ASSESSING THE EFFECT OF CLIMATE CHANGE ON THE GLOBAL DISTRIBUTION OF PCBS

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Introduction

Long-term changes in climate have been observed at both the global and local scales; these include changes in surface temperatures and ice cover in the Arctic, widespread changes in precipitation pattern and amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and intensity of tropical cyclones [1]. Since climate change is a serious challenge that humankind currently faces, international agreements have been established, e.g. the Kyoto Protocol, and international scientific cooperation is facilitated by the Intergovernmental Panel on Climate Change (IPCC, 1988).

Like climate change, environmental contamination caused by Persistent Organic Pollutants (POPs) is an issue of global concern. POPs are defined in the Stockholm Convention (2001) as priority toxic pollutants because they persist in the environment and undergo Long-Range Atmospheric Transport (LRAT) and deposition, and have potential for bioaccumulation and adverse effects on human health even in locations far from their sources.

As the environmental behavior of POPs depends on the complex interaction of many factors, any significant environmental alteration is likely to affect their distribution and fate. Some examples are temperature, wind and oceanic current patterns, precipitations distribution, and land cover characteristics. The alteration of any of these factors will influence the environmental distribution and fate of POPs, through changes in reaction rates and partition coefficients, and release rates from secondary sources (e.g. contaminated soil).

This project aims at identifying the consequence of climate change on pollutant distribution at a global scale. In order to reach this objective, a global multimedia fugacity model (BETR Global) was updated and applied under two different climate scenarios. Our climate scenarios simulate changes in temperature, wind patterns, ocean circulation patterns and precipitation. We selected two PCB congeners, PCB-28 and PCB-153 as reference compounds for our analysis because physical-chemical properties, sampling data and emission estimates [2] are available for these two congeners.

Material and Methods

BETR Global is a multimedia fate and exposure model with a spatial resolution of 15° x 15°, resulting in 288 regions, and a monthly resolved description of environmental conditions. Each region consists of 7 environmental compartments (oceanic water, fresh water, lower and upper atmosphere, soil, sediment, vegetation). The model represents advective transport between the regions in air and water as well as intermedia transport processes like deposition and revolatilization within the regions [3].

BETR Global uses prescribed meteorological and oceanic data, i.e. total precipitation rates, 3-dimensional temperature fields and global atmospheric and oceanic circulation fluxes. In this project, these data were derived from the output of ECHAM5/MPI-OM, an atmosphere-ocean general circulation model (AOGCM) The datasets were obtained from the Coupled Model Intercomparison Project (CMIP3) and are representative of the forecasts of the ensemble of models that were used for the Fourth Assessment Report (AR4) of IPCC [4].

We used the 20th century control experiment (20C3M) datasets from the years 1981 to 2000 to construct a climatology representative of the current "status quo" conditions. The CO_2 emission scenario "SRES-A2" defined in the Special Report on Emission Scenarios [5] assumes an increase of the annual global CO_2 emissions to about 30 Gt C/y in the year 2100. We used AOGCM output from 2080 to 2099 based on this emission scenario to derive a climatology representing extreme future climate conditions. The highly resolved datasets from the AOGCM were averaged temporally and spatially to match the resolution of BETR, and used an input to our chemical fate model.

We performed dynamic and steady state calculations using the PCB emission scenarios reported by Breivik et al. [2] and compared the hindcast of present conditions with available field data for different years and locations, provided by EMEP [8] for European countries and by IADN for North American areas [9]. The model results are in satisfactory agreement with observations: in Figure 1 the comparison between model calculations assuming both the default and the maximum emission scenarios is shown for Finland (Pallas, EMEP measurements [8]). Model results for PCB 28 show very good agreement with the field data for this site under the maximum emission scenario, whereas observed PCB 153 concentrations fall between the model results for the maximum emission scenario and the default scenario.

Results and discussion: Influence of a climate change scenario on the fate of PCBs

We performed steady state and dynamic calculations in order to investigate the climate change impact on PCBs environmental behavior. First, we carried out steady state calculations using generic emission and future climate scenarios in order to assess the relative importance of each climate variable in influencing PCBs environmental distribution. Then, we performed dynamic calculations using realistic emission estimates to forecast the effect of climate change on global PCB distribution. Attention was focused on the concentration of PCB in the lower atmosphere compartment of the model, because the model performance was evaluated in our work and in the past for the atmospheric compartment [3].

Steady State calculations

In order to identify the PCB distribution trends from different source areas, we considered five hypothetical emission scenarios assuming respectively North America, Europe, Asia, South America, and Africa as emission regions. At steady state, the PCBs concentrations in air at the emission sources are lower under the climate change scenario than under assumed status quo climatic conditions. Downwind of the source regions however, the model forecasts higher concentrations under the climate change scenario. This trend is most evident when the European region is considered as the source region, and is attributable to the change in wind patterns in both the lower air and the upper air compartments under the climate change scenario, especially accelerated wind speed in the eastward direction.

Future climatic scenarios that assume a change in only one of the factors considered here, i.e., temperature, total precipitation, atmospheric and oceanic circulation, demonstrate that the most influential factors are changes in wind speed, wind direction and temperature. In these model runs, we assumed a real emission scenario [6], and compared the results with the original SRES-A2 future climate scenario, where all parameters change compared to the status quo scenario. For both PCB 28 and PCB 153 increasing temperature under the climate change scenario plays an important role in determining the increasing concentration towards the Poles, while the wind patterns are most important in determining changes in concentration closer to the Equator. These trends are observed for both PCB 28 and 153, but the magnitude of the increase in concentration in the future is higher for PCB 153, possibly due to its higher half life in air (29-90 d compared to 14-29 d for PCB 28 [10]).

Dynamic calculations

We performed model calculations for the status quo scenario and for the SRES-A2 future scenario for both PCB congeners in order to analyze the effect of climate change on the environmental distribution of PCBs in a 100-years future perspective. To this end, we considered updated PCBs emission estimates for the years 1930-2100 [2] for both the status quo and the SRES-A2 future scenarios, and calculations have been performed as follows:

1. we considered a status quo climate scenario for the entire period from 1930 to 2100 in order to define the environmental contamination in the year 2000 for the second calculation; years 2000-2100 were the reference years for comparison with the SRES-A2 scenario;
2. we performed a second calculation assuming a future climate scenario SRES-A2 starting in 2000 and lasting until 2100.

We present the dynamic results in terms of exposure, ε, defined as the time integral of the environmental contaminant concentration c(t): $\varepsilon = \int_{2000}^{2100} c(t)dt$ [7], in our case we considered the integral over the period 2000-2100.

We calculated exposure for both status quo and SRES-A2 scenario in the period 2000-2100 in the lower air compartment and then we considered the ratio between the two values.

Figure 2 shows the ratio $\varepsilon_{fut}/\varepsilon_{pres}$, between the exposure in the future scenario that includes climate change and in the status quo scenario, where the present environmental conditions continue indefinitely. The highest increase in ε in the climate change future occurs for PCB 153, whereas PCB 28 has a smaller increase in exposure under the climate change scenario. This is probably due to its lower half-life in air, and this is consistent with the results found with the steady state calculations.

It can be observed that the ε increases everywhere in the climate change scenario, but exceptionally strong so in the Equatorial regions. This is probably due to the wind patterns, as this trend is also observed for the steady state calculations which define a future climate scenario assuming only a change in wind patterns.

In summary, steady state calculations allow us to identify temperature and wind speed and direction as the most relevant parameters in driving PCBs distribution changes in the lower air compartment due to climate change. Furthermore, the results show that climate change is making the world smaller, because chemical transport is enhanced in the future, and this causes an increasing exposure in the remote regions in the lower air compartment.

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Figure 1: Example of the comparison of the model results with available field data for the sampling station Pallas, Finland.

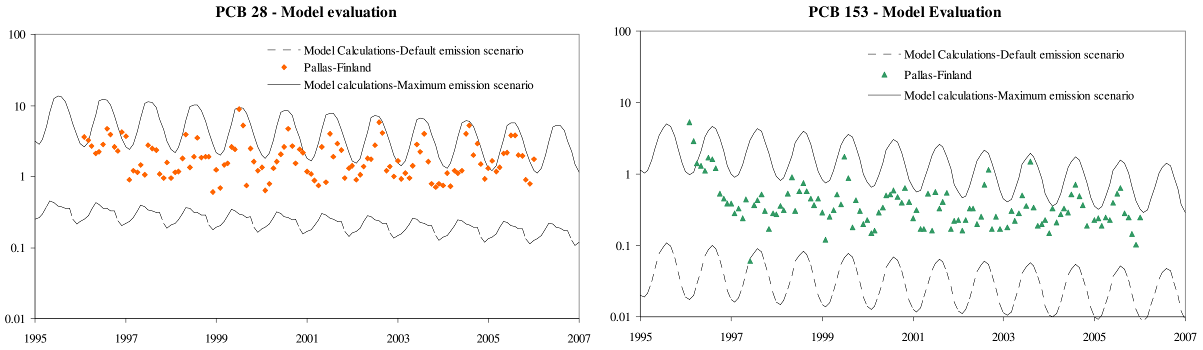

Figure 2: ε ratio between the SRES-A2 and the status quo scenarios for the lower air compartment for PCB 153 and PCB 28 in the period 2000-2100