Observations of snowpack properties to evaluate ground-based microwave remote sensing

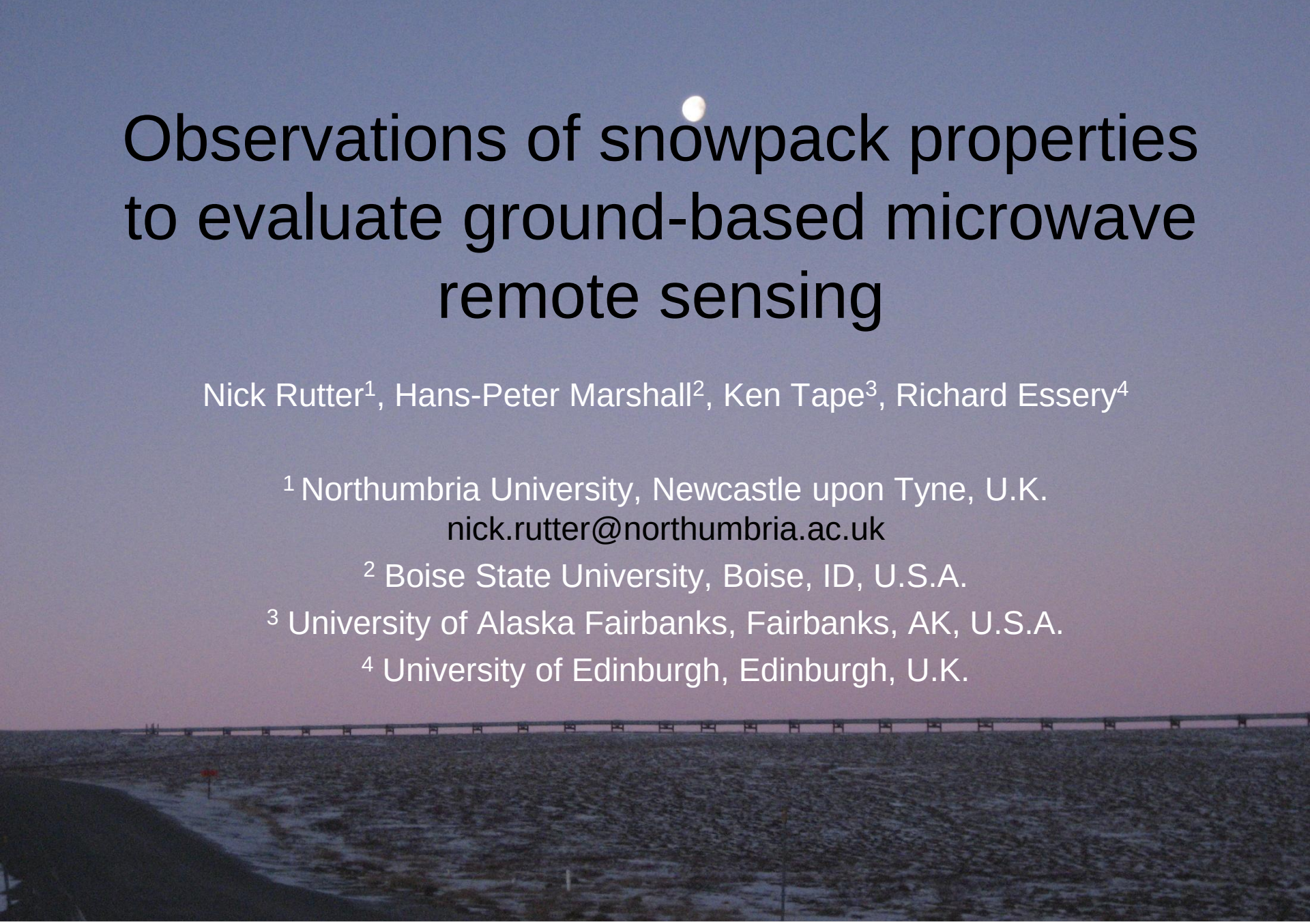
Nick Rutter[1], Hans-Peter Marshall[2], Ken Tape[3], Richard Essery[4]

[1] Northumbria University, Newcastle upon Tyne, U.K.
nick.rutter@northumbria.ac.uk

[2] Boise State University, Boise, ID, U.S.A.

[3] University of Alaska Fairbanks, Fairbanks, AK, U.S.A.

[4] University of Edinburgh, Edinburgh, U.K.



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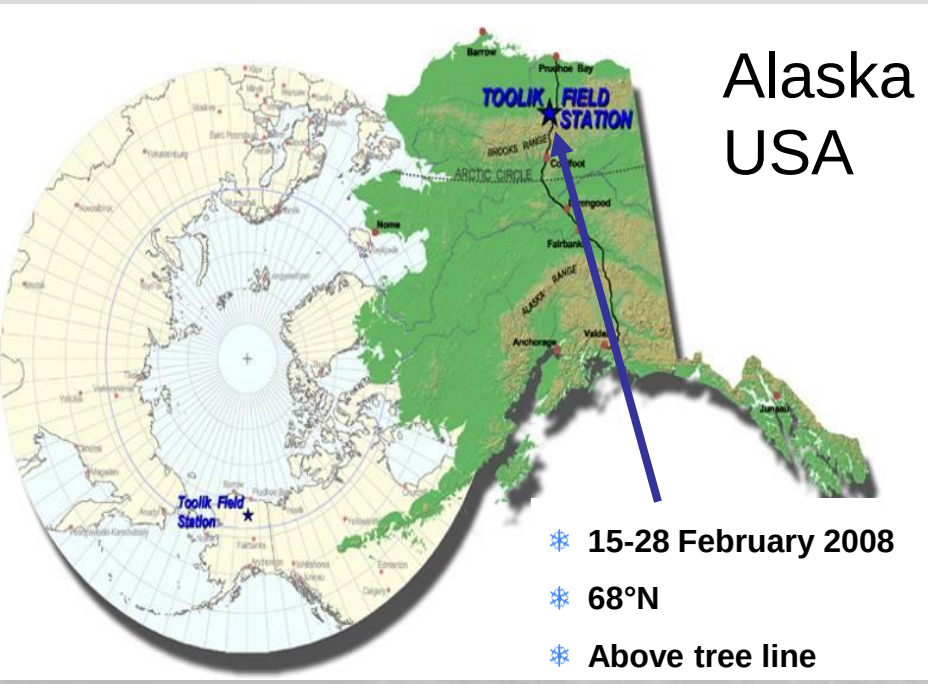
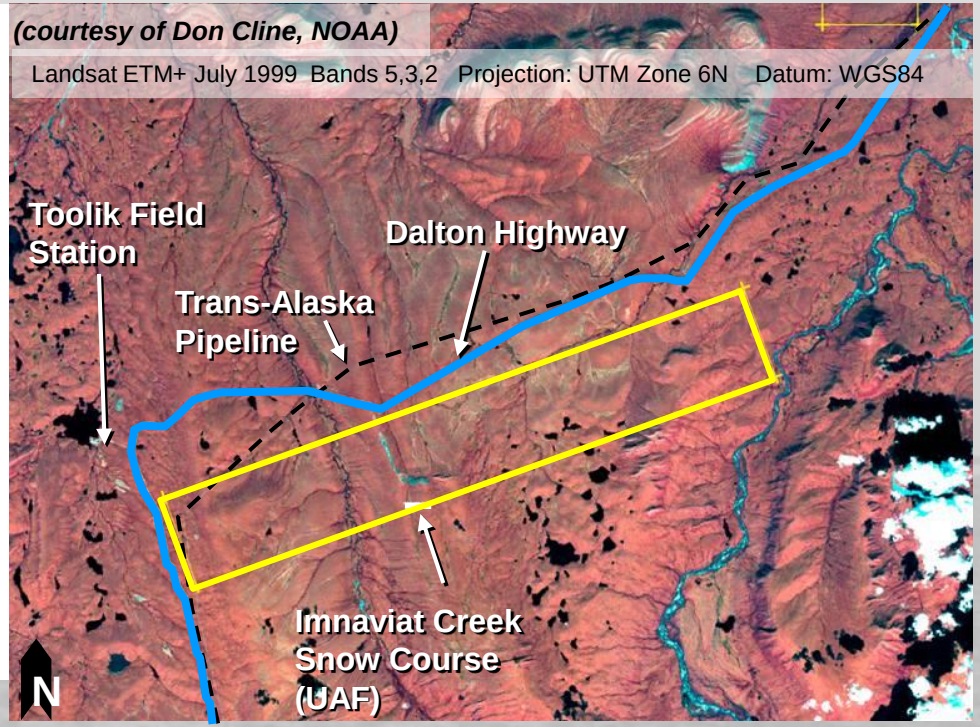
NATURAL ENVIRONMENT RESEARCH COUNCIL

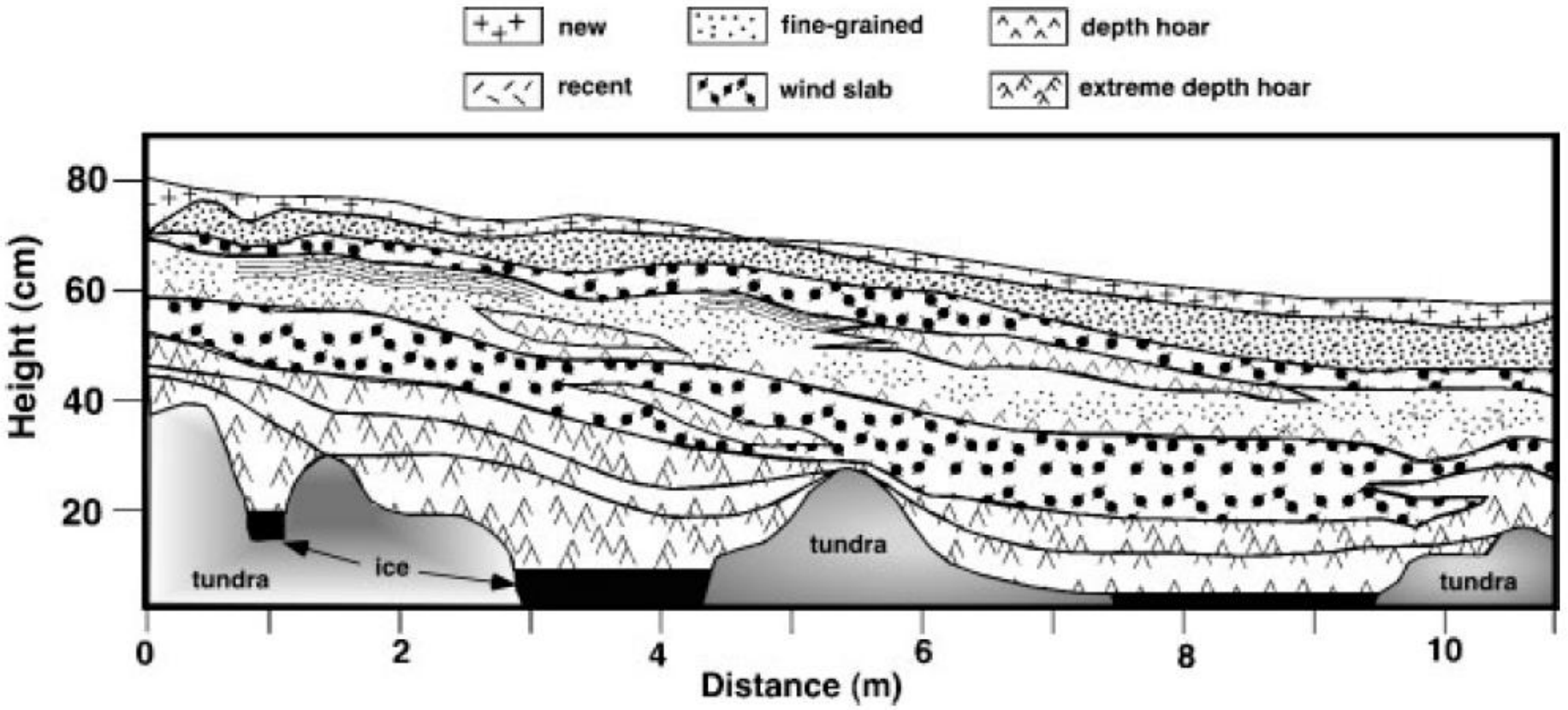
ESA Workshop on Cold Regions Hydrology: 29 April 2010

- Part of 2nd NASA Cold Land Processes Experiment
  - General goals to evaluate airborne Ku-band scatterometer
  - Our part in that was:
    - Evaluation of ground-based FMCW radar (12-18 GHz, nadir, cross-pol)
    - Heterogeneity of internal snowpack stratigraphy & impact on radar
- Thanks to Don Cline, Kelly Elder, Matthew Sturm and University of Alaska Fairbanks

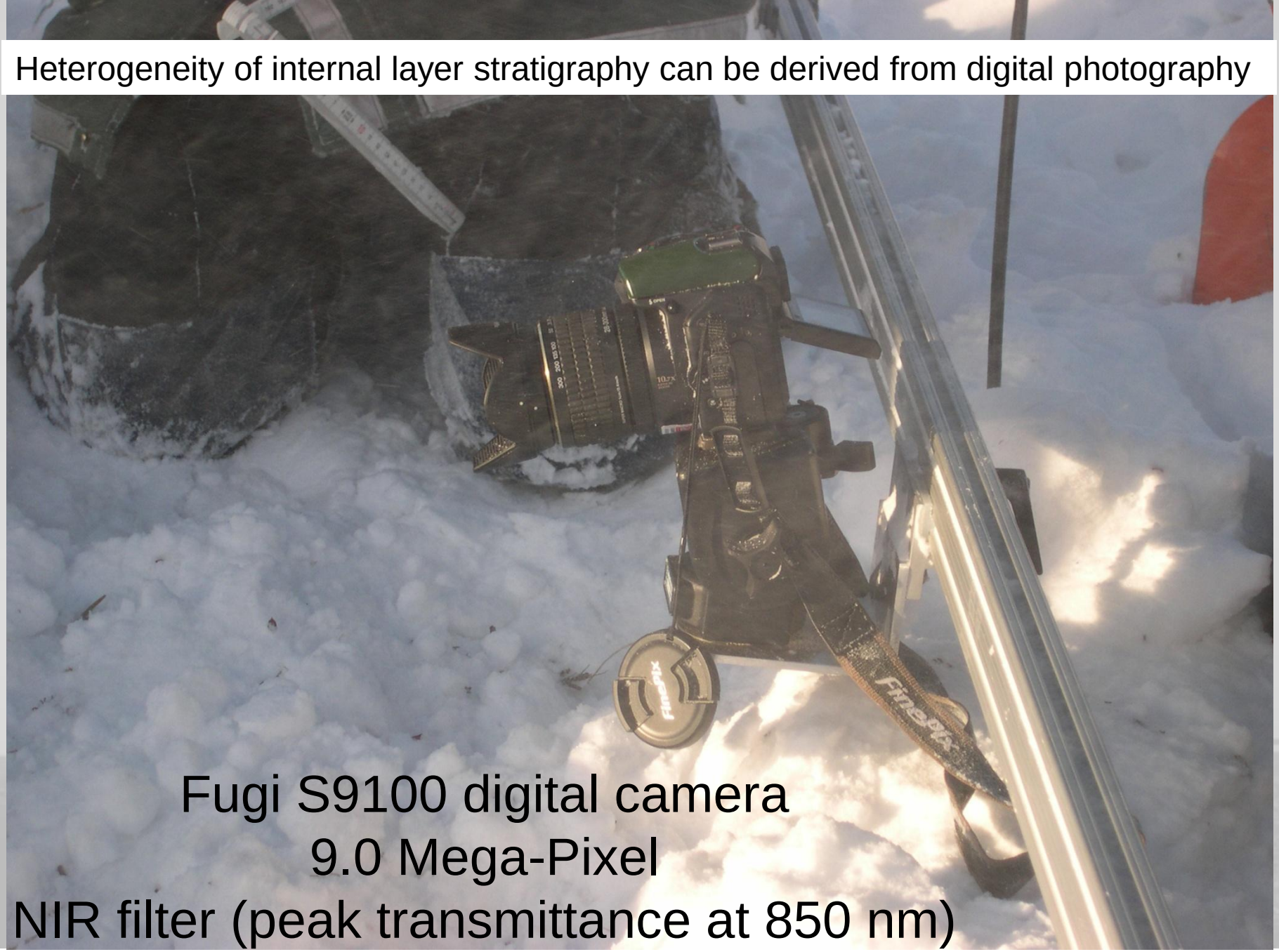




- Surface roughness previously quantified (e.g. Fassnacht et al. 2009)
- Quantifying subsurface stratigraphic roughness at the centimetre scale is laborious and rarely observed (Sturm et al. 2004)
- Dielectric permittivities influenced by heterogenous internal layer stratigraphy
- Scattering influence at Ku-band requires 1-2 cm scale resolution



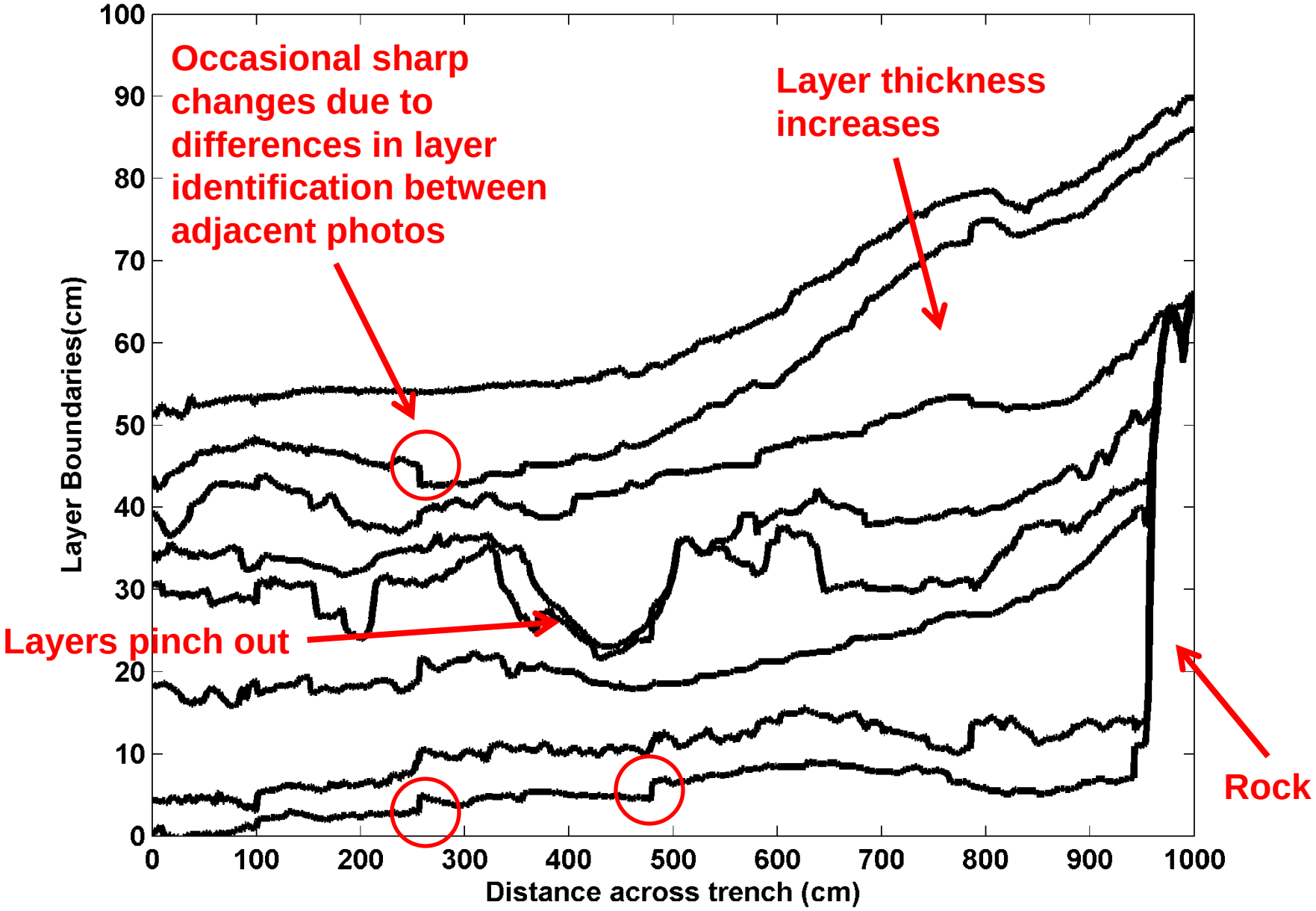
Heterogeneity of internal layer stratigraphy can be derived from digital photography

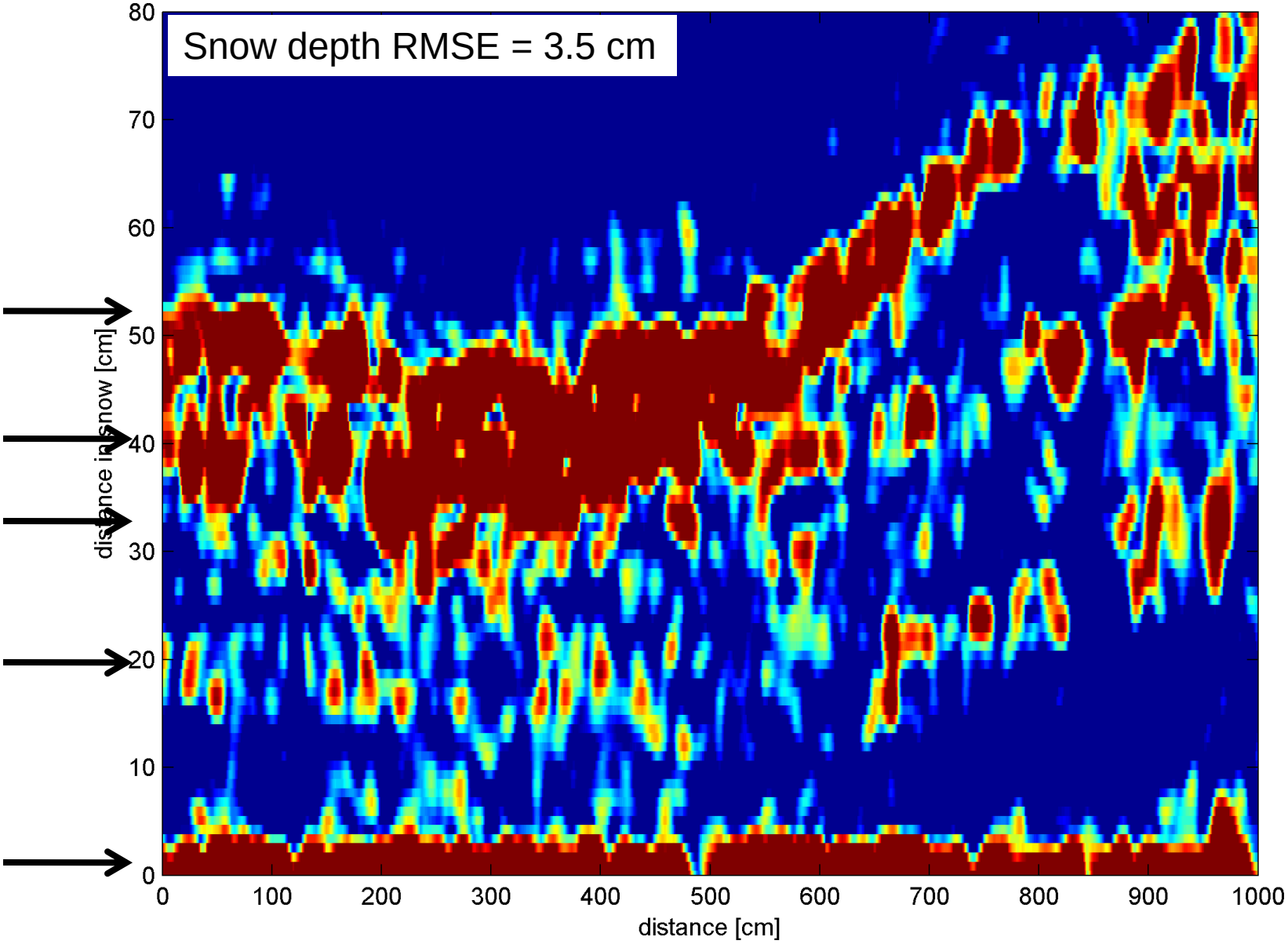


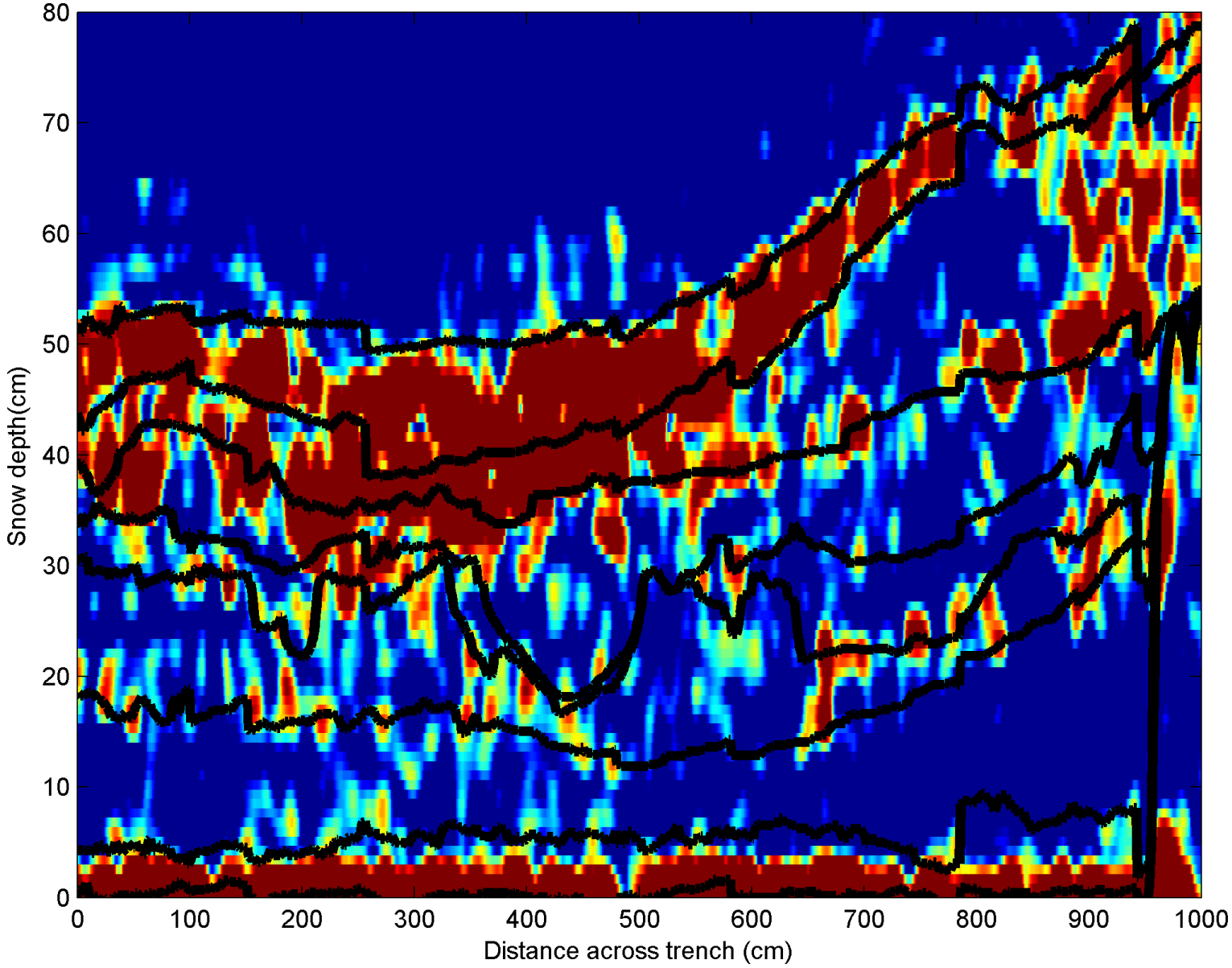
Fugi S9100 digital camera
9.0 Mega-Pixel
NIR filter (peak transmittance at 850 nm)

Dig trench and clean trench wall

- Processed and georeferenced NIR images (see Tape et al. 2010. J. Glac.)
  - high resolution (0.02 cm) and low error (0.3 cm)
  - layer boundaries estimated with a median difference of <2 cm compared to field observations
- Automated stitching does not work as nodal point shifts too far (parallax)
- Auto-picking of layers not effective, better to visually pick layers

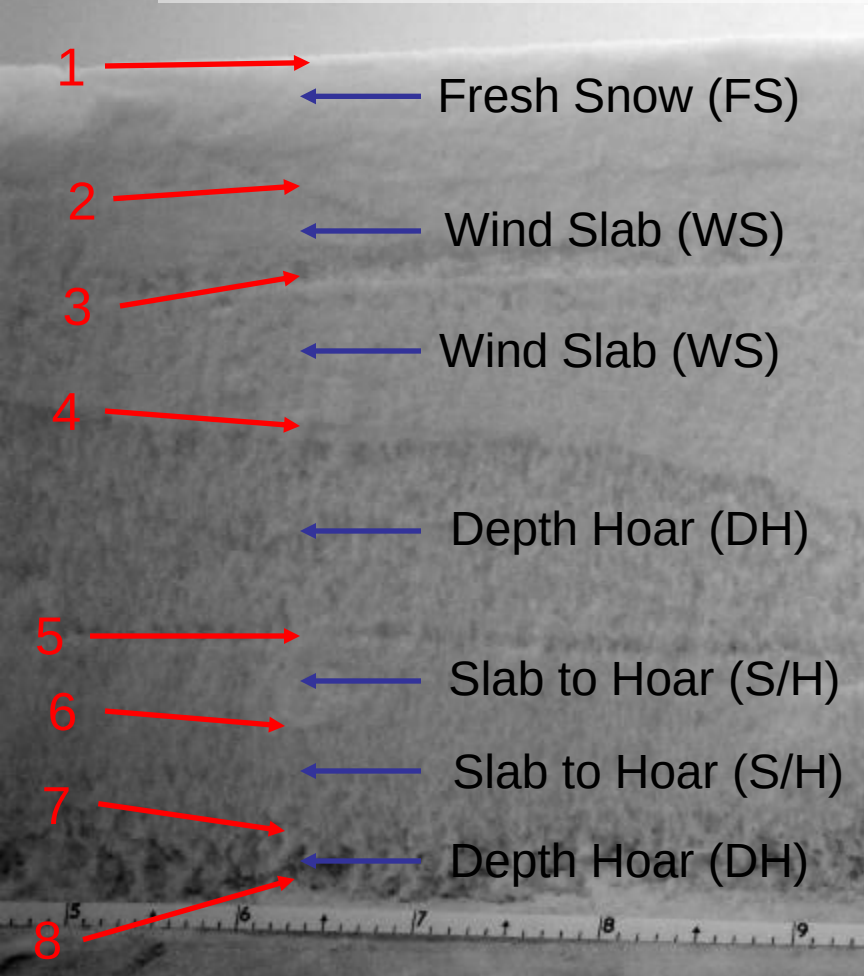

Occasional sharp changes due to differences in layer identification between adjacent photos
Layer thickness increases
Layers pinch out
Rock
Layer Boundaries(cm)
Distance across trench (cm)
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000

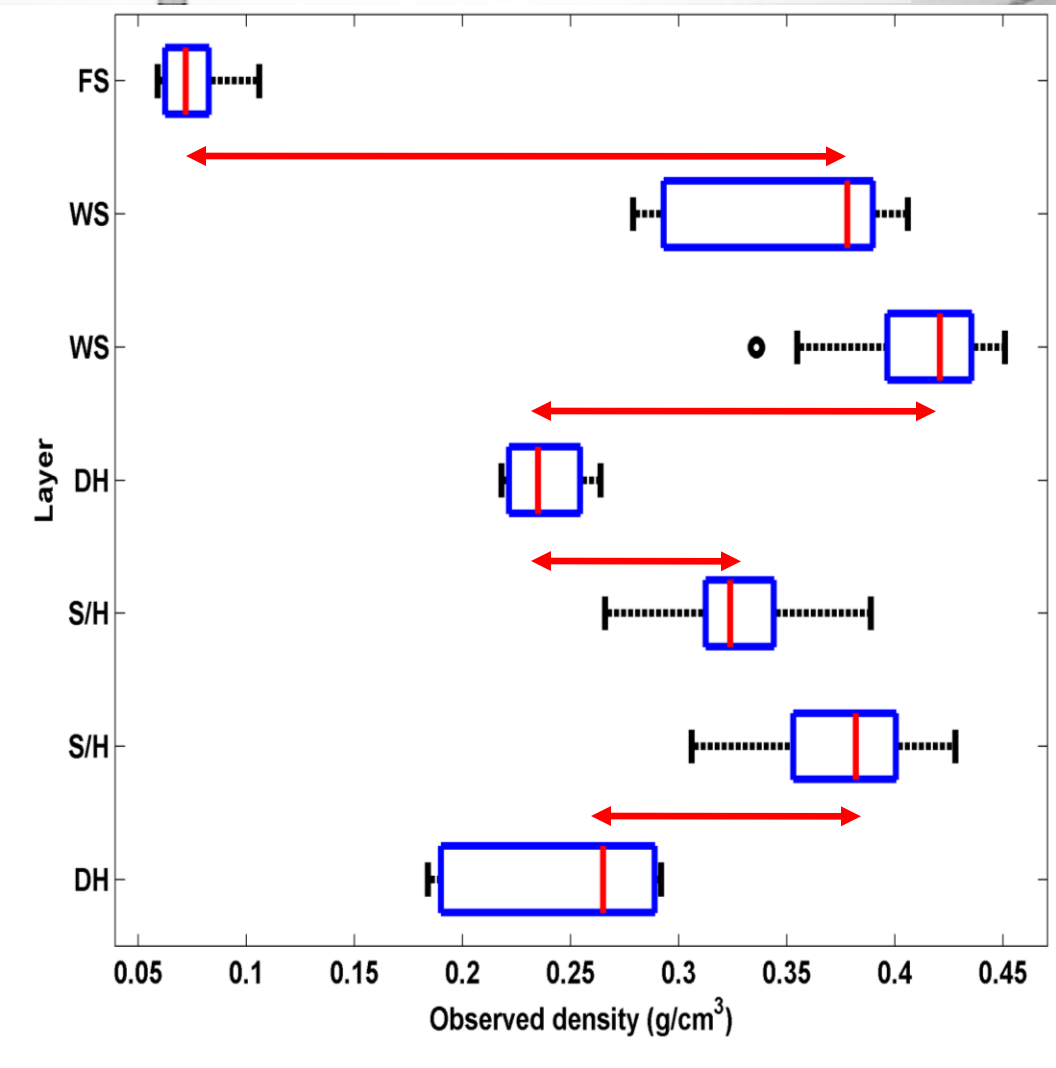

Snow depth RMSE = 3.5 cm
distance in snow [cm]
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
distance [cm]

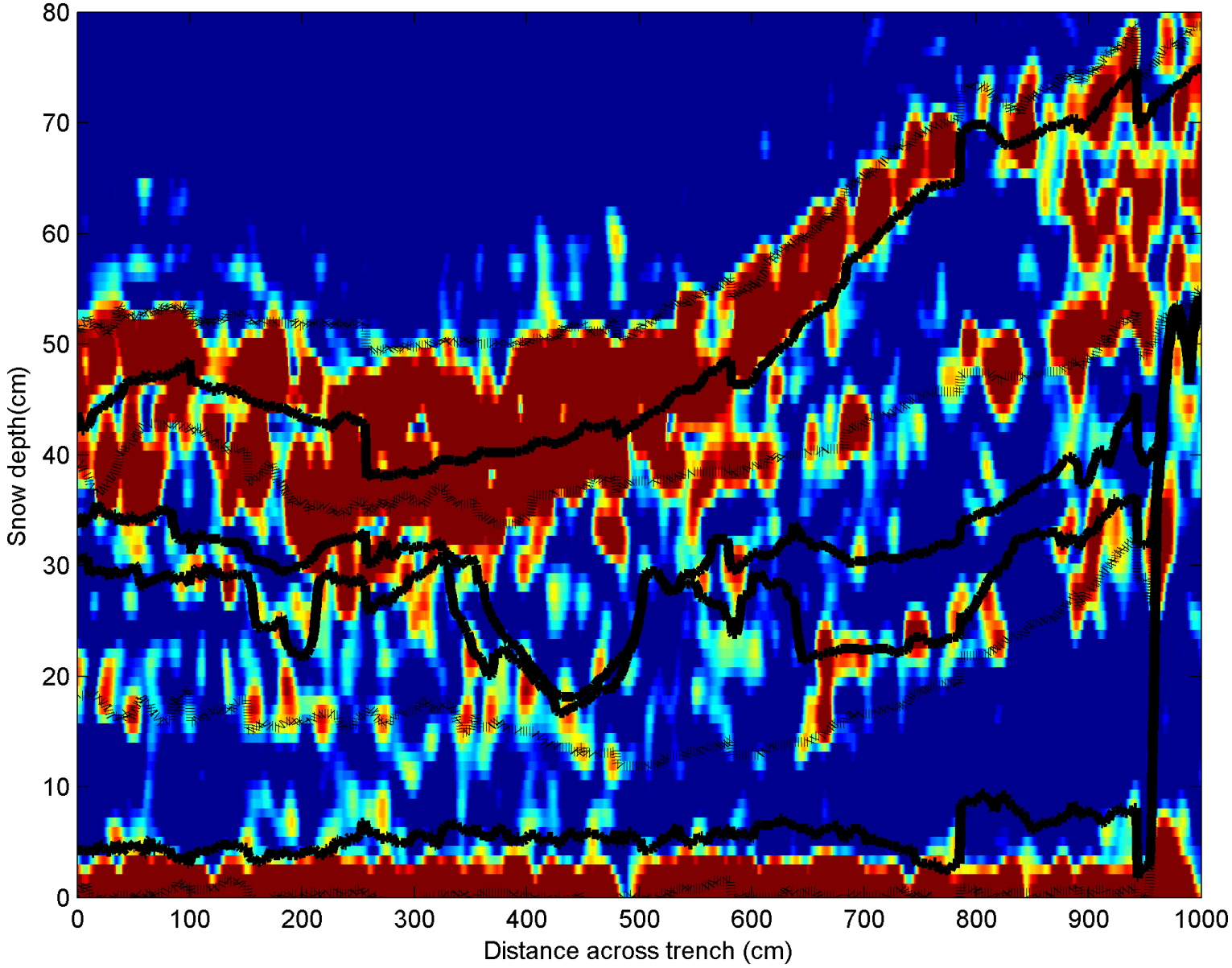

Snow depth(cm)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Distance across trench (cm)

Up to 14 density samples within each stratigraphic layer

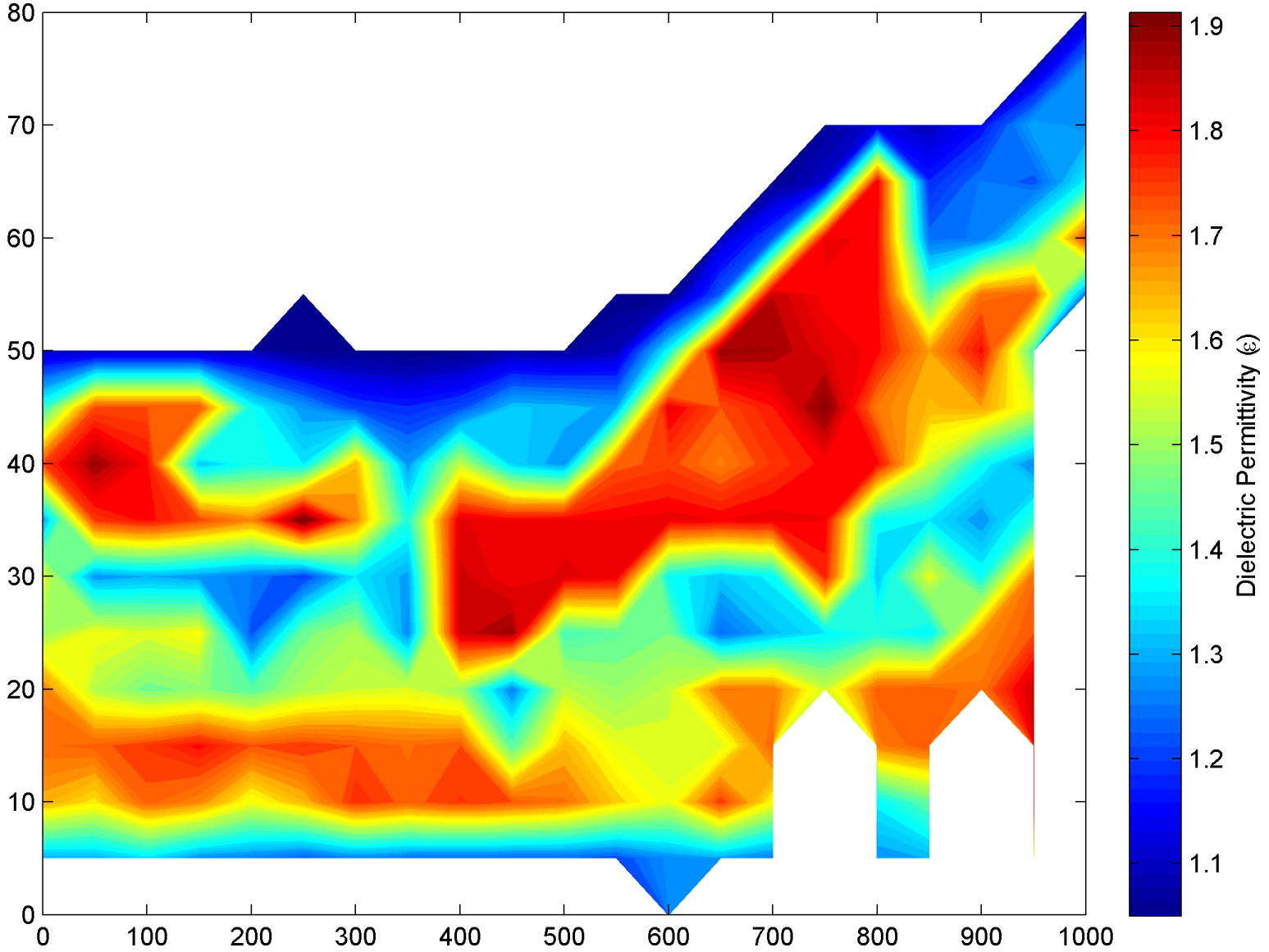
Example NIR image of trench wall section (enhanced contrast)

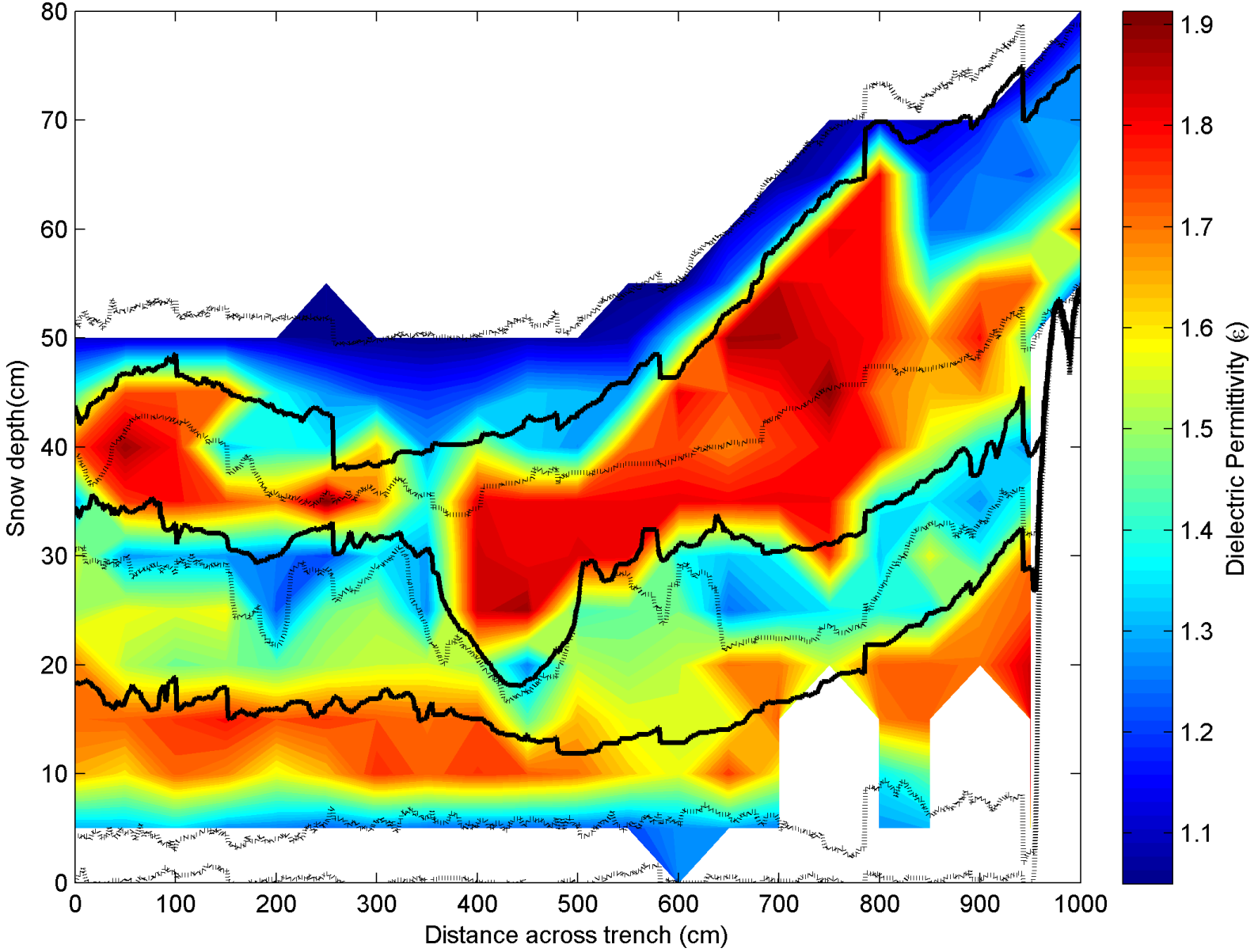


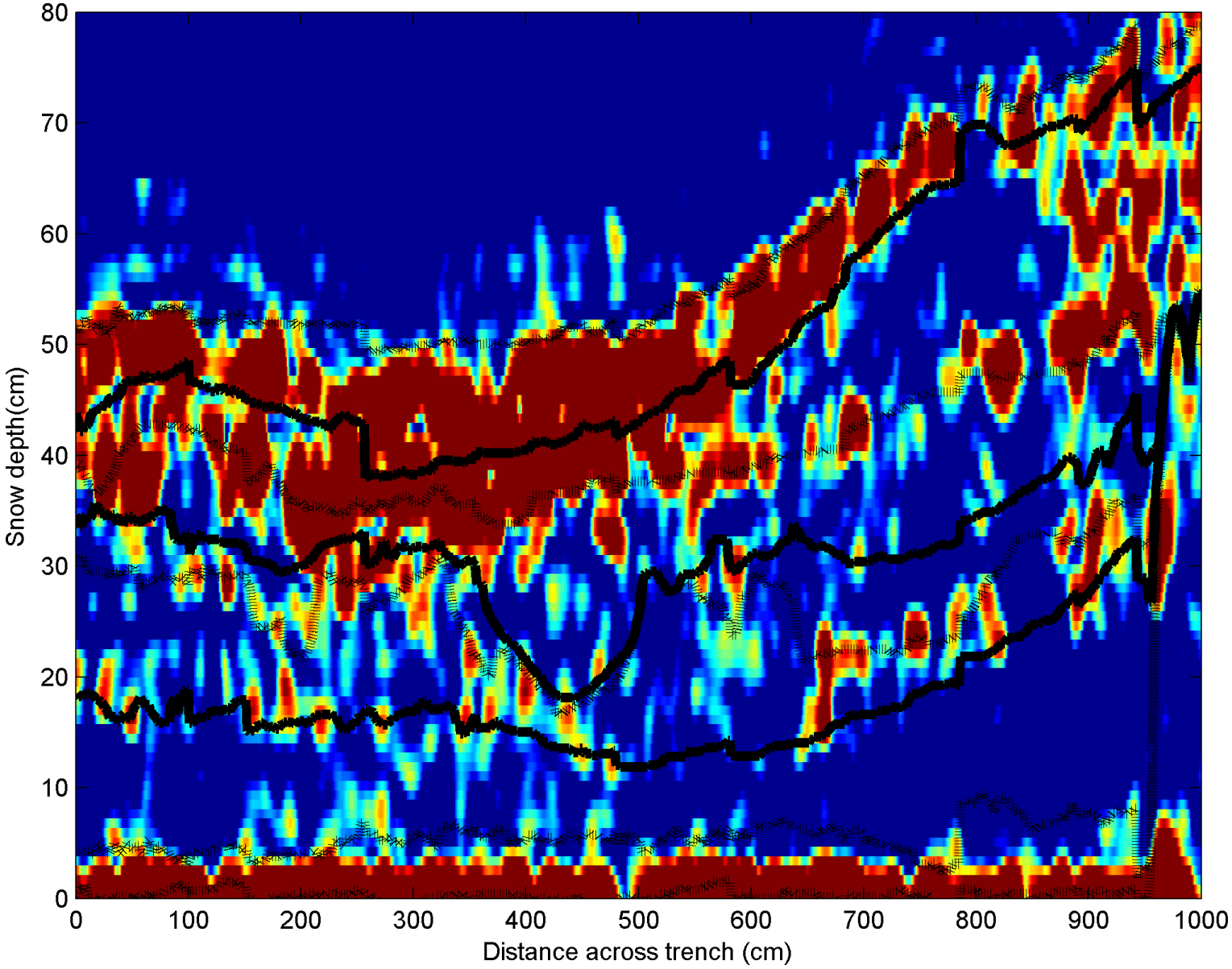



Snow depth(cm)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Distance across trench (cm)

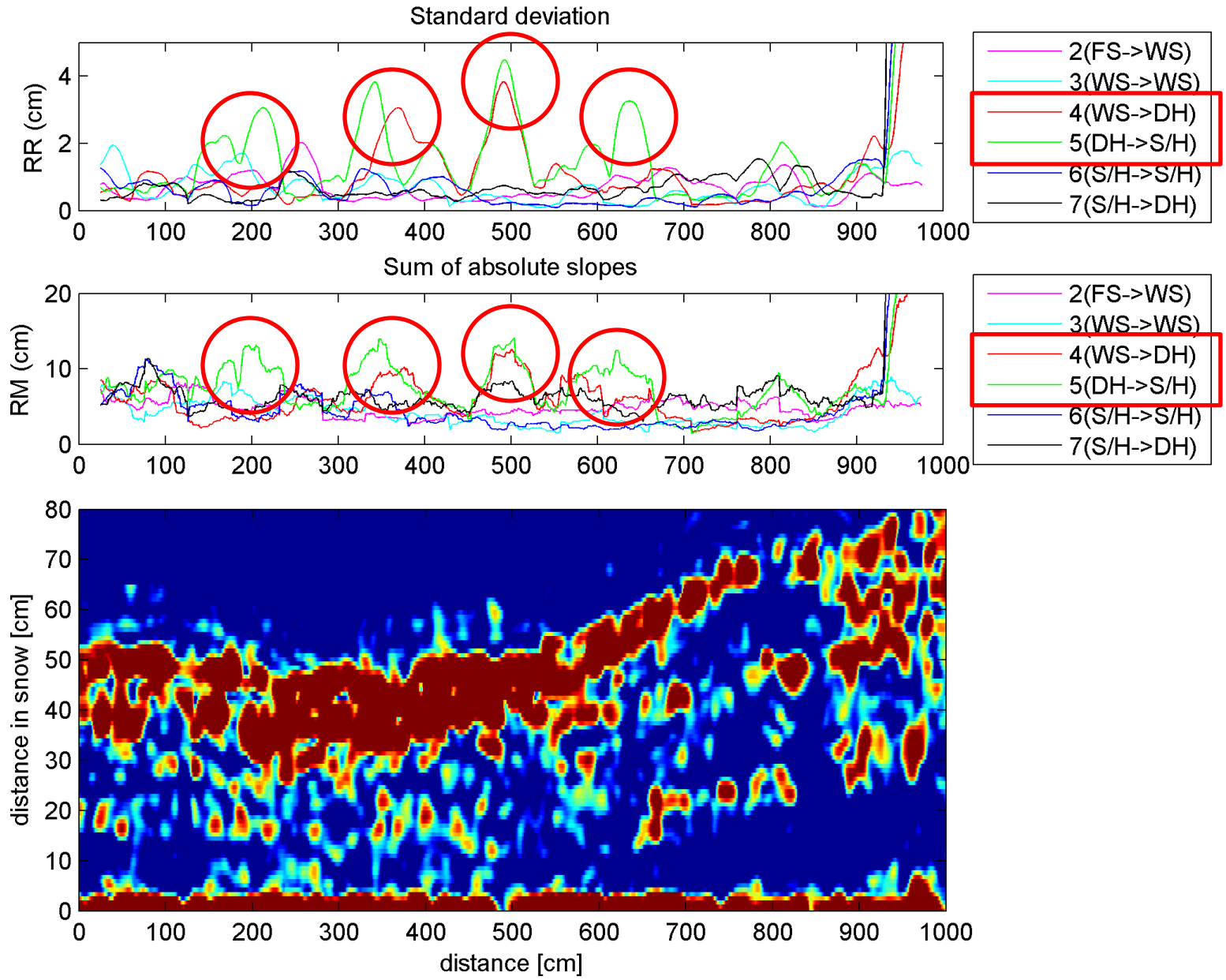
- Finnish Snowfork – dielectric permittivity
  - Vertical profiles (5 cm spacing) every 50 cm along trench

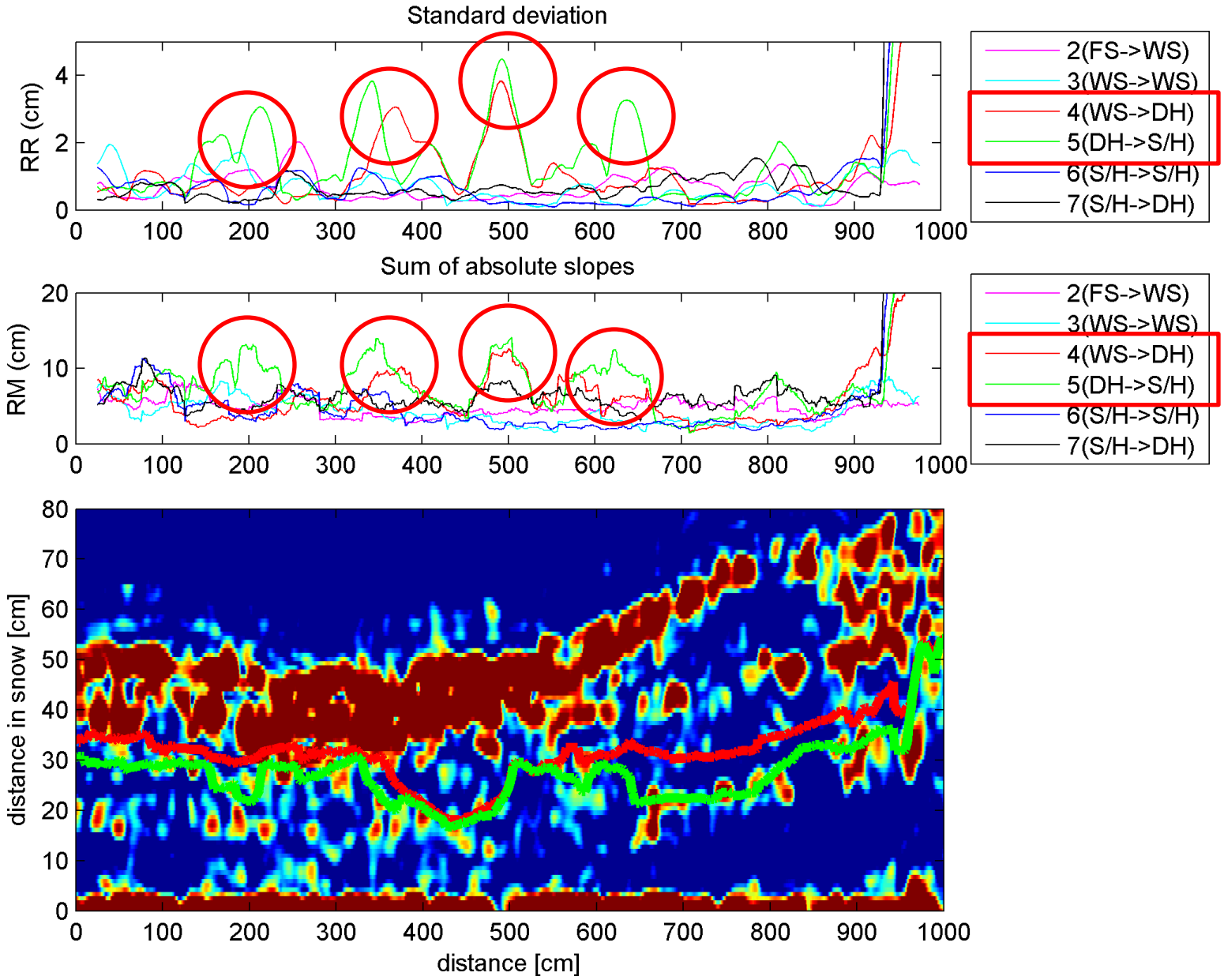

80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
Dielectric Permittivity (ε)

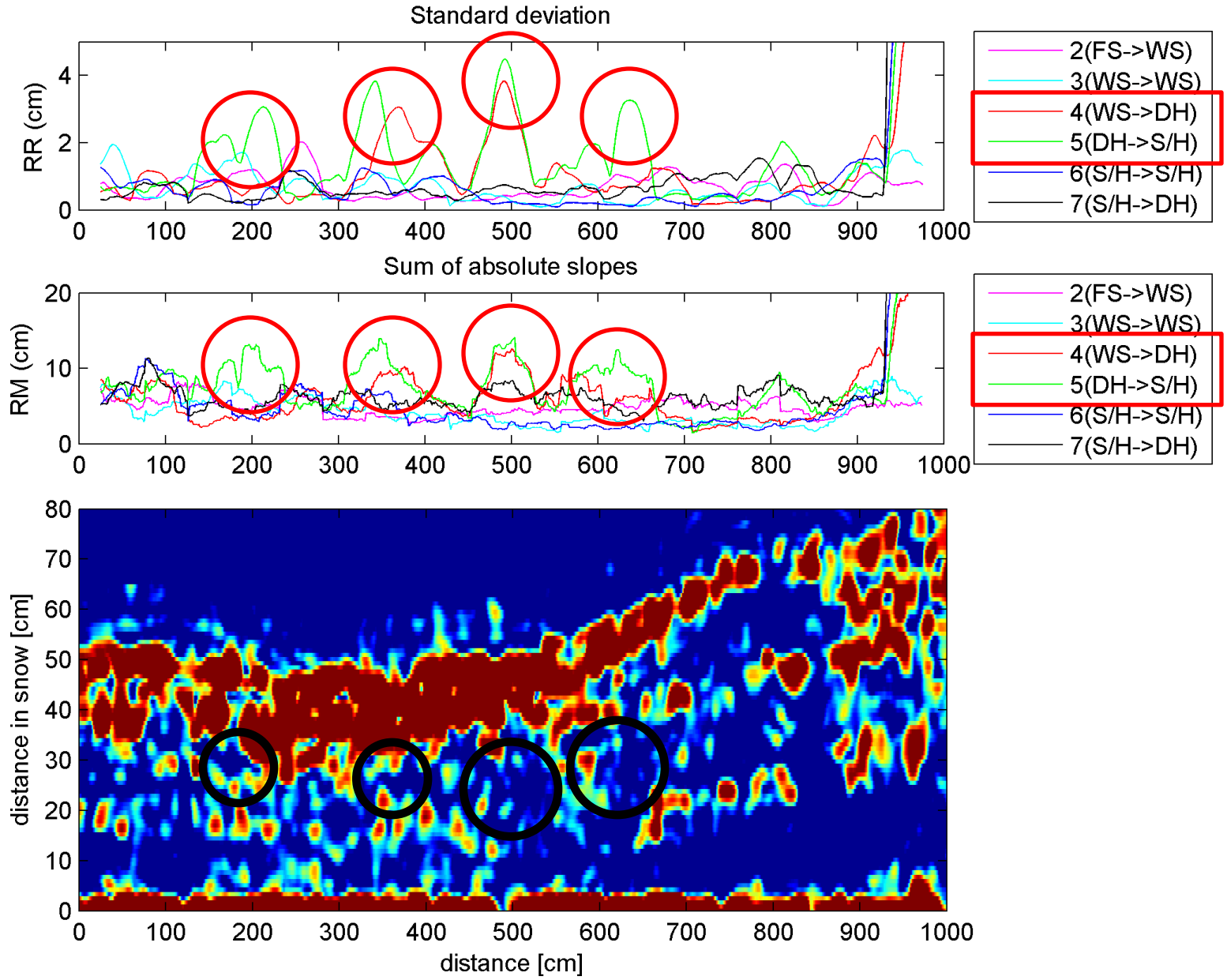

Snow depth(cm)
Distance across trench (cm)
Dielectric Permittivity (ε)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9


Snow depth(cm)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Distance across trench (cm)

- De-trended data (residuals from a linear best fit trend line) to remove any influence of slope
- Roughness coefficients calculated over 50 cm moving windows (replicate ~50 cm footprint of radar)
- Two roughness metrics were used (Fassnacht et al. 2009)
  - Standard deviation
  - Sum of absolute slopes

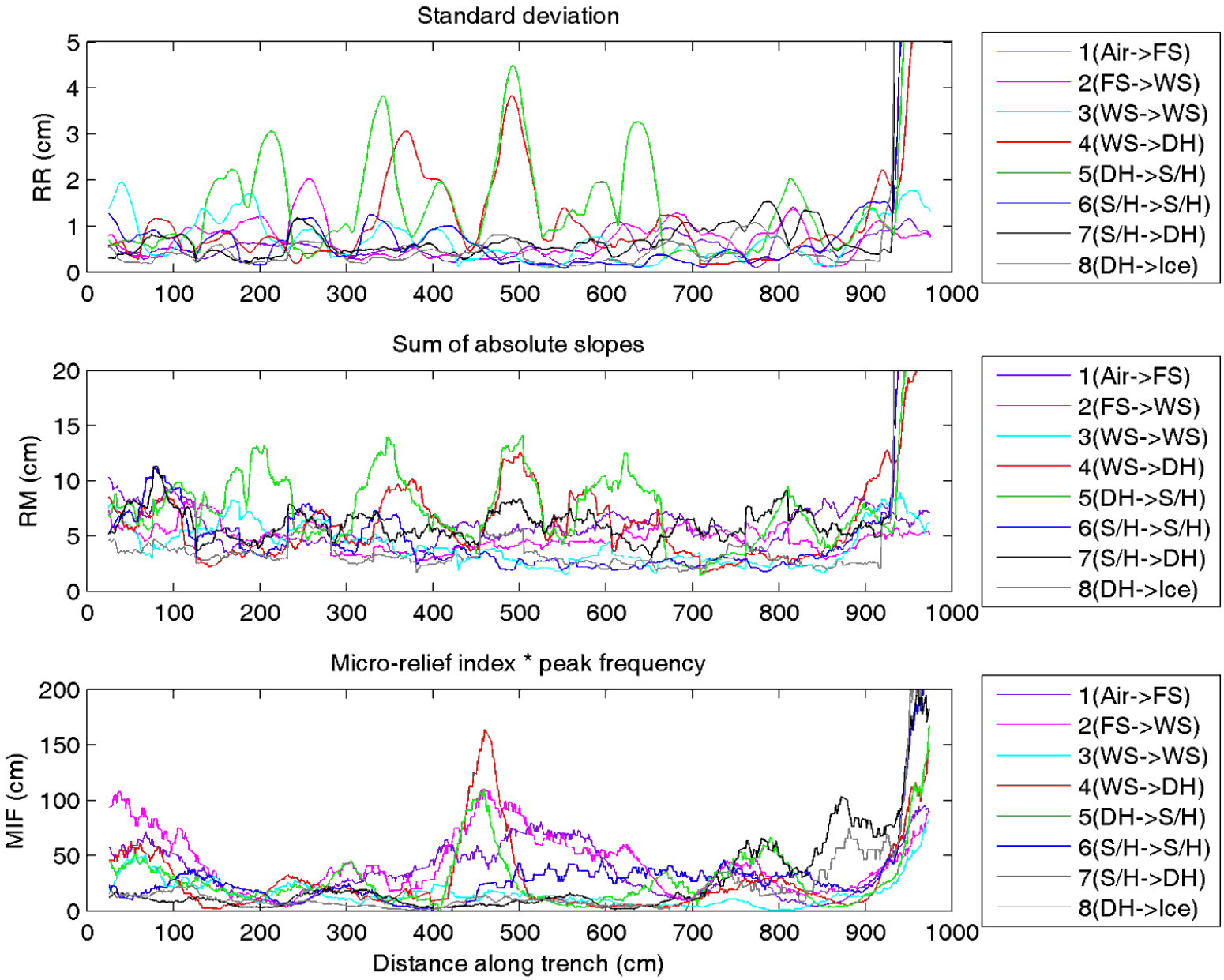

Standard deviation
RR (cm)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
Sum of absolute slopes
RM (cm)
distance in snow [cm]
distance [cm]

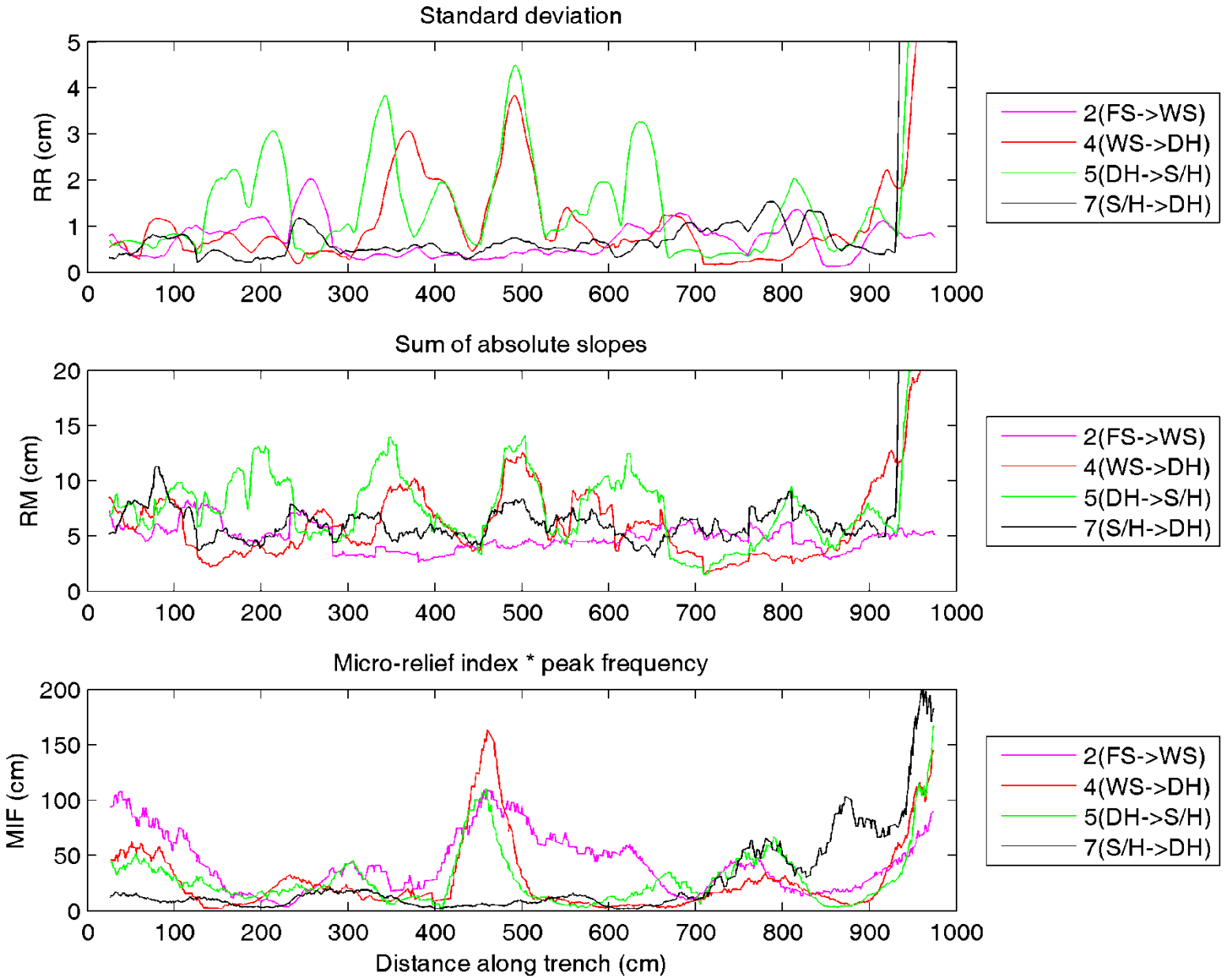

Standard deviation
RR (cm)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
Sum of absolute slopes
RM (cm)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
distance in snow [cm]
distance [cm]

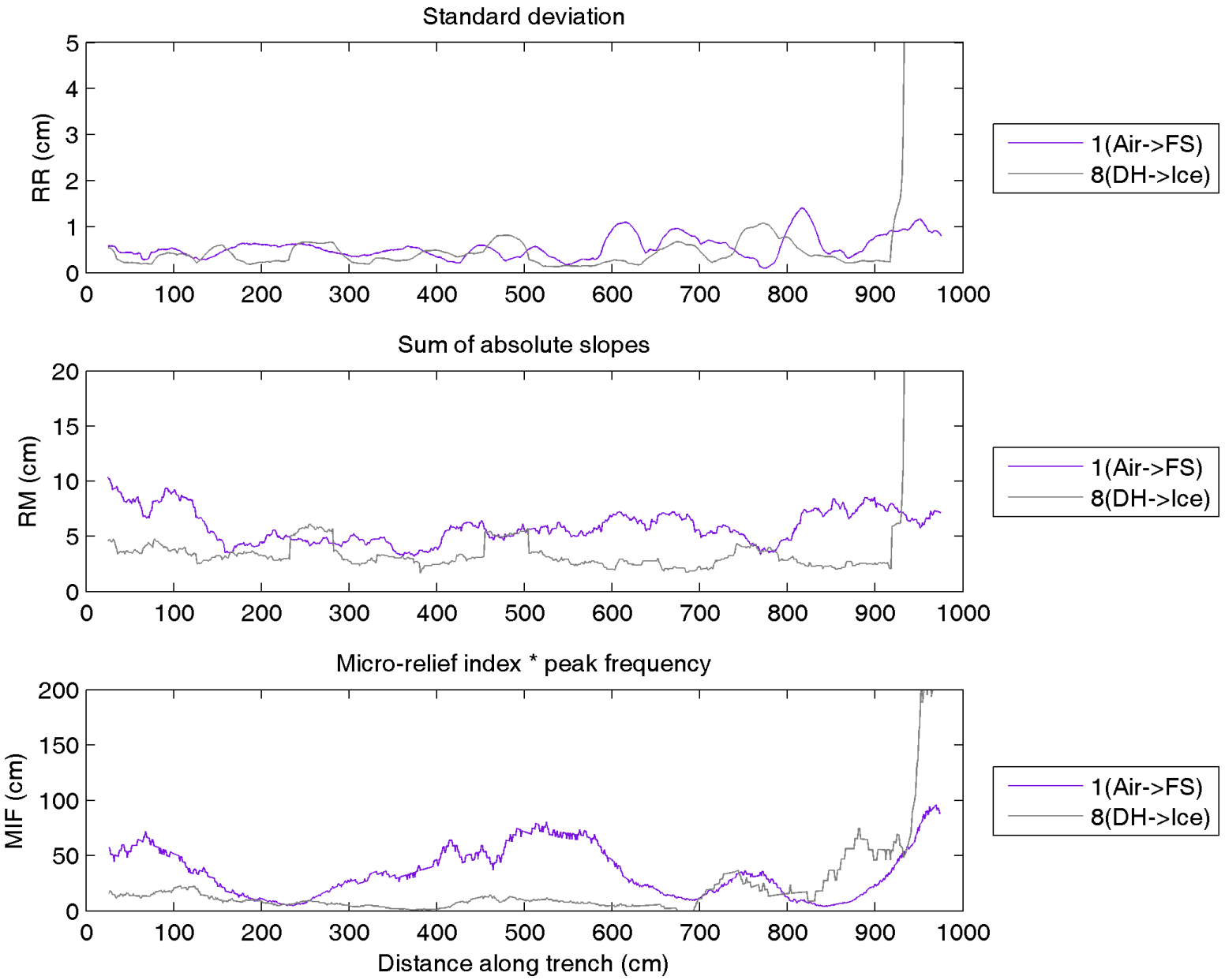

Standard deviation
RR (cm)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
Sum of absolute slopes
RM (cm)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
distance in snow [cm]
distance [cm]

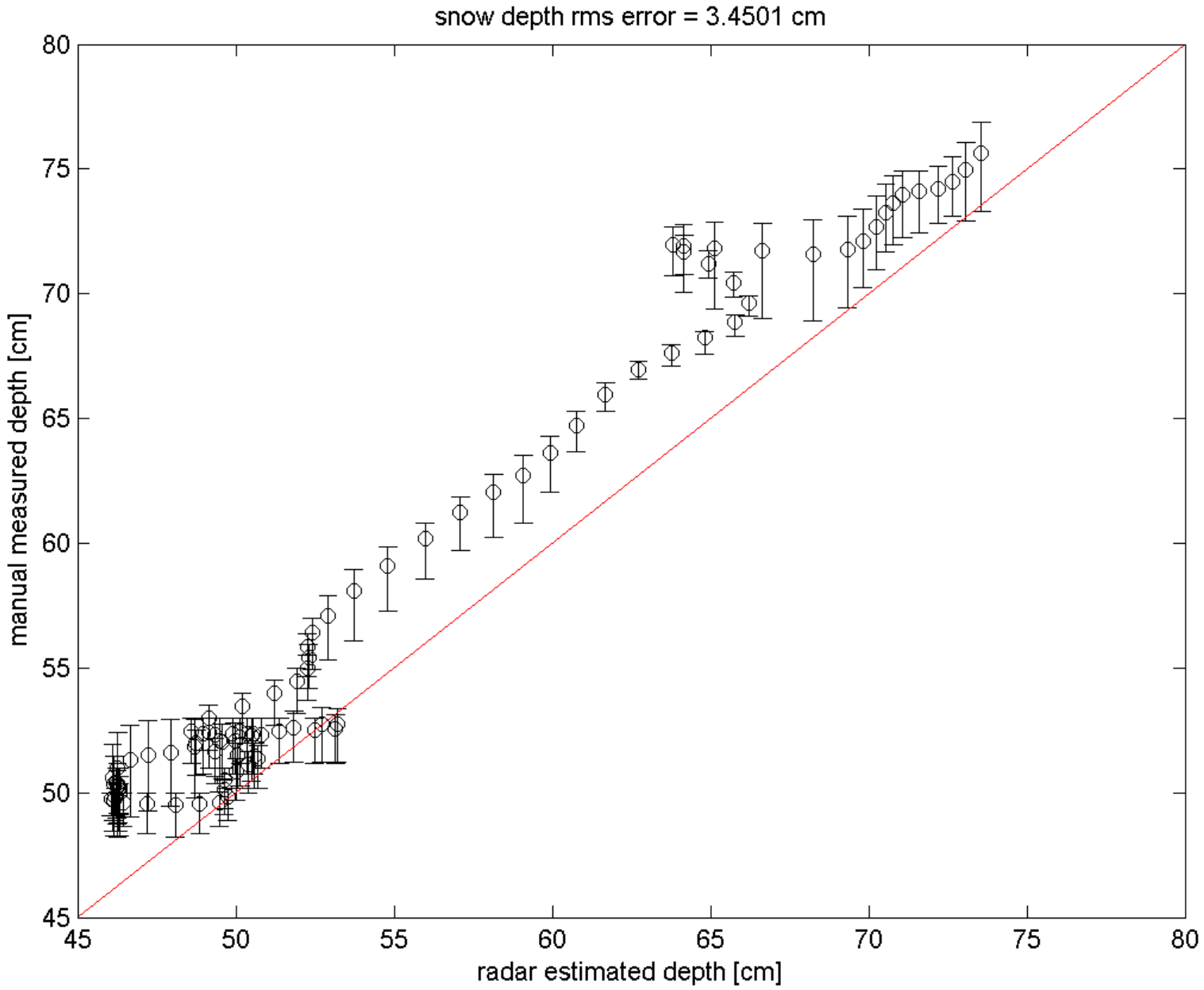
- Conclusions
  - NIR photography at 1 cm resolution identifies all scattering boundaries
  - Major contrasts of density and dielectric permittivity aid identification of internal scattering boundaries
  - Surface roughness (around internal depth hoar) explains some areas of weak backscatter
  - A suite of observations are necessary to adequately test ground-based active Ku-band microwave sensors
- Future
  - NIR trench photos taken as part of April 2010 field campaigns in Churchill (Canadian CoReH20 Snow and Ice Experiment) coincident with ground-based radiometers and X- and Ku-band scatterometers
  - Link layer thicknesses variations in sensor footprints to n-layer HUT model

Extra Slides


Standard deviation
RR (cm)
0
1
2
3
4
5
0
100
200
300
400
500
600
700
800
900
1000
1(Air->FS)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
8(DH->Ice)
Sum of absolute slopes
RM (cm)
0
5
10
15
20
0
100
200
300
400
500
600
700
800
900
1000
1(Air->FS)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
8(DH->Ice)
Micro-relief index * peak frequency
MIF (cm)
0
50
100
150
200
0
100
200
300
400
500
600
700
800
900
1000
Distance along trench (cm)
1(Air->FS)
2(FS->WS)
3(WS->WS)
4(WS->DH)
5(DH->S/H)
6(S/H->S/H)
7(S/H->DH)
8(DH->Ice)


Standard deviation
RR (cm)
0
1
2
3
4
5
0
100
200
300
400
500
600
700
800
900
1000
2(FS->WS)
4(WS->DH)
5(DH->S/H)
7(S/H->DH)
Sum of absolute slopes
RM (cm)
0
5
10
15
20
0
100
200
300
400
500
600
700
800
900
1000
2(FS->WS)
4(WS->DH)
5(DH->S/H)
7(S/H->DH)
Micro-relief index * peak frequency
MIF (cm)
0
50
100
150
200
0
100
200
300
400
500
600
700
800
900
1000
Distance along trench (cm)
2(FS->WS)
4(WS->DH)
5(DH->S/H)
7(S/H->DH)


Standard deviation
RR (cm)
0
1
2
3
4
5
0
100
200
300
400
500
600
700
800
900
1000
1(Air->FS)
8(DH->Ice)
Sum of absolute slopes
RM (cm)
0
5
10
15
20
1(Air->FS)
8(DH->Ice)
Micro-relief index * peak frequency
MIF (cm)
0
50
100
150
200
Distance along trench (cm)
1(Air->FS)
8(DH->Ice)


snow depth rms error = 3.4501 cm
manual measured depth [cm]
radar estimated depth [cm]
80
75
70
65
60
55
50
45
45
50
55
60
65
70
75
80