Influence of the Tropopause Height on the Global Stratospheric Aerosol Burden and Implications for the Recent Increase in Ozone

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ABSTRACT

Seasonal tropopause height variations are utilized in studying the global stratospheric aerosol burden and possible ozone asymmetries and long-term variations. It is concluded that an intimate relationship between tropopause height and total stratospheric aerosol exists and that seasonal fluctuations in tropopause height may be responsible for at least a portion of the north-south hemisphere total ozone asymmetry and the recent long-term increase trend in total ozone.

Although one of the most characteristic signatures of a temperature sounding of the lower atmosphere (<30 km) is the generally abrupt break in the negative temperature lapse rate, i.e., the "tropopause," its possible importance in interpreting stratospheric parameters has only recently been realized. Thus, Angell and Korshover (1973) have suggested that the warming trend in the tropopause temperature during the last 15 years may be connected with an apparent corresponding increase in stratospheric water vapor. It is the purpose of this note to point out the additional importance of the tropopause in influencing the global stratospheric aerosol burden and to suggest that it may also play a role in the global ozone distribution and in the recent long-term increase trend in total ozone as reported by Komhyr *et al.* (1971) and Johnston *et al.* (1973).

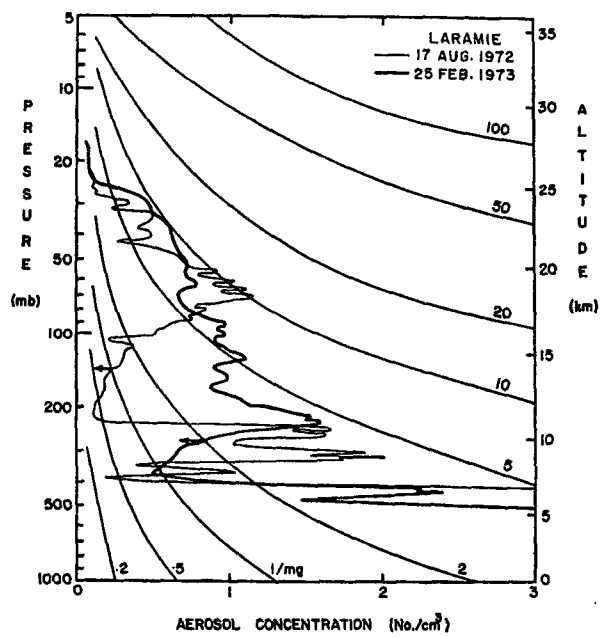

FIG. 1. Typical summer and winter aerosol profiles from Laramie, Wyo., for particle sizes $\gtrsim 0.3$ μm in diameter. The arrows indicate the height of the tropopause and the sloping curves are lines of constant mixing ratio in units of number per milligram of air.

A program to study the stratospheric aerosol layer, commonly called the sulphate layer, has been underway at the University of Wyoming since early in 1972. During this period no volcanic eruptions deemed violent enough to directly inject particles into the stratosphere are believed to have occurred. The absence of volcanic activity has allowed for the study of the so-called "natural stratospheric aerosol background." Considerable new information concerning this layer of submicrometer particles is now at hand. We report here one of the more interesting findings, a remarkably simple global relation between the position of the tropopause and the total stratospheric aerosol loading. This result has led us to investigate the possible importance of the tropopause in the global ozone problem. Previous studies of this relation were carried out by Dütsch (1963) using Umkehr measurements at Arosa, Switzerland. He found a negative correlation with a coefficient of about 0.5 to exist between tropopause height and total ozone.

The particles measured in this research program are detected *in-situ* during balloon ascent by light-scattering detectors of the type described by Rosen (1964). Fig. 1 shows typical vertical concentrations of aerosol particles having diameters $\gtrsim 0.3$ μm. These soundings were made at Laramie (41N), during the summer and winter. The

height of the observed tropopause is marked with an arrow on each sounding. Note the higher particle concentrations in the lower stratosphere (10–15 km) during winter.

A useful parameter for measuring the total stratospheric aerosol loading is the area under the vertical concentration curves above the tropopause. This area is the total number of particles in a vertical column integrated throughout the stratosphere. This quantity is shown plotted as a function of observed tropopause pressure in Fig. 2 for all soundings with identifiable tropopauses made from all stations during the first two years of the program. These stations were distributed between 85N and 90S. A correlation coefficient of about 0.8 is observed, indicating that the seasonal variation of total stratospheric aerosol loading at any location can be estimated from the tropopause height variation provided the station is not under the influence of local disturbances such as volcanic activity.

Monthly mean tropopause heights from pole to pole were obtained during the IGY period 1957–58 (*Monthly Mean Aerological Cross Sections*, 1961). From these data the extreme tropopause heights which occurred during the IGY are reproduced in Fig. 3. This diagram can be used to estimate the seasonal variation in the total stratospheric aerosol loading as a function of latitude. For example, Fig. 3, along with the experimental evidence that tropopause height is related to total aerosol loading, implies that Panama and Australia will be experiencing a minimum in total stratospheric aerosol in January, while at the same time the North *and* South Poles will be experiencing a maximum. This is a proposed explanation for our observation of nearly identical aerosol loading during December and January at the two poles (Hofmann *et al.*, 1973a) and for an apparent six-month total aerosol phase difference which we have observed between Panama (9N) and Laramie (41N) (Hofmann *et al.*, 1974). The fact that the tropopause at the North and South Poles oscillates up and down approximately in phase has not been appreciated in the past.

Some asymmetries in the global distribution of total ozone can be explained in terms of the tropopause height variations. During local winter and spring in each hemisphere ozone is thought to be transported poleward from equatorial regions. A gradual buildup of ozone consequently occurs at high latitude and a marked increase in total ozone is noted. The latitudinal ozone distribution in the two hemispheres does not, however, appear to be symmetrical. While the maximum in the Northern Hemisphere in total ozone occurs near 90° latitude, in the Southern Hemisphere the maximum occurs at about 50° latitude. In addition, the magnitude of the observed buildup of total ozone in the south polar region is about 10–20% less than in the corresponding season in the north polar region (Reiter, 1973; Dütsch, 1969). While it is generally believed that this

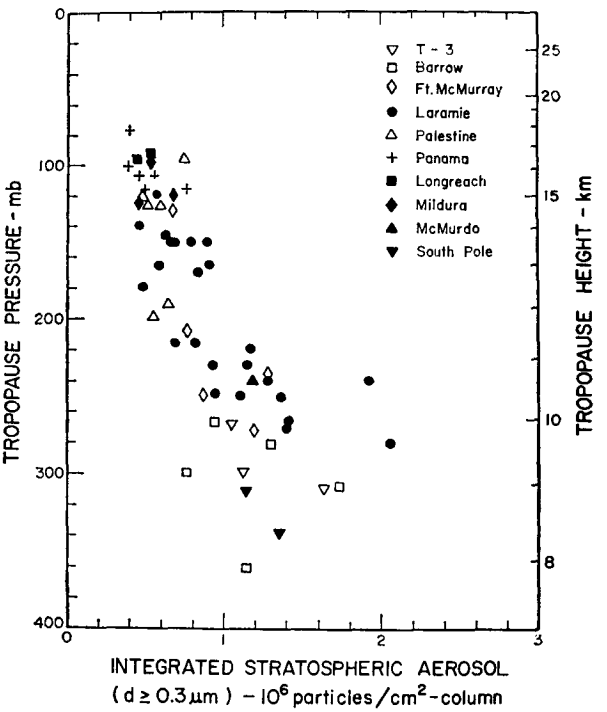

FIG. 2. Total stratospheric aerosol loading as a function of tropopause height.

asymmetry is caused by transport processes, the fact that the Southern Hemisphere ozone deficit occurs in the region where the tropopause behaves anomalously is interesting and further investigation is warranted. Toward this end we have utilized the South Pole ozone soundings reported by Komhyr and Grass (1968) and the Panama ozone soundings of Hering and Borden

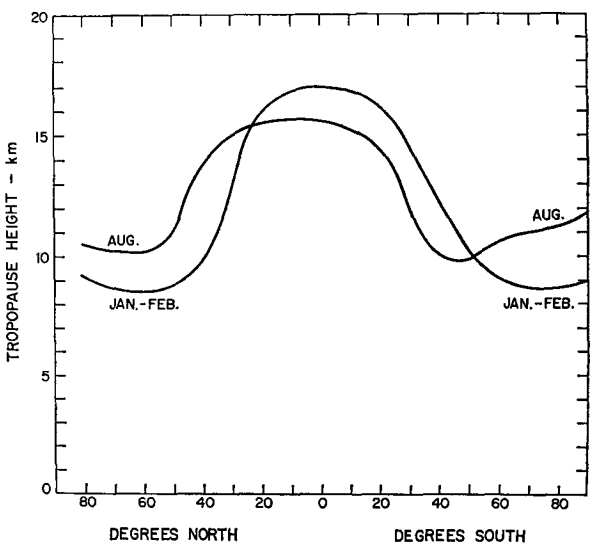

FIG. 3. Average tropopause location as a function of latitude. The tropopause height is at extreme values for the months chosen.

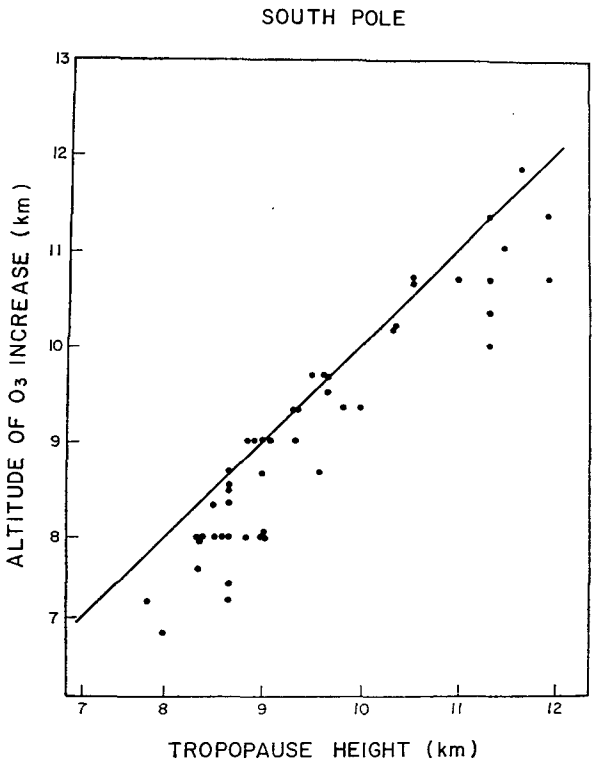

FIG. 4. Altitude at which the South Pole ozone mixing ratio begins to increase as a function of tropopause height. The data are taken from Komhyr and Grass (1968).

(1967) as reported by Wu (1973) to estimate the influence of tropopause height on total ozone.

Typical ozone profiles at the South Pole show an increasing concentration beginning at the approximate level of the local tropopause. This feature is demonstrated in Fig. 4. This property is not unique to the soundings from the Antarctic, however. Because the altitude at which ozone begins to increase is so closely related to the tropopause height, the total ozone in a fixed region surrounding the tropopause should be strongly modulated by the tropopause height itself. An analysis of this effect for the South Pole ozone data is shown in Fig. 5. Here it can be seen that the total ozone in the altitude interval 500 to 200 mb oscillated out of phase with the tropopause height. This modulation is obscured in the total ozone by fluctuations due to other phenomena. The large increases in total ozone during October, November and December, for instance, are associated with stratospheric warmings. Fig. 5 implies that the 2.8-km total annual variation in average tropopause height produces approximately a 30 m atm-cm variation in the total ozone between 500 and 200 mb. This corresponds to about 10% of the total ozone, or about a 3.5% decrease in total ozone per 1 km increase in tropopause height. This figure may be considered a lower limit since effects above the 200-mb layer have been neglected. Using individual South Pole ozone profiles in which the tropopause height was well defined (see, for example, 8 December 1964 and 21 September 1965), we have calculated a 5% decrease in total ozone per 1 km increase in tropopause height. These two soundings have very similar mixing ratio profiles except that they are shifted vertically by the difference in their respective tropopause heights. A similar analysis for the Panama data, though less accurate due to smaller seasonal excursions of the tropopause, yields similar results.

One can also estimate the theoretical effect of tropopause height on total ozone by utilizing ozone models such as the empirical model of Craig (1971). Carrying out this calculation for a number of stations and using values of the parameters published by Craig [see Hofmann *et al.* (1973b) for details of the calculation] reveals that a 1 km increase in tropopause height will produce approximately a 15% decrease in total ozone. This procedure neglects any compensating effects of the tropopause movement or accompanying seasonal effects and should thus be considered an upper limit. The difference in tropopause height during local winter between the north and south polar regions was 2.5 km in 1957–58. Thus, the lower limit percentage change value, derived from actual data (3.5% km^{-1}), results in about a 9% total ozone difference, a sizable fraction of the difference actually observed. Thus, the tropopause height appears to be a significant factor in the interpretation of total ozone.

It is of interest to note that the tropopause height in the Northern Hemisphere has, on the average, been decreasing over approximately the past ten years (Angell and Korshover, 1973). Insufficient data apparently exist to make a similar assessment in the Southern Hemisphere. During this period the total ozone has increased by approximately 5% (Komhyr *et al.*, 1971; Johnston *et al.*, 1973). This increase in ozone has been attributed to the recovery of the stratosphere from nuclear bomb tests that were conducted in the early sixties (Johnston *et al.*, 1973). Chemical destruction of ozone was attributed to the catalytic effects of nitrogen oxides introduced into the stratosphere by the explosions. The long-term decreases in tropopause height reported by Angell and Korshover (1973) varied between 0.1 and 0.5 km for five stations between 0° and 80N. The largest decrease occurred between 0° and 30N. A 0.5 km decrease in tropopause height would result in at least a 2% increase in total ozone, again a sizable fraction of the long-term trend reported by Johnston *et al.* for approximately the same period. This suggests the possible importance of tropopause height in interpreting data such as total ozone and warrants a thorough scrutiny of temperature soundings worldwide to determine the global significance of this effect and the importance that it might have for future work dealing with the long-term changes of the ozone shield.

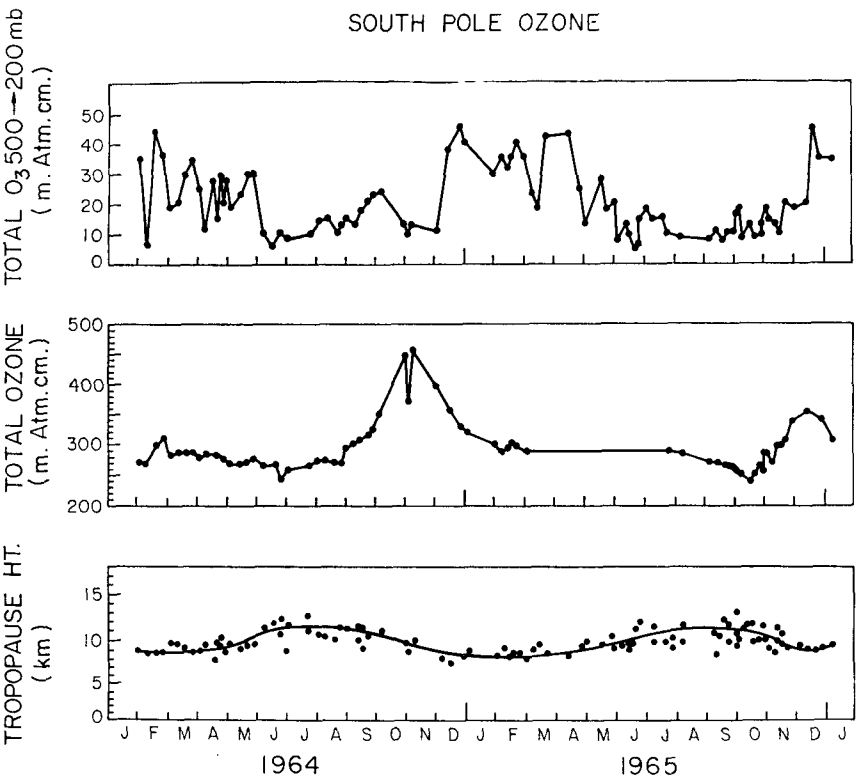

FIG. 5. Modulation of the total ozone between 500 and 200 mb at the South Pole. The data are taken from Komhyr and Grass (1968).

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