UPPSALA UNIVERSITET

CLIMATE CHANGE IMPACTS

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Hydrological Processes
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Overview

INTRODUCTION

It is well know that climate change has a major role on water cycle, affecting both evaporation and precipitation. Climate change is expected to accelerate water cycle and cause major change in seasonal patterns. Because the processes involved are highly dependent on temperature, changes in one have consequences on the other. We know that in the water cycle water evaporates from the land and sea, which eventually returns to Earth as rain and snow. Climate change intensifies this cycle because as air temperatures increase, more water evaporates into the air. Warmer air can hold more water vapour, which can lead to more intense rainstorms, causing major problems like extreme flooding and major changes in climate models like precipitation, sea level, river flow, soil moisture, and evapotranspiration, groundwater, and cryosphere characteristics.

Hydrological cycle can be interpreted as a set of water fluxes, which transfer water between reservoirs in the geosphere and biosphere (water contained in living organisms, plants and animals) (Z. W. Kundzewicz et al 2008). Even though there is a lot of water on Earth, only about 2.5% is fresh water, and because most of that water is stored as glaciers or deep groundwater, only a small amount of water is easily accessible (Oki et al 2006). The total global water resources constitute approximately 1.385 billion km 3, with 96.5% of their volume (1.338 billion km 3) contained in oceans, the largest water store (Shiklomanov, Rodda 2003). The water is on a perpetual move. Major hydrological processes partaking in the water cycle are: evapotranspiration, precipitation, runoff, sublimation, infiltration, snowmelt, interception, subsurface flow, and capillary rise, being precipitation, evaporation and runoff the most affected by climate change (Z. W. Kundzewicz et al 2008).

Climate and water on the planet Earth are closely linked. Water takes part in a large scale exchange of mass and heat between the atmosphere, the ocean, and the land surface, thus influencing the climate, and also being influenced by the climate (Z. W. Kundzewicz et al 2008). In past decades there has been a sharp decline in per capita water availability in many countries, and this is expected to get worse with growing populations and economic growth (R. Grafton et al 2012). Earth's climate has always been changing, reflecting regular, periodic, shifts in Earth's orbit and such factors as solar activity and radiation, and volcanic eruptions. However, most of the climate change observed recently is very likely due to human activity (IPCC 2007). Warming of the global climate system is unequivocal (IPCC 2007)

Many climate-change impacts on freshwater resources have already been observed, and further (and more pronounced) impacts have been projected, depending on region and season. The weight of observational evidence indicates an ongoing intensification of the water cycle, with increasing rates of evaporation and precipitation (Z. W. Kundzewicz et al 2008). The ultimate objectives of future-oriented world water resource assessments are to show the international community what will happen if we continue to manage our water resources as we do today and to indicate what actions may be needed to prevent undesirable outcomes. In the agricultural sector, which is estimated to withdraw two-thirds of world water withdrawals and which accounts for 90% of total water consumption in the world, in the period from 1961 to 2004, crop yield per area increased by a factor of 2.3, more than the rate of population growth (2.0), and the total crop yield increased by a factor of 2.4, even though the area of cropland increased by only 10% and harvested area increased less than that (Oki et al 2006).

Globally, the negative impacts of climate change on freshwater systems are very likely to outweigh their benefits. Water stress is modelled to increase on most of the global land area (Z. W. Kundzewicz et al 2008). Many of the presently water stressed semiarid and arid areas are likely to suffer from decreasing water resource availability due to climate change, as both river flows and groundwater recharge decline (Z. W. Kundzewicz et al 2007b). As glaciers retreat due to warming, river flows will decline once the glaciers disappear. The beneficial impacts of projected increases in annual runoff in such areas as eastern and south-eastern Asia will be tempered by adverse impacts of increased variability and seasonal runoff shifts on water supply, water quality and flood risk, in particular in heavily populated low-lying river deltas (Z. W. Kundzewicz et al 2008). Saline intrusion due to excessive water withdrawals from aquifers is expected to be exacerbated by the effect of sea-level rise, leading to reduction of freshwater availability in the coasts, consequently declining water quality (Z. W. Kundzewicz et al 2008). Model-based projections for the future, particularly related to expected changes in precipitation, are highly uncertain, hence directly unusable for credible assessment of future freshwater availability. Although quantitative projections of climate change impacts on water resources are available, they should be understood as plausible scenarios, whose probability of occurrence is difficult to estimate (Z. W. Kundzewicz et al 2008).

Climate change has been the talk of scholarly circles throughout the world. In the 20th century, most called this an unnecessary hindrance and labelled it as a false speculation. But as we progress in time we are seeing visible effects of climate change. Storms over regions that were once peaceful, flash floods and extreme or scanty rainfall events taking place all over the world. The overall temperatures have most certainly gone up, and the total greenhouse gas content has been steadily rising. By now, it is almost certain that there is a definite change taking place in the climate. And most of this is due to human activities, from deforestation to burning of fossil fuels, nearly all forms of human activities have been contributing to the rise in global surface temperatures all over the globe. Globally averaged water vapour concentrations, evaporation and precipitation are projected to increase, with subsequent impacts on land surface hydrology (Beldring et al., 2008). Hence it is very important for us to study the effects of climate change, as these will directly impact our water resources in the near future. By designing climate models for specific catchment, we can simulate how the catchment might behave in the near future. Daily values of at site measurements of temperature and precipitation are generally used as inputs for the model (Beldring et al., 2008). Also Hydrological models which are to be used for climate change impact studies must perform well under conditions of non-stationarity as defined by Kleme’s

(1986). Non-stationarity means that a significant change in climate, land use or other basin characteristics occurs (Beldring et al., 2008).

Various such models were used to predict the behaviour of climate change in sweden. The country was divided into three parts, Northern, Central and Southern part. It is truly astonishing to understand how different these regions are from one another in terms of temperature, precipitation and day-light. By running simulations on such models, it was interpreted that, an average for the whole of Sweden, temperature increases by 2.5 to 4.6°C, precipitation increases by 7 to 23%, and mean annual runoff increases by 5 to 24%, according to the scenario simulations (Johan Andréasson et al., 2004). In the northern part of Sweden run-off will most certainly increase due to faster and earlier snow melt. Although 'how much', is a topic of debate as all models predict a different run-off pattern and quantity over time. This could be due to different values of the snow-water equivalent that is used in these models, which allows the models to calculate the amount of water that results from snow melt. Southern Sweden will see a decrease in run-off, all of Sweden will see decrease in spring floods, an increased autumn and winter run-off are some of the principle conclusions from the simulations of the hydrological models for Sweden (Johan Andréasson et al., 2004). 'The climate change impact simulations with the Sweden Model revealed a deficiency that had previously been suspected regarding the regions used for summarizing climate model output. They are still too large and do not properly represent the geographical pattern of change in the climate change signal from the climate models, resulting in artificial discontinuities in the climate change signal between nearby basins in different regions (Johan Andréasson et al., 2004)'.

1. METHOD

The data given from three catchments namely,

a. Storbacken
b. Vatholmaan
c. Ronne A

(both simulated and observed), was analysed using python and Excel. The observed data is from the Year 1961 to 1990 and the simulated data (future) is from 2021 to 2050. Two models were used namely, HadRM3Q0 and RCA1, to simulate the precipitation, temperature and runoff values. These models have also simulated the values of the above parameters for the period from 1961 to 1990. We plotted the yearly mean(run-off) of the simulations vs time and the yearly mean(run-off) of the observed values to see of the two models were well calibrated.

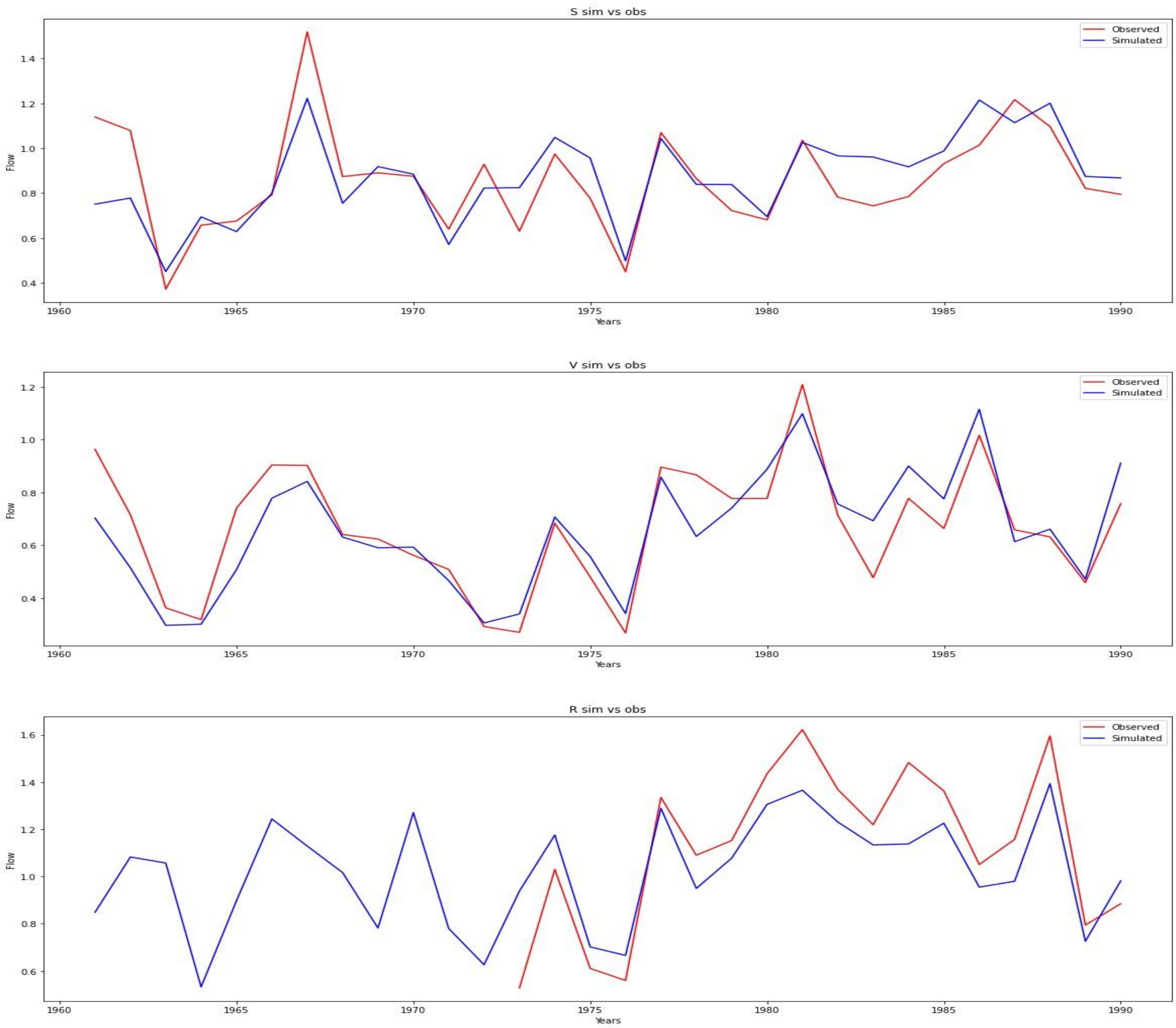

Fig.1 : This figure shows three graphs, the red line indicating the observed values and the blue line indicating the simulated values for the three catchments. From top to bottom,

Strobacken, vathollam, and Ronne. On the x axis we have years and on the y axis we have yearly mean flow in millimetres(mm).

Two signatures were analysed for each of the above mentioned catchments. The first was water balance and the second was low flows. In water balance the mean streamflow, the season mean stream flow and the run-off co-efficient were calculated from the given data. In the low flows, the low flow frequency and the minimum low flow during the consecutive 30 days were calculated.

The catchment of Storbacken, is located in the northern part of Sweden N 64° 7' 59" and E 20° 49' 59". There is a Unesco heritage site in the catchment.

Fig.2: In the picture you can find a flower called as guckusko, which can be found in the reserves. Photo: Andreas Garpebring.

The catchment of Vatholman, is located in the central part of Sweden in Uppsala county. Located about 20 km north of Uppsala city 60° 0′ 55″ N, 17° 44′ 14″ E. It has a population of 1376 people. The Catchment of Ronne A, is located in the southern part of Sweden 56° 14′ 10.07″ N, 12° 55′ 8.58″ E.

1.1. Water Balance

For the water balance signature, we first have the analysis of the Mean annual streamflow in the observed and simulated data for the years 1961 to 1990. To look the accuracy of both models we plot the mean annual streamflow and observe how far apart they are form each other. As we can see in figure 1 below. We can observe that the red line which is the simulated data is slightly higher than the blue line that is the observed data. Even though the values for both is not too different due to the size of the catchments, this is enough to choose one of the models and work with it. For the purpose of this report we decided to choose the observed data for the next hydrological analysis in the results section.

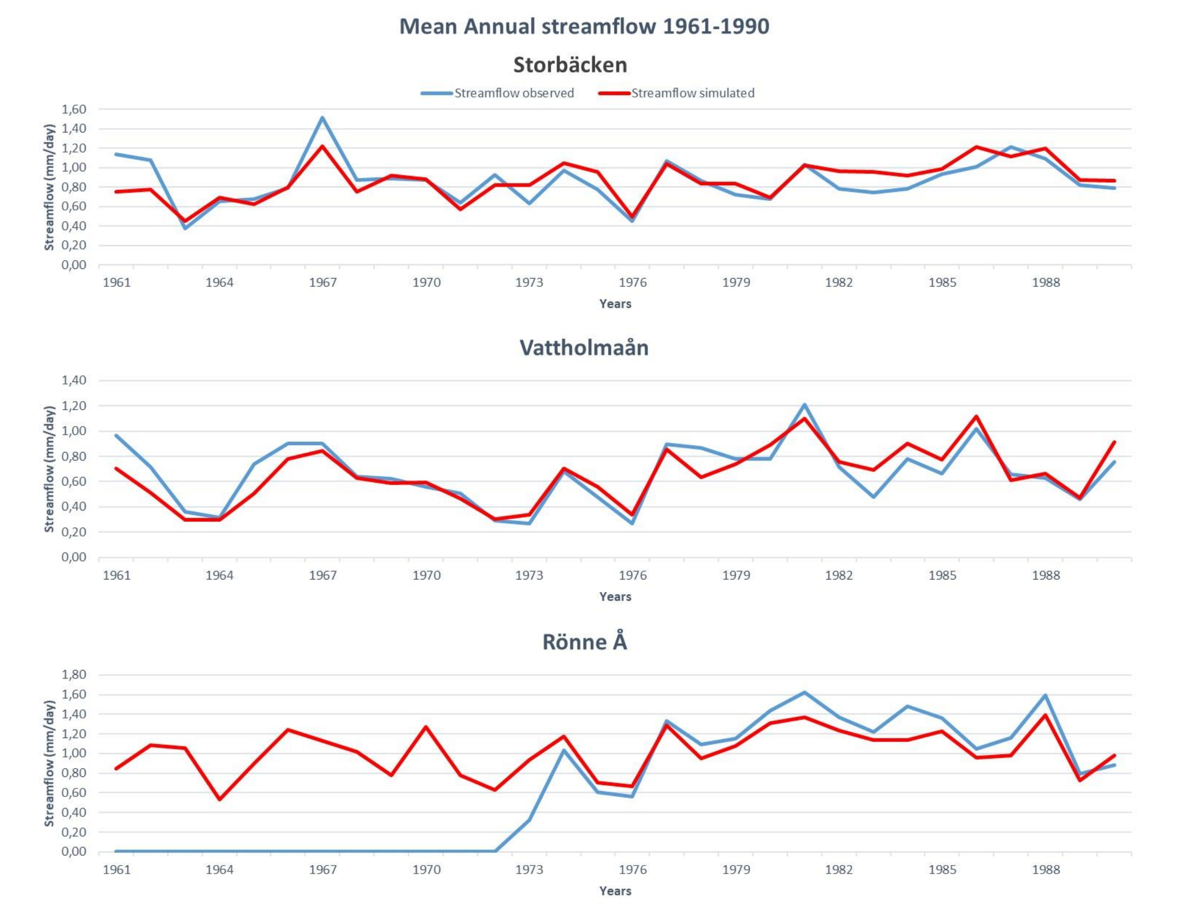

Figure 1: Mean Annual Streamflow for the observed and simulated data for the period 1961 to 1990 for the Storbäcken, Vattholmaån and Rönne Å catchments. In blue color is plotted the observed data and in red color is plotted the simulated data.

For a better understanding of the effects of climate change in the catchments we have to consider not only all the hydrological process that control the system of the catchments but the temperature of the environment. This one is a clear parameter that let us know that temperature is increasing and affecting the behavior of the three catchments. As we can see in Figure 2 below, we can clearly observe that the temperature for both models in the next 50 years is increasing for the warmer months and decreasing for the colder months, therefore this is going to affect direct to the different signature analysis of the catchments. Further we have to consider that the increasing in temperature means the increasing of the evapotranspiration which is a key factor to the catchment behavior.

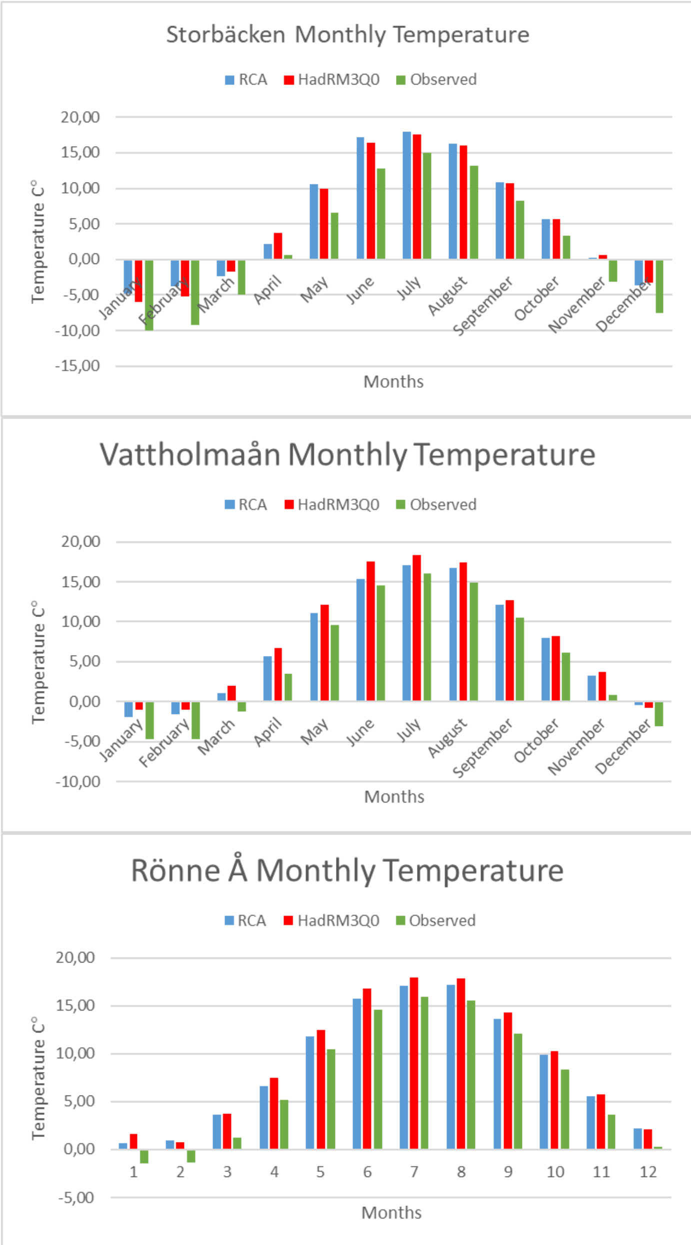

Figure 2: *Monthly temperature observed for the tree catchment. In green color we have the temperature observed during 1961 till 1990 and in blue and red color we have the predicted temperatures for the two models: RCA and HadRM3Q0 respectively*.

1.2. Low flows

A minimum 30 day low flow was calculated for every catchment for both observed and predicted. A 30 day low flow was calculated as a rolling average of time period of thirty days over the entire year. Out of the 330 values that came up for one year(360 days), the lowest were selected. Also, the start day of this 30 day low flow was noted and plotted for comparison.

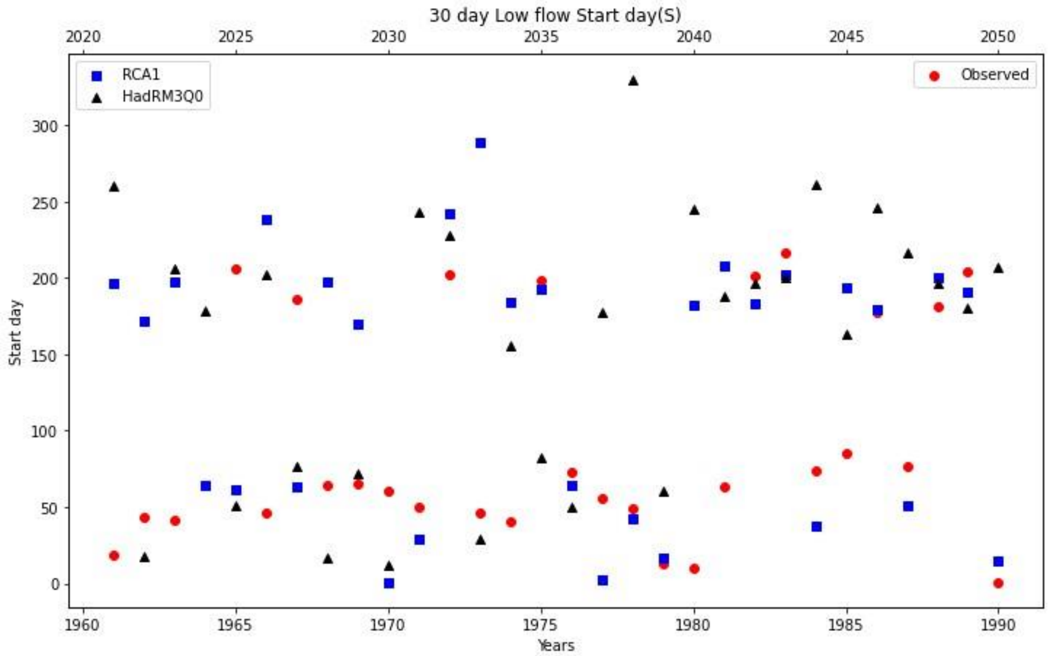

Fig.3 : This graph represents the start day of the 30 day low flow for the catchment of storbacken. On the y axis is the start day of the year. And on the two x axis are the years.

As we can see in Figure 3, the red dots represent the observed values and are generally located at the bottom of the graph. Suggesting that from 1961 to 1990, the 30 day low flow occurred or started within the first three months of the year. The triangles and the squares represent the simulated values. These suggest that the 30 day low flow might get pushed up, that is it might occur in the 5th to 8th month of the year. We know that this catchment is located in the northern part of the Sweden. It has been predicted that the temperatures will rise in this part of Sweden. Hence an early snowmelt, might occur from the end of winter and will last until the end of summer. We can say that the 30 day low flow for this catchment will be in the summer, or in the months of June, July and August.

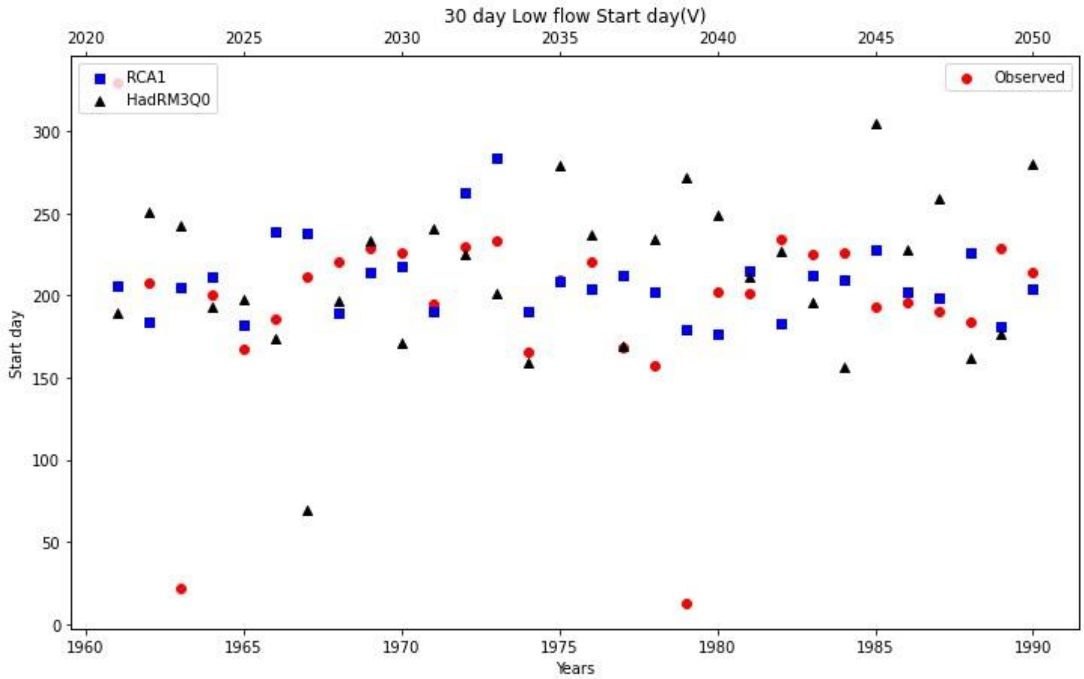

Fig.4: This graph represents the start of the 30 day low flow for the catchment of vatholmaan. On the y axis is the start day of the year. And on the two x axis are the years.

From the Figure 4, we can clearly see that the models are predicting almost no change in the start of the 30 day low flow. Both the models are showing similar results for the catchment. This catchment is located in the central Sweden, and hence is not that affected in terms of this particular signature.

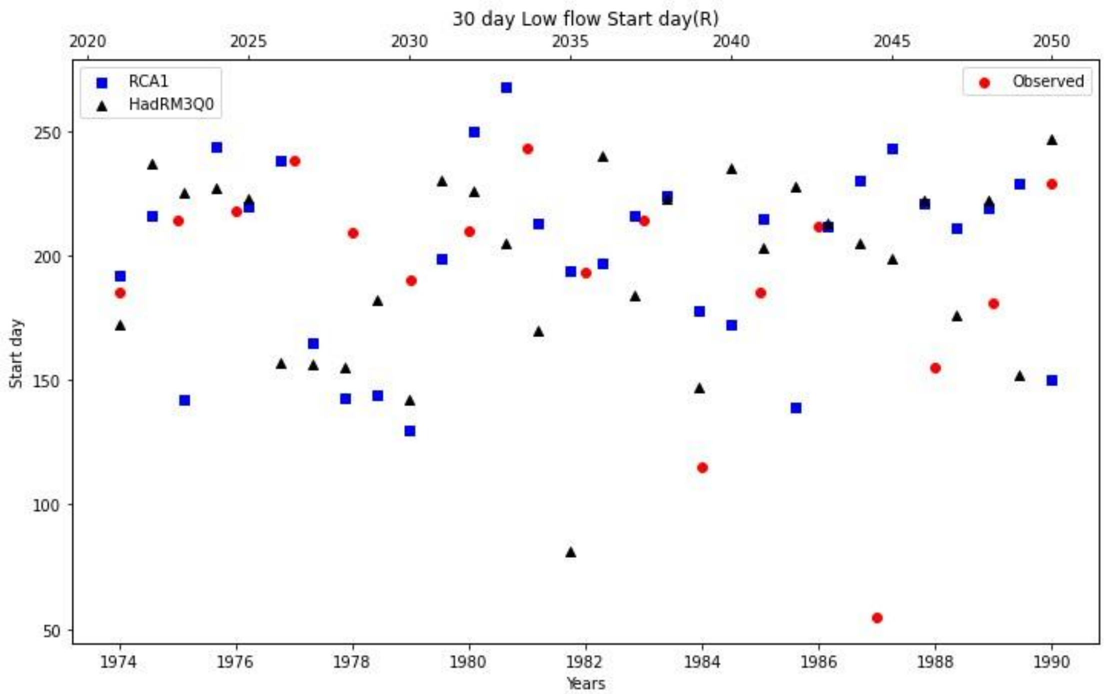

Fig.5: This graph represents the start of the 30 day low flow for the catchment of Ronne A. On the y axis is the start day of the year. And on the two x axis are the years.

From the figure 5, we can see that the 30 day low flow start day might start earlier for the Ronne A catchment. Although most of the models are predicting a reduction in run-off for southern Sweden, where this catchment is located, the 30 day average of the low flow is increasing. From figure 5 we see that the low flow is being pushed down the graph, and some of the values are suggesting that the low flows might occur at the start of the summer rather than the end of the summer.

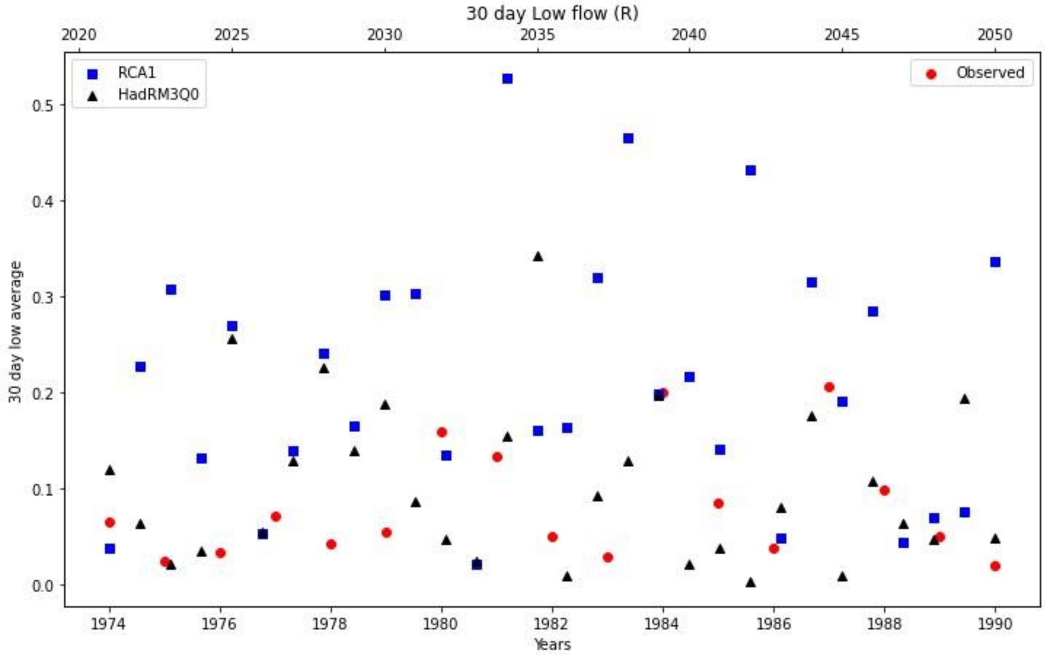

Fig.6 : This graph represents the 30 day average value on the y axis in millimeters and years on both the x axis.

From this figure we can see that the 30 day low flow average is increasing for this catchment. The value of the lowest flows of the year seems to be increasing, this might be because of the rise in precipitation in the region.

2. RESULTS

2.1. Water Balance

2.1.1. Mean annual Streamflow

As we can see from Figure 3 below, the green line that is the observe data from 1961 till 1990 is shown closer to the bottom than both of the future models. This is show us that there is an increasing trend in the future for the annual streamflow, and this due to the effects of climate change on the tree catchments. In addition, when we observe the two model's prediction for the future streamflow we can see that both almost synchronize and they are on top of each other and letting us know that both models' results are almost similar.

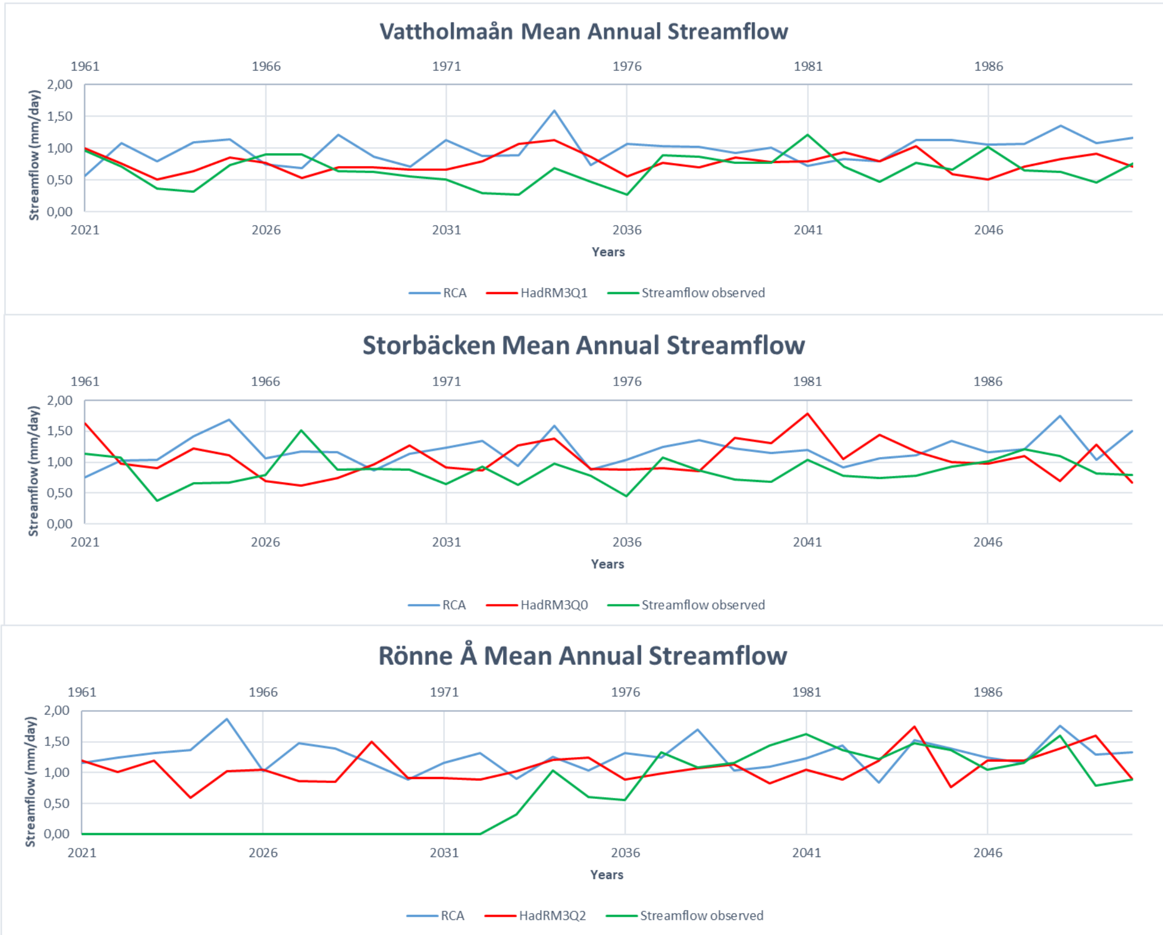

Figure 3: *Annual Mean Streamflow of the 3 catchments Storbäcken, Vattholmaån and Rönne Å. In color blue we have the RCA model from 2021 - 2050, in red color we have the HadRM3Q0 model from 2021 - 2050 and in green color we have the observed data from 1961 – 1990.*

2.1.2. Mean streamflow in particular seasons

In Figure 4 we have the seasonal Mean streamflow for the Storbäcken catchment. As we can observe the data in green line that represent the observed data from the past is located to the bottom off the plot in three of the seasons. For the other two model for the future data we can see an increase on the streamflow data in blue and red line, even though we can see the increasing on the due to climate change the increase is not too significant due to the size of the catchment. But we have to consider that this catchment is located far to the north and the effects of climate change are observed to affect faster in these areas, with faster melting of glaciers and permafrost and realizes of methane gas that are trap in the permafrost. Therefore, the faster melting and release of gasses contribute to global warming increasing the temperatures.

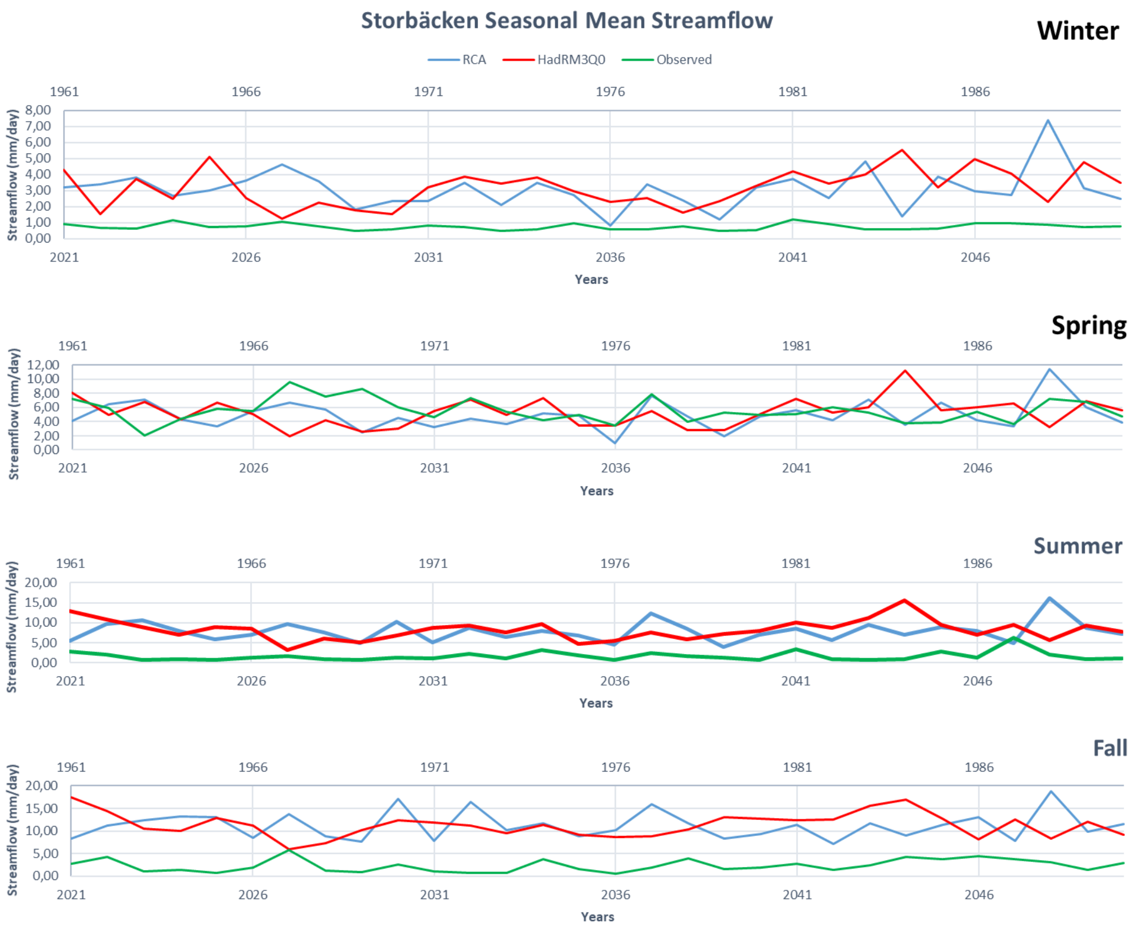

Figure 4: *Storbäcken Seasonal streamflow for the observed and the two models. In green color we can see the observed data from 1961 till 1990, and in blue and red color we have the future two model's data from 2021 to 2050 for all the seasons.*

For figure 5 we have the seasonal streamflow for Vattholmaån catchment. Here just as the figure 4 above we can see the observed data for the period 1961 to 1990 in green color is located almost to the bottom of the plot. As for the two future models the blue and red line show a similar increase for the next 50 years of the catchment. Compare to the Storbäcken catchment values, in this catchment the increase in the streamflow is slightly less, but significant compare to the observed data, show an increasing trend for the future values in both models.

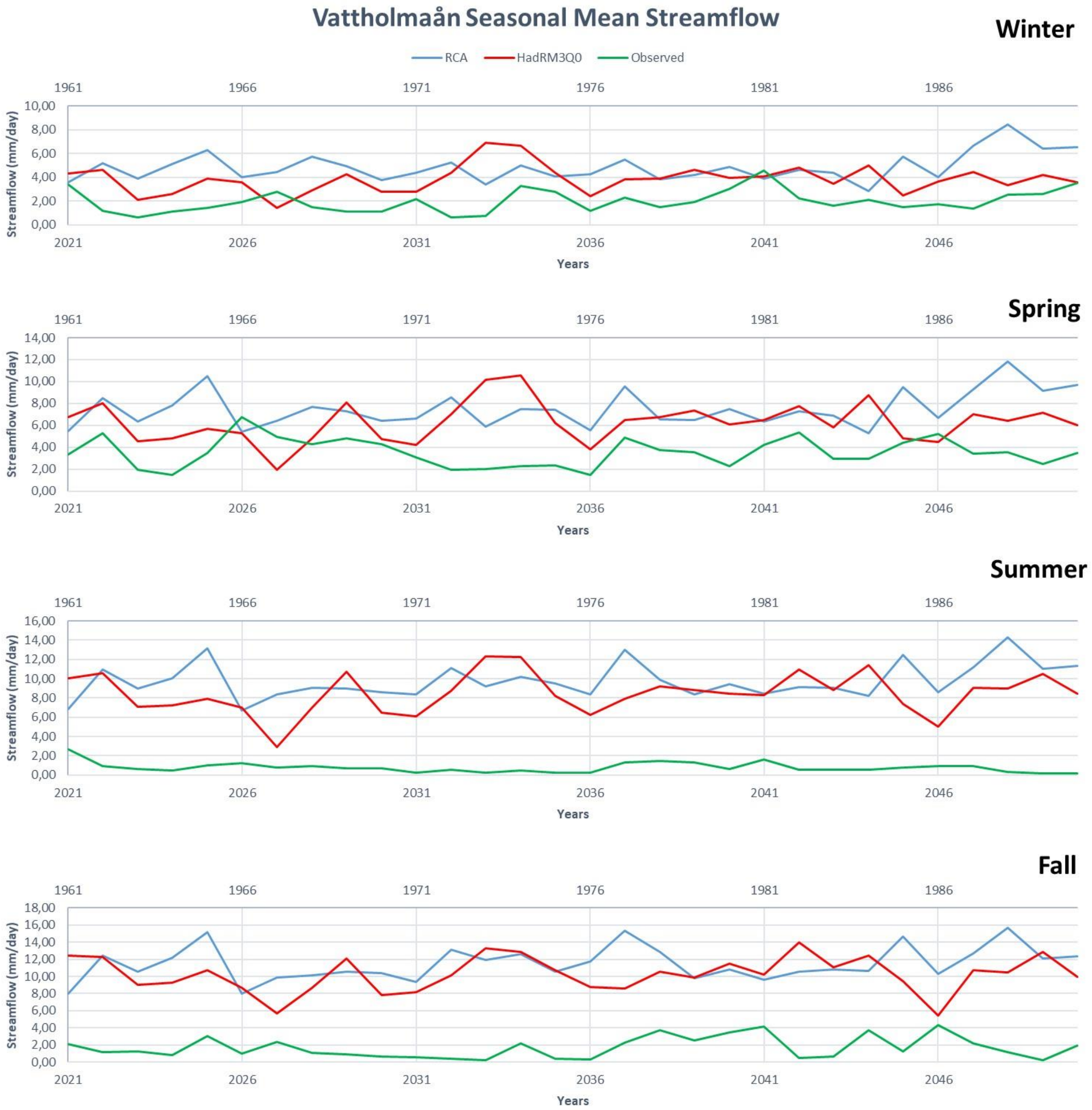

Figure 5: *Vattholmaån Seasonal streamflow for the observed and the two models. In green color we can see the observed data from 1961 till 1990, and in blue and red color we have the future two model's data from 2021 to 2050 for all the seasons.*

For Figure 6 we have the Rönne Å catchment data for observed seasonal streamflow values and future seasonal streamflow values of two models. Just like the two catchments before in green color we have the observed data on the period 1961 to 1990 and in blue and red we have the two models for the next 50 years in the catchment. This catchment is situated further south in Sweden and in the figure, we can see for winter and spring seasons the streamflow doesn't increase significative for both models. As for the summer and fall season we can see a significant increase in the streamflow as much as the Vattholmaån catchment. As mention before with the seasonal data for both model for the following 50 years we can see that the effect of climate change will affect in the streamflow of the catchments. Although the size of the catchments is small for a significant change and increase in the future we can still see the effects of climate change.

Figure 6: *Rönne Å Seasonal streamflow for the observed and the two models. In green color we can see the observed data from 1961 till 1990, and in blue and red color we have the future two model's data from 2021 to 2050 for all the seasons.*

2.1.3. Runoff Coefficient

For the runoff coefficient data, we have plotted figure 7 below with the observed data from the period 1961 to 1990 and two models for the following 50 years. Since in the plots above we acknowledge the effect of climate change with increase of the streamflow annually and seasonal, just like those values in figure 7 below we can see the same effects on the increase of the runoff coefficient. Even though the increase is not big for the observed and simulated data, we can still observe a trend that increase for both models (RCA and HadRM3Q0).

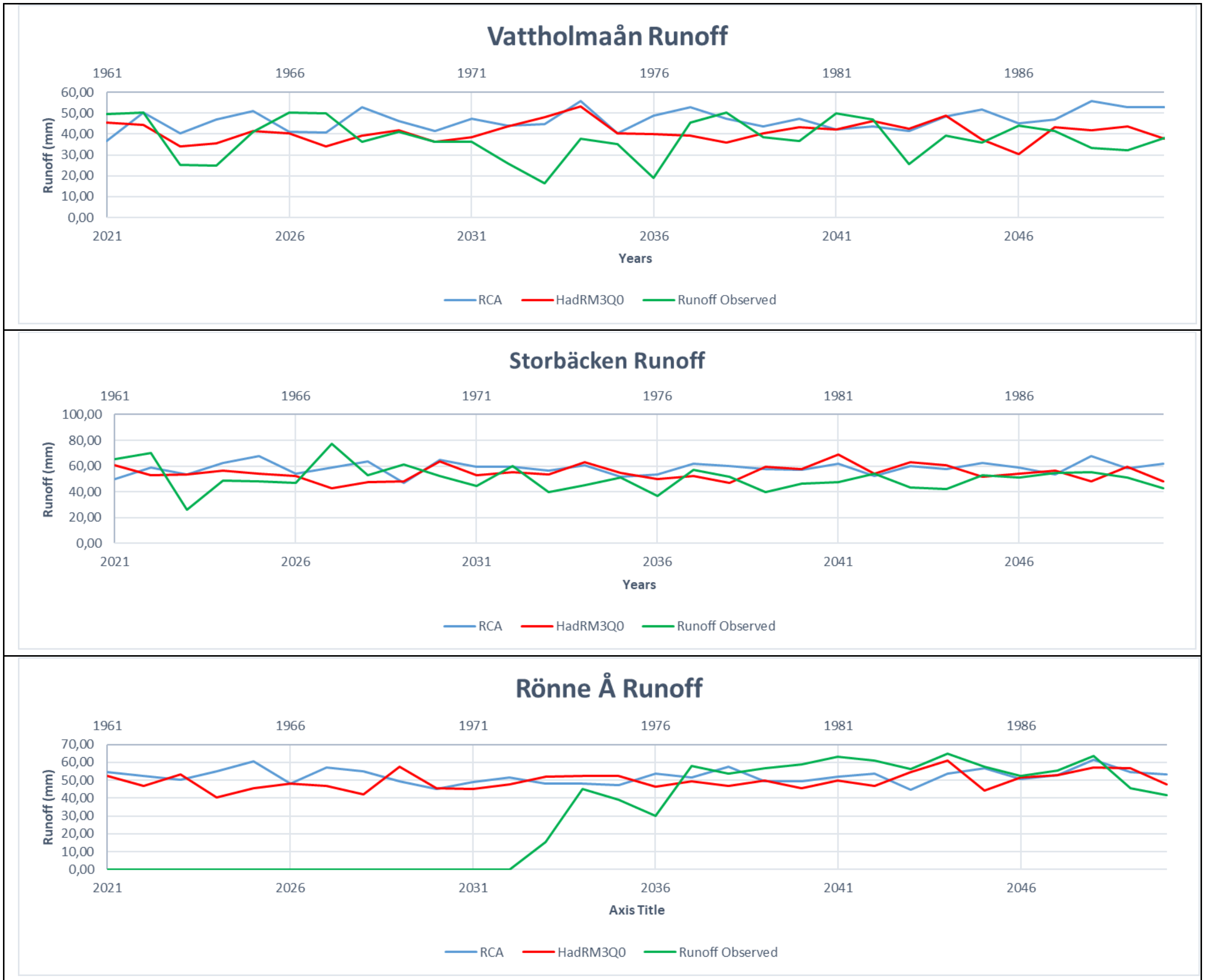

Figure 7*: runoff coefficient for the tree catchment. In green color we have the observed runoff data from 1961 till 1990 and in blue and red color we have the two model's runoff data from 2021 to 2050.*

2.2. Low Flow Frequency

Firstly, the mean flow of the year was calculated. Then the days in a year that were less than twenty per cent of the mean were noted and plotted on graphs for comparison.

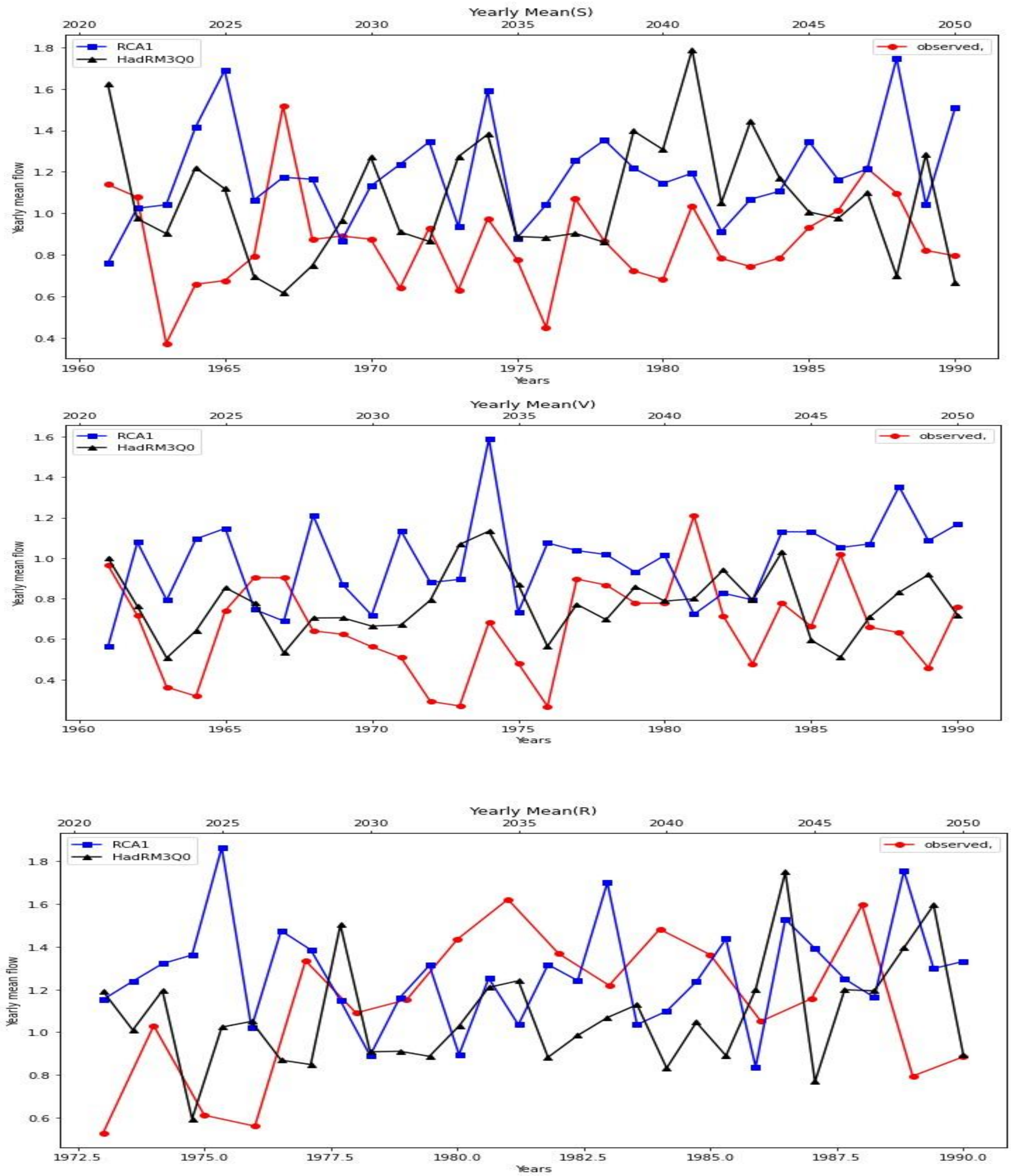

Fig.7 : This graph represents the yearly mean of the Storbacken, Vatholmann and Ronne A catchment(From top to bottom). The y axis represents the yearly mean flow in millimeter(mm). Both the x axis represent years.

We can see from Figure 7, that for the southern catchment(bottom most graph) both the models are predicting a reduction in the yearly mean value. While the other two graphs have a clear increase in the yearly mean.

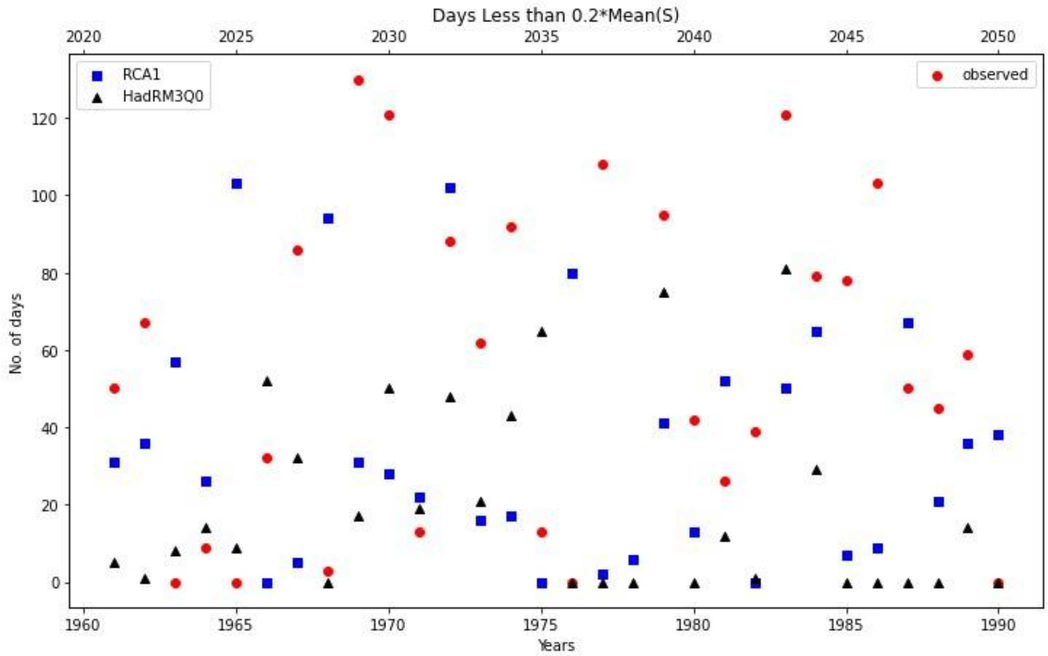

Fig.8: This graph represents the number of days that are less than 20 per cent of the yearly mean for a given year for the Storbacken catchment.

In Figure 8 we can see a clear reduction in the number of days that are below 20 percent of the yearly mean. Both the models are predicting an increased in run-off as suggested from Figure 7 for the storbacken catchment. We can see that very few values of the RCA1 are above 60, and even fewer of the HadRM3Q0 model for this catchment. The HadRM3Q0 model is predicting very few days of low flow, but the yearly average for this catchment is seen to rise in the RCA1 model. This suggest that the latter is suggesting peak flows in this catchment, and the earlier model is suggesting a relatively more uniform flow throughout the year.

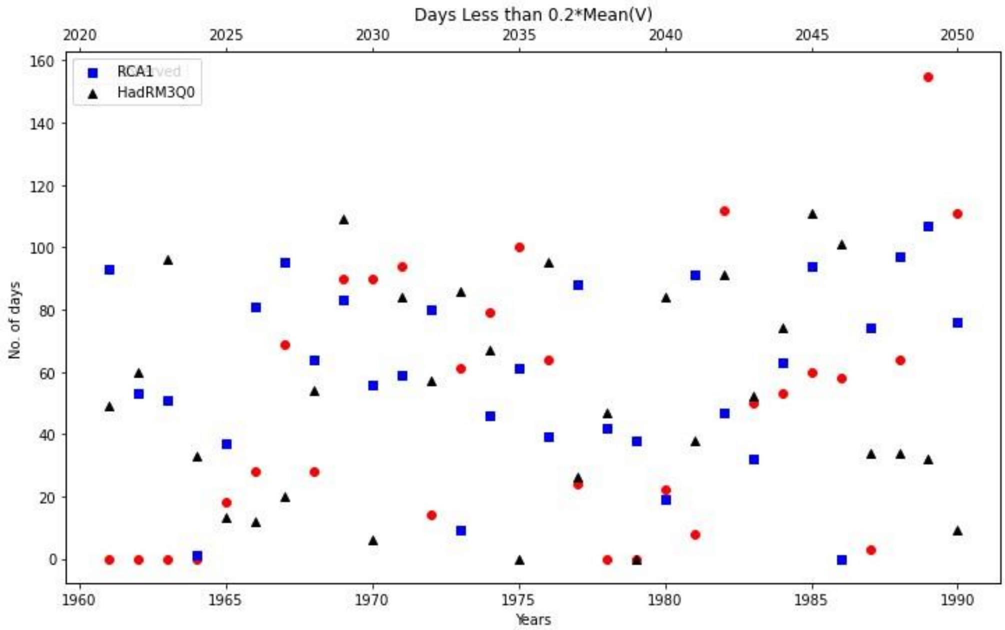

Fig.9: This graph represents the number of days that are less than 20 per cent of the yearly mean for a given year for the Vatholmaan catchment.

Both models are showing almost no change in the number of days that are below 20 percent. The RCA1 model in Figure 7 is showing a considerable rise in the yearly mean, yet it does not reflect in the number of days in Figure 9. This might suggest a non-uniform flow, and higher peak values for this catchment.

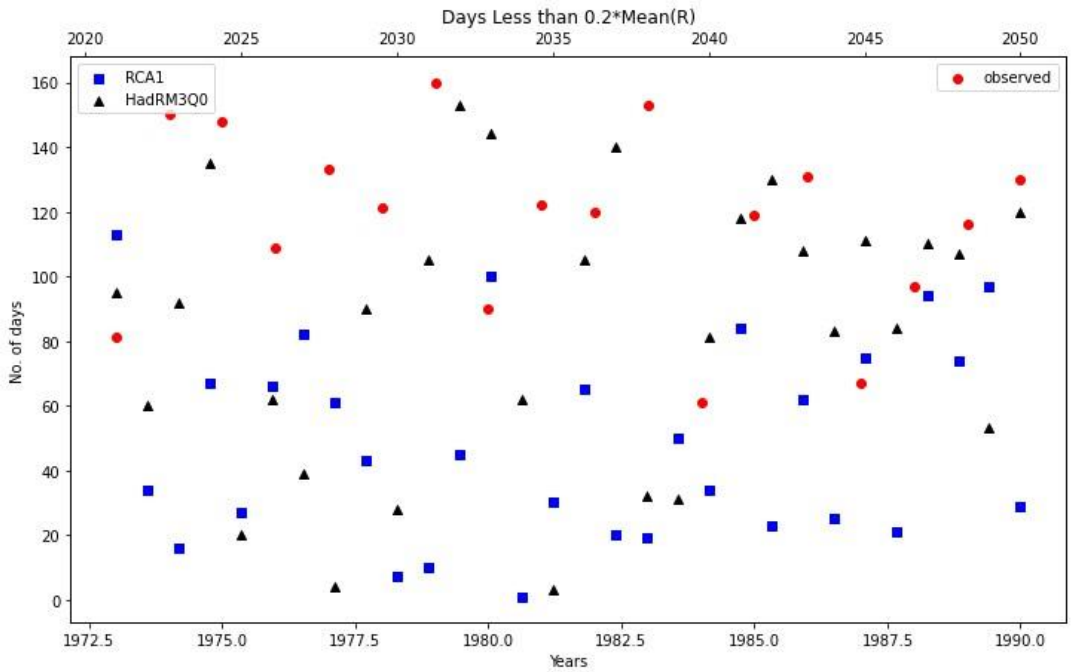

Fig.10: This graph represents the number of days that are less than 20 per cent of the yearly mean for a given year for the Ronne A catchment.

Figure 10 clearly shows a reduction in the number of days below the 20 percent mark for this catchment. Although both the models are predicting a lower yearly average mean, they seem to suggest that the low flows will also reduce. The HadRM3Q0 model has higher values than the RCA1for this catchment.

2.2. MIN(Q30)

A minimum flow during the consecutive 30 day low flow was calculated for every year. A rolling average was used to calculate and locate this flow in every year, as is mentioned above.

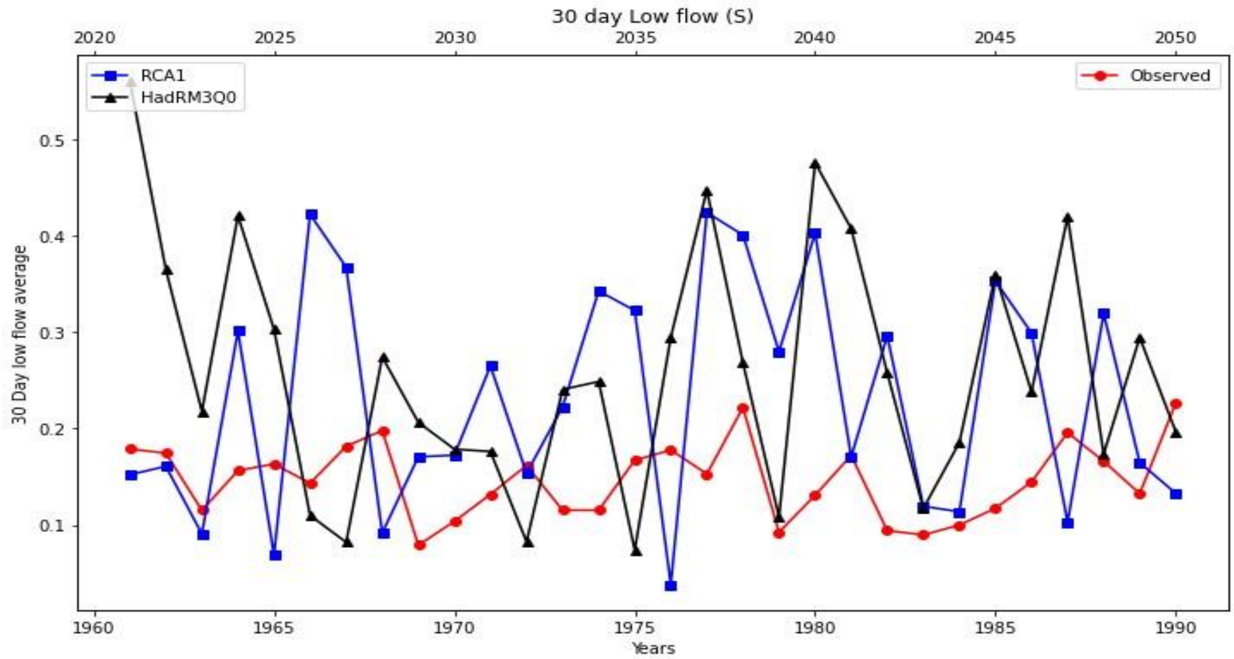

Fig.11 : This graph represents the 30 day low flow average(Y – axis) for any given year(x axis) for the Storbacken catchment. The values on the Y axis are in millimetres(mm).

As we can clearly see from Figure 11 that both the models are showing a clear rise in the value of the minimum 30 day low flow. Hence suggesting an increase in run-off throughout the year.

As the value of the lowest flow is on the rise. This is certainly because of the snow melt and also because of the rise in precipitation as predicted by both the models for this catchment in northern Sweden.

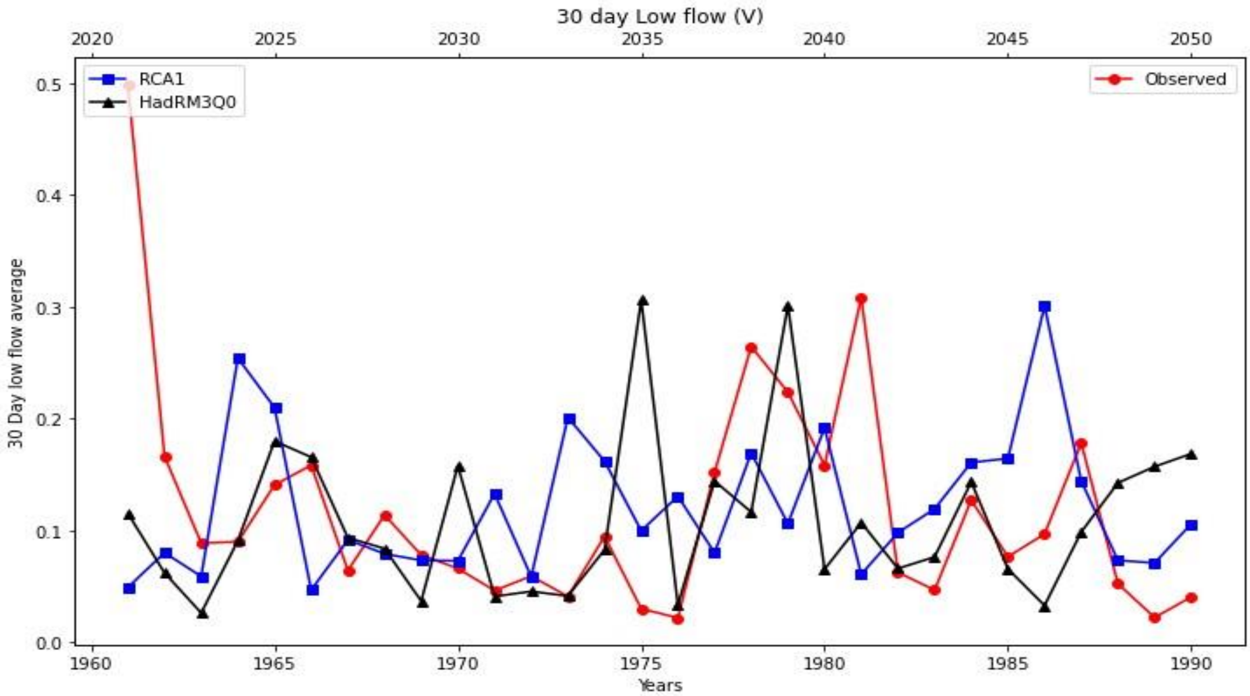

Fig.12 : This graph represents the 30 day low flow average(Y – axis) for any given year(x axis) for the Vatholmaan cathcment. The values on the Y axis are in millimetres(mm).

The RCA1 model, shows a slight increase in the 30 day low flow average over the period of fifty years. But the HadRM3Q0 model shows almost the same values as that of the observed. Hence we can conclude that the run-off patterns for central Sweden will more or less be the same, if a thirty day low flow has to be considered as a signature for comparison. This conclusion matches the results we saw in figure 4.

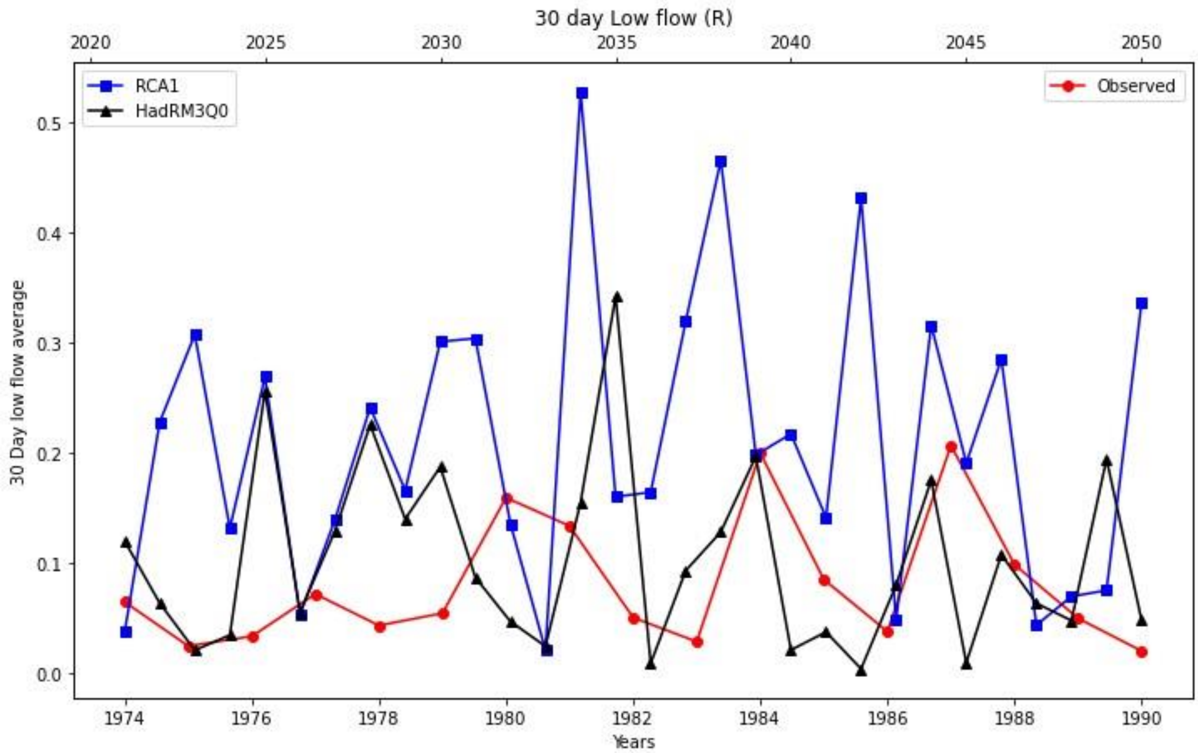

Fig.13 : This graph represents the 30 day low flow average(Y – axis) for any given year(x axis) for the Ronne A cathcment. The values on the Y axis are in millimetres(mm).

In figure 13 we can clearly see that the HadRM3Q0 is predicting higher values of a 30 day low flow for the Ronne A catchment, while the RCA1 model is predicting almost the same values with significant difference for the years 2025,2028, 2030 and 2035.

3. DISCUSSION

From the observation and analysis of the plots in water balance it can be determine that the effects of climate change play an important role for the behavior of the hydrological processes of the three catchments. As for the Mean annual streamflow in figure 3 we can see that there is a trend that increase in time, because the catchments for this study are small the significant in change is small. As we need to understand better the possible changes in the catchments it was necessary to work with two models and simulated predicted data that can give a possible result of the change in the behavior of the three catchments. For this purpose, the means seasonal streamflow was plotted in figures 4, 5 and 6 and for all the rivers we can see that there is and increase in the streamflow amount for all the seasons, but specially a significant increase for the summer and fall seasons. This is an indicator of how the increase in the temperature can affect the streamflow of the catchments, due to snow, glacier and permafrost melting that add to the streamflow.

Finally, for figure 7 the runoff values for the catchments in the observed and future models is shown a small increase in the runoff. Even thought the change is small for both models it is a

result of the effect of climate change and the effects on the catchment behavior. Because of the stream annual and season increases, the runoff contributes to this and is clearly that because the catchments are small the contribution of the runoff to the increase in the streamflow is clear. All the plots in the water balance overall show an increase on the values for both models in the future and they show the local effect of climate change in small catchments.

From Figure 7 we can see that for the catchments in northern and central part of Sweden show an increase in the yearly mean by both the models. Less for the central and a higher increase in the yearly mean can be observed for the catchment in northern Sweden namely Storbacken. Generally rivers in northern Sweden are dependent on snow melt. The rise in temperatures will surely affect the run-off patterns for this catchment. Also, both the models show a rise in precipitation for this catchment. Most precipitation in northern Sweden is in the form of snow. We can see that a delayed low flow start day in figure 3. Which means that most of the snow might melt away before the start of the summer. Hence low flows will occur in the summer for this catchment. For the catchment in central Sweden, namely Vatholmaan, we can see almost no change in low flows. With the yearly mean slightly increasing as seen in Figure 7, the rest of the parameters show no significant change for low flows in this catchment. As for the catchment in southern Sweden namely, Ronne A, we see a slight decrease in the yearly mean(figure7) but also a decrease in the number of days that are below 20 per cent of the yearly mean(figure 10). This could be because of the increase in the values of the 30 day low flow average(figure 13).

The water quality is largely affected by the flow. Reduction in flow, will result in lower water quality. Water shortage is normally not a major problem in Sweden but temporarily low flows may affect water quality and supply, in particular in the southeastern parts of the country (Bergström et al., 2001). On the contrary, very high flows could result in property damage and also the damage of large dams. Hydrological models are a good way to predict the behaviour of a catchment. But they also have some deficiencies. Most of them fail to include change in land use patterns, evapotranspiration and may have different values of the snow-melt coefficient. More serious is the uncertainty in the modelling of evapotranspiration in a future climate (Bergström et al., 2001).

4.CONCLUSION

As climate change is increasingly affecting the water bodies behavior around the world, it is expected that with this the droughts and dry events will be intensified as much as local and global levels. In the last decades Europe has been experience several floods and droughts, and in the norther part of Europe like Sweden these events are happening faster than other parts of Europe. The effects of climate change are show in the change of the hydrological cycle, the melting of glaciers and the reduction of ice coverage and regions that are wet become even wetter and dry regions become arid. As a result of a combination of all these events due to the elevation in temperature of the atmosphere and the pollution, the average water flow that was modeled with two model for the following 50 years, shows a clear example of this changes in water cycle locally. Higher catchment flow and a significant change in the seasonal flow is the result of climate change affects locally. Knowing that climate and land use are important factors in the water catchment behavior, it is important that from now on climate change is consider a crucial environmental problem, and both factors needs to be properly assessed for future land use planning and water resources management. Even thought the two models (RCA and HadRM3Q0) have results close to each other in predicting the hydrological water cycle of the catchments, in the future refine models for hydrological changes due to climate change will be needed, specially with the significant speed climate change is impacting the water cycle.

5. REFRENCES

Beldring, S., Engen-Skaugen, T., Førland, E.J., Roald, L.A., 2008. Climate change impacts on hydrological processes in Norway based on two methods for transferring regional climate model results to meteorological station sites. Tellus A 60, 439–450. https://doi.org/10.1111/j.1600-0870.2008.00306.x

Bergström, S., Carlsson, B., Gardelin, M., Lindström, G., Pettersson, A., Rummukainen, M., 2001. Climate change impacts on runoff in Sweden-assessments by global climate models, dynamical downscaling and hydrological modelling. Clim. Res. 16, 101–112. https://doi.org/10.3354/cr016101

Johan Andréasson, Sten Bergström, Bengt Carlsson, L. Phil Graham, Göran Lindström, 2004. Hydrological Change – Climate Change Impact Simulations for Sweden. AMBIO J. Hum. Environ. 33, 228–234. https://doi.org/10.1579/0044-7447-33.4.228

KUNDZEWICZ, Zbigniew W. Climate change impacts on the hydrological cycle. Ecohydrology & Hydrobiology, 2008, vol. 8, no 2-4, p. 195-203. https://doi.org/10.2478/v10104-009-0015-y

OKI, Taikan; KANAE, Shinjiro. Global hydrological cycles and world water resources. science, 2006, vol. 313, no 5790, p. 1068-1072. https://doi.org/10.1126/science.1128845

GRAFTON, R. Quentin, et al. Global insights into water resources, climate change and governance. Nature Climate Change, 2013, vol. 3, no 4, p. 315-321. https://doi.org/10.1038/nclimate1746

MILLY, Paul CD; DUNNE, Kathryn A.; VECCHIA, Aldo V. Global pattern of trends in streamflow and water availability in a changing climate. Nature, 2005, vol. 438, no 7066, p. 347-350. https://doi.org/10.1038/nature04312