Method of back trajectories to identify sources of atmospheric aerosols on the regional and global scales

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Using the model HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory Model) of the National Oceanic and Atmospheric Administration (USA) based on the standard meteorological data the back trajectories have been constructed of the air mass flow in the atmospheric boundary layer for different seasons (for 30 days in each season) in the north of Western Siberia (in a settlement of Tarko-Sale of the Yamalo-Nenetskii Autonomous District). In this paper we describe the widespread types of the trajectories with regard to their direction and length.

Starting from 1996 the monitoring of atmospheric aerosols (AA) is being performed in the north of Western Siberia to assess the environmental pollution from the sources of local, regional, and global scales.[1–5] By now a considerable amount of experimental data on the spatiotemporal variation of chemical composition of atmospheric aerosols in the northern regions of Western Siberia has been collected. A start has been made on the creation of database of different AA characteristics in Siberia.[6]

The values of daily mean concentrations of different components of chemical composition of AA (element, ion), measured during a long period (about one month), varied over a wide range (by tens times). The interval of these variations depends on the season. The nature of such variations was studied in detail in the 1960–70s after the beginning of large-scale nuclear weapon tests. It was shown that these tests have caused peculiarities in the aerosol transport by air mass in the atmosphere. The complexity and the variety of meteorological processes, describing these regularities, have resulted in the formation of a new research area, which was given the name “nuclear meteorology.”[7–11] In the late 1970’s and early 1980’s the methods of nuclear meteorology were widely used in solving the problems of contamination of the environment.[12–20]

We tried to elucidate the regularities of the observed spatiotemporal variations of the concentration of one or other type of impurities using the meteorological data on the air mass transport. The emission source, as a rule, was well known and clearly identified by a specific characteristic, for example, by a specific radionuclid. For chemical substances in the atmosphere, it is difficult to determine a source of impurity. This is because there exist, as a rule, a great number of possible sources of chemical elements or compounds. Moreover, these sources have different power and are randomly distributed over the territory. In the case when the source power and the position are known, we can calculate rather closely the concentration field and its temporal variation provided that the meteorological conditions are given (see, for example, Ref. 11). In the majority of cases, no complete information, necessary for making calculations, is available, and, hence, other approaches are required. One of the possible ways of solving this problem is described in Refs. 4 and 5.

When arranging the monitoring of atmospheric pollution, connected with the determination of the transport on regional and global scales, at an observation point the concentration of several ingredients is measured simultaneously. Each of the ingredients may originate from several sources. Therefore, one of the primary problems of monitoring is determination (identification) of a specific source as well as the determination of an assumed location of this source.

To identify the remote pollution sources affecting the levels of atmospheric pollution at the points, where the systematic observations are made, either the method of “imprints”,[21,22] or the method of back trajectories of air mass flow are widely used.[15–20,23–28] The basis for the imprints method is the ratio of the concentration of different elements to the basic element concentration. Depending on the problems to be solved a basic element is selected as the most significant tracer representing specific peculiarities of the territory surveyed. The method of back trajectories enables the tracing to be made of the long-distance transport of aerosols of submicron size by air mass, which characterizes the specific properties of meteorological conditions during the observation period.

The trajectories of air mass transport are calculated using different mathematical models with the meteorological database. In these investigations we used the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory Model)[29] and the archived meteorological data (FNL archive) of National Oceanic and Atmospheric Administration (NOAA). The FNL archive of contains information on meteorological parameters in the two hemispherical networks of the polar stereographic projection 129×129 with a step of 190.5 km at 60°N as well as all the basic meteorological parameters at 14 levels from the Earth’s surface up to the level of 20 mbar. The model of the calculation of

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trajectories of the air mass transport enables one to build up the direct and back trajectories with the account for vertical displacements. The maximum period used in the calculations is 5 days, the time step is 6 hours.

The goal of our investigations is to assess the characteristic types of the air mass trajectories at one of the observation points (the settlement of Tarko-Sale of Purovskii Region of Yamalo-Nenetskii Autonomous District) in different seasons. The settlement of Tarko-Sale is located in the subpolar region of low pressure in the area of influence of the Iceland minimum. This region can be considered as a background territory of the atmospheric air pollution since in this region there are no large industrial centers and the soil is covered with snow during 8 or 9 months a year.

For this point the back trajectories were constructed (65°N and 78°E) for all seasons of 1999 for one month in every season, namely, from January 5 to February 10; from April 1 to April 30, from July 1 to July 31, and from November 1 to November 30. The calculations were made for those periods when in 1999 in Tarko-Sale the atmospheric aerosol sampling was performed. The trajectories of 120 hours duration (5 days) were calculated at the heights of 10, 500, and 1000 m. At 10-m height standard meteorological observations were made of the wind velocity and direction. The wind direction at this height is determined by the processes of heat and mass exchange in the atmospheric boundary layer. Therefore, the trajectories at 10-m height show more precisely the specific properties of the variation of pollutant concentration when performing monitoring from the ground.

The height of 500 m is typical for the condition of the atmospheric boundary layer and 1000 m height, to some extent, characterizes the dynamics of air masses in the free atmosphere (the wind speed at this height is close to the value of the geostrophic wind speed). The trajectories at these heights are representative of the long-range transport of pollutants of regional and global scales.

To test the correctness of constructing the back trajectories from final points, the forward trajectories were built up for several periods. In the majority of cases the back and forward trajectories coincided but in some cases they diverged. Therefore, when using this method to identify the aerosol sources, it is recommended that this test should be made.

From all 128 trajectories, we managed to classify 93. These are the trajectories with a definite, although compound, direction. The rest 35 trajectories differ from the above in that during 120 hours the trajectories change repeatedly their direction or at different heights they converge quickly. Table 1 shows the types and subtypes of the trajectories. Six types of the trajectories are recognized, which indicate the main directions from where the air mass moves: N – the north; NE – the north-east; W – the west; S – the south, SW – the southwest; NW – the northwest. Because the 120 hours trajectories are the complicated curves, and the classification contains the subtypes, taking into account all azimuth directions with respect to Tarko-Sale, along which the air mass transport is observed. The subtypes indicate the path length as well as the air mass transport only over the dry land or over the dry land and the sea.

Table 1. Types of air mass transport trajectories

Type No.	Type	Subtype	Direction	Comments	Date, month	Number of subtype days	Number of type days	Number of type days in season	Number of days with stable direction	Type %
1	N	N1	NNW	Till Novaya Zemlya	1–5, 19 Apr; 9, 11, 22 July	9	33	Spring – 16	21	35
		N2	NNW	+ Novaya Zemlya	16–18, 23–24, 26–30 Apr; 2–5, 8, 12–13, 18–21, 30–31 July; 8 Nov	24		Summer – 16 Fall – 1		(26)
2	NE	NE1	NE	Land	22–24, 26–27 Jan	5				
		NE2	NE	+ sea	20–21, 25, 28 Jan; 15, 20–22 Apr; 7, 19–22 Nov	13	18	Winter – 9 Spring – 4 Fall – 5	10	19 (14)
3	W	W1	W	Scandinavia	6 Jan; 27–28 Apr; 1, 14, 23–25, 29 July; 4, 24 Nov	11	13	Winter – 2 Spring – 3 Summer – 6	3	14 (10)
		W2	W	Till 30°E	5 Jan; 25 Apr	2		Fall – 2		
4	S	S	S		9, 15 Jan; 3–4, 10 Feb; 1–2 Nov	7	7	Winter – 5 Fall – 2		8 (5)
5	SW	WS1	WS	Land up to Caspian Sea	10, 13 Jan; 12–13 Apr; 26 July; 14–15 Nov	7	12	Winter – 7 Spring – 2 Summer – 1		13 (9)
		WS2	WS	+ Caspian Sea	7–8, 11 Jan; 8–9 Feb	5		Fall – 2		
6	NW	NWS	NWS		12 Jan; 5–7 Feb; 7–11 Apr; 13 Nov	10	10	Winter– 4 Spring – 5 Fall– 1	8	11 (8)

We have calculated the number of days in the seasons and the total number of days for all the types and subtypes of the trajectories. Of special interest are the days with stable circulation when the type of the trajectory keeps the same during three and more days. In these cases it is easy to identify the sources of pollutants transported by the air mass and to compare the calculations and the results of the experimental observations. The total number of days with stable direction of transport is 42, from those a half (21 days) refers to the north type of trajectories.

In the last column of the table the percentage of the trajectory types is given. The upper number is the percentage of a given type from 93 values, included in this classification, the lower number is the percentage of all the considered 128 trajectories. It is seen from the table that in this region the northwest air mass transport dominates. The northwest component is of 3 types, i.e., the 1st, 3rd, 6th types that is 60% (35+14+11) from 93 trajectories and 44% (26+10+8) from 128. These types of the trajectories are often observed in summer and in spring. The southern and southwestern air mass transport is typical for the winter period. This agrees with the climatic data.

Description of trajectory types

In describing the types of the trajectories N denotes the north direction with the air mass transport from the Arctic regions. The subtype determines the location of the trajectory over the island Novaya Zemlya. NE denotes the transport of the north-eastern direction, most often – from Yakutiya (140°E) but at strong winds the transport of air mass is much farther (on November 22, 1999 the trajectory at 1000 m height originates in America at the longitude of 120°W). The difference between the subtypes depends on that which transport of the air mass can take place over dry land or over dry land and the sea. The majority of the trajectories of the east direction can also be observed over the seas of the Arctic Ocean.

W denotes the trajectories of west direction. Most of the trajectories start in the region of Scandinavian Peninsula and the surrounding seas. However, there are short trajectories, which pass only over dry land.

S denotes the trajectories of the south direction, which have their origin in the area of the lake Balkhash or in the northern areas of this lake.

SW denotes the trajectories of the southwest direction, which either pass over the Caspian Sea, or not.

NW denote the trajectories, which often originate in the polar latitudes, pass along the European territory to the south down to the 50°N not reaching the Caspian Sea.

Figures 1–6 show the calculated 120-hours back trajectories for Tarko-Sale, characterizing the basic types given in Table 1. The upper part of these figures shows the trajectories projections on the horizontal plane, and in the low part of these figures the vertical path projections are given as well as the dates and time. The trajectories are calculated for heights of 10, 500, and 1000 m for the following dates: July 2, 1999 – the type N (Fig. 1), April 20, 1999 – the type NE (Fig. 2), July 24, 1999 – the type W (Fig. 3), January 9, 1999 – type S (Fig. 4), January 10, 1999 – type SW (Fig. 5), and April 8, 1999 – the type NW (Fig. 6).

From the above examples we notice that the trajectories of air mass transport are very complicated. As a rule, at an observation point during a 5-day observation period the air masses from different regions are observed. In this case the regions, from which the pollutants reach an observation point, are different for the sample points located at different heights.

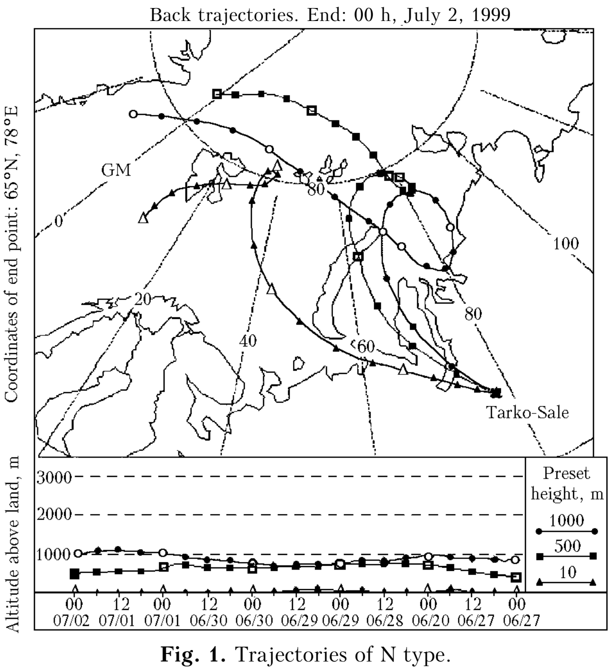

Fig. 1. Trajectories of N type.

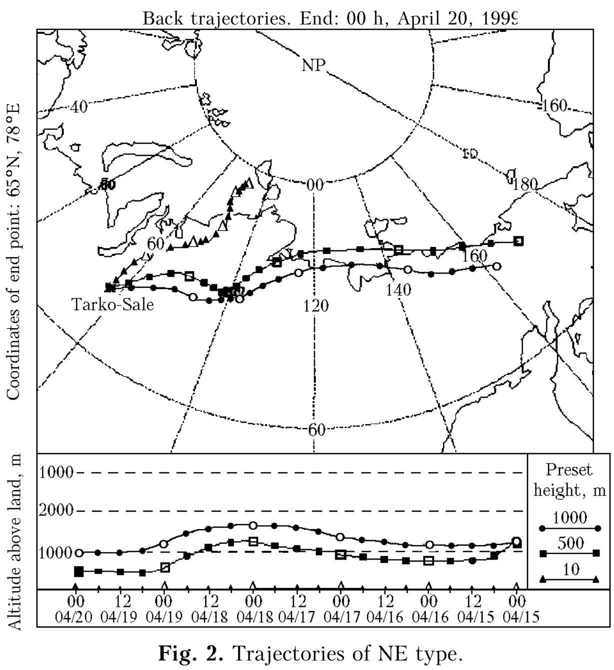

Fig. 2. Trajectories of NE type.

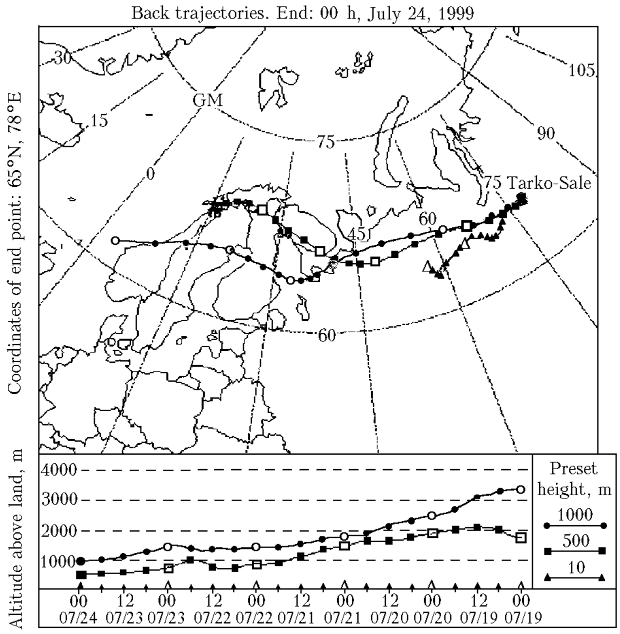

Fig. 3. Trajectories of W type.

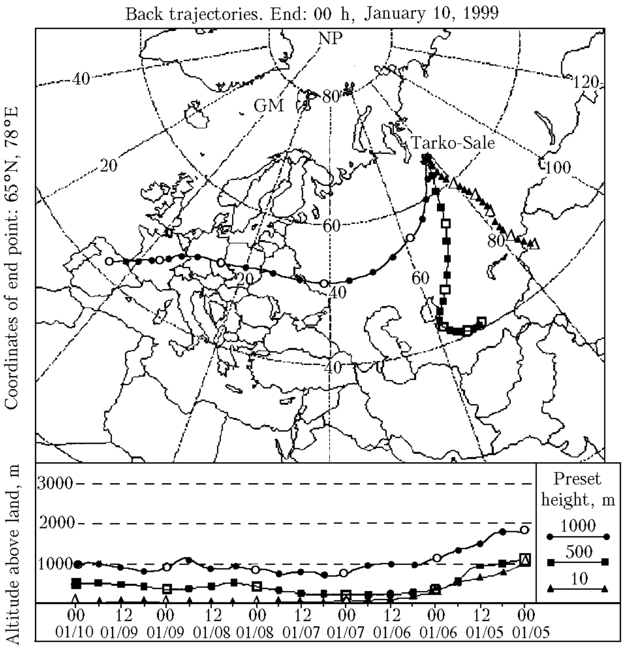

Fig. 5. Trajectories of SW type.

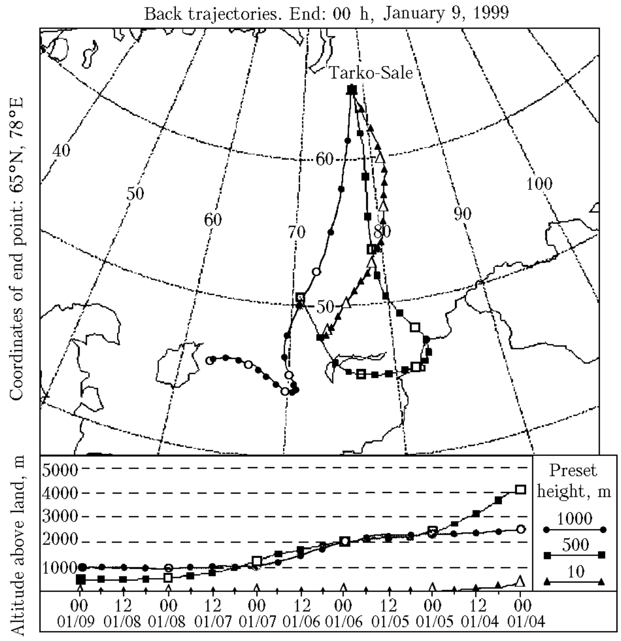

Fig. 4. Trajectories of S type.

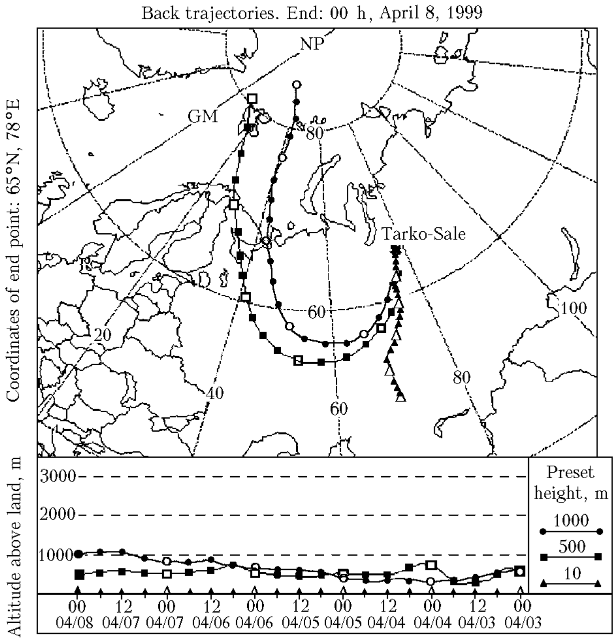

Fig. 6. Trajectories of NW type.

Therefore, when comparing the measurement results on vertical profiles of chemical composition of AA even at one observation point the above fact should be kept in mind, because the average test for aerosols, selected at different heights, can represent the chemical composition of particles from different sources.

The most correct results can be obtained when comparing the chemical composition of aerosol particles, characterizing the type of sources, in case if an indication is given of the spatial location of a sampling point, time, and duration of sampling. The most suitable conditions for interpreting the results of these measurements will be the period when the back trajectories at different heights are in close agreement. Therefore one of the most important problems to be solved using the back trajectories method is the determination of conditions when the above-mentioned requirements are fulfilled. For example, if the sampling was made at 500 m, the most favorable conditions were observed on April 20, 1999 (Fig. 2) and on April 8, 1999 (Fig. 6).

For us, the next problem to be solved consists in seeking optimal conditions to interpret the ground-based observations.

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