# Modelling snow water equivalent and depth in Watershed Simulation and Forecasting System at SYKE

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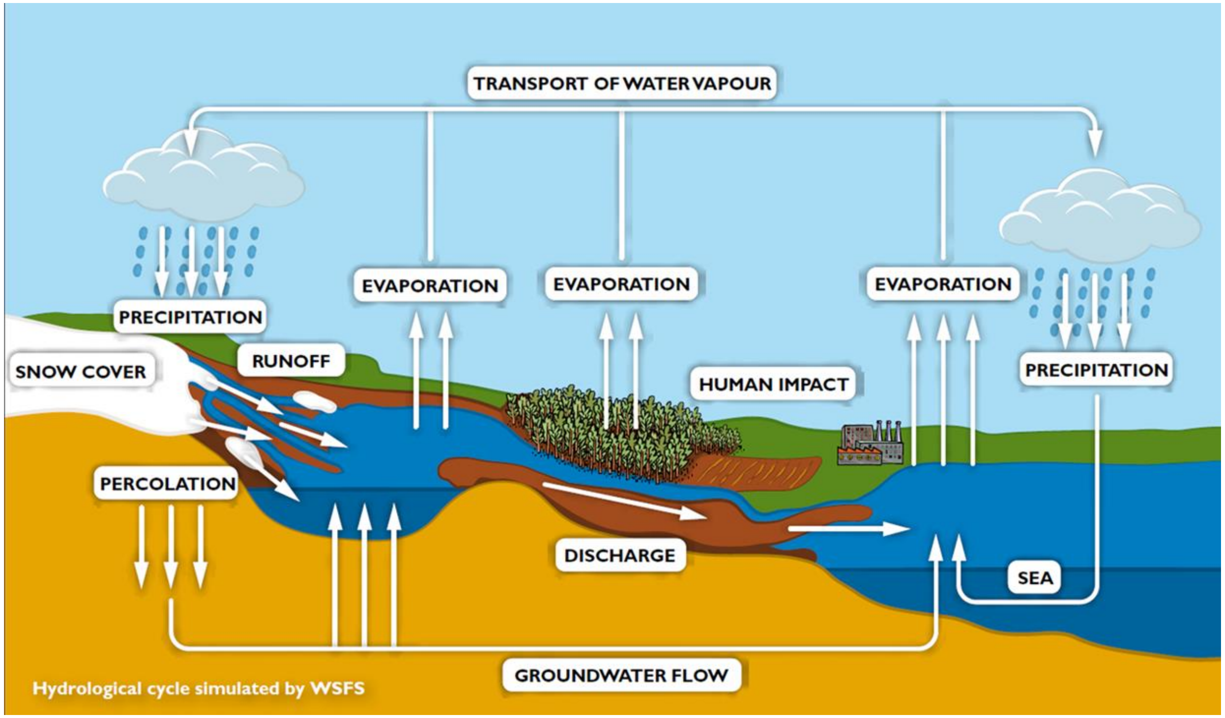
# WSFS – Watershed Simulation and Forecasting System

- WSFS is a system which used to simulate hydrological cycle, and to forecast water balance, water level, discharge, etc. in Finland (and parts of Sweden)
- System includes several subprocess models for quantities:
  - Snow water equivalent, snow depth, ground frost, evaporation, global radiation, ice depth, etc.



# Importance of snow modelling

- Precipitation during winter is (usually) stored in snow pack
- Water from snow pack flows into rivers and lakes during melting season in spring, causing spring floods
- Measurements and reliable simulations of snow water equivalent is essential for discharge and flood forecasts

- Snow water equivalent and depth model in WSFS
  - B. Vehviläinen: Snow cover models in operational watershed forecasting, Publications of Water and Environment Research Institute 11/1992, ISBN 951-47-5712-2, ISSN 0783-9472
  - One-dimensional, single layer model (old+fresh snow)
  - Average snow water equivalent, depth and density for each (3rd level) watershed area
  - Ice model: snow depth on lake ice
  - New version of depth being implemnented:
    - better calibration

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# Snow water equivalent and depth model

Precipitation: liquid/snow

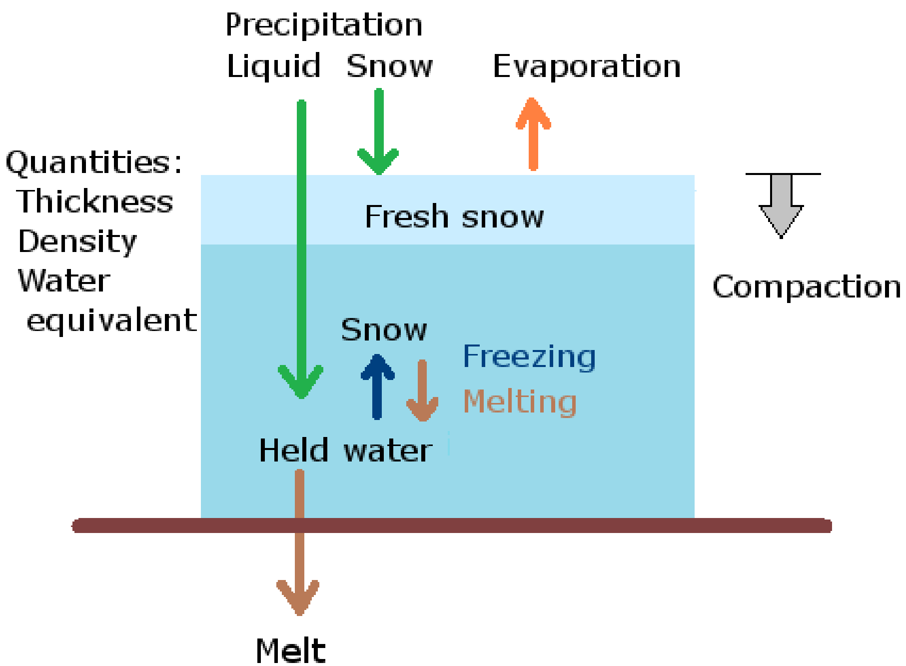
Density of new snow from air temperature :

$$\rho = 0.13 + 0.013T + 0.00045T^2$$

Compaction from snow depth and temperature

New snow density and depth calculated

Simulation for open and forest areas (later: possibly different forest types)



# Snow model – processes

Inputs:
- Precipitation (in)
- Evaporation (out)

Potential melt and freezing:
- Changes amount of liquid and solid water in snow pack

Compaction
- Changes snow depth
- Also retention capasity

Yield from snow pack

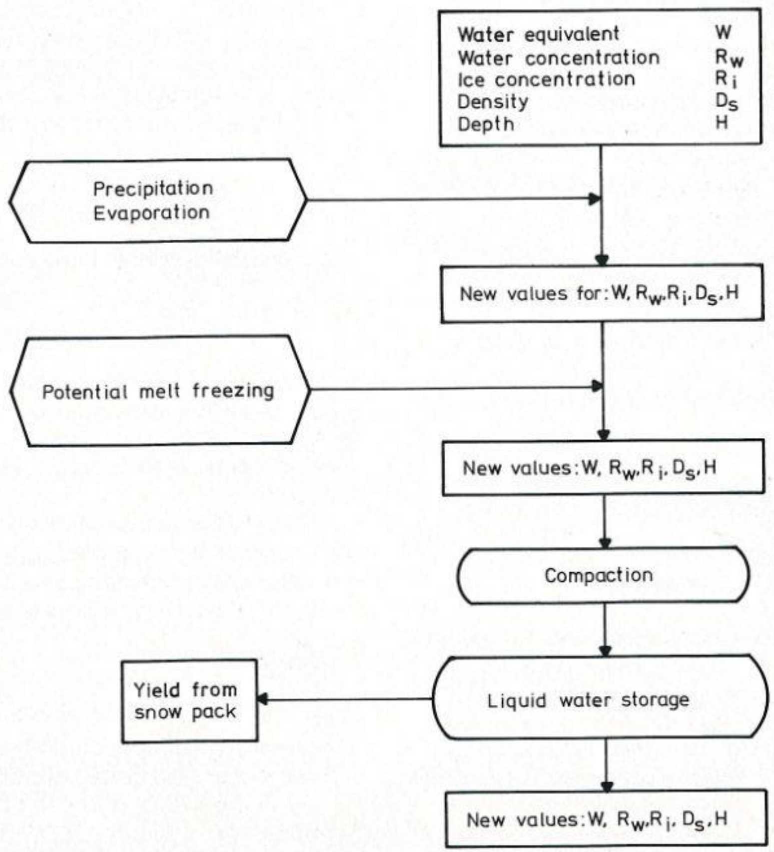



Fig. 24. The structure of the snow cover model.

# Snow model

Surface snow melt:

- Driven by air temperature

Evaporation from snow surface

Liquid precipitation/melt snow flows into snow pack

- Retention capasity: how much water snow pack can hold

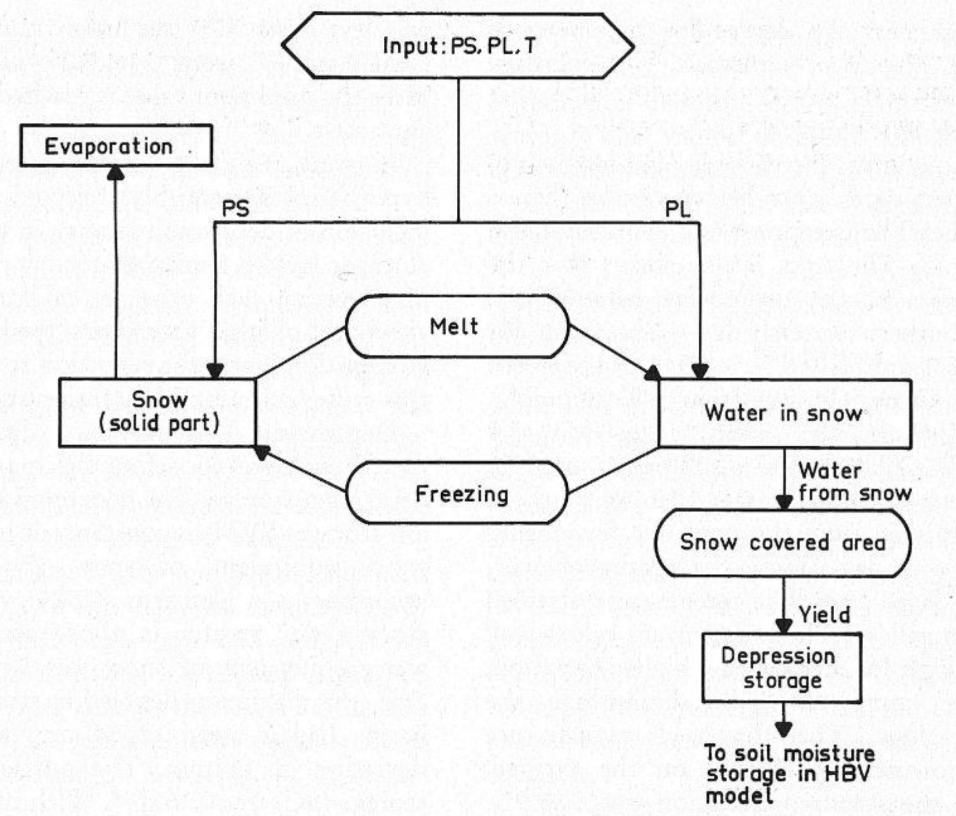



Fig. 7. The basic temperature index snowmelt model.

# Snow model – melting

- Melting snow: currently uses degree-day method
- More physical energy balance model being implemented
  - Utilizes short and long wave radiation, sensible and latent heat fluxes
  - Is expected to give better description of snow melt especially during the spring time

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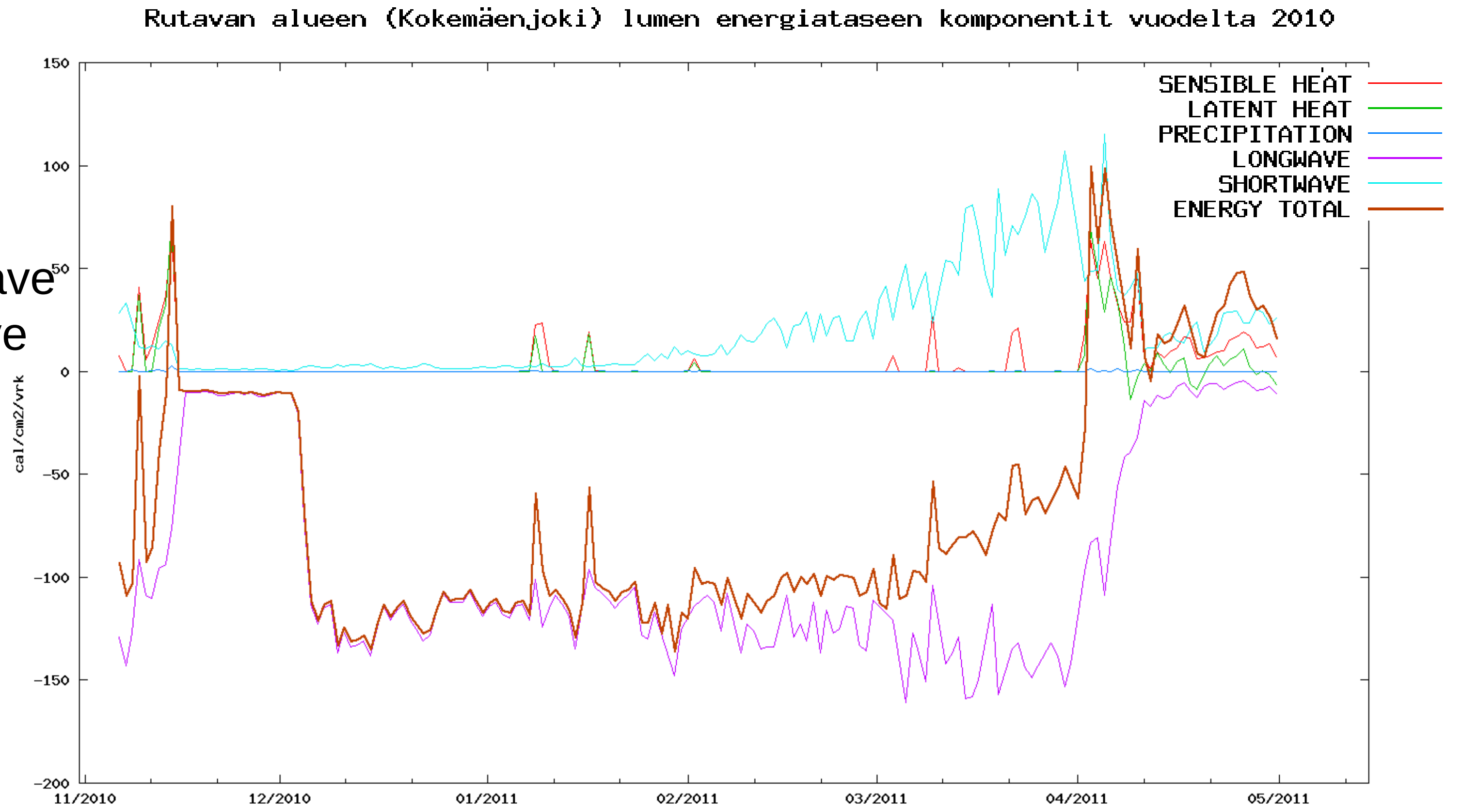
# Snow energy balance for melting snow

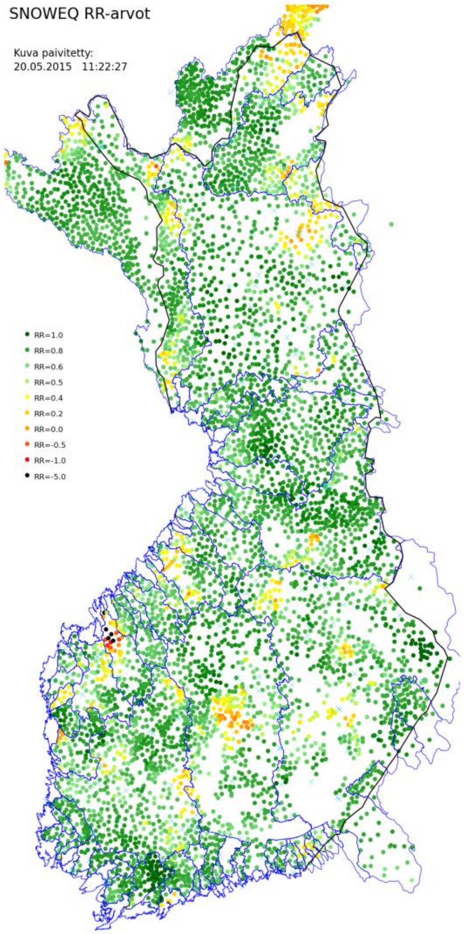
- Snow melt simulation is based on energy fluxes affecting to snow layer
- More physical approach to snow melt process compared to simpler day-degree method

- Important factors: precipitation heat, shortwave and long wave radiation, sensible and latent heat fluxes



# Calibration and validation

- Free parameters of the model are calibrated using
    - Snow line measurements (water equiv., depth, density)
    - Precipitation stations (depth)
- Simulations for open and forest areas
    - Snow line measurements for different forest types (pine,spruce,leaf forest, clearing, open area, swamp)
    - Can be included later




Goodness of fit $R^2$ map for snow water eqv.

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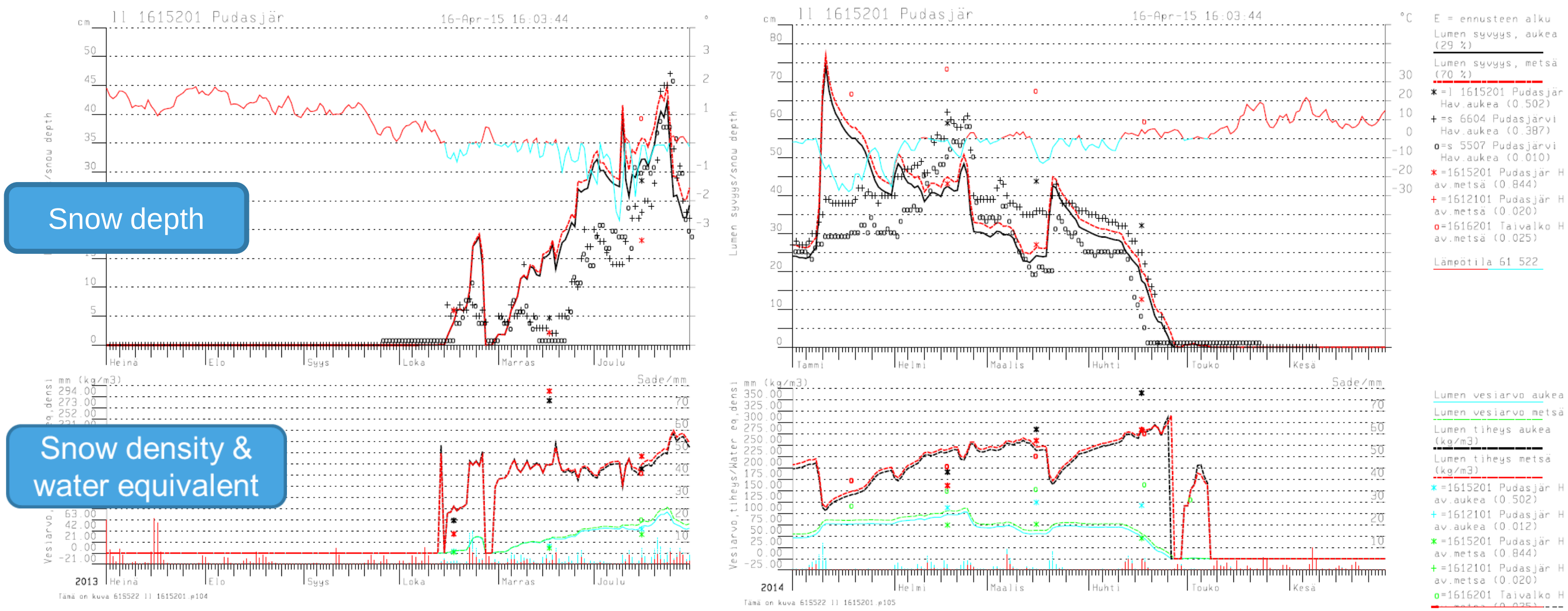
# Results

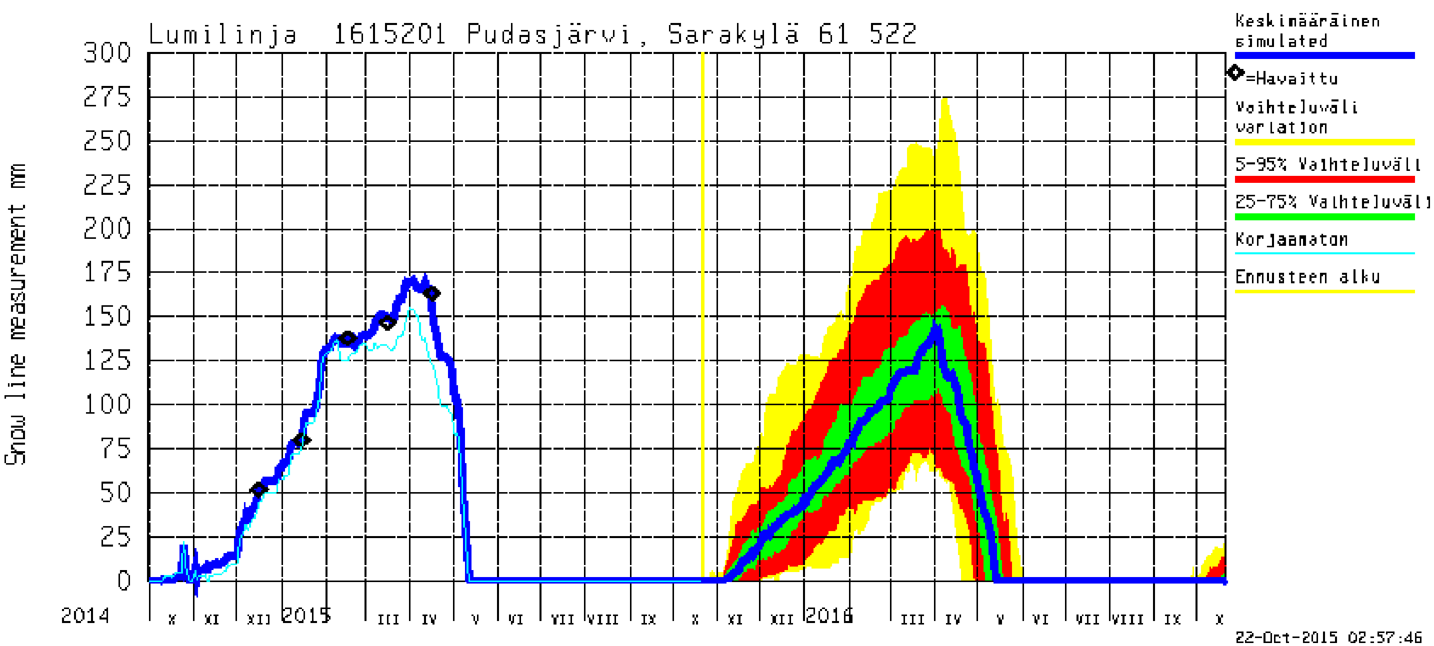


Snow depth
Snow density & water equivalent
Il 1615201 Pudasjär
16-Apr-15 16:03:44
Il 1615201 Pudasjär
16-Apr-15 16:03:44

# Results

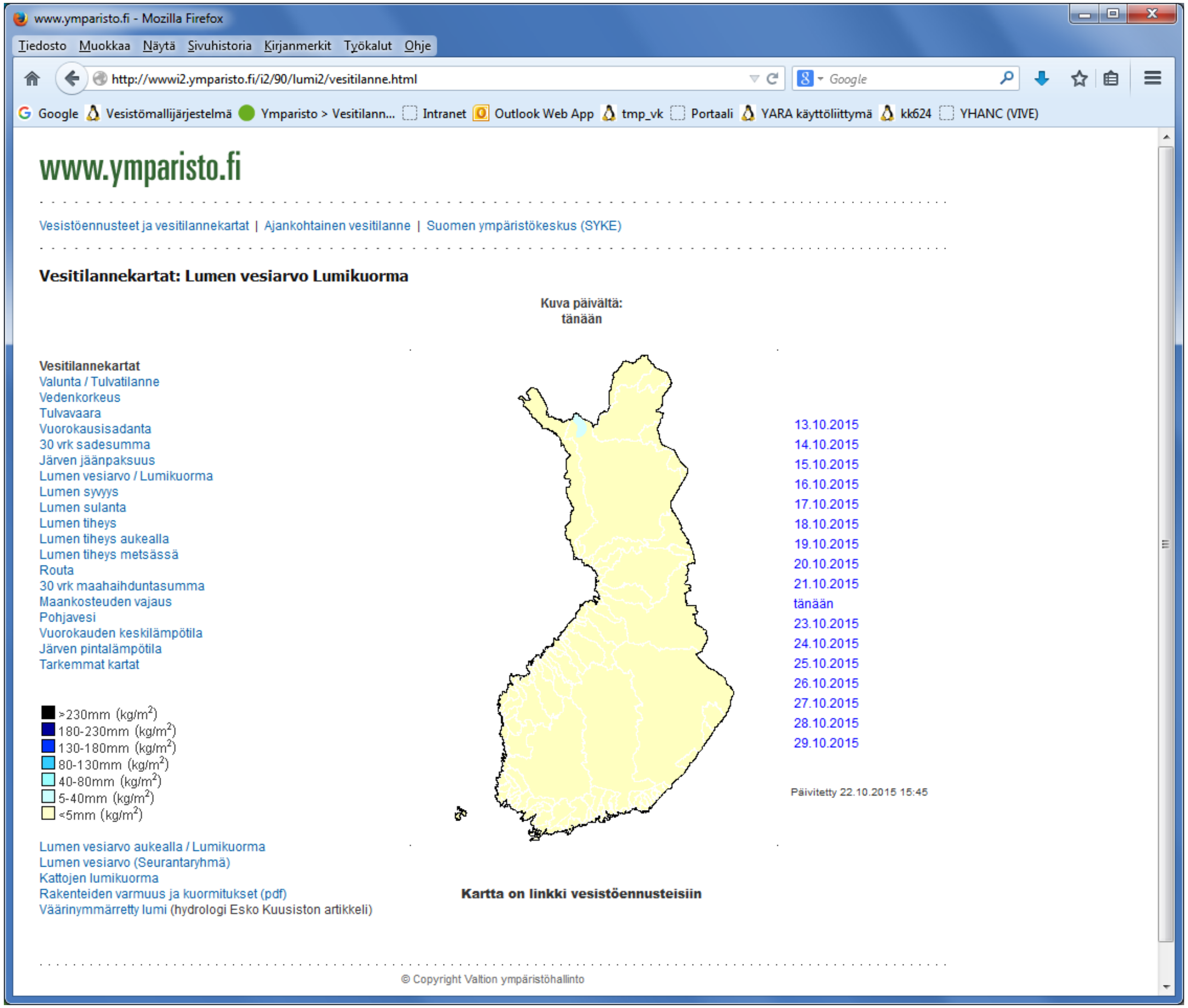
Maps: snow water equivalent, depth

Graphs: For each snow line



# Results

Available from www (http://www.ymparisto.fi/fi-FI/Vesi/Vesitilanne_ja_ennusteet)

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# Development

- Implementation to WSFS
  - replaces the current day degree snow melt method
  - Support processes: shortwave radiation simulation using cloudiness observations, snow internal energy
  - Parameter calibration
  - Testing and validation

- Expected to improve snow simulation especially during the spring time due more physically correct method

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# Ground frost model

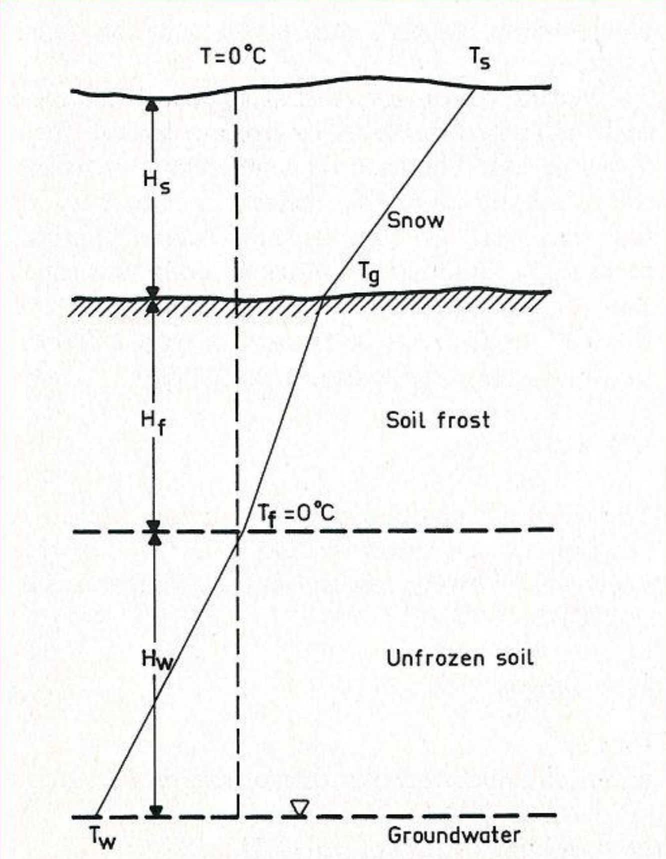



Fig. 37. Schematic soil section and temperature distribution.

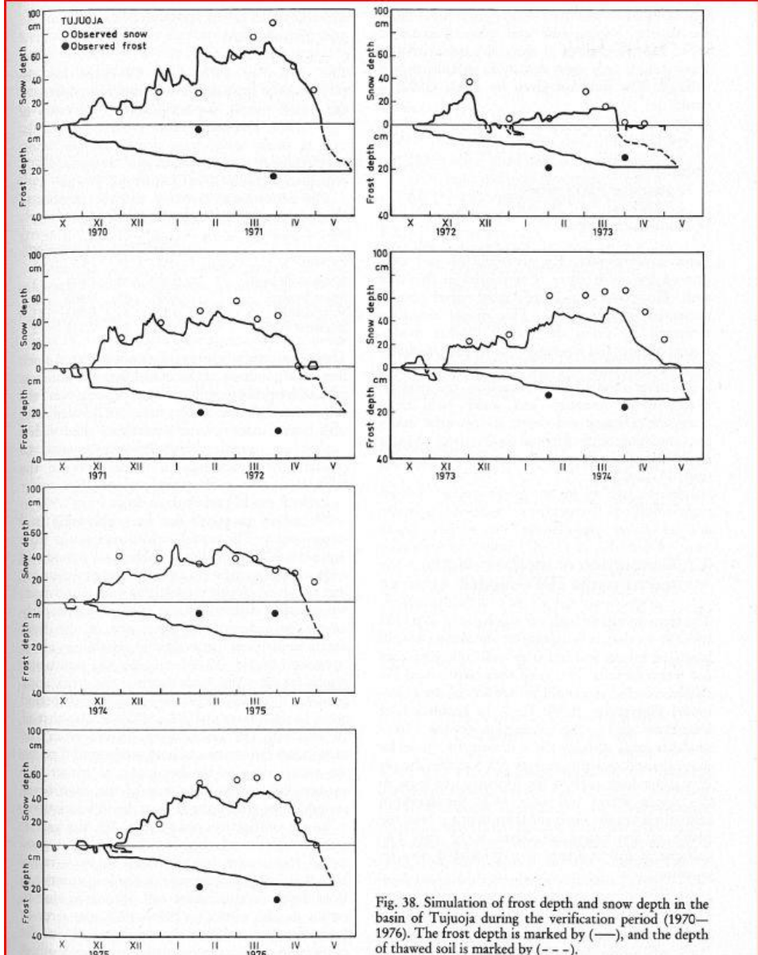
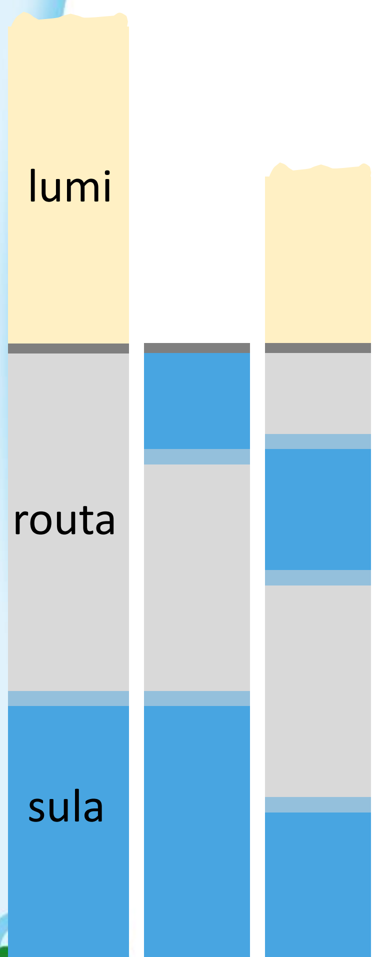


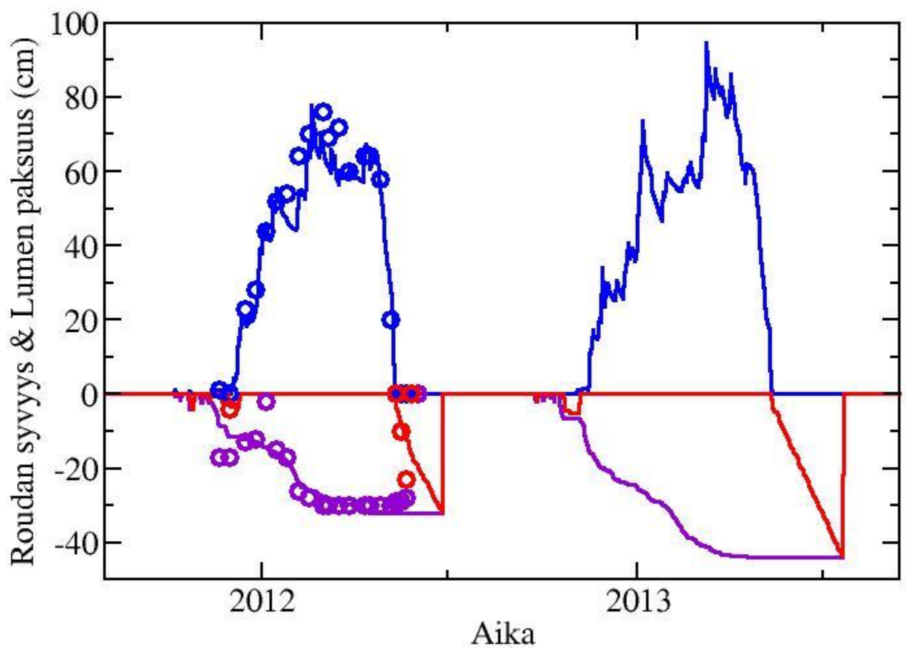

Fig. 38. Simulation of frost depth and snow depth in the basin of Tujuoja during the verification period (1970—1976). The frost depth is marked by (—), and the depth of thawed soil is marked by (- - -).

# Ground frost modelling




- Ground frost model to be included into operative forecast model
- Different forest types (open, forest, swamp) taken into account
- Possible to have several frost/non-frost layers

- Simple model:
  - All heat will be used for melting/freezing
  - Parameters describing the heat conductivity of soil will be calibrated




Example: swamp, Ylitornio Meltosjärvi (preliminary results)

**Snow**
**Freezing line**
**Melting line**

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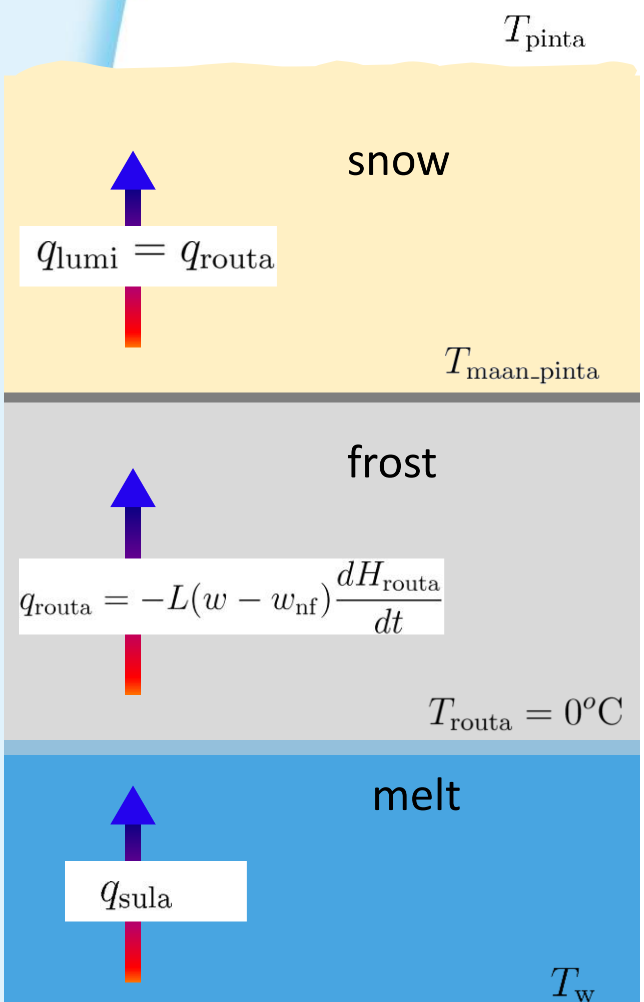
# Modelling ground frost – closer look




Equation for heat conduction:

$$q = -k\frac{dT}{dz}, \quad C \approx 0$$

Growth of the frost layer:

$$H_{\mathrm{routa,t+\Delta t}} = -\frac{k_{\mathrm{routa}}}{k_{\mathrm{lumi}}}H_{\mathrm{lumi}} + \sqrt{\left(\frac{k_{\mathrm{routa}}}{k_{\mathrm{lumi}}}H_{\mathrm{lumi}} + H_{\mathrm{routa,t}}\right)^2 - \frac{2k_{\mathrm{routa}}T_{\mathrm{pinta}}\Delta t}{L(w - w_{\mathrm{nf}})}}$$

Correspondingly: growth of the melt soil:

$q_{\mathrm{sula}}$

$$H_{\mathrm{sula,t+\Delta t}} = \sqrt{(H_{\mathrm{sula,t}})^2 - \frac{2k_{\mathrm{sula}}T_{\mathrm{pinta}}\Delta t}{L(w - w_{\mathrm{nf}})}}$$

Heat conductivity ( $k_{\mathrm{lumi}}, k_{\mathrm{sula}}, k_{\mathrm{routa}}$ ) depend on temperature, soil type, humidity, snow density and snow microstructure. The model utilizes simplified formulae combined fit parameters to be fitted to data.

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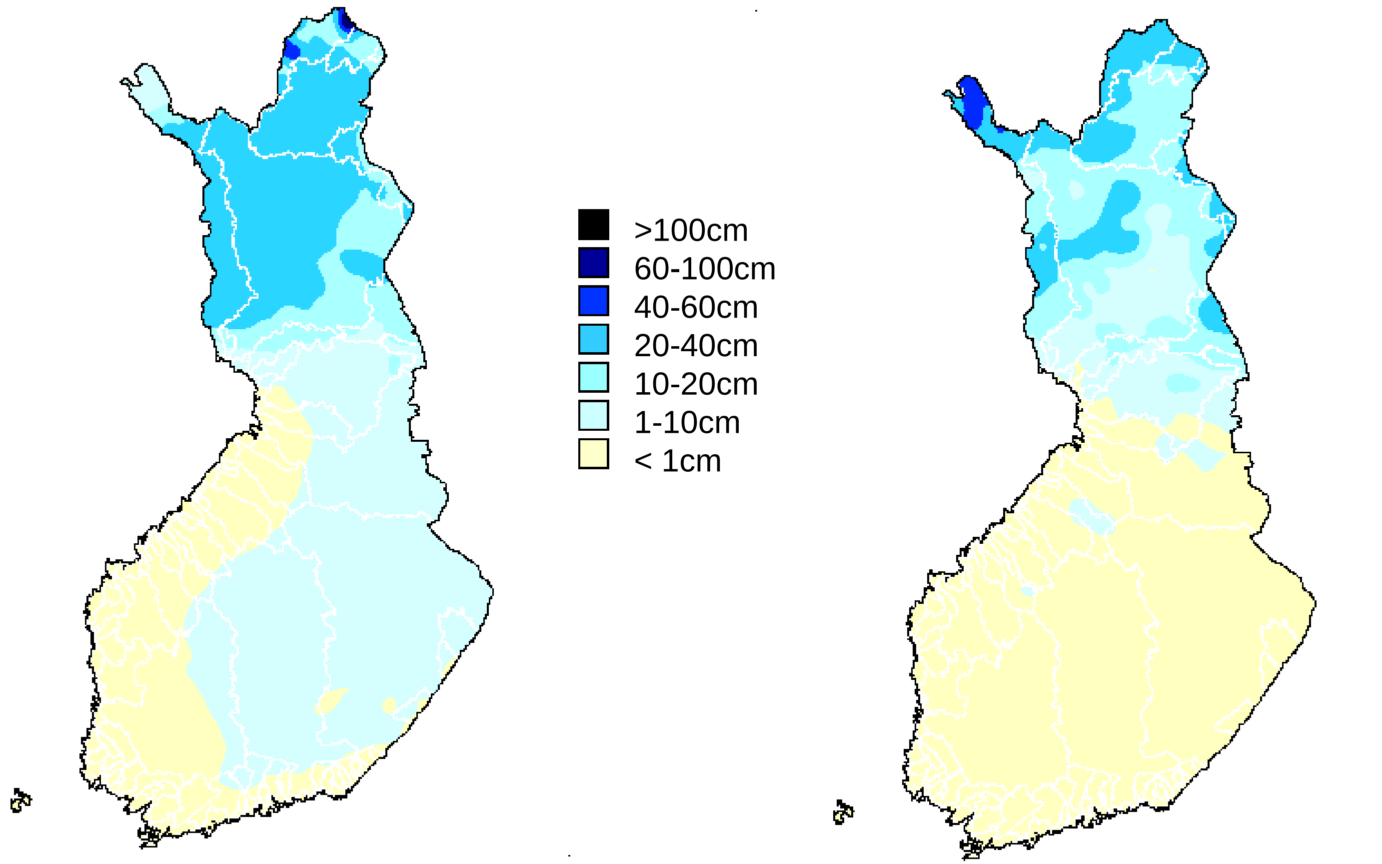
# Ground frost and snow modelling: maps

Ground frost depth

Snow depth

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# Acknowledgements

- This work has been contributed by Paula Havu and Panu Juntunen

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