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OZONE MEASUREMENTS IN THE MESOSPHERE AND STRATOSPHERE DURING TWO SIGNIFICANT GEOPHYSICAL EVENTS

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CONTENTS

ABSTRACT

Measurements of ozone have been performed in the mesosphere and stratosphere by means of a chemiluminescent, self-pumping, parachute sonde released from a rocket developed by Goddard Space Flight Center. Two ozone flights were performed in the Arctic winter at Pt. Barrow, Alaska (71N), in January 1969, during a seasonal transition in the upper atmosphere. The change in the measured profiles was consistent with the model of a simple oxygen atmosphere in chemical equilibrium, if the supply of atomic oxygen is assumed to be constant. A diurnal measurement was performed in March 1970 at Wallops Island, Virginia. The ozone concentration measured below 30 km was in good agreement with data from simultaneously flown balloon sondes. The data were also in general agreement with contemporary moist-atmosphere models and other empirical data above these altitudes. The nighttime mixing ratio between 60 and 67 km was approximately twice that measured during the day. The altitude resolution of the experiment is about 1 km, the precision 10%, and the absolute accuracy approximately 20%.

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1. INTRODUCTION

The horizontal and vertical distributions of the trace constituents, such as ozone, atomic oxygen, and water vapor, play an important role in the processes occurring in the mesosphere and stratosphere; therefore, knowledge of these distributions would provide for a more complete understanding of the upper atmosphere, which has in the past been inaccessible to or ignored by experimental observation. The Chapman model gives a reasonable estimate of the amounts and variations of ozone and atomic oxygen and the formation of the stratopause. This simple atmospheric model recently has given way to one that is more complex, including the photochemistry of water vapor.

The data from the very few measurements of ozone in the stratosphere and mesosphere vary as much as the models, and vice versa. The experimental

technique and calibration procedures used to obtain the ozone profiles presented in this paper have been described in detail by Hilsenrath et al. (1969). The ozone content in the region from 70 to 15 km is measured by means of a self-pumping parachute sonde released from a rocket. The sonde, developed by Goddard Space Flight Center, determines the ozone mixing ratio, in situ, as a function of altitude and is capable of day or night measurements. Calibration of the sensor is accomplished immediately prior to flight by sampling known concentrations of ozone at rates expected during flight.

2. FLIGHTS

A. Polar Winter Measurements

During January 1969, two rocket ozone measurements in the mesosphere and stratosphere were conducted from Pt. Barrow, Alaska (71N). The objective of the Pt. Barrow experiments was not only to measure the ozone distribution in the polar winter night but also to measure this distribution before and after a stratospheric disturbance. Other phenomena relevant to these measurements are heating in the polar mesosphere and the variation of atomic oxygen and ozone during auroral events, as suggested by Maeda and Aiken (1968). Bright aurorae were visible most of the month; however, there were no measurements of the hard spectrum ($\sim$ 100 keV) auroral electrons necessary for the formation of atomic oxygen. Rocket grenade soundings as described by Smith et al. (1970) were performed routinely during most of the 1968-69 winter at this site. Figure 1 shows the temperature profiles measured within three

hours of the ozone soundings on 10 January and 30 January. This figure clearly demonstrates the warm mesosphere in early January and the establishment of a stratopause in late January, indicating the transition from the winter to the summerlike patterns. There was no classical "sudden warming" that winter. Of significance, however, is the temperature decrease of about 50K at 60 km.

Figure 2 shows the results of the two ozone soundings. The solar zenith angle was about 125° for both flights, and the minimum zenith angles during the days of the flights were 93° and 89° for the 10th and 30th, respectively; therefore, photochemical processes can be neglected at the altitudes under discussion. Both profiles are in general agreement with the calculations of Leovy (1969) for January at 45N (the highest latitude for which these calculations were carried out). The ozone profiles are also essentially monotonic, which is in contrast with what is observed in the lower atmosphere, where the ozone content is considered more or less a conservative property and generally related to the circulation of the lower stratosphere. It was thought that with the absence of photochemical processes, some structure would appear in these profiles, especially in light of the highly disturbed temperature and wind fields that occur at high latitudes during the winter. Since this structure did not appear, one might conclude that chemical-restoration time constants are short enough or that mixing is rapid enough to yield a broad region of relatively constant mixing ratio of ozone between 30 and 50 km.

The most striking difference between the two flights occurred above 50 km, where the temperature dropped 50K as shown in Figure 1, while the ozone

concentration increased by a factor of almost 4. This result is consistent with a simple oxygen model, which can be summarized by (1) and (2).

$$O + O_2 + M \rightarrow O_3 + M \qquad k_{12} = 8 \times 10^{-35} \exp(890/RT) \tag{1}$$

$$O + O_3 \rightarrow 2O_2 \qquad k_{13} = 5.6 \times 10^{-11} \exp(-5700/RT) \tag{2}$$

Ozone is formed by recombination of atomic oxygen and molecular oxygen, which is favored by the colder temperature seen in late January; and ozone is dissociated by atomic oxygen plus ozone, yielding molecular oxygen, which is a slightly exothermic reaction. Also, in the moist atmospheric model ozone above 40 km is controlled by the reactions of OH and HO_2. These reaction rates are not temperature sensitive, whereas the reactions in (1) and (2) are. Therefore, these measurements have shown a relatively smooth ozone distribution despite a very disturbed atmosphere, which can be qualitatively explained by a model of a dry atmosphere in chemical equilibrium if one can assume a constant supply of atomic oxygen down to 50 km.

B. Diurnal Measurement

On 6 and 7 March 1970, three ozone experiments were launched at Wallops Island, Virginia. The objective of these flights was to measure both the diurnal variation of ozone and its distribution during a total solar eclipse. Because of the numerous rockets flown on 7 March, the day of the eclipse, the predawn flight was flown on 6 March at 0427 EST; the sonde was in darkness during the entire flight. The post-sunrise flight occurred at 1100 EST 7 March, and the eclipse occurred at 1347 EST. Unfortunately, no data were obtained during the eclipse because of a malfunction in the payload.

Though the diurnal measurement was performed over a 30-hour interval, that is the post-sunrise flight occurred the following day, the changes in the mesosphere from one day to the next are believed to be very small. The times of the launches, however, were scheduled close to the predicted maximum and minimum distributions. Figure 3 shows the results of those flights. These data are compared with the nighttime measurement of ozone on 9 December 1965 by Carver et al. (1966), who used an optical sonde and the sunlit moon as an ultraviolet light source. Below 60 km the Wallops Island profiles are essentially identical, and below 30 km the predawn-flight data agree very well with those of an ESSA balloon sonde flown practically simultaneously. Due to another payload problem, the daytime-flight data were obtained down to only 30 km.

Figure 4, which indicates the diurnal change in the ozone mixing ratio, has more meaning with respect to these data and the overall capability of the experiment. Altitude resolution is about 1 km from apogee to 60 km and increases below that. The precision between flights is about 10%, and the absolute accuracy is about 20% throughout the entire altitude range. The same is true for the Pt. Barrow, Alaska, flights previously discussed. The magnitude of the diurnal difference below 55 km is near the 10% precision of the measurement; hence, a low level of significance should be attached to this result. Of significance are the data above 60 km, where the predawn ozone concentration is higher than after sunrise by a factor of 2. These results are more consistent with the model of a moist atmosphere (Hunt, 1966), where ozone is controlled by the hydrogen compounds rather than directly by the available atomic oxygen.

It is reasonably certain that the differences between the two sets of balloon data shown in Figure 3 do not represent a diurnal variation due to photochemical processes in the lower stratosphere. The total (integrated) ozone differs by about 20%. Wallop's RAOB data do not indicate significant changes in winds or temperatures up to 50 mb; however, examination of meteorological maps at the 100- and 50-mb levels did indicate the movement of a weak trough through the Eastern Coast during 6 and 7 March, which could account for this difference.

3. CONCLUDING REMARKS

The ozone data presented in this paper represent two significant observations concerning processes that occur in the mesosphere and stratosphere. The measurements are of sufficient accuracy to be used in atmospheric models requiring ozone profiles. However, these data suggest that water vapor, or the other hydrogen compounds and their variations, are parameters at least as important to measure as ozone. For example, the measured magnitude of the diurnal variation above 60 km over Wallops Island suggests a moist atmosphere, whereas the large variations in ozone densities and the associated temperature variations above Pt. Barrow suggest the applicability of the dry oxygen model.

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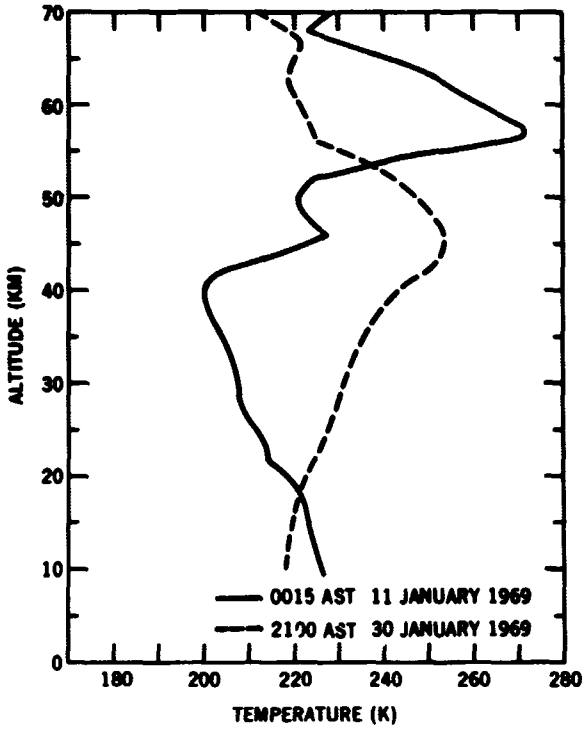

Figure 1–Temperature profiles, Pt. Barrow, Alaska (71N).

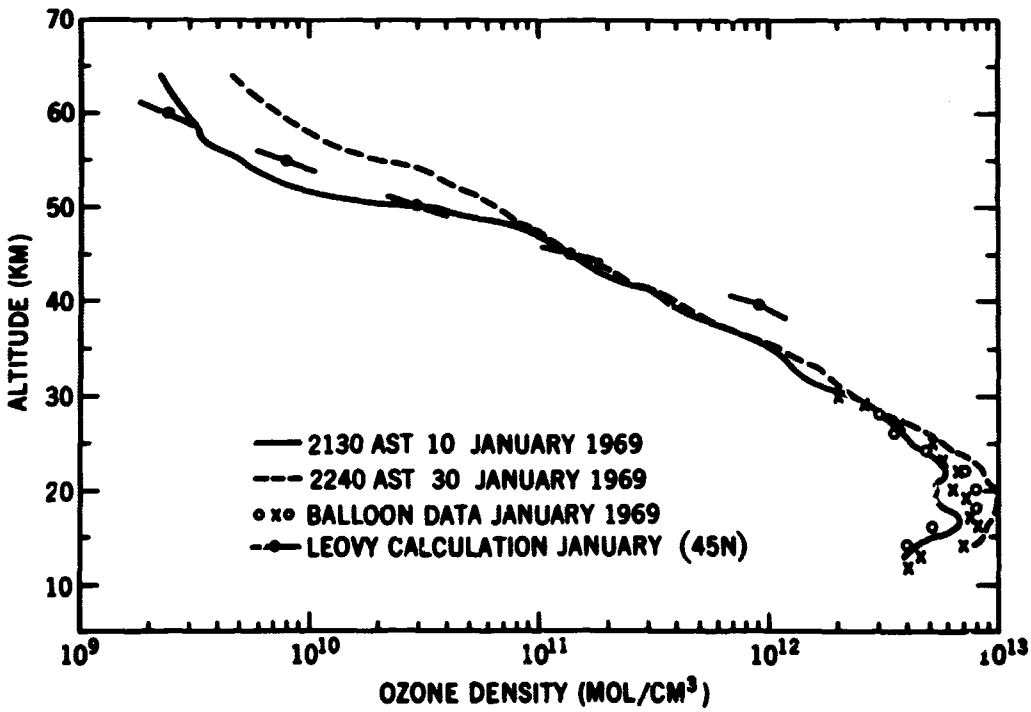

Figure 2–Seasonal transition of ozone density, Pt. Barrow, Alaska (71N).

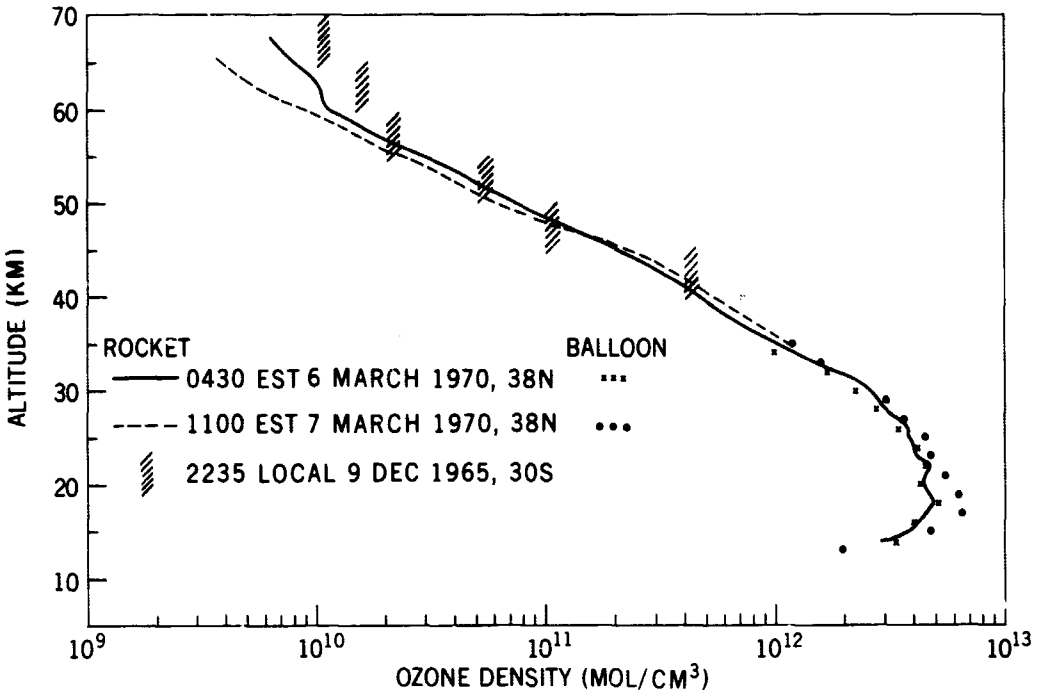

Figure 3–Diurnal variation of ozone density, Wallops Island, Virginia (38N), and nighttime ozone measurement, Australia (30S).

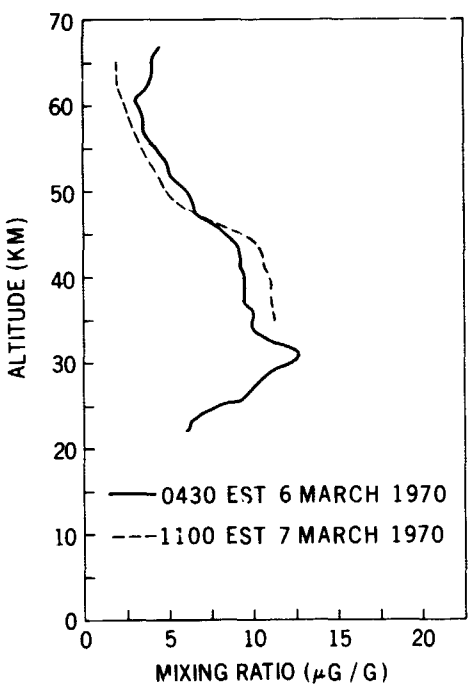

Figure 4–Measured diurnal variation of ozone mixing ratio, Wallops Island, Virginia.