# Atmospheric Microwave Absorption Parameter Estimation Near 22 GHz

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Abstract--Atmospheric absorption parameters at microwave frequencies are estimated using synthesizer radiometer data from experiments at San Diego Miramar, CA and at West Palm Beach, FL. Measurements of well-calibrated downwelling brightness temperatures, $T_B$, at up to nine frequencies spanning the 22.235 GHz water vapor line are compared to model predictions using radiosonde measurements at each site. Model parameters are adjusted by non-linear regression to fit the radiometer data.

## INTRODUCTION

Water vapor emission model uncertainty is often the dominant error source for microwave remote sensing of the troposphere [1]-[3]. Absorption line shape models have been developed by Gross [4], Van Vleck-Weisskopf (V-W)[5], and Lorentz [5] based on the rotational-vibrational resonances of water vapor molecules. The V-W line-shape function agrees better [6] with the laboratory-controlled data measured by Becker and Autler [7]. This line shape has been used in Liebe [8] and, with some modifications, Rosenkranz [9] models to describe water and oxygen emission spectra. An empirical continuum term has been added to account for excess attenuation between absorption spectra data and theoretical models. The physical phenomena behind the excess absorption in the continuum might be due to inaccuracies in the far wing line shape of vapor resonances [10], the exclusion of the effects of water clusters [11] and/or forbidden transition between energy levels on these line functions [12]. Although this excess has still to be understood, empirical modifications are needed to obtain more accurate agreement between measurements and theory.

In this work, the Liebe and Rosenkranz models are modified to optimally adjust the line strength, line width, oxygen strength and continuum terms in the 20 to 30 GHz range. The water vapor absorption coefficient is given by,

$$\alpha_{water} = 0.0419 f^2 \left[ T_L + T_S + T_C \right] \tag{1}$$

where, $T_L$, $T_S$ and $T_C$, refer to the line strength, line shape and continuum terms and are given by,

$$T_L = 0.0109\ C_L\ e\ \theta^{3.5} \exp\left(2.143(1-\theta)\right) \tag{2}$$

$$T_S = \frac{w}{f_z}\left[ 1/X + 1/Y \right]$$

$$\text{with,}\quad X = (f_z - f)^2 + w^2) \qquad Y = (f_z + f)^2 + w^2) \tag{3}$$

$$T_C = C_C\left(1.13\times10^{-8}\, e\, p\, \theta^3 + 3.57\times10^{-7} e^2 \theta^{10.5}\right). \tag{4}$$

The width parameter, w, is given by,

$$w = 0.002784\ C_W \left(p\ \theta^{0.6} + 4.8\ e\ \theta^{1.1}\right). \tag{5}$$

In the above equations, $\theta$ denotes the temperature ratio, 300/T, where T is in Kelvin, $p$ denotes the dry air partial pressure, and $e$ the water vapor partial pressure, both in millibars. The oxygen absorption coefficient is a copy of the Rosenkranz 1992 model with a scalar factor $C_X$, defined as,

$$\alpha_{oxygen} = C_X\ \alpha_{R'92} \quad . \tag{6}$$

Equations (1)-(6) introduce the following parameters; water vapor line strength $C_L$, line width $C_W$, continuum $C_C$ and oxygen strength $C_X$. This modified model is used to compare the radiosonde-derived brightness temperatures with measured water vapor radiometer (WVR) data.

## EXPERIMENT DESCRIPTION

The experiment consisted of the collection of data at two National Weather Service radiosonde launch sites. These were chosen for their contrasting (winter-San Diego (dry) and spring-West Palm Beach (humid)) natural conditions to provide constraints on both the 22.235 GHz vapor emission line and the level of oxygen emission in the 20-32 GHz interval.

The experiment included two independently calibrated WVR's which provided measurements at 20.0, 20.3, 20.7, 21.5, 22.2, 22.8, 23.5, 24.0 and 31.4 GHz. Inter-comparison of $T_B$ data at frequencies common to both instruments indicate absolute calibration accuracies of about 0.5 K [13].

At both sites, radiosonde data were obtained from the National Climatic Data Center (NCDC). These provided height profiles of pressure, air temperature and dew point temperature. The relative humidity was derived from the temperature, dew point and air pressure information using the Goff-Gratch formulation [14] for saturation water vapor density.

## DATA ANALYSIS AND RESULTS

The radiometer data was averaged over one half hour for the times corresponding to the radiosonde balloon data launch. This was then used as the ground truth for comparison purposes with the radiosonde derived $T_B$.

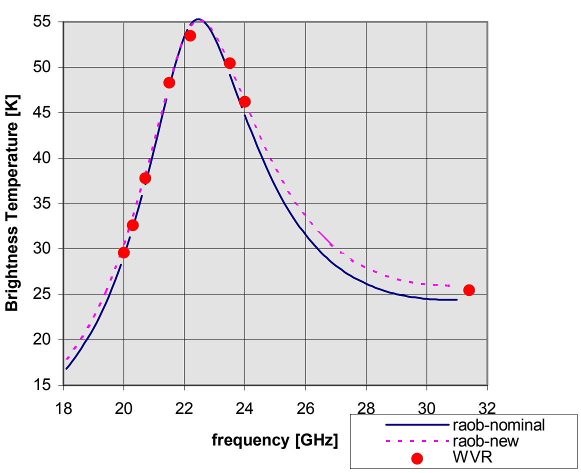


Fig. 1 Brightness temperature spectra comparison between radiometer data (WVR) and radiosonde-derived data with new and nominal parameters for a vapor burden of 2.9 g/cm$^2$.

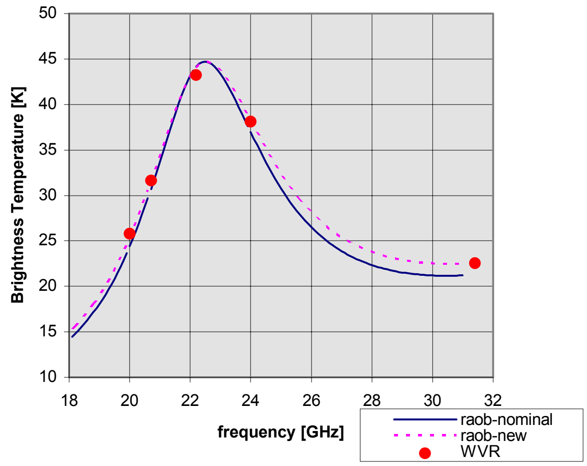


Fig. 2 Brightness temperature spectra comparison between radiometer data (WVR) and radiosonde-derived data with new and nominal parameters for a vapor burden of 2.3 g/cm$^2$.

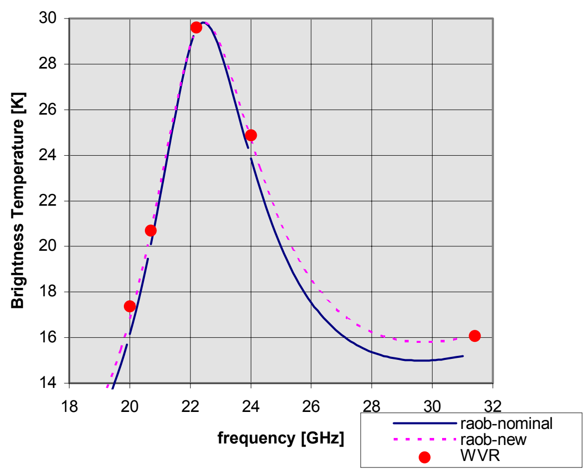


Fig. 3 Brightness temperature spectra comparison between radiometer data (WVR) and radiosonde-derived data with new and nominal parameters for a vapor burden of 1.3 g/cm$^2$.

The $T_B$ was calculated using the radiative transfer integral applied to the balloon profiles. The parameters $C_L$, $C_W$, $C_C$ and $C_X$ were estimated using the Newton-Raphson iteration method. A selection of $C_L$ =1.0, $C_W$ =1.0, $C_C$ =1.2 and $C_X$ =1.0 yields absorption values within 0.5% of Liebe's (1987) [8] model and the exact Rosenkranz's(1992) [9] model. These are referred to as the nominal values of the parameters.

The NCDC data suffered from the radiosondes inability to properly measure dew point temperature for levels of relative humidity outside a range of 22% to 95%. To reduce this effect, a 50% probability factor was applied to relative humidity values outside this range, i.e., the relative humidity is set to 11% whenever it is less than 22% and to 50% whenever it is higher than 100%.

Only those profiles with small differences between $T_B$ calculated this way and with the uncorrected relative humidity values were used. The retrieved parameters were found to be $C_L$=1.058, $C_W$=1.073, $C_C$=1.281 and $C_X$=1.036, indicating that the current parameters underestimate the emission spectra by 3 to 7 percent.

Figs. 1-3 depict plots of the brightness temperature for three climatological conditions. Each graph has a plot corresponding to the model with the nominal values of the four parameters and the new parameters. Also shown are the radiometer measured brightnesses. The plots show that the new estimated parameters agree closer to the WVR data.

The rms difference between modeled and measured $T_B$ was reduced by 32%, from 1.56 K to 1.06 K, with the new parameters. Sensitivity analysis shows that the standard deviations on the $C_L$, $C_W$, $C_X$ parameters are 5% or less, and 8% for $C_C$ assuming 0.5K noise in the TB data. Correlation analysis between coefficients shows a high correlation between the errors in oxygen and the continuum terms.

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