

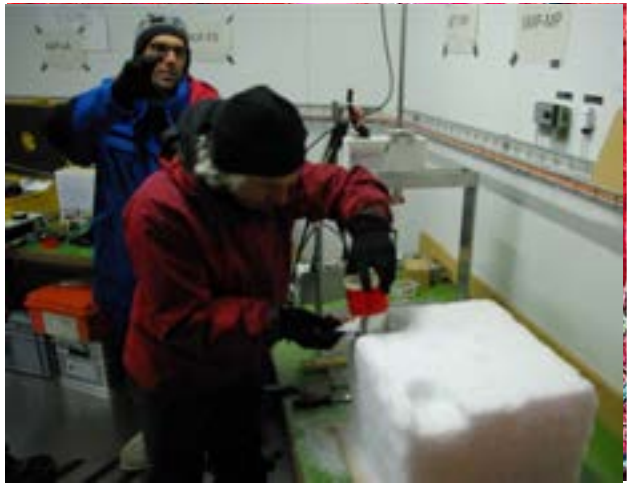
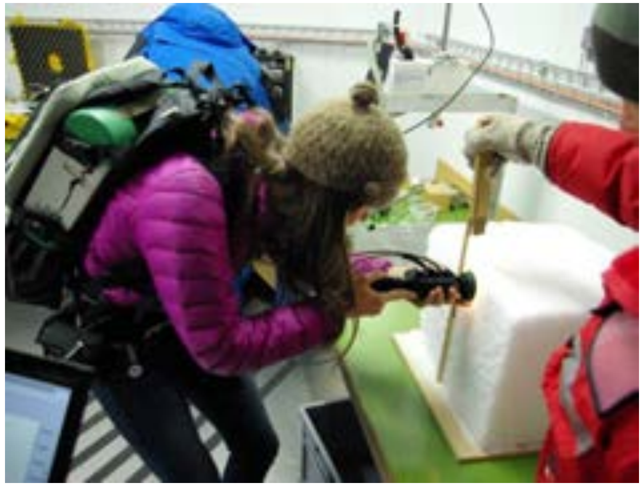

The Snowgrain Size Workshop 2014: a step from a semi-qualitative science to a quantitative science

Martin Schneebeli

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SLF, Davos Dorf, Switzerland

SLF

"snow grain size"?

- "However, it is loosely defined from a geometrical point of view because snow crystals often have very complex shapes, leading to imprecise and subjective measurements." (Picard et al,AGU Adv., 2022).

- "The classical grain size *E* of a snow layer is the average size of its grains. The size of a grain or particle is its greatest extension measured in millimetres." (Int. Snow Classification, 2009)

The grain size is precisely defined, but with limited physical relevance

a snow sample from the MOSAiC expedition

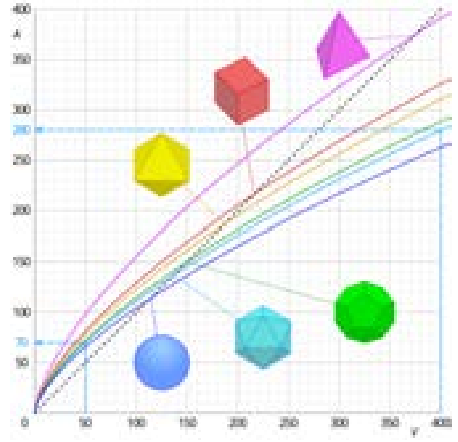
Snow is more than "porous spheres"

Heterogenous porous media can be described by n-point correlation functions (Torquato, 2002). Much simplified, die ice volume fraction ϕ is the first moment, the specific surface area S_v the second moment, etc.

For a random heterogeneous material consisting of *M* phases, the general effective property K_e is the following function:

$$\boldsymbol{K}_e = f(\boldsymbol{K}_1, \boldsymbol{K}_2, \ldots, \boldsymbol{K}_M; \phi_1, \phi_2, \ldots, \phi_M; \boldsymbol{\Omega}),$$

where Ω indicates functionals of higher-order microstructural information



wikipedia: https://en.wikipedia.org/wiki/File:Comparison_of_surface_area_vs_volume_of_shapes.svg

Definition of the properties of porous media

Polydispersivity in the size of the particles constitutes a fundamental feature of the microstructure of a wide class of dispersions (Torquato, 2002)

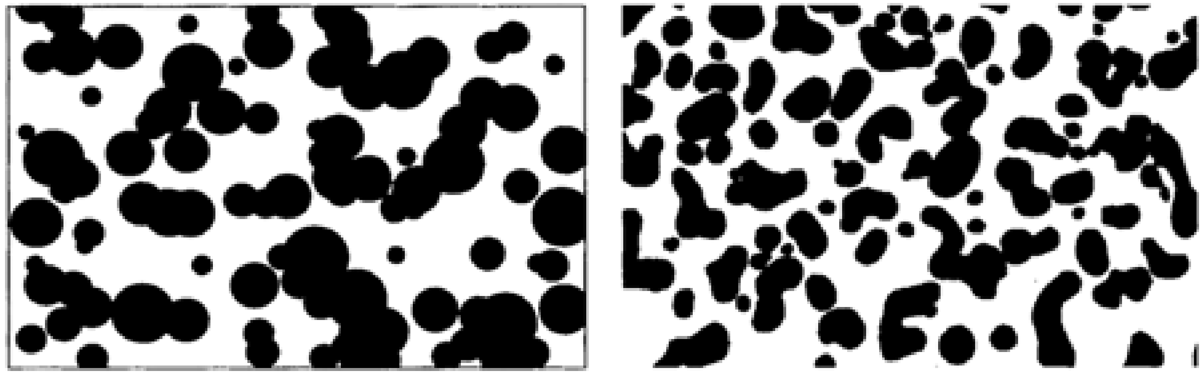


Figure 6.2 Left panel: Polydisperse system of overlapping spheres. Right panel: Micrograph of a silver-magnesium fluoride cermet (Poladian 1990). The inclusions are made of silver and form a variety of shapes from simple globules to long filaments.

Picard, G., Löwe, H., Domine, F., Arnaud, L., Larue, F., Favier, V., Le Meur, E., Lefebvre, E., Savarino, J., and Royer, A.: The Microwave Snow Grain Size: A New Concept to Predict Satellite Observations Over Snow-Covered Regions, AGU Advances, 3, e2021AV000630, https://doi.org/10.1029/2021AV000630, 2022.

Motivation for the Snow Grain Size Intercomparison Workshop 2013 and 2014

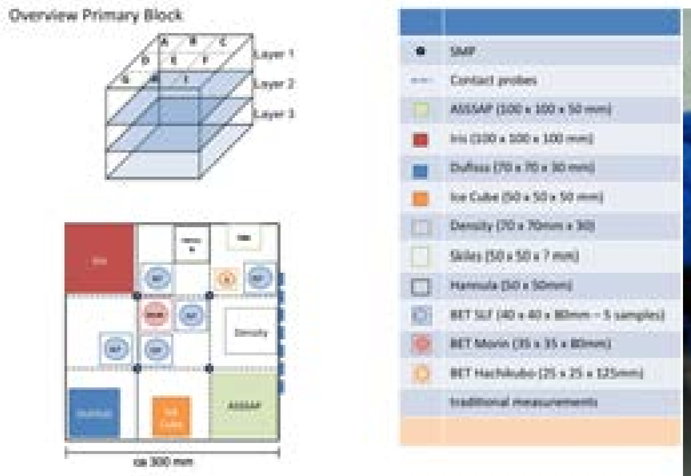
- Several methods to measure specific surface area were developed between ca. 2000 – 2010

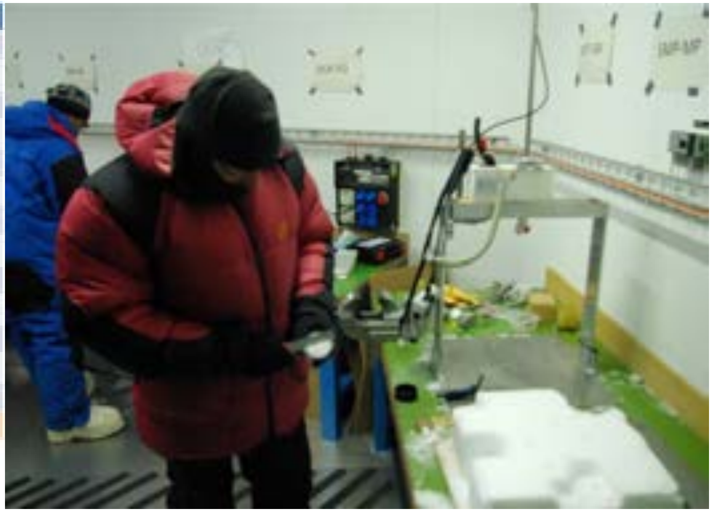
- Precision and accuracy of methods contradicting

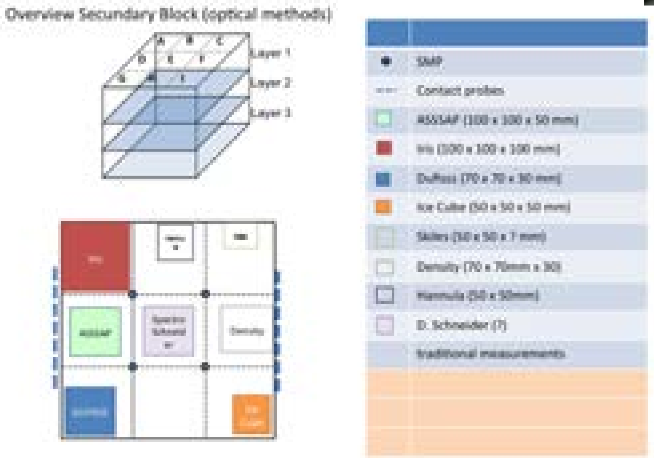
- We need to know more ... supported by IACS, MeteoFrance CEN, WSL – SLF

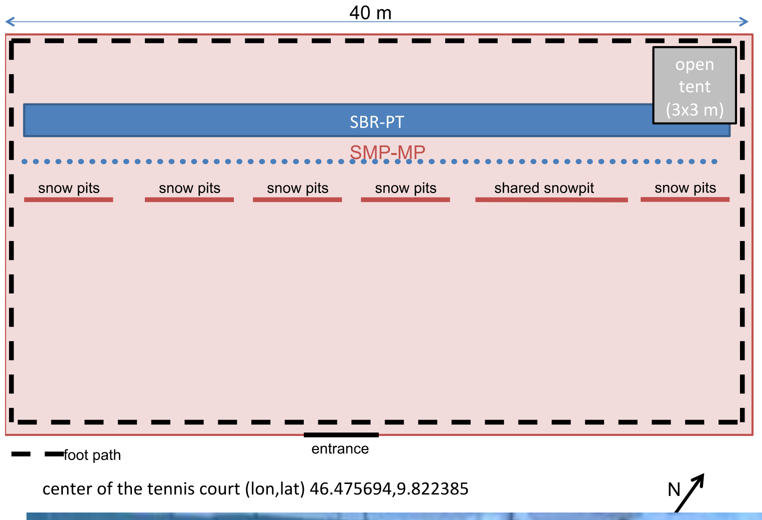
- followed by a workshop in Reading, GB.

setup of the workshop in Davos: lab and field









Participating instruments

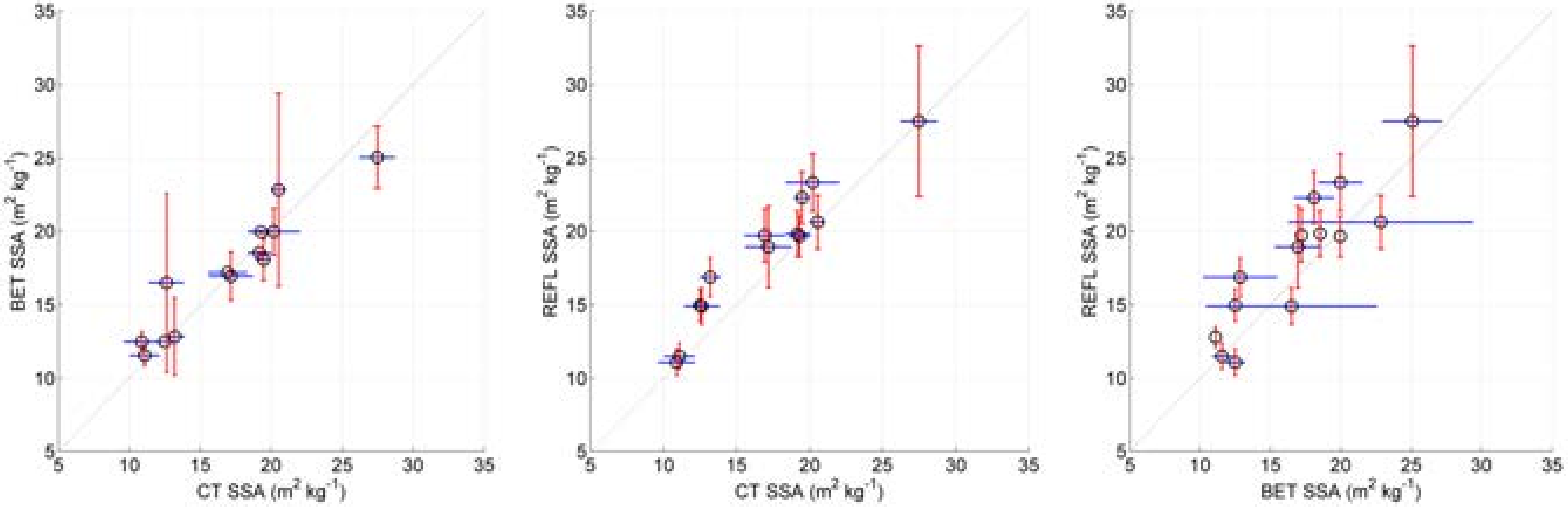
Instrument(s)	Key
computer tomography	MCT-MM
gas adsorption	BET-AH
gas adsorption	BET-MJ
gas adsorption	BET-SM
nir photography	NIP-TA
short wave photography	SWIR-TA
translucent and nir photography	TRA-MS
ASSSAP	ASP-LA
SPAM-stick	SPAM-PL
DUFISSS	DUF-FD
IRIS	IRIS-AL
ICECUBE	ICE-LL
ASD FieldSpec3 Spectroradiometer	ASD-RP
In-Situ Contact Spectroscopy Probe	SSP-DS
SWIR	SWIR-AR
snow reflectivity at 950nm	INF-FW
NIR Emitting Reflectance Dome (NERD)/Radiation	NERD-AS
contact probe	FCP-MKS

Instrument(s)	Key
Aoki grain size	AGS-TA
crystal screen, magnifying lense	TRAD-CF
gridded plate, macrophotography	GRI-HH
macro photography grain size	MACP-RP
snow micro pen	SMP-MP

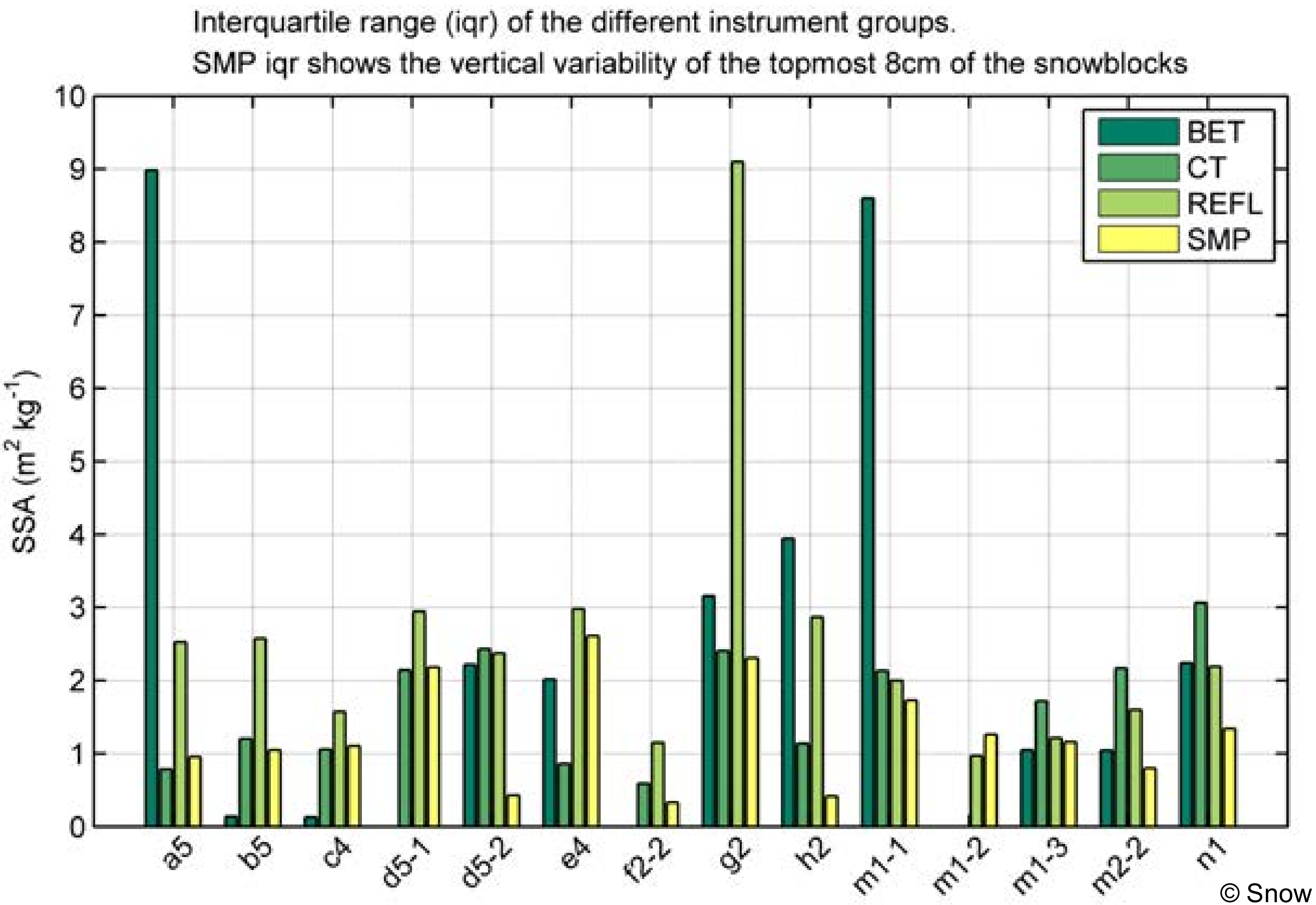
Results from the workshop

- results from the snow blocks under constant temperature in the cold lab
- results from the wind-sheltered snow on the tennis court of St. Moritz

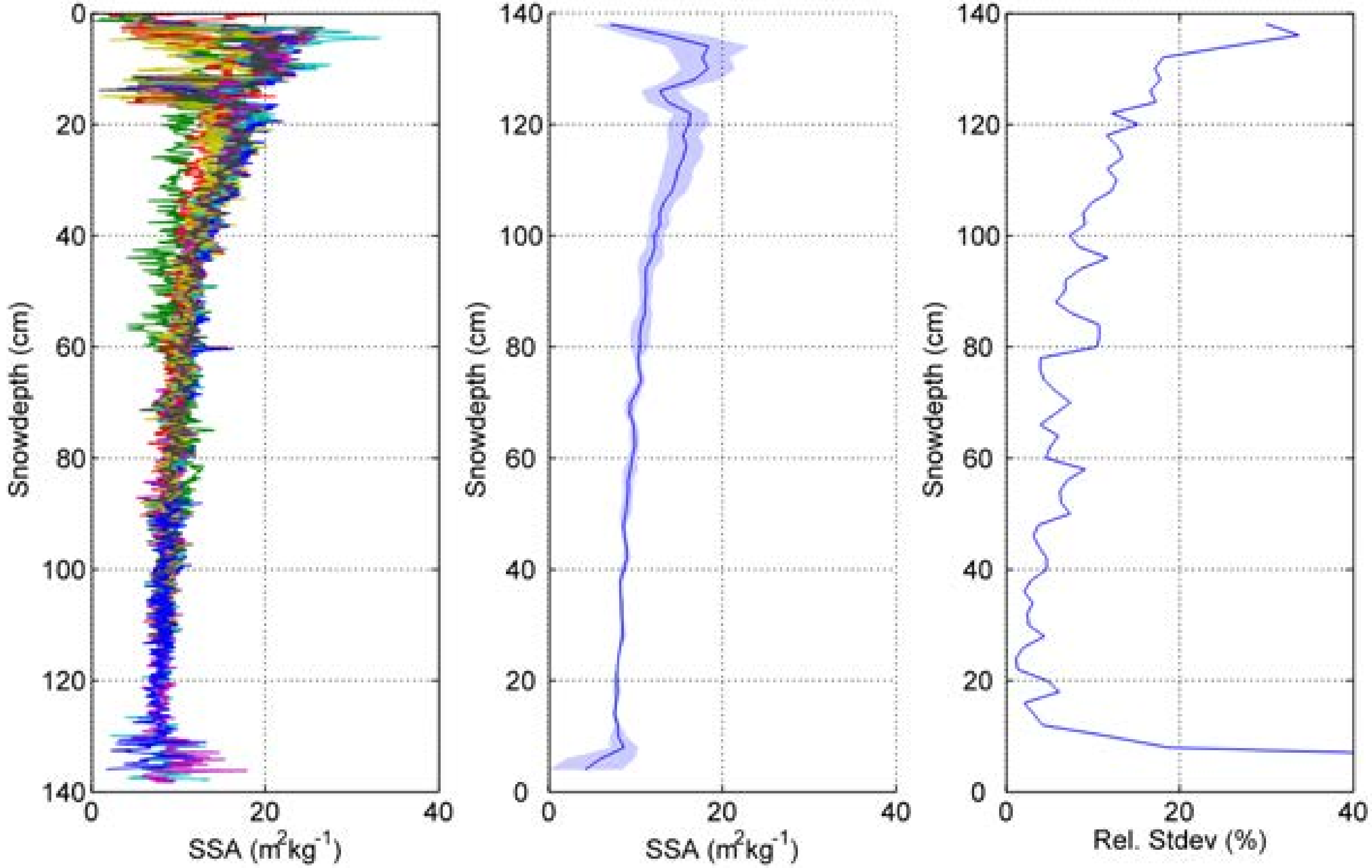
Comparison of model-free direct methods

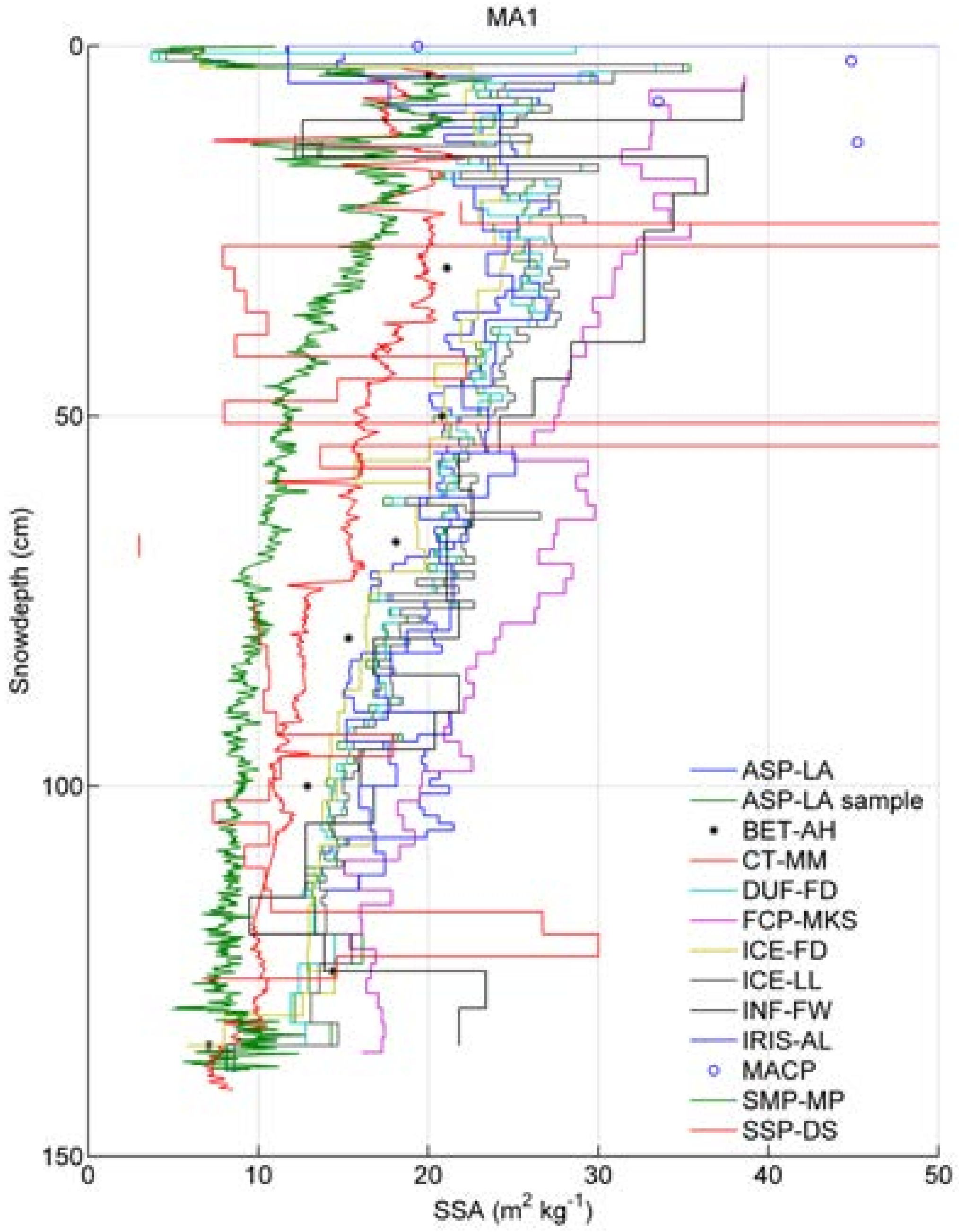


Blocks: all instrument groups differences



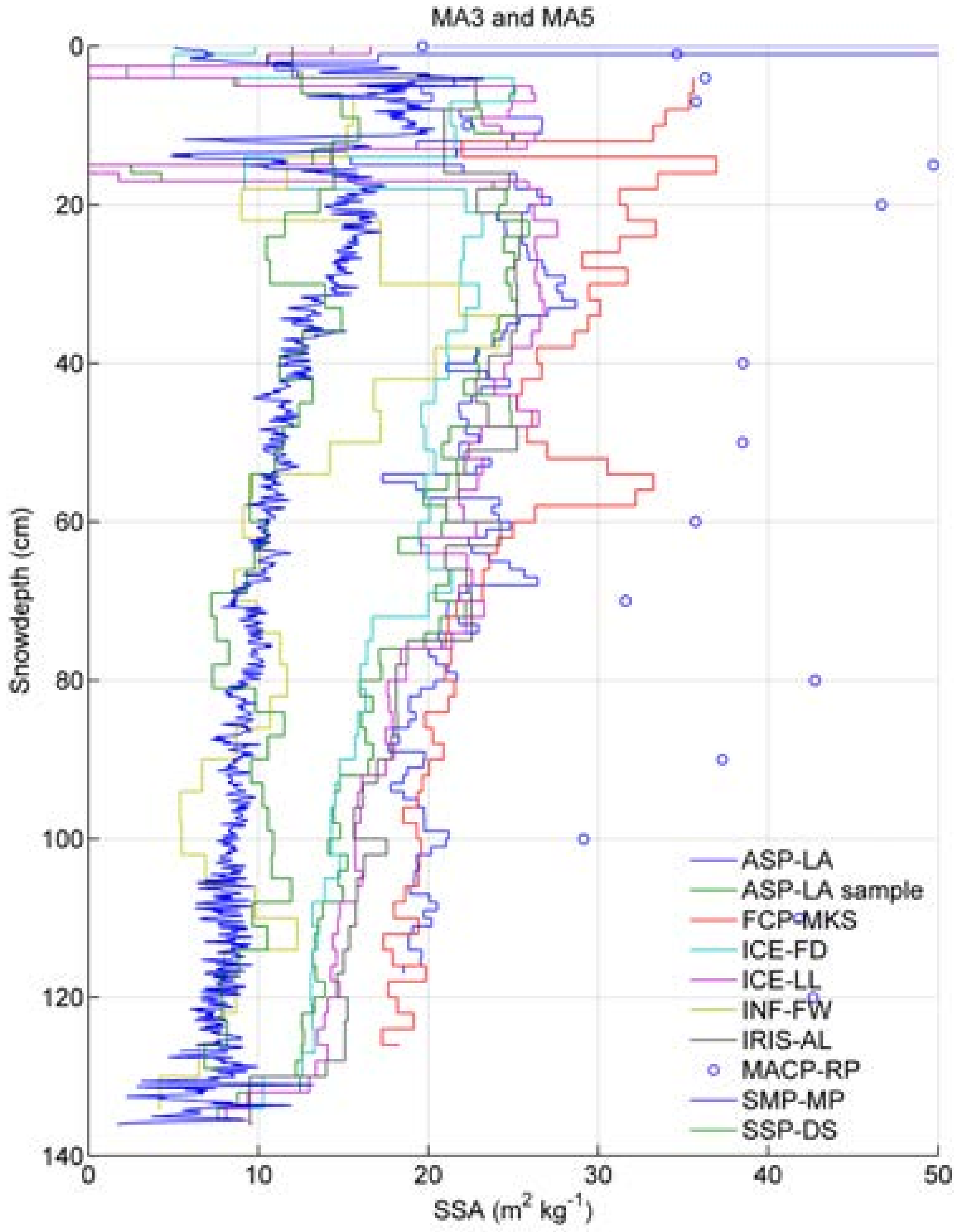
St. Moritz – SSA_{SMP} field homogeneity




MA1
Snowdepth (cm)
SSA (m^2 kg^{-1})
0
50
100
150
0
10
20
30
40
50
ASP-LA
ASP-LA sample
BET-AH
CT-MM
DUF-FD
FCP-MKS
ICE-FD
ICE-LL
INF-FW
IRIS-AL
MACP
SMP-MP
SSP-DS

MA1

- SSA



MA3 and MA5
Snowdepth (cm)
0
20
40
60
80
100
120
140
0
10
20
30
40
50
SSA (m^2 kg^{-1})
ASP-LA
ASP-LA sample
FCP-MKS
ICE-FD
ICE-LL
INF-FW
IRIS-AL
MACP-RP
SMP-MP
SSP-DS

MA3 & 5

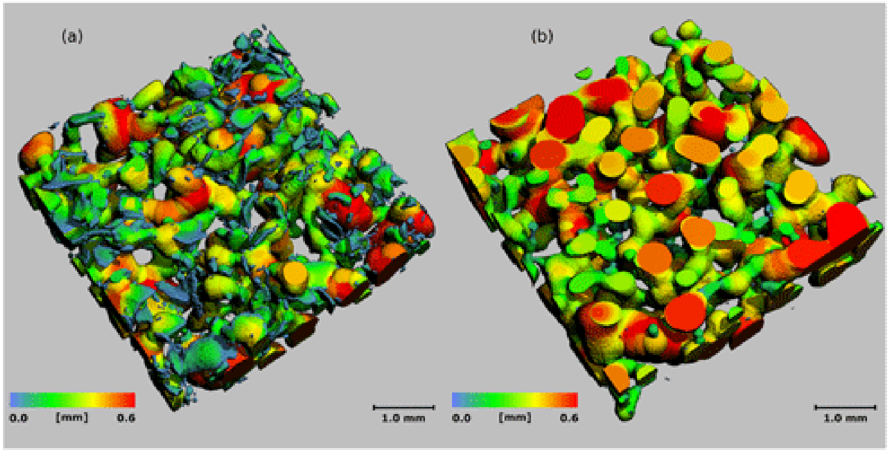
- SSA

Summary of the workshop results

- the measurements on the snow blocks were in general within a reasonable accuracy and variability
- the measurements in the field show large and distinct differences. No explanation for the obvious differences could be identified during the workshop.
- the workshop motivated to continue improved instrument design as well as further experiments to understand the instruments

Effects of surface preparation on reflectance at different NIR wavelengths

- snow surface cutting causes broken bonds and (small) particles
- not for each snow type same impact
- sensitivity to small particles is near-infrared wavelength dependent



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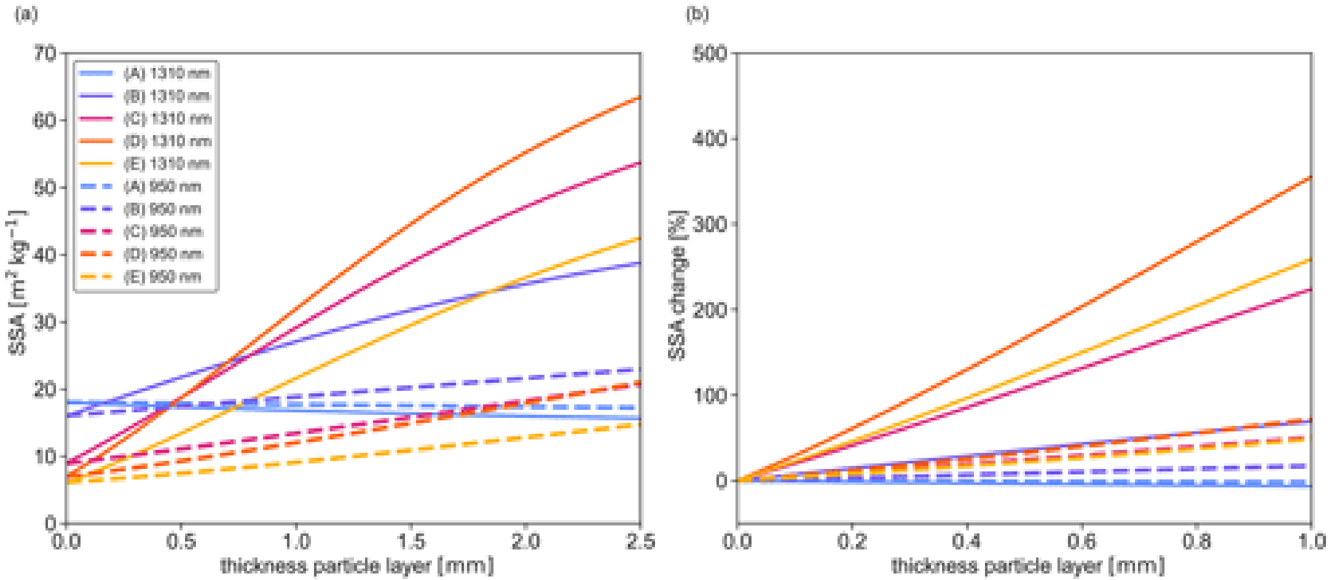
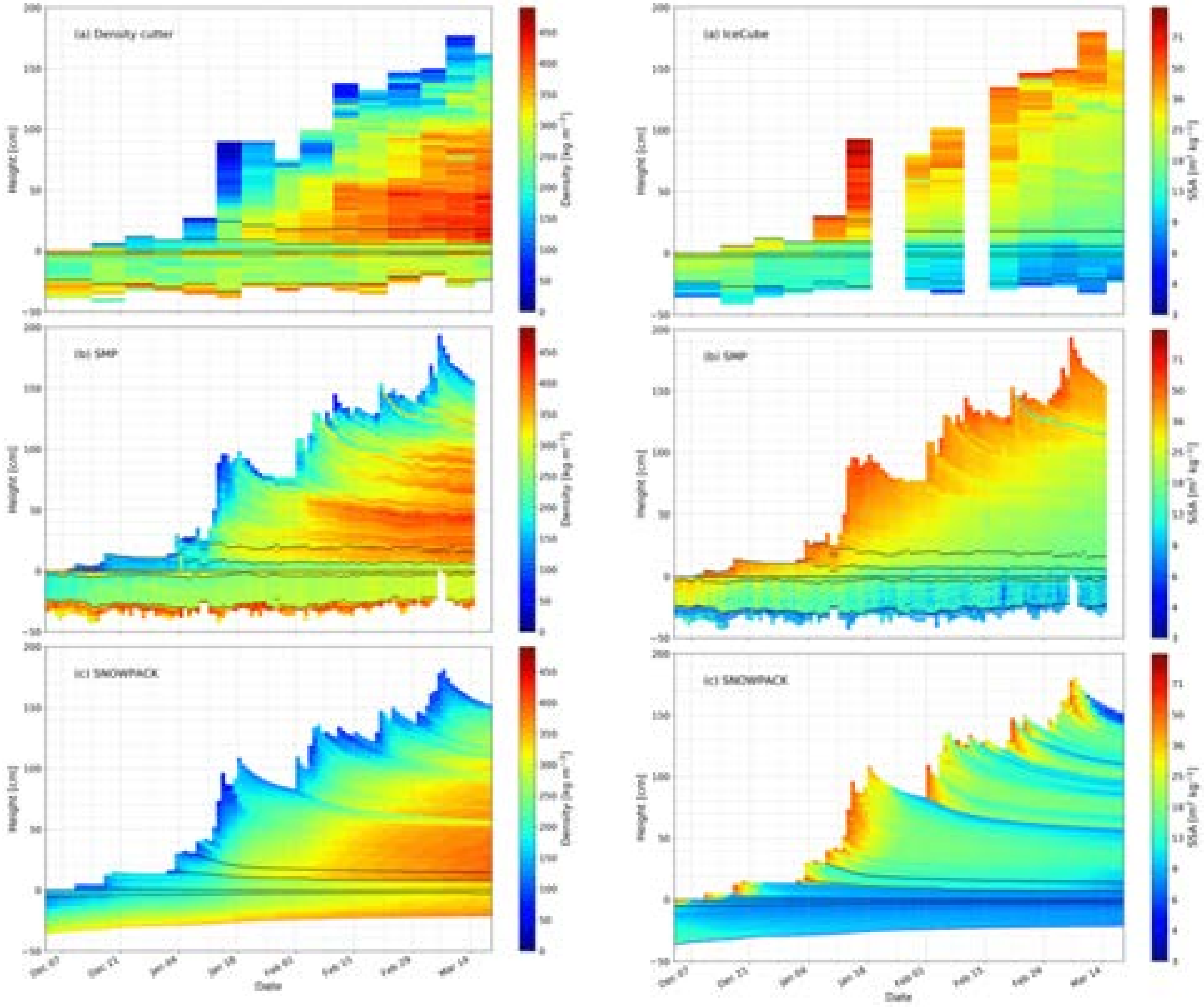


Why care about more precise measurements?



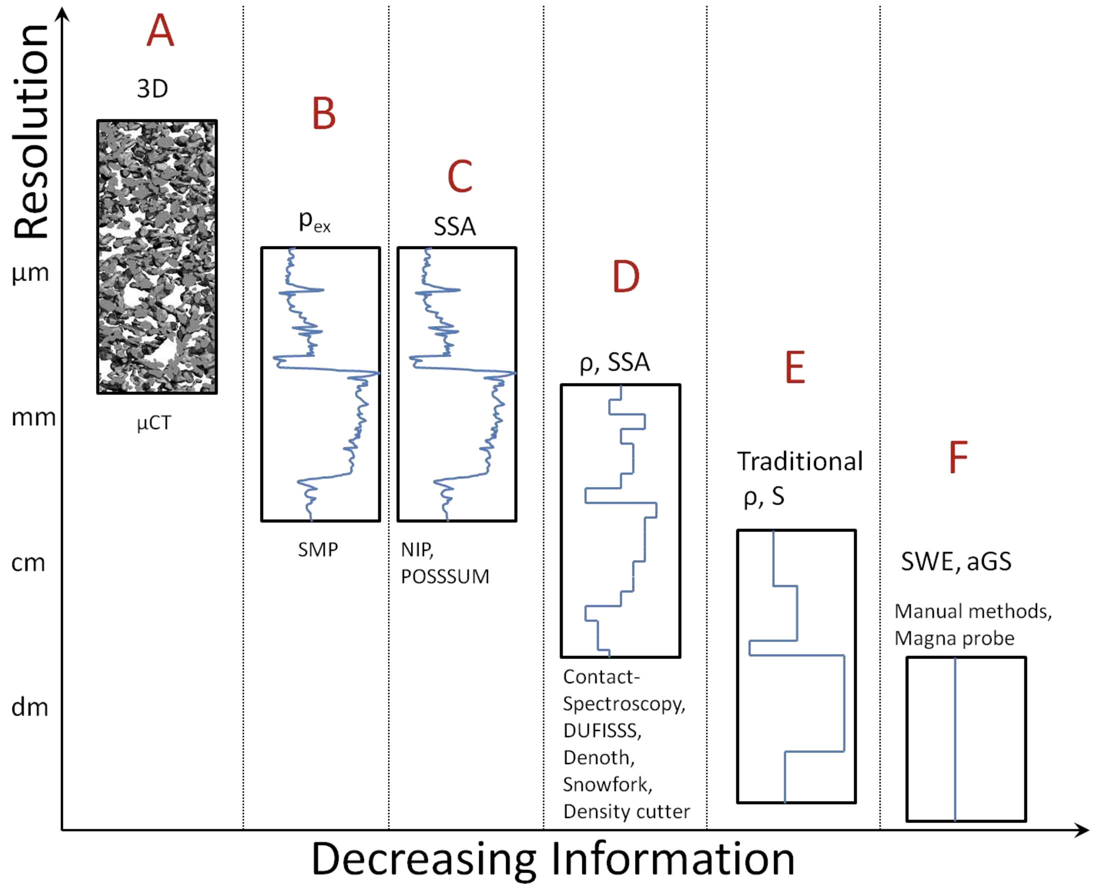
- $d\rho$ / dt?
- dSSA / dt?
- $SSA_{m1} \neq SSA_{m2} \neq SSA_{model}$?
- no improvement without better methods

Calonne., Richter et al.: The RHOSSA campaign: Multi-resolution monitoring of the seasonal evolution of the structure and mechanical stability of an alpine snowpack, Cryosphere, 14, 1829–1848, https://doi.org/10.5194/tc-14-1829-2020, 2020.

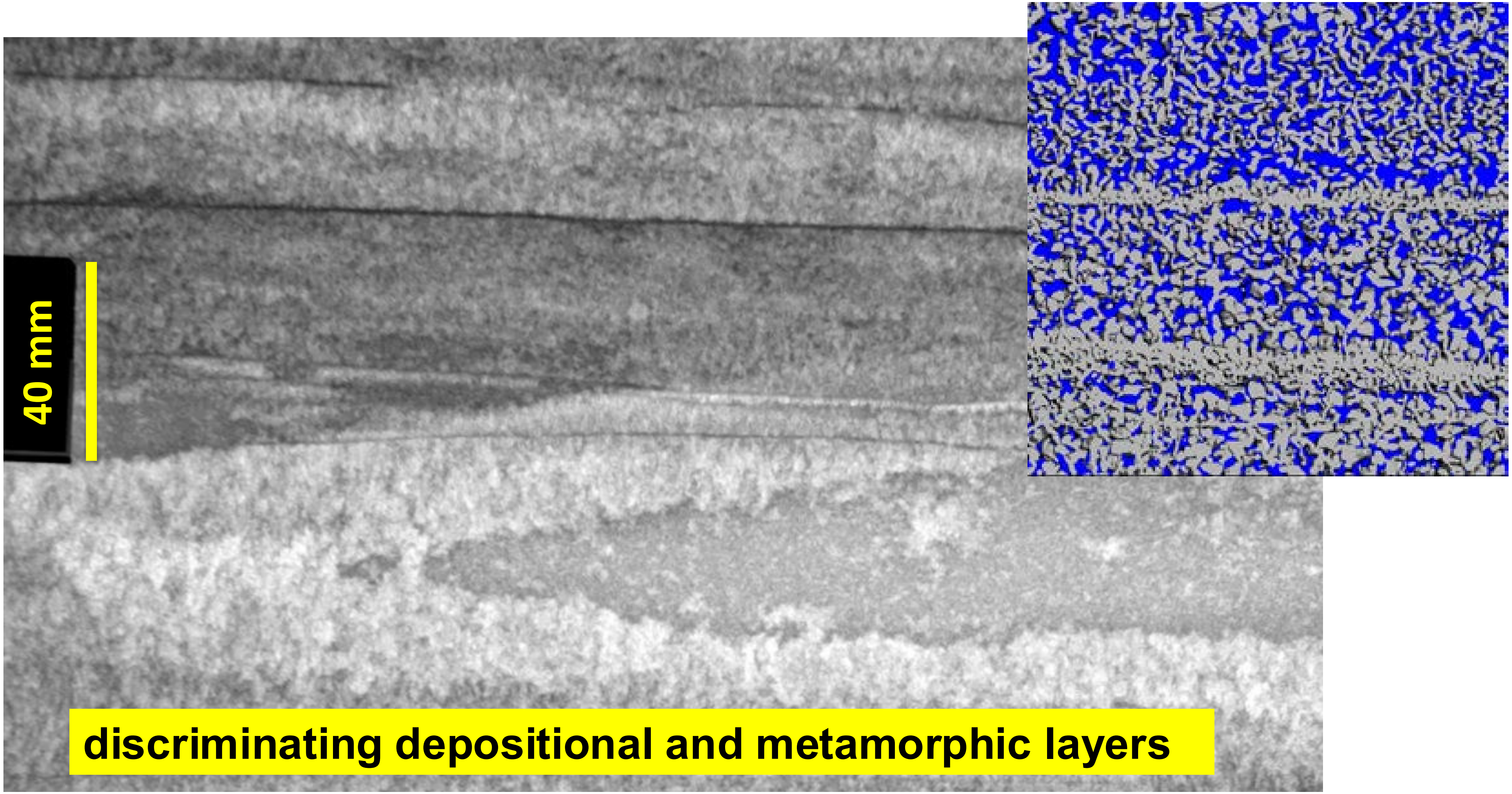
looking beyond the Snow Grain Size Workshops

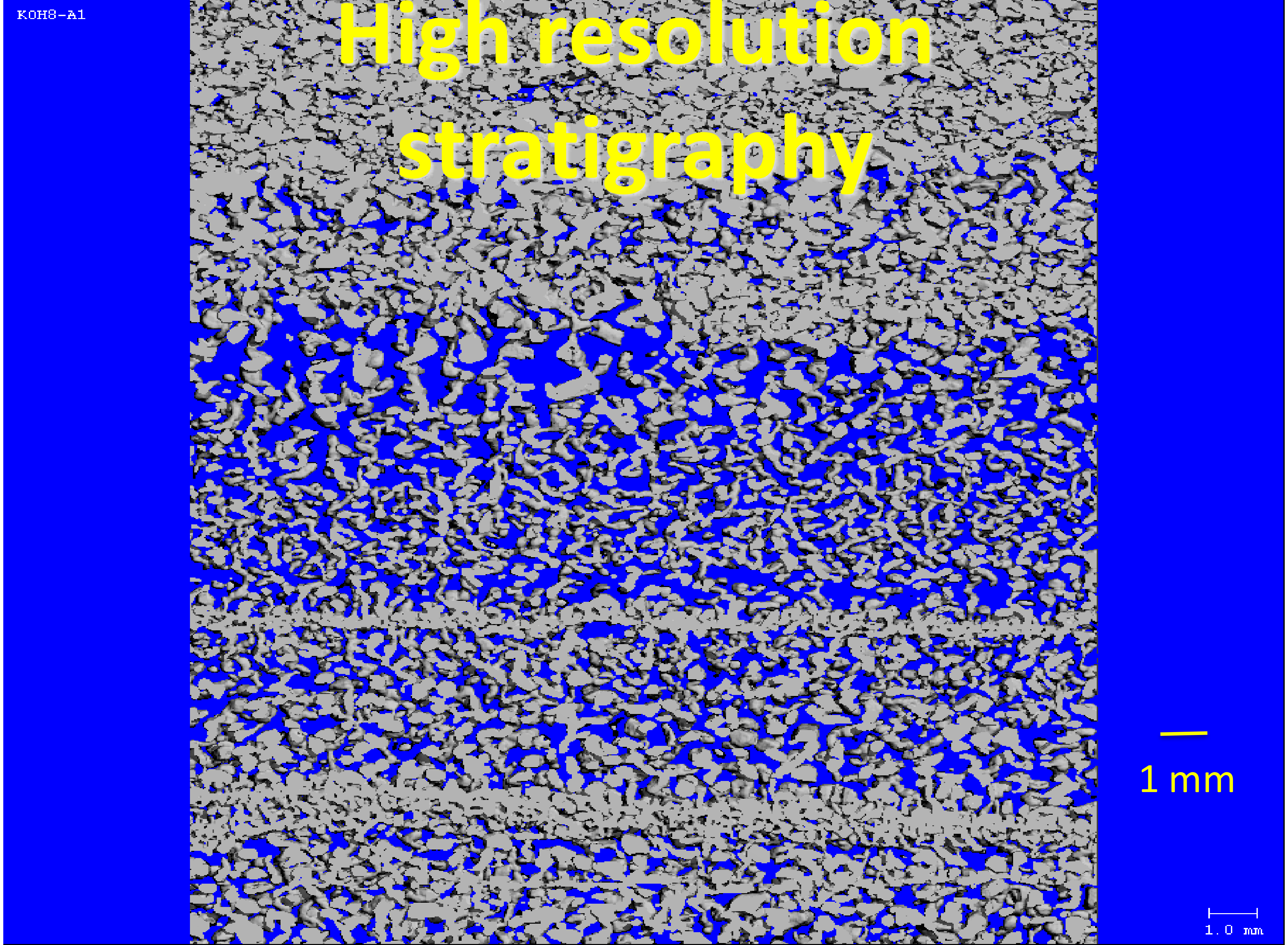
- Examples of complex stratigraphies
- Examples of multi-instrument campaigns: dealing with spatial variability and temporal evolution
- Multiple-metric instruments

The information challenge

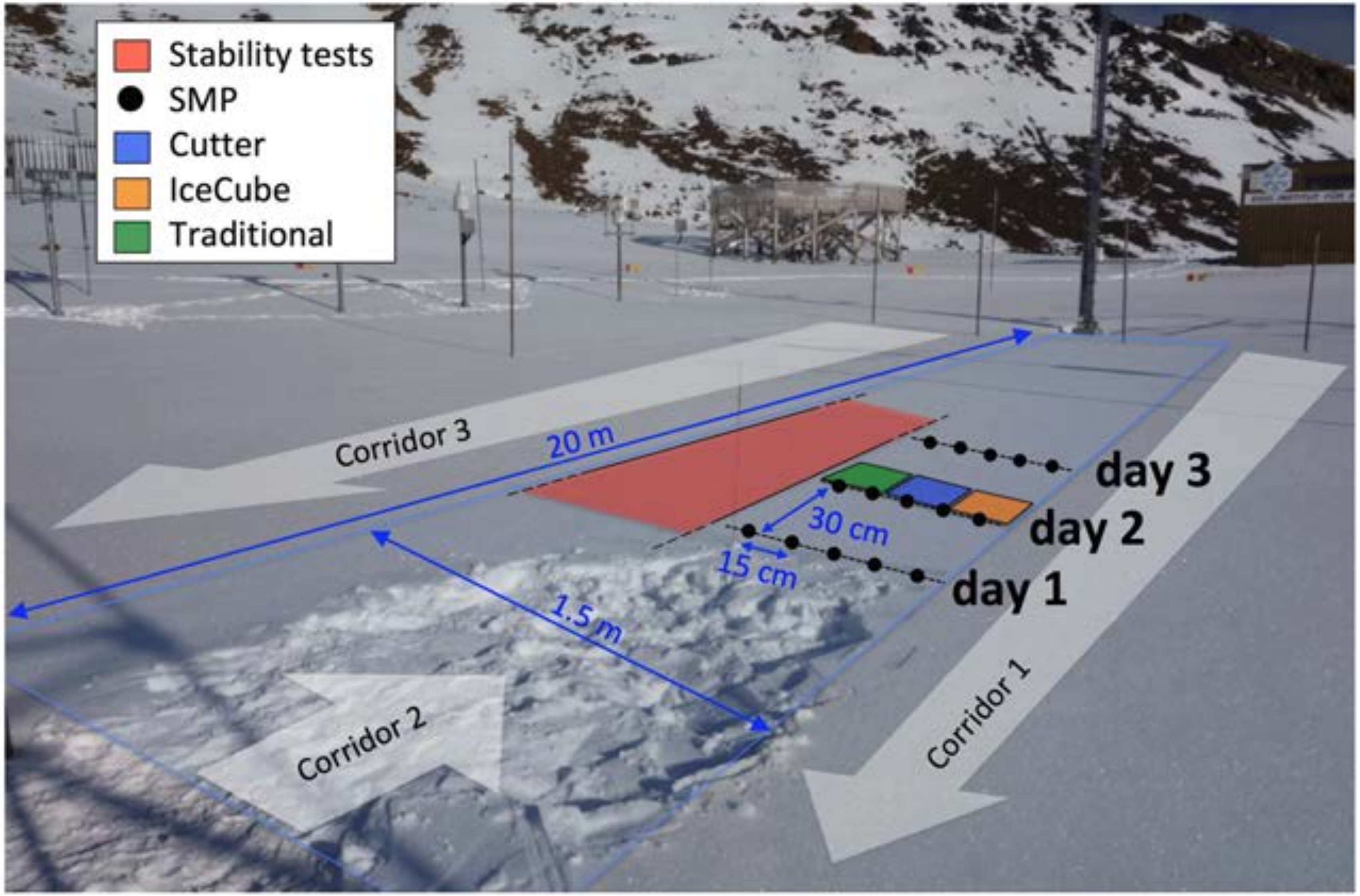


Stratigraphy and Layers at Kohnen




KOH8-A1
High resolution stratigraphy
1 mm
1.0 mm

the RhoSSA campaign at Weissfluhjoch



The RHOSSA campaign: multi-resolution monitoring of the seasonal evolution of the structure and mechanical stability of an alpine snowpack

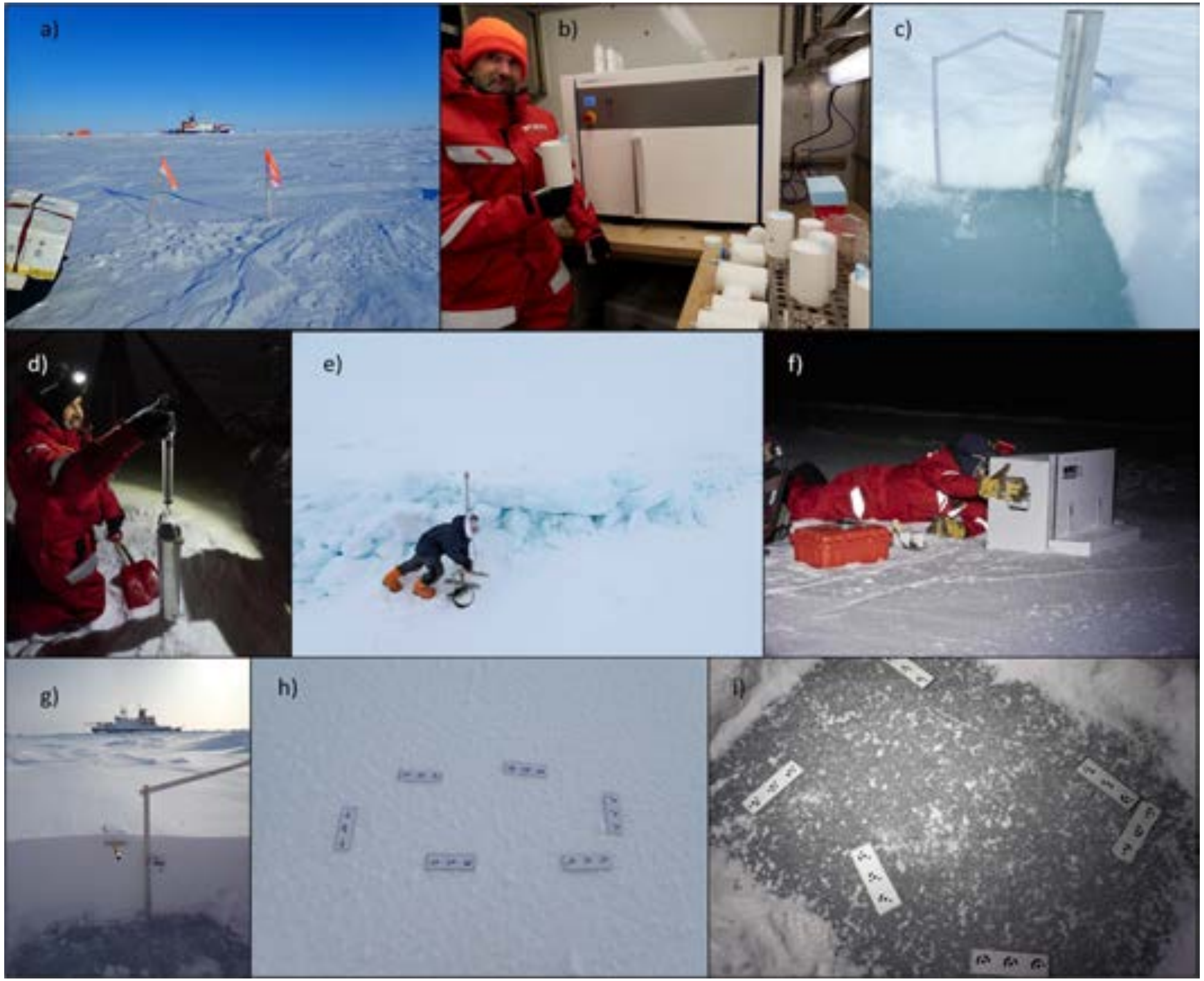
MOSAiC: an instrumented snow campaign

challenge: 4 observation periods

goal: no observation bias

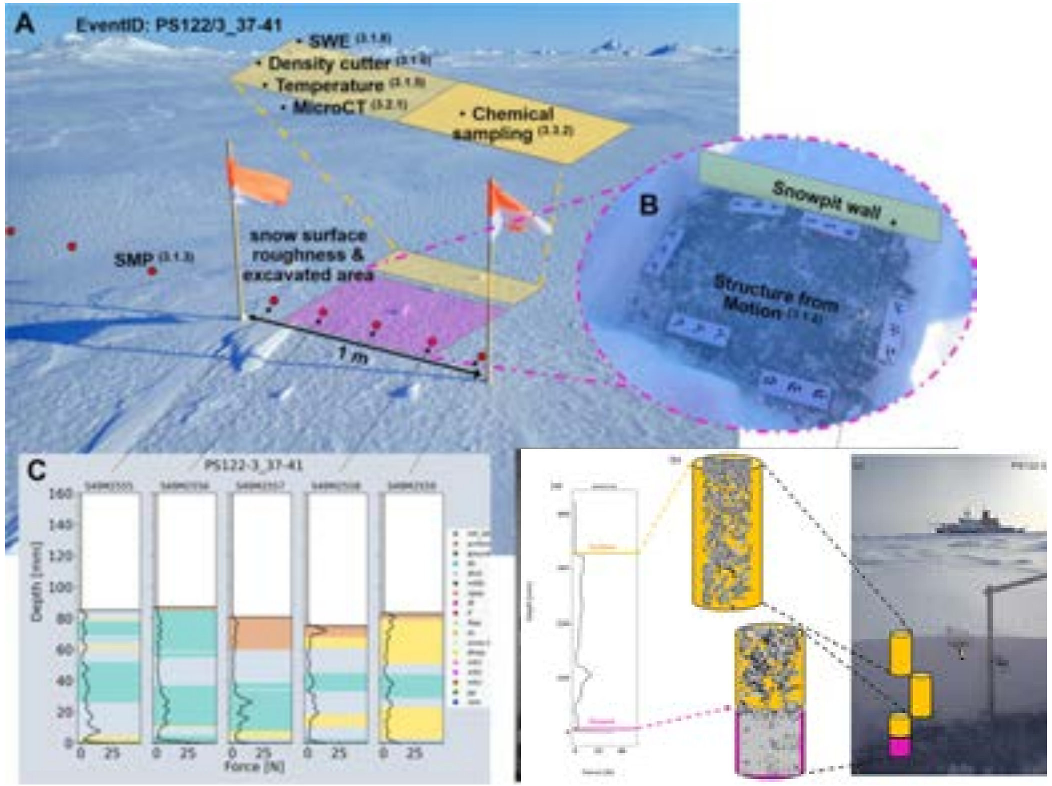
solution:

- micro-CT
- SnowMicroPen
- NIR-Box
- surface roughness topography
- supplemented by classical density and SWE-tube measurement

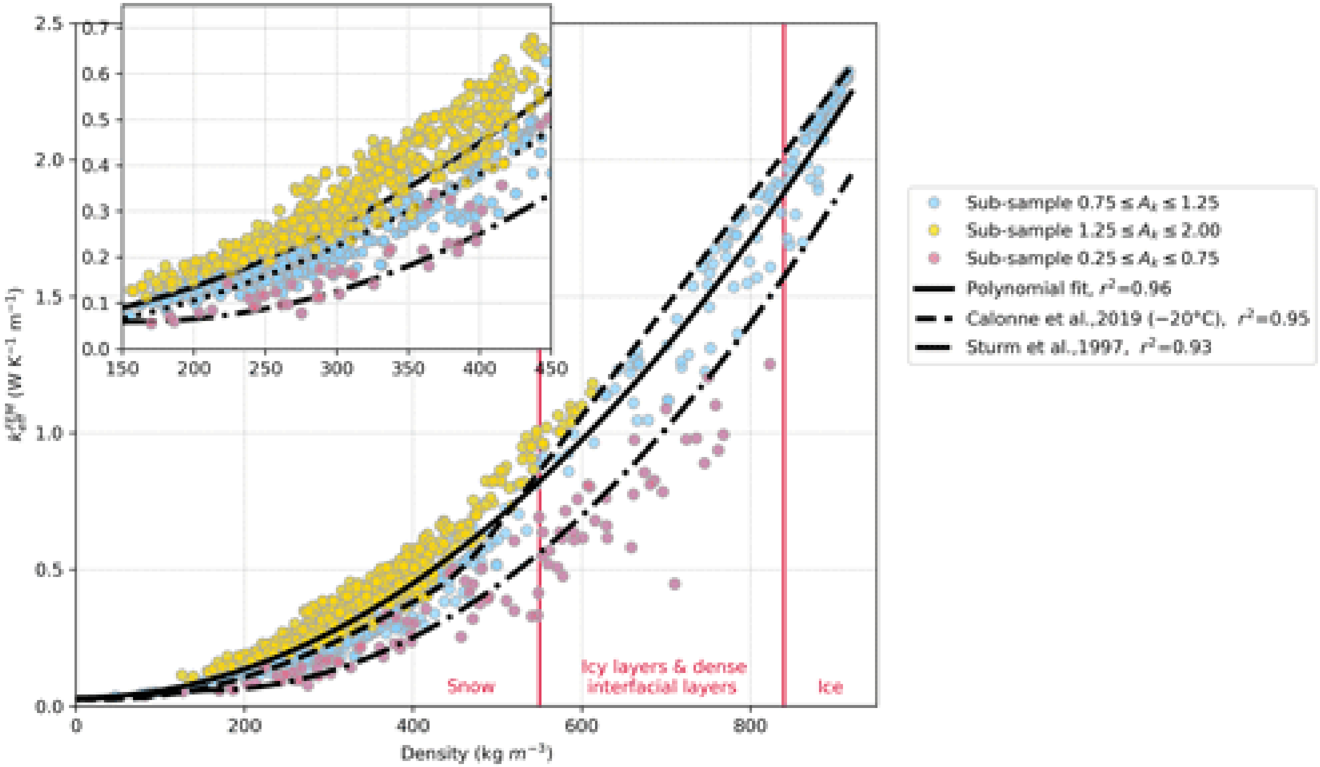


Macfarlane, A. R., et al.: A Database of Snow on Sea Ice in the Central Arctic Collected during the MOSAiC expedition, Scientific Data, 10, https://doi.org/10.1038/s41597-023-02273-1, 2023.

MOSAiC: an instrumented snow campaign



one example: calculating metrics and thermal conductivity based on micro-CT



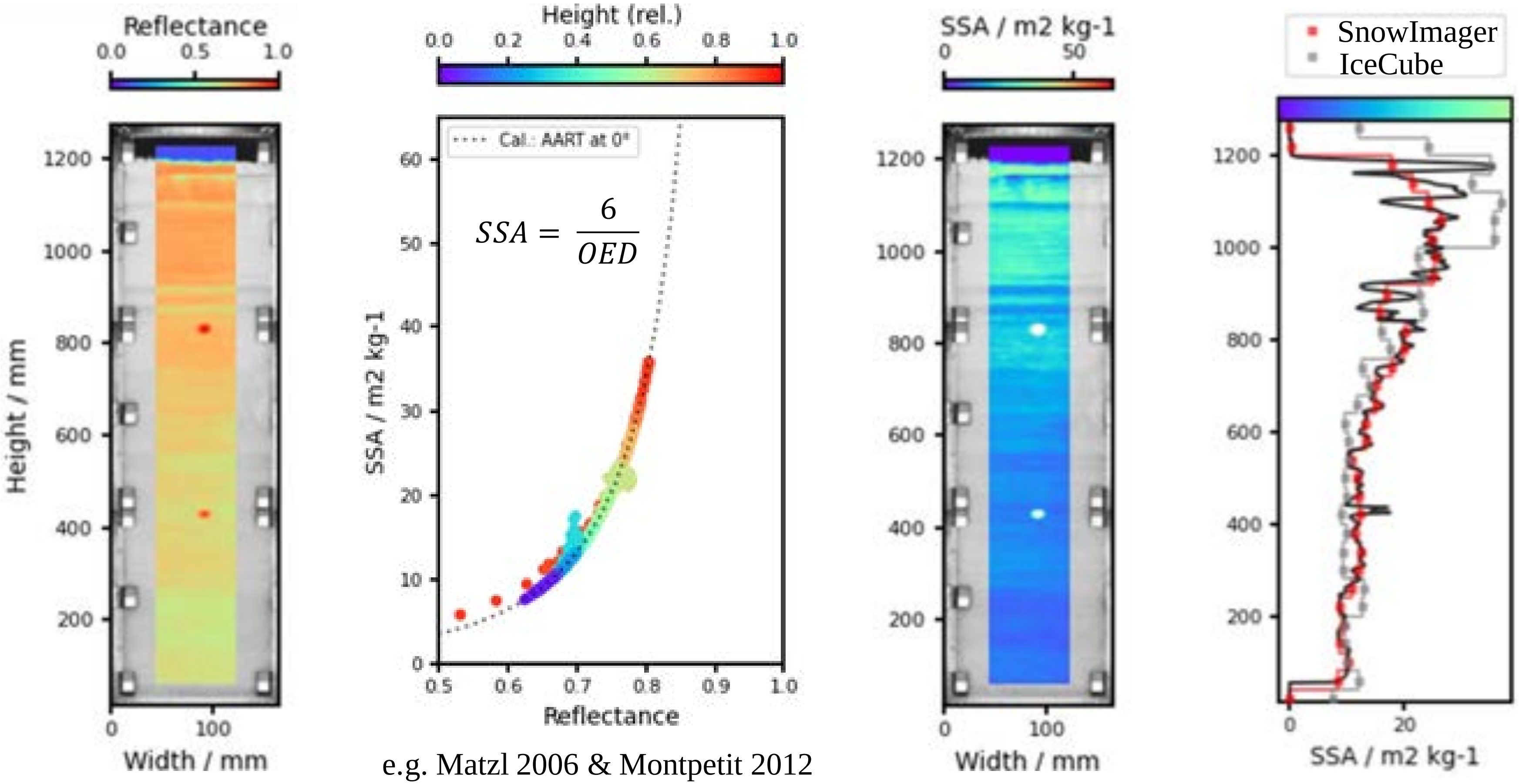
Macfarlane, A. R., Löwe, et al.: Temporospatial variability of snow’s thermal conductivity on Arctic sea ice, The Cryosphere, 17, 5417–5434, https://doi.org/10.5194/tc-17-5417-2023, 2023.

A multi-metric instrument: SnowImager

- Simultaneous model-based calculation of density and SSA
- By making a mosaic of the images large profile walls can be mapped

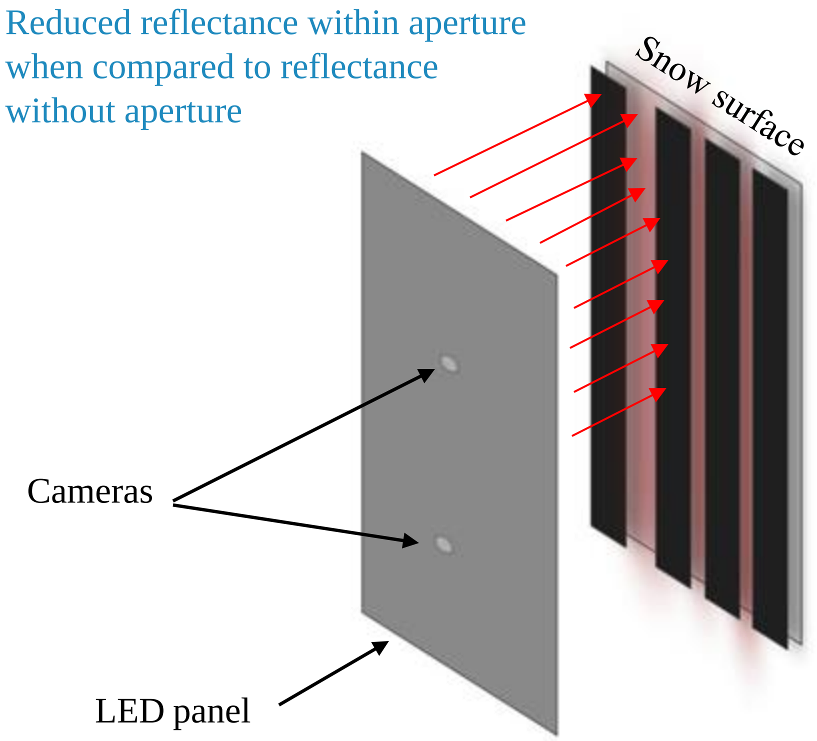
- Illumination: 2D array of 850nm and 940nm LED's
- Two Cameras
- Reflectance Targets: r = 0.5 and 0.94 for image calibration
- Low-cost components
- SSA (2D) / density (1D)
- Potential for 2D LWC distribution retrieval

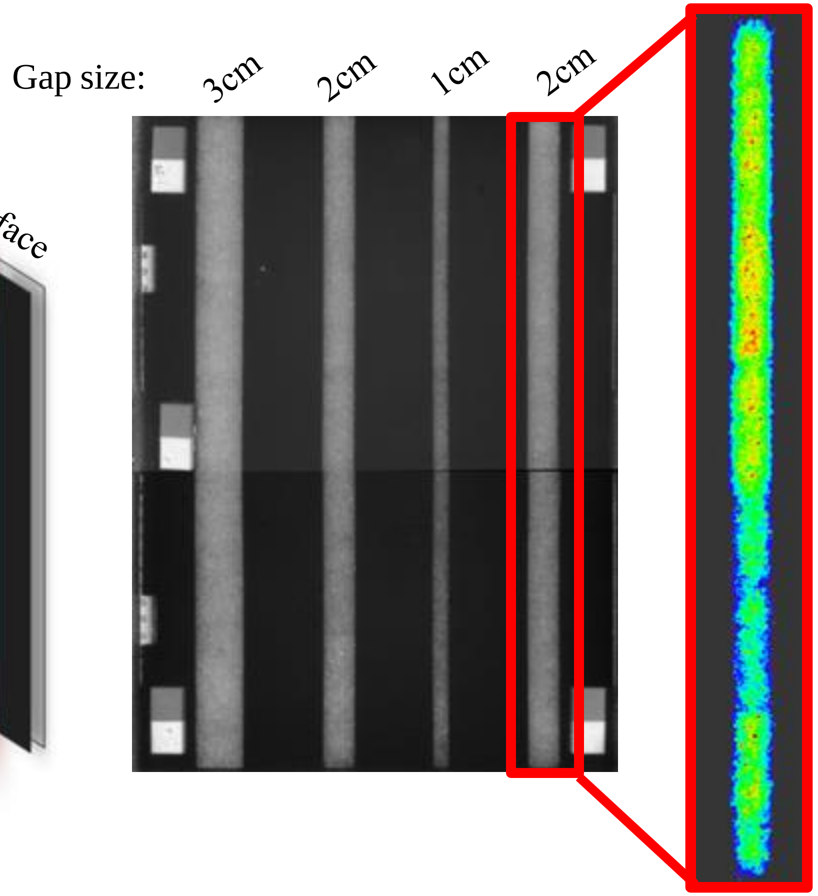
Specific Surface Area (SSA)

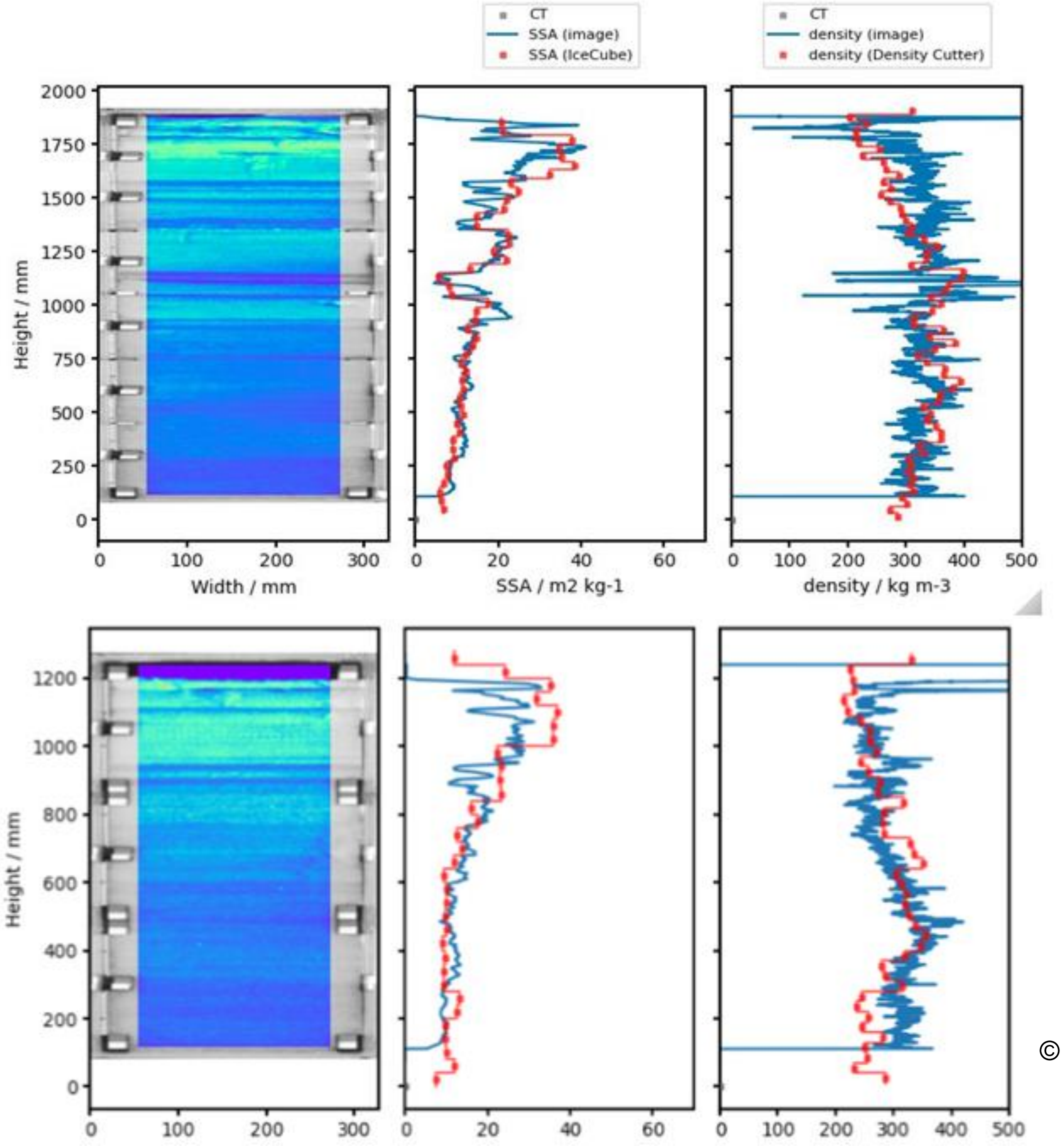


e.g. Matzl 2006 & Montpetit 2012

Snow Density: Novel SnowImager retrieval method







SnowImager®

- Semi-empirical method for density determination
- Good agreement between SnowImager, µCT and IceCube / DensityCutter
- Millimeter resolution
- Sharp transitions between layers, broadened by sub-surface photon scattering

final thoughts: huge progress ☺

- MicroCT tomography is the gold standard to measure the information necessary to calculate all relevant geometrical metrics
- Full-profile measurements need multiple instruments: micro-CT, SnowMicroPen, NIR-photography, SnowImager, gravimetric density, point SSA
- environmental conditions often challenging for instruments and persons
- spatial variability can be measured with modern tools
- rapid developments in the past 20 years from a qualitative to a quantitative science
- Robust, cheap, precise field instrumentation in the future?
- We should speak about snow metrics (density, SSA, curvatures, anisotropy, ...) and drop "snow grain size" to describe the snow microstructure, as it's an incomplete metric

References 1

Ingvander, S., Johansson, C., Jansson, P., and Pettersson, R.: Comparison of digital and manual methods of snow particle size estimation, Hydrology Research, 43, 192, https://doi.org/10.2166/nh.2012.078, 2012.

Adolph, A. C., Albert, M. R., Lazarcik, J., Dibb, J. E., Amante, J. M., and Price, A.: Dominance of grain size impacts on seasonal snow albedo at open sites in New Hampshire, Journal of Geophysical Research: Atmospheres, https://doi.org/10.1002/2016JD025362, 2017.

Aoki, T., Yamaguchi, S., Motoyoshi, H., Kuchiki, K., Niwano, M., Fujita, K., Matoba, S., Hachikubo, A., Tanikawa, T., Hori, M., Takeuchi, Y., and Sugiura, K.: Comparison of snow grain size measurements, in: JSSI & JSSE Joint Conference – 2014/Hachinohe, Hachinohe, Citation Key: Aoki2014, 2014.

Berisford, D. F., Molotch, N. P., Durand, M. T., and Painter, T. H.: Portable spectral profiler probe for rapid snow grain size stratigraphy, Cold Regions Science and Technology, 85, 183–190, https://doi.org/10.1016/j.coldregions.2012.09.007, 2013.

Bouvet, L., Calonne, N., Flin, F., and Geindreau, C.: Heterogeneous grain growth and vertical mass transfer within a snow layer under temperature gradient, The Cryosphere Discussions, 1–30, https://doi.org/10.5194/tc-2022-255, 2023.

Brandt, R. E. and Warren, S. G.: Snow albedo and grain size on a traverse from the East Antarctic Plateau down to the coast, J. Glaciology, submitted, 2008.

Brun, E. and Pahaut, E.: An efficient method for a delayed and accurate characterization of snow grains from natural snowpacks, J. Glaciology, 37, 420–422, 1991.

Carlsen, T., Birnbaum, G., Ehrlich, A., Freitag, J., Heygster, G., Istomina, L., Kipfstuhl, S., Orsi, A., Schäfer, M., and Wendisch, M.: Comparison of different methods to retrieve optical-equivalent snow grain size in central Antarctica, The Cryosphere, 11, 2727–2741, https://doi.org/10.5194/tc-11-2727-2017, 2017.

Donahue, C., Skiles, S. M. K., and Hammonds, K.: In situ effective snow grain size mapping using a compact hyperspectral imager, Journal of Glaciology, 67, 49–57, https://doi.org/10.1017/jog.2020.68, 2021.

Durand, M., Molotch, N. P., Kim, E. J., Margulis, S. A., Courville, Z., Schneebeli, M., Painter, H., Berisford, D. F., and Jagt, B. V.: A comparison of field methods for grain size characterization in the context of passive microwave modeling of snow, 70, C33A-0512, 2010.

Erbe, E. F., Rango, A., Foster, J., Josberger, E. G., Pooley, C., and Wergin, W. P.: Collecting, shipping, storing, and imaging snow crystals and ice grains with low-temperature scanning electron microscopy., Microscopy Research and Technique, 62, 19–32, https://doi.org/10.1002/jemt.10383, 2003.

Gay, M., Fily, M., Genthon, C., Frezzotti, M., Oerter, H., and Winther, J.-G.: Snow grain-size measurements in Antarctica, Journal of Glaciology, 48, 527–535, https://doi.org/10.3189/172756502781831016, 2002.

Gergely, M., Matzl, M., and Schneebeli, M.: Reflectance and translucent snow profile photography for coincident measurements of snow optically equivalent grain size and density, J. Glaciology, first vers, 1–20, 2015.

Havens, S., Marshall, H.-P., Pielmeier, C., and Elder, K.: Automatic grain type classification of snow micro penetrometer signals with random forests, IEEE Transactions on Geoscience and Remote Sensing, 51, 3328–3335, https://doi.org/10.1109/TGRS.2012.2220549, 2013.

Ingvander, S., Johansson, C., Jansson, P., and Pettersson, R.: Comparison of digital and manual methods of snow particle size estimation, Hydrology Research, 43, 192, https://doi.org/10.2166/nh.2012.078, 2012.

Krol, Q. and Löwe, H.: Relating optical and microwave grain metrics of snow: the relevance of grain shape, The Cryosphere, 10, 2847–2863, https://doi.org/10.5194/tc-10-2847-2016, 2016.

Langlois, A., Royer, A., Montpetit, B., Roy, A., and Durocher, M.: Presenting Snow Grain Size and Shape Distributions in Northern Canada Using a New Photographic Device Allowing 2D and 3D Representation of Snow Grains, Frontiers in Earth Science, 7, 1–19, https://doi.org/10.3389/feart.2019.00347, 2020.

Leppänen, L., Kontu, A., Vehviläinen, J., Lemmetyinen, J., and Pulliainen, J.: Comparison of traditional and optical grain-size field measurements with SNOWPACK simulations in a taiga snowpack, Journal of Glaciology, 61, 151–162, https://doi.org/10.3189/2015JoG14J026, 2015.

References 2

Lesaffre, B., Pougatch, E., and Martin, E.: Objective determination of snow-grain characteristics from images, Ann. Glaciol., 26, 112–118, 1998.

Mätzler, C.: Relation between grain-size and correlation length of snow, Journal of Glaciology, 48, 461–466, https://doi.org/10.3189/172756502781831287, 2002.

Nolin, A. W. and Dozier, J.: Estimating snow grain size using AVIRIS data, Remote Sensing of Environment, 44, 231–238, 1993.

Painter, T. H. and Schneebeli, M.: Snow grains, Encyc. Snow, Ice and Glaciers, 1–11, 2011.

Painter, T. H., Molotch, N. P., Cassidy, M., Flanner, M., and Steffen, K.: Contact spectroscopy for determination of stratigraphy of snow optical grain size, Journal of Glaciology, 53, 121–127, https://doi.org/10.3189/172756507781833947, 2007.

Picard, G., Arnaud, L., Domine, F., and Fily, M.: Determining snow specific surface area from near-infrared reflectance measurements : Numerical study of the influence of grain shape, Cold Regions Science and Technology, 56, 10–17, https://doi.org/10.1016/j.coldregions.2008.10.001, 2009.

Picard, G., Löwe, H., Domine, F., Arnaud, L., Larue, F., Favier, V., Le Meur, E., Lefebvre, E., Savarino, J., and Royer, A.: The Microwave Snow Grain Size: A New Concept to Predict Satellite Observations Over Snow-Covered Regions, AGU Advances, 3, e2021AV000630, https://doi.org/10.1029/2021AV000630, 2022a.

Picard, G., Löwe, H., Domine, F., Arnaud, L., Larue, F., Favier, V., Le Meur, E., Lefebvre, E., Savarino, J., and Royer, A.: The Microwave Snow Grain Size: A New Concept to Predict Satellite Observations Over Snow-Covered Regions, AGU Advances, 3, e2021AV000630, https://doi.org/10.1029/2021AV000630, 2022b.

Räisänen, P., Makkonen, R., Kirkevåg, A., and Debernard, J. B.: Effects of snow grain shape on climate simulations: sensitivity tests with the Norwegian Earth System Model, The Cryosphere, 11, 2919–2942, https://doi.org/10.5194/tc-11-2919-2017, 2017.

Sundu, K., Ottersberg, R., Jaggi, M., and Löwe, H.: A grain-size driven transition in the deformation mechanism in slow snow compression, Acta Materialia, 119359, https://doi.org/10.1016/j.actamat.2023.119359, 2023.

Willibald, C., Löwe, H., Theile, T., Dual, J., and Schneebeli, M.: Angle of repose experiments with snow: Role of grain shape and cohesion, Journal of Glaciology, 66, 658–666, https://doi.org/10.1017/jog.2020.36, 2020.

Zatko, M. C., Grenfell, T. C., Alexander, B., Doherty, S. J., Thomas, J. L., and Yang, X.: The influence of snow grain size and impurities on the vertical profiles of actinic flux and associated NO_x emissions on the Antarctic and Greenland ice sheets, Atmospheric Chemistry and Physics, 13, 3547–3567, https://doi.org/10.5194/acp-13-3547-2013, 2013.

appendix: results from Davos / Reading

Snow Grain Size Intercomparison Workshop:
Results

Reading, UK, August 4-5, 2014

Combined Results

Outline

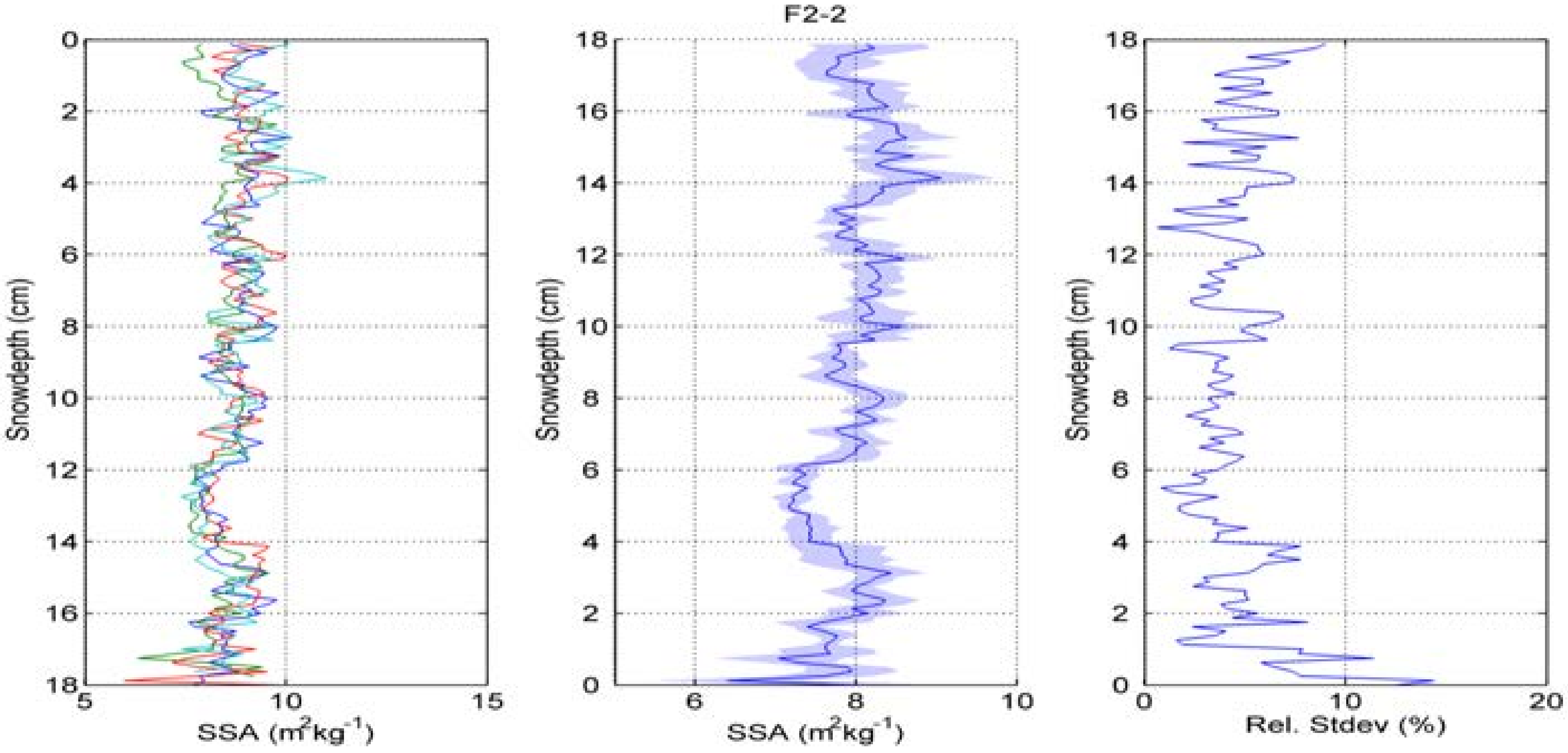
Snow blocks

- Homogeneity of the blocks
- Instrument comparisons

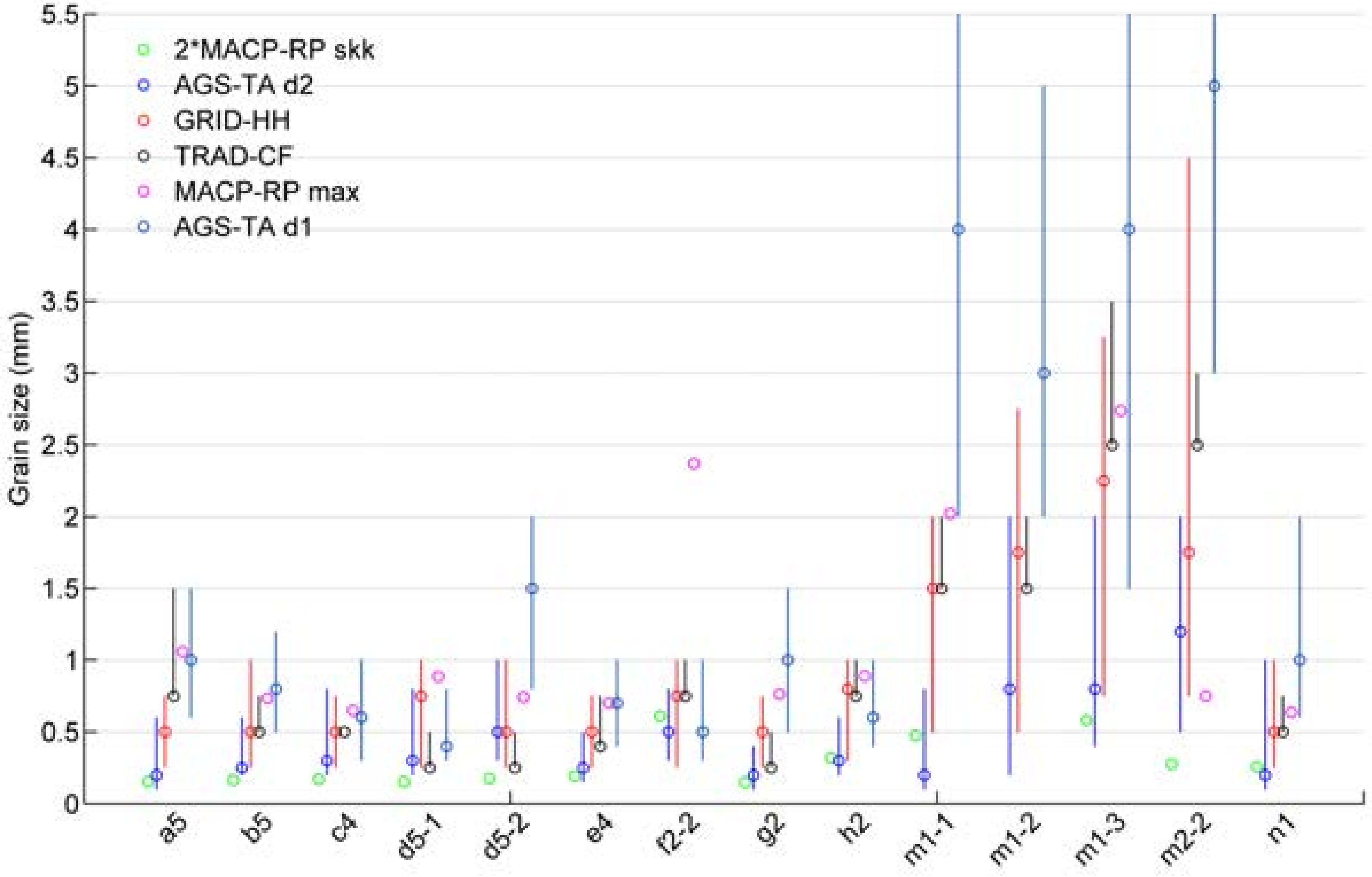
Field

- Spatial and temporal homogenity
- Instrument comparisons

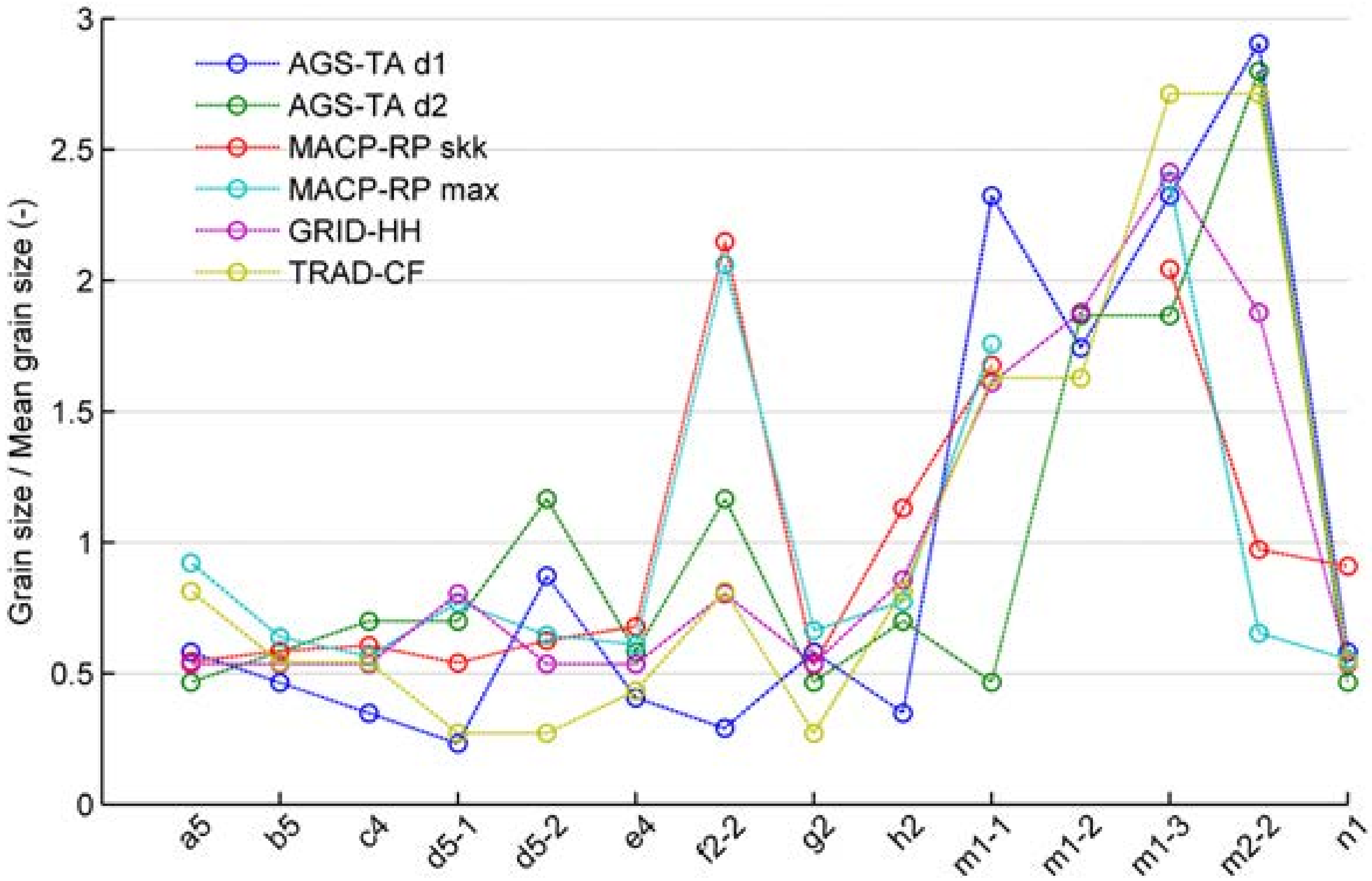
snow blocks


F2-2
Snowdepth (cm)
SSA (m^2kg^{-1})
Snowdepth (cm)
SSA (m^2kg^{-1})
Snowdepth (cm)
Rel. Stdev (%)

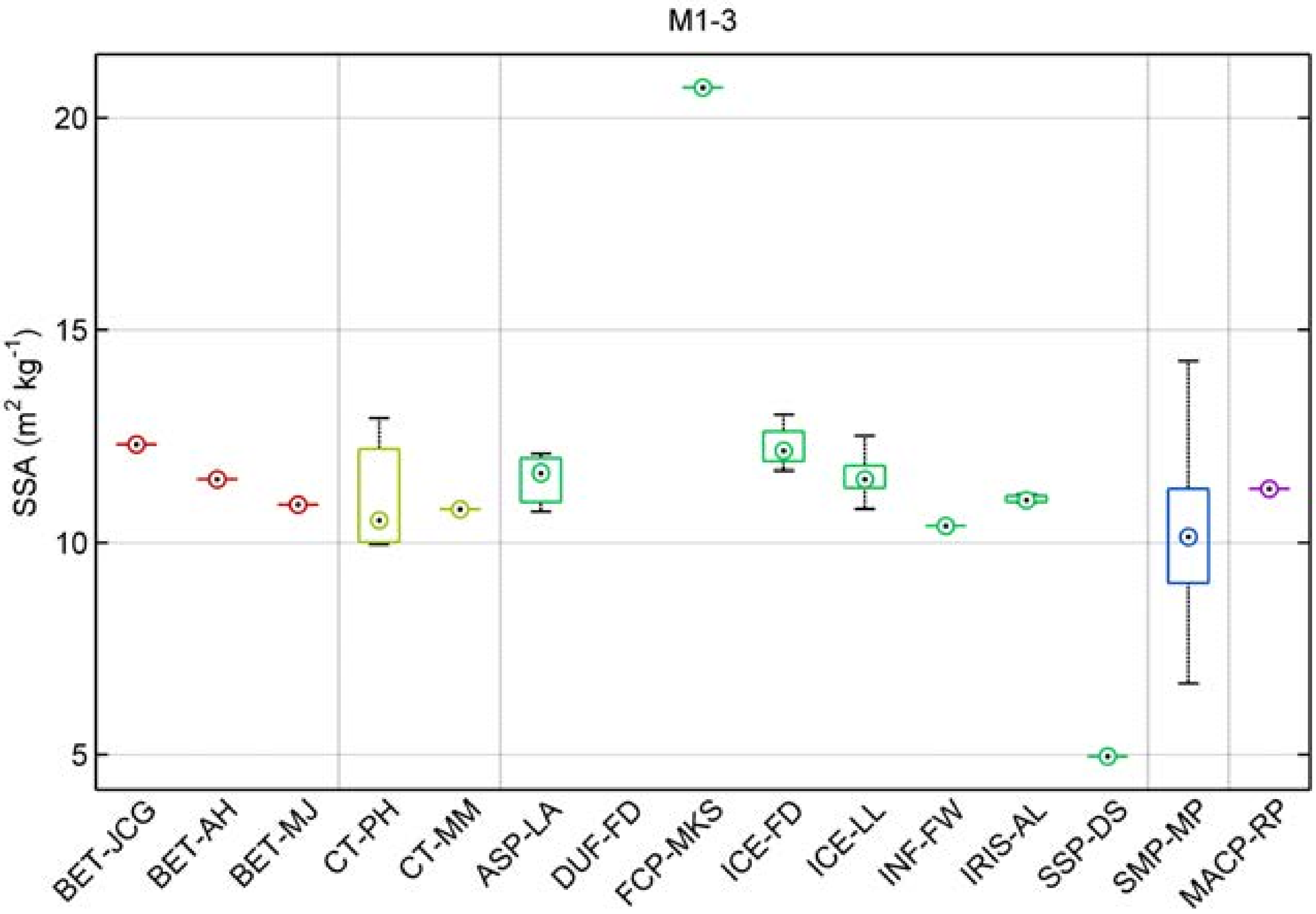
Blocks: grain size



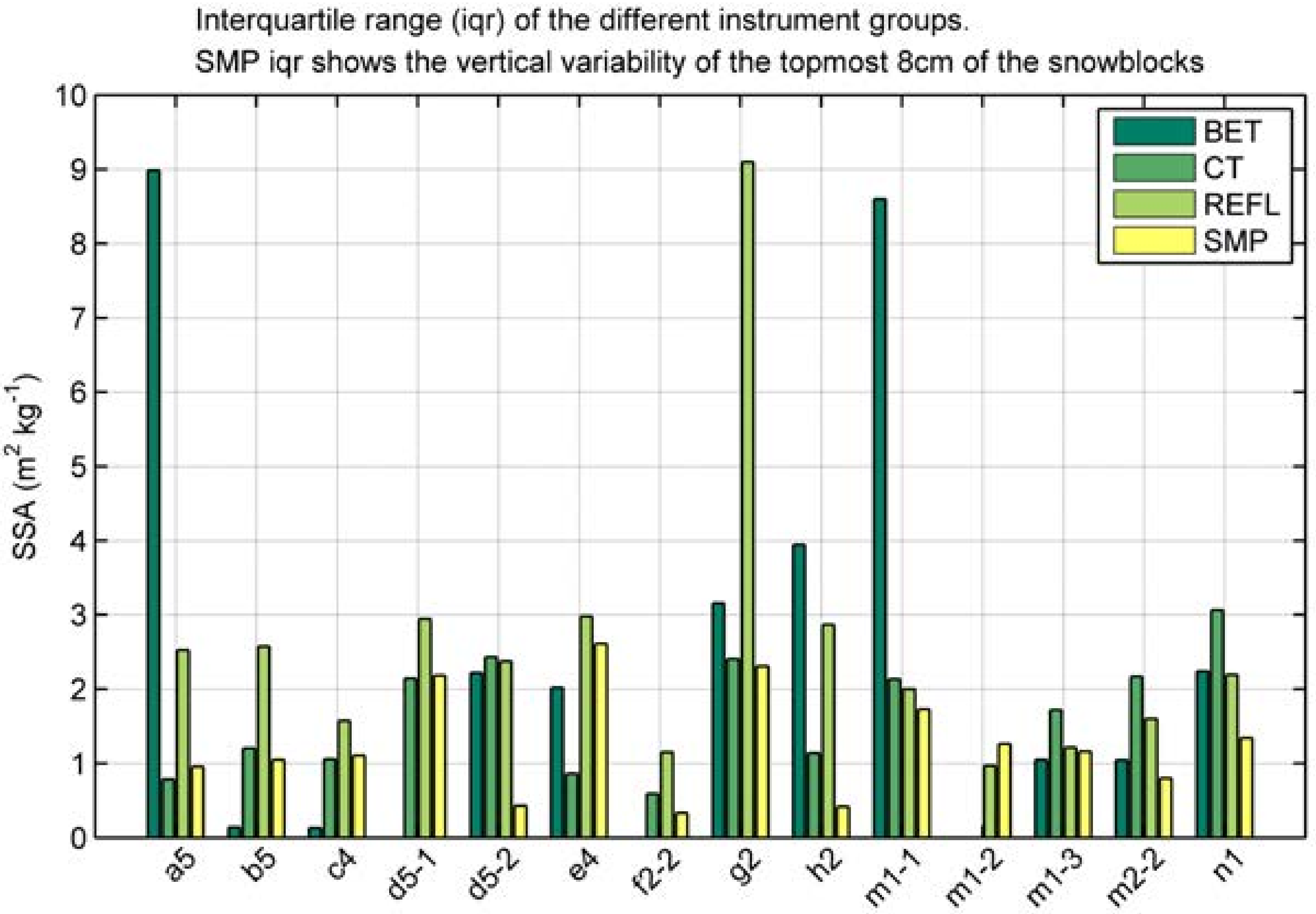
Blocks: relative grain size



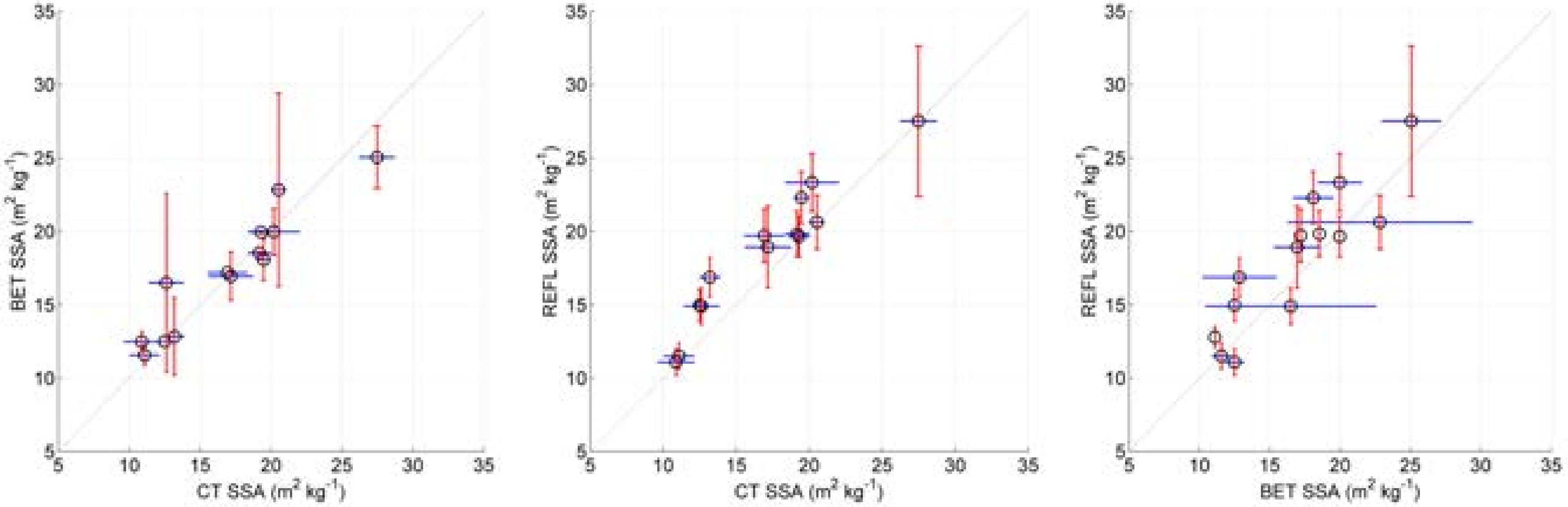
Block M1-3


M1-3
SSA (m2 kg-1)
20
15
10
5
BET-JCG
BET-AH
BET-MJ
CT-PH
CT-MM
ASP-LA
DUF-FD
FCP-MKS
ICE-FD
ICE-LL
INF-FW
IRIS-AL
SSP-DS
SMP-MP
MACP-RP

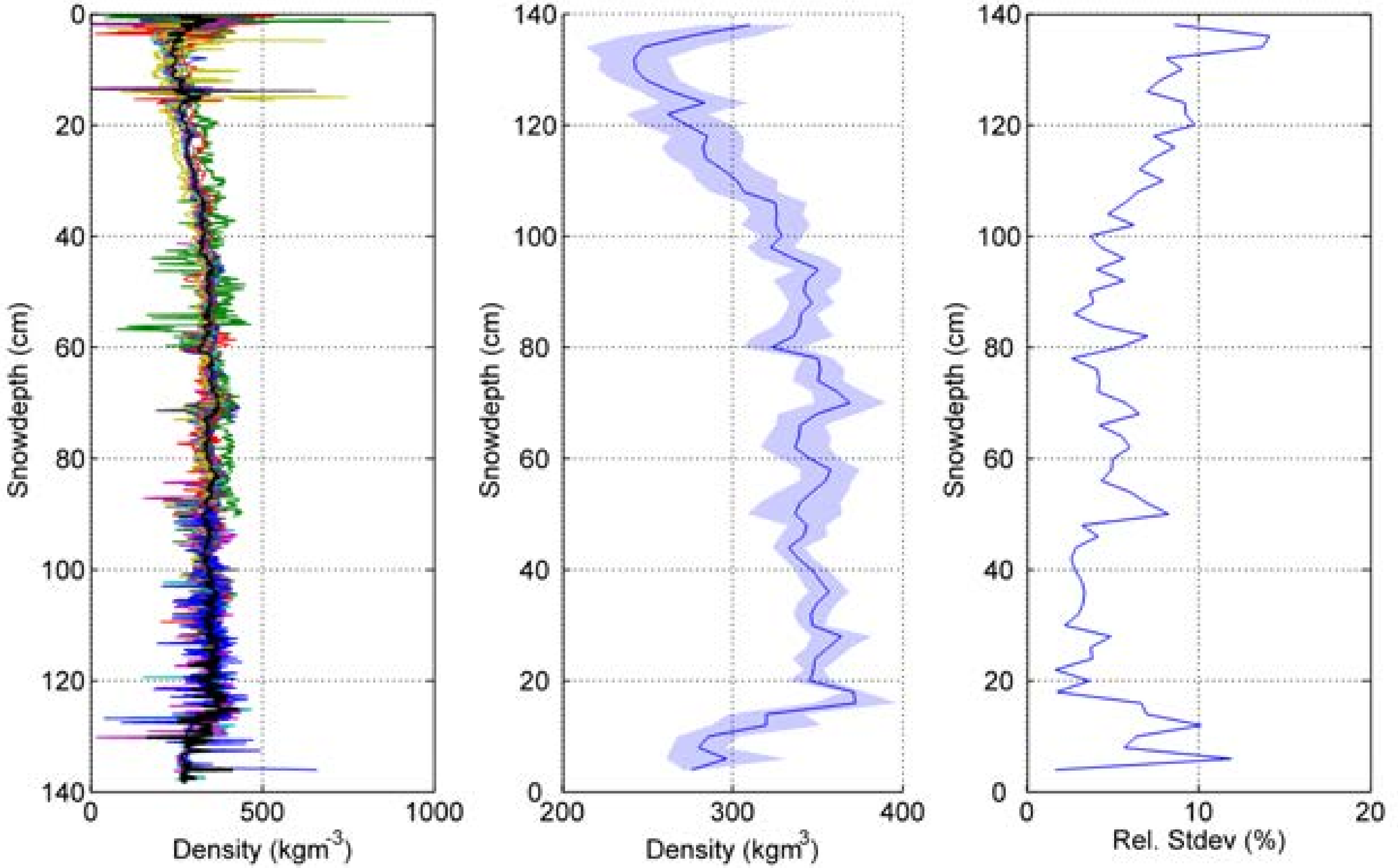
Blocks: all instrument groups



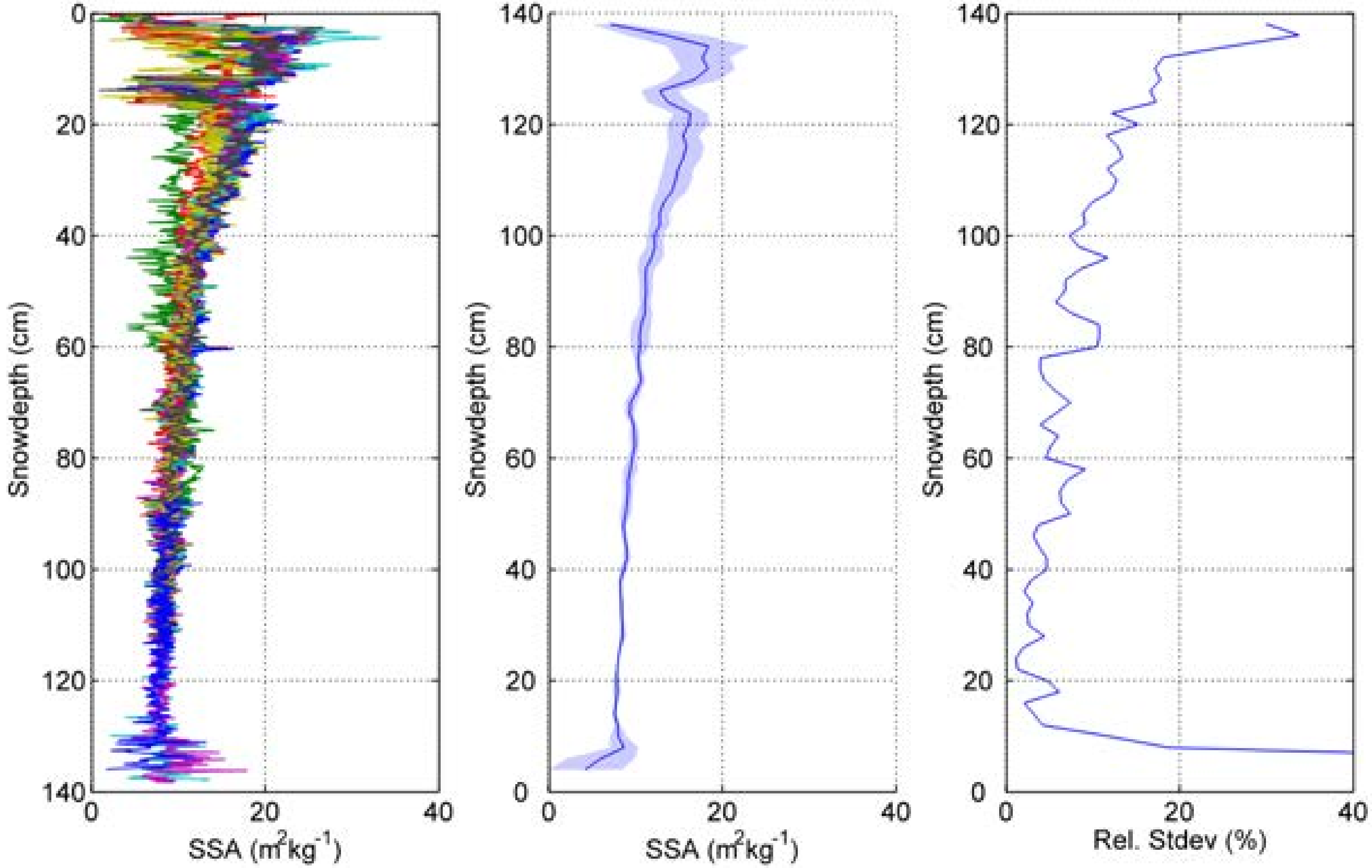
Blocks: scatter plots



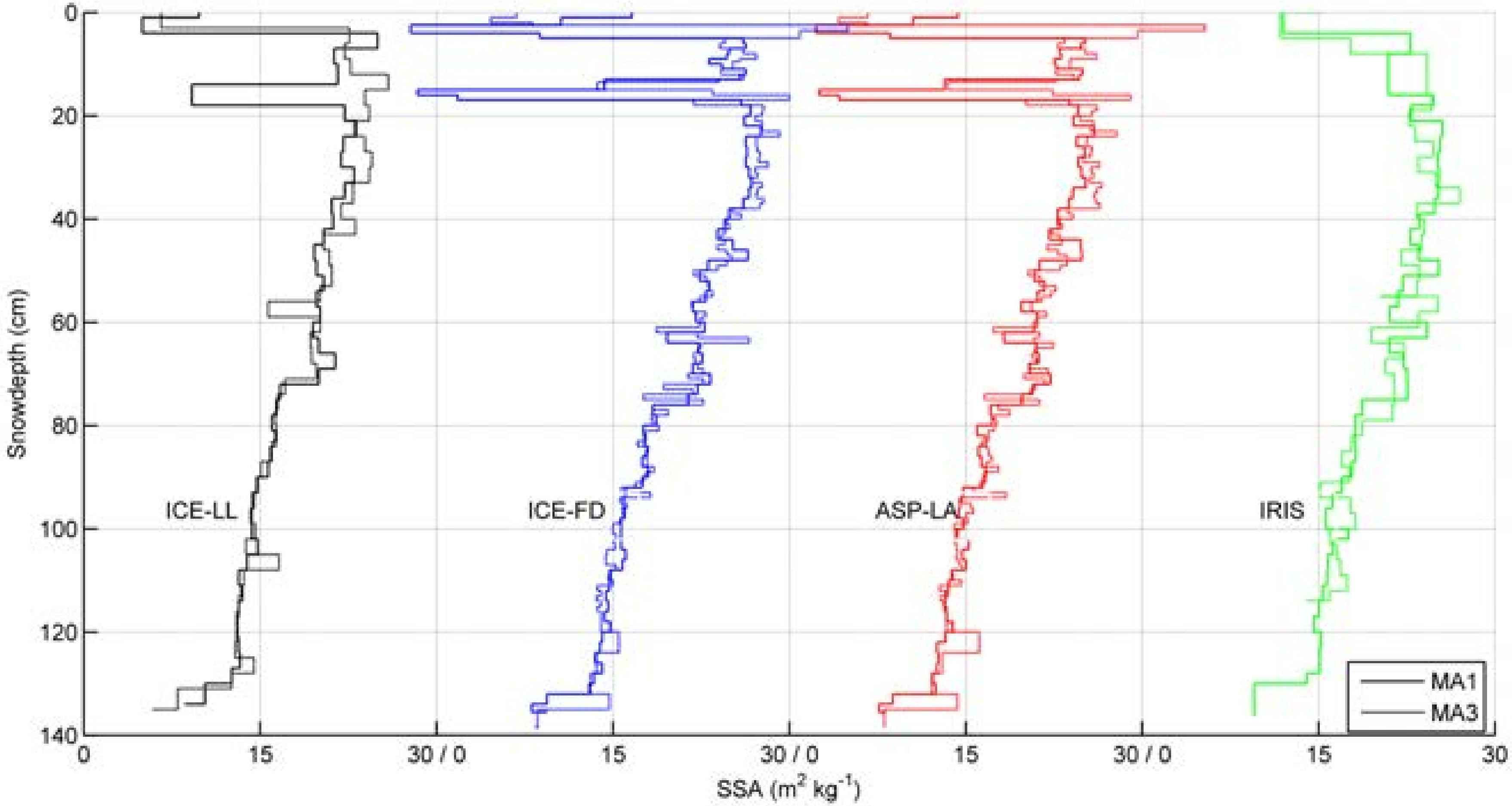
field Sankt Moritz - density

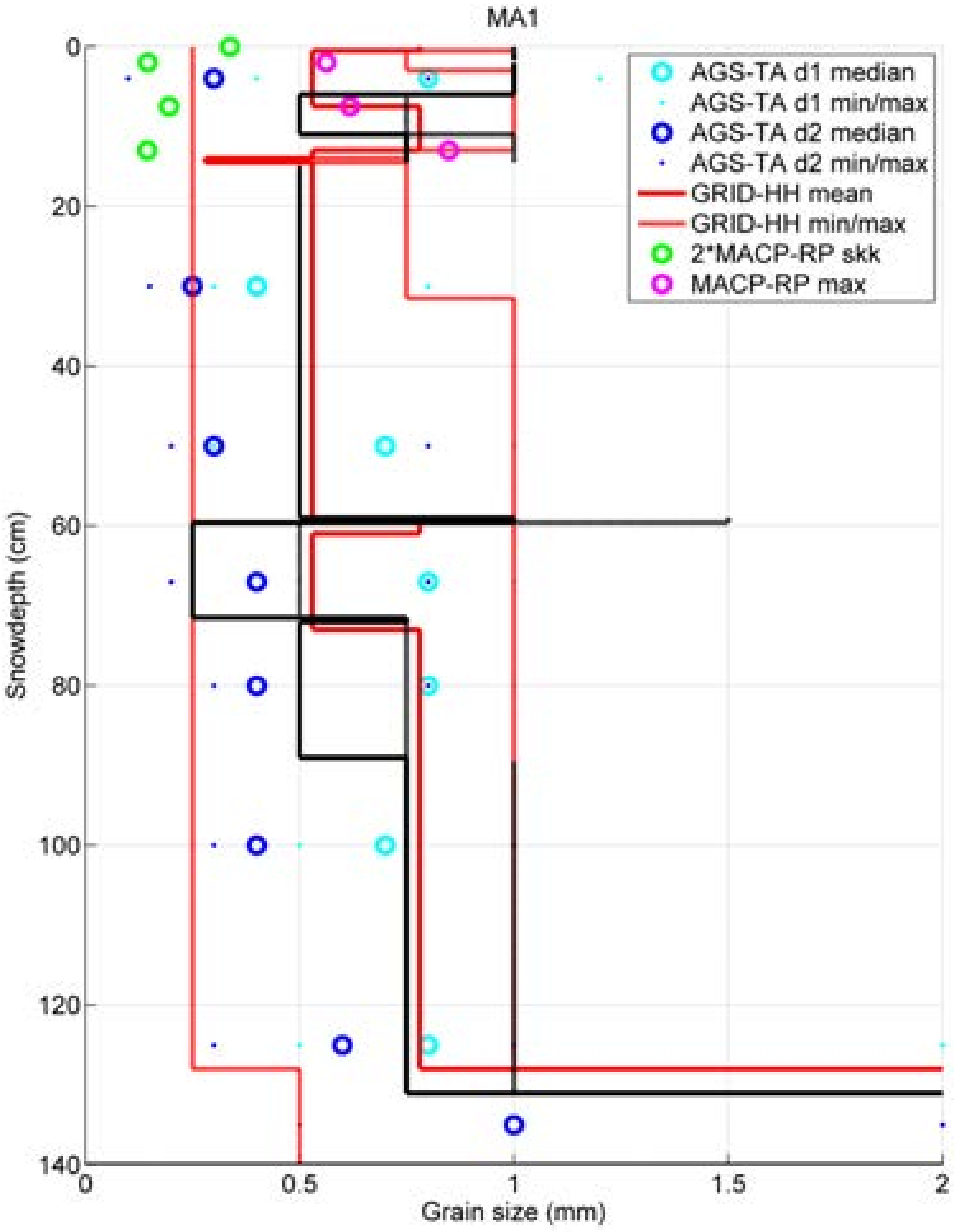


field Sankt Moritz - SSA



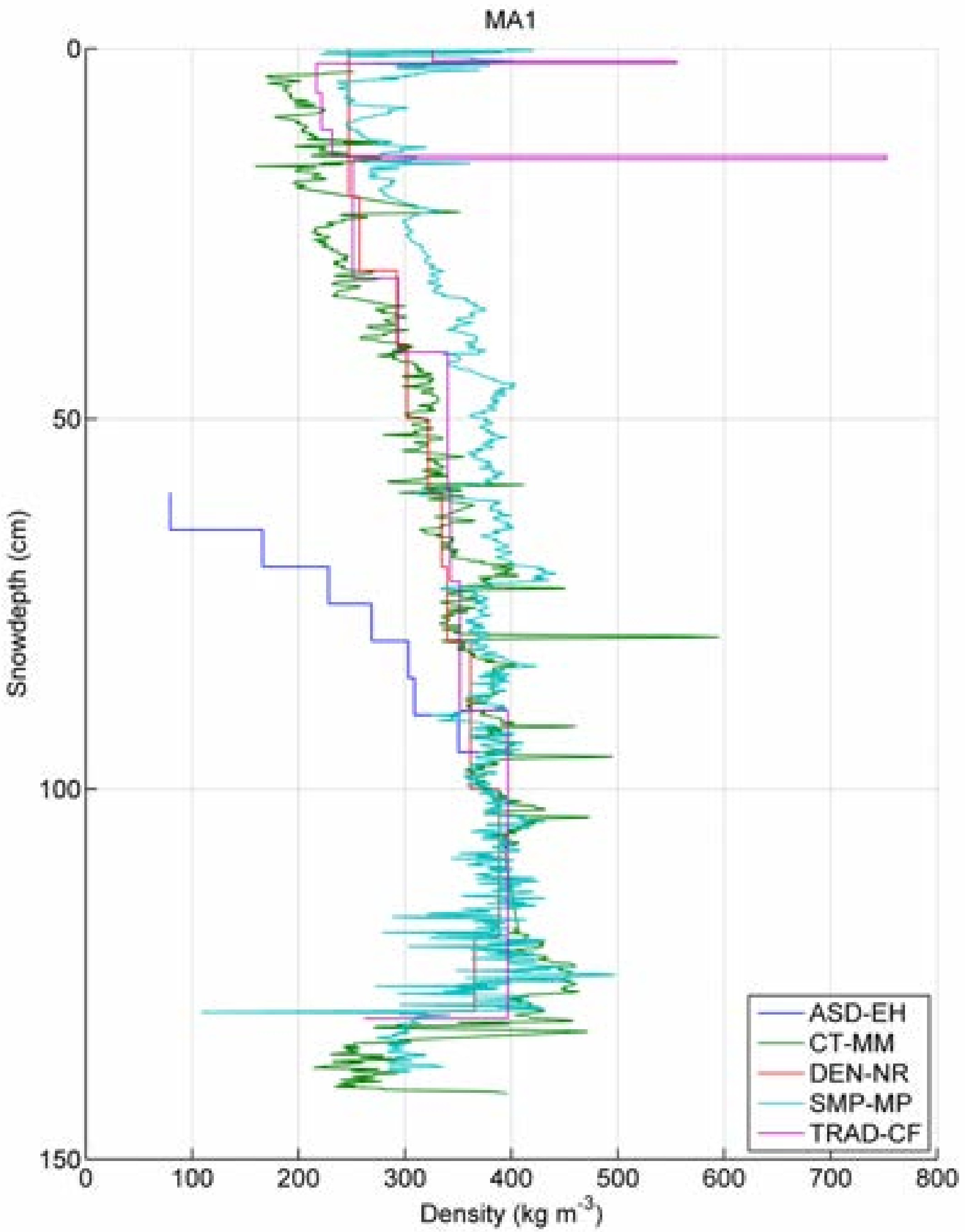
St. Moritz: temporal stability



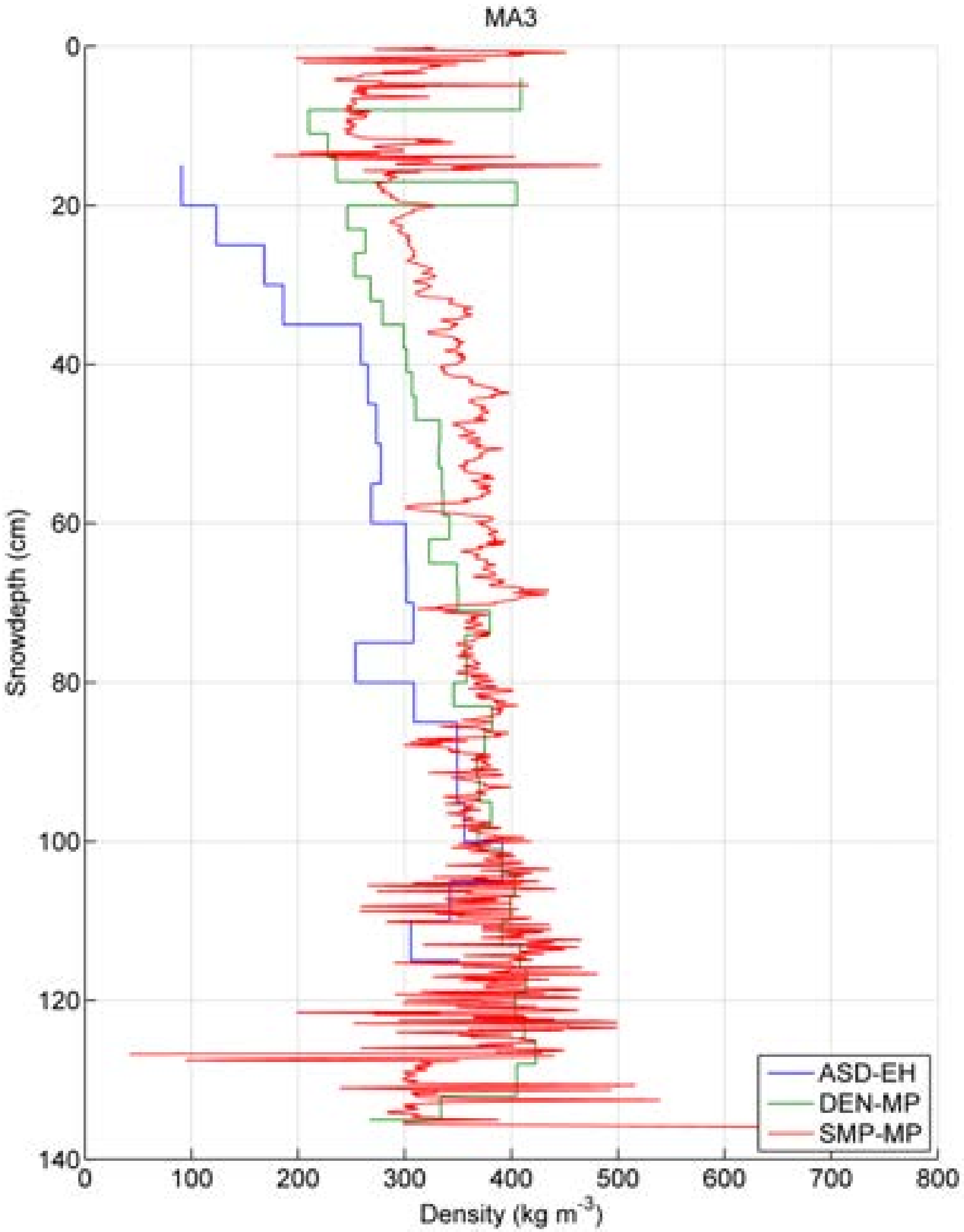


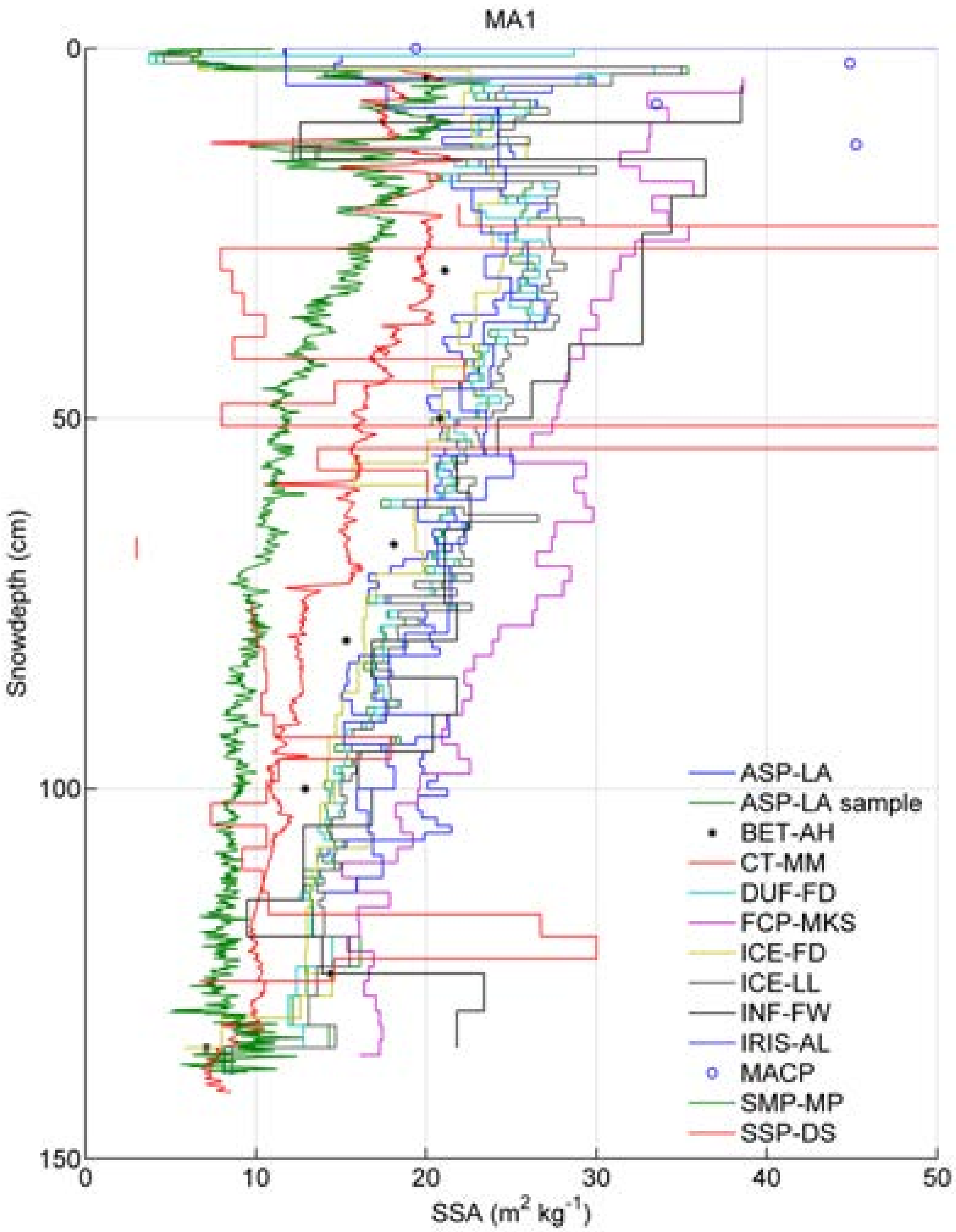
MA1 traditional

MA1 density


MA1
Snowdepth (cm)
Density (kg m^{-3})
0
50
100
150
0
100
200
300
400
500
600
700
800
ASD-EH
CT-MM
DEN-NR
SMP-MP
TRAD-CF

MA3 density

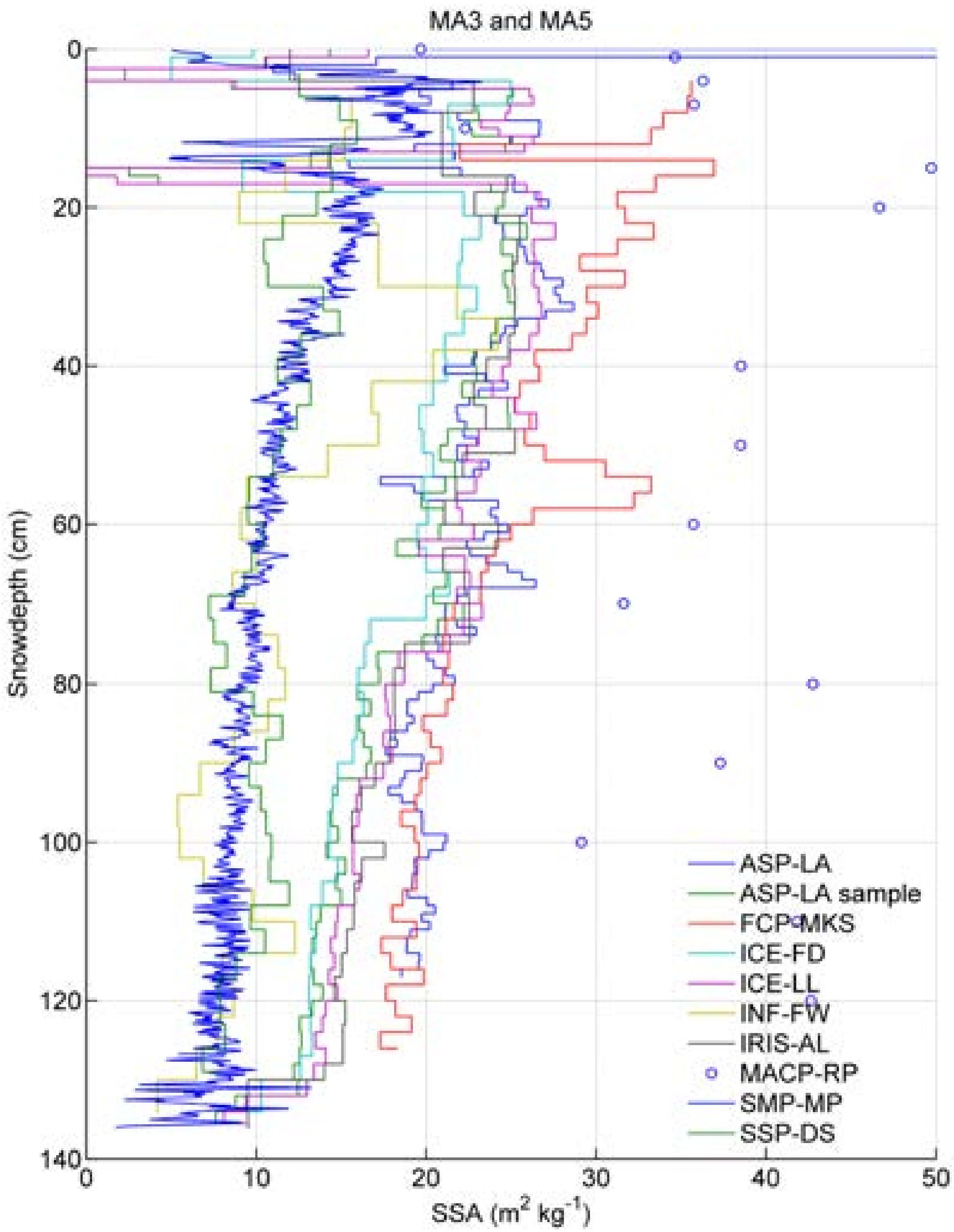

MA3
Snowdepth (cm)
Density (kg m^{-3})
ASD-EH
DEN-MP
SMP-MP
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800



MA1
Snowdepth (cm)
SSA (m² kg⁻¹)
0
50
100
150
0
10
20
30
40
50
ASP-LA
ASP-LA sample
BET-AH
CT-MM
DUF-FD
FCP-MKS
ICE-FD
ICE-LL
INF-FW
IRIS-AL
MACP
SMP-MP
SSP-DS

MA1

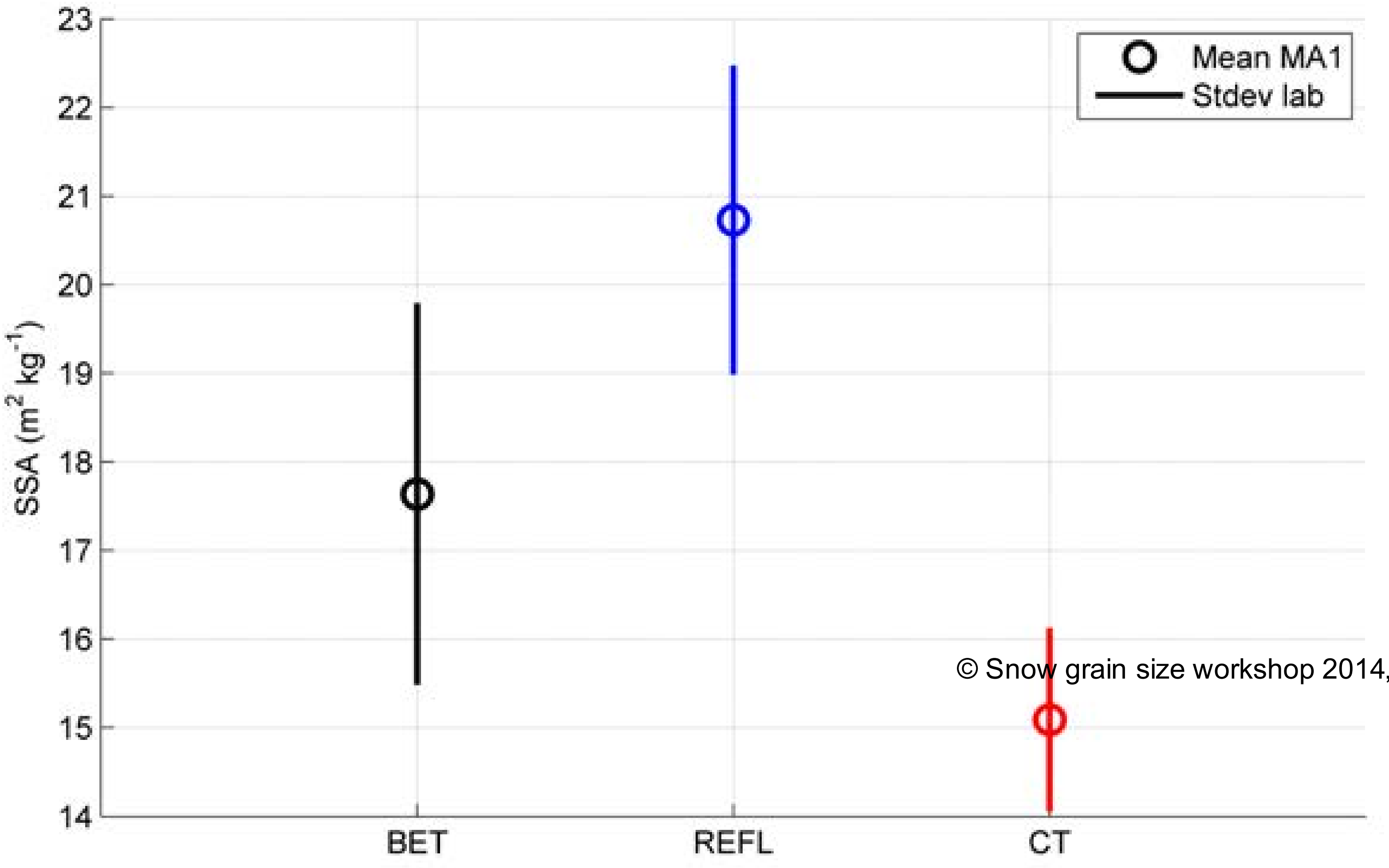
- SSA

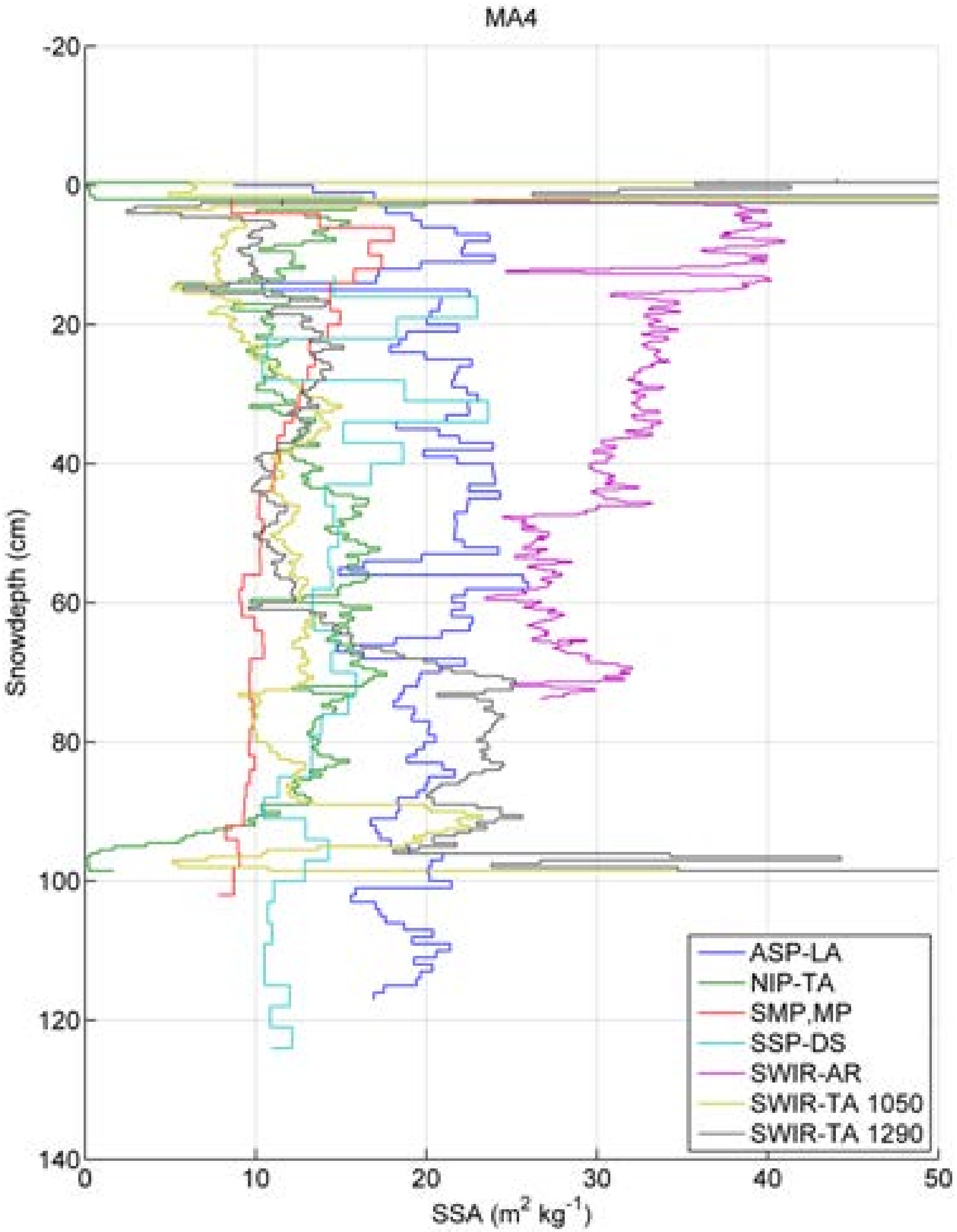

MA3 and MA5
Snowdepth (cm)
SSA ($m^2\ kg^{-1}$)
0
20
40
60
80
100
120
140
0
10
20
30
40
50
ASP-LA
ASP-LA sample
FCP-MKS
ICE-FD
ICE-LL
INF-FW
IRIS-AL
MACP-RP
SMP-MP
SSP-DS

A3 & 5

- SSA

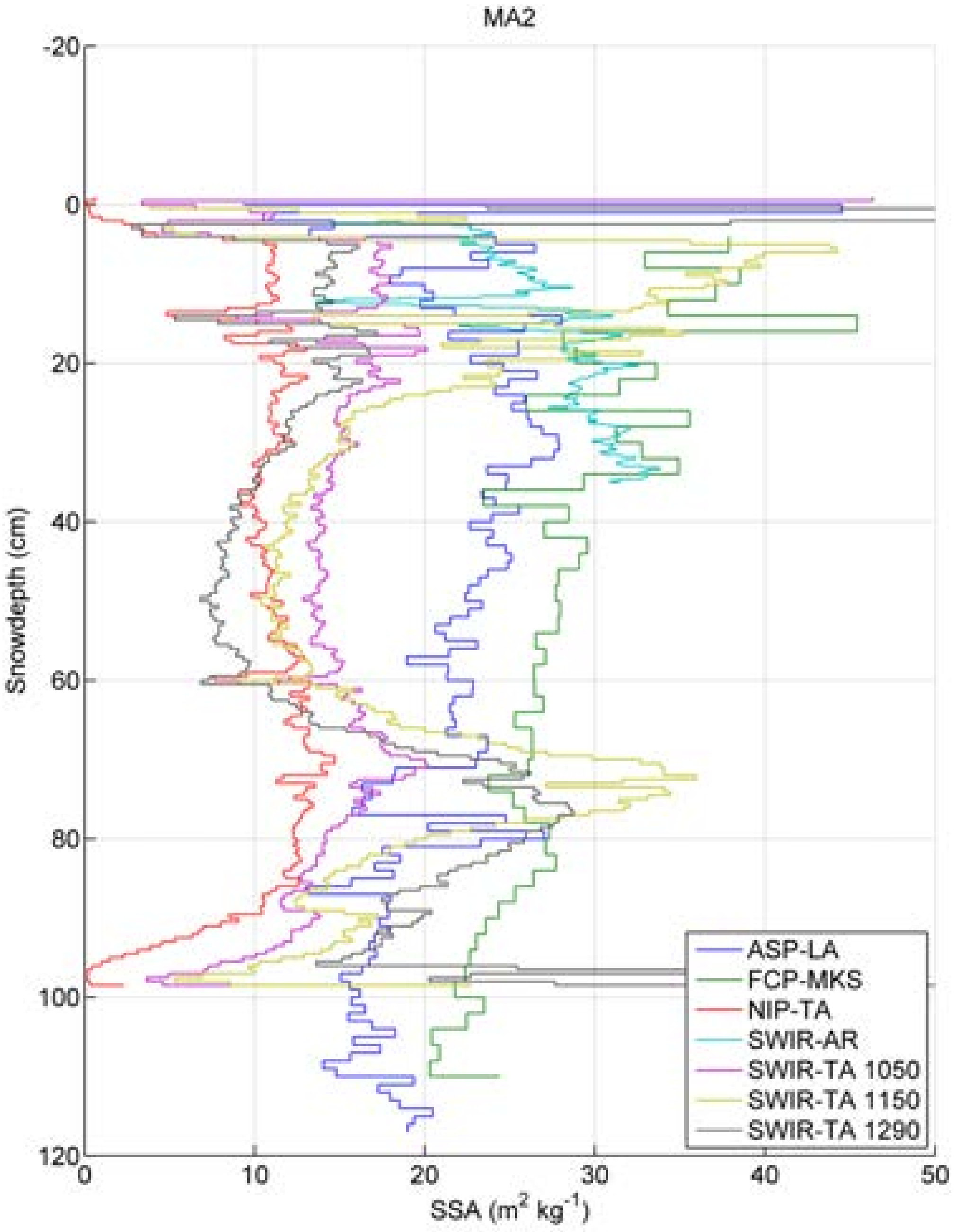
MA1 averages (30-100 cm SD) and lab std. deviation




MA4
Snowdepth (cm)
SSA (m² kg⁻¹)
-20
0
20
40
60
80
100
120
140
0
10
20
30
40
50
ASP-LA
NIP-TA
SMP,MP
SSP-DS
SWIR-AR
SWIR-TA 1050
SWIR-TA 1290

MA4 SSA

MA2 SSA


MA2
Snowdepth (cm)
SSA (m^2 kg^{-1})
-20
0
20
40
60
80
100
120
0
10
20
30
40
50
ASP-LA
FCP-MKS
NIP-TA
SWIR-AR
SWIR-TA 1050
SWIR-TA 1150
SWIR-TA 1290