Environmental pollution impact on radiation properties of atmosphere, snow and ice cover: Study from Barentsburg (Spitsbergen Archipelago)

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Abstract
The value of the albedo of snow and ice surface is associated with the texture and structure of the surface layer of snow or ice (sea ice, glaciers), the peculiarities of the vertical redistribution of contaminations in this layer (mineral or organic particles of various concentrations, the size and shape), temperature regime of the surface layer of the atmosphere. Identifying links with the albedo characteristics of natural and artificial contamination is very important. For example, the results of mathematic modeling the evolution of ice sheets, sea ice and snow cover demonstrate the high sensitivity of the model to this parameter. Original results in the framework of this problem were obtained by researches from AARI and St. Petersburg State University during the 2010-2012 years on Svalbard in the vicinity of the Russian mining settlement Barentsburg. We present original results showing the relationship of "albedo-contaminations" and the influence of anthropogenic factors. The estimation of solar radiation that penetrates deep into the snow, and the impact of contamination on its redistribution in the snow thickness were obtained.

Key words: Spitsbergen, snow cover, atmosphere, anthropogenic pollution

***List of symbols and abbreviations*:** TPP – thermal power plant, HMO – hydro-meteorological observatory, PAR – photosynthetic active radiation, AARI – Arctic and Antarctic Research Institute, BC – Black carbon, p – transparency coefficient, S_0 – solar constant value, S – direct radiation flux value measured by the actinometers, m – mass of the atmosphere.

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Introduction

Climatic system in polar areas is the most sensitive to external impacts, including anthropogenic. At present Russian and foreign climatologists actively discuss the problem of current global warming and possible reasons for this phenomenon. According to the opinion of most of scientists the main reason for current warming is the concentration of carbon dioxide in the atmosphere constantly growing due to the burning of hydrocarbon fuel. The high content of anthropogenic aerosols in the vicinity of large industrial objects leads to a direct effect on the radiation balance of the underlying surface (Khoreva et al. 2012) However, the anthropogenic impact on the climatic system connected with mining and burning of mineral coal significantly impacts the fluxes of short-wave and long-wave radiation which causes significant climatic changes which occur both in the immediate proximity of the pollution source and at various distances. The Russian mining settlement of Barentsburg serves an example of such impact. It is located on the Spitsbergen Archipelago (Western Spitsbergen Island). Coal mining started there in 1931, and has been going till the present time with the interruption due to the World War II. As a result of industrial activity a large quantity of aerosols enters the atmosphere in the form of soot generated by TPP operation and coal particles blown away from coal stockpiles (open type of storage) and piles of rock located in the immediate proximity of the settlement. Afterwards these particles settle on the snow surface causing the penetration of a large amount of carbon particles into the depth of the snow cover. On Svalbard high BC content in snow is common for the areas in the vicinity of mining settlements (Forsström et al. 2009, Aamaas et al. 2011). Transparency of the atmosphere reduces albedo of the underlying surface decreases, flux of solar radiation penetrating into the snow depth changes (Gerland et al. 1999, Wójcik et Marciniak 2002, Kejna et al. 2012, Maturili et al. 2013). Thus, the radiation balance of the underlying surface changes significantly due to the anthropogenic impact.

Material and Methods

In order to assess the anthropogenic impact of carbon-related pollution from 2007 through 2012 scientists of the Arctic and Antarctic Scientific Research Institute and the St. Petersburg State University (Department of Climatology and Environmental Monitoring) were carried out special field observations in the settlement of Barentsburg itself and in its vicinity.

Aerosol attenuation of incoming short-wave radiation was studied by simultaneous (synchronized) measurements of direct solar radiation. One observation post was located in the settlement of Barentsburg, in the immediate proximity of the TPP. The second was established in place not impacted by the emission of aerosols (Cape Fineset, 1.5 km to the south from the settlement). Synchronous measurements were carried out by standard Yanishevsky-Savinov network actinometers AT-50 in the spectral range from 0.3 to 3.0 microns (measurement discreteness 60 seconds). Signals were recorded by one-type portable multimeters Escort EDM-1341 (Germany), resolution 0.01 mV. Observations were performed in compliance with instructional guidelines for actinometrical observations (Guide to hydrometeorological stations on solar radiation observation. L., Hydromet. Publ. 1971).

Actinometrical observations performed in April 2011 in the settlement of Barentsburg and its vicinity allowed calculating the aerosol attenuation of the solar radiation in the atmosphere. The synchronous measurements of the direct radiation flux by AT-50 actinometers were carried out in such a manner that one actinometer received a signal through a "clean" atmosphere (the area of the Cape Fineset), and the second was located on the meteorological site of the HMO "Barentsburg" (area of the settlement near the TPP). Primary measurements were averaged in 10-minute intervals and transparency factors were calculated based on averaged values. Integral transparency coefficients of the atmosphere were calculated according to the special formula (Kondratiev 1969):

$$p = \sqrt[m]{S/S_0}$$

where: p – transparency coefficient, S_0 - solar constant value equal to 1361 W. m^{-2} (http://lasp.colorado.edu/), S – direct radiation flux value measured by the actinometer, m – mass of the atmosphere.

Fluctuations of the solar constant value during the year, mass of the atmosphere and the solar elevation at the time of measurement were taken into account in the calculations (Kondratiev 1969). For experiment conditions the mass of the atmosphere was close to m=2 value. Calculation results are given in Fig. 1.

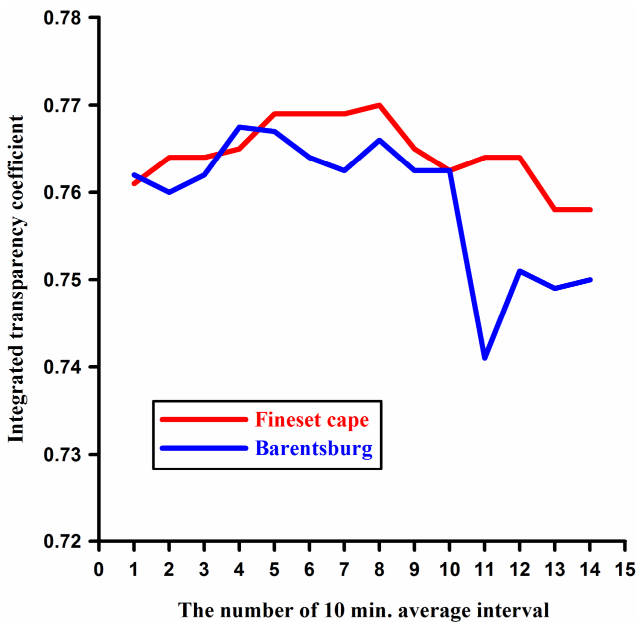

Fig. 1. Value of integral atmosphere transparency factors averaged in 10-minute intervals.

Results and Discussion

Temporal variation of transparency coefficients values corresponds to various conditions of the experiment. At the beginning measurements were made under similar transparency conditions, during the second stage of observations the aerosol cloud (TPP emissions) weakened the solar radiation measured in the settlement, and measurements carried out on the Cape Fineset corresponded to the previous conditions of "clean" atmosphere. Time-averaged integral transparency coefficients amounted to 0.740-0.750 with aerosol pollution and 0.760 without it. Total aerosol attenuation amounted to 21.5 W.m^{-2}. In comparison with similar measurements performed at the same time in 2010 the aerosol attenuation reduced approximately 4 times. Apparently, the recorded reduction of the aerosol attenuation is related to the installation at the TPP of new filters and fuel afterburning systems which took place in summer of 2010.

Similar results were obtained in the analysis of the pollution level of sea ice samples collected from the land-fast ice in the Green Fjord Bay. Collection of ice samples for further determination of contaminants concentration was performed by a tubular drill, dia. 20 cm. Ice samples were prepared directly on ice after the completion of ice temperature measurements. Ice core was placed on a special preparation table. Using a manual stainless saw samples about 10-cm long were prepared on this table. In this case side surfaces of the core which experienced the strongest contact with sea water when extracted from an ice-hole were preliminary cropped to obtain representative values of particle concentration (minimization of the impact of particle wash-out from an ice sample). Then the samples were placed in tight plastic bags and delivered to HMO "Barentsburg" for further laboratory analysis. In order to determine the concentration of suspended particles in molten ice samples (water samples) standard synthetic filters, dia. 42 cm, with calibrated holes, dia. 45 microns, were used. Preliminary preparation of filters and further processing of filters with the suspended matter (drying, weighing) was performed in the Russian-German laboratory named after O.Yu. Schmidt (AARI). A standard muffle furnace and precision electronic weighing device LA230S-0CE (*Sartorius*, Germany) was used. This device weighing accuracy is ±0.01 mg. Water samples were filtered at the chemical laboratory of HMO "Barentsburg" by standard filtration device. In order to determine a volume of filtered sample a graduated flask, volume 500 ml, scale interval 25 ml, was used. Filters with the suspended matter were placed in special plastic cap ("*Petri*" cap) for transportation to AARI.

In order to study the specifics of anthropogenic pollution of the shore ice samples were collected in various areas of the Green Fjord Bay. The main sources of the land-fast ice anthropogenic pollution, similar to the atmospheric pollution, is represented by aerosol emissions from TPP, piles of rock sites located near the Cape Fineset, and coal stockpiles located in the settlement. TPP, without any doubt, is the main source. Taking into account the prevailing wind rose, specifics of stratification on the boundary layer of the atmosphere, granulometry of aerosol one may state that particles mainly settle on the surface of the land-fast ice to the south of the settlement. Penetrating inside the ice and on its surface aerosol particles modify its albedo and represent the interlayer hearth melting which contributes to the accelerated melting of the ace cover in the fjord water area. When the land-fast ice breaks dynamically (tides, ripple) the particles present in the ice can be taken out to the water areas adjacent to Green Fjord Bay (Ice Fjord Bay, Fram Strait). Minimum concentrations of particles (2.9 mg.l^{-1}) were recorded in the southern part of the fjord, maximum (6.1mg.l^{-1}) – on the land-fast ice in the settlement area. These are so-called "weighted average" values for the overall ice thickness which varied from 85 to 65 cm respectively. The method of melted ice sample (water sample) filtration allows determining the "total" concentration of suspended particles in a sample (of mineral or biological genesis), only. We believe that it is aerosol particles of the anthropogenic genesis, in total, because the spring algal bloom typical for the Arctic Region has not started yet during this period (April). It is worth noting relatively low values of maximum concentrations compared to the values obtained in 2009 and 2010. Thus, in 2009, the maximum values reached 30 mg.l^{-1}, in 2009 - 60 mg.l^{-1}. In April of 2011 the maximum concentrations in individual layers did not exceed 8 mg.l^{-1}. The obtained results are explained not only by the improvement of industrial activity at "*Arctic Coal Company*" enterprises (new filters, *etc.*) but also by the reclamation of coal dumps.

Measurements of the reflectivity of the snow cover under the condition of its pollution were performed by Russian standard pyranometers M-80 in the range of wave lengths 0.3-3.0 microns and American pyranometers LI-190SA and LI-192SA in the range of PAR (0.4-0.7 microns). Signals from sensors were recorded by a multi-channel programmable data-logger Li-Cor-1400.

According to the results of measurements snow cover albedo varies within a wide range depending on the degree of surface contamination. The data presented in Table 1 contain mean albedo values for the PAR range averaged for four gradations. It is observed that the fresh snow albedo is more than twice lower that the albedo of heavily contaminated snow covers. As a result of pollution, the share of the solar radiation absorbed by the snow surface increases which, in its turn, accelerates the process of snow cover melting.

Type of surface	Albedo, %
Fresh snow	83
Slightly contaminated surface	80
Moderately contaminated surface	64
Strongly contaminated surfaces	41

Table 1. The results of albedo measurements in visible spectral range over the different type of surface.

The comparison of snow cover albedo values in the Barentsburg settlement, where coal mining activities are in progress, with similar values typical for the Norwegian settlement of Ny-Alesund, where only scientific studies take place and aerosol pollution is minimized, demonstrated than, on average, snow albedo in the range from 0.3 to 3.0 microns in Barentsburg is 15-20% lower than in Ny-Alesund. Comparison results are presented in Fig. 2.

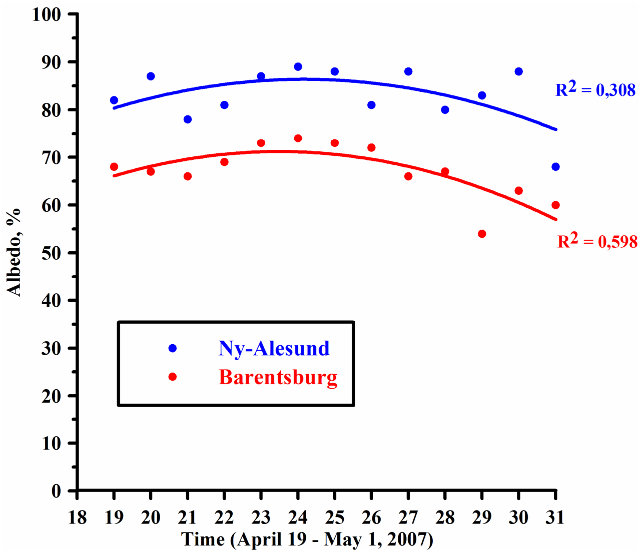

Fig. 2. Snow albedo in Barentsburg and Ny-Alesund settlements in April 2007.

Observation of the impact of pollution on the solar radiation penetrating to the depth of the snow cover included synchronized measurements of incoming, reflected and penetrating radiation in the visible range of wave length. Penetrating radiation was measured at the depth of 5 cm. At each observation point a snow sample was collected from the surface of a 5-cm layer for further filtration of melted samples (water samples) and determination of the pollution level (methodology is described above). Actinometric observations were performed in various places of the Barentsburg settlement which differed in snow contamination degree. The maximum quantities of contaminants were recorded in the area of coal stockpiles which amounted to 1.93 $g.l^{-1}$, minimum values of snow contamination in the settlement amounted to about 0.1 $g.l^{-1}$.

Synchronous measurements of incoming, reflected and penetrating solar radiation in the visible range allowed evaluating radiation attenuation value in the upper five-centimeter layer, taking into account the concentration of contaminants. Attenuation in the upper 5-cm layer varies within broad limits from 50 to 100%. In the pollution interval from 0.12 $g.l^{-1}$ to 0.73 $g.l^{-1}$ it was not possible to clearly reveal the effect of penetrating radiation attenuation increase due to the absorption by carbon-containing particles. Continuation of such field observations and accumulation of new data will allow the evaluation of the dependence.

Performed observations of radiation characteristics of the atmosphere, snow and ice cover demonstrate a significant impact on the surface radiation balance of aerosol components penetrating in the atmosphere and snow-ice cover as a result of coal mining and burning. Without any doubt such impact causes the reduction of (PAR) the lack of which impacts the health of settlement residents. Installation of the modern fuel afterburning system and new filters at the TPP noticeably improved the ecological situation in the Barentsburg settlement.

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