Representativeness of the coastal measurements for the open sea – experience of the model applications in the Baltic region

A contribution to the subproject CAPMAN

M.Hongisto and M.Sofiev

Finnish Meteorological Institute, Vuorikatu, 19, 00100, Helsinki, Finland.

Introduction and General characteristics of the load

Within the EU-MAST III BASYS project (BAltic Sea SYstem Study), the regional 3D model HILATAR (Hongisto, 1998) was used for estimation of the airborne pollution load to the Baltic Sea over the period 1993 – 1998.

In order to quantify the dependence of the representativeness of the measurements in the open sea upon the meteorology, averaging period and location with respect to emission areas, two methods were applied. First, monthly coast to sea gradients along 10 cross-sections were extracted from the 26 x 26 km^2 resolution model data base. Second, the modelled load and concentrations were integrated over the main sub-basins of the Baltic Sea and then compared with the coastal measurements.

The sulphur and nitrogen loads and concentrations were found to be geographically non-homogenous, highly episodic and having quite high annual and seasonal variation. While the NO_x emissions over Europe declined by 6 % in 1993 - 1996 the deposition was the smallest during 1995 to 1997 and increased then slightly. NOx concentrations in air decreased until 1996 and were slightly increased afterwards. Results were sensitive to boundary values (either EMEP 150 km trajectory model for acid compounds or European Hilatar-model boundary concentrations were used). Summer HNO_3 concentrations were in south the lowest during 1993 and 1998, which were rather cold and cloudy. Wet deposition was the main part of the total annual load, the dry deposition share was 23 / 35% for NO_x / NH_x.

The load was sensitive to the prevailing large-scale weather type, which determines the flow direction with respect to main emission areas. The share of the primarily south-western or SW-S flows was 76-82 % of the winter days in the years 1993-95 and 1997-98, dropping to 27 % during winter 1996, when the share of the clean air sectors, NW-N-NE-E, was 57 % of all days when a strong, dry, almost permanent high-pressure area extended from over Russia also over Scandinavia. 1995 was exceptional with high northern and north-eastern flows and cooler, usually rather dry air outbreaks.

Deposition gradient was also influenced by the ice cover fraction, which varied between 68000 km^2 in 1993-95 up to 262000 km^2 in 1995-96. Winters 1994-95 so as 93-94 were extremely mild, winter 95-96 was the coldest and dryest. There was no big variation in the spring temperatures. Summers 93 and 98 were the coldest with +58 and +75 % excess precipitation.

Most of the precipitation, as well as nitrogen deposition to the Baltic Sea, was received during autumn and winter. Monthly variation was large. Deposition to the sea surfaces varied also with the marine atmospheric boundary layer conditions.

Local coast-to-sea gradients

Example of one of West-East gradients is presented on Figure 1. In general, direct extrapolation of the coastal measurements to the open sea is safe when it is made with offshore wind. When the flow direction is from land there is a stepwise change in all meteorological parameters, and, consequently, concentrations. Emission density is in most cases higher in the coastal zone than over the sea or inland areas. Additional uncertainty is caused by sub-grid sea breeze circulation, which can turn the wind direction against the mean flow, especially if the stability over the sea is different from the coastal areas.

For winter conditions the main specifics of the deposition gradients are:

Along the latitude cross-sections from Atlantic to the east, the total depositions have their maxima over the mountains in comparison with sea and coastal areas (mountain effect). From the other side, strong winter precipitation over the North Atlantic created another peak over the open sea. Also dry deposition was higher over the open sea than over the remote non-polluted coastal zone. As a result, total deposition was 20-40 % (NO_x) and 10-29 % (SO_x) higher over the sea at 50 km distance from the coast. For NH_x the difference was ± 15 %. Similar gradient was detected over the North Sea for NO_x and SO_x; however wintertime total NH_x-deposition (up to 60 %), and dry deposition of all compounds were higher over Denmark than over the surrounding sea areas.

For the west-east cross-sections: from Southern Baltic to Northern Bothnian Bay the wintertime deposition was smaller over either western or eastern coastal lines in comparison with the surrounding water areas. Over the sea it increased towards the east, the relative gradient being the strongest over the Bothnian Sea, where the east-coast deposition exceeded the level near the Swedish coastline by 64 / 78 / 116 % for NO_x, NH_x and SO_x, respectively.

In the north-south direction: generally both wet and dry deposition decreased towards the north-east; but the gradient depends on emission intensity: along the Central European coast deposition is stronger than over Southern Baltic proper, but over North Sea it is higher than over Southern Norway.

During summertime: over the North Atlantic coast the wet deposition increased both to the open sea due to strong precipitation and inland because of higher concentrations, which, in turn, resulted in growth of dry deposition as well.

In southern part of the domain both dry and wet deposition of all compounds were lower over the North and Baltic seas than over the land with slight general increase towards the east.

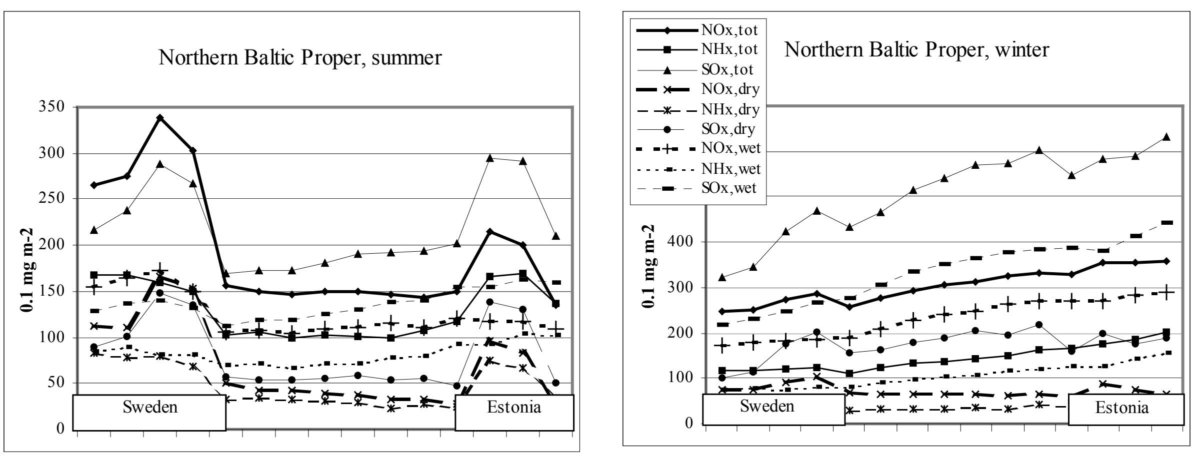

Figure 1. West-East deposition gradients over the northern Baltic Proper.

Statistical extrapolation of the Station data to sub-basins

The EMEP measurements for 1993-1996 were compared with HILATAR modelling results in order to select the most representative stations for the specific Baltic Sea sub-basins. The considered parameters were: SO_2, $SO_4^{=}$, NO_x, NO_3^-, NH_3+NH_4^+ concentrations and SO_x, NO_x, NH_x wet deposition with daily and monthly averaging. Linear regression coefficients provided the scaling factors, while non-parametric statistics show the uncertainty. Table 1 presents the most representative stations for the Baltic Sea sub-basins for daily averaging. The analysis was also made for warm (May-Sep) and cold (Nov-Mar) seasons. Station notations see e.g. in (Hjellbrekke & Hanssen, 1998), sub-basins are in (Baltic GIS).
It appeared that the "representative" station (bold font in Table 1) for the particular sub-basin is not necessarily located on the island in the middle of it. Thus, Hoburg (SE_8) is located on the island in Baltic Proper, but it took the "best-fit" position only for sulphur concentrations, nitrates and NO_x (the last - during cold season only), but not for ammonia and not for any deposition. The other sites catch them better probably because they are located on the pathways and better correlated with the large-scale precipitation events.

Table 1. The best-correlated stations for the Baltic Sea sub-basins

	BB	BS	GF	GR	BP	DS	KT	Baltic Sea
SO2								
	FI_4	**FI_9**	**FI_9**	**RU14**	**SE_8**	**DE_2**	**DK_8**	**SE_8**
Corr. Coef	0.70	0.72	0.60	0.63	0.67	0.67	0.73	0.68
Regr Slope	0.44	0.34	0.87	0.33	0.58	0.32	0.42	0.44
SO4								
	FI_4	FI_9	RU16	RU14	**SE_8**	DK_3	SE_2	**SE_8**
Corr. Coef	0.46	0.55	0.52	0.47	0.63	0.57	0.58	0.66
Regr Slope	0.16	0.18	0.59	0.22	0.39	0.55	0.39	0.29
SOx wet deposition								
	FI_4	FI_9	FI17	FI17	FI_9	DK_5	SE_2	FI_9
Corr. Coef	0.31	0.35	0.51	0.38	0.35	0.44	0.33	0.39
Regr Slope	3901	8453	5853	2521	39103	3739	3082	60767
NOx								
	RU14	EE_9	RU14	RU14	SE11	DE_7	**DK_8**	RU14
Corr. Coef	0.45	0.52	0.48	0.43	0.54	0.56	0.63	0.55
Regr Slope	0.29	0.22	0.45	0.32	0.22	0.35	0.34	0.42
NO3+HNO3								
	FI_4	FI_4	FI17	SE12	SE11	**DK_3**	**DK_8**	**DK_8**
Corr. Coef	0.52	0.55	0.45	0.48	0.58	0.60	0.68	0.60
Regr Slope	1.43	1.66	0.75	0.87	0.55	0.76	0.61	0.27
NOx wet deposition								
	EE11	FI_4	EE_9	FI17	FI_9	DK_5	SE_2	FI_9
Corr. Coef	0.47	0.54	0.47	0.38	0.46	0.48	0.48	0.50
Regr Slope	90	37032	1725	3735	45543	5066	6094	73658
NH3+NH4								
	PL_1	FI_9	SE_8	SE_8	**PL_4**	**DK_5**	**DK_8**	**PL_4**
Corr. Coef	0.49	0.56	0.54	0.53	0.67	0.65	0.70	0.68
Regr Slope	0.03	0.31	0.21	0.29	0.39	0.30	0.39	0.29
NHx wet deposition								
	FI_4	FI_4	FI17	FI_9	FI_9	DK_5	SE_2	FI_9
Corr. Coef	0.28	0.34	0.39	0.32	0.34	0.45	0.42	0.39
Regr Slope	3605	14839	3763	3251	32027	3801	3670	54024

In some cases (e.g. Gulf of Riga) the load does not correlate with any of the station data, which demonstrates the multi-source pollution pattern of the area. As a result, one single station can not describe the situation.
Seasonal variations of emission intensity and meteorology have greatly affected station representativity. The most stochastic period has proved to be summer months. Correlation coefficients during that time were considerably lower than corresponding values for winter and even for non-split annual data. It points out that spatial and temporal diversity of the meteorological transport conditions in the Baltic Sea region is considerably higher for the

warm period than for cold one, which does not allow the straightforward extrapolation of the point data over large sea areas. To the contrary, for cold part of year, almost all sub-basins can be matched with specific coastal station, whose data can be extrapolated via simple linear regression.

Another important feature connected with pollution seasonality is location of the station, representative for the specific sub-basin. The results show that practically no single station out of considered list can be selected both for cold and warm seasons and for all (or most of) substances. More than that, the same station can be the best-fit for different parts of the sea depending on the season and type of pollutant. Thus, for SO_2 concentrations over the Bothnian Sea, the best site during summer is Swedish SE12, while in winter –it is Finnish site FI_9. Similar variability is seen for different substances. Thus, during summer, Hoburg SE_8 showed the best-fit with the Baltic Proper for sulphates and nitrates, but not for ammonia and not for sulphur and nitrogen oxides. Ammonia is coming from the continental part of Europe, so Polish stations are the best for it, while SO_x and NO_x can not be extrapolated from any station data.

Conclusions

The deposition over the Baltic Sea is not homogeneous. Depending on the compound and distance from the main sources, it has generally decreasing gradient towards the north and, over water, increasing gradient towards the east. During autumn and winter the deposition increases towards the open sea, during spring and summer it decreases. The gradient strength varies depending on the compound. Over the northern parts of the Baltic Sea the coastal deposition density is considerably lower than that over the sea. Depending on the season, wind direction, and intensity of emission density of the area, the coastal measurements can either over- or under-predict the open-sea load.

Preliminary statistical analysis showed that several stations in the Baltic region still provide observations well correlated with the integrated estimates for some sub-basins. These stations are on the pollution pathway and/or affected by the same meteorological phenomena as specific sub-basin. Some sub-basins (e.g. Gulf of Riga) appeared to be polluted by several sources, so that no single station is representative for them (at least no one from the considered list).

Warm part of the year was more stochastic then cold season, so for several species and sub-basins no representative station was found.

The study showed principal possibility to build a statistical model for the extrapolation of the station data to some Baltic Sea sub-basins.

References

Baltic GIS. Baltic Sea Region GIS, Maps and Statistical Database. http://www.grida.no/baltic/index.htm.

Hjellbrekke A.-G., J.E.Hanssen (1998) Data report 1996. EMEP / CCC report 2/98, NILU, Norway.

Hongisto M. (1998) HILATAR, a regional scale grid model for the transport of sulphur and nitrogen compounds. Description of the model and simulation results for the year 1993. *Finnish Meteorological Institute Contributions*, **21**, Helsinki, 152 pp.