COMPLEX ASSESSMENT OF THE TOXIC POLLUTION OF THE LAKE BAIKAL REGION

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INTRODUCTION

Current paper describes the problem statement, motivation and goals of modelling efforts inside an INTAS-sponsored project "Sources, long range transport and risk assessment of polychlorinated biphenyls (PCBs) in the Lake Baikal region" lead by Prof. M. McLachlan (IOW Warnemunde).

Since the project was started in August 2001, only the model setup and some preliminary results are presented. Considered case is important from methodological point of view as it highlights the challenges to the regulation mechanisms and their application to the local and regional toxic pollution. In particular, many toxic species do not stay only in atmosphere but rather migrate to soil, water, canopies and biota with a potential to survive there for a long time and to emit later to the atmosphere in case of favourable conditions. As a result, the harmful effect of the pollution is not limited by a short time since the release. It may extend to decades with gradual expanding of the contaminated territory. After some time the initial pollution source may be of less importance than the secondary emission occurring from the contaminated environmental compartments.

PROJECT OUTLINE

This chapter presents some extractions from the project work programme.

The project goals are:

1. To identify the primary source(s) of PCBs in the Lake Baikal region.
2. To quantify the spatial distribution of PCB contamination in the Lake Baikal region.
3. To quantify the accumulation of PCBs in the human food chain and human exposure.
4. To assemble a mathematical multimedia model of the fate of PCBs in the Lake Baikal region and to calibrate this model for long range transport of persistent organic pollutants using field data and source information.
5. To conduct a risk assessment of human exposure to PCBs and evaluate the potential to reduce the risk through different management options.

The project addresses a pressing environmental problem in Russia with a particular social urgency. Several studies – e.g. (Mamontov *et al.*, 2000), (Kucklick *et al.*, 1994) – indicate that the whole Lake Baikal region including the sensitive and unique Lake Baikal ecosystem has been contaminated with PCBs at levels up to 1000 times above background by an atmospheric source located in the vicinity of Usol'e Sibirskoe, a centre of the chemical industry. This source has not only impacted the environment; it has contaminated the agriculture food chain and increased human exposure to these compounds.

Lake Baikal, located in east-central Asia, is the deepest (1,637 m) and oldest (25 million years) lake in the world. Almost 20% (or 23,000 $(km)^3$) of the earth's non-frozen surface freshwater is contained in its basin. Lake Baikal is a unique ecosystem; 70 % of the species found there are endemic (including the world's only freshwater seal), and it has been designated a UNESCO World Heritage Site.

Polychlorinated biphenyls (PCBs) are a group of chemicals consisting of 209 different congeners, many of which are highly persistent in the environment and have been shown to be toxic to wildlife and humans. They found widespread use in the 1960's and 1970's, particularly as insulating fluids in electrical equipment, until their production was banned in most industrial countries in the 1980's.

MODELLING SUB-TASK

One of large parts of the project is a development and application of a numerical model capable of simulation of the PCBs transport and fate over a period of decades throughout the whole Baikal region (ca. 700 × 700 km). The model will be tuned and verified against actual environmental observations obtained during the current project.

The multi-media fugacity model forms the basis for the development. The split of the region was largely based on its geophysical properties and PCB levels estimated from the previous measurements and the results of the long-term atmospheric dispersion experiment. Each sub-region constitutes of separate compartments for the most important media (atmosphere, water, soil, sediment, forest canopy, etc.).

LONG-TERM ATMOSPHERIC DISPERSION SIMULATIONS

Since most PCBs have quite low water solubility, it is a natural assumption that the main dispersion in the region happens only due to the atmospheric transport. Consequently, the split of the region in the fugacity model has to take into account the prevailing transport directions, specifics of the expected load pattern, etc. To obtain a qualitative picture of the PCB distribution in the lake Baikal region, a long-term run of the atmospheric dispersion model DMAT (Sofiev, 2000), (Sofiev, in press) was performed.

For the needs of the current experiment, the DMAT was run through the period of 22 years 1967-1988 plus a separate year 1995. Simulations were done in polar stereographical projection with 150 km × 150 km horizontal resolution and 8 non-equidistant vertically staggered layers up to 4350 m altitude. Grid size was 50×50 cells, thus covering the area of ~7500 × 7500 km^2 with the lake Baikal in its centre (Figure 2). Model time step was 1 hour, output 3-D concentration and 2-D deposition fields were generated at a monthly level, except for the 1995, where the daily output was made. Additionally, the daily output was also produced for 1977. Meteorological data for 1967-1988 were taken from the pre-processed NCAR re-analysis archive version 1; data for 1995 were obtained from the numerical forecast model of the Russian Hydrometcentre.

A single particulate point source was put in the same grid cell as the town Usolye Sibirskoye located at the Angara river valley at ~100 km distance north-west from Irkutsk. Particles were assumed to be in 0.1 – 1 μm diameter range, thus corresponding to the most long-range transported range of aerosol spectrum. Being usual for the dispersion simulations of many toxic pollutants, this setup contains high level of uncertainty because the source type in Usolye and, thus, the true size spectrum, are unknown. Two possible source elevations were considered - below and above 100m.

The results (Figure 2) indicate a high non-uniformity of the pollution pattern. Most of the time the pollution plume from Usolye passes through Irkutsk and covers the southern part of the lake Baikal. Detailed simulations for 1995 showed the correlation of ~0.7 between the daily patterns and the multi-annual one presented in the Figure 2.

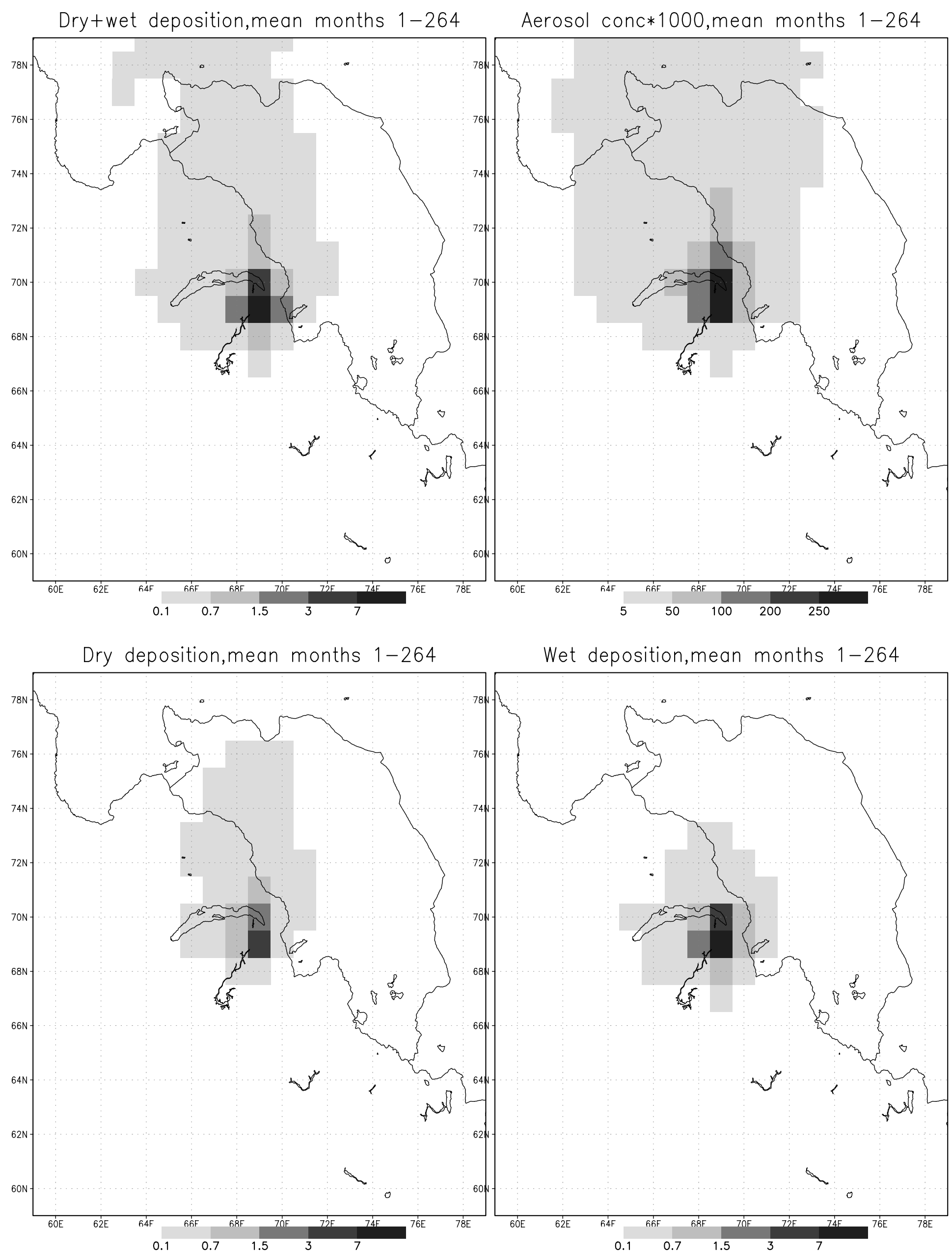

Figure 2. 22-years mean concentrations and monthly deposition (high source). Relative units.

Limitations of the current model run come from the nature of the simulated pollutant – inert aerosol particles with no ability for the re-suspension. Should a typical transport-deposition-re-emission cycle of persistent pollutants is taken into account, the contaminated area will, most probably, be larger. This will be the task for the multi-media fugacity model developed inside the project.

FUGACITY MULTI-MEDIA MODEL FOR THE LAKE BAIKAL

One of specific features of the persistent pollutants is that the main reservoir for the particular species may not coincide with the primary transport medium (usually, atmosphere). For many PCBs the situation is so that they can stay in soil and biota for much longer time than in atmosphere due to chemical degradation. From the other side, solubility in water of these species is quite limited, so the direct soil-air interface (dry deposition and evaporation) starts to play one of the key roles in the contamination dynamics. For the lake Baikal region this interface is affected by the forest coverage, which introduces another chain of the bi-directional pollution exchange, and long-lasting snow cover, which greatly affects the water budget of the whole system and freezes / delays the soil-air exchange processes for several months every year. In the water bodies the amount of dissolved PCBs largely depends on the concentration of organic carbon, which, in turn, makes a link with bio productivity of the water system.

The above-outlined complexity of the PCBs life in the environment require adequate tools for reasonably complete and accurate simulations of their dispersion. As decided for the current project, such tool should be developed on the basis of the multi-media fugacity model (Mackay, 1991), (Wania *et al.*, 1999). Such model has been successfully implemented in the Baltic Sea region during the EU project POPCYCLING (Pacyna, 1999).

Following that approach, the Baikal model considers three basic compartments: atmosphere, water and terrestrial systems (see also Figure 3 for the geographical split of the region). Due to the regional character of the problem and lack of reliable meteorological data, the atmospheric compartment consists of just one well-mixed layer of about 1 km height. The long-term dispersion simulations with DMAT, which showed virtually no pollution above 1 km altitude, also support this configuration. Water compartment is considered as a stacked column of the bottom sediments and the overlying well-mixed water level. They exchange with the organic carbon and the PCBs, plus there is a sedimentation of the particulate matter. Horizontal exchange between the parts of the lake is also taken into account, although believed to be small compare to the atmospheric dispersion.

Terrestrial ecosystems include deciduous and coniferous forest, different types of soil and, during wintertime, snow coverage. Water budget inside the compartment and the exchange with water and atmospheric systems are based on the river discharge, precipitation (rain and snow) and evaporation.

Compare to the POPCYCLING model, the Baikal version explicitly distinguishes between the deciduous and coniferous forest, takes snow into account and provides much more flexibility for the user allowing to him change virtually all model parameters and even to modify the split of the region to the sub-regions. So high level of the program flexibility will be reached via object-oriented programming style of coding combined with intensive use of the relational databases for storing both the model parameters and the simulation results.

ACKNOWLEDGEMENTS

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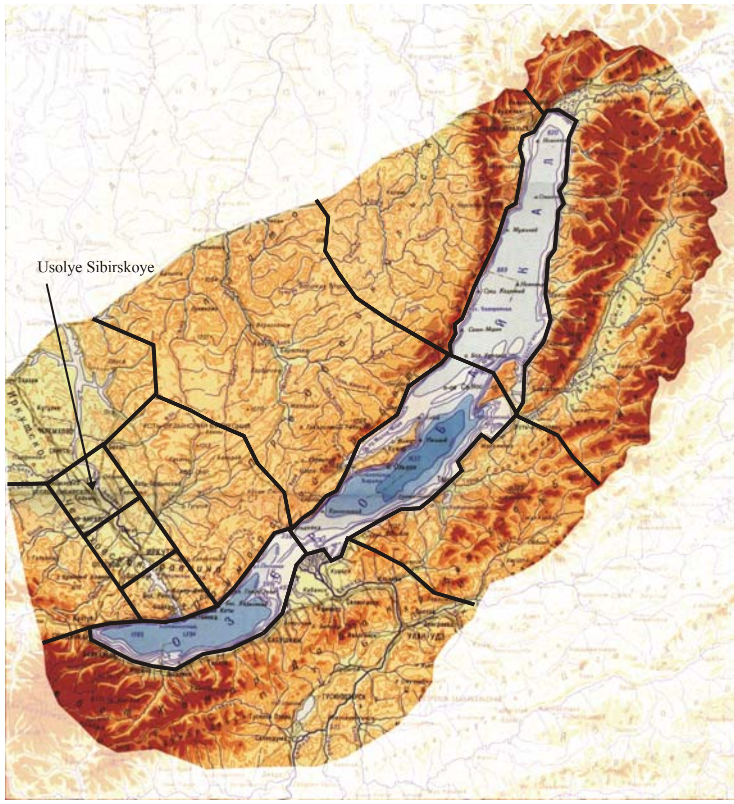

Figure 3. Geographical split of the lake Baikal region. Suspected source in Usolye Sibirskoye is pointed by the arrow.

REFERENCES

Kucklick J.R., T.F. Bidleman, L.L. McConnell, M.D. Walla, G.P. Ivanov, 1994. Organochlorines in the water and biota of lake Baikal, Siberia. Environ. Sci. Technol. **24**, 31-37.

Mackay, D. 1991. Multimedia Environmental Models: The Fugacity Approach. Chelsea, MI: Lewis. 257 pp.

Mamontov A.A., E.A. Mamontova, E.N. Tarasova, M.S. McLachlan, 2000. Tracing the sources of PCDD/Fs and PCBs to Lake Baikal. Environmental Sci. and Technology, **34**, N 5, 741-747.

Pacyna J.M.(ed.) 1999. Environmental cycling of selected persistent organic pollutants (POPs) in the Baltic region. Technical report of the EU POPCYCLING-Baltic project. 151 pp.

Sofiev M. 2000 A model for the evaluation of long-term airborne pollution transport at regional and continental scales. *Atmospheric Environment.* **34**, No.15, 2481-2493.

Wania F., D. Broman, J. Axelman, C. Näf, C. Agrell. 1999. A Multi-Compartmental, Multibasin Fugacity Model Describing the Fate of PCBs in the Baltic Sea. In: Wulff, F., P. Larsson, L. Rahm (Eds.) A Systems Analysis of the Changing Baltic Sea, Springer-Verlag.