ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Satellite-based research, services and products for high latitude terrestrial areas: FMI contribution

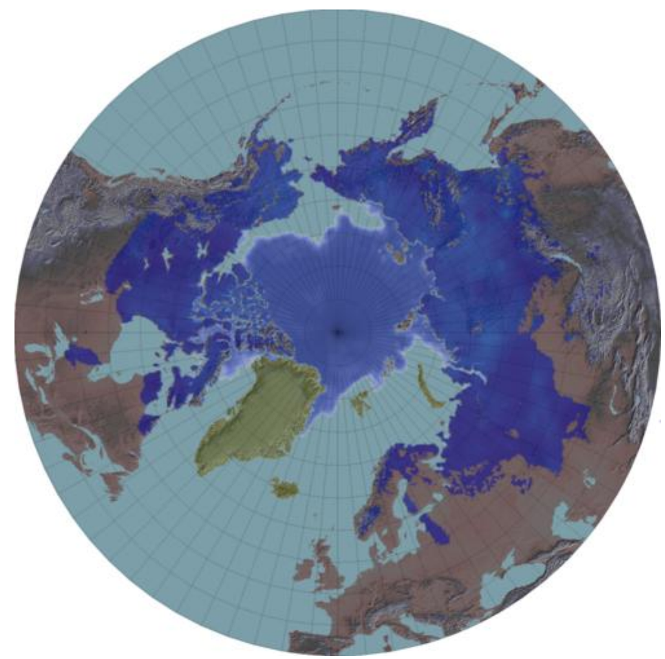
Jouni Pulliainen
Finnish Meteorological Institute

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

FMI Arctic Space Centre at Sodankylä (FMI-ASC)

- **National Satellite Data Centre (NSDC) as a key function**
  - Co-operation with ESA, NASA, EUMETSAT and institutes and companies in Italy, China, Japan and USA
  - Public-Private-Parnership and shared systems with Finnish R&D institutes
- **Continuous monitoring of polar regions by satellites**
  - Atmosphere, land and sea ice
  - Space weather
  - Unique products on cryosphere for research and operational applications
- **Reception of data from Earth Observation (EO) satellites**
  - Part of Colloborative Ground Segment for EU Copernicus Sentinel satellites
  - Data/product archives and real-time situational awareness

Snow mass and ice cover (29 Oct. 2017)



ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

NSDC Real-Time Satellite Data Acquisition and Processing

Current operational (free access)

- EOS-Terra/MODIS (USA)
- EOS-Aura/OMI (USA)
- Suomi-NPP/VIIRS, OMPS (USA)
- FY-3B & FY-3C / MERSI (China)

Current operational (commercial)

- COSMO-SkyMed (Italy)

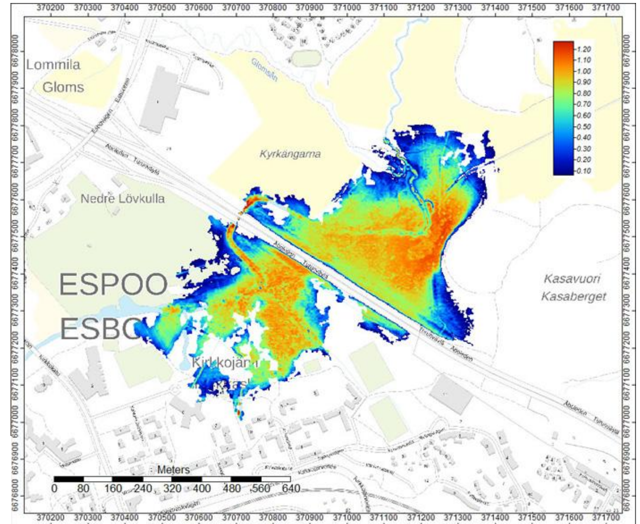
Copernicus Sentinel ground segment (free access)

- **Sentinel-1 Collaborative GS:** National Mirror Site and data downlink (local reception)
- **Sentinel-2/3 Collaborative GS :** National Mirror Site

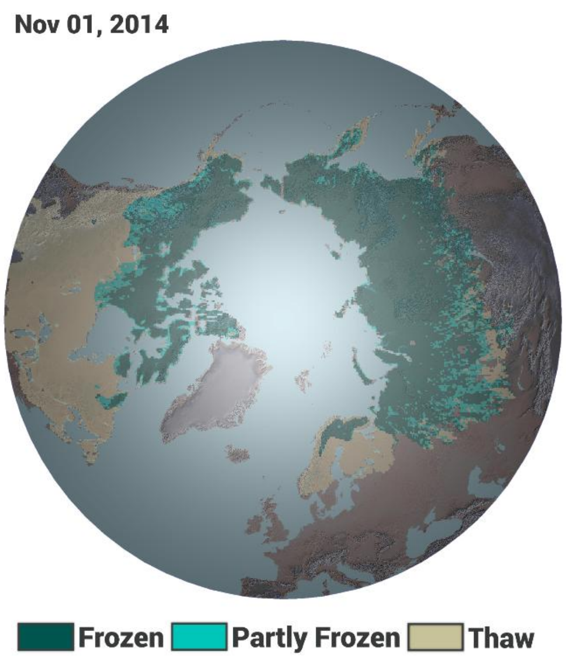
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Land cryosphere products

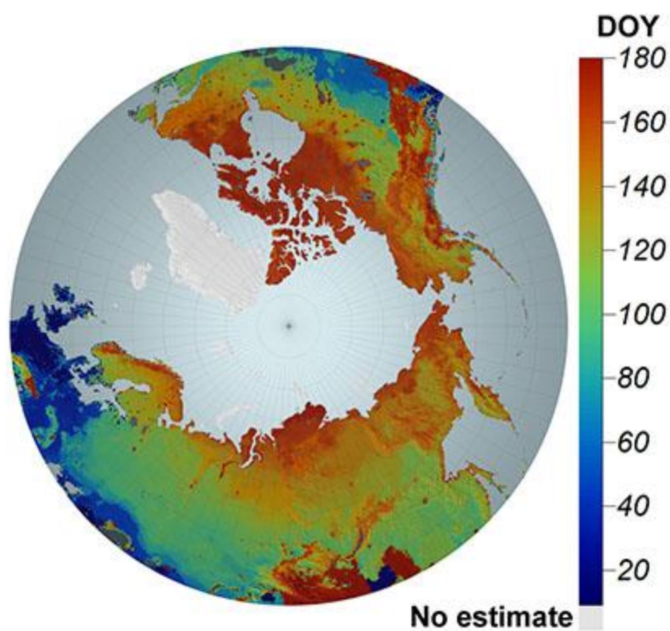
- Near-Real-Time information and Climate Data Records on snow and seasonal frost
- Quasi-real-time information also related to floodings (and on sea ice conditions for winter-time navigation)



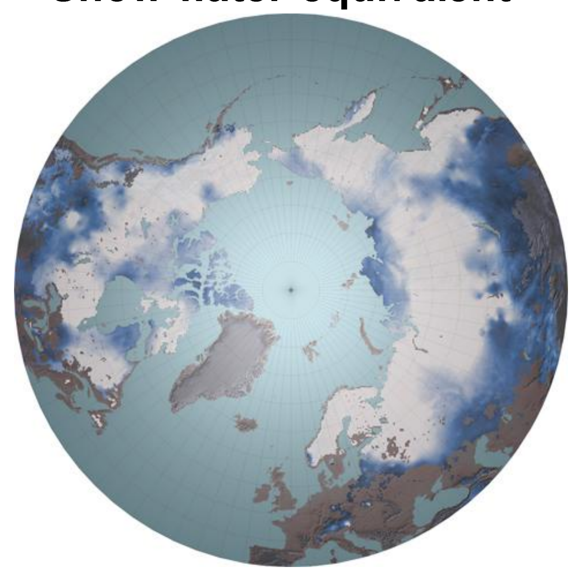
Soil frost



Day of Snow Clearance Year 2000



Snow water equivalent



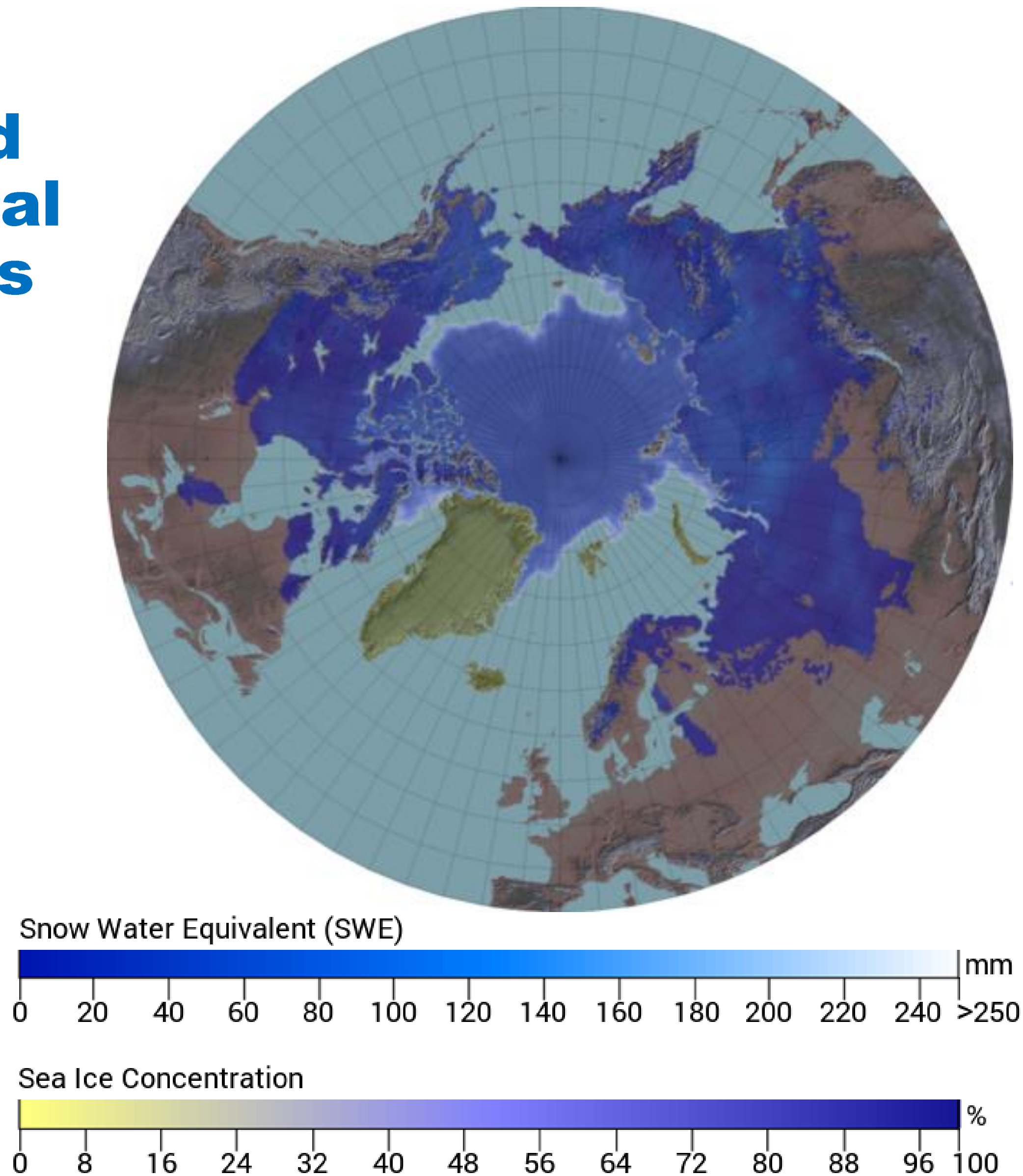
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Snow and ice in the Arctic:

Space-borne data-derived information for operational and research applications

- A FMI product on snow (SWE) and sea ice conditions
    - EUMETSAT OSI/H-SAFs and ESA GlobSnow heritage
    - Assimilation of SSMI-S microwave radiometer data and synoptic snow depth observations
    - Situation on 29 October 2017
    - Example on information feasible to support dowstream services

Snow mass and ice cover (29 Oct. 2017)



ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

FMI-NSDC Products for Hemispheric and Regional SWE: Snow extent and mass using space-borne microwave radiometry

GlobSnow Hemispheric 25-km-SWE

- ❑ 1979 – 2015 daily CDR on SWE (**EaseGrid/0.25º lat-lon grid**)
  - ❖ Revision in 2016 under FP-7 ERA-CLIM2 project
- ❑ NRT processing in operation: daily, September – May
  - ❖ Implemented in former ESA GlobSnow project, future with EUMETSAT H-SAF
- ❑ www.globsnow.info

EU-Copernicus Land Monitoring Service's Hemispheric 5-km-SWE

- ❑ NRT processing starting 2016: daily, year-round (**EaseGrid**)
- ❑ VIIRS/IMS-mask for the snow extent (Sentinel-3 SLSTR in future)
- ❑ Data services TBD

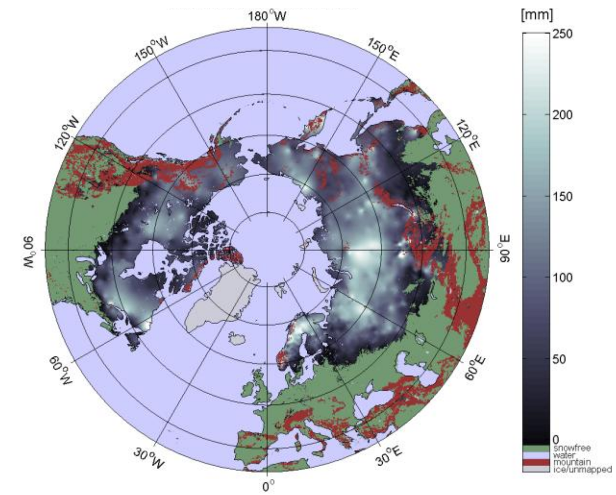
EUMETSAT H-SAF Pan-European 0.25º-SWE (H13)

- ❑ NRT processing in operation: daily, year-round (**lat-lon grid**)
- ❑ hsaf.meteoam.it

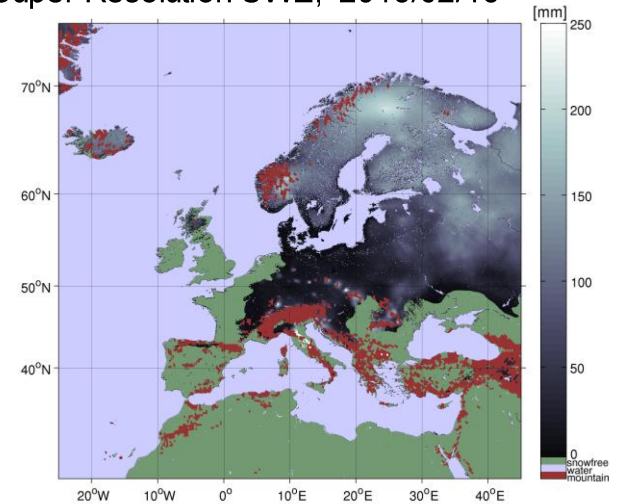
Prototype Pan-European 0.05º-Super-Resolution-SWE (SR-SWE)

- ❑ NRT processing in operation: daily, year-round (**lat-lon grid**)
- ❑ VIIRS/IMS-mask for the snow extent (Sentinel-3 SLSTR in future)
- ❑ saana.nsdc.fi

Copernicus Hemispheric 5-km-SWE, 2016/03/16

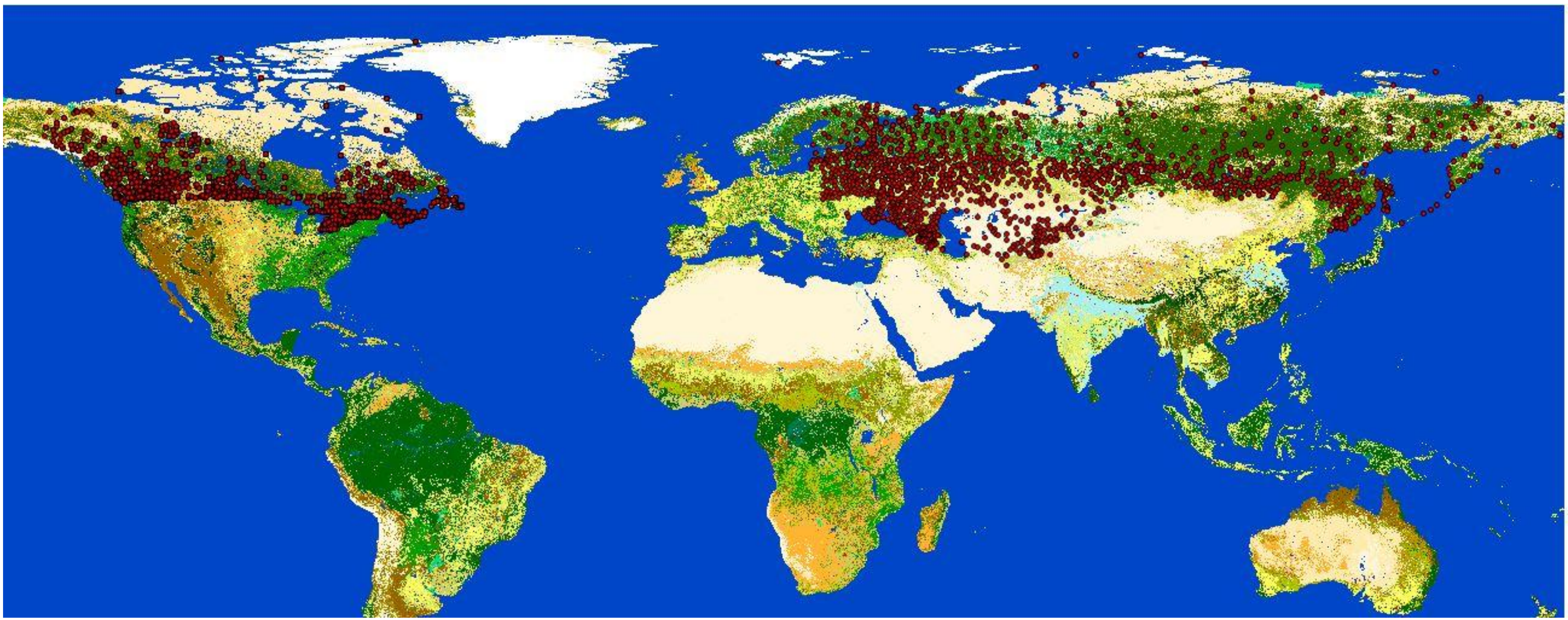


Super-Resolution-SWE, 2013/02/16



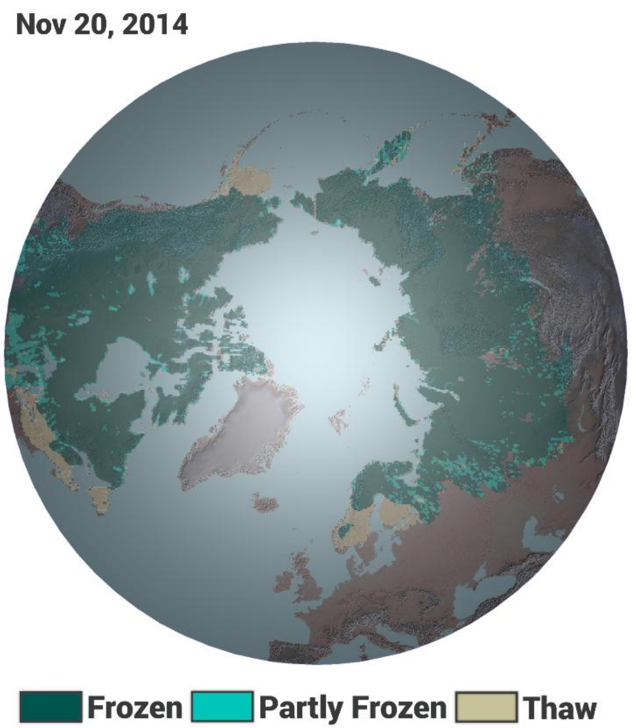
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

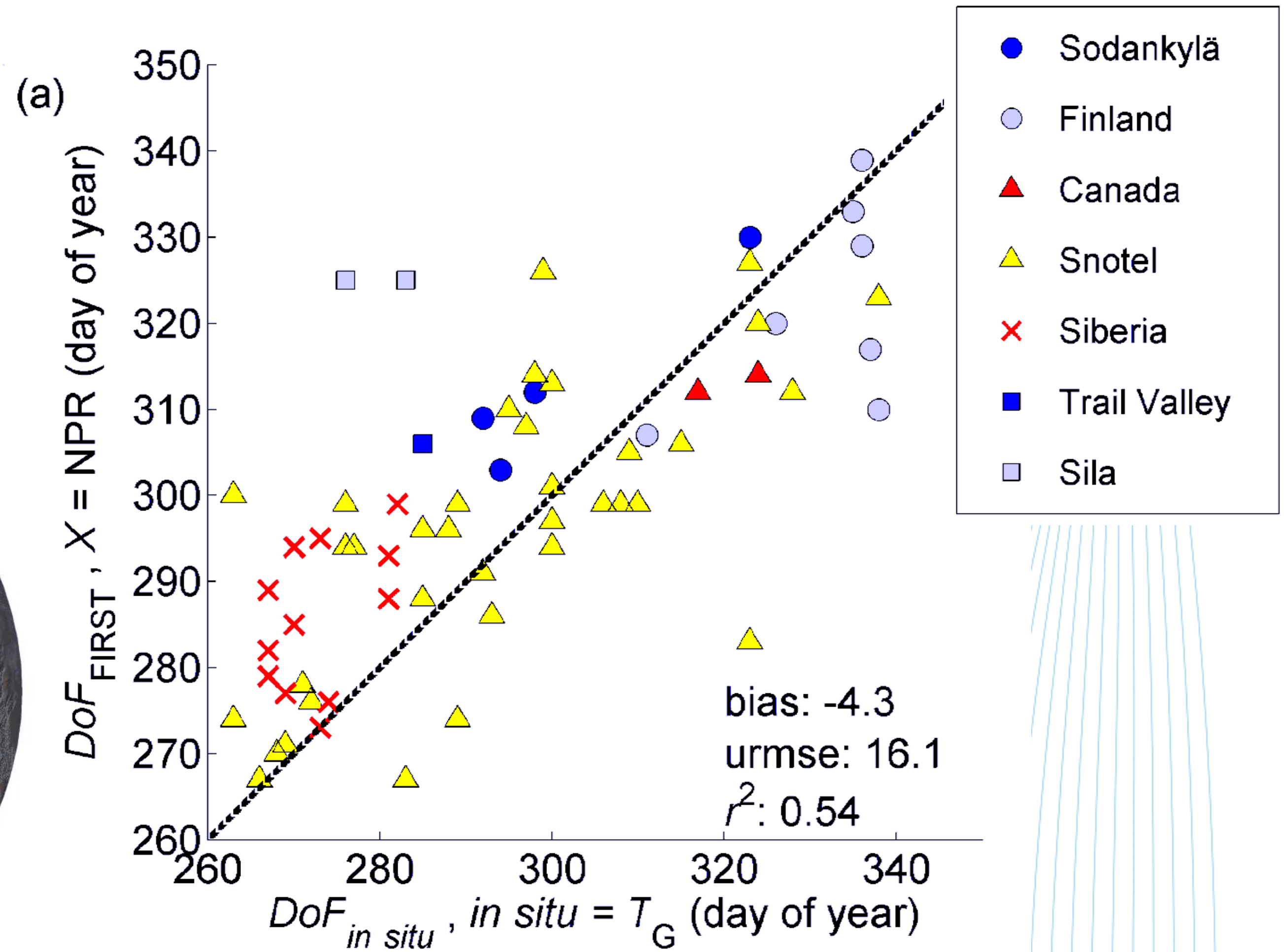
Validation of SWE products using independent (historical) reference data from snow courses



SMOS FT vs *in situ* data – day of freezing

- Day of freezing compared (2010 – 2015)
- *In situ* data: soil temperature at depth of 5 cm





ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Research on snow-related satellite applications utilizing Sodankylä CAL-VAL infrastructure

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Calibration and Validation at NSDC


Mixed / spruce
forest, thicker
organic layer

Pine forest,
mineral soil

Saariselkä
tundra site

Sparse forested
wetland

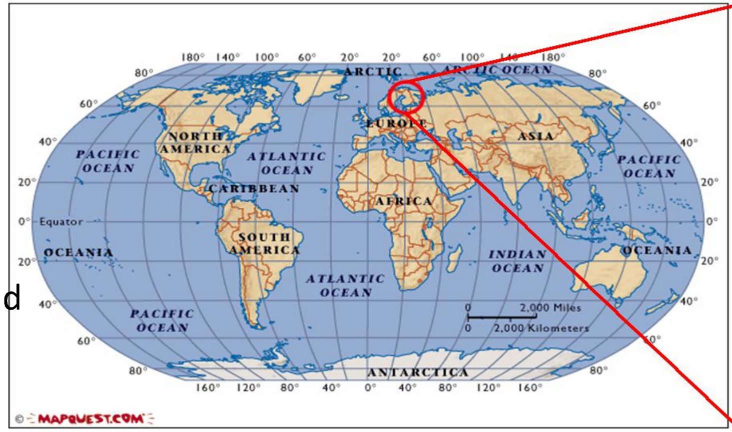
Open wetland

Finnish Meteorological Institute

Arctic Research Centre/NSDC

Main focus on

- Satellite activities: reception, processing and archiving
- CAL-VAL super-site
- Freeze/thaw measurements
- Snow measurements: in-situ, airborne and spaceborne
- Atmospheric soundings
- Meteorological observatory
- CO2 and CH4 fluxes (different ecosystems)



Campaigns and training schools

- ESA/NoSREx (2009-2013)
- COST-Pergamon summer school (2013)
- WMO/SPICE meeting (2014)
- Snow physics training school (2015, 2017)

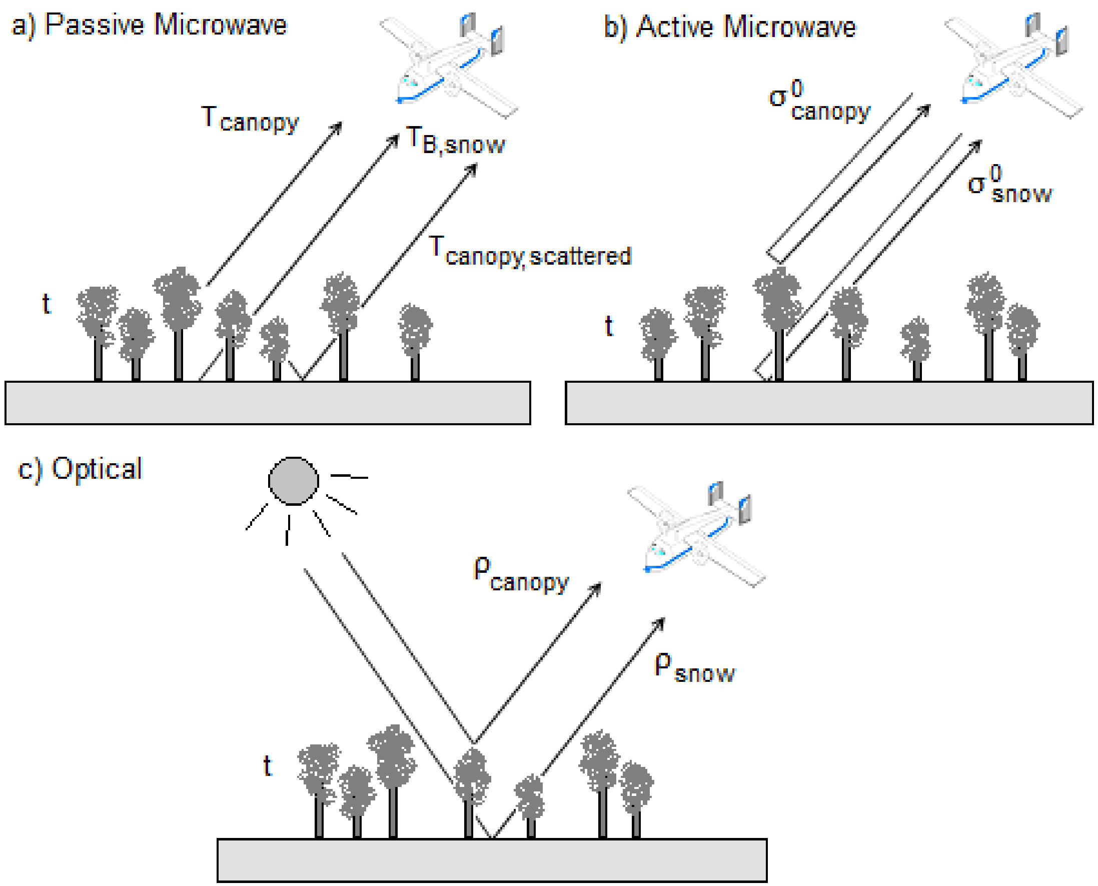
On-site facilities

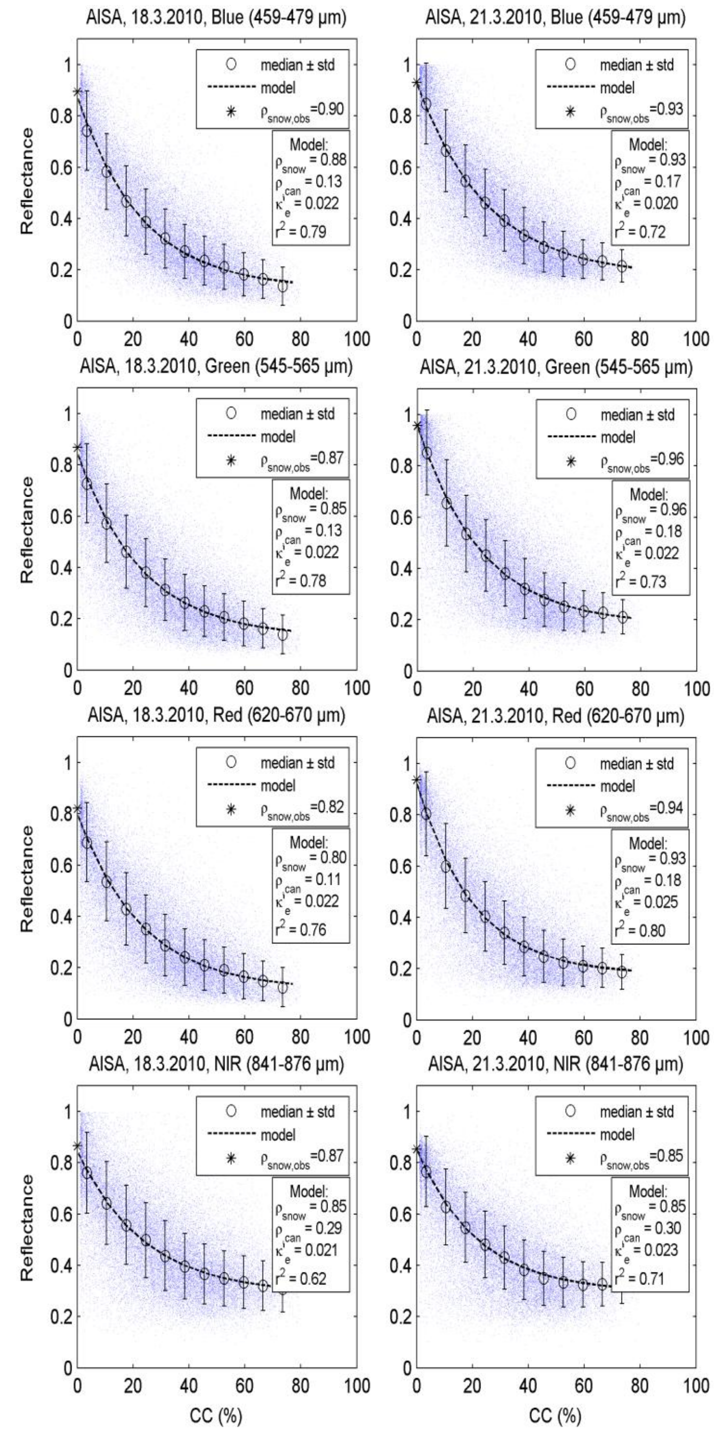
- **Accommodation up to 40 persons, canteen**
- **Lecture hall**
- **Several meeting rooms**
- **Extensive wifi**
- **Workshops: metal, wood, electronics**
- **Biological laboratory**
- **Dark room**
- **Several saunas and river-side hut**

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

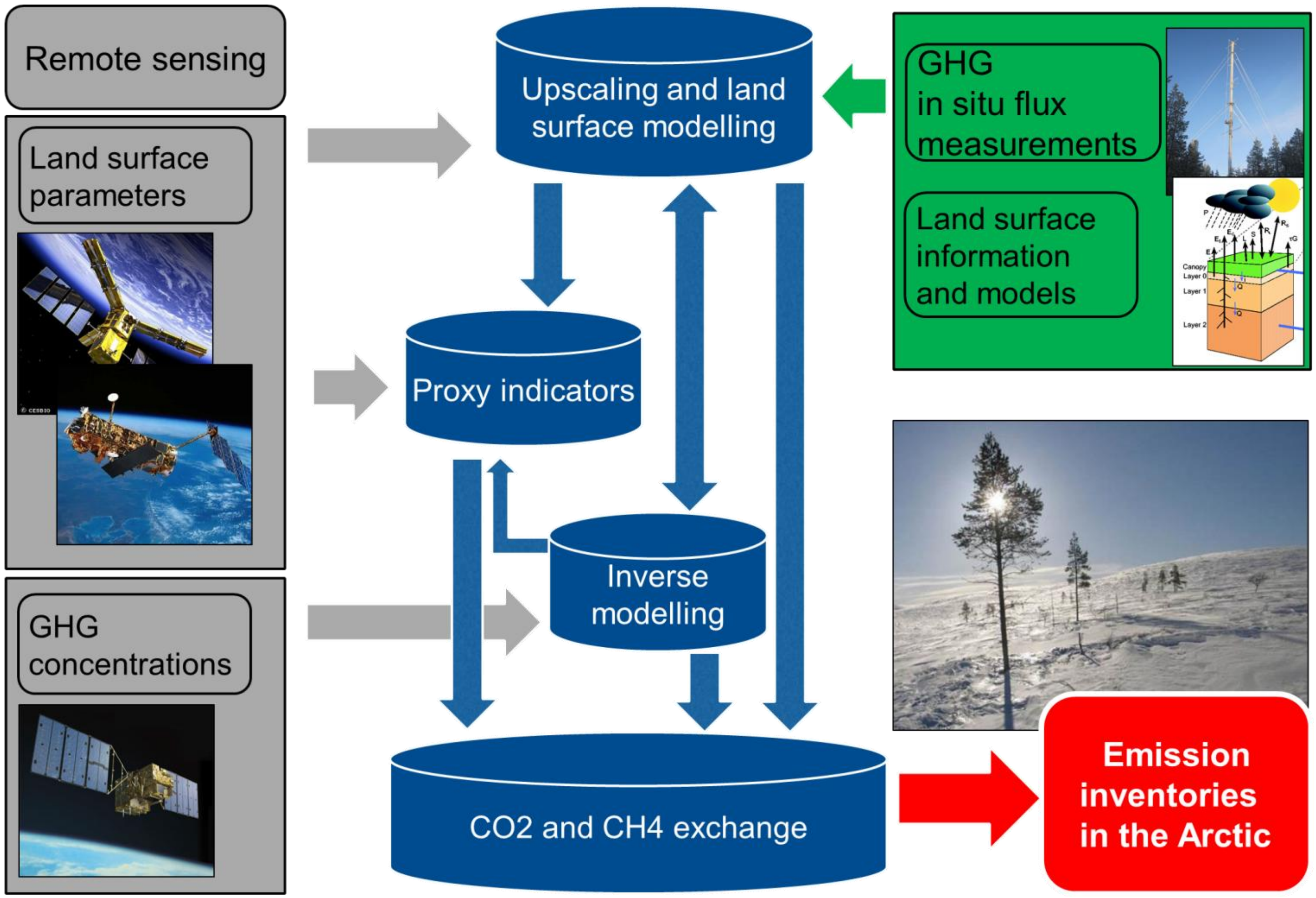
Snow remote sensing campaign activities

- Airborne
- Tower- and ground-based

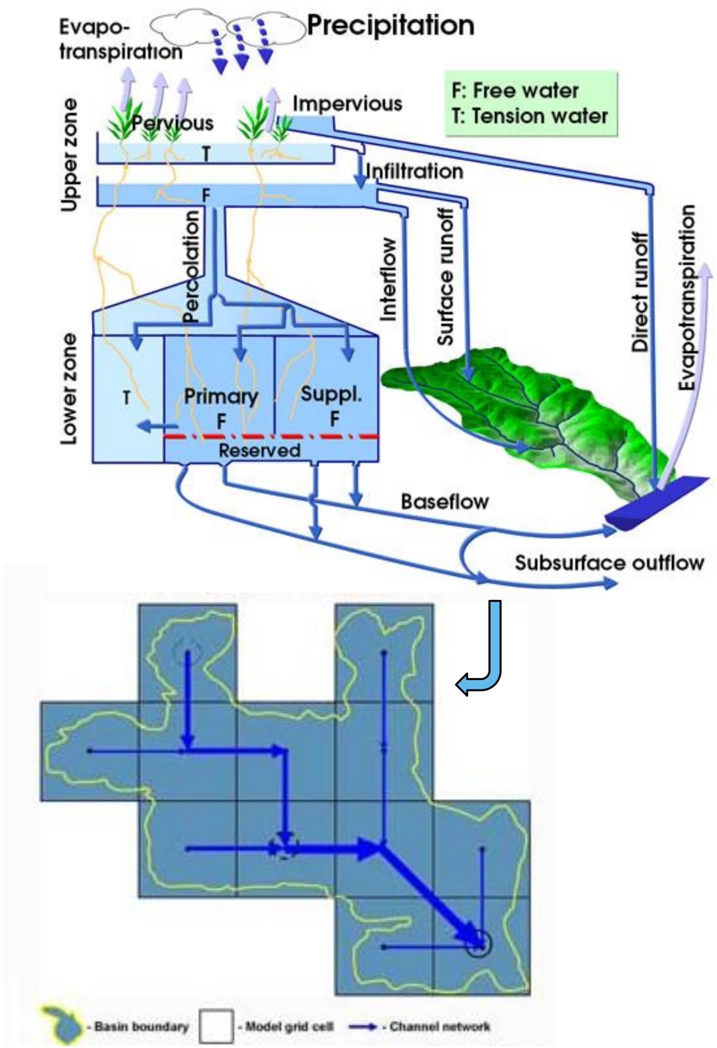




Strategy in connecting EO, *in situ* data and models in high latitude carbon studies



Hydrological Modelling at FMI



Development of FMI in-house Operational Hydrologic Forecasting Capability (HOPS)

- "Gridded" Conceptual model with physically based parameterization schemas as a basis
  - Detailed modeling of actual watershed processes is excessively complex for operational applications
  - Physically based models requires more data than available in many areas
- A simple conceptual model with physically based parameter estimation enables faster model implementation and likely more or less similar results
- System components adapted from NWS (USA) operational hydrological models

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

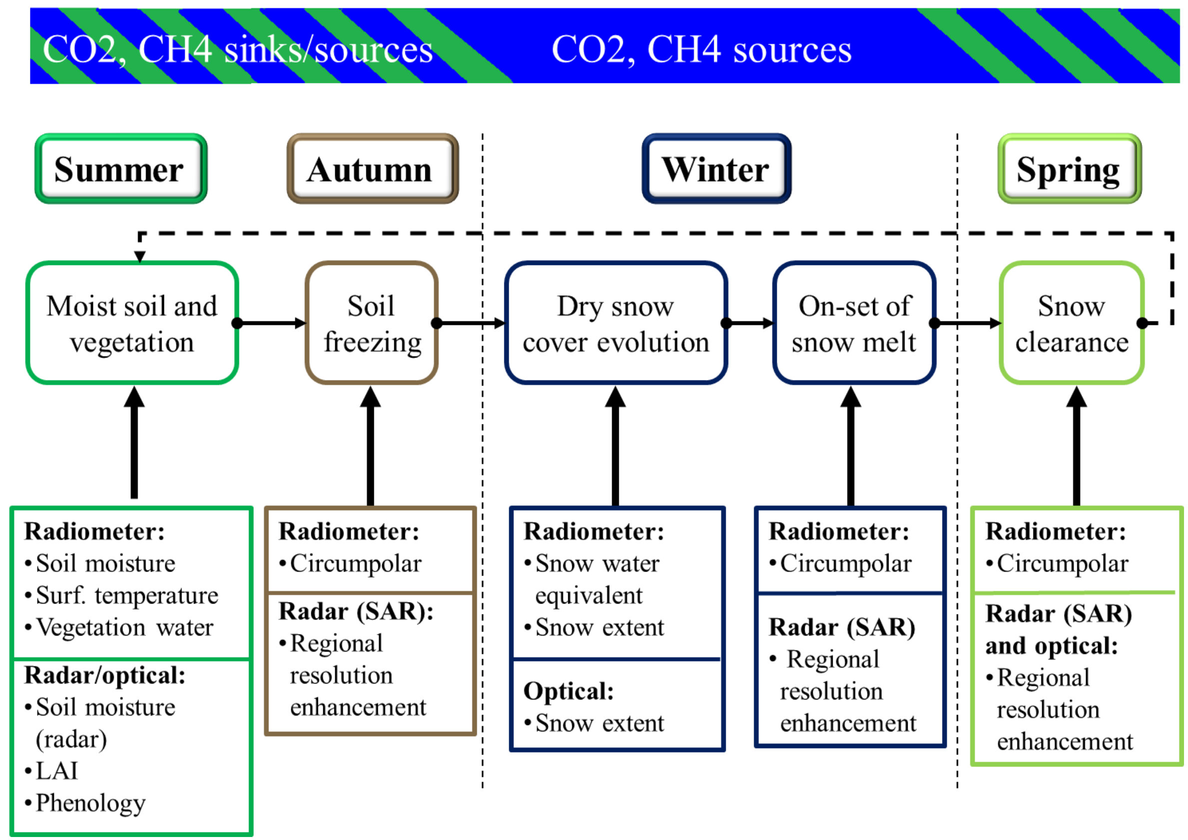
Integrated view on the terrestrial cryosphere's snow-soil-vegetation processes: The CARB-ARC approach

Using diverse satellite data at high latitudes allows full seasonal view on phenomena relevant to

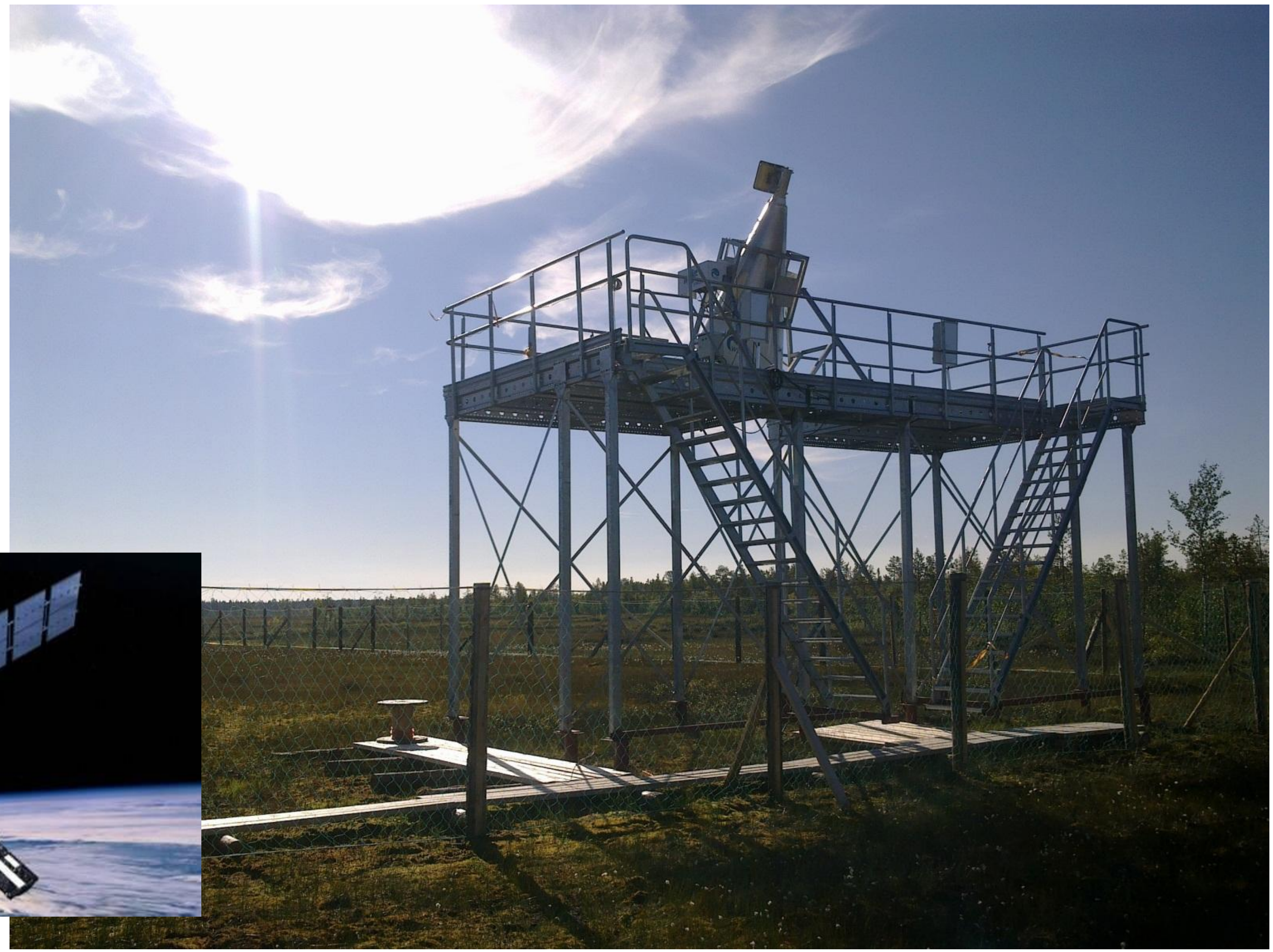
- *carbon exchange*
- *annual carbon balance*

Several phenomena can be observed depending on sensor type

Extensive datasets are available from microwave radiometers, radars and optical instruments



Use of cryospehere monitoring satellites to monitor soil frost and its relation to CH4 and CO2 emissions (wetlands/mineral soil)



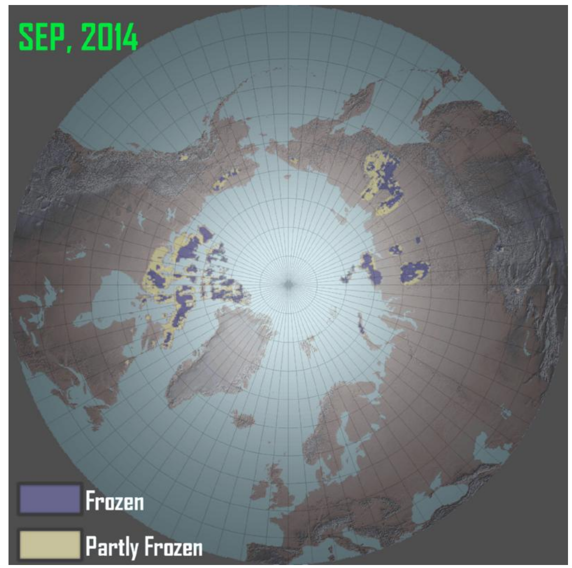
SMOS

Soil freezing and snow melt from space-borne passive microwave radiometry

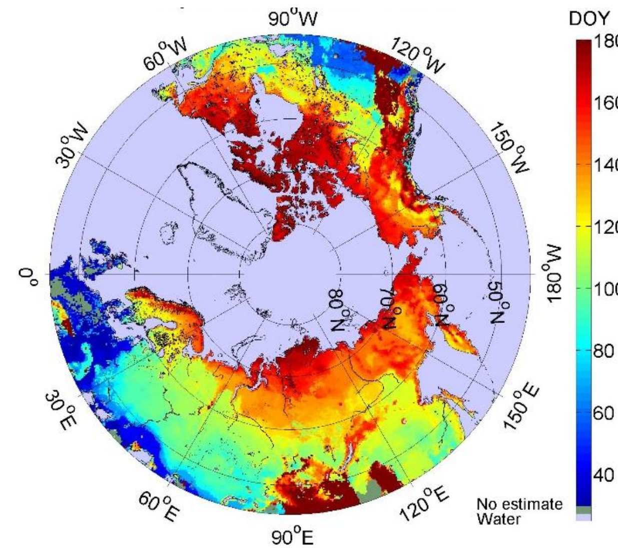
Daily hemispheric observations spanning ~38 years

Sensitive to

- snow cover (SWE, snow extent, snow melt onset and melt-off)
- soil (moisture, freeze/thaw)
- vegetation



Day of autumn soil freezing in 2014-2015 (ESA SMOS; Rautiainen et al., 2016)



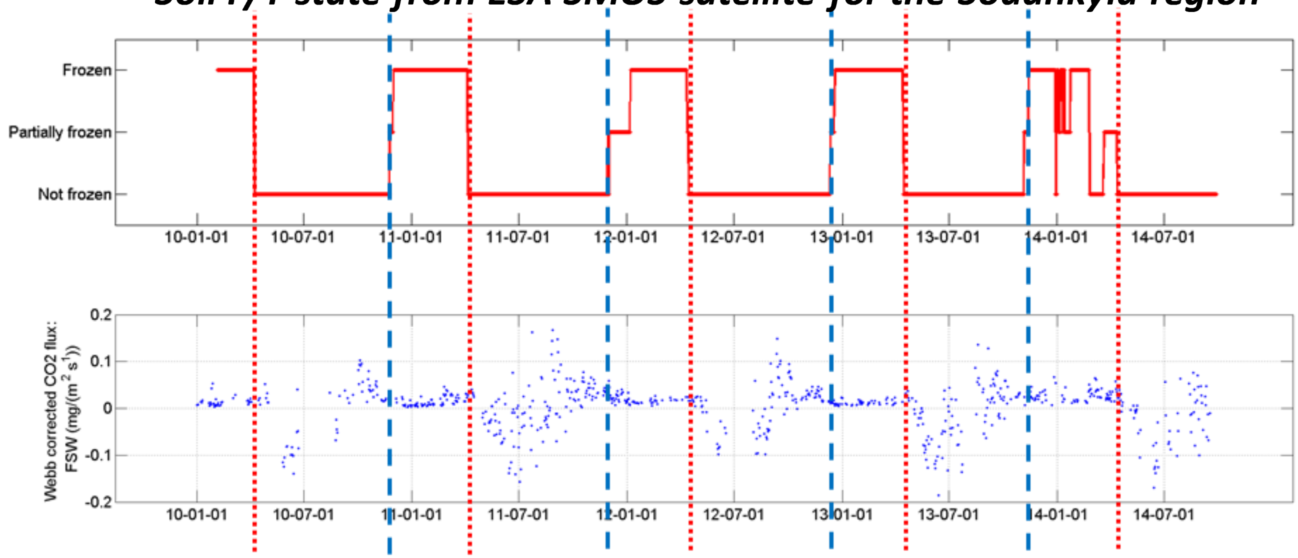
Day of spring snow clearance in 2012 (US DoD SSM/I; Takala et al., 2009)

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

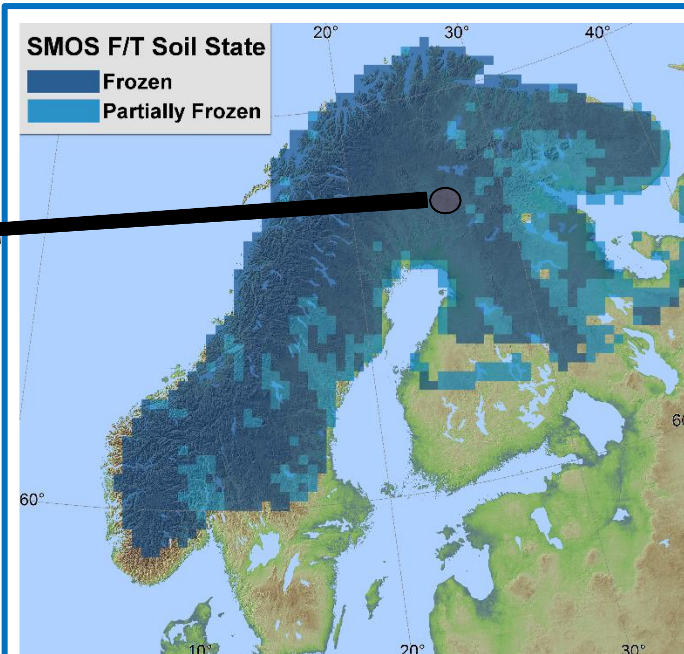
Science drivers: why soil freezing/thaw and snow melt?

- ***~49 % of Northern Hemisphere land areas undergo seasonal soil freezing***
- ***Soil freeze/thaw state has an effect on***
  - surface energy balance
  - surface and subsurface water flow
  - exchange rates of carbon with the atmosphere
  - photosynthetic activity of plants
  - microbial activity within soils

Soil F/T state from ESA SMOS satellite for the Sodankylä region

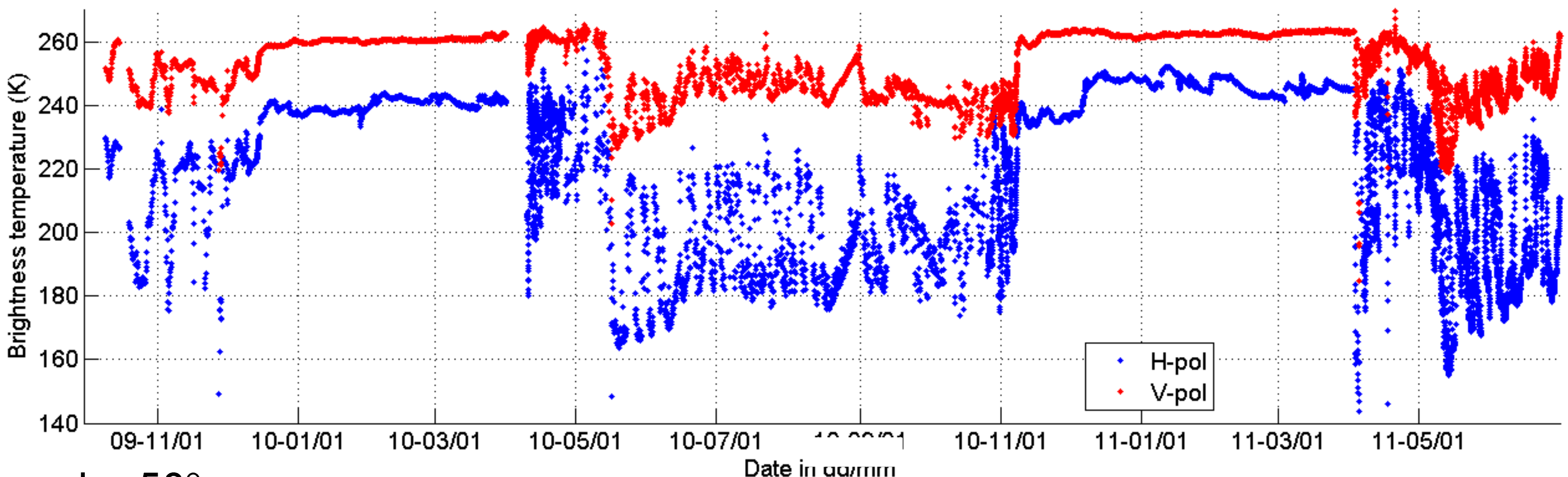


Daily NEE at the Sodankylä pine forest site (CO_2 flux)

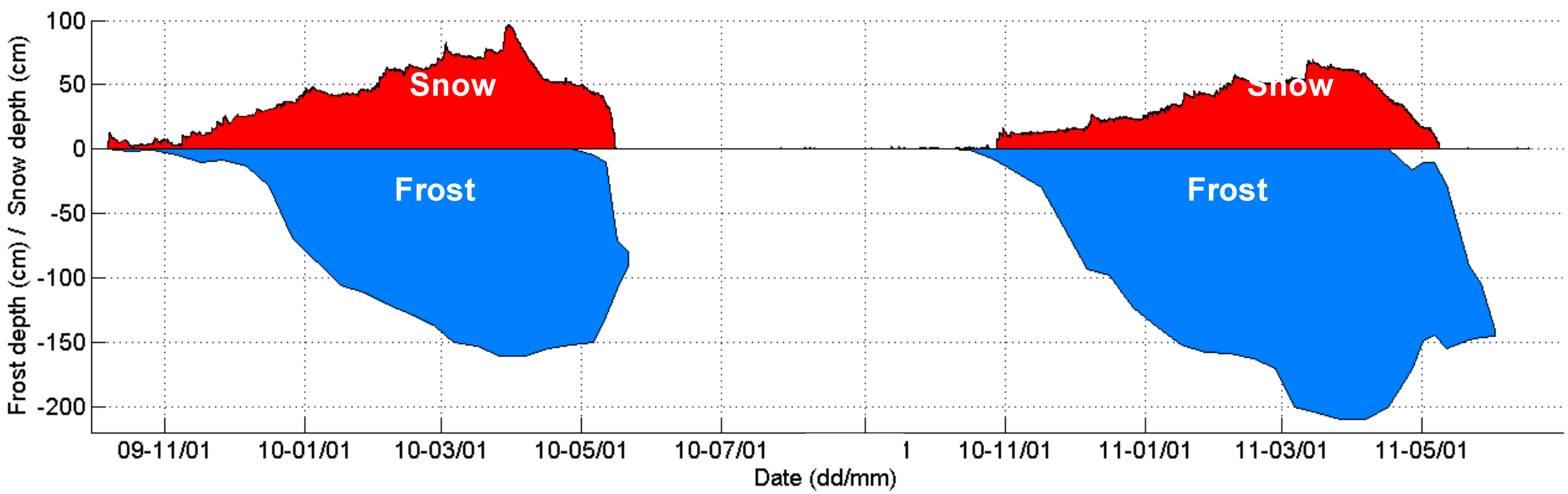


FMI product on soil freeze-thaw (F/T soil state) based on ESA SMOS observations

Two winter time-series: ELBARA-II and frost/snow (mineral soil site in Sodankylä)



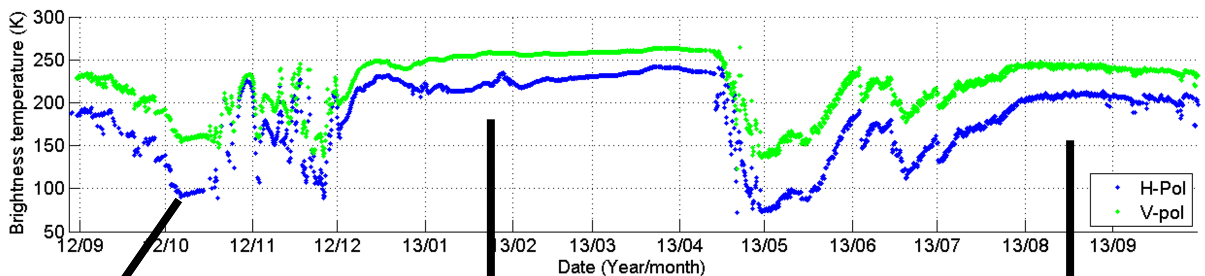
Inc. angle: 50°

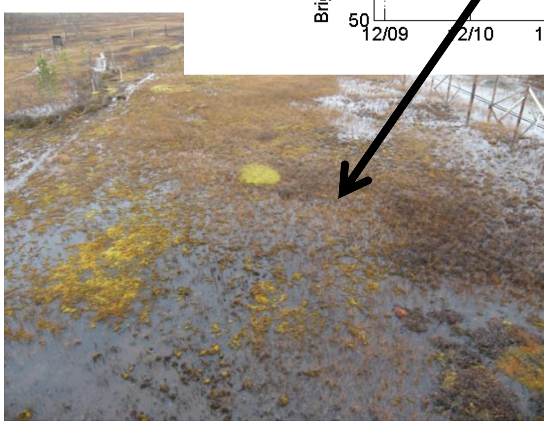


Approach representing SMAP products

- Soil moisture: Top layer sensors at 5 cm depth assumed to represent the SMAP measurements.
  - Effect of water table height strong at wetlands; at extreme wet conditions wetlands as open water areas, end of summer thick vegetation layer.

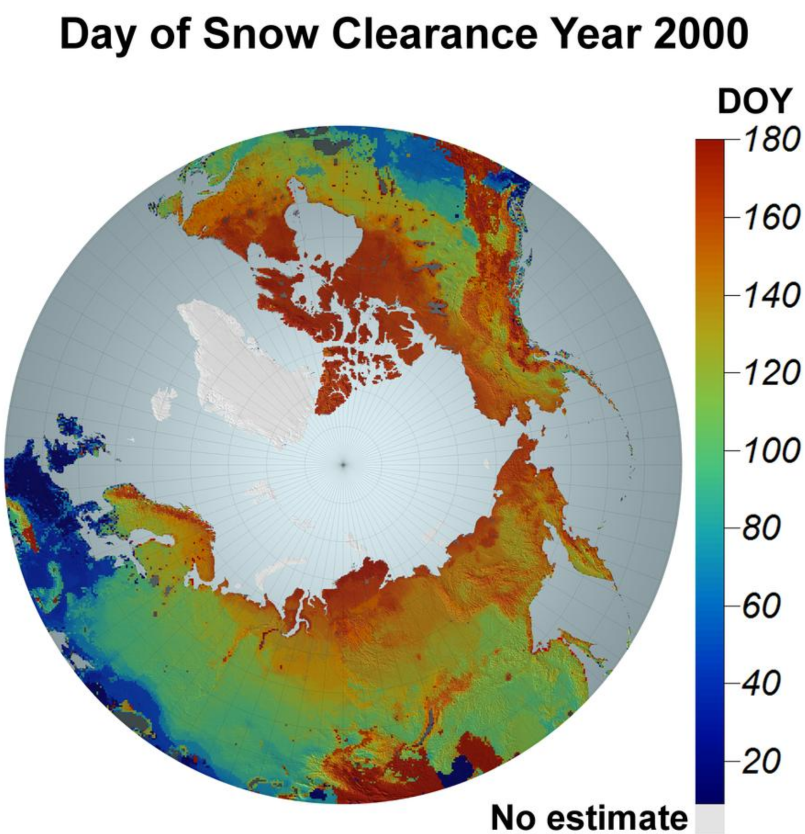
ELBARA-II, L-band radiometer obs. In Sodankylä:

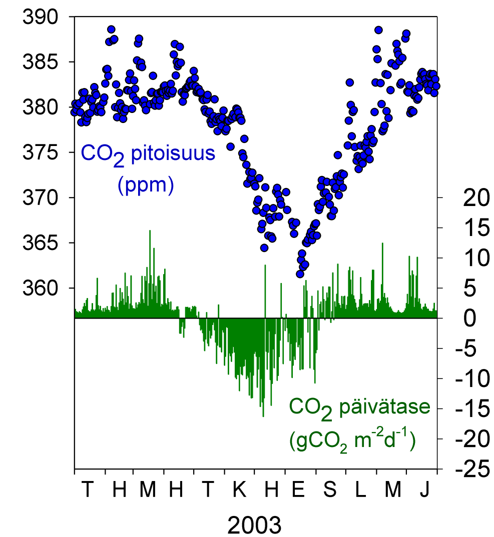




- Freeze/thaw: Temperature and SM profile from test sites (5,10,20 cm)
  - Can be used for validation of correct threshold levels to active measurements

The developed approach:
Snow melt derived from space-borne microwave radiometry as proxy to estimate Spring Recovery of photosyntehesis with the aid of distributed CO_2 flux observations

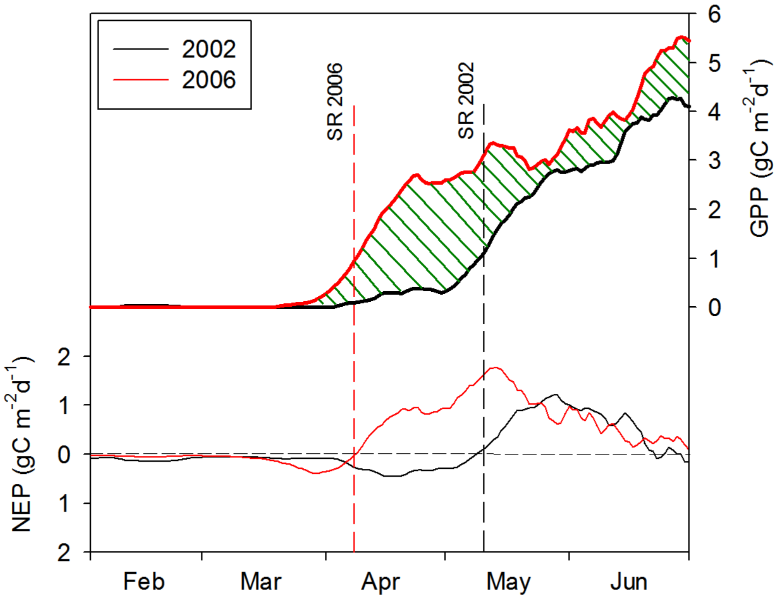




Snow melt and recovery of spring carbon uptake

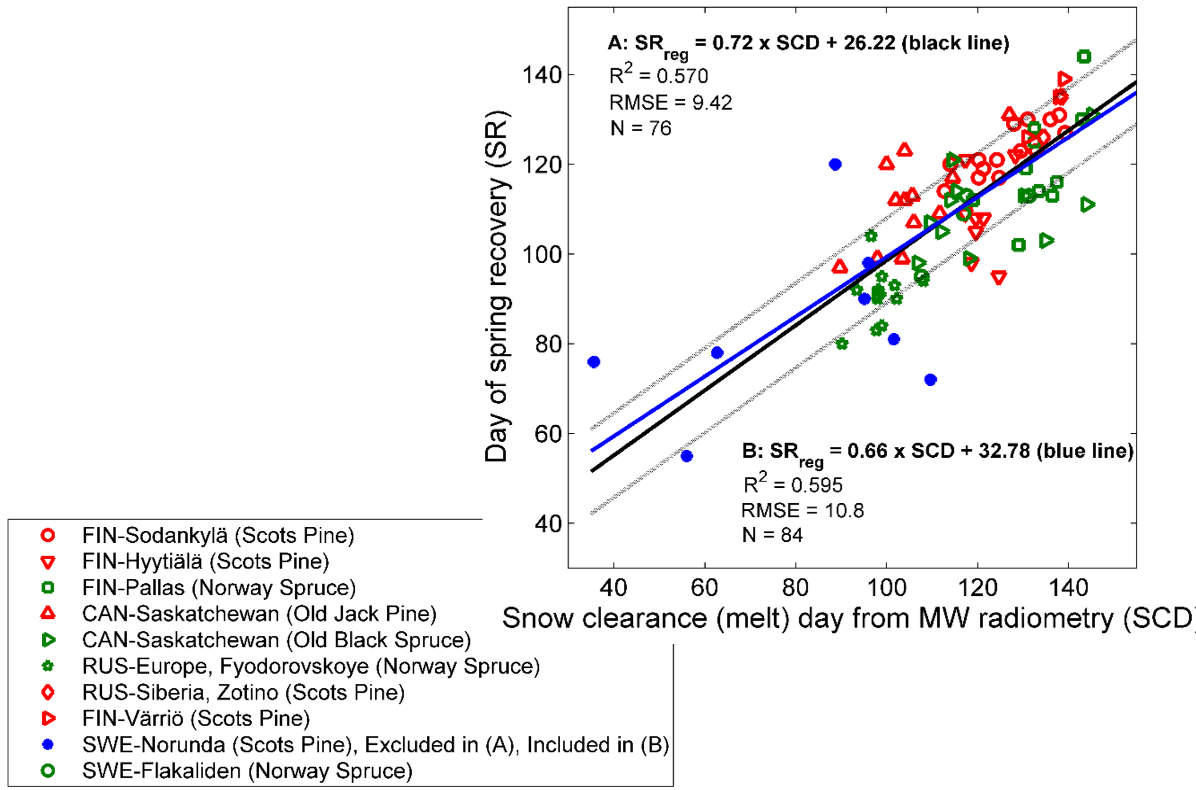
Change in spring recovery and carbon uptake with the advance of Day of Spring Recovery (SR)

NEP and GPP in comparison with satellite data-derived Day of Spring Recovery (SR)
(Jack Pine forest flux station in Canada)

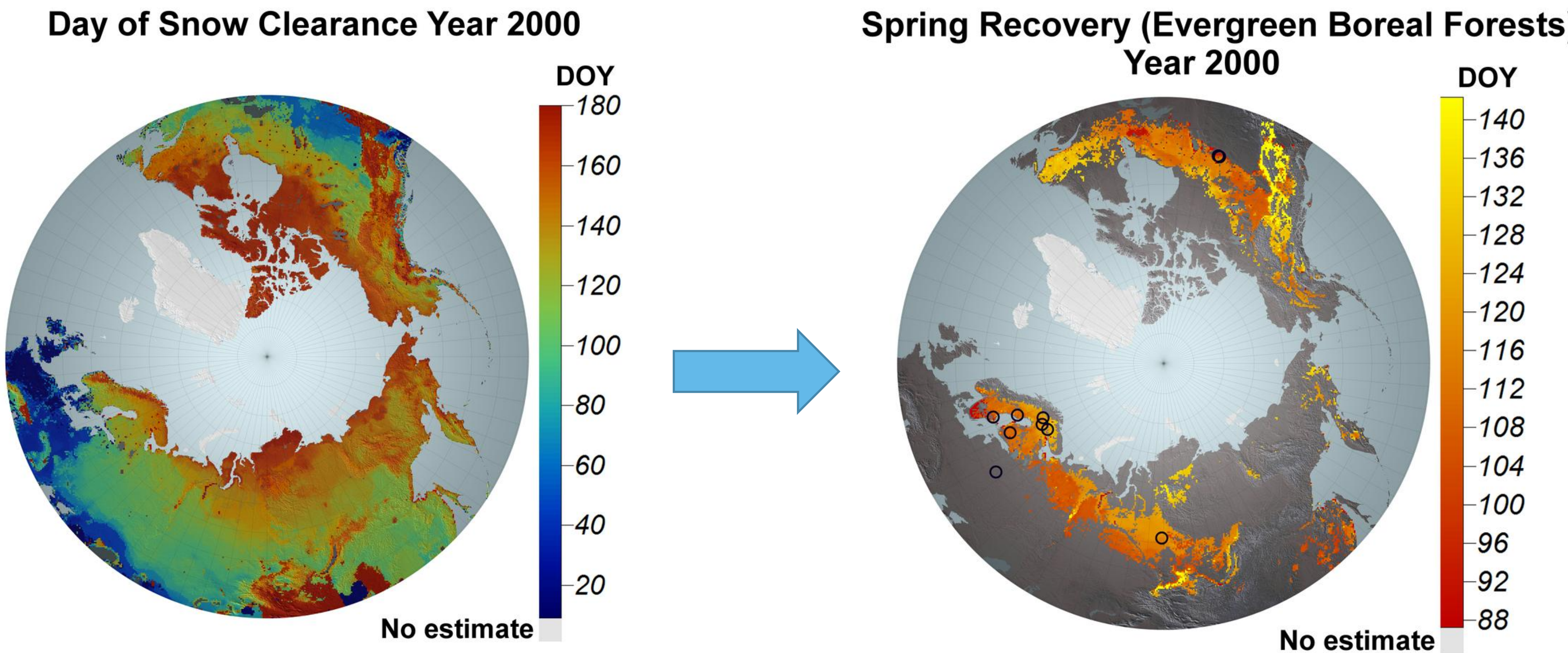


Spring snow melt from Microwave Radiometry (Takala et al., 2009) as proxy indicator of Day of Spring Recovery (SR)

Snow Clearance Day vs. flux data-derived Day of Spring Recovery (10 flux stations in Northern boreal forest zone)

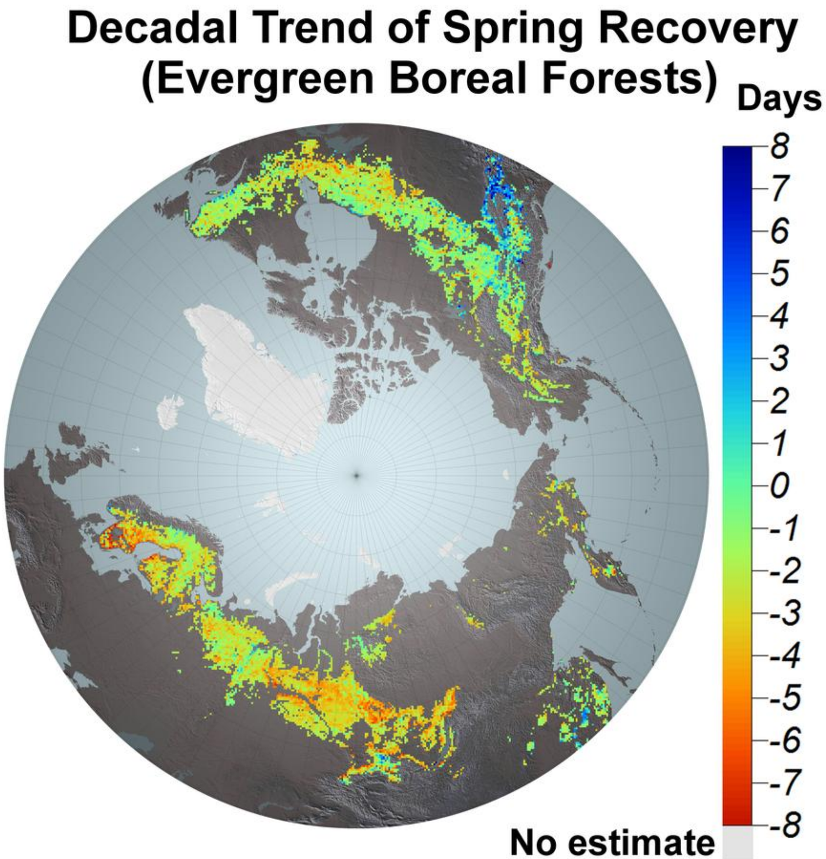


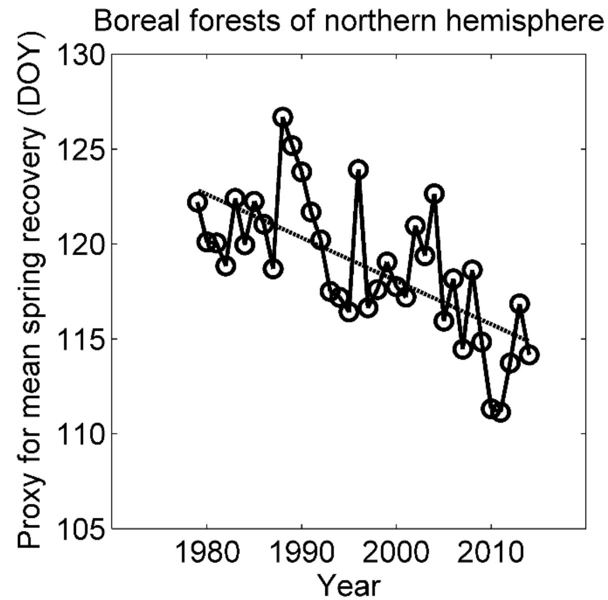
From snow clearance to spatial estimate on Spring Recovery

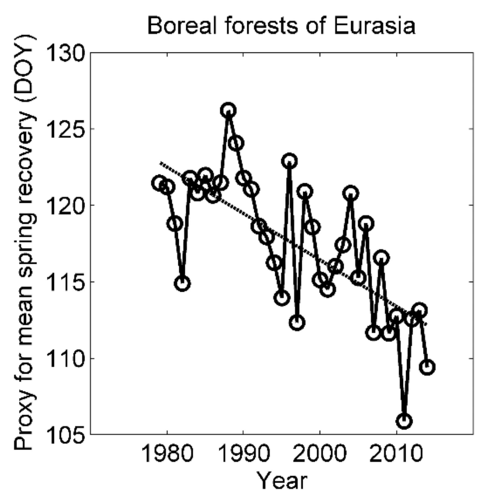


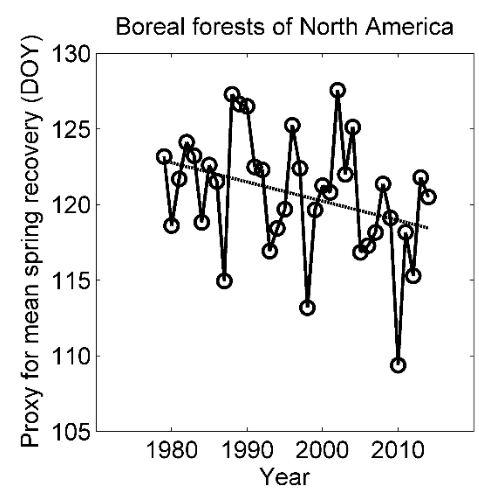
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Determination of the decadal trend of Spring Recovery (SR) for the applied satellite data set (1979 -2014)









ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Influence of advanced Spring Recovery to springtime sum of Gross Primary Production (6 month GPP sum)

- **3.7%** by experimental data analysis (satellite snow melt and flux data)
- **5.8%** by model simulation (JSBACH ecosystem model coupled with ECHAM6 GCM)

Region	Forested area, 10^6 km^2	ΔSR, change of spring recovery,* d/decade	*P* value for SR trend line	ΔGPP$_{spring}$, increase of springtime GPP† Pg C/decade	g·C·m^{-2}/decade
Northern hemisphere	3.95	−2.28 ± 0.46 (−1.99 ± 0.46)	$1.0 \cdot 10^{-5}$	0.052† (5.8%)	13.1†
				0.033 ± 0.004‡	8.4 ± 1.7‡
Eurasia	2.26	−3.04 ± 0.61 (−2.40 ± 0.55)	$1.4 \cdot 10^{-6}$	0.035† (6.8%)	15.5†
				0.022 ± 0.005‡	9.9 ± 2.0‡
North America	1.69	−1.27 ± 0.25 (−1.44 ± 0.33)	0.05	0.017† (4.4%)	9.8†
				0.009 ± 0.002‡	5.2 ± 1.0‡

In parentheses is the change of SR estimated from the FT-ESDR dataset, using the same regression method.
*ΔSR estimated from the satellite observations.
†Global model-simulated ΔGPP$_{spring}$ (6-mo sum of daily GPP).
‡Increase of GPP estimated using ΔSR values of the three regions and average δGPP$_{spring}$/δSR values determined for (*i*) two flux stations in Eurasia, (*ii*) two stations in North America, and (*iii*) all four stations in the hemispheric case: ΔGPP$_{spring}$ = ΔSR × δGPP$_{spring}$/δSR.

J. Pulliainen, M. Aurela, T. Laurila, T. Aalto, M. Takala, M. Salminen, M. Kulmala, A. Barr, M. Heimann, A. Lindroth, A. Laaksonen, C. Derksen, A. Mäkelä, T. Markkanen, J. Lemmetyinen, J. Susiluoto, S. Dengel, I. Mammarella, J-P. Tuovinen, T. Vesala, "Early snowmelt significantly enhances boreal springtime carbon uptake" *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, October 2017


Thank You for Your Attention!
Kuva: Matias Takala