Towards a combined meteorological-hydrological forecasting system

Assimilation of in-situ and satellite snow data for hydrological forecasting in Sweden - a hydropower case study

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Met-Hyd collaboration for surface DA at SMHI

Land surface model (parts of) – SURFEX.

Data assimilation method – EnKF.

Observations – towards raw radiances / backscatter.

Work together in research projects:

- SNSB: DA for satellite-based measurements of the hydrosphere
- EU H2020: IMproving PRedictions and managment of hydrological Extremes

Collaboration with NILU, Météo France and HIRLAM partners.

SNSB 2015-2017 (30pm)

SYNOP, runoff
satellite radiances → Soil & hydrology
SURFEX, HYPE
EnKF → Upper air analysis
HARMONIE (AROME) → (feedback to Soil & hydrology)

Assimilation of satellite-based measurements of the hydrosphere
- towards a combined meteorological-hydrological forecasting system

AMSR2 (GCOM-W1)

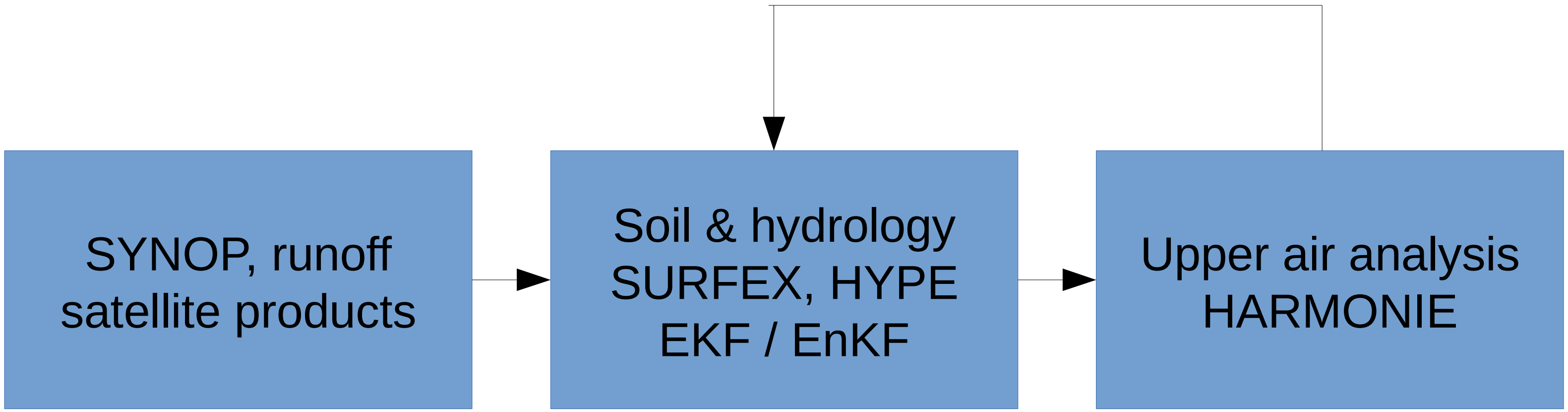
MIRAS (SMOS)

SAR (Sentinel-1)

SMHI

EU IMPREX 2015-2018 (43pm)

IMproving PRedictions and management of hydrological Extremes



Soil moisture from ASCAT, SMOS and AMSR2.

Snow water equivalent from H-SAF / GLOBSNOW / NASA (SSMIS, AMSR2)

Harmonie MetCoOp

AROME cycle 38h1.b2

2.5 km, 750 x 960 grid points, 65 levels

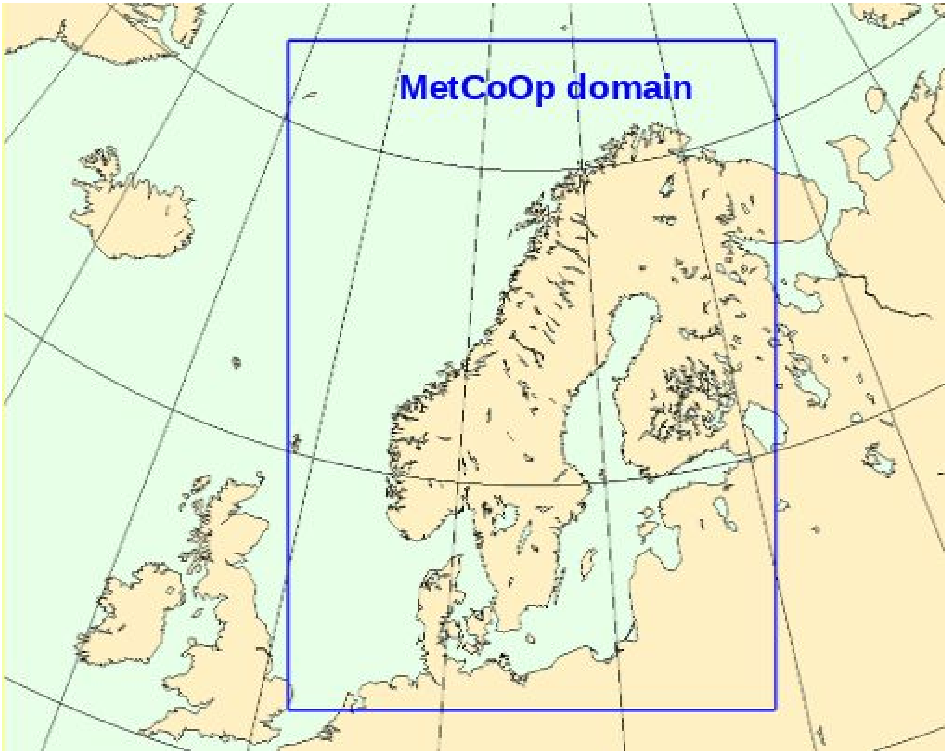
3D-Var, fc +60 hours

8 an + 8 fc per day @ 00,03,...,21

Obs: SYNOP, Aircraft, Buoy, Temp, GPS,
AMSU-A, AMSU-B/MHS, IASI
Radar, ASCAT winds.

ECMWF boundaries

Surface DA: CANARI-OI_main



SURFEX

Version 8

- Stable OpenMP implementation.
- ISBA-ES “Explicit snow” with multi layer snow packs.

Two patches (low and high veg) to match CMEM observation operator.

Couple with hydrological model

- Extend HYPE surface model with SURFEX.
- Introduce SURFEX river routing via OASIS.
- Interface with topological databases (e.g. Hydro1k).

Remote sensing data and observation operators

Sentinel-1/SAR-C: wet snow, snow extent, (dry snow?)

- S1A_EW_GRDM_1SDH
- Extra Wide swath mode VV+VH and HH+HV, ca 25 x 80 m
- MEMLS3&a by Proksch et al. (2015)

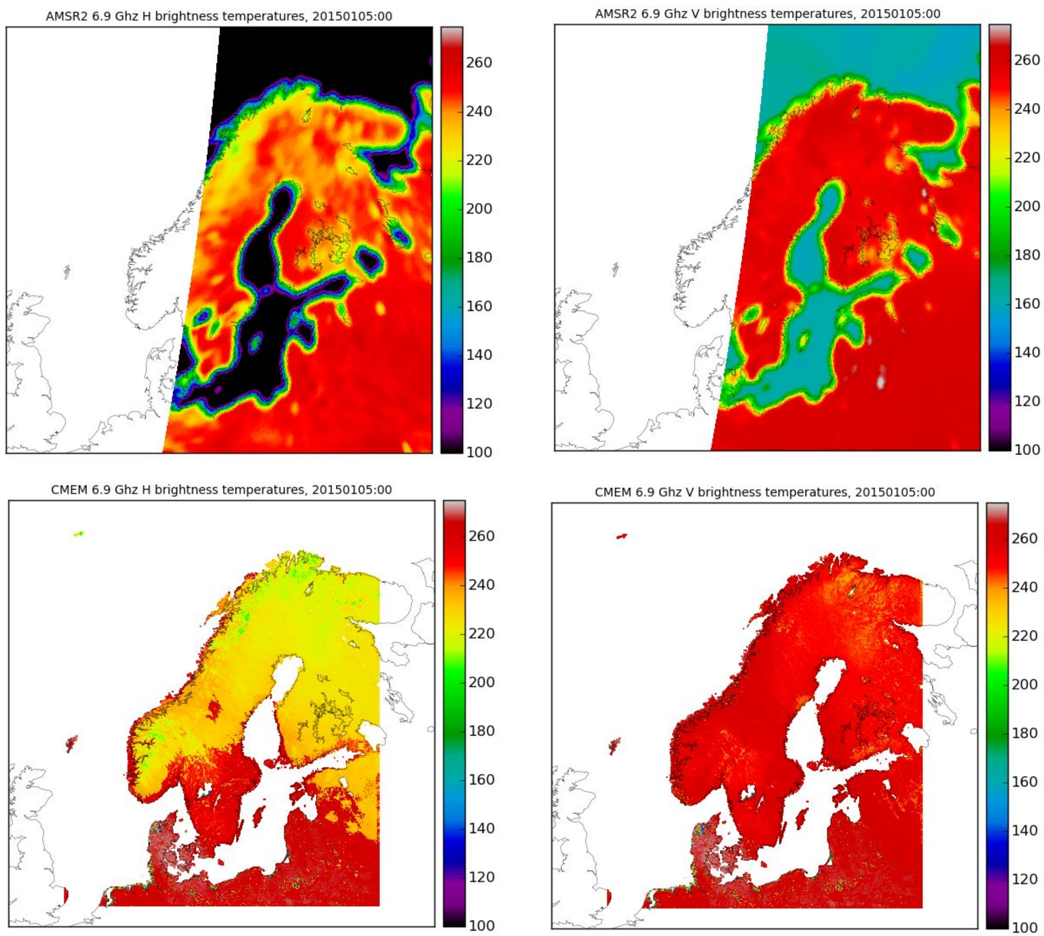
GCOM-W1/AMSR2
soilm (7 Ghz), deep (10, 19 GHz), moderate (37 GHz), shallow snow (89 GHz)

- L1SGRTBR
- Level 1R V,H, ca 40 x 60 km
- Community Microwave Emission Modelling Platform (CMEM): 1 – 20 Ghz
- FASTEM + RTTOV?

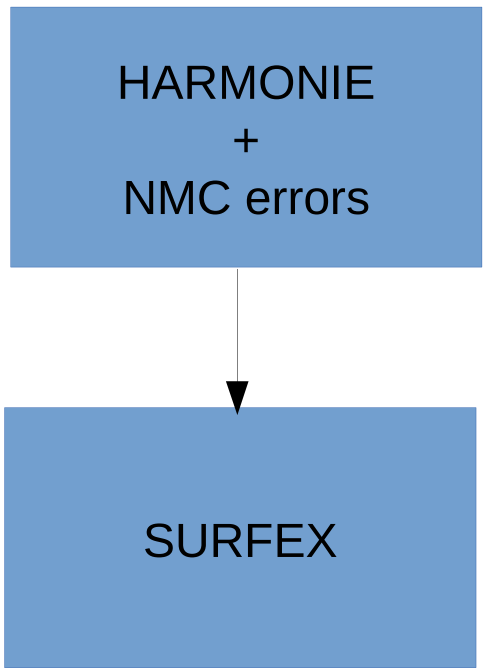
SMOS/MIRAS, L band 1.4 GHz: soil moisture

- MIR_BWSD1C
- Level 1C Browse Brightness Temperatures, dual (or full) polarization, ca 50 x 50 km, ISEA 4-9 hexagonal grid.
- CMEM + FASTEM (water)?

First technical test: AMSR2 level 1C, 6.9 GHz



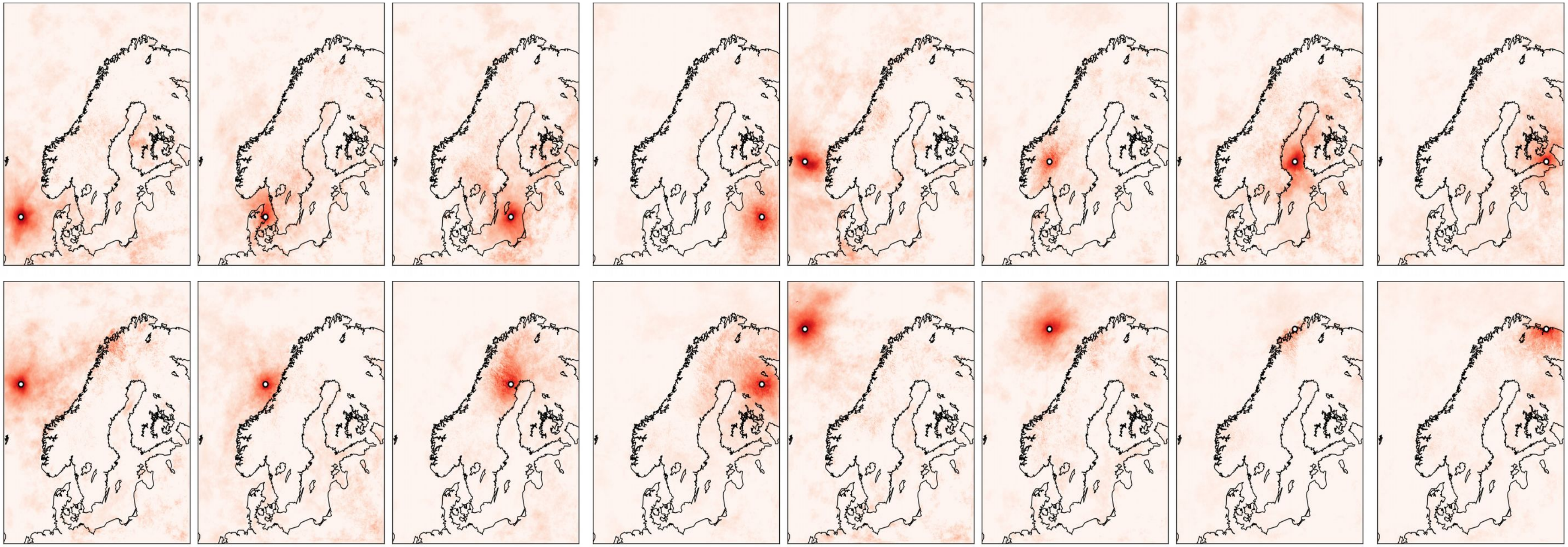
Spatially correlated errors in the forcing



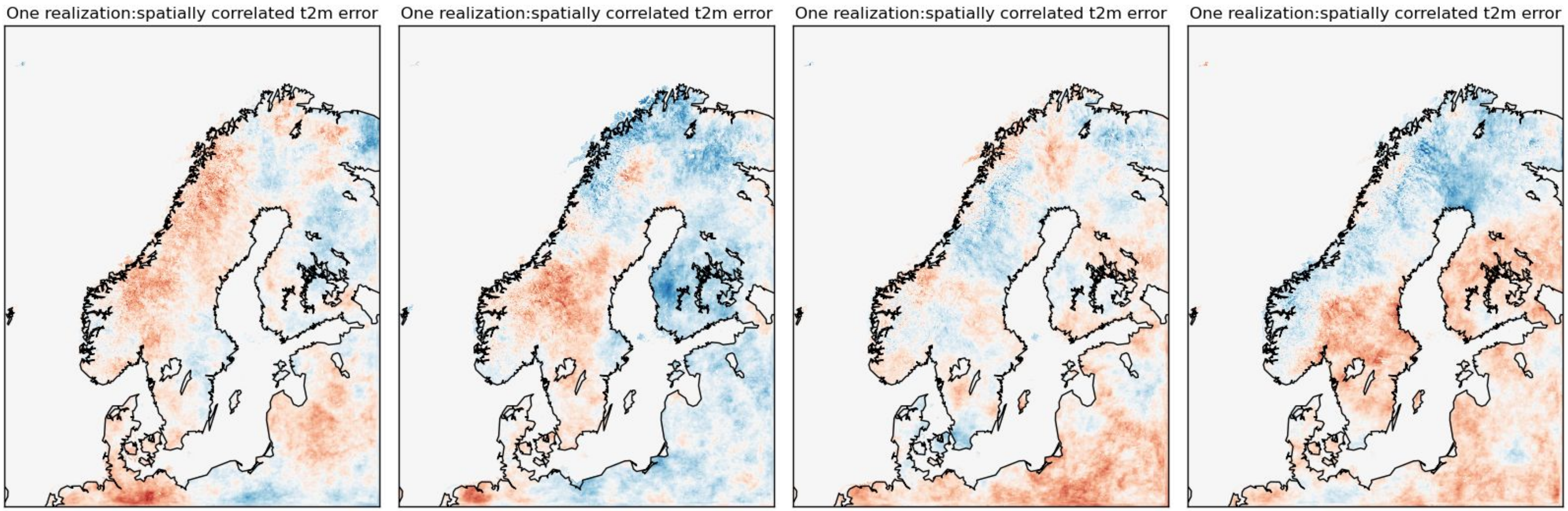
$$
\begin{aligned}
x_k &= fc_{48} - fc_{24} (m\,x\,1) \\
X &= [x_1, \ldots, x_n] (m\,x\,n) \\
B &= X X^T (m\,x\,m) \\
B_s &= X^T X = E_s D_s E_s^T (n\,x\,n) \\
X E_s (X E_s)^T &= X X^T = B \\
&= E_l D_s E_l^T \;,\; E_l = X \hat{E}_s (m\,x\,n) \\
z &= E_l D_s^{1/2} e \;,\; e \in N(0, I) \\
E\{z z^T\} &= E_l D_s E_l^T = B
\end{aligned}
$$

$$m\,x\,n \approx npar * 500\,000\,x\,n$$

16 columns of B (t2m), fc48-fc24: 20140401-1231

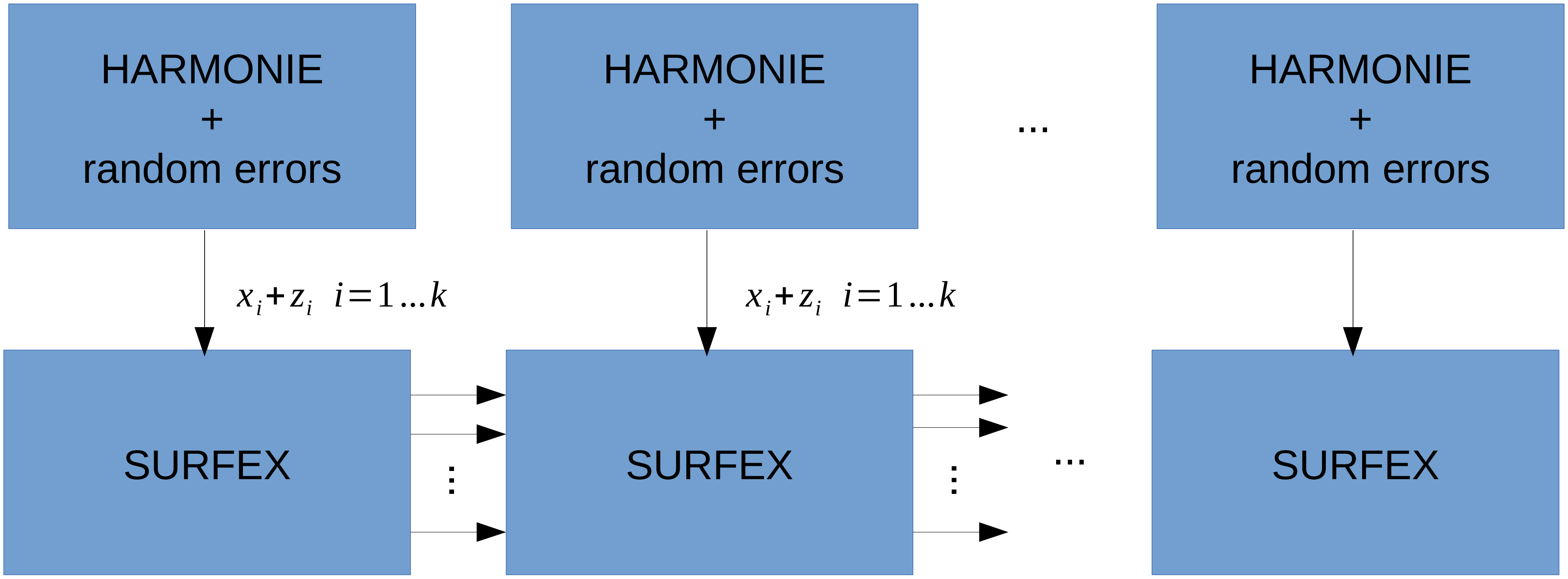


Four examples of spatially correlated t2m errors (z)



These are not fc48-fc24 differences, but samples drawn using $z = E_l D_s^{1/2} e, \quad e \in N(0, I)$

Creating an initial SURFEX ensemble (spin-up)



How many members (k) are called for?
How long time do we need to run to spin up a sufficiently rich ensemble?

Questions

NWP

Alternative (EnKF or En2DVar) DA for t2m and rh2m?

EnKF

Ensemble Kalman Filter for SURFEX – from N 1D to 1 ND. Cycling members?

How to introduce systematic perturbations? Time shifts?

Need for adding horizontally/vertically correlated errors to the SURFEX state?

How to assimilate runoff observations – long time window EnKF?

Observations and observers (obop)

How to make Sentinel-1 data fit HARMONIE scale – work with pdf:s?

How to make HARMONIE fit scale of SMOS/AMSR2 – footprint/antenna func?

Water emissivity at SMOS freq, FASTEM? RTTOV for AMSR2 37 and 89 GHz?

SMHI

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EO and in-situ snow data in Sweden

<u>Forcing data</u>

- P, T interpolated (4x4 km^2)
- Elevation EU-DEM (25x25 m^2)

<u>Snow data</u>

SMHI snow depth stations (point, daily)

Hydropower companies:

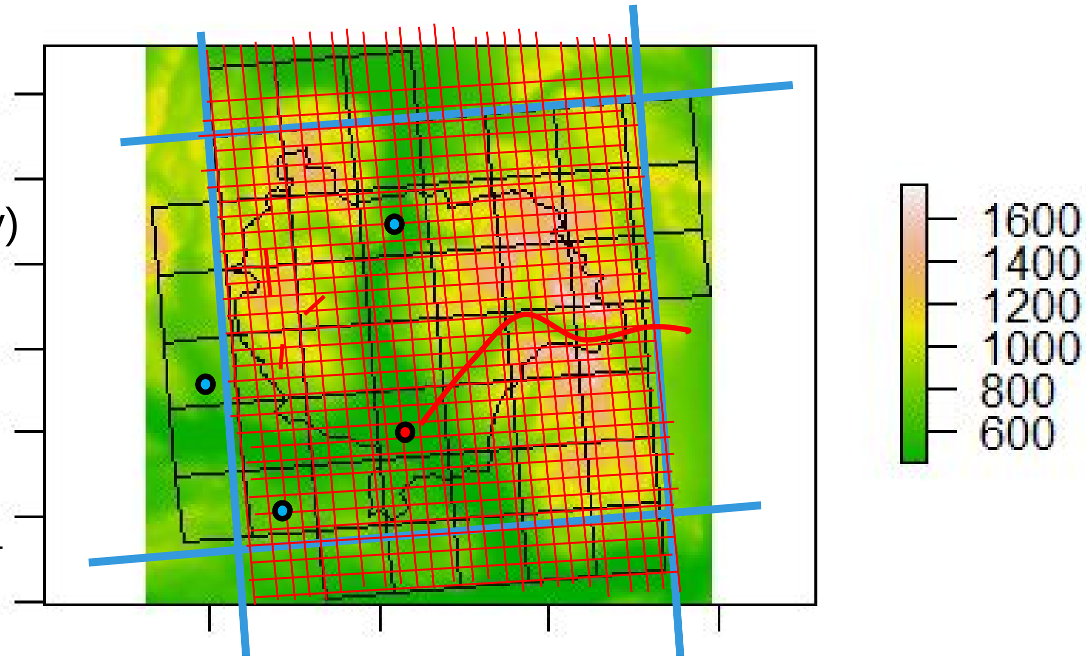
SWE point data (bi-weekly)

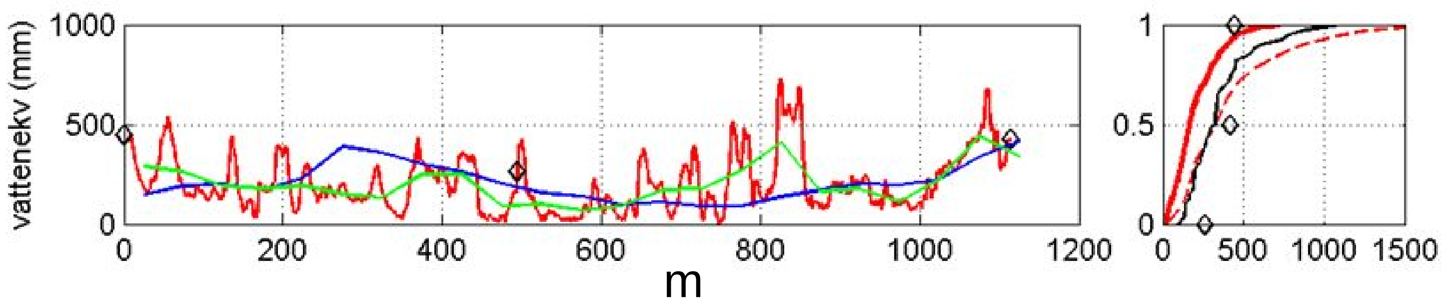
Snow courses (once per year)

<u>Satellitdata (GlobSnow, CryoLand,etc)</u>

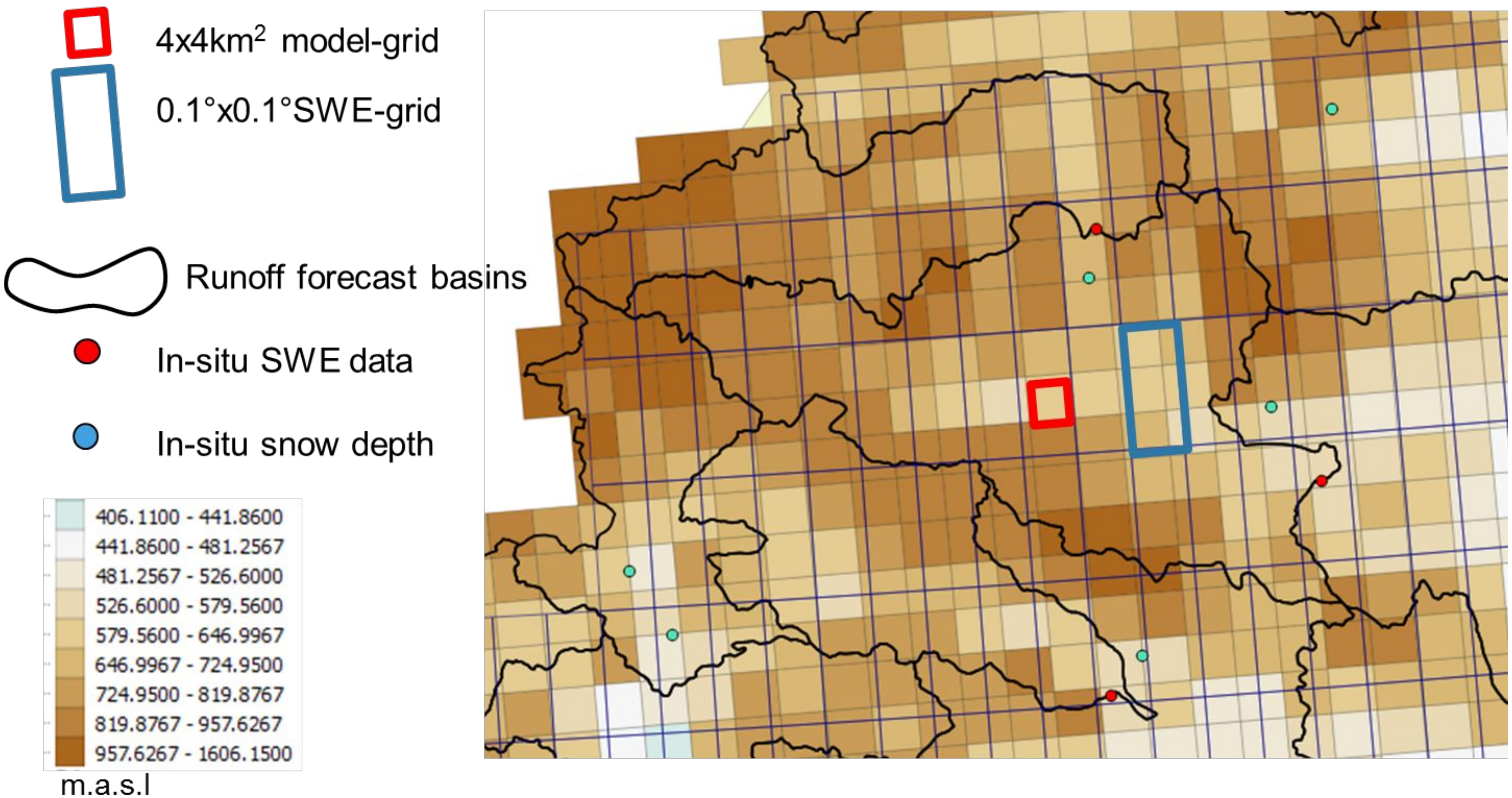
Fractional snow cover 1x1 km^2

Snow water equivalent 25x25 km^2

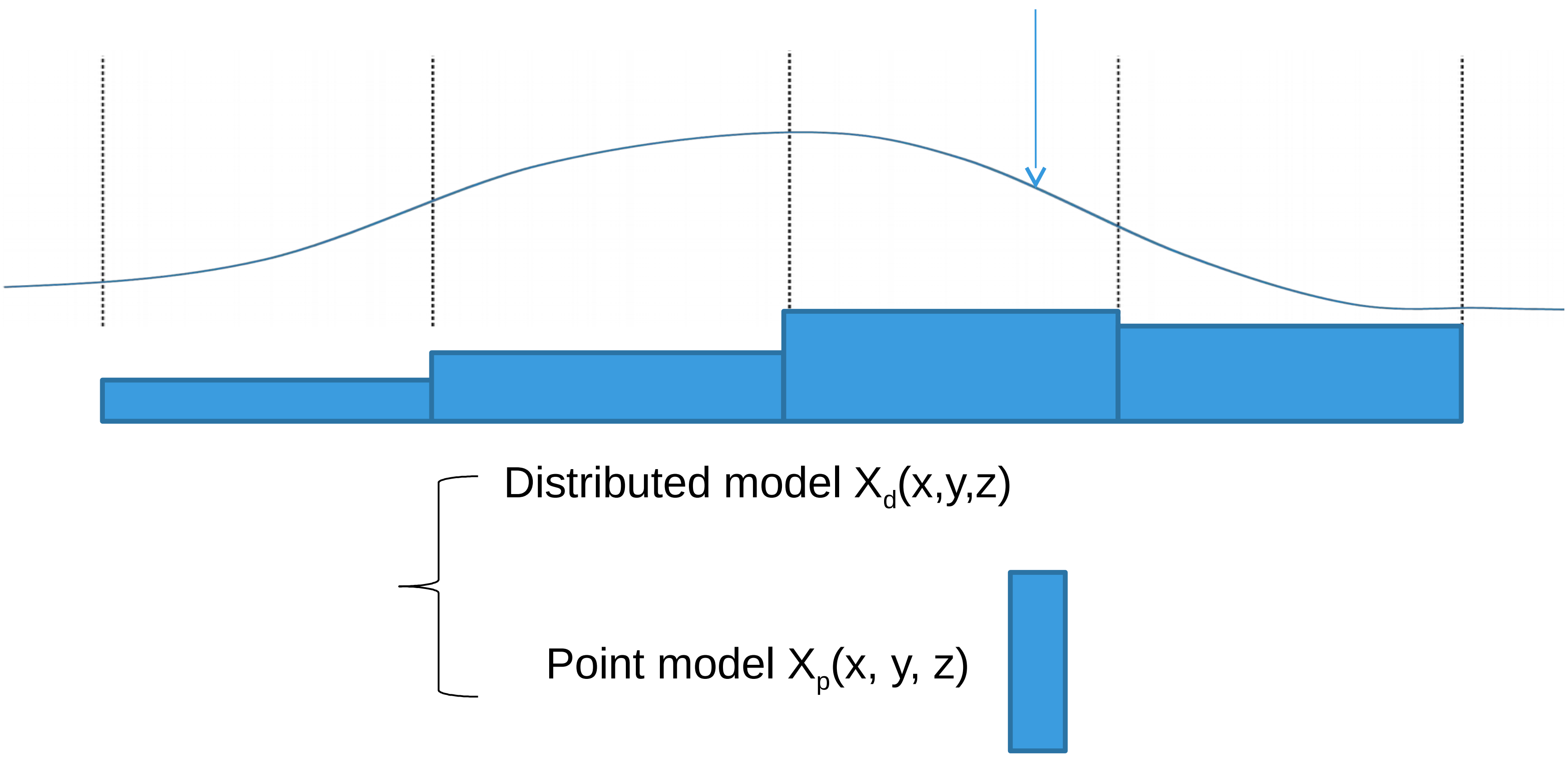




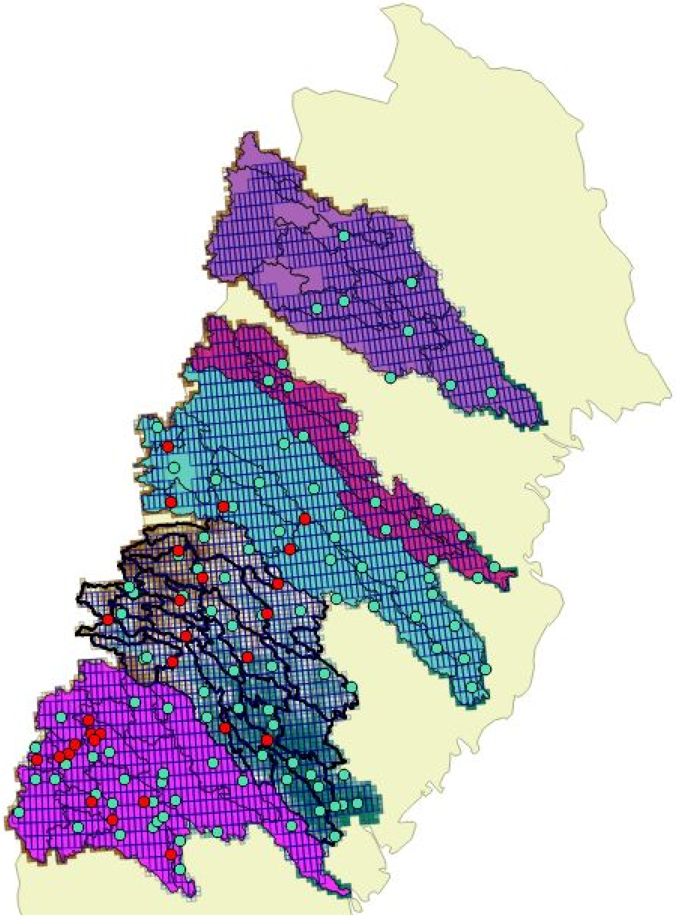
Distributed hydrological model (HBV-type)



Assimilation of point observations in a distributed model



SMHI



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
- Runoff is aggregated for the VRF forecast areas in Lule river, Skellefte river, Ume river, Ångerman river and Indals river.

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

Two options for snow data integration:

1) Evaluation of Model and Data agreement

KGE = agreement in terms of **mean value, standard deviation** and **correlation**

2) Model state-updating using EnKF (Evensen, 1994)

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

All model states (non only snow) updated as a function of co-variance between the states and the 'innovation' in the snow variables

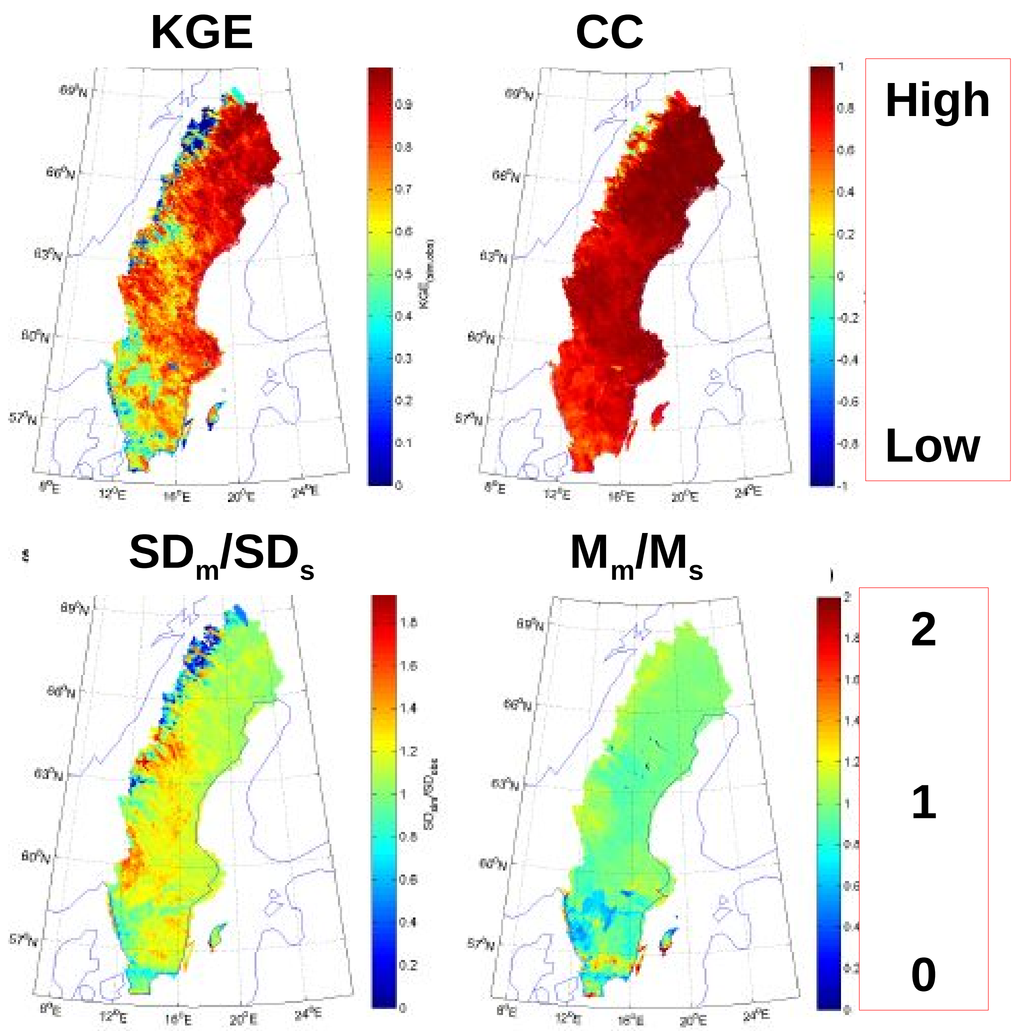
Important that model and data do not disagree too much!

Model and data comparison – FSC

optical product ENVEO/SYKE

Pan-European

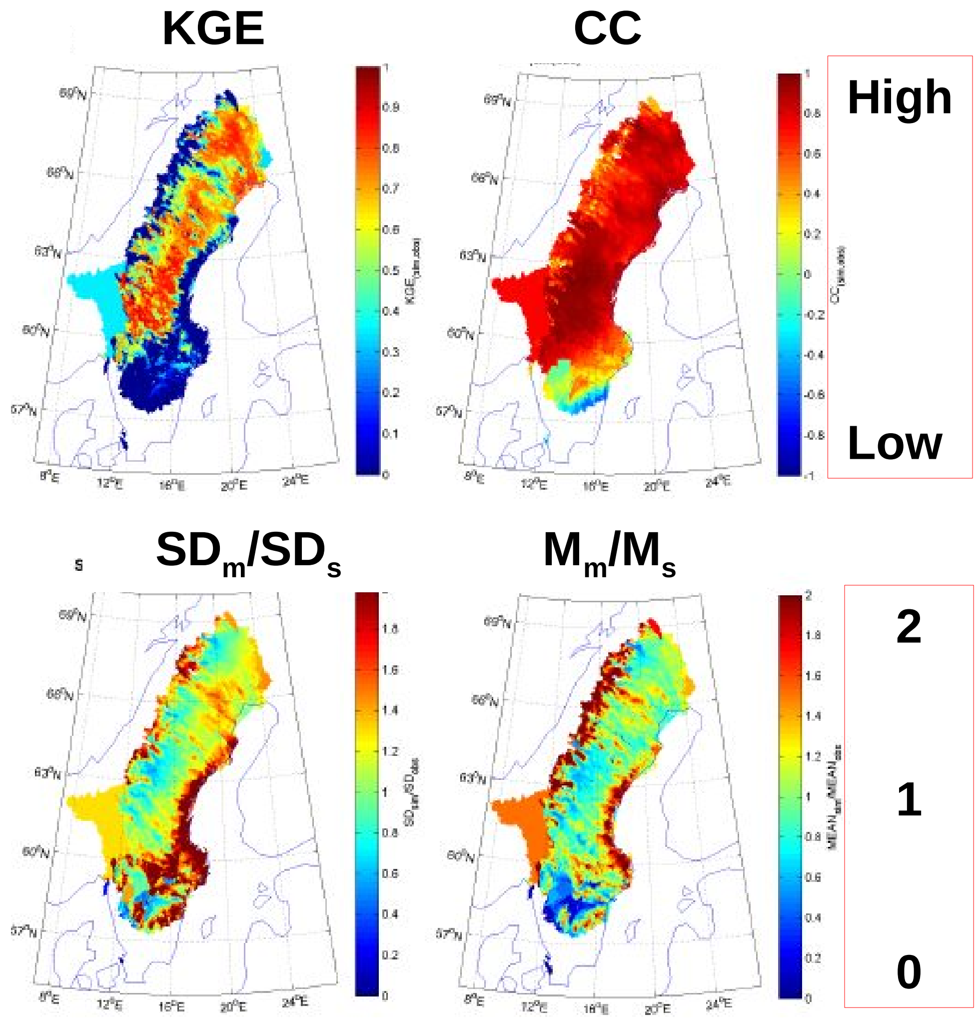
- **In general a very good agreement** between model and satellite data throughout Sweden
- However, the **temporal variability is different** in the most alpine part of the mountains in northern Sweden
- **Transmissivity model** is well-adapted to boreal forests.



CryoLand SWE vs S-HYPE modellen

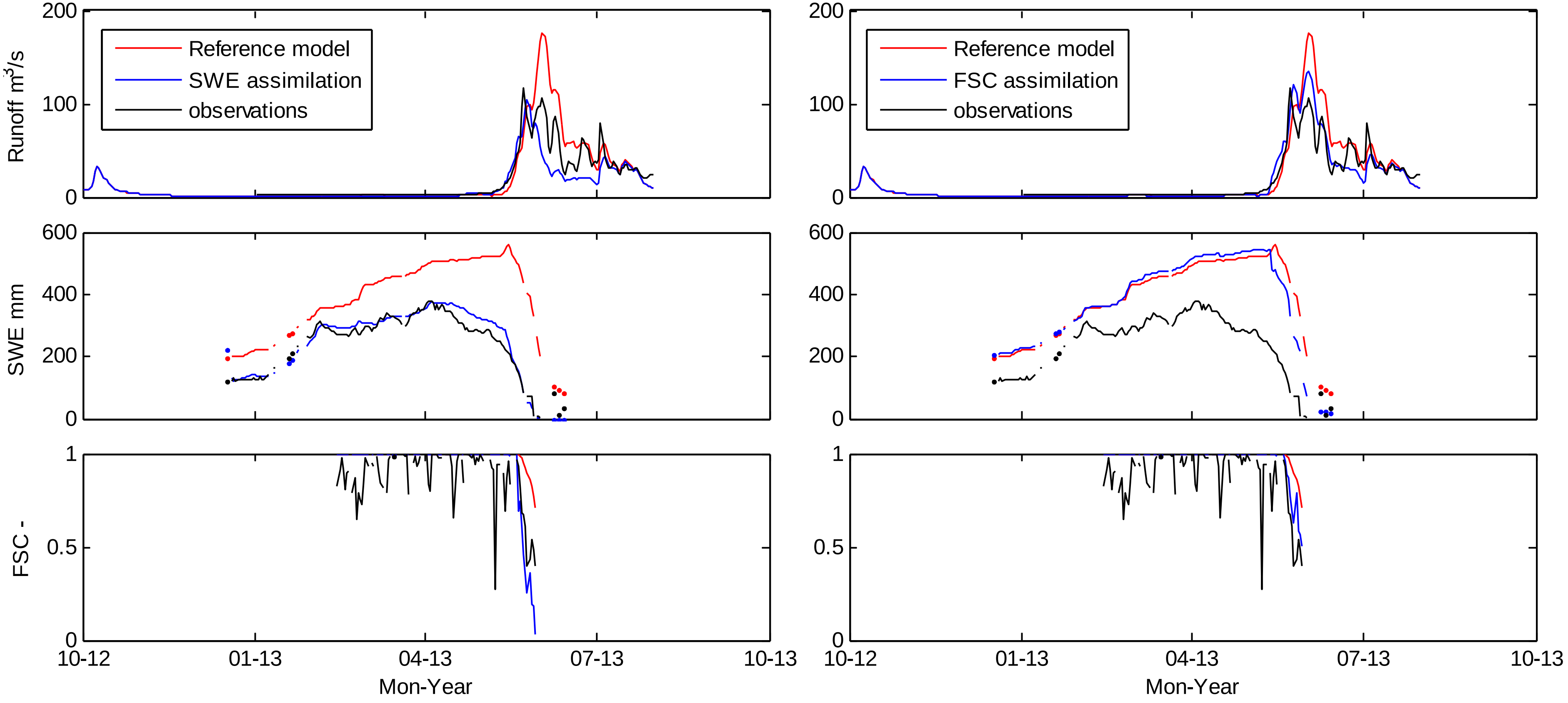
Pan-European SWE product (FMI)

- **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, spatial distribution of snow



Good exmple: Abiskojokki, northern Sweden.

Both SWE and FSC data improve stream flow simulations



Spring flood forecast assimilation experiments

- 5 test areas
- 6 year snow observations (2010-2015)
- Initialization for forecast start dates 15/2, 15/4 och 15/6 assimilating:
  - Local runoff (Q)
  - Snow water equivalen (SWE) – in-situ
  - Snow depth (SD) – in situ
  - Snow fraction area (FSC) – from CryoLand

		Area	**Snow water equivalent at forecast start (mean 2010-2015)**			
Område	Älv	km2	15/2	15/4	15/6	15/6 (% av 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%

Results spring melt volume forecasts

- Assimilation until forecast start – forecast usig ensemble of historical years
- Assimilation initialization is better in most cases than the reference run
- In-situ SWE and satellite based FSC is the most consistent improvement

Relativt volymfel (%)   (medel av absolut volym fel 2010-2015)

Prognos 15/4-31/7							
Område	**Ref**	**Ens0**	**EnsQ**	**EnsSWE**	**EnsSD**	**EnsFSC**	**EnsAll**
Tjaktjajaure	74.8	71.2	70.0	**39.8**	41.6	301.4	46.7
Riebnes	35.2	31.6	41.2	**15.3**	18.8	28.9	25.5
Överuman	20.8	20.1	22.3	20.1	21.6	**12.8**	26.9
Kultsjön	10.2	9.3	15.4	16.0	32.9	**5.4**	42.2
Landösjön	26.4	24.8	40.9	23.7	15.2	**14.6**	23.2
antal lägst fel				2		3	
antal < Ref		5	1	4	3	4	3

Comparing forecasts 15/2 15/4 och 15/6

- Snow data assimilation important throughout winter
- Largest improvement later in the winter and through the melt period

		Ref	Ens0	EnsQ	**EnsSWE**	EnsSD	**EnsFSC**	EnsAll
Relativt volymfel (%)	15/2	12.8	12.6	15.1	**13.5**	15.9	**12.6**	15.9
	15/4	23.1	21.5	29.9	**18.8**	22.1	**15.4**	29.4
	15/6	28.6	26.8	34.6	**23.0**	23.1	**22.8**	27.6
Relativ förbättring (%)	15/2		-2	20	**-13**	19	**-26**	26
	15/4		-7	37	**-48**	14	**-29**	61
	15/6		-6	27	**-41**	0	**-1**	17

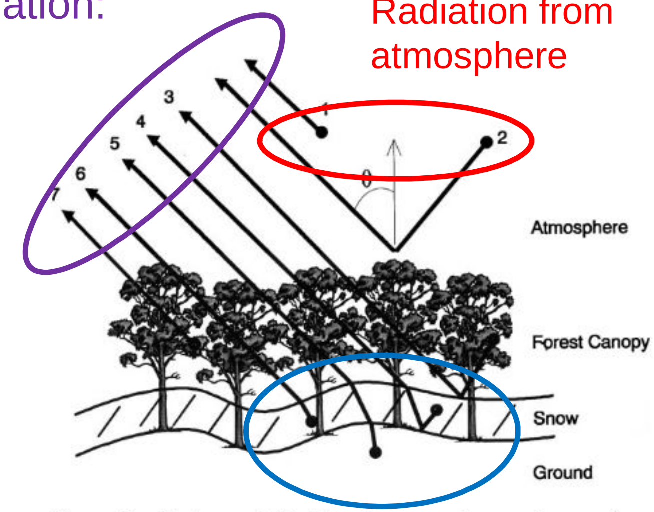
Next step: assimilate in-situ data, passive microwave data directly in the hydrological model?

Radiation emission model

Ex from Pullianen and Hallikainen (2001)

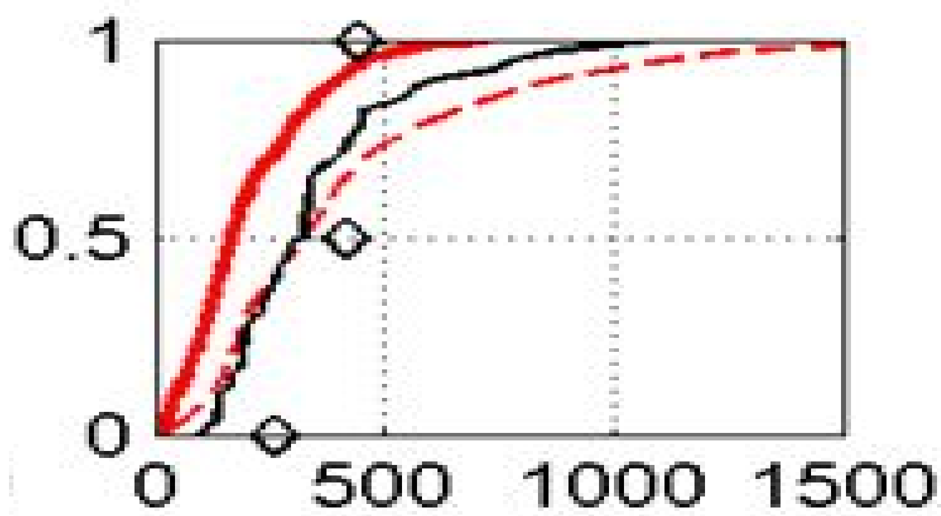
Satellite observed radiation:

Radiation from atmosphere



Radiation from ground (soil, snow, vegetation)

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



Conclusions

- Assimilation of satellite and in-situ snow data reduced snow melt runoff forecast errors with 5-50%.
- In-situ snow water equivalent and satellite based fractional snow cover gave the most consistent improvements when assimilated in the mdoel.
- Further studies will be focused on assimilation of passive microwave data and in-situ data directly in the snow hydrological models.


Tack för uppmärksamheten