Aalto University
School of Electrical
Engineering

# From Sea Ice Research to Aalto Satellites: 40+ Years of Remote Sensing and Space Technology Research

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Remote Sensing Days 2014

# Outline of Presentation

- Early years: Remote sensing of sea ice and snow
- Space technology in Finland: International context
- Establishment of framework for education and reseach
- Construction of instruments for remote sensing
- Research projects and field campaigns
- Space technology research
- Conferences

# Remote Sensing of Sea Ice 1971-1979

## Development of sensors and methods for monitoring ice situation

- Funding for several years: Finnish-Swedish Board for Winter Navigation
- 3-channel radiometer operating at 500-900 MHz
- 5-channel microwave radiometer operating at 5 GHz
- Airborne  measurements in the Gulf of Bothnia, 1974-78
- Dielectric measurements and modelling of sea ice
- Brightness temperature modelling of sea ice
- Operational by FIMR / FMI: Ice monitoring by SAR
- Still a problem: water on top of ice

# Ground-based Snow Studies 1979-1985

First BT studies 1979:
Very promising results
=> Work was continued

Retrieval of snow water equivalent and snow extent from radiometer data is challenging

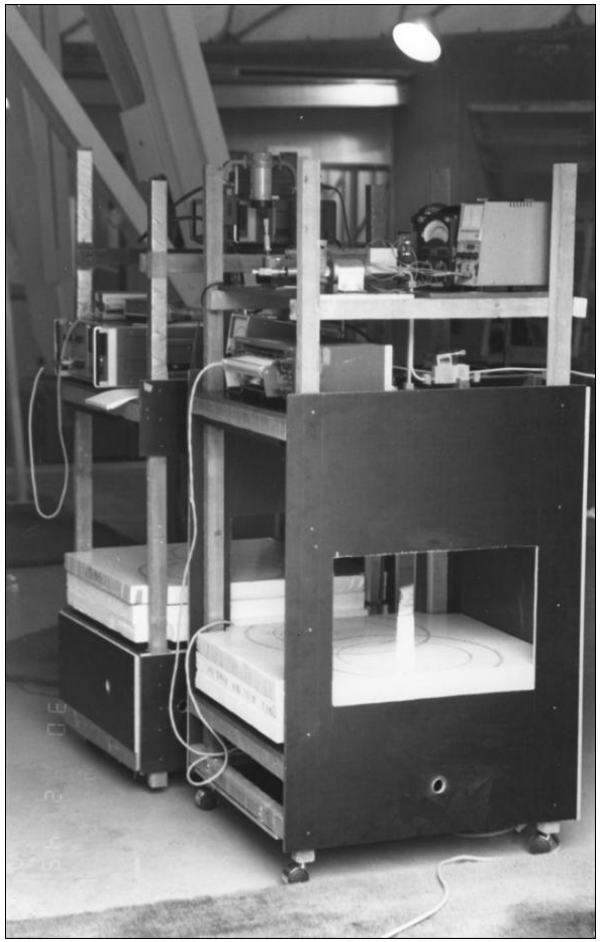
TB Campaign over entire snow season 1985

Dielectric and extinction studies (1981-1985) contributed to HUT Snow Emission Model

Presently: Snow monitoring with optical, SAR, and radiometer data

Brightness temperature (BT) measurements 1-37 GHz, Kirkkonummi

Dielectric and extinction studies 3-90 GHz, Kirkkonummi and Otaniemi



# Space Technology

## International Context in the 1980's

HUT joined European Association of Remote Sensing Laboratories (EARSeL) in 1978

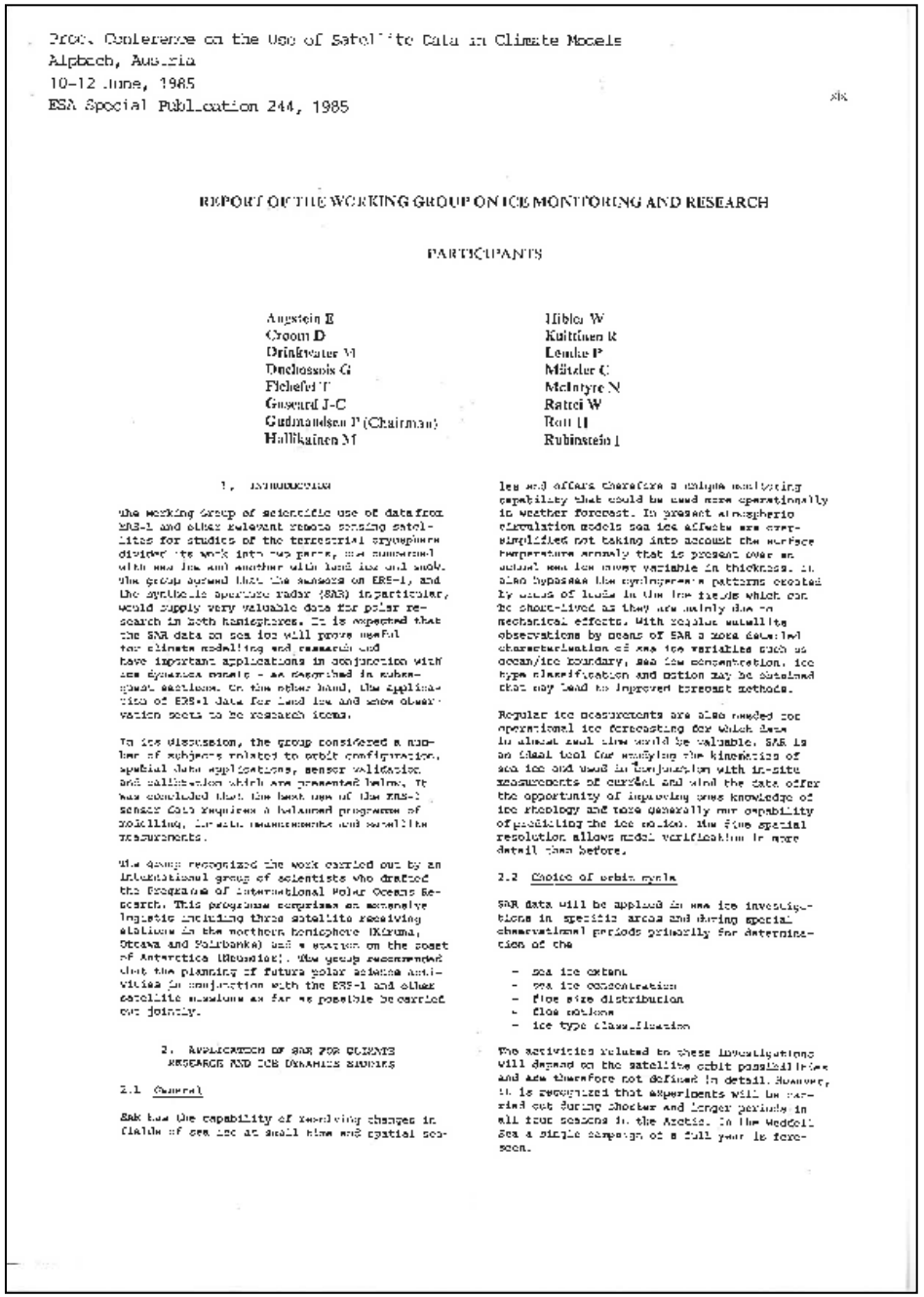
Finland joined EUMETSAT in 1983

Finnish-Soviet cooperation since 1985

Further international agreements with:

- European Space Agency (ESA) as an Associate Member Jan. 1, 1987
- Soviet Union on space research cooperation Jan. 7, 1987
- European Union (EU) Jan. 1, 1995
- European Space Agency as a Full Member Jan. 1, 1995

One of the first Finnish ESA remote sensing conference reports: Conf. on the Use of Satellite Data in Climate Models, June 1985 ➔



Proc. Conference on the Use of Satellite Data in Climate Models
Alpbach, Austria
10-12 June, 1985
ESA Special Publication 244, 1985

REPORT OF THE WORKING GROUP ON ICE MONITORING AND RESEARCH

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1. Introduction

The working group of scientific use of data from ERS-1 and other relevant remote sensing satellites for studies of the terrestrial cryosphere divided its work into two parts, one concerned with sea ice and another with land ice and snow. The group agreed that the sensors on ERS-1, and the synthetic aperture radar (SAR) in particular, would supply very valuable data for polar research in both hemispheres. It is expected that the SAR data on sea ice will prove useful for climate modelling and research and have important applications in conjunction with sea dynamics models - as described in subsequent sections. On the other hand, the applications of ERS-1 data for land ice and snow observation needs to be researched [illegible].

In its discussion, the group considered a number of subjects related to orbit configuration, spatial data applications, sensor validation and calibration which are presented below. It was concluded that the best use of the ERS-1 sensor data requires a balanced programme of modelling, [illegible] measurements and satellite measurements.

The group recognized the work carried out by an international group of scientists who drafted the Programme of International Polar Oceans Research. This programme comprises an oceanographic logistic including three satellite receiving stations in the northern hemisphere (Kiruna, Ottawa and Yellowknife) and a station on the coast of Antarctica (Weddell). The group recommended that the planning of future polar science activities in conjunction with the ERS-1 and other satellite missions as far as possible be carried out jointly.

2. Application of SAR for Oceans Research and Ice Dynamics Studies

2.1 General

SAR has the capability of resolving changes in fields of sea ice at small time and spatial scales and offers therefore a unique monitoring capability that could be used more operationally in weather forecast. In present atmospheric circulation models sea ice effects are oversimplified not taking into account the surface temperature anomaly that is present over an actual sea ice cover variable in thickness. It also bypasses the cyclogenesis patterns created by areas of leads in the ice fields which can be short-lived as they are mainly due to mechanical effects. With regular satellite observations by means of SAR a more detailed characterization of sea ice variables such as ocean/ice boundary, sea ice concentration, ice type classification and motion may be obtained that may lead to improved forecast methods.

Regular ice measurements are also needed for operational ice forecasting for which data in almost real time would be valuable. SAR is an ideal tool for studying the kinematics of sea ice and used in conjunction with in-situ measurements of current and wind the data offer the opportunity of improving our knowledge of ice rheology and more generally our capability of modelling the ice motion. The fine spatial resolution allows model verification in more detail than before.

2.2 Choice of orbit cycle

SAR data will be applied in sea ice investigations in specific areas and during special observational periods primarily for determination of the

- sea ice extent
- sea ice concentration
- floe size distribution
- floe motions
- ice type classification

The activities related to these investigations will depend on the satellite orbit possibilities and are therefore not defined in detail. However, it is recognized that experiments will be carried out during shorter and longer periods in all four seasons in the Arctic. In the Weddell Sea a single campaign of a full year is foreseen.

# HUT Framework for Education and Research

- Professorship in Space Technology 1987
- Master's Program in Space Technology in 1987
- Doctoral Program in Space Technology in 1988
- Course topics:
  - Remote sensing
  - Spaceflight instrumentation
  - Radio astronomy
  - Satellite communications
  - Space physics
- Laboratory of Space Technology in 1988
  - Main research field: Microwave remote sensing
  - One of the largest laboratories in Electrical Engineering Dept.

# Reasoning for Microwave Sensor Construction

**First spaceborne SARs:**
- SeaSat 1978 (100 days)
- ESA ERS-1 1991
- Data availability was poor
- Spatial resolution OK

**First spaceborne radiometers:**
- Nimbus-7 1978 (calibration?)
- SSMI series1987, AMSR-E 1999
- Data availability was OK
- Spatial resolution poor

=>

Build your own sensors to get high-resolution data when/where you want it

Data can be used for model development and verification

Airborne demonstrators provide proof of concept for satellite sensors

Provides hands-on opportunities for students

University of Kansas truck-based system 1982

# Airborne HUTSCAT Scatterometer 1990

8-channel radar

5.4 and 9.8 GHz

VV, HH, VH, HV pol

Built in anticipation of ESA ERS-1 launch to study various applications

Special feature: Measures backscatter vs. distance with 0.65 m resolution (provides eg. tree height)

Used for studies of
- Forests
- Sea ice
- Snow

# Skyvan Research Aircraft 1994

Modified for remote sensing research:

- 28 VDC / 230 VAC power outlets
- local area network
- central computer
- advanced navigation system

Accommodates 2 pilots, 8 researchers, and up to 300 kg of instrumentation

Used for data collection and campaigns in Europe

# Airborne HUTRAD Radiometer 1995/2001

16-channel radiometer

Operates at 6 frequencies between 6.9 and 93 GHz, V and H polarisation

36.5 GHz radiometer fully polarimetric including calibrator (2001)

Built in anticipation of ESA MIMR (never materialised) and U.S. AMSR-E (nearly identical technical parameters)

Used for studies of
- Snow
- Sea ice
- Forests

# Instrumentation Highlights

HUTSCAT: National Research Project of the Year 1989

T&T
VUODEN TUTKIMUS-PROJEKTI

**Mikroaalto-tutkasta vuoden tutkimusprojekti**

Teknisessä Korkeakoulussa kehitetty mikroaaltotutka valittiin vuoden tutkimusprojektiksi Tekniikka- &Talous-lehden järjestämässä kilpailussa.

Tutkan kehittämistyötä on vetänyt avaruusteknikan professori Martti Hallikainen. Tutka tarjoaa lupaavia mahdollisuuksia erityisesti metsien kartoituksessa. Sen uskotaan pystyvän mm. metsien terveydentilan seurantaan.

SIVU 12

*Tutka mittaa kahdeksalta kanavalta samanaikaisesti ja tieto voidaan käsitellä reaaliajassa.*

HUTSCAT measures backscatter profile 1990

RESEARCH

## A FINNISH FIRST IN REMOTE SENSING

An advanced helicopter-borne remote sensing instrument has been developed at the Laboratory of Space Technology of the Helsinki University of Technology. The first of its kind in the world, the 8-channel radar scatterometer can be used to identify tree species and determine tree height. Measurement of forest pollution is another possible area of application. Possibilities of using it for identifying sea ice types have also been investigated.

Forest radar profile.

"The method is based on the use of microwaves which can penetrate, for instance, the various layers of a forest, allowing the radar to make measurements from tree top to ground level," says Professor *Martti Hallikainen*, Director of the Laboratory of Space Technology.

The instrument measures the radar return spectrum for eight channels in 17 milliseconds, which corresponds to an along-track distance of 34 cm for the helicopter speed of 20 m/s. The incidence angle can be varied between 0 and 60 degrees off nadir. The shape of the radar return spectrum (backscattered amplitude vs. range) was found to have high correlation with tree species. Using the principal component analysis, identification of tree species was shown to be possible. Another novel feature of the new scatterometer is its capability to determine the tree height along the flight path.

"Unlike optical measuring instruments which can only be used in clear weather, the scatterometer functions in cloudy and misty weather as well -- an added advantage when it comes to mapping forests in Finland," Professor Hallikainen observes.

What is now the Space Technology Lab's main asset, and a forerunner worldwide, became as sophisticated as it is by chance.

"Our original idea was much simpler. But we happened to embark on the project at a time of rapid development in the field of signal processors; had we started earlier we could not have come as far simply because the right components were not available. It was a case of doing the right thing at the right time."

The microwave radar project is being financed by the *Technology Development Centre* TEKES.

In addition to the forest mapping studies, the Space Technology Lab has tested the instrument's capability to identify sea ice types. Results indicate that it is a promising tool for this purpose, being capable of differentiating between thick level ice, hummocks and ice ridges. Next on the agenda is monitoring of forest pollution. According to Professor Hallikainen a new and improved version of the scatterometer, which is now being designed, will be able to gather three-dimensional data from a wide area, a big step forward from the one-flight-path measurements now possible. No such remote sensing instrument exists anywhere in the world.

The Laboratory of Space Technology was officially established in 1988. Construction of microwave remote sensing instruments and investigation of various remote sensing applications are the main areas of research, the emphasis being on radar remote sensing to. The Laboratory also undertakes atmospheric research; Professor Hallikainen mentions an ozone-measuring instrument being built there, which is planned to be operational in 1991.

■

(dm)

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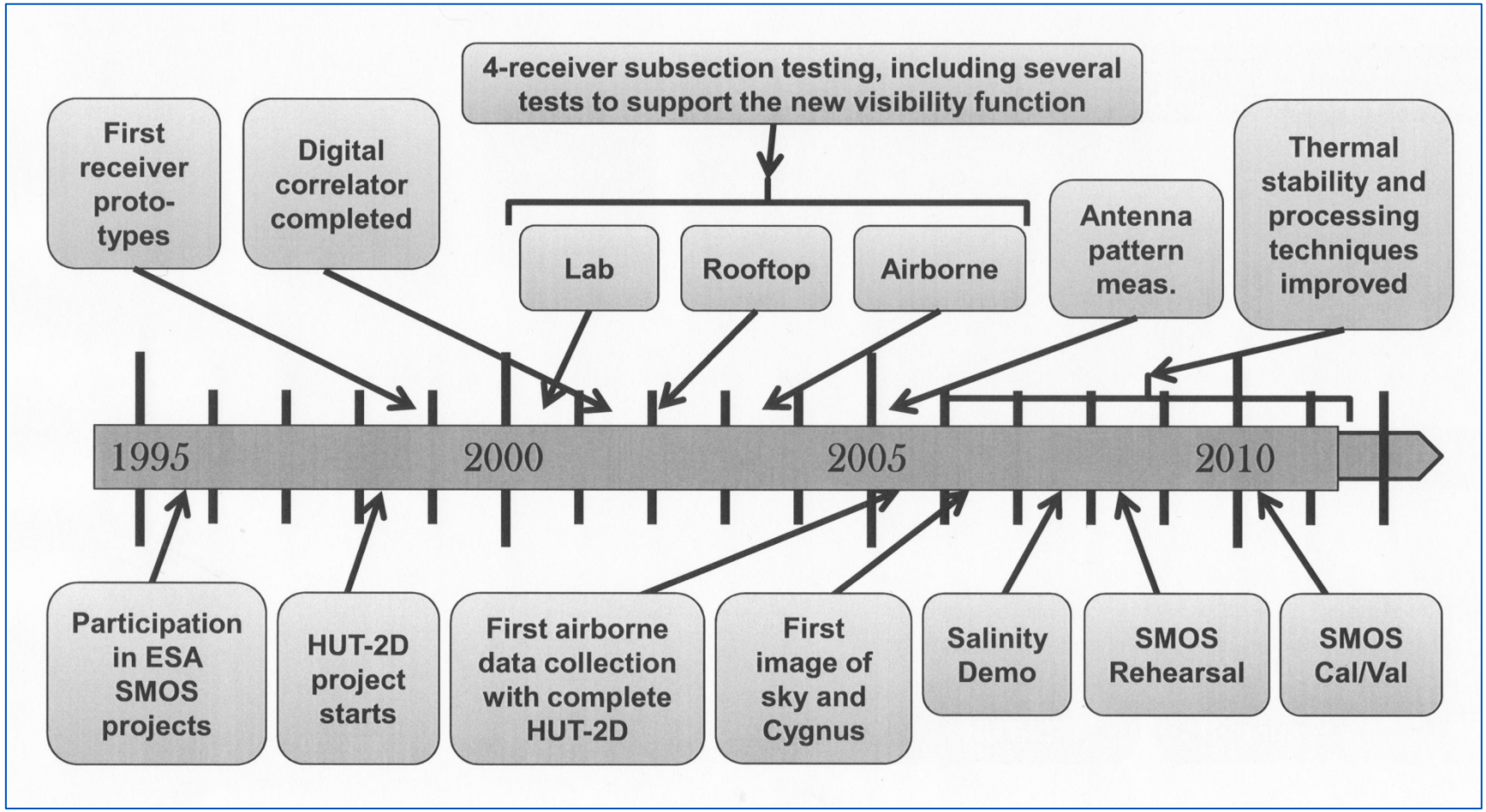
Calibrator for 36.5 GHz fully polarimetric radiometer 1999

IEEE

GEOSCIENCE and REMOTE SENSING
*Newsletter*

December 1999

# Timeline for Airborne HUT-2D Radiometer



# Airborne HUT-2D Interferometric Radiometer 2005

1.4 GHz radiometer
- 36 identical receiver / antenna units
- correlator
- 2 calibration systems
- 2 m by 2 m, 100 kg
- accommodated below Skyvan fuselage

Improved spatial resolution and data vs. incidence angle

World's first airborne interferometric radiometer for remote sensing

Proof of concept for ESA SMOS mission's interferometric radiometer

# First International Research Projects

- ESA AO Application of ERS-1 AMI data to remote sensing of snow (1988); Finnish funding 1991-1994
  - HUT (PI), VTT, Finnish National Board of Waters and Environment, Canada Centre for Remote Sensing, Atmospheric Environment Service (Canada), National Weather Service (USA), NASA GSFC (USA), Lund University of Technology (S)
- ESA Microwave interaction with the Earth's surface (1989)
  - HUT (PI), FIMR, CESR (F), MIT (USA)
  - ESA contact: Maurice Borgeaud (presently Head of the Science, Applications, and Future Technologies Department)
- EU EUFORA (1996): European forest observations by radars
  - CESBIO (PI) (F), and 8 other participants
- EU SNOW-TOOLS (1996): Research and development of remote sensing methods with main focus on snow hydrology
  - NORUT (PI) (N), and 6 other participants
- These and subsequent ESA / EU projects helped to establish HUT as a regular partner in international projects

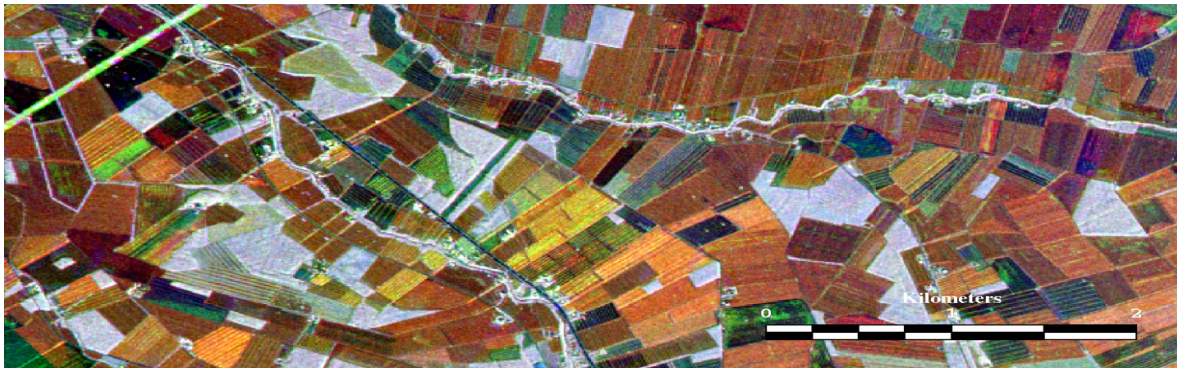
# First International Airborne Campaigns

- SAAMEX (1990): Surface and Atmospheric Airborne Microwave Experiment (Base for operations: Oulu)
  - HUT (PI): HUTSCAT and early version of HUTRAD (helicopter)
  - British Meteorological Office: 89 and 157 GHz radiometers (C130)
  - Test sites: Sea ice, snow, forest
- ESA EMAC (1995) European Microwave Airborne Campaign (Base for operations: Oulu)
  - HUT (PI), British Met Office (BMO), DLR, Tech Univ Denmark
  - HUT: HUTRAD onboard Skyvan
  - BMO: 89 and 157 GHz radiometers onboard C130
  - TUD EMISAR: L- and C-band SAR
  - DLR ESAR: early version of SAR
  - Test sites: Sea ice, snow
- Good learning opportunities for HUT for organising campaigns
- The campaigns helped to establish reputation of HUT as an airborne  data provider

# Radar Studies of Land-Use and Forest

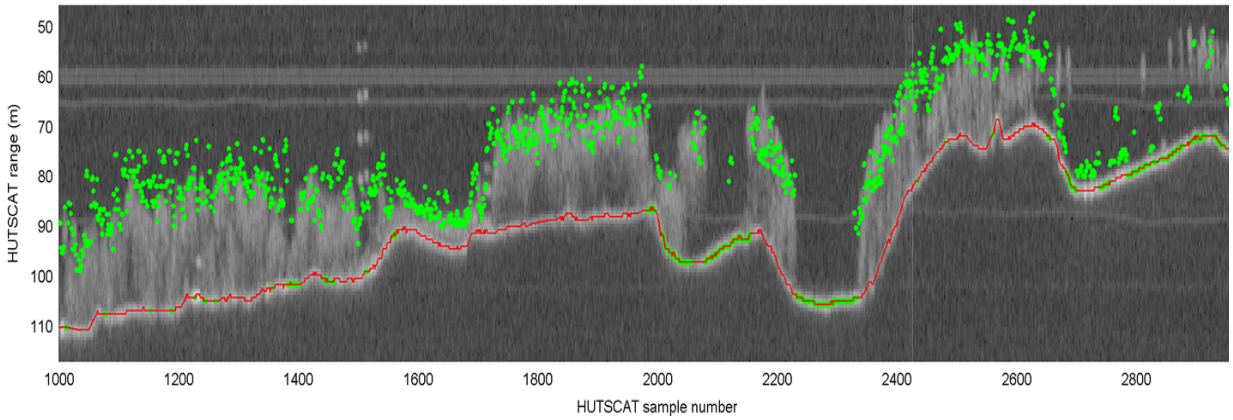
**ESA EMAC Campaign 1995**
**EMISAR**, Tyrnävä:

**Red: L-Band total power, May**
**Green: L-Band total power, March**
**Blue: C-Band total power, March**




**FinSAR Campaign 2003**
**ESAR,** Kirkkonummi:

Comparison of HUTSCAT-derived forest profile and Random Volume ov Ground Model -derived tree height



# Contributions to Space-based Applications for Operational / Semioperational Use

- Retrieval of snow water equivalent from microwave radiometer data (FMI)
- Retrieval of snow extent from SAR data (FMI)
- Monitoring of sea ice in Finnish waters by SAR (FIMR/FMI)
- Monitoring of water quality with optical data (SYKE)

# Missed Opportunities

- Building airborne Synthetic Aperture Radar (around 1989)
  - Funding proposal failed
  - Denmark, Germany and  Netherlands built SAR systems
- Building flight model of HUTSAT satellite (1990's)
  - Funding proposal failed
  - Now Aalto-1/2 projects in progress
- Participating in Russian Mars subsurface radar project (1990's)
  - Goal: Find out whether there is liquid water below the surface
  - 2-year preparatory project started 1991, agreement with Russia OK
  - Then Finland decided not to cooperate with Russia
- Writing articles...

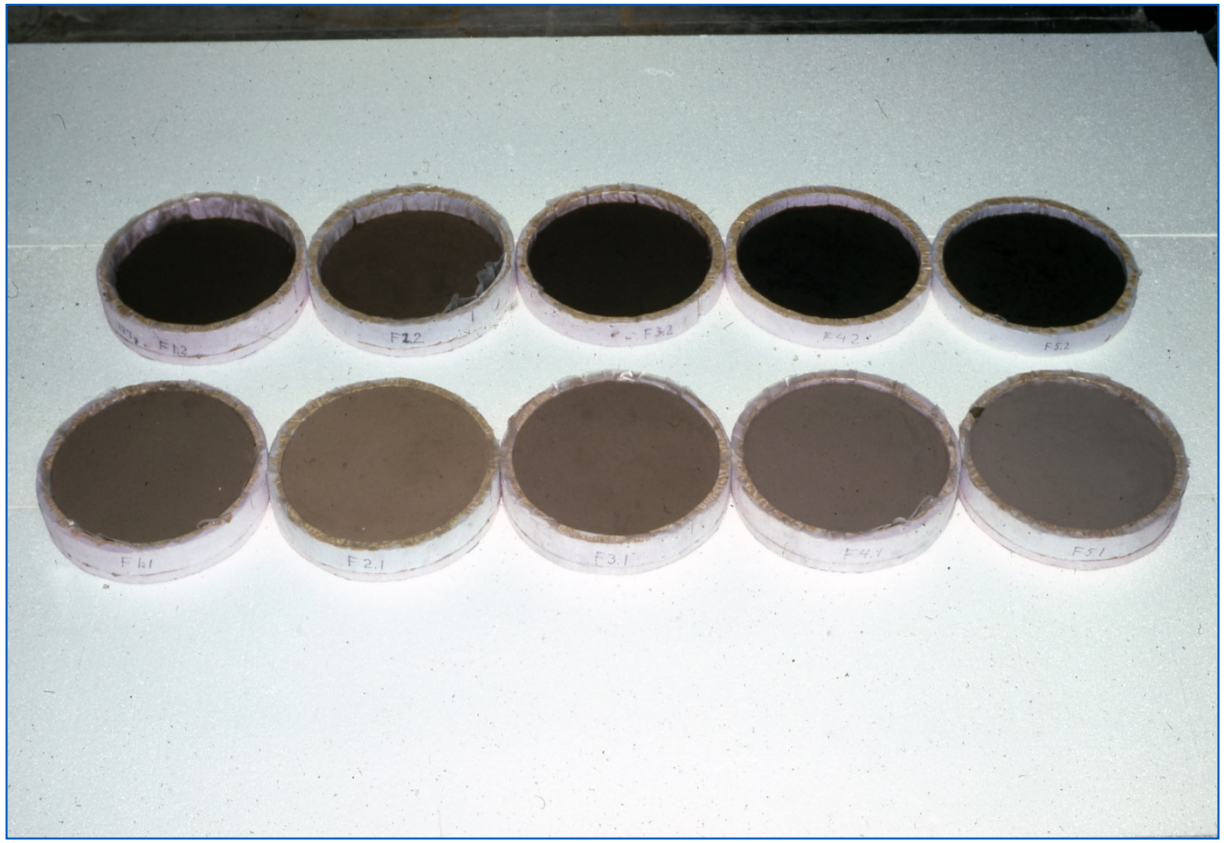
# Want Citations?
## Do Not Build Sensors, Do Basic Research

Unlike sensor building projects, basic research yields citations in the literature

Retrieval of soil moisture was a hot topic in the U.S. already in the early 1980's (still is)

Our two-part article on dielectric measurements and modelling of soils in the 1.4-18 GHz range (1985) is still one of the most highly cited publications of IEEE Trans. Geosci. Remote Sensing

Samples of 5 different soils ready for dielectric measurements at the University of Kansas Remote Sensing Laboratory



# Contributions to ESA SMOS Mission

## SMOS Launched in November 2009

- HUT-2D radiometer provided proof of concept for SMOS interferometric radiometer
- First testing of SMOS on-board calibration system concept on HUT-2D
- Verification of SMOS external calibration strategy using HUT-2D
- Prototyping of SMOS Noise Injection Radiometer (NIR) and Calibration System (CAS), with Finnish industry
- Characterization of NIR and CAS; data used by SMOS Level-1 data processor
- First-ever SMOS-like retrieval of Sea Surface Salinity with HUT-2D
- Participation in SMOS Cal/Val airborne campaigns in Central and Southern Europe 2008 and 2010 with HUT-2D onboard Skyvan aircraft

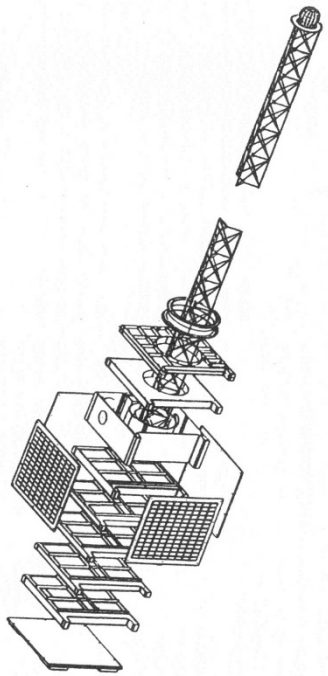
# Building a Finnish Satellite

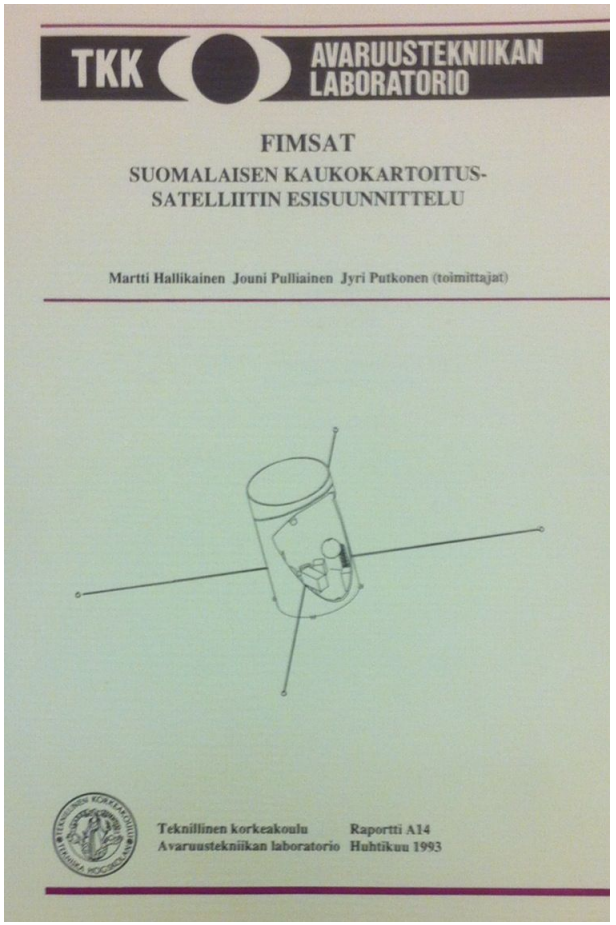
The outcome from the HUTSAT project in 1994 was a half-finished engineering model

Obtaining further funding failed

Doctoral courses were used to familiarise students with various tasks of satellite and payload design

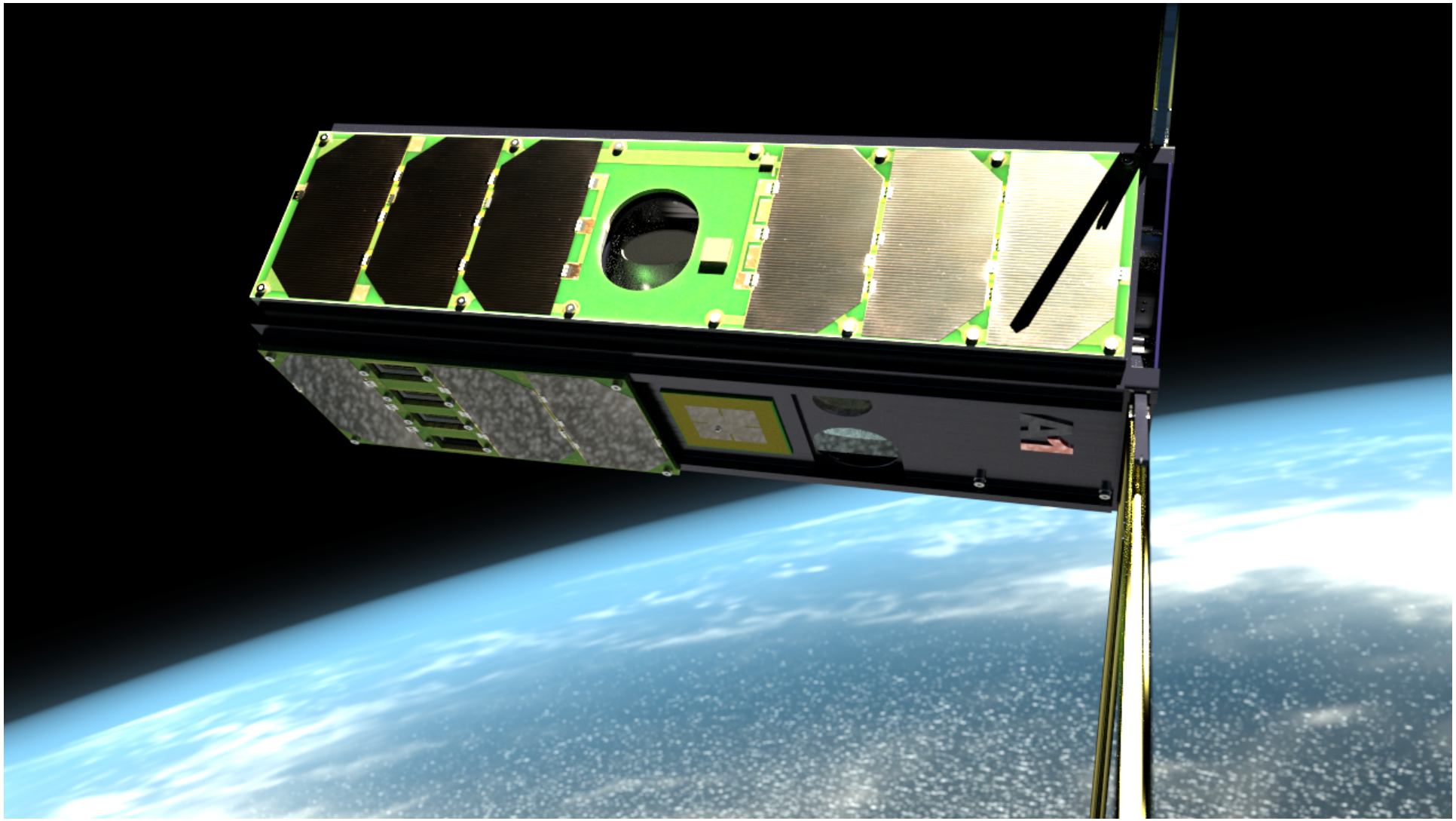
HUTSAT mechanical structure





# Building a Finnish Satellite

# The First Finnish Satellite – Aalto-1



# Organising International Conferences

URSI General Assembly, Espoo, 1978: 1200 attendees

EARSeL General Assembly and Symposium, Espoo, 1989: 160 attendees

IEEE IGARSS 1991, Espoo: 700 attendees

URSI Commission F Microwave Signatures 2013, Espoo: 80 attendees

IEEE MicroRad 2016, Espoo: 11-14 April 2016; Further information soon available

# Supervision of Ph.D. Dissertations

1994: Juha Hyyppä, Merja Tornikoski*, Jouni Pulliainen
1995: Kari Leppänen*
1998: Silja Pohjolainen*
1999: Lauri Kurvonen, Anne Lähteenmäki*
2000: Jochen Grandell
2001: Jarkko Koskinen, Wang Huining, Tarja Liljeström*
2002: Kaj Wiik*
2003: Janne Lahtinen
2005: Matti Anttila, Zhang Yuanzhi
2006: Ali Arslan, Sampsa Koponen
2007: Marko Mäkynen, Andreas Colliander
2008: Ilona Torniainen*
2009: Kari Luojus, Talvikki Hovatta*
2010: Elina Nieppola*
2012: Molera Guifre*, Jaan Praks, Juha Lemmetyinen
2013: Minttu Uunila*, Karri Koljonen*, Marcus Engdahl, Juha Kainulainen
2014: Aku Riihelä, Oleg Antropov

* Radio astronomy