HEPEX Seasonal hydrological forecasting workshop, Norrköping 21-23 September 2015

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VALUE OF IN-SITU AND SATELLITE BASED SNOW OBSERVATIONS FOR IMPROVING SEASONAL RUNOFF PREDICTIONS

(work in progress)

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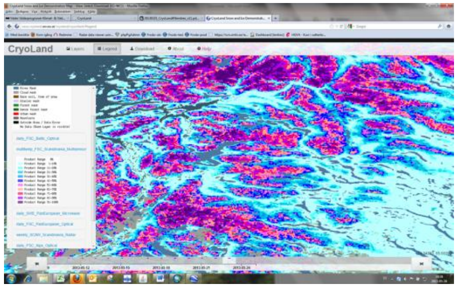
Background

ELFORSK CryoLand

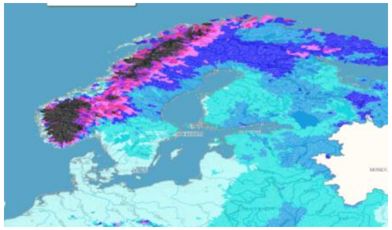
How to integrating snow observations in seasonal runoff predictions for hydropower management?

- Currently and in the past - numerous projects with Swedish hydropower industry (Elforsk/HUVA)



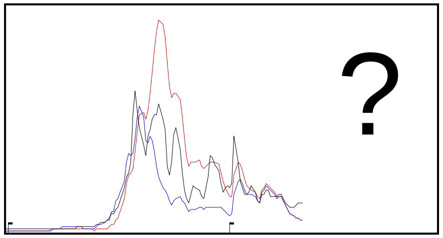
EU FP7 CryoLand 2011-2015

- Products and Services for satellite based Snow and Land Ice data



Data integration

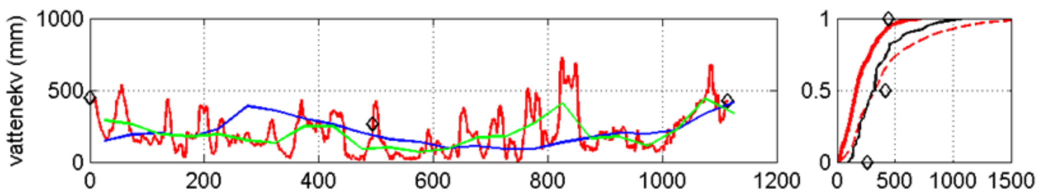
- Tools for integration of CryoLand snow products in hydrological models:
  - download, pre-process, assimilation

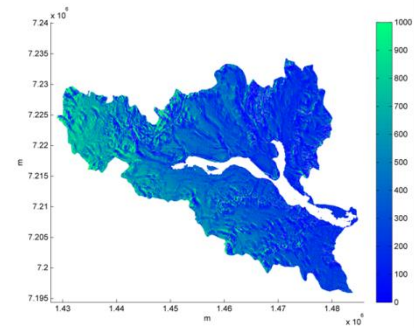


Hydrological modelling

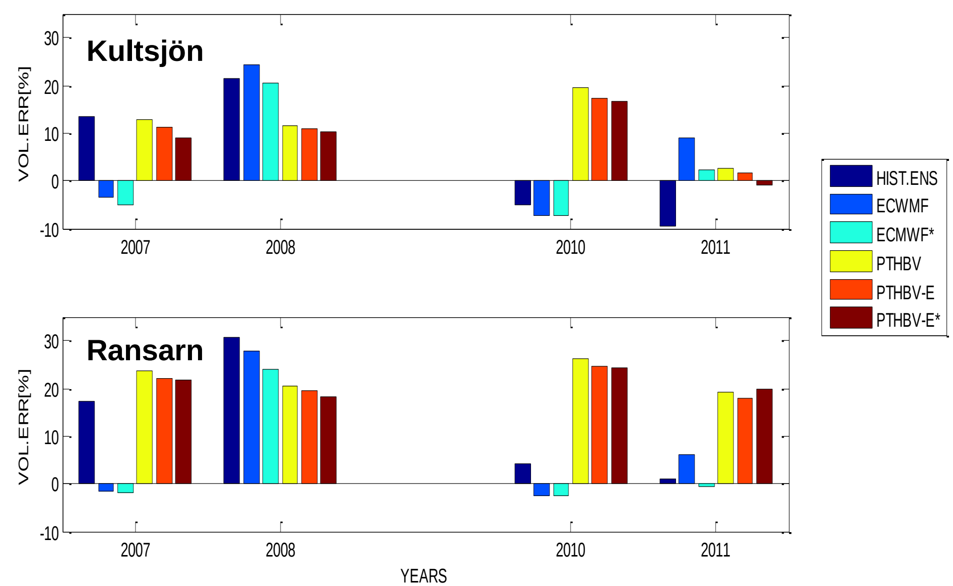
- Evaluate impact on stream flow simulations of assimilating satellite snow data

In-situ data case-study: assimilation in seasonal hydrological forecasts





- **High resolution SWE** data along representative measurement lines
- **Spatial interpolation** to hydropower reservoir basins
- **Spring melt forecasts** (15 April-31 July):
  - Ensembles of historical years/ECMWF seasonal forecasts (v4?)
  - **Improved** by updating model snow storage to the interpolated in-situ data
  - **Not consistent** year-to-year.



Gustafsson et al, 2009-2012: NHC2012

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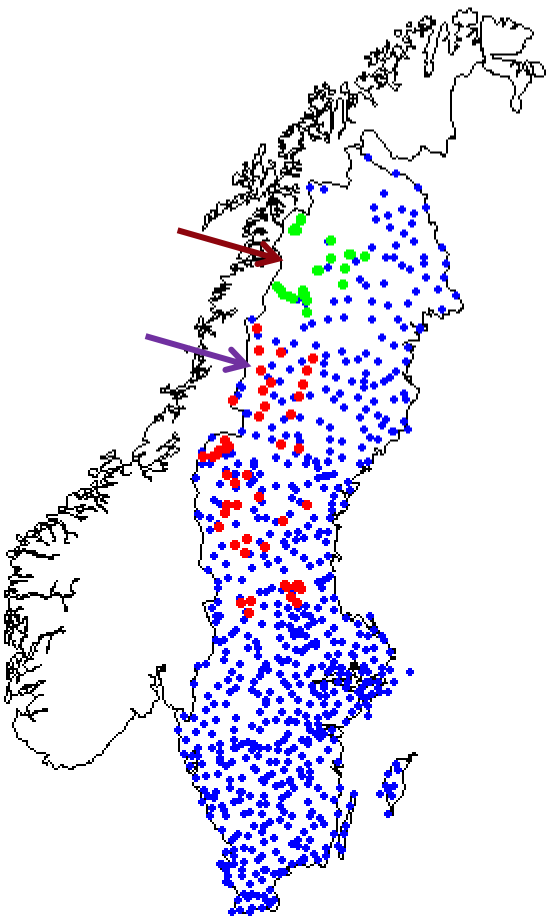
Operational observations of snow and the use of these observations in Sweden?

- Daily snow depth observations by SMHI at ~600 stations:

- ~20 Annual snow courses by hydropower companies
- ~10^2 km Helicopter GPR surveys (by Vattenfall AB)

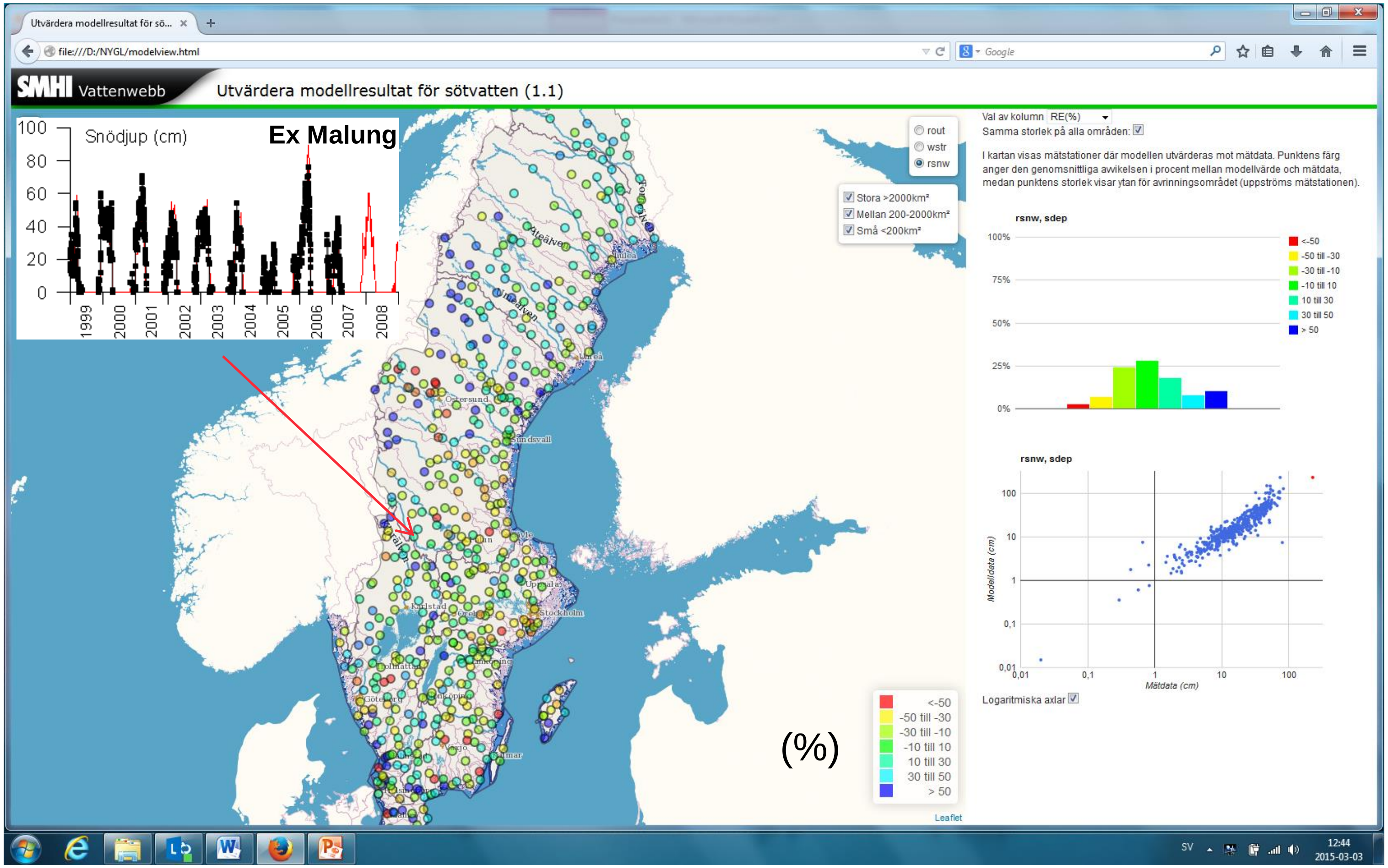
- Bi-weekly observation of depth, density and SWE by hydropower companies (VRF AB) at ~50 reservoir dams:

- Snow-mobile GPR surveys 2007-2015 (~30km by KTH/SMHI/SU/VRF)



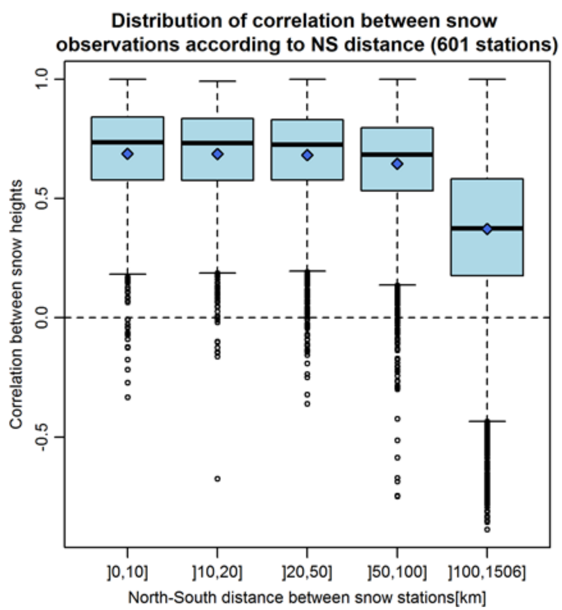
Deviation in mean snow depth (mod vs obs)

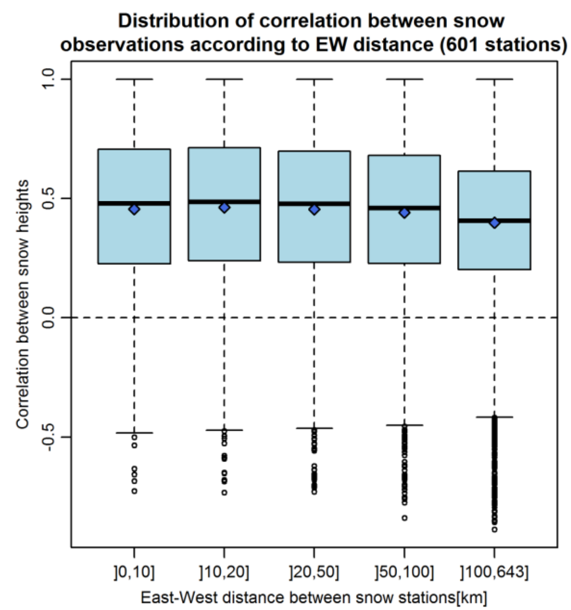
601 stations



Correlation analysis

Snow depth correlation higher North-South than East-West





Cryoland 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 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.

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CryoLand SWE vs S-HYPE modellen

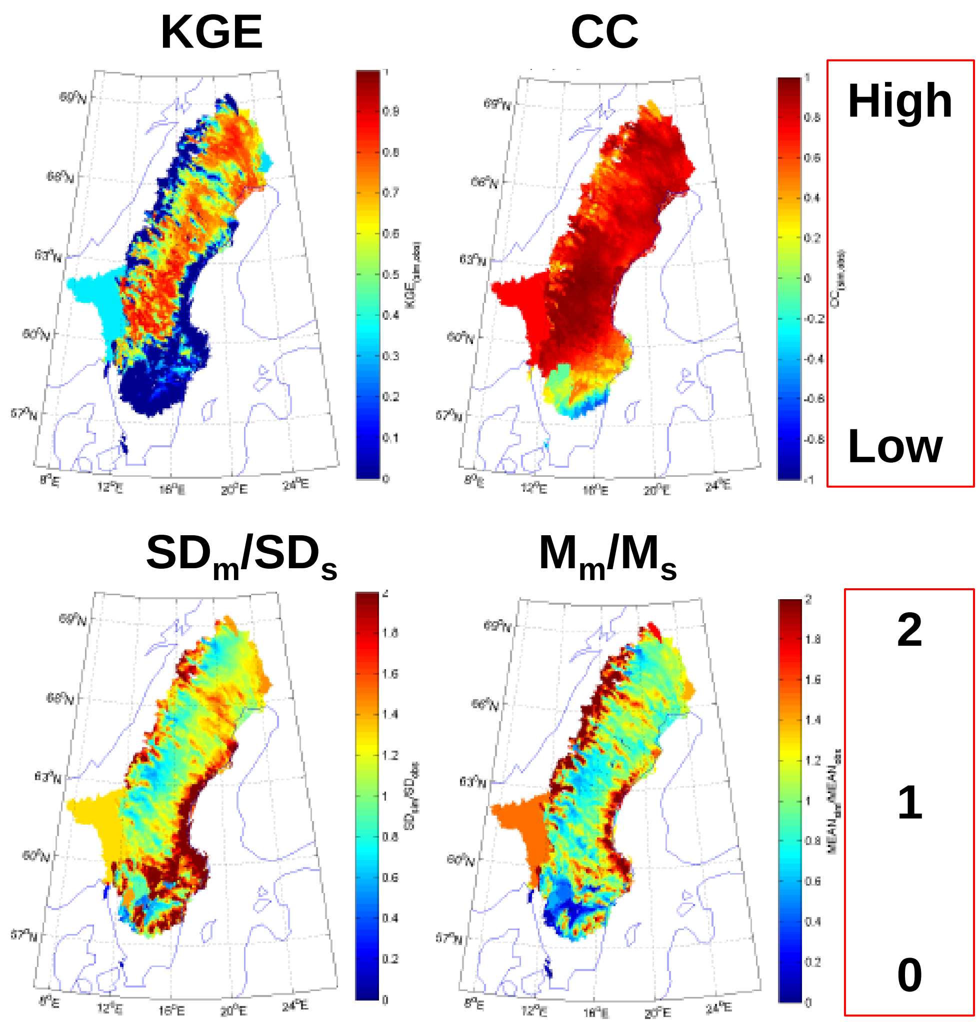
Pan-European SWE product (FMI)

- **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



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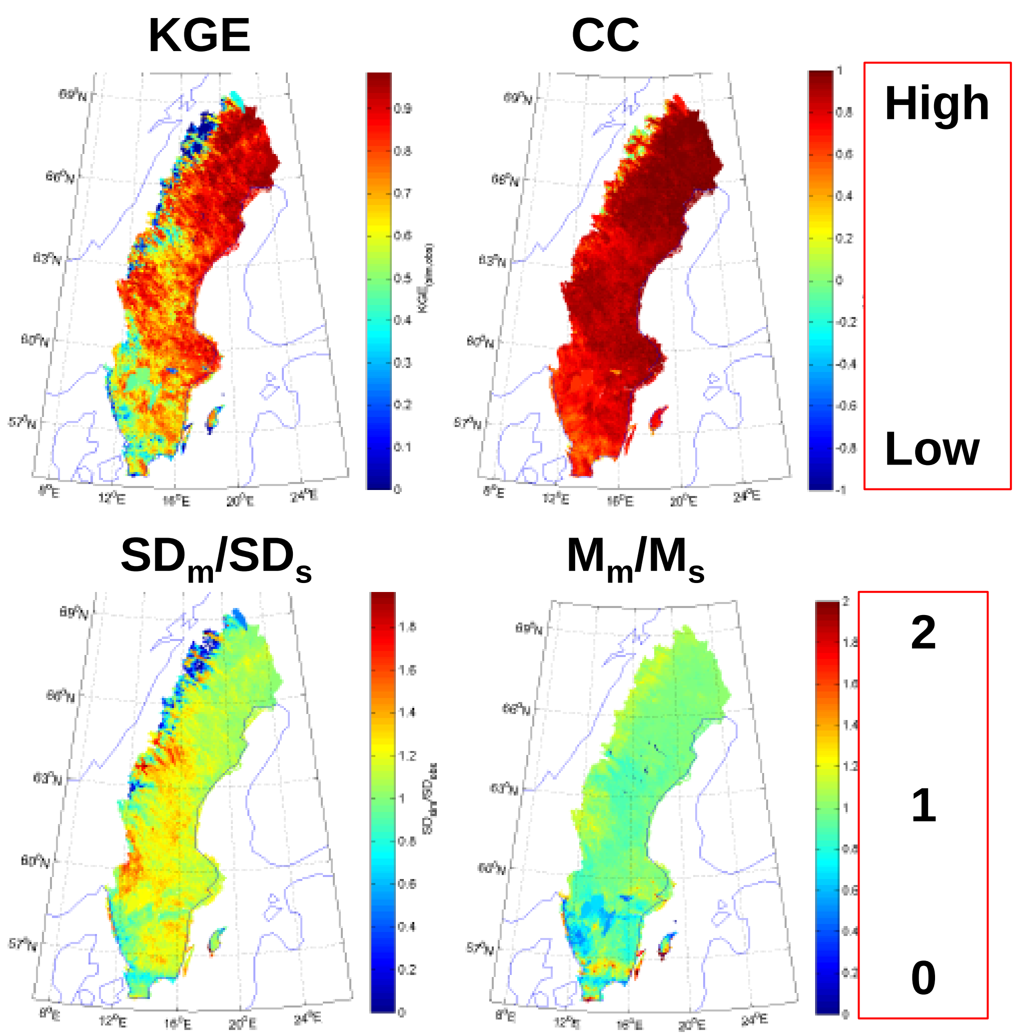
Model and data comparison – FSC

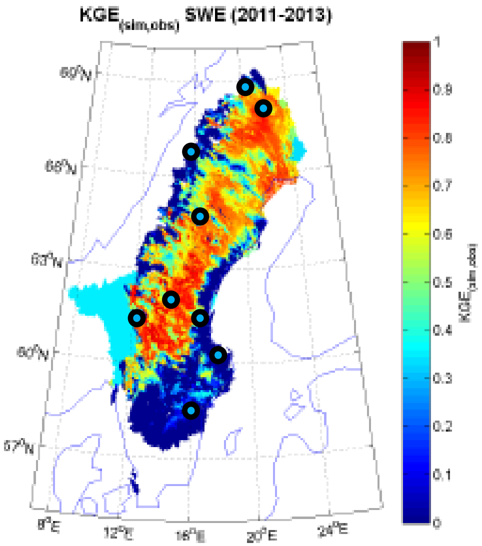
Pan-European optical product ENVEO/SYKE

- **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.



Assimilation experiment

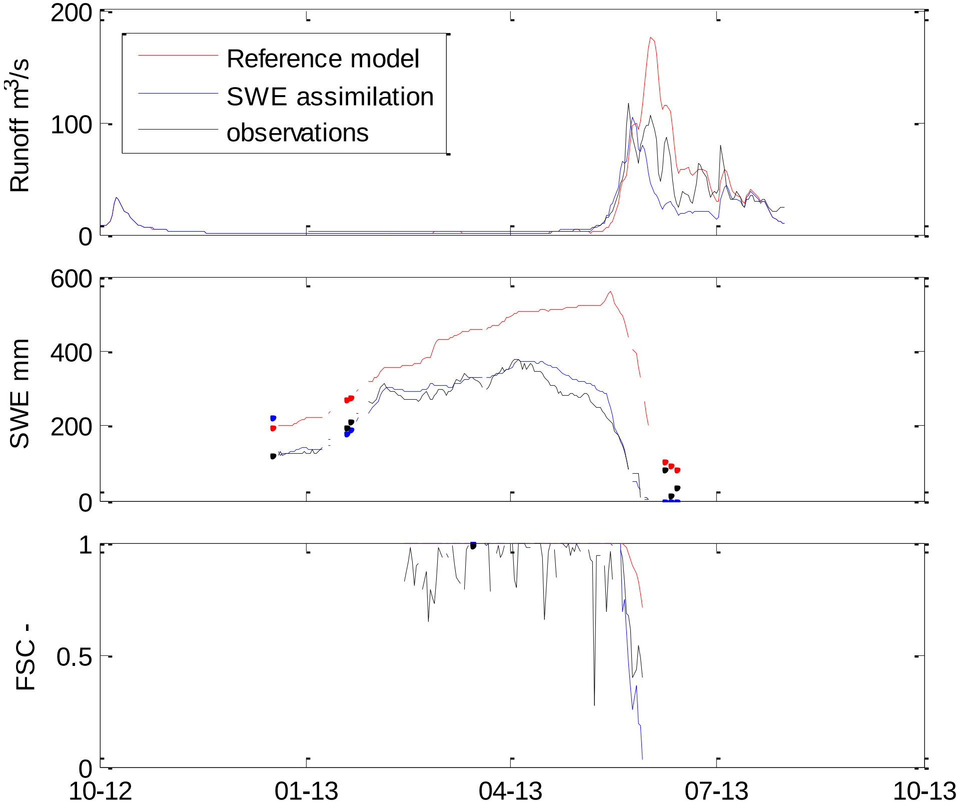
- 9 non-regulated basins with discharge observations
- Rather small (~1000 km^2)
- Distributed on “good” and “bad” areas according to previous comparison
- <u>5 types of simulations:</u>
  1) Deterministic (single simulation)
  2) Ensemble without assimilation
     - 100 ensemble members
     - Random perturbation on P and T
  3-5) EnKF assimilation with
     3) SWE
     4) FSC (optical)
     5) FSCM (multi-temporal optical)

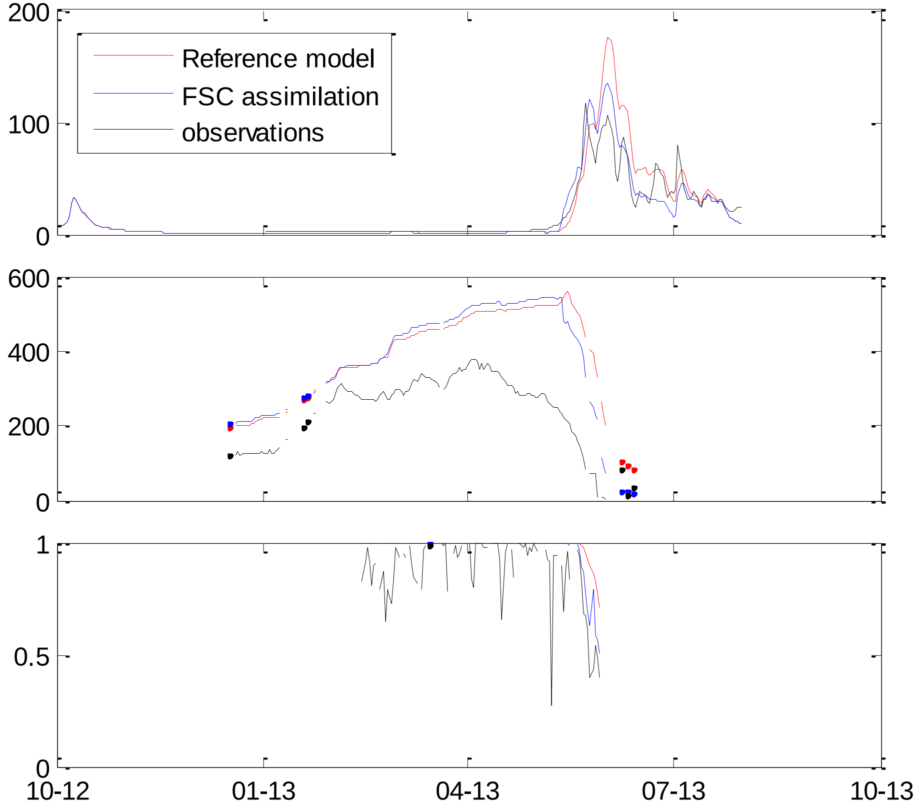


<u>Test-basins represent:</u>
10-85% forest cover
40-950 m.a.s.l (mean)
7-1100 km^2

Good exmple: Abiskojokki, northern Sweden.

Both SWE and FSC data improve stream flow simulations

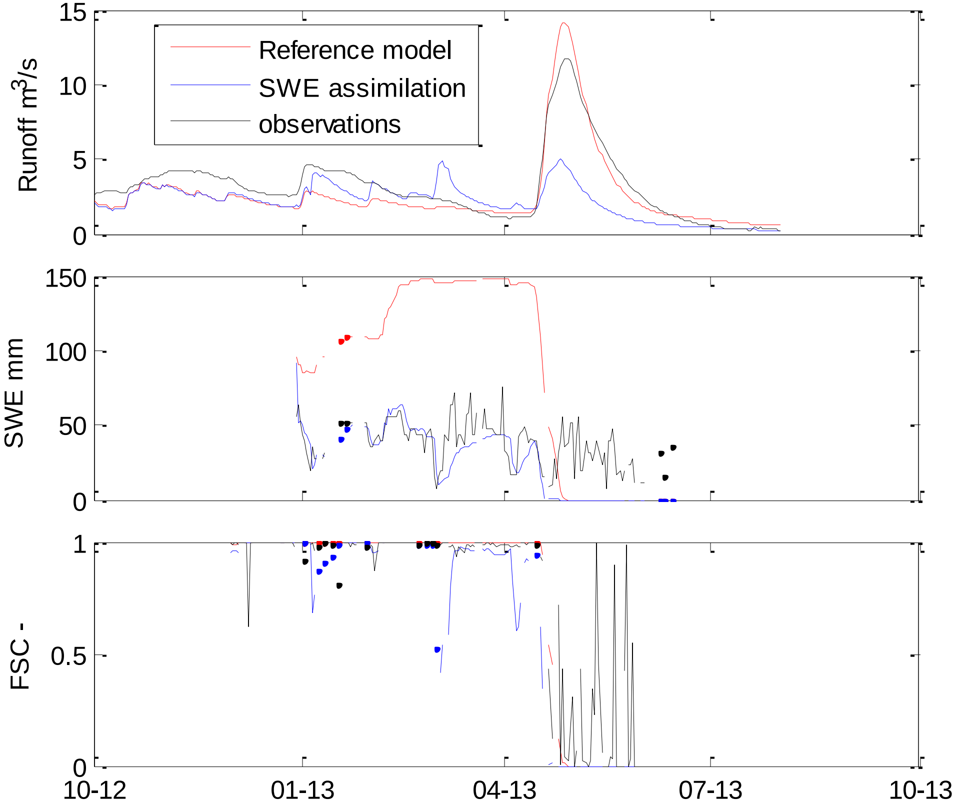


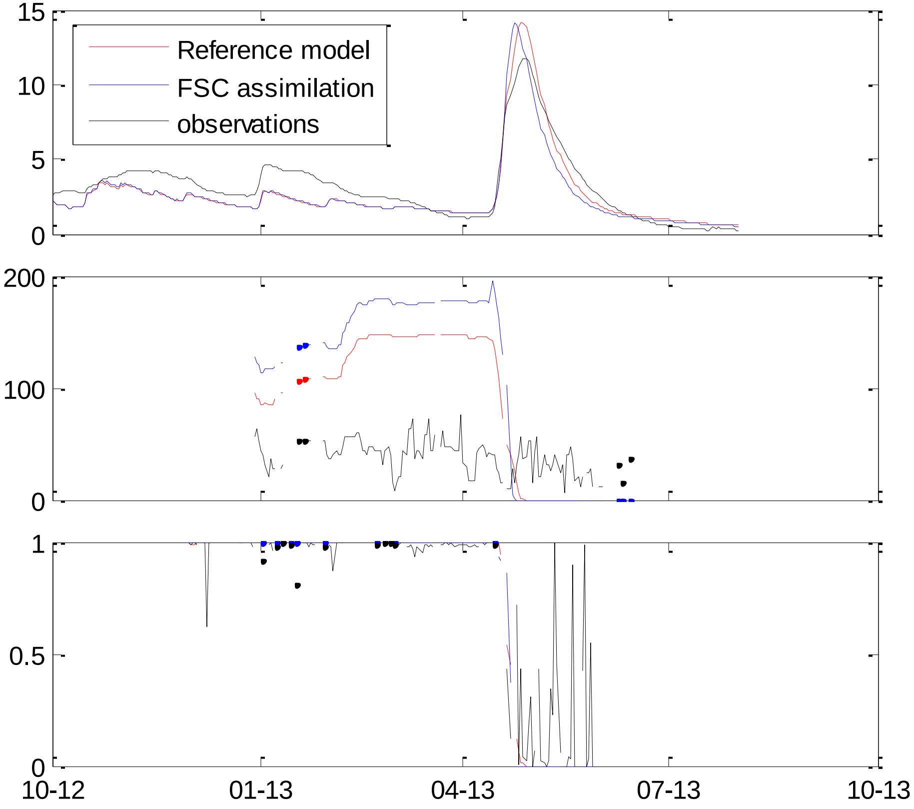


Bad exmple: Vattholma, south-east Sweden.

FSC data improve stream flow simulations

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





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Overall 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)

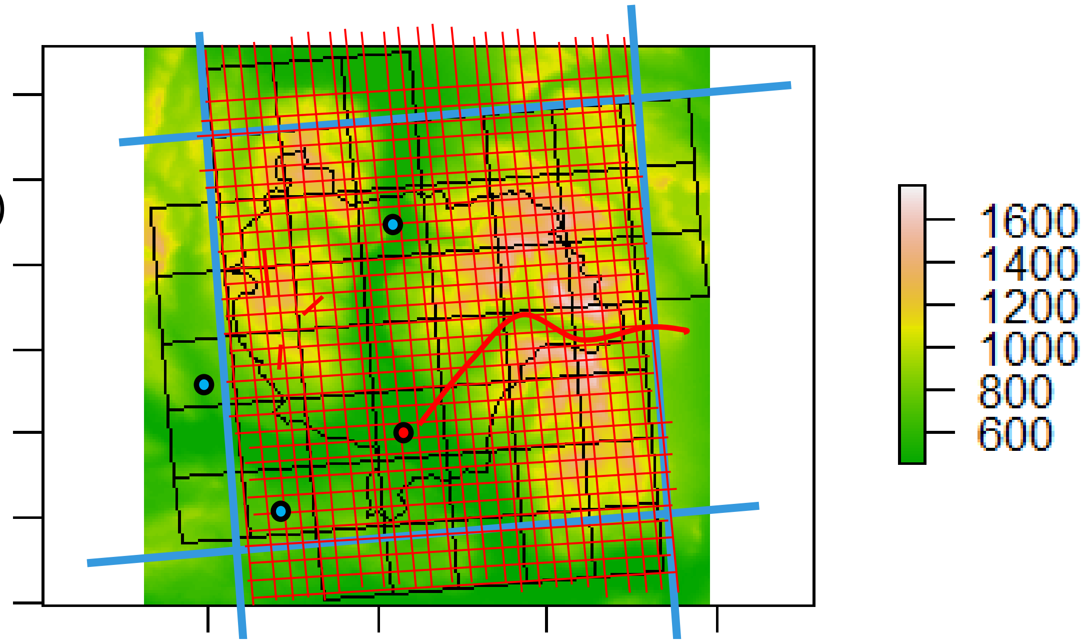
A closer look at the satellite and in-situ snow data

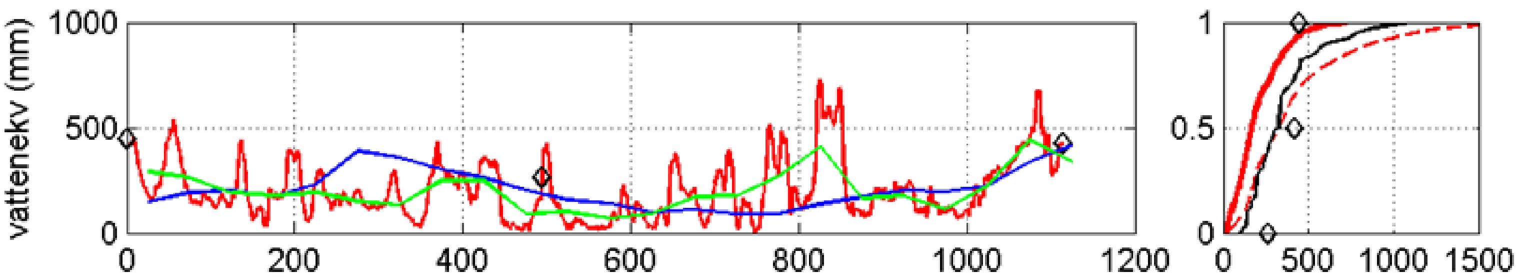
Forcing data
- P, T PTHBV-grid (4x4 km²)
- Elevation EU-DEM, 25x25 m²

Snow data
- SMHI snowdepth stations (point, daily)

Hydropower companies:
- SWE point data (bi-weekly)
- Snow courses (once per year)

Satellitdata (CryoLand, HSAF, etc
Fractional snow cover 1x1 km²
Snow water equivalent 25x25 km²





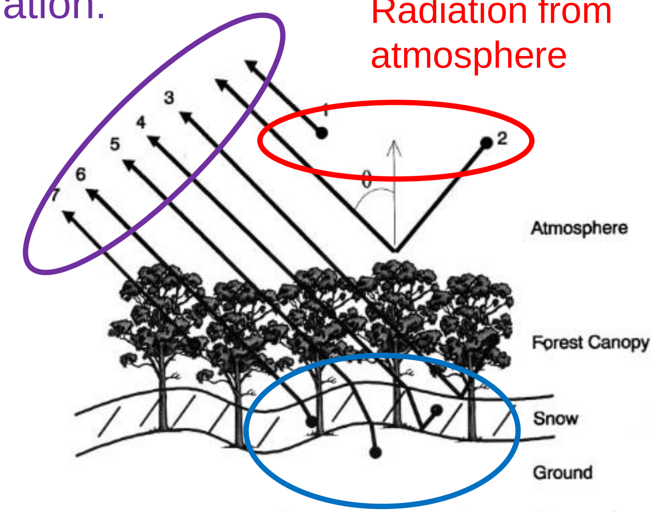
How to combine model and in-situ data information for assimilation of the passive microwave satellite observation?

Radiation emission model

Ex from Pullianen and Hallikainen (2001)

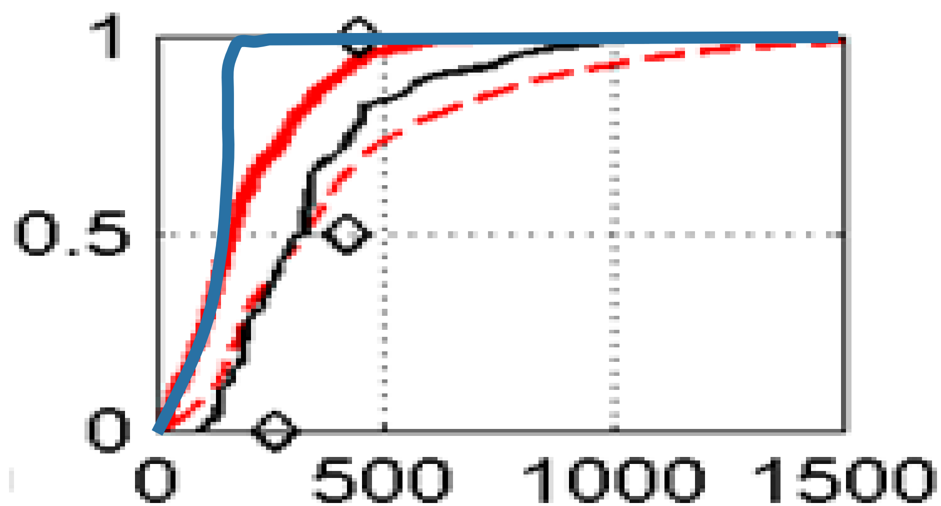
Satellite observed radiation:

Radiation from atmosphere



Radiation from ground (soil, snow, vegetation)

Spatial distribution of snow (from model or from in-situ data)



Saturation of MW emission from snow depths larger than some threshold (150-200 mm)

On-going work:

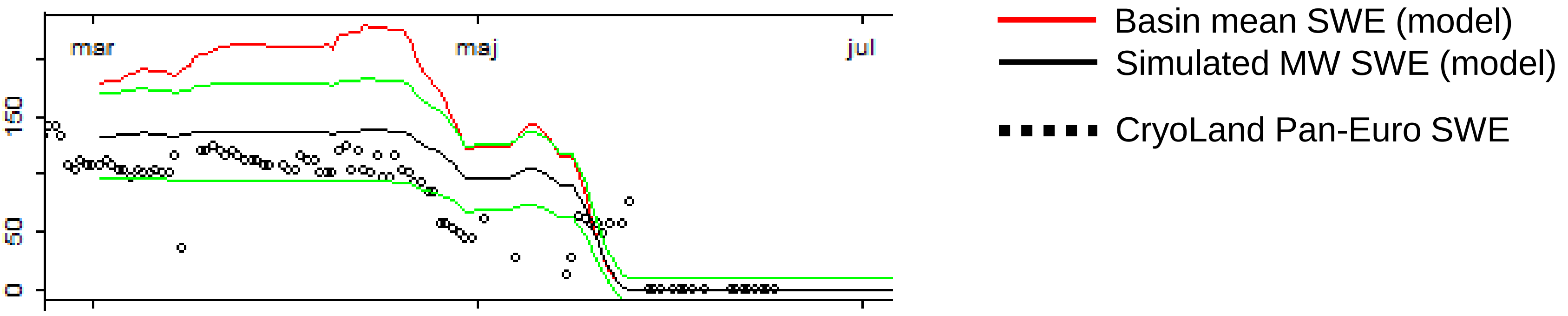
Combined assimilation of in-situ snow data, passive microwave radiance data and spatially distributed snow models

- Forward radiation emission modelling taking snow distribution and snow properties into account
- Model necessary surface properties in the models
- Integration of ground based observations (snow, runoff, water levels, etc)

- Evaluation of impacti on stream flow simulations and seasonal hydrological forecasts

Preliminary resultat:

Modelled GlobSnow SWE by taking snow distribution into account.



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Conclusions

- Spatially distributed in-situ snow data do improve seasonal runoff forecasts

- Systematic biases in satellite passive microwave snow data
  - especially in the areas of interest from hydropower point of view
  - areas with high mean SWE and large spatial variability

- Outlook for using satellite based SWE data::
  - Combine information on snow distribution and snow properties from models and in-situ data in forward radiation emission modelling.


Thank you!

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