12	4.114	98232.3	6.40E-03
7.9	271.5	0.00E+00	0.00E+00	280.696	0.666	4.052	98260.6	6.43E-03
7.9	272.5	0.00E+00	0.00E+00	280.85	0.946	4.039	98260.3	6.51E-03
12	273.8	0.00E+00	0.00E+00	281.088	1.223	4.933	98268.2	6.57E-03
13.6	275.2	0.00E+00	0.00E+00	281.274	0.867	5.575	98274.9	6.68E-03
14.4	276.9	0.00E+00	0.00E+00	281.504	0.827	6.202	98274.2	6.82E-03
10.6	278.1	0.00E+00	0.00E+00	281.68	0.999	6.224	98259.1	6.91E-03
4.9	278	2.59E-04	0.00E+00	281.672	0.449	5.029	98232.9	6.92E-03
9.5	278.1	0.00E+00	0.00E+00	281.716	0.151	4.43	98226.4	6.91E-03
13.9	279.6	0.00E+00	0.00E+00	281.974	1.228	5.617	98235	6.99E-03
11.7	281.1	2.59E-04	0.00E+00	282.253	1.305	6.184	98212	7.06E-03
10.8	281.9	0.00E+00	0.00E+00	282.401	1.113	6.594	98193.6	7.11E-03
6.1	282	0.00E+00	0.00E+00	282.37	1.066	6.306	98197.5	7.14E-03
0.6	282	0.00E+00	0.00E+00	282.333	0.959	6.1	98190.9	7.17E-03
5.2	282.4	2.59E-04	0.00E+00	282.41	1.152	7.009	98178.9	7.19E-03
12	282.7	0.00E+00	0.00E+00	282.471	1.666	7.216	98203.2	7.21E-03
10.6	283	2.59E-04	0.00E+00	282.558	1.888	6.858	98217.2	7.20E-03
10.9	283.6	2.59E-04	0.00E+00	282.622	2.415	6.532	98221.2	7.19E-03
21.5	281.2	0.00E+00	0.00E+00	282.58	3.147	6.315	98243.7	7.10E-03
35	285.6	0.00E+00	0.00E+00	282.419	3.267	5.807	98276.1	6.96E-03

Preparation of MOSES weather data for Camborne, Rothamsted and Watnall

Data for the parameters shown in Table 2 were purchased from UKMO in April 2005 for the three experimental sites. These data were then transposed to enable input to MOSES. The various methods of transposition are described below.

Table 2 Data purchased from UKMO for the three experimental sites

Parameter		Units	Parameter		Units
Total cloud	amount	8ths	Temperature	dry bulb	°C
Cloud Group 1	amount	8ths		dew point	°C
	type	Code	Precipitation	rainfall	mm
	height	FT		snow	falling
Cloud Group 2	amount	8ths	Wind	direction	deg true
	type	Code		speed	kn
	height	FT	Pressure	MSLP	mbar
Cloud Group 3	amount	8ths	Radiation	global	KJ/m^2
	type	Code		height	FT
	height	FT			

The above data were converted into MOSES input requirements according to the following equations:

SW - Surface downward shortwave radiation

$$SW\ (W/m^2) = (KJ/m^2 / 3600) * 1000$$

LW - Surface downward longwave radiation based on Finch and Best (2004)

LW (W/m^2)

$$L\downarrow = \varepsilon_e \sigma T_k^4 \qquad \text{where } \varepsilon_e = \varepsilon_a K$$

$$\varepsilon_a = 1 - 0.261\exp\left(-7.77\cdot10^{-4}\left(273.16 - T_a\right)^2\right)$$

$$K = 1 + \left(k_L c_L + k_M c_M + k_H c_H\right)c$$

where c is the total fractional cloud cover and the values of $k_L = 0.21$, $k_M = 0.16$ and $k_H = 0.06$ based on those of Arnfield (1979).

RAIN - Precipitation

RAIN ($kg/m^2/s$) = mm/3600
[1 mm = 1litre/m^2 = 1 kg/m^2 and 1 hour = 3600 seconds]

SNOW - Snowfall

Units $kg/m^2/s$

TA - Air temperature

TA (K) = degree Celsius + 272.15

U - Westerly winds

U (m/s) = wind speed (kn) * 0.5144

V - Southerly winds

V (m/s) = 0

PSTAR - Surface pressure

PSTAR (Pa) = MSLP (mbar) *100

QA - Specific humidity

Specific humidity (ratio) according to the methods of Guyot (1997)

QA (kg/kg) = q

and $q = 0.622 \frac{e_a}{P}$

where e_a = actual vapour pressure (mbar)
P = total atmospheric pressure (mbar)

where

$$e_a = 6.112 \exp((17.67 * dew \cdot point) / (dew \cdot point + 237.3))$$

$$P = 1010 - 0.1115 * ALT + (0.00175 * ALT)^2$$

where ALT = altitutde (m)

References

Arnfield, A.J. (1979). Evaluation of empirical expressions for the estimation of hourly and daily totals of atmospheric longwave emission under all sky conditions. Q. J. R. Meteorol. Soc. 105: 1041-1052

Finch, J.W. and Best, M.J. (2004). The accuracy of downward short- and long-wave radiation at the earth's surface calculated using simple models. Meteorol. Appl. 11:33-39

Guyot, G. (1997). Physics of the Environment and Climate. John Wiley & Sons.

APPENDIX 2

Soil physical property input data for NSRI-modified MOSES

Soil input files containing the following parameters are required by MOSES (Table 1).

Table 1 Hydrological parameters for MOSES soil data files

Parameter	Description	Units
NSOIL	Number of soil layers	-/-
DZSOIL	Soil thickness	m
B_EXP	Exponent used in calculation of soil water suction and hydraulic	-/-
SATCON	Saturated hydrological conductivity of the soil	$kg/m^2/s$
SATHH	Saturated soil water suction; SATHH = 1/ALPHA	-/-
V_SAT	Volumetric soil moisture content at saturation	m^3/m^3 soil
V_CRIT	Volumetric soil moisture content at the critical point	m^3/m^3 soil
V_WILT	Volumetric soil moisture content at the wilting point	m^3/m^3 soil
HCAP	Soil heat capacity	$J/K/m^3$
HCON	Soil thermal conductivity	W/m/K

Soil series specific information stored in the computerised Land Information System (LandIS) or derived from measured laboratory analyses of soils at the experimental sites was converted into MOSES input requirements according to the following equations:

Soil thickness (m)

dzsoil = (REAL(zbl-ztl))/100.

ztl depth to top of the horizon (cm)

zbl depth to bottom of horizon (cm)

Volumetric soil moisture content at saturation (m^3/m^3)

$v\_sat = \theta_{max}$

θ_{max} maximum volumetric water content (m^3/m^3)

Critical volumetric soil moisture for evaporation (m^3/m^3)

0.033 MPa = 336.6 cm H20

$v\_crit = \theta_{res} + (\theta_{max}-\theta_{res})*(1.0/(1.0+(alpha*336.6)**n))**m$

θ_{max} maximum volumentric water content (m^3/m^3)

θres residual volumetric water content (m^3/m^3)

alpha van Genuchten alpha parameter

n van Genuchten n parameter

m van Genuchten m parameter

Volumetric soil moisture content at wilting point (m^3/m^3)

1.5 MPa = 15300 cm H_20

v_wilt = θ_{res}(l) + (θ_{max}-θ_{res})*(1.0/(1.0+(alpha*15300)**n))**m

θ_{max}	maximum volumentric water content (m^3/m^3)
θres	residual volumetric water content (m^3/m^3)
alpha	van Genuchten alpha parameter
n	van Genuchten n parameter
m	van Genuchten m parameter

Van Genuchten parameter (b)

b_exp = 1/(n-1.0)

where; n is van Genuchten n parameter

Van Genuchten parameter (ψ_s)

sathh = (1.0/alpha)/100

where; alpha is van Genuchten alpha parameter

Hydraulic conductivity ($kg/m^2/s$)

satcon = (K_{sat}*10)/86400

K_{sat}	saturated hydraulic conductivity (cm/day)

Heat capacity - dry soil ($J/K/m^3$)

Hubrechts and Feyen (1996)

cap = 0.077 + 0.754 * b_d + 4.195 * .01 * 1000000

hcap = cap

b_d	bulk density (g cm^3/cm^3)

Thermal conductivity - dry soil (W/m/K)

Hubrechts and Feyen (1996)

a = -0.295 + 0.0126*clay + 0.388*b_d

b = -1.776 + 2.0476*b_d + 0.124*oc

c = EXP(0.976+0.0650*clay+0.263*OC)

cond = a + b*EXP(-c/1.0)

clay	clay content (%)
OC	organic carbon (%)

Thermanl conductivity [W/m/K = 1 W/m/^{o}C]

hcon = cond

References:

Hubrechts, L. and Feyen, J. (1996) Pedotransfer Functions for Thermal Soil Properties. Katholieke Universiteit Leuven

External soil parameter input files for MOSES, formulated in the order of parameters given in Table 1. Tsoil and Stheta are *not* included in the soil file but are parameterised in the nlsts file. Commas delimit values for each layer, starting with layer 1.

Andover 0031 [soil0031r.DAT]

```
1
0.2500
4.2
0.027
0.245
0.575
0.355
0.205
0.825E6
0.34
```

Stheta =0.8

Batcombe 0109 [soil0109r.DAT]

```
4
0.150, 0.400, 0.400, 0.550
4.3, 4.4, 5.0, 5.4
0.023, 0.008, 0.001, 0.001
0.258, 0.258, 0.230, 0.223
0.558, 0.490, 0.458, 0.413
0.352, 0.315, 0.329, 0.311
0.207, 0.190, 0.233, 0.234
0.87E6, 0.11E7, 0.12E7, 0.13E7
0.39, 0.51 ,0.93, 1.09
```

Stheta =0.8, 0.8, 0.9, 0.9

Blackwood 0124 [soil0124r.DAT)

```
5
0.200, 0.250, 0.350, 0.200, 0.500
3.1, 2.7, 2.4, 2.2, 1.9
0.044, 0.037, 0.027, 0.040, 0.064
0.119, 0.100, 0.086, 0.077, 0.067
```

```
0.526, 0.416, 0.357, 0.383, 0.371
0.222, 0.146, 0.102, 0.094, 0.072
0.111, 0.069, 0.046, 0.042, 0.034
0.95E6, 0.11E7, 0.13E7, 0.12E7, 0.12E7
0.27, 0.32 ,0.40, 0.34, 0.36
```

Stheta =0.7, 0.6, 0.5, 0.5, 0.4

Bridgnorth 0144 [soil0144r.DAT]

```
3
0.200, 0.300, 0.200
2.4, 2.3, 2.0
0.024, 0.034, 0.065
0.088, 0.080, 0.070
0.465, 0.378, 0.379
0.146, 0.105, 0.080
0.073, 0.051, 0.037
0.11E7, 0.12E7, 0.12E7
0.32, 0.37 ,0.34
```

Stheta = 0.5, 0.5, 0.4

Bromsgrove 0149 [soil0149r.DAT]

```
5
0.200, 0.250, 0.300, 0.150, 0.400
3.6, 3.4, 3.4, 3.1, 3.1
0.026, 0.039, 0.039, 0.040, 0.040
0.149, 0.132, 0.124, 0.107, 0.104
0.486, 0.436, 0.419, 0.392, 0.387
0.245, 0.204, 0.192, 0.161, 0.158
0.132, 0.106, 0.099, 0.080, 0.079
0.11E7, 0.11E7, 0.12E7, 0.12E7, 0.12E7
0.36, 0.36 ,0.37, 0.39, 0.40
```

Stheta = 0.7, 0.7, 0.7, 0.6, 0.6

Clifton 0226 [soil0226r.DAT]

```
4
0.200, 0.200, 0.350, 0.750,
3.9, 3.8, 4.4, 4.6
0.027, 0.020, 0.006, 0.002
0.163, 0.153, 0.186, 0.189
0.514, 0.413, 0.415, 0.386
0.280, 0.221, 0.262, 0.253
0.159, 0.126, 0.167, 0.167
0.98E6, 0.12E7, 0.13E7, 0.14E7
0.40, 0.49, 0.67, 0.74
```

Stheta = 0.8, 0.7, 0.8, 0.8

Coombe 0237 [soil0237r.DAT]

```
4
0.200, 0.300, 0.300, 0.700,
4.4, 4.5, 4.4, 4.5
0.021, 0.020, 0.009, 0.009
0.265, 0.258, 0.234, 0.227
0.558, 0.544 ,0.473, 0.459
0.359, 0.350, 0.302, 0.291
0.215, 0.210, 0.185, 0.177
0.87E6, 0.95E6, 0.11E7, 0.12E7
0.43, 0.45, 0.55, 0.53
```

Stheta = 0.8, 0.8, 0.8, 0.8

Milford 1237 [soil1237r.DAT]

```
4
0.250, 0.450, 0.400, 0.400
4.2, 4.3, 4.3, 4.5
0.021, 0.019, 0.014, 0.012
0.220, 0.225, 0.188, 0.197
0.529, 0.504, 0.440, 0.444
0.321, 0.313, 0.265, 0.279
0.188, 0.186, 0.159, 0.173
0.94E6, 0.10E7, 0.12E7, 0.12E7
0.42, 0.47 ,0.53, 0.57
```

Stheta = 0.8, 0.8, 0.8, 0.8

Newport 1310 [soil1310r.DAT]

```
4
0.250, 0.300, 0.450, 0.500,
2.9, 2.3, 2.3, 6.4
0.040, 0.037, 0.042, 0.078
0.110, 0.081, 0.080, 0.065
0.497, 0.386, 0.399, 0.382
0.190, 0.103, 0.103, 0.097
0.093, 0.048, 0.047, 0.043
0.10E7, 0.12E7, 0.12E7, 0.12E7
0.27, 0.34, 0.31, 0.33
```

Stheta = 0.6, 0.5, 0.5, 0.5

Quorndon 1600 [soil1600r.DAT]

```
4
0.300, 0.500, 0.500, 0.200,
3.5, 3.3, 3.1, 3.1
0.026, 0.038, 0.042, 0.044
0.138, 0.120, 0.109, 0.110
0.480, 0.411, 0.401, 0.408
0.236, 0.182, 0.165, 0.170
0.128, 0.094, 0.082, 0.086
0.11E7, 0.12E7, 0.12E7, 0.12E7
```

```
0.38, 0.39, 0.38, 0.38
```

Stheta = 0.7, 0.7, 0.6, 0.6

Worcester 2249 [soil2249r.DAT]

```
5
0.200, 0.100, 0.300, 0.300, 0.600
4.6, 4.5, 5.0, 4.8, 5.0
0.013, 0.004, 0.001, 0.001, 0.001
0.258, 0.272, 0.279, 0.266, 0.248
0.532, 0.498, 0.510, 0.469, 0.432
0.357, 0.337, 0.367, 0.330, 0.305
0.227, 0.217, 0.258, 0.222, 0.209
0.93E6, 0.11E7, 0.11E7, 0.12E7, 0.13E7
0.60, 0.68 ,0.89, 0.78, 0.81
```

Stheta = 0.9, 0.9, 0.9, 0.9, 0.9

APPENDIX 3

Sensitivity analysis of the NSRI-modified MOSES model; the effects of changing soil properties

A range of input files were set up

1 Weather data file

Weather data from Cardington, Bedfordshire (DCNN 3456, 508100 246400) were supplied by UKMO at quarter hourly intervals for a 6-month time period (1st January – 30th June 2001), providing 17,472 time steps. The data arrived in appropriate units and parameters for MOSES (Table 1).

Table 1 Weather data parameters required by MOSES

Original data	**Code**	**Units**
Surface downward shortwave radiation	SW	$W\ m^{-2}$
Surface downward longwave radiation	LW	$W\ m^{-2}$
Rainfall rate	RAIN	$kg\ m^{-2}\ s^{-1}$
Snowfall rate	SNOW	$kg\ m^{-2}\ s^{-1}$
Air temperature	TA	K
Westerly wind component	U	$m\ s^{-1}$
Southerly wind component	V	$m\ s^{-1}$
Surface Pressure*	PSTAR	Pa
Specific humidity	QA	$kg\ kg^{-1}$

2 Soil data files

Soil files containing the number of layers present, the depth of each layer and their soil hydrological parameters was prepared (Table 2). Hydraulic parameters were derived from pedotransfer functions.

Table 2 Hydrological parameters required for MOSES soil data input files

Code	Description	Units
NSOIL	Number of soil layers	-/-
DZSOIL	Soil thickness	m
B_EXP	Exponent used in calculation of soil water suction and hydraulic	-/-
SATCON	Saturated hydrological conductivity of the soil	$kg\ m^{-2}\ s^{-1}$
SATHH	Saturated soil water suction	-/-
V_SAT	Volumetric soil moisture content at saturation	$m^3\ m^{-3}$ soil
V_CRIT	Volumetric soil moisture content at the critical point	$m^3\ m^{-3}$ soil
V_WILT	Volumetric soil moisture content at the wilting point	$m^3\ m^{-3}$ soil
HCAP	Soil heat capacity	$J\ K^{-1}\ m^{-3}$
HCON	Soil thermal conductivity	$W\ m^{-1}\ K^{-1}$

Appendix 2 provides soil parameter values for the eleven soil series used to test MOSES and listed in Table 3.

Table 3 Number of layers within each soil series

1 layer	3 layers	4 layers	5 layers
Andover (0031)	Bridgnorth (0144)	Quorndon (1600)	Worcester (2249)
		Newport (1310)	Bromsgrove (0149)
		Clifton (0226)	Blackwood (0124)
		Coombe (0237)	
		Batcombe (0109)	
		Milford (1237)	

3 Other input files

The MOSES nlsts file had to be amended to record the following information (Table 4)

Table 4 Changes required to MOSES nlsts file

Parameter	Setting
timestep	900 seconds [1/4 hr]
number timesteps	17472
spec_albedo	FALSE
zref	2.
met file	Cardington
soil file	11 soil types
stheta	initial soil moisture for each layer was set to the field capacity value as a fraction of V_SAT
tsoil	initial soil temperature [set to 280 for all runs and layers]

Initial soil temperature conditions were the same for each layer and each soil type (280 K). Initial soil moisture conditions varied for each soil type and layer. Field capacity moisture content was chosen as a realistic starting point for soil moisture values for each layer as it is assumed all soils would be at or close to field capacity on 1 January (starting point for the weather data). During the run if soil temperature is below zero Celsius the modelled value is set to zero rather than the appropriate negative temperature. Appendix 1 details Stheta values used for each soil layer and soil type.

Output files

Executing MOSES with the weather, soil data and nlsts files produces a results file. The file contains soil moisture and soil temperature values for each soil layer at each timestep. Appendix 6 contains a detailed analysis of the results.

Figures 1 to 4 provide examples of the results obtained for soil moisture and soil temperature values. Differences in soil response are evident.

Results

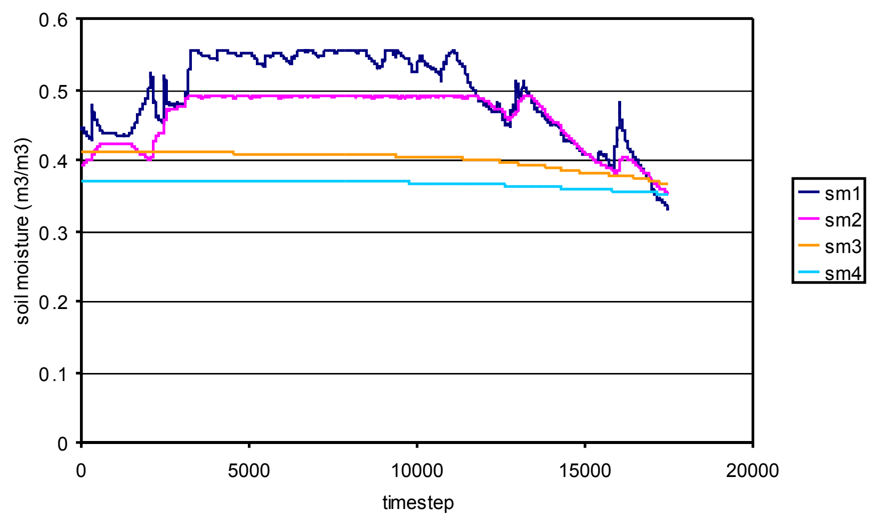

Figure 1: Batcombe series soil moisture

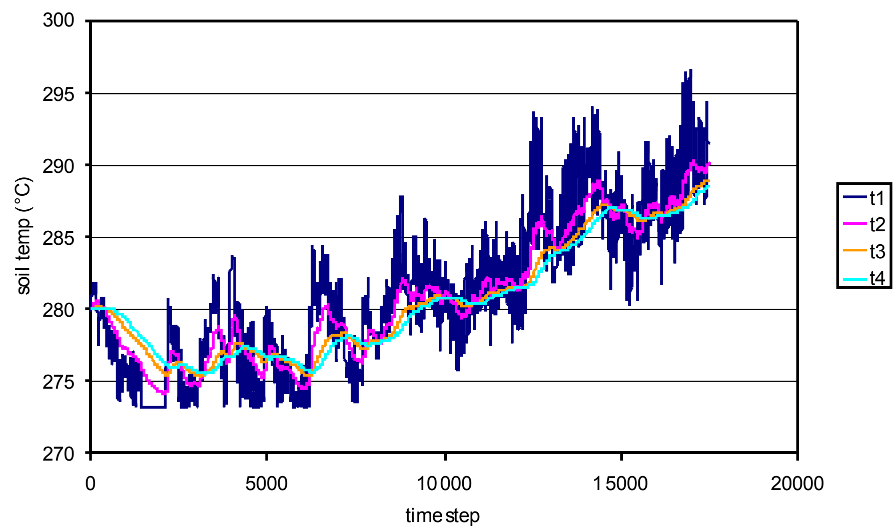

Figure 2: Batcombe series soil temperature

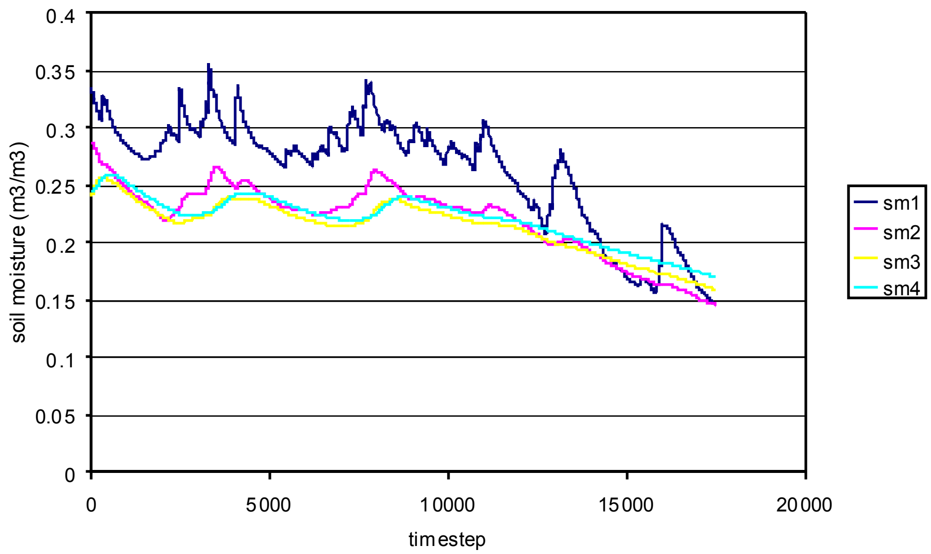

Figure 3: Quorndon series soil moisture

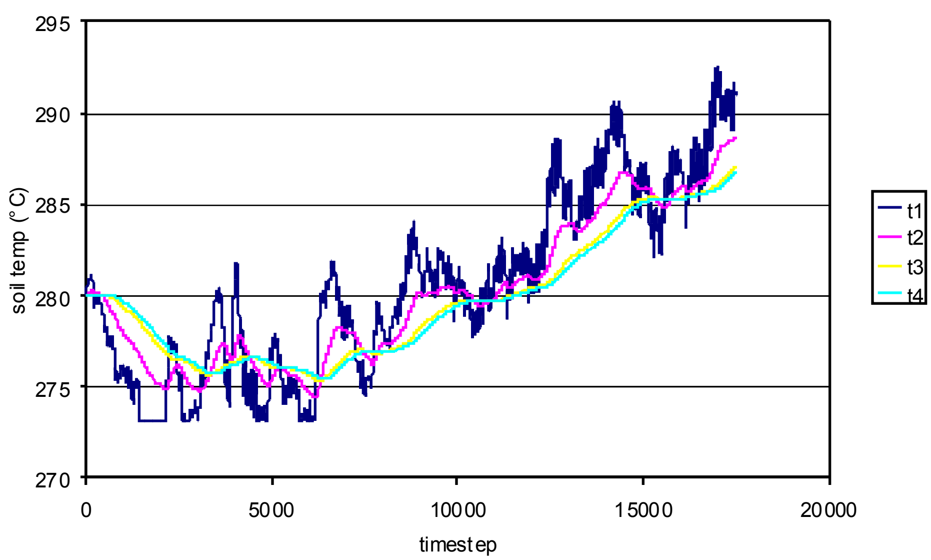

Figure 4: Quorndon series soil temperature

APPENDIX 4

Soil profile descriptions at Meteorological Stations

Kehelland, Camborne, Cornwall

Profile no:	SW64/27090674 - 3 m in from N boundary fence and half way between 6th and 7th concrete post from NW corner of Met Station compound. 50, 13, 06.080 N & 5, 19, 39.901 W
Grid reference	162709 040674
Soil Series:	Denbigh/Milford Series?
Classification:	Typical (stagnogleyic?) brown earth
Date:	14th April 2004
Land use:	Permanent mown grass in Met Station compound
Weather	Drying wind, sunny at time of sampling, no rain in last 48 hours
Slope and aspect	0.5^0 NW

Horizons:

0 to 10 cm **Ah**
Dark brown to brown (7.5YR 4/4) slightly stony clay loam (20%C; 40%S); stones small and very small subangular shale stones; moist; strongly developed fine and very fine subangular blocky structure; medium packing density, very porous; weak ped strength, moderately firm soil strength; abundant fine and very fine fibrous roots; abrupt smooth boundary.

10 to 25 cm **Bw1**
Reddish brown (6YR 4/4) moderately stony clay loam (29%C; 45%S); stones as above; moist; moderately developed fine subangular blocky structure; medium packing density, very porous; weak ped strength, moderately firm soil strength; many fine and very fine fibrous roots; abrupt smooth boundary.

25 to 68 cm **Bw2**
Reddish brown (5YR 4/4) very stony clay loam (29%C; 35%S) with occasional patches of common, extremely fine, sharp, strong brown (7.5YR5/6) and brown (10YR5/3) mottles; stones, angular as above; moist; weakly developed medium subangular and angular blocky structure, largely determined by stones; medium to high packing density, moderately porous; common fine fibrous roots; clear smooth boundary.

68 to 78 cm **BC**
Reddish brown (5YR 4/4) very stony (55%) clay loam (30%C; 50%S); stones large and medium angular shale fragments; very moist; structureless? but difficult to assess between stones, however, shale bedding planes visible within pit; high packing density, moderately porous; no roots visible; clear smooth boundary.

78 to 85 cm **Cu**
Reddish brown (5YR 4/4) extremely stony clay loam (34%C; 40%S); between bedded shale; very moist.
Stopped by stones at **85 cm** depth **Cr**

Samples taken;

Horizon	Sample type	
	Bag for Particle size class taken from (cm)	Tins for Water release taken from (cm)
Ah	0-10	2-7
Bw1	10-25	11-16
Bw2	25-68	27-32
BC	68-78	70-75
Cu	78-85	78-83 (just one tin)

Anlayses

Horizons	**Ah**	**Bw1**	**Bw2**	**BC**	**Cu**
Depth (cm)	0-10	10-25	25-68	68-78	78-85
Sand >600µm-2mm %	17.2	19.1	18.0	19.0	20.3
200-600µm %	11.7	15.0	20.0	25.5	26.2
106-212um %	5.8	6.5	8.2	12.2	10.5
63-106µm %	4.0	4.3	4.6	6.8	5.9
Silt 2-63µm %	38.8	35.8	36.1	25.8	25.9
Clay <2µm %	22.5	19.4	13.1	10.7	11.3
Organic carbon %	3.7	2.5	0.5	0.3	0.4
pH in water (1:5)	5.5	6.3	7.5	7.3	7.3
Bulk density $g.cm^{-3}$	0.83	1.20	1.33	1.6	1.6
Total pore space %vol	65.0	43.4	36.3	35.2	28.5
Water content at field capacity (0.05bar) %vol	53.4	31.9	26.3	28.6	21.1
Water content at 0.1bar %vol	48.4	29.7	25.3	27.9	20.6
Water content at 0.4bar %vol	45.1	28.1	24.3	27.2	20.0
Water content at 2.0bar %vol	43.9	26.8	22.8	26.7	19.8
Water content at wilting point (15bar) %vol	40.8	25.8	22.5	26.2	19.7

Watnall, Nottinghamshire

Profile no:
Grid reference
Soil Series: Bromsgrove series
Classification: Typical brown earth
Date: 14th April 2004
Land use: Permanent mown grass in Met Station compound
Weather
Slope and aspect
Horizons:

0 to 15 cm **Ah1**
Dark reddish brown (5YR 3/2) stoneless sandy loam; low packing density

15 to 30 cm **Ah2**
Reddish brown (5YR 4/3) stoneless sandy loam; low packing density

30-40 cm **Bw1**
Reddish brown (5YR 4/4) stoneless sandy loam; low packing density

40- **Bw2**

Samples taken;

Horizon	Sample type	
	Bag for Particle size class taken from (cm)	Tins for Water release taken from (cm)
Ah	0-30	0-5
Bw1		20-25
Bw2	40-	40-45

Analyses

Horizons	Ah	Ah/Bw1?	Bw2	BC	Cu
Depth (cm)	0-15	15-30	30-45-		
Sand >600µm-2mm %		5.8	0.6		
200-600µm %		11.2	12.2		
106-212um %		30.3	33.9		
63-106µm %		13.7	16.2		
Silt 2-63µm %		23.0	19.4		
Clay <2µm %		16.0	17.7		
Organic carbon %		3.4	0.7		
pH in water (1:5)		6.6	7.0		
Bulk density $g.cm^{-3}$	1.00	1.17	1.00		
Total pore space %vol	52.5	44.1	24.6		
Water content at field capacity (0.05bar) %vol	41.4	33.2	17.5		
Water content at 0.1bar %vol	37.8	29.7	15.4		
Water content at 0.4bar %vol	33.9	28.5	14.3		
Water content at 2.0bar %vol	31.1	26.4	13.4		
Water content at wilting point (15bar) %vol	29.9	25.8	13.2		

Rothamsted, Hertfordshire

Profile no:	TL11/3133
Grid reference	51316 21330
Soil Series:	Batcombe Series?
Classification:	Stagnogleyic palaeoargillic brown earth
Date:	
Land use:	Permanent mown grass in Met Station compound?
Weather	
Slope and aspect	
Horizons:	

0 to 10 cm	**Ah**
10 to 25 cm	**Bw1**
25 to 68 cm	**Bw2**
68 to 78 cm	**BC**
78 to 85 cm	**Cu**
	Cr

Samples taken;

Horizon	Sample type	
	Bag for Particle size class taken from (cm)	Tins for Water release taken from (cm)
0-		
20-		
40-		
65-		

Analyses

Horizons	Ah			
Depth (cm)	10	20	40	65
Sand >600µm-2mm %				
200-600µm %				
106-212um %				
63-106µm %				
Silt 2-63µm %				
Clay <2µm %				
Organic carbon %	3.4	2.0	0.6	0.5
pH in water (1:5)				
Bulk density $g.cm^{-3}$				
Total pore space %vol				
Water content at field capacity (0.05bar) %vol				
Water content at 0.1bar %vol				
Water content at 0.4bar %vol				
Water content at 2.0bar %vol				
Water content at wilting point (15bar) %vol				

Location Green Farm, Lancaster Road, Gringley-on-the-Hill, DN10 4RL
Recorder Mr L W Hardy
Profile no: SK79/427905
Grid reference 474268 390504
Soil Series: Newport (Rudge?)
Classification: Typical brown sand – (close to stagnogleyic brown sand?)
Date: 10th December 2003
Land use: Permanent mown grass
Horizons:

0 to 35 cm **Ah**
10YR4/2 stoneless mSL

35 to 75 cm **Bw**
10YR 5/3 mLS with common distinct 10YR 5/6 mottles

75 to 85 cm **Btg**
10YR 5/2 SCL with common distinct 10YR 5/6 and 2.5Y 5/2 mottles

85-110 cm **BCg**
10YR 5/4 mS with common faint 10YR 5/6 mottles

110-120 cm **2Cu**
10YR 5/5 CL with many distinct 10YR 6/2 mottles

Location Buxton Town Hall, Derbyshire
Recorder Mr Steve Green 0845 129 7777 X4560
Profile no: SK07/580340
Grid reference 405800 373400
Soil Series: Wetton series
Classification: Humic ranker
Date: 11th December 2003
Land use: Mown grass within weather compound
Weather
Slope and aspect
Horizons:

0 to 39 cm **Ah**
10YR 3/2 slightly stony humose CL; stones small to medium angular limestones

At 39 cm **R**
Bedded limestone

Location Lake Vyrnwy No.2
Recorder Steve Haynes, Met Office 01392 885857
Profile no: SJ01/12098743
Grid reference 301209 318743
Soil Series: Manod series
Classification: Typical brown podzolic soils
Date: 11th December 2003
Land use: Permanent grass just outside of compound
Weather
Slope and aspect
Horizons:

0 to 22 cm **Ah**
10YR 4/3 very slightly stony ZCL (18% S; 20% C); stones small angular tabular slates; moderate packing density;

22 to 35 cm **Bw**
10YR 5/5 slightly stony CL (23% S; 24% C); stones as above; moderate packing density;

35 to 48 cm
2.5Y 5/2 moderately stony CL (23% S; 23% C); stones as above but increasing in abundance downwards; medium packing density

At 48 cm **Cr**
Stopped by bedded slate

Location Bronydd Mawr, Llandovery – [Prof Pollock IGER Aberystwyth]
Recorder Arthur Davies (Head) or Jim Vale, Elaine Rees Tel: 01874 636 480
Profile no: SN83/830090
Grid reference 288300 230900
Soil Series: Middleton series (CL-variant)
Classification: Stagnogleyic argillic brown earth
Date: 12th December 2003
Land use: Permanent grass in compound
Weather Wet overnight and during assessment
Slope and aspect
Horizons:

0 to 22 cm **Ah**
10YR 4/3 slightly stony SZL (17% C; 28% S); stones small angular sandstones

22 to 30 cm **Bw(g)1**
10YR 5/3 with few faint 10YR 5/6 mottles moderately stony CL (23% C; 35% S); stones as above

30 to 50 cm **Bw(g)2**
2.5YR 4/3 with common distinct 10YR 5/6 mottles moderately stony CL-ZCL (20% C; 22% S)

50 to 90 cm **Bg**
2.5YR 4/3 moderately stony ZCL (22% C; 18% S); stones as above

At 90 cm **Cr**
Stopped by sandstone

Location	Cockle Park Experimental Farm, Morpeth, Northumberland
Recorder	NIAB, Senior Trials Officer – David Young Tel: 01670 790 227 (Farm office)
Profile no:	NZ19/997101
Grid reference	419968 591009
Soil Series:	Rivington series
Classification:	Typical brown earth
Date:	16th December 2003
Land use:	Permanent grass adjacent to enclosure
Weather	
Slope and aspect	
Horizons:	

0 to 25 cm **Ah**
10YR 4/3 slightly stony SL; few small angular sandstones
25 to 40 cm **Bw**
2.5Y 5/4 LS-S (ground soft sandstone?)
At 40 cm **Cr**
Stopped by sandstone rock – verified in two further holes

Location	Hunt Hall Farm, Forest-in-Teesdale, Barnard Castle, Durham DL12 0HJ
Recorder	Mr Ian Findlay Tel: 01833 622285
Profile no:	NY83/5297 0574
Grid reference	3852297 530574
Soil Series:	Ellerbeck series
Classification:	Typical brown earth
Date:	16th December 2003
Land use:	Permanent grass adjacent to enclosure
Weather	
Slope and aspect	
Horizons:	

0 to 20 cm **Ah**
7.5YR 4/4 very slightly stony humose SL; stones small to large angular sandstones; low packing density
20 to 32 cm **Bw**
10YR 4/4/ very stony SL to SZL; stones as above; low packing density
32 cm
Stopped by large stone

Location ADAS High Mowthorpe, Duggleby, Malton, North Yorkshire YO17 8BP
Recorder Kate Snowden Tel: 01944 738646
Profile no: SE86/882853
Grid reference 488821 468527
Soil Series: Panholes series (a bit too deep)
Classification: Typical brown calcareous earth
Date: 17th December 2003
Land use: Permanent grass adjacent to enclosure
Weather
Slope and aspect
Horizons:

0 to 25 cm **Ah**
10YR4/3 very slightly stony ZCL; stones small and very small fragments of chalk; high packing density

25 to 45 cm **Bw1**
10YR 5/4 very slightly stony ZCL; stones as above; medium packing density

45 to 85 cm **Bw2**
10YR 4/4 slightly stony ZCL; stones as above; Medium packing density

At 85 cm **Cr**
Chalk

APPENDIX 5

Analysis of soil temperature data measured by INTERMET instruments and UKMO equipment at Camborne, Watnall and Rothamsted

Soil temperature was recorded at three sites using two different probes. The UKMO probe measured soil temp at depths of 10cm, 30cm and 100cm. The NSRI INTERMET probes measured temperature at the surface, 20cm 40cm 60cm 80cm and 100cm.

Rothamsted site

Comparing NSRI surface temp with UKMO at 10cm gave a correlation coefficient of 0.933. Using the reduced major axis[1] (as both measurements contain errors) an equation of the relationship is as follows:

$NSRItempsurf = 4.094 + 0.667 x Metoffice10cm$ (Fig. 1)

The slope has a confidence interval of (0.637, 0.697). This slope is significantly different to unity so there is a significant bias in the data – the temperature measured by NSRI at the surface being consistently higher than the UKMO data measured at 10cm at low temperatures but lower above about 15^0 C.

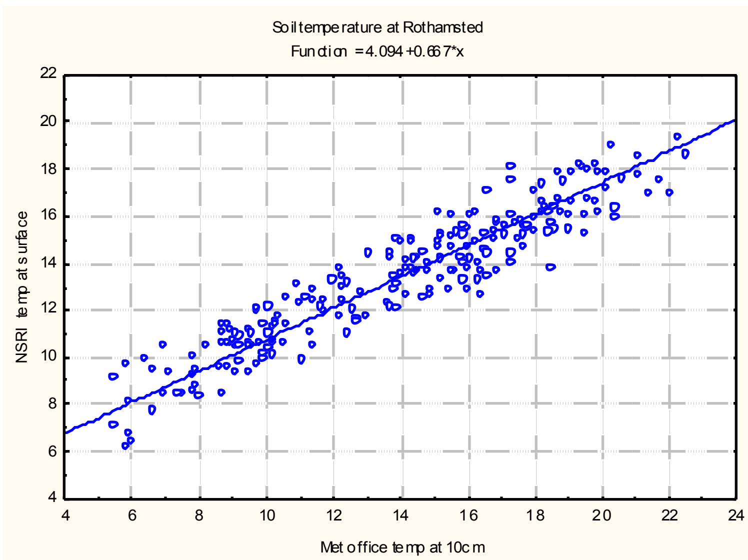

Fig. 1 Soil temperatures from NSRI probe at surface compared with UKMO data at 10 cm depth

To examine if this effect is caused by the NSRI measurement being at the surface, the NSRI measurement at 20cm was compared to the met office at 10cm.

In this case the correlation was 0.933 and the reduced major axis line with a relationship of

$NSRItempsurf = 4.546 + 0.643 x Metoffice10cm$

The slope has a CI of (0.612, 0.674). This line is not significantly different to the one using the NSRI surface data so it reasonable to conclude that the NSRI instrument measures lower than the UKMO instrument near the surface of the soil profile.

Comparing NSRI temp at 40cm with UKMO at 30cm gave a correlation coefficient of 0.983 and a line with the following relationship

$NSRItemp40 = 2.332 + 0.773 x Metoffice30cm$ (Fig. 2)

The slope has a confidence interval of (0.754, 0.792). This again shows a consistent bias between the two instruments but this bias is not as large as near the surface.

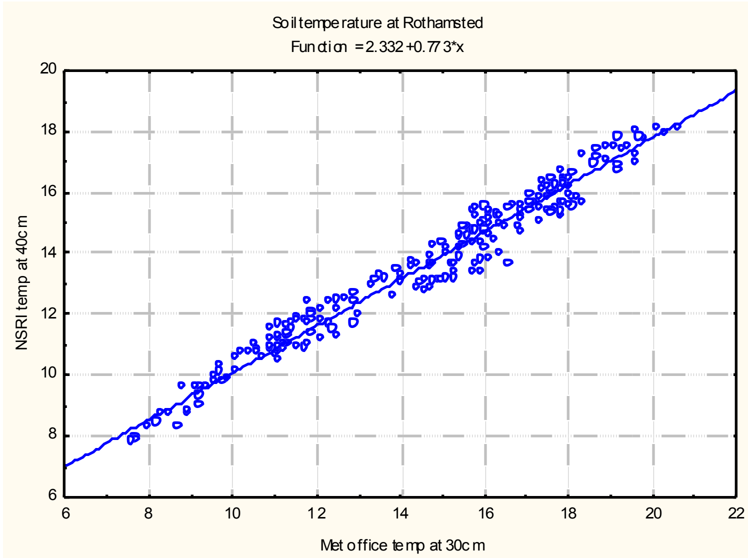

Fig. 2 Soil temperatures from NSRI probe at 40 cm depth compared with UKMO data at 30 cm depth

Comparing NSRI temp at 100cm with Met office data also at 100cm gives a correlation coefficient of 0.989 and equation

$NSRItemp100 = 1.929 + 0.806xMetoffice100cm$ (Fig. 3)

The slope has a confidence interval of (0.791, 0.821)

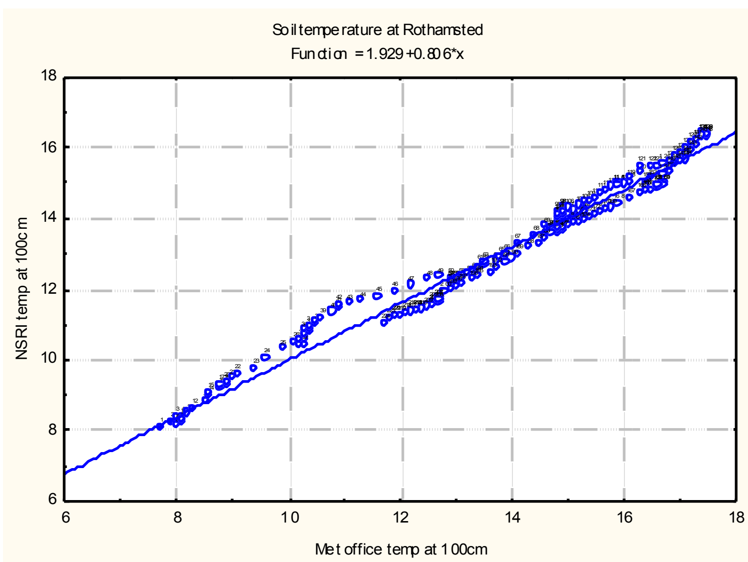

Fig. 3 Soil temperatures from NSRI probe at 100 cm depth compared with UKMO data at 100 cm depth

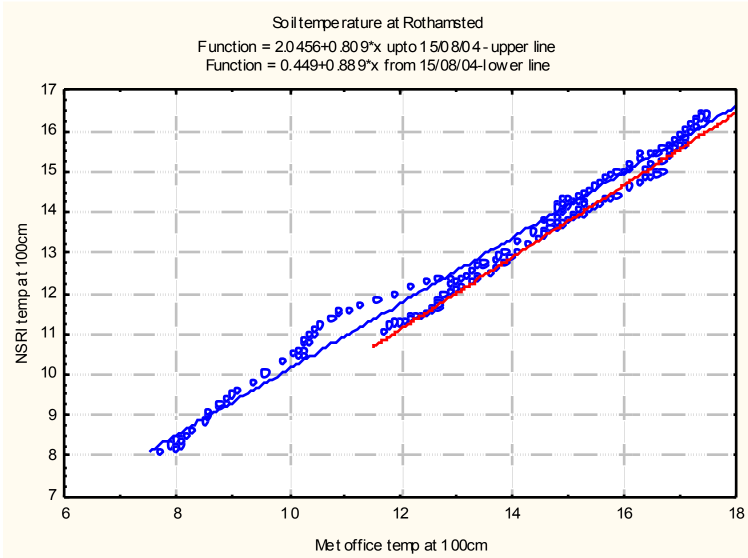

Fig. 4 Soil temperatures from NSRI probe at 100 cm depth compared with UKMO data at 100 cm depth

It can be seen from Fig. 3 that there appears to be a change in the relationship of the measurements over time – the points are numbered in time order. This is not apparent at the other depths in this soil.
The data have been divided into two sets using the highest temperature as the dividing point. This gives two different equations with significantly different slopes and intercepts (Fig. 4).

$$NSRItemp100 = 2.0456 + 0.809xMetoffice100cm$$

For increasing temperature (correlation coefficient = 0.994) and

$$NSRItemp100 = 0.449 + 0.889xMetoffice100cm$$

For decreasing temperature (correlation coefficient = 0.995)

Camborne site

Comparing NSRI surface temp with metoffice at 10cm gave a correlation coefficient of 0.964. Using the reduced major axis an equation of the relationship is as follows:

$$NSRItempsurf = 2.699 + 0.899xMetoffice10cm$$

the slope has a confidence interval of (0.867,0.931)

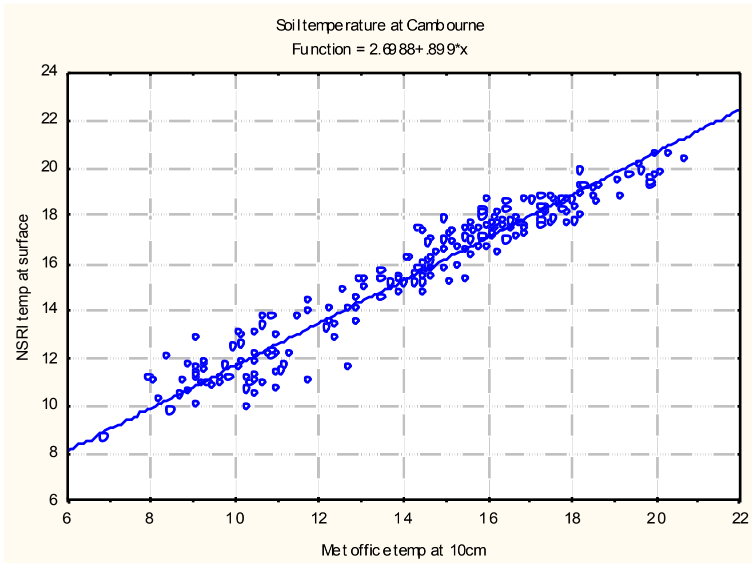

Fig. 5 Soil temperatures from NSRI probe at the surface compared with UKMO data at 10 cm depth

The NSRI instrument consistently measures lower than the UKMO at this site but this bias is not as large at this site at this depth as it was at Rothamsted. The NSRI data at 20cm was compared with the UKMO at 10cm and the following equation determined.

$$NSRItemp20cm = 3.790 + 0.800xMetoffice10cm$$

This relationship has a correlation coefficient of 0.958 (Fig. 6)

This equation is significantly different to that using the NSRI surface probe data.

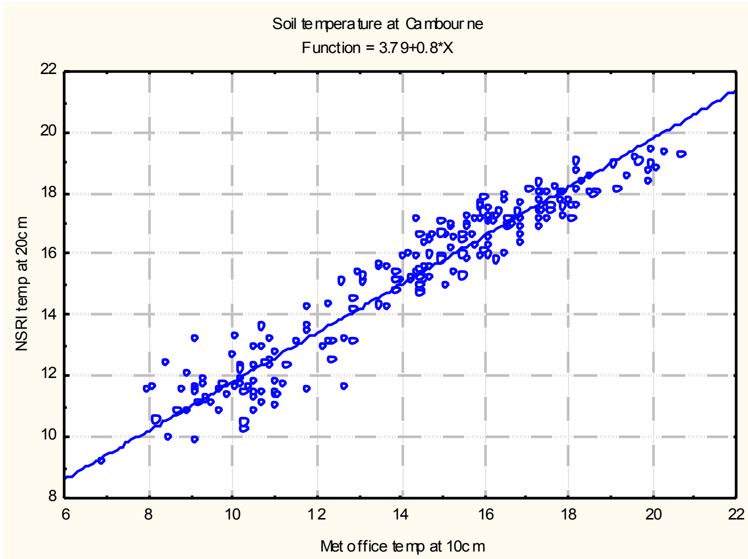

Fig. 6 Soil temperatures from NSRI probe at 20 cm depth compared with UKMO data at 10 cm depth

Comparing NSRI temp at 40cm with met office at 30cm gave a correlation coefficient of 0.991 and equation

$$NSRItemp40 = -0.0009 + 0.997xMetoffice30cm$$

The slope has a confidence interval of (0.979,1.015)

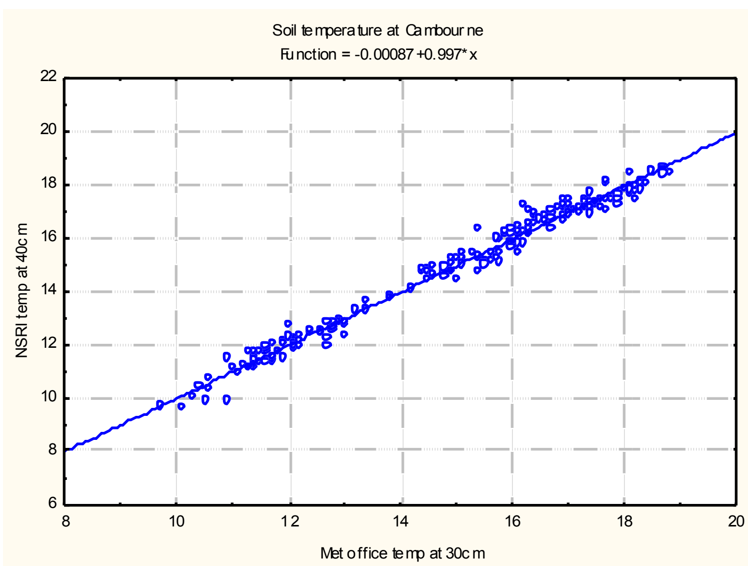

Fig. 7 Soil temperatures from NSRI probe at 40 cm depth compared with UKMO data at 30 cm depth

At 30 - 40 cm there is no significant difference between the two instruments – there is no bias and also there is no shift in the data as the constant is not different from zero.

Comparing NSRI temp at 100cm with Met office data also at 100cm gives a correlation coefficient of 0.993 and equation

$NSRItemp100 = 0.512 + 0.934xMetoffice100cm$

the slope has a confidence interval of (0.920,0.947)

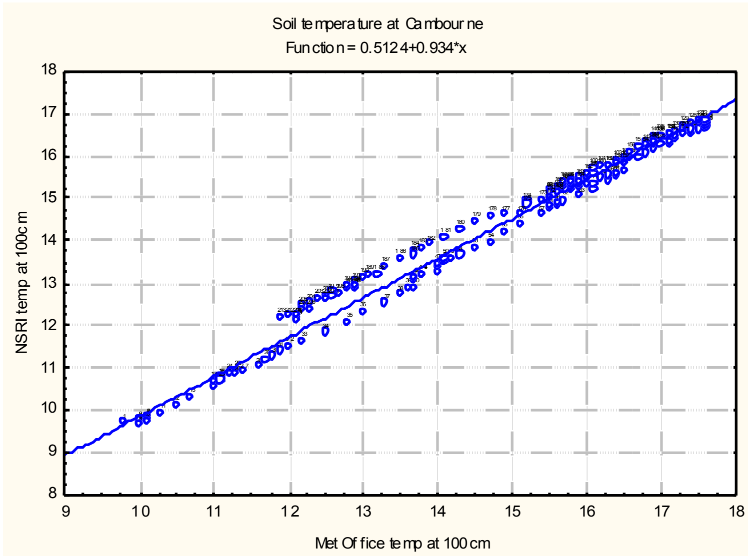

Fig. 8 Soil temperatures from NSRI probe at 100 cm depth compared with UKMO data at 100 cm depth

From Fig. 8 it is apparent that there are two relationships between the temperature measurements, one where the soil is warming up and one where the soil is cooling down. The data was split into two sets (as with the Rothamsted data). At this site the data was split at 11/08/04 (Fig. 9). This gives two equations with significantly different slopes:

$NSRItemp100 = 0.061 + 0.956xMetoffice100cm$

For increasing temperature (correlation coefficient = 0.998) and

$NSRItemp100 = 2.207 + 0.834xMetoffice100cm$

For decreasing temperature (correlation coefficient = 0.999)

It can be seen that the bias increases (ie., the slope is further from 1) when the soil is cooling at Camborne whereas at the Rothamsted site the bias decreases when the soil is cooling.

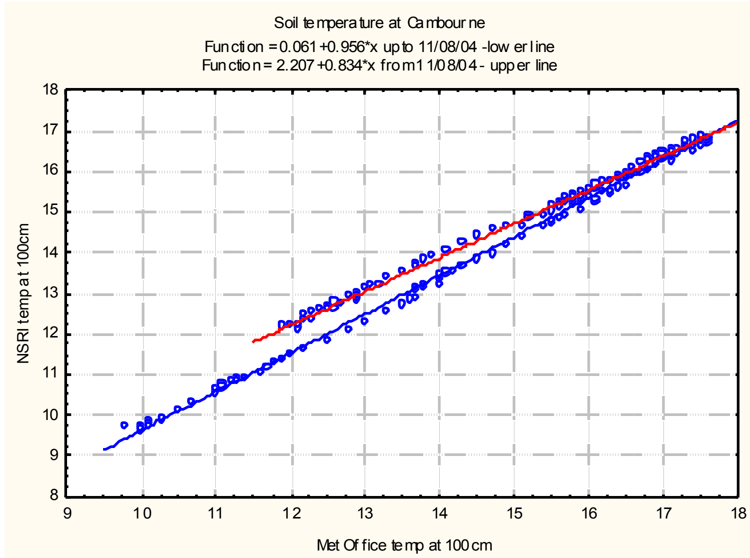

Fig. 9 Soil temperatures from NSRI probe at 100 cm depth compared with UKMO data at 100 cm depth

Watnall site

Comparing NSRI temp at 20cm with UKMO at 10cm gave a correlation coefficient of 0.975. Using the reduced major axis (as both measurements contain errors) an equation of the relationship is as follows:

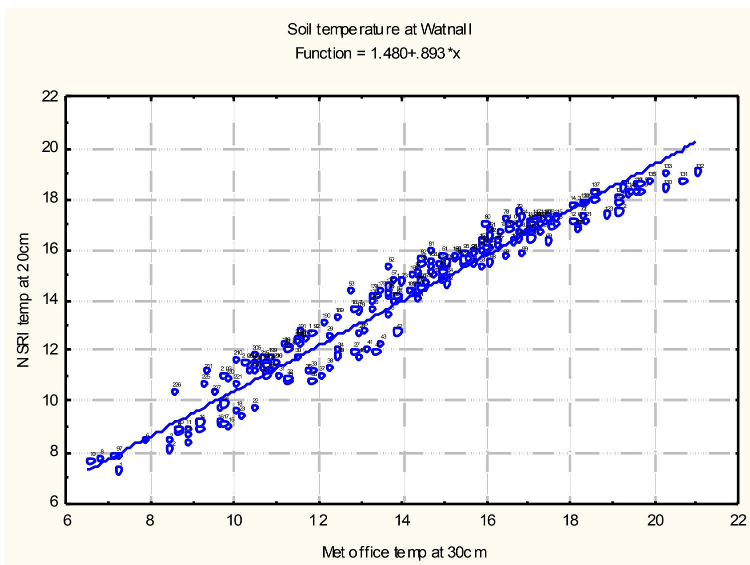

Fig. 10 Soil temperatures from NSRI probe at 20 cm depth compared with UKMO data at 30 cm depth

$$NSRItemp20cm = 1.480 + 0.893xMetoffice10cm$$

The slope has a confidence interval of (0.867,0.919)

There is some evidence at this depth that there is a differential between the warming up and the cooling down relationship. The numbers refer to the time sequence of the observations. The data was split into two sets (as with the Rothamsted and Camborne data). At Watnall the data were split at 10/08/04. This produces two equations with significantly different slopes (fig. 11):

$$NSRItemp20cm = 0.484 + 0.948xMetoffice10cm$$

for increasing temperature (correlation coefficient = 0.976) and

$$NSRItemp20cm = 3.041 + 0.803xMetoffice10cm$$

for decreasing temperature (correlation coefficient = 0.992)

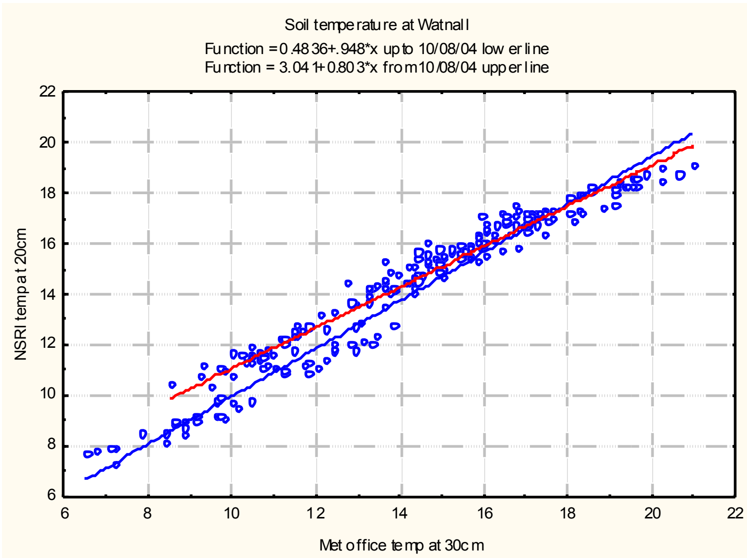

Fig. 11 Soil temperatures from NSRI probe at 20 cm depth compared with UKMO data at 30 cm depth

Comparing NSRI temperatures at 40cm depth with UKMO data at 30cm depth gave a correlation coefficient of 0.982 and equation (Fig. 12).

$$NSRItemp40 = 1.497 + 0.860xMetoffice30cm$$

The slope has a confidence interval of (0.838,0.882)

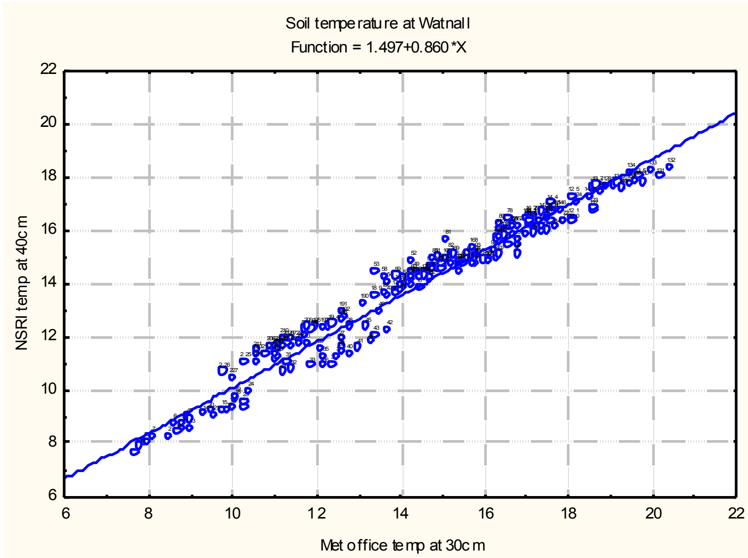

Fig. 12 Soil temperatures from NSRI probe at 40 cm depth compared with UKMO data at 30 cm depth

Again there is some evidence of a difference in the warming up and cooling down relationships between the two measurement setups. Dividing the data using the same split as at the surface gives two equations with significantly different slopes (Fig. 13)

$$NSRItemp40 = 0.573 + 0.912xMetoffice30cm$$

for increasing temperature (correlation coefficient = 0.984) and:

$$NSRItemp40 = 3.082 + 0.767xMetoffice30cm$$

for decreasing temperature (correlation coefficient = 0.996)

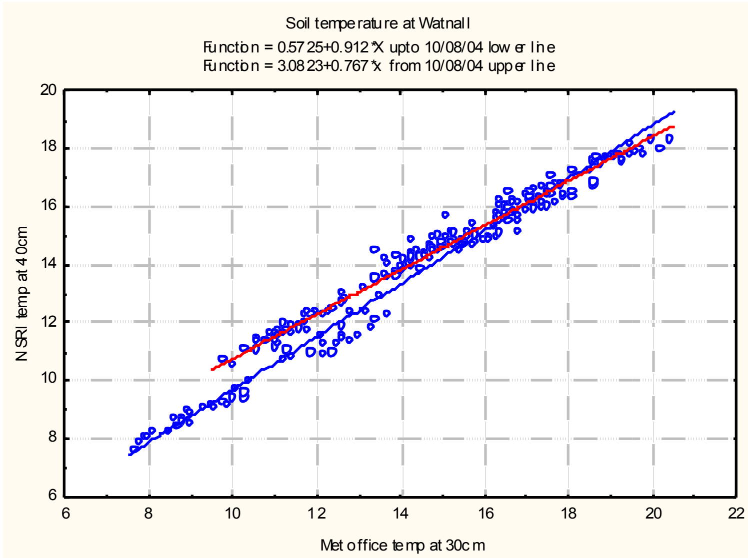

Fig. 13 Soil temperatures from NSRI probe at 40 cm depth compared with UKMO data at 30 cm depth

The temperature was measured every hour for the NSRI instrument and once a day at the UKMO instrument. For the analysis above the reading at 9am from the NSRI data was selected as the UKMO data was read at this time. However the hourly data was available and was examined for Watnall to investigate whether the change in the relationship was a lag problem i.e. did one set up warm up (or cool down) faster than the other.

In examining this hourly data it was apparent that the NSRI instrument was much more variable in the first week of observations with the data showing a diurnal pattern – this stopped abruptly at 1am on 07/04/2005 (Fig. 14). This is thought to be caused by any air gap around the installation being filled as the diurnal pattern should not be detectable at 100cm. The first week of data was discarded at Watnall. This effect was not apparent at any other site.

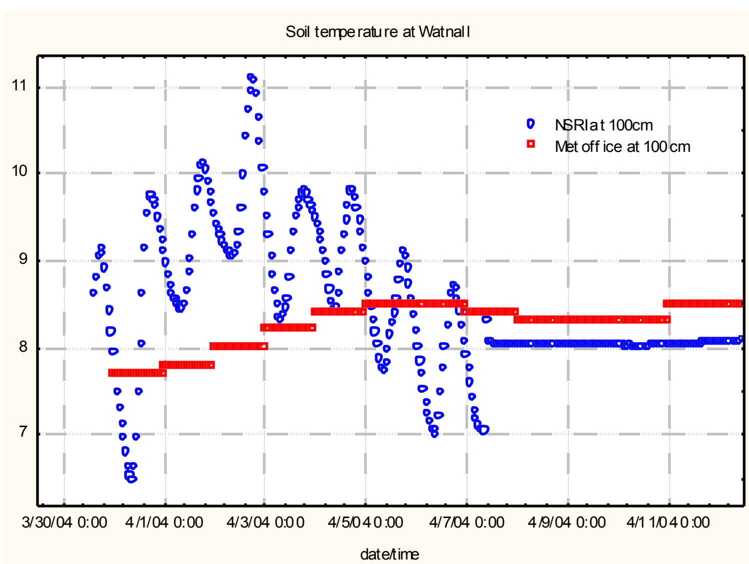

Fig. 14 Soil temperatures from NSRI probe at 100 cm depth compared with UKMO data at 100 cm depth for first few days of analysis

Comparing NSRI temp at 100cm with Met office data also at 100cm gives a correlation coefficient of 0.959 and equation

$$NSRItemp100 = 0.097 + 0.944xMetoffice100cm$$

The slope has a confidence interval of (0.907, 0.980)

However on examination of the data it was apparent that there were two distinct relationships (Fig. 15). These are shown on the graph for temperature rising (correlation coefficient= 0.992 CI of slope (0.944, 0.988)) and temperature falling (correlation coefficient=0.996 CI of slope (0.697, 0.725)).

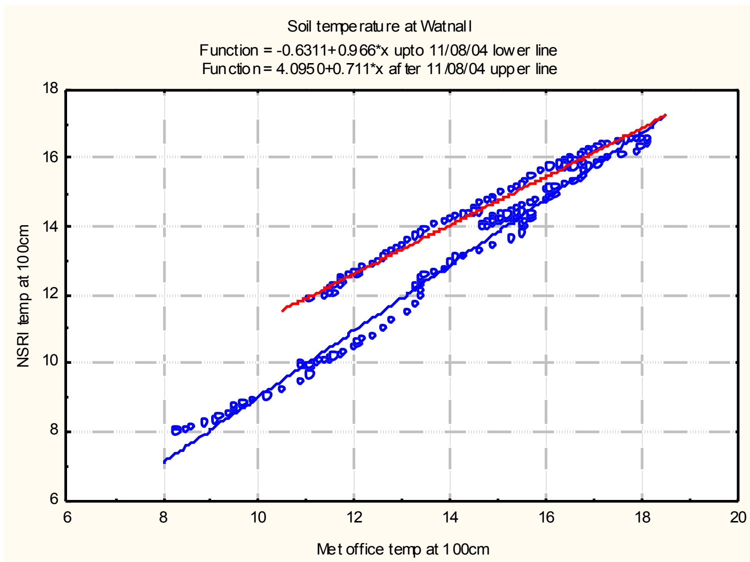

Fig. 15 Soil temperatures from NSRI probe at 100 cm depth compared with UKMO data at 100 cm depth

Table 1 Analysis of results

Site	Depth	Warming/cooling	Constant	Slope	Equation type
Rothamsted	10cm/20cm	N/A	4.546	0.643	B
	30cm/40cm	N/A	2.332	0.773	B
	100cm	Warming	2.046	0.809	B
	100cm	Cooling	0.449	0.889	A
Camborne	10cm/20cm	N/A	3.79	0.800	B
	30cm/40cm	N/A	-0.001	0.997	A
	100cm	Warming	0.061	0.956	A
	100cm	Cooling	2.207	0.834	B
Watnall	10cm/20cm	warming	0.484	0.948	A
		cooling	3.041	0.803	B
	30cm/40cm	warming	0.573	0.912	A
		cooling	3.082	0.767	B
	100cm	warming	-0.631	0.966	A
		cooling	4.095	0.711	B

There appear to be two groups of equations – those with a small intercept lying between -0.63 and +0.57 and slopes varying from 0.889 to 0.997 (labelled A equations in Table 1) and equations with a larger intercept between 2.05 and 4.55 and smaller slope between 0.643 and 0.834 (labelled B equations). It is apparent that the differences between the NSRI instrument and the Met office one depend on the soil type and the depth. At Rothamsted and Camborne the difference between warming and cooling is only apparent at 100cm whereas there are real differences at Watnall all down the profile.

References

Sokal, R.R. and Rohlf, F.J. (1981). *Biometry*. W.H. Freeman, New York.

APPENDIX 6

A review of NSRI measured soil temperature and soil moisture data vs NSRI-modified MOSES modelled output

Input data files

Hourly weather data for the closest weather station to each of the 3 sites was obtained for the same period (April 2004- March 2005) from the UKMO. Weather data were converted into appropriate units for MOSES input (see Appendix 1).

Soil hydrological parameters are detailed in Appendix 2. The soils at each site are;
Camborne – Milford series; Rothamsted – Batcombe series; Watnall – Bromsgrove series:

The settings for the inlstsfile are given in Table 1.

Parameter	Setting
timestep	3600 seconds [1 hr]
number timesteps	10224
spec_albedo	FALSE
zref	2.
met file	Site specific
soil file	Site specific
stheta	initial soil moisture was taken from the measured data and Stheta set to the fraction of vsat the initial measured soil moisture value represents
tsoil	initial soil temperature for each layer was taken from the measured data to provide realistic starting temperatures

met file= change for each different site
soil file= change for each different site

Table 1 Settings required for inlsts input file

Output data files

Results files include the modelled MOSES soil moisture and temperatures and the corresponding measured data from the site.

Results

1. Soil moisture

The modelled values represent an average for the layer depth and do not necessarily correspond exactly to the measured depths. Generally the upper layers tend to indicate a better correlation with the corresponding measured soil depth or depths. Higher measured soil moisture contents in the lower layers may be due the influence of groundwater or simply to a poor selection of initial soil moisture within the model.

a) Camborne

A plot of the surface layer is shown below. It can be seen that the measured data have a bimodal distribution which is not demonstrated by the modelled data.

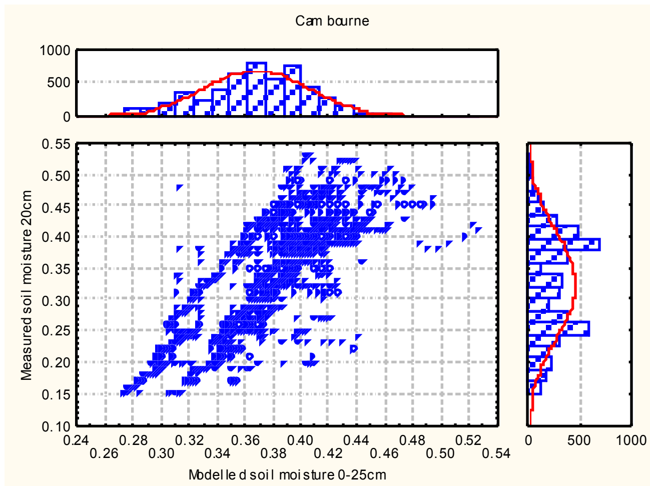

Fig. 1 Scatter plot with histograms of measured soil moisture at 20 cm depth and modelled data at 0-25 cm depth

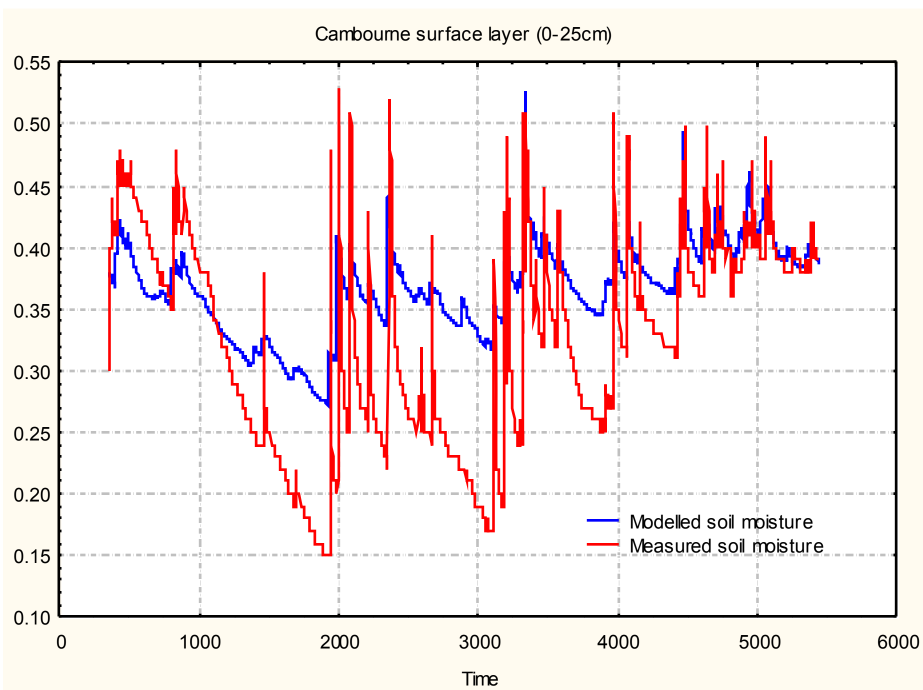

Fig. 2 Plot of Measured soil moisture at 20 cm depth and modelled soil moisture at 0-20 cm depth

It is apparent from Fig. 2 that the model is not fully representing the variability in the measured data.

At 25-75 cm depth it is again apparent that the model is not representing the variability in the measured data. Whilst the general trends in soil moisture change is modelled fairly well the variability is not predicted (Fig. 5). The modelled data have a much smaller range of values than the measured data (Fig. 4).

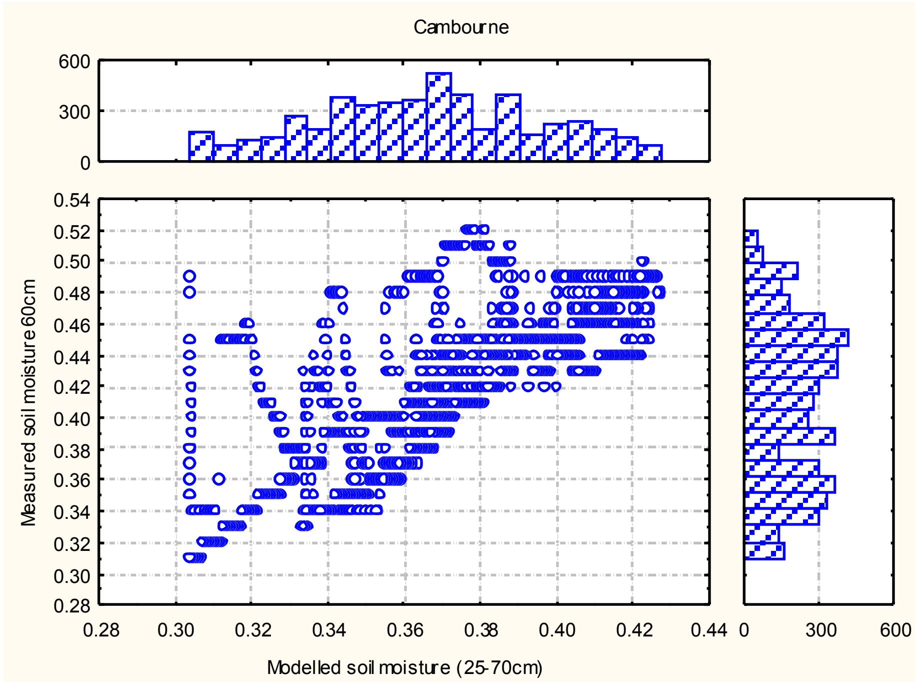

Fig. 3 Scatter plot with histograms of measured soil moisture at 60 cm depth and modelled data at 25-70 cm depth

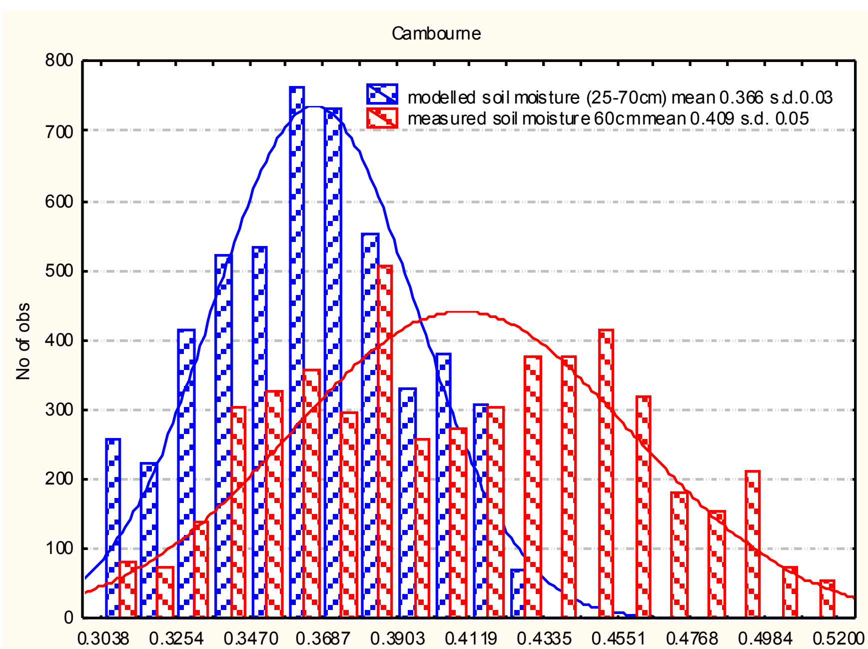

Fig. 4 Histogram of modelled (25-70 cm) and measured (60 cm depth) soil moisture data

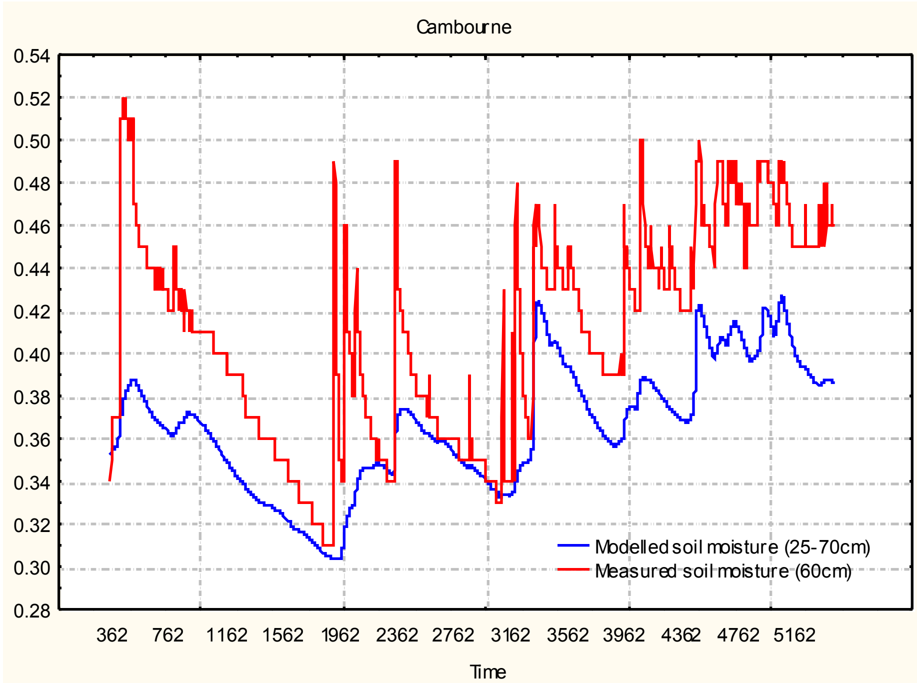

Fig. 5 Plot of Measured soil moisture at 60 cm depth and modelled soil moisture at 25-70 cm depth

At 70-110 cm depth soil moisture values appear poorly predicted. On close inspection, however, it is clear that the measured fluctuations are well represented by the modelled data but at greatly reduced moisture content (Fig. 7). It is likely that the initial moisture content ascribed at the start of the model run was too low. In both the measured and modelled data the variation is small (4 and 7 per cent moisture content respectively. These findings are also true at 110-150 cm depth (Fig. 8).

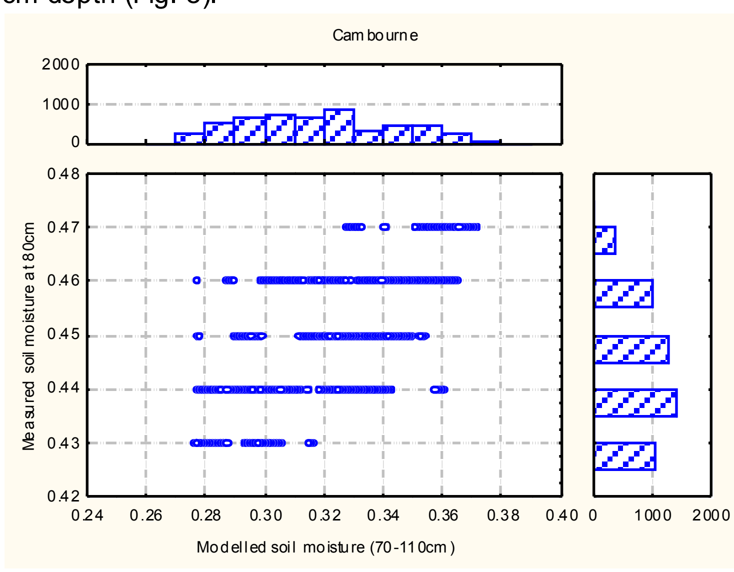

Fig. 6 Scatter plot with histograms of measured soil moisture at 80 cm depth and modelled data at 70-110 cm depth

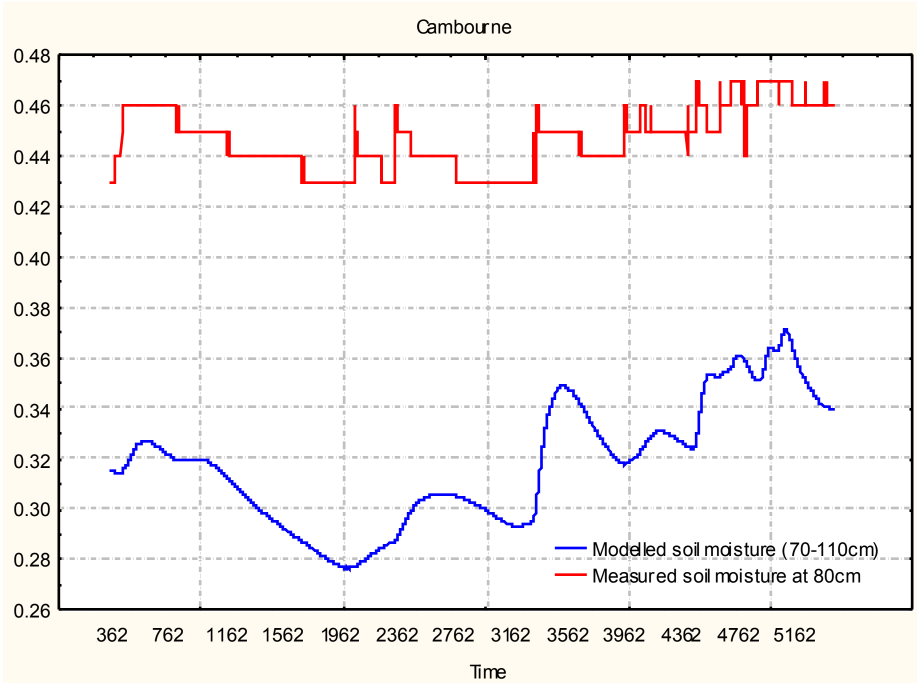

Fig. 7 Plot of Measured soil moisture at 80 cm depth and modelled soil moisture at 70-110 cm depth

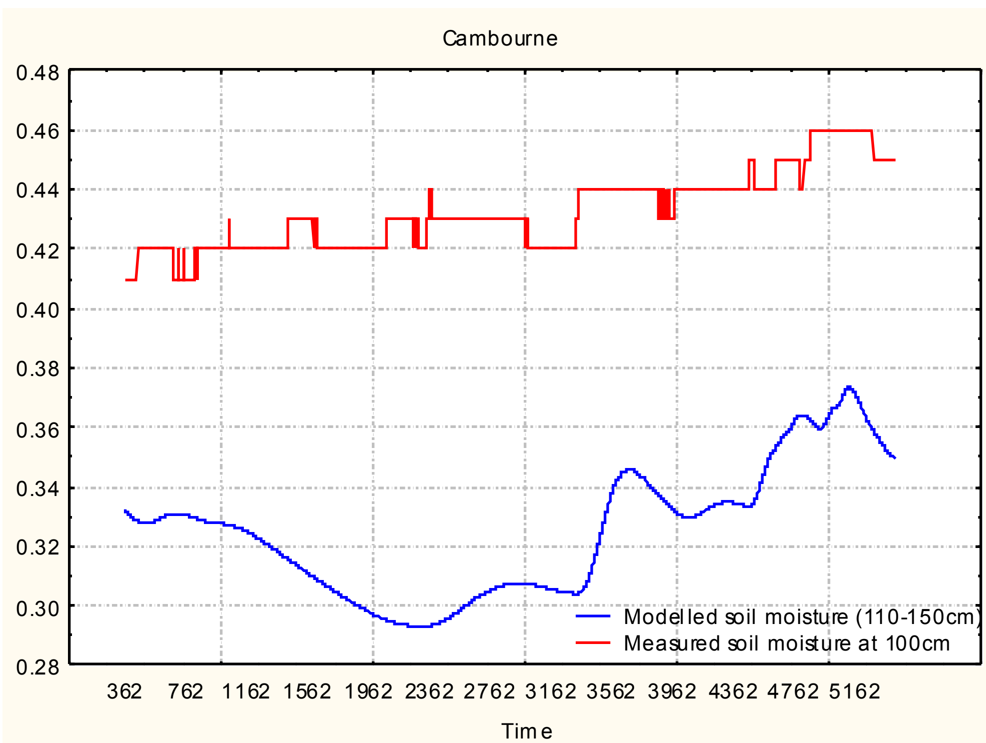

Fig. 8 Plot of Measured soil moisture at 100 cm depth and modelled soil moisture at 70-110 cm depth

b) Rothamsted

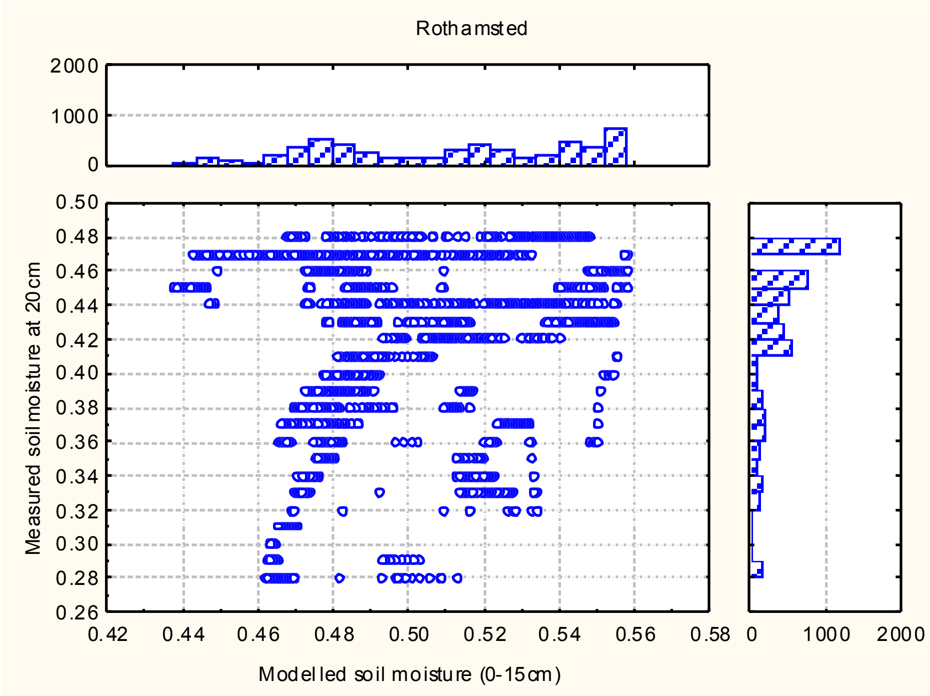

Fig. 9 Scatter plot with histograms of measured soil moisture at 20 cm depth and modelled data at 0-15 cm depth

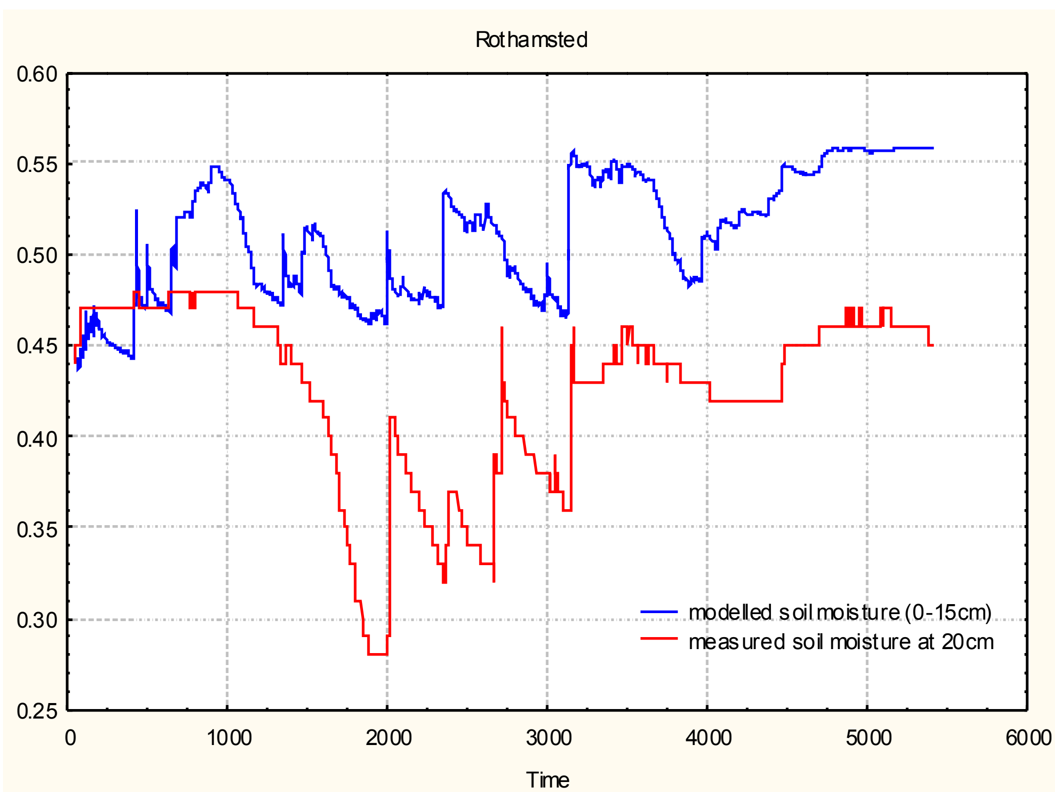

Fig. 10 Plot of Measured soil moisture at 20 cm depth and modelled soil moisture at 0-15 cm depth

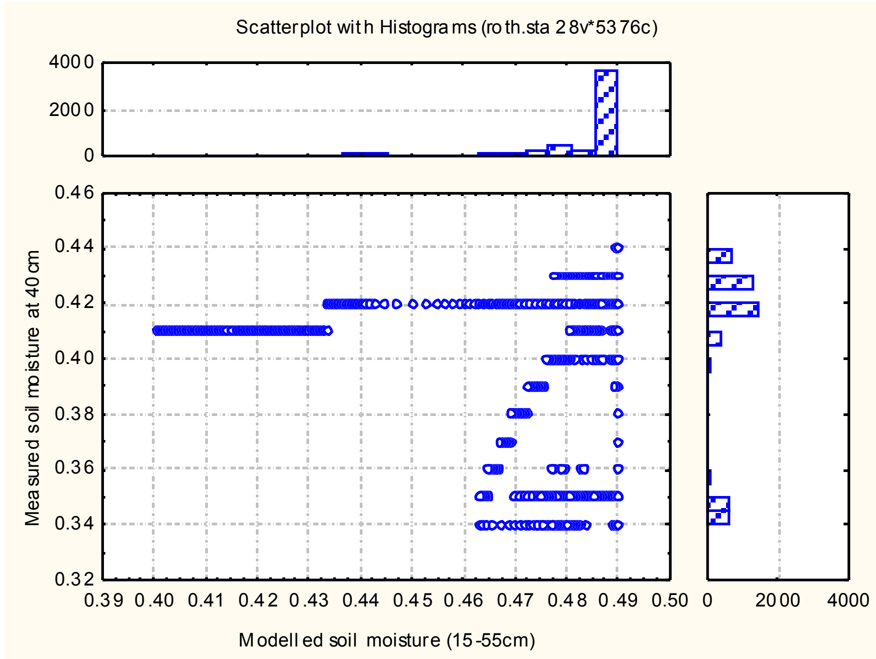

Fig. 11 Scatter plot with histograms of measured soil moisture at 40 cm depth and modelled data at 15-55 cm depth

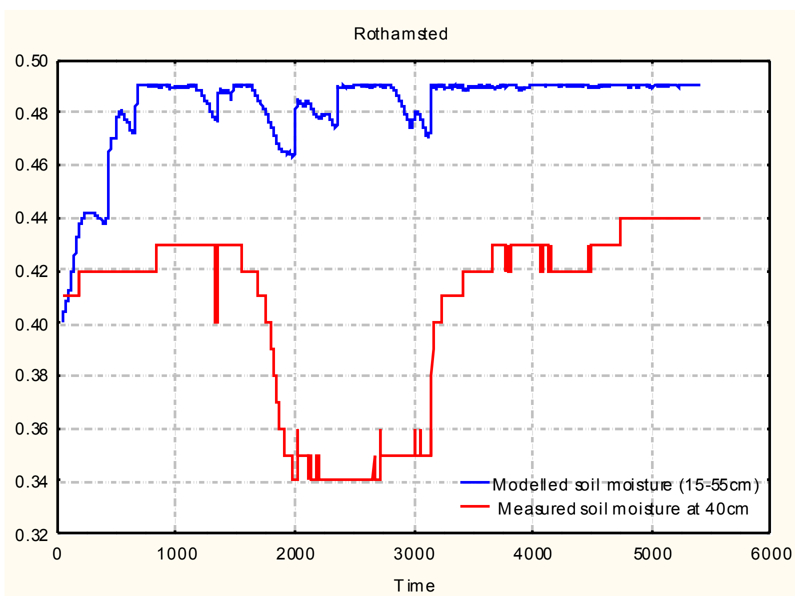

Fig. 12 Plot of Measured soil moisture at 40 cm depth and modelled soil moisture at 15-55 cm depth

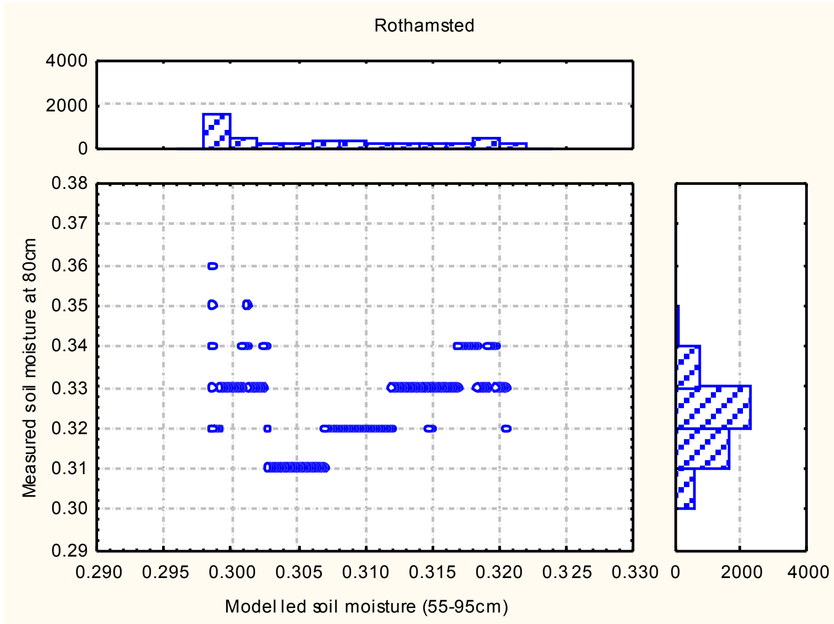

Fig. 13 Scatter plot with histograms of measured soil moisture at 80 cm depth and modelled data at 55-95 cm depth

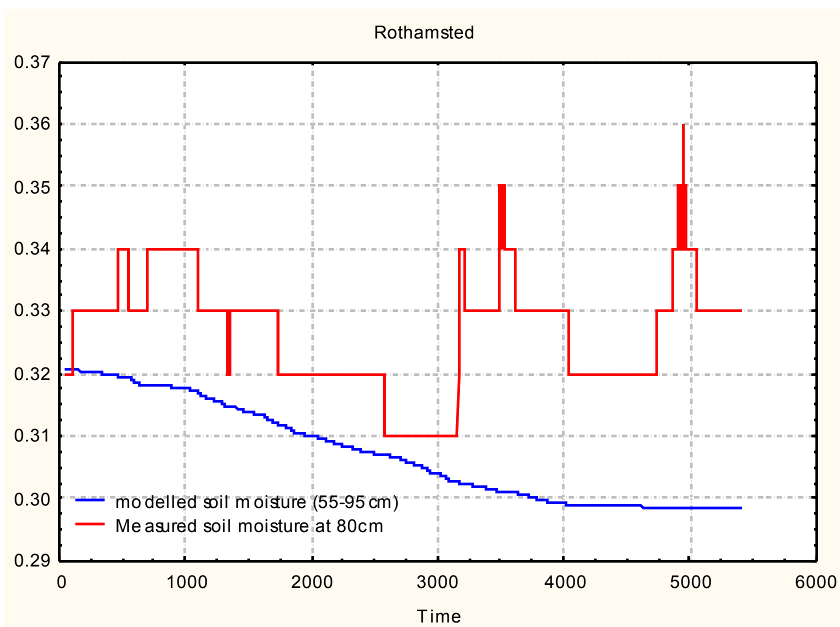

Fig. 14 Plot of Measured soil moisture at 80 cm depth and modelled soil moisture at 55-95 cm depth

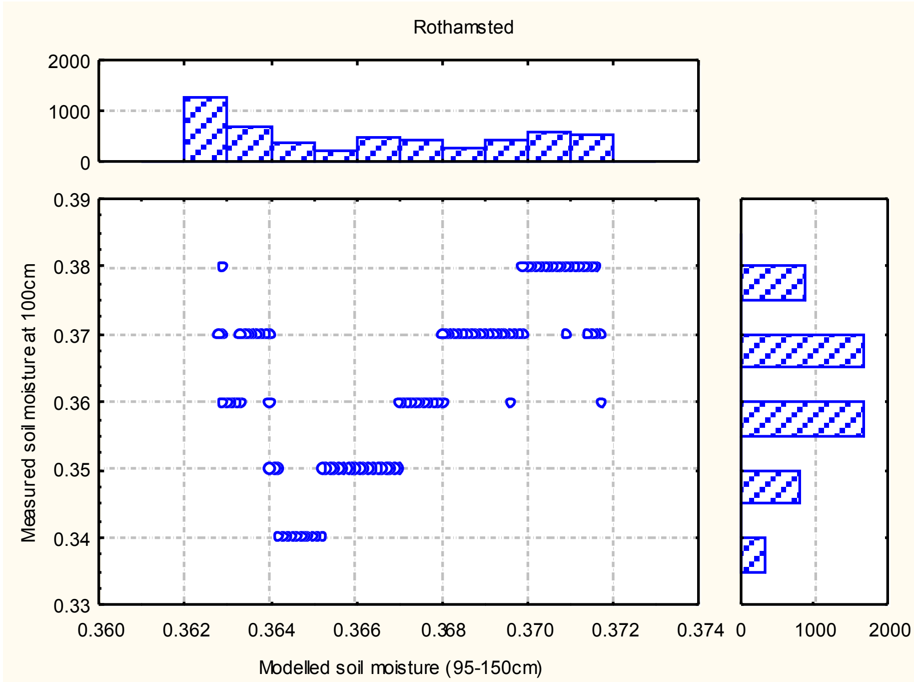

Fig. 15 Scatter plot with histograms of measured soil moisture at 100 cm depth and modelled data at 95-150 cm depth

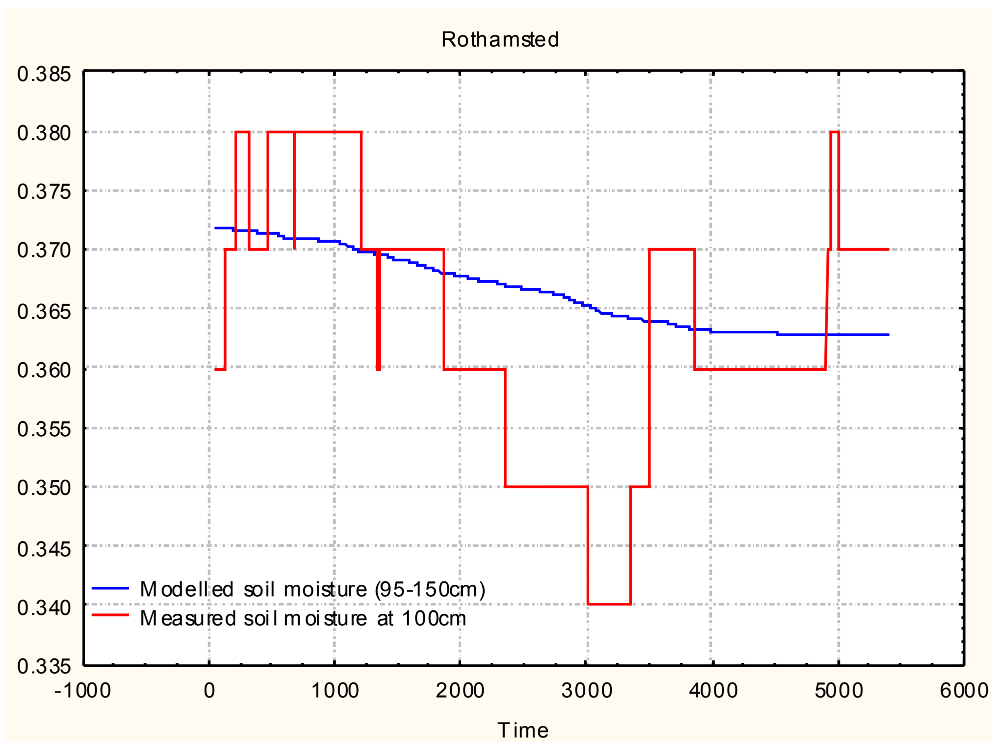

Fig. 16 Plot of Measured soil moisture at 100 cm depth and modelled soil moisture at 95-150 cm depth

c) Watnall

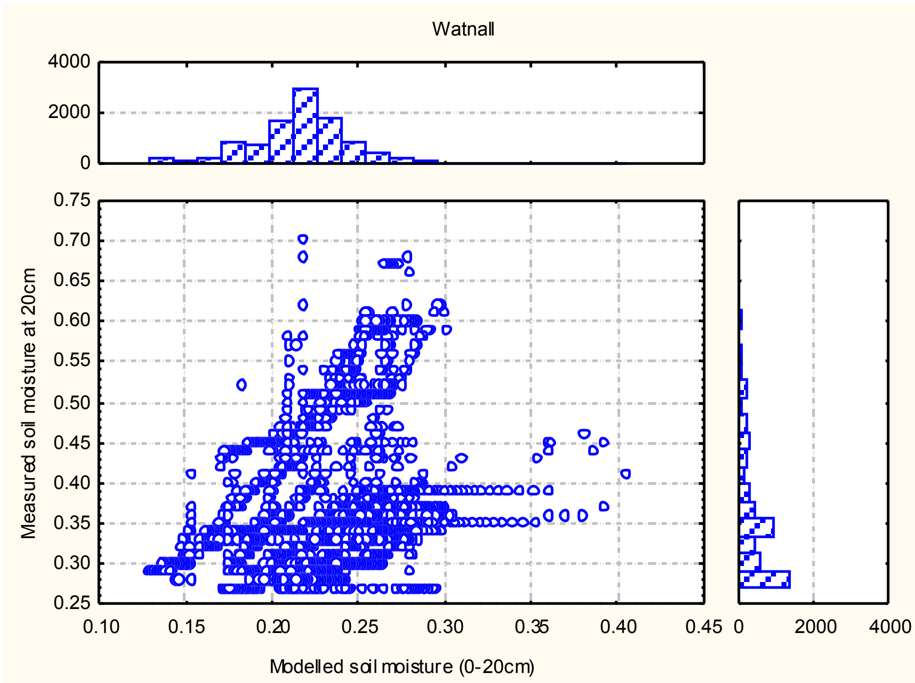

Fig. 17 Scatter plot with histograms of measured soil moisture at 20 cm depth and modelled data at 0-20 cm depth

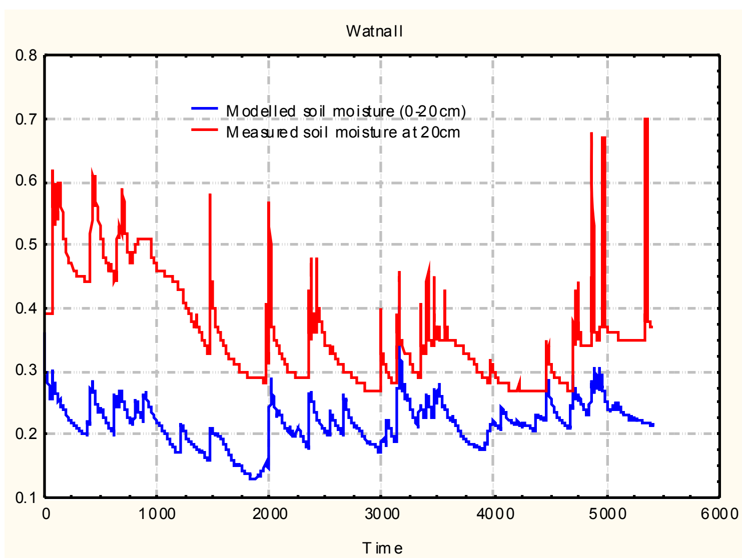

Fig. 18 Plot of Measured soil moisture at 20 cm depth and modelled soil moisture at 0-20 cm depth

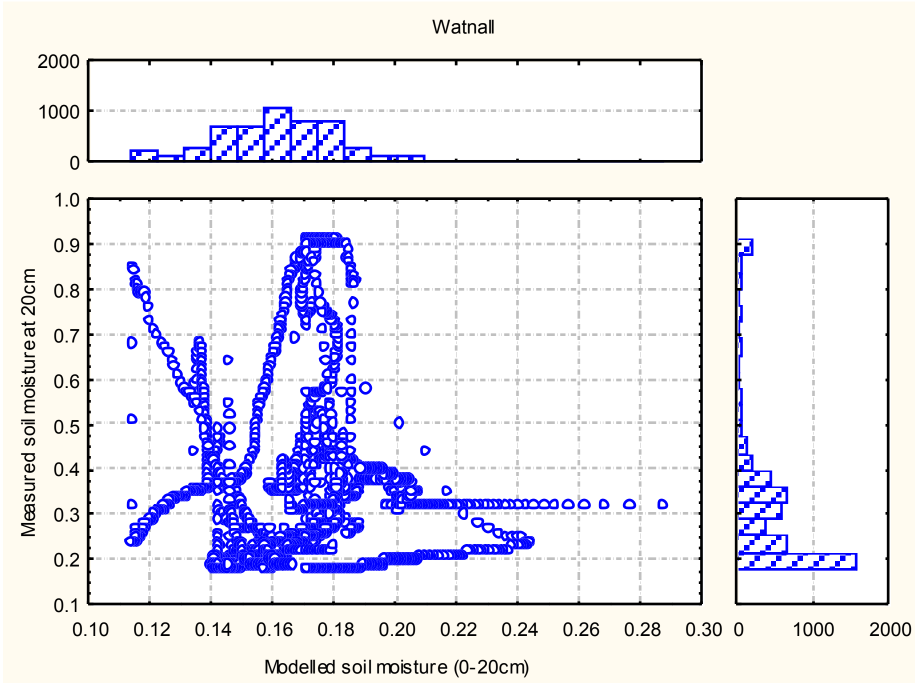

Fig. 19 Scatter plot with histograms of measured soil moisture at 40 cm depth and modelled data at 25-50 cm depth

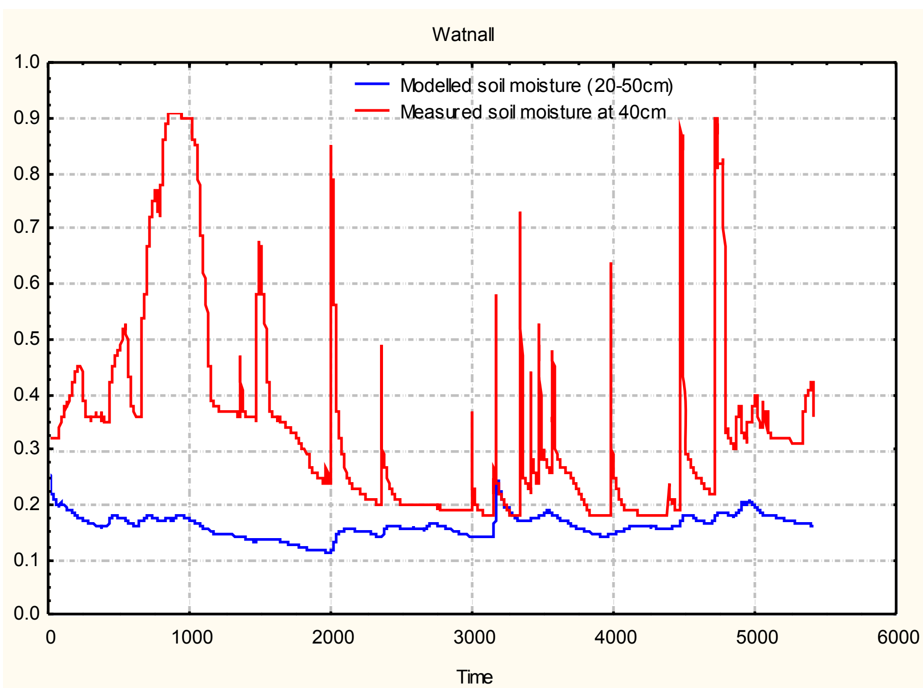

Fig. 20 Plot of Measured soil moisture at 40 cm depth and modelled soil moisture at 20-50 cm depth

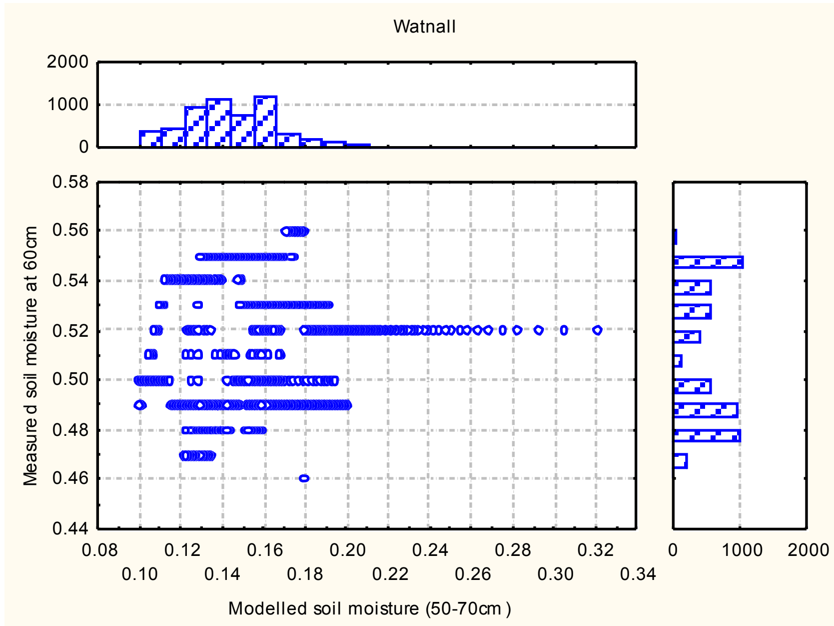

Fig. 21 Scatter plot with histograms of measured soil moisture at 60 cm depth and modelled data at 50-70 cm depth

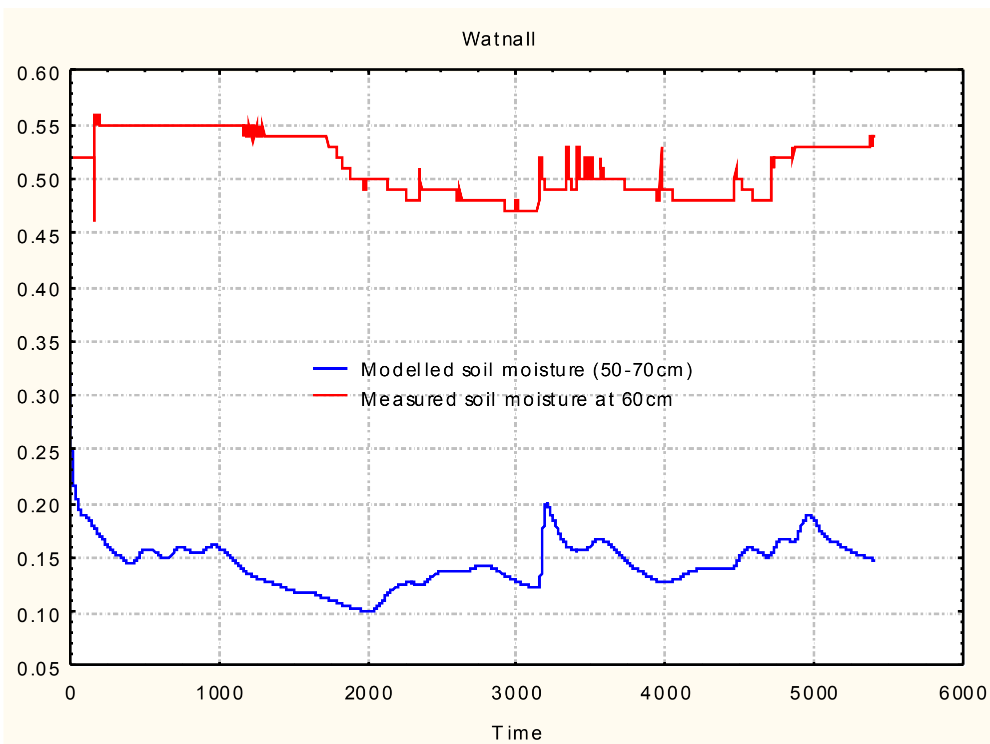

Fig. 22 Plot of Measured soil moisture at 60 cm depth and modelled soil moisture at 50-70 cm depth

2 Soil temperature

a) Camborne

The graph below (Fig. 23) shows the modelled and measured soil temperature near the surface. It is apparent that the modelled soil temperature is showing more variation than the measured soil temperature. In this case both distributions show a bimodal distribution although it is stronger in measured data (Fig. 24).

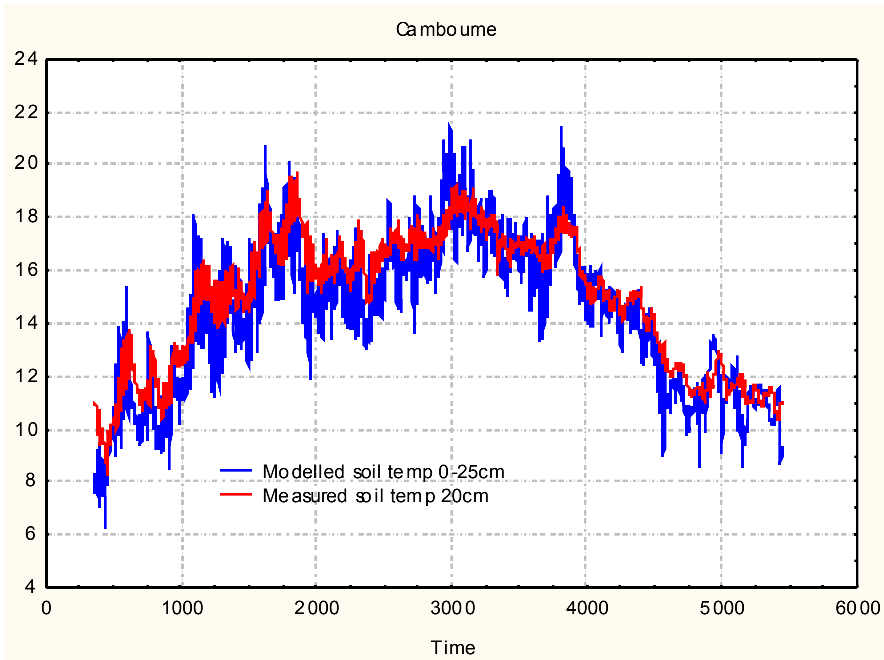

Fig. 23 Plot of Measured soil temperature at 20 cm depth and modelled soil temperature at 0-20 cm depth

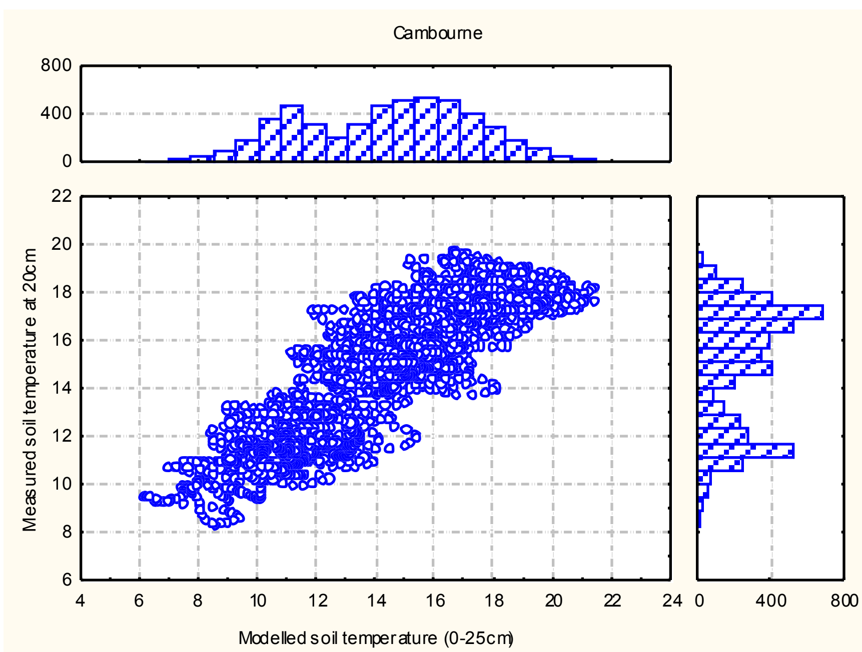

Fig. 24 Scatter plot with histograms of measured soil temperature at 20 cm depth and modelled data at 0-20 cm depth

At 25-70cm the measured and modelled data show a much stronger relationship which is apparent throughout the remainder of the profile.

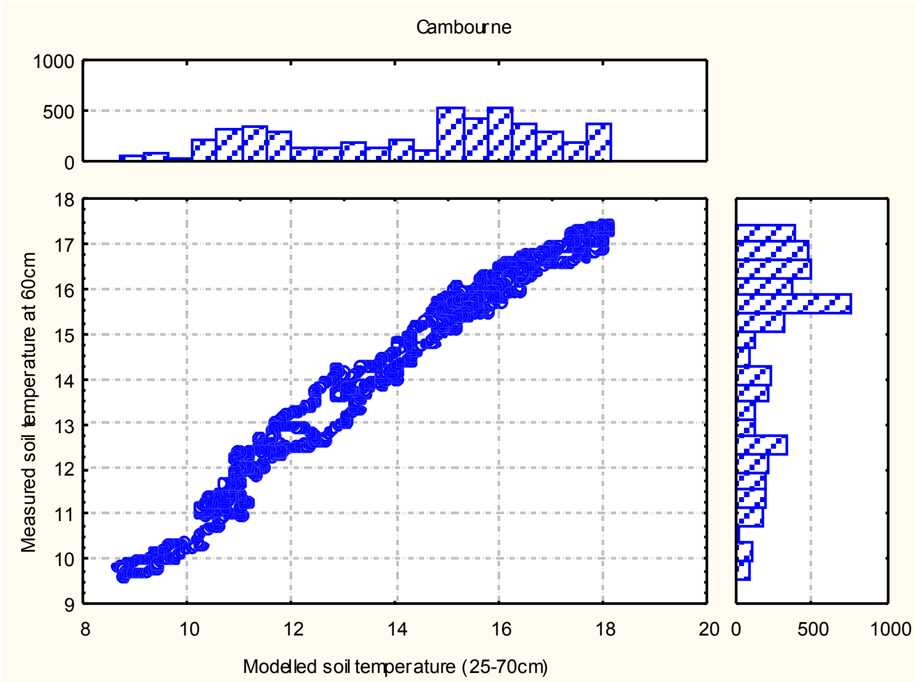

Fig. 25 Scatter plot with histograms of measured soil temperature at 60 cm depth and modelled data at 25-70 cm depth

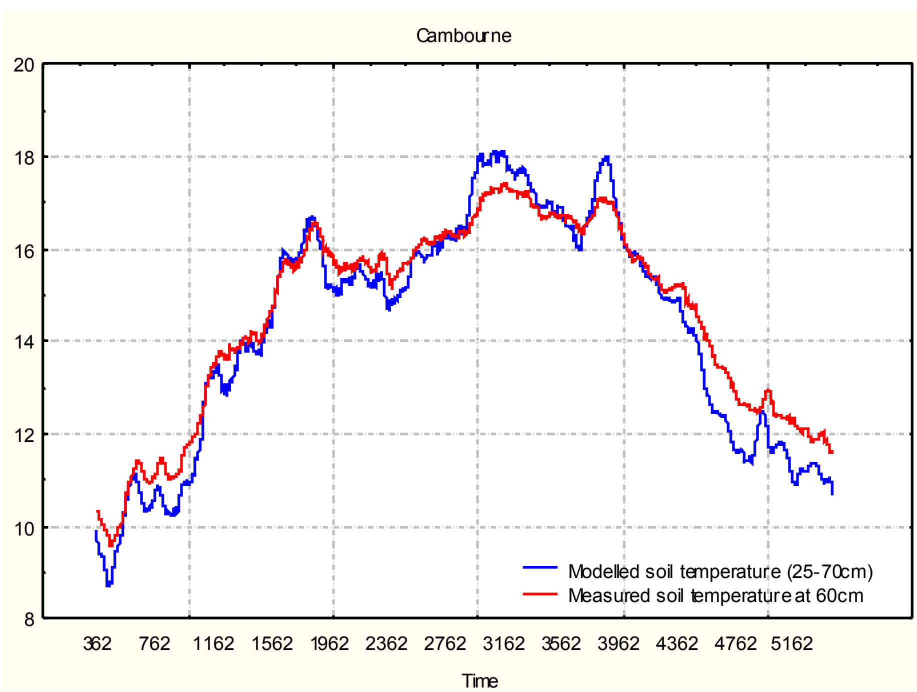

Fig. 26 Plot of Measured soil temperature at 60 cm depth and modelled soil temperature at 25-70 cm depth

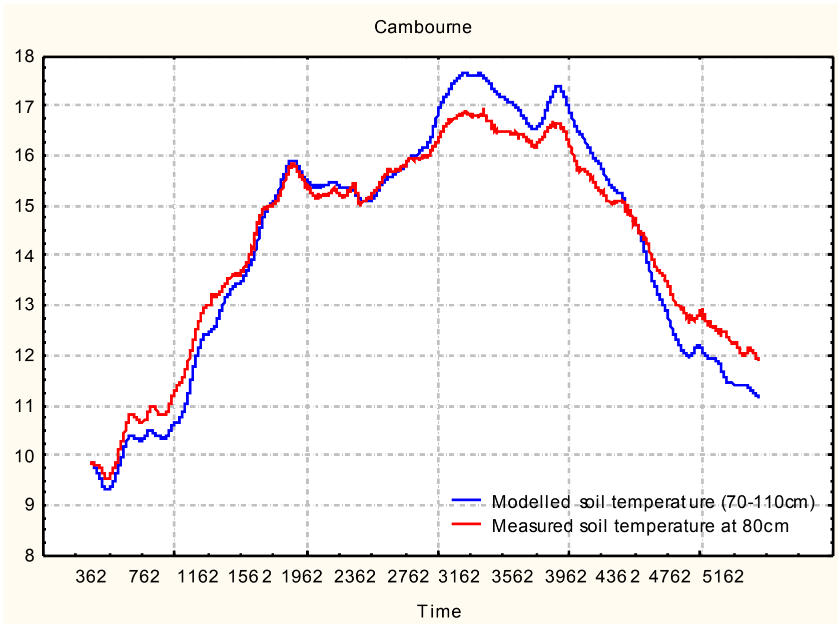

Fig. 27 Plot of Measured soil temperature at 80 cm depth and modelled soil temperature at 70-110 cm depth

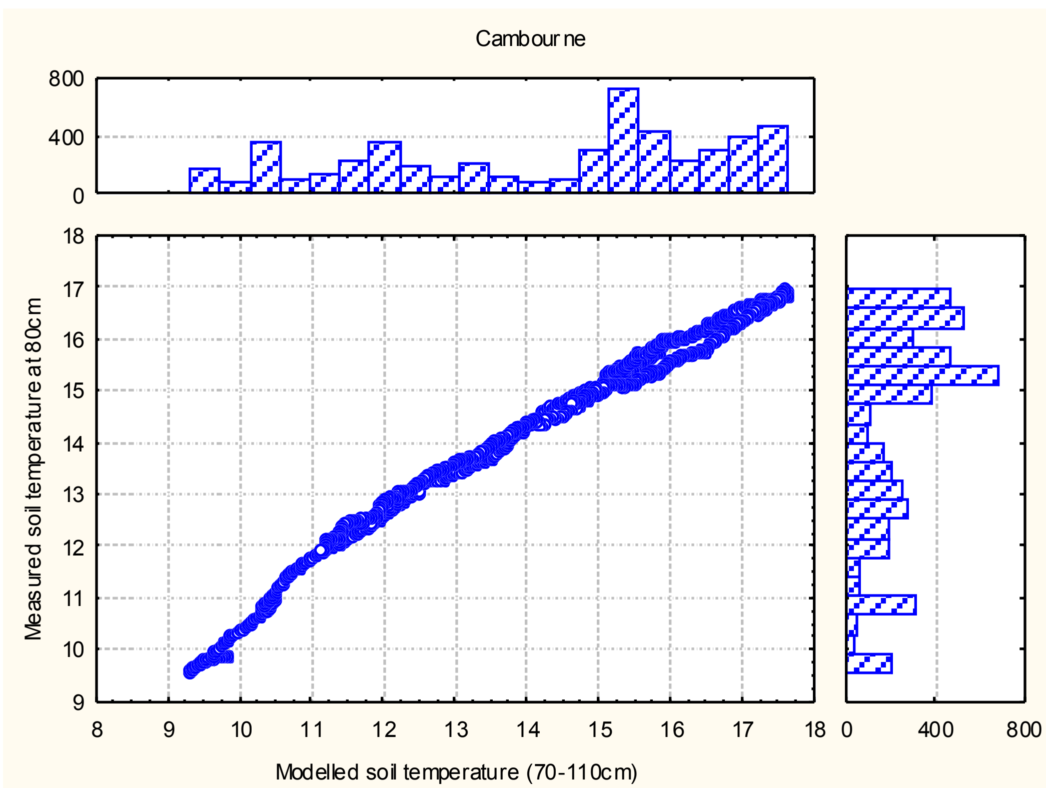

Fig. 28 Scatter plot with histograms of measured soil temperature at 80 cm depth and modelled data at 70-110 cm depth

b) Rothamsted

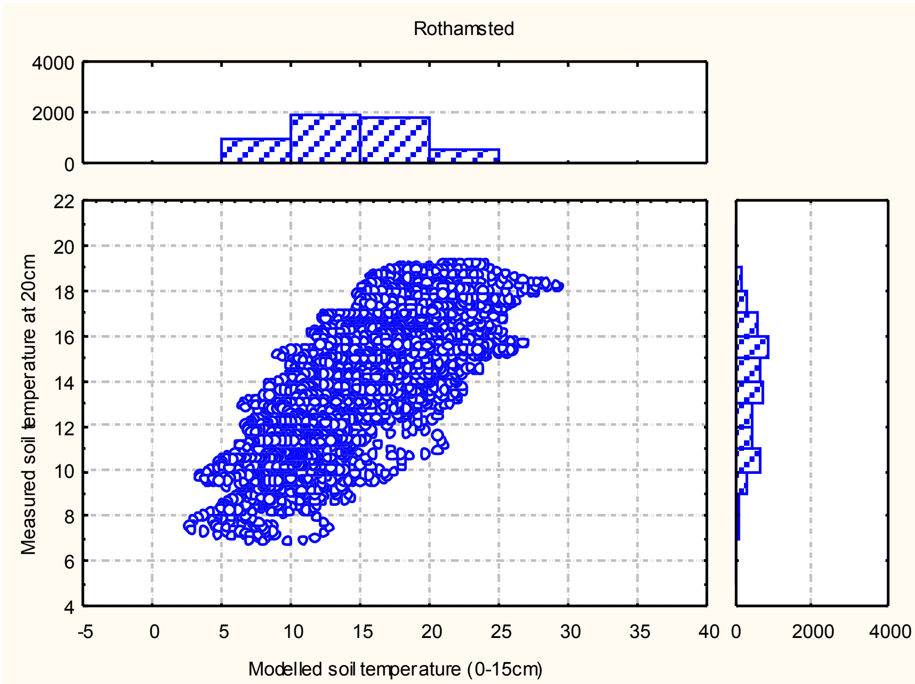

Fig. 29 Scatter plot with histograms of measured soil temperature at 20 cm depth and modelled data at 0-15 cm depth

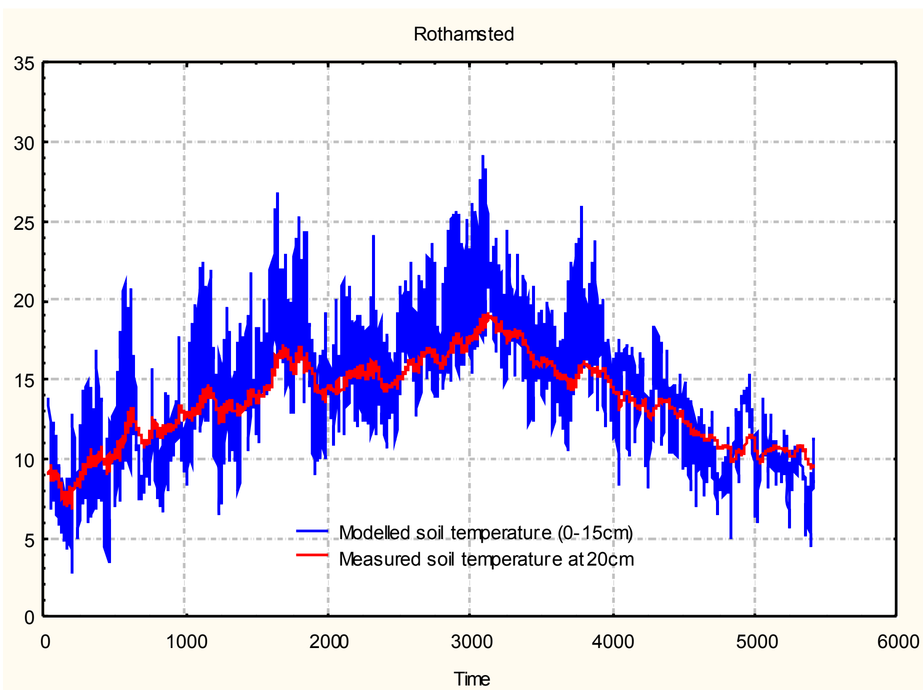

Fig. 30 Plot of Measured soil temperature at 20 cm depth and modelled soil temperature at 0-15 cm depth

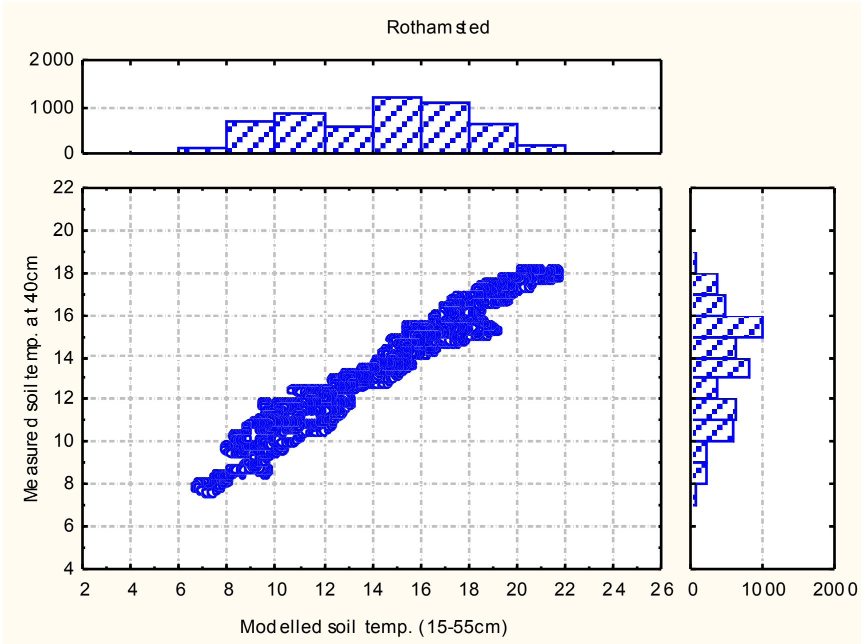

Fig. 31 Scatter plot with histograms of measured soil temperature at 40 cm depth and modelled data at 15-55 cm depth

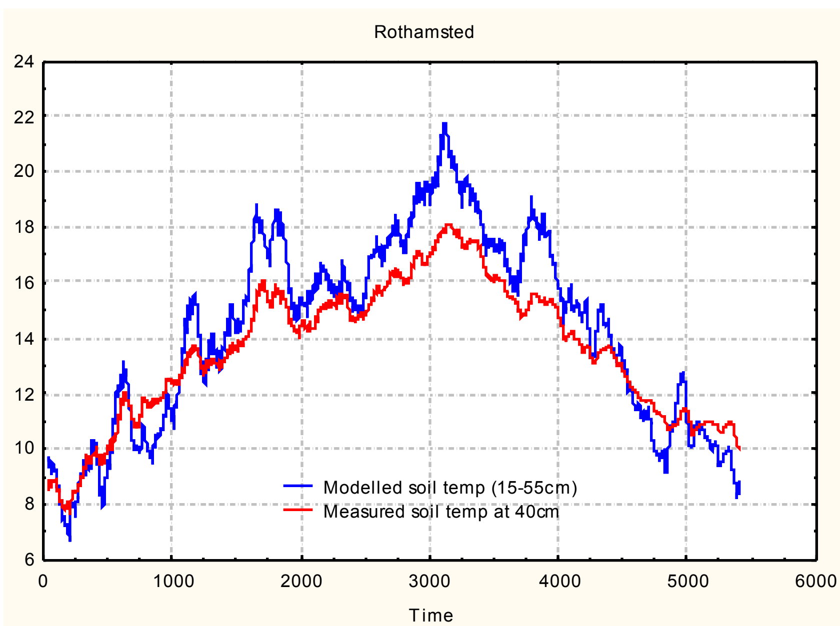

Fig. 32 Plot of Measured soil temperature at 40 cm depth and modelled soil temperature at 15-55 cm depth

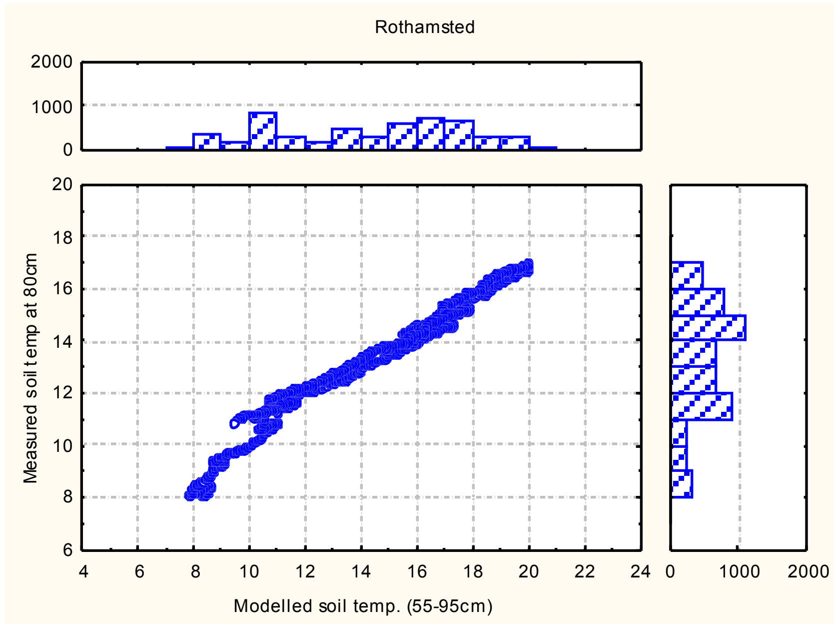

Fig. 33 Scatter plot with histograms of measured soil temperature at 80 cm depth and modelled data at 55-95 cm depth

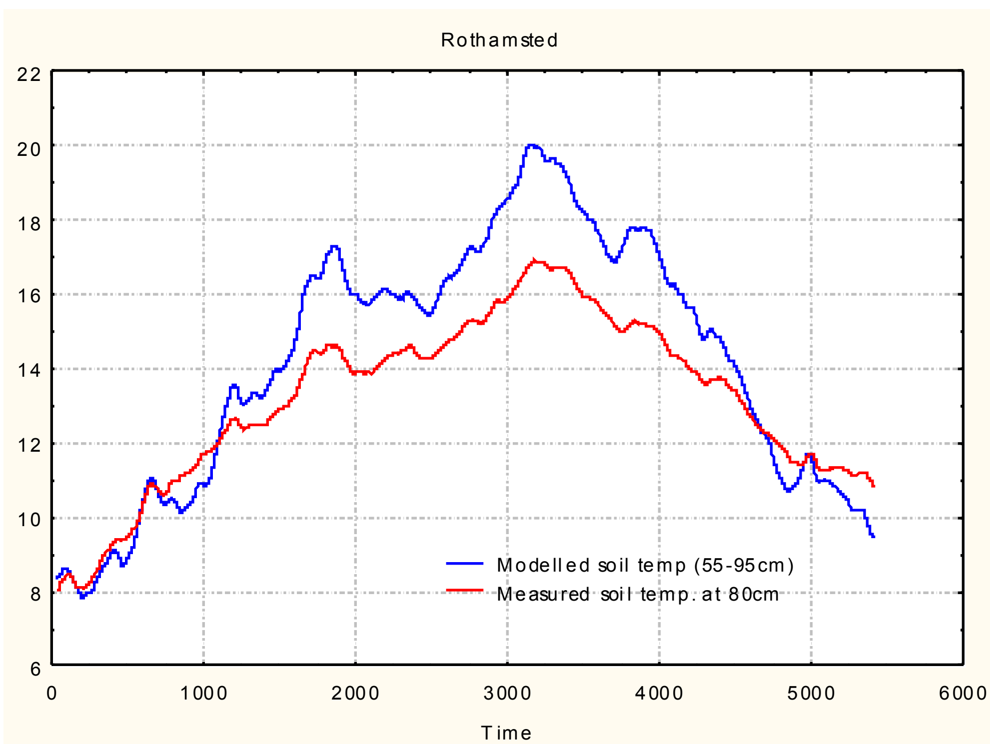

Fig. 34 Plot of Measured soil temperature at 80 cm depth and modelled soil temperature at 55-95 cm depth

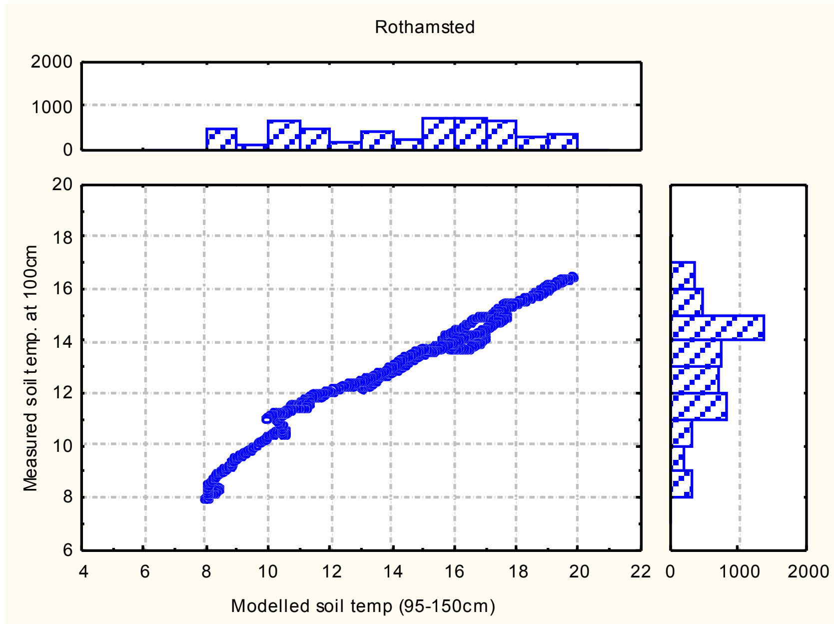

Fig. 35 Scatter plot with histograms of measured soil temperature at 100 cm depth and modelled data at 95-150 cm depth

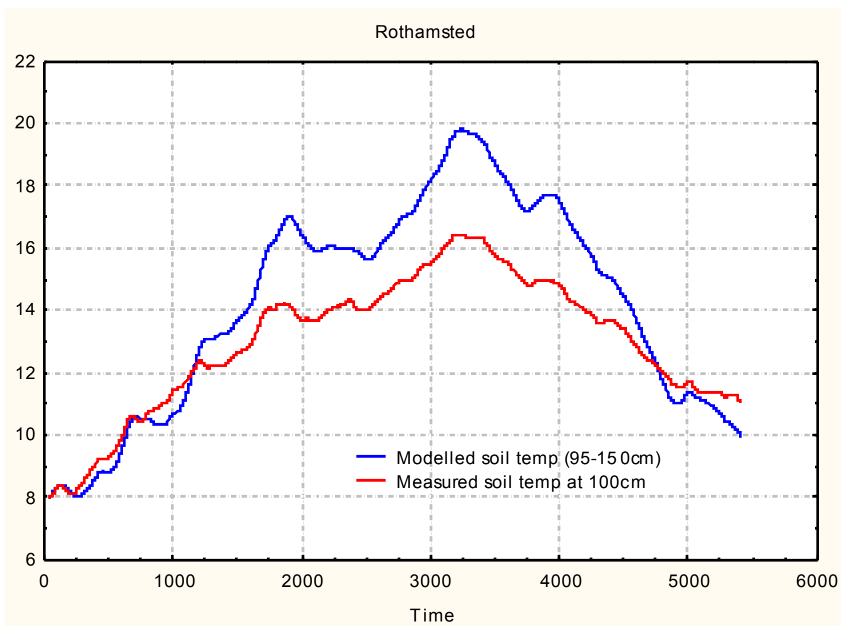

Fig. 36 Plot of Measured soil temperature at 100 cm depth and modelled soil temperature at 95-150 cm depth

c) Watnall

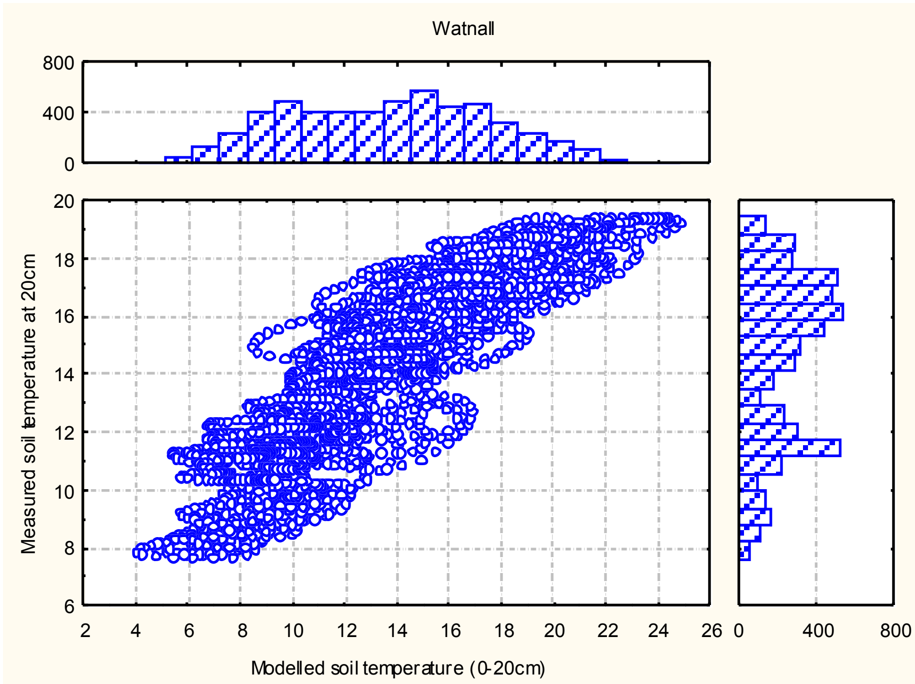

Fig. 37 Scatter plot with histograms of measured soil temperature at 20 cm depth and modelled data at 0-20 cm depth

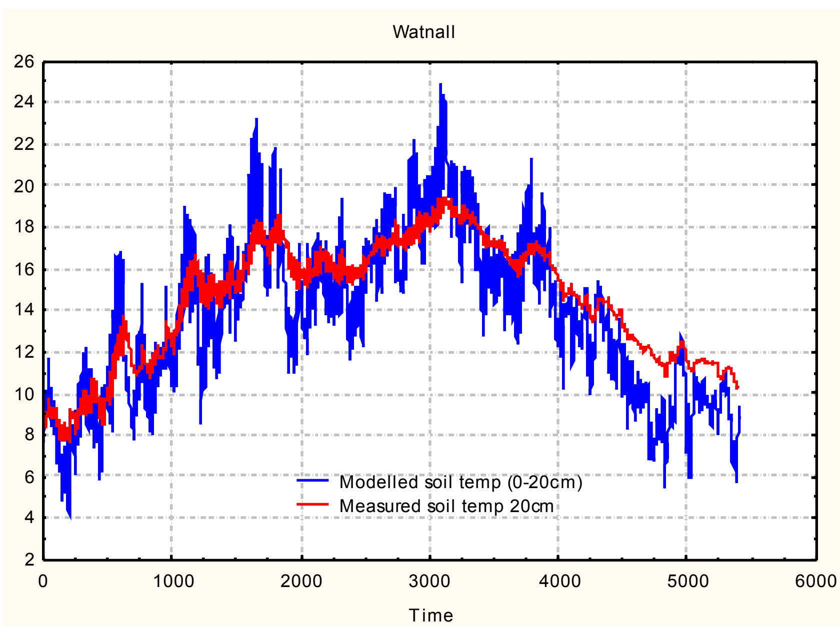

Fig. 38 Plot of Measured soil temperature at 20 cm depth and modelled soil temperature at 0-20 cm depth

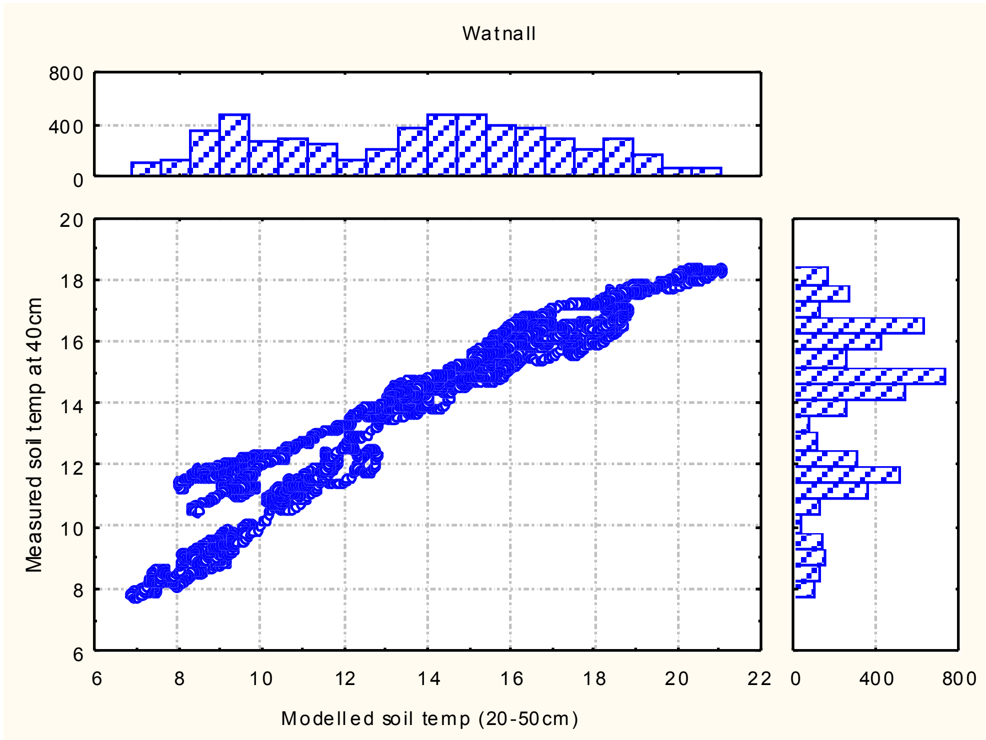

Fig. 39 Scatter plot with histograms of measured soil temperature at 40 cm depth and modelled data at 20-50 cm depth

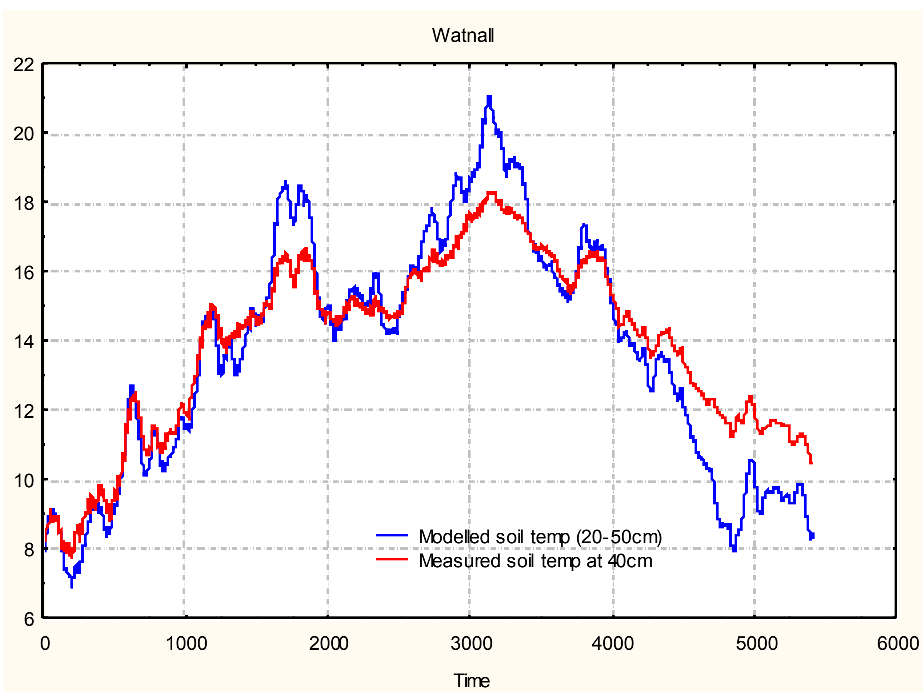

Fig. 40 Plot of Measured soil temperature at 40 cm depth and modelled soil temperature at 20-50 cm depth

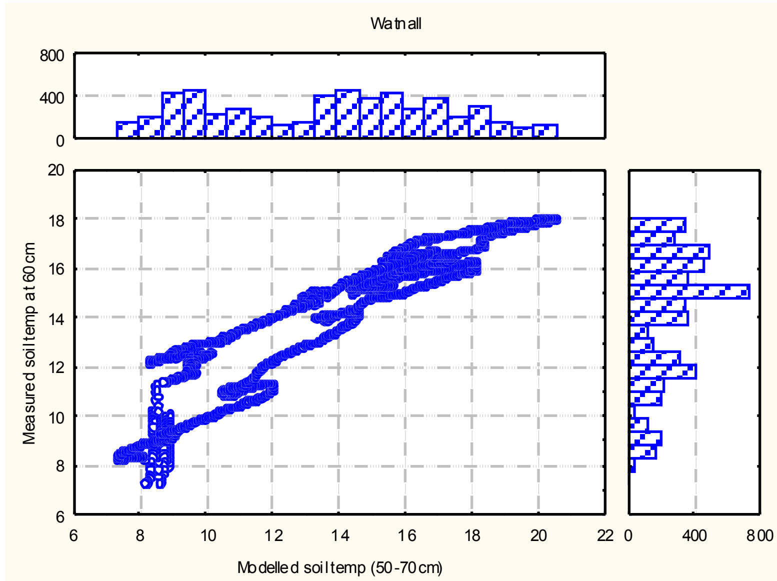

Fig. 41 Scatter plot with histograms of measured soil temperature at 60 cm depth and modelled data at 50-70 cm depth

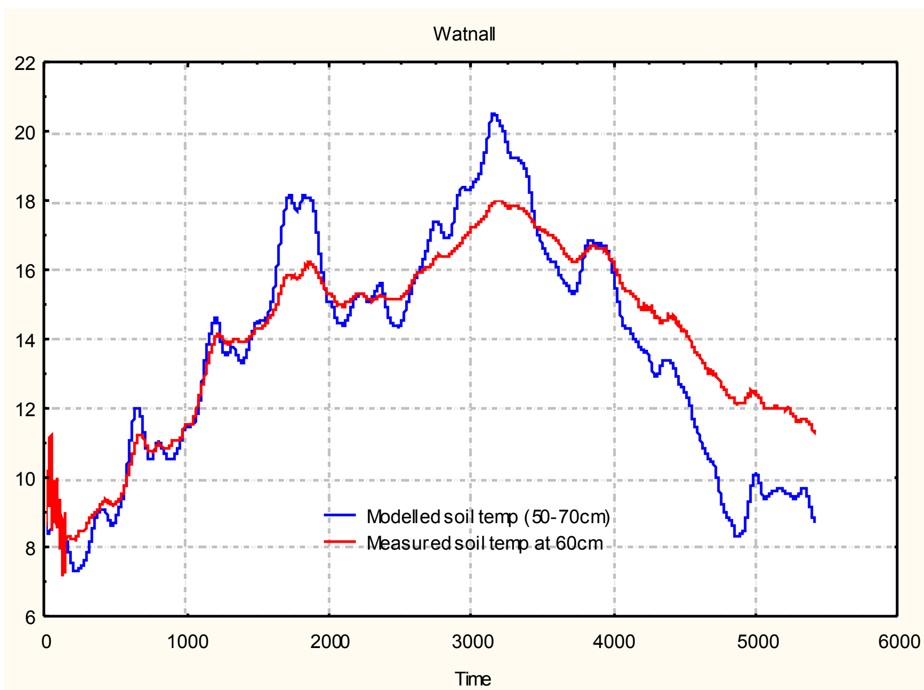

Fig. 42 Plot of Measured soil temperature at 60 cm depth and modelled soil temperature at 50-70 cm depth