WATER AND VEGETATION TOWER RADAR EXPERIMENTS FOR IMPROVED CLIMATE MONITORING

WAVETRAX

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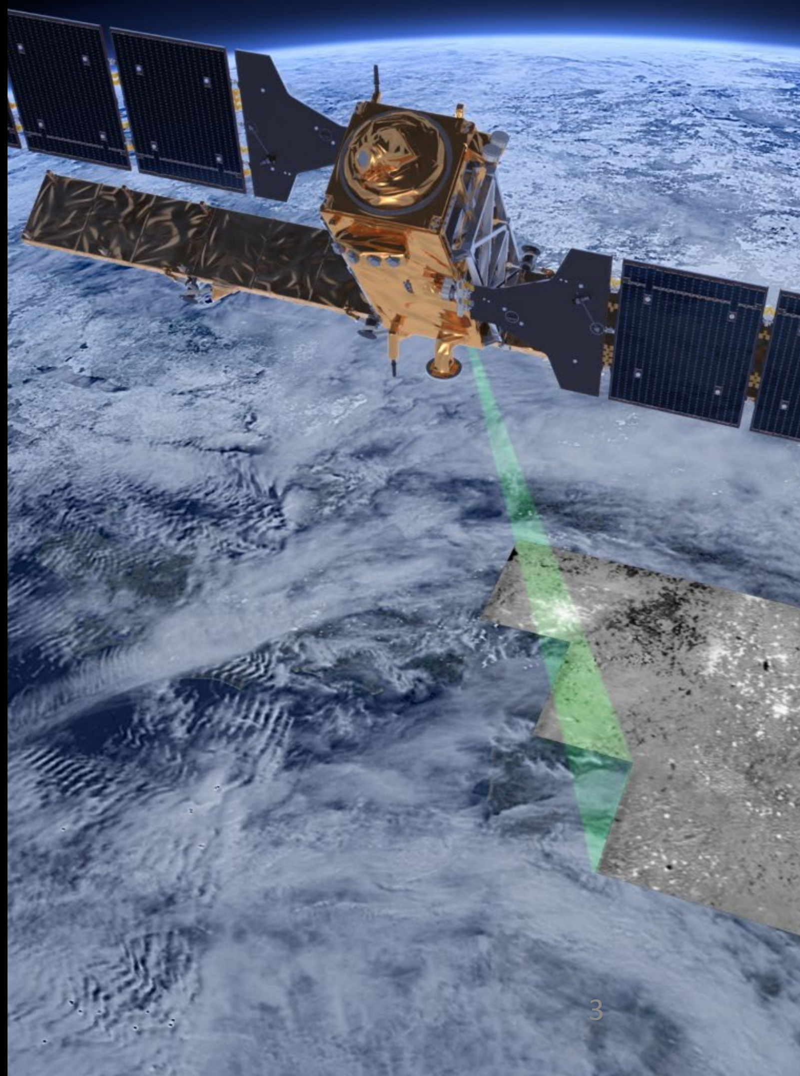
Radar remote sensing of Essential Climate Variables (ECV)

- Surface soil moisture (SSM):
- Root-zone soil moisture (RZSM)
- Vegetation biomass (or VOD)
- Snow water equivalent (SWE)
- Land evaporation (E)

Challenges in radar remote sensing of ECVs

Lack of frequent observations limits monitoring capabilities

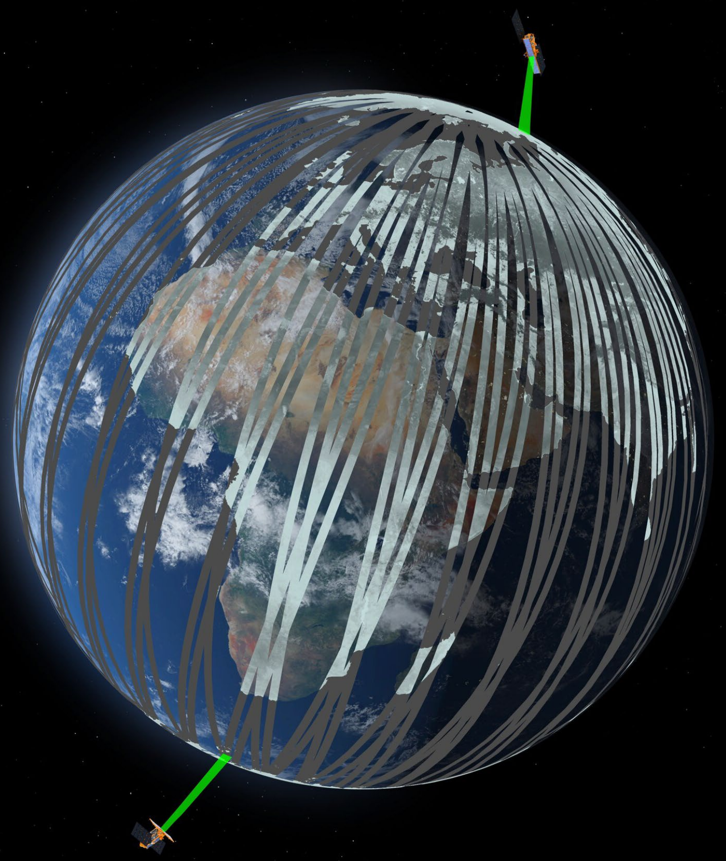
- Satellite observations are snapshots
- Short-term dynamics are unobserved
- Can have long-lasting impacts
  - Processes: vegetation stress event -> biomass
  - Retrievals: rain-on-snow event -> SWE retrieval



The near future of radar remote sensing

Towards higher temporal frequencies

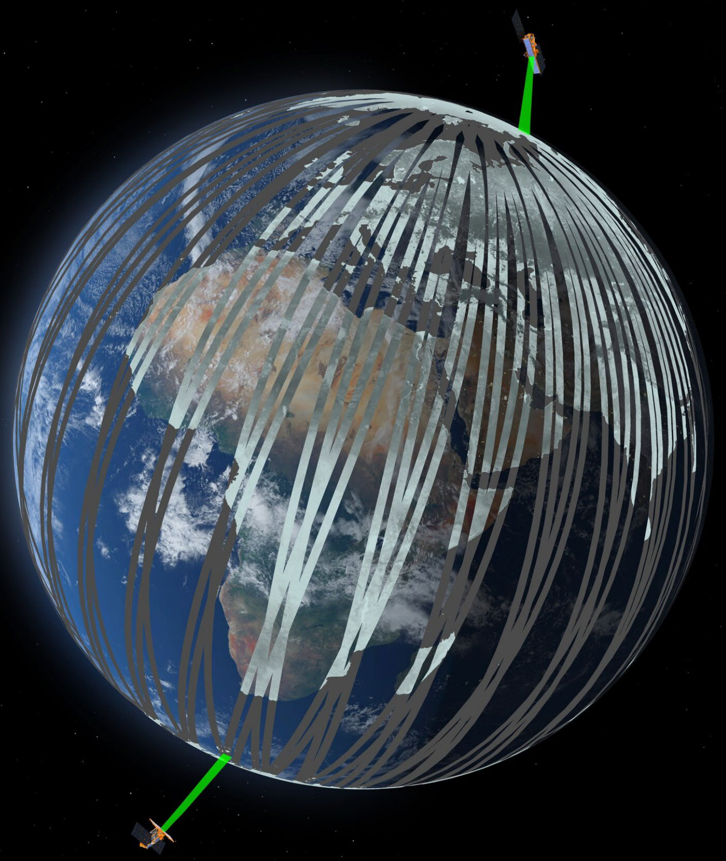
- Expanding current satellite missions
  - Sentinel-1 (1C & 1D coming soon): C-band SAR constellation
  - ROSE-L: Copernicus Expansion L-band SAR
  - TSMM: Canadian Ku-band SAR for snow mass
  - …
- New satellite constellation concepts
  - SLAINTE (ESA EE12): 3-satellite constellation
    - Sub-daily variations in water stored within soil-vegetation
    - Improved understanding of land-atmosphere interactions
- Geostationary satellite concept
  - HYDROTERRA (ESA EE12)
    - Sub-daily water cycle observations



The near future of radar remote sensing

But: what do we know about radar remote sensing of diurnal processes?

- Which processes can we observe?
  - Moisture movement through soil-plant (vegetation stress, drought)
  - Short-term evaporation dynamics (interception loss)
  - Snowpack changes (metamorphism, melt/freeze)
  - …
- What temporal resolutions, microwave frequencies and polarizations are needed?



To support future radar missions, improved understanding of microwave responses to sub-daily processes is essential

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Hypotheses

1. Improved physical understanding of how sub-daily processes impact radar measurements offers opportunity to improve ECV retrievals
2. Tower radar experiments are the best way to achieve improved understanding

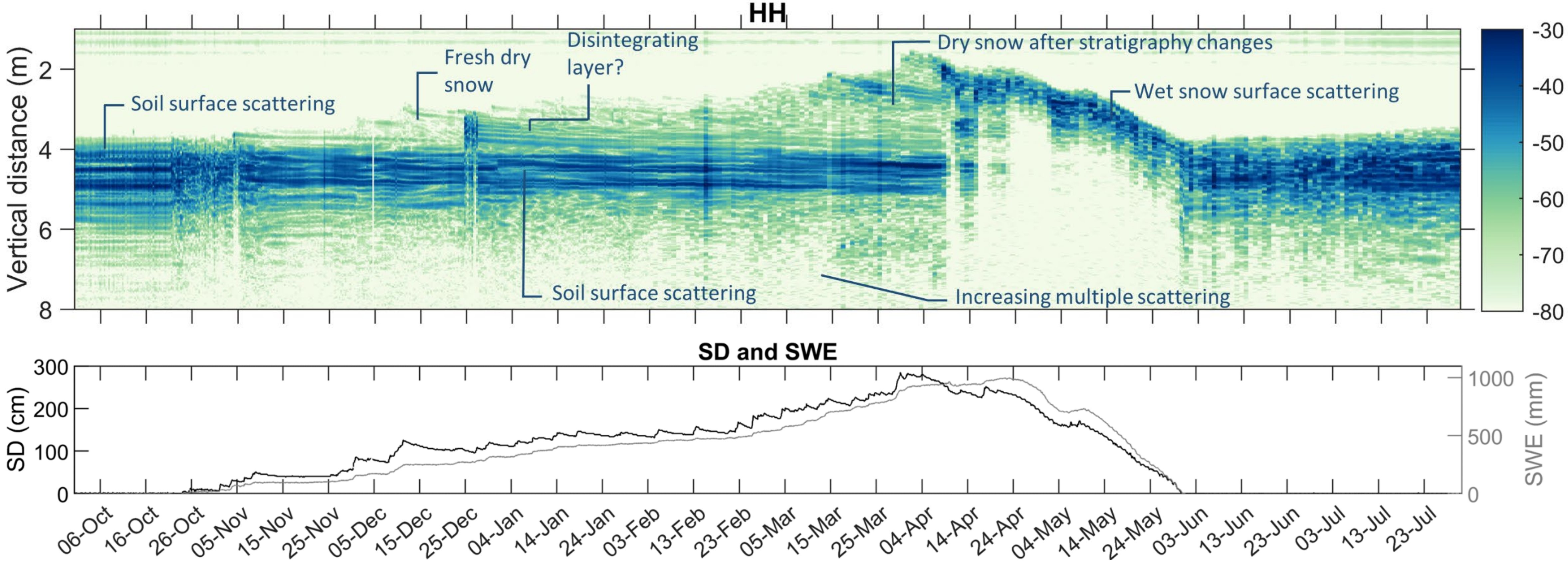
Objectives

1. Build new radar sensors [WP2: Sensor design]
2. Improve understanding of sub-daily scattering signatures [WP3: Field experiments]
3. Improve methods for radar retrievals of ECVs [WP4: Modelling]

WP2: Sensor design

6 radar sensors

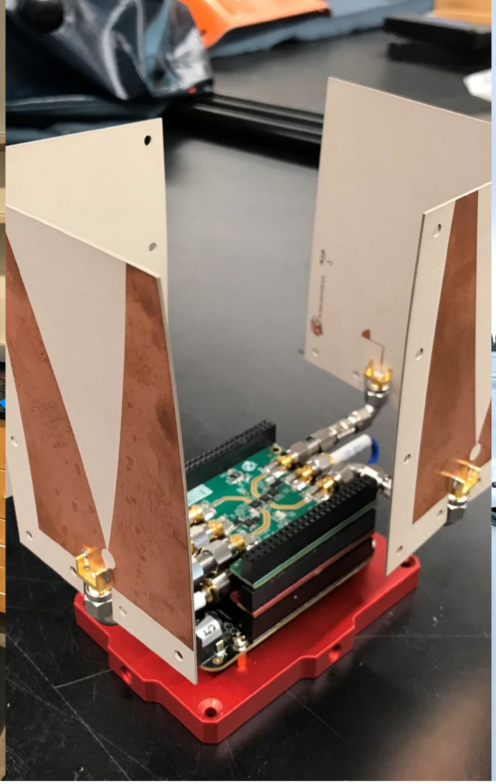
- 4 C-band (5.4 GHz), 1 L-band (1.3 GHz), 1 Ku-band (13.5 GHz)
- 2 sensors at each of 3 study sites
- Tomographic principle: scatter sources within soil/vegetation/snow

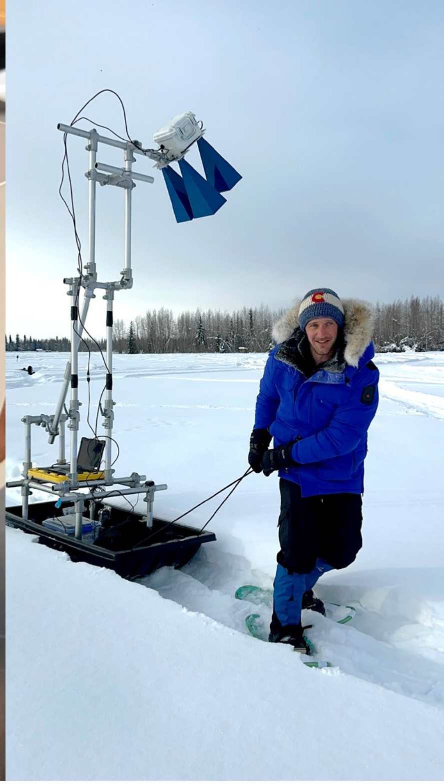


WP2: Sensor design

Components

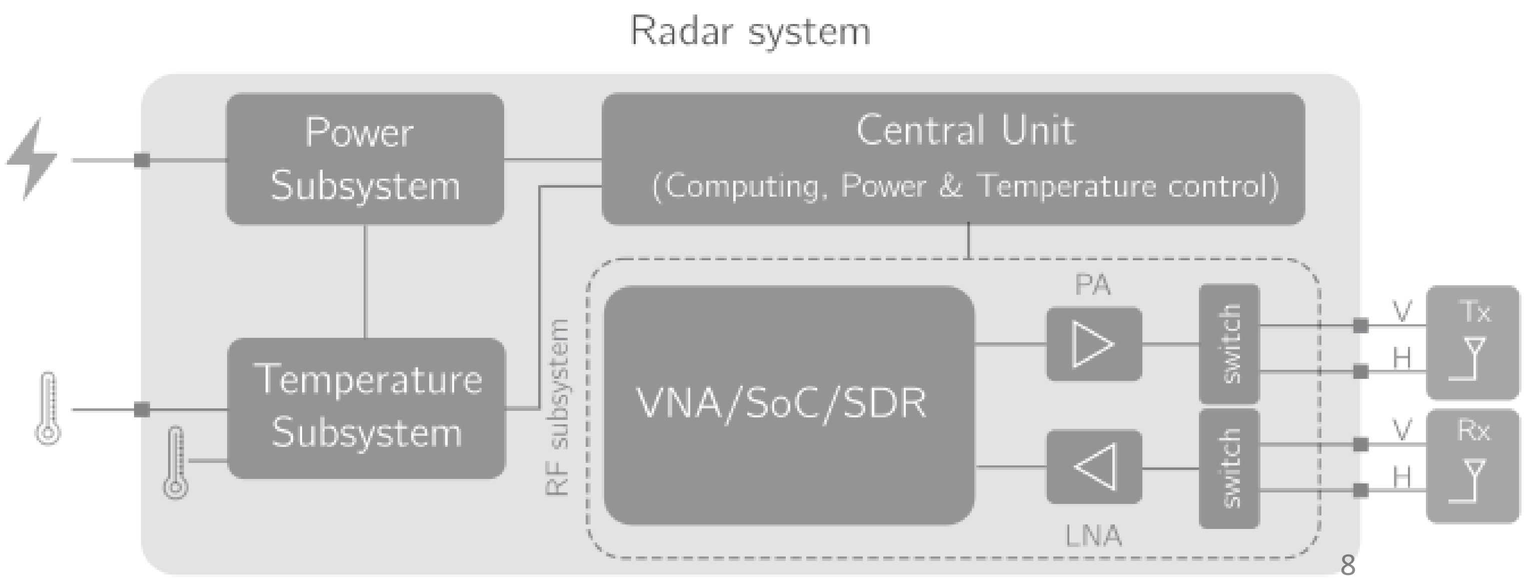
- Radio-Frequency system
  - [VNA] Vector Network Analyzer
  - [SoC] System-on-chip pulsed radar
  - [SDR] Software-defined radio
- Antennas
  - Linear tapered slot
  - Standard gain horns
- Enclosure with thermal control





Calibration

- Anechoic chamber
- Calibration targets
- Comparison between radars



WP3: Field experiments

1. FERM, Belgium (50.66°N, 4.64°E)
Agricultural crops (cereal)
UCL experimental research site

2. Bogus Basin, USA (43.77°N, 116.10°W)
1930 m, soil & shrubs, montane forest snow
Previous radar experiments in BELSPO C-SNOW

3. Weissfluhjoch, Switzerland (46.83°N, 9.81°E)
2536 m, rocks, tundra snow
WSL SLF research site since 1936

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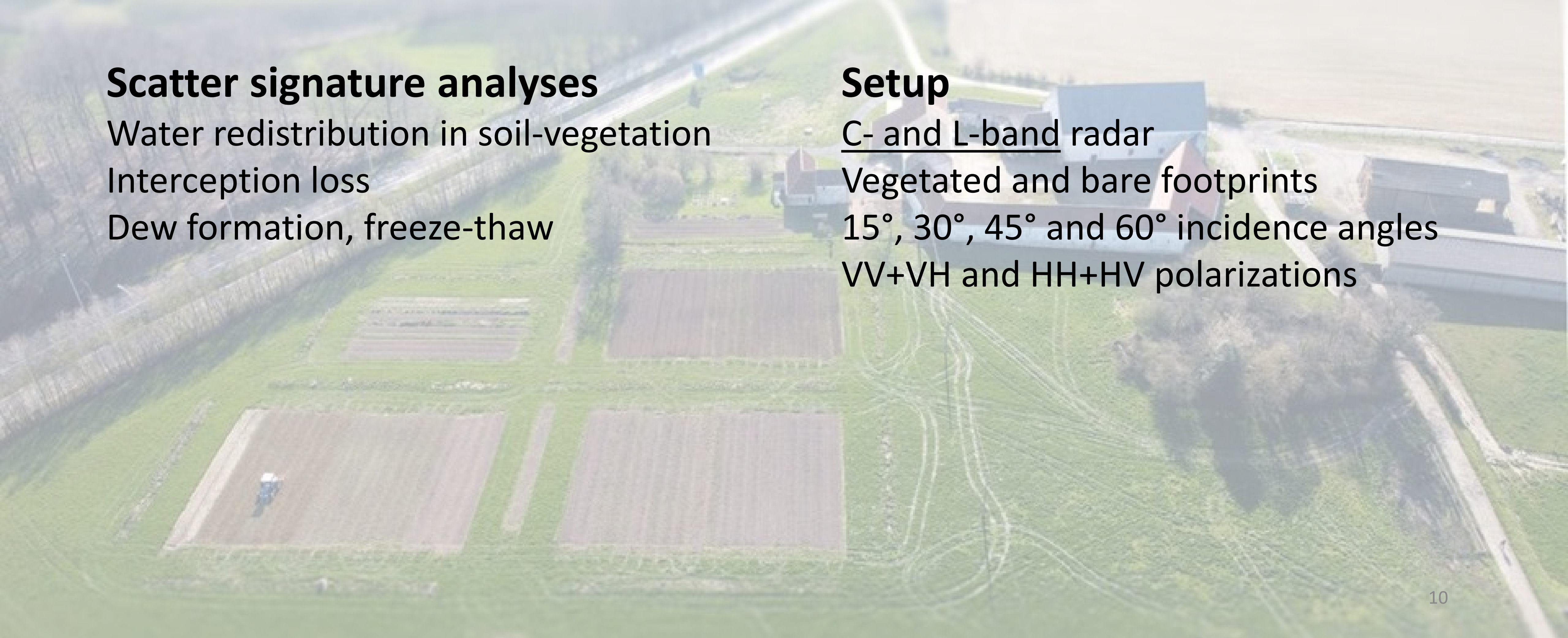

Scatter signature analyses

Water redistribution in soil-vegetation
Interception loss
Dew formation, freeze-thaw

Setup

C- and L-band radar
Vegetated and bare footprints
15°, 30°, 45° and 60° incidence angles
VV+VH and HH+HV polarizations

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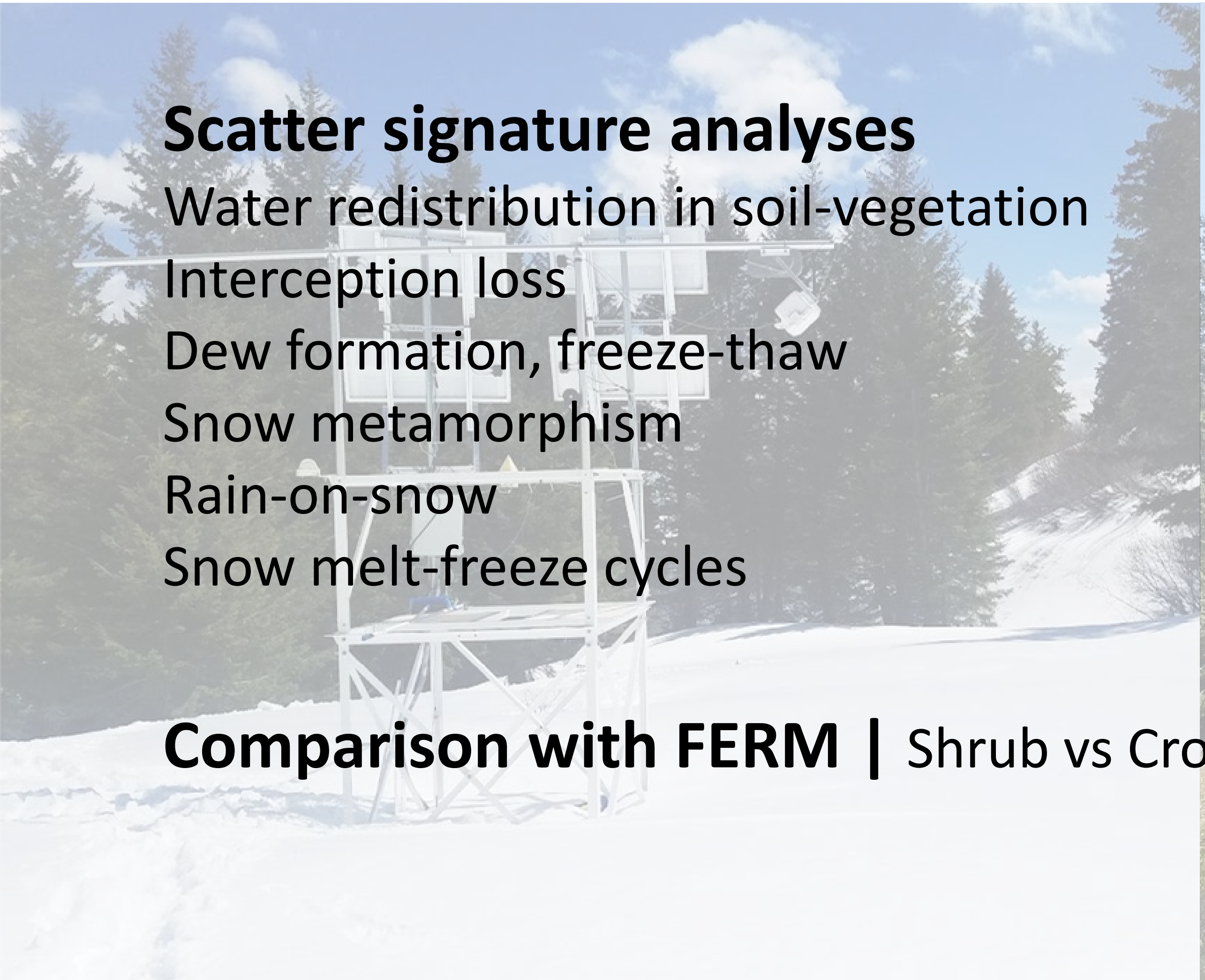

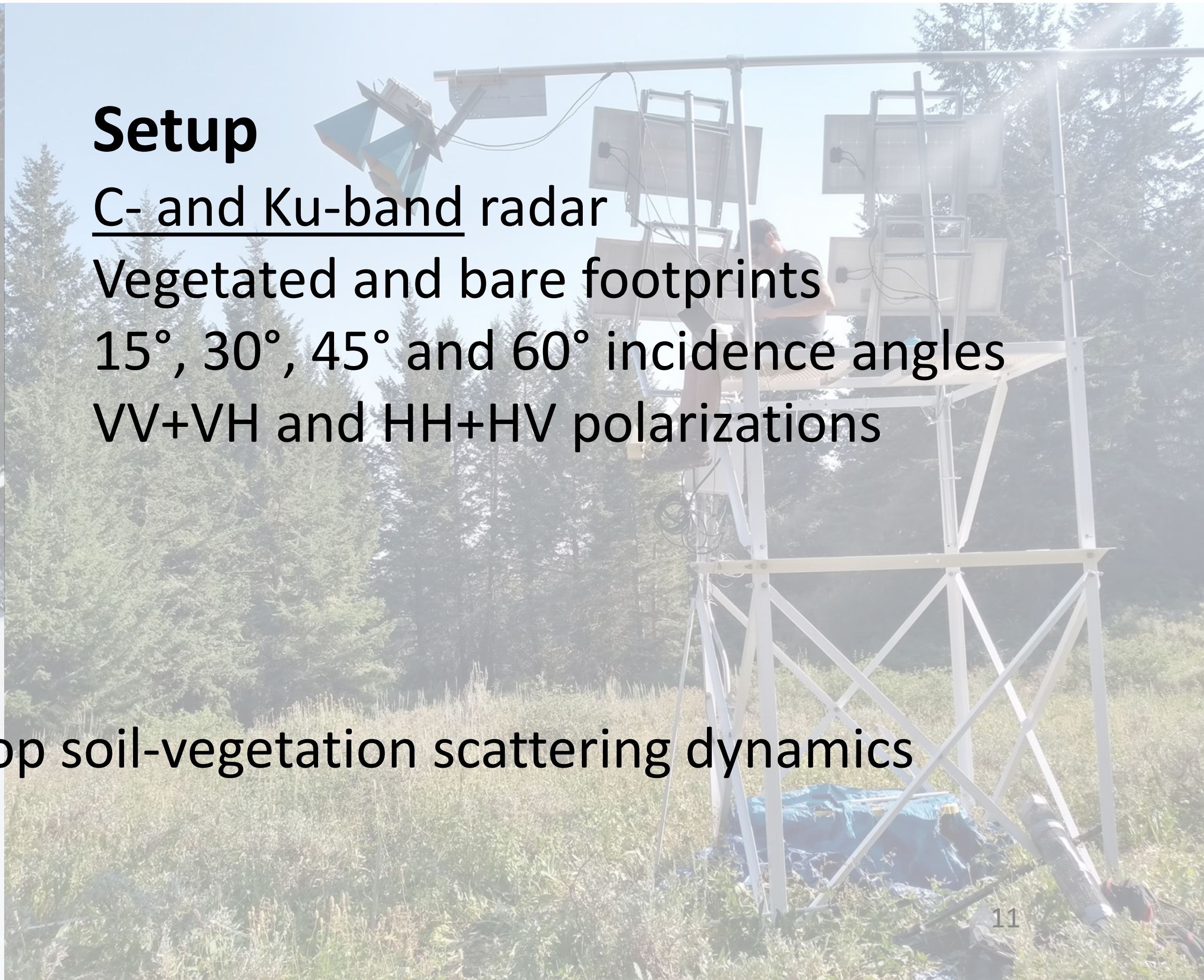

Scatter signature analyses

Water redistribution in soil-vegetation
Interception loss
Dew formation, freeze-thaw
Snow metamorphism
Rain-on-snow
Snow melt-freeze cycles

Setup

C- and Ku-band radar
Vegetated and bare footprints
15°, 30°, 45° and 60° incidence angles
VV+VH and HH+HV polarizations

Comparison with FERM | Shrub vs Crop soil-vegetation scattering dynamics

WP3: Field experiments

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2536 m, rocks, tundra snow
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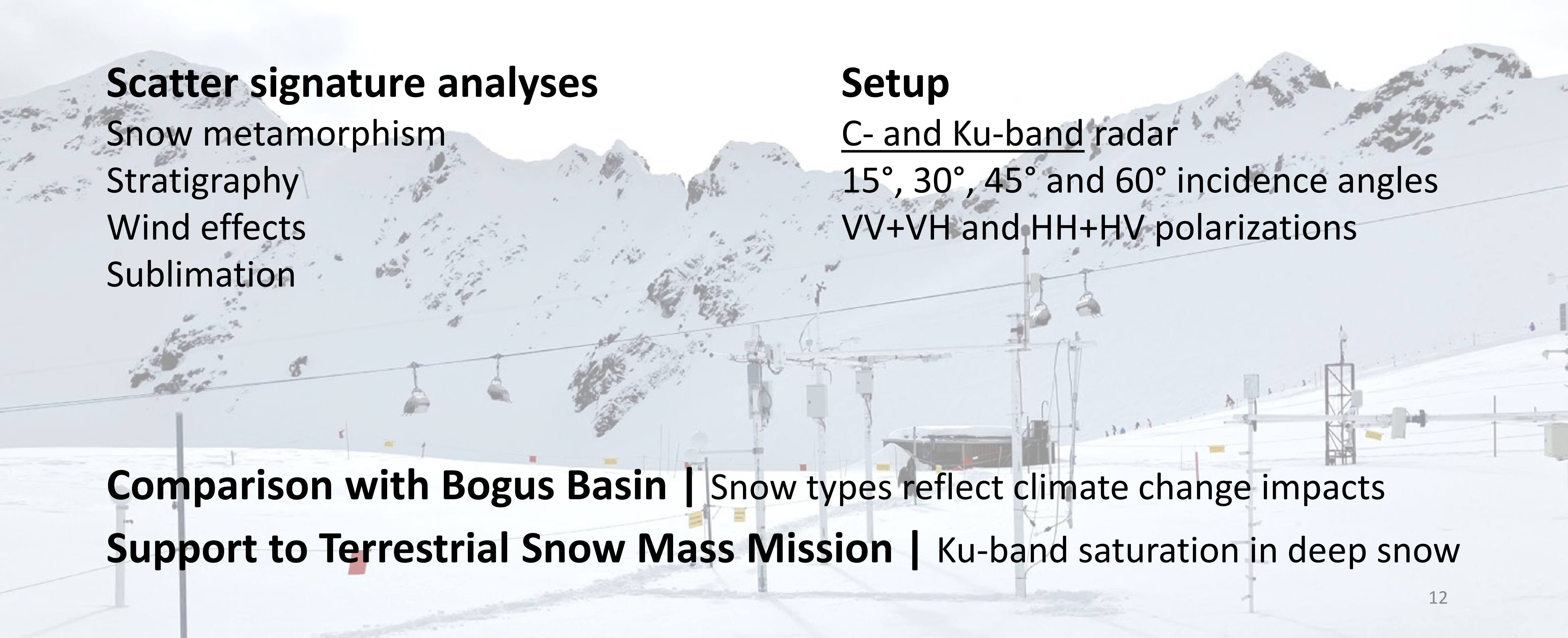


Scatter signature analyses
Snow metamorphism
Stratigraphy
Wind effects
Sublimation

Setup
C- and Ku-band radar
15°, 30°, 45° and 60° incidence angles
VV+VH and HH+HV polarizations

Comparison with Bogus Basin | Snow types reflect climate change impacts

Support to Terrestrial Snow Mass Mission | Ku-band saturation in deep snow

WP3: Field experiments

	Sensors	Soil	vegetation	snow	atmosphere
FERM	**C-band, L-band** Hyperspectral camera Lidar Drone radar (L-band) GNSS-R (L-band)	**Soil moisture**: 5, 30, 50, 100 cm **Temperature**: 5, 30, 50, 100 cm **Surface roughness**: pin-profiler Rhizosphere probes (TDR, tensiometers) Deep geophysical monitoring (ERT electrodes)	**Interception**: leaf water mass per 20 cm (conductance) **LAI and biomass**: manual sampling Ecophysiological: fluorimeter, Infrared gas analyzers, GreenSeeker, psychrometer, sap flow probes Minirhizotron cameras and tubes Solid isotope analyzer (13C, 15N), Nitrogen analyzer, Water isotope analyzer (d18O, dD)	NA	**Evaporation**: Eddy covariance **Weather station**: precipitation, air temp, wind speed & direction, relative humidity, pressure, etc.
Bogus Basin	**C-band, Ku-band** Hyperspectral camera Snow depth laser Helicopter radar	**Soil moisture**: 5, 30, 50, 100 cm **Temperature**: 5, 30, 50, 100 cm **Surface roughness**: pin-profiler	**Interception**: leaf water mass per 20 cm (conductance) **LAI and biomass**: manual sampling	**Snow pits**: depth, density, temp, grain size & shape, hardness, liquid water, stratigraphy SNOTEL station: depth, SWE, soil temp, soil moisture	**Evaporation**: Eddy covariance **Weather station**: precipitation, air temp, wind speed & direction, relative humidity, pressure, etc.
Weissfluhjoch	**C-band, Ku-band** GPS Webcam	**Surface roughness**: pin-profiler	NA	**Snow pits**: depth, density, temp, grain size & shape, hardness, liquid water, stratigraphy Snow stratigraphy (SMP) Snow scale & pillow Snow temperature profile (IMIS station)	**Evaporation:** lysimeter **Weather station:** IMIS automated measuring station Double Fence Intercomparison Reference (DFIR) precipitation gauge Laser disdrometer (precipitation type and intensity)

WP4: Modelling

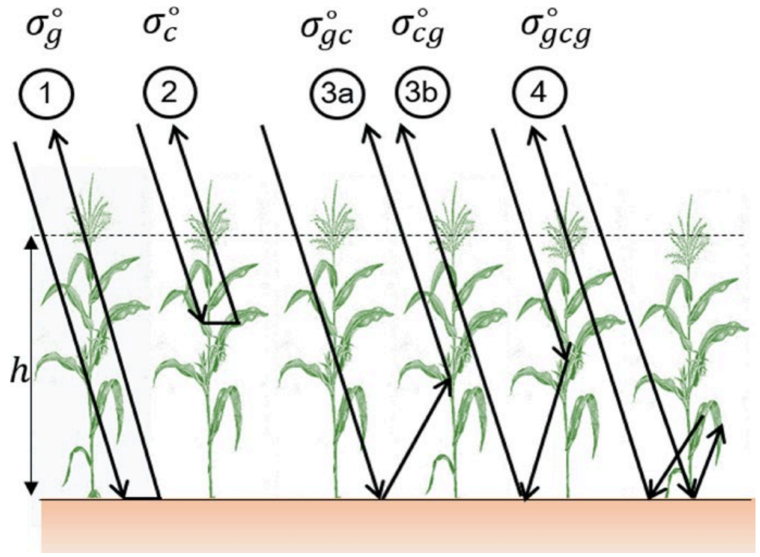
Direct retrievals of SSM, VOD, SWE

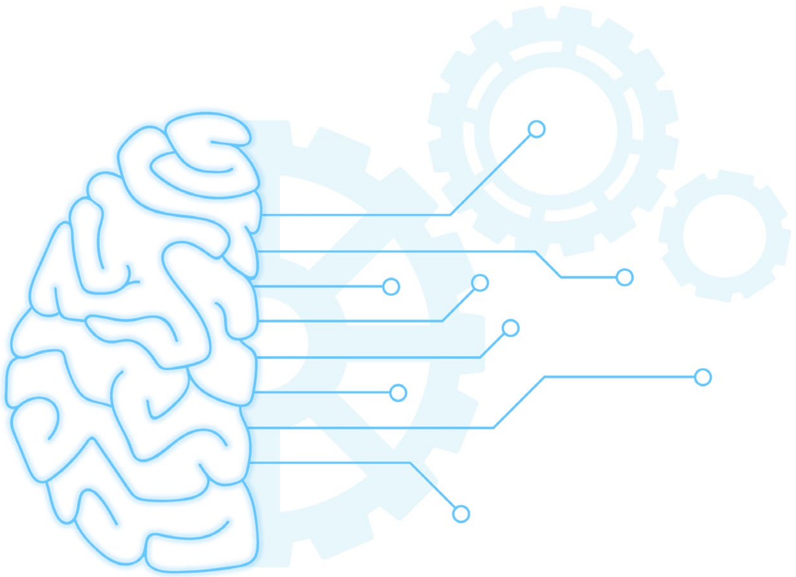
- Radiative Transfer Models for soil, vegetation and snow
- Machine learning algorithms
  - Neural networks
  - Boosting methods

Indirect retrievals of RZSM and E

- GLEAM: Global Land Evaporation Amsterdam Model
  - Simulates water balance and evaporation components
  - Assimilation of SSM, VOD, SWE

Input & validation data: in situ measurements at tower sites





Greetings from our team

UGENT

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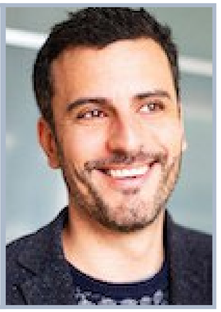

? PhD 4yr

? Postdoc 1yr

Coordination – Machine learning – GLEAM data assimilation

UCL

Sébastien Lambot

? PhD 4yr

Soil RTM

BSU

Hans-Peter Marshall

Snow RTM

TUD

Susan Steele-Dunne

Vegetation RTM

KUL

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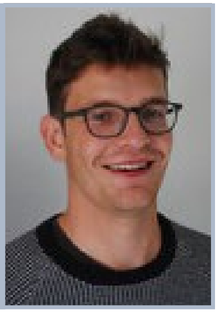

Radar sensors

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Conclusions:

- Detailed radar remote sensing insights for highly-dynamic processes in hydrosphere, biosphere and cryosphere
- Opportunity to improve monitoring of 5 ECVs (SSM, RZSM, VOD, SWE, E)
- Detailed appraisal of current (e.g., Sentinel-1) and prospective (e.g., SLAINTE, ROSE-L, Hydroterra, TSMM) radar satellites
- Reference dataset for development of RTM and retrieval algorithms for soil, vegetation, snow

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