INTRODUCTION

Arctic ecosystems are very sensitive to anthropogenic impact. The contamination in the Arctic region to a considerable extent is connected with pollutants emitted from sources located far away from it. Peculiar conditions such as geographical position, low temperatures, sharply defined seasonal variations of solar radiation influence the contamination in various components of Arctic ecosystems.

According to recent investigations of the Arctic contamination the most serious impact on human health in this region inflict mercury and some POPs, in particular PCBs, dioxins and organochlorines similar to dioxins [*AMAP*, 2002a]. As it is reflected in a number of documents there is a public concern that indigenous population of the Arctic is among the most exposed to persistent toxic substances on the Earth [*AMAP*, 1998].

Persistent toxic substances are globally dispersed. Due to their physical-chemical properties they are resistant to degradation, highly volatile and capable to be accumulated in environmental compartments and in biological chains. The contamination of the Arctic region occurs through different ways. An essential role plays airborne transport of contamination from industrial regions as well as, local sources and the riverine runoff and transport by sea currents. In comparison with other natural compartments the atmosphere is one of the main pathways of contamination transport to the Arctic from remote regions of the globe.

Emission sources of the Northern Hemisphere make the most contribution to the pollution of the Arctic domain. Due to the character of atmospheric circulation in the Northern Hemisphere emission sources located in Europe and Asia play a dominating role in the contamination of the Arctic.

The main objective of this work is the assessment of the long-range atmospheric transport of Hg, selected PCBs, and γ-HCH to the five northern regions of the Russian Federation (administrative units): Murmansk Oblast, the Nenets Autonomous Okrug, the Yamalo-Nenets Autonomous Okrug and the Taimyr (Dolgano-Nenets) Autonomous Okrug, Sakha Republic (Yakutia), and the Chukotka Autonomous Okrug.

Physical-chemical properties of Hg and POPs and spatial distribution of emission sources require that evaluation of the long-range airborne transport to the Arctic region are made on hemispheric/global scale with the use of multi-compartment approach. To meet these requirements appropriate modeling tools should be elaborated. Modeling should provide estimates of the major pollution pathways, contamination levels in main environmental compartments and source-receptor relationships.

Extensive efforts were made for preparation of the input data for modeling. These data involved meteorological and geophysical information, physical-chemical properties of the selected substances and their emissions.

As the first step a set of meteorological information for the Northern Hemisphere was prepared. For this purpose a special System of Diagnosis of lower Atmosphere (SDA) was elaborated. The system provides meteorological information for the Northern Hemisphere on the basis of the objective analysis of meteorological fields. Using the SDA system meteorological input data for modeling were generated.

Geophysical data consist of information on land cover, leaf area index, organic carbon content in soil, ozone, sulphur dioxide, and chemical reactant concentrations in the atmosphere. These data were collected from different sources and redistributed over the model grid system.

Available emission data including both official information and expert estimates were collected and processed. Global emission inventory of Hg for 1995 [*Pacyna and Pacyna*, 2002] was provided by the AMAP Secretariat in the framework of this project. Estimates of Hg emissions from natural sources was performed by EMEP/MSC-E. The global emission inventory for 1930-2000 of PCB congeners was taken from [*Breivik et al.,* 2002]. γ-HCH emission data were prepared on the basis of available official information, expert estimates and information on its use in different regions of the Northern Hemisphere.

Physical-chemical properties of Hg, selected PCBs (PCB-28, PCB-118, PCB-153, PCB-180), and γ-HCH were reviewed and analyzed and the model parameterization of main processes of POP behaviour in various compartments was prepared.

Model development was started from the elaboration of the atmospheric transport module for the Northern Hemisphere. This module was extensively tested and the results showed that it could adequately simulate pollutant transport in the atmosphere and did not produce significant numerical errors or distortions. For the description of peculiarities of the mentioned pollutants behaviour in different environmental compartments additional modules (for soil, seawater, vegetation) were worked out.

The hemispheric Hg model was supplied with the module describing chemical transformations of mercury in the atmosphere. This module was elaborated using the experience of ongoing Hg model intercomparison study performed under EMEP. For the hemispheric POP model additional modules describing the distribution of POPs within soil, vegetation, and seawater were elaborated. The model description of POP fate in the seawater compartment takes into account POP transport with sea currents, POP partitioning in seawater and the influence of ice cover dynamics in the Arctic. It is believed that the inclusion of these processes is of importance for proper description of POP fate on the hemispheric scale and in particularly in the Arctic region. The present level of understanding the processes taking place in soil, seawater, and vegetation compartments is insufficient and further investigations are needed.

Special attention is paid to the verification of models and their results. The analysis of sensitivity of model output to variations of different model parameters was made. The developed models participate in the model intercomparison studies, demonstrating reasonable results. Provisional modeling results of Hg and POP transport within the Northern Hemisphere and to individual regions were discussed at various workshops and conferences [*Ryaboshapko et al.*, 2002; *AMAP,* 2002b] and considered by the Steering Body to EMEP [EB.AIR/GE.1/2002/2].

In accordance with the objective of the project the assessment of pollution of the five selected regions of the Russian North by Hg, selected PCBs and γ-HCH from Russian emission sources and from sources of the whole Northern Hemisphere was made. The assessment includes the evaluation of concentration and deposition levels, their seasonal variations and source-receptor relationship for selected areas and the Arctic as a whole. Main pathways of Hg, PCBs and γ–HCH from remote sources to the Arctic were evaluated. Particular attention was given to the fate of these contaminants in different environmental compartments. The effect of Mercury Depletion Events (MDE) on the Arctic pollution was considered. For POPs the transport with sea currents and the effect of ice cover dynamics in the Arctic region were taken into account.

All the results, obtained in the framework of this study, including input data preparation, model development and testing, model outputs are described in this Technical Report. The report is organized in nine chapters and four annexes. Brief outline of its contents is given below.

The first chapter is devoted to a brief description of selected regions of the Russian North from the point of their view of their geographical location and climate conditions affecting the long-range transport of the pollutants under consideration. Along with the main features of air masses and seawater circulation, ice cover dynamics in the Arctic region are discussed.

The second chapter is focused on physical-chemical properties of Hg, PCBs and γ-HCH. Basic properties of the considered pollutants which define their behaviour in various environmental media including partitioning between the gaseous, aqueous and particle phase, removal processes and chemical degradation reactions are discussed. Besides the model description of Mercury Depletion Events (MDE) is also presented.

Chapter 3 is devoted to the model description including processes and parameterization defining the transport and behaviour of persistent toxic substances in the environment. A short review of different modeling approaches to the investigation of the global or hemispheric pollution by toxic substances is given.

Information on emissions of Hg, PCBs, γ-HCH used for modeling in this study and selection of main groups of sources is described in Chapter 4.

Next three Chapters (5, 6, and 7) comprise the main results of the assessment of pollution of the Russian Arctic by Hg, selected PCB congeners, and γ-HCH. Brief description of modeling results for the Northern Hemisphere and the Arctic region is added. General features of the Arctic pollution by these contaminants are outlined. The main attention is concentrated on the selected regions of the Russian North. Levels of concentrations in the ambient air and deposition fields along with their seasonal variations are given. Main contributors to the contamination of the regions are determined and prevailing pathways of the long-range transport are considered.

Chapter 8 is focused on model verification and uncertainties.

Main conclusions are summarized in the end of the Technical Report.

Additional information and modeling results are presented in a number of annexes. Annex A describes supplementary modeling results for PCB-28, PCB-118, and PCB-180. Annex B – atmospheric transport module, Annex C - input data for hemispheric models, Annexes D, E, F – model sensitivity analysis.

For readers convenience the basic outcome of this study is generalized in the Executive Summary issued separately.

References

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