EMEP Centres Joint Report for HELCOM
EMEP/MSC-W TECHNICAL REPORT 2/2018

Atmospheric Supply of Nitrogen, Cadmium, Mercury, Benzo(a)pyrene, and PCB-153 to the Baltic Sea in 2016

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Preface

The Co-operative Program for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) and the Baltic Marine Environment Protection Commission (HELCOM) are both conducting work on air monitoring modelling and compilation of emission inventories. In 1995, HELCOM decided to rationalise its current programs by avoiding duplication of efforts with specialised international organizations. At the request of HELCOM, the steering Body of EMEP at its nineteenth session agreed to assume the management of atmospheric monitoring data, the preparation of air emission inventories and the modelling of air pollution in the Baltic region.

Following the coordination meeting held in Potsdam in Germany and the Pollution Load Input meeting held in Klaipeda-Joudkrante in Lithuania, both in 1996, it was agreed that EMEP Centres should be responsible for regular evaluation of the state of the atmosphere in the Baltic Sea region and should produce an annual joint summary report which includes updated emissions of selected air pollution, modelled deposition fields, allocation budgets and measurement data.

This EMEP Centres Joint Report for HELCOM is an update of the comprehensive report that was prepared for HELCOM in 2017 (http://emep.int/publ/helcom/2017) and consists of a brief overview of this year's results (i.e. up to 2016), an account of any updates in the methodology, and a collection of Baltic Sea Environmental Fact Sheets (BSEFS) for Nitrogen, Heavy metals and POPs. The results are based on the modelling and monitoring data presented to the Fourth Joint session of the Working Group on Effects and the Steering Body to EMEP which took place 10-14 September 2018 in Geneva. They include measurements (reported by CCC), as well as emissions and depositions calculated by the EMEP models (MSC-W and MSC-E).

Acknowledgements

The authors are indebted to their colleagues at MSC-E, MSC-W, and CCC for their help in providing the results included in this report.

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Introduction

The first EMEP Centres Joint Report for HELCOM was delivered in 1997 (Tarrason *et al*. 1997) and was followed by nineteen annual reports with the last one in 2017 (Bartnicki *et al*., 2017). The present EMEP Centres Joint Report for HELCOM is focused on the year 2016. It is based on the modelling and monitoring data presented to the Fourth Joint session of the Working Group on Effects and the Steering Body to EMEP which took place 10-14 September 2018 in Geneva.

Measurements

Eight countries have submitted data for 2016 from a total of eighteen HELCOM stations, which is one less than last year, as the Finnish site Hailuoto II has been closed down. In addition, one Swedish site (Vavihill) has been closed down, but the measurements have been relocated to a new site in Hallahus which is located close by.

The stations are distributed in eight of the nine sub-basins. Not all sites measure all HELCOM relevant parameters. Sixteen sites measured oxidized and/or reduced nitrogen compounds in air and seventeen sites in precipitation. For heavy metals there were thirteen stations with cadmium and lead in precipitation, while eleven sites reported data for measurements in the air. There were six sites with mercury measurements in precipitation and five in air. Six sites report data on various compounds of persistent organic pollutants (POPs). All the data can be downloaded from ebas.nilu.no.

Nitrogen modelling (EMEP/MSC-W)

The EMEP/MSC-W model, a multi-pollutant 3D Eulerian Chemical transport model, has been used for all nitrogen computations presented here. The model takes into account processes of emissions, advection, turbulent diffusion, chemical transformations, wet and dry depositions and inflow of pollutants into the model domain. It was documented in detail by Simpson et al., 2012 and in the annual chapters on model updates in subsequent EMEP status reports (Tsyro et al., 2014; Simpson et al., 2015; 2016; 2017; 2018).

The model is regularly evaluated against measurements from the EMEP network under the LRTAP convention (e.g. Gauss et al., 2018a/b; Tsyro et al., 2018), but also in a large number of international research projects and operational services (e.g. Copernicus Atmosphere Modelling Service, http://macc-raq-op.meteo.fr/). The performance of the EMEP/MSC-W model can be considered as state-of-the-art over a large range of both gaseous species and particulate matter. The model code (software) is also available as

Open Source (https://github.com/metno/emep-ctm) and has been widely used both as a research tool and for underpinning of air quality legislation.

The EMEP/MSC-W model version rv4.17a has been used for the 2018 model runs and deposition calculations (EMEP Status Report 1/2018). This year, for the second time, the model has been run on 0.1×0.1 degree resolution, within the EMEP domain outlined in green in Figure 1.1. Meteorological data have been taken from ECMWF, emissions are based on officially reported data to CEIP, and boundary conditions and forest fires for 2016 are based on observations and the GFED data base, respectively. DMS emissions from marine surfaces are calculated dynamically during the model run, i.e. they respond to variations in meteorology. Anthropogenic emissions from shipping were provided to EMEP by FMI (Finnish Meteorological Institute) for the year 2015, based on AIS data and the STEAM model described in Jalkanen et al. 2016. These data were used also in the calculations for 2016.

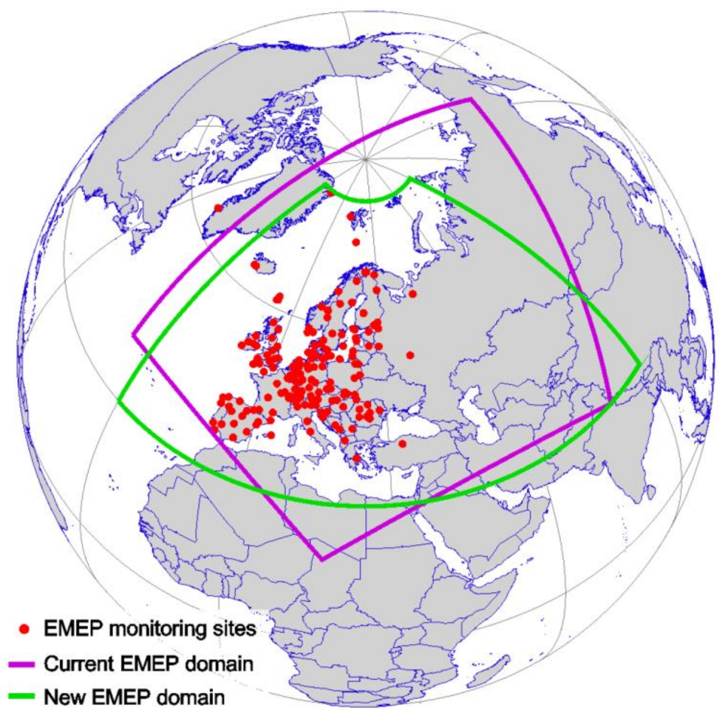

Figure 1.1. The old (purple) and new (green) official EMEP domains. The new domain has been used for the second time this year. The model resolution has increased from about 50×50 km^2 (polar-stereographic grid) to 0.1×0.1 degrees (regular longitude-latitude grid).

Following the decision of the EMEP bureau, no source-receptor matrices for nitrogen were calculated last year. However, this year they were calculated again, on a 0.3°

longitude x 0.2° latitude grid. Contributions of nitrogen sources to nitrogen deposition to the Baltic Sea are thus presented this year for 2016. Country-to-basin blame matrices have been calculated based on normalized depositions of oxidized, reduced and total nitrogen, and are provided on Excel format rather than being included in the fact sheets (due to the large size of the blame matrix).

Heavy metals and POPs (EMEP/MSC-E)

Atmospheric input and source allocation budgets of heavy metals (cadmium, lead, and mercury) to the Baltic Sea were computed using the latest version of MSCE-HM model. MSCE-HM is the regional-scale model operating within the EMEP region. This is a three-dimensional Eulerian-type chemistry transport model driven by off-line meteorological data. The model considers HM emissions from anthropogenic and natural sources, transport in the atmosphere, chemical transformations (of mercury only) both in gaseous and aqueous phases, and deposition to the surface. The model domain is defined on polar stereographic projection and covers the standard EMEP region by a regular grid with 50x50 km spatial resolution at 60º latitude. For national scale applications finer resolution is applied (e.g. 5x5, 10x10 km). Vertical structure of the model is formulated in the sigma-pressure coordinate system, particularly, 15 irregular sigma-layers are used in the model covering the whole troposphere. Detailed description of the model is available in (Travnikov and Ilyin, 2005).

It is assumed in the model that such HMs as lead and cadmium and their compounds are transported in the atmosphere in composition of aerosol particles. It is believed that possible chemical transformations of lead and cadmium do not change properties of carrying particles with regard to removal processes. On the contrary, for mercury the model considers its transformations in the atmosphere including transitions between the gaseous, aqueous and solid phases, and chemical reactions in the gaseous and aqueous environment. Model description of removal processes includes dry deposition and wet scavenging. The dry deposition scheme is based on the resistance analogy and allows taking into account deposition to different land cover types. The model distinguishes in-cloud and sub-cloud wet scavenging of particulate species and highly soluble reactive gaseous mercury. Wind re-suspension of particle-bound lead and cadmium from soil and seawater is an important process which affects essentially ambient pollution levels, particularly, in areas with low direct anthropogenic emissions. The model includes parameterization of HM re-suspension with dust aerosol particles from soil and generation of sea-salt and wind suspension of HMs from sea surface.

Evaluation of PCDD/F, PAH (B(a)P), and PCB atmospheric input to the Baltic Sea was carried out using the latest version of MSCE-POP model. Similar to MSCE-HM model the MSCE-POP model is a three-dimensional Eulerian multimedia POP transport model operating within the geographical scope of EMEP region with spatial resolution 50 km at

60º latitude. Both models share the same description of atmospheric transport and structure of the atmospheric compartment. The MSCE-POP model considers the following environmental compartments: air, soil, sea, vegetation and forest litter fall. The following basic processes are included in the model to describe POP fate: emission, advective transport, turbulent diffusion, dry and wet deposition, gas/particle partitioning, degradation, and gaseous exchange between the atmosphere and the underlying surface (soil, seawater, vegetation). Detailed description of MSCE-POP model is given in EMEP report (Gusev et al., 2005).

The formulation of MSCE-HM and MSCE-POP models and their performance were thoroughly evaluated within the framework of activity of EMEP/TFMM on the EMEP Models Review (EMEP, 2006). One of the main conclusions of the TFMM Workshop held in Moscow in 2005 was that MSCE-HM and MSCE-POP models represent the state of the science and fit for the purpose of evaluating the contribution of long-range transport to the environmental impacts caused by HMs and POPs.

There is ongoing development of the multimedia multiscale modelling approach for HMs and POPs at the MSC-E (Travnikov et al., 2009). The Global EMEP Multi-media Modelling System (GLEMOS) is being used to evaluate HM and POP pollution at different scales (from global to country scale) along with older MSCE-HM and MSCE-POP models.

The sub-basins of the Baltic Sea

In 2013, an important change was made by HELCOM concerning sub-basins of the Baltic Sea. Until 2012, all depositions, as well as source allocation budgets had been calculated for the six sub-basins of the Baltic Sea (Gulf of Bothnia (GUB), Gulf of Finland (GUF), Gulf of Riga (GUR), Baltic Proper (BAP), Belt Sea (BES) and Kattegat (KAT)). In 2013, nine sub-basins of the Baltic Sea were introduced and used for EMEP reporting to HELCOM. The same nine sub-basins have also been used in the computations for 2016. They are listed in Table 1.2, in alphabetical order, together with their abbreviations and surface area in km^2. There are large differences in the sizes of individual sub-basins. The area of the largest one – Baltic Proper is almost two orders of magnitude higher than the area of the smallest sub-basin – The Sound. The areas of the remaining sub-basins are within a factor-of-two range.

The area of the entire Baltic Sea basin, calculated as a sum of sub-basins is 417 587 km^2. The locations of individual sub-basins are presented in Fig. 1.2. These sub-basins have been used for all computations presented and discussed in the present report.

Table 1.2. The sub-basins of the Baltic Sea used for computing atmospheric nitrogen deposition from the year 2013, listed in alphabetical order. The abbreviations and areas of sub-basins of the Baltic Sea and the entire Baltic Sea basin are also shown.

Sub-basin	**Abbreviation**	**Area in km^2**
Archipelago Sea	ARC	13405
Baltic Proper	BAP	209258
Bothnian Bay	BOB	36249
Bothnian Sea	BOS	65397
Gulf of Finland	GUF	29998
Gulf of Riga	GUR	18646
Kattegat	KAT	23659
The Sound	SOU	2328
Western Baltic	WEB	18647
Baltic Sea basin	**BAS**	**417587**

Fig 1.2. Locations of the sub-basins of the Baltic Sea listed in Table 1.2 and used for all nitrogen deposition calculations presented in this report. The original figure with the sub-basins was provided by the Baltic Nest Institute (BNI).

In the results presented in the present report the names of countries, sources and receptors are often abbreviated. The list of these abbreviations is given below together with the EMEP identification number.

CODE	**EMEP ID**	**NAME**
AL	1	Albania
AT	2	Austria
BE	3	Belgium
BG	4	Bulgaria
FCS	5	Former Czechoslovakia
DK	6	Denmark
FI	7	Finland
FR	8	France
FGD	9	Former German Democratic Republic
FFR	10	Former Federal Republic of Germany
GR	11	Greece
HU	12	Hungary
IS	13	Iceland
IE	14	Ireland
IT	15	Italy
LU	16	Luxembourg
NL	17	Netherlands
NO	18	Norway
PL	19	Poland
PT	20	Portugal
RO	21	Romania
ES	22	Spain
SE	23	Sweden
CH	24	Switzerland
TR	25	Turkey
FSU	26	Former USSR
GB	27	United Kingdom
VOL	28	Volcanic emissions
REM	29	Remaining land Areas
BAS	30	Baltic Sea
NOS	31	North Sea
ATL	32	Remaining North-East Atlantic Ocean
MED	33	Mediterranean Sea
BLS	34	Black Sea

NAT	35	Natural marine emissions
RUO	36	Kola & Karelia
RUP	37	St.Petersburg & Novgorod-Pskov
RUA	38	Kaliningrad
BY	39	Belarus
UA	40	Ukraine
MD	41	Republic of Moldova
RUR	42	Rest of the Russian Federation
EE	43	Estonia
LV	44	Latvia
LT	45	Lithuania
CZ	46	Czech Republic
SK	47	Slovakia
SI	48	Slovenia
HR	49	Croatia
BA	50	Bosnia and Herzegovina
CS	51	Serbia and Montenegro
MK	52	The former Yugoslav Republic of Macedonia
KZ	53	Kazakhstan in the former official EMEP domain
GE	54	Georgia
CY	55	Cyprus
AM	56	Armenia
MT	57	Malta
ASI	58	Remaining Asian areas
LI	59	Liechtenstein
DE	60	Germany
RU	61	Russian Federation in the former official EMEP domain
MC	62	Monaco
NOA	63	North Africa
EU	64	European Community
US	65	United States
CA	66	Canada
BIC	67	Boundary and Initial Conditions
KG	68	Kyrgyzstan
AZ	69	Azerbaijan
ATX	70	EMEP-external Remaining North-East Atlantic Ocean
RUX	71	EMEP-external part of Russian Federation
RS	72	Serbia
ME	73	Montenegro
RFE	74	Rest of Russian Federation in the extended EMEP domain
KZE	75	Rest of Kazakhstan in the extended EMEP domain

UZO	76	Uzbekistan in the former official EMEP domain
TMO	77	Turkmenistan in the former official EMEP domain
UZE	78	Rest of Uzbekistan in the extended EMEP domain
TME	79	Rest of Turkmenistan in the extended EMEP domain
CAS	80	Caspian Sea
TJ	81	Tajikistan
ARO	82	Aral Lake in the former official EMEP domain
ARE	83	Rest of Aral Lake in the extended EMEP domain
ASM	84	Modified Remaining Asian Areas in the former official EMEP domain
ASE	85	Remaining Asian Areas in the extended EMEP domain
AOE	86	Arctic Ocean in the extended EMEP domain
KZT	92	Kazakhstan
RUE	93	Russian Federation in the extended EMEP domain (RU + RFE + RUX)
UZ	94	Uzbekistan
TM	95	Turkmenistan
AST	96	Asian areas in the extended EMEP domain (ASM + ASE + ARO + ARE + CAS)
FYU	99	Former Yugoslavia
BEF	301	Belgium (Flanders)
BA2	302	Baltic Sea EU Cargo o12m
BA3	303	Baltic Sea ROW Cargo o12m
BA4	304	Baltic Sea EU Cargo i12m
BA5	305	Baltic Sea ROW Cargo i12m
BA6	306	Baltic Sea EU Ferry o12m
BA7	307	Baltic Sea ROW Ferry o12m
BA8	308	Baltic Sea EU Ferry i12m
BA9	309	Baltic Sea ROW Ferry i12m
NO2	312	North Sea EU Cargo o12m
NO3	313	North Sea ROW Cargo o12m
NO4	314	North Sea EU Cargo i12m
NO5	315	North Sea ROW Cargo i12m
NO6	316	North Sea EU Ferry o12m
NO7	317	North Sea ROW Ferry o12m
NO8	318	North Sea EU Ferry i12m
NO9	319	North Sea ROW Ferry i12m
AT2	322	Remaining North-East Atlantic Ocean EU Cargo o12m
AT3	323	Remaining North-East Atlantic Ocean ROW Cargo o12m
AT4	324	Remaining North-East Atlantic Ocean EU Cargo i12m
AT5	325	Remaining North-East Atlantic Ocean ROW Cargo i12m

AT6	326	Remaining North-East Atlantic Ocean EU Ferry o12m
AT7	327	Remaining North-East Atlantic Ocean ROW Ferry o12m
AT8	328	Remaining North-East Atlantic Ocean EU Ferry i12m
AT9	329	Remaining North-East Atlantic Ocean ROW Ferry i12m
ME2	332	Mediterranean Sea EU Cargo o12m
ME3	333	Mediterranean Sea ROW Cargo o12m
ME4	334	Mediterranean Sea EU Cargo i12m
ME5	335	Mediterranean Sea ROW Cargo i12m
ME6	336	Mediterranean Sea EU Ferry o12m
ME7	337	Mediterranean Sea ROW Ferry o12m
ME8	338	Mediterranean Sea EU Ferry i12m
ME9	339	Mediterranean Sea ROW Ferry i12m
BL2	342	Black Sea EU Cargo o12m
BL3	343	Black Sea ROW Cargo o12m
BL4	344	Black Sea EU Cargo i12m
BL5	345	Black Sea ROW Cargo i12m
BL6	346	Black Sea EU Ferry o12m
BL7	347	Black Sea ROW Ferry o12m
BL8	348	Black Sea EU Ferry i12m
BL9	349	Black Sea ROW Ferry i12m
GL	601	Greenland