Crystal orientation fabric development of Dome Fuji ice core inferred from dielectric permittivity tensor measurement

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Deformation and flow of ice-sheet ice are highly controlled by crystal orientation fabric (COF). The orientation of c-axis is usually measured using ice thin sections and crystal fabric analyzers using optical principles. However, optical methods require making many thin sections of ice, which is time consuming. Intervals of such measurements with thin sections are often of the order of tens meters or more, and numbers of ice grains within a thin section are often of the order of several hundreds. Though recent advances of the automated fabric analyzers improved amount of measurements dramatically, there are still limitations. For example, there are always questions as to how limited number of grains within thin sections represent statistics of crystal orientation fabrics in larger ice volumes. For the bulk ice-core based measurements of COF, we developed a new measurement method for COF of ice core by measuring tensorial components of the dielectric permittivity. Hexagonal ice crystal has the dielectric property with uniaxial symmetry around the c-axis. We can estimate the degree of c-axis clustering around the vertical by measuring the macroscopic dielectric permittivity parallel and perpendicular to the ice core axis. Advantages of the method include that; (i) we measure COF of the bulk volume of ice cores and (ii) the measurement is quick thus easy to measure COF continuously. Thus, the results will represent statistics of COF in much larger ice volumes than thin sections.

We used Dome Fuji Station ice cores drilled at Dome Fuji, the second-highest dome summit in East Antarctica. To understand the dielectric property and COF development of ice core, we performed three different settings of measurements (i) 5 m-intervals measurement with almost full bulk of ice cores to a depth of 2400 m, (ii) continuous and high-resolution measurement using half bulk of ice cores along brittle zone (600-860 m), and (iii) measurements with horizontally cut planes of ice cores. We used an open resonator of microwave using frequencies between 15 and 20 GHz. The resolution and step of measurements are about 30 mm and 20 mm, respectively. All measurements were conducted under -30 C in a cold temperature room. Ice core samples have slab-shaped with a thickness between 35 and 75 mm. The numbers of ice grains are c.a. 1000 times larger compared with thin section measurements.

We call dielectric anisotropy for difference between the macroscopic dielectric permittivity parallel and perpendicular to the ice core axis. This indicates clustering strength of the c-axes around the single pole maximum fabric. As a result of measurements down to 2400 m, we found the increase of dielectric anisotropy with increasing depth. This trend is consistent with the c-axis clustering toward the core axis due to the grain rotation caused by uniaxial compression. In addition to the large-scale increase of the anisotropy, we observed the small fluctuations of the dielectric anisotropy, suggesting fluctuations of the c-axis clustering with scales of 10-100 m. In the continuous measurements between 600-860 m depth with 20 mm resolution, we found fluctuations in far smaller scales such as 10-100 cm. Using conventional thin section methods, it is obviously difficult to detect this kind of small-scale. Using horizontally cut planes of the ice core, we investigated the dielectric and c-axis clustering anisotropy within horizontal planes. If the ice-sheet ice deforms under completely uniaxial compressional field, no horizontal anisotropy should appear. However, depending on amount of lateral strains, actual ice fabric normally has a kind of elliptically elongated single pole fabric. It is the case in the Dome Fuji ice core; We found very small dielectric anisotropy on horizontal directions.

In this presentation, we discuss variations of dielectric anisotropy along ice core depth and horizontal planes in terms of (i) the other physical and chemical properties of ice core and (ii) insolation at the timing of snow deposition.