The SNODDAS project

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Tomorrow's forecast for snow water equivalents - preliminary results of an updated toolbox for mountain catchments

SNODDAS (SNOw Distribution and Data Assimilation for improved spring flood forecast and Sustainable hydropower reservoir regulation) is financed by the Swedish Energy Agency call HÅVA (Sustainable Hydropower) 2018/06-2021/06.

SNODDAS participants:

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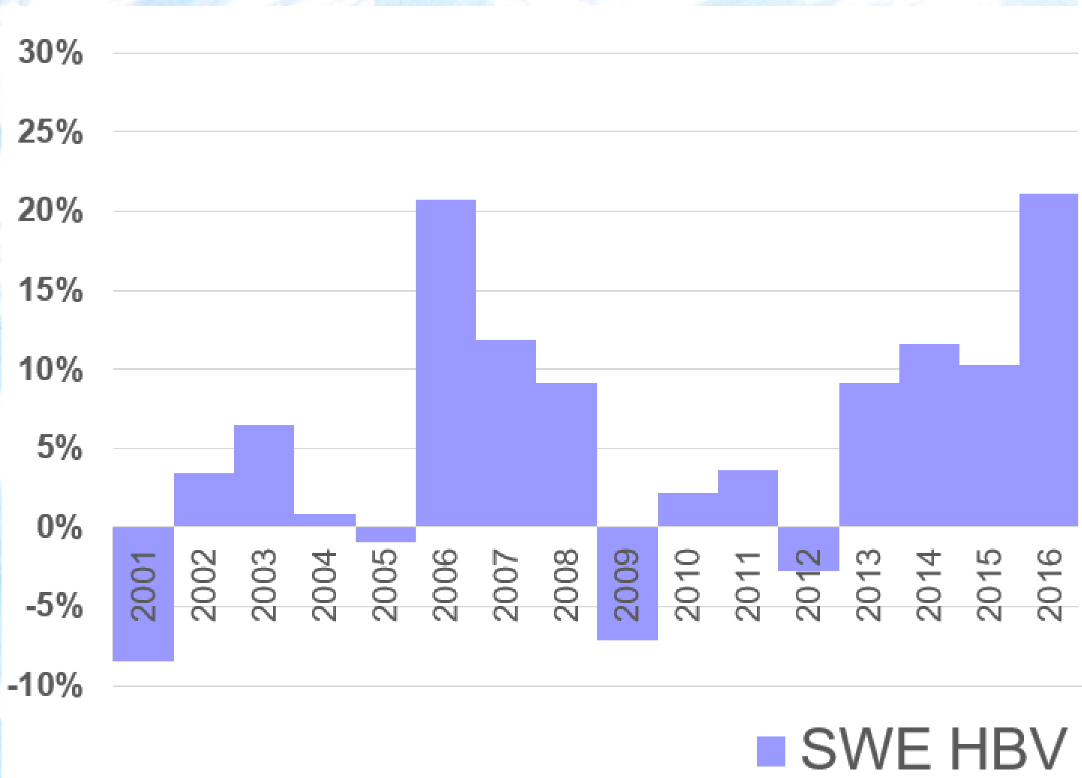
Jie Zhang, Rickard Pettersson, Veijo Pohjola *(presenter)*, Viktor Fagerström, **Uppsala universitet**

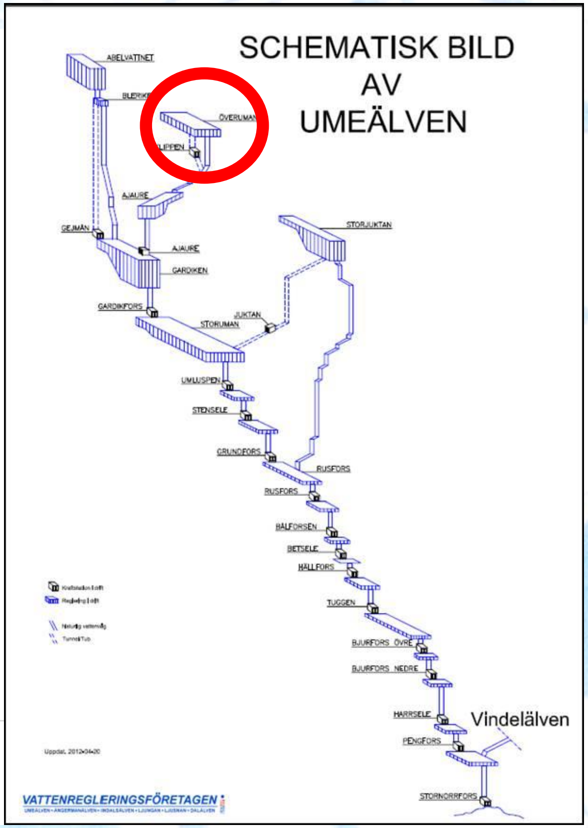
Industrial partner

Björn Norell, **Vattenregleringsföretagen**

Motivation

Errors in the estimation of SWE during the meltperiod in the Överuman catchment





Modeled routing vs measured routing into the Umfors dam. Positive values show an overestimation of the routing by the HBV model in prognostic mode as compared to the observed routing into the dam.

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Goals for SNODDAS (I)

To develop a method that better estimate the snow water storage to improve the spring flood prognostics for the hydro power industry.

Our aim is to **lower the uncertainty marginals below the 10% level** of the snow water volumes, and such improve prognostics of the spring time inflow of water in a hydro power dam.

We will deliver:

- A systematic method to **integrate and assimilate information from available satellite and ground bound measurements of snow/water into models delivering snow and spring flood prognostics.**

Goals for SNODDAS (II)

- To develop the method in a defined area adapted to the needs of the hydro power industry such as **the data can be used independent of method / model of preference**.

- **Widen the forum started among Nordic snow hydrologists** to enhance experience and knowledge to estimate the snow water equivalent, their distribution in the terrain and how discharge out from them can be properly simulated.

- **Our ambition is that the methods we produce should be applicable in industrial production**, such as they without intermediate steps can be used by the industry without expert consultation. The work to bring forward user friendly products is not a part of the present project, but is an option for the future if the present work reach its goals.

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SMHI Energimyndigheten

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Work Packages

WP 1: Ground truthing (field observations)

WP 2: Modelling spatial snow distribution (remote sensing and data assimilation)

WP 3: Hydrological modelling and forecasting (snow drift modelling, data assimilation, HYPE)

WP 4: Sustainability and cost assessment (value of improved snow data and forecasts)

WP 5: Dissemination

Ground Truthing:
The Överuman Catchment

Area 652 km^2

Elevation 524 – 1575 m ö h

Forest app. 31 % (birch)

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Ground Truthing: Field Observations

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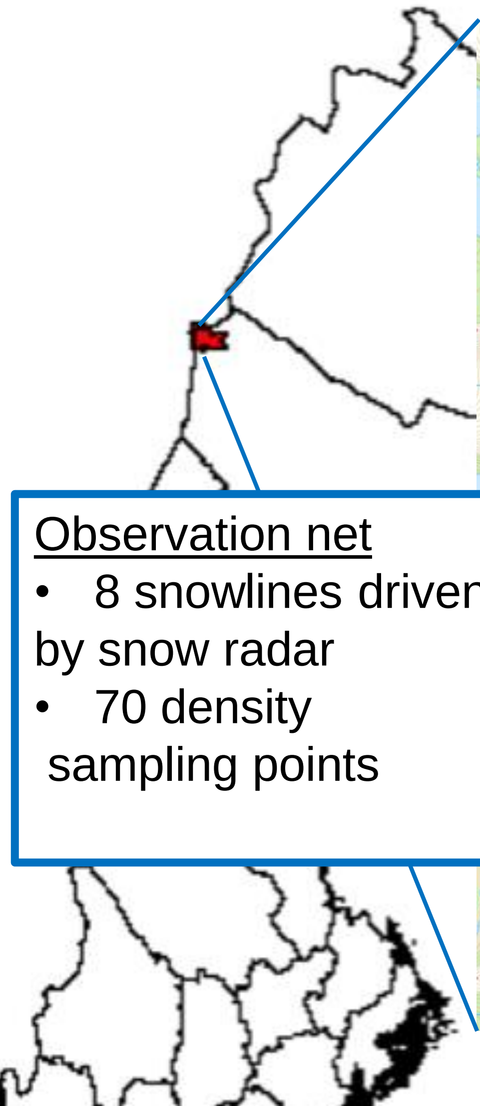
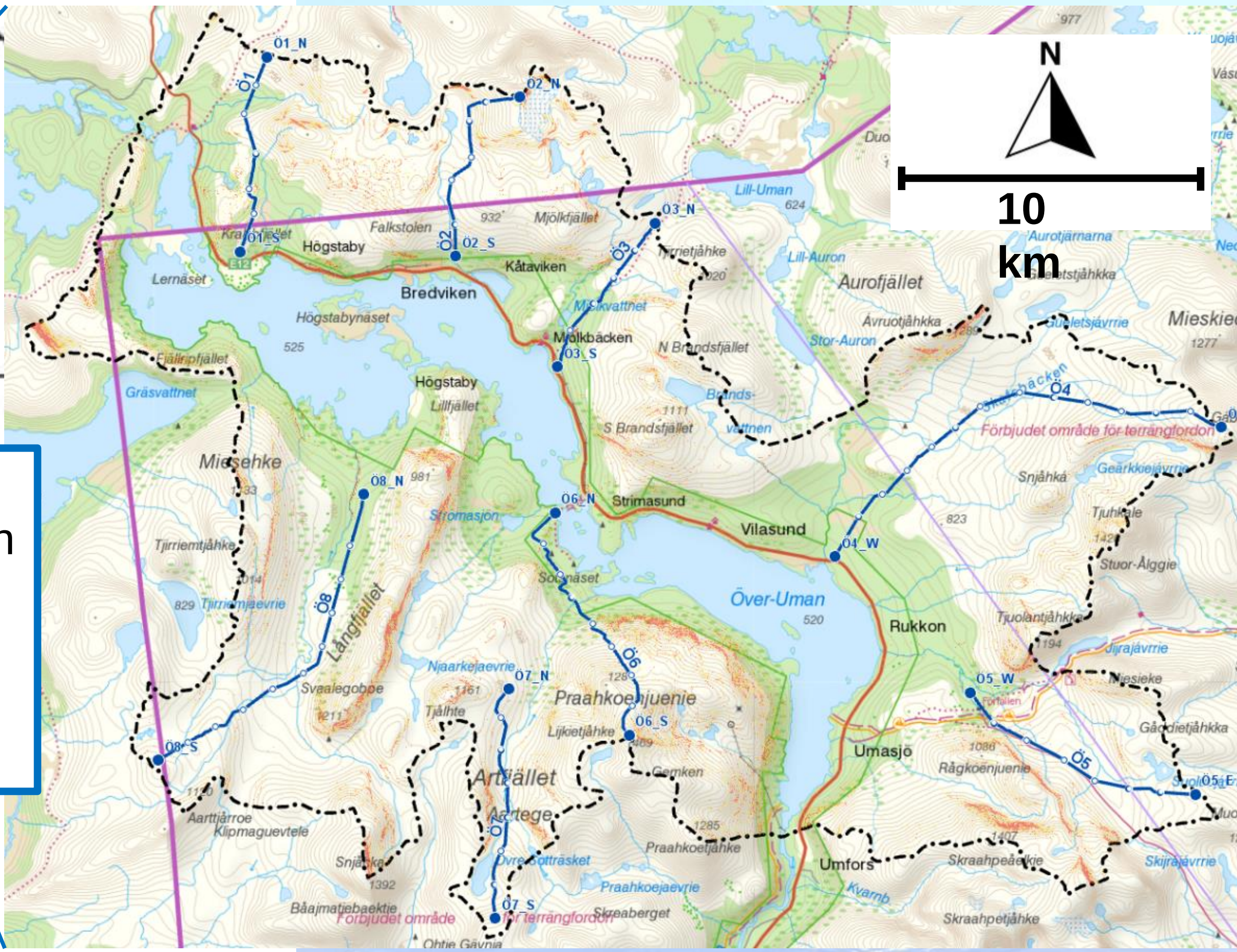
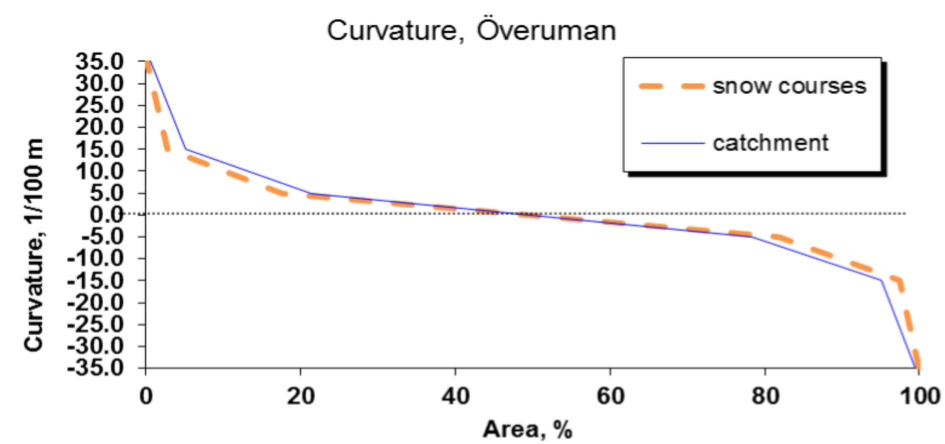


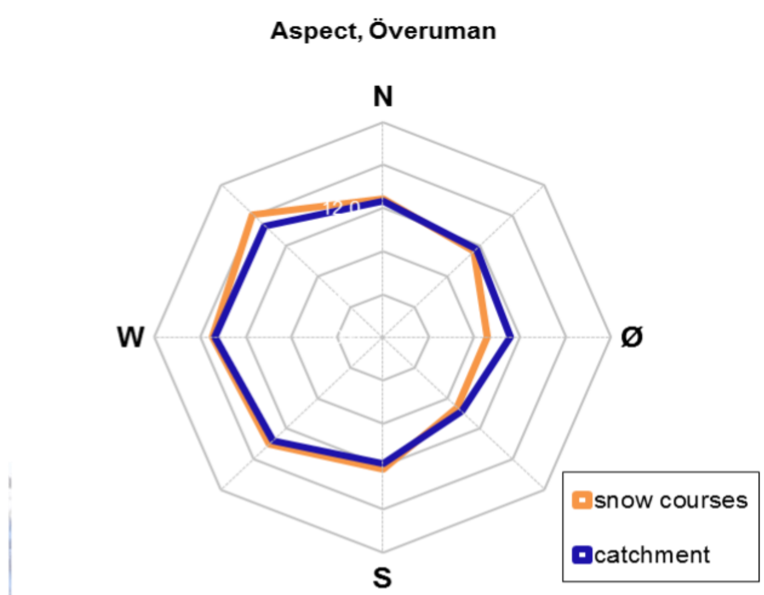


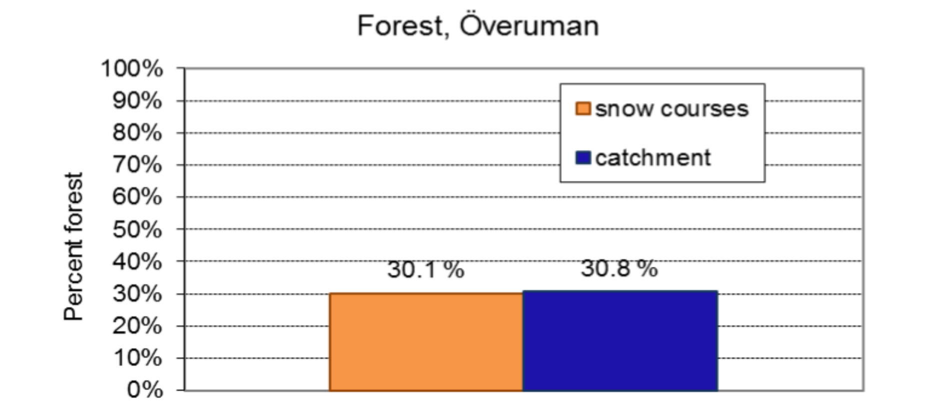
Observation net

- 8 snowlines driven by snow radar
- 70 density sampling points

Ground truthing: Representability of snow lines







Area 652 km^2

Elevation 524 – 1575 m ö h

Forest app. 31 % (birch)

Ground truthing: Field work

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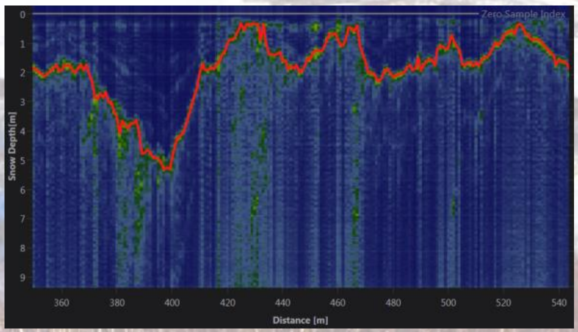
Probing for snow depth

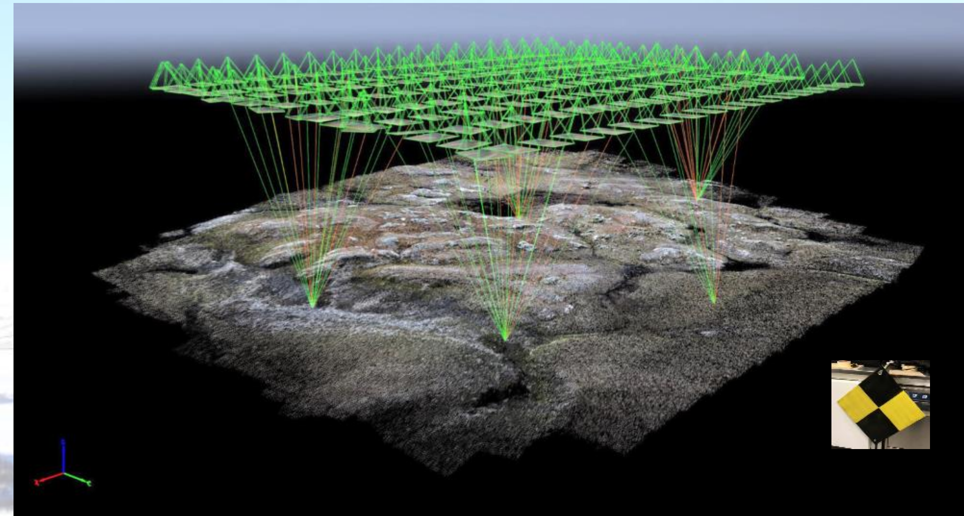
Snow density measurements



Continous snow radar observations

Remote sensing: using drones to estimate snow depths

DJI Matrice 210 V2



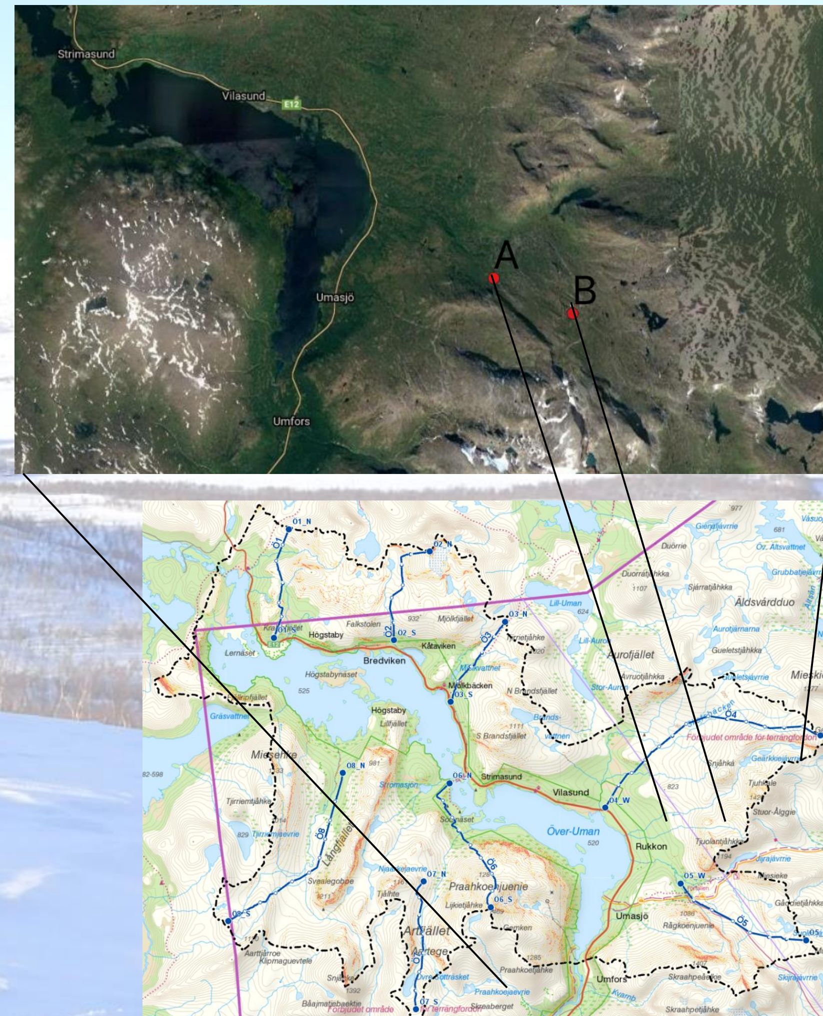
- Digital elevation models (DEM) from photographs captured with Unmanned Aerial Vehicles (UAVs/Drones) was tested to extend the snow depth data from the snow lines.
- This method provides high resolution (2cm/pixel) data over small to medium sized areas at relativley fast speed. Overlapping photographs was used to calculate a 3d point cloud model of a surface using the Pix4d software.

Study sites for drone operations 2020

We use two sites east of Umfors close to snowline 4.

Site A at 800 m a.s.l. in birch forest with generally lower snow depths and more variable terrain.

Site B at 950 m a.s.l. above the tree line, with higher snow depth and a more uniform flatter terrain.



Remote sensing: estimates of SWE using satellite data

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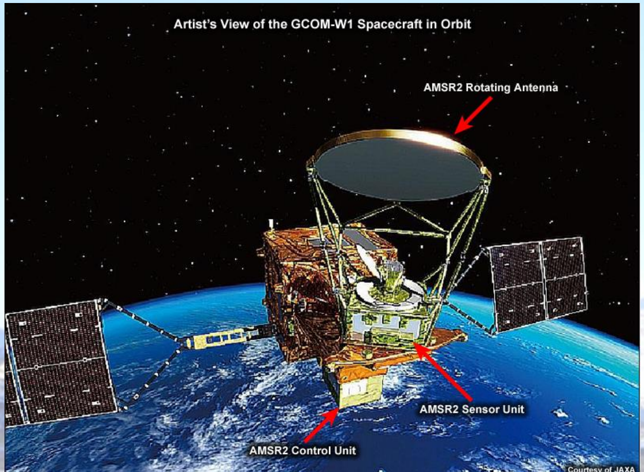
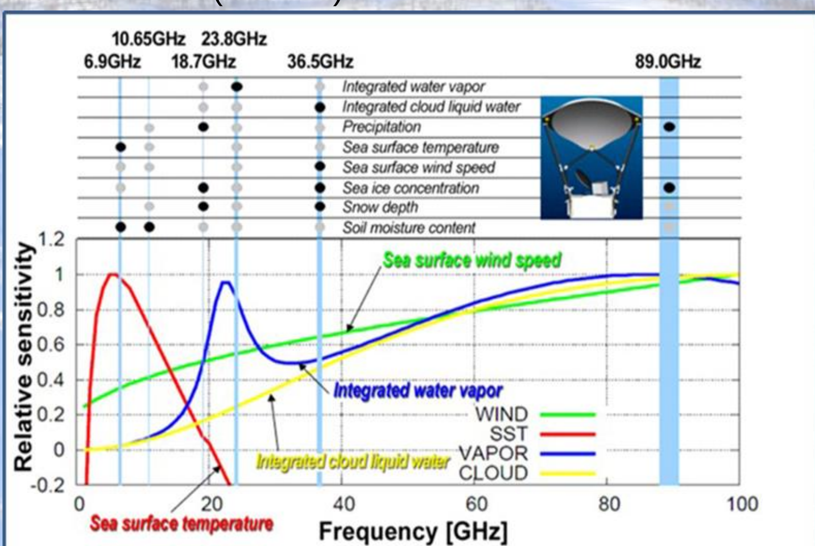
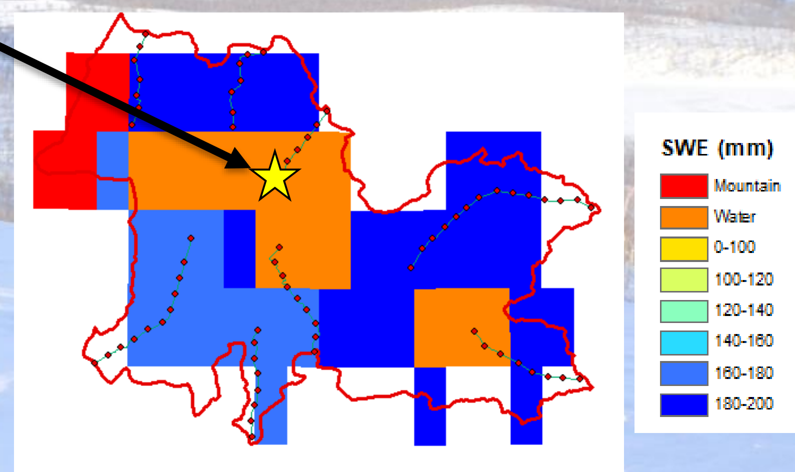


The Advanced Microwave Scanning Radiometer 2 (AMSR2)



The microwave emission from the planet is related to the water content in the atmospheric column, and in the ground, including snow packs.

We identify snow sensitive satellite signals by comparing AMSR2 brightness temperature at all frequencies with the snow depth from SMHI snow measurement station (Mjölkbäcken), and derive SWE distribution at improved accuracy and spatial resolution.



Passive microwave satellite images have a large footprint and each pixel covers several kilometers

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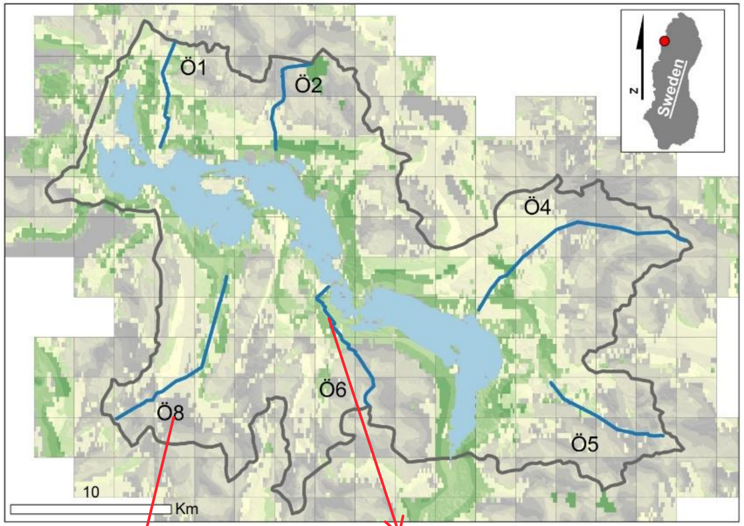
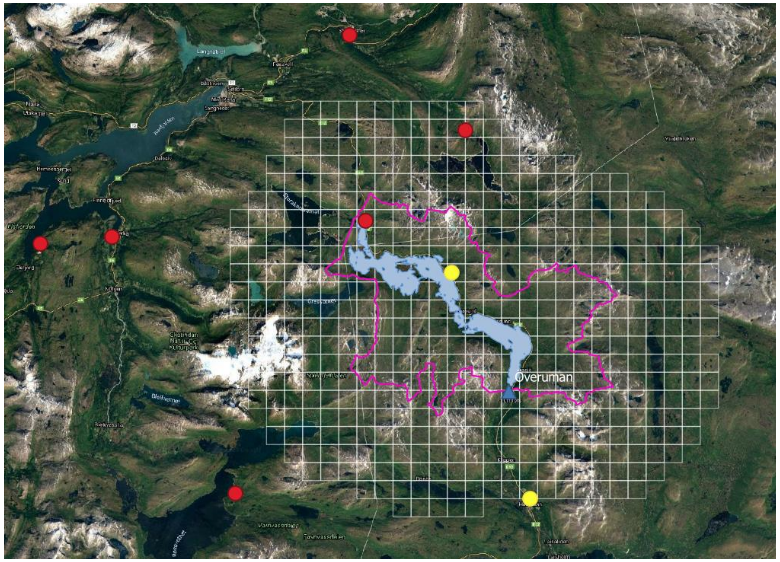
HYPE-gridded model för Lake Överuman:
>> 496 sub-basins á 2.5x2.5 km^2 (12.5 km buffer to utilize 25x25 km^2 EO data)

Model domain with VRF snow radar lines



open land
forest

Full model domain with
snow depth stations in Norway and Sweden



38 sub-classes within each sub-basin:

- water, open, shrubs, forest, glacier
- 3 elevation bands
- 3 aspect bands

Meteo input

- Precipitation (PTHBV, 4x4 km^2)
- Temp. winddir (MESAN-Arome, 2.5x2.5km^2)

Snowfall distribution model

1) Gridded PTHBV information interpolated to each model gridcell

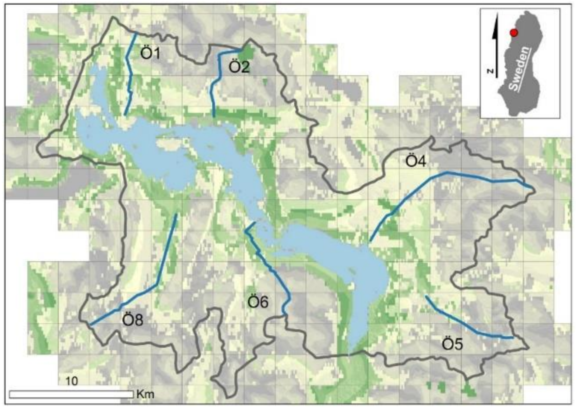
2) Mean snowfall S_{mean} in a gridcell is distributed between sub-classes based on wind direction and **Winstral** wind shelter index (*Clemenzi et al, in prep*):

$$\frac{S_{subclass}}{S_{mean}} = w_N \cdot 10^{(w_s \cdot WSF_{subclass})}$$

WSF = maximum slope (deg) within a relevant distance (~300m)

w_s = scaling parameter (related to veg.type?)

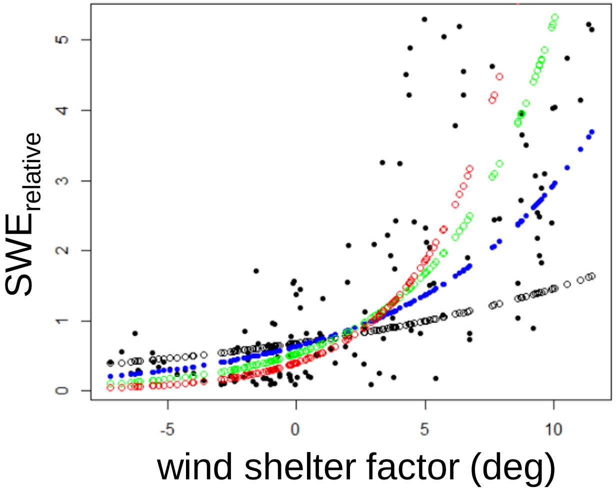
w_N = identified for each sub-basin to normalize sum of correction to 1



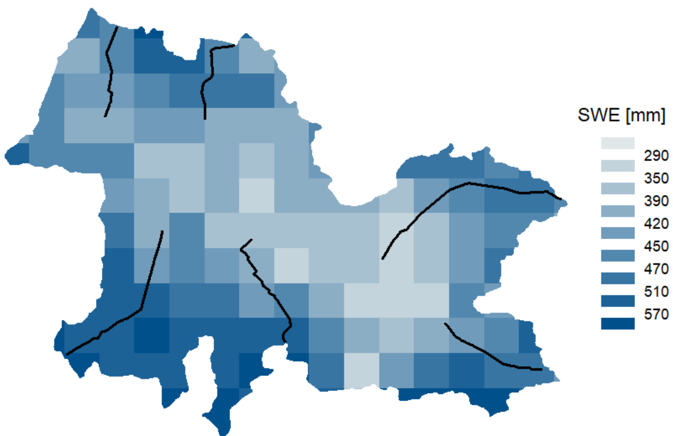
The **log-linear relationship** was identified from the GPR survey data!

Relative SWE from Ö6 vs WSF derived from Arctic-DEM (10x10m²):

w.scale = 0.05, 0.1, 0.15, 0.2



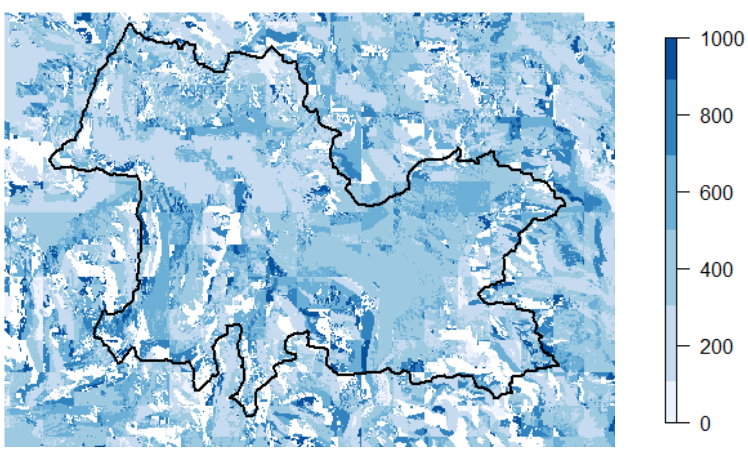
Simulated SWE after calibration versus reservoir inflow data



SWE at GPR survey date 2019-03-28

SNODDAS-HYPE mean sub-basin SWE at 2.5x2.5 km^2 resolution

SWE_{mean} ~ meteo input distribution

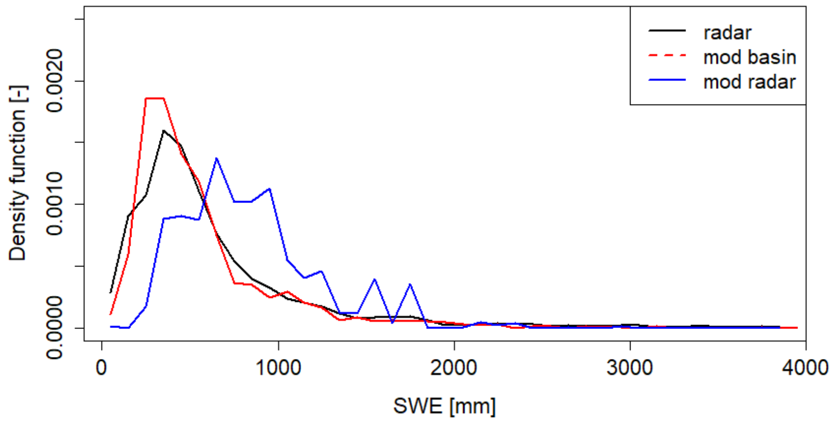


SWE from 38 model sub-classes mapped to the original 25x25 m^2 land use and elevation raster

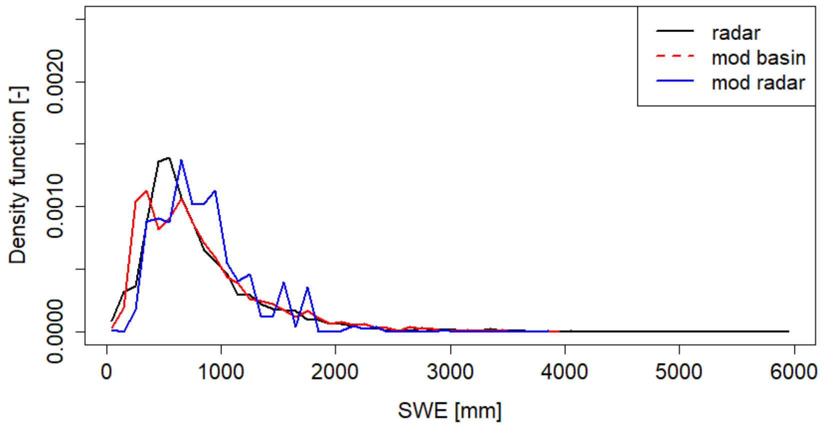
$SWE_{[x,y]}$ ~ meteo input + wind distribution

Simulated snow distribution vs GPR surveys

2019



2020



Results:
Simulated SWE distribution sampled over the full Överuman catchment (**red line**) agrees quite well with the GPR survey data (**black line**) – actually better than the simulated SWE when sampled along the radarlines (blue lines)!

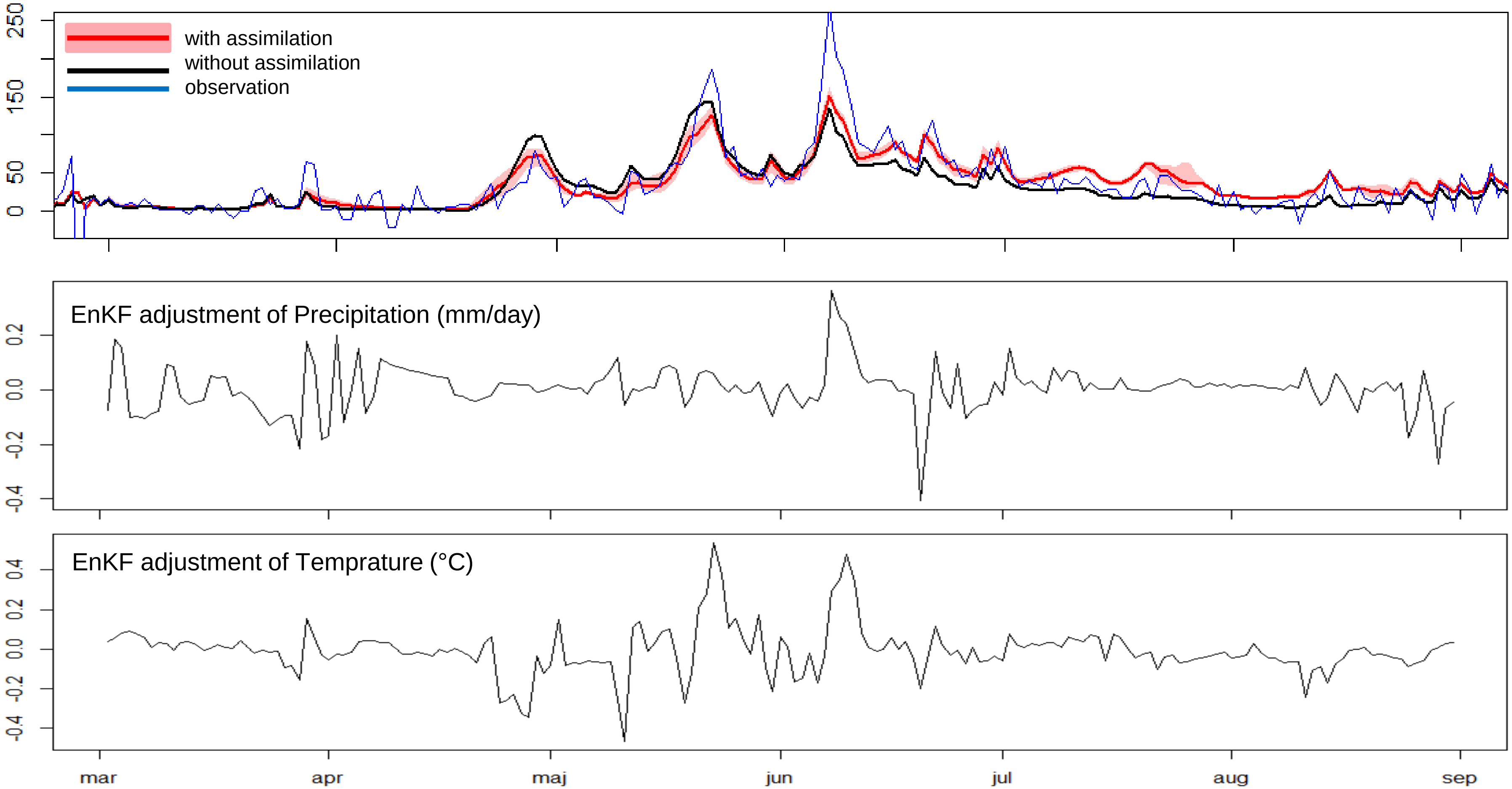
Note:
GPR data were not used for calibration in this results. Not all lines were observed in 2019!

Conclusions:

- SWE distribution obtained by calibrating with inflow data generated distribution similar to what the GPR lines represent
- Inflow data provide valuable information about snow and snow melt distribution (*ref. back to initial results from Björn Norell*)
- GPR lines seems to be in good locations

Data assimilation with EnKF

Example: assimilation of inflow observations with EnKF – and corresponding automatic adjustment of precipitation and temperature

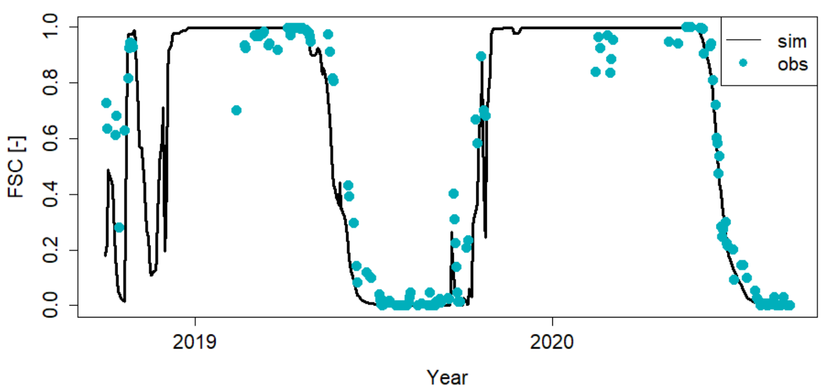


SMHI

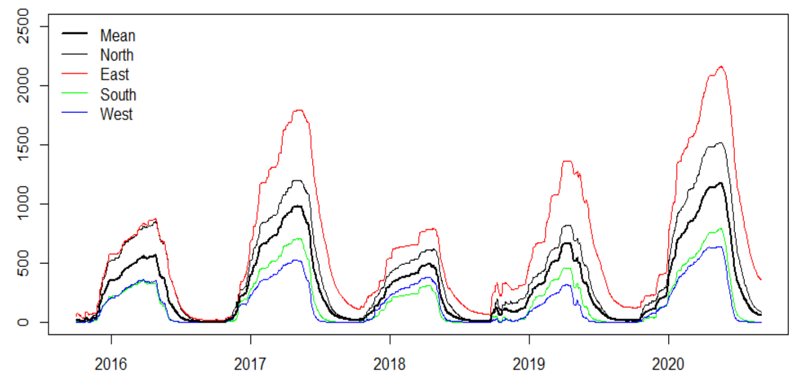
Data assimilation and forecast evaluation

GPR + satellite based FSC and SWE data (from SNODDAS and other projects) and inflow observations to be assimilated in re-analysis and forecast evaluation!

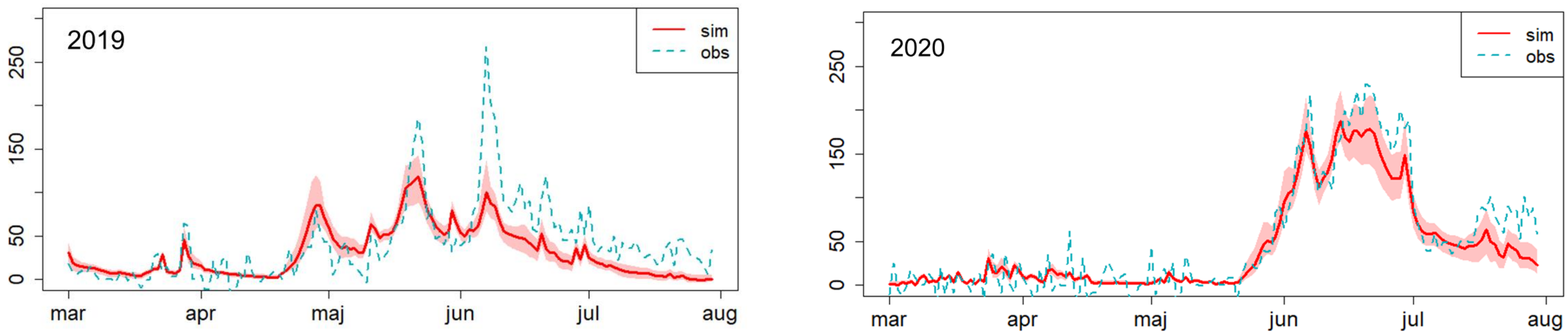
FSC from cryoland.eu



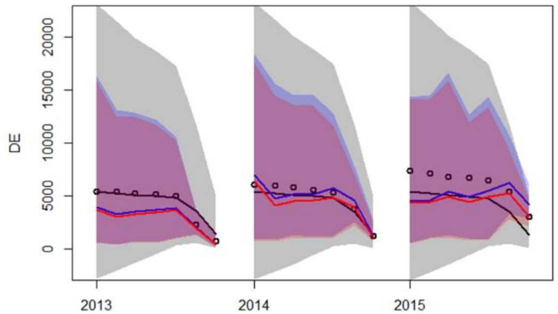
Simulated SWE by aspect-class



Simulated and observed reservoir inflow Överuman 2019-2020



To be updated > forecast evaluation



From previous projects: assimilation of inflow and satellite FSC data improves seasonal inflow forecast compared to climatological benchmark, but mainly during later part of snow melt season (June-July)

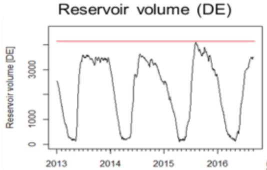
Economical model for forecast evaluation

1. Production volume = (inflow_forecast – reservoir_demand) (until_31July)
2. Production **value** = Production volume * MWh/volume * MSEK/MWh
3. Forecase gain = |value(obs) – value(benchmark)| - |value(obs) - value(forecast)|

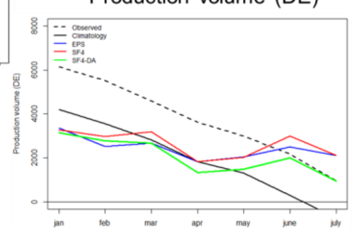
maximum possible gain from bechmark

remaining gain from forecast to max

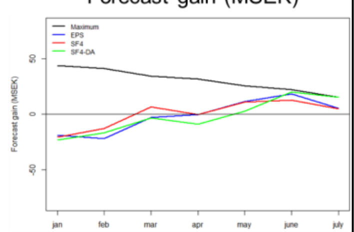
Reservoir volume (DE)



Production volume (DE)



Forecast gain (MSEK)



Seasonal forecasts (Överuman) from 1st month to 31st July

Framework for economical forecast evaluation will be used to assess the potential of new snow products and assimilation methods to improve economical gain while introducing more regulation constraints to meet sustainability requirements.

Conclusion and outlook Hydrological modeling

- Distributed snow model including wind driven distribution of snowfall have been developed within the hydrological model HYPE using the GPR survey snow observations from Överuman

- Calibration with inflow data alone already provided an improved representation of the snow distribution (calibration with the snow data still to be completed/improved)

- Assimilation with EnKF is a practical and efficient method for integrating information from different types of observation in forecast model initialization and analysis of current snow conditions

- Outlook for 2021:
    - Assimilation and Forecast evaluation using the new snow data from the SNODDAS project

General conclusions

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1. We have four years of SWE snowline data distributed over the Överuman catchment which greatly improves the estimate of the total SWE, and such reduces uncertainties and errors when calcultaing the routing of meltwater pulses into the Umfors hydropower dam using HBV in operational mode. The manual observation is an important benchmark for the following parts of our study.
2. We find we can use remotely sensed data from drones and satellites to extrapolate the distribution of SWE in the catchment. By using machine learning techniques we further improve the distribution and the prediction capability.
3. We find that assimilation of snow and inflow observations improve inflow forecasts into the HYPE routing model.
4. We have developed a simple model to assess the economical value of an improved inflow forecasts.
5. Dissemination is important.