ALOS PALSAR FOR BOREAL FOREST AND FREEZE / THAW MONITORING

Martti Hallikainen and Erkki Tomppo*

Helsinki University of Technology

*Finnish Forest Research Institute

HUT Research Aircraft

- Acquired in 1994 and modified for remote sensing research

- Twin-engine turboprop aircraft Skyvan SC-7

- Sensor accommodation: Cargo bay, nose radome and port-side of fuselage (>300 kg)

- DGPS navigation system

- Min. air speed 105 km/h

# 16-Channel Microwave Radiometer HUTRAD

- Center frequencies: 6.8, 10.65, 18.7, 23.8, 36.5, 93, and 94 GHz
- Vertical and horizontal polarization at each frequency
- Incidence angle 50° off nadir
- Fully polarimetric 36.5 GHz receiver (four Stokes parameters)
- Imaging 93 GHz receiver

Airborne Interferometric 1.4 GHz Radiometer HUT-2D

- The first airborne interferometric microwave radiometer in the world
- Will be completed and tested in 2005; first flight tests with a subunit conducted in December 2003 successfully
- 36 antenna/receiver elements in U-shape of size 2 m by 2 m
- Subsystems:
  - Antenna/receiver elements
  - Local oscillator and clock
  - Calibration
  - Correlator
  - Data recording
- Mass:
  - Instrument: 55 kg
  - Support frame: 30 kg
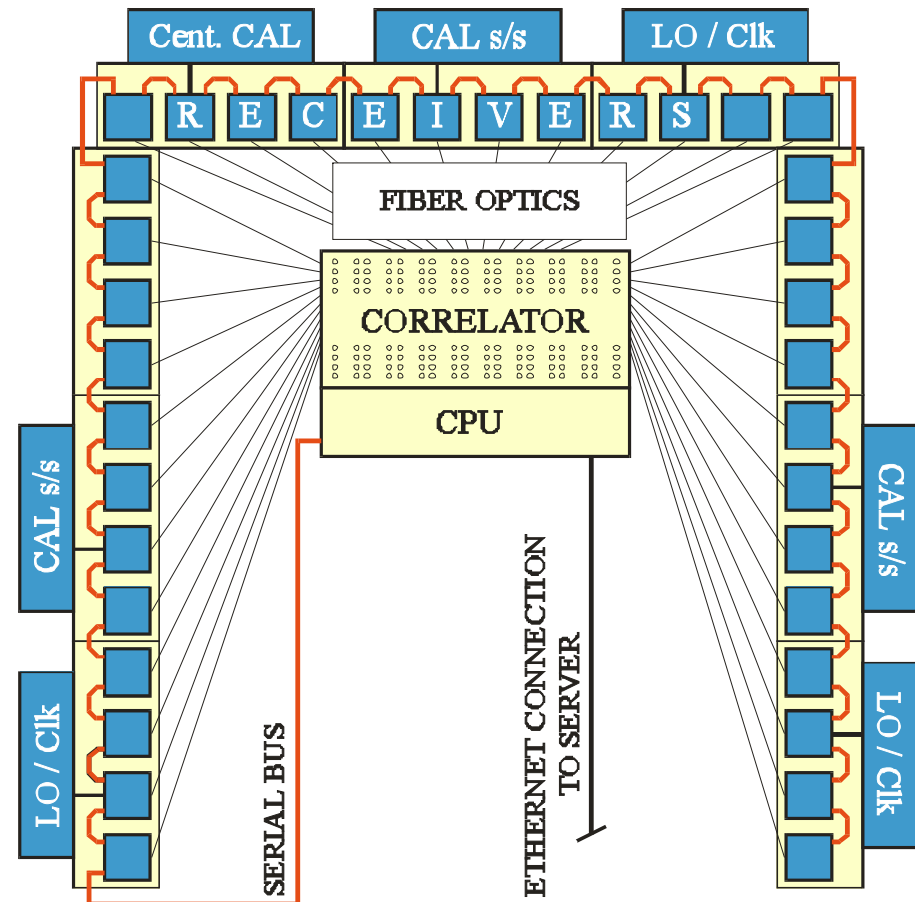
HUTSCAT Scatterometer

- Helicopter-borne non-imaging FM-CW ranging scatterometer (radar), completed in 1990
- Operating frequencies 9.8 GHz (X-band) and 5.4 GHz (C-band), with VV, HH, VH, and HV polarizations at each frequency.
- Backscatter at eight channels measured quasi-simultaneously as a function of distance, 65 cm distance resolution
- HUTSCAT main applications:
  - Forest tree height measurement
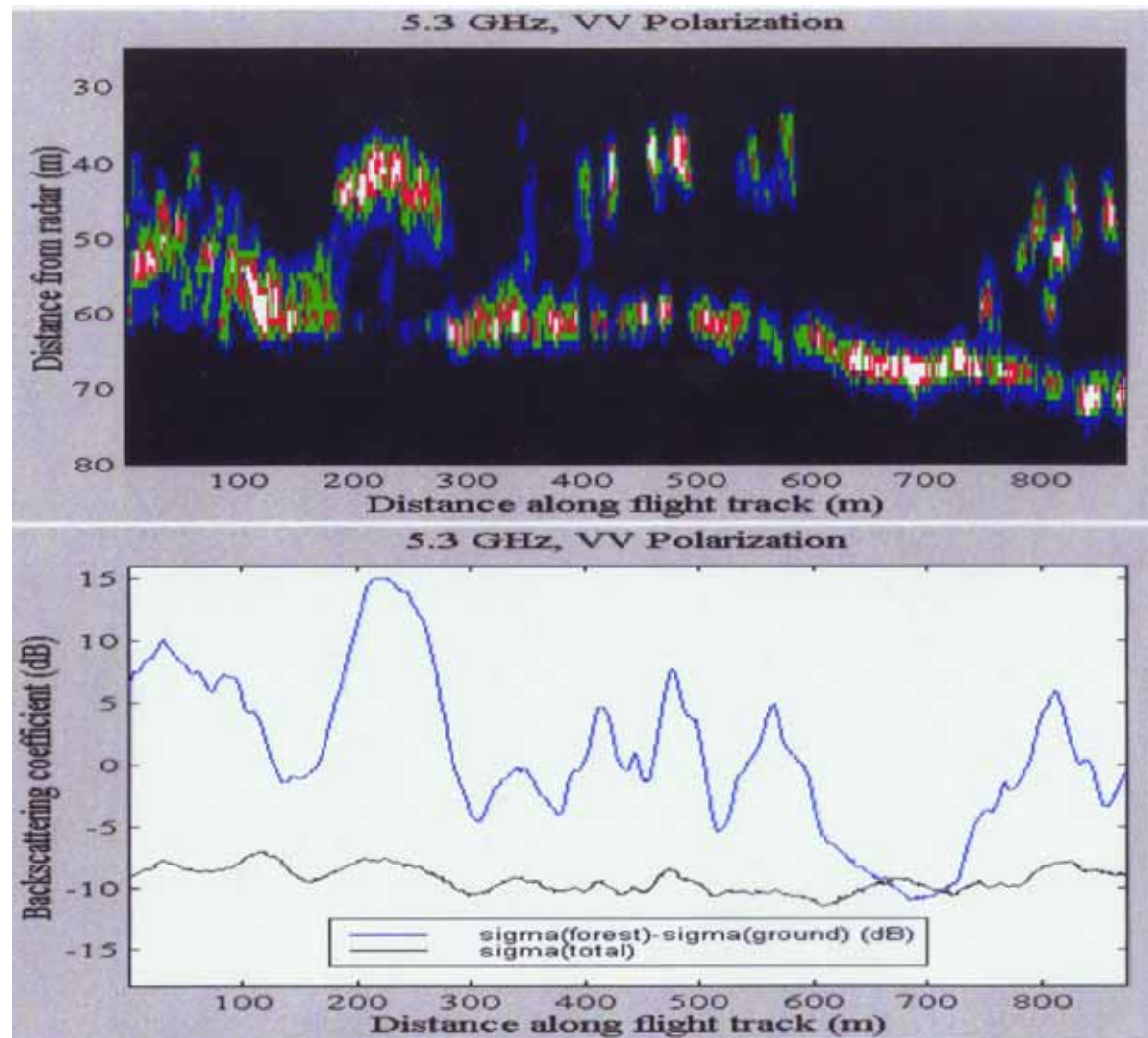 - Forest stem volume and biomass estimation

Use of HUTSCAT Data for Forest Research

- A radar backscatter profile of boreal forest over 850 m distance (C-band, VV-pol.)
  - White: strongest signal
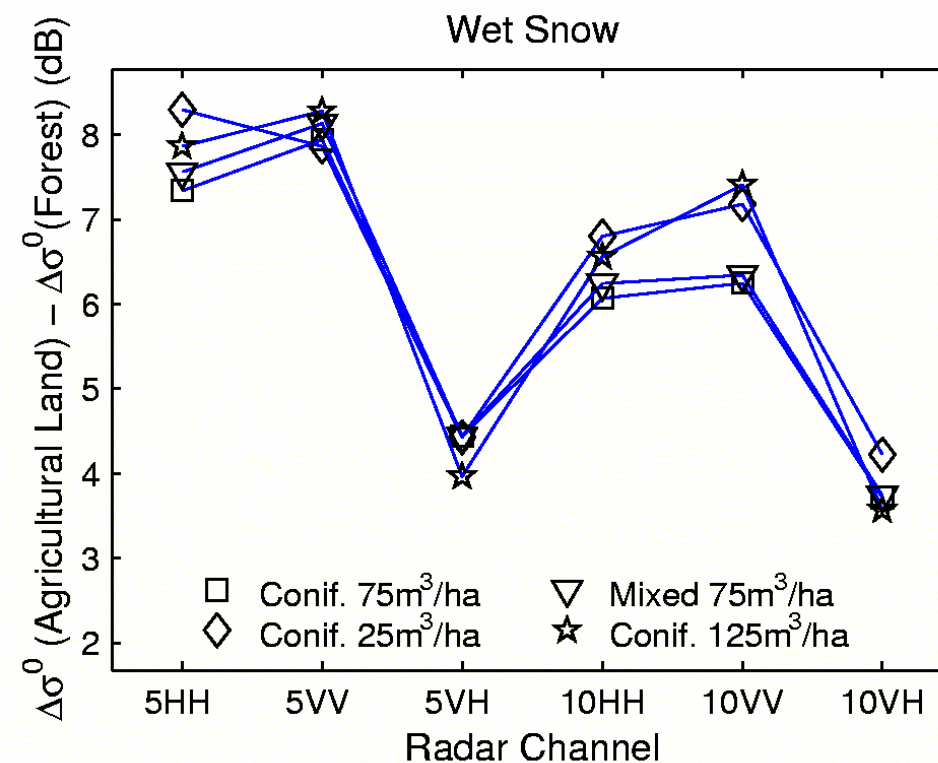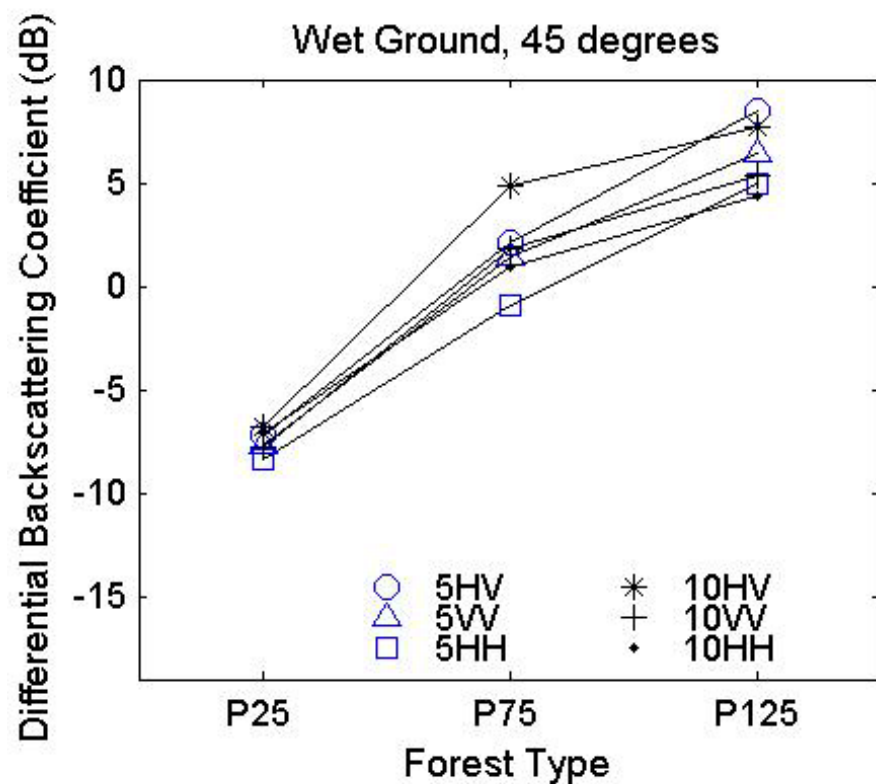 - Blue: weakest signal
  - Black: no backscatter

- Backscattering coefficient
  - Blue: forest contribution (total - ground)
  - Black: total value

5.3 GHz, VV Polarization

Samples of HUTSCAT Data for
Forest and Land Use Research

HUT Semiempirical Forest Backscattering Model

- **Starting point:** Relationship of sigma0 with biomass, canopy moisture and soil moisture is complex => use training areas

- **Radiative transfer model**, used as follows:

- **1) For the training area**, the <u>soil and vegetation moisture</u> parameters are estimated from the backscattering coefficients and stem volume (must be known for training areas) with the semi-empirical backscattering model.

- **2) For the whole area of interest**, the stem volume is estimated from the backscattering coefficients using the semi-empirical backscattering model with the moisture parameters.

- **3) If several SAR images are used**, the stem volume estimates are combined with a multiple linear regression. The regression equation is defined using the stem volume estimates for the training area.

- **Current Modeling Activities**: Polarimetric scattering model under development (tree made up of cylinders; tree growth model)
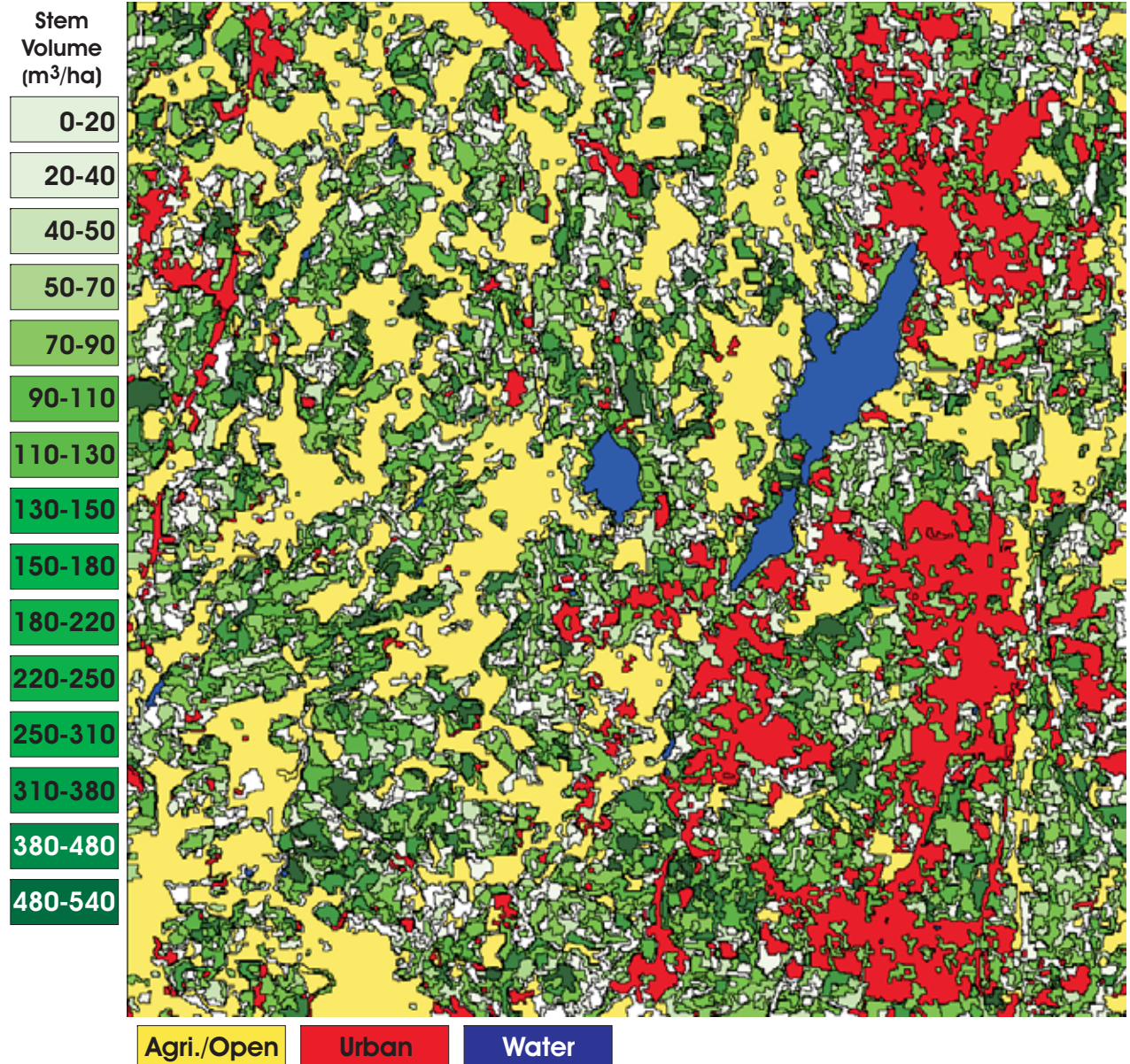
Land Use by SAR Interferometry

- Land use map of Helsinki Metropolitan Area

- 28 images from ERS-1 and ERS-2 SAR over a period of one year

- RGB image

- R = average intensity

- G = average coherence of 14 ERS Tandem image pairs for discriminating forested areas

- B = average of two long-term coherences (35 and 245 days) for discriminating urban areas

- Compares favorably with ground truth

Land-Cover and Stem Volume Map for Tuusula Region (ERS SAR)

- Except for the used training stand information the map is completely radar-based

- Continuous stem-volume estimates are here discretized for display.

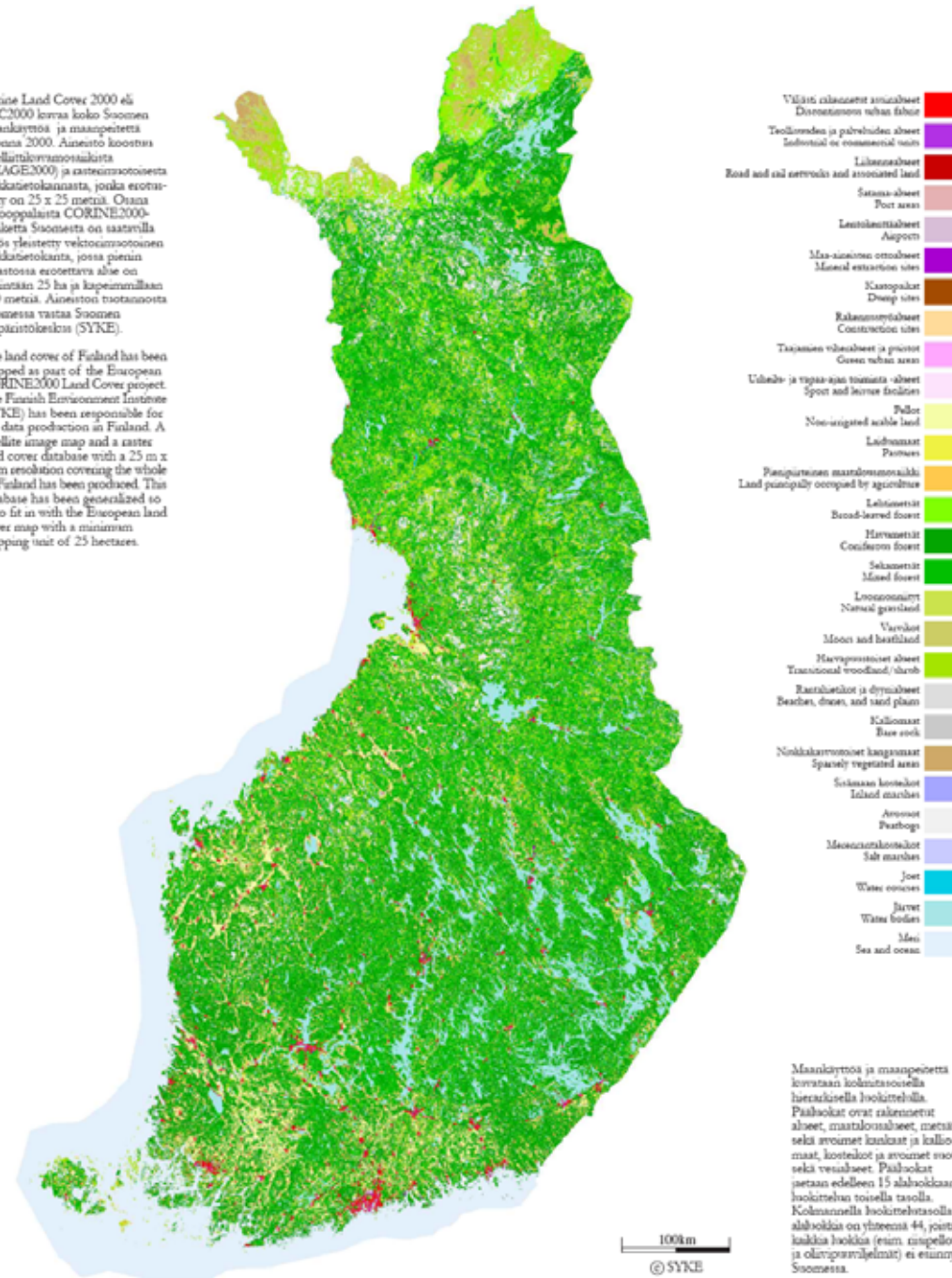**Stem Volume (m³/ha)**

0-20
20-40
40-50
50-70
70-90
90-110
110-130
130-150
150-180
180-220
220-250
250-310
310-380
380-480
480-540

Agri./Open **Urban** **Water**

Source: EEA

Corine land cover 2000

Land Cover and Land Use in Finland Corine 2000

Source:

Finnish Environment Institute

Land use and land cover in Finland

Mean Value of Growing Stock (m³/ha) 1989-1994

Source: Finnish Forest Research Institute
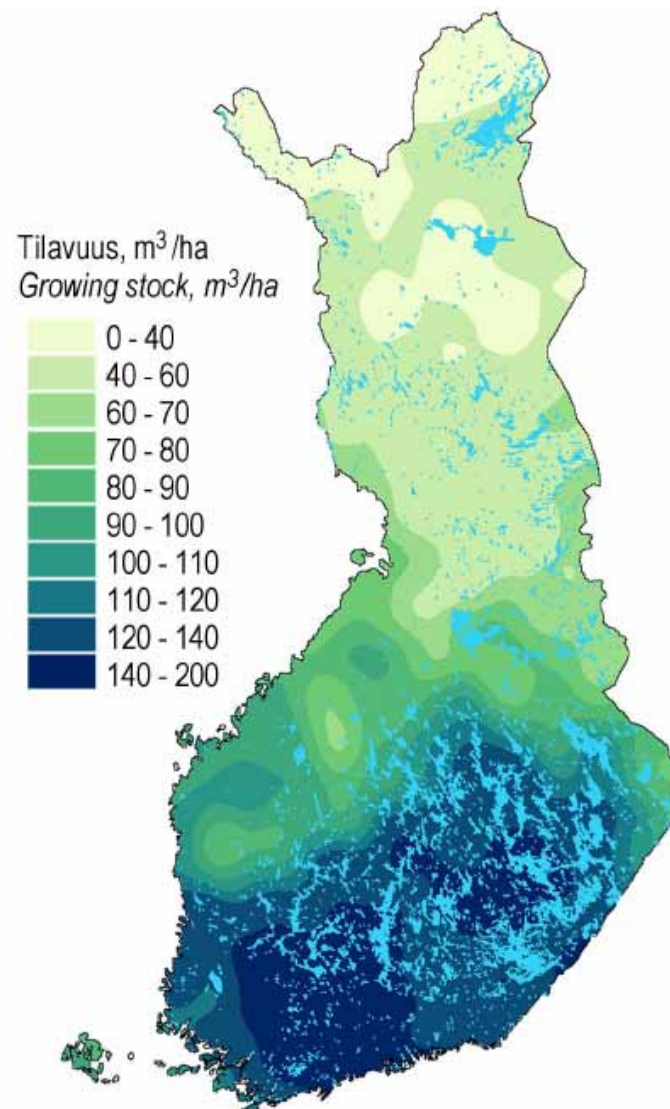
Tilavuus, m³/ha
Growing stock, m³/ha

0 - 40
40 - 60
60 - 70
70 - 80
80 - 90
90 - 100
100 - 110
110 - 120
120 - 140
140 - 200

Lähde: Metsäntutkimuslaitos, valtakunnan metsien inventointi – Source: Finnish Forest Research Institute

Kuva 1.1   Puuston keskitilavuus metsä- ja kitumaalla 1989–94
Figure 1.1   Mean volume of the growing stock on forest and scrub land, 1989–94
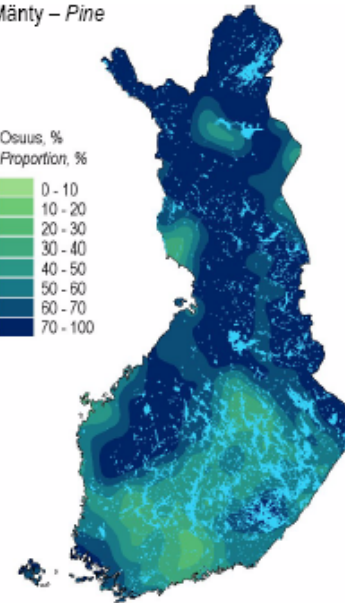
Proportions of pine, spruce and birch on forest land 1989-1994

Source:

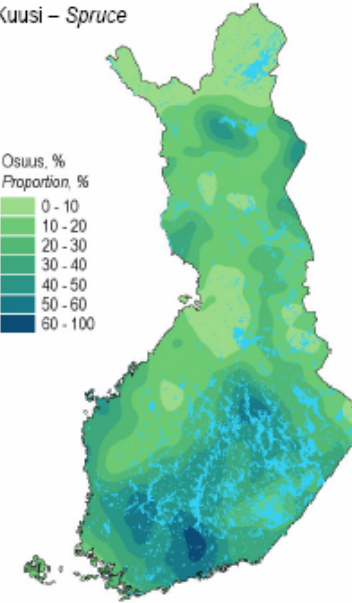Finnish Forest Research Institute

Mänty – Pine

Osuus, %
Proportion, %

0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 100

Kuusi – Spruce

Osuus, %
Proportion, %

0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 100

Koivu – Birch

Osuus, %
Proportion, %

0 - 10
10 - 20
20 - 30
30 - 40
40 - 100
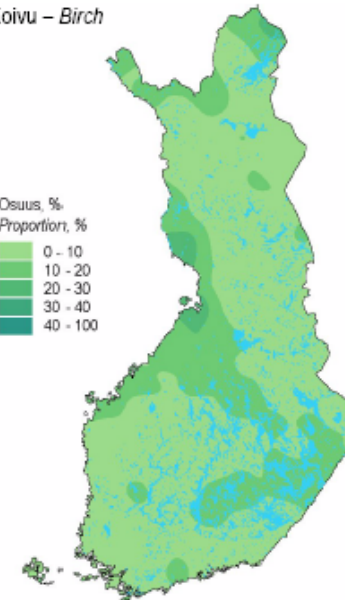
Lähde: Metsäntutkimuslaitos, valtakunnan metsien inventointi – *Source: Finnish Forest Research Institute*

Kuva 1. 2   Mänty-, kuusi- ja koivuvaltaisten metsien osuudet metsämaan alasta 1989–94
Figure 1.2   *Proportions of pine, spruce and birch forests on forest land, 1989–94*

Problem Statement for Boreal Forest, v1

⚙ Estimate the areas of six land use categories (Forest, Cropland, Grassland, Wetlands, Settlements and Other land) and changes between categories as defined in the Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF) of the Intergovernmental Panel on Climate Change (IPCC).

⚙ In addition to UNFCCC LULUCF reporting, the methods could be applied in identifying Deforestation, Afforestation and Reforestation defined in Kyoto Protocol.

Relevance of ALOS and
Problem Statement for Boreal Forest, v2

⟫ The low frequency and cross-pol of ALOS PALSAR provide sensitivity to biomass but probably less so to differences between the other five categories. Hence, more practical tasks for using ALOS PALSAR are:

⟫ Test its feasibility to estimate changes between Forest and the other five land use categories

⟫ Test its feasibility to estimate above ground living biomass

Forest Definition

⟩ Forests are lands of
more than 0.5
hectares, with trees
able to reach a
minimum height of 5
meters maturity in situ
and with a canopy
cover of more than 10
percent, which are not
primarily under
agricultural or urban
land use.

Old-growth forest stand in northern Finland

Source: Finnish Forest Research Institute

Prototype Area and Ground Truth

ↆ Prototype area: Finland

ↆ Ground truth:

    ↆ National Forest Inventory data

    ↆ CORINE 2000 land use information

Planned Output Products and Product Developers

◈ Output products:

    ◈ Feasibility of ALOS PALSAR to produce maps of annual change of forest land vs. other five land use categories

    ◈ Feasibility of ALOS PALSAR to produce above ground living biomass

◈ Product developers:

    ◈ Helsinki University of Technology

    ◈ Finnish Forest Research Institute

Source:
S.R. Eyre
(1968)

Eurasian boreal forest zone

Source: S. R. Eyre: Vegetation and soils (1968)

1 000 km
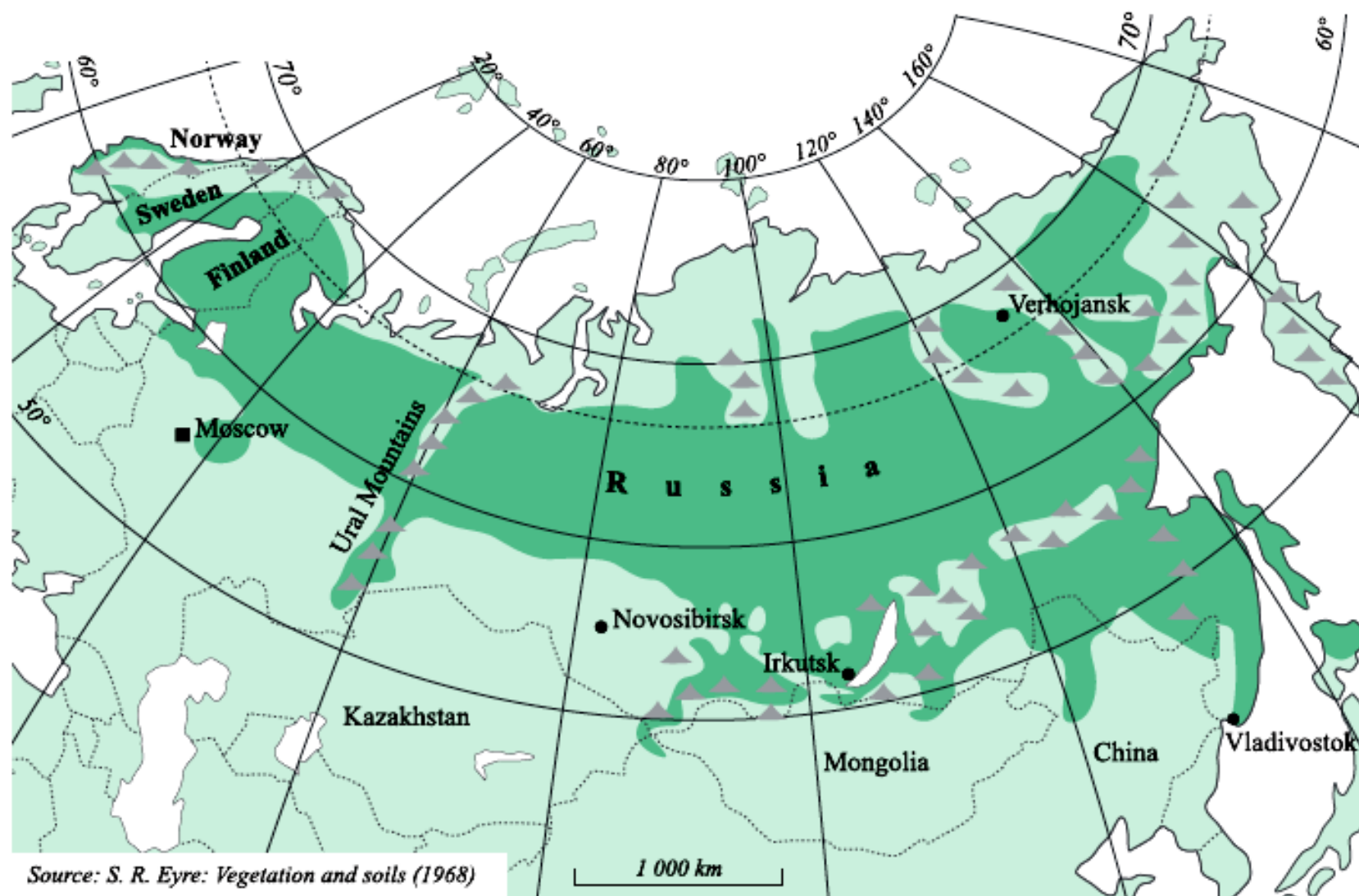
Accuracy of Finnish DEM

⟋ Green: Mean error 1.76 m

⟋ Pink: 1.76 – 5 m

⟋ Light brown: 5-10 m

⟋ Dark brown <10 m

⟋ Blank: no estimate

KORKEUSMALLIN TARKKUUS

- keskivirhe < 1.76 m
- keskivirhe 1.76 - 5 m
- keskivirhe 5 - 10 m
- keskivirhe > 10 m
- ei referenssiaineistoa
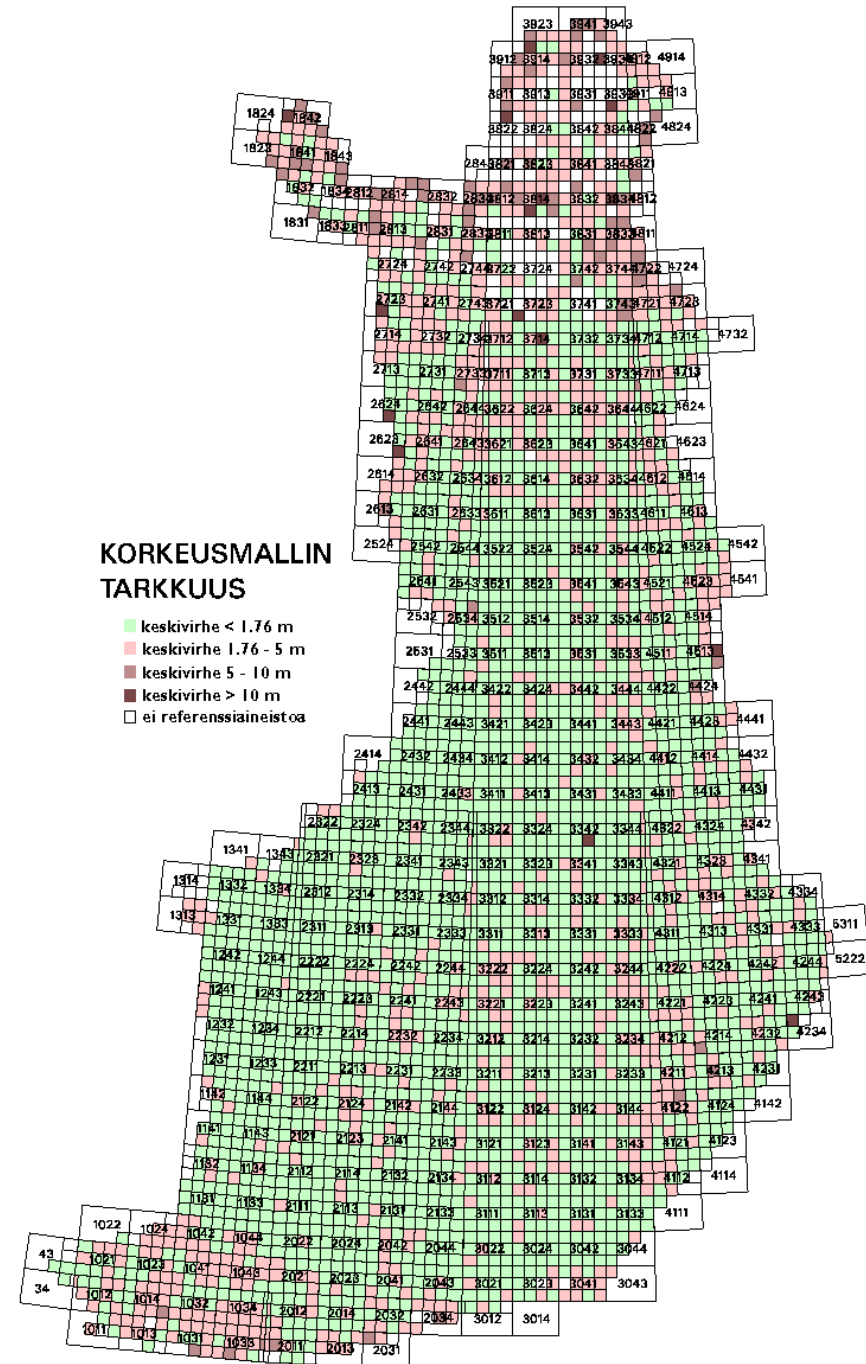
Use of HUT Semiempirical Forest Backscattering Model for Freeze / Thaw Monitoring

⟩ Instead of determining biomass / stem volume using the backscatter model, determine soil moisture

⟩ Then, biomass / stem volume has to be known with reasonable accuracy

⟩ Our experimental results indicate that if derived soil moisture is smaller than 9 % by volume, soil is frozen (C-band SAR data)

    ⟩ Diectric constant does not saturate at 0 deg Celsius but, rather, decreases with decreasing temperature

Other HUT Activities for Soil State Monitoring

- Airborne measurements with our multi-frequency HUTRAD radiometer starting in spring 2005 (C/X-band)

- Ground-based measurements with L-band radiometer starting in summer 2005; later airborne measurements

- Soil state:
  - Frozen / thawed
  - Effect of land-cover categories to the observed results

- => Determine possibilities of L-band for freeze / thaw (few results in literature; Wegmuller: good separability)

- Earlier: dielectric measurements of frozen soil by HUT

- Modeling of emission/backscatter based on literature

Every 10 days In-Situ Observations at 38 Finnish Stations: Ground Frost and Snow Depth for Forested / Non-forested Areas

Source:

Finnish Environment Institute

The ground frost and snow depth in Tuusula, open area, soil type clay

Frost depth 2004-05 — Snow depth 2004-05

Frost depth mean value 1976-2000 — Snow mean value 1976-2000

Frost depth maximum 1976-2000 — Snow maximum value 1976-2000

The ground frost and snow depth in Salla, forest, soil type fine sand
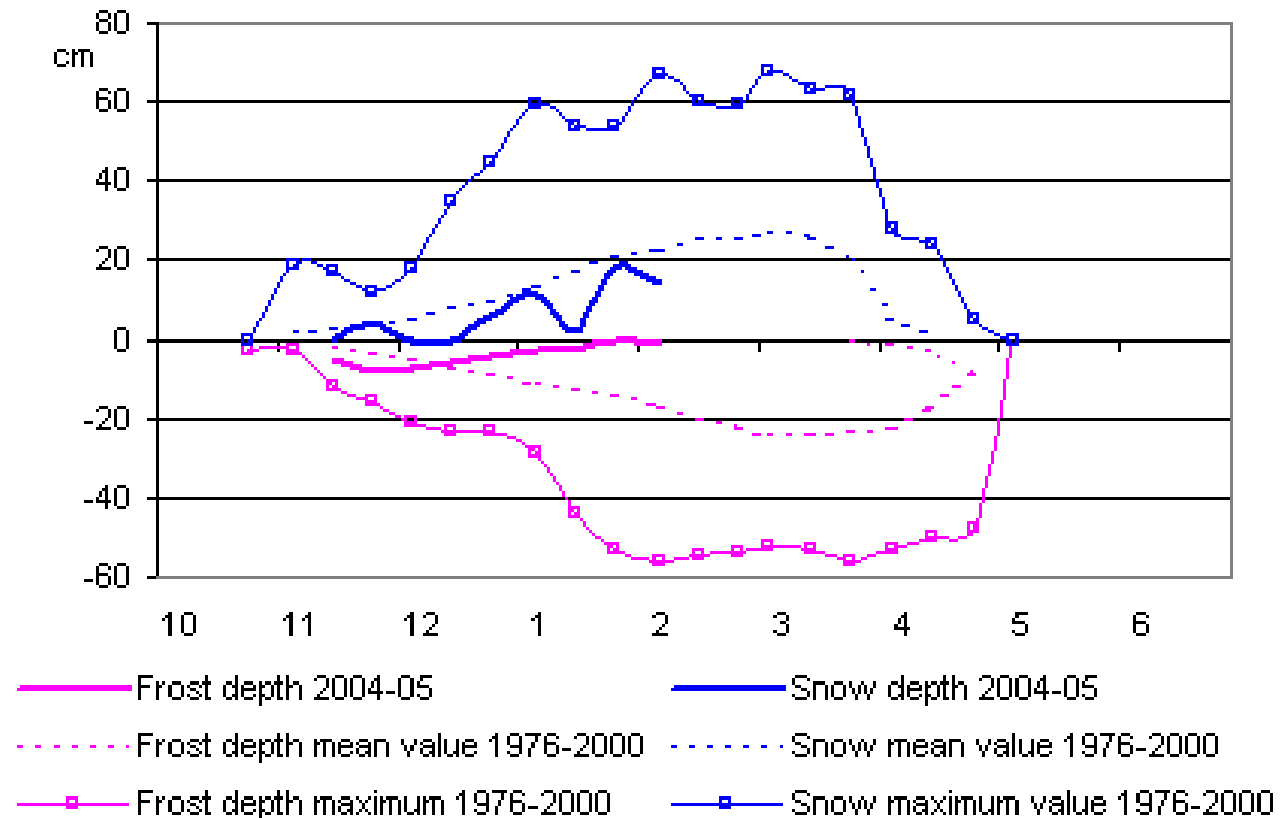
Northern Finland: Maximum mean ground frost 160 cm

Source: Finnish Environment Institute

Frost depth 2004-05
Snow depth 2004-05
Frost depth mean value 1971-2000
Snow mean value 1971-2000
Frost depth maximum 1971-2000
Snow maximum value 1971-2000
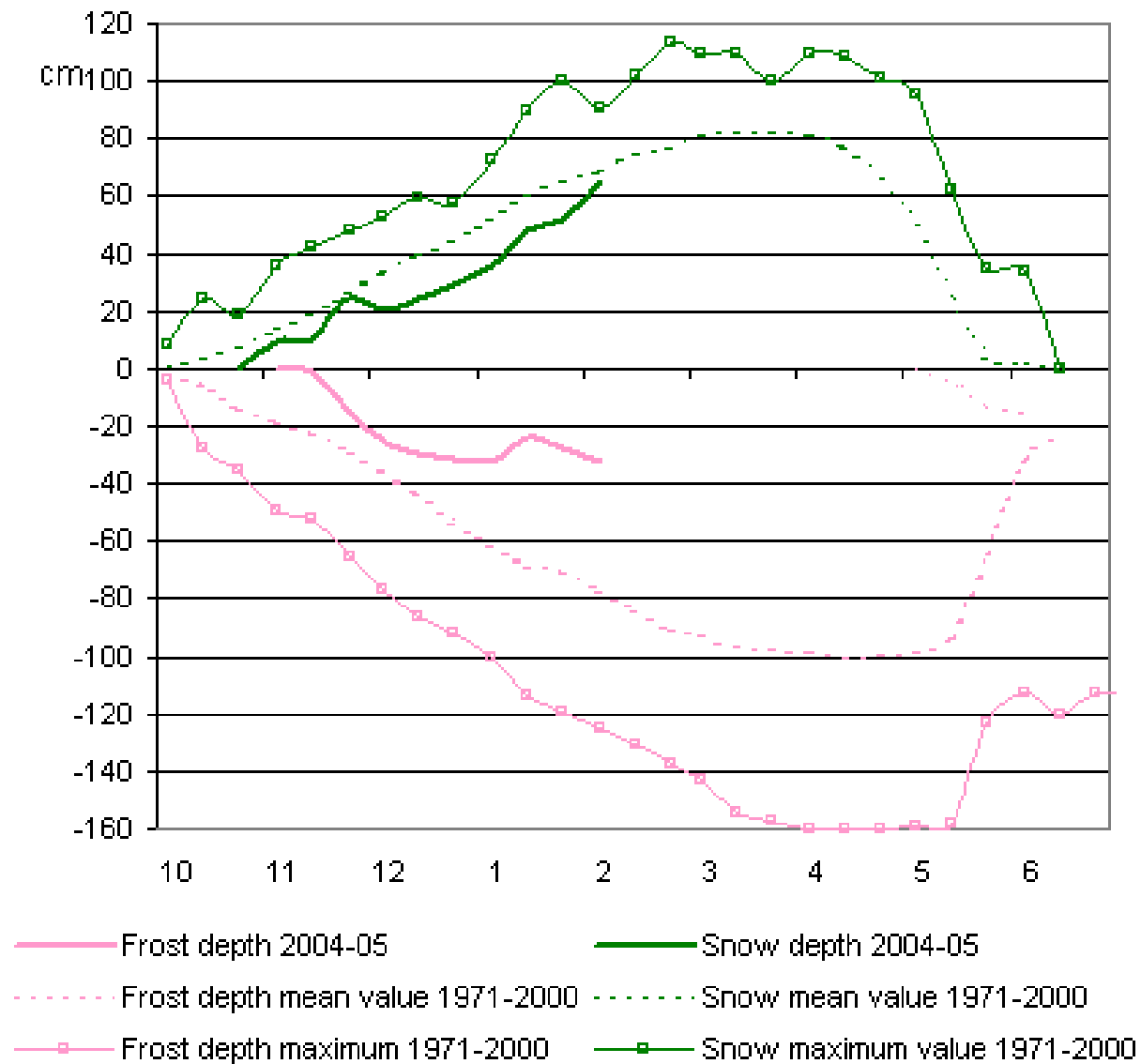
Network of Phenology Observation Stations

Source:

Finnish Environment Institute

Fell Lapland

Forest Lapland

Southern Lapland

Pohjanmaa-Kainuu

Southern Finland

Oak Zone

Observed Leafing in Spring in 2002-204

Helsinki University of Technology
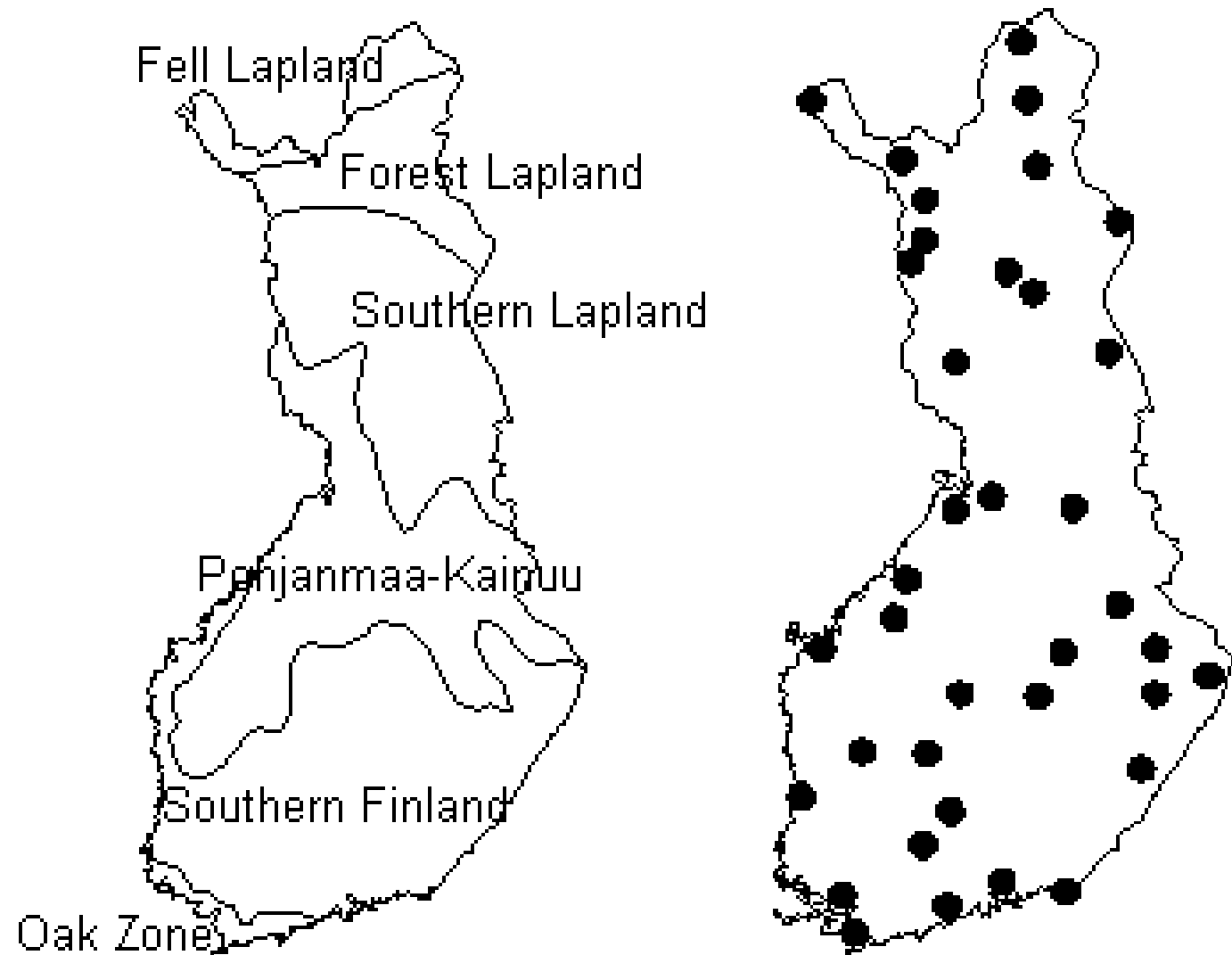
Downy birch: Leafing

- The emerging of the leaves
- The onset of leafing
- The full growth of the leaves

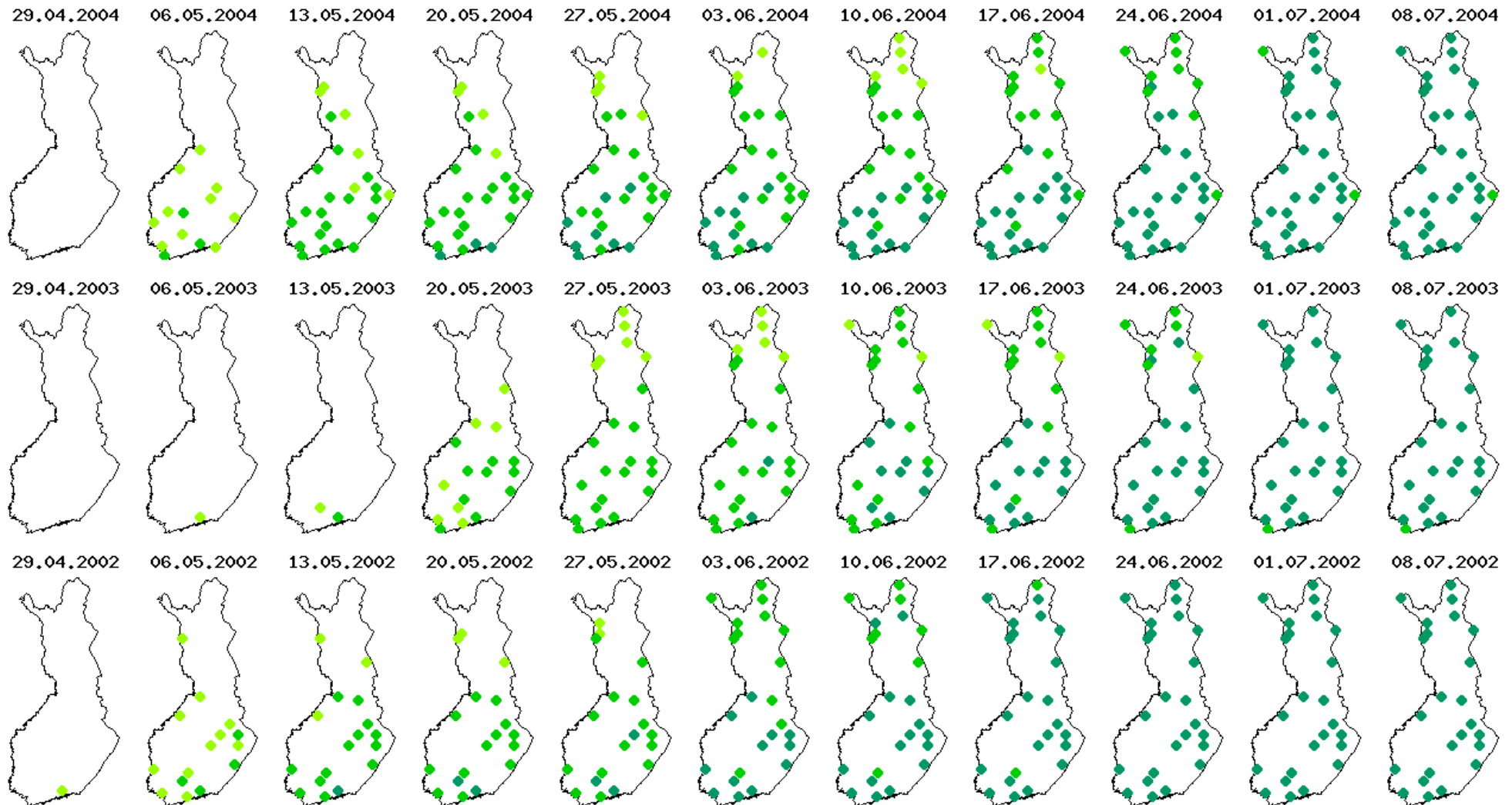Observations are at intervals of one week.

29.04.2004 | 06.05.2004 | 13.05.2004 | 20.05.2004 | 27.05.2004 | 03.06.2004 | 10.06.2004 | 17.06.2004 | 24.06.2004 | 01.07.2004 | 08.07.2004

29.04.2003 | 06.05.2003 | 13.05.2003 | 20.05.2003 | 27.05.2003 | 03.06.2003 | 10.06.2003 | 17.06.2003 | 24.06.2003 | 01.07.2003 | 08.07.2003

29.04.2002 | 06.05.2002 | 13.05.2002 | 20.05.2002 | 27.05.2002 | 03.06.2002 | 10.06.2002 | 17.06.2002 | 24.06.2002 | 01.07.2002 | 08.07.2002

Yellowing of leaves in Fall in 2002-204

Downy birch: Yellowing of leaves

- ▇ (green) The full growth of the leaves
- ▢ (yellow) Leaves yellowed

Observations are at intervals of one week.

| 29.08.2004 | 05.09.2004 | 12.09.2004 | 19.09.2004 | 26.09.2004 | 03.10.2004 | 10.10.2004 | 17.10.2004 | 24.10.2004 |
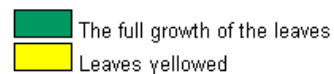
Source:
Finnish
Environ-
mental
Institute

| 29.08.2003 | 05.09.2003 | 12.09.2003 | 19.09.2003 | 26.09.2003 | 03.10.2003 | 10.10.2003 | 17.10.2003 | 24.10.2003 |

| 29.08.2002 | 05.09.2002 | 12.09.2002 | 19.09.2002 | 26.09.2002 | 03.10.2002 | 10.10.2002 | 17.10.2002 | 24.10.2002 |
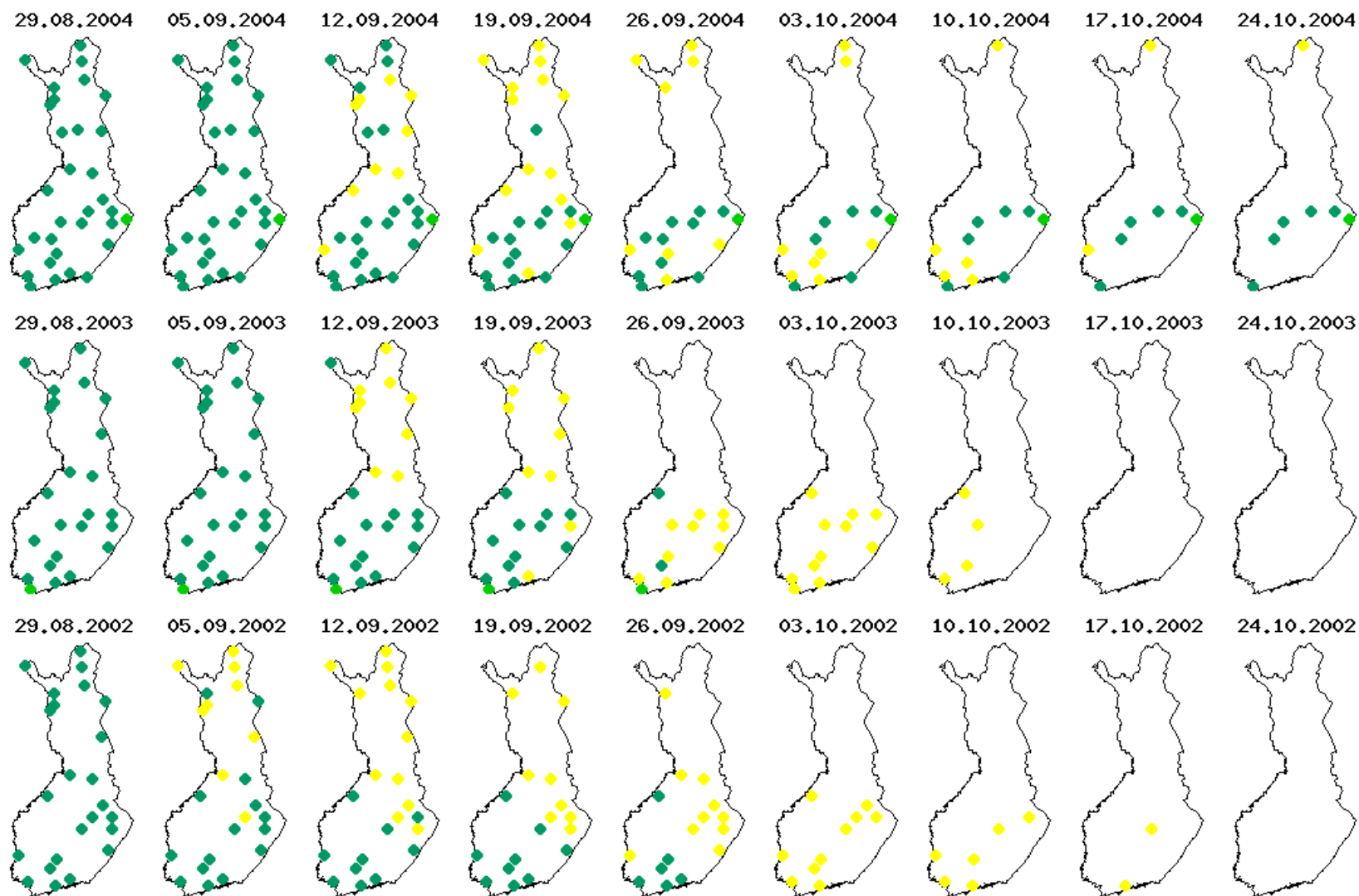
Goal Statement for Freeze / Thaw

⟫ Develop annual maps of landscape freeze/thaw state within the prototype areas

⟫ Provide estimates of thaw onset and freeze-up within the temporal fidelity allowed by ALOS PALSAR coverage

⟫ Support development with satellite scatterometer (QuikScat for snow melt onset / end) and possibly mw. radiometer (SMOS: Launch 2007) data

Prototype Area and Ground Truth

⟩⟩ Prototype area: Finland

⟩⟩ Ground truth:

   ⟩⟩ Weather data from the Finnish Met Office

   ⟩⟩ Ground-based ground frost and snow data from Finnish Environment Institute's observation stations

⟩⟩ Supporting data

   ⟩⟩ Satellite scatterometer data and microwave radiometer data to fill in the gaps in ALOS PALSAR data

Planned Output Products and Product Developers

➤ Output products:

  ➤ Annual maps of landscape freeze / thaw status

➤ Product developers:

  ➤ Helsinki University of Technology

  ➤ Finnish Forest Research Institute

  ➤ Finnish Environment Institute

Permafrost in Russia

Permafrost Regions in the Soviet Union