Quantitative assessment of aquifer recharge from snowmelt

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Introduction

Water derived from **melting snow** recharges **soil moisture** and **groundwater** and replenishes reservoirs, lakes and rivers.

Prediction of **groundwater recharge** from snowmelt is critical to assess water resources necessary for *agricultural, economic and ecological activities.*

*For example, in western United States **70% of the water supply comes from melting snow** which also constitutes the 50% of the stream flow (Bales and Harrington, 1994).*

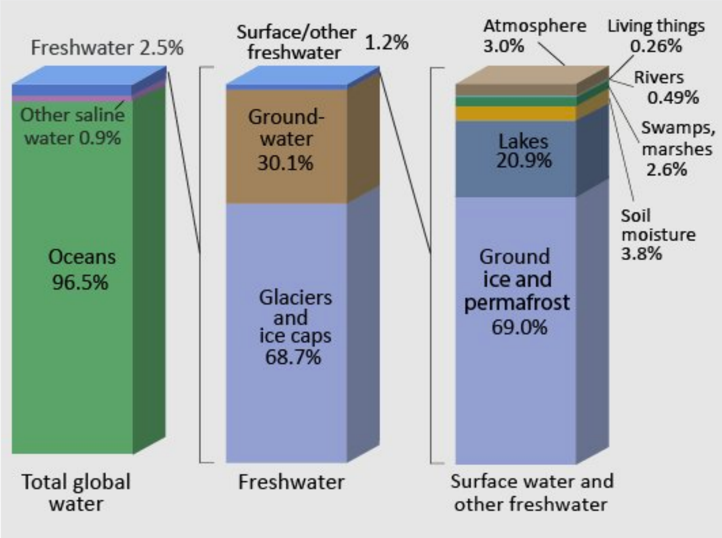
Introduction

Infiltration of melt water into frozen soil is a complex process to analyze as it involves coupled heat and mass flow with phase changes.

Basic approaches used to model snowmelt are physically based methods (**Energy balance models-EBM**) requiring detailed description of the mass or energy balance (*USDA, 2004*) and **Temperature index models - TIM** (e.g. empirical) in which air temperature is used to index all of the energy fluxes or their combination as a hybrid method.

WHY WE SHOULD MODEL GROUNDWATER RECHARGE FROM SNOWMELT ?

GROUNDWATER RESERVOIR RESOURCES



GROUNDWATER REPRESENTS

30 % of TOTAL FRESH WATER RESOURCES ON EARTH

GROUNWATER IS THE BIGGEST FRESH WATER EXPLOITABLE RESERVOIR

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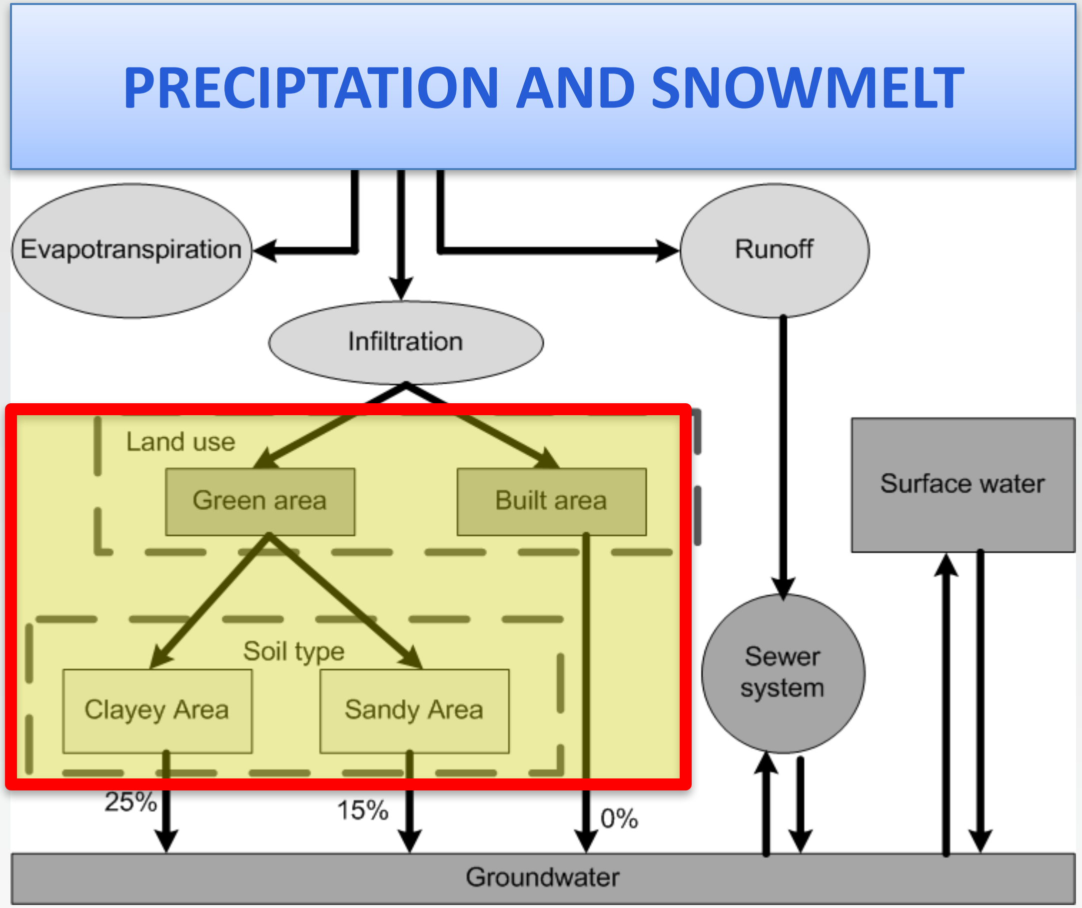
GROUNDWATER RECHARGE FROM SNOWMELT IN URBAN AREAS



Due to the **duration of the snowmelt process** most urban surfaces have **reduced infiltration capacity** and combination of frozen ground, spring melt, and rainfall can easily cause spring flooding.

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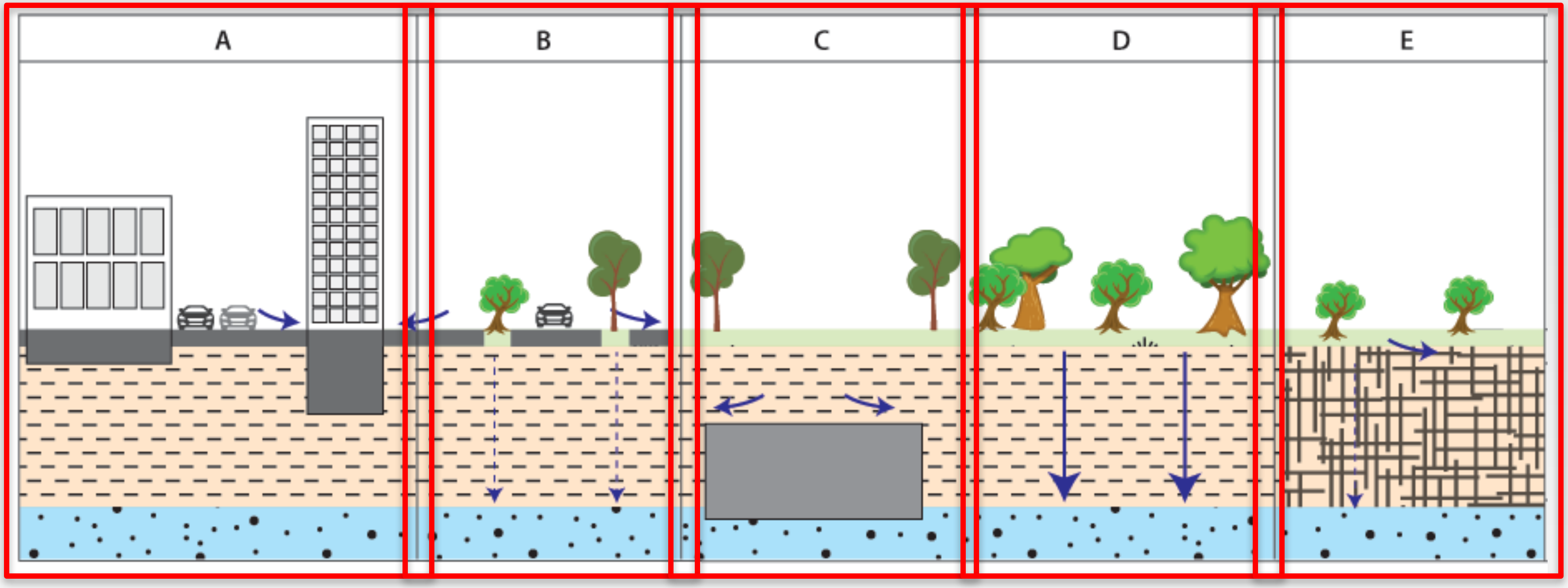
GROUNDWATER RECHARGE FROM SNOWMELT IN URBAN AREAS



QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

The water arriving at the bottom of the snowpack **infiltrates** into the soil and/or accumulates to create a saturated zone at the base of the snowpack. *In order to calculate the groundwater recharge, snowmelt represents a surface water input.*

Snowmelt runoff can reach stream channels via various paths. In the case of unfrozen ground if water table is at depth and the ground above is unsaturated, **the entire water output infiltrates and moves as subsurface flow.**

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

In the case of frozen ground, the soil becomes essentially **impermeable** and severely limit the infiltration of the snowmelt water. Many studies have shown that seasonal infiltration is inversely related to the total moisture content (water and ice) of a frozen soil at the time of melt.

Infiltration from snowmelt is calculated only when heat transport is considered.

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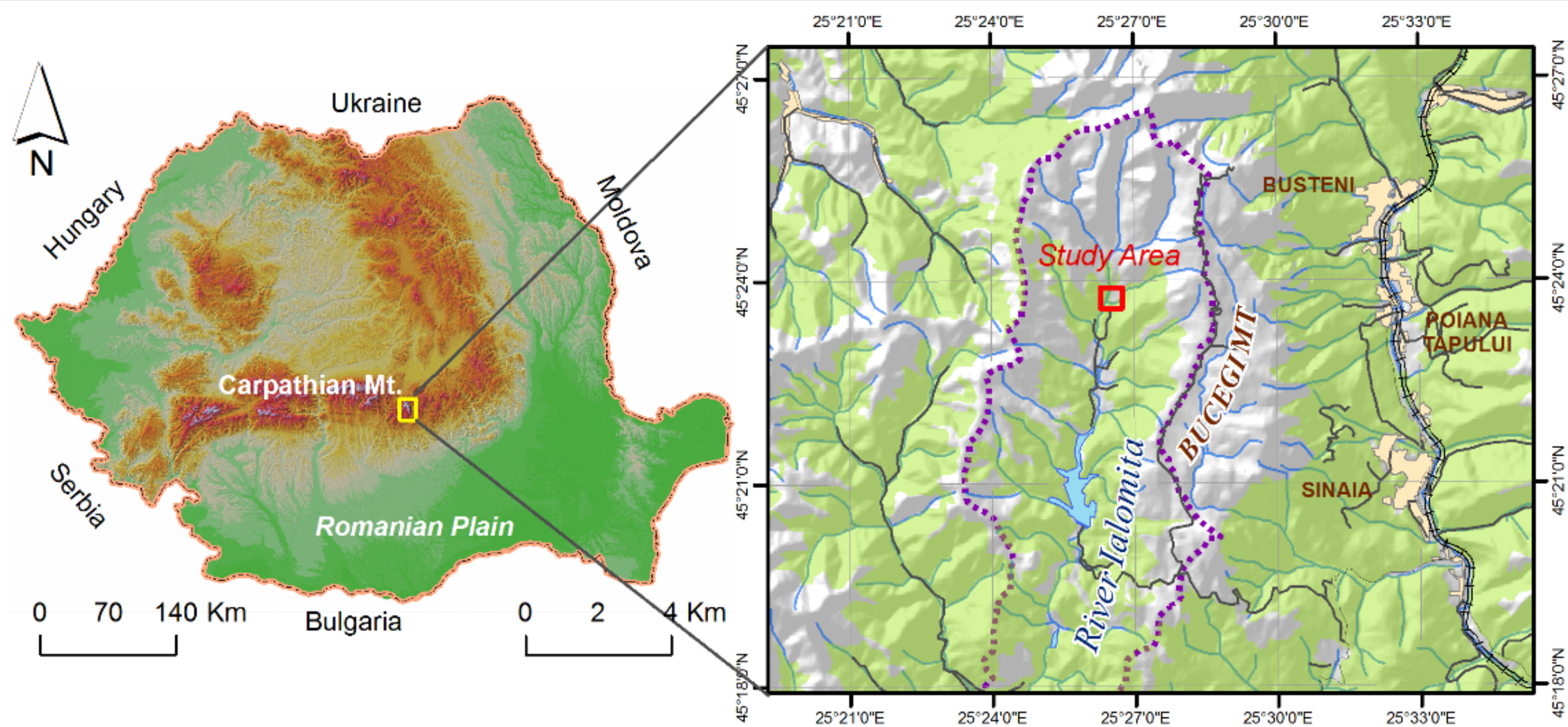

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

The area is located in the upper part of the river Ialomita - Bucegi Mountains. The main hydrogeological unit is Bucegi Hydrostructure. The hydrostructure is characterized by 2 aquifer formation:

- **Fissured – detritus formations (conglomerate, sandstones, etc.)**
- **Karst – limestone**

Aquifer system recharge - Entire outcrop areas:

- **Liquid infiltration**
- **Snowmelt infiltration.**

Discharge trought springs

-They appear at the limit between permeable and impermeable formations (limestones and shale)

-Flow rates between : 1 l/s to 500 l/s (Slavoaca et. al. 2000).

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QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

FIELD MEASUREMENTS

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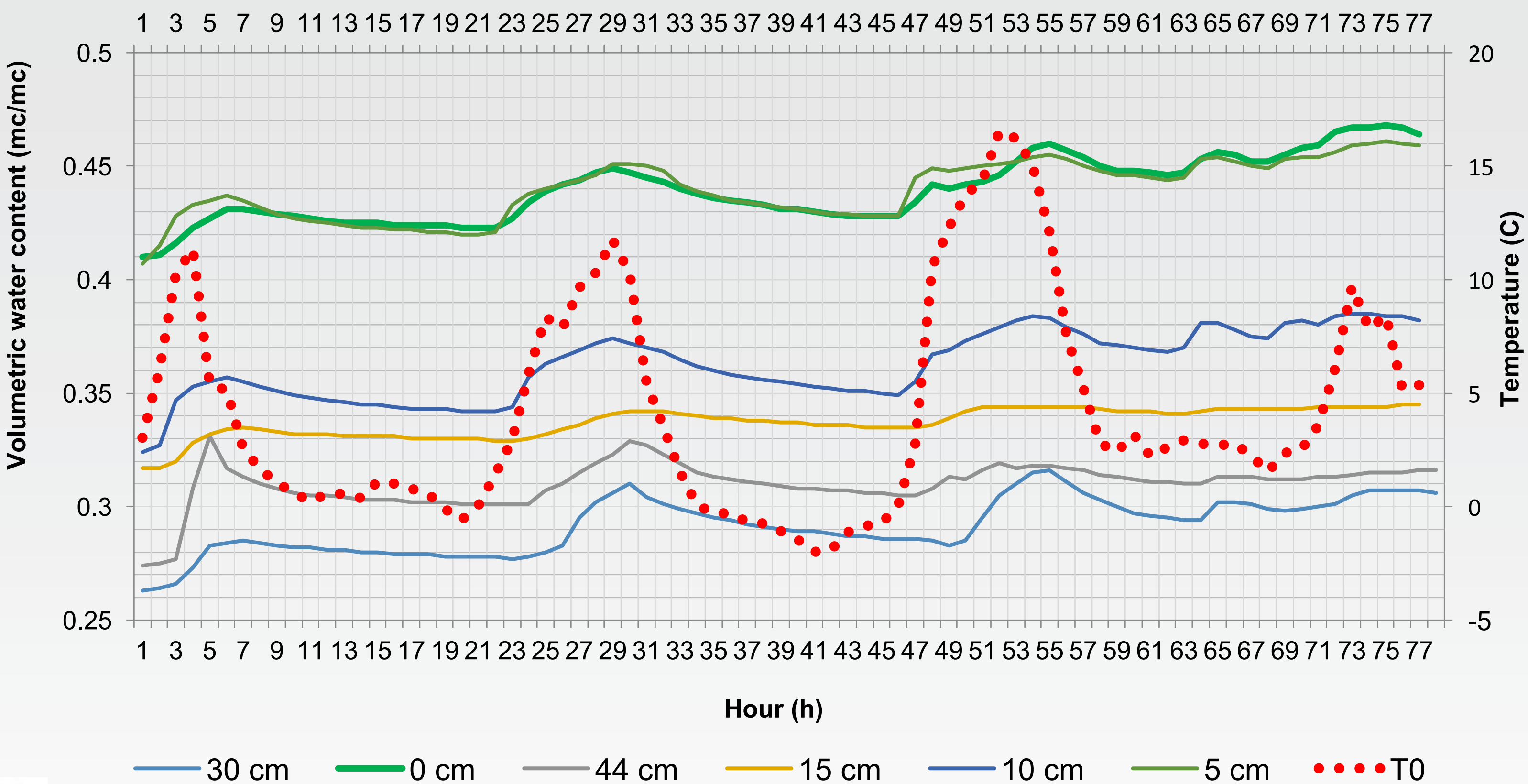
QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

FIELD MEASUREMENTS



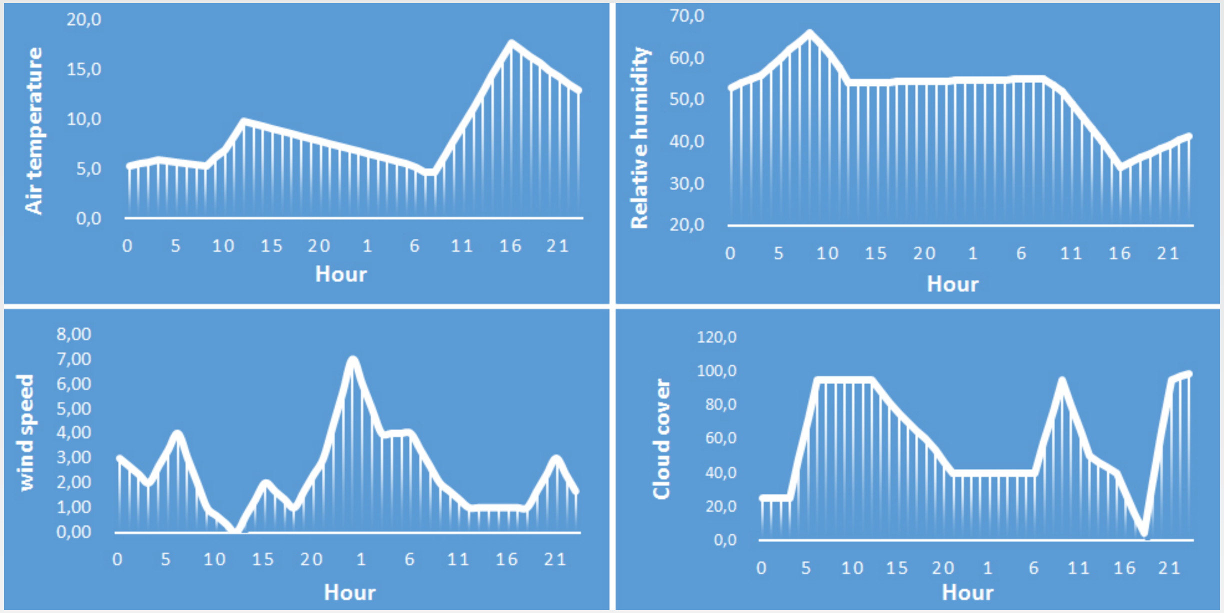
QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

SOIL TYPE

No	DEPTH [cm]	HUMIDITY %	Organic matter %	Sand %	Silt %	Clay %	Gravel %	Soil type:
1	0-5	44.86	20.00	61	30	4	5	**Silty sand**
2	5-10	37.69	13.2	61	27	9	3	**Clayey sand**
3	10-15	29.67	10	59	23	3	15	**Silty sand**
4	15-30	15.39	5	51	18	3	28	**Gravelly silty sand**
5	30-40	27.45	3.9	57	21	2	20	**Silty sand**

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

METEOROLOGICAL DATA



The Sinaia meteorological station located in the vicinity of Padina (latitude , longitude) and at the same altitude (1510 m), provided measurements with a three hour time step (time 0, 3,6,9,12, 15, 18, 21) of the following parameters: air temperature at 2m above ground, relative humidity [%], cloud cover, and wind speed at 10m above ground.

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

MODELLING

Using meteorological observations data from Padina, a surface point energy balance model has been developed. The model computes the energy balance components and the surface melt rate using a modified version of the ESCIMO algorithm (*Strasser and Marke, 2010*) called **modESC**. It can be applied for spring season, when adverse combination of frozen ground, snowmelt, and rainfall can easily cause flooding.

To evaluate the near-surface water balance and estimate groundwater recharge for a snow cover area, with specific soil, vegetation, and climate conditions **HYDRUS-1D** incorporate a specific routine (snow routine).

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

modESC

The energy balance (EB) for a snow pack can be expressed as:

$$E = R_n + H + L + A + G$$

where

E is the energy available for snowmelt and the following fluxes are taken into account

Rn - the net radiation ,

H - the sensible heat flux ,

L the latent heat flux ,

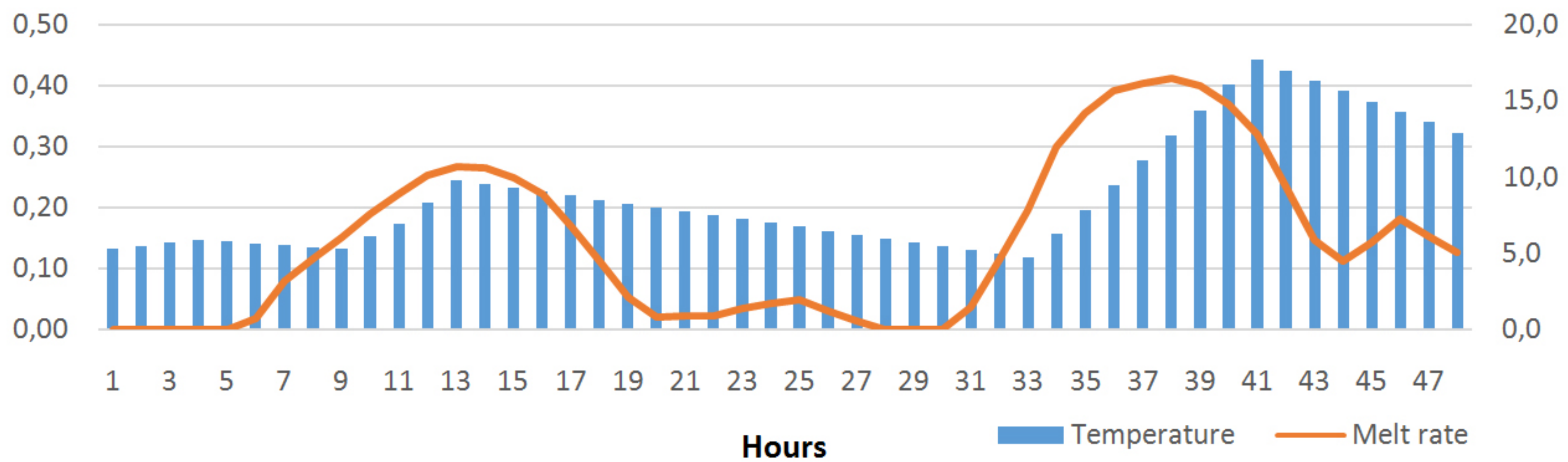
A - the advective energy supplied by solid or liquid precipitation

G - the soil heat flux.

All energy flux densities are expressed in for houry step and in for daily step.

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

modESC



After 48 hours the snowmelt was **7 cm of the total SWE of 14.38 cm** (at the beginning of the simulation period). **This massive melting resulted due to the increase of the air temperature between 5.3 ℃ and 17.7 ℃** in this period of time.

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

HYDRUS 1D

The general equation of the water movement in the unsaturated media is described by a modified form of the Richards equation using the assumption that the air phase plays an insignificant role in the liquid flow process and that water flow due to thermal gradient can be neglected:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}[K \cdot (\frac{\partial h}{\partial z} + 1)] - S$$

where h is the hydraulic head $[L]$, θ is the volumetric water content $[L^3 \cdot L^{-3}]$, t is time $[T]$, z is the spatial coordinate $[L]$, S is the sink term $[L^3 \cdot L^{-3} \cdot T^{-1}]$ and K is the unsaturated hydraulic conductivity function $[L \cdot T^{-1}]$ given by

$$K(h,z) = K_s(z) \cdot K_r(h,z)$$

where K_r is the relative hydraulic conductivity $[-]$ and K_s the saturated hydraulic conductivity $[L \cdot T^{-1}]$

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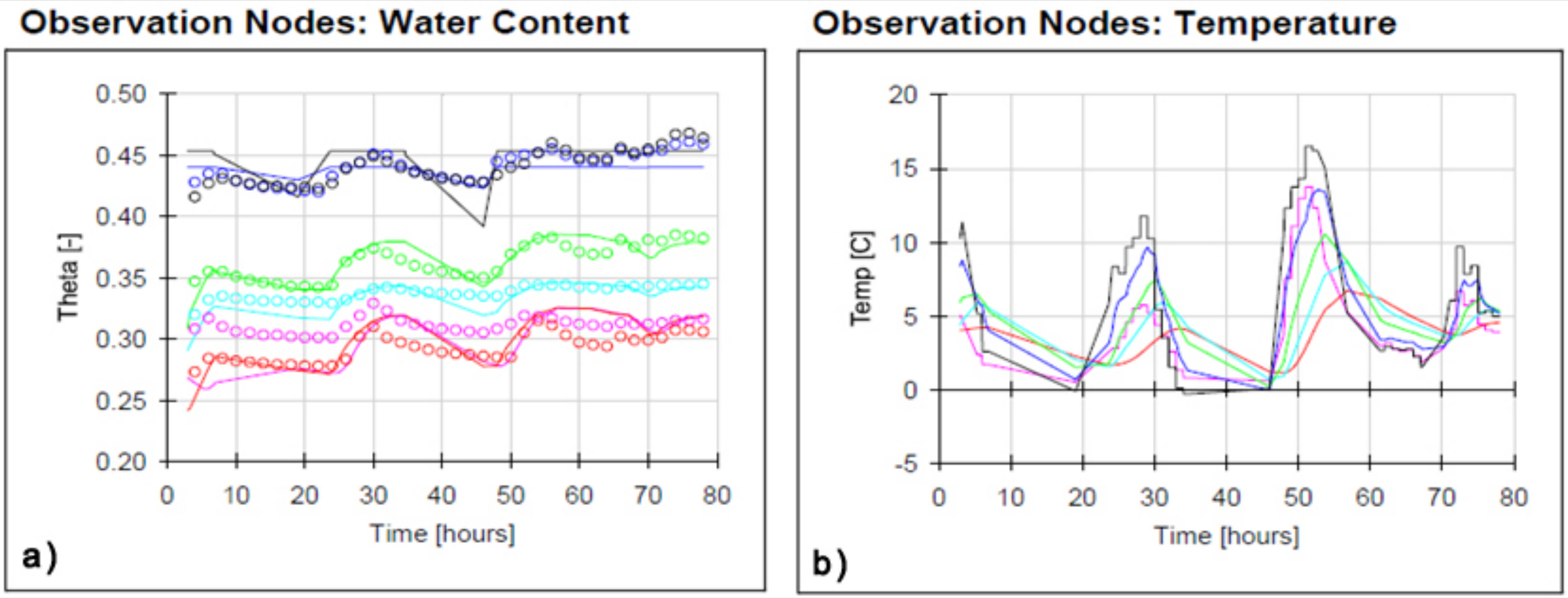
HYDRUS 1D



Resulted values at specified six observation points (at depths of 0,5,10,15,30,44 cm) of: a) Measured and calculated water content; b)Temperature

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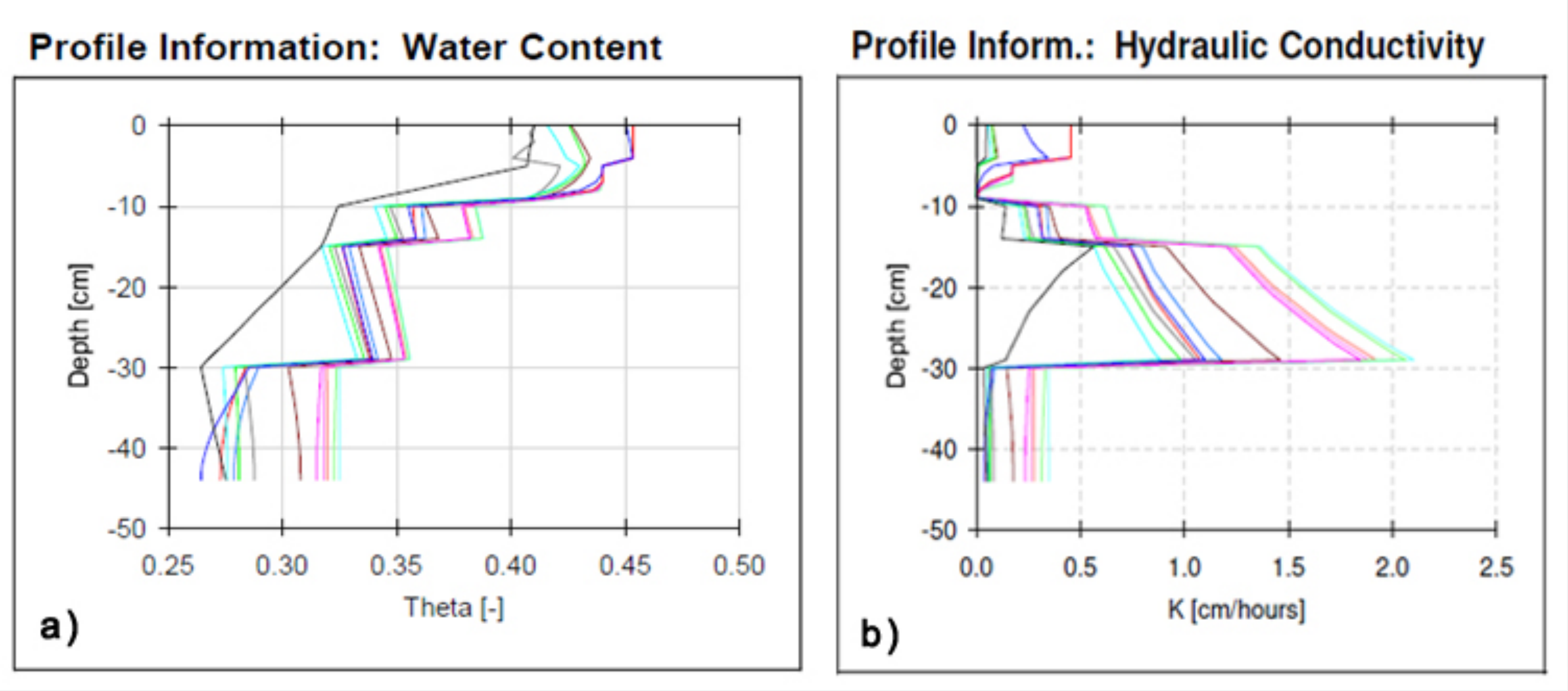
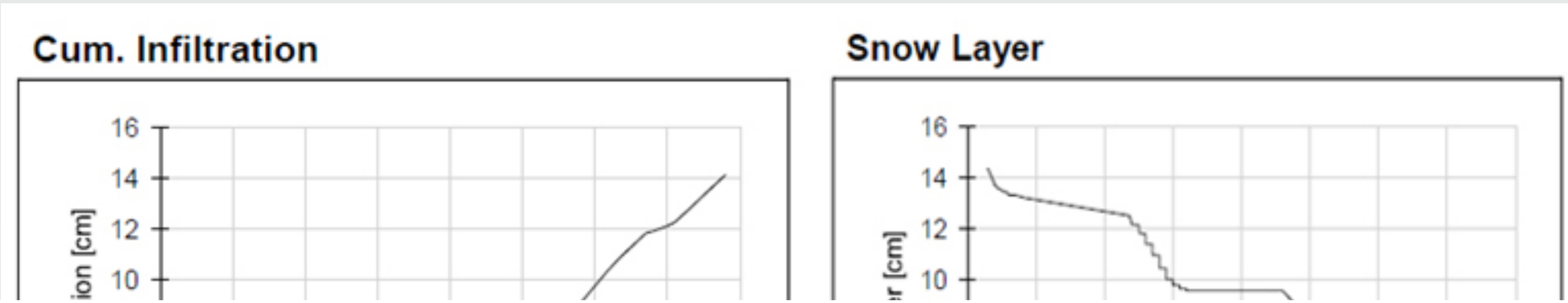
HYDRUS 1D



Soil profile information. Resulted values for 12 steps on: a) Water content; b)Hydraulic conductivity

QUANTITATIVE ASSESSMENT OF SNOWMELT INFILTRATION

HYDRUS 1D



For the studied period of time of 76 hours, there is a decrease from **40 cm to 4 cm** of the snow height. This is emphasized by snow layer SWE calculated with HYDRUS-1D: **the initial SWE was 14.81 and the last result was 1.595** (corresponding to a calculated snow height of **4.31 cm**).

Results of water flow and boundary fluxes: a) Cumulative infiltration; b) Snow layer evolution

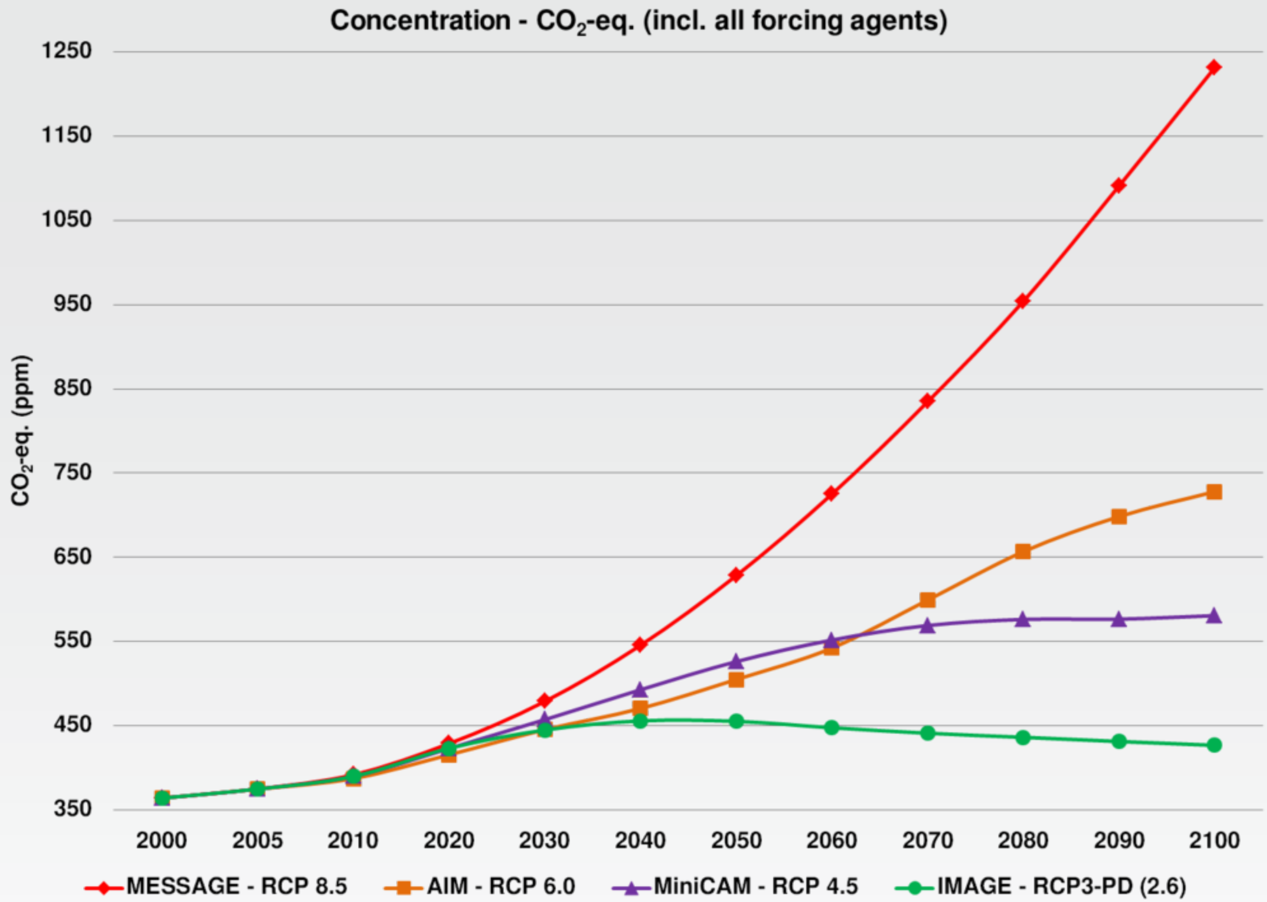
CLIMATE CHANGE

The effect of potential climate change on the seasonal evolution of the snow cover can be estimated by modifying the **time series of observed temperature and precipitation by means of adjustable parameters.**

This is technically facilitated by implementation of climate change parameters for assumed **temperature and precipitation trends.**

It is possible to simulate the evolution of a seasonal snow cover under conditions of climate change by flexible adjustment of modified temperature and/or precipitation.

CLIMATE CHANGE



https://en.wikipedia.org/wiki/Representative_Concentration_Pathways

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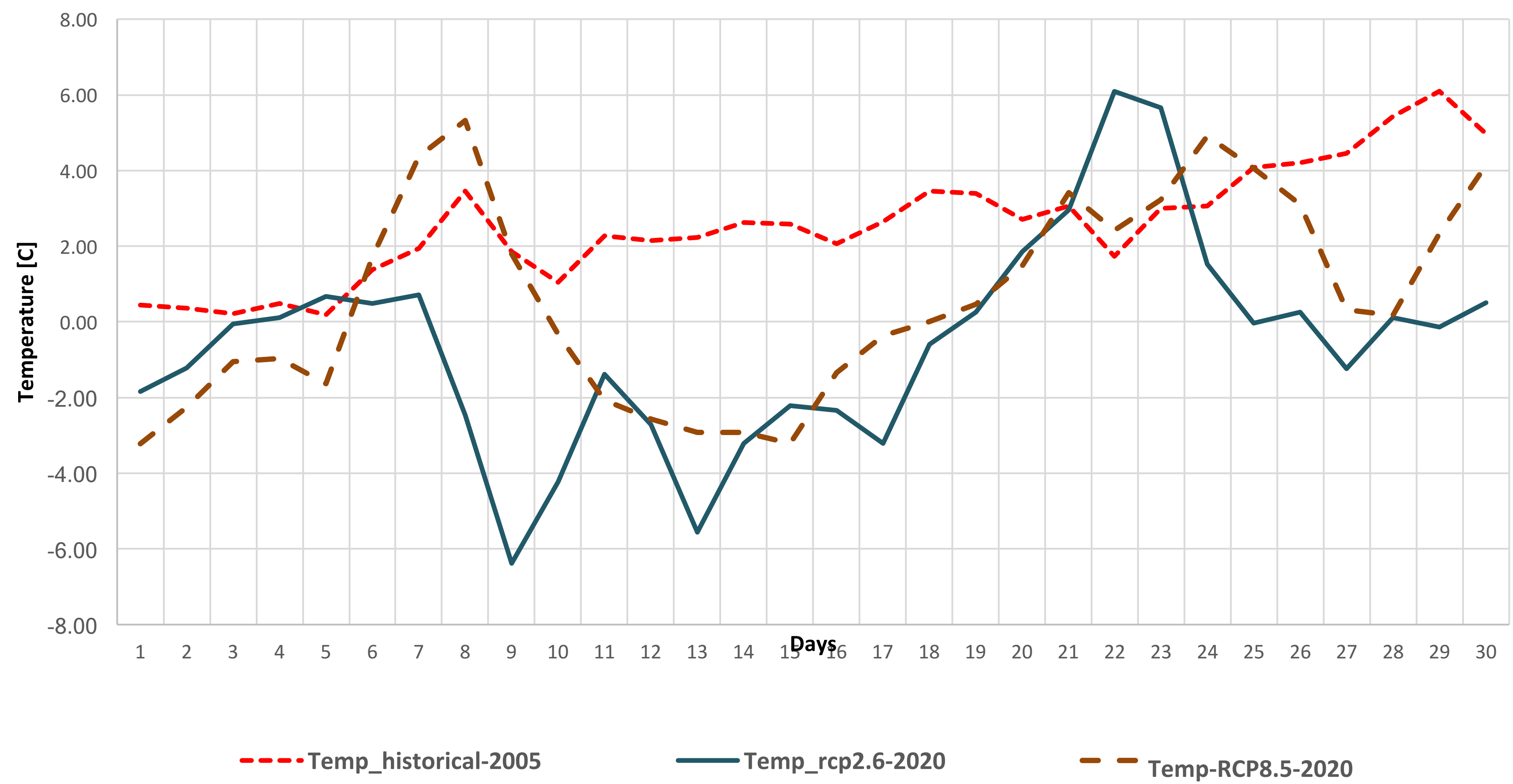
CLIMATE CHANGE



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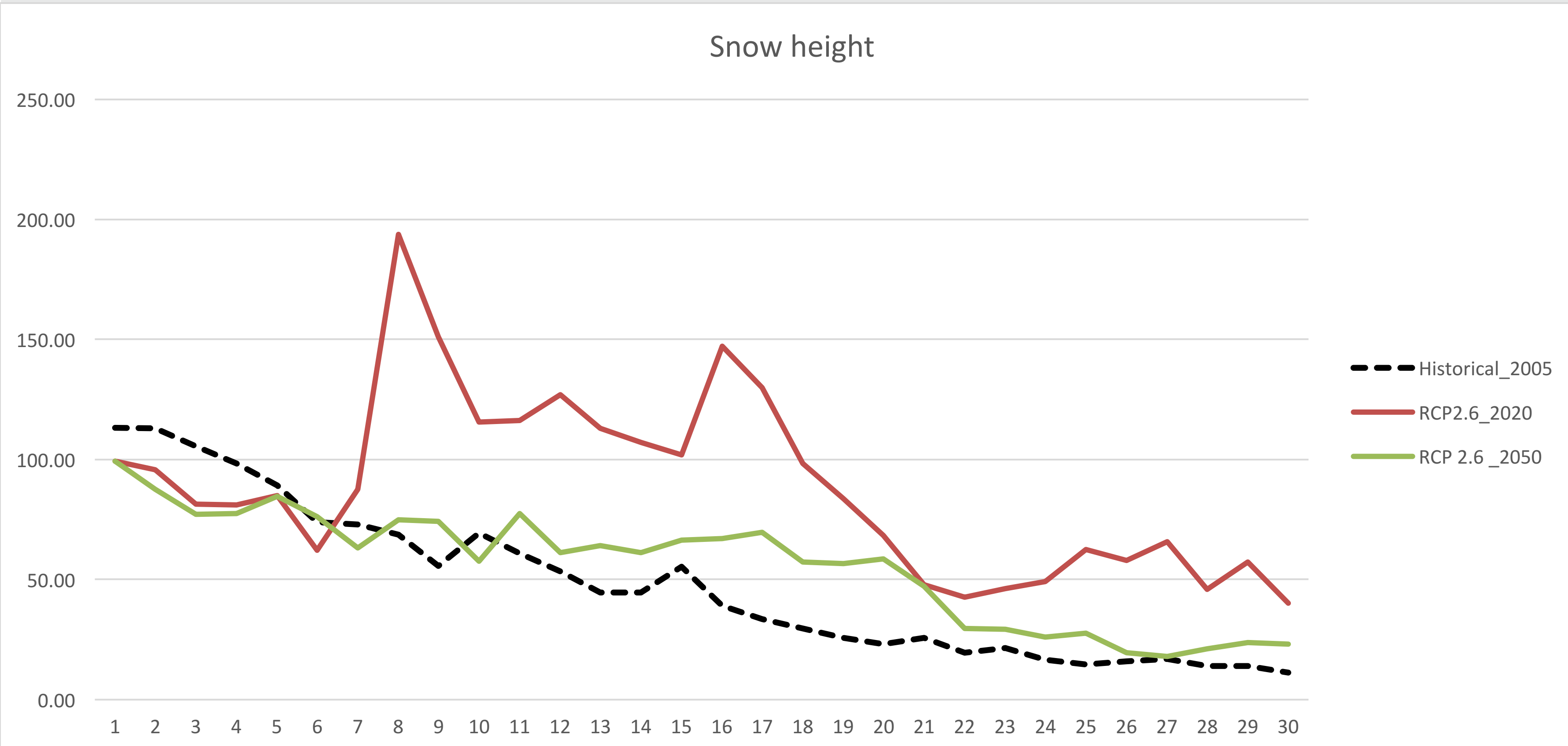

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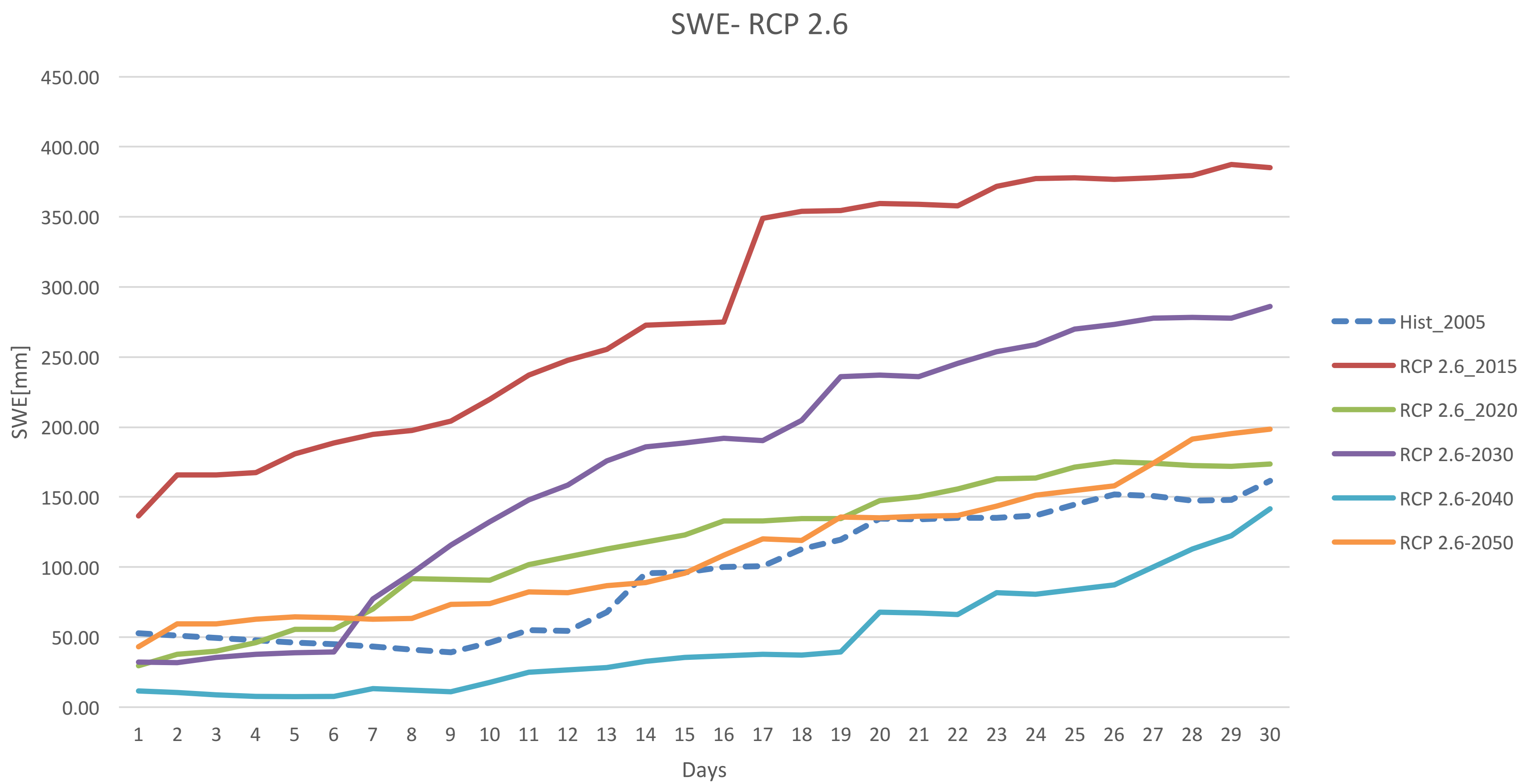

CONCLUSIONS

An important aspect in modelling snowmelt infiltration is that a frozen soil layer generally increases the amount of snowmelt runoff by decreasing soil permeability and thereby impeding infiltration, reduce soil moisture recharge and restrict deep percolation.

An accurate evaluation of the infiltration and run-off processes from the snowmelt are key elements for groundwater recharge assessment.

THANK YOU !