

Updating Historical Global Inventories of Anthropogenic Mercury Emissions to Air

S. Wilson, J. Munthe, K. Sundseth, K. Kindbom, P. Maxson, J. Pacyna and F. Steenhuisen

Citation: AMAP / Wilson et al., 2010. Updating Historical Global Inventories of Anthropogenic Mercury Emissions to Air. AMAP Technical Report No. 3 (2010), Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

(available as an electronic document from www.amap.no)

Authors: S. Wilson¹, J. Munthe², K. Sundseth³, K. Kindbom², P. Maxson⁴, J. Pacyna³ and F. Steenhuisen⁵

¹AMAP Secretariat, Oslo, Norway.

²Swedish Environmental Research Institute (IVL), Gothenburg, Sweden.

³Norwegian Institute for Air Research (NILU), Kjeller, Norway.

⁴Concorde East/West, Brussels, Belgium.

⁵Arctic Centre, University of Groningen, Groningen, Netherlands.

The Arctic Monitoring and Assessment Programme (AMAP) was established in June 1991 by the eight Arctic countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States) to implement parts of the Arctic Environmental Protection Strategy (AEPS). AMAP is now one of six working groups of the Arctic Council, members of which include the eight Arctic countries, the six Arctic Council Permanent Participants (indigenous peoples' organizations), together with observing countries and organizations.

AMAP's objective is to provide 'reliable and sufficient information on the status of, and threats to, the Arctic environment, and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions to reduce adverse effects of contaminants and climate change'.

AMAP produces, at regular intervals, assessment reports that address a range of Arctic pollution and climate change issues, including effects on health of Arctic human populations. These are presented to Arctic Council Ministers in 'State of the Arctic Environment' reports that form a basis for necessary steps to be taken to protect the Arctic and its inhabitants.

AMAP technical reports are intended to communicate the results of scientific work that contributes to the AMAP assessment process. The results and any views expressed in this series are the responsibility of those scientists and experts engaged in the preparation of the reports and have not been approved by either the AMAP working group or the Arctic Council.

The AMAP Secretariat located in Oslo, Norway. For further information regarding AMAP or ordering of reports, please contact the AMAP Secretariat or visit the AMAP website at www.amap.no.

1. Introduction

Atmospheric emissions of mercury (Hg) occur during burning of fossil fuels (in particular coal) for energy production; during the manufacture of industrial products (such as non-ferrous metals, and cement); and from the use of mercury in a range of applications (including artisanal and small scale gold mining, and dentistry) and consumer products, and their subsequent disposal as waste. Mercury is also emitted to the atmosphere from non-anthropogenic sources, including re-emissions from aquatic and terrestrial surfaces.

A large part of these emissions are (globally) distributed via atmospheric transport, with the result that environmental consequences of atmospheric mercury are observed in areas such as the Arctic, that are far from the main anthropogenic source regions.

In order to address policy-related questions relating to mitigation of mercury pollution, including international efforts aimed at establishing a global agreement on mercury, information is needed on the sources and atmospheric transport of mercury. Due to the lack of adequate (global) measurement data, indirect approaches such as compilation of emissions data and modeling air transport are important components in addressing some of these questions. Consequently, effort is directed at obtaining the best available information on anthropogenic mercury emissions and trends, and reducing the uncertainties associated with the resulting estimates.

In 2009, a project was initiated to re-evaluate the available global inventories of anthropogenic mercury emissions to air. The project was coordinated by the Arctic Monitoring and Assessment Programme (AMAP) Secretariat and implemented through contractors at the Swedish Institute for Environmental Research, IVL (Sweden); Norwegian Institute for Air Research, NILU (Norway); CE/W (Belgium); and Arctic Centre-University of Groningen, ACUG (Netherlands), based on support from Canada and Denmark. The main products of the project – a series of updated (and consistently constructed) emission inventories for the years 1990, 1995, 2000 and 2005 – have been used to develop information for inclusion in the 2010 AMAP Assessment of Mercury in the Arctic and reports commissioned by UNEP in connection with the UNEP 2009 Governing Council's 'Paragraph 29' decision. They have also been provided (in the form of geo-spatially 'gridded' datasets) to modeling groups in Canada (Meteorological Service of Canada, MSC), Denmark (National Environmental Research Institute, NERI) and Russia (Meteorological Synthesizing Centre-East, MSC-E), and others, for use in mercury atmospheric transport modeling and investigation of source-receptor relationships, etc.

Main project results are summarised in a non-technical form in Section 3, which also constitutes the description of results that has been made available to the authors of the AMAP mercury assessment report and to the authors of the UNEP 'Paragraph 29' report.

2. Methodology and Technical Data Products

The basic approaches used to re-evaluate estimates of emissions from 'by-product' and 'intentional-use' emission sectors are described in Annex 1.

A series of intermediate and final technical data products have been compiled in the course of the work – these are listed in Annex 2, which also indicates the party responsible for the work and the data-file identifier. Final data products (datasets) have been made available to relevant modeling groups and are available to additional groups on request.

3. Summary of Project Results

The 2005 global inventory of anthropogenic emissions to air, described in AMAP/UNEP (2008) and summarized in UNEP-Chemicals Branch (2008) was the most comprehensive such inventory presented to date. Unlike previous global inventories, which

essentially only addressed 'by-product' mercury emissions from main energy production and industrial sectors, the 2005 inventory also includes estimates of emissions associated with a number of 'intentional-use' sectors, including artisanal and small scale gold production (ASGM).

The 2005 inventory was produced using a generally similar approach to that employed to produce ('by-product' sector) emission inventories for the nominal

years 1990, 1995 and 2000 (Pacyna and Pacyna, 2002; Pacyna et al., 2006; Pacyna et al. 2009; AMAP/UNEP, 2008), namely combining reported national emissions for specific sectors with expert estimates for the remaining countries for the same range of sectors. The expert estimates were obtained using information on production and consumption of raw materials in relevant industries, in combination with applicable emission factors. However, since each inventory was produced independently, at approximately five year intervals, the underlying source data used varied in terms of its sources, availability and quality; and emission factors and the assumptions regarding technologies employed changed as knowledge was improved.

Each of the four available global inventories has also been geospatially distributed (gridded), again using similar but not identical methods (see Wilson et al., 2006; Pacyna et al., 2003; AMAP/UNEP, 2008), and used by modelers to model transport of mercury, and investigate source-receptor relationship, etc. (see AMAP/UNEP, 2008; Christensen et al., 2005; Dastoor and Larocque, 2004; Dastoor et al., 2008; Travnikov, 2005).

The AMAP/UNEP (2008) report included a preliminary discussion of the general trends in global emissions as implied from comparing the available 1990, 1995, 2000 and 2005 inventories. However, this discussion clearly recognized that such a comparison would be largely invalidated by differences due to the factors mentioned above.

Consequently, and as part of its 2010 assessment of mercury in the Arctic, the Arctic Monitoring and Assessment Programme (AMAP) undertook a re-analysis of the 1990-2005 global mercury inventories in an attempt to prepare a series of more comparable

historical global emission inventories. This re-analysis employed a common methodology, a more consistent information base for estimating certain emissions, and updating of the earlier inventories to account for improved knowledge gained during the process of preparing the inventories over the 15 years or so. The re-analysis also involved correcting certain questionable estimates in older inventories according to updated information on practices and technologies, including a few apparent errors. It also involved further revising the 2005 inventory for newly available data on regional mercury consumption that form the basis for estimates of emissions associated with 'intentional-use' sectors. The main results of this re-analysis are presented below.

Revised estimates of total emissions of mercury to air in 1990, 1995, 2000 and 2005 from 'by-product' and 'intentional-use' sectors are presented in Figure 1. 'By-product' sectors comprise: stationary combustion of fossil fuels in power plants and for residential heating; pig iron and steel production; non-ferrous metal production; cement production; mercury production; large scale gold production; and certain 'other' sources. Mercury emissions from the chlor-alkali industry are also accounted in the 'by-product' sector inventory. Intentional-use sectors include artisanal and small-scale gold mining; emissions from dental use of mercury associated with cremations; secondary steel production; and waste disposal (including waste incineration). Data presented for emissions from 'intentional-use' waste disposal sectors represent 'conservative estimates'.

Regional trends in (combined) emissions from 'by-product' and 'intentional-use' sectors for 1990, 1995, 2000 and 2005 (series 1-4, respectively) are summarized in Figure 2.

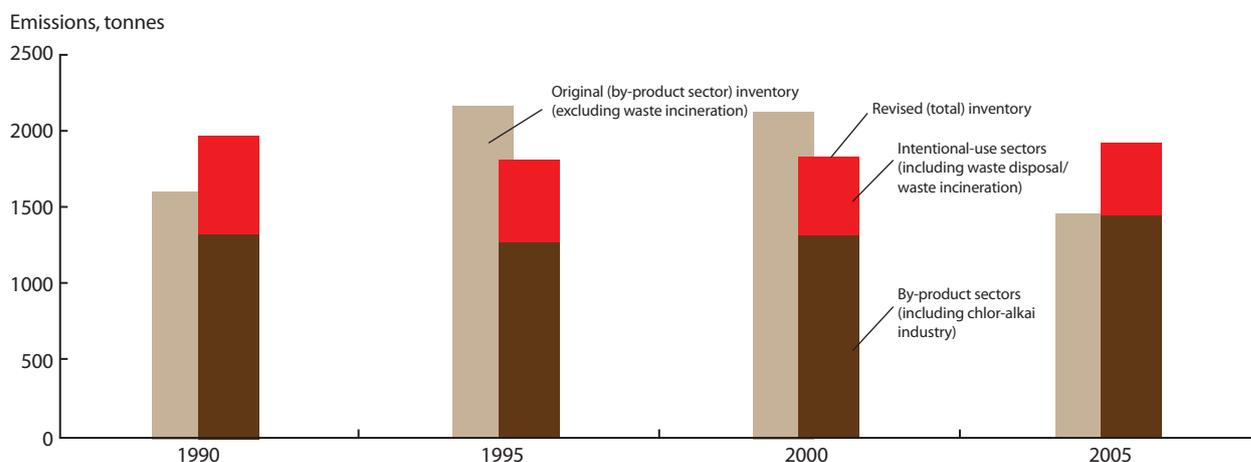


Figure 1. Revised estimates of total global anthropogenic mercury emissions to air (tonnes) from 'by-product' and 'intentional-use' emission sectors in 1990, 1995, 2000 and 2005.

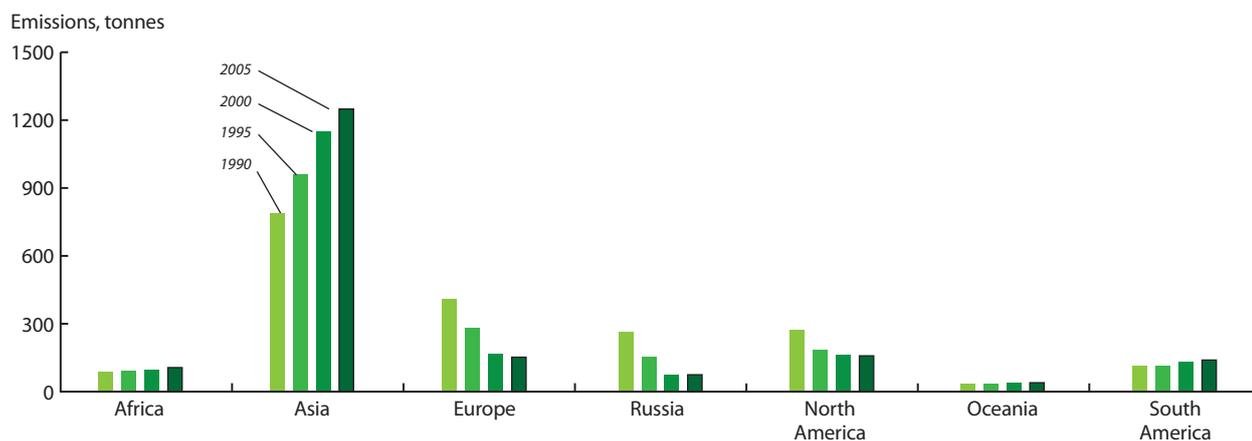


Figure 2. Revised estimates of anthropogenic mercury emissions to air (tonnes) in 1990, 1995, 2000 and 2005 from different continents/regions.

Revisions to the 1990, 1995 and 2000 inventories resulted in significant reductions in total 'by-product' sector emission estimates compared to previously published (Pacyna and Pacyna, 2002; Pacyna and Pacyna, 2005; Pacyna et al., 2006; Pacyna et al. 2008) estimates (see Figure 1 and Table 1, Line 5).

Newly compiled information on consumption and use of mercury allowed new inventories for emissions from 'intentional-use' sectors to be prepared for 1990, 1995 and 2000, and also changed the patterns (i.e. relative distribution of emissions from different sectors), and to a lesser extent the magnitude of 'intentional-use' sector emissions in 2005.

Differences between the revised (updated) inventories produced during this project and previously published inventories are detailed in Table 1, below.

Analysis of Changes in By-Product emissions

The differences in the revised estimates for the 'by-product' sector emissions (Table 1, row 5.) exceed the reported uncertainties associated with these estimates (which vary from ca. +/- 20 to 40% for the main industrial sectors, depending on the region). On closer examination, the explanations for the differences are associated with a relatively few specific emission estimates, as listed below:

- South African gold production emission estimates were revised down by 169.2 tonnes in each of 1990, 1995 and 2000 due to new national information received during compilation of the 2005 inventory on the technology employed in this activity.

Table 1. Differences between the originally-published global inventories of anthropogenic mercury emissions to air - and the revised inventories for 1990, 1995, 2000 and 2005.

	1990	1995	2000	2005
1. Original 'by-product' sector inventory	1731.8	2213.3	2189.6	1483.2
2. Waste incineration component of original inventory	139.0	51.6	60.8	35.0
3. Original 'by-product' sector inventory excl. waste incineration	1592.8	2161.7	2128.8	1448.2
4. Revised 'by-product' sector inventory	1317.5	1276.7	1316.3	1448.2
5. Difference (3. minus 4.)	-275.3	-885.0	-812.5	0.0
6. Original 'intentional-use' sector inventory	Not available	Not available	Not available	442.5
7. Revised 'intentional-use' sector inventory	649.8	537.3	502.3	472.4
8. Difference (6. minus 7.)	-	-	-	29.9
9. Original total inventory	1731.8*	2214.0*	2189.8*	1925.7
10. Revised total inventory	1967.3	1813.9	1818.6	1920.6
11. Difference (9. minus 10.)	235.5	-400.0	-371.2	-5.1

*by-product sectors only (plus waste incineration for Europe (EU countries), USA and Canada)

- South African stationary combustion emission estimates were revised down by 29.8, 48.5 and 52.3 tonnes in 1990, 1995 and 2000, respectively, according to new information received during compilation of the 2005 inventory.
- Emissions associated with stationary combustion in Zaire (Dem. Republic of Congo) in 1995 and 2000 were removed from the inventories in favour of alternative estimates prepared for the Dem. Republic of Congo; the original estimates of 90 tonnes of emissions in 1995 and 2000 likely incorporated units errors in the original reporting.
- Use of revised coal consumption data for China resulted in reduced emission estimates for this country-sector of 247.3 and 90.6 tonnes in 1995 and 2000, respectively.
- Use of revised coal consumption data for Australia resulted in reduced emission estimates for this country-sector of 84.4 and 93.9 tonnes in 1995 and 2000, respectively.
- Major revisions affecting the 1990 inventory included a reduction of 41.6 tonnes of emissions from stationary combustion sources in the former Soviet Union (following the development of independent estimates for Russia and other FSU countries), and an increase in the stationary combustion emissions estimate for India of 26.8 tonnes (due to use of revised coal consumption data). Finally, the 1990 inventory included an estimated emission of 118.1 tonnes from the USA associated with waste incineration, which was revised down to 63.2 tonnes in the (conservative) estimates of the new intentional-use sector inventory.

These revisions to the estimates for South Africa (gold production and stationary combustion), China (stationary combustion), Australia (stationary combustion), Dem. Republic of Congo (stationary combustion), Russia (stationary combustion) and USA (waste incineration) include the five largest changes in any given inventory for estimates for particular sectors for individual countries. Taken together, the five largest changes in any given inventory account for at least 95% of the changes in the total inventories for 1990, 1995 and 2000. With some exceptions, generally where countries had provided new information on timing of phase-out of mercury-emitting processes, revised estimates for other country-sector emissions associated with use of revised consumption/production data fell within the quoted ranges for uncertainties. It should be noted that no attempt was made to derive new emissions factors for specific 'by-product' sectors over time. The emission factors used when producing the 2005 global emissions inventory (Pa-

cyna et al., 2008) were applied to all 'by-product' sector estimates that were subject to revision. Updated emissions factors were employed in revision of the 2005 estimates associated with 'intentional-use' sectors.

Analysis of changes in Intentional-Use Emissions

Considering the 'intentional-use' sector emissions, previously published inventories (for 1990, 1995 and 2000) only included information on emissions resulting from incineration of waste, and then only for some European countries, Canada and the USA.

In the revised global inventory estimates, it was decided to use the 'waste disposal' emission estimates (which include a separate specification of estimated emissions from waste incineration and from other waste disposal methods, such as landfill) from the newly constructed 'intentional-use' inventory for all countries. This is different from the method employed in the AMAP/UNEP 2008 presentation of the 2005 inventory, where the 'by-product' inventory emissions for waste incineration for European countries, Canada and the USA were used rather than the equivalent estimates from the 'intentional-use' inventory compilation.

Comparing the (conservative) waste incineration emission estimates from the 'intentional-use' inventory with those derived from the 'by-product' inventory showed generally good agreement, and well within the large uncertainties associated with these emissions. The new data compilations for 'intentional-use' sector emissions in 1990, 1995, 2000, 2005 also include upper-range estimates for the waste and scrap sectors of 572, 443, 324, and 232 tonnes, respectively. These can be compared with the conservative estimates of 419, 286, 199 and 122 tonnes, respectively, which are used in the revised global emissions inventories presented above.

Geospatial Distribution of Revised Emissions Inventories

The newly constructed emissions inventories for 1990, 1995, 2000 and 2005 represent a more consistent set of global inventories of mercury emissions to air than those previously available, in terms of the underlying data and the methods used to produce and compile estimates of emissions for the various countries and source sectors concerned. The emission factors used in preparing the 2005 inventory (AMAP/UNEP, 2008) were applied to updated statistical data on production and consumption of raw materials

and products to generate new emission estimates. The revised global emission inventories have also been geospatially distributed (to a 0.5 by 0.5 degree latitude/longitude grid) using a consistent approach.

Accounting for changes in point source emissions (and more importantly for changes in availability of information concerning these over the past 20 years) was outside the scope of the work and resources available for the re-analysis of the historical global inventories. In practice, therefore, the approach to geospatially distribute emissions involved use of a series of 'surrogate' data distributions that reflect the geospatial distributions for the sectors concerned. The 'surrogate distributions' used were those employed in work on the 2005 inventory as reported in Pacyna et al. (2008). Available information on emissions from specific point sources (that was used in previous geospatial distribution of the 2000 and 2005 inventories in particular, to more accurately locate a part of the emissions) was therefore ignored. While this implies a somewhat less precise geospatial distribution of emissions, this will mainly influence the emissions distributions at the more local scale, especially those from Europe and North America in 2000 and 2005 (for which data on major point sources are available). The distribution of

emissions in other regions, where point source information is relatively sparse, will be unaffected, and, at the global scale, the pattern of emissions distributions is essentially the same as when point source information is employed.

Acknowledgements:

The work to re-analyses the 1990-2005 global inventories of mercury emissions to air was commissioned by the Arctic Monitoring and Assessment Programme (AMAP) and conducted using finances provided to support this work by the Danish Ministry of the Environment and Environment Canada. Consumption and use datasets used to prepare revised 'intentional-use' sector emissions estimates were provided by Peter Maxson (CE/W, Brussels). Revised 'intentional-use' sector emissions estimates were prepared by John Munthe and Karin Kindbom (IVL, Gothenburg, Sweden). Revision of historical 'by-product' sector emission estimates was conducted by Kyrre Sundseth and Jozef Pacyna (NILU, Kjeller, Norway) and Simon Wilson (AMAP Secretariat, Oslo, Norway). Geospatial distribution of revised emissions datasets was done by Frits Steenhuisen (ACUG, Groningen, Netherlands).

References:

- AMAP/UNEP, 2008. Technical Background Report to the Global Atmospheric Mercury Assessment. Arctic Monitoring and Assessment Programme / UNEP Chemicals Branch. 159 pp. (http://www.chem.unep.ch/mercury/Atmospheric_Emissions/Technical_background_report.pdf)
- Christensen, J.H., J. Brandt, L.M. Frohn and H. Skov, 2004. Modelling of mercury in the Arctic with the Danish Eulerian Hemispheric Model. *Atmospheric Chemistry and Physics*, 4: 2251-2257.
- Dastoor, A.P. and Y. Larocque, 2004. Global circulation of atmospheric mercury: a modelling study. *Atmospheric Environment*, 38: 147-161.
- Dastoor, A.P., D. Davignon, N. Theys, M.V. Roozendaal, A. Steffen and P.A. Ariya, 2008. Modeling Dynamic Exchange of Gaseous Elemental Mercury at Polar Sunrise. *Environ. Sci. Technol.*, 42, 14, 5183-5188, 10.1021/es800291w.
- Pacyna, E.G. and J.M. Pacyna, 2002. Global emission of mercury from anthropogenic sources in 1995. *Water, Air and Soil Pollution*, 137: 149-165.
- Pacyna, E.G., J.M. Pacyna, F. Steenhuisen and S. Wilson, 2006. Global anthropogenic mercury emission inventory for 2000. *Atmospheric Environment*, 40: 4048-4063.
- Pacyna, J.M. and E.G. Pacyna, 2005. Anthropogenic sources and global inventory of mercury emissions. In: Parsons, M.B. and J.B. Percival (eds.), *Mercury: Sources, Measurements, Cycles, and Effects*. Mineralogical Association of Canada, Short Course Series Volume No. 32.
- Pacyna, J.M., E.G. Pacyna, F. Steenhuisen and S. Wilson, 2003. Mapping 1995 global anthropogenic emissions of mercury. *Atmospheric Environment*, 37-S: 109-117.
- Pacyna, E.G., J.M. Pacyna, K. Sundseth, J. Munthe, K. Kindbom, S. Wilson, F. Steenhuisen and P. Maxson, 2009 (in press). Global emission of mercury to the atmosphere from anthropogenic sources in 2005 and projections to 2020. *Atmospheric Environment* (2009), doi:10.1016/j.atmosenv.2009.06.009.
- Telmer, K. and M. Veiga, 2008. World emissions of mercury from artisanal and small scale gold mining. Chapter 6. In: Interim Report of the UNEP Global Partnership on Atmospheric Mercury Transport and Fate Research. Pirrone, N. and R. Mason (eds.)
- Travnikov, O., 2005. Contribution of the intercontinental atmospheric transport to mercury pollution in the Northern Hemisphere. *Atmospheric Environment*, 39: 7541-7548.
- UNEP Chemicals Branch, 2008. The Global Atmospheric Mercury Assessment: Sources, Emissions and Transport. UNEP-Chemicals, Geneva. 42 pp. (http://www.chem.unep.ch/mercury/Atmospheric_Emissions/UNEP%20SUMMARY%20REPORT%20-%20final%20for%20WEB%20Dec%202008.pdf)
- Wilson, S., F. Steenhuisen, J.M. Pacyna and E.G. Pacyna, 2006. Mapping the spatial distribution of global anthropogenic mercury atmospheric emission inventories. *Atmospheric Environment*, 40: 4621-4632.

Annex 1. Methodology

(1) By-product sector emissions estimates

Estimated emissions from 10 major source sectors in each of the inventories (1990, 1995, 2000 and 2005) were tabulated on a country-by-country basis. The sectors concerned included:

- Stationary combustion of fossil fuels in large power plants
- Stationary combustion of fossil fuels for residential heating
- Non-ferrous metal production (Cu, Zn, Pb; primarily in large smelting facilities)
- Production of gold (in large scale facilities)
- Production of mercury
- Pig iron and steel production
- Cement production
- Chlor-alkali industry (caustic soda production)
- Waste incineration (primarily USA, Canada, and Western European countries)
- Other (undefined sector emissions)

Temporal trends in emissions for each country-sector combination were then examined to identify significant changes (on either a relative or absolute basis) in the magnitude of the emissions between consecutive inventory periods. Where such significant 'changes' occurred, these were then further considered in relation to possible 'valid' explanations for changes in emissions over a 5-year period. These could include:

- Possible introduction of technology, including emissions control technology that could lead to changes in emission factors accounting for the observed differences in emissions over time.
- Possible changes in reporting/registration of emissions in the different inventory periods, for example, as a result of improvements in national data reporting over time. Examples might include categorization of the (national) emissions estimate from a particular sector under the 'other' category in one period and under the appropriately defined sector category in the next.
- Possible changes in reporting/compilation of data as a result of changes in (national) jurisdiction, including, for example the break-up of the former Soviet Union and Yugoslavia, reorganization and emergence of new countries in Africa, return of Hong Kong to Chinese jurisdiction, and in some cases simply renaming of countries.

Table A. References to statistical data used to derived revised emissions estimates.

Source sector	Reference to statistical data used
Stationary combustion	EIA data on coal consumption http://www.eia.doe.gov/iea/coal.html UN Energy statistics database on crude petroleum consumption. http://data.un.org/Browse.aspx?d=EDATA
Cement production	USGS data on cement production http://minerals.usgs.gov/minerals/pubs/mcs/
Caustic soda production	UN database on industrial commodities, data on caustic soda production http://data.un.org/Browse.aspx?d=ICS
Non-ferrous metals production	USGS data on copper, zinc and lead production http://minerals.usgs.gov/minerals/pubs/mcs/
Large scale gold production	USGS data on gold production http://minerals.usgs.gov/minerals/pubs/mcs/
Pig iron and steel production	USGS data on iron and steel production http://minerals.usgs.gov/minerals/pubs/mcs/

Note: If data was available for several commodities within a source sector (e.g. both coal and crude petroleum consumption), emission estimates were calculated by using the relative difference in consumption as well as the source specific emission factor. In cases where time series data were missing, the consumption was checked against the trend data and generally assumed to be the same as the latest available inventory or reference year.

Where 'reasonable' explanations for large difference between country-sector emissions over a 5-year period could not be inferred, the statistical data on which emissions estimates are based were re-evaluated. This also involved the utilization of more consistent sources of primary statistical data to derive the estimates of emissions for different years (as detailed in Table A). As a result, changes were made to some country-sector emissions estimates based on the availability of new or revised statistical data on, e.g., consumption or production of raw materials.

In other cases, even where 'valid' explanations for apparent major changes in emissions were identified, the datasets were revised as far as possible to make them consistent between years, for example where improved data allowed an appropriate re-classification of emissions from the 'other' category to more appropriate sectors, or from one country to another to reflect changes in jurisdiction.

Finally, a number of revisions were made on the basis of information received during the preparation of the 2005 emission inventory that also affected inventories for earlier years.

(2) By-product sector emissions estimates

The methodology employed to derive revised estimates for 'intentional-use' sector emissions was

essentially that described in AMAP/UNEP (2008) and used to produce the estimates for these sectors included in the original 2005 global emissions inventory. The developments under this project relate to (a) the availability of data on consumption and use of mercury in 1990, 1995 and 2000, which allowed estimates of intentional-use sector emissions to be derived for these years for the first time, and (b) the availability of updated information on consumption and use of mercury in 2005 which led to revisions to the previously published estimates of intentional-use sector emissions for 2005.

Global mercury consumption

Global mercury consumption data used to produce estimates of emissions for 'intentional-use' sectors are tabulated below (Table B). Consumption data for various component products and processes are detailed in subsequent tables. Note: For purposes of calculating product related emissions, mercury 'consumption' is defined here in terms of regional consumption of mercury products. For example, although most measuring and control devices are produced in China, many of them are exported, 'consumed' and disposed of in other countries. Furthermore, some of the mercury 'consumed' each year is recycled or otherwise recovered and returned to commercial use.

Emissions from artisanal and small-scale gold mining

Updated estimates of national consumption of mercury in ASGM were derived from the regional estimates tabulated below (Table C). Regional estimates were distributed between countries in a similar manner to that employed in the develop-

ment of the 2005 inventory (AMAP/UNEP, 2008), i.e. based on the work of Telmer and Veiga (2008). The total estimated mercury emissions from ASGM for 2005 (ca. 325 tonnes) were slightly lower than those reported in the original 2005 inventory (ca. 350 tonnes) due to the revised mercury consumption data used. For most countries the differences were small to moderate, but more pronounced for countries like China with significant emissions from ASGM. The difference between the total consumption of mercury in ASGM activities and the amount emitted to air is accounted for by releases to aquatic systems, and recovery and re-use, etc. National consumption estimates for 1990, 1995 and 2000 were scaled to the 2005 distribution.

Emissions from cremation sources (use of mercury in dental amalgam)

The original 2005 inventory estimates for this source (published in AMAP/UNEP, 2008) were calculated by multiplying the number of cremations (obtained from Cremation Society of Great Britain: <http://www.srgw.demon.co.uk/CremSoc5/Stats/Interntl/2006/StatsIF.html>) by an average emissions of 2-5 g per cremation (European value). Emissions from countries outside Europe were estimated in the same way as for Europe, but the results were scaled to the national consumption of mercury for dental purposes provided by Peter Maxson.

In preparation of the historical emissions inventories, a slightly more consistent method was used involving two different approaches:

1. Estimating emissions for all regions using the default value for Hg per cremation from the UNEP Toolkit (1-4 g Hg /cremation, average 2.5) and number of cremations in each region. This

Table B. Global Mercury Consumption 1990-2005: All products and processes

Region	1990	1995	2000	2005
East and Southeast Asia	1330	1550	1732	1874
South Asia	574	462	322	190
European Union (25 countries)	1803	1118	642	458
CIS and other European countries	600	469	360	236
Middle Eastern States	214	210	173	114
North Africa	95	85	59	37
Sub-Saharan Africa	136	134	135	139
North America (excl. Mexico)	1333	705	434	332
Central America and the Caribbean	178	162	123	85
South America	493	444	406	369
Australia New Zealand and Oceania	45	36	26	22
TOTAL	6801	5375	4412	3853

Region	1990	1995	2000	2005
East and Southeast Asia	300	360	450	516
South Asia	2	4	6	8
European Union (25 countries)	3	3	4	5
CIS and other European countries	25	28	31	33
Middle Eastern States	1	1	2	2
North Africa	3	4	5	6
Sub-Saharan Africa	50	60	80	100
North America (excl. Mexico)	20	12	6	3
Central America and the Caribbean	10	14	18	23
South America	180	160	190	227
Australia New Zealand and Oceania	2	2	3	3
TOTAL	596	648	795	925

is straightforward but relies on the (unlikely) assumption that the Hg emitted per cremation is constant globally. Using an average emission factor of 2.5 g/cremation yields an upper limit (global) emission estimate of about 37 tonnes.

- Calculating an emission factor for Europe based on the average 2.5 g per cremation divided by the total consumption of dental amalgam in Europe (95 tonnes). The resulting emission factor is 0.0398 g Hg emitted per g dental Hg used. Emissions from regions outside Europe are then estimated by multiplying their consumption of dental Hg with this emission factor. This may result in an underestimate of the emission if it is assumed that crematories in Europe are (to a greater extent) equipped with emissions control technology. The results obtained using this method (global emissions of about 12 tonnes) are thus considered a lower limit estimate.

A 'best estimate' was derived for 2005 by averag-

ing the results obtained using the two different approaches described above. This yields an estimate of global emissions of about 27 tonnes. On a global basis this revised total does not differ greatly from that previously reported, however this approach did result in changes in emissions for some regions compared with the original 2005 inventory estimates.

Emissions estimates for 1990, 1995 and 2000 were obtained by scaling to consumption values (in the Table D, below) for these years, thus adopting the (not unreasonable) assumption that cremation sources have changed little over the period 1990-2005.

It should be noted that the estimates only represent emissions from dental use following cremations and do not include emissions during manufacture or handling of dental amalgam. Emissions from these latter activities can be substantial, and are sometimes reported in national emissions data (and for some countries may be included under the

Region	1990	1995	2000	2005
East and Southeast Asia	55	60	65	70
South Asia	13	15	20	25
European Union (25 countries)	90	105	105	95
CIS and other European countries	20	20	15	11
Middle Eastern States	18	20	20	17
North Africa	3	4	5	5
Sub-Saharan Africa	4	5	6	6
North America (excl. Mexico)	55	48	38	36
Central America and the Caribbean	14	16	18	18
South America	25	30	35	35
Australia New Zealand and Oceania	5	5	4	4
TOTAL	302	328	331	321

'other' category in the by-product emissions compilations). Uncertainties regarding which countries actually report these emissions and lack of sufficient information on production prevents the preparation of global estimates for these other categories of emissions related to mercury use in dentistry.

Emissions from product-use, waste incineration, waste disposal and scrap recycling for secondary steel production

Estimates of emissions from mercury in products and their subsequent fate (including breakage, recycling, and disposal or incineration as waste) were produced in a similar manner to that employed in the development of the 2005 inventory (AMAP/UNEP, 2008), based on the consumption data presented in Tables E to H, below. Note: emissions of mercury due to its use in the chlor-alkali industry were not produced as these are addressed under the by-product sector inventory activities; similarly, emissions of mercury from its use in VCM and acetaldehyde processes were not estimated due to the large uncertainties associated with mercury consumption and resulting emissions from this use (see discussions in AMAP/UNEP, 2008).

The revised consumption data presented in the tables below resulted in some differences between the updated 2005 estimates and those reported in the 2005 inventory presented in AMAP/UNEP, 2008. Emissions estimates for 1990, 1995 and 2000 were derived by scaling the 2005 estimates to the consumption data for other years.

The updated information on consumption and use also included improved information on waste handling practices in different regions/countries, and the proportions of waste entering different components of the waste stream. The updated inventories therefore include separate estimation of emissions from waste incineration and other waste disposal (principally land-fill in controlled or open land-fill sites).

The method of estimating emissions from product use is based on a simple material flow analysis approach. In this approach, the mercury consumed annually in a product category is assumed to be distributed among several compartments, e.g., continued use, waste landfill, waste incineration, steel scrap smelters or recycling, using distribution factors. From each of these compartments, emissions of mercury are estimated using emission factors, the size of which varies depending on the nature of the compartment; e.g., in waste incineration a large fraction of the mercury is emitted to air, whereas for continued use the emissions are very low. In many cases, the uncertainties in both distribution factors and emission factors are large and very little data is available for corroboration of the assumptions. In a few cases, such as emissions from waste incineration (where the mercury can be assumed to originate from products, i.e., intentional use) a comparison between nationally reported emissions data and emissions estimated using the material flow approach is possible, and have shown that these estimates are within a reasonable range.

Region	Batteries				Lamps			
	1990	1995	2000	2005	1990	1995	2000	2005
East and Southeast Asia	350	400	350	240	35	40	42	42
South Asia	150	130	90	33	9	10	11	12
European Union (25 countries)	400	200	60	28	40	40	23	20
CIS and other European countries	100	90	60	10	7	7	8	8
Middle Eastern States	60	50	30	7	5	5	6	6
North Africa	20	13	7	3	1	1	2	2
Sub-Saharan Africa	40	30	15	5	3	3	4	4
North America (excl. Mexico)	450	110	30	14	41	45	20	17
Central America and the Caribbean	60	50	30	5	3	3	4	4
South America	80	80	60	20	6	7	8	8
Australia New Zealand and Oceania	10	6	4	3	2	2	2	2
TOTAL	1720	1159	736	365	152	163	130	122

Table F. Global Mercury Consumption 1990-2005:	Measuring devices				Electrical and electronic switches and relays			
	1990	1995	2000	2005	1990	1995	2000	2005
Region								
East and Southeast Asia	140	160	150	129	60	70	70	61
South Asia	50	60	55	36	25	30	25	17
European Union (25 countries)	130	80	50	18	80	60	20	4
CIS and other European countries	40	40	30	24	15	18	14	11
Middle Eastern States	25	25	20	17	11	13	10	8
North Africa	7	8	7	6	3	4	4	4
Sub-Saharan Africa	15	15	14	12	7	8	7	6
North America (excl. Mexico)	125	72	48	45	77	88	72	60
Central America and the Caribbean	25	25	18	13	11	12	9	6
South America	40	40	30	24	15	18	14	12
Australia New Zealand and Oceania	7	7	6	6	5	4	4	3
TOTAL	604	532	428	328	309	325	249	189

Table G. Global Mercury Consumption 1990-2005:	VCM and acetaldehyde processes				Mercury cell chlor-alkali process*			
	1990	1995	2000	2005	1990	1995	2000	2005
Region								
East and Southeast Asia	200	300	500	750	25	20	10	6
South Asia	0	0	0	0	250	150	75	38
European Union (25 countries)	30	10	0	0	750	450	250	178
CIS and other European countries	40	30	30	20	300	200	150	105
Middle Eastern States	0	0	0	0	70	80	75	53
North Africa	0	0	0	0	50	45	25	9
Sub-Saharan Africa	0	0	0	0	3	3	2	1
North America (excl. Mexico)	15	0	0	0	280	190	110	75
Central America and the Caribbean	0	0	0	0	30	25	15	10
South America	0	0	0	0	100	80	50	30
Australia New Zealand and Oceania	0	0	0	0	6	5	0	0
TOTAL	285	340	530	770	1864	1248	762	504

* Although an intentional-use, emissions from this sector are estimated as part of the by-product inventory data compilations

Table H. Global Mercury Consumption 1990-2005:	Compounds and other applications			
	1990	1995	2000	2005
Region				
East and Southeast Asia	165	140	95	60
South Asia	75	63	40	23
European Union (25 countries)	280	170	130	113
CIS and other European countries	53	36	22	14
Middle Eastern States	24	16	10	7
North Africa	8	6	4	3
Sub-Saharan Africa	14	10	7	5
North America (excl. Mexico)	270	140	110	83
Central America and the Caribbean	25	17	11	8
South America	47	29	19	14
Australia New Zealand and Oceania	8	5	3	3
TOTAL	969	632	451	330

Annex 2. Datasets compiled under the project

Dataset	Produced by	Filename reference
Compilation of information on consumption and use of mercury in 'intentional-use' sectors, 1990-2005	CE/W (Peter Maxson)	<i>peter maxson - historic mercury consumption 1990-2005.xlsx</i>
Estimates of mercury emissions from intentional use – artisanal and small scale gold mining (ASGM), 1990-2005	IVL (John Munthe, Karin Kindbom)	<i>asg for john to check 29122009.xls</i>
Estimates of mercury emissions from intentional use – dental use following cremations, 1990-2005	IVL (John Munthe, Karin Kindbom)	<i>crematories new estimates 2010-01-06.xls</i> <i>new estimates of mercury emissions from cremation.doc</i>
Estimates of mercury emissions from intentional use – waste incineration, waste disposal, recycling and secondary steel, 1990-2005	IVL (John Munthe, Karin Kindbom)	<i>waste and scrap for John to check.xls</i>
Revised estimates of mercury 'by-product' emissions from energy production and industrial sectors	NILU (Kyrre Sundseth, Jozef Pacyna); AMAP Secretariat (Simon Wilson)	<i>inventories january 2010.xls</i>
Compiled estimates of mercury emissions from 'intentional-use' sectors	IVL (John Munthe, Karin Kindbom); AMAP Secretariat (Simon Wilson)	<i>historical mercury update - revised intentional use datasets.xls</i>
Compiled estimates of mercury emissions from combined 'intentional-use' and 'by-product' sectors	AMAP Secretariat (Simon Wilson)	<i>final dataset.xls</i>
Gridded global emission datasets for 1990, 1995, 2000 and 2005	ACUG (Frits Steenhuisen); AMAP Secretariat (Simon Wilson)	<i>1990_V6_historical_em_ALL_sectors.dat</i> <i>1995_V6_historical_em_ALL_sectors.dat</i> <i>2000_V6_historical_em_ALL_sectors.dat</i> <i>2005_V6_historical_em_ALL_sectors.dat</i>