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Snow cover at the Akademik Vernadsky station: response on wind, temperature and precipitation variations

Abstract. We analyze the changes in snow depth at different time scales (from within a day to over many years) and its dependence on the precipitation phases, wind regime, and air temperature. The study employs observational data for snow cover and regular meteorological records of the air temperature (2 m), precipitation, and wind (direction and speed at 10 m) in 2002—2022. The data were processed by classical climatological methods. To compare the data on snow depth with precipitation phases, air temperature, wind speed and direction, we used temporal interpolation. It is shown that solid precipitation occurs most often, when the annual distribution of precipitation is considered. A significant percentage of precipitation in the liquid phase is observed during the Antarctic summer and Antarctic autumn. The portion of the mixed precipitation is the smallest throughout the year. The influence of the precipitation phases on the accumulation/melting of snow has seasonal character. The period from April to November is favorable for snow accumulation. In December, the solid precipitation leads to an increase in snow depth, but the mixed and liquid phases are accompanied the melting of the snow cover. The most significant snow cover grows smaller in January-February due to melting. The emphasis is on the local effect of the snow depth decrease due to strong winds in a setting with the accompanying effect of the thermal factor. Further analysis showed that the parameter most closely associated with snow cover depth reduction was a combination of wind speed and direction. Snow cover depth was reduced the most in January—March due to melting, yet on a daily scale, the reduction's intensity was not the highest. The highest frequency of cases of intense reduction in snow cover depth by more than 1 cm/3h is seen if the wind is either northerly, northeasterly, or southerly. The most frequent reduction in snow cover depth is seen under the northerly and northeasterly winds and positive temperatures. The north and northeastern air masses' advection is mostly associated with heat advection, and thus, the snow cover depth is reduced by melting. The eastern, northeastern, and southeasterly winds can be connected to the effect of the foehn winds due to the closeness of the continent. The most frequent occurrence of a significant reduction in the snow cover under the southern wind is noted under a high wind speed and negative air temperature.

Keywords: advection, air temperature, precipitation phases, snow depth, wind

1 Introduction

The Antarctic is, in many ways, unique. Its geography and climate and the limits to human activities (such as prohibition of mining) came to define it as the least polluted continent on the planet, with the least anthropogenic impact. Studying climate changes here allows to evaluate the trends, to trace the direct and indirect connections in the global climate system, and to model the effects of such changes. Jones et al. (2019) and Turner et al. (2019) point out that the Antarctic Peninsula has one of the most pronounced warming rates in the region; the Ukrainian Antarctic Akademik Vernadsky station (hereafter – Vernadsky Station) is situated close to it. Studies on the local and regional climate changes (van den Broeke, 2000; Turner et al., 2005; 2019; 2021; Marshall et al., 2006; 2013; van Lipzig, 2008; Franzke, 2010; Ding & Steig, 2013; Autret et al., 2013; Carrasco, 2013; van Wessem et al., 2015; Clem et al., 2017; Jones et al., 2019; Bozkurt et al., 2020; Evtushensky et al., 2020; Gorbachova et al., 2022; Khrystiuk et al., 2022; Tewari et al., 2022; Greve et al., 2023) showed that the researchers mostly considered the air temperature factor. The other important objects of investigations are the atmospheric circulation, its direct and indirect relations with climate features in Antarctic region, and the wind regime, as one of the most marked features of the Antarctic climate system (Turner et al., 2005; 2009; van Wessem et al., 2015; Tymofeyev et al., 2017; Jones et al., 2019; Dong et al., 2020; Evtushensky et al., 2020; Andres-Martin et al., 2024).

Compared to the air temperature, the snow cover in the Antarctic has been the subject of much fewer investigations despite being globally and regionally significant. The global warming is accompanied by a reduction in the snow and ice cover. For example, one of the most significant declines of spring snow cover was found in the Northern Hemisphere, with the largest decreases over higher latitudes and mountain regions (Bormann et al., 2018). The reduction's long-term cumulative effect is an aggregate of smaller-timescale (days, weeks) processes related to the specifics of atmospheric circulation and the relevant thermodynamic properties of surface air (Grischenko et al., 2005; Tymofeyev & Grishchenko, 2010). Thus, for instance, the loss of snow and ice on the Antarctic Peninsula is brought about by several circulation mechanisms from the tropics to middle latitudes, which move the heat and humidity by specific trajectories and create the conditions for the extremely warm weather on the Antarctic Peninsula, promoting the melting (Gorodetskaya et al., 2023). Warm weather events in the Antarctic are caused by abnormally warm and highly humid air masses forming over the Southern Ocean in lower latitudes and spreading eastwards and polewards until they dissipate, losing their baroclinic energy near the Antarctic continent (Uotila et al., 2013; Grieger et al., 2018; Gorodetskaya et al., 2023). On the other hand, some processes are related to the stationing of baric systems near the Antarctic Peninsula. In such cases, a powerful high-pressure system over the Southern Ocean blocks the processes. The cyclones stay in place for days, bringing in ever more heat and humidity from the subtropical and temperate latitudes to Antarctica (Sinclair, 1996; Massom et al., 2004; Schlosser et al., 2010; Hirasawa et al., 2013).

Besides the direct advection influences causing the melting, the literature also describes the effects of powerful katabatic winds, foehn winds, and atmospheric river events (often followed by liquid precipitation with some impact on the snow cover reduction) (Bozkurt et al., 2018; Zou et al., 2023).

The snow cover at Vernadsky Station fully melts away in some years, despite being observed in many days in the summer (Tymofeyev & Grishchenko, 2010; Klok, 2016). As Klok (2016) estimated for 2016, the mean annual snow cover duration is 340 days. Snow accumulates from late March – early April to November. In general, the snow cover studies at Vernadsky Station have included both analysis of systematic observations of snow stakes near the meteorological station and periodical expeditionary measurements further away (Grischenko et al., 2005; Belokrinitskaya et al., 2006; Klok, 2015; Klok & Afteniuk, 2017; Klok et al., 2021). Mostly, the papers discuss the fluctuations in snow cover parameters, the starting dates of the snow cover accumulation and melting, moisture content estimates, etc. Very few studies address how the thermal, moisture, or wind regimes of the near-surface layer affect the snow cover. As a rule, they refer to separate cases or seasons, sometimes other periods. One should note the study by Tymofeyev and Grishchenko (2010). Based on mass-balance measurements in 1996–2007 for the Woozle Hill that is situated on Galindez Island (the center of polygon had the following geographical coordinates: 65.2503678° S, 64.2474809° W) and the data for two snow stakes of Vernadsky Station's meteorological observatory, the authors found an increase in snow depth (SD) and positive mass balance of the glacier under negative temperature abnormalities and ablation and snow cover reduction under positive ones. They also consider the precipitation regime's effect on the snow cover in two years (2005 and 2006) with different conditions of snow accumulation; the largest snow cover reduction occurred when the average monthly air temperature was above zero, and the liquid precipitation was 46–50%.

Our study aimed to analyze the dynamics of changes in snow cover thickness at different time scales (from fluctuations within a single day to multiannual changes in mean monthly values) and its dependence on the wind regime and near-surface air temperature.

2 Materials and methods

The series of meteorological observations from Vernadsky Station are 21 years long (2002–2022). Snow cover depth was read from a snow stake at 13 UTC. The speed and direction of the wind were taken from standard observations (00, 03, 06, 09, 12, 15, 18, and 21 UTC). Air temperature (2 m) and wind speed and direction (10 m) were recorded by automatic meteorological stations (AWS): MAWS (Modular Automatic Weather Station), Mobile Meteorological Complex "Troposphere" (Mobile AWS "Troposphere" was developed and manufactured in Ukraine) and Vaisala AWS-310. The data measured by MAWS covered the period from January 1, 2002, up to February 19, 2011. The data from AWS "Troposphere" covered the period from February 19, 2011, to March 31, 2020. Since April 1, 2020, the Vaisala AWS-310 data has been used.

To make the two datasets comparable, we used linear interpolation to obtain snow cover depth and its 3-hourly rate of change. It is clearly an approximation and does not reflect the real dynamics of the snow cover within a day, yet it can be employed if higher-resolution data are lacking. We considered all cases of SD decreasing from the date range with the aim of evaluating the effect of snow cover reduction due to melting and blowing-off by the wind. If a factor was evaluated, all datapoints with liquid or solid precipitation were discarded. If the telegrams lacked the *ww* group (weather during the observation period or within the last hour before the observation) and the W1W2 group (past weather, when it was impossible to determine if there had been any precipitation in the preceding day), it was taken as a given that there had been no precipitation since a lack of record is more probably related to a lack of observed phenomenon.

3 Results

3.1 Geography of the observation point and some potential factors influencing the changes in snow cover

The main factors that can decrease the snow cover depth directly at Vernadsky Station are the following: 1) blowing-out by strong winds; 2) melting (under warm air advection or/and short-wave solar radiation or/and liquid- or mixed-phase precipitation); 3) evaporation; 4) increase of snow density (as a function of time and melting factors). The station's location on an island and the closeness of the mountains on the Antarctic Peninsula form specific settings of temperature and wind regimes and thus significantly impact the snow cover dynamics.

Vernadsky Station is located on Galindez Island, approximately 7 km off the Antarctic Peninsula's western coast at 65.245° S, 64.256° W. Fig-

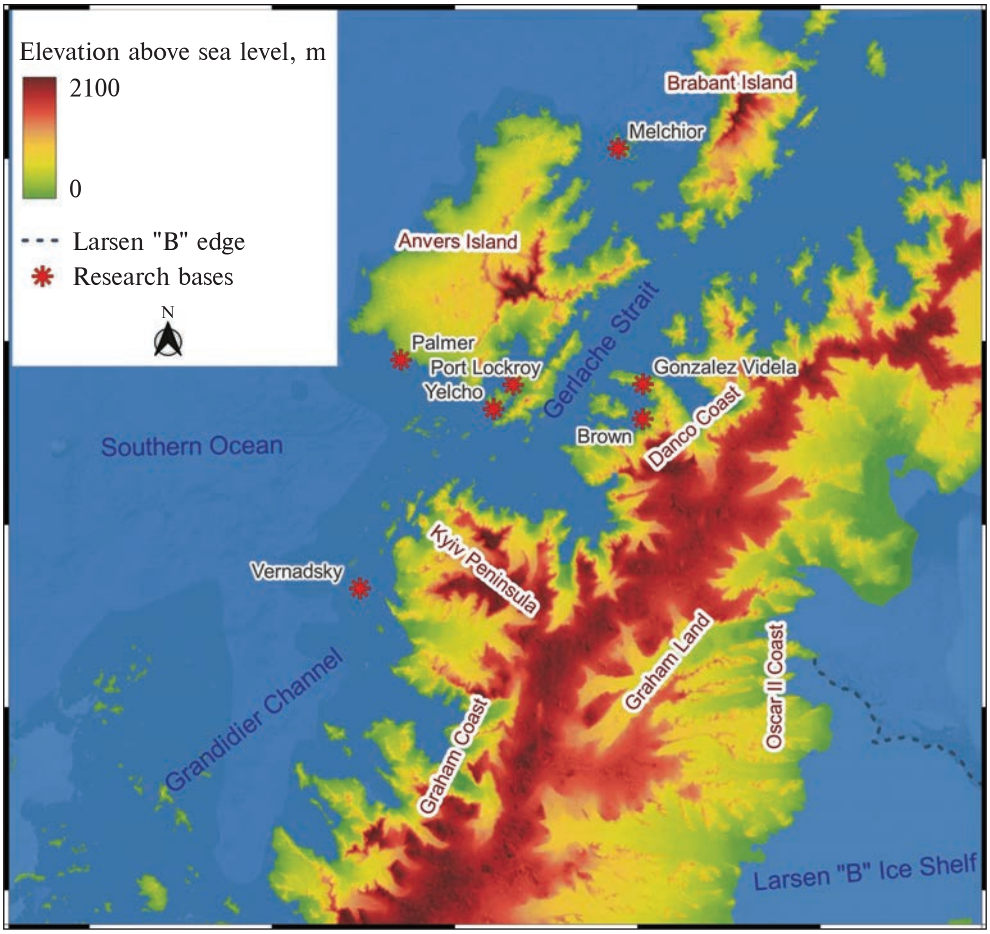

Figure 1. Relief of the central part of the Antarctic Peninsula

ure 1 was drawn using the digital data of the ASTER project (NASA/METI/AIST/Japan Space systems and U.S./Japan ASTER Science Team, 2019 (https://doi.org/10.5067/ASTER/ASTGTM.003)) to present the region's relief east of the island. The AP's coast (in particular, the Kyiv Peninsula) extends from north to south. Moving inland, elevation sharply rises to 1000 m several dozens of kilometers away from the shoreline; 50 km away, there is a mountain range with heights exceeding 2000 m. In relation to the location of Vernadsky Station, this barrier curbs air transfer when easterly winds predominate, diverting them to the west or to the north or to the south. The southern, southwestern, western, and northwestern winds meet no orographic obstacles for at least hundreds of kilometers (Southern Ocean and the Grandidier Channel).

Absolute heights on Galindez Island vary within several meters above sea level. The observation point itself is in an open place. The station is south of the westerlies, yet it feels the effects of western cyclones passing over the Antarctic Peninsula. Cyclones can cause accumulation or reduction of snowpacks depending on the thermodynamic parameters of the air mass. Thus, if the station is blanketed by a warm conveyor belt with positive temperatures, the snowpack can melt. Liquid precipitation can also occur, adding more energy to the snowpack and intensifying the melting.

On the other hand, the precipitation brought in by a cold front or even a warm one under negative temperatures will favor snow accumulation. In 2002–2022, there have been registered 29.2% of cases of periods with positive temperatures. More than half of them happened in January–March, making the melting in this period the most intense.

3.2 Influence of precipitation phases on snow cover changes

As already mentioned, precipitation influences the accumulation and melting of snow in different ways depending on the phase (solid, mixed, and liquid). We analyzed all cases that occurred in the standard time of observation or within the last hour before it (*ww* group) and between them (W1W2 group) separately because precipitation during falling can change its phase. Most precipitation cases have a solid-phase during March–December (Tables 1 and 2). The yearly average percentage of precipitation cases with a solid-phase is 74–75% of their total number. The minimal amount of solid-phase precipitation is observed in January and February. Its repeatability is much higher than that of liquid and mixed precipitation.

Over the year, the liquid precipitation has the opposite pattern. It peaks in the austral summer (January and February), with a gradual decrease in cases during the autumn and reaching minimum values in June–October (Tables 1 and 2). The percentage of liquid precipitation events per year averages between 16.84% and 18.84% and has a fairly wide range, from about 5% in June to above 40% in February.

Mixed precipitation occurs most frequently in January–March and October–December. On average, it is the least frequent (less than 10% of cases).

Let us consider the distribution of snow depth changes (increase/decrease) by months and phases of precipitation throughout the year (Fig. 2). Positive values correspond to the multiannual average for a given month of snow depth increase, and negative values correspond to its decrease. The unit of the rate of SD increase/decrease (snow depth change) is 1 cm/3h.

In Figure 2, the calculated average rates of snow depth changes based on data in standard

Table 1. Precipitation phases at Vernadsky Station during 2002–2022 in standard terms of observations

Month	Precipitation, cases			Total number of cases of precipitation	Precipitation, %		
	Solid	Mixed	Liquid		Solid	Mixed	Liquid
1	541	108	441	1090	49.63	9.91	40.46
2	631	90	673	1394	45.27	6.45	48.28
3	879	121	532	1532	57.38	7.90	34.72
4	1078	72	325	1475	73.09	4.88	22.03
5	1155	100	244	1499	77.05	6.67	16.28
6	1341	43	71	1455	92.16	2.96	4.88
7	1384	43	108	1535	90.16	2.80	7.04
8	1395	38	78	1511	92.32	2.52	5.16
9	1567	82	139	1788	87.64	4.59	7.77
10	1415	117	144	1676	84.43	6.98	8.59
11	1024	118	174	1316	77.81	8.97	13.22
12	796	84	188	1068	74.53	7.87	17.60
Sum	13206	1016	3117	17339	–	–	–
Mean	–	–	–	–	75.12	6.04	18.84

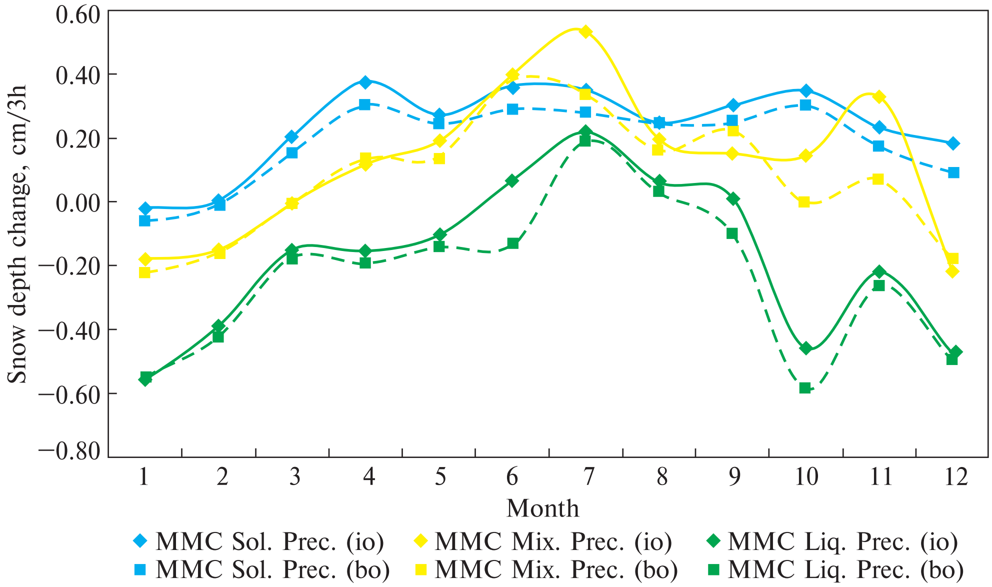

Figure 2. The monthly mean distribution of snow depth changes and precipitation phases. The mean monthly change of snow depth (MMC) for solid-phase (Sol. Prec.), mixed-phase (Mix. Prec.), and liquid-phase (Liq. Prec.) precipitation at standard terms (io) and between standard terms (bo)

terms of observations and between them are in good agreement for the solid and liquid phases. Except for June, when a slight increase in SD was obtained for the liquid phase (while the general trend still held) in the standard terms of observations, while between the standard terms of

Table 2. Precipitation phases at Vernadsky Station during 2002—2022 between standard terms of observations

Month	Precipitation, cases			Total number of cases of precipitation	Precipitation, %		
	Solid	Mixed	Liquid		Solid	Mixed	Liquid
1	768	164	611	1543	49.77	10.63	39.60
2	857	199	838	1894	45.25	10.51	44.24
3	1252	201	604	2057	60.87	9.77	29.36
4	1367	136	362	1865	73.30	7.29	19.41
5	1439	165	256	1860	77.37	8.87	13.76
6	1472	86	80	1638	89.87	5.25	4.88
7	1395	121	96	1612	86.54	7.51	5.95
8	1354	132	76	1562	86.68	8.45	4.87
9	1517	163	123	1803	84.14	9.04	6.82
10	1546	172	134	1852	83.48	9.29	7.23
11	1291	152	176	1619	79.74	9.39	10.87
12	1098	168	226	1492	73.59	11.26	15.15
Sum	15356	1859	3582	20797	—	—	—
Mean	—	—	—	—	74.22	8.94	16.84

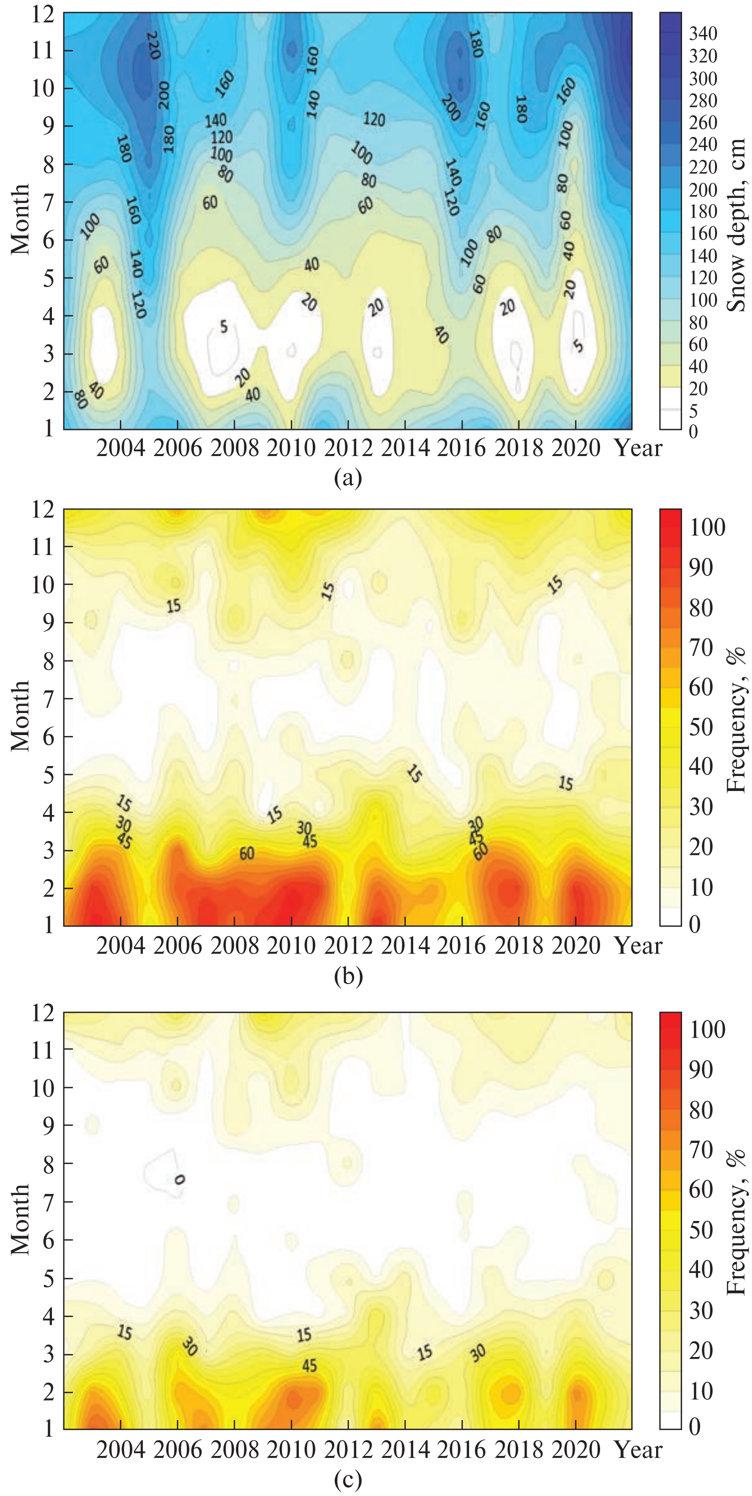

Figure 3. Heatmap of monthly mean snow depth at Vernadsky Station in cm (a), the frequency of 2 m air temperature >0.0 °C (b), and the frequency of 2 m air temperature >1.0 °C (c)

observations, a decrease in SD was obtained. Also, the significant difference between the two data sets is the precipitation in the mixed phase for October and November. However, this discrepancy only consists of the difference in average values while preserving the sign of changes and the physical essence. The differences between the results obtained using the two data sets for all three phases can be interpreted as an error of the proposed approach.

In the summer (January and February), precipitation in the liquid phase leads to snow melting at an average rate of −0.56 to −0.41 cm/3h. During this period, mixed precipitation has a similar effect, but the melting rate is almost half as low (approximately −0.20 cm/3h and −0.15 cm/3h). Precipitation in the solid-phase was accompanied by further melting, which, in turn, caused the melting of the existing snow cover. The obtained range varied from −0.06 cm/3h in January to approximately 0 cm/3h in February.

In the autumn (March—May), liquid-phase precipitation still leads to snowmelt. However, mixed- and solid-phase precipitation leads to snow accumulation and increasing snow depth.

In the winter (June—August), all kinds of precipitation generally lead to an increase in the SD.

In the spring (September—November), precipitation in the liquid phase causes melting. At this time, precipitation in the mixed and solid phases still adds to the snow depth. In December, the first month of the Antarctic summer, the average rate of SD change is positive only when the solid-phase occurs. Precipitation in the mixed and liquid phases leads to the melting of the snow cover.

We can assume that the precipitation phase distribution throughout the year is largely determined by the temperature of the ocean, which is very inert. Analyzing the precipitation regime, we can see two periods favorable for accumulation (April—November), when the percentage of solid and mixed phases of precipitation is still high and the average rates of snow depth changes have positive values.

The reduction (melting) of the snowpack takes place from December to March. Snowpack dynamics are presented in more detail in Section 3.3.

3.3 Snowpack and wind dynamics in 2002—2022

At a yearly scale, the snowpack dynamics have no clear tendencies over the 21 years. Instead, there are separate abnormal years with high snowpacks. Thus, on average, in 2002, 2005, 2021, and 2022, snow depth exceeded 150 cm. Meanwhile, mean annual SD in 2002—2022 was 112 cm. Most years do not differ from the mean annual value by more than a standard deviation (except the abnormally high values for 2005, 2021, and 2022 and the abnormally low for 2020).

Figure 3a shows that the average minimum snow cover depth typically occurs in March (35.6 cm on average). However, in some years, this minimum can be delayed until April (42.4 cm on average). Subsequently, the snow cover depth increases each month, typically peaking in November. Notably, larger yearly fluctuations relative to the mean yearly values are seen exactly when the lowest snow depth values are recorded. In particular, that is where the periods of abnormally low values lie in 2006—2011.

On the other hand, based on the calculated mean monthly abnormalities in SD, there were periods with abnormally high values at the start and the end of the 21-year-long period (2002—2005 and 2021—2022, respectively). Maximal SD is in October (on average, 180.8 cm) or November (on average, 193.6 cm); see Figures 3a and 4a. Typical for the part of the year (including several months on either end) is that the annual variability is less than that of February—May.

On average, since the end of November, SD begins to decrease due to melting. The process generally agrees with the repeating positive temperatures (Fig. 3b), which in January—March are seen over 50% of the time (in some years, like 2006 or 2011, in over 70—80%). The correlation coefficient (r) between the mean SD and the repeatability of above-zero temperatures is −0.22. If one com-

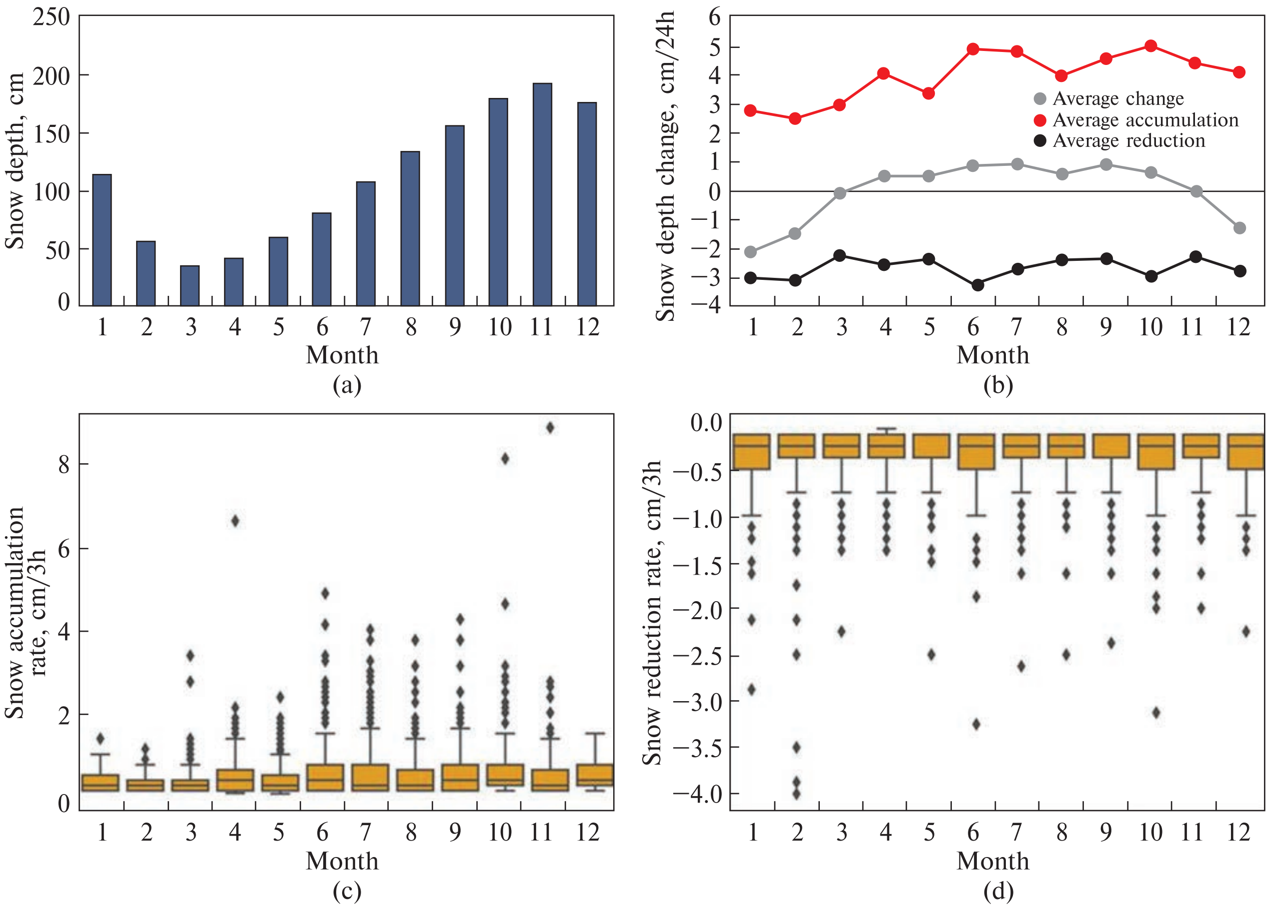

Figure 4. Monthly mean snow depth at Vernadsky Station (a); average daily snow depth change in different months (b); snow accumulation rate based on the period 2002—2022, cm/3h (c); snow depth reduction rate, cm/3h (d)

pares the mean SD with the repeatability of temperatures above 1 °C, the absolute value of *r* grows somewhat, and it becomes −0.26 (Fig. 3c).

The average snow accumulation in January—March is 2.5—3 cm/24h; in June—December, it is higher (4—5 cm/24h), as shown in Figure 4b. Conversely, snow cover reduction in absolute values is, on average, 2—3 cm/24h, see Figure 4b. These estimates were obtained based on the 2002—2022 time series, excluding the days without a change in SD (33.6 %). The records of snow accumulating over the last 24 hours are 26.3% of the dataset, and the records of snowpack growing smaller number 40.1% cases.

Regarding the variations in SD throughout the seasons, there are discernible patterns in snow accumulation. For example, the third quartile (75%) of the SD increase rate approaches 1.7—1.9 cm/3h in June—December, while in January—March, it is far lower (c. 1.0—1.2 cm/3h) (Fig. 4c). The former case is explained by processes favoring snow accumulation under low temperatures, the latter by snow falling and melting under positive temperatures. In contrast, the snow cover reduction range shows no seasonality (Fig. 4d); months from different seasons (January, June, October, and December) vary the most. As the values in Figure 4c, d are changes in snow depth linearly interpolated to 3-hourly intervals between the daily records, they fully reflect the tendencies of SD change over a day despite differing in the absolute values (divided by 8).

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3.4 Evaluating the connection between the wind and the changes in snow depth

Figure 5a, b shows that for the accumulation and cases of snow cover reduction, the main wind directions are southern and northern. For any other wind direction, under the intense accumulation of the snowpack, the share of each gradation of snowpack change is approximately proportional to the general repeatability of the direction. Accumulation of snow under no precipitation is an artifact of linear interpolation. The problem is that in the previous periods until the moment of measuring SD, during the days, there could be observed brief precipitation episodes or blizzards. If SD is reduced, the process occurs under the predominating northern and northeastern winds (over 1 cm/3h).

Depending on whether the air temperature is below or above zero, one can see significant differences in the predominating wind direction (Fig. 6).

At positive temperatures, the most intense decrease in SD happens under the northern wind, while at negative temperatures – under the southern (Fig. 6). Cases of decreasing SD under northern and northeastern winds are connected to snow melting under warm air advection when the cyclones passed over the Antarctic Peninsula. Significant repeatability of southern winds, associated with the advection of the colder continental air, is not frequently followed by a strong reduction in SD, *per se*. It can be a consequence of the fact that in such cases, mild winds (up to 5 m · s^{-1}) prevailed (Tymofeyev et al., 2017).

To test if this pattern is traced in different seasons with different temperature regimes, we drew two samples and plotted the results for November—March (Fig. 7) and April—October (Fig. 8).

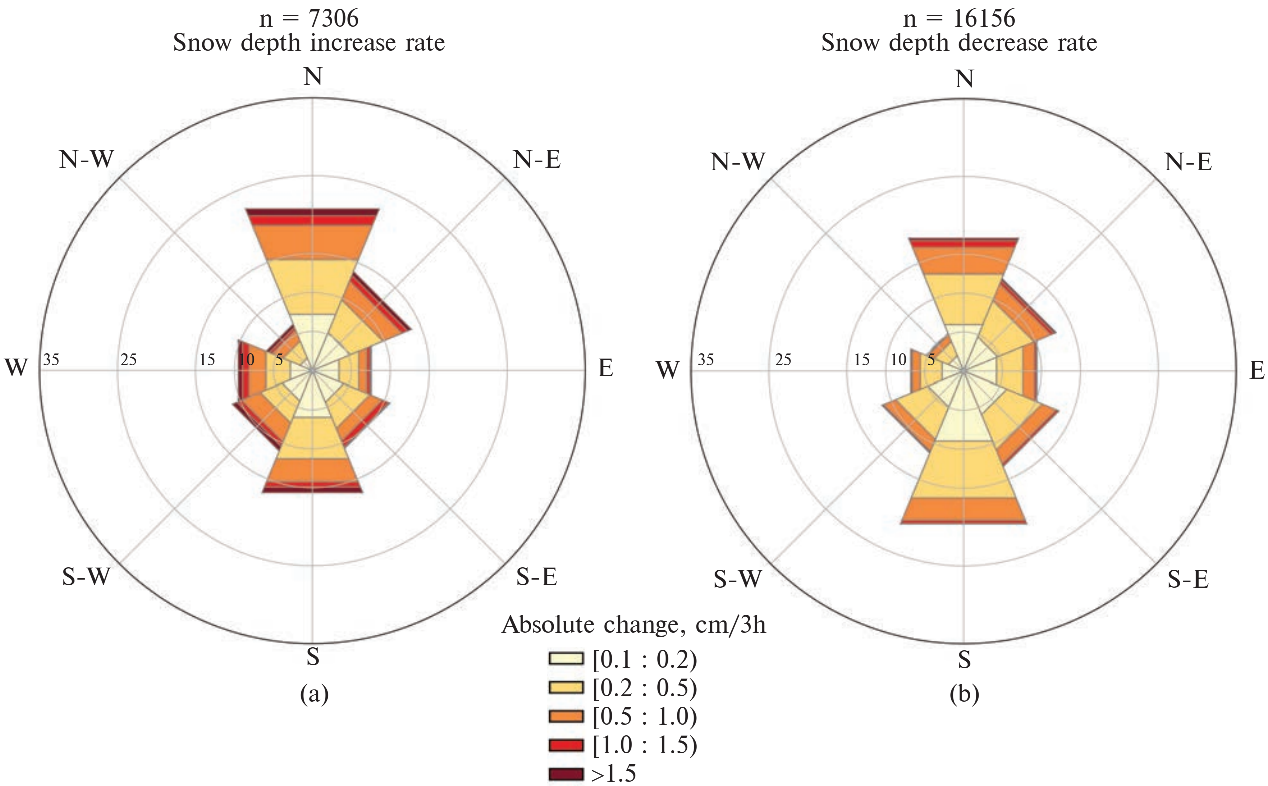

Figure 5. Repeatability of cases of snow depth increasing (a) and decreasing (b) over three hours under different directions of the wind (wind speed over 1 m · s^{-1}, no precipitation) over the year

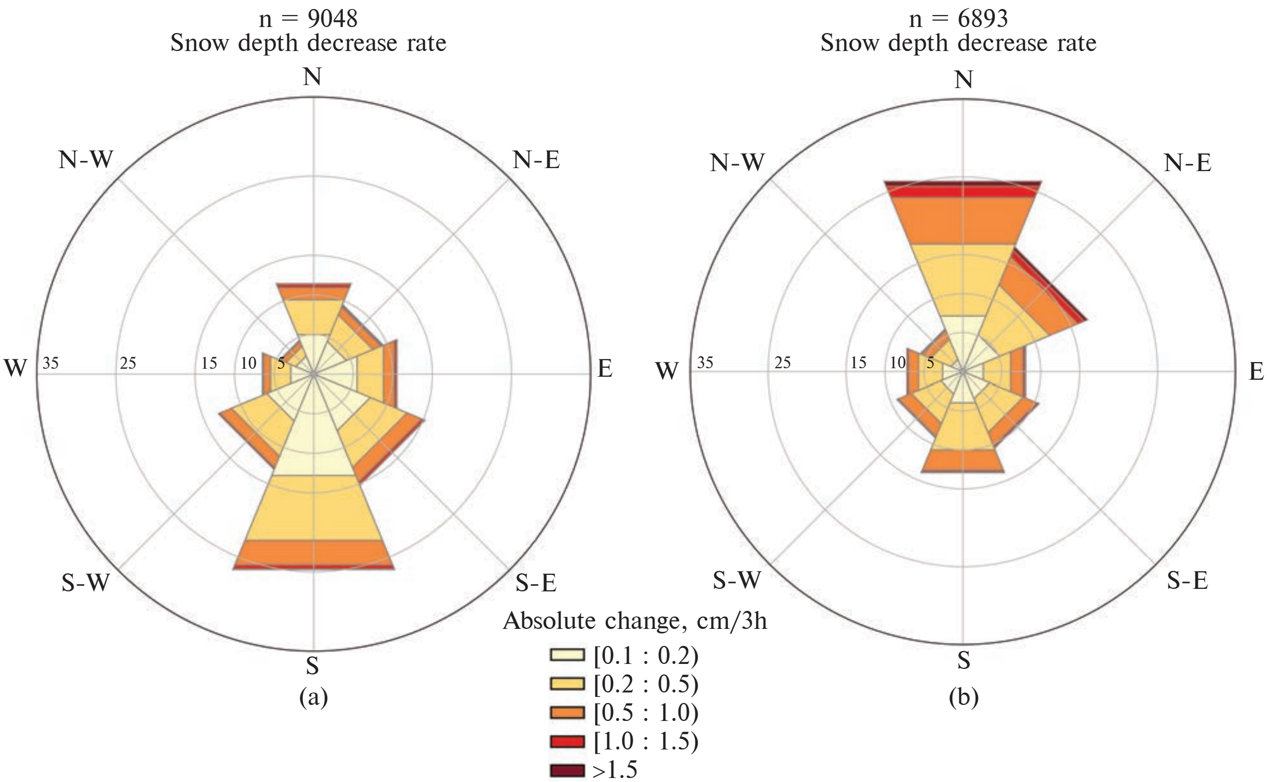

Figure 6. Repeatability of cases of snow depth decreasing over 3 hours under different wind directions and wind speed over 1 m · s^{-1}, in periods without precipitation: a) at T2m < 0 °C; b) at T2m > 0 °C

According to our assumption, the relatively high and fairly often above-zero temperatures in November—March should have better reflected wind's effects on the snowpack. One can see in Figure 7b (cases of below-zero temperatures and wind over 1 m · s^{-1}) that there is a relatively high repeatability of rather intense snow cover reduction (0.5—1.5 cm/3h) for precisely southern wind directions. However, for a sample with high wind speed (over 10 m · s^{-1}), the maximum is observed for the northern directions.

Similar plots for the April—October period (with typically lower temperatures) show a sizable snow cover reduction under northern and northeastern winds (Fig. 8).

Relatively high and fairly often positive temperatures should have showed better the effect of temperature increase on snowpack due to melting. However, in these months, more intense snow cover reduction is also seen under northern and northeastern winds. According to observations, the insignificant repeatability of very intense snow cover reduction per day has place at the eastern and (somewhat lesser) at the southeastern winds when air temperatures are slightly below zero (Fig. 8d). Such cases can be explained by the effect of foehn winds which are noted at the station exactly at such wind directions given the specifics of local orography east- and southeastwards from Galindez Island (see Fig. 1).

4 Discussion

Determining the relationship between the snow cover depth dynamics and other meteorological parameters can find practical application in the parametrization of the snow cover formation and change over the territory not covered by the ob-

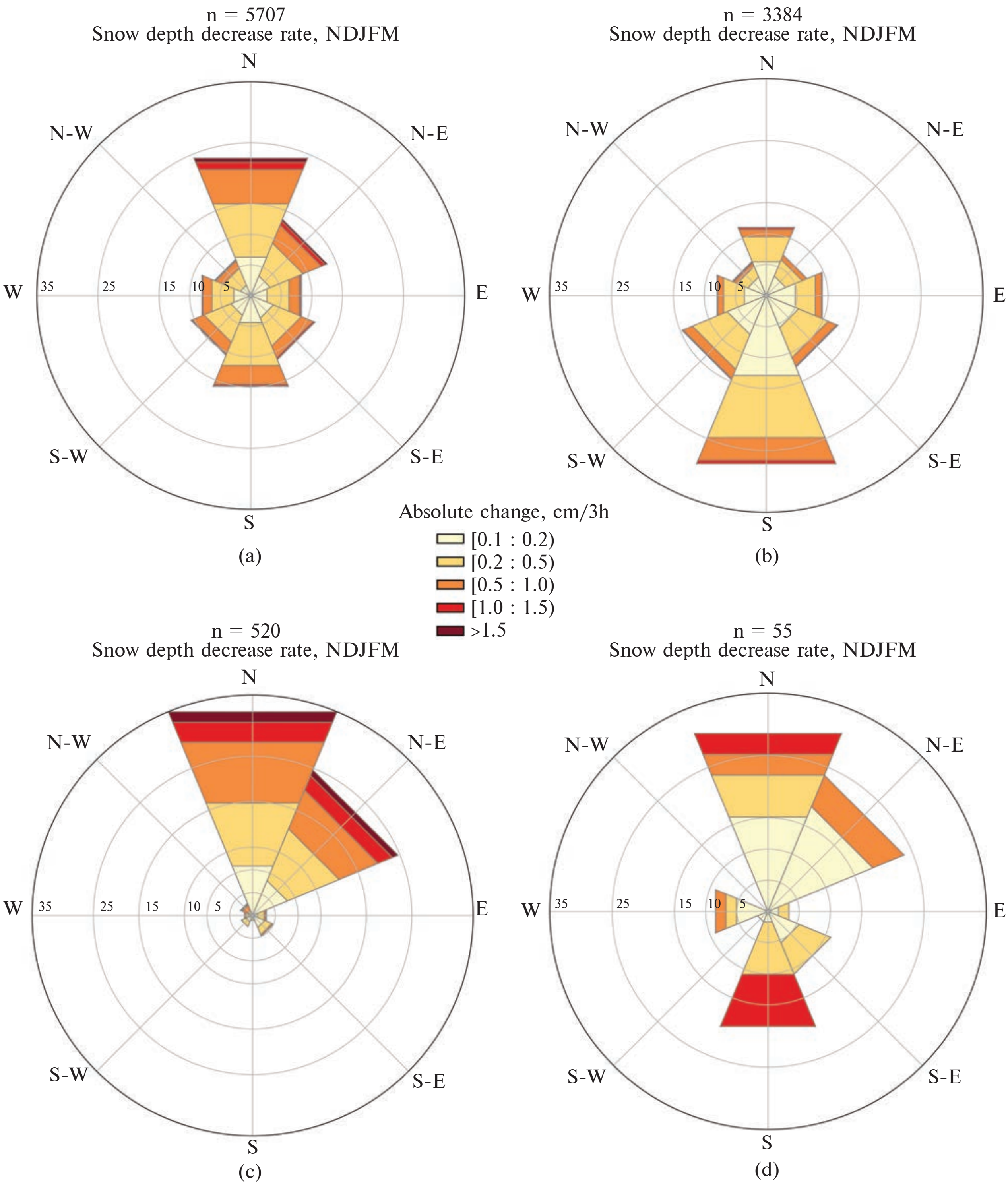

Figure 7. Decrease in snow depth under no precipitation per 3 hours in November—March (NDJFM) at a) T2m > 0 °C, WS10m > 1 m · s^{-1}, b) T2m < 0 °C, WS10m > 1 m · s^{-1}; c) T2m > 0 °C, WS10m > 10 m · s^{-1}; d) T2m < 0 °C, WS10m > 10 m · s^{-1}

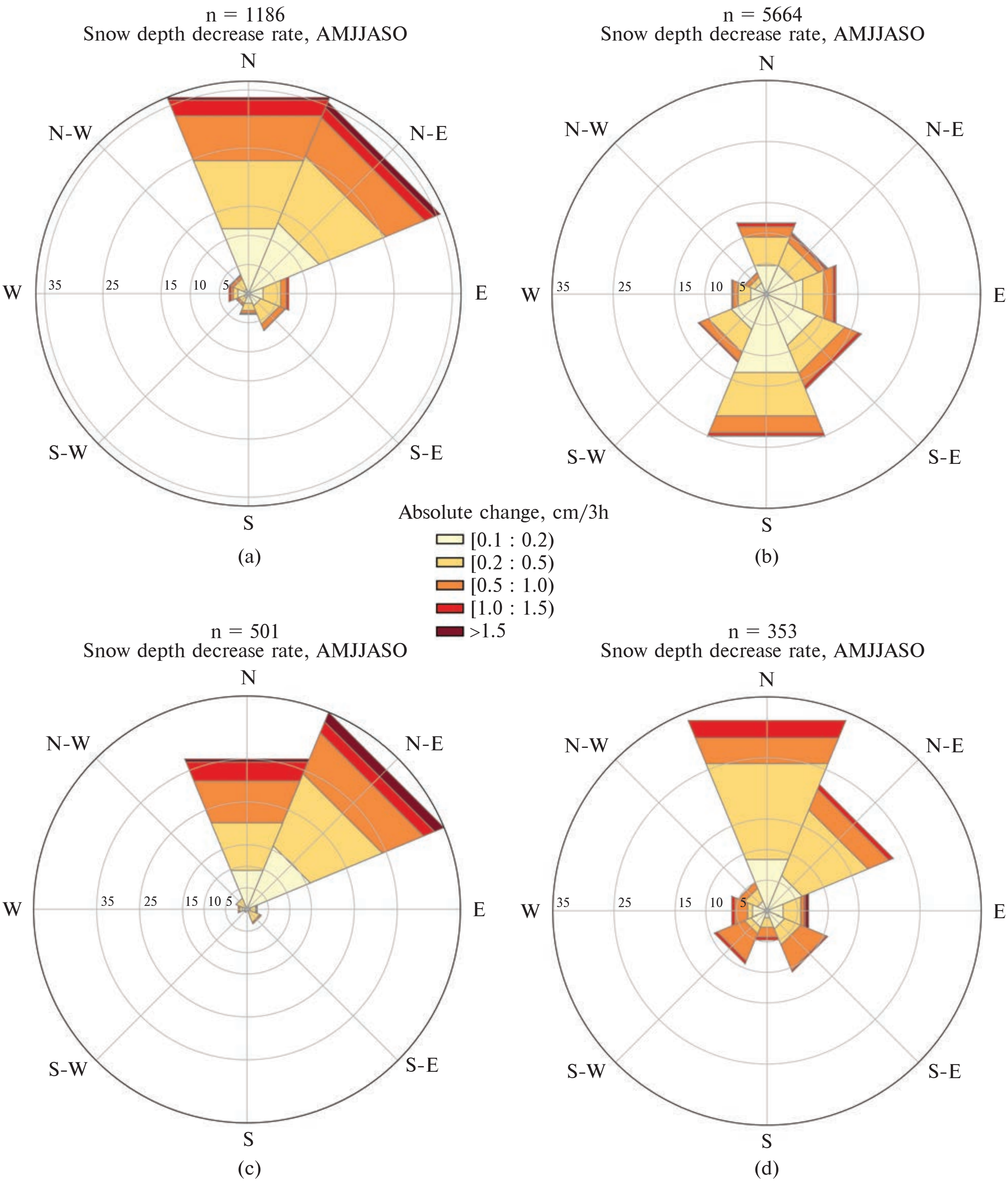

Figure 8. Decrease in snow depth under no precipitation per 3 hours in April—October (AMJJASO) at a) T2m > 0 °C, WS10m > 1 m · s^{-1}, b) T2m < 0 °C, WS10m > 1 m · s^{-1}; c) T2m > 0 °C, WS10m > 10 m · s^{-1}; d) T2m < 0 °C, WS10m > 10 m · s^{-1}

servation network. However, the climatological conditions at the coastal stations of the Antarctic Peninsula, such as Akademik Vernadsky, are significantly different from Antarctica's continental areas. For example, van Lipzig et al. (2004) emphasized that the average amount of precipitation over the grounded ice of the Antarctic Peninsula is six times larger than the mean value over the grounded ice of Antarctica. On the other hand, quite a lot of papers have been published on the study of snow cover dynamics and its role in changing the Antarctic ice sheet's total mass based on the data from continental research stations (Souverijns et al., 2018; Picard et al., 2019, etc.). At continental stations, the process of snow drift plays a significant role in the snow cover's dynamics. According to (Souverijns et al., 2018), a significant portion of the accumulation at the station happens when prior snowfall events occur in upstream coastal regions. Thus, the fresh snow is easily lifted and carried in shallow drifting layers to more inland areas. On the other hand, the opposite role in such regions is played by katabatic winds causing ablation. In such cases, the freshly fallen snow is ablated by the wind during the event (Souverijns et al., 2018).

In this article, we wanted to highlight that the specific conditions of the location of Vernadsky Station lead to seasonality and dynamical day-to-day changes in the snow cover. The snow cover depth on the station is sensitive to certain wind directions, often indicating specific processes, such as foehn wind or processes associated with warm air advection and/or liquid precipitation, which cause intense snow melting. Thus, atmospheric river episodes, which bring anomalous heat and rainfall, can affect a sharp change in the snow cover depth (Gorodetskaya et al., 2023). In wintertime liquid and mixed precipitation phases have the opposite effect, contributing to increased snow depth. It is probably achieved by the sticking of snow.

In general, it is worth acknowledging that our approach of matching meteorological data and snow cover data at a single point (snow gauge rail) has several shortcomings that could be improved by the following steps: 1) to avoid snow cover daily data interpolation for a time interval of 3 hours the solution may be to install automated sensors for recording changes in snow cover and relevant meteorological parameters; 2) increasing the number of measurement points (both snow cover and meteorological parameters). So, for example, in Nicolaus et al. (2021), a network of "snow buoys" is used, which allows one to draw conclusions covering a large area. The methods of expanding the results include modern observation methods of snow cover, such as laser scanning. For example, at Dome C, using an automatic laser scanner allows to cover an area of 40–100 m^2 (Picard et al., 2019); 3) involving more parameters as predictors (snowpack moisture content, its actual area, the short- and longwave radiation, albedo, air temperature, surface temperature, precipitation, etc.). Including more parameters allows using models such as SNOWPACK, as shown in (Wever et al., 2022).

However, suppose one wants to use the discontinuous ground observations of snow depth to obtain new physical relations (at the time scale of a day or less), to parametrize processes within the snowpack, to test the current mesoscale atmospheric models such as Polar-WRF and so on. In that case, one should increase the frequency of observations to synchronize the information on the phase composition of the precipitation, current and maximum air temperature, air humidity, and maximum wind speed. The best way to do it would be through acquiring measuring equipment, which would allow automated measurements accounting for the local specifics of snow translocation given the wind regime, which was the subject of our work.

5 Conclusions

The article considers the snowpack regime, characterizing its depth changes at different time scales, from the multiannual changes in mean monthly values to within a day. It was shown that during

April—December, the part of solid precipitation is much more than half (more than 70% of all fixed cases), and in January—March, it is quite significant (close to half of the total amount). The part of liquid precipitation is significant during the Antarctic summer and autumn. The part of mixed precipitation is the smallest. It is most frequent in January—March and October—December (10% and less). It was found that the period from April to November is favorable for snow accumulation. In December, the precipitation in the solid-phase leads to increasing SD, but the mixed and liquid phases were followed by melting. The most significant snow cover reduction occurs in January—February due to melting. The strongest positive rate of SD is associated with mixed-phase precipitation in July.

Analysis of how the wind speed (in relation to wind direction and temperature regime) affected snow depth showed that cases of the most intense snow cover reduction over three hours are seen at the northern and northeastern winds and above-zero temperatures. The reverse correlation with wind speed was statistically significant.

At positive temperatures and low wind speeds (except for the northern and northeastern directions), snow cover reduction is less intense.

The second most frequent wind direction, which promotes intense snow cover reduction, is southern. On average, the intensity of snow cover reduction is less than that of the northern direction.

Some of the cases of the significant snow cover reduction occurred under eastern, northeastern and southeastern winds at slightly negative temperatures and high wind speed. They can be explained by the effect of foehn winds at Vernadsky Station.

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Сніговий покрив на станції «Академік Вернадський»: відгук на варіації вітру, температури та опадів

Реферат. У статті проаналізовано зміну висоти снігового покриву на різних часових масштабах (від доби до багатолітніх змін середньомісячних значень) та її залежність від фази опадів, вітрового режиму та температури повітря. У дослідженні було використано дані спостережень за сніговим покривом і регулярні метеорологічні спостереження за температурою повітря (2 м), опадами і вітром (напрямок і швидкість на висоті 10 м) за період з 2002 по 2022 роки. Обробка даних здійснювалася із використанням класичних кліматологічних методів. Для узгодження даних щодо висоти снігу із даними щодо опадів (їх фазового стану), температури повітря, швидкості і напрямку вітру застосовувалася інтерполяція за часом. Розглянуто річний розподіл опадів. Показано, що найчастіше мають місце опади у твердій фазі. Значний відсоток опадів у рідкій фазі спостерігається під час антарктичного літа та антарктичної осені. Частка змішаних опадів найменша протягом року. Вплив фаз опадів на накопичення/танення снігу має сезонний характер. Період з квітня по листопад сприятливий для накопичення снігу. У грудні тверді опади призводять до збільшення висоти снігу, але випадання опадів у змішаній та рідкій фазах сприяє її зменшенню. Найбільше сніговий покрив зменшується в січні-лютому внаслідок танення. У цій роботі акцент зроблено на локальному впливі зменшення висоти снігу внаслідок дії сильного вітру в умовах із супутнім впливом термічного фактора. Подальший аналіз показав, що параметром, найбільш тісно пов'язаним зі зменшенням висоти снігового покриву, була комбінація швидкості та напрямку вітру. Найсуттєвіше зменшення снігового покриву припадає на січень-березень за рахунок процесів танення, проте у добовому масштабі інтенсивність зменшення в цей період не є найвищою. Найбільша частота випадків інтенсивного зменшення висоти снігового покриву (більше, ніж на 1 см / 3 години) спостерігається при північному, північно-східному або південному напрямках вітру. Найбільш часто інтенсивне зменшення висоти снігового покриву спостерігається при північному та північно-східному напрямках вітру за додатних температур. Північний та північно-східний напрямки вітру здебільшого пов'язані з адвекцією тепла і тому зменшення снігового покриву відбувається за рахунок танення. Східний, північно-східний і південно-східний напрямки вітру можна пов'язати із впливом фенових вітрів за рахунок близькості континенту. При південному напрямку найбільша частка інтенсивного зменшення висоти снігового покриву протягом доби має місце за наявності високої швидкості вітру та від'ємної температури повітря.

Ключові слова: адвекція, висота снігу, вітер, температура повітря, фаза опадів