Monitoring of freezing dynamics in trees: an insight into complexity

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Context

During winters, trees have to cope with harsh conditions. Water in planta can change between physical states, generating mechanical and hydraulic strains. Alpine plants are an impressive example of plants exposed to these phase shifts on a frequent basis, especially in late winter to early spring, when freeze-thaw cycles can occur daily.

We aimed at identifying the disturbances generated in the hydraulic system by monitoring ice formation and propagation as well as xylem sap cavitation, water shifts and cellular damages.

Material & Methods

Figure 1. *Picea abies* trees growing in the Tyrolian timberline (1600m a.s.l.)

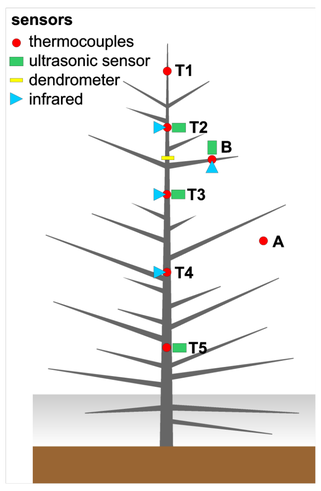

Figure 2. Sensor positions

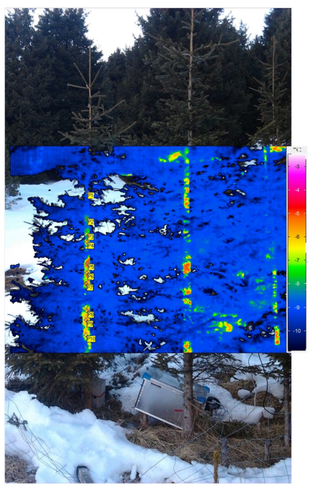

Figure 3. Infra-red thermography

Figure 4. Ultrasonic acoustic sensor, Thermocouple

Figure 5. Dendrometer

Results

Three distinct freezing patterns were observed: (I) from the top of the tree toward the base, (II) from thin branches toward the main stem's top and base, and (III) from the base toward the top. Infrared imaging showed freezing within branches from their base toward distal parts (Fig. 6). Such complex freezing causes dynamic and heterogenous patterns in water potential and probably in cavitation (Fig. 7).

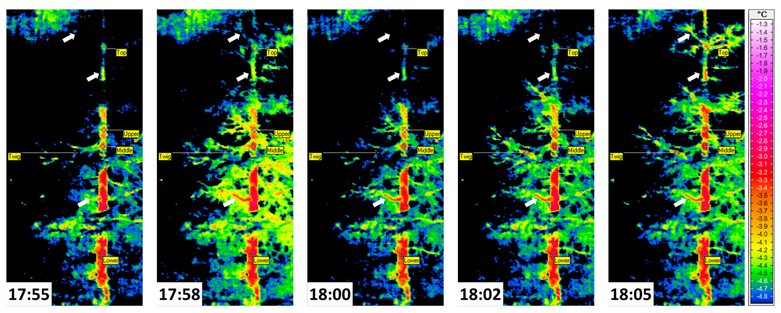

Figure 6. Spatial temperature patterns at the time of freezing (after sunset; 17:55 to 18:05) monitored via infrared imaging. Letters (B, T_1-T_4) indicate sensor positions, arrows indicate additional positions with very pronounced changes (*i.e.* xylem exotherms).

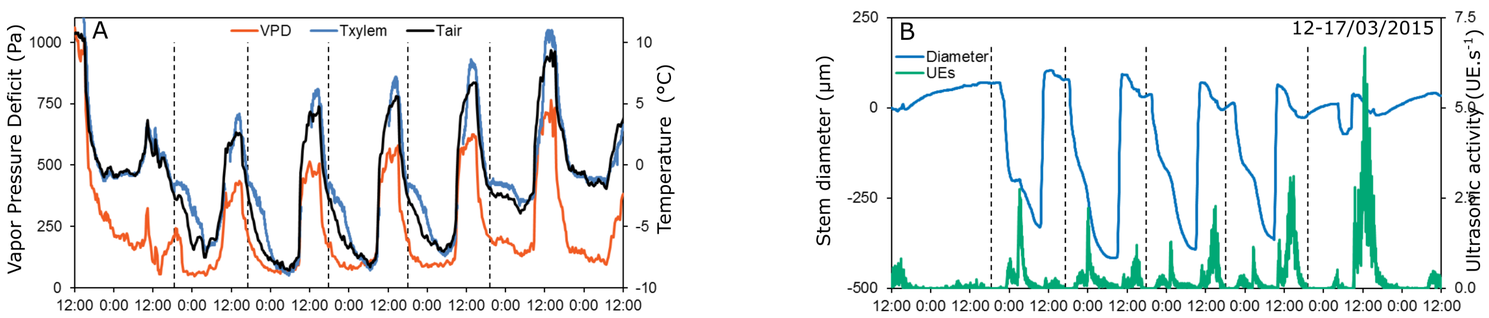

Figure 7. Diurnal sequences of environmental conditions (air and xylem temperature, vapor pressure deficit; A), stem diameter changes, and ultrasonic activity (B) during six days with five freeze-thaw cycles. Stem diameter is given as differential with respect to initial diameter (*i.e.* Day 1, 12:00) to highlight dynamic changes. Vertical dashed lines indicate the onset of the freezing exotherms as observed by thermocouples.

Conclusion & Perspectives

The combined use of several sensing technologies enabled to demonstrate not only **contrasting ice propagation patterns**, but also the link between **ice formation, diameter changes due to water shifts and ultrasonic activity due to cavitation (Fig. 8)**. These processes are highly relevant for plant hydraulics and freezing stress, and their understanding is a prerequisite for studies on winter stress not only in timberline species but also for temperate trees in general.

References

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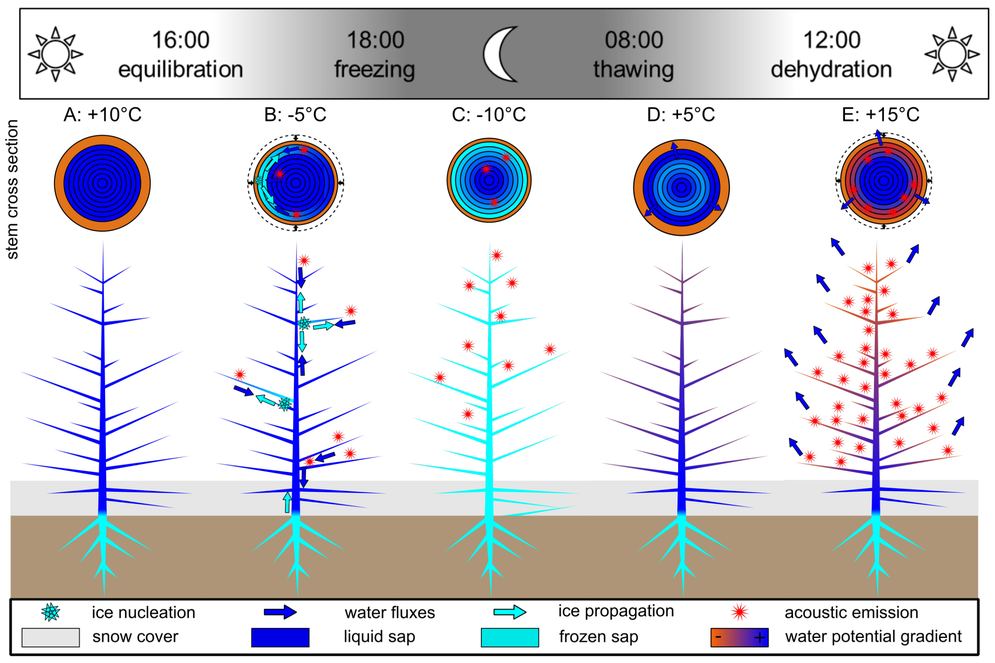

Figure 8. Generalized scheme of observed patterns and underlying water fluxes during a freeze-thaw cycle in late winter. Initial equilibrated state (A), ice nucleation and propagation with associated water fluxes, stem shrinkage and ultrasonic emissions (B), ultrasonic activity after exotherm dissipation (C), stem diameter increase and developing water potential gradient during thawing (D), and stem shrinkage and high ultrasonic activity during daytime transpiration with frozen soil (E).

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