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Comparison of modelled and monitored deposition fluxes to different ecosystems in Europe

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1 Summary and conclusions

The purpose of the study was to compare EMEP deposition fluxes (Eulerian Acid Deposition Model) to different ecosystems with monitoring data from ICP-Forest (Level II). Modelled data from 1997 and 2000 on deposition to forests and open areas were compared with observed deposition data from forest plots. The study is comparing two completely different methods to estimate deposition levels to ecosystems. It should be kept in mind that both methods have uncertainties and no “true” values are available. Conclusions should not be drawn from comparing single sites, but systematic differences between a number of monitored sites and model calculated values give valuable information on the possible causes of uncertainty.

The general conclusion is that the similarities between modelled and observed deposition in this study were reasonably good, despite the uncertainty in comparing measured plot data (point) with modelled grid data integrated for a range of plots. The largest observed differences between modelled and observed data were higher model calculated dry deposition of SO_4-S to forests, and lower precipitation amounts used by EMEP model.

The EMEP performance of modelling sulphur and nitrogen deposition compared to observed data at ICP sites during 1997 and 2000 can be summarised:

- EMEP slightly overestimates the total deposition of SO_4-S to forests, and the excess is mainly established during the summer period.
- EMEP slightly underestimates the average, median and percentile SO_4-S, NO_3-N and NH_4-N wet deposition in the whole deposition gradient, but the correlation between modelled and observed data is rather low.
- Modelled and observed concentrations of SO_4-S, NO_3-N and NH_4-N in precipitation are very similar as average, median and percentiles, and the correlation between modelled and observed data is rather high. The differences in deposition are mainly caused by differences in precipitation amount used by EMEP and ICP.

2. Introduction

The study was conducted as part of the ASTA program[1]. The project was co-ordinated with EMEP/MSC_W[2], who supplied EMEP data. The purpose was to compare EMEP deposition fluxes to different ecosystems with monitoring data. Results from the long-range transport model (EMEP, Eulerian Acid Deposition Model) on deposition to forests and open areas were compared with monitored deposition data from forest plots. The monitoring data was collected from the EU/ICP-F Pan European Intensive (Level II) Monitoring Program via FIMCI[3]. The integrated monitoring of forest plots all over Europe also includes deposition monitoring comprising throughfall, stemflow and bulk and wet only precipitation in open field. The study includes comparison of modelled and monitored data on a yearly basis, as well as with seasonal resolution (month).

3 Methods

The study comprises a selection of countries in Europe, representing various deposition levels, and with monitored deposition data of good quality. Modelled and monitored data of wet and dry deposition and precipitation amount were compared on monthly and yearly basis. Sweden, France, Norway, Finland, Germany, Ireland, and Italy were included in the study. Monthly data were only possible to compare in Sweden, Germany and at some sites in Finland and Ireland, due to sampling intervals not corresponding to months in monitoring programs in other countries. Monitoring data during the period 1997 to 2000 was delivered from FIMCI[4], after approval from ICP Forest[5]. Data comprised bulk precipitation in open field, throughfall in coniferous and deciduous forest plots and stemflow in some deciduous plots (Table 1). After quality check obviously contaminated or unrealistic values were removed from the data set. Missing values (ca 3 %) were estimated by inserting the monthly mean value for that parameter, site and year

[1] International and National Abatement Strategies for Transboundary Air Pollution http://asta.ivl.se/.

[2] The Co-operative Program for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP)/ Meteorological Synthesizing Centre - West (MSC-W), http://www.emep.int.

[3] Forest Intensive Monitoring Coordinating Institute, http://www.fimci.nl/.

[4] Methods are described in annual reports, the latest Technical report 2003 produced by FIMCI, and the ICP Manual for Forest Monitoring (level II)

[5] The permission to use data from ICP-Forest (Level II) was administrated by Thomas Haussmann.

to enable calculations of annual deposition. Sites with data covering less than 315 days during one year were excluded from the study during that year.

EMEP/MSC_W[6] delivered modelled data from the eulerian EMEP model from the years 1997 and 2000 with monthly resolution and separated in the forest classes coniferous and deciduous. The monitored plots with coniferous and deciduous forests were matched by the corresponding EMEP grid (50*50 km). Deposition data (SO_4-S, NH_4-N and NO_3-N) were compared in pairs, wet and dry deposition separately.

The study includes 160 ICP sites in seven countries distributed in totally 140 EMEP grids. The countries, number of ICP sites and the monitoring programs generating data are shown in Table 1.

Table 1. ICP sites and monitoring programs included in the study.

Country	**Throughfall**		**Stemflow**	**Open field**	**EMEP grids**
	Coniferous	**Deciduous**	**Deciduous**		
Germany	29	20	4	51	46
Finland	17			17	11
France	13	7		20	18
Italy				2	2
Norway	15			19	15
Ireland	2	1		3	3
Sweden	41	6		48	45
Total	117	34	4	160	140

ICP Forest data was collected at monthly intervals in Sweden and Finland, weekly in Ireland and parts of Germany, and on an irregular basis in Italy, Norway and some of the German regions. France collected data at 27 or 28 day intervals throughout the year (13 periods). Weekly or bi-weekly collections were transformed into monthly data if the break between resulting records fell within 4 days from the calendar months end.

In accordance with ICP Forest guidelines, stemflow is only measured at level II sites with beech stands. However, data was not available for all the beech stands for which through-fall was provided.

[6] Data was provided by David Simpson at EMEP/MSC_W.

4 Results and discussion

The study compares two completely different methods used to estimate deposition to ecosystems. It should be kept in mind that both methods have uncertainties and no “true” values are available. Measured data from a spot, normally a forest plot 30*30 m with varying exposure, tree species, leaf area index, etc., is here compared with the model calculated average deposition to the same forest type in a corresponding grid 50*50 km. Conclusions should not be drawn from comparing single sites, but systematic differences between measurements at several monitored sites and model calculated values give valuable information on the causes and dimension of uncertainty.

The comparison of modelled and observed data from 1997 and 2000 comprises:

- Total deposition of SO_4-S to coniferous and deciduous forests,
- wet deposition of SO_4-S, NO_3-N and NH_4-N in open field,
- concentrations of SO_4-S, NO_3-N and NH_4-N in precipitation and,
- precipitation amount.

Total deposition from the ICP sites is represented by throughfall monitoring, representing both wet and dry deposition to forests, and wet deposition by bulk precipitation in open field. The results are compared to calculated wet and dry deposition from the EMEP model.

4.1 Deposition of SO_4-S

The correlation between modelled (EMEP) and observed (ICP) deposition of SO_4-S in coniferous forests is rather strong during both 1997 and 2000, especially if a few ICP sites with extremely high reported deposition values are excluded (Figure 1, the extreme values included). The general pattern is that EMEP overestimate the SO_4-S deposition slightly, both 1997 and 2000 compared to the ICP sites, which can also be seen in average, median and most percentile values in Table 2. The opposite is expected, because the EMEP calculation represents an “average forest” with all age classes of trees. The ICP sites are normally located in mature forest stands, which generally reveal higher dry deposition than the “average forest stand”.

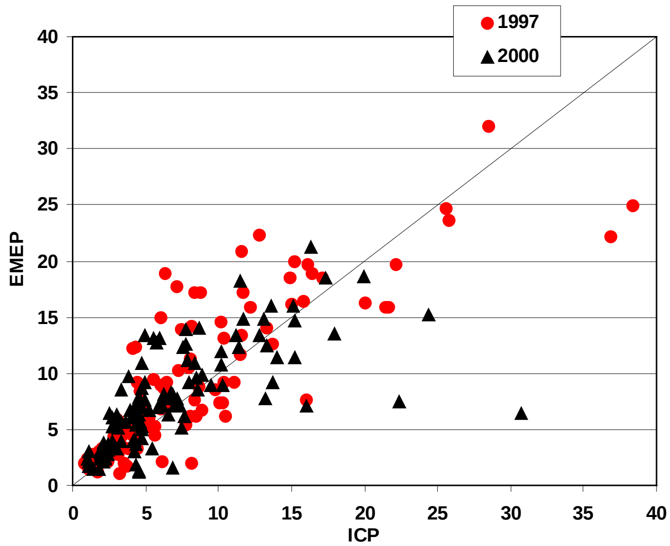

Figure 1. Total deposition of SO_4-S in coniferous forests, kg per ha and year. $EMEP_{modelled}$ wet + dry vs. ICP throughfall during 1997 and 2000.

Table 2. Deposition of SO_4-S in coniferous forests. $EMEP_{modelled}$ wet + dry and ICP throughfall (115 sites) during 1997 and 2000.

Deposition of SO_4-S	EMEP 1997 kg/ha	ICP 1997 kg/ha	EMEP 2000 kg/ha	ICP 2000 kg/ha
average	8.80	7.90	7.79	7.00
median	6.22	5.63	7.03	4.98
max	32.01	38.34	21.22	30.78
p80	15.82	11.62	12.35	10.24
p60	8.58	7.36	7.93	6.57
p40	5.24	4.36	6.25	4.55
p20	2.81	3.04	3.47	2.94
min	1.01	0.83	1.14	1.06

The monthly resolution of modelled and observed SO_4-S deposition was studied in 1997 with ICP sites in Germany and Sweden, for which had monthly deposition data was available (Figure 2). EMEP underestimated the deposition during some winter months, and overestimated during several summer months in both a high (Germany) and a moderate (Sweden) deposition area.

The modelled and observed deposition of SO_4-S in deciduous forests (Figure 3) showed similar correlation as coniferous forests. However, the ICP deposition is uncertain due to the limited data on stemflow. Based on the few data throughfall deposition was multiplied with 1.25 in Germany, and 1.1 in Sweden, in order to include also the stemflow deposition[7]. With this correction of the throughfall data EMEP overestimated the SO_4-S deposition slightly in most cases.

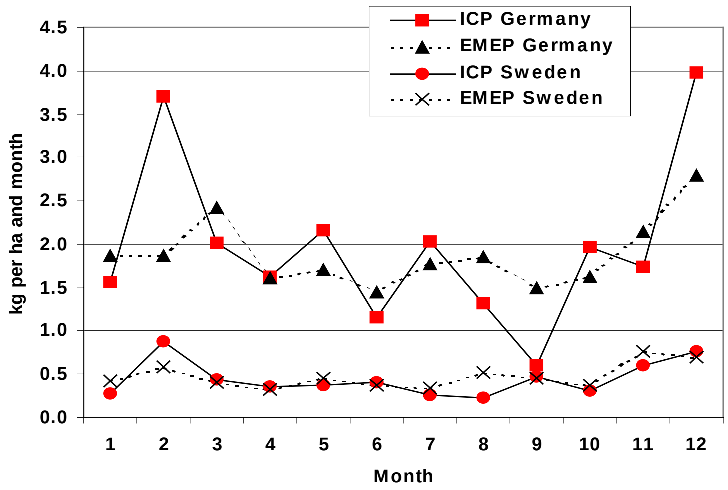

Figure 2. Monthly average total deposition of SO_4-S in coniferous forests, kg per ha and month, 41 ICP sites in Sweden and 10 ICP sites in Germany. $EMEP_{modelled}$ wet + dry vs. ICP throughfall during 1997.

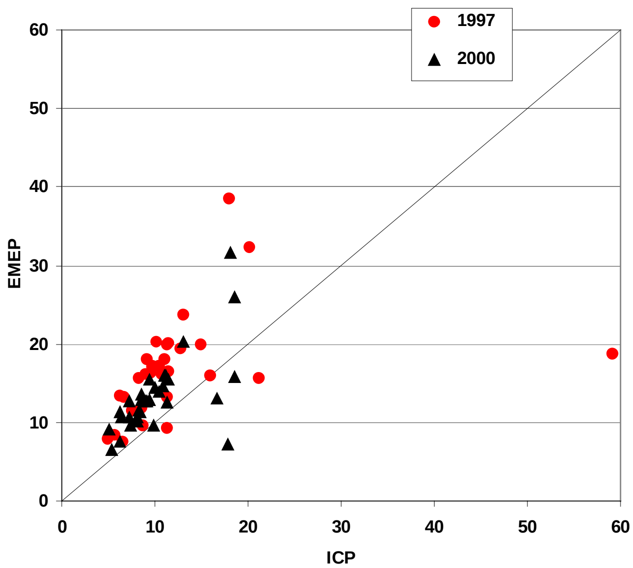

Figure 3. Total deposition of SO_4-S in deciduous forests, kg per ha and year. $EMEP_{modelled}$ wet + dry vs. ICP throughfall + stemflow during 1997 and 2000.

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[7] The correction for Germany is based on the average of available stemflow data, and the correction for Sweden on estimated difference to Germany (lower dry deposition) and unpublished stemflow measurements from beech and oak forests in Sweden.

The comparison between modelled and observed deposition of SO_4-S in precipitation (Figure 4) is more scattered compared to deposition in forests. EMEP is slightly underestimating the deposition as average, median and all percentiles, both 1997 and 2000 (Table 3), in comparison to observed data.

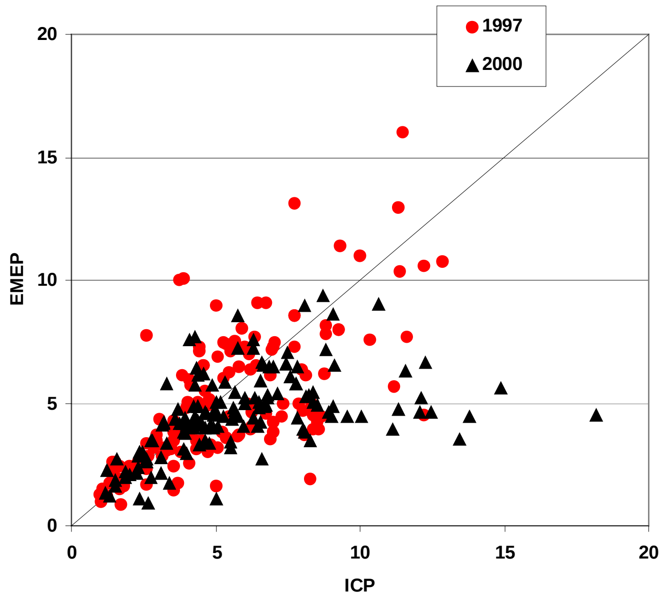

Figure 4. Deposition of SO_4-S in open field, kg per ha and year. $EMEP_{modelled}$ wet vs. ICP bulk precipitation during 1997 and 2000.

Table 3. Deposition of SO_4-S in precipitation. $EMEP_{modelled}$ wet and ICP bulk precipitation (149 sites) during 1997 and 2000.

Deposition of SO_4-S	**EMEP 1997 kg/ha**	**ICP 1997 kg/ha**	**EMEP 2000 kg/ha**	**ICP 2000 kg/ha**
average	4.95	5.30	4.52	5.73
median	4.45	4.80	4.43	5.02
max	16.01	12.86	9.35	18.18
p80	7.28	7.83	5.76	7.93
p60	4.98	5.78	4.75	5.92
p40	3.75	4.29	4.17	4.40
p20	2.55	2.63	3.17	3.26
min	0.88	1.00	0.90	1.18

The observed deposition in open field, collected with bulk samplers, could normally be expected to be 5 to 15% higher than wet only deposition, due to dry deposition in the open samplers in open field[8]. However, the main reason for the higher deposition in observed data is higher measured precipitation amount at the ICP sites, in comparison to the values used in the EMEP calculations in the corresponding grids. This is further discussed in Section 3.3. The correlation of modelled and observed concentration of SO_4-S in precipitation (Figure 5) is higher and average, median and percentiles are very close (se Table 7 in Section 3.3), in comparison to deposition.

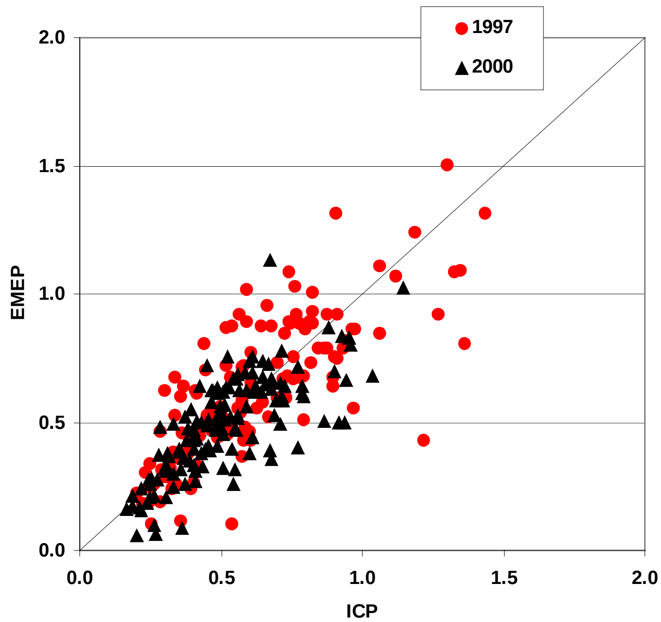

Figure 5. Volume weighted concentrations of SO_4-S in precipitation, mg per L., $EMEP_{modelled}$ wet vs. ICP bulk precipitation during 1997 and 2000.

The EMEP performance of modelling SO_4-S deposition compared to observed data at ICP sites 1997 and 2000 can be summarised:

- EMEP slightly overestimates the total (wet and dry) deposition of SO_4-S to forests, and the overestimate mainly occurs during the summer half year.

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[8] Unpublished data from the Throughfall Monitoring Network in Sweden and wet only monitoring in the ICP-Forest Level II program.

- EMEP slightly underestimates the wet deposition of SO_4-S, mainly due to lower precipitation amounts in the EMEP calculations.
- The modelled concentrations of SO_4-S in precipitation is very similar to observed, but the modelled data should be 5 to 15% lower due to dry deposition in observed data in open field with bulk samplers.
- The consequence of the first two statements above is that EMEP overestimates the dry deposition of SO_4-S to forests, compared to observed dry deposition in ICP forest plots (throughfall minus deposition in open field).

4.2 Deposition of nitrogen

Modelled and observed nitrogen deposition is only possible to compare in precipitation, due to canopy exchange (uptake) of nitrogen affecting the chemical composition of throughfall. Comparison of modelled and observed deposition of NO_3-N in open field shows a scattered picture (Figure 6). The average, median and percentiles indicate an underestimation by EMEP, compared to observations (Table 4). The correlation between modelled and observed concentrations of NO_3-N is much higher (Figure 7), compared to deposition, showing that the scattered picture in deposition is mainly caused by differences in precipitation amounts used by EMEP and ICP.

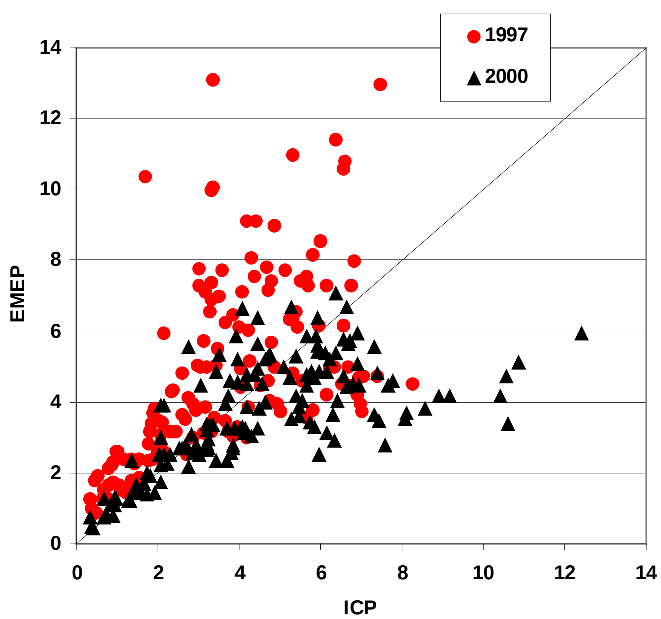

Figure 6. Deposition of NO_3-N in open field, kg per ha and year. EMEP$_{modelled}$ wet vs. ICP bulk precipitation during 1997 and 2000.

Table 4. Deposition of NO_3-N in open field. EMEP$_{modelled}$ wet and ICP bulk precipitation (157 sites) during 1997 and 2000.

Deposition of NO_3-N	EMEP 1997 kg/ha	ICP 1997 kg/ha	EMEP 2000 kg/ha	ICP 2000 kg/ha
average	3.25	3.65	3.65	4.44
median	3.13	3.37	3.66	4.16
max	7.46	8.26	7.06	12.41
p80	4.95	5.65	5.08	6.37
p60	3.54	4.09	4.18	4.74
p40	2.54	3.03	3.25	3.72
p20	1.58	1.74	2.36	2.13
min	0.33	0.36	0.44	0.34

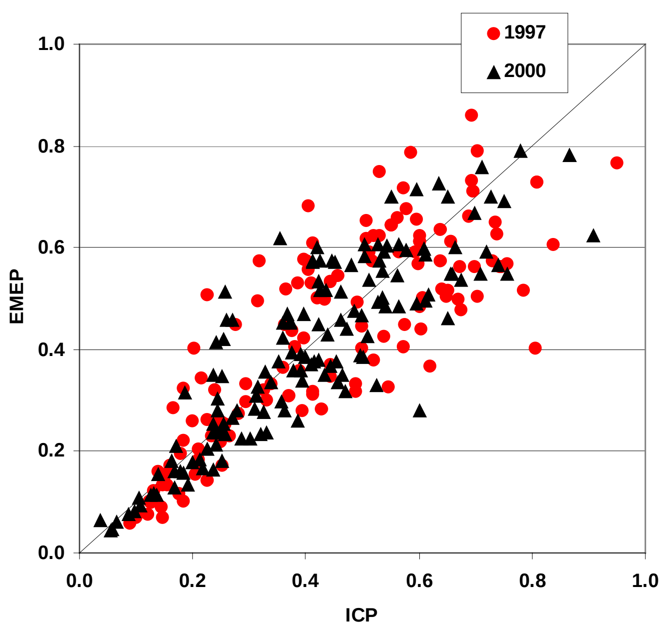

Figure 7. Volume weighted concentrations of NO_3-N in precipitation, mg per L., EMEP$_{modelled}$ wet vs. ICP bulk precipitation during 1997 and 2000.

The comparison between modelled and observed deposition of NH_4-N (Figure 8) in open field is very similar to deposition of NO_3-N, but the pattern is even more scattered for NH_4-N. The average and median values are at the same level for NH_4-N (Table 5) and NO_3-N (Table 4). By comparing concentrations the correlation between modelled and observed data becomes much higher, except for high concentrations at a few ICP sites.

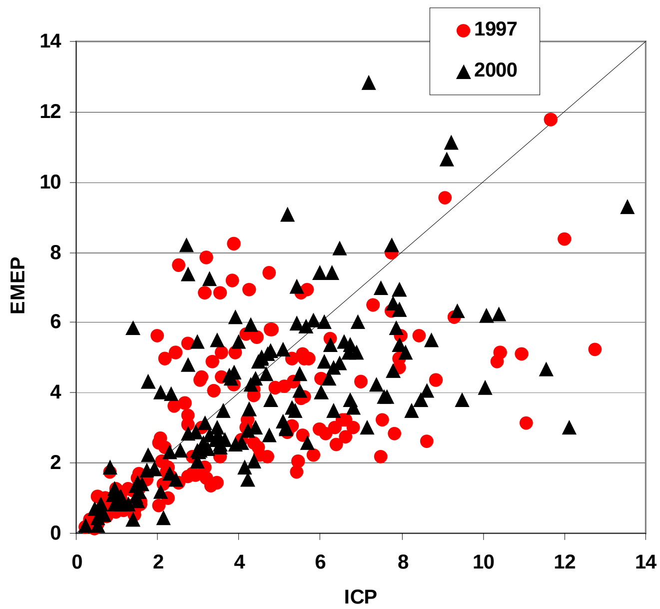

Figure 8. Deposition of NH_4-N in open field, kg per ha and year. $EMEP_{modelled}$ wet vs. ICP bulk precipitation during 1997 and 2000.

Table 5. Deposition of NH_4-N in open field. $EMEP_{modelled}$ wet and ICP bulk precipitation (157 sites) during 1997 and 2000.

Deposition of NH_4-N	EMEP 1997 kg/ha	ICP 1997 kg/ha	EMEP 2000 kg/ha	ICP 2000 kg/ha
average	3.31	4.07	3.94	4.67
median	2.91	3.50	3.80	4.28
max	11.78	12.77	12.83	13.56
p80	5.15	6.31	5.83	7.16
p60	3.74	4.37	4.42	5.16
p40	2.20	2.84	3.00	3.63
p20	1.13	1.42	1.84	2.00
min	0.14	0.23	0.20	0.23

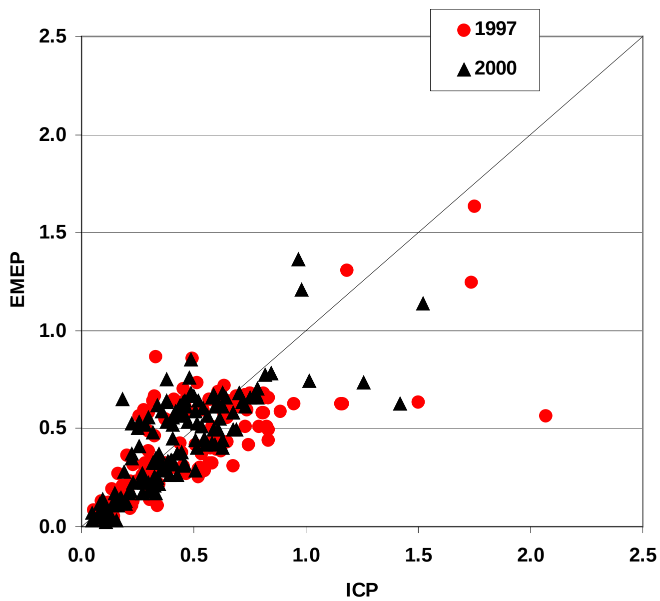

Figure 9. Volume weighted concentrations of NH_4-N in precipitation, mg per L. $EMEP_{modelled}$ wet vs. ICP bulk precipitation during 1997 and 2000.

The EMEP performance of modelling nitrogen deposition compared to observed data at ICP sites 1997 and 2000 can be summarised:

- EMEP slightly underestimates the average, median and percentile NO_3-N and NH4-N deposition in the whole deposition gradient, but the correlation between modelled and observed data is rather low.

- Modelled and observed concentrations of both NO_3-N and NH4-N are very similar as average, median and percentiles, and the correlation between modelled and observed data is rather high. The differences in deposition are mainly caused by differences in precipitation amount used by EMEP and ICP.

4.3 Precipitation

The precipitation amount at the ICP sites is normally measured in the same collectors that sample precipitation for chemical analysis and the methods are standardised in the ICP Forest manual. The comparison between precipitation used in the EMEP calculations and observed data at the ICP sites show rather large differences (Figure 10) with notably lower precipitation in EMEP grids expressed as average, median and percentiles, except for the areas with the lowest precipitation, the 20 percentile (Table 6).

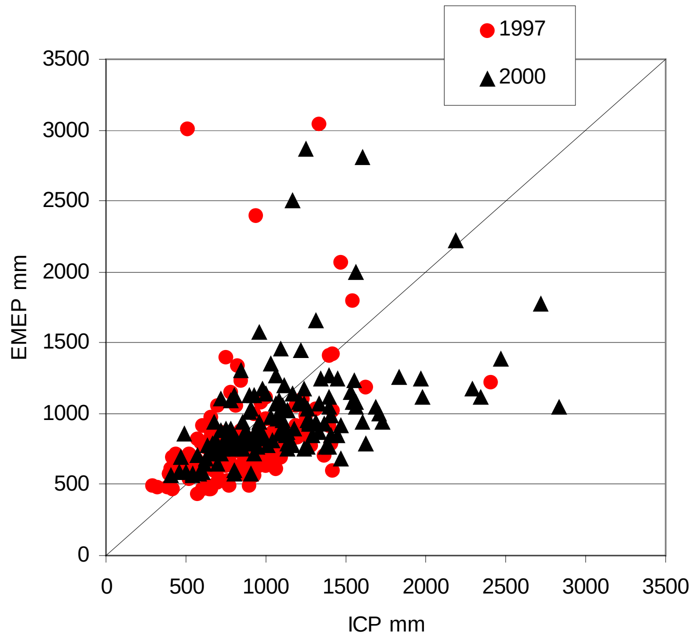

Figure 10. Precipitation in mm during 1997 and 2000. EMEP$_{modelled}$ vs. ICP bulk.

Table 6. Annual precipitation during 1997 and 2000. EMEP$_{modelled}$ and ICP bulk (147 sites).

Annual precipitation	EMEP 1997 mm	ICP 1997 mm	EMEP 2000 mm	ICP 2000 mm
average	825	856	992	1108
median	719	823	898	1064
max	3038	2403	2865	2829
p80	917	1068	1130	1396
p60	794	898	957	1136
p40	691	729	841	932
p20	613	593	756	740
min	430	293	560	404

The differences in precipitation amounts used in EMEP and ICP are accompanied by a low correlation between modelled and observed data, as described in Section 4.1 and 4.2. The accuracy of the EMEP modelled wet deposition is probably better described by comparing modelled and observed concentrations in precipitation.

The similarities between modelled and observed concentrations in precipitation are summarised in Table 7.

The ICP sites in this study are probably too few to clearly show uncertainties in the data that EMEP uses, or to replace the precipitation data for the EMEP grids. But the observed systematic differences between EMEP and ICP data implies that the accuracy of the precipitation data used in EMEP should be evaluated against data from national precipitation networks or other independent data at the fine resolution that is required by the model.

Table 7. Volume weighted concentrations in precipitation 1997 and 2000.

Concentrations in precipitation		**EMEP 1997 mg/L**	**ICP 1997 mg/L**	**EMEP 2000 mg/L**	**ICP 2000 mg/L**
SO_4-S	average	0.64	0.63	0.49	0.52
SO_4-S	median	0.62	0.58	0.50	0.50
NO_3-N	average	0.44	0.45	0.40	0.41
NO_3-N	median	0.48	0.44	0.39	0.40
NH_4-N	average	0.43	0.49	0.42	0.43
NH_4-N	median	0.42	0.45	0.42	0.39