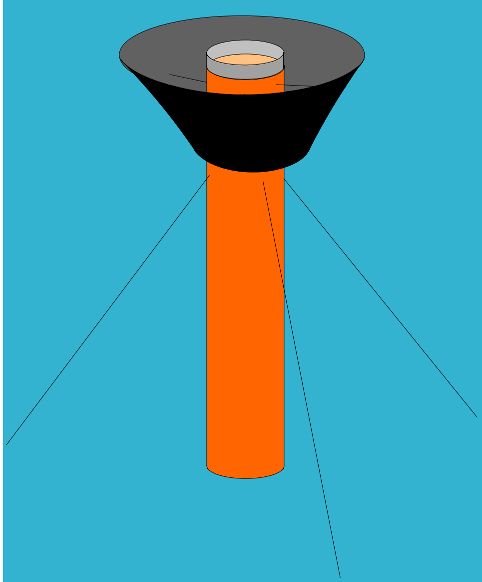
REPORT



Testing and development of a new precipitation gauge for chemical analysis

Martin Ferm

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Karin Sjöberg
Avdelningschef

IVL Swedish Environmental Research Institute

IVL Swedish Environmental Research Institute

Organization

IVL Swedish Environmental Research Institute Ltd.

Address

P.O. Box 5302
SE-400 14 Göteborg

Telephone

+46 (0)31-725 62 00

Report Summary

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Testing and development of new precipitation gauge for chemical analysis

Summary

Representative sampling of precipitation above ground is very difficult because the sampler itself affects the trajectory of the meteor. If chemical analysis of the precipitation is of interest, the sampling has to be made well above the ground. Samplers made of suitable material but not of optimal aerodynamical shape are traditionally used for collecting precipitation for chemical analysis by environmentalists worldwide. The obtained concentration is multiplied by the precipitation amount to obtain the wet deposition. Sometimes the precipitation amount from the same sampler that collects precipitation for chemical analysis is used and sometimes it is obtained from a standard gauge or from model calculations. Even if the material in the sampler is inert with respect to the ions analysed, the concentration can be wrong. If the sampling efficiency varies with time (due to changes in wind speed or droplet size), the precipitation weighted average concentration will not be correct. A sampler consisting of a snow sack in a wind protective tube has been modified in several steps to resemble a sampler used by meteorologist for measuring the precipitation amount on a daily basis. The two samplers measured similar precipitation amounts when a thinner rim was introduced on top of the tube containing the snow sack.

Keyword

Snow sack, Katterjåkk, SMHI gauge, wind induced error

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To Olle Westling who tragically died before the project was finished

Summary

Representative sampling of precipitation above ground is very difficult because the sampler itself affects the trajectory of the meteor. If chemical analysis of the precipitation is of interest, the sampling has to be made well above the ground. Samplers made of suitable material but not of optimal aerodynamical shape are traditionally used for collecting precipitation for chemical analysis by environmentalists worldwide. The obtained concentration is multiplied by the precipitation amount to obtain the wet deposition. Sometimes the precipitation amount from the same sampler that collects precipitation for chemical analysis is used and sometimes it is obtained from a standard gauge or from model calculations. Even if the material in the sampler is inert with respect to the ions analysed, the concentration can be wrong. If the sampling efficiency varies with time (due to changes in wind speed or droplet size), the precipitation weighted average concentration will not be correct. A sampler consisting of a snow sack in a wind protective tube has been modified in several steps to resemble a sampler used by meteorologist for measuring the precipitation amount on a daily basis. The two samplers measured similar precipitation amounts when a thinner rim was introduced on top of the tube containing the snow sack.

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1 Background

IVL is since 1990 responsible for The Swedish Precipitation Chemistry Network, "nederbördskemiska nätet". The precipitation collectors that were used from the very start of this network are still used today. Two different types of bulk collectors are used. "Snow sacks" are used during the winter season and funnels connected to bottles during the other seasons. At some stations wet-only collectors are also used.

IVL also runs other networks with wet deposition measurements such as the EMEP network in Sweden (www.ivl.se). Another network run by IVL is the Throughfall Monitoring Network in Sweden, "krondroppsnätet" (www.ivl.se). In this network, the dry deposition is calculated from the difference between the throughfall and wet deposition (measured with bulk collectors). Correct sampling of the wet deposition amount of different ions is crucial with this technique. Earlier the wet deposition was measured with bulk collectors placed in clearings, but today most of these measurements have, due to quality problems, been replaced by model calculations.

There are large differences between measured and modelled deposition of different pollutants in Sweden (Persson and Magnusson 2003). A special project was started to find the reasons for these differences. The result of this project showed that the most important improvement is to introduce a new precipitation gauge having a collection efficiency close to 100 % for collecting precipitation for subsequent chemical analysis (Persson et al., 2004).

Snow sacks have been used within The Swedish Precipitation Chemistry Network since the early 1980's. IVL has found that the snow sacks overestimate the precipitation amount. It is probably caused by the "pumping" effect of the sack when the wind blows around it. If the snow sack is placed inside a wind protective tube, it will give a small underestimation instead (Ferm et al., 2004).

It is difficult to collect the precipitation amount correctly without contaminating the sample. The sampler itself affects the wind field above its opening and thereby the trajectory of the meteors. Snow and small raindrops fall slower than larger rain drops. Snow and small raindrops also have less inertia, i.e. they can change their horizontal speed component faster if the wind speed is increasing. The lower fall speed of snow and drizzle compared to rain drops causes a longer residence time in the zone with increased wind speed above the sampler. The longer residence time in combination with a fast adaptation to the increased wind velocity above the sampler both contributes to an underestimation of the deposition of water. This is illustrated in Figure 1.

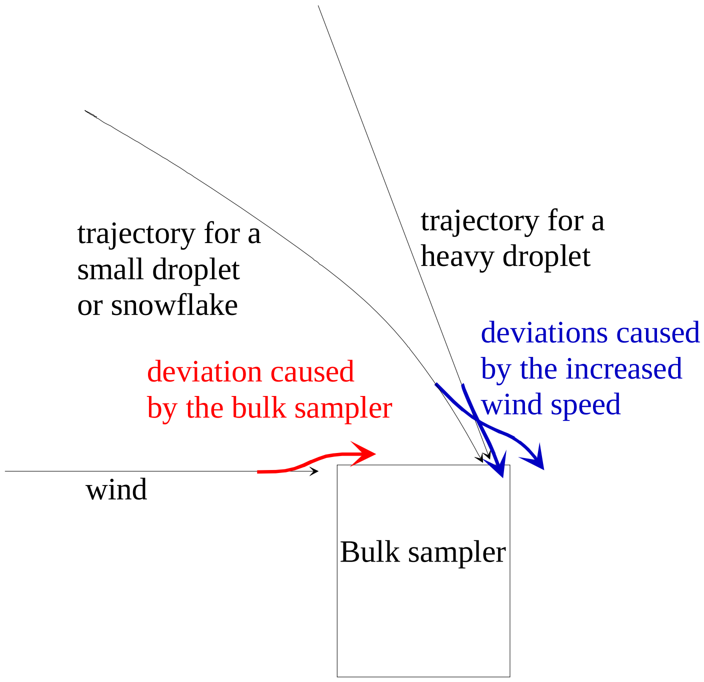

Figure 1. Schematic illustration of the sampling errors for meteors with low fall speed (drizzle, snow) and higher fall speed (large droplets or hail).

It is very difficult to make corrections for this artefact (Chvíla et al., 2005) because the collection efficiency will vary both with local wind speed and the fall speed, which is a function of shape (snow) and droplet size (rain intensity).

The easiest solution may seem to avoid windy places and mount the collector in a wind shielded place such as a clearing in a forest. This solution is used as often as possible. Another alternative is to collect the precipitation at ground level. This can be achieved with a pit gauge. A pit gauge is sometimes used as a reference method for precipitation amount when testing other samplers. Resuspension of soil or dust can, however, contaminate the sample in this case. For that reason the sampler should be placed well above the ground when deposition of different chemicals should be measured. This complicates the collection of the correct precipitation amount.

An incorrect precipitation amount will also affect the concentration of pollutants in the precipitation. The wet precipitation rate and concentrations both vary with time. The deposition (mg/m^2) is the integrated product of the rate (ml/m^2/h) and concentration (mg/l) over time. If the wind speed and/or droplet size changes with time, the collection efficiency will vary and the precipitation amount weighted average concentration will be biased. Since smaller droplets often have higher concentration of pollutants than larger ones the effect of reduced collection efficiency and higher pollutant concentration will have a synergistic effect on the measured deposition.

2 Introduction

Precipitation collection for chemical analysis is not only a problem in Sweden, but also in other parts of Europe. Erisman et al., (2003) have published the results from a partly EU financed intercomparison of rain collection and analysis. Günther and Graf (1991) have published results from an intercomparison during snowy conditions. Both these studies were performed on large open windy fields and show that the quality of many precipitation gauges used within different networks can be very poor.

Since a lot of money is spent to monitor wet-deposition using gauges of questionable quality, IVL proposed a study to test and improve a precipitation sampler that can be used all over Sweden. A project was financed by Swedish EPA and EU.

Meteorologists have for a long time used precipitation gauges that collect the precipitation with high collection efficiency. Their gauges are made of metal and not suitable for chemical analysis of the precipitation. Environmentalists on the other hand have collected precipitation in plastic materials that are suitable for chemical analysis, but the collection efficiencies of their gauges have not been tested and optimised.

Different ways of improving the precipitation collector have earlier been used.

Seibert and Morén (1999) mounted a flange around the gauge at the level of the orifice to reduce the wind effect. This will, however, cause problems if it snows. Westling and Ferm (1998) used ca 5 cm deep trays placed on the snow. The sample was cut out using a special device and transferred to a box in which it was melted. This technique avoided the error caused by the wind since the trays were very soon covered with snow and the new snow is falling on a natural snow surface. The technique can possibly be used as a reference technique, but it was not practical to use. Barrett et al. (1985) used an inverted Frisbee type gauge to collect snow. The aerodynamically formed shape reduced the effect of wind. Alternatively some have used a snow fence to reduce the wind speed around the sampler (Førland et al., 1996 and Allerup et al., 1997).

3 Experimental

The collection efficiencies of the tested samplers were determined by comparison with the best sampler from SMHI. The SMHI sampler is made of aluminium and consists of a wind shield in the form of a 45° funnel that surrounds a cylinder (Fredriksson and Ståhl 1994), see Fig. 2. The sampler is constructed for 24 h sampling and measurement of precipitation amount only.

A very robust sampler is used within a project called "deposition at high altitudes". The samplers are mounted near the tree border in the mountain areas of north-western Sweden.

A sampler is shown in Figure 3. It consists of a polypropylene tube (outer diameter 194 mm) with a disposable plastic bag inside.

Figure 2. The SMHI gauge

Figure 3. The regular bulk collector in Katterjåkk

A similar wind shield as the SMHI gauge has been constructed for this bulk collector. The funnel was made from a large sheet of 3 mm thick high density polyethylene. This material is very smooth and slides very well on snow. To facilitate for the snow that deposit on the wind shield to slide off, a 60 degree angle was chosen here instead of the 45 degree angle used in the SMHI gauge. The construction is shown in Figure 4.

The precipitation amount collected with this sampler was within this project not good when compared to the SMHI gauge. A new rim was then constructed from a polypropylene tube using a lathe. It was introduced in the bulk sampler as shown in Figure 5. No special arrangement for attaching the rim was needed. It was held in place by the narrow space between the rim and the tube.

Figure 4. The wind shield (60° funnel) mounted on the bulk collector. The disposable plastic bag is held in place by a thin polyethylene ring.

Figure 5. A rim has been constructed of a polypropylene tube. It is fitted into the sampling tube and levelled with the rain shield.

At two stations the collection efficiencies relative the SMHI gauge was determined on a daily basis for different samplers. The station at Katterjåkk (68°25'13"N, 18°10'09"E) was chosen here because it is the most northerly precipitation station in Sweden and because it is very windy. This station is also a SMHI meteorological station with manual observations around the clock.

Another station, which is less windy and mostly receives precipitation in the form of rain, was chosen in southern Sweden (Asa, 57°08'48"N, 14°46'18"E).

Comparison of the deposition (and concentration) of different ions in precipitation was performed at two other sites on a monthly basis, Aneboda (57°07'20"N, 14°32'E) and Jädraås (60°49'12"N, 16°30'18"E).

4 Results

4.1 Collection efficiencies

The precipitation amounts obtained with the two regular samplers (Figure 3) and a similar one provided with a wind shield (60° funnel, Figure 4) as a function of the deposition in the SMHI gauge (Figure 2) are shown in Figure 6. The sampling efficiency relative the SMHI gauge as a function of time is shown in Figure 7. As can be seen from the figure the bulk samplers without wind shield seem to have lower collection efficiency during the winter season than the summer season in comparison to the SMHI-sampler. The regular sampler denoted B, generally showed a higher sampling efficiency (average 76 %) than the similar sampler A (average 70 %) placed 10 m apart. The sampling efficiency of the wind shielded bulk sampler showed less seasonal variation, but with slightly lower efficiency during the summer 2006 and with a slightly higher average collection efficiency (79 %). The low and rather variable sampling efficiency of the wind shielded bulk sampler was unexpected.

The results from the SMHI gauge (Figure 2) and the similar copy made of polyethylene (wind shield consisting of a 60° funnel, Figure 4) are compared on a daily sampling basis in Figure 8. As can be seen the efficiency is low and variable. Katterjåkk is a windy place and mostly receives precipitation in the form of snow. The same comparison was repeated in the south of Sweden at the station Asa, see Figure 9. The sampling efficiency was higher there and so constant that a correction term could be used.

Different parts of the sampler were changed in order to understand what governs the collection efficiency. At Katterjåkk the rim was moved a few cm above the rain shield. The efficiency improved slightly (Figure 10), but this can as well have been an effect of the season. In the next experiment a wind shield with an angle of 45° was constructed and tested. The results are shown in Figure 11. As can be seen the correlation coefficient is very high and the results are not different from those obtained in a parallel sampler equipped with a 60° funnel as wind shield. The high correlation coefficient is probably due to the fact that the precipitation was in the form of rain.

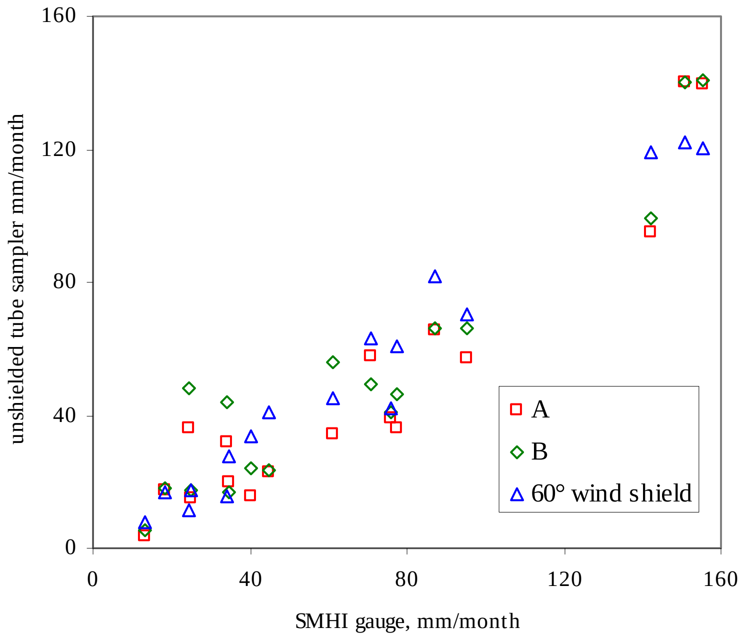

Figure 6. Monthly precipitation amounts obtained with two similar bulk collectors A and B (Figure 3) and a similar one surrounded by a wind shield (daily measurement (Figure 4)) as a function of the precipitation amount obtained with the SMHI gauge (daily measurement (Figure 2)). The measurements were performed in Katterjåkk.

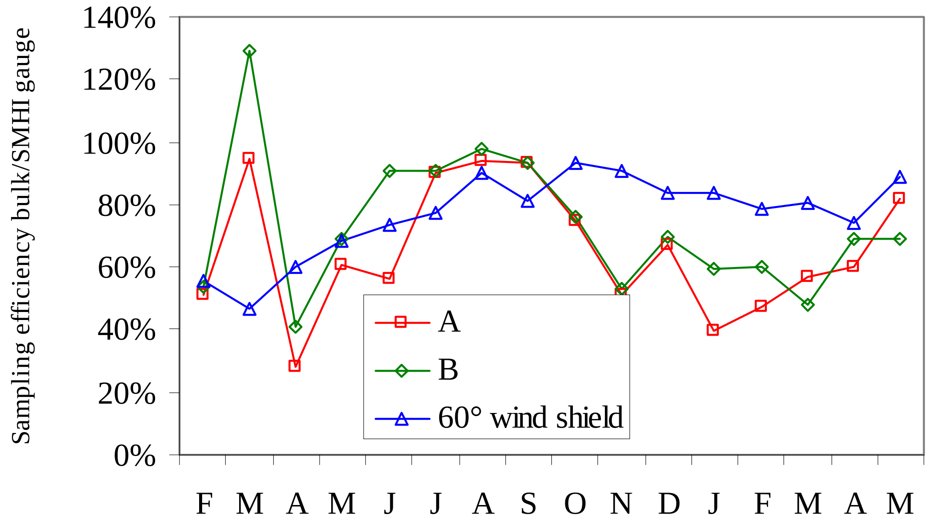

Figure 7. The same data as in Figure 4 plotted as a function of the month (2006-2007).

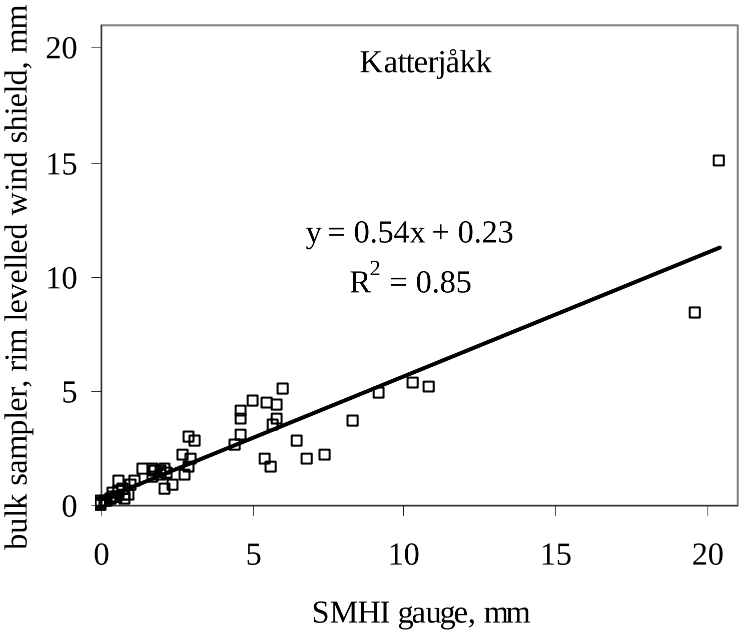

Figure 8. Daily deposition amounts in the bulk sampler (Figure 4) during November 2005 to February 2006 in Katterjåkk as a function of the precipitation amounts obtained with the SMHI gauge.

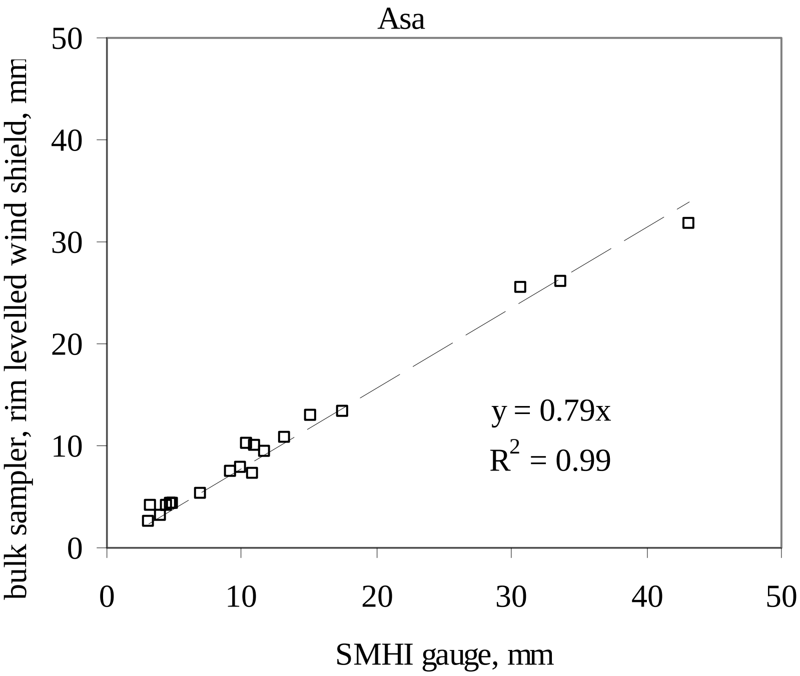

Figure 9. Short term deposition amounts in the bulk sampler (Figure 4) during January 2000 to May 2006 in Asa as a function of the precipitation amount obtained with the SMHI gauge.

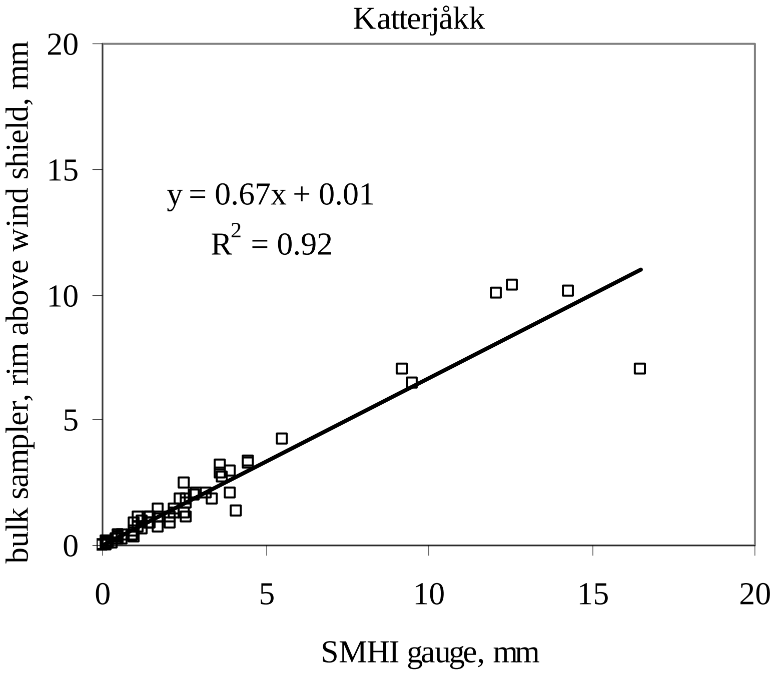

Figure 10. Daily deposition amounts in the bulk sampler (60° funnel, with the rim slightly elevated above the wind shield) during March to June 2006 in Katterjåkk as a function of the precipitation amount obtained with the SMHI gauge.

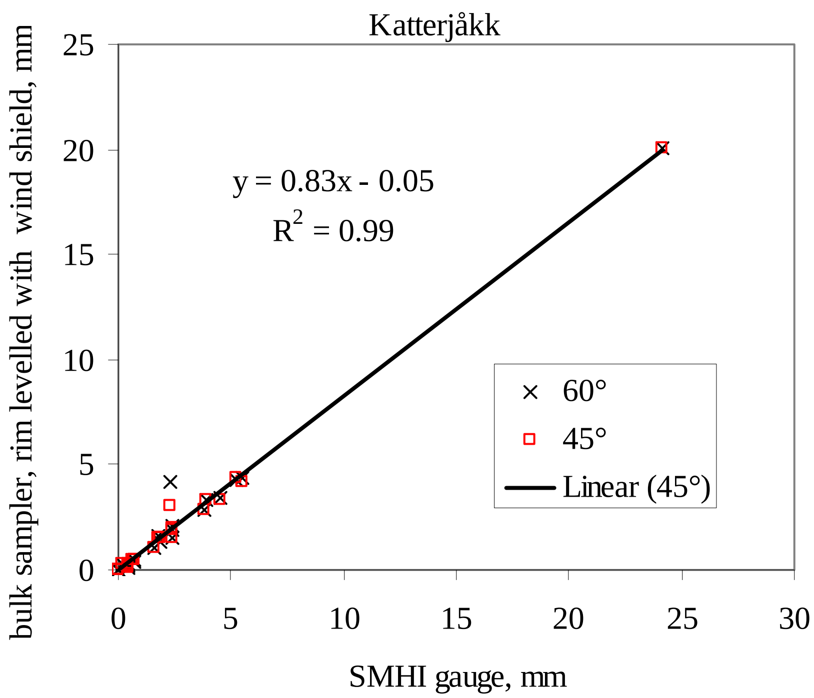

Figure 11. Daily deposition amounts in the bulk sampler (60° and 45° funnels as wind shields) during July to September 2006 in Katterjåkk as a function of the precipitation amount obtained with the SMHI gauge.

The orifice and its rim are very important for the collection efficiency (Nešpor and Sevruk, 1999). The correlation as well as the sampling efficiency increased when a new rim was introduced on the sampler having a wind shield consisting of a 45° funnel (Figure 5). Results from northern Sweden are shown in Figure 12 and from southern in Figure 13.

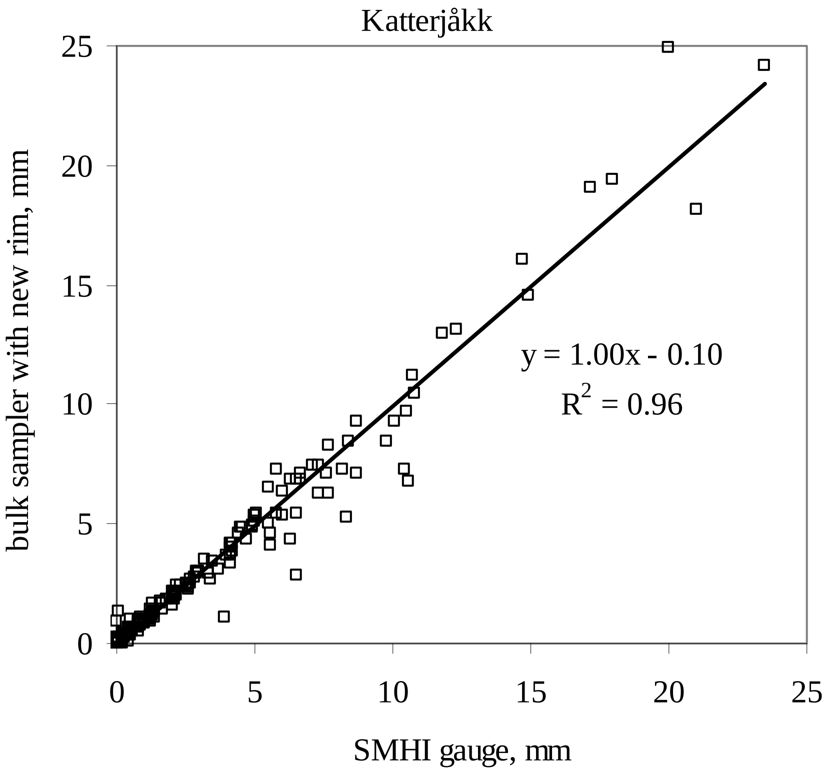

Figure 12. Comparison of daily measurements of precipitation using the bulk sampler with a rim and a 45° funnel as wind shield and the SMHI gauge. Measurements from October 2006 to June 2007 in Northern Sweden.

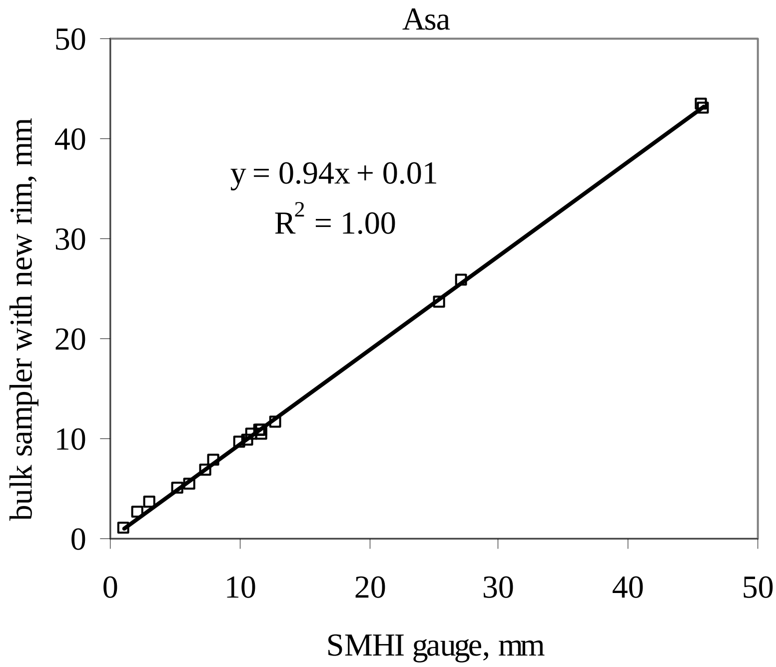

Figure 13. Comparison of short term (one day to three weeks) measurements of precipitation using the bulk sampler with a rim and a wind shield (60° funnel) and the SMHI gauge. Measurements from November 2006 to February 2007 in Southern Sweden.

As can be seen from Figures 12 and 13, the sampling efficiencies on a daily basis are now comparable with the SMHI gauge.

4.2 Chemistry of precipitation

Unfortunately the good effect of the new rim was not known when these measurements were made. This rim was therefore not used. The precipitation volumes measured with the new wind shielded bulk collector was therefore too low.

At two sampling sites, the chemistry was compared in samples collected with the wind shielded bulk collector and the standard collector (Figures 14 and 15). The standard collector was a snow sack during winter (Figure 14) or a cylindrical sampler during other seasons (Figure 15). Sampling was performed in duplicate with these samplers, but only one was analysed for all ions. The wind shields had an angle of 60° at both sites. At Jädraås the precipitation volume measured with the wind shielded collector was only 80 % of the average of the standard collector (one outlier was removed). At Aneboda it was also 80% (also with one outlier removed). The concentrations obtained with the wind shielded bulk collector (without the new rim) was during some periods much lower than the standard sampler at Jädraås, see Figure 16. The concentrations at Aneboda were more similar in the two samplers, see Figure 17.

Figure 14. The regular precipitation sampler at Jädraås during winter time.

Figure 15. The regular precipitation sampler at Aneboda during summer time.

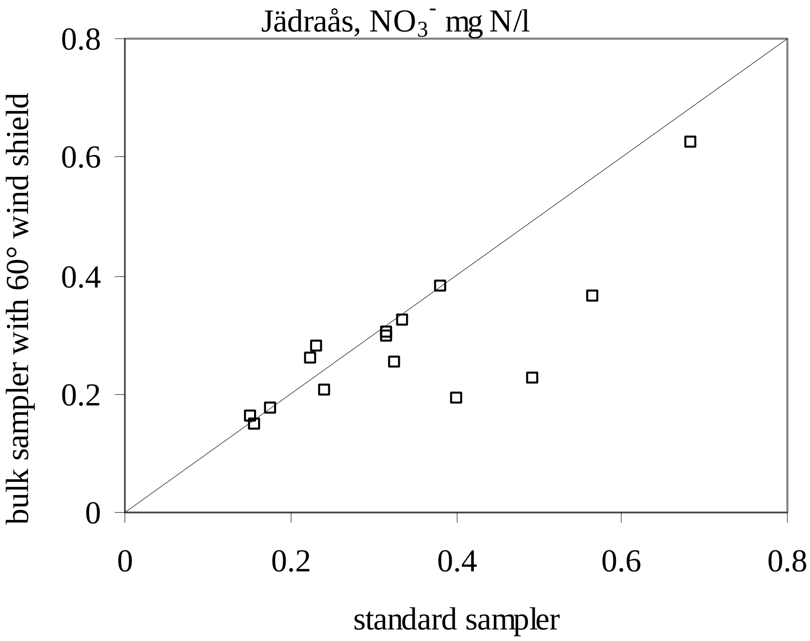

Figure 16. Nitrate concentrations observed in precipitation collected with the wind shielded sampler as a function of the standard sampler at Jädraås.

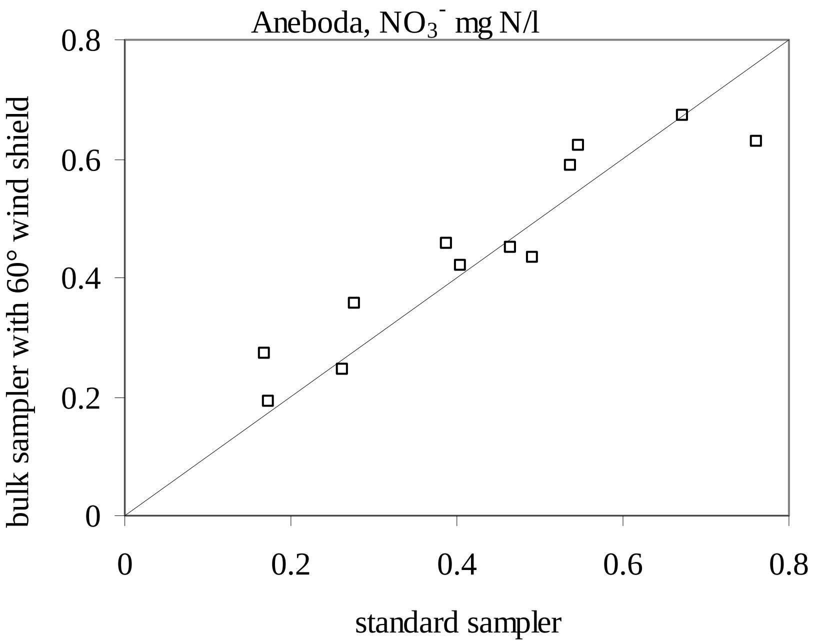

Figure 17. Nitrate concentrations observed in precipitation collected with the wind shielded sampler as a function of the standard sampler at Aneboda.

The average concentrations for all analysed ions are presented in Table 1.

Table 1. Concentration of different ions in precipitation obtained with the standard sampler (ss) at the site as well as the wind shielded bulk sampler (ws) in Figure 4.

		H^+	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+
	mm	mg/l	mg/l	mgN/l	mgS/l	mgN/l	mg/l	mg/l	mg/l	mg/l
Aneboda ss	71	0.016	1.13	0.46	0.45	0.85	0.18	0.12	0.74	0.35
Aneboda ws	57	0.013	1.22	0.51	0.64	1.38	0.13	0.10	0.87	0.80
(ss-ws)/ws	25%	27%	-7%	-9%	-29%	-38%	43%	24%	-15%	-56%
Jädraås	50	0.018	0.38	0.33	0.34	0.61	0.14	0.05	0.27	0.27
Jädraås ws	40	0.017	0.36	0.28	0.28	0.33	0.11	0.05	0.25	0.31
(ss-ws)/ws	25%	5%	6%	19%	23%	86%	33%	-2%	10%	-12%

5 Discussion

The distinguished effect of the rim in the form of a ring placed on the top of the tube was unexpected. The results with the rim on the new bulk collector compare favourably with the results of the SMHI gauge, at least as tested here on a daily basis. When the snow is sticky at the same time as the wind speed is low, snow can pile up on the wind shield and on the rim. This can affect the collection efficiency. This happens both on the SMHI gauge and on the gauge made of plastic material as shown in Figures 18 and 19. The SMHI gauge used by the meteorologists is emptied and rinsed from snow once a day, but the bulk collector used in the chemical networks is only visited and emptied once a month. There is generally no electricity at the sampling sites so occasional electric heating of the wind shield or rim can not be used to remove the snow. Experiments with different soft material around the wind shield such as cloth or soft plastic film did not solve the problem of piling snow. A wind-driven scraper may be possible to develop but this is beyond the scope of this study.

At Katterjåkk it is possible to perform monthly sampling with the new bulk collector and compare the precipitation amount with an integrated value from the SMHI gauge.

Figure 18. Snow on the wind shield of the SMHI gauge. On the right picture the bulk collectors having 60° and 45° funnels as wind shields can be seen in the background.

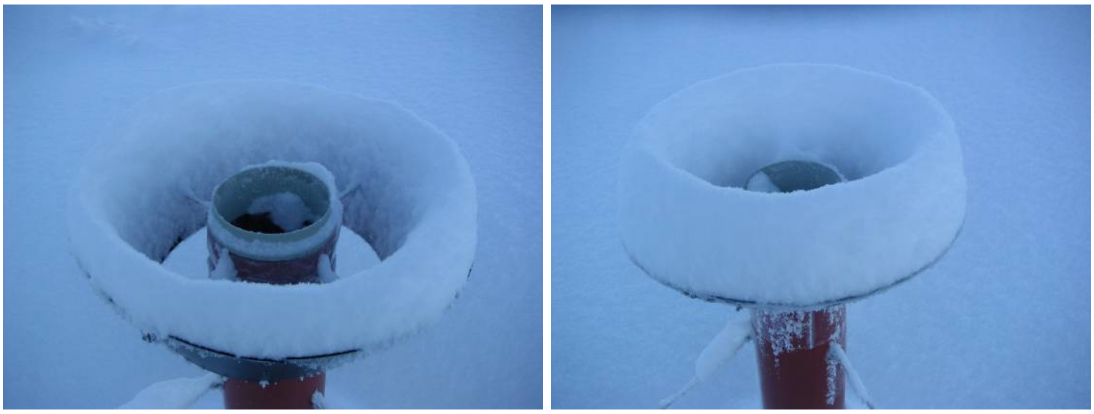

Figure 19. Snow on the wind shield of the bulk collectors.

6 Acknowledgements

I want to thank Olle Westling who initiated this project as well as the Swedish EPA and EU who has financed it. I also want to thank David Segersson and Christer Persson at SMHI for fruitful discussions. Special thanks to Theres Janacek and Annika Carlsson at Katterjåkk, Elisabeth Henningsson at Jädraås, and Fredrik Zetterqvist at Aneboda for performing the sampling.

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