Variations in Stratospheric Circulation & Ozone during Selected Periods of 1971-1972 Winter Storm

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An experimental study was undertaken to investigate the atmospheric circulation and temperature effects on stratospheric ozone during the winter storm period of 1971-1972. Rocket-borne ozone-temperature sondes were used to monitor ozone density, temperature and wind field on three different days. The results obtained show that at one time during this study, meridional and zonal flow did undergo a change, and on that occasion, the ozone structure changed to a three-peak distribution. Possible contribution from the vertical motions in the atmosphere is considered.

1. Introduction

Ozone present in the earth's atmosphere in minute quantities absorbs solar radiation between 2000 and 3000 Å and in the infrared region. The energy so absorbed is the principal source of thermal energy in the stratosphere and is responsible for the increase in temperature with height in upper stratosphere. Over a long term period, the earth-atmosphere system as a whole must radiate back to space as much energy as it receives; however, a radiative balance need not and, in general, does not occur during particular time-periods at particular locations. This radiative imbalance is regarded as the driving force for atmospheric circulation.

In the northern hemisphere, circulation in the stratosphere exhibits a monsoonal zonal flow, with winter westerlies and summer easterlies. The winter westerlies appear at about the time of the fall equinox and develop rapidly into a strong flow within a month's time. These winds undergo a marked change during the middle winter period, with a rapid decrease in speed occurring over a few days' time. At midlatitudes these interruptions of the winter westerlies are short-lived. This highly variable period (15 December to 15 February) known as the 'winter storm period' is associated with perturbations occurring in atmospheric structure and composition1. The summer easterlies, on the other hand, show a very conservative pattern both in development and in decay.

Ozone concentration from the surface of the earth up to the tropopause level is relatively low. In the vicinity of the tropopause, the density begins to increase, and it attains its maximum value somewhere between 12 and 30 km. After this maximum, there is a steady decrease in ozone density, and this decrease has been observed to continue right up to the maximum height at which ozone has been measured by rockets, viz. 70 km.

2. Experiment

An experiment was conducted at White Sands Missile Range (WSMR), New Mexico (32°N) during winter 1971-72 (19 January, 1 and 11 February 1972) to investigate the circulation as well as temperature effects on ozone distribution in the upper stratosphere. Rocket-borne payloads (Fig. 1) were used to measure the ozone density, temperature and wind field in the upper atmosphere2. The chemiluminescent ozone detector is capable of measuring ozone concentration from 65 to 10 km altitude with an uncertainty estimated to be of the order of ± 10%. The payloads were deployed by Arcas meteorological rockets to reach an altitude of 60 to 65 km. After ejection, the sensors descended on radar-reflective parachutes (4.5 m diameter). The transmitted signals were pulse-modulated and received by a meteorological receiver on a carrier frequency of 1680 MHz. Each payload was calibrated before launch by passing air containing a known concentration of ozone over the sensor and setting the instrument sensitivity at the proper range. Three soundings were made, one on 19 January, the second on 1 February, and the third on 11 February 1972. Ozone distribution in the upper stratosphere as measured on these three days in the winter storm period shows considerable variation from one day to another (Fig. 2). Temperature profiles for these soundings are shown in Fig. 3. The lower altitude data in Fig. 3 were obtained from radiosondes flown on these days. Component winds obtained on 19 and 31 January, and 1, 2, 10, and 11 February are plotted in Fig. 4.
Fig. 1—Photograph of rocket-borne ozone sonde

Fig. 2—Ozone concentration over White Sands Missile Range, at 1100 hrs MST, during 19 January 1972, 1 and 11 February 1972

Fig. 3—Temperatures recorded over White Sands Missile Range on 19 January 1972, 1 and 11 February 1972
3. Discussion

The ozone density, temperature and wind variations with altitude as observed in this study are significant. The purpose of this communication is to present the factors which could have influenced these changes. These factors are: (i) circulation effects and (ii) temperature dependence of the reaction rates.

(i) Circulation effects — Wind structure as shown in Fig. 4 has some significant day-to-day variations. On 19 January, the wind circulation varies from northeast at 40 km to southwest at 50 km. Circulation patterns on 31 January and 1 February indicate near-zero winds from 20 km to stratopause level and westerly winds at higher altitudes. This change in the circulation is accompanied by a non-typical ozone distribution on 1 February. It has been observed that vertical motions are present in the atmosphere at all altitudes. The magnitude of these motions varies, but large values have been measured both above and below the stratopause level. Marshall states that extreme motions are certainly larger than 5 m/sec and may exceed 15 m/sec. Areas of greatest vertical motion occur in a region of high wind shears which in this case (on 1 February) is near the 50 km level. On 2 February, the circulation changed from the previous day, and the only significant change on 10 and 11 February from the circulation on 2 February is the change from a south component on 2 February to a north component on 10 and 11 February.

(ii) Temperature dependence of reaction rates — The equilibrium number density of ozone calculated for a simple oxygen atmosphere is given by

\[ n_3 = \frac{K_{12}}{K_{13}} \cdot \frac{n_m n_2}{q_2 + q_3} \]

where

- \( n_3 \) = number density of ozone
- \( n_m \) = number density of air molecules
- \( n_2 \) = number density of oxygen
- \( q_2 \) = number of dissociating quanta absorbed by oxygen per unit time and unit volume
- \( q_3 \) = number of dissociating quanta absorbed by ozone per unit time and unit volume
- \( K_{12} \) = rate coefficient between molecular and atomic oxygen
- \( K_{13} \) = rate coefficient between atomic oxygen and ozone

The rate coefficients \( K_{12} \) and \( K_{13} \) are temperature-dependent as given by the following expressions:

\[ K_{12} = 5.5 \times 10^{-34} \left( \frac{T}{300} \right)^{2.4} \text{ cm}^6 \text{ molecule}^{-2} \text{ sec}^{-1} \]

\[ K_{13} = 1.2 \times 10^{-11} \exp \left( -4.0/RT \right) \text{ cm}^3 \text{ molecule}^{-1} \text{ sec}^{-1} \]
In this study, which was made during the winter storm period of 1971-1972, a non-typical ozone distribution has been observed in the upper atmosphere. Ozone distribution changed to a triple-peak distribution from the normal one-peak when zonal and meridional circulation changed in the upper stratosphere. This midwinter phenomenon was observed only on one occasion and is probably the result of vertical motions. Further observations are needed to verify this conclusion.

4. Conclusion

In this study, which was made during the winter storm period of 1971-1972, a non-typical ozone distribution has been observed in the upper atmosphere. Ozone distribution changed to a triple-peak distribution from the normal one-peak when zonal and meridional circulation changed in the upper stratosphere. This midwinter phenomenon was observed only on one occasion and is probably the result of vertical motions. Further observations are needed to verify this conclusion.

References