POLICY BRIEFING:

Current understanding of the global mercury cycle: implications in the context of reducing anthropogenic emissions

An output from a workshop held at the University of Oxford (UK) on 24th and 25th May 2011

Introduction

Mercury in the environment is a major concern. It is a neurotoxin that can bioaccumulate, especially in aquatic food chains. Over 20 international experts (see list below) attended a workshop on 24 - 25th May 2011 at the University of Oxford to evaluate current understanding of the global mercury cycle, and to consider the implications of that understanding for current initiatives to reduce anthropogenic emissions of mercury. This report summarises the conclusions of the workshop to inform current policy discussions at national, European Union, and international levels: in particular, the current negotiations to develop a global treaty on mercury under the auspices of the United Nations Environment Programme.

Main points from the workshop:

The discussions of the workshop were extensive and wide ranging. This paper focuses on issues that are of particular importance in the context of current efforts to reduce anthropogenic mercury emissions:

1. There is clear evidence from the global mercury cycle of the urgent need to reduce anthropogenic mercury emissions at source.

2. There will be a time lag between anthropogenic mercury emissions reductions and the response, seen throughout the global mercury cycle.

3. It will be important to evaluate the effectiveness of measures to reduce anthropogenic mercury emissions and to do this within a sound scientific framework.

4. Climate change will have impacts on the global mercury cycle.

Further details:

1. There is clear evidence from the global mercury cycle of the urgent need for action to reduce anthropogenic mercury emissions.

Many natural mercury sources include a significant component of “legacy” mercury. Legacy sources of mercury are those that have been previously released by human and natural activities, and are still being cycled around the environment. For example, mercury deposited from the atmosphere to oceans, soils and vegetation may be remobilised by processes such as volatilisation, biomass burning or surface runoff. Current mercury emissions to the atmosphere are estimated to be equally distributed among anthropogenic, legacy and natural emissions (Fig. 1). Legacy sources already play a significant role in the mercury cycle and will continue to increase with continuing current and future anthropogenic releases.

While the magnitude of the natural mercury flux (e.g., volcanic, evasion from oceans) is uncertain, it is clear from many studies of historical mercury accumulations in peat bogs, lake sediments, ice cores and biological samples that the global atmospheric mercury burden has increased on average by a factor of 3 ± 1 since the industrial revolution[1]. In some regions localised Hg pollution in soils has increased 10-fold. The impact of this increase on biota is considerable: Fig. 2 shows the steep rise in mercury in animal tissues from the Arctic since 1900. The impact of post-industrial mercury emissions on remote ecosystems (such as the Arctic[2] and South American moorlands[3]) confirms that mercury pollution is a global problem, regardless of where emissions occur. The elevated mercury levels in many parts of the environment from previous human activities may take many years to return to the pre-industrial baseline (see section 2) even if future emissions are dramatically reduced.

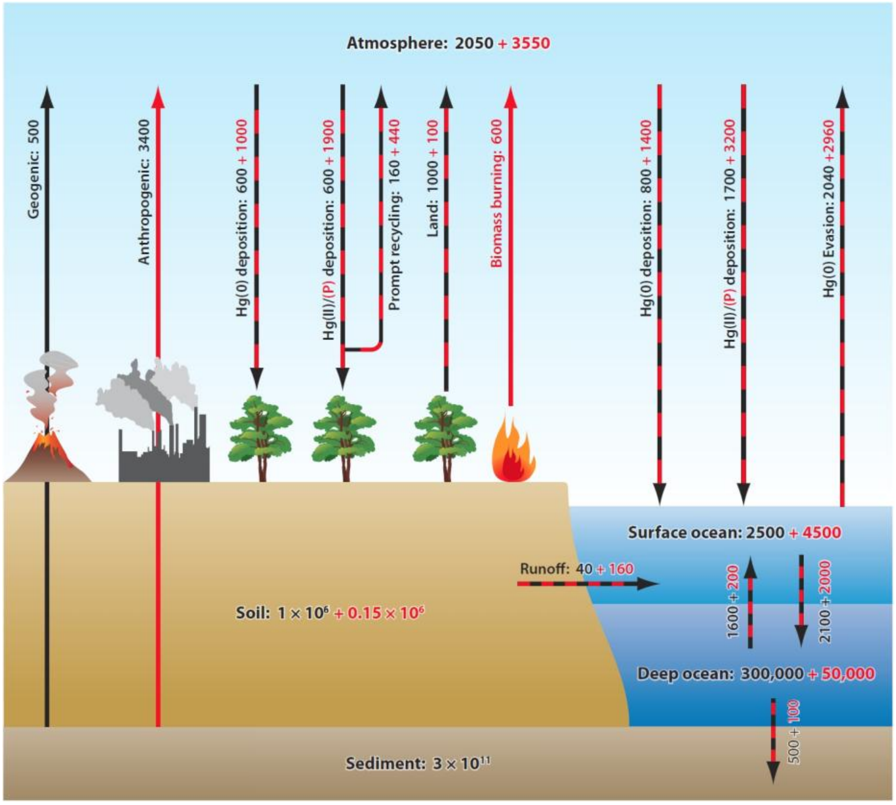

Figure 1. Global biogeochemical cycle for mercury[4]. Natural (preindustrial) fluxes [tonnes year^{-1}] and inventories, in tonnes, are noted in black. Anthropogenic fluxes and inventories are in red. Present-day fluxes from natural processes are augmented by legacy anthropogenic mercury and are noted by red-and-black dotted lines.

2. There will be a time lag between anthropogenic mercury emissions reductions and the response seen throughout the global mercury cycle.

Mercury, like all naturally-occurring elements, is involved in a global chemical cycle in which it is transported between different reservoirs: the atmosphere, the oceans and ice caps, soils and the biosphere. Because some of these reservoirs are very large, and the chemical exchanges between them can be slow, this means that perturbations to the global system can take many decades to be removed (Fig. 3).

As long as anthropogenic emissions continue to outpace the natural processes that eventually lock mercury away in inorganic (geological) reservoirs, largely the sediments of the deep ocean, the magnitude of re-emission of legacy sources of mercury will continue to grow. Some reservoirs, for example the oceans, have not yet reached a balance with present-day mercury emission rates, and the mercury contents of these reservoirs may continue to increase into the future.

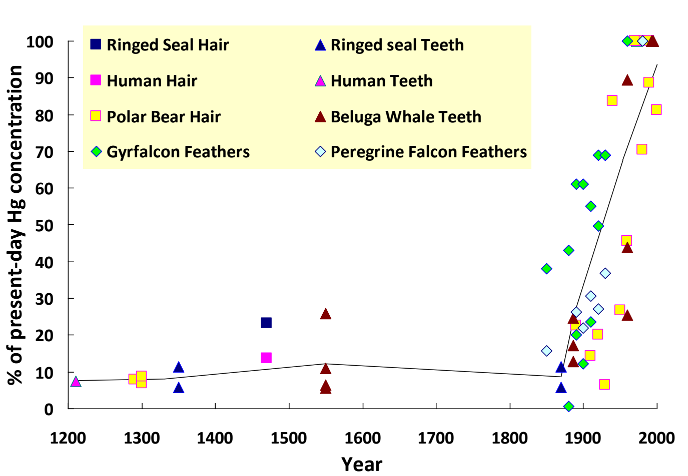

Figure 2. The rise in mercury content in hard tissues of Arctic biota as a percentage of present-day concentrations illustrating the rise since the industrial revolution[2].

From our current understanding of the global mercury cycle, the critical places where legacy mercury has accumulated is in soils, vegetation and surface ocean waters. If emissions were to cease today, human-induced changes to the global average mercury content in soils would still take between 100 and 500 years to decline; and it may take thousands of years for the perturbation to be entirely removed. However, the localised response in natural reservoirs to large point sources of mercury can be much larger than the global average, as much of the metal may be released in reactive forms that are quickly removed from the atmosphere. Such local contamination of reservoirs may also respond on shorter time-scales to reduced emissions.

3. It will be important to evaluate the effectiveness of measures to reduce anthropogenic mercury emissions and to do this within a sound scientific framework.

The workshop considered how best to assess the effectiveness of human efforts to decrease anthropogenic mercury emissions. Mercury presents a more complex situation compared to, for example, CO_2 emissions. As with CO_2 most anthropogenic emissions are to the atmosphere but, unlike CO_2 emissions, this is not where most of the mercury remains and it is not where it causes problems. Mercury reduction policies must aim to reduce mercury emissions so that mercury levels in the food chain decrease, thus reducing the impact on human and animal health. But before mercury can be taken up into biological tissues, it must be converted into methylmercury, usually by bacterial processes in soils or surface waters. For mercury, there is a complex processing pathway through the environment between the point of emission and the point where it ends up in the food chain and does damage. Elevated methylmercury in biota has resulted in a number of advisories to limit human consumption of certain fish species, and adverse effects in populations of fish, mammals and birds.

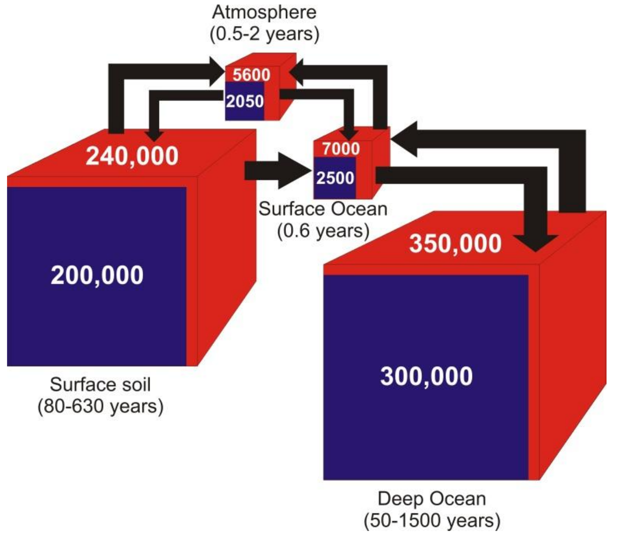

Figure 3. Characteristic sizes and timescales of the major reservoirs in the global mercury cycle[4,5,6]. Cube volume is proportional to reservoir size. Indicative sizes in tonnes of mercury are given in the cubes. Purple cubes indicate the pre-industrial reservoir size, red cubes the current totals. Timescales in brackets are indicative of the lifetime of mercury in each reservoir (note that the atmospheric value is for Hg(0) not Hg(II).

Deciding the correct indicators to monitor is obviously key in terms of assessing the success of efforts to decrease mercury emissions. Targets could be set at any stage along the chain from emission to effect. Given the complexity of the processes linking emissions and effects for mercury, a progressive 3-stage approach was suggested. Stage 1: set targets for emissions reduction and improvement of emission inventories. Stage 2: set targets for mercury concentrations in environmental reservoirs (e.g. air, soil, waters). Stage 3: set targets for body burdens in top predators or large fish species such as tuna (reducing mercury in the food chain is after all the overall aim of mercury emissions reduction). Stage 1 targets are the easiest to make progress towards on a short timescale. Legacy emissions and the response timescale of the different environmental reservoirs (see section 2) mean that stage 2 and stage 3 targets will be slower to respond to emissions reduction, but reducing mercury in the environment and biological tissues should be the long-term target of mercury emissions reduction.

Scientific understanding of the link between emissions reductions and mercury levels in the environment and biota reduces from stage 1 to stage 3. For example, the workshop identified the need for better quantification of the variability of mercury concentrations in global reservoirs, better knowledge of reaction kinetics for atmospheric and marine models, better understanding of methylation and reduction processes and better measurements of reactive mercury species as among the key priorities for further research. A major goal for the scientific community is to develop a holistic model to integrate and couple models of mercury transfers and transformations in biotic and abiotic systems. Such a model would be used i) to assess the likely magnitude and timescale of responses of the Earth system to mercury emissions reductions, thereby managing expectations of reduction strategies; ii) to develop scenario-based strategies; and iii) to predict the effects of climate change on targets set by mankind (see section 4). The workshop concluded that while it is important to continue to address remaining scientific uncertainties, the overall picture of the magnitude and impact of anthropogenic mercury emissions is sufficiently clear to warrant urgent international action to reduce emissions.

Setting target levels and assessing their success should be done within a sound scientific framework. Since about a third of current mercury emissions to the environment come from human activities and since these emissions add to legacy emissions (also roughly a third of emissions), the greater the emissions reductions the better. Ultimate target levels in environment reservoirs and biological samples might be pre-industrial levels where such information is available (e.g., sediment and ice archives and archives of hard biological tissues, Fig 2).

4. Climate change will have impacts on the global mercury cycle.

A recent report on mercury in the Arctic[2] has highlighted the many ways in which climate change might perturb the mercury cycle. These effects divide into physical, chemical and biological changes. Physical changes include changing wind and ocean circulation patterns, affecting the transport of mercury into and out of the Polar Regions, and the release of mercury incorporated into permafrost, glaciers and ice sheets as they melt. Chemical changes include increased production of methylmercury in wetlands as they remain unfrozen for greater proportions of the year; and decreased sea ice impacting atmospheric chemical cycles. Biological changes include changes in biological productivity, food chain dynamics and biodiversity. In terms of mercury exposure, changes that influence methylmercury production may have the most important consequences for human health. It is also clear that it is difficult to predict how climate change will affect human exposure to mercury, even within the Arctic region.

Less is known about the likely response of the mercury cycle to global change in tropical and temperate regions, and efforts to understand this are to be encouraged. The workshop highlighted changes in land use, and the implications in terms of soil chemistry as key areas of concern. Mercury binds to soil organic matter, so changes in soil and water carbon pools and fluxes, for example, as tropical forests are destroyed may have important implications for the mercury cycle.

Much of the mercury previously released to the atmosphere by human activity has been deposited to the global soil pool. Global mercury levels in surface soils are estimated to have increased by 10-15 % on average since pre-industrial times[4], although there is much spatial variability in the level of contamination. Increase in precipitation rates and changes in land-use may lead to the degradation of soils, resulting in the release of mercury. An increase in wildfires due to warmer temperatures, longer drier summers and earlier snowmelt, may also result in the loss of mercury stored in soils and vegetation to more mobile reservoirs.

Global change in the tropics may also have important implications for how quickly inorganic mercury is converted to the more toxic methylmercury as changes in precipitation rates, solar radiation, land disturbance and nutrient load may impact atmospheric mercury transport and methylation rates in waters and sediments. An increasing use of floodplains to manage floods and an increase in coastal wetlands as a result of coastal erosion may also affect methylation rates.

With future global changes leading to increased rates of methylation, possible release of mercury from previously stable reservoirs and alterations to mercury exposure routes, it is important that the amounts of mercury being added to the mercury legacy are reduced. It is not known whether changes to the mercury cycle in response to climate change will be gradual or episodic: are there likely to be pulses of mercury release as areas of the globe pass critical thresholds?

IKIMP
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Concluding comments

Mercury pollution is a global problem. The atmospheric mercury burden is now on average around three times pre-industrial levels. Emissions from natural, anthropogenic and legacy sources contribute broadly equal amounts to current atmospheric loadings of mercury. Mercury moves between environmental compartments, but these processes can be slow and even if anthropogenic emissions were to cease today, while localised responses may be more rapid, human-induced changes to global levels of mercury in soil, for example, could take between 100 and 500 years to disappear.

It will be important to assess the impacts of efforts to reduce mercury emissions. Staged targets could be set starting with (i) mercury emissions, and then progressing to (ii) mercury concentrations in environmental reservoirs, and (iii) body burdens in top predators. While this sequence of targets gets progressively closer to the measures of human exposure to mercury in the food chain, which is the key societal concern, the timescales of their response to anthropogenic emissions (that which we can control) becomes progressively more uncertain. When setting targets, however, policy makers should be aware that climate change will impact the mercury cycle in ways in which we currently only have limited understanding.

The workshop identified priorities for future work to further develop the scientific basis underpinning international efforts to address mercury pollution, including integrated models of mercury transfers and transformations in biotic and abiotic systems, and developing a better understanding of the impacts of climate change. However, the workshop concluded that current scientific understanding already supports the urgent need for action by the international community to reduce mercury emissions. This is a key action that will have positive short-term and long-term effects on decreasing the environmental mercury burden.

Sources of additional information

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2. Arctic Pollution 2011 (Mercury in the Arctic) is available to download from the AMAP website (http://www.amap.no/) or Outridge PM, Dietz R, Wilson S (eds.) (2011). AMAP Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo. 193 p. ISBN - 13 978-82-7971-068-4.
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The IKIMP Initiative

The Integrating Knowledge to Inform Mercury Policy (IKIMP) knowledge exchange initiative has been set up to ensure the scientific and technical knowledge base is used to inform and guide public policy relating to mercury. The 3-year initiative, which started in October 2008, has core funding from the UK Natural Environment Research Council. For more information, see http://www.mercurynetwork.org.uk.

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