Effect from polynyas in the Siberian Arctic seas to atmospheric transport of heat and moisture

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Abstract. Coastal and fast ice polynyas in the Arctic seas can have a noticeable effect on the Arctic climate, increasing the temperature of the cold air which coming from continental Siberia in winter to these seas and in the Arctic basin [1-2]. In this paper, were studied the effect of polynyas on surface air temperature and on the meridional heat and moisture transfers according to expeditionary observations and ERA-Interim reanalysis. According to the results of expeditionary observations carried out in the 1990s, estimates of heat inflows from the surface of the polynya were calculated. From reanalysis, meridional heat transfers were obtained through 70 ° N, air temperature profiles, wind speed in the region of the Laptev Sea (100 - 140 ° E.), and polynya which located in the Laptev Sea (120 - 130 ° E). It was confirmed that winter transfers of cold air from the mainland do not have a cooling effect on the average winter air temperature north of 70 ° N due to the heating effect of polynya.

1. Introduction
The decisive contribution of atmospheric meridional heat transfer (MHT) to the Arctic energy budget northern than 70 ° N in winter, was established in [3, 4, 5-6]. However, in the calculations of atmospheric transport to the Arctic from reanalysis, aerological observations, and modeling, it was not possible to obtain consistent conclusions about the effect of transport on warming in the Arctic. Moreover, the obtained model and empirical estimations indicated a decrease in atmospheric MHT as opposed to an increase in air temperature [7, 8-10], or the absence of significant changes in MHT [11-12].

The reason for the discrepancies was established in [1–2], in which the distribution of MHT along 70 ° N and in height was taken into account. It was shown that the main MHT in the Arctic in winter enters through the Atlantic sector at 70 ° N between 0° and 80° E ("Atlantic Gate") in the layer from the surface to 750 hPa. But the question remained of the lack of connection between the fluctuations in
the integral transfer of sensible heat through the entire circle of 70 ° N and an average temperature in the region of 70-90°N.

A possible explanation for this was that in calculations of the total influx of sensible heat, the cold air transport from Eurasia through 80-150 ° E makes a big contribution, where in winter the direction of the wind from south to north prevails. But this influx does not have a noticeable effect on the average air temperature in the region of 70-90 ° N, due to the influx of heat from the fast-ice polynyas in the Arctic seas.

Coastal and fast ice polynyas are an important feature of the sea ice cover in the Arctic ocean, where they form between fast ice and drifting ice under the influence of wind [13]. Polynyas play an important role in heat transfer between the ocean and the atmosphere [14,15-16] and in the formation of new ice [17]. The temporal variability of the occurrence of polynyas increased over the period from 1978 to 2008 from 30–70% to 80–100%, and the area of most polynyas in the Arctic Ocean increased 2–5 times [18]. In accordance with this, the volume of ice formed in the fast-ice polynyas also increased. Moreover, an increase in the volume of ice due to an increase in the area of polynyas significantly exceeds the effect of an increase in air temperature during warming in the Arctic [18].

The fast-ice polynya in the Laptev Sea, considered in this study, is located in the region from 120 to 130 ° East, where it was detected by satellite images [19] and confirmed by observations in the expedition as part of the Russian-German project [20], as well as ice cohesion data on the Met Office Hadley Center website (https://www.metoffice.gov.uk/hadobs/). In order to test the assumption about the influence of fast-ice polynyas on the winter heat influx into the Arctic, this paper analyzes the influence of polynya in the Laptev Sea, which is part of the Great Siberian polynya.

2. Data and methods
To detect and take into account the temporal variability of the position of the polynya in the Laptev Sea, a daily archive of sea ice concentration data was used - HadleySST from the Met Office Hadley Center website for the period from 1979 to 2018. Based on the minimum concentration values, it was determined that the polynya considered in this study is between 120-130 ° E and 73-74 ° N (Fig. 1).

![Figure 1. Sea ice concentration (from 0 to 1) for the Laptev sea region, from 1979 to 2018.](image)

For the assessment spatial variability of heat and moisture transfers, as well as a number of meteorological parameters at the surface and pressure levels, daily (00 and 12 UTC) ERA - Interim reanalysis data were used for the entire available period from 1979 to 2018 with a spatial resolution of 0.125x0.125 mesh ° for more detail on the displayed processes.

The calculation of the meridional heat transport JT and moisture JQ through 70° N and 74° N was carried out according to the method which describes in [1-3, 7, 21-22]:

\[
(JT)_g = (Cp t <TV>) g (1)
\]
\[
(JQ)_g = (Lp q <QV>) g (2)
\]

\(t\) - air temperature, °K; \(q\) - specific humidity value, kg / m³; \(v\) is the value of the meridional component of the wind speed, m / s; \(\rho\) - average air density, kg / m³; \(Cp\) - specific heat of moist air at
constant pressure, 1005 J / (kg × K); L - specific heat of vaporization, 2.50 × 106 J / kg; g - time reference (day - month - year).

3. Results
Coastal The effect of polynya on the atmosphere is shown in spatial (latitudinal and longitudinal) profiles of temperature, humidity, wind speed, components of the heat balance.
For greater clarity, in changing the properties of air masses as they move north, the results were calculated and presented for both 74 ° N, where the polynya is located, and for continental air masses by 70 ° N.
From Table 1, the difference in the meteorological parameters between the air masses coming from the continent and their change when moving northward to 74 ° N is obvious: in the region of 115-130 ° E, the air temperature increases, as well as the outgoing longwave flux, the v component of wind decreases.

Table 1. Longitudinal mean profile on 70 °N and 74 °N of surface temperature (T2M), 10 metre v-wind component (V10), sensible heat flux (SSHF) and outgoing longwave radiation (LWU) from 1979 to 2018 in the Laptev sea region.

| Longitude ° E | T2M 70°N °C | T2M 74°N °C | V10 70°N m/s | V10 74°N m/s | SSHF 70°N W/m² | SSHF 74°N W/m² | LWU 70°N W/m² | LWU 74°N W/m² |
|--------------|-------------|-------------|--------------|--------------|----------------|----------------|---------------|---------------|
| 100-110      | -32.6       | -30.2       | 1.3          | 0.3          | -14.8          | -11.5          | 181.7         | 193.7         |
| 110-120      | -33.2       | -27.1       | 1.0          | 1.6          | -22.1          | 14.4           | 183.4         | 212.9         |
| 120-130      | -34.3       | -26.1       | 1.7          | 2.0          | -19.0          | 4.7            | 177.0         | 212.6         |
| 130-140      | -35.0       | -25.6       | 2.2          | 1.5          | -12.4          | -0.5           | 175.6         | 213.2         |
| 140-150      | -33.7       | -25.4       | 0.5          | 0.8          | -10.7          | 0.5            | 181.1         | 214.3         |
| 150-160      | -31.2       | -25.4       | -0.2         | 0.3          | -11.6          | -5.4           | 190.2         | 212.7         |

In the spatial distribution, the effect of fast-ice polynya is noticeable and expressed in a sharp change in the surface air temperature, sensible heat, and the ascending long-wave flow, and in the latitudinal profile, the effect of polynya on the parameters during north-directional air transport can be visually assessed. (Fig. 2)
Ultimately, we can conclude that the Laptev Sea’s characteristic flow of air masses from the continent with low temperatures [23], which noticeably heat up over the polynya region and with their further northward movement over drifting ice, the temperature continues to rise. The warming effect extends only to the surface air layer from the surface level to 950 hPa.

Table 2. Longitudinal mean profile on 70 °N and 74 °N of meridional heat (TV.) and moisture (QV.) transport on the 1000 hPa level, from 1979 to 2018 in the Laptev sea region.

| Longitude | QV       | TV       |
|-----------|----------|----------|
|           | 70° N    | 74° N    | 70° N    | 74° N    |
| deg. E    | kg·m⁻¹s⁻¹ | kg·m⁻¹s⁻¹ | W·m⁻¹    | W·m⁻¹    |
| 100-110   | 0.9      | 0.4      | 3.0      | 1.1      |
| 110-120   | 0.5      | 1.6      | 1.9      | 4.1      |
| **120-130** | **1.0** | **2.3** | **4.3** | **5.8** |
| 130-140   | 1.1      | 1.8      | 5.9      | 4.5      |
| 140-150   | 0.2      | 1.0      | 0.8      | 2.3      |
| 150-160   | -0.5     | 0.4      | -1.4     | 0.9      |

A consequence of the influx of heat from the polynya is the increase in heat transfer to the north in the region of 74 ° N. in comparison with transfer through 70 ° N (Tab.2). In the moisture transfer, it is found that the maximum values fall precisely on the area of the polynya, which is due to evaporation from the surface of open water.

4. Conclusion

The study confirmed that polynya have a significant role in shaping the climate of the Laptev Sea region in the winter. It has been shown that in the transport of heat and moisture, the effect of polynya is clearly traced in the form of an increase in values during heat transfer and, especially, of moisture through 74 ° N in the region of 120-130 ° E., which significantly exceed the transfers through 70 ° N passing over land. This confirms the assumption that the winter transport of cold air from the mainland does not have a cooling effect on the average winter air temperature north of 70 ° N due to the warming effect of polynya.

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