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Ozone during sudden stratospheric warming a three-dimensional simulation

by

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FOREWORD

This paper was presented at the ozone symposium held in Thessaloniki (Greece) on September 3-7, 1984. It will be published in the proceedings of the meeting.

AVANT-PROPOS

Cette note a été présentée au symposium de l'ozone qui s'est tenu à Salonique (Grèce) du 3 au 7 septembre 1984. Elle sera publiée dans les compte-rendus de la réunion.

VOORWOORD

Deze tekst werd voorgesteld op het ozonsymposium dat gehouden werd te Thessaloniki (Griekenland) van 3 tot 7 september 1984. Hij zal gepubliceerd worden in de verslagen van de vergadering.

VORWORT

Dieser Text wurde präsentiert auf der Ozontagung abgehaltet in Thessaloniki (Griekenland) von 3 vis zum 7 September 1984. Er wird publiziert werden in den Berichten der Tagung.

OZONE DURING SUDDEN STRATOSPHERIC WARMING

A THREE-DIMENSIONAL SIMULATION

by

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Abstract

This paper presents preliminary results of a 3-D coupled dynamical-chemical model which simulates the behavior of ozone during a winter stratospheric warming.

Résumé

Cette note présente des résultats preliminaires d'un modèle tridimensionnel qui, en couplant les mécanismes dynamiques et chimiques, simule le comportement de l'ozone à l'occasion d'un réchauffement stratosphérique observé durant l'hiver.

Samenvatting

Deze geeft ons voorlopige resultaten van een driedimensionaal gekoppeld dynamisch en chemisch model dat het gedrag van ozon simuleert bij een stratosferische stijging van de temperatuur tijdens de winter.

Zusammenfassung

Dieser Text präsentiert vorläufige Resultaten eines dreidimensionalen gekoppelten dynamischen und chemischen Modelles das das Benehmen des Ozones simuliert bei einer stratosphärischen Steigung der Temperatur während des Winteres.

1. INTRODUCTION

Sudden warmings which are currently observed in the winter stratosphere are believed to be due to the upward propagation of planetary waves originating in the troposphere. Major warmings are characterized by local increases of the temperature in a deep layer beyond the stratopause with values of the order of 50 K at 10 mbar appearing over a short period of time (a few days) and leading to significant changes in the rate constant of several chemical reactions. During such events, the dynamical fields in the stratosphere are completely altered, so that dramatic changes in the transport of trace constituents are expected.

The purpose of this short note is to report preliminary results of a 3-D model simulation of the ozone behavior during winter in connection with the appearance of a stratospheric warming. This paper will concentrate mainly on the middle stratosphere (12 mb or approximately 32 km) where the chemical lifetime of odd oxygen is quite long and consequently transport plays a major role. Further studies will deal with the response of ozone at higher altitude (where the direct relation between ozone chemistry and temperature becomes more important) and extend into a 3 dimensional frame the previous 2-D studies of Hartmann and Garcia (1979) and Kawahira (1982).

2. BRIEF MODEL DESCRIPTION

The 3-D dynamical model which is used in the present study is described by Rose (1983). It is based on the so-called primitive equations which are solved using a finite difference technique in a space of grid-points with a longitudinal interval of 22°5, a latitudinal interval of 5° and a vertical resolution of 3 km. The model is hemispheric and extends from 10 to 80 km altitude. Diabatic processes are parameterized using a Newtonian cooling approximation. In order to

simulate the propagation of planetary waves, a wavenumber 1 and 2 forcing in the geopotential height is imposed at the lower boundary.

The distribution and evolution of ozone is derived by solving for odd oxygen a continuity equation (see e.g. Brasseur and Solomon, 1984). The chemical source term takes into account the production of odd oxygen by photodissociation of O_2 and its destruction by direct recombination of O and O_3 as well as the loss due to the presence of odd hydrogen and odd nitrogen. In the present stage of development of the model, the water vapor (H_2O) and odd nitrogen (NO_x = NO + NO_2) content is specified by a given mixing ratio (5 ppmv for H_2O and an altitude dependent value for NO_x). Photochemical equilibrium conditions are assumed for $O(^3P)$, $O(^1D)$, H, OH and HO_2. Moreover, NO_2 is assumed to be in immediate equilibrium with NO. The model does not yet consider any diurnal variation in the solar illumination and consequently in the photodissociation rates, which is a good approximation for the low levels under consideration, where the photochemical lifetime of odd oxygen is much longer than a day. Further development of the model will include longitudinal variations in the source term instead of a zonally averaged value, as in these preliminary calculations.

3. RESULTS

In order to perform an initialisation of the odd oxygen distribution, we first run the chemical model for 25 days with the initial temperature field of the dynamical model. After this initialisation, a numerical simulation of a sudden stratospheric warming is started and performed as described in detail by Rose (1983).

At day 21 of this simulation, the zonal mean temperature between 30 km and 35 km near the pole has increased by 32°K as compared to the initial state (fig. 1). As in the real atmosphere, a simultaneous cooling in the stratosphere at low latitude and in the mesosphere at

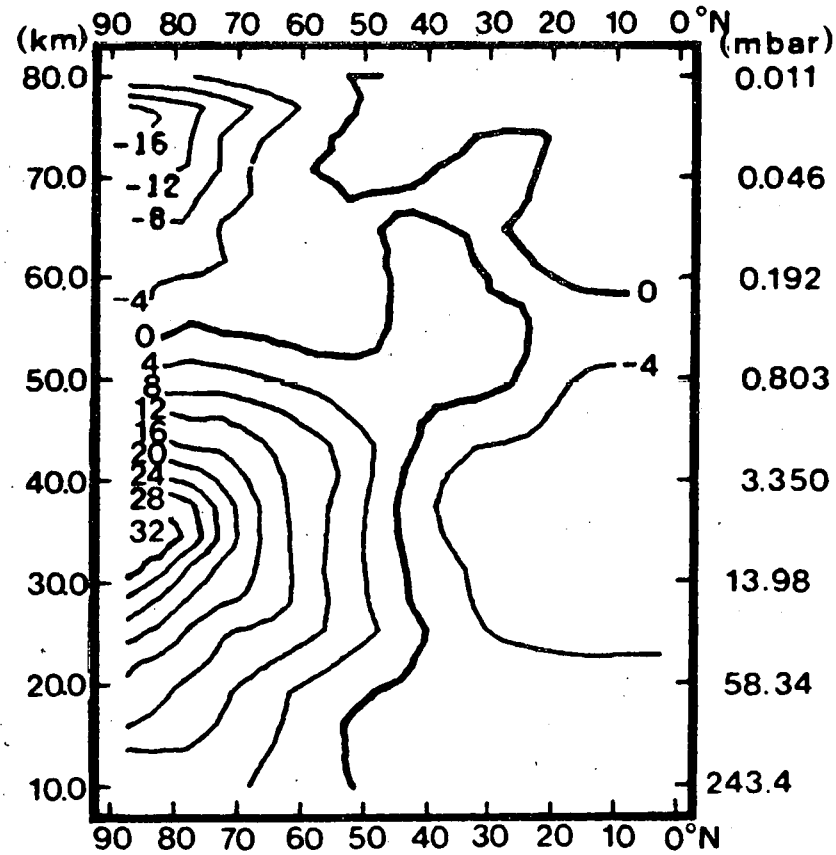

Fig. 1.- Meridional cross section of the difference in the mean zonal temperature at day 21 relative to the initial state (°K).

high latitude is observed. This change of the mean state corresponds to a southward displacement of the polar vortex (fig. 2), which had its center directly upon the pole in the zonally symmetric initial conditions. The O_3 mixing ratio, which, had also a minimum value directly upon the pole in the initial distribution at 12 mbar and which behaves as a perfect tracer in the polar night at the altitude of the 12 mbar level (fig. 3) reveals that the polar vortex might be interpreted as a material entity, since the air parcels with low O_3 mixing ratio remain in the center at the displaced vortex (cf. fig. 2). Air of relatively high O_3 mixing ratio is advected counterclockwise around the polar vortex leading to higher values in polar latitudes. In the further course of the simulation, the polar vortex is split and air from the region of highest O_3 mixing ratio is advected across the pole. At day 21, the region of small gradients in both, geopotential height and O_3 mixing ratio, seems to be the location where mixing of polar air and air from the lower latitudes takes place. So, according to ideas of McIntyre (1982), the southward displacement of the polar vortex is not a reversible moving to and fro, but rather the result of nonconservative upward propagating waves.

The meridional cross section of the percentage change of O_3 mixing ratio relative to the start of the simulation (fig. 4) displays a nearly overall increase of O_3 in the model atmosphere below 60 km. While the large changes north of 60° N are due to transport the slight increase south of 30°N is probably connected with the temperature decrease, which leads to a somewhat lower O_3 destruction rate. Thus, a sudden stratospheric warming, as simulated in the present model, leads to an hemispheric increase of O_3 in the middle atmosphere up to 60 km.

ACKNOWLEDGMENT

We would like to thank E. Falise for his very efficient help in preparing computer programs.

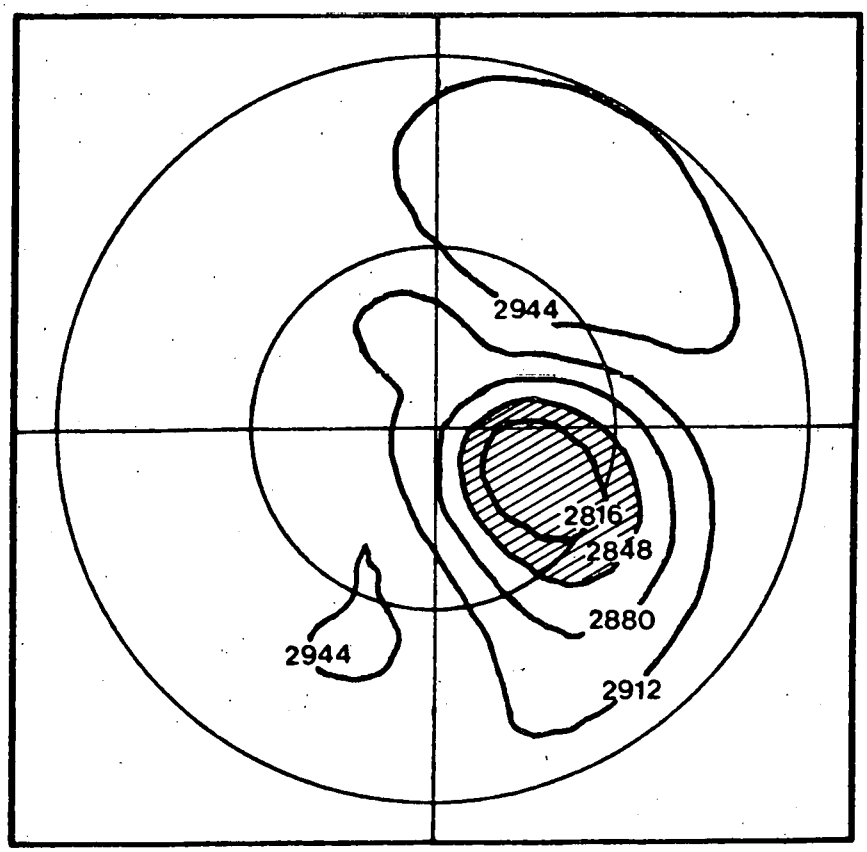

Fig. 2.- Geopotential height (gpdam) for the 12 mbar level at day 21.

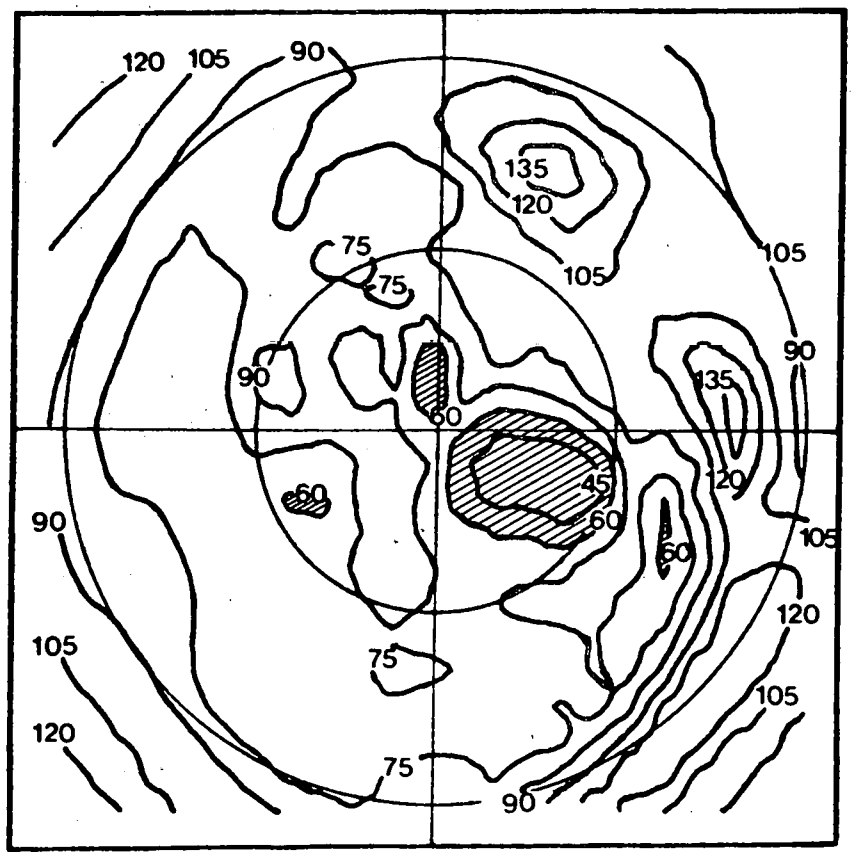

Fig. 3.- Isopleths of O_3 mixing ratio at the 12 mbar level at day 21 (10 ppm).

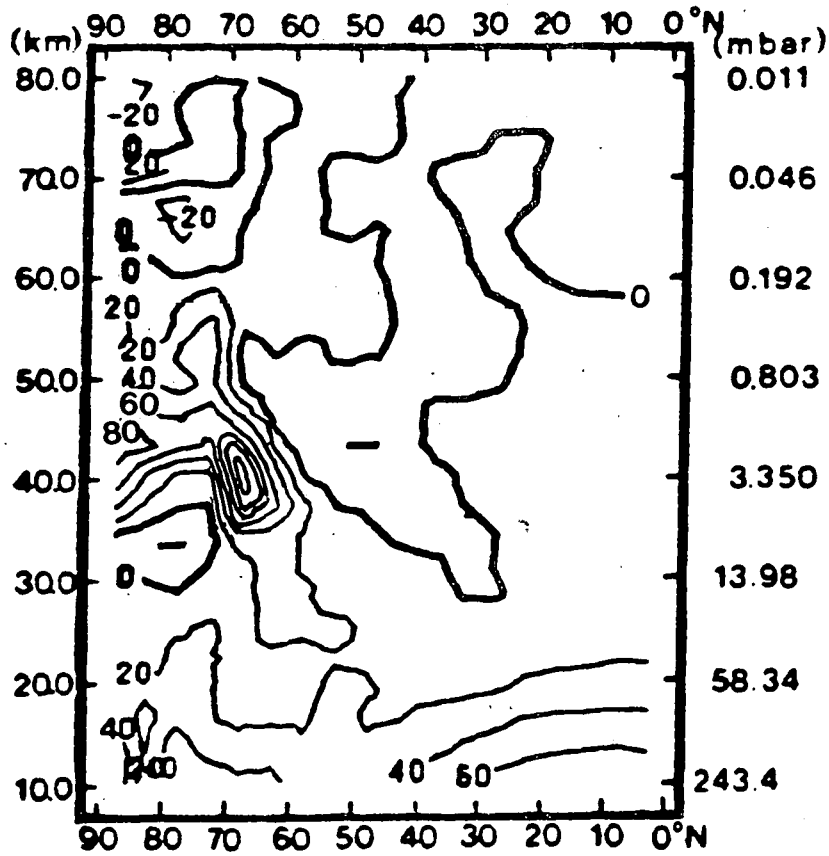

Fig. 4.- Meridional cross section of the percentage change of the O_3 mixing ratio relative to the first day os simulation (the large increase near 65°N and 40 km is due to a local minimum in the initial state).

REFERENCES

BRASSEUR, G. and S. SOLOMON, Aeronomy of the middle atmosphere, D. Reidel Publ. Cy., Dordrecht, Nederland, 441 pp.

HARTMANN, D.L. and R.R. GARCIA, A mechanistic model of ozone transport by planetary waves in the stratosphere, J. Atm. Sci., 36, 350-364, 1979.

KAWAHIRA, K., A two-dimensional model for ozone changes by planetary waves in the stratosphere. I. Formulation and the effect of temperature waves on the zonal mean ozone concentration, J. Met. Soc. Japan, 60, 1058-1062, 1982.

McINTYRE, M.E., How well do we understand the dynamics of stratospheric warmings ? J. Met. Soc. Jap., 60, 37-65, 1982.

ROSE, K., On the influence of non linear wave-wave interaction in a 3-D primitive equation model for sudden stratospheric warmings, Beitr. Phys. Atmosph., 56, 14-40, 1983.