Atmospheric water vapour measurement at Maitri, Antarctica

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Atmospheric water vapour content has been measured during the 14th Indian Antarctica Scientific Expedition at Maitri (70° 46' S, 110° 45'E), Antarctica. The measurements were carried out on clear sunny days during January and February 1995. The average precipitate water vapour at zenith was found ranging from 1.7 to 2.4 mm.

1 Introduction

The measurement of atmospheric water vapour plays an important role in meteorology, climatology, infrared astronomy and cloud physics. Unlike other gases of the atmosphere, the amount of atmospheric water vapour varies considerably with temperature and relative humidity. Water vapour is the primary absorber of thermal and near infrared radiation in the earth's atmosphere and has considerable effect on radiation field, radiative albedo, and energy balance of the earth-atmosphere system.

The integrated water vapour content in the vertical column of the atmosphere can be obtained from ground with sun photometer or microwave radiometer. A sun photometer measures direct solar radiation in two wavelength regions — one at the centre of an absorption band and the other outside the absorption band which is assumed as reference. The method has already been successfully used by Tomasi and Guzzi, Greve, Kondratvey et al., Robson and Robinson, Martin et al., Buischer and Lemke, and Symthe and Jackson. Gao and Goetz have derived high spatial resolution column atmospheric water vapour contents from spectra obtained from airborne infrared imaging spectrometer.

In the present paper we report measurements of water vapour during the 14th Indian Scientific Antarctic Expedition in 1994-95 at the Indian station Maitri (70° 46'S, 110° 45'E), Antarctica. Total water vapour content was measured using infrared grating spectrometer designed and developed at National Physical Laboratory, New Delhi.

2 Experimental set up

The block diagram of IR grating spectrometer, designed and developed at NPL, New Delhi, is depicted in Fig. 1. A polar heliostat, stationed outside the laser heterodyne hut at Maitri, Antarctica, is used to get solar image in a fixed direction in the laboratory. The incoming solar radiation is chopped and focussed by ZnSe lenses of focal lengths 10" and 2.5" respectively on the entrance slit of a monochromator. The signal is detected with the help of a pyroelectric detector. The signal output from detector is fed to the lock-in amplifier for synchronous detection and is directly recorded on a strip chart recorder and floppy diskette. The details of monochromator and pyroelectric detector are given below.

2.1 Specifications of high resolution grating monochromator

The monochromator used is a Czerny-Turner scanning type with focal length 240 mm having two grating covering wavelength regions of 800-3100 nm and 3500-12500 nm. The resolution of monochromator is better than 0.1 nm with 600g/mm and 20 micron slit. The monochromator is controlled by an onboard microprocessor, and the connection between the control module and the monochromator body is an RS-232C serial port. Alternately it can also be controlled by PC through RS-232C serial port. The wavelength selection slit width and scan speed are controlled by microprocessor.

2.2 Characteristics of pyroelectric detector

The characteristics of the pyroelectric detector are as follows: wavelength range, 0.001 to 1000 μm; maximum input average power, 0.05 W; current responsivity, 0.5 μA/W; noise equivalent power (NEP)
Fig. 1 — Block diagram of infrared grating spectrometer.

Fig. 2 — A typical solar absorption spectra taken on 23 Jan. 1995 at Maitri, Antarctica.

3 Discussion and results

The solar radiation absorption spectra were monitored using IR grating spectrometer from 0.75 \( \mu \text{m} \) to 1.6 \( \mu \text{m} \) spectral range at various zenith angles of the sun. The bandwidth of the monochromator is 1.5 nm. Extra care was taken so that solar image was accurately focussed and aligned on the entrance slit of the monochromator. Measurements were carried out on clear sunny days of 20, 21 and 23 Jan. 1995 and 4 Feb. 1995. The visibility was very good at Maitri during the time of observation. A typical solar absorption spectra taken at Maitri, Antarctica, is shown in Fig. 2. The signatures of absorption of water vapour bands centred at 0.94, 1.14 and 1.38 \( \mu \text{m} \) are clearly seen.

To derive total water vapour content in the atmosphere with high precision from absorption band, the transmittance of the band must be sensitive to the change in water vapour molecules in the line of sight. We have used 1.14 \( \mu \text{m} \) absorption band for the deduction of total water vapour content of the atmosphere. The 1.38 \( \mu \text{m} \) band is stronger than 1.14 \( \mu \text{m} \) and 0.94 \( \mu \text{m} \) bands. The integrated absorption at 1.38 \( \mu \text{m} \) band tends to saturate for low values of water vapour amount\(^1\). The 1.14 \( \mu \text{m} \) and 0.94 \( \mu \text{m} \) absorption bands more or less retain their shapes even under the conditions of long optical path. In view of the above discussion, the observations at 0.94 \( \mu \text{m} \) and 1.14 \( \mu \text{m} \) bands are most useful to measure water vapour content in the long optical path of the atmosphere.

The total water vapour content in the zenith was calculated by comparing the irradiance readings at 1.14 \( \mu \text{m} \), i.e. the centre of the absorption band and 1.23 \( \mu \text{m} \) window region lying between 1.14 \( \mu \text{m} \) band and O\(_2\) band centred at 1.264 \( \mu \text{m} \). The aerosol extinc-
... (1)

\[ w = \frac{p}{m_p o} \left( \frac{\ln \frac{D_0(\lambda_1)}{D(\lambda_1)} \frac{D(\lambda_2)}{D_0(\lambda_2)}}{2} \right) \]

where

- \( p \) Pressure in mb
- \( p_o \) Pressure at sea level
- \( k \) Absorption coefficient of water vapour in \( \text{mm}^{-1/2} \)
- \( D(\lambda_1) \) Signal strength at the centre of absorption band at wavelength \( \lambda_1 \)
- \( D_0(\lambda_1) \) Extrapolated signal strength for zero air mass at wavelength \( \lambda_1 \)
- \( D(\lambda_2) \) Signal strength at wavelength \( \lambda_2 \) (window region)
- \( D_0(\lambda_2) \) Extrapolated signal strength for zero air mass at wavelength \( \lambda_2 \)

\( D_0(\lambda_1) \) was computed making use of Langley plot method by plotting logarithm of signal strength as a function of square root of air mass for wavelength 1.14 \( \mu \text{m} \). \( D(\lambda_2) \) was computed by plotting logarithm of signal strength as a function of air mass for wavelength 1.24 \( \mu \text{m} \). The typical Langley plots for wavelengths 1.14 \( \mu \text{m} \) and 1.24 \( \mu \text{m} \) are shown in Figs 3 and 4 respectively for 21 Jan. 1995.

The air mass \( (m) \) is defined as the ratio of the slant path length for solar ray through the atmosphere to the path length if the sun is at zenith. When the sun is over head (i.e. solar zenith angle is zero), the air mass is 1.00. The relative air mass at a given location changes with both time of day and year. For zenith angle \( \chi < 60^\circ \), the relative air mass is accurately represented by \( \sec \chi \). Due to the refraction of the atmosphere and the earth’s curvature, the calculation of air mass by \( \sec \chi \) gives an error in computing air mass values at zenith angles greater than 60°. Therefore Kasten expression was used for the calculation of air mass at Maitri, Antarctica, for the days of observation. Kasten expression is quite accurate and gives results within 1% accuracy up to the zenith angles less than 89° and also accounts for the earth’s curvature and atmospheric refraction of light.

\[ m = [\cos \chi + 0.15 (93.885 - \chi)^{1.253}]^{-1} \]

where \( \chi \) is the zenith angle.

The zenith angles on observational days were computed using the following expression:

\[ \cos \chi = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \Omega \]

where \( \delta \) is the angle of declination of the sun, \( \Omega \) the hour angle, and \( \phi \) the latitude of the place of observation.
Table I—Values of relative air mass over Maitri, Antarctica

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>20 Jan.95</th>
<th>21 Jan.95</th>
<th>23 Jan.95</th>
<th>4 Feb.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>1100</td>
<td>1.5732</td>
<td>1.5840</td>
<td>1.5958</td>
<td>1.7176</td>
</tr>
<tr>
<td>1200</td>
<td>1.5884</td>
<td>1.5924</td>
<td>1.6116</td>
<td>1.7366</td>
</tr>
<tr>
<td>1300</td>
<td>1.6583</td>
<td>1.6666</td>
<td>1.6843</td>
<td>1.822</td>
</tr>
<tr>
<td>1400</td>
<td>1.7932</td>
<td>1.8033</td>
<td>1.8241</td>
<td>1.9917</td>
</tr>
<tr>
<td>1500</td>
<td>2.0129</td>
<td>2.0262</td>
<td>2.0536</td>
<td>2.2741</td>
</tr>
<tr>
<td>1600</td>
<td>2.3582</td>
<td>2.3758</td>
<td>2.4150</td>
<td>2.7549</td>
</tr>
<tr>
<td>1700</td>
<td>2.8953</td>
<td>2.9252</td>
<td>2.9844</td>
<td>3.4789</td>
</tr>
<tr>
<td>1800</td>
<td>3.7644</td>
<td>3.8161</td>
<td>3.9197</td>
<td>4.8959</td>
</tr>
<tr>
<td>1900</td>
<td>5.2158</td>
<td>5.3478</td>
<td>5.5630</td>
<td>7.7773</td>
</tr>
<tr>
<td>2000</td>
<td>7.8610</td>
<td>8.1593</td>
<td>8.6600</td>
<td>15.1611</td>
</tr>
</tbody>
</table>

Table 2—Values of average water vapour obtained on different days during January and February 1995 at Maitri, Antarctica

<table>
<thead>
<tr>
<th>Day</th>
<th>Av. water vapour value at zenith mm</th>
<th>Av. value of pressure mb</th>
<th>Av. value of temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Jan. 95</td>
<td>2.4</td>
<td>985.3</td>
<td>+1.4</td>
</tr>
<tr>
<td>21 Jan. 95</td>
<td>1.72</td>
<td>983.8</td>
<td>+0.3</td>
</tr>
<tr>
<td>23 Jan. 95</td>
<td>2.00</td>
<td>984.8</td>
<td>+1.1</td>
</tr>
<tr>
<td>4 Feb. 95</td>
<td>2.1</td>
<td>982.3</td>
<td>+0.7</td>
</tr>
</tbody>
</table>

The values of declination and hour angle were taken from Star Almanac for land surveyor 1995.

The values of relative air mass computed by the Kasten’s formula as per Eq. (2) are given in Table 1. The values of water vapour measured in the present study are given in Table 2. It will be noticed from Table 2 that the average precipitable water vapour at zenith was found to be in the range 1.7 mm to 2.4 mm at Maitri, Antarctica. The measurements are in good agreement with those carried out at Terra Nova Bay (74° 41.61' S, 164° 6.89' E), Antarctica 14, during 4-12 Jan. 1987 by the Italian Antarctica Summer Expedition. The precipitable water vapour measured by them was in the range 3.5 mm to 1.7 mm at zenith. The low water vapour values observed over Antarctica compared to low latitude locations suggest that Antarctica is a very good site for astronomical observations in infrared region.

The diurnal variation of water vapour is depicted in Fig. 5.

Fig. 5 — Diurnal variation of water vapour.

Acknowledgments

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References