Comparison of Snow Density Measurements Using Different Equipment

Tingjun Zhang\textsuperscript{1}, Hang Su\textsuperscript{1}, Kang Wang\textsuperscript{2}

\textsuperscript{1} College of Earth and Environmental Sciences, Lanzhou University, CHINA
\textsuperscript{2} Institute of Arctic and Alpine Research, University of Colorado Boulder, USA

First Workshop on NASA SnowEx Results
Longmont, Colorado
August 8-10, 2017
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

\[ \rho = \frac{m_{\text{snow}}}{v_{\text{snow}}} \]
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:

\[ \rho = \frac{m}{SD \times s} \]
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).

\[ \rho = \frac{(m_{\text{snow}})}{v_{\text{snow}}} \]
<table>
<thead>
<tr>
<th></th>
<th>diameter (cm)</th>
<th>cross-section area (cm²)</th>
<th>length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal Sampler</td>
<td>3.77</td>
<td>11.16</td>
<td>500.00</td>
</tr>
<tr>
<td>Russian Model VS-43</td>
<td>7.98</td>
<td>50.00</td>
<td>60.00</td>
</tr>
<tr>
<td>Snow Tube</td>
<td>10.00</td>
<td>78.54</td>
<td>50, 100</td>
</tr>
</tbody>
</table>
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).
3. Data

3.1 Study area

The Altay Mountains in Xinjiang province, China
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):

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (OBS_i - REF_i)^2}
\]

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

\[
MRPE = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{OBS_i - REF_i}{REF_i} \right) \times 100\%
\]
### Snow Tube vs. Snow Fork and 1000 cm³ wedge cutter

<table>
<thead>
<tr>
<th></th>
<th>( \rho_1 )</th>
<th>( \rho_2 )</th>
<th>Min</th>
<th>Max</th>
<th>Medium</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow tube</td>
<td>Snow fork</td>
<td>-7.3%</td>
<td>-44.8%</td>
<td>-38.7%</td>
<td>-32.4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000WC</td>
<td>13.6%</td>
<td>-29.0%</td>
<td>-8.6%</td>
<td>-8.6%</td>
<td></td>
</tr>
</tbody>
</table>

### Study sites

- Snow tube
- Snow fork
- 1000WC
Using mean snow density of all measurements as the reference value.

Snow fork:
Underestimate

1000 cm³ wedge cutter:
overestimate

Federal sampler and VS-43:
best

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Snow density kg m⁻³</th>
<th>R²</th>
<th>RMSE kg m⁻³</th>
<th>BIAS kg m⁻³</th>
<th>MRPE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal sampler</td>
<td>0.84</td>
<td>13</td>
<td>4</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>VS-43</td>
<td>0.83</td>
<td>11</td>
<td>3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Snow fork</td>
<td>0.92</td>
<td>27</td>
<td>-25</td>
<td>-11.2</td>
<td></td>
</tr>
<tr>
<td>1000WC</td>
<td>0.84</td>
<td>21</td>
<td>18</td>
<td>7.7</td>
<td></td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>( \rho_1 )</th>
<th>Snow fork</th>
<th>1000WC</th>
<th>VS-43</th>
<th>Snow fork</th>
<th>1000WC</th>
<th>VS-43</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_2 )</td>
<td>FS</td>
<td>VS-43</td>
<td>1000WC</td>
<td>FS</td>
<td>VS-43</td>
<td>FS</td>
<td>FS</td>
</tr>
<tr>
<td>Max</td>
<td>-35.4%</td>
<td>-35.4%</td>
<td>-33.2%</td>
<td>36.3%</td>
<td>25.1%</td>
<td>21.7%</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>2.6%</td>
<td>2.4%</td>
<td>5.8%</td>
<td>-12.7%</td>
<td>-12.7%</td>
<td>-17.0%</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>-12.5%</td>
<td>-12.5%</td>
<td>-17.8%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>0.3%</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-12.5%</td>
<td>-12.7%</td>
<td>-15.9%</td>
<td>6.5%</td>
<td>5.4%</td>
<td>-0.2%</td>
<td></td>
</tr>
</tbody>
</table>
Performance of different methods in forest and grass

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Federal sampler</th>
<th>VS-43</th>
<th>Snow fork</th>
<th>1000WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>0.87</td>
<td>0.78</td>
<td>0.94</td>
<td>0.78</td>
</tr>
<tr>
<td>Grass</td>
<td>0.77</td>
<td>0.83</td>
<td>0.89</td>
<td>0.78</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMSE</td>
<td>10</td>
<td>12</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Bias</td>
<td>0</td>
<td>2</td>
<td>-20</td>
<td>18</td>
</tr>
<tr>
<td>MPRE(%)</td>
<td>-1.8</td>
<td>-0.4</td>
<td>-11.0</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>1.2</td>
<td>-11.2</td>
<td>7.8</td>
</tr>
</tbody>
</table>
4. Results——The comparison of each two methods
## Performance of Snow Fork and Wedge Cutter

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Snow fork &amp; 1000WC</th>
<th>Snow fork &amp; 250WC</th>
<th>250WC &amp; 1000WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow stratify</td>
<td>Non-depth hoar</td>
<td>Depth hoar</td>
<td>Non-depth hoar</td>
</tr>
<tr>
<td>R²</td>
<td>0.87</td>
<td>0.43</td>
<td>0.92</td>
</tr>
<tr>
<td>RMSE</td>
<td>30</td>
<td>39</td>
<td>27</td>
</tr>
<tr>
<td>BIAS</td>
<td>-23</td>
<td>-34</td>
<td>-25</td>
</tr>
<tr>
<td>MPRE (%)</td>
<td>-9.6</td>
<td>-12.1</td>
<td>-11.1</td>
</tr>
</tbody>
</table>

### Wedge cutter - snow density (kg/m³)

**Non-depth hoar**

- 1000WC
- 250WC

**Depth hoar**

- 1000WC
- 250WC

---

**Graphs:**

- Left: Snow fork - snow density (kg/m³) vs. Wedge cutter - snow density (kg/m³) for Non-depth hoar.
- Right: Snow fork - snow density (kg/m³) vs. Wedge cutter - snow density (kg/m³) for Depth hoar.
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 !