MiniCASCC – A Battery Driven Fog Collector for Ecological Applications

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ABSTRACT

We developed a small version of the Caltech active strand cloud water collector (CASCC) for ecological applications. The device is battery powered and thus allows operation at locations where mains power is not available. The collector is designed for sampling periods of up to one week, depending on fog frequency. The collecting efficiency is determined by air speed, number of strands, strand spacing and dimensions. The only free parameter for controlling the collection rate is the number of rows, since air speed must be high enough and fan power is a limiting factor. From such theoretical assumptions we expected collection rates of around 6 ml h⁻¹ (one sample in 8 h of fog with an assumed liquid water content of 50 mg m⁻³), which we could confirm with first field tests. Our new device is equipped with standard sensors for air temperature, relative humidity, and wind, as well as with a low-cost visibility sensor. These variables are needed to estimate deposition rates. The visibility sensor we use was compared against a reference instrument and showed good data quality under ideal conditions. However, we found that in mountain areas when clouds are thin the installation of the visibility sensor is a key issue. After having resolved such open issues, our new fog collector can be constructed and operated at relatively low costs at research sites that do not provide mains power.

1. INTRODUCTION

Collecting sufficient amounts of fogwater for the analysis of solutes and stable isotopes is an important problem with fog research at remote sites without mains electricity. Passive fog gauges solve the problem with electricity, but they do not distinguish between true fog, drizzle, horizontal and conventional precipitation. Thus, for scientific studies where the chemistry of fogwater is compared with that of rain water, the Caltech active strand cloud water collector [Daube et al. 1987] has been the preferred sampling instrument in many studies (e.g., Thalmann et al. 2002; Wrzesinsky and Klemm 2000; Collett Jr. et al. 2002), but this sampler type has a relatively high power consumption and the site must provide mains power.

Large collectors of the CASCC type are described e.g. in Fuzzi et al. [1997]. Moore et al. [2002] developed a CASCC which collects fogwater by different size fractions. These collectors provide a sophisticated sampling, but the construction and operation of these large collectors generate high costs. For ecological applications it would be ideal to have a fogwater collector which can be built at relatively low costs and has an operation autonomy of about one week, depending on fog frequency. In this work we present a new variant of the CASCC which is independent from mains power and thus allows operation at more remote and/or exposed sites.

2. METHODS

2.1 Efficiency Considerations

This section is mainly based on the work by Demoz et al. [1996], where a more comprehensive overview on the Caltech active strand cloudwater collectors (CASCC) can be found. Demoz et al. [1996] showed that the collection efficiency of these types of collectors varies with drop size. The collection efficiency of a single strand can be expressed in terms of the dimensionless Stokes number, which is defined as

\[ St = \frac{\rho d_p^2 U \cos \theta}{9 \mu d_c} \]

where \( \rho \) is the droplet density, \( d_p \) the droplet diameter, \( U \) the air speed, \( \theta \) the inclination angle of the bank of strands from vertical, \( \mu \) the air viscosity and \( d_c \) the
Efficiency is given in terms of the Stokes number as to calculate the efficiency of the strands. The equation used the equation by Davidson and Friedlander [1978] to calculate the efficiency of the CASCC2 as indicated in Demoz et al. [1996].

\[ \eta_s = \frac{St^3}{St^3 + 0.753St^2 + 2.796St - 0.202} \]  

They provide the theoretical collection efficiency for each collector stage (as total efficiency of the bank of strands) then as

\[ \eta = 1 - (1 - \eta_s \times fr)^r \]  

with \( fr \) as fractional coverage per row (cross-sectional area of the strands in a row divided by the total cross sectional area of the collector), and \( r \) as number of rows.

Figure 1 shows the collection efficiency as a function of air speed (\( U \)), number of rows (\( r \)), strand diameter (\( d_c \)), strand spacing (\( d_s \)), compared to the CASCC2 as shown in Demoz et al. [1996].

The overall calculated efficiency depends strongly on the number of rows, diameter of the strands and the strand spacing. Whereas one row reaches an efficiency of less than 20%, six rows (as used in the CASCC2) are predicted to collect with an efficiency over 70%. Similar results were found for the strand diameter and the strand spacing. An important characteristic of this set of curves is a pronounced cutoff around 5 \( \mu m \), which means that these factors control the overall efficiency of the collector and do not introduce a size-fractionation of the droplet spectrum. The fourth considered factor, the air speed at the strands, shows a different behaviour compared to the previous three factors. For low air speeds (\( U < 2 \text{ m s}^{-1} \)) a substantial size-fractionation is predicted, which could have negative effects on solute and stable isotope concentrations in the samples in cases when they depend on drop size. For large droplets (\( d_p \approx 60 \mu m \)) the efficiency amounts to roughly 70% for all air speeds in the range 0.5 to 8.0 \text{ m s}^{-1}, whereas the sampling efficiency at an air speed of 0.5 \text{ m s}^{-1} is below 35% for droplet sizes below 15 \( \mu m \) and below 5% for droplet sizes of 10 \( \mu m \) and smaller. Moreover, at this air speed no clear cutoff size could be found. At air speeds of 4 \text{ m s}^{-1} and higher, no remarkable decrease of the efficiency occurs (efficiency greater than 70%) above a droplet diameter of 20 \( \mu m \). The calculated efficiency of 35% is found for an air speed of 4 \text{ m s}^{-1} to be at a droplet size of 5 \( \mu m \) and at roughly 8 \( \mu m \) for an air speed of 2 \text{ m s}^{-1}.

This result shows, that the air speed at the strands is the most important factor which controls the size-fractionation of the droplet spectrum.
fractionation of collected droplets. This implies that the remaining factors can be selected from a wide range without negative side effects. The air speed however needs to reach a sufficiently high value to avoid a considerable size-fractionation effect. A reasonable value might therefore be above 4 \(\text{m s}^{-1}\).

2.2 Dimensions of the Device

The device is restricted by two requirements, namely that it has to be powered by a battery and that is has to collect enough fogwater from a single event (minimum 30 ml). Bützberger [2002] found for the Lägeren site from mid of September 2001 to mid of April 2002 typical liquid water contents of fog between 25 and 200 mg m\(^{-3}\) for fog under advective influence, i.e. that type of fog which we expect in most cases during summer in Switzerland. Wrzesinsky and Klemm [2000] used a CASCC type fog collector in their study with a flow rate of 1150 m\(^3\)h\(^{-1}\). They reported fogwater collection rates between 6.6 and 432 ml h\(^{-1}\), with a mean of 90 ml h\(^{-1}\).

For estimating the collection rates, we chose a conservative LWC value of 50 mg m\(^{-3}\). At least 30 ml of fogwater are needed for ion chromatography, isotope samples, pH and conductivity measurements. With 5 h of fog during one event and a collection efficiency of 0.8 a ventilator with an airflow \(> 250 \text{ m}^3\text{h}^{-1}\) is needed. Consequently, the airspeed would amount to 6.9 m \(\text{s}^{-1}\) when using a \(10 \times 10 \text{ cm}\) inlet.

2.3 Instrumentation

Visibility at the Lägeren research site was measured from 03 June 2005 to 25 October 2005 with a MiniOFS Mk II sensor (Sten Löfving, Optical Sensors, Göteborg, Sweden) and was compared with a Vaisala PWD-11 (Vaisala Oyj, Helsinki, Finland). The MiniOFS was sampled every 10 s, whereas the PWD-11 automatically produced 1 min means. Data averaging showed reasonable agreement between the PWD-11 and the MiniOFS if averaged over 10 min or more (Figure 2). Because the MiniOFS overestimates visibilities below 1000 m, a solution had to be found for minimizing the number of cases where the occurrence of dense fog (here defined with a visibility below 500 m) was not indicated correctly. We parameterized a linear model with a cutoff value of 1075 m: \(V_{\text{PWD-11}} = (0.624 \pm 0.006) \cdot V_{\text{MiniOFS}} - (44.9 \pm 3.9)\). Dense fog occurred during 8.9% of the measurement period. After the transformation, the MiniOFS matched 95.8% of the time with dense fog correctly.

Air temperature and relative humidity were measured using Rotronic Hygroclip S3 and Rotronic MP-103A sensors (Rotronic AG, Switzerland), wind speed and wind direction were measured with a Young W-Monitor (R. M. Young Company, Michigan, USA). Data storage and collector control were done with Campbell CR510 and CR10X dataloggers (Campbell Scientific Ltd, UK).

2.4 Collector Construction and Operation

The MiniCASCC can be divided into three units, namely the collector itself, the boom for mounting the meteorological sensors and the panel box (Figure 3). The collector has a \(10 \times 10 \text{ cm}\) profile and a total length of 90 cm. Air is drawn by a fan with a performance of 280 m\(^3\)h\(^{-1}\) through six rows of 0.5 mm diameter teflon strands. The resulting air speed equals to 7.8 m \(\text{s}^{-1}\).

We equipped the fog collectors with two 12 V batteries with a total 72 Ah capacity. With a power consumption of roughly 1.5 A, the device can collect fog during 50 h. The standby power consumption is around 300 mA. The sample bucket is closed with a valve to minimize evaporation of the fogwater during non-fog conditions.

The sampler starts collecting fogwater if the visibility drops below 300 m (or to another predefined value) and the relative humidity is above 90%. At air temperatures below 2 °C, collection stops to prevent fan damage from riming.
3. FIELD TESTS

Since 7 November 2005 one MiniCASCC is operated at the Lägeren research tower at 30 m above ground (690 m a.s.l.). During the operation period up to April 2007 only very few fog events at conditions where the collector can run occurred, and thus only few fogwater samples could be collected so far. At this site, the MiniCASCC was connected to mains power using a battery charger for simpler maintenance.

From 22 June to 6 October 2006 two MiniCASCC were operated on the slope of the Niesen mountain in the Swiss Alps. One device was installed on an avalanche protection at 1680 m a.s.l. in a wood glade on a south-east facing slope, the second device was installed at 2330 m a.s.l. on a south facing slope just below the mountain summit (alpine grassland and rock).

From both devices it was in most cases possible to gain weekly sample sizes > 30 ml. However, at both sites in several cases the visibility sensor did not yet work as expected and showed a clear diurnal cycle with low visibilities during nighttime, although spot checks of the meteorological visibility showed sometimes a massive disagreement between sensor measured visibility and observed meteorological visibility. The first program version started collecting fog below a visibility of 500 m, later the threshold was set to 300 m to minimize erroneous collector runtime.

4. CONCLUSIONS

After a season with first field tests we can conclude that the MiniCASCC is suitable for the intended application. The collecting efficiency is in most cases high enough to provide sample amounts of \( \approx 40 - 50 \) ml. The weakest part of the MiniCASCC is however the fog detection itself. The herein used low-cost sensors are very sensitive to light oversaturation and reflection. Minimizing errors due to sensor malfunction is still an open issue, to be resolved during our research project duration.

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References


