Maladaptive plastic responses of flowering time to geothermal heating (Cerastium 2)

Analyses with logger data

Alicia Valdés

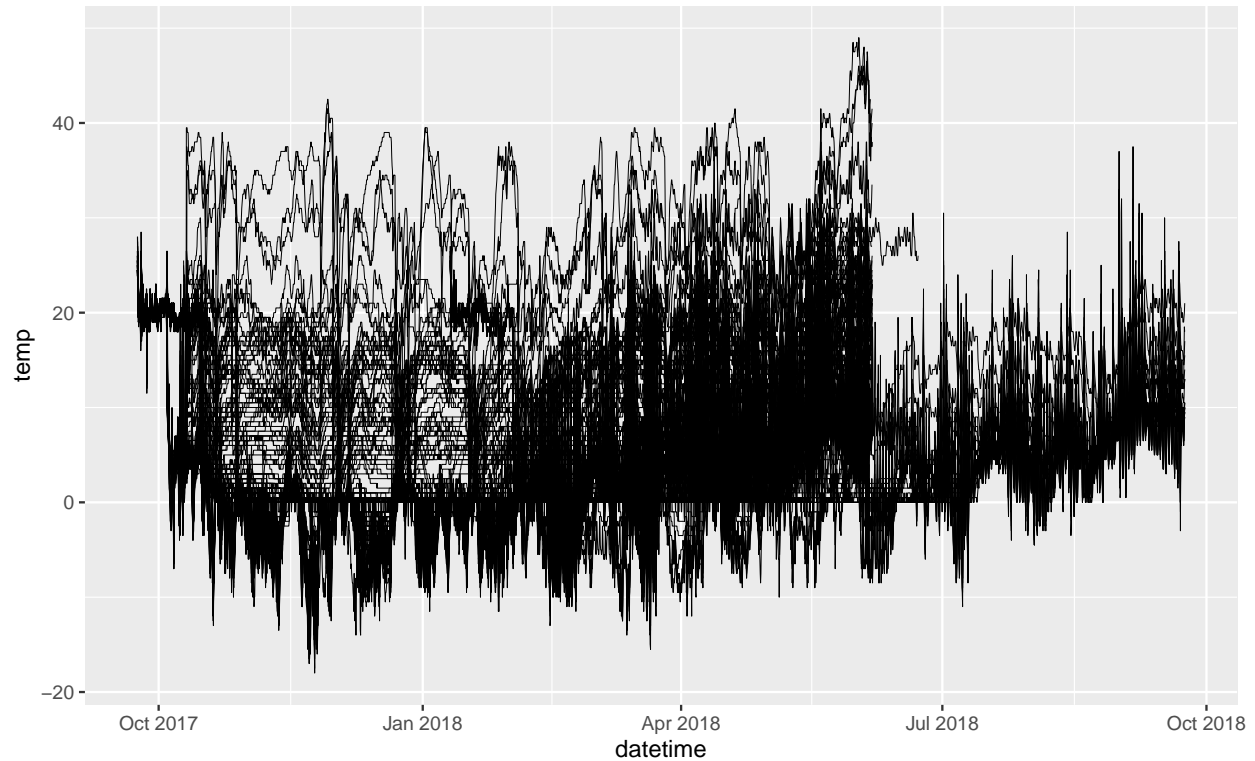# Contents

Read data

Plot with all logger data, one line per logger id

Q1: Are instantaneous measures of soil temperature representative for the conditions during the entire spring/growing season?

Correlations logger temperature - instant temperature

May

For each logger_nr, get mean temperature during May 2017 and compare with temp_term (which was measured with a thermometer at 10 cm depth on May 2017):

Observations	78
Dependent variable	meanmay_logger
Type	OLS linear regression

$F_{(1,76)}$	1.233
R^2	0.016
Adj. R^2	0.003

	Est.	S.E.	t val.	p
(Intercept)	6.507	0.547	11.900	0.000
temp_term	0.040	0.036	1.111	0.270

Standard errors: OLS

Observations	141
Dependent variable	meanmay_logger
Type	OLS linear regression

$F_{(1,139)}$	399.799
R^2	0.742
Adj. R^2	0.740

	Est.	S.E.	t val.	p
(Intercept)	-0.727	0.625	-1.163	0.247
temp_term	0.853	0.043	19.995	0.000

Standard errors: OLS

Correlation mean temperature of may from logger data and soil temperature measured in may with thermometer:

```
## [1] 0.6446784
```

Correlation mean temperature of may from logger data (only belowground loggers) and soil temperature measured in may with thermometer:

```
## [1] 0.8614051
```

Correlation mean temperature of may from logger data (only aboveground loggers) and soil temperature measured in may with thermometer:

```
## [1] 0.1263677
```

Whole period

For each logger_nr, get mean temperature during the whole period available and compare with temp_term (which was measured with a thermometer at 10 cm depth on May 2017):

Observations	78
Dependent variable	mean_logger
Type	OLS linear regression

F(1,76)	54.027
R²	0.416
Adj. R²	0.408

	Est.	S.E.	t val.	p
(Intercept)	1.633	0.138	11.819	0.000
temp_term	0.066	0.009	7.350	0.000

Standard errors: OLS

Correlation mean temperature from logger data and soil temperature measured in may with thermometer:

Observations		141
Dependent variable		mean_logger
Type		OLS linear regression

F(1,139)	686.807
R²	0.832
Adj. R²	0.830

	Est.	S.E.	t val.	p
(Intercept)	-3.547	0.465	-7.623	0.000
temp_term	0.832	0.032	26.207	0.000

Standard errors: OLS

[1] 0.6700633

Correlation mean temperature from logger data (only belowground loggers) and soil temperature measured in may with thermometer:

[1] 0.9119648

Correlation mean temperature from logger data (only aboveground loggers) and soil temperature measured in may with thermometer:

[1] 0.6445959

The correlation values seem to indicate that the temperature measured with a thermometer represents quite well longer-term conditions

Q2: Do differences between soil and air temperatures change with soil temperature?

For the plants with aboveground loggers, we have air temperature and soil temperature measured at the same exact location (air temperature measured by the aboveground logger and soil temperature measured with the thermometer). We use these plants to test for correlations between air and soil temperature.

All temperature values

Logger data for the whole period:

Observations	78
Dependent variable	mean_logger
Type	OLS linear regression

F(1,76)	54.027
R²	0.416
Adj. R²	0.408

	Est.	S.E.	t val.	p
(Intercept)	1.633	0.138	11.819	0.000
temp_term	0.066	0.009	7.350	0.000

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: mean_logger ~ temp_term
##
##   Res.Df    RSS Df Sum of Sq      F    Pr(>F)
## 1     77 3339.5
## 2     76   23.6  1    3315.9 10658 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The slope is significantly different from 1: differences between soil and air temperature change with soil temperature, being larger at higher soil temperatures.

Logger data for May:

Observations	78
Dependent variable	meanmay_logger
Type	OLS linear regression

F(1,76)	1.233
R²	0.016
Adj. R²	0.003

	Est.	S.E.	t val.	p
(Intercept)	6.507	0.547	11.900	0.000
temp_term	0.040	0.036	1.111	0.270

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: meanmay_logger ~ temp_term
##
##   Res.Df    RSS Df Sum of Sq      F    Pr(>F)
## 1     77 3878.6
## 2     76  370.1  1    3508.5 720.54 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

When looking only at air temperature in May, the slope is also significantly different from 1. But it is not significantly different from zero! So there is no relationship between soil and air temperature.

Logger data for April-May-June:

Observations	78
Dependent variable	meanspring_logger
Type	OLS linear regression

F(1,76)	4.642
R²	0.058
Adj. R²	0.045

	Est.	S.E.	t val.	p
(Intercept)	4.805	0.501	9.592	0.000
temp_term	0.071	0.033	2.154	0.034

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: meanspring_logger ~ temp_term
##
##   Res.Df    RSS Df Sum of Sq      F    Pr(>F)
## 1     77 3597.1
## 2     76  310.6  1   3286.5 804.06 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

9

When looking at air temperature in the period April-May-June, the slope is also significantly different from 1: differences between soil and air temperature change with soil temperature, being larger at higher soil temperatures.

Daily temperature values

Repeat what was done above using only daily values of air temperature (after 8 am and before or equal to 8 pm).

Logger data for the whole period:

Observations	78
Dependent variable	mean_logger
Type	OLS linear regression

F(1,76)	50.038
R²	0.397
Adj. R²	0.389

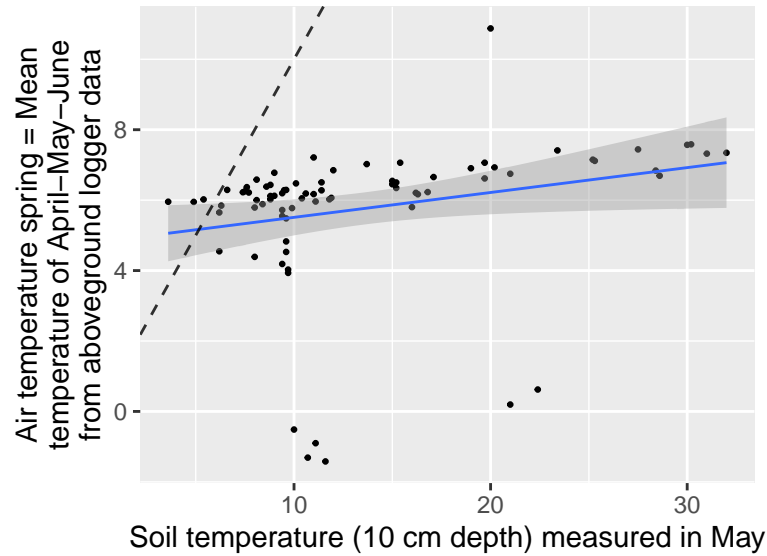|	Est.	S.E.	t val.	p
(Intercept)	2.566	0.157	16.343	0.000
temp_term	0.073	0.010	7.074	0.000

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
```

10

```
## Model 2: mean_logger ~ temp_term
##
##   Res.Df    RSS Df Sum of Sq    F    Pr(>F)
## 1     77 3302.6
## 2     76   30.5  1   3272.1 8152 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Logger data for May:

Soil temperature (10 cm depth) measured in May
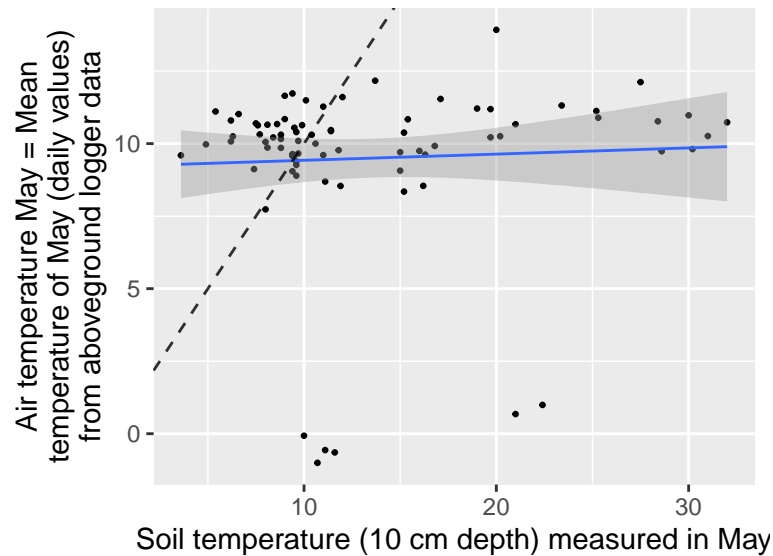
Observations	78
Dependent variable	meanmay_logger
Type	OLS linear regression

$F(1,76)$	0.196
R^2	0.003
Adj. R^2	-0.011

	Est.	S.E.	t val.	p
(Intercept)	9.212	0.736	12.516	0.000
temp_term	0.021	0.048	0.443	0.659

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: meanmay_logger ~ temp_term
##
```

```
##    Res.Df     RSS Df Sum of Sq      F    Pr(>F)
## 1      77 4314.9
## 2      76  670.6  1    3644.3 413.04 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Logger data for April-May-June:

Soil temperature (10 cm depth) measured in May
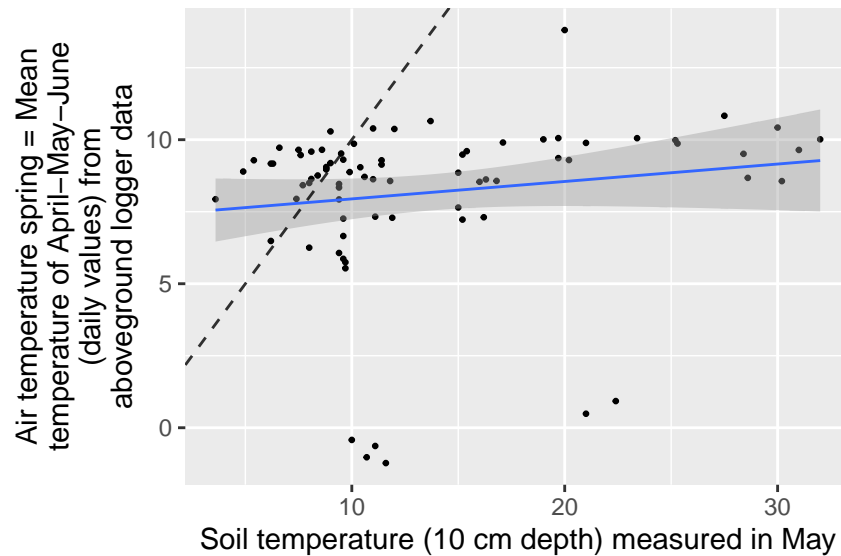
Observations	78
Dependent variable	meanspring_logger
Type	OLS linear regression

F(1,76)	1.799
R²	0.023
Adj. R²	0.010

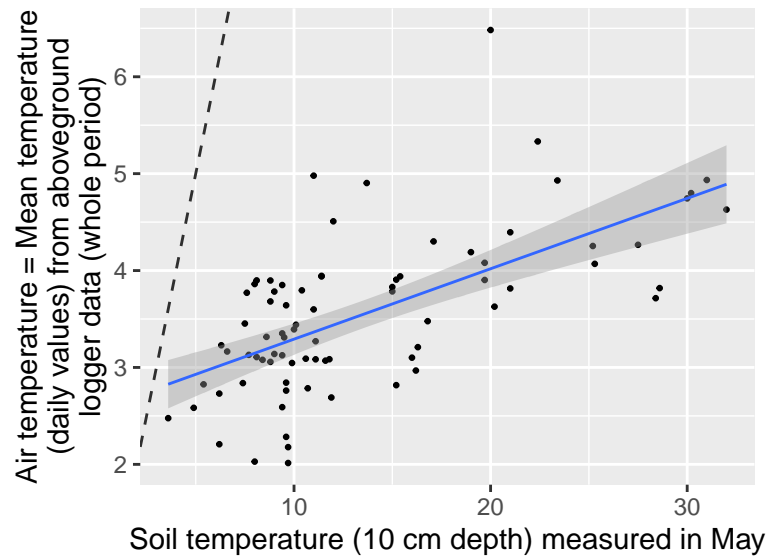|	Est.	S.E.	t val.	p
(Intercept)	7.340	0.689	10.651	0.000
temp_term	0.060	0.045	1.341	0.184

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: meanspring_logger ~ temp_term
##
##    Res.Df     RSS Df Sum of Sq      F    Pr(>F)
## 1      77 3946.4
```

```
## 2     76  587.9  1    3358.5 434.13 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Positive temperature values

Logger data for the whole period:

Observations	78
Dependent variable	mean_logger
Type	OLS linear regression

F(1,76)	5.296
R²	0.065
Adj. R²	0.053

	Est.	S.E.	t val.	p
(Intercept)	6.208	0.218	28.499	0.000
temp_term	0.033	0.014	2.301	0.024

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: mean_logger ~ temp_term
##
##   Res.Df    RSS Df Sum of Sq    F    Pr(>F)
```

```
## 1       77 3618.1
## 2       76   58.7  1     3559.4 4606 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Logger data for May:
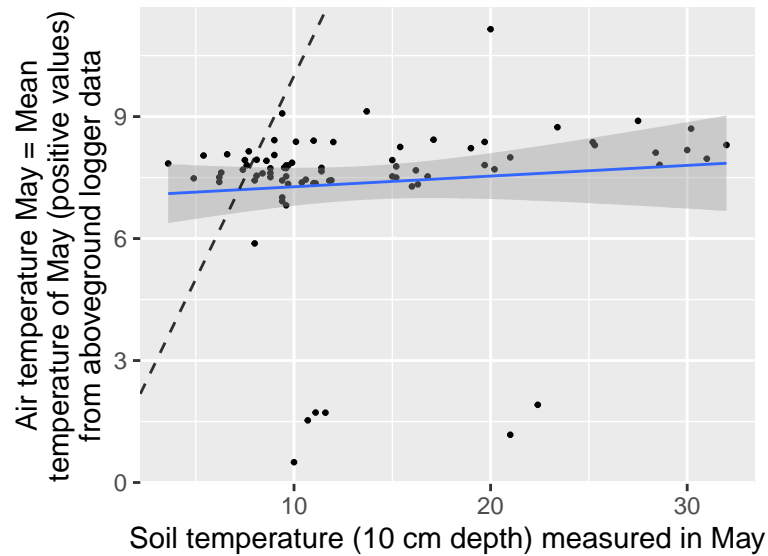
Observations	78
Dependent variable	meanmay_logger
Type	OLS linear regression

F(1,76)	0.773
R²	0.010
Adj. R²	-0.003

	Est.	S.E.	t val.	p
(Intercept)	7.011	0.457	15.342	0.000
temp_term	0.026	0.030	0.879	0.382

Standard errors: OLS

```
## Linear hypothesis test
##
## Hypothesis:
## temp_term = 1
##
## Model 1: restricted model
## Model 2: meanmay_logger ~ temp_term
##
##   Res.Df    RSS Df Sum of Sq       F     Pr(>F)
## 1     77 3866.0
## 2     76  258.5  1    3607.5 1060.6 < 2.2e-16 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Logger data for April-May-June:
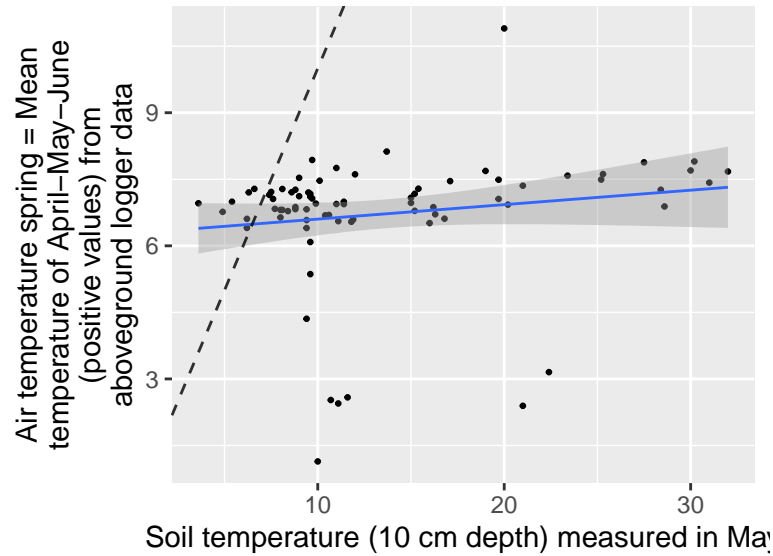
Observations	78
Dependent variable	meanspring_logger
Type	OLS linear regression

F(1,76)	1.944
R²	0.025
Adj. R²	0.012

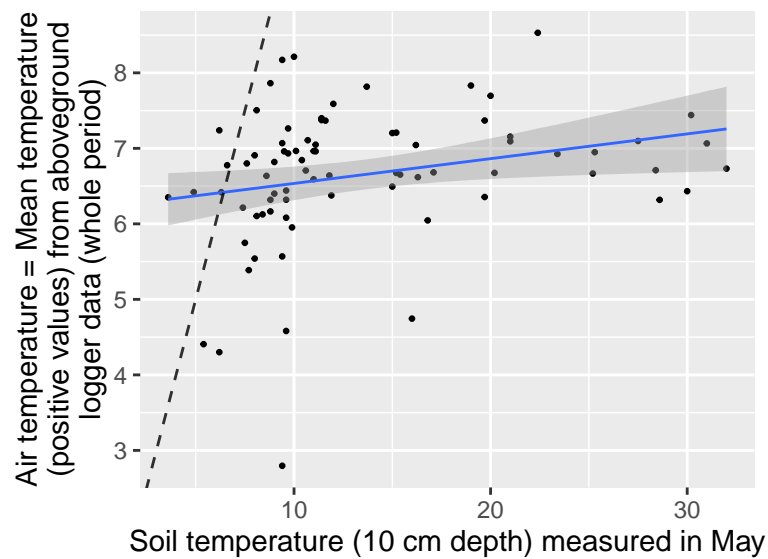|	Est.	S.E.	t val.	p
(Intercept)	6.277	0.357	17.573	0.000
temp_term	0.033	0.023	1.394	0.167

Standard errors: OLS

```
## Linear hypothesis test
## 
## Hypothesis:
## temp_term = 1
## 
## Model 1: restricted model
## Model 2: meanspring_logger ~ temp_term
## 
##   Res.Df    RSS Df Sum of Sq      F    Pr(>F)
## 1     77 3718.9
## 2     76  157.9  1    3560.9 1713.6 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Q3: Do correlations between soil and air temperature vary with soil temperature?

Or: How useful soil temperature is as a cue for air temperature, i.e., as a cue for spring advancement?

Option 1 (probably not used): use plots to calculate correlations between soil and air logger temperatures

Correlations soil-air temperature over the period April-May-June

For each date and plot, calculate mean, max and min of air and soil temperature (from, respectively, above and belowground loggers). Then, calculate the correlation coefficient for air and soil temperatures over the period April-May-June. Finally, regress these correlation coefficients on mean soil temperature for each plot for the same period.
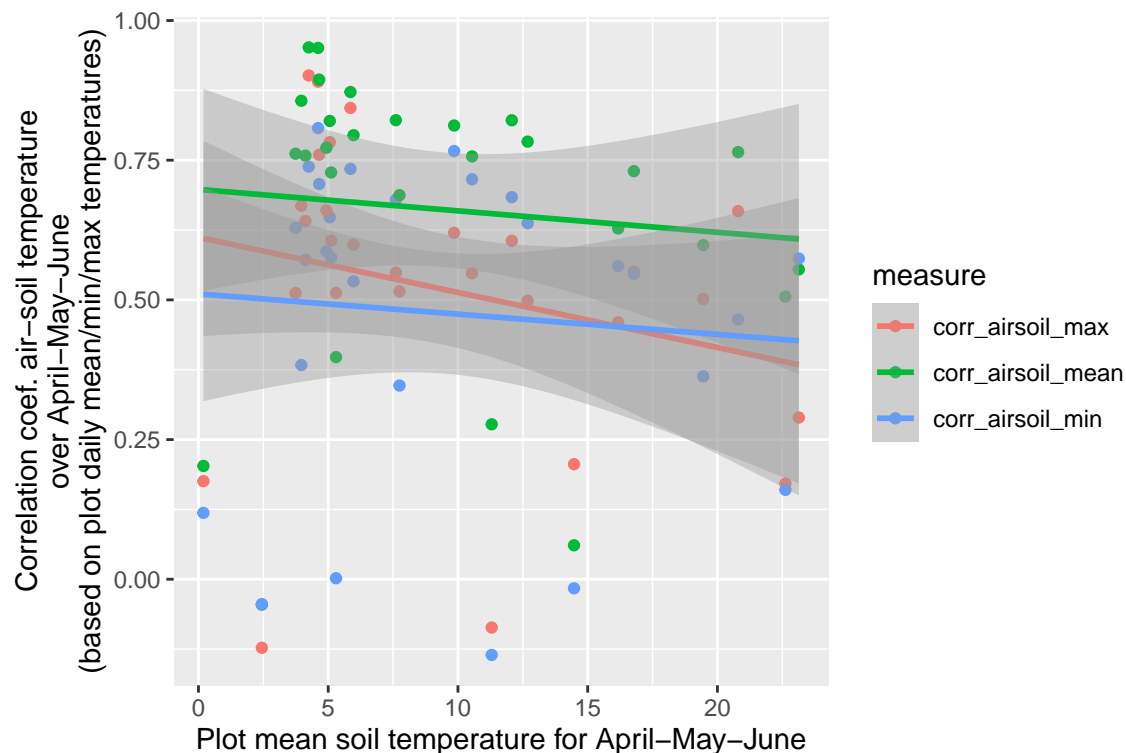
Several plots with negative correlations!

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6119703	0.0862149	7.0981923	0.0000002
corr_airsoil_max	meansoiltemp	-0.0098613	0.0075418	-1.3075468	0.2024719
corr_airsoil_mean	(Intercept)	0.6977323	0.0892365	7.8189095	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0038386	0.0078061	-0.4917393	0.6270297
corr_airsoil_min	(Intercept)	0.5107733	0.0943600	5.4130303	0.0000113
corr_airsoil_min	meansoiltemp	-0.0036281	0.0082543	-0.4395358	0.6639051

Non-significant in all cases.

Correlations soil-air temperature for May only

For each date and plot, calculate mean, max and min of air and soil temperature (from, respectively, above and belowground loggers). Then, calculate the correlation coefficient for air and soil temperatures over the month of May. Finally, regress these correlation coefficients on mean soil temperature for each plot for the same period.
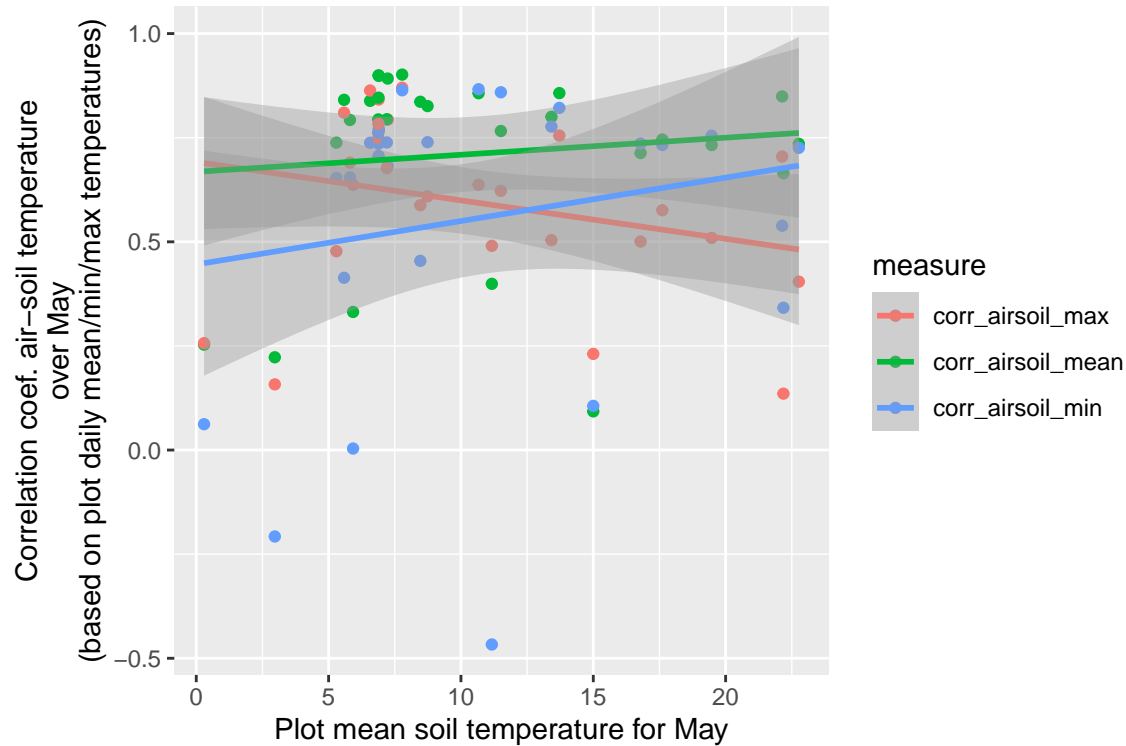
Several plots with negative correlations!

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6919312	0.0788774	8.7722341	0.0000000
corr_airsoil_max	meansoiltemp	-0.0092418	0.0065041	-1.4209164	0.1672242
corr_airsoil_mean	(Intercept)	0.6680271	0.0884666	7.5511777	0.0000001
corr_airsoil_mean	meansoiltemp	0.0041009	0.0072948	0.5621674	0.5788169
corr_airsoil_min	(Intercept)	0.4456083	0.1342556	3.3191049	0.0026774
corr_airsoil_min	meansoiltemp	0.0104284	0.0110705	0.9419963	0.3548655

Non-significant in all cases.

Option 2: try to pair loggers

Paired logger data

Plot with all paired logger data, one line per logger id
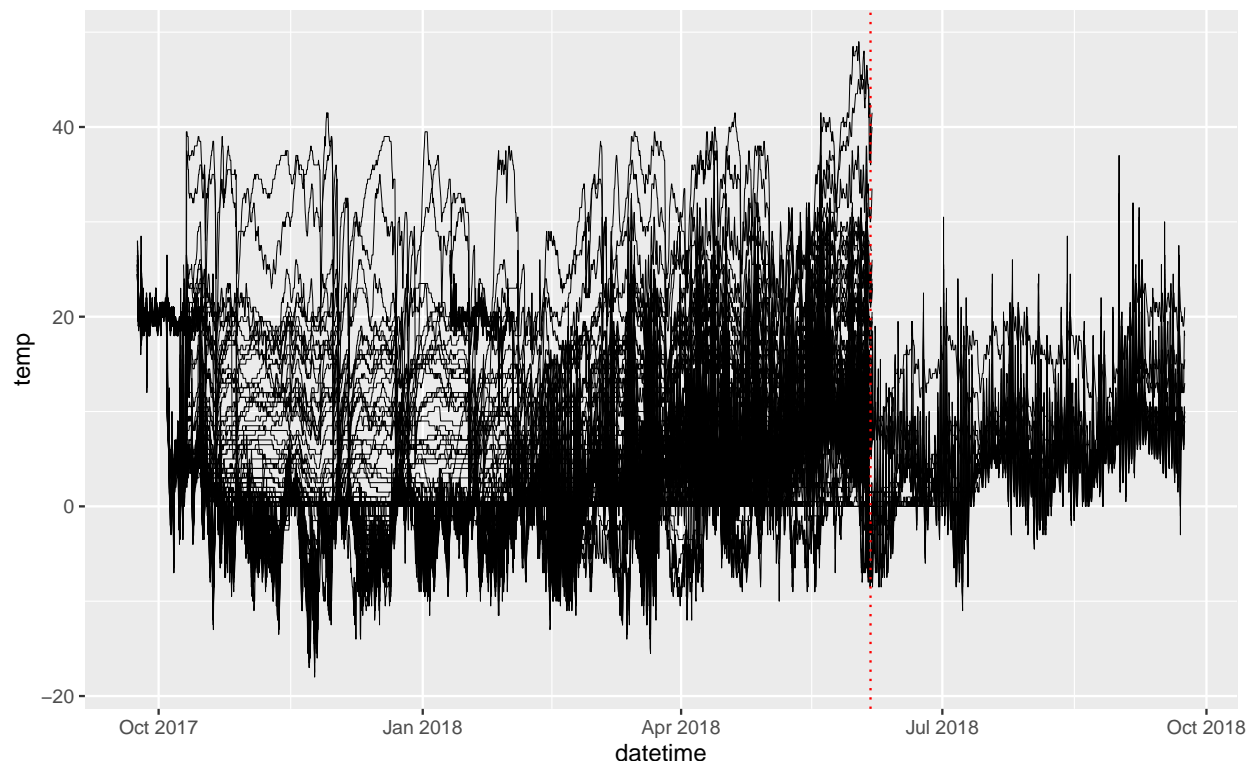
```
## # A tibble: 146 x 3
##    logger_nr  pair last_date
##        <dbl> <dbl> <dttm>
## 1        103     1 2018-06-06 12:11:00
## 2        105     1 2018-06-06 13:44:00
## 3        101     2 2018-06-06 11:34:00
## 4        104     2 2018-06-06 13:16:00
## 5        108     3 2018-06-06 12:52:00
## 6        113     3 2018-06-06 11:02:00
## 7        111     4 2018-06-06 12:59:00
## 8        115     4 2018-06-06 12:04:00
## 9        117     5 2018-06-06 10:43:00
## 10       122     5 2018-06-06 13:36:00
## # ... with 136 more rows
```

Most loggers (131 out of 145) end up on June 6th. So probably using May is OK.

Analyses using all pairs

Correlations soil-air temperature over the period April-May-June

Based on 24-h values   For each date and logger pair, calculate mean, max and min of air and soil temperature (from, respectively, the above and belowground logger). Then, calculate the correlation coefficient for air and soil temperatures over the period April-May-June. Finally, regress these correlation coefficients on mean soil temperature (from the belowground logger) **for the same period (April-May-June)**.

Using only data till June 5th, included (as most loggers stop on June 6th).

Look at the pairs with negative correlations in detail

Pairs with negative correlations: 36 (only for min), 63, 66, 68, 71, 73.

I cannot see anything worrying in the graph. As the negative correlation is only for the min temperature,

and it is also not very negative, maybe there is nothing strange here?
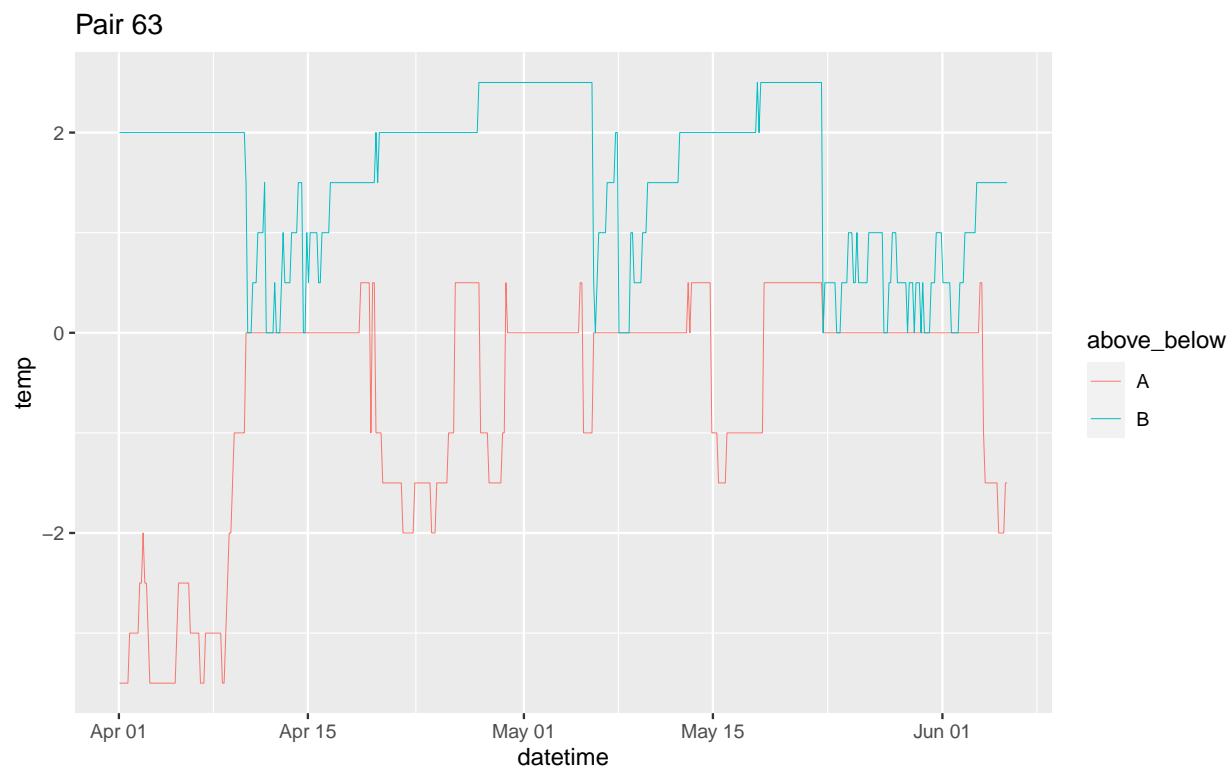
Pair 63

Here, both loggers have constant values of temperature for several periods of time.

The next graph shows all loggers in the same plot as pair 63:
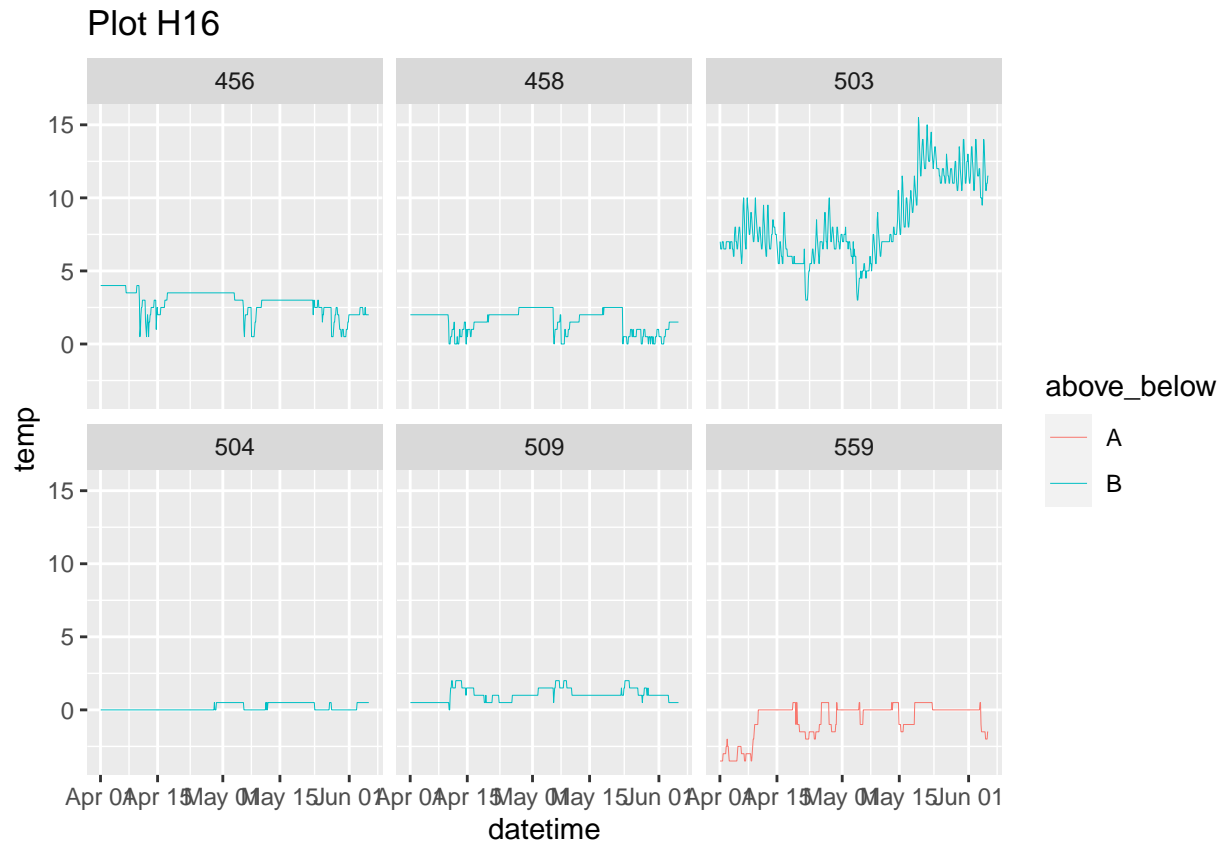
All but one have similar patterns, with constant values for some time periods.

Here is the spatial distribution of the loggers in the plot:

Plot H16
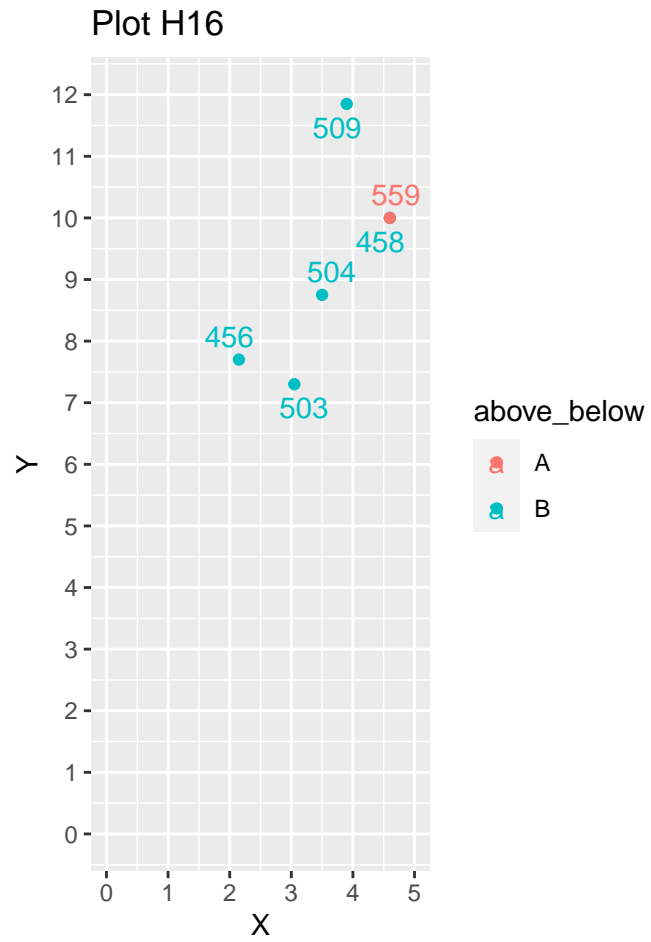
Maybe part of the plot was covered by snow, causing this low variation, and logger 503 was not?
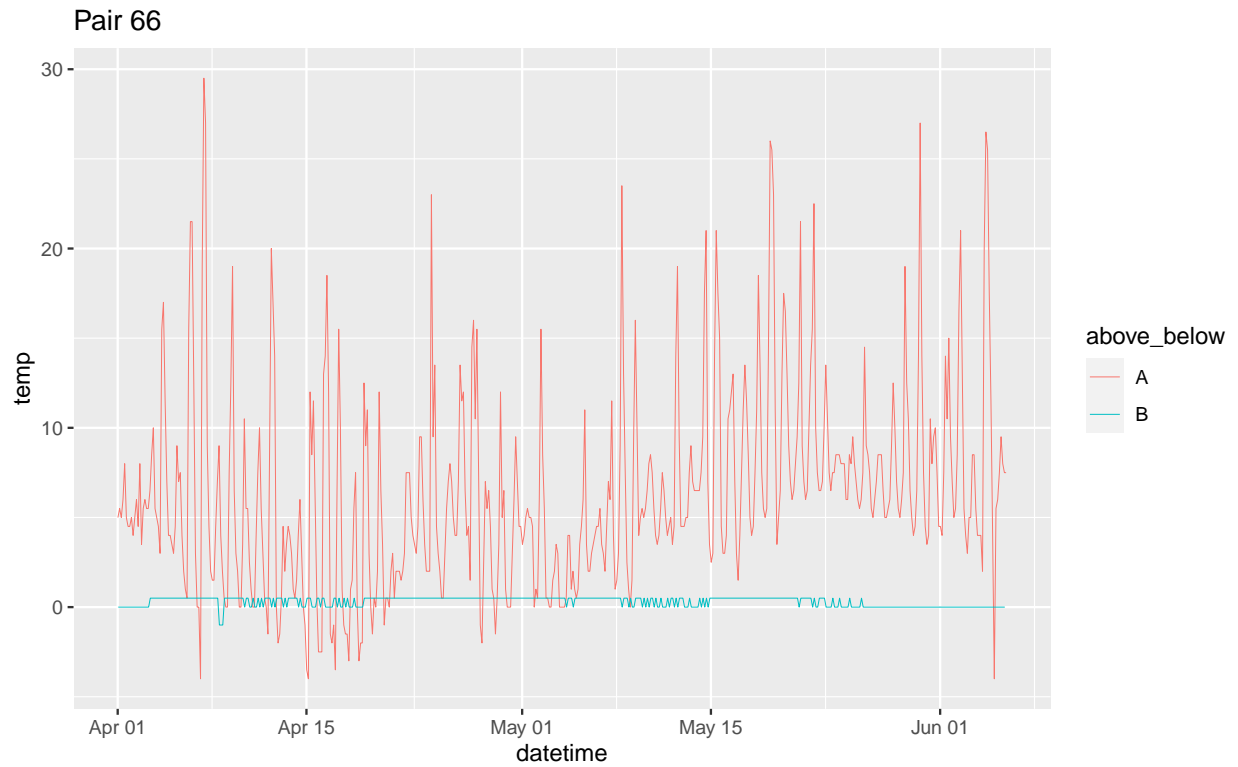
Pair 66

The next graph shows all loggers in the same plot as pair 66:

Plot H17
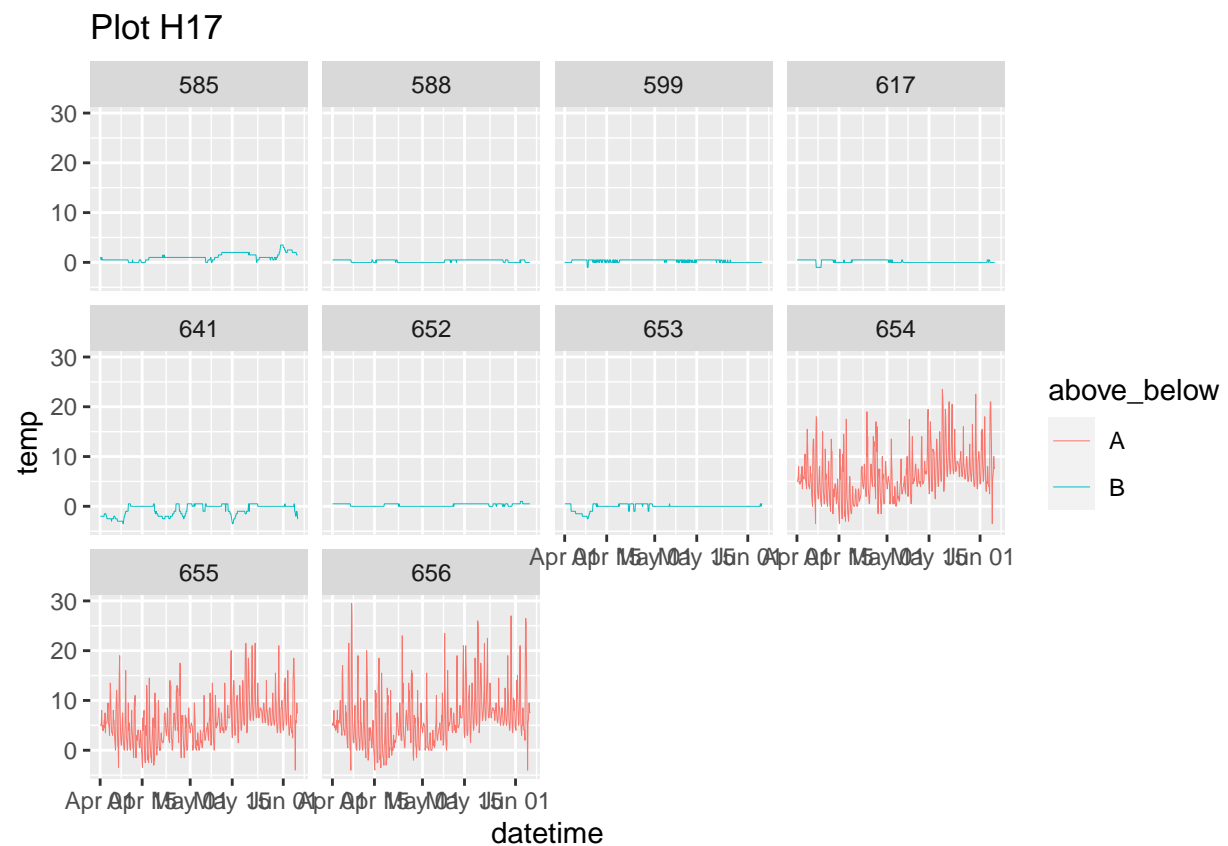
All the belowground loggers show similar patters, with very low variation. However, the aboveground loggers look fine, even if they are located at the same plant that a belowground logger (see locations in the graph below). So this is probably not due to effects of snow? Or could it be that the aboveground loggers are out of the snow but the belowground ones are covered by snow?

And the locations in the plot:
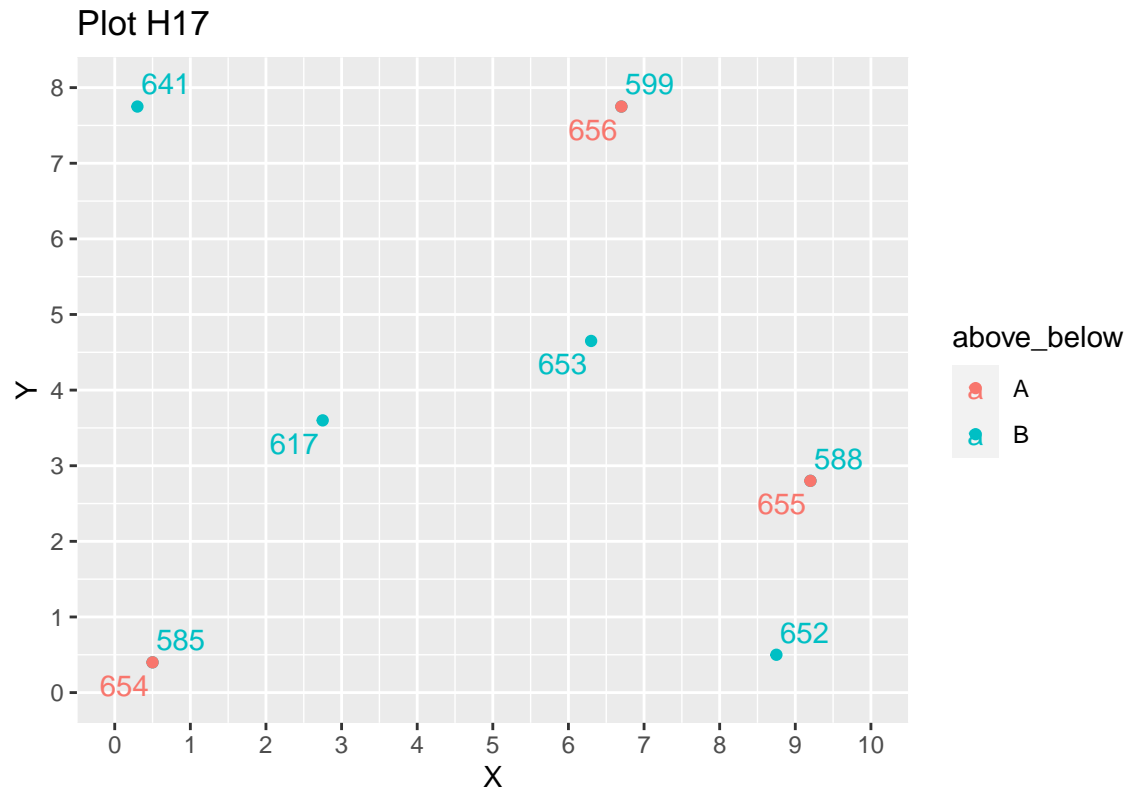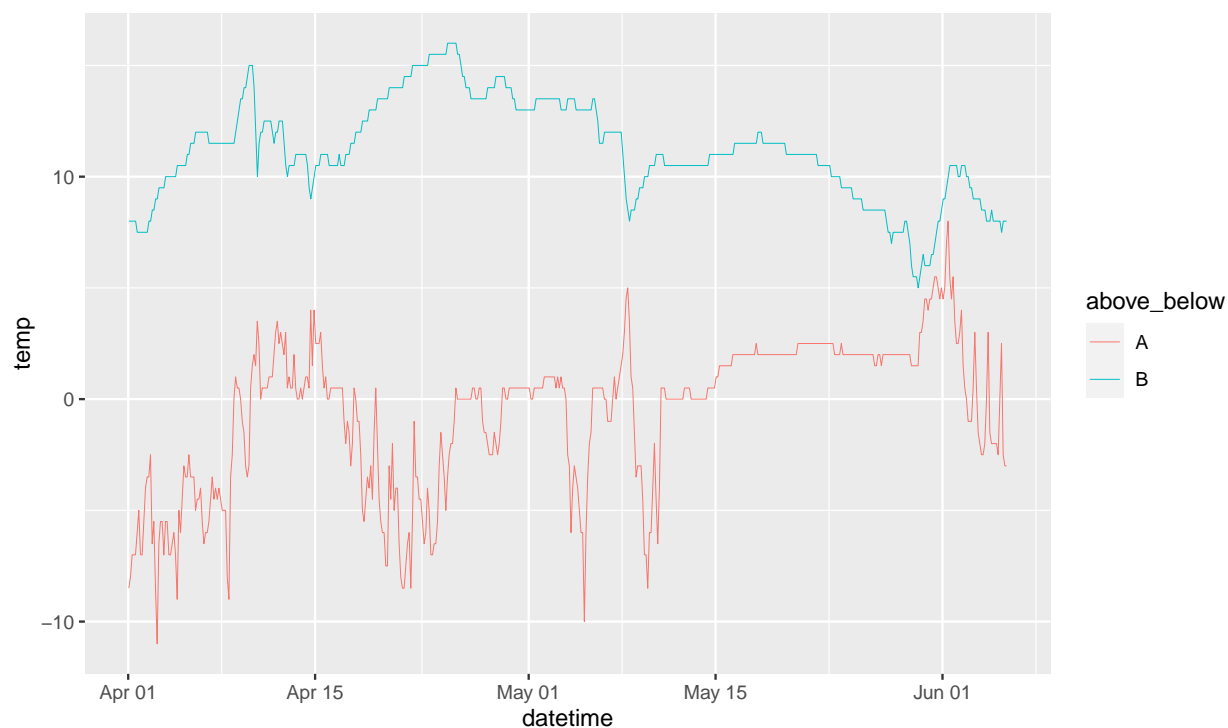
The next graph shows all loggers in the same plot as pair 68:

And the locations in the plot:
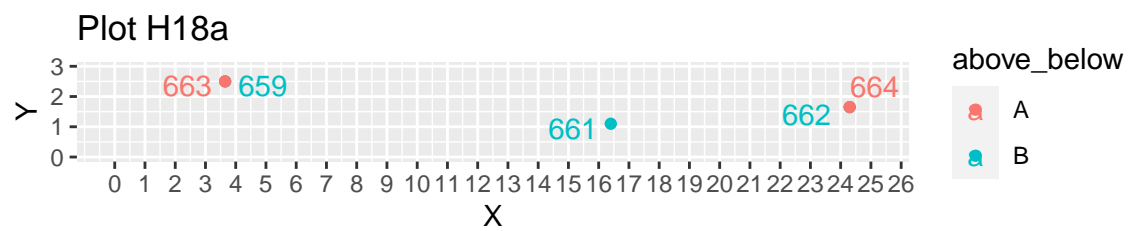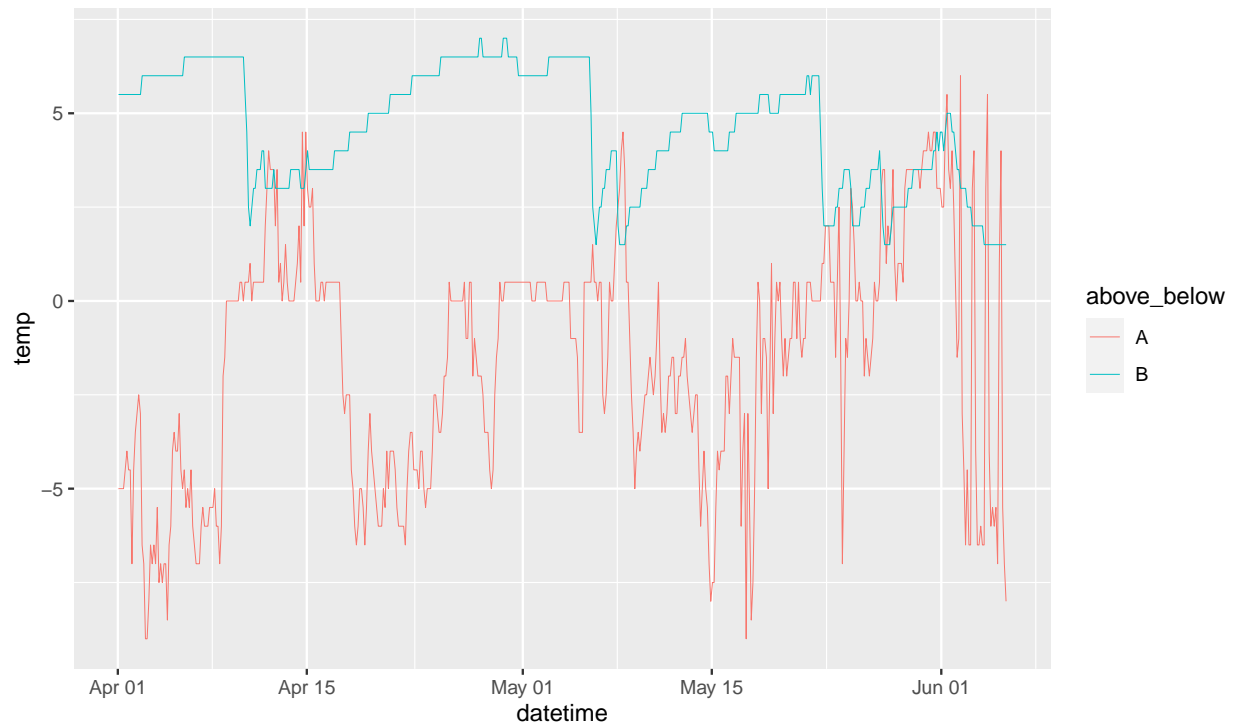
Plot H18a

Pair 71

One can really see the negative correlation in this pair! The "peaks" for the aboveground logger coincide with the "valleys" for the belowground one.

Pair 73
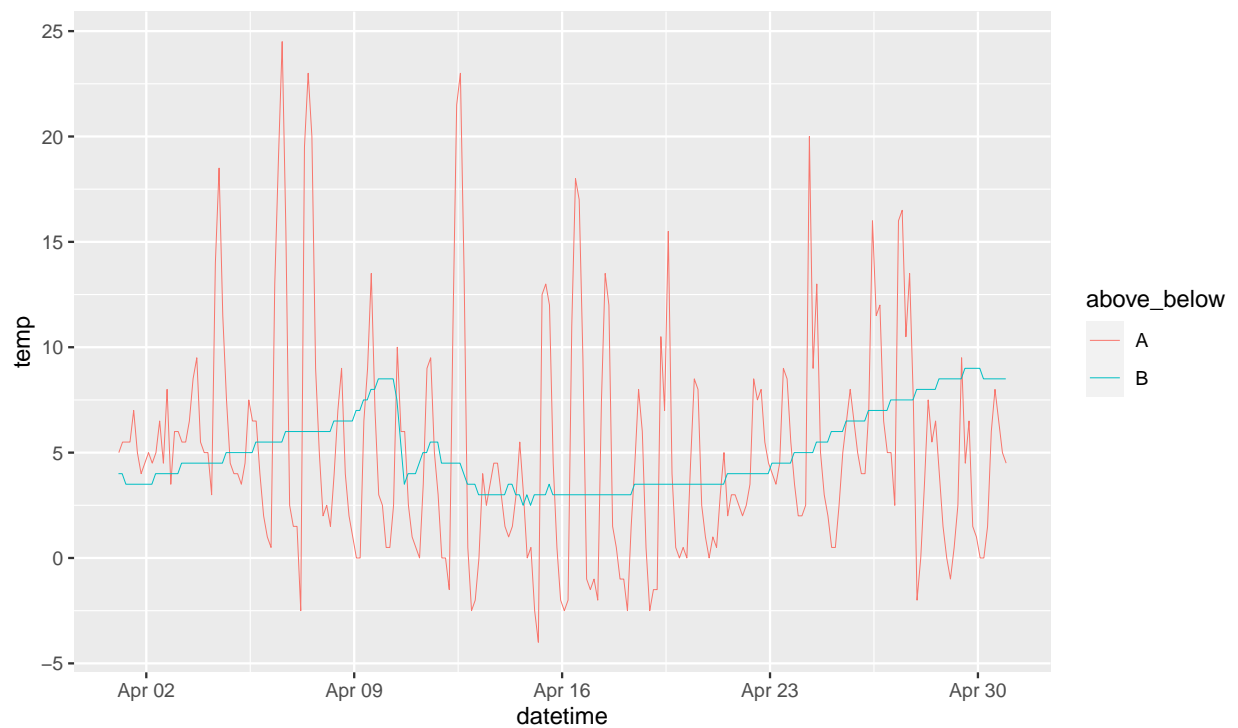
The next graph shows all loggers in the same plot as pair 71 and 73:

Plot H19
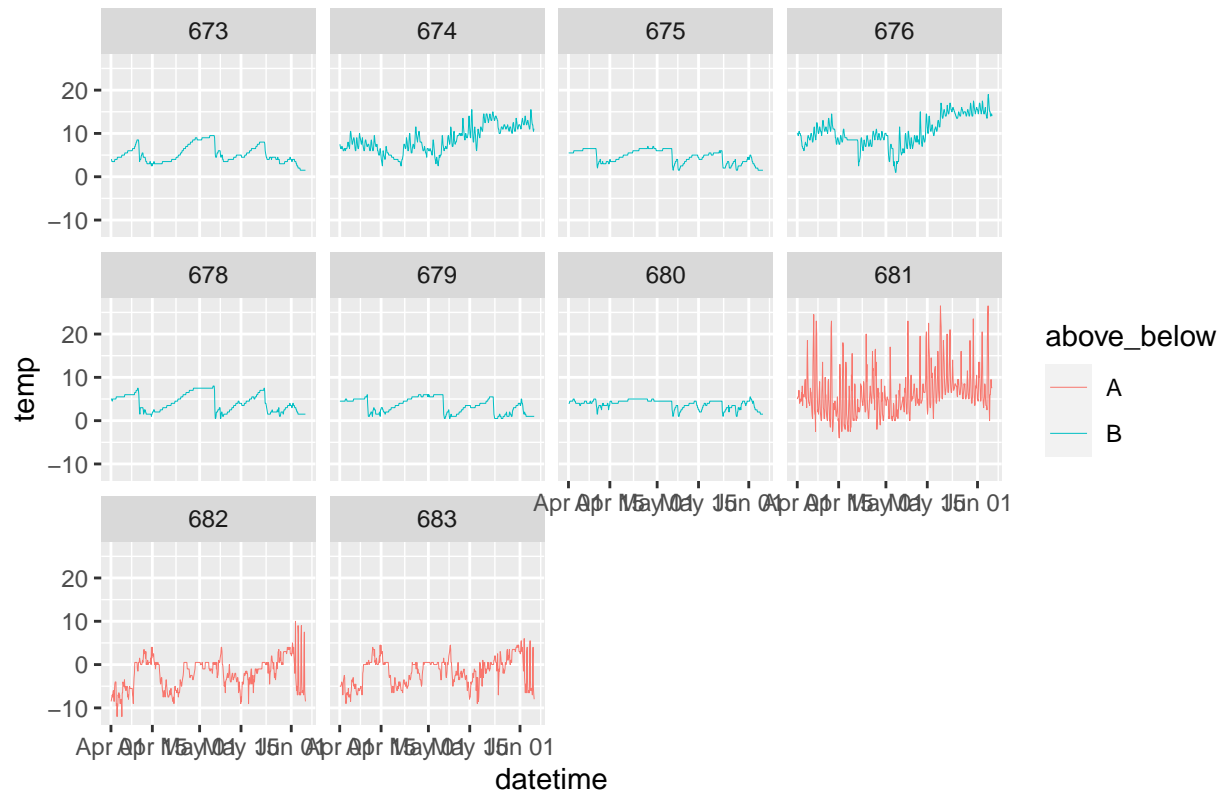
And the locations in the plot:
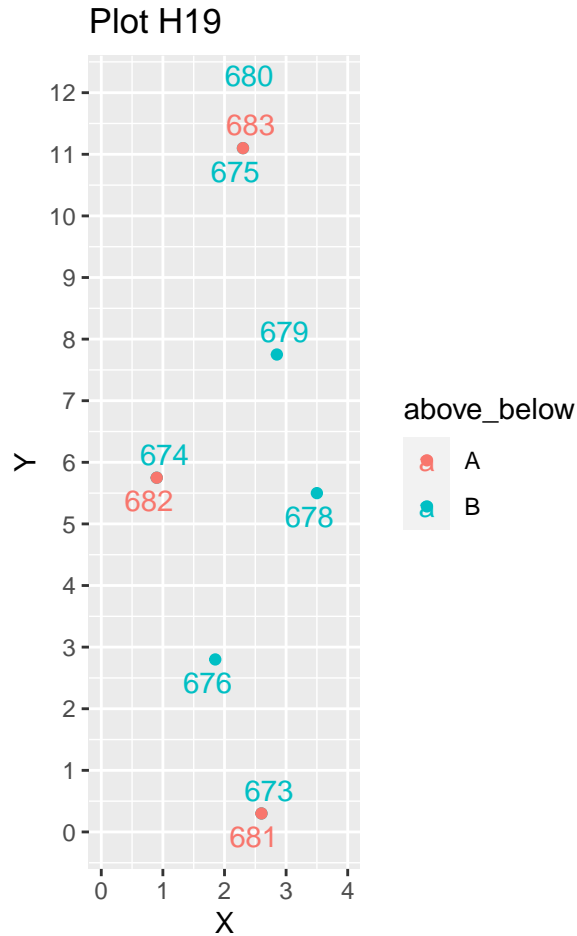
Plot H19

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5414445	0.0532531	10.1673811	0.0000000
corr_airsoil_max	meansoiltemp	-0.0017789	0.0041961	-0.4239331	0.6728962
corr_airsoil_mean	(Intercept)	0.6639691	0.0590038	11.2529902	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0040923	0.0046493	-0.8801977	0.3817219
corr_airsoil_min	(Intercept)	0.5528005	0.0510155	10.8359418	0.0000000
corr_airsoil_min	meansoiltemp	-0.0062181	0.0040198	-1.5468504	0.1263454

Non-significant in all cases.

Linear models testing the effect of soil temperature on correlations between soil and air temperature, removing pairs with negative correlations (5-6 pairs):

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6532763	0.0357085	18.294692	0.0000000
corr_airsoil_max	meansoiltemp	-0.0071265	0.0027362	-2.604566	0.0113544
corr_airsoil_mean	(Intercept)	0.7963235	0.0374644	21.255451	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0105272	0.0028707	-3.667091	0.0004913
corr_airsoil_min	(Intercept)	0.6686414	0.0301222	22.197651	0.0000000
corr_airsoil_min	meansoiltemp	-0.0111786	0.0023113	-4.836430	0.0000085

All significant!

And the graph:

Based on 12-h (day) values   Using only daily values of temperature (after 8 am and before or equal to 8 pm).
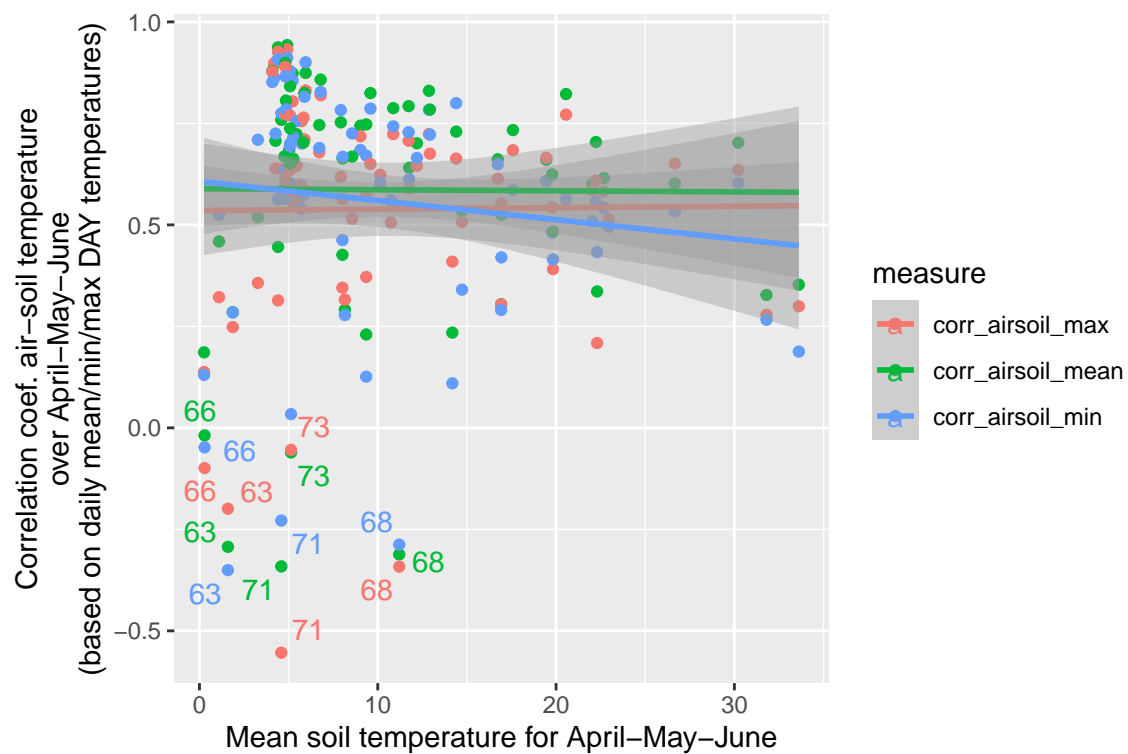
Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5368293	0.0557102	9.6360999	0.0000000
corr_airsoil_max	meansoiltemp	0.0002100	0.0043195	0.0486128	0.9613644
corr_airsoil_mean	(Intercept)	0.5909129	0.0561507	10.5236931	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0004269	0.0043536	-0.0980494	0.9221693
corr_airsoil_min	(Intercept)	0.6083944	0.0548987	11.0821241	0.0000000
corr_airsoil_min	meansoiltemp	-0.0048871	0.0042566	-1.1481222	0.2547718

Non-significant in all cases.

Linear models testing the effect of soil temperature on correlations between soil and air temperature, removing pairs with negative correlations (5-6 pairs):

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6568292	0.0368735	17.813044	0.0000000
corr_airsoil_max	meansoiltemp	-0.0055417	0.0027795	-1.993793	0.0503097
corr_airsoil_mean	(Intercept)	0.7124420	0.0377785	18.858386	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0062753	0.0028477	-2.203630	0.0310445
corr_airsoil_min	(Intercept)	0.7085154	0.0404277	17.525472	0.0000000
corr_airsoil_min	meansoiltemp	-0.0098199	0.0030664	-3.202460	0.0020856

All but max are significant.

And the graph:

Based on positive values Using only positive values of temperature (>0).

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

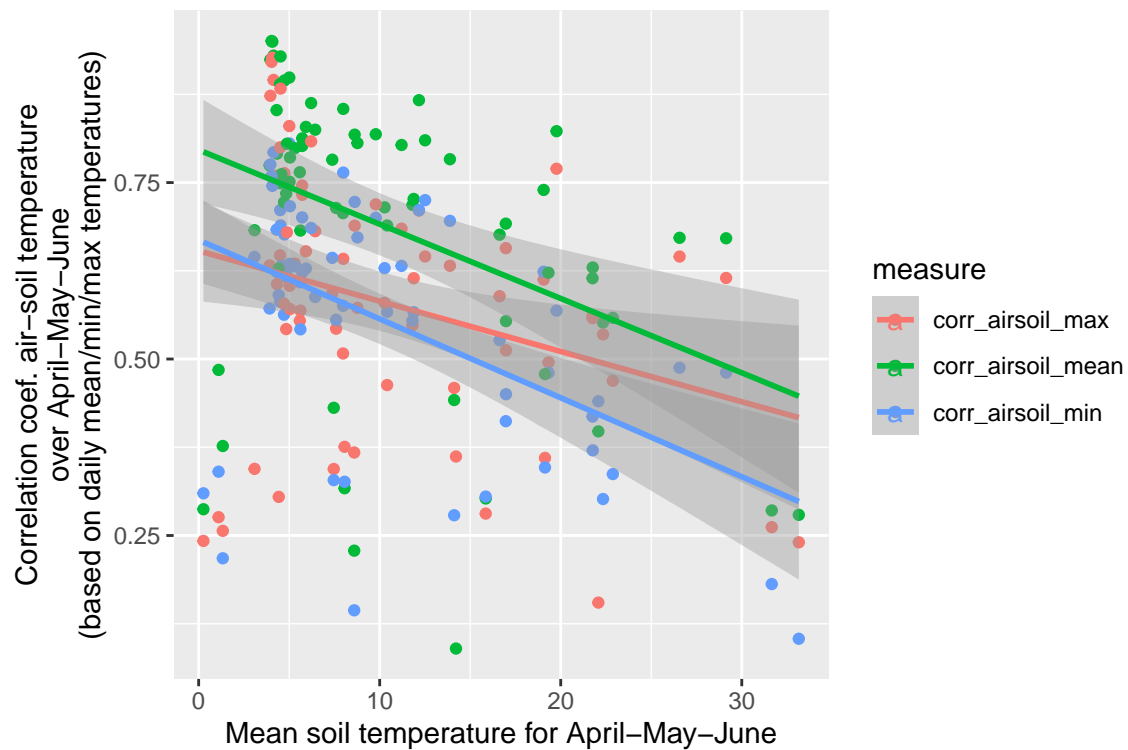| measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5722864	0.0568255	10.0709394	0.0000000
corr_airsoil_max	meansoiltemp	-0.0039756	0.0043611	-0.9115950	0.3652024
corr_airsoil_mean	(Intercept)	0.6207873	0.0603391	10.2883137	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0035835	0.0046308	-0.7738308	0.4417129
corr_airsoil_min	(Intercept)	0.6056288	0.0528874	11.4512789	0.0000000
corr_airsoil_min	meansoiltemp	-0.0080822	0.0040589	-1.9912301	0.0504750

Non-significant in all cases.

Linear models testing the effect of soil temperature on correlations between soil and air temperature, removing pairs with negative correlations:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6487076	0.0359797	18.029844	0.0000000
corr_airsoil_max	meansoiltemp	-0.0070385	0.0027214	-2.586353	0.0119480
corr_airsoil_mean	(Intercept)	0.7033320	0.0362586	19.397672	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0067764	0.0027425	-2.470886	0.0161089
corr_airsoil_min	(Intercept)	0.6757173	0.0320621	21.075270	0.0000000
corr_airsoil_min	meansoiltemp	-0.0100510	0.0024280	-4.139708	0.0001037

All significant!

And the graph:
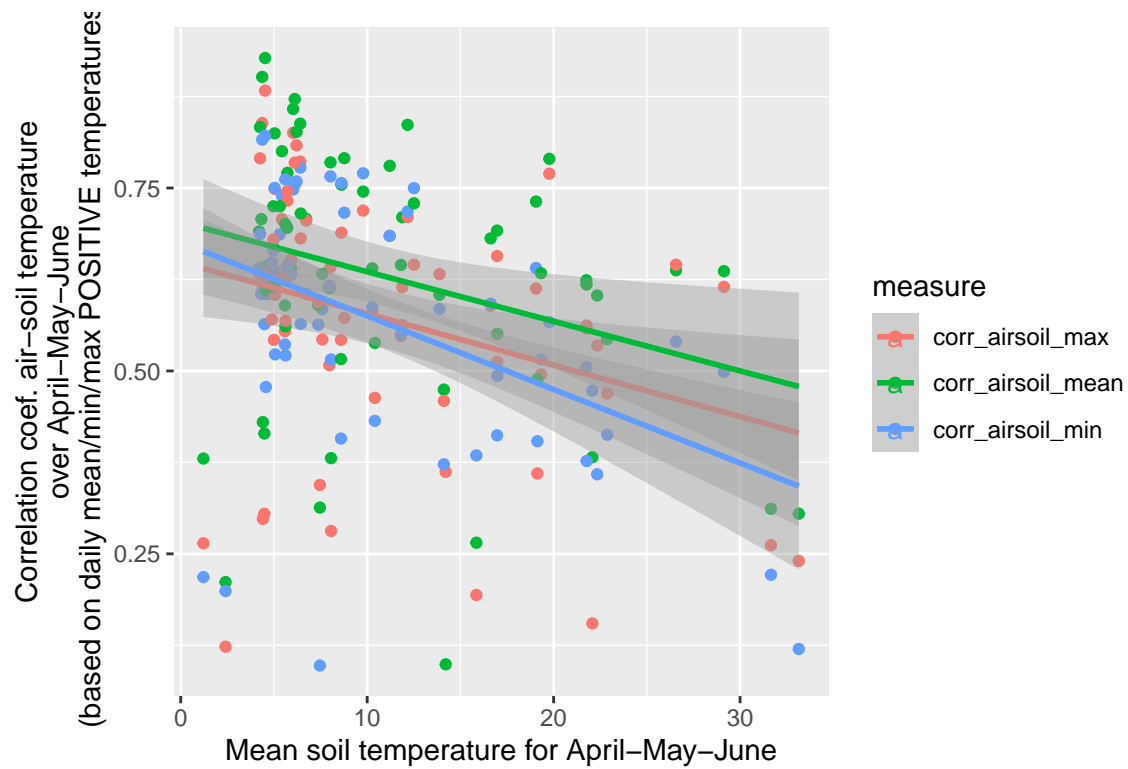
Correlations soil-air temperature for May only

Based on 24-h values For each date and logger pair, calculate mean, max and min of air and soil temperature (from, respectively, the above and belowground logger). Then, calculate the correlation coefficient for air and soil temperatures over the month of May. Finally, regress these correlation coefficients on mean soil temperature (from the belowground logger) **for the same period (May).**

Pairs with negative correlations: 63 (not for max), 66, 68, 71, 72 (not for min), 73.

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

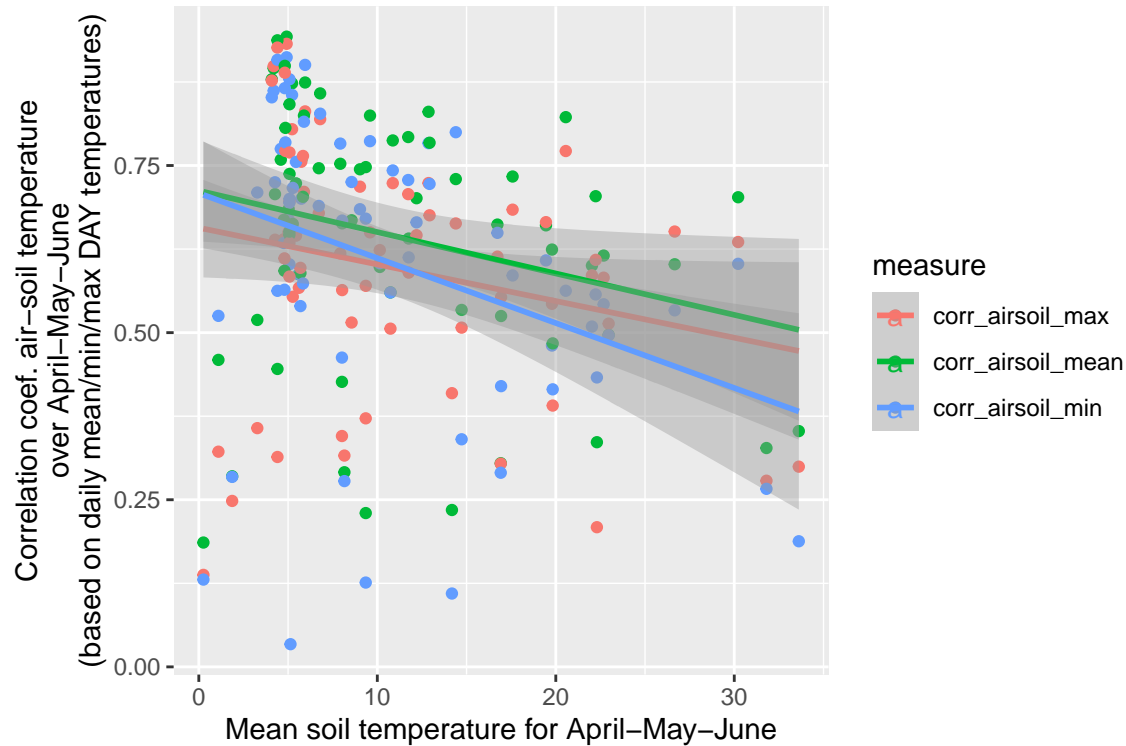| measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5339495	0.0643113	8.3025835	0.0000000
corr_airsoil_max	meansoiltemp	0.0011776	0.0048546	0.2425635	0.8090429
corr_airsoil_mean	(Intercept)	0.5984971	0.0681018	8.7882702	0.0000000
corr_airsoil_mean	meansoiltemp	0.0056804	0.0051408	1.1049748	0.2729010
corr_airsoil_min	(Intercept)	0.5200282	0.0656467	7.9216145	0.0000000
corr_airsoil_min	meansoiltemp	0.0078510	0.0049554	1.5843210	0.1175651

Non-significant in all cases.

Linear models testing the effect of soil temperature on correlations between soil and air temperature, removing pairs with negative correlations:

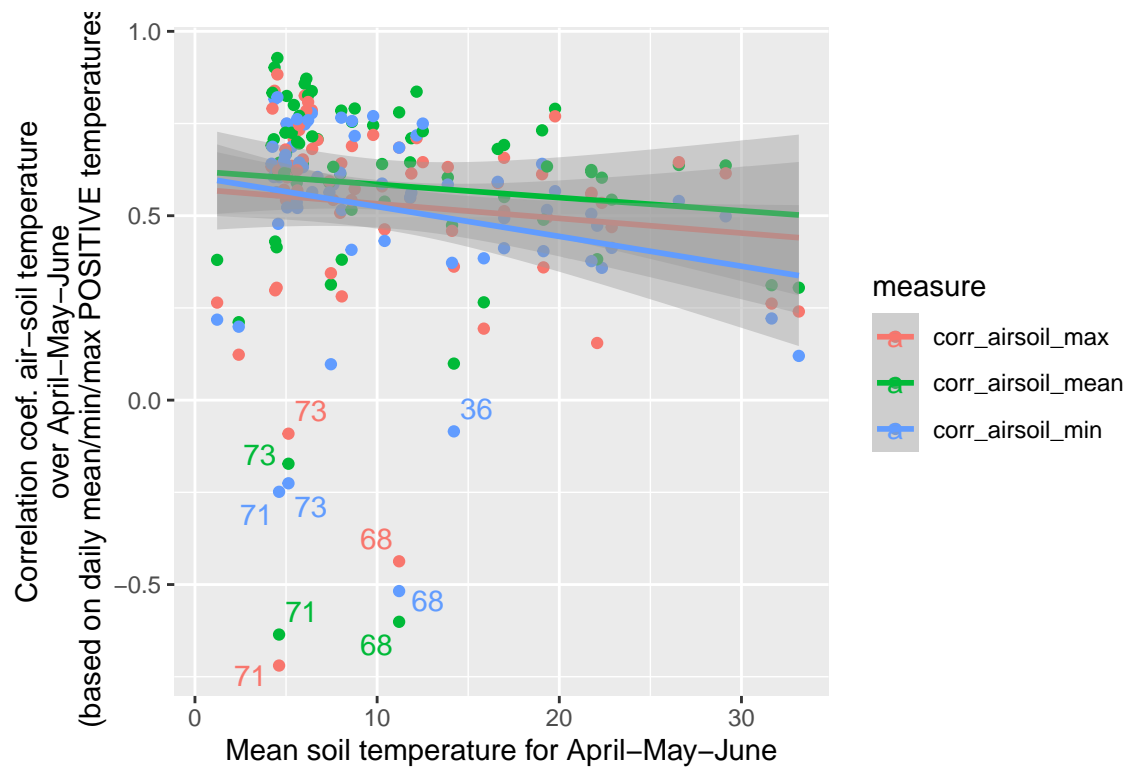| measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6609397	0.0454706	14.5355395	0.0000000
corr_airsoil_max	meansoiltemp	-0.0047924	0.0033466	-1.4320039	0.1568618
corr_airsoil_mean	(Intercept)	0.7613055	0.0462880	16.4471484	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0028649	0.0033939	-0.8441434	0.4016387
corr_airsoil_min	(Intercept)	0.6923881	0.0370413	18.6923258	0.0000000
corr_airsoil_min	meansoiltemp	-0.0006942	0.0027174	-0.2554693	0.7991673

Non-significant in all cases.

Based on 12-h (day) values

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

| measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5251973	0.0646679	8.1214504	0.0000000
corr_airsoil_max	meansoiltemp	0.0033714	0.0047894	0.7039205	0.4837846
corr_airsoil_mean	(Intercept)	0.5395430	0.0639890	8.4318116	0.0000000
corr_airsoil_mean	meansoiltemp	0.0057828	0.0047392	1.2202272	0.2264162
corr_airsoil_min	(Intercept)	0.5120213	0.0626557	8.1719839	0.0000000
corr_airsoil_min	meansoiltemp	0.0076132	0.0046404	1.6406225	0.1052990

Non-significant in all cases.

Linear models testing the effect of soil temperature on correlations between soil and air temperature, removing pairs with negative correlations:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6481733	0.0470410	13.7789019	0.0000000
corr_airsoil_max	meansoiltemp	-0.0023223	0.0033970	-0.6836405	0.4965954
corr_airsoil_mean	(Intercept)	0.7023117	0.0419326	16.7485765	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0022867	0.0030060	-0.7607030	0.4495853
corr_airsoil_min	(Intercept)	0.6675056	0.0435184	15.3384720	0.0000000
corr_airsoil_min	meansoiltemp	-0.0006324	0.0031297	-0.2020717	0.8404823

Non-significant in all cases.
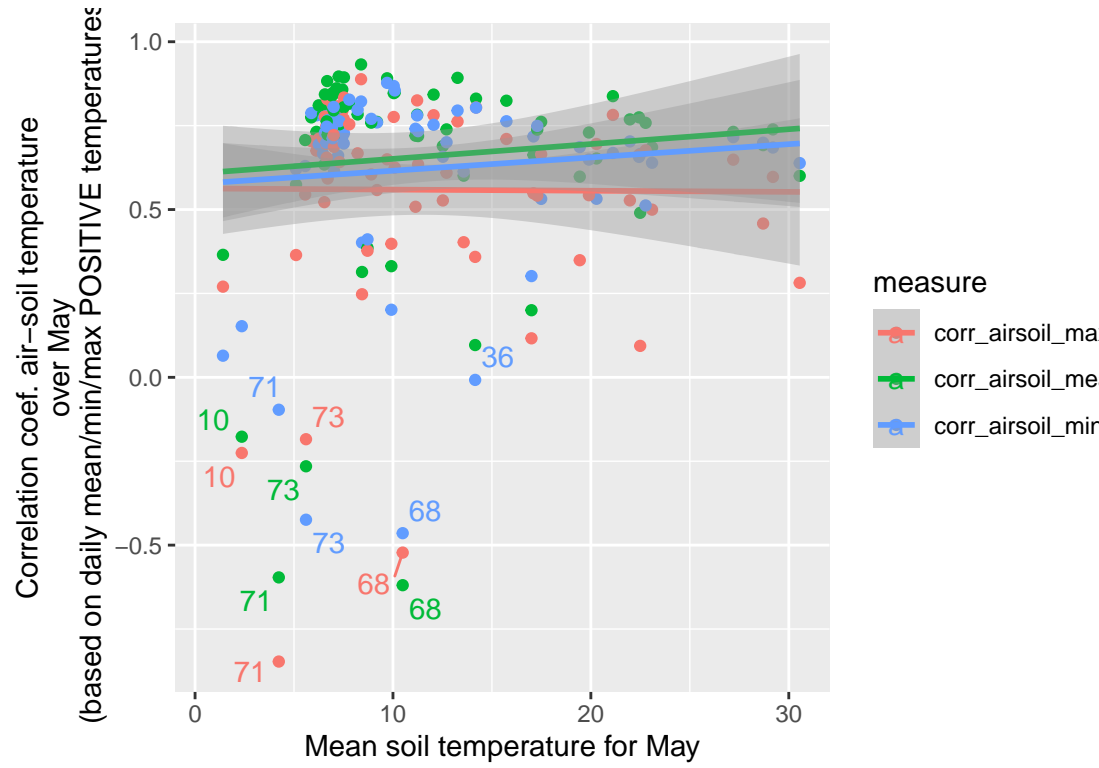
Based on positive values

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5628730	0.0742157	7.5842894	0.0000000
corr_airsoil_max	meansoiltemp	-0.0003401	0.0054842	-0.0620071	0.9507391
corr_airsoil_mean	(Intercept)	0.6069705	0.0750138	8.0914467	0.0000000
corr_airsoil_mean	meansoiltemp	0.0044108	0.0055432	0.7957273	0.4289596
corr_airsoil_min	(Intercept)	0.5762232	0.0640076	9.0024205	0.0000000
corr_airsoil_min	meansoiltemp	0.0039519	0.0047299	0.8355228	0.4063496

Non-significant in all cases.

Linear models testing the effect of soil temperature on correlations between soil and air temperature, removing pairs with negative correlations:

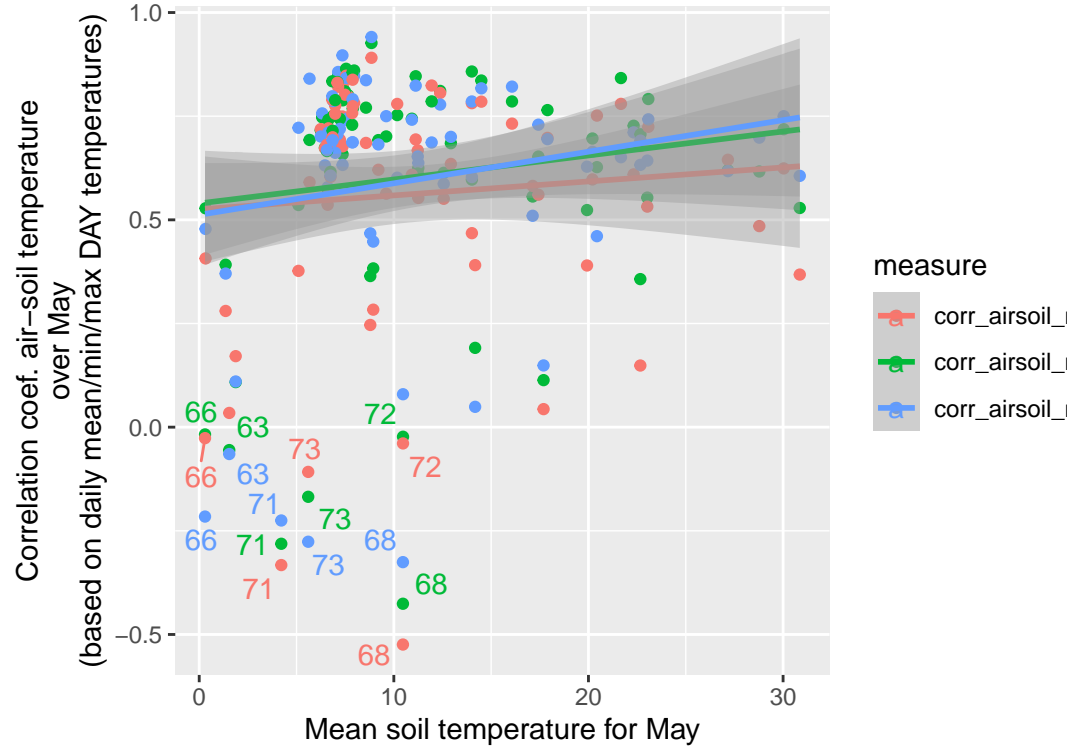| measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.7228953	0.0427540	16.9082551	0.0000000
corr_airsoil_max	meansoiltemp	-0.0085574	0.0030877	-2.7715005	0.0072976
corr_airsoil_mean	(Intercept)	0.7689999	0.0416724	18.4534644	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0037683	0.0030095	-1.2521306	0.2150789
corr_airsoil_min	(Intercept)	0.6725041	0.0389746	17.2549451	0.0000000
corr_airsoil_min	meansoiltemp	0.0002265	0.0028366	0.0798603	0.9365976

Only significant for max.

And the graph:
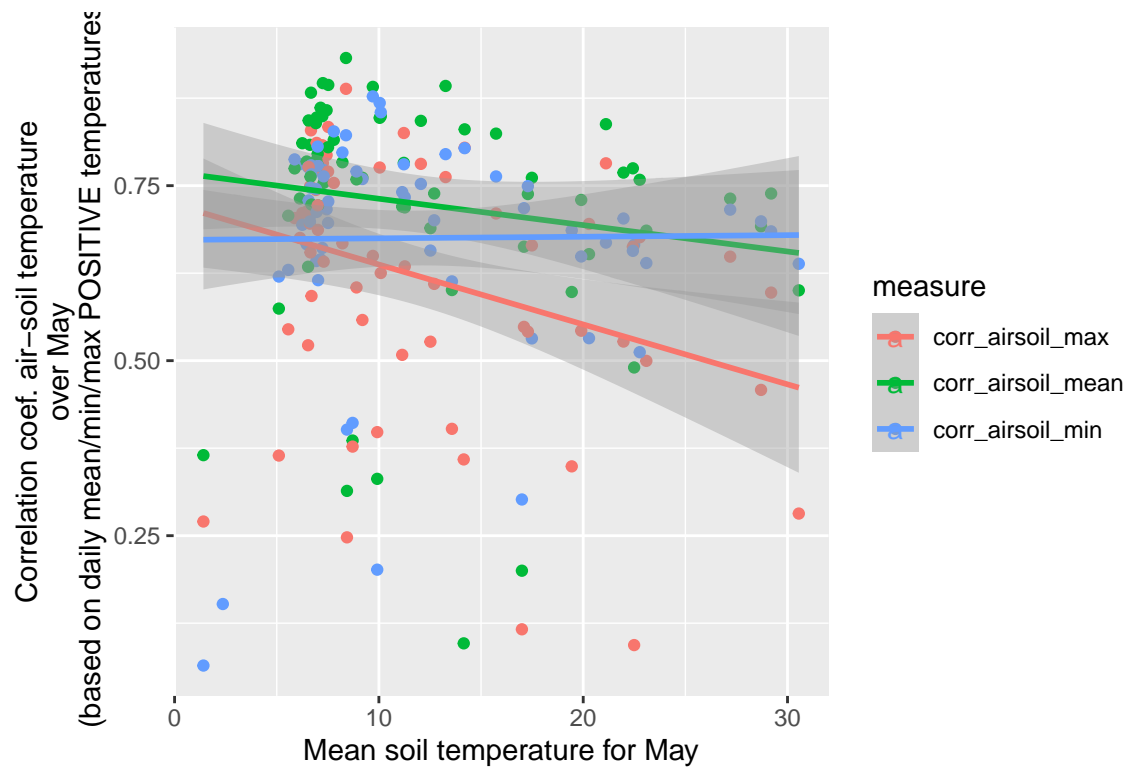
Correlations soil-air temperature for June 1-5

Based on 24-h values   For each date and logger pair, calculate mean, max and min of air and soil temperature (from, respectively, the above and belowground logger). Then, calculate the correlation coefficient for air and soil temperatures over the month of May. Finally, regress these correlation coefficients on mean soil temperature (from the belowground logger) **for the same period (June)**.
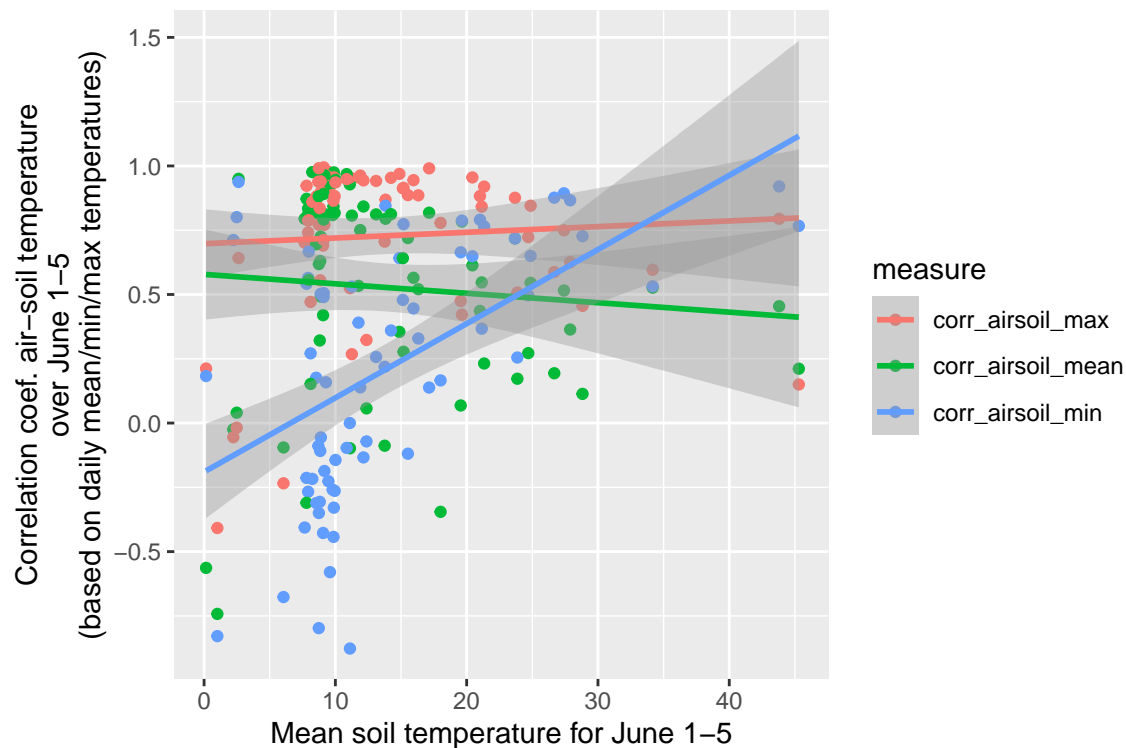
Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6976189	0.0671604	10.3873576	0.0000000
corr_airsoil_max	meansoiltemp	0.0022117	0.0040996	0.5394888	0.5912616
corr_airsoil_mean	(Intercept)	0.5783569	0.0884769	6.5368106	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0036764	0.0054008	-0.6807220	0.4982930
corr_airsoil_min	(Intercept)	-0.1903270	0.0932753	-2.0404863	0.0450754
corr_airsoil_min	meansoiltemp	0.0288402	0.0056937	5.0653113	0.0000032

Positive significant for min.

Analyses using pairs with distance < 2

Correlations soil-air temperature over the period April-May-June For each date and logger pair, calculate mean, max and min of air and soil temperature (from, respectively, the above and belowground logger). Then, calculate the correlation coefficient for air and soil temperatures over the period April-May-June. Finally, regress these correlation coefficients on mean soil temperature (from the belowground logger) **for the same period (April-May-June)**.

Using only data till June 5th, included (as most loggers stop on June 6th).

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5304296	0.0708280	7.4889832	0.0000000
corr_airsoil_max	meansoiltemp	-0.0039004	0.0056562	-0.6895793	0.4937792
corr_airsoil_mean	(Intercept)	0.6288761	0.0788602	7.9745647	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0041705	0.0062976	-0.6622335	0.5109888
corr_airsoil_min	(Intercept)	0.5156739	0.0658971	7.8254368	0.0000000
corr_airsoil_min	meansoiltemp	-0.0054906	0.0052624	-1.0433740	0.3020016

Non-significant in all cases.

Correlations soil-air temperature for May only   For each date and logger pair, calculate mean, max and min of air and soil temperature (from, respectively, the above and belowground logger). Then, calculate the correlation coefficient for air and soil temperatures over the month of May. Finally, regress these correlation coefficients on mean soil temperature (from the belowground logger) **for the same period (May)**.

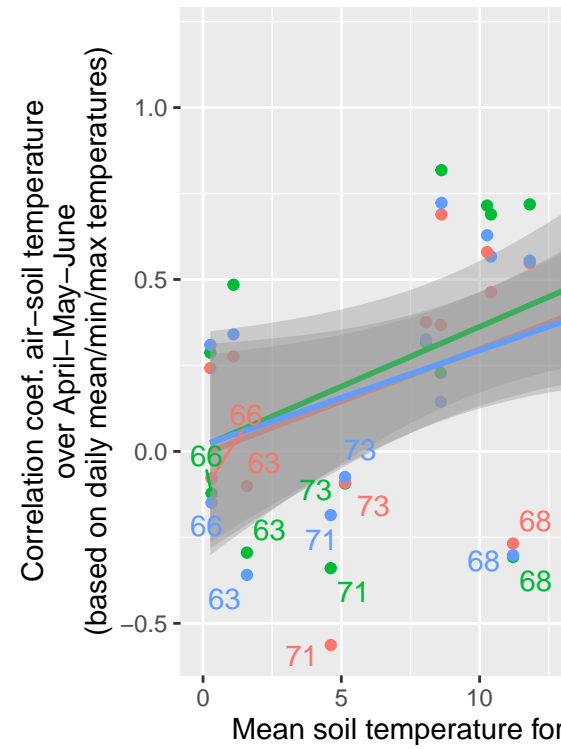Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.5200013	0.0864699	6.0136709	0.0000002
corr_airsoil_max	meansoiltemp	-0.0001031	0.0066566	-0.0154872	0.9877077
corr_airsoil_mean	(Intercept)	0.5552980	0.0904358	6.1402436	0.0000002
corr_airsoil_mean	meansoiltemp	0.0068462	0.0069619	0.9833771	0.3303528
corr_airsoil_min	(Intercept)	0.4477096	0.0868626	5.1542293	0.0000048
corr_airsoil_min	meansoiltemp	0.0109771	0.0066868	1.6416126	0.1072072

Non-significant in all cases.

**Analyses using the 17 pairs where above- and belowground loggers are at the same plant**

Correlations soil-air temperature over the period April-May-June

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	-0.0071435	0.1349315	-0.0529414	0.9584772
corr_airsoil_max	meansoiltemp	0.0304788	0.0123633	2.4652678	0.0262418
corr_airsoil_mean	(Intercept)	0.0149601	0.1556400	0.0961197	0.9246980
corr_airsoil_mean	meansoiltemp	0.0347551	0.0142607	2.4371243	0.0277336
corr_airsoil_min	(Intercept)	0.0177846	0.1378222	0.1290399	0.8990405
corr_airsoil_min	meansoiltemp	0.0276366	0.0126281	2.1884936	0.0448694

Postive relationships are significant in all cases!
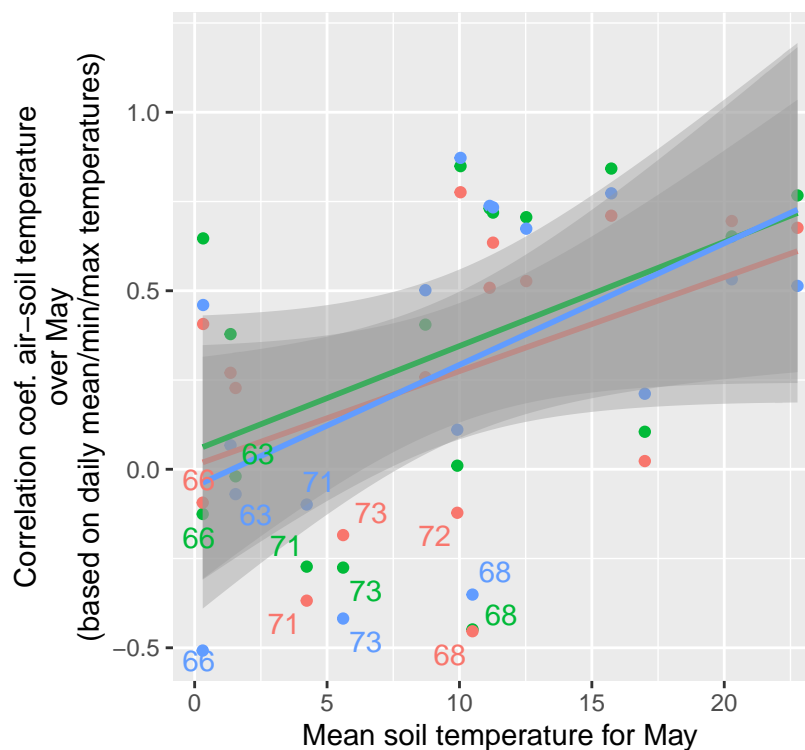
Correlations soil-air temperature for May only

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.0112482	0.1574775	0.0714276	0.9440011
corr_airsoil_max	meansoiltemp	0.0263462	0.0135001	1.9515526	0.0699213
corr_airsoil_mean	(Intercept)	0.0531767	0.1768662	0.3006604	0.7678006
corr_airsoil_mean	meansoiltemp	0.0291942	0.0151623	1.9254520	0.0733463
corr_airsoil_min	(Intercept)	-0.0480644	0.1690743	-0.2842799	0.7800827
corr_airsoil_min	meansoiltemp	0.0340534	0.0144943	2.3494321	0.0329145

Significant only for min, near significance for the others.

Plot all logger pairs

Make one plot for each logger pair and save all as a pdf in output folder.

After looking at the plots, make a new variable pair_problem: - 0 = no problem - 1 = some problems (remove)

Q3 Option 2 with logger pairs with no problems

Analyses using all pairs

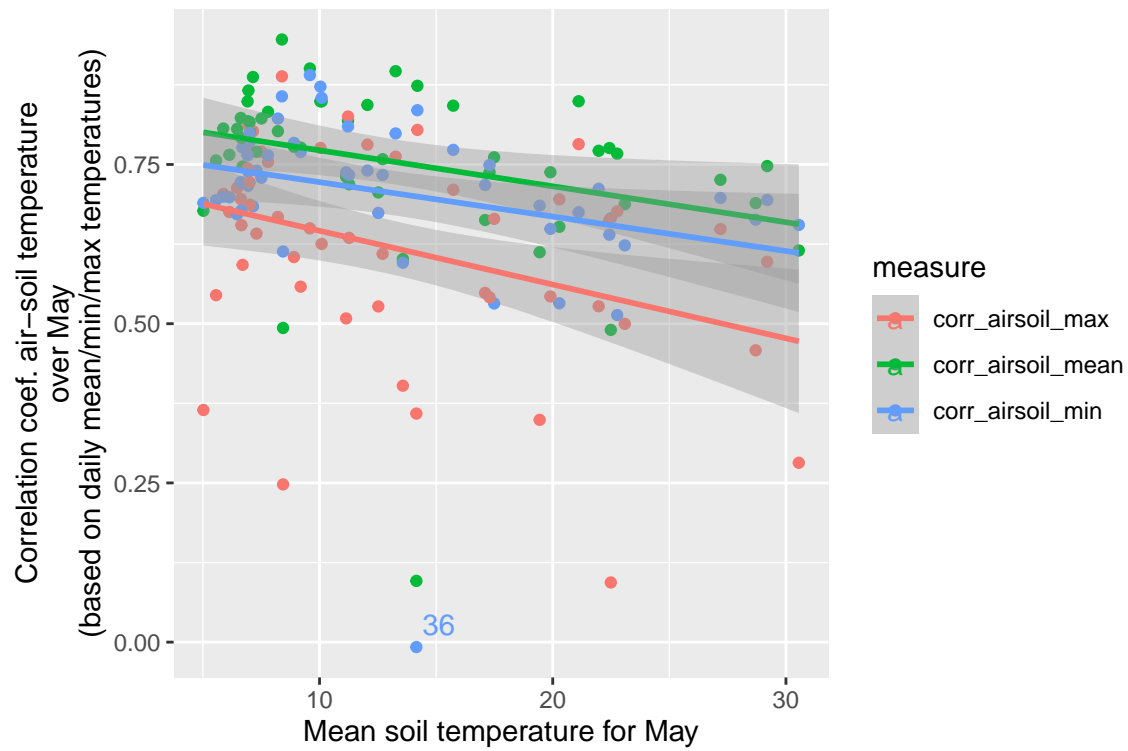**Correlations soil-air temperature over the period April-May-June**
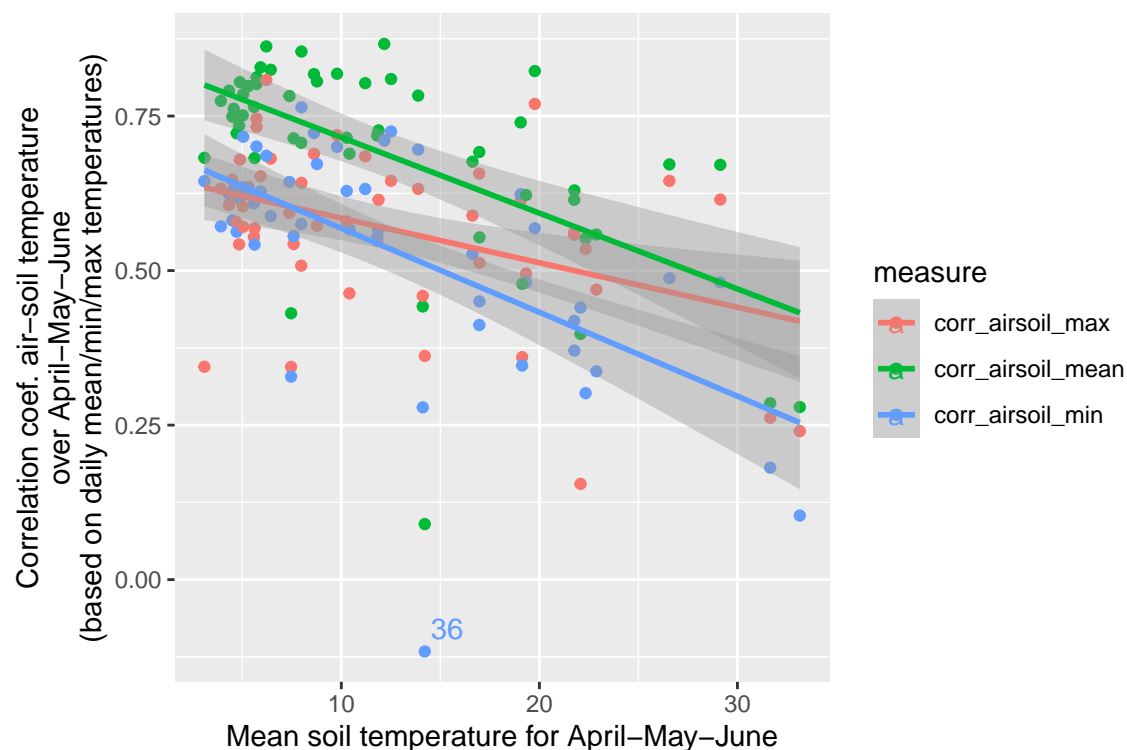
Most of the pairs with negative correlations have disappeared when considering only pairs without problems!

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.6568341	0.0319380	20.565933	0.0000000
corr_airsoil_max	meansoiltemp	-0.0072069	0.0021963	-3.281420	0.0018870
corr_airsoil_mean	(Intercept)	0.8381035	0.0345061	24.288540	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0122582	0.0023729	-5.165940	0.0000042
corr_airsoil_min	(Intercept)	0.7043187	0.0350510	20.094122	0.0000000
corr_airsoil_min	meansoiltemp	-0.0135863	0.0024104	-5.636639	0.0000008

All significant.

Correlations soil-air temperature for May only

Linear models testing the effect of soil temperature on correlations between soil and air temperature:

measure	term	estimate	std.error	statistic	p.value
corr_airsoil_max	(Intercept)	0.7303409	0.0450862	16.198769	0.0000000
corr_airsoil_max	meansoiltemp	-0.0084423	0.0030049	-2.809453	0.0070638
corr_airsoil_mean	(Intercept)	0.8286498	0.0376102	22.032561	0.0000000
corr_airsoil_mean	meansoiltemp	-0.0056441	0.0025067	-2.251634	0.0287701
corr_airsoil_min	(Intercept)	0.7763669	0.0370992	20.926806	0.0000000
corr_airsoil_min	meansoiltemp	-0.0054087	0.0024726	-2.187446	0.0334132

Non-significant in all cases.

Session Info