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Intraseasonal changes in aeolian deposition rates in Ebba Valley, central Spitsbergen

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Abstract: This study investigates seasonal variations in aeolian deposition within the Ebba Valley, focusing on a single summer season 2022. Measurements revealed that aeolian deposition rates were low at the start of the season, ranging from 0.3 to 0.6 g·m^{-2} per day, but peaked at 25.4 g·m^{-2} per day towards the end of the season. The findings suggest that late summer conditions, with stronger winds and higher precipitation, including lower river water levels and the availability of fresh fluvioglacial material, may enhance aeolian deposition. Understanding these dynamics is crucial for modelling aeolian processes in the context of ongoing climate change.

Keywords: aeolian deposition, aeolian trap, periglacial conditions, Svalbard, Arctic

Introduction

Subsequent research seasons in the polar areas are characterized by an increasing intensity of above-average processes and phenomena, which are related to the observed climate change (Koenigk et al. 2020). However, in addition to tracking long-term trends, it is extremely important, to further investigate the nature and variability of processes and phenomena in the environment also in shorter periods like within a single season.

Arctic ecosystems are still not yet well recognized, both quantitatively and qualitatively, and all new data constitutes an important addition to the existing knowledge and models (Beylich et al. 2016). Despite the existence of several fundamental works devoted to the subject of aeolian processes (see McKenna Neuman 1993, Seppälä 2004, Brookfield 2011, Bullard 2012, and Bateman 2013) usually most of the research was only realised on a small number of test sites for the limited time in the past (Maher 2011).

In central Spitsbergen, a comprehensive geological and geographical study of the Ebba Valley area (see Fig. 1) was conducted for over 30 years, but the aeolian issue was raised extremely rarely for this particular region. Taking into account the current state of knowledge and specific climatic conditions, this valley was chosen as the test site for the measurements carried out and presented in the current study. It should be mentioned that in the Ebba Valley measurements of the efficiency of transport and accumulation of aeolian material were conducted during the summer of 2002 (Paluszkiewicz 2003). It was shown that deflation and accumulation mainly pertain to the silt fraction. The largest aeolian transport efficiency was observed when the wind reached velocities exceeding 5–6 m·s^{-1}. The most important influence on the intensity of aeolian processes was generated by air and soil humidity, terrain morphology, and vegetation cover. Due to the lack of constant and strong winds in the summer of 2002, the efficiency of transport and aeolian accumulation was relatively small. Studies of aeolian processes in the Ebba Valley were also conducted in the summer of 2005. However, this research was limited to the identification of the accumulation and erosion of landforms of aeolian origin (Górska-Zabielska 2007). Moreover, the aeolian deposition component was estimated and included as an important factor of soil formation in the Ebba Valley (van der Meij et al. 2016). The influence of wind activity on vegetation cover was also analysed by Borysiak et al. (2020). Kavan et al. (2020) estimated the total sediment (dust) concentration in snow samples for 2.66–24.56 g·m^{-2} per snow season in the area of Petunia Bay. Aeolian deposition for summer seasons 2012–2018 was measured in Ebba Valley by Rymer et al. (2022) and estimated for 2.1 to 12.3 g·m^{-2} per day.

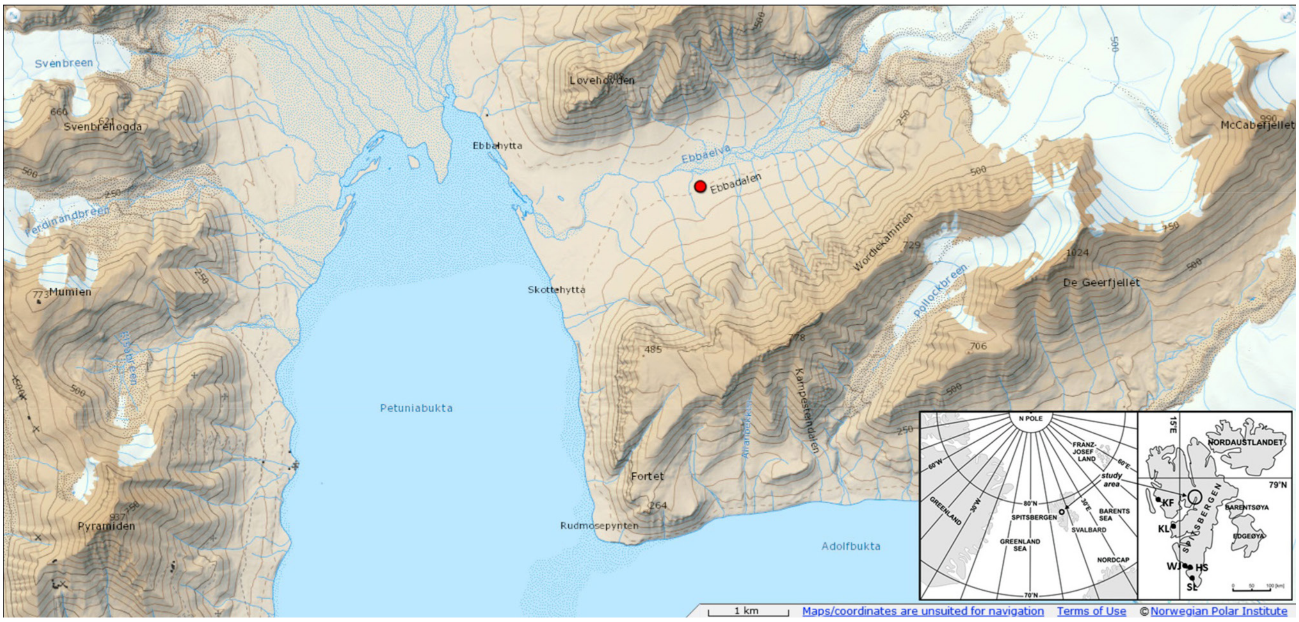

Fig. 1. Map of the study area with aeolian deposition test site (red dot) location within the Ebba Valley. Inner map shows the location of the study area (black arrows and circle) in the central Spitsbergen, High Arctic. Map source: Norwegian Polar Institute

The main goal of the study was to quantify aeolian deposition rates in periglacial conditions of the postglacial valley over a seasonal scale (across one summer season), and to investigate possible relationships between aeolian deposition and meteorological condition changes over the summer season, i.e. in July and August.

Study area

Ebbadalen (eng. Ebba Valley) is located in the central part of Spitsbergen, the largest island of the Svalbard Archipelago (Fig. 1). This postglacial valley is surrounded by steep mountain ranges, with clearly marked glacial features (Rachlewicz 2009, Rymer et al. 2022). *Ebbadalen* geologically is built of pre-Devonian metamorphic rocks overlapped by sedimentary formations, primarily from the Carboniferous period. Those layers include sequences of shales, sandstones, limestone, and anhydrite (Harland 1997, Dallmann et al. 2002). The geological stratification in many places is much more complex due to tectonic activity in this area in the past. The valley basis is composed of glaciofluvial and morainic forms generated by retreating glaciers and proglacial streams. Typical features in the mouth section of the valley are a series of raised marine terraces. Terraces are elevated up to 30 m a.s.l. and their TL age was determined from around 13.3 to 1.3 ka (Kłysz et al. 1989, Rachlewicz 2009, van der Meij et al. 2016). The terraces were also dated using AMS radiocarbon dating of *Astarte borealis* shells and their ^{14}C ages varied from 9.9 to ca. 3 ka (Long et al. 2012).

The environment of Ebba Valley is typical for high Arctic areas and is characterized by a cold climate, with mean annual temperature usually below −6.0°C. Positive temperatures are observed between May and October and the warmest months are July and August when the temperature rises to 5–6°C of the daily average (Rachlewicz and Szczuciński 2008, Rymer and Rachlewicz 2014). The inner-archipelago location is responsible for the quasi-continental individuality of the whole area. Usually, it is slightly warmer during summer and much dryer than in southern and western parts of Spitsbergen with total precipitation not reaching 200 mm per year (Rachlewicz and Styszyńska 2007, Przybylak et al. 2014). Due to observed climate change recent data shows warming trends, which cause melting seasons to be longer. Increased rainfall rather than snowfall from spring to autumn is also more common (Førland et al. 2011, Sobota et al. 2020). Snow cover is usually not thick and is present in the area during winter and early spring months (Przybylak et al. 2006). Southern and north-eastern winds dominate, but the strongest gusts are most often observed from the north and north-west, conditioned by the morphology of surrounding mountain chains (Rachlewicz 2003, Przybylak et al. 2006, Małecki 2015).

The very sparse vegetation adapts to Arctic conditions and consists mostly of mosses, lichens, and shrubby species. This fragile tundra ecosystem is colonizing areas uncovered by glaciers retreat, to reach the best conditions for development on terraces in the valley mouths (Stawska 2017). Individual vegetation types were described in this area by Prach et al. (2012) and Johansen et al. (2012). Tundra plants are quite often shaped by aeolian activity and grow on the aeolian sediments (Borysiak et al. 2020). The limited vegetation is an important archive and marker of ecological responses to changing climate (Elvebakk 2005, Buchwal et al. 2013).

Methods

The measurements were taken at a single test site located in the central part of the Ebba Valley (Fig. 1). Previous studies have shown that this site recorded aeolian deposition values close to the average deposition calculated for the entire valley based on a comparison of nine test sites (Rymer et al. 2022). In order to measure the amount of aeolian deposition, measurement equipment (three traps) was set out three times during the summer season in 2022 for a period between 11 and 17 days (traps A, B, and C). Additionally, three traps were set out for 41 days during the whole measuring season (traps X, Y, and Z). All traps were placed approximately 1–1.5 meters from each other. The measurement periods and the number of days are listed in Table 1. To compare and standardise the obtained results, they were divided by the number of days.

The traps were arranged by using 195 mm diameter plastic trays filled with glass marbles (*phi* = 15 mm). After the measurement was completed, the trays and glass marbles were washed with filtered water to isolate the collected material. It was then dried and weighed. The original method was first proposed to measure vertical dust flux (Hall and Upton 1988). However, further research proved that this type of trap can be used to measure aeolian sediment concentration and deposition (Goossens and Offer 2000). The details and modifications to the method implemented during measurements in Ebba Valley have been widely described by Rymer et al. (2022).

Meteorological data for Pyramiden (daily average temperature and daily average wind speed) and Longyearbyen (daily precipitation) meteorological stations (located respectively 10 and 60 km southwest from the study area) were acquired via the Seklima database (NMI 2024).

Table 1. Time periods for aeolian deposition measurements during summer season 2022

Traps	Start date	End date	Number of days
X, Y, Z	16.07.2022	26.08.2022	41
A1, B1, C1	16.07.2022	29.07.2022	13
A2, B2, C2	29.07.2022	9.08.2022	11
A3, B3, C3	9.08.2022	26.08.2022	17

Results

The day the measurements started fell on the period of the highest temperatures in the summer season of 2022. Since then, there has been a systematic decline in average daily temperatures (Fig. 2. and Table 2). The situation was slightly different in the case of average wind speed, where wind speeds exceeding an average of 5 m·s^{-1} were observed only towards the end of the measurement season. The above statement excludes two days in the second half of July when average wind speeds were close to 5 m·s^{-1}. The intensity of rainfall also increased towards the end of the measurement period.

The obtained amount of aeolian deposition varied between 0.05–0.10 g (during the shortest period of 11 days in the middle of the season) and 11.50–14.85 g (during the period of 17 days at the end of

Table 2. Selected weather variables measured at the Pyramiden and Longyearbyen weather stations for the summer season 2022

Period	Average temperature	Total precipitation	Average wind speed
	[°C]	[mm]	[m s^{-1}]
16–29.07.2022	10.1	3.2	2.18
29.07–9.08.2022	9.0	9.5	1.20
9–26.08.2022	7.0	32.7	2.62

Table 3. Aeolian deposition rates in Ebba Valley in summer season 2022

Trap	Period	Aeolian deposition measured in the trap	Mean aeolian deposition measured in the traps	Standardized aeolian deposition
		[g]		[g·m^{-2} day^{-1}]
X	16.07–26.08.2022	13.35		
Y	16.07–26.08.2022	10.75	11.20	9.1
Z	16.07–26.08.2022	9.50		
A1	16–29.07.2022	0.20		
B1	16–29.07.2022	0.35	0.25	0.6
C1	16–29.07.2022	0.20		
A2	29.07–9.08.2022	0.05		
B2	29.07–9.08.2022	0.10	0.08	0.3
C2	29.07–9.08.2022	0.10		
A3	9–26.08.2022	12.45		
B3	9–26.08.2022	11.50	12.93	25.4
C3	9–26.08.2022	14.85		

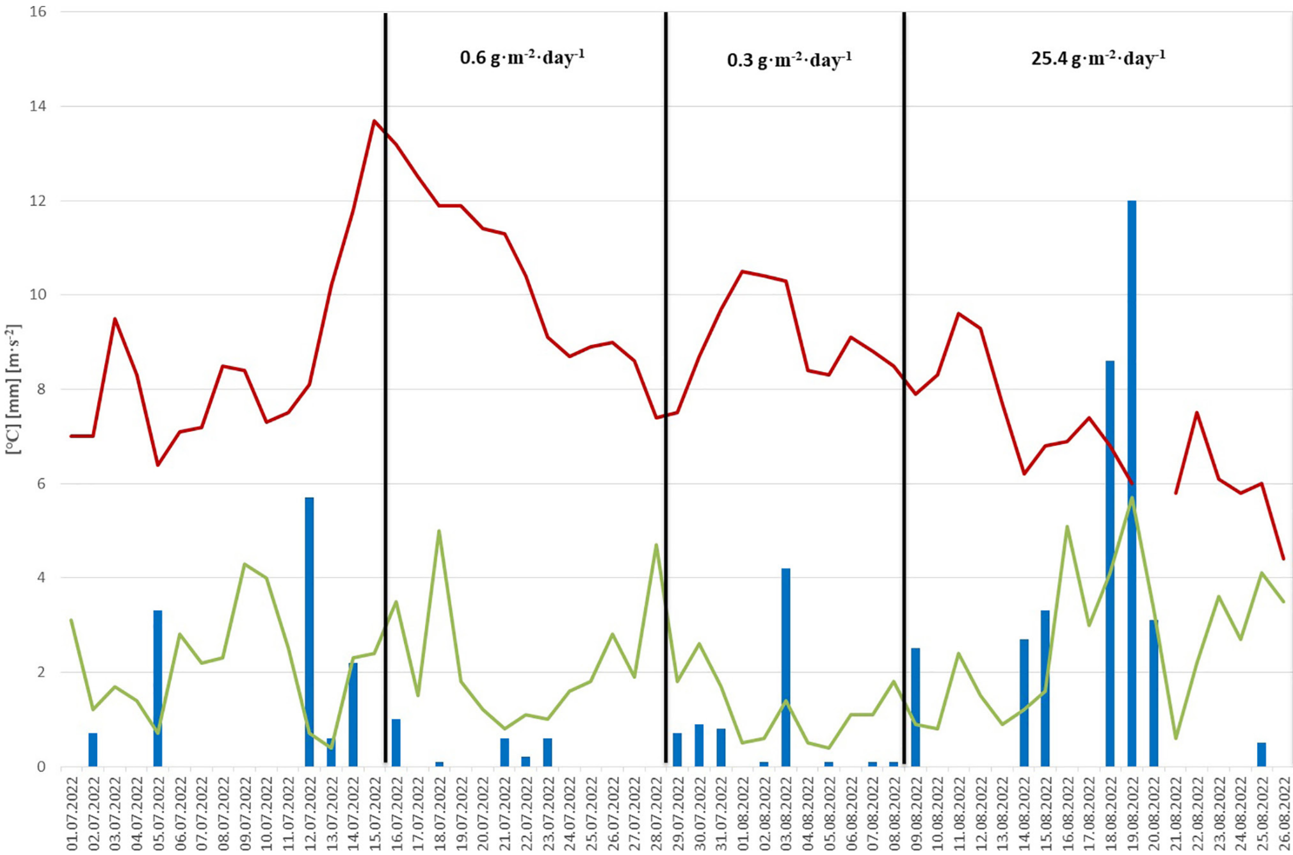

Fig. 2. Selected weather variables measured at the Pyramiden (temperature and wind speed) and Longyearbyen (precipitation) weather stations for the aeolian deposition measurement periods during summer season 2022. Red colour indicates average daily air temperature. Green colour indicates average daily wind speed. Blue bars indicate daily precipitation totals

the season). After the standardization, this resulted in values in the range from 0.3 g·m^{-2} per day (in the middle of the season), through 0.6 g·m^{-2} per day (at the beginning of the measurements) to 25.4 g·m^{-2} per day (at the end of the season). The mean standardized aeolian deposition during the whole summer season of 2022 reached 9.1 g·m^{-2} per day (Table 3). Previous research showed that the deposited material mainly consisted of moderately sorted fine sands (Rymer et al. 2022).

Discussion

Although the research conducted in the summer season of 2022 was relatively shorter than the measurements conducted in the years 2012–2018 (compare Rymer et al. 2022), the obtained value of mean standardized aeolian deposition (9.1 g·m^{-2} per day) was in a similar range to the results from previous years for this test site (2.0–16.4 g·m^{-2} per day). However, this value was slightly higher than the multi-year average (3.2 g·m^{-2} per day higher than the 2012–2018 average). The selected measurement period in 2022 was also characterized by a significantly higher average air temperature than in previous years (by 1–2°C). Therefore, at this stage of work, a broader comparison with the model proposed by Rymer et al. (2022) was omitted. It is therefore necessary to collect further data that will allow for the identification of critical values in terms of weather conditions, especially in times of climate change.

However, it should be noticed that values of aeolian deposition during the season were not equal and much higher results were obtained at the end of the season. This could have been due to the occurrence of stronger winds. The occurrence of more rainfall certainly also had an impact on the greater capacity of the traps (but also of the ground surface) to absorb all material transported by the wind during that period. On the other hand, rainfall is one of the factors limiting the uplift and movement of aeolian material (Jackson and Nordstrom 1998). A trap drainage system should certainly be used in further research, which would result in greater accuracy of the measurements. Although no statistically important correlations were found between meteorological conditions and values of the aeolian deposition (Table 4), high r Pearson values may suggest some

Table 4. Correlation between different weather variables and aeolian deposition rates during measurement periods in Ebba Valley in summer season 2022

Parameter	Precipitation	Temperature	Wind speed
r Pearson	0.98	−0.93	0.75
p value	0.13451	0.23591	0.46233

kind of combination of relations between the precipitation, air temperature, and aeolian deposition.

The drop-in air temperature at the end of the season contributes to the drop in water levels of proglacial rivers. This results in the increased presence and availability of fresh glaciofluvial material, which can then be blown by the wind around the valley. The existence of the relationship between glaciofluvial and aeolian activities was previously discussed by Dijkmans and Tørnqvist (1991), Bullard and Austin (2011), as well as, Rymer et al. (2022). Similar regularities have been also found by Gilbert et al. (2018) and Rasmussen et al. (2023).

Conclusions

The undertaken research was one of the first aimed at a more detailed quantitative assessment of the amount of aeolian deposition within one summer season on Svalbard. Although the year 2022 was different in terms of weather conditions from the previous years, the measured seasonal values are similar to those obtained for the study area in the past. Differences in aeolian deposition rates through the season are significant. For most of the summer, the daily values of aeolian deposition reach 0.3–0.6 $g \cdot m^{-2}$. Then, at the end of the season, they can even reach up to 25.4 $g \cdot m^{-2}$ per day.

The results indicate that the processes of deposition of wind-borne material are intensifying only at the end of the summer season, mainly due to stronger winds and lower air temperatures. The lower air temperatures cause the water level in rivers to drop, which in turn exposes the sediment carried by the river. Then the fresh glaciofluvial material can be transported by the wind and deposited at the bottom of the valley.

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