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Mesospheric Molecular Oxygen Density, Pressure and Temperature Profiles Obtained from Measurements of Solar H Lyman-α Radiation

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Abstract. The extinction in the mesosphere of hydrogen Lyman-α radiation from the Sun was measured by ionization chambers being part of a complex payload (BII) flown on two rockets of type Skylark. The rockets were launched from El Arenosillo, Spain, (37.10° N; 6.73° W), at 1630 UT on 4 and 21 January 1976. From these measurements molecular oxygen density, pressure, and temperature profiles were determined, and are presented for the height range 70–90 km. The oxygen density and temperature profiles differ considerably from the CIRA 1972, but in a reasonable tendency. We suggest this to be due to the strong winteranomalous conditions during the days of measurement.

Key words: Extinction – Mesosphere – Solar H Lyman-α.

Introduction

From measurement of the absorption in the mesosphere of hydrogen Lyman-α radiation from the Sun the density of molecular oxygen can be determined. The technique of applying ionization chambers for such an experiment is well known, and has been used by many workers (Carver et al., 1964; Hall, 1972; Smith and Miller, 1974). Below heights of about 85 km, the dissoziation of molecular oxygen may be neglected, and the major constituents of the mesosphere are well mixed. Thus, from the molecular-oxygen density-profile, the corresponding mesospheric pressure and temperature profiles can be calculated.

The described experiment was made in the framework of a comprehensive aeronomy programme in order to take advantage of this rare opportunity, that is, to measure simultaneously, and at the same location, a variety of essential parameters of the mesosphere, the same parameters redundantly, and also by different methods.

In this paper only the very experiment and its results are presented. The combination of these results with those from the other experiments will be the subject of another paper.

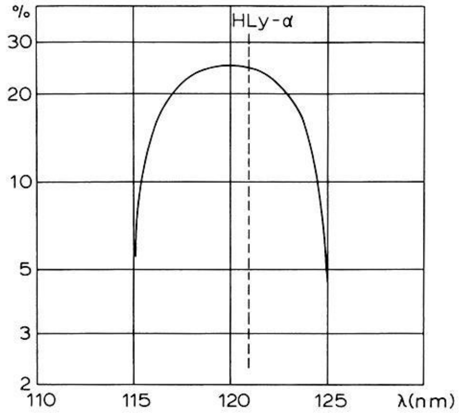

Fig. 1. Relative spectral sensitivity of the ionization chambers (RTC; type CIU 3); λ wavelength of the ultraviolet radiation. The H Lyman-α line is at 121.567 nm (central absorption core; see Bruner and Parker, 1969)

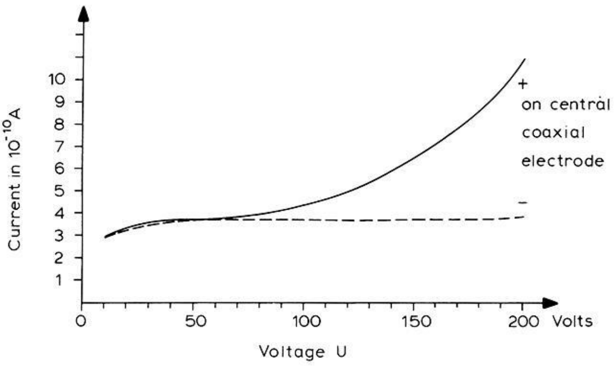

Fig. 2. Quantum efficiency of the ionization chambers as a function of the applied voltage U, in volts, as measured in the laboratory; comparison of sensor with a windowless NBS Diode (Al_2O_3/Al cathode)

Method of Measurement

The solar H Lyman-α radiation was measured redundantly by two ionization chambers (type CIU 4c) with magnesium fluoride end windows and carbondisulfid filling gas under a pressure of 20 millibar. The spectral sensitivity of these sensors, as determined by the material of the window and the filling gas, is shown in Figure 1. An absolut calibration was carried out using a vacuum ultraviolet monochromator and comparing the ionization chambers with a windowless NBS ultraviolet photodiode. For suppressing photoelectric emission from the wall, the shell electrodes of the ionization chambers were operated at a positive potential (about + 50 V; unity gas gain). Figure 2 shows the quantum efficiency of the chambers, as a function of the applied voltage, and Figure 3 their relative sensitivity, as a function of the angle of incidence of the radiation. Particular care was taken to protect the ionization chambers against humidity. Therefore, that section of the rocket where the sensors were mounted was filled with dry nitrogen.

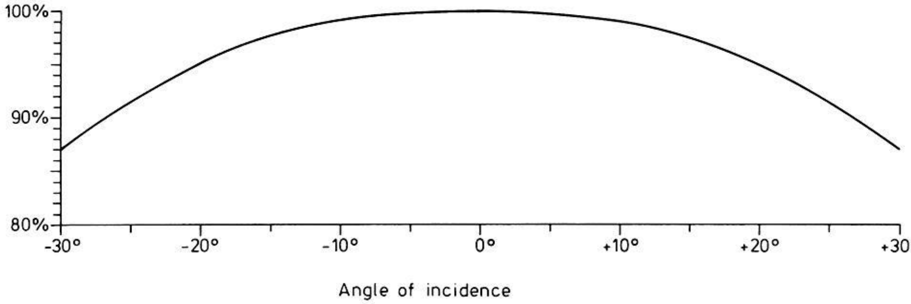

Fig. 3. Relative variation of current of an ionization chamber as a function of the angle of incidence of the H Lyman-α radiation

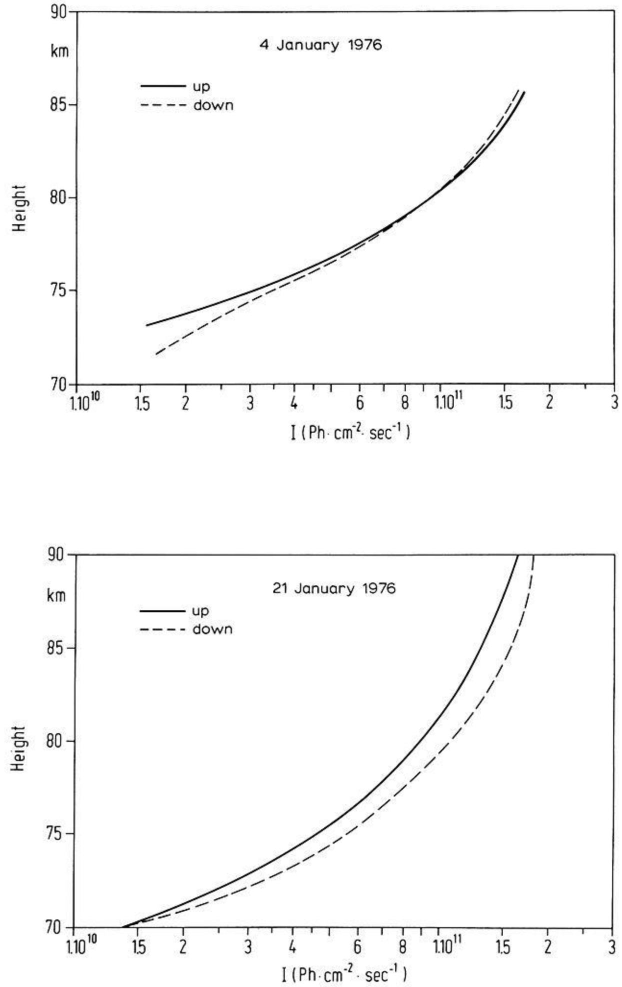

Fig. 4a and b. Solar H Lyman-α intensities measured on 4 and 21 January 1976 at latitude 37.10° N, longitude 6.73° W

Before the rockets were launched, the sensors were turned to definite angles against the axis of the rocket by a remote control, depending on the actual solar zenith angle. Since the rockets were trajectory stabilized, the sensors had to be traversed by means of a programmed timer near the apogee in order to be directed towards the Sun also on the downleg.

The electric currents obtained from the ionizations chambers were amplified; and at each rotation, their peak value was converted into a digital word, and this stored in a memory, from which it was read out by the telemetry system. Triggered by a particular solar sensor, at each rotation of the rocket, two measurements were made, one, when the sensor pointed at the Sun, and the other, when the sensor was opposite to the Sun. By the second measurement the scattered radiation could be found.

The first rocket was launched at 1630 UT on 4 January 1976 at a solar zenith angle of 73°22′, the second at 1631 UT on 21 January 1976 at 70°02′. Both flights were successful. Unfortunately, the real flight trajectories of both rockets deviated considerably from the nominal trajectory for which the experiment was adjusted. Therefore, the sensors did not point at the Sun during the entire part of the trajectory as it was planned.

A detailed description of the experiment is given in a technical report (Loidl and Boogaerts, 1976).

Results

Figure 4 shows the measured solar H Lyman-α intensities of each flight. The absorption profiles are slightly different, crossing at 80 km. Perhaps a cause for the differences in the upleg and downleg curves may be that the distance between up and down trajectory was about 200 km. Due to the deviation of the rocket from the planned trajectory, it was not possible to measure $I\infty$. But it can be extrapolated using the formula

$$I_{\infty}=I_h \exp\frac{\sigma\cdot p(h)}{K\cdot\cos\chi}, \tag{1}$$

where $\sigma=0.8\times10^{-24}$ m^2, $p(h)$ pressure (taken from CIRA 1972 and introducing some uncertainty) at height h, $K=2.2\times10^{-24}$ $N=g\sum n_i m_i/n(O_2)$, χ solar zenith anlge, $h=85$ km (flight 4 January 1976), $h=119$ km (flight 21 January 1976). So it was calculated $I\infty=2.71\times10^{11}$ Ph cm^{-2} s^{-1} on January 4, and $I\infty=2.43\times10^{11}$ Ph cm^{-2} s^{-1} on January 21. This value is about 10% lower than the value published by Hinteregger et al. (1965) which is $I\infty=2.7\times10^{11}$ Ph cm^{-2} s^{-1}. An explanation for this may be a decrease in quantum efficiency of the ionization chambers which were calibrated at 30 October 1975 and flown in January 1976. For, three chambers were treated under comparable circumstances but not flown in a rocket, and recalibrated in March 1976. The result was a loss in efficiency up to 50%. For the flight of 21 January 1976, a larger inaccuracy was introduced by uncertainties concerning the real flight trajectory.

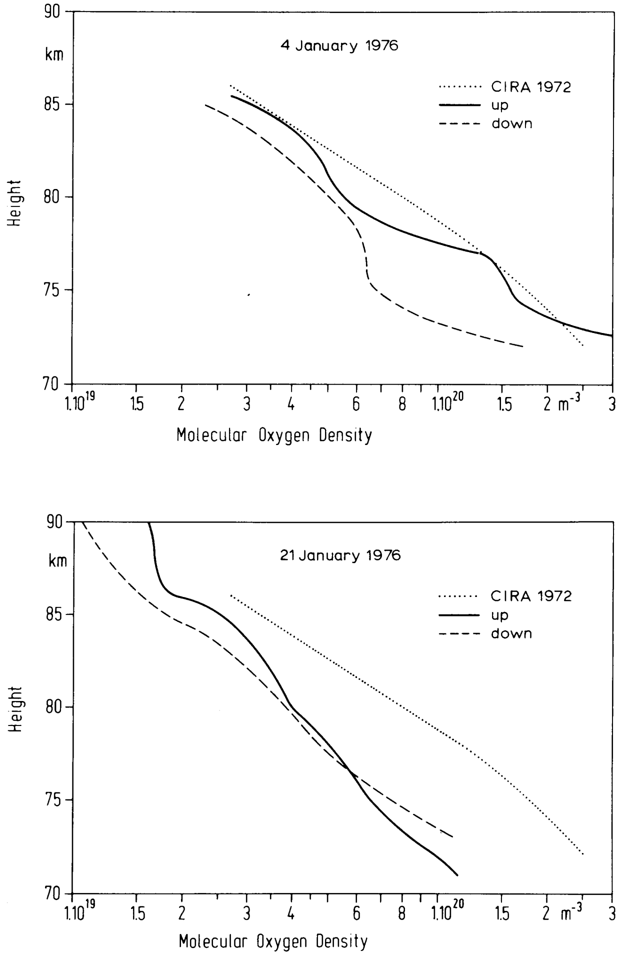

Fig. 5a and b. Measured molecular oxygen densities at latitude 37.10° N on 4 and 21 January 1976 compared with model mesosphere densites adjusted to the same latitude and month (CIRA 1972)

Planning the experiment it was hoped that the US Naval Research Laboratory would start the announced two Solar Radiation (SOLRAD) Satellites in time, so that the solar H Lyman-α intensity could be determined absolutely by satellite. Thus, a comparison of the spot-check measurements by the rockets with the continuous measurements aboard the satellites would have been possible in real time. Unfortunately, the SOLRAD satellites 11a and 11b were not started earlier than on 15 March 1976. Therefore, it is an open question which the absolute intensities of solar H Lyman-α radiation were, and which difference in the intensities really occurred between 4 and 21 January 1976.

Since for the calculation of the molecular oxygen density, pressure and temperature profiles only the *relative* variation in H Lyman-α intensity is important, and thus, a longterm variation in the response of the chambers must not be taken into account, more reliable data should be expected for those profiles.

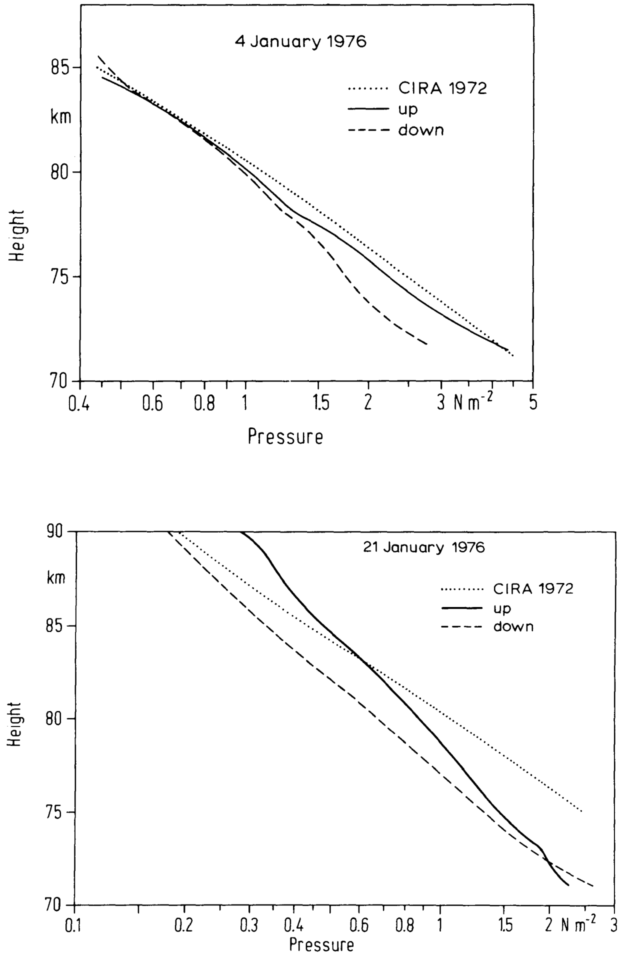

Fig. 6a and b. Calculated mesospheric pressure profiles based on measurement of H Lyman-α intensities at latitude 37.10° N on 4 and 21 January at winteranomalous conditions compared with the CIRA 1972 adjusted to the same latitude and month

The O_2-density profiles were determined using a fixed absorption cross-section $\sigma = 0.8 \times 10^{-24}$ m^2 for the entire height range, although a theoretical consideration by Hall (1972) recommends to apply a cross-section varying with height in order to achieve higher accuracy. Smith and Miller (1974), however, showed comparing data obtained from simultaneous measurements using various other techniques, that the assumption of a constant cross section leads to the best agreement with these measurements.

No correction was applied for the effect of dissociation of molecular oxygen, because up to heights of about 85 km this effect seems to be negligible. The molecular oxygen density-profiles are shown in Figure 5. These profiles do not only show smaller densities than the CIRA 1972, up to a factor of two, but also deviations from a steady decrease.

In a discussion of these curves it should be kept in mind that a model atmosphere like the CIRA gives something like a climatic average from which –

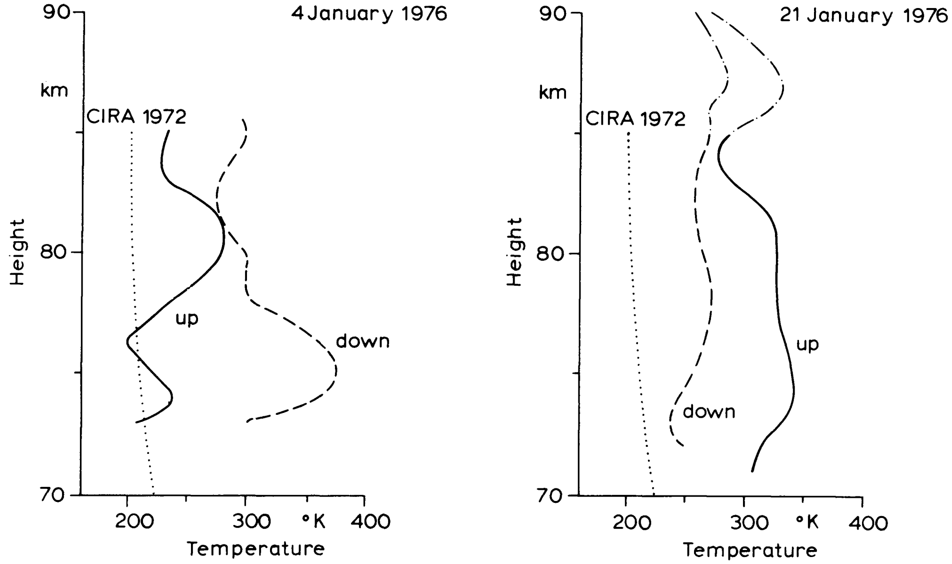

Fig. 7. Calculated mesospheric temperature profiles based on measurement of H Lyman-α intensities at latitude 37.10°N on 4 and 21 January at winteranomalous conditions compared with the CIRA 1972 adjusted to the same latitude and month

particularly during winteranomalous conditions—larger deviations are to be expected. A similar case is found in the stratosphere when a period of stratospheric warming occurs.

The mesospheric pressure and temperature profiles presented in Figure 6 and Figure 7 were calculated using a constant value $K = 2.2 \times 10^{-24}$ N (Hall, 1972).

Estimation of Possible Errors

The extinction of the solar H Lyman-α radiation, and also the windows of the ionization chambers, may be affected by water vapor. In order to avoid at least an influence of water vapor on the windows, up to 60 km, that part of the rocket containing the H Lyman-α sensors was washed round by N_2. The influence of water vapor on extinction and windows which really occurred in the mesosphere is not yet known and may be a source of error. Perhaps an estimate will be still possible when relevant simultaneous measurements have been evaluated.

A possible increase of the signal produced by other solar radiation than H Lyman-α was reduced as much as possible by use of MgF_2-windows and a CS_2 gas filling which—combined with each other—give a relative narrow spectral bandwidth of the sensors.

An influence of the Frigen gas which was used for the attitude control system of the rocket can be excluded. An experiment in the laboratory showed no absorption effect on H Lyman-α radiation.

It should be mentioned that the use of H Lyman-α intensity as done in this experiment implies that the intensity does not vary during the flight of the rocket. This is an assumption which is not yet proved. It is known that considerable short-time fluctuations in H Lyman-α intensity are possible. This point should be kept in mind interpreting the results.

An effect on the signal produced by deviation from pointing of the sensors at the Sun was corrected as far as necessary.

Due to an uncertainty in the knowledge of the real trajectory of the rocket, the height scales shown in Figures 4 to 7 perhaps may be wrong by up to ± 5 km on 4 January, and up to ± 10 km on 21 January 1976.

Conclusions

An early synoptic comparison of strato-mesospheric density and temperature profiles obtained from various methods of measurement, seperated for summer and winter, showed that, in winter, at middle latitudes, the densities were lower and the temperature above 60 km considerably higher and more variable than in summer (Schwentek, 1968). This situation was considered as a regular atmospheric background for the occurrence of an average winteranomaly in ionospheric absorption. The molecular oxygen, pressure and temperature profiles obtained by calculation from the experiments carried out in Janury 1976 differ more or less considerably from the CIRA 1972 as valid for January at 40° N, but in the same tendency as mentioned above: The molecular oxygen densities are lower, the temperatures higher than those given by the CIRA 1972. We suggest this result to be due to the strong winteranomalous conditions during the days of measurement. A further, more detailed analysis and discussion on how these results fit with the others obtained simultaneously is beyond the scope of this paper.

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