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Real-time monitoring and long term data of snow conditions in the Baltic Sea drainage basin from space-borne observations

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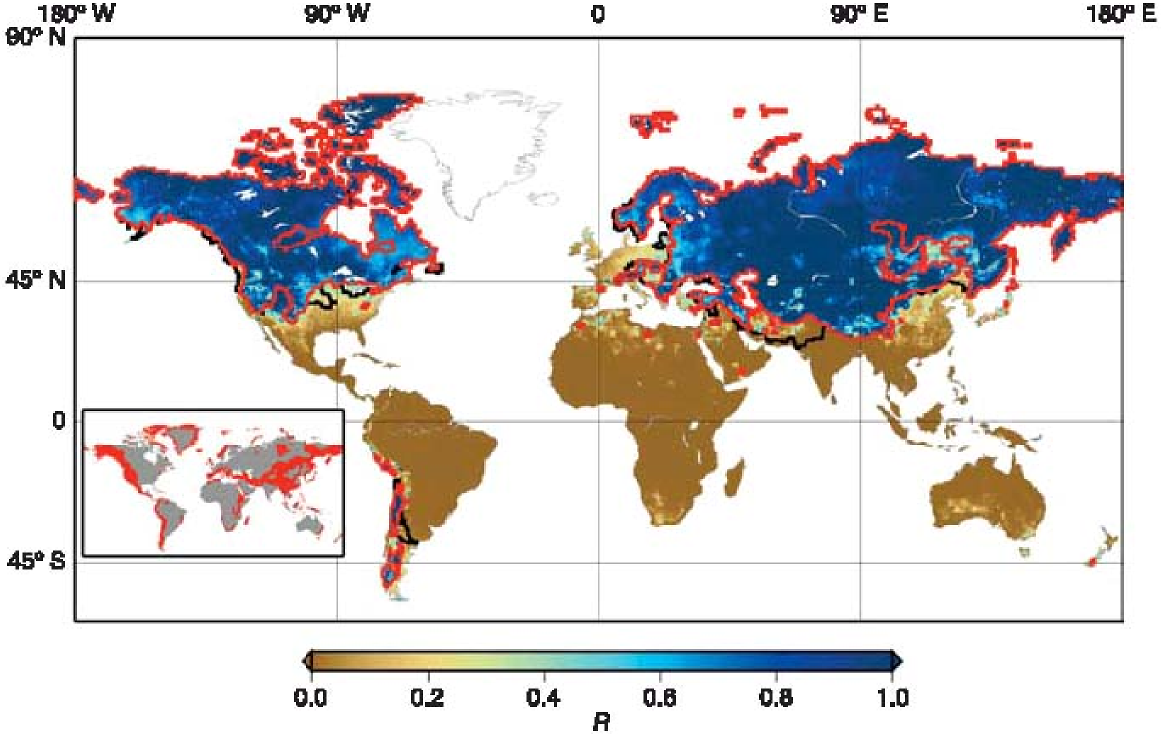
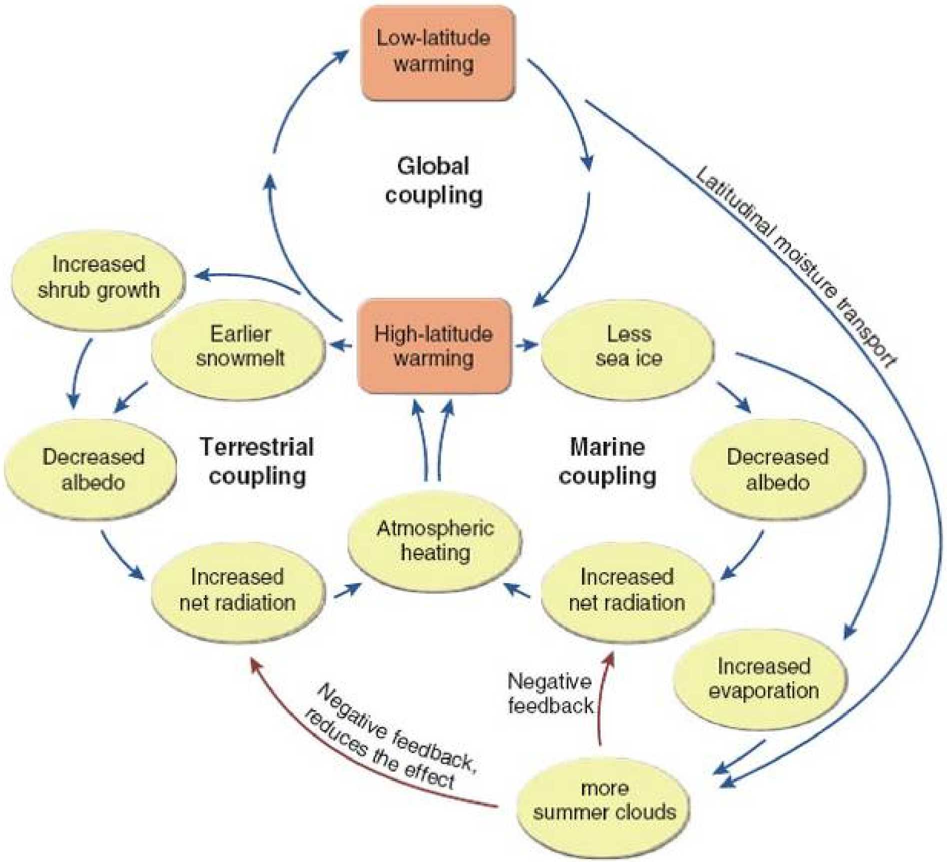
Significance of snow information for runoff

- **Accumulated annual snowfall divided by annual runoff (colour scaled between 0 and 1). Red lines: streamflow is snowmelt-dominated, no adequate reservoir storage capacity to buffer shifts in the seasonal hydrograph.**
- **Black lines: additional areas where water availability is dominantly influenced by snowmelt**
- **Inset: regions of the globe that have complex topography. (From Barnett et al., 2005).**



Snow, climate and water cycle

Conceptual diagram on the connectivity of the positive ice/snow albedo feedback, terrestrial snow and vegetation feedbacks and the negative cloud/radiation feedback (From UNEP, 2007).



Problems of ground-based observations

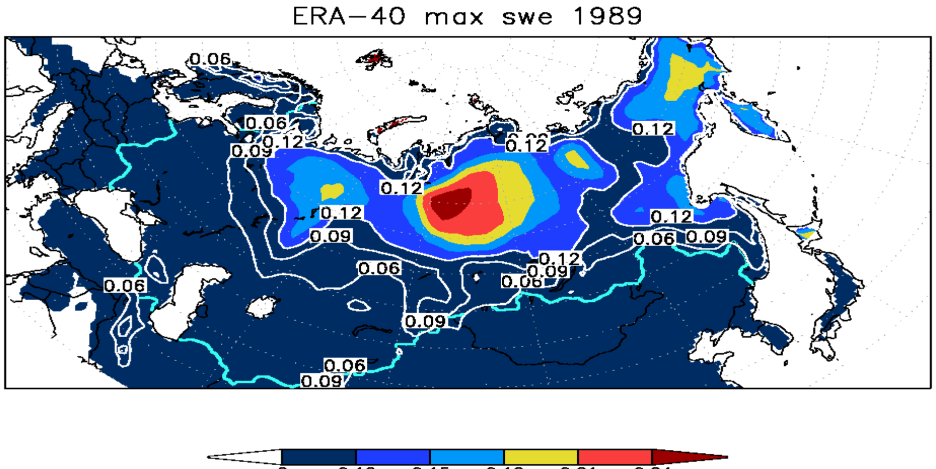
- **Sparseness of hydrological and meteorological observation networks**
  - Automatic observation networks replacing manual systems provide data from fewer locations (even though temporal frequency has improved in some cases)
  - Northern Eurasia: decrease of observations due to political/economical changes
  - Areal parameters most urgently needed for climate, hydrological and meterorological models, but they are typically difficult to observe:
    - Regional values of SWE
    - Fraction of Snow Covered Area (SCA) or binary snow information at high resolution (e.g. during spring in regions of seasonal snow cover)

Climate trends and validation of GCMs and regional climate models: Relation to snow cover

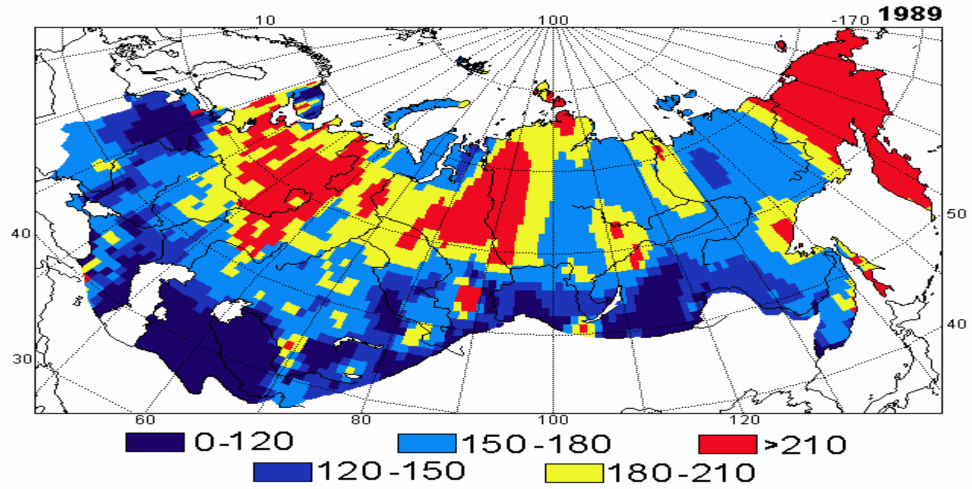
- **Snow cover parameters important climate change indicators:**
  - Lenght of snow season
  - Snow melt
  - Snow climatology (e.g. maximum SWE)
- **Time-series of snow information for validation of GCMs and climate (trend) projections**
  - Requires statistical information for long time-series ~30 years (statistics of satellite data retrivals should be compared with corresponding statistics of climate model simulations)
  - Key question: how reliable are the models simulations and future projections if snow cover is unreliably simulated

Deficits of re-analysis data and ground data interpolation

- ERA-40 re-analysis data of ECMWF:
  - Maximum SWE in 1989

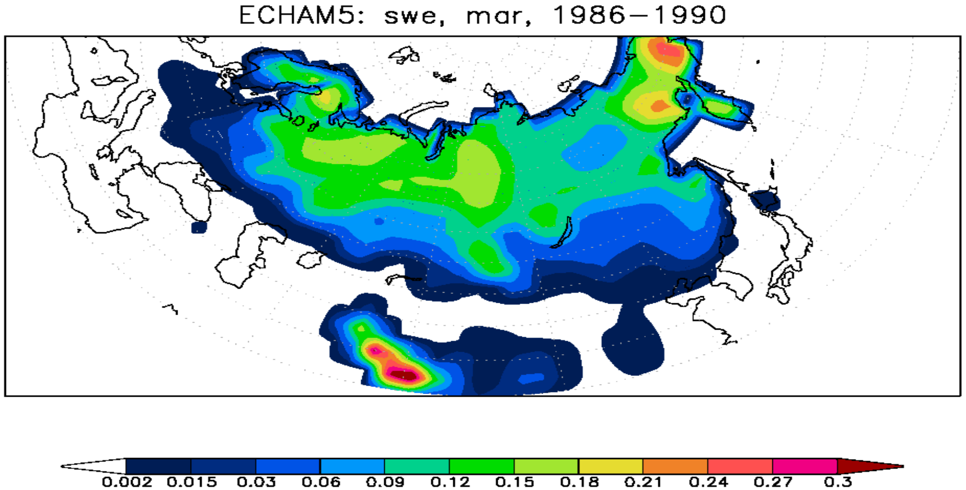


- Corresponding INTAS-SCCONE Russian ground based observations (SWE from 210 snow courses around northern Eurasia)

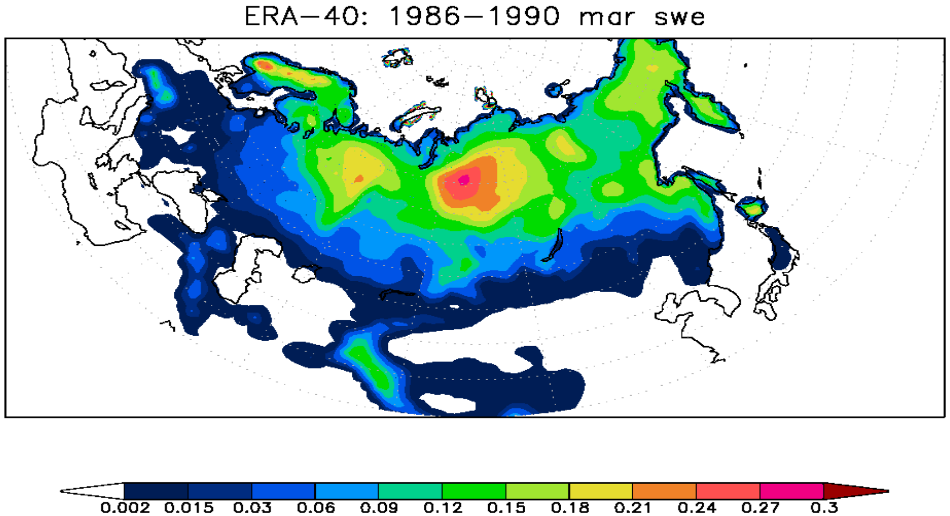


Deficits of climate modeling

ECHAM-5 GCM prediction



ERA-40 reanalysis data of ECMWF



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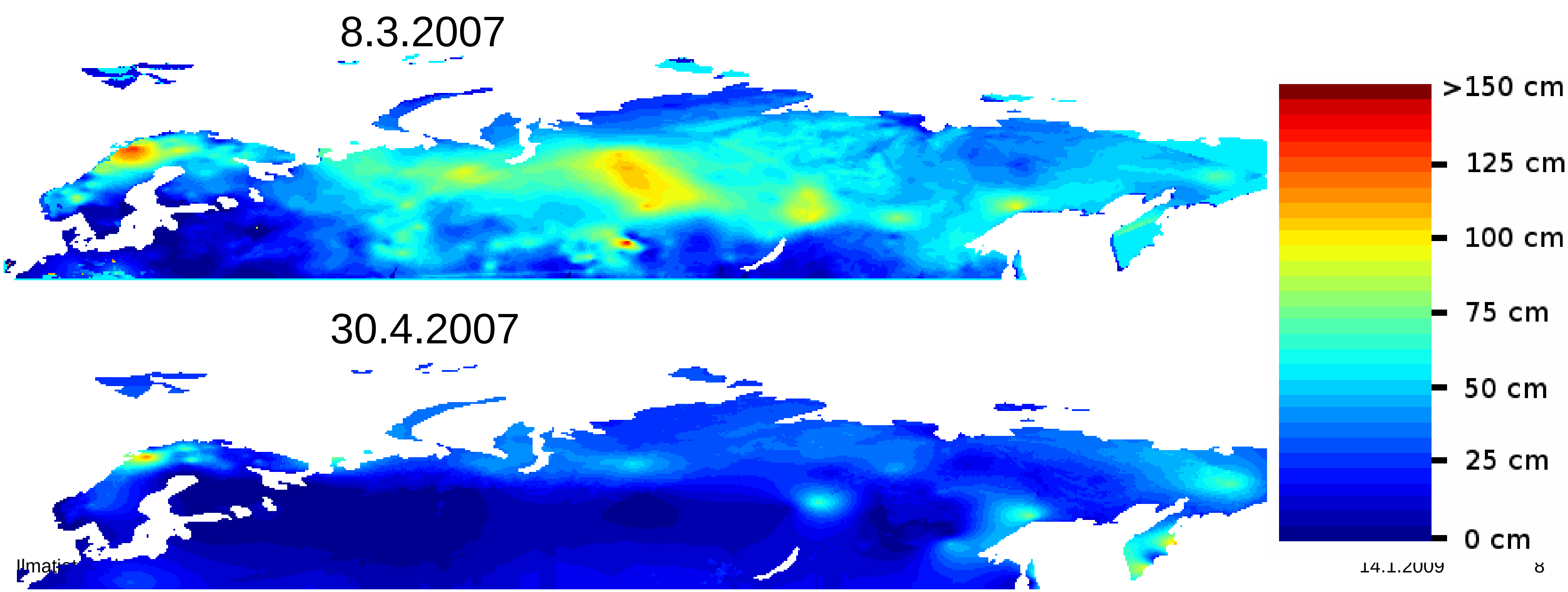
Polar View

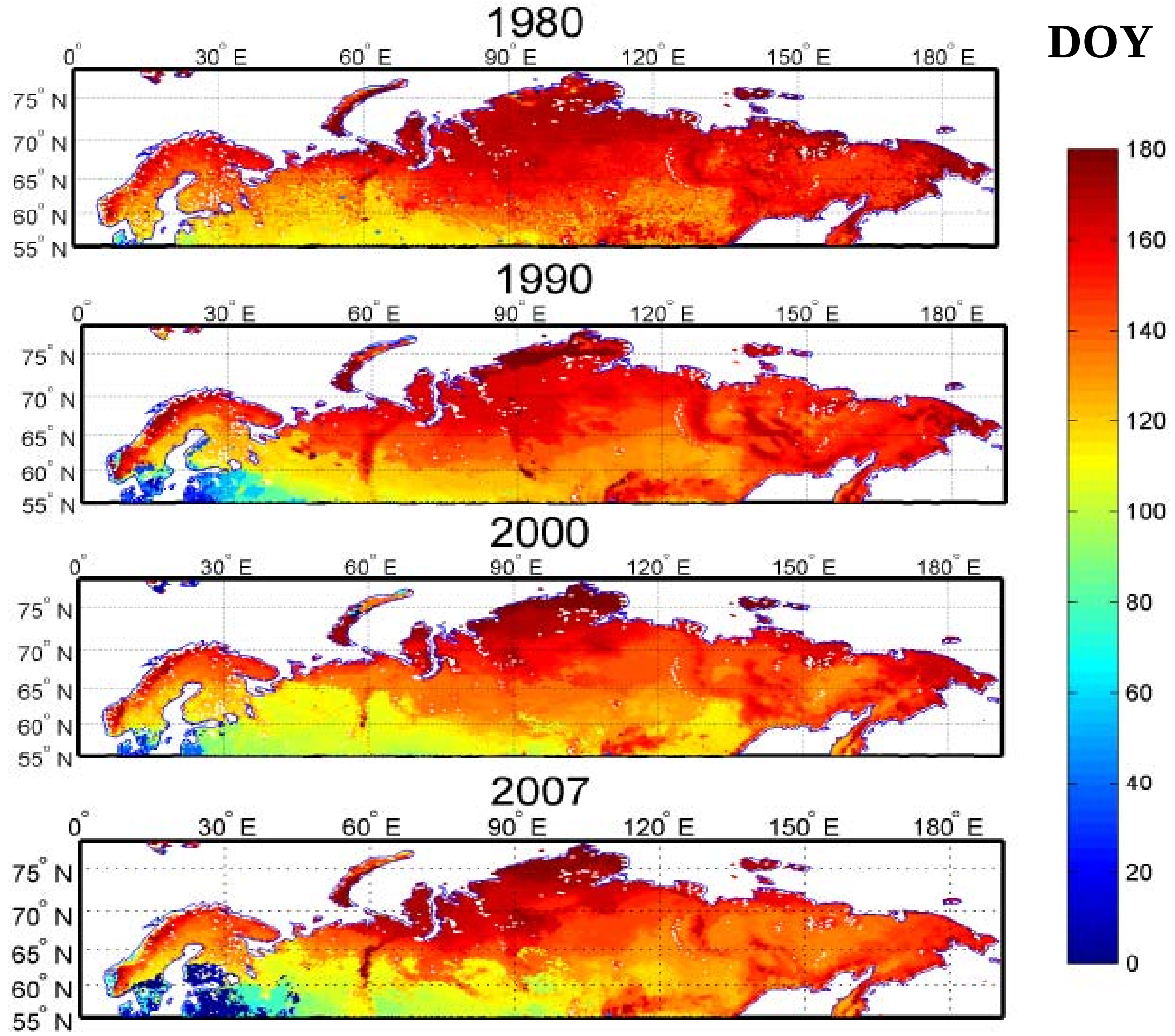
Current ESA GMES PolarView Service of FMI: Northern Eurasian Snow Monitoring

- Snow Water Equivalent and Snow Depth by assimilating AMSR-E microwave radiometer and synoptic weather station data
- Currently validation against snow courses (~210 in Russia with length of some kilometers each)



Snow melt date for ~30 years in northern Eurasia from space-borne microwave radiometer data

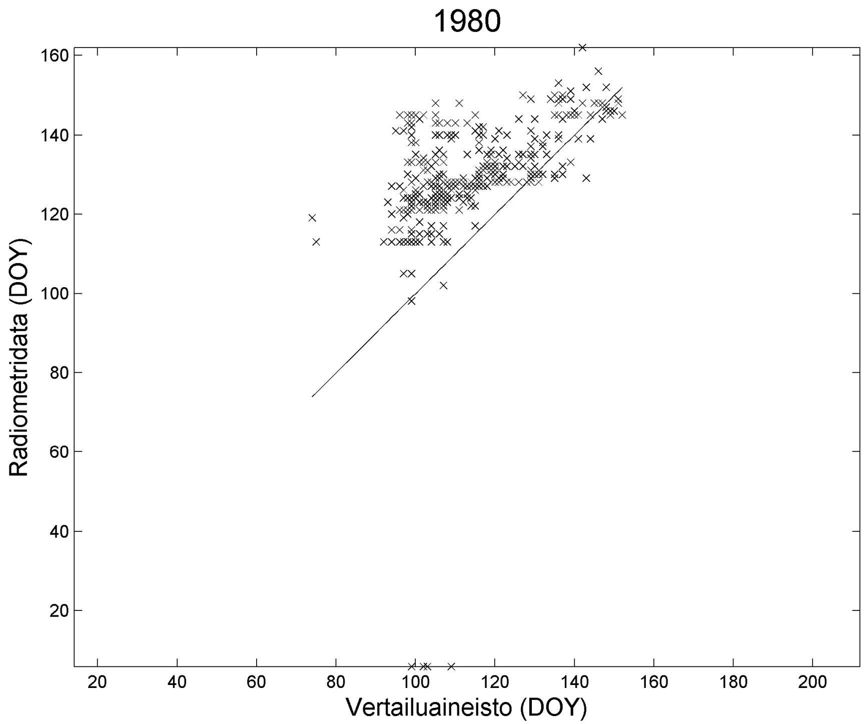
- Calibration here against ground-based observations at ~200 stations
- Some additional validation and calibration of melt detection algorithms can be carried out using e.g. optical data (cloud cover being a major obstacle)

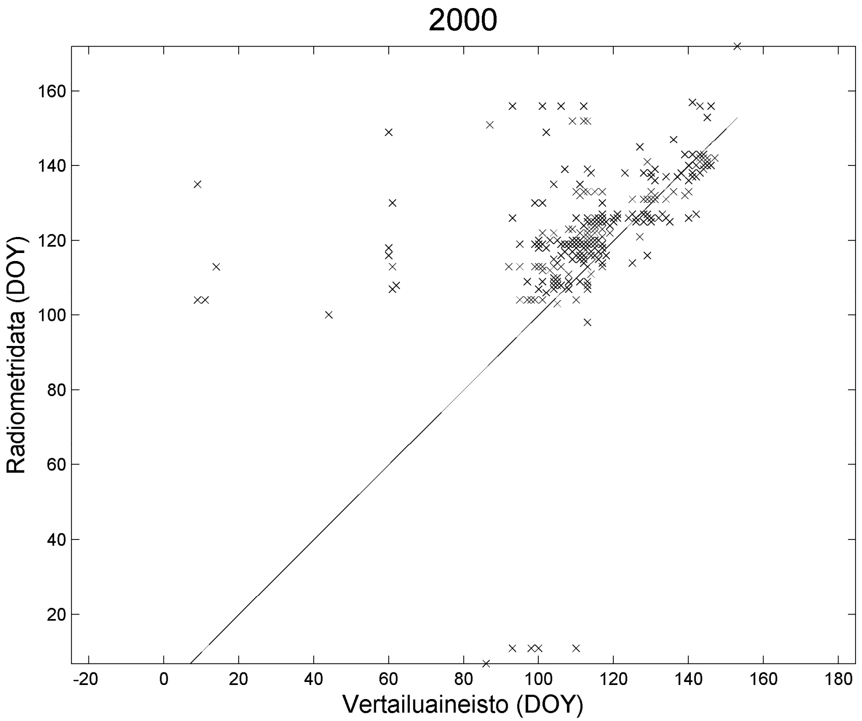


The color code is the number of the melt date since January 1.

Comparison with point-wise in situ data

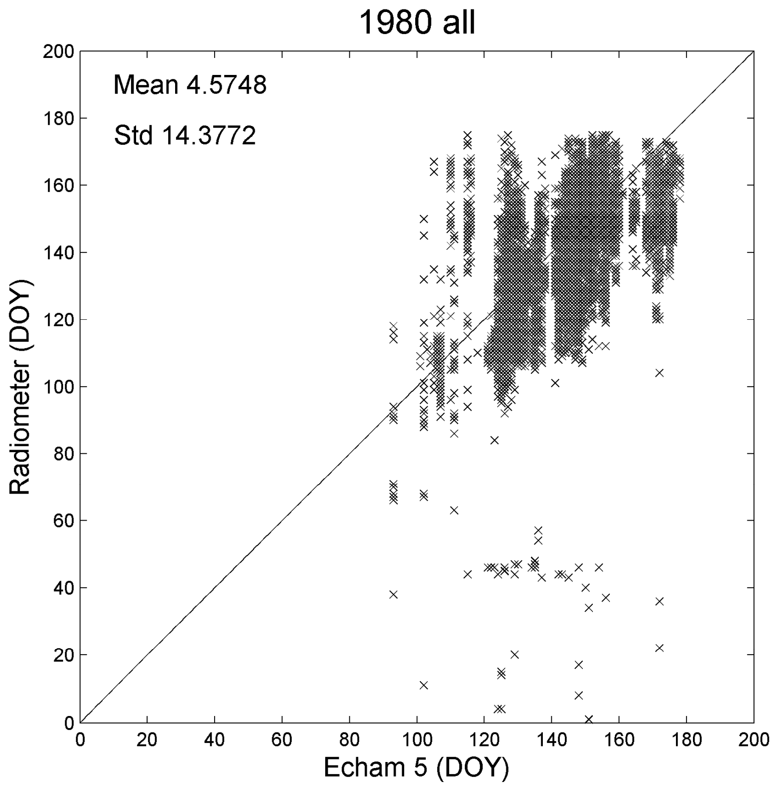
- Satellite data-derived snow clearance dates compared with Finnish weather station observations (zero snow depth observed for the first time)





Comparison with climate models

- Aim: To validate global and regional climate model predictions
- By investigating how well models simulate some key characteristics of snow cover:
  - Day of snow melt (snow clearance)
  - SWE



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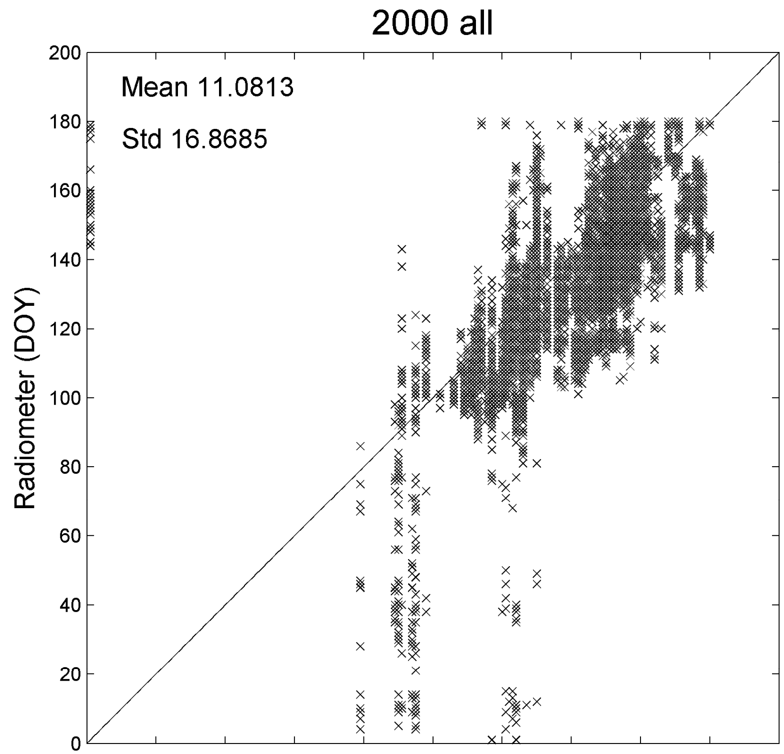
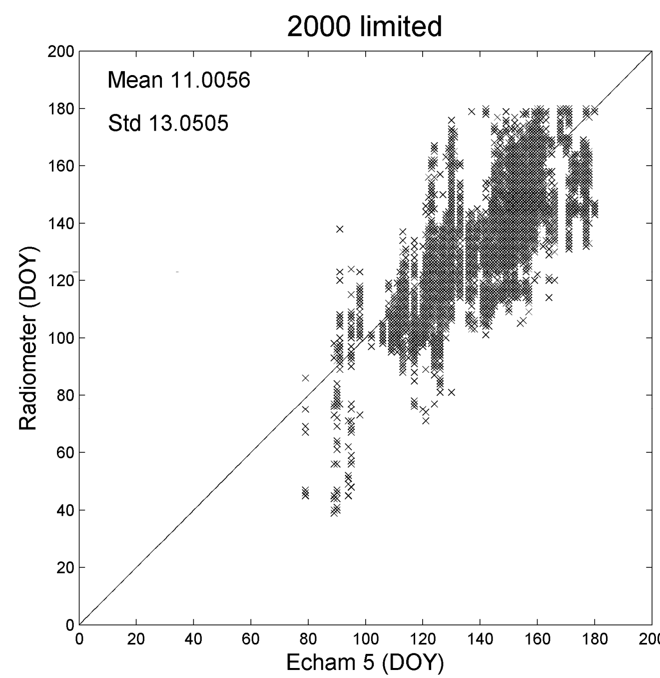
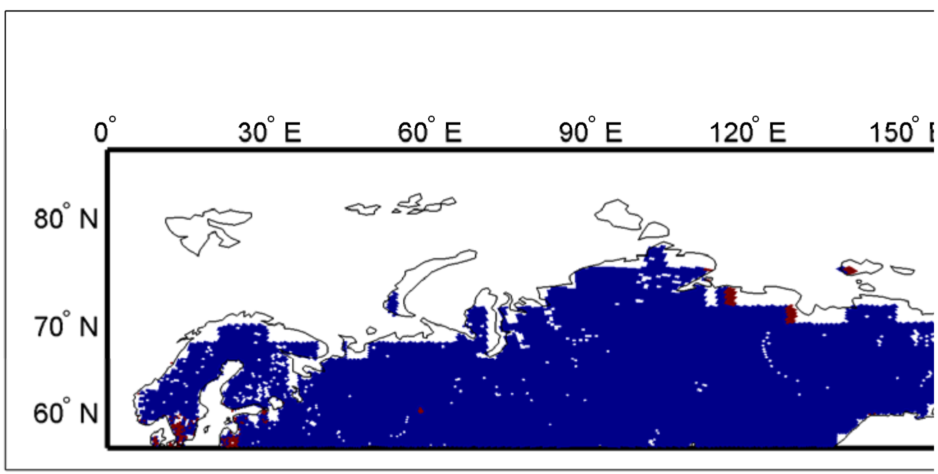
Same for the year 2000

- Radiometer data provides similar results as ECHAM-5 with ocean forcing, except for some southern coastal regions and arctic coastal regions





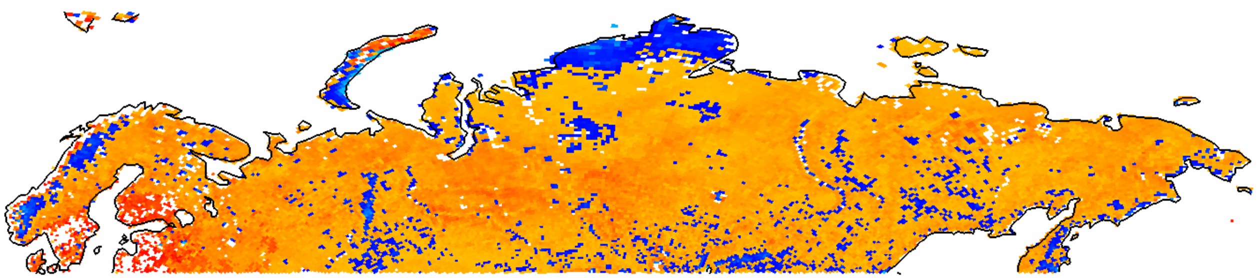


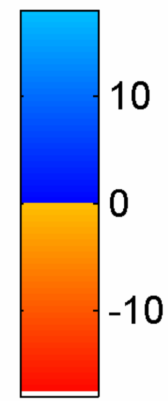
Estimated decadal trend for snow melt date

- Snow melt date estimates validated against ground-based observations
  - Trend estimated from the evolution of yearly snow melt (clearance) date
- Realistic values for off-coastal areas (mountains?)

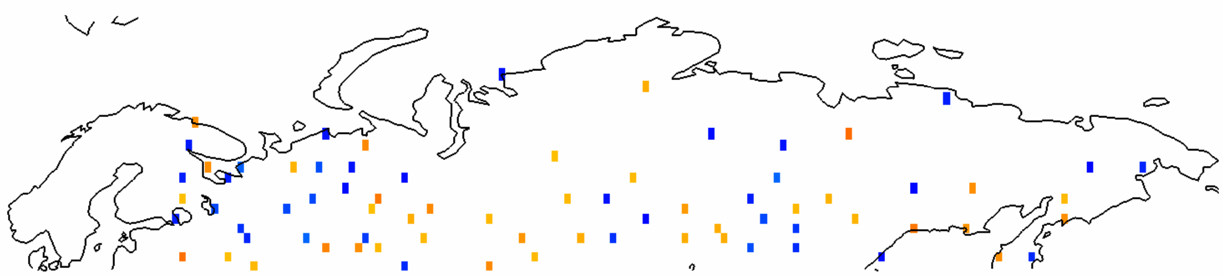
Days/decade

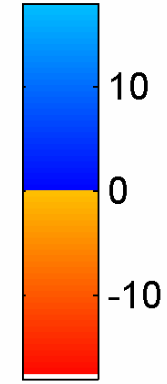
Satellite data-derived trend (from 1978-2007)





Trends in point-wise in situ observations (from 1978-2001)





Applications in hydrology and meteorology

- **Water cycle:**
  - Hydro-power production: use of SAR-derived snow cover information as input to hydrological models even operational in several countries
  - Flooding (flood forecasting)
  - Availability of water resources
- **Meteorology:**
  - Snow cover currently poorly represented (interpolation of ground data inadequate especially at high latitudes)
  - Dominates the surface albedo
  - Development of mesoscale models requires information on snow cover with higher spatial reslotion and down sclaling of coarse resolution data
- **Near Real-Time (NRT) typically required**

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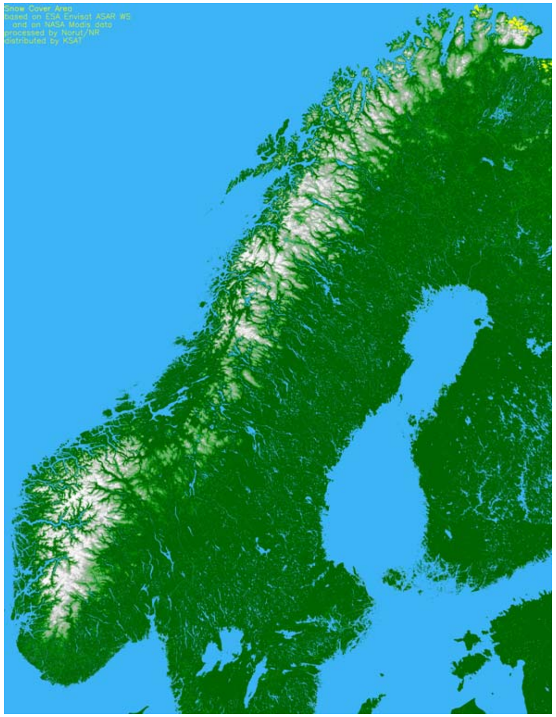
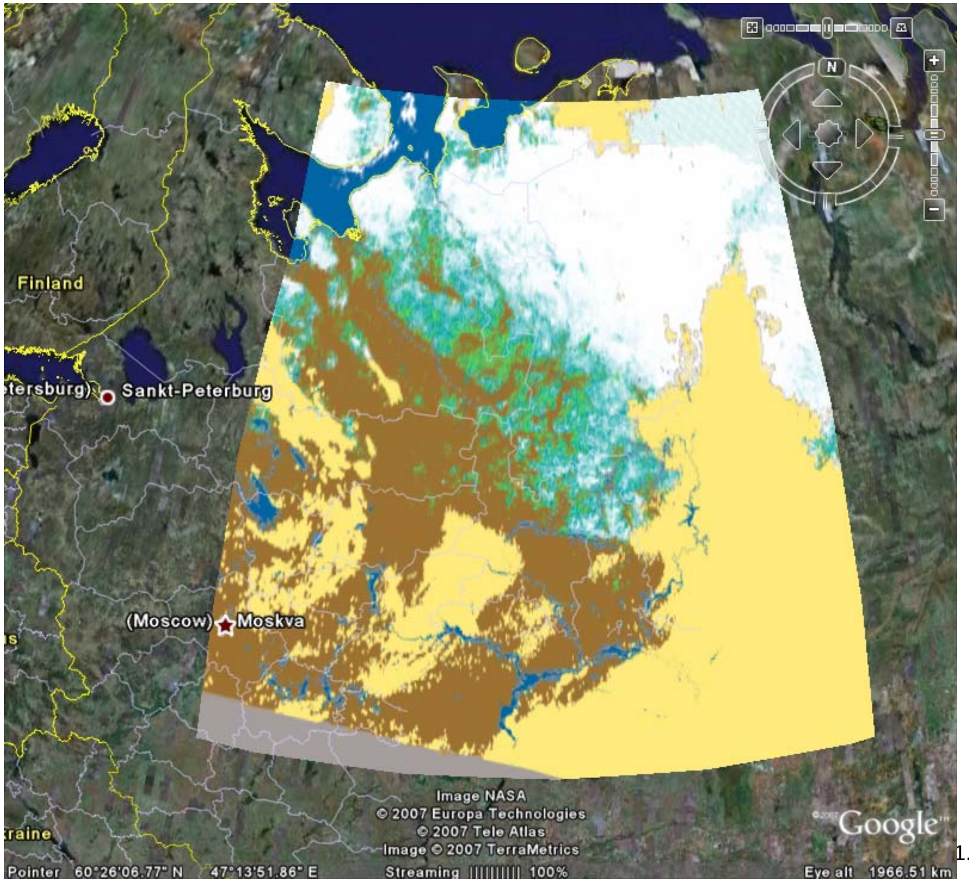
Examples of snow cover information at high resolution

- drawback: only small areas are currently operationally covered with C-band SAR system; clouds in case of optical data retrievals

Snow cover at Norwegian mountains based on combined Envisat ASAR and Modis data



Modis data-based fractional snow-covered area



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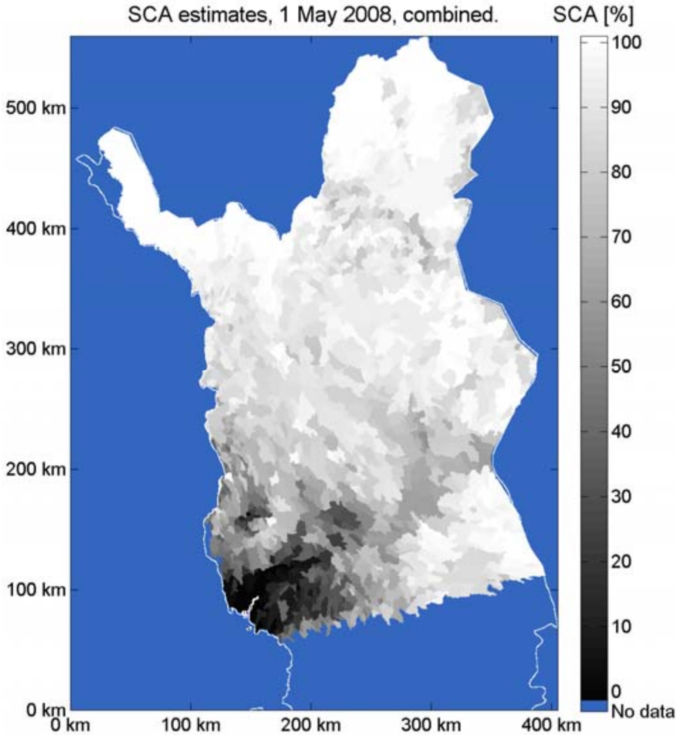
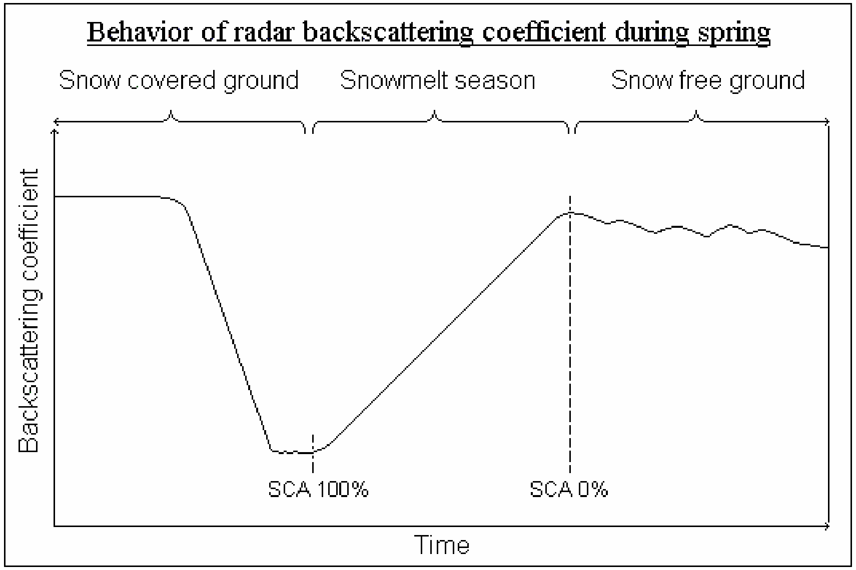
Example on application development for SAR: SCA for hydrological monitoring and forecasting

Radarsat-1 based
fraction of snow-covered area (SCA)
during the melting period





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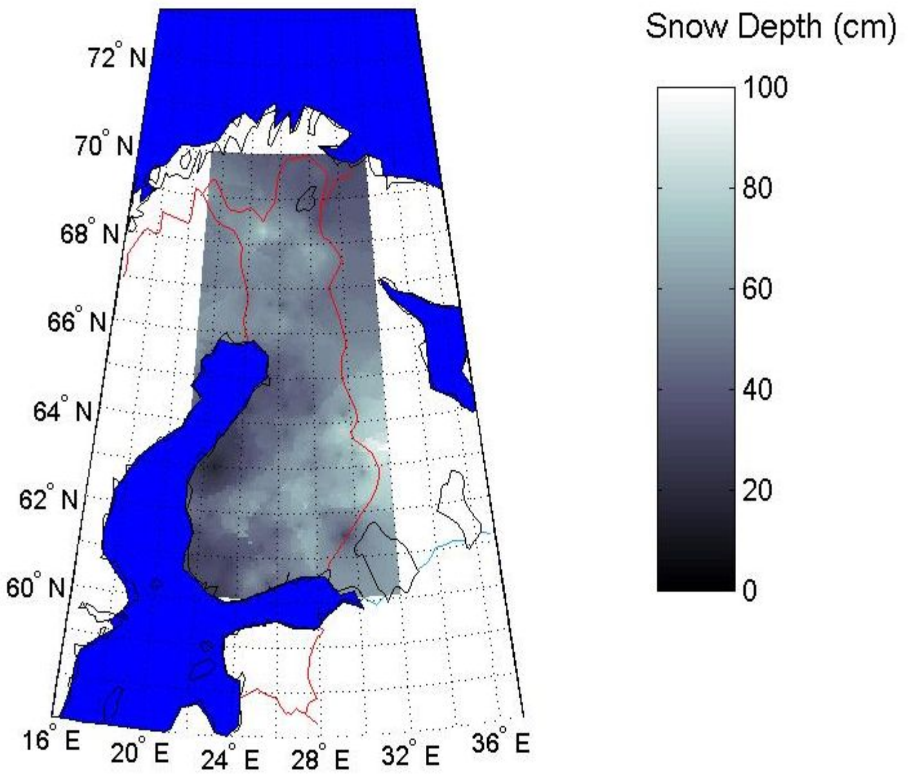
Snow water equivalent (SWE) and snow depth (SD) estimates from satellite microwave radiometer data

Technology: assimilation of satellite data with in situ observations (weather and hydrological stations)

Applications/end-users: hydrological models (e.g. floods), climate change studies, hydropower industry, numerical weather prediction, transportation

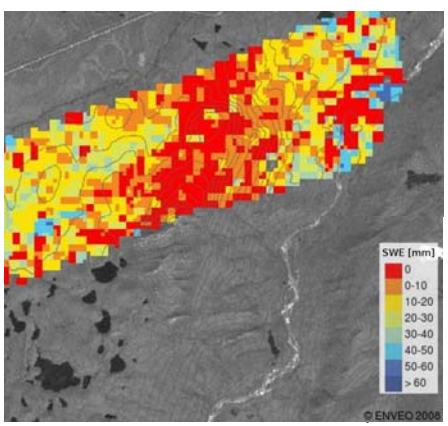
AMSR-derived snow depth for 2 Feb. 2004



Outline of satellite data assimilation

SWE from satellite data

Hydrological model



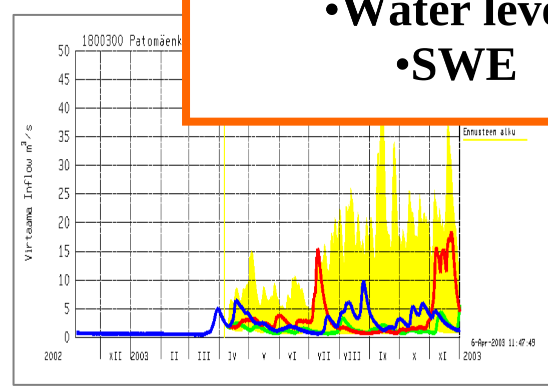
Model input:

SWE

Iterate precipitation and temperature

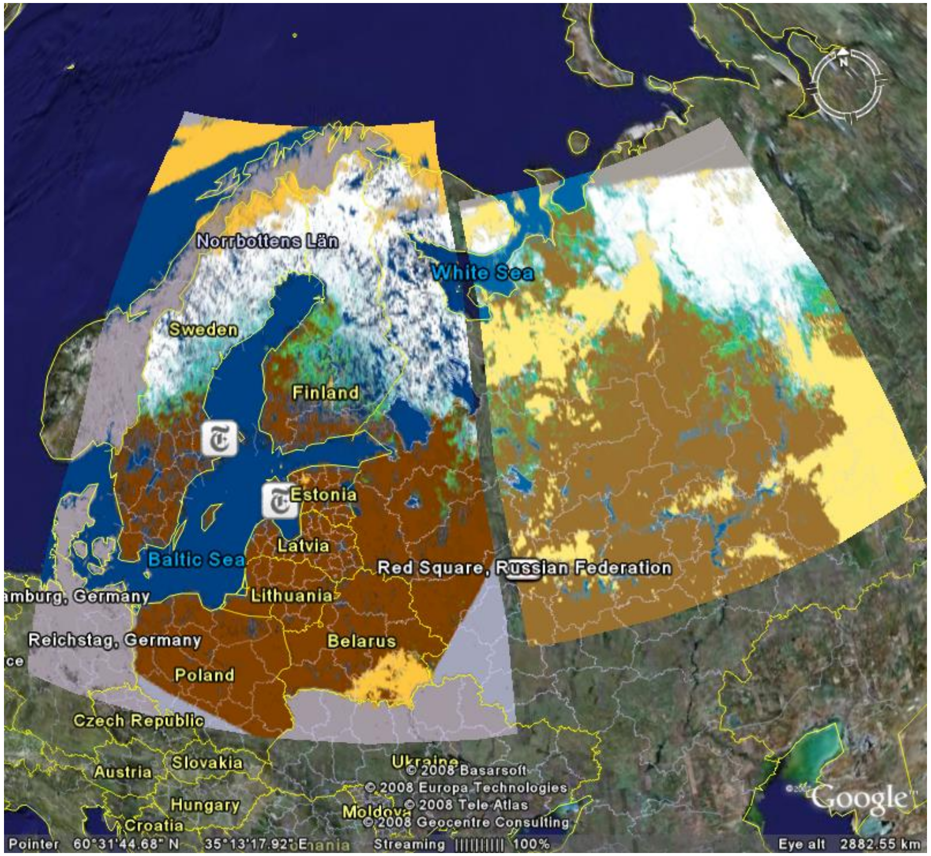
Model output:

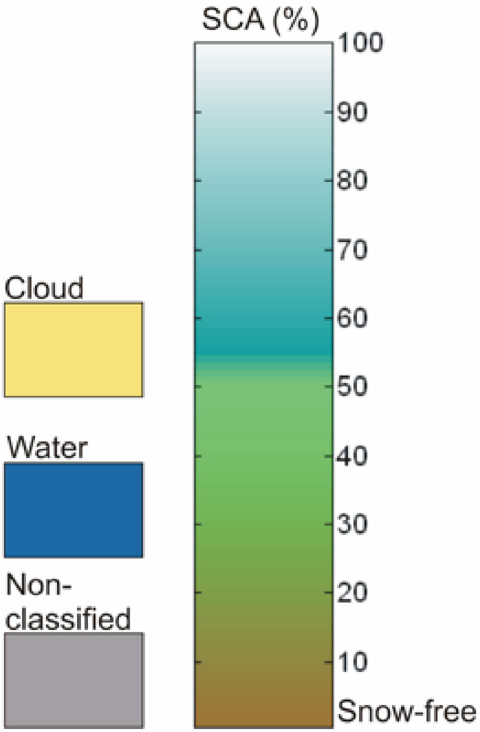
- Discharge
- Water level
- SWE

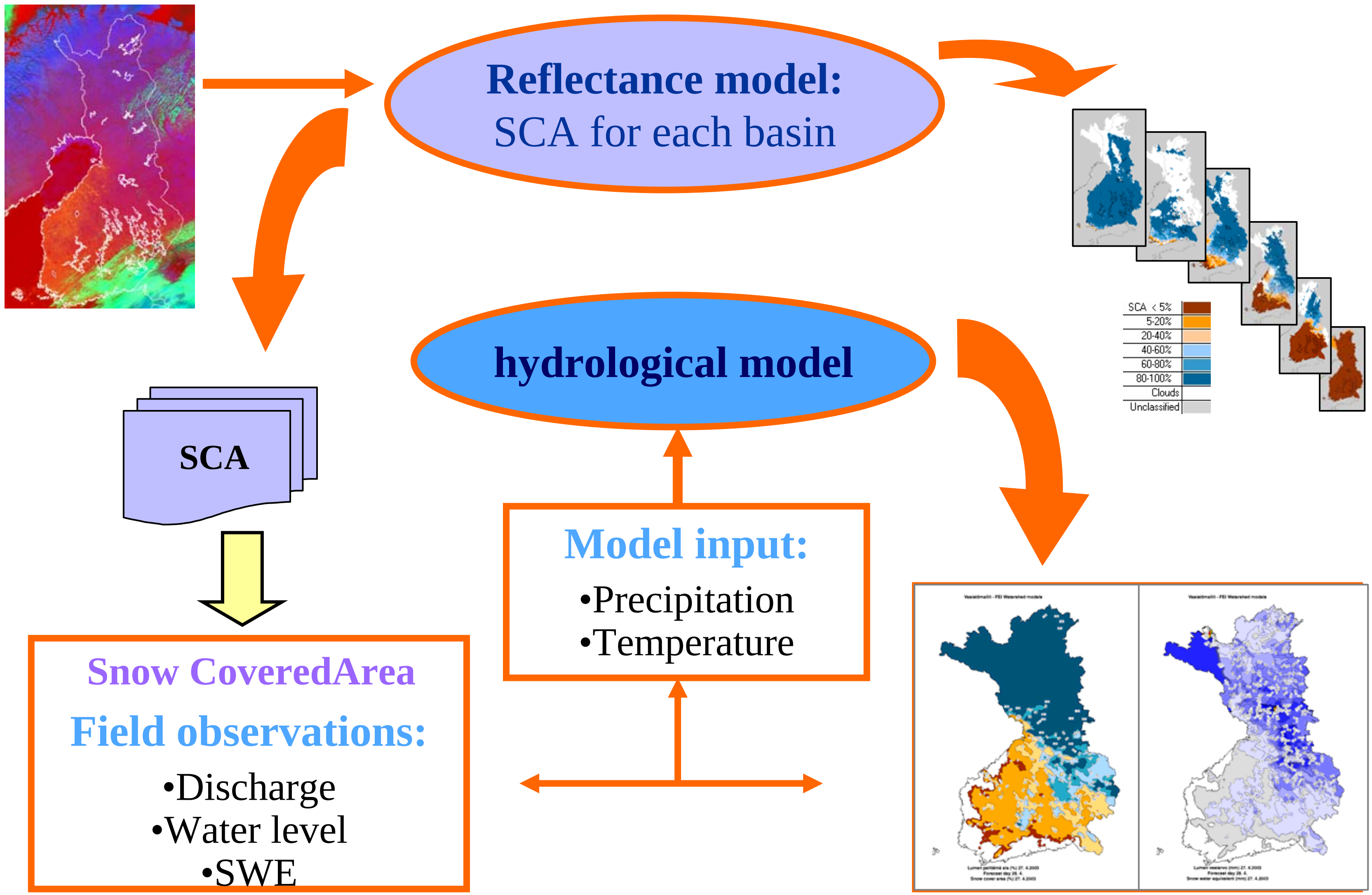


Example on SYKE snow maps produced with SCAmod: Polarview-product (25.4.2007) and Russia-product (24.4.2006)

SCAmod is based on a reflectance model, where the at-satellite observed reflectance is expressed as a function of SCA (%). Model uses three reflectance contributors (wet snow, snow-free ground and forest) as constant parameters. The partial obscurance of forest canopy is accounted for by *apparent forest transmissivity,* which is *a priori* calculated for target area, also using at-satellite reflectance data, but acquired with full dry snow cover conditions

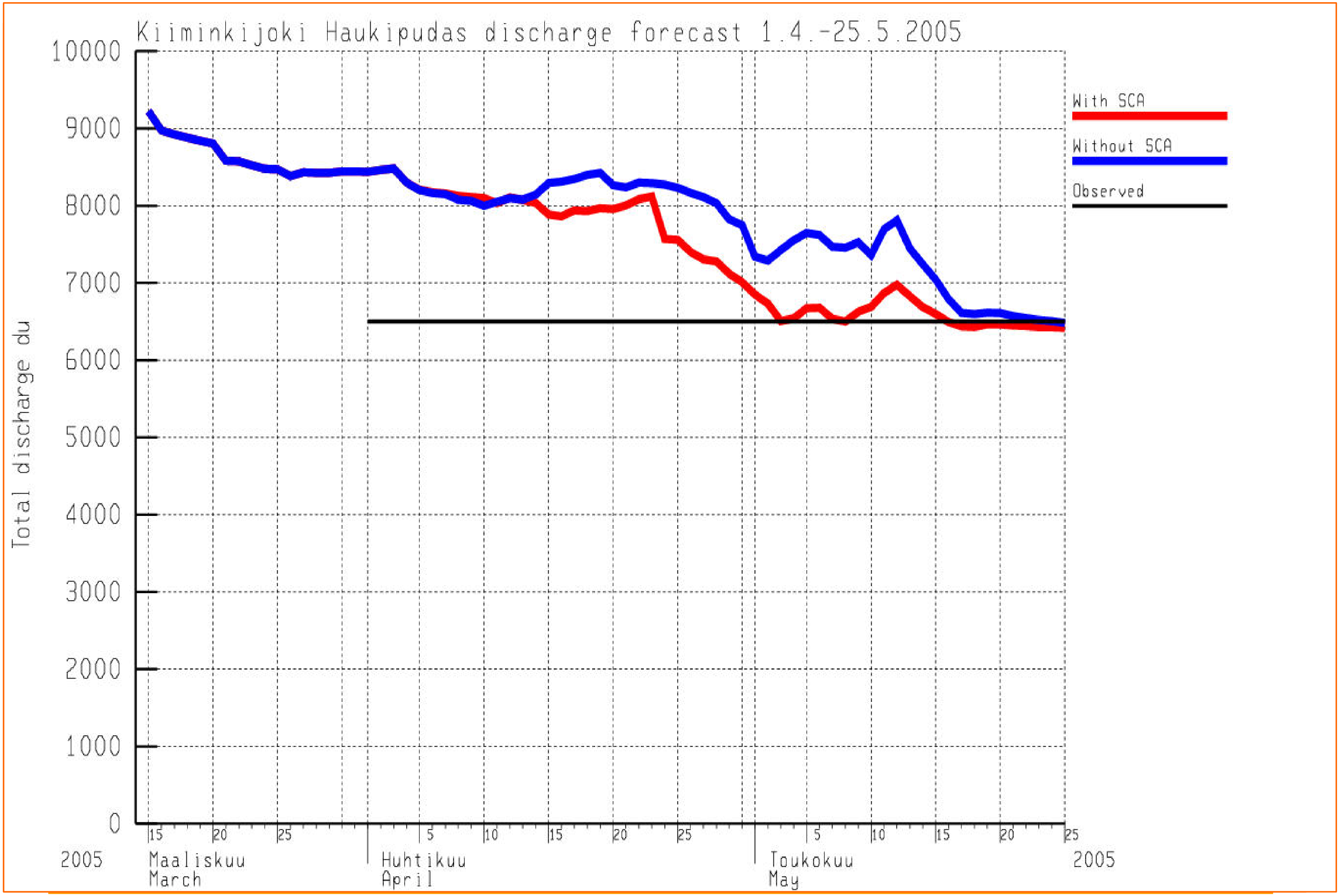




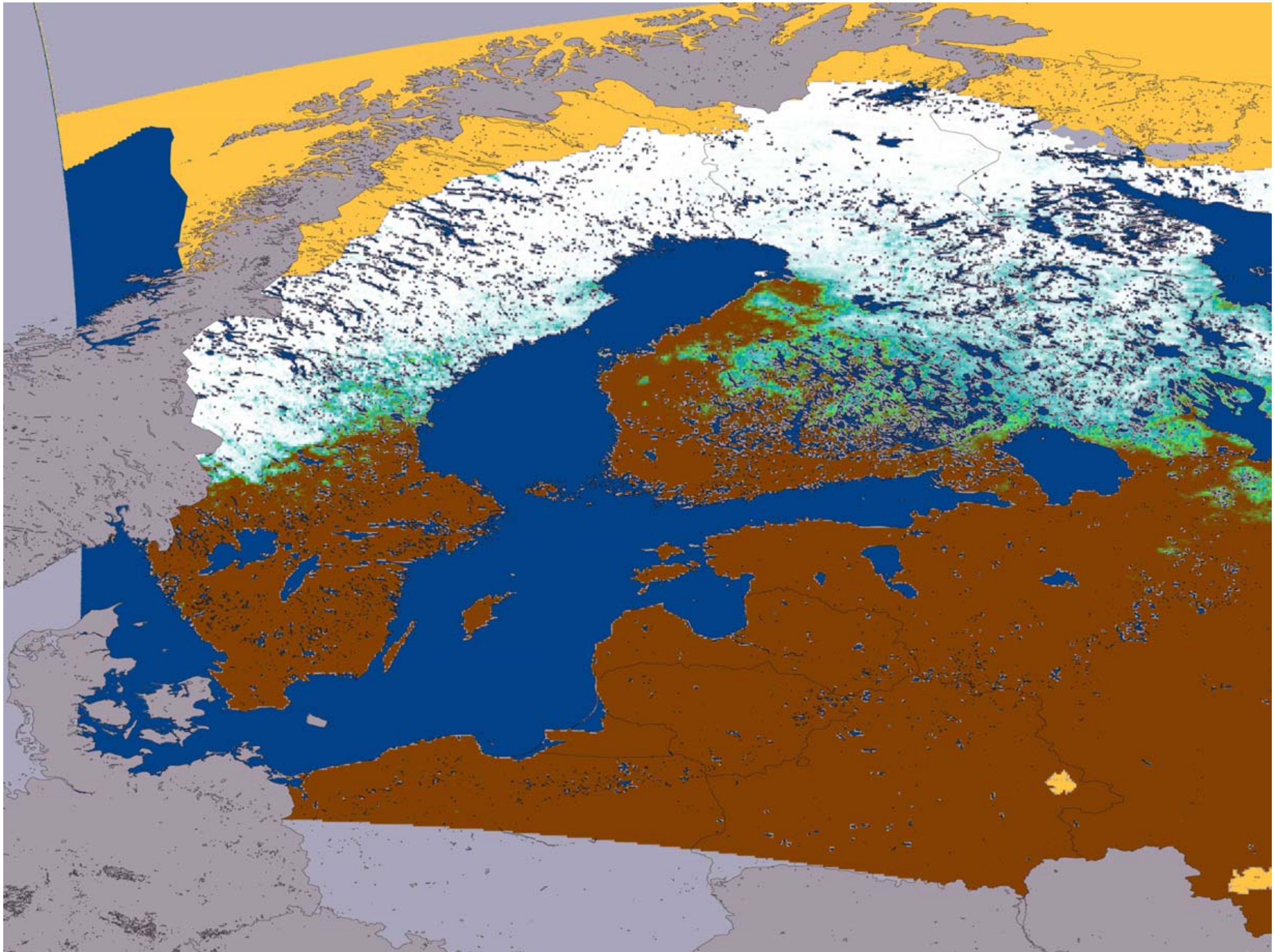


Reflectance model:
SCA for each basin
SCA < 5%
5-20%
20-40%
40-60%
60-80%
80-100%
Clouds
Unclassified
hydrological model
SCA
Model input:
•Precipitation
•Temperature
Snow CoveredArea
Field observations:
•Discharge
•Water level
•SWE

SCA data assimilated to hydrological model

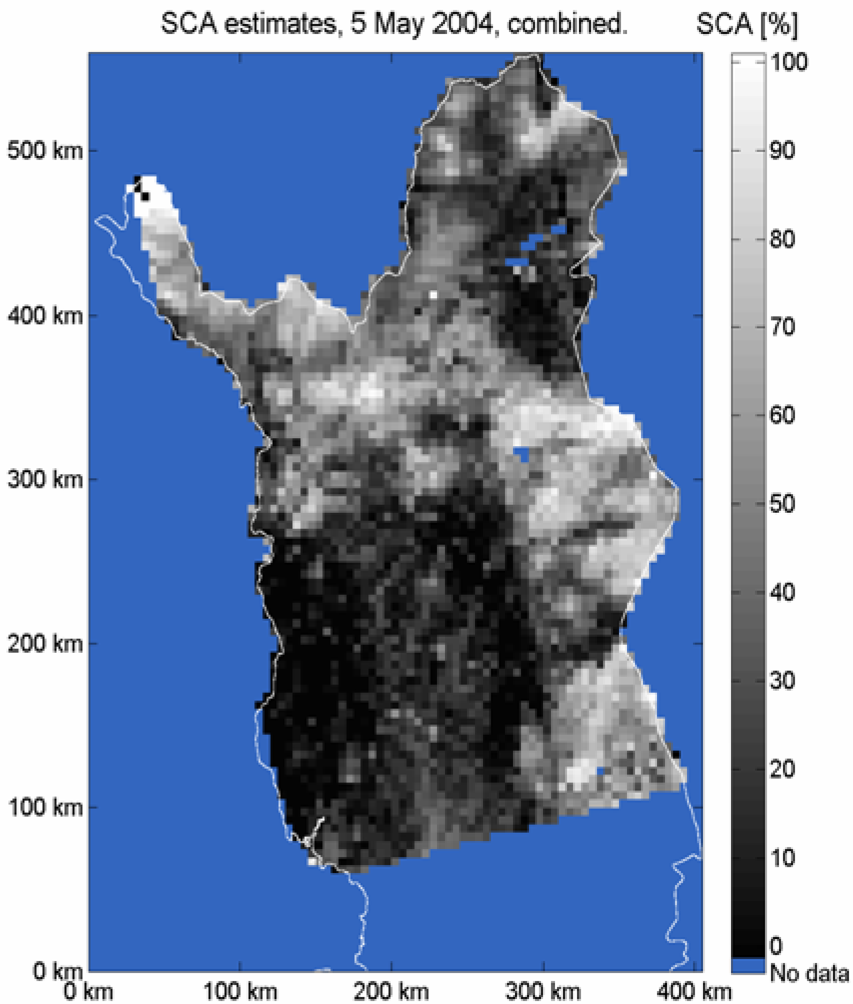


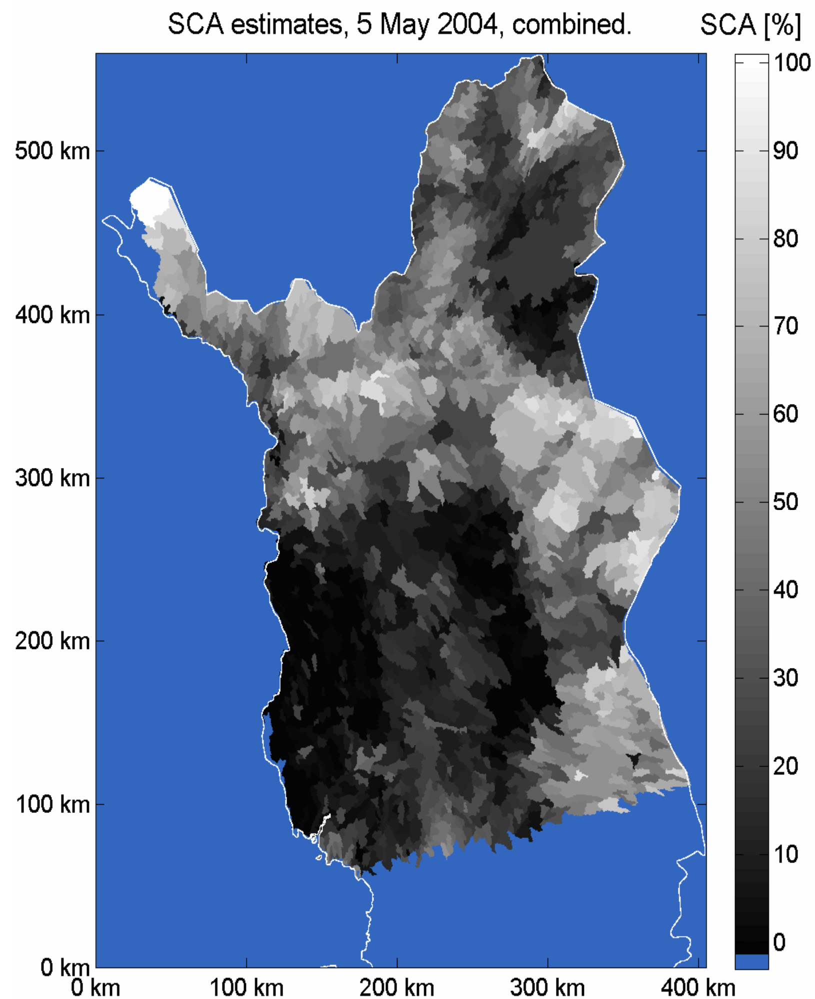
SCA in Baltic region from MODIS data: 28 March 2007



Example on corresponding satellite radar-based NRT product

- Processing for 5 x 5 km grid cells or for drainage basins (Radarsat-1 SAR)

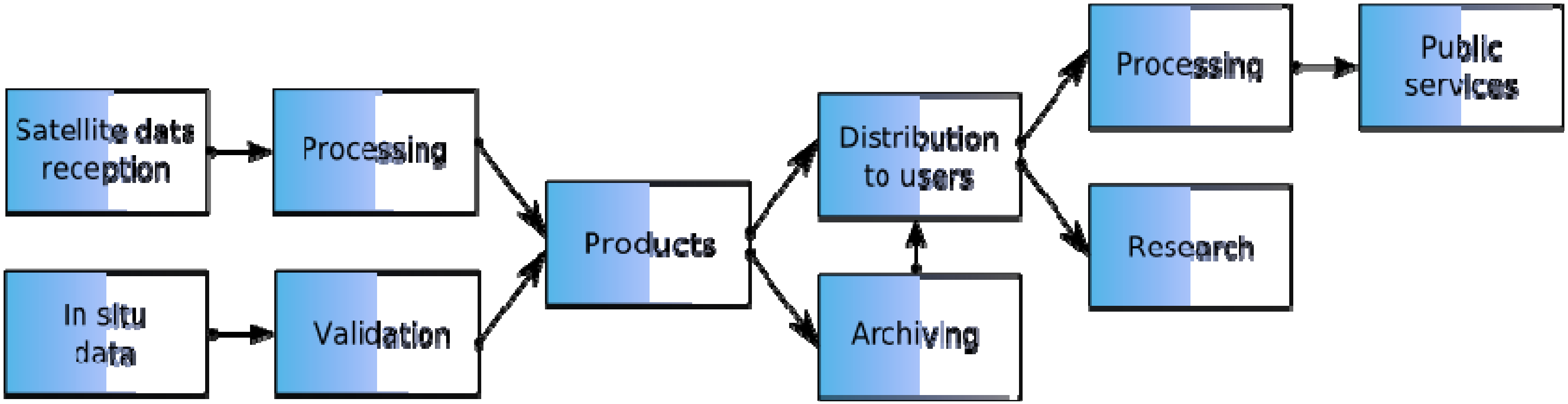




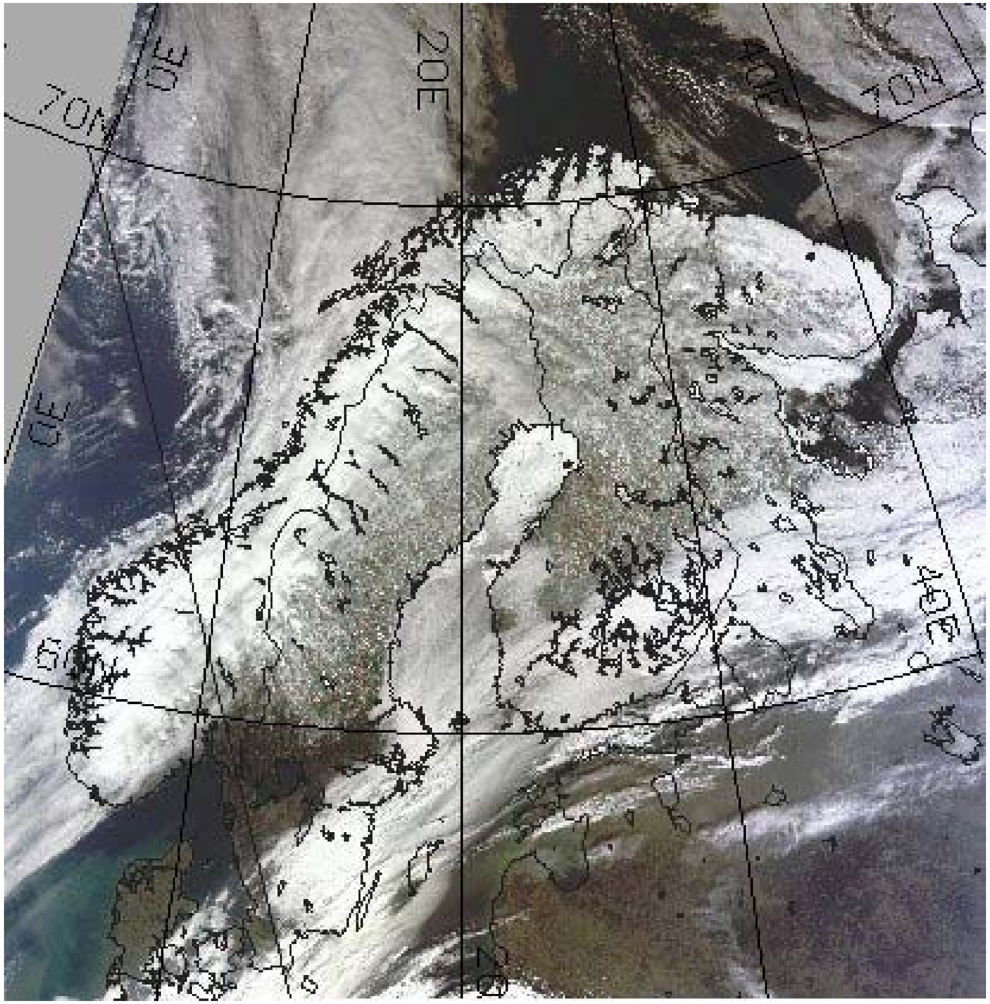
Reception system of FMI at Sodankylä

- **Direct reception of NASA EOS satellites**
- **Currently:**
  - EOS Aura/OMI since 2004
  - EOS Terra/MODIS and Aqua/MODIS since 2003
  - 2.4 m antenna

Satellite operations



MODIS products: satellite image



Summary

- **Satellite data provides time-series of ~30-years relevant to snow cover monitoring**
  - Microwave data applicable even for global monitoring with full spatial and temporal coverage
  - Enables the production of reference data also for the Baltic Sea drainage basin on
    - SWE, SD, snow extent, snow melt and fraction of snow covered area during the melt period (SCA)
- **NRT operational systems running for the Baltic Sea region**
  - SYKE and FMI GMES PolarView-services (SCA, SWE)
  - Operational systems to aid hydrology (currently SCA, soon SWE)
- **ESA GLOBSNOW project coordinated by FMI**

  - Global and regional databases of snow cover for climate research