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AFGL-TR-80-0332
ENVIRONMENTAL RESEARCH PAPERS, NO. 716

The Diurnal Variation of Turbopause Height

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3 November 1980

AERONOMY DIVISION PROJECT 6690
AIR FORCE GEOPHYSICS LABORATORY
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AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Howard

Chief Scientist

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

[redacted]

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFGL-TR-80-0332
2. GOVT ACCESSION NO.: AD-A099340
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): THE DIURNAL VARIATION OF TURBOPAUSE HEIGHT.
5. TYPE OF REPORT & PERIOD COVERED: Scientific. Interim.
6. PERFORMING ORG. REPORT NUMBER: ERP No. 716
7. AUTHOR(s): Samuel P. Zimmerman
8. ~~CONTRACT OR GRANT NUMBER(s)~~

9 Environmental research papers

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Air Force Geophysics Laboratory (LKB)
Hanscom AFB
Massachusetts 01731

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
62101F
16) 66900705 17) 07

11. CONTROLLING OFFICE NAME AND ADDRESS: 11
Air Force Geophysics Laboratory (LKB)
Hanscom AFB
Massachusetts 01731

12. REPORT DATE: 3 November 1980
13. NUMBER OF PAGES: 11 12) 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

14 [illegible]-TR- [illegible],
AFGL-ERP-716

15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Turbulence
Turbopause
Diurnal
Latitude

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Utilizing chemical release observations, and recently reported turbopause heights based upon mass spectrometer measurements of the Ar/N_2 ratio, the diurnal variability of turbopause height is determined. Separation of the data, on a seasonal basis, shows that there is a strong winter diurnal variability with turbulence carrying to its highest altitude (approximately 115 km) between sunset and midnight, and minimizing at the noon hour. The spring data shows a similar variability, but at an overall lower altitude than that of winter, and a

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possible latitudinal difference, while the fall results demonstrate no real diurnal variation, and an average turbopause height at approximately 106 km.

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Illustrations

The Diurnal Variation of Turbopause Height

Mesopheric and lower thermospheric turbulence coupled with thermosphere pressure gradients provide the major driving mechanisms of the neutral thermospheric species. Turbulence, through its action upon atomic oxygen[1] in the lower thermosphere, can enhance or delete the atomic-oxygen flow from the turbopause into the thermosphere, at which point the pressure gradients, both horizontal and vertical, begin their influence upon the [O] motion. Then, since [O] becomes the major atmospheric species above ~ 180 kms, the mechanisms controlling the [O] flow also control the thermospheric mass motions. For modeling purposes the necessary turbulent parameters are the spatial and temporal distributions of the coefficient of momentum transfer (K_m), the coefficient of heat transfer (K_H), and the rate of dissipation of turbulent kinetic energy (or the rate at which turbulent energy goes into heating the atmosphere). At the moment many of these unknown parameters still remain unknown, with some small pockets of data[2,3] demonstrating the variability of turbulence as a function of season and latitude, but based upon a limited altitude, latitude, and time data base.

(Received for publication 3 November 1980)

1. Keneshea, T. J. and Zimmerman, S. P. (1970) The effect of mixing upon atomic and molecular oxygen in the 70-170 km region of the atmosphere, J. Atmos. Sci., pp. 831-840.
2. Izakov, M. N. (1978) Effect of turbulence on the thermal regime of planetary thermospheres, Kosmich. Issled., 18:1707-1712.
3. Zimmerman, S. P. and Murphy, E. A. (1977) Stratosphere and mesospheric turbulence, Dynamical and Chemical Coupling, D. Reidel, Dordrecht, Holland, pp. 35-47.

Recently, in line with this approach, Danilov et al[4] reported on the variations of the turbopause and some correlations with other atmospheric parameters, such as the neutral temperature at 120 km and a_k, a magnetic index. They demonstrate that a significant inverse relationship exists between turbopause height (h_T) and thermospheric temperature at 120 km (T_{120}); wherein the T_{120} becomes smaller as the turbopause height increases. They also demonstrate that the turbopause height (h_r) and a sum over 3 a_k's show some correlation wherein the increase in $\sum_{i=1}^{3} a_{ki}$ roughly corresponds to an increase in h_T. Further, they find some seasonal variations wherein the northern latitude turbopause is higher in winter than in summer, in contradiction to the analysis of Blum and Schuchhardt[5] who deduce a higher turbopause in the high-latitude summer than those of the high-latitude winter.

Having demonstrated that there is a seasonal variability, particularly in the summer-winter differences, the questions that remain that may be soluble with this data base are "What is the diurnal variability of the turbopause?" and "Is there a seasonal difference to this diurnal variation?" To examine these questions we have enlarged the data base, and the results do demonstrate that there is a diurnal variability and that, as expected, there is a seasonal difference to the diurnal variability.

Part of the data base used here is the turbopause determined from the Ar/N_2 ratio[3] at Heiss Island (80°N latitude) where the mass spectrometer measured the Ar/N_2 ratio from 110 km upward. For those cases where the turbopause, as measured by diffusive separation, was above 110 km, the measurement was direct, but for those where the turbopause was below 110 km, the argon and nitrogen profiles were extrapolated downward till the Ar/N_2 ratio equaled the ground value; thus, the direct measurements above 110 km are quite probably more accurate than those extrapolated to lower altitudes. The extrapolated results, however, are still useful in assigning rough values of the turbopause. These data do not allow us to determine the distribution of multi-turbulent layers below the final cessation of atmospheric turbulence.

The remainder of the data is based upon chemical trails launched from Eglin AFB, Florida (30°N latitude), covering the period from 1962 to 1970. Here the turbopause is defined as the altitude at which the turbulent fluctuations are observed to cease. The spatial accuracy for altitude identification possible at the 100-110 km

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[4] Danilov, A. D., Kalgin, V. A., and Pokhunkov, A. A. (1979) Variations of the turbopause level in the polar regions, Space Res. XIX, Pergamon Press, New York, pp. 173-175.

[5] Blum, P. W. and Schuchhardt, K. G. H. (1978) The role of eddy turbulence for long period variations of upper atmospheric density, Space Res. XVIII, Pergamon Press, New York, pp. 191-194.

level from these data is quoted at approximately 100 m;[6] thus the turbopause determined from the chemical trails is quite accurate within 500 m.

These two bodies of data are then used conjunctly after separation into seasonal groups. This joining of divergent groups of data from widely different latitudes and derived from different observational techniques, immediately raises a question as to the propriety of such groupings. The justification (a posteriori) is that the diurnal variability for fall, winter, and spring seasons are quite similar, with divergences only being apparent for the summer data. Due to the paucity of the summer data we have, however, included them into the spring ensemble; thus we have only three seasons for this analysis. Additional reasons for the combining of the data will be discussed later when we consider possible driving mechanisms of turbulence and their latitude dependence.

The seasonal periods selected are (1) Winter, December 1 - March 15; (2) Spring - Summer, March 16 - September 15, and (3) Fall, September 16 - November 30. The reason for the long winter and short fall periods is that the winter chemical release data are quite sparse and we wished to have equal statistics for each seasonal group. This then places the December 1 - 15 data in the winter compilation rather than into the fall group.

The winter results (Figure 1) show that there is a strong preponderance of data near the twilight periods, but mostly for the Eglin experiments. This is because the chemical release data are examined best during these periods when background radiance, that interferes with the detection of solar resonance radiation in the daytime, is at a minimum, thus allowing good photographic measurements. Superposed (dash-dot) upon the figure is the mean diurnal variability of the winter turbopause. The variability is quite pronounced: low at the noon period, with a marked rise at evening twilight, maximizing before midnight, and continuing the decrease through the A.M. twilight. The chemical release sequence labeled 1, 2, 3 strongly supports these averages. This sequence is composed of three chemical releases on the same evening and separated, as shown, in time. The turbopause, at ~ 103 km shortly after 1700 (LT), shows a rapid rise to ~ 109 km continuing to ~ 119 km before 2200 (LT). This period of continuous observation nicely supports the general behavior of this late fall-winter period.

The spring-summer data (Figure 2) demonstrate that there is a larger dispersion of the turbopause as a function of time. This is, however, predominantly in the late afternoon and post-sunset period. The post-midnight into the early-morning

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[6] Albritton, D. L., Young, L. C., Edwards, H. D., and Brown, J. L. (1962) Position determination of artificial clouds in the upper atmosphere, Project Firefly, Volume IV, D. Golomb, Editor, AFCRL Report 62-826, pp. 81-86.

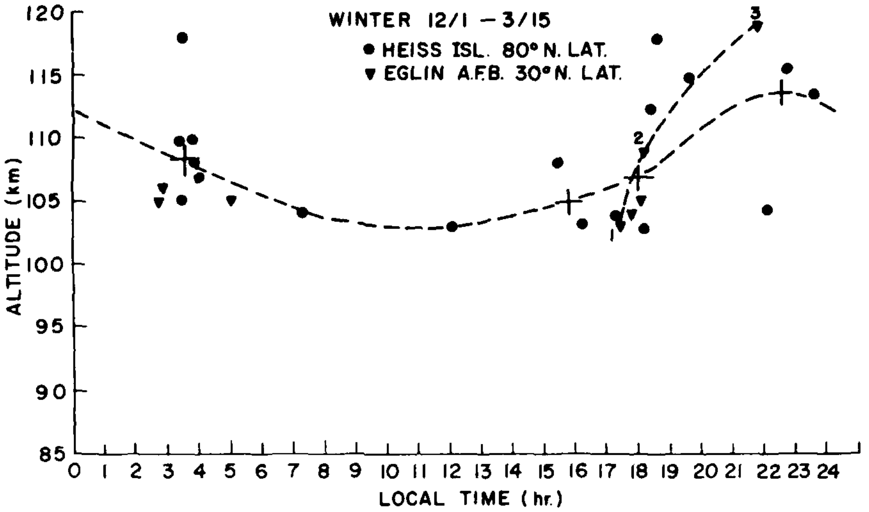

Figure 1. The Winter Diurnal Variation of the Turbopause as Determined From Chemical Trail Release Analysis and Mass Spectrometer Analysis of Diffusive Separation. The dashed line connecting the crosses is the average of all the data. The dashed line connecting the numerals 1, 2, and 3 represents three time-sequential experiments that graphically shows the nighttime rise of the turbopause.

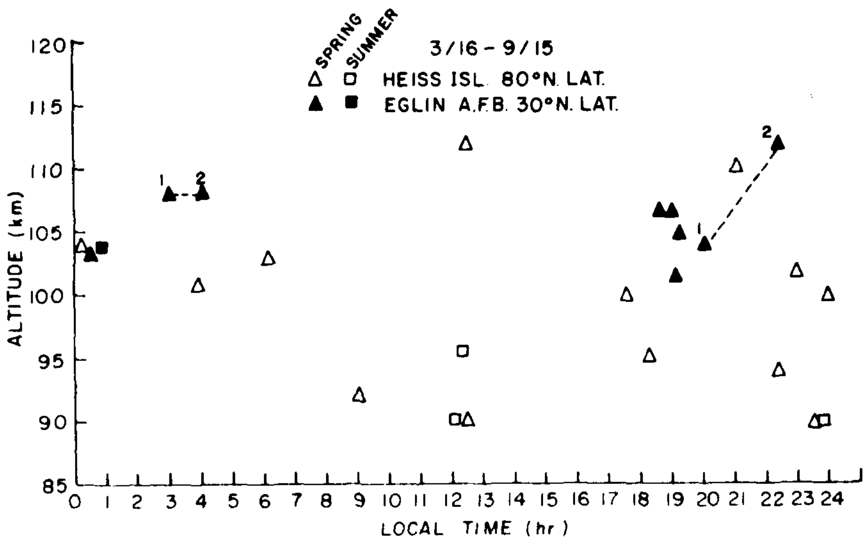

Figure 2. As in Figure 1, Except for Spring-Summer. There is no curve drawn through these points because of the large scatter of data. There is, however, a suggestion of midday minima and a nighttime rise, particularly evident in the sequential nighttime data labeled 1 and 2.

spring data, from both sites, are quite similar, showing an average turbopause around 105 km. The Heiss Island data then shows a lowering of the turbopause to ~ 98 km at noon, and the following evening data demonstrate the above-mentioned variability of evening to midnight turbopause. The evening differences may be due to latitudinal variability since the Eglin data all lie above the ~ 101 km altitude, while the Heiss Island data, with the exception of one point, lie wholly below this altitude. The mid-latitude summer data (one datum) is significantly different from the high-latitude data, showing a turbopause at 104 km at ~ 0100, as compared to 90 to 95 km high-latitude turbopause at 1145 and 1200, respectively. The fall data are displayed in Figure 3. It is quite obvious that there appears to be little diurnal variability in the average turbopause altitude; that is, at ~ 107 km. There is, however, an apparent large scatter in the data, particularly as demonstrated in the period ~ 0400 to 0600. But these data (Table 1b) are of particular interest since they were determined for the month of October, and predominantly in this 0400 to 0600 time period. A rough distribution of occurrence of turbopause altitude is presented in Figure 4 for the fall data and Figure 5 for the winter data. The fall data, in particular, demonstrate that there is a rough Gaussian distribution around the mean turbopause altitude, with a 5 km half-width.

The obvious differences in the spring and summer data between the two latitudinal observational points, create a question on the validity of using both bodies of data together. This is in spite of the apparent agreement of the fall and winter data. Our only justification, outside of the above a posteriori observed agreement of the fall-winter ensembles, is to refer to other data that support this usage. To our knowledge, the only other body of data examining the latitudinal and seasonal variability of turbulent parameters is that of Zimmerman and Murphy.[3] They utilized the rocket-grenade data[7] to determine the regions of dynamic instabilities, and thus estimated the turbulent occurrence rates, intensity, diffusion coefficients and rates of dissipation from 40 to ~ 90 km at four latitudinal sites (6° N, 38° N, 60° N, and 70° N). These data were then separated into summer and winter six-month averages, because of the meagerness of experiments. In these analyses we observe similar synoptic reactions: relatively active turbulence in the winter and summer mid-latitude (38° N) data, and extreme variability between the summer and winter polar atmosphere. The summer turbopause data, in particular, and although sparse, follow the results of the grenade analysis. The mid-latitude results show a turbopause at midnight at 104 km, while the Heiss Island data has a midnight turbopause at 90 km, and a noon turbopause at 90 to 95 km. The grenade data show a relatively quiescent summer mesosphere at 70° N latitude, while the

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[7] Smith, W. S., Theon, J. S., Swartz, D. C., Katchem, L. B., and Howath, T. T. (1961-1967) NASA Tech. Rep. TR R-211, 245, 263, 288.

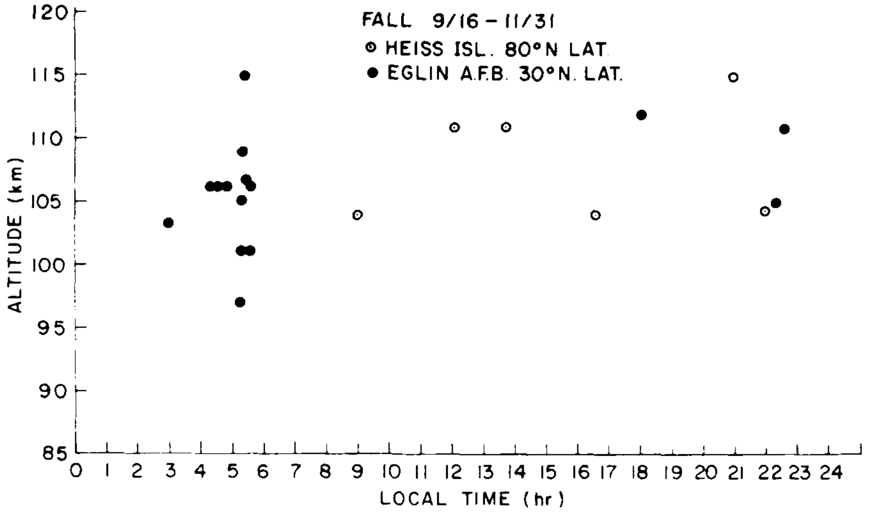

Figure 3. The Same as Figure 1, Except for Fall. As in Figure 2, there is large scatter of these data, and there appears to be no diurnal variability of the turbopause. There does appear, however, to be a roughly constant turbopause near 106 km.

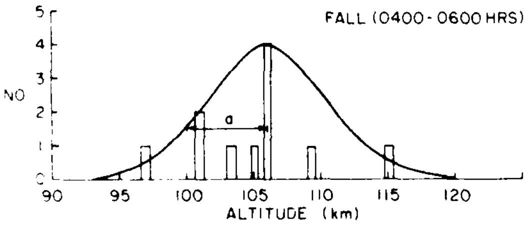

Figure 4. Histogram Showing the Number of Occurrences of the Turbopause at Each km for the Time Period 0400 to 0600 hrs. The solid line is a Gaussian distribution, with a 6 km half-width drawn through the data points, and it roughly describes the observations.

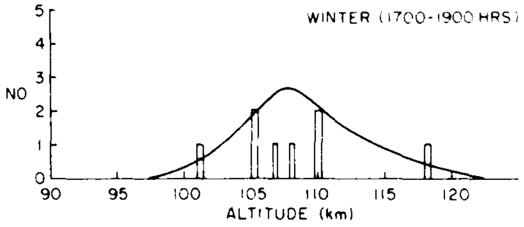

Figure 5. The Same as Figure 4, Except for the Winter Season and the Time Period 1700 to 1900 hrs

mid-latitude data (38° N) indicate quite an active turbulent atmosphere. If the mechanism of turbulent generation is the breakdown or destabilization of internal gravity wave propagating from the tropopause upwards, then these results suggest that there is a more active generation of IGW in the northern latitude winter than in the northern latitude summer. The more active production further suggests a larger amplitude IGW generation that would lead to a higher turbopause before kinematic viscosity completely damps the turbulence production. This is also the conclusion of the study by Manson and Meek.[8]

In conclusion, we have shown that the analysis of the joint ensembles of turbopause data can result in a rough quantitative description of the seasonal-diurnal variation of turbopause.

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[8] Manson, A. H. and Meek, C. E. (1980) Gravity waves of short period (5-90 min) in the lower thermosphere at 52° N (Saskatoon, Canada), J.A.T.P., pp. 103-114.

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2. Izakov, M. N. (1978) Effect of turbulence on the thermal regime of planetary thermospheres, <u>Kosmich. Assled.</u>, **18**:1707-171[illegible].
3. Zimmerman, S. P. and Murphy, E. A. (1977) Stratosphere and mesospheric turbulence, <u>Dynamical and Chemical Coupling</u>, D. Reidel, Dordrecht, Holland, pp. 35-47.
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