Water Potential in an Unsaturated Soil during Freezing and Thawing Processes

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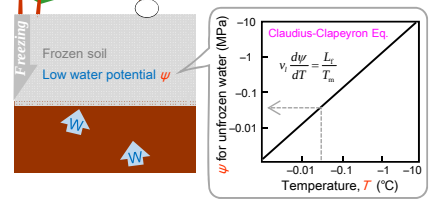
Introduction

When ground freezes, water flows from unfrozen to frozen soil due to the low water potential ψ of frozen soil.

Direct measurement of ψ was difficult !

New sensor was now available !!



ψ is sometimes estimated from temperature through phase equilibrium equation (the Claudius-Clapeyron Eq.: ψ_{cc}).

Calculation using ψ_{cc} tends to overestimate soil water flow to the freezing front.

In soil, pore ice might grow behind decrease of the soil temperature.

[Objective]

Investigate ψ gradient in frozen soil by new sensor and find out limitation of C-C eq.

Sample and Methods

Sample (Iwate Andisol)

Packed into acrylic cylinder with a constant water content θ = 0.39 m³/m³ and bulk density ρ_b = 1.14 g/cm³

Inserted 7 TDRs & tensiometers, 35 TCs, 2 FINEDEW potential sensors

TDR was preliminary calibrated for unfrozen water measurement

Initial cond. (Settled at cold room for 1d)

Uniform temperature (3 ºC)

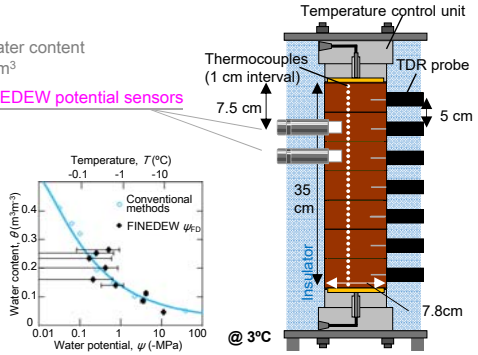
Gravimetric water distribution

Boundary cond.

Top -12 ºC for freezing (48 h)
-7 ºC for thawing (48 h)

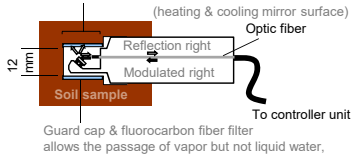
Bottom 3 ºC during experiment

No water flux was allowed from both ends.



Water potential sensor (FINEDEW)

Micro chilled mirror dew point sensor



- No sampling chamber is required
- Can be inserted directly into a soil
- Rapid response time (low heat capacity)

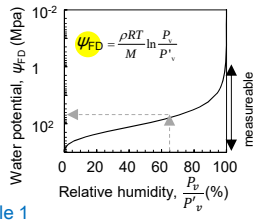
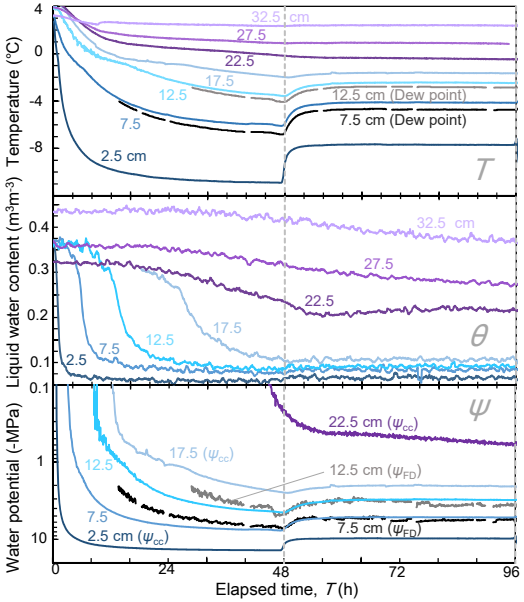
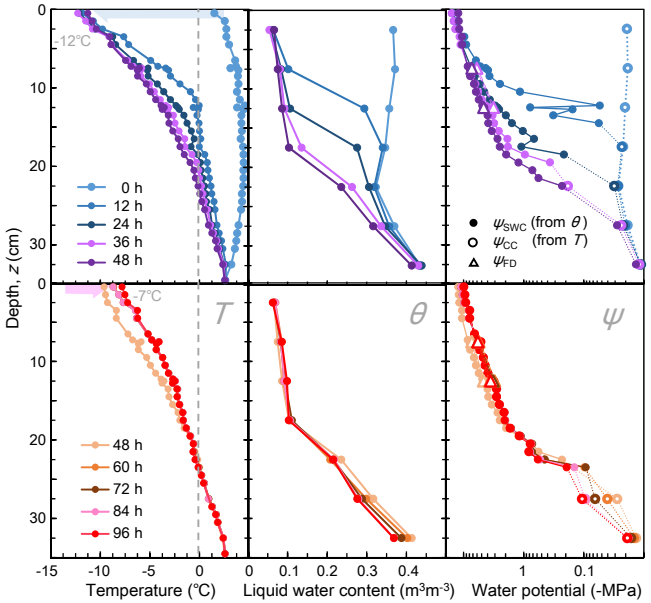


Table 1

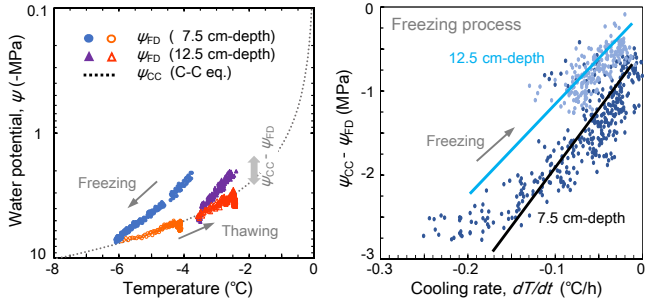
Time [h]	Water flux [cm/h]	$\Delta\psi_{cc}/\Delta z$ [kPa/cm]	K [cm/s]	$K_{unfrozen}$ [cm/s]
0-12	0.010	100	2.9×10^{-9}	3.2×10^{-8}
12-24	0.008	80	2.8×10^{-9}	3.2×10^{-8}
24-48	0.003	40	2.0×10^{-9}	3.2×10^{-8}

Results and Discussion

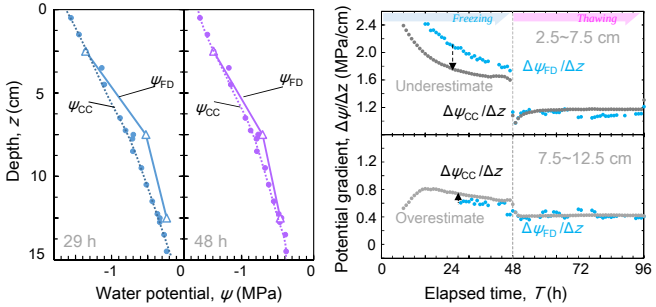




- At freezing front, hydraulic conductivity K estimated from $d\psi_{cc}/dz$ is 1-order smaller than K of unfrozen soil with same liquid water content (see Table 1).
- During thawing, water flow from unfrozen region was continued.



- Hysteresis like behavior was observed in ψ_{FD}-T relationship during freeze/thaw.
- Freezing process: ψ_{cc} underestimated ψ_{FD} due to non-equilibrium ice growth
- Thawing process: $\psi_{cc} \fallingdotseq \psi_{FD}$ under very slow temperature rise.
- The difference between ψ_{cc} and ψ_{FD} increased with cooling rate; non-negligible when the soil was frozen with $dT/dt > 0.01$ °C/h.



Near surface, ψ_{FD} is close to ψ_{cc} because ice nearly reached the equilibrium size.
At the middle part of frozen soil, ψ_{cc} underestimate ψ_{FD} (phase change of water)
Near freezing front, ψ_{FD} and ψ_{cc} does not differ very much, since dT/dt is slow.

- ▶ ψ_{cc} tends to underestimate $d\psi/dz$ near soil surface, and overestimate $d\psi/dz$ near the freezing front.
- ▶ This might cause overestimation of water flow to the freezing front

Care should be needed to use C-C eq. when a soil exposed large T change