Investigation of the Effect of Natural Phenomena and Industrial
Activity on Stratospheric Ozone Trends

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Motivation:

The long term goal of our work is to separate the effects of natural variability and anthropogenic emissions on the chemical composition of the atmosphere. In particular, we are concerned with the variability of ozone in the stratosphere and the supply of ozone from the stratosphere to the upper troposphere.

Downward trends in total ozone columns have been measured during the decade of the 1980s. The trend is small in the tropics. Ozone depletion in midlatitudes has occurred at the rate of about 2% per decade. The observed trends are partially a result of known changes in the chemical composition of the stratosphere due to the release of industrial gases which are photo-dissociated in the stratosphere. However, recent analyses of long term meteorological data sets (National Center for Environmental Prediction (NCEP)) have provided evidence that transport also subject to modulations of timescales of decades. Therefore, the trends have a dynamical component due to natural variations in planetary wave activity.

Work performed during the first 2 years of the project:

During the first phase of this project we developed an interactive two - dimensional (2D) model of the dynamics, radiation, and chemistry of the stratosphere. Details of the model and some applications are described in Schneider et al.(1998). The dynamics of the model troposphere is highly parameterized. The most important features of our model are the use of the full primitive equations in two dimensions, small horizontal mixing in the tropical regions and small mechanical damping in the lower stratosphere. As a result, transport in the tropics and the mass exchange between the tropics and midlatitude are controlled advectively. The rates of advection

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are not adjustable parameters in the model but are computed and are consistent with the ozone amounts produced within the model.

The model results exhibit several interesting characteristics. Among others, the model can explain observed ozone changes and observed temperature trends in the lower stratosphere in a consistent manner as a result of changes in the zonal forcing by planetary waves (Poster presented at the 1998 ACP meeting). Furthermore, the tropical circulation and temperature profile in the model troposphere adjusts to stratospheric changes induced by midlatitude processes (Rossby wave activity) in the troposphere. In other words, the Hadley cell does respond to changes of its upper boundary condition which is determined by stratospheric processes. An analysis of tropical temperature trends in the troposphere and lower stratosphere in the 1990s at NOAA by Lang et al. (paper presented at the AGU spring meeting) seems to support the dynamical coupling between midlatitudes and the tropics via the stratosphere as seen in our model.

Work performed during the remaining contract period.

Our representation of transport may not depend strongly on adjustable parameters, but considering our poor understanding of the dynamics of the lower stratosphere it is necessary to compare the model results with available data on long lived tracers to determine if the physical processes included in the model are indeed the dominant mechanisms which control transport.

The importance of representing transport accurately in models has also been realized in connection with the assessment of the effects of a planned fleet of supersonic aircraft. As part of this assessment, measurement campaigns have been conducted that have provided a wealth of new information on the distribution of long lived tracers and, therefore, transport in the lower stratosphere. Reproducing these measurements is an important test for models.

During the contract period, we have finalized several model analyses that were began earlier and have began to investigate the propagation of seasonally varying tracers like CO₂ and water vapor into the stratosphere. Our work consisted of:

(a) Analysing the distribution of the mean age of air as derived from Sf_6 and CO_2 measurements in the stratosphere and investigating the seasonality of the mass exchange between tropics and midlatitudes using measured $\text{CO}_2/\text{N}_2\text{O}$ correlations. We were able to show that the model reproduces the age in the lower stratosphere fairly well. The seasonally varying advective flow through the subtropics provides an explanation for the observed seasonal change of the $\text{CO}_2/\text{N}_2\text{O}$ correlation curves. In addition, we have validated the model results for N_2O , CH_4 and the CFCs against UARS and ATMOS data and shown that the results are fairly robust to changes in model parameters.

(b) Another set of observations which contains information about stratospheric transport in the tropics and subtropics are ozone and temperature fluctuations associated with the Quasi Biennial Oscillation (QBO). The QBO is also an important source of interannual variability in the stratosphere. The gravity wave momentum flux which gives rise to the QBO has been included in a version of the model and the effects of the QBO on ozone have been investigated. We have shown that the combination of using the full primitive equations and the assumption of advective control in the tropics provides a natural explanation for observed asymmetries in the ozone signal of the QBO and enables us to understand a large subset of the observed ozone fluctuations in the tropics as well as midlatitudes.

(c) In order to better understand the mass exchange between the troposphere and the stratosphere, we are in the process of analysing ozone profiles in mid and high latitudes and passive tracer profiles in the tropics in high resolution versions of the model. The propagation of tracers whose concentrations vary with season in the troposphere is an important test case for determining the relative roles of advection, vertical diffusion and horizontal mixing at the edge of the tropical regime on tracer distributions. We have completed a first part of this study and shown that the seasonal cycle of the lower stratospheric circulation can lead to different attenuation rates for the seasonal maxima and minima of CO_2 and water vapor.

Publications.

- Schneider, H. R., D. B. A. Jones, G.-Y. Shi, and M. B. McElroy: Analysis of residual mean transport in the stratosphere. Part 1: Model description and comparison with satellite data. Submitted to *J. Geophys. Res.*, , 1998
- Schneider, H. R., D. B. A. Jones, S. C. Wofsy, and M. B. McElroy: Analysis of residual mean transport in the stratosphere. Part 2: Distributions of CO₂ and mean age. Submitted to *J. Geophys. Res.*, , 1998
- Jones, D. B. A., H. R. Schneider, and M. B. McElroy: Effects of the Quasi-Biennial Oscillation on the zonally averaged transport of tracers, *J. Geophys. Res.*, *103*, , 11,235-11,249, 1998
- Jones, D. B. A., H. R. Schneider, and M. B. McElroy: An analysis of the mechanisms for the QBO in ozone in the tropical and subtropical lower stratosphere. Submitted to *J. Geophys. Res.*, , 1998
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