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Meteorological winter conditions in the Central Arctic according to the drifting stations "North Pole 35-40"

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Abstract. The effect of clouds, wind speed and long-wave radiative balance on the surface and near-surface air temperature in the Arctic during polar night is presented. The most pronounced bimodality in frequency distributions of the cloud fraction corresponding to cloudy and clear-sky situations is found for the stations NP-35 (2007-2008), NP-37 (2009-2010) and NP-38 (2010-2011). A strong impact of the presence or absence of clouds on the air-surface temperature difference is shown. For clear-sky situations nonmonotonic dependency of near-surface air temperature on wind speed is found.

The variability of the near-surface air temperature in the Arctic results from complex interactions of many processes from small scale turbulence, sea ice thermodynamics to large-scale advection of temperature and moisture. To identify and quantify the role of each process is crucial. However, this is a complex task and represents a longstanding problem for the atmospheric research.

Previous studies [1, 2] revealed the key factors that have the strongest impact on the near-surface temperature over sea ice. These include the presence or absence of clouds, wind speed and horizontal advection of temperature and moisture. In particular, two typical states of the atmospheric boundary layer (ABL) in winter were identified [3, 4]. The first state is characterized by low surface air temperature, absence of clouds, strong temperature inversion and radiative cooling of the snow/ice surface. Another typical state is a relatively warm, moist and well-mixed boundary layer in the presence of clouds. The predominance of these two states results in the bimodal temperature distribution, which was demonstrated on the basis of observations from Surface Heat Budget of the Arctic (SHEBA) project in the period 1998-1999 [3]. Similar results were obtained during the Norwegian young sea-ICE experiment on January-February 2015 [4].

Factors controlling the magnitude and short-term variability of the potential 2m-air temperature and the surface temperature in the Arctic during winter discussed by [1]. Their study is based on field observations at the Russian drifting stations "North Pole-27, 28" in 1986-1988. They showed that in the situations of clear sky, weak wind and cold advection, surface temperature and air temperature reached the lowest values (-42.3 °C and -40.2 °C, respectively). The effect of wind speed and clouds on the surface air temperature was also presented by [2]. In their study, monthly air temperature averaged over 1950-1991 with various combinations of clear/cloudy skies and strong/weak winds was calculated using the data from the Russian drifting stations "North Pole" (NP). They showed that the average air temperature in February was -40 °C in situations with clear sky and weak winds and -25 °C in cloudy and strong wind conditions.

The main goal of the present study is to assess the effect of clouds, wind speed and long-wave radiative balance on the surface and near-surface air temperature. We used the data of meteorological observations that were carried out at the drifting stations "North Pole 35-40" (NP-35 - NP-40) during the polar-night period (November-February) since 2007 to 2013. Automatic weather station (MAWS 110 and MAWS 420 (Vaisala, Finland)) measured each minute values of the atmospheric pressure, wind speed at 2 and 10 meter height, air temperature and humidity at 2 and 8 meters, the incoming and reflected short-wave radiation, as well as the upward and downward fluxes of long-wave radiation. After the data control procedures, the datasets of hourly mean values were created. The cloud fraction was obtained from visual observations.

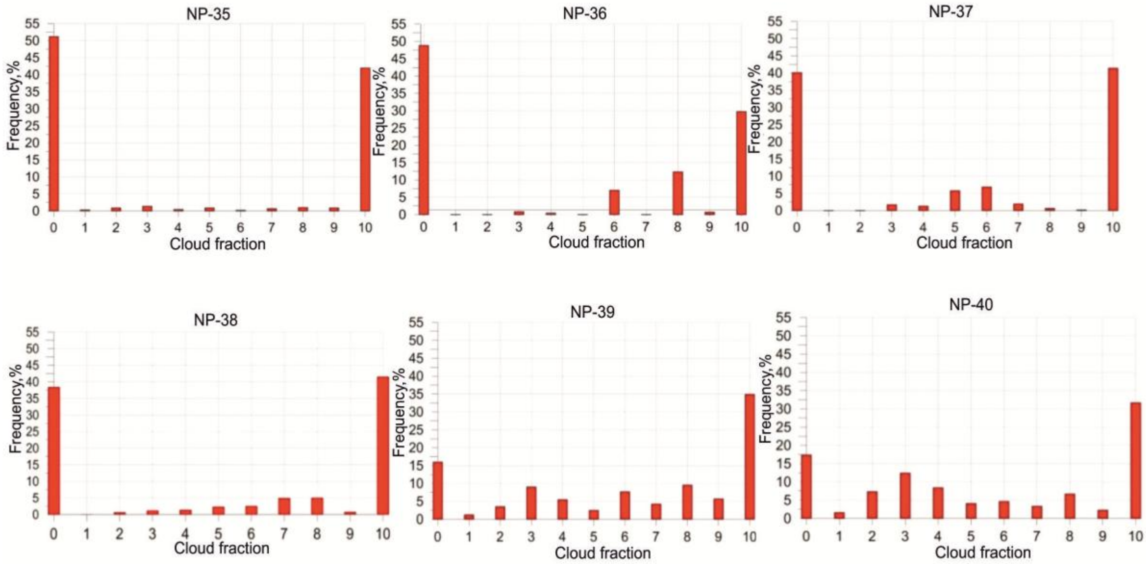

Figure 1. Histogram of the frequency of occurrence of the cloud fraction observed at NP 35-40 in winter.

Figure 1 shows the observed frequency distributions of the cloud fraction (in tenths). The most pronounced bimodality is found for the stations NP-35, NP-37 and NP-38. This is in agreement with earlier study [5]. The frequency of the clear sky at NP-35, 36, 37, 38 varied from 40% to 50%, while at NP-39, 40 it was less than 20%.

The values of air temperature at 2m height, as well as air and surface temperature differences were combined in the following groups, depending on the total cloud amount: 0-2 tenths, 3-7 tenths and 8-10 tenths, and then averaged over the intervals of wind speed in steps of 1 ms^{-1}. The results are shown in Figure 2 (a-e) for the most complete datasets of the stations NP-37, 39, 40.

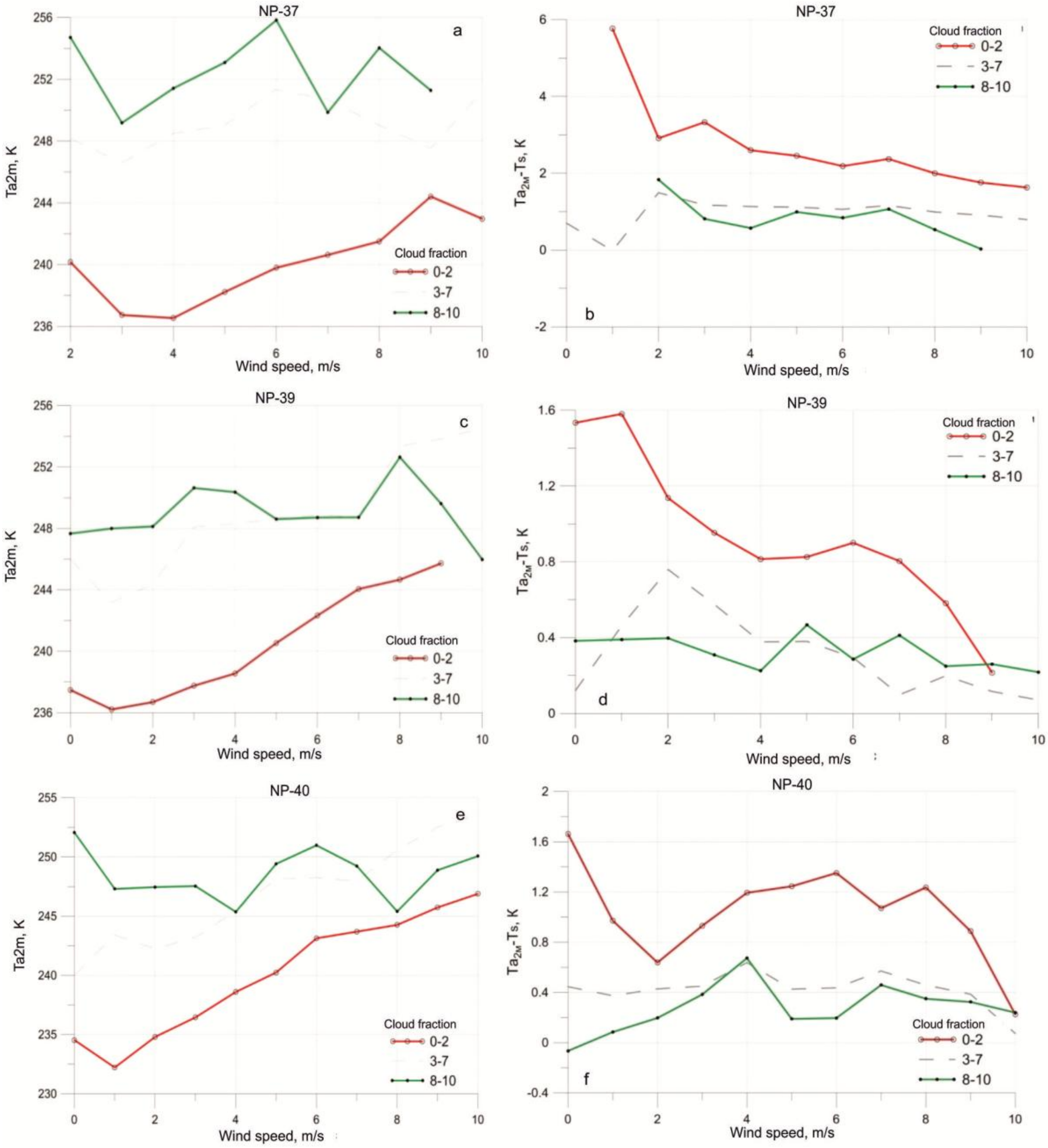

Figure 2. Averaged air temperatures at 2m (a, c, d) and air and surface temperature differences (b, d, e) observed with different wind speeds and cloud conditions in winter at NP-37, 39, 40.

First of all, figure 2 shows that cloudy states are much warmer than the clear-sky cases. The temperature difference between the two states is most pronounced for weak winds and reaches about 15 K. In clear sky conditions (0-2 tenths), the air temperature shows also a pronounced dependency on wind speed. Namely, it increases with increasing wind speed. The lowest temperature corresponds to a value of wind speed 1-4 ms^{-1}, not to the minimum of wind speed. This phenomenon could be explained by the air-surface decoupling at low wind speeds. Decoupling means that the underlying surface and the adjacent air layer become thermally disconnected. The air does not cool from the surface due to very weak turbulence suppressed by stratification and remains warmer than at higher wind speeds. With a further increase in a wind speed (more than a threshold value of 1-4 ms^{-1}), turbulence becomes stronger and warmer air is entrained downward to the level of temperature measurements (2m) and the temperature increases [1]. Another explanation was proposed by [6] and suggested that thicker ABL is associated with stronger wind and it takes longer to cool it. In addition, in the presence of open water areas (polynyas and leads) in the region of observations, stronger wind results in an extraction of larger amounts of heat from the leads which warm the ABL. Assessing the impact of these and other possible factors will be the subject of future research.

Figure 2 also shows that the presence or absence of clouds has a strong impact on the air-surface temperature difference. The explanation for such a dependency was given in [5]. They showed that clear sky conditions are associated with large negative values of the long-wave radiative balance at the surface, which drives surface cooling and results in large temperature difference between air and surface. Indeed, in our dataset, the greatest temperature difference is observed in clear-sky cases. Our analysis also reveals a strong dependency of the air-surface temperature difference on wind speed. Namely, the temperature difference is increasing when wind speed is decreasing. At NP-37, the maximum difference was observed at weak wind and amounted to about 6 K. However, for NP-39, 40 it was less than 2 K. The difference can be explained by a relatively frequent occurrence of the clear sky at NP-37 (40%) and a lower frequency (20%) at NP-39, 40. In cases of a cloudy sky (8-10 tenths), the temperature difference on NP-37 at a wind speed of 2 ms^{-1} does not exceed 2 K, and on NP-39, 40 is less than 1 K.

It is interesting to note that, despite the low frequency of clear-sky situations, the lowest temperature was observed at NP-40 (Figure 2e). Intensive cooling at this station could be formed due to the high frequency of weak winds under prevailing of stationary anticyclones. This assumption can be made on the basis of the frequency distributions of wind speed and atmospheric pressure, shown in Figures 3a, b. It is surprising, however, that no large temperature difference between the air and the surface was observed at NP-40 in such conditions (Figure 2e).

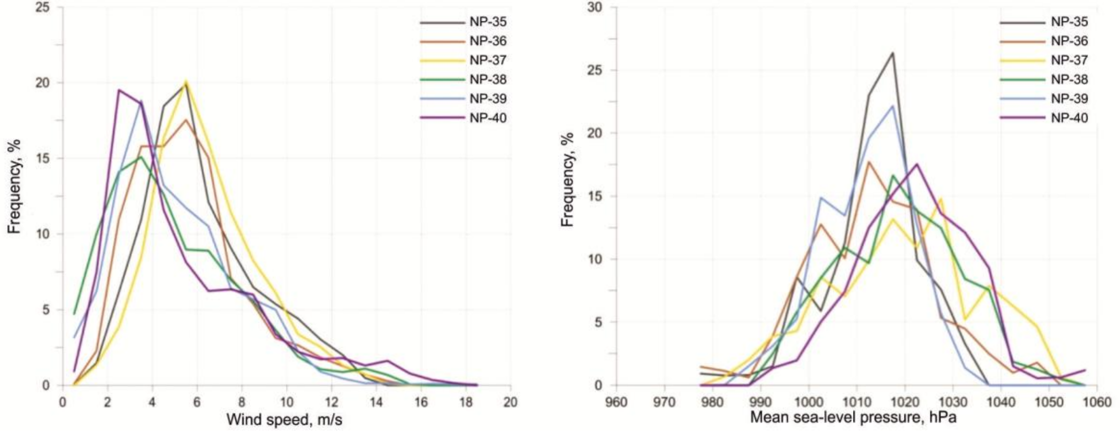

Figure 3. Frequency of a) wind speed and b) mean sea-level pressure at NP 35-40.

The frequency distribution of the net long-wave radiative flux at the surface is shown on Figure 4a. A clear bimodality can be identified related to the bimodality of the distribution of the cloud fraction. However, there are large differences between the stations. Namely, at NP-39, the negative “clear-sky” mode is shifted to less negative values. This might be due to the almost constant presence of clouds at NP-39 for the entire winter (Figure 1). As in [3, 4], the frequency of air temperature was calculated for the net balance intervals of more than -10 Wm^{-2} (cloudy state) and less than -30 Wm^{-2} (clear sky state).

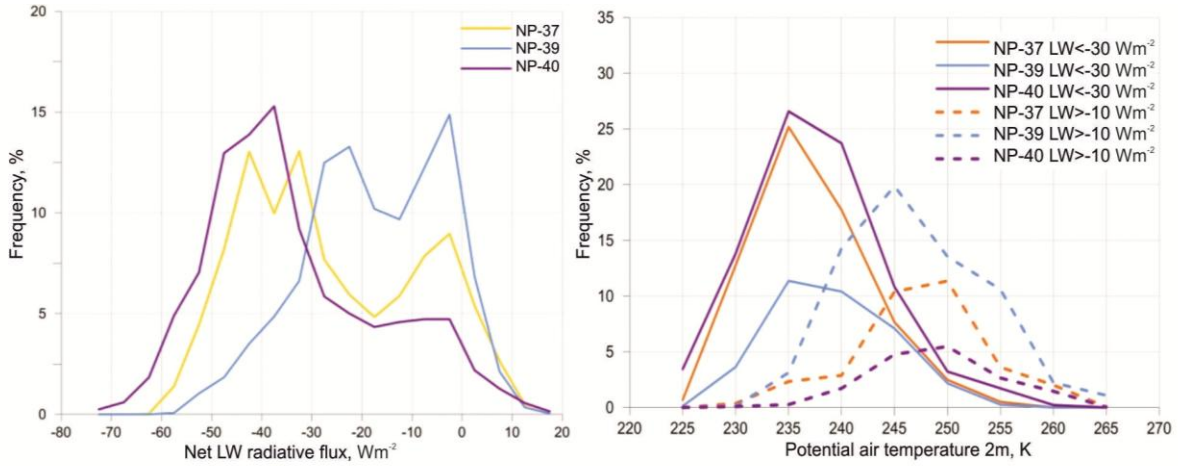

Figure 4. a) Frequency of net long-wave radiation in winter according to NP-37, 39, 40. b) Frequency of air temperature at 2m corresponding to cloudy and clear states (thick dashed and solid lines, respectively).

The typical temperature values for clear-sky cases corresponds to 235 K (-38 °C), for cloudy situations to 245-250 K (-23…-28 °C) (Figure 4b).

The obtained bimodal distributions of cloud fraction and long-wave radiative balance confirm the presence of two states of ABL in the Arctic during winter. One is clear-sky and cold and another is cloudy and relatively warm. High frequency of cloudy days at NP-39 resulted in a less negative balance of long-wave radiation and higher air temperatures.

At the same time, the potential air temperature could reach extremely low values of 226 K (February 2013, NP-40) even in the presence of clouds visually observable but transparent to the long-wave radiative flux.

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References

[1] Vihma T, and Pirazzini R 2005 On the factors controlling the snow surface and 2-m air temperatures over the Arctic sea ice in winter *Boundary Layer Meteorol.* **117** 73–90

[2] Walsh J E and Chapman W L 1998 Arctic cloud-radiation temperature associations in observational data and atmospheric reanalyses *J. Climate* **11** 3030–45

[3] Stramler K, Del Genio A D and Rossow W B 2011 Synoptically driven Arctic winter states *J.Clim.* **24(6)** 1747–62

[4] Graham R M, Rinke A, Cohen L, Hudson S R, Walden V P, Granskog M A, Dorn W, Kayser M and Maturilli M 2017 A comparison of the two Arctic atmospheric winter states observed during N-ICE2015 and SHEBA *J. Geophys. Res. Atmos.* **122**

[5] Makshtas A P, Andreas E L, Svyashchennikov P N, Timachev V F 1999 Accounting for clouds in sea ice models *Atmospheric Research* **52** 77-113

[6] Lüpkes C, Vihma T, Birnbaum G and Wacker U 2008 Influence of leads in sea ice on the temperature of the atmospheric boundary layer during polar night *Geophys. Res. Lett.* **35** L03805