IMPACT OF CLIMATE CHANGE ON EMISSIONS AND ENVIRONMENTAL FATE OF PERSISTENT ORGANIC POLLUTANTS

Bogdal C[1], Scheringer M[1]

[1]Swiss Federal Institute of Technology, ETH Zurich, Wolfgang-Pauli-Strasse 10, CH-8093 Zürich, Switzerland.

Introduction

Persistent Organic Pollutants (POPs) are considered as a major environmental concern and are globally regulated under the United Nations Environmental Programme (UNEP) Stockholm Convention on POPs[1]. Much research has been performed to investigate emissions and environmental fate of POPs. Also the Stockholm Convention initiated global monitoring programs to perform an effectiveness evaluation of the measures undertaken under the convention to eliminate or reduce POP contamination. Emissions and environmental distribution of POPs result directly from the anthropogenic use of POPs and POP-containing applications, or from the unintentional generation of POPs. However, the environmental fate of POPs is also highly dependent on the prevailing environmental conditions, which are currently undergoing significant modifications in the course of climate change.

Climate change is recognized as a key global issue at present, resulting in many environmental, health-related, social, and economic impacts[2]. Beyond the potential harmful effects of climate change alone, in conjunction with other environmental stressors climate change may present additional serious threats to society and the environment. The potential impact of climate change on the environmental fate of POPs has been investigated only in few individual studies. A comprehensive compilation of existing studies, evaluation of consistent predictions, as well as identification of most urgent knowledge gaps on the relation between climate change and POPs have so far hardly been performed.

To support decision makers, the Secretariat of the Stockholm Convention, in collaboration with the Arctic Council's Monitoring and Assessment Programme (AMAP) invited a number of experts in the field to review the existing scientific knowledge on climate change effects on POPs. In an extensive report, the current state of knowledge about this issue has been presented[3]. Here the chapters about the impact of climate change on emissions and fate, including long-range transport of POPs are summarized and the key findings are presented and discussed in a global and long-term perspective.

Methodology

An extensive review of the existing studies on climate change and POPs was performed, including studies performed by the authors themselves. Confirmed findings and unresolved questions were identified. In intensive discussions with several experts from all over the world, the list of findings was discussed. A classification of the relevance of the different impacts of climate change on emissions and fate of POPs was established. Moreover, needs for further research and policy recommendations were identified and prioritized.

Results

Use and primary sources of POPs

Climate change may affect primary emissions of POPs by changing their use patterns. Furthermore, their rate of mobilization from stockpiles of POPs or POP-containing materials may be increased by higher temperatures.

Currently DDT (dichlorodiphenyltrichloroethane) is the only POP pesticide that is produced and applied in appreciable amounts for malaria control. Increasing global temperatures are expected to intensify the propagation and spread of malaria and other vector-borne diseases. Therefore, larger areas than currently may need malaria control. The existing public health exemption on the use of DDT for combating malaria may, thus, lead to enhanced demand for DDT and, consequently, to increasing primary emissions of DDT.

Increasing ambient temperatures will also directly lead to enhanced emissions of POPs that volatilize from existing POP-containing applications. The vapor pressure of chemicals increases exponentially with temperature, which shifts the partitioning between air and soil, as well as between air and water towards air. Thus, increasing temperatures enhance volatilization and, therefore, lead to increased emissions into air (UNEP/AMAP report[3] and references therein).

Secondary sources and environmental fate of POPs
Climate change will also affect the environmental fate of POPs, once they have been emitted into the environment from primary sources. There are several main factors that are relevant for the environmental fate and long-range transport of POPs and that may be affected by climate change (see Figure 1) (UNEP/AMAP report[3] and references therein).

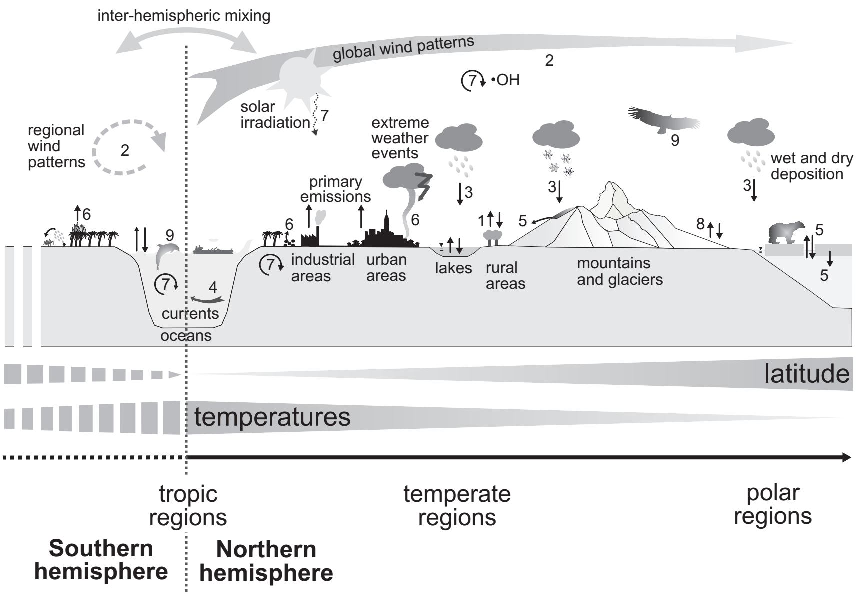

Figure 1 (adapted from UNEP/AMAP report[3]). Conceptual representation of key factors influencing the environmental fate and transport of POPs under a climate change scenario. Numbers in the figure correspond to the enumerated processes in the text below. Note that the processes depicted for the Northern hemisphere are the same in the Southern hemisphere.

(1) Secondary re-volatilization sources. Similar to increased volatilization from primary sources, also releases from secondary sources (soils, water bodies, oceans) are enhanced by higher temperature.
(2) Wind fields and speed. Higher wind speeds lead to more effective transport of POPs. Higher levels of POPs are expected in regions downwind of relevant primary and secondary sources.
(3) Precipitation patterns. Precipitation will mainly be important at the regional scale: in regions with increased precipitation, deposition of POPs from air to surface media will increase; in regions with low precipitation, airborne POPs will be transported more effectively.
(4) Ocean currents. Modifications of ocean currents occurring under climate change will affect the transport of POPs, in particular that of highly water soluble ones such as perfluorooctane sulfonate (PFOS).
(5) Melting ice caps and glaciers. Ocean ice melting will result in air-water exchange of POPs in large areas of the Arctic oceans when they are no longer ice covered. Melting ice leads also to release of POPs trapped in glaciers.
(6) Extreme events. More frequent extreme weather events such as heat waves, floods, and forest fires may occur as a result of global warming. Extreme weather events can lead to remobilization of POPs. For instance, flooding events may cause re-emission and redistribution of POPs formerly stored in sediment and agricultural soils.
(7) Degradation and transformation. Higher temperatures probably lead to increased degradation of POPs. However, it is not clear to what extent the capacity of microorganisms to degrade POPs will increase with increasing temperature, or whether microorganisms will experience thermal stress under climate change.

(8) Chemical partitioning. Climate change can affect partitioning of POPs between different environmental compartments. A key factor is the increase in the vapor pressure of POPs with increasing temperature. This affects both partitioning between bulk phases (air *versus* soil, water, and vegetation) and between the gaseous and particle-bound phases of POPs in air. Stronger emissions from sources (see above) and a shift towards higher gaseous fractions in air may be observed. All of these factors make POPs more available for long-range transport.
(9) Biotic transport. Altered migration patterns of contaminated species (e.g. fish and seabirds) may cause future transport of POPs to previously uncontaminated regions. Recent studies have suggested that, next to atmospheric and oceanic transport, biotic transport of bioaccumulative contaminants (e.g. from guano of Arctic and Antarctic seabirds and death of migrating fish) may be of relevance.

Discussion

Use and primary sources of POPs

Primary emissions of POPs are expected to increase in the future. For DDT, primary emissions may directly increase due to intensified DDT spraying for malaria control when temperatures increase. For POPs that are not used any more, the effect of temperature on their primary emissions is probably the most important effect, stronger than many other effects of climate change on the environmental fate of POPs. Indications for this have been obtained in a computer experiment with a global environmental fate model that compared the effect of increasing temperature, changing wind fields, changing ocean currents, and changing precipitation on the global distribution of polychlorinated biphenyls (PCBs) [4]. In this computer experiment higher concentrations of PCBs in air were observed in all parts of the world. This is mainly caused by stronger emissions from primary sources and, to a lesser extent, also by increased re-volatilization from POP reservoirs in soils and seawater (see secondary sources discussed below).
For *semi*-volatile chemicals, such as most POPs, the emissions by volatilization are particularly sensitive to a small change of their vapor pressure by modified temperature. The global average of surface temperatures has increased by about 0.74°C in the period 1906 to 2005[2]. However, the warming has been neither steady nor the same in different seasons or at different locations. Eleven of the twelve warmest years occurred between 1995 and 2006. Warming has been slightly greater in the northern hemisphere. An increase in temperature of 1°C, which is to be expected in the near future[2], will result in approximately 10%–15% increase in the volatility of a typical *semi*-volatile POP (e.g., PCBs). Locally, temperatures may, however, increase considerably more[2]. A 10°C rise of ambient temperature will result in approximately a three fold increase in the volatility of a typical POP. Therefore, emissions of POPs present in open applications are expected to increase, such as PCBs used as plasticizers in paints and joint sealants, or polybrominated diphenyl ethers (PBDEs) used as flame retardants.

Secondary sources and environmental fate of POPs

The environmental fate of POPs at the global, regional, and local scale will be affected by numerous factors related to climate change. The main effects of climate change on the fate of POPs indicated by the current scientific knowledge include: *(i)* increased mobilization of POPs from environmental reservoirs (e.g. soils, glaciers, the Arctic Sea) by increased temperature, extreme weather events such as flooding, and increased erosion; *(ii)* increased airborne transport to locations downwind of main emission areas because of higher wind speeds (mainly relevant on regional scale); *(iii)* enhanced degradation of POPs (under the assumption that warmer temperature leads to higher degradation capacity of microorganisms), but also increased potential for formation of harmful transformation products; and *(iv)* changes in deposition patterns due to changing precipitation patterns (spatially and temporally); this is mainly relevant on the local to regional scale.

Significance of climate change on emissions and fate of POPs

Due to the effect of climate change on the greater demand for some POPs and increased volatilization of POPs from remaining primary sources, the overall trend of future releases of POPs is likely to increase although predictions still have limited confidence. For some POPs, climate-change-induced enhancement of emissions may reduce the expected effectiveness of the Stockholm Convention, resulting in releases decreasing less rapidly than targeted. For other POPs, such as DDT, continuing or even increasing demand and increasing volatilization of POPs may outweigh reduction efforts, possibly leading to stabilizing or even increasing overall releases of POPs into the environment.

An important component of the Stockholm Convention consists in the effectiveness evaluation. Therefore, a global monitoring program has been initiated under the convention, with the goal to provide comparable data about environmental contamination by POPs in all regions in the world. For the interpretation of global long-term monitoring studies, it will be important to take into account the possible interferences of climate change. For instance, increased re-volatilization from environmental reservoirs such as soil or glaciers will increase levels detected by monitoring programs. In the interpretation of these data and the development of control options under the Stockholm Convention, it will be important to understand the relative roles played by primary and secondary sources, because only then conclusions on the effectiveness of measures to reduce emissions from primary sources can be drawn. Currently, for most POPs primary sources are still expected to be more important than secondary sources. At least for PCBs, the predominance of primary sources has recently been shown[5,6]. In the future, however, secondary sources may take over.

Conclusions

Climate change affects emissions and environmental fate of POPs in several interconnected ways. Releases and environmental circulation of POPs are at the beginning of a complete cascade of further processes that may be affected by climate change. The extensive UNEP/AMAP report[3] includes also chapters about possible impacts of climate change on human and environmental exposure to POPs, human and environmental toxicology of POPs, as well as co-benefits of climate change mitigation activities and POPs emission reduction measures.

The most important research needs associated with climate change and the fate of POPs include: *(i)* better characterization of both primary and secondary sources of POPs (this is highly relevant for the prediction of future levels and trends and for the interpretation of monitoring data); *(ii)* better understanding of the fate of POPs, including the reaction of microorganisms in soil and water to climate change and, in particular, higher temperature (will metabolic activity and thereby the capacity to degrade POPs increase or will thermal stress reduce the capacity to degrade chemicals?); and *(iii)* identification of transformation products of POPs that may be formed in relevant amounts under the conditions of climate change, as well as their potential impacts on the health of ecosystems and human populations.

A key policy recommendation is that political and financial support be provided for long-term POP monitoring programs in all regions of the world. The effects of climate change should be considered as an integral part of the interpretation of long-term monitoring data.

Acknowledgements

The authors appreciate the opportunity for participating in the UNEP/AMAP study and acknowledge international experts for their valuable comments and advice during the preparation of the UNEP/AMAP report[3]. Andy Gilman is acknowledged for the support in the UNEP/AMAP study.

References

1. UNEP. (2001); *United Nations Environmental Programme - Stockholm Convention on Persistent Organic Pollutants.* Available at: http://chm.pops.int.
2. IPCC. (2007); *International Panel on Climate Change Climate Change.* Available at: www.ipcc.ch
3. UNEP/AMAP. (2011). *Climate change and POPs: predicting the impacts.* Available at: http://chm.pops.int.
4. Lamon L, von Waldow H, MacLeod M, Scheringer M, Marcomini A, Hungerbuhler K. (2009); *Environ. Sci. Technol.* 43(15): 5818-24.
5. Schuster JK, Gioia R, Breivik K, Steinnes E, Scheringer M, Jones KC. (2010); *Environ. Sci. Technol.* 44(17): 6760-6.
6. Nizzetto L, MacLeod M, Borga K, Cabrerizo A, Dachs J, Di Guardo A, Ghirardello D, Hansen KM, Jarvis A, Lindroth A, Ludwig B, Monteith D, Perlinger JA, Scheringer M, Schwendenmann L, Semple Kt, Wick LY, Zhang G, Jones KC. (2010); *Environ. Sci. Technol.* 44(17): 6526-31.