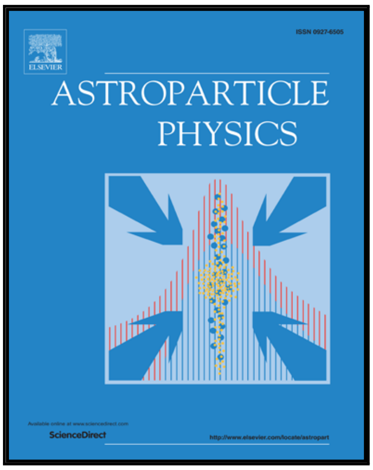

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The effect of the atmospheric refractive index on the radio signal of extensive air showers

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Abstract

For the interpretation of measurements of radio emission from extensive air showers, an important systematic uncertainty arises from natural variations of the atmospheric refractive index n. At a given altitude, the refractivity $N = 10^6\,(n-1)$ can have relative variations on the order of 10 % depending on temperature, humidity, and air pressure. Typical corrections to be applied to N are about 4 %. Using CoREAS simulations of radio emission from air showers, we have evaluated the effect of varying N on measurements of the depth of shower maximum $X_{\max}$. For an observation band of 30 to 80 MHz, a difference of 4 % in refractivity gives rise to a systematic error in the inferred $X_{\max}$ between 3.5 and 11 g/cm^2, for proton showers with zenith angles ranging from 15 to 50 degrees. At higher frequencies, from 120 to 250 MHz, the offset ranges from 10 to 22 g/cm^2. These offsets were found to be proportional to the geometric distance to $X_{\max}$. We have compared the results to a simple model based on the Cherenkov angle. For the $120-250$ MHz band, the model is in qualitative agreement with the simulations. In typical circumstances, we find a slight decrease in $X_{\max}$ compared to the default refractivity treatment in CoREAS. While this is within commonly treated systematic uncertainties, accounting for it explicitly improves the accuracy of $X_{\max}$ measurements.

Keywords: Cosmic rays, extensive air showers, radio emission, atmospheric effects

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1. Introduction

In recent years, the techniques for measuring and modelling radio emission from air showers induced by high-energy cosmic rays have developed rapidly [1]. The radio detection method has achieved high precision in estimating the air shower and primary particle properties [2, 3, 4] which allows for very precise measurements of the primary particle type and the energy of the primary cosmic ray [5]. In particular, the LOFAR radio telescope [6] has been used successfully for this, due to its densely instrumented core region located in the Netherlands. In an inner ring of 320 m diameter, we can use 288 low-band antennas, measuring in the $30-80$ MHz range, for cosmic-ray measurements. Additionally, there are also 288 high-band antennas measuring in the 110 to 190 MHz range. In an extended core region of about 6 km^2, nearly 1800 additional

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