FUTURE USE OF DDT TO COMBAT MALARIA: MODEL RESULTS CAN PREDICT EXPOSURE FOR HUMANS AND THE ENVIRONMENT

Schenker U[1], Scheringer M[1], Hungerbühler K[1]

[1] Safety and Environmental Technology Group, ETH Zurich, Wolfgang-Pauli-Strasse 10, 8093 Zurich, Switzerland

Abstract
The insecticide DDT has been used for agriculture and malaria vector combat in the past. It has been phased out in many countries due to concerns about its hazards for the environment and human health. However, the World Health Organization has recently announced that DDT will play an important role in future malaria combat programs, given that it is still very efficient, cheap, and has a low acute toxicity. We have used a global fate model to predict environmental concentrations for the next 50 years in the tropical, temperate, and arctic regions. Results suggest that concentrations in Arctic oceans will be influenced by emissions in the tropics, whereas Arctic soils mainly contain residues from past emissions. The steady-state concentrations in the Arctic (with ongoing emissions for malaria combat) are lower than concentrations in the 1970s by about a factor of 100. In the tropics, the decrease is stopped by the ongoing emissions: steady-state concentrations are only a factor of five lower than maximal concentrations from the 1970s. This suggests that future DDT emissions will threaten the Arctic significantly less than past emissions to temperate regions did. In the tropics, where also the benefits of DDT occur, a significant exposure persists.

Introduction
The insecticide dichlorodiphenyltrichloroethane (DDT) has been widely used in agriculture and against insects that transmit diseases, in particular the anopheles mosquito, the vector for malaria. Although DDT was highly efficient in malaria combat[1] after its first applications in the 1950s and 1960s, its adverse effects on humans and the environment[2-5] have given it a bad reputation. Due to its persistence and potential for long-range transport, DDT can be found at remote locations on the earth[6, 7], and the elevated levels in predators on top of the food chain demonstrate its potential to bioaccumulate[8, 9]. On the other hand, DDT is even today one of the most efficient substances against the anopheles mosquito, has long-lasting effects, is cheap, and the acute toxicity to humans and mammals is lower than for other insecticides[10]. It is believed that the death toll due to malaria could be reduced if DDT were used more frequently[11].

After the widespread usage of DDT in the 1960s in many industrialized countries, the substance was phased out in these regions in the 1960s and 1970s, but it has still been widely used in tropical regions. With the entry into force of the Stockholm Convention on Persistent Organic Pollutants (POPs)[12], DDT use has been restricted to public health purposes. The World Health Organization (WHO), which takes part in many malaria combat programs, encouraged countries to further reduce their reliance on DDT[13], suggesting that the substance be used only if other measures proved unsuccessful. In recent years, many countries have therefore voluntarily agreed to stop DDT usage completely. Therefore, estimated future DDT usage was close to zero. In September 2006, however, the WHO announced that DDT will play an important role in future malaria combat programs[14]. This has re-launched a large discussion on the benefits and risks of DDT.

It is unclear what impact future DDT usage will have on levels in the environment: given that future DDT emissions will primarily occur in the tropics, the persistence of DDT and the extent of its transport to the Arctic will be lower than for earlier emissions that occurred in temperate regions. In the present project, we aim at predicting future levels of DDT using a global environmental fate model and estimated future DDT emission scenarios. On the one hand, this allows us to attribute future levels in the environment to past or future emissions. On the other hand, the model makes it possible to predict “normalized concentrations” (future DDT concentrations as compared to maximal levels in the 1970s) for different geographical regions and environmental media for the next 50 years.

Materials and Methods

We have used the environmental fate model CliMoChem[15, 16] to calculate the fate of DDT in the environment. The model is a zonally averaged global multi-media box model, and assembles a variable number of zones in the north-south direction, within which concentrations are assumed to be homogeneous. Each zone is composed of ocean-water, bare soil, vegetation-covered soil, vegetation, and atmosphere. Environmental processes such as degradation, transport between zones, and exchange between phases are calculated individually for each zone, assuming zone-specific environmental parameters (temperature, soil-type, vegetation cover…). In addition, the model simultaneously calculates the fate of DDT and its transformation products DDE and DDD, which are known to accumulate in the environment, too.

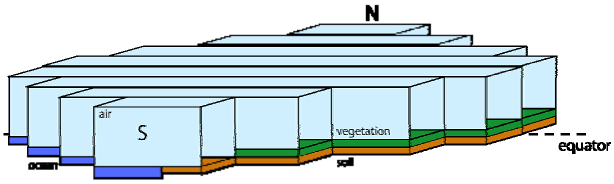


Figure 1: Model structure of the global environmental fate model CliMoChem

Substance property data for DDT and its transformation products were compiled from the literature as described in detail by Schenker et al[17]. The model requires partition coefficients and degradation half-lives of all compounds. Measured partition coefficients usually were available[18, 19], but degradation half-lives, especially for the transformation products, had to be estimated from QSAR software[20].

In order to make our predictions for the future as accurate as possible, we have first assessed the performance of the model and the accuracy of the substance parameters for the past: we have compiled historic emissions of DDT between 1940 and 2005 from three individual studies[21-23]. These emissions were used as input data for the model. Second, we have established a method to compare global multi-media models with measurements in a qualitative and quantitative way and applied this method to the case of DDT[17]. This comparison showed that the model reproduces levels in the environment fairly well. The model performance can be significantly improved if, instead of predicting absolute values, concentration ratios are calculated. This can be the ratio between tropical and temperate regions, the ratio between atmosphere and water, or the normalized concentration (the ratio between the concentrations in a given year, and the maximal historic concentration). Substance properties and model setup parameters generally do not influence the normalized concentration significantly, so that it can be said that future predictions based on this indicator are relatively accurate. Therefore, the normalized concentration was used in the present study.

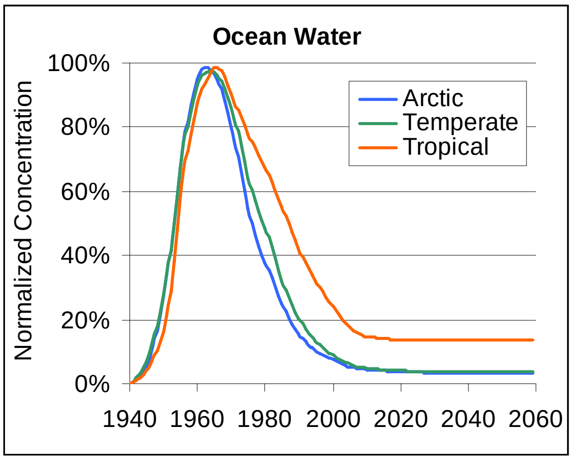
There are, to our knowledge, no estimations available on how much DDT is planned to be used in the future for malaria combat. Therefore, we assumed that from 2005 on continuous emissions of 15’000 tonnes of DDT per year take place. This is about 10% of the maximal sprayed amount in the 1970s (for agriculture and public health purposes). If used only for public health purposes, this amount allows the yearly treatment of 15 millions of households[7, 10]. Estimations from the 1990s[7] state that about 30’000 tonnes of DDT were used yearly for malaria combat[7]. Our assumed future emissions thus represent approximately 50% of the emissions in the 1990s. The costs of these emissions can be estimated, too: the costs of spraying of one household range from $1.60 to $10 per year[10, 24]. The new amount of DDT would thus cost between $25 millions and $150 millions yearly. The yearly US budget for indoor house spraying against DDT until 2005 was only $1 million yearly. The US administration announced that this amount will be increased to $20 million dollars in 2007. Together with direct funding from WHO, governments, and NGOs, this would lie within the amount that is required to treat 15 millions of households.

Results

Figure 2 below displays the evolution of the normalized concentration between 1940 and 2060 based on reported emissions for the past, and estimated emissions for the future. The left panel shows the temporal evolution of the concentration in ocean water, whereas the right panel shows the evolution in vegetation soils. The evolution in atmosphere follows closely the ocean water compartment and is therefore not shown.

Steady-state levels for the time after 2010 differ strongly between tropical regions and the temperate and arctic regions. In the tropical regions, relatively high levels persist (between 15% and 20% of the maximal levels in the 1970s), both in soils and ocean water. On the other hand, in the temperate and arctic regions, steady-state levels will be below 5% in water, and below 1% in soil. The long-term exposure reduction rate is therefore much higher in the arctic and temperate regions than in the tropical regions (which is mainly caused by the restriction of emissions to tropical regions).

Differences between the ocean water and vegetation covered soil can be seen in the rate at which steady-state concentrations are reached: in ocean water, this takes only about 10 years, whereas in the vegetation soil compartment, in particular in the arctic region, concentrations will continue to decrease until after 2060. This shows that levels in the arctic soils are mainly influenced by past emissions, and that future emissions in the tropical regions (as long as they remain on a small scale), do not significantly influence levels in the Arctic soils.



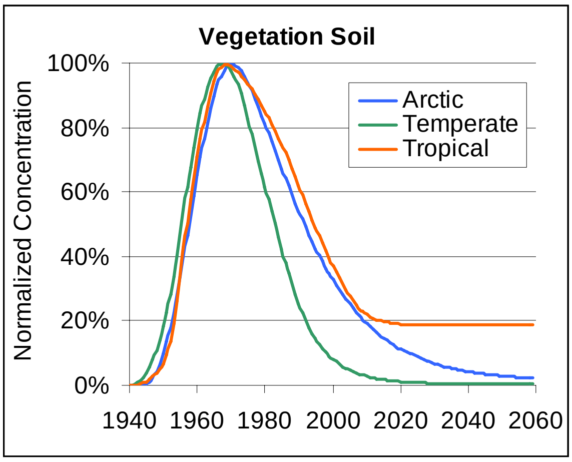


Figure 2: Predicted future levels of ΣDDT (the sum of DDT, DDE, and DDD) in ocean water and vegetation soils of the arctic, temperate and tropical regions.

Estimations of future concentrations can also be made if emissions cease completely in 2005 (not shown). In this case, all concentrations continue to decrease. Again it can be seen that the ocean water concentrations decrease much faster than soil concentrations: by 2015, normalized concentrations of less than 1% are reached in oceans. The soil concentrations, especially in the arctic, take much longer to decrease: a normalized concentration of 1% in vegetation covered soil is reached only in 2060.

Discussion

The results provide insight into the relative importance of future and past emissions for the tropical and arctic regions. If emissions persist at a low level, the environmental concentrations in the tropical regions will remain relatively high, showing that the environmental levels in the tropical regions are dominated by present emissions. In the arctic regions, on the other hand, steady-state levels are much lower than in the past. In addition, the DDT load in Arctic soils is, according to the model, not transferred to Arctic oceans but seems to remain in the soils. Whereas this load may be a source of contamination for land-living organisms, the load of the ocean water is more directly influenced by emissions in the tropics and long-range transport.

The accuracy of the prediction of future emissions is crucial for the findings of our study: there is very little knowledge on how much DDT will be used in the future, and it is thus possible that our emission estimate is not correct. In that case, normalized concentrations (especially for the tropical regions) might be inaccurate: if, in reality, twice as much DDT will be used as predicted here, the normalized concentration would increase to about 40%. On the other hand, if DDT were used in a very restrictive way, the levels in the tropics might decrease to less than 10% of the levels in the 1970s.

Another important limitation is the question of whether it will be possible to restrict DDT usage for malaria combat: once the substance will be widely available in developing countries, it is unclear whether applications of the substance for agricultural usage can be prevented. Non-public-health usages of DDT should absolutely be prevented, as they are believed to increase resistances of the mosquitoes to DDT[25-27]. This would, in term, threaten the success of public health programs.

In an overall assessment, which transcends the purely scientific domain, different aspects of DDT risks and benefits will have to be weighted: the threat to the Arctic marine ecosystem due to persisting levels in the Arctic Ocean, and the risks related to relatively high levels in the tropic soils and oceans (and likely also in food) should be balanced against the benefits from a reduced numbers of malaria cases.

References

1. Annand PN. *J Econ Entomol* 1944; 37: 125-126.
2. Carson RL (1994) in: Silent spring, Boston [etc.]
3. Fry DM. *Environ Health Perspect* 1995; 103: 165-171.
4. Fry DM, Toone CK. *Science* 1981; 213: 922-924.
5. Guillette LJ, Gross TS, Masson GR, Matter JM, Percival HF, Woodward AR. *Environ Health Perspect* 1994; 102: 680-688.
6. McGinn AP. In: *Malaria, Mosquitoes, and DDT,* Worldwatch Institute, Washington DC, 2002.
7. WWF. In: *Resolving the DDT Dilemma,* WWF Canada and WWF US, 1998.
8. AINC-INAC. In: *Canadian Arcitc Contaminants Assessment Report II,* Ottawa, 2003.
9. AMAP. In: *AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic,* Arctic Monitoring and Assessment Program (AMAP), Oslo, 2004.
10. Walker K. *Med Vet Entomol* 2000; 14: 345-354.
11. Bate R, *Without DDT, malaria bites back* in Spiked Science, April 24. 2001.
12. Secretariat for the Stockholm Convention on Persistent Organic Pollutants, *Homepage of the Stockholm Convention on Persistent Organic Pollutants*, http://www.pops.int/
13. UNEP. *Information Document on the World Health Organization's Action Plan for the Reduction of Reliance on DDT for Public Health Purposes* 2000.
14. *News release from 15 September 2006*, http://www.who.int/mediacentre/news/releases/2006/pr50/en/
15. Scheringer M, Wegmann F, Fenner K, Hungerbühler K. *Environ Sci Technol* 2000; 34: 1842-1850.
16. Wegmann F, Scheringer M, Moller M, Hungerbühler K. *Environ Sci Technol* 2004; 38: 1505-1512.
17. Schenker U, Scheringer M, Hungerbühler K. *Environ Sci Technol* 2007; submitted:
18. Howard PH (1991) in: Handbook of environmental fate and exposure data for organic chemicals, Vol. III. Pesticides, Chelsea, Michigan
19. Mackay D, Shiu WY, Ma KC (1997) in: Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Boca-Raton
20. Syracuse Research Corporation, *EPIWin Suite*, http://www.epa.gov/oppt/p2framework/docs/epiwin.htm
21. Li YF, Bidleman TF. In: *Canadian Arctic contaminants assessment report II,* Minister of Indian Affairs and Northern Development, Ottawa, 2003.
22. Semeena S, Lammel G. *Fresenius Environ Bull* 2003; 12: 925-939.
23. Wegmann F. PhD Thesis, Institute for Chemical and Bioengineering, Swiss Federal Institute of Technology Zurich, Zürich, 2004.
24. Brown D, *WHO urges Use of DDT in Africa* in Washington Post, September 16, 2006.
25. Chapin G, Wasserstrom R. *Soc Sci Med* 1983; 17: 273-290.
26. Chapin G, Wasserstrom R. *Soc Sci Med* 1983; 17: 290-290.
27. Curtis CF. *Soc Sci Med* 1983; 17: 287-288.