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THE LONG RANGE TRANSPORT OF  
PHOTOCHEMICAL OXIDANTS:

REPORT FROM A PLANNING CONFERENCE ON  
FUTURE RESEARCH CO-OPERATION

OSLO, 12 - 14 SEPTEMBER 1978

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## INTRODUCTION

The plans for this conference were first discussed at the meeting in March 1977 in the OECD Group of Experts on Photochemical Oxidants and their Precursors in the Atmosphere. During the preparation of the third report from the Group of Experts, some delegates suggested that the phenomenon of long range transport of oxidants and oxidant precursors could be relevant for international co-operation after the Group had fulfilled its mandate.

At the Group of Experts meeting in June 1977, the Norwegian delegate offered, on behalf of the Norwegian Institute for Air Research, to host the conference. In November 1977, the OECD Air Management Group gave full support to the idea of having a planning conference in Norway to define areas for future research co-operation in the field of long range transport of photochemical oxidants. Patronage to the conference was given by the OECD Executive Committee, and the plans were finalized during the spring and summer 1978.

Invitations were extended to all national delegates to the OECD Air Management Group. These delegates were requested to distribute the information on the conference to interested persons and institutions within their countries.

MAIN POINTS AND CONCLUSIONS

1. Recent trend studies by OECD, based on 1972-1985 data and projections, have indicated that while sulphur dioxide emissions are being reduced in many countries, emissions of hydrocarbons and nitrogen oxides are increasing at an annual rate of about 5% in Europe. Control technology cannot significantly impact on this trend before 1985. Consequently, concern was expressed over the likelihood of significantly higher oxidant levels and more widespread effects during photochemical episodes.
  
2. In order to assess the regional nature of photochemical episodes, it is clearly important to harmonize the monitoring methods, calibration techniques, siting of monitoring equipment and the methods of data reporting. Previous OECD reports have emphasized the importance of these issues and have provided valuable guidance to those procedures which should be adopted. Further guidance should be sought on how to establish a monitoring network of sampling stations in the OECD countries of Europe from which data can be routinely reported and exchanged between participating countries.

The purpose of a unified measurement programme within OECD would be to provide data for

- i) the evaluation of urban control programmes,
  - ii) the validation of regional models using rural monitoring data,
  - iii) the investigation of any long-term trends in the concentrations of photochemically generated secondary pollutants and their precursors.
- 
3. Evidence was presented in several papers for the transport of ozone over distances which may exceed several hundreds of kilometres. In certain instances, the origin of air masses containing elevated ozone concentrations were found to be in neighbouring countries. It is, therefore, of interest

to attempt to quantify how much of the elevated ozone levels result from local production and how much from sources hundreds of kilometres upwind. The general view was that during some photochemical pollution episodes in certain member countries, ozone concentrations of as much as 100 ppb hourly mean levels could be explained by long-range transport with additional contributions of a similar magnitude from local sources.

4. The advection of air masses containing elevated ozone concentrations from United States into southern Ontario, Canada, has been demonstrated by the investigation of several summer photochemical episodes. Sources located in Ontario itself have been shown to add a further contribution to ozone concentrations downwind of major urban centres. It is clear that a control strategy that might result in lower ozone levels that meet Canadian objectives, would require a concerted abatement programme in both Ontario, Canada, and in the eastern United States.
5. In Europe, the long range transport of ozone and precursors was evident from measurements in
  - i) Scandinavia of photochemically polluted air masses advected from distant sources.
  - ii) the vicinity of the major urban-industrial centres on the continent and in the United Kingdom.

Furthermore, the available measurements clearly demonstrated the differences between urban and rural areas and the importance of a number of physical and chemical processes in the description of the formation, transport and ultimate removal of ozone and other photochemically generated secondary pollutants.

6. Evidence was presented illustrating that those photochemical episodes which led to the production of elevated ozone concentrations, also led to the simultaneous production of other secondary pollutants. These species include PAN (peroxyacetyl nitrate), sulphuric and nitric acids, sulphate

and nitrate aerosols, all of which may have some adverse effects upon human health, visibility and vegetation.

7. Evidence was presented of the value of measurements of the vertical and horizontal distribution of ozone in the atmospheric boundary layer. The further application of aeroplane, balloon, and remote sensing techniques for ozone, nitric oxide, nitrogen dioxide and hydrocarbons was suggested as valuable research activities.
8. The OECD has previously studied individual large scale photochemical ozone episodes in member countries during 1973-1975. Since the completion of these analyses, a number of other member countries have commenced measurements of ozone, and it would seem worthwhile extending these episode analyses to 1976-1978, as they would be based on a much more comprehensive monitoring data base.
9. Evidence from North America has shown that a reduction in the yield, grade and value of commercial crops takes place at ozone levels which are currently observed in many OECD member countries. It was agreed that European studies should start with an evaluation of the current situation based on available information supplemented by special studies in the vicinity of the major urban-industrial centres. Biological monitoring using indicator plants should preferably aim at providing definitive information on the dose/effect relationships for commercial crops, trees and native flora, complemented by air monitoring.
10. It was generally accepted that there is currently an urgent need for the compilation of emission inventories of photochemical precursors on a unified basis in OECD countries. There may well also be a strong case for using the same format for these precursors as previously employed for sulphur dioxide ( $\frac{1}{2}^{\circ}$  latitude x  $1^{\circ}$  longitude).

In order to provide some guidance to the current OECD programme in this field, a number of proposals were made, and these are listed below.

- a. It was agreed that a consistent breakdown of source categories should be used throughout this compilation together with their respective emission factors unless specific factors are known to operate within individual OECD member countries.
- b. As a first approach it was felt adequate to use a lower limit to the reactivity of hydrocarbons (or volatile organic compounds) to be included in the inventory. The choice of this limit is, of course, somewhat subjective, but present understanding would place the limit of reactivity at greater than or equal to C<sub>4</sub> paraffins.
- c. Further studies could then be directed to the subdivision of hydrocarbons according to the nature of the secondary photochemical products and the time scale for the formation of these products. There may well be some merit in considering the control of individual hydrocarbons for the alleviation of local problems due to the effects of particular photochemically generated secondary pollutants.
- d. The attention of the OECD was directed to recent CONCAWE reevaluations of hydrocarbon emissions from the marketing of petroleum products and refinery operations.
- e. The importance of the individual NO and NO<sub>2</sub> emissions was stressed for the application of emission inventories in modelling studies. An effort should be made to compile the results of research studies on individual NO and NO<sub>2</sub> emissions with the purpose of producing emission factors.
- f. It was suggested that simple rule-of-thumb procedures should be investigated to produce inventories appropriate to photochemical pollution episodes. This applies, for instance, to seasonal and diurnal variations.

11. Considerable attention is directed, particularly in the USA, to the development and application of models to the prediction of photochemical ozone concentrations produced in urban areas over distance scales of 50-100 km. It would clearly be of interest to study their possible application in the urban industrial areas of other OECD countries.

Models for the investigation of the long-range transport of ozone and other photochemically generated pollutants are under development at the present time as ongoing or proposed research programmes. These research activities are invaluable in the investigation of the detailed meteorology, physics and chemistry of photochemical pollution episodes and are important to the establishment of more firmly based control strategies. The development of dispersion models would greatly enhance these possibilities.

12. It was suggested that a survey of present concentrations of photochemically produced secondary pollutants should be conducted to assess their effects on health, materials and vegetation.
13. The OECD should consider the nature and economic impact of possible control strategies for particular regions. The envisaged programmes could be investigated along the following possible lines:
  - i) Multi-country programmes of hydrocarbon control.
  - ii) Control of individual processes or activities giving rise to specific hydrocarbon emissions common to a number of OECD countries.
  - iii) Multi-country programmes of NO<sub>x</sub> control.

Because of the complex interrelationship between photochemical pollutant precursors in the atmosphere, the evaluation of proposed control strategies should include an evaluation of their impact on all photochemically generated secondary pollutants.

APPENDIX 1

AGENDA

THE LONG RANGE TRANSPORT OF PHOTOCHEMICAL OXIDANTS:  
A PLANNING CONFERENCE ON FUTURE RESEARCH CO-OPERATION

AGENDA

Session 1 ----- *Chairman: G. Foley (OECD)*

L. Shenfeld (Canada):

Long range transport into and across  
Southern Ontario, Canada.

R. Guicherit (Netherlands):

Photochemical smogformation  
in the Netherlands.

P. Grennfelt (Sweden):

Observations of high ozone levels in  
Sweden.

M. Benarie (France):

Origins of the oxidant at the  
Vert-le-Petit station.

W. Rudolf (Federal Republic of Germany):

Ozone concentrations upwind and downwind  
of polluted areas during a flight from  
München to Rotterdam.

J. Schjoldager (Norway):

Observations of elevated ozone levels in  
Oslo and Telemark, Norway.

L. Skärby (Sweden):

Ozone damage to vegetation:  
Potential risks and field observations  
in Sweden.

H. Ro-Poulsen (Denmark):

Ozone monitoring in and around Copenhagen with sensitive tobacco plants.

Preparation of draft report from Session 1.

Session 2 ----- *Chairman: R. Guicherit (Netherlands)*

G. Foley (OECD):

Emission inventories of organics and nitrogen oxides.

R.G. Derwent (UK):

Some aspects of the formation, transport and destruction of photochemical oxidants in Europe.

I.S.A. Isaksen (Norway):

Characteristic times for generation and loss of ozone in polluted air masses.

K. Horntveth (Norway):

On the use of 850 mb trajectories in studies of long range transport of oxidants. Some critical remarks.

A. Eliassen (Norway):

What can be expected from photochemical transport models on the synoptic scale?

J. Padgett (USA):

Ozone control strategies in the United States and the role of long range transport.

Preparation of draft report from Session 2.

Session 3 ----- *Chairman: D.G. Kelley (Canada):*

A. Bromley (OECD):

The role of the OECD in the field of long range transport of photochemical oxidants.

B. Ottar (Norway):

The ECE co-operative programme on monitoring and evaluation of long range transmission of air pollutants in Europe.

Adoption of the report from the conference.

APPENDIX 2

SUMMARIES OF PAPERS

LONG RANGE TRANSPORT OF OZONE INTO AND ACROSS  
SOUTHERN ONTARIO, CANADA

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Studies were conducted to characterize the long range transport of ozone into and across Southern Ontario, Canada, using 1976 and 1977 data from a dense network of over 20 monitors (one per 2500 sq.km), located in both urban and rural areas. Ozone episodes with widespread, persistent levels, typically 80 to 150 parts per billion (ppb), were primarily associated with warm moist south-southwest airflows in large-scale motion systems. These airflows advect ozone and other long-lived pollutants, e.g. sulphates, over distances of several hundred kilometres.

Investigations indicated that during the summer the southern most portion of Ontario is often in the northern extension of an ozone laden air mass centred over northeastern United States. The high levels of ozone in the area just north of Lake Erie are likely due to long range transport as there are no major sources of the precursors in this portion of Ontario.

A mixed layer air parcel trajectory of air entering Southern Ontario during an ozone episode indicated a path that passed through regions of United States that have both high hydrocarbon and nitrogen oxide emissions. Both the precursors and their photochemical reaction products are apparently advected in the air mass over large distances. During episodes, the ozone levels peak during the daytime with mixing through the boundary layer, and are significantly reduced at night near the ground due to the trapping of pollutants above the surface based nocturnal inversion.

The spatial pattern of ozone concentrations during episodes in Southern Ontario shows depressed levels within Metropolitan Toronto and the build-up of levels downwind of the urban area. Within the City automobile emissions of nitrogen oxides result in local scavenging of ozone. The photochemical reaction time and the non-methane hydrocarbon/nitrogen oxides ratio favour the build-up of ozone 30 to 50 km downwind of the city. For each episode the pattern is generally similar with maximum levels occurring over two areas, these being the southern most portion of the Province, and the other some 30 to 50 km downwind of the major urban centre of Metropolitan Toronto.

The advection of air containing elevated ozone concentrations from United States into Ontario was shown to result in recorded maximum hourly levels of ozone of about twice Canada's objective of 80 ppb for this pollutant. A further increase in levels above the objective was shown to occur downwind of Ontario's major urban centre. It is evident that a control strategy that could result in ozone levels meeting the objective would require a concerted abatement program of the precursors emissions in both Ontario and eastern United States.

## PHOTOCHEMICAL SMOGFORMATION IN THE NETHERLANDS

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During smogforming episodes maximum recorded hourly ozone concentrations can reach values of over 0.25 ppm in the Netherlands. The WHO long term goal for 1 hour maximum of 0.06 ppm oxidant as ozone, which is also the legal Japanese oxidant standard, could be exceeded on up to 100 days of the year (No. of violations up to 700 hr), while the standard set by the EPA of the US of 0.08 ppm could be exceeded up to 50 days of the year (No. of violations up to 300 hr).

An analysis of air mass flow for episodes which have occurred in the Netherlands between 1973 and 1977 revealed that although for any flow direction elevated ozone concentrations may occur, photochemical pollution is often found in association with easterly winds. This, however, does not necessarily imply that the ozone is largely transported into the Netherlands from countries that surround us. Our opinion is that there are only higher correlations between easterly winds and meteorological conditions favourable to ozone formation, such as high solar radiation, low wind speeds and radiation inversions, than for westerly winds. These conditions, long associated with photochemical pollution, are features of anticyclonic air masses. Because the anticyclones are often situated over the North Sea, northern Germany or Finland/Scandinavia; the Netherlands, parts of Germany and the UK tend to experience light easterly winds during these episodes. From air mass trajectory analyses, we came to the conclusion that no specific source areas could be indicated for the problems in the Netherlands. We rather favour the hypothesis that precursors seem to be present in a sufficient quantity over large areas, probably as large as thousands of square kilometers, to initiate photochemical smogformation in Western Europe.

What has been discussed in the previous paragraphs, by no means denies the occurrence of long range transport of pollutants in Western Europe. It has been established from aircraft measurements that under certain meteorological conditions there is an influx of  $\text{NO}_x$  and HC into the Netherlands from e.g. the Ruhr area and the Antwerp area, which is well in excess of the local production of these pollutants, e.g. in the Rijnmond area.

From aircraft measurements it further follows that the highest ozone concentrations are recorded some kilometers downwind of specific source areas. From upwind and downwind flux measurements it can also be concluded that considerable quantities of ozone are locally produced by emissions from such areas. In other words there is a local problem superimposed on a more regional one.

The control of photochemical oxidants is a complex dynamic process involving major technical uncertainties. An effective way to deal with the dynamic and uncertain aspects of the problem is to adopt a feedback approach in control strategy planning; trends in ambient air quality should be continually reviewed. If statistically significant trends in pollutant concentrations are recognized as early a data as possible, one can, hereby, rely on forecasting the need of more stringent, less stringent and even alternative abatement policies.

If we look at trends in air quality of primary pollutants in the Netherlands, for  $\text{SO}_2$  and PAH (polycyclic aromatic hydrocarbons) a most dramatic decrease of ambient air concentrations levels has been observed. This was mainly due to switching from coal and heavy fuel oil to natural gas as the most important energy source. However, since we started monitoring  $\text{NO}_x$ , an upward trend of about 6-7% each year for most of the measuring sites has been observed. The role of transportation as the single major  $\text{NO}_x$  emission source should be mentioned in this respect. For hydrocarbons emitted by mobile sources, an upward trend of 5-6% each year is observed.

From the previous paragraphs it is clear that, even if effectively carried out, ECE/EEC directives to limit exhaust gas HC emissions are grossly insufficient to lead to reduction in hydrocarbons emissions by a growing car population. The EEC directive relating to  $\text{NO}_x$  emissions from vehicles as it stands is only more or less a statement of the existing  $\text{NO}_x$  emission rates and will not lead to any reduction in ambient  $\text{NO}_x$  concentrations. There will rather only be a further increase in ambient  $\text{NO}_x$  and HC levels in the near future.

In an analysis of meteorological parameters and ozone levels it could be concluded that yearly fluctuations in ozone formation since 1968 are primarily determined by meteorological conditions and not by changes in precursor emissions. However, the number of hours per year with high ozone levels in relatively unpolluted areas have been rising when compared to more polluted areas. This is due to more chemical quenching of ozone in the polluted areas due to an increase of precursor emissions and an enhancement of photochemical activity in less polluted areas due to increased transport of precursors into these areas.

Predicted trends in air pollution give reason for great concern. Apart from the steady increase in HC and  $\text{NO}_x$  levels mentioned before, it is expected that also  $\text{SO}_2$  levels may dramatically increase in the near future due to a backshift from natural gas usage to the usage of fuel oil and even coal. Although  $\text{SO}_2$  itself is not a very toxic compound, it may under certain meteorological conditions, undergo a series of (photo)chemical conversion reactions in the atmosphere by which far more toxic compounds, such as sulfuric acid, are formed. However, our knowledge in the field of the air chemistry of  $\text{SO}_2$  is still incomplete.

The predicted degradation of the natural ecosystem, if no stringent abatement measure are taken by governments, may have serious socio-economic consequences. Also indirect effects on man's health and the direct effects on his welfare resulting from ecosystem deterioration by smog injury should be taken into account in developing air pollution control strategies.

OBSERVATIONS OF HIGH OZONE LEVELS  
IN SWEDEN

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In January 1972 ozone monitoring was started in Gothenburg. The main purpose was to find out whether oxidant formation could take place in Gothenburg. Already after about two months of measurements, on March 16th, the ozone concentration rose to 0.09 ppm. On the same day, the concentrations of other pollutants, such as soot and sulphur dioxide, were extremely high and the visibility at noon was only 7 km; it could therefore be excluded that the ozone was caused by natural sources.

The continuing measurements have shown that several episodes of high ozone concentrations occur every year, mainly in the summer. Sometimes high ozone concentrations have been found even in March and April.

From 1975 measurements are also carried out at Rørvik, about 40 km south of Gothenburg. This station is situated close to the coast and is normally unaffected by local sources.

The ozone concentrations at the two stations covariate rather well. The concentrations at Rørvik is however mostly higher than in Gothenburg. The lower concentrations in Gothenburg probably depend on locally emitted ozone destroying compounds. The highest ozone concentration observed at Rørvik is 0.20 ppm (August 1975) and in Gothenburg 0.13 ppm (June 1977). Table 1 lists the number of days with high ozone concentrations every year at the two stations.

Analyses of the meteorological conditions during the ozone episodes indicate that they mostly occur either during high pressure

situations or before cold fronts moving in over Europe from the west or the south-west. Trajectories (48 hours at 850 mb) for the former situations normally show that the air has moved clockwise over Europe. For the latter situations straight trajectories mostly from the sector ESE-WSW are observed.

The high pressure situations will give elevated ozone concentrations over large regions. Comparisons of the ozone concentration at Rørvik and Bjørnstadjordet (in southern Norway) for the days with high ozone concentrations 1976 show a striking agreement. <sup>1)</sup>

Many but not all of the ozone episodes are connected with reduced visibility due to high particle concentrations. The first observed episode in March 1972, as well as an episode August 25-26, 1974, are excellent examples of occasions with decreased visibility. On both these occasions the visibility at noon was only 6-7 km. Some of the high pressure ozone episodes did not give a reduced visibility. During almost the whole episode in the beginning of August 1975 the visibility was above 25 km.

The ozone episodes are normally connected with increased concentrations of sulphates on particles, soot, nitrogen oxides and sulphur dioxide. There are indications that episodes of acid particles are connected with high ozone concentrations. At four of the five most acid situations during the summer 1975 high ozone concentrations were observed.

It may also be valuable to note that at most of the ozone episodes the concentration of nitrogen oxides is still a few ppb and above the nitrate concentration. Thus all nitrogen oxides are not converted to nitrates, and there always seem to be a small amount of nitrogen oxides left which may contribute to further production of ozone.

<sup>1)</sup> The measurements in Norway were carried out by the Norwegian Institute for Air Research (NILU).

DAYS WITH HIGH OZONE CONCENTRATIONS IN GOTHENBURG AND RØRVIK 1972 - 1978.

NUMBER OF DAYS WITH 1-HOUR MEAN OF OZONE EXCEEDING THRESHOLD VALUES.

Year	≥0.08 ppm	≥0.10 ppm	≥0.12 ppm	≥0.15 ppm	Max hourly mean (ppm)
<u>Gothenburg</u>					
1972	18	3	0	0	0.11
1973	12	1	0	0	0.10
1974	4	3	0	0	0.11
1975	13	1	0	0	0.10
1976	11	1	0	0	0.11
1977	9	1	1	0	0.13
1978 <sup>1)</sup>	8	6	2	0	0.12
<u>Rørvik</u>					
1975	-	18	11	5	0.20
1976	-	17	5	0	0.13
1977	-	6	0	0	0.11
1978 <sup>1)</sup>	-	12	8	1	0.15
<u>Romelanda</u>					
1978	6	1	0	0	0.10

<sup>1)</sup> Includes data only until June 30, 1978.

ORIGINS OF THE OXIDANT AT THE  
VERT-LE-PETIT STATION

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Routine continuous observations of ozone, (Beckman 950), NO and NO<sub>2</sub> (Beckman 952) are executed at Vert-le-Petit, 35 km from Paris, since January 1976. Another Beckman 950 A measures O<sub>3</sub> at the University of Paris VI (Jussieu) since September 1977. From the beginning, the equipment logged about 80% of valid, intercalibrated data. The 20% loss of recording includes that of all peripheral equipment.

Our own observations are completed by those of the Lab. Central de la Préfecture de Police, rue de Dantzig, in the south of the urban area of Paris.

The continuous recording at Vert-le-Petit usually shows the well-known afternoon (14-20 h) ozone maximum. There is no well developed, characteristic daily cycle of NO<sub>2</sub> and NO and in general, local concentrations are quite low, around 18 µg NO<sub>2</sub> and 14 µg NO per cubic meter air, with occasional short-time peaks attaining 70 µg NO<sub>2</sub> and 100 µg NO per m<sup>3</sup>. On the other hand, Paris shows the ubiquitous traffic-linked maxima of NO<sub>2</sub> and NO attaining easily the five or tenfold of the simultaneously observed values at Vert-le-Petit.

The available data were analyzed:

- a) from the point of view of the frequency of their occurrence as function of wind direction, hour of the day, and atmospheric stability;

- b) concerning their multiple correlation with each other and with meteorological data;
- c) with respect to individual days.

Frequency analysis, multiple correlation with meteorological factors and episode-day scrutiny, all point into the direction, that in Western Europe in general with perhaps the exception of the centre of some highly populated and industrialized areas, ozone is neither locally formed, nor locally quenched by the "Los Angeles" precursor-photochemical mechanism.

It is instead suggested, that ozone is being formed above the boundary of the mixing layer in large pools over extended areas. It is not within the scope of the paper to analyze by which mechanism ozone is formed, and if anthropogenic precursors are involved or not. On the other hand, evidence is presented that even strong local precursor emissions do not influence very much sites only 35 km from the sources.

The ozone formed by whichever mechanism may be transported, at least occasionally, at distance. At favourable conditions (strong vertical exchange during the afternoon) high ozone concentrations may appear at ground level. These concentrations are neither correlated with local, nor with nearby precursors. If precursors are involved, the search must be on continental basis.

OZONE CONCENTRATIONS UPWIND AND DOWNWIND OF POLLUTED  
AREAS DURING A FLIGHT FROM MUNCHEN TO ROTTERDAM

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Ground based measurements of ozone carried out in Europe have shown elevated high ozone concentrations during high pressure periods combined with high temperatures and sun radiation. From these measurements it can be concluded that in special areas man-made ozone reaches levels of more than 100 ppb some times more than 200 ppb. The difficulty is to estimate from point measurements the spatial and temporal patterns of ozone concentration fields. Mobile measurements of ozone and ozone precursors are useful to investigate this problem. Single urban and industrial areas can be investigated by measuring cars. Investigation of the concentration fields on a sub-regional scale and especially the assessment of the vertical distribution is only possible by airborne measurements.

Since 1973 in the frame of a special investigation programme of the Federal Republic of Germany, ozone and its precursors are measured. This programme includes airborne measurements, especially on a regional scale in the Köln area. Within this programme, and within the Dutch-German co-operation, a flight from München to Rotterdam was carried out.

The airplane was equipped with a chemiluminescence monitor and a particle counter. The flight height was monitored as well. Chemiluminescence ozone instruments were chosen because of their high sensitivity and rapid response to changes in concentration. Basic calibration was done with the UV absorption method. Intercomparison with the wet chemical KI-method has shown an agreement within 5%. The calibration dependency of air pressure was tested in a pressure chamber by means of

plastic bags. The result of this calibration experiment was that the measuring signal is proportional to the ambient pressure.

To investigate the ozone concentration field and transport phenomena involved, the flight direction was chosen between München and Rotterdam. Flight length was about 800 km and some of the main German and Dutch industrial areas were covered. The flight was carried out during the 8th of July 1975. The flight time was 3 hours 15 minutes, a time which is short enough to differentiate between the local and the diurnal patterns.

Some further aspects by planning the flight were:

The flight direction should cross the downwind sections of the industrial areas of Stuttgart, Karlsruhe, Frankfurt and the Rhein/Ruhr area. Having reached the downwind section, descents and ascents should give information of the vertical ozone profiles.

From the 6th to the 9th of July 1975, middle Europe was influenced by a high pressure system with weak winds and temperatures up to 30°C. During the evening of the 8th of July, a cold front passed the Netherlands. Wind direction turned from SE to SW, and the continental warm air masses were replaced by cold maritime air masses.

As mentioned above, flight height, particle and ozone concentrations were measured and recorded. Enhanced particle concentration is an indicator of polluted air masses. Enhanced particle and ozone concentrations indicate man-made ozone.

Reaching the area of Stuttgart and descending into the downwind section, an increase in particle concentration indicated polluted air, but ozone concentrations did not change. The descent in the downwind section of Karlsruhe showed pronounced ozone and particle peaks. It is important to state that the ozone concentrations decreased while the flight level was constant

at 300 m. This indicates a pronounced ozone structure and an enhanced regional level of about 50 ppb above the background in this area.

Reaching the Rhein/Main area, the particle concentrations increased again. Ozone concentrations went up about 30 ppb above background. Because of the increased turbulence and because flight direction crossed the mountain area of the Taunus (800 m), the profiles were not as clear as before but the regional effect could still be seen.

The next ozone peak was measured crossing the Rhein and flying into the downwind section of the Rhein/Ruhr area. The maximum of this ozone peak reached 120 ppb and decreased to 90 ppb some kilometres before crossing the border of the Netherlands.

Some minutes after having crossed Eindhoven ozone concentrations peaked to 135 ppb. But this time the peak could not be traced back because wind direction turned to the east, an indication of the arriving cold front. The most pronounced peak during this flight was measured 250 m above the airport of Rotterdam. The weather situation was not quite clear because wind direction had turned again to southwest. An analysis of the trajectories showed that the air mass we measured during our descent to Rotterdam had drifted in the morning hours to the North Sea and - caused by the cold front passage - had come back during the noon hours.

Next day when the cold front really had passed the Netherlands, the ozone concentrations at ground reached only 60 ppb; the day before concentrations up to 125 ppb had been measured.

OBSERVATIONS OF ELEVATED OZONE LEVELS IN  
OSLO AND TELEMAR, NORWAY

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Studies related to the formation of photochemical oxidants in the troposphere have been carried out since 1973, when plans for the construction of a petrochemical complex in Norway became public.

An evaluation of the oxidant potential due to Norway's location (58°N - 71°N) has shown that even at high latitudes there is enough solar radiation in the summer months to initiate and sustain the photochemical reaction chains. At noon the radiation at the wavelengths of interest is only slightly less at high latitudes than at low latitudes. This difference in maximum radiation is compensated for by the longer solar days at the high latitudes.

Ambient ozone monitoring was started in 1975 in the lower Telemark area, 150 km SW of Oslo. Since the summer of 1977, continuous measurement of ozone has been carried out both in the Telemark and in the Oslo area. Three measurement methods are now in use: chemiluminescence with ethylene (Bendix), chemiluminescence with Rhodamine B (Philips) and UV-absorption (Dasibi). All monitors are checked with an ozone generator which is calibrated by means of the 1% KI-method, the former reference method of the U.S. EPA.

We are aware of the ozone measurement controversy in the United States a few years ago, but unfortunately we have no gas phase titration or absolute UV reference method available. We also feel that the discrepancy between the reference methods is not critical at the observed concentration levels in Norway (up to 240  $\mu\text{g}/\text{m}^3$  or 120 ppb).

The average diurnal ozone concentration distribution in Norway has been the same as recorded elsewhere: low values during the night, increasing through the morning hours, maximum levels in the afternoon with the concentration decreasing in the late evening.

During the warm and dry summer of 1976 in Telemark, 22% of the hourly observations at one site were higher than the World Health Organization (WHO) standard of  $120 \mu\text{g}/\text{m}^3$ , and 4.8% of the observations were higher than the United States standard of  $160 \mu\text{g}/\text{m}^3$ . 75% and 25% of the days had one or more hourly values higher than  $120 \mu\text{g}/\text{m}^3$  and  $160 \mu\text{g}/\text{m}^3$ , respectively. The highest hourly value was  $240 \mu\text{g}/\text{m}^3$  (120 ppb).

During the summer of 1977 which was less warm and sunny than that of 1976, the ozone concentrations outside the centre of Oslo were higher than those in Telemark. 14% and 2.7% of the hourly ozone concentrations at one site in Oslo was higher than  $120 \mu\text{g}/\text{m}^3$  and  $160 \mu\text{g}/\text{m}^3$ , respectively. 39% and 15% of the days had one more hourly values higher than  $120 \mu\text{g}/\text{m}^3$  and  $160 \mu\text{g}/\text{m}^3$ , respectively. The highest hourly value was  $218 \mu\text{g}/\text{m}^3$  (109 ppb).

The episodes with elevated ozone concentration normally took place during prevailing high pressure situations. The winds were weak and the land/sea breeze effect was pronounced. The co-variation of ozone with ambient temperature was generally good and better than the co-variation with radiation (measured or calculated).

By means of 850-mb trajectory calculations we have tried to separate the ozone episodes into two categories. The first category includes the cases in which the ozone formation seems to be a local or mesoscale phenomenon; the other category includes cases where transport of ozone or ozone precursors from other countries is probable.

Several cases of each category have been found. Also cases occur where a combination of local/mesoscale and long range transport is most probable. So far it seems that there have been more cases in the first category i.e. local or mesoscale formation, than in the second one i.e. long range transport.

OZONE DAMAGE TO VEGETATION:  
POTENTIAL HAZARDS AND FIELD OBSERVATIONS IN SWEDEN

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During the last seven summers the ozone concentrations on the Swedish west coast very often have exceeded the American National Ambient Air Quality Standard and occasionally also the Swedish limit for occupational health (100 ppb/8 hr). This paper will focus upon effects of ozone on vegetation in the Scandinavian countries.

To date, not much research has been carried out on biological effects due to high ozone concentrations; nor have many negative effects on crops or trees been reported.

In view of the high ozone levels measured lately, an idea is needed of their potential hazards in the Scandinavian countries. Therefore, it is necessary to investigate what effects and problems other countries, primarily the U.S., have today.

Some research results from the eastern U.S. will be presented together with one interesting oxidant project taking place in California. In order to discuss potential hazards of ozone in Scandinavia, however, reports from the eastern parts of U.S. are more adequate since the climatic conditions and ozone concentrations are more similar to Scandinavian conditions. Therefore, effects of extremely high ozone concentrations such as those in California seem to be of less interest in this context.

The American results have shown that sensitive trees and crops are under stress due to chronic and sometimes acute levels of oxidants. Some very well known consequences are decreased

quality and quantity. Sometimes very obvious injury like yellow spots (necrosis and chlorosis) is seen, but a problem of equal or greater magnitude are injuries such as growth and yield reductions.

Four different effect studies have been conducted during 1977 and 1978 at the Swedish Water and Air Pollution Research Laboratory in Gothenburg. These are:

1. Studies of ozone levels on the Swedish west coast and in the south of Sweden (Skåne) using tobacco as an indicator plant.

Injuries on the tobacco leaves (Bel W 3) were recorded at each of the 12 localities under investigation. At some localities also injuries on the less ozone sensitive tobacco varieties, Bel C and Bel B, were registered. Injuries were often seen shortly after ozone episodes.

2. Susceptibility studies of some important Swedish crops. Experimental fumigations and field observations.

Wheat, green beans, spinach and broccoly have been exposed in exposure chambers to ozone (200 ppb during 4 hr). All four species exhibited injury of different severity.

In the south of Sweden injury on spinach leaves in the field has been reported and is considered a problem today. The injury is most likely an effect of high ozone concentrations.

3. Effects of ozone on net photosynthesis, respiration, and transpiration rates of Scots pine seedlings.

The pine seedlings were exposed to ozone (200 ppb during 48 hr) in exposure cuvettes. After ozone exposure net photosynthesis, respiration and transpiration was reduced to a level of 80%, 65% and 75% respectively of the controls.

4. Effects of ozone (60-200 ppb during 17 days) on 10 year old pines in the field.

The experiment was carried out in the summer of 1978. No results have been evaluated yet.

OZONE MONITORING IN AND AROUND COPENHAGEN  
WITH SENSITIVE TOBACCO PLANTS

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In the period June 4 to September 29, 1977 two varieties of *Nicotiana tabacum*: The extremely ozone-sensitive Bel-W<sub>3</sub> and the moderately susceptible Bel-C (threshold limits about 0.05 and 0.10 ppm for 3 hr respectively), were used to establish a monitoring programme with 14 stations in and around Copenhagen. Three of the stations were situated in City, four in the suburbs about 10 km from City, three in the near rural areas about 20 km from City, and four in far rural areas (40-50 km from City). At each station 10 plants were permanently situated under standardized conditions, as two sets of each three Bel-W<sub>3</sub> and two Bel-C. Every three weeks each set was exchanged successively with new plants. Each set was exposed for 6 weeks then. The City and suburb stations were visited twice a week, the rest once a week or less. Each leaf was examined for density of the characteristic ozone-damage leaf spots (flecks), and the total leaf area damaged was estimated.

Based on the data from the City and suburb stations it was attempted to establish periods with elevated ozone-levels (episodes). For the purpose, a 1 to 6 index was constructed based on significant differences in number of leafspots between two examinations, the Bel-C's being heavier weighted than the Bel-W<sub>3</sub>'s. If the indexes at two or more stations were high in the same period, it was taken as a high-possibility indication of episodes with elevated ozone-levels. Such an indication was given in the following periods: June 4-6, 7-9, 10-13, 17-20, 21-23, 24-27, 28-30, July 1-4, 5-7, 12-14, 22-25, July 29-August 1, 27-29, August 30-September 1, 16-19.

Twelve of the episodes could be explained by favourable local meteorological conditions for ozone formation: wind velocity below 5 m/s, temperature higher than 15°C, daily UV radiation dose more than 500 kJ/m<sup>2</sup>. Further 1000-mb trajectories were constructed for the above mentioned periods. The airmasses came from the European continent or the UK (SSE to W) in 9 of the 15 periods. In total, 2 episodes can only be explained by long-range transport, 6 by local ozone formation or long range transport, and 6 only by local ozone formation. One period cannot be explained.

To estimate the general ozone levels in the area, the total damaged leaf area of each set of three Bel-W<sub>3</sub> plants over 6 weeks was used. The 6-weeks values were averaged over the whole period.

It was found that the injury levels of the stations in the rural areas was significantly higher than the levels in the City. The suburbs were characterized by levels between the rural and City levels, but not statistically different from City stations. The mean levels of the City and the suburbs were 43% and 54% of rural station levels, respectively.

The frequency distribution of the leaf area injury increase indicated that the stations westward from the City were exposed to fewer, but heavier, ozone doses depending on the increase in distance from the City. Northward from the City the picture is more obscure. To the south the Airport presumably affects the frequency distribution in the same way as the City.

Comparison with known dose-response relationships for the indicator plants clearly points out a potential risk for ozone damage to susceptible agricultural crops and herbs, and further investigations are absolutely necessary.

In conclusion, it has been demonstrated that the use of tobacco plants is a useful method to clarify overall ozone levels and

their distribution. Further improvements of the method can easily be made by using more plants per station. It is our opinion that the integrated response picture, given by standardized monitor plants, is very valuable to the evaluation of potential risks from the photochemical smog complex, and must be additional to any physical-chemical monitoring programme.

## EMISSION INVENTORIES OF ORGANICS AND NO<sub>x</sub>

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### Emission Inventories and Forecasts

During the early 1970's many countries have made estimates of the NO<sub>x</sub> and hydrocarbon emissions in their countries. These emissions are basically the uncontrolled emissions since at that time automotive emission controls had little effect and stationary source controls were not commonly in use.

It is possible with the aid of GDP (Gross Domestic Product) growth rates and energy forecasts to make a rough projection of these emission estimates into the future as shown below. These projections will also represent uncontrolled emissions against which control technologies must act.

Summary of Emission Projections (10<sup>3</sup> metric tonnes).

Country	Base year(1)		1985		1990	
	NO <sub>x</sub>	HC	NO <sub>x</sub>	HC	NO <sub>x</sub>	HC
Canada (1972)	1914	2564	2612	3519	2884	3896
Australia (1972)	858	1430	1639	1787	1980	2027
Germany (1975)	1843	1807	2198	2528	2353	2662
Netherlands (1975)	550	780	820	935	954	1177
Norway (1975)	102	160	141	206	173	258
Italy (1972)	960	1209	1502	1844	1639	2097
Sweden (1975)	333	432	394	553	420	600
United States (1972)	22200	29700	28070	39110	30530	43190

(1) Base year is 1972 or 1975 depending on country.

These projections show that HC and NO<sub>x</sub> emissions will increase about 40-60% from 1972 to 1985. Analysis also shows that, perhaps with the exception of the United States and Japan, control technology will have little impact on these emissions in 1985. Further examination of energy growth forecasts show that HC and NO<sub>x</sub> emissions could potentially increase by 40-50% from 1985 to 2000.

#### Emission Factors

Since, within OECD, there exist detailed energy statistics and forecasts to the year 2000, the current programme on photochemical oxidants is first examining the emission inventories and emission factors provided by countries to determine if a consistent set of emission factors can be developed. From this set of factors, it would then be easy to examine future HC and NO<sub>x</sub> emissions and control technology needs in the light of different future energy scenarios.

As a part of this emission factor compilation, consideration is being given to total hydrocarbon emissions, non-methane hydrocarbon emissions, reactive hydrocarbon emissions and the diurnal and seasonal variation in emissions.

#### The Need for Emission Inventories

The photochemical oxidants problem can be of two types. Photochemical oxidants are only a local problem in the large urban areas of Australia, Japan and western United States because of either topography or population distribution. However, recent evidence from field studies conducted in Europe and eastern North America has established that photochemical pollutants and their precursors can be transported up to several hundred kilometres. The existence of long range transport greatly complicates the development of abatement strategies. It implies that emission control of the precursors on a local scale may be grossly insufficient to solve the problem in Europe and eastern North America.

In the present phase of the project, attention will be focussed on abatement strategies for areas where photochemical pollution is a local problem. The USEPA isopleth method can be used to estimate the abatement requirements for different areas described by their NMHC/NO<sub>x</sub> ratio (as measured from 6 a.m. to 9 a.m.). The emissions of non-methane hydrocarbons and nitrogen oxides will need to be known for average days during 6 a.m. to 9 a.m.

Some hypothetical examples of the method have shown that only when the NMHC/NO<sub>x</sub> ratio is below 10, less than 80 per cent control of HC and nitrogen oxides emissions is required to meet an objective of 0.08 ppm of ozone (maximum one hour average).

These observations lead to several questions:

- 1) Is it technologically possible to achieve the present reduction in NO<sub>x</sub> and NMHC which are indicated?
- 2) What are the costs of obtaining such reductions?
- 3) How will the situation change in the future?

If the participants at this Conference wish to propose a programme to examine the long range transport of photochemical oxidants and their precursors, detailed emission inventories will be needed for this programme. Several questions need to be raised concerning the degree of detail required.

- . Should the inventory be of
  - NO and NO<sub>2</sub> or total NO<sub>x</sub>?
  - Total HC, total NMHC or HC by reactivity class?
- . What spatial resolution is required?
- . What time variation is required - hourly, daily?
- . Is it sufficient to consider only a part of the year, for example, one or more summer months?

SOME ASPECTS OF THE FORMATION, TRANSPORT AND  
DESTRUCTION OF PHOTOCHEMICAL OXIDANTS IN EUROPE

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Photochemical oxidant formation is discussed within the framework of a simple consecutive reaction model which defines two time scales:

- i) the time scale for hydrocarbon oxidation,
- ii) the time scale for the smog product sink process.

The time scales for the smog product sink process fix the mean transport distance for that species. For ozone, PAN and aerosol species this means that the transport distance may be in excess of 100 km, defining a long range transport process. The origins of the sink processes for these species are indicated and quantified.

The time scale for hydrocarbon oxidation is limited by the rate constant,  $k$ , for the reaction of that hydrocarbon and the OH concentration  $[OH]$ . At present, there is no routine way of measuring OH, its concentration must be calculated using a sophisticated computer model. The magnitude of  $k [OH]$  defines the time scale for hydrocarbon oxidation. The concept of reactivity is really one of time scale, but notice that the distribution between high and low reactivity depends on prevailing conditions, viz.  $[OH]$ .

To complete the picture, we need to know something of the atmospheric chemistry of individual hydrocarbons, so that their ability to produce each smog product can be quantitatively assessed.

CHARACTERISTIC TIMES FOR GENERATION AND LOSS  
OF OZONE IN POLLUTED AIR MASSES

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Ozone generation in polluted air is a result of reactions between peroxy radicals ( $\text{HO}_2$ ,  $\text{RO}_2$ ) and nitrogen oxides. Peroxy radicals are formed mainly by the photochemical reactions of hydroxyl radicals with hydrocarbons. The strong coupling which exists between the chemistry of hydrogen radicals, nitrogen oxides and ozone in the troposphere, leads to large variations in the efficiency of ozone formation under different pollution situations. In order to evaluate time scales for ozone generation, and to get an idea of the maximum concentration ozone may reach under different atmospheric conditions and different degree of pollution, model simulations of the ozone chemistry are performed.

Ozone is found to build up on a time scale of a few hours or less in pollution situations which are typical for urban areas, or in urban plumes under sunny weather situations. Ozone generation is found to be much slower over rural areas. Here the scale is of the order of days. However, the chemical loss of ozone is rather slow, resulting in lifetimes of several days. An important consequence of this is that unacceptably high values of ozone may build up over large regional areas if sunny weather persists for days. This may even be true during the winter season at mid latitudes, although the generation is considerably slower.

Model calculations indicate that cloud cover will have a strong influence on the amount of ozone formed, while temperature variations are not critical. The type of hydrocarbons present (olefins, paraffins, aromatics) are critical for the time it

takes before high ozone concentrations are reached. It is, however, important to note that air mixtures of pollutants which do not lead to elevated ozone levels during the first day of exposure to solar radiation, may give rather high ozone concentrations during the following days due to slower chemical activity.

Free radical concentrations ( $\text{HO}_2$ ,  $\text{RO}_2$ ,  $\text{OH}$ ) which are found to be representative for the range of pollution situations often found in industrialized countries, result in gas phase conversions of  $\text{SO}_2$  to sulfate in the range  $0.2\text{-}5\% \text{ h}^{-1}$  with diurnal averages around  $1\% \text{ h}^{-1}$ . Gas phase production of sulfate may therefore be an important source of sulfate in the atmosphere.

Formation of ozone in the polluted troposphere is a result of chemical processes which takes place on different time scales, depending on the degree of pollution, on the type of primary pollutants present, and on meteorological conditions. It will therefore often be very difficult to identify the sources of long range transported ozone. Combined chemical-transport models, which take into account the processes mentioned above, must therefore be used as a necessary tool in order to understand which pollution sources are responsible for high ozone levels in an area.

ON THE USE OF 850 MB TRAJECTORIES IN STUDIES OF  
LONG RANGE TRANSPORT OF OXIDANTS.  
SOME CRITICAL REMARKS

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Back track 850 mb trajectories are widely used to find the origin of polluted air both in studies of acid rain and in studies of ozone and its precursors. But, acid rain and elevated ozone levels occur during quite different weather conditions. In frontal situations with ascending air and strong vertical mixing, the SO<sub>2</sub> reaches a height of 1-2 km rather quickly, making it reasonable to use 850 mb trajectories in the search for the SO<sub>2</sub> emission areas. Now, elevated ozone levels occur in fair, stable weather with a relatively low inversion height. Such inversions cause a time lag of the order of 24 hours for the pollutants to reach a height where 850 mb trajectories can be adopted to represent the transport channel. The trajectory adopted near the source results in large uncertainties in the direction of transport; furthermore, the wind speed may be strongly overestimated, resulting in overestimates of the transport distance. It must be said that there has been a tendency to use the 850 mb trajectories rather uncritically, pointing out the source area of an observed high concentration with great accuracy.

Until the synoptic level 925 mb is available, representative trajectories can be constructed by combining 850 mb and ground trajectories. The ground trajectories are attached to the 850 mb trajectories at 6 hours intervals, making a pollutant collecting fan or skirt. Instead of a thin line pointing at one specific site we now obtain a collecting area or a collecting sector.

Now, applying this technique to one specific situation at Bjørnstadjordet in southern Telemark, Norway, July 14 to July 17, 1976, gives some interesting results. Each of these days ozone levels exceed the U.S. National Ambient Air Quality Standard of 80 ppb, with a peak in the evening on July 16 of 103 ppb. In all the studies the trajectories have the typical skirt pattern, but at the 12 GMT and 18 GMT calculations, with the 850 mb trajectories indicating transport from southern England, the ground trajectories bend almost parallel to the 850 mb trajectories. Hence, the wind direction is in this case constant by height, with a minimum of horizontal diffusion out from the channel, and one might conclude that long range transport of air pollutants from southern England is a major contributor to the elevated ozone on this day from noon until late evening.

## WHAT CAN BE EXPECTED FROM PHOTOCHEMICAL TRANSPORT MODELS ON THE SYNOPTIC SCALE ?

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Some kind of answer to the question in the title may emerge if one looks at the performance of present-day synoptic scale transport models. An attempt is made to locate the main sources of error for concentration predictions with these models. As the models mostly have been applied to sulphur transport, the only chemistry included being simple parameterizations of sulphur dioxide to sulphate transformation, emphasis is put on errors arising from simplifying model assumptions concerning meteorology.

### Types of models

Synoptic scale transport of photochemical oxidants should be considered as an "event" phenomenon. The type of model which has been most extensively applied, and which is capable of giving predictions on an event basis, is the simple advection model. Its main features are:

- constant mixing height
- variables are  $f(x, y, t)$
- horizontal resolution usually  $\approx 100$  km, and so horizontal diffusion is usually neglected.

Integration can be performed either in a Eulerian or a Lagrangian manner.

### Eulerian integration:

All variables are specified at points in regular grid. A photochemical box model must be run for each gridpoint. Storage problems on computer may occur. Undesired computational dispersion should be reduced by the use of suitable numerical integration methods.

Lagrangian integration:

Air parcels are followed along trajectories; box models are used for air parcel chemistry. It is difficult to treat horizontal or vertical diffusion properly if these processes are included.

In other models, puffs of various shapes are tracked (cylindrical puffs, Gaussian puffs, etc.). Obviously, chemistry will eventually distort puffs with Gaussian concentration distributions, thus such models are only useful for inert species.

What sort of results do we get with advection models?

When applied to sulphur transport, comparison between predicted and measured values using correlation coefficient  $R$ , gave the following results.

- Spatial distribution over Europe of 24 hour average concentrations on preselected days:

$R$  = insignificant to 0,80 (N = 30 stations)

- Time series of 24 hour average concentrations at one station:

$R(\text{SO}_2)$  = insignificant to 0,7

$R(\text{particulate SO}_4)$  = 0,3 to 0,8 (N = 180 days)

Particulate sulphate predictions fit better with observed values than do the sulphur dioxide predictions, in spite of the simple parametrization of the transformation using a constant rate.

Main sources of errors for concentration prediction with advection models arising from meteorological factors

a) Uncertainty arises in trajectory calculations, or, for Eulerian models in advection wind. Errors accumulate along trajectories. Average "angular distance" between different types of trajectories for a transport distance of 1000 km were:

850 mb vs. surface geostrophic:	Mean 246, Median 140 km
Surf. wind vs. surf. geostrophic:	Mean 566, Median 560 km
Surf. wind vs. 850 mb	Mean 626, Median 520 km

- b) No description is made of varying vertical concentration distribution. This is increasingly important for averaging time shorter than 24 hours.
- c) Wind shear and vertical diffusion are important for averaging times less than 24 hours, particularly in stagnant situations.

#### Tentative conclusion

Using techniques similar to the ones outlined above, agreement between measured and predicted concentrations might be expected to be "somewhat better than just qualitative" provided the averaging (sampling) time is comparable to 24 hours. Such time averaging may not hopelessly reduce the number of interesting events, since ozone concentrations due to long range transport may persist both night and day. Advection models on the synoptic scale are near to useless for 6 hr averaging times in stagnant (high-pressure) situations.

## OZONE CONTROL STRATEGIES IN THE UNITED STATES AND THE ROLE OF LONG-RANGE TRANSPORT

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### 1 History-Status-Requirements

The Clean Air Act of 1970 required States to adopt regulations to achieve the National Ambient Air Quality Standards for photochemical oxidants. States submitted their regulations to EPA for approval as part of their implementation plan in April 1971. At this date 97 urban areas over 200,000 population (representing approximately one half of the U.S. population) still have ambient concentrations greater than the present 0.08 ppm oxidant standard. Revised State implementation plans with additional regulations to achieve the national standards are required for all non-attainment areas by January 1979. Standards must be achieved by 1982. In areas where States can demonstrate that standards cannot be achieved by 1982 through the use of reasonably available control technology an extension can be granted to 1987.

### 2 Transport Studies

A number of long-range transport studies have been conducted in the U.S. to study the behavior of air pollutants in the atmosphere. These studies have focused on the chemical and meteorological processes by which gaseous effluents are reacted or transformed during transport.

Additional studies are underway or planned in a number of areas throughout the U.S. to validate models. Much of the work over the next 2-3 years will focus on improvement of urban models. Studies will be conducted in 5-6 urban areas across the U.S.

Although urban scale models have been well developed, they have not been adequately validated. These field studies are designed to validate and demonstrate model applicability in diverse geographic urban areas. In addition, studies are continuing to validate long range regional models using data from an already completed study of the northeastern U.S.

### 3 Models

The U.S. currently uses four basic types of models to understand the photochemical oxidant problem. These models include: (1) photochemical dispersion models, (2) linear rollback, (3) empirical kinetic modeling approach (EKMA), and (4) statistical methods. Dispersion models have the greatest potential for evaluating the effectiveness of oxidant control strategies but require significant data before they can be utilized. EKMA uses a kinetics model to express maximum afternoon ozone concentrations as a function of non-methane hydrocarbons. Linear rollback is an alternative for estimating limits on control requirements for organic precursors. Data requirements for linear rollback are less than EKMA. Statistical approaches are generally limited to considering moderate changes from base controls. The basic purpose of these models in air quality management is to estimate controls needed to attain standards and to estimate reductions in ozone concentrations resulting from precursor emission reductions.

### 4 Control Strategy

Over the next few years, EPA's strategy for implementation will be oriented to controls in individual urban areas. Such a strategy will reduce the highest ozone levels where most of the population resides. This approach also considers the limits of currently available models, which provide reasonable means for control strategy planning on the urban scale. A key problem in implementing the current U.S. strategy is the difficulty in accounting for regional transport of ozone and precursors. This problem is particularly acute in the northeast corridor of the U.S. where inter-urban transport is significant.

THE ROLE OF THE OECD IN THE FIELD OF LONG RANGE  
TRANSPORT OF PHOTOCHEMICAL OXIDANTS

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Given the proposals for future research co-operation, we have to agree on:

- a) what is necessary,
- b) the form of the work,
- c) the timing of the work,
- d) the forum for the research co-operation.

The framework within which the OECD Air Management Group functions, is the 24 member countries, the Council and Secretary General, and the Environment Committee and Environment Directorate.

The Air Management Group of the OECD has carried out work on photochemical oxidants and their precursors since the early 1970's:

- a) Case studies of the oxidant situation in United States, Japan and Australia.
- b) The situation on photochemical oxidants in western Europe and Canada.
- c) The scientific aspects of emissions of precursors, formation, transformation, transport and effects.

The current phase of the OECD work on oxidants is on emission sources of oxidant precursors and techniques and cost of controls. The final objective of the programme will be to consider various control strategies and their impacts from an international perspective.

The OECD carried out as a "Part II" programme a long range transport study of sulphur in Western Europe, and this has provided the platform for the current ECE programme on sulphur transport.

THE ECE CO-OPERATIVE PROGRAMME ON MONITORING AND EVALUATION  
OF LONG RANGE TRANSMISSION OF AIR POLLUTANTS IN EUROPE

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The "Co-operative programme for monitoring and evaluation of long range transmission of air pollutants in Europe" is carried out under the auspices of the United Nations Economic Commission for Europe (ECE) in co-operation with United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO). The Programme started 1 October 1977 and its main objective is to "provide governments with information on the deposition and concentration of air pollutants, as well as on the quantity and significance of long range transmission of pollutants and fluxes across boundaries". The basic components of the Programme are emission data, daily sampling of air and precipitation, and atmospheric transport models. Three centres have been established for co-ordination of the work; a chemical centre at the Norwegian Institute for Air Research, and two meteorological centres, one at the Norwegian Meteorological Institute in Oslo and one at the Hydrometeorological Institute in Moscow. The work at the centres is funded by UNEP.

At present, 42 stations are in operation in 12 countries. In the near future, stations will be established in 6 additional countries. Initially the Programme is devoted to the study of sulphur compounds in air and precipitation, although it is anticipated that subsequently it may be expanded to include other air pollutants. Measurements of nitrate and ammonium in precipitation is already undertaken at a number of stations. At a smaller number of stations also concentrations of nitrogen dioxide are determined.

APPENDIX 3

LIST OF PARTICIPANTS

THE LONG RANGE TRANSPORT OF PHOTOCHEMICAL OXIDANTS:  
A PLANNING CONFERENCE ON FUTURE RESEARCH CO-OPERATION

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