POPs in the Arctic: Modelling Transport and Fate

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Introduction

The realisation that many chemicals of commerce are found in the Arctic ecosystem raises a number of questions. Which substances have a high potential to be transported to, and become persistent in the Arctic ecosystem? How long will they persist in the Arctic? Is the Arctic more vulnerable than temperate regions because of "cold condensation"? It is suggested that mass balance models can contribute as tools to help answer these questions, especially if developed and calibrated to be consistent with monitoring data.[1,2] It is argued that the optimal modelling path forward is to develop and compare a variety of models that differ in approach, in complexity and in purpose. In this paper we explore features and potential contributions of some of these models with a view to help answering these questions.

Methods

Existing models are reviewed briefly, including Lagrangian and Eulerian, steady-state and dynamic models.[3,4] Here we focus on Eulerian or "multi-box" models in which the regional continental global environment is represented as a number of "boxes". Some of the properties of these models are discussed, especially the concepts of average chemical residence times and distributions of chemical residence times. It is suggested that a useful approach may be to focus on the fate of chemicals in a steady-state situation in which there is introduction of chemical into only one segment or box and the resulting concentrations in all other segments are estimated. By repeating this with separate introduction into each segment a complete picture can be assembled, in matrix form, of how discharges throughout the various environmental compartments in, for example, the temperate regions can be translated into estimates of steady-state concentrations throughout the entire system and especially in the Arctic. Although the results reflect steady-state and thus hypothetical conditions, the information gained is believed to be applicable to dynamic conditions as actually exist in the global environment. It is shown that solution of the steady-state algebraic equations is most easily accomplished by numerical integration of the corresponding differential equations.

A second and essential step is to estimate the time response of the system, i.e. how long it will take the system to reach or recover from steady state conditions.

A series of simple calculations is described to illustrate these concepts.

Results and Discussion

Results are presented, first for a simple linear or one dimensional configuration of boxes connected by forward and reverse flows. This configuration is similar to the Wania GloboPOP model[8] and the Scheringer model[6]. It transpires that the relationship between the steady-state chemical inventory in a box (g) and the discharge rate into that or another box (g/h) is determined for systems that are linear in chemical concentration by a proportionality constant, namely a residence time (h). This can also be considered to be a persistence and a characteristic response time. This concept is well-accepted for calculating persistence in the box into which chemical is discharged. Residence or characteristic times can be calculated for advective, reaction and total or overall losses.

When the receiving box (e.g. in the Arctic) is distant from the discharge box (e.g. Europe) we term this proportionality constant a "distant residence time" DRT as distinct from a local residence time when the receiving and discharge boxes are the same. The DRT proves to be a useful indicator of the potential of a chemical to be transported long distances. It can, we suggest, be used as a simple criterion of long range transport and is similar in concept to Wania's Arctic Contamination Potential[9]. A distant characteristic time, DCT can also be estimated, but it differs from the residence time. It is best evaluated by applying the unsteady-state or dynamic model.

It is constructive to explore the quantities that control the DRT. These prove to be the overall residence times the chemical experiences in each box as it journeys from source to destination and the forward and backward advective residence times. These can be shown to define a series of “transport fractions”, i.e. the fraction of the chemical entering a region or box that continues its journey to further boxes. These residence times and fractions are likely influenced by temperature (a cold condensation effect?) by the presence of forests (a forest filter effect?) and they are different for different chemicals thus different chemicals migrate at different rates (global fractionation?). If all the boxes have identical properties it can be shown that there is no need to undertake the multi-box calculation. Only a one box simulation is needed.

Results are also presented for a two-dimensional system in which the source to destination journey can be accomplished by a variety of parallel journeys as actually occurs globally. Presumably the chemical’s primary journey is largely controlled by the easiest route involving large transport fractions en route.

Discussion and Conclusions

It is suggested that these concepts can be applied to multi-region, multi-media Eulerian models of transport to the Arctic in both steady-state and dynamic configurations such as the BETR-WORLD[10] GloboPop[8] and even to global circulation models such as that of Leip and Lammel[11]. Further, while the use of average residence time is believed to be key determinant of concentrations and exposures (and presumably of effects), the interpretation of time trend data obtained from monitoring programs requires the use of dynamic models that give distributions of these residence times. Insights into recovery times in the Arctic can, however, be obtained from information on global residence times deduced using these models.

Finally, it is argued that Eulerian multi-box and Lagrangian trajectory models should be viewed as entirely complementary, but to achieve credibility both must be subjected to tests of mutual consistency, and case-specific validation, using monitoring data. The information from these models can help identify new POPs and especially those that have the potential to impact Arctic ecosystems and communities.

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