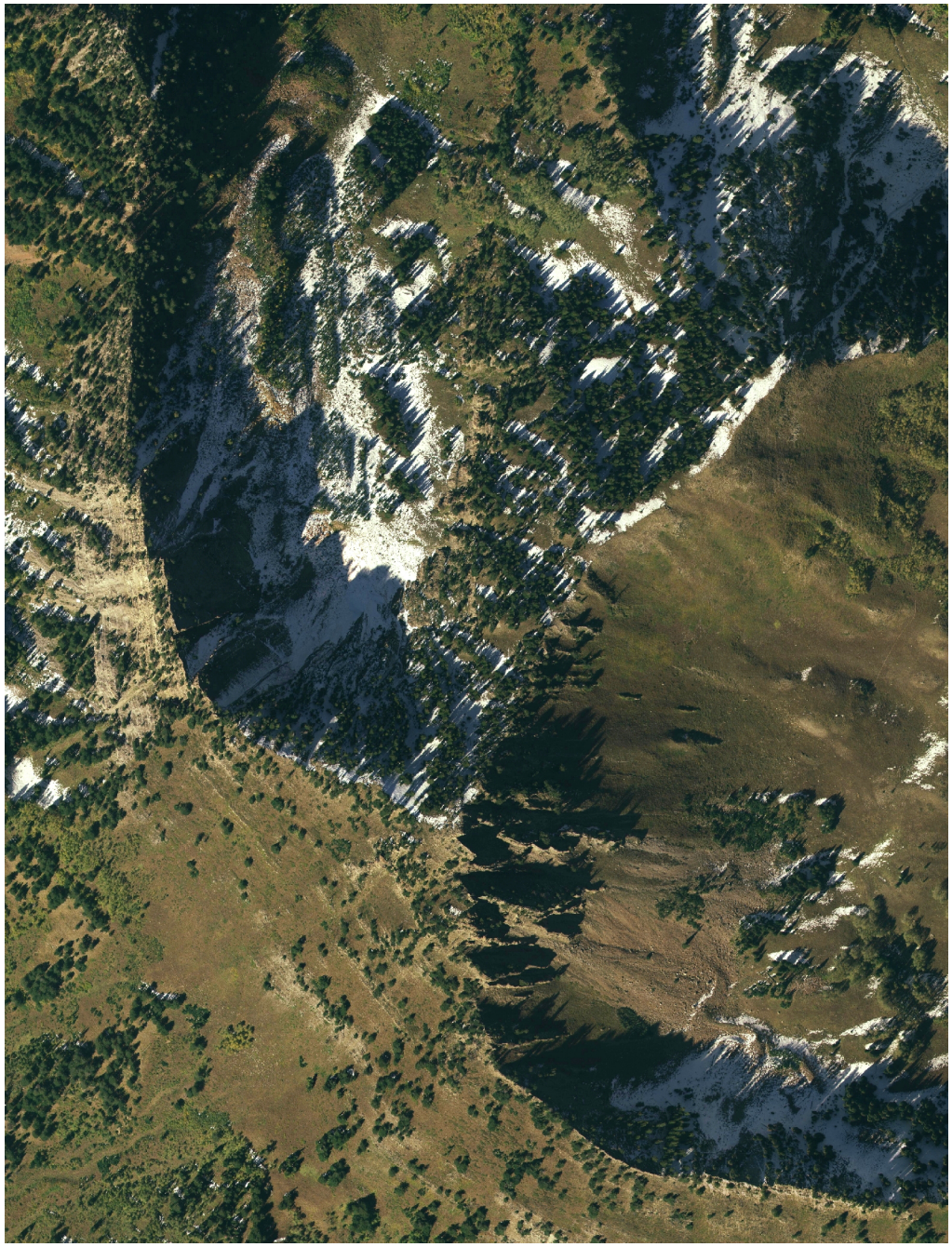


Sensitivity of soil temperature and soil moisture to seasonal snowpack variability in western U.S. mountain ecosystems.

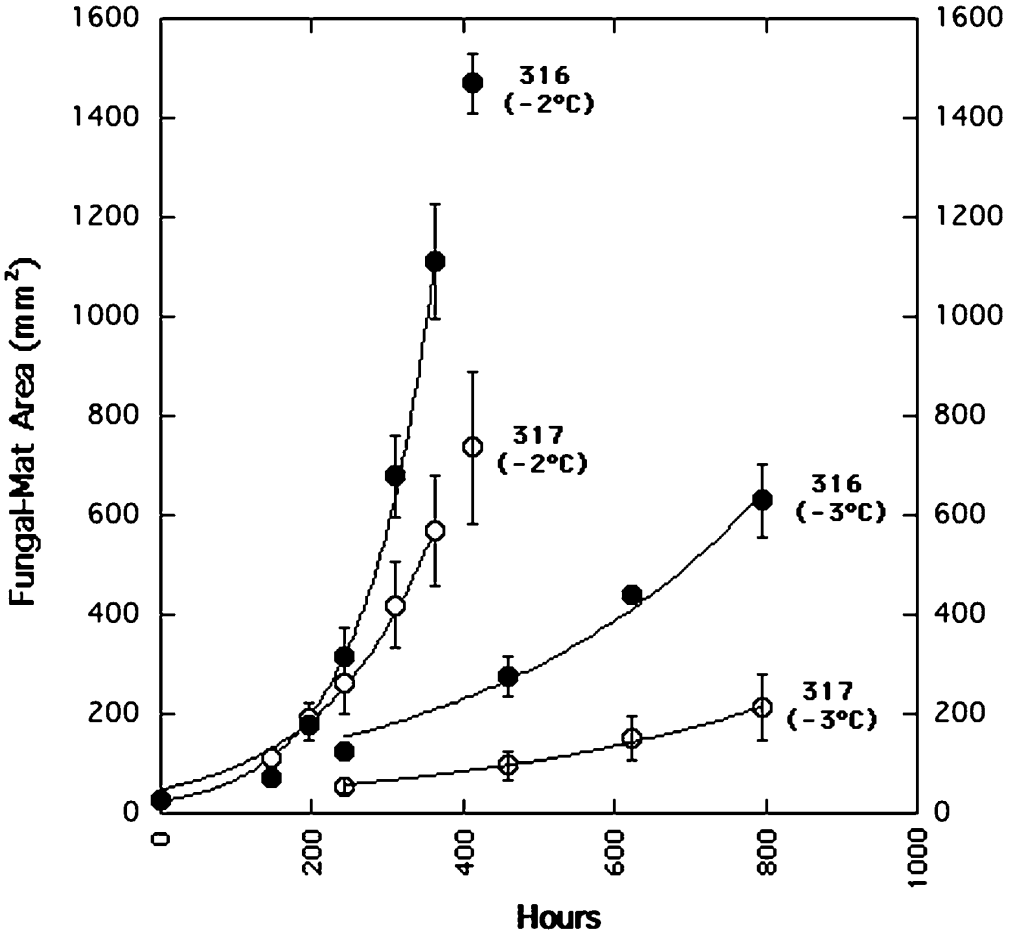
"The Weather Underground"

Gregory E. Maurer & David R. Bowling
University of Utah Biology Dept.

Persistent snowcover *decouples* soil from the atmosphere

- Insulation from air temperature extremes.
- Storage and timely delivery of winter precipitation.
- Altered seasonal & inter-annual variability in:
  - Soil temperature(T_{soil})
  - Soil water content(*VWC*).
- Ecological effects?

A highly specialized below-snow fungus

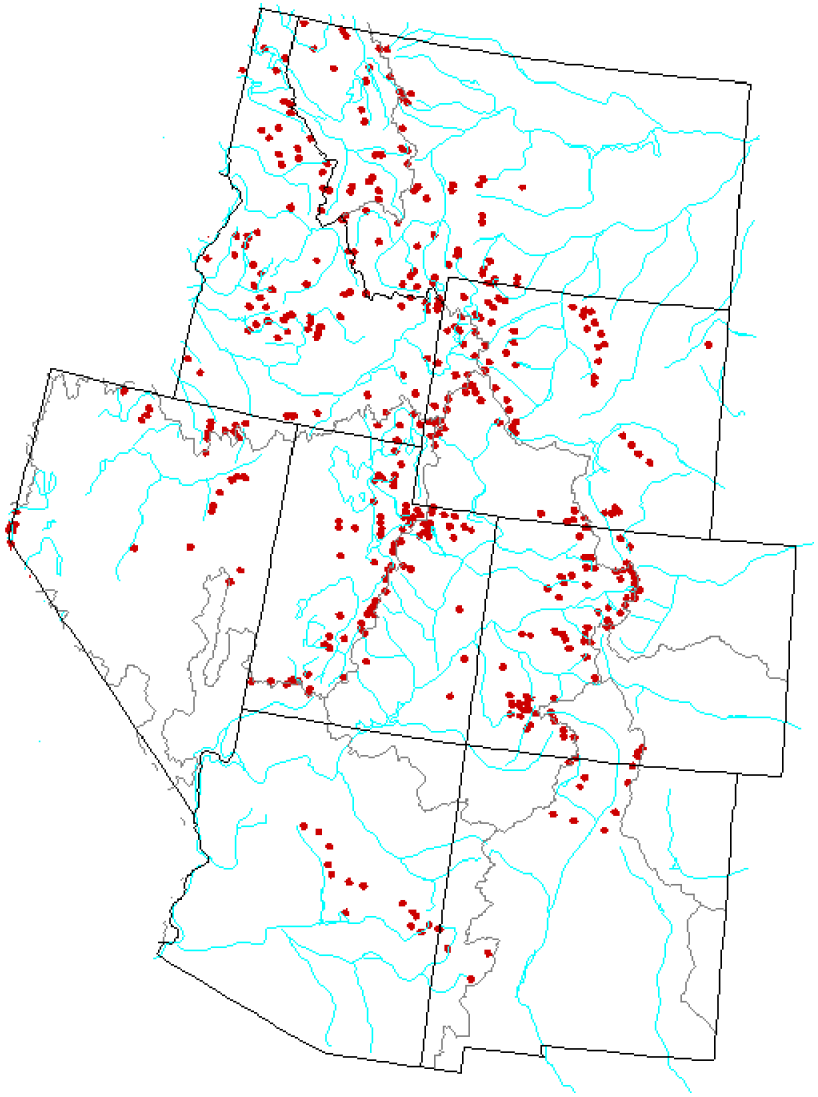


- 30% (or more !) of soil respiration occurs below-snow (*Liptzen et al., 2009*)
- Below-snow microbial activity is commonly stimulated by snowmelt water (*Liptzen et al 2009, Mast et al, 1998*).
- Change in snowcover = change in ecosystem processes
- Western U.S. soils are snow-covered for much of the year.

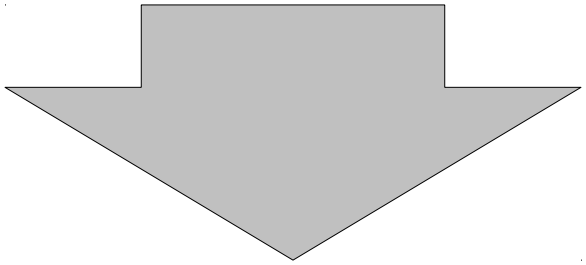
Schmidt, S.K., Wilson, K.L., Monson, R.K. & Lipson, D.A. Exponential growth of “snow molds” at sub-zero temperatures: An explanation for high beneath-snow respiration rates and Q 10 values. Biogeochemistry 95, 13-21 (2009).

SNOTEL soil profiles

- ~530 total SNOTEL sites in AZ, CO, ID, MT, NM, NV, UT, WY.
- ~252 sites with soil profiles (plus some brand new ones).
- T_{soil} and *VWC* measured at 5, 20, and 50cm.
- Avg. # of years = 6.3



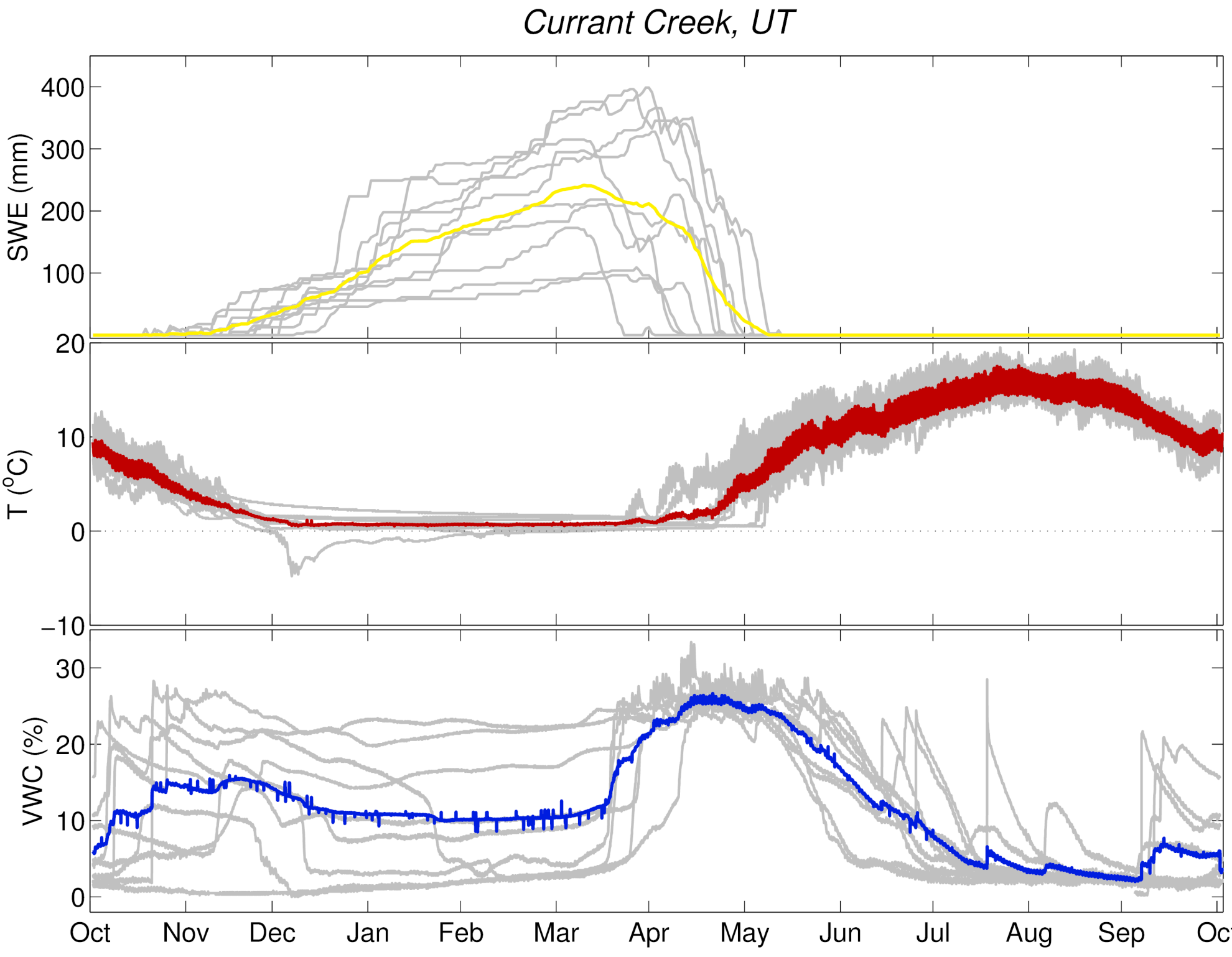
- **Onset day** = first day of persistent snowcover
- **Pre-onset** T_{air} or *VWC* = 2 week mean prior to onset.
- **Peak SWE** = peak snow accumulation
- **Early season SWE** = December snow accumulation
- **Snowmelt day** = day of spring when no measurable snow remains

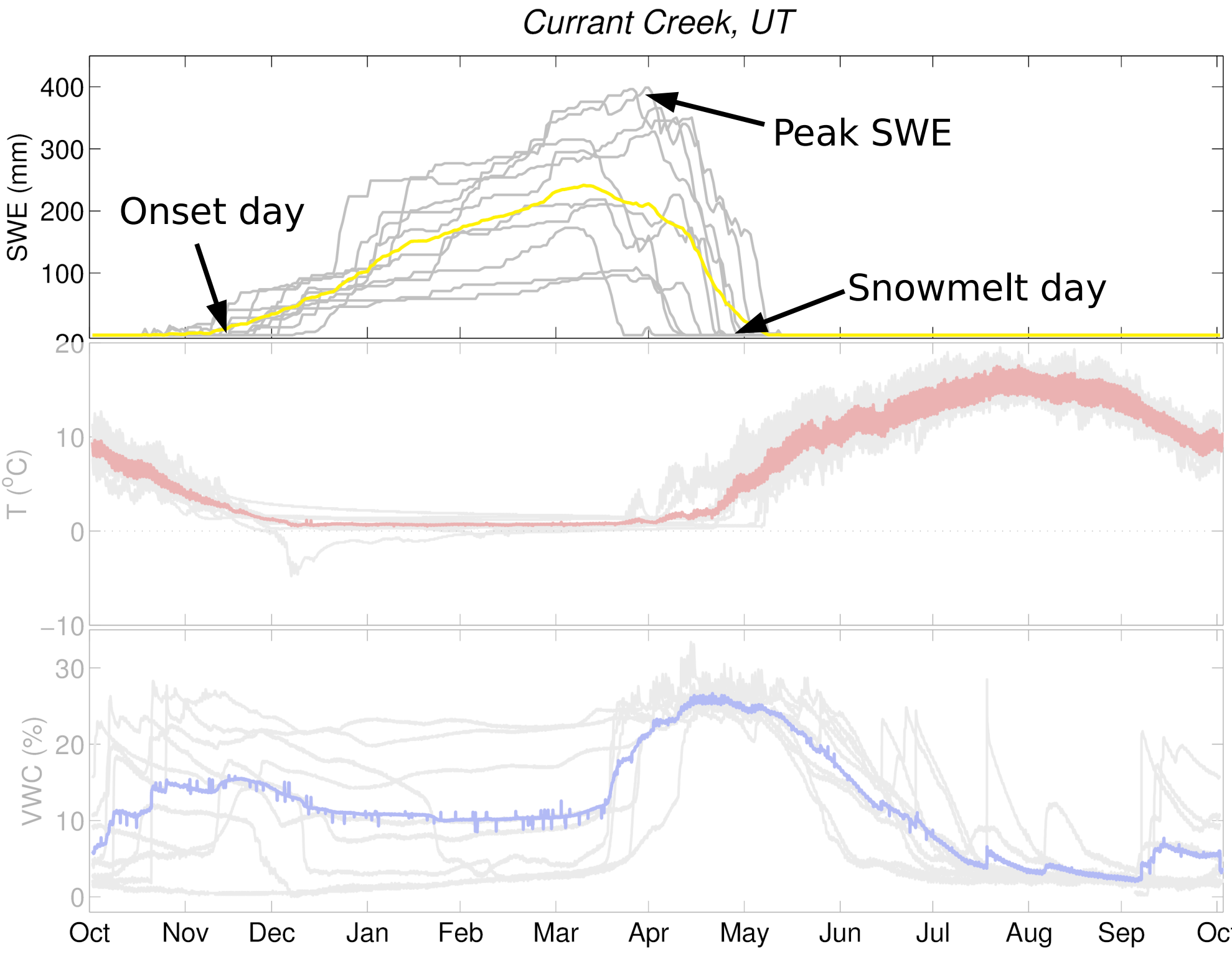


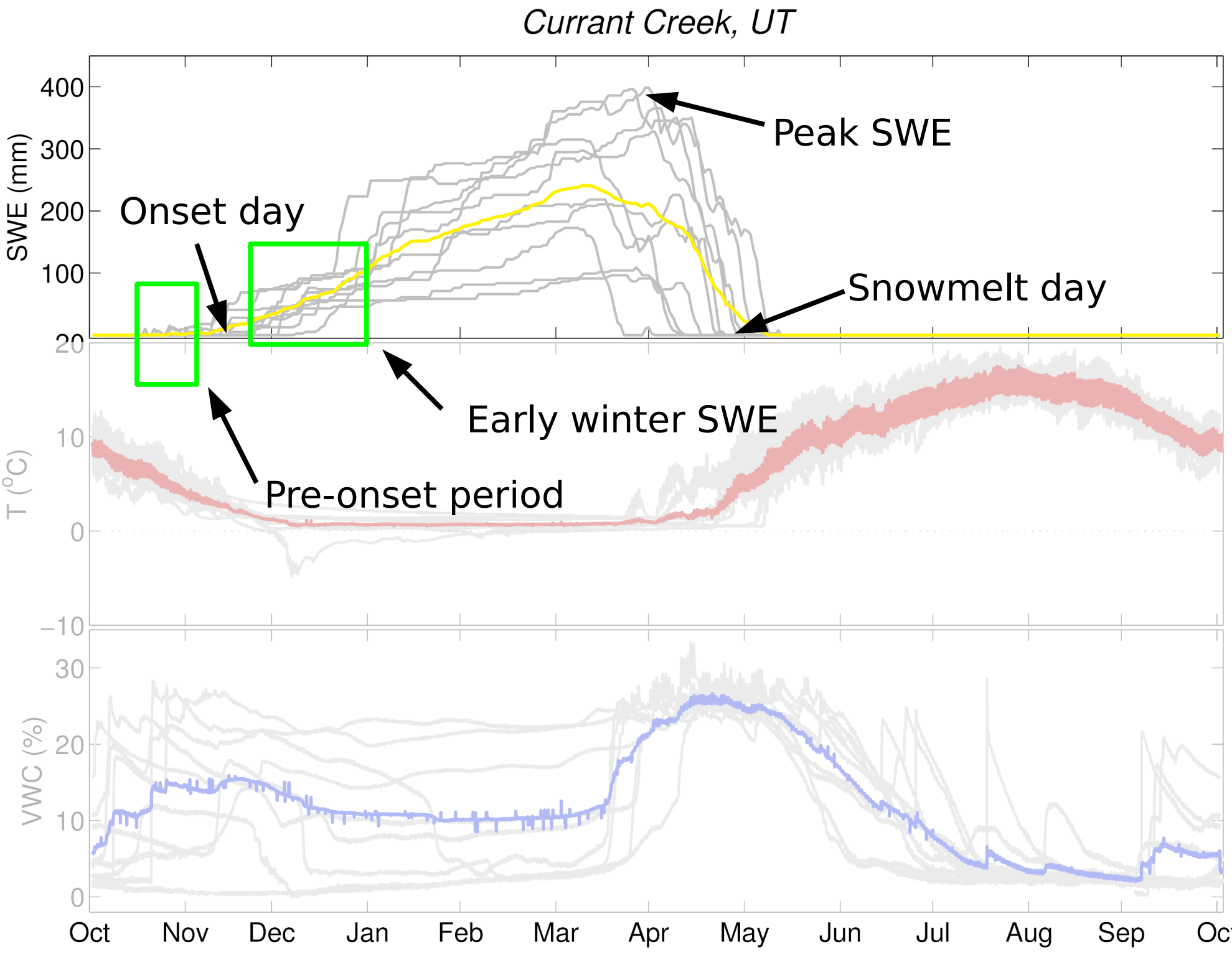
1) **Below-snow *soil temperature***

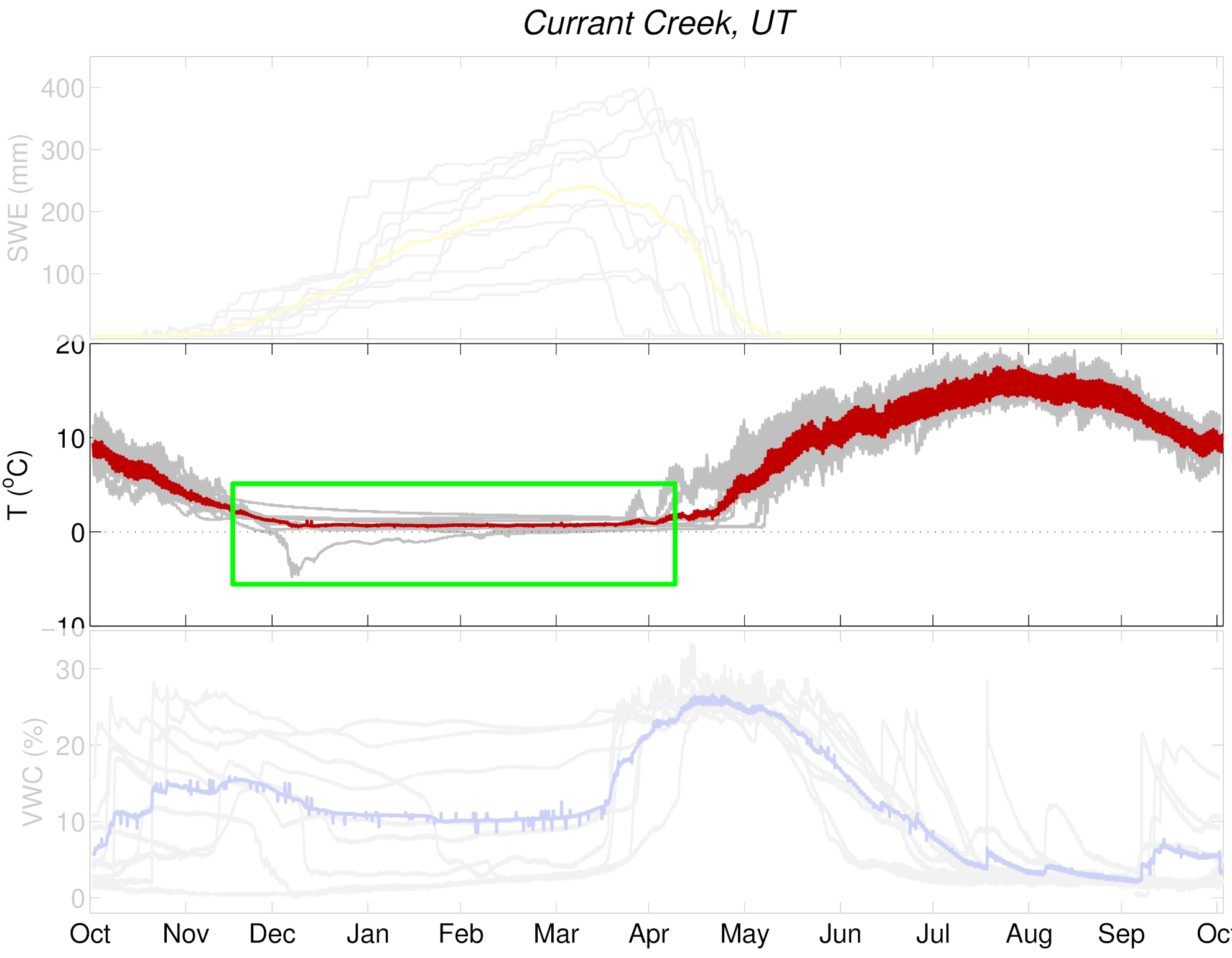
2) **Winter soil water content**

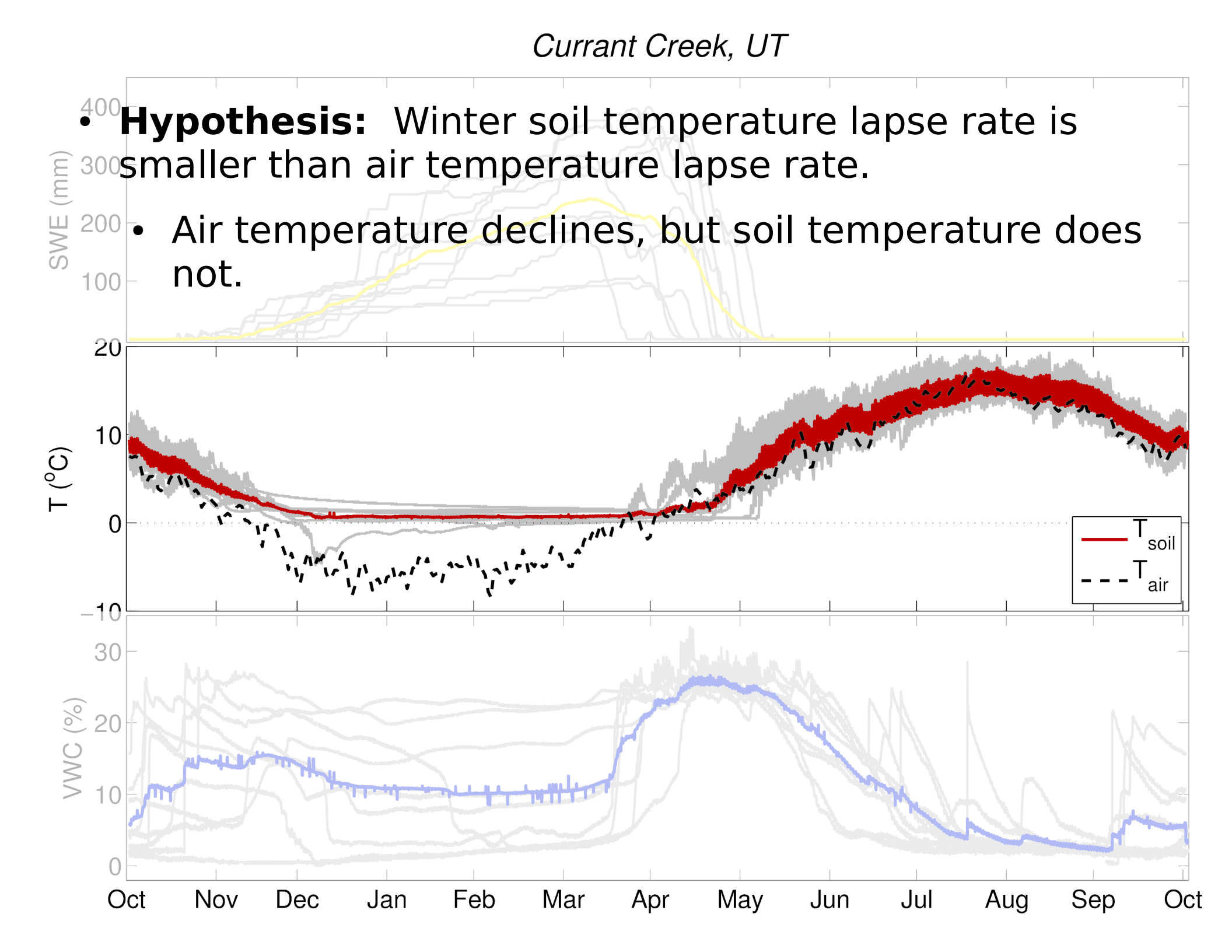
T_{air} and precipitation are also important!


Currant Creek, UT
SWE (mm)
400
300
200
100
20
T (°C)
20
10
0
−10
VWC (%)
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct


Currant Creek, UT
SWE (mm)
400
300
200
100
20
Peak SWE
Onset day
Snowmelt day
T (°C)
20
10
0
−10
VWC (%)
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct

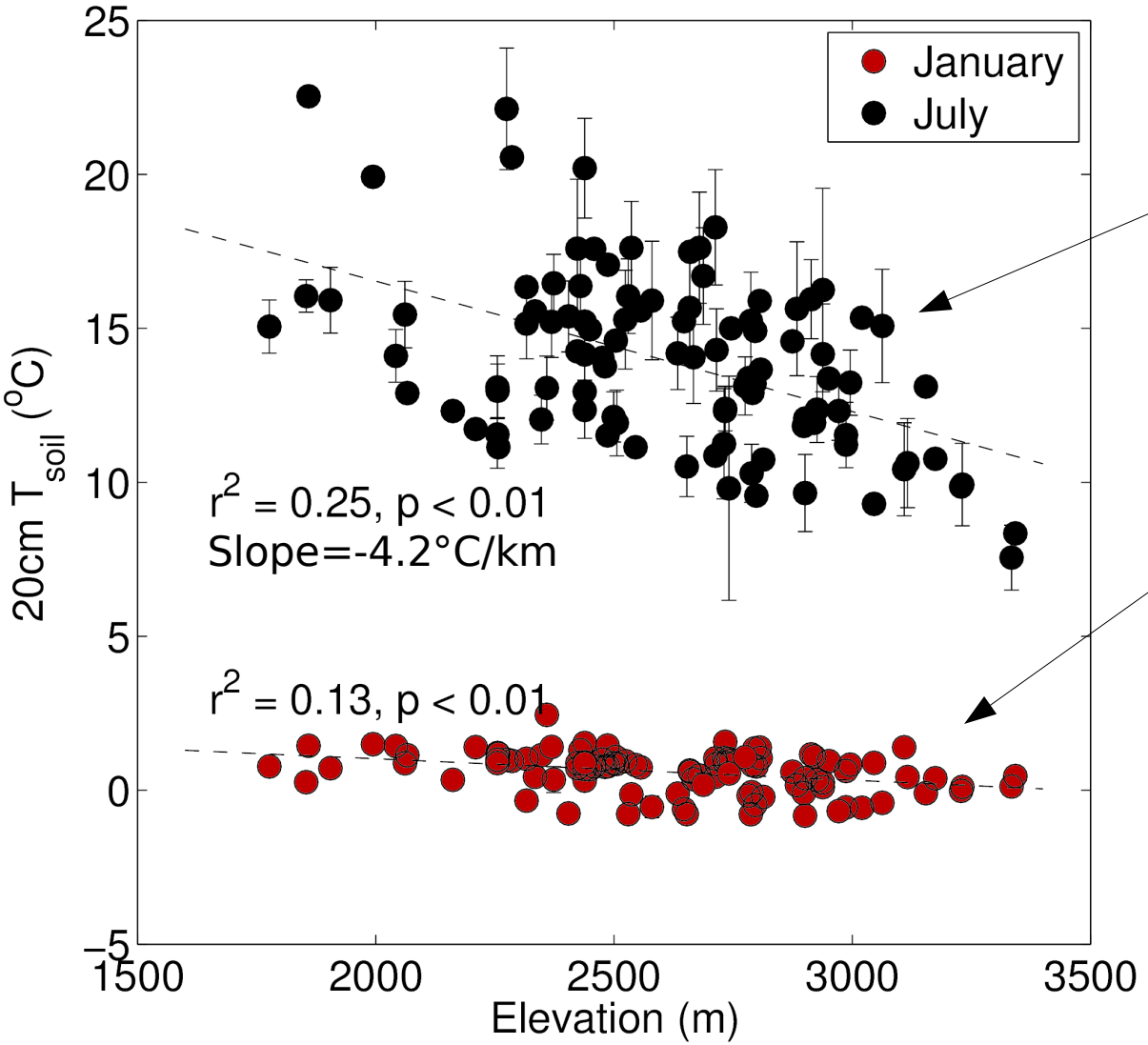

Currant Creek, UT
SWE (mm)
400
300
200
100
20
Peak SWE
Onset day
Snowmelt day
Early winter SWE
Pre-onset period
T (°C)
10
0
−10
VWC (%)
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct


Currant Creek, UT
SWE (mm)
400
300
200
100
20
T (°C)
20
10
0
−10
VWC (%)
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct



- **Hypothesis:** Winter soil temperature lapse rate is smaller than air temperature lapse rate.
  - Air temperature declines, but soil temperature does not.

Soil temperature lapse with elevation

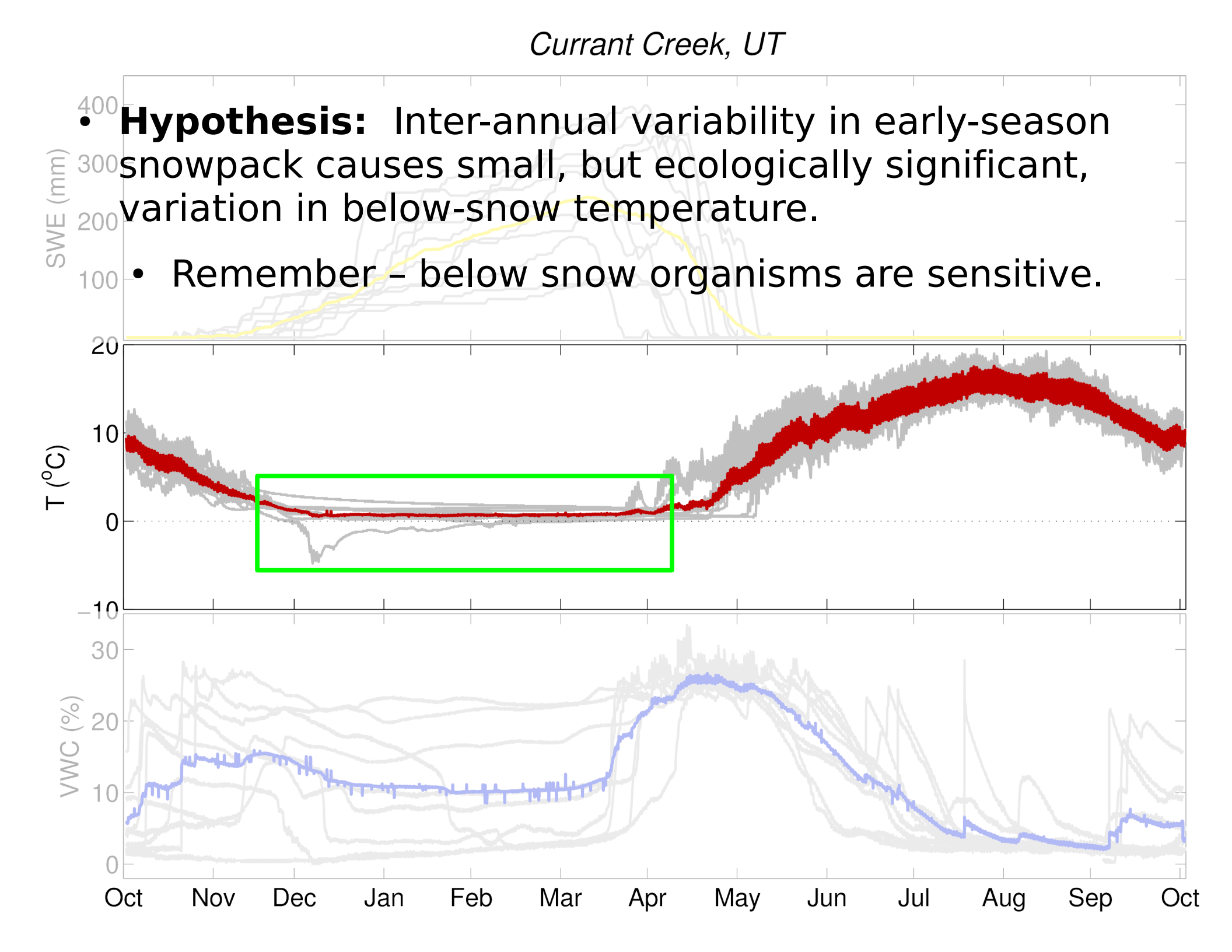


Growing season T_{soil} decreases with elevation.

Below-snow T_{soil} is stable across the landscape.

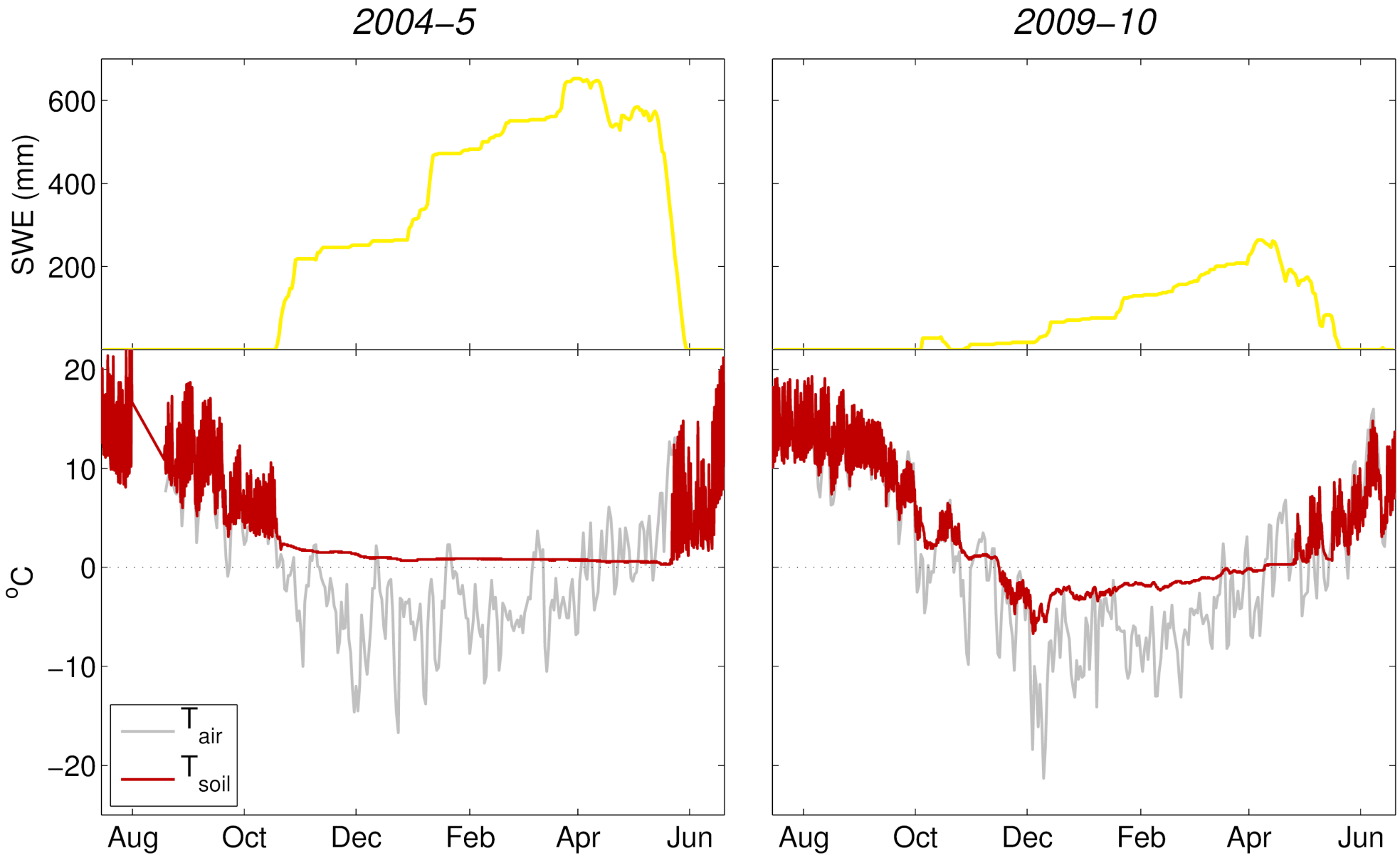
Atmospheric lapse rate is about -5.5°C/km.

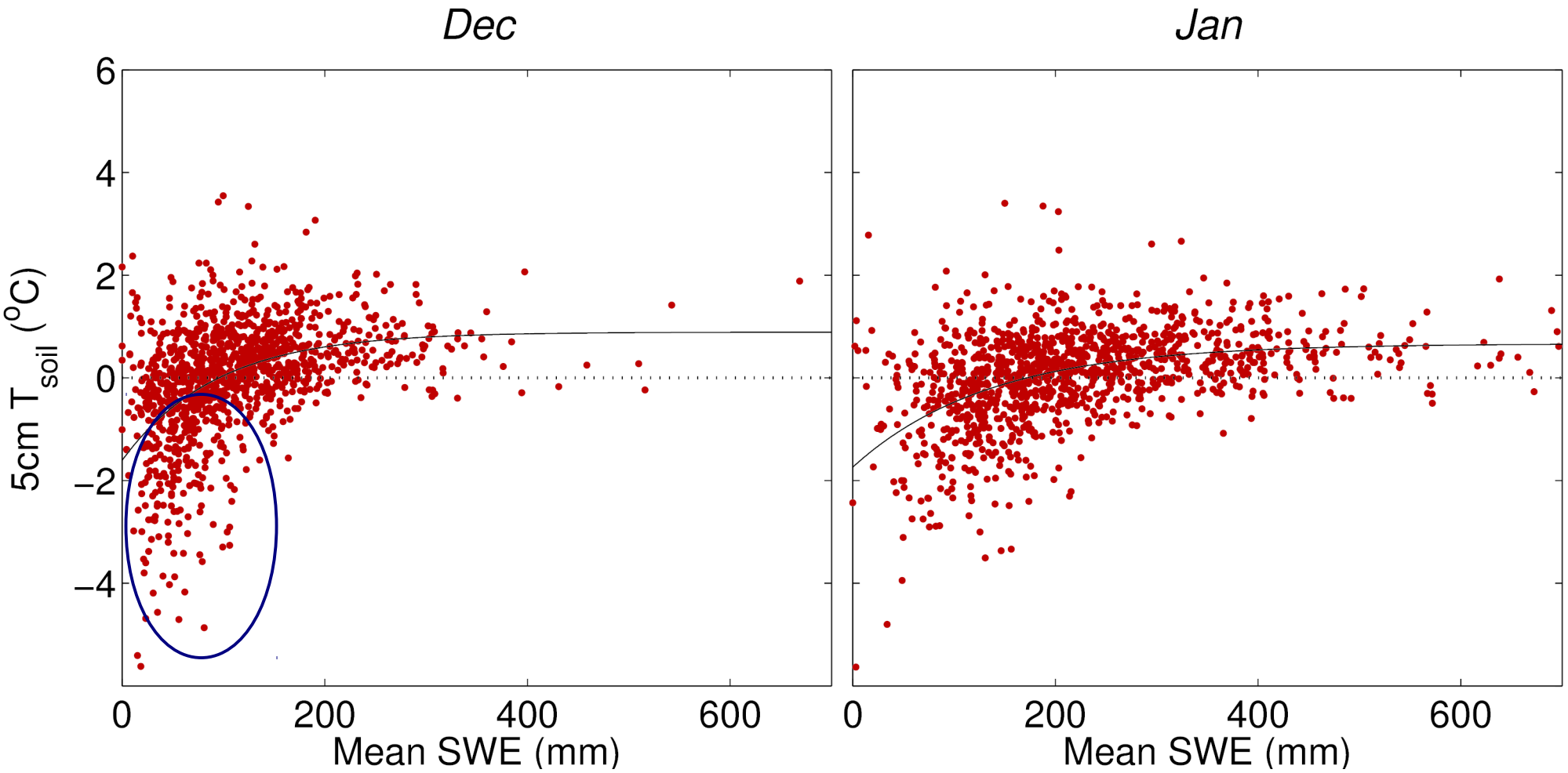
UT sites, 20cm sensors, Jan & July T_{soil} averaged for all water years, bars=StdDev



- **Hypothesis:** Inter-annual variability in early-season snowpack causes small, but ecologically significant, variation in below-snow temperature.
  - Remember – below snow organisms are sensitive.

Low snowpack = low soil temperature

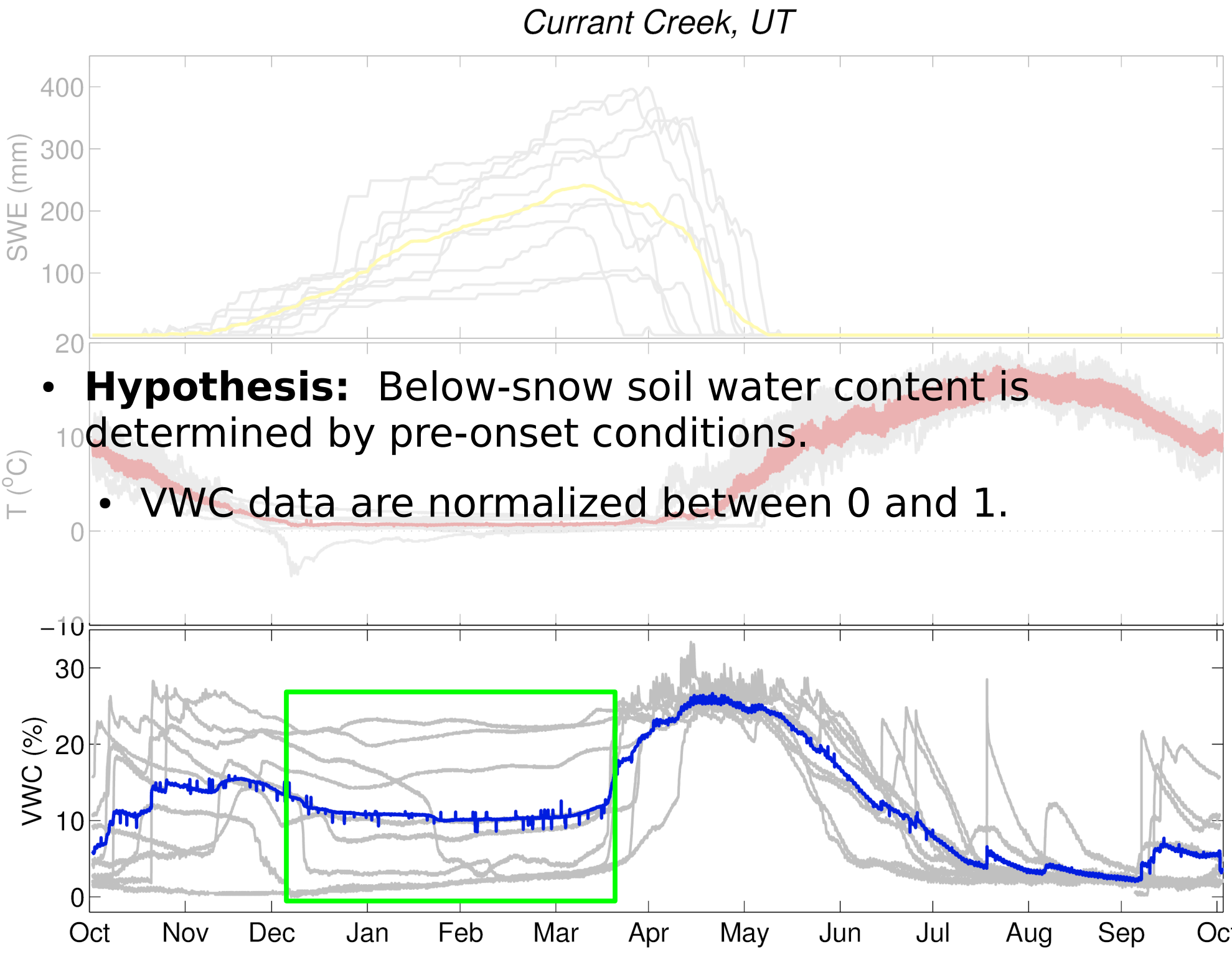




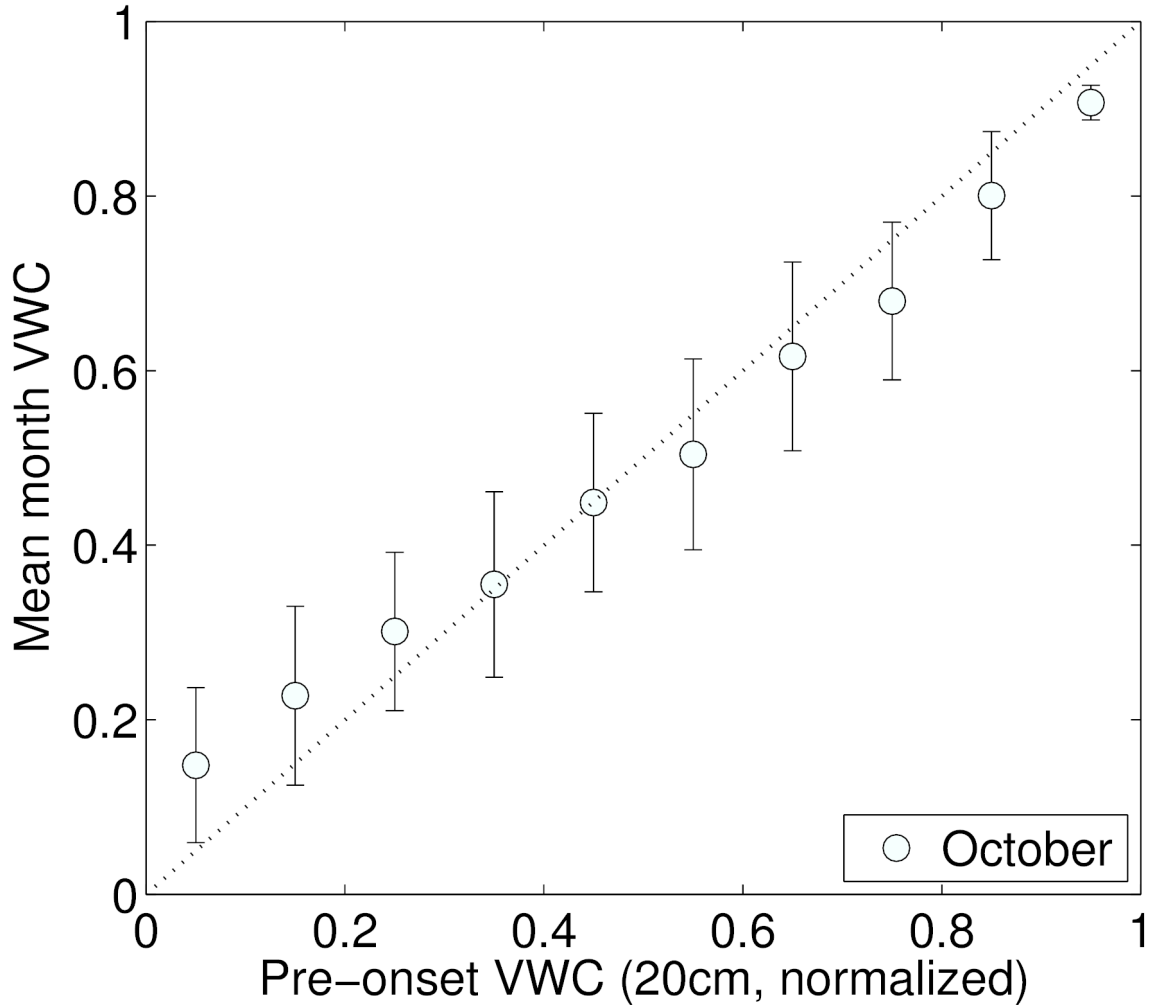
All snotel sites, means for individual water years

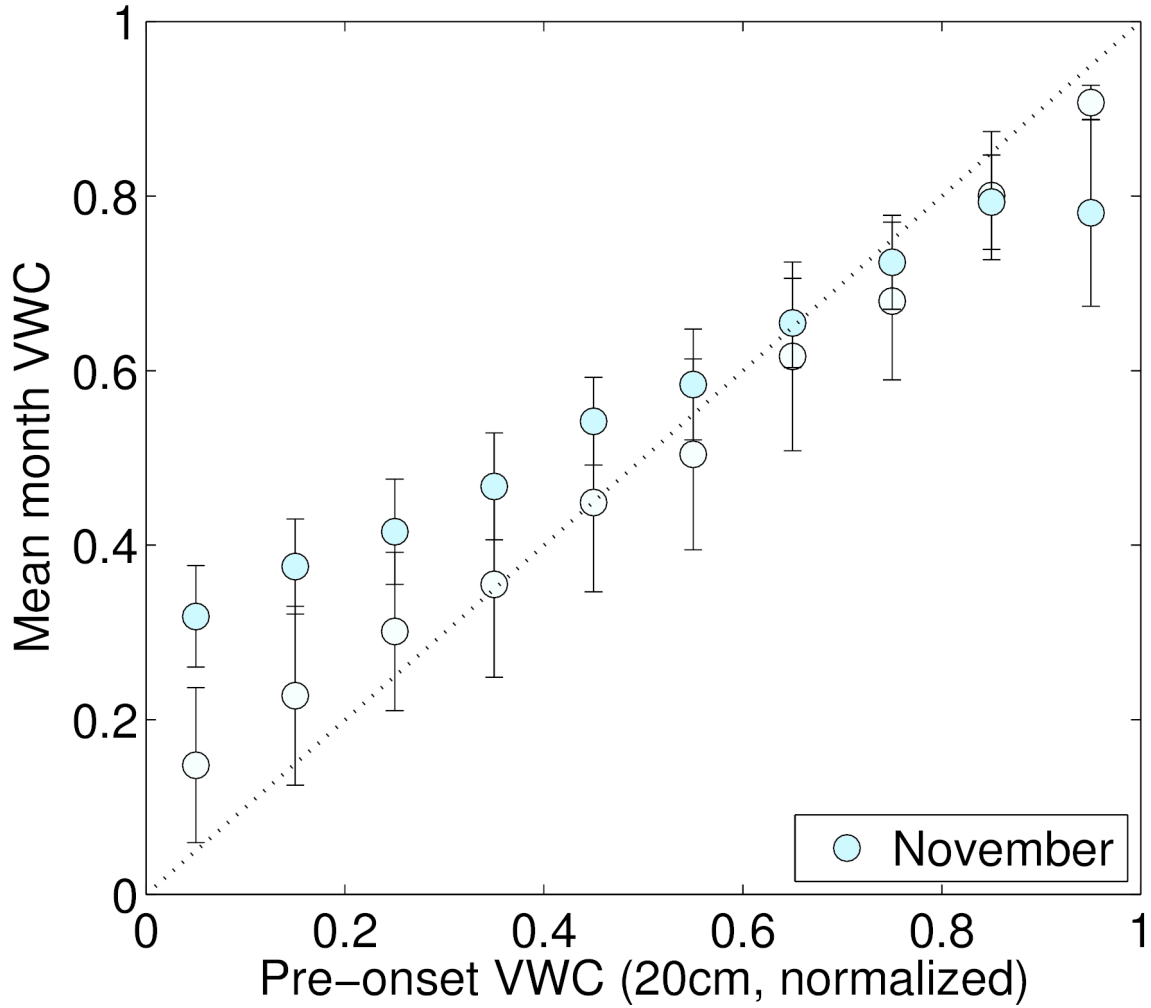
Low below-snow T_{soil} correlated with low Dec. SWE

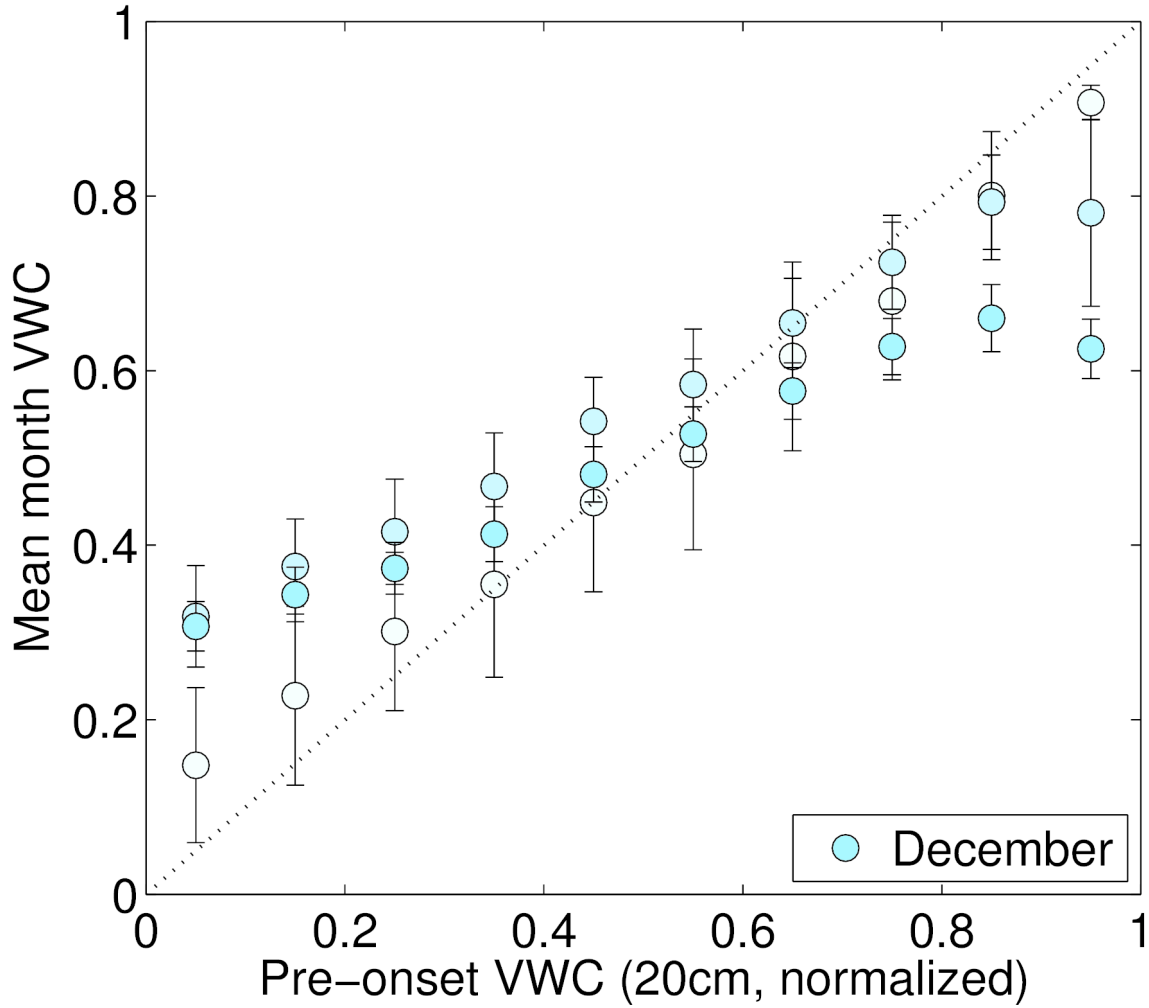
Predictor	Est. β	p-value
Mean Dec. SWE	0.090	<0.01 ***
Pre-onset T_{air}	0.036	<0.01 ***

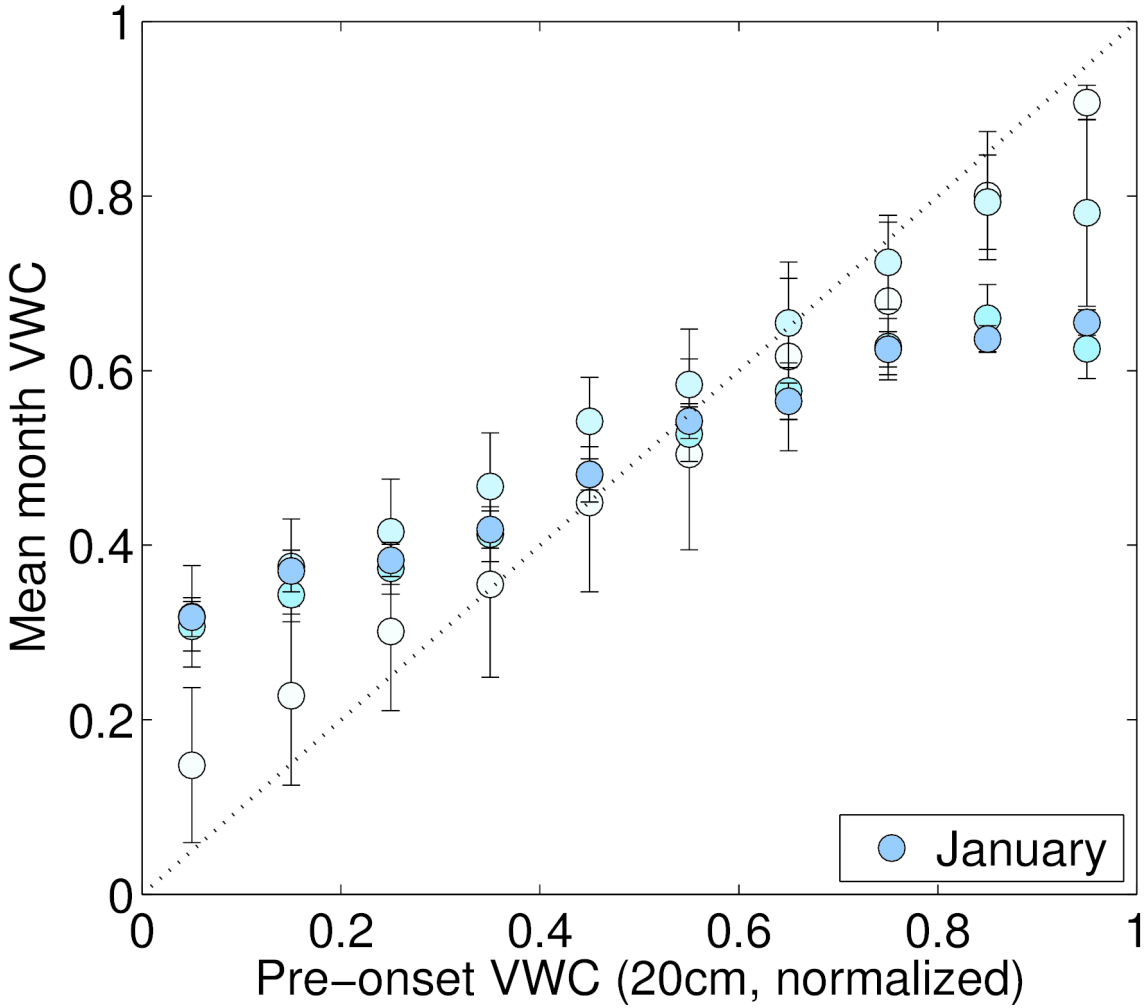


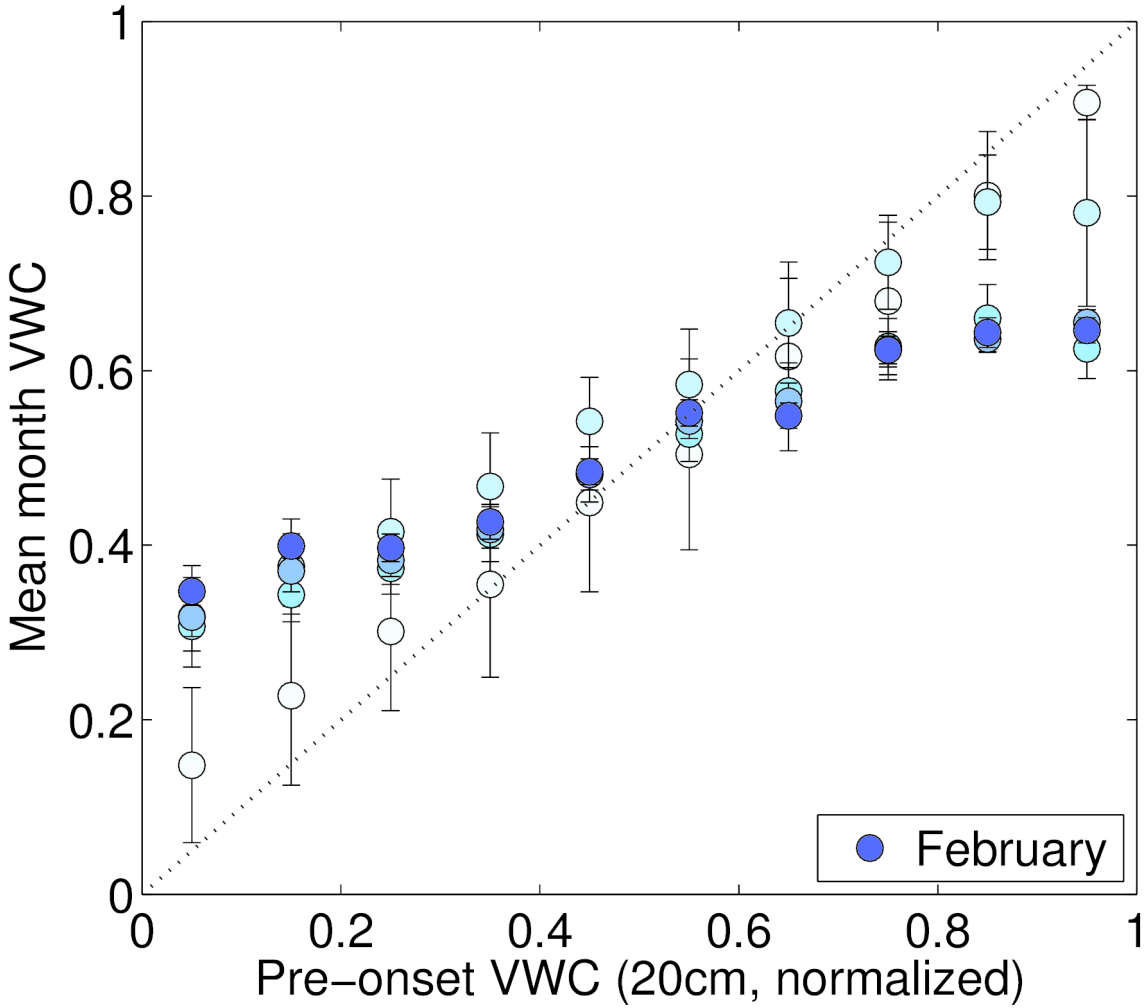
- **Hypothesis:** Below-snow soil water content is determined by pre-onset conditions.
  - VWC data are normalized between 0 and 1.

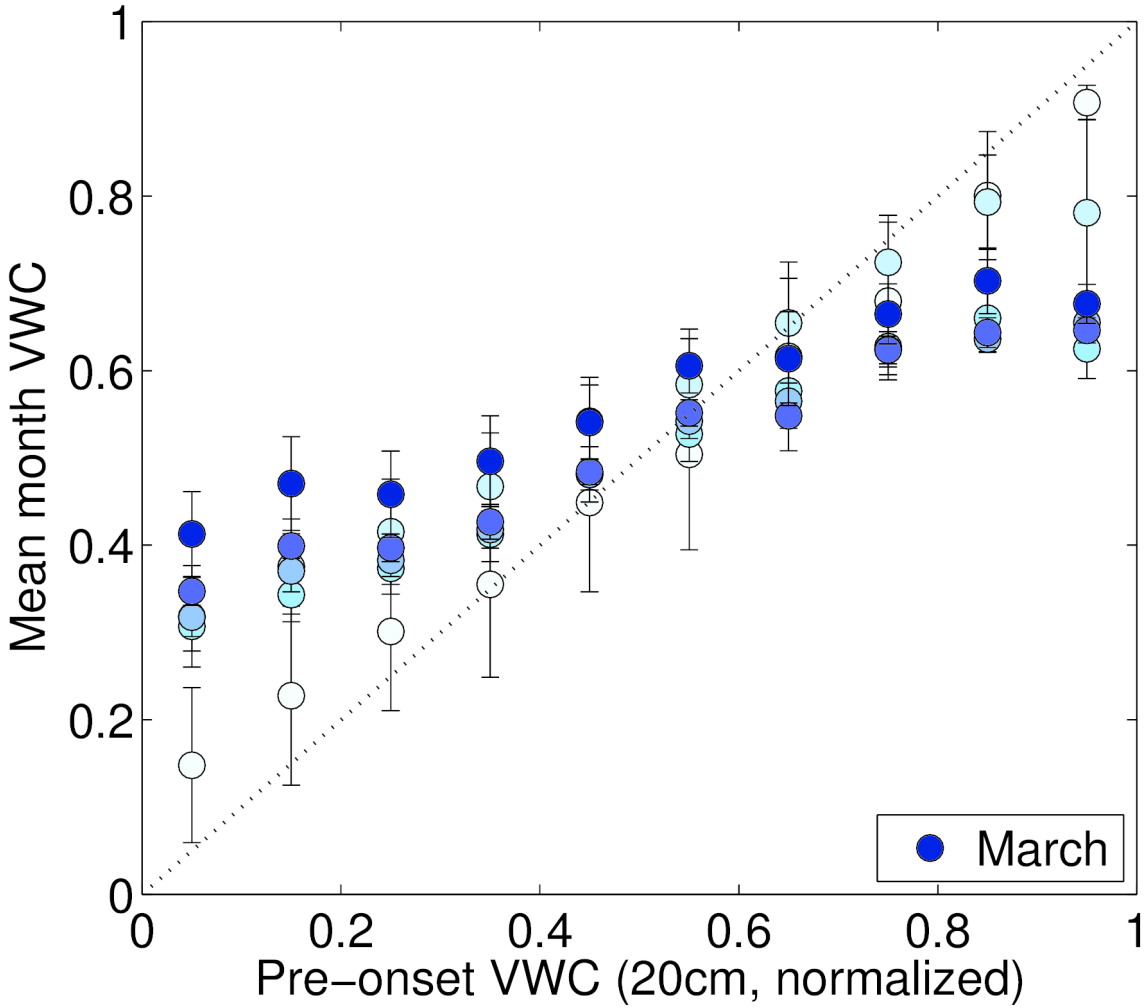

Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
October

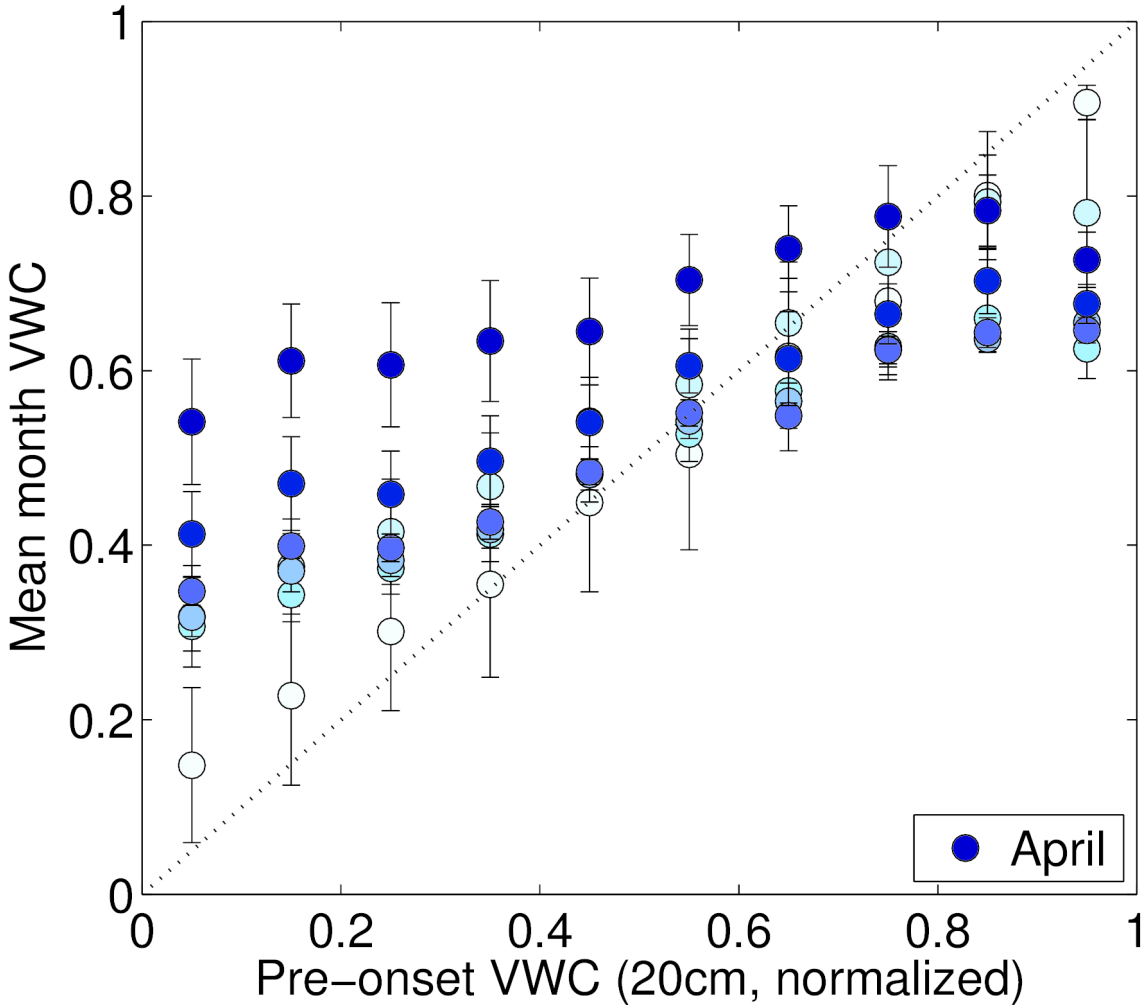

Mean month VWC
Pre−onset VWC (20cm, normalized)
November
0
0.2
0.4
0.6
0.8
1

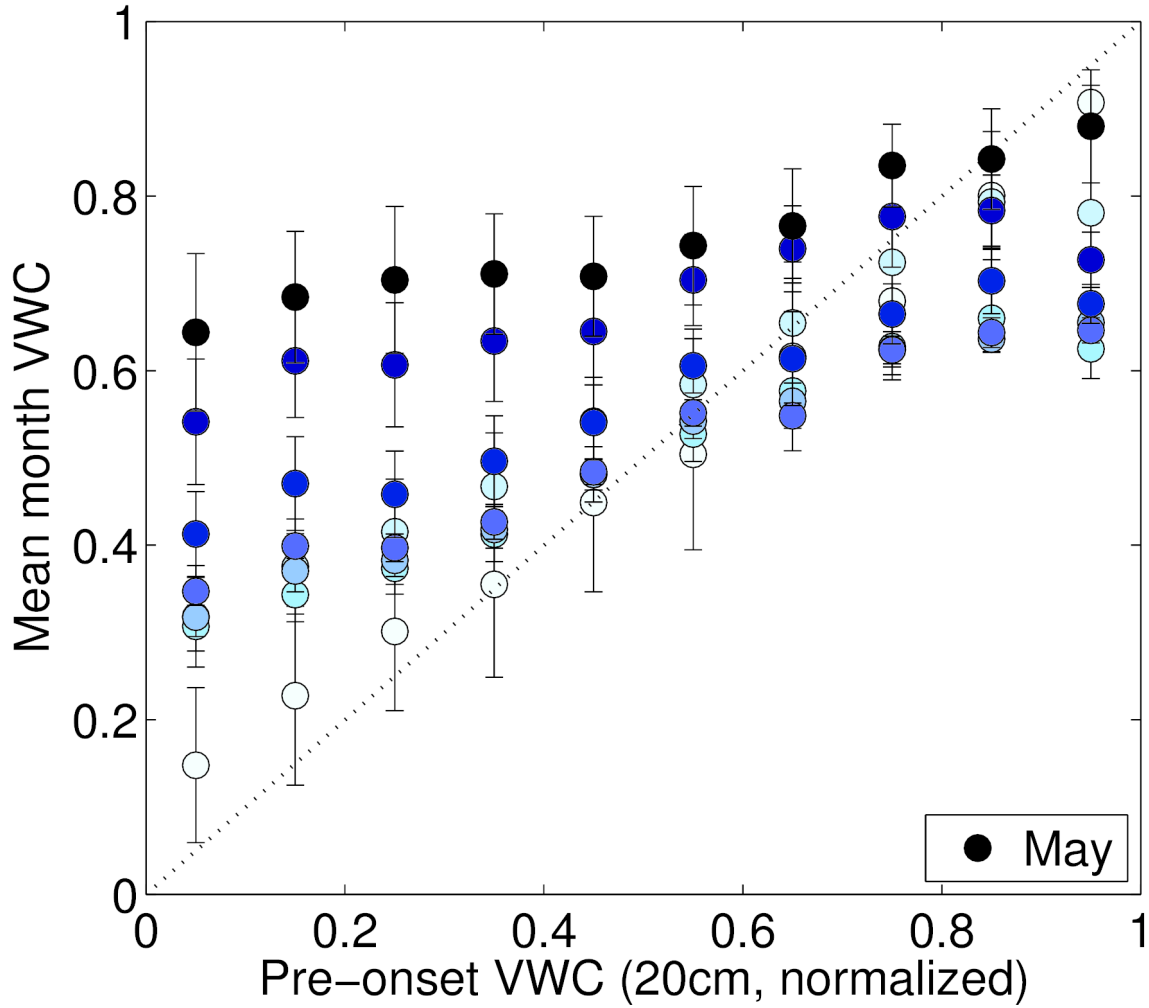

Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
December

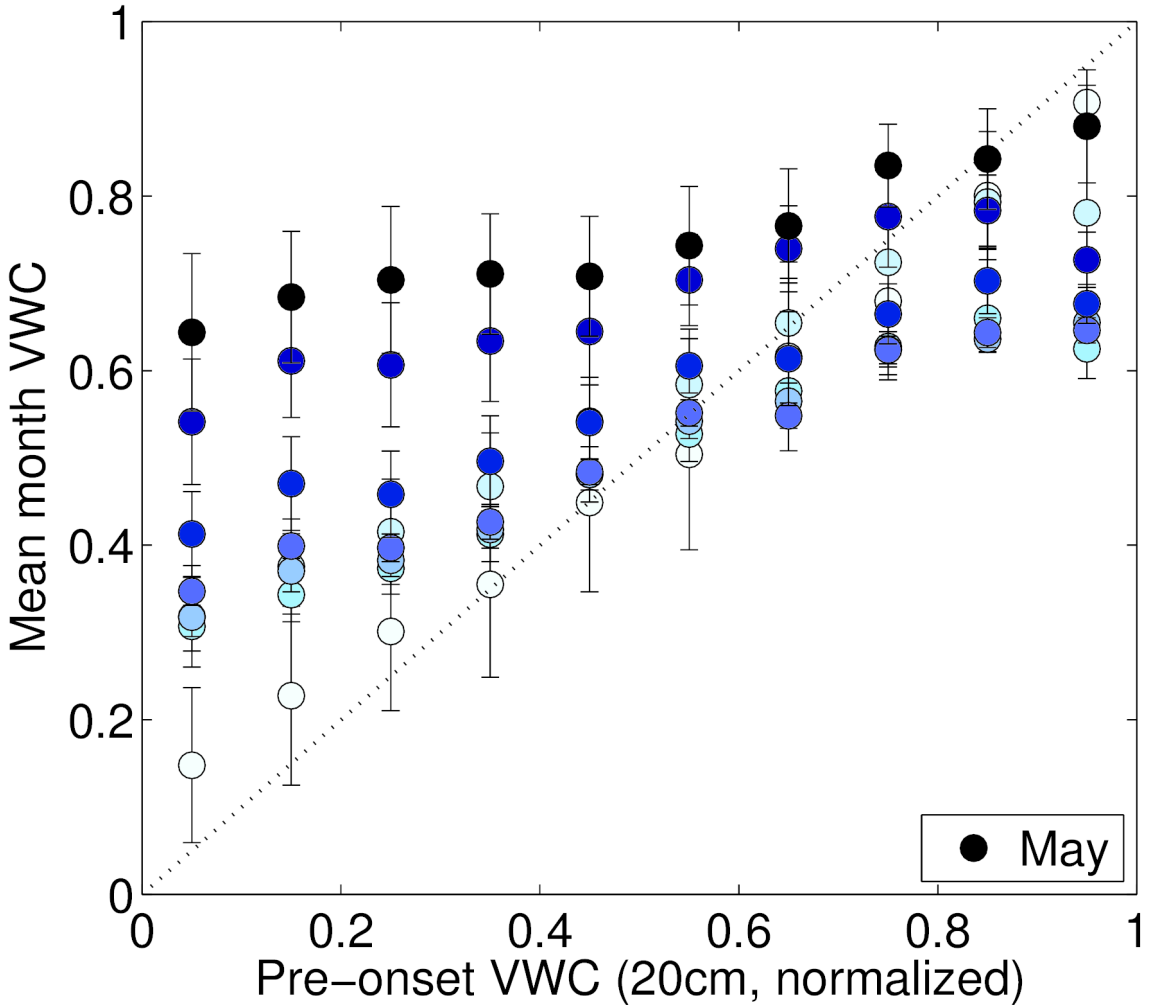

Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
January


Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
February


Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
March


Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
April


Mean month VWC
Pre−onset VWC (20cm, normalized)
0
0.2
0.4
0.6
0.8
1
May



Early fall/winter conditions are most important.

... until snowmelt (~April)

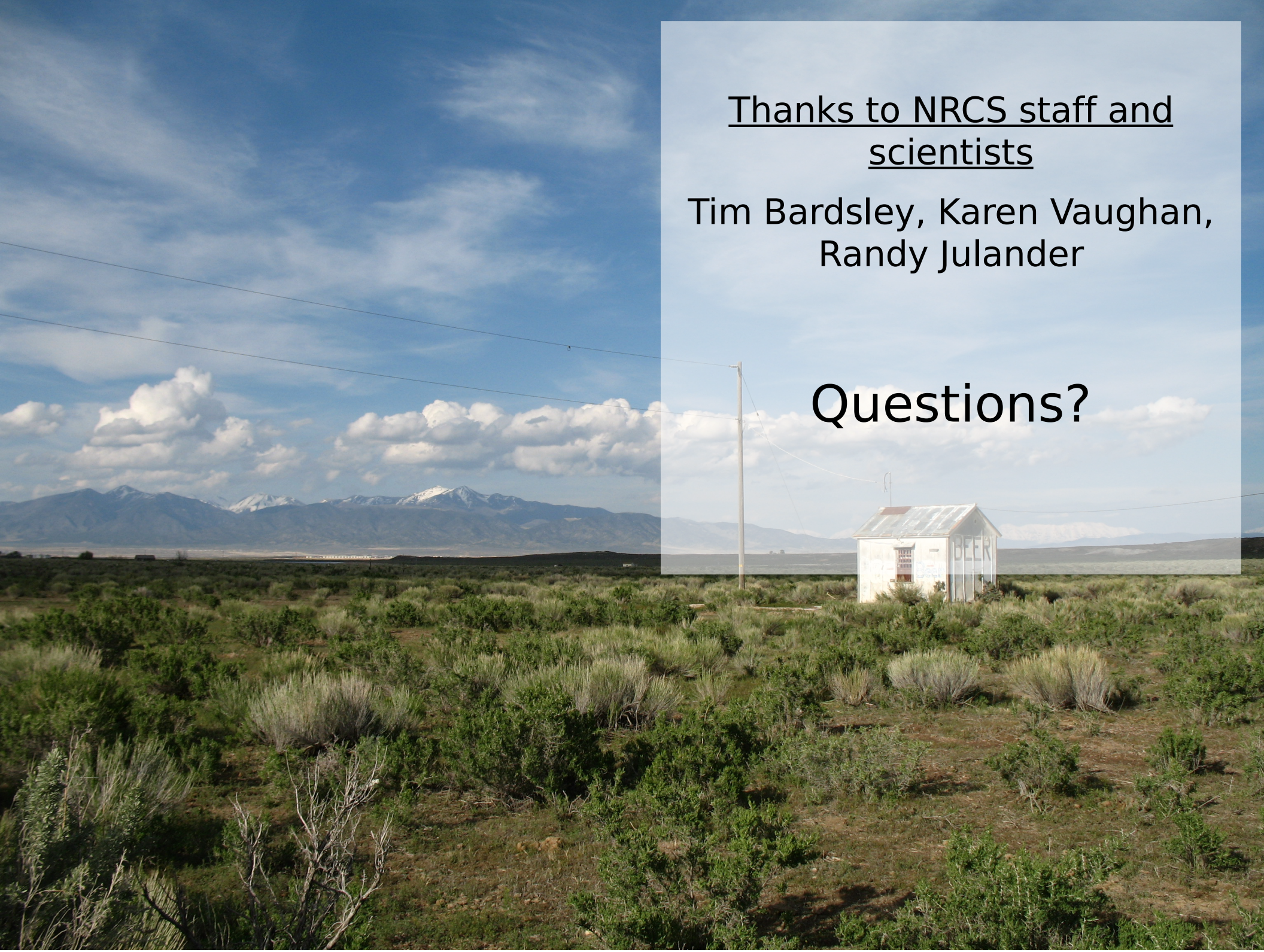
Summary

The below-snow soil environment is similar across the landscape

- T_{soil} is seasonally decoupled from T_{air}
- T_{soil} has a small elevation lapse compared to T_{air}

Inter-annual variability in early-winter conditions (snowpack, VWC, T_{air}) is ecologically important

- Low early-winter SWE → cold below-snow T_{soil}
- Pre-onset *VWC* → winter *VWC* (until snowmelt)



Thanks to NRCS staff and scientists

Tim Bardsley, Karen Vaughan, Randy Julander

Questions?

Growing season (July, Aug, Sep) *VWC*

VWC tends to be lower when T_{air} is high.

Growing season *VWC* is positively correlated with precip

Predictor	Est. β	p-value	Site p<0.05
(Intercept)	0.258	<0.01 ***	
Mean T_{air}	-0.007	<0.01 ***	18 (-0.024)
Total precip	0.016	<0.01 ***	18 (0.029)
Peak SWE	0.002	<0.01 ***	16 (0.013)
Snowmelt day	0.0005	0.054 .	12 (0.005)
$Adj\ R^2 = 0.78$			

Growing season *VWC* is positively correlated with peak SWE

Snowmelt day is (weakly) positively correlated with *VWC*

Snow-free T_{soil}

Snowmelt day has a small but significant influence on T_{soil}

Mainly, T_{soil} tracks T_{air} during the growing season

Predictor	Est. β	p-value	Site p<0.05
(Intercept)	5.081	<0.01 ***	
Mean T_{air}	0.612	<0.01 ***	93 (0.845)
Snowmelt day	-0.008	<0.01 ***	6 (-0.014)
Below-snow T_{soil}	0.720	<0.01 ***	40 (1.90)
Adj. R^2 = 0.93			

* Site effects omitted for clarity

Snow-free T_{soil} and below-snow T_{soil} *are* correlated

Below-snow T_{soil}

Below-snow T_{soil} is correlated with pre-onset T_{air}

T_{soil} tends to be warmer with greater early-season SWE accumulation

Predictor	Est. β	p-value	Site p<0.05
(Intercept)	-0.238	0.419	
Mean Dec. SWE	0.090	<0.01 ***	39 (0.241)
Pre-onset T_{air}	0.036	<0.01 ***	8 (0.176)
Mean T_{air}	-0.054	0.021 *	14 (0.507)
Adj. R^2 = 0.66			

* Site effects omitted for clarity

Below-snow T_{soil} is negatively correlated with winter T_{air}. There is probably a snow interaction effect here.

Winter (Jan, Feb, Mar) *VWC*

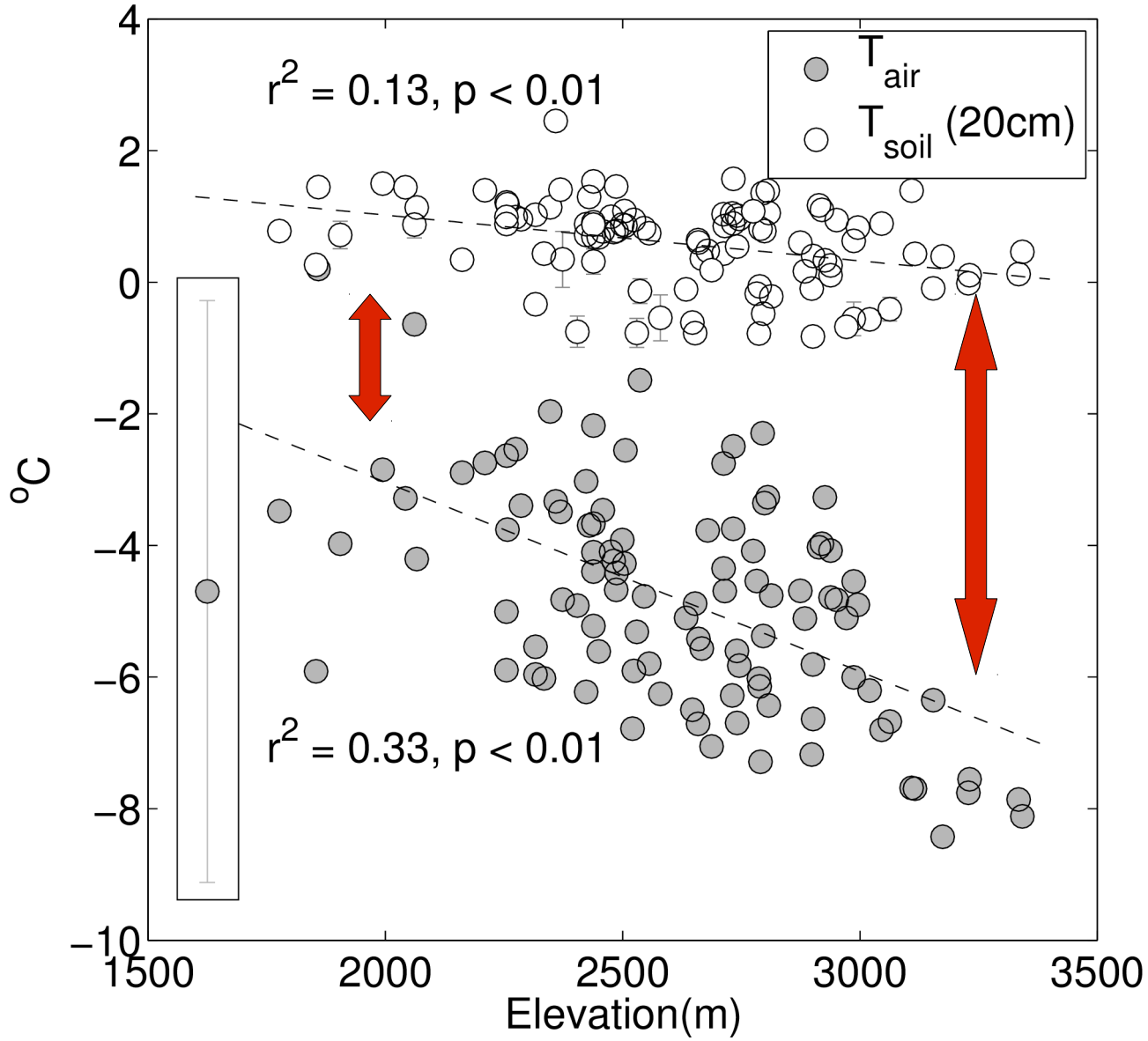
Winter *VWC* is positively correlated with pre-onset *VWC*

Early season snow accumulation raises below-snow *VWC*

Predictor	Est. β	p-value	Site p<0.5
(Intercept)	0.046	0.536	
Dec. SWE	0.031	<0.01 ***	48 (0.084)
Pre-onset VWC	0.240	<0.01 ***	12 (0.571)
Adj $R^2 = 0.71$			

* Site effects omitted for clarity

Insulative value of snow increases with elevation



- This gradient in T_{soil}-T_{air} offset also occurs on a mean annual basis but is not always positive.
- UT sites, 20cm sensors, Jan temps averaged for all water years.