POTENTIAL USE OF OZONE MEASUREMENTS IN NUMERICAL WEATHER MODELS

D. Cariolle and S. Muller
Direction de la Météorologie
EERM/Centre National de Recherches Météorologiques
42 Avenue Coriolis, 31057 Toulouse, France

Summary: This article discusses the possible use of ozone measurements in numerical weather models and analysis. It is shown that the displacement of small scale irregularities in the ozone field is correlated to the upper tropospheric wind and that using the NOAA-TOVS operational data a consistent set of "100 hPa satellite winds" can be obtained. In addition a very good consistency is found between the behaviours of the total ozone column and the potential vorticity evaluated on the 350 K potential temperature surface, near the tropopause.
The possibility of the introduction of ozone as an interactive variable in weather forecasting models is discussed. Despite that the ozone concentration results from a delicate balance between photochemical processes (which involve about 30 minor species and 100 chemical reactions) and transport, a simple scheme has been derived to compute the chemical ozone sources and sinks. The cost of this scheme is moderated, of the order of 7% of the total computational cost.
It is concluded that valuable data and model predictions of upper tropospheric-lower stratospheric dynamics can be obtained by a continuous monitoring of the ozone density: the total ozone columns and the vertical profiles. This can only be achieved by a long term satellite measurement program, which is unfortunately not yet planned.

1. INTRODUCTION

Ozone is the main absorbent of the U.V. solar radiation and contributes to the thermal structure of the upper atmosphere. Most of the recent studies on the ozone behaviour have been related to the actual concern on the long term evolution of the ozone layer, with evidences of ozone depletion (the springtime Antarctic "ozone hole" phenomenon) due to the destruction by the chlorine released by the photodissociation of the chlorofluorocarbons.

Much less attention has been paid to the possible use of ozone data to study atmospheric dynamics. Because of its long photochemical lifetime in the lower stratosphere-upper troposphere, it is a very good tracer of motions at the tropopause level. As such it can give valuable informations on the tropopause level and the upper troposphere jet intensity during events of upper level cyclogenesis (Shapiro et al., 1982). It is the purpose of this short article to give further examples of the use of ozone measurements to obtain wind determinations, and more generally to discuss the possible introduction of ozone data in weather forecasting systems.

2. THE MAIN CHARACTERISTICS OF THE OZONE LAYER

2.1 Structure of the ozone field in the stratosphere

Due to the extension into the equatorial stratosphere of the vertical motions associated to the hadley cell, there is less ozone at low latitudes than at high latitudes (figure 1). The maximum ozone densities are encountered at equatorial latitudes near the 30 hPa level, and shift progressively poleward and downward to the lower stratosphere.

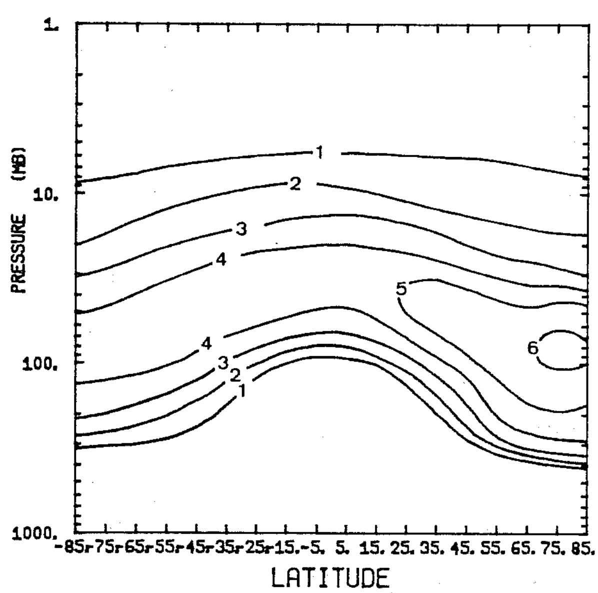


Fig.1 Climatological mean distribution of the ozone density in January

Ozone is produced by photodissociation of molecular oxygen in the upper stratosphere near 40 km (about 4 hPa).

This production is counterbalanced by destruction due to various chemical catalytic cycles. The nitrogen oxide cycles dominate between 20 to 40 km.

In the lower stratosphere, the chemical destruction is mainly due to the hydrogen cycles. Nonetheless the destructions rates are small and the photochemical lifetime is long below 20 hPa (Figure 2). In particular between 200 hPa and 30 hPa the relaxation time is larger than 100 days and ozone can be considered as a passive tracer.

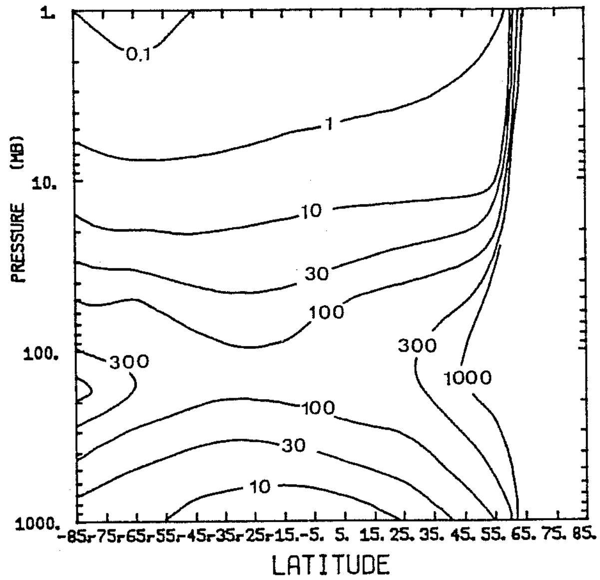


Fig.2 Ozone photochemical relaxation time (days) (from Cariolle and Déqué,1986).

2.2 Available ozone measurements

The ground-based Dobson ozone network provides total ozone column measurements which are suitable to search for a possible long term trend in the ozone content. But for the purpose of dynamical studies this network clearly lacks for spatial resolution.

Satellite measurements are the only means to obtain a continuous O_3 monitoring at the global scale. The Total Ozone Mapping Spectrometer (TOMS) provides daily global total ozone maps during day-time with a resolution of 100 km and an accuracy of about 5%. Several algorithms have been derived in the US and France to obtain ozone column measurements from the TOVS/HIRS2 radiances (see description below). It is now possible to determine O_3 during day and night with an accuracy of 10% and a resolution of 35 km. With two satellites in operation, a global O_3 map can be obtained every 6 hours.

Vertical O_3 profiles are given by ground based stations, and SBUV and SAGE instruments. The accuracy is better than 10% with a vertical resolution of about 2 km above the tropopause level for the satellite determinations, and better than a few hundreds of meter for the chemical sondes launched from the stations. However the horizontal resolution that can be obtained from the combination of all those vertical profiles is very coarse compared to the current resolution of weather forecasting models.

3. MEASUREMENTS OF STRATOSPHERIC WINDS FROM THE TOVS DATA

3.1 TOVS/HIRS2 Data analysis at DMN/EERM

Total ozone column determinations are obtained from the TOVS/HIRS2 radiances using the algorithm described by Muller and Cayla (1983). The ozone transmittance is deduced from the 9.6 micron, the 11 micron (surface temperature) and the 14.7 micron (ozone layer mean temperature) raw radiances. A statistical regression relating ozone content and Tr has been derived using the 4A transmittance model (Scott et al.,1981).

Comparison with TOMS made during the MAP/GLOBUS campaign in September 1983 over Europe (Muller and Krueger,1987) has shown good agreement between the two methods. In clear sky condition the accuracy of the IR method is about 5% at midlatitudes.

In case of partially cloudy spots, our method gives an over-estimation of Tr that leads to an underevaluation of the total ozone content, which can be as large as 10% in case of high tropospheric cirrus clouds. The very special case of Polar Stratospheric Clouds has been discussed by Cariolle et al.,1988. The area covered by these clouds are clearly identified by the very cold brightness temperature at 11 micron and the failure of the retrieval algorithm.

In any case only the time-evolution of the relative ozone maxima are considered to obtain displacements and the cloud contamination problem is alleviated.

3.2 Determination of O_3 winds.

Satellite NOAA 9 and 10 data have been collected twice a day over Europe during March 1987. They have been calibrated and localised at the Centre de Météorologie Spatiale (DMN/EERM, Lannion, France) and processed using the above method to obtain total ozone content. The time resolution was about 6 hours and more than 120 fields have been obtained for the duration of the campaign.

The small scale (about 100km) maxima are localized using an interactive image processing system, with an enhancement

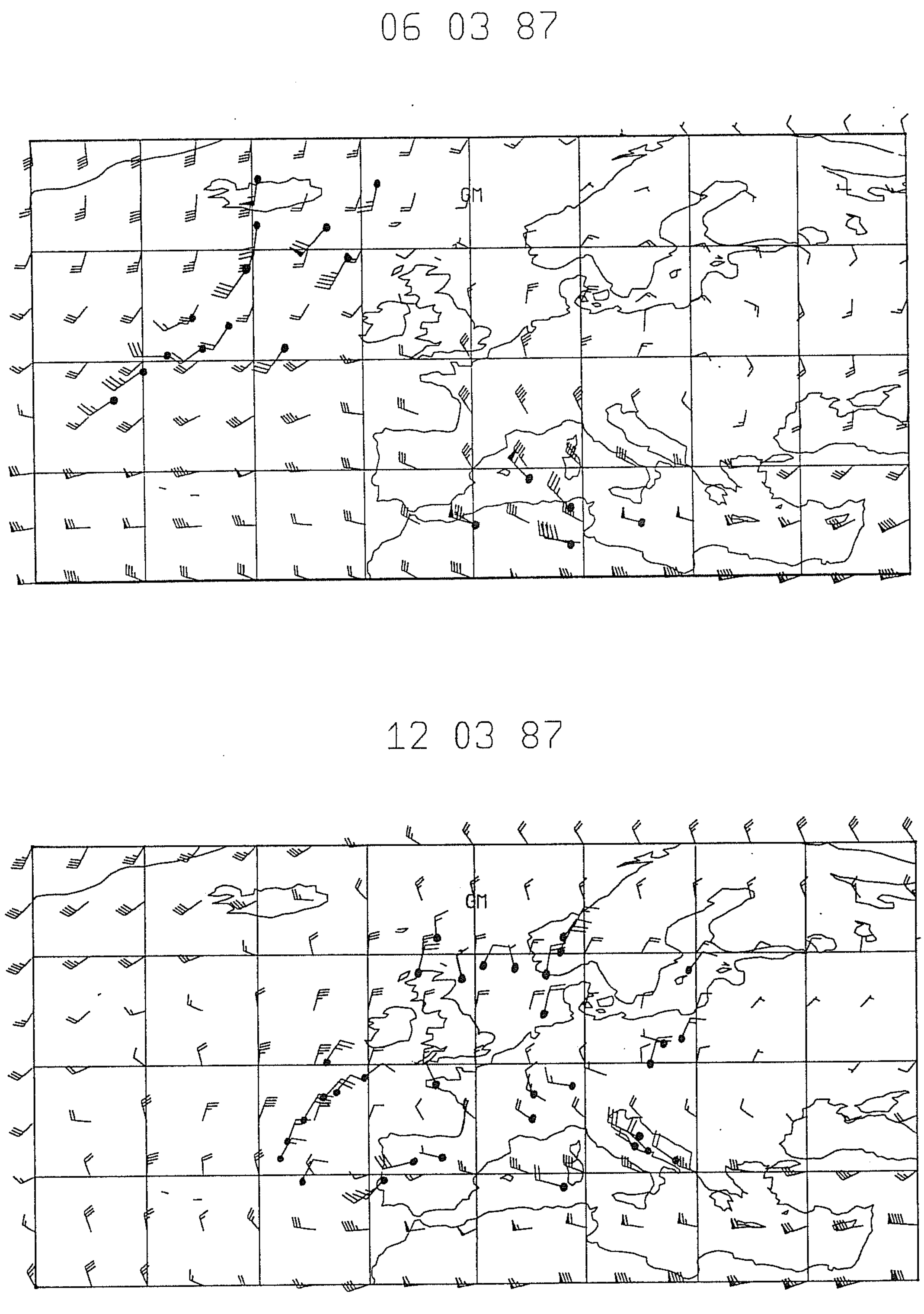


Fig.3 "ozone winds" (pointed arrows) and 100 hPa ECMWF analysed winds for (a) March 6, and (b) March 12, 1987.

contrast facility to point out more easily the ozone gradient. Maxima were retained when the ozone content exceeded the surrounding values by at least 15 Dobson units. Their time rate of change may be up to 40 Dobson units per day, so that typically, maxima could disappear in less than one day. The study of the evolution of the ozone field from map to map shows that these small-scale features can be successfully tracked. Thus horizontal winds can be derived from the displacements of the local maxima. About 200 of those winds have been obtained during the campaign.

To evaluate the altitude range where ozone maxima are advected, a comparison have been made with the ECMWF wind analysis. Ozone winds were found to be highly correlated to the 100 hPa wind of the analyses, 115 hPa being the level of best fit. The root mean square difference between the winds at that level and the ozone winds was less than 5 m/s, a value comparable to what is typically obtained from the cloud displacements in the troposphere.

Figures 3a and 3b give two examples of wind retrievals obtained the 6 and 12 March 1987. On March 6 most of the ozone winds are obtained in the vicinity of the jet located in the Atlantic, west of British Islands. The magnitude and the direction of those winds compare well to the 100 hPa winds from the ECMWF. On March 12 there is a cut off of the circulation, with the winds turning clockwise around the centre of minimum geopotential located north-west of Spain. A second branch of the circulation is encountered in the Mediterranean basin. Ozone winds consistent with analysed winds are determined over Italy in the north side of the jet.

4. OZONE AND POTENTIAL VORTICITY

The usefulness for dynamical studies of the determination of the Erterl's Potential Vorticity (EPV) has been demonstrated by Hoskins et al (1985). In particular they have shown that it is possible to compute winds and temperature from the knowledge of the EPV fields. In the upper troposphere- lower stratosphere sources and sinks of EPV due to radiative and diffusing processes are weak. The only notable source could be due to breaking of orographic gravity waves. Thus both lower stratospheric EPV and O_3 can be considered as passive tracers for timescales of the order of a few days.

Several observational and model studies have already given examples of the good correlation between EPV and O_3 behaviours in the mid and high stratosphere (Leovy et al.,1985; Cariolle and Simon,1988), as well as in the lower stratosphere during tropopause folding events (see the WMO report: Atmospheric Ozone 1985).

Further illustration of this property is given by the comparison of the evolution of the total ozone fields and the potential temperature on EPV surface (an other conservative quantity) during the 15-16 October 1987 storm, a very extreme case of upper atmospheric cyclogenese development.

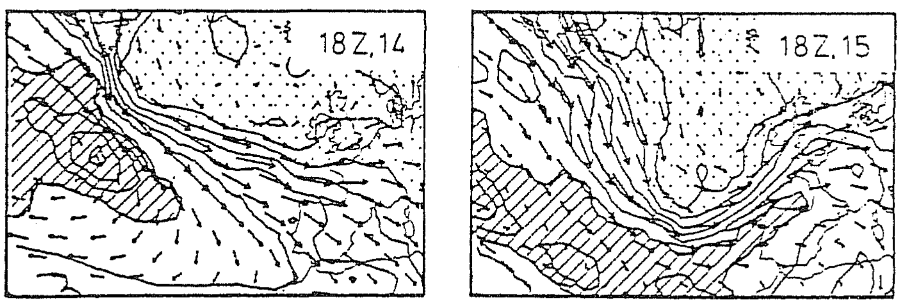


Fig.4a Contours of the potential temperature on a EPV surface close to the trpopause level on October 14 (14 UTC) and 15 (15 UTc),1987 (from Hoskins and Berrishford,1988).

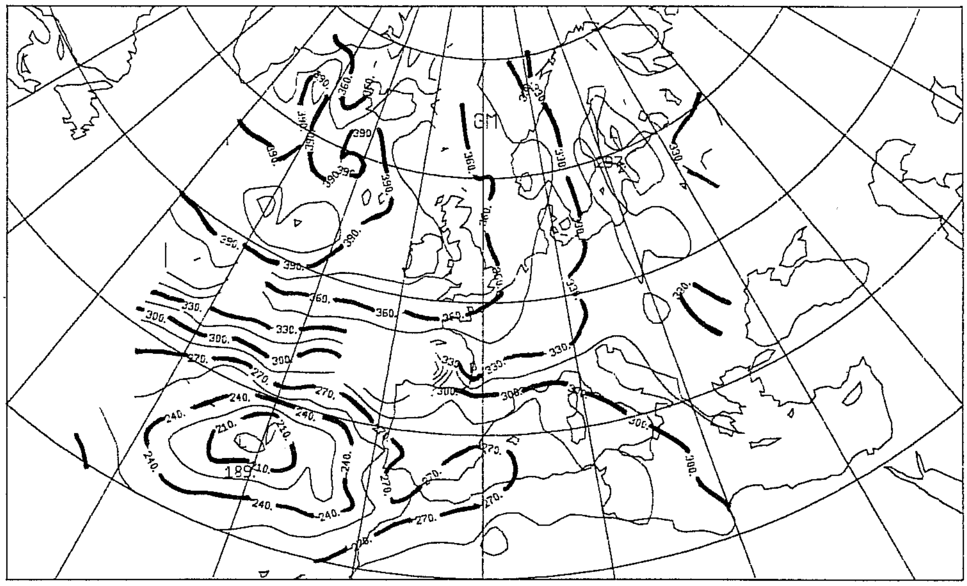
Figures 4a,b clearly show the very good consistency between variations of the potential temperature and ozone, with the advection of equatorial air (with low ozone content) from the Atlantic over Spain and France on the 14 October and the rapid descent of the polar air (with high ozone content) over the Atlantic, west of Great Britain.

It is thus likely that the knowledge of the ozone evolution will give very valuable information on the dynamical state of the lower stratosphere.

To take full advantage of this property numerical weather forecasting systems should assimilate the ozone measurements and hence must be also able to predict the ozone evolution.

At the present time O_3 mixing ratios in numerical weather prediction models (NWPM) are specified according to

TOTAL OZONE, OCTOBER 14, 1987



TOTAL OZONE, OCTOBER 15, 1987

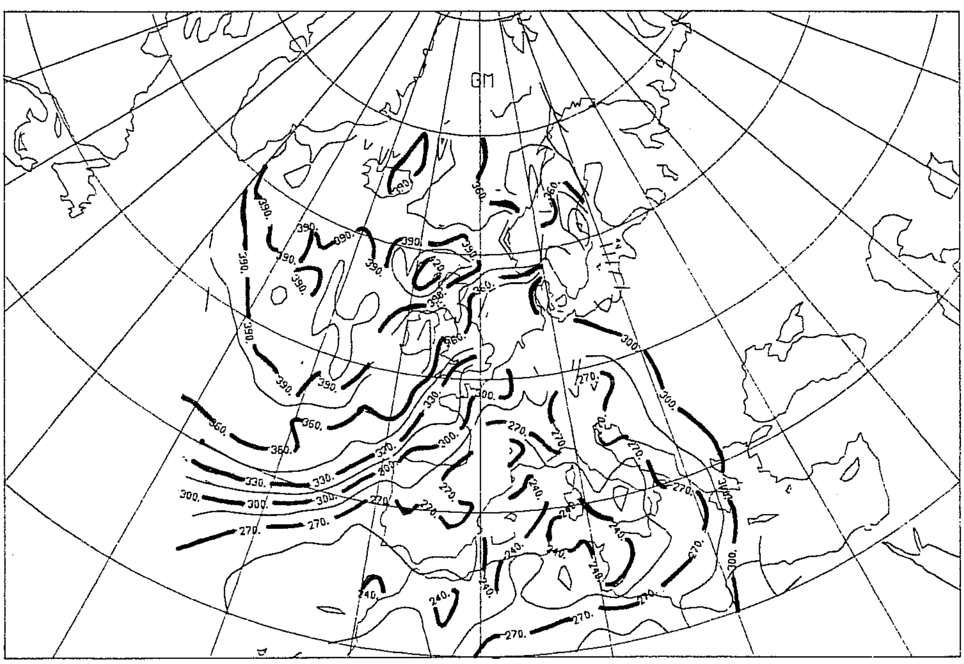


Fig.4b Total ozone maps (Dobson units) for the October 14 (between 18-20 UTC) and the 15 (20 UTC). Note the good consistency with the evolution of the potential temperature on constant EPV surface given by figure 4a.

climatological mean data, regardless of any information on the dynamical state of the upper troposphere and stratosphere.

A few GCM use interactive O_3 mixing ratio. For instance at the DMN/EERM (Cariolle and Déqué,1986) a scheme that calculates the O_3 photochemical production and loss rates has been derived and O_3 is treated as a fully interactive variable. The computational cost of this approach is of the order of 7% of the total.

5. CONCLUSIONS

Apart from the continuous research work on the improvement of existing algorithms to measure O_3, more work should also be directed toward the operational use of O_3 data in weather prediction systems.

Recent work has shown that the use of elaborated diagnostics like EPV can lead to a better interpretation and validation of the model results. A similar approach is conceivable and should be evaluated in the case of the O_3 data. This includes the possibility to introduce O_3 in the assimilation system as well as in the model itself.

6. REFERENCES

Cariolle, D. and M. Déqué,1986: Southern hemisphere medium-scale waves and total ozone disturbances in the spectral general circulation model. J.Geophys.Res.,91,825-846.

Cariolle, D., M. Déqué and P. Simon,1988: Simulation of the northern hemisphere ozone distribution with a general circulation model. Proceedings of the Quadrenniel Ozone Symposium, P. Fabian ed., in press.

Cariolle,D., S. Muller, F. Cayla and P. McCormick, 1989: Mountain waves, polar stratospheric clouds and the ozone depletion over Antarctica. J.Geophys.Res.,in press.

Hoskins,B.J., and M.E. McIntyre and A.W. Robertson,1985: On the use and significance of isentropic potential vorticity maps. Quart.J.Roy. Meteor.Soc.,111,877-946.

Hoskins,B.J. and P. Berrisford, 1988: A poptential vorticity perspective of the storm of 15-16 october 1987,Weather,43,122-129.

Leovy,C.B., C-R. Sun, M.H. Hitchman and E.E. Remsberg, 1985: transport of ozone in the Middle Stratosphere: Evidence for planetary wave breaking. J.Atmos.Sci.,42,230-244.

Muller,S. and F.R. Cayla,1983: Total ozone measurements derived from TOVS radiances. Planet. Space Sci.,31,779.

Muller,S. and A.J. Krueger,1987: Analysis and comparison of ozone maps obtained by TOMS and TOVS during the MAP/GLOBUS 1983 campaign, Planet. Space Sci.,35,539-545.

Scott,N.A. and A. Chedin,1981: A fast line-by-line method for atmospheric absorption computations: the automatized atmospheric absorption atlas, J.Appl.Meteor.,20,802-812.

Shapiro,M.A.,A.J. Krueger and P.J. Kennedy,1982: Nowcasting the position and intensity of jet streams using a satellite-borne Total Ozone Mapping Spectrometer, in Nowcasting, ed. by K.A. Browning, Academic Press, p137-145.