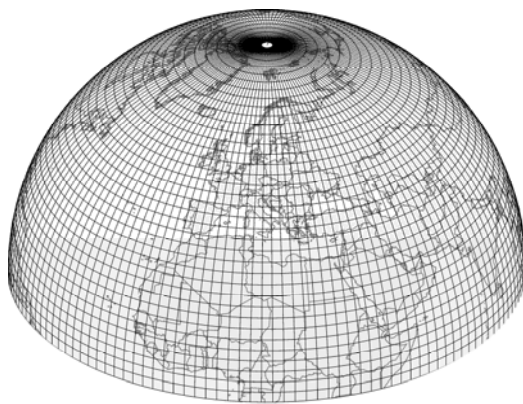


## Annex C

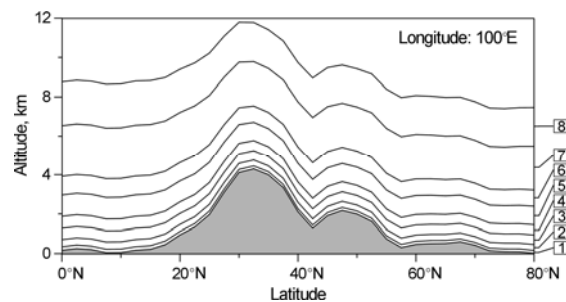
## HEMISPHERIC MODEL OF HEAVY METAL POLLUTION (MSCE-HM-Hem)

The hemispheric MSCE-HM-Hem model has been developed in MSC-East to meet the tasks of the Convention on Long-Range Transboundary Air Pollution on the assessment of the atmospheric transport and depositions of heavy metal in the Northern Hemisphere, evaluation of the intercontinental transport and support of the regional pollution modelling with the boundary conditions. The model considers mercury emissions from anthropogenic and natural sources, transport in the atmosphere, chemical transformations both in gaseous and aqueous phases, and deposition to the ground.

The model computation domain covers the whole Northern Hemisphere with spatial resolution  $2.5^\circ$  both in zonal and meridional directions. The surface grid structure of the model domain is shown in Fig. C.1. To avoid a singularity at the pole point, peculiar to the spherical coordinates, the grid has a special circular mesh of radius  $1.25^\circ$  including the North Pole. In the vertical direction the model domain consists of eight irregular levels of terrain-following sigma-pressure ( $\sigma$ -p) coordinate defined as a ratio of local atmospheric pressure to the ground surface pressure. The vertical grid structure of the model is presented in Fig. C.2.



**Fig. C.1.** Horizontal grid structure of the model domain. The model grid with resolution  $2.5^\circ \times 2.5^\circ$  and the pole grid cell



**Fig. C.2.** Vertical grid structure of the model domain. Eight terrain-following  $\sigma$ -levels: 1 –  $\sigma = 0.99$ ; 2 – 0.96; 3 – 0.91; 4 – 0.85; 5 – 0.77; 6 – 0.68; 7 – 0.55; 8 – 0.4

The model description of mercury atmospheric transport is based on the three-dimensional advection-diffusion equation adapted to the ( $\sigma$ -p) coordinate [Jacobson, 1999]:

$$\frac{\partial}{\partial t}(qp_s) = -\nabla_H \cdot (qp_s V_H) - \frac{\partial}{\partial \sigma}(qp_s \sigma) + \frac{\partial}{\partial \sigma} \left[ K_z \frac{g^2 \rho^2}{p_s^2} \frac{\partial}{\partial \sigma}(qp_s) \right] + \sum_i S_i \quad (\text{C.1})$$

Here  $q$  is the pollutant mixing ratio;  $\sigma$  is the vertical scalar velocity in the ( $\sigma$ - $p$ ) coordinate;  $\nabla_H$  and  $\mathbf{V}_H$  denote horizontal divergence operator and horizontal wind velocity respectively;  $K_z$  is the vertical eddy diffusion coefficient; and  $g$  is the gravitational acceleration. In Eq. (C.1) we omitted horizontal components of eddy diffusion because of the coarse horizontal grid resolution. The atmospheric advection is solved using the Bott scheme modified for the spherical co-ordinates. An implicit treatment of the vertical eddy diffusion is chosen in order to avoid restrictions on the integration time step because of possible sharp gradients of the pollutant mixing ratio.

Parameterizations of the removal processes and chemical transformations of mercury are the same as for the regional model (MSCE-HM) described above.

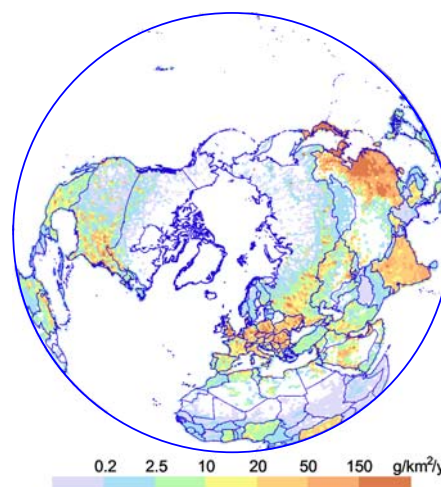
The model is driven by off-line meteorological parameters supplied by the low atmosphere diagnostics system (SDA) developed in co-operation with Hydro-meteorological Centre of Russia. The system provides 6-hour weather prediction data along with estimates of the atmospheric boundary layer parameters and covers the Northern Hemisphere with the model spatial resolution. NCEP/DOE re-analysis data is utilized as the input information for the system.

Anthropogenic emission of mercury in the Northern Hemisphere was evaluated basing on the global emission inventory for 1995 published by *J.Pacyna et al.* (2003). According to these data, anthropogenic emission of mercury in the Northern Hemisphere is about 1900 t/y. Spatial distribution of anthropogenic mercury emissions in the Northern Hemisphere is shown in Fig. C.3. As seen from the figure the most significant emission sources are located in South-Eastern Asia, Europe and eastern part of North America. Available data on the natural emission of mercury are rather uncertain. To take into account natural emission of mercury we used global estimates by *C.H.Lamborg et al.* [2002]. Spatial distribution of natural emission fluxes (including re-emission) was obtained by scattering the total value throughout the globe depending on mercury content in soils and the surface temperature. The total natural emission and re-emission of mercury in the Northern Hemisphere is estimated as much as 1600 t/y.

A uniform distribution of elemental mercury concentration is set at the upper boundary – 0.185 pptv (corresponding to about 1.5 ng/m<sup>3</sup> at 1 atm and 20°C). To take into account the inter-hemispheric transport of mercury a fixed gradient of elemental mercury concentration of 0.05 ng/m<sup>3</sup>/degree is set at the equator. One-year model spin-up is performed to fill up the atmosphere with mercury.

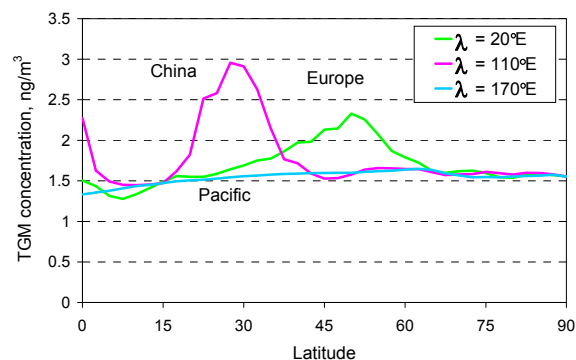
Modeling results show that elevated mercury concentrations in the ambient air are characteristics of regions with high emissions such as Europe, South-eastern Asia and eastern part of North America. Figure C.4 shows total gaseous mercury concentration profiles coming along meridians through two the most contaminated and one background region. As one can see from the figure even in the remote parts of the Pacific Ocean, as well as in the Arctic, mercury concentration in the ambient air does not fall below 1.5 ng/m<sup>3</sup>.

Spatial distribution of total annual mercury deposition (wet and dry) in the Northern Hemisphere is illustrated in Fig. C.5. High deposition fluxes were obtained for contaminated

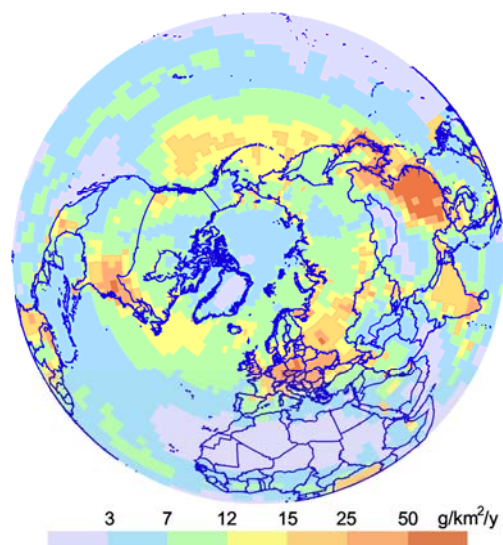


**Fig. C.3.** Spatial distribution of anthropogenic mercury emissions in the Northern Hemisphere in 1995

regions but also for some background regions characterized by large precipitation amount (North Atlantic and Pacific). This can be explained by wide dispersion of atmospheric mercury over the globe and prevailing role of wet scavenging in mercury removal from the atmosphere.

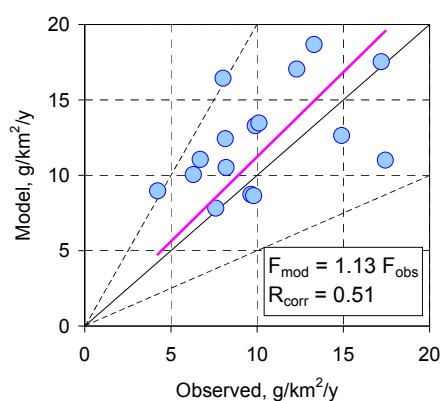


**Fig. C.4.** Profiles of total gaseous mercury concentration in the ambient air of the Northern Hemisphere



**Fig. C.5.** Spatial distribution of total annual mercury deposition (wet and dry) in the Northern Hemisphere

Comparison of modelled and measured values of mercury wet deposition is presented in Fig. C.6. Measurements from European (EMEP network) and North American (NADP/MDN network) monitoring sites was used in the comparison (Fig. C.7). As seen the mean ratio between measured and calculated values is close to unity; the maximum difference between them does not exceed a factor of two.



**Fig. C.6.** Calculated versus measured values of annual wet deposition of mercury. Dashed line shows the two-fold difference



**Fig. C.7.** Monitoring sites used in the model validation

Detailed description of the hemispheric model is published in [Travnikov and Ryaboshapko, 2002].

