Chapter 2

MODEL OUTPUT

MSCE-POP model is mainly designed to provide the Parties to the Convention with information on the long-range transport and deposition of POPs in accordance with the Protocol on POPs. In modelling the emphasis is given to the evaluation of atmospheric transport, air concentrations and depositions. Concentrations in other media (soil, vegetation and seawater) are calculated for more detailed consideration of re-emission process and its influence on atmospheric concentrations and depositions.

At present, the model is used for simulation of long-range transport of polyaromatic hydrocarbons (PAHs), polychlorinated dibenzo(p)dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), and γ-hexachlorocyclohexane (γ–HCH or lindane). Besides, the model is used for evaluation of pollutants – candidates for the inclusion in the POP Protocol: hexachlorobutadiene (HCBD), pentachloroben-zene (PeCB), polychlorinated naphthalenes (PCN-47 congener), α-endosulfan, dicofol and brominated diphenyl ethers (congeners BDE-47 and 99).

The aim of the present section is to demonstrate main output of MSCE-POP model. It includes:

1. Transboundary transport of a pollutant between European countries (country-to-country matrices).
2. Contributions of domestic and external sources to air concentrations and depositions to each European country. This information can be supplemented by country-specific information: pollution levels, emissions, monitoring data, etc.
3. Spatial distributions of depositions of the considered pollutant and its concentrations in main environmental media. The plots of spatial distribution can be of use for evaluation of pollution levels and (especially) for determination of “hot spots” of contamination in various environmental compartments.
4. Evaluation of intercontinental transport and transport to remote regions (such as the Arctic).
5. Spatial distribution of depositions of a pollutant to various types of underlying surface (soil, vegetation, seawater). This kind of information may be used as an input for risk assessment.
6. Long-term trends of contamination in main environmental media. The information on long-term trends may be used to analyze long-term accumulation of a pollutant in the environmental media and to evaluate characteristic times for accumulation/clearance processes.
7. Projections of contamination levels in future based on different emission scenarios.
8. Redistribution of total environmental content of a pollutant between main environmental media (the atmosphere, soil, seawater, vegetation). This information is important for determination of most polluted ecosystems. Description of differences in the environmental behavior of various congeners included in complex chemical mixtures such as PCBs, PCDD/Fs and others.
9. Evaluation of long-range transport potential of a pollutant and its overall persistence in the environment. This information can be used for evaluation of new substances for negotiation process concerning the revision of the Protocol on POPs.

2.1. Transboundary transport and country-specific information

Model evaluation of POP transboundary transport in the European region and country-specific information for Germany is exemplified by calculations of B[a]P transport for 2001.

The half-life period of B[a]P in the atmosphere is about 1 week; therefore, this pollutant can be transported with air masses over long distances. The transboundary transport from a country can be estimated by the quantity of pollutant exported, i.e., by the contributions to the total depositions to other countries. Fig. 2.1a shows a diagram illustrating contributions of a number of countries to transboundary transport. The highest exporters of B[a]P are France (8.3 t/y), Poland (5.8 t/y) and Spain (5.2 t/y).

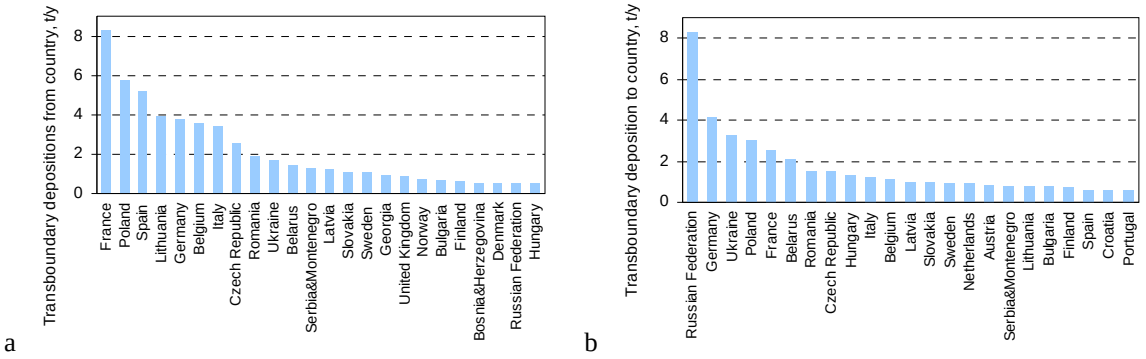


Fig. 2.1. *Contributions of some countries to B[a]P transboundary depositions (a) and contributions of external emission sources to B[a]P depositions to the territories of some countries (b)*

Inversely, countries can be ranked by the contribution of external sources to B[a]P total depositions to them (Fig. 2.1b). The greatest contributions of external-source to the total depositions are typical for the Russian Federation (8 t/y), Germany (4 t/y), Ukraine and Poland (about 3 t/y in each countries), i.e., for the countries with vast territories. Data on the contribution of transboundary transport to B[a]P depositions to each European country are available on the Internet (www.emep.int or www.msceast.org).

Another important characteristics of transboundary transport is its impact to average air B[a]P concentrations over European countries. In most of the European countries the contribution of external sources to B[a]P air pollution varies from 20 to 70% (Fig. 2.2). The contribution of external sources depends significantly on the levels of internal B[a]P emissions in the country under consideration as well as its geographic position and area. For instance in such countries as Luxembourg and Monaco external sources are almost entirely responsible for the surface air contamination by B[a]P. The effect of transboundary transport on air concentrations is more significant than that of domestic emission flux in such countries as Albania (88% of the total concentration), Portugal (74%) and Armenia (72%).

The absolute contribution of external sources to the B[a]P mean annual air concentrations over the territory of countries is also of interest. The countries, where this contribution exceeds the average annual European concentration (0.3 ng/m^3), are shown in Fig. 2.3. The most significant effect of transboundary transport is observed for Monaco (1.1 ng/m^3), Luxembourg (0.7 ng/m^3) and Belgium (0.5 ng/m^3).

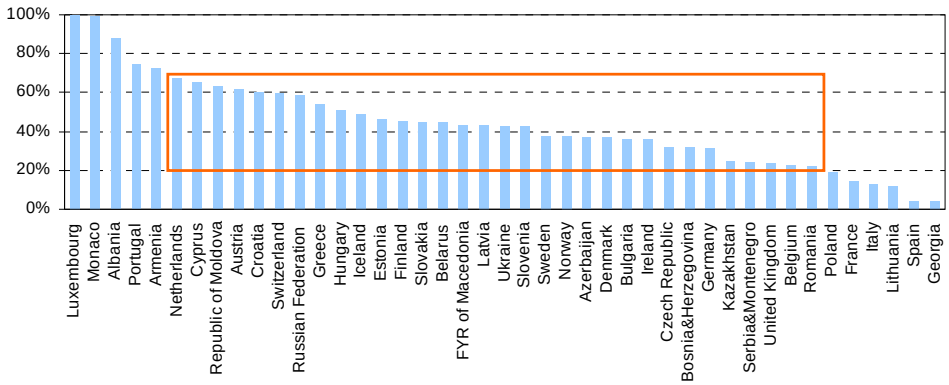


Fig. 2.2. *Contributions of external emission sources to the B[a]P mean annual air concentrations in EMEP countries*

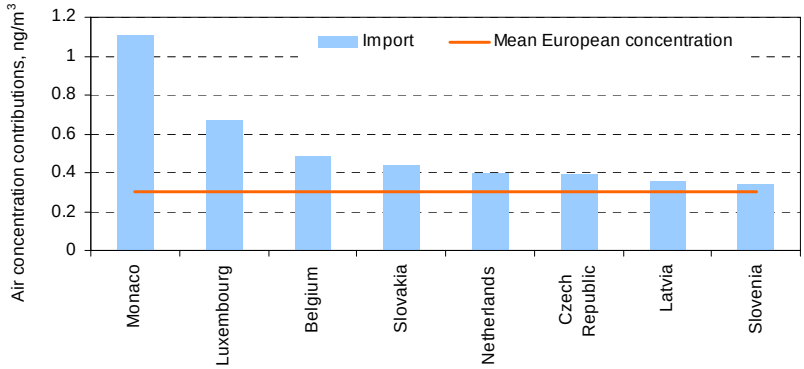
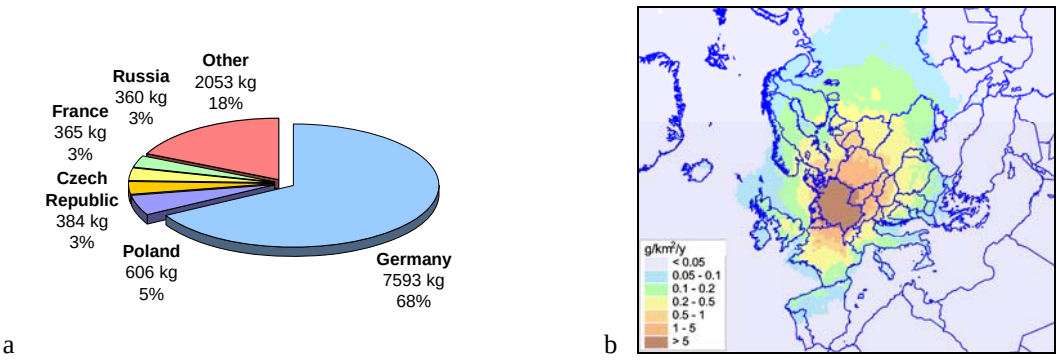


Fig. 2.3. *Contributions of external emission sources to the B[a]P mean annual air concentrations in some European countries*

At present elaboration of approaches to evaluation of transboundary transport for pollutants with essential fraction of gaseous phase is carried out on the basis of PCDD/Fs.

Country-specific information on pollution is exemplified by Germany. According to the official data, the total B[a]P emissions in Germany in 2001 were about 30 t, of which more than 13 t degraded in the air, 6 t were transported beyond the calculation grid, and more than 11 t deposited over the EMEP domain. Depositions are distributed in the following way: 7.6 t (68% of the total deposition) deposited to the territory of Germany; 0.6 t (5%) - to Poland; the Czech Republic, France and the Russian Federation received 0.4 t (3%) each; depositions to the rest of EMEP countries were 2 t (18%) (Fig. 2.4a).

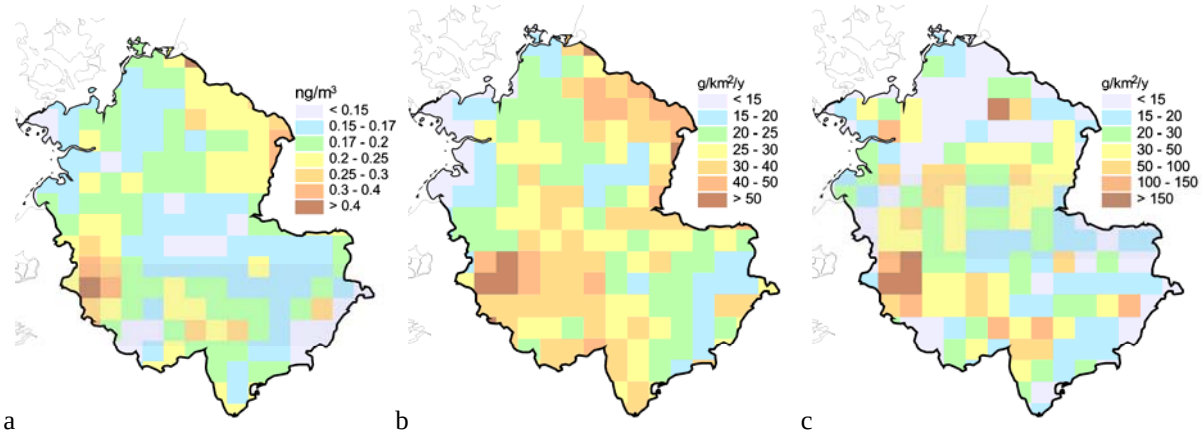
The estimated field of B[a]P depositions from German sources is shown in Fig. 2.4b. For most of the German territory B[a]P deposition exceeds the mean value for Europe (11 g/km^2/y). Depositions of B[a]P from German sources to the larger part of France and Belgium vary from 5 to 20 g/km^2/y. In most of the other European countries, depositions of B[a]P from German sources vary from 0.2 to 5 g/km^2/y. The same range is also typical for the areas located rather far from Germany, i.e., for the southern parts of Norway and Sweden.



a b

Fig. 2.4*. The distribution of B[a]P depositions from German sources over the territories of European countries (a) and their spatial distribution, g/km^2/y (b) in 2001*

Calculated spatial distributions of B[a]P air concentrations and depositions over the German territory in 2000 are shown in Fig. 2.5 together with domestic emissions in this year.



a b c

Fig. 2.5. *Spatial distribution of B[a]P air concentrations (a) and deposition flux (b) in Germany in comparison with emissions (c) in 2000*

High emission levels in Germany are characteristic of Northeastern and Southwestern parts. Values of emission flux in these parts of Germany exceed 50 g/km^2/y. This leads to comparably high levels of air concentrations in these regions (> 0.3 ng/m^3). The same situation takes place for deposition flux values, which reach 30 g/km^2/y and more in regions with high emission levels. Air concentration and deposition levels in the Northern part of Germany are lower (< 0.25 ng/m^3 for air concentrations and < 25 g/km^2/y for deposition flux). The same is characteristic of wide areas in the South-East of Germany.

The spatial distribution of the contributions from external sources to the territory of Germany is given in Fig. 2.6a. Over the major part of the territory the pollution import varies from 30 to 70%, however, in some regions near the boundaries the contribution of the neighbouring countries may be as high as 80% and more. The contribution of France to the total deposition of B[a]P to Germany is approximately 1.6 t/y (14% of the total deposition to the country, Fig. 2.6b). Noticeable contributions to the contamination of Germany are also made by Belgium – 1.1 t/y (9%), the Czech Republic – 0.4 t/y (3%) and Poland – 0.3 t/y (3%). Other European countries contribute to annual B[a]P depositions over Germany about 0.7 t/y (6%). Approximately the same values of contributions from external sources are typical for air concentrations of this pollutant in Germany.

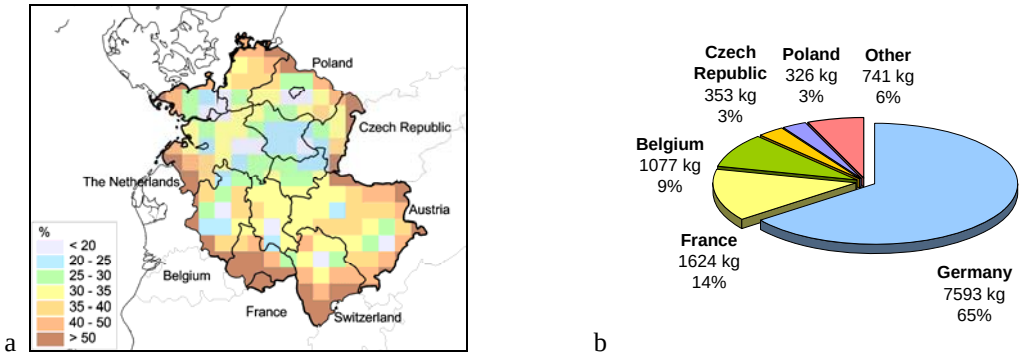


Fig. 2.6. *Spatial distributions of external sources contribution to B[a]P depositions over Germany in % (a) and contributions of European countries to B[a]P total annual depositions to Germany (b)*

Calculations allow evaluating the contribution of emission sources from different countries to depositions over specific regions within particular country. As an example, Fig. 2.7 illustrates the contribution of emission sources from European countries to depositions over particular German Lands.

The contribution of external emission sources varies from 12 to 70%. Significant contributions to depositions to particular Lands of Germany are made by France, Belgium, Poland and the Czech Republic. For instance the major input to B[a]P depositions to the territory of Saarland (73 kg/y, or 58%) is made by France.

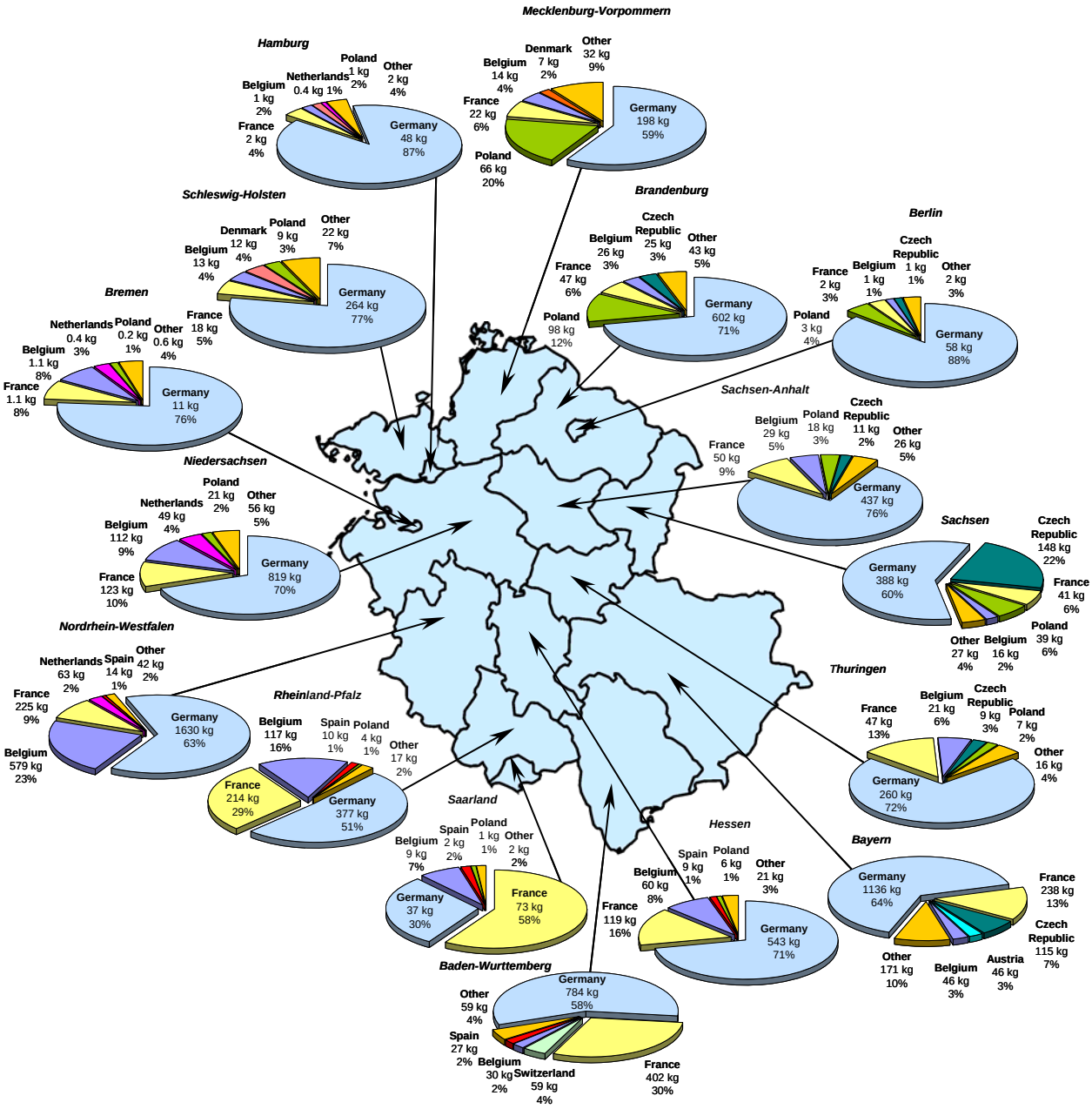
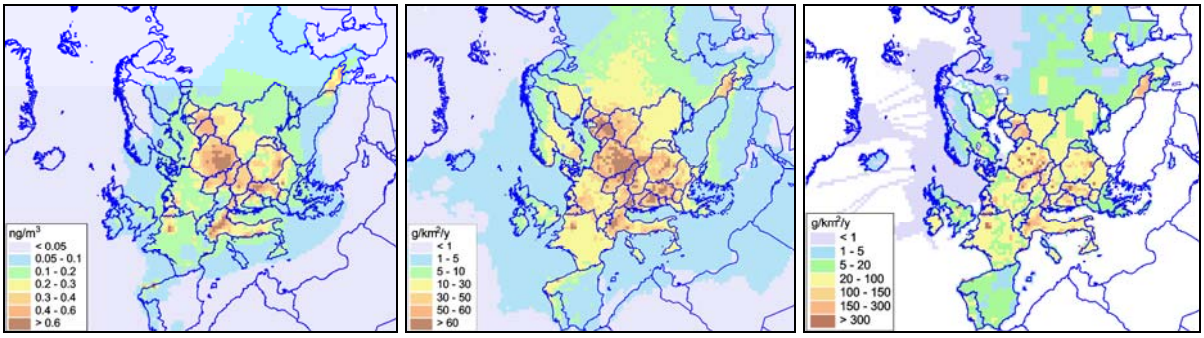


Fig. 2.7*. Contribution of emission sources of European countries to B[a]P deposition over different Lands of Germany*

2.2. Spatial distribution of contamination

Spatial distributions of pollution by considered POPs are exemplified by annual means of air concentration and deposition fields of B[a]P and lindane within the European region for 2000. Calculations are made with MSCE-POP regional model with spatial resolution 50×50 km on the basis of emission data compiled from official data and expert estimates. To take into account long-term accumulation of lindane in soil and seawater preliminary model run starting from 1995 with the help of hemispheric version of MSCE-POP model was performed. The influence of non-European sources of B[a]P and lindane was taken into account with the help of hemispheric calculations of their transport from these sources during 2000. The results of hemispheric simulations were re-calculated to 50×50 km grid and summed with the results of regional calculations.

The calculated levels of B[a]P air concentrations and deposition fluxes in European region are presented in Figs. 2.8a and b respectively. For comparison Fig. 2.8c presents spatial distribution of European emissions in 2000.

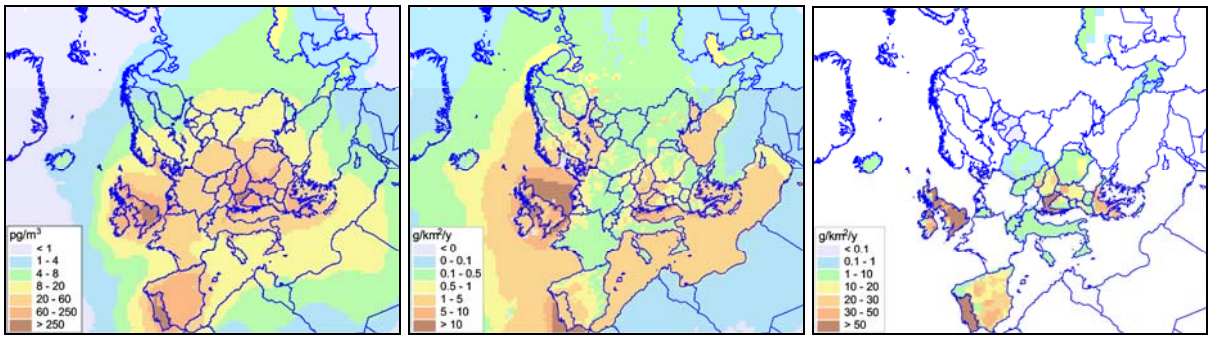


a b c

Fig. 2.8. *Spatial distribution of B[a]P air concentrations (a) and deposition flux (b) in European region in comparison with European emissions (c) in 2000*

Air concentrations in European region vary from low values (less than 0.05 ng/m^3) in Northern parts of the Scandinavian Peninsula to high values close to 1 ng/m^3 in the regions located near main emission sources. The same situation takes place with deposition fluxes, which range from 1 g/km^2/y to about 100 g/km^2/y. The value of deposition fluxes in the Northern part of Europe is rather low (< 30 g/km^2/y compared with 30 – 100 g/km^2/y in Central and Eastern Europe).

Computed mean annual concentrations of lindane in surface air and its net annual depositions for European region in 2000 are shown in Fig. 2.9.



a b c

Fig. 2.9*. Spatial distribution of γ-HCH mean annual concentrations in surface air (a), net annual depositions (b) and emission fluxes (c) in 2000*

Elevated levels of γ-HCH air concentrations (about 250 pg/m^3) can be seen near major emission sources, in particular, United Kingdom, Portugal, Croatia (Fig. 2.9a). Concentrations in remote regions, for instance, in Northern Europe are about 1 - 8 pg/m^3. Spatial distribution of deposition fluxes is illustrated in Fig. 2.9b. It can be seen that, following the model results, highest deposition fluxes (about 10 g/km^2/y) are obtained for the North Sea. Lower values (0.1 – 0.5 g/km^2/y and below) are characteristic of Northern Europe and other remote regions.

Information on transcontinental transport of POPs can be obtained from the results of hemispheric modelling. As an example, calculated fields of annual deposition flux of B[a]P in 2000 caused by European and American sources are presented in Figs. 2.10a and b, respectively.

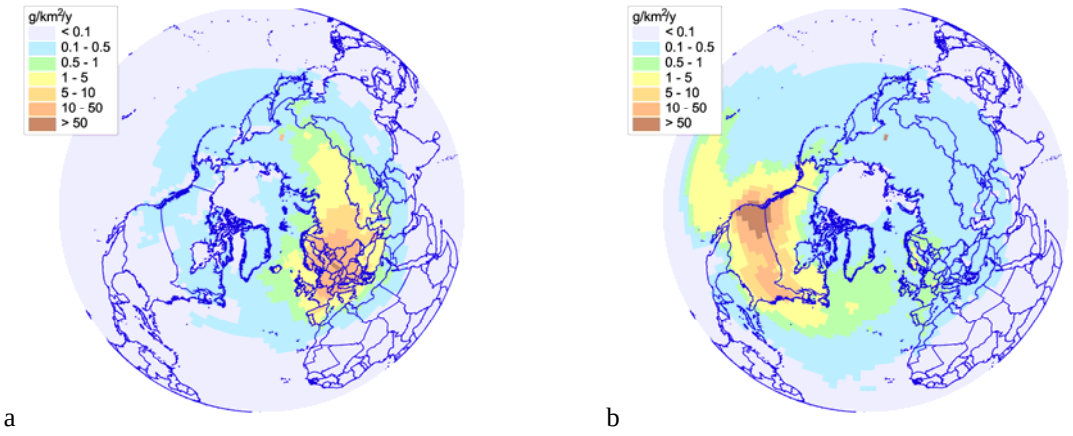


Fig. 2.10. *Spatial distributions of annual deposition flux of B[a]P, caused by European (a) and North American (b) sources in 2000*

It is seen that B[a]P pollution from American sources can reach European region. European emission sources can essentially contribute to the contamination of remote regions such as the Arctic.

Calculations by hemispheric MSCE-POP model can illustrate main atmospheric pathways of the transport of a pollutant. The maps of monthly averages of B[a]P air concentrations caused by European emission sources (Fig. 2.11) for January, March and August show the main direction of POP transport from Europe in eastern direction.

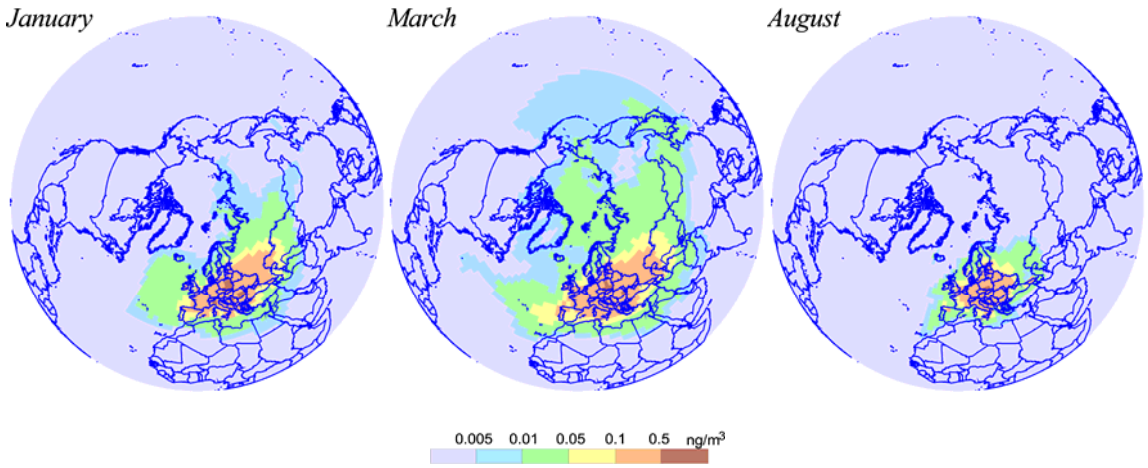
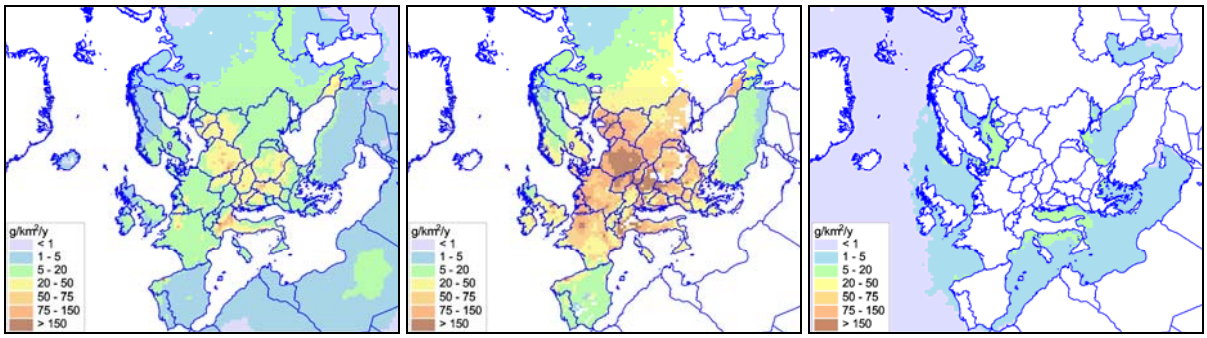


Fig. 2.11. *Monthly averages of B[a]P air concentrations caused by European sources in 2000*

Besides, calculations show strong decrease of B[a]P air pollution in summer months due to high degradation rate taking place for B[a]P in warm seasons.

2.3. Depositions to different types of underlying surface and possible contributions to risk assessment

Along with total deposition to underlying surface MSCE-POP model is also capable to evaluate deposition fluxes to different types of underlying surface (soil, seawater, different types of vegetation, etc.). The development of corresponding model approach is currently under way. As an example, maps of B[a]P deposition densities to three different types of underlying surface (grass, coniferous forest and seawater) is shown in Fig. 2.12.



a b c

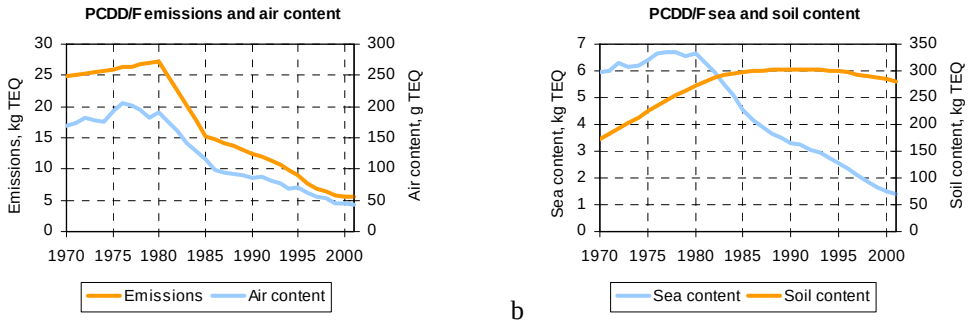
Fig. 2.12. *Spatial distribution of B[a]P deposition flux to grass (a) coniferous forest (b) and seawater (c) in 2000, g/km^2/y*

This information may be helpful in the development of risk-assessment approach for POPs to evaluate their impact on human health and various ecosystems.

2.4. Long-term trends of contamination

Model results on long-term trends of POP content in the atmosphere, soil and seawater are exemplified by calculations of PCDD/F long-range transport within the Europe for the period 1970 - 2001 (Fig. 2.13).

Total PCDD/F emissions in Europe decreased five-fold in the period from 1980 to 2001. In general the trends of PCDD/F content in air and seawater follow the emission variation. The trend of PCDD/F soil accumulation is different from that of emissions. Emissions began to reduce in 1980, whereas the decrease in soil contamination started in 1990 only.



a b

Fig. 2.13. *Trend of PCDD/Fs content in the main environmental compartments as compared with that of emissions in Europe for a period from 1970 to 2001*

The rate of soil content decrease is much lower. This causes the substantial PCDD/F re-emission flux from soil amounting to about 20% of the annual emissions in 2001 (Fig. 2.14). In its turn re-emission slows down the tendency for a decrease in PCDD/F content in the atmosphere (Fig. 2.13a).

As seen from calculations the clearance of the soil compartment under emission reduction is rather slow. The characteristic time for the decrease of soil concentrations amounts to several decades (Fig. 2.13b).

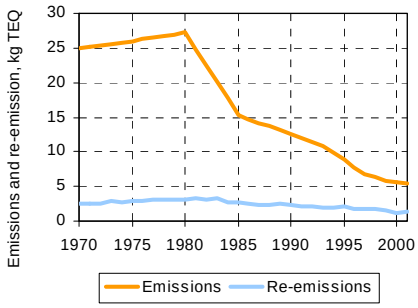


Fig. 2.14. *PCDD/Fs re-emission from soil compared with their emission in Europe from 1970 to 2001*

2.5. Evaluation of emission reduction scenarios

The application of model calculation for evaluation of media response to POP emission reduction is exemplified by two conventional scenarios for PCDD/Fs. These two scenarios are prepared to illustrate the effect of emission reduction in different parts of Europe on levels of pollution of European region on the whole and in particular countries.

According to both scenarios the total PCDD/F emissions in Europe is decreased in period 2001-2010 by 8%. The first scenario suggests PCDD/F emission reduction in several countries of Central Europe, in particular, 5% annual reduction in the Czech Republic and Poland, and 2% annual reduction in Germany. Emissions of other countries would remain constant throughout the calculation period (2001 - 2010). The second scenario suggests PCDD/F emission reduction in Eastern Europe, in particular, by 5% annually in the Russian Federation and the Ukraine. The emissions of rest of European countries are assumed to remain constant.

The results of calculations show that with the first scenario a significant reduction in the level of air pollution (exceeding 8% - the mean reduction of European emissions) is observed in 11 countries (Austria, Belarus, Germany, Lithuania, Poland, Slovakia, Latvia, Slovenia, Czech Republic, Sweden and Hungary). With the second scenario the relevant decrease is observed in 7 countries (Belarus, Kazakhstan, Moldova, Russian Federation, Turkey, Finland and Ukraine) (Fig. 2.15).

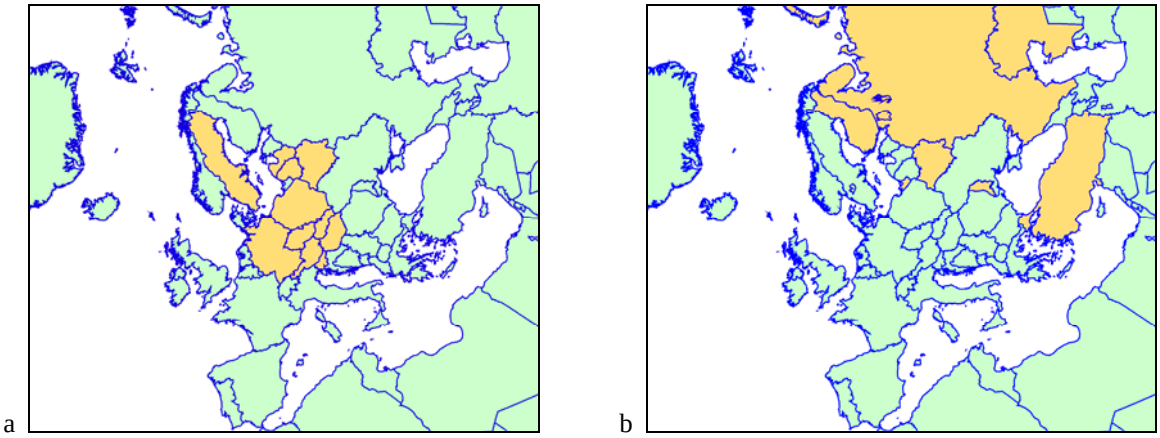


Fig. 2.15. *Countries with a significant reduction in air concentrations of PCDD/Fs according to the first (a) and second (b) scenarios of the toxic congener emission reduction*

According to calculations, reduction of air concentrations averaged over all European countries with the first scenario amounts to 11.5%. Model calculations allow also to obtain estimates of air pollution reduction in particular European countries. The results obtained on the basis of the first scenario are shown in Fig. 2.16.

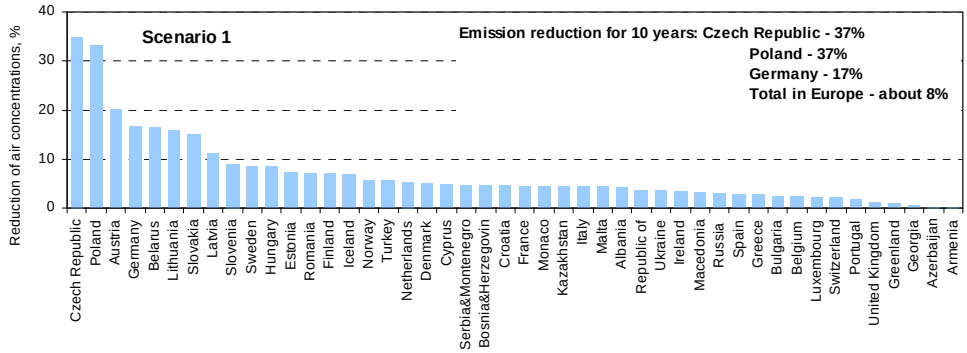


Fig. 2.16. *Reductions in PCDD/F air concentrations in European countries in period from 2001 to 2010 calculated on the basis of the first emission reduction scenario*

Reduction of mean air concentrations over all European countries with the second scenario amounts to 10.5%. Slightly less figure of mean reduction of air concentrations in this case is conditioned by the influence of prevailing atmospheric transport in eastern direction. Thus the reduction of emissions from Russian Federation and the Ukraine would be less significant for the mean European level of air pollution. Estimates of air pollution reduction in each European country achieved with the implementation of the second scenario are shown in Fig. 2.17.

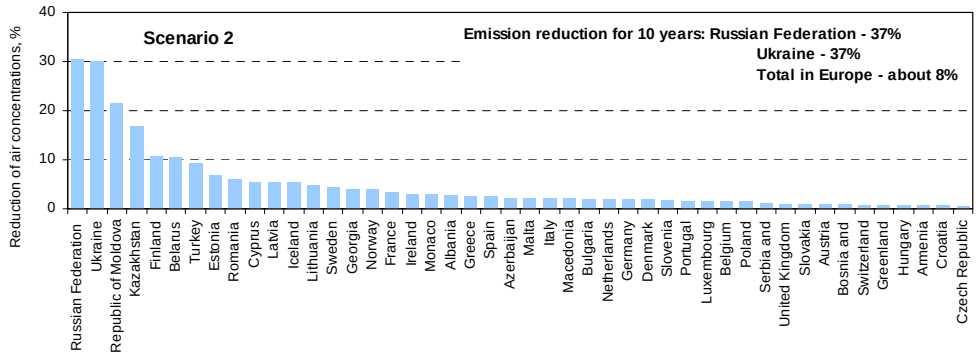


Fig. 2.17. *Reductions in PCDD/F air concentrations in European countries in period from 2001 to 2010 calculated on the basis of the second emission reduction scenario*

Therefore, the model calculations make it possible to estimate the decrease in air concentrations for each European country in line with the selected scenario and identify the countries where air pollution would be most strongly affected. Such information might be useful for developing different scenarios of the POP emission reduction in the European region.

2.6. Redistribution between main environmental media

Calculated spatial distributions can be aggregated to evaluate redistribution of total content of considered POP between main environmental media (the atmosphere, soil, vegetation and seawater). Fot this purpose the calculations of POP transport were performed for the period from 1970 to 2001 with emission data compiled from official data and expert estimates. Simulations for the long period are necessary to take into account accumulation of a pollutant in question in such environmental media as soil and seawater.

Fig. 2.18 shows distribution between main environmental media for a number of pollutants: γ-HCH, HCB, four PCB congeners, four PCDD/F congeners and B[b]F. Consideration of media distribution for different congeners from large groups allows analyzing the differences between their behavior in the environment.

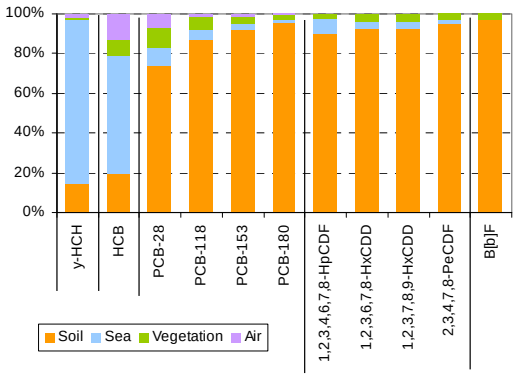


Fig. 2.18. *Distribution of total content of a number of POPs between main environmental media (the atmosphere, soil, seawater and vegetation)*

Model results demonstrate that POPs with relatively high solubility and low octanol/water partitioning coefficient (γ-HCH and HCB) are mainly accumulated in seawater. Due to high stability of HCB in the atmosphere high atmospheric content (about 13%) is characteristic of this substance. More lipophilic pollutants with lower solubility are mainly accumulated in soil. So, the fraction of total environmental PCB content accumulated in soil ranges from 75% to 95% being higher for heavy PCB congeners. For PCDD/F congeners due to high stability in soil the fraction of environmental content in this compartment ranges from 90% to 95%. Similar results are obtained for B[b]F.

This information can be used for selection environmental media most polluted by various POPs.

2.7. Long-range transport potential and overall persistence

The possibility of usage the model for evaluation of long-range transport potential and overall persistence is illustrated by calculations for two BDE congeners (BDE-47 and 99). These two congeners make major contribution to PentaBDE product (about 70%). This product was proposed by Norway to be added as a new POP to Annexes of the Protocol on POPs and is under consideration at the Task Force on POPs.

Long-range transport potential (LRTP). According to the Executive Body Decision 1998/2 the LRTP criterion for the evaluation of new substances as potential candidates for the inclusion into the Protocol on POPs is characterized by indicative numerical values of their vapor pressure and atmospheric half-life, which should be greater than two days. The half-life of the pollutants in air ($T_{1/2}^{air}$) with allowance of all processes removing a POP from the atmosphere can be estimated on the basis of model calculations of their atmospheric transport.

For illustration calculated values of $T_{1/2}^{air}$ for two BDE congeners are shown in Table 2.1. Of note that the numerical values of this characteristic of LRTP for both congeners fully meet the existing criterion (atmospheric half-life is greater than two days).

Table 2.1. *Characteristics of LRTP ($T_{1/2}^{air}$) calculated for BDE-47 and BDE-99*

Congener	$T_{1/2}^{air}$, days
BDE-47	7
BDE-99	11

Another numerical characterization of LRTP can be done with the help of *Transport Distance* (*TD*). Numerical values of *TD* are defined with the help of Eq. (2.1) as the average distance from the source at which annual mean atmospheric concentration of a chemical in question drops 1000 times compared with the concentration near the point source (as an example See Fig. 2.19):

$$TD_{0.001} = \sqrt{\frac{S_{0.001}}{\pi}} \qquad (2.1)$$

where $S_{0.001}$ is the area covered by air concentrations dropped less than 1000 times.

It should be noted that such an approach is similar to that suggested in [*Rodan et al*., 1999].

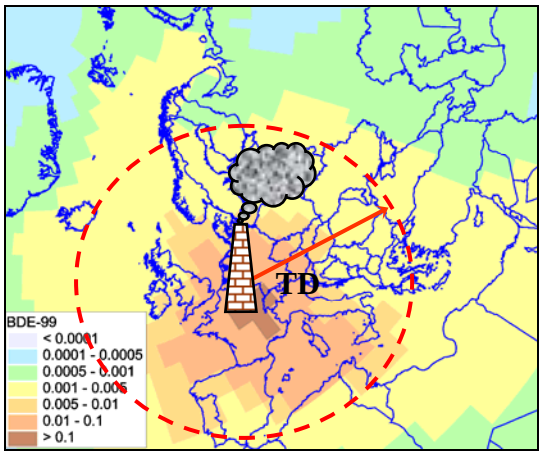


Fig. 2.19. *Definition of the transport distance*

To characterize LRTP of BDE-47 and BDE-99 the numerical values of *TD* calculated on the basis of the spatial distributions of air pollution caused by emissions from the conventional point source are demonstrated in Table 2.2. For the sake of comparison, values of $T_{1/2}^{air}$ obtained for the considered congeners taking into account the main processes removing a pollutant from the atmosphere (degradation, depositions and gaseous exchange with underlying surface) are also shown in the table.

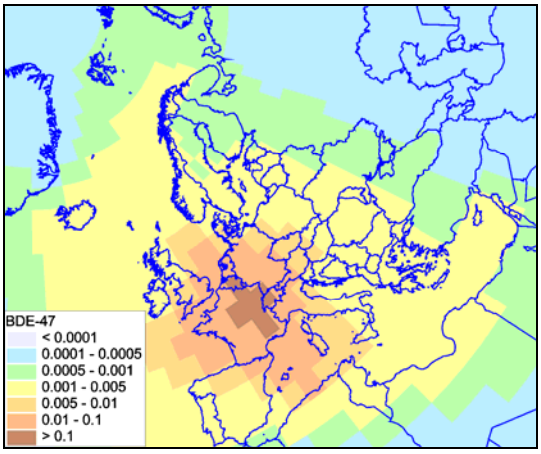
Table 2.2. *Calculated characteristics of LRTP ($T_{1/2}^{air}$ and TD) for BDE-47 and BDE-99*

Congener	$T_{1/2}^{air}$, days	*TD*, km
BDE-47	7	2300
BDE-99	11	2800

According to the calculated values of $T_{1/2}^{air}$ and *TD,* BDE-99 possesses higher LRTP than BDE-47.

To illustrate the model estimates of *TD* for these congeners visually, the calculated fields of air pollution formed by their annual emissions from a conventional point source with conventional intensity located in France can be used. For convenience, we present air concentrations of BDE-47 and BDE-99 in the relative units so that the maximum value equals 1 near the source (Fig. 2.20). Spatial distributions of air concentrations provide complementary information on the main directions of their atmospheric transport and the regions mostly affected by BDE-47 and BDE-99 pollution from the conventional emission source.

a



b

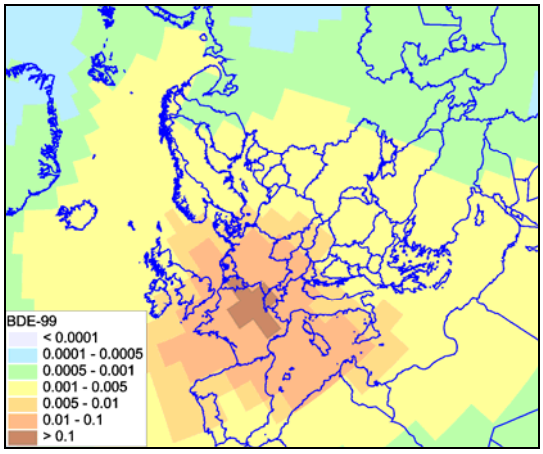


Fig. 2.20. *Spatial distribution of BDE-47 (a) and BDE-99 (b) concentrations in the above-ground air in the EMEP domain*

Due to peculiarities in the physical-chemical properties of BDE-47 and BDE-99, their ability to the atmospheric transport is somewhat different. On the assumption of equal emissions BDE-99 pollution in the atmosphere spreads over longer distances than that of BDE-47.

Overall persistence in the environment (Pover). In compliance with the Executive Body Decision 1998/2 the persistence of new substances in terms of their possible inclusion into the Protocol on POPs is demonstrated by indicative numerical values of their half-life in water, which should be greater than two months, or half-life in soil, which should be greater than six months, or half-life in sediments, which should be greater than six months also. In addition to these parameters characterizing the persistence for particular media, multimedia model calculations allow estimating complementary characteristics of persistence in the whole environment – overall residence time or overall environmental persistence [*Scheringer*, 1996; *Webster et al*., 1998; *Gouin et al*., 2000, etc]. In this assessment such characteristic as *Half-life in the environment* ($T_{1/2}^{env}$) is estimated for the considered congeners on the basis of the model calculations of their atmospheric transport taking into account deposition processes, degradation and exchange of a pollutant between main environmental media.

The model assessment of persistence of BDE-47 and 99 is demonstrated by the numerical values of their $T_{1/2}^{env}$ calculated with the help of Eq. (2.2) as inverse values of weighted mean of degradation rate constants k_j in the environmental media (atmosphere, soil, seawater, vegetation, sediments) with weights being the fractions f_j of a pollutant accumulated in j-th medium:

$$T_{1/2}^{\boldsymbol{env}} = \ln 2 / \sum k_i \cdot f_i \qquad (2.2)$$

Here fractions f_i are evaluated on the basis of the model calculations.

Thus, the values of $T_{1/2}^{env}$ are affected by the distribution of the total environmental content of the considered congeners between main environmental media (air, soil, water, sediment and vegetation) and the values of their half-life in each particular medium due to degradation process. For the congeners under consideration the distribution of their total content in the environment between main environmental media and relative fractions of these pollutants degraded in each media were obtained on the basis of simulations for one-year period. It should be noted that seawater includes pollutant content in sediments, and only degradation in forest litter is considered as degradation in vegetation.

The values of $\boldsymbol{T_{1/2}^{env}}$ for BDE-47 and 99 calculated on the basis of the above media balances and the values of half-lives in the considered environmental compartments are presented in Table 2.3.

Table 2.3. *Calculated characteristics of persistence ($T_{1/2}^{env}$) for BDE-47 and BDE-99*

Congener	$T_{1/2}^{env}$	
	days	months
BDE-47	166	5.5
BDE-99	184	6.1

According to the model results BDE-99 is more persistent congener then BDE-47. Due to rather high ability of the congeners to accumulate in soil and seawater these components of PentaBDE should be considered as pollutants that may cause long-term adverse affect on living organisms in these media. Besides, high values of relative fractions of their total content in the environment are observed in vegetation.

Benchmark approach. Since the numerical values of $T_{1/2}^{air}$ and $T_{1/2}^{env}$ of particular chemicals are model dependent, one of the possible ways to diminish uncertainties in evaluating new substances proposed by *M.Scheringer* [1997] and *A.D.Beyer et al*. [2000] and discussed at the OECD/UNEP Workshop on the Use of Multimedia Models for the Estimation of Environmental Persistence and Long-Range Transport (Ottawa, Canada, 2001) is to use a “benchmark” substance. This approach suggests that modeling results on LRTP and persistence are used to compare the pollutants under study with some adequately studied “benchmark substance” with known values of the considered parameters.

The comparison of calculated characteristics of LRTP and persistence for the considered congeners against those obtained for benchmark pollutants is presented in this subsection. All calculations were performed for one-year period from the conventional point source with one and the same location (France) and one and the same emissions intensity.

Here benzo[a]pyrene (B[a]P) and hexachlorobenzene (HCB) were used as examples of such benchmark substances. Characteristics of their behavior in the environment are well studied and clearly meet UN ECE criteria. They are already included in the Protocol on POPs and are considered as pollutants of regional and global concern, respectively.

The considered BDE congeners, B[a]P and HCB have been ranked in ascending order according to their values of *TD* (Fig. 2.21a) and $T_{1/2}^{env}$ (Fig. 2.21b).

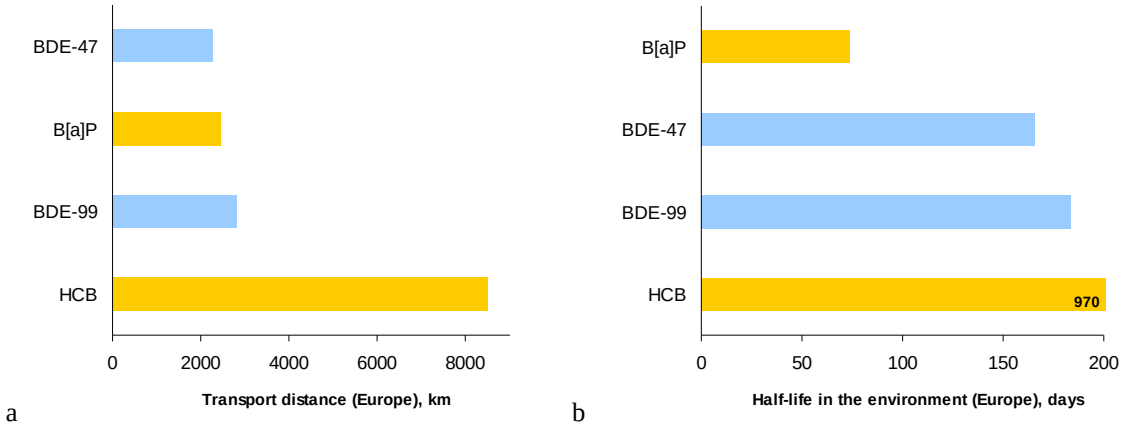


Fig. 2.21. *Transport distance and half-life in the environment calculated for BDE congeners, B[a]P and HCB*

According to the model calculations of *TD*, LRTP of BDE-99 is found to be comparable with that of B[a]P but much less than that of HCB. Thus, these congeners forming the most part of PentaBDE content are found to be pollutants with potential for long-range atmospheric transboundary transport to be viewed at least at regional/hemispheric level.

The ranging of the considered congeners and benchmark pollutants with respect to $T_{1/2}^{env}$ values to some extent differs from that obtained on the basis of *TD*. BDE-47 and BDE-99 are found to be much more persistent in the environment than B[a]P and are in respect to this characteristic in between B[a]P and HCB. Thus, they can be considered as pollutants which are able to have a long-term exposure in the environment after being emitted in the atmosphere, and correspondingly due to their high toxicity - adverse effect on human beings and ecosystems.