Atmospheric deposition of B(a)P on the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2022

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Key message

Levels of annual total atmospheric deposition of B(a)P to the Baltic Sea have decreased in period from 1990 to 2020 by 34%, although the decrease was higher during the period 1990-2002 comparing to the subsequent period 2003-2020.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This BSEFS shows the levels and trends in B(a)P atmospheric deposition to the Baltic Sea. The deposition of B(a)P represents the pressure of the emission sources on the Baltic Sea aquatic environment as described in the BSEFS "Atmospheric emissions of B(a)P in the Baltic Sea region".

Policy relevance and policy reference

The updated Baltic Sea Action Plan states the ecological objectives that concentrations of hazardous substances in the environment are to be close to background values for naturally occurring substances. HELCOM Recommendation 31E/1 identifies the list of regional priority substances for the Baltic Sea.

The relevant policy to the control of emissions of B(a)P to the atmosphere on European scale is set in the framework of UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). According to the CLRTAP Protocol on Persistent Organic Pollutants (1998), the emissions of B(a)P must be reduced below the emission levels in 1990.

For EU member states the policy frame is set by the EU IED Directive, whereas for the Russian Federation the corresponding policy framework is embraced by the Russian Federal Act on the environmental protection and the Act on protection of atmospheric air.

Assessment

In order to assess long-term changes of B(a)P atmospheric input to the Baltic Sea, model simulations based on officially reported emission data were carried out. Uncertainties of officially reported B(a)P emission inventories are relatively high varying from about 50-60% for Poland Latvia up to 800% for Denmark. Though high level of uncertainties in the official emissions of some of the HELCOM countries, model estimates of B(a)P pollution for the Baltic Sea region show generally reasonable agreement with the observed levels of concentrations.

Airborne input of B(a)P to the Baltic Sea has decreased by 34% in the period from 1990 to 2020 (Figure 1, Table 1). The strongest decline is estimated for the Sound sub-basin (-57%). At the same time, no significant changes of deposition are seen in the Bothnian Sea and the Gulf of Finland sub-basins.

The decrease of B(a)P deposition to the Baltic Sea was stronger in the period 1990-2002 comparing to subsequent period 2003-2020. Trends of deposition fluxes for both periods were analysed using Mann-Kendall test methodology [*Gilbert*, 1987; *Connor et al*., 2012]. In the period from 1990 to 2002, stronger decline is estimated with the mean annual rate of deposition decline about 0.12 tonnes per year with confidence factor >99%. The subsequent period of time 2003-2020 is characterised by less intensive mean annual decline rate of about 0.05 tonnes per year with confidence factor >99%. The values of the confidence factors indicates that the trends for the both parts of the assessment period are significant. Reduction of atmospheric input of B(a)P to the Baltic Sea is connected with the realization of various abatement measures, which took place in the HELCOM countries as well as other EMEP countries.

The highest total annual B(a)P deposition fluxes over the Baltic Sea in 2020 are estimated for the Gulf of Finland and the Sound sub-basins (Figures 2, 3). The lowest deposition flux is obtained for the Bosnian Sea sub-basin. Annual emissions of HELCOM countries in 2020 contributed to B(a)P deposition over the Baltic Sea about 75% (Table 2), with the largest shares made by Poland and Finland (Figure 4).

The main contribution to total B(a)P deposition is made by emissions from *Residential Combustion* sector. Following the officially reported information, in the majority of EMEP countries dominating source of B(a)P emissions in this sector is wood combustion for domestic heating. At the same time, some of the countries are characterized by substantial contribution of coal combustion sources (e.g. Poland). Other important contributors include emissions from *Industry*, *Fugitive*, and *Agriculture* sectors.

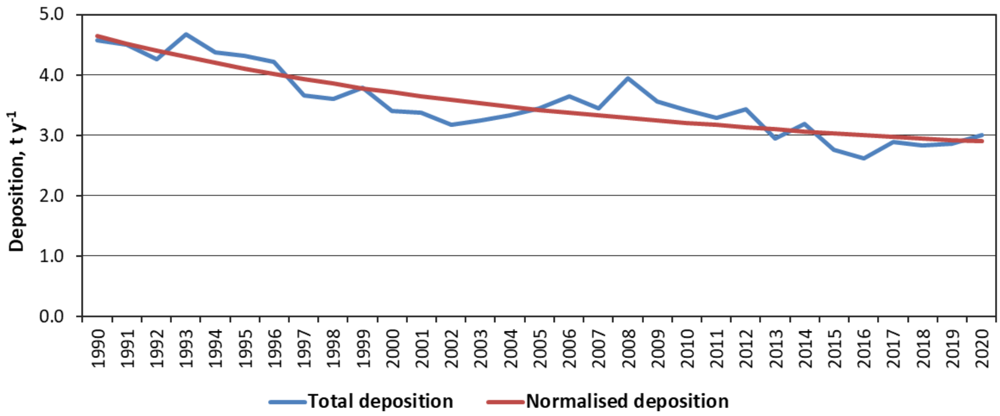

Figure 1. Long-term changes of total annual modelled atmospheric deposition (blue line) and estimates of normalized deposition (red line) of B(a)P to the Baltic Sea for the period 1990-2020, (t y^{-1}). Normalized depositions were obtained using the methodology described below in the metadata section 5.

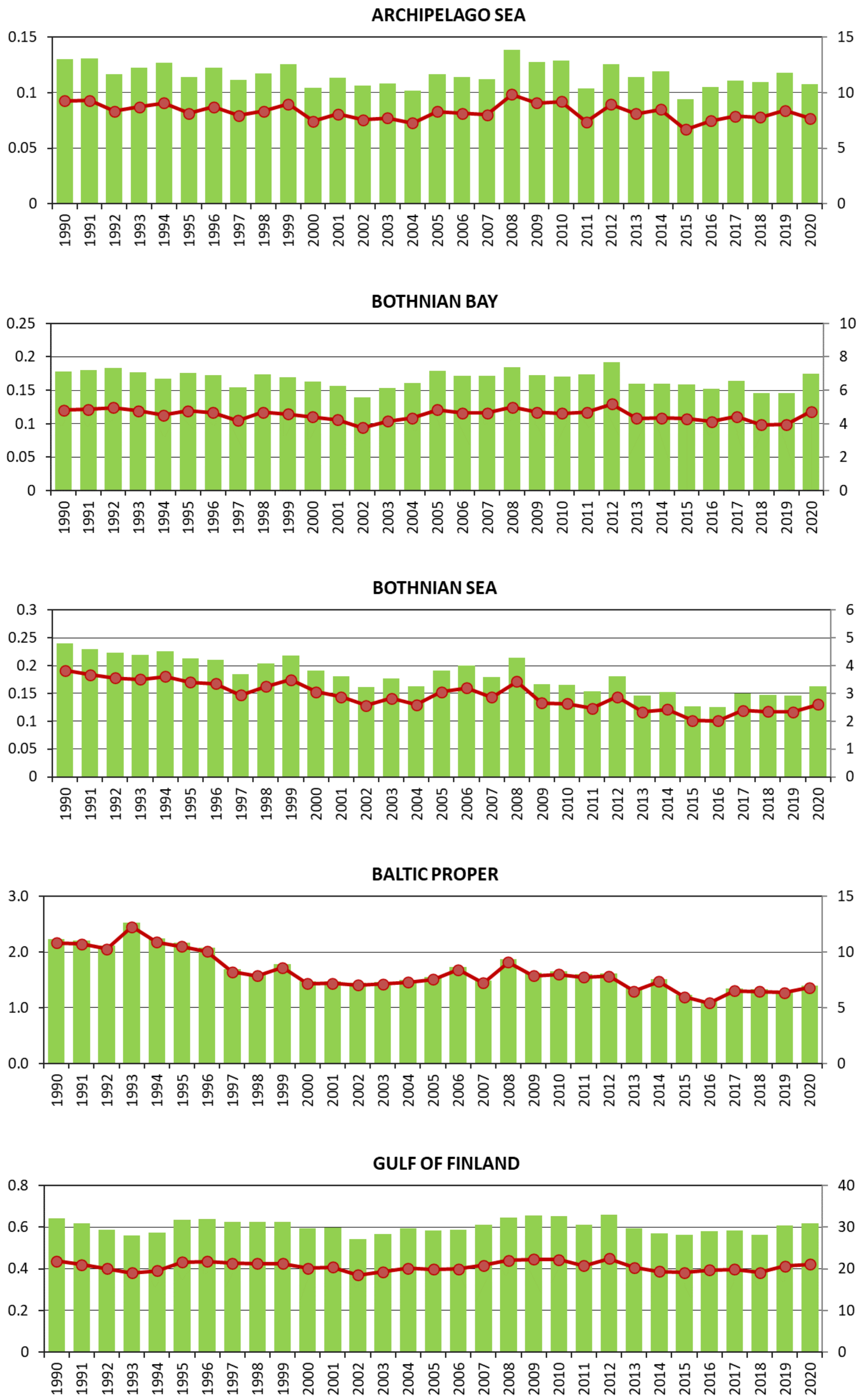

Figure 2. Time-series of computed total annual atmospheric deposition of B(a)P to nine sub-basins of the Baltic Sea for the period 1990-2020 in t y^{-1} as green bars (left axis) and total deposition fluxes in g km^{-2} y^{-1} as red lines (right axis).

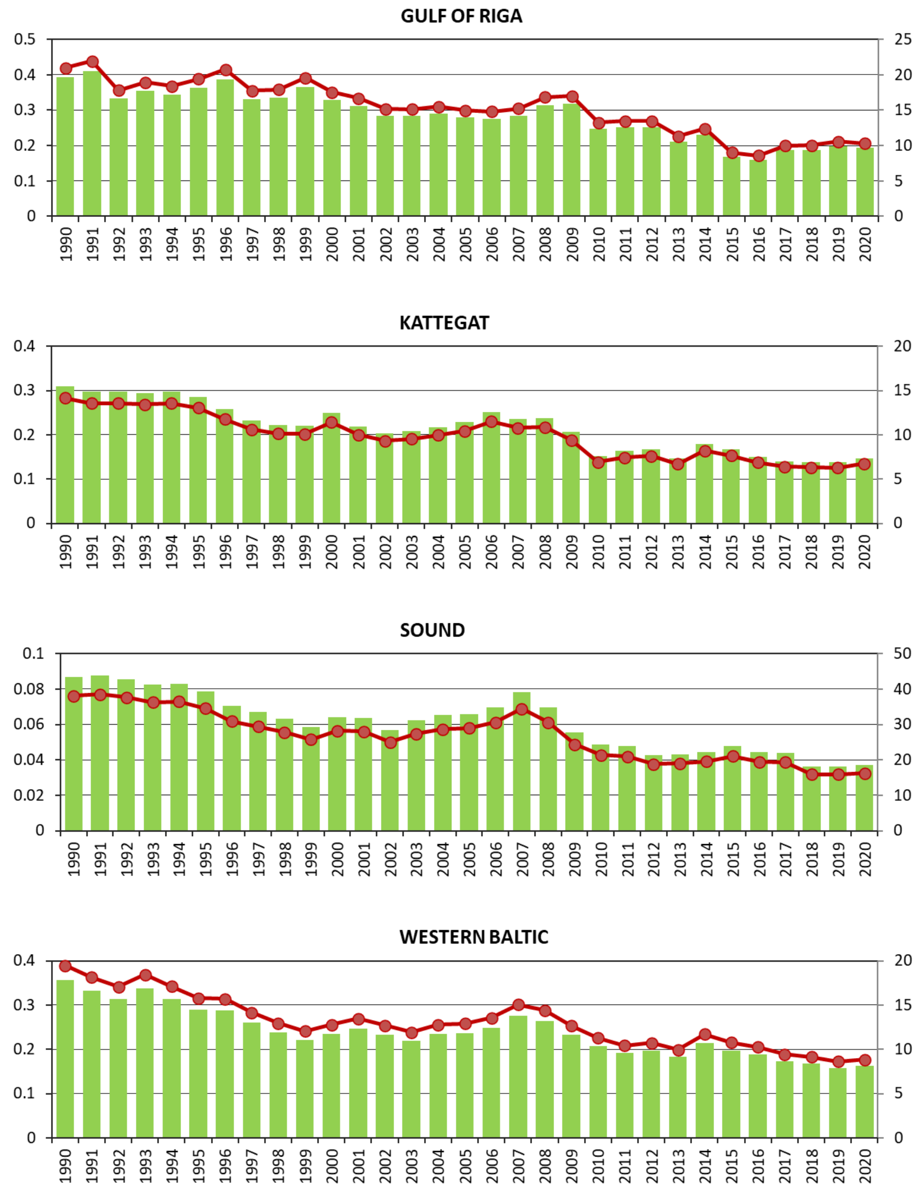

Figure 2. (continued). Time-series of computed total annual atmospheric deposition of B(a)P to nine sub-basins of the Baltic Sea for the period 1990-2020 in t y^{-1} as green bars (left axis) and total deposition fluxes in g km^{-2} y^{-1} as red lines (right axis).

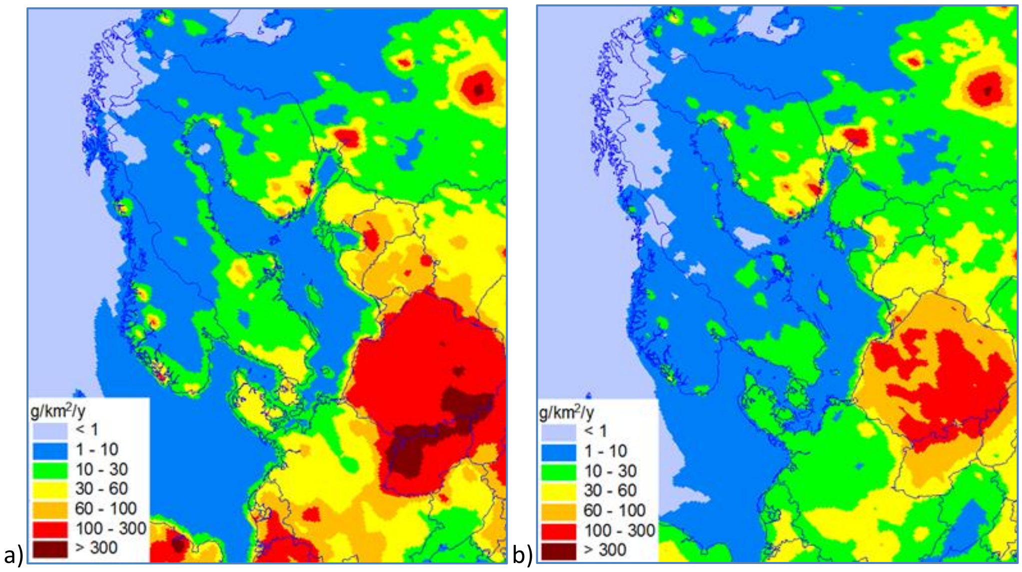

Figure 3. Spatial distribution of modelled annual total deposition fluxes of B(a)P in the Baltic Sea region for 1990 (a) and 2020 (b), g km^{-2} y^{-1}.

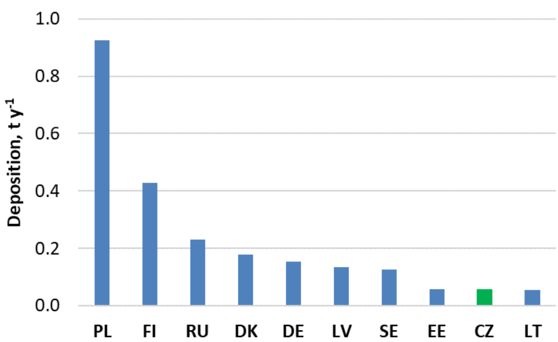

Figure 4. Ten countries with the highest contribution to annual total deposition of B(a)P to the Baltic Sea estimated for 2020, t y^{-1}. Green bars indicate depositions from non-HELCOM countries.

Data

Numerical data on computed B(a)P depositions to the Baltic Sea are given in the following tables.

Table 1. Computed total annual deposition of B(a)P to nine Baltic Sea sub-basins, the whole Baltic Sea (BAS) and normalized deposition* to the Baltic Sea (Norm) for the period 1990-2020. Units: t y^{-1}.

	ARC	BOB	BOS	BAP	GUF	GUR	KAT	SOU	WEB	BAS	Norm
1990	0.13	0.18	0.24	2.24	0.64	0.39	0.31	0.09	0.36	4.57	4.64
1991	0.13	0.18	0.23	2.21	0.62	0.41	0.30	0.09	0.33	4.50	4.52
1992	0.12	0.18	0.22	2.12	0.59	0.33	0.30	0.09	0.31	4.26	4.40
1993	0.12	0.18	0.22	2.53	0.56	0.35	0.29	0.08	0.34	4.68	4.30
1994	0.13	0.17	0.23	2.25	0.57	0.34	0.30	0.08	0.31	4.38	4.20
1995	0.11	0.18	0.21	2.17	0.63	0.36	0.29	0.08	0.29	4.32	4.10
1996	0.12	0.17	0.21	2.07	0.64	0.39	0.26	0.07	0.29	4.22	4.01
1997	0.11	0.15	0.18	1.70	0.63	0.33	0.23	0.07	0.26	3.66	3.93
1998	0.12	0.17	0.20	1.62	0.62	0.33	0.22	0.06	0.24	3.60	3.85
1999	0.13	0.17	0.22	1.78	0.63	0.37	0.22	0.06	0.22	3.78	3.78
2000	0.10	0.16	0.19	1.48	0.59	0.33	0.25	0.06	0.23	3.41	3.71
2001	0.11	0.16	0.18	1.48	0.60	0.31	0.22	0.06	0.25	3.37	3.65
2002	0.11	0.14	0.16	1.45	0.54	0.28	0.20	0.06	0.23	3.18	3.59
2003	0.11	0.15	0.18	1.47	0.57	0.28	0.21	0.06	0.22	3.25	3.53
2004	0.10	0.16	0.16	1.51	0.59	0.29	0.22	0.07	0.23	3.33	3.48
2005	0.12	0.18	0.19	1.56	0.59	0.28	0.23	0.07	0.24	3.44	3.42
2006	0.11	0.17	0.20	1.73	0.59	0.28	0.25	0.07	0.25	3.65	3.38
2007	0.11	0.17	0.18	1.49	0.61	0.28	0.24	0.08	0.28	3.44	3.33
2008	0.14	0.18	0.21	1.87	0.65	0.31	0.24	0.07	0.26	3.94	3.29
2009	0.13	0.17	0.17	1.63	0.66	0.32	0.21	0.06	0.23	3.56	3.24
2010	0.13	0.17	0.16	1.65	0.65	0.25	0.15	0.05	0.21	3.42	3.21
2011	0.10	0.17	0.15	1.60	0.61	0.25	0.16	0.05	0.19	3.29	3.17
2012	0.13	0.19	0.18	1.62	0.66	0.25	0.17	0.04	0.20	3.43	3.13
2013	0.11	0.16	0.15	1.34	0.60	0.21	0.15	0.04	0.18	2.94	3.10
2014	0.12	0.16	0.15	1.52	0.57	0.23	0.18	0.04	0.21	3.19	3.07
2015	0.09	0.16	0.13	1.23	0.56	0.17	0.17	0.05	0.20	2.75	3.03
2016	0.10	0.15	0.13	1.12	0.58	0.16	0.15	0.04	0.19	2.63	3.00
2017	0.11	0.16	0.15	1.34	0.58	0.19	0.14	0.04	0.17	2.90	2.98
2018	0.11	0.15	0.15	1.33	0.56	0.19	0.14	0.04	0.17	2.83	2.95
2019	0.12	0.15	0.15	1.31	0.61	0.20	0.14	0.04	0.16	2.86	2.92
2020	0.11	0.17	0.16	1.40	0.62	0.19	0.15	0.04	0.16	3.01	2.90

* - normalized depositions were obtained using the methodology described below in the metadata section 5.

Table 2. Computed contributions by country to annual total deposition of B(a)P to nine Baltic Sea sub-basins for the year 2020. Units: t y^{-1}. (*HELCOM*: contribution of anthropogenic sources of HELCOM countries; *EMEP*: contribution of anthropogenic sources in other EMEP countries; *Other*: contributions of secondary and remote non-EMEP emission sources).

Country	ARC	BOB	BOS	BAP	GUF	GUR	KAT	SOU	WEB	BAS
DK	3.38E-04	1.79E-04	7.33E-04	3.04E-02	3.36E-04	5.83E-04	6.53E-02	2.15E-02	5.95E-02	1.79E-01
EE	1.36E-03	5.43E-04	1.56E-03	5.98E-03	3.00E-02	1.86E-02	2.93E-06	3.00E-07	6.59E-07	5.81E-02
FI	4.77E-02	9.62E-02	5.30E-02	6.56E-03	2.23E-01	2.61E-03	7.92E-06	8.43E-07	3.03E-06	4.29E-01
DE	1.24E-03	5.18E-04	2.17E-03	8.23E-02	1.43E-03	2.18E-03	1.67E-02	2.90E-03	4.38E-02	1.53E-01
LV	3.07E-03	8.66E-04	3.59E-03	3.04E-02	7.65E-03	8.86E-02	1.58E-05	1.42E-06	3.44E-06	1.34E-01
LT	1.70E-03	4.84E-04	2.36E-03	3.44E-02	2.99E-03	1.36E-02	4.94E-05	4.33E-06	1.08E-05	5.56E-02
PL	1.48E-02	4.54E-03	2.19E-02	8.16E-01	1.40E-02	2.47E-02	1.46E-02	2.25E-03	1.16E-02	9.24E-01
RU	1.29E-03	2.41E-03	3.01E-03	4.92E-02	1.73E-01	2.43E-03	8.29E-05	9.08E-06	2.44E-05	2.31E-01
SE	4.44E-03	2.04E-02	3.54E-02	5.07E-02	1.65E-03	1.68E-03	1.01E-02	1.17E-03	4.04E-04	1.26E-01
AL	3.96E-09	2.63E-09	1.06E-08	1.91E-07	5.27E-09	6.59E-09	1.71E-08	1.77E-09	8.96E-09	2.48E-07
AM	2.06E-10	3.23E-10	5.11E-10	4.73E-09	6.91E-10	6.91E-10	1.47E-10	2.07E-11	1.25E-10	7.44E-09
AT	3.10E-05	1.01E-05	4.70E-05	1.25E-03	4.28E-05	6.18E-05	1.34E-04	1.94E-05	1.27E-04	1.73E-03
AZ	1.16E-10	9.25E-10	2.58E-10	1.24E-09	7.03E-09	5.16E-10	3.88E-11	4.86E-12	2.62E-11	1.01E-08
BA	9.10E-07	4.15E-07	1.71E-06	6.60E-05	1.66E-06	2.71E-06	6.58E-06	8.62E-07	4.64E-06	8.54E-05
BE	1.06E-04	6.81E-05	2.26E-04	3.17E-03	1.27E-04	1.61E-04	1.73E-03	1.73E-04	1.62E-03	7.38E-03
BG	9.23E-07	6.74E-07	3.31E-06	5.24E-05	1.17E-06	1.24E-06	9.16E-06	9.63E-07	5.63E-06	7.55E-05
BY	7.14E-04	2.32E-04	1.28E-03	7.30E-03	1.51E-03	2.85E-03	4.78E-05	5.03E-06	1.60E-05	1.40E-02
CH	9.90E-06	3.45E-06	1.59E-05	3.38E-04	1.20E-05	1.50E-05	6.50E-05	8.49E-06	7.17E-05	5.39E-04
CY	1.90E-10	1.04E-10	7.15E-10	5.71E-09	2.43E-10	2.86E-10	1.40E-10	9.13E-12	5.21E-11	7.45E-09
CZ	1.33E-03	4.25E-04	2.21E-03	4.34E-02	1.30E-03	1.76E-03	3.24E-03	5.30E-04	2.73E-03	5.69E-02
ES	6.69E-06	7.61E-06	2.29E-05	1.84E-04	9.19E-06	1.00E-05	8.49E-05	7.02E-06	7.31E-05	4.05E-04
FR	8.11E-05	6.03E-05	1.88E-04	2.49E-03	1.03E-04	1.25E-04	1.11E-03	1.12E-04	1.02E-03	5.29E-03
GB	1.86E-04	1.58E-04	4.83E-04	4.29E-03	2.12E-04	2.47E-04	2.61E-03	2.22E-04	2.06E-03	1.05E-02
GE	3.02E-08	3.37E-08	1.07E-07	3.85E-07	7.74E-08	5.52E-08	4.88E-09	5.39E-10	2.97E-09	6.97E-07
GR	2.04E-07	1.54E-07	8.88E-07	1.23E-05	2.77E-07	2.52E-07	2.49E-06	2.42E-07	1.41E-06	1.82E-05
HR	5.70E-06	1.95E-06	9.41E-06	3.12E-04	1.20E-05	2.02E-05	2.75E-05	4.09E-06	3.14E-05	4.24E-04
HU	4.82E-05	2.02E-05	8.29E-05	2.23E-03	9.33E-05	1.37E-04	2.93E-04	3.74E-05	2.36E-04	3.17E-03
IE	1.83E-05	1.50E-05	4.51E-05	3.86E-04	2.20E-05	2.36E-05	1.96E-04	1.94E-05	1.68E-04	8.94E-04
IS	1.42E-08	1.18E-07	5.51E-08	1.24E-07	1.66E-08	1.31E-08	1.04E-07	5.87E-09	3.62E-08	4.87E-07
IT	9.99E-06	2.42E-06	1.45E-05	2.84E-04	1.21E-05	1.57E-05	4.13E-05	4.75E-06	4.14E-05	4.27E-04
KY	3.32E-14	1.89E-14	6.91E-14	3.28E-13	1.01E-13	8.15E-14	3.72E-15	3.90E-16	1.53E-15	6.37E-13
KZ	5.17E-08	1.09E-07	7.19E-08	4.43E-07	5.97E-07	1.80E-07	1.39E-08	1.74E-09	9.62E-09	1.48E-06
LI	5.66E-08	1.89E-08	8.78E-08	1.91E-06	6.70E-08	8.45E-08	3.29E-07	4.04E-08	3.51E-07	2.94E-06
LU	3.65E-06	2.33E-06	7.97E-06	1.36E-04	4.45E-06	6.10E-06	6.05E-05	6.98E-06	6.44E-05	2.92E-04
MC	1.32E-11	5.66E-12	2.30E-11	3.62E-10	1.36E-11	1.73E-11	9.05E-11	9.87E-12	9.29E-11	6.28E-10
MD	2.45E-05	1.80E-05	6.92E-05	9.55E-04	1.85E-05	3.19E-05	2.84E-05	2.82E-06	1.37E-05	1.16E-03
ME	5.71E-10	3.81E-10	1.54E-09	3.76E-08	7.99E-10	1.14E-09	4.84E-09	5.40E-10	2.82E-09	5.02E-08
MK	2.37E-07	1.75E-07	5.10E-07	1.55E-05	3.86E-07	4.18E-07	1.96E-06	2.13E-07	1.22E-06	2.06E-05
MT	4.62E-10	2.76E-10	1.50E-09	1.70E-08	5.95E-10	6.22E-10	1.51E-09	1.56E-10	9.53E-10	2.30E-08
NL	1.17E-04	7.21E-05	2.49E-04	4.18E-03	1.38E-04	1.84E-04	2.19E-03	2.36E-04	2.46E-03	9.83E-03
NO	7.76E-05	1.34E-04	3.06E-04	2.94E-04	5.51E-05	3.58E-05	5.56E-04	1.37E-05	9.64E-05	1.57E-03
PT	9.06E-07	7.70E-07	2.88E-06	1.25E-05	1.30E-06	1.13E-06	5.77E-06	4.27E-07	3.66E-06	2.93E-05
RO	3.71E-05	3.27E-05	1.16E-04	1.90E-03	3.49E-05	5.04E-05	1.35E-04	1.42E-05	8.02E-05	2.40E-03
RS	4.25E-06	2.69E-06	7.74E-06	3.42E-04	7.79E-06	1.07E-05	5.88E-05	6.94E-06	4.39E-05	4.85E-04
SI	2.99E-06	9.58E-07	4.96E-06	1.45E-04	5.82E-06	9.89E-06	1.15E-05	1.67E-06	1.60E-05	1.99E-04
SK	2.00E-04	6.09E-05	2.90E-04	6.81E-03	2.97E-04	3.86E-04	4.76E-04	5.82E-05	3.56E-04	8.94E-03
TJ	9.73E-14	4.58E-14	1.80E-13	6.86E-13	1.68E-13	1.41E-13	1.72E-15	1.12E-16	2.82E-16	1.32E-12
TM	2.64E-11	1.71E-10	6.12E-11	2.01E-10	1.25E-09	5.87E-11	1.39E-12	1.45E-13	6.46E-13	1.77E-09
TR	3.18E-06	1.69E-06	1.22E-05	8.65E-05	4.50E-06	4.90E-06	2.48E-06	1.97E-07	1.17E-06	1.17E-04
UA	7.28E-04	3.09E-04	1.59E-03	1.34E-02	8.17E-04	1.83E-03	2.54E-04	2.89E-05	1.40E-04	1.91E-02
UZ	1.12E-11	5.08E-12	1.96E-11	1.12E-10	2.47E-11	2.30E-11	1.62E-12	1.87E-13	9.92E-13	1.98E-10
HELCOM	0.08	0.13	0.12	1.11	0.45	0.15	0.11	0.03	0.12	2.29
EMEP	0.00	0.00	0.01	0.09	0.00	0.01	0.01	0.00	0.01	0.15
Other	0.02	0.04	0.03	0.25	0.11	0.04	0.03	0.01	0.04	0.57
Total	0.10	0.17	0.16	1.45	0.57	0.20	0.15	0.04	0.16	3.01

Metadata

Technical information

1. Source:

Meteorological Synthesizing Centre East (MSC-E) of EMEP

2. Description of data:

Atmospheric depositions of B(a)P to the Baltic Sea for the period from 1990 to 2020 were estimated using the latest version of GLEMOS model developed at EMEP/MSC-E (http://en.msceast.org/index.php/j-stuff/glemos). Annual B(a)P emissions, officially reported by EMEP countries in 2021, were used in model computations for the years 1990-2019. Pollution levels of B(a)P in 2020 were evaluated using emission data, reported for the previous year 2019. These data are available from the web site of the EMEP Centre on Emission Inventories and Projections (CEIP) (http://www.ceip.at/). Detailed description of reported emission data, gap-filling methods, and expert estimates can be found in the CEIP Technical report [*Poupa*, 2021].

3. Geographical coverage:

Model predictions of B(a)P atmospheric deposition were obtained for the European region and surrounding areas covered by the EMEP modelling domain.

4. Temporal coverage:

Time-series of annual atmospheric deposition of B(a)P were estimated for the period 1990 – 2020.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budget of B(a)P deposition to the Baltic Sea were computed using the latest version of GLEMOS model using the EMEP domain (https://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid/). Model estimates describe regional scale distribution of pollution levels and source-receptor relationships.

GLEMOS modelling framework is a multi-scale multi-pollutant simulation platform developed for operational and research applications within the EMEP programme [*Tarrason and Gusev,* 2008; *Travnikov et al.,* 2009; *Jonson and Travnikov*, 2010; *Travnikov and Jonson*, 2011]. The framework allows simulations of dispersion and cycling of different classes of pollutants (e.g. heavy metals and persistent organic pollutants) in the environment with a flexible choice of the simulation domain (from global to local scale) and spatial resolution. The vertical structure consists of 20 irregular terrain-following sigma layers covering the height up to 10 hPa (ca. 30 km). Among these layers 10 lowest layers cover the first 5 km of the troposphere and height of the lowest model layer is about 75 m.

Anthropogenic emission data for modelling of B(a)P have been prepared based on the gridded emissions fields provided by CEIP for the EMEP longitude-latitude grid system with spatial resolution 0.1x0.1 degree. Gridded emissions are complemented by additional emission parameters required for model runs (e. g. intra-annual variations and vertical distribution). Atmospheric concentrations of chemical reactants and particulate matter, which are required for the description of B(a)P gas-particle partitioning and degradation, were imported from the MOZART model [*Emmons et al.*, 2010]. Boundary conditions for model simulations over EMEP domain were estimated using the global scale GLEMOS model simulations [*Ilyin et al.*, 2022].

Meteorological data used in model simulations for 1990-2020 were obtained using WRF meteorological data pre-processor [*Skamarock et al*., 2008] on the basis of meteorological re-analyses data (ERA-Interim) of European Centre for Medium-Range Weather Forecasts (ECMWF).

Model assessment of atmospheric transport and deposition of B(a)P is carried out on regular basis annually two years in arrears on the basis of emission data officially submitted by the Parties to LRTAP Convention.

The changes of B(a)P deposition to the Baltic Sea in the period 1990-2020 were non-linear with faster decline in the 1990s and slower decline after the 2000s. In order to characterize varying rate of temporal changes of B(a)P atmospheric input, the normalized deposition values were calculated using bi-exponential approximation [*Colette et al.*, 2016], which assumed that long-term changes in the beginning of the period were approximated by "fast" exponent, and decline in subsequent period by "slow" exponent.

Quality information

6. Strength and weakness:

Strength: annually updated information on atmospheric input of B(a)P to the Baltic Sea and its sub-basins.

Weakness: uncertainties of officially submitted inventories of B(a)P emissions, and of model estimates of secondary emissions from terrestrial and aquatic compartments.

7. Uncertainty:

Modelling approach, developed by the MSC-E for POPs, has been verified using regular comparisons of modelling results with measurements of the EMEP monitoring network [*Gusev et al*., 2005, 2006; *Shatalov et al.,* 2005; *Ilyin et al.*, 2021] and thoroughly reviewed at the workshop held in October, 2005 under supervision of the EMEP Task Force of Measurements and Modelling (TFMM). It was concluded that "MSC-E model is suitable for the evaluation of long-range transboundary transport and deposition of POPs in Europe" [ECE/EB.AIR/GE.1/2006/4].

8. Further work required:

Further work is required to reduce uncertainties of B(a)P pollution model assessment including uncertainties of monitoring data, emission inventories, and modelling approach applied in the EMEP GLEMOS model.

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