Investigation of high resolved snow height measurements at Neumayer Station, Antarctica, 2013

Internship from 10.3.2014 till 4.4.2014 at
Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Bremerhaven

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Bremerhaven, 04.04.14

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1 Introduction

Antarctica is a continent with a strong character. High wind speeds, very low temperatures and heavy snow storms. All these parameters are well known due to observations and measurements, but precipitation measurements are still rare because the number of manned stations is very limited in Antarctica.
In such a polar snow region many wind driven phenomena associated with snow fall exist like snow drift, blowing snow or sastrugi. Snow drift is defined as a layer of snow formed by the wind during a snowstorm. The horizontal visibility is below eye level. Blowing snow is specified as an ensemble of snow particles raised by the wind to moderate or great heights above the ground; the horizontal visibility at eye level is generally very poor (National Snow And Ice Data Center (NSIDC), 2013). Sastrugi are complex, fragile and sharp ridges or grooves formed on land or over sea ice. They arise from wind erosion, saltation of snow particles and deposition. To get more details about these procedures better instruments than the conventional stake array are required.
This small report introduces a new measuring technique and therefore offers a never used dataset of snow heights. It is very common to measure the snow height with a stake array in Antarctica (f.e. Neumayer Station, Kohnen Station) but not with a laser beam. Thus the idea was born to install a new instrument in December 2012 at Neumayer Station.

2 Measuring technique

All data were measured between the 1st of January and 31st of December in 2013 with a snow height sensor SHM 30 (SHM) from Jenoptik at the Neumayer Station in Antarctica (coordinates: S70°41.359'W8°16.258'). The SHM was installed between the 30th and 31st of December 2012 on a steel mast at 6.8 m above snow surface (Fig. 1), which is fixed on a wood palette buried 1.50 m under the snow. With this installation the snow height was set to 0.000 m. The emitted laser beam points towards the west on the snow surface. The tilt angle between the mast and the SHM is 24.62 ° (since the rebuilding on 27.01.13, before 30 °). To avoid snow cover on the instrument the SHM is heated inside.

The measuring principle is based on an electronic distance measurement and is called phase shift method. For this a laser beam with a sinusoidally modulated amplitude is sent to a reflector. The phase shift is monitored by a photo diode and the phase of the amplitude modulation is compared with the phase of the emitted wave. Through this phase shift a distance can be obtained by means of Equation 1:

$$2L = n * \lambda + \triangle\lambda \tag{1}$$

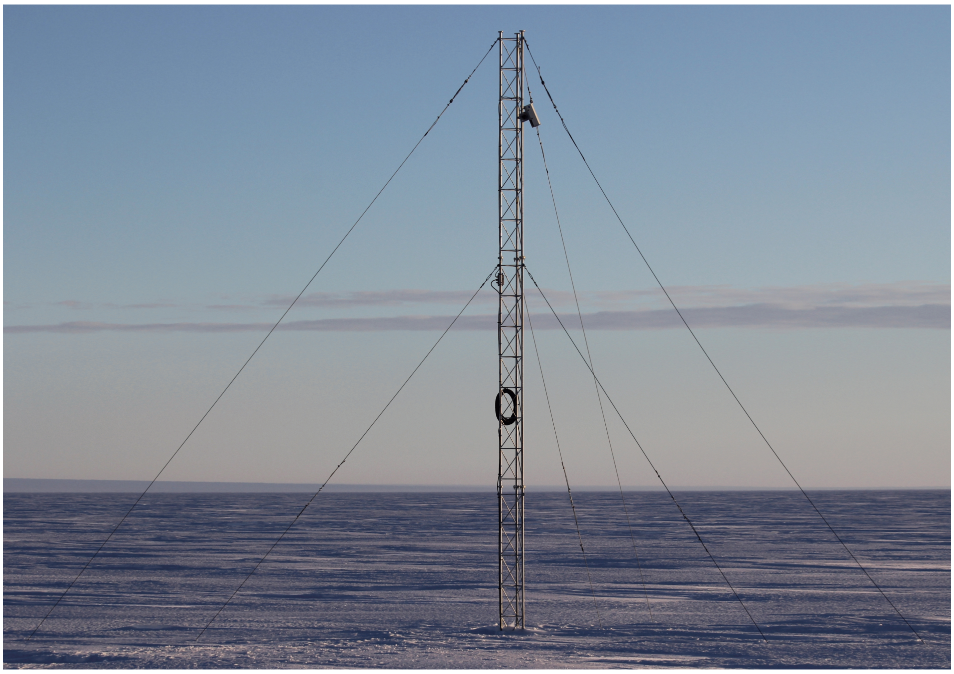

Figure 1: The SHM installation at Neumayer Station (König-Langlo, 2013).

where n is the number of wavelengths, λ the wavelength and $\triangle\lambda$ the rest, determined by the phase shift of the sent and reflected wave.
From the distance measurements the snow height is determined. Every 45 s the SHM produces the snow height (m) for 6 s and records the collected data (also time, error, signal and inside temperature of the instrument) in a raw data file, which is used for analysing (Eq. 2). The spatial resolution of the laser beam diameter is around 7 mm with a laser beam length of 7.5 m.

$$DD.MM.YY\ HH:MM:SS\ > eee.eee\ sss.sss\ TTT\ EE\ P < \tag{2}$$

e is the snow height in m, s the signal strength, T the temperature of the instrument, E the error code and P the check byte. For further information and details about the SHM 30 and its measure parameters read the manual on:
$www.jenoptik.com/en\_40633\_shm\_30$. Some technical specifications and accuracy of the instrument are given in Table 1.

3 Data

To analyse the time series from 2013 the parameters (snow level, error, signal) were processed with MATLAB. At first the data had to be validated to ensure

Table 1: Technical specifications and accuracy of the SHM (from the manual of the SHM 30).

temperature range	-40 °C ... +50 °C
laser	laser diode 650 nm; red light
laser classification	laser class 2
wavelength	visible, 650 nm
laser power	< 1 mW
laser divergence	0.6 mrad
beam diameter	< 11 mm in 10 m distance
snow depth	0.1 ... 10 m
measuring accuracy snow (95 % scattering)	< +- 5 mm
time for single measurements	6 s

work with a cleared dataset. For this, big peaks above 2 m and below -1 m, due to snowdrift, were deleted in the snow level data. Additionally some small single unrealistic snow height changes were deleted. When the SHM revealed an error, because of internal instrument disturbances, the data points were deleted as well. 8.11 % of the snow level dataset were influenced by the error report of the instrument.
The data from Raffel and König-Langlo (2014) are archived persistently in the Data Publisher for Earth & Environmental Science (PANGAEA).

3.1 Annual accumulation

To get an overview of the development of the snow level Figure 2 shows the annual trend of 2013. Because of the high sample rate (every 45 s) and the tiny foot print (7 mm) many special micro-scale processes are visible in the plot. In the beginning (Jan.-April) no increasing trend is seen and the snow level stays more or less constant at a height of 10 cm with small variations of a few centimeters. But from April to August a strong raise with a magnitude of 80 cm can be observed. Obviously the main snow accumulation occurs during this time. This is followed by a period of slight continuous ablation of the snow level from August until November. In November a strong snow accumulation event begins and continues for around 15 days. Then a compaction and potential melting starts.
Summarizing it should be noted that the snow level increases to 1.18 m and does not exceed the normal range significantly.

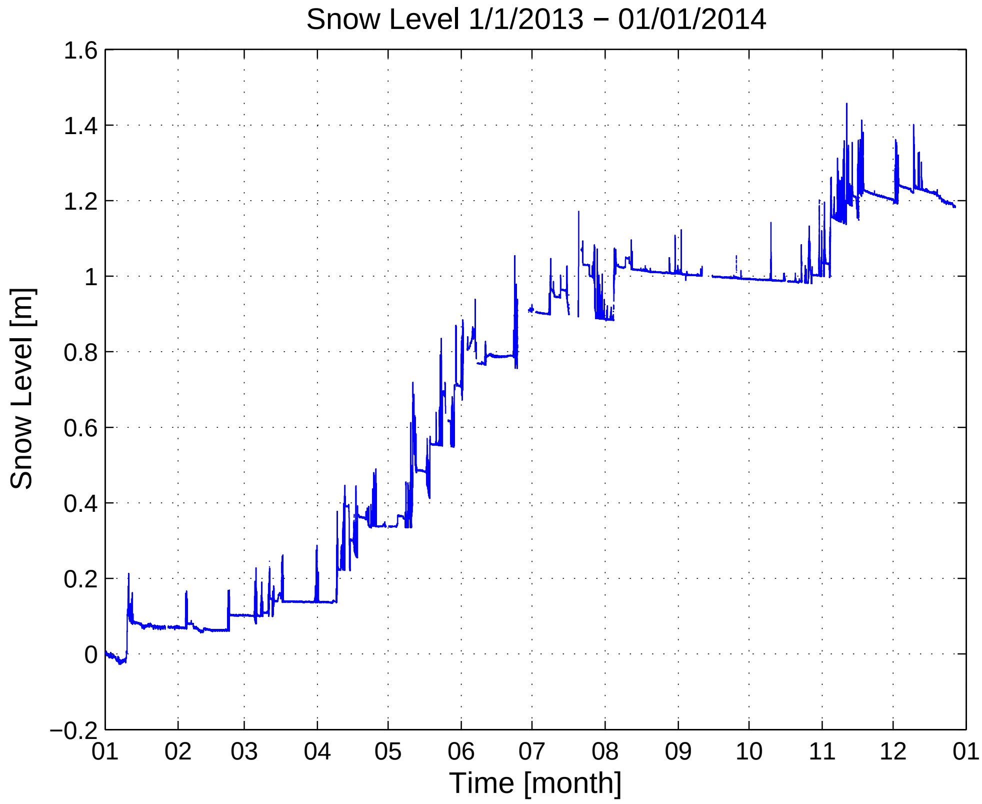

Figure 2: Snow level development in m from 1.1.2013 until 27.12.2013 at Neumayer Station, Antarctica, 2013.

3.2 Comparison with the air chemistry laboratory stake array

Around 193 m away from the SHM installation in southern direction a snow height measuring array with 16 aluminium sticks exists. There was a snow height accumulation of 1.26 m measured for 2013. Due to different places different snow height accumulations appear.

Figure 3 displays, that many more details about single events can be identified with the SHM than with the stake array. Via the point-shaped high resolution measurement more micro-scale processes can be observed and analysed. Because of the low measuring frequency of the stake array (approximately 4 times per month the snow level is read from the sticks) the graph looks like a running mean of the SHM measurement. The stake array fits well on the SHM, but shows also some deviations. As mentioned above, due to different places different local events can occur. The two data sets in these figure have different arbitrary reference points.

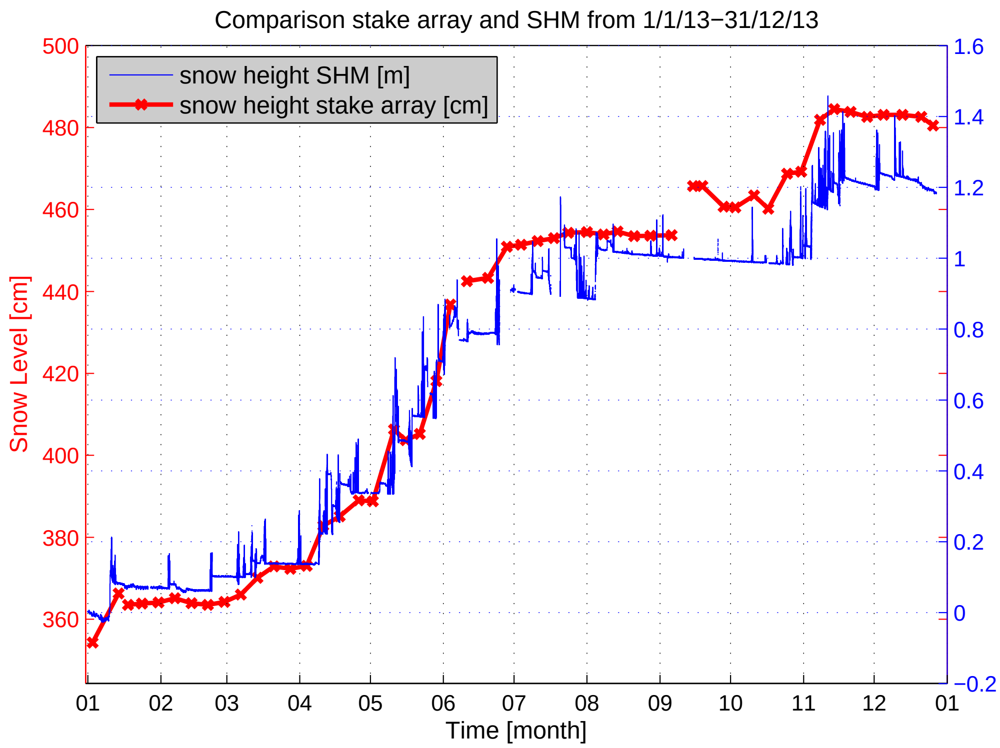

Figure 3: Snow level development according to two different measurement methods from 1.1.2013 until 27.12.2013 at Neumayer Station, Antarctica, 2013. The blue line shows the snow height of the SHM (in m) and the red line indicates the snow height of the stake array (in cm). The small crosses mark the measured values.

3.3 Diurnal variation

A special effect is the diurnal variation in the snow level from the 22nd of January to the 3rd of February 2013 (Fig. 4). The snow level shows a night-day variation of 5 mm which is observed only in austral summer (November-February). The high correlation between the global radiation and the snow level, as well as between the temperature and the snow level (Fig. 5) is evidence for a warming effect. One reason for this effect might be the expansion of the steel mast and the cables influenced by the temperature change. If the temperature difference is 10 K, the length of the steel mast (6.847 m) will change by 0.787 mm (expansion coefficient of steel $11.5 * 10^{-6}$ K^{-1}). But this rough estimate can explain just a small part of the diurnal variation.

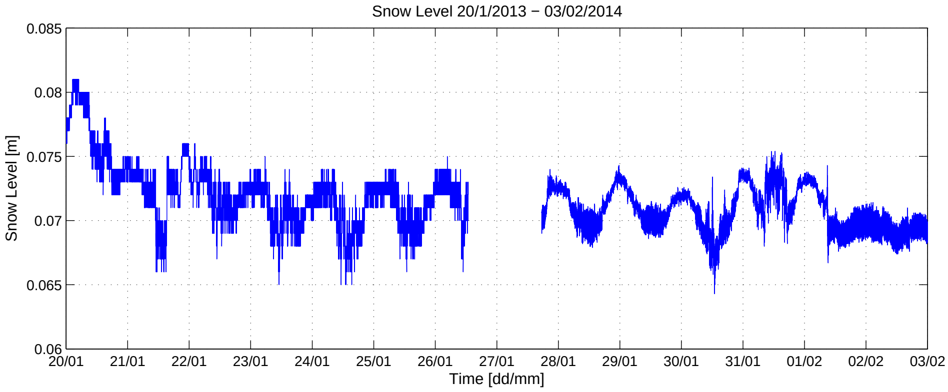

Figure 4: Snow level development in m from 20.1.2013 until 3.2.2013 at Neumayer Station, Antarctica, 2013.

3.4 Stepwise accumulation

The 22nd of February is a good example for a stepwise accumulation of snow. In Figure 6 the big step from 6 cm to around 10 cm snow height is very obvious. The whole accumulation is forced by two weather phenomena, which are known from the visual synoptic observations by Neumayer Station. At first snow precipitates and then heavy snow drift follows. It is interesting to note that snow level and wind speed both drop simultaneously on the 22nd around afternoon. With decreasing wind speed the snow level decreases as well to a height of 10 cm. On the 22nd, from 0 am to 12 pm, the dominant weather phenomenon was a slight continuous fall of snow flakes with drifting snow < 20 cm. Thereafter heavily drifting snow below eye level of 20-150 cm occurred and stayed until 9 pm. Thus, the main reason for this kind of accumulation could be the sudden drop of wind speed accidentally right at the time of high snow level below the sensor.

3.5 Moving sastrugi

Between the 24th and 26th of April moving sastrugi can be seen (Fig. 7). Temporarily the snow height increases, but always drops to its basic level of 34 cm. This effect is caused only by the blowing snow and the high wind speed since no solid precipitation was observed. Compared to the stepwise accumulation where the wind speed drops suddenly, the wind speed in this event decreases slowly and continuously. From measurements and observations König-Langlo and Loose (2007) determined, that snow begins to drift at wind speeds of 6-12 ms^{-1} and if the saltated snow reaches heights above eye level of the observer, the phenomenon is called blowing snow (Fig. 8). In this case, the blowing snow stays the whole period.

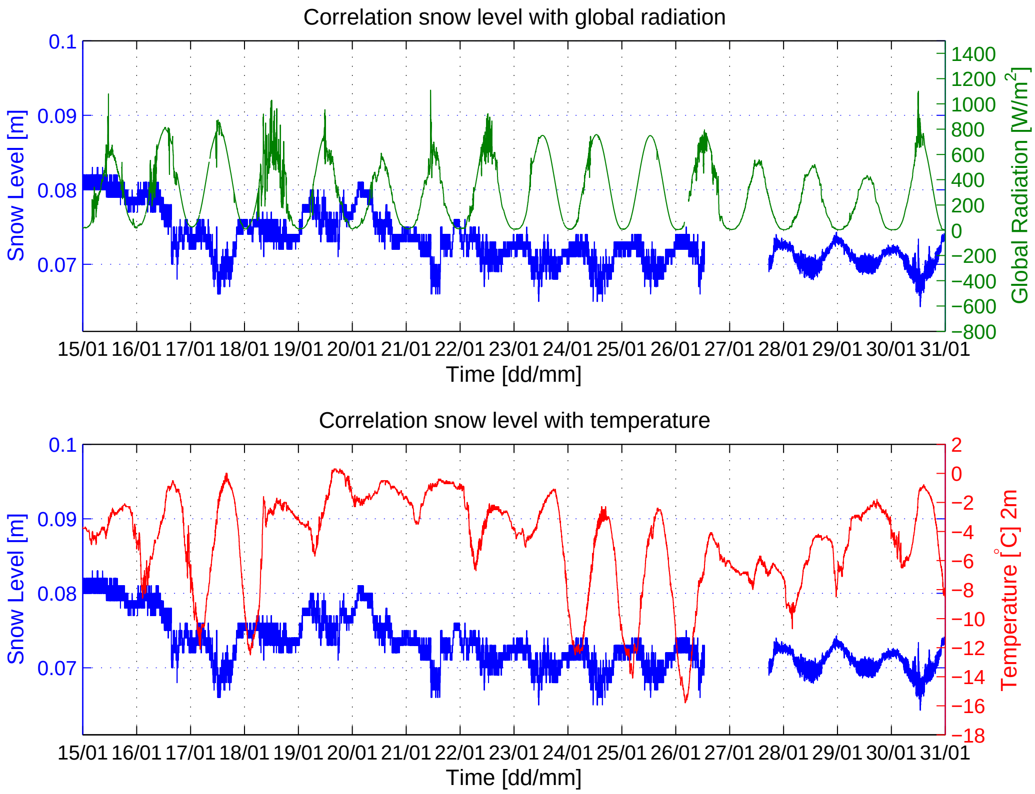

Figure 5: Correlation between the snow level development in m (blue line) and the global radiation in W/m² (green line) as well as temperature in °C (red line) during the event at Neumayer Station, Antarctica, 2013.

Very characteristic for such moving sastrugi are low pressure events, constant temperature and heavy and easterly wind (Birnbaum et al., 2010). In all events recorded in this dataset where moving sastrugi were observed all meteorological parameters had the same properties.

3.6 Compaction

The main processes at the end of the year might be compaction and potential melting. From August to November a long continuous ablation of approximately 7 cm of the snow level can be seen. Afterwards a strong snow accumulation period starts with a duration of approximately 15 days. It seems that in the middle of November melting starts and lasts until January.
The weather during this time has not such a big influence on these processes, since

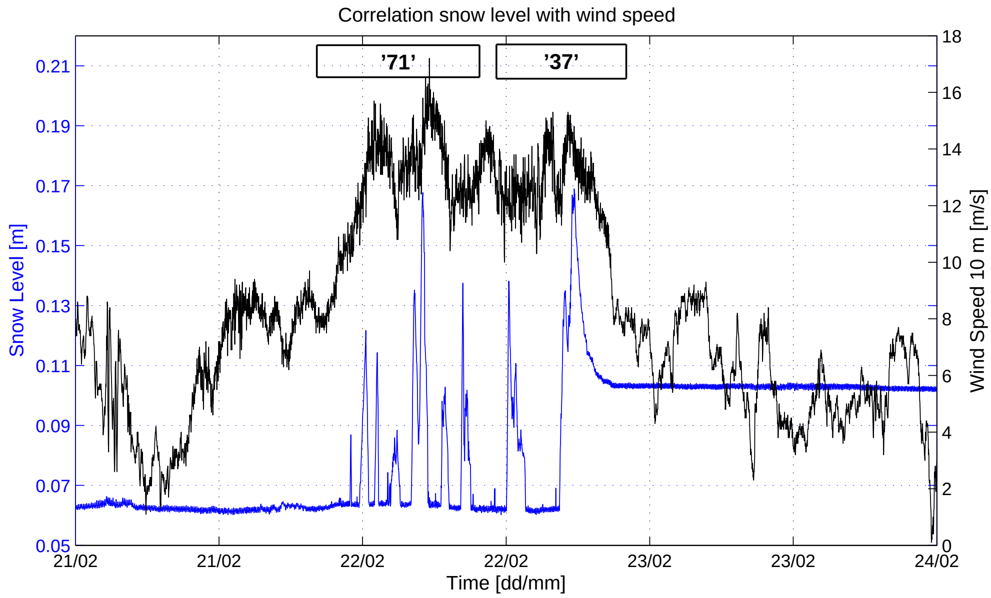

Figure 6: Snow level measurement from 21.2. to 24.2.2013 at Neumayer Station, Antarctica. The black line shows the wind speed at 10 m and the blue line shows the snow level in m. The boxes at the top of the plot mark the present weather phenomenon. '71' means slight fall of snow flakes, continuous, and '37' means drifting snow, below eye level, heavy.

the temperature varies a lot between austral winter and summer months. Also the wind speed reaches very high levels (30 m/s) but also very low levels (1 m/s). Thus there is no correlation between the visual synoptic observations and the compaction process. Hence no significant conclusion can be made at the moment. There were snowfall / snowdrift observations during the compaction process but it did not lead to an ablation of snow.

No precise explanation can be given for the compaction and melting processes yet. But first calculations for the compaction phase (Freitag, 2014) with the Herron-Langway compaction model, with an averaged temperature of -16 °C and an initial snow density of 0.33 g/cm^3, showed a height change by compaction of 4 mm per month. That means, only 1.2 cm of 7 cm are ablated by compaction in these 3 months. In this calculation it is assumed that the density increases in the first 1.2 m by 0.03 g/cm^3.

If there is melting from the middle of November until January another compaction process could be possible. At first a strong accumulation is seen (1.11-17.11), which could lead to a high mass impact on the snow surface and thereby more compaction. Because of the higher temperature during the melting time the compaction model

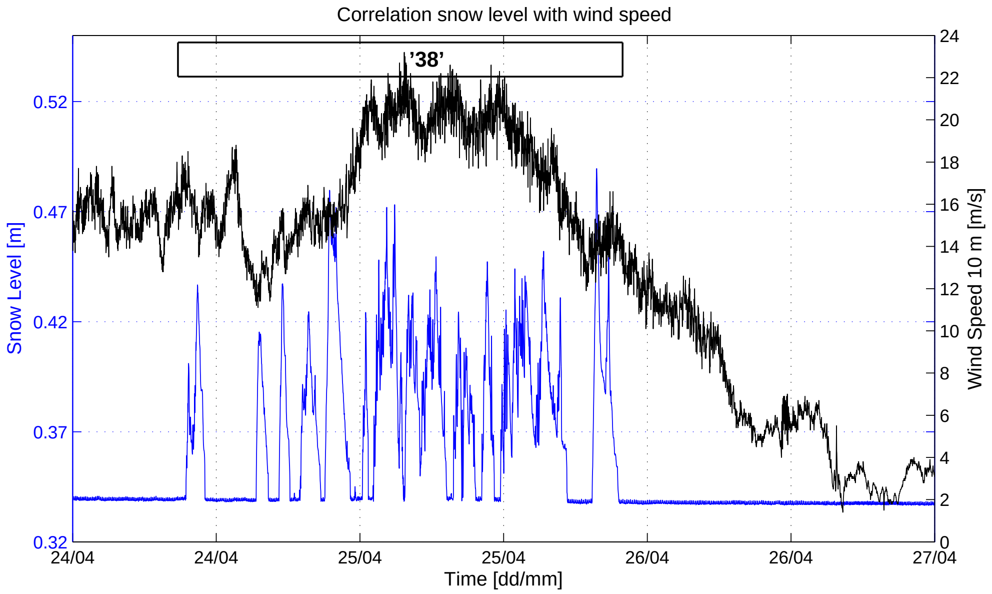

Figure 7: Snow level measurement from 24.4. to 27.4.2013 at Neumayer Station, Antarctica. The black line shows the wind speed at 10 m and the blue line shows the snow level in m. The box at the top of the plot marks the present weather phenomenon. '38' means blowing snow, above eye level, slight or moderate.

ran with an averaged temperature of 0 °C and calculated a snow height change of 3-3.5 cm. But melting water plays an important role, since it reduces the surface height and penetrates the snow and refreezes again which leads to compaction. This melting and refreezing makes the snow denser up to 0.92 g/cm^3. If there were a melting of 10 cm snow, the snow height would sag by 6.4 cm.
Summing up, the entire processes are still unclear and require more intense study and research. But it can be expected that a small part of this long ablation of snow from August to November is caused by compaction. And melting followed by compaction steers the snow level development from November until January.

4 Conclusion

The measurements with the SHM show, that many snow processes can be identified which help to understand the movement of sastrugi, snow dunes and their influence on the accumulation and ablation of snow. More detailed studying of this dataset is needed to understand and explain the processes. Compared with the stake array technique the SHM enlarges the knowledge about snow accumulation enormously.

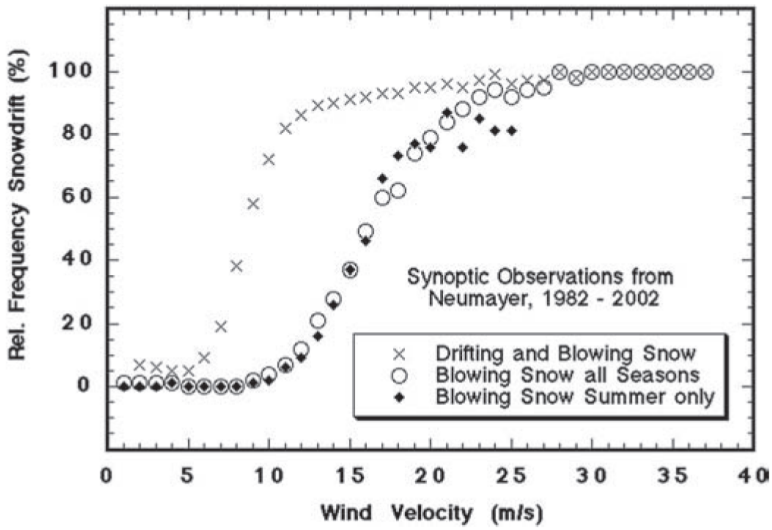

Figure 8: Accumulated frequency distribution of snow-drift observations at Neumayer station versus wind velocity 10 m above the snow surface (König-Langlo and Loose, 2007).

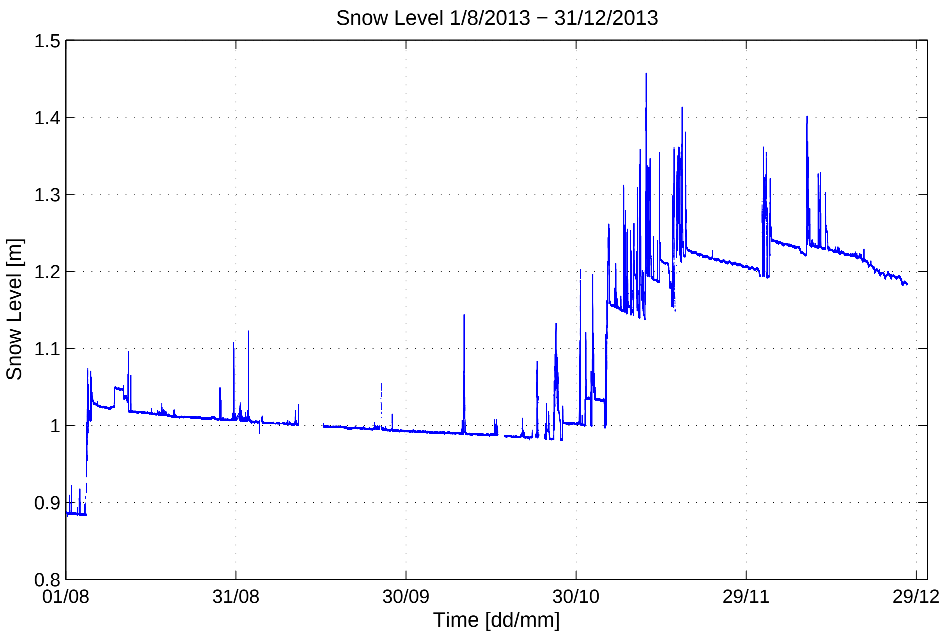

Figure 9: Snow level measurement from 1.8. until 31.12.2013 at Neumayer Station, Antarctica.

For the future it would be useful to install an array of SHMs (or 3D scanner) to investigate the spatial spread of snow events. While sastrugi and stepwise accumulations are more or less understood, compaction, potential melting and diurnal variations need more monitoring. Maybe there are even more processes which are not listed in this report and remain unknown.

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