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Snow Melt Runoff Simulation using Ensemble Kalman Filter assimilation of Distributed Snow Data

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Background

- Snow Melt Runoff predictions for Hydropower management in Sweden:

  - Hydrological model HBV

  - Snow depth and SWE data
    - Helicopter borne radar
    - Manual transects

  - Unclear if assimilation of this data improve predictions

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Questions

- Model structure problem?
  - Day-degree or Energy Balance?
  - Lumped or Distributed?
- Data problem?
  - Non-representative?
  - Measurement errors? (e.g. Radar on wet snow)
  - Input data?
- Both?
  - Model structure and Data structure?
  - Data assimilation methods?

”HUVA” project

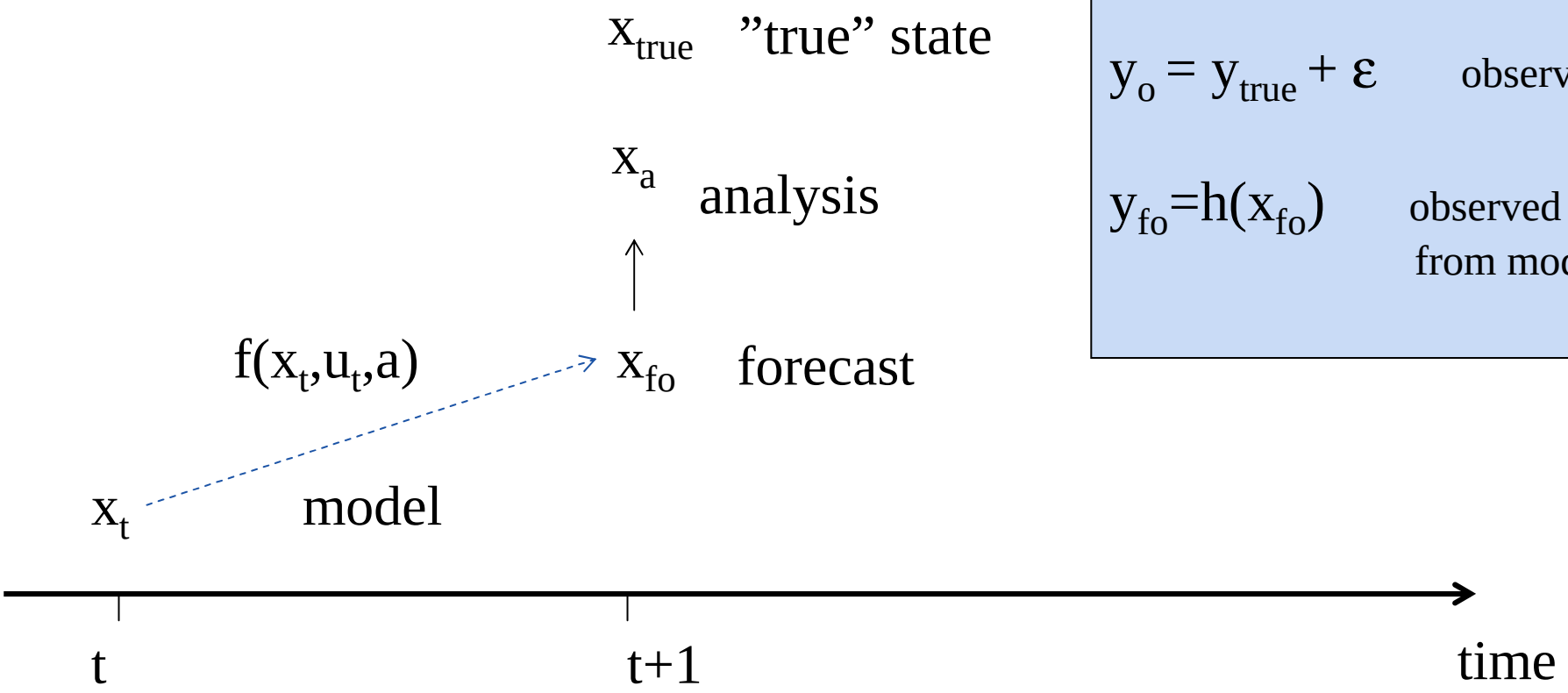
- Distributed measurement systems for improved snow melt runoff predictions – integration into hydrological models (KTH, LTU, KTH) – supported by ELFORSK/SVC

- Objective:

  - Investigate how the
    - model structure
      - (process representation, spatial distribution and temporal resolution)
    - Nature of snow data
      - (depth, mass, wetness, etc, distribution in space and time, measurement types)
  - influence snow model predictions

Data assimilation

- What is the best estimate $\mathbf{x_a}$ of the true state $\mathbf{x_{true}}$ given an observation $\mathbf{y_0}$ and a forecast state $\mathbf{x_{fo}}$ at observation time?



$y_o = y_{true} + \varepsilon$ observed quantity

$y_{fo}=h(x_{fo})$ observed quantity from model state

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Data assimilation

- Best estimate by **Minimize cost function:**

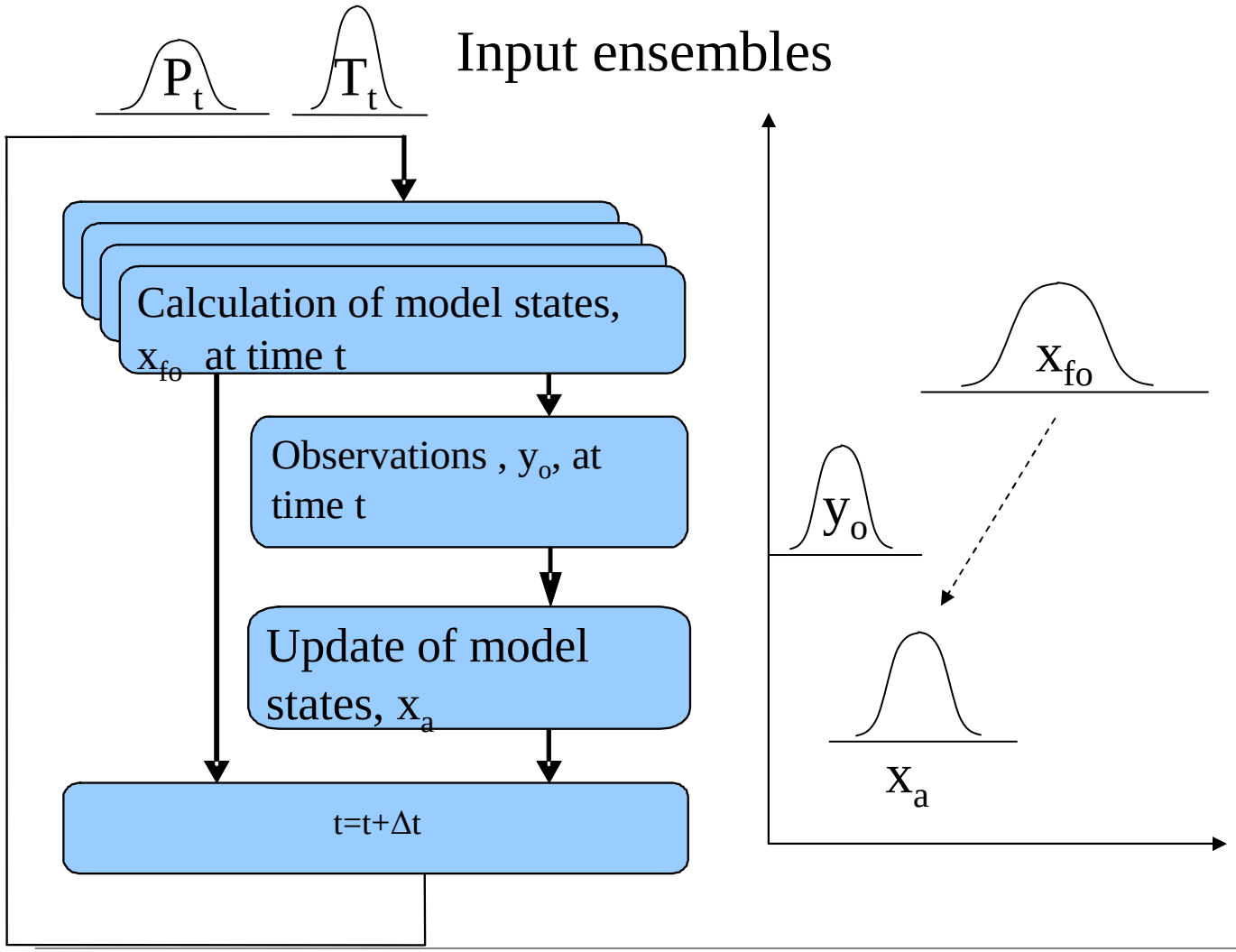
$$J = 0.5\,(x-x_{fo})^{T}B^{-1}(x-x_{fo}) \;+\; 0.5\,(h[x]-y_o)^{T}R^{-1}(h[x]-y_o)$$

$$J \approx \underbrace{(\text{deviation from forecast})^2}_{\text{Model error}} + \underbrace{(\text{deviation from observation})^2}_{\text{Data error}}$$

B error covariance matrix of model state x
R error covariance matrix of observation y

EnKF ensemble Kalman filter

- Estimate covariance matrix from ensemble



Combine model states and parameters in the X matrix!

$$x_a = x_{fo} + K\left(y_o - h\left(x_{fo}\right)\right)$$

$$K = \frac{BH^T}{HBH^T + R}$$

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Examples:

- Assimilation of distributed SWE data (at one time) into a distributed snowmodel

  - Improve the snow runoff volume?

- Assimilation of snow wetness data (time series) into a lumped model

  - Improve the snow melt timing?

Distributed snow hydrological model

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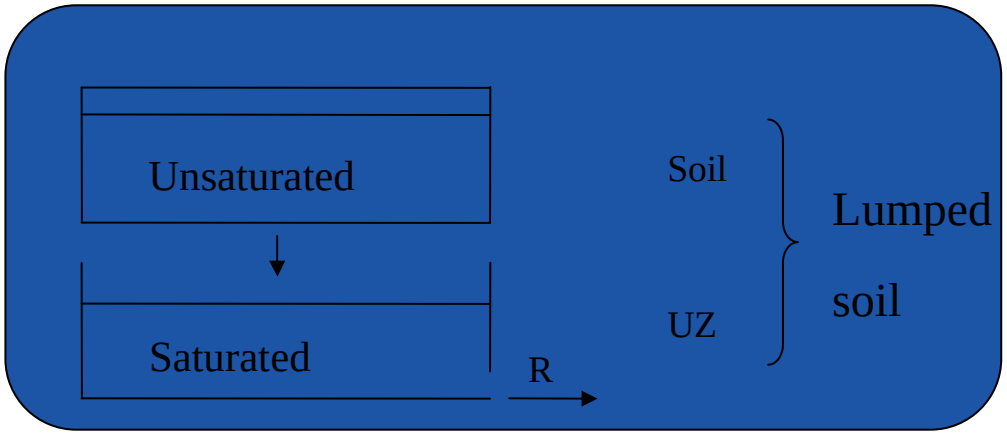
Distribution

Meteorological forcing

Distributed (HRU) snow model

Model states

- Snow mass
- Snow depth
- Snow age
- Liquid water
- (Snow heat)



Process representation

Distribution of weather station data:

$P_{local}=(p_0+p_1*slope+p_2*curvature+p_3*windaspect)*P_{station}$

$T_{Local}=T_{station}+L*(\Delta_{altitude})$

Day-degree model: $M = c_T(T-T_t) + c_R R_s$

(Energy balance model: $M = (R_n-H-LE-c\delta T)/L_f$)

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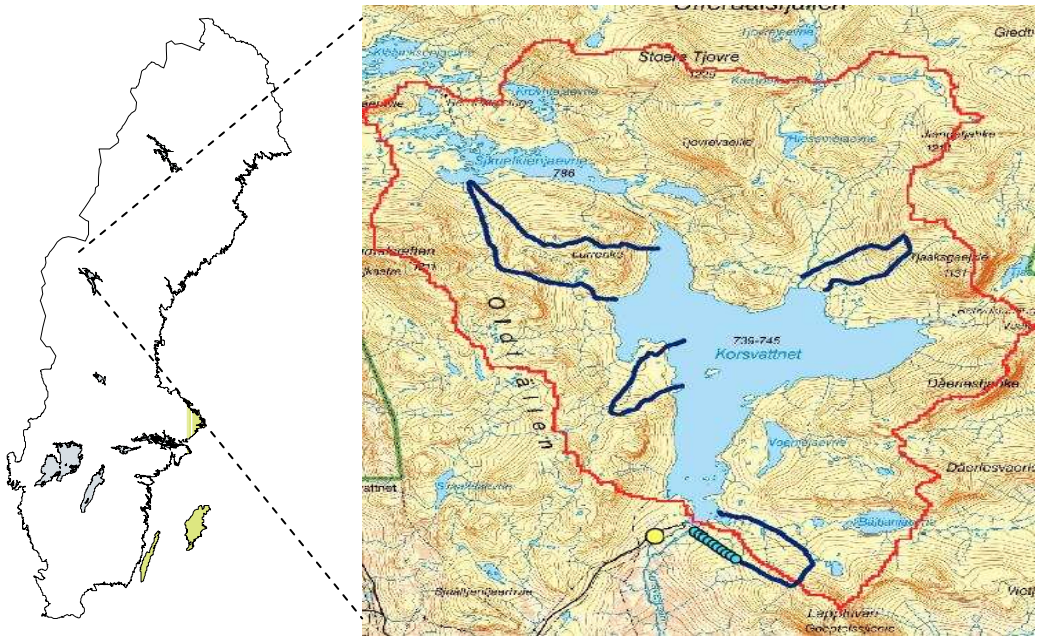
Hydrological Respons Units(HRU)

- Modeling area has been classified into different classes depending on terrain properties.
- Combinations of Slope, Aspect, Curvature and Height have given a total of 124 different classes.

- Alternatively fully distributed on a rectangular grid

Study site: lake Korsvattnet, Jämtland

- Radar (GPR) snow data 2008-2009 (~20 km)
- Radar equipment carried by a snow mobile.
- Runoff to the lake



(84 km^2 watershed, 64°N13°E)

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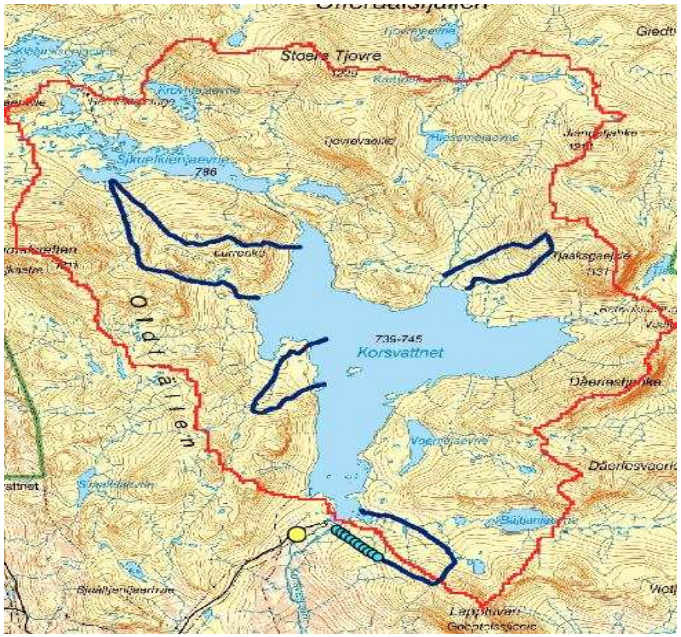
Automatic snow measurements

- snow water equivalen SWE (snow pillow)
- Snow depth (ultrasonic)
- Snow wetness (impedance sensor)
- Snow temperature

Example 1: Distributed SWE data

Ahlberg, Jesper & Gustafsson, David (2010): Snow Melt Runoff simulations using Ensemble Kalman filter assimilation of Distributed Snow Data, Nordic Hydrology Conference, Riga, August 2010.



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Assimilation of distributed data

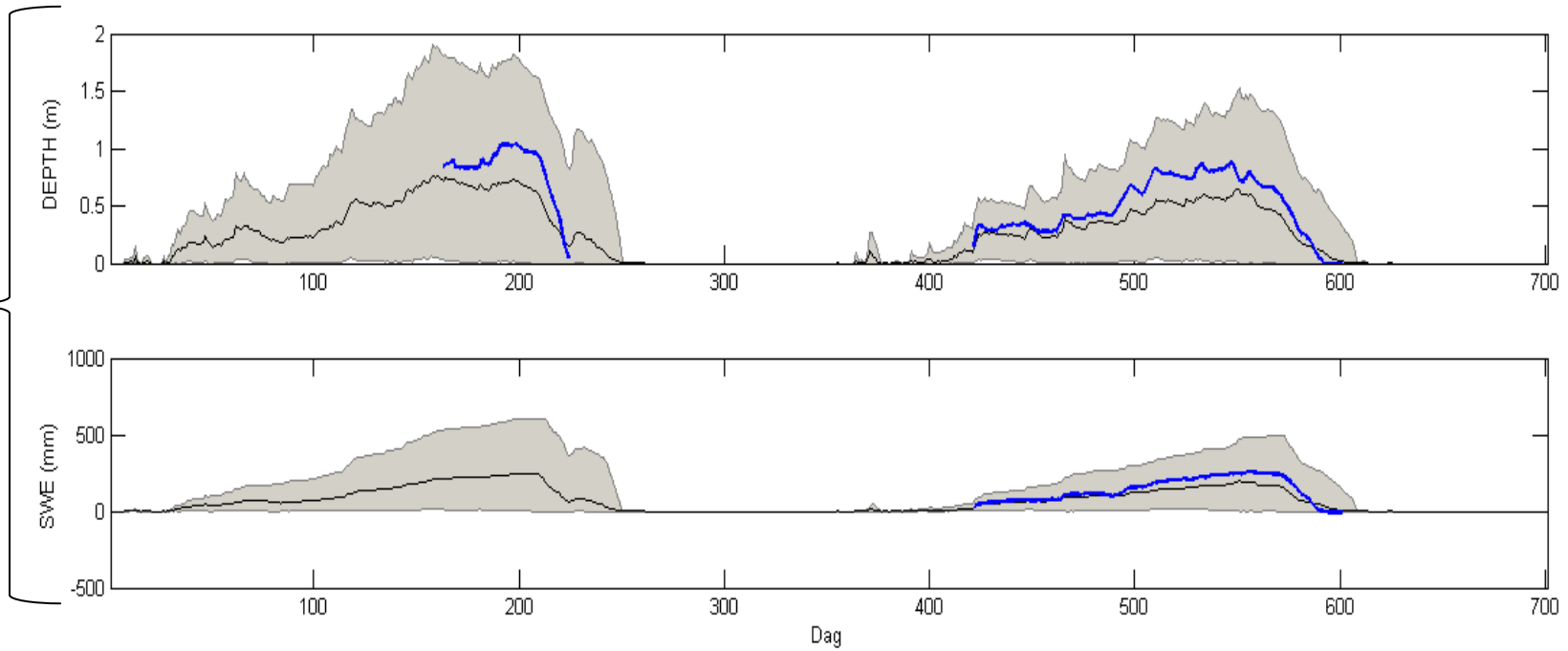
Simulation	Model	Data Assimilated
1	Lumped	No
2	Lumped	Average of distributed snow data(SWE)
3	Distributed (HRU)	No
4	Distributed (HRU)	Distributed data(SWE)

Without assimilation

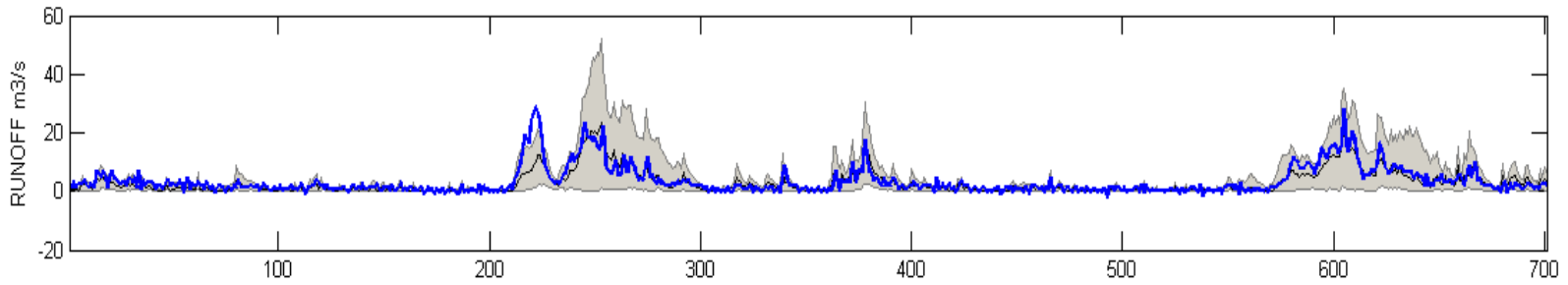
Simulation nr 3.
Distributed model. No Data Assimilation

Observation
Modelled

Snow depth and SWE simulated for the snow station



Runoff to the lake

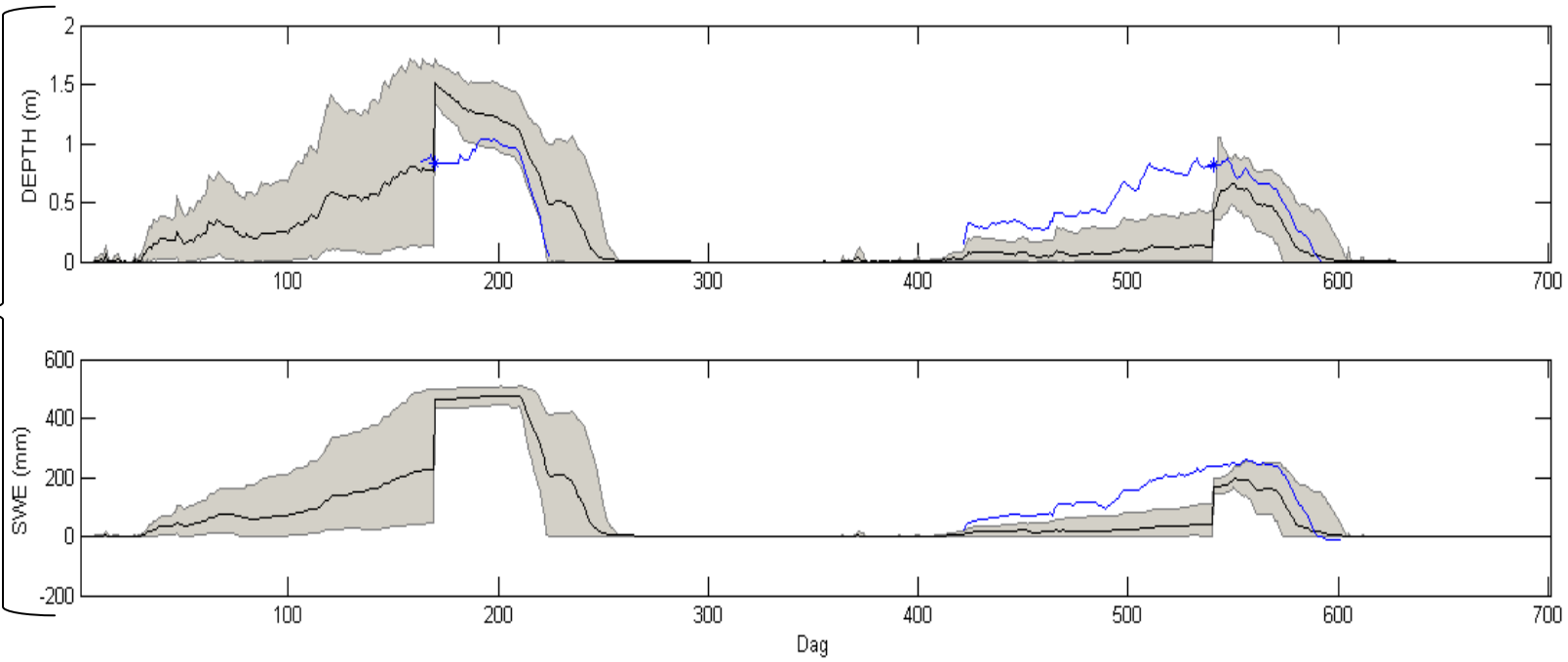


With assimilation

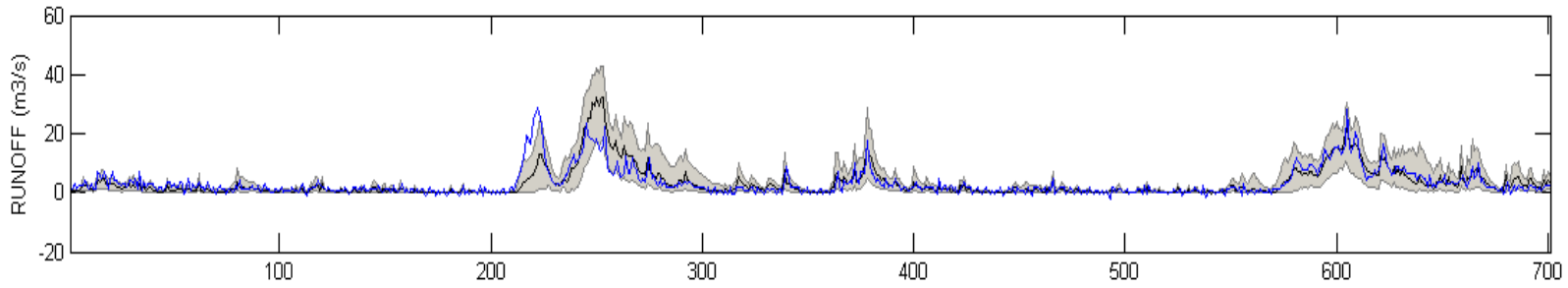
Simulation nr 4.
Distributed model.

Observation
Modelled

Snow depth and SWE simulated for the snow station



Runoff to the lake



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Results (Korsvattnet)

Simulation	Model	Data Assimilated	VolErr 2008 (%)	VolErr 2009 (%)	Nash 2008 (-)	Nash 2009(-)
1	Lumped	No	-6.7	-5.8	0.64	0.91
2	Lumped	Average of dist snow data	-5.1	-3.4	0.61	0.92
3	Distributed (HRU)	No	-10.7	-8.6	0.67	0.87
4	Distributed (HRU)	Distributed data	8.43	-1.0	0.36	0.93

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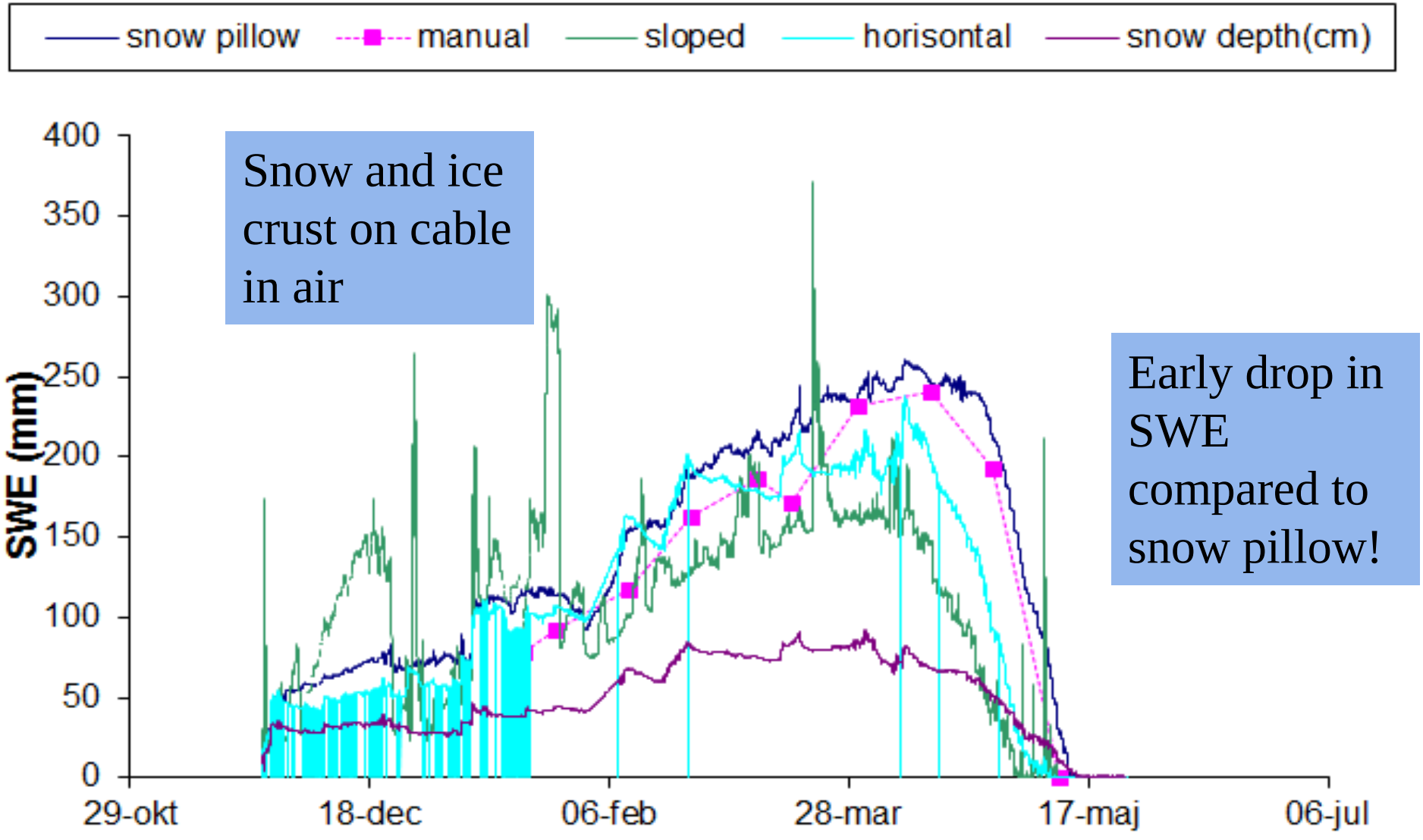
Example 2: Snow wetness data

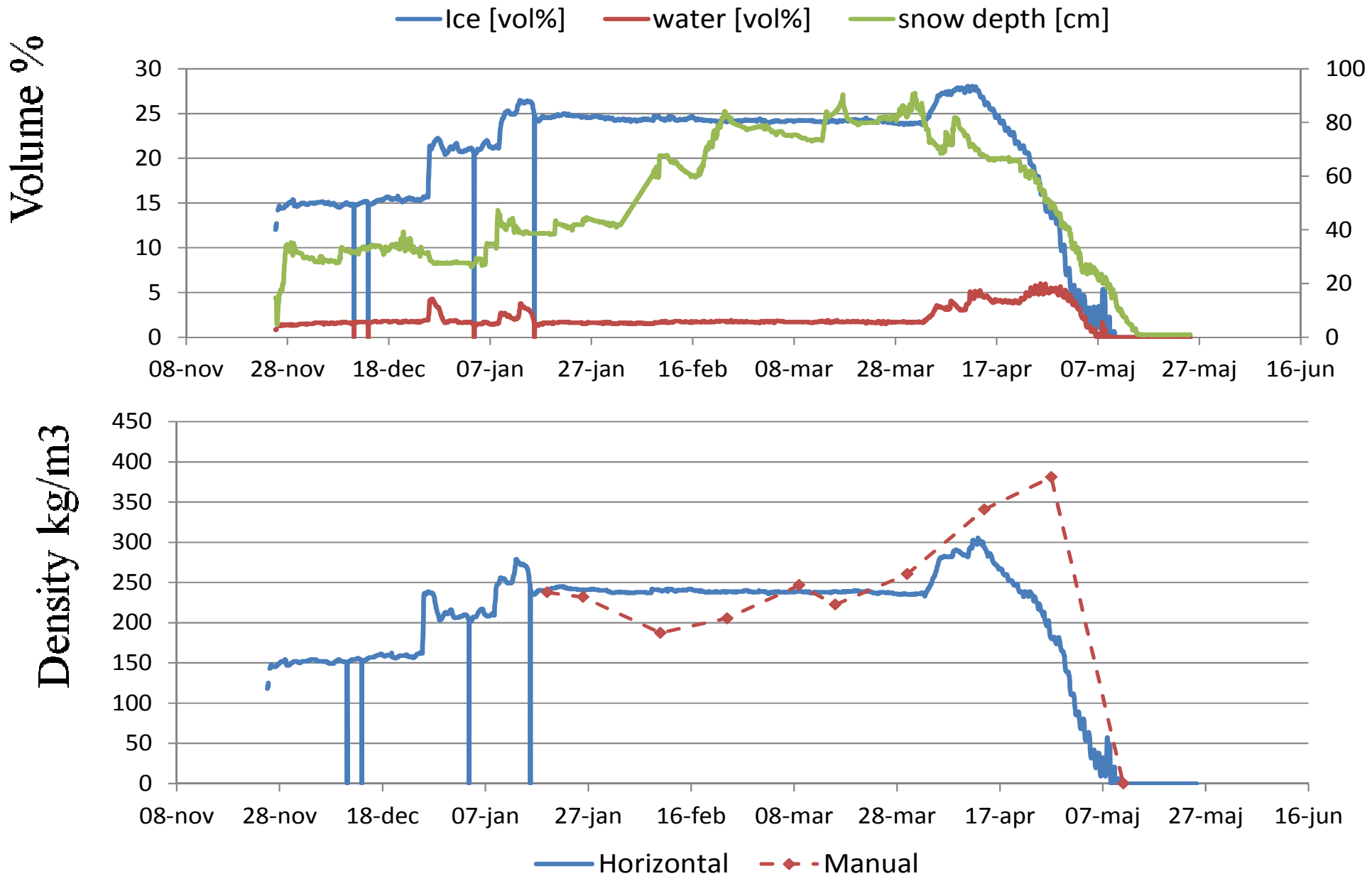
Gustafsson, Sommer, Ahlberg (2010). MEASUREMENT OF LIQUID WATER CONTENT IN SNOW AND ITS APPLICATION IN SNOW HYDROLOGICAL MODELLING. Nordic Hydrological Conference, Riga, August 2010.

Korsvattnet 2008-09



Overall good correspondance with snow pillow and manual

Korsvattnet Horizontal



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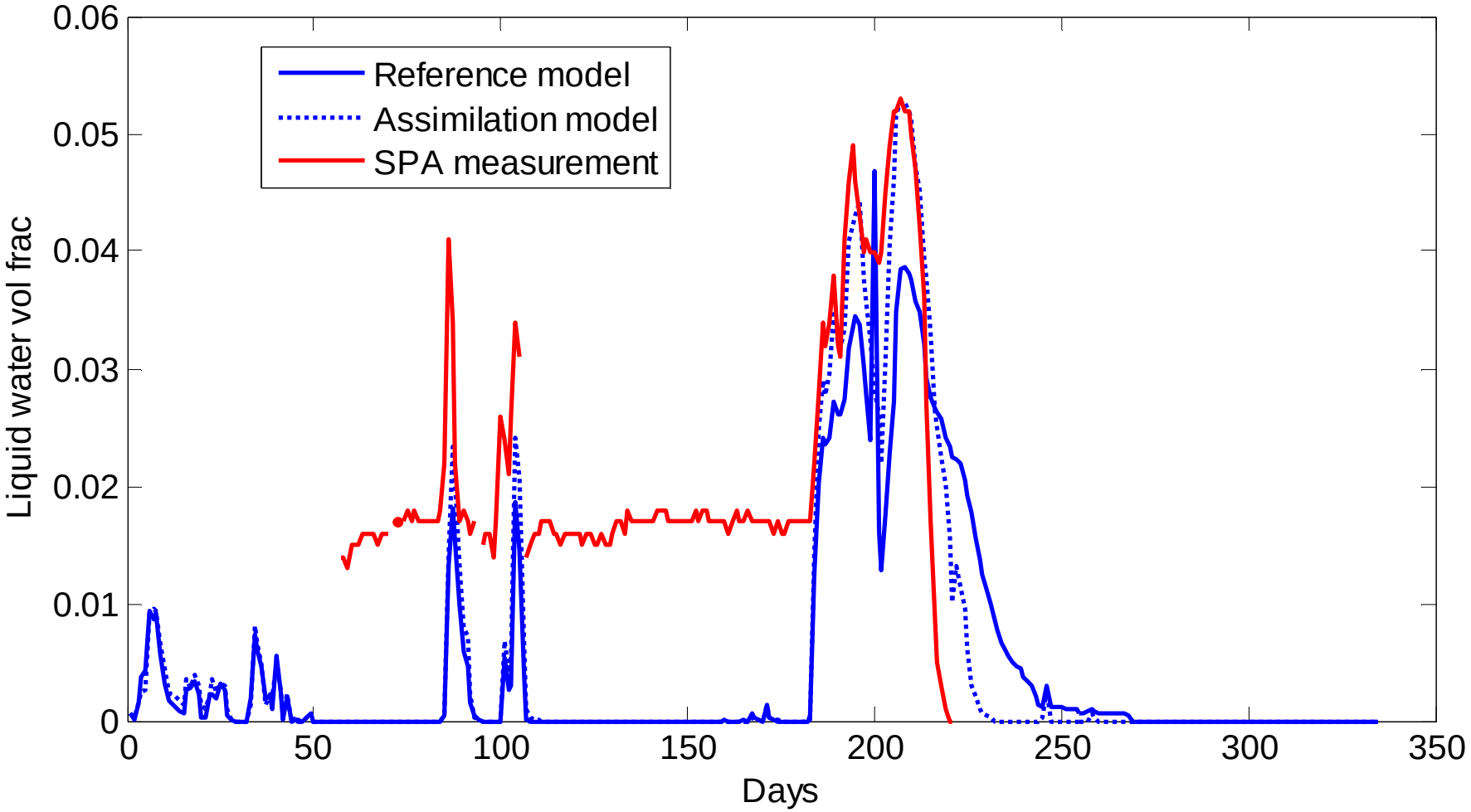
Simulated snow liquid water



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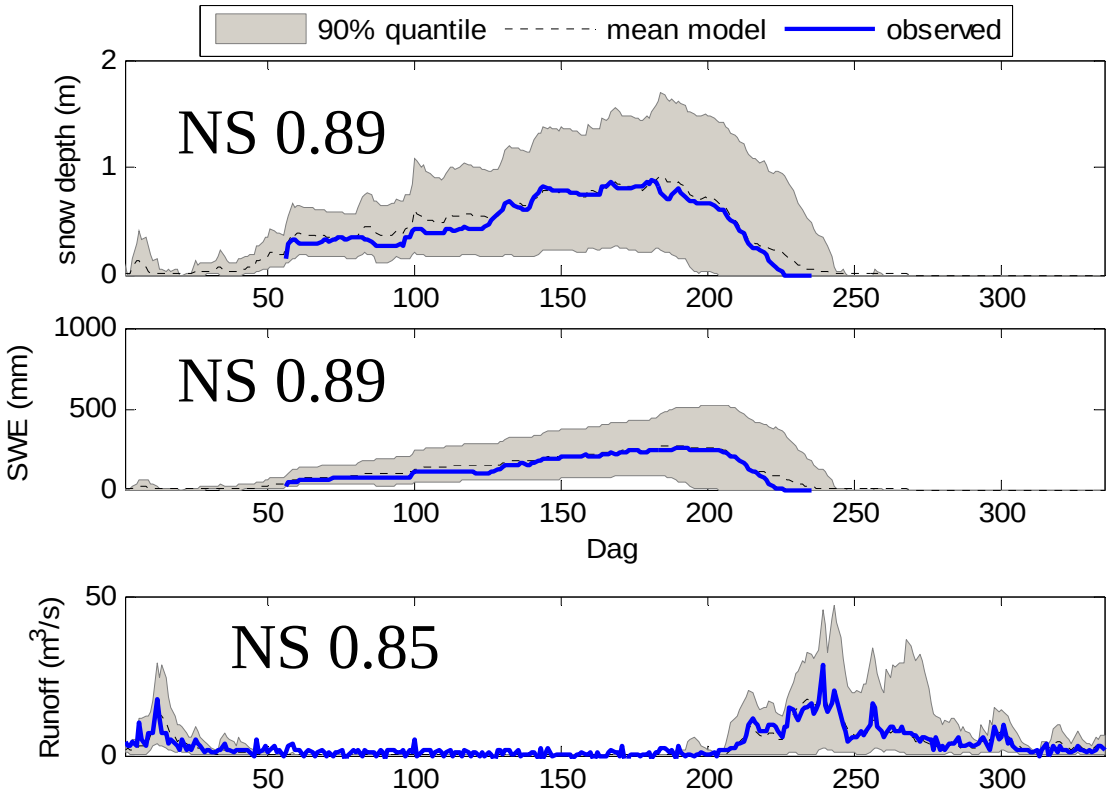
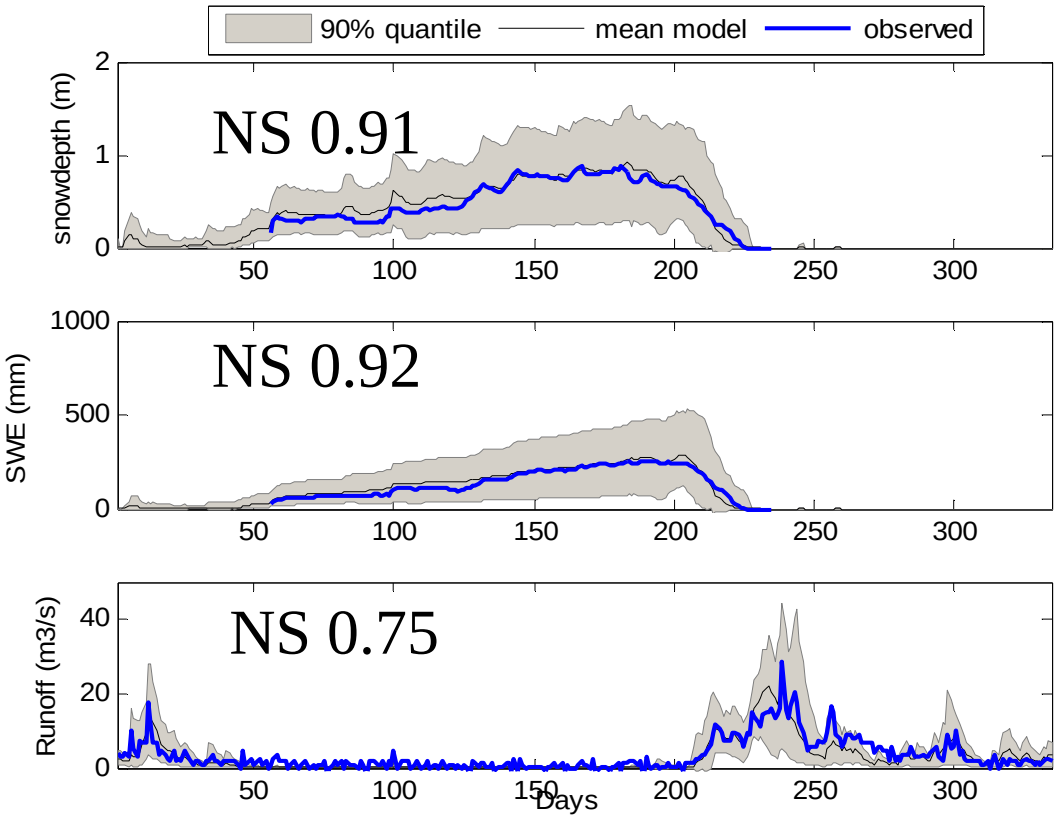
Without assimilation



Assimilation of snow wetness data



Improved local snowmelt….but regional runoff deteriorated
(problem with snow depletion curve)

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CONCLUSIONS AND OUTLOOK

- EnKF useful method for assimilation of snow data in hydrological models
- Acknowledge errors in both data and model
- Smooth automatic ”update” of the models
- Data sets
  - Too few years to make general conclusions
  - 4 year with distributed data from project
  - ~15 years of old helicopter data further mined

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Furthermore

- Implement snow assimilation routine into S-HYPE
- Evaluate operational snow depth measurements

Acknowledgement

This study was performed with support from the project “Distributed measurement systems for improved snow- and runoff forecasts – integration into hydrological models” supported by the "Swedish Hydropower Centre - SVC" www.svc.nu.

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