Spatial variations in ice-crystal alignments deduced from englacial radar polarimetry, central West Antarctica

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Need for new radar data?

GIS dataset at http://icebridge.sr.unh.edu/icebridge/ant/
Radar technique characterizing ice properties

- Dual frequency to determine primary reflection causes
  - Density or crystal-orientation fabrics (COF)
  - Acidity

- Multi polarization planes to determine anisotropy in ice properties
Motivations

• Detect Crystal-Orientation Fabrics (COF)
  – COF discontinuities? (radar reflection)
  – Anisotropic COF patterns? (polarimetric patterns)
  – Depth trends or regional patterns in the COF?

• As ice deforms, non-uniform COF patterns are produced which, in turn, influence further deformation.
  – Infer variations of current ice rheology
  – Infer past ice topography
COF patterns deduced from radar

Matsuoka et al. (2003, JGR); Matsuoka et al. (2004, J. Glac)
Flow/strain measurements (right panel) were made with GPS surveys
The anomaly $\delta [P_i]_{dB}$ of the returned power at the $i$-th polarization plane from the polarization-mean returned power $\langle P \rangle_{dB}$ can be defined as:

$$\delta [P_i]_{dB} = [P_i]_{dB} - \langle P \rangle_{dB},$$

(2)

where

$$\langle P \rangle_{dB} = 10 \log_{10} \left( \frac{1}{12} \sum_{i=0}^{11} P_i \right).$$

(3)
Polarization-mean returned power
Polarimetric variations (I)

179 MHz data:
- Alternations of strongly/weakly anisotropic layers
- The primary periodicity is 180°
- Azimuthal shift of the strong-echo (radar) axis

60 MHz data:
- More isotropic in the upper 1000 m or so
- More anisotropic in the deeper ice
- The primary periodicity is 180°
- Some 90°-periodic features at greater depths
60M: isotropic shallow layer and 180°-periodic deep layer
179M: 180°-periodic features with distinct azimuthal shifts
- Nearly isotropic 60-MHz returned power at < 1000 m
- Only 60 MHz returned power decreased with depth
- Anisotropic 179-MHz returned power at all depths
Two different effects of COF

(a) Birefringence $\delta[B]_{dB}$

Phase difference $\theta$ (rad)

0
$\pi$
$2\pi$

(b) Reflection $\delta[R]_{dB}$

Orientation of the polarization plane measured from one of principal axes $c_1$ (deg)

Anomalies (dB)

Depth-integrated COF anisotropy

Abrupt contrasts in COF patterns
Expected effects of COF (theory)

Weakly anisotropic reflection + birefringence
180° periodic + 90° periodic

Strongly anisotropic reflection + birefringence
180° periodic (distorted)

Stronger returned power at the principal axes of COF
Radar axis and current strain/vel.
Regional patterns of the radar axes

The radar axes show azimuthal shifts in the southern region and in the vicinity of the flow divide.

The radar axes are depth uniform around the local ice dome (except for the divide site).
• Regionally consistent features are found in englacial polarimetric, dual-frequency radar data.

• Distinct properties of the radar data agree with theoretical predictions of COF’s effects on the radio-wave propagation.

• COF contrasts make reflections as shallow as 200-500 m.

• COF patterns are more complicated at greater depths (but in the upper half to two thirds of the ice thickness).

• Azimuthal shifts of the radar (COF) axes infer that flowline through the WAIS Divide core site has likely migrated.
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