Assimilation of snow data for modeling snow distribution in forested and non-forested areas of Sweden

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Snow-Ice-Atmosphere interactions

Background – ongoing work

- Snow-vegetation interaction studies
  Manfred Stähli, Tobias Jonas (Switzerland)
  Sirpa Rasmus (University Helsinki)

- MERGE - ModElling the Regional and Global Earth system

  Terrestrial biosphere as a critical climate system component
  Data and model uncertainty issues

  Lund University, University of Gothenburg, Rossby Centre/SMHI, University of Kalmar/Linnaeus University, Chalmers University of Technology and Royal Institute of Technology

- Assimilation of snow data in hydrological forecasting for hydropower regulation
  - Royal Institute of Technology, Luleå Technical University and SMHI

Topic for this presentation

- 1) Radiation transmission models in snow covered canopy:
  Impact on land surface heat exchange

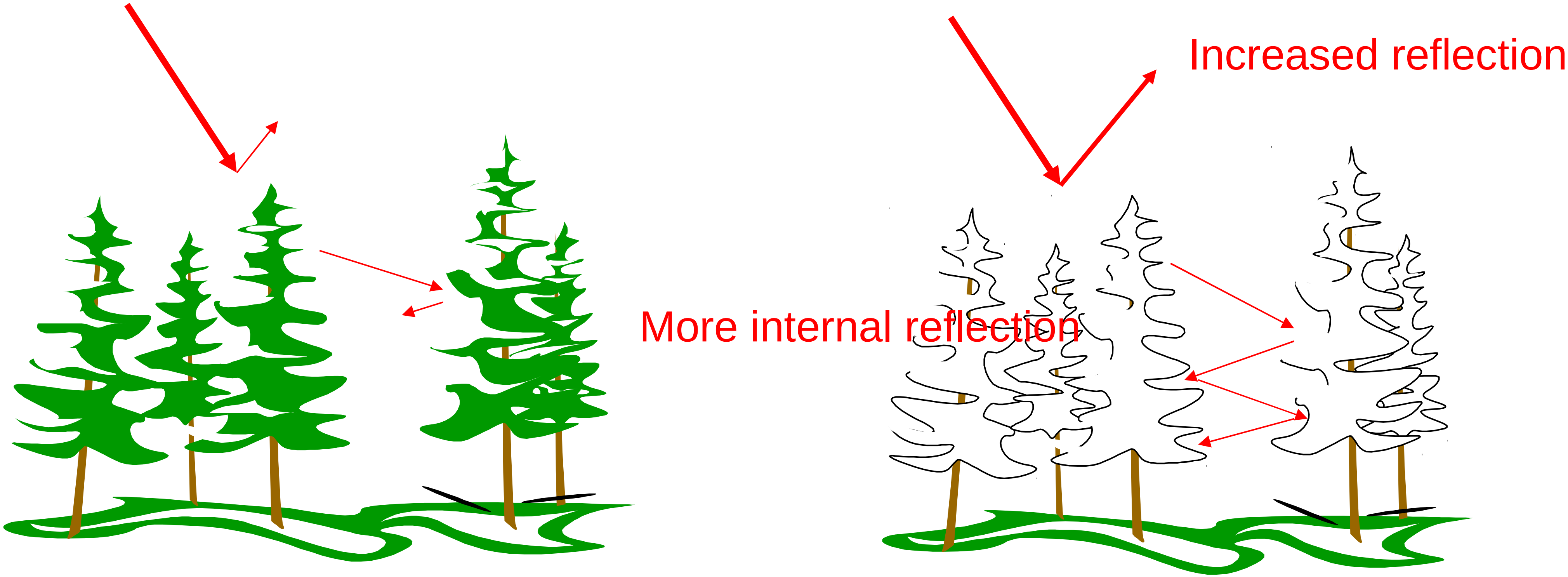
- 2) Snow data assimilation in hydrological modelling

Canopy radiation balance
Alptal, central Switzerland

Moving net-radiometer on a 10 meter long rack below the canopy

Stähli, Jonas and Gustafsson, 2009, Hydr Proc, DOI: 10.1002/hyp.7180

Effects of snow interception on radiation transmission in forest canopies?



Transmissivity?

$$\tau_{canopy} = \frac{S_{\downarrow, below}}{S_{\downarrow, above}}$$

Canopy transmission models

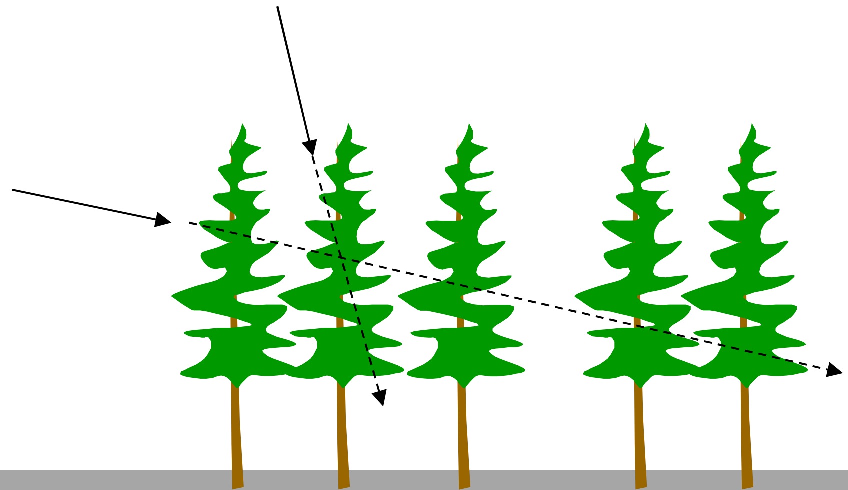
$$\sigma_f = 1 - e^{-k_{LAI} LAI}$$

Beer's law f(LAI=leaf area index)

$$\sigma_{f,dir} = 1 - e^{-k_{LAI} LAI / \sin(\Omega)}$$

Direct radiation = f (solar elevation Ω)

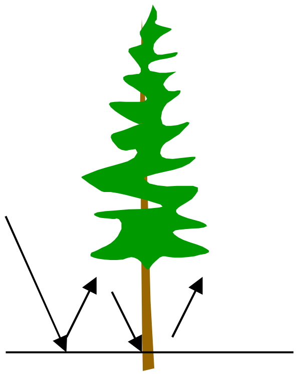
Chen et al (1997)



Sparse forest effetcs:
Gryning et al, BLM 2001 (Sodankylä)

(Stähli et al, 2009, Hydr Proc, DOI: 10.1002/hyp.71

Multiple reflections between snow and canopy



$$S_{net,canopy} = S_{\downarrow,above} - \sigma_f \alpha_{canopy} S_{\downarrow,above} - \left(1-\sigma_f\right) S_{\downarrow,above}$$

$$+\sum_{n=1}^{\infty} \left(\alpha_{floor}\right)^n \left(\sigma_f \alpha_{canopy}\right)^{n-1} \left(1-\sigma_f\right) S_{\downarrow,above}$$

$$-\sum_{n=1}^{\infty} \left(\alpha_{floor}\right)^n \left(\sigma_f \alpha_{canopy}\right)^{n} \left(1-\sigma_f\right) S_{\downarrow,above}$$

$$-\sum_{n=1}^{\infty} \left(\alpha_{floor}\right)^n \left(\sigma_f \alpha_{canopy}\right)^{n-1} \left(1-\sigma_f\right)^2 S_{\downarrow,above}$$

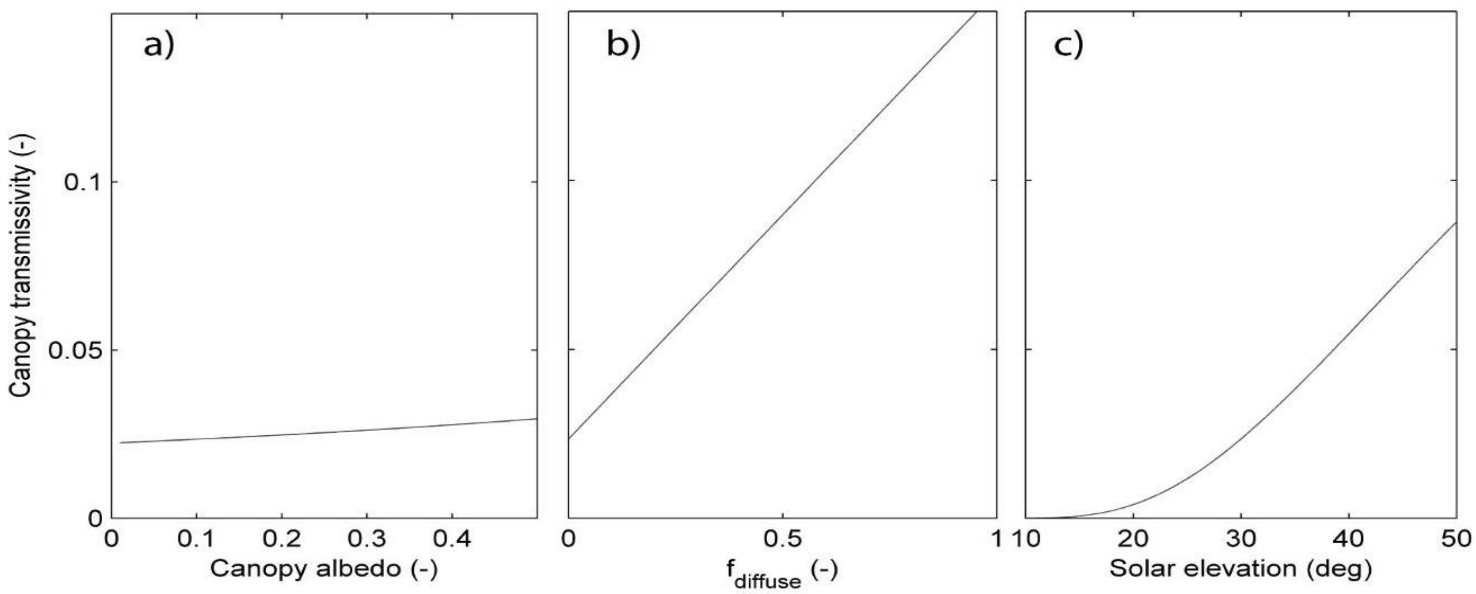
$$S_{net,canopy} = S_{\downarrow,above} \left(1-\alpha_{canopy}\right) \sigma_f \left(1 + \frac{\alpha_{canopy}\left(1-\sigma_f\right)}{1-\sigma_f \alpha_{floor} \alpha_{canopy}}\right)$$

Taconet et al (1986)

(Stähli et al, 2009, Hydr Proc, DOI: 10.1002/hyp.718

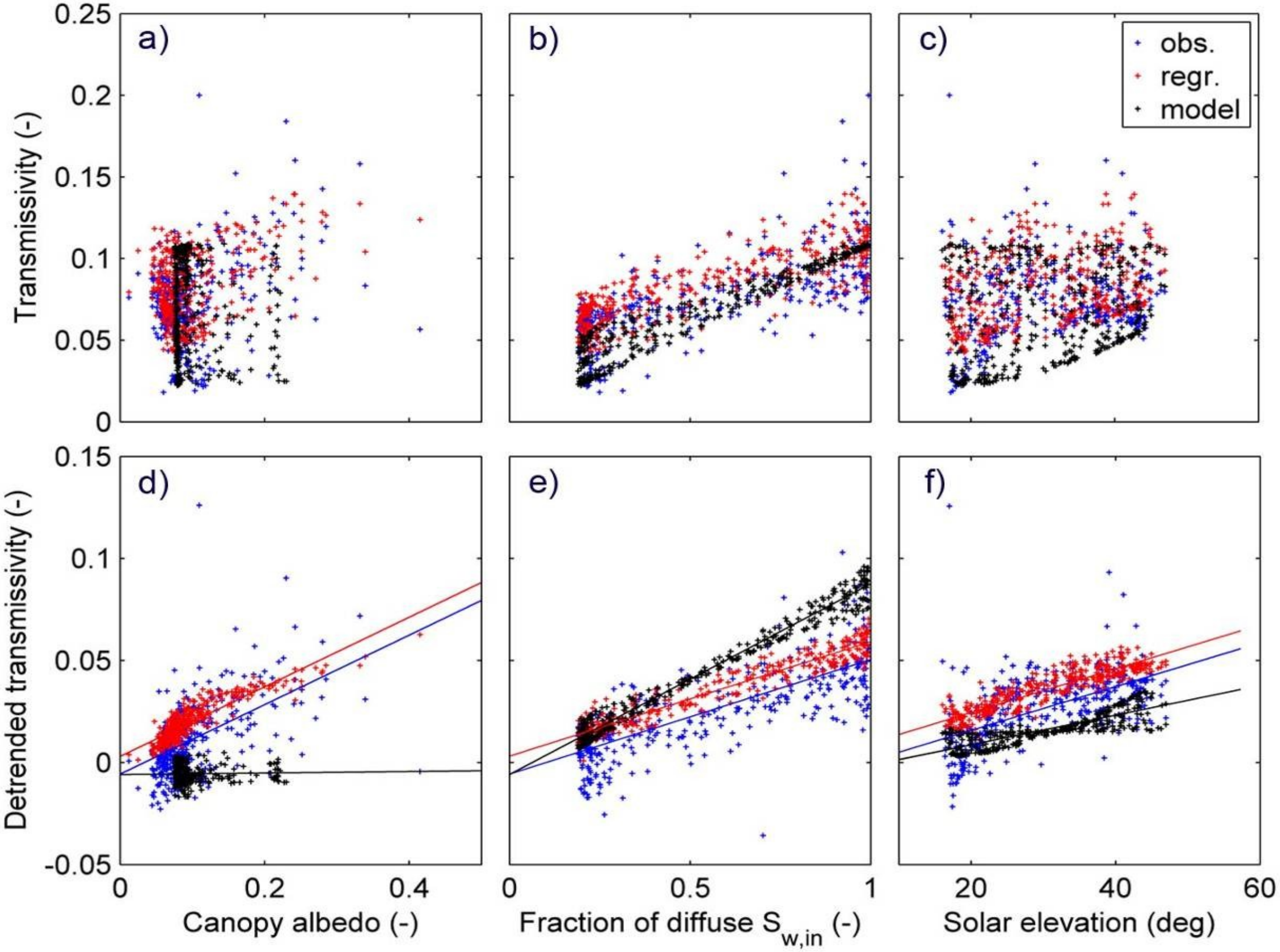
Canopy transmissivity model

$$\tau_{canopy} = f_{direct} \frac{\left(1-\sigma_{f,direct}\right)}{1-\sigma_{f,direct}\,\alpha_{floor}\,\alpha_{canopy}} + \left(1-f_{direct}\right) \frac{\left(1-\sigma_{f,diffuse}\right)}{1-\sigma_{f,diffuse}\,\alpha_{floor}\,\alpha_{canopy}}$$



(Stähli et al, 2009, Hydr Proc, DOI: 10.1002/hyp.7180)

Canopy transmission data, Alptal, Switzerland



(Stähli et al, 2009, Hydr Proc, DOI: 10.1002/hyp.7180)

Implications?

$$\sigma_{f,dir} = 1 - e^{-k_{LAI} LAI/\sin(\Omega)}$$

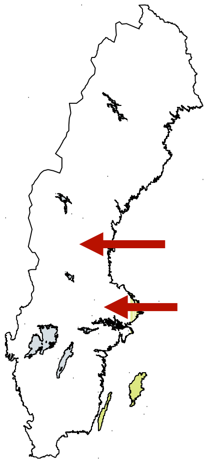
Fraction of radiation absorbed in canopy:

- increased at low solar elevation
- decreased at high diffuse fraction

$$S_{net,canopy} = S_{\downarrow,above}\left(1-\alpha_{canopy}\right)\sigma_f\left(1+\frac{\alpha_{canopy}\left(1-\sigma_f\right)}{1-\sigma_f\alpha_{floor}\alpha_{canopy}}\right)$$

- decreased due to snow interception and multiple reflections

Impact on snow model simulations?



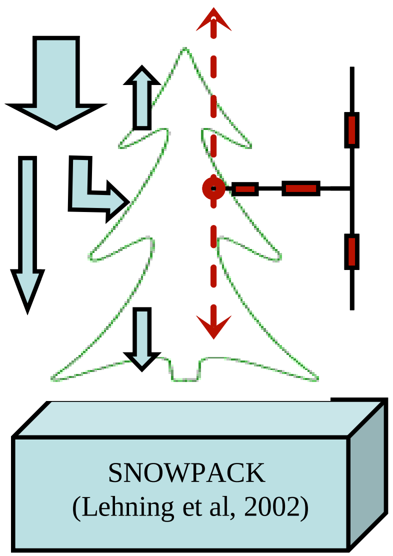
- Data from forest sites in Sweden, Finland, Switzerland

  (on-going work with Sirpa Rasmus, Univ Helsinki)

- Examples:

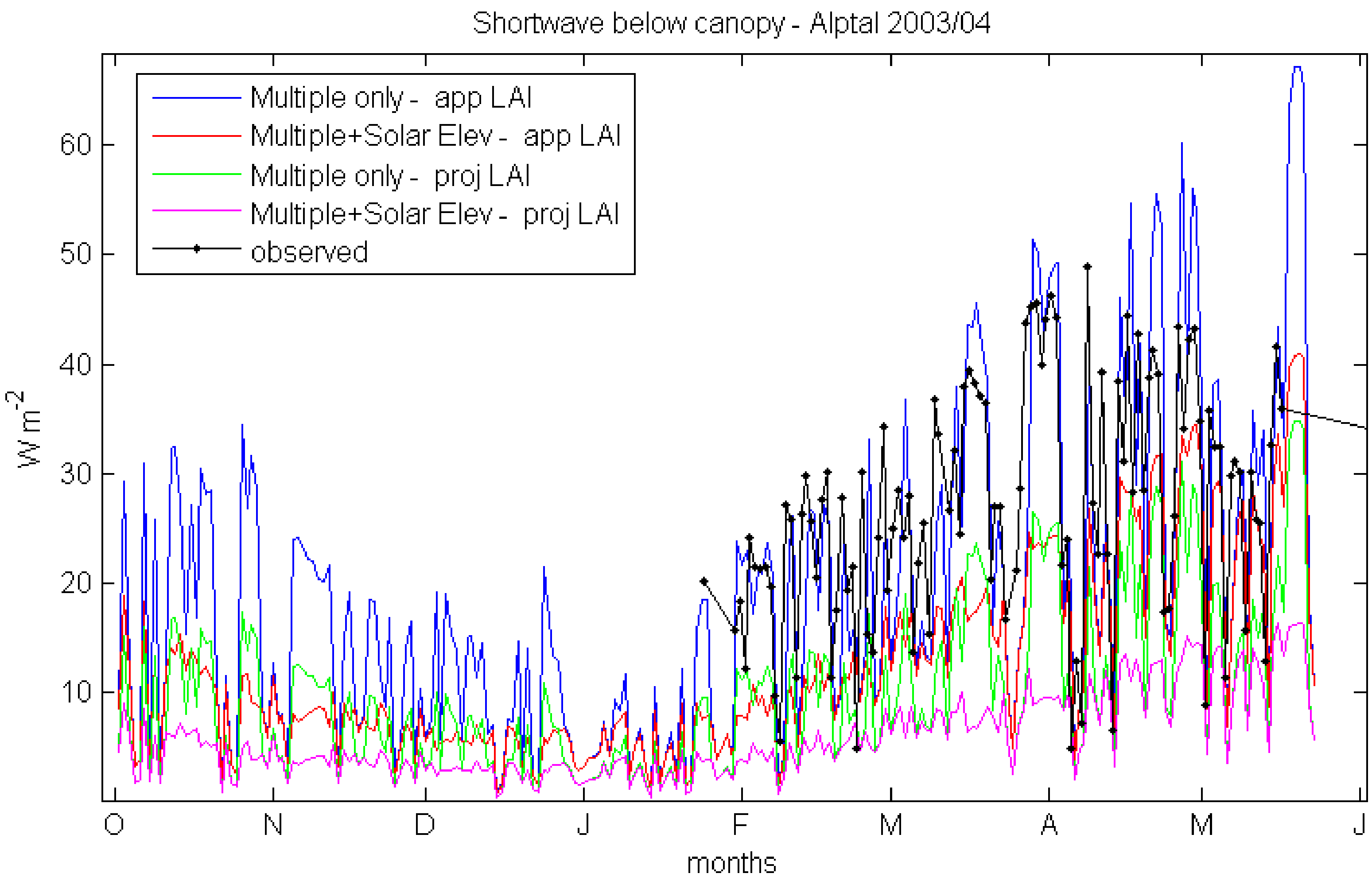
  Knottåsen (Lustra-project) . Projected LAI ~3.5

  Alptal, Swiss SnowMIP2 site

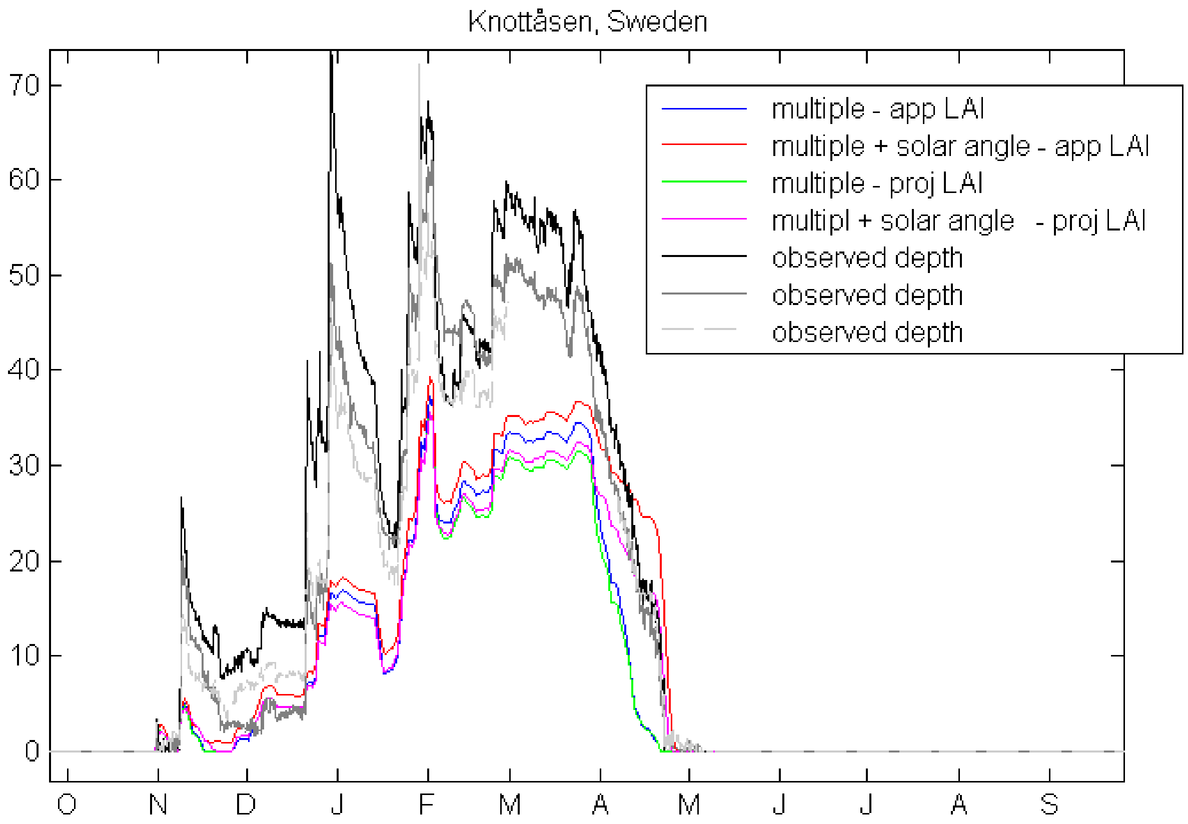


- SNOWPACK with energybalance canopy model (Lehning et al, 2006 Stähli et al, 2009)

Shortwave below canopy

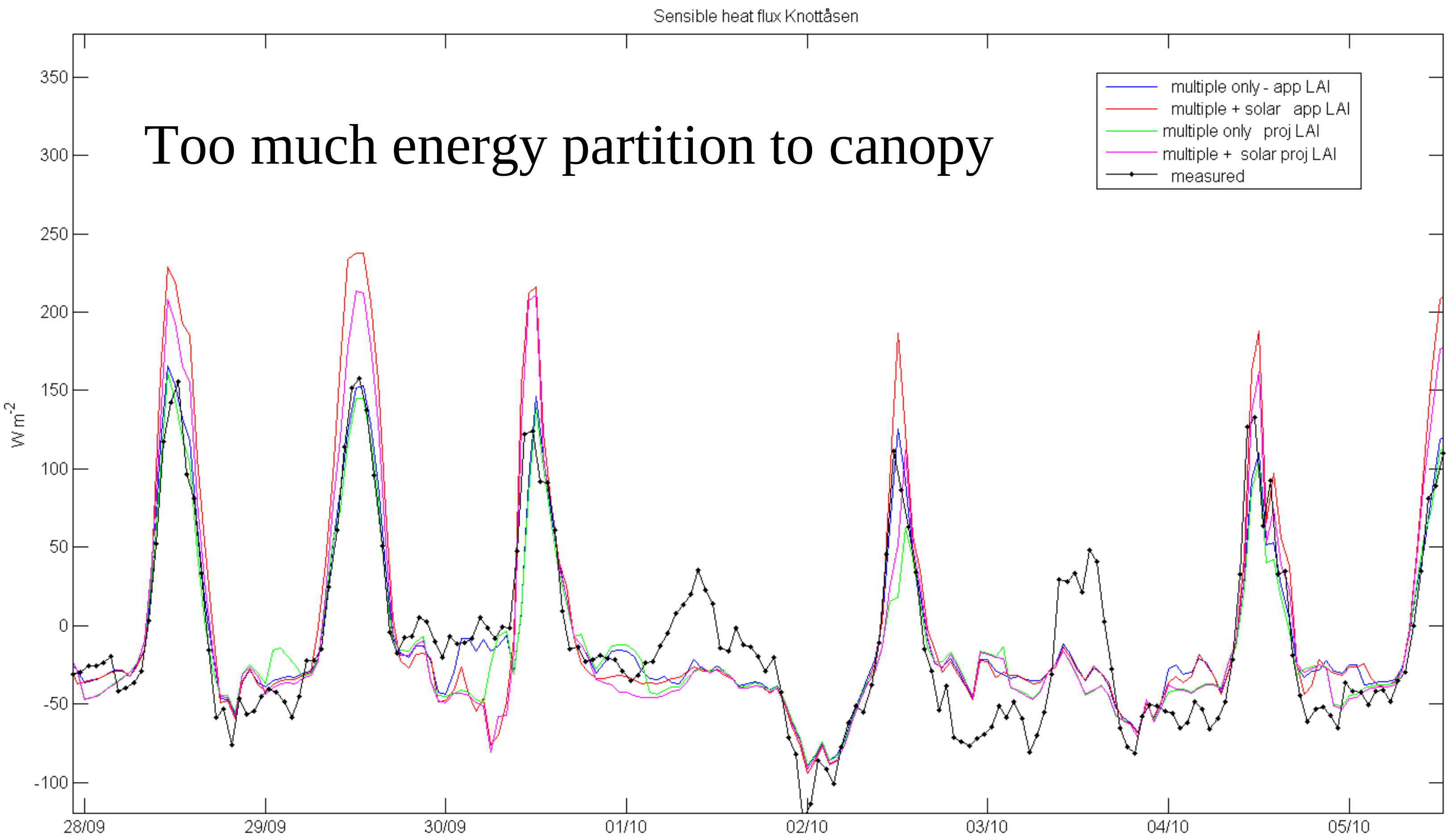


Impact on snow simulation



Delayed snow melt with the solar elevation function

Impact on sensible heat flux

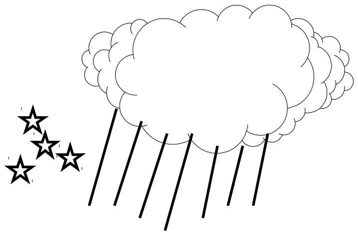


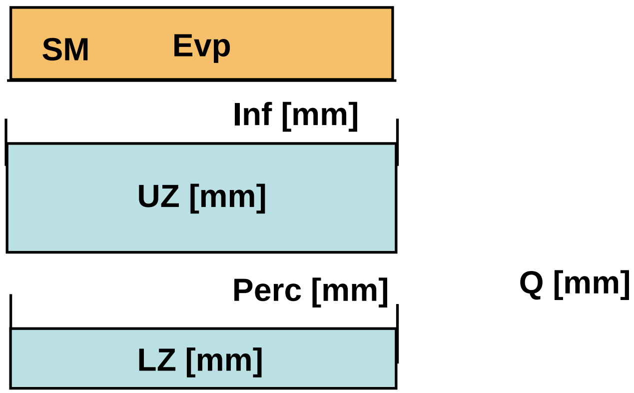
Preliminar conclusions

- Solar elevation function seems to reduce radiation transmission too much
- Delayed snow melt
- Too much energy into the canopy
- Also assess sensitivity of multiple reflection algorithm
- Evaluate impact of solar elevation function in sparse forest at high latitudes (cf. Gryning et al, 2001, Sodankylä)


Snow hydrology
Runoff forecasts
Data assimilation

Why do we not always get better runoff forecasts with more snow data?





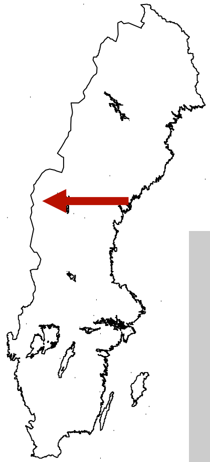
Numerous attempts in Sweden over the years.
Time to learn from Finland!

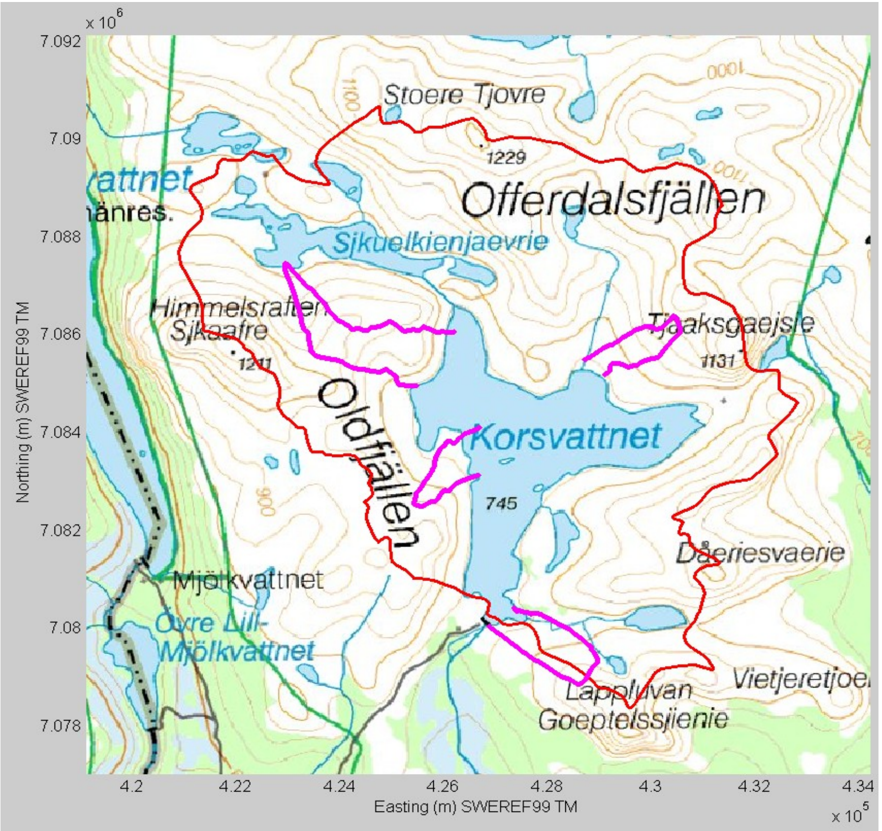
Factors for successful snow data assimilation?

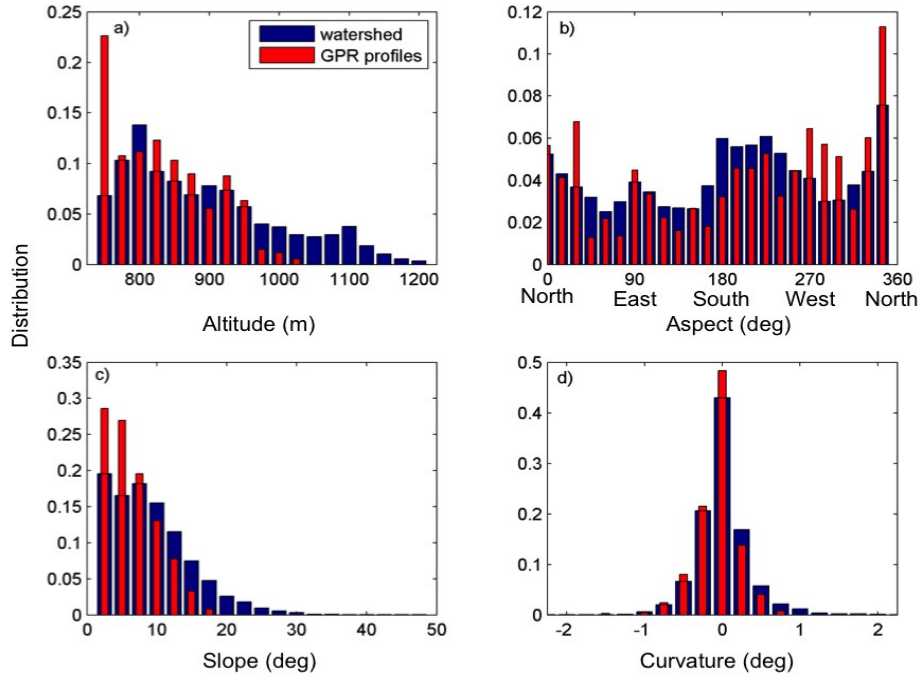
- Spatial and temporal resolution of model and data?
- Representation of processes?
- Methods for assimilation of snow cover data in hydrological model?
- Assumption on error variances

(Gustafsson et al, 2009, ELFORSK 09-84: KTH, LTU, SMHI, SVC, ELFORSK/HUVA)

Snow surveys using ground-penetrating radar





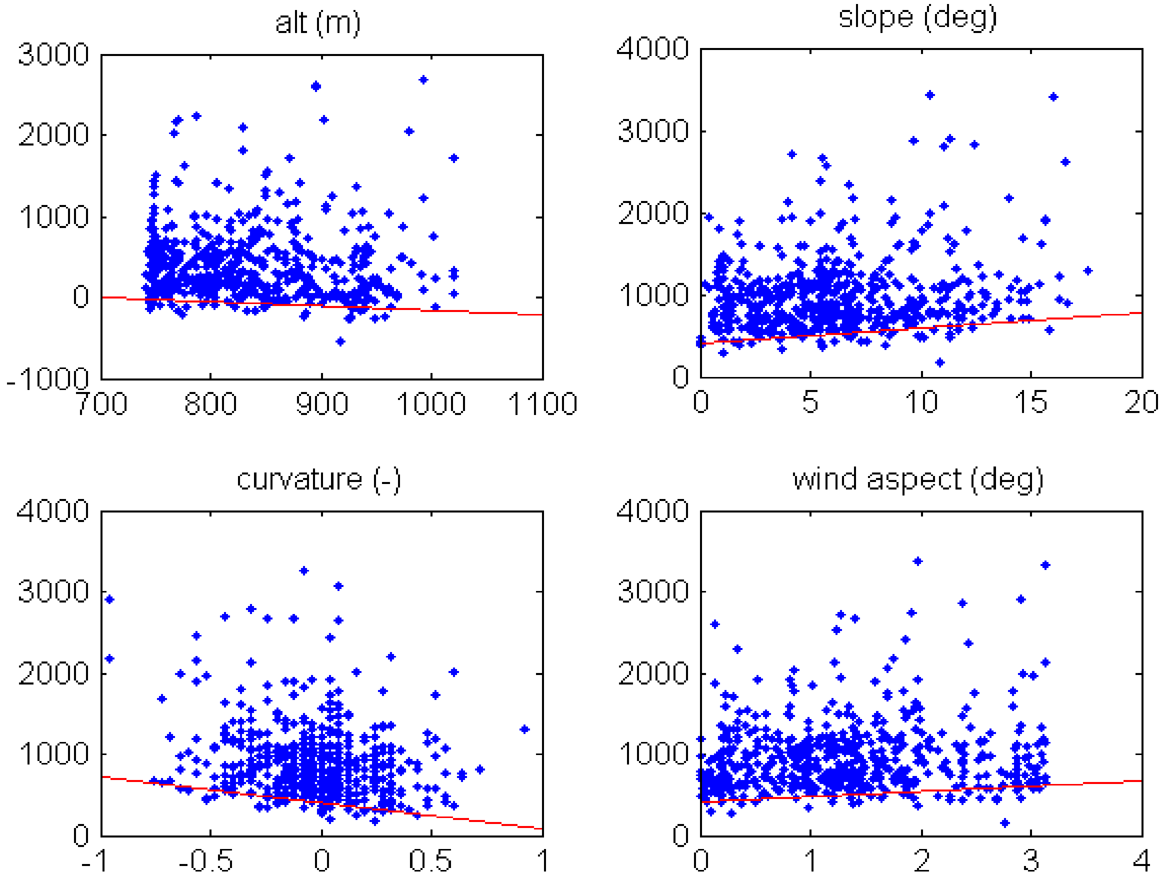


GPR snow survey Watershed boundary

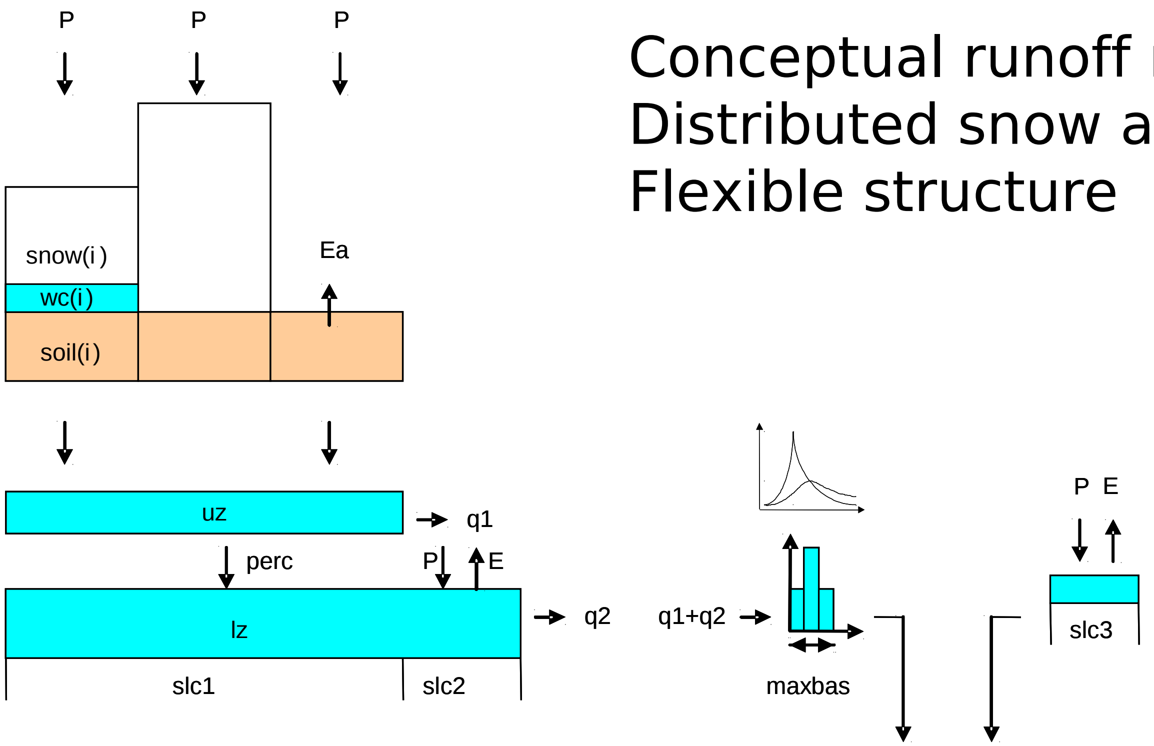
(Gustafsson et al, 2009, ELFORSK 09-

Snowfall distribution function:

$$P_{x,y}=P_{obs}\left(p_0+p_{alt}\left(z_{x,y}-z_{obs}\right)+p_{curv}C_{x,y}+p_{slope}S_{x,y}+p_{wind}\left|A_{x,y}-u_{dir}\right|\right)$$

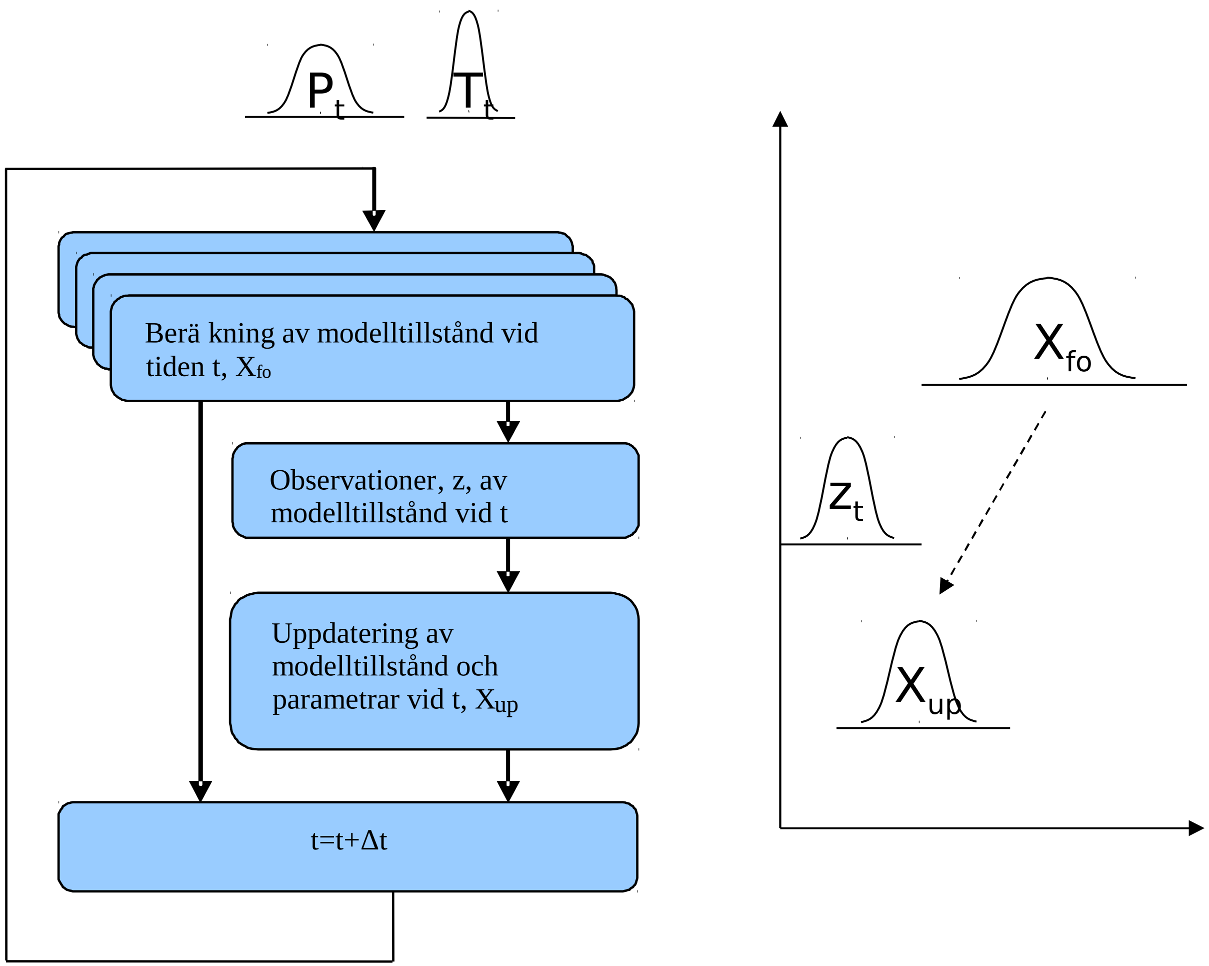


Distributed snow hydrological model



Conceptual runoff model
Distributed snow and soil model
Flexible structure

Data assimilation
Ensemble Kalman filter

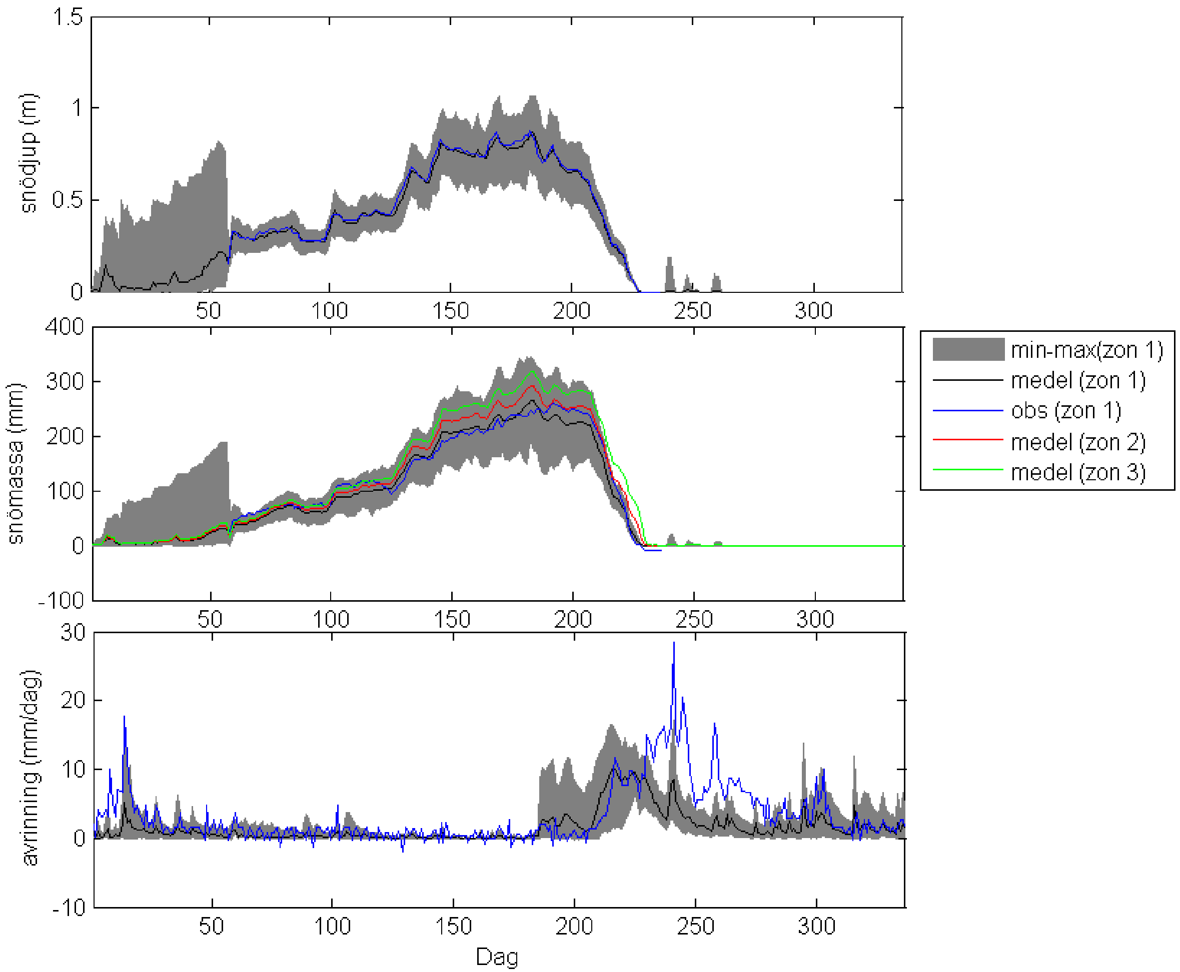


$$K = \frac{\operatorname{cov} X_{fo}}{\operatorname{cov} X_{fo} + \operatorname{cov} Z_t}$$

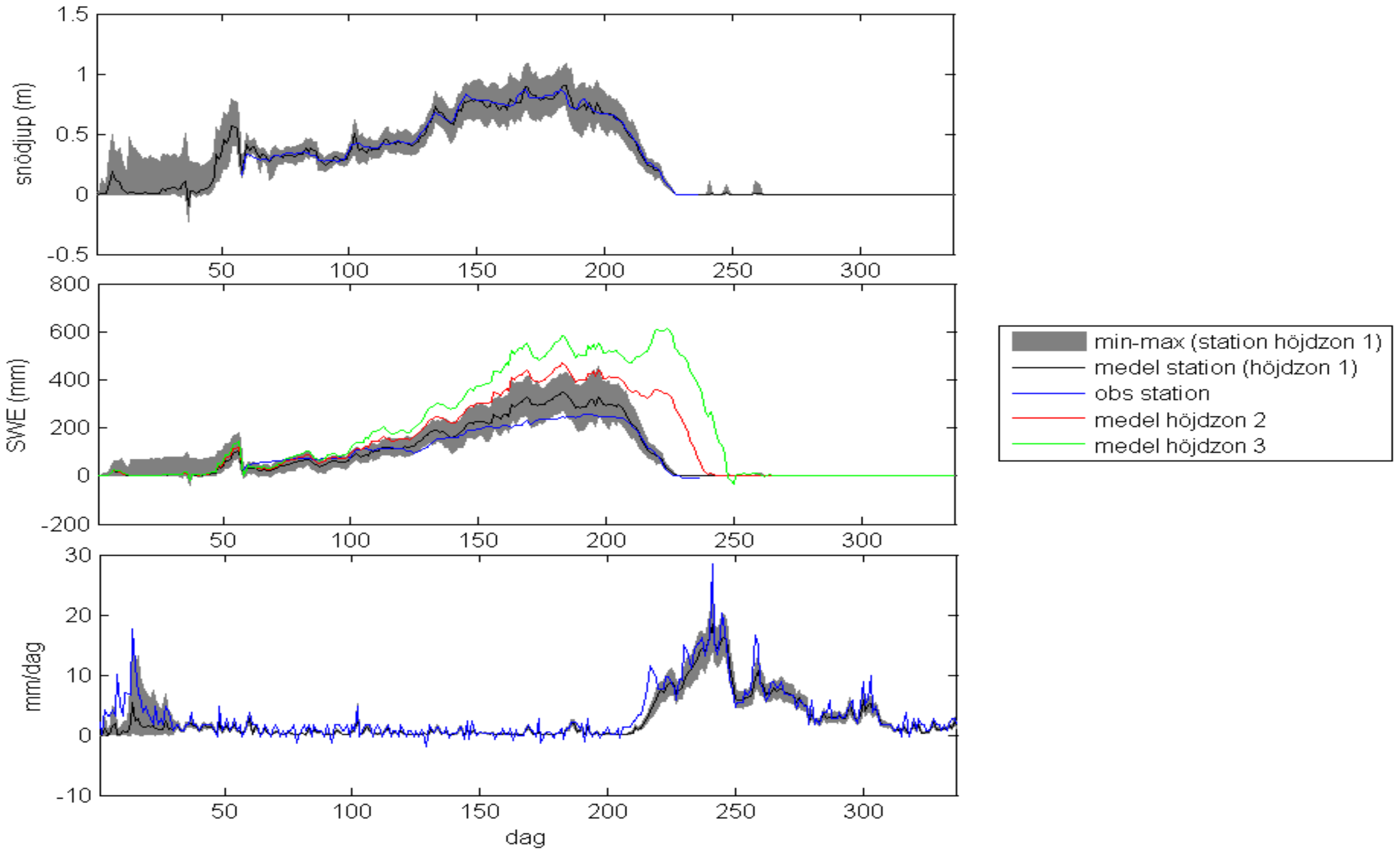
$$X_{up} = X_{fo} + K(Z_t - X_{fo})$$

(Gustafsson et al, 2009; Ahlberg & Gustafsson, 2010, in pre

Assimilation of snow in one point



Assimilation of runoff data



Conclusions

- Representation of Snow distribution in DATA and in MODELS necessary to further improve snow melt runoff predictions
- Ensemble Kalman filter useful method to assimilate Snow data and acknowledge uncertainty in DATA, MODEL and INPUT
- Sensitivity to what variables are assimilated and how ensembles are generated?


Thank you!