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The national smog warning system in The Netherlands; a combination of measuring and modelling

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ABSTRACT

A national smog warning system has been operational in the Netherlands for several years. This system is based on the combination of measurements and air pollution models. In summer, ozone forecasts are made, whereas in winter the system is based on the sum of SO_2 and PM_{10} (fine particles). In the case of ozone, the statistical procedure appears to be superior to the atmospheric transport model. Only a few minor winter smog episodes have been recorded in the past years, the reliability of the models for SO_2 is therefore less well known than for ozone.

1 INTRODUCTION

During smog episodes, concentrations of a number of air pollutants are elevated to levels which may cause harmful health effects. In summer, the concentration of ozone serves as an indicator of the existing smog situation, whereas in winter the concentrations of SO_2 and PM_{10} (fine particles) are indicators. In order to minimize harmful effects, the Queens Commissioners in the Netherlands, responsible for the provincial governments, have the power to take measures.

Since 1989, a smog warning system has been operational at RIVM. In the first year, air pollution transport models were adapted to produce automatically, on a daily basis, smog forecasts. Soon statistical procedures were developed in addition to these models. From the start of 1992, daily smog reports are made available to the Dutch press to inform the public.

2 DESCRIPTION OF THE MODELS

In 1989, two models were able to make smog forecasts; the MPA-model and

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the EUROS model. MPA presents an ozone forecast for several areas in the Netherlands, whereas EUROS provides prognostic concentration fields of SO_2 over nearly entire Europe (Table 1).

Soon thereafter, the statistical model OZONPRO was developed. As the reliability of the model was encouraging, a new software package, CREAMOD, was developed which allows a very fast development of statistical models. With CREAMOD, the models ZWAPRO and ZWAPRUBA were developed for SO_2 and PROZON for ozone.

Table 1 Basic information on the smog models used in the Netherlands

model	compound	forecast period	regional differentiation	type of model
mpa	O_3	1-3 days	5 Dutch regions	transport
prozon		1-5 days	all Dutch monitoring sites	statistical
ozonpro		1-12 hours		
euros	SO_2	1-3 days	Europe (grids)	transport
zwapro		1 day	all Dutch monitoring sites	statistical
zwapruba				

2.1 DETERMINISTIC MODELS

2.1.1 MPA The MPA-model is a lagrangian long-range air transport model [De Leeuw[1]]. Two air parcels are followed along 96 hour back trajectories, one at 1000 mbar representative for the mixed layer, the other at 800 meter altitude, representative for the polluted layer above the mixed layer (the aged smog layer). The model discriminates between two layers which follow the same trajectory. The model includes emissions, non-linear atmospheric chemistry, deposition, exchange between boundary layer and free troposphere and fumigation between the mixed layer and the aged smog layer. The input information is prepared automatically from Dutch observations, prognostic wind fields of ECMWF and a 5-day weather report for cloud cover and temperature.

2.1.2 EUROS The model EUROS is an eulerian numerical grid model. It includes simple linear chemistry [Van Rheineck Leyssius[2]]. The meteorological input consists of prognostic wind fields from ECMWF at pressure levels of 1000 and 850 mbar. For other meteorological parameters (cloud cover, radiation, temperature, the altitude of the mixing layer) no prognostic fields on a European scale are available. These fields are estimated from Dutch measurements or prognoses. The vertical stratification is modelled by separation into four layers.

2.2 STATISTICAL MODELS

2.2.1 BASIC METHODS IN THE CREAMOD SOFTWARE The basic equation to forecast concentrations is:

$$P(t_2,l) = M(t_1,l) \times F(c) \quad (1)$$

where

$P(t_2,l)$ = the prognosis, valid for time t_2 at location l
$M(t_1,l)$ = the measured value at time t_1 at location l
$F(c)$ = is a scaling factor, valid for class c

The scaling factors are derived from statistics of measurements in the past. The factors are specific for a certain class, defined by e.g. meteorology, type of measurement location, season and the current concentration level. Meteorological data are necessary for both the acual day and the day for which the prognosis is derived. The scaling factors F_c are defined as:

$$F(c) = \Sigma_{t,l} [M(t_2,l) / M(t_1,l)] \times \delta_c \quad (2)$$

where

δ_c = 1 if the class for these measurements equals c, otherwise δ_c is 0

The procedure followed by CREAMOD to make a statistical prognosis model takes three steps. First the prognosis model is defined. Then the statistics of the scaling factors F(c) are derived from the monitoring results of several years. In general, a data set of two years of hourly measurements is a minimum requirement. Longer monitoring periods are often necessary, depending on the complexity of the model and on the variability of the weather in the period covered. Finally, the model is tested. The tests compare model forecasts with measurements. The statistics of the scaling factors exclude the measurements from the period tested.

Execution of a model run takes about 10 seconds, which allows a fast interactive investigation of (meteorologically) different options. The time necessary to develop a model from the definition up to the execution of a sufficient testing programme is in the order of one or more hours for the investigator and about one day for the computer system of RIVM.

2.2.2 OZONPRO The statistical model OZONPRO derives a prognosis of ozone one to about twelve hours in advance for all monitoring sites. First a forecast of oxidant (O_3+NO_2) is made, which is converted to a forecast of ozone. The forecast of oxidant is based on the last available measurements and of the diurnal patterns of oxidant measured in the past. The conversion to ozone is based on statistics of the maximum concentrations of ozone and oxidant. Eight diurnal patterns are distinguished, depending on the meteorology. Difference is made between wind from the continent or from sea, between 2 classes of cloud cover and 2 classes of wind velocity. The diurnal patterns are derived from the monitoring results of the last five years. They are specific for each combination of month and monitoring site.

The procedure seems to be rather complicated, because a prognosis of ozone is also possible on the basis of diurnal patterns of ozone without the intermediate use of oxidant. However, the diurnal patterns of oxidant are more stable than those of ozone and a close relation exists between the maximum concentrations of ozone and oxidant.

2.2.3 PROZON Prozon is able to forecast daily maximum ozone concentrations one to five days in advance for all monitoring sites. The model uses CREAMOD. The classification of the scaling factors discriminates between rural, urban and traffic sites, 6 periods of two months, 6 concentration classes, 5 temperature classes and 3 classes of radiation.

2.2.4 ZWAPRO The model ZWAPRO forecasts daily avarages of SO_2 one day in advance. It uses CREAMOD. The classification of the scaling factors discriminates between rural, urban and traffic sites, 6 periods of two months, 4 concentration classes, 4 wind direction classes, presence or absence of snow cover and 3 classes of radiation.

2.2.5 ZWAPRUBA The model ZWAPRUBA forecasts daily avarages of SO_2 one day in advance, based on CREAMOD. In contrast to ZWAPRO, concentrations of SO_2 are needed from six monitoring locations of the German Umweltbundesamt (UBA). On the basis of wind direction and wind speed, measured in the Netherlands, an assessment is made of the 'present' locations of the air which will arrive 'tomorrow' in the north, centre and south of the Netherlands. The concentrations of SO_2 in those air parcels is assessed by spatial interpolation of the Dutch and German measurements. The concentrations in the coming air parcels are modified with scaling factors which discriminate between rural, urban and traffic sites, 3 Dutch regions, 2 temperature and 2 concentration classes.

3 EVALUATION OF THE MODEL RESULTS

3.1 THE EVALUATION PROCEDURE

Figures are made which show the dynamics of the measured and modelled concentrations, based on regional averages. Additionally, evaluation statistics, based on the separate locations, are derived for the statistical models. Three evaluation quantities are calculated.

(1) The bias B is given by:

$$B = 1/N \times \Sigma_{t,l} [P(t_2,l) - M(t_2,l)] \qquad (3)$$

where

N = number of pairs of measurements and forecasts

(2) The skill score S is a measure of the accuracy of the model, relative to a reference model. The reference model is here:

$$P(t_2,l) = M(t_1,l) \qquad (4)$$

This reference - often referred to as 'persistency' - can easily be compared

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to the statistical models as these are based on 'meteorologically scaled persistency'. The skill score is now defined as:

$$S = 100 \times \{1 - \Sigma_{t,l} ([P(t_2,l) - M(t_2,l)]^2 / [M(t_1,l) - M(t_2,l)]^2)\} \qquad (5)$$

A negative skill indicates that the model performs worse than persistency.
(3) An assessment is made of the percentage of measured smog situations which are forecast, and the percentage of the forecast smog situations which are confirmed by measurements.

3.2 EVALUATION RESULTS

3.2.1 SUMMER SMOG The forecasts of PROZON, one day in advance and based on measured meteorological input, is rather good for the centre of the Netherlands (Figure 1). The results in the north are better and in the south slightly worse than those presented here for the centre of the Netherlands. Even up to five days in advance, the forecast is not really bad (Table 2). The prognosis based on forecast meteorological input is slightly worse than if based on measured input. After the measurements of oxidant of 11 AM have become available, the quality of the OZONPRO forecast becomes better than that of PROZON (Table 2). The results of the transport model MPA are poor (Figure 2).

3.2.2 WINTER SMOG The evaluation of wintersmog is hindered by the lack of smog episodes in recent years, due to reductions in the emissions of SO_2 over the northwest of Europe. All evaluations are based on measured meteorological input.

The forecasts of the eulerian model EUROS has been compared to those of ZWAPRO for the winter of 1992-1993 (Table 3). EUROS overestimates the concentrations in the eastern part of the Netherlands, for which a correction is made. The forecasts of both models are not very reliable.

The model ZWAPRUBA has only been tested for several winters in the eighties. On part of the days model results are not available, as measurements are lacking from the German UBA-locations. In general, ZWAPRUBA (Figure 3) forecasts better than ZWAPRO (Figure 4), which is also the case for other regions and other periods than those presented here.

4 DISCUSSION

Why do statistical models perform better than more 'scientifical' models, especially those for ozone? In the case of ozone, an accurate description of the formation and loss of ozone is difficult, as the underlying chemistry is very complex. Further, the emissions of volatile organic compounds (VOCs), the fuel for tropospheric ozone production, are not accurately known. Statistical models for ozone do not use emission estimates or chemistry, this information is hidden in the statistics and the measurements used. Further, ozone concentrations are closely related to the weather. Air from the continent contains much more precursors than air from sea. A higher wind velocity leads to faster removal of polluted air and thus to reduced ozone levels. An increase in radiation increases ozone production. For all these meteorological parameters, a change which leads to increasing ozone levels will also increase the temperature. The high quality of a smog prognosis based on ozone monitoring and a prognosis of temperature changes is therefore not really surprising. However, temperature anomalies, such as a high temperature combined with wind from sea, can disturb the forecast.

Table 2 Additional statistical data on the evaluation of PROZON and OZONPRO for 1 May until 31 August 1992, based on pairs of forecasts and measurements per monitoring location. The percentages of Measured Exceedances which are Forecast (%MEF) and Forecast Exceedances which are confirmed by Measurements (%FEM) are based on 99 measured excess values of the level of 180 $\mu g/m^3$. Skill and bias (see 3.1) refer to situations where measured ozone levels exceeded 150 $\mu g/m^3$. Forecasts are based on measured meteorological input.

model	time	meteo	%MEF	%FEM	skill	bias
prozon	1 day	measured	58	43	31	-6
		prognostic	60	48		
	2 days	measured	56	39	18	-5
		prognostic	50	40		
	3 days	measured	48	51	16	-19
		prognostic	30	38		
	4 days	measured	42	34	7	-9
		prognostic	53	31		
	5 days	measured	42	39	5	-6
		prognostic	44	31		
ozonpro	9 AM	measured	41	42		
	11 AM	measured	52	49		
	1 PM	measured	68	55		

The quality of the model forecasts for winter smog is rather poor. In the case of the model EUROS, this could be caused by the rather large grid size of the model (a few grids represent the entire territory of the Netherlands). The model ZWAPRO performs in fact better than one would expect, as this model uses only Dutch measurements of SO_2 and meteorology, whereas

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winter smog episodes are in general 'imported' from other countries. The model ZWAPRUBA gives the best forecasts. It uses the measured concentrations of SO_2 in the air parcel which is expected to arrive the next day. The effects of removal processes and of emissions over one day are limited, which allows a forecast via the simple statistics of ZWAPRUBA.

Table 3 The number of Measured Exceedances of 30 $\mu g/m^3$ SO_2 which are Forecast for a region (MEF), the number of Measured Exceedances which are Not Forecast (MENF) and the number of 'False Alarms' (FA), forecast exceedances which are not confirmed by measurements) for EUROS and ZWAPRO over the winter of 1992/1993.

REGION	MODEL	MEF	MENF	FA
north	EUROS	1	1	2
	ZWAPRO	2	0	7
centre	EUROS	3	2	7
	ZWAPRO	2	3	7
south	EUROS	1	4	8
	ZWAPRO	2	2	6

5 CONCLUSIONS

At this moment, the best Dutch models to forecast smog are not transport models, but models based on measurements in combination with simple statistical rules. Further, a prognosis of summer smog is in general more reliable than forecasts of winter smog. Information on the current smog situation in other countries is essential for the forecast of winter smog. For summer smog this information is less relevant.

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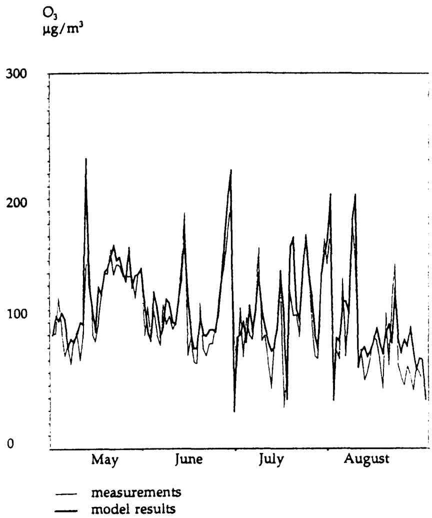

Figure 1 PROZON forecasts over the summer of 1992

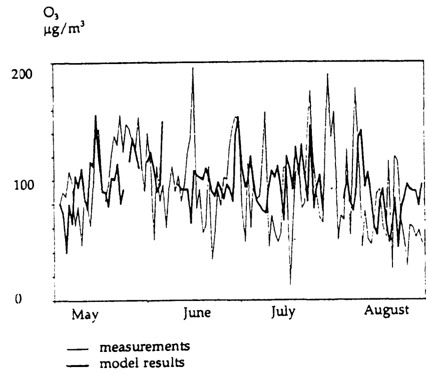

Figure 2 MPA forecasts over the summer of 1992

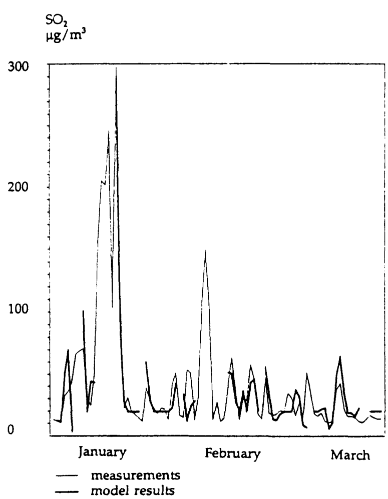

Figure 3 ZWAPRUBA forecasts over the winter of 1985

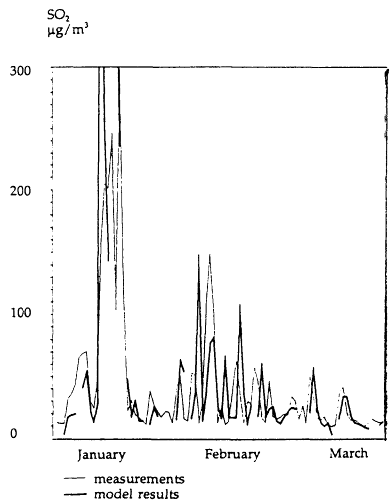

Figure 4 ZWAPRO forecasts over the winter of 1985