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Water vapour and ozone in the mesosphere as measured by UARS MLS

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Abstract. Until recently, measurements of water vapour in the upper mesosphere were scarce. Instruments on the UARS platform have made the first global measurements of upper mesospheric H_2O; the Microwave Limb Sounder is one of these instruments. It has also measured upper mesospheric ozone. So far, various random and systematic errors have prevented accurate retrievals of either species in the upper mesosphere but much can be learned from the raw radiance measurements. In this paper we present these measurements and show how they can provide information on the dynamics of the mesosphere.

Introduction

The dynamics of the earth's mesosphere and the transport of chemical species within it are not adequately understood. Until recently, measurements of winds, temperature and constituents in this region of the atmosphere were mostly ground-based. Various instruments on the Upper Atmosphere Research Satellite (UARS) have done much to improve our knowledge of the mesosphere. The Microwave Limb Sounder (MLS) on UARS has made measurements of radiation from the 183.3 GHz water vapour line; these are the first daily global measurements of water vapour in the upper mesosphere. Water vapour is a useful tracer of atmospheric motion in the mesosphere and is also responsible for the formation of Noctilucent Clouds; the MLS measurements can potentially improve our understanding of both of these areas.

Water vapour is also the source gas for the active hydrogen species which control the ozone mixing ratio in the upper mesosphere [Allen et al. 1984]. MLS made measurements of radiation from the 184.4 GHz ozone line at the same times and places as the water vapour measurements; by studying these measurements we can gain information about the ozone chemistry of the mesosphere as well as its dynamics.

The instrument and the data

The instrument

The MLS instrument [Barath et al. 1993] measures microwave radiation which is thermally emitted from the atmosphere. The radiation is received by a parabolic dish antenna whose field of view is scanned vertically across the earth's limb. One scan is made every 65.536 seconds giving about 1318 profiles per day. Once inside the instrument, the radiation is downconverted and ends up in six filter banks, or bands, each consisting of fifteen filters. Each band is centred on an emission line of a particular molecule. One band is centred on an oxygen line and is used for measuring temperature and pressure. The other bands are used for measuring concentrations of various molecules. The UARS satellite is in an orbit inclined at 57° to the equator and which precesses by about 20 minutes local time per day. The MLS instrument looks out from the side of the satellite away from the sun in a direction perpendicular to the satellite velocity. Approximately every 36 days the orbital precession brings the sun round to the cold side of the satellite, which is then rotated, or yawed, through 180°. The result of this is that MLS makes measurements between 34°S and 80°N for about 36 days and between 34°N and 80 °S for the next 36.

In this paper we concentrate on band 5, which is centred on the 183.3 GHz H_2O line and band 6 which is centred on the 184.4 GHz ozone line. The centre filter in each band is sensitive to species concentration between 60 and 85 km. We present measurements of the

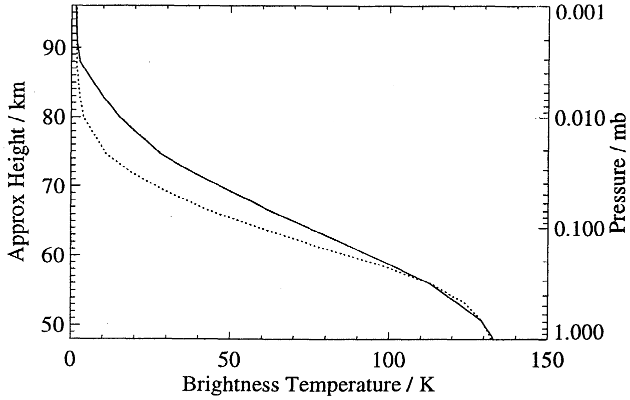

Figure 1. Two profiles of MLS brightness temperature as measured in the line centre channel of the water vapour band. The channel is 2 MHz wide and the line lies at its centre. The two profiles were taken at about 80° N, the solid line in summer (20 July 1992) and the dotted line in winter (30 Dec. 1991).

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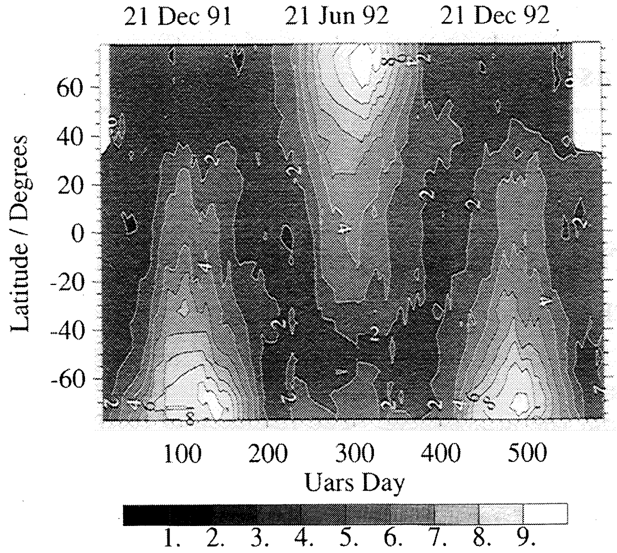

Figure 2. Zonal mean brightness temperature in Kelvin in a channel centred on the 183.3 GHz water vapour line as a function of time and latitude at a pressure of 0.0046 mb (about 85 km). Time is in UARS days (day 1 was 12 September 1991). Data from every fifth day of the mission was used to make the plot. Note that poleward of 34° the data has gaps of about 36 days in alternating hemispheres which have been interpolated over to make the pattern easier for the eye to follow. There also are a few periods of missing data around day 280.

brightness temperature in these two filters, corrected for baseline (frequency independent) artefacts by subtracting the wing channels and interpolated onto UARS pressure surfaces.

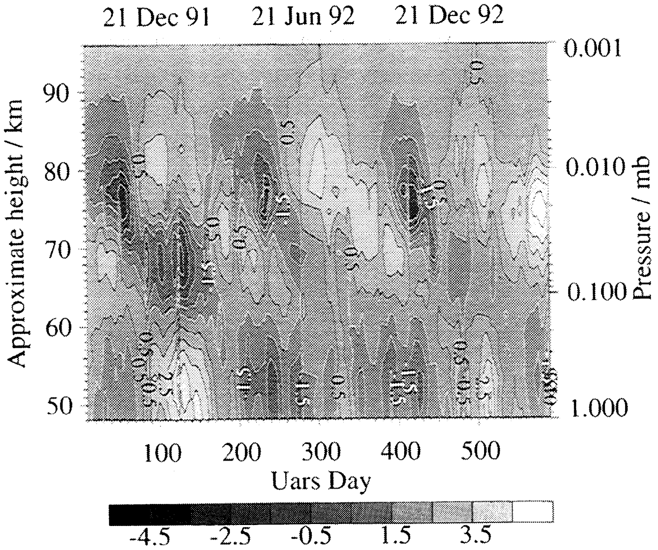

Figure 3. Zonal mean brightness temperature in Kelvin in a channel centred on the 183.3 GHz water vapour line as a function of time and pressure altitude for the region between 5°N and 5°S. The time mean profile has been subtracted to make the time variation clearer.

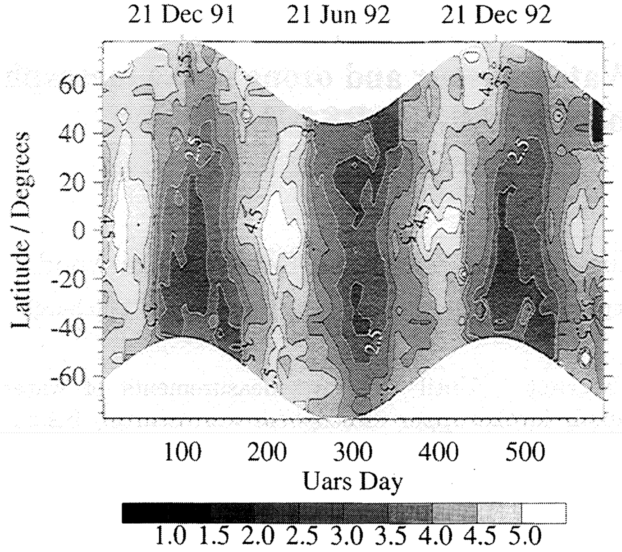

Figure 4. As Figure 2 but for a channel centred on the 184.4 GHz ozone line. The time series is noisier than the water vapour data, so a gaussian smoothing with a 6-day half width has been performed. The figure shows nighttime data only so there are missing data in the polar summers.

The data

Figure 1 shows two typical profiles of band 5 brightness temperature, both made near 80° North. The brightness temperature at a given pressure is proportional to the water vapour concentration as long as the viewing path is optically thin (pressure < 0.1 mb, height > 65 km), and depends somewhat on the temperature as well. Radiative transfer calculations suggest that in the polar mesosphere where there is a large annual temperature cycle, less than 15% of the observed variation in brightness is caused by the variation in temperature.

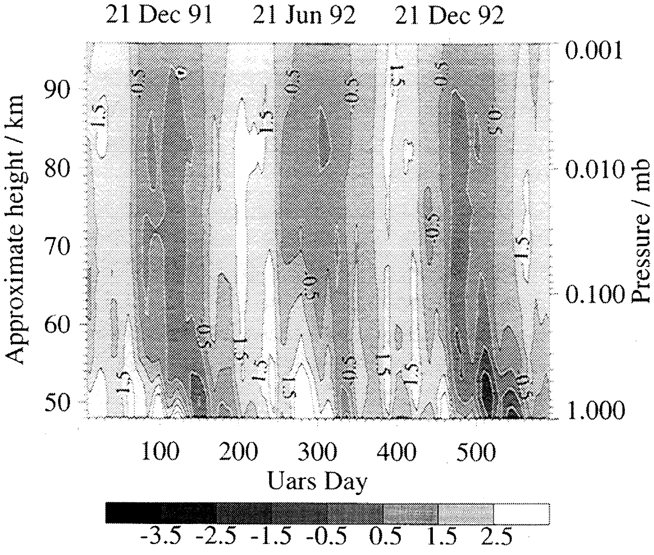

Figure 5. As Figure 3 but for a channel centred on the 184.4 GHz ozone line. Nighttime data only is shown and is smoothed as in Fig. 4.

The solid profile was measured in summer, the dashed one in winter. Clearly, the upper mesosphere is wetter in summer than in winter. We form zonal means of the data and present them as time series. Figure 2 shows water vapour data at 0.0046 mb (85 km). Note the annual cycle at poles and semiannual cycle at the equator. The annual cycle is wet in the summer and dry in the winter. The semiannual cycle is wet at the solstices and dry at the equinoxes. This is consistent with ground based measurements taken at 34.4°N and 45°S [Nedoluha et al., 1996] which show large increases in water vapour at the summer solstices and much smaller ones at the winter solstices. The ground-based measurements at 45°S show a larger annual component than those at 34.4°N, again consistent with the MLS measurements. At 70 km the equatorial semiannual cycle is still present, but is now wet at equinoxes and dry at solstices ; this can be seen in Fig. 3 where we show the time series at the equator with the time mean subtracted to bring out the time variation. Note how the phase of the semiannual oscillation varies with height with the maxima and minima at lower altitudes appearing at later times. Some of these features are seen in other data, particularly that of the HALOE [Jackson et al. 1997] and WVMS [Nedoluha et al., 1996] instruments.

The ozone data are presented in a similar manner in Figures 4 and 5. Ozone has a very strong diurnal cycle in the mesosphere, so only night-time data were used to make these figures. Figure 4 shows the time variation at 0.0046 mb while Fig. 5 shows the time variation at the equator with the time mean removed. Comparison with the water vapour data in figures 2 and 3 shows that the two species behave very differently. Note in particular that both species have a strong semiannual oscillation in the tropics, but that with ozone this persists at higher latitudes, while with water vapour it is replaced by an annual oscillation at higher latitudes. Note also that the semiannual oscillation in ozone occurs over a greater vertical range and does not vary in phase over this range. The ozone data are qualitatively similar to the daytime measurements made by the SME satellite [Thomas et al. 1984].

MLS data may be used to study the diurnal cycle of mesospheric ozone because the UARS orbit precesses such that the local time of measurements at a given location changes by 20 minutes from one day to the next. If we can assume that the seasonal change over a yaw period is smaller than the diurnal cycle, we can build up a complete diurnal cycle. Figure 6 shows an example.

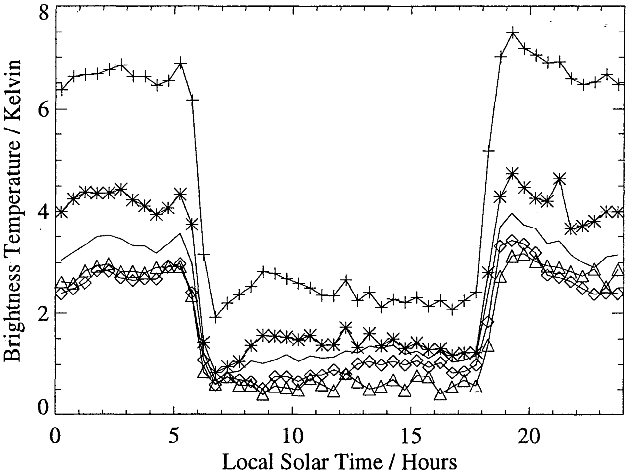

Figure 6. Diurnal variation of the brightness temperature in the centre channel of MLS band 6 for 14 August to 20 September 1992 in a latitude band from 30°S - 40°S. The lines are for various pressures: ‘+’: 0.046 mb, ‘*’: 0.031 mb, plain: 0.022, diamond: 0.01 mb, triangle: 0.0022 mb.

Discussion

Mesospheric Dynamics

The general circulation in the mesosphere is from summer pole to winter pole, with upwelling at the summer pole and downwelling at the winter one. This circulation is driven predominantly by breaking gravity waves [e.g. Garcia and Solomon 1985]. Water is transported partly by this circulation and partly by turbulent diffusion. The water molecule is photolysed with a lifetime of several months at the stratopause, but only a few days at 80 km. We can therefore infer that unusually wet air in the mesosphere has arrived there quite recently from below, while dry air has either been there some time or has been brought down from above. Many models of the mesosphere show a semiannual oscillation of water vapour even at the poles, linked to a semiannual variation in turbulent diffusive transport [Garcia 1989, Smith and Brasseur 1991]. If these models are forced to assume that most of the transport is advective, they tend to show an annual cycle at the poles instead. The data suggest, therefore, that advective transport is more important. We show in Figure 7 the seasonal vari-

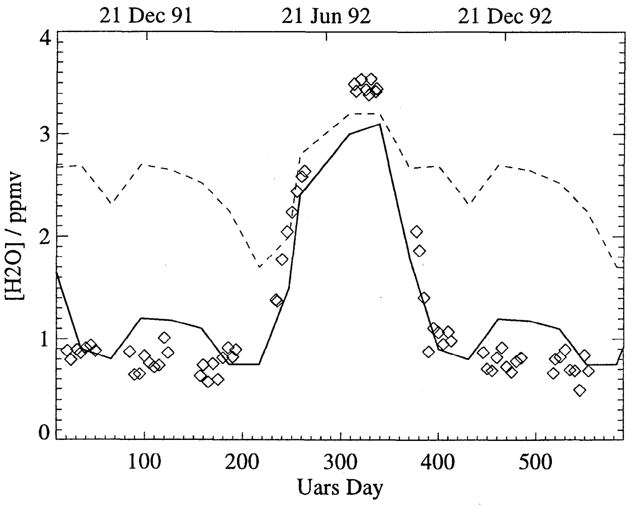

Figure 7. Water vapour mixing ratio at 80 km from the model of Garcia [1989]. Dashed line is for Pr = 1, solid line for Pr = 10. The diamonds are MLS brightness temperature, at 0.01 mb, in Kelvin multiplied by 0.2.

ation of water vapour mixing ratio at 80 km taken from Garcia [1989]. The dashed line is from a run with the Prandtl number Pr set to 1, indicating that advective and diffusive transport are of equal importance. The solid line is from a run with Pr = 10, indicating that most of the transport is advective. The MLS radiances are marked on the plot as diamonds, they clearly agree better with the Pr = 10 model run.

The conclusion that water vapour in the mesosphere is transported mainly by advection helps to explain several qualitative features of the data shown in Figs 2 and 3. There is known to be a very strong meridional wind in the mesosphere at the solstices, blowing from the summer to the winter pole. Taken together with the fact that most mesospheric water vapour reaches the mesosphere over the summer pole, this suggests that the pattern seen in Fig. 2 is at least partly caused by water vapour being rapidly transported by the meridional wind and being photolysed as it goes. The equatorial mesopause is therefore wet at the solstices when this transport is strongest (from one pole or the other) and dry at the equinoxes as the meridional flow reverses and the water vapour is photolysed.

Mesospheric ozone

Ozone in the mesosphere is in photochemical equilibrium with atomic oxygen. In the daytime, the photolysis of ozone to oxygen molecules and atoms is balanced by their recombination. At night the photolysis ceases and all the oxygen atoms recombine to form ozone. Both processes are very rapid, but the recombination becomes less so with increasing height. Figure 6 shows that a rather simple pattern of high ozone at night and low ozone in the daytime, with a sharp transition between the two regimes is found at all altitudes between 65 km (0.1 mb) and 90 km (0.0022 mb). In addition, the daytime values show a small peak at about two hours after sunrise, between 0.1 mb and 0.03 mb (72 km). The behaviour at these altitudes is very similar to that seen in ground-based measurements and models [Connor et al. 1994, Ricaud et al. 1996, Allen et al. 1984]. The model of Allen et al.[1984] predicts the simple behaviour seen at 0.0022 mb (90 km), however it also predicts that the daytime peak should be very large at 80 km, giving a quite different diurnal cycle. There is no sign of this behaviour in the data.

Conclusions

UARS MLS has made an extensive set of measurements of radiation emitted by water vapour and ozone in the upper mesosphere. It is not yet possible to retrieve concentrations from these measurements, chiefly because the pressure and temperature measurements in this region are not accurate enough. It is hoped that this situation will be remedied in a future version of the data, if not, it may be possible to retrieve zonal mean concentrations from zonally averaged radiances. Meanwhile, the raw radiances can provide us with a great deal of information on the diurnal and seasonal variation of these species.

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