IOP Conf. Series: Earth and Environmental Science **606** (2020) 012032 doi:10.1088/1755-1315/606/1/012032

Sea ice – atmosphere heat exchange during expedition "Transarctica-2019"

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Abstract. This paper describes the characteristics of atmospheric surface layer and heat balance components of snow-ice cover during drift of RV "Akademik Treshnikov" to the north of the archipelagos Franz Josef Land and Svalbard, in the area 80 – 82N, 30 – 45E, in comparison with observations at drifting station 'North Pole-35", worked in the same area in April 2008, and "Ice Base Cape Baranova" in April 2019. Characteristics of atmospheric surface layer and the energy exchange processes during the drift of the expedition"Transarctica-2019" were significantly affected by the presence of clouds and the state of the ice cover. The influence of these factors led to a decrease in the radiative cooling of the surface, the formation of a warmer and wetter ABL and to a weakening of the turbulent exchange between the atmosphere and the snow-ice cover. Comparison of energy exchange characteristics, calculated for the Bolshevik Island (79° N) and for expedition "Transarctica 2019" area shows good agreement between the monthly averaged values and trends in heat fluxes, despite the fact that in the first case the underlying surface was sea ice cover, and in the second it was the land surface.

The expedition "Transarctica-2019" in the northern part of the Barents Sea aimed to study processes in the system "atmosphere – sea ice – ocean upper layer". It focused on the structure and dynamics of the ABL, thermodynamic interaction of atmosphere and snow cover at the end of the polar night and also the heat transfer from Atlantic waters to the sea ice. This paper describes the characteristics of atmospheric surface layer and heat balance components of snow-ice cover during drift of RV "Akademik Treshnikov" to the north of the archipelagos Franz Josef Land and Svalbard, in the area 80 – 82N, 30 – 45E. We compare results of expedition with observations at drifting station "North Pole-35", worked in the same area in April 2008, and "Ice Base Cape Baranova" (Severnaya Zemlya archipelago, Bolshevik island) in April 2019.

To calculate heat balance components of snow-ice cover we use the measurements of the Campbell Scientific gradient meteorological complex. It was installed on sea ice at the distance about 400 m from the ship (Fig.1). This complex provided continuous every minute registration of atmospheric surface pressure (Pa), air temperature (Ta) and relative humidity (RH) at height 2 meters, wind speed (V) at height 10 m, and components of the surface radiation balance (incoming Qdn and reflected Qup short-wave radiation, long-wave radiation of atmosphere Rdn and surface Rup).

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Figure 1. Campbell Scientific gradient meteorological complex in the Ice camp.

Figure 2 shows the spatiotemporal variability of the main parameters of atmospheric surface layer in April 2019 in the area of RV "Akademik Treshnikov" drift. Atmospheric surface pressure Pa, except the first days of observations, varies from 1000 to 1035 hPa. Wind speed V shows a strong variability (0 to 12 m/s).The air temperature Ta reaches a maximum value in the period of atmospheric surface pressure decreasing (April 15-20). For the entire period of measurements the correlation coefficient between Ta and Pa is -0.61 at a significance level of 0.95. The values of relative (RH) and specific (q) humidity changes with air temperature (correlation coefficients are 0.89 and 0.96, respectively). It is interesting that correlation coefficients calculated using dataset from "Ice Base Cape Baranova" for the same period are 0.64 and 0.97. Relatively low correlation coefficient between Ta and RH here shows probably the different origin of the air masses that determine air humidity (mainly of oceanic origin in the drift area and continental for the Bolshevik island).

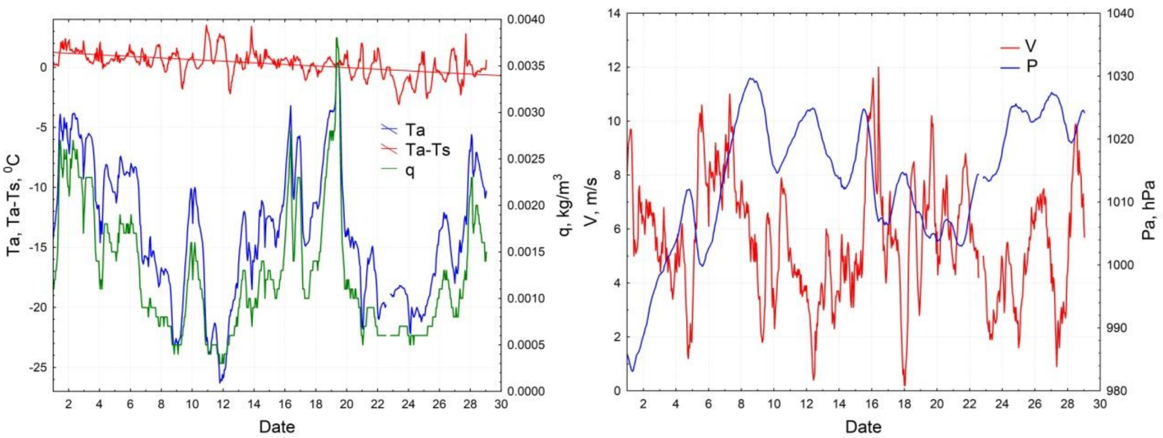

Figure 2. Temporal variability of air temperature and specific air humidity (a), atmospheric pressure and wind speed (b) in April 2019 in the area of RV "Akademik Treshnikov" drift.

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To estimate the components of the snow-ice cover heat balance we use the approach described in [1]. Turbulent sensible (H) and latent (LE) heat fluxes are calculated within a numerical scheme, based on the Obukhov similarity theory [2]. We use the data of wind speed at 10 meters, air temperature and humidity at 2 m and surface temperature, calculated from surface long-wave radiation balance [1]. Specific humidity at z_0 is parameterized under the assumption that relative humidity near the surface is 100%. For unstable stratification of atmospheric surface layer the universal functions, proposed in [3, 4], are used. For stable stratification the stability functions, based on SHEBA experiment [5] are used. The system of equations is solved using iterative procedure for the Monin - Obukhov length parameter (L). Turbulent fluxes are positive from the surface to atmosphere. Shortwave (Q) and long-wave (R) radiation balances are calculated as Q = Qdn-Qup, and R = Rdn-Rup, respectively. Total heat flux to the snow-ice surface (B), calculated as B = Q + R-H-LE is positive from atmosphere to surface.

Figure 3 shows the variability of heat fluxes in the "atmosphere – snow-ice cover" system in April 2019 in the region of drift. The increase of the short-wave radiation balance (Q) due to the longer duration of daylight and the increase of angle of incidence by the end of the month is observed. Latent heat flux is also slightly increasing. At the same time long-wave radiative cooling is shown. Besides, a huge number of cases with unstable stratification (see the figure 3d, histogram) resulted in a significant decrease of sensible heat flux H, usually directed to the surface. So, the total heat flux from the atmosphere to surface decreases from the beginning to the end of April and changes the sign (from 4 to -8 W / m^2).

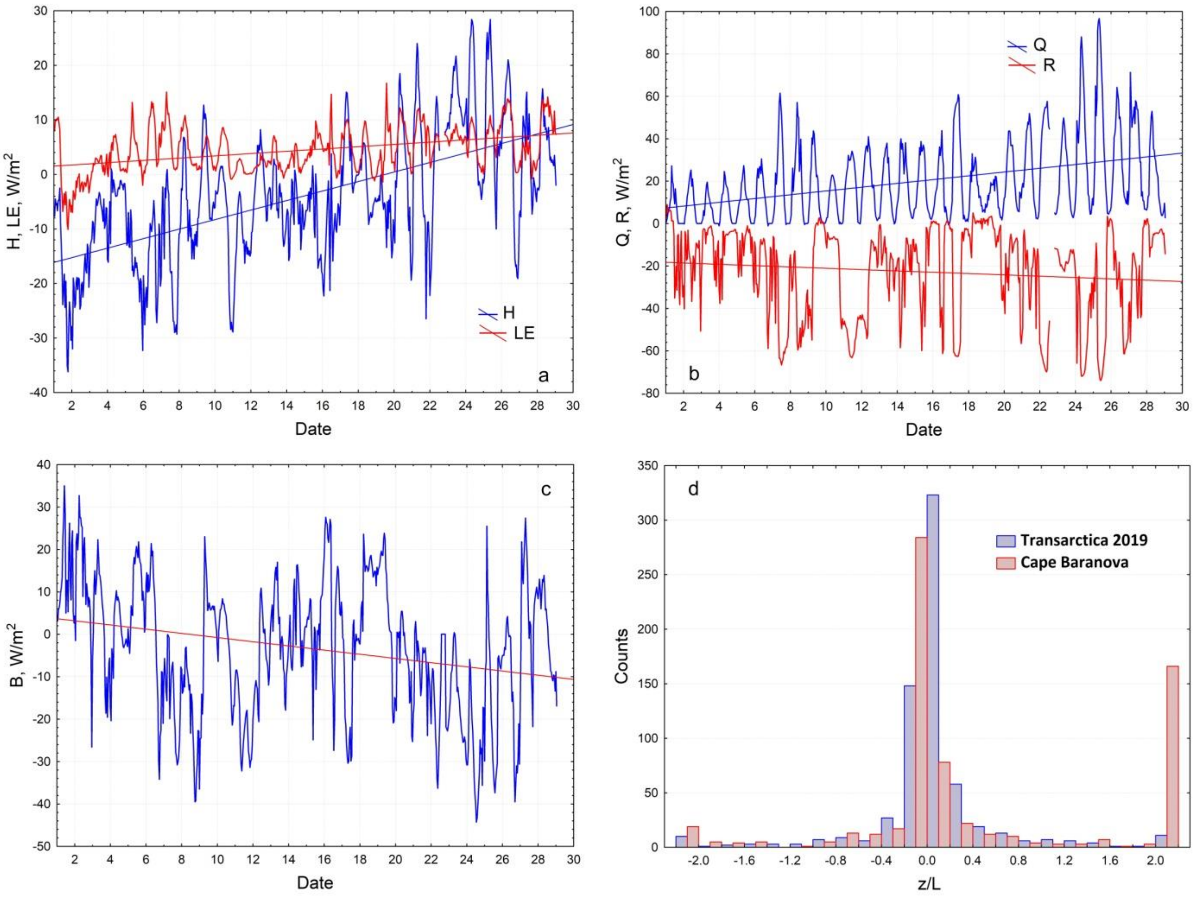

Figure 3. Characteristics of energy exchange processes in the system atmosphere - snow and ice cover in April 2019: a - turbulent fluxes of sensible and latent heat, b - short-wave and long-wave balances of the surface, c - total heat flux from the atmosphere to the snow surface, d - histogram of the frequency of atmospheric stratification parameter during the drift period (Transarctica-2019).

To better understand the meteorological conditions in the northern part of the Barents Sea in April 2019, we analyze atmospheric parameters at drifting station "North Pole-35". It worked close to the "Transarctica" drift area (84° N) in April 2008 (Table 1). For the deeper analysis we add to this comparison meteorological and energy exchange characteristics, obtained at the research station "Ice base Cape Baranova" (79° N, 101 E), in April 2019.

Table 1. Characteristics of atmospheric surface layer and heat balance components of snow-ice cover during drift of RV "Akademik Treshnikov" in comparison with observations at drifting station 'North Pole-35" in April 2008, and "Ice Base Cape Baranova" in April 2019.

Parameter	**Transarctica 2019**				**Cape Baranova (2019)**				**North Pole-35 (2008)**			
	mean	min	max	STD	mean	min	max	STD	mean	min	max	STD
RH 8 m, %	85,9	76,2	93,0	4,6	83,8	73,2	91,4	3,9	82,5	72,8	92,2	5.8
RH 2 m, %	85,9	76,2	92,9	4,6	83,9	74,1	92,5	3,8	84,0	74,0	94,4	6,0
Ta 8 m, ^{0}C	-13,6	-23,3	-5,2	5,0	-16,6	-24,0	-4,3	5,2	-19,2	-29,6	-8,1	6,5
Ta 2 m, ^{0}C	-13,6	-23,6	-5,3	5,0	-16,8	-24,9	-4,8	5,1	-19,4	-29,8	-8,3	6,5
Ts, ^{0}C	-13,9	-25,4	-5,8	4,8	-17,6	-28,3	-7,6	5,1	-21,4	-32,0	-10,1	6,6
Ws 10m, m/s	5,6	2,5	8,4	1,7	4,5	1,2	8,5	2,1	5,2	2,0	9,9	2,0
Pa, hPa	1014	985	1029	10	1004	991	1019	6	1002	991	1044	14
Qdn, W/m^2	107,5	41,0	207,6	47,2	123,1	50,2	239,0	45,6	126,5	60,4	220,8	42,9
Qup, W/m^2	88,5	33,8	171,3	37,6	102,4	32,5	197,7	40,3	103,0	49,8	179,0	34,4
Rdn, W/m^2	234,2	159,8	283,4	31,6	217,7	160,7	269,0	28,5	190,4	142,7	258,7	35,6
Rup, W/m^2	256,3	221,8	290,2	19,1	242,1	203,1	281,7	19,5	228,1	190,9	271,4	24,3
R, W/m^2	-22,1	-53,0	-6,8	12,4	-24,4	-42,4	-12,7	9,0	-37,7	-48,3	-12,7	11,3
H, W/m^2	-3,9	-20,5	13,7	8,6	-3,0	-15,9	4,6	5,6	-22,1	-44,5	-3,2	12,0
LE, W/m^2	4,6	-2,4	10,0	2,7	3,7	-0,3	10,3	2,7	-1,1	-9,4	0,7	2,5
z/L	0,072	-1,09	1,159	0,420	1,962	-0,38	10,52	2,906	1,108	0,067	5,458	1,466

The difference between air and surface temperature and turbulent heat fluxes during the expedition are relatively small compared to those observed at the Cape Baranova and, especially, at drifting station "North Pole-35" (see Table 1, Figure 4). The presence of cloud cover, as it is indicated by lower values of the incoming short-wave radiation, provided predominance of unstable or weakly stable atmospheric stratification (see Figure 3d) and the formation of a mixed boundary layer in the drift region in April 2019.

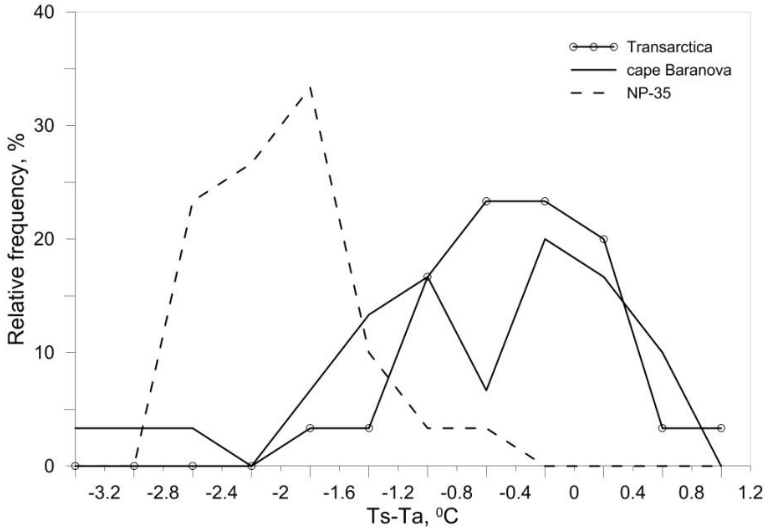

Figure 4. The relative frequency of the difference between the surface temperature and air temperature at a height of 2m.

It is interesting, that comparison of energy exchange characteristics, calculated for the Bolshevik Island (79° N) and for expedition "Transarctica 2019" area shows good agreement between the monthly averaged values (Table 1). Also tendencies in time series of sensible and latent heat fluxes during April (Figure 5) looks similarly, despite the fact that in the first case the underlying surface is sea ice cover, and in the second it is the land surface.

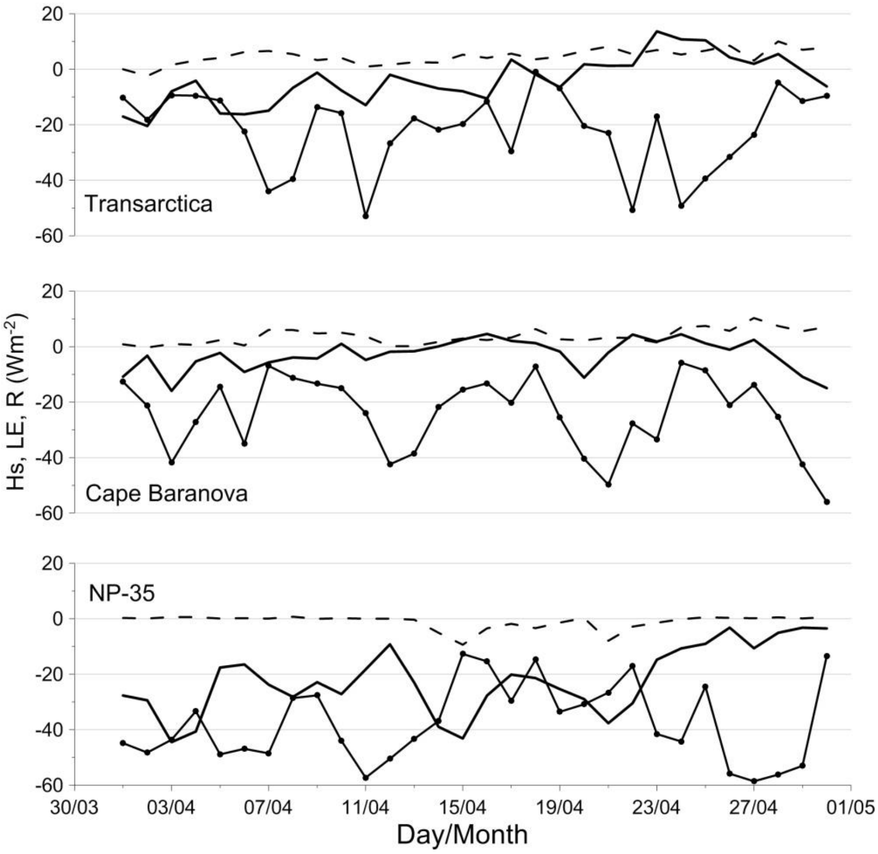

Figure 5. Temporal variability of the daily values of long-wave radiation balance (line with dots) and sensible (solid line) and latent (dashed line) heat fluxes in April in Transarctica, the Ice Base Cape Baranova and the North Pole-35 drifting station.

Drifting station "North Pole-35" (NP-35) worked in April 2008 at about 300 km to the north of the expedition "Transarctica 2019" area. Meteorological conditions and heat fluxes observed in this region in 2008 and 2019 were quite different. We suppose that one of the reasons is the older and thicker sea ice cover at NP-35 (Figure 6). In combination with frequent occurrence of cloudless days it results in strong negative long-wave balance and cooling of the surface. Such conditions provide the formation of a stable boundary layer, and large negative values of the sensible heat flux. Ice Base of the expedition "Transarctica 2019" located to the south of the massifs of old and thick ice, in the area with medium-thick ice and intensive heat flux through the ice. Presence of open water areas and heat advection associated with fractures determine higher temperatures and relative humidity. Thus the characteristics of atmospheric surface layer and the energy exchange processes during the drift of the expedition"Transarctica-2019" were significantly affected by the presence of clouds and the state of the ice cover. The influence of these factors led to a decrease in the radiative cooling of the surface, the formation of a warmer and wetter ABL and to a weakening of the turbulent exchange between the atmosphere and the snow-ice cover.

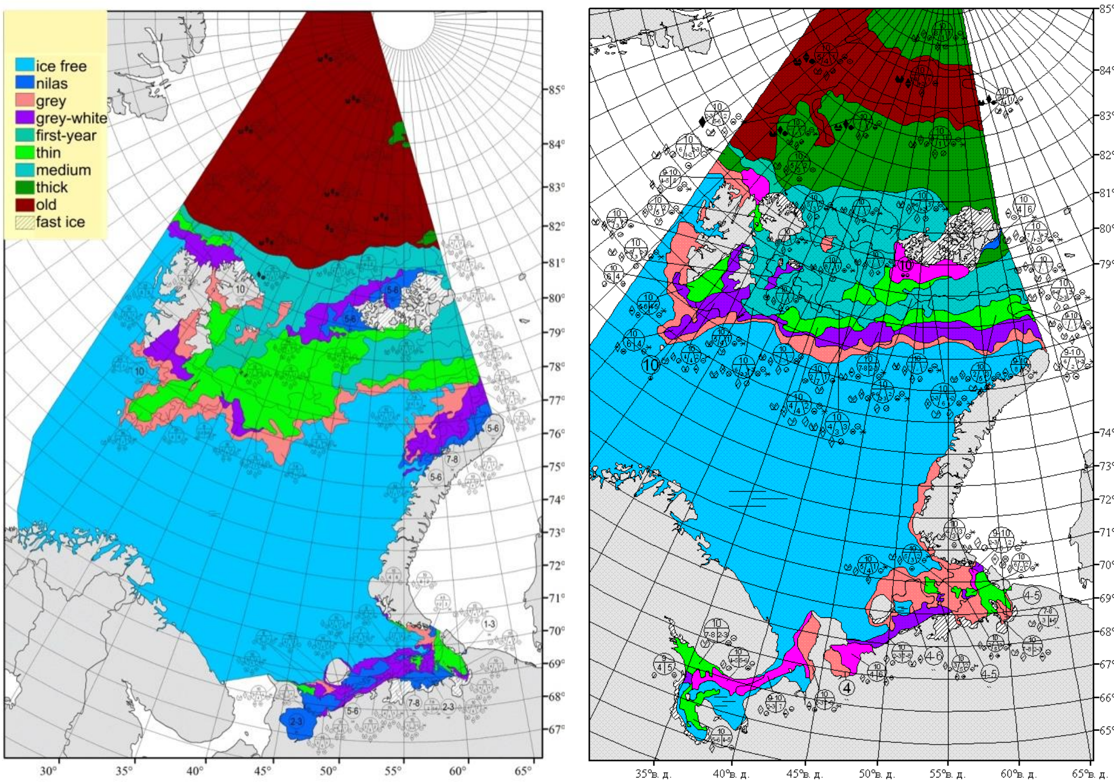

Figure 6. Ice maps: Transarctica April 2019 (left), NP-35 April 2008 (right). http://wdc.aari.ru/datasets/

Obtaining the correct estimates of turbulent heat fluxes, based on various parameterizations, is still an important task. Different assumptions may lead to discrepancies in the values of calculated fluxes (Makshtas et al., 2012). For example, it should be taken into account in sea ice modeling especially for periods of snow-ice transformation in spring. So, slight increase in heat influx sometimes results in a sharp decrease in albedo that intensifies melting processes. We believe that further data analysis of complex observations performed during the expedition “Transarctica 2019” would provide new knowledge about heat exchange processes in “atmosphere – sea ice – ocean” system in the Arctic.

Acknowledgements. This work was supported by the project of the Ministry of Science and Higher Education of the Russian Federation RFMEFI61619X0108.

References

[1] Makshtas A P, Timachev V F, Sokolov V T, Kustov V Yu and Govorina I A 2014 Turbulent energy exchange processes on the border of sea ice - atmosphere according to historical data and data from the North Pole-35 and North Pole-39 drifting stations *Problems of the Arctic and Antarctic* **1(99)** 53-64

[2] Monin A Obukhov A 1954 The main laws of turbulent mixing in the surface layer of the atmosphere *Trudy GI AN USSR* **24(151)** 163-187

[3] Businger J A, Wyngaard J C, Izamai I, Bradley E F 1971 Flux-profile relationships in the atmospheric surface layer *J. Atmospheric Science* **28** 181-189

[4] Dyer A J 1974 A review of flux-profile relationships *Boundary-Layer Meteorology* 7 363-372

[5] Grachev A A, Andreas E L, Fairall C W, Guest P S, Persson P O 2007 SHEBA flux-profile relationships in the stable atmospheric boundary layer *Boundary-Layer Meteorology* **124** 315-333