Improving the accuracy of hydrological modeling using Snow Water Equivalent (SWE) during spring flooding in the Moroccan High Atlas

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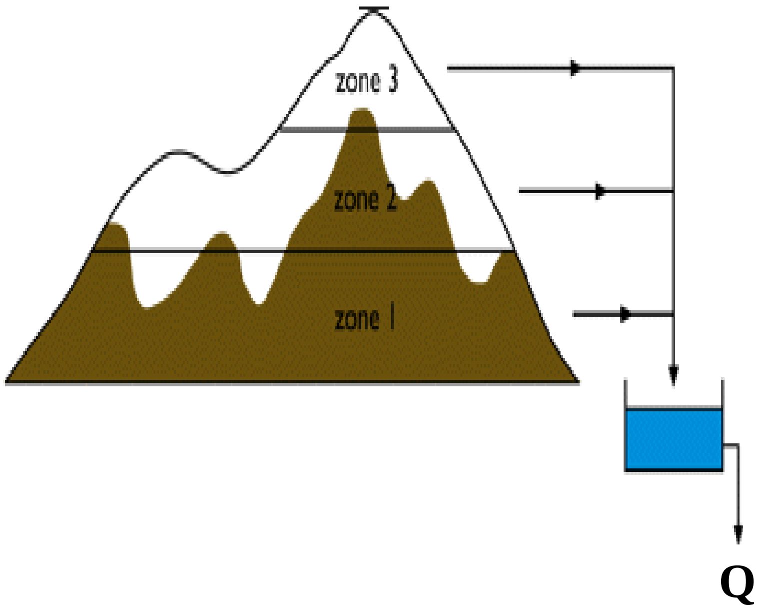
Climate change impact the seasonality of precipitation and flows in Mediterranean mountain catchments

*Stormy **Autumn** causing extreme flooding,
*Mixed **Winter** rain and snow,
*__Spring__ low rain, floods caused by snowmelt,
*Dry **Summer** with heavy flash floods.

Snowfall in the mountains acts as a natural reservoir to store precipitation during the cold season. During the spring season, the snow melts and flows into the river

Stream flows derived from the melt are extremely important. Understanding the snowmelt process is essential for effective water resource management.

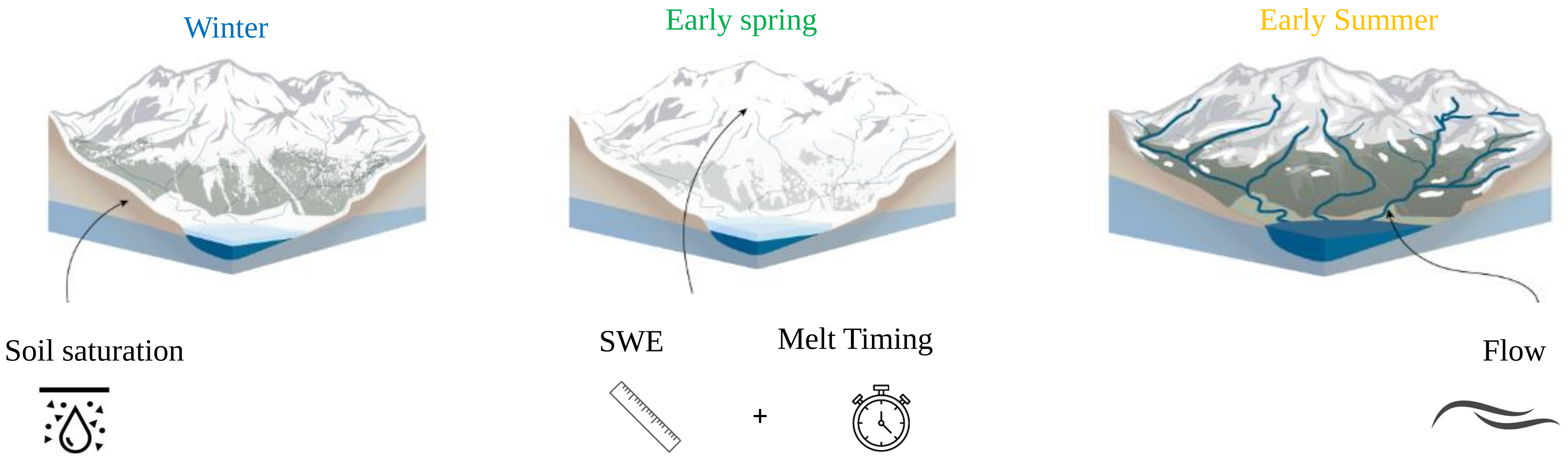
Hydrological models are useful tools for focasting flows and interactions between hydrological variables within the hydrological cycle



From a hydrological perspective, 3 methods are generally used to simulate snowmelt.

Main issue

Studying snowmelt dynamics is critical to understanding how water moves through the watershed, contributes to streamflow, and becomes available for use.



Winter snow accumulation as well as spring snowmelt affect streamflow and water availability

The **objectives** of this study are:

(1) To assess the seasonal variation of snow across the Atlas Mountains during the periods of winter / spring;

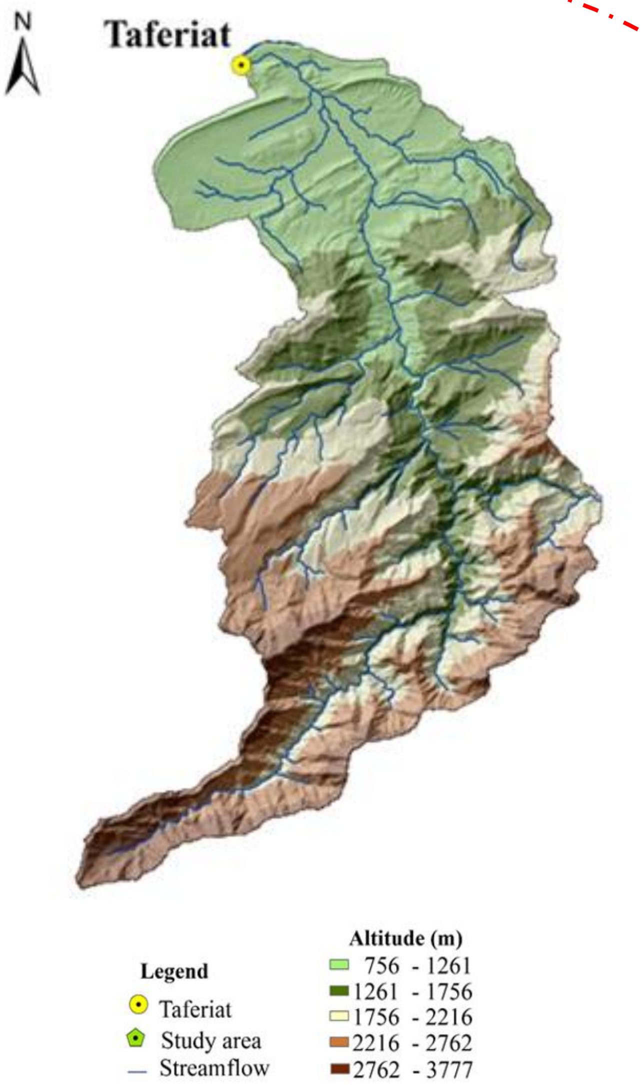
(2) To analyze topographic factors, including elevation, and slope, in snow cover variability;

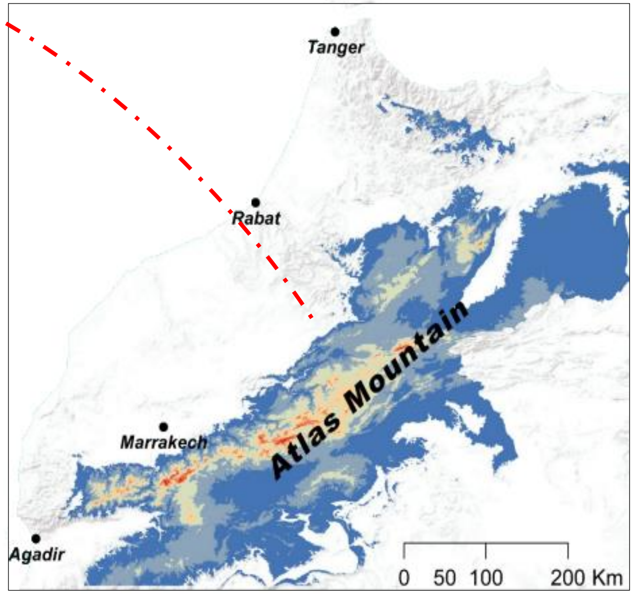
(3) Estimate the altitudinal gradient using long-term trends in selected snow parameters;

(4) Quantify the snowmelt contribution rate in the river discharge at Zat Basin.

Zat basin is a dynamic snow basin due to its topography and elevation, and characterized by an arid to semi-arid climate.
The river is torrential and subject to flash floods.

Morphological characteristics of Zat	
Perimeter (P) (Km)	177,58
Area (A) (Km²)	521
Average slope P Avg %	33,60
Length of main stream (Km)	52,15
Hydrographic density (Km²)	2,14





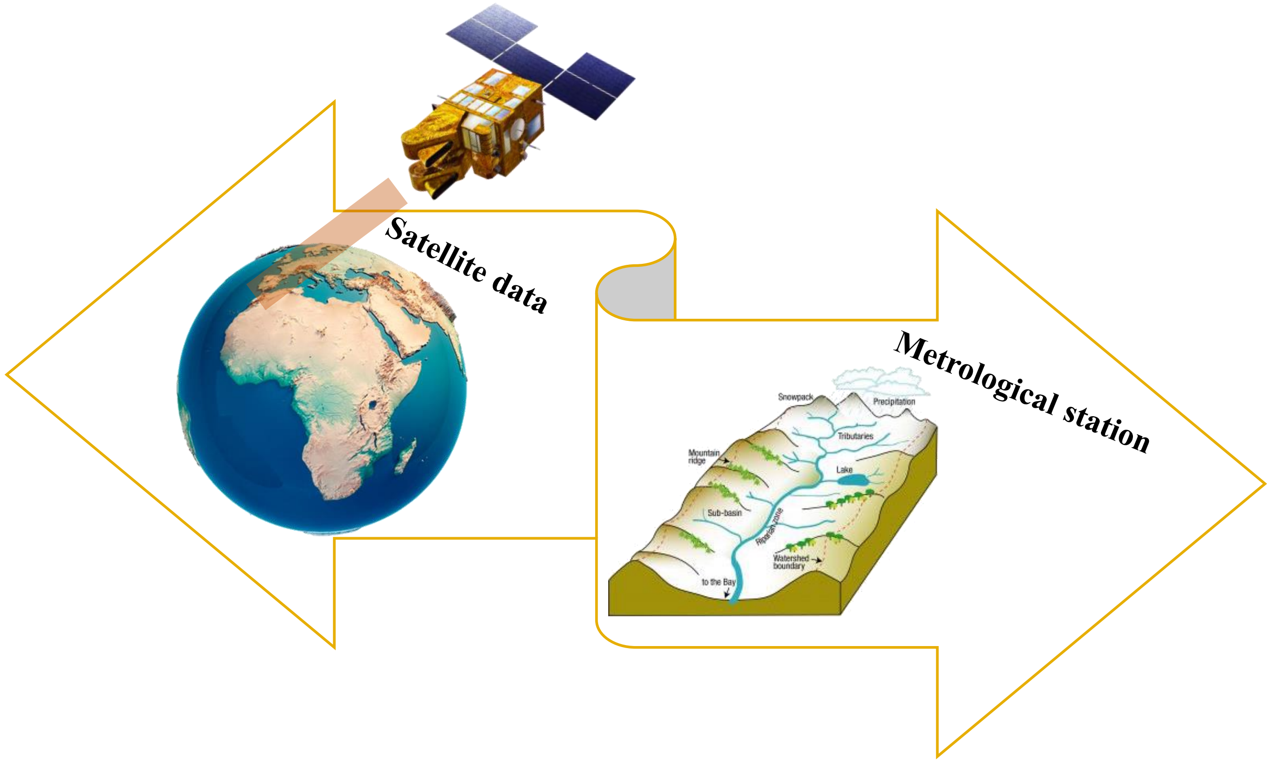
Moroccan High Atlas mountainous regions are strongly **affected** by **a high spatio-temporal variability** of **Rainfall - Runoff**.

Temporal dynamics of snow cover

- Start of the fall **Nov / Dec**
- Snowing period 2 to 5 months
- Total snow melt April

Pre-processing data

Satellite data were used to quantify the amount of snow, and to determine the percentages of vegetation per season over the Zat basins in order to assess the effect of snowmelt and vegetation on flash flood. Snow Water Equivalent data were extracted from SnowModel, especially from MicroMet ERA5, at daily time scale.



Data were provided by the Moroccan Meteorological Agency,

From an automatic meteorological stations that record a range of hydroclimatic data at a 10-minute scale,

From September 1, 2011 to August 31, 2018.

Snowmelt Simulation Capabilities within HEC-HMS

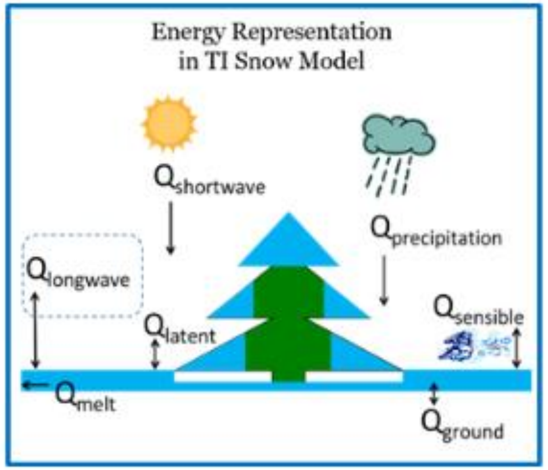
HEC-HMS include three methods for accumulating and melting snow.

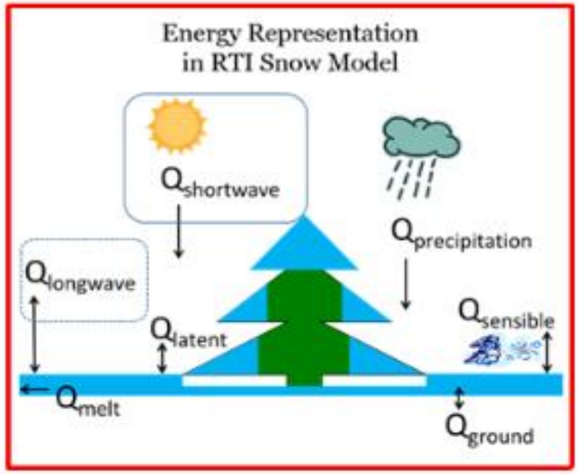
All three methods include means to discriminate between precipitation falling as rain or snow, form a snowpack, melt the snowpack, reformulate the snowpack when temperatures drop below a defined threshold, and eventually melt the entire snowpack.

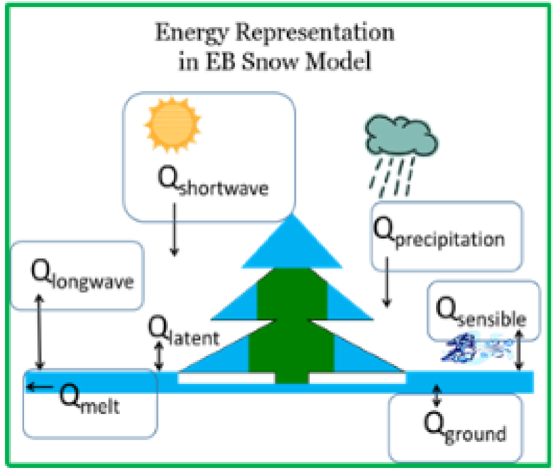
1- Temperature Index

2- Radiation-Derived Temperature Index (Hybrid)

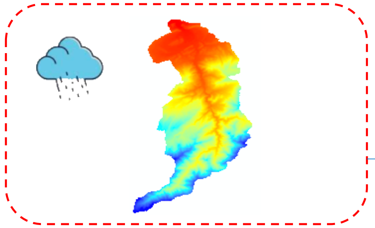
3- Energy Balance



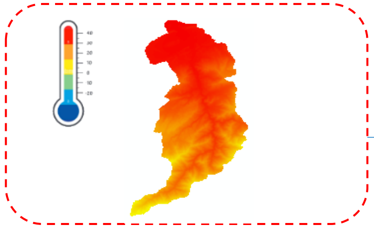




Rainfall

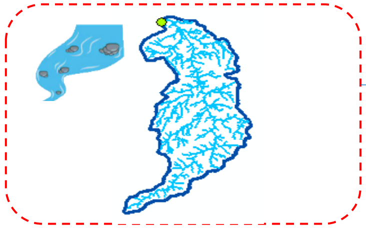


Air Temperature

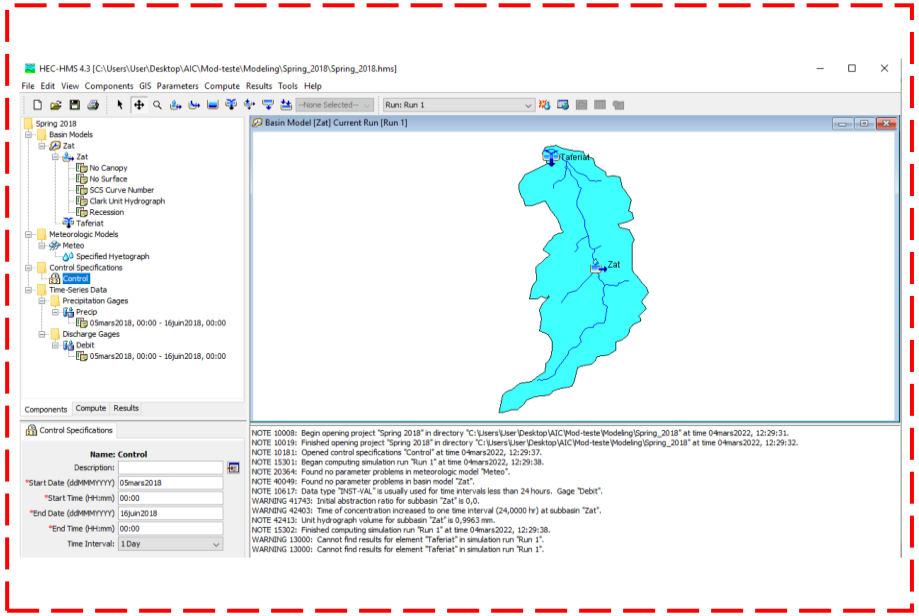


Snow Water Equivalent

Runoff



Steps to follow for Snowmelt Modeling on HEC-HMS



1. Create sub basins for observed temperature, precipitation and SWE data.

2. Create precipitation and temperature gages with all of the observed data (the temperature gages will require an elevation).

3. Create a meteorological model using specified hyetograph and temperature index methods for the Precipitation and Snowmelt components.

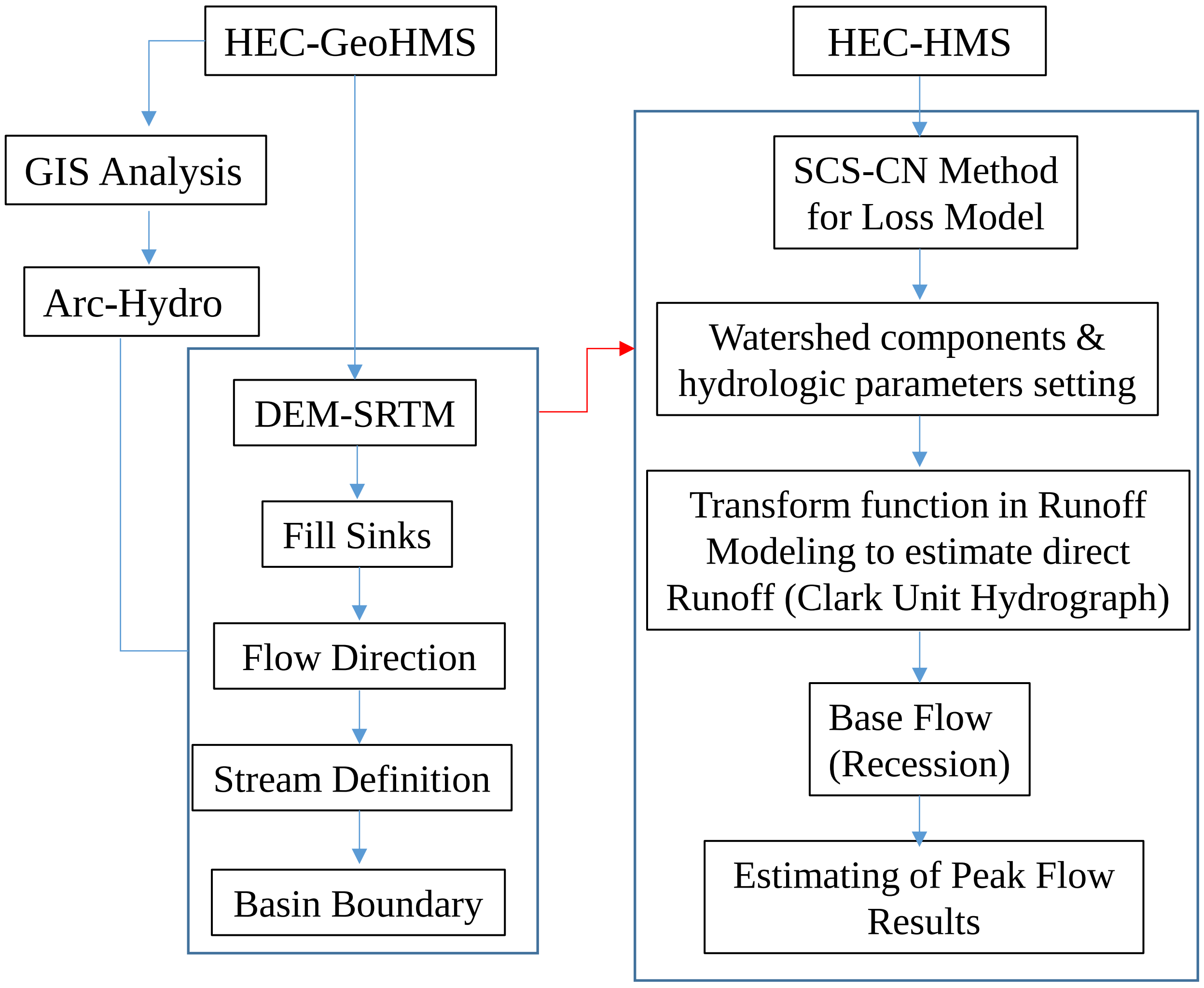
4. Enter initial temperature index parameters and assign all precipitation and temperature gages to the sub basin.

5. Create a control specification to run a desired length of time, which typically includes the complete snow accumulation and melt cycle for a given year.

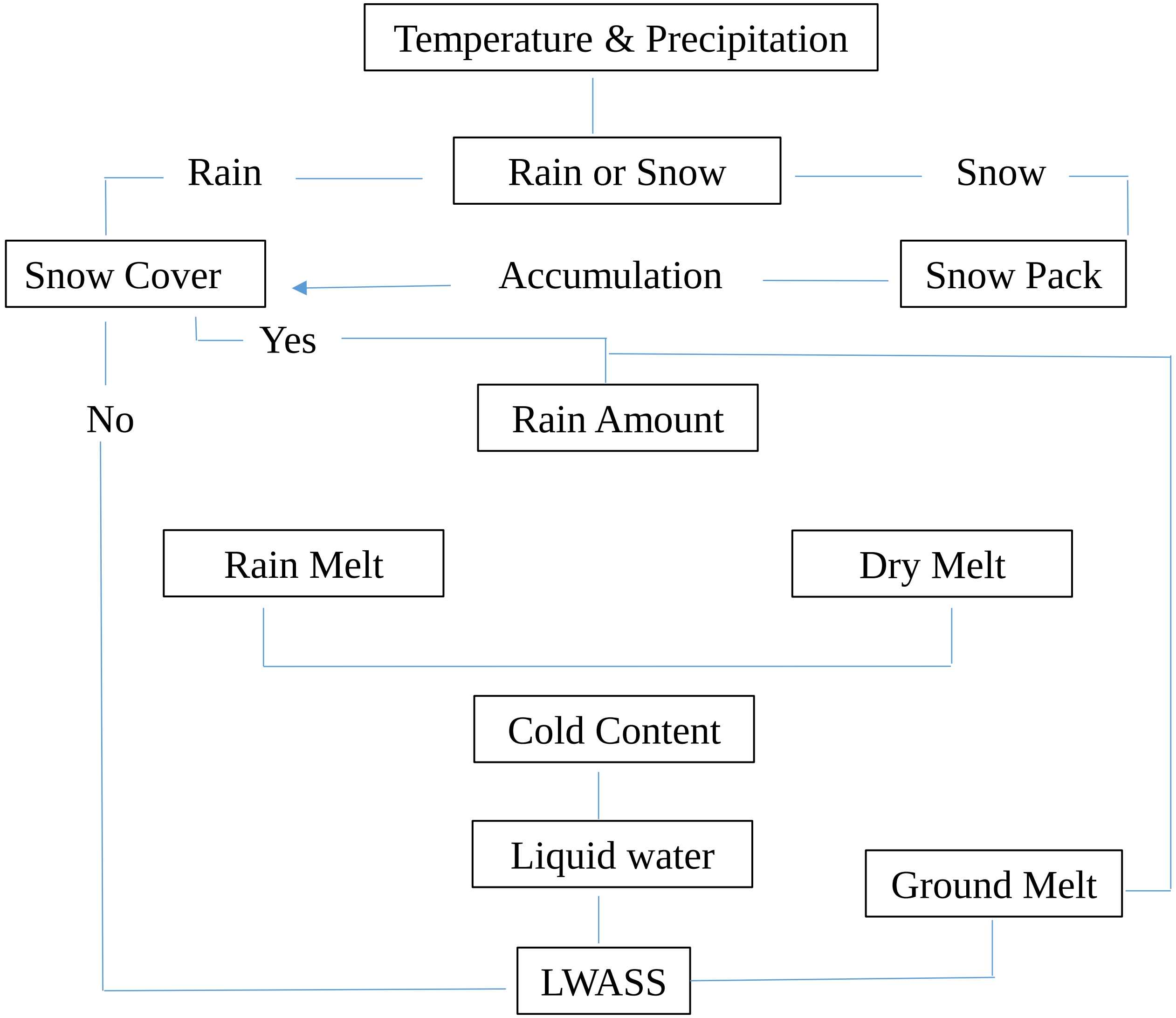
6. Create a simulation run and compare modeled and observed SWE at the outlet location.

7. Make changes to parameters and continue calibrating simulations to match the observed results.

Hydrological modeling (Rainfall – Runoff)



Hydrological modeling (Temperature Index)

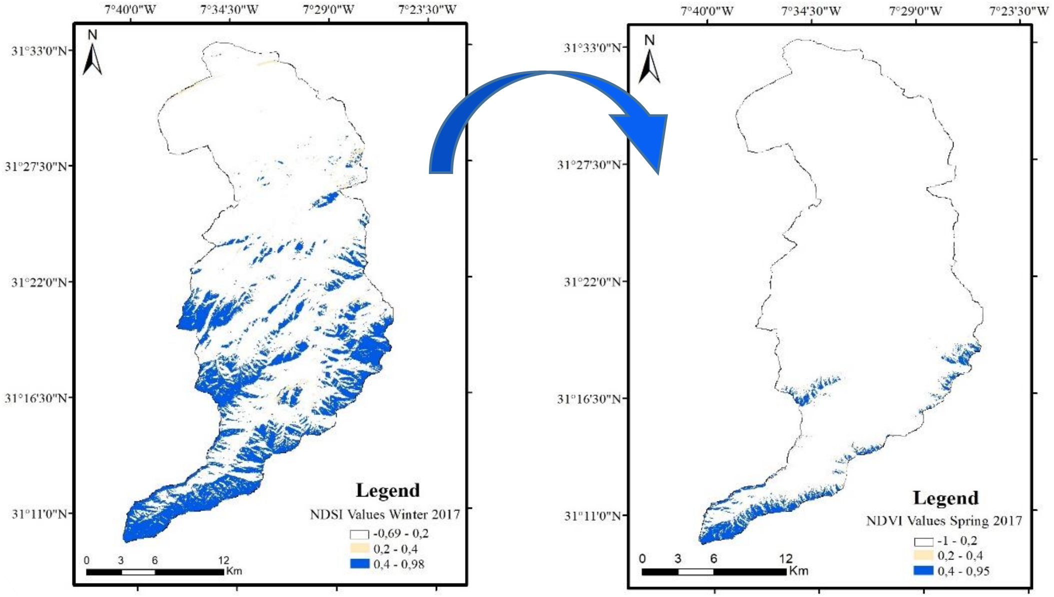


Spatio-temporal dynamics of snow cover by remote sensing

From Winter Snow to Spring Flow

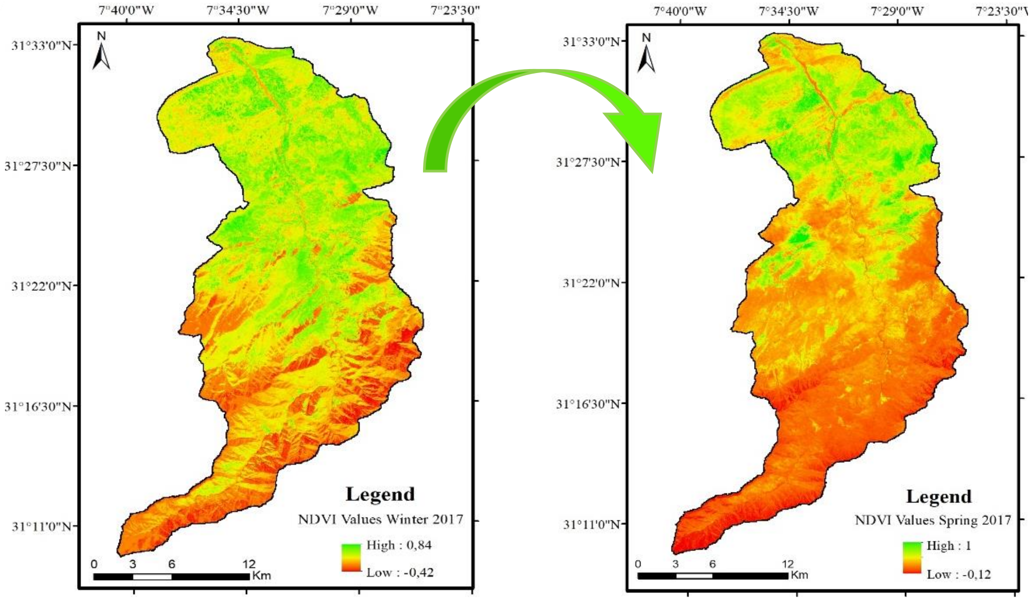
Basin	Season	Snow Area (%)
Zat	Winter	36.92
	Spring	26.84

N D S I

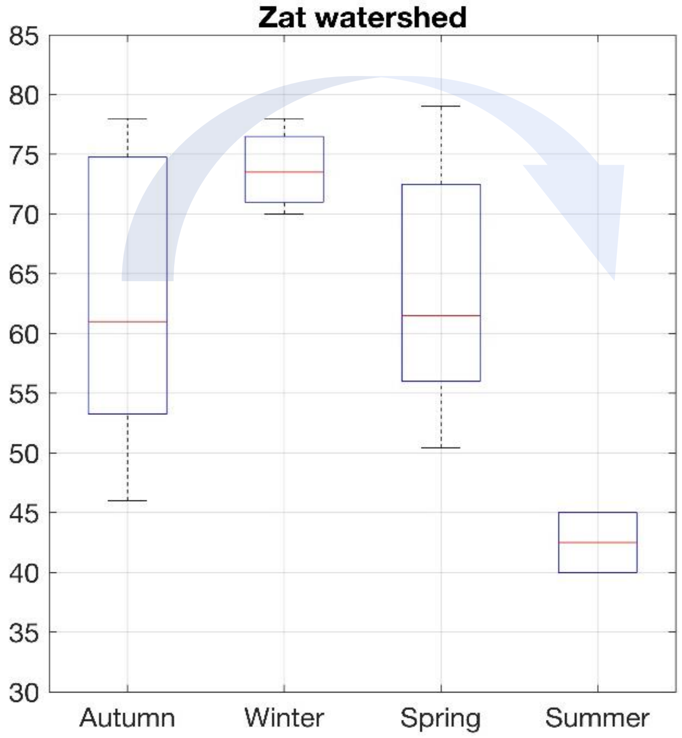


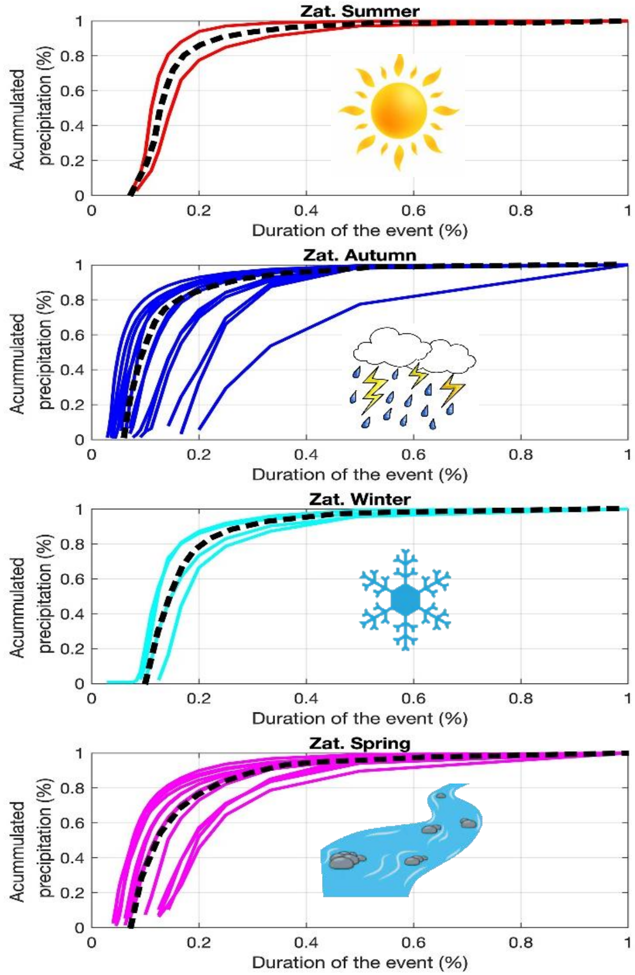
Théia Land data centre

N D V I

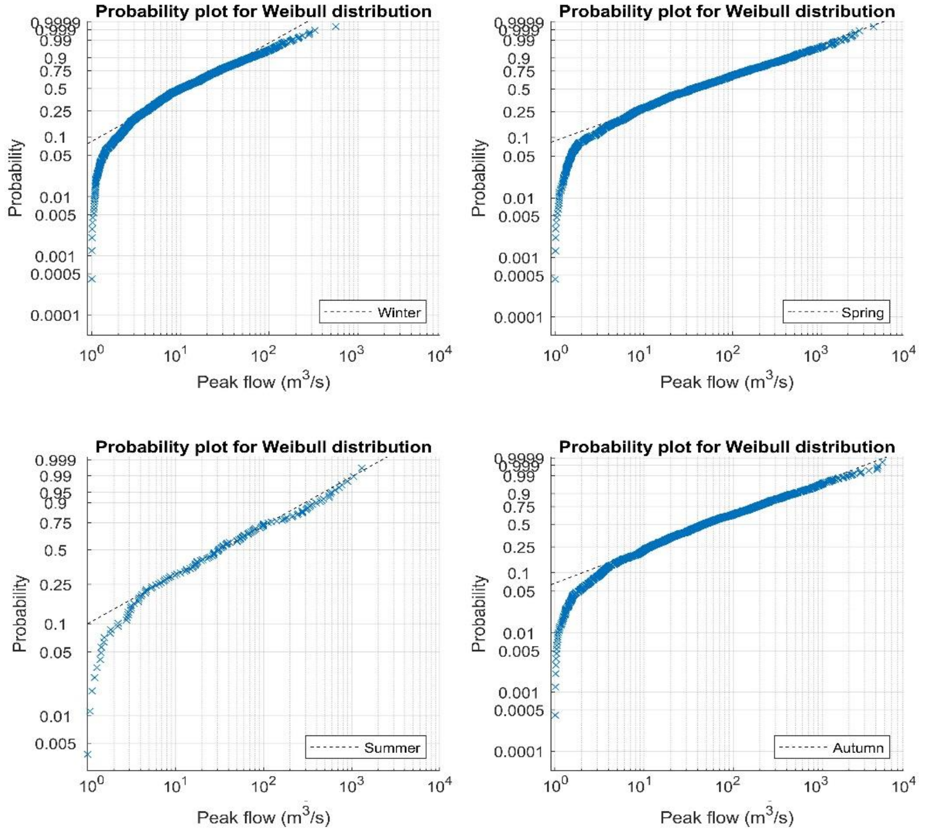


The seasonal behavior of the streamflow, can illustrate the effect of snowfall and snowmelt during winter and spring on the river discharge.

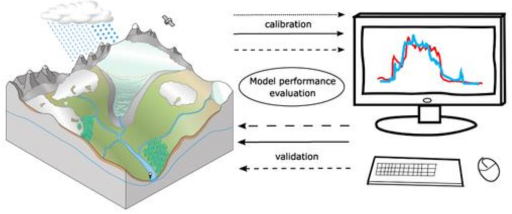


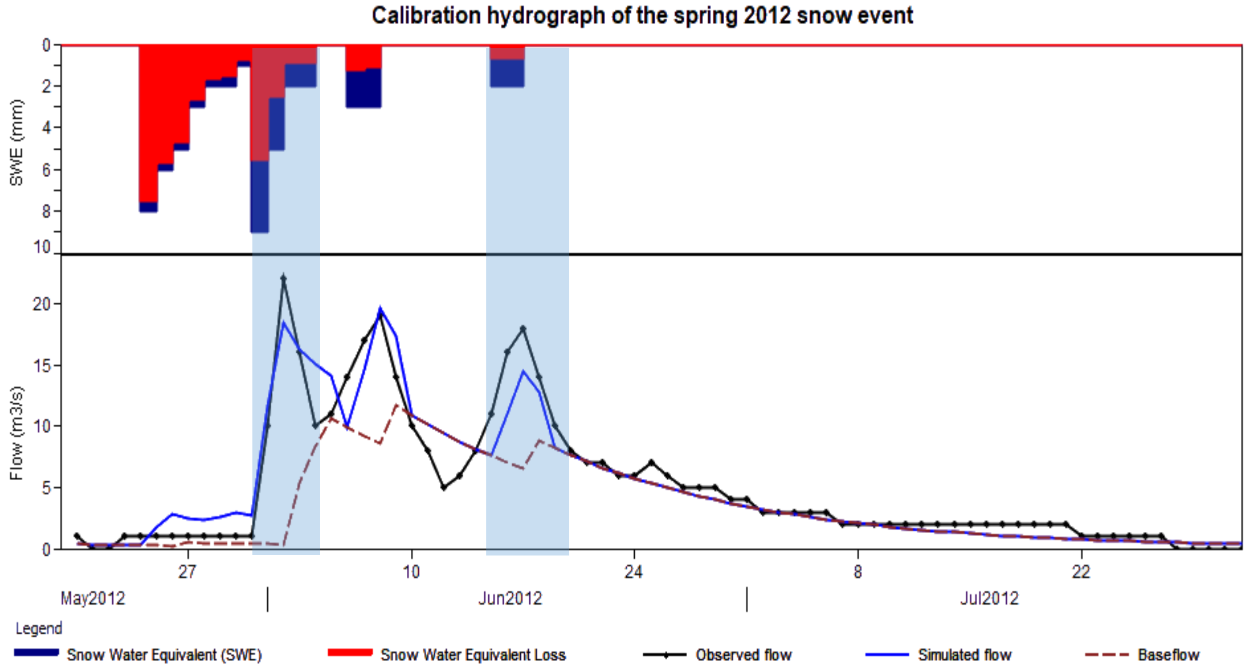


The probability of flooding has marked seasonal character, with the spring and autumn seasons showing the highest probability of extreme events. Thus, the probability of exceeding a maximum flow of 100 m3/s is 15% in winter, 30% in spring, 25% in summer, and 30% in autumn.



Based events modeling

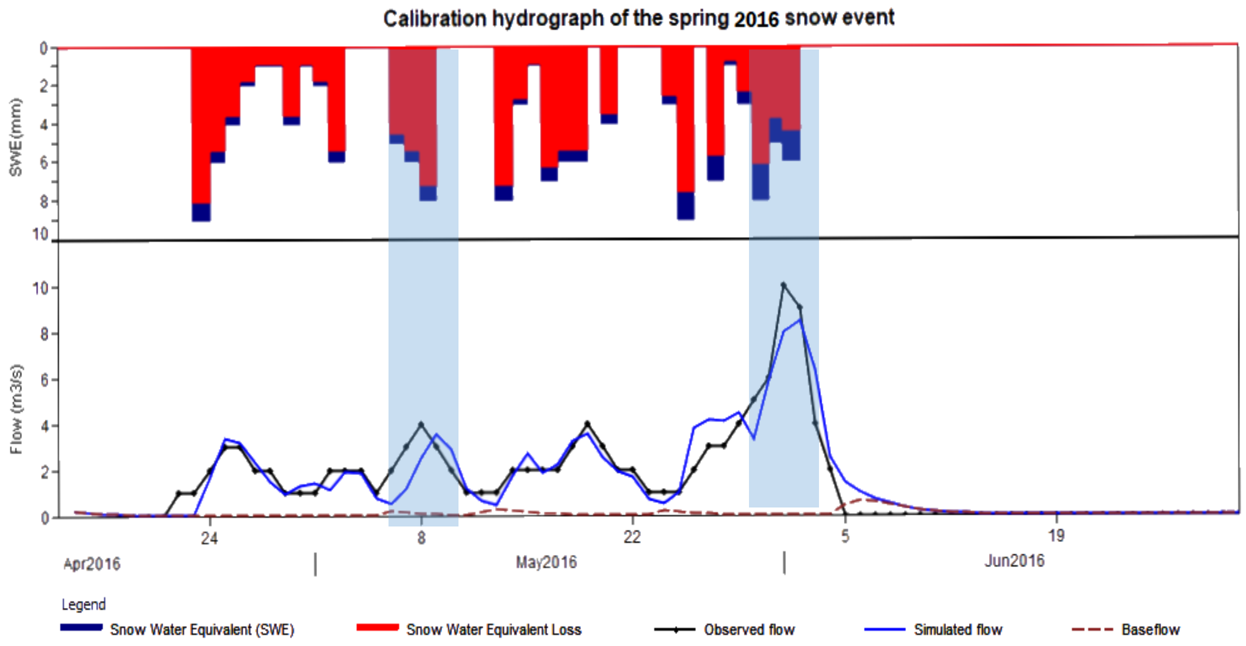




The HEC HMS model was able to reproduce a reasonable simulation of snowmelt runoff in the watershed. Thus, the obtained NSE were greater than 0.85 for the majority of snow events.

The Curve Number, percent impervious surface, and the runoff coefficient were the most sensitive parameters in the snowmelt calibration process.

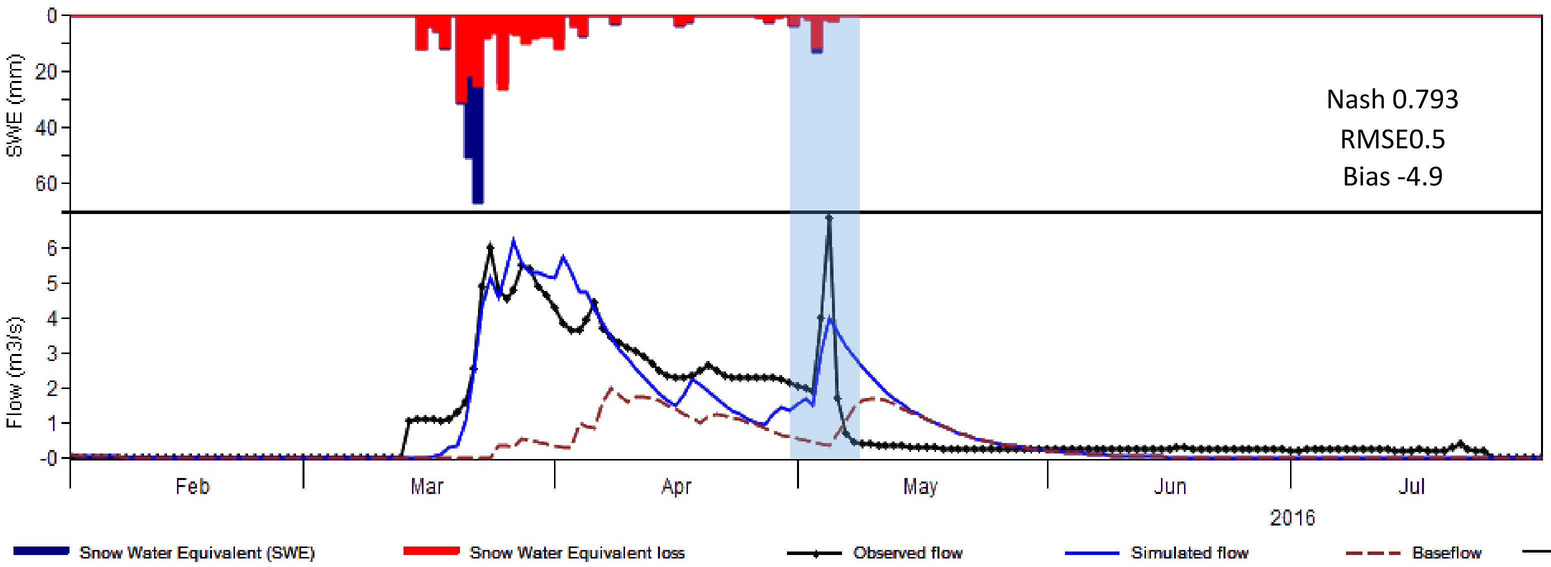
Events	Observed volume	Simulated volume	RMSE	NSE
Spring 2012	61.39	59.99	0.3	**90%**
Spring 2016	18.94	18.9	0.4	**86.50%**



Continuous modeling

The meteorological model consists of precipitation, temperature, and snowmelt processes

Calibration hydrograph for continus modeling "Feb / Jul 2016"



In this study, temperature index method is performed to compute the melt rate based on current atmospheric conditions and past conditions in the snowpack.

Basin model	Components	
	Initial Abstraction	0
Loss	Curve Number	6
	Impervious (%)	0
Transform	Time of concentration (HR)	1
	Storage coefficient (HR)	58
	Initial discharge	0.1
Baseflow	Recession	0.9
	Ratio	0.99

16 parameters in selected basin and meteorology component methods in HEC-HMS.

A manual calibration process of snow–water equivalent simulations have been made, each characteristic detail of the SWE curve, especially during the melting period, was primarily modeled in a physically meaningful way to analyze the events for future studies.

Meteorological models	
Lapse rate	5
Px Temperature (c°)	-2
Base Temperature (C°)	2
ATI coef	0.98
Wet Melt rate (mm/deg c-day)	1
Rain Rate limit (mm/day)	1
Cold limit (mm/day)	2
Cold rate coef	0.5
Water capacity (%)	4
Ground melt (mm/day)	10

- The study was designed for assessing the general performance of models regarding all aspects of hydrographs (low, medium, and high flows).
- The HEC-HMS model was successfully calibrated for the Zat basin on a daily time scale for the spring events 2012 - 2016.
- The sensitivity analysis of the model reveals that Curve Number, Percentage of Impervious Surface, and Runoff Coefficient are the most sensitive calibration parameters (in Based event).
- The NESs evaluation criteria's were between 90% for the 2012 event and 86.50% for the 2016 event at event scale modeling and 79.3% for the 2016, at continuous modeling, which demonstrates a good model adjustment.
- Based on the overall evaluation, it can be concluded that the used methodology can be applied to similar regions to asses the snowmelt effect.

THANK YOU FOR YOUR ATTENTION

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