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LONG-TERM HYDROLOGICAL MODELING OF 16 ARABLE LAND STATIONS, USING MEASURED AND INTERPOLATED CLIMATE DATA

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FOREWORD

This degree project is a part of a bigger project with the aim to describe trends and variability in the water balance for 16 selected agricultural fields during the latest 50-years period in Sweden. There are several specific objectives for achieving this purpose :

- Trends in measured runoff from selected agricultural fields.
- Estimation of the meteorological data for this 16 stations based by using complete meteorological data and a inverse distance weighting interpolation method.
- To clarify if trends in measured snow could be explained without consideration of land use changes.
- To estimate to which extent the uncertainty in simulation of runoff and snow depth will depend on the closeness to meteorological stations.
- To clarify to which extent the simulation of the water balance can be improved for a selected station if the parameters are allowed to vary between years as a possible result of corresponding variability of land use.
- To clarify if the trends in measured runoff and simulated evapotranspiration could be explained without consideration of land use changes.
- To describe to which extent obtained calibrated parameters differs between the different locations in Sweden.
- To clarify to which extent the simulation runoff can be improved by using a more detailed model structure compared with a simple model structure.

In this report, the first five objectives will discuss and explain explicitly.

SUMMARY

There are evidences and increasing intensity in debates that climate and land-use changes in recent decades imposed new behaviors of the environment in Sweden. With knowledge on significance and effects of these changes, it is easier and more solid to design monitoring measurements and risk assessment for future. The effects on water balance are related to changes in precipitation, climate, run-off and evapotranspitration trends.

In this project, changes in water balance were studied for different parts of Sweden in 16 research sites located in agricultural fields, where measured run-off were available. Run-off is a function of climate, soil and plants conditions. Changes in run-off response to climate in the long-run are therefore also indication of changes to the soil and plant conditions.

Meteorological variables (precipitation, mean, minimum, maximum and dew point temperature, wind speed, cloudiness and snow depth) were estimated by using a modified version of inverse distance weighting interpolation technique (IDW).

The major data used originated from the Swedish University of Agriculture Sciences (SLU) and Swedish Meteorological and Hydrological Institute (SMHI). The National Oceanic and Atmospheric Administration (NOAA) database available on internet was used for daily meteorological conditions.

Trend analyses were based on non-parametric Mann-Kendal statistical method with acceptance level of significance at 95%. In addition, hydrological simulations were made by the process oriented CoupModel. Performances of calibrations were described by using mean error and coefficient of determination between measured and simulated values of run-off and snow depth. There were three major sources of uncertainties of data used. Firstly, the uncertainty in the input meteorological data from the synoptic meteorological stations. Secondly, the uncertainty in the interpolation procedure to estimate the meteorological data for the runoff stations. Finally, the uncertainties in the measured runoff .In addition we have to consider uncertainty in the principles of the hydrological model itself that was used to describe the response of the climate and land-use on runoff. It was observed that the run-off had some trends according to geographical locations. Moreover, there were trend in yearly temperature for all stations. On the other hand, it was expected to find some trends in snow depth over the study period, but in contrast to expectations, there was not any significant trend in snow. By comparing the model performances for different stations, it was understood that the closeness of meteorological stations to the run-off stations have positive effects on the models results.

Land-use change was detected by the improved accuracy of allowing model parameters to change over time.

SUMMARY IN SWEDISH

Sammanfattning

Det finns många fakta och ökande intensiteti debatter gällande de avvikande beteendena i miljön i Sverige som klimat- och markanvändnings förändringarnaunder de senaste decennierna kan ha orsakat.Med kunskap om signifikansen och effekten av dessa förändringar är det enklare och mer säkert att genomföramiljöövervakningsmätnngar och riskbedömningar för framtiden.Effekterna på vattenbalansen är relaterade till förändringar i nederbörd, klimat, avrinning och avdunsting.

I detta projekt har förändringar i vattenbalansen studerats för olika delar av Sverige i 16 forskningslokalerpå åkermark, där mätningar avrinning har har gjorts. Avrinningen är beror av klimat-, jordmån- och växtförhållanden. Förändringar i avrinningsbeteendet indikerar därför och möjliga färändringar i mark- och växtförhållanden.Variabler som nederbörd, medelvärde, minimum, maximum, daggpunktstemperatur, vindhastighet, molnighet och snödjuphar uppskattas med hjälp av en modifierad version av interpolationstekniken som bygger på omvänt viktade avståndetskoefficienter.

De primära data som användsför trendanalys och indata i den hydrologiska modelleringen kom från; Svenska Lantbruksuniversitet (SLU) Sveriges Meteorologiska och Hydrologiska Institut (SMHI). En allmänt tillgänglig databasfrån National Oceanic and Atmospheric Administration (NOAA) användes för meteorologiska data.Trendanalyserna baserades på icke-parametriska Mann-Kendal statistiskametoder med signifikansnivå på 95 %.Förutom detta har hydrologiska simuleringar gjorts med processorienterad modelCoupModel. Modellens förmåga att återge mätningarna har beskrivits genom att använda medelfelet och determinationskoefficientenför uppmätta och simuleradevärden av avrinningen samt snödjup.

Tre grundläggande källor av osäkerhetfanns i de data som användes. Det första gällde osäkerhet i de ursprungliga meteorologiska data från synoptiska stationer, den andra gäller interpolationsfelen för att skatta de data som representerar de stationer där avrinningen har registrerats och den sista är osäkerheten i avrinningsmätningen. Dessutom tillkommerosäkerheter i antaganden som finns i den hydrologiska modellenDet observerades att det fanns en trend mellan avrinning och geografisk plats.Dessutom fanns det en trend i den årliga temperaturen för alla stationer.Förväntade trender för snödjup under den studerade perioden kunde dock inte urskiljas,Genom att jämföra modellens förmåga att återge mätningar för olikastationerkunder betydelsen av närheten meteorologiska stationer och avrinningspåvisast some en positiv effekt på modellresultaten. Färändrinar i mark-växt egenskaper indikerades genom att simulationsnoggrannheten förbättrades om parametrarna fick anta nya värden mellan olika delperioder.

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ABBREVIATIONS AND SYMBOLS

SLU	Swedish University of Agriculture Sciences
SMHI	Swedish Meteorological and Hydrological Institute
NOAA	National Oceanic and Atmospheric Administration
IDW	Inverse distance weighting interpolation
ME	Mean error
R^2	Coefficient of determination

ABSTRACT

The impact of anthropogenic activities on environment, especially the effect of land-use and climate changes was investigated in a series of studies. A comprehensive study of 16 research sites in different parts of Sweden was evaluated by using one dimensional hydrological model (CoupModel) to represent water and heat dynamics in layered soil profile covered with vegetation. Simulations are based on daily values and the results are representatives of variations in daily values and changes over years. The models accuracies controlled by measured run-off and snow depth values. However, there are uncertainties in both input data and simulated parameters. The interaction between run-off and snow depth were obtained when the models constrained by both run-off and snow depth. Parameters values variations and models performances changes in different time domains indicate the changes in land-use and climate over time and the model ability to handle these changes respectively. The strong interaction between meteorological stations density and models performances were indicated by comparing results with interpolation radius used for input data preparation.

Keywords: Climate change; Land-use change; CoupModel; Sweden

1 INTRODUCTION

Northern Eurasia is already known to be a sensitive responder to global climate variability and change, this region is being increasingly recognized as an active modulator of global climate. Anthropogenic climate change is likely to have a strong impact on seasonal snow cover over Northern Eurasia, which may in turn have climatic consequences throughout the Northern Hemisphere (Gong *et al.*, 2007).

There are concerns that climate change have effects on Sweden water balance. There are increasing trends for snow depth in Sweden by 0.3% per year (Kohler, 2006). There are evidence that there would be more water available in the northern part of Sweden (Bergström *et al.*, 2001).

There are also concerns on effects of land-use changes in Sweden. There are considerable changes in agricultural landscape over 50 years since 1945 (Ihse, 1995).

In general, there are coincidence of both land-use and climate changes. These changes can be evaluated by using hydrological models for understanding and prediction of environment behaviors. Even though using hydrological models is a little bit challenging and complicated, these are the best tools for understanding complex relations between air, plant and soil characteristics and different spatial and temporal variations.

Plant and soil regulating processes are complexly related to aboveground and belowground climate, especially in boreal regions. The heterogeneity at different temporal and spatial scales increases the difficulties in interpreting the dynamics of ecosystem processes. The use of a modelling tool provides a means to describe and understand interactions between forest and agricultural ecosystems and climate (Wu, 2011).

There are different models that can simulate environment behavior in the past or forecast the future. Different model structures ans setups results to different outcomes. It is obvious that model setup has a better application to south Sweden than middle Sweden according to their number of accepted runs. In general, all the sub-catchments show that the simulation from the second period (1982-2003) is better than the first period (1961-1981) (Zhang, 2011).

Models are limited to the availability of data. Data availability, consistency and validity are important aspects of every scientific research. In computer simulations and modelings, this is one of the most challenging parts. Long-term reliable data decrease uncertainties in trends evaluations of the data and the output results from models.

In this project changes in water balance are studied for 16 sites located in agricultural fields in different parts of Sweden. The environment is modeled by using the process-based hydrological model CoupModel . Simulations are based on seven meteorological variables (precipitation, minimum, maximum , mean and dew point temperature, wind speed and cloudiness) estimated by inverse distance weighing interpolation, and the accuracy controlled by comparing calculated run-off and snow depth values with measured run-off and interpolated snow depth.

1.1 Study objectives

The General objective is to describe trends and variability in the water balance for selected agricultural fields during the latest 50-years period in Sweden. This aim needs the following tasks to be done:

- To describe the trends in measured runoff from selected agricultural fields.
- To estimate the meteorological data for 16 stations based by using complete meteorological data and a inverse distance weighting interpolation method.
- To clarify if trends in measured snow could be explained without consideration of land use changes.
- To estimate to which extent the uncertainty in simulation of runoff and snow depth will depend on the closeness to meteorological stations.
- To clarify to which extent the simulation of the water balance can be improved for a selected station if the parameters are allowed to vary between years as a possible result of corresponding variability of land use.

2 MATERIALS AND METHODS

The study sites, trends analysis, and modeling are described here.

2.1 Study sites

The study sites in this project are located in 16 agricultural fields distributed in different parts of Sweden. Based on distribution of stations, the study areas divided to the North (above latitude 60), South (below latitude 58) and middle where is between the North and South (Figure.1). There are two stations in the north, ten in middle and the remaining four are in the south.

In the last 50 years, annual precipitation were 657, 691 and 727 mm and the mean annual temperature were 3.1, 6.4 and 7.8°C for the north, middle and the south sites respectively.

The data for these sites are measured data and estimated data.

2.1.1 Measured data

There are measured daily run-off for all these 16 sites by Swedish University of Agriculture Sciences (SLU) for 1972-2010. The longest dataset is for a station in the south with 37 years and the shortest is in the north with 14 years of data(Figure.3).

In general, there are some similarities in run-off between stations in different regions. In winter, there are usually no runoff in the north as all the precipitations are in snow, while in the south there are maximum run-off as a result of higher temperature (Figure.2).

On the other hand, there are high amount of run-off in summer as a result of snow melting in the north. In the middle in summer, there are peaks like in the north with lower amounts and there are run-off in winter and autumn like the south with lower amounts .

2.1.2 Estimated data

Meteorological stations are distributed over the country based on several regulations. Unfortunately, there were not meteorological stations with long-term data in our study sites. Therefore, eight meteorological variables are estimated based on nearby stations. These are precipitation, mean, minimum, maximum and dew point temperature, wind speed, cloudiness and snow depth.

For meteorological variables in Sweden, there are two major recourses. Firstly, the Swedish Meteorological and Hydrological Institute (SMHI) that is responsible for managing and developing information on weather and climate. There are free online records for 52 meteorological stations all around the country for 1961 - 2009. On the other hand, there is the National Oceanic and Atmospheric Administration (NOAA) that is a US federal agency focused on the condition of the oceans and the atmosphere. There are records for 405 meteorological stations in Sweden for 1973 - 2010.

There are various techniques for data interpolation like Thiessen, Kriging or Inverse distance weighting interpolation method (IDW). In this project, the IDW

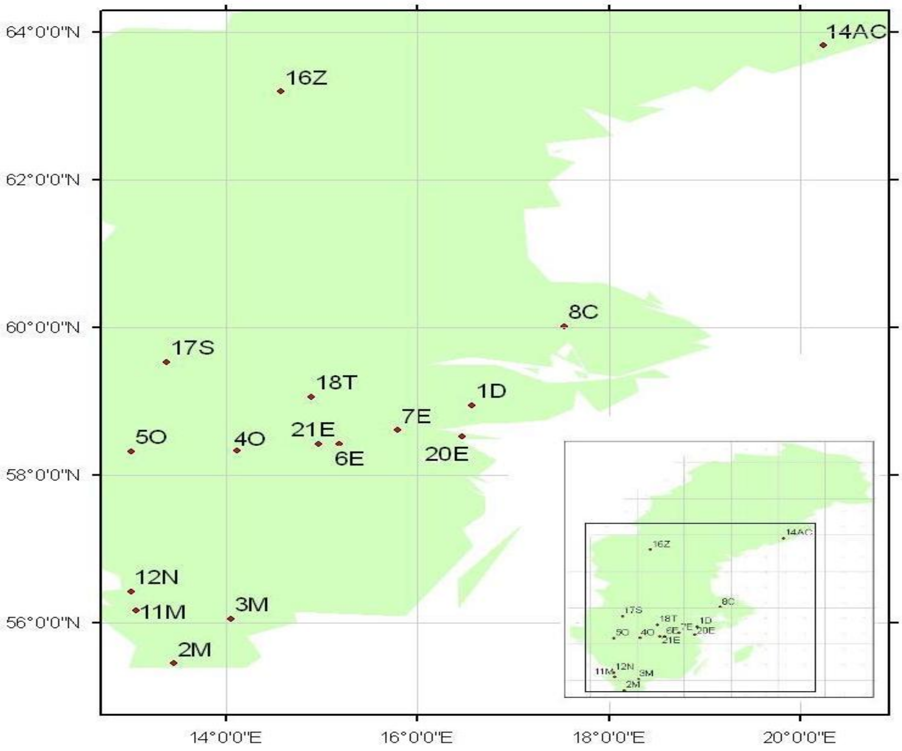


Fig. 1: Study sites and run-off stations used for models validation.

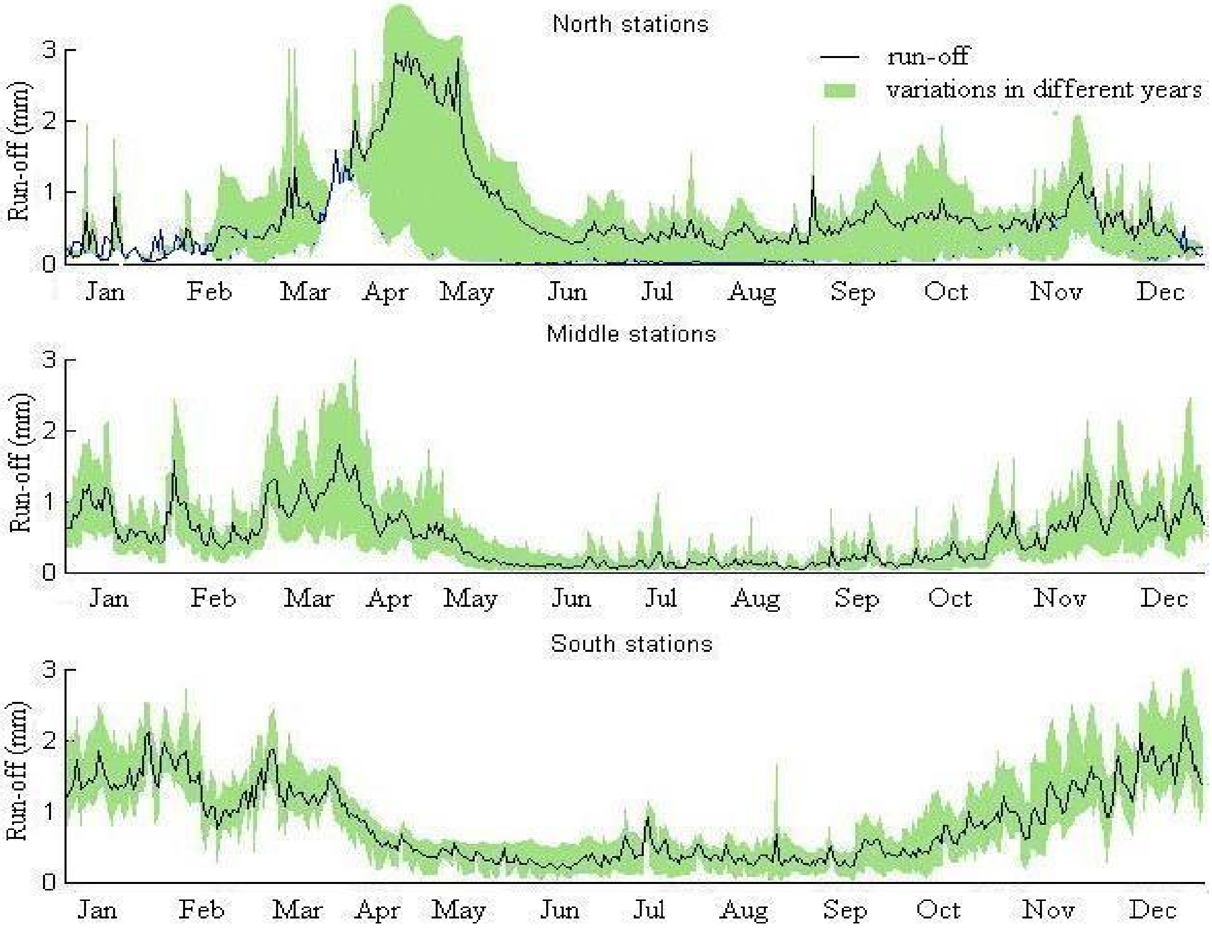


Fig. 2: Run-off for a common mean year in north, middle and south.

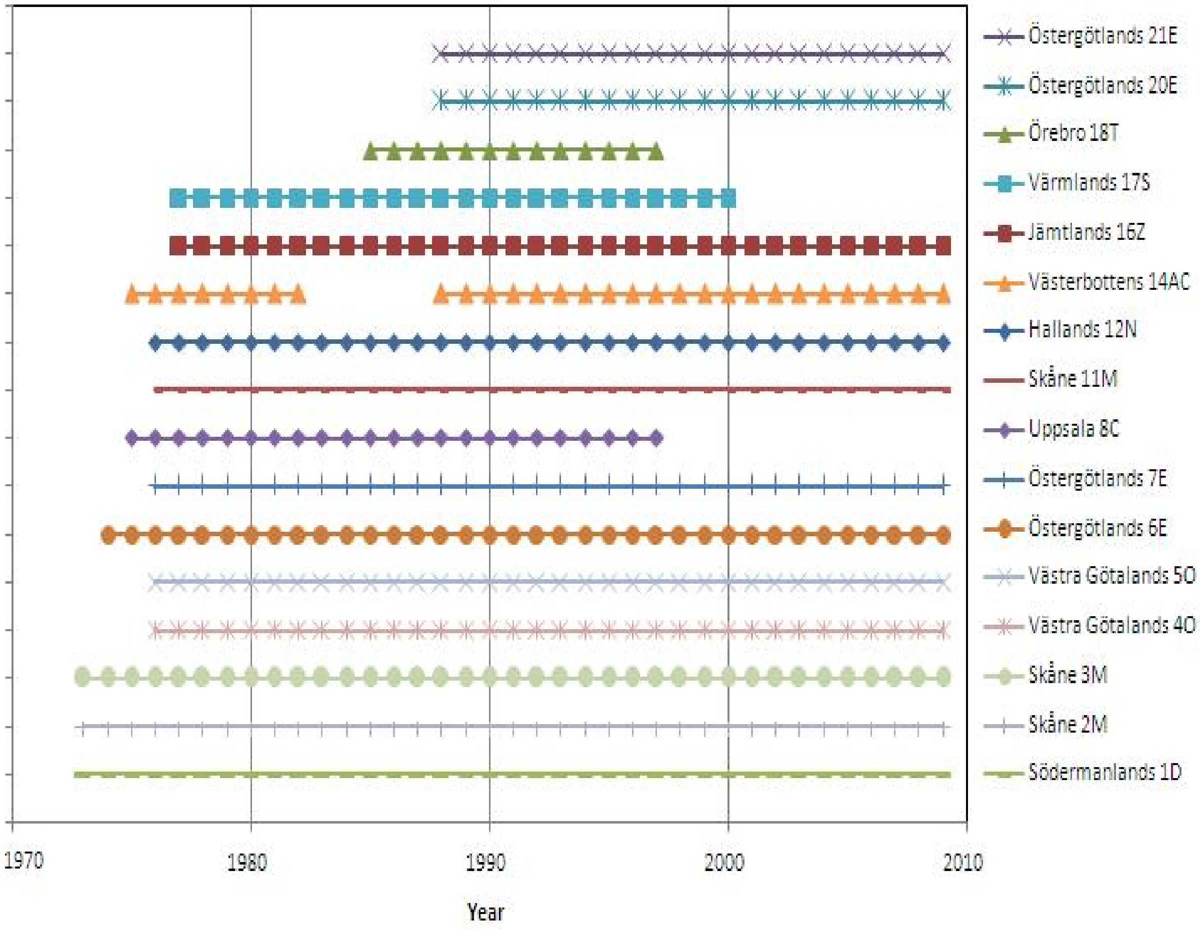
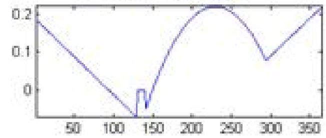
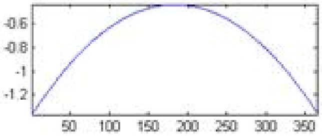
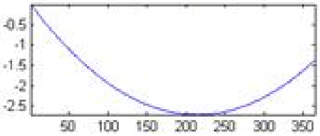
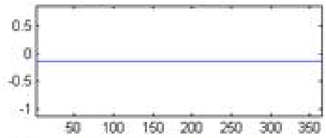
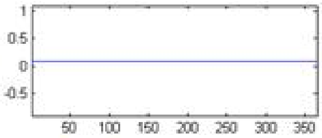
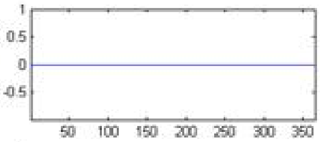
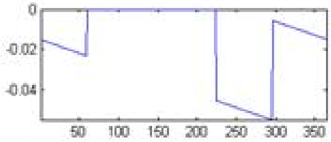
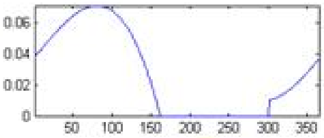
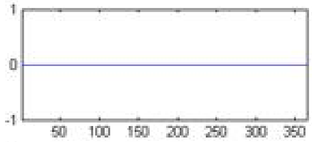
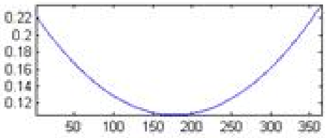
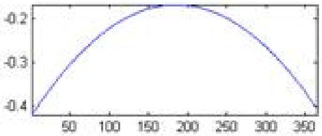
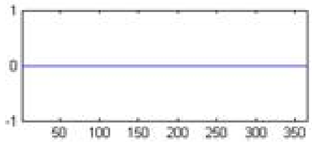
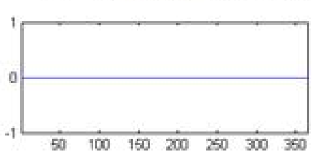
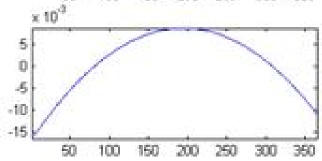
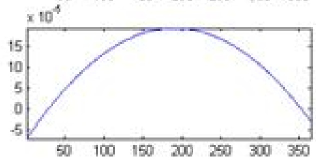


Fig. 3: Recorded run-off duration for different stations.

Table 1: Spatial trends in meteorological data based on days number.

Parameters	Longitude (x)		Latitude (y)		Altitude (z)
Temperature (mean, min, max and dew point)	c= -2.01e-3 d = 0.19	0 <x <130	b= -2.78e-5 c= 1.03e-2 d= -1.38		b= 5.93e-9 c= -2.55e-6 d= 1.87e-6
	b = -3.46e-5 c= 1.59e-2 d = -1.60	140<x <295			
	c= 1.97e-3 d = -0.50	295 <x<366			
Precipitation	d=-0.13		d=0.10		d=2.00e-4
Snow depth	c = -1.35e-4 d = -5.40e-3	x <130 x=x +71	a= -3.51e-8 b= 7.51e-6 c= 6.78e-5 d= 0.01	x >300 x = x - 300	No trend
		x >295 x=x-295			
	No trend	130 <x <295		x <300 x= x +66	
Wind speed	b= 3.69e-6 c = -1.31e-3 d = 0.22		b = -7.38e-6 c = 2.74e-3 d = -0.42		No trend
Cloudiness	No trend		b= -6.81e-7 c = 2.65e-4 d = -1.69e-2		b= -7.38e-9 c= 2.81e-6 d = -7.36e-5

Table 2: Spatial trends in meteorological data based on days number.

Parameters	Longitude (x)	Latitude (y)	Altitude (z)
Temperature (mean, min, max and dew point)			
Precipitation			
Snow depth			
Wind speed			
Cloudiness			

interpolation method (Lu & Wong, 2008) is used for building the databases for each study site.

Several factors influence the results of interpolations such as trends in different directions or number of stations involved in calculations. For instance, it is obvious that when we are going towards the north Pole the temperature decreases, therefore we have to remove these effects prior to starting interpolations.

In case of a trend, first we have to remove the trend and after interpolation return the trend back. Sometimes, de-trend and re-trend lead to negative values that is not correct for some variables like precipitation. We have to substitute negative values with zero for precipitation, snow depth, wind speed and cloudiness.

It is find out that there are trends as longitude, latitude and altitude changes for different variables by using stepwise regression technique (Draper & Smith, 1998) . However, the significance of these trends in different months is also another issue. For instance, mean temperature difference between the north and south in Sweden is about 50°C in winter while it is about 20°C in summer. Therefore, the trends are more significant in winter compare to summer for variables that relates to temperature. Table.1 contains trends equations for each variable based on the time of year and table.2 shows the trends .

In order to find the correlations in different directions a MATLAB code is used. The code arranges the available data for all the stations in last 50 years in Sweden and performs correlation tests for different directions and different days.

The relationship between trends and day of the year are in some cases polynomial for some linear and for some other independent with day of year.

Consider that the relationship as $y = ax^3 + bx^2 + cx + d$ where y is the trend in day x, and x is the day number (1 to 366). For the variables with linear relationship the *a* and *b* are zero and for those that are independent with day number *a* , *b* and *c* are zero (Table.1).

In order to build a database it is important to know how trustful the resources and methods are. One useful method for such purpose is to exclude a station and try to calculate the value of different variables for that station by using nearby stations. It is a good way to test not only the databases accuracy, the interpolation accuracy. Both SMHI and NOAA databases tested for such a test by using IDW interpolation technique . The variables are precipitation,mean, minimum, maximum and dew point temperature, snow depth and wind for both databases and cloudiness for SMHI only. The best results obtained when the number of nearby stations put to ten.

The inverse distance weighting interpolation method is very common for points that are distributed irregularly through space. Each point (station here) would have a weight dependent to its distance to reference point. The value in each point is the total of product of each station value and its weight divided to the total weights.

$$Z_p = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

$$W_i = \frac{1}{d_i^2} \tag{2}$$

Where Z_p is the interpolated value , Z_i is the variable (e.g. precipitation) value at location i, n is number of sample points, W_i is the weighting function and d_i is distance between Z_p and Z_i.

The variables value for each day calculated based on the nearest ten stations. If for a certain day one of these stations had no data the next station in nearby used. Moreover, we should be careful not to use values for one station two times as they can be the same for SMHI and NOAA. This problem solved by considering a minimum distance for using data of stations that are close to each other (i.e. 500 meters).

We used a pre-interpolation for filling gaps in databases where there were 1-2 days missing values in weeks with at least 5 days with records. Next , in case of a trend, we returned the trends back and corrected the negative values for precipitation, snow depth, wind speed and cloudiness. Finally yet importantly, we should be careful about snow depth. When there are not stations with values nearby the next station with data will be used for calculating the data. However, this lead to some errors for snow depth. Therefore, for days where the mean temperature of the day and average of mean temperature of the week are above zero we put the snow depth to zero. At the end, we use a normal interpolation to fill the gaps in databases similar the one in pre-interpolation part. Now we have meteorological values for each specific point in Sweden for 1961 - 2010.

2.2 Trend analysis

In order to find a pattern over time for measured and estimated data the non-parametric Mann-Kendall statistical method is used. The method is explicitly explained in appendix 1.

The results for Mann-Kendall test are from a code in MATLAB by Madaeni (2012). In Mann-Kendall test, the criterion for accepting the availability of a trend is level of confidence (F(Z)) at 95%.

Trends were studied for all eight meteorological variables and the measured run-off in the study sites.

2.3 Modeling

A hydrologic model may be defined as a simplified conceptual representation of a part of the hydrologic cycle of a real-world system (Gupta, 2010). There are two major types of hydrological models; Stochastic models that are mainly based on finding relationships between parameters and calculating the data based each other(e.g. simulating run-off by using precipitation with help of regression technique) and process-based models are representative of real world physical processes. These models are more complicated than stochastic models.

2.3.1 *CoupModel*

Numerical modelling is just the final stage of a prediction exercise, and its success relies solely on the conceptual model that has been developed at a very preliminary stage from the coupling of data of different origin (Cesano *et al.*, 2000). In this project the used numerical models is physically based CoupModel. In addition, the Hydrologiska Byråns Vattenbalansavdelning model (HBV) which is an complementary module inside CoupModel is also used.

The CoupModel is a one-dimensional model for simulation of fluxes of water, heat, carbon, and nitrogen in a soil-plant-atmosphere system (Gustafsson *et al.*, 2006). The model represents water and heat dynamics in a layered soil profile covered with vegetation (Jansson & Kalberg, 2011).

Models have the ability to work with different setups and assumptions. Furthermore, there are also differences between CoupModel and HBV structures. Models structures and setups used in this project are available in Table.9.

2.3.2 Models variables

Driving variables used in models are precipitation, mean, minimum, maximum and dew point temperature, wind speed and cloudiness.

There are totally 33 parameters related to soil, plant and air that are calibrated by using the Monte Carlo sampling method (Table.10). Calibrations are based on 20000 multi-runs for 1961-2010 for each station. Other parameters set to fixed values based on experiences in the previous studies (Zhang, 2011).

2.3.3 Models validation and calibration

Models accuracies controlled by comparing simulated values for run-off with measured values by SLU, snow depth with estimated values by interpolation and constraining both run-off and snow depth simultaneously.

The criteria that were used are mean error (Eq. 9) and coefficient of determination (Eq. 10). As a general validations criteria, all the accepted simulations should have a mean error of less than |0.1|. However, R^2 is different in different regions

3 RESULTS

Results for trends analysis and modeling are presented here.

3.1 Trends of run-off and climate conditions

For all measured and estimated data, trends calculated based on non parametric Mann-Kendall method. For measured run-off in winter[1], there were increasing trends mainly in the stations that are located in the north and middle. Trends in summer were just in middle and in one station in the south (12N), when in spring only two stations in the middle (20E and 21E) had trends. Moreover, in autumn there were only increasing trend in 21E station in middle.

In general, trends in the north were in winter, in the south in summer and in the middle in all season there were trends in different station. What is more, in yearly run-off there are only increasing run-off in some stations in the middle.

S in table.5 is the strength of Mann-Kendall statistics (Eq.3) and works as an indication for magnitude of the trends. As a whole, there are some relations between the S and the level of confidence (f(Z)). The higher the S the higher the f(Z).

Among climate variables, temperature is predominant in trends in all parts of the country. All the stations had increasing trends in yearly statistics as well as in spring in seasonal statistics. In winter and summer, 15 stations out of 16 stations had trends but for autumn only seven stations showed trends.

Precipitation had increasing trends in some stations in the north and middle and they occurred especially in the winter or summer.

Furthermore, there is only in Jämtlands (16Z) that there was an increasing trend for wind speed.

For snow depth and cloudiness, there were no trend based on Mann-Kendall tests (Table.3). Trends in snow depth were interesting as it was also a validation variable. However, there are not any significant trend for snow depth in both seasonal and yearly considerations. The highest obtained value is in Värmlands (17S) with $f(z) = 0.86$ in winter which is lower than the acceptable range of 95% (Table.6).

Moreover, trends in run-off are to some extent visible by looking to the figure 4 for two 10-year periods from 1989 until 2008.

3.2 Simulated run-off and snow

Models results are for 1961-2010 with the specific models setups (Table.9) used for calculations . Accuracy in results are dependent to simulations accuracy. Models accuracies controlled by using mean error and coefficient of determinations (R^2). The results are based on highest R^2 and mean error of less than |0.1| for run-off and snow depth independently and together (Table.4). Constraining both run-off and snow depth together provides further information on how each variable influence the other one performance as well as the whole model performance.

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[1] Seasons are based on calender days. winter (Dec-Feb), spring (Mar- May), summer (Jun-Aug) & Autumn (Sep-Nov)

Table 3: Increasing trends (stations sorted from north to south)
R = run off, T = temperature, P = precipitation, W = wind speed.

Station	ID	winter	Spring	summer	autumn	yearly
Västerbottens	14AC		T	T		T
Jämtlands	16Z	R T P W	T	T	T	T P
Värmlands	17S	R T	T			T
Uppsala	8C	R T	T	T		T
Örebro	18T	T P	T	T P	T	T P
Östergötlands	7E	R T	T	T	T	T
Västra Götalands	4O	R T	T	R T	T	R T
Västra Götalands	5O	R T P	T	R T		R T
Östergötlands	20E	T	R T	T	T	R T
Östergötlands	21E	T	R T	R T	R T	R T
Södermanlands	1D	T	T	R T		T
Östergötlands	6E	T	T	R T	T	T
Hallands	12N	T	T	R T		T
Skåne	11M	T	T	T		T
Skåne	3M	T	T	T		T
Skåne	2M	T	T	T		T

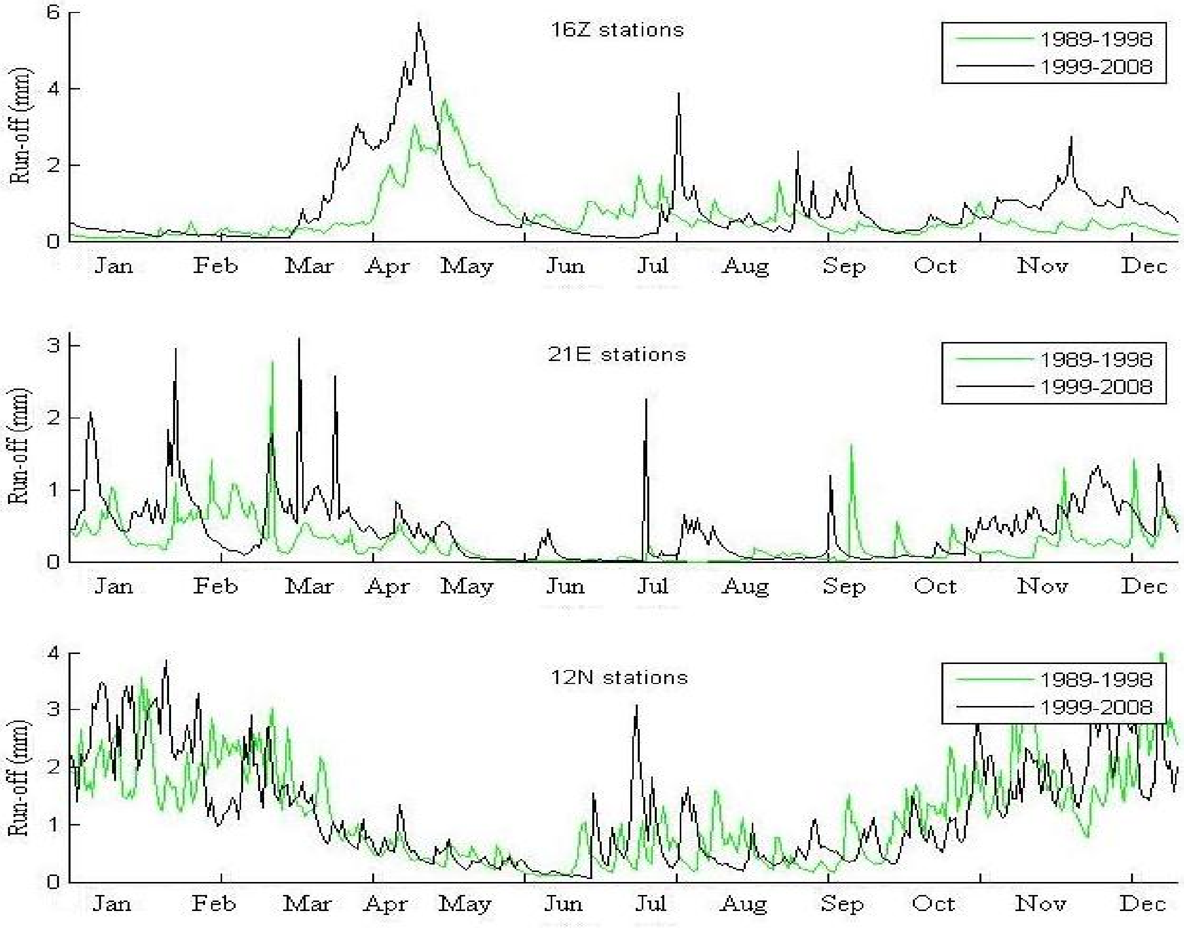

Fig. 4: Run-off for a common mean year in 16Z, 21E & 12N stations (north, middle & south).

Table 4: Model performances (R^2) in different time domains & interpolation radius .

Region	ID	Snow		HBV		Both		Interpolation radius (km)
		All	$\binom{1st}{2nd}$	All	$\binom{1st}{2nd}$	$\binom{Snow}{HBV}$	Accepted runs	
Södermanlands	1D	0.64	$\binom{0.73}{0.52}$	0.32	$\binom{0.38}{0.30}$	$\binom{0.59-0.61}{0.30-0.31}$	6	143
Skåne	2M	0.13	$\binom{0.19}{0.13}$	0.48	$\binom{0.49}{0.51}$	$\binom{0.10-0.11}{0.38-0.44}$	5	135
Skåne	3M	0.28	$\binom{0.43}{0.24}$	0.37	$\binom{0.57}{0.30}$	$\binom{0.24-0.25}{0.32-0.34}$	7	110
Västra Göta-lands	4O	0.56	$\binom{0.71}{0.42}$	0.33	$\binom{0.42}{0.34}$	$\binom{0.50-0.51}{0.32-0.33}$	5	92
Västra Göta-lands	5O	0.42	$\binom{0.67}{0.25}$	0.47	$\binom{0.55}{0.46}$	$\binom{0.40-0.40}{0.40-0.42}$	11	80
Östergötlands	6E	0.63	$\binom{0.74}{0.48}$	0.34	$\binom{0.40}{0.31}$	$\binom{0.60-0.62}{0.31-0.34}$	6	92
Östergötlands	7E	0.66	$\binom{0.74}{0.46}$	0.41	$\binom{0.47}{0.41}$	$\binom{0.60-0.61}{0.40-0.41}$	5	115
Uppsala	8C	0.54	$\binom{0.64}{0.43}$	0.19	$\binom{0.16}{0.30}$	$\binom{0.49-0.52}{0.17-0.19}$	7	159
Skåne	11M	0.19	$\binom{0.33}{0.24}$	0.35	$\binom{0.45}{0.26}$	$\binom{0.17-0.18}{0.20-0.29}$	6	102
Hallands	12N	0.34	$\binom{0.52}{0.25}$	0.51	$\binom{0.55}{0.50}$	$\binom{0.32-0.33}{0.40-0.44}$	6	101
Västerbottens	14AC	0.39	$\binom{0.39}{0.40}$	0.06	$\binom{0.12}{0.01}$	$\binom{0.31-0.39}{0.001-0.06}$	6	165
Jämtlands	16Z	0.73	$\binom{0.78}{0.70}$	0.50	$\binom{0.60}{0.45}$	$\binom{0.71-0.73}{0.48-0.50}$	7	81
Värmlands	17S	0.53	$\binom{0.72}{0.32}$	0.21	$\binom{0.32}{0.14}$	$\binom{0.48-0.52}{0.18-0.21}$	6	101
Örebro	18T	0.55	$\binom{0.65}{0.46}$	0.13	$\binom{0.06}{0.22}$	$\binom{0.46-0.50}{0.11-0.13}$	8	117
Östergötlands	20E	0.63	$\binom{0.73}{0.50}$	0.31	$\binom{0.39}{0.31}$	$\binom{0.53-0.59}{0.30-0.31}$	7	122
Östergötlands	21E	0.60	$\binom{0.70}{0.48}$	0.31	$\binom{0.33}{0.35}$	$\binom{0.55-0.57}{0.29-0.30}$	5	92

The average interpolation radius, which is the average distance in km between the desired point and the ten nearest stations with data in nearby, for each station is also included in the Table.4 for finding the relationships between closeness to meteorological stations and model accuracy. In general, for both snow depth and run-off by HBV the performance decreases as distance increases. There are about 0.2 and 0.1 decline in R^2 value (20% & 10% in model performance) for run-off and snow depth respectively per each 100 km (Figure.5).

Mean error behaviors also had variations based on interpolations radius. Stations with smaller interpolations radius had smaller mean error ranges compared with those with larger distance to meteorological stations (Figure 6 & 7).

CoupModel provides the ability to divide the completed simulations to several sub-periods. For further investigation, the simulations were divided into two sub-periods in order to evaluate the changes in performance when the plant and soil parameters can change during each sub-period. In general, There are improvement in performance in the first period for both run-off and snow depth ,while this is reverse for the second period (Figure.8).

Changes in performances had some relations with the stations locations. For snow, R^2 values increased from north to south in first sub-period, while in the second sub-period there were decreasing of R^2 in the middle. On the other hand, run-off simulations had improvements in the north and the south in the first sub-period and became worse in the second sub-period.

Changes in soil and plants parameters values in different sub-periods are representative of changes in surrounding environment. There were not regular changes in different stations (Figures 9 & 10). In general, h_{Opt} and a_{veg} had the lowest variations and m_T , m_{Rmin} and r_{Start} had the greatest changes between different sub-periods. The direction of changes were not the same. However, in some parameters increasing were predominant and in some other decreasing.

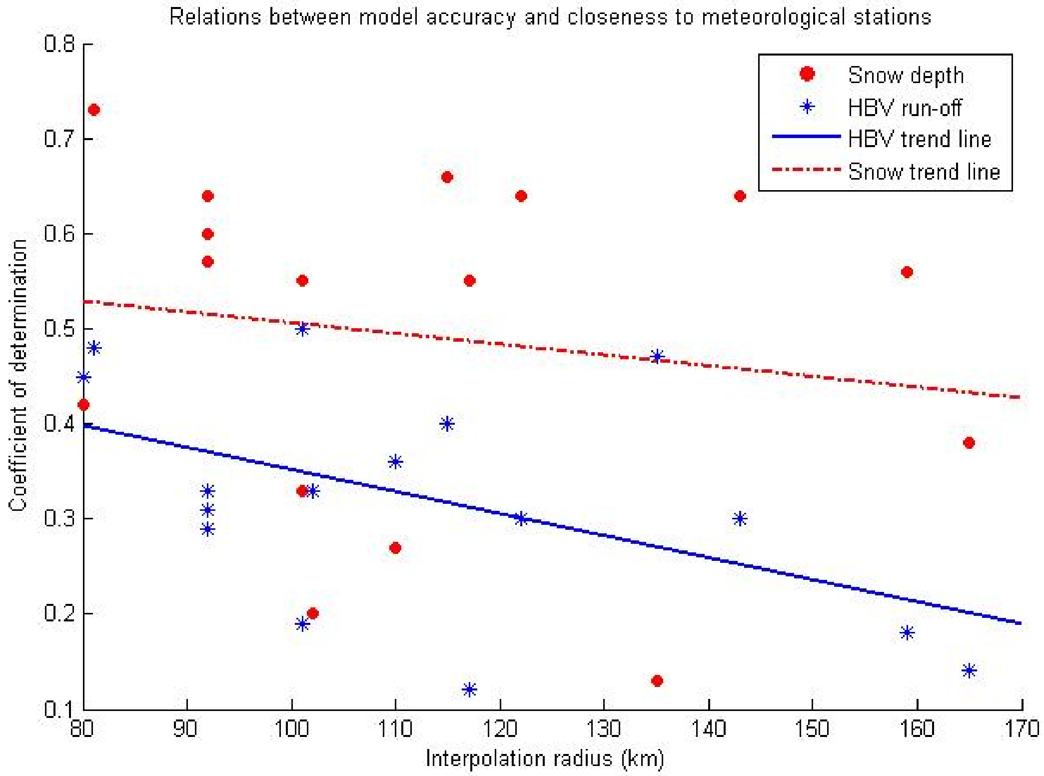

Fig. 5: Changes in model performance by increasing interpolation radius.

4 DISCUSSION

Increasing trends in measured run-off in winter in the north can be as a result of warmer winters. Normally, all the precipitation in the north was as snow in winter and there was no run-off for this season. However, as a result of increasing trends in air temperature a proportion of precipitation or a fraction of the snow on the ground could become as run-off (Figure.2).

Run-off trends in the south were in summer. In summers there was neither snow for melting nor increasing trend for precipitation in this region, therefore it was not possible to explain the trends just by considering climate change effects. There were probably other variables that were responsible for these changes. These trends can originate from land-use changes as alteration in soil and plants characteristics can lead to increases in surface run-off.

Trends in run-off were in winter, summer and yearly in the middle. In general, there were run-off for the whole year only in the middle, therefore, the increasing trends in yearly runoff were only visible in the stations in this region. Except for one station, trends in yearly run-ff were only for the stations that had trends in seasonal run-off for more than one season (Table.3).

Increasing trends in yearly air temperature were detected in all the stations. Moreover, except for autumn the increasing trends in temperature were visible for almost all the regions. Furthermore, similar to run-off trends in precipitation had correlations with latitudes, where there were trends in precipitation only for the stations in the northern part of the country.

According to previous studies (Kohler, 2006) there were observations that had shown trends in snow depth. As far as, observed trends need a strong probability, we did not consider any trends for snow depth as all the trends had a level of confidence of less than 95%.

What is more, there were changes in models performance in relation to the distance to the stations that used for data preparation. When the average distance of stations that were used in preparing input data was small that meant the density of stations that had data were good for that region. In the north, the distance between the stations were more than what was in the

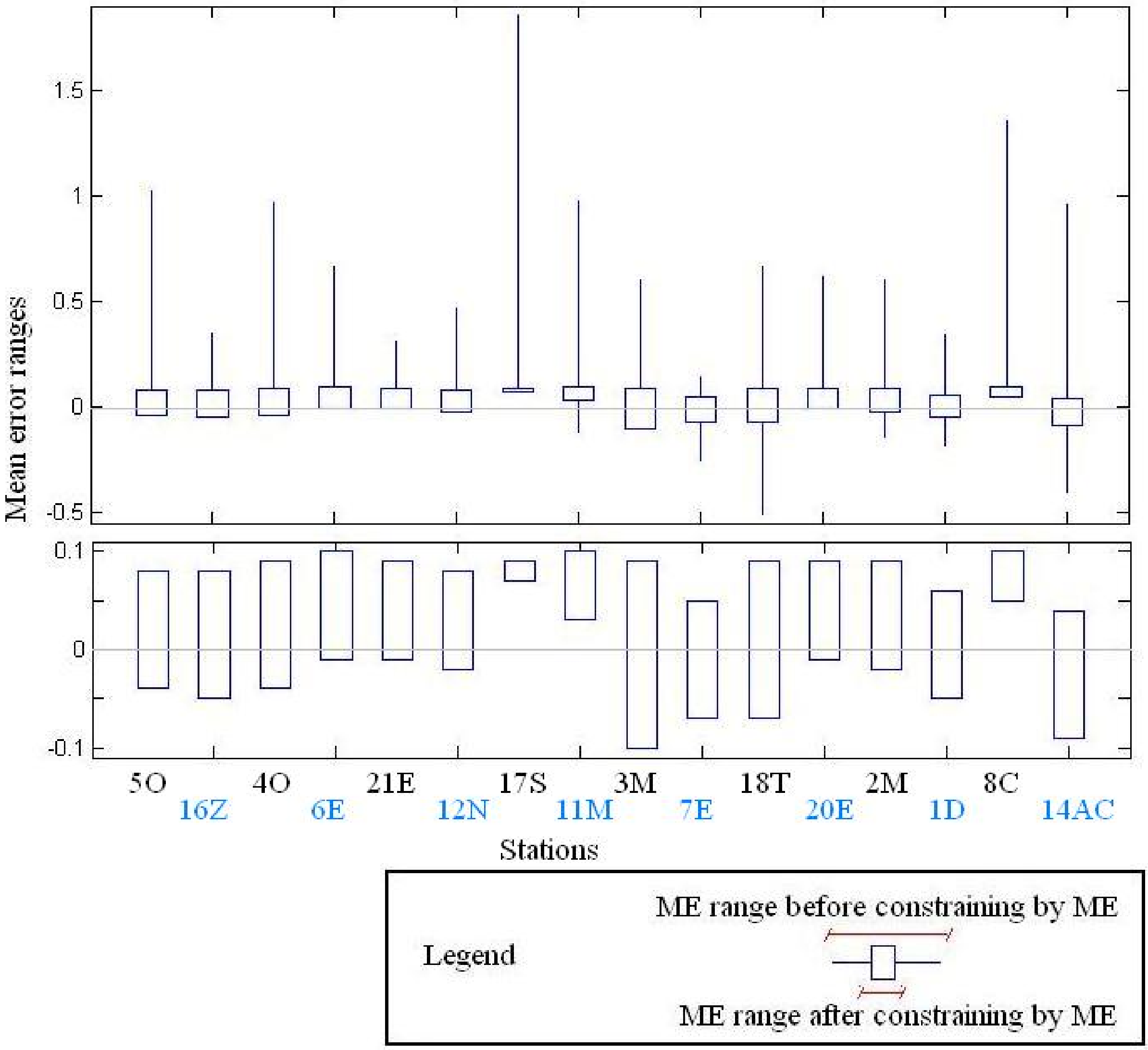

Fig. 6: HBV run-off mean error ranges befor and after constraining by -01<ME<0.1 (Stations sorted from left to right based on interpolation radius).

middle and the south. Therefore, it was normal when the model performances for the stations in the north be worse than those located in the middle and the south. This was true in the case of Västerbottens (14AC) with the the worst R^2. However, the Jämtlands (16Z) was an exception. Although, this station was located in the north it was very close to one of the SMHI meteorological stations (Frösön ID:13411). This meteorological station covered a long term reliable data, so the performance of 16Z station was the best among all the other stations. This was also interesting in terms of trend analysis as there were more trends for this stations compare to the others. It was probable that significant trends were removed because of interpolation smoothing in other stations in relation with their interpolation radius.

Furthermore, obtained R^2 for snow depth was approximately twice as HBV run-off in all the stations except for those that were in the south. There were two possibilities for lower R^2 in the south, firstly the model could not calculate snow depth in low latitudes correctly, secondly and more probably the estimated values for snow in the south stations had overestimations. It was as a result of lack of a maximum range in estimation of hydrological variables when there was stations without data in nearby. In such a case, the code would take the next station with data. Introducing a maximum interpolation radius probably would fix this problem.

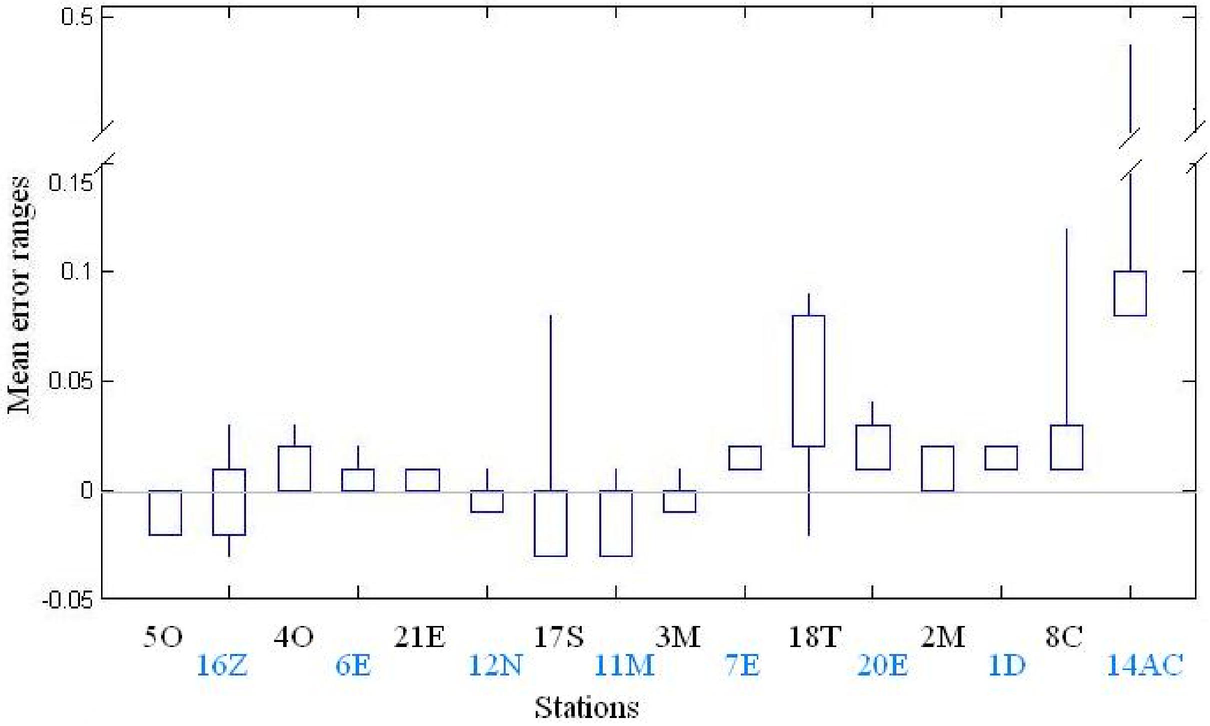

Fig. 7: Snow depth mean error ranges befor and after constraining by -01 <ME< 0.1 (Stations sorted from left to right based on interpolation radius).

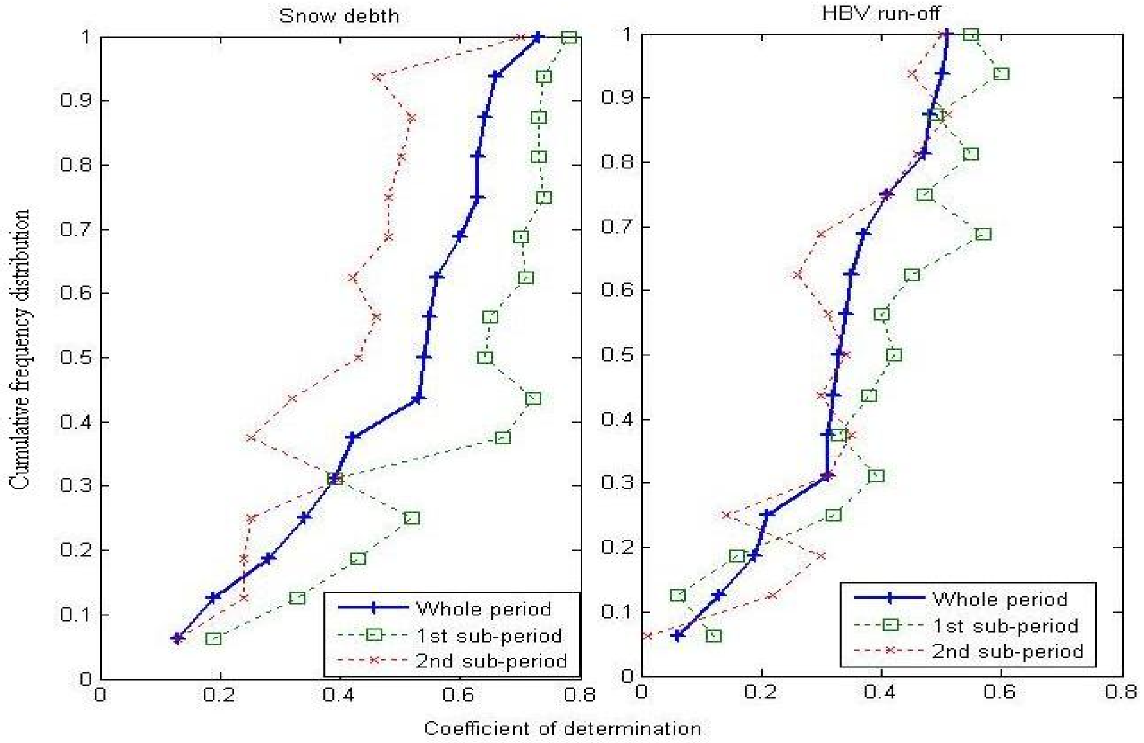

Fig. 8: Changes in model performance in different time domains.

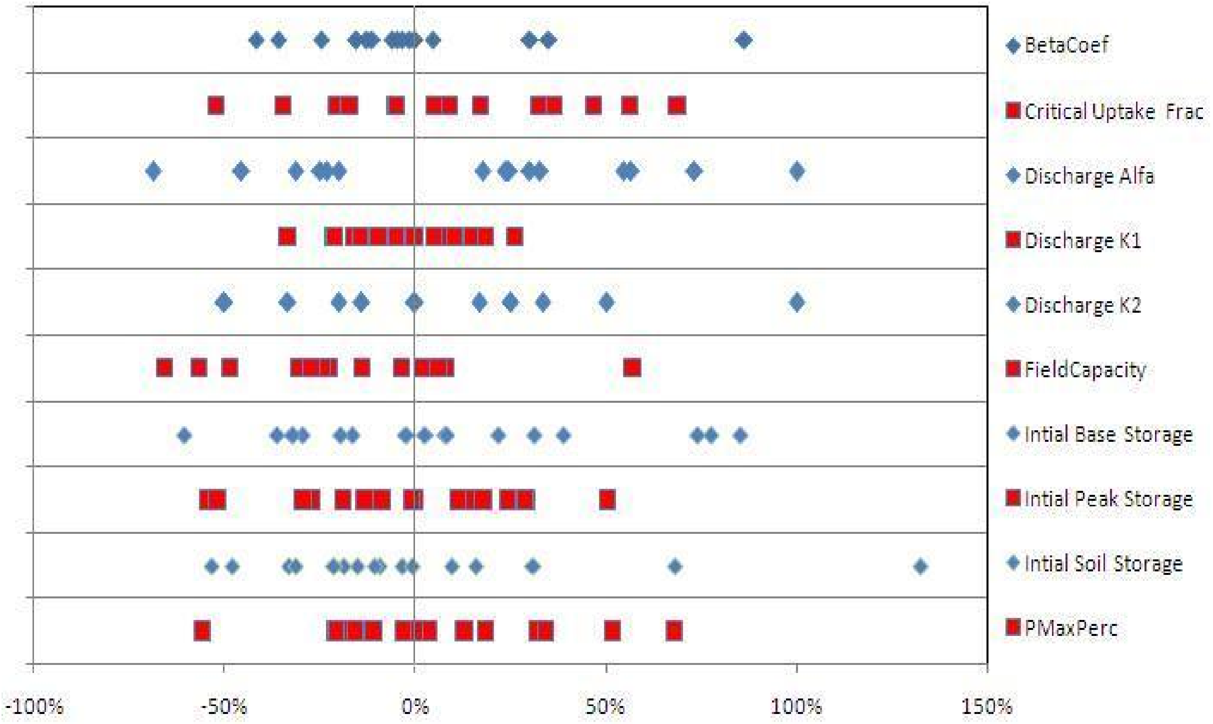

Fig. 9: Soil parameters values changes in sub-periods.

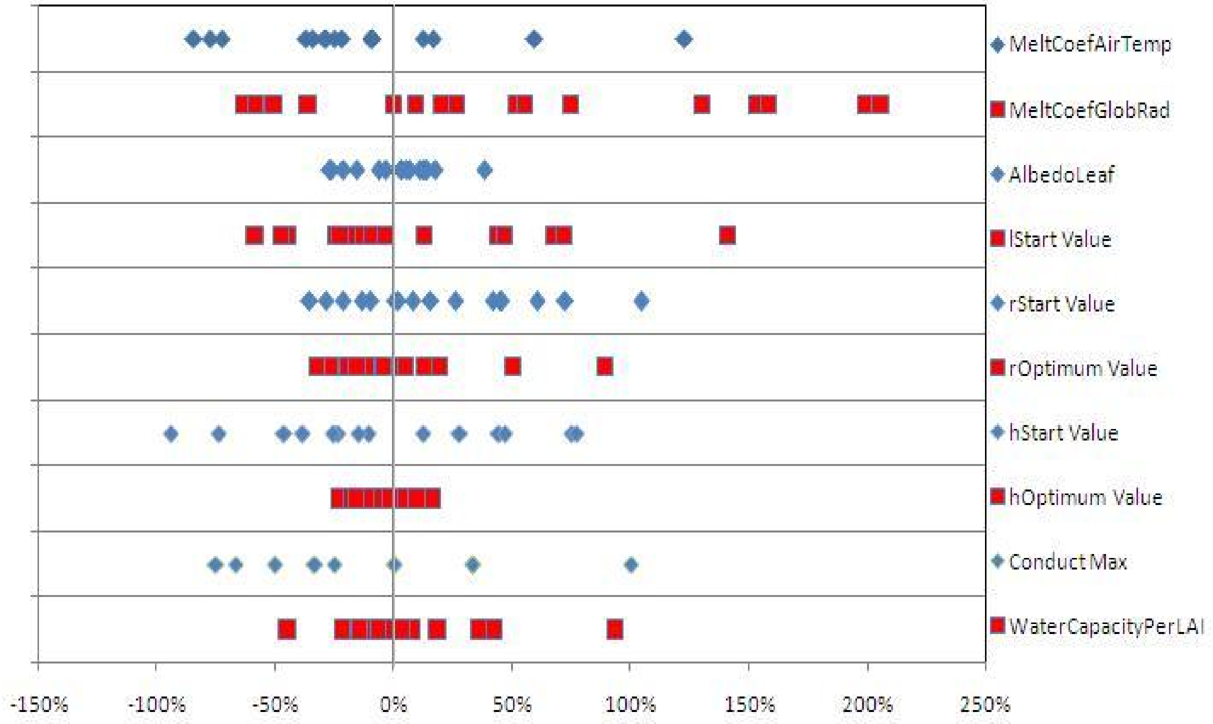

Fig. 10: Climate & plant parameters values changes in sub-periods.

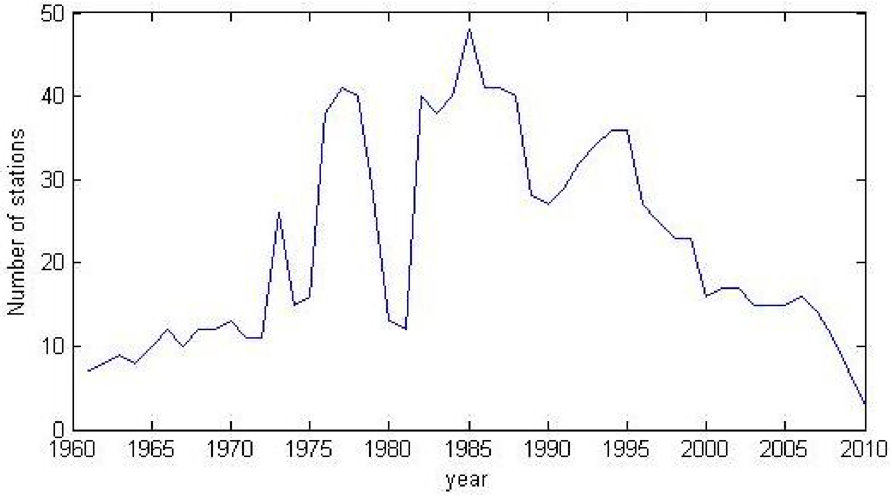

Fig. 11: Average number of stations with reported snow depth data in different years in Sweden.

The model (CoupModel) enables the user to check the environment behavior in different time domains. This was very useful for comparing the model performances in different sub-periods. Moreover, it was very informative when it was not possible to interpret the results only by considering climate change effects. It means, the model can have different values for each parameter (mainly soil and plant parameters) during each sub-period.

It was expected that the model gave a better performance for the second sub-periods as the accuracy of data normally became better as time passes. However, the results were completely reverse and the model performance for stations decreased in second sub-period for almost all stations. Although, there were changes in R^2 in sub-periods, the changes were not so severe and the model performances stayed good for the ones that had a high R^2 before devision.

In general, with developments in measurement instruments over years measurements are more easier and more accurate nowadays. However, for snow depth it is still dependent to labor force, therefore due to increases in labor force expenses snow depth stations reduced over the years in Sweden (Figure.11). This is one of the main reasons for lower R^2 in the second sub-period.

Changes in variables values were also interesting. As the recorded run-off durations were different for each stations it was too optimistic to expect regular trends in variables values changes. Moreover, the level of accuracy of models also differed in different locations. Therefore, variations in variables for a stations with a low R^2 may be irrelevant.

Parameters that have relations with climate had the highest variations in sub-periods (m_{Rmin} and m_T). On the other hand, parameters that related to soil and plant characteristics had both large and small variations.

It is worth mentioning that it is important to look at the parameters variations based on their effects on the final results. It is possible that small changes in a parameters has stronger effects than another parameter that changed significantly.

5 CONCLUSION

Except for run-off, other data in this project were estimated values. The meteorological variables for simulations were interpolated data from SMHI and NOAA databases. Even though there were lots of effort to prepare a reliable dataset and to minimize the errors, there are always uncertainties after data estimations. Therefore, there were three major uncertainties in data for this project in addition to uncertainties in hydrological models themselves. Uncertainties in data can summarized to: Firstly, the uncertainties in measured run-off data. Secondly, uncertainties measured meteorological variables that were available in SMHI and NOAA databases and finally, uncertainties in interpolation procedure.

It was observed that the run-off had some trends according to geographical locations. In the south, the precipitation made run-off in winter while in the north it was mainly as snow. In the north, the snow started to melt in spring and made peaks in late spring while in the south the run-off was in its lowest amount at this time. In the middle, there were run-off in both winter and spring with milder values compare to the north and the south.

Trends in time domains were also to some extent dependent to the spatial distribution. There were only increasing trends in run-off in some stations. In the north, these trends were only in winter, while in the south they occurred in summer. In general, when there were trends for more than one season there was also trend in yearly values. In middle, there were run-off all the year round, therefore yearly trends in run-off only were visible in this region.

In general, there were trend in yearly temperature for all stations. Therefore, increasing trends for run off in winter in the north could be explained by warmer winters. Warmer winters in the north means a proportion of snow would melt to run-off.

In the middle, increasing trends in run-off were in winter, summer and yearly measurements, while in the south the trends were only in summer. However, there were not any trends in climate variables except for temperature. Therefore, the increasing trend for runoff in summer could not explain only by climate change effects. There were probably other explanations like land use changes.

Snow depth which was a validation variable was obtained by interpolation technique. It was expected to find some trends in snow depth over the study period. However, in contrast to expectations there was not any significant trend in snow (trends with f(Z) > 95%).

By comparing the model performances for different stations, it was understood that the closeness of meteorological stations to the run-off stations have positive effects on the models results. In average, the coefficient of determination decreased by 0.1 and 0.2 (10% & 20% in model performance) for snow depth and HBV run-off respectively per 100 km distance.

The simulation accuracy can change if the variables have the ability to change in different sub-periods. Based on coefficient of determination, models performances improved for first sub-periods and became worse for the second sub-periods after dividing the models in two sub-periods. This was true especially for those that had a R^2 of greater than 0.2.

For snow depth, all the stations had 50 years of data, therefore all the sub-periods were equal. It was reasonable to claim that the improvement in R^2 could be as a result of accuracy of data (data for first sub-period were mainly from SMHI database). What is more, a worse performance in the second sub-period for snow depth were mainly because of reducing the number of snow depth measurements in Sweden as a consequence of increases in the costs.

On the other hand, the run-off data did not have the same time series so it was a bit strange that why the first sub-periods gave better performances.

Looking in different sub-periods soil and plant parameters demonstrated that in addition to changes in climate conditions there were both improving and worsening changes in land-use in the different parts of the country. However, for finding some regular trends in the changes it was a need to have long- term recorded data with same durations for different locations.

5.1 Future works

- Based on SMHI stations map there are more than 1200 stations for recording precipitation and more than 600 stations for recording temperature in Sweden. It is a pity that only 52 stations from this huge database are available for researchers. It is really a need to make these databases available at least for the projects that their results bring benefits for the country.

- Introducing a maximum interpolation radius probably would fix overestimation problem with snow depth estimation in the southern parts.

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SLU (Swedish University of Agriculture Sciences) surface run off database.
SMHI online database: `data.smhi.se/met/climate/time_series/3hours/`
USGS online database: `ftp://ftp.ncdc.noaa.gov/pub/data/gsod`

I Appendix 1 Mann-Kendall Analysis

This is a trend test that is used frequently in the filed of hydrology for finding trends in different parameters especially in long term time domains (Burn, 1994). There are several parameters that are results of the test:
S is the Mann-Kendall is the strength of the statistics and calculated as :

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{3}$$

Where n is the number of observations and j is the observation at time j. sgn is the sign and calculates as below:

$$sgn(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \tag{4}$$

The Z is calculated as below:

$$Z = \begin{cases} \frac{S-1}{[VAR(S)]^{0.5}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{[VAR(S)]^{0.5}} & \text{if } S < 0 \end{cases} \tag{5}$$

Where VAR(S) is :

$$VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{g}(t_p - 1)(2t_p + 5)] \tag{6}$$

F(Z) is:

$$F(Z) = \frac{1}{\sqrt{2\pi}} \exp \frac{-z^2}{2} \tag{7}$$

Increasing if F(Z) > 95% and Z > 0
Decreasing if F(Z) > 95% and Z < 0
No trends if F(Z) < 95%

If we want to use the method for seasonal trends we have to use a modified version of the equations above (Madaeni, 2012).

$$\begin{aligned} VAR(S_i) &= \tfrac{1}{18}[n_i(n_i-1)(2n_i+5) - \textstyle\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1)(2t_{ip}+5) - \sum_{q=1}^{h_i} \mu_{ip}(\mu_{ip}-1)(2\mu_{ip}+5)] \\ &\quad + \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1)(t_{ip}-2) \sum_{q=1}^{h_i} \mu_{ip}(\mu_{ip}-1)(\mu_{ip}-2)}{9n_i(n_i-1)(n_i-2)} \\ &\quad + \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip}-1) \sum_{q=1}^{h_i} \mu_{ip}(\mu_{ip}-1)}{2n_i(n_i-1)} \end{aligned} \tag{8}$$

Where g_i is number of groups that have same values. For example in Table below the $g_2 = 2$ and $g_3 = 1$ (there are two 5 and two 7 so $g_2 = 2$, there are three 2 so $g_3 = 1$) .
h_j is in the case that in a season there are more than one measurement for that parameters.

2	5	2
2	4	5
3	7	7

II Appendix 2 Mann-Kendall trend analysis results

Table 5: Trends in measured run-off (stations are sorted from north to south).

Station	ID	period	Time	S	Z	f(Z)	Trend(at 95% level of significance)
Jämtlands	16Z	1977-2009	Winter	192.00	3.25	1.00	Increasing
Värmlands	17S	1977-2000	Winter	61.00	1.69	0.95	Increasing
Uppsala	8C	1975-1997	Winter	59.00	1.75	0.96	Increasing
Östergötlands	7E	1976-2009	Winter	128.00	2.06	0.98	Increasing
Södermanlands	1D	1973-2009	Summer	156.00	2.11	0.98	Increasing
Östergötlands	6E	1974-2009	Summer	161.00	2.38	0.99	Increasing
Östergötlands	20E	1988-2009	Yearly	68.00	2.17	0.99	Increasing
			Spring	65.00	2.24	0.99	Increasing
	21E	1988-2009	Yearly	76.00	2.43	0.99	Increasing
			Spring	74.00	2.37	0.99	Increasing
			Summer	71.00	2.29	0.99	Increasing
			Autumn	67.00	2.16	0.98	Increasing
Västra Götalands	4O	1976-2009	Yearly	120.00	1.84	0.97	Increasing
			Winter	142.00	2.29	0.99	Increasing
			Summer	148.00	2.38	0.99	Increasing
	5O	1976-2009	Yearly	128.00	2.06	0.98	Increasing
			Winter	226.00	3.65	1.00	Increasing
			Summer	155.00	2.51	0.99	Increasing
Hallands	12N	1976-2009	Summer	116.00	1.86	0.97	Increasing

Table 6: Mann-Kendall results for snow depth.

Station ID	Time	S	Z	f(Z)	Station ID	Time	S	Z	f(Z)
1D	Yearly	-118	-1.01	0.16	11M	Yearly	58	0.49	0.69
	Winter	-75	-0.66	0.26		Winter	-9	-0.07	0.47
	Spring	-140	-1.24	0.11		Spring	-112	-0.99	0.16
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-144	-1.27	0.10		Autumn	-25	-0.21	0.42
2M	Yearly	50	0.42	0.66	12N	Yearly	-50	-0.42	0.34
	Winter	31	0.27	0.61		Winter	-104	-0.92	0.18
	Spring	-85	-0.75	0.23		Spring	-124	-1.10	0.14
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-93	-0.82	0.21		Autumn	-8	-0.06	0.48
3M	Yearly	-18	-0.15	0.44	14AC	Yearly	-156	-1.34	0.09
	Winter	-57	-0.50	0.31		Winter	-76	-0.67	0.25
	Spring	-149	-1.32	0.09		Spring	-150	-1.32	0.09
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-33	-0.29	0.39		Autumn	-57	-0.50	0.31
4O	Yearly	-144	-1.23	0.11	16Z	Yearly	-92	-0.78	0.22
	Winter	-92	-0.81	0.21		Winter	-60	-0.52	0.30
	Spring	-73	-0.64	0.26		Spring	-66	-0.58	0.28
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-161	-1.43	0.08		Autumn	-40	-0.35	0.36
5O	Yearly	110	0.94	0.83	17S	Yearly	124	1.06	0.86
	Winter	96	0.84	0.80		Winter	104	0.92	0.82
	Spring	-4	-0.03	0.49		Spring	-15	-0.12	0.45
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-109	-0.96	0.17		Autumn	-118	-1.04	0.15
6E	Yearly	-150	-1.28	0.10	18T	Yearly	-88	-0.75	0.23
	Winter	-136	-1.20	0.12		Winter	-49	-0.43	0.33
	Spring	-44	-0.38	0.35		Spring	-128	-1.13	0.13
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-162	-1.43	0.08		Autumn	-135	-1.19	0.12
7E	Yearly	-162	-1.39	0.08	20E	Yearly	-168	-1.44	0.08
	Winter	-132	-1.16	0.12		Winter	-104	-0.92	0.18
	Spring	-80	-0.70	0.24		Spring	-102	-0.90	0.18
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-199	-1.76	0.04		Autumn	-177	-1.57	0.06
8C	Yearly	-150	-1.28	0.10	21E	Yearly	-132	-1.13	0.13
	Winter	-120	-1.06	0.15		Winter	-122	-1.08	0.14
	Spring	-223	-1.97	0.02		Spring	-54	-0.47	0.32
	Summer	0	0.00	0.50		Summer	0	0.00	0.50
	Autumn	-150	-1.33	0.09		Autumn	-164	-1.45	0.07

Table 7: Mann-Kendall results for temperature.

Station ID	Time	S	Z	f(Z)
1D	Yearly	442	3.80	1.00
	Winter	280	2.48	0.99
	Spring	422	3.74	1.00
	Summer	228	2.02	0.98
2M	Yearly	314	2.70	1.00
	Spring	474	4.20	1.00
	Summer	240	2.12	0.98
3M	Yearly	478	4.11	1.00
	Winter	306	2.71	1.00
	Spring	518	4.60	1.00
	Summer	298	2.64	1.00
4O	Yearly	500	4.30	1.00
	Winter	372	3.30	1.00
	Spring	504	4.47	1.00
	Summer	270	2.39	0.99
	Autumn	306	2.71	1.00
5O	Yearly	462	3.97	1.00
	Winter	294	2.60	1.00
	Spring	452	4.01	1.00
	Summer	258	2.29	0.99
6E	Yearly	458	3.94	1.00
	Winter	324	2.87	1.00
	Spring	446	3.96	1.00
	Summer	224	1.98	0.98
	Autumn	240	2.12	0.98
7E	Yearly	488	4.20	1.00
	Winter	326	2.89	1.00
	Spring	470	4.17	1.00
	Summer	264	2.34	0.99
	Autumn	246	2.18	0.99
8C	Yearly	460	3.96	1.00
	Winter	284	2.52	0.99
	Spring	444	3.94	1.00
	Summer	226	2.00	0.98
11M	Yearly	460	3.96	1.00
	Winter	282	2.50	0.99
	Spring	512	4.54	1.00
	Summer	276	2.45	0.99
12N	Yearly	476	4.10	1.00
	Winter	292	2.59	1.00
	Spring	526	4.67	1.00
	Summer	280	2.48	0.99
14AC	Yearly	290	2.49	0.99
	Spring	402	3.56	1.00
	Summer	338	3.00	1.00
16Z	Yearly	438	3.77	1.00
	Winter	246	2.18	0.99
	Spring	290	2.57	0.99
	Summer	248	2.20	0.99
	Autumn	288	2.55	0.99
17S	Yearly	326	2.80	1.00
	Winter	236	2.09	0.98
	Spring	324	2.87	1.00
18T	Yearly	494	4.25	1.00
	Winter	310	2.75	1.00
	Spring	504	4.47	1.00
	Summer	266	2.36	0.99
	Autumn	234	2.07	0.98
20E	Yearly	466	4.01	1.00
	Winter	310	2.75	1.00
	Spring	408	3.62	1.00
	Summer	250	2.21	0.99
	Autumn	256	2.27	0.99
21E	Yearly	480	4.13	1.00
	Winter	342	3.03	1.00
	Spring	444	3.94	1.00
	Summer	240	2.13	0.98
	Autumn	248	2.20	0.99

Table 8: Mann-Kendall results for precipitation (left) and wind speed (right) .

Station ID	Time	S	Z	f(Z)	Station ID	Time	S	Z	f(Z)
5O	Winter	188	1.66	0.95	16Z	Winter	228	2.02	0.98
18T	Yearly	204	1.75	0.96					
	Winter	208	1.84	0.97					
	Summer	188	1.66	0.95					
16Z	Yearly	294	2.53	0.99					
	Winter	206	1.82	0.97					
	Autumn	264	2.34	0.99					

III Appendix 3 Validation criteria explanation

- **Mean error (ME)**

Mean error for each simulation is the difference between the observed value and the calculated value. If there are more than one simulation the the average of these differences is the mean error for those calculations. The lower the mean error the lower is the differences and therefore the better the model performances. In our studies, the mean error range is -0.1 < ME < +0.1 .

$$ME = \frac{\sum_{k=1}^{n}(y_i - f_i)}{n} \tag{9}$$

Where y_i is the observation and f_i is the simulated value. n is number of observations.

- **Coefficient of determinations (R^2)**

Coefficient of determinations is another statistical tool to evaluate the accuracy of the modeled values. in contrast to mean error the higher the R^2 the better the model performance . in Eq.12 $\bar{y}$ is the average of observed values.

$$R^2 = 1 - \frac{SS_{err}}{SS_{tot}} \tag{10}$$

$$SS_{tot} = \sum_{i=1}^{n}(y_i - f_i)^2 \tag{11}$$

$$SS_{err} = \sum_{i=1}^{n}(y_i - \bar{y})^2 \tag{12}$$

IV Appendix 4 models structure

HBV model structure

The HBV model (Bergstrom, 1976, 1992) is a rainfall-runoff model, which includes conceptual numerical descriptions of hydrological processes at the catchment scale. The general water balance can be described as:

$$P - E - Q = \frac{d}{dt}[S_P + S_M + U_Z + L_Z + lake] \qquad (13)$$

where:
P = precipitation
E = evapotranspiration
Q = runoff
SP = snow pack
SM = soil moisture
UZ = upper groundwater zone
LZ = lower groundwater zone
lakes = lake volume

Fig. 12: Schematic CoupModel & HBV models structures.

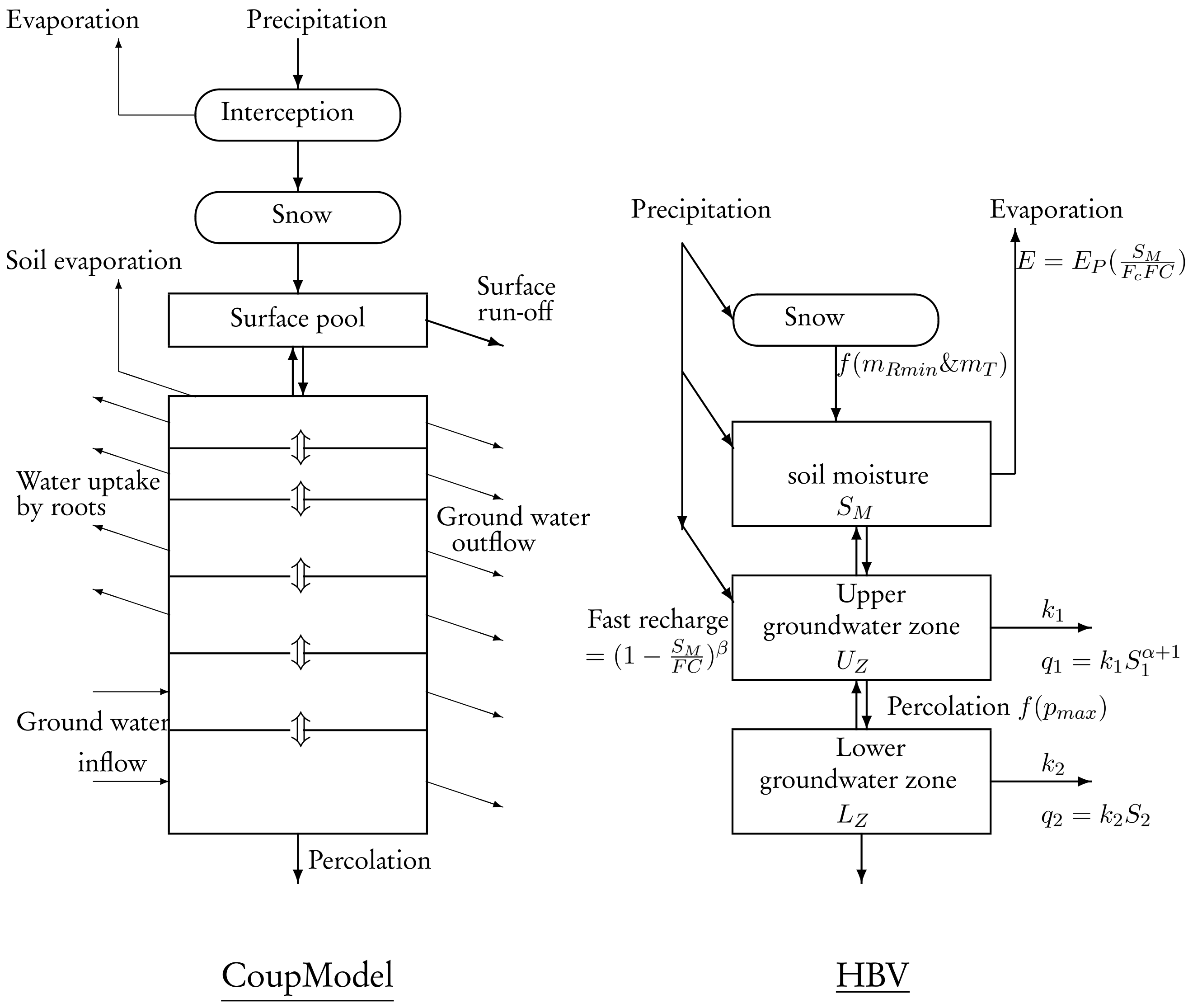

Table 9: CoupModel & HBV models setups.

Module	**Option**	**CoupModel**	**HBV**
Drainage& deep percolation	Physical drainage Eq.	Linear model	-
Interception	Precipitation	On	On
	Snow	On	On
Meteorological data	Precipitation	Input	Input
	Temperature	Input	Input
	Min temperature	Input	Input
	Max temperature	Input	Input
	Dew point	Input	Input
	Wind Speed	Input	Input
	Cloudiness	Input	Input
	Global radiation	Estimated	Estimated
Model structure	Evaporation	Radiation input style	Radiation input style
	Ground water flow	On	On
	HBV soil module	As a complementary model	Excluding Richard equation
	Iteration per day	96	1
	Plant type	Explicit big leaves	Explicit big leaves
	Snow pack	On	On
	Water Equation	With complete soil profile	Without Richard equation
Potential transpiration	Roughness	f(canopy)	f(canopy)
Soil evaporation	Evaporation method	Iterative energy balance	
	Surface temperature	$f(E_{BalanceSolution})$	-
Soil water flow	Crack	Bypass flow	-
Validation	validation parameters	3	2

The parameters definitions are mainly from CoupModel manual (Jansson & Kalberg, 2011).
• MeltCoefGlobRad (kg/J): global radiation coefficient in the empirical snow melt function.
• MeltCoefAirTemp (kg/J): temperature coefficient in the empirical snow melt function.
• AlbedoLeaf: the value of plant albedo.
• WatercapacityLAI (mm/m^2): interception water storage per LAI input.
• EquilAdjustPsi: a factor to account for differences between water tension in the middle of top layer and actual vapour pressure at soil surface.
• RoughLBareSoilMom (m): Surface roughness length for momentum above bare soil, is a factor aerodynamic resistance function that has inverse relationship with that.
• SurfCoef: a first order rate coefficient uses for calculating the surface runoff from the surface pool exceeding the residual storage.
• IStart, Optimum and End values: start, optimum and end vegetation growing period values of leaf area index. LAI is a dimensionless quantity, equal to the leaf area per unit area of soil below it. It is expressed as m^2 leaf area perm^2 ground area.
• hStart, End and optimum values (m): the plant height for the start and the end of vegetation growing period and the optimum height of the plant.
• rStart,End and Optimum values (m): root depth for the start and the end of vegetation growing period and the optimum root depth of the plant.
• Lambda: pore size distribution index. It is used to estimate effective saturation together with air entry.
• Air Entry (cm): air entry tension.
• Conduct max: the maximal conductance of fully open stomata.
• Pmaxperc: the fraction of precipitation that goes directly to deep percolation.

Table 10: CoupModel & HBV models parameters.

Module	Parameter	Symbol	CoupModel	HBV
Drainage & deep percolation	DrainLevel	Z_p	✓	
	DrainSpacing	d_p	✓	
HBV	BetaCoef	β		✓
	Critical Uptake Frac	F_c		✓
	Discharge Alfa	α		✓
	Discharge K1	K_1		✓
	Discharge K2	K_2		✓
	FieldCapacity	FC		✓
	Intial Base Storage	S_2		✓
	Intial Peak Storage	S_1		✓
	Intial Soil Storage	S_M		✓
	PMaxPerc	P_{max}		✓
Plant	AlbedoLeaf	a_{veg}	✓	✓
	RootFracExpTail	r_{farc}	✓	
	lStart Value	l_{Start}	✓	✓
	lEnd Value	l_{End}	✓	✓
	rStart Value	r_{Start}	✓	✓
	rOptimum Value	r_{Opt}	✓	✓
	rEnd Value	r_{End}	✓	✓
	hStart Value	h_{Start}	✓	✓
	hOptimum Value	h_{Opt}	✓	✓
	hEnd Value	h_{End}	✓	✓
Potential transpiration	Conduct Max	g_{max}	✓	✓
Interception	WaterCapacityPerLAI	i_{LAI}	✓	✓
Soil hydraulic	Air Entry	ψ_a	✓	
	Lambda	λ	✓	
	Wilting Point	θ_{wilt}	✓	
Snow pack	MeltCoefAirTemp	m_T	✓	✓
	MeltCoefGlobRad	m_{Rmin}	✓	✓
Surface water	SurfCoef	a_{surf}	✓	
Soil evaporation	EquilAdjustPsip	ψ_{eg}	✓	
	RoughLBareSoilMom	Z_{0M}	✓	
Soil water flow	AScaleSorption	a_{scale}	✓	

- Field capacity: the ability of the soil to store water.
- RootFracExpTail: root distribution.
- Drainlevel: the level of water in the drainage system.
- Drainspacing: the distance between drainage pipes.
- DischargeK_2: discharge Coefficient from the base storage. $q_2 = K_2 S_2$
- Wilting point: the minimal point of soil moisture the plant requires not wilting.
- Discharge K_1: discharge coefficient from the peak storage.$q_1 = K_1 S_1^{(\alpha+1)}$
- Initial soil storage: Initial storage of water in soil layer.
- Initial peak storage: initial storage of water in peak layer.
- Initial base storage: initial storage of water in base layer.
- Discharge alfa:$q_1 = K_1 * S_1(\alpha + 1)$
- Beta coef: a HBV parameter, which governs how sensitive the fraction of fast recharge is to the water storage in the unsaturated zone.

V Appendix 5 Soil and plant parameters values in sub-periods

Table 11: Soil parameters values in sub-periods $\binom{1st}{2nd}$.

Station	β	S_M	FC	F_c	α	K_1	S_1	K_2	S_2	P_{max}	a_{scale}
1D	$\binom{3.35}{3.51}$	$\binom{204}{140}$	$\binom{182}{63}$	$\binom{0.46}{0.61}$	$\binom{0.90}{0.69}$	$\binom{0.28}{0.24}$	$\binom{276}{240}$	$\binom{0.08}{0.04}$	$\binom{173}{169}$	$\binom{0.35}{0.34}$	$\binom{0.61}{0.33}$
2M	$\binom{4.73}{3.57}$	$\binom{83}{193}$	$\binom{174}{150}$	$\binom{0.64}{0.61}$	$\binom{0.45}{0.78}$	$\binom{0.26}{0.26}$	$\binom{163}{162}$	$\binom{0.06}{0.04}$	$\binom{181}{196}$	$\binom{0.45}{0.2}$	$\binom{0.49}{0.57}$
3M	$\binom{2.79}{2.79}$	$\binom{118}{117}$	$\binom{128}{201}$	$\binom{0.54}{0.59}$	$\binom{0.10}{0.13}$	$\binom{0.16}{0.19}$	$\binom{186}{151}$	$\binom{0.06}{0.06}$	$\binom{178}{143}$	$\binom{0.37}{0.33}$	$\binom{0.47}{0.2}$
4O	$\binom{3.77}{3.28}$	$\binom{149}{144}$	$\binom{148}{160}$	$\binom{0.64}{0.53}$	$\binom{0.55}{0.73}$	$\binom{0.21}{0.20}$	$\binom{186}{207}$	$\binom{0.06}{0.08}$	$\binom{103}{183}$	$\binom{0.36}{0.29}$	$\binom{0.52}{0.41}$
5O	$\binom{3.23}{4.2}$	$\binom{160}{107}$	$\binom{224}{238}$	$\binom{0.55}{0.75}$	$\binom{0.97}{0.73}$	$\binom{0.25}{0.21}$	$\binom{273}{125}$	$\binom{0.06}{0.06}$	$\binom{108}{150}$	$\binom{0.43}{0.34}$	$\binom{0.37}{0.42}$
6E	$\binom{4.42}{4.21}$	$\binom{198}{161}$	$\binom{380}{165}$	$\binom{0.32}{0.54}$	$\binom{0.73}{0.91}$	$\binom{0.19}{0.21}$	$\binom{163}{163}$	$\binom{0.07}{0.06}$	$\binom{100}{174}$	$\binom{0.23}{0.26}$	$\binom{0.33}{0.46}$
7E	$\binom{3.39}{2.86}$	$\binom{113}{190}$	$\binom{202}{215}$	$\binom{0.61}{0.65}$	$\binom{0.55}{0.44}$	$\binom{0.2}{0.21}$	$\binom{162}{148}$	$\binom{0.05}{0.05}$	$\binom{125}{85}$	$\binom{0.39}{0.39}$	$\binom{0.5}{0.52}$
8C	$\binom{4.4}{3.72}$	$\binom{134}{147}$	$\binom{358}{365}$	$\binom{0.32}{0.5}$	$\binom{0.35}{0.24}$	$\binom{0.2}{0.21}$	$\binom{157}{180}$	$\binom{0.04}{0.05}$	$\binom{135}{95}$	$\binom{0.32}{0.38}$	$\binom{0.61}{0.41}$
11M	$\binom{3}{2.66}$	$\binom{141}{126}$	$\binom{181}{132}$	$\binom{0.58}{0.61}$	$\binom{0.76}{0.94}$	$\binom{0.25}{0.25}$	$\binom{181}{128}$	$\binom{0.05}{0.04}$	$\binom{205}{171}$	$\binom{0.32}{0.27}$	$\binom{0.46}{0.37}$
12N	$\binom{4.07}{3.93}$	$\binom{188}{148}$	$\binom{120}{116}$	$\binom{0.75}{0.71}$	$\binom{0.22}{0.34}$	$\binom{0.21}{0.19}$	$\binom{144}{179}$	$\binom{0.04}{0.05}$	$\binom{179}{114}$	$\binom{0.37}{0.31}$	$\binom{0.55}{0.59}$
14AC	$\binom{4.49}{2.88}$	$\binom{182}{85}$	$\binom{350}{272}$	$\binom{0.44}{0.35}$	$\binom{0.11}{0.06}$	$\binom{0.14}{0.11}$	$\binom{149}{193}$	$\binom{0.04}{0.06}$	$\binom{243}{96}$	$\binom{0.25}{0.33}$	$\binom{0.51}{0.61}$
16Z	$\binom{2.62}{4.88}$	$\binom{129}{169}$	$\binom{155}{108}$	$\binom{0.58}{0.38}$	$\binom{0.14}{0.28}$	$\binom{0.13}{0.14}$	$\binom{146}{107}$	$\binom{0.04}{0.08}$	$\binom{134}{176}$	$\binom{0.28}{0.29}$	$\binom{0.57}{0.63}$
17S	$\binom{4.45}{4.38}$	$\binom{153}{139}$	$\binom{310}{329}$	$\binom{0.29}{0.34}$	$\binom{0.68}{0.80}$	$\binom{0.2}{0.23}$	$\binom{146}{220}$	$\binom{0.04}{0.05}$	$\binom{101}{187}$	$\binom{0.29}{0.39}$	$\binom{0.55}{0.43}$
18T	$\binom{2.26}{3.05}$	$\binom{159}{135}$	$\binom{305}{230}$	$\binom{0.45}{0.6}$	$\binom{0.16}{0.05}$	$\binom{0.18}{0.12}$	$\binom{123}{145}$	$\binom{0.06}{0.07}$	$\binom{114}{117}$	$\binom{0.22}{0.37}$	$\binom{0.57}{0.48}$
20E	$\binom{3.98}{3.73}$	$\binom{217}{113}$	$\binom{268}{203}$	$\binom{0.51}{0.75}$	$\binom{0.53}{0.83}$	$\binom{0.24}{0.19}$	$\binom{166}{80}$	$\binom{0.04}{0.02}$	$\binom{198}{214}$	$\binom{0.34}{0.27}$	$\binom{0.44}{0.53}$
21E	$\binom{4.75}{2.77}$	$\binom{145}{168}$	$\binom{332}{171}$	$\binom{0.79}{0.38}$	$\binom{0.70}{0.87}$	$\binom{0.19}{0.24}$	$\binom{128}{165}$	$\binom{0.07}{0.06}$	$\binom{161}{196}$	$\binom{0.27}{0.41}$	$\binom{0.60}{0.47}$

Table 12: Plant parameters values in sub-periods $\binom{1st}{2nd}$.

Station	l_{Start}	r_{Start}	r_{Opt}	h_{Start}	h_{Opt}	g_{max}	i_{LAI}	a_{veg}	m_T	m_{Rmin}
1D	$\binom{0.96}{0.93}$	$\binom{-0.38}{-0.61}$	$\binom{-0.89}{-1.34}$	$\binom{0.17}{0.25}$	$\binom{0.75}{0.58}$	$\binom{0.03}{0.03}$	$\binom{0.25}{0.34}$	$\binom{20.3}{22.9}$	$\binom{1.9}{3.03}$	$\binom{3.20E-07}{3.50E-07}$
2M	$\binom{1.87}{3.22}$	$\binom{-0.27}{-0.34}$	$\binom{-1.06}{-0.72}$	$\binom{0.17}{0.01}$	$\binom{0.76}{0.64}$	$\binom{0.04}{0.02}$	$\binom{0.16}{0.31}$	$\binom{23.7}{17.5}$	$\binom{4.57}{0.71}$	$\binom{4.30E-07}{1.80E-07}$
3M	$\binom{1.96}{1.52}$	$\binom{-0.4}{-0.69}$	$\binom{-0.97}{-0.93}$	$\binom{0.36}{0.22}$	$\binom{0.8}{0.71}$	$\binom{0.04}{0.02}$	$\binom{0.29}{0.3}$	$\binom{23.2}{17}$	$\binom{5.83}{1.31}$	$\binom{4.10E-07}{5.20E-07}$
4O	$\binom{1.75}{2.57}$	$\binom{-0.37}{-0.29}$	$\binom{-0.97}{-0.86}$	$\binom{0.39}{0.21}$	$\binom{0.8}{0.8}$	$\binom{0.04}{0.03}$	$\binom{0.3}{0.27}$	$\binom{18.1}{21.3}$	$\binom{4.34}{3.94}$	$\binom{5.30E-07}{6.40E-07}$
5O	$\binom{3.85}{2.02}$	$\binom{-0.51}{-0.44}$	$\binom{-0.75}{-1.42}$	$\binom{0.4}{0.34}$	$\binom{0.66}{0.63}$	$\binom{0.03}{0.04}$	$\binom{0.27}{0.28}$	$\binom{17.2}{19.1}$	$\binom{3.72}{4.34}$	$\binom{2.90E-07}{2.90E-07}$
6E	$\binom{1.95}{3.28}$	$\binom{-0.5}{-0.51}$	$\binom{-1.12}{-0.95}$	$\binom{0.17}{0.13}$	$\binom{0.71}{0.78}$	$\binom{0.03}{0.04}$	$\binom{0.28}{0.24}$	$\binom{16.8}{19.2}$	$\binom{5.4}{3.83}$	$\binom{1.80E-07}{5.50E-07}$
7E	$\binom{2.22}{2.51}$	$\binom{-0.53}{-0.48}$	$\binom{-0.98}{-1.03}$	$\binom{0.24}{0.27}$	$\binom{0.73}{0.79}$	$\binom{0.04}{0.01}$	$\binom{0.25}{0.27}$	$\binom{14.3}{19.8}$	$\binom{6.59}{7.41}$	$\binom{1.70E-07}{5.10E-07}$
8C	$\binom{4.25}{3.85}$	$\binom{-0.63}{-0.45}$	$\binom{-1.16}{-0.99}$	$\binom{0.08}{0.06}$	$\binom{0.77}{0.8}$	$\binom{0.04}{0.04}$	$\binom{0.39}{0.35}$	$\binom{20.8}{21.5}$	$\binom{4.51}{2.98}$	$\binom{2.80E-07}{4.90E-07}$
11M	$\binom{4.22}{1.75}$	$\binom{-0.48}{-0.31}$	$\binom{-0.99}{-1.12}$	$\binom{0.39}{0.24}$	$\binom{0.8}{0.79}$	$\binom{0.02}{0.04}$	$\binom{0.32}{0.3}$	$\binom{17.5}{19.8}$	$\binom{2.16}{1.69}$	$\binom{1.50E-06}{7.40E-07}$
12N	$\binom{1.82}{1.38}$	$\binom{-0.35}{-0.51}$	$\binom{-0.86}{-1.03}$	$\binom{0.43}{0.32}$	$\binom{0.84}{0.69}$	$\binom{0.02}{0.02}$	$\binom{0.29}{0.16}$	$\binom{21.6}{20.2}$	$\binom{6.82}{1.88}$	$\binom{9.00E-07}{1.40E-06}$
14AC	$\binom{1.96}{1.71}$	$\binom{-0.4}{-0.58}$	$\binom{-1.04}{-0.94}$	$\binom{0.37}{0.33}$	$\binom{0.84}{0.87}$	$\binom{0.03}{0.04}$	$\binom{0.27}{0.29}$	$\binom{19}{18.4}$	$\binom{3.02}{2.26}$	$\binom{8.00E-07}{5.10E-07}$
16Z	$\binom{1.7}{4.1}$	$\binom{-0.22}{-0.45}$	$\binom{-0.89}{-1.04}$	$\binom{0.27}{0.07}$	$\binom{0.69}{0.75}$	$\binom{0.03}{0.01}$	$\binom{0.23}{0.32}$	$\binom{19.9}{20.9}$	$\binom{2.99}{1.89}$	$\binom{6.70E-08}{1.70E-07}$
17S	$\binom{2.38}{3.43}$	$\binom{-0.51}{-0.59}$	$\binom{-0.79}{-0.82}$	$\binom{0.16}{0.28}$	$\binom{0.67}{0.78}$	$\binom{0.03}{0.04}$	$\binom{0.27}{0.32}$	$\binom{19.1}{15.1}$	$\binom{2.7}{6.02}$	$\binom{9.80E-07}{3.60E-07}$
18T	$\binom{2.37}{1.31}$	$\binom{-0.62}{-0.67}$	$\binom{-0.99}{-1.18}$	$\binom{0.22}{0.39}$	$\binom{0.74}{0.81}$	$\binom{0.03}{0.02}$	$\binom{0.24}{0.24}$	$\binom{18}{18.6}$	$\binom{1.7}{1.55}$	$\binom{2.50E-07}{3.80E-07}$
20E	$\binom{2.37}{1.91}$	$\binom{-0.38}{-0.54}$	$\binom{-1.21}{-0.98}$	$\binom{0.25}{0.32}$	$\binom{0.9}{0.89}$	$\binom{0.03}{0.04}$	$\binom{0.33}{0.26}$	$\binom{20.3}{21.7}$	$\binom{6.06}{5.47}$	$\binom{3.60E-07}{9.30E-07}$
21E	$\binom{3.5}{2.83}$	$\binom{-0.52}{-0.52}$	$\binom{-1.05}{-0.77}$	$\binom{0.18}{0.26}$	$\binom{0.73}{0.75}$	$\binom{0.03}{0.02}$	$\binom{0.21}{0.3}$	$\binom{21.6}{18.2}$	$\binom{5.39}{3.85}$	$\binom{4.30E-07}{9.90E-07}$