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The Estimation of Tropospheric Electrical Path Length by Microwave Radiometry

Abstract—Results of numerical experiments on model atmospheres obtained from radiosonde observations indicate that the contribution of the troposphere to the electrical path length at zenith is about 200 cm, and that this length can be inferred to an accuracy of 1 or 2 cm from ground-based microwave radiometric measurements.

One problem encountered in any experiment requiring coherent reception of radio waves at separated stations is the determination of the electrical path length changes caused by the atmosphere. For example, in radio astronomy such a problem arises when long-baseline interferometers are used to observe small radio sources, and phase preservation is desired. From ground-level measurements of temperature, pressure, and relative humidity at each of the receiving stations, the variations in tropospheric electrical path length can be estimated. More accurate methods for inferring these path length variations involve measurements of atmospheric temperature structure and water vapor distribution at higher altitudes. These atmospheric parameters can readily be sensed by ground-based microwave radiometers measuring the atmospheric thermal emission near the 22.235-GHz resonance line of water vapor and the 60-GHz resonance band of oxygen. The radiometers would have narrow-beam antennas pointed along each ray path for which the atmospheric path length is to be estimated.

Westwater [1] has calculated the errors expected when inferring electrical path length from single-frequency measurements of thermal emission near 22 GHz. Based on calculations from two radiosonde records, he predicts an error of approximately 0.8 cm in estimating the water vapor contribution to the zenith electrical path. Our calculations, presented here, give estimated errors in inferring zenith electrical path lengths due to the combined effect of water vapor and dry air. Methods of inferring electrical path by measurements of surface meteorological variables, atmospheric thermal emission near the 22.235-GHz water vapor line, and atmospheric thermal emission near the 60-GHz oxygen band are considered.

The increase in electrical path length caused by the atmosphere is

$$\Delta L = \int_L (n - 1)\, dl, \tag{1}$$

where n is the index of refraction, and L is the path of the electrical signal. The index of refraction of the atmosphere may be related to meteorological quantities. For frequencies below approximately 30 GHz, the relation [2] is

$$(n - 1) = \frac{7.76 \times 10^{-5}}{T} \cdot \left(P + 4.8 \times 10^3 \frac{e}{T}\right), \tag{2}$$

where T is temperature (°K), P is total pressure (mb), and e is partial pressure of water vapor (mb). Ionospheric effects are not included.

The variability in the electrical path length is dominated by the variability in water vapor content of the atmosphere, although the average value is determined mainly by the dry-air contribution. Because surface humidity is not well correlated with humidity at higher altitudes and ΔL is given by an integral over the radio signal path, surface measurements of meteorological quantities do not permit an accurate estimate. The sky

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