Final Report to the

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STUDIES OF EXTENDED PLANETARY ATMOSPHERES

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Objectives and Approach Theoretical study of physical and chemical processes in the stratosphere, later broadened to include the mesosphere. Particular emphasis was laid on testing of proposed height profiles of the eddy diffusion coefficient against observed tracer data. Eventually the effort shifted to study of ozone time series in satellite data, and interpretation in terms of aeronomical processes. Since all this work is computer-intensive, the first year of funding also contributed to the acquisition of a powerful mini-computer system, in collaboration with several other faculty members. This has proven to be highly successful and cost-effective.

Accomplishments Stress is laid on published papers, abstracts of which are included as part of this report. Included are a few papers on related work, supported mainly by other grants.

A major original objective was to revive a time-dependent 1D (one-dimensional) model of eddy diffusion and apply it to a data base of carbon-14 from the years 1963-65. Although such a study had been made by Johnston, Kattenhorn, and Whitten in 1976, their code was no longer available to test more recently proposed eddy coefficients. The problem proved rather difficult, and was only solved when Dr. Massie arrived, late in 1979. His comprehensive study was completed a year later and published in October 1981. (A similar study of the Venus thermosphere, but with a steady-state approach, was subsequently published.)

While this was going on, Hunten initiated a collaboration with R.P. Turco and O.B. Toon of the fate of the silicate vapor from ablating meteoroids. The condensation, coagulation, and fallout of this vapor was modeled and predictions were made of the density and size distribution of particles as a function of height. Although it seems likely that such particles serve as condensation nuclei for the sulfate droplets in the 20-km Junge layer, they are so small and so scarce that there seems little prospect of detecting them directly. Nevertheless, their reality can hardly be doubted. The first page of this 1980 paper is attached.

One motivation for this study was Hunten's long-standing interest in the layer of free sodium that exists around 90 km, and in particular in the huge seasonal abundance variation at latitudes above 50°. A successful model of this layer was produced on the assumption that 2% of the evaporated meteoric material is Na atoms, with photo-ionization, charge-excahnge ionization, and deposition on the dust particles as sinks. The ions are subject to a large downward velocity of electrodynamic origin and also deposit on the dust. No further assumptions are needed to produce a layer of the observed low-latitude abundance. To match the high-latitude winter enhancement, the ionization processes are essentially turned off.

In May 1981, Hunten participated in the Hampton, Va. workshop and in the writing of its report, *The stratosphere, 1981: theory and measurements*. He also was a member of the NRC study panel for its report *Causes and effects of* *stratospheric ozone reduction*. An outgrowth of this was the conception of a new second-order effect related to eddy diffusion, published in a 1983 note. It applies to a molecule, such as fluorocarbon-11, that has a very steep vertical gradient of lifetime. As it moves randomly up and down in the atmosphere, it suffers fast destruction at some times, and slow at others. The mean lifetime can, under the right conditions, be much shorter than the lifetime at the mean height. Test computations showed a potentially large effect for F-11, and the possibility of an improved fit to observations.

A 1983 paper by Bevilacqua et al. reported a set of microwave measurements of water vapor from 50 to 85 km, a region for which such information is very scarce. They also attempted to analyze the vertical gradients to generate eddy diffusion coefficients, obtaining values considerably greater than found in other studies. However, they used an analytic solution of the eddy and continuity equations that does not apply to the actual situation. Hunten, in collaboration with T.M. Donahue (University of Michigan) published a note drawing attention to this problem and suggesting a more appropriate method of analysis. This is to use the eddy and continuity equations separately instead of combining them. Both our analysis and a re-analysis by Bevilacqua et al. gave more reasonable results.

In February 1983, Dr. Massie resigned to take a position at the National Center for Atmospheric Research, a serious loss to the program. Fortunately, another member of the Laboratory faculty, Dr. L. Hood, had already begun to take an interest in stratospheric aeronomy, and the present grant was able to support a programmer for him. His approach has been to analyze existing satellite data sets to determine the amplitude and phase lags of stratospheric ozone and temperature responses to solar uv flux changes occurring on the time scale of the solar rotation period. Such results allow more accurate estimates of these responses to uv changes on longer time scales, such as that of the solar cycle. Any assessment of long-term trends in stratospheric ozone must be able to remove these solar effects first.

The first product, published in 1984, was an analysis of Nimbus 4 BUV data for short-term responses to variations in solar uv. SCR temperature data from the same spacecraft were used to obtain temperature effects, and the expected strong negative correlation was found and removed from the data with the aid of a simple theoretical model. The uv effect could then be studied; better correlation was found with the uv estimated by the method of Lean et al. than with 10.7 cm fluxes. Linear regression analyses gave estimates for the average percent change of ozone near 2 mbar and at low latitudes for a given change in the solar uv variables.

A second study, in press as this is written (April 1986), used Nimbus 7 SBUV ozone and SAMS temperature data for December 1978 to October 1980. This work was also presented at the Prague meeting of the International Association of Geomagnetism and Aeronomy and the Salzburg workshop of the Middle Atmosphere Program on climatic ozone variations, both in August 1985. The SBUV measurements were improved in coverage and accuracy over the BUV measurements and were obtained near solar maximum when there were relatively strong solar uv variations on the solar rotation time scale. In addition, direct measurements of the solar uv flux were available for wavelengths near 200 nm where photodissociation of molecular oxygen is important. It was therefore much easier to detect ozone responses in the SBUV data set to short-term solar uv variability, and it was not necessary to apply a model for the ozone-temperature relationship prior to cross-correlation analyses. Measurements of both ozone response amplitudes and phase lags relative to the uv flux changes were obtained at a series of pressure levels between 0.7 and 10 mbar. In addition, an independent analysis of the SAMS temperature data yielded evidence for small-amplitude temperature responses with phase lags from 3 days near 0.3 mbar to 10-14 days at 20 mbar. The observed ozone and temperature responses were interpreted using a linearized model for coupled ozone and temperature perturbations in the upper stratosphere where direct transport effects on ozone could be neglected.

An outgrowth of the above work was Hood's participation in an AGU session on solar variability and its effects on the atmosphere. The title page and abstract of the printed version are attached. The phase lags referred to above are interpreted as signatures of dynamical effects in the stratosphere. A proposed major source of dynamical coupling is alteration of the reflection-transmission properties of planetary waves, a process for which some observational evidence exists on the time scale of solar rotation. It is expected that this paper will be published in the JGR.

With the termination of the present grant, a continuation and expansion of this effort was proposed by Hood, Lunine, and Hunten and has been approved for funding.