Wind-direction-dependent differences between model calculations and field measurements as indicator for inaccuracies in emission inventories

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ABSTRACT

When comparing results from atmospheric dispersion models with measurements it is difficult to trace the cause of the differences, because every emission inventory, atmospheric dispersion model, and atmospheric measurement contains inaccuracies. To assess inaccuracies in an inventory of European SO_2 emission in 1994, we have plotted the calculated SO_2 concentrations from the LOTOS model together with the measured SO_2 concentrations from the EMEP network in wind direction sectors of 30 degrees. We argue that when the wind direction dependent differences at several measurement stations in different countries point to a specific region, the emission estimate for that specific region is the likely cause for the difference between model calculation and observation. This work has been published in Atmospheric Environment 36 (2002) 1195-1204.

INTRODUCTION

Emissions of air pollutants within a country or region are the result of a variety of individual sources. Since it is not practical to measure each emission source individually, the estimation of large-scale emissions is in most cases based on calculation of emissions using an emission factor approach. This emission factor approach aggregates information of sources in both, time and space, which will (amongst other reasons, e.g. error in emission measurement) lead to an inaccurate representation of the emission that has actually occurred.

By performing an uncertainty assessment an attempt is made to identify the sources of inaccuracy and to quantify their impact on the accuracy of the emission estimate. In this paper we focus on a so-called external assessment of inaccuracy uncertainty through forward air quality modelling (Van Aardenne, (1) and presention of Van Aardenne and Pulles at this conference). In forward air qualiy modelling, an emission inventory is used as input into an atmospheric dispersion model, which calculates atmospheric concentrations of the pollutant. The deviation between modelled and observed concentrations can be an indicator for the inaccuracy of the emission inventory (2). The problem with this type of assessment is that it is not easy to pinpoint emission inventory inaccuracy as a single cause for the difference between model and observations. In this paper we argue that when wind-direction-dependent differences at several measurement stations in different countries point towards a specific region, the emission estimate for that specific region is the likely casuse for the difference between modelled and observed concentrations. The results presented here are described in (3).

METHODOLOGY

To assess inaccuracy in an European SO_2 emissions inventory for 1994 (4), (5) we plotted calculated SO_2 concentrations from the LOTOS model (5) with SO_2 concentrations measured at 72 stations in the EMEP network (7), (8).

Selection of EMEP stations

We used EMEP measurements from stations for which SO_2 measurements data are available and that are located within the domain of the LOTOS model. These measurement data are unreliable when (i) measurements show rather low SO_2 concentrations (possible near detection limit), (ii) measurement data are erroneous, or (iii) the coverage (number of days for which measurements are available) is low. 70 out of the 91 stations of 1994 EMEP were used

Calculation of daily averaged data

Since the EMEP measurements are daily averaged values and the LOTOS calculations are hourly averaged values we:

- ✓ Calculated daily averaged SO_2 (LOTOS)
- ✓ Calculated daily averaged wind direction (LOTOS)
- ✓ Accounted for large wind direction shifts over one day by excluding days with standard deviation of hourly winds that is larger than 30^0

Classification of data in wind sectors and graphical display

The daily averaged EMEP and LOTOS SO_2 concentrations that met the criteria of standard deviation of wind and availability of measurement data were classified in wind direction sector of 30 degrees. This means, for example that wind directions ranging from 345^0 to 15^0 are classified with class midpoint of 0^0.

The wind-direction-dependent differences between modelled and measured SO_2 concentrations were analysed by displaying the data in three different graphs. Figure 1 presents a concentration rose that illustrates the wind-direction-dependent differences between LOTOS and EMEP SO_2 concentrations for the EMEP station NL09: Kollumerwaard, The Netherlands.

Figure 1 Concentration rose presenting wind-direction-dependent differences between LOTOS and EMEP SO2 concentrations (mg SO2) in 1994, station NL09: Kollumerwaard, The Netherlands.

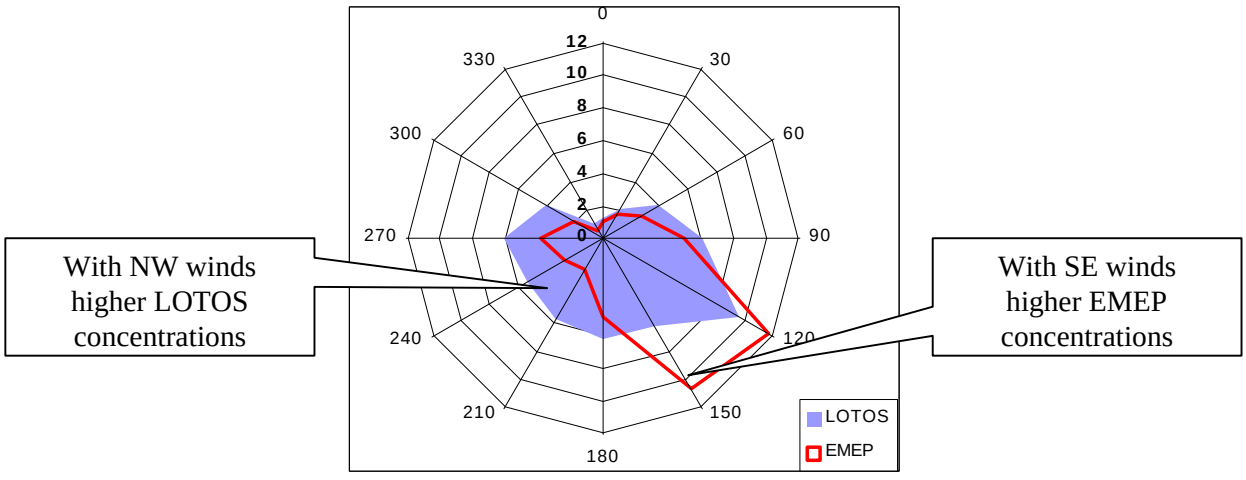


Figure 2 Frequency histogram for wind direction classes of 30 degrees. Shown are the days that are included or excluded from the analysis

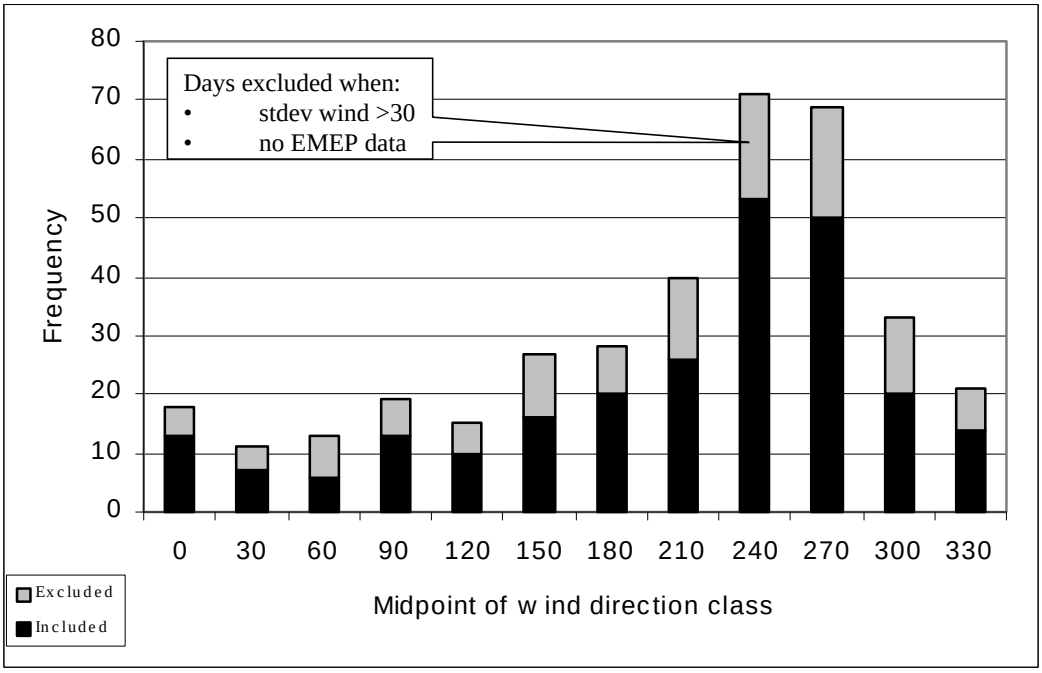
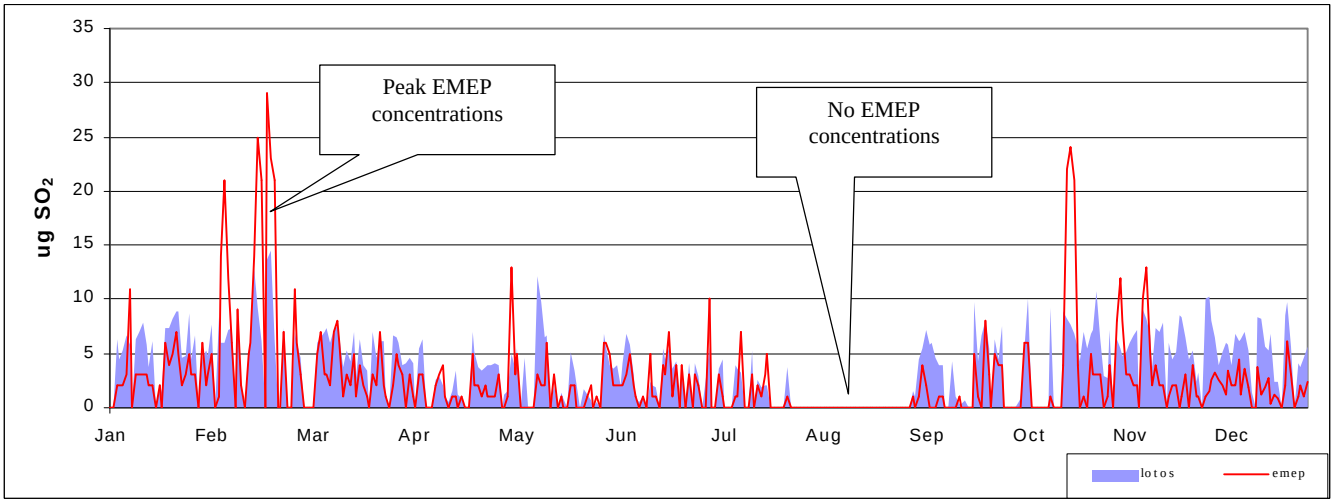


Figure 3 LOTOS and EMEP SO2 concentrations per day in 1994 (mg SO2).



For winds from north to northeast (330^0- 90^0) there is a good agreement between (LOTOS) modelled and measured (EMEP) concentrations (Figure 1) With wind from south-eastern direction (classes 120^o and 150^0) the measurement shows higher concentrations with a clear discrepancy in wind direction 150^0 where the difference is a factor 1.7. With winds from southwest to northwest (210^0-330^0) the model shows higher SO_2 concentrations than the measurements with about a factor of two.

The frequency histogram for wind direction categories (Figure 2) indicates that the wind-direction-dependent difference plot is based on results from several days per wind direction. Figure 3 shows that the higher measurement values from southeastern wind directions are found on several days in February and October, and that the higher model values from southwest to northwest seem to occur especially in the winter months November to January.

Analysing the result for only the one station does not allow a clear distinction between emission error, model error or measurement error as cause for the discrepancy between modelled and measured SO_2 concentrations. For that we need information from other stations. If other stations in the Netherlands and neighbouring countries show a comparable wind direction dependent difference (higher measurement values in South-eastern direction or higher model values in Southwest-North-western direction) the conclusion can be drawn that the discrepancy is caused by an erroneous emission estimate in source region that is influencing the LOTOS grid cell of station NL09.

In the same manner as discussed for station NL09 we analysed the results for the other stations. We used as criterion for selecting inaccuracy in the emission estimate for a certain region as possible cause for the discrepancy between model and measurement that the wind-direction-dependent differences from several measurement stations from different countries point towards that specific region. If this criterion is not met, we did not distinguish between model error, emission error or measurement error.

RESULTS

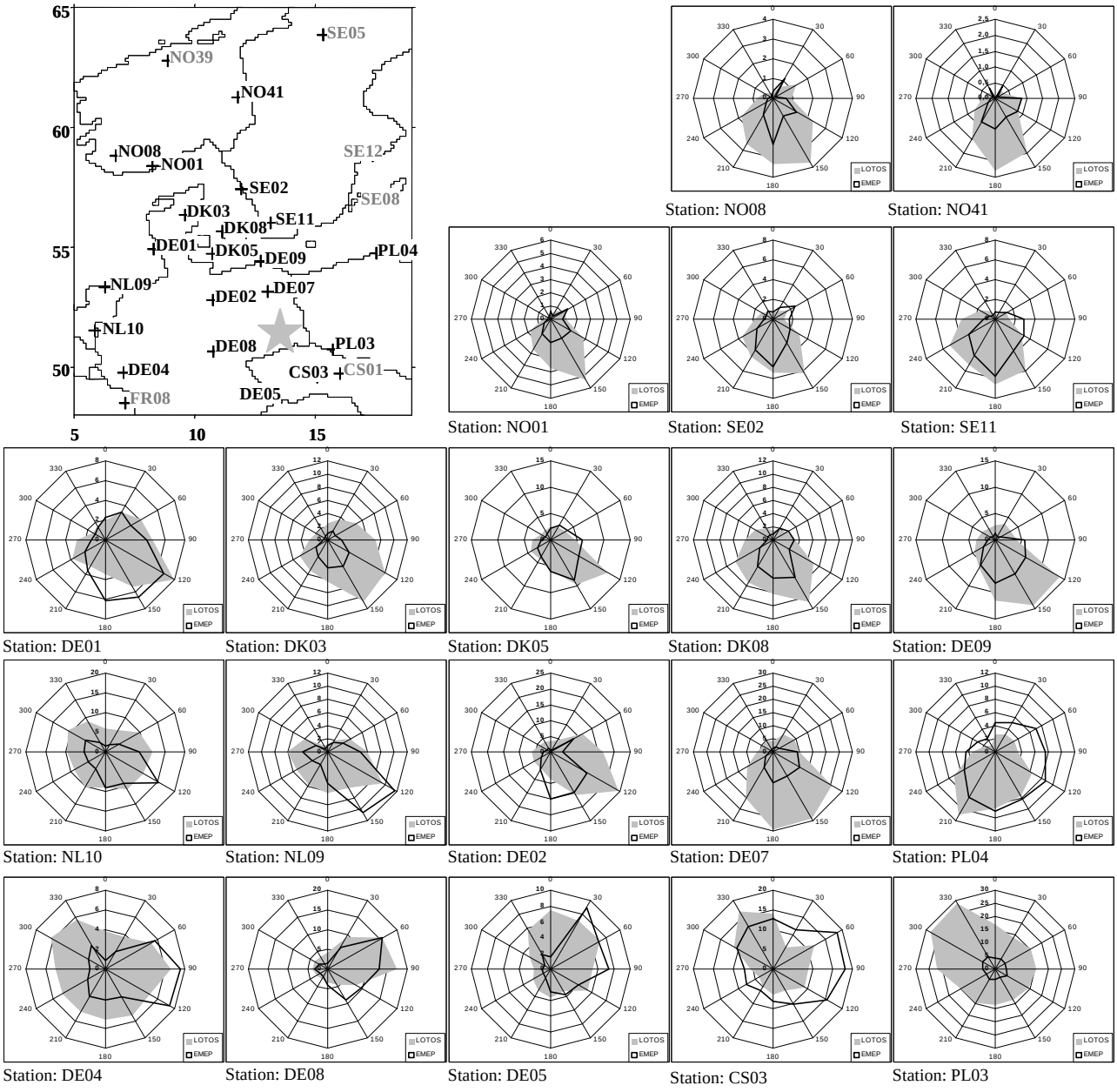
Example: Germany, Sachsen/brandenburg region

The group of measuring stations surrounding the German "Länder" Sachsen and Brandenburg (Figure 4) show a clear overestimation of calculated SO2 concentrations at wind directions from these "Länder" towards the stations. At south-eastern (SE) winds, calculated concentrations are higher at the stations NO01, NO08, DK03, DK05, DK08 and DE09. The same occurs at southern (S) wind directions at the stations NO41, SE05 and DE07. At northern (N) wind directions overestimation occurs at DE05 and to a lesser extent CS03. The station PL03 shows a clear overestimation by the calculation at northwestern (NW) wind directions.

These observations can consistently be explained by the assumption that the emissions in Sachsen and Brandenburg might be overestimated. At some other stations in this area this is less clearly visible, but in none of the stations surrounding the area observations were made that contradict this assumption.

The graphs of the daily averaged SO2 concentrations from LOTOS versus those from EMEP (see Figure 3 for an example) for all of the stations discussed above do not show a deviation in temporal patterns between measured and observed concentrations over the year. The apparent overestimation of emissions might be caused by inaccuracy in the spatial distribution (emission per grid cell) of the national German SO2 emission budget due to changes since 1990 in relative importance of sources in the former GDR compared to the western parts of the country. Since the spatial distribution of emissions for 1994 (after the German unification) was based on the one for 1990 (before the German unification), the shut down of major parts of the industry in the former GDR might not be reflected in the emission inventory.

Figure 4 Wind-direction-dependent modelled (EMEP) and observed (LOTOS) SO_2 concentrations (in mg SO_2) at measuring stations surrounding the Sachsen-Brandenburg region and stations surrounding the Nordrhein-Westphalia region. The stations included in the analysis are marked in bold on the map



CONCLUSIONS

This type of analysis has several limitations (for example: comparing grid cell averages with point estimates, aggregation of modelled SO_2 concentrations because difference in temporal resolution of model observation.

Although this type of analysis is accompanied with several limitations, this rather straightforward methodology allows to use inhomogeneous and incomplete measurement data to comparte model calculations with measurement data.

Results show that this type of uncertainty analysis can be a usefull tool in the assessment of inaccuracies in emission inventories, provided that measurement data from different countries are available.

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