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Long-term ground-based microwave radiometric measurements of atmospheric brightness temperature in SKYNET Hefei (31.90N, 117.17E) site

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ABSTRACT

A dual-frequency, ground-based microwave radiometer (WVR-1100) is used to investigate the behavior of the atmosphere in terms of zenith brightness temperature (T_B) at 23.8 and 31.4 GHz respectively. Some experimental findings in SKYNET Hefei site from September 2002 to August 2012 are presented. The cumulative distributions of T_B at both frequencies for all sky conditions show four different regions, while only two regions can be identified for clear, lightly cloudy and cloudy condition. Annual cycle of T_B at 23.8 GHz is apparently remarkable, indicating the large annual cycle of atmospheric water vapor. Regular seasonal variations of T_B are observed with the strongest value in summer and the weakest in winter.

1. Introduction

Atmospheric water vapor is the most important and most variable greenhouse gas, although its concentration in the troposphere is approximately 1% [7]. By absorbing the outgoing thermal radiation from the earth, water vapor provides about 30 K of heating and, simultaneously, it absorbs about 10 to 20% of the incoming solar radiation [2]. A change in its concentration is associated with a change in climate, which would alter the greenhouse effect of the atmosphere, thus would produce a feedback mechanism [4]. Hence, understanding of the variability of atmospheric water vapor is essential [10]. However, the information of water vapor and its variation is limited by inadequate observations, especially long-term observations.

At microwave wavelengths, both water vapor and liquid water in the atmosphere possess absorptive properties. The former has a weak emission line centered at 22.235 GHz and the latter emits in a continuum that increases with frequency. Radiometry is a passive remote sensing technique related to the measurement of the incoherent electromagnetic energy naturally emitted by material media [1]. Ground-based microwave radiometers have been widely used to measure brightness temperatures (T_B) to derive atmospheric integrated water vapor at a site. In particular, the radiometers at 23.8 and 31.4 GHz have shown high reliability for the accurate estimation of these parameters [8], and often these retrievals are used as a reference for

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other techniques or as a reliable first guess in integration approaches [5].

The atmospheric T_B depends on the vertical profile of the atmospheric physical temperature and absorption coefficients through the radiative transfer equation. The latter, in turn, corresponds to the vertical distribution and physical properties of the relevant atmospheric components, such as water vapor, oxygen, and cloud liquid water. The radiative transfer equation involves both absorption and scattering processes and leads, in the general case, to highly complicated formulations. The radiative transfer can be drastically simplified when scattering may be neglected. This is a good approximation at microwave band in the absence of liquid [1].

In the work reported here, ground-based, dual-channel microwave radiometric measurements of the atmospheric brightness temperatures in zenith direction from September 2002 to August 2012 are analyzed. This instrument is installed in Hefei (31.90 °N, 117.16 °E, 30 m), China as a supersite of the skyradiometer network (SKYNET) [9,12]. The cumulative distributions of T_B for clear, lightly cloudy, cloudy and all sky conditions are presented and discussed. Intercomparisons are made among the distribution curves for T_B under the considered weather conditions and many statistical characteristics are found. Remarkable annual cycles of T_B at both frequencies are presented, showing the maximum value in August and the minimum in December, not only for clear sky but for all sky conditions.

2. Instrumentation

2.1. WVR-1100 description

The radiometer (model WVR-1100) manufactured by the Radiometrics Corporation, USA, operating at 23.8 GHz (K band) and 31.4 GHz (Ka band). The 23.8 GHz frequency was selected because it is in a reserved frequency band, free from satellite downlink transmissions, which could cause erroneous results in sky observations. To diminish the effects of pressure broadening upon the observed brightness, observations are made at the "hinge point" of 22.235 GHz at 23.8 GHz, wherein water vapor emission does not change with altitude. Cloud liquid water in the atmosphere dominates the 31.4 GHz observation, whereas water vapor dominates the 23.8 GHz channel. Observing at these two frequencies can therefore separate the water vapor and cloud liquid water signals.

Specifications of the Radiometrics WVR-1100 water vapor and liquid water radiometer are summarized in Table 1.

Table 1
WVR-1100 radiometer specifications.

Specifications	Value	
Operating frequencies	23.8 GHz	31.4 GHz
Beam width	5.8°	4.5°
Gain	31 dBi	33 dBi
Sample time	< 1 min	
Resolution	0.25 K	
Accuracy	0.5 K	
Radiometric range	0 K–700 K	
Angular coverage	All sky	
Pointing slew rate	3 °s^{-1}, azimuth; > 90 °s^{-1}, elevation	

2.2.. Brightness temperature measurements

In general, the non-scattering assumption is valid for any atmosphere below 10 GHz–50 GHz for non-precipitating clouds or in the presence of light rain. For the lower and denser layers of the atmosphere, which is responsible for most of the absorption, local thermodynamic equilibrium is assumed up to 20 km [1]. At the zenith view, Sky T_B can be described by Chandrasekhar's radiative transfer equation for a non-scattering medium

$$T_B = T_C \exp[-\tau(\infty)] + \int_{sfc}^{\infty} T(s)\alpha(s)\exp[-\tau(s)]ds \tag{1}$$

where $\alpha(s)$ is the absorption coefficient at the frequency of interest; $\tau(s) = \int_{sfc}^{\infty} \alpha(s')ds'$ is the frequency dependent atmospheric opacity; s is the spatial position of the emitting air volume (in kilometers); and T_C is the blackbody temperature of the cosmos, commonly assumed as 2.73 K. This equation can be linearized to

$$T_B = T_C \exp(-\tau) + [1-\exp(-\tau)]T_{MR} \tag{2}$$

where τ is defined as

$$\tau = \ln [(T_{MR} - T_C)/(T_{MR} - T_B)] \tag{3}$$

The mean radiating temperature of the atmosphere T_{MR} is defined using the Mean Value Theorem of calculus

$$T_{MR} = \int_{sfc}^{\infty} \alpha(s)T(s)\exp(-\int_{sfc}^{S} \alpha dt)ds / \int_{sfc}^{\infty} \alpha(s)\exp\left(-\int_{sfc}^{S} \alpha dt\right)ds \tag{4}$$

The opacity τ includes contributions from oxygen, water vapor, and suspended water droplets (cloud liquid, when present), and is dependent on frequency, temperature and pressure. T_B is measured in the following manner [6]

$$T_B = T_{ref} + (V_{sky} - V_{ref})/G \tag{5}$$

$T_{ref}(K)$ is the actual temperature of the ambient blackbody reference target, V_{sky} (counts) is the signal observed when viewing the sky, V_{ref} (counts) is the signal observed when viewing the reference target, and G is the system gain (counts K^{-1}). The gain is extremely sensitive to the temperature of the microwave hardware and is determined as

$$G = (V_{ref+nd} - V_{ref})/T_{nd} \tag{6}$$

V_{ref} and V_{ref+nd} is the signal when viewing the reference target with the noise diode off and on, and T_{nd} (K) is the noise diode output determined by prior calibration. Combining Eqs. (5) and (6) the following is given:

$$T_B = T_{ref} + T_{nd}(V_{sky} - V_{ref})/(V_{ref+nd} - V_{ref}) \tag{7}$$

During each observing cycle, the three signals in Eq. (7) are obtained for each channel. The mirror is rotated to view the sky, then the Gunn diode oscillators for each channel are sequentially energized and the signals are recorded. After that, the mirror is rotated to view the