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BEHIND THE PAPER

The unlikely fate of a term paper

This article belongs to* Ambio*'s 50th Anniversary Collection. Theme: Environmental contaminants

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More than 25 years ago, when I was a doctoral student under the supervision of Don Mackay, *Ambio* published my second peer-reviewed, scientific paper on the global fractionation and cold condensation of low volatility organochlorine compounds in polar regions (Wania and Mackay 1993a). The context of the paper was the discovery, a few years earlier, of concentrations in Inuit populations being surprisingly high relative to those of populations living in urban environments further South (Dewailly et al. 1989). While it was clear quite quickly that this is related to the unique diet of the Inuit, which includes marine mammals that eat at a high trophic level (Muir et al. 1988), it was somewhat unclear whether it is long range transport (Oehme and Ottar 1984) or local contaminant sources, such as the military radar stations of the Distant Early Warning line (Bright et al. 1995), that are primarily responsible for contaminating the Arctic Ocean environment.

The publication had its origin in a student term paper I wrote for a graduate course in the Institute for Environmental Studies at the University of Toronto. At the time, the idea of contaminants "condensing" from the atmosphere at the low temperatures prevailing in the polar regions had been floated a number of times, but had not been defined or explored in detail to any significant extent. The term paper had three parts: (i) an attempt at clarifying the concepts of cold condensation and global distillation of contaminants in the environment, (ii) a compilation of measured contaminant data from the literature to investigate whether any of them can provide evidence of cold condensation phenomena, and (iii) simple mass balance calculations involving "unit world" environments of different temperatures that are linked by advective atmospheric transport. The review of available data, in particular, revealed notable differences in the distribution patterns of compounds of high volatility (such as hexachlorobenzene and hexachlorocyclohexanes) and low volatility (such as the polychlorinated biphenyls and DDT), which we related to the temperatures, at which these compounds shift their equilibrium phase distribution from the atmospheric gas phase to condensed phases, such as aerosol particles and the Earth's surface.

The idea to submit the paper to *Ambio* was mine and I still marvel at my supervisor's magnanimity to let me make that decision. I had enthusiastically read the journal as an undergraduate student, admired the scope and quality of the material it published, and having a paper appear in it was the height of my ambition as a fledgling researcher. In retrospect, it was an inspired choice, because the paper reached a very receptive audience in Scandinavia, where much of the work on which it relied had been done.

The modelling calculations did not make it into the published *Ambio* paper, because editor Elisabeth Kessler was quite adamant about enforcing the word limit on submissions. It was disappointing at the time, because it appeared to me to be the more genuinely novel contribution of the paper, which for the most part was a review of earlier studies. However, it was probably a wise decision, as empirical research has since found evidence that a paper's impact is diminished the more equations appear on its pages (Fawcett and Higginson 2012). In any case, a more elaborate version of those calculations eventually found its way into print (Wania and Mackay 1993b) and, indeed, that paper has merely a fraction of the citations of the *Ambio* paper.

While it is apparent that the concepts of global scale distillation and cold trapping captured the imagination of many concerned with chemical pollution, the surprisingly large impact of the *Ambio* paper was likely related to the international efforts towards a global treaty on banning the most troublesome organic pollutants that were initiated in the early 1990s and that eventually led to the signing of the

Stockholm Convention on Persistent Organic Pollutants. Our paper synthesized the state of knowledge at the time concerning the ability for contaminants to disperse globally across national boundaries and to build up to levels in remote oceans that lead to unacceptable exposure of wildlife and human populations. The paper thereby made a compelling case why urgent, international cooperation was warranted (Stone 2015). As a young researcher it was incredibly motivating and exciting to work on a topic that so immediately and directly was relevant to, and informed, global, environmental policy being shaped at the time.

In the years since, the concepts of cold condensation and global fractionation introduced in the paper have occasionally come under scrutiny. Clearly, the choice of the term "condensation" was unfortunate, as it implied precipitation of a pure chemical once its partial pressure exceeds its saturation vapor pressure, when in fact concentrations of contaminants in the atmospheric gas phase always remain well below saturation. To avoid misunderstandings, the term cold-trapping has become the preferred terminology.

As an admittedly biased observer, I find that some criticism over the years was aimed at misrepresentations of what had actually been stated in the paper. This includes the misconception that all contaminants will eventually migrate to reach polar regions, when, in fact, only some chemicals can undergo long range transport and, of those, only a small fraction of the total circulating amount will ever reach polar regions. Another misconception is that the deposition of contaminants in polar regions is irreversible, even though the Arctic cold-trap does not have to be a permanent sink, which had been stated explicitly in the original paper.

There have been, however, also contributions that have led to indisputably valid modifications and extensions of the ideas expressed in the original paper and they have generally diminished the role afforded to temperature-dependent partitioning in controlling large scale contaminant distributions. This includes the idea that concentrations that increase with latitude can also arise from rates of degradation that decrease with latitude (Wania and Mackay 1999) and the realization that contaminant fractionation can occur in the absence of temperature gradients, as long as the constituents of a contaminant mixture vary in their atmospheric residence times (von Waldow et al. 2010).

On my personal scientific journey, the work described in the *Ambio* paper has continued to inform and inspire my work over the following almost three decades, e.g. by developing and applying models that seek to simulate the processes of global contaminant dispersion and distribution (Wania and Su 2004), by designing air sampling techniques capable of recording latitudinal trends in contaminant composition (Shen et al. 2005), or by investigating what differentiates cold-trapping in polar regions from that in mountains (Wania and Westgate 2008). Who knows, maybe the penultimate paper I will write eventually will be related to contaminant cold trapping and fractionation phenomena. And maybe *Ambio* will see fit to publish it.

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