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Environmental sciences

Differences in response to rising CO_2 between forest and agriculturally dominated basins

A study of two basins in southern Sweden

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Bachelor thesis in Environmental science

ES1510 Environmental science: Degree project, 15 HEC
Spring 2018
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Abstract

The concentration of CO_2 in the air is currently on levels higher than in at least a million years. Possible plant responses to this increase, such as stomatal conductance decrease and LAI increase, are affecting the evapotranspiration from land ecosystems and therefor directly the global hydrological cycle. These responses are starting to be accounted for in global climate models but no model covers the difference in responses within different ecosystems. In this study two basins in southern Sweden, the agriculturally dominated Kävlingeån basin and the nearby forest dominated Lyckebyån basin, were compared to see if vegetation type specific responses should be considered. The basins were plotted into Budyko space, a model consisting of an aridity index and an evapotranspiration index where observed changes can be attributed to climate or other factors. By comparing the movement within the Budyko space it is possible to see if a basin is only affected by climate or by ecosystem factors not taken into account by the model. Changes in hydrology over time were investigated and compared for the two basins. For the Kävlingeån basin no change that could not be explained by climate could be observed, indicating that the responses to elevated CO_2 are either not present or compensating. For the Lyckebyån basin a non-climate related increase in evapotranspiration was seen, indicating the presence of an ecosystem response changing the hydrological cycle within the basin. The response differences in the two basins indicate that the type of vegetation in the studied area and its specific responses to elevated CO_2 needs to be accounted for in land hydrological models for Sweden.

Sammanfattning

Halten av CO_2 i luften ligger idag på dem hösta nivåerna på minst en miljon år. Växters möjliga respons till denna ökning av CO_2, så som att stomata konduktansen kan minska och LAI kan öka, påverkas landekosystems evapotranspirationen och även den globala hydrologiska cykeln. Dessa växtresponser börjar bli inkorporerade i globala klimatmodeller men än finns ingen modell som täcker de varierande responserna av de olika ekosystemen. I denna studie har två närliggande avrinningsområden i södra Sverige, det jordbruksdominerade Kävlingeån och det skogsdominerade Lyckebyån, studerats för att se om man bör ta hänsyn till ekosystemens specifika responser. Områdena plottades in i Budyko space, en modell bestående av ett evapotranspiratiorisk index och ett torrhetsindex där observerade skillnader kan tillräknas klimatförändringar eller ekosystemresponser som inte tas hänsyn till i modellen. Förändringar inom hydrologi över tid undersöktes och jämfördes för de två avrinningsområdena. För Kävlingeåns avrinningsområde syntes inga förändringar som inte kan förklaras av klimatet. Detta tyder på att de responser som finns till ökad CO_2 halt antingen inte finns eller att de kompenserar varandra. För Lyckebyåns avrinningsområde finns en icke-klimatrelaterad ökning i evapotranspirationen vilket tyder på att det finns ekostytemresponser som påverkar den hydrologiska cykeln inom området. Skillnaden i respons mellan de två områdena tyder på att vegetationstyp i de studerade områdena och dess specifika respons till ökad CO_2 halt måste tas hänsyn till i hydrologiska modeller för Sverige.

Keywords: Hydrological cycle, Budyko framework, LAI, stomatal conductance, agriculture, forests, CO_2

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Introduction

Background

Change in climate

The climate on our planet is changing. Since the 1950s there has been an unmistakable warming of the earth, both in seas and in the atmosphere. Furthermore, in the latest report from the IPCC, Intergovernmental Panel on Climate Change, the assessment was made that there is a high confidence that the precipitation in the northern hemisphere has increased (Intergovernmental Panel on Climate Change, 2013). The trend for the future is now that the number of days with little precipitation will decrease and that days with heavy precipitation will increase, a trend that is already evident (Fischer & Knutti, 2016). These changes in temperature and in precipitation have already and will continue to transform the hydrological conditions, changing the climate and changing the living conditions for the plants (Helfer, Lemckert, & Zhang, 2012).

CO_2 is rising

According to measurements performed by the Mauna Loa Observatory in Hawaii, the CO_2 concentration in the air has been rising since 1958 when the measurements started. The concentration has increased from around 320 ppm in 1958 to 410 ppm in April of 2018 and with pre industrial levels being as low as 280 ppm (ESRL, 2018; Wigley, 1983). The IPCC has stated that levels are now substantially higher than the pre-industrial levels and that cause for the rise in CO_2 is human activity such as burning fossil fuel and deforestation (Intergovernmental Panel on Climate Change, 2013). The concentration of CO_2 has not been on these high levels in a significant amount of time. There is a disagreement within the scientific community on exactly how far back it can be said with certainty that the levels have not been this high, with methods showing results from close to a million years ago up to twenty million years ago (Franks et al., 2014). Scientists are able to track the CO_2 levels back as far as 800 000 years with the help of ice cores and even further with the help of fossils and models but the exact period in which levels were this high is hard to tell (Franks et al., 2014; Zhang, Pagani, Liu, Bohaty, & Deconto, 2013).

Plants react differently to CO_2

The elevated CO_2 levels have two effects on plants. Firstly it affects the stomata, leading to stomata being more closed that would lead to a decrease in evapotranspiration. Secondly, it acts as a fertiliser, resulting in more growth and increased leaf area and therefore more evapotranspiration (Gustavson, 2014). The response of elevated CO_2 levels varies however between different divisions in the taxonomy of plants. Angiosperms show a greater response to the elevated levels than gymnosperms, but this is also depending on the climate they grow in (Bonan, 2008; Gustavson, 2014; Hasper, 2015; Haworth, Elliott-Kingston, & McElwain, 2013).

Leaf area index
LAI stands for leaf area index and is the ratio of the total projected leaf area per unit ground area. As a response to elevated CO_2 levels, trees can grow leaves in places where there is less light, leading to an increase in LAI (Hirose, Ackerly, Traw, Ramseier, & Bazzaz, 1997). For a tree to produce more leaves there have to be more carbonates generated by photosynthesis than used during respiration. With elevated CO_2 levels, this enables leaves to grow in more shadow and still produce an excess of carbonates (Dermody, Long, & DeLucia, 2006). This response leads to an increase in evapotranspiration and counteracts the water saving response by the decrease in stomatal conductance (Hirose et al., 1997; Raymond, Oh, Turner, & Broussard, 2008). This response is more prominent in forest than in crops, with forests growing for multiple years and crops mostly only having a one-year cycle, the LAI response is hardly seen in agriculture (Ainsworth & Long, 2005).

Stomatal conductance
On the leaf surface of plants, there are small regulating openings that are called stomata. The stomata control two important functions in the plant, CO_2 uptake and water loss (Buckley, 2005; Medlyn, Duursma, De Kauwe, & Prentice, 2013). The plant constantly has to balance the carbon uptake with the water loss when opening the stomata. The stomata directly interact with the hydrological climate around the plant by closing when there is a lack of available water and opening when there is a surplus (Buckley, 2005). The stomata also respond to different concentrations of CO_2 both in short-term and in long-term. Experiments have shown that plants growing in an environment with elevated levels of CO_2 typically show a reduction in their stomata conductance (Haworth et al., 2013).

Many models on effects by rising CO_2 levels have assumed a decrease in stomatal conductance and in plant water use. There is, however, no total consensus about this statement since the water use of plants is also strongly affected by precipitation, temperature and land-use (Hasper et al., 2016), as well as by possible changes in LAI (Piao et al., 2007). Numerous studies (Betts et al., 2007; Gedney et al., 2006) have linked the change in stomatal conductance to the global increase in runoff, with the water saving response in plants resulting in higher soil moisture and higher runoff. These studies are however in conflict with other studies (Wisser, Fekete, Vorosmarty, & Schumann, 2010) suggesting that the global increase in runoff is a result of a global increase in temperature and precipitation or a combination of climate effects and land-use (Hasper, 2015; Raymond et al., 2008).

Differences in agriculture and forests
Forests cover around 30 % of the total landarea. In later years the complexity of how forests affect the global climate has been more and more studied. The forests affect a lot of factors relevant to the global climate and in mitigating the global effects created by humans (Bonan, 2008). Forests play a huge roll in the global carbon cycle, absorbing almost a third of all global emissions of CO_2, but they also regulate ecosystems, affect the regional patterns in temperature, runoff and precipitation and protect biodiversity (International Union on Conservation of Nature, 2017). Agriculture on the other hand plays a more negative role for the climate. With a growing population and a growing food demand agricultural lands are replacing forests around the world. Many processes within agriculture contribute to large amounts of greenhouse gases being emitted to the air. Deforestation to make room for more agricultural land is also a problem all around the globe (European Environment Agency, 2015). Agriculture is also vulnerable to climate change with higher temperature both resulting in a longer growing season for the northern parts but resulting in extreme heat waves in the

southern parts of Europe (European Environment Agency, 2015; Intergovernmental Panel on Climate Change, 2013). With rising levels of CO_2 causing different responses in LAI and in stomatal conductance depending on taxonomy, the role of vegetation becomes more important for understanding the climate.

The Budyko framework

Mikhail Budyko, a Russian climatologist, created the Budyko framework in 1974. The Budyko framework is widely used within climatology and hydrology as a way of understanding a basin and its future changes (Berghuijs & Greve, 2015; Garrison, 2017). The basic framework is a plot with the aridity index consisting of potential evapotranspiration, (PET) divided by precipitation (P) on the x-axis, and the evapotranspiration index consisting of actual evapotranspiration (AET) divided by precipitation (P) on the y-axis. By studying how a catchment moves within this so-called Budyko space it is possible to see if it is affected only by climate and therefore follows the Budyko curve, or if it does not and therefore other factors are involved (Berghuijs & Greve, 2015).

Aim

This study investigates the changes seen in the runoff, precipitation, and temperature, potential and actual evapotranspiration within two basins dominated by either agriculture or forestry. The aim is to see if the changes observed are because of climatic change (in temperature or precipitation) or depending on other factors (e.g. effects of rising CO_2 on stomatal conductance and/or LAI).

Hypothesis

Kävlingeån: For the agricultural dominated basin of Kävlingeån the stomata conductance will have an effect on the basin, decreasing its evapotranspiration index resulting in a downward trend within the Budyko space. The LAI will not have any effect on the basin since the response is very small in crops, therefor giving no increase in evapotranspiration. The basin will not follow the predicted curve and will instead show a drop in AET/P compared to the Budyko curve.

Lyckebyån: In the forest dominated basin of Lyckebyån, the stomata conductance response will be much lower than the LAI response resulting in an increase in evapotranspiration. The movement of the basin within Budyko space will not follow the predicted curve and instead show an increase in AET/P.

Vegetation type impacts: These responses to elevated CO_2 will vary enough between the two basins that the main type of vegetation should be considered when model predictions are made. A forest will respond differently than an area dominated by agriculture and therefore affecting the hydrology differently.

Method

Collecting the data

First two basins were chosen from the Swedish metrological and hydrological institute, SMHI, via their map of basins in Sweden from the database Vattenwebb (http://vattenweb.smhi.se/station/). The requirements set up for the basins to be selected was:

- To be dominated by (>70%) either agriculture forest according to the Vattenwebb map
- Be in roughly the same part of Sweden, preferably located in the same climate zone
- Be of similar basin size - preferably around 1000 km^2
- Have as long time period of data as possible

Two basins that met all of these requirements were chosen - Kävlingeån with a coverage of 78 % for agriculture and Lyckebyån with a coverage of 73 % for forests (Kävlingeåns vattenråd, n.d.; Lyckebyåns vattenförbund, n.d.).

Data for precipitation and temperature for the time period 1970-2016 was collected from SMHIs database Luftwebb (http://Luftwebb.smhi.se/). Luftwebb is a tool made by the SMHI that is a bias-corrected gridded dataset for temperature and precipitation for the period 1961-2017. It is based on data from stations for precipitation and temperature all around Sweden and has a resolution on 4x4 km (Jaramillo et al., 2017). To get a value that represents the entire basin, data was collected from six evenly distributed positions within the basin and then a mean was calculated from these.

Runoff data were collected from the gauging station closest to the mouth of each river. The two basins' active gauging station did not, however, cover enough time and were therefore complemented with data from closed gauging stations, located in close proximity to the active gauging station. From the three gauging stations (two active + two closed) all data from 1970 to 2016 was collected. For Lyckebyån there was a data overlap between 1987-11-25 and 1988-02-21 for the active and the closed station. Between these years, a mean of the two stations was created. The stations differed so little that no adjustments for the years before and after the overlap was needed. For Kävlingeån there was no overlap since the old station stopped at 1975-07-31 and the active started at 1975-08-01.

Handling of data

Four time periods were chosen to be able to see if there was any change and if that change would be distinct. The reason to choose four time periods was to be able to trace the differences and to reduce the importance of extremes. The time periods selected were two ten-year periods 1970-1979 and 2007-2016, and two twenty-year periods 1970-1989 and 1997-2016. These time periods were later compared in three different plots: first a 10-year mean series for both basins, secondly a 20 year-mean series for both basins and finally a comparison between the 10-year mean series and the 20-year mean series for each basin.

To calculate the potential evapotranspiration, PET, two different methods were uses, Langbein Eq. 1 and Thornthwaite Eq. 2, displayed on the next page. The difference between these two methods was used to identify any abnormality so that these could be disregarded. When a correlation was made and showed a very strong correlation (Table 1), a mean of these two methods was calculated and then used when plotting in Budyko space. To calculate the actual evapotranspiration, AET, the water balance equation, Eq. 3 was used, see next page. In the water balance equation, the change in storage (ΔS) was assumed to be negligible since this study focuses on a long time perspective and change in storage is thought to have no effect over multi-year periods of time (Jaramillo et al., 2017).

The four different equations used in this paper was:
Eq 1: Langbein:

$$PET = 325 + 21T + 0,9T^2$$

PET= Potential evapotranspiration, T=mean annual temperature

Eq 2: Thornthwaite

$$i = \left(\frac{T_m}{5}\right)^{1,51} \quad I = \sum_{j=1}^{1} i_j \qquad PET = C\left(\frac{10T_m}{I}\right)^{a}$$

$$C = 16 \quad a = 67,5 * 10^{-8}I^3 - 77,1 * 10^{-6}I^2 + 0,0179I + 0,492$$

T_m= mean monthly temperature, I= annual heat index, i=monthly heat index – when T≤0 i=0, j=number of months

Eq 3: Water balance equation

$$AET_{WB} = P - Q\ (-\Delta S) \qquad P = Q + AET + \Delta S$$

P=precipitation, Q=runoff, ΔS=change in storage

Eq 4: Turc

$$AET = \frac{P}{\sqrt{0,9 + \left(\frac{P}{PET}\right)^2}}$$

P=annual precipitation, PET= annual PET
Turc was used for both the PET calculated by Eq 1 and Eq 2.
References for Eq 1,2 and 4(Berghuijs & Greve, 2015; Langbein, 1949; Thornthwaite & Mather, 1957).

Statistical analysis and Budyko space plotting

To be able to ensure that the trends observed in the data were not due to differences in metrology between the two basins total annual precipitation, annual mean temperature and total runoff were plotted for all years. The mean difference in precipitation, temperature and runoff was calculated for all four time periods and for the whole time period. A correlation test was also conducted.

The values for precipitation, runoff and temperature were used to calculate evapotranspiration index (AET/P), which is the y-axis in Budyko space, and the aridity index (PET/P), which is the x-axis in Budyko space, for the whole time period of 1970-2016. Afterwards means were calculated for the periods 1970-1979, 2007-2016, 1970-1989 and 1997-2016. These values were plotted into Budyko space to see movement between the different time periods, 1970-1979 vs. 2007-2016 and 1970-1989 vs. 1997-2016 for both basins and then a comparison for each basin between the 10-year series and the 20-year series. For each time period and basin, a specific Budyko curve was made using the Turc equation, Eq 4. For these curves, the mean total annual precipitation for that specific time period was used as "P" in the Turc equation. Here random PET values between 0 and 1000 were used to generate the curve. When all curves were made a mean curve was created from this to use as a reference curve in the Budyko space. Within the Budyko space the energy limit (AET=PET) and the water limit (AET=P) were plotted.

Results

Meteorological and correlation

Table 1 shows the correlation between the two methods for calculating PET for both basins. PET is a potential factor and therefore it is not surprising that both basins show the same coefficient for the correlation since they are similar in climate. The correlation is very strong with a coefficient close to 1, justifying the use a mean of the two methods to plot in Budyko space.

Table 1- Correlation coefficients between the different methods for calculating PET; Langbein and Thornthwaite,

Correlation	Kävlingeån	Lyckebyån
$PET_{Langbain}$ and $PET_{Thornthwaite}$	0,96	0,96

In Figure 1a-1c total annual precipitation, mean annual temperature and total annual runoff are plotted for all years. Together with Table 2 which shows the correlation coefficients for all four time periods and Table 3 showing the mean difference between in precipitation, temperature and runoff for all time periods it is clear that the two basins are very similar in climate. In Figure 1b it is clear that the two basins follow the same temperature pattern over the years, this is further supported by Table 3 were the mean difference is only around 0,8 C° and Table 2 were the correlation coefficient is on 1,00. For precipitation, the basins differ a bit more than for temperature but in Figure 1a it still shows a lot of the same variations over the years and with a mean difference for all years of 52,13 mm and a correlation coefficient of 0,85 for all years. Even though there are bigger differences for precipitation than for temperature the basins are still very much alike when it comes to climate. For runoff, bigger differences are seen and the mean difference between all years 67,03 with the biggest difference being seen in the time period of 1970-1989. There are hydropower plants within both rivers that could be affecting the runoff data but the differences seen are still too small to show a difference in climate between the two basins (Kävlingeåns vattenråd, n.d.; Lyckebyåns vattenförbund, n.d.).

Table 2- Correlations coefficients for correlation between Kävlingeån and Lyckebyån for precipitation, temperature and runoff for four different time periods. The correlation is determined based on data of monthly mean temperature, total monthly precipitation and total monthly runoff for all periods.

Correlation	1970-1979	2007-2016	1970-1989	1997-2016	1970-2016
Precipitation	0,86	0,81	0,87	0,81	0,85
Temperature	1,00	1,00	1,00	1,00	1,00
Runoff	0,70	0,77	0,69	0,77	0,74

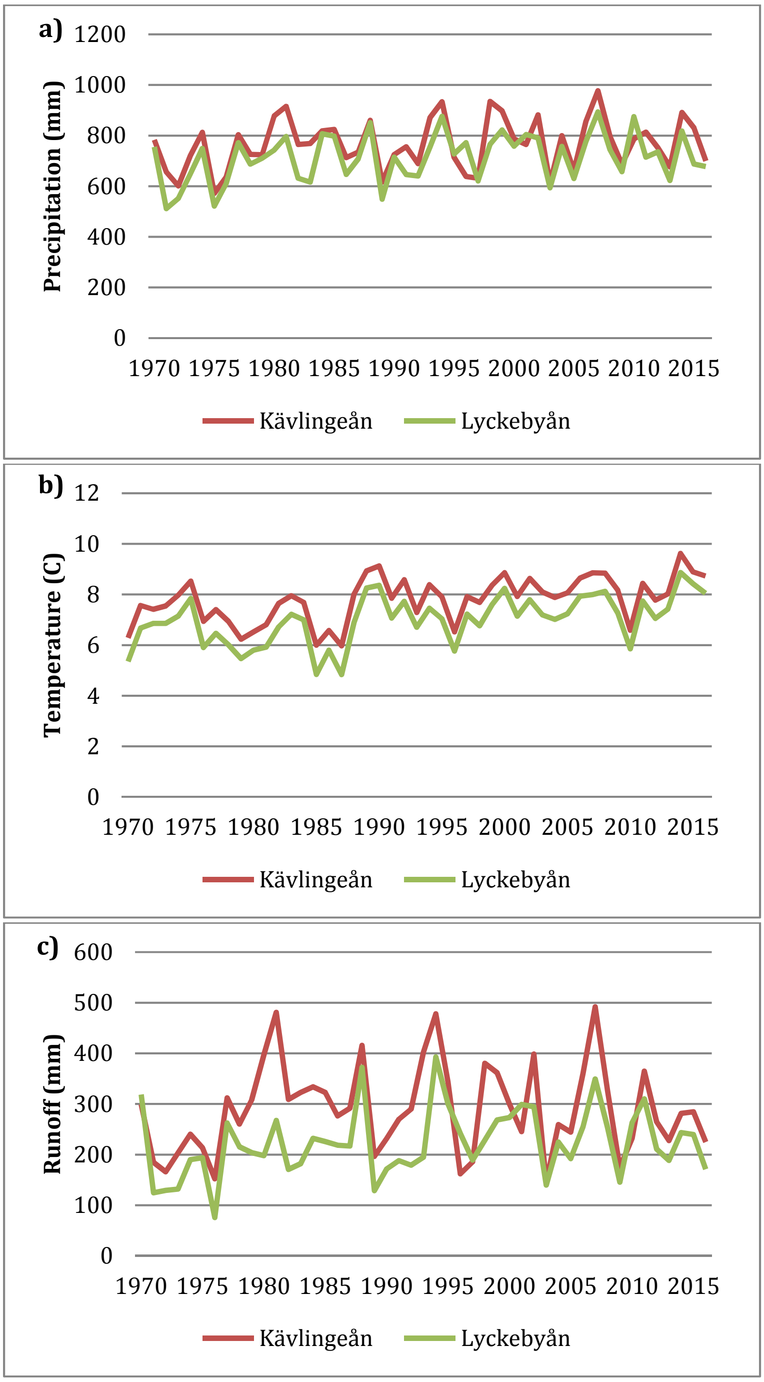

Figure 1: Graphs for a) precipitation in total annual, b) temperature in mean annual c) runoff in total annual for the years 1970-2016.

Table 3: Mean difference in precipitation, temperature and runoff between Kävlingeån and Lyckebyån for all four time periods and for all years combined.

	Precipitation (mm)	Temperature (C°)	Runoff (mm)
1970-1979	51,73	0,83	49,32
2007-2016	48,31	0,71	49,73
1970-1989	63,24	0,85	81,35
1997-2016	49,48	0,75	50,74
1970-2016	52,13	0,80	67,03

10 year mean

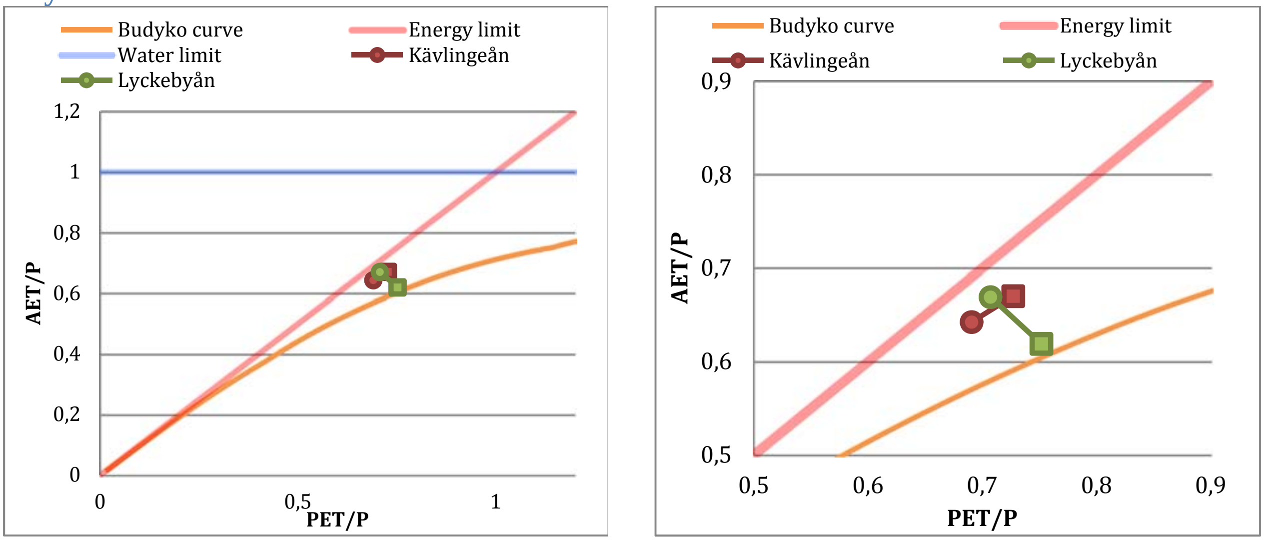

Figure 2a Figure 2b

Figure 2: Budyko space over both Kävlingeån (agriculture) and Lyckebyån (forest) basins for time periods 1970-1979 and 2007-2016. Both graphs show the same Budyko space only on different scales with a being on normal scale and b having higher resolution. The square point in the plot refers to the 1970-1979 mean and the circle to the 2007-2016 for the basin.

The Figure 2 shows that the two basins move in different directions of each other within the Budyko space with different AET/P responses. Kävlingeån is following the Budyko curve in its movement, having a decreasing AET/P linked with a decrease in PET/P, while Lyckebyån moves in the opposite of the Budyko curve, showing an increase in AET/P paired with a decrease in PET/P. For Kävlingeån there are no signs of any other effect on the basin than climate since there is no movement differing for the movement of the Budyko curve.

20 year mean

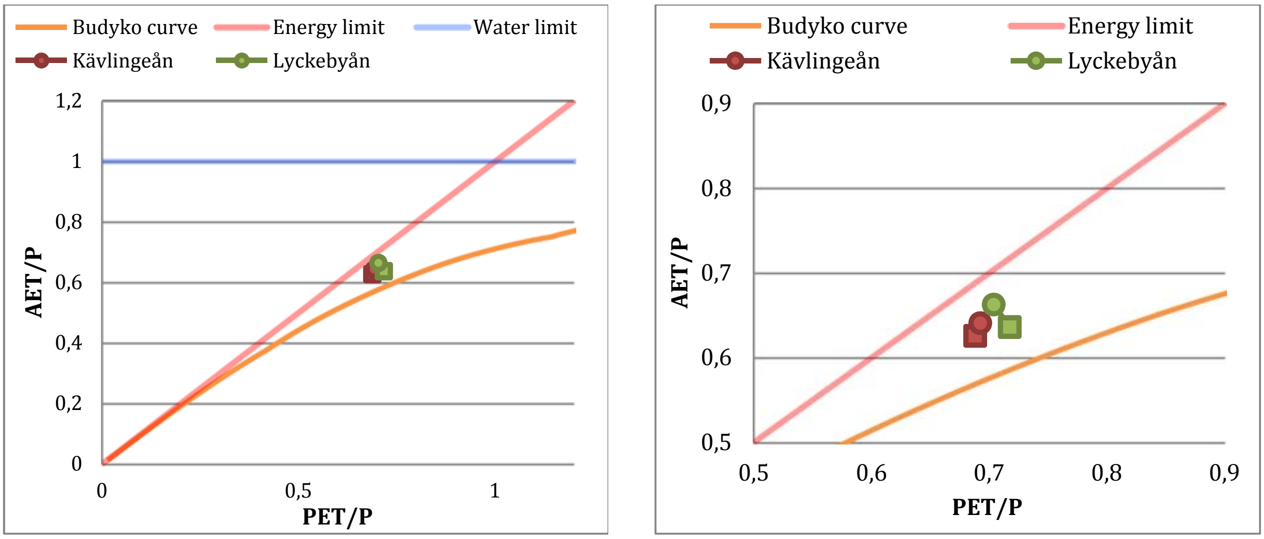

Figure 3a Figure 3b

Figure 3: Budyko space over both Kävlingeån (agriculture) and Lyckebyån (forest) basins for time periods 1970-1989 and 1997-2016. Both graphs show the same Budyko space only on different scales with a being on normal scale and b having higher resolution. The square point in the plot refers to the 1970-1989 mean and the circle to the 1997-2016 mean for the basin.

For Kävlingeån there is almost no movement within the Budyko space between the two 20-year means, as seen in Figure 3. There seems to be a very small increase AET/P and PET/P for the mean of 1997-2016 but this difference between the means are too small to be of any significance. For Lyckebyån the same movement that is seen in Figure 2 can be seen here in Figure 3. The difference is, however, not as great as seen in Figure 2. This is most likely due to having a mean covering more years and extremes playing less affect on the mean it self. The increase in AET/P is still clear and the trend for the movement being in a different direct direction than that of the Budyko curve. Both basins have a less extreme movement within the space when compared to the movement seen in Figure 2. The reason that there are not as great movements between the two twenty-year means than between the ten-year means is most likely that over a longer time period extremes are evened out with less extreme years, the more years that are used the less visibly become the extremes.

Comparison between the 10 and 20 year periods

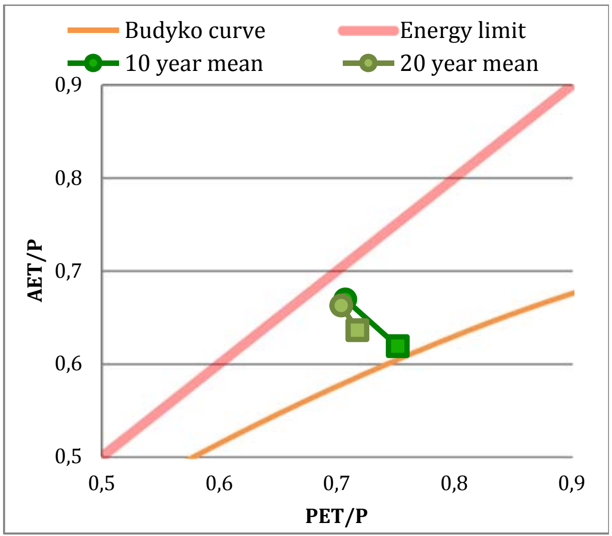

Figure 4a

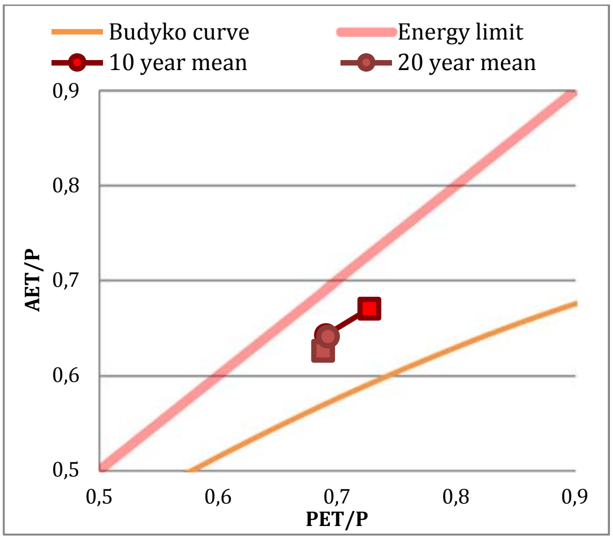

Figure 4b

Figure 4: Budyko space for Lyckebyån, Figure 4a, and Kävlingeån, Figure 4b, for both the ten-year series and the twenty-year series. A zoomed in view is chosen to illustrate the differences in placement within Budyko space better

In Figure 4a and 4b, the difference between the 10-year means and the 20-year means becomes clear. For both Lyckebyån and Kävlingeån, it is the mean of the period 1970-1979 that stands out more than the rest of the means, being located further away from the other means plotted on the aridity index. This would suggest that these years were much warmer or had less precipitation than any other of the time periods. When studying Figure 4a it is clear that the LAI response is present with both series showing a clear trend in increasing evapotranspiration as PET/P decreases, as opposed to the Budyko curve which predicts a decrease with lower PET/P values. The fact that this response exists in both series is important since it then eliminates the possibility of this just being a small abnormality for a fixed set of years. In Figure 4b for Kävlingeån the only trend seen is the decrease in AET/P that follows the curve for the 10-year series, this decrease is not visible at all in the 20-year series. In none of the series a response that differs from the predicted movement according to the Budyko curve can be observed.

Discussion

Kävlingeån

There is no strong evidence that the stomatal conductance decrease has had any decreasing effect on the evapotranspiration within the basin over the last 30 years or more. This is supported by the observation that there is very little movement between the twenty-yeas means, best seen in Figure 4. The dominating agriculture in the Kävlingeån basin consists of mostly wheat and rapeseed, as told by Anna Olsson, biologist at Kävlingeåns Vattenråd in personal correspondence. Both of these plants show a partial stomatal closure when exposed to elevated CO_2 levels (Houshmandfar, Fitzgerald, Armstrong, Macabuhay, & Tausz, 2015; Mishra, Abdin, & Uprety, 1999). Therefore, there are two explanations to the lack of decrease in evapotranspiration. Firstly, that the response is not great enough to affect the basins hydrological cycle at all, therefor only climate responses show in the Budyko space. Secondly, that there has to be another response increases evapotranspiration within the basin counteracting the stomatal response for decrease of evapotranspiration in the crops. When comparing harvest per hectare data from the Swedish board of agriculture for the periods of 1970-1974 and 2003-2007 it becomes clear that the harvests per hectare have increased (Jordbruksverket, 2007). It is unclear whether this is a result of higher total aboveground crop biomass or higher harvest index (higher harvested fraction of the aboveground biomass). If the harvest increase is associated with an increase in cropland LAI, it counteracts the decrease in stomatal conductance and would explain why there is little movement between the twenty-year means. If there is any response at all to stomatal conductance in the basin, or if it is the increase in crops that is counteracting the response or if there are other factors within the basin at works is impossible to tell without making further studies of the basin.

Lyckebyån

When studying the results in Figures 2-4 for Lyckebyån it is clear that, as hypothesized, the basin does not follow the predicted curve of Budyko. When a decrease in AET/P over time should be seen according to the Budyko framework, there is an increase instead and a movement upward instead of downward movement within Budyko space was observed. This response is conclusive with the response expected with elevated CO_2 concentrations and an increase in LAI as a response of the elevated CO_2 (Hirose et al., 1997).

With an increase in LAI leading to an increase in the evapotranspiration index it seems clear that the stomatal conductance response is in no way close to counteracting the response of the increase of LAI within Lyckebyån. Over the time period studied there has been a notable increase in forest biomass in the southern parts of Sweden (Riksskogstaxeringen, 2014) supporting that there has been an increase in LAI. It is also likely that this response has been going on for the whole covered time period when viewing Figure 4b. This is drawn from the fact that the difference in means for the ten-year mean of 1970-1979 and the twenty-year mean of 1970-1989 is showing a movement in Budyko space towards higher evapotranspiration. With the twenty-year mean being positioned closer to the newer mean of its period than the ten-year mean this would suggest that the years of 1980-1989 contains values of higher AET/P then the period of 1970-1979 and therefor diving the mean upwards on the evapotranspiration index. The indication here being that the LAI response in the plants has been present during the whole period and that the response grows in magnitude.

Vegetation type impacts

It could be argued that the differences in response could be the result of differences in metrological factors but this is found highly unlikely when considering Table 2,3 and Figure 1. The correlation between the two basins when it comes to temperature, runoff and precipitation are high to very high for all time periods. In Figure 1 both basins follow each other over most years and the mean difference, show in Table 3 between them are too low to indicate any major variations in climate. The high correlation together with low mean differences and similar trends supports the claim that the differences seen between the basins are due to differences in dominating vegetation and not due to climate.

By comparing the Figures 2-4 it is clear that the forest-dominated basin of Lyckebyån is displaying a much greater change within the Budyko space than the agriculturally dominated basin of Kävlingeån. With the stomata response and the LAI differences between agricultural corps and forests trees (Ainsworth & Long, 2005; Raymond et al., 2008), this would be able to explain the differences between the two basins. With an expected continued increase in both temperature and CO_2 concentration (Intergovernmental Panel on Climate Change, 2013) and taking these responses into account, future predictions becomes more and more important (Cintas et al., 2016). Since this study only has one replicate, it is difficult to draw upon definite or general conclusions for bigger systems from this data. The changes and correlations seen could be random or be specific for these two basins. Nevertheless, numerous studies (e.g. (Hasper, 2015; Hasper et al., 2016; Haworth et al., 2013; Raymond et al., 2008) has shown that there is a difference between cropland and forestry when it comes to response to elevated CO_2 concentrations. With ecosystem models incorporated into global climate models now assuming water saving response due to decreases in stomatal conductance, important factors are missed and conclusions drawn from inconclusive facts. To make sure that the models show the correct ecosystem response, the aim should be that the model should cover all responses possible. Though it is nearly impossible to take every single factor into account, the LAI response is big enough that it needs to be considered.

Conclusion

Kävlingeån

In Kävlingeån there are no signs of the decrease in stomatal conductance having any effect within the basin. We cannot say if this is due to the weak stomatal response or if there is another response within the basin counteracting the response.

Lyckebyån

As predicted Lyckebyån basin showed an increase in evapotranspiration index and did not follow the curve, the explanation for this most possibly being an increase in forest biomass and LAI.

Vegetation type impact

The different behaviours shown by the two basins support the claim that dominating vegetation type and its specific responses to rising CO_2 levels need to be considered when making climate predictions for the future.

Uncertainties

This study is only made by hydrological data and only focuses on two basins in the southern part of Sweden that are located within the same climate zone. There has been no studies on land-use differences between the basins or an extensive study of the exact structure of vegetation within the basins. Both of these factors can be affecting the hydrological cycle within the basin but to what extent is not covered here.

Recommendation

For further studies more basins in Sweden and from other parts of the world and from other climates zones should be studied to make sure that this response is not only limited to the southern part of Sweden and these two basins. Important here is to make sure that the basins compared are in similar climate and that they have similar meteorological conditions.

Acknowledgements

To my supervisor Johan Uddling for helping me keep on track, giving good advice and providing motivating insights.
To my supervisor Fernando Jaramillo for assisting with the technical parts of my thesis, helping me work outside the box and providing good advice when I was stuck.
To all students in room 3135 for giving good recommendation and keeping the spirit high even in the toughest of times.

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