

# Hemispheric Transport of Air Pollution 2010

Part B: Mercury



Air Pollution Studies No. 18



UNITED NATIONS



Printed at United Nations, Geneva  
GE.11-22145-June 2011-2,130

ECE/EB.AIR/101

United Nations publication  
Sales No. E.11.II.E.8  
ISSN 1014-4625



**ECONOMIC COMMISSION FOR EUROPE**  
**Geneva**

**HEMISPHERIC TRANSPORT OF  
AIR POLLUTION  
2010**

**PART B: MERCURY**

**AIR POLLUTION STUDIES No. 18**

Edited by Nicola Pirrone and Terry Keating

Prepared by the Task Force on Hemispheric Transport of Air Pollution  
acting within the framework of the  
Convention on Long-range Transboundary Air Pollution



**UNITED NATIONS**  
New York and Geneva, 2010

## NOTE

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such symbols indicates a reference to a United Nations document.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

In United Nations texts, the term “ton” refers to metric tons (1,000 kg or 2,204.6 lbs).

### *Acknowledgements*

*The task force co-chairs and the secretariat would like to acknowledge the assistance of EC/R, Inc., in preparing this publication. We would also like to acknowledge the invaluable contribution of the individual experts and the Convention’s Programme Centres and Task Forces.*

ECE/EB.AIR/101

UNITED NATIONS PUBLICATION
<i>Sales No. E.11.II.E.8</i>
<i>ISSN 1014-4625</i>
<i>ISBN 978-92-1-117044-3</i>

Copyright ® United Nations, 2010  
All rights reserved

UNECE Information Service  
Palais des Nations  
CH-1211 Geneva 10  
Switzerland

Phone: +41 (0) 22 917 44 44  
Fax: +41 (0) 22 917 05 05  
E-mail: [info.ece@unece.org](mailto:info.ece@unece.org)  
Website: <http://www.unece.org>

## Contents

Tables.....	vii
Figures .....	ix
Chemical Symbols, Acronyms and Abbreviations .....	xi
Preface .....	xvii

<b>Chapter 1 Conceptual Overview .....</b>	<b>1</b>
1.1.    Introduction and Background .....	1
1.2.    Concepts Related to Sources and Inter-Continental Cycling of Mercury .....	5
1.3.    Overview of Atmospheric Mercury Dynamics .....	7
1.4.    Spatial and Temporal Variability in Inter-Continental Transport.....	9
1.5.    Assessing Global Natural and Anthropogenic Sources and Deposition .....	11
1.6.    Data and Knowledge Gaps in Atmospheric Chemistry, Transport and Fate .....	14
1.6.1. <i>Understanding and Modelling Atmospheric Mercury Chemistry</i> .....	15
1.7.    The Impact of Climate Change on the Long Range Transport of Mercury .....	17
References.....	19

<b>Chapter 2 Observations.....</b>	<b>27</b>
2.1.    Spatial coverage and temporal trends of land-based atmospheric mercury measurements in the northern and southern hemispheres.....	27
2.1.1. <i>Observations of air concentrations at single locations in the Northern Hemisphere</i> .....	28
2.1.2. <i>Trends of air concentrations at single locations in the Northern Hemisphere</i> .....	32
2.1.3. <i>Monitoring Networks and trends in the Northern Hemisphere</i> .....	32
2.1.4. <i>Observations of air concentrations at single locations in the Southern Hemisphere</i> .....	34
2.1.5. <i>Trends of air concentrations at single locations in the Southern Hemisphere</i> .....	35
2.1.6. <i>Monitoring Networks and trends in the Southern Hemisphere</i> .....	35
2.1.7. <i>Mercury speciation in ambient air</i> .....	36
2.1.8. <i>Measurements related to source attribution and intercontinental transport</i> .....	39
2.1.9. <i>Summary and conclusion for observations in the temperate Northern and Southern Hemispheres</i> .....	41
2.2.    Spatial coverage & temporal trends of atmospheric mercury measurements in Polar Regions .....	43
2.2.1. <i>Atmospheric mercury in the Arctic</i> .....	44
2.2.2. <i>Atmospheric Mercury in the Antarctic</i> .....	48
2.2.3. <i>The role of snow surfaces on atmospheric Hg trends</i> .....	50
2.2.4. <i>Summary and Conclusion for Observations in the Arctic and Antarctic regions</i> ...51	51
2.3.    Spatial coverage and temporal trends of over-water, air-surface exchange, surface and deep sea water mercury measurements .....	51
2.3.1. <i>Atlantic Ocean</i> .....	52
2.3.2. <i>Pacific Ocean</i> .....	53
2.3.3. <i>Mediterranean Sea</i> .....	55
2.3.4. <i>Air-Water Mercury Exchange</i> .....	58

2.4.	The need for a coordinated global mercury monitoring network for global and regional models validations .....	60
2.4.1.	<i>Existing Global Monitoring Programs</i> .....	61
2.4.2.	<i>Ambient measurements</i> .....	61
2.4.3.	<i>Mercury measurements at altitude</i> .....	62
2.4.4.	<i>Meteorological measurements</i> .....	62
2.4.5.	<i>Atmospheric deposition</i> .....	62
2.4.6.	<i>Proposed Measurements to enhance model development</i> .....	63
2.4.7.	<i>Establishment of the Coordinated Global Mercury Observation System</i> .....	63
	References.....	64
<b>Chapter 3 Emissions .....</b>		<b>75</b>
3.1	Introduction.....	75
3.2	Emissions .....	76
3.3	Uncertainty of assessments .....	82
3.4	Future emission scenarios .....	84
3.5	Policy implications.....	89
3.6	Findings, gaps and recommendations .....	90
3.6.1.	<i>Findings</i> .....	90
3.6.2.	<i>Gaps</i> .....	91
3.6.3.	<i>Recommendations</i> .....	92
	References.....	93
<b>Chapter 4 Global and Regional Modelling .....</b>		<b>97</b>
4.1.	Introduction.....	97
4.2.	Model methods for quantifying mercury dispersion and fate in the environment .....	97
4.2.1.	<i>Overview of model approaches</i> .....	97
4.2.2.	<i>Goals and conditions of HTAP multi-model experiment for mercury</i> .....	100
4.3.	Global concentration and deposition levels .....	102
4.3.1.	<i>Review of previous mercury modelling studies</i> .....	102
4.3.2.	<i>Findings of HTAP experiment (SR1)</i> .....	105
4.4.	Intercontinental transport of mercury .....	113
4.4.1.	<i>Characteristics of mercury intercontinental transport</i> .....	113
4.4.2.	<i>Current knowledge from previous modelling assessments</i> .....	114
4.4.3.	<i>Source-receptor relationships from HTAP experiment (SR7)</i> .....	116
4.5.	Future trends of mercury pollution: HTAP experiment results (FE1, FE7) .....	123
4.6.	Modelling uncertainty .....	128
4.6.1.	<i>Sources of modelling uncertainty</i> .....	128
4.6.2.	<i>Variability of model results based on HTAP experiment</i> .....	134
4.7.	Key findings and recommendations.....	136
	References.....	138
<b>Chapter 5 Impacts of Intercontinental Mercury Transport on Human &amp; Ecological Health...145</b>		<b>145</b>
5.1.	Introduction.....	145
5.1.1.	<i>Effects of methylmercury on childhood neurodevelopmental outcomes</i> .....	146
5.1.2.	<i>Effects of methylmercury on cardiovascular outcomes in adults</i> .....	146
5.1.3.	<i>Safety reference doses</i> .....	147
5.2.	Human and ecological mercury exposures attributable to intercontinental sources .....	148
5.2.1.	<i>Human exposure and safety standards</i> .....	148
5.2.2.	<i>Fish consumption patterns and human exposures</i> .....	148
5.3.	Contribution of intercontinental transport to atmospheric mercury deposition .....	150
5.4.	Impacts on terrestrial and freshwater ecosystems .....	152
5.4.1.	<i>Freshwater and terrestrial ecosystems</i> .....	152
5.4.2.	<i>Impacts on ecosystem health based on fish and wildlife exposure</i> .....	154

5.5.	Impacts on marine ecosystems.....	156
5.5.1.	<i>Source attribution of deposition to major ocean regions.....</i>	156
5.5.2.	<i>Intercontinental transport from major hydrographic circulation patterns in the oceans .....</i>	157
5.5.3.	<i>Enrichment of oceans from anthropogenic mercury inputs .....</i>	158
5.5.4.	<i>Impacts on marine fish mercury levels and trends .....</i>	159
5.6.	Impacts on polar ecosystems .....	159
5.7.	Implications for policy .....	161
5.7.1.	<i>Projected changes in mercury deposition and exposure between 2020-2050.....</i>	161
5.7.2.	<i>Potential impacts of climate change on mercury deposition and exposures .....</i>	163
5.7.3.	<i>Biomass burning as a present and future emission source.....</i>	164
5.7.4.	<i>Future effectiveness of local and regional source emissions control.....</i>	166
	References.....	167

<b>Chapter 6 Summary .....</b>	<b>179</b>	
6.1	A Global Mercury Observation System.....	180
6.1.1	<i>Emissions .....</i>	180
6.1.2	<i>Modelling.....</i>	180
6.1.3	<i>Exchange fluxes at environmental interfaces .....</i>	181
6.2	Atmospheric chemistry studies .....	182
6.3	Field measurements to determine mercury exchange fluxes at interfaces .....	183
6.3.1	<i>Emissions .....</i>	183
6.3.2	<i>Modelling.....</i>	183
6.3.3	<i>Ecosystem Impacts.....</i>	184
6.4	Improved measurement techniques.....	184
6.4.1	<i>Atmospheric Mercury and Mercury Compounds .....</i>	184
6.4.2	<i>Emission speciation .....</i>	184
6.4.3	<i>Mercury Species Flux Measurements .....</i>	185
6.5	The Link Among Air, Water and Biota Concentrations of Mercury .....	186
6.6	Conclusions.....	186
	References.....	187

## Appendix

<b>Appendix A Editors, Authors, &amp; Reviewers .....</b>	<b>189</b>
---	------------



## Tables

### Chapter 1

Table 1.1.	Conceptual Overview	
------------	---------------------	--

Classification of emissions of mercury to the atmosphere .....	6
--	---

### Chapter 2

Table 2.1.	Observations	
------------	--------------	--

Summary of Hg <sup>0</sup> , RGM and Hg(p) measurements made at remote, rural and urban locations in the United States. NR means “not reported”.....	30
--	----

Table 2.2.	TGM, RGM and TPM average values observed at the five sites in the Mediterranean during the 4 sampling campaigns of the MAMCS project .....	38
------------	--	----

Table 2.3.	Average TGM, RGM and TPM values from coastal stations during four seasons.....	39
------------	--	----

Table 2.4.	Atmospheric mercury measurements conducted in arctic and sub-arctic sites.....	45
------------	--	----

Table 2.5.	Summary of atmospheric mercury measurements performed at different Antarctic locations from 1985 to 2005 .....	49
------------	--	----

Table 2.6.	Summary of measurements of Total Gaseous Mercury over the Atlantic Ocean.....	54
------------	---	----

Table 2.7.	Mercury measurements programme carried out during the cruises over the Mediterranean Sea from 2000 to 2007.....	56
------------	---	----

Table 2.8.	Main Statistical Parameters for atmospheric Hg species concentrations observed over the Mediterranean Sea Basin during the MED-OCEANOR campaigns from 2000 to 2007 .....	56
------------	--	----

Table 2.9.	Main Statistical Parameters for atmospheric Hg species concentrations observed over the East sector of the Mediterranean Sea Basin during the MED-OCEANOR campaigns from 2000 to 2006.....	57
------------	--	----

Table 2.10.	Main Statistical Parameters for atmospheric Hg species concentrations observed over the West sector of the Mediterranean Sea Basin during the MED-OCEANOR campaigns from 2000 to 2007.....	57
-------------	--	----

Table 2.11.	Main Statistical Parameters for atmospheric Hg species concentrations observed over the Adriatic Sea during the MED-OCEANOR campaigns from 2004 to 2005 ..	57
-------------	--	----

Table 2.12.	Mercury evasion from some aquatic environments reported in the literature including this study .....	59
-------------	--	----

### Chapter 3

Table 3.1.	Emissions	
------------	-----------	--

Comparison of global mercury emission from anthropogenic sources.....	77
---	----

Table 3.2.	Comparison of global mercury emission from natural sources .....	79
------------	--	----

Table 3.3.	Comparison of mercury emission from anthropogenic sources as reported in literature and National Pollution Inventories (NPIs) .....	82
------------	---	----

Table 3.4.	Uncertainty of Hg emission estimates by source category. ....	83
------------	---	----

Table 3.5.	Uncertainty of Hg emission estimates by continent.....	83
------------	--	----

Table 3.6.	DROPS scenario assumptions .....	87
------------	----------------------------------	----

Table 3.7.	Degree of FGD penetration in coal-fired power plants in 2050 by scenario .....	87
------------	--	----

Table 3.8	Mercury Emissions in 2020 and 2050 by Scenario and World	87
-----------	--	----

预览已结束，完整报告链接和

[https://www.yunbaogao.cn/report/index/report?](https://www.yunbaogao.cn/report/index/report)