LOSTinFTC: L-band Observations of Soil and Trees in Freezing/Thawing Conditions

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LIVING PLANET FELLOWSHIP

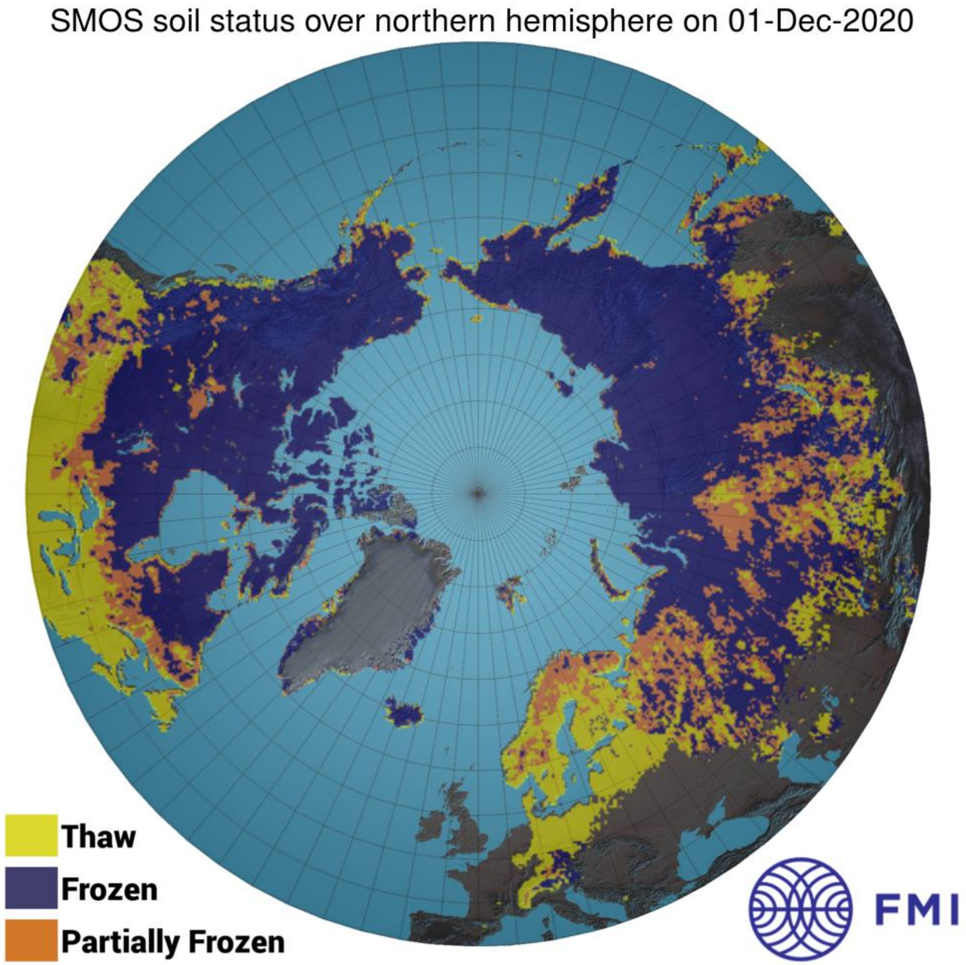
BIOSPHERE

Motivation 1: canopy transmissivity

- Microwave remote sensing of snow and soil frost in boreal forests requires modeling of forest properties
- Typically forest canopy transmissivity modeled as a function of biomass only
- Models often based on short measurement campaigns – no temperature variation
- Measurements show significant variation in forest transmissivity as a function of temperature
- GOAL 1: temperature dependence of boreal forest transmissivity at L-band in freezing conditions

Motivation 2: soil thawing

- Detection of thawed/frozen soil is based on permittivity difference of water and ice
- Soil freezing can be detected using L-band https://nsdc.fmi.fi/services/SMOSService/
- Water in melting snow masks out signal from thawing soil
- GOAL 2: study possibilities for soil thaw detection using advanced modeling

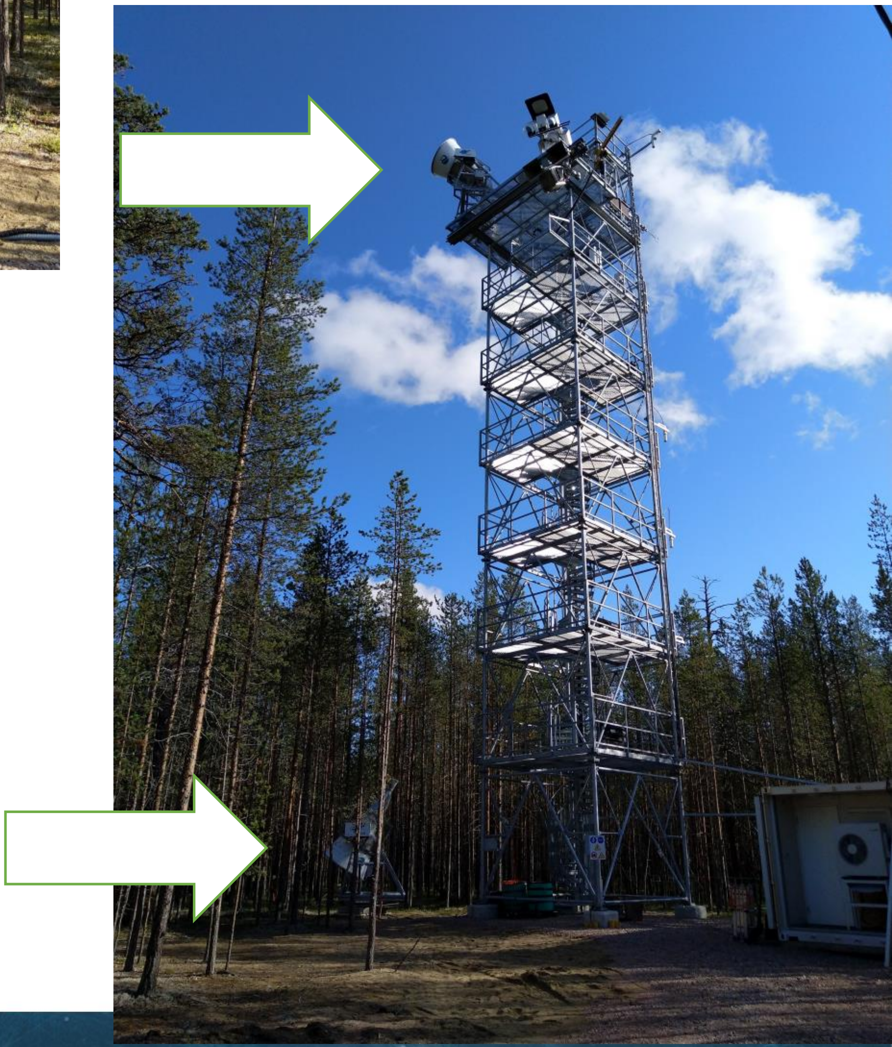


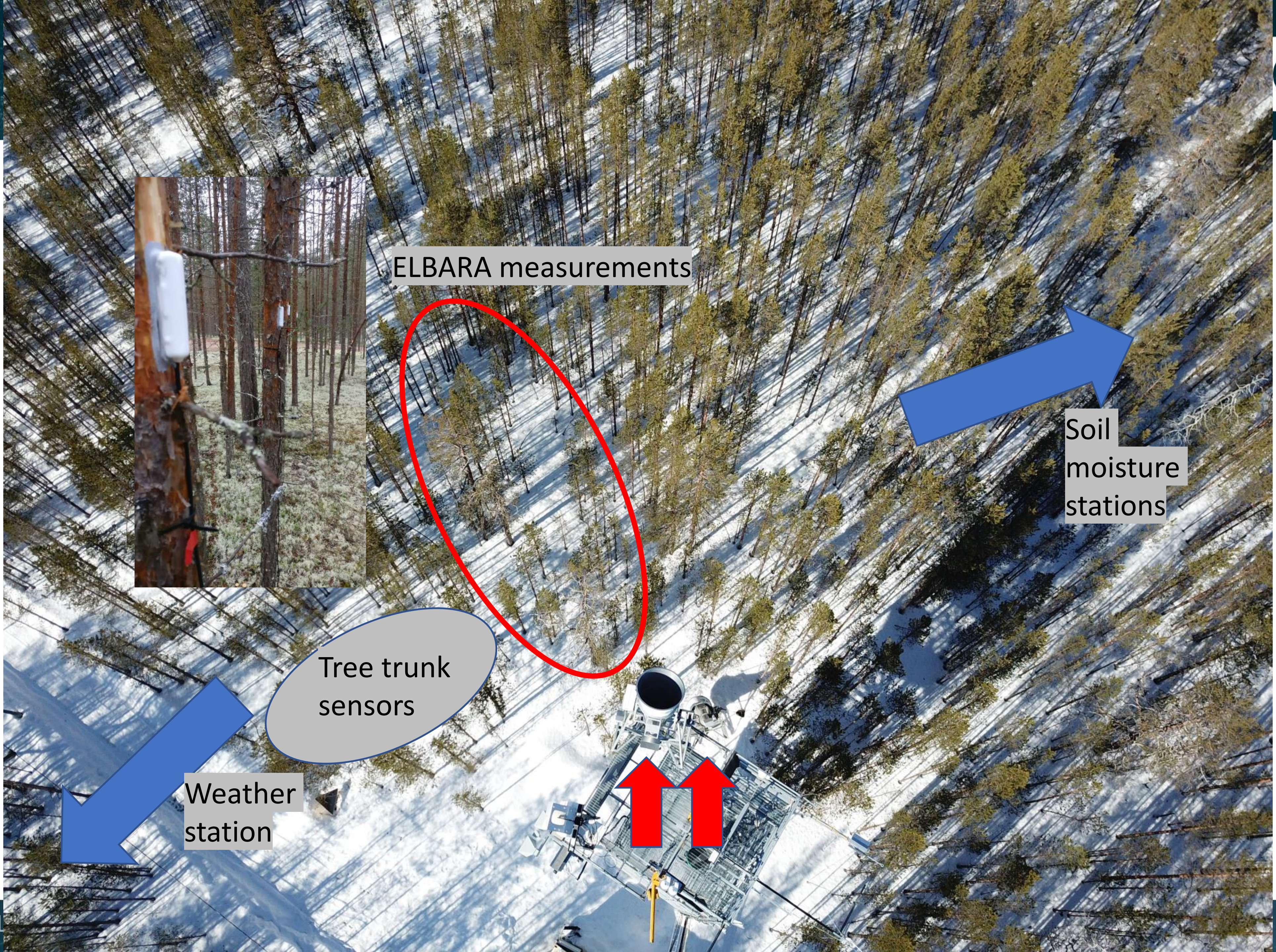
Background

- Relative permittivity of liquid water (~80) differs from ice (~3)
- In sandy soils almost all the liquid water freezes when temperature drops below 0 °C => soil frost detection
- In trees water can stay in metastable liquid state down to -40 °C
- Relative permittivity and L-band transmissivity of trees changes gradually when temperature drops below 0 °C

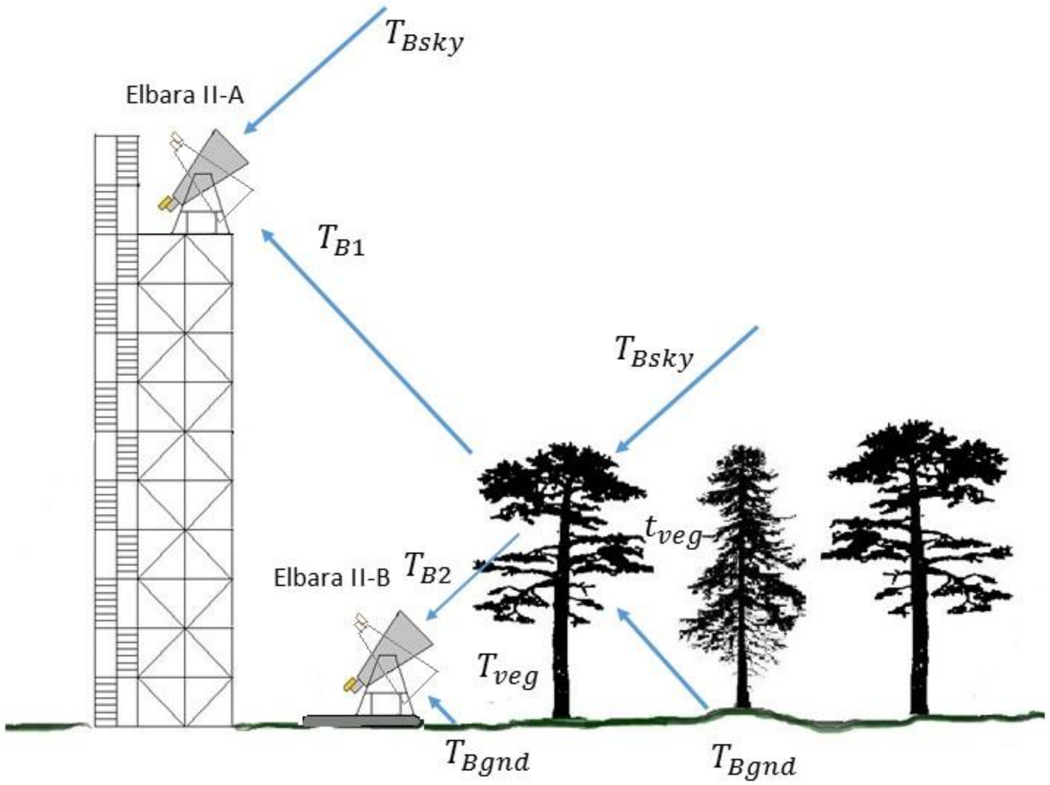
Measurement setup

- FMI Arctic Space Centre in Sodankylä, Finland
- 24-m ICOS tower
- 2 ESA ELBARA instruments: L-band radiometer 1.4 GHz (SMOS reference)
- Measurements since Jan 2019
- Sparse pine-dominated forest on sandy soil
- Reference measurements:
  - Tree trunk permittivity, skin temperature
  - Soil, snow and meteorological measurements
  - (CO_2 flux)




ELBARA measurements
Soil moisture stations
Tree trunk sensors
Weather station

Simplified model for canopy transmissivity



- Simplified approach (Mätzler et al., 1994)
  - Vegetation layer with no reflections or scattering
  - T_{B2},T_{Bsky}

$$T_{B2} = t_{veg}T_{Bsky} + r_{veg}T_{Bgnd} + (1 - r_{\mathrm{veg}} - t_{veg})T_{veg}$$

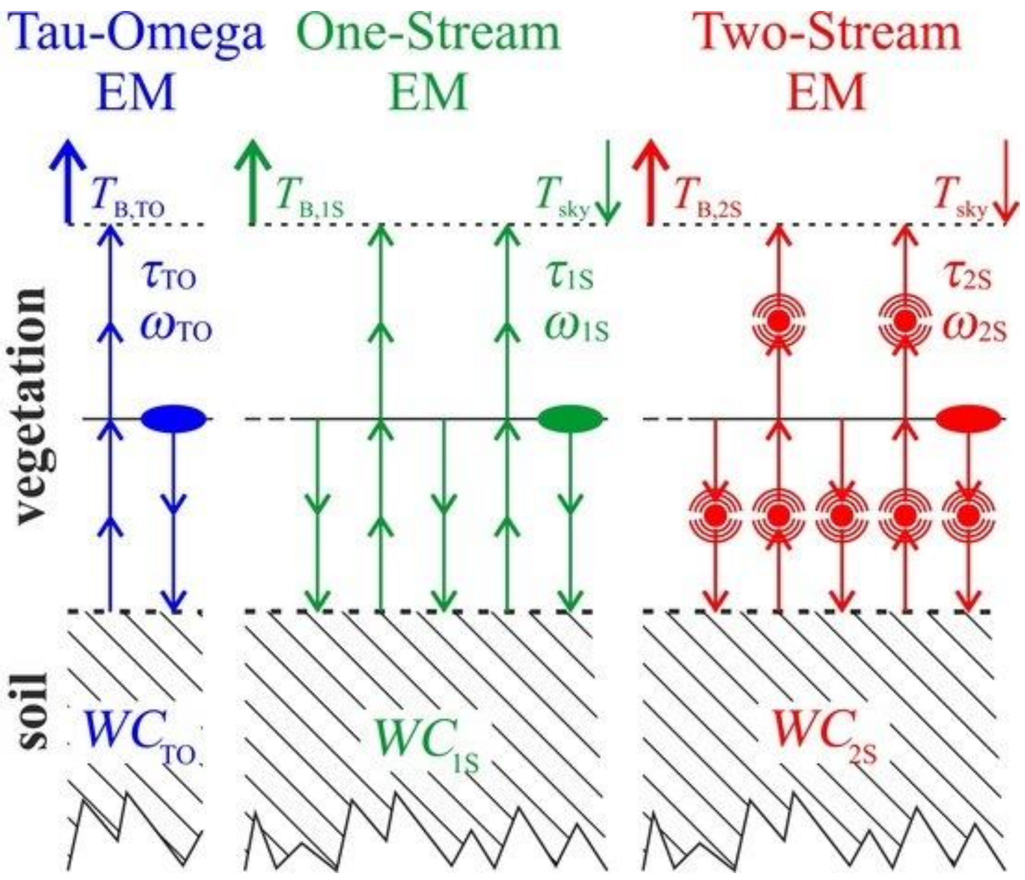
$$r_{\mathrm{veg}} \approx 0 \Longrightarrow \quad t_{veg} = \frac{T_{veg} - T_{B2}}{T_{veg} - T_{Bsky}}$$

- Schwank et al. 2S model
  - Reflections and scattering in vegetation
  - T_{B1},T_{B2},T_{Bsky},T_{Bgnd}

2-stream EM model

- Often τ −ω – model used
- 2S: multiple reflections and scattering
- Better for dense scattering vegetation

- τ – vegetation optical depth (VOD)
- ω – single scattering albedo
- t – transmissivity
- $t \sim e^{-\tau}$



Schwank et al. 2018

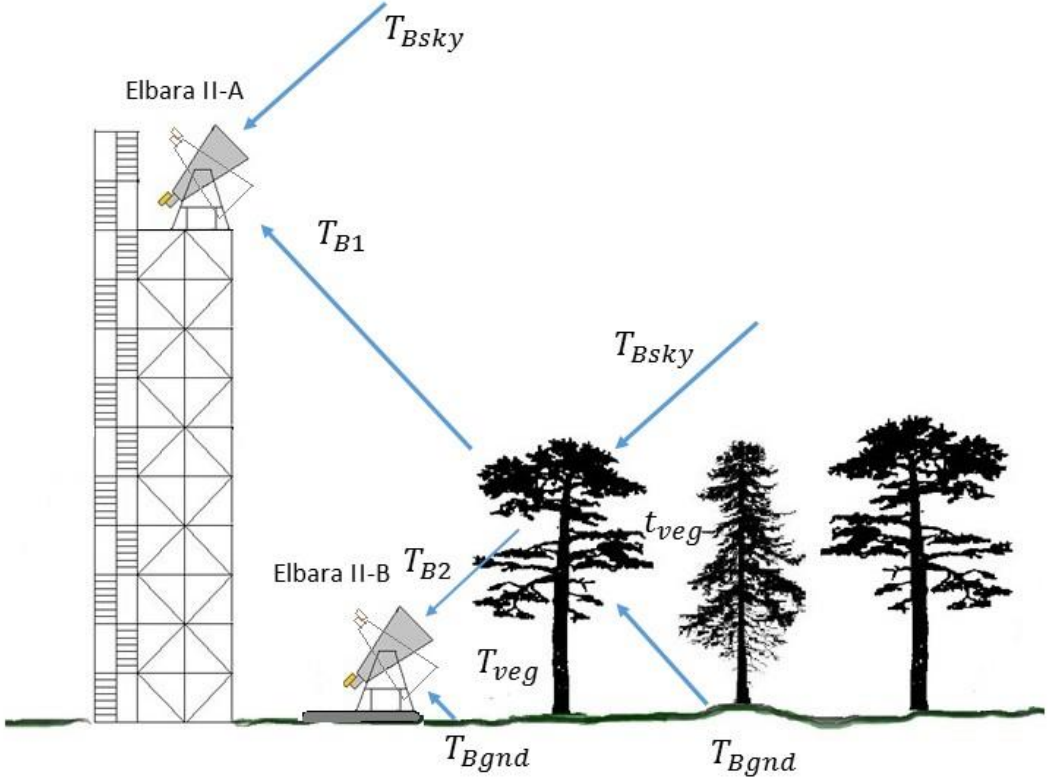
2-stream equations

- General form: $T_{B1} = T_B^{p,\theta} = T_{gnd} \cdot e_{gnd}^{p,\theta} + T_{veg} \cdot e_{veg}^{p,\theta} + T_{sky} \cdot e_{sky}^{p,\theta}$
- 2-stream model:

$$e_{gnd}^{p,\theta} = t_{veg}^{\theta}\left(1 - s_{gnd}^{p,\theta}\right)/\left(1 - s_{gnd}^{p,\theta} r_{veg}^{\theta}\right)$$
$$e_{veg}^{p,\theta} = \left(1 - r_{veg}^{\theta} - t_{veg}^{\theta}\right)\left(1 - s_{gnd}^{p,\theta} r_{veg}^{\theta} + s_{gnd}^{p,\theta} t_{veg}^{\theta}\right)/\left(1 - s_{gnd}^{p,\theta} r_{veg}^{\theta}\right)$$
$$e_{sky}^{p,\theta} = \left(1 - e_{gnd}^{p,\theta} - e_{veg}^{p,\theta}\right)$$

$$t_{veg}^{\theta} = \frac{2 \cdot exp\left(\tau\sqrt{1-\omega^2}/\cos\theta\right) \cdot \left(1 - \omega^2 + \sqrt{1-\omega^2}\right)}{exp\left(2\tau\sqrt{1-\omega^2}/\cos\theta\right) \cdot \left(2 - \omega^2 + 2\sqrt{1-\omega^2}\right) - \omega^2}$$
$$r_{veg}^{\theta} = \frac{\omega \cdot \left[exp\left(2\tau\sqrt{1-\omega^2}/\cos\theta\right) - 1\right] \cdot \left(1 + \sqrt{1-\omega^2}\right)}{exp\left(2\tau\sqrt{1-\omega^2}/\cos\theta\right) \cdot \left(2 - \omega^2 + 2\sqrt{1-\omega^2}\right) - \omega^2}$$

Retrieval of canopy transmissivity

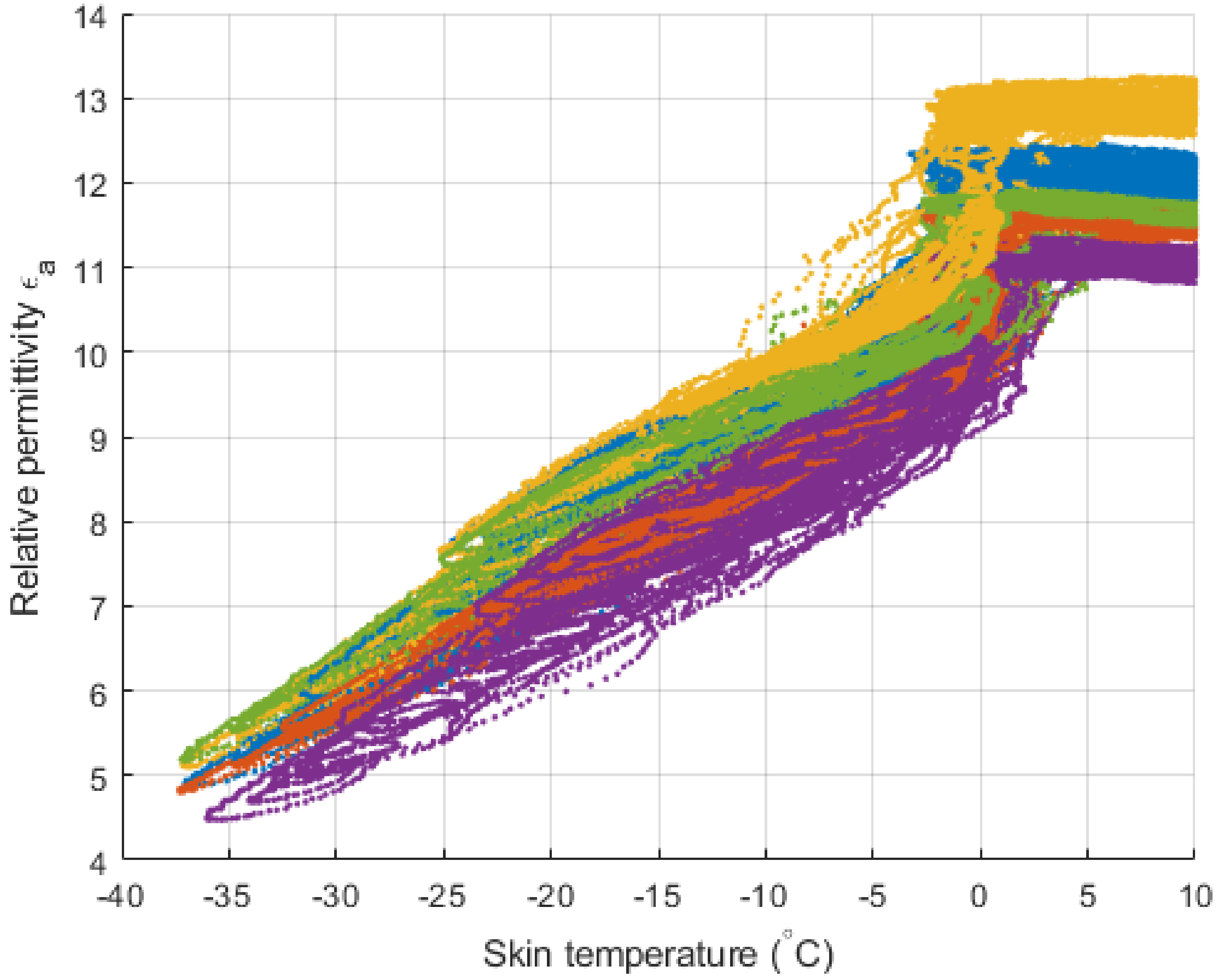


- Hourly elevation scans
  - Canopy from above and below
  - Background signals
- Retrieval approach:

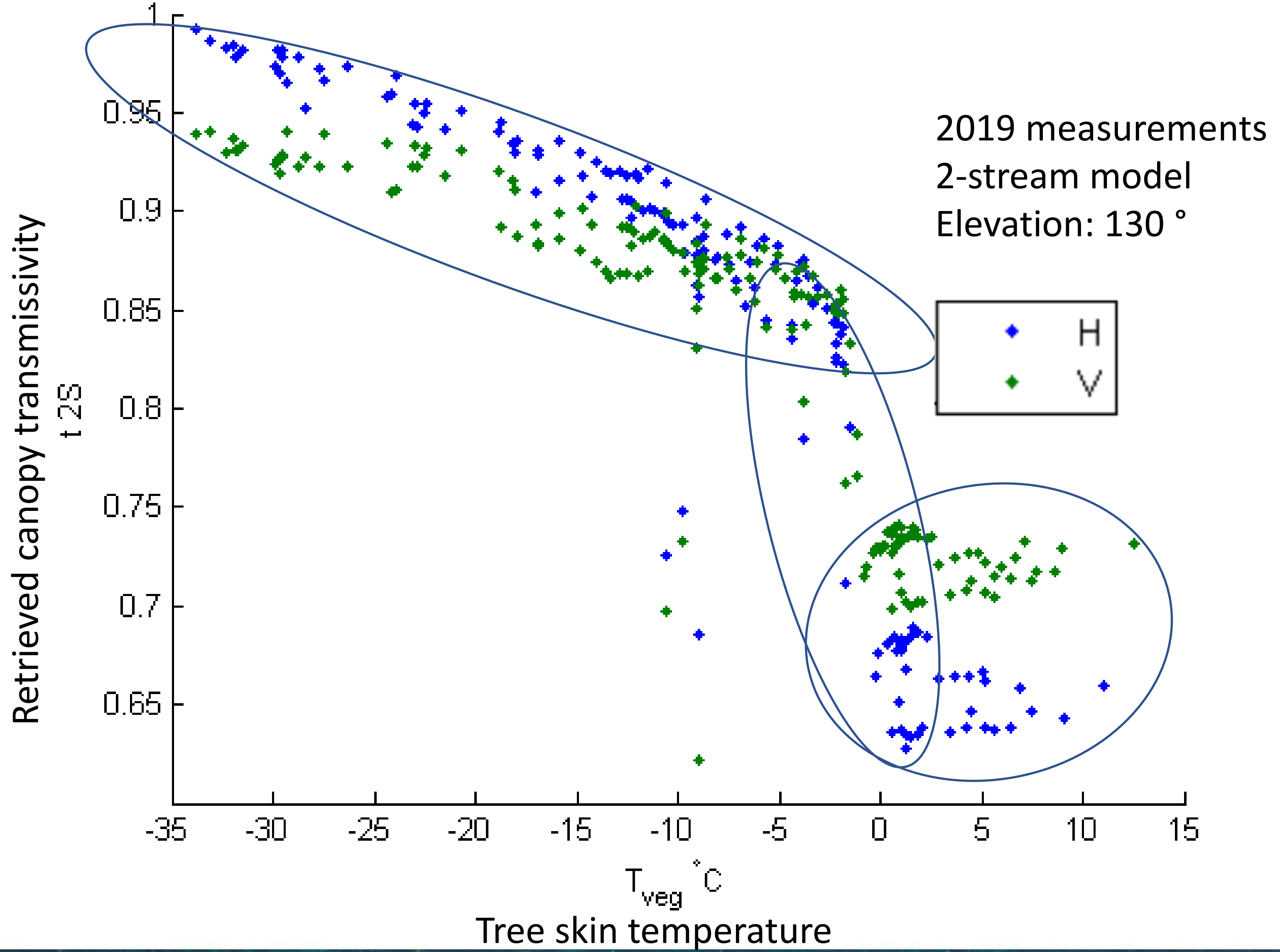
1. Vegetation optical depth τ from measured T_{B2} and T_{bsky}
2. (Soil permittivity ε_g from T_{Bgnd})
3. Single-scattering albedo ω fom T_{B1}

Tree relative permittivity vs. temperature

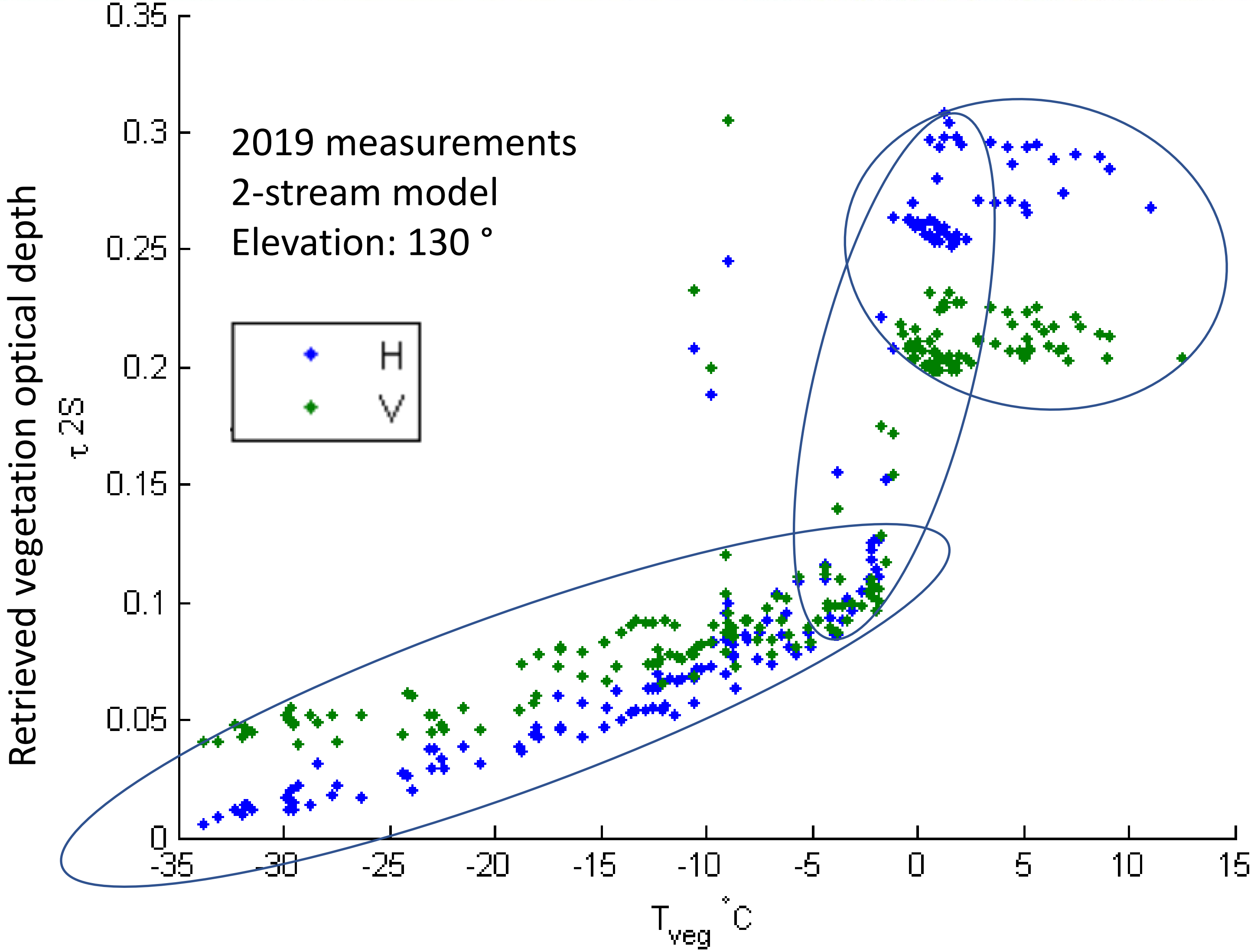
- Tree relative permittivity and tree skin temperature correlate when T<0 °C (r^2 0.8-0.9)
- Tree skin temperature good proxy for freezing
- Easier to measure



Transmissivity - temperature

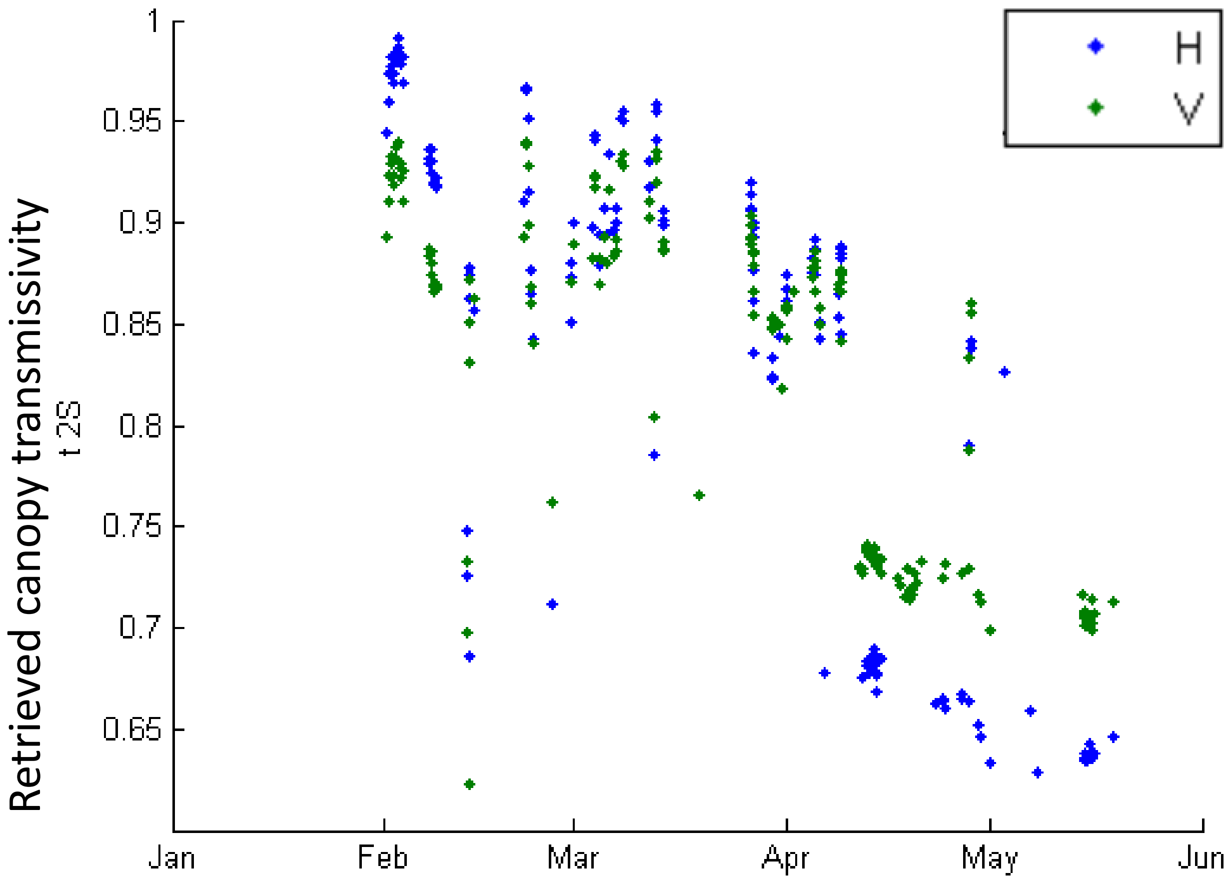


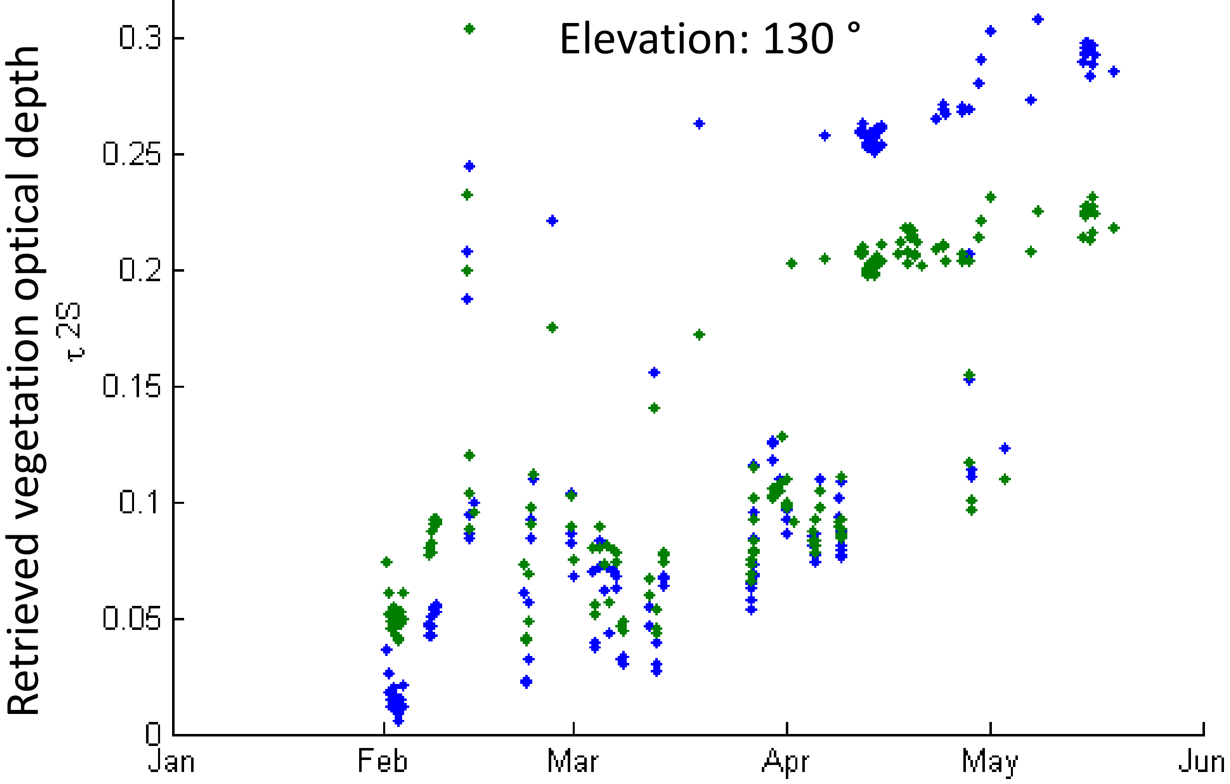
L-VOD - temperature



Tree skin temperature

Results – time series

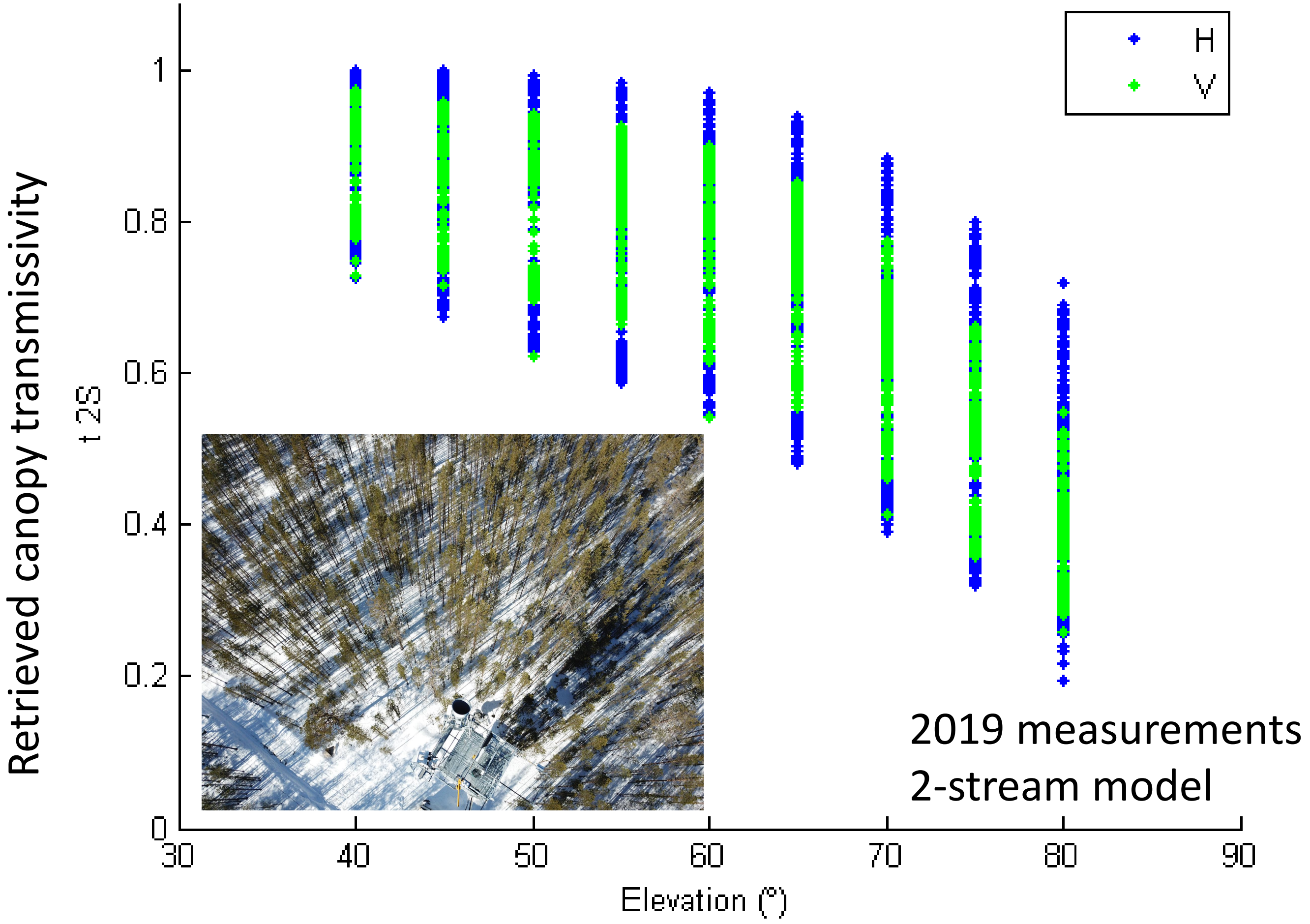




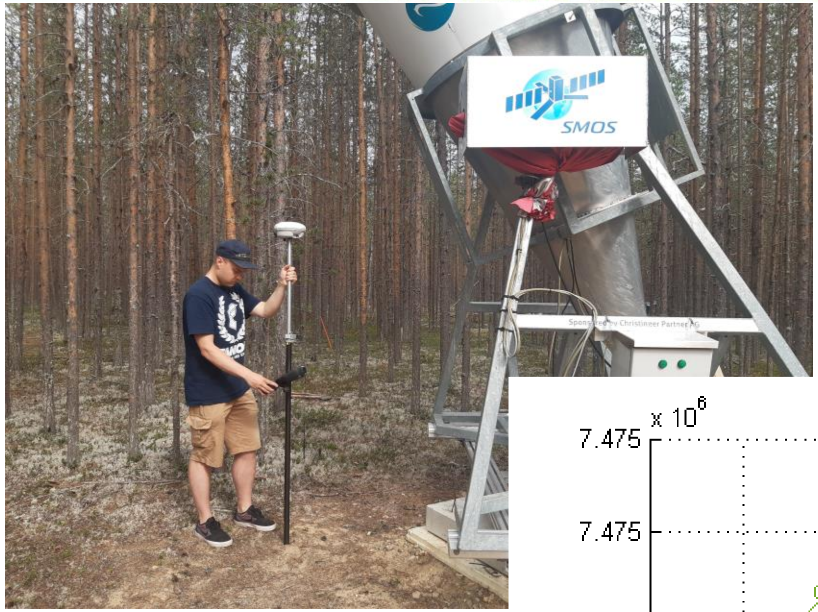
2019 measurements
2-stream model
Elevation: 130 °

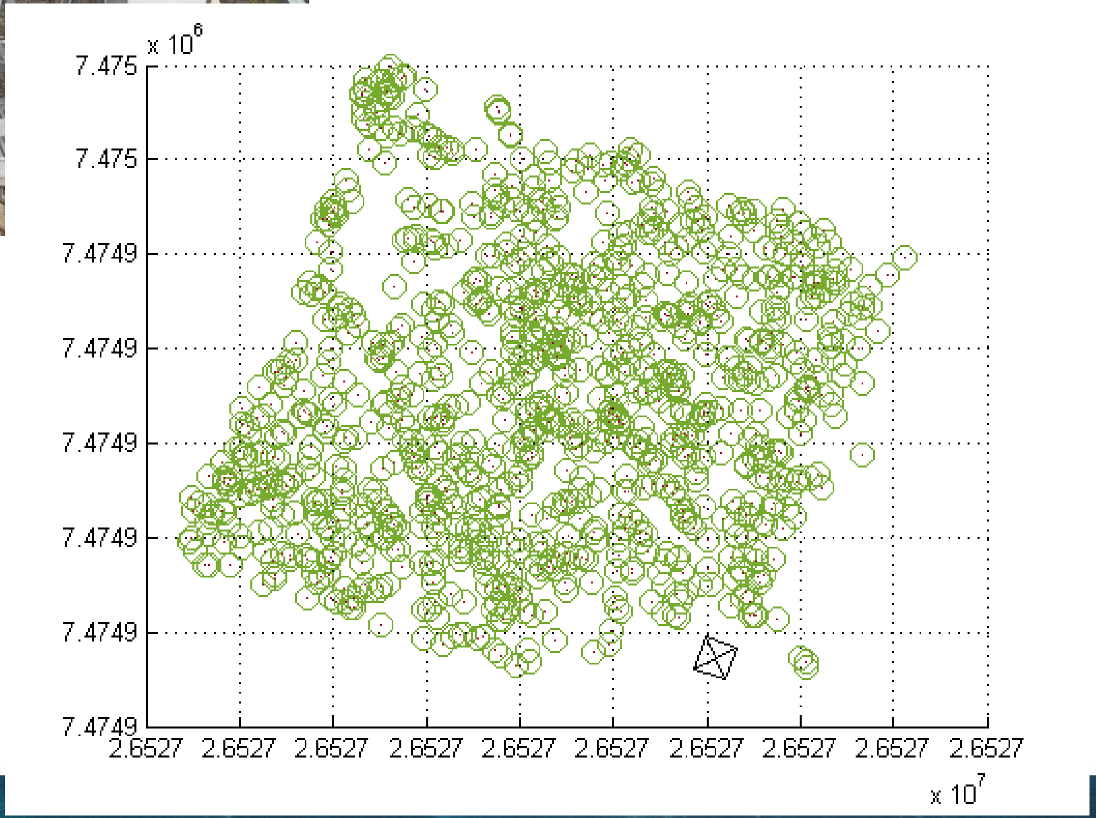
Forest biomass

- Forest biomass changes between footprints
- Multi-angle measurements (comparable with satellite data) cannot be used without biomass
- Transmissivity as a function of elevation cannot be determined without biomass

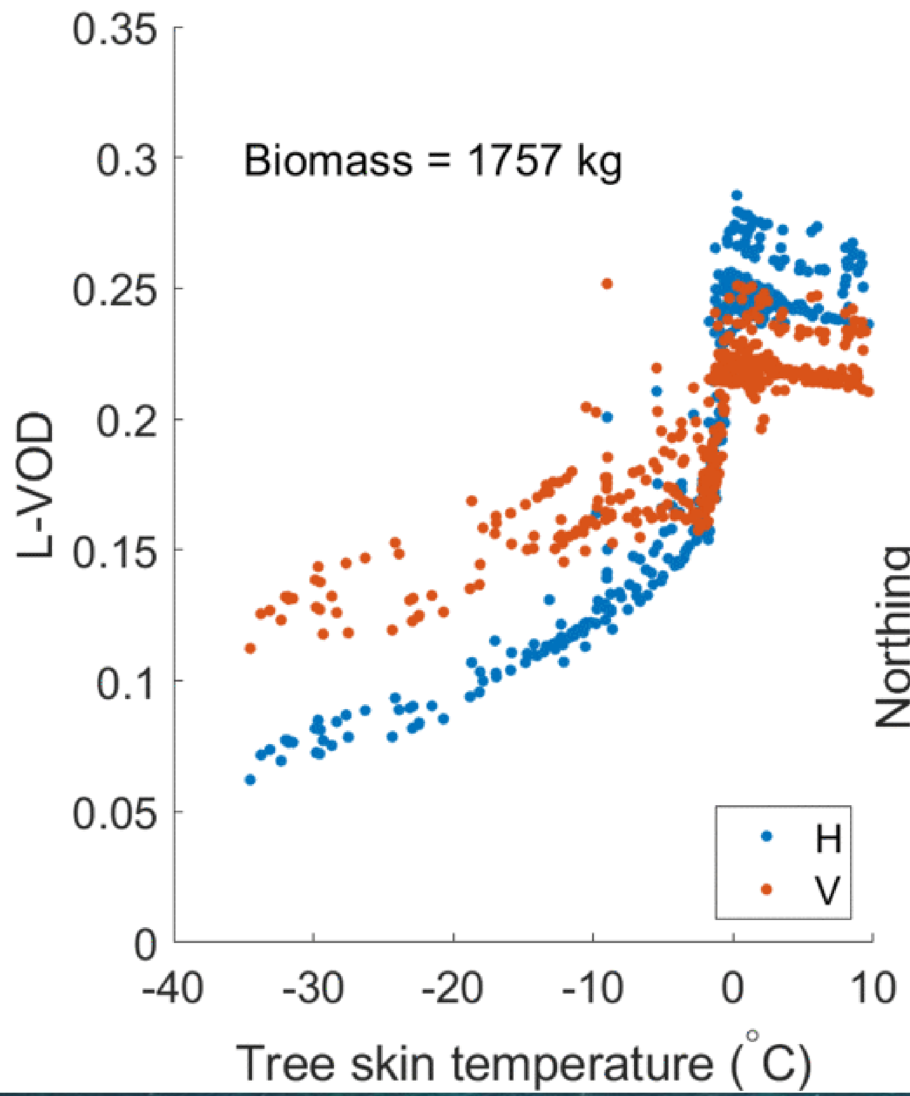


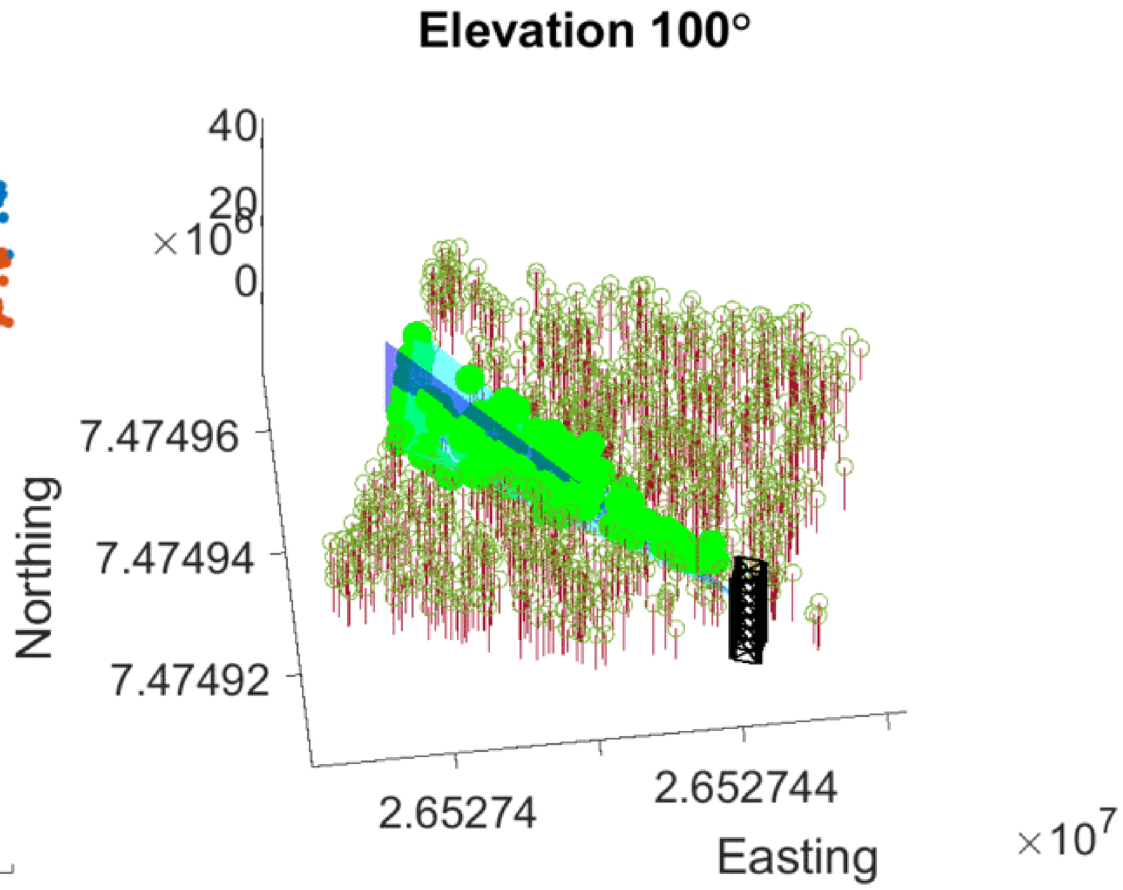
Biomass measurements





L-VOD and biomass





Highlights

- Variation in transmissivity from 0.5 to 1
- Rapid changes in transmissivity if temperature changes
- Coming: transmissivity as a function of temperature and biomass

- Two papers being prepared (Kontu et al.; Schwank, Kontu et al.)
- Work presented in Microrad 2020 and SMOS meetings (SMOS Expert Support Laboratory 2020+: Task-2 Soil Moisture, SMOS REVEX)