



ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

IDEAS-QA4EO

Snow product calibration and validation

+ FMI Sodankylä snow Cal/Val Infrastructure

Kari Luojus, Matias Takala, Cemal
Tanis, Juha Lemmetyinen, Anna Kontu,
Roberta Pirazzini
+ FMI personnel in Helsinki & Sodankylä

24.2.2020



Outline

1. Validation of satellite-based snow products (ESA SnowPEX)

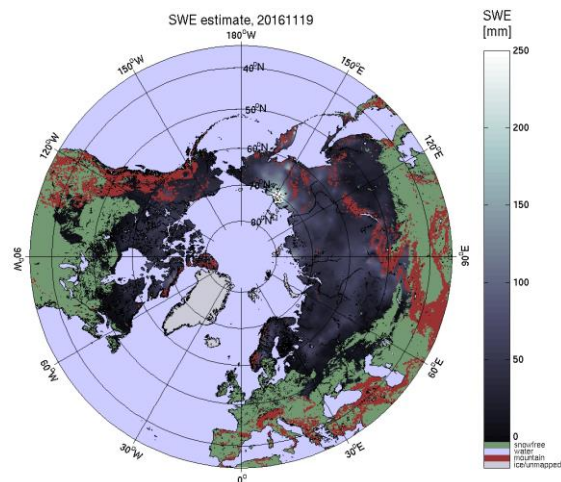
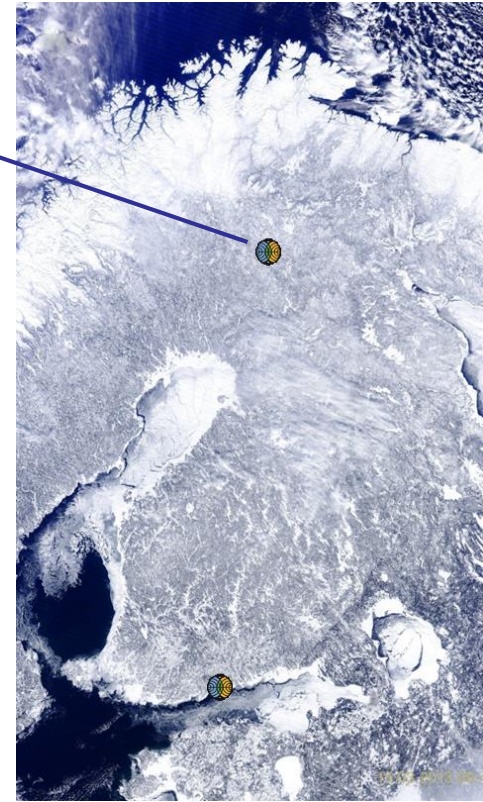
- Snow Cover Extent (SCE), Snow Water Equivalent (SWE)

2. Sodankylä Cal/Val Super-site

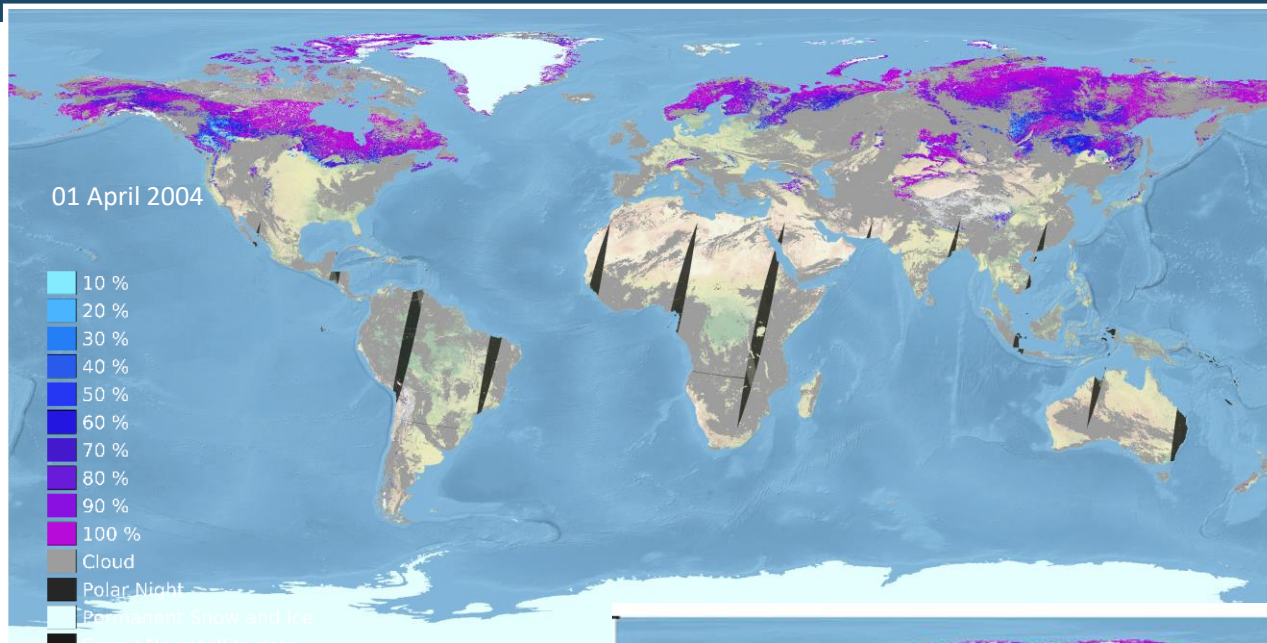
- Wealth of measurements on snow + other parameters
- Reference instrumentation for satellite sensors

3. Utilization of web-cam images for validation of snow products

Sodankylä



ESA Snow CCI SCF prototype products

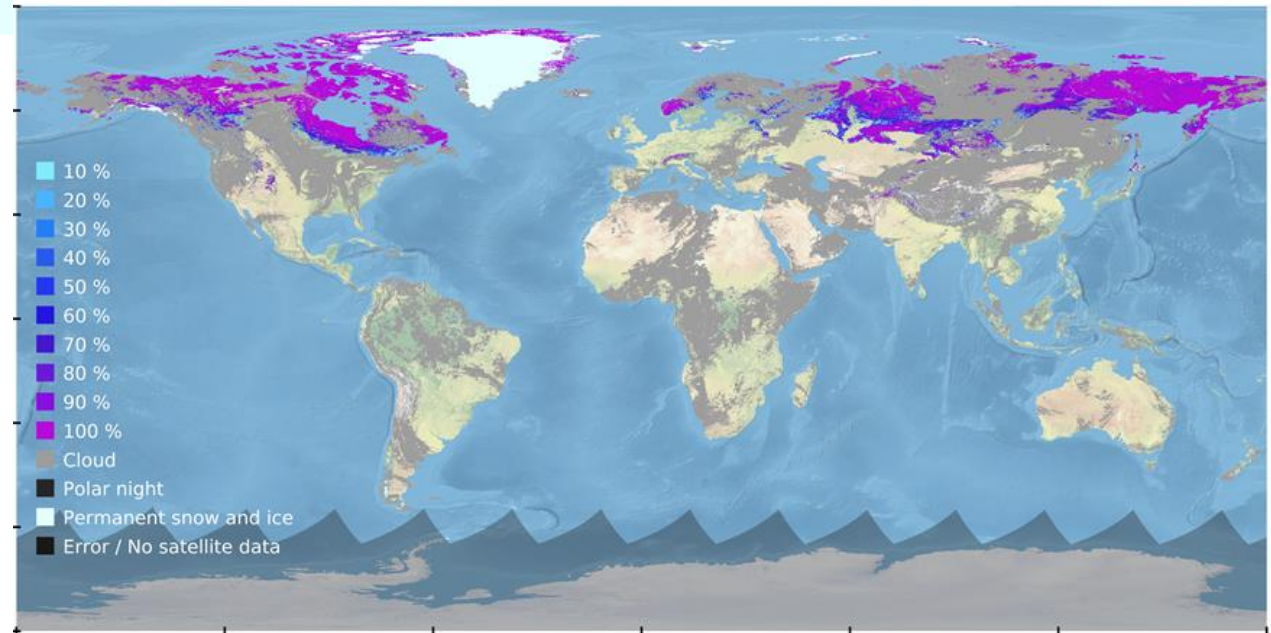


AVHRR 5km

Time series: 1982-2018

MODIS 1km

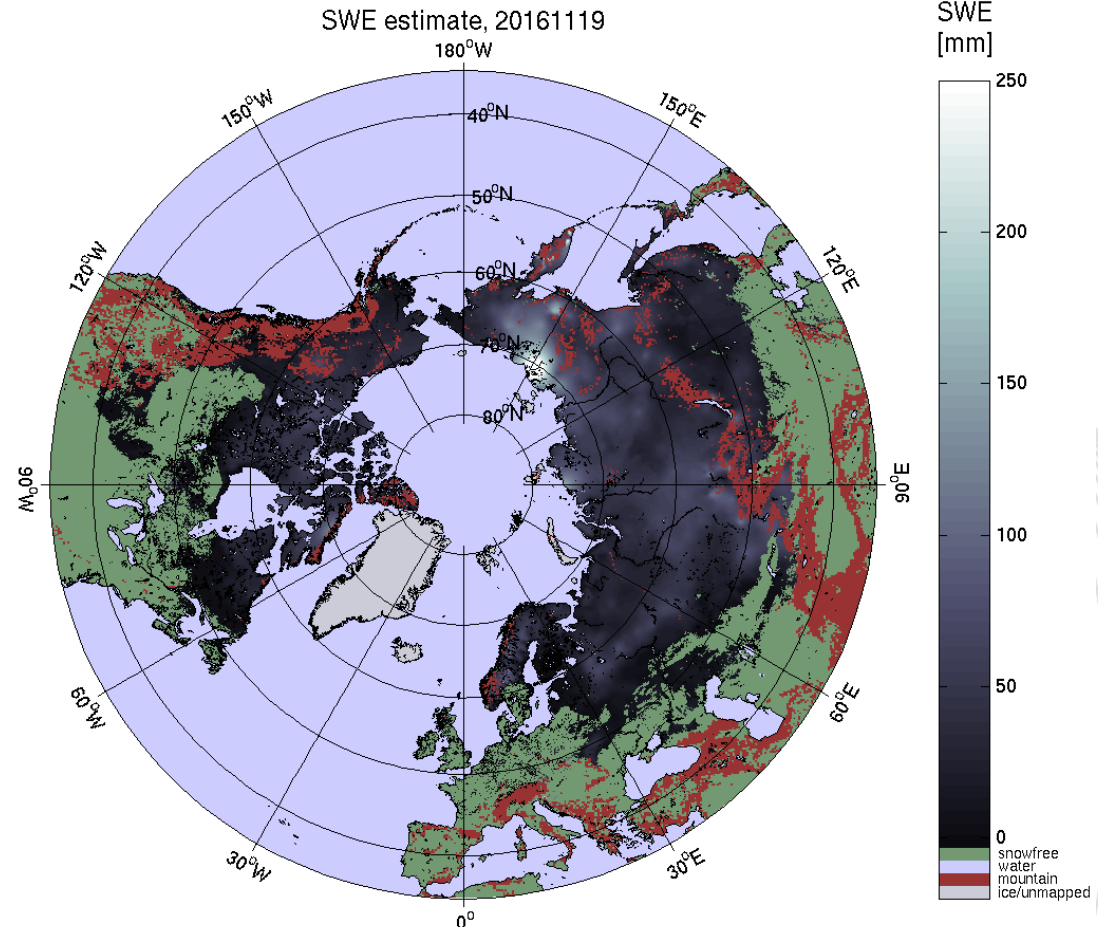
Time series: 2000-2018





40 year-long CDR time-series on snow conditions of Northern Hemisphere (ESA GlobSnow / Snow CCI SWE)

- First time reliable daily spatial information on SWE (snow cover):
 - Snow Water Equivalent (SWE)
 - Snow Extent and melt (+grain size)
 - 25 km resolution (EASE-grid)
 - Time-series for 1979-2019
- Passive microwave radiometer data combined with ground-based synoptic snow observations
 - Variational data-assimilation
- Greenland, glaciers & mountains masked out
- Openly available (FTP / CCI portal)



ESA SnowPEX (2014-2018)



ISSPI-1 WS July 2014



ISSPI-2 WS Sep 2015

SnowPEX Activities

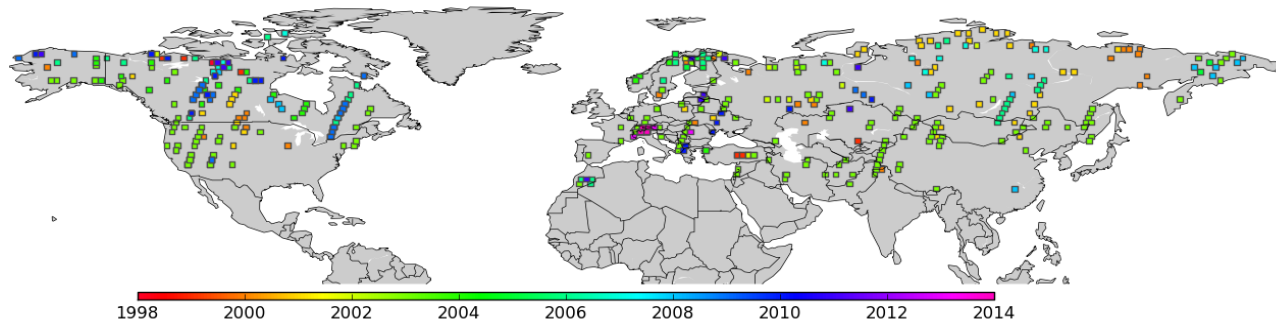
- **Intercompare** and **evaluate** global / hemispheric (pre) operational **snow products** derived from different EO sensors and generated by means of different algorithms, assessing the product quality by objective means.
- Evaluate and intercompare temporal **trends of seasonal snow parameters** from various EO based products in order to achieve well-founded **uncertainty estimates for climate change** monitoring.

SnowPEX Reports are publicly available, publications coming

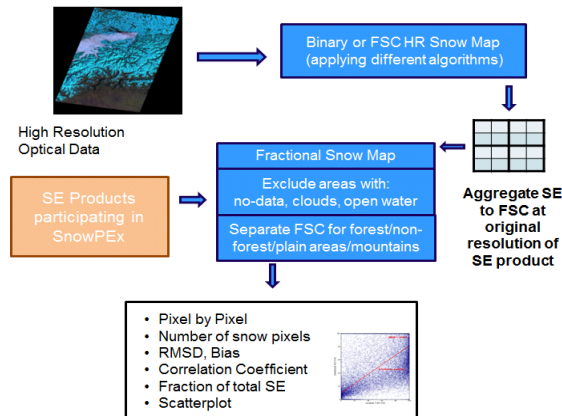


Validation of SCE products – different approaches

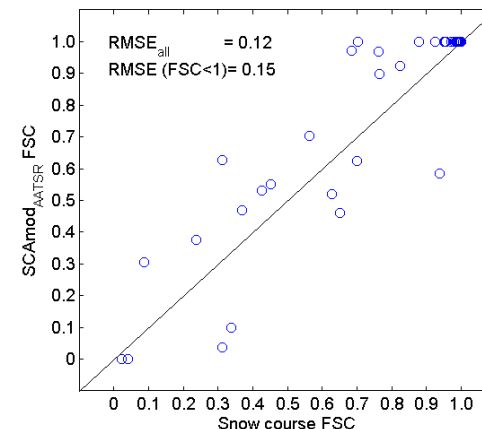
Validation using High resolution (S-2/Landsat) reference data



Intercomparison of Snow products



In-situ validation:
Snow courses / synop SD data

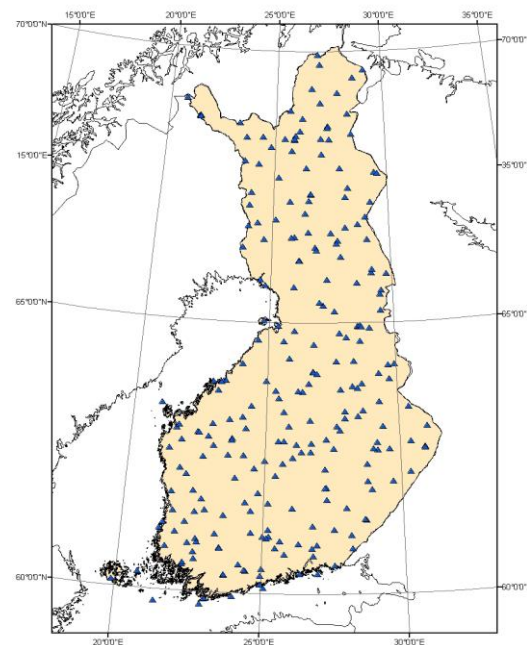
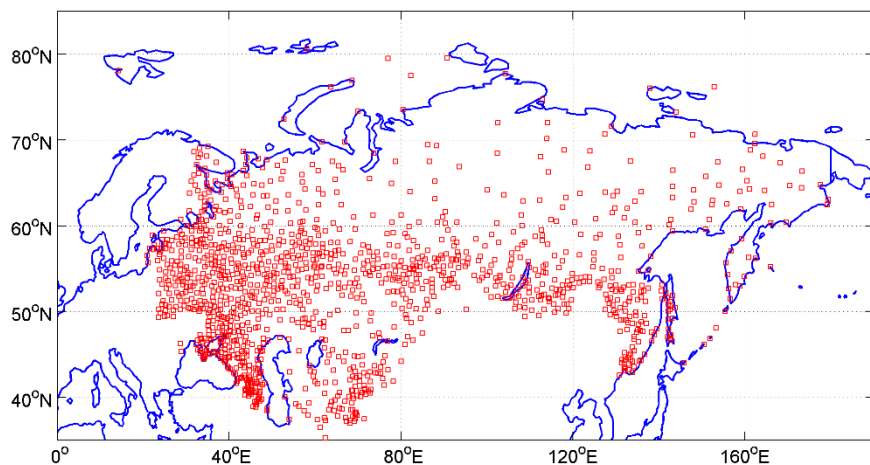




Reference data – snow transects

- Russia, a total of 1346 snow transects
- Finland, 100+ national snow courses
- Vast geographical domain with diverse conditions

The snow transect reference data from Russia



- Point-wise measurements can not be used for validation of coarse resolution SWE products

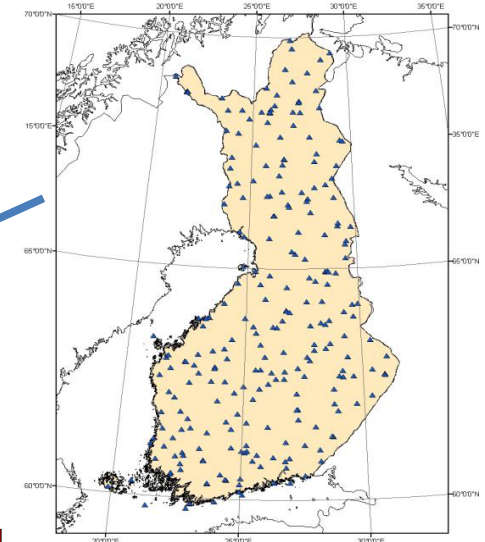
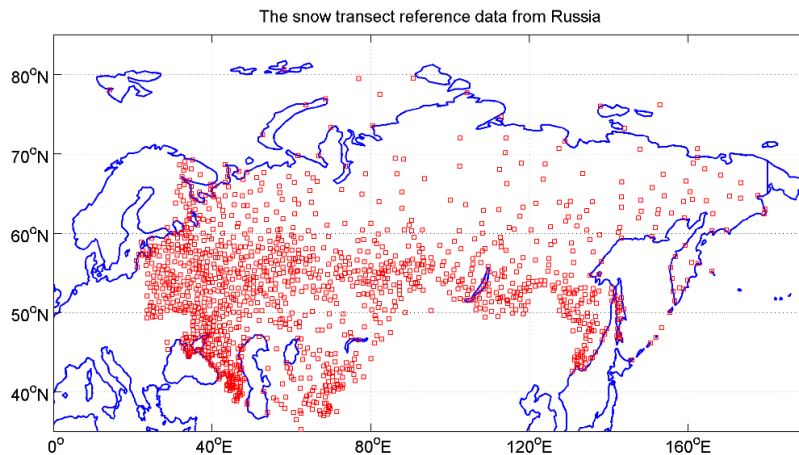




Validation of satellite-based coarse resolution SWE products

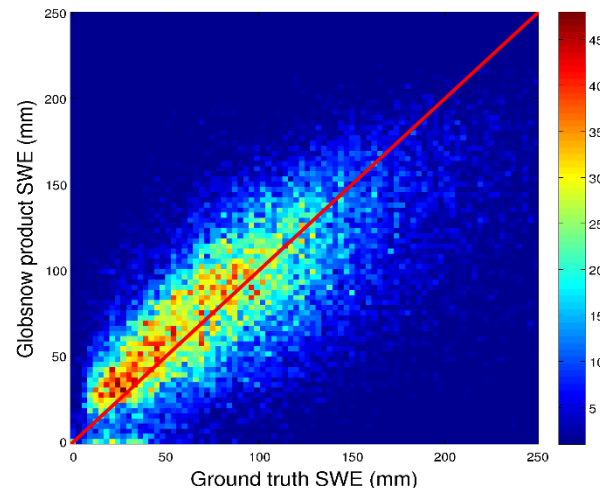
Russia: 1300+ snow transects from a vast geographical domain & diverse conditions

Finland: 100+ snow courses



SWE
retrieval
accuracy

SWE product accuracy can be determined from an independent & diverse multi-decadal reference dataset across NH



ESA SnowPEX (2014-2018)



SnowPEX Achievements & potential next steps

- **Protocols and best practices** for evaluating and validation satellite-based snow product were established with the international snow remote sensing community, focus on Snow Cover Extent (**SCE**) and Snow Water Equivalent (**SWE**)
- **Intercomparison tools** were developed and **validation datasets** collected
- Further potential work:
 - Make the validation tools available for the snow remote sensing community
 - Make the reference datasets available for the wider community
 - Continuation to the efforts, partly within ESA SnowPEX CCN (upcoming in 2020?)

Outline

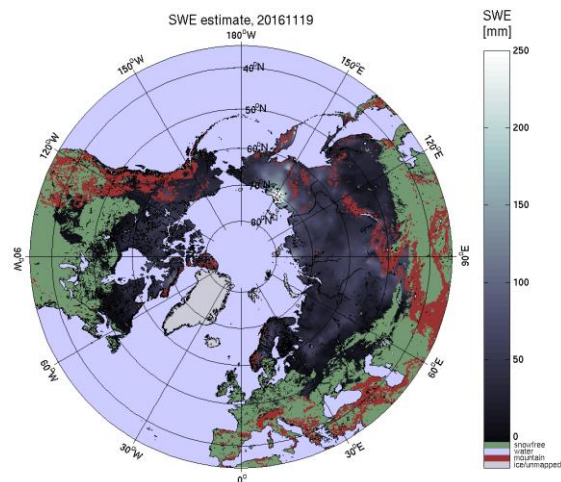
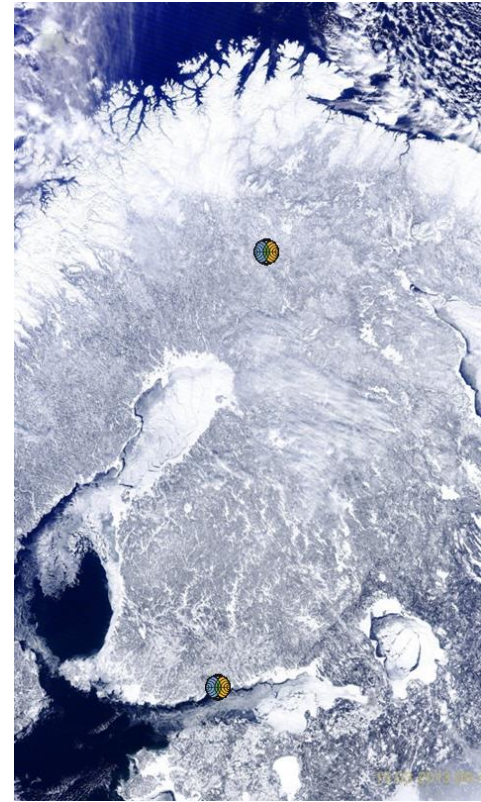
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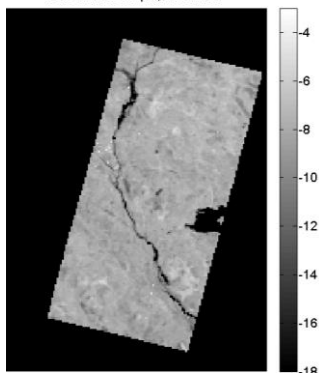




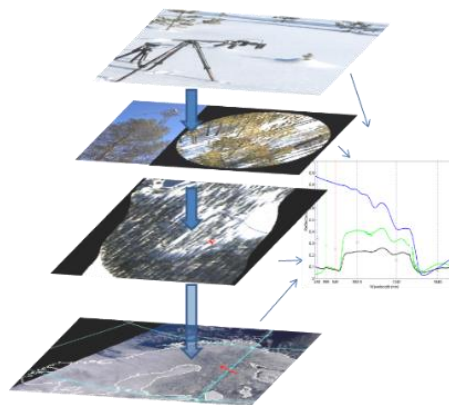
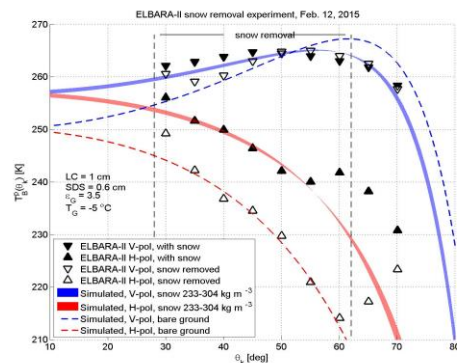
EXPERIMENTS



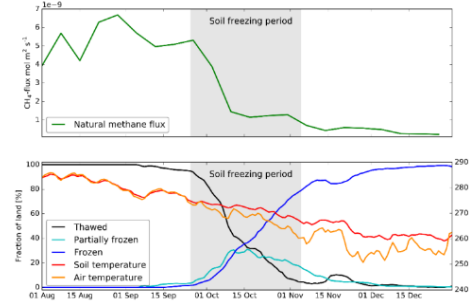
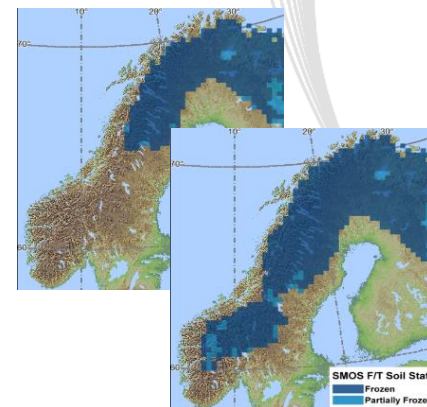
TerraSAR-X VV-pol, 20101105

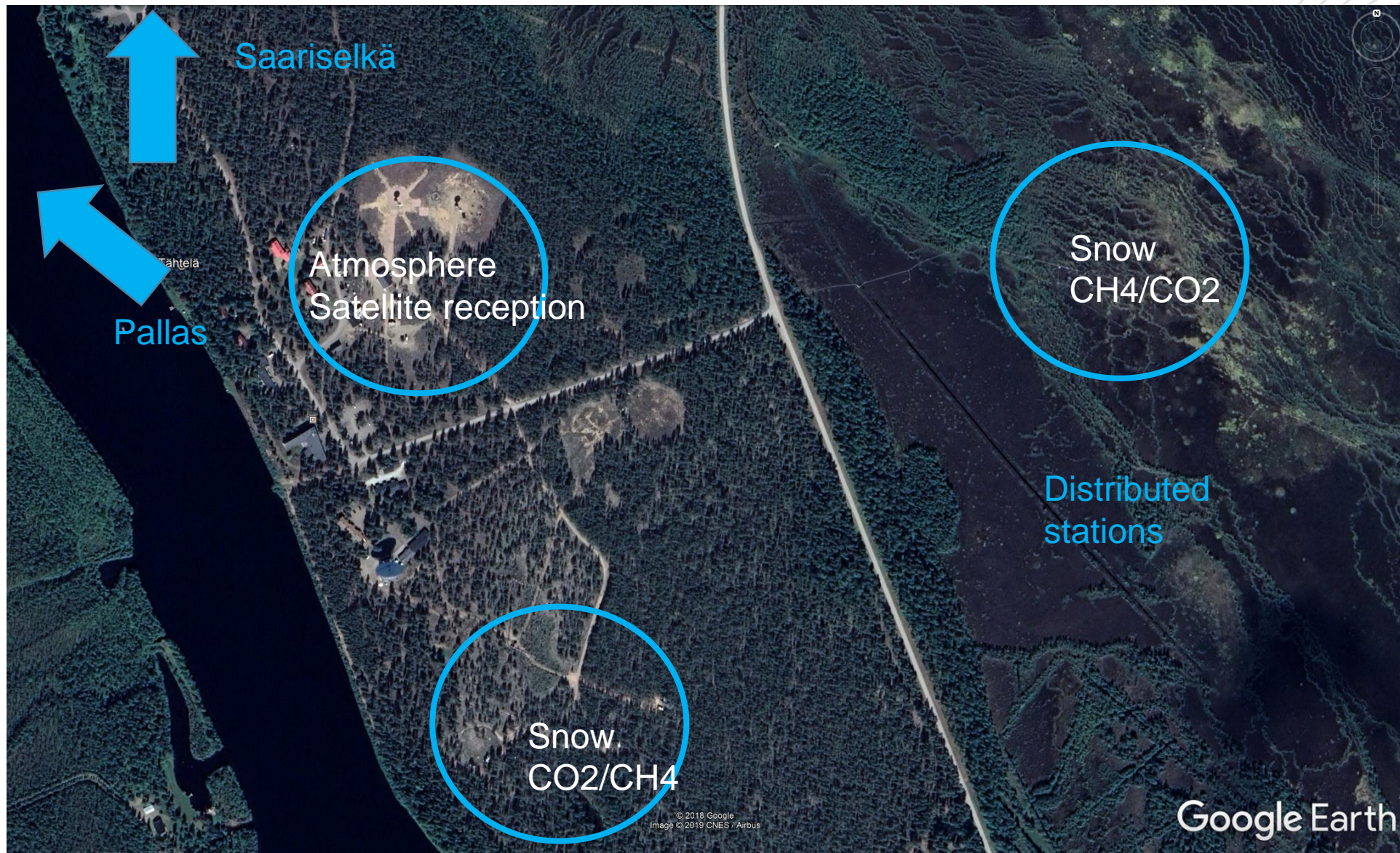


FORWARD MODELS



APPLICATIONS



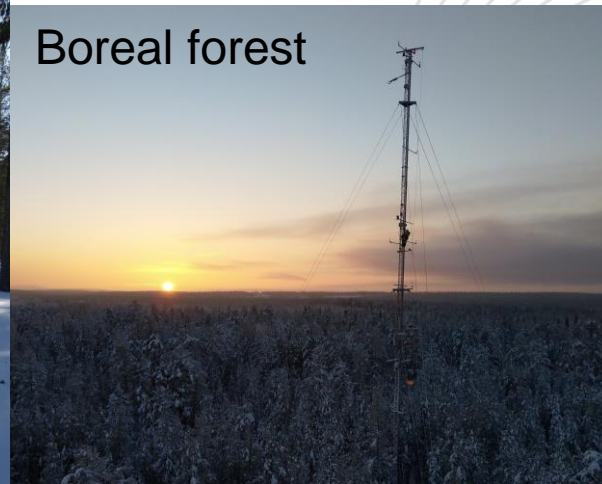




Saariselkä tundra



Boreal forest



Bog site



Freshwater areas

Experiments

Season-long observational datasets using ground based Cal/Val instruments

- Multi-frequency **microwave radiometry**
- Multi-frequency **microwave radar**
- Multi-band **optical spectrometry**

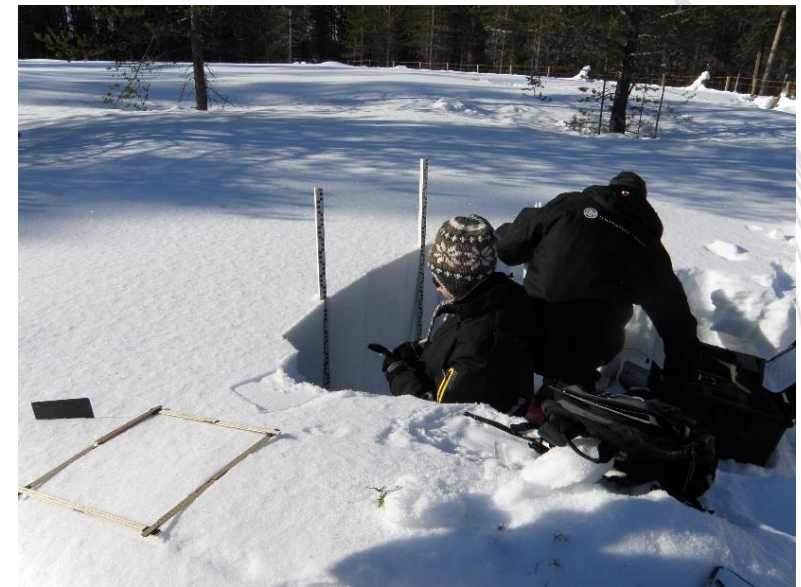
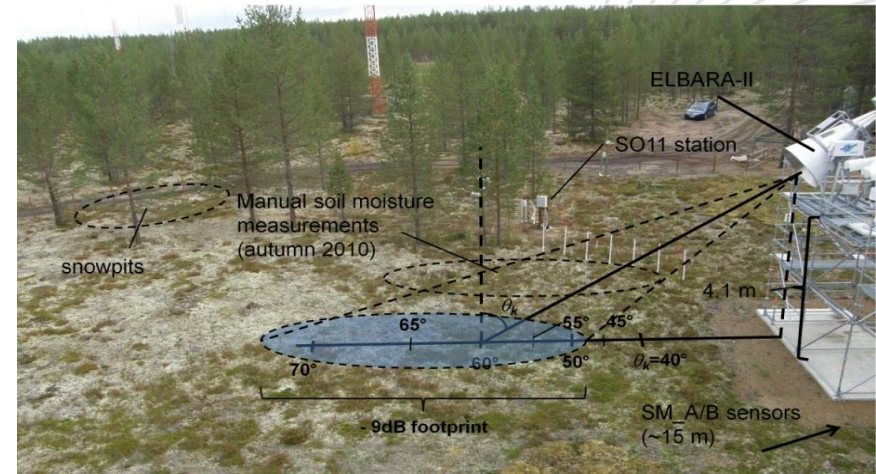
Focus areas

- Snow cover properties (SWE, reflectance)
- Soil dynamics (soil freezing/thawing, soil moisture)
- Forest canopy properties (for removal from satellite observations)

Support by relevant ancillary data

- constantly developing automated instrumentation
- manual soil and snow survey program
- dedicated campaign activities (ground-based, airborne)

Most instrumentation based at FMI Sodankylä Arctic Research centre





Sodankylä radiometer systems (SodRad)

Sodrad 1:

- Reference instrument for
- AMSR-E, SSMIS 10.65, 21, 18.7, 37 GHz
- Dual pol
- Azimuth/elevation scanning
- Operated since 2009 (continuous time series in winter)

Main applications:

- Snow cover
- cal/val

Sodrad 2:

- high frequency configuration (e.g. AMSU)
- 90, 150 GHz
- azimuth/elevation scanning
- Dual pol
- operated since 2013

Main application:

- atmosphere water vapour, precipitable water



Manufacturer: RPG GmbH



ELBARA-II

ESA reference instrument for SMOS

- 1.4 GHz, dual pol
- Operated at FMI-ARC since 2009; uninterrupted time series
- 2009-2012 mineral soil site
- 2012 – 2015 wetland site
- 2016-2018 mineral soil site (+vegetation canopy measurements)
- 2018 – (forest vegetation measurements)

Main application areas

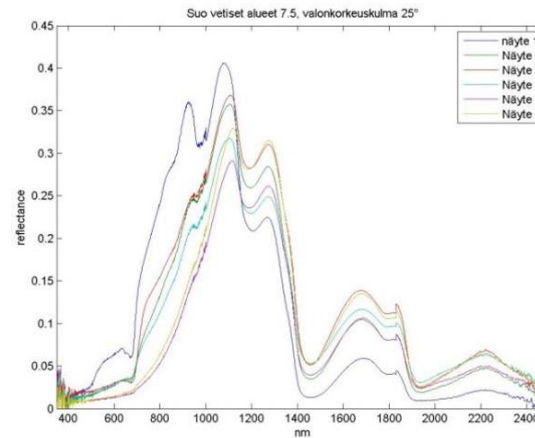
- soil moisture
- soil freezing





Spectrometry

- ASD FieldSpec Pro Jr
 - VIS and NIR spectrum, 350-2500 nm
Installed in a 30 m mast,
measures forest and open area
 - Similar instrument used in field and
dark room laboratory
measurements
 - Since 2006
- RIKOLA Hyperspectral Camera
 - 500-900 nm
 - UAV-capable
 - Since 2018
- Applications: snow cover, vegetation
(NDVI; relation to biochemical
processes)





Sodankylä Synthetic Aperture Radar (SodSAR)

- FM-CW radar with full polarimetric capacity
- Based on commercial VNA system (Agilent FieldFox) with RF front-end for radar use
- Current design covers 1-10 GHz (update in 2020 to 1-18 GHz)
- VV, VH, HV, HH
- Design and implementation: Harp Technologies, Finland
- 3-axis pointing device and 5 m displacement rail (SAR imaging capability)
- Current installation on 21 m platform overlooking sparse coniferous forest

Main application:

- Soil, snow and forest vegetation investigations
- Satellite cal/val (Sentinel-1, TerraSAR-X, Cosmo-SkyMed)
- Synergistic L, X-band active/passive observations with radiometer systems





ICOS tower

- At present houses most of FMI remote sensing equipment
- 24 m high platform
- Heated shed
- Setup following ICOS (Integrated Carbon Observing System) standards
 - CO₂ flux, meteorological measurements, surface measurements
- RS equipment in tower:
 - ELBARA II (1.4 GHz)
 - High frequency radiometers (10.65, 18.7, 21, 37 GHz)
 - Radar (1-10 GHz)
 - Hyperspectral camera (optical & IR)
 - Cameras
- Site *in situ* observations:
 - Soil moisture and temperature
 - Tree trunk diameter variations (dendrometers)
 - Tree trunk temperature
 - Tree permittivity
 - Frost tubes





Radar (scatterometry)
L-band radiometer

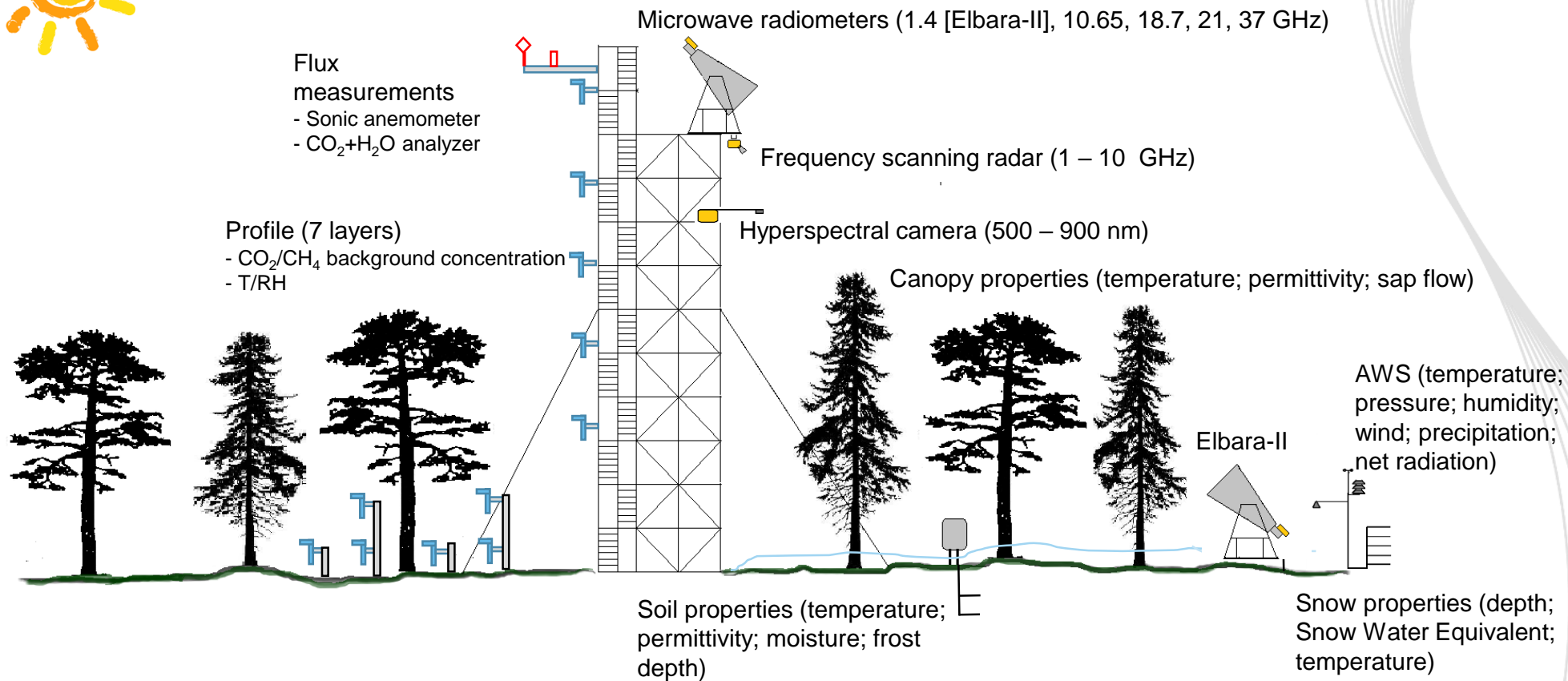
The image shows a vast, snow-covered forest under a twilight sky. A tall, metal research tower stands in the center. Three semi-transparent colored polygons are overlaid on the forest: a blue one on the left, a yellow one on the right, and a light green one at the bottom. The blue polygon is labeled 'Radar (scatterometry) L-band radiometer', the yellow one is labeled 'High frequency radiometers', and the light green one is labeled 'All instruments Radar SAR imaging'.

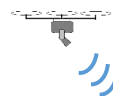
High frequency radiometers

All instruments
Radar SAR imaging



ICOS tower





Measurements: atmosphere

- Soundings, radar, lidar and spectrometry
- Ozone columns and profiles
- CO₂, CH₄ and energy exchange between atmosphere and ecosystem
- Total column observations (CO₂, CH₄, N₂O, HF, CO, H₂O, HDO)
- CH₄, CO₂, CO, vertical profiles
- Precipitation, meteorology
- Radiation

Measurements: dynamic 3D surface quantification

- Continuous 3D laser scanning
- Vegetation state and growth
- Snow cover

Measurements: Satellite cal/val

- Ground-based, drones and sounding
- Passive microwave (radiometer)
- Active microwave (radar)
- Optical/IR
- Lidar
- Snow cover
- Vegetation & soil processes
- Solar induced chlorophyll Fluorescence
- Atmospheric gases and aerosols
- Radiation
- Meteorological observations



Ecosystem processes (summer)

Water bodies (lake/river)

- CO₂ / CH₄ exchange
- Water level
- Surface temperature
- Sensible and latent heat exchange

Wetland

- CO₂/CH₄ exchange
- Long-term greening
- Plant phenology
- Water level
- Sensible and latent heat exchange

Forest

- CO₂ exchange
- Long-term greening
- Plant phenology
- Soil humidity
- Sensible and latent heat exchange

Ecosystem processes (winter)

Forest

- Snow - soil - forest interactions
- Snow Water Equivalent
- Soil freezing

Wetland

- Snow - soil - vegetation interactions
- Snow Water Equivalent
- Soil freezing

Water bodies (lake/river)

- Snow - ice interactions
- Freezing



Reference measurements

Snow depth, air temperature and humidity

Disdrometer (precipitation type and intensity)

Soil permittivity/temperature/moisture +
Snow temperature

Snow scale (SWE)

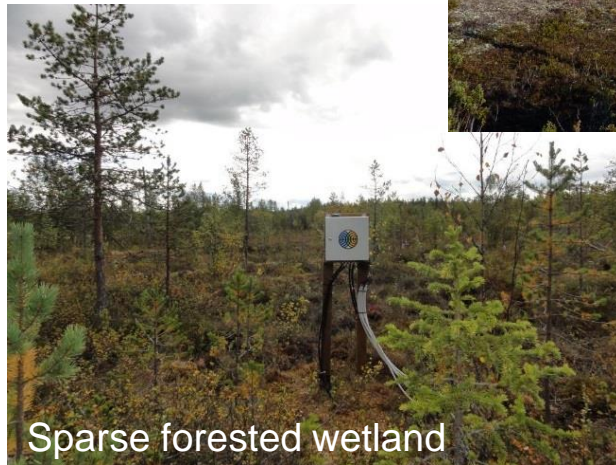




Soil moisture stations



Mixed / spruce forest, thicker organic layer



Sparse forested wetland



Saariselkä tundra site

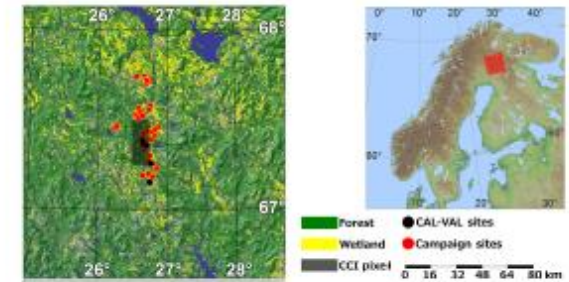


Figure 1. Locations of the Sodankylä study area, FMI's soil moisture CAL-VAL sites, the field campaign measurement sites and the ESA CCI soil moisture data product pixel.

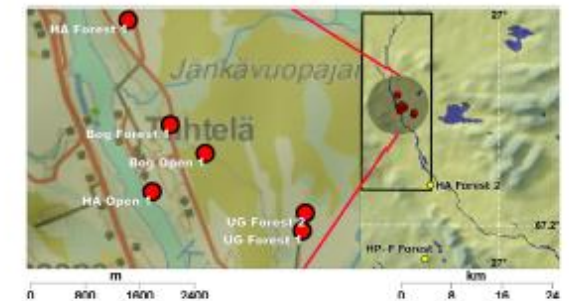


Figure 2. Distribution of FMI's soil moisture CAL-VAL sites within the ESA CCI soil moisture data product pixel. The in situ observation sites indicated in yellow (HA forest 2 and HP-F forest 1) where not included in deriving in situ soil moisture comparison results against the ESA CCI data soil moisture product.



Manual snow survey program

- Weekly snow profiles at several sites
 - Snow stratification (visual, SMP)
 - Grain size (visual, macrophotos)
 - SSA (IceCube)
 - Density and SWE (Snowfork, scale)
 - Temperature
 - Wetness (Snowfork)
- Key for understanding snow interactions with EO at all wavelengths





Intensive Field campaigns 2019 & 2020

Sodankylä "Arctic bog" 68°N

8 weeks of intense snow observations in **2019** (18.3-12.4) and **2020** (16.3-9.4) at the Arctic Space Centre, **Sodankylä, Finland** (68.37° N, 26.63° E)

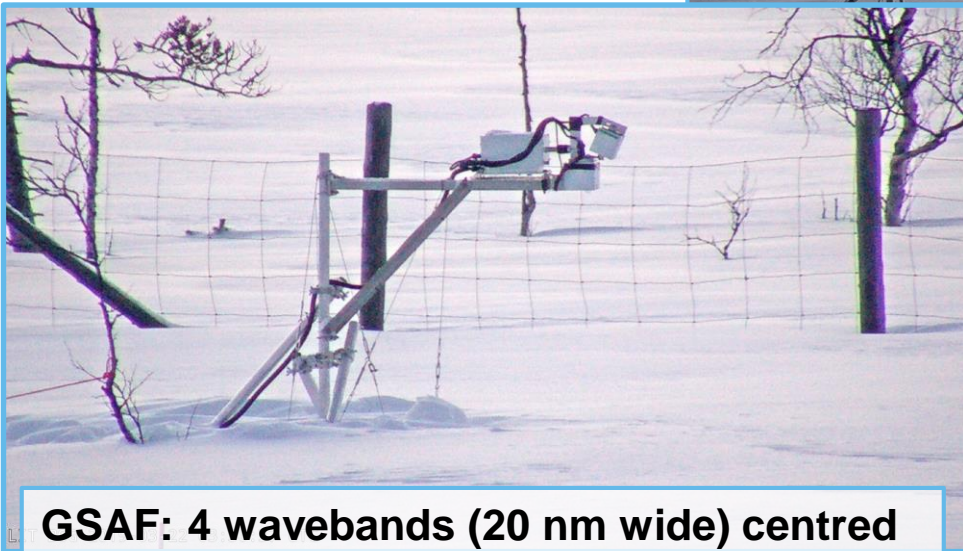




Continuous spectral albedo measurements



SVC-FMI: 350-2500 nm at 3-10 nm resolution (FMI, Finland)



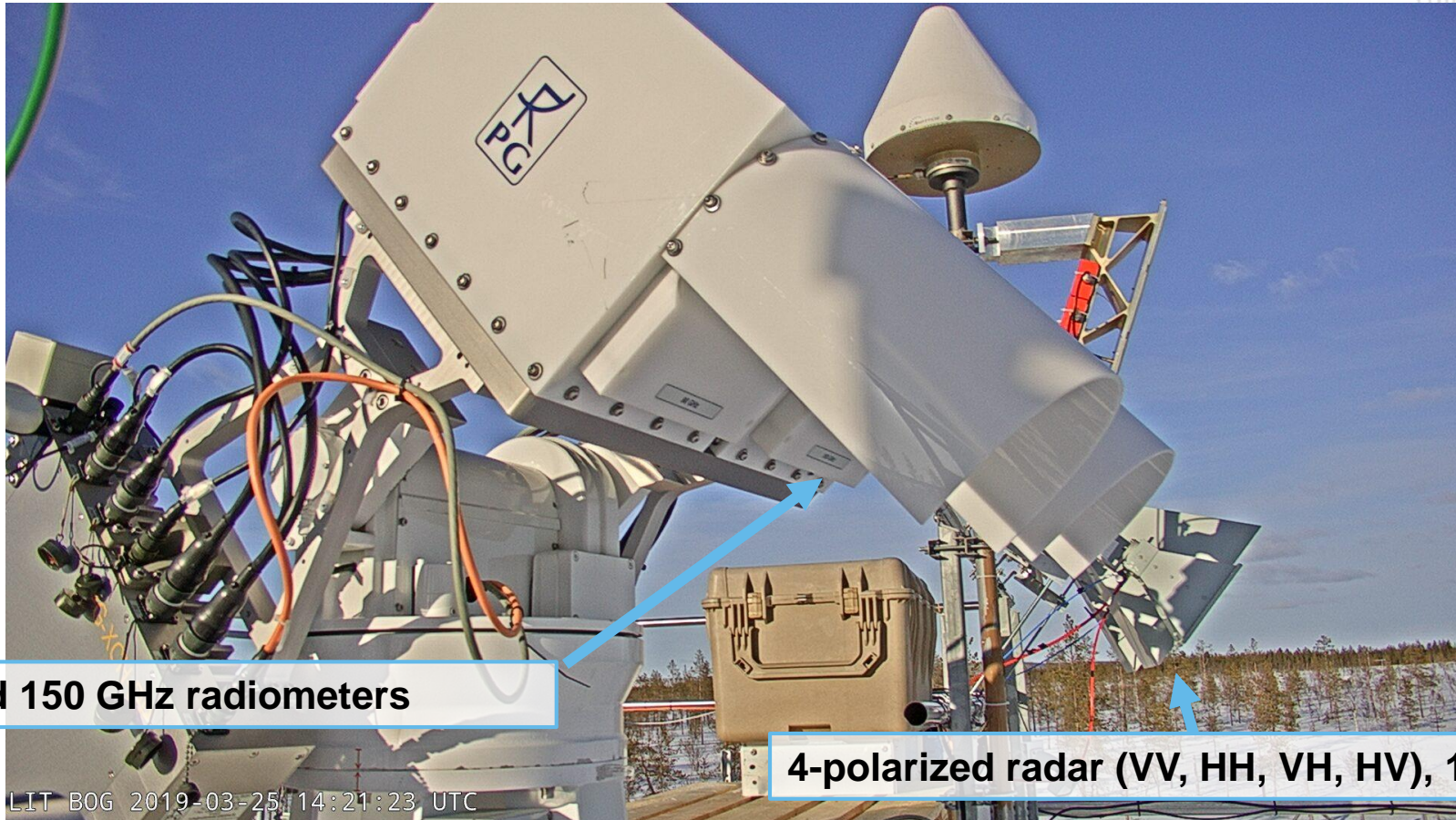
GSAF: 4 wavebands (20 nm wide) centred at 440, 870, 1230, 1600 nm (National Institute of Polar Research, Japan)



Autosolexs: 350-1050 nm, at 3 nm resolution (Université de Grenoble Alps, France)



Continuous active and passive microwave measurements



89 and 150 GHz radiometers

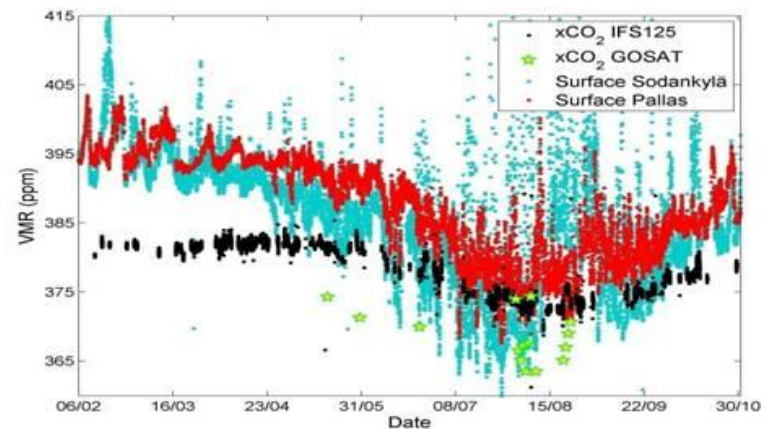
4-polarized radar (VV, HH, VH, HV), 1-9 GHz

LIT BOG 2019-03-25 14:21:23 UTC

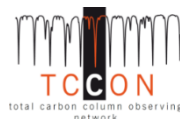
Sodankylä FTS station



- Fourier transform infrared spectrometer
- Primary FTS products:
 - column amounts of CO₂
 - other important GHGs such as CH₄ and N₂O
- Columns can be converted to average volume mixing ratios enabling comparison with surface measurements



Sodankylä FTS



Bruker *IFS 125HR* spectrometer with *A547N* solar tracker.

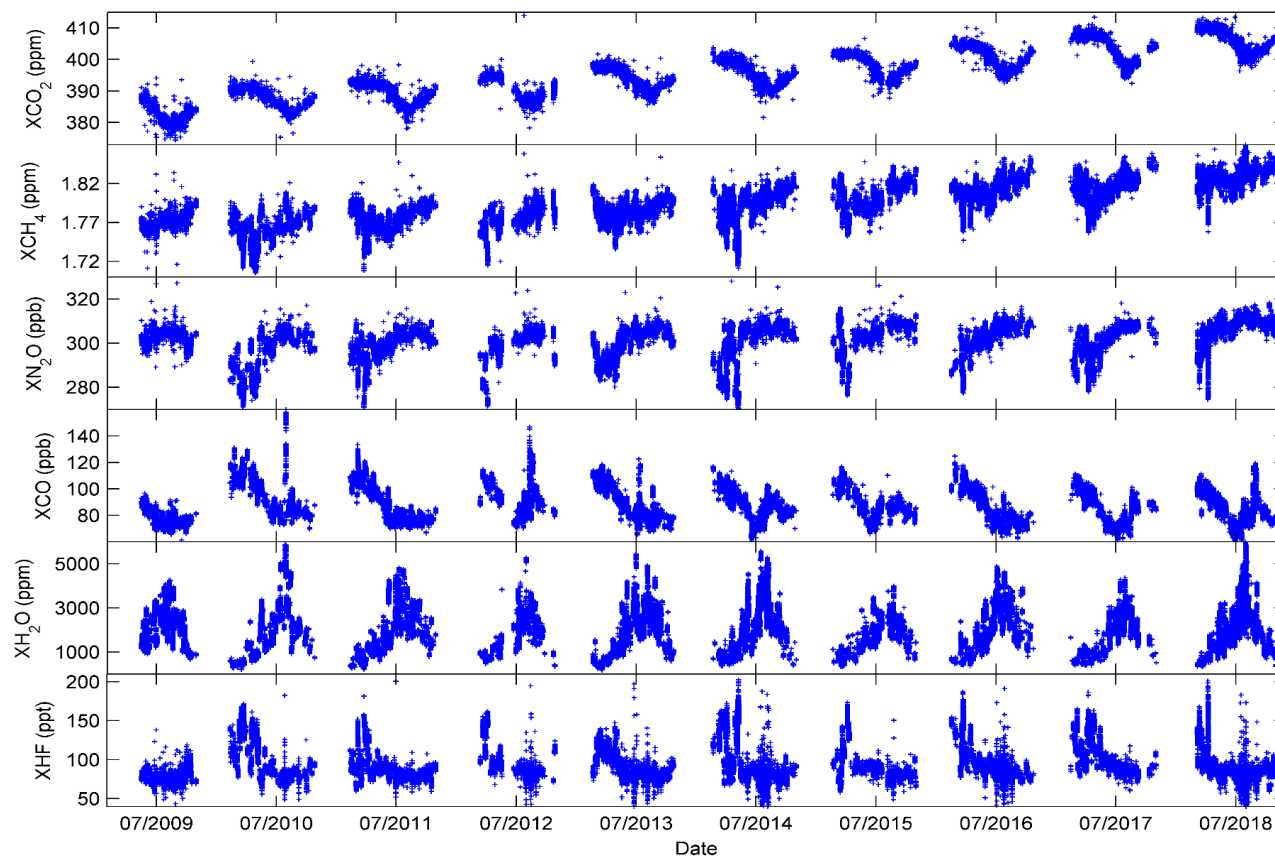
Detectors:

RT-InGaAs: 12800 - 4000 cm^{-1}

RT-Si: 25000 - 9000 cm^{-1}

LN-InSb: 10000 - 1850 cm^{-1}

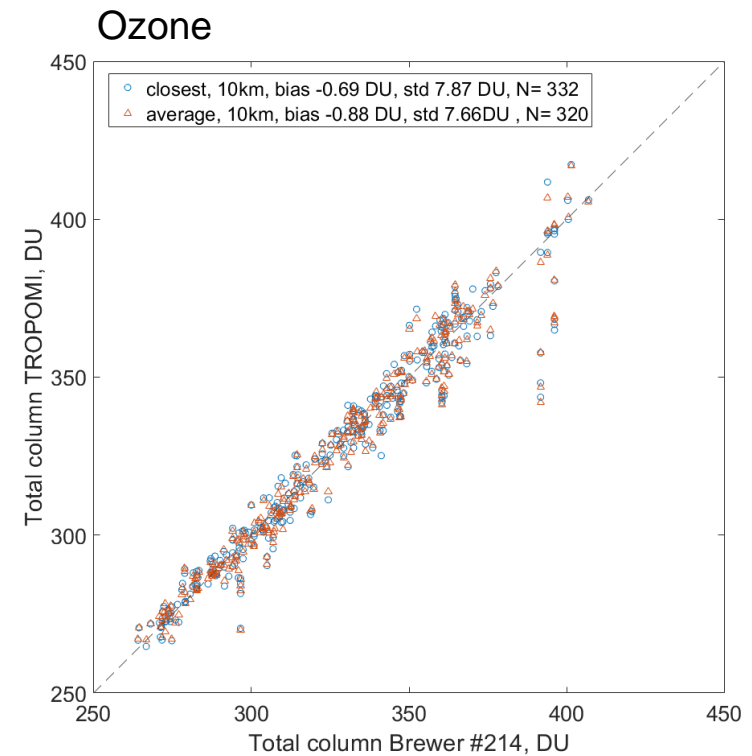
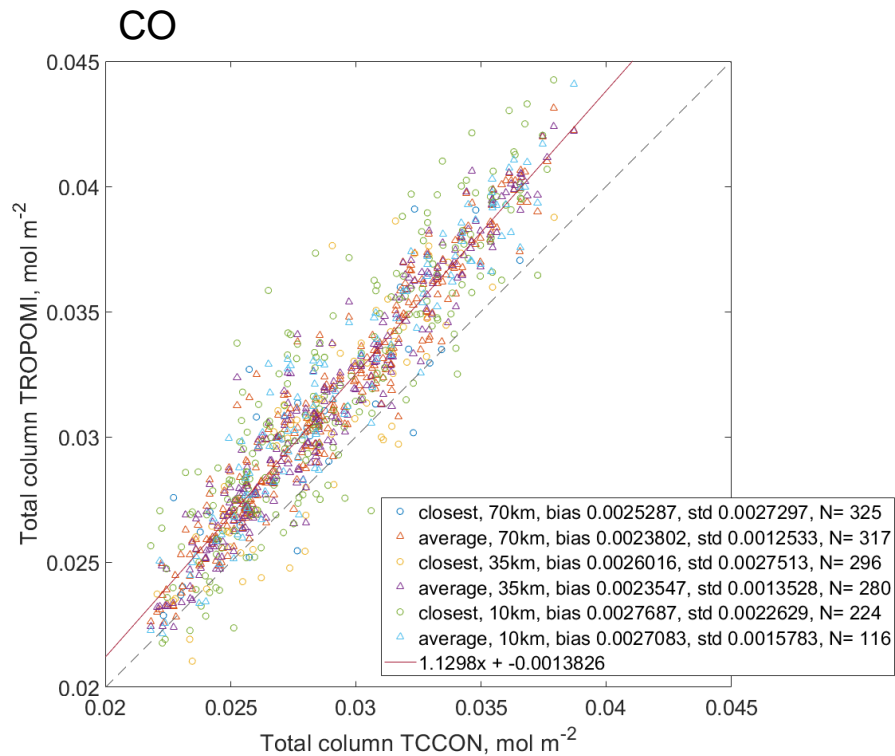
In operation since FEB-2009,
participates in the TCCON network



Sodankylä FTS (Fourier Transform Spectrometer)
measurements from 2009 until end of 2018. Updated from Kivi
and Heikkinen (2016).



Sentinel-5P TROPOMI validation (using FTS & Brewer measurements)

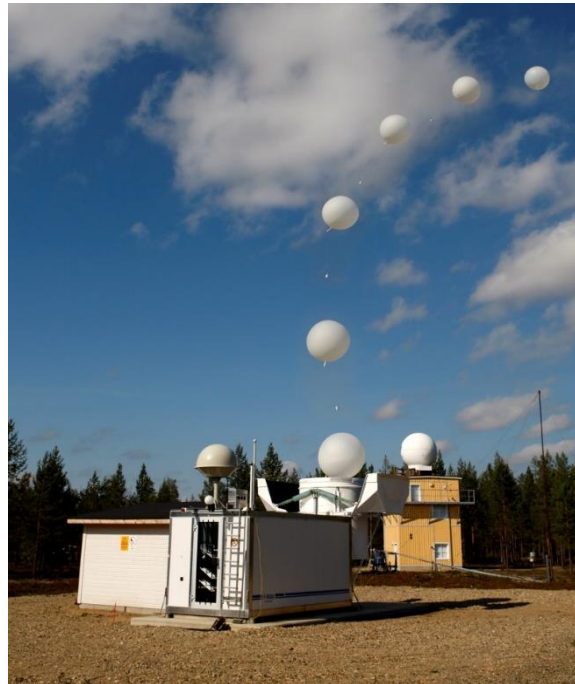


Results from Tomi Karppinen



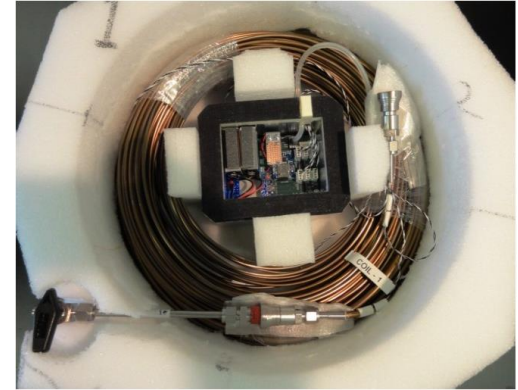
Balloon soundings

- PTU
- Ozone
- Water vapour
- Aerosol
- Radioactivity
- AirCore



AirCore

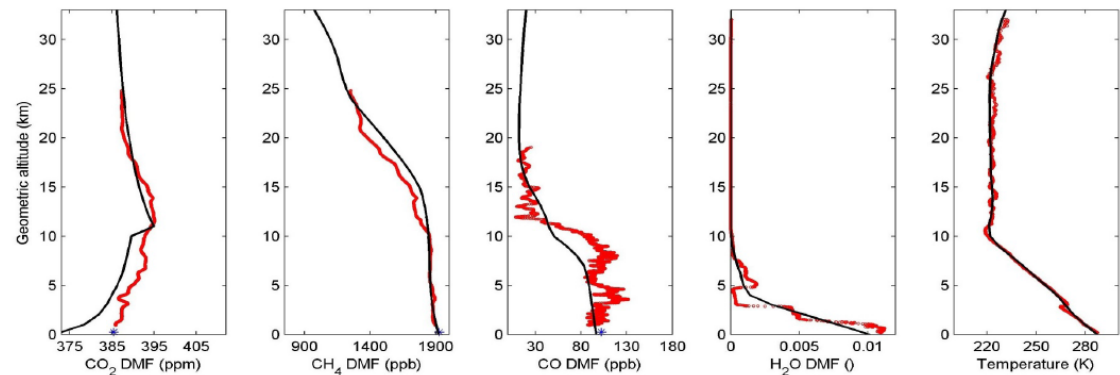
- Atmospheric sampling system to measure vertical profiles of greenhouse gases in the troposphere and stratosphere
- 100 m of stainless tube
- Retrieval, gas analysis
- A priori profile for FTS
- Primarily via balloon
+ drone from 2018



Black line: TCCON a priori

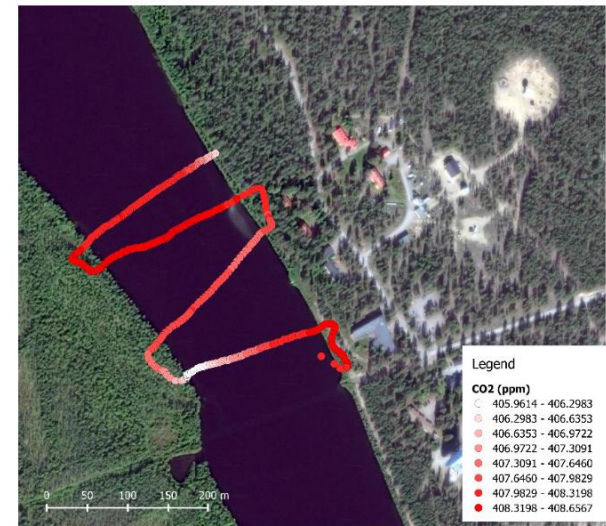
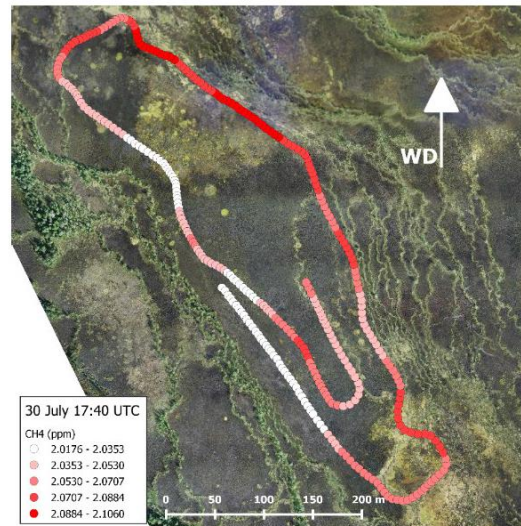
Red dots: AirCore and radiosonde profiles

2013-09-03



Drone-AirCore

- DJI Matrice 600 for load-bearing
- DJI Mavic Pro for aerial photography and mapping
- Load:
 - Max ~6 kg
 - 30 m 1/4" AirCore (<4 kg)
- Measurements in summer 2018



30/7 17:40 17:51 UTC

2/8 7:21 7:23 UTC



Cal/Val summary

Season-long observational datasets using ground based EO Cal/Val instruments

- Multi-frequency **microwave radiometry, scatterometry and SAR**
- Multi-band **optical spectrometry**

Support by relevant ancillary data

- Meteorological observations including radiation measurements (incoming and reflected)
- Snow cover measurements (depth, SWE) with automatic sensors accompanied by a manual sampling programme
- Soil frost, soil moisture (dielectric constant) and temperature profile measurements with a distributed automatic sensor network (Boreal forest-site, wetlands-site, tundra-site)
- Absolute concentrations of CO₂ and CH₄ (Pallas GAW station)
- CO₂ and CH₄ fluxes between different ecosystems and atmosphere
- CO₂ in spruce and pine forests (mineral soil sites) & CH₄ in wetland ecosystems
- Columnar CO₂ and CH₄ measurements through ground-based IR Fourier-spectrometry
- Routine atmospheric soundings (incl. ozone)

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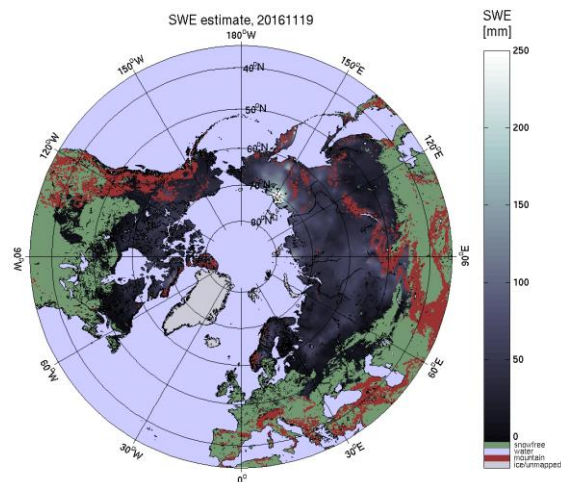
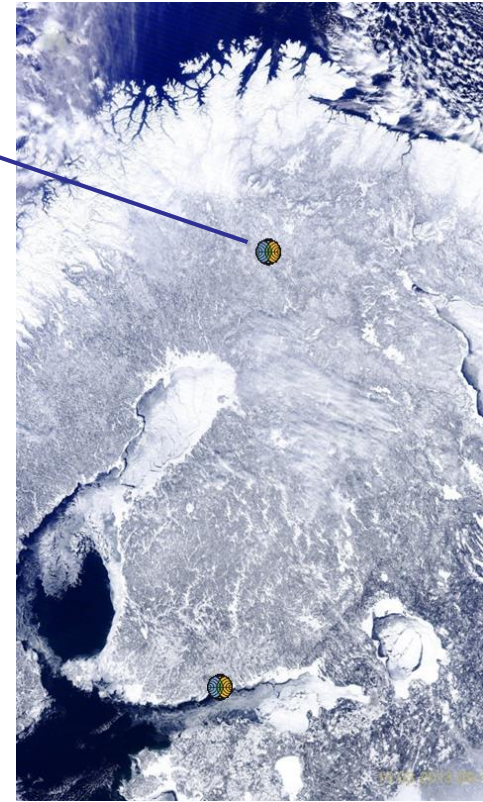
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Sodankylä



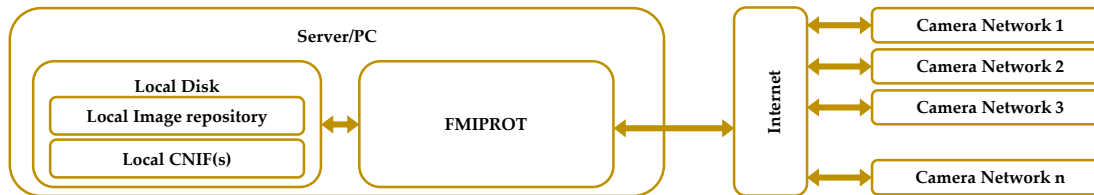


FMIPROT (webcam toolbox)

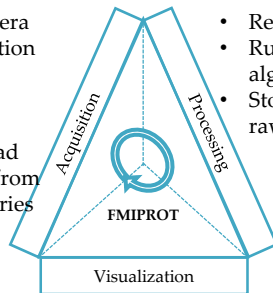
- What?
 - User friendly toolbox to process images from camera networks for research and operational services
- How?
 - Graphical user interface
 - Defining multiple camera networks
 - Automatic image acquisition from camera networks
 - Application of different algorithms on the images
 - Visualization of results
 - Scheduled runs of setup files
- Where?
 - <http://fmiprot.fmi.fi>
 - <https://github.com/tanisc/FMIPROT>



FMIPROT System Concept

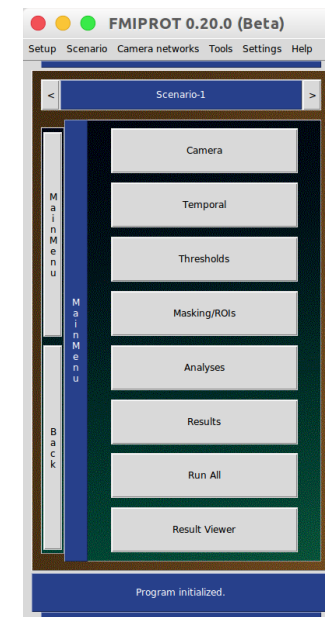
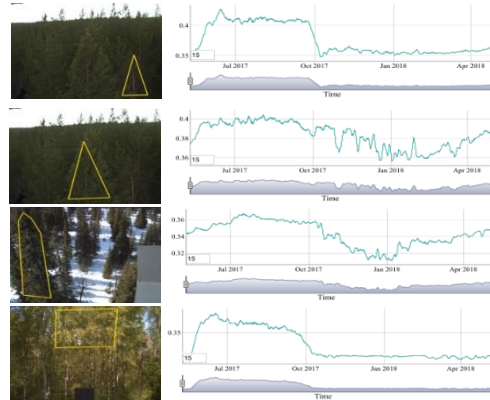


- Get camera information from CNIF(s)
- List and download images from repositories



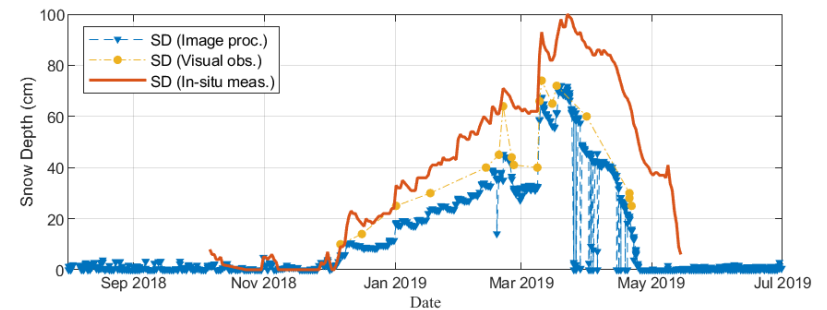
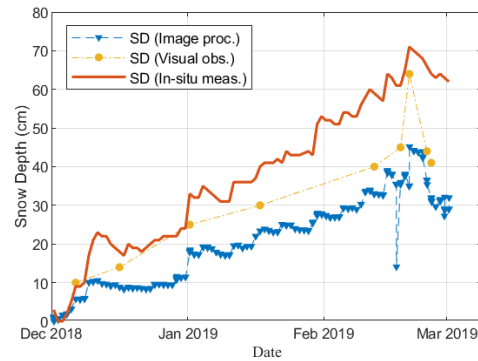
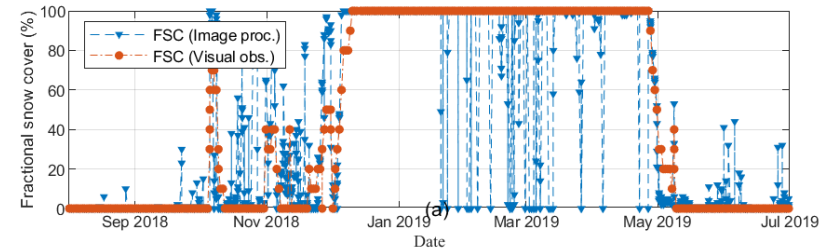
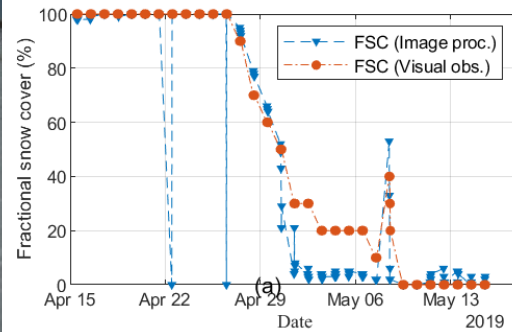
- Read images
- Run algorithms
- Store results as raw data

- Generate report with visualized results





Snow Cover Algorithms (FSC & SD)





Operational monitoring

fmiprot.fmi.fi

FMIPROT

- Downloads
- Publications
- Tutorials

Camera Network Portal

- MONIMET
- UEF
- PHENOCAM
- EUROPHEN

Operational Monitoring

- MONIMET SD
- MONIMET FSC
- MONIMET Vegetation
- UEF Vegetation

Contact Information



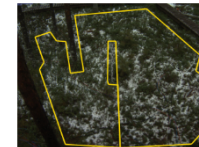
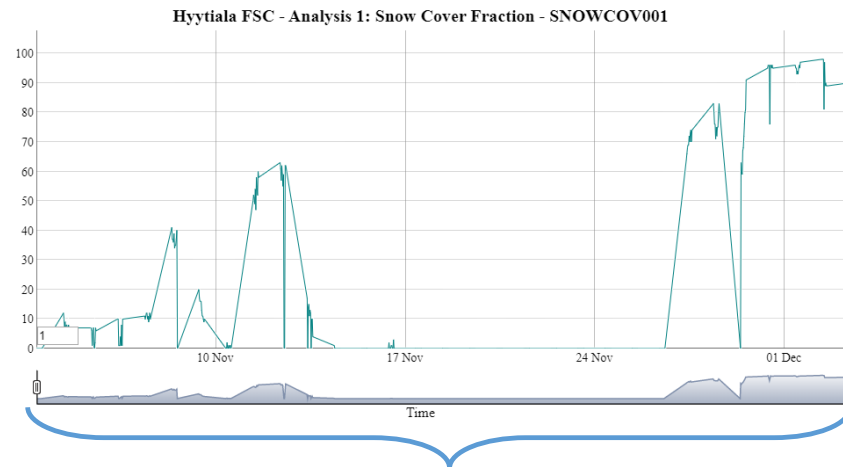
Fractional snow cover monitoring with MONIMET Camera Network

Results

7 setups are defined for operational monitoring. Click on the buttons to switch to the results of the setups.

1 2 3 4 5 6 7

hyytiala



>Setup report page
>Download/Open data file
Plot:

☒ Snow Cover Fraction
Reset plot Toggle help

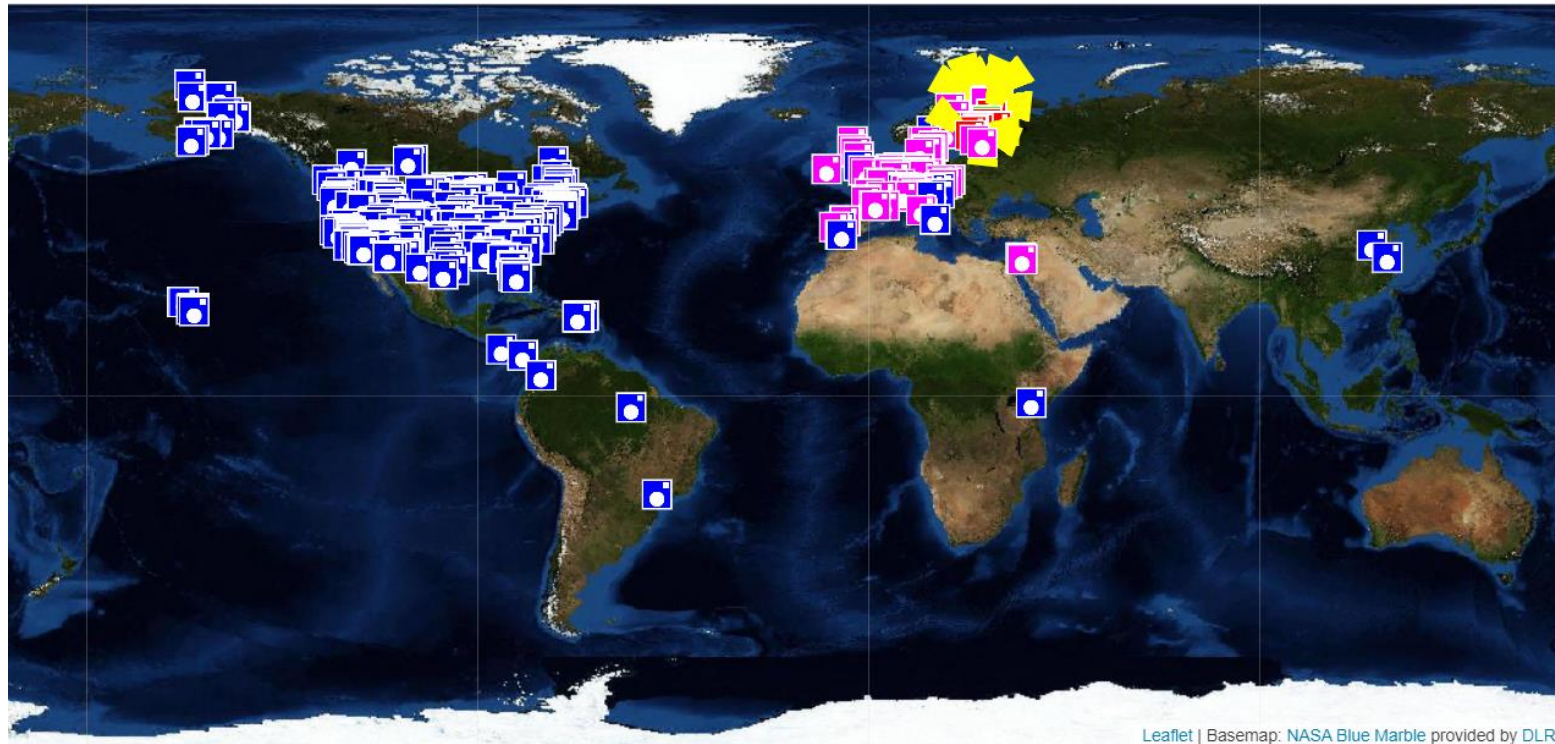
ROI

Data available
in CSV

Latest one month (updated twice every day)



Camera networks & camera availability



**Globally available camera networks can be used
with collaboration (only 4 shown here)**



Future/potential development

- JSON Metadata in the web server for results
 - So that data can be searched and downloaded
 - So that NRT results can be shown on map globally
- Web interface for submitting setups (scenarios) to be run by users
- Machine learning algorithms for more accurate snow extent detection
- NRT processing of mass webcam data by collaboration with camera network owners, either distributed or centralized processing

Such system would provide a vast stream of snow cover data available from many locations in the northern hemisphere in NRT and as historical data which can be used for cal/val activities.



ESA IDEAS-QA4EO -WP2 potential tasks

- 1) Further Satellite-based snow product cal/val development
(in conjunction with future ESA SnowPEX activities)
- 2) Bringing Sodankylä Cal/Val measurements to ESA IDEAS-QA4EO
framework (building collaboration within the IDEAS-project)
- 3) Further development of the webcam-based snow cal/val capabilities