Comparison of Snow Density Measurements Using Different Equipment

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Snow Density Measurements:

- Bilello et al (1969,1984) reported that snow density in the former USSR was about 18 to 27% lower than the records measured in North America.
- Zhong et al. (2014) found that snow density in Russia was up to 20% lower than the values by Sturm and Holmgren (1998) over North America.
- For tundra snow, snow density in Russia (Zhong et al., 2014) was about 20 to 33% lower than the records in Canada (McKay and FindLay, 1971).
- Bomann et al. (2013) reported that densities of spring alpine and prairie snow were about 20% lower in Russia than in USA.

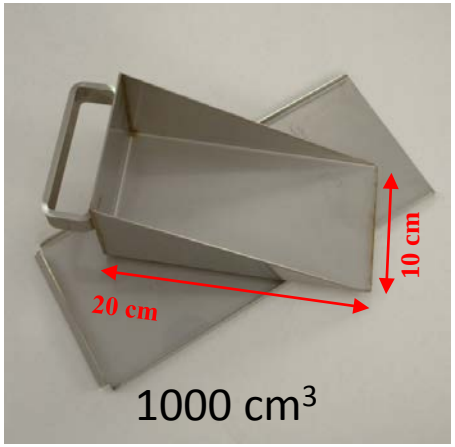
Questions： What caused huge differences in snow densities between Eurasia and North America?

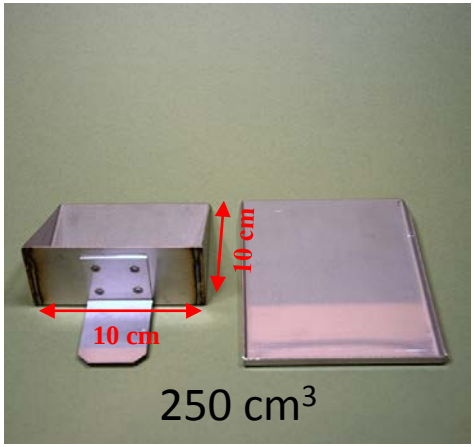
One possibility is: differences in measurement methods and instrumentation.

The objective of this study is to conduct field comparing studies using different snow density measurement methods and equipment.

Instruments —— snow density wedge cutters

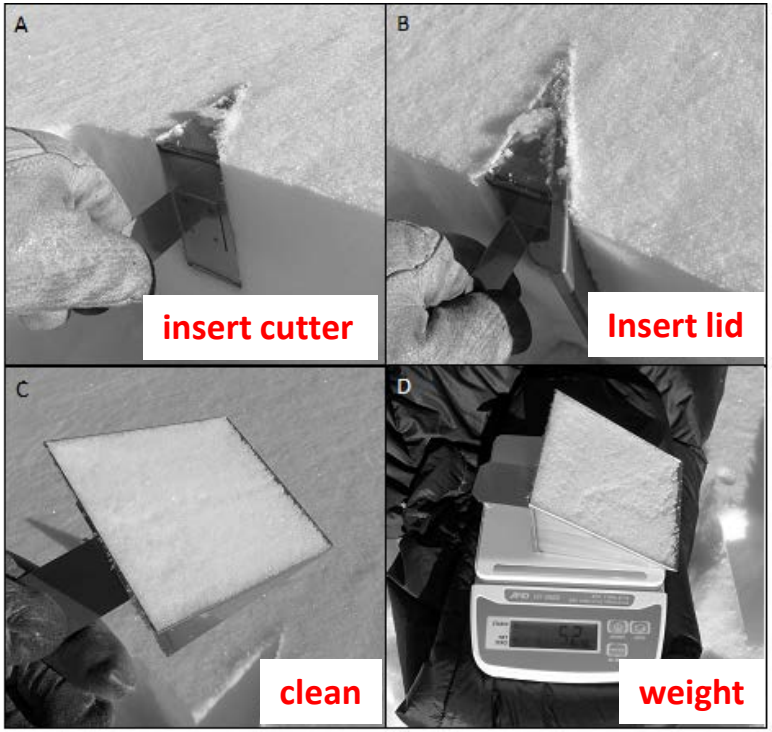
Wedge cutters are designed of the triangular stainless steel box and the cutter lid, manufactured by Snowmetrics.





Gravimetric Measuring Method

$$\rho = \frac{m_{snow}}{v_{snow}}$$



(picture from http://snow metrics.com/shop)

Instruments—— Federal sampler (North America)

Diameter : 3.77 cm

Length: add section of tube to reach the requirements of the snow depth 5 m（± 1 cm), slots design

Weigh: snow water equivalent (SWE) can be read by the calibrated spring scale.

$$\rho = \frac{SWE \times \rho_w}{SD}$$

Instruments—— Model VS-43 snow-density gauge (Russia & China)

Cross section area： 50 cm^2

Length： 60 cm (±1cm)

Weigh： using the balance and the accuracy of the balance is 5g (one gradation on the balance's scale and the scale of 0 is the weigh of the tube).

The snow density is calculated using the formula:

$$\rho = \frac{m}{SD \times s}$$

Model VS-43 snow-density gauge (Radionov et al, 1997)

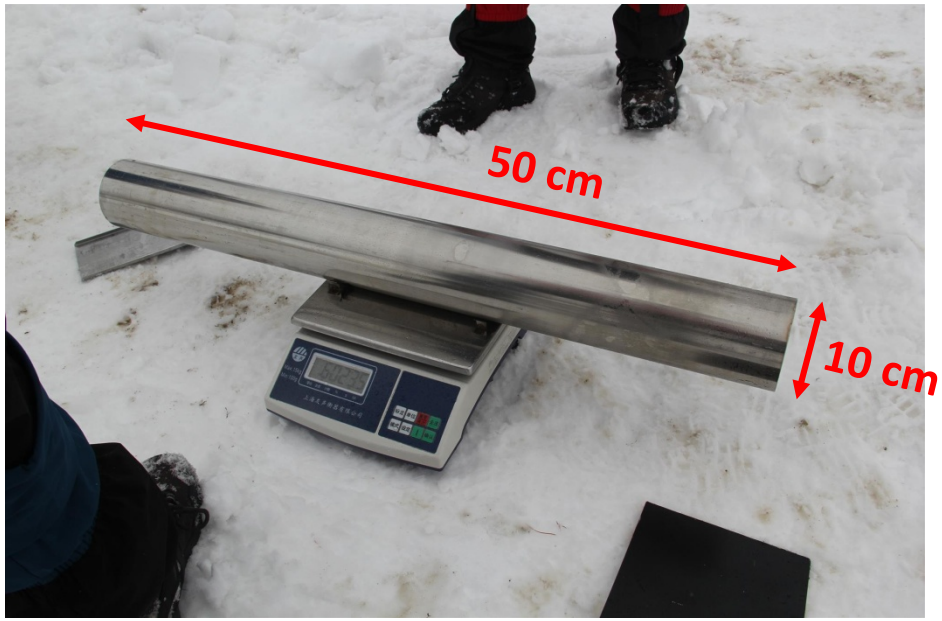
3.2 Instruments

Instruments——Snow tube

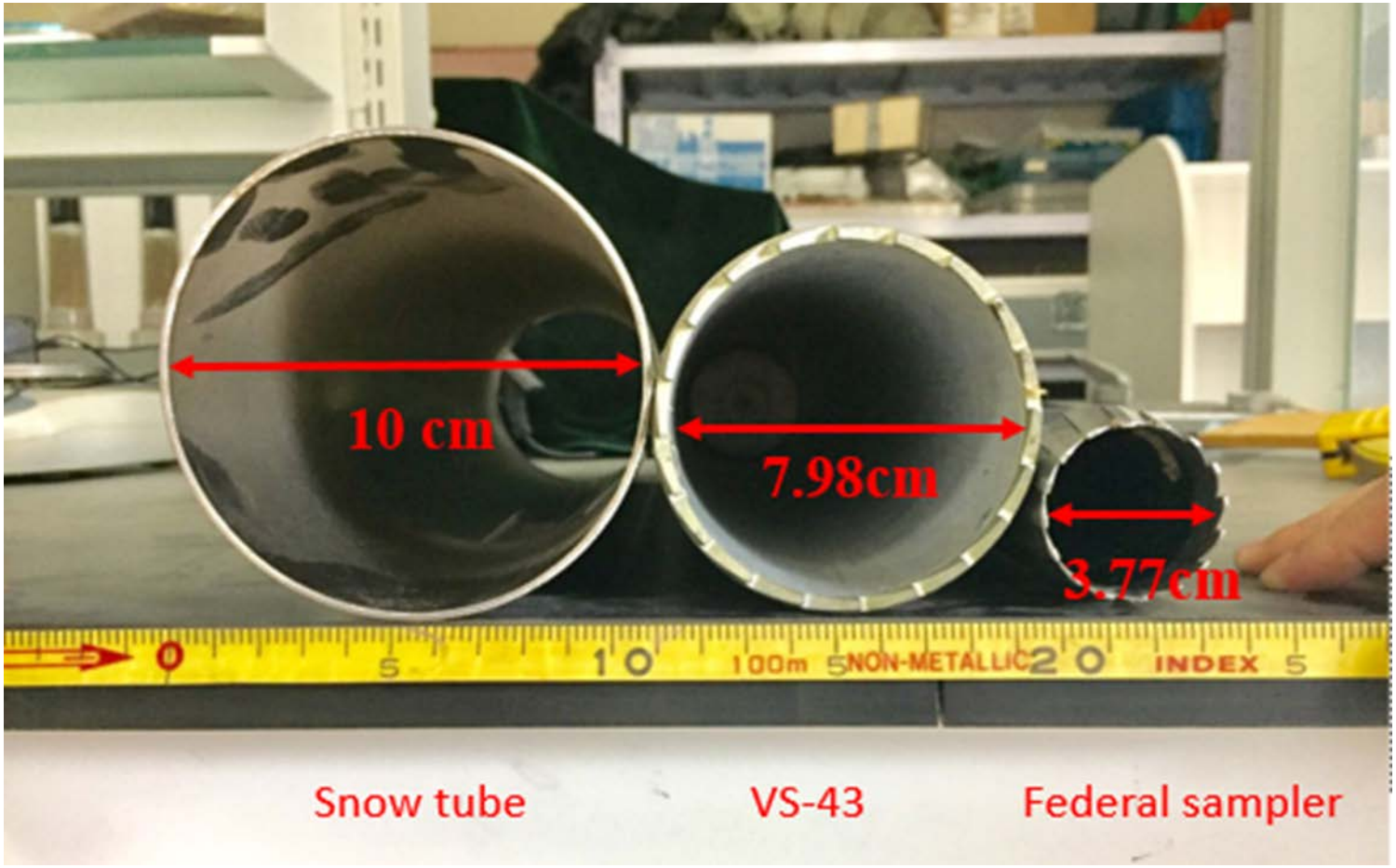
(1) Material: metal，
Diameter :10 cm,
Length: 50, 100 cm

(2) Weigh： using the electronic balance (± 0.1 g).

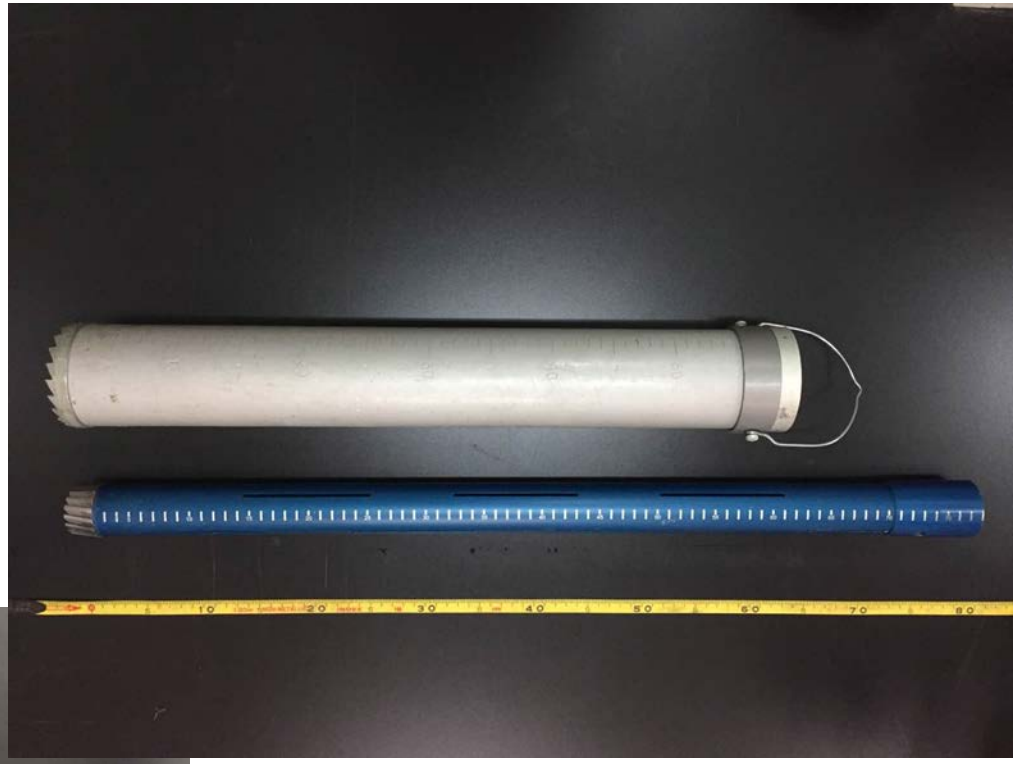
$$\rho = \frac{(m_{snow})}{v_{snow}}$$

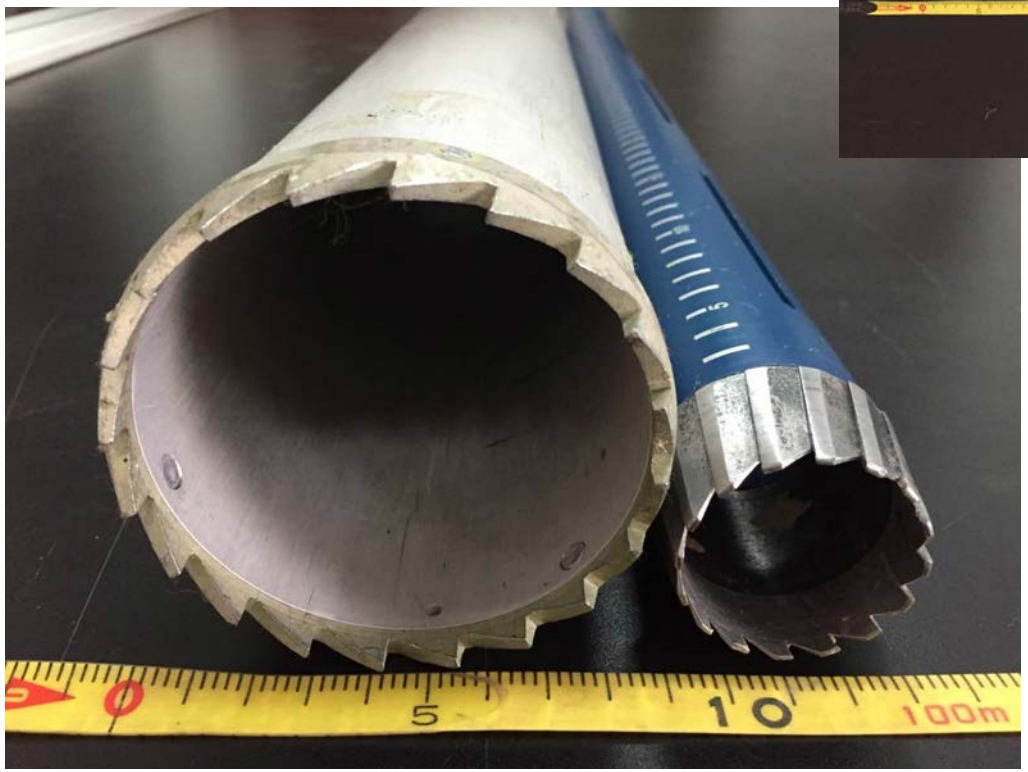


	diameter (cm)	cross-section area (cm^2)	length (cm)
Federal Sampler	3.77	11.16	500.00
Russian Model VS-43	7.98	50.00	60.00
Snow Tube	10.00	78.54	50, 100



The world two dominant equipment for snow density measurement: NA Federal Sampler and Russian Model VS-43.



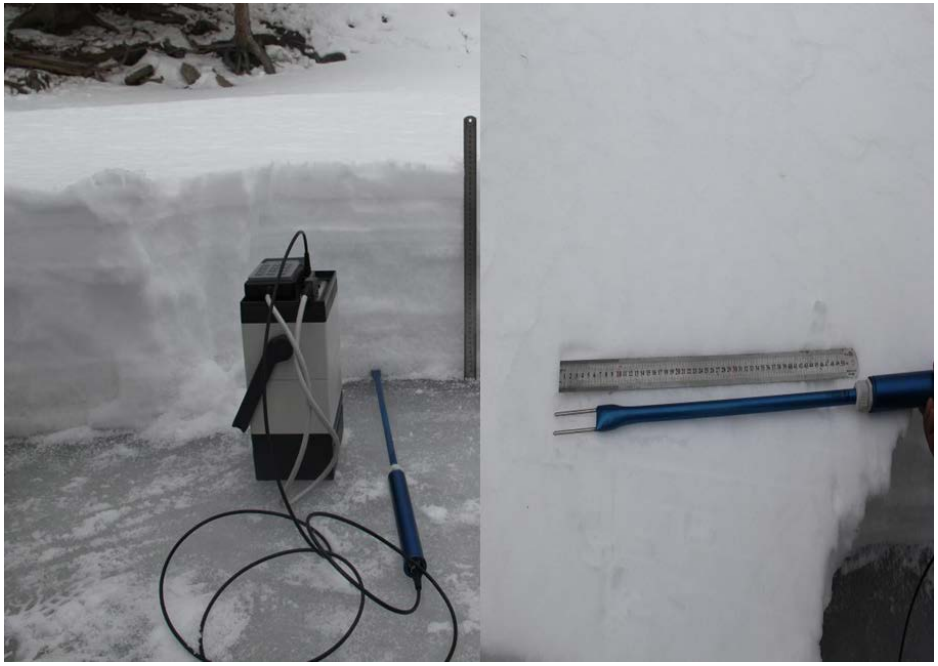


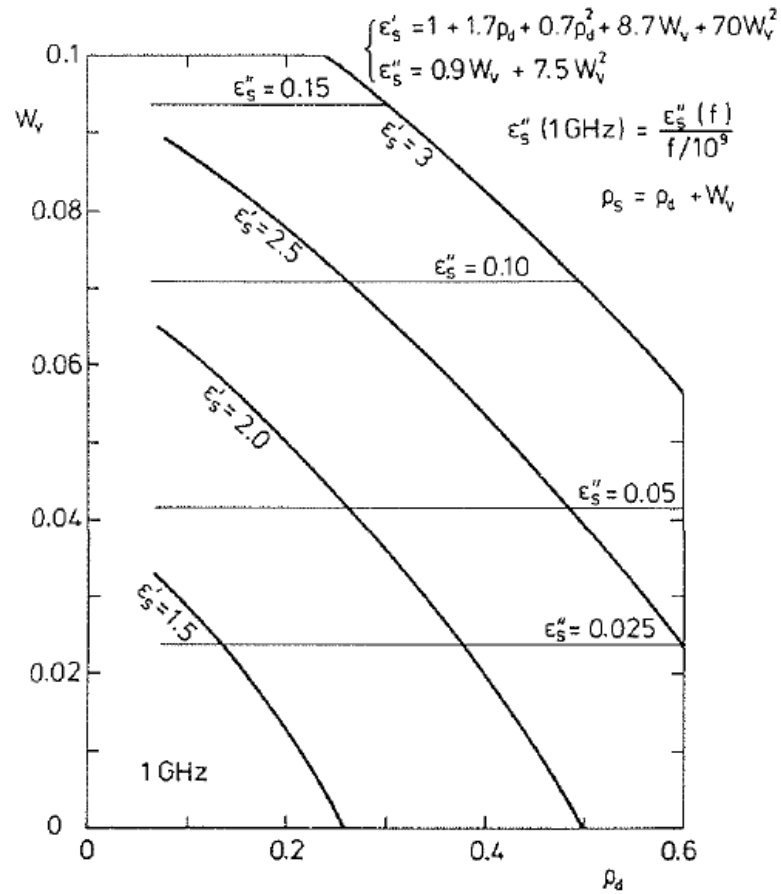
Russian Model VS-43 are used for snow density measurements across Eurasian continent.

Instruments——Snow Fork

Snow Fork: resonance cure between air and snow.

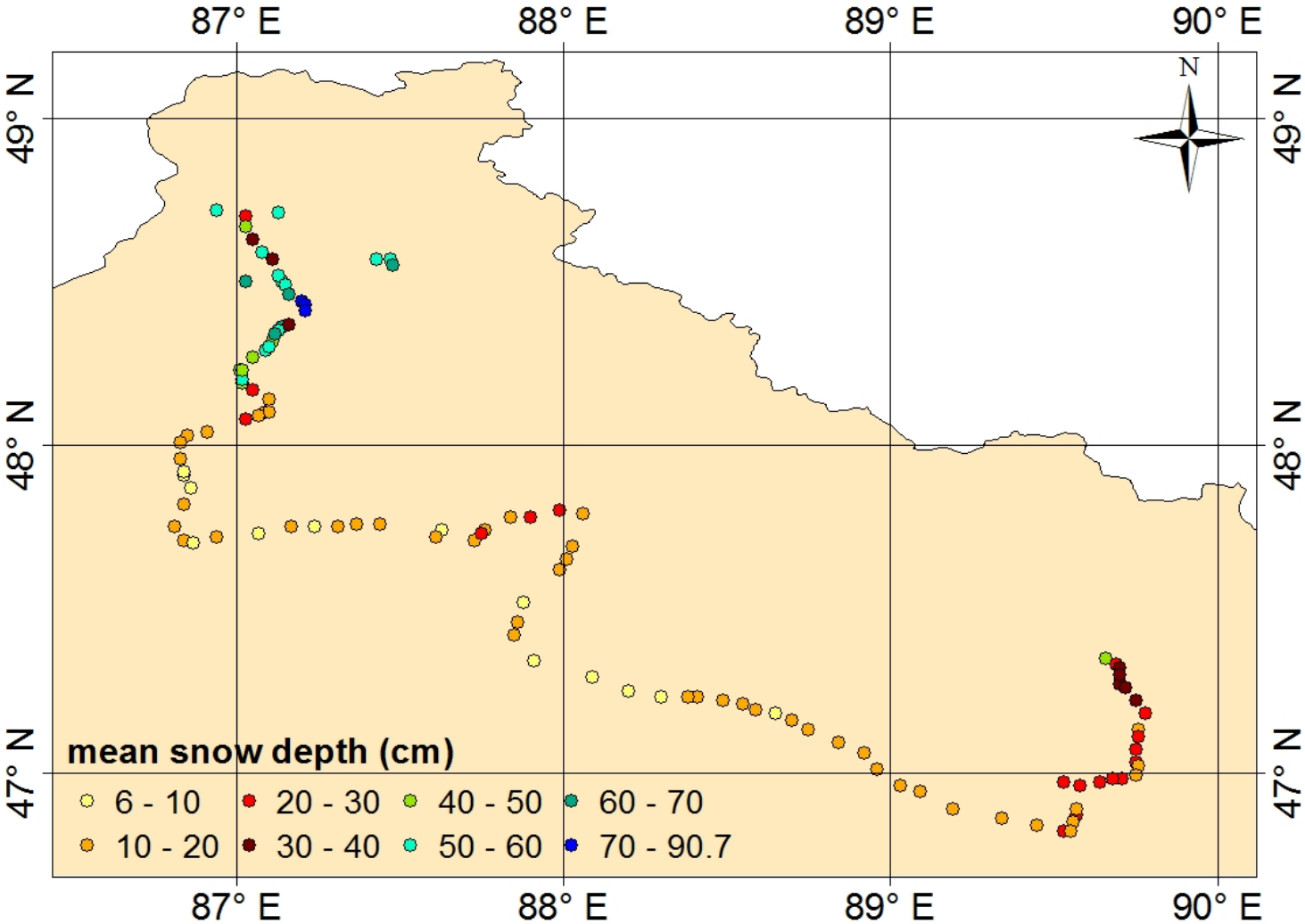
effectivity, portable, high-resolution, wetness…





Nomograph for determining the wetness and density of snow from its complex dielectric constant at 1 GHz. (Sihvola and Tiuri 1986).

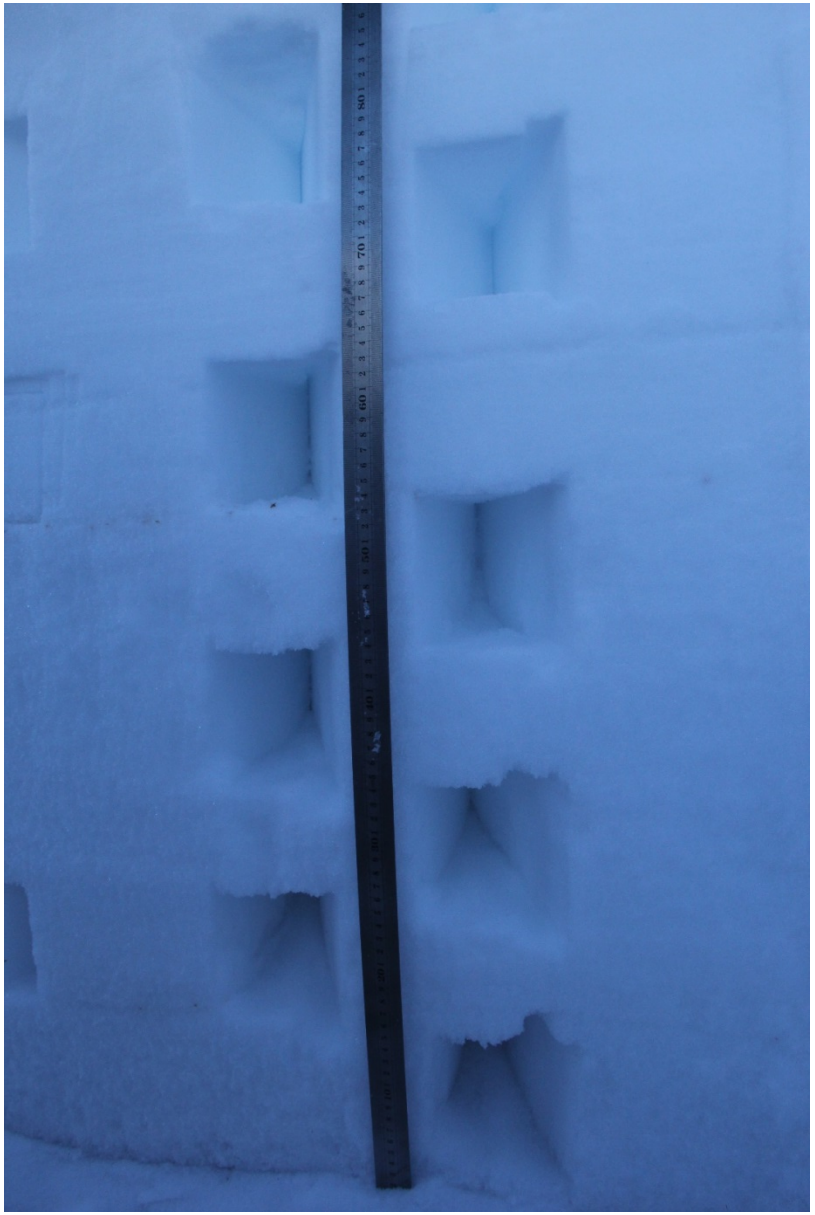
Study area and field sites



3. Data

3.1 Study area

The Altay Mountains in Xinjiang province, China



3.3 Data analysis

Different methods to measure snow density have different vertical resolution. To compare the snow density at the same resolution, the high-resolution were depth-weighted averaged to match the low resolution.

The criterion to evaluate precision of snow density measurements including the coefficient of determination (R^2), and the Root Mean Square Error (RMSE), and the BIAS, and the mean relative percent error (MRPE):

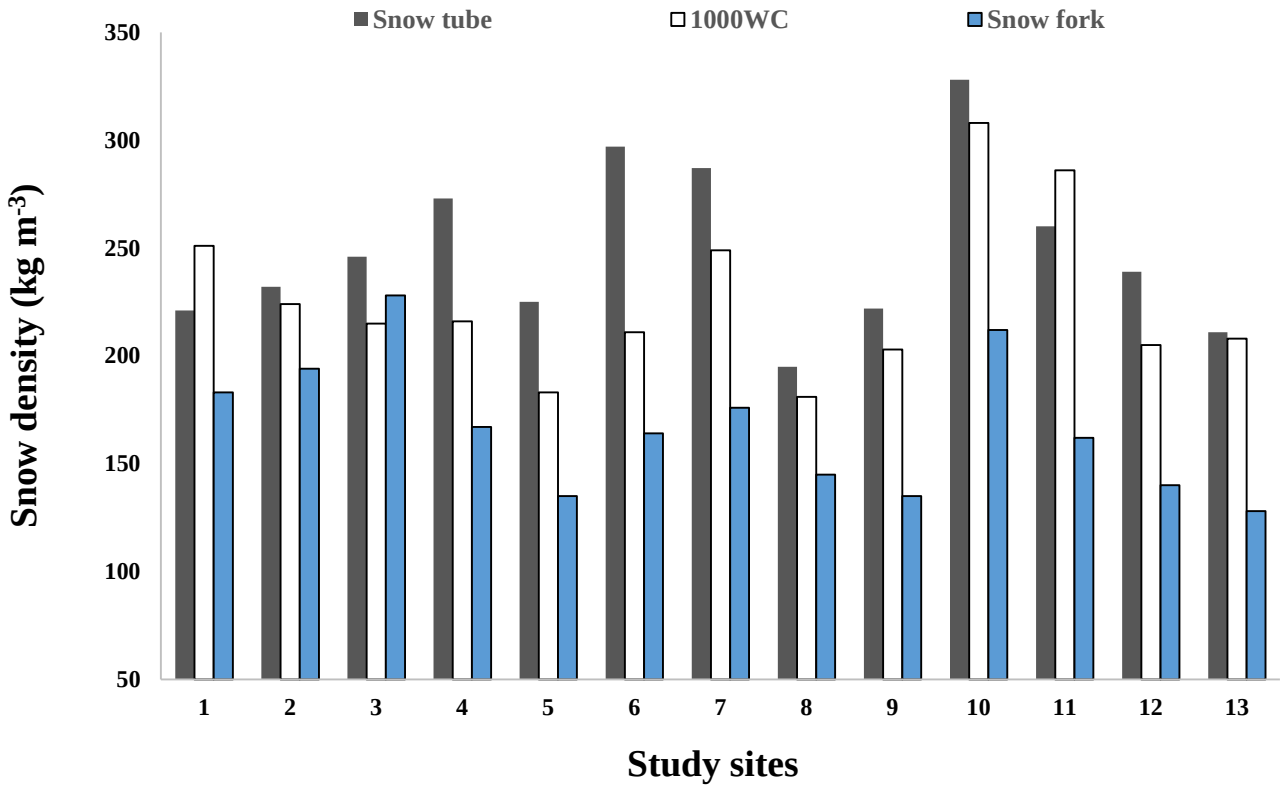
$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{n}^{1}(OBS_i - REF_i)^2}$$

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}(OBS_i - REF_i)$$

$$MRPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{(OBS_i - REF_i)}{REF_i}\right) \times 100\%$$

Snow Tube vs. Snow Fork and 1000 cm^3 wedge cutter

ρ_1	ρ_2	Min	Max	Medium	Mean
Snow tube	Snow fork	-7.3%	-44.8%	-38.7%	-32.4%
	1000WC	13.6%	-29.0%	-8.6%	-8.6%

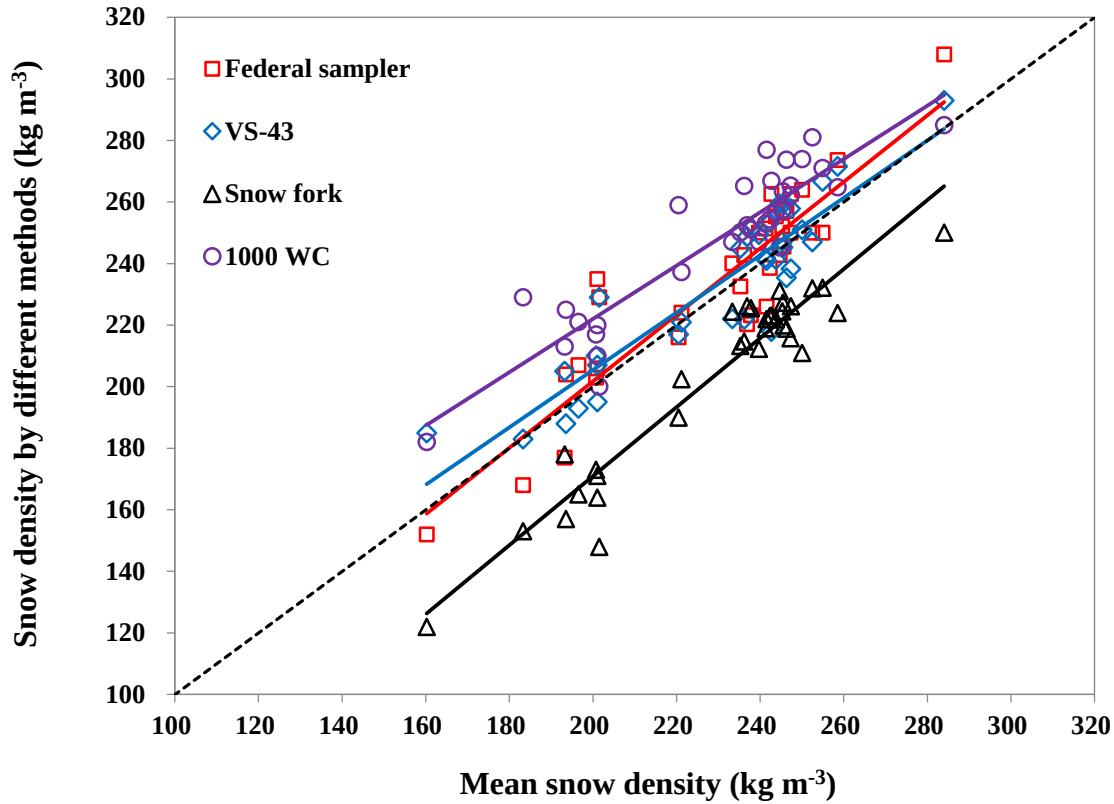


Using mean snow density of all measurements as the reference value.

Snow fork:
Underestimate

1000 cm^3 wedge cutter:
overestimate

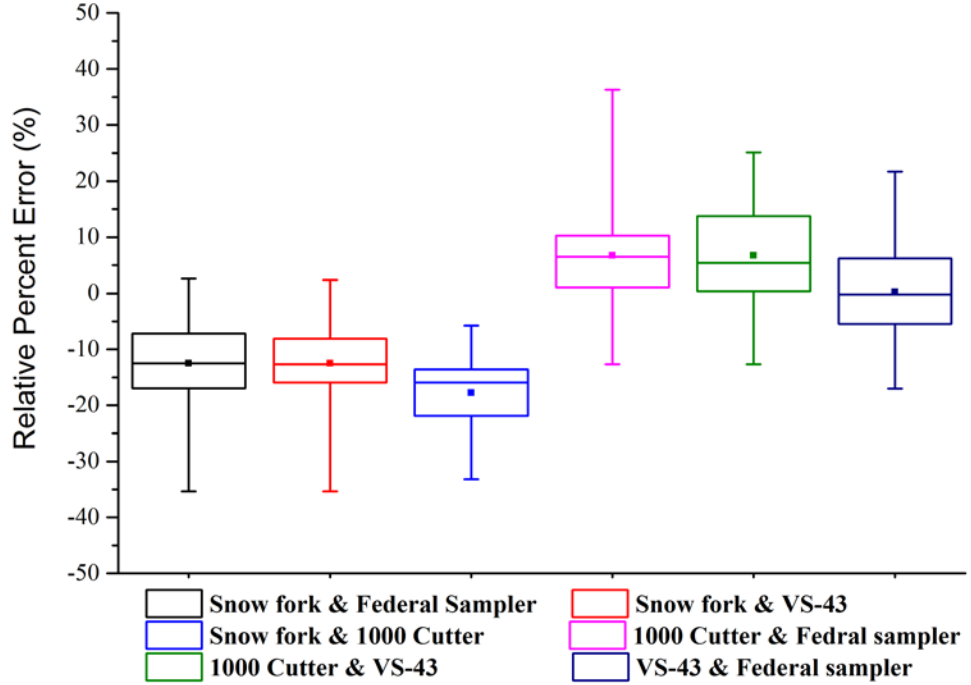
Federal sampler and VS-43:
best



Instruments	Snow density kg m^{-3}	R^2	RMSE kg m^{-3}	BIAS kg m^{-3}	MRPE (%)
Federal sampler		0.84	13	4	1.7
VS-43		0.83	11	3	1.0
Snow fork		0.92	27	-25	-11.2
1000WC		0.84	21	18	7.7

Comparing between any two methods

$$RPE = \frac{(\rho_1 - \rho_2)}{\rho_2} \times 100\%$$



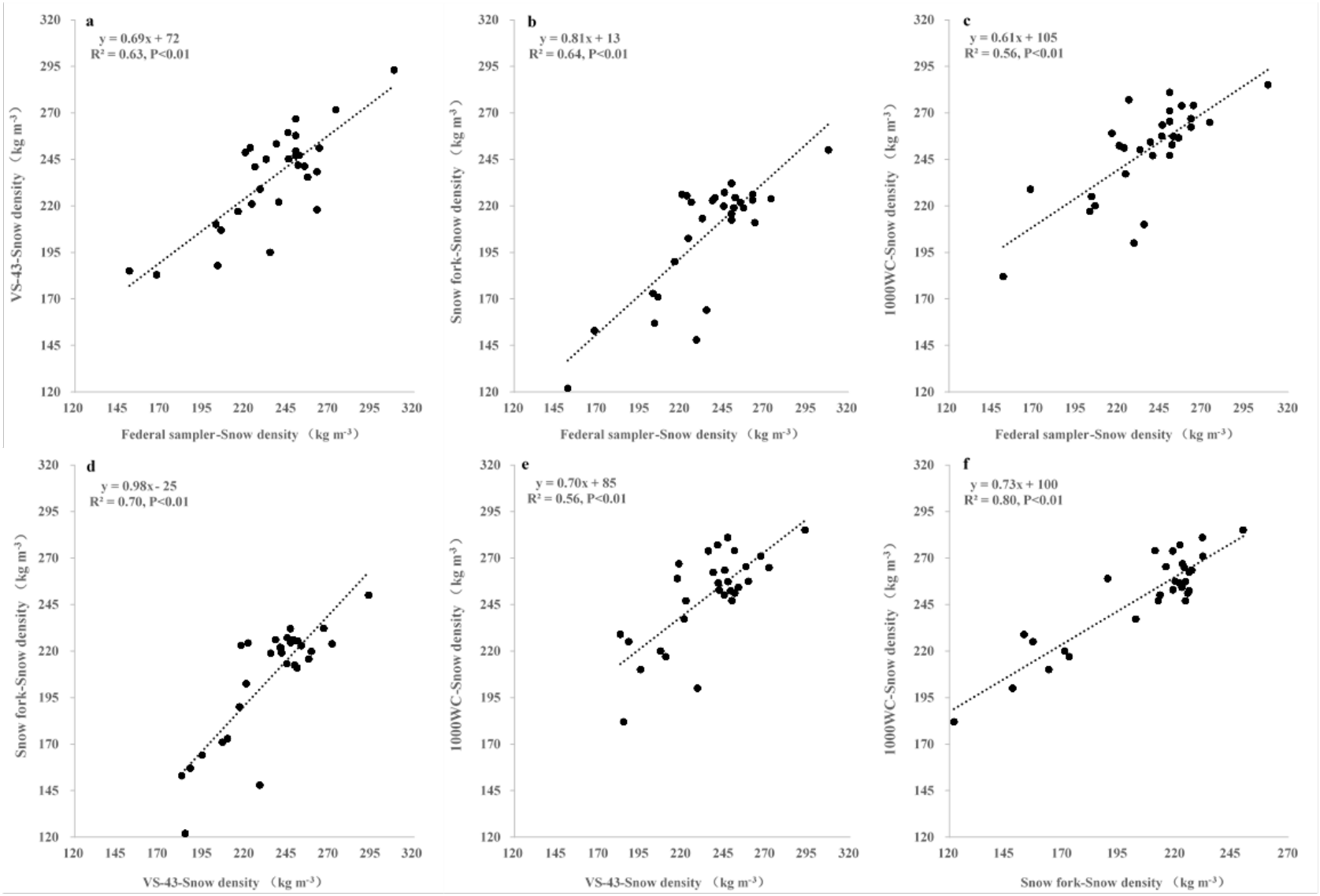
Box show 25th and 75th percentiles, the square dot represents the mean value, and bars represent maximum and minimum value.

ρ_1	Snow fork			1000WC		VS-43
ρ_2	FS	VS-43	1000WC	FS	VS-43	FS
Max	-35.4%	-35.4%	-33.2%	36.3%	25.1%	21.7%
Min	2.6%	2.4%	5.8%	-12.7%	-12.7%	-17.0%
Medium	-12.5%	-12.5%	-17.8%	6.7%	6.7%	0.3%
Mean	-12.5%	-12.7%	-15.9%	6.5%	5.4%	-0.2%

Performance of different methods in forest and grass

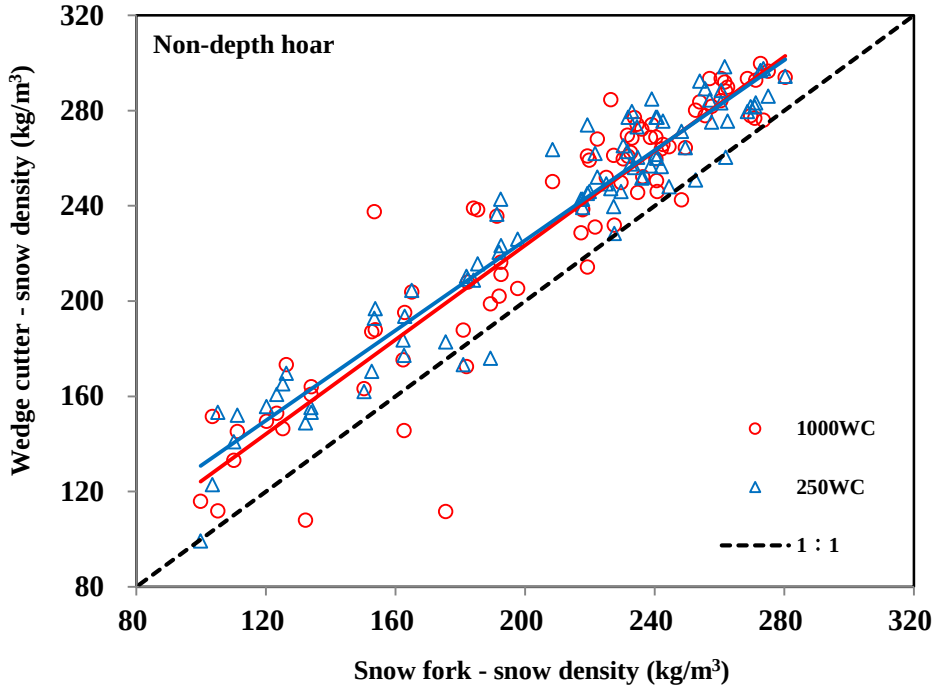
Instruments	Federal sampler		VS-43		Snow fork		1000WC	
Vegetation	Forest	Grass	Forest	Grass	Forest	Grass	Forest	Grass
R^2	0.87	0.77	0.78	0.83	0.94	0.89	0.78	0.78
RMSE	10	14	12	11	21	27	21	21
Bias	0	5	2	3	-20	-26	18	18
MPRE(%)	-1.8	2.2	-0.4	1.2	-11.0	-11.2	7.2	7.8

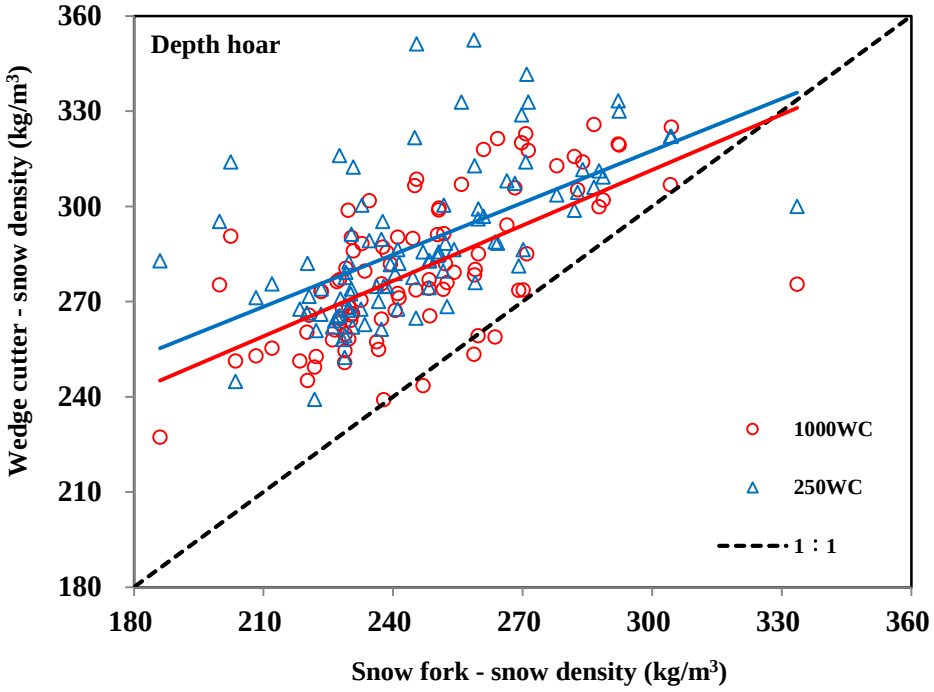
4. Results——The comparison of each two methods



Performance of Snow Fork and Wedge Cutter

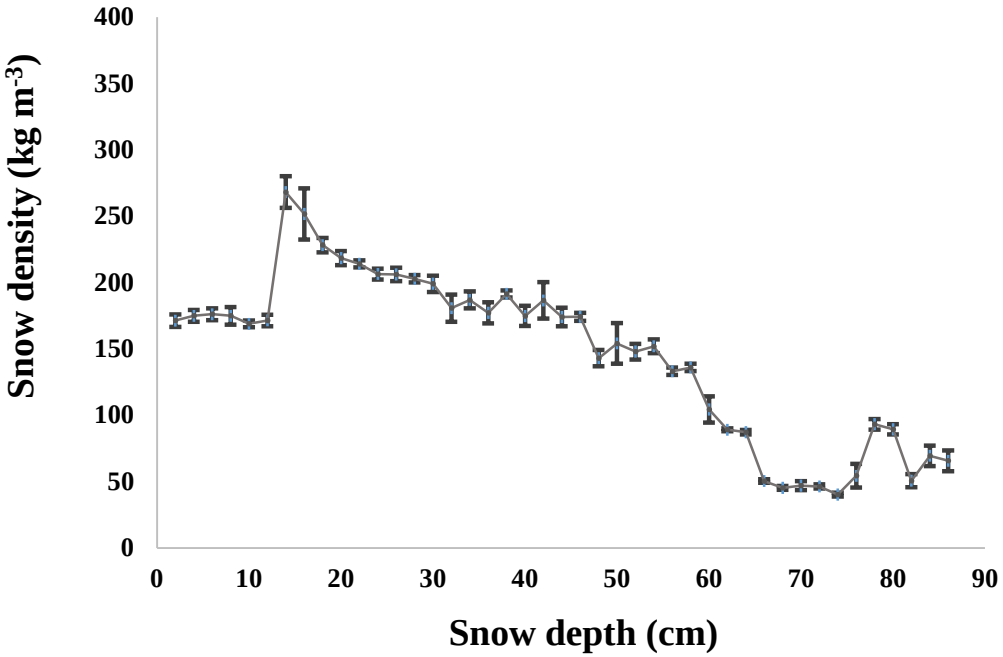
Instruments	Snow fork & 1000WC		Snow fork & 250WC		250WC & 1000WC	
Snow stratify	Non-depth hoar	Depth hoar	Non-depth hoar	Depth hoar	Non-depth hoar	Depth hoar
R^2	0.87	0.43	0.92	0.35	0.87	0.42
RMSE	30	39	27	47	19	21
BIAS	-23	-34	-25	-42	2	8
MPRE (%)	-9.6	-12.1	-11.1	-14.5	1.9	3.1



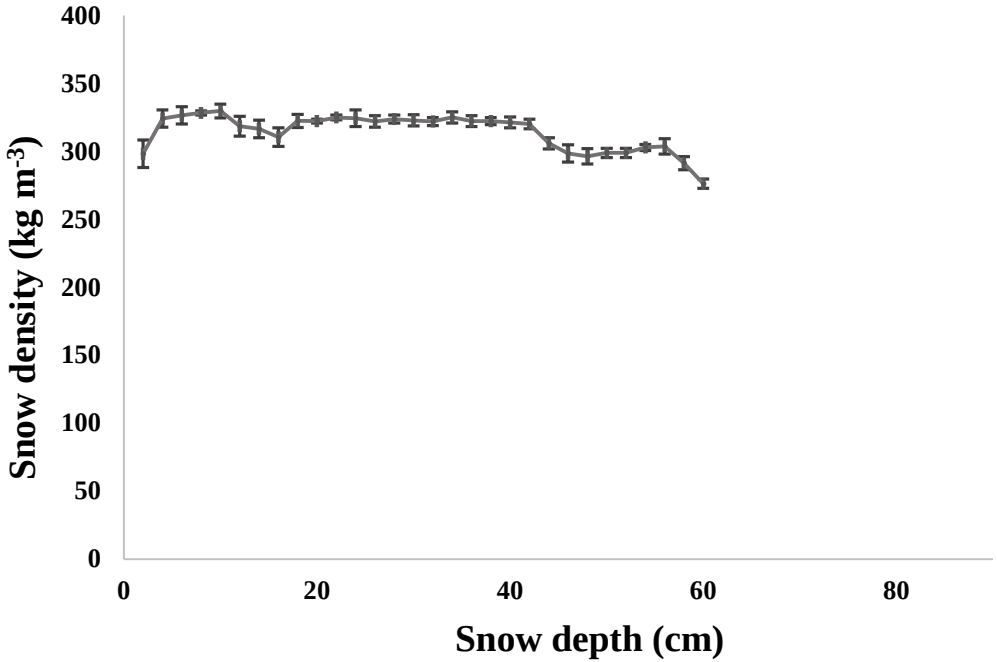


Stability of Snow Fork Measurements

Repeated (5 times) measurements to the same snow pit by Snow fork. Anomaly was within ± 40 kg m^{-3}.



For higher density and homogeneous snow, performance of Snow fork was better.



5. Conclusion

- Snow fork systematically underestimates snow density comparing with all other equipment measurements, on average by 12-16% with extreme of up to 45%. However, for homogenous and high density dry snow, snow fork measurements were closer to measurements by the other equipment.

- Using the mean value of all measurements as reference: Snow fork underestimated snow density, 1000WC overestimated snow density, the Federal sampler and the VS-43 were relatively closer to the reference.

- The mean and medium value differences between the Federal Sampler and Russian VS-43 measurements were essentially close to zero. In other words, the two measurements were essentially the same.

- The question why Eurasian continent snow density systematically lower than the value in North America is still unanswered.

Thank you !