Technical Report No. 9

National Ozone Forecasting Systems and International Data Exchange in Northwest Europe

Prepared by:
Report of the Technical Working Group on
Data Exchange and Forecasting for Ozone episodes
in Northwest Europe (TWG-DFO)

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SUMMARY

This report is a joint effort of experts from 10 European countries, co-ordinated by the European Topic Centre on Air Quality, on request of the Environment Ministers at a conference held in London in May 1996. The report reviews systems for forecasting and information on ozone episodes, as currently in use and under development in the countries. Once a forecast has been made, it is released to the target groups using a range of communication channels (press release, Internet, teletext systems, etc.). The forecast bulletin gives information on maximum ozone concentrations expected for the coming 10-48 hours. In a few cases the forecast is made for specific locations but more generally a national or regional forecast is made. To make the bulletin more understandable to the general public, air quality indicators (e.g. *good air quality, severe smog*) rather than concentration levels are presented. Criteria for testing the validity and reliability of forecasting systems are discussed, and recommendations are made to improve and speed up current systems for exchange of national ozone data. Recommendations for further work conclude the report.

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1. INTRODUCTION

1.1. Background and terms of reference of the work

In May 1996, the Ministerial Conference on Tropospheric Ozone in Northwest Europe was held in London. In the Statement by the Ministers for the Environment at the Conference, under point 4, the European Environment Agency was called, in co-operation with technical experts throughout Europe, to develop an action plan for a co-ordinated European system for data exchange and for forecasting air pollution episodes. The Ministers committed their eight countries to full co-operation with the Agency for this work, and agreed to establish a pilot group for the North European sub-region.

The European Environment Agency (EEA) agreed to take up this task. Under co-ordination of the European Topic Centre on Air Quality (ETC-AQ), a Technical Working Group on Data exchange and Forecasting for Ozone episodes in Northwest Europe (TWG-DFO) was formed. Members of the Group are scientific experts, nominated by the eight countries participating in the Ministerial Conference and by other interested EEA member countries connected to the north-western European ozone episode systems, and experts from the ETC-AQ. The experts participating in the group are listed in Annex 1.

The terms of reference for the work of the group as agreed were: to develop an action plan for a co-ordinated system for data exchange and for forecasting ozone episodes in North-west Europe as they occur, and providing a basis for the member countries to supply information to the public about these episodes.

The work of the Group included:
- reviewing and reporting on systems currently in use in the participating countries for data exchange and forecasting of ozone episodes, and current research for development and improvement of such systems, on the basis of national reports and information presented at the Ministerial conference;
- developing common criteria for testing the validity and reliability of ozone forecasting systems, and reporting on evaluation of existing forecasting systems, using these criteria;
- making recommendations for improving existing data exchange systems for ozone, reducing the current delays in information, and taking advantage of new technologies, such as the Internet.

In the time period between July 1996 and March 1997, the group had two meetings in Bilthoven, the Netherlands, on 11 October 1996 and on 24 January 1997. This report provides the results of the work in this time period.

1.2. Ozone forecasting and data exchange

Episodes of photochemical air pollution are periods of some days to some weeks with calm, warm, sunny weather, in which atmospheric photochemical reactions of nitrogen oxides and volatile organic compounds lead to a host of mostly noxious air pollutants. Ozone is considered to be the most important of these in view of its concentrations and its effects on human health.

Ozone episode information and forecasts are issued publicly in various European countries. Explicitly or implicitly, the goals of this information are (van Aalst, 1996):

1. to satisfy needs of public information;
2. to further reduction and prevention of exposure;
3. to alert authorities, industry and the public to take measures for emission reduction;
4. to increase public support for structural measures.

These goals require that reliable information is provided on a timely basis. Typically, the first two goals require the information to be available in near real time, and a forecast to be available for one day in advance. The time required to prepare emission reduction measures is at least one day, and preferentially a few days, depending on the logistics.

Current national smog information systems, as in operation in various European countries, can provide near real time information and/or forecasts for one day in advance. These information systems operate on the basis of empirical methods and/or expert opinions, statistical models, causal models or combinations. (Fromage, 1996)

The simplest empirical model is persistence, assuming that the forecasted concentration is equal to the actual one. Expert opinion, based on measured data and personal experience may lead to improved predictions.

In statistical models, the prediction is generated from actual measuring data, combined with statistical information on the most likely evolution of the concentration at the given or predicted meteorological conditions. The statistical information is extracted from a database of measurements over several years. In so-called artificial neural networks, the system is self-learning in the sense that it optimises predictions on the basis of earlier experience.

In causal models, the concentration is calculated from emissions of ozone precursors (volatile organic compounds and nitrogen oxides) and forecasted meteorological conditions in Europe, taking into account relevant atmospheric processes such as dispersion, transport, chemical conversion and deposition.

Experience in European countries has shown that expert judgement can increase the performance of more formal ozone episode prediction systems considerably. Information from measurements in countries upwind may improve the quality of the forecast. Some European countries routinely exchange very recent or actual ozone concentration data (see Chapter 4).

In the past few years, several European countries, both EU Member States and Central European countries, have exchanged information on air pollution and on information and forecasting systems in a series of informal workshops on international exchange of data for smog warning and air pollution information systems in Europe.

1.3. EU Air Quality legislation on ozone and work in progress

Council Directive 92/72/EEC on air pollution by ozone, which is currently in force, defines five threshold values for the concentration of ozone, and provides guidelines on measurements of ozone and reporting of the data. Threshold values have been set for protection of human health (110 µg/m^3 8-h average) and of vegetation (200 µg/m^3 hourly average and 65 µg/m^3 24-h average). The relevant threshold values in the context of this report are the population information threshold value of 180 µg/m^3 as an hourly average and the population warning threshold value of 360 µg/m^3 as an hourly average. In case of exceedance of these values, Member States shall take the necessary steps to inform the public. Information to be provided includes time, duration, and place of the exceedances, the threshold exceeded, the population concerned, and precautions to be taken, and also forecasts concerning the change in concentration, the geographical area concerned, and the duration of the exceedance in future.

Member States must report to the European Commission the method used to determine ozone concentrations, the co-ordinates of the measuring stations, a description of the area covered by the stations, the site-selection criteria and the result of any indicative measuring programme.

Exceedances of all five threshold values, periods of exceedance, and statistics (maximum, median, 98-percentile) of hourly and eight-hourly concentrations recorded should be reported within six months after the year. Exceedances of the information and warning threshold levels should be reported before the end of the month following the month of the exceedance, if possible complemented with relevant information, which might explain the reasons.

Annually, the Commission reports on the reported levels in the previous year, and provides an information document on exceedances in the summer period of the current year. In addition to the annual reporting the Commission is obliged to submit to the Council no later than four years after implementation of the Directive (i.e. March 1998) a consolidated report on the information collected containing an evaluation of the photochemical pollution in the Community. Currently, these reports are prepared for the Commission by the EEA European Topic Centre on Air Quality (ETC-AQ) (see De Leeuw *et al.*, 1996; Sluyter *et al.*, 1996). All information submitted to the Commission under this Directive is also available at the ETC-AQ.

Preparations are now underway by the Commission and Member States for a new ozone Directive under the so-called Framework Directive (Council Directive 96/62/EC on ambient air quality assessment and management). This Daughter Directive will contain inter alia revised standards for Ozone serving as a rational framework for the Commission's development of an abatement strategy demanded by the current Ozone Directive and which has been started recently by establishing a joint Ad hoc Working Group for both issues.

Under Council Decision 97/101 on Exchange of Information, adopted on 27 January 1997 (OJ/35/14), a reciprocal exchange of information and data from networks and individual stations measuring ambient air pollution within the Member States will be established. Among other pollutants, exchange of more extended information on ozone and related substances (NOx, NO_2, PAN, (NM)VOC, and various individual organics) is foreseen. The first transfer with regard to this decision should take place by October 1998 at the latest and concern the year 1997. The information will be collected in an information system, and regular reports will be provided. EEA will be called upon by the Commission regarding the practical implementation of these information systems and reports.

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2. NATIONAL SYSTEMS FOR FORECASTING OZONE

2.1. Introduction

In this chapter, brief descriptive information is provided for each of the ten countries participating in this study on operational systems for ozone forecasting, and on national research and development efforts for such systems.
For each country, and for each of the systems in operation in that country, summary tables in section 2.13 provide concise information on:

- what purpose/use the system is intended to support
- model or system type
- type of output produced
- input needed
- validation/performance evaluation

2.2. Austria

2.2.1. Operational systems

In Austria, the Federal Environment Agency has developed a system for the forecast of daily maximum ozone values. The system is currently tested and the output is planned to be presented regularly to the public, starting from 1997.

The system was established to provide information to the public concerning the maximum ozone concentration of the next day.

For this purpose a simple statistical model was developed. A detailed description of the model can be found in *Trendprognose regionaler Ozonmaxima unter Einbezug verschiedener meteorologischer Daten (1996), UBA-BE-058, Umweltbundesamt Wien, Austria*.

The system calculates the expected maximum ozone concentrations for 50 measurement stations distributed over the whole federal territory of Austria. Ozone forecast maps are calculated by spatial interpolation of these 50 values.

The output is a *spatial* map of Austria showing the expected maximum three hour mean value of the next day. Different classes of concentration ranges are shown in different colours.

The forecast is calculated once every day in the late afternoon during the summer season (i.e. from 1 April till 30 September). There is no explicit uncertainty indication, but, as mentioned above, concentration ranges instead of values are presented.

As an input the model needs air quality and meteorological data. Ozone data are transmitted routinely to the Federal Environment Agency from its own and the Provincial measurement sites via the *Ozondatenverbund* (ODV, in English: Ozone data network). Additionally, predicted maximum temperatures of the next day are obtained from the Austrian Central Institute for Meteorology and Geodynamics, which is also connected to the ODV.

The system requires almost no maintenance during normal operation. Computer capacity is no problem, but this is due to the use of already existing utilities of the ODV and its computers. Most time consuming are validation and performance evaluation.

Systematic validations and performance evaluation are performed once a year at the end of the ozone season. For this process, the calculated maximum ozone values are compared to measured ones. The differences of the two values are subjected to statistical analysis.

The main advantage of the system is its simplicity. The maps are calculated on a routinely basis and require no additional manpower.

The main disadvantage is a poor prediction quality especially on days with high ozone values.

2.2.2. Austrian research and development efforts

As described in 2.2.1 the system currently used in Austria for ozone forecast has a poor performance especially on days with high ozone exposure. Consequently, research is done to improve the system.

At present two different approaches are investigated.

1. Within the *Pannonian Ozone Project* a Lagrangian photochemical-meteorological model was developed for the simulation of ozone formation in north-eastern Austria. Modelling is based on the calculation of physical and chemical processes within an air parcel that is transported along a 96-hour back-trajectory. Primarily, the model was developed for the assessment of ozone precursor reduction strategies. Anyhow, this model is also able to predict ozone concentrations and initial tests have been performed during the summer 1996.

   The model itself is quite complex and needs a multitude of input data, e.g. a temporally and spatially disaggregated emission inventory with a resolution of 5 x 5 km in the Pannonian area (Austria, Hungary, Czech Republic and Slovakia) and several meteorological data. These data originate from ECMWF/Reading, UK and are further processed by the Austrian Central Institute for Meteorology and Geodynamics. Especially for forecasts, real time transfer of these data has to be ensured.

   The main advantage of the model is that, in principle, it is able to deal with problems like unusual high photochemical ozone formation and transport phenomena due to special weather conditions.

   The major disadvantage is its complexity and the huge amount of necessary input data.

2. The Federal Environment Agency plans to implement an ozone forecast system based on artificial neural networks. Such systems are already in use by some provincial authorities in Germany. One main advantage compared to the system currently used in Austria is that a lot of different input-parameters can be included simultaneously within a relatively simple system.

2.3. Belgium

2.3.1. Operational system in Belgium

SMOGSTOP: (Statistical Models Of Ground level Short Term Ozone Pollution) judged by an "expert opinion".

Since 1-5-1995 a set of three types of ozone forecasting models - clustered under the SMOGSTOP name - are routinely operated at CELINE-IRCEL (Interregional Cell for the Environment) in Belgium. The Flanders, Wallonia and Brussels Regions co-operate in this Cell for organising a standby follow up of episodes of photochemical pollution. By an "Air Quality Bulletin" broadcast by IRCEL according to the Ozone Directive 92/72/EEC the public is informed on the exceedances of information/alert thresholds. The bulletin includes verbalised model predictions for further exceedances of the thresholds for the same day and for the next two days.

SMOGSTOP has been developed by VITO (Flemish Institute for Technological Research) and is described in Dumont *et al.* (1995), and in Lissens *et al.*(1997).

The purpose of the ozone forecasting model cluster is to inform people so they can take measures to reduce exposure to high ozone concentrations. The model therefore only operates on days with reasonable risk of exceeding the EU public information threshold of 180 $\mu g/m^3$ somewhere in Belgium (risk of a so-called "ozone day").

Ozone forecasts for the next two days are not used to trigger short term measures at all because temporary measures would not have any effect on ozone maxima in Belgium. They may even be counterproductive, as has been demonstrated by Vanderstraeten *et al.* (1996) and Dumont (1996).

The SMOGSTOP model cluster consists of two classical regression models, two "nearest neighbour"-like models and four stratified casuistic models. The "nearest neighbour"-like models look in a multi-dimensional space, made up by the explanatory variables weighted by their regression t-value, for the shortest distance between the actual observed data point and the points in the set of historical data. The casuistic models finally use neural network algorithms. Before being broadcast, the results from the various model types are evaluated by an IRCEL staff member and integrated into a single forecast ("expert opinion").

The models predict the maximal ozone concentrations for day+0 (same day), for day+1 and day+2 at the 22 measuring points in Belgium. By means of a spatial interpolation in a 5x5 km nation-wide grid, maps are drawn showing the expected daily maximal ozone concentrations all over the country. If somewhere in Belgium the maximum predicted value exceeds 180 $\mu g/m^3$, the public is informed to take precautions on that day. The degree of probability of the exceedance of 180 $\mu g/m^3$ is not expressed numerically in the Air Quality Bulletin but the assessing expert may indicate it as well as its geographical spread, taking into account also the uncertainty on meteorological forecast.

SMOGSTOP input consists of three meteorological forecast parameters (1-3) provided by a specialised weather forecasting bureau, and two pollution parameters actually measured in the air quality networks of the Regions (4 and 5):

- the daily maximum temperature (TMAX)
- the difference between maximum and minimum temperature (TRANGE)
- the daily average wind speed (AVGWSP)
- the early morning ozone and - if available - NO_2-concentration (MORNOX)
- the maximum ozone concentration of the previous day (O3-1).

Those five input parameters are needed at all 22 ozone measuring sites in Belgium and for each of the three days of the forecasting time span (O3-1 for day+1 and day+2 being the model's own previsions for day+0 and day+1 respectively).

By the nature of the model (non-deterministic) no emission data are required. However, the expert may consider the type of traffic emissions of ozone precursors (NOx and VOC) which are to be expected: on the first day of reduced traffic emissions (e.g. on Saturdays) ozone maxima tend to be underestimated by the model.

Operating the models, including the acquisition of input information, production of tables and maps, assessment of results, redaction and broadcasting of the final Air Quality Bulletin (fax, phone, Internet,..), answering to questions from policy people, press and public, represent a full-time job for an experienced staff member during the summer months. Taking into account the validation, upgrading, updating, reporting, etc. the staff resources mount up to a half-time job on a yearly basis.

Model performances are evaluated after each summer season. It is done by means of a four-element contingency matrix (model/observation versus yes/no) for the individual 22 ozone monitoring sites as well as for the nation-wide prediction of an "ozone-day". Stratified casuistic (neural network based) models clearly perform better than the other models in predicting the extreme ozone concentration values: 24 out of 29 ozone days (conc. > 180 $\mu g/m^3$) during the summer of 1995 were predicted correctly, with only 8 false alarms. Regression models predicted only 2 out of the 29 ozone days and in fact outscore the other models only in predicting non-ozone days.

2.3.2. National research and development efforts in Belgium

SMOGSTOP-model

- Since 15 December 1996 the model has been extended with a wintersmog (SO_2) prevision module that has almost the same characteristics as the ozone prevision module.
- Except for some empirical considerations of different types of ozone precursor emission days (working days versus weekends and holidays) no substantial modifications will be implemented to the model's philosophy.
- Pre- and post-processing facilities will be worked out:
    1. amelioration (automation) of the acquisition of input data - especially acquisition and input of meteorological previsions;
    2. a wider diffusion of the forecasting bulletins - in the form of a map with regionally forecast maximal ozone values - will be considered.

HIGH TOWER permanent measuring site

In 1997 a fixed 200m measuring site (continuously monitoring O_3, NO, NO_2 and wind vector and temperature) will become operational in Flanders, south-west of Brussels. Nocturnal and early morning values of O_3 and of NOx at this altitude will be evaluated as a possible estimator of a nation-wide "photochemical reservoir" preluding high ground level ozone concentrations on the next day.

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2.4. Denmark

2.4.1. Operational systems

An ozone information system has been established as an implementation of the EU ozone directive (EEC, 1992) by a Danish Regulation (no. 184, March 1994). The system was established in March 1994; it is part of the national SMOG-warning system. In addition, co-operation has been established between National Environmental Research Institute (NERI) and Danish Meteorological Institute (DMI) concerning the development of an operational prognostic model for photochemical episodes in Denmark and neighbouring areas. This is described in 2.4.2.

The main purpose of the ozone part of the SMOG-warning system is public information and guidance to special sensitive persons. Assessment of the ozone episodes is based on air quality data and expert opinions and experience on the episode types in Denmark. Most of the ozone episodes occur in connection with high pressure summer episodes over Central Europe. The weather situation is assessed in connection with the weather forecast from DMI. Actual information about the ozone level is only given to the public, when the information threshold (180 µg/m^3) is exceeded. The warning threshold (360 µg/m^3) has never been exceeded. The information is given by a press release, which will be broadcast in the regional or nation-wide broadcasting system (Denmark's Radio). The information is given in accordance with the EU-directive for one or more regions or the whole country, depending on the situation. The ozone concentration at the specific station(s) and the expected development is given. The low ozone level situations are reported quarterly, i.a. on the Internet.

The system is mainly based on data from the Danish national Air Quality Monitoring Programme (DAQMP). Ozone monitoring stations exist at three rural sites and three urban background sites evenly distributed over the country. Description of the monitoring programme and summary of data are available at the Internet (http://www.dmu.dk/AtmosphericEnvironment/netw.htm). These data are the main input to the system. In addition, weather forecasts from DMI are used. DMI shall as far as possible also forecast weather situations which may lead to ozone episodes. The system is based on the DAQMP with an estimated staff of approx. 6 man-years and 1 mill. DKK (yearly cost of materials etc.). The ozone information system was a marginal expansion of DAQMP.

2.4.2. National research and development efforts

Co-operation has been established between NERI and DMI concerning the development of an operational prognostic model for photochemical episodes in Denmark and neighbouring areas. The general objective is to develop a public information system. The available model tools in the project are based on mathematical descriptions of the physical and chemical processes governing the production and transport of photochemical products in the atmosphere, what is also termed causal model.

The NERI part of the project will result in a further development of NERI's ACDEP (Atmospheric Chemistry and Deposition) model (Hertel *et al.*, 1995). ACDEP is a variable scale trajectory model, and was originally developed to describe nitrogen deposition to Danish waters. The chemical mechanism in the model is based on the Carbon Bond Mechanism IV (CBM-IV) and contains 37 compounds and about 80 chemical reactions (see Hertel *et al.* (1993) for the numerical solution of the chemistry and the application of the chemical mechanism). The model domain is Europe but with emphasis on Denmark and closer surroundings.

The ACDEP-model needs emission data for NOx, NMVOC, NH_3, and SO_2 as input for the calculations. For calculations in the Danish Background Monitoring Programme, an emission database for the period 1989 to 1995 has been established. This database was originally developed for the year 1990 in connection with the Danish Marine Research Programme. For Denmark and closer surroundings a fine resolution of 15 km x 15 km is used, whereas for the rest of Europe the EMEP emission inventories on 150 km x 150 km are used. The original emission database has been updated using a very simple procedure based on the EMEP emission inventories.

ACDEP is a trajectory model of the EMEP kind, and calculations have mainly been performed using EMEP meteorological data (on 150 km x 150 km). However, in the present project the model is applied to meteorological data from the HIRLAM weather forecast model at DMI on a much higher resolution (25 km x 25 km). The model uses the following meteorological parameters: wind speed, wind direction and temperature both at boundary layer height and at the surface, height of the boundary layer, precipitation, cloud cover, relative humidity, heat flux and momentum flux. For the calculations HIRLAM data are provided for every 15 min along the 96 h back-trajectories.

Results of model calculations with the ACDEP-model have been compared to field campaign data during photochemical episodes (Nielsen *et al.*, 1996). These calculations are performed using EMEP meteorological data. An intensive test of the model performance is planned on monitoring data from Danish as well as European stations.

Another part of the model development is a forecasting system at DMI based on a coupling of the chemical routine of the EMEP MSC-W oxidant model and DMI's 3-D Lagrangian transport model utilising forecast data from DMI's numerical weather prediction model DMI-HIRLAM (DMI-High Resolution Limited Area Model). The system is called Danish Atmospheric Chemistry Forecasting System (DACFOS) (Jensen *et al.*, 1996).

The system has been in a test operation since March 1995, and is set up to make + 36 hours forecasts automatically twice a day for selected sites or receptor points within the EMEP-grid covering all of Europe.

The transport model is calculating 3-D back-trajectories covering at least the four days preceding the arrival time with exception of trajectories traversing the boundaries of the DMI-HIRLAM area (the version used in the Europe version (E) covering most of Europe, with horizontal resolution of 23 km x 23 km and vertical resolution of 31 layers).

Parameters along the trajectories are:

- Co-ordinates
- Orography
- Height above ground
- Horizontal wind (u, v)
- Temperature
- Relative humidity
- 10-meter horizontal wind (u, v)
- Surface temperature
- Precipitation intensity
- Total cloud cover
- Surface temperature
- Surface fluxes of heat
- Surface fluxes of momentum
- Height of mixing layer

The concentration of about 70 chemical species are calculated by a chemistry model employing approximately 130 chemical reactions. Emission data are from EMEP on a 50x50 km grid.

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2.5. Finland

2.5.1. Operational systems

There is no system specifically devoted to ozone forecasting in Finland. In episode situations, i.e. when the ozone concentration exceeds the public information threshold 180 µg m^{-3}, according to the EU directive on ozone, the ozone concentration for tomorrow is forecast based on the weather situation, trajectory analysis, and former experience of ozone episodes in Finland. In addition, neighbouring countries are contacted for information on the ozone situation development. This system was implemented in July 1994, when the EU directive on ozone became valid in Finland. In this connection, the responsibility for ozone monitoring and public information was given to the Finnish Meteorological Institute (FMI). The FMI operates nine background ozone monitoring stations covering the whole country. In addition, the FMI co-operates with those cities in Finland in which ozone monitoring is performed by local authorities. In 1996, ozone forecasting has been integrated more closely to the weather service of the FMI to ensure 24-hour surveillance of episode situations and to make the information more accessible for the public. Based on several years of Finnish ozone monitoring data and research, this system is normally active only from 1 April to 30 September.

In Finland, ozone levels and ozone episodes are mainly the result of long range transport from the continental, eastern, or north-western parts of Europe. Ozone formation during the transport depends essentially on the weather situation, especially the temperature and solar intensity. The ozone forecasting system is limited by the fact that, at present, the atmospheric chemistry models at the FMI are not as such suitable for routine calculations of ozone concentrations and their development over large areas. Ozone exceedance situations in Finland are relatively rare - until the end of 1996 there were only two exceedances. It will therefore take some time before all meteorologists become familiar with the forecasting of ozone episodes. To overcome this problem, all meteorologists are given training in atmospheric chemistry and in recognising which weather situations favour enhanced ozone concentrations and long range transport to Finland.

2.5.2. National research and development efforts

In Finland, ozone forecasting is based on experience and expert opinion. Due to the rarity of exceedance situations, the research concerning transport and chemistry of tropospheric ozone has not been specifically aimed at forecasting.

2.6. France

2.6.1. Operational systems

In France, the only operational ozone forecasting system has been developed for the Paris area by the regional monitoring network AIRPARIF (Dacunha-Castelle *et al.*, 1997). Two systems are used:

- a general trend one day in advance in collaboration with the French meteorological services (Météo France). This trend is based on meteorological conditions conducive to high ozone levels;
- a forecast of the expected maximum value of ozone in the morning for the same day. This model has been developed by a research team of statisticians (French Universities of Orsay and Lyon) for the Paris area.

Since the first system provides only a trend, more emphasis will be put on the second one.

This model was tested for the first time during Summer 1996 (June-August). In fact, two types of statistical models were running during the same period:

- the linear model is based on a classification (4 classes, according to the calculation of a distance between two days) upon different daily profiles ($[O_3]$, [NOx], wind speed, surface temperature and $\Delta T_{0\text{-}40\text{ m}}$), followed by a multiple regression within each class. A day is classified into one class according to the profiles of the previous day and night;
- the non-linear auto-regressive (non-parametrical) model is based on a similarity index between the present day and past days of the data base. The computation of the index takes into account the same profiles as the linear models. The predicted ozone maximum is the barycentre of the observed ozone maximum of the nearest neighbours in the data base.

It provides each morning at 8 a.m. a 10-hours ozone forecast, that is to say the expected maximum value of the ozone concentration of the afternoon for each ozone monitoring site of Paris agglomeration (8 sites). Not only do they produce $[O_3]_{max}$, but they also give for each site a confidence interval and the probability of exceedance of the first two levels of the alert system implemented in Paris area: 130 $\mu g/m^3$ (information of the authorities) and 180 $\mu g/m^3$ (information of the population). The alert threshold is 360 μg/m3 but since it never occurred in the past the forecast of the threshold is very difficult.

Due to these eight predictions, the model then forecasts the probability of issuing an ozone warning of level 1 (130 $\mu g/m^3$) or level 2 (180 $\mu g/m^3$); the local regulation over Paris metropolitan area requires that a threshold be exceeded in at least two measuring sites in a time span less than one hour. The enforcement of this alert system can involve temporary measures such as free public transportation on days of high pollution.

Both models use the same predictors: hourly values of $[O_3]$ and [NOx], hourly averages of wind speed, surface temperature and temperature difference between 0 and 40 m. Due to data availability, only measured data are employed; note that no numerically predicted meteorological parameter is used. The non linear model though gives the possibility of forecasting T_{max} and the average wind speed between 2 and 6 p.m. before forecasting $[O_3]_{max}$, using the same statistical method. Moreover, no air quality data from other air quality monitoring networks outside the Paris area are used, thus minimising the effect of long-range transport.

Summer 1996 was a clean period in Paris thanks to "bad" meteorological conditions. Consequently no exceedance of 180 $\mu g/m^3$ was reported and only a few exceedances of 130 $\mu g/m^3$ were measured. Last summer was therefore not a good validation data set. The models will be better evaluated after 1997 ozone season.

AIRPARIF intends to run the models every summer season (June to August) and to evaluate its performances after each period. The models are still under improvement. Relying on their knowledge gained with the development of the short term forecast system (10 hours), the statisticians now work on a one day in advance forecast.

Because no meteorological forecast is used, these models assume a stability of weather conditions from the morning to the afternoon: it is therefore expected that they failed to predict correctly $[O_3]_{max}$ in case of a sudden change in weather conditions. Moreover, the calibration data set consists of the summers 1990-1995. But in 1990 and 1991 there were only 4 ozone measuring sites. Consequently the data base is not homogeneous for each station.

In the near future, this model will be improved, in collaboration with Météo France, with the introduction of forecast meteorological parameters. The objective is to provide a forecast of the maximum ozone concentration one day in advance over Paris metropolitan area.

The forecasting tools run on a PC (Pentium 133); the program can run every day from 8 a.m. (local time)

Costs of the forecasting program:
investment budget (preliminary survey, model development and computer purchase):
2 millions French Francs for 2 years
running budget:
management of the program by an Air Pollution Engineer: 4 man-months.

2.6.2. National research and development efforts

Several research projects on ozone forecasting are supported by a national research fund of the French Ministry of the Environment (PRIMEQUAL).

In Strasbourg, ASPA (air quality monitoring network of Alsace) intends to frame a statistical model to forecast a photochemical pollution index 24 hours in advance (ASPA, 1996). It is aimed at supporting public information (pi) and at taking temporary measures such as the intensification of public transportation. The calculation of the index relies on the forecast $[O_3]_{max}$. In the first instance, the model will produce a forecast for the Strasbourg-Kehl area, with a view of a possible extension to the whole Rhine basin.

The forecasting system will be based on discriminant analysis, but will also take into account emissions, using an hourly emission scheme (anthropogenic and biogenic) built in the wake of a cadaster of 1990 (REKLIP program). It will use daily a numerical weather forecast, the emissions and local air quality measurements.

In Nantes, the CSTB (*Centre Scientifique et technique du Bâtiment*) will develop a statistical model to forecast the full concentration series of $[O_3]$ of the day and the following day (24 h forecast) (CSTB, 1996). In a first step, a factoral analysis (clustering followed by a hierarchical classification technique) will identify different situation types. Then an ARIMA model will be developed within each class. The situation type of the previous day will be determined by local $[O_3]$ measurements (4 sites), meteorological observations and emissions (traffic and industries) of the previous day, whereas the situation type of the day and the following day will be determined by the meteorological forecast.

The CSTB intends to develop a software that could be used for other cities than Nantes when it is showed that the model is reasonably successful.

In Paris area, the LMD team (University laboratory of dynamic meteorology) has proposed to develop an original hybrid model, which uses both causal and statistical methods (LMD, 1996). This system consists of a simplified deterministic model (box model) whose parameters (e.g. constants of the photochemical reactions) are adjusted to fit the data set of air quality measured data (AIRPARIF sites since 1991): this technique is named inverted modelling, unlike usual deterministic modelling for which the parameters are fixed once and for all. The box model involves a simplification of:

- the dynamic: use of the average wind speed only, and classification according to meteorological parameters (temperature, humidity...), a mixing coefficient being assigned to each class;
- the chemistry: simplified MELCHIOR model, with a limited number of reactions and with adjustable parameters.

The LMD model will produce a full concentration series (causal output) and a probability of exceedance (statistical output): therefore it includes an uncertainty indication. Because of the use of a deterministic sub-module, initial conditions are needed. The missing values will be "restored" thanks to different data assimilation methods (e.g. Kalman filters).

References

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Dacunha-Castelle D. *et al.,* 1997. Forecasting ozone peaks in Paris area; to be published.

LMD, 1996. Prévision et prévisibilité des pointes de pollution à l'échelle urbaine par modélisation inverse; LMD CNRS, Université Pierre et Marie Curie, mai 1996.

2.7. Germany

As already mentioned in the Statement by Ministers for the Environment[1], Germany introduced an „*Ozone Law*“ amendment to the Federal Air Quality Control Act (Bundesimmissionsschutzgesetz, BImSchG), enacted it on the 26th of July 1995, and restricted it to the five year period ending in 1999.

The Ozone Law includes restrictions on highly polluting vehicles. Provisions include:
Motor vehicle traffic shall be prohibited in the case of increased ozone concentrations in a federal state (Bundesland) or parts of a federal state if at least 3 measuring sites, located more than 50 km apart but less than 250 km apart, and of which at least 2 are located in the same federal state and

1. measuring an ozone concentration of 240 µg/m3 as a mean value during one hour on the same day and

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[1] Statement by Ministers for the Environment of Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands and the UK or their personal representatives; Ministerial Conference on Tropospheric Ozone in Northwest Europe, Lancaster House, London 20 - 21 May 1996.

2. projecting that 240 µg/m3 (based on meteorological information by the German Weather Service, DWD) will be measured by these measuring sites in the course of the following day.

The traffic ban shall not apply to motor vehicles with low exhaust emissions (e.g. 3-way-cat, modern diesel). Some further exceptions are made, i.e. for public traffic and public supply vehicles.

The competent authorities are to request the drivers and owners of motor vehicles as well as the operators of internal combustion engines in the non commercial field not to use them as soon as an ozone concentration of 180 µg/m3 is measured.

2.7.1. Operational systems

To deal with the above mentioned Ozone Law's criteria, the UMEG[2] has organised a centre for ozone data exchange on behalf of the FRG's federal states. Ozone data and met data measured in each of the federal states, will be sent to the centre and will be made available for all. Relying on this data base and on the weather forecast of the German Weather Service (DWD), each federal state has to provide an ozone prognosis. Depending on the individual federal state, different methods are applied to forecasting, if it can be assumed that an ozone value of 240 $\mu g/m^3$ will be exceeded on the next day. The methods to be applied are mostly based on expert knowledge, statistical/(multiple) regression models or neural networks. An overview of these methods is compiled at the end of this section (Tables 2.7.1 and 2.7.2; see section 2.13 for explanation of the symbols used) according to the scheme for the countries' synopsis.

The Federal Environmental Agency of Germany (UBA) additionally provides a description of the expected ozone pattern in Germany for the next day during the summer season to inform the public[3]. That information may be downloaded via phone[4]. The calculation is based on a multiple linear regression involving about 100 measuring sites in Germany. The maximum ozone concentration for the following day (O_3 prog) is output. The maximum ozone concentration (max O_3 act) and the temperature maximum (max Tact) for the actual day, as well as the maximum temperature forecast (max Tprog) supplied by DWD are input and coupled by the following equation:

$$\max O_3\,\text{prog} = k + a\,(\max \text{Tact})^3 + b\,(\max \text{Tprog})^3 + c\,(\max O_3\,\text{act})$$

where k, a, b, and c are regression coefficients.

The regression equation implicitly shows a dynamic link to the evolving weather situation with respect to the maximum temperature forecast by the DWD's EUROPA model. The yearly ozone prognosis evaluation shows significant biases and variances for the various stations. Frequently, a large root mean square error (rmse) corresponds to a significant bias. By eliminating the bias a diminishing of the rmse of about 40% was achieved and was coupled with a clear improvement of the predictive capabilities of this regression method compared with the assumption of persistence (in terms of reduction of the variance (rv) (e.g. for a station in Bavaria the improvement was from -0,16 to +0,58).

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[2] Gesellschaft für Umweltmessungen und Umwelterhebungen GmbH.

[3] This activity does not refer to the ozone law whose execution is in the federal state's competence exclusively.

[4] *phone: ++30 8903 2759; USER: Presse; Baud: 9600, N 8 1 (No Parity, 8 databits, 1 stopbit); Terminal: ANSI-BBS; protocol for download: ZMODEM or XMODEM*

Table 2.7.1

federal state[5]	**operation**	**purpose**	**sys type**	**output** **conc space span unc**
BW	1991	pi, meas	emp	max regio 1d no
BY	1995	pi, meas	stat/neur	max point 1d no
BE	1995	pi, meas	stat/regr, emp	max regio 1d no
BB	1992	pi	stat/neur	max point 1d no
HH	1989	pi, meas	emp	max regio 1d no
HE	1990	pi, meas	stat/neur	max regio 1d no
NI	1992	pi	stat/regr	max regio, point 3d no
NW	1995	meas	emp	max point 1d no
RP		pi	emp	max 1d no
SL	1995	pi	emp	max regio 1d no
SN	1994	pi	stat/neur	max point 3d no
ST	1995	pi	stat/neur	max point 1d yes
SH		meas	stat/regr	max point 1d no
TH	1995	pi	stat/regr, emp	series, max 3d no

Table 2.7.2:

federal state[5]	**input** **AQ reg; met reg; em. reg**	**comp**	**val**
BW	O_3-, NO_2-, NMVOC-, T-series (actual day) max T, precipitation, OCT, DD, FF (forecast for the next day from German Weather Service)		reg 1y
BY	O_3, NO_2, DD, FF, T, RH, p		reg
BE	O_3, O_3 regio, NOx, T, DD		
BB	O_3-, NOx-, CO-, DD-, FF-, T-, RH-series, OCT, max T (forecast)		reg
HH	O_3, O_3 regio, DD, FF, T, RH (actual day and forecast from the Sea Weather Service), origin of the air mass		inc
HE	O_3, T		reg
NI	O_3, T		reg
NW	O_3 (actual), DD, FF, T, OCT (forecast of the German Weather Service)		inc
RP	O_3 (actual), T, OCT (forecast of the German Weather Service)		
SL	O_3 (actual), T		reg
SN	O_3, DD, FF, T, RH, OCT		reg
ST	O_3, NO, NO_2, CO, DD, FF, T, RH, OCT (actual day) T (forecast)		reg
SH	O_3, T		reg
TH	O_3, CO, NO, NO_2, NOx		reg

2.7.2. Research and development efforts

UBA is funding an R & D project for improving the actual method described in section 2.7.1. The main objective of this R & D project is the development and

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[5] *BW: Baden-Württemberg, BY: Bayern, BE: Berlin, BB: Brandenburg, HH: Hamburg, HE: Hessen, NI: Niedersachsen, NW: Nordrhein-Westfalen, RP: Rheinland-Pfalz, SL: Saarland, SN: Sachsen, ST: Sachsen-Anhalt, SH: Schleswig-Holstein, TH: Thüringen*

comparison of different procedures to forecast daily maxima and a three-day trend of low level ozone over Germany. Hourly ozone values of 180 mg/m^3 and higher are of particular interest. The basic idea is that a weighted combination of specific approaches might be more successful than one scheme alone. The approaches are:

- the Eulerian chemical transport model REM3 with three complex chemical codes and a lateral grid resolution of about 30 km. The model area covers West and Central Europe and uses the PHOXA emission database. The meteorological forecast is given by the DWD's EUROPA model. REM3 should describe the broad scale transport of chemical constituents and the general formation of episodes with high ozone concentrations and, additionally, provide trend information.

- statistical analysis of 150 local groups of time series by combining hierarchical cluster analysis and regression methods. For these examinations, time series of meteorological parameters and ambient air concentration of ozone, plus a special procedure for determining series of objective large scale weather situations, are taken into consideration. Because many of the time series are relatively short (about 5 years) and contain only a relatively small number of high ozone episodes concentrations (with respect to statistical evaluation) regression methods and standard statistical techniques can run into problems in some cases.

- to overcome these limitations and to get a better description of the local and highly non-linear processes of ozone generation, some tests are made to utilise fuzzy and neurofuzzy concepts. Such systems can deal with poorly defined parameter distributions to some extent and with qualitative sets of rules determined by cluster analysis and expert advice. Different concepts are developed to get rule bases by use of special cluster algorithms. In this context the neurofuzzy systems can combine controlled or uncontrolled learning procedures with the tuning of the fuzzy system rule bases.

All the separate tools mentioned above will be brought into a neurofuzzy system, so that for each region and episode the best combination of the different procedures can be found. The system will support both a better local forecast of low level ozone concentrations and a better insight into the daily weather patterns and chemical processes related to those concentrations.

2.8. Luxembourg

2.8.1. Operational air quality measuring and ozone forecasting system

The existing measuring net for air quality ("réseau national de mesure et de contrôle de la qualité de l'air") has been operational since 1989. A brochure to document the existing measuring equipment is available. The forecasting of maximum ozone levels for the next day has been done every year since 1993 during the warm season. Since July 1996 a graphic showing the maximum ozone values of the day and a forecast of the maximum ozone level of the next day have been published.

The net comprises five measuring stations, which today analyse 10 groups of pollutants (SO_2, NO, NO_2, O_3, CH_4, TOC, CO, CO_2, BTX, PM_{10}) depending on the station.

The purpose of the ozone forecasting is public information about the next day's ozone concentration. Moreover, the message contains additional information with behavioural guidelines for individuals to avoid unnecessary emissions of ozone precursor pollutants. The ozone forecasting is also intended to help ozone sensitive individuals avoid exposure to high ground level ozone concentrations for extended time periods. The ozone forecast message is sent out twice a day (morning and late afternoon). At the same time an answering machine ("Ozontelefon") has been set up to allow people to call on the phone at any time during the day for information on current ozone levels and on the next day's forecast level.

The model in use to determine the next day's ozone level is empirical and based mainly on the current ozone concentrations and on meteorological data. It is also important to have an experienced operator predict the ozone level.

The output of the model allows to forecast a concentration band of approx. 60 $\mu g/m^3$, which the actual ozone maximum of the next day is expected to reach. The forecast time span is 24 hours. No statistical information is available at this moment about the forecasting accuracy.

The input data for the forecasting of ozone are derived partly from the information available from the air quality measuring net. Most of the required input data are taken from the meteorological station of the environment agency and from the national meteorological service.

The ozone forecasting is done by the staff in charge of the air quality measuring net. The message on future ozone levels is transmitted to the media together with information on the latest measured ozone concentrations. Therefore the time required just for the prediction of ozone is low, as the equipment and the staff are in place anyway. The required time for the forecasting itself is therefore estimated at 15 man days per year only.

The validation of the ozone analysers is done automatically every day by the equipment itself (zero check and span check). The ozone analysers are validated annually in spring during the participation in international intercomparison tests.

The validation of the ozone forecasting system is done irregularly.

Experience with the forecasting system:

Advantages:	easy to use	- due to its integration in the air quality measuring network - due to small number of input parameters

Disadvantages: the exact maximum ozone value cannot be forecast

Limitations: currently the low number of measuring sites and the small operating team does not allow an extension of the forecasting system

Practical problems: none

Forecasting of long range transport (LRT) episodes: limited possibilities to forecast LRT episodes on a national level

2.8.2. National research and development efforts

National research and development on tropospheric ozone forecasting do not exist at this moment.

2.9. The Netherlands

2.9.1. Operational systems

The Dutch ozone forecasting system is based on two models, a causal and a statistical model, and expert opinion. The expert makes the prognosis on the basis of the model output and recent measurements and meteorology. Since 1989 RIVM issues daily ozone forecasts. From the summer of 1992, the forecasting system has its present form. The aim of the forecasting system is to inform the public. The forecast gives the expected maximum concentration of the next day for five Dutch regions in a map, including the areas over which alert levels are expected to become exceeded (120, 180, 240 and 360 µg/m^3 in different grey shades). Also, the expected alert levels that are exceeded for the following day are presented in a table per region.

The causal model is the Lagrangian MPA-model (De Leeuw *et al.* 1988, 1990; Noordijk 1994). The model gives the concentration on 4.00 PM local summer time, on five locations in the Netherlands for one, two and three days in advance. Also, the concentration profile over the backward trajectory is generated. No uncertainty indication is given. The model includes non-linear atmospheric chemistry, deposition and exchange between different atmospheric layers. It needs emissions of VOC and NOx on a European scale. A prognosis of European scale wind fields, received from ECMWF, Reading (UK), is necessary to compute the required 96 hour back trajectories. Further, the weather prognosis of KNMI gives the input for cloud cover and temperature. The MPA-forecasts are computed during the night.

The statistical model PROZON computes the maximum concentration for each site of the Dutch monitoring network, one to three days in advance (Noordijk 1994). No uncertainty indication is given. The model requires the maximum concentrations of the Dutch monitoring sites of the last day, statistics from the past, the maximum temperature of the last day and the forecasted temperature, both as an average over the Netherlands. The model takes the season (month) and site specific characteristics (rural versus city/street locations) into account. The model is started at 8.50 AM and 3.50 PM.

In many cases the concentrations expected by PROZON are the basis for the smog forecast, for example when the model and the expert expect a continuation of low concentrations. In those cases only a quality control by the expert is required. As further input the results of the MPA-model, especially the derived trajectories, is often used in combination with the last concentration measurements and the most recent weather forecast. Eventually, more detailed information on the weather is used and/or additional PROZON forecasts are made.

The smog forecasts issued by RIVM and the automatically started forecasts of PROZON are evaluated after each summer (Van Doesburg 1995). The main criteria are the bias and standard deviation, the number of exceedances that are measured, the total number of forecasted exceedances and the number of correctly forecasted exceedances. For a visual interpretation, time series of forecasts and measurements and X/Y plots of both are included.

In general, the system performs well enough. The model PROZON is a good basis on most days. In abnormal situations, such as high temperatures with wind from sea or from northerly directions, the model is known to produce false forecasts. On the basis of more detailed or recent meteorological information extra model runs can be executed, as the model is easy to run and the computing time requires only a few seconds. The output of the model MPA is much less reliable, and a model run is not easy to start and takes about 2 hours. MPA is therefore only used on an automatic basis. The expert opinion is known to lead to a moderate improvement of the forecast.

In order to operate the system, 5 weeks of the expert is necessary. MPA requires during the summer about 300 hours computing time on a UNIX machine, PROZON needs less than one. Evaluation takes a few weeks per year. Maintenance requires about one week per year.

2.9.2. National research efforts

At this moment, no research efforts to improve the ozone forecast system are foreseen.

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2.10. Sweden

2.10.1.Operational systems

Sweden has no ozone forecasting system in routine operation yet. In 1995 an ozone information system was implemented, due to the EU ozone directive. The Swedish Environmental Research Institute has the responsibility for this ozone information system on behalf of the Swedish Environmental Protection Agency. The system is based on ozone concentrations measured at a number of monitoring sites over the country. If the ozone concentration exceeds the information threshold (180 $\mu g/m^3$) the public will be informed. A prognosis of the expected development is also given, based on the forecast weather situation and experiences from similar former ozone episodes.

2.10.2. National research and development efforts

The Swedish Meteorological and Hydrological Institute has developed a limited area, off-line, Eulerian atmospheric transport model, called MATCH (Meso-scale Atmospheric Transport and Chemistry modelling system). The model is based on a terrain following vertical coordinate and mass conserving, positive definite advection scheme, with small phase and amplitude errors.

The model includes modules for emission input, vertical turbulent diffusion and deposition processes. The model can handle an arbitrary number of chemical components and provides a framework for inclusion of modules describing physical and chemical transformation processes between different components.

Simulations on historical data show good correlation with measurements over Europe, indicating good possibilities to forecast LRT-episodes in the future.

The MATCH forecasting model will be improved concerning emissions and chemical fate of biogenic VOC during spring 1997. The model results for VOC, ozone and NO_2 will be compared to measured data obtained during spring and summer 1994, from the EMEP, TOR and Hansa measurement networks in Europe

References

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2.11. United Kingdom

2.11.1.Operational systems

UK Air Pollution Forecasting System
This incorporates the 'Trajectory Ozone Forecasting Model' and expert analysis of monitoring data and meteorological forecasts. Details of the forecasting system can be found in Stedman and Willis (1996) and the model has been described by Stedman and Williams (1992).

The system has been operational since 1 April 1992.

Description of system:

- The system is intended to support public information and reduce exposure.
- The system incorporates an expert opinion/empirical analysis of monitoring data and meteorological forecasts and the results of a causal model.
- The output of the forecasting system is a forecast of air quality band for nine geographical regions for the following day. Forecasts are issued each afternoon and a revised forecast can be issued in the morning during air pollution episodes. This air quality band represents the maximum expected hourly average ozone concentration. The Trajectory Ozone Forecasting Model calculates maximum ozone concentrations for individual site locations for 1,2 or 3 days ahead. No uncertainty indication is included in the model or the output forecast.
- National O_3 data are required (and international O_3 data would be useful) for expert analysis. Newspaper type weather forecasts are also required for expert

analysis. Forecast air mass back trajectories, forecast maximum temperatures and a VOC emission inventory for Europe are required for the model.
- Approx. five man-weeks effort are required each year and about 20 kECU are required to cover the costs of extracting met data and running the model. The model runs on Sun UNIX workstation.
- Regular performance testing of the results of the forecasting system is undertaken. Performance is assessed four times a year.

The combination of a transport model and expert analysis of these model results along with monitoring data and forecast meteorological information have proved successful in the UK. The model incorporates Long Range Transport, which is important for the UK because Ozone concentrations can be highly dependent on trajectory direction. A visual analysis of back trajectory plots has also been found to be valuable. The model results are easy to interpret because of the simplified linear chemical scheme adopted.

The model is a worst case model and therefore tends to over-estimate ozone concentrations in early and late summer. This is not a big problem since expert analysis is always available. Expert analysis is also useful on occasions when meteorological forecasts are not accurate.

The forecasts that are issued tend to err on the side of caution and predict more occurrences of high ozone concentrations than are measured. This is because the main purpose of the forecasting system is to provide the public with information and enable individuals to moderate exposure.

2.11.2. National research and development efforts

The possibility of updating the simplified chemical scheme in the model to incorporate revised “Photochemical Oxidant Creation Potentials” of VOCs is currently being investigated. This study is due to be completed before the summer of 1997.

References

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2.12. Information from other countries

Air pollution forecasting is a field which began to be developed about 20 years ago, see e.g. Revlett (1978). Numerous ozone forecasting models - in complexity ranging from simple regression models to sophisticated photochemical transport models have been developed. A global inventory of currently operational forecast systems has been prepared by AIRPARIF (Fromage, 1996). Outside the 10 European countries discussed here, operational systems can be found in a number of cities and states of USA, Canada, Japan (Tokyo), Hong Kong, Mexico, South Korea, and Australia. Within Europe there is, besides the systems discussed here, only one system operational, in Zürich, Switzerland; in Norway and Greece forecast systems are under development.

Most of the systems use statistical (multiple regression) models. Temperature and previous day's ozone levels are commonly used as independent variable. In the more recently developed systems the use of neural networks is frequently introduced. Output of the system is tomorrow's maximum ozone level, that is a forecast span of less than 24h; forecasts for 48h are given by one or two systems only.

References

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Revlett G.H., 1978. Ozone forecasting using empirical modelling. *J. Air Pollut. Contr. Assoc.* **28,** 338-343.

2.13. Overview and discussion

Tables 2.13.1 and 2.13.2 provide an overview of systems that are now operational or will become operational in the near future in the ten participating countries. For each country, and for each of the systems in operation in that country, the tables summarise the following characteristics:

system	short name or acronym of the forecast system;
operation	date when system became (or will be) operational;
purpose	what purpose/use the system is intended to support: public information (**pi**), reduce exposure (**exp**), take temporary measures (**meas**);
sys typ	methodology used in the forecast system: statistical/regression model (**stat**; this type may be further subdivided into (multiple) regression (**regr**), neural networks (**neur**) and other (**other**)), causal or deterministic model (**caus**), expert opinion and/or empirical models (**emp**), or combinations;
output	type of output produced: conc: full time series of hourly concentrations (**series**), or maximum level only (**max**); space: spatial representativeness of forecast: for a single location (**point**), area averages (**regio**) or national averages (**natl**); span: forecast time span (in **h**ours or **d**ays); unc: uncertainty indication (**yes/no**);
input	required input AQ: air quality data: O_3 and/or other components at local, national or international scale; met: meteorological data: u, T, RH, ... at local, national or international (e.g. European) scale; em: emission data: NOx, VOC, CO, ... at local, national or international (e.g. European) scale;
comp	hardware requirements;
val	frequency of validation of the forecast system and/or frequency of performance evaluation incidentally (**inc.**) or at regular intervals (**reg**, frequency).

According to the Tables all countries have one or more forecast systems in operation. Development of forecast systems started as early as 1990-1992, that is, well before the ozone directive was adopted. However, in some cases forecasts are not issued for the whole country but only for a (limited) number of cities/regions. Expert judgement forms an important input in most countries; in some countries there is a tendency towards causal modelling.

Table 2.13.1

country	**system**	**operation**	**purpose**	**sys type**	**output conc space span unc**
Austria		1-4-1996	pi	regr	max spatial conc.1d no
	expert opinion	1-4-1993	pi/exp	exp	max regio 1d no
Belgium	SMOGSTOP	1-5-1995	pi/exp	neur	max point /natl 3d no
	expert opinion	1-8-1990	pi/exp	emp	max natl 1d yes
Denmark	SMOG	1-3-1994	pi	emp	ser/max point/reg/natl no no
	Forecast	1997-1998	pi	caus	ser/max point/reg/natl 24h yes
	DACFOS	1-3-1995 (test)	pi/meas	caus/stat	series point 36h yes
Finland	FMI	July 1994	pi	emp	max reg 1d no
France		1-6-1996	pi/exp/ meas	stat: regr/ other/emp	max point 10h yes
Germany	UBA	summer '94	pi	stat/regr	max point 1d no
Luxembourg	AQ network	since 1989	pi, exp, meas	emp	max regio 24h no
Netherlands	RIVM	1-4-1992	pi	other/caus / emp	max point/regio 3d no
Sweden		1-1-1995	pi	emp/exp	series point 1d no
	MATCH	1-4-1998	pi	caus	series regio 3D 48h no
UK	UK APFS	1-4-1992	pi/exp	caus/exp	max area 1d no
	UK TOFM	1-4-1992	pi/exp	caus	max point 1,2,3d no

Table 2.13.2.

country	system	input AQ reg; met reg; em. reg	comp.	val.
Austria		O_3 loc; T prog		reg.
	expert opinion	O_3, NOx loc; meteo internatl.		inc.
Belgium	SMOG-STOP	O_3, NOx natl; FF, T natl; -	PC Pentium	reg 1/y
	expert opinion	O_3, NOx natl; FF, DD, T, RH, OCT[6] natl; -	-	reg 1/y
Denmark	SMOG	AQ local; met natl	PC & mainframe	reg
	Forecast	-; met. Europe; em. Europe	workstation	reg
	DACFOS	NOx, SO_2, CO, VOC; Eu, u T, RH, Prec, N h T0; Eu O_3; Eu	Supercomputer/ large workstation	reg 1d inc 1/y
Finland	FMI	O_3 loc; weather forecast, meteorol. observations	-	-
France		O_3 loc; T, u, $\Delta T_{0\text{-}40\ m}$; NOx loc	PC	inc.
Germany	UBA	max O_3 loc; max T loc (actual day) max T (forecast for next day)	PC	reg.
Luxembourg	AQ network	O_3 loc; met: T, RH, u 24h forec; -	--	inc.
Netherlands	RIVM	O_3, T, RH (local) u, NOx, VOC (Eu)	UNIX workstation	reg, 1/y
Sweden		O_3 local; met Europe	PC, mainframe	-
	MATCH	(O_3 internat.), Europe: u, T Europe: NOx, VOC, CO	mainframe	reg
UK	UK APFS	O_3 loc, T, u, cloud loc		reg 4/y
	UK TOFM	back trajectories, T, VOC emissions: Europe	Unix Workstation	

Public information is by far the most important application of the forecast systems; only in a small number of countries or regions does the forecast support temporary measures on highly polluting activities (industry, traffic).

The forecast span of the systems is generally one day (that is, tomorrow's maximum value). The TWG noted that an extension of the span is important especially when the forecast forms the basis for temporary abatement measures. Information on ozone levels in neighbouring countries might improve the performance of the current systems.

All countries evaluate the performances of their systems on a regular basis. The evaluation methods are, however, quite different and a need to harmonise them has been recognised.

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[6] FF: horizontal wind speed
DD: horizontal wind direction
T: Tmax, Tmin, (=> Trange (Tmax - Tmin))
RH: relative humidity
OCT: cloud cover (octas) or solar radiation

Once a forecast has been made, it is released to the target groups using a range of communication channels (press release, Internet, teletext-systems, etc.). The forecast bulletin gives information on maximum ozone concentrations expected for the coming 10-48 hours. In a few cases the forecast is made for specific locations but more generally a national or regional forecast is made. To make the bulletin more understandable to the general public, air quality indicators (e.g. *good air quality, severe smog*) rather than concentration levels are presented.

During its meetings, the Working Group discussed the options of one central forecast system providing information for the whole of the EU-region. The general view was that next to such a central system, local forecast systems at national or regional scale are needed. The aims of forecasts in the various countries are so diverse that a central system can hardly meet all specific requirements. Moreover, it is judged that models, in particular statistical models, based on local conditions and local inputs will have better performance than a European-scale model. On the other hand, a joint European forecast system would provide information on larger spatial scales that would improve insight into the build-up and further development of an actual ozone episode. In principle, a continental scale forecast model is able to evaluate the effectiveness of (local scale) abatement measures. The development of a common photochemical transport model is encouraged by the TWG. The results of such a causal model will form essential inputs to national systems for extending the forecast period to a medium-range period of 3 to 4 days. Moreover, when the current forecast models are used in combination with the results of such a photochemical model, a better performance should be realised.

3. CRITERIA FOR TESTING VALIDITY AND RELIABILITY OF SMOG FORECAST SYSTEMS

3.1. Introduction

Operational smog forecasting systems may use several types of forecast instruments. As discussed in Chapter 2, three major tools can be defined:

- statistical models using multiple regression or a classification strategy and/or models based on neural networks;
- causal models linking emissions with air quality; the deterministic models used here may show different levels in sophistication in describing the underlying physico-chemical processes of smog formation;
- the human expert.

In an operational system each of these tools has its own weight in the preparation of the *end-product.* The end-product is defined here as the forecast message that is actually provided to the users (e.g. authorities, public, newspapers). As the end users might adapt their behaviour depending on the forecast, it is important to know how reliable the final forecast is. Here criteria for validation of this end-product will be discussed.

A forecast system may have different objectives (e.g. used for information to the public or used as trigger for short-term abatement measures). Depending on the application it will be necessary to introduce several performance indicators, each evaluating different aspects of the forecast system. As a stepping stone in the development of harmonised evaluation criteria in this chapter two sets of skill parameters are discussed in some detail. The first set of indicators is designed for evaluating qualitative information (the forecast/measurements are above/below a threshold value). The second set can be applied when more numerical information is available. On the basis of results from the Dutch forecast system the practical application of the proposed parameters is demonstrated.

Obviously, criteria and methods developed here can (or even should) not only be applied to the end products but also to intermediate products from the (mathematical) sub-models. This, however, is more an internal matter for the forecasting group; evaluating the performance of the existing tools may provide information on where and how to improve the system.

A forecast message may have various presentation forms where major differences are mainly in a quantitative or qualitative representation of concentrations, and in the spatial coverage (point *vs.* area) of the forecast. In the current systems only maximum ozone concentration and/or air quality level is forecast; in contrast to weather forecasts a probability range of the expected values is generally not included in the forecast. An indication of the time of exceedance is generally also not included in the message. Including a time indicator might increase the value of the forecast message; especially for sensitive groups information on the expected time and duration of a smog event (e.g. whether high concentrations expected during the whole day or only in the late afternoon) might be important.

As presented in Chapter 2 the operational forecast systems generally provide information at a qualitative level for a certain area (e.g. "*in SE England air quality will be poor*"). In this chapter first of all evaluation methods for this type of forecast are discussed. Additionally, methods for performance evaluation of the numerical output of the forecast system (and/or its sub-systems) are presented. However, as any type of evaluation requires a reliable set of observation for comparison with the predicted values, a short note on this topic precedes the discussion on evaluation techniques.

3.2. Construction of a validation set using monitoring data

For validation of the forecast an observational data set is needed. The primary information for such a data set will come from a (routine) monitoring network. The observed parameter that serves as a reference value for the forecast must have a similar form as the forecast itself. Similar to the forecast, the observed value should provide (classified) information on ozone levels representative for a certain (pre-defined) area. When in the selected area more than one ozone station is operational a pre-processing of monitoring data is required. In this case an area representative value can be obtained by:

1. an interpolation technique (e.g. Kriging) taking into account the representativeness of the ozone stations (rural/urban/traffic). Stations outside the area may be included with appropriate weighting factors;
2. a numerical averaging over all stations within the area;
3. by selecting the highest value measured at any station at any time within the study area.

The most representative set will be obtained by the first procedure; however, relatively high costs are involved in this procedure. By the second method possibly a large bias is introduced when the ozone stations are not equally distributed over the area and/or over the various ozone environments (rural/urban/street). A smog event is defined as a day on which at least one hourly average concentration exceeds a certain threshold value. In the first two methods it is not straightforward to handle the time dimension: should the daily maximum values observed at the stations be selected first and then the interpolation/averaging procedure be applied or should the maximum value of the hourly interpolated/averaged values be selected? The third method is recommended for its simplicity and unambiguous results; it will, however, lead to some bias towards high ozone classes but, in view of protection of human health this will be acceptable. Both method 2 and 3 have the disadvantage that a dependency on the network configuration (number of stations, location of stations) may occur.

For validation of the forecast procedure independent data, that is data not used in the development of a (statistical) model is needed. As the yearly number of exceedances is generally low and the number might show large variations from year to year, it is desirable to have several years of data available for evaluating model performance. If this is not feasible, an alternative procedure may be followed: parameterising the model on the available data excluding the data for one year and evaluating the model against the data for this year. By excluding successively each year in the available time period, a reliable evaluation may still be obtained.

3.3. Criteria for validation

For qualitative information, the skill of a forecast system can be tested by using a binary system for comparison of forecast and observed occurrence of air quality classes, that is using a standard contingency table of the type displayed in Table 3.1. When N is the total number of data points and defining: f = total number of forecast exceedances, m = total number of observed exceedances, a = number of correctly forecast exceedances, the other matrix elements in Table 3.1 can be expressed in N, m, f, and a.

Table 3.3.1. Contingency table used for verification of ozone forecasts. See text for explanation of symbols

	observed		
forecast	**yes**	**no**	**total**
yes	a	$f-a$	f
no	$m-a$	$N+a-m-f$	$N-f$
total	m	$N-m$	N

Using these definitions, various skill parameters can be defined:

- fraction of correct forecast smog events (probability of detection) $SP= a/m.100\%$.
  Note that the fraction of "unexpected" events is given by $(100-SP)\%$.
- fraction of realised forecast smog events $SR = a/f.100\%$.
  Note that the fraction of "false alarm" is given by $(100-SR)\%$.

Both SP and SR range from 0 to 100 with a best value of 100.

The skill of forecasting non-events (smog event not forecast and not occurred, or, in other words the forecasting of "clean" days) is given by the correct null forecast:
$CN = (N+a-m-f)/ (N-m).\ 100\%$
Excluding the successful null forecast the *threat score, ST,* that is, the ratio of correct forecast events and total potential risk events can be defined:
$ST = a / (m + f - a).100\%$.
ST ranges from 0 to 100 with a best value of 100.

In an overall assessment of the forecast skill all four matrix elements have to be considered. The weighting of each of the four elements in the total skill might depend on the objectives of the forecast system. When the main objective is a warning of sensitive population groups the number of unexpected smog events should be minimal. In cases where the forecast is used as a trigger for short-term abatement measures (e.g. traffic ban) the "false alarms" should be minimal in view of the high costs involved in taking this kind of measures. A high false alarm rate will also reduce the confidence of the general public in the system.

Assuming an equal weight to the correct forecasting of smog events and of a non-smog event, the scoring parameters SP and SR can be combined to a *success index, SI,* ranging from -100 to 100 with a best value of 100:

$$SI = \left(\frac{a}{m} + \frac{N+a-m-f}{N-m} - 1 \right) \cdot 100\%$$

Table 3.3.2. Contingency tables for the AIRPARIF ozone forecast system (see section 2.6.1 for details on the models used).

Level 1: 130 $\mu g.m^{-3}$ (information to the authorities)

	SP correct forecast	1 - *SP* unexpected events	1 - *SR* false alarm	*CN* non-events	*ST* Threat score
Non linear model					
summers 1994-95	48 %	52 %	35 %	93 %	38 %
summer 1996	29 %	81 %	54 %	90 %	22 %
Linear model					
summers 1994-95	62 %	38 %	31 %	93 %	25 %
summer 1996	64 %	36 %	63 %	70 %	30 %

Level 2: 180 $\mu g.m^{-3}$ (information to the public)

	SP correct forecast	1 - *SP* unexpected events	1 - *SR* false alarm	*CN* non-events	*ST* Threat score
Non linear model					
summers 1994-95	18 %	82 %	0 %	100 %	18 %
summer 1996	-	-	-	100 %	-
Linear model					
summers 1994-95	36 %	64 %	42 %	99 %	29 %
summer 1996	-	-	-	100 %	-

Alternative names used in literature for the *success index* are “True Skill Score (TSS)” and “Hanssen-Kuipers Skill Score”.

As an example, the contingency tables of the AIRPARIF forecast system are presented in table 3.2, see section 2.6.1 on more details on the models applied. This table shows that the score parameters strongly vary from one summer to the other and they depend on the evaluation level (see the discussion in § 3.4). Note that an evaluation of the skill parameters *SP, SR,* and *SI* can only be done when there is at least one correctly forecast smog event ($a > 1$)[7].

In the evaluation of skill parameters a reference model should be included. The *persistency model* is recommended as reference model. The persistency model is an extreme simple model assuming that the forecast situation equals the present situation. In view of the phenomenology and averaged duration of ozone smog episodes the persistency model will be reasonable successful; the skill of the forecast system should be better. In practice this means that the forecast systems should be able to predict abrupt changes in air quality levels.

Although most forecast systems provide qualitative information as end-product, numerical information is frequently available in the step prior to the classification. Using the numerical data more extensive sets of skill parameters can be evaluated.

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[7] For events that are rare, the Heidke Skill Score, *HS*, is used. This score is a measure of the skill of a set of forecasts compared to the skill of a random forecast (see for a description of this parameter Doswell C.A. III, Jones R. and Keller D.L. (1990) On summary measures of forecast skill in rare event forecasting based on contingency tables. *Wea. Forecasting,* **5,** 576-585).

By means of these skill parameters a proper evaluation of the forecast system as a whole can be obtained as long as the classified information of the end-product is based on direct classification of the raw numerical data. When expert judgement comes into play during or after the classification step, the given skill parameters can only be used to evaluate intermediate products.

Using standard statistics like root-mean-square-error, correlation coefficients and regression lines between observed and forecast values the performance of the systems can be evaluated. In addition, other parameters characteristic for the performance of a model can be evaluated. For evaluating of the numerical output of a forecast (sub)-system the following skill parameters, each evaluating different aspects of the system, can be considered:

- the fractional bias, FB, between averaged values for forecast and observation

$$FB = 2\frac{\left(\overline{P} - \overline{M}\right)}{\left(\overline{P} + \overline{M}\right)}$$

where P is the forecast value and M is the observed value. FB will detect any systematic difference between observation and forecast. FB ranges between -2 and +2 with a best value of 0.

- the skill score, S defined as:

$$S = 100\left\{1 - \frac{\sum\left(P_{i+1} - M_{i+1}\right)^2}{\sum\left(M_i - M_{i+1}\right)^2}\right\}$$

where P_i and M_i are forecast, respectively observed values at day i. The score S includes the persistency model as reference model. A value $S<0$ indicates that the forecast model is worse than the persistency model. A score $S=100$ indicates the perfect model.

- the hit score, H, can be defined as:

$$H = 100\frac{1}{N}\sum\frac{2r - \Delta}{2r}$$

where

$$\Delta = \min\left(|P - M|, 2r\right)$$

and r is an uncertainty range around the forecast and observed value. The uncertainty in the observed value will depend on, e.g. uncertainties in the measurements but more important will be the spatial variability of M within the study area. The uncertainties in forecast value will result from uncertainties in the input parameters (e.g. weather forecast) and from the model concept. When these uncertainties are not known, the hit score may provide a simple estimate of their impact on forecast performance. The hit score H indicates the overlap between the interval $(P\pm r)$ and $(M\pm r)$. H ranges between 0 and 100 with a best value of 100. Disadvantage of H is that it assumes a uniform distribution of P, M within the interval $\pm r$ and it assumes equal ranges around both P and M.

Two or more of the above defined skill parameters can be combined in a so-called performance equation[8]. The precise formulation of the performance equation will

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[8] Cassmassi, for example, proposes a total performance score, PF, given by:

PF = SP - 10 E +PC +PC10

where PF is the total performance score
SP is the fraction of correct forecast smog events
E is the mean absolute error of prediction

depend on the aim of the forecast: if the main objective is to forecast high ozone events, high weight should be given to e.g. *SP;* is the main objective the forecast the prediction of ozone levels irrespective of the air quality class, high weights should be given to, e.g. *S* or *H*. The development of a performance equation will be region specific and falls therefore outside the scope of this paper. Here the discussion is limited to the development of building blocks for such a performance equation.

3.4. Discussion

For a smog forecast system it can be argued that less stringent requirements are needed on the forecast skills for days on which air pollution levels are much lower than smog levels than on days on which ambient levels approach smog levels.[9] Therefore, a *mask value* for evaluation[10] should be introduced. Table 3.3 gives the evaluation of the smog forecasts made during summer 1996 for 3 regions in the Netherlands (data provided by Erik Noordijk, see section 2.9 for a description of the Dutch forecast system). In the daily Dutch smog message five regions are presented; the results obtained for the regions south-west and east, which are not reproduced here, are similar to the regions presented in Table 3.3. In the upper part of the table all days are used in the evaluation; in the middle part, only days with an observed ozone maximum exceeding 120 μg/m^3; the lower part gives the evaluation based on days on which the 150 μg/m^3 level has been exceeded.

A detailed analysis of the performance of the Dutch systems is beyond the scope of this paper, only a more general discussion will presented here. In 1996 the observed number of smog days was low. The results are therefore only indicative; final conclusions can only be made when the evaluation is based on more summer periods.

The mask value will mainly change the number of “not observed/not forecast”-events. Therefore, the fraction of correct forecast smog events, *SP*, and the fraction of realised forecast smog events, *SR*, do not depend on the choice of the mask value as long as the mask value is well below the smog threshold value. Note that this is to a lesser extent true for the persistency model; here for some of the regions an increase in *SR* with increasing mask value is found. Clearly there are sudden endings of a smog period with day-to-day changes in ozone levels of 60 μg/m^3 or more. The persistency model is not able to foresee these sudden changes; by introducing a mask level the days directly after an episode (the persistency model will forecast the event but it is not observed) are excluded from the analysis.

PC	is the percentage of predictions within 40 μg/m^3 of observed concentrations
PC10	is the percentage of predictions within 40 μg/m^3 of observed concentrations on days when the observed changes from the preceding day was equal to or greater than 200 μg/m^3.

The skill parameters *S* and *H* are similar but not equivalent to PC10 and PC.

(reference: J. C. Cassmassi (1987) Development of an objective ozone forecast model for the South coast air basin. Paper presented at the 80th annual meeting of APCA, New York, June 21-26, 1987).

[9] Note that this is in contrast to the evaluation of an atmospheric chemical transport model. Here one requires that the performance of the system is independent of the actual levels. Only in this case, one may assume that the model includes all relevant processes. Any bias may indicate that specific processes are incorrectly represented in the model.

[10] To avoid confusion with threshold values or screening values defined in other sense (for example, for warning of the public), threshold values used in the evaluation of smog forecasting skills will be indicated as *mask values.* A mask value of e.g. 150 μg/m^3 means that only events with an observed value exceeding 150 μg/m^3 are included in the evaluation.

The Success Index, *SI*, decreases with increasing mask value for all situation when *SR* is less than 100%. When *SR* equals 100%, the Success Index becomes equal to *SP* and is virtually independent of mask value as long as the mask value is well below the smog threshold value.

The Skill Score, *S*, shows no systematic behaviour with increasing mask value; in one case (region south east, mask value is 150 μg/m^3) *S* becomes negative that implies that the persistency model performs better than the forecast system. A positive *S*-value indicates that - on the average - the difference between forecast and realised concentrations is smaller for the system than for the persistency model; this, however, does not guarantee a better skill in forecasting of smog events: in a number of cases the forecast system has smaller values for the fractions *SP* and *SR* than the persistency model.

The fractional bias changes from slightly positive to negative values when a mask value is introduced: in the Dutch system there is a tendency to underestimate the peak values. The persistency model has a similar behaviour. As the forecast system (the Dutch system is largely based on a classified extrapolation of measurement of the previous 24h) and the persistency model both have (to a small, respectively large extent) a memory effect the introduction of a mask value will systematically exclude more days with forecast value exceeding the observed value.

The hit score, *H*, has been evaluated with a range $r = 10$ μg/m^3. A mask value does not seem to have a systematic effect on the value of *H* although *H* tends to be higher when no mask is applied. Again it should be mentioned that a positive *S* does not guarantee that the hit score of the forecast system is higher than the one for the persistency model. The different behaviour of the chosen skill parameters indicates that to get insight into the performance of a forecast system, various skill parameters should be evaluated.

Evaluation of *SP, SR* and *SI* for several region in the UK shows that from year to year large variations can be expected: in 1996 - a year with a relatively low number of days with poor air quality - *SP* and *SI* are 90% or higher, *SR* ranges from 10 to 50% but in 5 out of 8 regions *SR* is below 30%. In 1995 *SP* and *SI* indicate a less good performance (ranging from 50-90%), the *SR*-score is for 3 out of 6 regions below 30%. For a proper evaluation of a forecast system it is recommended to use data of several summer periods, especially when the number of smog events is low. As each skill parameter evaluates only specific characteristics of the forecast, the use of various skill parameters is recommended. When skill parameters are all scaled between 0 and 100 summarising graphs like Figure 3.1 can be made. Using such a figure, a direct comparison between the forecast model and the reference (persistency) model can be made.

Table 3.3. Evaluation of the smog forecast of summer 1996 (May 22 - September 30) made for three regions in the Netherlands; a smog event is defined as a day with maximum ozone concentration exceeding 180 µg/m^3. The skill parameters SP, SR, SI, FB, S and H are defined in the text. The performance of the persistency model is given in the second column in italics.

south east

>0	observed		
forecast	yes	no	total
yes	2	1	3
no	3	124	127
total	5	125	130

SP=	40.0		*40.0*
SR=	66.7		*40.0*
SI=	39.2		*37.6*
FB=	0.049	*0.004*	
S=	21.3		*na*
H=	30.9		*37.0*

>120	observed		
forecast	yes	no	total
yes	2	1	3
no	3	21	24
total	5	22	27

SP=	40.0		*40.0*
SR=	66.7		*50.0*
SI=	35.5		*30.9*
FB=	-0.116	*-0.126*	
S=	15.5		*na*
H=	18.1		*16.9*

>150	observed		
forecast	yes	no	total
yes	2	1	3
no	3	9	12
total	5	10	15

SP=	40.0		*40.0*
SR=	66.7		*66.7*
SI=	30.0		*30.0*
FB=	-0.094	*-0.100*	
S=	-51.5		*na*
H=	24.3		*28.3*

west

>0	observed		
forecast	yes	no	total
yes	3	0	3
no	5	122	127
total	8	0.94	130

SP=	37.5		*62.5*
SR=	100.0		*62.5*
SI=	37.5		*60.0*
FB=	0.004		*0.0*
S=	34.4		*na*
H=	33.5		*35.9*

>120	observed		
forecast	yes	no	total
yes	3	0	3
no	5	14	19
total	8	14	22

SP=	37.5		*62.5*
SR=	100.0		*83.3*
SI=	37.5		*55.4*
FB=	-0.146	*-0.153*	
S=	26.1		*na*
H=	15.5		*11.8*

>150	observed		
forecast	yes	no	total
yes	3	0	3
no	5	5	10
total	8	5	13

SP=	37.5		*62.5*
SR=	100.0	*100.0*	
SI=	37.5		*62.5*
FB=	-0.161	*-0.132*	
S=	3.6		*na*
H=	19.6		*14.2*

north

>0	observed	
forecast	yes	no
yes	2	0
no	4	124
total	6	124

SP=	33.3	
SR=	100.0	
SI=	33.3	
FB=	0.050	*0.001*
S=	31.7	
H=	36.0	

>120	observed	
forecast	yes	no
yes	2	0
no	4	14
total	6	14

SP=	33.3	
SR=	100.0	
SI=	33.3	
FB=	-0.135	*-0.143*
S=	47.2	
H=	20.3	

>150	observed	
forecast	yes	no
yes	2	0
no	4	4
total	6	4

SP=	33.3	
SR=	100.0	
SI=	33.3	
FB=	-0.120	*-0.176*
S=	57.4	
H=	22.0	

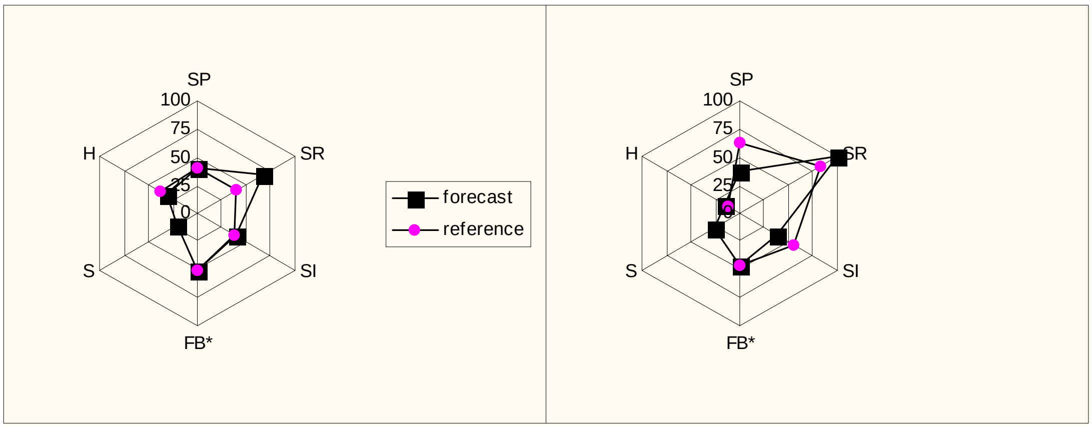

Figure 3.1. Summary of the evaluation of the Dutch smog forecast system in Summer 1996. Left: region south-east; all data. Right: west region; only days with ozone exceeding 120 μg/m^3 are included in the analysis. As reference the persistency model is included.

3.5. Recommendations

In preparation of an observational data set for evaluating forecast systems for a certain region, the highest observed value in that region should be selected. This will introduce some bias towards high ozone levels but this will give the best guarantees for information to the public.

In assessment of the skill of a forecast procedure both the correctly predicted smog events and non-smog events (false highs, missed highs) should be considered, for example by evaluating the *success index*. As reference the persistency model should always be included.

When quantitative information is available, skill parameters like fractional bias, skill score and hit score should be evaluated. In these evaluations not all data but only moderately high ozone levels (recommended screening value is 120 μg/m^3) should be included. Again a comparison with a reference persistency model is essential.

For a proper evaluation of a forecast system it is recommended to use data of several summer periods, especially when the number of smog events is low.

Further study on the incorporation of probability ranges in forecasts and evaluation procedures is recommended.

It is recommended to provide information on the performance of the forecast systems to the end-users. However, the complexity of a smog forecast system will make it difficult to explain to the general public the meaning of the various skill parameters. Therefore, it is recommended to limit the information to easily understandable parameters such as *S1* (probability of detection of smog events) and *1 - S2* (false alarm rate).

It is recommended to evaluate the forecast systems operational in the various countries using the set of skill parameters presented here. As a next step to harmonise the evaluation procedures, the results should be presented and discussed during a follow-up meeting of the TWG.

4. NEEDS AND OPTIONS FOR NEAR REAL TIME DATA EXCHANGE

4.1. The requirement for data exchange

Ozone episodes in Northwest Europe are a transboundary phenomenon. The presence of high concentrations of photochemically derived ozone at ground level at a particular location may stem in part from the transport of ozone and its precursors in air parcels which have travelled significant distances (hundreds of km). Typically, the paths that such air parcels follow cross several European national boundaries. Information on the very recent (near real time) concentrations of ozone in neighbouring and more distant countries can provide useful additional information for national ozone forecasting activities. National ozone forecasting systems generally include an element of expert analysis in the preparation of a forecast. Near real time ozone data from other countries can be included in the analysis at this stage. It can provide information on the general spatial distribution of high ozone concentrations across North West Europe during episodes. More importantly, in conjunction with meteorological forecasts, it can provide an indication of the ozone concentrations in upwind areas. Exchanged data can therefore improve the accuracy of national ozone forecasts and may also assist in the development of more accurate long range forecasts (forecasts for more days ahead). The computer models used by national ozone forecasting systems are currently not designed to incorporate exchanged ozone data; such systems may, however, be developed in the future. Ozone measurement data, meteorological forecasts and air quality models are all required for a comprehensive forecasting system.

The aims of data exchange are twofold:

- it provides an input to national experts and assists in improving the accuracy of ozone forecasts;
- if exchanged data is made directly available to the public, for instance via a World Wide Web page, then it serves to emphasise the transboundary nature of ozone episodes in Northwest Europe.

4.2. The possibility of a co-ordinated system of data exchange

Informal arrangements for the bilateral exchange of ozone measurement data between individual pairs of countries have been in place for several years. For example: the UK with the Netherlands and Belgium with Germany. There has been a significant increase in the accessibility of Internet technology in the last few years. Most institutes and companies now have e-mail facilities and many also have access to the World Wide Web. This provides an opportunity to develop a co-ordinated system of exchange of near real time ozone data in Northwest Europe utilising these existing data communication facilities.

A formal co-ordinated system in which data is sent to a central information hub, collated and a single message disseminated to all participants has several advantages over more informal bilateral arrangements:

- Consistent information is exchanged in a standard format;
- The information exchanged is optimised because it has been specified by national experts (e.g. the members of TWG-DFO);

- Data from all participating countries will arrive in one message rather than in several messages;
- It should be possible to present a map showing ozone concentrations in Northwest Europe each day. Ozone concentrations could be represented by coloured dots or numbers on these maps.

A co-ordinated data exchange system should encourage countries to participate in data exchange and the contacts established may also encourage harmonisation of forecasting methods.

4.3. The Working Group's recommendation

The national experts participating in the Technical Working Group on Data exchange and Forecasting Ozone episodes in Northwest Europe have considered the needs and options for near real time data exchange. The participants indicated their positive interest in a co-ordinated system of data exchange and their willingness to participate in such a system (with some restrictions as to technical capabilities). The group considered two options:

- A 'closed' system of data exchange with dissemination to participating institutes by e-mail only;
- An 'open' system of data exchange with dissemination via a freely accessible World Wide Web page in addition to distribution to participants by e-mail.

The Technical Working Group recommended that an 'open' system be established and that this system be restricted to exchange of ozone data, excluding meteorological information, which is generally available at the national level. The group also recommended that ozone concentrations should be given in μgm^{-3} to be consistent with the EU directive and that all exchanged data should be clearly marked as provisional.

4.4. Recommended specification for a co-ordinated system of data exchange

Consultants from AEA Technology's National Environmental Technology Centre have carried out a study of the feasibility of setting up a co-ordinated ozone data exchange system for Northwest Europe at the request of the UK Department of the Environment. This feasibility study included the preparation of a draft specification for a data exchange system, compiled in conjunction with national ozone forecasting experts. The detailed draft specification is included as Annex A.

This specification includes:

- The provision of ozone data from a small number of regionally representative rural monitoring sites from each participating country (the number of sites being determined by the size of each country). The sites should be chosen to reflect ozone concentrations relating to long range transport of ozone and its precursors. This data should include yesterday's maximum hourly ozone concentration and an example of this morning's ozone concentration.
- This data to be transmitted by e-mail to a central information hub in late morning.
- These messages to be collated to form a single page summary that is then e-mailed to all participants and made available on a world wide web page.

It is anticipated that participation in the data exchange should not entail significant costs and it is suggested that participants incorporate this work into their ozone forecasting activities. The co-ordination activities of the central information hub will entail some costs. These will consist of liaison with national ozone forecasting centres to initiate data exchange and some programming and program maintenance tasks.

4.5. Readiness of countries to participate

AEA Technology's feasibility study also explored whether the enthusiasm and technical infrastructure exist for a co-ordinated data exchange system to be established. The responses received by AEA Technology and information provided by participants in the Technical Working Group are summarised in this section.

The following counties participated in the Ministerial Conference on Tropospheric ozone in Northwest Europe in London in May 1996.

Belgium: Belgian data is already published on the World Wide Web, so there should be no technical difficulties in exchanging data.

Denmark: Two institutions collect ozone data in Denmark: The Meteorological Office and the National Environmental Research Institute (NERI). The UK already receives data from the Meteorological Office and NERI is willing and able to participate.

France: Ozone is monitored by regional authorities. The authority for Greater Paris is willing to exchange data and now has access to the Internet via a service provider.

Germany: Umwelbundesamt would like to participate in the data exchange.

Ireland: Ozone is monitored by the EPA. A system is set up to automatically send faxes containing hourly average data when triggered by ozone episodes. The EPA may have access to e-mail but they envisage technical problems in participating in the co-ordinated data exchange system. Ozone forecasting for Ireland is done by the Irish Meteorological Office, who will be able to receive e-mail messages.

Luxembourg: Luxembourg would like to participate in the data exchange.

The Netherlands: When ozone levels are enhanced, RIVM already exchanges data with neighbouring countries (Belgium, Germany, Luxembourg, France, UK) and would like to participate in the data exchange system.

UK: AEA Technology has both the technical capability and the desire to be involved.

The following countries did not participate in the Ministerial Conference but are members of the Technical Working Group and expressed the wish to participate in a co-ordinated data exchange system: Austria, Finland, and Sweden

ANNEX A: DATA EXCHANGE PROTOCOL

Introduction

The aim is to set up a largely automatic system, with very little intervention required to maintain the flow of information. The intention is to disseminate the information by e-mail and via a world wide web page.

It is hoped that if an authority is willing to contribute information, it will be able to do so by sending it as e-mail, or by placing it in a file that can be recovered by 'ftp'.

In an ideal scenario, it is hoped that a message with one or two data items will be sent daily, for a small number (<<10) of representative rural stations from each participating country. As a target it is hoped to receive daily, in the late morning, by e-mail or using 'ftp', a data file containing the information listed here for each station:

- yesterday's maximum hourly average ozone concentration;
- the date and time of the maximum hourly average ozone concentration;
- an example hourly average ozone concentration from recently this morning;
- the date and time of the example hourly average concentration;
- station latitude;
- station longitude;
- station altitude.

If an authority wishes to participate, it needs to choose a small number of stations whose data would be useful to its neighbour countries in forecasting ozone episodes. The stations should be identified by name and latitude, longitude and altitude to the person who is asked to set up the technical aspects.

Proposed format

The intention is to issue e-mail messages containing the aggregated information at 10:00 UT (GMT). To do this the data needs to be received by 09:00 UT.

The e-mail account to send data to is to be decided.

Please use plain e-mail text rather than 'attached' word processor or spreadsheet files. Please use a message subject of ozone data from [country code]. For example ozone data from B.

An e-mail account to send queries and comments to is to be decided.

The international standard abbreviation country names should be used (e.g. D for Germany, B for Belgium) at the start of each data line. Twenty-two characters are allowed for site names.

The ozone data should be right aligned in the three columns allocated for them, to the nearest whole $\mu g/m^3$. If on this occasion no datum is available please put 'not available' lined up with the right hand end of the time and date (some examples are given).

Times should be given in 24-hour format but without colons (:), for compactness. The dates should have two characters for the number (e.g. 27 or 09 or 9 with a space in front of it) and use three-letter abbreviations for month names in all-lower-case. The set of standard abbreviations in English is jan, feb, mar, apr, may, jun, jul, aug, sep, oct, nov, dec.

Latitudes and longitudes should be given in degrees and minutes (not decimal degrees). As the degree symbol is not available in the 'standard' e-mail character set, it is suggested that d and m are used in place of the degree symbol and the minute symbol.

At the beginning of each message a header should be included as in the example.

- If it is very simple to do, the time and date of the last data update in the format '0627 on 21-Apr-96' should be given. Otherwise, simply a fixed time and the date of the message.
- The ozone data should be in μgm^{-3}. Notice that the 'μ' symbol has been replaced by u in the title lines.
- It is assumed that all data will be provided as hourly averages (to be consistent with the EU directive).

Example of proposed message format

```
Data last updated          Yesterday's   Example from
hhmm on dd-mmm-yy              maximum      this morning
                          conc @ time   conc @ time                Alt
 Country   Station Name        (ugm-3)       (ugm-3)     Lat   Long   (m)


B    site name             26 @1500,19jan  20 @0900,20jan 54d27mN 07d52mW  130
B    another site          30 @1600,19jan  21 @0800,20jan 54d27mN 07d52mW  130

D    a site name           78 @1800,19jan  50 @0900,20jan 47d03mN 10d14mE   85
D    more names            60 @2000,19jan  48 @0900,20jan 47d03mN 10d14mE   85
D    site                  58 @1400,19jan  33 @0900,20jan 47d03mN 10d14mE   85
D    another site          40 @1800,19jan  12 @0900,20jan 48d16mN 11d26mE  105

GB   Lough Navar           36 @1500,19jan  35 @0900,20jan 54d27mN 07d52mW  130
GB   Lullington Heath      74 @1400,19jan  52 @0900,20jan 50d48mN 00d11mE  120
GB   Strath Vaich          24 @0600,19jan  26 @0800,20jan 57d44mN 04d46mW  270
GB   Yarner Wood           58 @1100,19jan   not available 50d36mN 03d43mW  119

L    site name             20 @1500,19jan  18 @0900,20jan 50d36mN 03d43mW  119

NL   Wijnandsrade          48 @1400,19jan  12 @0700,20jan 48d31mN 10d02mE   10
NL   Houtakker             53 @1600,19jan  32 @0700,20jan 48d28mN 11d35mE  120
NL   Braakman              13 @1700,19jan  35 @0600,20jan 47d03mN 10d14mE   85
NL   Leiduin              not available   not available 47d28mN  8d41mE   75
NL   Eibergen              31 @1500,19jan  31 @0700,20jan 48d16mN 11d26mE  105
NL   Kollumerwaard         43 @1700,19jan  28 @0600,20jan 48d11mN 09d41mE   75

 ruler   1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

^--v ^-------------------v ^-v ^---------v ^-v ^---------v ^-----v ^-----v ^--v
starts of fields marked using '^'s.  ends marked using 'v's
```

5. RECOMMENDATIONS

The national experts participating in the Technical Working Group on Data Exchange and Forecasting Ozone episodes in Northwest Europe have considered the current situation with respect to forecasting of ozone episode in Northwest Europe. For improvement of the operational forecast system the Working Group made the following recommendations:

- extension of the region
  Only Northwest European countries participated in the Technical Working Group. An extension of the group with South, Central and East European countries is recommended.

- exchange of data

  The participating countries indicated their positive interest in a co-ordinated system of data exchange and their willingness to participate in such a system.

  The Technical Working Group recommended that an 'open' system with dissemination via a freely accessible World Wide Web page in addition to distribution to participants by e-mail be established and that this system be restricted to exchange of ozone data, excluding meteorological information, which is generally available at the national level. The group also recommended that ozone concentrations should be given in $\mu g/m^3$ to be consistent with the EU directive and that all exchanged data should be clearly marked as provisional. Specification for a co-ordinated system of data exchange is presented (see Chapter 4).

  A European-wide ozone exceedance information system, preferably accessible to all countries via the Internet, would greatly help ozone forecasting in countries situated in the less densely populated regions of Europe.

- development of a joint forecast system

  The option to develop a joint ozone forecast system has been discussed within the TWG. However, such a European forecast system can never replace the systems operational at a national or local level. The requirements of a forecast system differ so widely from one country to the other (e.g. time of forecast, threshold levels etc.) that “one” system can never fulfil all requirements. Moreover, it is expected that systems based on locally collected input data will generally have better performance than a European system having a more coarse resolution. However, a central system based on a numerical photochemical model link to a weather prediction model would provide basic information that is needed to extend the forecast period as requested by many countries.

- evaluation of operational systems

  Procedures to evaluate the performance of ozone forecast systems were discussed by the Group and the use of a set of skill parameters is recommended (see Chapter 3). For a proper evaluation of a forecast system it is recommended to use data of several summer periods, especially when the number of smog events is low. Information on the performance of the forecast systems should be provided to the end-users. However, the complexity of a smog forecast system will make it difficult to explain to the general public the meaning of the various skill parameters. Therefore, it is recommended to limit the information to easily understandable parameters such as *S1* (probability of detection of smog events) and *1 - S2* (false alarm rate).

It is recommended to evaluate the forecast systems and to present and discuss the results during a workshop as a next step to harmonise the evaluation procedures.

Further study on the incorporation of probability ranges in forecast and evaluation procedures is also recommended.

ANNEX 1. PARTICIPATING EXPERTS

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