Integration of CryoLand snow data into hydrological modelling

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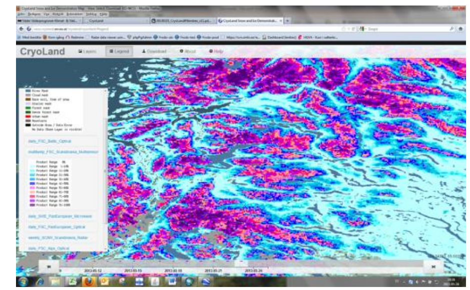
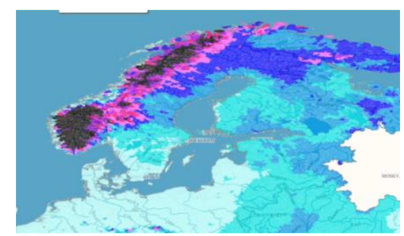
Introduction

EU FP7 CryoLand 2011-2015

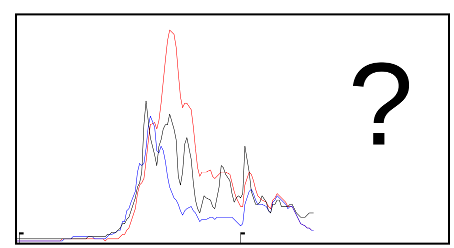
- Products and Services for satellite based Snow and Land Ice data
- Fully operational demonstration service with Pan-European data is available at www.cryoland.eu
- Interactive web-portal or automatic download from WMS server





Integration of CryoLand data in hydrological modelling

- Tools for integration of CryoLand snow products in hydrological models
- Download, pre-processing, assimilation



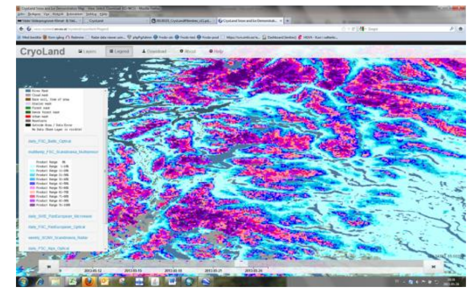
Hydrological modelling

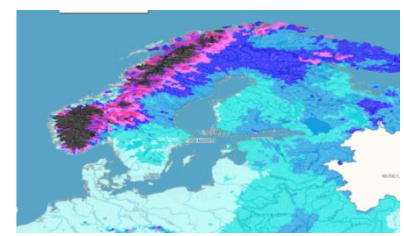
- Evaluate impact on stream flow simulations of assimilating satellite snow data

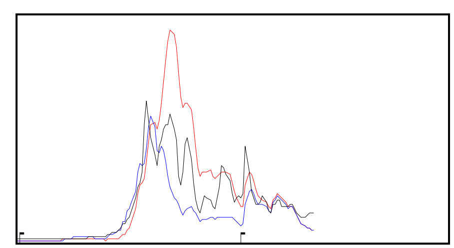
Data integration in hydrological models

Functionalities:

- **Automatic download** of CryoLand data for a particular area and time of interest.
- **Transformation** of **raster** data into **time-series** for hydrological **drainage basins.**
- ***Assimilation*** of snow data in hydrological model for comparison and/or model state updating.







Developed tools:

- ***Scripts*** for automated download and transformation of raster -> basin averages.
- **Data assimilation** module in the open source HYPE model.

Case-study: Sweden

Hydrological model S-HYPE

- Swedish operational application of HYPE model

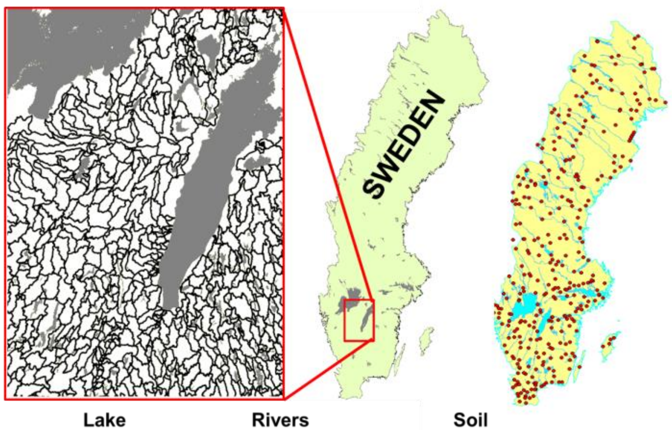
CryoLand satellite snow products used in the study:

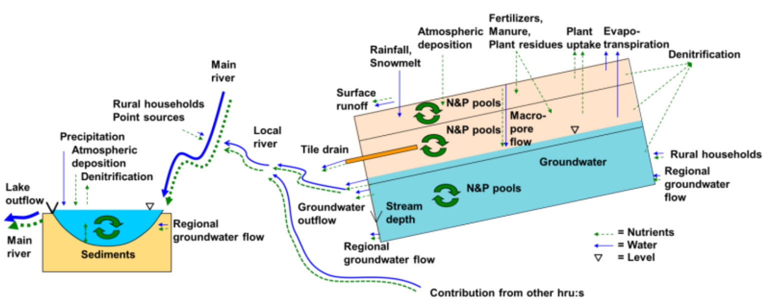
- **Pan-European Snow Water Equivalent (SWE) - FMI**
  - Satellite-based microwave radiometer data (DMSP SSM/I) and weather station snow depth data
  - Pixel size 0.1°x 0.1° (~10x10km^2)
- **Pan-European Fractional Snow Cover (FSC) –ENVEO/SYKE**
  - Optical satellite data (MODIS/Terra)
  - Pixel size 0.005°x0.005° (~500x500m^2)
- **Scandinavian Multi-temporal/sensor FSC products - NR/NORUT**
  - Multi-temporal (latest cloud-free information last 7 days)
  - MODIS/Terra (250x250m^2)

- Daily data 2011-2013
- Pan-European area:

72°N / 11°W to 35°N / 50°E.

Hydrological Predictions for the Environment Model





Lindström et al., 2010, *Hydrol. Res 41.3-4:295-319.*
Strömqvist et al, 2012.

HYPE Open Source Community!

http://hypeweb.smhi.se

S-HYPE

- 450 000 km^2
- 38 000 sub-basins
- Mean sub-basin size: 11 km^2

- Input data
  - Land and soil characteristics
  - Elevation
  - Sub-basin and Lake delineation
  - Interpolated P and T station data

- Step-wise calibration
  - General, Soil, Landuse, Regional parameters
  - Discharge observations (~300 stations)

Two options for snow data integration:

1) **Evaluation** of model and data agreement (visual or numerical)

Correlation, mean, standard deviation, spatial patterns

2) **Data Assimilation** for model state-updating using Ensemble Kalman filter

$$X^a = X^p + K\left(Y - HX^p\right) \qquad K = \frac{C_{XY}}{C_{yy} + R}$$

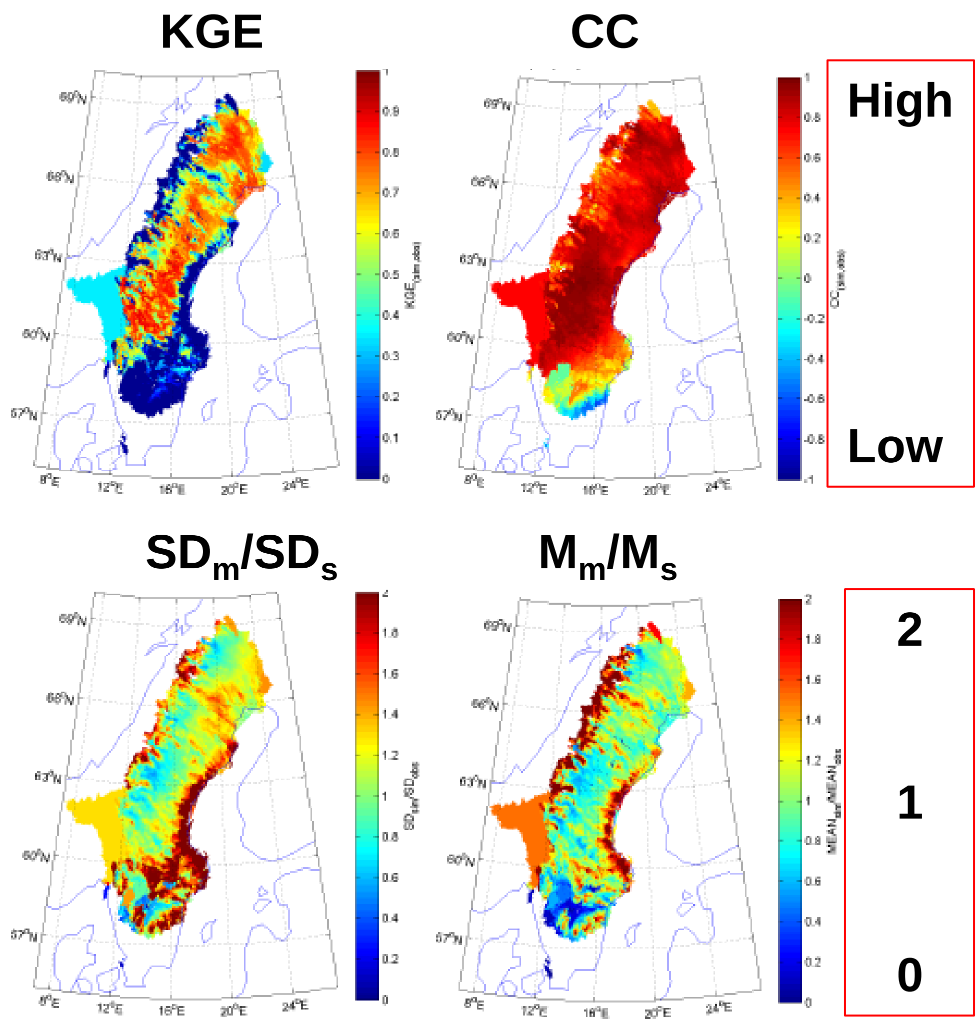
Model states are updated as a function of co-variance between the model states and the discrepancy between model prediction and observed data (aka ’innovation’)

Important that model and data do not disagree too much!

Model and data comparison – SWE

Pan-European SWE product (FMI)

- **Good agreement** in central part of middle and northern Sweden:
  - Forests
  - Non-mountain areas
- **Correlation is high** (except for the south)
- **Variability and Mean value differs**:
  - In the south (little snow and lakes)
  - along the east coast
  - western mountain range
- **Problem for the satellite or model?**
  - Mountains, surface water, coastal areas, areas with small amount of snow



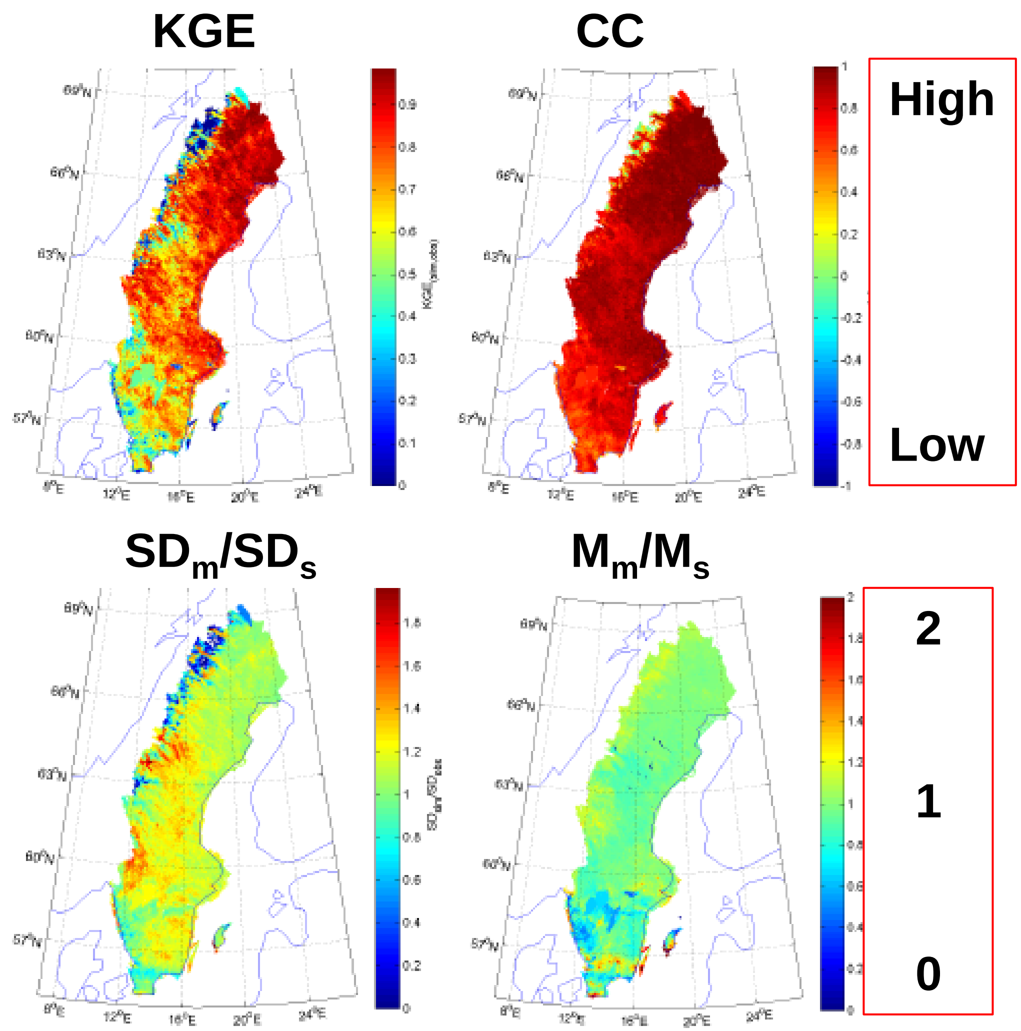
Model and data comparison – FSC

Pan-European optical product ENVEO/SYKE

- **In general a very good agreement** between model and satellite data throughout Sweden

- However, the **temporal variability is different** in the most alpine part of the mountains in northern Sweden

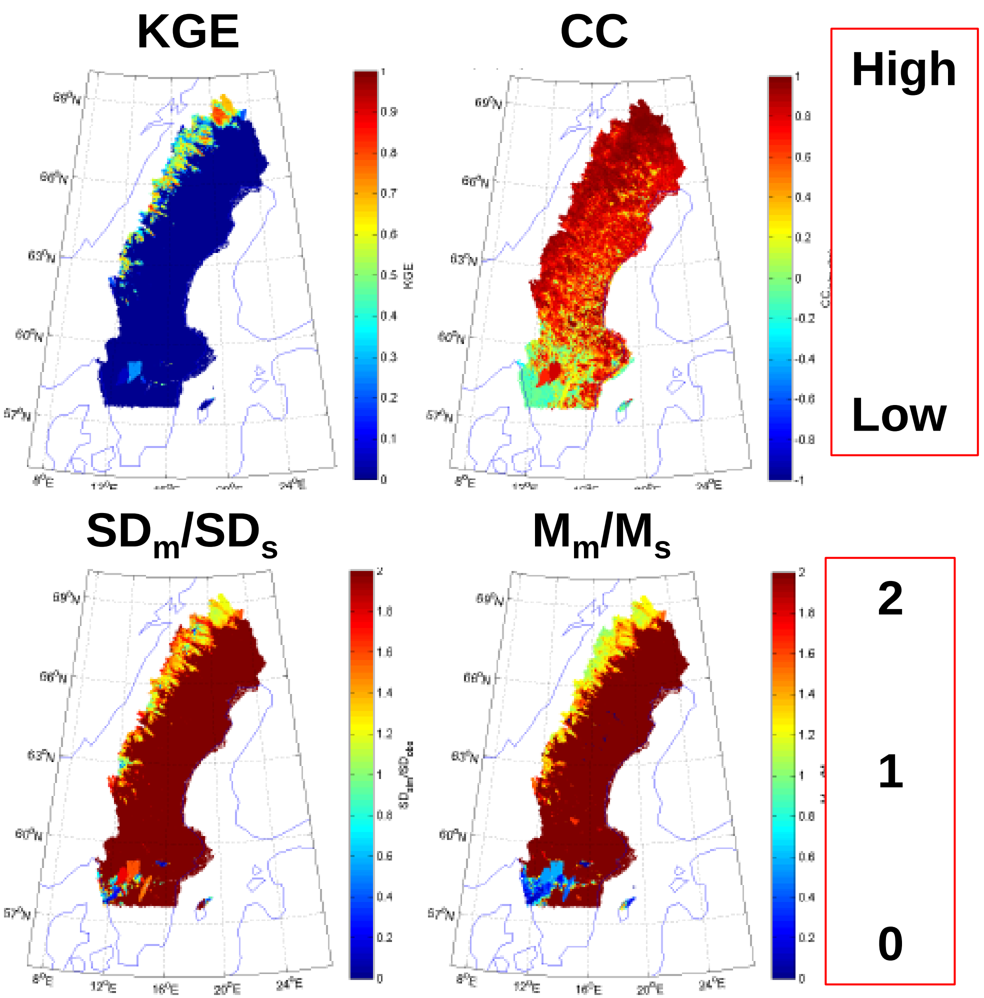
- **Transmissivity model** is well-adapted to boreal forests.



Model and data comparison – FSC

Multi-temporal/multi-sensor Scandinavian product (NR/NORUT)

- **Best agreement in the mountain area!s**
- Satellite product originally developed for Norwegian mountain areas
- Better temporal coverage – less cloud masking
- Not intended for forested areas
- Correlation still high in forest
  - *Potential to improve for forest areas?*



Intermediate discussion

- **Good agreement** between **Pan-European optical FSC** product and S-HYPE in most parts of Sweden.
- **Multi-temporal FSC product** had a better agreement in mountain areas
- **Pan-European SWE product** and the model agreed rather well in central-northern Sweden – disagreements in the mountains and along the coast.

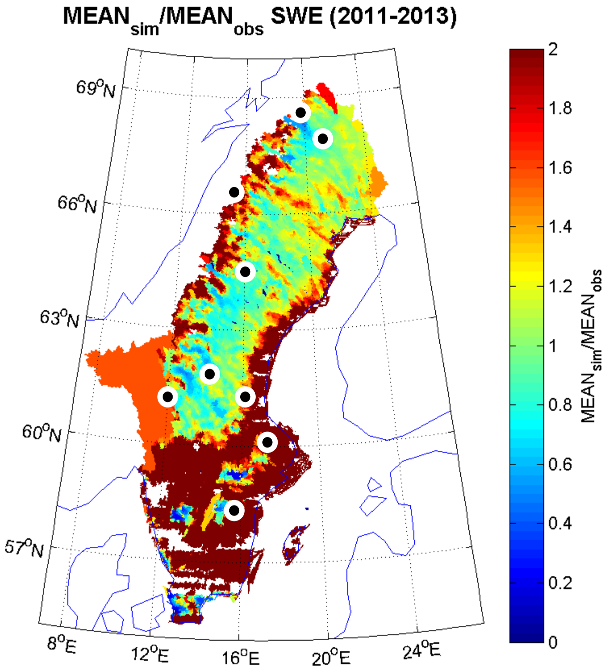
- **How** will the quality of river discharge simulations change if we assimilate the satellite snow data in the simulations?
- **Can** the satellite information help explaining inter-annual variations better even if mean value is wrong?

Assimilation experiment

- 9 non-regulated basins with discharge observations
- Rather small (~1000 km^2)
- Distributed on “good” and “bad” areas according to previous comparison
- <u>5 types of simulations:</u>
  1) Deterministic (single simulation)
  2) Ensemble without assimilation
     - 100 ensemble members
     - Random perturbation on P and T

  3-5) EnKF assimilation with

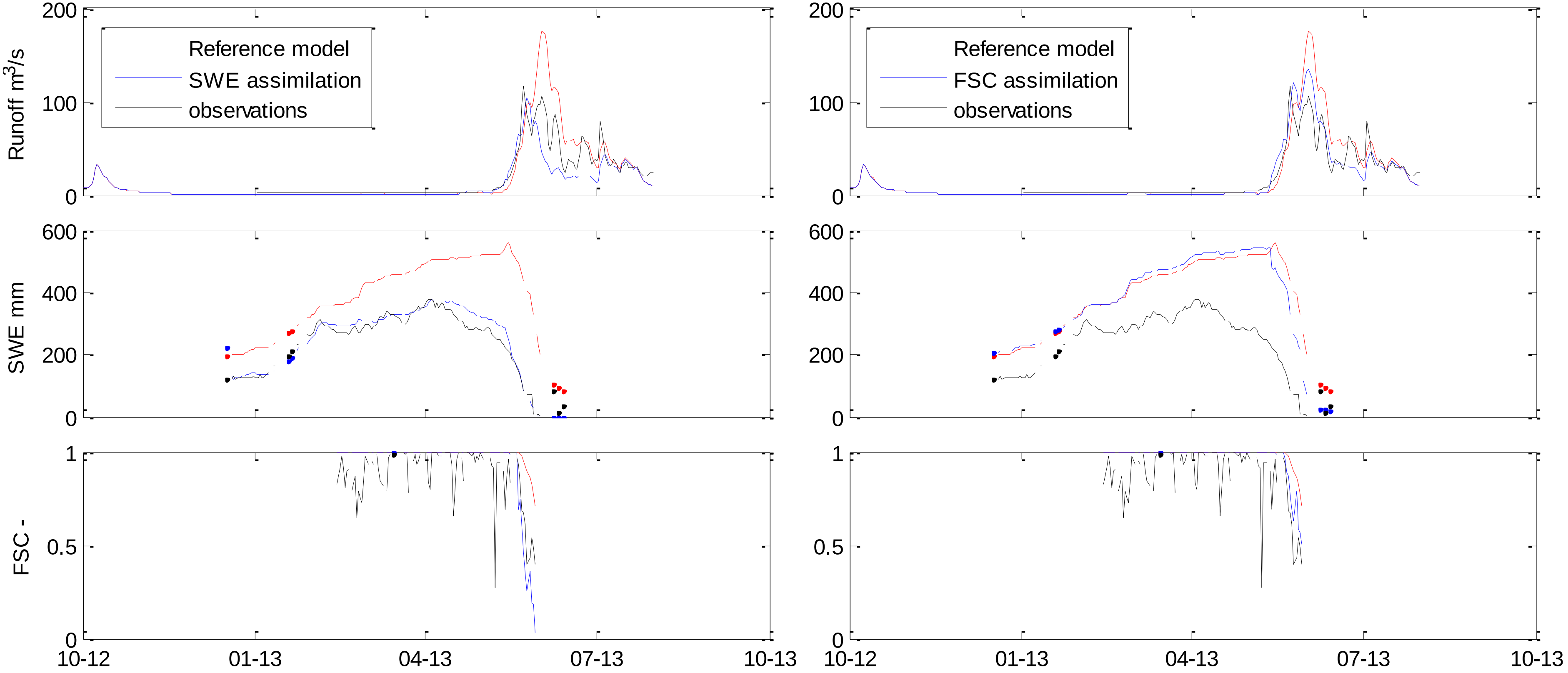
  3) SWE
  4) FSC (optical)
  5) FSCM (multi-temporal optical)



<u>Test-basins represent:</u>
10-85% forest cover
40-950 m.a.s.l (mean)
7-1100 km^2

Good exmple: Abiskojokki, northern Sweden.

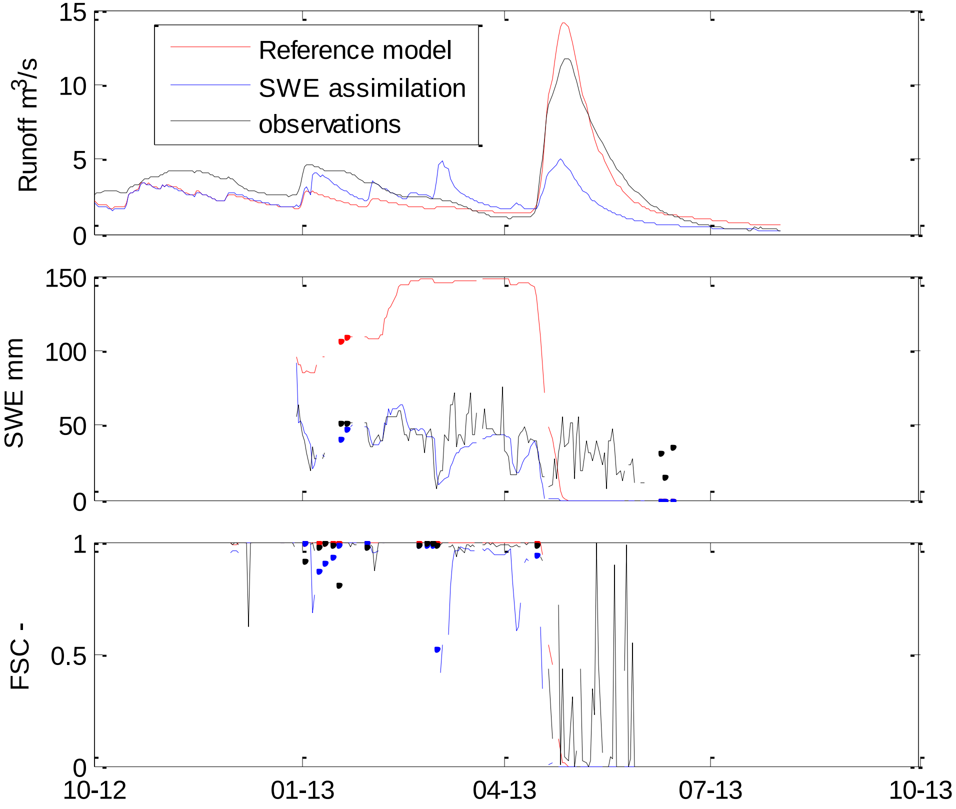
Both SWE and FSC data improve stream flow simulations

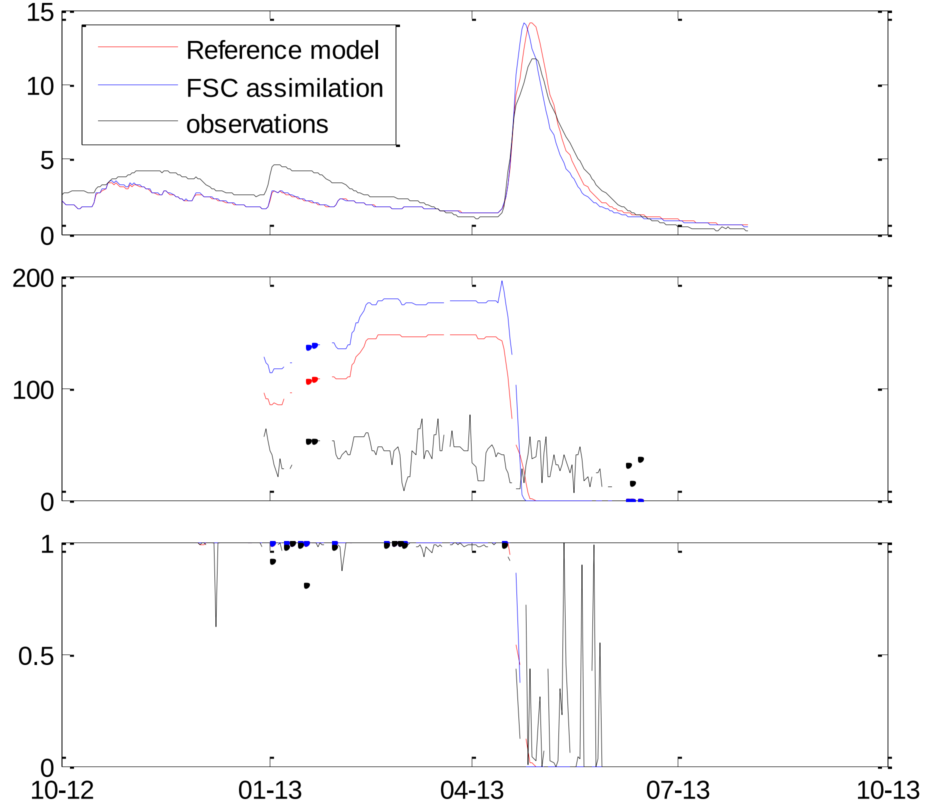


Bad exmple: Vattholma, south-east Sweden.

FSC data improve stream flow simulations

SWE data deteriorate the stream flow simulations (amount and melt problem)



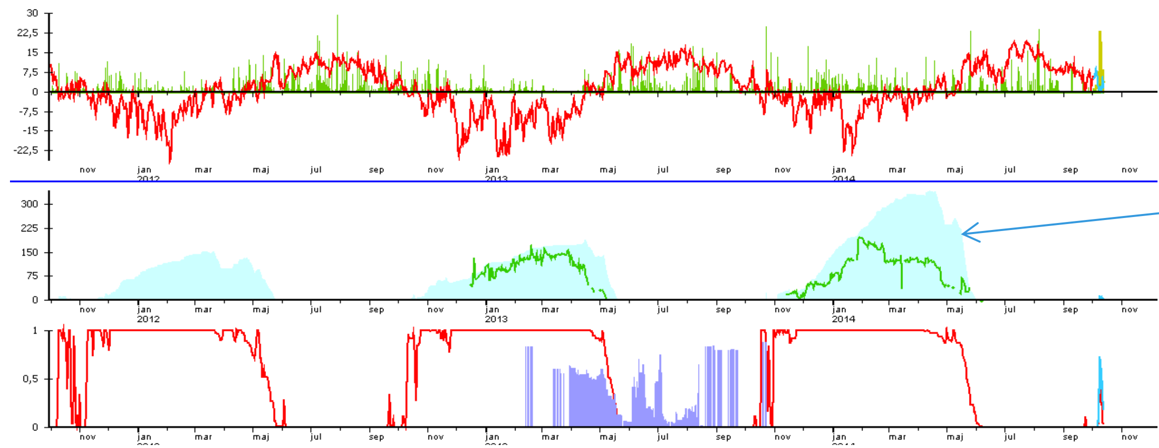


Impact on river discharge simulations

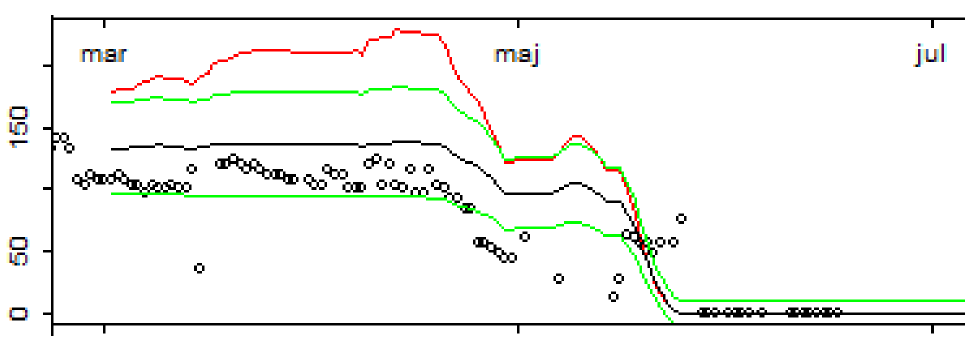
- Overall, rather small changes - small improvements just by ensemble-mean
- SWE-assimilation reduced the model performance in 7 and improved in 2 cases
- FSC-assimilation improved model performance in 5 cases

Simulation	KGE	A	B	C	D	E	F	G	H	I	Improved/reduced performance (sum)
Deterministic	Q	0.44	0.84	0.55	0.67	0.41	0.82	0.82	0.88	0.57	reference
Ensemble	Q	**0.47**	**0.86**	*0.53*	*0.64*	**0.44**	**0.85**	0.82	**0.90**	0.56	5 improved, 3 reduced (+2)
EnKF_SWE	Q	**0.83**	0.80	0.19	0.34	**0.55**	0.49	0.81	0.53	0.56	2 improved, 7 reduced (-5)
EnKF_FSC	Q	**0.61**	**0.85**	**0.56**	**0.72**	-0.04	0.64	0.82	0.88	**0.62**	5 improved, 2 reduced (+3)
EnKF_FSCM	Q	0.41	0.68	0.55	0.54	**0.47**	0.64	0.58	0.80	0.54	1 improved, 7 reduced (-6)

Known issues with SWE microwave data



Saturation at ~150-200mm
Fixed snow density
Spatial swe distribution



Basin mean SWE (model)
Effective SWE (model)
CryoLand Pan-Euro SWE

Potential ways forward:

Estimation of the (microwave) effective SWE using the spatial variation in the hydrological model and assuming a certain saturation level.

Summary

- Tools were developed for integration of CryoLand data in hydrological model and are available to interested users.

- Comparison between CryoLand Satellite Snow products and S-HYPE model simulations in Sweden using the KGE-index was **useful to identify the spatio-temporal** properties of the data and the model

- **CryoLand Satellite snow data** seem to provide useful information to improve river discharge simulations in Sweden (both FSC and SWE)

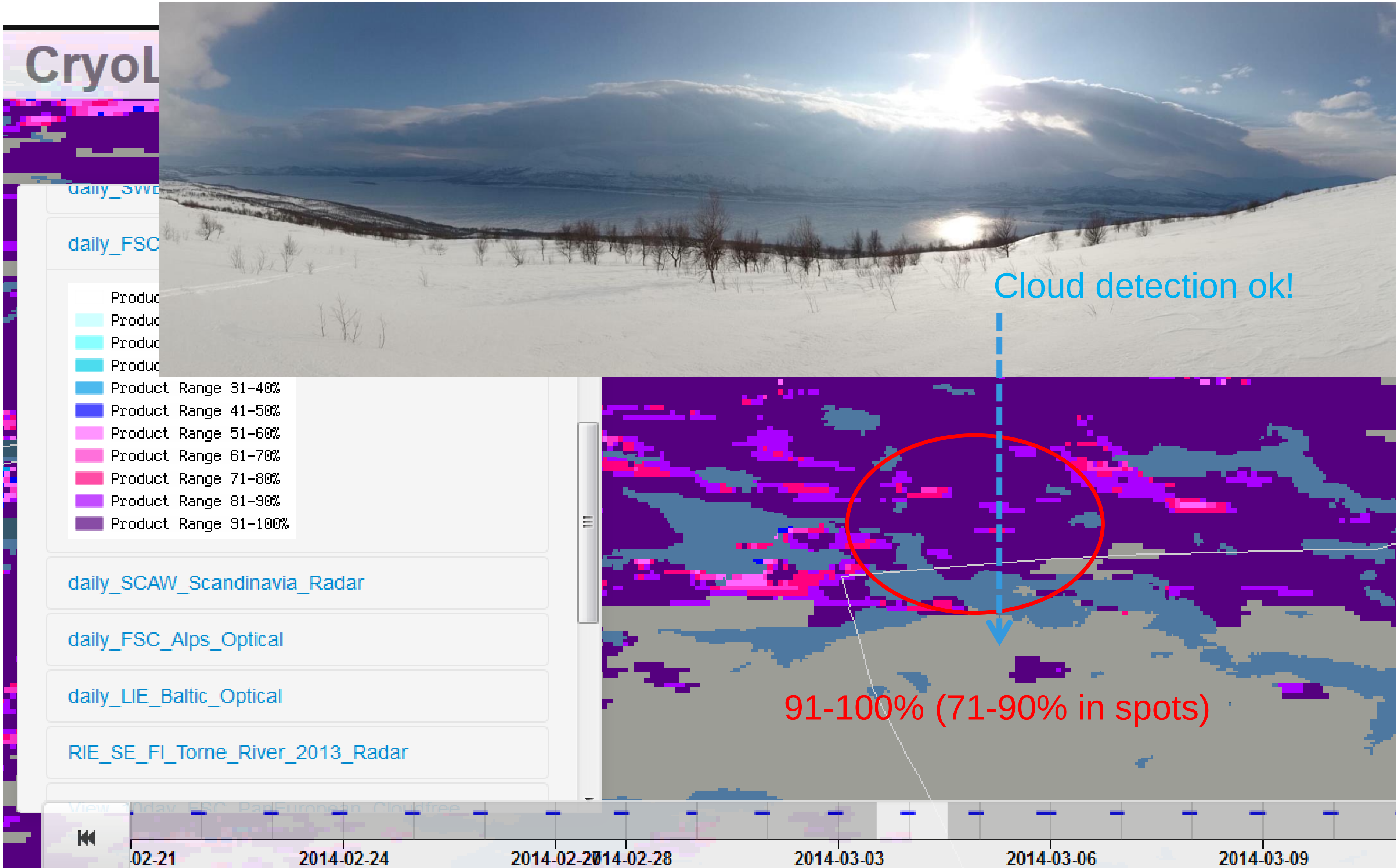
- **SWE data** would be the most valuable, but also the most uncertain.

- **However,** it seem to be possible to relate systematic biases in microwave SWE data to snow spatial distribution and snow structure simulated by a model or in-situ data.

- SMHI will continue testing CryoLand data operationally during 2014-2015.

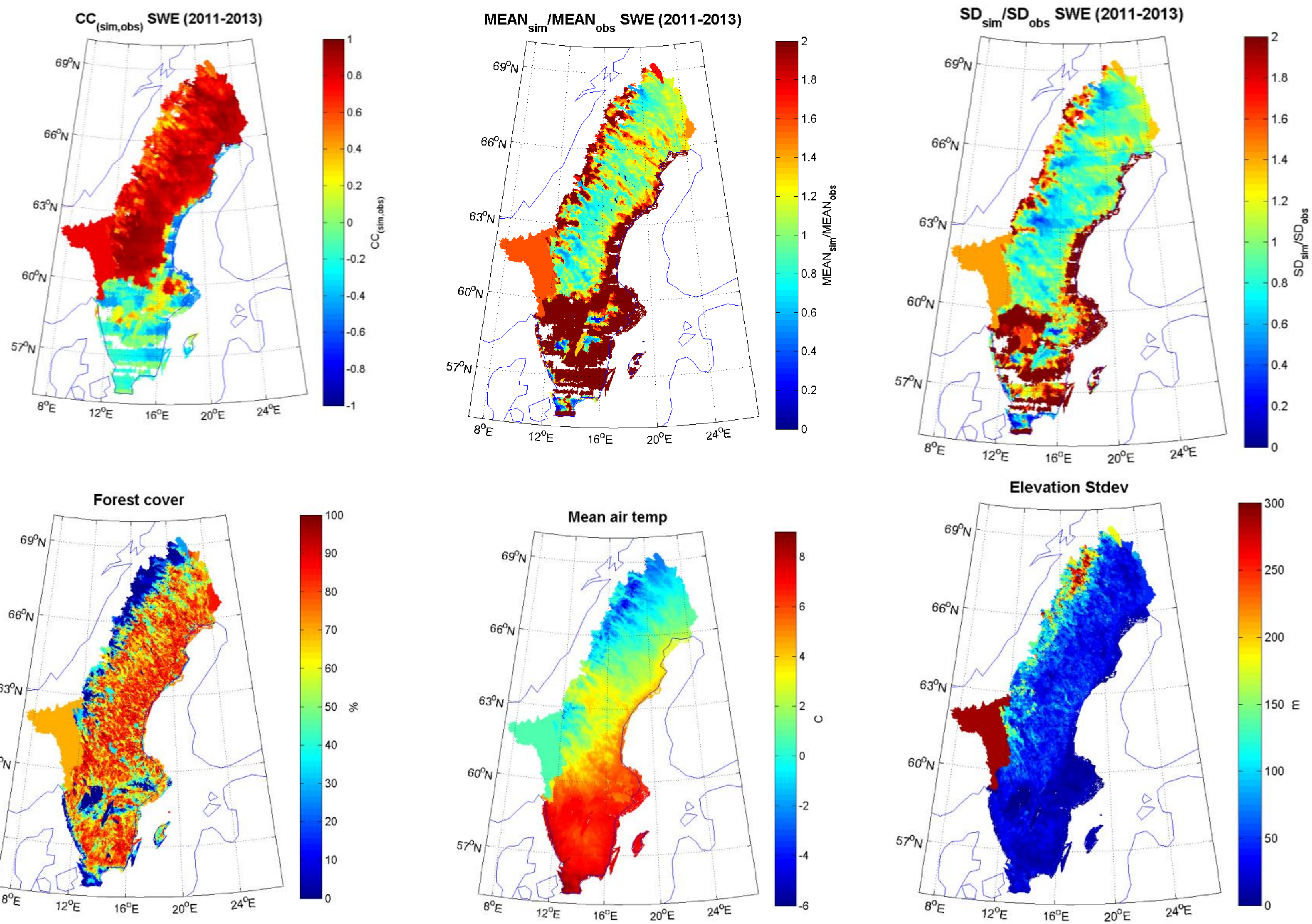
Thanks for your attention!

What’s the fractional snow cover here?


daily_FSC
Product Range 31-40%
Product Range 41-50%
Product Range 51-60%
Product Range 61-70%
Product Range 71-80%
Product Range 81-90%
Product Range 91-100%
daily_SCAW_Scandinavia_Radar
daily_FSC_Alps_Optical
daily_LIE_Baltic_Optical
RIE_SE_FI_Torne_River_2013_Radar
Cloud detection ok!
91-100% (71-90% in spots)
02-21
2014-02-24
2014-02-27
2014-02-28
2014-03-03
2014-03-06
2014-03-09

Possible to relate model-data-biases to basin characteristics?

Gustafsson et al., EGU 2014-16020, HS2.2.2



SMHI

Test basins:

River basin	Stream flow Station/Code	Code	Lat	Lon	Area (km^2)	Elev, mean (m)	Elev, std (m)	Forest (%)	Lake (%)	Description
Tornionjoki	Övre Abiskojokk	A	68.3	18.5	565.1	953.4	261.2	9.9	2.6	North, mountain, alpine
Tornionjoki	Mertajärvi	B	68.3	22.1	390.8	419.4	46.3	47.9	5.2	North, inland forest
Umeälven	Tängvattnet	C	65.9	14.7	194.6	718.1	167.0	18.5	9.0	North-west, mountains
Indalsälven	Medstugan nedre	D	63.6	12.3	224.7	654.7	83.5	24.2	10.6	Central-west, lake area
Ljusnan	Ryggesbo	E	61.6	15.7	148.9	303.3	71.6	83.4	6.5	Central, inland forest
Testeboån	Konstedalsströmmen	F	61.0	16.4	997.8	255.7	95.6	82.3	5.4	Central-east, coastal forest
Dalälven	Ersbo	G	61.4	12.7	1103.2	732.0	171.8	51.9	0.3	Central-west, mountain, forest
Norrström	Vattholma	H	60.2	17.8	293.7	38.6	10.4	74.3	3.1	South-east, coastal forest
Söderköpings ån	Ryttarbacken	I	58.5	16.0	7.3	61.8	9.6	35.2	0.0	South-east, agricultural