STUDIES, and the SYMPOSIUM ON GLOBAL ELECTRICAL CIRCUIT, GLOBAL CHANGE, AND THE METEOROLOGICAL APPLICATIONS OF LIGHTNING INFORMATION, January 23-28, 1994, Nashville, TN. Published by the American Meteorological Society, Boston, MA.

# CLIMATOLOGY OF WATER VAPOR IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE DETERMINED FROM SAGE II OBSERVATIONS

NASA-TM-111547

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## 1. INTRODUCTION

Water vapor in the upper troposphere and stratosphere, though much less abundant than near the earth's surface, plays a major role in the chemistry and physics of the atmosphere. For example, the results of recent studies (Peng et al., 1987; Arking, 1990) indicate that climate is just as sensitive to percentage changes in upper tropospheric water vapor, where the mixing ratio is very small, as it is to percentage changes in the planetary boundary layer. Unfortunately, earlier compilations of climatological water vapor distributions (such as Oort, 1983; Newell et al., 1973), which were based largely on radiosonde measurements over land, provide very limited information on the water vapor distributions for levels above 300mb and in many cases for lower levels also.

Current airborne and balloon-borne instruments (such as Lyman-alpha and Frost point hygrometers) capable of measuring water vapor in the upper troposphere and stratosphere are too expensive for routine use. Satellite-borne sensors, therefore, provide an excellent opportunity to obtain a unique set of measurements for this altitude region. The Limb Infrared Monitor of the Stratosphere (LIMS) instrument on Nimbus-7 (Russell, 1984) has illustrated the advantages of global remote sensing of stratospheric water vapor. The LIMS data set, although nearly global, is only for the 7-month period (November 1978 to May 1979) and, therefore, no seasonal or multiyear climatology could be developed. The Stratospheric Aerosol and Gas Experiment II (SAGE II) aboard the Earth Radiation Budget Satellite (ERBS), however, has been determining water vapor profiles in the stratosphere and troposphere all the way down to cloud tops since its launch in October 1984 (Rind et al., 1993; McCormick et al., 1993; Chu et al., 1993). Six papers on SAGE II water vapor validation were just published in the March 1993 issue of JGR. The applications of the SAGE II water vapor data have been published in a number of recent articles. For example, it was demostrated by Rind et al(1991) that SAGE II observations have led to the confirmation of positive water vapor feedback in climate models, extremely important to understanding greenhouse warming. Other examples of the application of these data include the use of SAGE II water vapor profiles measured over Antarctic during October 1987 in a sensitivity analysis of the differential absorption lidar (DIAL) technique (Ismail et al., 1991). A SAGE II-derived water vapor climatology has been used in a photochemical model for the studies of stratospheric species (Callis et al., 1991).

The purpose of this paper is to present a vertically-resolved global climatology of water vapor in the upper troposphere and lower stratosphere based on multi-year SAGE II observations. Seasonally averaged zonal mean profiles are illustrated in terms of both mixing ratio and relative humidity.

## 2. SAGE II WATER VAPOR MEASUREMENTS

The SAGE II water vapor data set has several unique advantages: (1) a solar occultation technique is used which has the inherent capability of self-calibration, high accuracy and high vertical resolution; (2) measurements are made down to cloud tops, covering not only the stratosphere but also the upper- and middle-troposphere; and (3) the archived data are near global and cover a four-year period (1986-89). Sensitivity analyses for the SAGE II water vapor retrieval (Chu et al., 1993) revealed that the SAGE II data are characterized by: (1) a random error of 18% for single profiles which is reduced when profiles are averaged (i.e. for the zonal mean); and (2) systematic errors are estimated to be about 20% from 10km to 40km for periods of low-to-moderate aerosol loading.

## 3. RESULTS AND DISCUSSIONS

In order to obtain the vertical distributions of water vapor in a climatological manner, we have used the 4-year (1986-89) archived SAGE II water vapor data set to derive the seasonally averaged mixing ratio profiles for each of the eight 20-degree latitudinal bands between 80S and 80N.

As pointed out by Yang et al.(1987), using averaged data in converting mixing ratio to relative humidity always has the potential to increase uncertainty because saturation vapor pressure is very nonlinear with temperature. Since SAGE II archived water vapor data includes the pressure and temperature at 1km intervals for each water vapor profile, the information allows us to compute the relative humidity profile for each individual event before carrying out the seasonal zonal average. Thus, more accurate and more representative results for seasonal zonal mean relative humidity are obtained.

The listing of zonally averaged water vapor mixing ratio (in ppmv) for different seasons are given in Tables 1(a), 1(b), 1(c), and 1(d). The corresponding listings for relative humidity (in percentage) are given in Tables 2(a), 2(b), 2(c), and 2(d), respectively. Relative humidities are omitted for the region above 16.5km because the values are very small and not commonly used.

The zonally averaged mixing ratio profiles for DJF and JJA in each hemisphere are depicted in Figures 1(a) and 1(b), and Figures 2(a) and 2(b), respectively. The crosses in these figures denote the values at the average tropopause altitude.

Comparison of the two pairs of figures [1(a) and 2(b) - summer, 1(b) and 2(a) - winter] indicates that for the same season (local summer and local winter), the averaged profiles exhibit similar patterns in both hemispheres. A number of interesting features emerge upon further investigation of these figures: (1) The existence of a region of minimum water vapor mixing ratio (the hygropause) has been found in all latitude bands; (2) the distances between tropopause and hygropause altitudes vary between 1km to 4km, being greater at higher latitudes; (3) most defined hygropauses appear at low latitudes (0-20S and 0-20N); (4) the smallest water vapor mixing ratios at lower latitudes appear in December-January-February for both hemispheres; and (5) for all latitude bands, there is a consistent positive poleward gradient of water vapor mixing ratio throughout the lower and middle stratosphere.

The profiles of zonally averaged relative humidity for DJF and JJA are depicted in figures 3(a) and 3(b), and 4(a) and 4(b) respectively. These results represent an extension of previous studies based on preliminary SAGE II observations (Chiou et al.,1992).

Due to the lack of relative humidity above 300mb, Yang et al.(1987) in their study of outgoing longwave radiation used the interpolation methods developed by Briegleb and Ramanathan (1982) and the formula derived by Harries (1976) to estimate the relative humidity at these pressure levels. The SAGE II-derived climatology of relative humidity presented herein can be used to avoid these empirical interpolation schemes. The vertical structure of relative humidity, which was derived from averaged mixing ratio and averaged temperature, presented in a recent study by Sun et al. (1993), could also be replaced by the more accurate climatology presented herein.

## 4. CONCLUDING REMARKS

In this paper, a climatology of water vapor in the upper troposphere and lower stratosphere is developed using the multi-year (1986-89) SAGE II observations. Zonally-averaged profiles of mixing ratio and relative humidity for the tropics and the mid- and high- latitudes are obtained for both hemispheres. The results are presented in graphical and tabulated form for various seasons.

It should be noted that the climatology presented is global for both stratosphere and troposphere but the tropospheric climatology represents clear-sky condition only because occultation data are taken from cloud tops and above. The information will be very useful for studies of stratospheric circulations, radiative budget of the stratosphere, and the atmospheric effects of stratospheric aircrafts. The inability of current GCMs to properly simulate many of the important details of moist processes are associated with our inadequate knowledge of atmospheric moisture content, especially at middle and upper tropospheric levels (Starr et al., 1990). Further, the existing upper tropospheric climatology is wetter than it should be due to in-situ instrument response times. Thus, the archived SAGE II water vapor data set should be more widely exploited to increase our understanding of atmospheric chemistry, dynamics, climate effects, and the global water cycle.

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Table 1(a) Zonally averaged H2O mixing ratio (ppmv) for DJF

| | 80S<br>-60S | 60S<br>-40S | 40S<br>-20S | 20S<br>-0 | 0<br>-20N | 20N<br>-40N | 40N<br>-60N | 60N<br>-80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | 186.00 | 349.00 | 619.00 | 807.00 | 738.00 | 375.00 | 138.00 | .00 |
| 7.5KM | 110.00 | 217.00 | 448.00 | 602.00 | 437.00 | 248.00 | 76.80 | .00 |
| 8.5KM | 52.50 | 120.00 | 289.00 | 397.00 | 270.00 | 144.00 | 42.10 | .00 |
| 9.5KM | 21.90 | 61.50 | 161.00 | 230.00 | 172.00 | 82.60 | 23.50 | .00 |
| 10.5KM | 7.68 | 27.70 | 88.90 | 129.00 | 102.00 | 44.00 | 11.80 | .00 |
| 11.5KM | 3.65 | 11.80 | 43.70 | 59.40 | 48.90 | 20.60 | 5.88 | .00 |
| 12.5KM | 2.99 | 6.14 | 22.00 | 31.90 | 24.90 | 10.10 | 3.99 | .00 |
| 13.5KM | 2.96 | 3.88 | 10.80 | 16.00 | 12.70 | 5.37 | 3.32 | .00 |
| 14.5KM | 3.06 | 3.09 | 5.61 | 8.20 | 6.61 | 3.36 | 3.17 | .00 |
| 15.5KM | 3.44 | 3.21 | 3.62 | 4.50 | 3.60 | 2.87 | 3.50 | .00 |
| 16.5KM | 3.79 | 3.49 | 3.10 | 2.82 | 2.47 | 2.92 | 3.81 | .00 |
| 17.5KM | 4.14 | 3.71 | 3.19 | 2.47 | 2.18 | 3.21 | 4.00 | .00 |
| 18.5KM | 4.53 | 3.95 | 3.59 | 2.97 | 2.80 | 3.70 | 4.17 | .00 |
| 19.5KM | 4.79 | 4.19 | 3.77 | 3.20 | 3.12 | 3.94 | 4.37 | .00 |
| 20.5KM | 5.01 | 4.44 | 3.99 | 3.51 | 3.50 | 4.20 | 4.57 | .00 |
| 21.5KM | 5.18 | 4.69 | 4.22 | 3.74 | 3.74 | 4.46 | 4.77 | .00 |
| 22.5KM | 5.28 | 4.90 | 4.45 | 3.88 | 3.93 | 4.69 | 4.95 | .00 |
| 23.5KM | 5.34 | 5.07 | 4.68 | 4.02 | 4.16 | 4.90 | 5.10 | .00 |
| 24.5KM | 5.38 | 5.20 | 4.89 | 4.19 | 4.37 | 5.05 | 5.22 | .00 |
| 25.5KM | 5.41 | 5.28 | 5.05 | 4.35 | 4.54 | 5.15 | 5.30 | .00 |
| 26.5KM | 5.44 | 5.33 | 5.16 | 4.51 | 4.69 | 5.20 | 5.35 | .00 |
| 27.5KM | 5.47 | 5.36 | 5.24 | 4.65 | 4.78 | 5.23 | 5.41 | .00 |
| 28.5KM | 5.52 | 5.39 | 5.28 | 4.74 | 4.82 | 5.25 | 5.46 | .00 |
| 29.5KM | 5.57 | 5.43 | 5.30 | 4.82 | 4.84 | 5.27 | 5.52 | .00 |
| 30.5KM | 5.62 | 5.47 | 5.32 | 4.87 | 4.87 | 5.30 | 5.59 | .00 |
| 31.5KM | 5.69 | 5.53 | 5.34 | 4.90 | 4.89 | 5.36 | 5.69 | .00 |
| 32.5KM | 5.75 | 5.58 | 5.36 | 4.90 | 4.93 | 5.43 | 5.78 | .00 |
| 33.5KM | 5.83 | 5.65 | 5.39 | 4.89 | 4.98 | 5.52 | 5.88 | .00 |
| 34.5KM | 5.91 | 5.71 | 5.43 | 4.89 | 5.03 | 5.62 | 5.98 | .00 |
| 35.5KM | 5.99 | 5.77 | 5.49 | 4.91 | 5.08 | 5.72 | 6.07 | .00 |
| 36.5KM | 6.08 | 5.83 | 5.54 | 4.95 | 5.12 | 5.81 | 6.15 | .00 |
| 37.5KM | 6.18 | 5.90 | 5.59 | 5.00 | 5.15 | 5.88 | 6.22 | .00 |
| 38.5KM | 6.28 | 5.96 | 5.66 | 5.05 | 5.19 | 5.94 | 6.27 | .00 |
| 39.5KM | 6.38 | 6.03 | 5.73 | 5.10 | 5.24 | 5.99 | 6.31 | .00 |
| 40.5KM | 6.47 | 6.10 | 5.80 | 5.16 | 5.30 | 6.05 | 6.37 | .00 |

Table 1(b) Zonally averaged H2O mixing ratio (ppmv) for MAM

| | 80S<br>-60S | 60S<br>-40S | 40S<br>-20S | 20S<br>-0 | 0<br>-20N | 20N<br>-40N | 40N<br>-60N | 60N<br>-80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | 156.00 | 243.00 | 479.00 | 753.00 | 1090.00 | 477.00 | 150.00 | 103.00 |
| 7.5KM | 88.50 | 143.00 | 323.00 | 437.00 | 736.00 | 318.00 | 88.30 | 57.60 |
| 8.5KM | 43.50 | 80.70 | 198.00 | 267.00 | 411.00 | 186.00 | 50.80 | 32.70 |
| 9.5KM | 18.80 | 44.40 | 116.00 | 166.00 | 242.00 | 105.00 | 27.60 | 17.50 |
| 10.5KM | 7.00 | 22.00 | 62.80 | 100.00 | 138.00 | 55.50 | 12.50 | 7.36 |
| 11.5KM | 3.42 | 9.99 | 30.70 | 51.90 | 66.20 | 25.20 | 5.82 | 3.72 |
| 12.5KM | 2.84 | 5.15 | 15.30 | 28.30 | 33.50 | 12.20 | 3.70 | 3.11 |
| 13.5KM | 2.79 | 3.34 | 7.50 | 14.70 | 15.60 | 6.52 | 3.02 | 3.09 |
| 14.5KM | 2.89 | 2.85 | 4.23 | 7.72 | 7.61 | 3.86 | 2.86 | 3.23 |
| 15.5KM | 3.31 | 3.06 | 3.16 | 4.18 | 4.13 | 3.08 | 3.27 | 3.76 |
| 16.5KM | 3.70 | 3.37 | 2.91 | 2.67 | 2.67 | 2.97 | 3.70 | 4.19 |
| 17.5KM | 4.03 | 3.64 | 3.02 | 2.40 | 2.34 | 3.16 | 4.03 | 4.48 |
| 18.5KM | 4.36 | 3.93 | 3.43 | 2.78 | 2.66 | 3.62 | 4.33 | 4.74 |
| 19.5KM | 4.59 | 4.14 | 3.69 | 3.02 | 2.94 | 3.94 | 4.53 | 4.91 |
| 20.5KM | 4.81 | 4.36 | 3.96 | 3.42 | 3.38 | 4.26 | 4.73 | 5.06 |
| 21.5KM | 4.99 | 4.58 | 4.20 | 3.72 | 3.71 | 4.54 | 4.92 | 5.18 |
| 22.5KM | 5.13 | 4.80 | 4.42 | 3.90 | 3.91 | 4.77 | 5.07 | 5.27 |
| 23.5KM | 5.22 | 4.99 | 4.63 | 3.99 | 4.05 | 4.94 | 5.20 | 5.34 |
| 24.5KM | 5.30 | 5.16 | 4.81 | 4.06 | 4.14 | 5.07 | 5.31 | 5.40 |
| 25.5KM | 5.36 | 5.30 | 4.96 | 4.20 | 4.25 | 5.17 | 5.41 | 5.45 |
| 26.5KM | 5.42 | 5.42 | 5.08 | 4.39 | 4.39 | 5.23 | 5.49 | 5.51 |
| 27.5KM | 5.49 | 5.51 | 5.18 | 4.49 | 4.50 | 5.29 | 5.56 | 5.57 |
| 28.5KM | 5.57 | 5.59 | 5.24 | 4.59 | 4.56 | 5.33 | 5.64 | 5.63 |
| 29.5KM | 5.65 | 5.66 | 5.27 | 4.68 | 4.63 | 5.36 | 5.71 | 5.69 |
| 30.5KM | 5.72 | 5.72 | 5.28 | 4.76 | 4.70 | 5.38 | 5.77 | 5.75 |
| 31.5KM | 5.80 | 5.78 | 5.28 | 4.82 | 4.76 | 5.40 | 5.84 | 5.82 |
| 32.5KM | 5.89 | 5.84 | 5.29 | 4.87 | 4.81 | 5.43 | 5.91 | 5.90 |
| 33.5KM | 5.99 | 5.89 | 5.31 | 4.93 | 4.90 | 5.47 | 5.96 | 5.97 |
| 34.5KM | 6.08 | 5.93 | 5.35 | 5.01 | 5.01 | 5.53 | 6.00 | 6.01 |
| 35.5KM | 6.17 | 5.98 | 5.39 | 5.10 | 5.14 | 5.59 | 6.02 | 6.04 |
| 36.5KM | 6.26 | 6.04 | 5.43 | 5.20 | 5.26 | 5.65 | 6.03 | 6.06 |
| 37.5KM | 6.35 | 6.10 | 5.48 | 5.28 | 5.33 | 5.67 | 6.04 | 6.08 |
| 38.5KM | 6.43 | 6.17 | 5.54 | 5.37 | 5.40 | 5.69 | 6.06 | 6.10 |
| 39.5KM | 6.51 | 6.25 | 5.61 | 5.45 | 5.46 | 5.72 | 6.09 | 6.14 |
| 40.5KM | 6.59 | 6.35 | 5.69 | 5.55 | 5.53 | 5.76 | 6.14 | 6.20 |

Table 1(c) Zonally averaged H2O mixing ratio (ppmv) for JJA

| | 80S -60S | 60S -40S | 40S -20S | 20S -0 | 0 -20N | 20N -40N | 40N -60N | 60N -80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | .00 | 155.00 | 316.00 | 420.00 | 979.00 | 694.00 | 624.00 | 399.00 |
| 7.5KM | .00 | 86.20 | 205.00 | 300.00 | 659.00 | 520.00 | 374.00 | 233.00 |
| 8.5KM | .00 | 46.10 | 130.00 | 202.00 | 425.00 | 309.00 | 224.00 | 135.00 |
| 9.5KM | .00 | 25.00 | 77.40 | 146.00 | 266.00 | 185.00 | 127.00 | 67.80 |
| 10.5KM | .00 | 12.50 | 44.30 | 93.50 | 150.00 | 109.00 | 62.80 | 27.00 |
| 11.5KM | .00 | 6.05 | 22.10 | 50.40 | 71.40 | 54.40 | 26.00 | 9.71 |
| 12.5KM | .00 | 3.74 | 11.90 | 28.10 | 34.80 | 29.00 | 11.00 | 4.56 |
| 13.5KM | .00 | 2.99 | 6.71 | 15.50 | 17.20 | 15.20 | 5.53 | 3.30 |
| 14.5KM | .00 | 2.80 | 4.37 | 8.77 | 9.49 | 8.41 | 3.75 | 3.00 |
| 15.5KM | .00 | 3.10 | 3.53 | 5.49 | 5.92 | 5.42 | 3.39 | 3.19 |
| 16.5KM | .00 | 3.43 | 3.24 | 3.87 | 4.13 | 4.10 | 3.40 | 3.51 |
| 17.5KM | .00 | 3.68 | 3.25 | 3.16 | 3.43 | 3.66 | 3.53 | 3.87 |
| 18.5KM | .00 | 3.93 | 3.58 | 3.08 | 3.24 | 3.65 | 3.83 | 4.29 |
| 19.5KM | .00 | 4.08 | 3.82 | 3.36 | 3.41 | 3.79 | 4.06 | 4.53 |
| 20.5KM | .00 | 4.24 | 4.07 | 3.49 | 3.53 | 4.00 | 4.30 | 4.77 |
| 21.5KM | .00 | 4.41 | 4.28 | 3.68 | 3.67 | 4.23 | 4.54 | 4.97 |
| 22.5KM | .00 | 4.58 | 4.46 | 3.84 | 3.87 | 4.42 | 4.76 | 5.13 |
| 23.5KM | .00 | 4.76 | 4.62 | 4.05 | 4.07 | 4.60 | 4.96 | 5.25 |
| 24.5KM | .00 | 4.92 | 4.76 | 4.25 | 4.20 | 4.76 | 5.13 | 5.34 |
| 25.5KM | .00 | 5.06 | 4.86 | 4.35 | 4.28 | 4.89 | 5.27 | 5.44 |
| 26.5KM | .00 | 5.17 | 4.92 | 4.45 | 4.39 | 5.00 | 5.37 | 5.52 |
| 27.5KM | .00 | 5.26 | 4.96 | 4.52 | 4.49 | 5.08 | 5.45 | 5.61 |
| 28.5KM | .00 | 5.34 | 4.98 | 4.60 | 4.58 | 5.13 | 5.53 | 5.71 |
| 29.5KM | .00 | 5.40 | 5.00 | 4.68 | 4.66 | 5.17 | 5.61 | 5.81 |
| 30.5KM | .00 | 5.47 | 5.03 | 4.77 | 4.70 | 5.20 | 5.68 | 5.90 |
| 31.5KM | .00 | 5.55 | 5.08 | 4.87 | 4.74 | 5.23 | 5.75 | 5.97 |
| 32.5KM | .00 | 5.62 | 5.16 | 4.99 | 4.78 | 5.28 | 5.83 | 6.05 |
| 33.5KM | .00 | 5.69 | 5.27 | 5.13 | 4.85 | 5.34 | 5.93 | 6.13 |
| 34.5KM | .00 | 5.75 | 5.40 | 5.30 | 4.95 | 5.41 | 6.02 | 6.21 |
| 35.5KM | .00 | 5.81 | 5.55 | 5.46 | 5.05 | 5.48 | 6.10 | 6.28 |
| 36.5KM | .00 | 5.88 | 5.71 | 5.59 | 5.13 | 5.56 | 6.16 | 6.34 |
| 37.5KM | .00 | 5.94 | 5.85 | 5.70 | 5.19 | 5.62 | 6.20 | 6.38 |
| 38.5KM | .00 | 6.00 | 5.97 | 5.77 | 5.24 | 5.66 | 6.25 | 6.42 |
| 39.5KM | .00 | 6.09 | 6.07 | 5.83 | 5.29 | 5.70 | 6.30 | 6.46 |
| 40.5KM | .00 | 6.19 | 6.18 | 5.88 | 5.34 | 5.74 | 6.36 | 6.52 |

Table 1(d) Zonally averaged H2O mixing ratio (ppmv) for SON

| | 80S -60S | 60S -40S | 40S -20S | 20S -0 | 0 -20N | 20N -40N | 40N -60N | 60N -80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | 53.70 | 143.00 | 453.00 | 491.00 | 1140.00 | 597.00 | 266.00 | 362.00 |
| 7.5KM | 29.50 | 79.80 | 330.00 | 310.00 | 654.00 | 415.00 | 163.00 | 198.00 |
| 8.5KM | 16.10 | 44.50 | 218.00 | 231.00 | 383.00 | 247.00 | 91.80 | 107.00 |
| 9.5KM | 9.89 | 24.80 | 128.00 | 159.00 | 239.00 | 139.00 | 50.10 | 55.40 |
| 10.5KM | 4.75 | 12.20 | 67.50 | 102.00 | 160.00 | 75.00 | 25.00 | 23.90 |
| 11.5KM | 2.78 | 5.92 | 30.80 | 54.00 | 78.00 | 36.00 | 12.10 | 9.98 |
| 12.5KM | 2.37 | 3.88 | 14.10 | 29.20 | 37.30 | 18.60 | 6.88 | 5.00 |
| 13.5KM | 2.30 | 3.27 | 7.49 | 15.30 | 18.10 | 9.97 | 4.69 | 3.69 |
| 14.5KM | 2.39 | 3.11 | 4.83 | 8.23 | 9.12 | 5.90 | 3.89 | 3.27 |
| 15.5KM | 2.81 | 3.37 | 4.05 | 5.11 | 5.03 | 4.48 | 3.81 | 3.28 |
| 16.5KM | 3.24 | 3.63 | 3.84 | 3.77 | 3.67 | 4.01 | 3.80 | 3.43 |
| 17.5KM | 3.63 | 3.84 | 3.79 | 3.45 | 3.49 | 3.92 | 3.81 | 3.68 |
| 18.5KM | 4.08 | 4.09 | 3.82 | 3.47 | 3.64 | 3.88 | 3.94 | 4.03 |
| 19.5KM | 4.49 | 4.29 | 3.96 | 3.50 | 3.58 | 3.95 | 4.13 | 4.26 |
| 20.5KM | 4.90 | 4.49 | 4.12 | 3.54 | 3.58 | 4.10 | 4.34 | 4.49 |
| 21.5KM | 5.28 | 4.69 | 4.29 | 3.66 | 3.67 | 4.27 | 4.56 | 4.71 |
| 22.5KM | 5.57 | 4.88 | 4.45 | 3.88 | 3.85 | 4.46 | 4.77 | 4.90 |
| 23.5KM | 5.76 | 5.04 | 4.60 | 4.08 | 4.07 | 4.64 | 4.96 | 5.05 |
| 24.5KM | 5.85 | 5.17 | 4.73 | 4.20 | 4.23 | 4.81 | 5.13 | 5.18 |
| 25.5KM | 5.87 | 5.26 | 4.84 | 4.30 | 4.39 | 4.94 | 5.26 | 5.30 |
| 26.5KM | 5.86 | 5.31 | 4.91 | 4.42 | 4.54 | 5.05 | 5.36 | 5.40 |
| 27.5KM | 5.84 | 5.35 | 4.97 | 4.48 | 4.64 | 5.13 | 5.44 | 5.50 |
| 28.5KM | 5.84 | 5.38 | 5.02 | 4.53 | 4.70 | 5.17 | 5.51 | 5.61 |
| 29.5KM | 5.85 | 5.41 | 5.07 | 4.58 | 4.74 | 5.19 | 5.56 | 5.71 |
| 30.5KM | 5.87 | 5.47 | 5.13 | 4.64 | 4.76 | 5.19 | 5.61 | 5.80 |
| 31.5KM | 5.91 | 5.54 | 5.19 | 4.70 | 4.78 | 5.20 | 5.66 | 5.86 |
| 32.5KM | 5.95 | 5.62 | 5.28 | 4.80 | 4.82 | 5.22 | 5.72 | 5.94 |
| 33.5KM | 6.00 | 5.72 | 5.38 | 4.91 | 4.89 | 5.26 | 5.79 | 6.01 |
| 34.5KM | 6.05 | 5.82 | 5.49 | 5.05 | 5.00 | 5.31 | 5.86 | 6.09 |
| 35.5KM | 6.09 | 5.91 | 5.60 | 5.20 | 5.11 | 5.38 | 5.93 | 6.15 |
| 36.5KM | 6.13 | 5.99 | 5.71 | 5.34 | 5.23 | 5.45 | 6.02 | 6.20 |
| 37.5KM | 6.17 | 6.05 | 5.81 | 5.46 | 5.33 | 5.53 | 6.10 | 6.27 |
| 38.5KM | 6.20 | 6.10 | 5.91 | 5.57 | 5.43 | 5.62 | 6.18 | 6.34 |
| 39.5KM | 6.25 | 6.15 | 6.00 | 5.68 | 5.52 | 5.71 | 6.26 | 6.41 |
| 40.5KM | 6.29 | 6.21 | 6.08 | 5.77 | 5.61 | 5.81 | 6.35 | 6.50 |

Table 2(a) Zonally averaged relative humidity (%) for DJF

|  | 80S -60S | 60S -40S | 40S -20S | 20S -0 | 0 -20N | 20N -40N | 40N -60N | 60N -80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | 58.900 | 37.500 | 15.900 | 15.800 | 14.400 | 18.500 | 32.600 | .000 |
| 7.5KM | 48.600 | 37.500 | 19.200 | 18.400 | 13.600 | 20.700 | 30.100 | .000 |
| 8.5KM | 33.100 | 31.600 | 22.100 | 20.400 | 14.600 | 20.700 | 28.400 | .000 |
| 9.5KM | 14.300 | 23.600 | 23.200 | 22.000 | 16.800 | 21.000 | 23.000 | .000 |
| 10.5KM | 4.430 | 14.800 | 24.100 | 24.400 | 18.800 | 19.200 | 14.100 | .000 |
| 11.5KM | 1.670 | 7.510 | 21.000 | 22.600 | 18.000 | 13.700 | 7.150 | .000 |
| 12.5KM | .990 | 4.250 | 18.500 | 25.100 | 19.100 | 9.980 | 4.100 | .000 |
| 13.5KM | .748 | 2.570 | 14.700 | 25.000 | 19.900 | 7.510 | 2.810 | .000 |
| 14.5KM | .617 | 1.750 | 11.700 | 24.400 | 20.100 | 6.210 | 2.420 | .000 |
| 15.5KM | .558 | 1.570 | 8.860 | 19.200 | 16.100 | 5.970 | 2.450 | .000 |
| 16.5KM | .488 | 1.540 | 9.140 | 17.700 | 16.600 | 7.070 | 2.490 | .000 |

Table 2(b) Zonally averaged relative humidity (%) for MAM

|  | 80S -60S | 60S -40S | 40S -20S | 20S -0 | 0 -20N | 20N -40N | 40N -60N | 60N -80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | 47.500 | 31.700 | 17.500 | 13.700 | 20.800 | 17.800 | 33.200 | 43.100 |
| 7.5KM | 37.400 | 31.900 | 20.200 | 12.000 | 22.400 | 19.900 | 30.400 | 33.400 |
| 8.5KM | 25.500 | 29.800 | 22.000 | 12.600 | 21.300 | 21.600 | 28.900 | 27.600 |
| 9.5KM | 11.300 | 25.400 | 23.600 | 14.200 | 22.800 | 23.100 | 22.500 | 17.500 |
| 10.5KM | 3.720 | 17.800 | 23.300 | 16.700 | 24.900 | 22.300 | 12.200 | 7.160 |
| 11.5KM | 1.480 | 9.390 | 18.300 | 17.500 | 24.700 | 16.600 | 5.850 | 3.020 |
| 12.5KM | .957 | 4.790 | 14.200 | 19.900 | 26.700 | 12.400 | 3.250 | 1.920 |
| 13.5KM | .766 | 2.830 | 10.200 | 21.000 | 25.000 | 9.250 | 2.180 | 1.550 |
| 14.5KM | .675 | 2.140 | 7.870 | 22.000 | 23.300 | 7.100 | 1.810 | 1.370 |
| 15.5KM | .661 | 2.050 | 6.500 | 16.900 | 17.500 | 6.170 | 1.810 | 1.390 |
| 16.5KM | .635 | 2.010 | 6.700 | 16.100 | 16.000 | 6.620 | 1.830 | 1.360 |

Table 2(c) Zonally averaged relative humidity (%) for JJA

|  | 80S -60S | 60S -40S | 40S -20S | 20S -0 | 0 -20N | 20N -40N | 40N -60N | 60N -80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | .000 | 29.800 | 16.600 | 7.810 | 17.200 | 14.800 | 28.300 | 42.300 |
| 7.5KM | .000 | 29.400 | 17.700 | 8.630 | 18.300 | 17.800 | 29.300 | 43.600 |
| 8.5KM | .000 | 26.700 | 18.300 | 10.100 | 19.700 | 18.200 | 31.000 | 42.700 |
| 9.5KM | .000 | 23.000 | 18.700 | 13.500 | 22.500 | 19.900 | 31.400 | 32.100 |
| 10.5KM | .000 | 14.900 | 17.300 | 16.600 | 25.200 | 21.800 | 25.900 | 16.900 |
| 11.5KM | .000 | 7.380 | 12.600 | 18.300 | 25.100 | 20.400 | 14.300 | 5.480 |
| 12.5KM | .000 | 4.430 | 10.300 | 21.600 | 27.100 | 19.800 | 7.470 | 2.020 |
| 13.5KM | .000 | 3.440 | 8.350 | 23.300 | 25.800 | 17.200 | 3.960 | 1.100 |
| 14.5KM | .000 | 2.790 | 6.950 | 24.200 | 26.200 | 15.200 | 2.580 | .788 |
| 15.5KM | .000 | 2.700 | 5.970 | 20.200 | 21.500 | 11.800 | 2.010 | .687 |
| 16.5KM | .000 | 2.670 | 5.950 | 19.200 | 20.000 | 11.900 | 1.830 | .637 |

Table 2(d) Zonally averaged relative humidity (%) for SON

|  | 80S -60S | 60S -40S | 40S -20S | 20S -0 | 0 -20N | 20N -40N | 40N -60N | 60N -80N |
|---|---|---|---|---|---|---|---|---|
| 6.5KM | 30.500 | 27.300 | 18.600 | 9.580 | 21.100 | 18.500 | 30.300 | 44.600 |
| 7.5KM | 27.600 | 25.200 | 22.200 | 9.360 | 18.200 | 21.200 | 33.200 | 42.200 |
| 8.5KM | 26.300 | 23.100 | 24.600 | 12.100 | 18.200 | 22.700 | 32.500 | 39.800 |
| 9.5KM | 26.700 | 19.800 | 26.000 | 15.300 | 20.700 | 23.500 | 28.600 | 31.600 |
| 10.5KM | 16.300 | 12.300 | 23.500 | 18.700 | 26.800 | 23.500 | 20.800 | 18.700 |
| 11.5KM | 10.000 | 6.580 | 16.700 | 20.100 | 27.700 | 20.000 | 11.800 | 7.280 |
| 12.5KM | 8.230 | 4.300 | 12.000 | 22.900 | 29.300 | 17.900 | 6.840 | 2.940 |
| 13.5KM | 7.290 | 3.430 | 9.190 | 24.300 | 30.100 | 15.000 | 4.230 | 1.680 |
| 14.5KM | 7.170 | 3.010 | 7.730 | 24.900 | 30.300 | 12.600 | 3.170 | 1.200 |
| 15.5KM | 7.410 | 2.990 | 6.820 | 19.900 | 22.200 | 10.600 | 2.770 | .981 |
| 16.5KM | 7.040 | 2.810 | 7.130 | 19.500 | 21.200 | 10.900 | 2.480 | .857 |

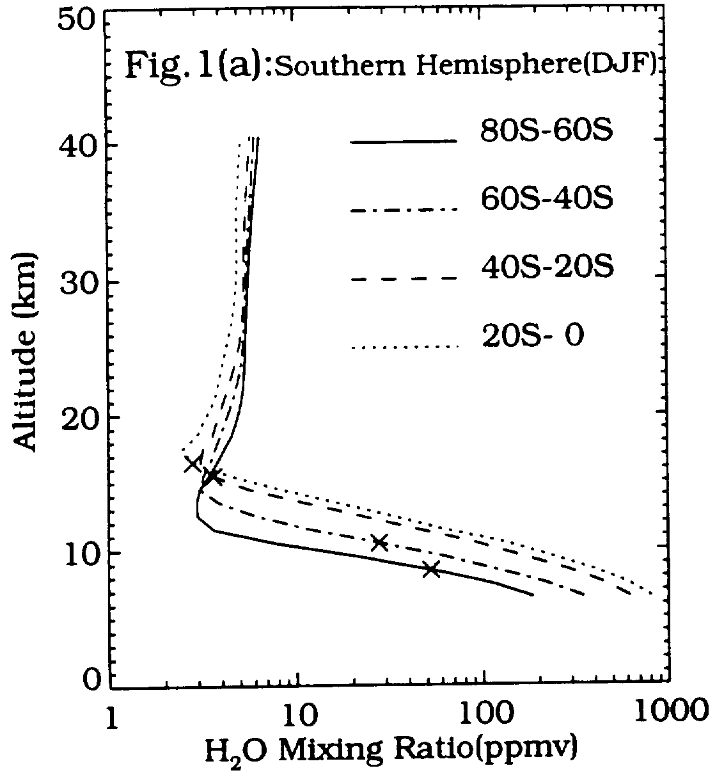
Fig. 1(a): Southern Hemisphere(DJF)

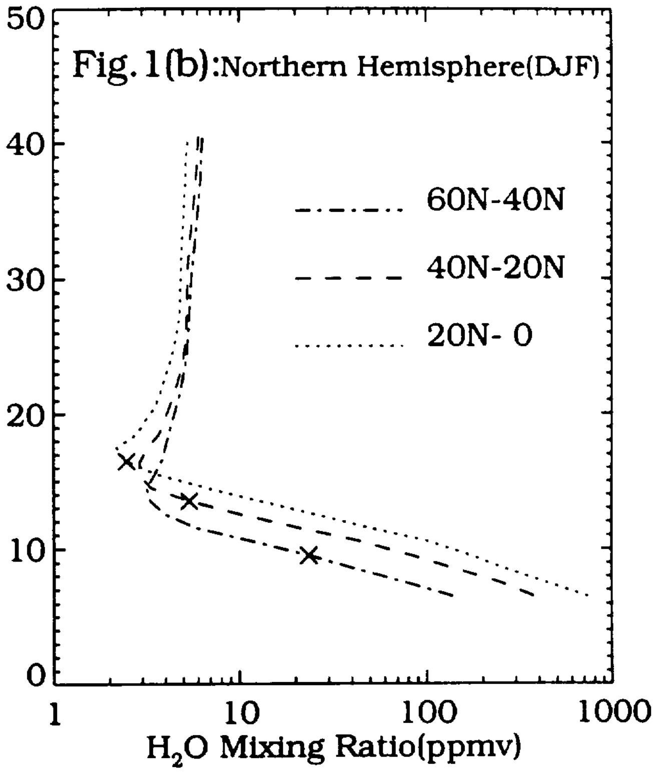
Fig. 1(b): Northern Hemisphere(DJF)

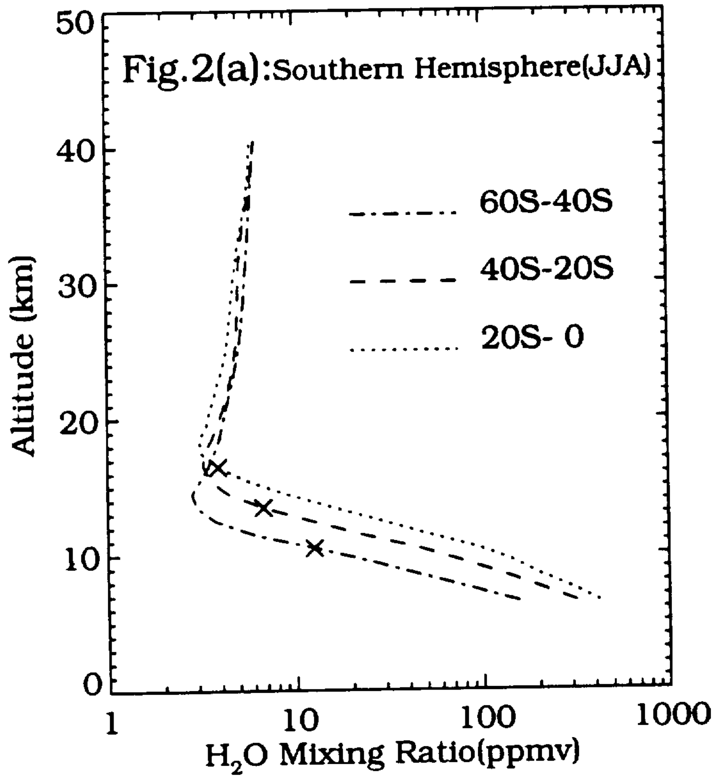
Fig. 2(a): Southern Hemisphere(JJA)

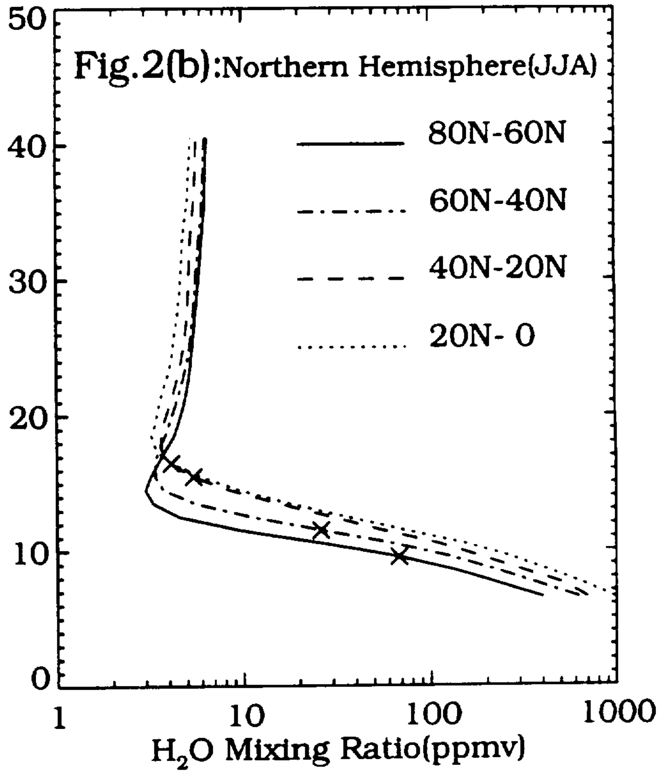
Fig. 2(b): Northern Hemisphere(JJA)

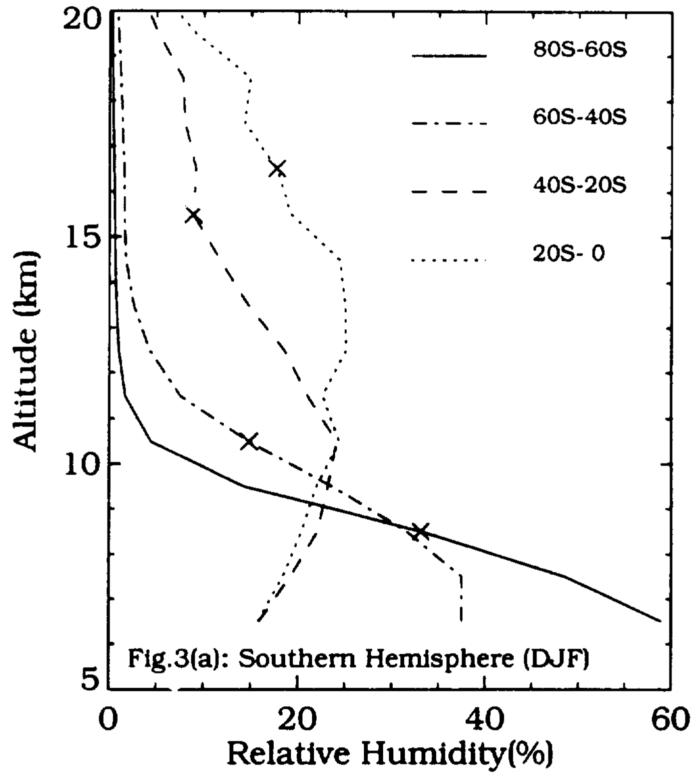
Fig.3(a): Southern Hemisphere (DJF)

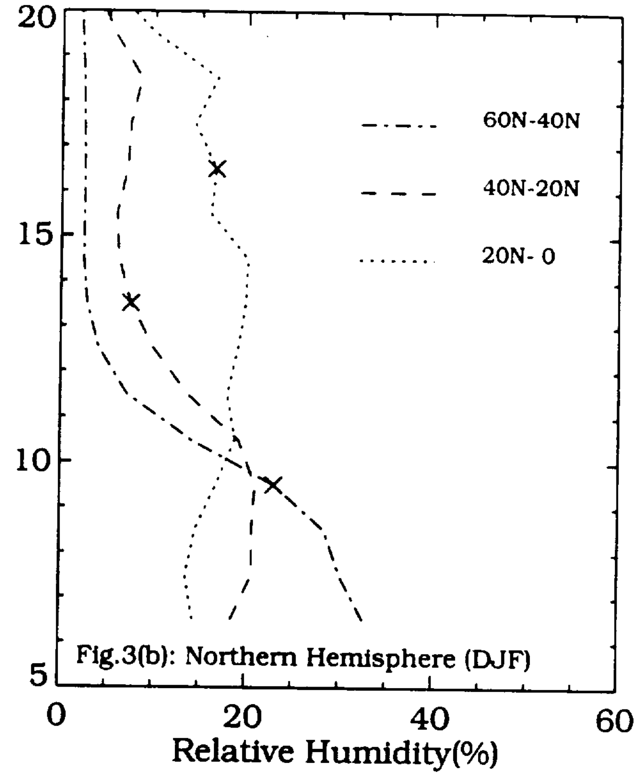
Fig.3(b): Northern Hemisphere (DJF)

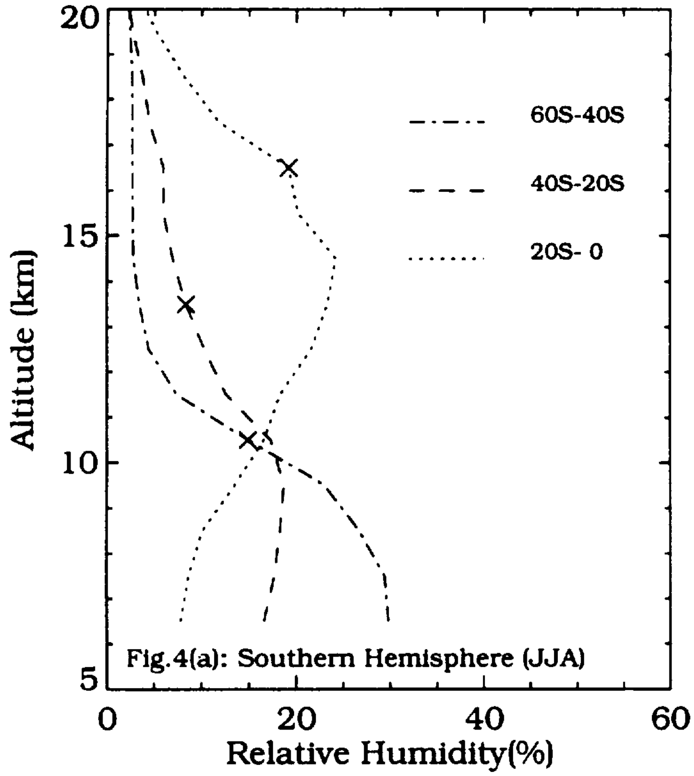
Fig.4(a): Southern Hemisphere (JJA)

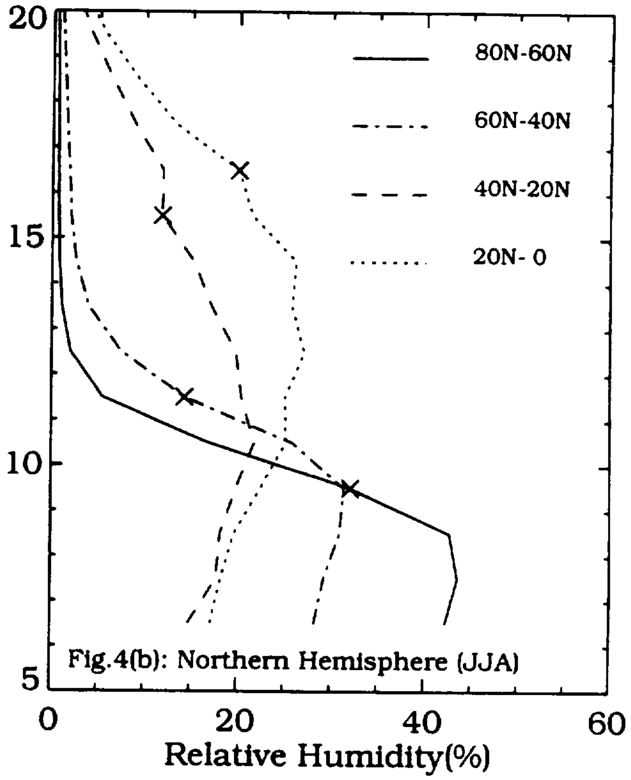
Fig.4(b): Northern Hemisphere (JJA)