Supplement of The Cryosphere, 11, 2755–2772, 2017
https://doi.org/10.5194/tc-11-2755-2017-supplement

The Cryosphere Open Access EGU

Supplement of

Blowing snow detection from ground-based ceilometers: application to East Antarctica

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1 Equation of the different metrics used in section 4.1.

Equations come from Allouche et al. (2006),
with a = N BS$_{both}$, b = N BS$_{ceilo}$, c = N BS$_{vis}$, d = N BS$_{none}$ and $n = a + b + c + d$.

$$accuracy = \frac{a+d}{n} \tag{1}$$

$$sensitivity = \frac{a}{a+c} \tag{2}$$

$$specificity = \frac{d}{b+d} \tag{3}$$

$$kappa = \frac{\left(\frac{a+d}{n}\right) - \frac{(a+b)(a+c)+(c+d)(d+b)}{n^2}}{1 - \frac{(a+b)(a+c)+(c+a)(d+b)}{n^2}} \tag{4}$$

$$TSS = sensitivity + specificity - 1 \tag{5}$$

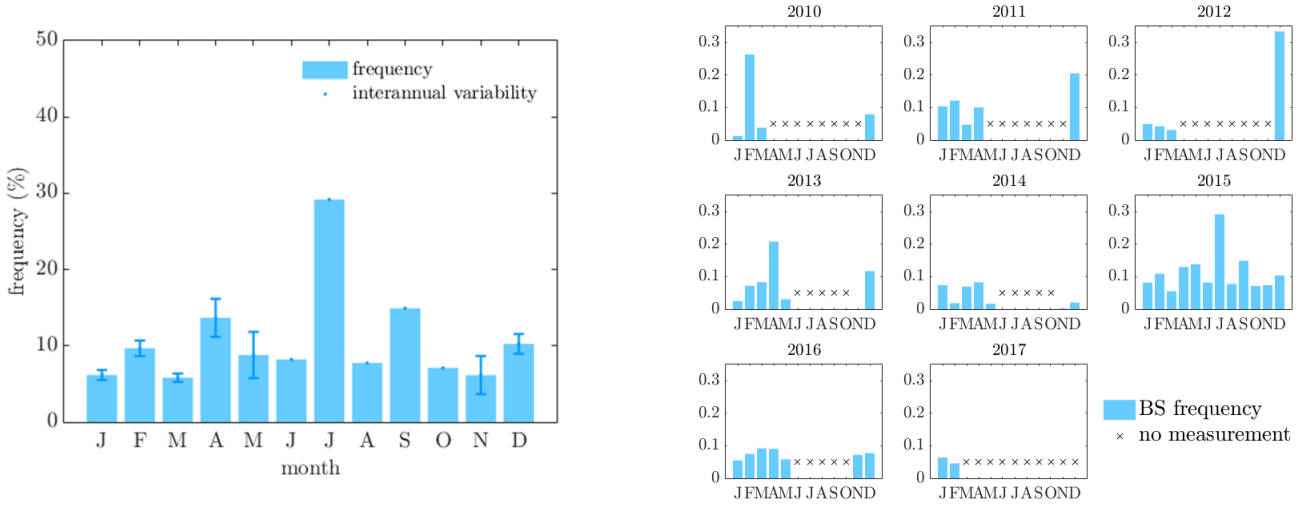

Figure S1. Annual cycle of blowing snow frequency at PE station, for the period 2010-2017. The error bar represents the inter annual variability. Note that the measurements between June and October are present in 2015 only.

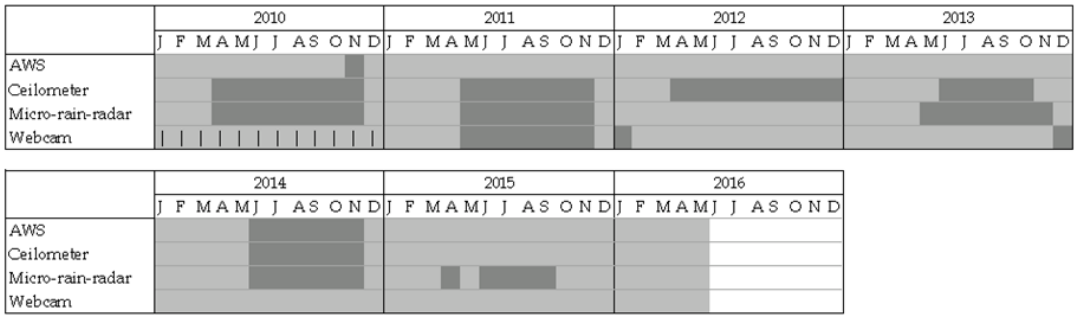

Figure S2. Availability of data for each of the PE instruments mentioned in the manuscript. Dark areas represent missing data, light grey areas represent available data and vertical lines represent a period when the instrument was not set up yet.

Table S1. Detail of the sensors and range used to measure the different meteorological variables by the AWS/IWS at PE station.

Variable measured	sensor	range $\pm$ accuracy
2m temperature	Vaisala HMP35AC	-80 to 56 °C $\pm$ 0,3 °C
2m humidity	Vaisala HMP35AC	0 to 100 % $\pm$ 2%
2m wind direction	Young 05103	0 to 360 °$\pm$ 3 °
2m wind speed	Young 05103	0 to 60 $\mathrm{m \cdot s^{-1}}$ $\pm$ 0,3 $\mathrm{m \cdot s^{-1}}$
2m pressure	Vaisala PTB1011B	600 to 1060 hPa $\pm$ 4 hPa
2m short wave radiation	Kipp CNR1	0 to 2000 $\mathrm{W \cdot m^{-2}}$ $\pm$ 2%
2m long wave radiation	Kipp CNR1	-250 to 250 $\mathrm{W \cdot m^{-2}}$ $\pm$ 15 $\mathrm{W \cdot m^{-2}}$
height of the instrument	SR50	0,5 to 10 m $\pm$ 0,01 m

References

Allouche, O., Tsoar, A. and Kadmon, R.: Assessing the accuracy of species distribution models: prevalence, kappa and the true skills statistics (TSS), Journal of applied Ecology, 43, 1223–1232, 2006.

Table S2. Details of sensors used to measure the different meteorological variables at Neumayer station

variable measured	sensor
2 and 10 m temperature	Thies 2.1265.10.000 PT-100 platinium resistance sensors
2 m dew point temperature	Vaisala HMP233 hygrometers
relative humidity	dew point temperature and temperature
surface air pressure	Digiquartz 215-AW002
wind vector	Thies 4.3323.21.002 cup anemometer and wind vane combined

Table S3. WMO categorization of blowing snow

WMO code	description
0	snow haze
1	Drifting snow, light or moderate, with or without snow falling
2	Drifting snow, heavy, without snow falling
3	Drifting snow, heavy, with snow falling
4	Blowing snow, slight or moderate, without snow falling
5	Blowing snow, heavy, without snow falling
6	Blowing snow, slight or moderate, with snow falling
7	Blowing snow, heavy, with snow falling
8	Drifting and blowing snow, slight or moderate, impossible to determine whether sno is falling or not
9	Drifting and blowing snow, heavy, impossible to determine whether sno is falling or not

Table S4. Detection rate of the different categories of observations. BS_{both} stands for the part of blowing snow detected by both the algorithm and the visual observations, BS_{none} is when both methods agree that there is no blowing snow. BS_{ceilo} and BS_{vis} represent detections rates by the algorithm and the observer only, respectively. All columns are expressed in %. B stands for blowing and D for drifting snow. The total number of measurements is 10584.

	BS_{both}	BS_{none}	BS_{ceilo}	BS_{vis}
B and D snow, with or without precipiation (WMO cat 01 to 09)	22	48	9	21
B and D snow, without precipitation (WMO cat 02, 04 and 05)	9	61	22	8
heavy B snow, without precipitation (WMO cat 05)	3	70	27	0
all B snow, without precipitation (WMO cat 04 and 05)	7	66	23	4
all B snow, with or without precipitation (WMO cat > 03)	17	61	14	8
heavy B snow, with or without precipitation (WMO cat 05, 07 and 09)	10	67	21	2

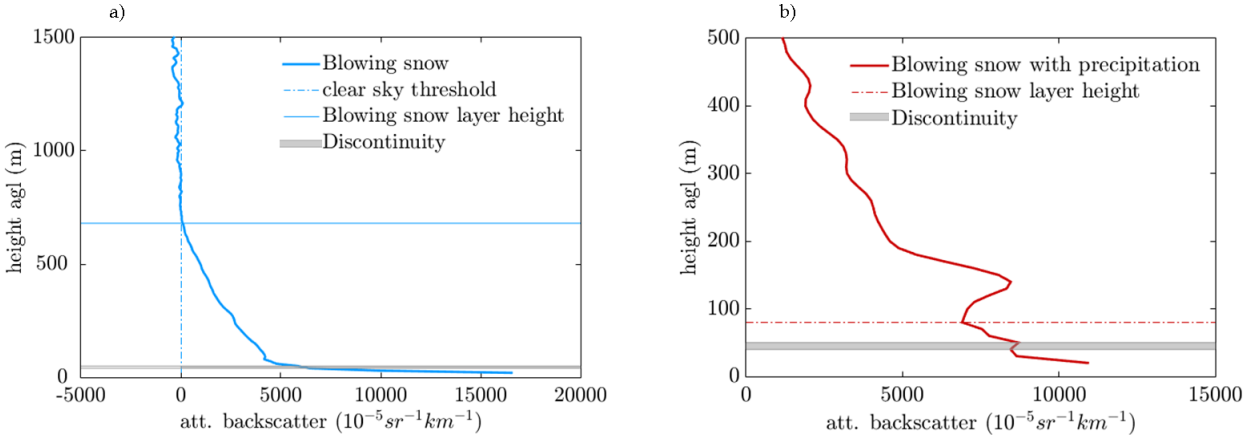

Figure S3. Determination of the height of the layer by the BSD algorithm. (a) in case of a cloudless blowing snow profile, the height of the layer (thin horizontal line) is attained when the backscatter intensity reaches the clear sky threshold (dashed vertical line). (b) in case of precipitation, the height of the blowing snow layer (dashed horizontal line) is reached when the intensity of the backscatter signal re-increases.

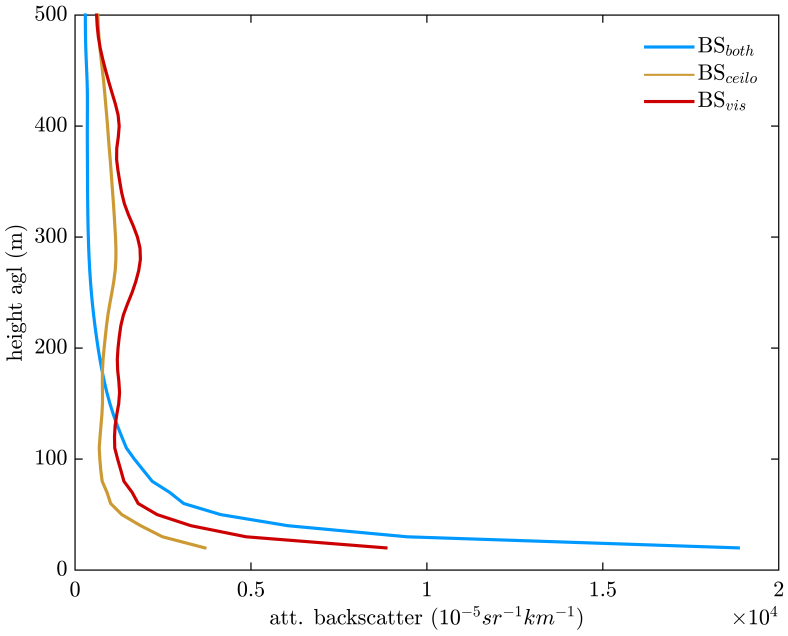

Figure S4. Mean profiles for each of the detection categories at Neumayer: BS_{both} when both methods detect blowing snow, BS_{ceilo} when blowing snow is reported by the BSD algorithm only, and BS_{vis} if blowing snow is detected by the visual observer, but not the BSD algorithm

Table S5. Meteorological conditions at Neumayer during the different events, for years 2011-2015 (mean ± standard deviation).

variable (units)	BS_{both}	BS_{ceilo}	BS_{vis}	BS_{none}
number of occurences	3416	23344	1451	1113
temperature 10m (°C)	-14.8 ± 06	-15.3 ± 08	-10.5 ± 06	-13.1 ± 08
temperature 2m (°C)	-14.8 ± 06	-15.5 ± 08	-10.5 ± 06	-13.2 ± 08
air temperature (°C)	-14.8 ± 06	-15.8 ± 09	-10.5 ± 06	-13.4 ± 08
wind speed 10m ($m \cdot s^{-1}$)	21.6 ± 04	13.3 ± 04	17.3 ± 03	11.4 ± 03
wind speed 2m ($m \cdot s^{-1}$)	18.2 ± 03	11.3 ± 03	14.6 ± 03	9.6 ± 03
wind direction 10m (°to N)	93.7 ± 30	118.0 ± 68	89.8 ± 27	111 ± 64
wind direction 2m (°to N)	93.7 ± 31	118.3 ± 68	89.8 ± 27	111.3 ± 65
relative humidity (%)	85.4 ± 04	81.0± 06	88.3 ± 05	81.9 ± 08
pressure (hPa)	972.3 ± 11	979.3 ± 09	972.6 ± 09	978.8 ± 10
dew/frost point (°C)	-16.4 ± 06	-18.0 ± 09	-11.8 ± 09	-15.5 ± 09
height (m)	340.0 ± 170	112.0 ± 122	-	-

Table S6. Meteorological conditions at Princess Elisabeth during the different events, for years 2010-2017 (mean ± standard deviation)

variable (units)	absence of blowing snow no precipitation	absence of blowing snow with precipitation	blowing snow no precipitation	blowing snow with precipitation	heavy mixed events
number of hours	12 671	10 232	1032	948	1490
wind direction (°to N)	147 ± 66	119 ± 65	120 ± 65	107± 60	87 ± 47
wind speed ($\mathrm{m \cdot s^{-1}}$)	4 ± 4	5 ± 3	7 ± 2	7± 4	10 ± 5
shortwave in ($\mathrm{W \cdot m^{-2}}$)	194 ± 206	173 ± 226	138 ± 253	142± 206	130 ± 187
shortwave out ($\mathrm{W \cdot m^{-2}}$)	155 ± 169	141 ± 182	116 ± 197	119± 172	112 ± 157
longwave in ($\mathrm{W \cdot m^{-2}}$)	154 ± 46	197 ± 37	190 ± 27	218 ± 36	238 ± 36
longwave out ($\mathrm{W \cdot m^{-2}}$)	218 ± 31	236 ± 33	234 ± 36	243 ± 31	251 ± 29
air temperature (°C)	-16 ± 6	-15 ± 6	-16.5 ± 7	-15 ± 6	14 ± 6
specific humidity ($\mathrm{g \cdot kg^{-1}}$)	0.65 ± 0.6	0.9 ± 0.6	0.96± 0.5	1.2 ± 0.7	1.4± 0.7
relative humidity (%)	46 ± 17	63 ± 18	73 ± 16	80 ± 16	94 ± 13
pressure (hPa)	827 ± 9	828 ± 7	827 ± 8	828 ± 9	827 ± 11
surface temperature ($^{\circ}\mathrm{C}$)	-24 ± 8	-19 ± 9	-20 ± 10	-18 ± 8	-15 ± 8
temp. inversion ($^{\circ}\mathrm{C \cdot m^{-1}}$)	8.0 ± 3	4.4 ± 4	3.5 ± 4	2.5 ± 3	1.2 ± 2
temp. gradient ($^{\circ}\mathrm{C \cdot m^{-1}}$)	2.5 ± 1	1.4 ± 1.0	1 ± 1.4	0.8 ± 1	0.5 ± 8
height of blowing snow layer (m)	-	-	78 ± 272	331 ± 643	255 ± 267

Table S7. Meteorological conditions at Neumayer III during the different events, for years 2011-2015 (mean ± standard deviation)

variable (units)	non blowing snow without precipitation	non blowing snow with precipitation	blowing snow without precipitation	blowing snow with precipitation	heavy mixed events
number of hours	9599	11 385	1237	3834	10 351
wind direction 2m (°to N)	191 ± 59	135 ± 68	77 ± 06	81 ± 06	65 ± 06
wind speed 2m ($\mathrm{m \cdot s^{-1}}$)	4 ± 3	5 ± 3	6 ± 4	7 ± 5	13 ± 6
air temperature 2m (°C)	-23 ± 11	-14 ± 9	-21 ± 10	-12 ± 8	-15 ± 7
relative humidity (%)	73 ± 7	79 ± 8	77 ± 6	81 ± 6	85 ± 6
height of blowing snow layer (m)	-	-	139 ± 180	110 ± 159	1303 ± 1581