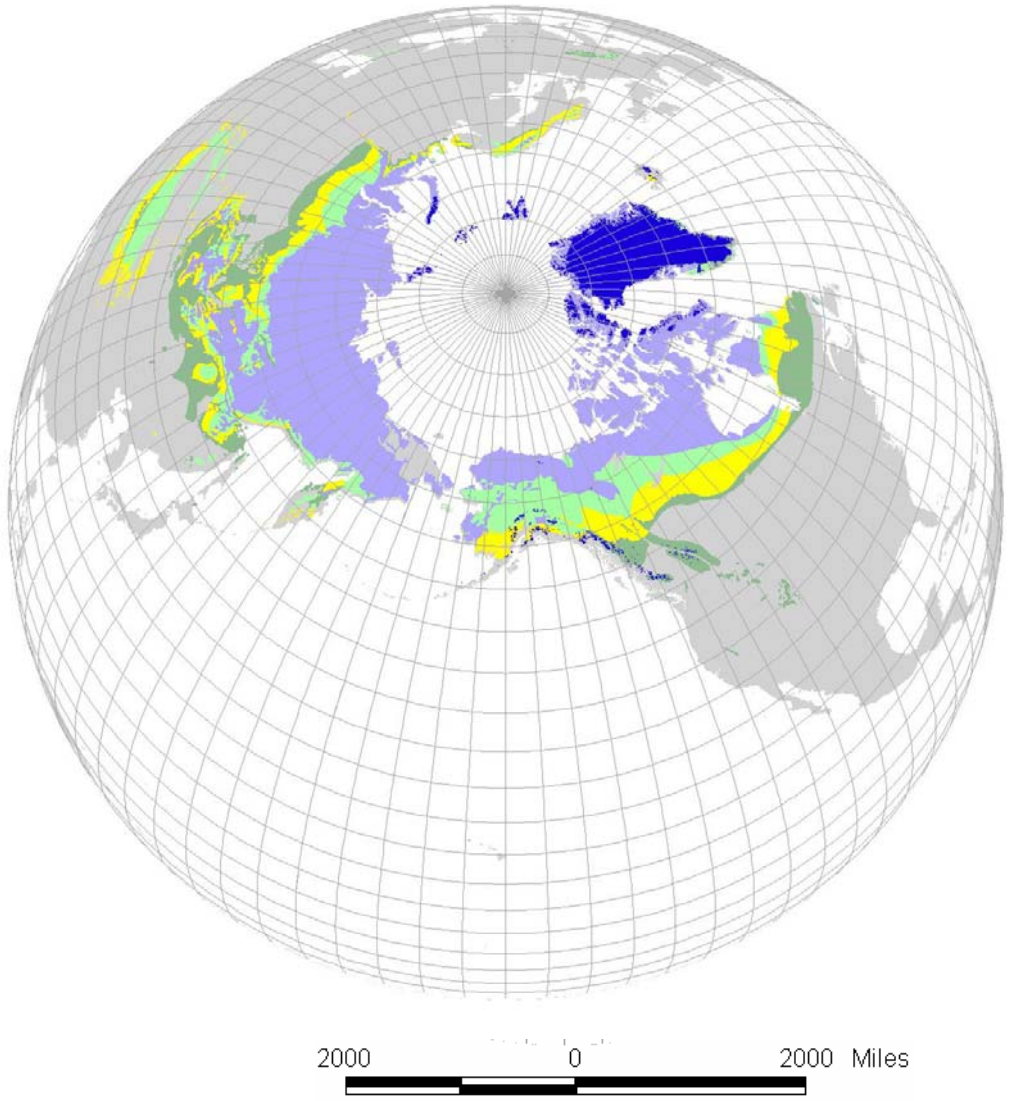
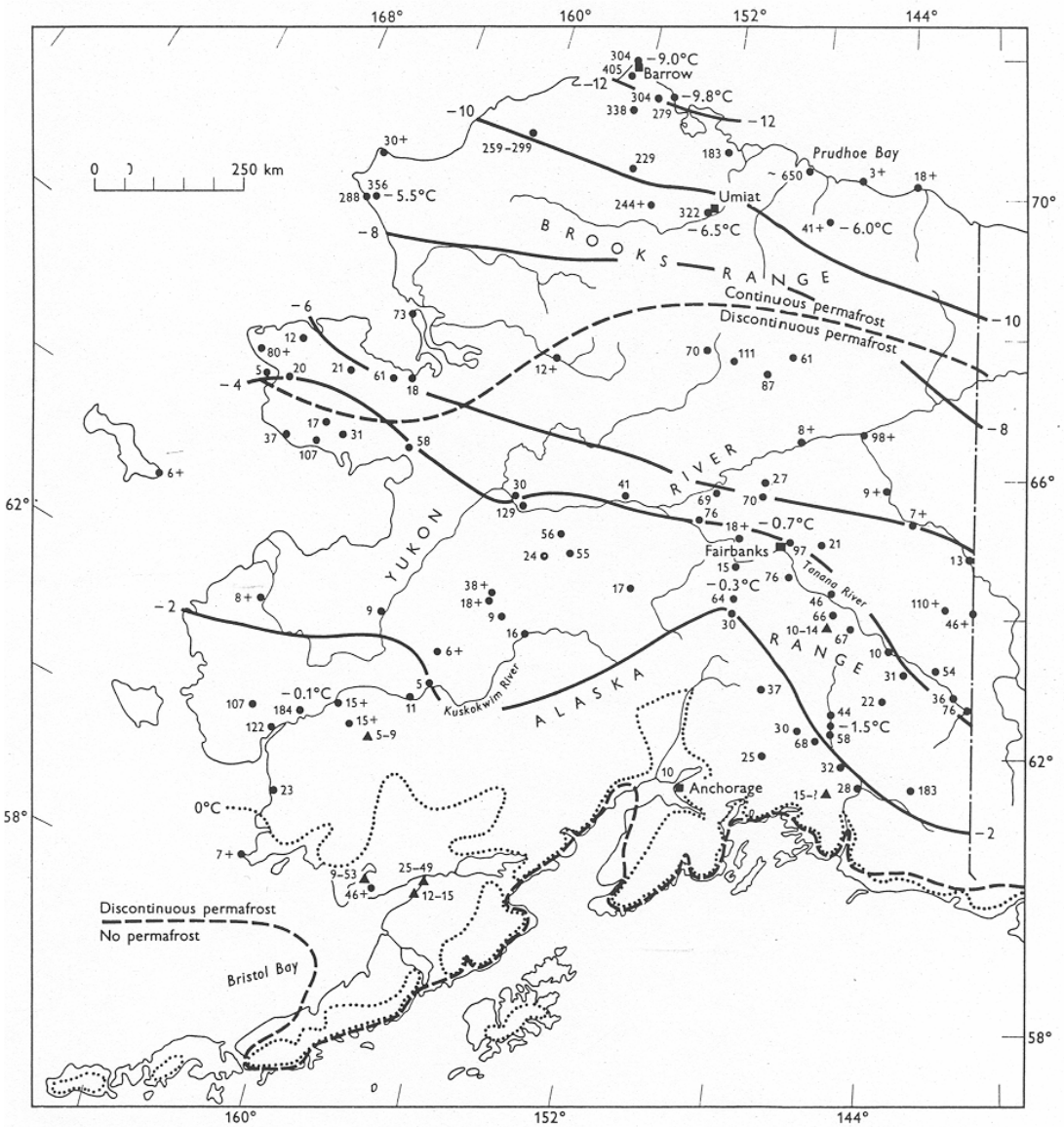
Geophysical Institute
University of Alaska Fairbanks

Permafrost, Active Layer, Soil Temperature and Moisture, Frost Heave and other Things

Vladimir Romanovsky

Circum-Arctic Map of Permafrost and Ground–Ice Conditions





PERMAFROST, data in metres

122 ● Thickness, depth to base

18+ ● Minimum thickness, base unknown

12–15 ▲ Relic permafrost, ground frozen between depths shown

−6.5°C ● Temperature of permafrost at 15 to 25 metres' depth

– – – – Permafrost zone boundary

CLIMATE

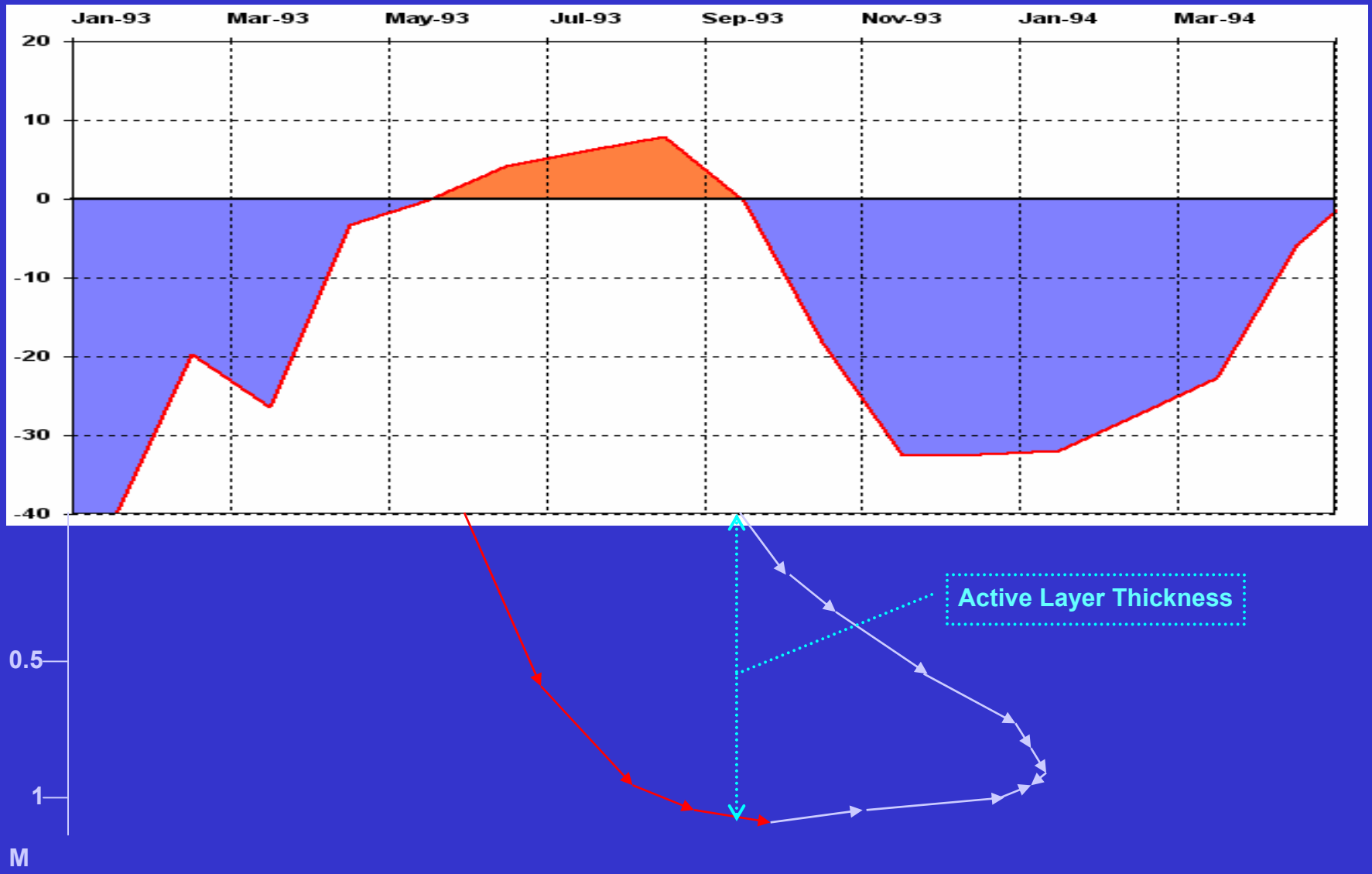
····· Approximate position of mean annual air temperature isotherm, 0°C

——— Mean annual air temperature, °C

Permafrost Characteristics

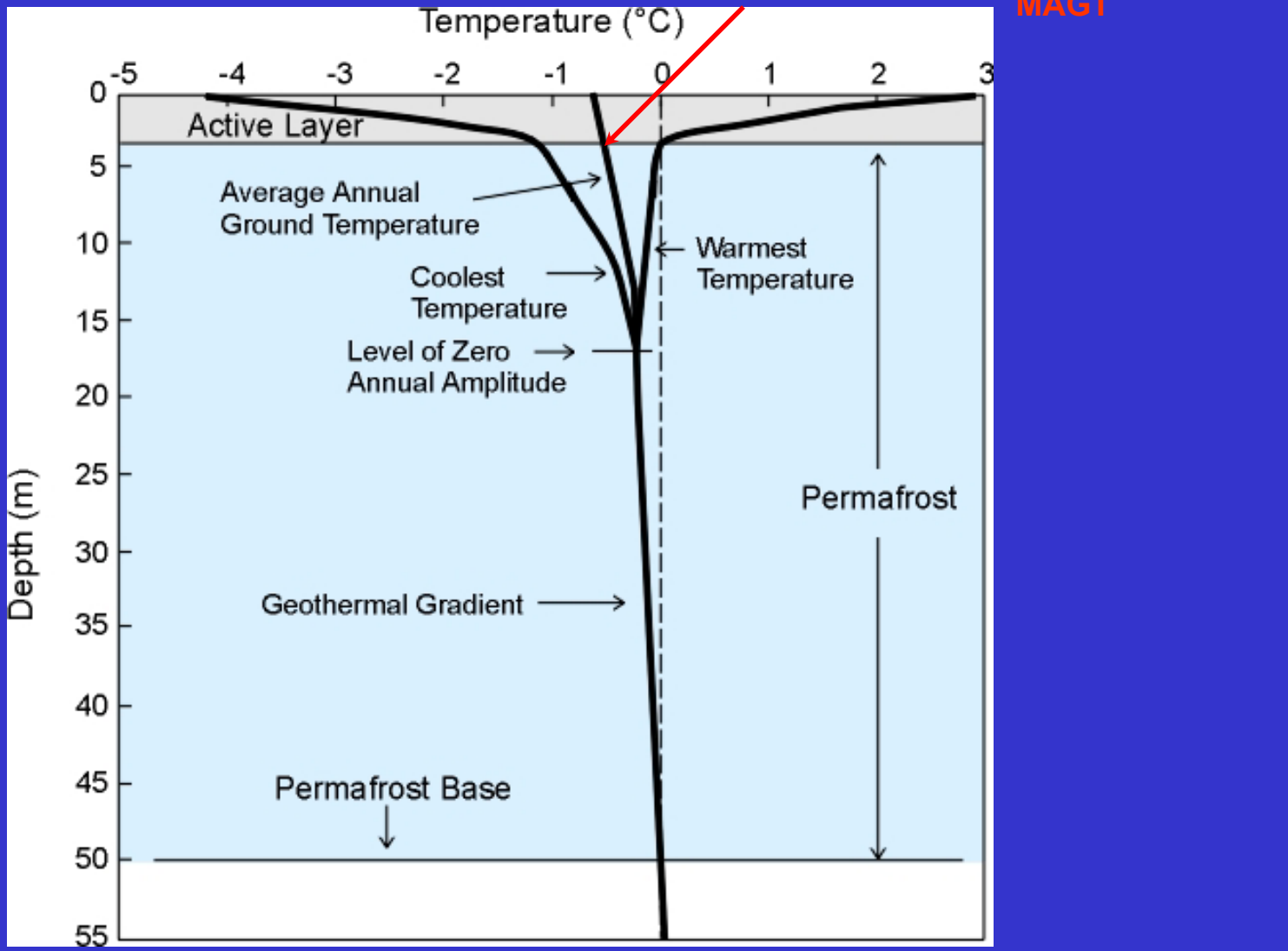
Active Layer Thickness

Mean Monthly Air Temperature



Permafrost Characteristics

Mean Annual Ground Temperature



Ice Complex

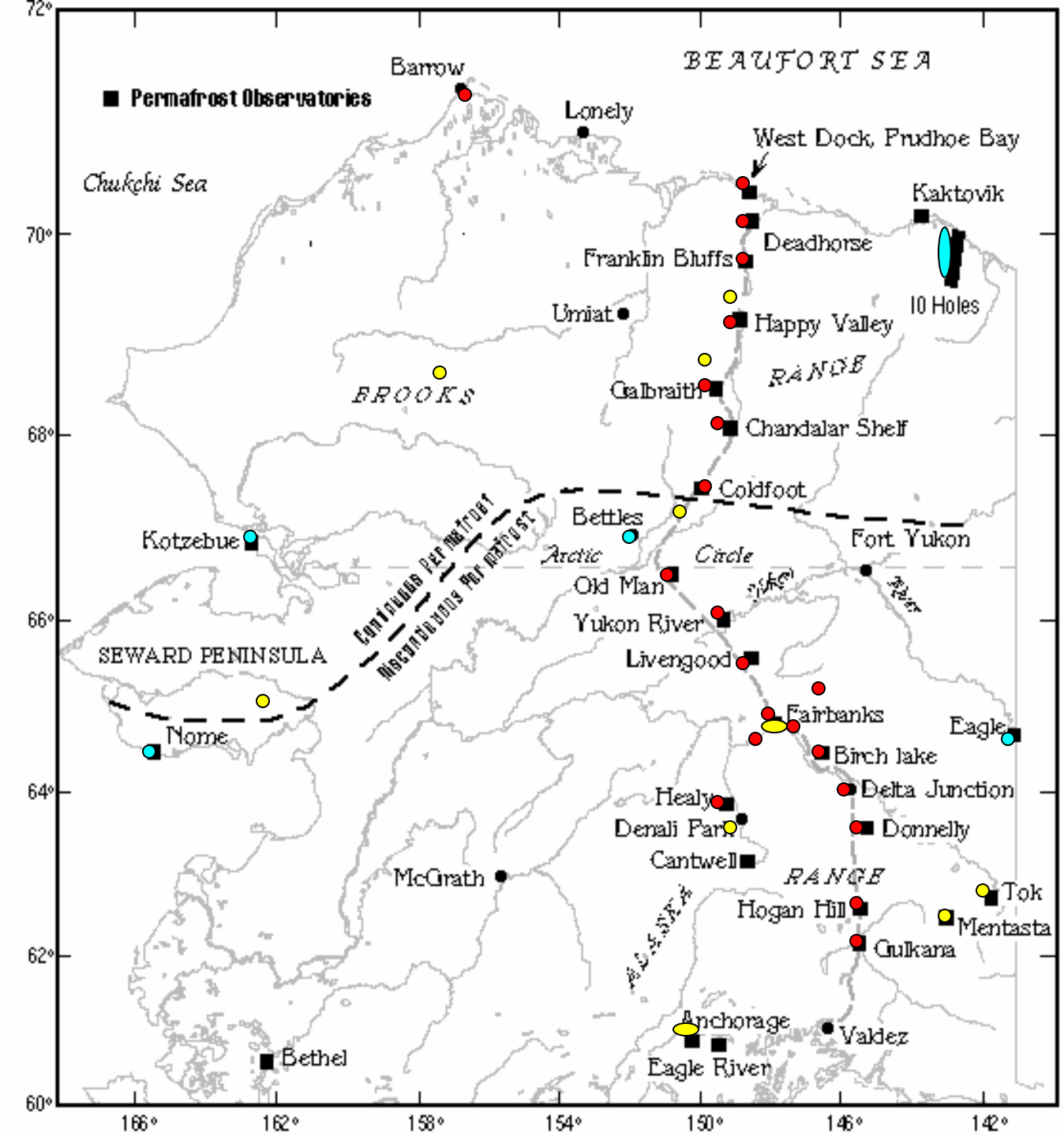
80% Ice content

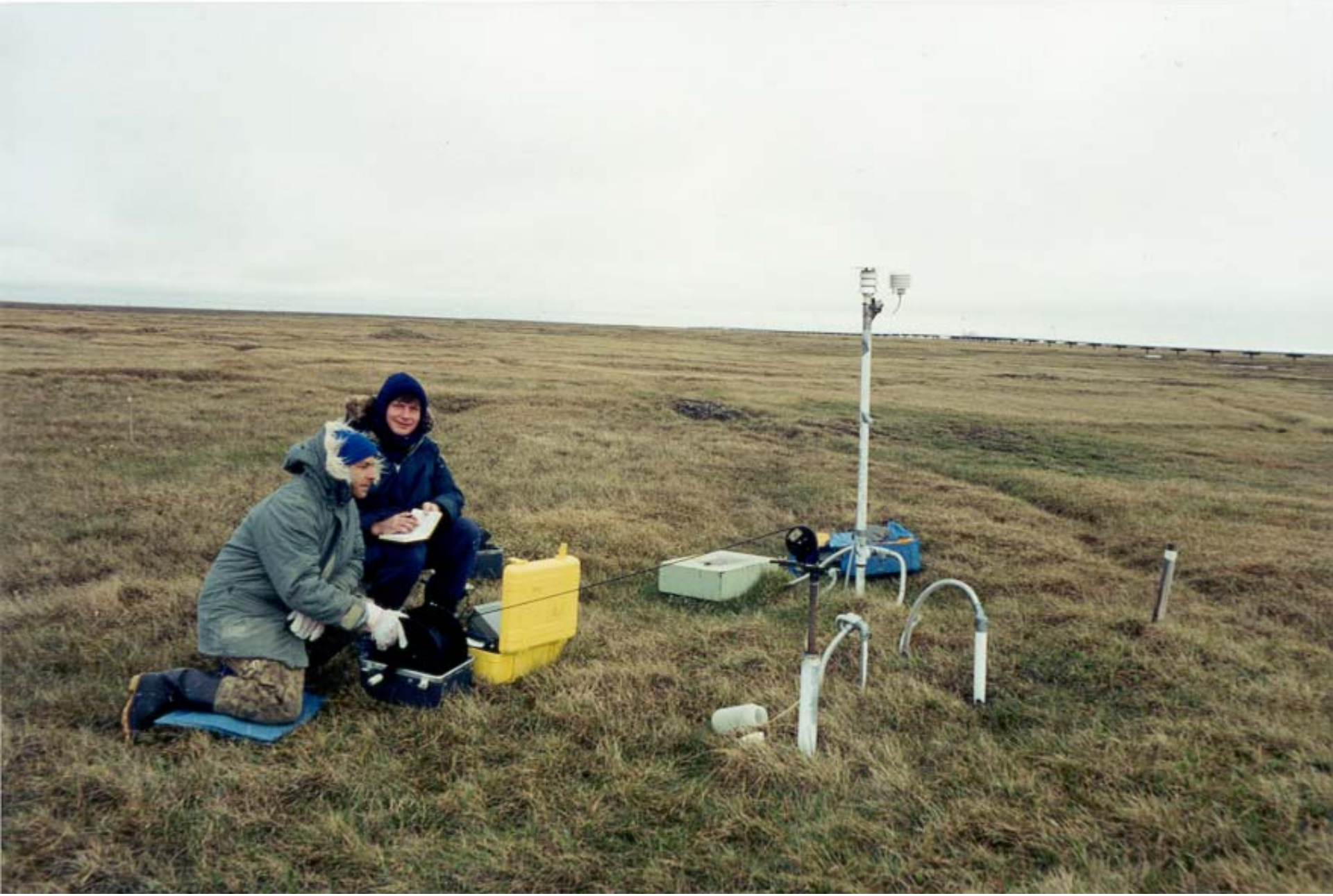
10 to 60 m thick

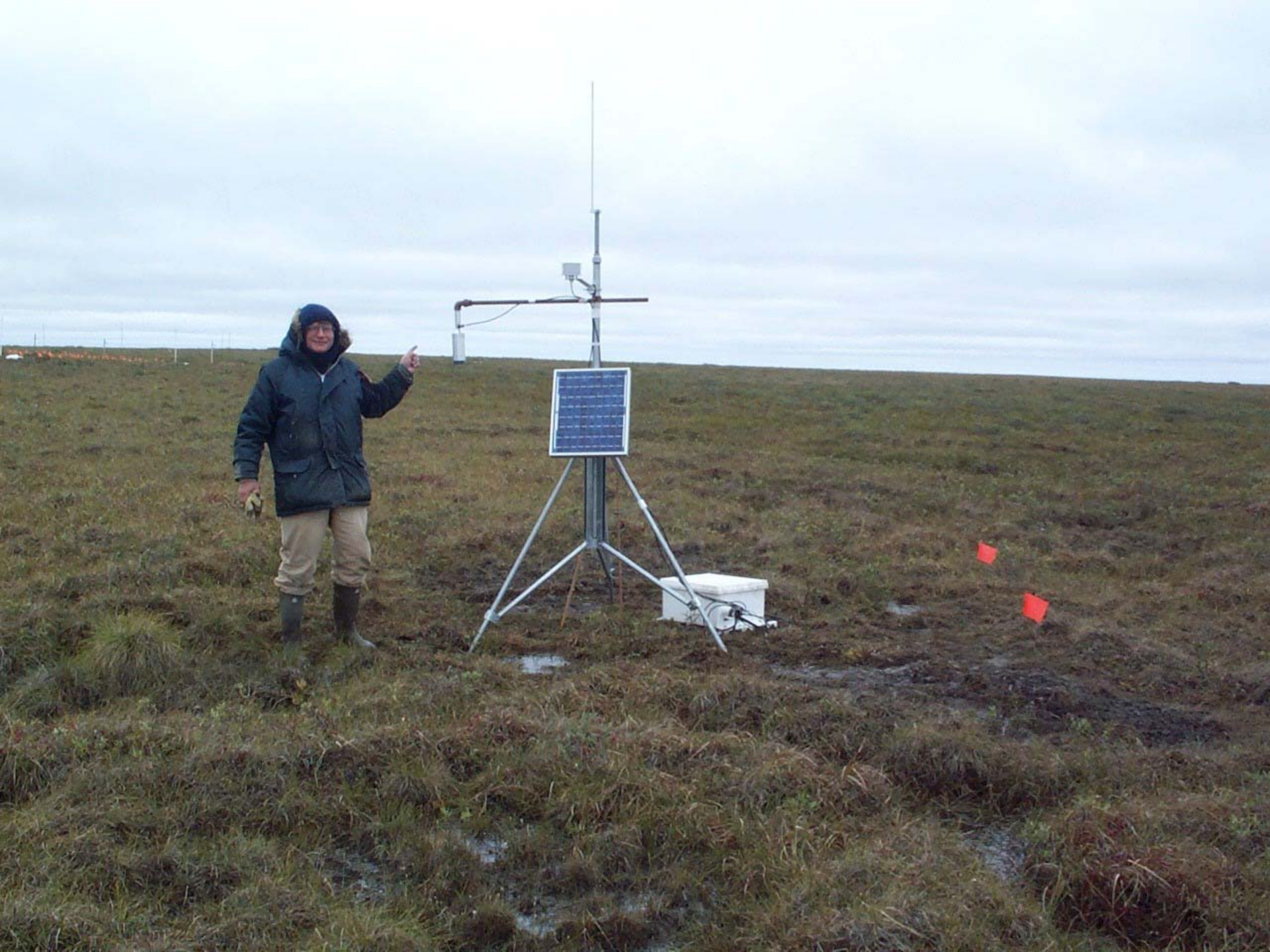
Covered with thin silty layer so-called “Protection Layer”

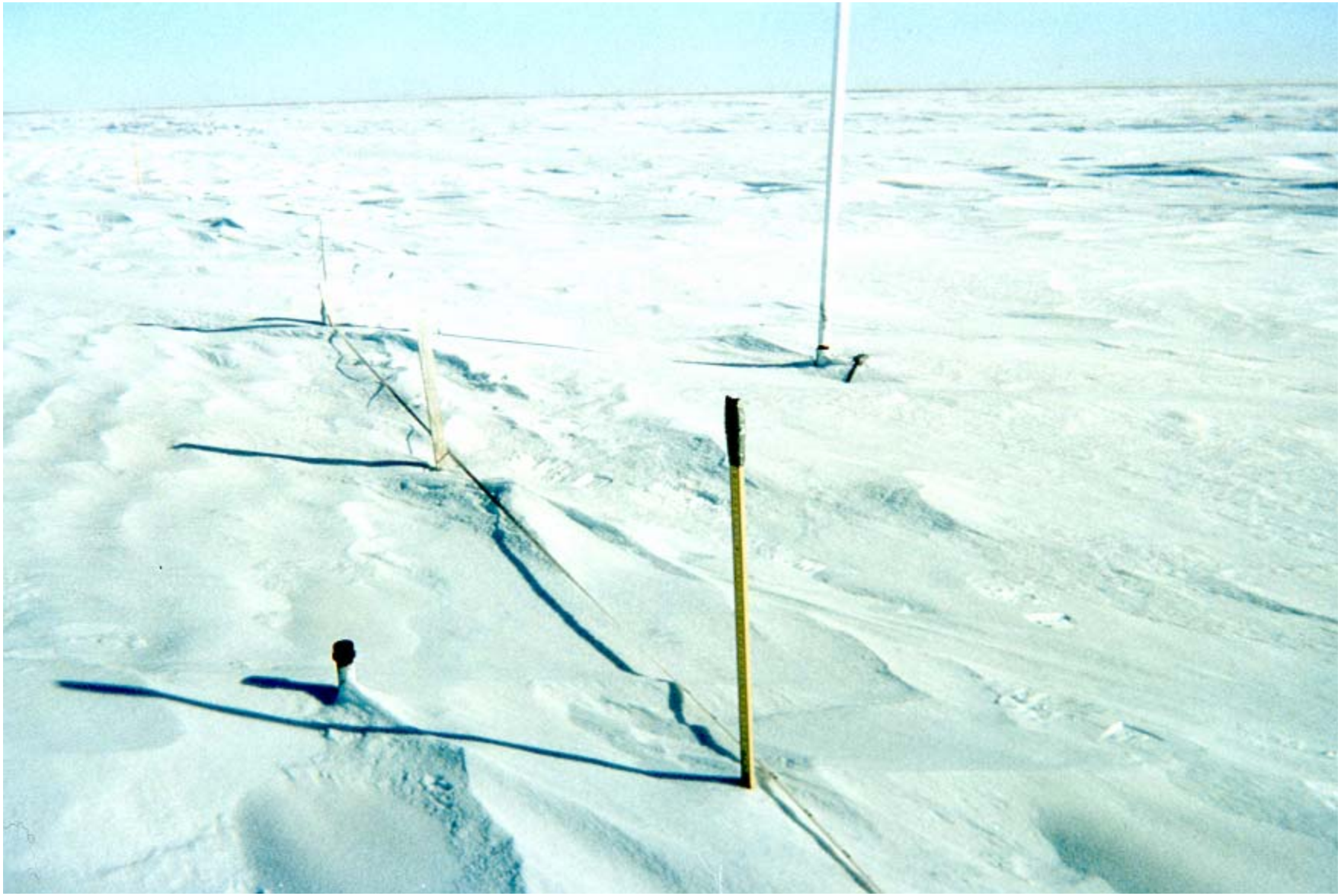
Occupies ~10 to 30% in East Siberia and Alaska

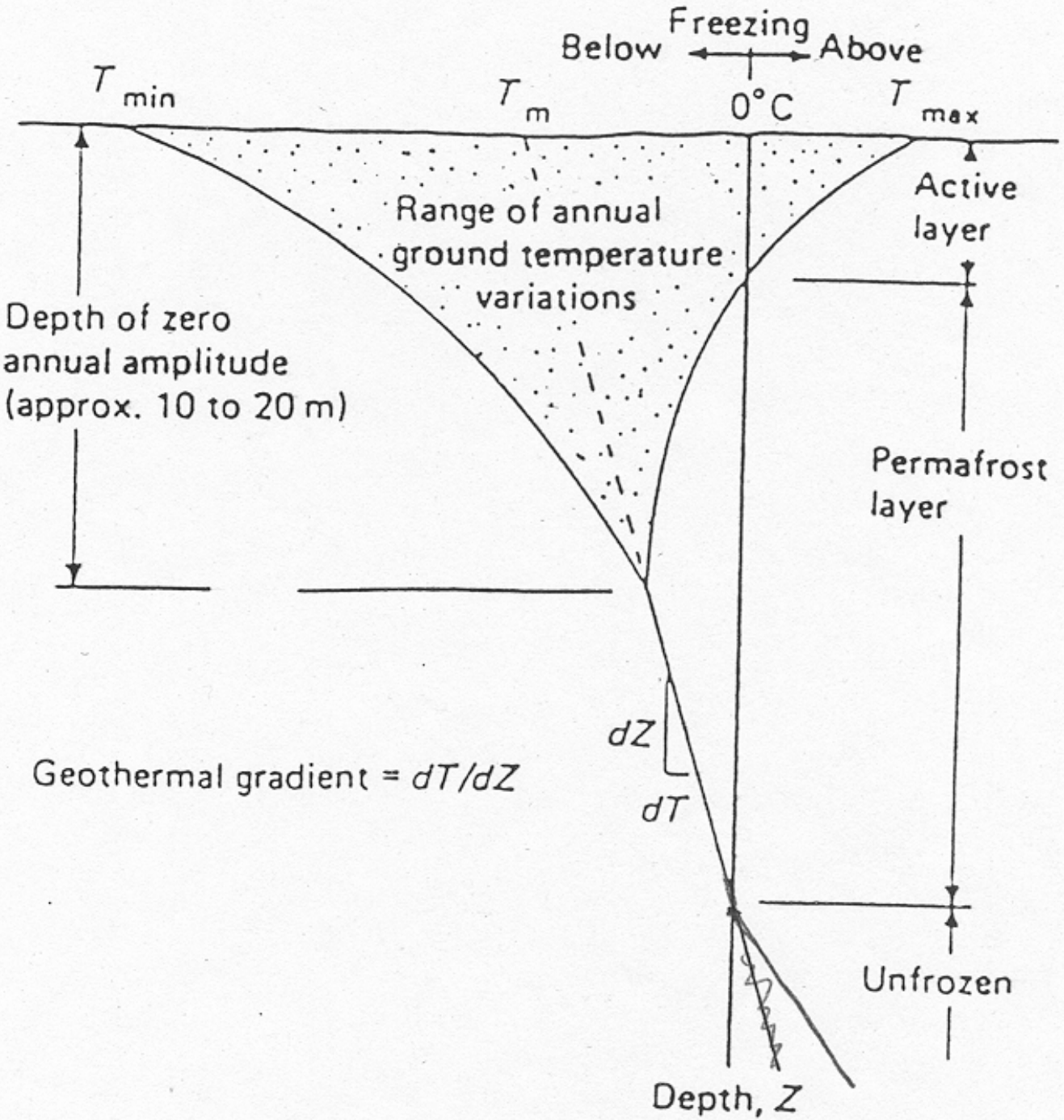
Field Measurements Program

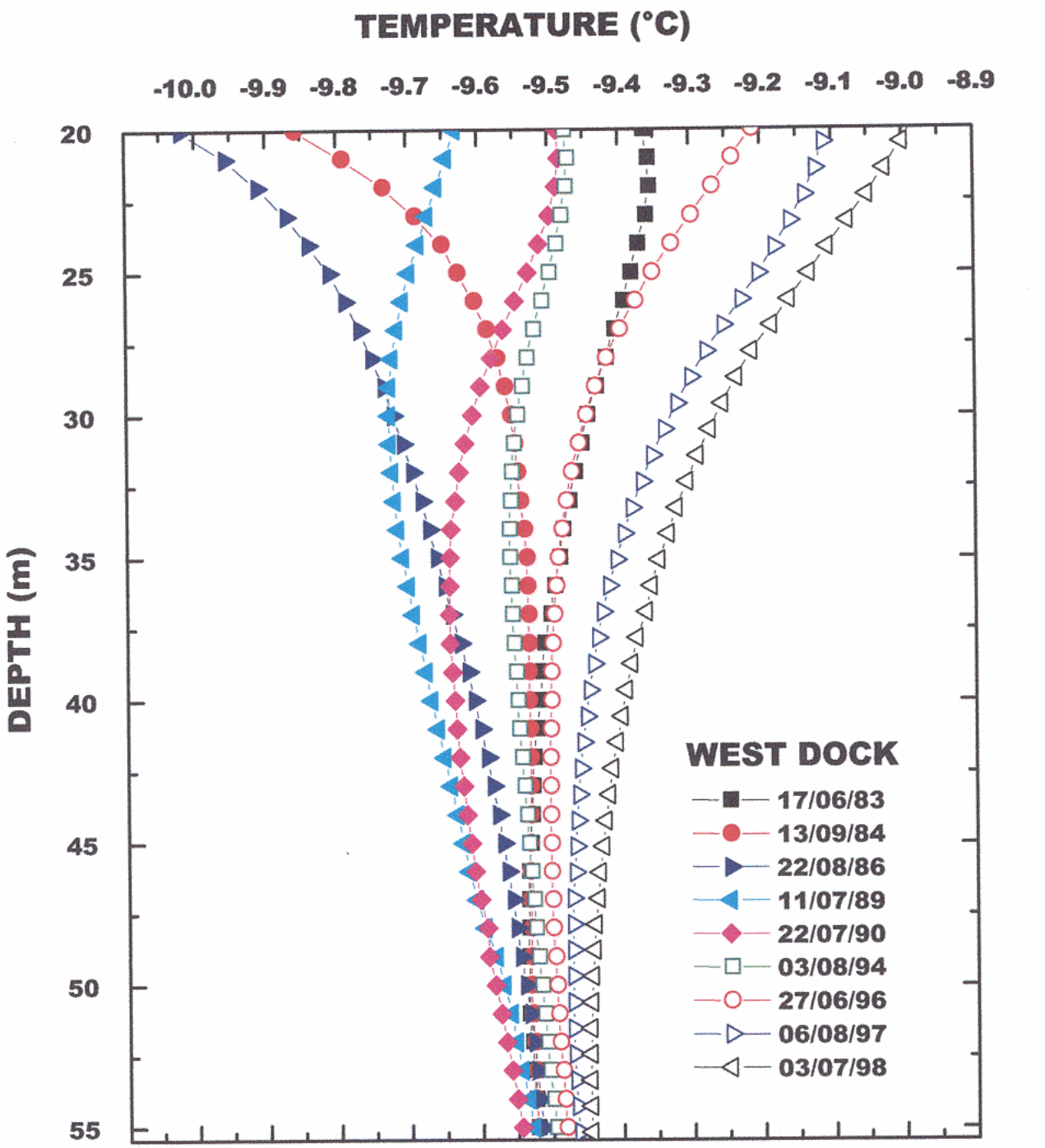

Permafrost Observatories
BEAUFORT SEA
Chukchi Sea
Barrow
Lonely
West Dock, Prudhoe Bay
Kaktovik
Deadhorse
Franklin Bluffs
10 Holes
Umiat
Happy Valley
BROOKS
RANGE
Galbraith
Chandalar Shelf
Coldfoot
Bettles
Kotzebue
Fort Yukon
Arctic
Circle
Old Man
Yukon River
Continuous Permafrost
Discontinuous Permafrost
SEWARD PENINSULA
Livengood
Fairbanks
Nome
Eagle
Birch lake
Delta Junction
Healy
Denali Park
Donnelly
Cantwell
McGrath
RANGE
Tok
Hogan Hill
Mentasta
Gulkana
ALASKA
Anchorage
Valdez
Bethel
Eagle River
72°
70°
68°
66°
64°
62°
60°
166°
162°
158°
154°
150°
146°
142°

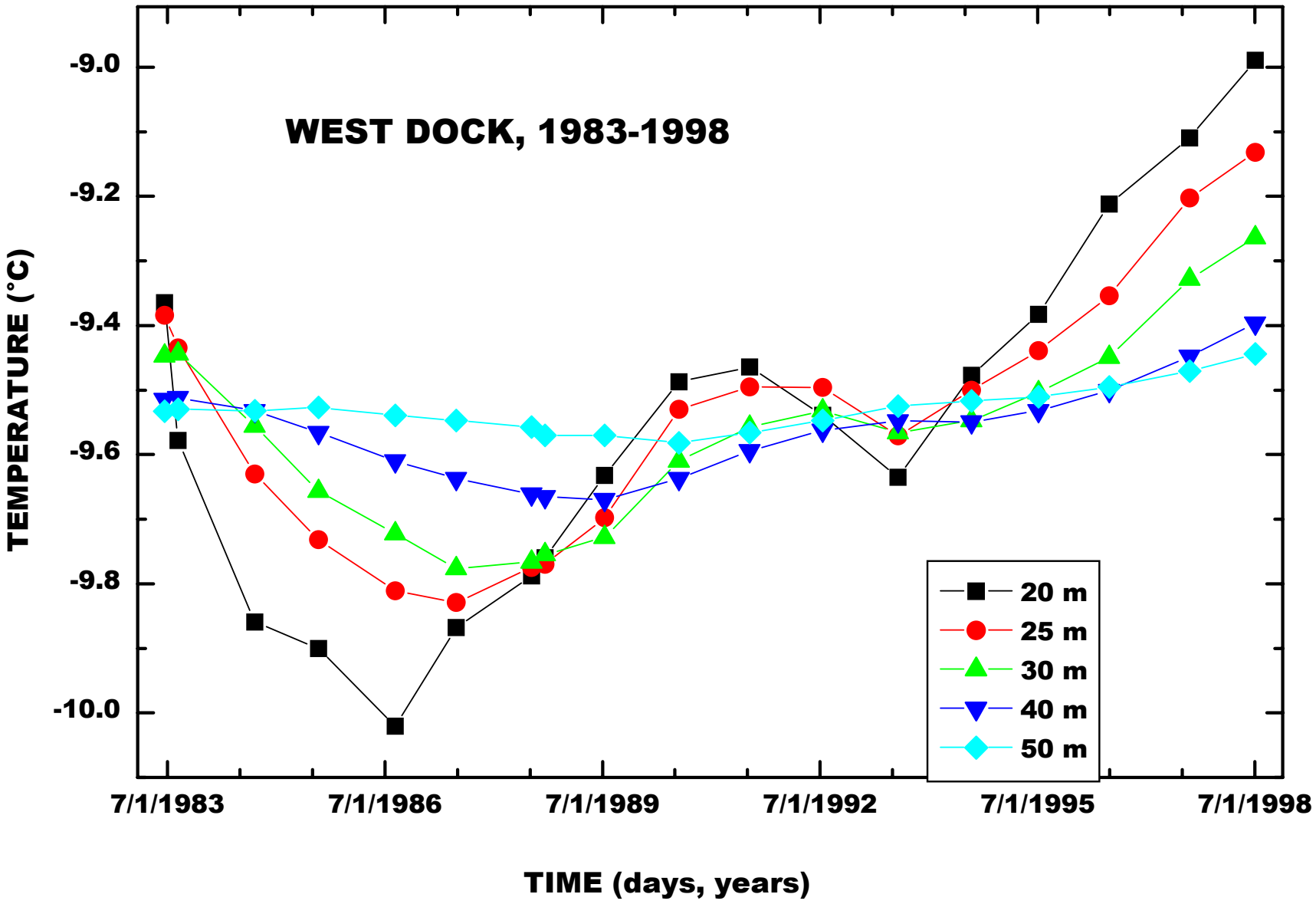


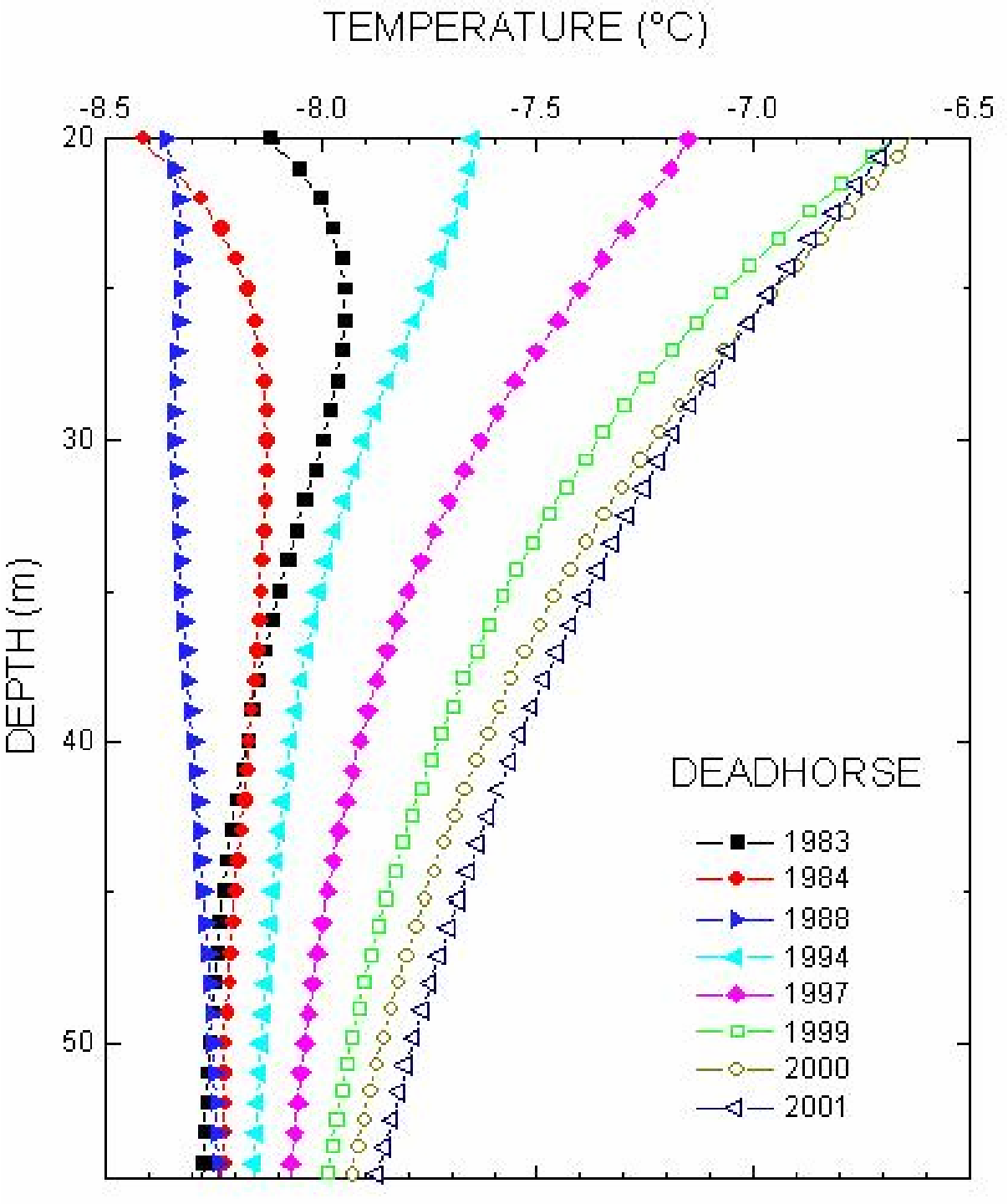


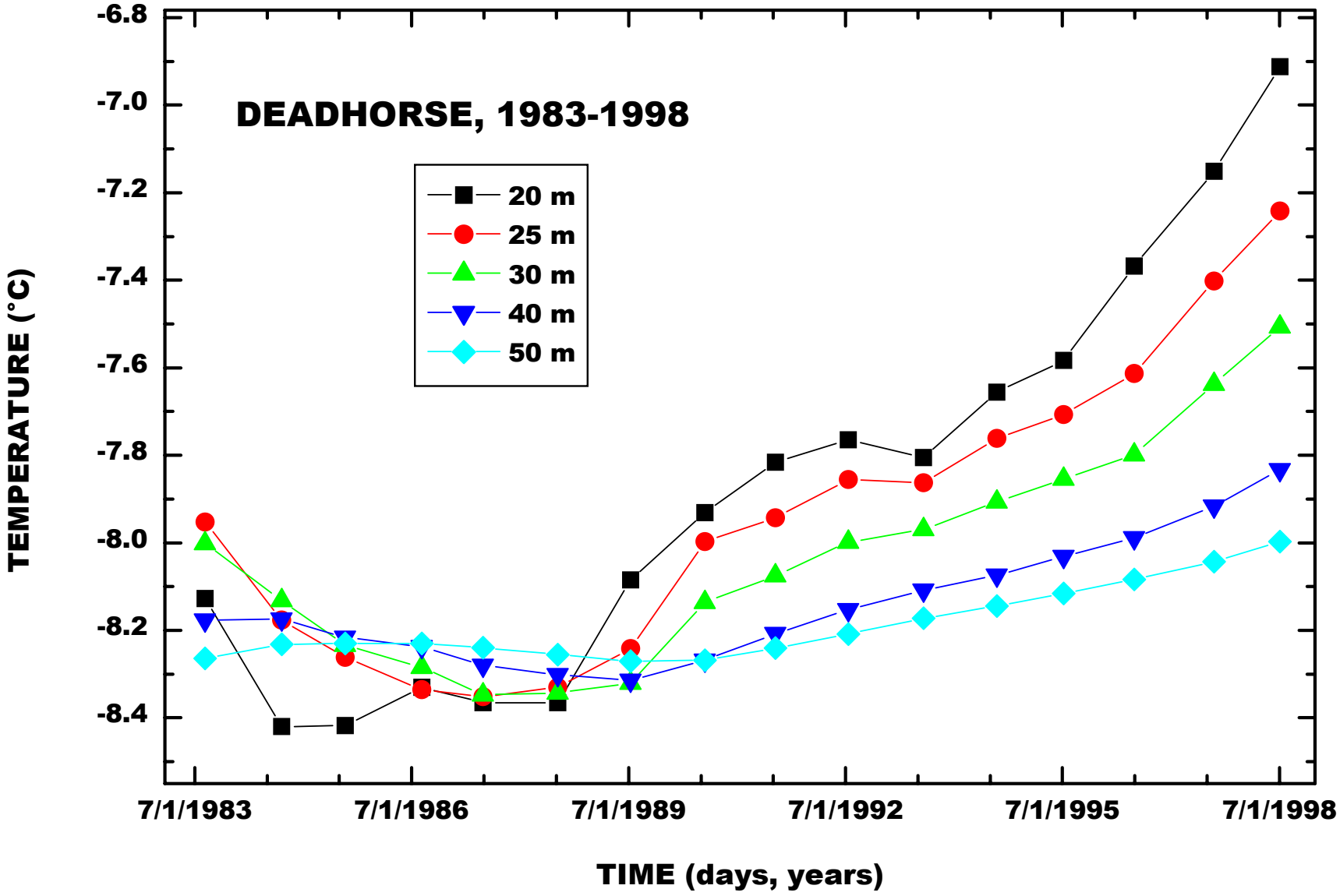


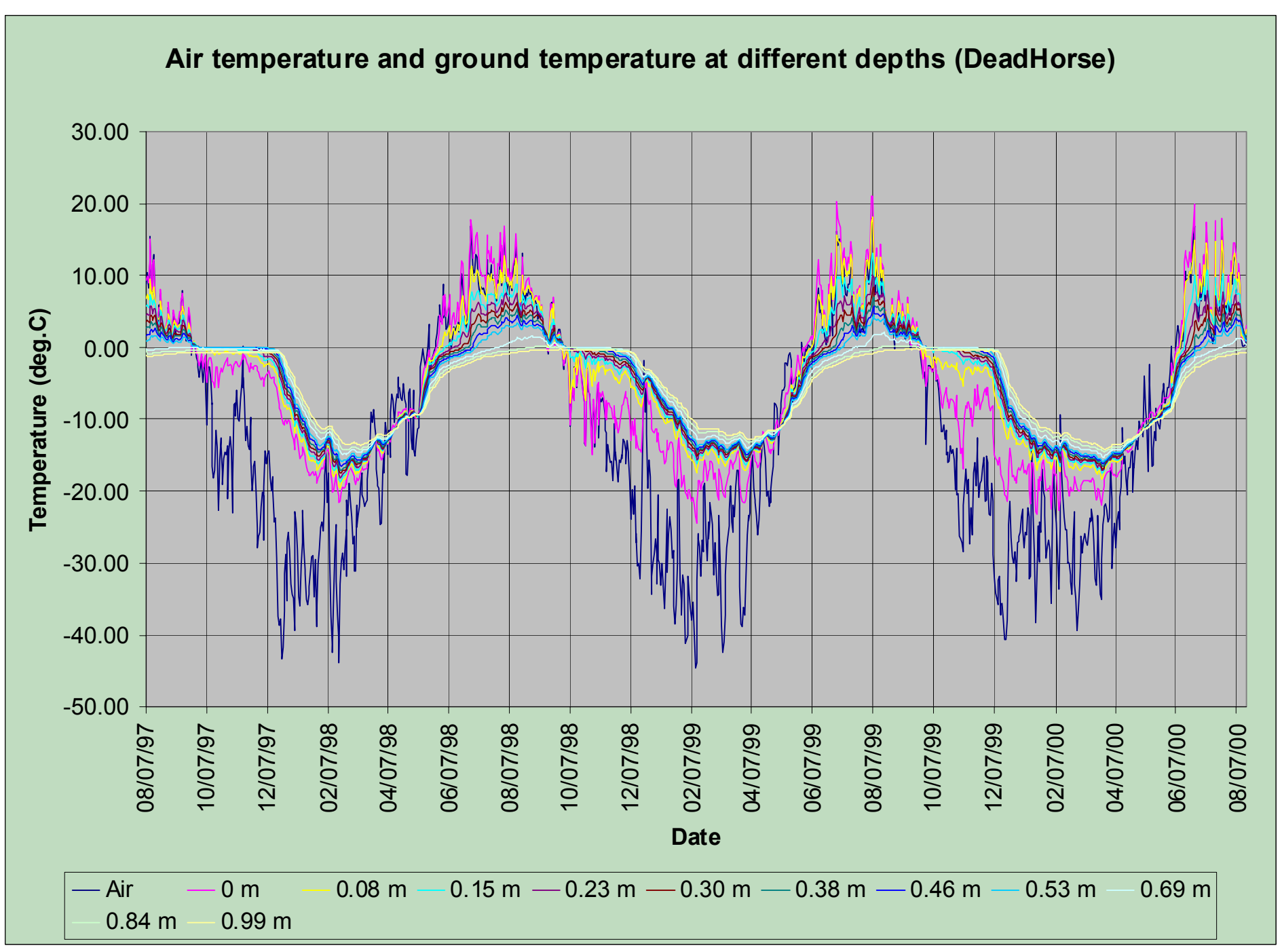

Freezing
Below
Above
T_{min}
T_m
0°C
T_{max}
Active layer
Range of annual ground temperature variations
Depth of zero annual amplitude (approx. 10 to 20 m)
Permafrost layer
dZ
dT
Geothermal gradient = dT/dZ
Unfrozen
Depth, Z

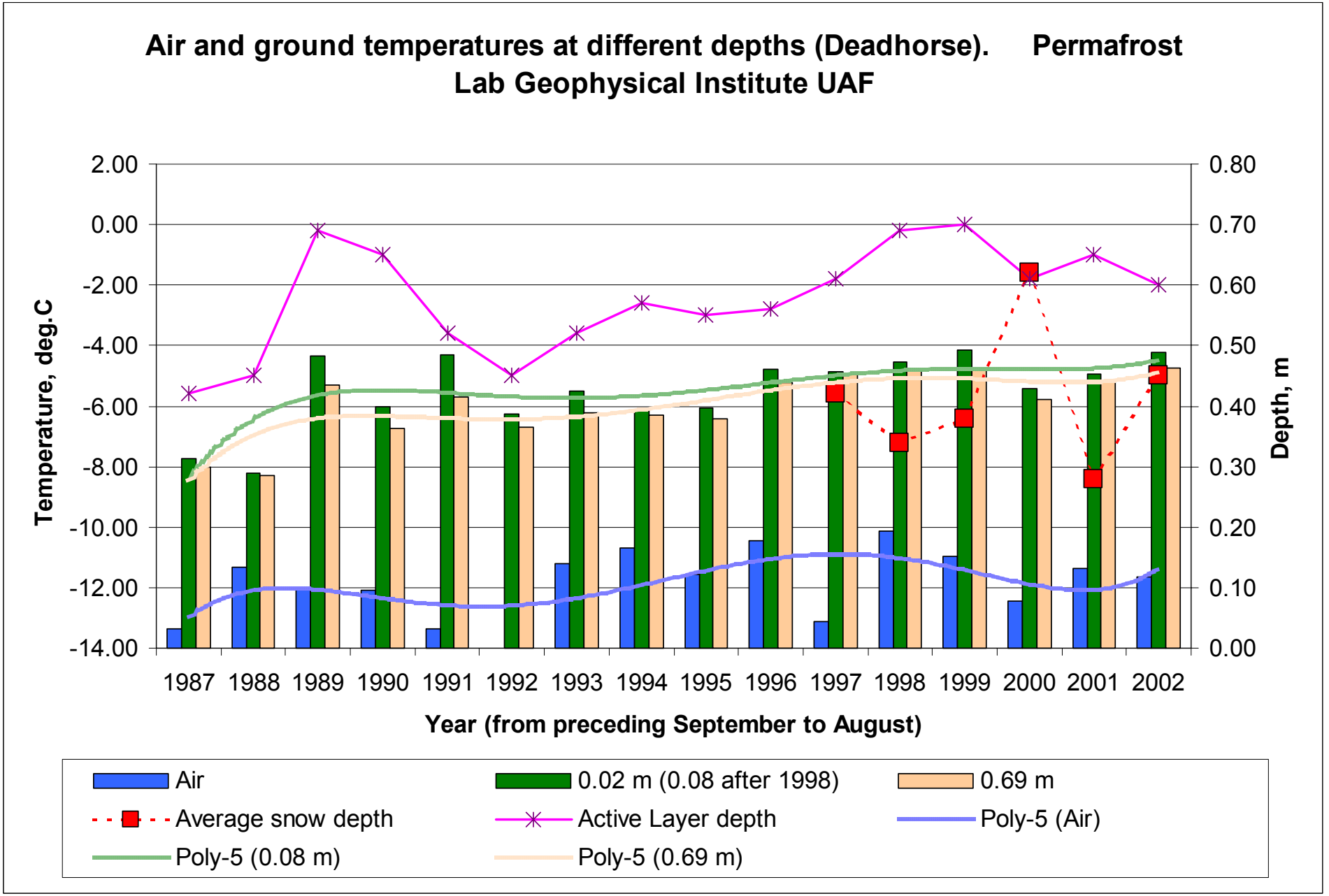

TEMPERATURE (°C)
-10.0
-9.9
-9.8
-9.7
-9.6
-9.5
-9.4
-9.3
-9.2
-9.1
-9.0
-8.9
DEPTH (m)
20
25
30
35
40
45
50
55
WEST DOCK
17/06/83
13/09/84
22/08/86
11/07/89
22/07/90
03/08/94
27/06/96
06/08/97
03/07/98

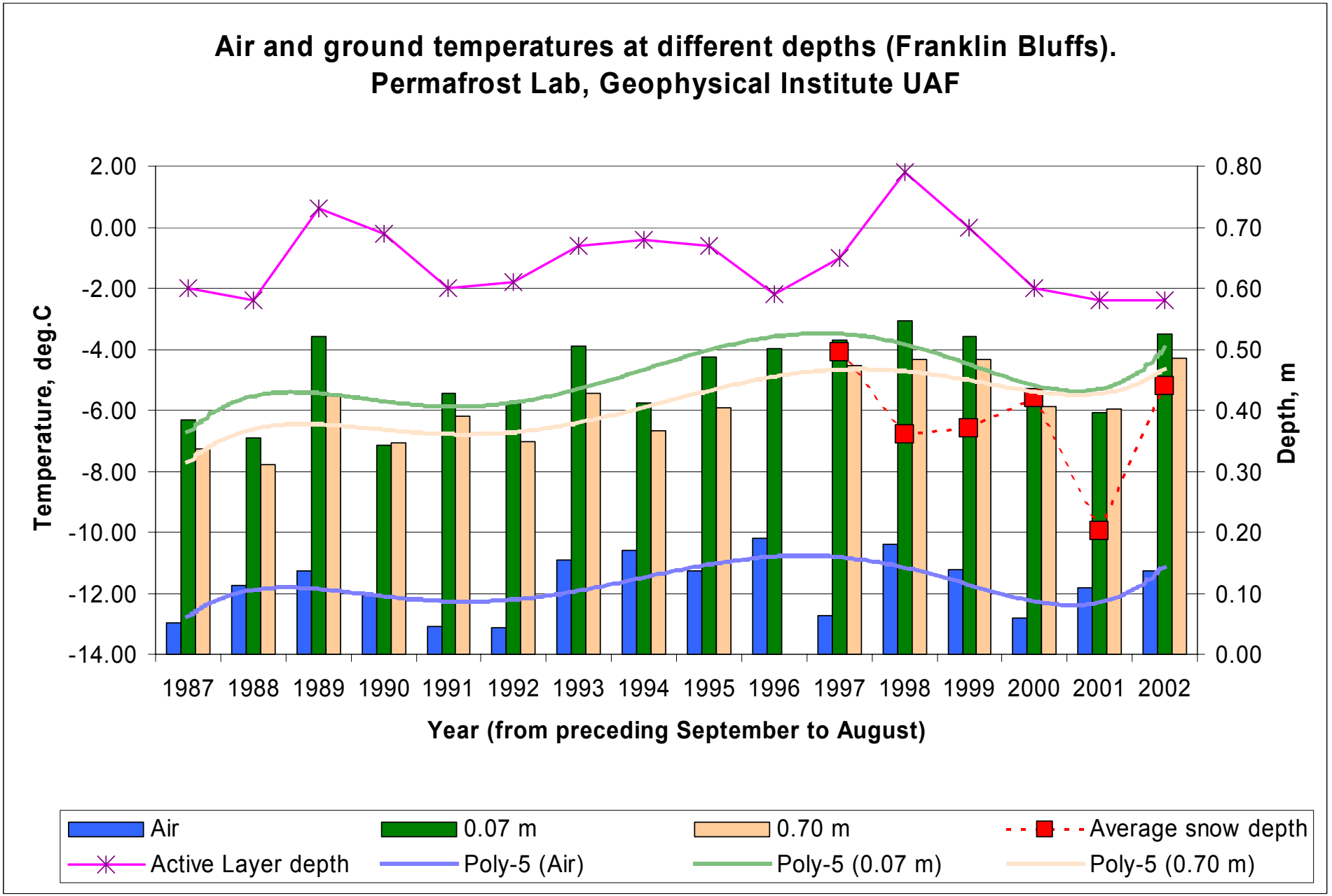

WEST DOCK, 1983-1998
TEMPERATURE (°C)
-9.0
-9.2
-9.4
-9.6
-9.8
-10.0
7/1/1983
7/1/1986
7/1/1989
7/1/1992
7/1/1995
7/1/1998
TIME (days, years)
20 m
25 m
30 m
40 m
50 m

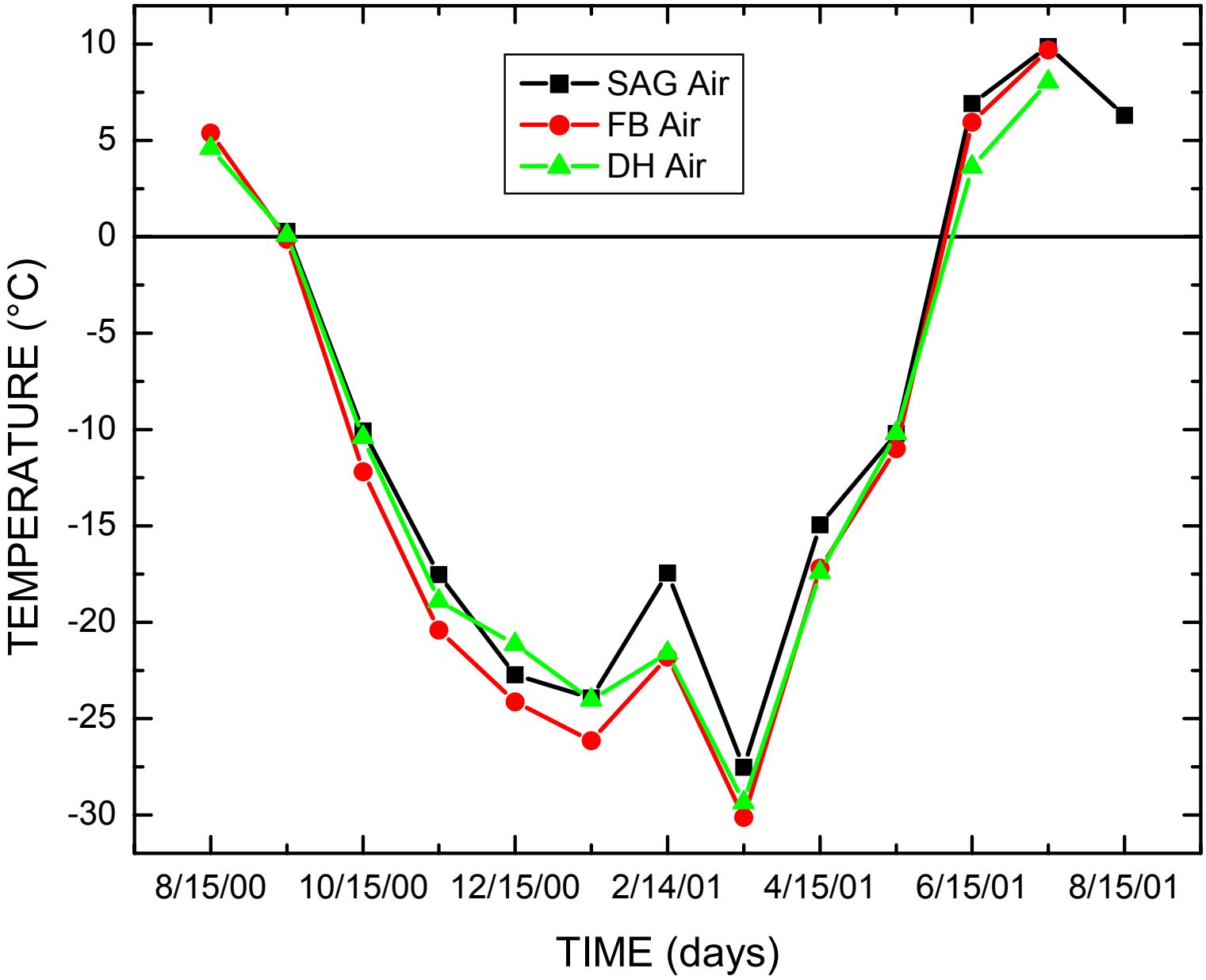

TEMPERATURE (°C)
-8.5
-8.0
-7.5
-7.0
-6.5
20
30
40
50
DEPTH (m)
DEADHORSE
1983
1984
1988
1994
1997
1999
2000
2001

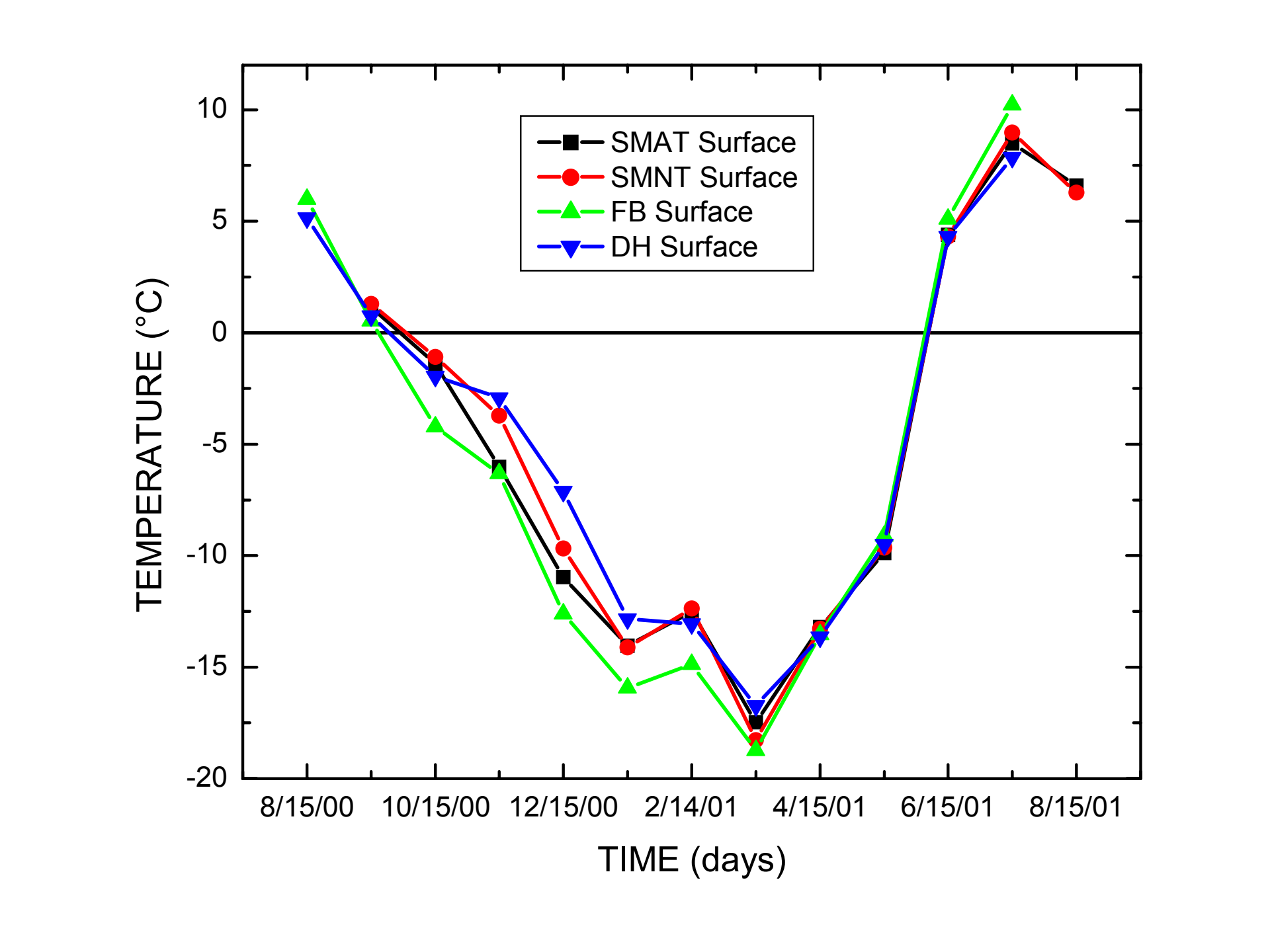

DEADHORSE, 1983-1998
20 m
25 m
30 m
40 m
50 m
TEMPERATURE (°C)
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
7/1/1983
7/1/1986
7/1/1989
7/1/1992
7/1/1995
7/1/1998
TIME (days, years)

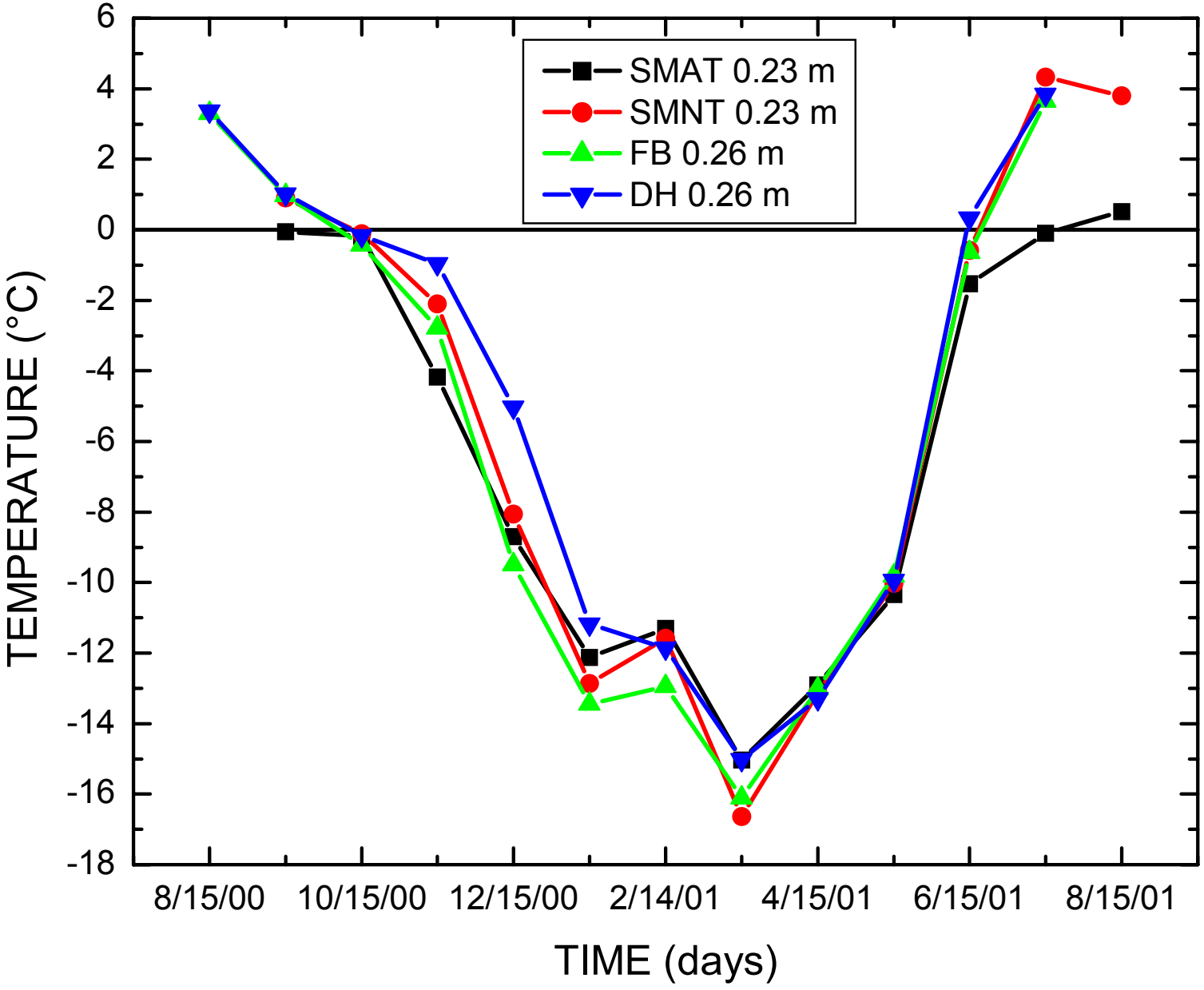

Air temperature and ground temperature at different depths (DeadHorse)
Temperature (deg.C)
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
08/07/97
10/07/97
12/07/97
02/07/98
04/07/98
06/07/98
08/07/98
10/07/98
12/07/98
02/07/99
04/07/99
06/07/99
08/07/99
10/07/99
12/07/99
02/07/00
04/07/00
06/07/00
08/07/00
Date
Air
0 m
0.08 m
0.15 m
0.23 m
0.30 m
0.38 m
0.46 m
0.53 m
0.69 m
0.84 m
0.99 m

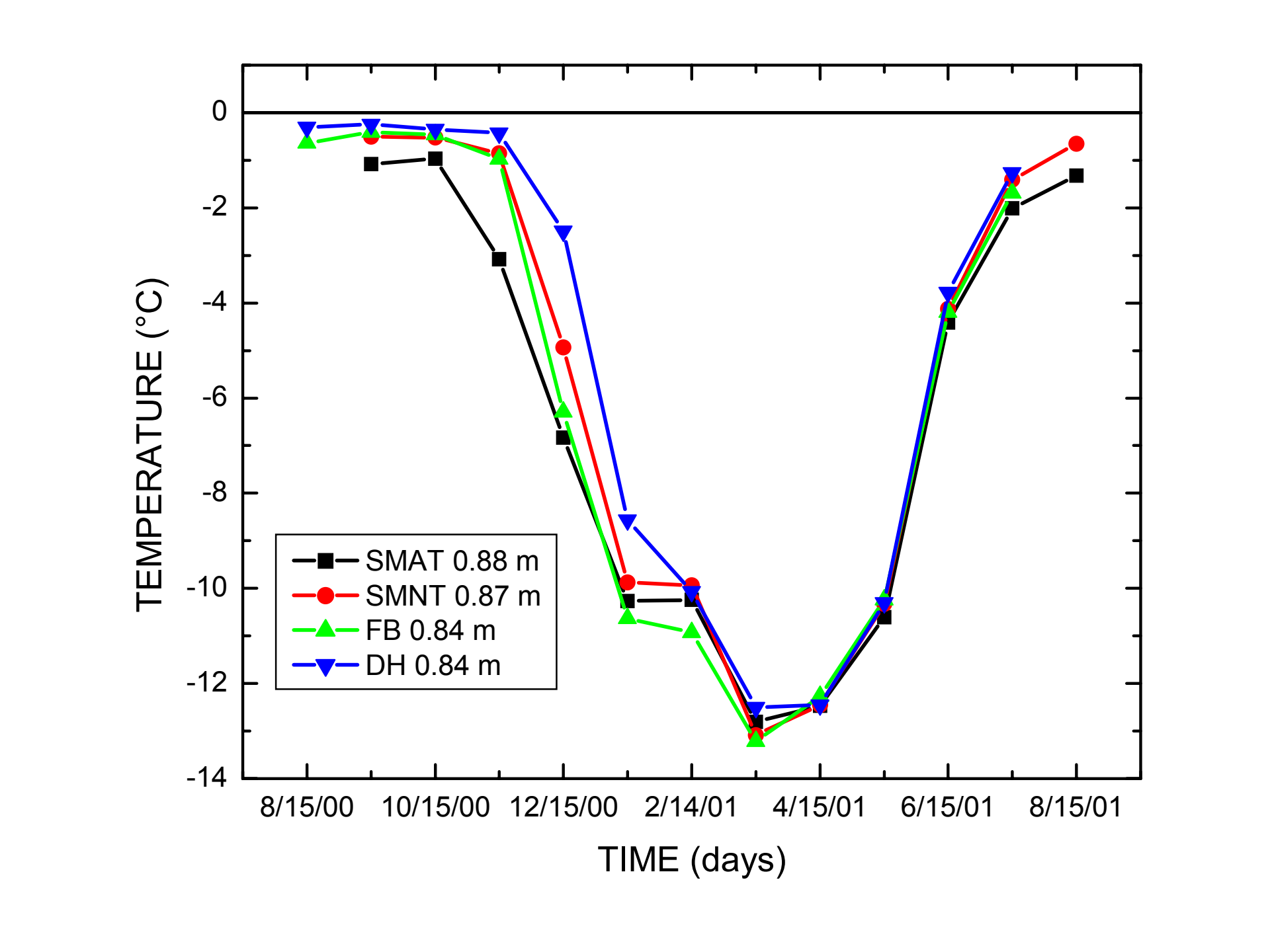

Air and ground temperatures at different depths (Deadhorse). Permafrost Lab Geophysical Institute UAF
Temperature, deg.C
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
Depth, m
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
Year (from preceding September to August)
Air
0.02 m (0.08 after 1998)
0.69 m
Average snow depth
Active Layer depth
Poly-5 (Air)
Poly-5 (0.08 m)
Poly-5 (0.69 m)


Air and ground temperatures at different depths (Franklin Bluffs).
Permafrost Lab, Geophysical Institute UAF
Temperature, deg.C
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
Depth, m
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
Year (from preceding September to August)
Air
0.07 m
0.70 m
Average snow depth
Active Layer depth
Poly-5 (Air)
Poly-5 (0.07 m)
Poly-5 (0.70 m)

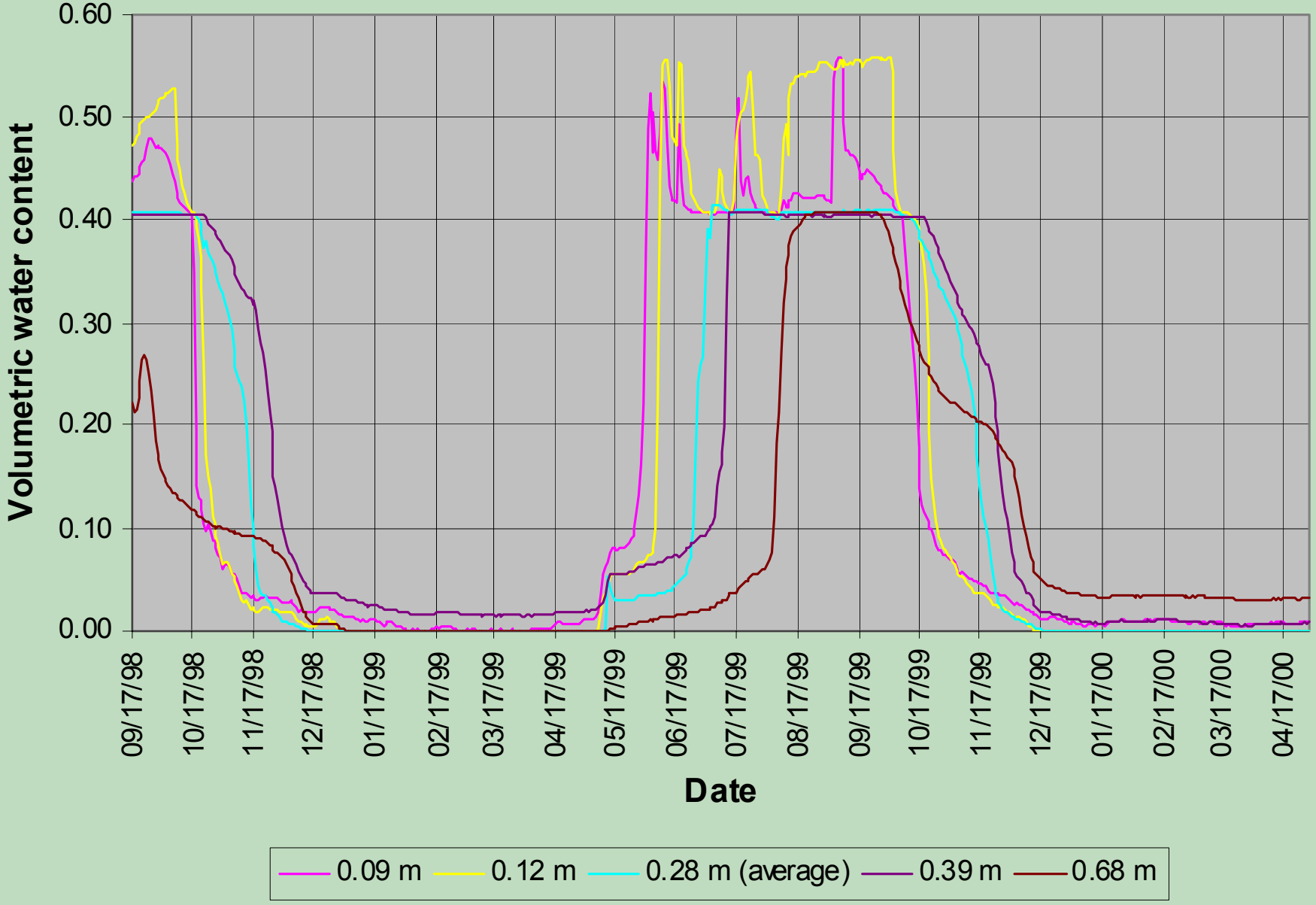

SAG Air
FB Air
DH Air
TEMPERATURE (°C)
10
5
0
-5
-10
-15
-20
-25
-30
8/15/00
10/15/00
12/15/00
2/14/01
4/15/01
6/15/01
8/15/01
TIME (days)

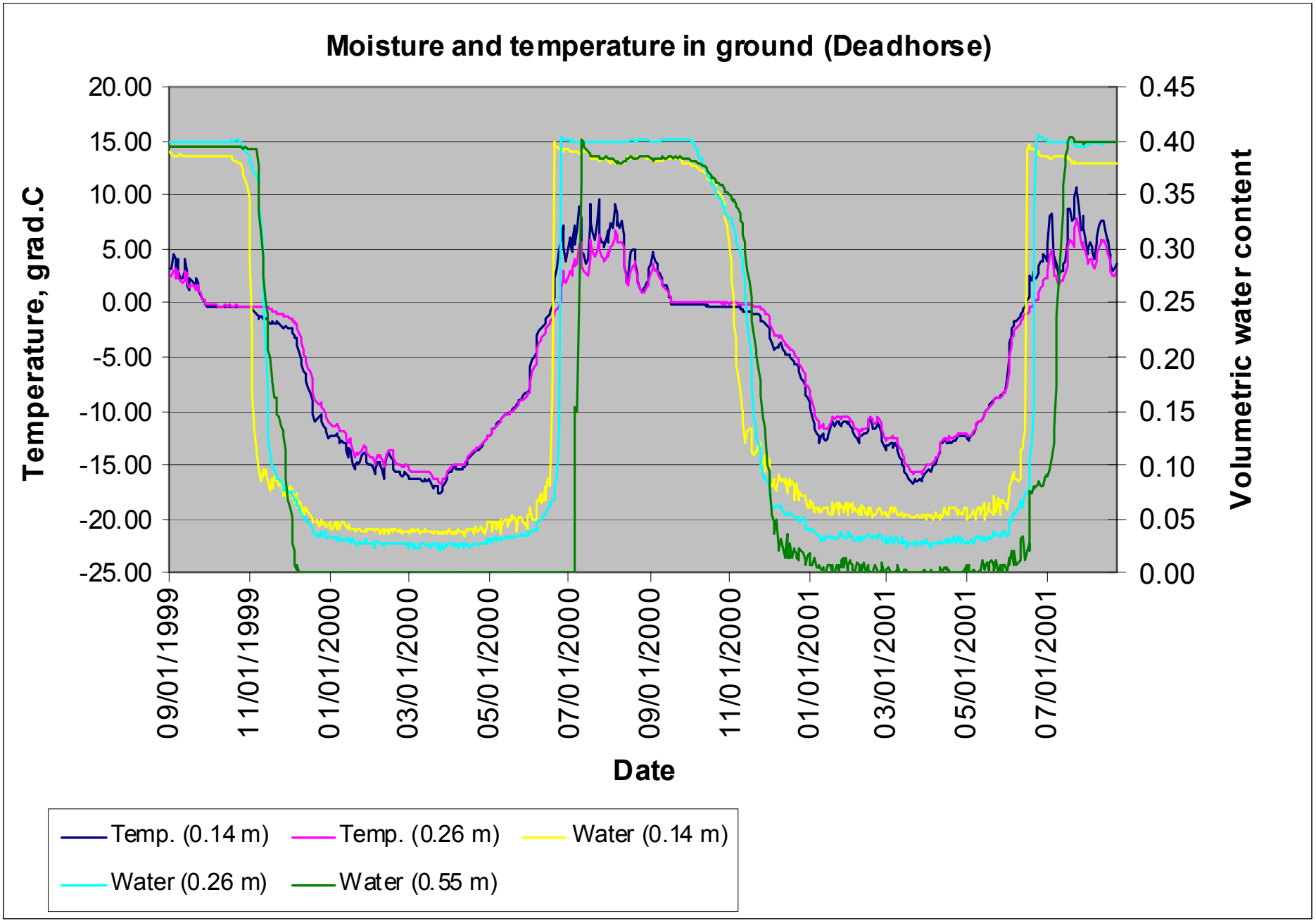

SMAT Surface
SMNT Surface
FB Surface
DH Surface
TEMPERATURE (°C)
10
5
0
-5
-10
-15
-20
8/15/00
10/15/00
12/15/00
2/14/01
4/15/01
6/15/01
8/15/01
TIME (days)

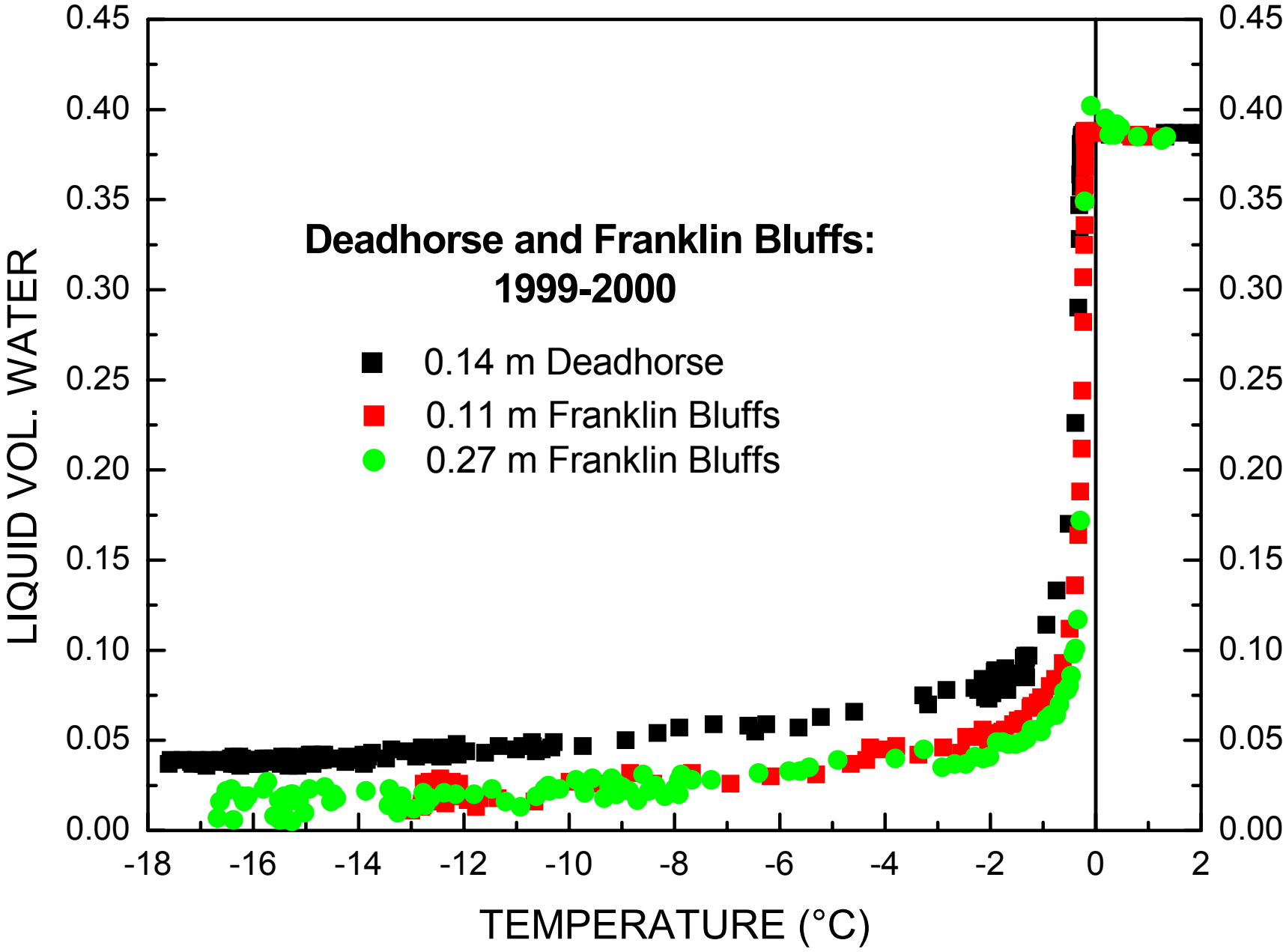

SMAT 0.23 m
SMNT 0.23 m
FB 0.26 m
DH 0.26 m
TEMPERATURE (°C)
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
8/15/00
10/15/00
12/15/00
2/14/01
4/15/01
6/15/01
8/15/01
TIME (days)

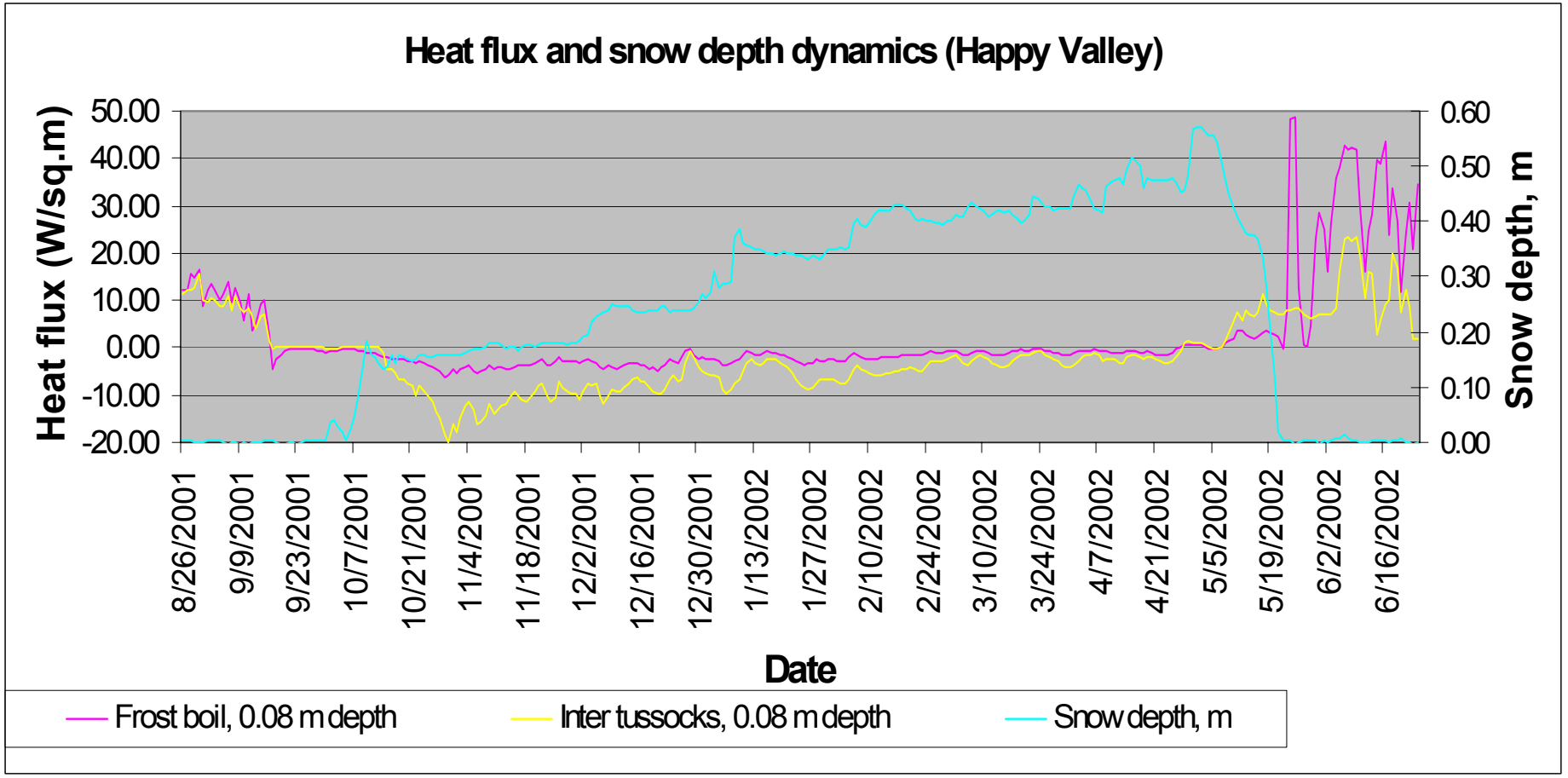

0
-2
-4
-6
-8
-10
-12
-14
TEMPERATURE (°C)
8/15/00
10/15/00
12/15/00
2/14/01
4/15/01
6/15/01
8/15/01
TIME (days)
SMAT 0.88 m
SMNT 0.87 m
FB 0.84 m
DH 0.84 m

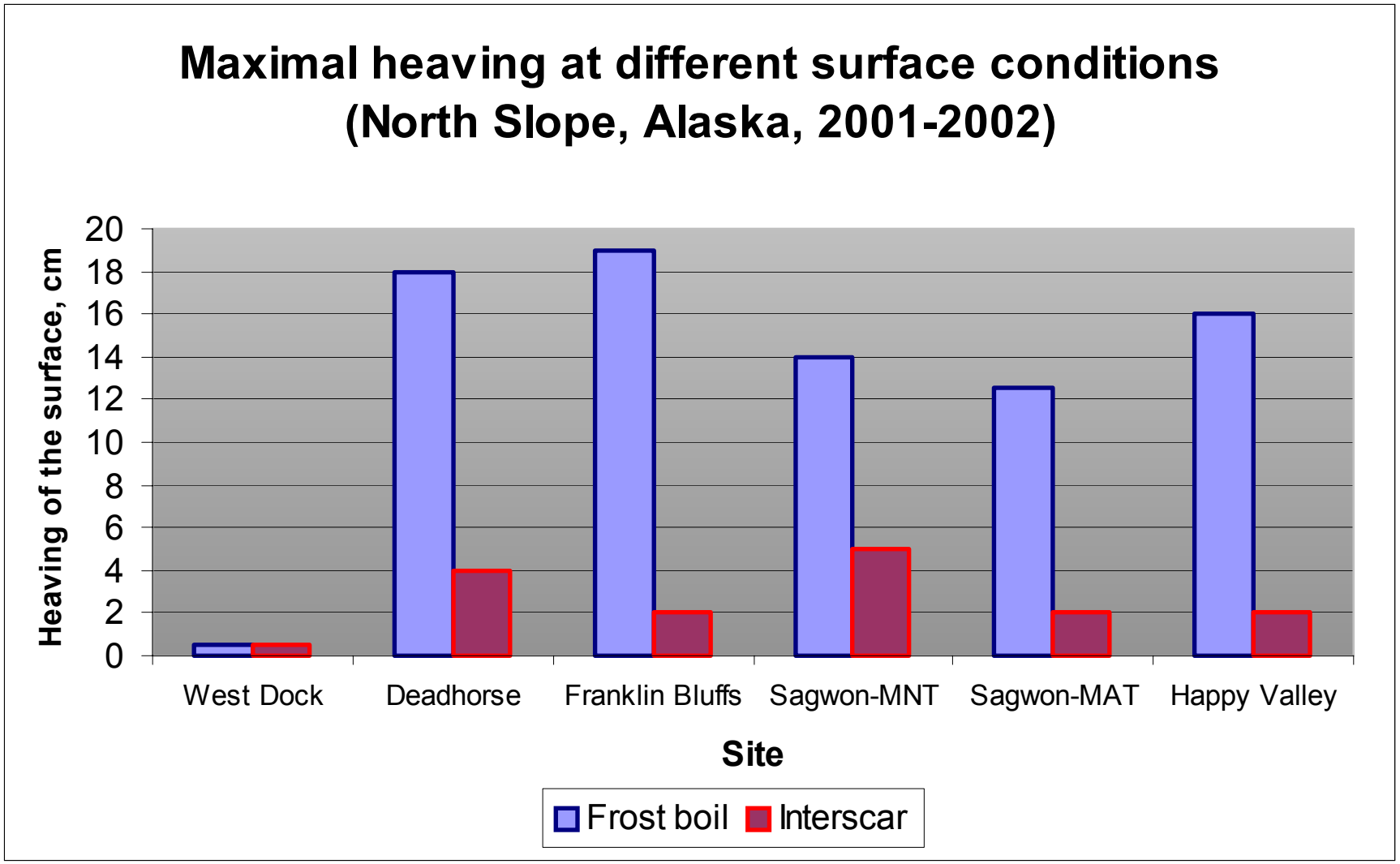
Ground moisture (Toolik Lake)

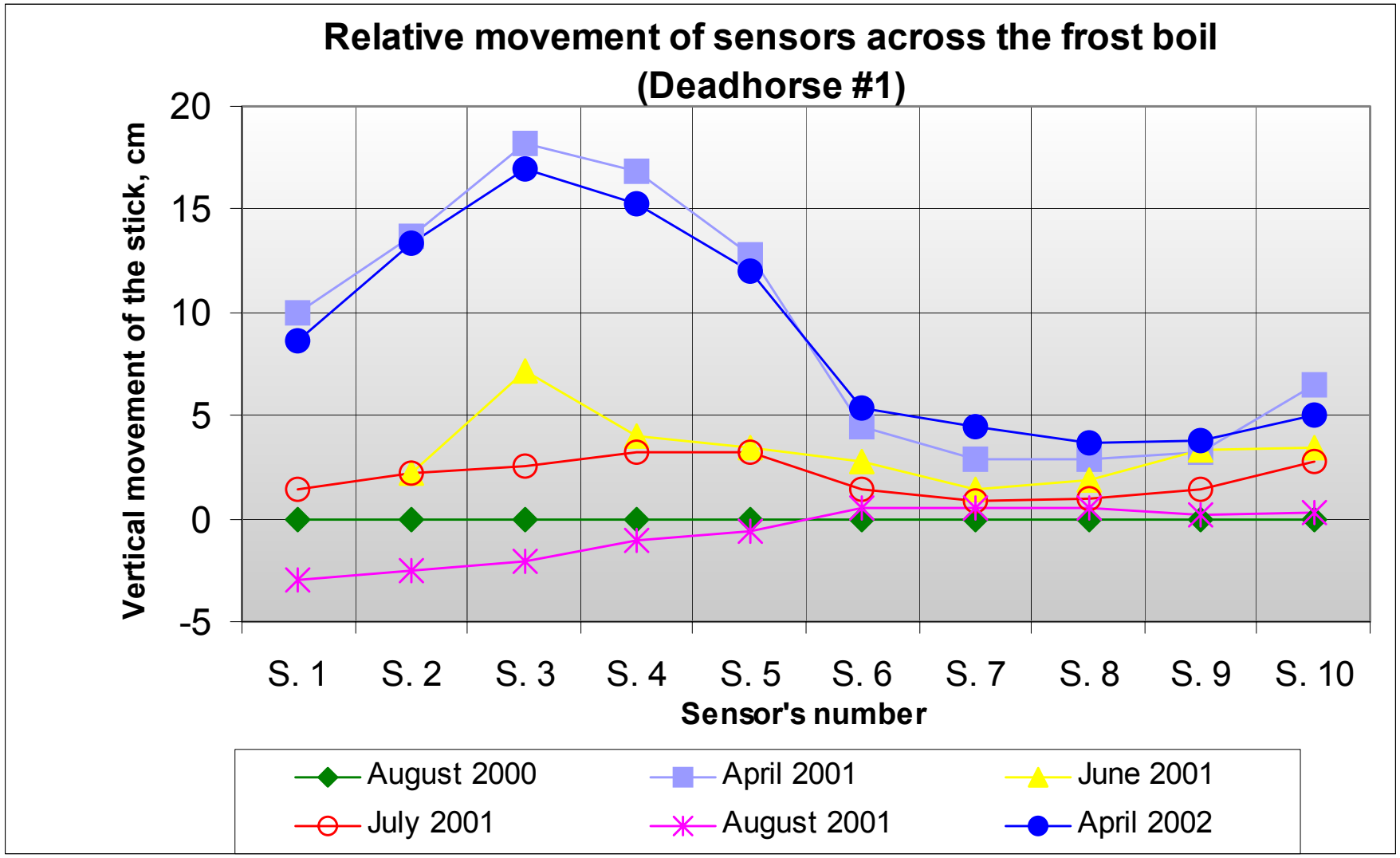


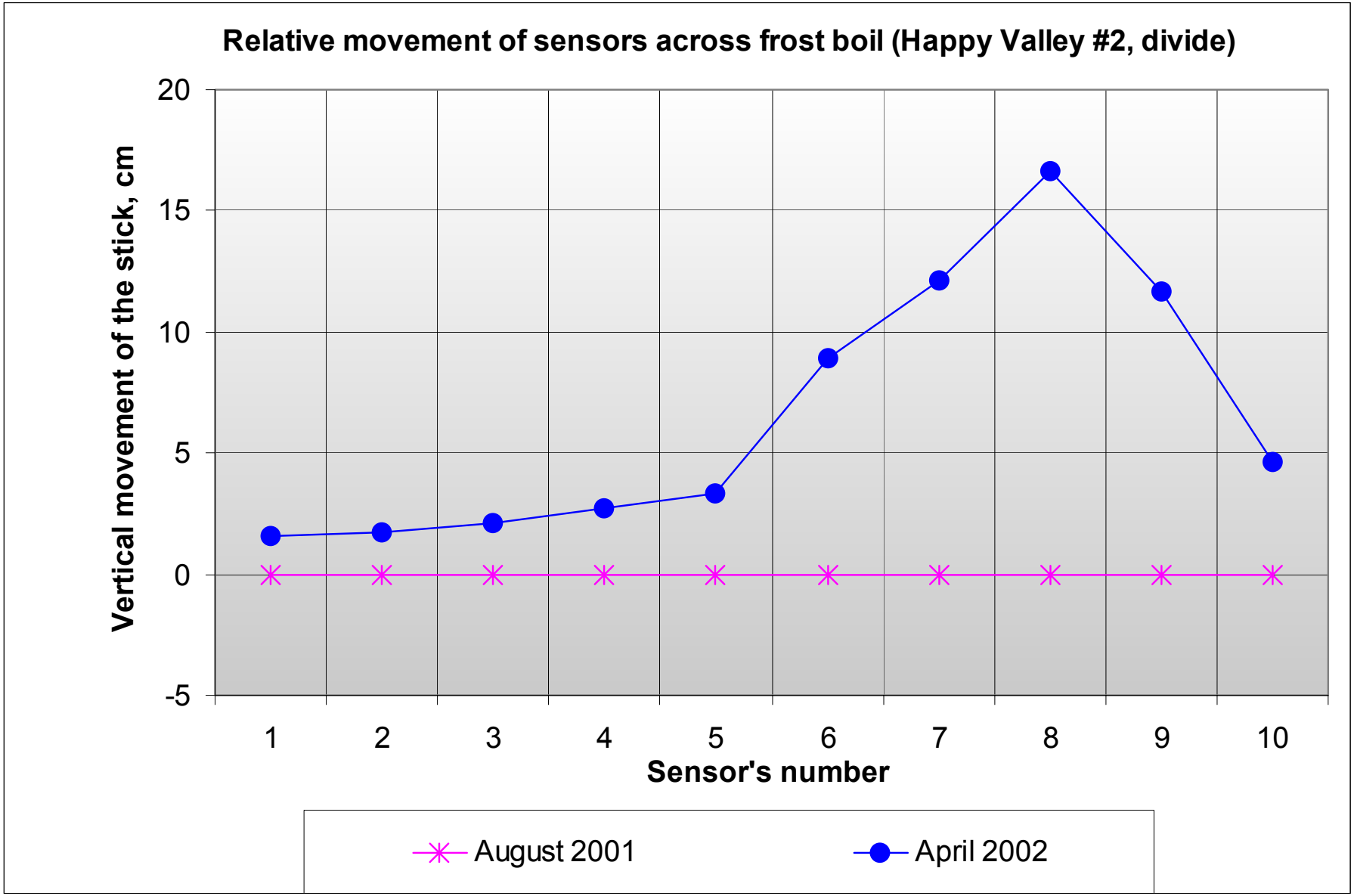

Moisture and temperature in ground (Deadhorse)
Temperature, grad.C
Volumetric water content
Date
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
09/01/1999
11/01/1999
01/01/2000
03/01/2000
05/01/2000
07/01/2000
09/01/2000
11/01/2000
01/01/2001
03/01/2001
05/01/2001
07/01/2001
Temp. (0.14 m)
Temp. (0.26 m)
Water (0.14 m)
Water (0.26 m)
Water (0.55 m)

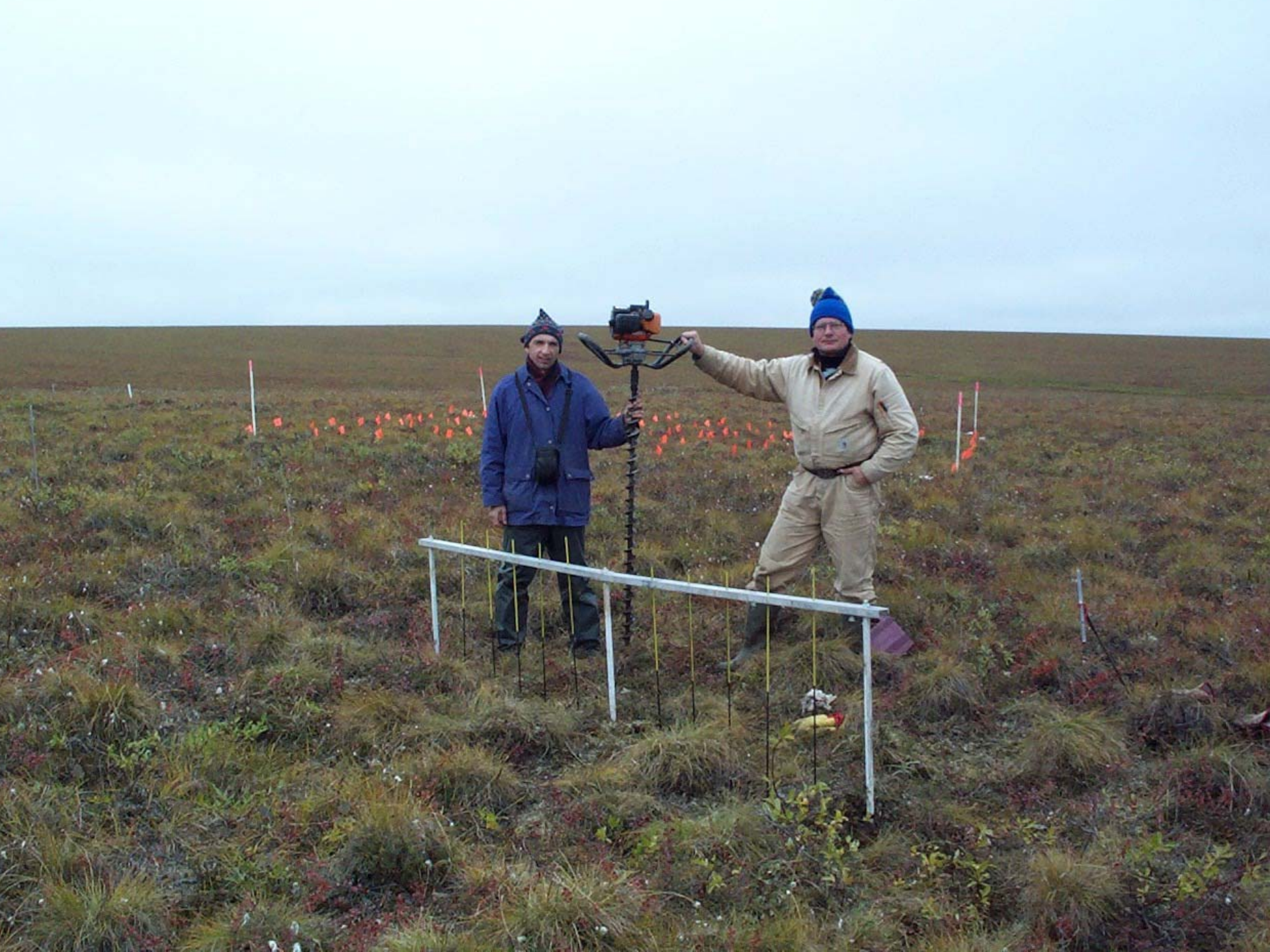

Deadhorse and Franklin Bluffs:
1999-2000
0.14 m Deadhorse
0.11 m Franklin Bluffs
0.27 m Franklin Bluffs
LIQUID VOL. WATER
TEMPERATURE (°C)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2

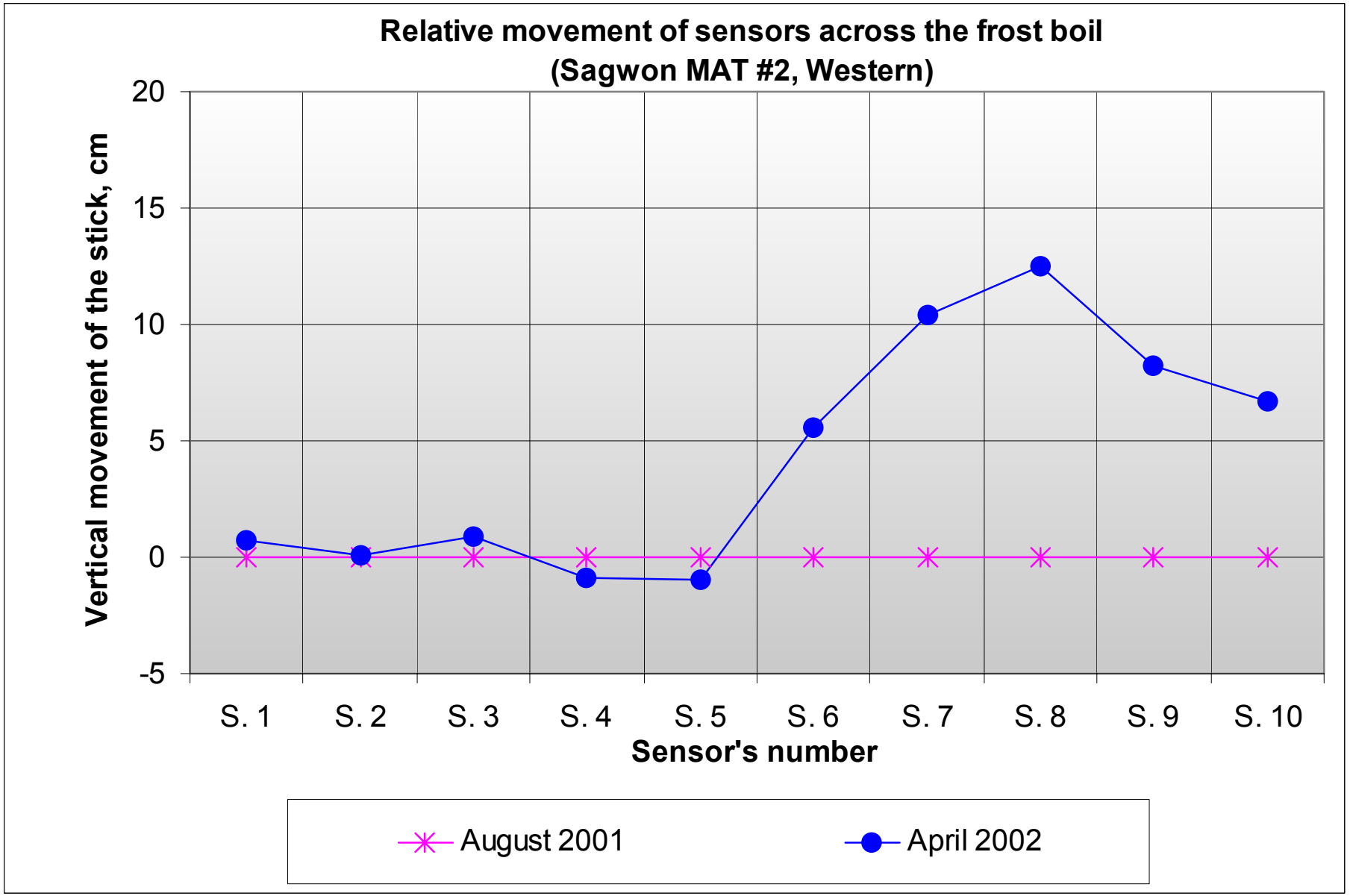

Heat flux and snow depth dynamics (Happy Valley)
Heat flux (W/sq.m)
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
Snow depth, m
0.60
0.50
0.40
0.30
0.20
0.10
0.00
8/26/2001
9/9/2001
9/23/2001
10/7/2001
10/21/2001
11/4/2001
11/18/2001
12/2/2001
12/16/2001
12/30/2001
1/13/2002
1/27/2002
2/10/2002
2/24/2002
3/10/2002
3/24/2002
4/7/2002
4/21/2002
5/5/2002
5/19/2002
6/2/2002
6/16/2002
Date
Frost boil, 0.08 m depth
Inter tussocks, 0.08 m depth
Snow depth, m

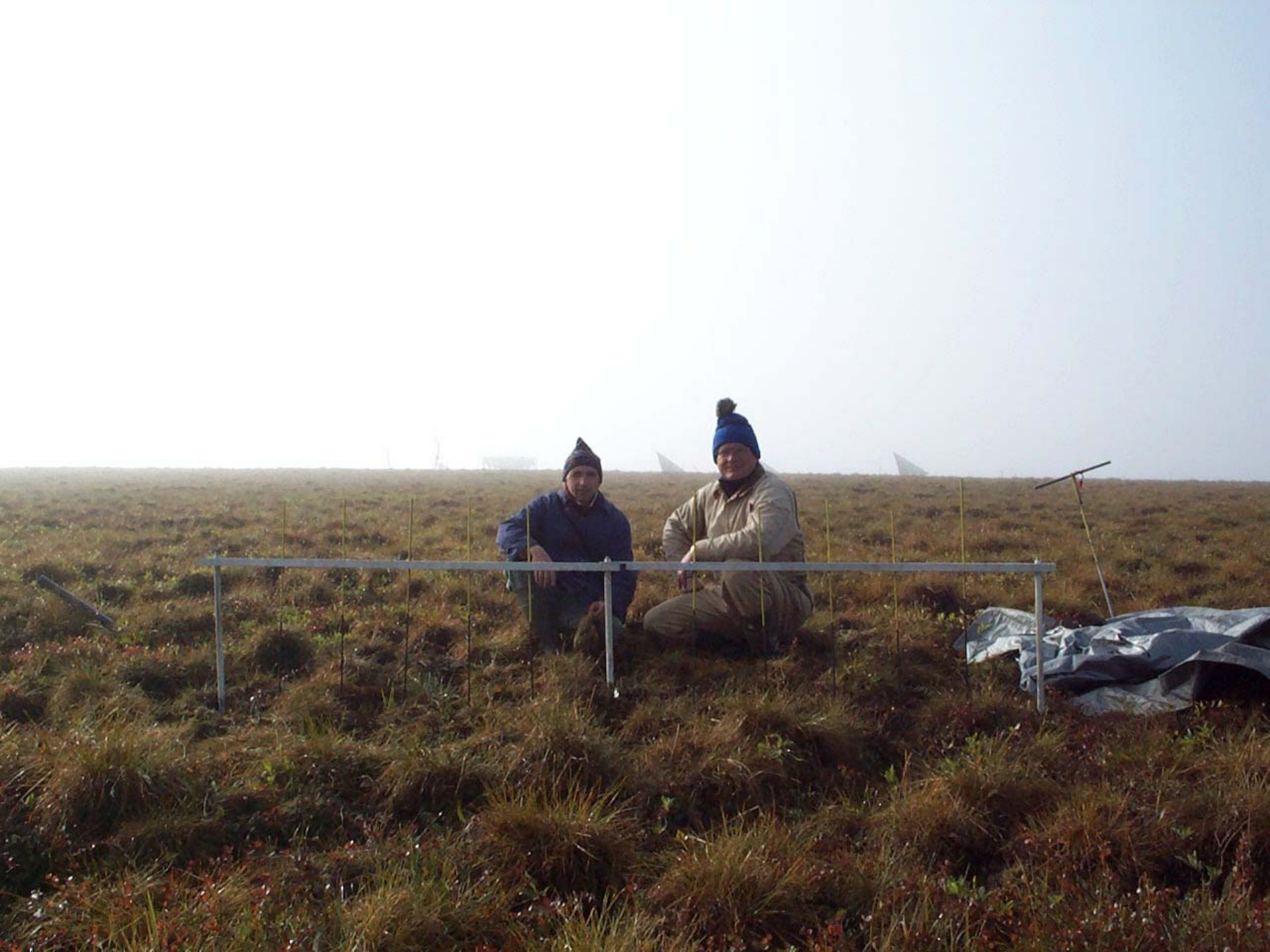

Maximal heaving at different surface conditions
(North Slope, Alaska, 2001-2002)
Heaving of the surface, cm
20
18
16
14
12
10
8
6
4
2
0
West Dock
Deadhorse
Franklin Bluffs
Sagwon-MNT
Sagwon-MAT
Happy Valley
Site
Frost boil
Interscar

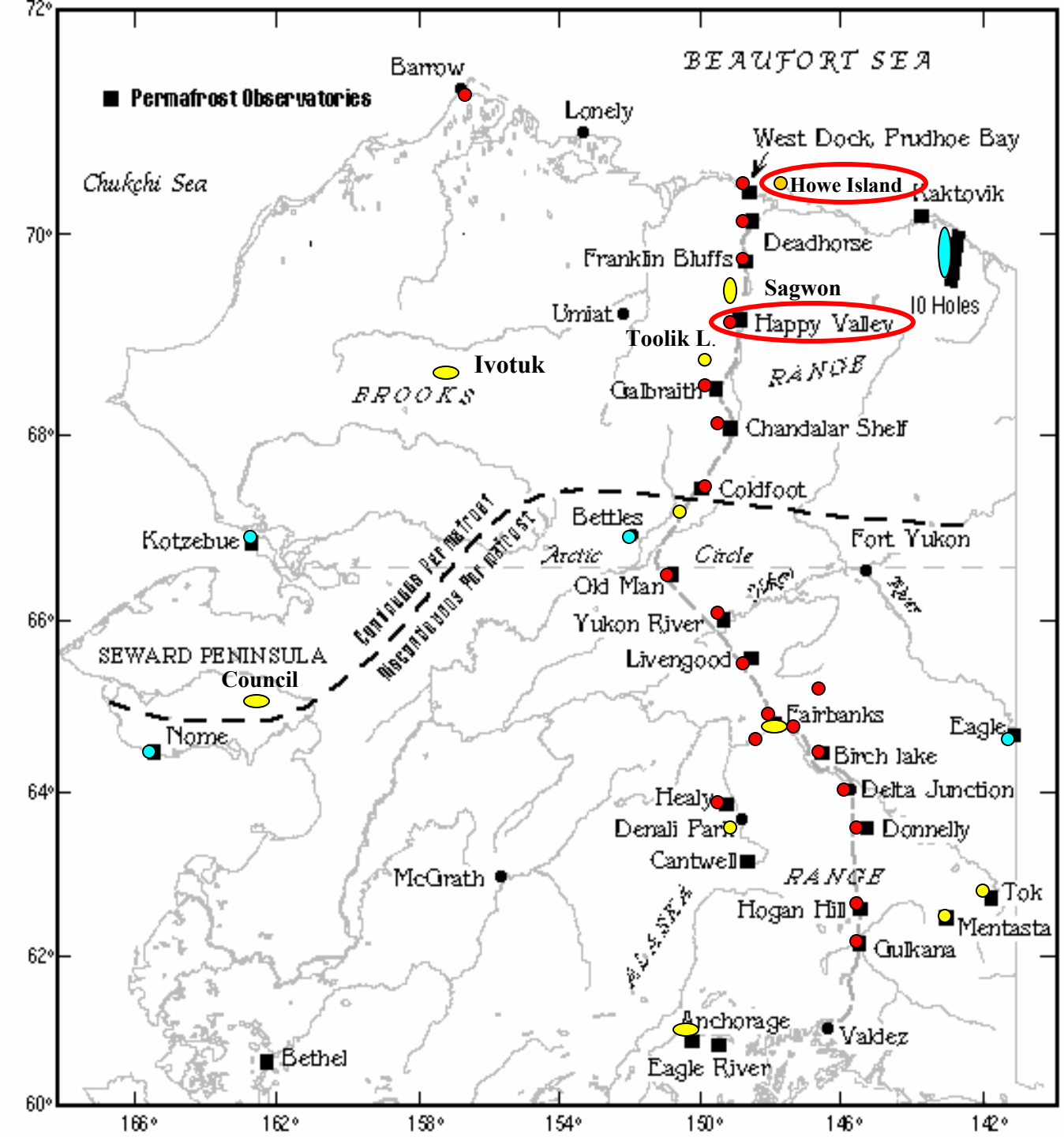

Relative movement of sensors across the frost boil
(Deadhorse #1)
Vertical movement of the stick, cm
20
15
10
5
0
-5
S. 1
S. 2
S. 3
S. 4
S. 5
S. 6
S. 7
S. 8
S. 9
S. 10
Sensor's number
August 2000
April 2001
June 2001
July 2001
August 2001
April 2002

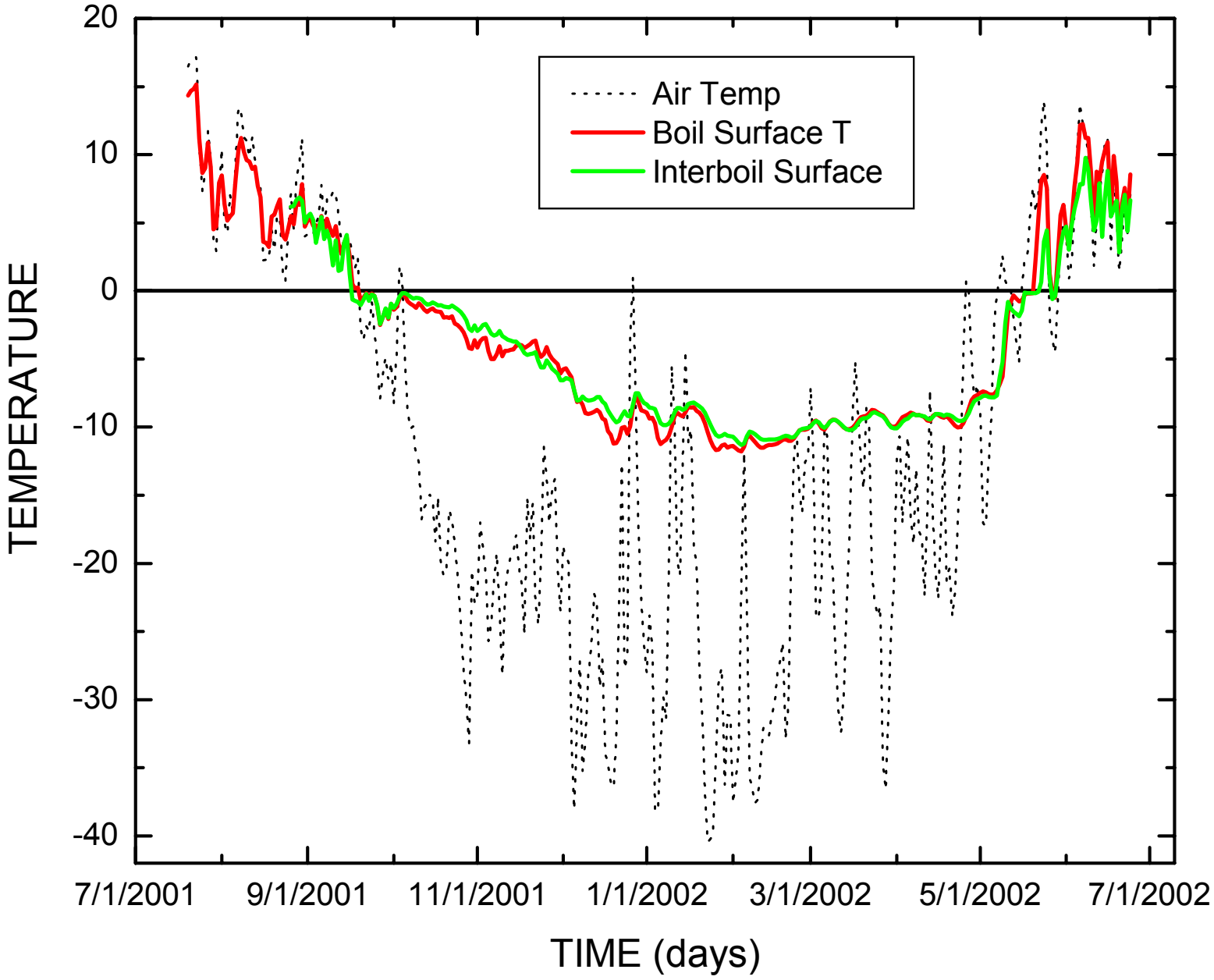

Relative movement of sensors across frost boil (Happy Valley #2, divide)
Vertical movement of the stick, cm
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
Sensor's number
August 2001
April 2002

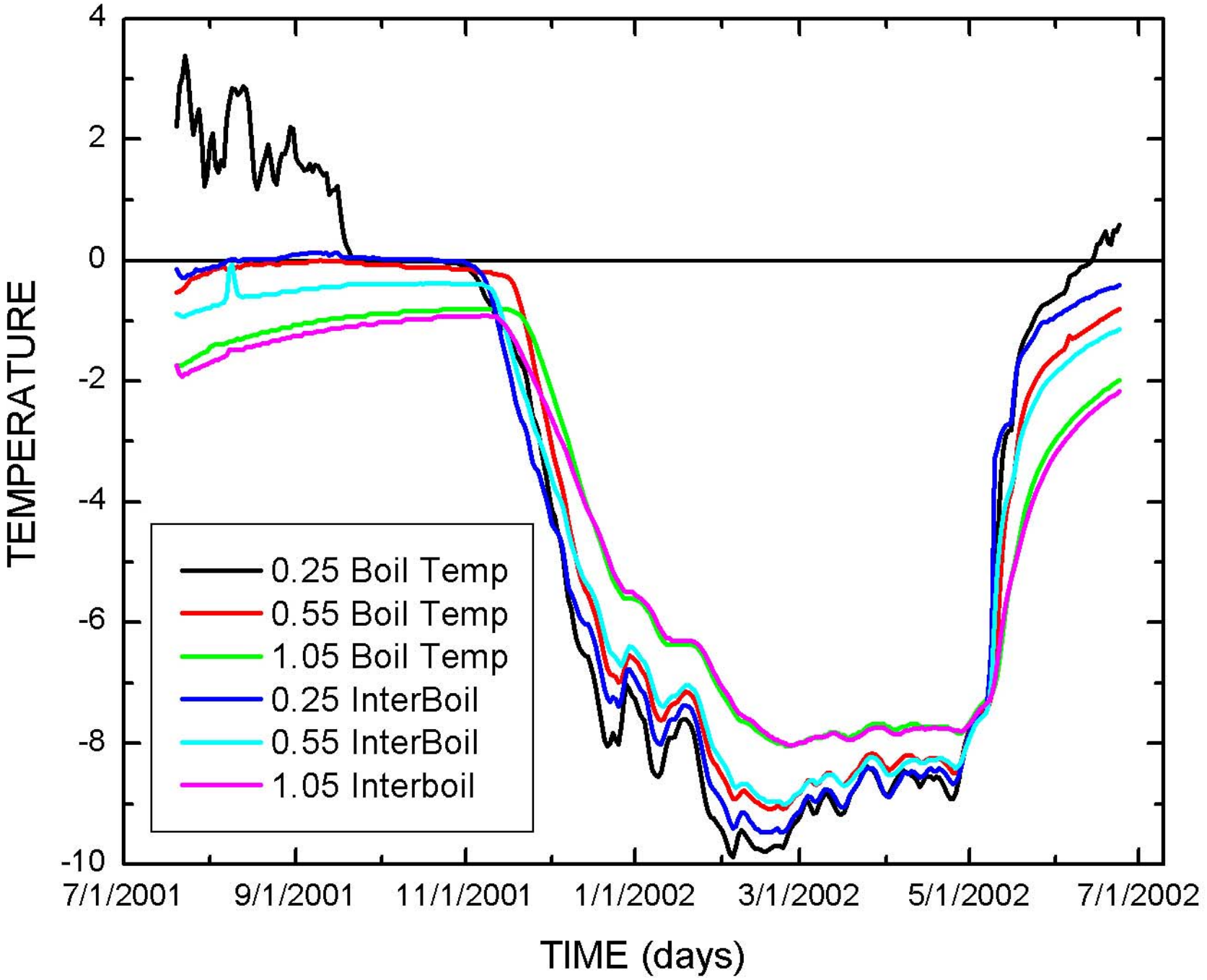


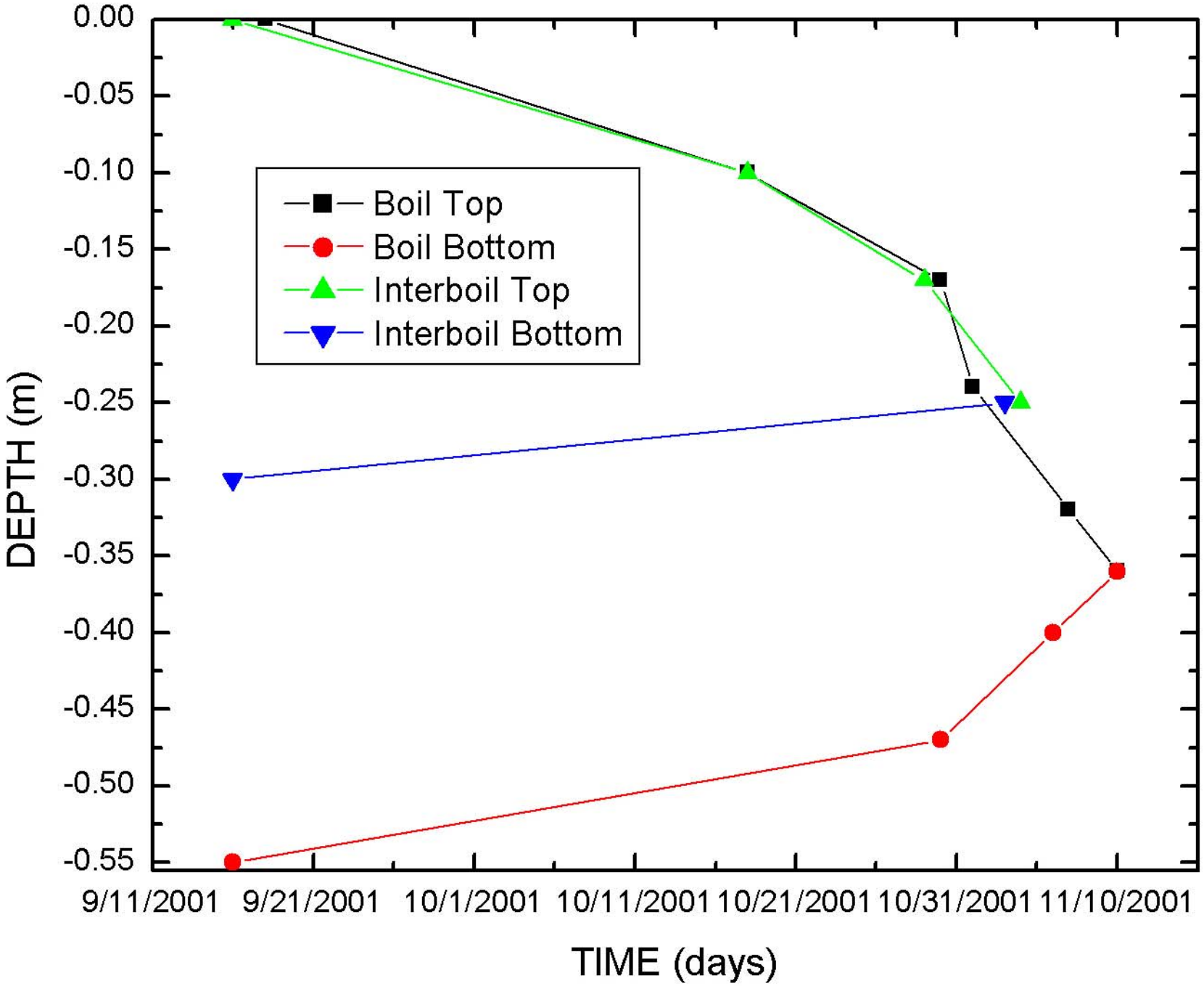

Relative movement of sensors across the frost boil
(Sagwon MAT #2, Western)
Vertical movement of the stick, cm
20
15
10
5
0
-5
S. 1
S. 2
S. 3
S. 4
S. 5
S. 6
S. 7
S. 8
S. 9
S. 10
Sensor's number
August 2001
April 2002

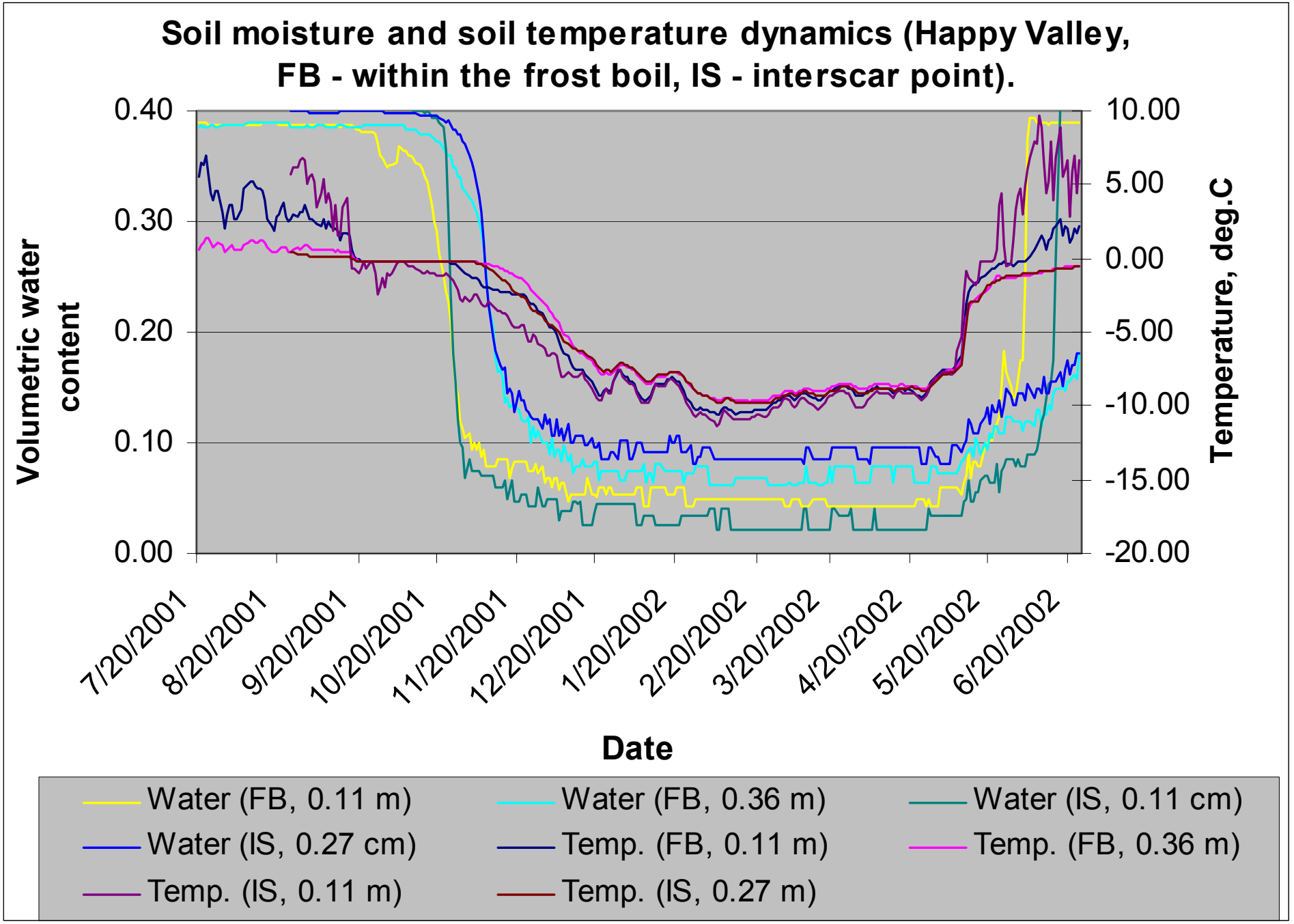


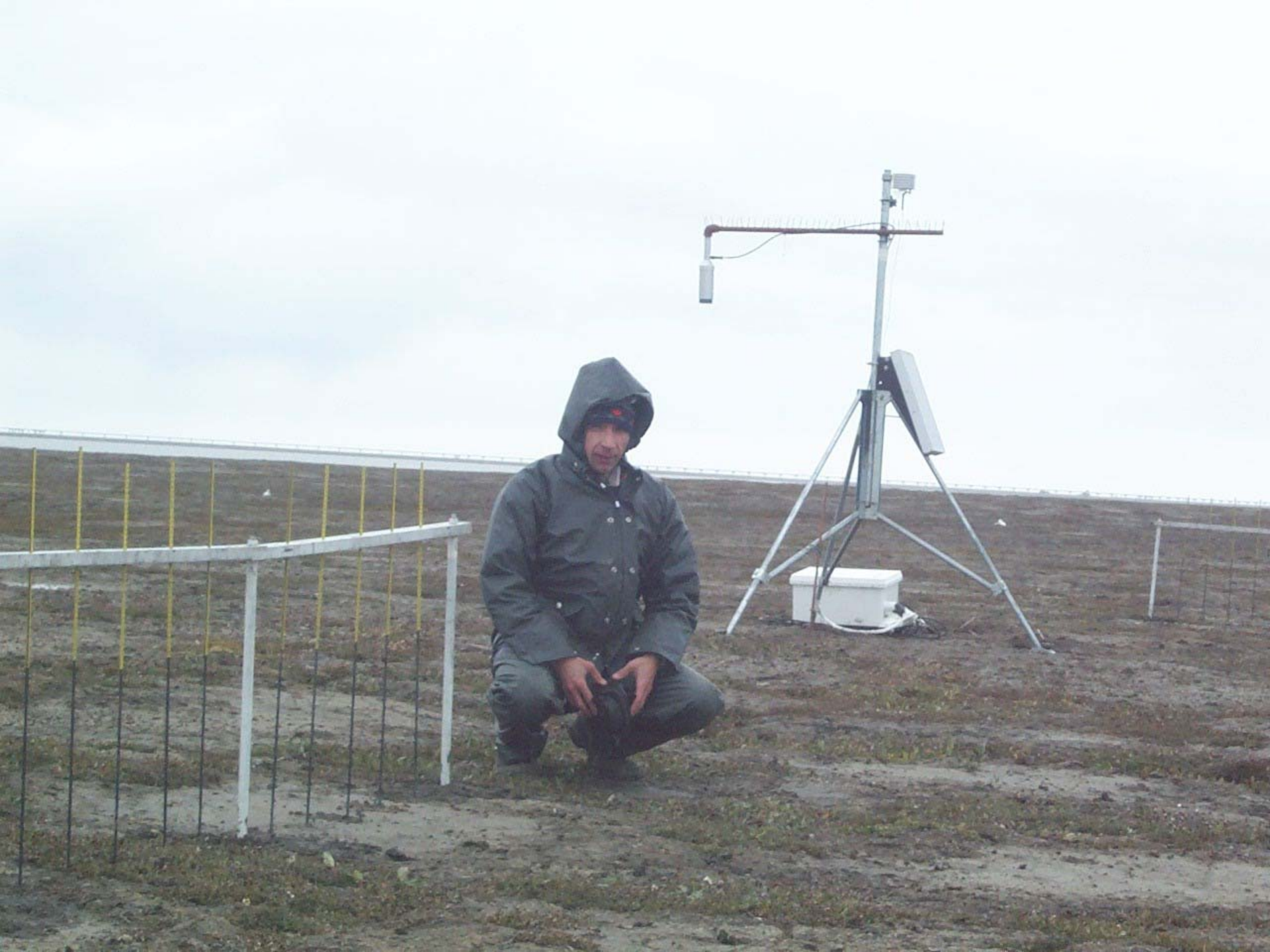

Permafrost Observatories
BEAUFORT SEA
Chukchi Sea
Barrow
Lonely
West Dock, Prudhoe Bay
Howe Island
Raktovik
Deadhorse
Franklin Bluffs
Sagwon
10 Holes
Umiat
Happy Valley
Toolik L.
Ivotuk
BROOKS
RANGE
Galbraith
Chandalar Shelf
Coldfoot
Bettles
Kotzebue
Fort Yukon
Arctic
Circle
Old Man
Yukon River
Continuous Permafrost
Discontinuous Permafrost
SEWARD PENINSULA
Council
Nome
Livengood
Fairbanks
Eagle
Birch lake
Delta Junction
Healy
Denali Park
Donnelly
Cantwell
McGrath
RANGE
Tok
Hogan Hill
Mentasta
Gulkana
ALASKA
Anchorage
Valdez
Bethel
Eagle River
72°
70°
68°
66°
64°
62°
60°
166°
162°
158°
154°
150°
146°
142°

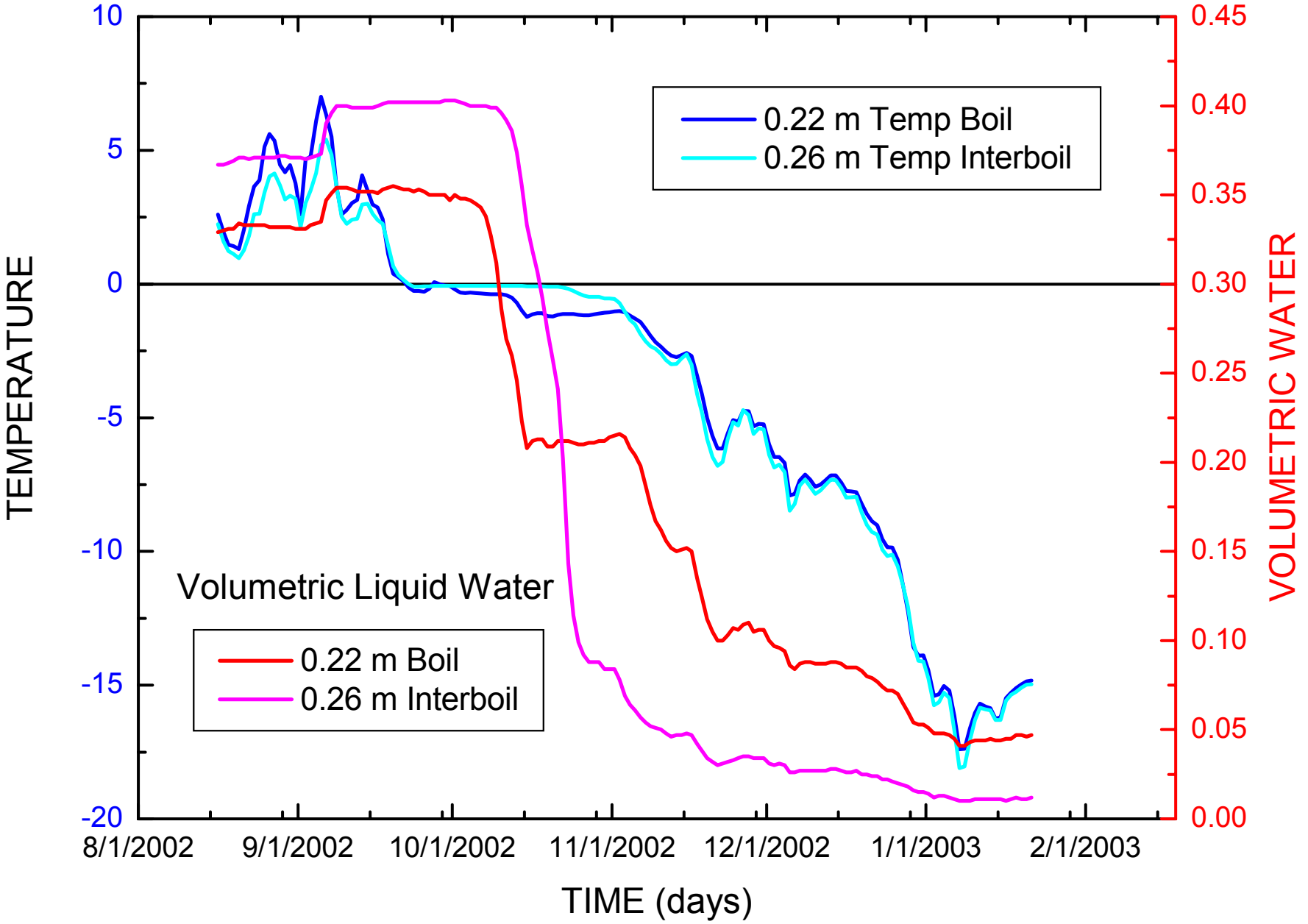

Air Temp
Boil Surface T
Interboil Surface
TEMPERATURE
20
10
0
-10
-20
-30
-40
7/1/2001
9/1/2001
11/1/2001
1/1/2002
3/1/2002
5/1/2002
7/1/2002
TIME (days)

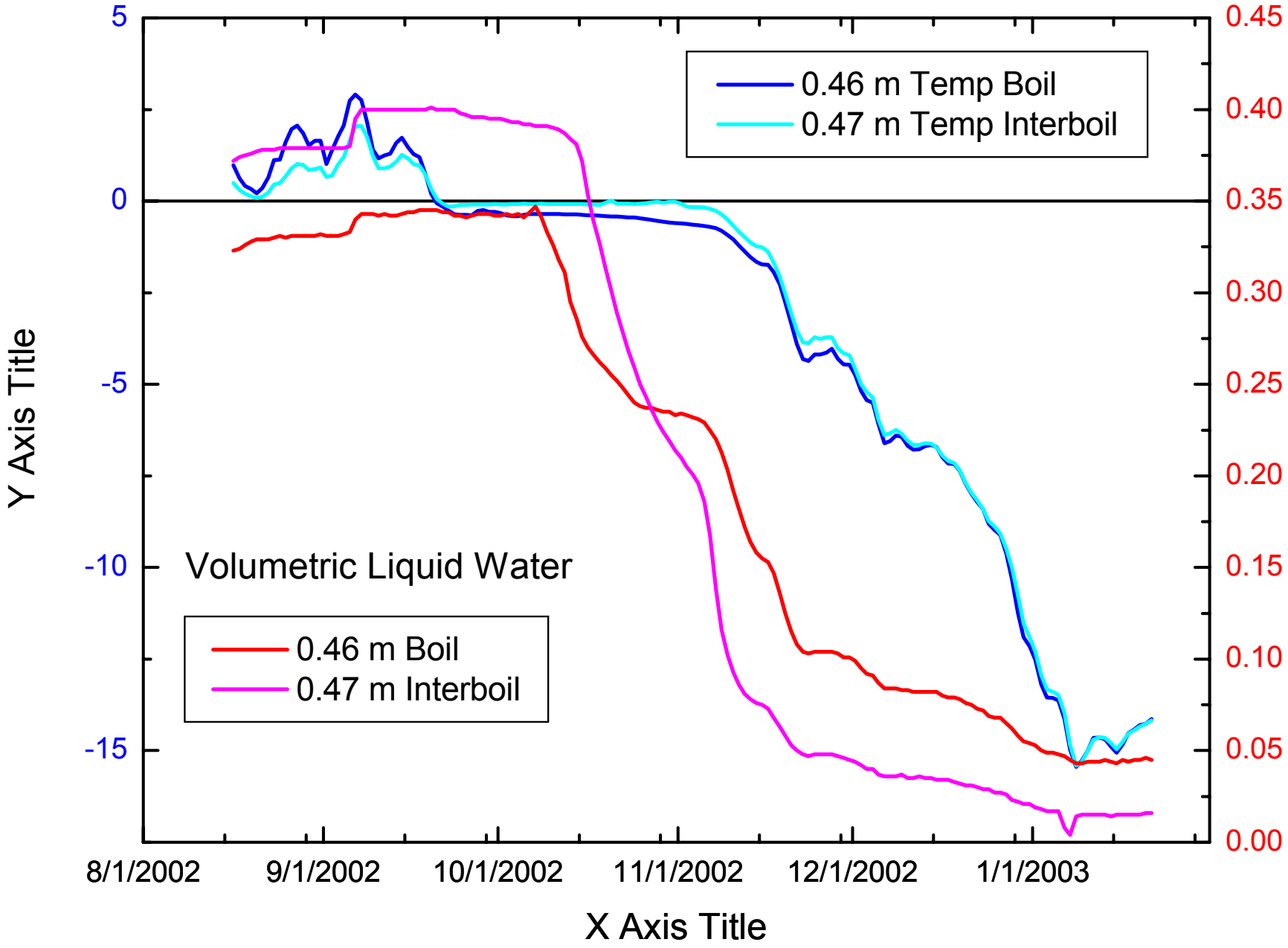

4
2
0
-2
-4
-6
-8
-10
TEMPERATURE
7/1/2001
9/1/2001
11/1/2001
1/1/2002
3/1/2002
5/1/2002
7/1/2002
TIME (days)
0.25 Boil Temp
0.55 Boil Temp
1.05 Boil Temp
0.25 InterBoil
0.55 InterBoil
1.05 Interboil

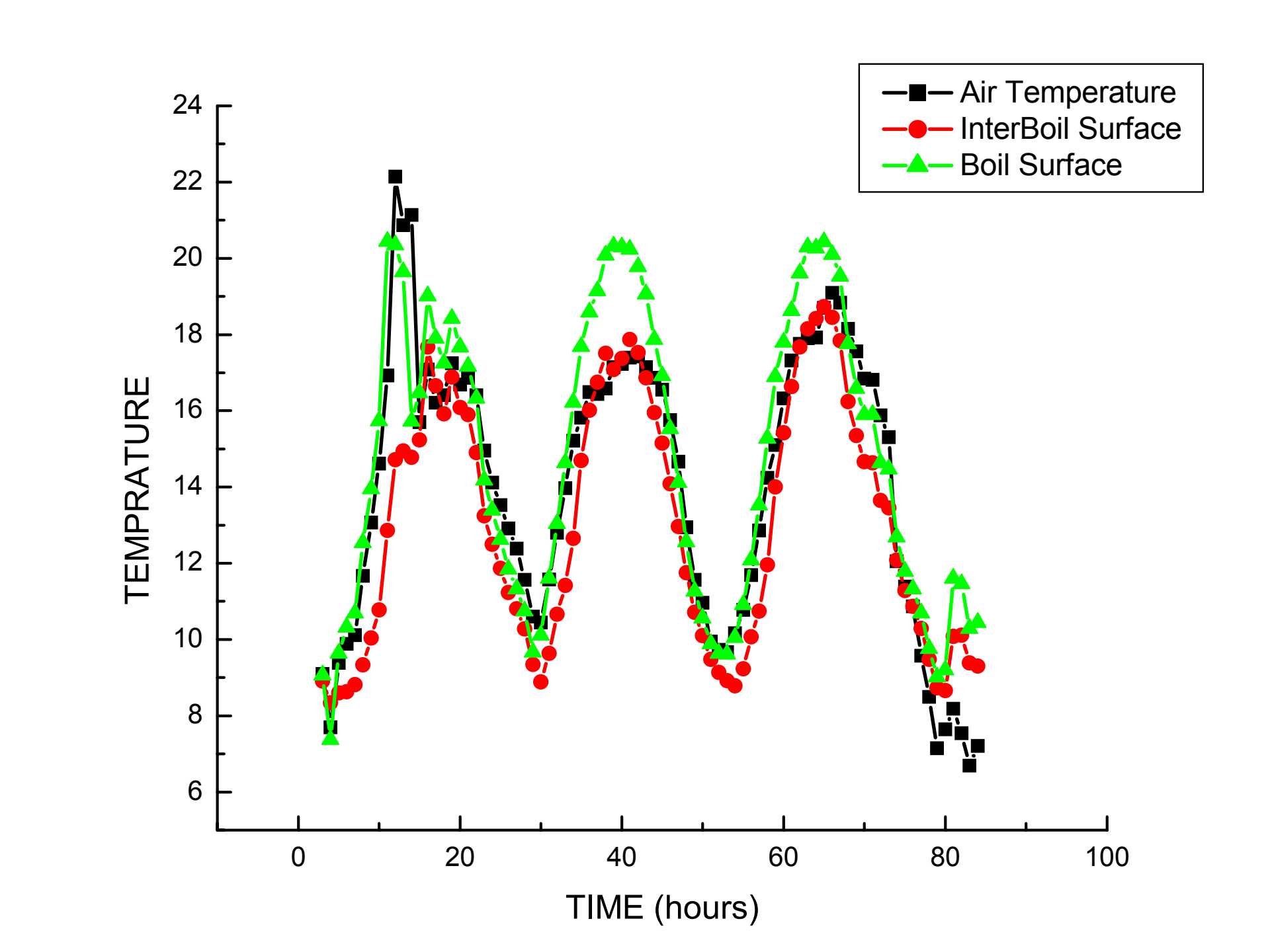

0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
-0.55
DEPTH (m)
Boil Top
Boil Bottom
Interboil Top
Interboil Bottom
9/11/2001
9/21/2001
10/1/2001
10/11/2001
10/21/2001
10/31/2001
11/10/2001
TIME (days)

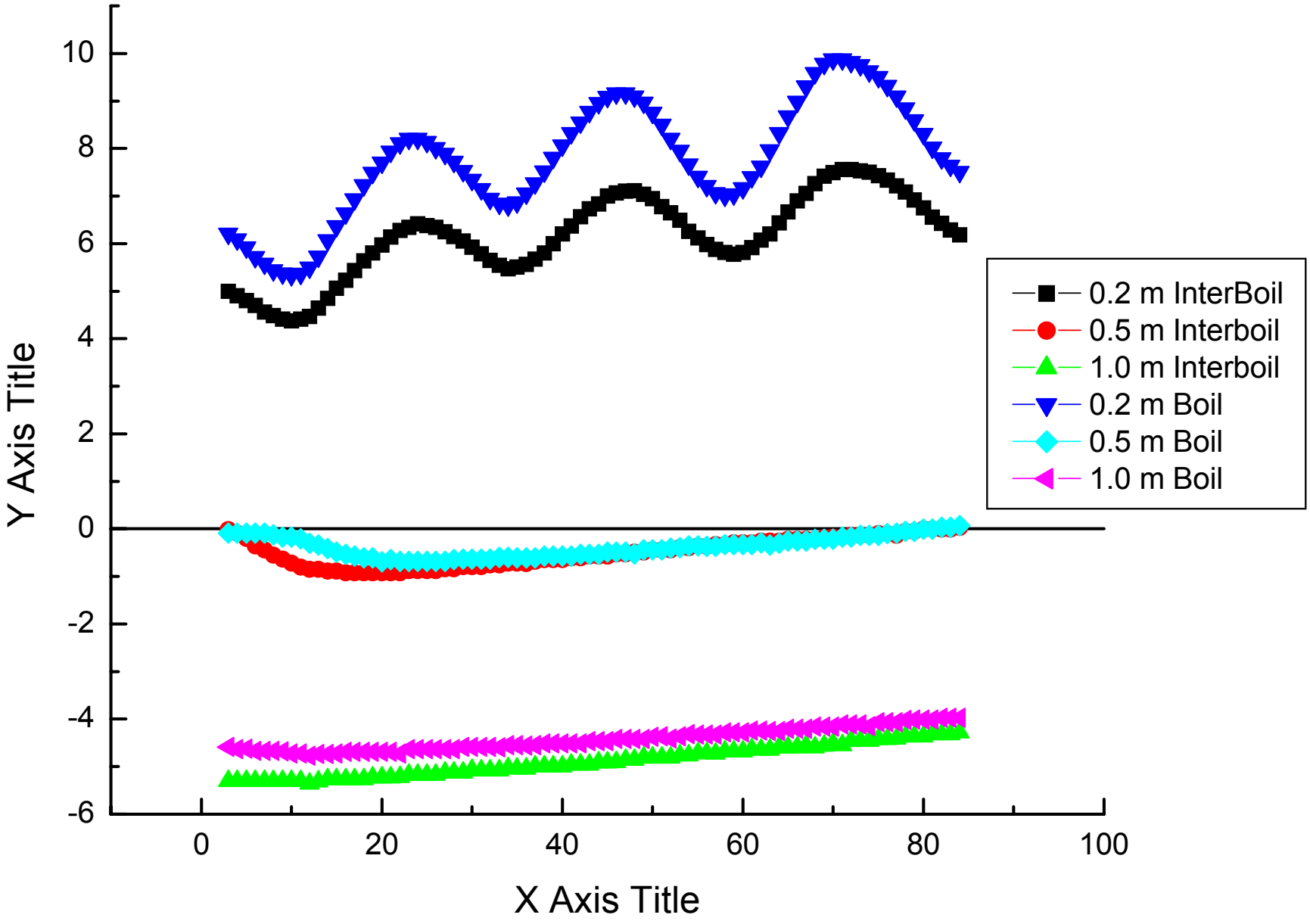

Soil moisture and soil temperature dynamics (Happy Valley, FB - within the frost boil, IS - interscar point).
Volumetric water content
Temperature, deg.C
0.40
0.30
0.20
0.10
0.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
7/20/2001
8/20/2001
9/20/2001
10/20/2001
11/20/2001
12/20/2001
1/20/2002
2/20/2002
3/20/2002
4/20/2002
5/20/2002
6/20/2002
Date
Water (FB, 0.11 m)
Water (FB, 0.36 m)
Water (IS, 0.11 cm)
Water (IS, 0.27 cm)
Temp. (FB, 0.11 m)
Temp. (FB, 0.36 m)
Temp. (IS, 0.11 m)
Temp. (IS, 0.27 m)

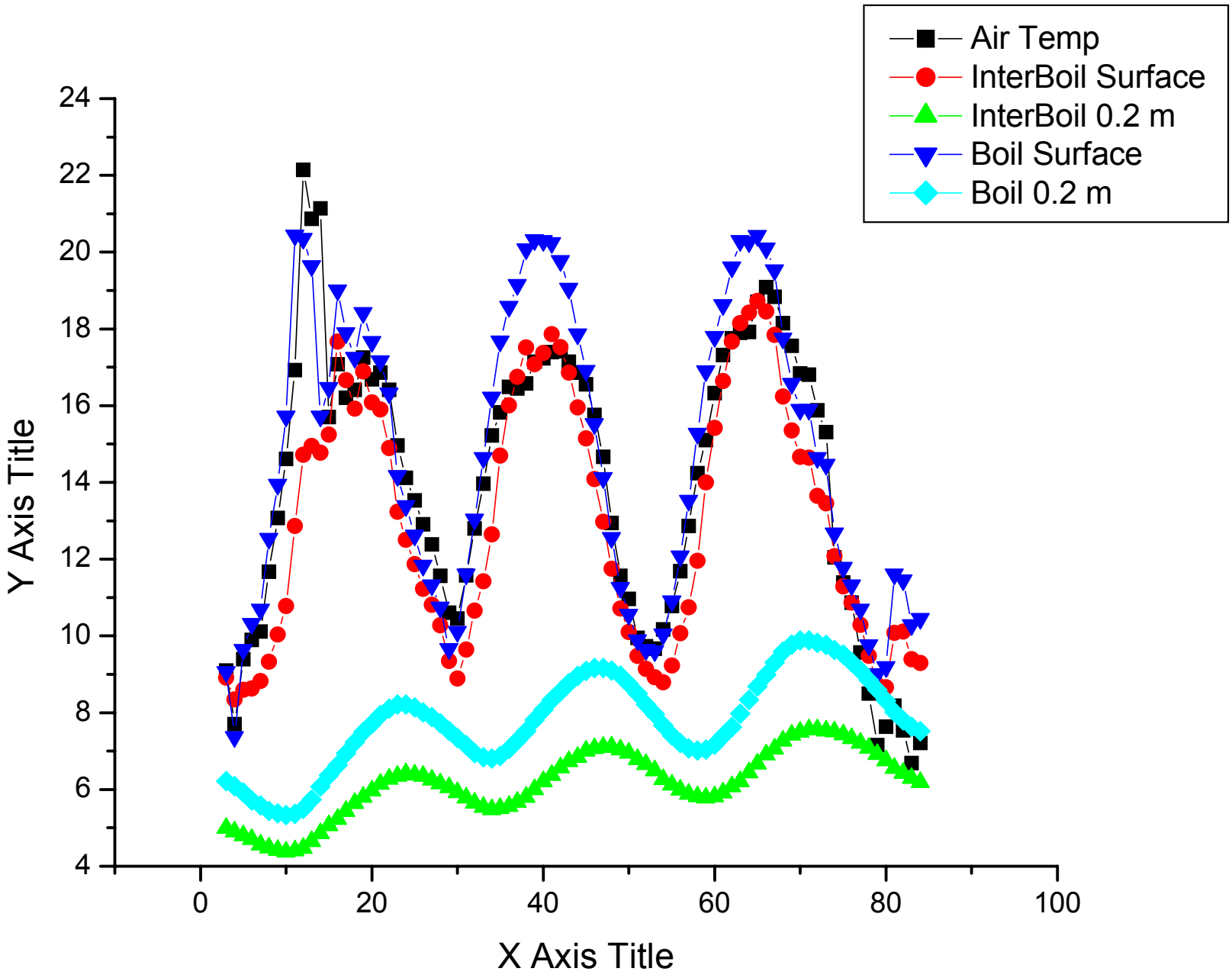


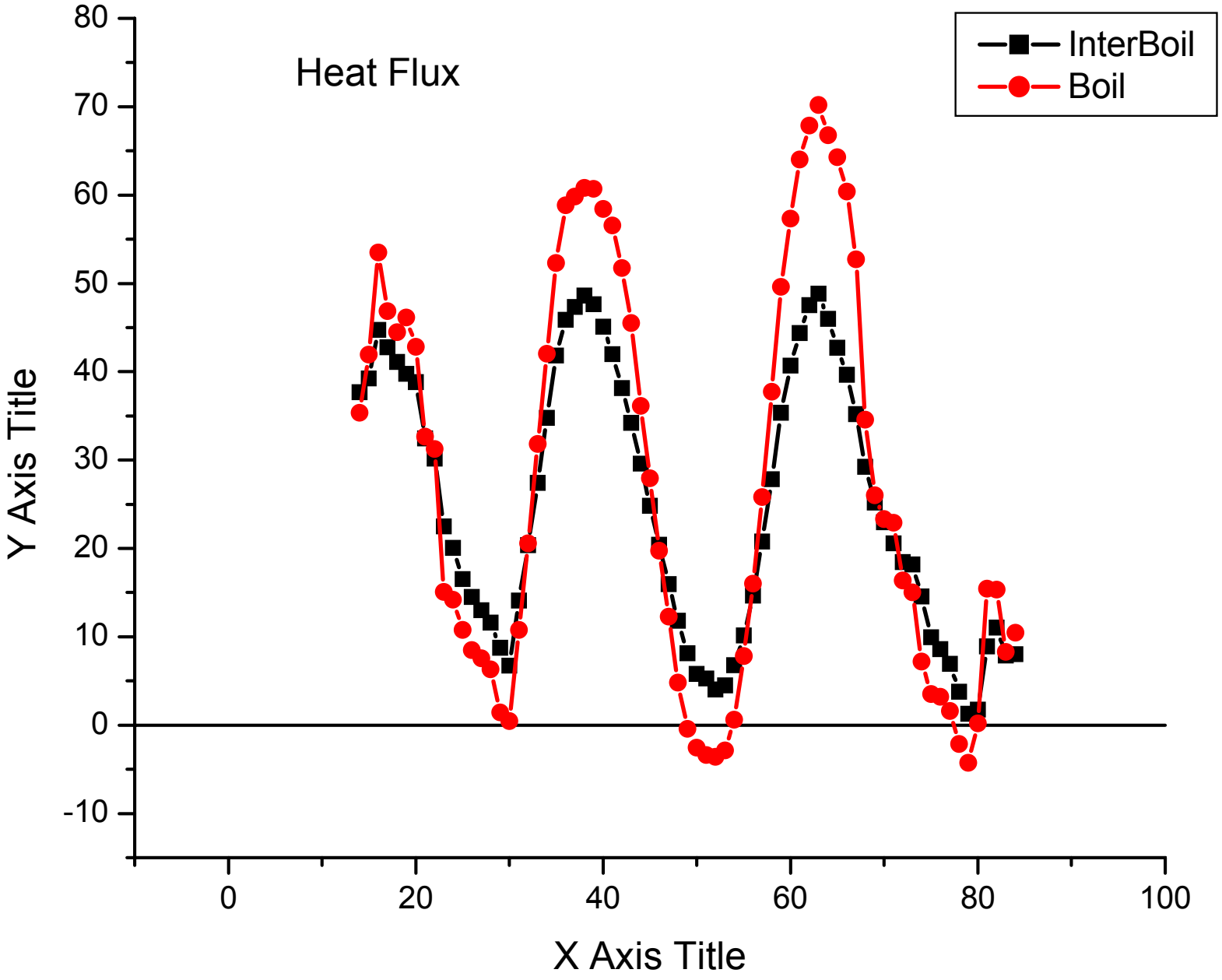

10
5
0
-5
-10
-15
-20
TEMPERATURE
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
VOLUMETRIC WATER
0.22 m Temp Boil
0.26 m Temp Interboil
Volumetric Liquid Water
0.22 m Boil
0.26 m Interboil
8/1/2002
9/1/2002
10/1/2002
11/1/2002
12/1/2002
1/1/2003
2/1/2003
TIME (days)

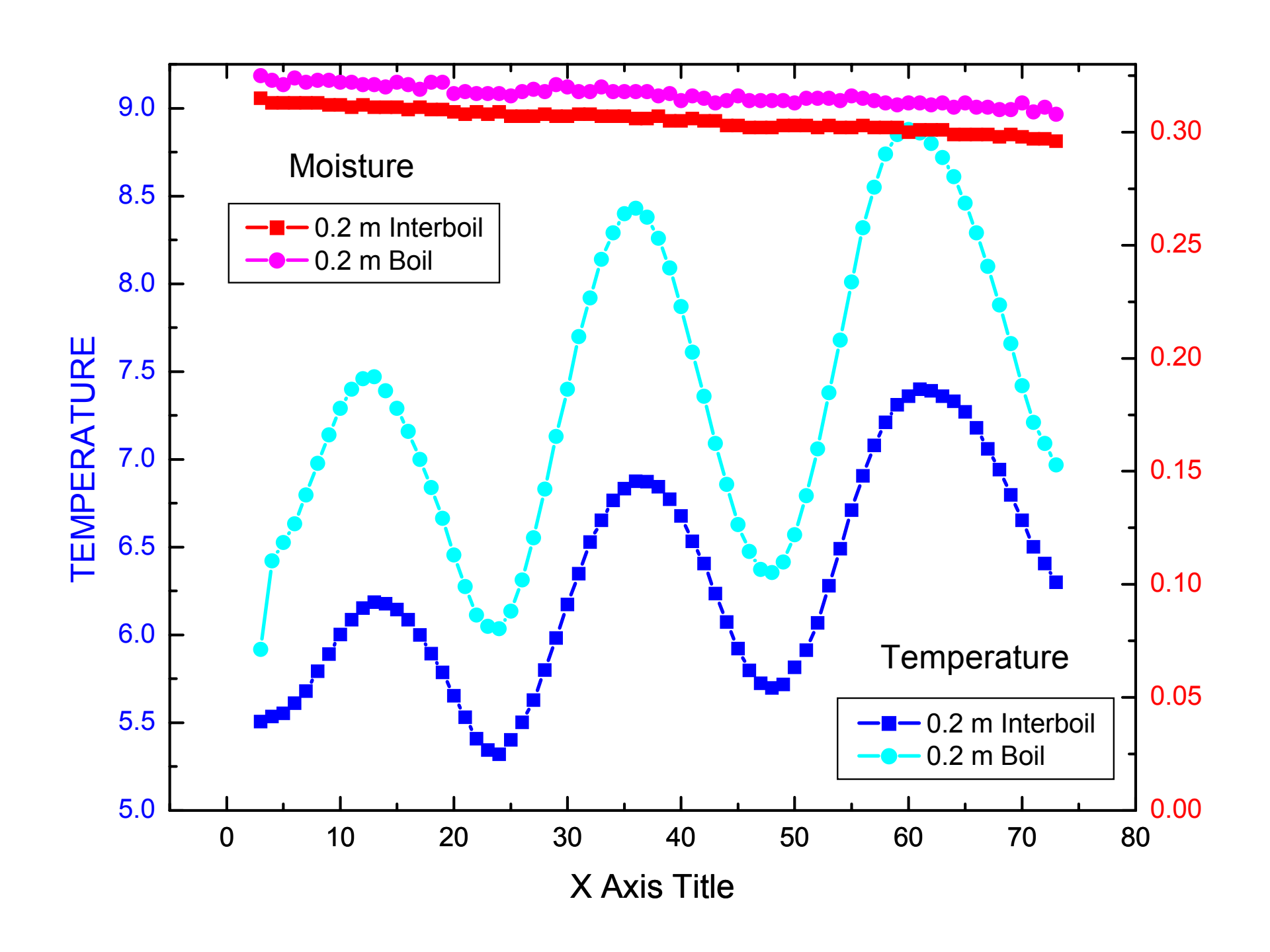

0.46 m Temp Boil
0.47 m Temp Interboil
Volumetric Liquid Water
0.46 m Boil
0.47 m Interboil
Y Axis Title
X Axis Title
5
0
-5
-10
-15
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
8/1/2002
9/1/2002
10/1/2002
11/1/2002
12/1/2002
1/1/2003

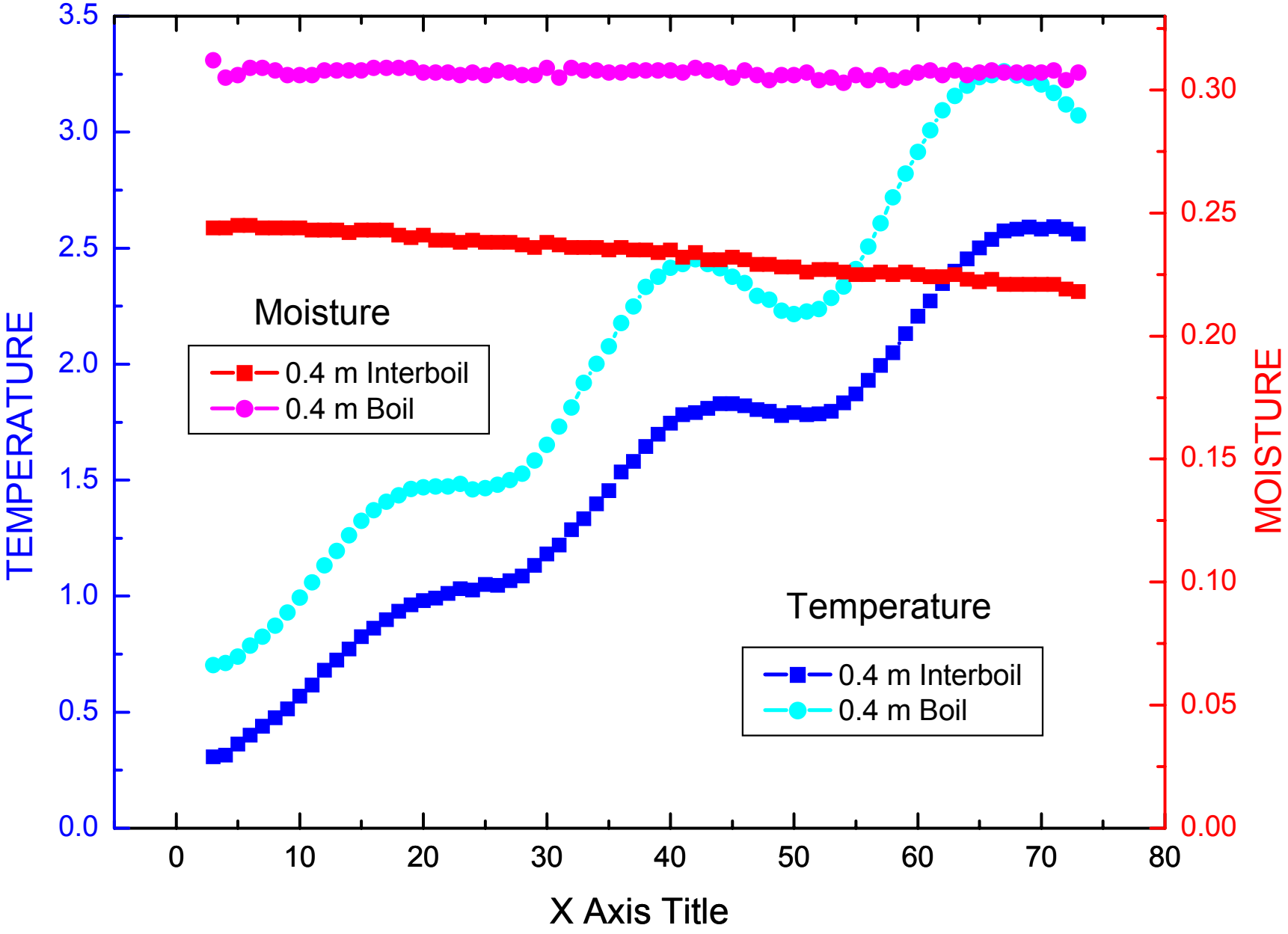

Air Temperature
InterBoil Surface
Boil Surface
TEMPRATURE
TIME (hours)
24
22
20
18
16
14
12
10
8
6
0
20
40
60
80
100


Y Axis Title
X Axis Title
10
8
6
4
2
0
-2
-4
-6
0
20
40
60
80
100
0.2 m InterBoil
0.5 m Interboil
1.0 m Interboil
0.2 m Boil
0.5 m Boil
1.0 m Boil


Air Temp
InterBoil Surface
InterBoil 0.2 m
Boil Surface
Boil 0.2 m
Y Axis Title
X Axis Title
24
22
20
18
16
14
12
10
8
6
4
0
20
40
60
80
100


Heat Flux
InterBoil
Boil
Y Axis Title
X Axis Title
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100


Moisture
0.2 m Interboil
0.2 m Boil
Temperature
0.2 m Interboil
0.2 m Boil
TEMPERATURE
X Axis Title
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
70
80


TEMPERATURE
MOISTURE
X Axis Title
Moisture
0.4 m Interboil
0.4 m Boil
Temperature
0.4 m Interboil
0.4 m Boil
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0
10
20
30
40
50
60
70
80