HUT-2D measurements of soil moisture in northern areas

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Contents

- **Soil Moisture test sites and measurement flights**
- **SM Model used for HUT-2D data**
- **Results with HUT-2D data**
- **Future actions**
  - Elbara measurements in FMI-ARC CAL-VAL station in Northern Finland

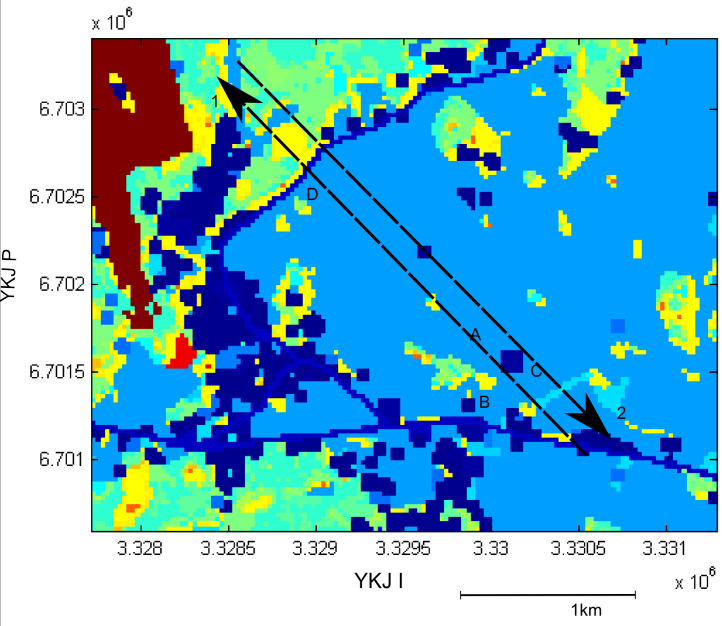
Soil Moisture Test sites in Finland

- **Two test sites in Southern Finland (Nummi and Viträsk)**
  - Three flights: April 2007, August 2007
- **Two test sites in Northern Finland (Sodankylä, Pallas)**
  - One flight: August 2007
  - Ground truth collected by Finnish Meteorological Institute (FMI)
- **Measurement equipment:**
  - HUT-2D
  - IR radiometer
  - HUTRAD – profiling radiometer system (6.8, 10.65, 18.7 GHz) for August 2007 flights

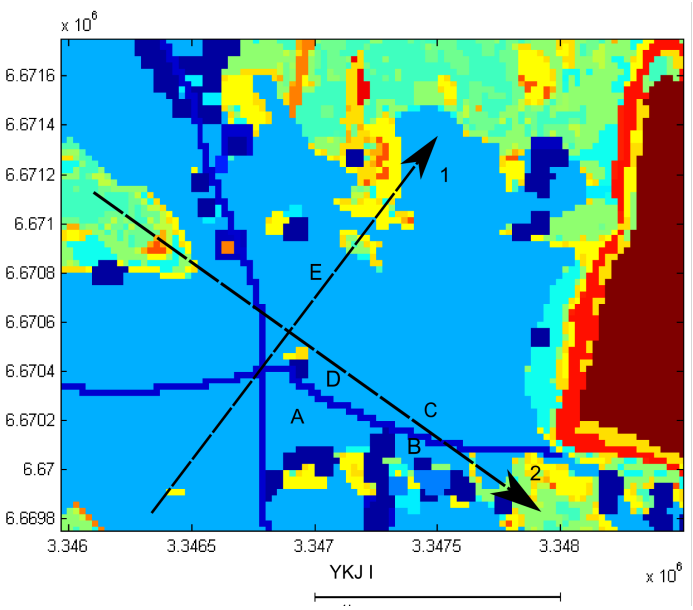
Soil Moisture Test sites in Finland

- **Test sites in Southern Finland**
  - Ground truth information: soil moisture, temperature, vegetation biomass, soil type

NUMMI



VITRÄSK



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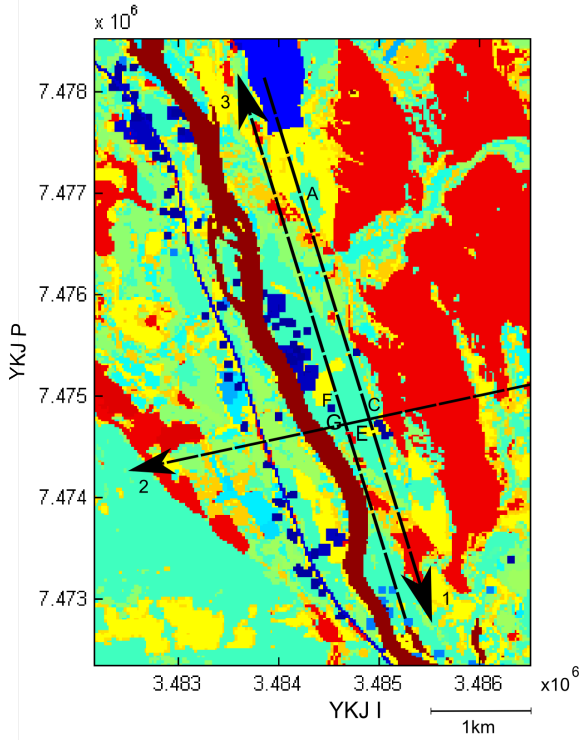
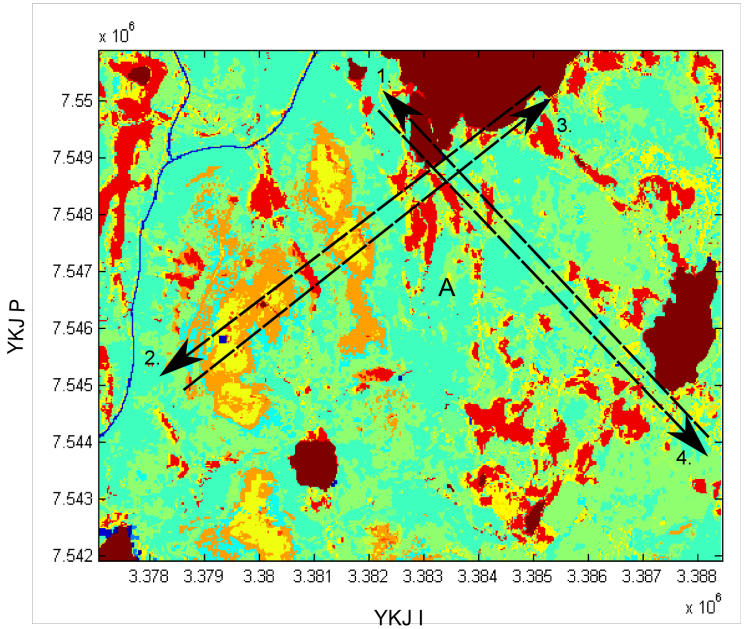
Soil Moisture Test sites in Finland

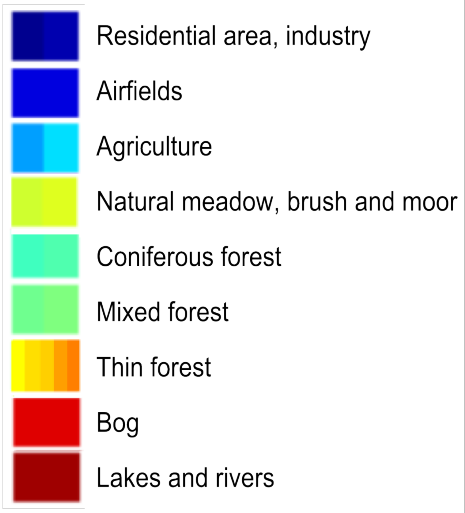
- **Test sites in Northern Finland**
  - Ground truth information: soil moisture, temperature, vegetation biomass, soil type

SODANKYLÄ



PALLAS





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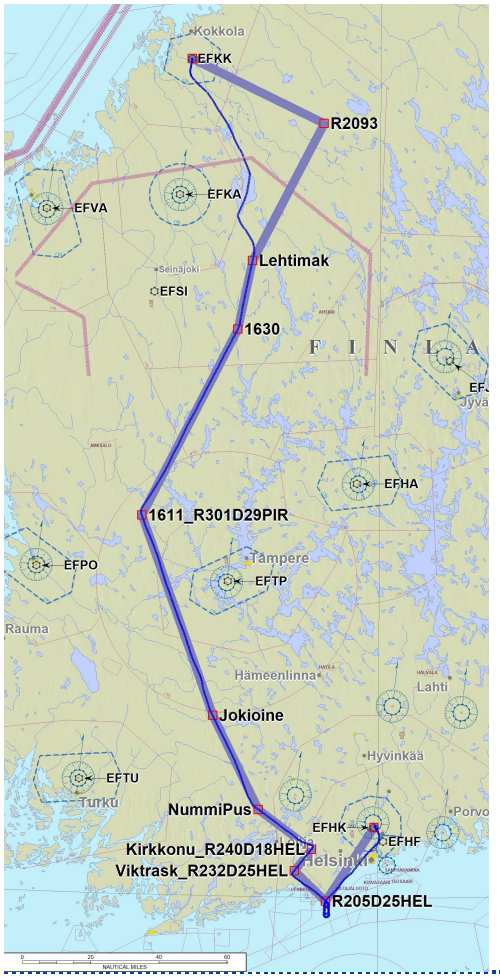
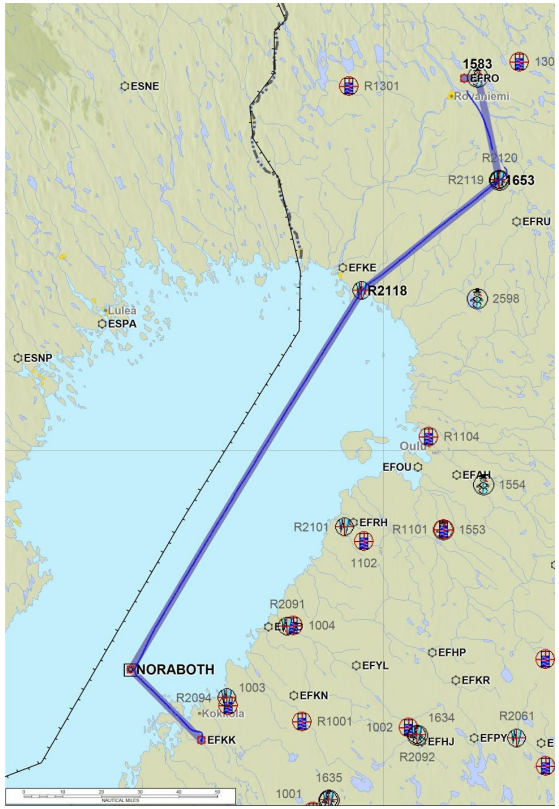
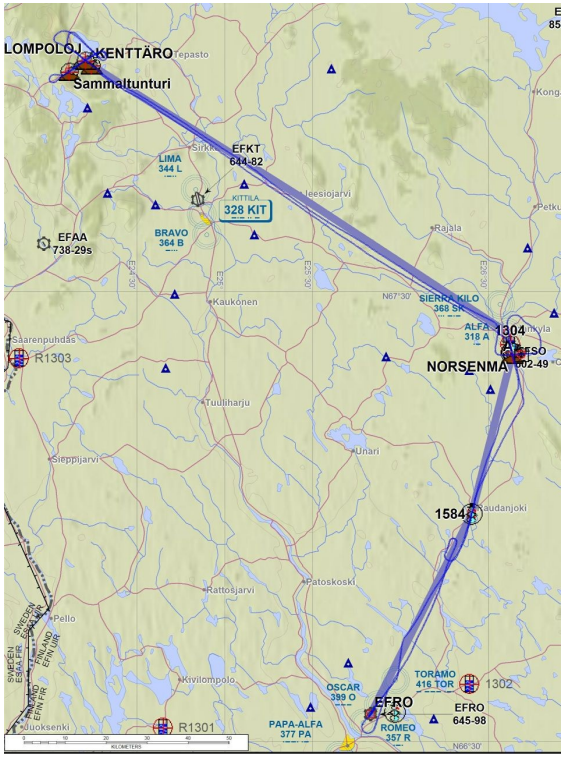
Flight route - August 2007

August 20 & 22





August 21



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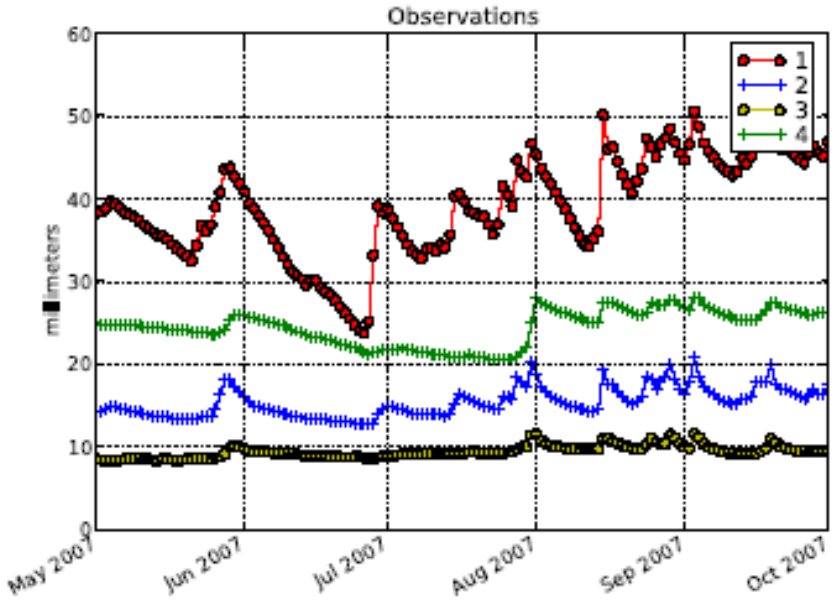
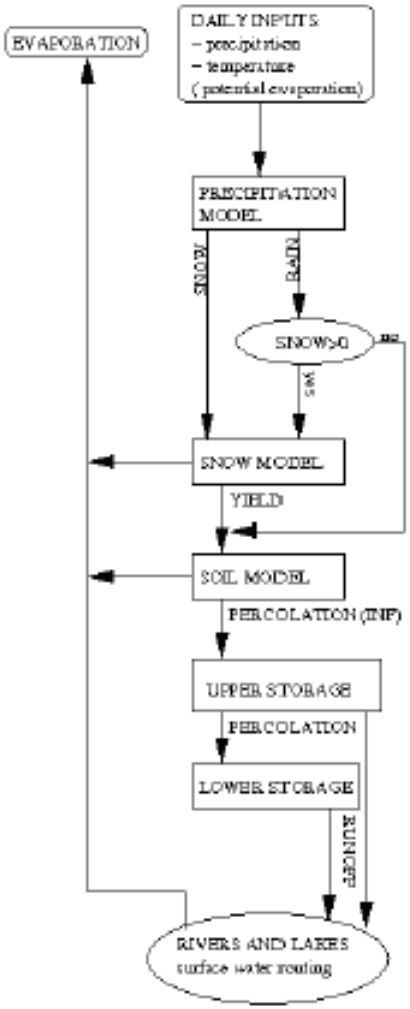
National SM information

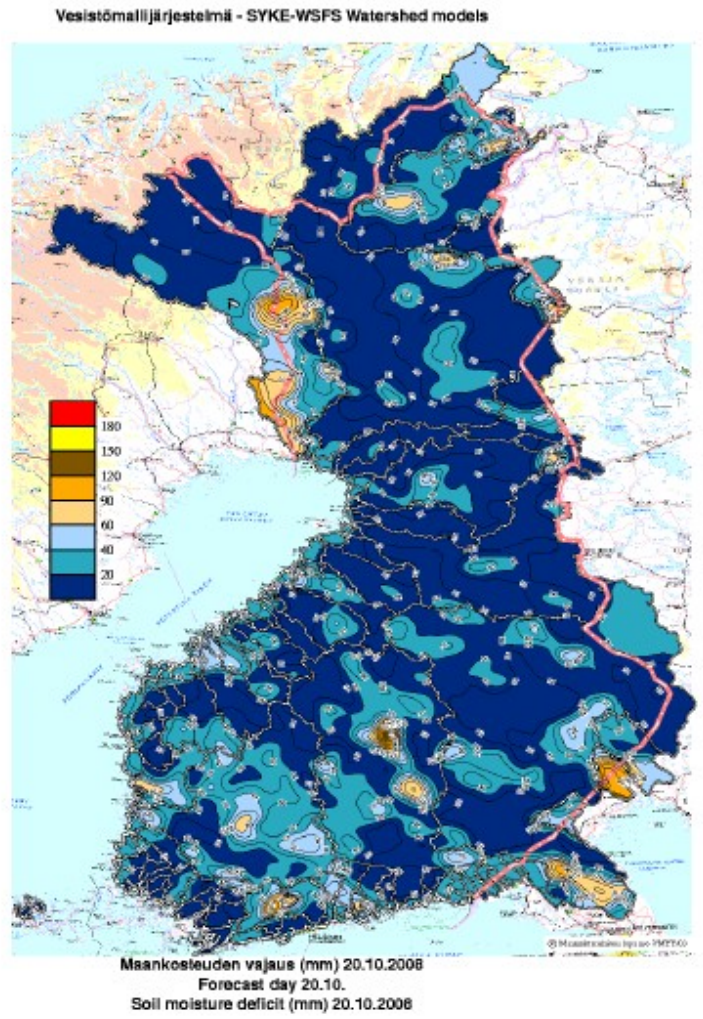
- **Finnish Environment Institute (SYKE) provides an operational watershed model for the whole Finland**
  - Soil moisture an input parameter



SYKE Watershed Model

- **Tells how much more moisture can be stored in the soil (SM deficit)**





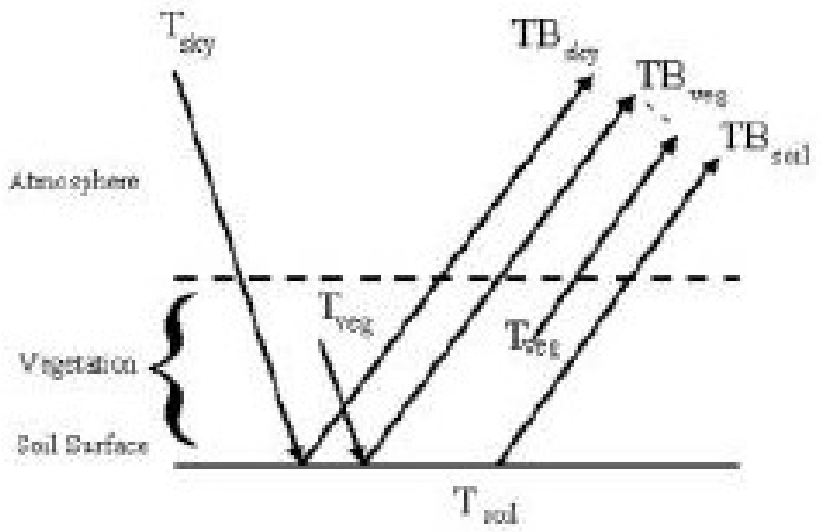
HUT-2D

- Airborne imaging radiometer operated on the TKK Short SC-7 Skyvan
- Similar to MIRAS in operation principle: suitable for testing the models and algorithms created for SMOS mission

SM model used for HUT-2D data

- According to radiative transfer equation the measured brightness temperature is the sum of the brightness temperatures of several sources:

$$TB_{obs} = TB_{sky} + TB_{veg} + TB_{soil}$$



$$TB_{obs} = TB_{veg} + TB_{soil}\, e^{-\tau veg} + (TB_{veg} + TB_{sky}\, e^{-\tau veg})\Gamma_{soil}\, e^{-\tau veg}$$

SM model used for HUT-2D data

- **Brightness temperature: function of physical temperature and reflection coefficient Γ**

$$TB_g = eT = (1 - \Gamma)T$$

- **Differences in soil water content affect the dielectric constant of the soil [Dobson et al. 1985]**

$$\epsilon_{soil} = (1 + \frac{\rho_b}{\rho_s}(\epsilon_s^{\alpha} - 1) + SM^{\beta'}\epsilon_{fw}'^{\alpha} - SM)^{\frac{1}{\alpha}} - j(SM^{\beta''}\epsilon_{fw}''^{\alpha})^{\frac{1}{\alpha}}$$

- **The reflection coefficients from the Fresnel equations**

$$\Gamma_h = \left| \frac{\cos\theta - \sqrt{\epsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\epsilon_r - \sin^2\theta}} \right|^2 \qquad \Gamma_v = \left| \frac{\epsilon_r \cos\theta - \sqrt{\epsilon_r - \sin^2\theta}}{\epsilon_r \cos\theta + \sqrt{\epsilon_r - \sin^2\theta}} \right|^2$$

- **Reflection coefficient for rough soil can be calculated with the Wang-Choudbury model [Wang 1983]:**

$$\Gamma_{rough,p}(\theta) = \left((1 - Q)\Gamma_p + Q\Gamma_q\right) e^{-h_k \cos^N(\theta)}$$

SM model used for HUT-2D data

- Vegetation is the main contributor in airborne measured TB. Vegetation radiates itself, and scatters, absorbs and reflects emission from other sources The $\tau - \omega$ model can be used to model the emission properties [Ulaby 1983]

$$T_B(\theta, p) = (1 - \omega_p)(1 - \gamma_p)(1 + \gamma_p \Gamma_{gp}) T_c + (1 - \Gamma_{gp}) \gamma_p T_g$$

$$\gamma_p = e^{-\tau_p / \cos\theta}$$

τ is vegetation optical density, function of vegetation biomass

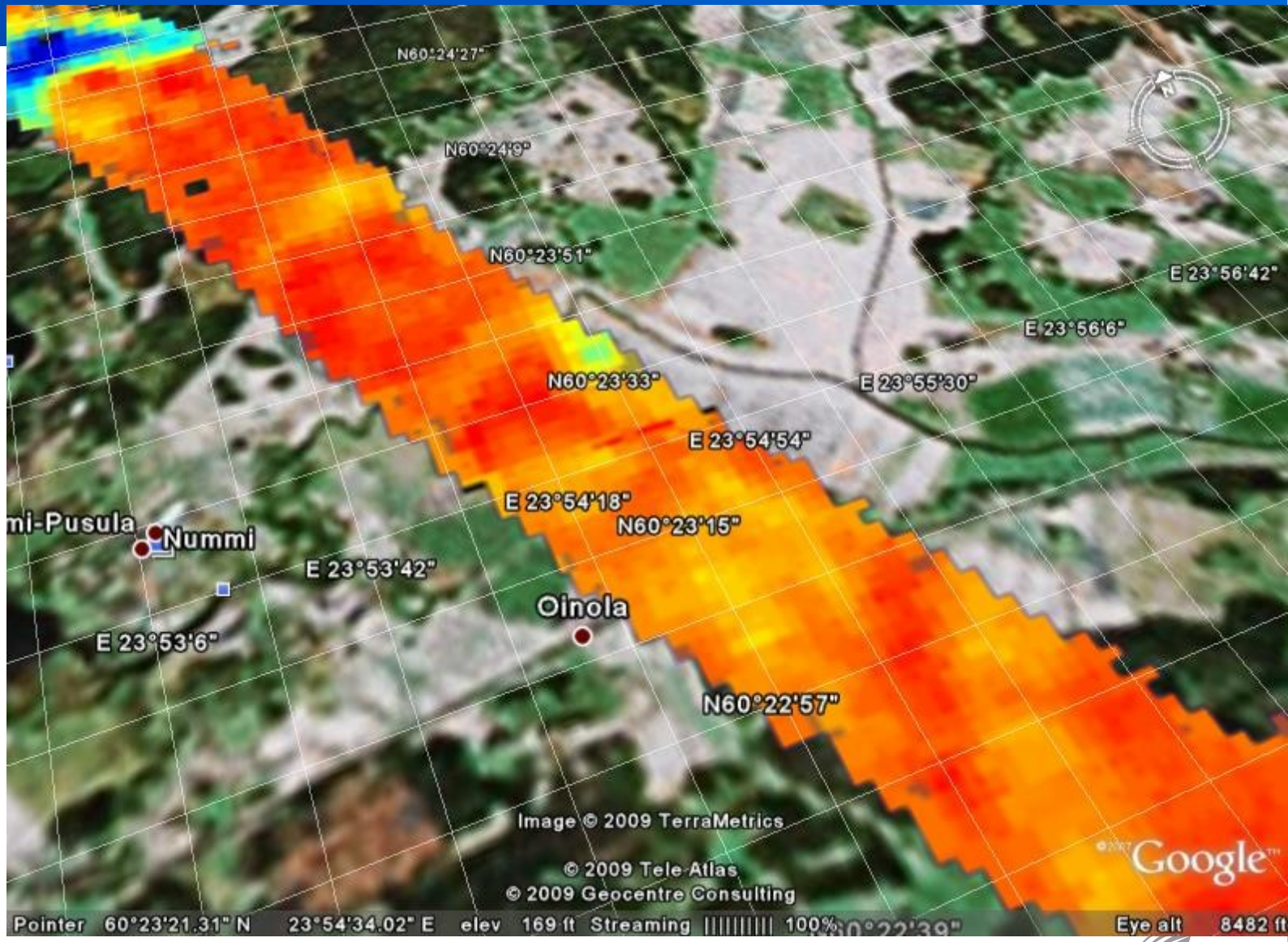
ω is single scattering albedo, function of vegetation structure

Soil moisture results

- **Three main soil types**
  - Bare soil (agricultural fields without crops)
  - Agricultural fields with crops
  - Forested areas

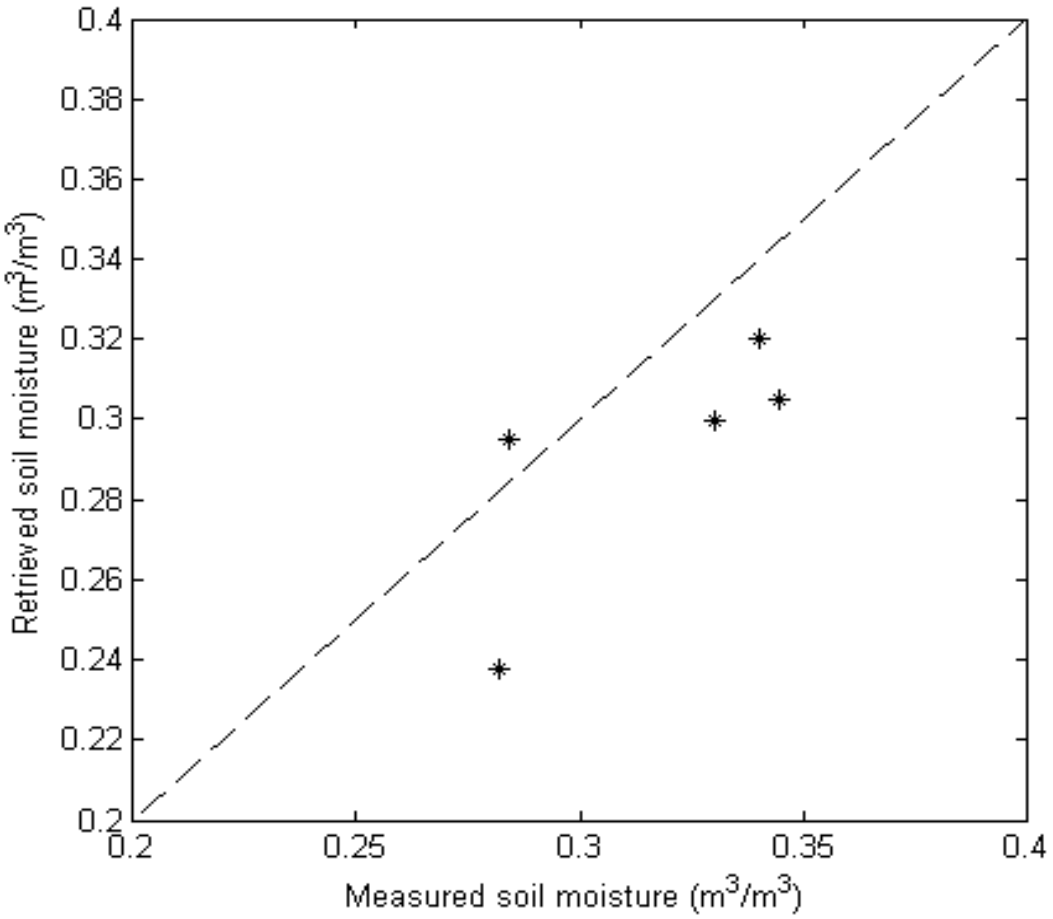
HUT-2D Brightness temperature map

- **Nummi test site**



Soil Moisture in bare soil

- **Bare soil field, measured in April 2007**



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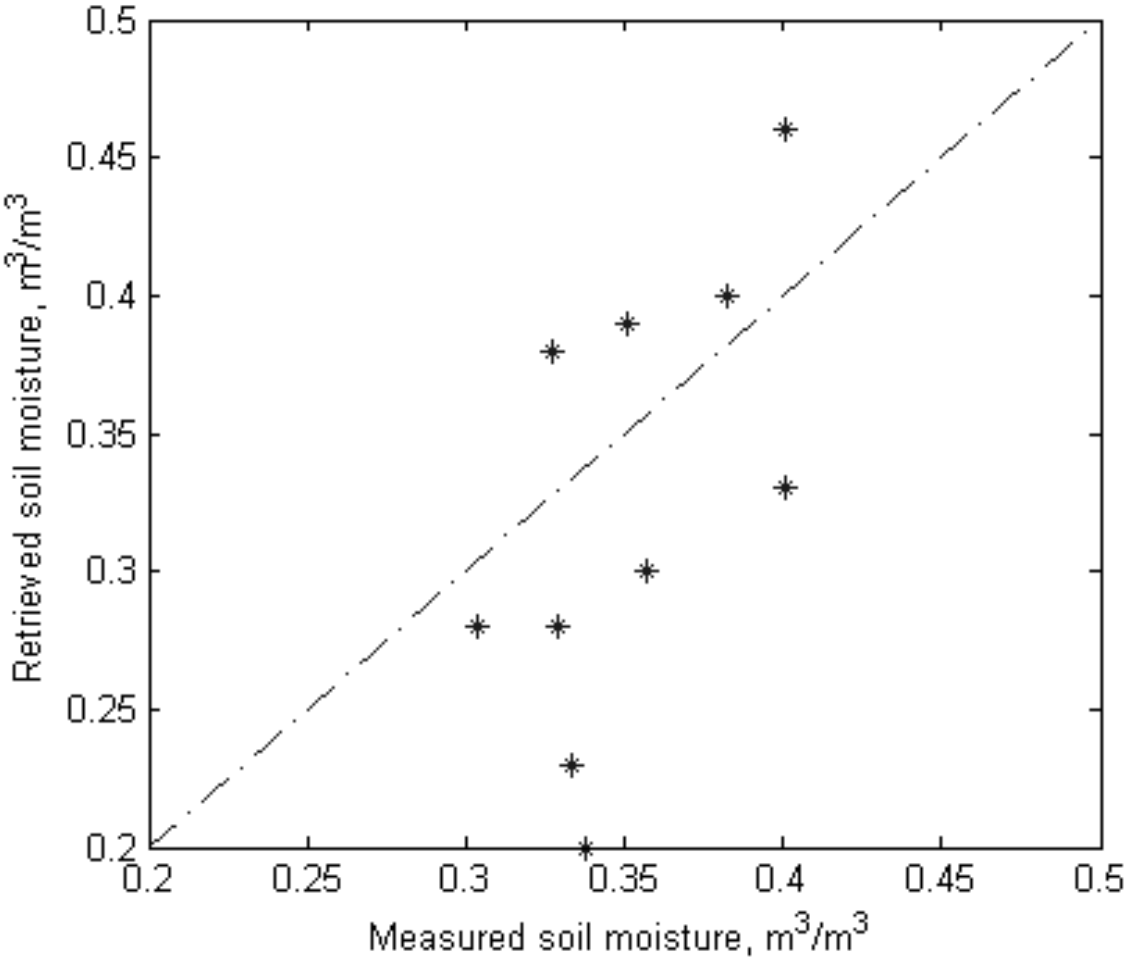
Soil moisture in agricultural fields

- **Barley and wheat fields**
- **August 2007 measurement campaign**
- **MODIS-based NDVI used to estimate vegetation biomass**



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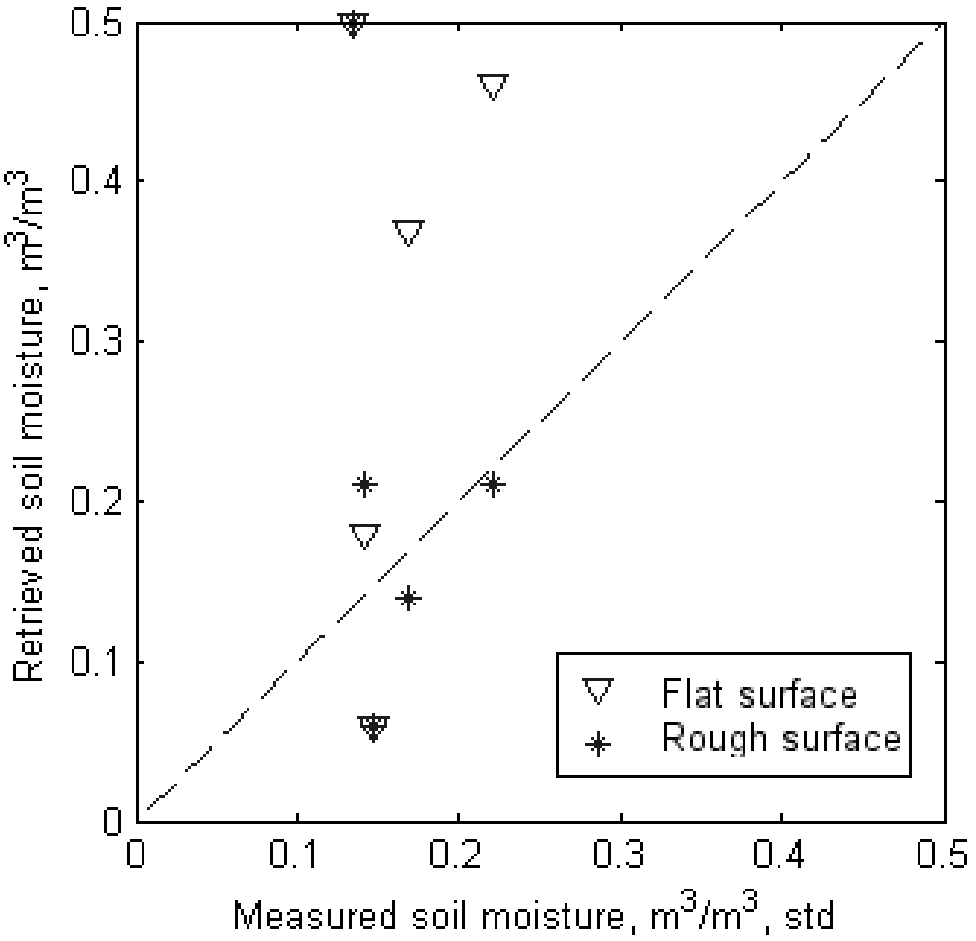
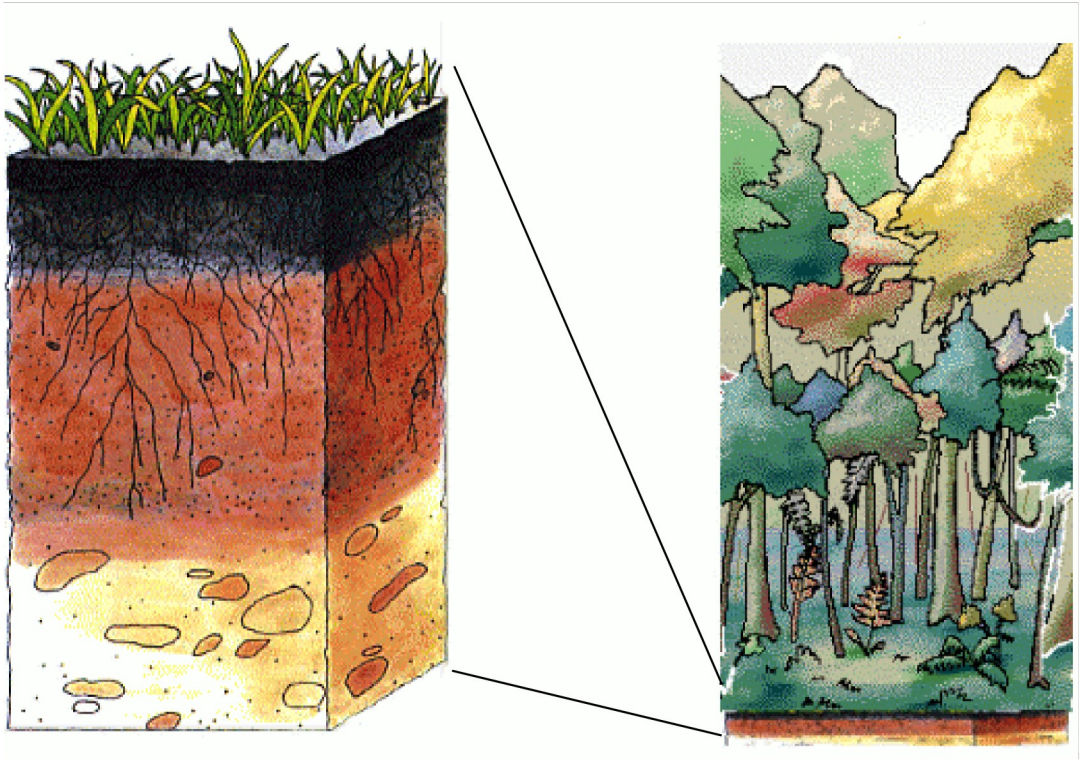
Soil moisture in forested areas

- **Coniferous and mixed forest in Sodankylä**
- **Measured in August 2007 campaign**
- **MODIS-based NDVI used to estimate forest biomass**



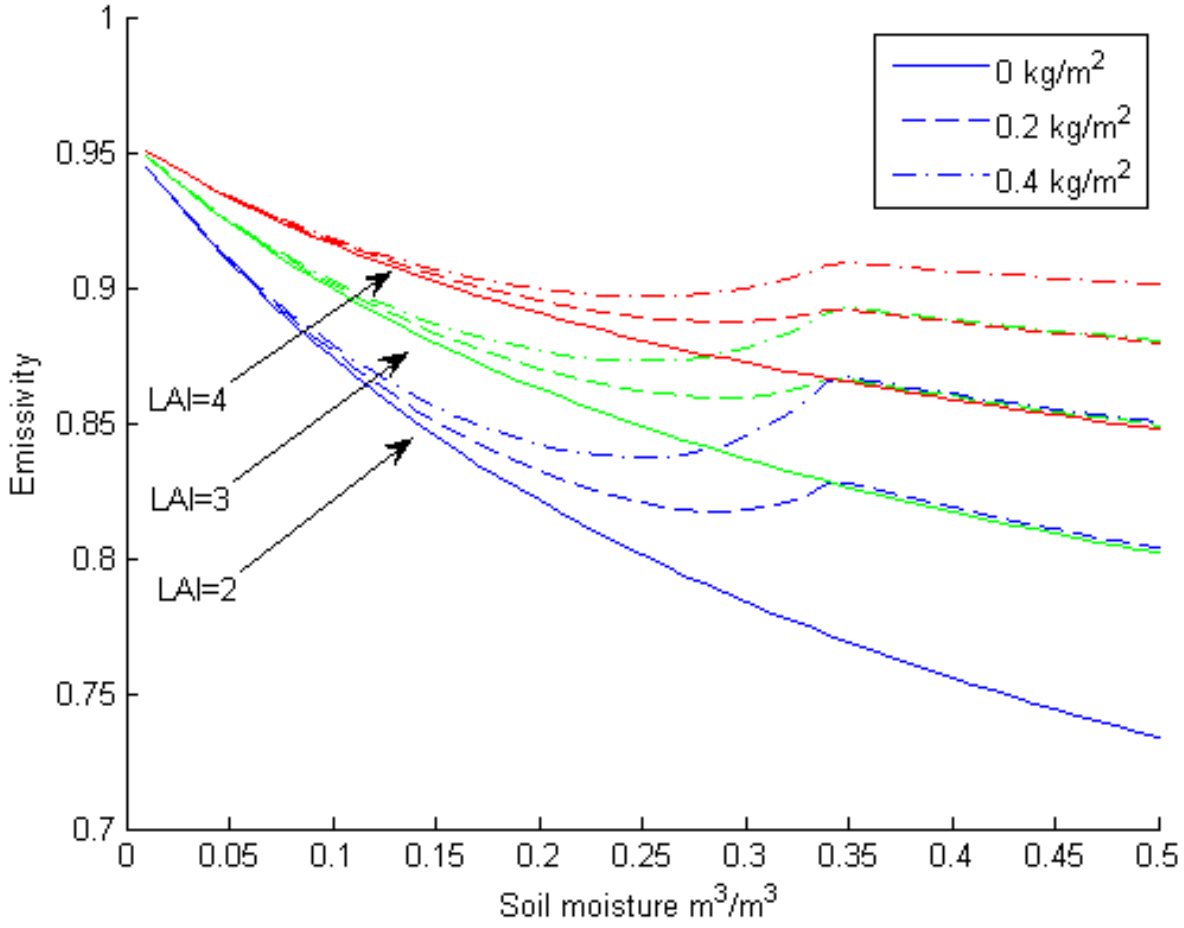
SM in forested areas

- First results for forested areas not very impressive
- A major problem is the forest litter between the vegetation and the soil; its moisture may block contribution from soil



Effect of litter

- **Theoretical emissivity of forest ground as a function of soil moisture with different values of litter (insert) and LAI**



Future actions

- **Need more ground truth for interpreting HUT-2D data and evaluating the feasibility of the SM algorithm**
  - Litter measurements for forested areas

- **FMI: Elbara measurements in FMI-ARC CAL-VAL station in Sodankylä, Northern Finland**
  - 12-month ground-based campaign

Future actions: ELBARA measurement campaign at FMI-ARC CAL-VAL Station

12 month measurement campaign at FMI Arctic Research Centre

- **ELBARA on fixed location (~5 m tower installation)**
- **Detailed in situ data on soil, snow cover, atmosphere available**
- **Several scanning options available (readiness for both elevation and azimuth scan)**
- **Start May 2009**

Instrument on lease from ESA according to SMOS cal/val AO 3281

esa

GAMMA REMOTE SENSING

Measurement site

ELBARA site

67°21.712′ N
26°38.270′ E

Site typical coniferous forest on mineral soil

Site allows 10-55 deg elevation scan + several optional azimuth scan directions (clear of vegetation)

In vicinity of meteorological mast, snow cover measurements

Easy access and technical support

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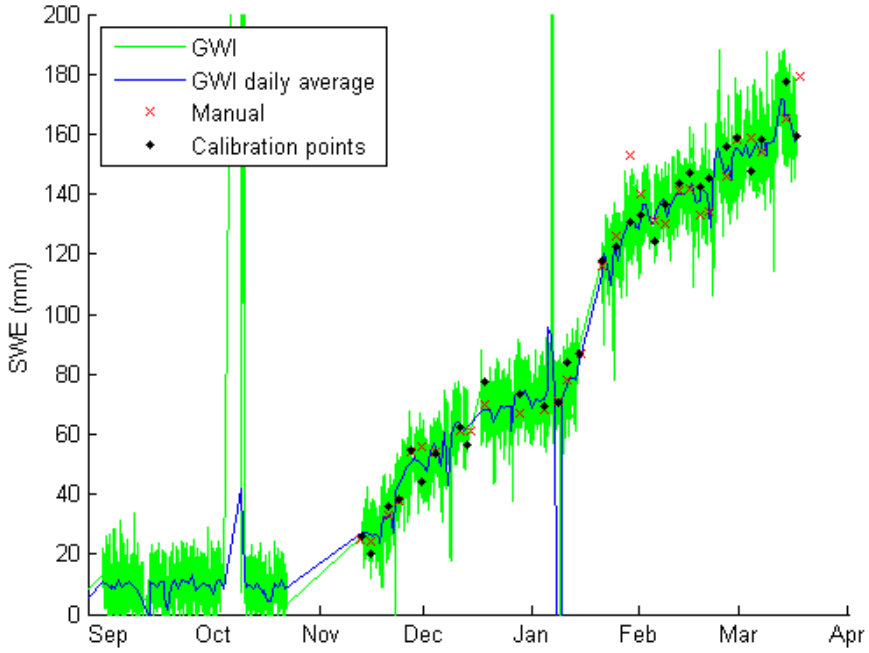
In situ data from FMI-ARC observatory

Continuous automatic measurements

- soil moisture vertical profile
- soil temperature profiles and frost depth,
- snow depth and snow water equivalent (acoustic and gamma ray mesurements)
- snow temperature profile
- weather and radiation measurements

Manual measurements

- bi-weekly manual snow measurements (snow grain size and stratigraphy)



GWI (Gamma Water Instrument) measured data on SWE

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Automatic weather station

- bottom of the 1st, 2nd, 3rd, 4th cloud layer
- amount of clouds in the 1st, 2nd, 3rd, 4th cloud layer
- wind speed and direction
- relative humidity
- air temperature and pressure
- dew point
- visibility
- rain intensity
- prevailing weather
- snow depth

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Measurements near ELBARA Site

- soil temperature at 0, -2, -5, -10, -20, -50, -100 cm
- soil volume moisture at -5, -10, -20, -30, -50, -100 cm
- soil heat flux
- skin temperature
- net radiation
- snow temperature every 10 cm up to 110 cm
- snow depth

- **GWI: snow water equivalent**