Lawrence Berkeley National Laboratory

Recent Work

Title

INSTANTANEOUS GLOBAL NITROUS OXIDE PHOTOCHEMICAL RATES

Permalink

<https://escholarship.org/uc/item/6599t1w7>

Author

Johnston, H.S.

Publication Date

1978-07-01

Submitted to Journal
of Geophysical Research

LBL-8055
Preprint

INSTANTANEOUS GLOBAL NITROUS OXIDE PHOTOCHEMICAL

LA
RCO
OST
COL

H. S. Johnston, O. Serang, and J. Podolske

RECEIVED
LAWRENCE
BERKELEY LABORATORY

July 1978

OCT 3 1978

LIBRARY AND
DOCUMENTS SECTION

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782

LBL-8055
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Instantaneous Global Nitrous Oxide Photochemical Rates

H. S. Johnston, O. Serang, and J. Podolske

Department of Chemistry and Materials and Molecule

Research Division, Lawrence Berkeley Laboratory,

University of California, Berkeley, CA 94720

Abstract

By interpolation and extrapolation of recently observed nitrous oxide vertical profiles, a global-average atmospheric distribution of N_2O has been constructed. From standard distributions of atmospheric temperature, oxygen, ozone, and radiation above the atmosphere, three-dimensional instantaneous rates involving N_2O have been calculated and zonal averages evaluated. The altitude of maximum and median photolysis of N_2O is about 30 km at all latitudes, and the rate of photolysis is a maximum in tropical latitudes. The altitude of maximum rate of formation of nitric oxide is latitude dependent, about 26 km at the equator, about 23 km over temperate zones, and 20 km at the summer pole. The global average rate of destruction of N_2O is $9.1 \times 10^{12} \text{ g(N) yr}^{-1}$, and the global rate of formation of NO from N_2O is $1.0 \times 10^{12} \text{ g(N) yr}^{-1}$. From the global average N_2O profile, a vertical eddy-diffusion profile was derived by the method of Schmeltekopf et al. [1977], and this profile agrees very closely with that of Stewart and Hoffert [1975].

Introduction

In recent years vertical profiles of nitrous oxide have been measured from ground level up to mid-stratosphere at several latitudes between 63°N and 78°S, including one profile in the tropical zone at 9°N. Two rocket flights [Ehhalt, 1974] measured nitrous oxide mixing ratios at 44 and 49 km. These data have been reviewed by Hard [1975], Sundararaman [1976], and Schmeltekopf et al. [1977]. From these experimental data plus a large amount of interpolation and extrapolation, we have estimated a global distribution of nitrous oxide. With standard global distributions of oxygen and ozone, we have carried out instantaneous, three-dimensional, global, photochemical calculations involving nitrous oxide. These photochemical calculations used the recently measured, temperature-dependent cross sections for nitrous oxide [Selwyn et al., 1977], and it was found that the altitude of N₂O photolysis is noticeably shifted by use of the temperature dependent data. The results are presented as zonal-average contour maps of various quantities, and finally certain instantaneous global-average rates are given. Following the method of Schmeltekopf et al. [1977] we have evaluated vertical eddy diffusion profiles at various latitudes and as a global average.

Experimental Data

The standard atmospheres for temperature, air density and ozone have been described before [Johnston, 1975]. In a series of balloon flights Schmeltekopf et al. [1977] observed nitrous oxide at Alaska (63°N), Saskatchewan (51°N), Wyoming (41°N), Colorado (40°N), New Mexico

(32°N), Panama (9°N), and Antarctica (78°S) between Jun 1975 and August 1976. Tyson et al. [1978] measured nitrous oxide by aircraft and by balloon, and their profile between 21 and 36 km at 32°N over Texas was quoted by Sundararaman [1976]. Ehhalt et al. [1974] and Ehhalt [1974] obtained a vertical profile of nitrous oxide up to 32 km by means of a balloon flight, and they collected air samples above 40 km in two rocket flights. These data are presented in detail by Hard [1975]. The rocket flights gave values of 2 ppbv at 49 ± 6 km and 6 ppbv at 44 ± 5 km.

The data of Ehhalt and of Tyson et al. at 31°N are entered on Figure 1, including the points at 49 and 44 km. The data are plotted as the logarithm of N_2O mixing ratio versus altitude. Ehhalt's profile has a hump in mixing ratio between 23 and 28 km, and the values are far larger than those of Tyson et al. A smooth curve was drawn through Ehhalt's and Tyson's measurements, Figure 1, including the measurements at 44 and 49 km. This curve is a straight line between 32 and 49 km, passing respectively through 80 and 2 ppbv.

Each observed profile was plotted as the logarithm of mixing ratio (ppbv) against altitude. The highest altitudes where measurements were made varied between 28 km at Antarctica to 36 km at Alaska and at Texas. Extrapolation to higher altitudes was based exclusively on Ehhalt's observations by balloon and by rocket. Between 45°N and 45°S, each profile was extended by a straight line from the highest observed point to Ehhalt's value of 2 ppbv at 49 km. For the data at Panama, this method of extrapolation is illustrated by Figure 1. Poleward of 45°N or 45°S, the

extrapolated straight line was taken to be parallel to Ehhalt's curve (2 ppb at 49 km, 80 ppb at 32 km), and this parallel line was anchored to the observations at the highest altitude.

These extrapolations were carried out before we saw the article by Schmeltekopf et al. [1977], and our method of extrapolation is different from theirs, especially so for the Panama data. In Figure 6 by Schmeltekopf et al., nitrous oxide mixing ratios are plotted on a logarithmic scale against altitude, which is the same sort of plot that we made. Apparently, the data were extrapolated as a straight line above the altitude of observations on the basis of the slope of the top of the observed curve in each case. Their extrapolated value for Panama is about 43 ppb at 45 km, whereas our value is 7 ppb at 45 km. Figure 1 shows the experimental points at Panama, 9°N, between 17 and 32 km. Also included are the extrapolated line as used in this study and that used by Schmeltekopf et al. It can be seen that Ehhalt's values of N_2O mixing ratios between 23 and 28 km are very nearly the same as those observed at Panama. At the altitude of 45 km, it seems unreasonable to us that the mixing ratio at 9°N would be six times greater than that at 31°N. The study by Schmeltekopf et al. used only their own data, but we also use the data of Ehhalt and of Tyson. We believe our extrapolation of the Panama data is more realistic than that of Schmeltekopf.

We prepared a large, blank, zonal-contour map, that is, latitude vs altitude. At each latitude where observations were made, we entered the mixing ratio for each kilometer altitude from the smooth, extrapolated profile through the experimental points. All profiles were reflected to

the same latitude in the opposite hemisphere. Constant values of the N_2O mixing ratios were connected with smooth curves from one latitude to another. It was found that the profile number 2 taken at Saskatchewan, 51°N , August 1975, was inconsistent with the other data, so far as a smooth global distribution was concerned. The Saskatchewan data were excluded from further consideration. Excepting the Saskatchewan data, the smooth contour lines of nitrous oxide mixing ratios as given in Figure 2 are consistent with the observed data. These mixing ratios are taken to be the same in the northern hemisphere and southern hemisphere and to be the same between spring-fall and winter-summer. However, the differences of standard temperature and gas density between seasons and between hemispheres give different concentrations. The global concentrations of nitrous oxide are given in Figure 3 for the standard spring-fall conditions.

Photochemical Calculations

The atmosphere was divided into a network of cells where $\Delta Z = 1$ km from 0 to 50 km, $\Delta\phi = 15^\circ$ longitude, and $\Delta\theta = 10^\circ$ latitude. Of these 21600 cells, half face the sun and half are in darkness. Radiation from the sun was attenuated by oxygen and by ozone, and the intensities of radiation at every wavelength between 180 and 750 nm were evaluated in each cell. In each sunlit cell, photolysis constants and $\text{O}(^1\text{D})$ concentrations were calculated; these quantities were taken to be zero on the dark side of the earth.

Solar radiation intensities above the atmosphere at wavelengths below 205 nm were taken from Bruekner et al. [1976] and at wavelengths above 205 nm from Ackerman [1971]. Attenuation of radiation by molecular

oxygen in the Schumann-Runge region was treated by the method of Hudson and Mahle [1972]. For wavelengths above 280 nm multiple-order Rayleigh scattering and surface reflection (albedo assumed to be 0.3) were treated by the model of Isaksen et al. [1976].

The rate of photolysis of nitrous oxide

was calculated in each volume element

$$j = \sum_{\lambda} I(\lambda) \sigma(\lambda, T) \quad (2)$$

where $I(\lambda)$ is the calculated intensity at each wavelength and $\sigma(\lambda, T)$ is the temperature-dependent, absorption cross section for nitrous oxide [Selwyn et al., 1977]. For fixed latitude and altitude, the rate of photolysis was averaged for 360° longitude to give an instantaneous, zonal-average value (if one prefers, this can be thought of as a 24 hour average above one longitude). For the standard spring-fall atmosphere, these zonal-average rates of N_2O photolysis are given by Figure 4. The contour lines on the figure are for photolysis rates in units of molecules $\text{cm}^{-3} \text{sec}^{-1}$ in increments of 120 units, with a minimum rate of 30. The altitude of maximum photolysis rate is 30 km, and 30 km is also the median altitude for N_2O photolysis. The contour line of maximum photolysis rate is 30 ± 4 km at the equator and $\pm 30^\circ$ latitude. Little photolysis occurs below 20 km.

The locus of N_2O photolysis in the standard winter-summer atmosphere is given by Figure 5. Again the altitude of maximum rate and median degree of photolysis is very close to 30 km. There is a substantial

amount of photolysis above the summer pole, about 25 percent of that above the equator.

The concentration of singlet oxygen atoms was calculated in each volume element. The photochemical reactions are

$$[\text{O}({}^1\text{D})] = j_2[\text{O}_3]/k_1[\text{M}] \quad (5)$$

where ϕ_λ is the quantum yield curve of Lin and DeMore [1974] and the deactivation constant is [Davidson et al., 1977]

$$k_1 = 2.0 \times 10^{-11} \exp(107/T) \text{ cm}^3 \text{ molecule}^{-1} \text{ sec}^{-1} \quad (6)$$

The relaxation time for singlet atomic oxygen is much less than one second throughout the stratosphere and troposphere, and the steady-state relation is an excellent approximation. The zonal-average values of singlet oxygen atoms are given for spring-fall by Figure 6 and for winter-summer by Figure 7. In the summer hemisphere the zonal average concentration of singlet atomic oxygen is as large over the pole as over the equator.

Nitrous oxide is destroyed by singlet atomic oxygen by two pathways

$$k_2 = k_3 = 5.5 \times 10^{-11} \text{ cm}^3 \text{ molecule}^{-1} \text{ sec}^{-1} \quad (9)$$

The rate of destruction of nitrous oxide by $O(^1D)$ is

$$\text{Rate} = (k_2 + k_3)[N_2O][O(^1D)] = 1.1 \times 10^{-10}[N_2O][O(^1D)] \quad (10)$$

The rate of formation of nitric oxide is twice the rate of reaction 2, since each occurrence of the reaction produces two molecules of NO

$$\frac{d[NO_x]}{dt} = 2 k_2[N_2O][O(^1D)] = 1.1 \times 10^{-10}[N_2O][O(^1D)] \quad (11)$$

The rate of production of nitric oxide for spring-fall conditions is given by Figure 8 and for winter-summer conditions by Figure 9. The locus of NO production is substantially different from that for N_2O photolysis. The photolysis rate is very nearly symmetrical in altitude about the altitude of maximum rate, Figures 4 and 5. The rate of NO production is arched over the tropics, the high rate in equatorial regions arises from the high N_2O mixing ratios there (Figure 2), and the high rate at lower altitudes in the temperate zones is caused by the high concentration of ozone and $O(^1D)$ there (Figures 6 and 7). Over the equatorial region, the maximum rate of NO formation occurs at 25 to 26 km, over temperate zones the maximum rate of NO formation occurs at 22 to 23 km, and over the summer polar region the altitude of maximum nitric oxide formation rate is 20 km, which is 10 km below the height of maximum photolysis rate there.

Average Rates and Global Rates

The zonal-average rates, Figures 4, 5, 8 and 9, were integrated over altitude at each 5° latitude to give integrated vertical column rates.

The total destruction of N_2O , (2) plus (10), is the upper curve of Figures 10 and 11. The rate of production of NO (11) is the lower curve in each of these two figures. Figure 10 gives the integrated column rates as a function of latitude for spring-fall equinox, and Figure 11 gives the rates for winter-summer conditions. The high photochemical activity of the summer polar stratosphere is interesting.

The cosine-weighted average of the column rates, Figures 10 and 11, over latitude gives the global average rate of nitrous oxide destruction. In units of molecules $cm^{-2} sec^{-1}$ these are

$$\begin{aligned} \left(\frac{dN_2O}{dt} \right) &= 1.25 \times 10^9, \text{ spring-fall} \\ &= 1.17 \times 10^9, \text{ winter-summer} \end{aligned} \quad (12)$$

and the rate of nitric oxide production is

$$\begin{aligned} \left(\frac{dNO}{dt} \right) &= 2.84 \times 10^8, \text{ spring-fall} \\ &= 2.73 \times 10^8, \text{ winter-summer} \end{aligned} \quad (13)$$

For the spring-fall situation, the global average rate of N_2O destruction (12) is equal to the local rate of N_2O destruction at 29° latitude, and the global rate of NO formation (13) is equal to the local rate of NO formation at 31° latitude. These facts are of some interest in terms of what latitude to use to simulate global average properties in terms of a one-dimensional model. The global rates of nitrous oxide loss and nitric oxide production in various units are given in Table 1. The fraction of N_2O destroyed by $O(^1D)$ relative to total N_2O loss is 23 percent.

The global average rate of production of nitric oxide according to this study is 2.8×10^8 molecules $\text{cm}^{-2} \text{sec}^{-1}$. Crutzen's [1971] original estimate of this quantity was between 0.29 and 1.5×10^8 molecules $\text{cm}^{-2} \text{sec}^{-1}$, and subsequent one-dimensional models have usually fallen within this range. However, Schmeltekopf et al. [1977] using the same data as used here found 4.5×10^8 molecules $\text{cm}^{-2} \text{sec}^{-1}$. Much of this discrepancy comes from our different methods of extrapolating the observations at Panama from 32 to 50 km (compare Figure 1). Also, we used different solar intensities above the atmosphere and slightly different models of correcting for the Schumann-Runge bands. Part of this difference depends on the strong temperature dependence of the nitrous oxide absorption of ultraviolet radiation [Selwyn et al., 1977].

Vertical Eddy Diffusion Constants

From vertical profiles of nitrous oxide and the rate of nitrous oxide loss L , Schmeltekopf et al. (page 733) gave a method for evaluating a vertical eddy diffusion profile

$$K(z) = - \frac{\int_z^\infty L(z) dz}{[M] \frac{df}{dz}} \quad (14)$$

where $f = [\text{N}_2\text{O}]/[\text{M}]$. Using cosine weighting (equal weight to equal area over the globe) over the northern hemisphere, we obtained an average profile of N_2O mixing ratio from Figure 2 and average N_2O loss profiles from Figures 4 and 8 for spring conditions. The "global average" vertical eddy diffusion profile as evaluated from (14) is given by Figure 12, and it is compared to one-dimensional K_z profiles used by

Hunten [1974], Stewart and Hoffert [1975], and Chang [1976]. The K_z function derived here is very nearly the same as that of Stewart et al. From 20 to 40 km, the present K_z function, Hunten's function, and Stewart et al.'s function are very nearly equal, but Chang's [1976] K_z is larger. Between 14 and 20 km, Hunten's K_z values are small and Chang's are larger than those of the present study. The K_z values derived here are smaller than those derived by Schmeltekopf et al., largely by virtue of our different extrapolation of the Panama data (Figure 1).

The smoothed, interpolated, extrapolated curves at each latitude 75°N, 65°N, ... 5°N, 5°S, ... 65°S, 75°S were inserted in (14) to derive local vertical eddy diffusion functions. The values are summarized as zonal average contour lines in Figure 13. The K_z profiles change strongly with latitude. At tropical latitudes ($\pm 25^\circ$) the K_z function is almost constant, $1 \text{ to } 3 \times 10^4 \text{ cm}^2 \text{ sec}^{-1}$, between 10 and 40 km. At temperate latitudes, the K_z function has a deep minimum at about 18 km and it increases smoothly to high values at high altitudes (compare Figure 12). In polar regions the apparent K_z function is vanishingly small, $10^2 \text{ cm}^2 \text{ sec}^{-1}$ between 10 and 25 km, and it builds up to values $10^4 \text{ cm}^2 \text{ sec}^{-1}$ at 40 km. If one uses some single K_z function as a global average, it appears from Figure 13 that such is an average over widely disparate local K_z functions. Figures 13 and 2 suggest that N_2O is transported into the stratosphere from the tropical troposphere by a large-scale net upward drift (Hadley cell), with diffuse subsidence in temperate and polar regions to balance the input [Brewer, 1949]. The vertical profiles of N_2O and its loss rate must be strongly influenced by meridional horizontal transport so that (14) is inappropriate for local profiles,

such as Figure 13. At best, a one-dimensional vertical eddy diffusion function applies to global average properties, and it should be evaluated and calibrated only in terms of global average properties.

Acknowledgment

This work was supported by the Division of Chemical Sciences, Office of Basic Energy Sciences, U.S. Department of Energy.

References

- Ackerman, M., Ultraviolet solar radiation related to mesospheric processes, in Mesospheric Models and Related Experiments, edited by Fiocco, pp. 149-159, D. Reidel Publishing, 1971.
- Brewer, A. W., Evidence for a world circulation provided by measurements of helium and water vapour distribution in the stratosphere, Quart. J. Roy. Met. Soc., 75, 351-363, 1949.
- Brueckner, G. E., J.-D. F. Bartoe, O. K. Moe, and M. E. Van Hoosier, Absolute solar ultraviolet intensities and their variations with solar activity. I. The wavelength region 1750-2100 Å, Astrophysical J., 209, 935-944, 1976.
- Chang, J. S., First Annual Report of Lawrence Livermore Laboratory to the High Altitude Pollution Program, F. M. Luther (Ed.), Report UCRL-50042-76, 1976.
- Crutzen, P. J., Ozone production rates in an oxygen-hydrogen-nitrogen oxide atmosphere, J. Geophys. Res., 76, 320-325, 1971.
- Davidson, J. A., H. I. Schiff, G. E. Streit, C. J. Howard, and A. L. Schmeltekopf, Temperature dependence of $O(^1D)$ rate constants for reactions with N_2O , H_2 , CH_4 , HCl , and NH_3 , J. Chem. Phys., 67, 5021-5025, 1977.
- Ehhalt, D. H., L. E. Heidt, R. H. Lueb, and N. Roper, Vertical profiles of CH_4 , H_2 , CO , N_2O , and CO in the stratosphere, Proceedings Third Conference Climatic Impact Assessment Program, U.S. Department of Transportation, 153-160, [available from NTIS as DOT-TSC-OST-74-15], 1974.
- Ehhalt, D. H., Sample of stratospheric trace constituents, Can. J. Chem., 52, 1510-1518, 1974.

- Hard, T., Summary of recent reports of stratospheric trace-gas profiles, CIAP Monograph 1, U.S. Department of Transportation, 3-168, [available from NTIS as DOT-TST-75-51], 1975.
- Hudson, R. D., and S. H. Mahle, Photodissociation rates of molecular oxygen in the mesosphere and lower thermosphere, J. Geophys. Res., 77, 2902-2914, 1972.
- Isaksen, I. S. A., K. Midtbö, J. Dunde, and P. J. Crutzen, A simplified method to include molecular scattering and reflection in calculations of photon fluxes and photodissociation rates, Report No. 20, Institute for Geophysics, University of Oslo, pp. 1-21, 1976.
- Johnston, H. S., Global ozone balance in the natural stratosphere, Rev. Geophys. Space Phys., 13, 637-649, 1975.
- Lin, C. L., W. B. DeMore, $O(^1D)$ production in ozone photolysis near 3100 Å, J. Photochem., 2, 161-164, 1974.
- Schmeltekopf, A. L., D. L. Albritton, P. J. Crutzen, P. D. Goldan, W. J. Harrop, W. R. Henderson, J. R. McAfee, M. McFarland, H. I. Schiff, T. L. Thompson, D. J. Hofmann, and N. T. Kjome, Stratospheric nitrous oxide altitude profiles at various latitudes. J. Atmos. Sci., 34, 729-736, 1977.
- Selwyn, G., J. Podolske, and H. S. Johnston, Nitrous oxide ultraviolet absorption spectrum at stratospheric temperatures, Geophys. Res. Lett., 4, 427-430, 1977.
- Stewart, R. W., and M. I. Hoffert, A chemical model of the troposphere and stratosphere, J. Atmos. Sci., 32, 195-210, 1975.
- Sundararaman, N., Summary of upper atmospheric data, FAA-EQ-77-2, U.S. Department of Transportation, Federal Aviation Administration, Office of Environmental Quality, Washington, D.C., 52 pp., October 1976.

Tyson, B. J., J. F. Vedder, J. C. Arvesen, and R. B. Brewer, Stratospheric measurements of CF_2Cl_2 and N_2O , Geophys. Res. Lett., 5, 369-373, 1978.

Table 1. Global rates of NO production and N₂O loss.

	Spring-fall	Winter-summer	Units
Global ave. N ₂ O loss	1.25	1.17	10 ⁹ molecules cm ⁻² sec ⁻¹
Global N ₂ O loss	6.40	5.99	10 ²⁷ molecules sec ⁻¹
	2.02	1.89	10 ³⁵ molecules yr ⁻¹
	14.7	13.8	10 ¹² g (N ₂ O) yr ⁻¹
	9.4	8.8	10 ¹² g (N) yr ⁻¹
Global ave. NO prod.	2.84	2.73	10 ⁸ molecules cm ⁻² sec ⁻¹
Global NO prod.	1.45	1.39	10 ²⁷ molecules yr ⁻¹
	4.56	4.38	10 ³⁴ molecules yr ⁻¹
	2.27	2.18	10 ¹² g (NO) yr ⁻¹
	1.06	1.02	10 ¹² g (N) yr ⁻¹
NO prod./N ₂ O loss	0.23	0.23	molecule/molecule
	0.11	0.12	g (N)/g (N)

Figure Captions

- Figure 1. Observed nitrous oxide profiles at 31°N and at 9°N with two different extrapolations of the 9°N profile from 32 to 50 km. One extrapolation is based on observed nitrous oxide upper limits at 31°N , and the other is based on the observations at 9°N only.
- Figure 2. Contour lines of global nitrous oxide mixing ratios. The contours from 2 to 322 parts per billion by volume are identified by numbers on the right-hand side of the figure. These contours were derived from observed N_2O profiles.
- Figure 3. Nitrous oxide concentrations for standard March 21 (spring-fall).
- Figure 4. Zonal-average instantaneous rate of photolysis of nitrous oxide for spring-fall.
- Figure 5. Zonal-average instantaneous rate of photolysis of nitrous oxide for standard January 15 (winter-summer).
- Figure 6. Calculated zonal-average concentrations of singlet oxygen atoms, spring-fall.
- Figure 7. Calculated zonal-average concentrations of singlet oxygen atoms, winter-summer.

Figure 8. Instantaneous rate of production of nitric oxide from nitrous oxide and singlet oxygen atoms, spring-fall.

Figure 9. Instantaneous rate of production of nitric oxide from nitrous oxide and singlet oxygen atoms, winter-summer.

Figure 10. Zonal average column rates of nitrous oxide destruction by photolysis plus reactions of $O(^1D)$ and column rates of NO production from nitrous oxide and $O(^1D)$, spring-fall.

Figure 11. Zonal average column rates of nitrous oxide destruction by photolysis plus reactions of $O(^1D)$ and column rates of NO production from nitrous oxide and $O(^1D)$, winter-summer.

Figure 12. Vertical eddy diffusion coefficients based on global average nitrous oxide profile, compared to one-dimensional profiles used by Hunten, Stewart, and Chang.

Figure 13. Contour map of K_z values derived from local N_2O profiles at $75^\circ N$, $65^\circ N$, ... $5^\circ N$, $5^\circ S$, ... $75^\circ S$. The dashed line gives the locus of the minimum value of K_z for each profile.

XBL 785-8853

XBL 785-8854

XBL 785-8855

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720