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A PRELIMINARY ZONAL MEAN CLIMATOLOGY OF WATER VAPOUR IN THE STRATOSPHERE AND MESOSPHERE

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ABSTRACT

The Microwave Limb Sounder on the UARS satellite measures water vapour concentration in the stratosphere and mesosphere. Water vapour profiles are retrieved from radiance measurements using a version of the optimal estimation algorithm. This requires an *a priori* profile which is obtained from a climatology.

The MLS retrieval currently uses the standard UARS pre-launch climatology, which contains water vapour based on a 2-D model constrained to LIMS data in the stratosphere. This climatology has several defects which affect the ability of MLS to retrieve water vapour. This paper presents a new climatology constructed from the HALOE (HALogen Occultation Experiment) and SAGE II (Stratospheric Aerosol and Gas Experiment) data, which have become available recently. The new climatology is more realistic in several ways, particularly in the mesosphere and near the tropopause. It is proving to be an improvement as an *a priori* for MLS retrievals and might also have other uses.

The paper will present the climatology, show how it was constructed, and compare it to the UARS pre-launch climatology and to various other data. As it stands, this climatology is not suitable for a reference atmosphere, but it is an improvement on CIRA part III in some ways simply because it contains more accurate data and shows a number of new features. Suggestions are made for constructing an improved reference climatology for middle atmosphere water vapour. ©1998 COSPAR. Published by Elsevier Science Ltd.

INTRODUCTION

The Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS) satellite measures water vapour concentration in the stratosphere and mesosphere (Lahoz *et al.*, 1996). Water vapour profiles are retrieved from radiance measurements using a version of the optimal estimation algorithm. This requires an *a priori* profile which is obtained from a climatology.

The MLS retrieval currently uses the pre-launch UARS climatology. This is a monthly zonal mean of temperature and several species concentrations in seventeen 10° latitude bins. It contains water vapour taken from a 2-D model which was constrained (R. Seals, private communication) to resemble the interim reference model of Remsberg *et al.* (1989). In the stratosphere, this model consists mainly of LIMS data (Russel *et al.* 1984). The pre-launch UARS climatology was intended as an interim measure and has several defects which affect the ability of MLS to retrieve water vapour. The most serious problem is shown in the left panel of Fig. 1.

This figure shows (dashed line with squares) a water vapour profile from the UARS pre-launch climatology. The climatology is not constructed on the standard UARS pressure levels used by MLS, so values on the MLS pressures are obtained by interpolation (dot-dash line with diamonds). Note how the interpolated value at 100 hPa is nearly 7 ppmv, much larger than the 3-4 ppmv usually measured at this pressure and large enough to confuse the MLS retrieval. The problem is partly due to the interpolation and partly to the fact that the UARS climatology has values which are too large in the upper troposphere.

Another defect of the water vapour in the UARS climatology is that it goes no higher in the atmosphere

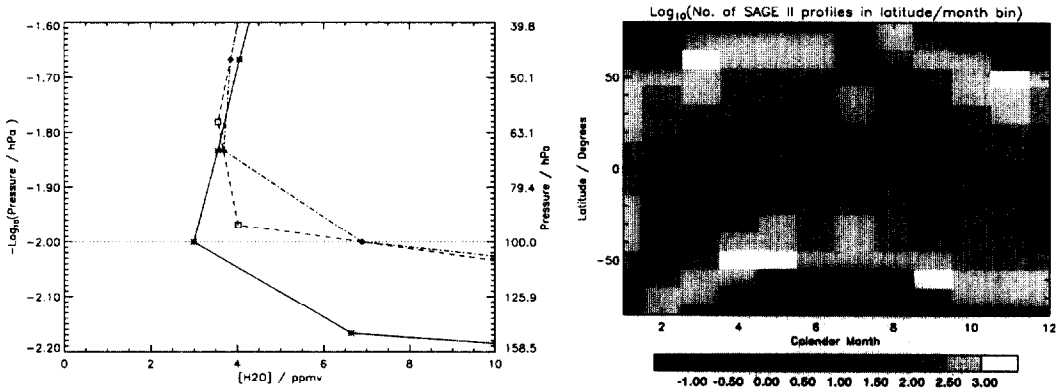

Fig. 1. Left panel shows why a new climatology was needed. The dashed line with squares is the pre-launch UARS climatology, the dot-dash line with diamonds is the same data interpolated onto UARS pressure surfaces. The solid line is the new climatology described in this paper; all profiles are for January at 30°S. Right panel shows SAGE II data coverage in the monthly 10° latitude bins used in this paper. The black bins contain no data.

than 0.01 hPa. MLS makes measurements somewhat higher than this, up to 0.001 hPa.

It was therefore decided that we should re-construct the water vapour climatology using the standard UARS pressure surfaces which include those used by MLS and with more realistic values in the tropopause region.

SOURCES OF DATA

We wanted to use non-UARS data where possible, so that the retrieved MLS water vapour was not unnecessarily dependent on other UARS instruments. We also wanted a data set which was several years long. The SAGE II data set (Rind *et al.* 1993) was ideal in the stratosphere and upper troposphere, so we used it where possible. Data from 1986–1991 were available at the time the climatology was constructed. SAGE II only takes data in cloud-free conditions so the climatology will have a dry bias in the troposphere. This is not a problem at present as the MLS retrieval does not extend this deep into the atmosphere. At altitudes above where SAGE II data is available, we used data from HALOE, another UARS instrument (Harries *et al.* 1996). The HALOE data we used were verson 17. There is some bias between the HALOE and SAGE II data sets, so it was necessary to avoid a rapid change between one set and the other. The climatology is therefore made entirely of SAGE II data at and below 31 hPa and entirely of HALOE data at and above above 2.1 hPa. Between these levels, the proportion of each data set used varies linearly with pressure height. At altitudes above the valid range of HALOE data, the climatology was extended with a decaying exponential.

GEOGRAPHICAL COVERAGE OF THE DATA

HALOE and SAGE II are both solar occultation instruments and only take data at sunrise and sunset. The right panel of Figure 1 shows how much SAGE II data there is in each month/latitude bin; the black bins have no data at all. The coverage of HALOE is very similar. The MLS retrieval reverts to a default profile if it finds a gap in the climatology; this tends to cause artefacts in the retrieved field. It was therefore decided that all gaps should be filled, even if that meant taking educated guesses. The internal gaps in months 2, 6, 8 and 12 were filled by taking the mean of the preceding and following months. The gaps at the north and south edges were filled by making a guess at a profile for the 80°S and 80°N bins for each month where there is no data and interpolating in latitude between this and the first bin with data in it.

COMPARISON WITH UARS PRE-LAUNCH CLIMATOLOGY

Figure 2 shows the data from both climatologies for the months of January and July. The pre-launch UARS climatology is on the top, the new one is on the bottom. There are clearly many differences.

In particular, the new climatology has useful values up to 0.001 hPa, shows some dehydration in the southern polar lower stratosphere in October, and shows a strong annual cycle above the tropical tropopause. Most importantly, the rapid increase in water vapour mixing ratio which occurs below the tropopause occurs at a lower altitude in the new climatology. There is also a strong annual cycle in the upper mesosphere, especially at the poles.

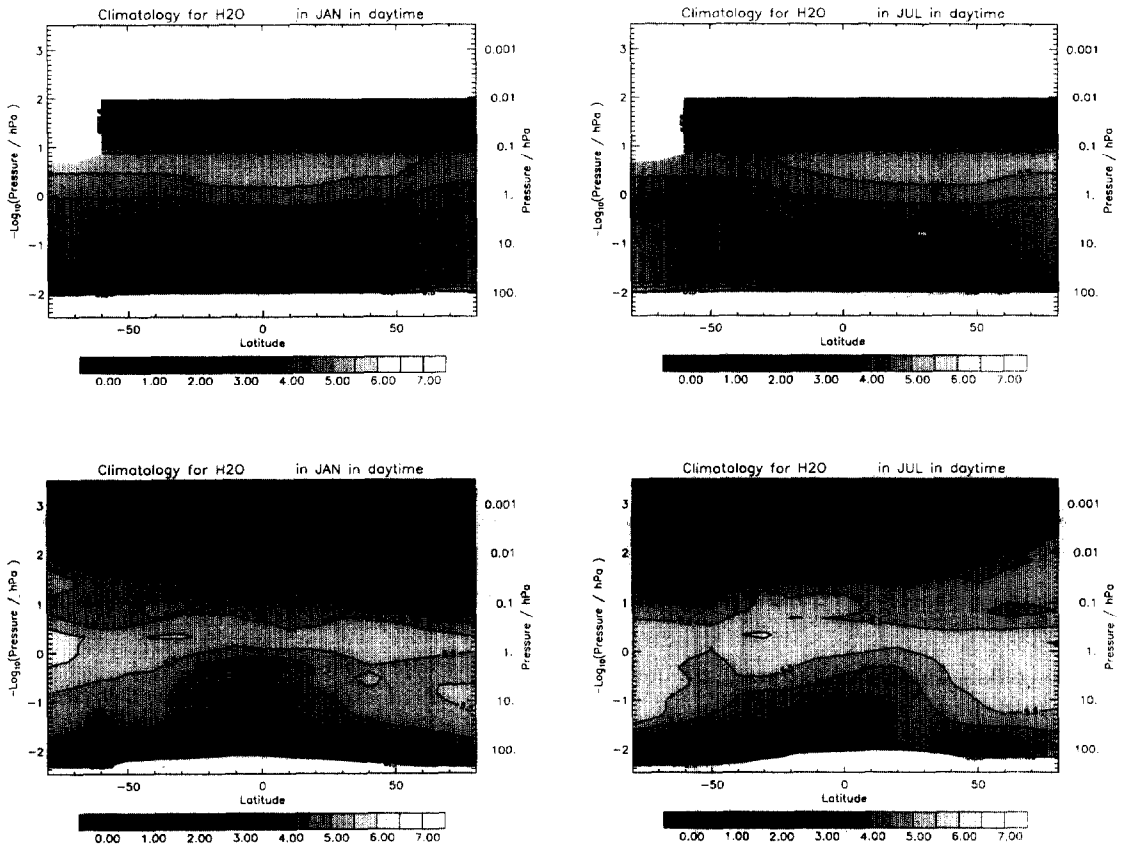

Fig. 2. Zonal means from the old (UARS pre-launch, top) and new (SAGE II + HALOE, bottom) climatologies for the months of January (left) and July (right). The quantity plotted is mixing ratio in parts per million by volume (ppmv)

IMPROVEMENT OVER UARS PRE-LAUNCH CLIMATOLOGY

As an *a priori* for MLS retrievals, the climatology presented is better than the UARS pre-launch climatology, mainly because it has more realistic values at the tropopause and in the mesosphere. Figure 3 shows two balloon-mounted frost point hygrometer profiles, together with the old climatology (dotted) and the new one (dashed). It is clear that in the old climatology, the rapid increase in water vapour mixing ratio occurs too high up in the atmosphere, while in the new climatology it occurs at the correct height. It is this feature of the old climatology which has the most potential for confusing the MLS retrieval program.

SUGGESTIONS FOR A CLIMATOLOGY FOR A FUTURE VERSION OF CIRA

The climatology as described already shows more features, covers a greater vertical range and has a higher time resolution than the climatology in CIRA part III (Chiou *et al.*, 1996). It is nevertheless not suitable for inclusion in a reference atmosphere as it stands, mainly because it does not include data from all possible instruments and because of the crude way the gaps were filled. A better climatology could be constructed by following these suggestions:

- Use more data sets. UARS instruments MLS and ISAMS measure water vapour and there are also the LIMS and SAMS data from Nimbus 7. Various nadir-sounding instruments and balloon data sets could provide data in the troposphere. HALOE data should be used for its full vertical range, not just to extend that of SAGE II.

- Remove biases between instruments. A height-dependent correction could be defined for each instrument so that they gave similar results in regions where several instruments can provide data. The corrections could be larger for instruments which have known biases. Choosing these corrections would be the most difficult part of the job; comparing the satellite instruments to various ground-based data sets could make this process more quantitative.

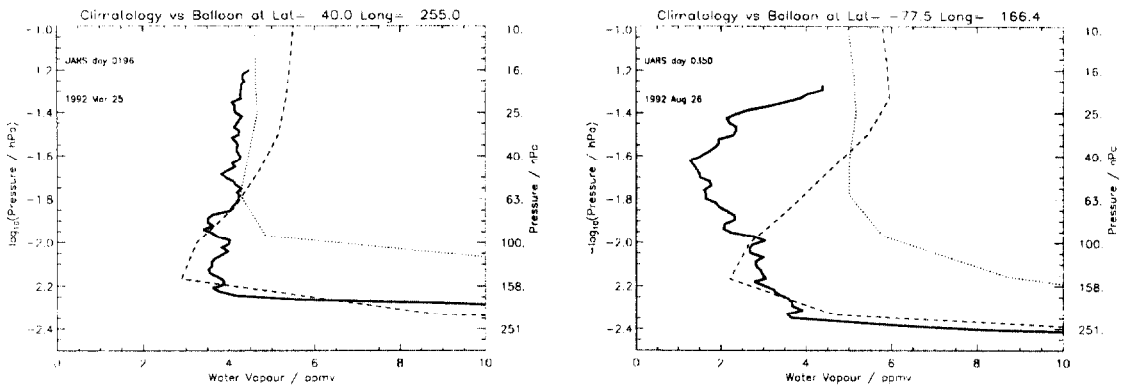

Fig. 3. Comparison of old (UARS pre-launch, dotted) and new (HALOE/SAGE II, dashed) climatology with two balloon profiles (solid lines). The balloon data was supplied to the UARS project by S. Oltmans

- Within each bin, take an average, weighted in some way, of all the instruments which have data in that bin. Removing the biases should ensure that there are no unrealistic jumps between bins containing data from different sets of instruments.
- Extend the climatology upwards with a function based on the photolysis rate of water vapour molecules.
- Provide good estimates of the standard deviation.

SUMMARY

- MLS water vapour retrievals require a climatology of H_2O as an *a priori.*
- The climatology supplied by the UARS project has values near the tropopause which are sufficiently wrong to adversely affect the retrieval.
- A new climatology composed of SAGE II and HALOE data fixes this problem.
- A better climatology for a reference atmosphere would include more data sets and combine them in a more suitable manner.

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