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A Final Technical Report to the
National Aeronautics and Space Administration
Pioneer Venus Guest Investigator Program

Entitled:

VENUS LOWER THERMOSPHERE STUDIES :

GRANT # NAG2-679

For The Period: October 1, 1990 - December 31, 1992

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(NASA-CR-193546) VENUS LOWER THERMOSPHERE STUDIES Final Technical Report, 1 Oct. 1990 - 31 Dec. 1992 (Arizona Univ.) 5 p

N94-19418

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G3/91 0177565

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14 December 1992

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To Whom It May Concern :

This letter contains a Final Report of my work as a Pioneer Venus Guest Investigator under grant # NAG2-679. This grant began October 1, 1990 and terminated December 31, 1992. Included is a brief summary of the research undertaken and the major scientific findings and accomplishments. A listing is also given of scientific meetings and Pioneer Project (SSG/SWG) meetings attended. Finally, a summary of publications, resulting from research funded fully or partially under this grant, is given at the end of this report.

SUMMARY OF ENTIRE PROJECT : Studies undertaken in this project have sought to understand lower thermospheric structure and dynamics ($\leq$ 145 km), particularly the processes responsible. This is a region just below the reach of in-situ instruments onboard PVO during the first few diurnal cycles. PVO remote airglow observations (nitric oxide, O_2 visible, O 1304A) have been coupled with ground-based observations (CO densities, winds, temperatures, O_2 IR nightglow) to address the behavior of lower thermospheric winds and chemistry over 95 to 150 km. This interpretation of PVO and related data is accomplished by using the NCAR Venus thermospheric general circulation model (VTGCM) [Bougher *et al.*,1988; 1990]. This model has been modified over the last two years to improve its ability to calculate O, CO, and O_2 densities, temperatures, nightglow, and subsolar-to-antisolar and zonal winds over 95 to 150 km [Bougher and Borucki, 1992].

Our VTGCM studies show that: (A) O_2 visible and IR nightglow distributions can be used to trace lower thermosphere / upper mesosphere winds over 100-130 km. Typically, weak zonal winds ($\leq$25 m/sec) and nightglow maximum patches near 0100 LT prevail. Occasionally, strong zonal winds (30-60 m/sec) and airglow patches peaking near 0300 LT characterize the Venus lower thermosphere. (B) It is clear that the dynamics of the Venus 90-130 km region is highly variable on time scales as short as an hour. This is most likely due to the time variable nature of upward propagating gravity waves, which grow in amplitude and eventually break. The resulting turbulence gives rise to local time variable eddy diffusion and momentum drag, both of which strongly impact global density and nightglow distributions.(C) The oxygen chemistry (O, O_2, etc.) over 90-120 km is strongly dependent on HO_x and CLO_x tracer species that must be properly included in any coupled chemical dynamical model. (D) The density profiles of light species (O, CO, N, He) are strongly affected by large-scale transport by the winds. Strong eddy diffusion is not a suitable model parameterization for approximating these light species, especially for extrapolation into the region below 140 km where PVO in-situ data is lacking. Instead, the fully coupled chemical dynamical VTGCM model should be used to improve estimates of densities within the VTS3 empirical model [Hedin *et al.*, 1983] below 140 km. Work is underway in this regard, using new PVO entry data of July-October 1992.

VTGCM predictions were also made of the Venus nightside thermosphere (100-150 km) for comparison to ONMS and OAD measurements taken during PVO entry. Solar medium fluxes (F107=150) were used, along with unchanged eddy diffusion, eddy wave drag, and prescribed VTGCM zonal winds. Preliminary comparisons [Kasprzak and Bougher, 1992] show that the Venus nightside thermospheric temperatures and densities are quite similar to those observed previously in the PVO mission (1978-80). Nightside exospheric temperatures ($\sim$120 K) appear to remain largely unchanged throughout the solar cycle. In addition, dayside mean exospheric temperatures of about 270 K were observed by the OAD instrument during entry, in very good agreement with VTGCM model predictions. This provides a confirmation of the weak solar cycle exospheric temperature variation predicted by several model studies; strong CO_2 cooling is likely responsible for providing the thermostatic control [Bougher and Roble, 1991; Keating and Bougher, 1992].

We have identified three thermospheric factors that have a crucial influence on the O_2 visible and IR nightglow distributions and intensities. These factors may indeed be responsible for some of the day-to-day or hourly variability seen in the O_2 IR maps that have recently been obtained. The factors are also adjustable parameters within the VTGCM formulation, subject only to empirical constraints peculiar to a specific days' features, as opposed to average conditions. These factors, in decreasing order of importance, are : (a) the zonal wind profile shape (vertical and latitudinal), (b) the prescribed Rayleigh friction (wave drag) magnitude controlling SS-AS winds, and (c) nightside variable eddy diffusion. Each of these factors has been varied in the VTGCM model to test the corresponding response by the simulated O_2 nightglow distributions. However, the upward propagation of gravity waves and their impact upon the thermosphere structure and dynamics is ultimately responsible for the variability in O_2 nightglow intensities and distributions observed. A comprehensive formulation of gravity wave breaking and eddy diffusion must be incorporated into the VTGCM code in order to better understand these wave-mean flow processes [Alexander, 1992].

Other PVGI research has also been productive. The calculation of a reasonable dayside Venus mesosphere/thermosphere heat budget, consistent with observed temperatures, has been an ongoing problem for nearly two decades [see review by Fox and Bougher, 1991]. Significant progress in understanding the heat budget has been made during this project using an updated Venus 1-D model [Keating and Bougher, 1992] to examine the observed dayside thermospheric temperature variations linked to the 27-day solar rotation. The small amplitude of these 27-day temperature oscillations ($\leq$25 K) combined with the cooling necessary to maintain 300 K dayside mean exospheric temperatures may only be explained by very strong 15-μm cooling, and not by eddy thermal conduction. The collisional excitation of the CO_2 ($\nu_2 = 1$) bending mode by atomic oxygen must be very efficient (relaxation rate 2-4 x 10^{-12} cm^3 sec^{-1}) to achieve the observed features on Venus. This strong CO_2 15-μm cooling allows EUV heating efficienices spanning 18-22% to be utilized in model simulations, in accord with values suggested by the energy partitioning calculations [see references in Fox and Bougher, 1991]. Strong 15-μm cooling is supported by recent rocket and lab measurements of the CO_2-O relaxation rate at 300 K of about 2-6 x 10^{-12} cm^3 sec^{-1}. It appears that the Venus "heat budget problem" is solved. However, new problems exist for the terrestrial lower thermosphere using these large relaxation rates [Bougher, Roble, and Keating, 1992]. This study emphasizes the need to continue comparative planetology studies of terrestrial-like atmospheres.

SCIENTIFIC MEETINGS : I have attended several DPS and AGU meetings in the past 2-years, discussing my research on four Venus topics: (a) Venus. Earth, Mars comparisons, (b) the Venus dayside heat budget and related implications for other planets, (c) the Venus nightglow and its implications for dynamics and chemistry, and (d) PVO entry in 1992. Lastly, I attended the AGU Chapman Conference in Asilomar, CA. in November 1992 and presented a paper discussing the importance of our Venus thermal budget calculations in understanding Earth heat budget problems near the mesopause. (see abstract below).

SSG & SWG MEETINGS: I attended all but 1 PVSSG/SWG meeting over the last 2-years, giving a progress report on my research each time. Collaboration with Drs. Borucki, Fox, Kasprzak, Keating, and Stewart of the Pioneer Venus program was enhanced by these periodic meetings. Also, I was able to participate in discussions concerning PVO entry planning.

PUBLICATIONS RESULTING FROM THIS GRANT :

A. Papers Published or Submitted

1. Fox, J. L., and S. W. Bougher, Structure, luminosity, and dynamics of the Venus thermosphere, **Space Sci. Rev., 55**, pp. 357-489, 1991.

2. Bougher, S. W., and R. G. Roble, Comparative terrestrial planet thermospheres: 1. Solar cycle variation of global mean temperatures, **J. Geophys. Res., 96**, 11045-11056, 1991.

3. Keating, G. M. and S. W. Bougher, Isolation of major Venus thermospheric cooling mechanism and implications for Earth and Mars, **J. Geophys. Res., 97**, 4189-4197, 1992.

4. Keating, G. M., and S. W. Bougher, Venus thermospheric response to short-term solar variations, **Adv. in Space Research, 12, 9**, 111-128, 1992.

5. Bougher, S. W., Comparative thermospheres: Venus and Mars, **Adv. in Space Research, XX**, submitted, 1992.

6. Bougher, S. W., and W. J. Borucki, Venus O_2 visible and IR nightglow: Implications for lower thermosphere dynamics and chemistry, **J. Geophys. Res. - Planets**, submitted, December 1992.

B. Meeting Abstracts Published

1. Bougher, S. W., and G. M. Keating, The Venus thermospheric heat budget problem revisited, **B. A. A. S., 22, 3**, 1053, 1990.

2. Bougher, S. W., and M. J. Alexander, Venus lower thermosphere: 3D model implications **B. A. A. S., 23, 3**, 1193-1194, 1991.

3. Alexander, M. J., A. I. F. Stewart, S. C. Solomon, and S. W. Bougher, Solar-locked features in Venus thermospheric oxygen, **B. A. A. S., 23, 3**, 1194, 1991.

4. Bougher, S. W., and A. I. F. Stewart, The Venus TGCM : Predictions for PVO entry in 1992, **Trans. Am. Geophys. Union, Supplement**, 191, 1992.

5. Bougher, S. W., R. G. Roble, and G. M. Keating, CO_2 cooling in the thermospheres of Earth and Venus, **AGU Chapman Conference, Asilomar, CA.**, November 1992.

6. Bougher, S. W., and W. J. Borucki, Venus O_2 visible and IR nightglow, **Trans. Am. Geophys. Union, Supplement**, 333, 1992.

7. Kasprzak, W. T., H. B. Niemann, and S. W. Bougher, Pioneer Venus Orbiter Neutral Mass Spectrometer (ONMS) measurements at low altitude during the re-entry, **Trans. Am. Geophys. Union, Supplement**, 333, 1992.

Lastly, I wish to express my sincerest thanks and gratitude to the Pioneer Mission Office for the opportunity to come aboard as a Pioneer Venus Guest Investigator. The research has been productive & rewarding, and the scientific and project personnel exceptionally helpful and warm! Pioneer Venus project-related research spans my entire scientific career to date. Thank you for launching my career!

Sincerely,

Stephen W. Bougher