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Measurement of sound speed vs. depth in South Pole ice for neutrino astronomy

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ABSTRACT

We have measured the speed of both pressure waves and shear waves as a function of depth between 80 and 500 m depth in South Pole ice with better than 1% precision. The measurements were made using the South Pole Acoustic Test Setup (SPATS), an array of transmitters and sensors deployed in the ice at the South Pole in order to measure the acoustic properties relevant to acoustic detection of astrophysical neutrinos. The transmitters and sensors use piezoceramics operating at ~5–25 kHz. Between 200 m and 500 m depth, the measured profile is consistent with zero variation of the sound speed with depth, resulting in zero refraction, for both pressure and shear waves. We also performed a complementary study featuring an explosive signal propagating vertically from 50 to 2250 m depth, from which we determined a value for the pressure wave speed consistent with that determined for shallower depths, higher frequencies, and horizontal propagation with the SPATS sensors. The sound speed profile presented here can be used to achieve good acoustic source position and emission time reconstruction in general, and neutrino direction and energy reconstruction in particular. The reconstructed quantities could also help separate neutrino signals from background.

1. Introduction

South Pole ice is uniquely suited as a medium for detection of high-energy (10^{11}–10^{20} eV) neutrinos of astrophysical origin. The interactions of these neutrinos in ice produce optical, radio, and acoustic radiation, each of which therefore provides a possible method of detecting the neutrinos. The optical method is well suited for neutrinos of energy up to 10^{17} eV, while the radio and acoustic methods are well suited for neutrinos of higher energy. Deep ice at the South Pole has been shown to be extremely transparent at optical wavelengths [1]. The AMANDA [2] and IceCube [3] detectors have been developed to exploit this for optical neutrino detection. Antarctic ice is even more transparent in radio wavelengths [4,5], and the Radio Ice Cherenkov Experiment (RICE) [6] was operated to search for radio signals from astrophysical neutrinos.

The acoustic properties of South Pole ice have also been predicted to be favorable for acoustic neutrino detection [7], and simulations based on these predictions [8] have indicated that good sensitivity to neutrinos in the EeV energy range could be achieved. This motivated us to design and construct an experimental setup at the South Pole to perform *in situ* measurements to test the theoretical predictions.

To detect the "cosmogenic," or Greisen–Zatsepen–Kuzmin (GZK), neutrinos of energy $\sim 10^{17-19}$ eV produced by ultra-high-energy cosmic rays interacting with the cosmic microwave background radiation, a detector with effective volume on the order of 100 km^3 is necessary. Such a large volume is necessary because the predicted rate of GZK neutrino-induced showers is on the order of 0.1 $km^{-3}\,yr^{-1}$ [9]. A 100 km^3 detector is therefore desirable to collect on the order of 10 events per year. While the optical method is well understood and calibrated with atmospheric neutrinos, it is