Executive Summary

1. Introduction

Mercury, primarily because of its existence and bioaccumulation as methylmercury in aquatic organisms, is a concern for the health of higher trophic level organisms, or to their consumers. This is the major factor driving current research in mercury globally and in environmental regulation, and is the driver for the current UNEP Global Partnership for Mercury Transport and Fate Research (UNEP-MFTP) initiative. The overall focus of the UNEP MFTP report is to assess the relative importance of different processes/mechanisms affecting the transfer of mercury (Hg) from emission sources to aquatic and terrestrial receptors and provide possible source-receptor relationships. This transfer occur through atmospheric transport, chemical transformations and subsequent deposition, and involves the intermittent recycling between reservoirs that occurs prior to ultimate removal of Hg from the atmosphere. Understanding the sources, the global Hg transport and fate, and the impact of human activity on the biosphere, requires improved knowledge of Hg movement and transformation in the atmosphere. An improved understanding of Hg emission sources, fate and transport is important if there is to be a focused and concerted effort to set priorities and goals for Hg emission management and reduction at the national, regional and global levels; and to develop and implement such policies and strategies. To achieve this, a series of coordinated scientific endeavors focused on the estimation of sources, measurement and validation of concentrations and processes, and modeling, coupled with interpretation of the results within a policy framework, is likely to be required. Details of what has been achieved to date are laid out in the UNEP-MFTP Report in three sections. The details concerning our understanding of emissions and inputs of Hg from human activity and via natural processes is dealt with in Section I of the report. Section II details the measurements that have been made and compiles the available information. Current modeling efforts and the understanding of atmospheric processes at regional and global scales are detailed in Section III.

Mercury is ubiquitous in the atmosphere and the ground level background concentrations appears to be relatively constant over hemispheric scales, varying by less than a factor of two for remote locations (Chapter 9). This is expected for a trace gas that has a relatively long residence time in the atmosphere. The southern hemisphere has a lower concentration than the northern hemisphere and this primarily reflects the current and historic concentration of anthropogenic emissions in the northern hemisphere. Recent measurements of free tropospheric air, either at high altitude sites or from measurements made on board aircraft, indicate that the concentration changes are usually but not always also relatively small vertically up to the tropopause, although there are differences apparent between measurement campaigns. In the stratosphere, Hg has been found associated with the stratospheric aerosol. Mercury fate and transport in the boundary layer is complex, and its concentration is modified by inputs and removal to the terrestrial/ocean surface (Chapter 15). In addition, rapid global transport of Hg can occur in the free troposphere. The fate of Hg is therefore determined by the different chemical environments that these regions of the atmosphere represent, the different physical and meteorological processes which occur in them, the differences in chemical reactivity, and also by exchange that occurs between reservoirs (Pirrone et al. 2005; Hedgecock et al. 2006; Lindberg et al. 2007).

Anthropogenic inputs of Hg have greatly exacerbated the global Hg cycle (Chapter 1). Much of this impact is related to energy resources exploitation, especially fossil fuel consumption. The impact of these enhanced emissions is such that atmospheric concentrations have increased by a factor of three on average since pre-industrial times. Globally, fossil fuel power plants are the single most important anthropogenic emission source of Hg to the atmosphere, and these emissions, in combination with the emissions of other co-emitted pollutants, have an impact on the atmospheric chemistry of Hg and influence its resultant deposition patterns. Such synergistic impacts are also apparent for other industrial sources that release Hg to the atmosphere. While the primary impacts are observable in the short term, the medium to long term impact that exploitation of fossil fuels and other anthropogenic activities have on atmospheric Hg cycling is through their impact and influence by global climate change (Hedgecock and Pirrone, 2004; Eisenreich et al. 2005).

For the thorough understanding of the atmospheric fate and transport of Hg it is necessary to document and comprehend the distribution and extent of emissions from point sources and from more diffuse sources, whether these are of anthropogenic origin or due to natural sources and processes. This report provides an evaluation and summation of the current state of the science and of the extent of current efforts to document and understand the degree to which concentrations in the atmosphere are changing, and whether this is entirely due to changes in inputs of Hg into the biosphere, or due to changes in other pollutants or chemicals, or global climate. Both direct and indirect impacts of Hg fate and transport through the atmosphere need to be considered.

1.1 Major Conclusions and Recommendations

1. About a third of the Hg currently emitted to the atmosphere is derived from point and other identifiable anthropogenic sources (2503Mg y^{-1}). Coal combustion is the largest anthropogenic source globally.
2. The remainder of the emissions are associated with natural processes 5207 Mg y^{-1} but many of these processes have been exacerbated by human activity (e.g. biomass burning) and much of the Hg emitted from these sources had an original anthropogenic source. Current estimates suggest that about a third of the current total Hg emissions to the atmosphere from natural processes are due to the pre-industrial (natural) emission component and the remainder is recycled (previously deposited) Hg.
3. Changes in atmospheric Hg concentration over time have been detected in some locations but at the global scale it has been difficult to demonstrate a measurable change for the remote atmosphere over the last 20 years because of the lack of detailed and coordinated measurements.
4. There is the need to coordinate activities at the global level to ensure that future research provides the maximum benefits in terms of assessing global and regional trends in Hg concentration. It is recommended that a global monitoring network be established as soon as possible to ensure that the relevant information is obtained, and to provide the information necessary for model testing and evaluation.
5. Model development and focused process studies must continue and be expanded and enhanced to ensure that the models are correctly parameterized and that there is agreement between individual models and between model output and experimental data. 6. Without accredited models, it is difficult to make the pertinent forecasts and scenario predictions that are crucial to the development of sound management strategies for the control and mitigation of the current global Hg problem.

2. Mercury Inputs to the Global Atmosphere

This section briefly outlines the conclusions and recommendations, and the details of the chapters in Section I of the report. There are 8 chapters in total for this section. Chapter 1 is an overall summary chapter, while the other chapters deal with emission estimates for countries where emissions exhibit an upward trend and represent a substantial contribution for the global atmospheric mercury budget, these include China (Chapters 2 & 3), India (Chapter 4) and South Africa (Chapter 5). Another important worldwide anthropogenic source, not accounted for in previous assessments the artisanal gold mining sector in which Hg amalgamation is used as basic component of the extraction process (Chapter 6). The remaining two chapters cover sources that are important but relatively more areal, and less well-characterized, and include Hg emissions from natural processes. It must be kept in mind that Hg released from natural processes may have an anthropogenic origin. Thus, the distinction should be made between Hg that is emitted from primary natural sources and that which is recycled (re-emitted) Hg from prior atmospheric deposition. However, this distinction is difficult to determine precisely. Natural processes contribute an important fraction of global emissions. Emission data related to sources and regions not reported in Chapters 2-8 were included in estimates in Chapter 1, to the extent possible, using data taken from the most recent peer-reviewed literature and from official technical reports released by reputable agencies, programs and governments. Section 1 therefore provides an up-to-date overview of global Hg emissions from natural and anthropogenic sources at country and/or at regional/continental scale.

Improved information on the relative magnitude of anthropogenic Hg sources, combined with the impact of various control technologies and other approaches on Hg release, especially from emission reductions in Europe and North America, have contributed to further advances in the assessment of regional impacts of Hg on terrestrial and aquatic environments (Pirrone et al., 2001a; Lindberg et al., 2007). At the same time, as discussed in detail below, major international activities have focused on assessing source - receptor relationships for Hg in the environment, and these are the core of many international efforts and conventions. These natural sources, which include the contribution from oceans and other surface waters, rocks, top soils and vegetation, volcanoes and other geothermal activities and also forest fires, release about 5207 Mg of Hg annually (Table 1). The values reported in the table are consensus values derived from evaluation of the literature, which often contains relatively disparate estimates. As noted, some fraction of this emission represents previously deposited Hg from the atmosphere to ecosystem-receptors and part is a new contribution from natural reservoirs.

Contributions from the various sources vary in time and space depending on a number of factors including the presence (heterogeneous distribution) of volcanic belts or geothermal activity, geological formations with high Hg concentration (e.g. cinnabar deposits), high rates of exchange of elemental Hg between waters and the atmosphere, re-emission of previously deposited Hg to top soils, and evasion mediated by plants (evaporation/interface processes), and forest fires (Pirrone et al., 2001b; Ferrara et al., 2000a; Ferrara et al., 2000b; Gustin et al., 2002; Mason, 2008). Biomass burning is an important input and the Hg from this source is obviously a mixture of Hg release due to natural processes and human-induced burning (Cinnirella and Pirrone, 2007; Friedli et al., 2008). Recently, improved knowledge of natural source behavior (i.e., emissions from oceans, vegetation) has resulted in better estimates, and these estimates are backed by up-to-date literature results. On average, volcanoes and geothermal activities release ~90 Mg y^{-1} of Hg to the atmosphere (Chapter 7).

Table 1 -Total mercury emissions by source category. Taken from Chapter 1 and references therein

Region	**Hg emission in atmosphere** (Mg y^{-1})	**Reference year**
Natural		
Oceans	2682	2008
Lakes	96	2008
Forest	342	2008
Tundra/Grassland/Savannah/Prairie/Chaparral	448	2008
Desert/Metalliferrous/ Non-vegetated Zones	546	2008
Agricultural areas	128	2008
Evasion after mercury depletion events	200	2008
Biomass burning	675	2008
Volcanoes and geothermal areas	90	2008
Total (Natural)	**5207**	
Anthropogenic		
Coal combustion, oil combustion	1422	2000
Pig iron and steel production	31	2000
Non-ferrous metal production	156	2007
Caustic soda production	65	2000
Cement production	140	2000
Coal bed fires	6	2008
Waste disposal	166	2007
Mercury production	50	2007
Artisanal Gold Mining Production	400	2008
Other	65	2007
Total (Anthropogenic)	**2503**	
TOTAL (Natural + Anthropogenic)	**7710**	

Overall, natural processes contribute 68% of the global atmospheric Hg input with the oceans releasing most of the Hg (35%) followed by biomass burning (forest 9% and agriculture 2%). As noted above and in other publications (e.g. Sunderland and Mason, 2007; Mason and Sheu, 2002), much of this emitted Hg, while being emitted from a natural process has an anthropogenic origin in being originally released to the biosphere as a result of human activity.

Direct anthropogenic sources, which include a large number of different industrial point sources, release about 2503 Mg of Hg on an annual basis, the major contribution being fossil fuel-fired power plant emissions of Hg (1422 Mg y^{-1}) (Table 1). Artisanal small scale gold mining (400 Mg y^{-1}), waste disposal (166 Mg y^{-1}), non-ferrous metals manufacturing (156 Mg y^{-1}) and cement production (140 Mg y^{-1}) are other important human-related inputs. All other direct anthropogenic sources contribute ~219 Mg yr^{-1} to the atmosphere. In some instances, the evaluation of global emissions presented here are substantially different from previous published assessments (e.g. Pacyna et al., 2003; 2006) although these assessments represent a different time period in the last decade. This is mainly because, in the past, emissions from several sources were poorly estimated due to the lack of reliable data, or were not included. Inputs from forest fires, gold production, cold-bed fires were not accounted for in previous estimates.

Our current estimate of global emissions suggests that the contribution from natural and anthropogenic sources to the global atmosphere is nearly 7710 Mg of Hg annually. Total Hg emission from direct anthropogenic sources account for 2503 Mg, or 32% of the total. The present assessment shows that the majority of Hg emissions originate from combustion of fossil fuels (18%), particularly in the Asian countries including China and India (62% of all fossil fuel emissions) where energy production from coal combustion is increasing at a rate of nearly 10% per year. Among industrialized countries, Europe and USA account for 23% of the total Hg emission from fossil fuel combustion. Combustion of coal is and will remain in the near future the main source of energy in most countries. An increase in global energy demand is clearly foreseen, and this will lead to an increase in annual emissions of Hg and other primary pollutants. However, such releases could be reduced by the installation of more efficient emission control devices; there are a number of approaches for reducing Hg emissions during combustion and other industrial processing.

3. Mercury Cycling within the Atmospheric Reservoir

The rationale for the focus of Part II is the need to collate the existing information on Hg concentration and its forms in the atmosphere. Furthermore, this section discusses the need to establish baseline concentrations and to document changes to allow an assessment of the effectiveness of Hg emission reductions, or other changes in emission distribution globally. It is clear that better and more extensive measurements and more coordination is needed and that the current level of measurement and evaluation is inadequate for determining the extent of change. Furthermore, modeling efforts also require sufficient data to test and validate model parameterization, and long-term datasets are needed for model testing. More investigation is also required on different key processes related to global transport and cycling of Hg. Finally, by comparing and contrasting model output and measurements it is possible to understand more clearly the exchange of Hg between reservoirs and the important reactions. Without this knowledge, the impact of changes in Hg in response to changes in atmospheric inputs can not be properly assessed.

The current state of the art and extent of measurement, which could form the basis of a global Hg monitoring network, is detailed in the chapters contained in this section of the report. Chapter 9 focuses on terrestrial measurements and studies, while chapter 10 focuses on polar regions. Chapter 11 reports on an important recent initiative in Japan while Chapter 12 summarizes the data and information on surface waters, with a particular emphasis on the open ocean, coastal areas and marginal seas. These chapters focus on and highlight current gaps and advances in monitoring and measurement since the UNEP 2002 report, and review the uncertainty in evaluating atmospheric changes in concentration, focusing where possible on the relevant policy issues and questions that need to be addressed.

Mercury exists in the atmosphere in three primary forms, which are characterized by current measurement approaches. Most of the Hg in the atmosphere is as elemental Hg (Hg^0 or alternatively referred to as GEM) (typically >95% of the total), which is relatively unreactive with an average atmospheric residence time of 0.5-1 year. In addition to Hg^0, two other atmospheric Hg fractions have been operationally defined based on physico-chemical properties and methods of measurement - the gaseous ionic Hg^{II} fraction, termed reactive gaseous Hg (RGM), and Hg associated with particulate matter, Hg_P (Lindberg and Stratton 1998; Sheu and Mason 2001; Landis et al. 2002; Mason and Sheu 2002). The speciation of RGM is not known in detail but it is assumed to consist of gaseous neutral Hg^{II} complexes (Ariya, Khalizov et al. 2002; Balabanov and Peterson 2003). Measurements of total gaseous Hg (TGM) are often made and in most situations these reflect the Hg^0 concentration as the RGM is a minor component. Anthropogenic inputs to the atmosphere can occur in all three forms and the distribution between forms depends on the type of emission and control technology that is used at the specific industrial site. Most of the inputs to the atmosphere from natural processes are Hg^0, although there is a small signal due to inputs of particulate-associated Hg (e.g., volcanoes, dust).

In principal, an increase of the global atmospheric pool should also be reflected in changes in the background Hg concentration. However, even though reliable atmospheric data were published as long as three decades ago, it is extremely difficult to derive a global trend estimate based on the available data as it is spatially and temporally too variable. For example, Asian Hg emissions are believed to have increased rapidly in the past decade, however, this is neither reflected in the long-term measurement of TGM at the remote site at Mace Head, Ireland (1996-2006), nor in the precipitation data of the North American Mercury Deposition Network (MDN) (Lindberg et al., 2007).

Given the *ad hoc* nature and heterogeneous distribution globally of such efforts to monitor and measure atmospheric Hg concentration and speciation it is clear that a coordinated global monitoring network is needed to provide information for a global assessment, and for global and regional model validation and extrapolation (Chapter 13). A coordinated global network would allow the important policy questions that are currently being debated to be answered more quantitatively. Extensive measurement and modeling will determine how intercontinental or hemispheric transport affects Hg deposition patterns in the Northern Hemisphere, for example, and provide information on regions that are most sensitive to Hg inputs from the atmosphere. The relative contribution of intercontinental transport to Hg accumulation in terrestrial, marine or freshwater ecosystems is clearly the most important question, as the answer impacts the management approach and the degree to which local efforts to reduce emissions will have a local impact.

General scientific consensus is that the current global background Hg concentration (the average sea-level atmospheric Hg^0 at remote sites) is about 1.5 to 1.7 ng m^{-3} for the Northern Hemisphere and 1.1 to 1.3 ng m^{-3} in the Southern Hemisphere (Lindberg et al., 2007). Concentrations of TGM are typically elevated close to sources and these include urban areas and areas that have been impacted by historical activity that used Hg (Chapter 9). In such locations, concentrations 10-100 times the background values can be found. It is not clear how these concentrations have changed over time and, overall, the trend analyses do not provide an entirely coherent story. This suggests that it is extremely difficult, given the variability in concentration with location, and the impact of other factors on the concentration measured in the boundary layer, to determine trends in concentration with time based on current monitoring and datasets. Clearly, a more comprehensive monitoring network is required if these questions are to be sufficiently answered at the global scale. Also, more measurements are needed within the free troposphere rather than in the boundary layer, so that more detailed information regarding the long range transport of Hg is available.

There are limited data on the temporal trends in concentration either in the atmosphere (TGM and speciation) or in wet deposition as there has been little reliable monitoring data until recently (Chapter 9). A number of regional monitoring networks that have been established in North America or Europe but unfortunately, there is even less data for Asia and for the Southern Hemisphere although this situation is changing. In Canada, there has been a decrease in concentration of Hg in both wet deposition and in TGM over the sampling period (1995-2005), especially for the central and eastern reaches of Canada, and for impacted sites. Overall, the trend is less than 1% yr^{-1} for the rural sites for TGM, the trends in wet deposition are slightly higher (but typically <2%). Similar trends have not been seen overall in the wet deposition data for the USA, and there has not been a coordinated TGM network studying continental scale changes. There are some regional trends in locations that have been historically more impacted (e.g. midwest and northeast). Thus, the information for the North American continent is not entirely consistent.

In Europe, trends also appear to be regionally dependent. An extensive evaluation at coastal sites around the North Sea (Wangberg et al., 2007) showed that between the period 1995-1998 and 1999-2002 there was an overall reduction in deposition fluxes of 10–30 %, and it was suggested that these changes reflect decreases in Hg emissions in Europe (Chapter 9). In contrast, no decreasing trend in TGM data could be observed during the same time period. Studies around the Mediterranean show that there are elevated concentrations at some locations and that there is a seasonal trend in the data which reflects the seasonal change in source strengths, and the changes that occur in atmospheric physical and chemical conditions.

The concentration and speciation of Hg in the polar atmosphere is much different and seasonally much more dynamic than that of the lower latitudes, especially for terrestrial environments. There is now substantial evidence for the dramatic in situ depletion of Hg^0 during “polar sunrise” where the release of reactive halogen species, destroys ozone and oxidize Hg^0. Such processes are occurring in both the Arctic and Antarctic (Ebinghaus et al., 2002; Sprovieri et al. 2002; Steffen et al., 2005). There are differences in the type of reactions and their timing and magnitude between the Arctic and Antarctic and this is somewhat related to location and the higher pollution impact on the Arctic. While seasonally dynamic, an examination of the data that are available for the Arctic region suggests that there is no long-term change in the last 10 years in the average annual concentration of total gaseous Hg in the Arctic (Chapter 10). However, there do appear to be seasonal and regional differences, especially at locations more impacted by pollution inputs from Europe and North America.

Information on the vertical distribution of Hg in the atmosphere and of RGM and TPM is somewhat contradictory, as discussed in detail in this section and elsewhere in the report. More recent measurements and modelling suggest that there is a decrease in concentration of Hg^0 in the upper atmosphere due to its conversion to RGM in the presence of high ozone concentrations and the further partitioning of the ionic Hg to particles.

Clearly, there is a need to monitor and assess progress on mandated Hg reductions in controllable anthropogenic inputs to the atmosphere, as well as the impact of changes in emissions due to natural variability and man-induced climate change (Chapter 13). Thus, there is a need to highlight the current status of the measurement and monitoring of Hg in the global atmosphere and to fully comprehend the need for further monitoring. There is a clear need for a concerted effort to develop a coordinated and structured global Hg monitoring program for a truly global assessment of the problem and its solution. Indeed, it must be a goal to characterize source-receptor relationships while taking into account the various mechanisms affecting Hg cycling (emission-chemistry-deposition-reemission) and the inherent spatial heterogeneity at both the regional and global scale. Modeling efforts allow comparison of actual measurements of atmospheric Hg concentrations and speciation with estimations based on emission inventories and model extrapolation. Detailed and spatially comprehensive measurements of Hg and ancillary parameters, other key atmospheric chemical reactants and meteorological data, is needed to constrain these estimates, which are often based on little data, and are needed to improve model capabilities, and flux estimates (evasion and deposition), which also require further method development. Climate change and other processes will result in changes in ozone and aerosol concentrations, for example, and the impact of these changes on Hg fate and transport need to be assessed. The information contained in the report will provide the necessary starting point for the determination of the required future monitoring and assessment of Hg in the atmosphere and in surface reservoirs, based on the current status. As detailed elsewhere in this report (Section III), there is also need to compare and contrast the modelling efforts on global and regional Hg cycling to ensure that these models produce similar results when using the same input parameters.

4. Mercury Processes and Modelling Studies

The overall processes contributing to the distribution and cycling of Hg in the atmosphere are detailed in Section III of the report, which cover both an examination of the studies of the interconversion processes between the oxidation states and forms of Hg in the atmosphere and the current state of modeling of the overall processes at the global scale. As measurements cannot be made extensively and intensively enough to fully understand the processes involved, there is a need to develop models to extend the measurement results and to make predictions about past and future trends. Models provide such capability but these models need to be sufficiently tested and validated prior to their use in prediction and hypothesis testing. Therefore models are important not only for probing the level of understanding of the processes involved and the current situation, but they also provide the tools for scenario testing and for future prediction under different emission reduction strategies and different climate change scenarios.

The chapters in Section III describe the current state of the various focused studies of atmospheric reactions and of the modeling products and the similarity and differences in their predictions. Chapter 14 reports on past studies on pertinent reactions and their kinetics, and examines the conclusions and mechanisms in the recent literature. Thus, the extent of knowledge on the atmospheric chemical reactions and current gaps in understanding are highlighted. The processes involved in exchange of Hg at environmental interfaces, and particularly at the air-sea and land-air interfaces are not well characterized through measurement and this is another important gap in knowledge and a hindrance in model development (Chapter 15). This is important for the understanding of the global Hg cycle and to elucidate the sensitivity of the models to the accuracy of the knowledge about the underlying chemical mechanisms. Chapter 16 discusses the application of regional models and their ability to examine source-receptor relationships for Hg. The remaining chapters (Chapters 17-21) deal with global models and their results and predictions. These models include the model developed by Canadian researchers (Chapter 17), the GEOS-Chem Model (Chapter 18), the ECHMERIT Model (Chapter 19), The EMEP/MSC-E Model (Chapter 20) and the AER/EPRI Model (Chapter 21). Intercomparisons of some of the models have been made and these have shown that model development and calibration and consistency is improving but there is need for continued work (Ryaboshapko et al., 2007a; Ryaboshapko et al., 2007b). It is necessary to ascertain which differences in the model frameworks account for the differences in the output. Such efforts are instructive as they allow the sensitivity of the model to various parameters to be properly ascertained. Thus, these current efforts in model comparison should continue in the future.

The rate of removal of Hg from the atmosphere is primarily controlled by the rate of oxidation of elemental Hg. Compared to ionic Hg, elemental Hg is a relatively insoluble gas which has a relatively low deposition velocity, and thus is removed from the atmosphere slowly compared to ionic Hg, which is rapidly deposited through both wet and dry deposition processes. Thus the mechanisms whereby elemental Hg can be oxidized to ionic Hg species, primarily through gas phase and heterogeneous reaction, need to be fully understood and well characterized. The rate of reaction varies both spatially and temporally, and both horizontally and vertically in the atmosphere. Unfortunately, at this juncture there are large discrepancies in the reported values for some of the kinetic constants associated with these reactions and some disagreement on the actual likely mechanisms of these oxidation reactions. There are a number of potential oxidation pathways given that there are a number of potential atmospheric oxidants, including ozone, the hydroxyl radical and reactive halogen species.

In addition, there is a lack of knowledge of the details of the important reduction reactions for ionic Hg in clouds and other atmospheric liquid phases. The models demonstrate that such reactions must be occurring but the exact nature of the reductants is again not well characterized. Overall, based on the current values for the various oxidation and reduction constants, the models predict that the residence time of elemental Hg in the atmosphere is shorter than that which is derived from observation and measurement. This suggests that further detailed examination of these reactions under controlled laboratory conditions is needed.

Some research groups are developing more detailed models to parameterize these processes, and there has been substantial recent research examining the oxidation and reduction processes for Hg in surface waters and snow (Chapter 15). Similarly, there is exchange of Hg between surface soils and the atmosphere and the interaction of atmospheric Hg with vegetation is still not clearly understood. It is clear from recent studies that the processes are dynamic and rapid, but the exact underlying mechanisms still need further elucidation.

In the context of understanding human impact on the global Hg cycle, the main purpose and need for atmospheric models is to determine accurate source-receptor relationships so that the fate and transport of anthropogenic emissions is properly accounted for, otherwise the models will provide inaccurate scenario predictions. However, as noted above, models also probe the understanding of the underlying mechanisms and their impact on global Hg distribution. The lack of extensive datasets at the global scale for model validation is clearly a limitation in their further development and it is therefore apparent that a detailed and coordinated examination of the concentration and distribution of Hg in the atmosphere at the global scale is needed. Most of the information gathered to date has been collected in North America and Europe, as discussed in the earlier chapters and thus the models have been mostly validated against these data. However, the coverage does not include all ecosystem and climate types worldwide and therefore the model predictions for the Asian continent, and for tropical and southern hemisphere locations cannot be properly tested. In addition, regional model intercomparison studies have demonstrated the importance of the boundary conditions used in these evaluations. The use of global models to provide boundary conditions for regional models appears to be indispensable but there is much work needed in the implementation of this approach.

The various models are described in their appropriate chapters and the individual models will not be discussed here. In constructing and evaluating these models it is necessary to constrain the fluxes and estimates of inputs to the atmosphere from the remainder of the biosphere, to correctly parameterize the interconversion between the principal forms of Hg in the gaseous and particulate phase, and to reproduce the global trends in atmospheric Hg concentration that have been determined through various studies and programs. The global models rely on the accurate prediction of the other components of the atmosphere that impact Hg, such as reactants in the atmosphere and the meteorological conditions that pertain. As noted in the first section of the report, the emission estimates for many countries are still being evaluated and constrained and there is a lack of data for many countries that are important sources of anthropogenic Hg. Other important sources need further scrutiny and observation, such as the factors controlling the rate of net evasion of Hg from the ocean surface , and that of the various terrestrial environments. Current parameterizations appear to provide reasonable estimates but these approaches must be further developed.

Overall, it is vitally important that there is a concerted international effort to monitor the concentration and speciation of Hg and the extent of deposition at remote global locations to provide the data and information for model validation, and for accurate future predictions of the impact of changing Hg emissions on the terrestrial and ocean environments, and on the concentrations of Hg in the food chain. Elevated levels of Hg, especially as methylmercury, in aquatic species and its impact on human and wildlife health is the primary driver for concern and regulation, and the potential impact and benefit of Hg reduction strategies cannot be properly evaluated without knowledge of the movement of Hg in the global atmosphere and the impact of human activity and climate change.