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Evolution in geometry of firn in ice sheets detected by dielectric anisotropy

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Processes of metamorphism and deformation from snow to ice

Importance

- … determine gas trapping process, influencing ice core signals related to gas, such as total air content, gas fractionation and close-off depths.

- … determine propagation/scattering processes of electromagnetic waves within ice.

Mechanisms related to metamorphism and densification

- **Accumulation rate, temperature and temperature gradient and wind give strong influence.**

We investigated effects of these in this study.

- **Textural effects (ice-ice bonding, geometry, c-axis orientation) control densification process.**

- **Ions such as Cl^-, F^- and NH_4^+ either soften or harden ice.**

Samples from various conditions

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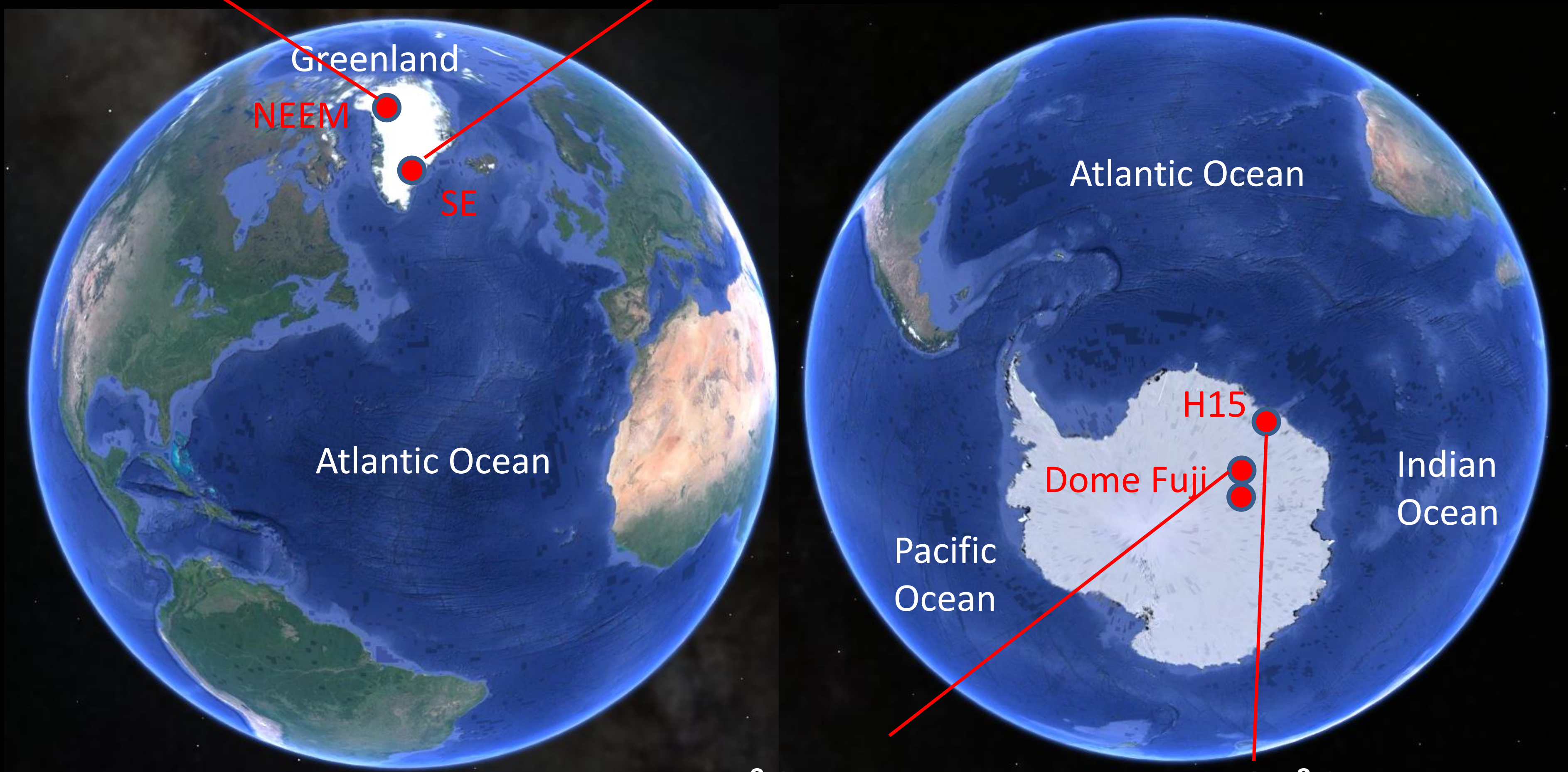
Comparison of firn cores drilled at five sites

T = –29˚C
0.22m ice eq. a^{-1}

T = –21˚C
1.15 m ice eq. a^{-1}



T = –54˚C
0.03 m ice eq. a^{-1}

T = –21˚C
0.35 m ice eq. a^{-1}

Figure 1. Location of core sites.

Measurement of tensorial values of the dielectric permittivity

- mm-wave (15 - 50 GHz) resonators for measurement
- Continuous 25 - 15mm resolution measurements

$\Delta\varepsilon = \varepsilon_{vertical} - \varepsilon_{horizontal}$

ε is a measure of denisty

Δε is a measure of vertical elongation of geometry.

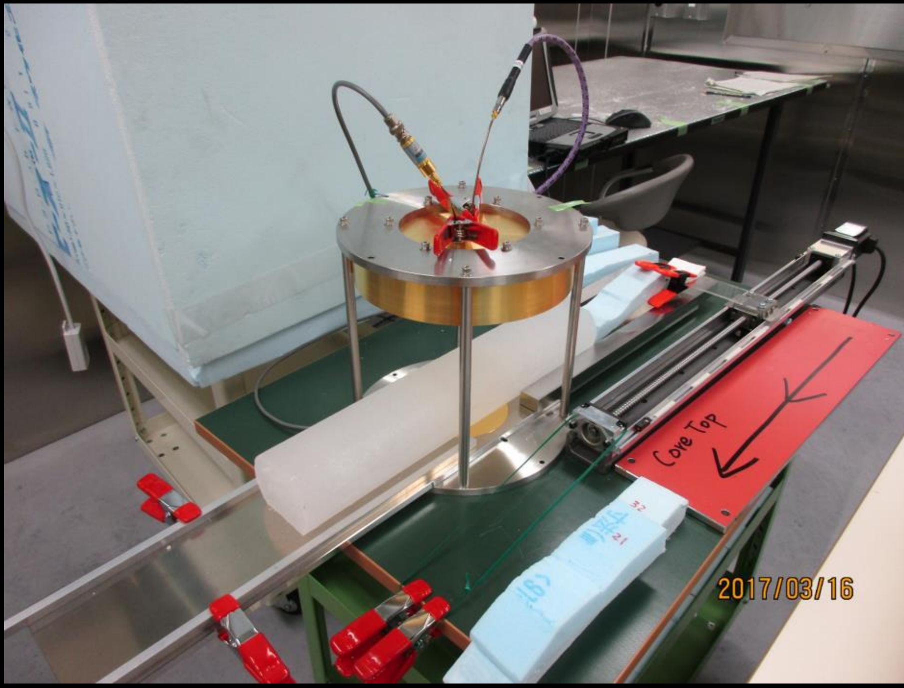


Figure 2. Firn core in the open resonator.

Results **Permittivity versus depth**

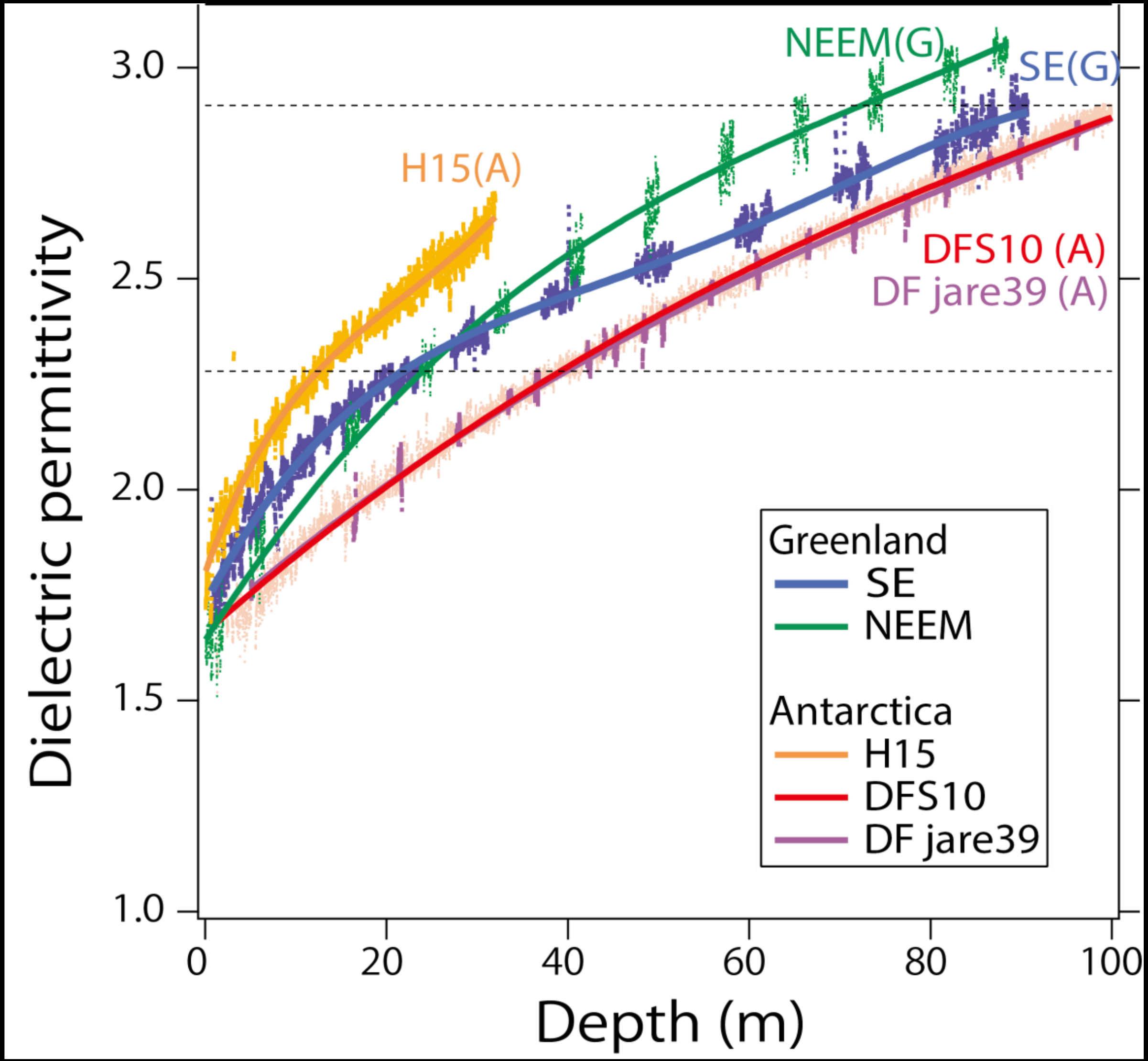


Figure 3. Permittivity versus depth.

As it is well-known, depth-density profile depends on accumulation rate and temperature. We can see this kind of variations in textbooks of Glaciology such as “Physics of Glaciers”.

Comparison between various sites

Δε was found to converge to a value ~0.01.

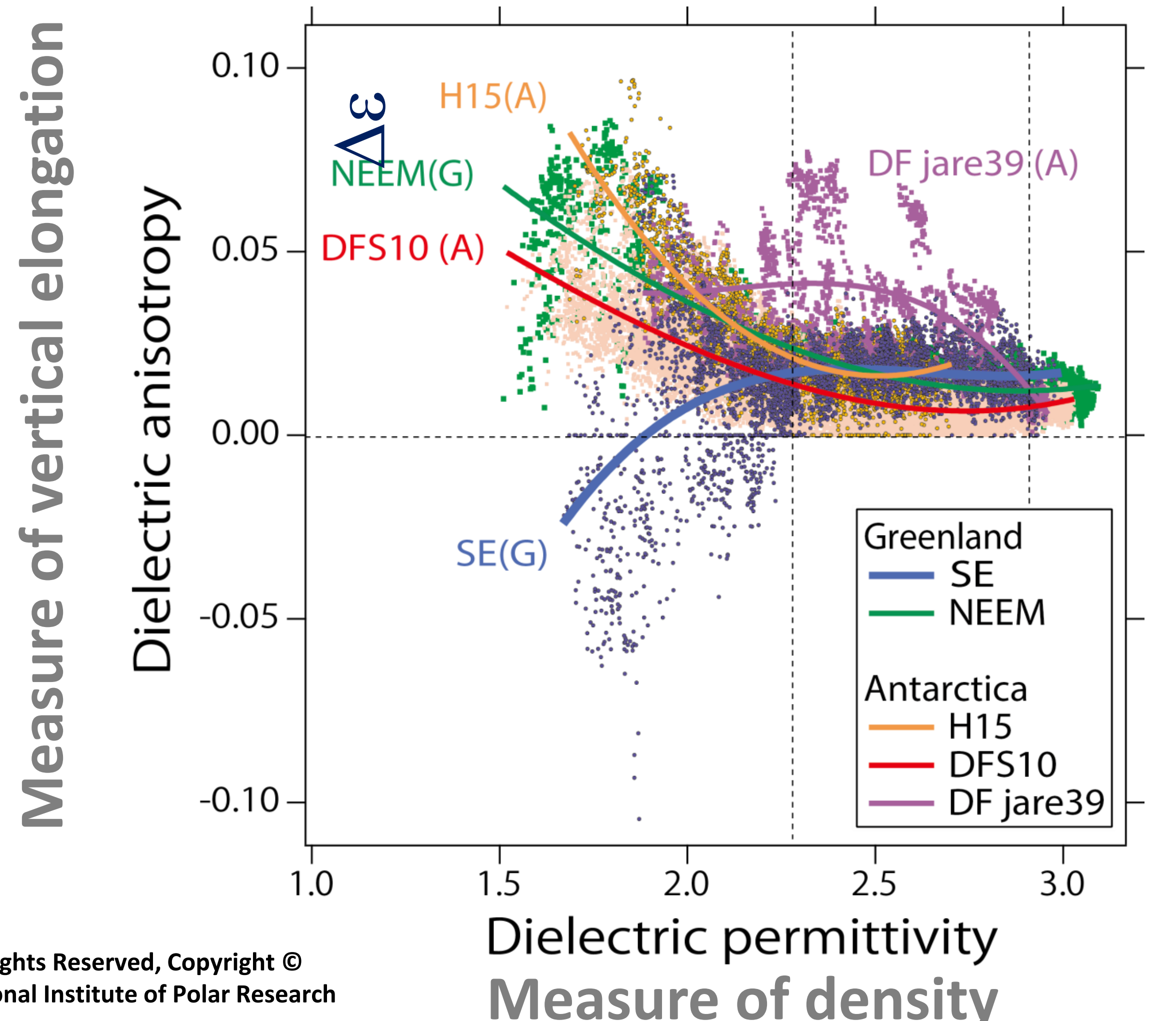


Figure 4.

Density-anisotropy relation also strongly depends on sites. Δε was found to converge to a value of ~0.01. This fact means that vertical compression causes vertically elongated geometry.

Summary

Observational fact (Please see Figure 4)

- We find that firn that have shorter residence time (with larger SMB) at near-surface depths does not form strong vertical anisotropy that is caused by vertical movement of moistures.
- In contrast, firn that have longer residence time (with smaller SMB) at near-surface depths tend to form vertical anisotropy.
- When density exceeds ~600 kg/m3, a common feature of firn at many polar sites is that there are evolution of vertically elongated features of pore spaces in firn despite growth of vertical compression.
- $\Delta\varepsilon$ was found to converge to a value of ~0.01 at depths close to bubble close off.

Explanation

- As firn becomes denser, air within firn needs to "escape" to upward directions as compared to sinking firn. In firn, porous structure tends to have vertically elongated structure because of this vertical escape movement of air.

Practical meaning

- This site-dependent porous structure is a kind of "finger print" of the surface conditions. This may need to be considered in gas trap process near the bottom of the firn, diffusion of gas within firn, and also in analysis of radio wave propagation in firn.

Thanks for your attention.

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