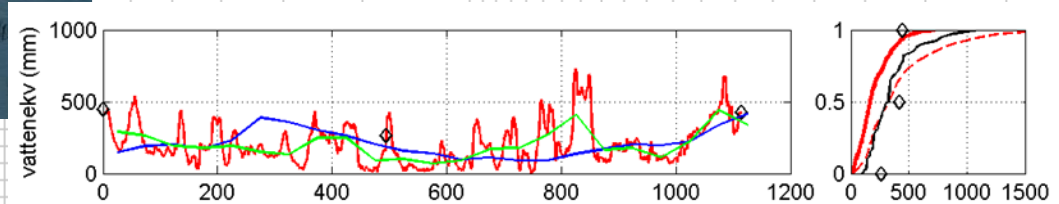
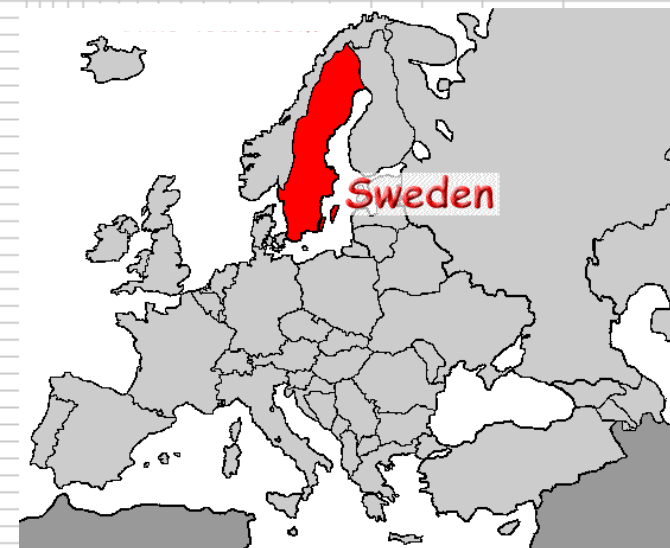


SMHI



How much can we improve the hydrological forecasting skill in snow dominated regions via snow data assimilation?

**David Gustafsson, Ilias G. Pechlivanidis,
Göran Lindström, Berit Arheimer**



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A never-ending struggle – Improving spring melt runoff forecast via snow information

Posted on May 17, 2016 by [Ilias Pechlivanidis](#)

Contributed by [David Gustafsson](#) (SMHI), member of the [SMHI Guest Columnist Team](#)

As long as we can remember, the Swedish hydropower hydrologists have tried to improve the spring melt runoff predictions by integrating snow measurements in their forecast models. Various measurements techniques have been used: traditional snow surveys with snow tube sampling; snowmobile and helicopter borne ground-penetrating radar and gamma-ray sensors; laser-scanning; and of course numerous attempts with satellite data (Photo 1). The usual conclusions have been, *“yes we can reduce the forecast error with this new snow data but ... improvements were not systematic between sites and years, and also very small compared to average errors in the HBV model. So why putting an effort on including snow data when it only increases the overall uncertainty?”*.



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Results from 3 investigations:

- ❑ S-HYPE model
 - using SD (point and spatially interpolated) observations
 - Added value of SD observation
 - using satellite- and ground-based data (SD, SWE, FSC)
 - 9 basins

- ❑ HOPE (gridded HBV type) model
 - using satellite- and ground-based data (SD, SWE, FSC)
 - 5 basins

Operational observations of snow in Sweden

- Daily snow depth observations by SMHI at ~600 stations

Since 1960-70s

- ~20 annual snow courses by hydropower companies

Since 1990s

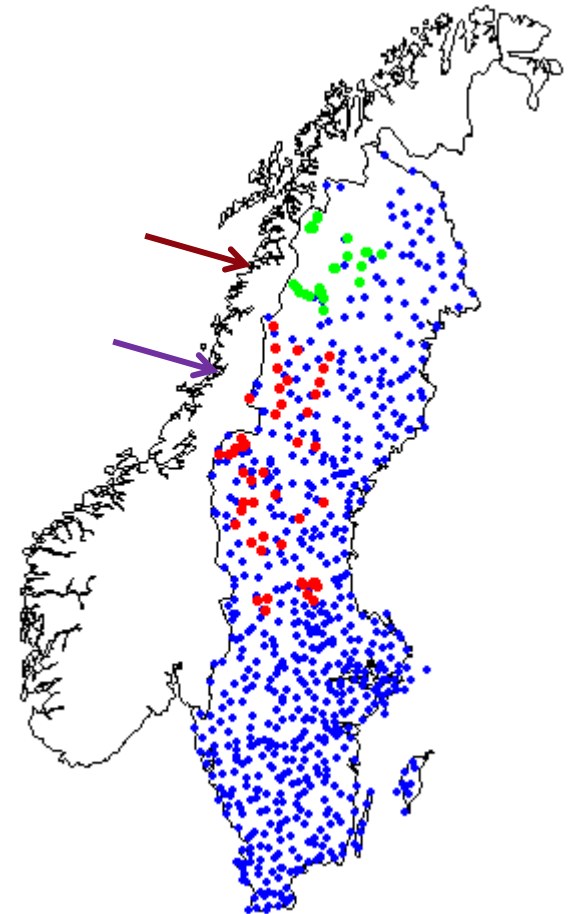
- ~10² km, Helicopter GPR surveys (by Vattenfall AB)

Since 2010

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

2007-2015

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

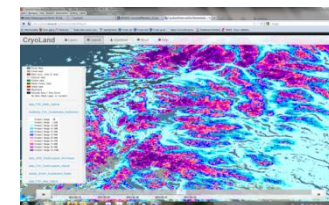


Satellite based snow information



Existing services

- CryoLand, www.cryoland.eu
- GlobSnow www.globsnow.info
- MODIS nsidc.org
- AMSR2 mfl



Snow variables

- Fractional snow cover - optical sensors – sensitive to clouds and sun
- Fractional snow cover - radar – expensive / less data
- Snow water equivalent – passive microwave + ground observations
- Wet snow - based on radar – not sensitive to clouds

Future services / sensors

- European satellite Sentinel:
 - Higher resolution, various sensors (not passive microwave)
 - Freely available data
 - Costly processing – expecting costly services!

Snow depth

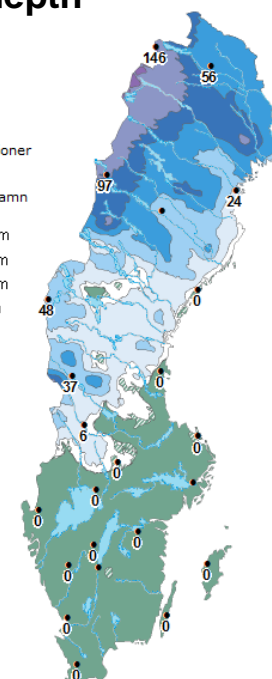
2015-03-18

[Mindre bild](#)

Visa i kartan:

- Vatten
- Observationer
- Ortsnamn
- Stationsnamn

- över 200 cm
- 150-200 cm
- 100-150 cm
- 75-100 cm
- 50-75 cm
- 30-50 cm
- 10-30 cm
- 3-10 cm
- >0-3 cm
- Barmark



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

Forcing data

- P, T PTHBV-grid (4 x 4 km²)
- Elevation EU-DEM (25 x 25 m²)

Snow data

- SMHI snow depth stations (point, daily)

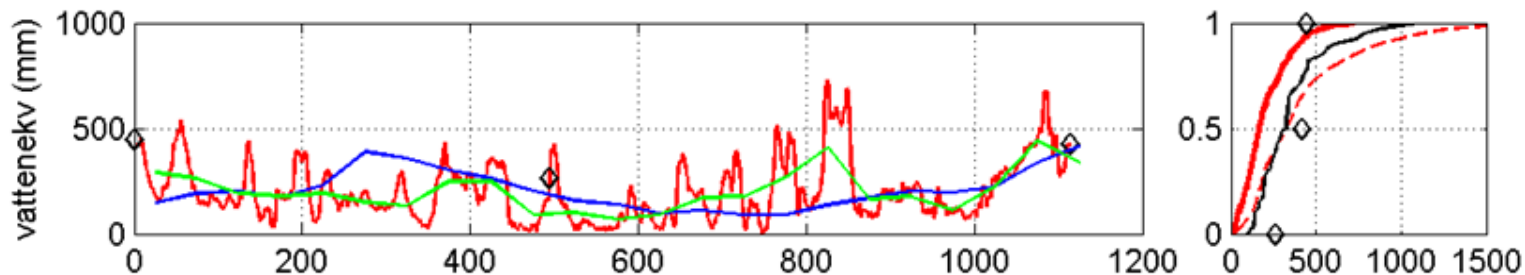
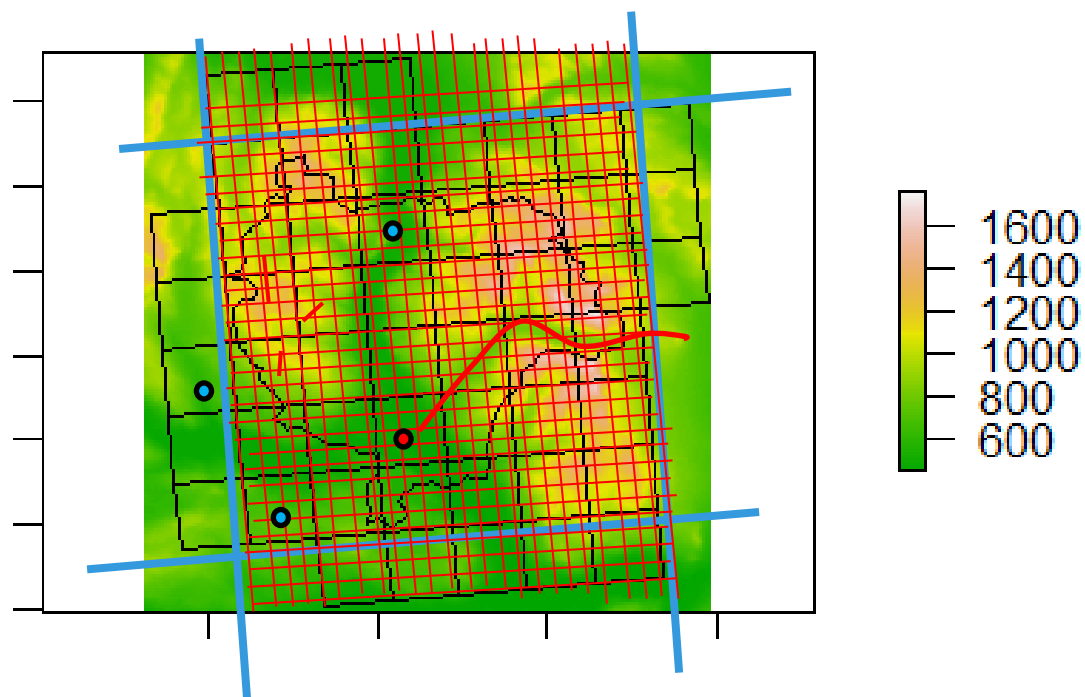
Hydropower companies:

- SWE point data (bi-weekly)
- Snow course (once per year)

Satellite data (CryoLand, HSAF etc)

Fractional snow cover (1 x 1 km²)

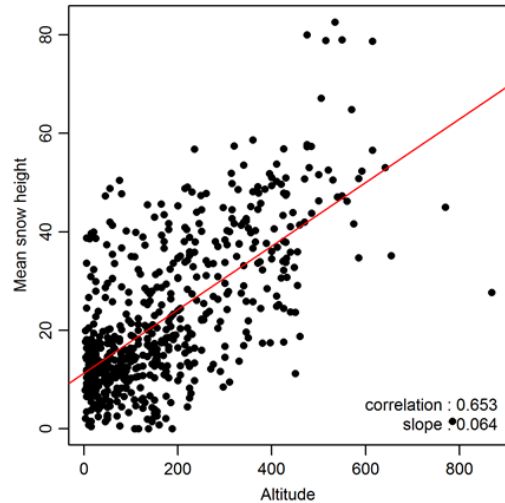
SWE (25 x 25 km²)



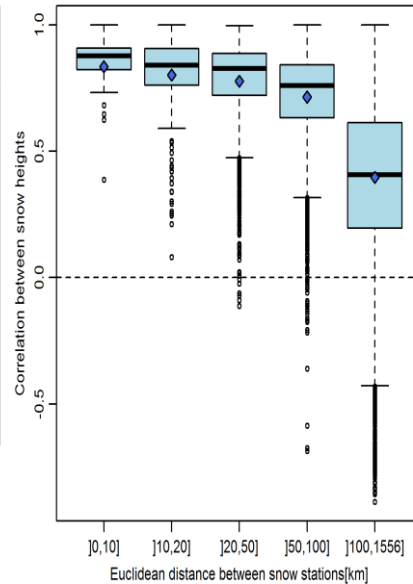
Snow depth analysis (observations, modelled)

601 stations in total
32 stations with good quality

Average depth (height)

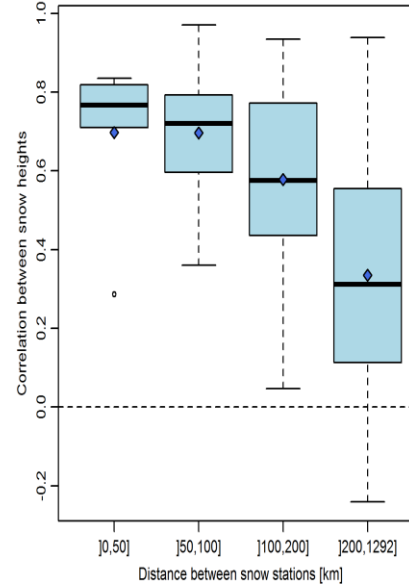


Distribution of correlation between snow observations according to distance (601 stations)

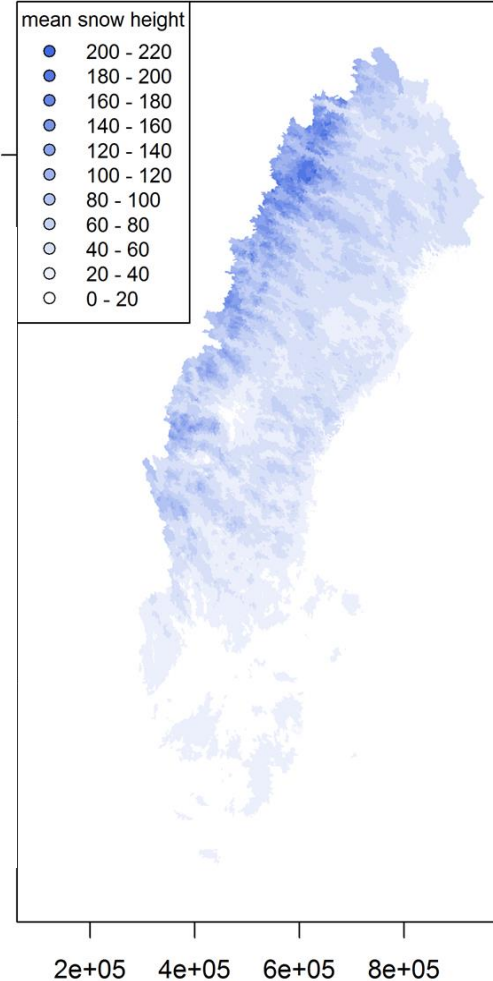


601 stations

Distribution of correlation between snow observations according to distance (32 stations)

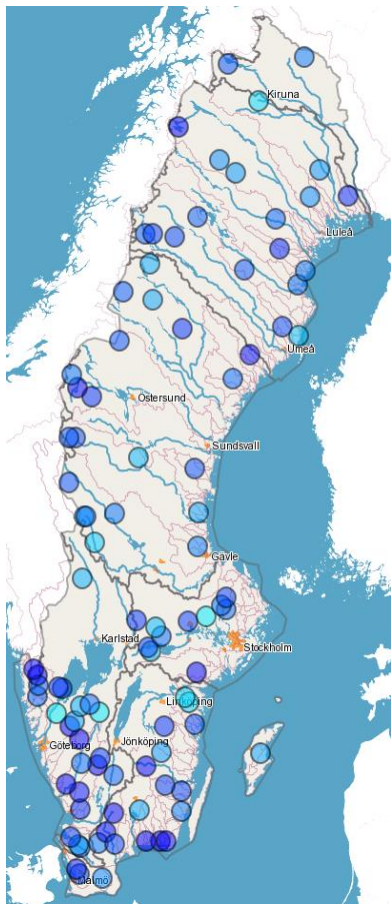
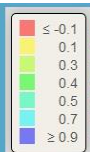


32 stations
(good quality)

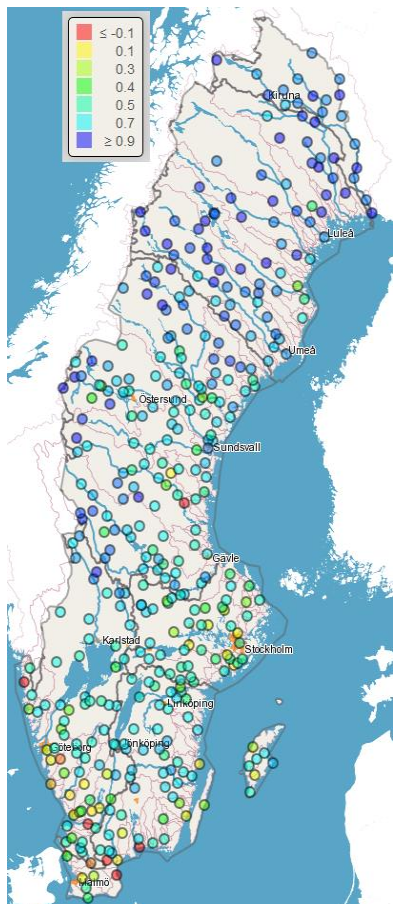


Modelling of discharge and snow depth

NSE

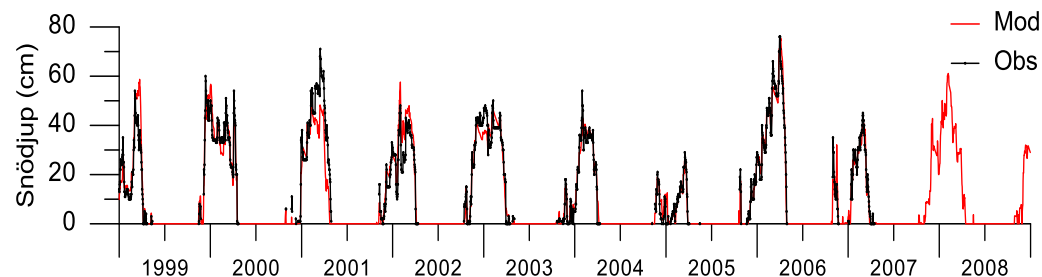


Discharge

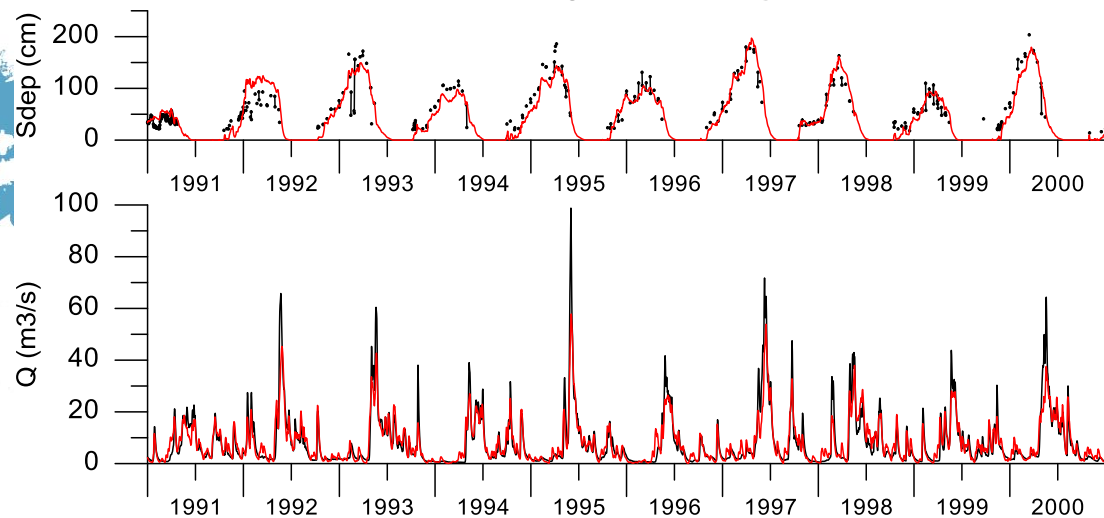


Snow depth

Snow depth, Malung station



Snow depth and discharge, Medstugusjöns station



Testing the updating method

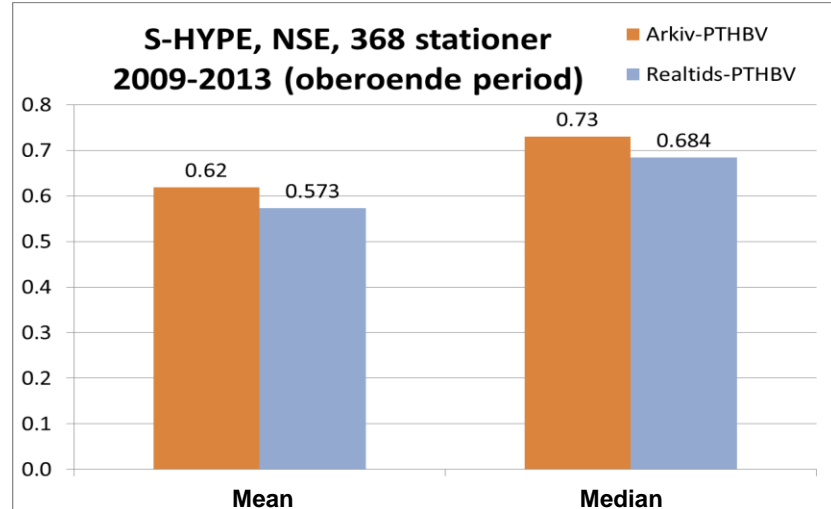
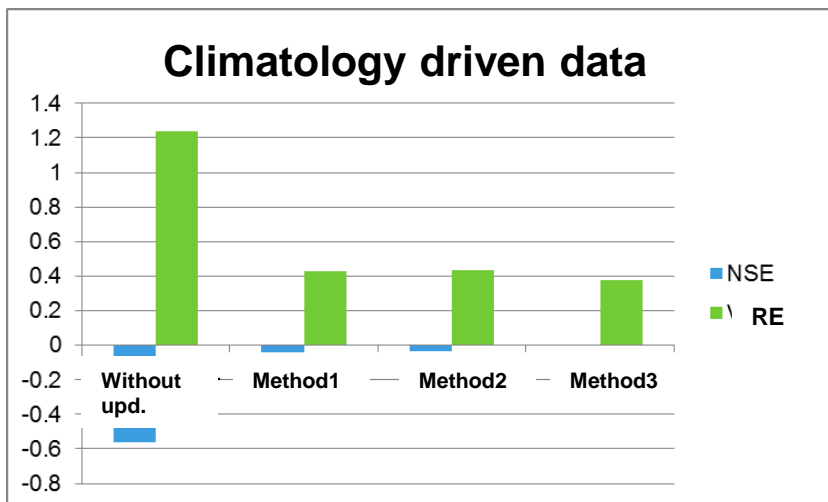
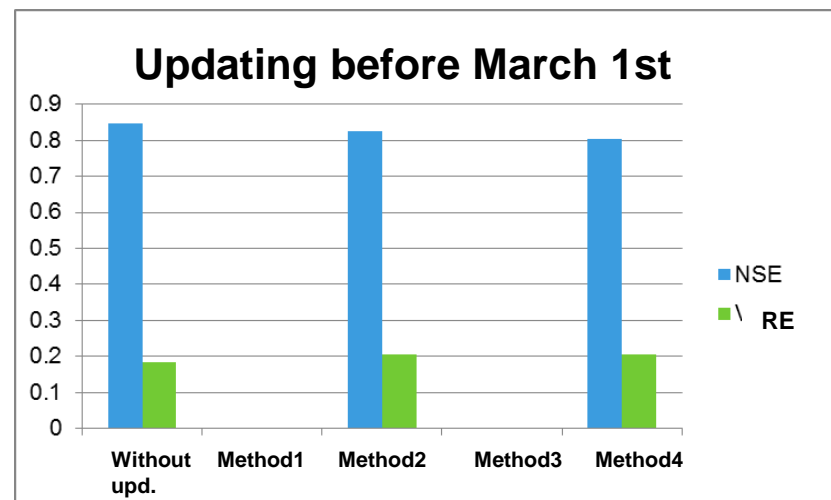
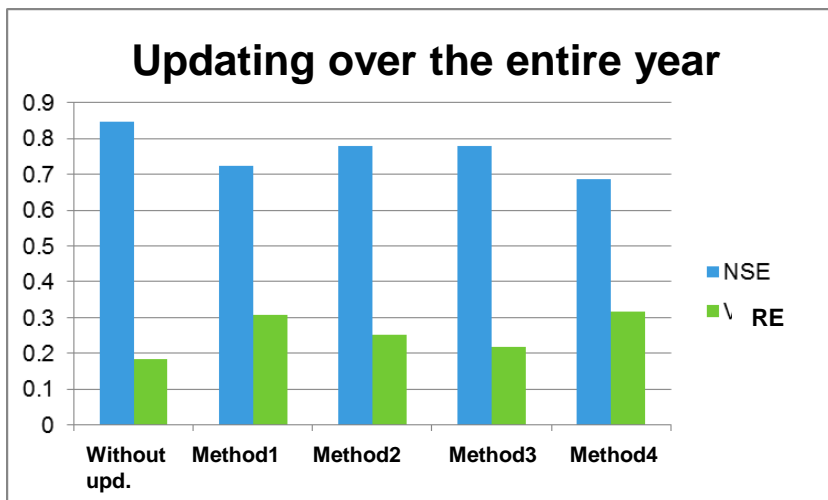
Direct methods or other methods

1. **Estimation of snow depth in each area:** Direct replacement of modeled depths with measured (interpolated) snow according to snow depth map. Systematic differences between the measured and modelled snow depths, corrected first in each catchment.
2. **Transfer of errors at the measuring points:** In each catchment an expected error in the snow is estimated (considering the error in the three surrounding snow stations). These errors were weighted to take account of the distance.
3. **Transfer of deviation from normal levels:** The difference in the snow from a normal value for the current day according to snow depth map was transferred to the model so that the deviation from the model's normal values were obtained.
4. **As in the first**, but with the snow height correction in % / 100 m instead of cm / 100 m.

Performance is evaluated in terms of NSE and RE over the spring flood period (1/4 - 30/6)

Results

Real time PTHBV is much better than climatology update during the melting period can lead to time shifts



Why updating did not help?

precipitation vs snowfall water content

- The snow depth is measured at rainfall stations
- The model worked quite well before the update, NSE = 0.85.
- The quality of snow depth measurements is uncertain, sporadic measurements
- ... ?



from www.smhi.se

Assimilation of satellite- and ground-based snow observations

Distributed snow model

- Distributed snow model (4x4 km²) for PTHBV-grid

Snow data

- Satellite data (cover area and water equivalent) from CryoLand
- Snow depth (SMHI + VRF)
- Water equivalent (VRF, VF line, SVF points)

Model updating with Ensemble Kalman filter

- Model ensemble of randomly generated perturbations in the driving data
- Updating according covariance model state, and , unlike the model – snow observations
- All model states updated (not just snow or snow water equivalent)

Background

How to integrate 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

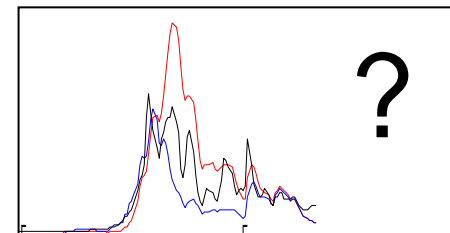
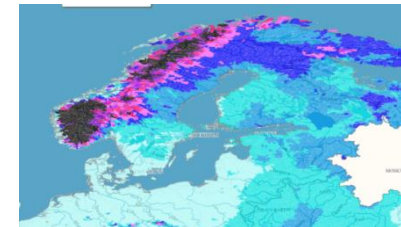
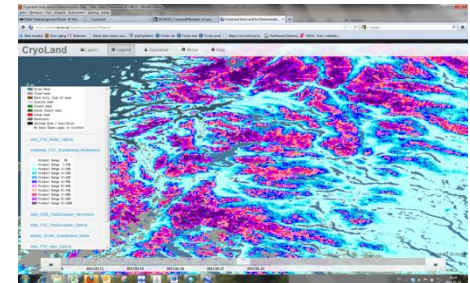
- Products and services for satellite based snow and land ice data

Data integration

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

Hydrological modelling

- Evaluate impact on streamflow simulations of assimilating satellite snow data



CryoLand SWE vs S-HYPE model

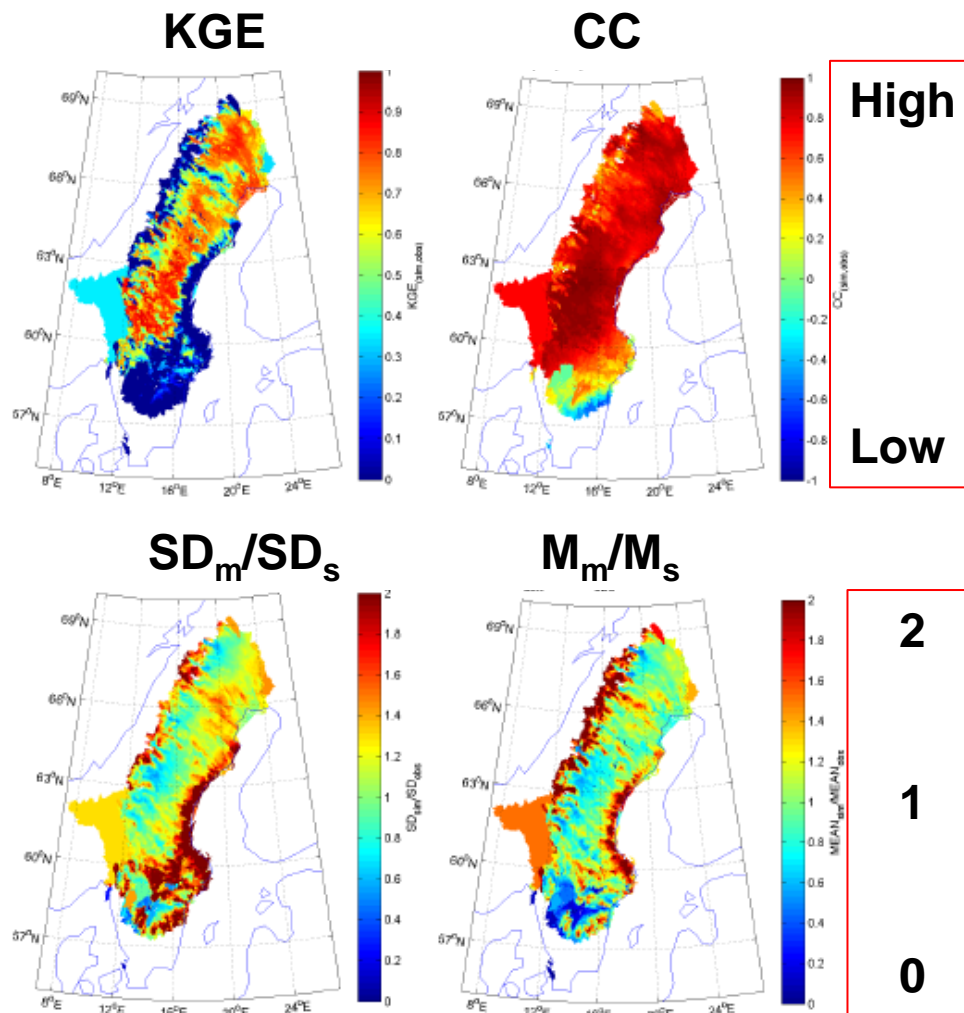
Pan-European SWE product (FMI)

- **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

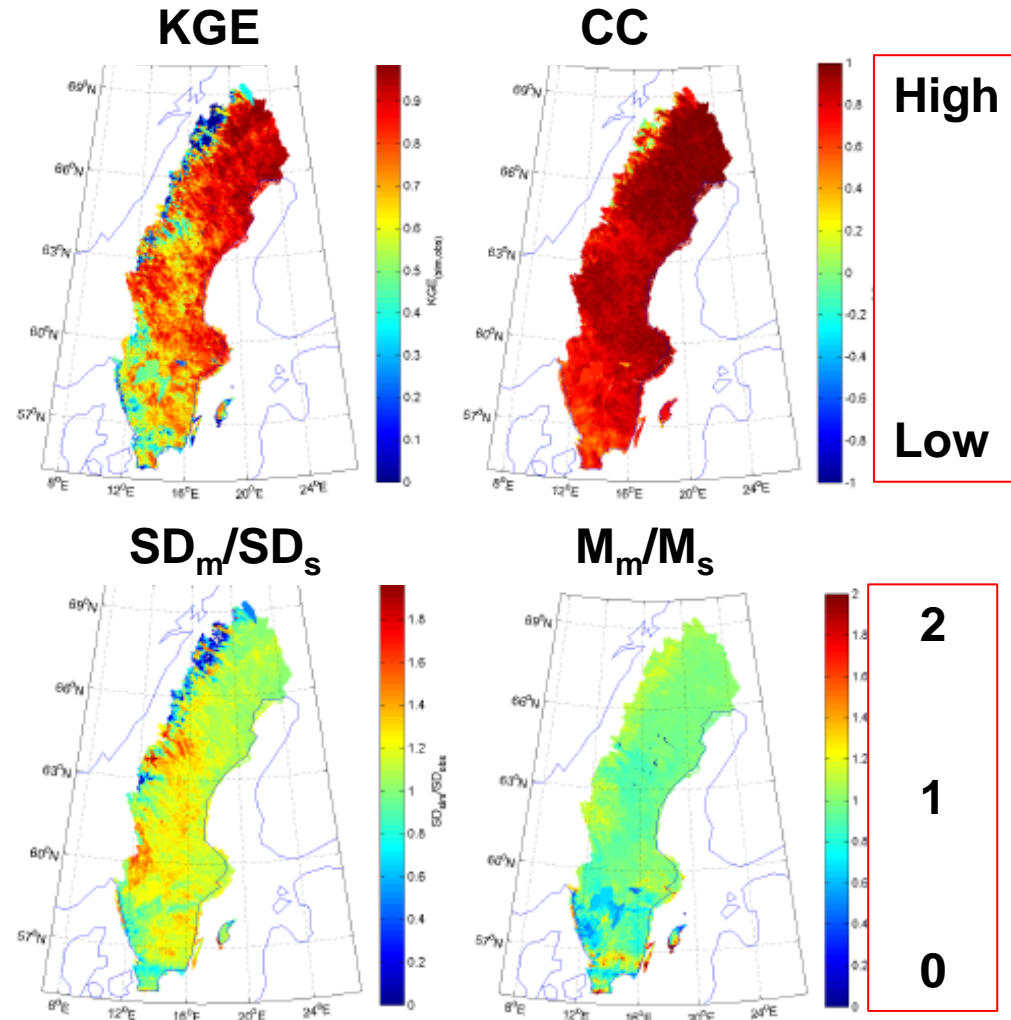
- **Problem for the satellite or model?**
 - Mountains, surface water, coastal areas, areas with small amount of snow



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.



High

Low

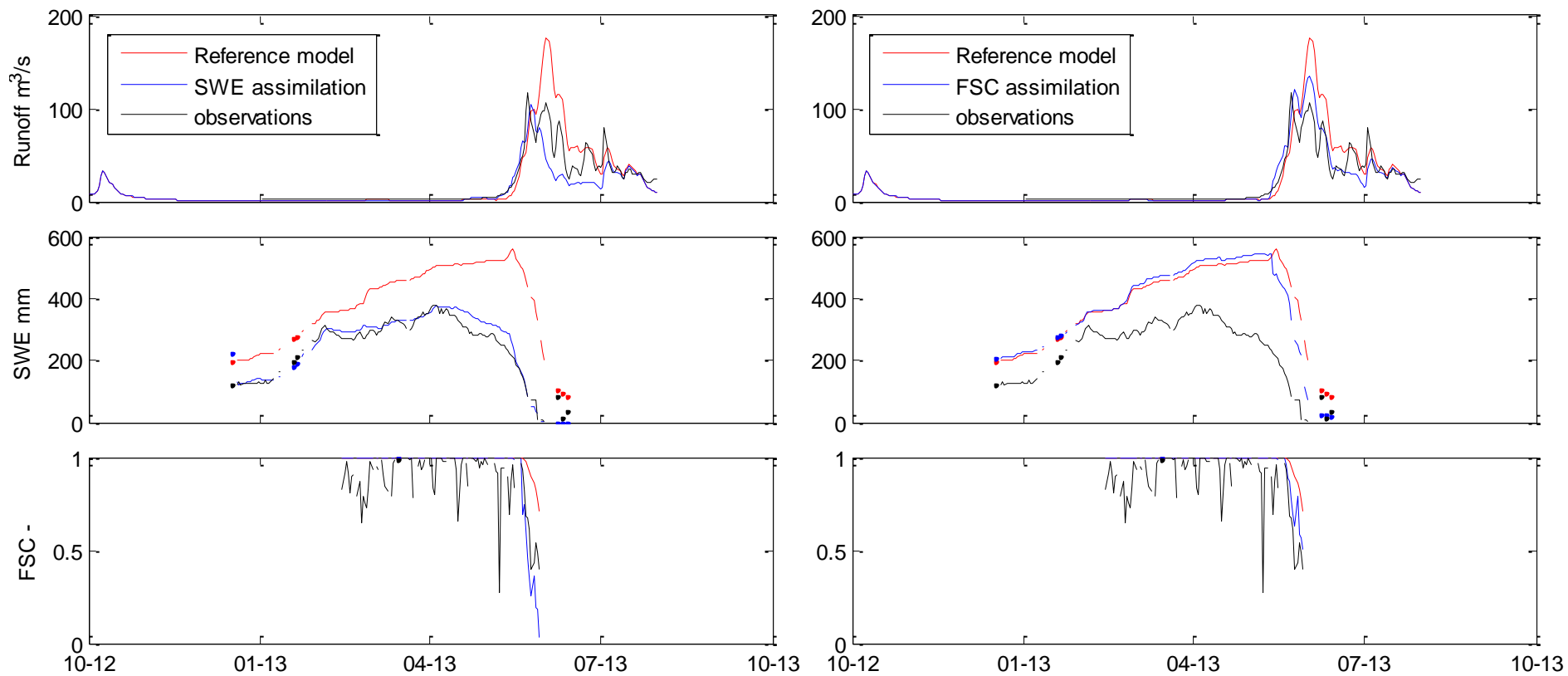
2

1

0

Good example: Abiskoajokki, northern Sweden.

Both SWE and FSC data improve streamflow simulations



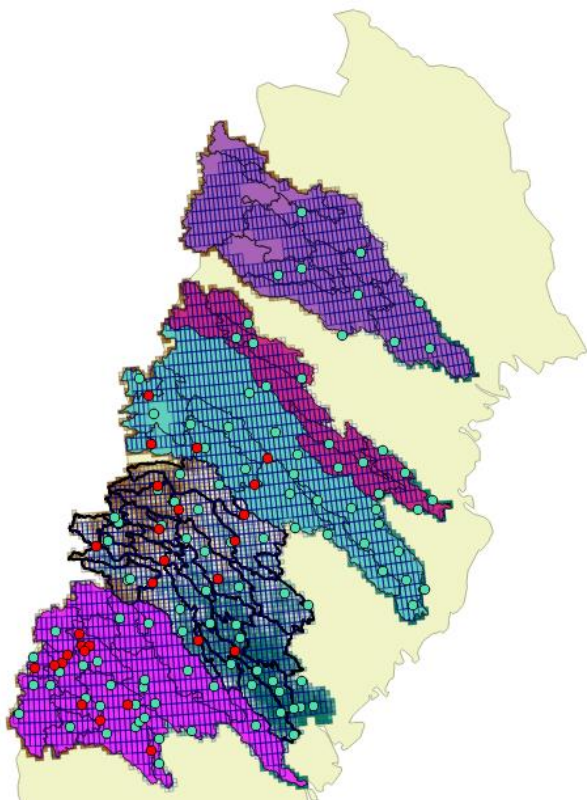
Overall impact on river discharge simulations

- Overall, 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	<i>0.53</i>	<i>0.64</i>	0.44	0.85	0.82	0.90	<i>0.56</i>	5 improved, 3 reduced (+2)
EnKF_SWE	Q	0.83	<i>0.80</i>	<i>0.19</i>	<i>0.34</i>	0.55	<i>0.49</i>	<i>0.81</i>	<i>0.53</i>	<i>0.56</i>	2 improved, 7 reduced (-5)
EnKF_FSC	Q	0.61	0.85	0.56	0.72	<i>-0.04</i>	<i>0.64</i>	0.82	0.88	0.62	5 improved, 2 reduced (+3)
EnKF_FSCM	Q	<i>0.41</i>	<i>0.68</i>	0.55	<i>0.54</i>	0.47	<i>0.64</i>	<i>0.58</i>	<i>0.80</i>	<i>0.54</i>	1 improved, 7 reduced (-6)

Calibration and Assimilation experiments

- Assimilation experiments:
 - Hindcast simulations for 6 years for the period 1 October - 31 July
 - 2009-10, 2010-11, 2011-12, 2012-13, 2013-14, and 2014-15
 - Initial values saved for forecasts issued 15/2, 15/4, and 15/6
 - *Deterministic simulation compared to open-loop ensemble simulations, and assimilation of local runoff (Q), in-situ snow water equivalent (SWE) and snow depth (SD), satellite based fractional snow cover (FSC), and all snow data (All).*
 - Forecasts based on input of ensemble of historical years (2000-2015 always leaving out the current year)



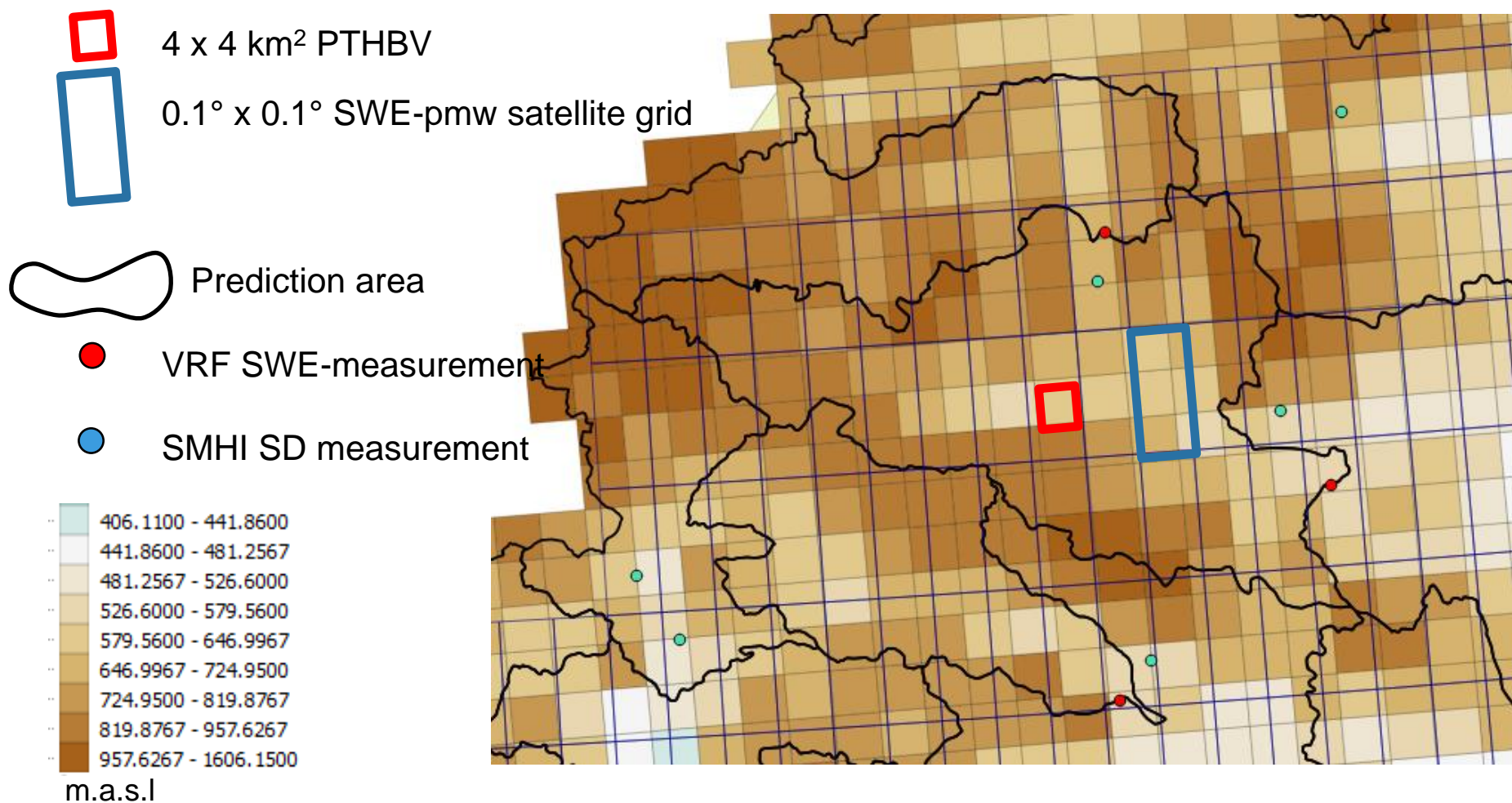
HOPE model application

- Simple HBV type of snow/soil model on the 4x4 km² PTHBV grid
- Up to 160 SLC classes for different snow accumulation/melt regimes

Snow data

- **SMHI** snow depth stations
- **VRF/VF/SVF** snow water equivalent point data at regulation dams
- CryoLand SWE and Snow cover (satellite)
- Local runoff estimated for each forecast area

Basin	River	Area (km ²)	15/2	15/4	15/6	15/6 (% of 15/4)
Tjaktjajaure	Luleälven	2256	376	520	258	50%
Riebnesjaure	Skellefteälven	976	290	440	147	33%
Överuman	Umeälven	653	402	663	236	36%
Kultsjön	Ångermanälven	1095	357	498	118	24%
Landösjön	Indalsälven	1453	148	182	11	6%



Assimilation in spring flood forecasting with HOPE

- 5 test basins
- 6 years with snow data (2010-2015)
- Model initialisation for 15/2, 15/4 och 15/6 with assimilation of:
 - flow (Q)
 - Snow water equivalent (SWE)
 - Snow depth (SD)
 - Fractional snow cover (FSC) – from CryoLand

Basin	River	Area km ²	Area (mean 2010-2015)			
			15/2	15/4	15/6	15/6 (% of 15/4)
Tjaktjajaure	Luleälven	2256	376	520	258	50%
Riebnesjaure	Skellefteälven	976	290	440	147	33%
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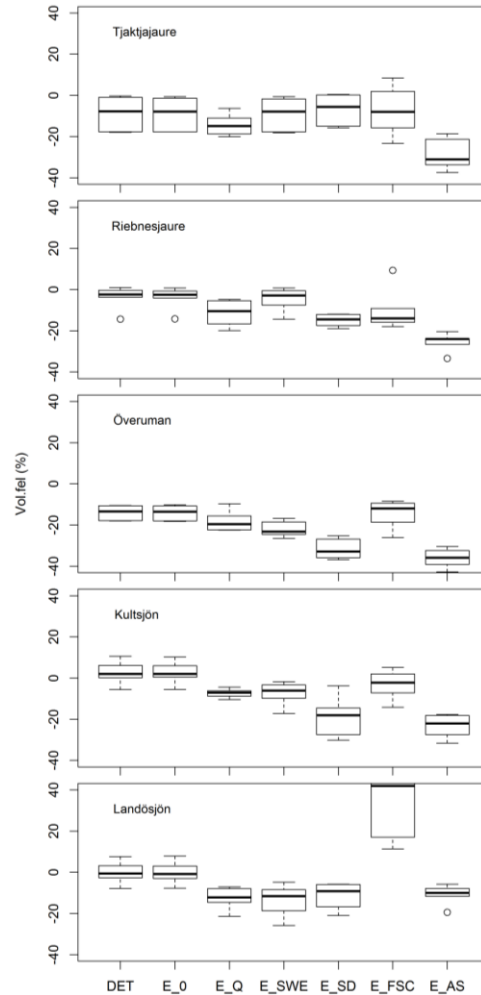
Hindcast simulation results separated on the 5 case study areas

North

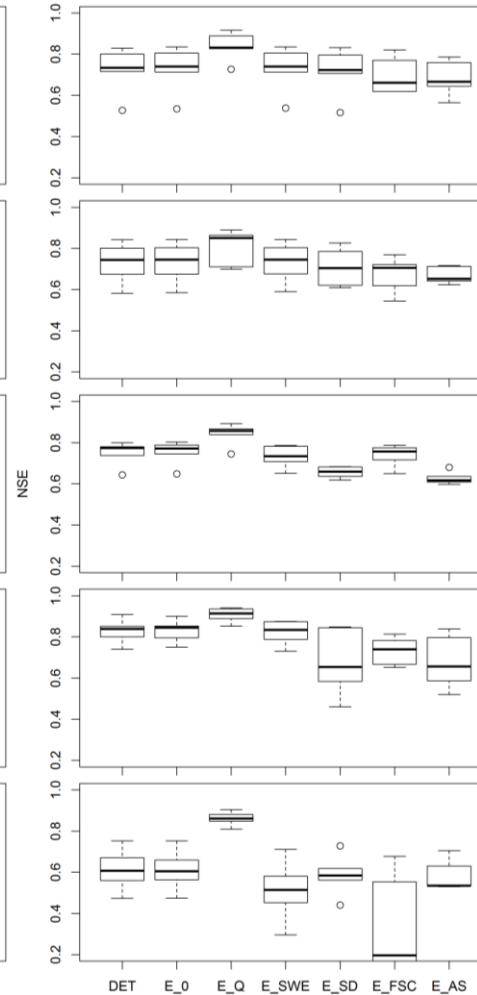


South

RE



NSE



Spring melt forecasts – summary results

		Type of initialisazion						
Prognosis start		DET	E_0	E_Q	E_SWE	E_SD	E_FSC	E_ALL
		<u>Excluding most southern site</u>						
15/2	RE %	13	13	15	14	16	13	16
15/4		23	21	30	19	22	15	29
15/6		29	27	35	23	23	23	28
15/2	Improvement %		1	-19	-6	-24	2	-24
15/4			7	-29	19	4	33	-27
15/6			6	-21	20	19	20	3
		<u>Including the most southern site</u>						
15/2	RE %	14	14	17	17	17	14	17
15/4		33	31	38	23	26	73	33
15/6		63	61	67	50	51	111	56
15/2	Improvement %		0	-24	-21	-25	2	-24
15/4			6	-13	31	22	-117	2
15/6			3	-7	21	19	-77	11

Conclusions (investigation 1)

- Snow depths are correlated in the space**, which can be used to produce a depth map based on the measured values.
- The update using SMHI's snow depth data deteriorate results compared to a model driven by PTHBV.
- Real-time PTHBV data are significantly better than the climatological data.
- Perhaps it is better to only **update during the accumulation season** (before 1st March).

- It is possible that new points where rainfall is not measured could improve results.

Conclusions (investigation 2 and 3)

- Assimilation of snow data had a systematic impact on both simulated and forecasted spring melt runoff:
- Systematic decrease in SWE and in runoff volume
 - Negative volume errors in hindcast increased (negative impact)
 - Positive volume errors in forecasts decreased (positive impact!)

- Impact of in-situ SWE and SD data largest in the south
- Impact of satellite FSC largest in the north

- Snow data assimilation improved spring melt forecasts issued at the start of the melting season as well as in the middle of end of snow melt season – but not in the middle of the winter.

- Analysis of relative importance of initial value and meteorological forecasts still to be evaluated.

Thanks for your attention!

