Effects of **improvements** in **near-infrared water vapour line** intensities on short-wave atmospheric absorption

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Abstract. The impact of updates of spectroscopic data on the short-wave absorption by atmospheric **water vapour** is examined and compared to **line** parameters from the 1996 edition of HITRAN database. First, the impact of the 1999 HITRAN update to **near-infrared water vapour line** intensities was examined. Second, new measurements of **water vapour** absorption for the 0.82- and 0.94- _m bands are updated in the model. The HITRAN-99 parameters cause a globally and annually averaged increase in short-wave absorption of 0.26 W m

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with values for a particular month and latitude reaching 0.41 W m

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. The new measurements lead to a globally

and annually averaged increase of 0.64 W m

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, reaching almost 1 W m

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in a particular month and latitude. These two cases increase the total short-wave absorption by the atmosphere by between 0.4 and 1 %. They contribute to resolving the discrepancy between observed and modelled short-wave absorption and indicate a need for the spectral data for other **near-infrared** and visible bands of **water vapour** to be re-examined.

1. Introduction

There has been a long history of theoretical underestimation of the observed short-wave absorption by the atmosphere. Until recently, general circulation models underestimated the global and annual average of the solar radiation absorbed by atmosphere by about 20-30 W m

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[Li et al., 1997]. Recent studies [Cusack et al., 1998; Wild, 1999] have shown that those discrepancies can be reduced by using improved radiative schemes and by including the **effects** of absorbing aerosols. But there is still a systematic model underestimation of around 10-20 W m

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, which jeopardises

our ability of modelling accurately the earth's energy balance, the hydrological processes and the transport

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2 of energy from low to high latitudes.

Attempts to understand the causes of such a discrepancy have created considerable debate in recent years. Some studies attribute them to clouds (e.g. Cess et al. [1999] and references therein). Others report similar discrepancies in clear-sky fluxes (e.g. Wild et al. [1998] and references therein). Others regard **water vapour** as the major cause of the discrepancy whilst acknowledging the possible importance of aerosols [Arking, 1999a][1999b]. The possibility of some missed gaseous absorption process at visible wavelengths was also pointed out [Kato et al., 1997] and evidence of the importance of absorbing aerosols has been presented [Cusack et al., 1998; Wild, 1999]. Learner et al. [1999] showed that previously neglected weak lines of **water vapour** in the visible spectral region add about 2 W m

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for an overhead sun situation, which translates to an enhancement of around 1 % of the global clear sky absorption. This work has recently been extended by W. Zhong et al. (manuscript submitted to Quarterly Journal of the Royal Meteorological Society) to other spectral regions, for clear sky standard atmospheres.

Our aim here is to show how recent updates to the **near-infrared** spectroscopic parameters could impact on the estimates of short-wave absorption by **water vapour**. The related question on the possible underestimation of the vertical **water vapour** distribution is not considered. Currently most of the radiative transfer schemes rely on spectroscopic databases in order to evaluate the absorption of radiation by atmospheric gases. In the 1996 edition of the HITRAN database the spectroscopic parameters for **water vapour** in the **near-infrared** region were derived from measurements at the Kitt Peak National Laboratory, USA [Rothman et al., 1992]. Some systematic differences between HITRAN-96 **line** intensities in the 8,000-22,700 cm

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region and the **line** intensities reported in the articles used as sources for HITRAN were found afterwards and attibuted to errors in unit transformation and in conversion to different temperatures [Giver et al., 2000]. As a result an update of HITRAN **water vapour line** intensities became public during November 1999. In the same year, a series of laboratory measurements for the European Space Agency (ESA) on the **near-infrared** and visible absorption bands of **water vapour** were carried out at the Molecular Spectroscopy Facility of the Rutherford Appleton Laboratory (RAL). These new measurements suggest that HITRAN **line** intensity values should be revised.

In this study, we compare estimates of short-wave broad-band absorption by the atmosphere based on

3 HITRAN-96, on the 1999 update of HITRAN and on measurements at RAL. Section 2 describes how the output of the measurements was converted to percent increase of HITRAN-96 **line** intensities and the radiative code employed. Section 3 presents zonal-mean and global estimates of the **effects** of HITRAN-99 and RAL modifications on short-wave absorption. Section 4 summarises the study and its main conclusions.

2. Data and methods 2.1. Intensity scaling factors

Intensity scaling factors for the **water vapour** absorption data in HITRAN-96 were determined from the new measurements covering the 8,500 to 15,000 cm

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region. The spectra were recorded in absorption using a high-resolution FTS and variable-temperature long path-length absorption cell at RAL. A full description of the measurements and an account of how these new data represent a substantial improvement on previously available measurements are given by Learner [2000] and Belmiloud et al. [2000].

Simulated spectra were calculated for the observation conditions using the Reference Forward Model (RFM) **line**-by-**line** code of the University of Oxford [Dudhia, 1997], with the **line** parameters input from HITRAN-96. Integrated absorption intensities for **water vapour** lines in the observed and calculated spectra for 100 cm

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wide intervals were compared using a method similar to that described by Belmiloud et al.[2000].

2.2. Radiative transfer code

The narrow-band delta-Eddington radiative transfer code of Slingo and Schrecker [1982] was initially modified to incorporate updated solar, Rayleigh, **water vapour** and ozone coefficients as produced by the model of Edwards and Slingo [1996]. In those models, the **water vapour** absorption is taken into account by using the exponential-sum fitting technique (ESFT) [Wiscombe and Evans, 1977]. The short-wave region is divided in 24 bands and the **water vapour** absorption is taken into account in 14 of them, from 2,500 to 14,500 cm

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. Edwards and Slingo [1996] calculated

the ESFT coefficients and exponents for **water vapour** from transmission-versus-**water-vapour**-amount curves obtained from **line-by-line** calculations at reference temperature and pressure. They carried out other sets of **line-by-line** calculations for different homogeneous paths and obtained coefficients for scaling the **water vapour** amounts to other temperatures and pressures--

4 via a quadratic formula--using a least-squares technique.

Because the introduction of new line parameters necessitates a very long recalculation of the fits, we calculated new sets of ESFT coefficients for the reference homogeneous path but kept the Edwards and Slingo's 1996 scaling coefficients in order to save computing time. We used the RFM to calculate the transmittances, which were combined with the Kurucz [1994] solar spectrum. The resulting transmissions were averaged over the model bands to obtain the ESFT coefficients used as input to the radiative code for the three situations: HITRAN-96, HITRAN-99 and ESAmodified HITRAN.

3. Results and discussion 3.1. Differences between datasets

Water vapour possesses a number of bands that contribute significantly to short wave absorption (most notably near 0.72, 0.82, 0.94, 1.14, 1.38, 1.87 and 3.2 _m; see e.g Goody and Yung [1989]). This study concentrates on those at wavelengths of 1.14 _m and less, covering the wavenumber range 8,000-15,000 cm

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The single spectroscopic parameter which is different in each data set is the line intensity. Percent differences of HITRAN-99 and ESA RAL line intensities compared to HITRAN-96 are shown in Figure 1. The HITRAN-99 corrections show increase in line intensities for the 0.94- and 0.82-_m bands and decrease for the other bands. As the 0.82-_m band is weak, the majority of the effect is due to the two more strongly absorbing bands and the effect on broadband absorption turns out to be small because of the cancellation of opposite sign contributions. The ESA RAL data (see also Table 1) show only increases in line intensity for some 100 cm

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intervals over two bands. It is then anticipated that the effect on broadband absorption should be bigger than the HITRAN-99 update.

5 Table 1. Percent Increase in HITRAN-96 Line from ESA RAL Measurements.

Interval Increase Interval Increase

(cm

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) (%) (cm

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) (%)

0.94-_m band 0.82-_m band 10,200-10,300 28 11,800-11,900 55 10,300-10,400 19 11,900-12,000 33 10,400-10,500 4 12,000-12,100 26 10,500-10,600 5 12,100-12,200 24 10,600-10,700 17 12,200-12,300 28 10,700-10,800 19 12,300-12,400 37 10,800-10,900 31 12,400-12,500 18 10,900-11,000 19 12,500-12,600 15 11,000-11,100 19 12,600-12,700 13 11,100-11,200 25

3.2. **Effects** on a typical atmospheric profile

Atmospheric heating rates obtained as described in Section 2.2 for a mid-latitude summer atmospheric profile, a surface albedo of 0.1 and a solar zenith angle of 60

0

for the three different sets of **water vapour** ESFT

coefficients are plotted in Figure 2. For this particular case, the total short-wave radiation absorbed by the atmosphere, based on HITRAN-96 **water vapour** parameters, is 133.5 W m

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. Ozone and **water vapour** are the

only gases taken into account. Updating **line** intensities according to HITRAN-99 and to ESA RAL caused an extra absorption of, respectively, 0.62 W m

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(0.5 %)

and 1.37 W m

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(1.0 %). **Effects** of ESA RAL-modified

parameters on heating (Figure 2) are bigger than the HITRAN-99 ones as expected. The peak heating rate increases from about 1.35 Kday

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to 1.4 Kday

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near

800 hPa.

3.3. Impact on climatological absorbed short-wave radiation

The radiative code was fed with monthly zonal mean climatological profiles of temperature, humidity, ozone and cloud plus surface albedo averaged over 10-degreewide latitude belts. There is an explicit integration of the solar zenith angle over the day using 6-point Gauss quadrature. The HITRAN-96 data yields a global and annual mean absorption of 60.7 W m

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for clear skies

and 1.6 W m

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higher when cloud is included.

Area-averaged increases in the absorbed solar irradiance in W m

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resulting from the HITRAN-99 and ESA

RAL-modified HITRAN relative to HITRAN-96 are presented in Table 2, which also shows values obtained when updates are made separately for only one band and when Hitran-99 is included together with ESA-RAL for the two bands where those measurements were available. Values for clear skies and for all-sky (i. e., includ 6 ing clouds) are displayed. For the all-sky situation, the **effects** of HITRAN-99 and ESA RAL-modified **line** intensities are more important in the southern hemisphere summer. For global and annual averages, the **effects** of the ESA RAL data are more than twice those of the HITRAN-99 corrections. When just the 0.82-_m band is updated, the **effects** of the ESA RAL data are three times larger than the **effects** of HITRAN-99. For the 0.94-_m band, the **effects** of the ESA RAL data are about 10 % bigger than HITRAN-99's.

The latitudinal and seasonal variation of the impacts of replacing HITRAN-96 **line** intensities by HITRAN99 and ESA RAL-modified ones is displayed on Figure 3. In general, the **effects** of ESA RAL-modified parameters are slightly more than twice the **effects** of HITRAN-99, partly because the HITRAN-99 total impact includes the decrease in the 1.14-_m band. The ESA RAL **effects** peak at 1 W m

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with the maximum

in January in the southern subtropics. If the ESA RAL data is used for the 0.82 and 0.94-_m bands, and the HITRAN-99 update is used for the remaining bands, our "best-estimate" for the increase in global and annual mean absorption is 0.45 W m

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(see final **line** of

all-sky entry in Table 2).

Table 2. Global Mean Solar Absorption Above That Inferred Using HITRAN-96 **Water Vapour Line** Intensities (W m

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JAN APR JUL OCT Average Clear sky: HITRAN-99 0.30 0.28 0.29 0.28 0.29 RAL-modified 0.74 0.70 0.73 0.72 0.72

All-sky: HITRAN-99 (Broadband) 0.27 0.26 0.25 0.26 0.26 HITRAN-99 (0.82-_m band) 0.07 0.07

0.08 0.07 0.07 HITRAN-99 (0.94-_m band) 0.38 0.37 0.38 0.38 0.38 RAL-modified (Broadband) 0.65 0.63 0.64 0.64 0.64 RAL-modified (0.82-_m band) 0.22 0.21 0.23 0.22 0.22 RAL-modified (0.94-_m band) 0.43 0.41 0.42 0.42 0.42 HITRAN-99 plus RAL-modified 0.47 0.44 0.45 0.45 0.45

4. Conclusions

In this study we assess the reliability of current estimates of **water vapour near-infrared** absorption based on HITRAN-96 line parameters. Three sets of estimates were made, one based on HITRAN-96 **line** intensites, another based on the 1999 update of **near-infrared water vapour** HITRAN **line** intensities and another on recent measurements at the Rutherford Appleton Laboratory. Both HITRAN-99 and ESA RAL-based calculations produce absorption values higher than the HITRAN-96- based ones. The estimates were made for monthly mean atmospheric profiles zonally averaged over 10-degree 7 latitude belts on four different mid-season months.

The HITRAN-99 update extends over the whole **water vapour** spectrum above 8,000 cm

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and the updated

line intensities are larger than previous values for some absorption bands and smaller for others. Because of the cancellation of opposite sign contributions, the net effect is an increase in short-wave absorption of 0.26 W m

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on a global and annual basis with individual

months and latitudes going up to 0.42 W m

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This study has investigated the **effects** of the ESA RAL data on two bands, the 0.94-_m band (strongly absorbing) and the 0.82-_m one (weakly absorbing). The **effects** of this new information is more than twice the total HITRAN-99 **effects**. Globally and annually averaged extra absorption was 0.64 W m

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and at some

locations in some months values approached 1 W m

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These results suggest that updates to spectral **line** databases can have a significant impact on the modelled short-wave absorption by **water vapour**. The two bands for which new measurement were available can contribute as much as about 0.6 W m

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to the global

annual absorption or about 1 % of the total. While small, it contributes a significant amount to the 10-20 W m

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discrepancy between models and observation,

and is of a similar size to the extra absorption due to the weak visible lines of **water vapour** reported by Learner et al. [1999]. For both bands there was an increase in integrated **line** intensity over that indicated by HITRAN-99. If the same trend of increasing **line** intensity were to be found for the other four strongly absorbing **near-infrared** bands, the impact on calculations of **water vapour** absorption would be bigger, probably a few W m

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. This indicates that further laboratory

studies of the **water vapour line** intensities are necessary to reduce uncertainties in the existing spectral **line** databases.

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Figure 1. Percent differences from HITRAN-96 **line** intensities for the 1999 update of **water vapour** HITRAN **line** intensities and as suggested by recent laboratory measurements at the Rutherford Appleton Laboratory. (Figures in _m show the approximate location of absorbing bands).

8 Figure 1. Percent differences from HITRAN-96 **line** intensities for the 1999 update of **water vapour** HITRAN **line** intensities and as suggested by recent laboratory measurements at the Rutherford Appleton Laboratory. (Figures in _m show the approximate location of absorbing bands).

Figure 2. Atmospheric heating rate due to short-wave absorption by ozone and **water vapour** for mid-latitude summer atmosphere, solar zenith angle = 60

o

and total

solar irradiance = 1359.15 W m

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. For each case, a

different set of ESFT coefficients was used to evaluate the **water vapour** absorption (see text for details).

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Figure 3. Extra absorption of solar irradiance by atmospheric ozone and **water vapour** above HITRAN96 for monthly climatological conditions averaged over 10-degree-latitude belts when (a) HITRAN-99 and (b) ESA RAL-modified HITRAN parameters are used, for the central month of each season.

Figure 3. Extra absorption of solar irradiance by atmospheric ozone and **water vapour** above HITRAN-96 for monthly climatological conditions averaged over 10-degree-latitude belts when (a) HITRAN-99 and (b) ESA RAL-modified HITRAN parameters are used, for the central month of each season.

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