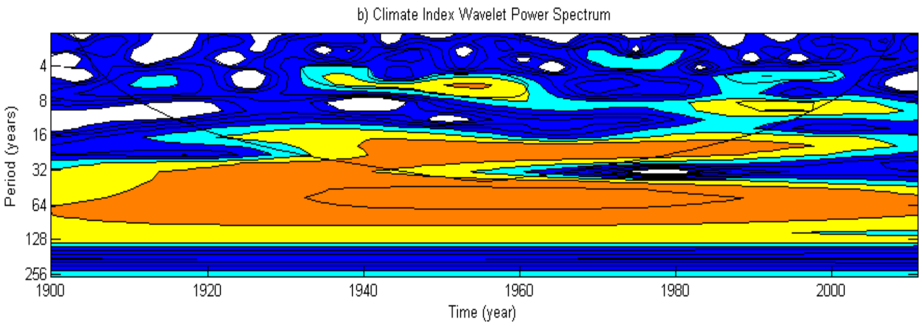
Examensarbete

TVVR 12/5005

Evaluation of Long-term Discharge in Swedish Rivers

In Search for Decadal Oscillations and the Relation to known Northern Hemisphere Teleconnection Patterns



Wavelet power spectrum for Pacific Decadal Oscillation (PDO)

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Utvärdering av långtidsvariationer av flödesdata från svenska floder

På jakt efter oscillationer med 10-åriga perioder och deras relation till kända klimatmönster på norra hemisfären

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Nyckelord: *Vattenflödestidsserier, Sverige, Wavelet analys, Northern Hemisphere Teleconnection Patterns och Lågfrekventa oscillationer.*

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Abstract

Seasonal forecasting is not an easy task to deal with. A number of large scale atmospheric phenomena, e.g. Northern Atlantic Oscillation (NAO), Scandinavia (SCA) and Pacific Decadal Oscillation (PDO) affect the climate in Sweden and the effect on rivers is an integration of all the complex inter-relation among all these atmospheric phenomena.

In this Master thesis, the river discharge from 107 stations, distributed over Sweden, were examined in the search for decadal oscillation. River discharge measurement data, collected from the Swedish Meteorological and Hydrological Institute, span periods between 40 to 100 years. In order to examine these time series, the Wavelet analysis was used. The discharge stations were divided into groups, depending on location and wavelet spectrum and these groups were compared to the wavelets of the climate indices that represent the atmospheric phenomena.

Results show the presence of decadal oscillations in the river discharge in Sweden. It was also possible to make a rough grouping of stations with common features in their river discharge wavelet spectrum. Such groups followed roughly the climate zone distribution.

Possible connections to climate indices were found, of which Pacific Decadal Oscillation (PDO) and Pacific/North American (PNA) were the two most evident. One thing to note is that SCA was the climate index that was least connected to the discharge. Why river discharge tends to depend more on PDO and PNA than on SCA, when SCA is the Scandinavian affecting pattern, could be due to the vast amount of decadal and multidecadal oscillations that PDO and PNA have, which also many of the river discharge time series have.

Sammanfattning

Sveriges årstider varierar allteftersom klimatet förändras. Än så länge är långtidsprognoser svåra att genomföra. Detta är för att atmosfären är ett komplext system, vars variationer påverkar klimatet. Storskaliga fenomen i atmosfärsen som t.ex. Northern Atlantic Oscillation (NAO), Scandinavia (SCA) and Pacific Decadal Oscillation (PDO), har alla en trolig påverkan på klimatet i Sverige. Detta påverkar givetvis även flödena i floderna.

107 mätstationer av flöden i svenska floder undersöktes i denna Master uppsats, för att försöka hitta lågfrekventa oscillationer (8-32 års intervall). Flödesdata från Svenska Meteorologiska och Hydrologiska Institutet SMHI hade mellan 40 till 100 års mätperiod. Dessa data analyserades med hjälp av Wavelet analysen, vilken skapar en 2D bild med tid och frekvens, från en 1D tidsserie. Beroende på stationernas plats i Sverige och deras wavelet spektrum, delades de in i grupper. Grupperna jämfördes därefter med motsvarande spektrum för klimat fenomenen, för att hitta möjliga samband.

Resultatet visar att det finns de låg-frekventa oscillationerna som söktes i flödena i Sverige. Det har även varit möjligt att indela de olika stationer i grupper eftersom där hittade liknande karaktär i olika spektrum. Oscillationer av liknande storlek hittades för stationer som återfanns i väldigt olika delar av Sverige, dock placerades endast närliggande stationer i samma grupp för att på så sätt försöka påvisa olika zoner i Sverige som gemensamt påverkas av specifika klimat fenomen.

Möjliga kopplingar mellan resultaten från wavelet analysen för flödesdata och kilmatindexarna hittades. Klimatfenomenet som referars till som Pacific Decadal Oscillation (PDO) liksom PNA tycks vara de vars spektrum har mest återkommande likheter med flödesdata. SCA, som annars kan förmodas ha stor inverkan på klimatet i Skandinavien, visade minst tecken på att vara kopplad till de lågfrekventa variationerna. Detta beror på att dessa oscillationer syns tydligt för både PDO och PNA, med ungefär samma frekvens som ofta återkommer för flödesdata i Sverige.

Acronyms

Northern Hemisphere Teleconnection Pattern acronym	**Full Northern Hemisphere Teleconnection Pattern name**
NAO	Northern Atlantic Oscillation
WP	West Pacific
PDO	Pacific Decadal Oscillation
PNA	Pacific/North American
EA	East Atlantic
EA/WR	East Atlantic/West Russia
SCA	Scandinavia

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1. Introduction

This master thesis marks the end of studies at the 5 year educational program of Environmental Engineering (300 ECTS) at the Faculty of Engineering, Lund University, Sweden. The topic of the thesis lies within the Master program in Water Resources at the Division of Water Resource Engineering. It has been developed under the frame of the HydroImpacts 2.0 project, a cooperation between Lund University and the Swedish Meteorological and Hydrological Institute (SMHI).

1.1 Background

Seasonal forecasting was of interest for researchers already in the end of the 19th century, prompted by the monsoon failure in 1877-1878 that caused a draught-related famine in India. This was later found out to be related to an abnormally high pressure extending to western Siberia, northern China and southern Australia (Troccoli, 2010). However, research has gone slowly and it is foremost weather forecasting that has been developed since the early 20th century. In 1930's the development of aviation required a better prediction of imminent flying conditions and ever since then weather forecasting has been ahead of seasonal forecasting, making an additional leap with the introduction of computers as a research tool (Troccoli, 2010).

Timescale predictions longer than 10-20 days cannot be determined from current conditions which is how the weather forecast is done. Instead seasonal forecast relies on known climate phenomena that can predict future conditions for 40-50 days which in turn with statistical methods can forecast the evolution from one phenomenon to another thus leading to a seasonal forecast (André et al., 2002). Nonetheless, it is not possible to rely on statistical occurrences of weather phenomena since the dynamical system in the atmosphere changes frequently. Hence, there are two types of models for seasonal forecasting; there is a dynamical one that is based on the physical components of Earth's system and there is a statistical one that is based on known relationships between parameters such as atmospheric pressure, precipitation and temperature (Troccoli, 2010). Statistical forecasting has been developed for more than a century whereas the dynamical forecasting is more recent – and with it the seasonal forecasting has grown (Troccoli, 2010).

On the southern hemisphere, the El Niño-Southern Oscillation (ENSO) is a well-known phenomenon that has been popularised by news media. The El Niño-La Niña (sea surface temperature on Tropical Pacific Ocean) and the Southern Oscillation (the atmospheric conditions over South Pacific and Indonesian regions) were in the 1970's recognised to be related to each other, which drew focus back to seasonal prediction (Troccoli, 2010). ENSO has a relatively high frequent variability i.e. around 4-8-year period that makes it possible to extend the prediction to a longer timescale (André et al., 2002). Even though ENSO is coupled to many regions on the globe by teleconnection, the seasonal forecast on the northern hemisphere is less skilful (André et al., 2002). Teleconnection patterns on the northern hemisphere have been identified by different researchers during the last century and are still studied (Panagitopoulos, 2002).

In Scandinavia the teleconnection patterns are of interest. If the regional climate could be related to the circulation patterns that have been identified so far, the seasonal prediction could be improved. In turn, this would be of economic interest for the society; among others it could facilitate the planning of hydropower and drainage infrastructure. To reflect the local climate, and foremost the seasonal precipitation and evaporation, seasonal average river discharge is a good indicator.

1.2 Aim

The aim with this Master thesis is to examine the presence of long-term oscillation in the river discharge in Sweden and possibly relate it to known teleconnection patterns (NAO, PDO, WP, EA, EA/WR, PNA and SCA).

1.3 Limitations

As the results in this Master thesis is about visually interpreting wavelet spectra, it is of importance to emphasise that this is mainly done with two human minds and that is taken from the knowledge gained so far.

Looking at the map of Sweden showing the station spatial distribution (Figure 17), most areas are covered by this thesis. Unfortunately, due to lack of available data in some areas of Sweden, it was not a possibility to fill these areas.

Most river discharge data length is around 50 to 100 years, though the data length in some of the stations might only reach up to around 30-40 years. The decision to analyse these stations anyway, was made, to improve the station distribution over Sweden.

2. Theory

2.1 Climate and climate zones in Sweden

Boreal forest dominates Sweden´s area, which is according to Köppens climate system a part of the group of cold temperate areas. Only the southern coast areas are according to Köppens climate system in the group of warm temperate areas, where deciduous forest are most common. (SMHI, 2009)

The Swedish climate is mostly affected by constant westerly and south westerly winds, due to the fact that it is situated in the Favonian Belt. This brings moist from the adjacent water bodies (Atlantic Ocean) which turns into precipitation over land. The low pressure zones moving in the Favonian Belt are diverting warm and cold air, which contributes to a fairly mild climate, even though Sweden is situated far north in the Northern Hemisphere. (ibid)

The temperature in Sweden varies considerably over the country, as it is quite an oblong country. In terms of temperature, the location of Sweden with respect to the Polar Front zone matters. During wintertime the polar front is situated around 30° latitude and in the summer the front is situated around 60° latitude. The Polar Front zone divides the polar and the tropical air masses, and in winter when polar and arctic air masses are moving south, Sweden gets low temperatures. In summer incoming tropical air masses make the air temperature and precipitation both to increase. The average winter temperature is around 0°C in the southern parts of Sweden and around -17°C in the northern parts. During the summer, the mean temperature in southern Sweden is around 17 °C , and 7°C in the northern parts. Due to climate change, an increasing temperature is seen in the last hundred years (SMHI, 2009).

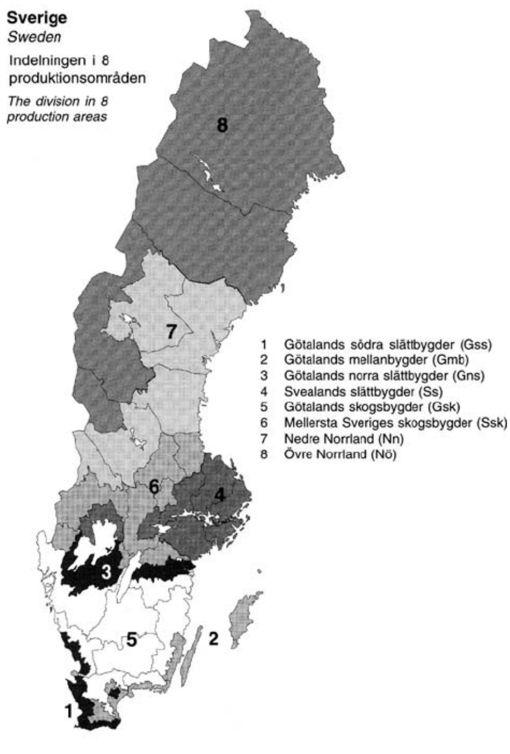


Figure 1 Agricultural climate zone (Larsson, 2006)

Summer and autumn are the seasons richest in rainfall, though there is rainfall all year around over Sweden. As said before, due to the Favonian Belt, westerly and south westerly winds bring much moist air over Sweden and therefore, west of Sweden is wetter than the eastern side. A precipitation rate of 400-2000 mm/year is expected in Sweden, with top notations in the mountains situated in the west and lowest precipitation amount in the very eastern parts (Gotland; 400 mm/year). Short periods of intense rainfall, is the characteristic summer precipitation. During winter, snow is the dominant precipitation form, except from the rain that falls in the very southern parts close to the sea (ibid).

Topography, soil type and climate, are the three most important area connected things to evaluate, when creating an agricultural division of Sweden. This is to be able to evaluate the area in terms of statistics and other tries. Central Bureau of Statistics has divided Sweden into eight zones of production areas (Figure 1). This is just one of the possible solutions to divide Sweden into, in terms of climate and vegetation possibilities. Though in order to discuss possible explanations in this thesis, one solution has to be chosen. (Larsson, 2006)

2.2 Seasons in Sweden

Sweden has four different seasons: winter, spring, summer and autumn and these conditions directly affects river discharge. In summer the flow could be much lower than normal or even close to zero in small rivers, as dry periods are most frequent during this time. In spring the discharge depends strongly on the winter precipitation and there could be very high flows when there is a fast melt rate of accumulated snow (SMHI, 2009).

Spring starts around the end of February in the very south of Sweden but in the northern parts spring starts first around the beginning of May (see Appendix 4). In the northern part of Sweden, spring brings high river flows when the snow accumulated during the winter melts. However, in the southern part of Sweden there is not always snow accumulation during winter and therefore the flow rates do not always increase very much. On the other hand, due to a higher amount of net heating, the spring flows increase all over the country, as the frozen grounds also melts (SMHI, 2012).

Summer starts in mid-May in the southern part of Sweden and in the northern parts; it starts first in the middle or end of June (Appendix 4). In summer the growing season is at its top, there is a surplus of incoming solar radiation and moist is available for the plants. The river flow is at varying rate, depending on the precipitation amount. The summer can be rather wet, as Sweden has a large amount of rainfall throughout the year, but it can also be very dry for longer periods, and the drying out of smaller rivers may cause problems to aquatic animals and plants (SMHI, 2012).

Around mid-October autumn starts in southern Sweden but it reaches northern Sweden already around mid-August (Appendix 4). Autumn prevails with strong winds, rainfall, and dropping temperatures. A higher river flow can be observed, which gives a better habitat for aquatic living species, with higher oxygen availability. (SMHI, 2012)

Winter reaches southern Sweden around December and northern Sweden around mid-October (Appendix 4). Temperatures below 0°C are typical for the Swedish winter climate, which contributes to water storage in form of snow and ice. In the northern and middle parts of Sweden this snow storage increases until spring. For the rivers this means a lower discharge rate and potentially forming of ice, during the cold days while, as explained above, a very rapid flow during melting season. In southern Sweden, it is not always certain that temperatures below 0°C will be reached or at least not kept for long time enough for any snow storage to be formed. Though during cold winters, storage in the south is also possible (SMHI, 2012).

2.3 Northern Hemisphere Teleconnection Patterns

In meteorology research, the concept of teleconnection patterns is of notable importance. Although Ångström was the first to use the term in a publication 1935 of his studies of the North Atlantic Oscillation (NAO), "teleconnection patterns" still misses a distinct definition (Panagiotopoulos et al., 2002). Even so, the term is generally used to describe the phenomenon of statistically related, and often semi-permanent, anomalies of the atmosphere. Although there seems to be a general belief that further knowledge of the teleconnection patterns could improve the accuracy of forecasting on the northern hemisphere, the research within the field is going slowly (Panagiotopoulos et al., 2002).

The description of teleconnection patterns are still not completely clear, but it is generally explained as at least two semi-permanent atmospheric anomalies centres i.e. with pressures with an clear difference from the immediate surrounding that prevails for a long time. They are connected to each other, even though they could be situated very far away from one another. These anomaly centres have opposing signs and are atmospherically and/or oceanic connected to each other. This connection makes wind patterns to occur in different ways depending on the strength of the different centres i.e. how strong or weak they are. The different ways of wind patterns to occur, affect the climate over large areas. For example, when Northern Atlantic Oscillation (NAO) is in a positive phase (positive NAO-index, with a strong high pressure zone and a weak low pressure zone), the strong winds are directed westerly towards Scandinavia. This makes the climate wet and mild, comparing with negative NAO-index, when the climate becomes cold and dry.

One obstacle in making the idea of teleconnection patterns more coherent is the different indicators that researchers have used to study the same patterns. Sea Level Pressure (SLP) and different geopotential heights as well as surface air temperature (SAT) have in some cases been analysed by different researches for the same patterns while sea surface temperature (SST) has been used in studies of other patterns. However, although using varying time-series, new results have overall confirmed already known patterns in addition to occasionally finding new ones (Panagiotopoulos et al., 2002). Making it even more confusing, researchers have when identifying patterns given new names to patterns already named by others, or chosen the same name already used for another pattern in an earlier publication (Panagiotopoulos et al., 2002).

So far the results have indicated that all the observed and named patterns are independent from each other (Panagiotopoulos et al., 2002). One notable aspect of this is the three different patterns that share a common centre in the north-east Pacific among which the Pacific/North American pattern (PNA) is the strongest one. In fact, during the winter months, PNA together with the even more dominating NAO, are the most prominent ones amongst all the documented patterns. Furthermore, when studying wintertime temperatures on Greenland, researchers have found that different strengths of both of these two patterns can be related to the temperature (Panagiotopoulos et al., 2002).

There are still several aspects of the teleconnection patterns that have to be further looked into to reach a sort of unanimity about the existence and characteristics of each separate pattern. For this study, the current known patterns that might have an effect on the climate and weather in Scandinavia are briefly presented.

2.3.1 North Atlantic Oscillation (NAO)

This phenomenon takes place in the Northern Hemisphere (NH), over the North Atlantic Ocean. It is present in the atmospheric circulation as the leading or second variability mode, in nine out of twelve months per year, but it is active all year around. (Barnston and Livezey, 1987) NAO can be expressed as an index (NAO index) that is the standardised difference in sea level pressure between the two semi-permanent surface pressure centres; the Icelandic low (Subpolar region) and the Azores high (Subtropical region) (see Figure 3). This surface pressure difference drives the complete wind pattern over the North Atlantic, (Andersson, 2002) that, on its turn, influences the climate in Scandinavia and Europe. Both the positive and the negative NAO phases, described below, are related to the NAO-index. (W. Hurrell and Van Loon, 1997)

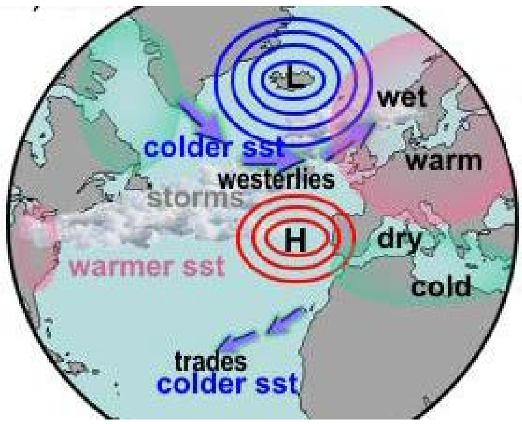


Figure 2 The H stands for the high pressure at the Azores high and the L stands for the low pressure at the Icelandic low. This is under a positive phase, when strong westerly winds blow towards Scandinavia. (Bojariu, 2008)

Figure 2 shows the variations in NAO-index. Here it is possible to see that there is not only a short term variability in the NAO-index i.e. interannual/interseasonal, but also a long term variability i.e.

decadal/multidecadal. The figure shows that there has been a positive trend during the latest 40 years (W. Hurrell and Van Loon, 1997)

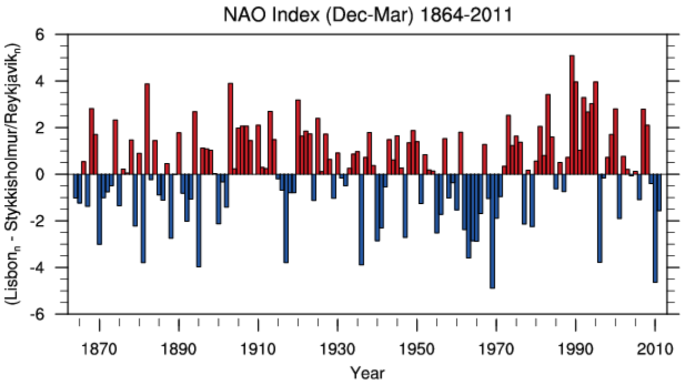


Figure 3 The NAO-index. The latest 40 years it has been mostly positive (NCAR, 2012)

A positive phase of NAO means that (positive index), the two pressure centres are stronger than normal. This means that there is a lower than normal pressure in the Icelandic low and a higher than normal pressure in the Azores high, which contributes to stronger than normal westerly wind (Figure 4) This brings a lot of moist and warmth and it also contributes too much stronger and more frequent storms over Scandinavia. Therefore under a positive NAO, the climate in the winter is milder, wetter and stormier, while central and southern Europe gets a drier climate condition. (W. Hurrell and Van Loon, 1997)

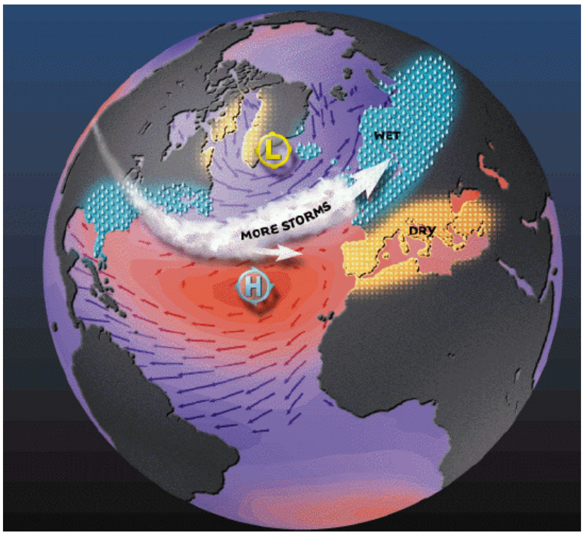


Figure 4 During very low pressures in the Icelandic low and very high pressures in the Azores high, there are strong westerly winds created (Bell, 2009)

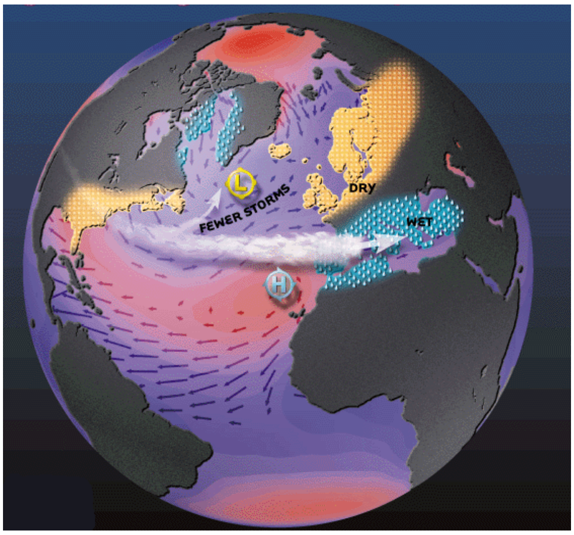
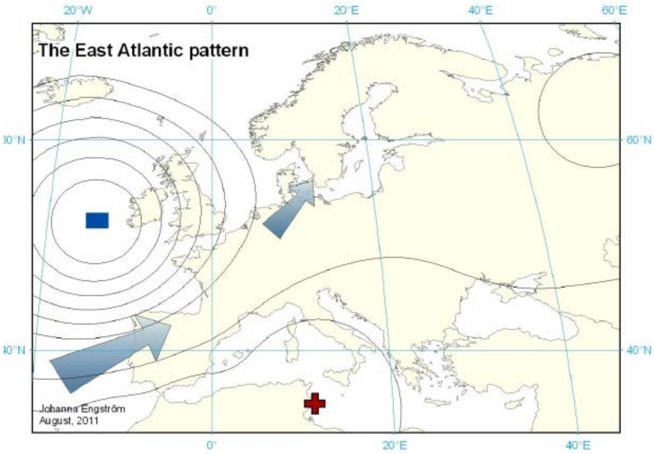


Figure 5 When the pressures in the Icelandic low and the Azores high are weak, the strong westerly winds become fewer towards Scandinavia and winds are in the direction of central and southern Europe instead (Bell, 2009)

Under the negative phase of NAO (negative index), the two pressures zones are weaker than normal. As the sea level pressure difference decreases, less and weaker storms goes towards Scandinavia, and the winter climate becomes dry and cold over Scandinavia, while central and southern Europe gets a wetter climate (Figure 5). (W. Hurrell and Van Loon, 1997)

2.3.2 East Atlantic (EA)

This climate phenomenon occurs over the north-eastern Atlantic Ocean. It is present during all months of the year and has a low-frequency variation,. The anomaly centres of this phenomenon are distributed on a north-south dipole but they also expand all the way from east to west in the North Atlantic (Figure 6) (Cherry et al., 2005 and Washington et al., 1999). The EA-pattern is often called a “southward shifted” NAO pattern, since the nodal lines of the NAO pattern are displaced south-eastward to the two centres of the EA pattern. Though in order to distinguish these two patterns, the EA patterns low-latitude centre has a connection to the subtropical ridge. This means that the positive centre of this phenomenon is located further towards the 30°N position in the Northern Hemisphere if compared to the positive centre of the NAO. (Climate Prediction Centre Internet Team, 2012 & Wang, 2006)



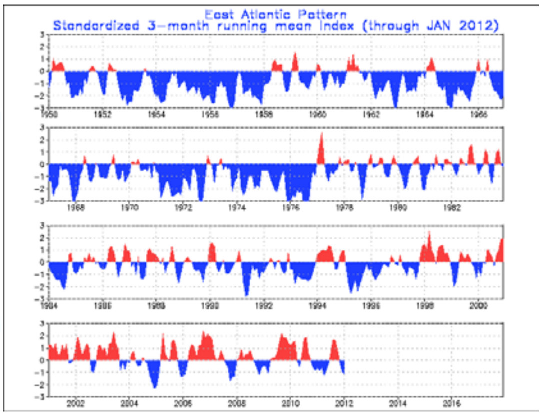


Figure 6 The East Atlantic pattern with its anomalies centres. This is under a positive phase. (Engström, 2011)

Figure 7 There is strong multidecadal variability in the EA pattern (Climate Prediction Center, 2012)

Above average precipitation over Scandinavia and northern Europe, above-average temperatures all year around in Europe and below-average precipitation across southern Europe; are all connected to the positive phase of EA (Figure 6). Decadal variations in the EA pattern are shown in Figure 7. (Climate Prediction Centre Internet Team, 2012)

2.3.3 East Atlantic/West Russia (EA/WR)

As one the three most important teleconnection patterns affecting Eurasia, this pattern is present all year around (Figure 8). It has four anomaly centres. During the positive phase, negative geopotential height anomalies are concentrated over the central North Atlantic and north of the Caspian Sea and positive height anomalies over Europe. The EA/WR positive phase is associated with below-average temperatures over north-eastern Africa and western Russia and above-average temperatures over eastern Asia. Precipitation changes in eastern China and across central Europe are associated with above-average in China and below-average in Europe. (Climate Prediction Center Internet Team, 2012)

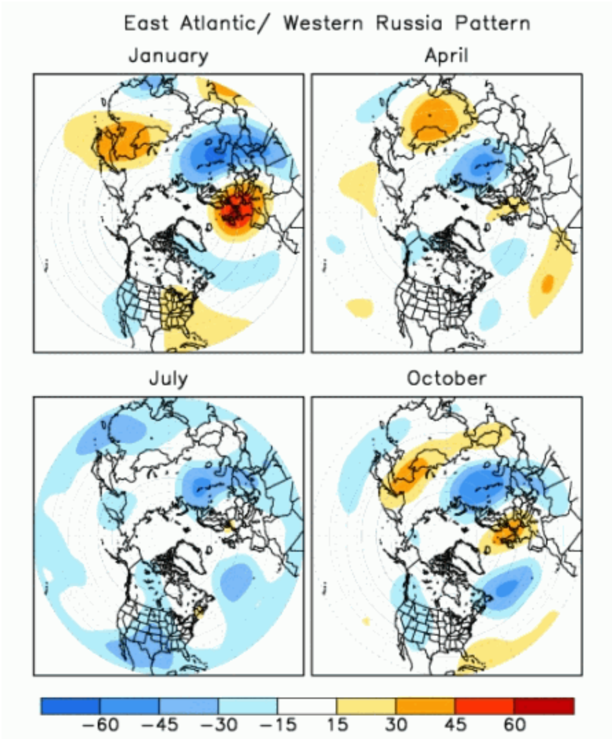


Figure 8 Temperature patterns in January, April, July and October, due to the effect of the EA/WR climate phenomenon (Climate Prediction Center, 2012)

2.3.4 Scandinavia (SCA)

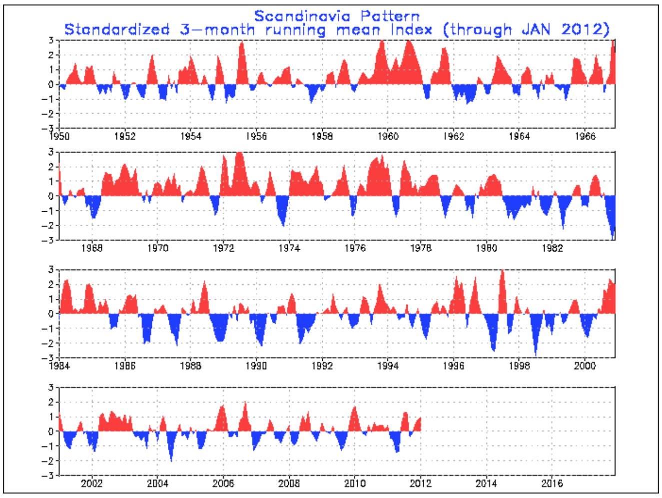


Figure 9 Scandinavia pattern, showing a historical perspective of the SCA-index, measuring constantly changing phase (CPC, 2012)

This pattern has its main circulation centre of over the Scandinavian Peninsula. The other two centres, with reverse sign, are situated over north-eastern Atlantic and over central Siberia. (Bueh and Nakamura, 2007) SCA has an interannual and interseasonal variability, which can be seen in Figure 9. It affects not only the Eurasian climate but also the North Atlantic sea surface temperature is changed differently during autumn and winter. This is due to a changed surface wind speed, which leads to an evaporative cooling anomalously and also due to local upwelling anomalously. (Bueh and Nakamura, 2007)

The SCA positive phase is related to positive geopotential height anomaly around the main centre and the negative phase is related with negative height anomaly. Below-average temperatures in central Russia and over Western Europe and above-average precipitation in southern and central Europe are connected to the positive SCA phase. (Climate Prediction Centre Internet Team, 2012) Scandinavia faces dry conditions in this positive phase (Bueh and Nakamura, 2007).

2.3.5 Pacific/North America (PNA)

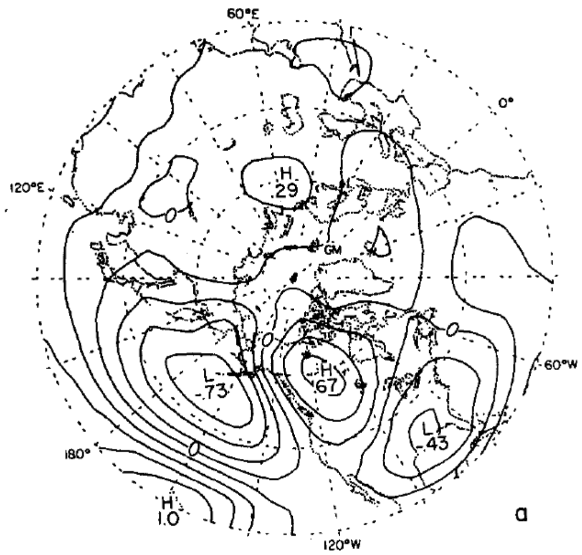


Figure 10 Location of the centres of PNA according to Wallace and Gutzler (1981)

In the mid-latitudes of the northern hemisphere, the mode of low frequency variability of the Pacific/North American pattern (PNA) is one of the most prominent ones, and it has been recognised by all major studies of teleconnection patterns (Panagiotopoulos et al., 2002). The four centres of PNA are located over the Pacific Ocean and the North American continent, hence the name (see Figure 10 and Figure 11). A strong centre is situated south of the Aleutian Islands in the northern Pacific, which have been referred to as the Aleutian low ([Wallace and Gutzler, 1981]; [Barnston and Livezey, 1987]). Another centre of opposite sign is according to Barnston and Livezey (1987) located between the Pacific Ocean and the Rocky Mountains, close to the US-Canadian border, while Wallace and Gutzler (1981) found its location to be further north; over Alberta. Of the same sign as of the previous centre, the third one is located south of the Aleutian low in the Pacific Ocean, close to Hawaii. The fourth centre, of same sign as of the Aleutian low, is located over the south-eastern U.S. and the Mexican Gulf ([Wallace and Gutzler, 1981] and [Barnston and Livezey, 1987]).

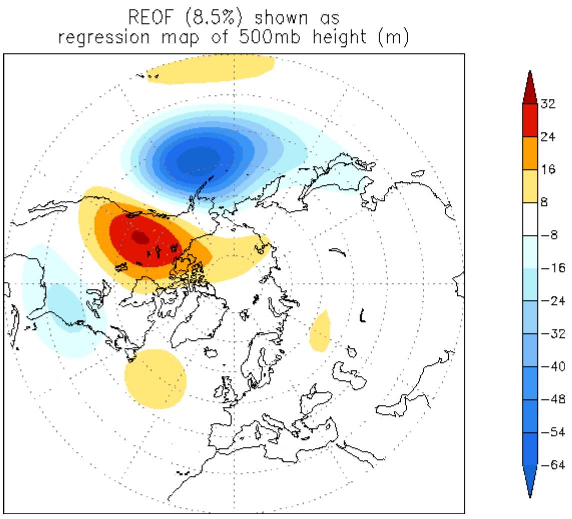


Figure 11 Location of the centres for PNA according to CPC (2012)

An Index for this pattern is based on the geopotential heights of the four centres (Wallace and Gutzler, 1981). Positive index is defined by deeper than normal Aleutian low and the high centres are higher than normal (Panagiotopoulos et al., 2002). PNA has a known impact on the weather in North America, and thus its variability is studied in relation to weather events in the U.S. and Canada. Although there could be a connection between PNA and the Southern Oscillation (SO) (Panagiotopoulos et al., 2002), the literature does not present any links to any other patterns, and its effect on the Scandinavian climate is unknown.

2.3.6 West Pacific (WP)

The West Pacific pattern consists of two strong, negatively correlated centres (Panagiotopoulos et al., 2002). The two centres; one over the Kamchatka peninsula (eastern Russia) and the other of opposite sign covering a part of Southeast Asia and western subtropical North Pacific (Figure 12) (CPC, 2012), have also been referred to as the West Pacific Oscillation (Barnston and Livezey, 1987). According to Wallace and Gutzler (1981) the correlation between the two centres is notably strong, and the longitudinal extent is wide at low latitudes. The position and extent makes this pattern analogous to the western Atlantic one (Wallace and Gutzler, 1981). The index is based on the difference in the geopotential heights between the two centres. A positive WP is characterised by a weak Aleutian low (Wallace and Gutzler, 1981) which is related to temperatures above average in the low latitudes of North Pacific in winter and spring, and temperatures below average in Siberia all year (CPC, 2012).

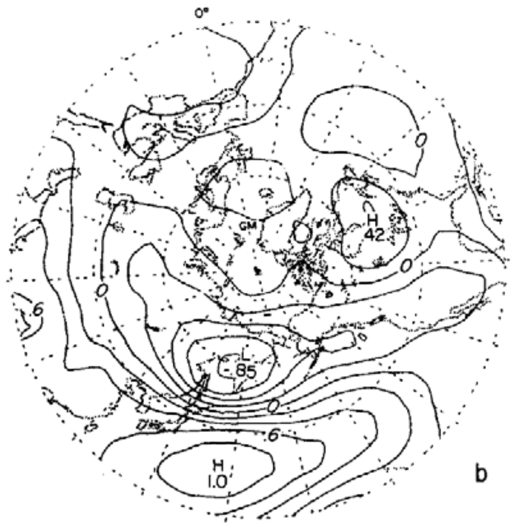


Figure 12 The centres of WP (Wallace and Gutzler, 1981)

2.3.7 Pacific Decadal Oscillation (PDO)

In more than one aspect the Pacific Decadal Oscillation (PDO) differs from the other, earlier described teleconnection patterns. One difference is in terms of frequency. As the name implies its variability occurs in longer intervals, and the oscillation has periods of decadal duration as can be seen in Figure 13 (NOAA, 2012). This is the teleconnection pattern on the northern hemisphere that shows the strongest indication of a connection to El Niño – Southern Oscillation (ENSO) (Biondi et al., 2001).

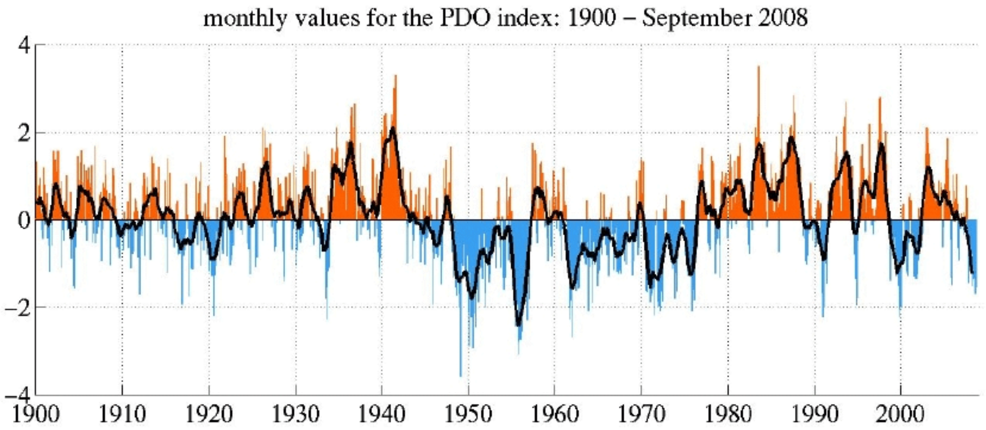


Figure 13 The variability of PDO (University of Washington, 2012)

Another aspects that set this pattern apart from the rest described here, is that this index is based on the difference of the sea surface temperature (SST) at two different locations, like the ENSO index. SST is related to the meteorological parameters of air pressure and wind circulation (NOAA, 2012). Hence, the weather in North America is related to PDO, especially on the west coast. The first location for the measuring points of the SST is in the northern Pacific Ocean and the other is near the west coast of North America, both located Poleward of 20° (Biondi et al., 2001). The positive phase of PDO is when the SST near the coast is warmer than the SST in the open sea of the northern Pacific Ocean, thus for the negative phase it is the other way round (NOAA, 2012). The warm phase i.e. positive phase, of PDO versus the warm phase of ENSO is illustrated in Figure 14, and there are obvious similarities.

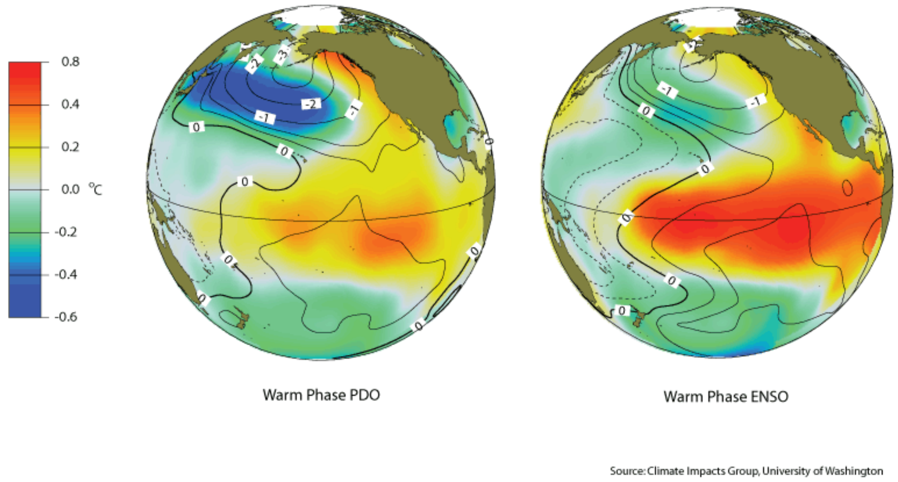


Figure 14 Warm phase of PDO and ENSO respectively (University of Washington, 2012)

3. Method & Methodology

In this thesis, river discharge time series were compared with teleconnection patterns by wavelet analysis. The time series are selected from stations at varying locations in Sweden and must not be affected to a wide extent by human activities. In the following chapter the data selection process is explained, as well as how the time series are analysed based on their location and the duration of the different seasons at the location. In addition there is a brief explanation of the wavelet analysis method included. It is done in a manner that the reader should be able to understand the results presented. All mathematical analyses and graphical illustrations have been done in Matlab (see Appendix 1 for specific codes).

3.1 River Discharge Time Series

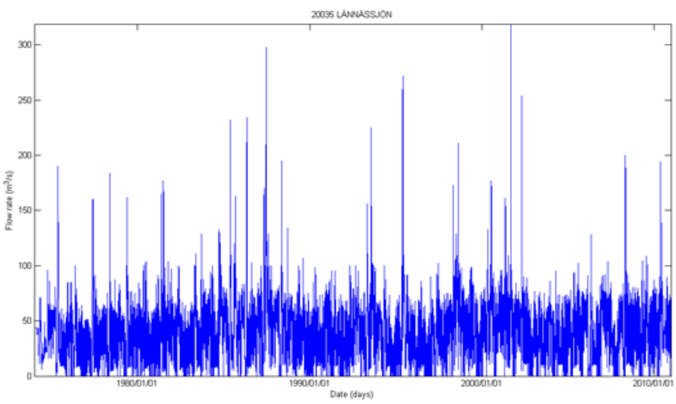


Figure 15 Station 73 - an example of regulated flow data

To achieve the aim of this thesis a large number of discharge time series from Swedish rivers were collected. Since the aim was to examine the natural water flow in Sweden, rivers with preferably no regulation or at least negligible one, were sought. Stations were selected so that a large part of Sweden´s area was covered. To be able to find long-term oscillations in the flow in Swedish rivers, the time series should cover a large part of a century to show any significant patterns through the wavelet analysis. However, this has not been possible in every part of Sweden; especially in southern Sweden some stations have a short time period of data which in some aspects gives a less reliable result.

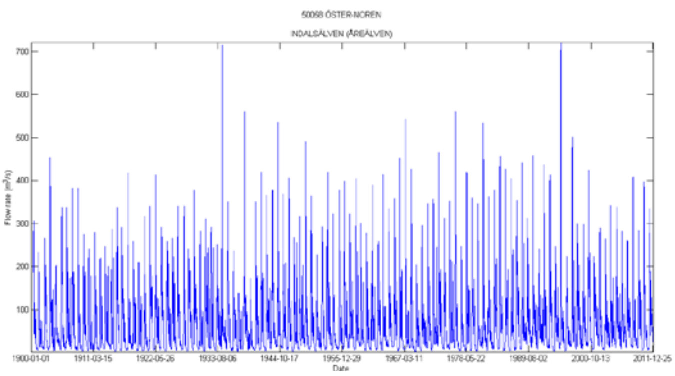


Figure 16 Station 241 – an example of flow data meeting the criteria

Time series data were provided by the Swedish Hydrological and Meteorological Institute (SMHI). Information about the stations includes the name of the water course, the coordinates, the size of the catchment area, lake percentage and of course the time series of daily measurement of rivers discharge with associated dates.

Information relevant for this thesis was transferred into new files that are numbered according to the order they were examined, and these numbers are later used throughout this thesis work. These files include the time series, first and last date of measurement, the SMHI original name and ID.no, water course name and number as well as coordinated. In appendix 3, the connection between the numbers distributed in this thesis and the SMHI ID.no, is found.

Daily discharge were illustrated in graphs with time (days) on the x-axis and river discharge (m^3/s) on the y-axis. From these graphs the time series that met the criteria of low regulation and long time period of measurement data were selected. The selection motivation can be viewed further in appendix 2. Figure 15 show an example of a time series that poorly meets the time and low regulation criteria since it has a short time period and it is heavily regulated. As a contrast, Figure 16 shows an example of a time series with a long time period and a "natural" flow pattern.

Coordinates for each station were used in the Mapping tool in Matlab to draw a map and illustrate the location for each station and the distance to the other stations around it (Figure 17). Time series not discarded due to heavy regulation or short time period were compared and to limit the amount of work, in areas with many stations, the ones that best met the mentioned criteria were kept while the others were considered unnecessary. In total 242 stations were examined, which decreased to107 stations after the selection process.

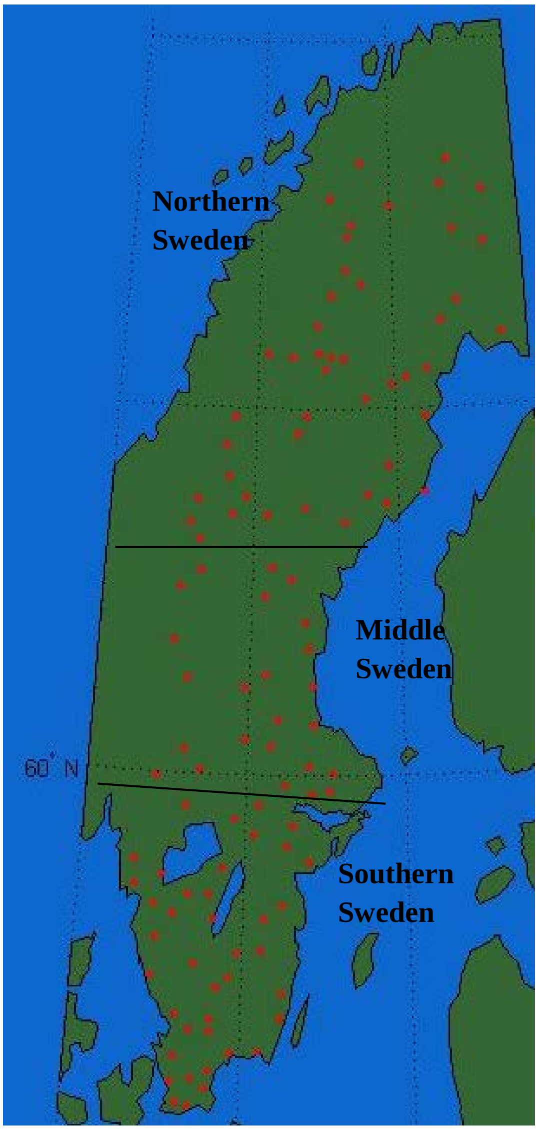


Figure 17 Locations of all selected stations of this thesis

3.2 Geographical Division

To be able to examine the different climate in Sweden, it was necessary to divide the country into different zones that have approximately the same arrival and duration of seasons (see next chapter). Based on the maps provided by SMHI (see appendix 5) and that a fair amount of stations were to be put in each group, three areas were determined.

3.3 Definition of Seasons

Seasons in Sweden are defined by SMHI (2012) based on the average daily temperature. Winter is defined as an average of below 0°C prevailing for more than five days, and winter turns into spring when the temperature is above 0°C for the same amount of days. Summer has arrived when the average daily temperature is above 10°C for five days, and five days of average daily temperature below 10°C mean the start of autumn (SMHI 2012). These definitions of the seasons impose a difficulty to make a general division of the months of the year into seasons. For the climate indices, which in this thesis will be analysed for the summer and winter months, the general view that June, July and August are the summer months and December, January, February and March gives a good enough basis. Primarily, southern Sweden was not compared to indices including March, however, since the differences in the wavelet spectrum between three or four months were negligible.

However, for the discharge data in the Swedish rivers, the dates when the seasons actually occurs need to be included in the analysis, especially for the spring during which the snowmelt occurs, which is a necessity to include it in the data every year for the analysis to be complete and consistent. For autumn and spring the first and last dates of the periods vary and to complicate it further the elongated country of Sweden result in a lag time of at least a couple of months for the occurrences of spring and autumn in furthest northern versus furthest southern Sweden. To cope with these issues but still making the solution not too complicated, the same geographical division of Sweden in three parts as previously illustrated is used for a generalisation of the season periods. For these periods statistics from SMHI

(2012) is the base for defining the time periods of the seasons for the three areas (see figures in appendix 4). In Table 1below, the season periods for the different parts of Sweden are presented.

Table 1 The duration of each season in this thesis

Part of Sweden	Spring	Autumn
North	April 16 – June 15	September 1 – October 31
Middle	April 1 – May 31	September 16 – November 15
South	March 16 – May 15	October 1 – November 30

3.4 Wavelet Analysis

Time series, or signals, are usually analysed by comparing them to known mathematical functions. To investigate the properties of each time series, the analysing method should be able to determine the frequency of signals at certain times. “Natural” signals are rarely uniform in frequency and it is of interest to determine both the frequency content of a signal and its temporal variation (Labat, 2005). The Fourier transform and Gabor transform (for the interested reader a brief explanation of these are found in e.g. Labat (2005)) is common ways to determine the frequency content of a signal but it cannot determine the frequency time-dependence (Labat, 2005). Also the non-stationary river discharge time series are usually an issue but it is shown that wavelet analysis has the ability to cope with this problem. For these purposes, the wavelet transform has been developed within the study of earth science, known as the method wavelet analysis and it has proven to be a good way of analysing hydrological signals, such as precipitation and river discharge (Labat, 2005). Through the wavelet transform a one-dimensional time series is transformed into a two-dimensional time-frequency image (Torrence and Compo, 1998).

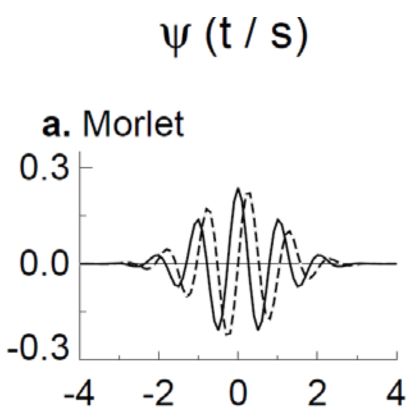


Figure 18 A Morlet wavelet (Torrence and Compo, 1998)

A wavelet can be explained as a brief oscillation with a finite extent (Torrence and Compo, 2012) that starts at zero, oscillates, and then finish at zero. A wavelet function, noted ψ(η) (η is a dimensionless time parameter), must have a mean of zero and be localised in time and frequency space (Torrence and Compo, 1998). This wavelet function could be chosen differently, which will affect the result of the wavelet analysis. In this report the Morlet wavelet (an example of this is found in Figure 18) has been chosen. Morlet wavelets contain more oscillations than other generally used functions, which means that both positive and negative peaks are combined in the wavelet power and are considered in the comparison (Torrence and Compo, 1998).

In equation 1 the Morlet wavelet illustrated is a complex function:

$$\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0\eta} e^{-\eta^2/2}$$

$$\Psi_0(\eta) = \pi^{-1/4} e^{i\omega_0\eta} e^{-\eta^2/2}$$

Equation 1 Morlet Wavelet function

where ω_0 is the non-dimensional frequency. This function is only an example of what the river discharge is compared to.

By varying the period i.e. the width of the wavelet in years, the significance level for the correlation between each wavelet and every position (at specific years) along the normalised river discharge curve can be determined (http://paos.colorado.edu/research/wavelets/wavelet2.html). The different significance levels for the periods are then illustrated in the colourful wavelet power spectrum (Figure 19). Matlab code for this has been retrieved from the homepage of Torrence and Compo (http://paos.colorado.edu/research/wavelets/software.html). In this report, patterns in the spectrum that are at least turquoise have been considered in the analysis (yellow and orange is even more significant). Nonetheless, the time series for the river discharge is padded with zeros for a wider comparison than what otherwise would have been possible, which affect all the results below the black, curved line (cone of influence) in the wavelet power spectrum as can be seen in Figure 19 (Torrence and Compo, 1998). In this thesis, the river discharge time series have been allowed to confirm each other, and patterns recurring in more than one spectra are still considered in the comparison even though they are found below this line. For the interested reader the method of wavelet analysis is described in Labat (2005) and explained as a step-by-step instruction in Torrence and Compo (1998).

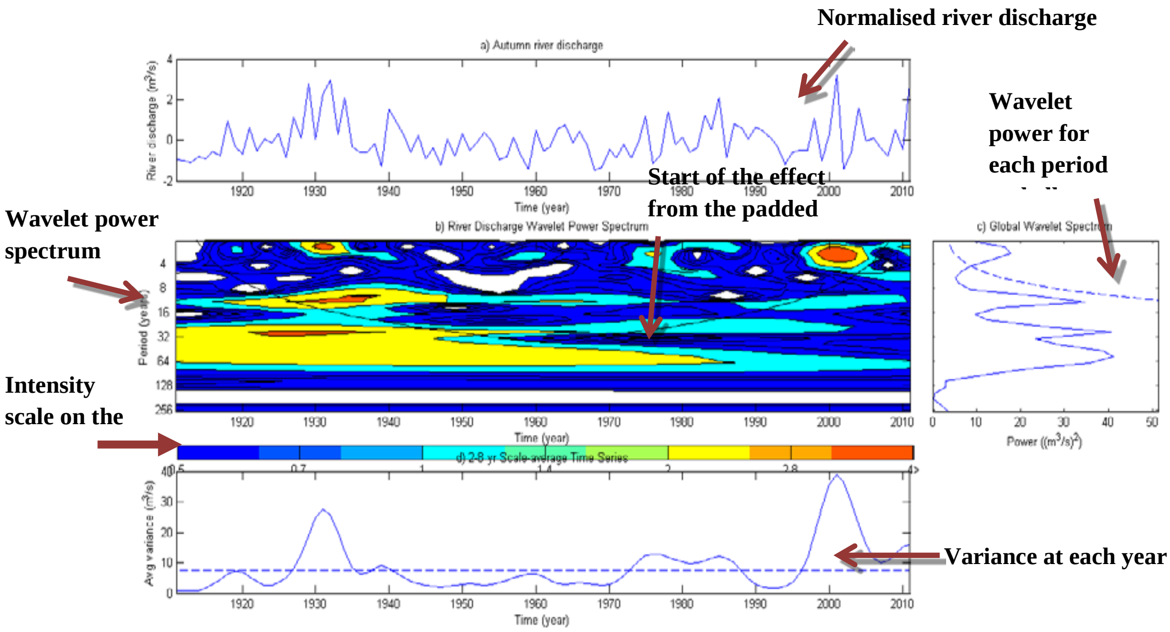


Figure 19 A wavelet spectrum graph exemplified by stations 242

Wavelet power spectra have been examined for all the chosen stations with average river discharge over the months that are described in the previous chapter. Stations were grouped together based on common, reoccurring patterns no matter if the significance level is exactly the same. Groups were divided due to their geographical location as well. The patterns of the spectra in each group were then compared to every spectrum of the chosen teleconnection patterns during both winter and summer to find out if there is any possible connection between the oscillation of the climate in Sweden and these patterns. The data for the teleconnection pattern indices were downloaded from http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-pc-based (NAO), http://jisao.washington.edu/pdo/PDO.latest (PDO) and ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh (remaining indices). The reader should keep in mind that the comparisons have been done by the human eye and is a first examination for any possible correlations.

4. Analysis of the Results

The results are presented following the division of Sweden into three parts, depending on an approximate seasonal changing pattern (Figure 17). In each of the three groups (Southern, Middle and Northern) there are two sub-groups consisting of spring and autumn. In this chapter only examples of the wavelet power spectra are presented for each group. All the wavelet power spectra for both river discharge and teleconnection pattern indices are found in appendix 5 and appendix 6, respectively.

4.1 Southern Sweden

The results for southern Sweden are presented below (Figure 20), for spring and autumn. It shows the number and location of the stations in southern Sweden.

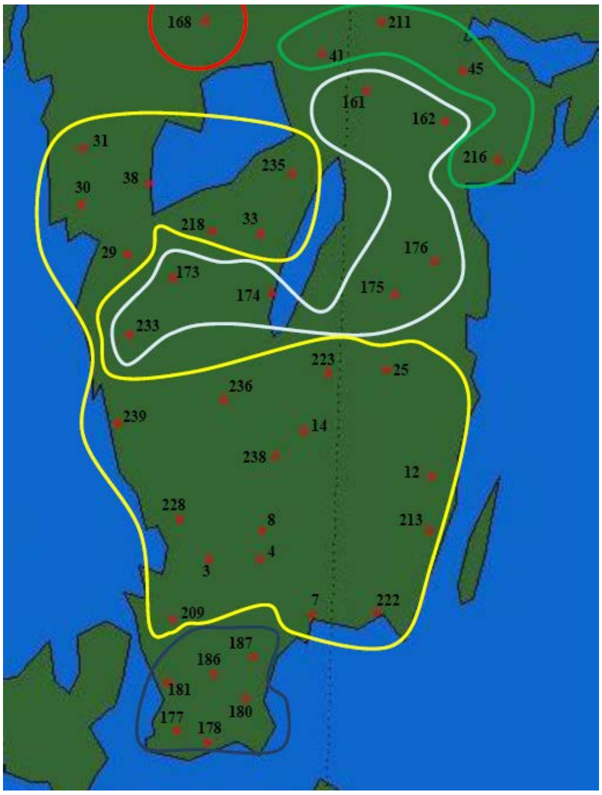


Figure 20 Grouping according to the spring wavelet spectra in southern Sweden

4.1.1 Spring

Spring enters southern Sweden around the end of February. For the discharge wavelets presented below, dependence on precipitation and storage of snow during winter time is an important factor affecting the outcome of these wavelets. In most southern Sweden, sometimes there is almost no storage of snow and as in all other seasons, the river discharge is dependent on actual precipitation.

An attempt to divide southern Sweden into parts is made, and stations with similar wavelets features are connected in groups (Figure 20).

<u>Coloured groups</u>

The coloured groups in Figure 20 have similar looking wavelet patterns as follows.

* Yellow group, presents 2-16 year oscillation with high energy patterns around mid-1900 to 1990, and some 2-8 years ones around year 2000 as in Figure 21.

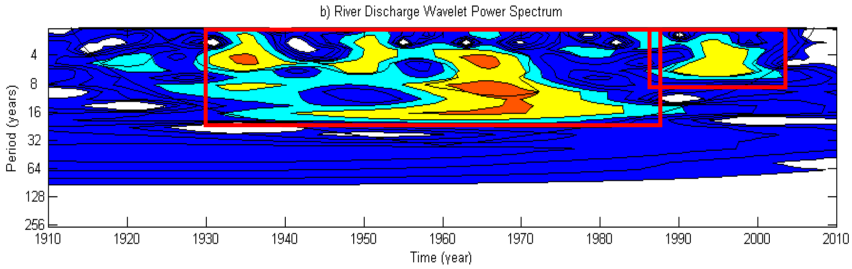


Figure 21 Station 7 – Spring – Yellow group

* White group presents a 16 and 32 year oscillation with high energy in almost the whole time period. It also shows some “dots” around 1980-1985 and one in around 2005 (Figure 22).

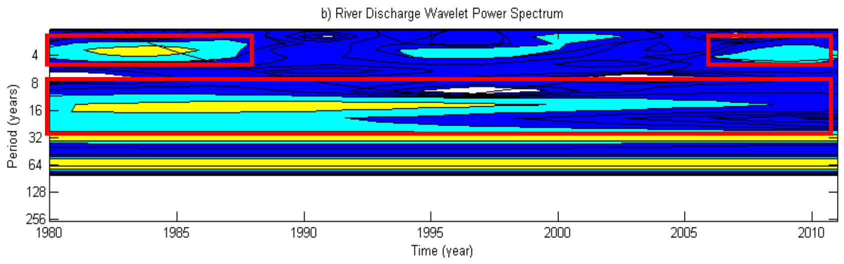


Figure 22 Station 161 – Spring – White group

* Green group, presents some 8 and 16 year oscillation starting around mid-1900 to around 1985 and some "dots" of 2-4 years pattern along the whole time period (Figure 23).

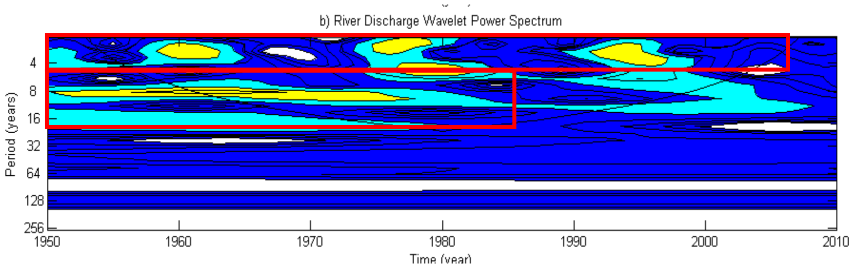


Figure 23 Station 41 – Spring – green group

* Red group, some 8-16 year oscillation starting around 1985 to 2005 and some 2-4 year ones around 1990 to 2010 (Figure 24).

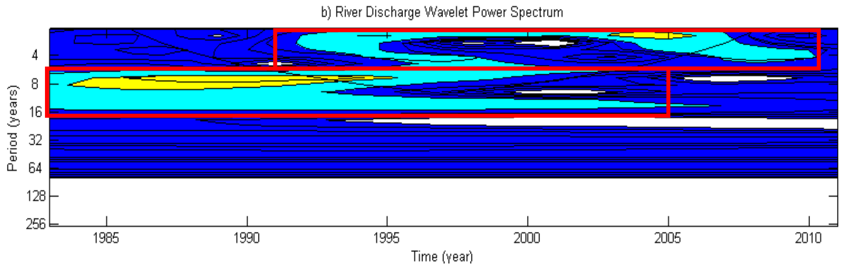


Figure 24 Station 168 – Spring – Red group

* Blue group, has some 2-8 year oscillation from around 1975 to 2005. There is also a 32 years pattern in the whole time period (Figure 25).

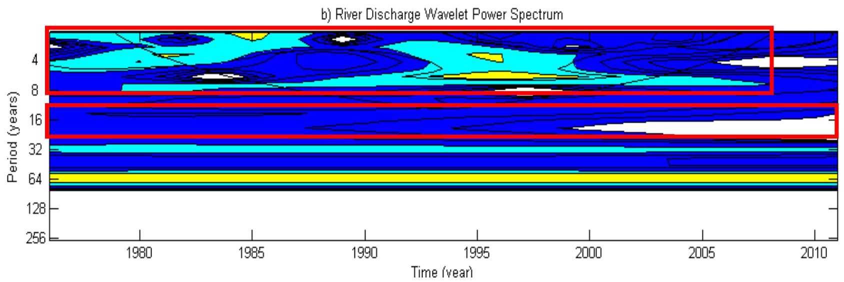


Figure 25 Station 181 – Spring – Blue group

Climate Indices

The typical patterns in the different groups are described in more detail below and also their potential connection to the climate indices.

Yellow group

1. The typical 16 years period in this group can be related to **winter PNA**, that presents similar pattern, though somewhat extended towards year 2000 (Figure 26).

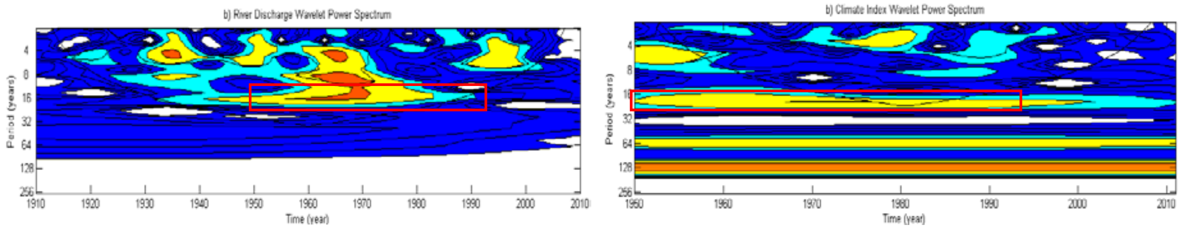


Figure 26 Station 7 (left) and wintertime PNA (right)

2. Summer WP seems to fit with the 16 years pattern found in this stations river discharge wavelet. **Summer WP** also seems to fit with the eight-year period in between 1950-1985 (Figure 27).

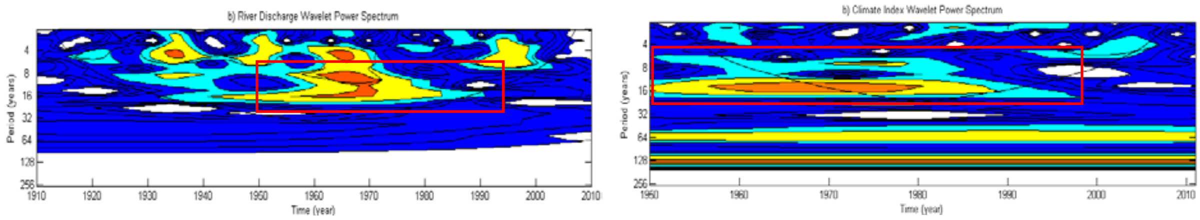


Figure 27 Station 7 (left) and summertime WP (right)

3. The 8-year pattern could probably be explained with **summer EA**, as both the wavelet for the river discharge time series and the wavelet for the climate index have an 8-year period in the same time (Figure 28).

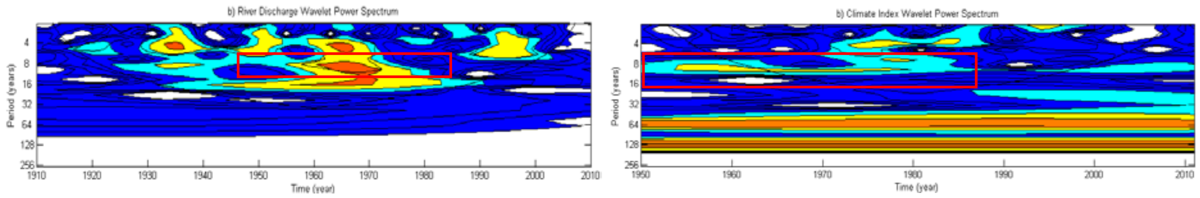


Figure 28 Station 7 (left) and summertime EA

4. What can be seen when comparing the time series with **winter EA** is that both the 16 years period, the eight-year period and also the period around year 2000 is visible in both wavelets (Figure 29).

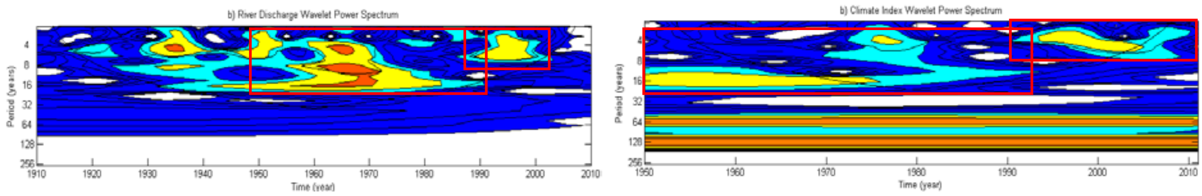


Figure 29 Station 7 (left) and wintertime EA (right)

White group

1. As this time series shows a 32 and 64 years pattern, **winter SCA**, might have been the pattern affecting this river discharge, as it shows a 32-64-year pattern, in the same time period (Figure 30).

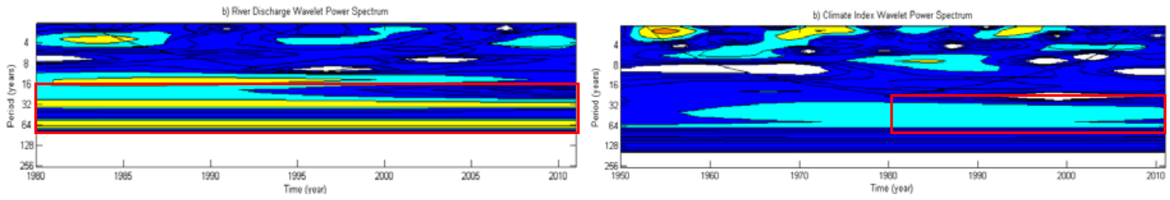


Figure 30 Station 161 (left) and wintertime SCA (right)

2. The 16-year period could be related to **winter PNA**, as it shows this similar pattern (Figure 31).

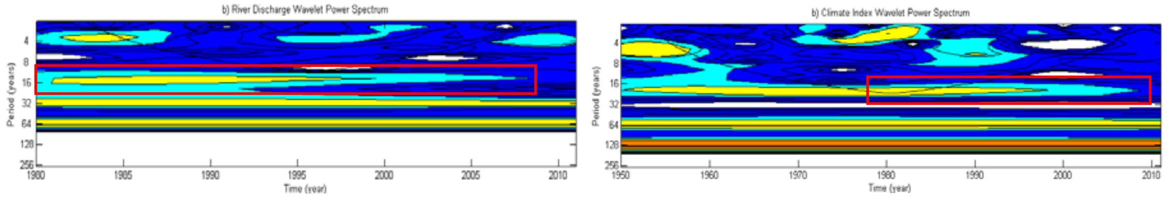


Figure 31 Station 161 (left) and wintertime PNA (right)

3. The 16-year period could also be related to **winter PDO**, as it also have a 16 years period in the same time (Figure 32).

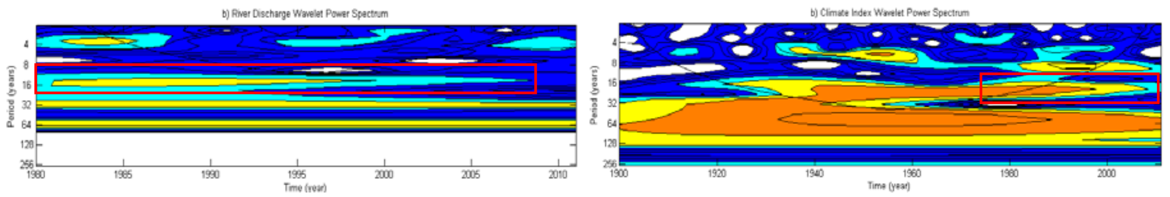


Figure 32 Station 161 (left) and wintertime PDO (right)

Green group

1. The 8-year period in between 1950 and 2010 in the river discharge wavelet, is also shown in the wavelet for **winter PDO** (Figure 33).

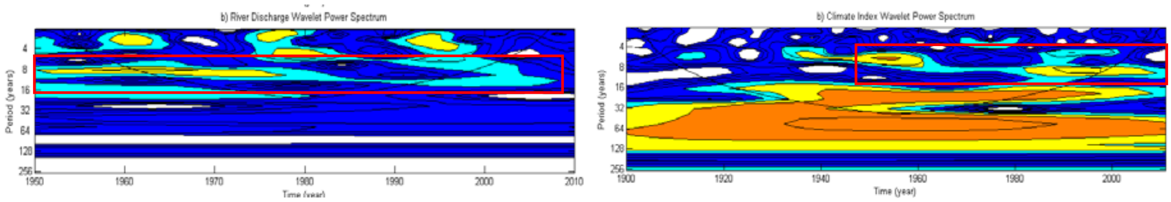


Figure 33 Station 41 (left) and wintertime PDO (right)

2. The 16-year pattern in between 1950-1990, could be related to **winter EA**, as almost the exact same pattern is visible in its wavelet plot (Figure 34).

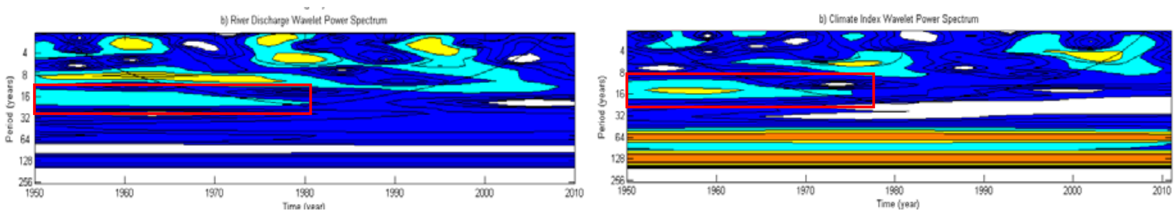


Figure 34 Station 41 (left) and wintertime EA (right)

3. A 2-8-year pattern is also visible in the river discharge wavelet, this could be related to **summer SCA** (Figure 35).

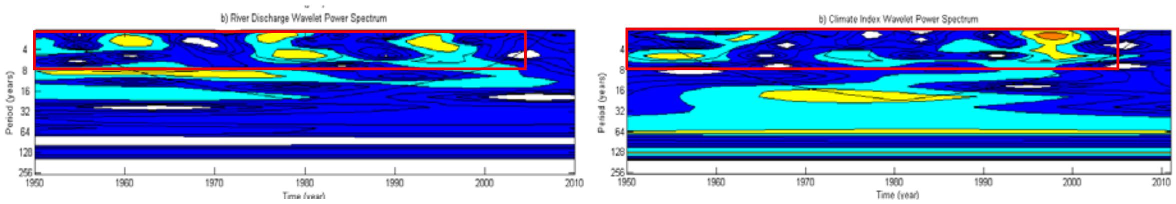


Figure 35 Station 41 (left) and summertime SCA (right)

Red group

1. The 2-8-year pattern in 1995 until 2010 could potentially be related to **summer PNA** that is showing a similar pattern (Figure 36).

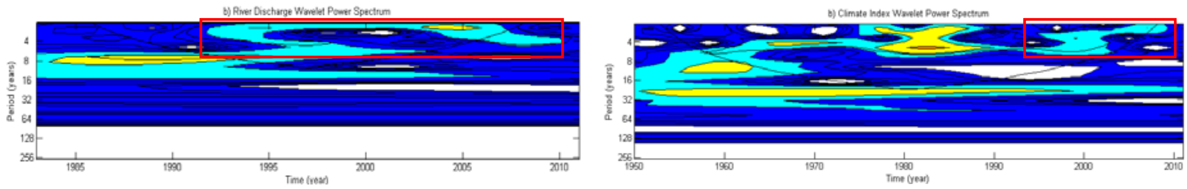


Figure 36 Station 168 (left) and summertime PNA (right)

2. Winter PDO and this river discharge wavelet have a similar 8 years period in the end of 1900 (Figure 37).

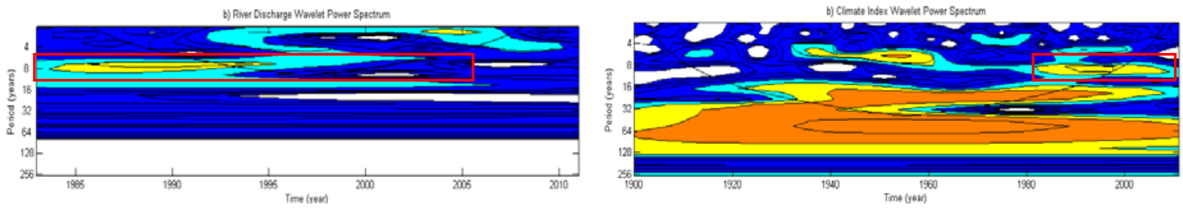


Figure 37 Station 168 (left) and wintertime PDO (right)

Blue group

1. Summer PNA could be the explanation for the behaviour of this river discharge (Figure 38).

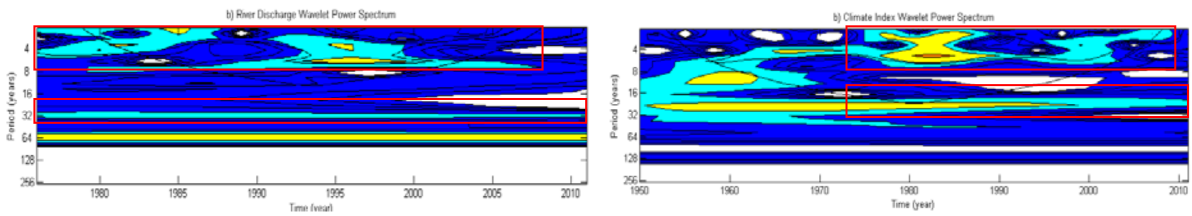


Figure 38 Station 181 (left) and summertime PNA (right)

4.1.2 Autumn

Autumn starts around mid October in southern Sweden. Autumn increases the slow summer river flows, as more rainfall enters. For the discharge wavelets presented below, dependence on precipitation over time, will affect the outcome of these wavelet plots.

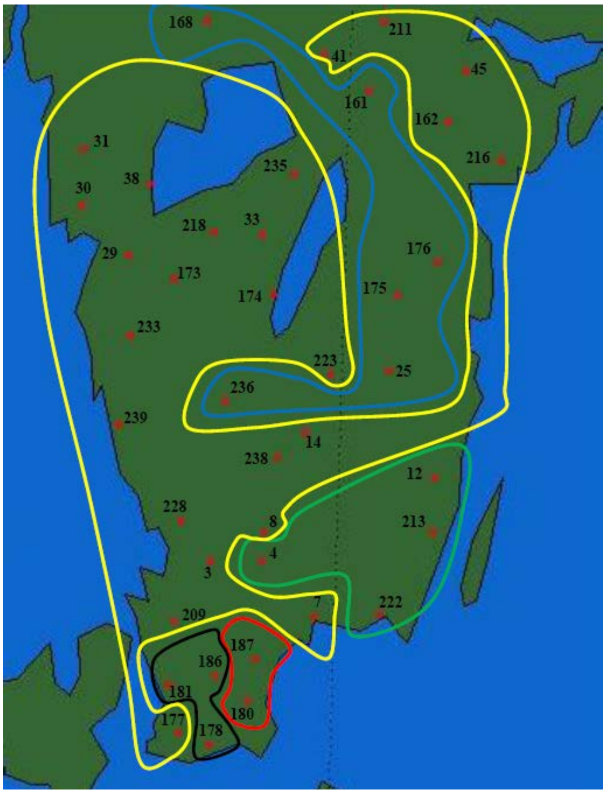


Figure 39 Grouping according to the autumn wavelet spectra in southern Sweden

Figure 39 shows the attempt to divide southern Sweden into groups, where the discharge wavelets have common features.

Coloured groups

A short explanation of the coloured groups follows (see Figure 39).

The different coloured groups all have non-similar looking wavelet patterns and that is why a division is made like it is. Though certain river discharge wavelets in different groups have some similar features, as for example the yellow and the blue groups, they have the equally looking 2-8 years pattern in between 1950 to 2000.

* Yellow group, has a cohesive or almost cohesive pattern going from mid-1900, a between 32-16 years period towards 2 years period around year 2000 (some river discharge wavelets have a longer time period, with the 32 years pattern starting earlier). Has also a 2-8 years pattern in almost the same period, in between 1950-2000 (Figure 40).

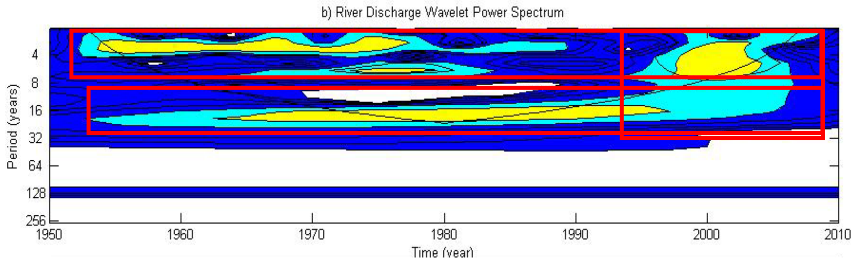


Figure 40 Station 41 – Autumn – Yellow group

* Green group, has a 16-32-year periodic pattern in early 1900, which continue to around 1950. It has also some 2-8-year pattern all from early 1900 to around 1975. A clear “dot” is shown around year 1980-1990 and another in around 2000 (Figure 41).

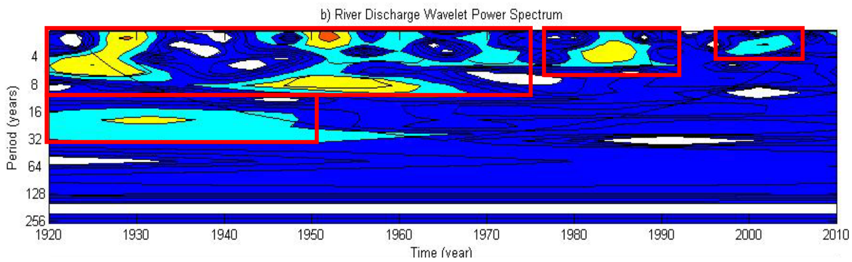


Figure 41 Station 12 – Autumn – Green group

* Red group, a 2-8-year pattern from around 1985 – 2010 (Figure 42).

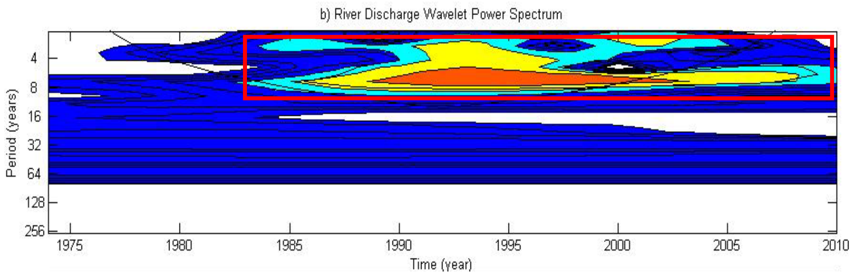


Figure 42 Station 180 – Autumn – Red group

[redacted] Black group, has a 2-16-year pattern in around 1975 – 2000 (Figure 43).

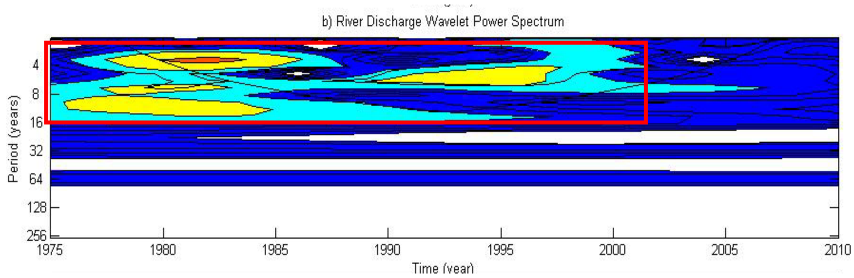


Figure 43 Station 181 – Autumn – Black group

*Blue group, has a 2-8-year pattern from around mid-1900 to around 1990 and some in the beginning of 2000 (Figure 44).

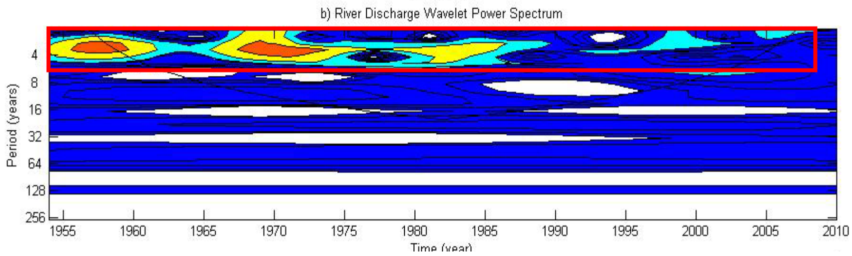


Figure 44 Station 25 – Autumn – Blue group

Climate Indices

The typical patterns in the different groups are below described in more detail and also their potential connection to the climate indices.

Yellow group,

1. Winter PDO shows the same cohesive 32- towards an 8-year pattern (Figure 45).

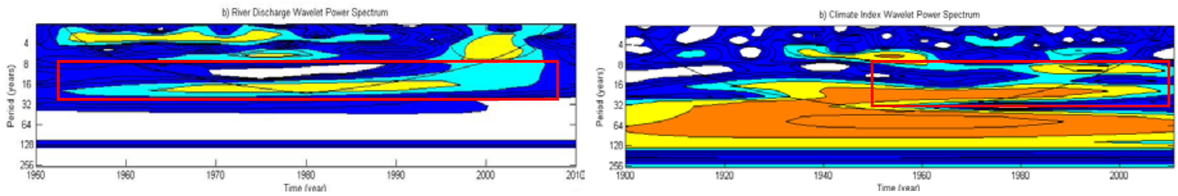


Figure 45 Station 41 (left) and wintertime PDO (right)

2. The 32-year period can also be seen in **summer PNA**´s wavelet (Figure 46).

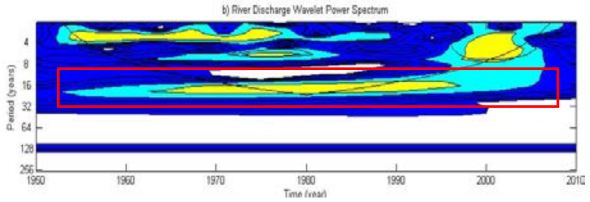


Figure 46 Station 41 (left) and summertime PNA (right)

3. Winter NAO has the similar 32- towards 8-year pattern, with a clear upcoming front in around year 2000 (Figure 47).

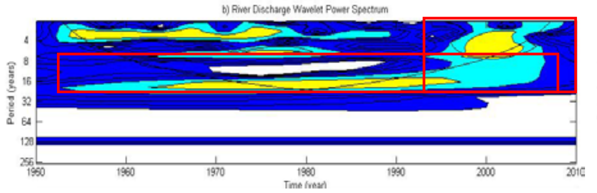


Figure 47 Station 41 (left) and wintertime NAO (right)

4. Winter EA/WR both shows the 32- towards 8-year pattern and also the 2-4-year period (Figure 48).

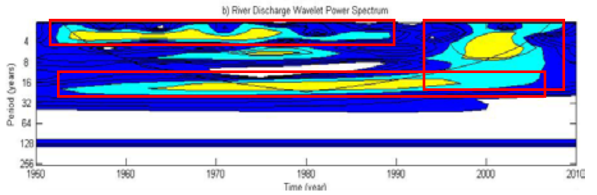


Figure 48 Station 41 (left) and wintertime EA/WR (right)

5. Summer PDO could have a potential relation to the 2-16-year pattern around year 2000 (Figure 49).

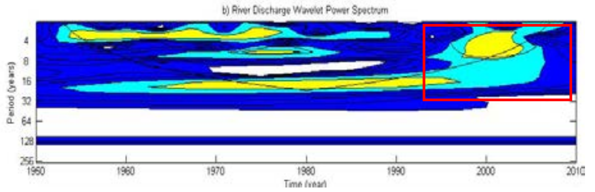


Figure 49 Station 41 (left) and summertime PDO (right)

6. Winter WP has the similar 2-4-year pattern around 1950 to 1990 (Figure 50).

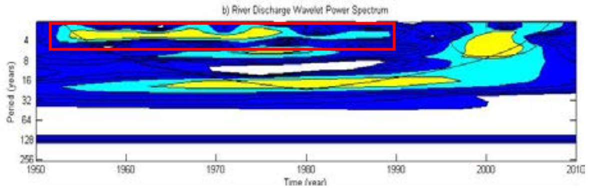


Figure 50 Station 41 (left) and wintertime WP (right)

Green group,

1. Similar features are shown in these two wavelet pictures, where **summer NAO** is the climate index to the right (Figure 51).

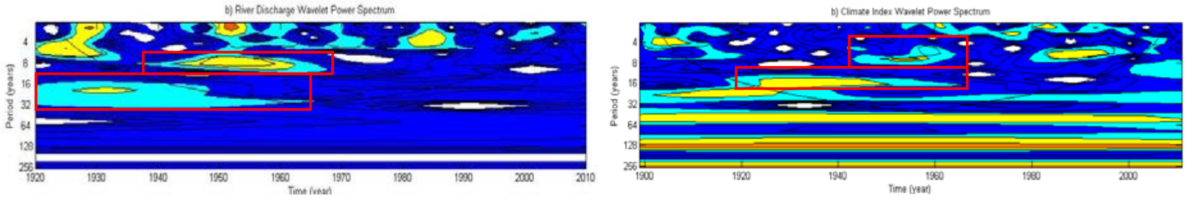


Figure 51 Station 12 (left) and summertime NAO (right)

2. Summer PNA shows some similar features at the same time period (Figure 52).

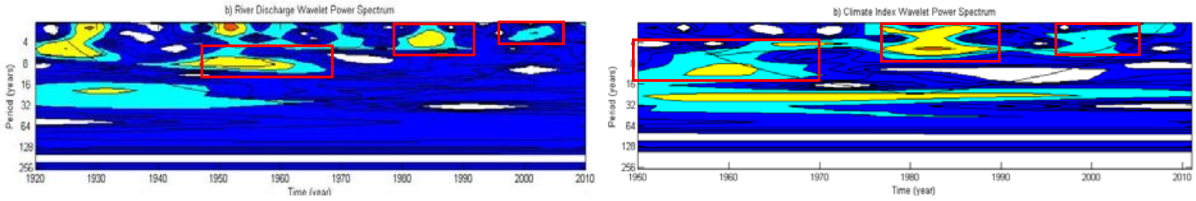


Figure 52 Station 12 (left) and summertime PNA (right)

3. Winter EA/WR has some periods with the equally looking patterns, mostly the one in between 1980-1990 but there is also some around year 2000 (Figure 53).

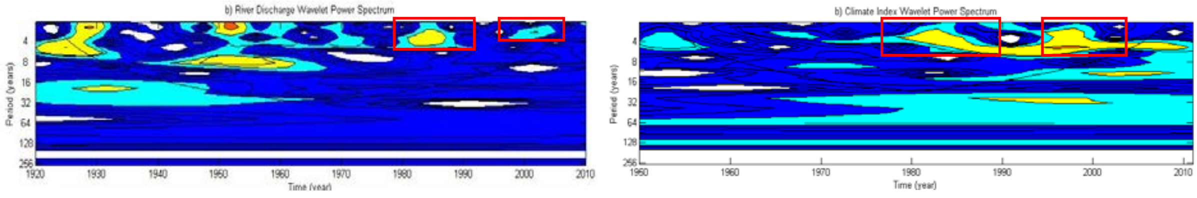


Figure 53 Station 12 (left) and wintertime EA/WR (right)

Red group

1. The wavelet for **winter EA/WR** shows the similar 2-8-year pattern as this river discharge wavelet does (Figure 54).

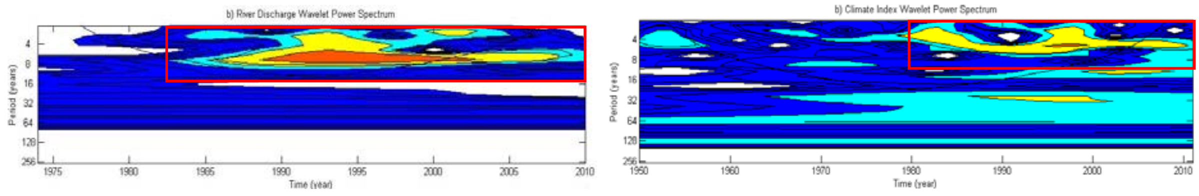


Figure 54 Station 180 (left) and wintertime EA/WR (right)

Black group

1. The **winter NAO** wavelet figure has some similar features to the river discharge wavelet figure (Figure 55).

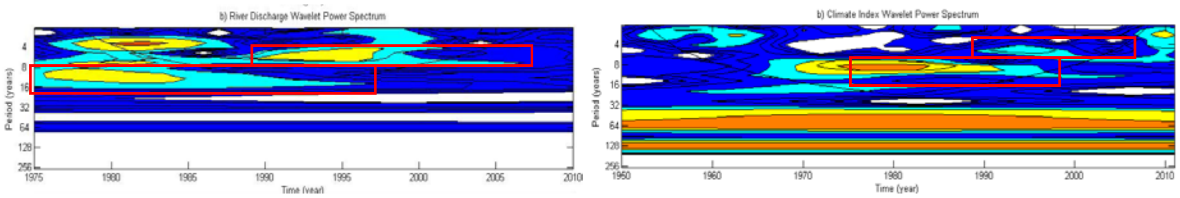


Figure 55 Station 181 (left) and wintertime NAO (right)

2. The 8-year pattern in the river discharge wavelet is shown also in the wavelet for **summer EA/WR** (Figure 56).

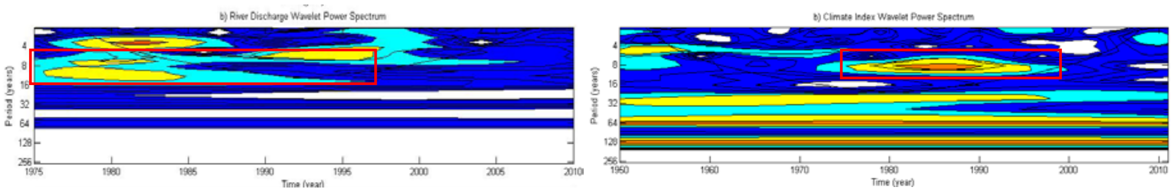


Figure 56 Station 181 (left) and summertime EA/WR (right)

3. Summer EA shows the similar 2-8-year pattern around year 1975-1985 (Figure 57).

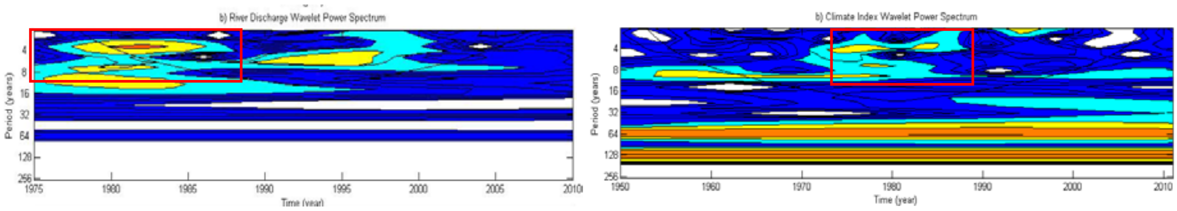


Figure 57 Station 181 (left) and summertime EA (right)

Blue group ,

4. Winter EA/WR has equally looking features in its wavelet, as the river discharge wavelet has, a clear 2-4-year pattern (Figure 58).

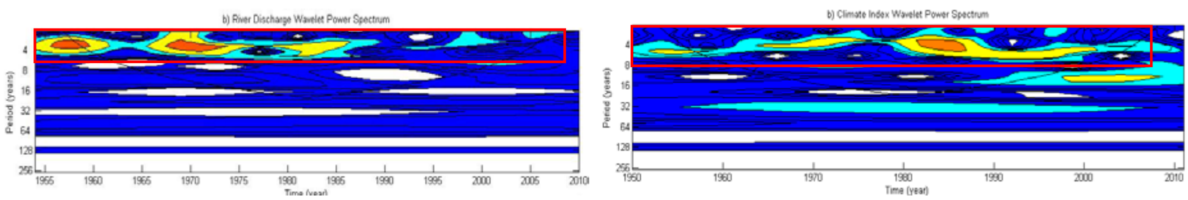


Figure 58 Station 25 (left) and wintertime EA/WR (right)

4.2 Middle Sweden

The results for "middle" Sweden are presented below, starting with the spring division and ending with the autumn division. The map right below (Figure 59) shows the number and situation of the stations in "middle" Sweden.

4.2.1 Spring

In the "middle" part of Sweden, as divided in this work, spring starts around mid-March. It is as said before, accompanied by higher flows due to melting of snow and frozen ground. This is something that will affect the outcome of the "middle" Sweden wavelet figures, as in this part of the country; some storage of snow is often the case.

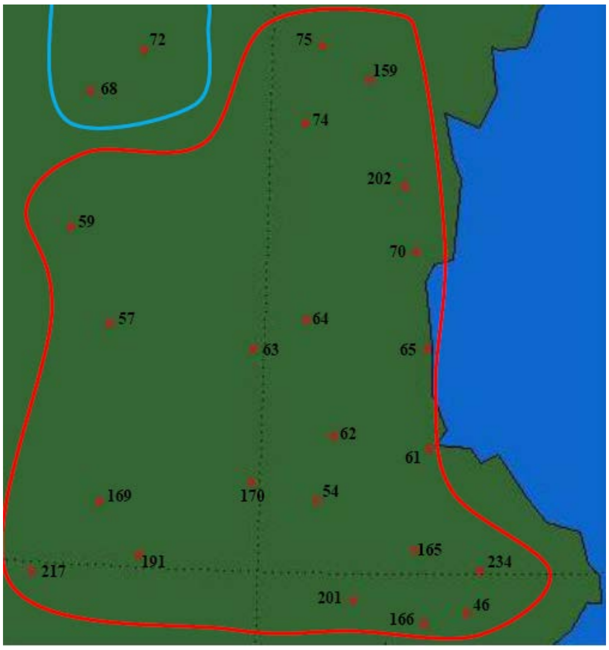


Figure 59 Grouping according to the spring wavelet spectra in middle Sweden

Coloured groups

A short explanation of the coloured groups will follow.

The red and the blue group have some similarities and non-similarities. Both have some strong pattern around year 2000, though not very equally looking and both have some 2-8-year pattern in between 1930-1970, though again these patterns look quite different.

* Red group, show a clear 16 years pattern stretching from early 1900 to late 1900/early 2000. Some time series have fewer years of this 16-year pattern but are still group together, as similarities occur. What can also be seen in many of the red stations are a 2-8-year "dot" in between 1990-2010 and also a clear 2-8-year pattern is also visible in between early 1900 to 1970 (Figure 60).

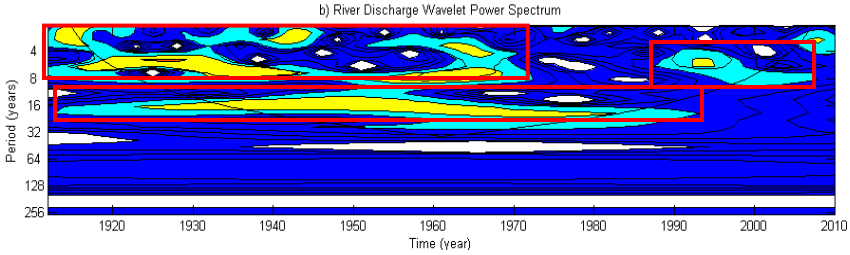


Figure 60 Station 57 – Spring – Red group

* Blue group, shows also a clear 16-year pattern, but it seems to end earlier then for the red group, already in around 1970. This group also has a strong 2-8-year pattern in between 1920 – 1970. Some 2-8-year pattern is also visible in around year 2000 (Figure 61).

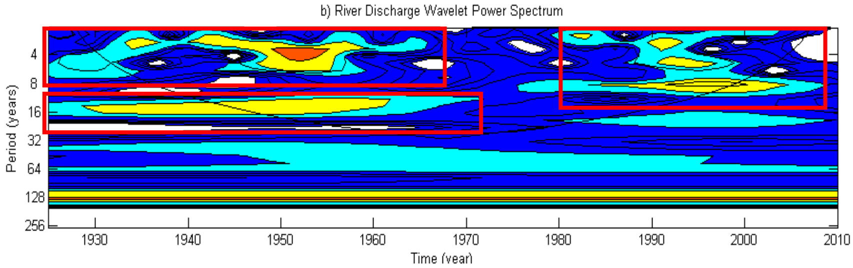


Figure 61 Station 68 - Spring – Blue group

Climate Indices

The typical patterns in the different groups are below described in more detail and also their potential connection to the climate indices.

Red group

1. Winter WP could be related to the 8-year pattern seen below (Figure 62).

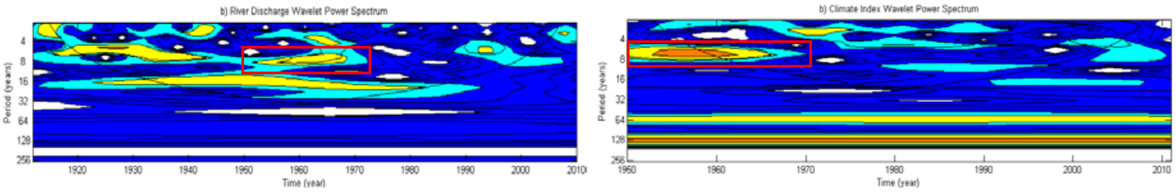


Figure 62 Station 57 (left) and wintertime WP (right)

2. The typical 16-year pattern could be related to **winter PNA** that shows a similar pattern (Figure 63).

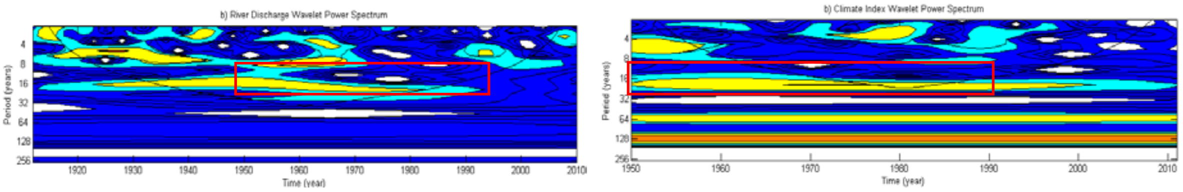


Figure 63 Station 57 (left) and wintertime PNA (right)

<u>**Blue group**</u>

1. Summer NAO has some similar features towards this river discharge wavelet (Figure 64).

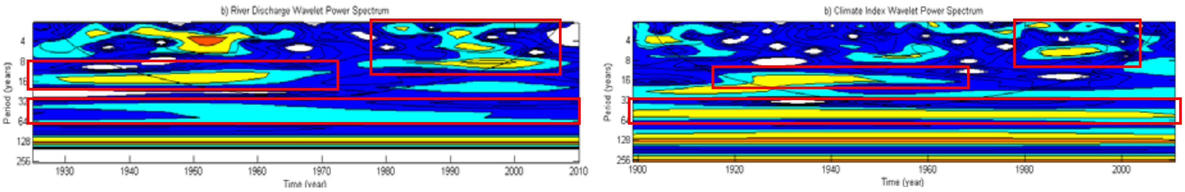


Figure 64 Station 68 (left) and summertime NAO (right)

5.2.2 Autumn

Autumn starts around mid-September, in this part of the country. It is, as said before, accompanied by higher flows due to a higher rainfall amount. This is something that will affect the outcome of the "middle" Sweden wavelet figures.

Here is an attempt to divide middle Sweden into groups, where the discharge wavelets have common features (Figure 65).

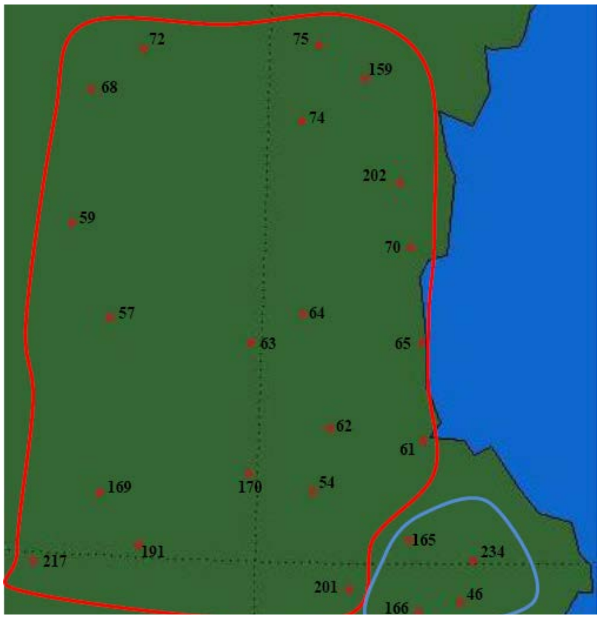


Figure 65 Grouping according to the autumn wavelet spectra in middle Sweden

<u>**Coloured groups**</u>

A short explanation of the coloured groups will follow.

The red and the blue group are hard to compare because many of the blue groups time period is very short and this makes the patterns in the wavelets very elongated, compared to longer time periods.

The two groups are pretty similar, with both having a 16-32-year pattern and some 2-8 years pattern, though some differences occur that divide these stations into different groups.

* Red group means a clear pattern of going from a 32-year period in the beginning of the time series towards an 8-year period in the end of the time series (of course depending on when the time series starts and ends) with a consistent or almost consistent line in the wavelet. This wavelet also shows a 2-8-years pattern in between 1930 and 2010 (Figure 66).

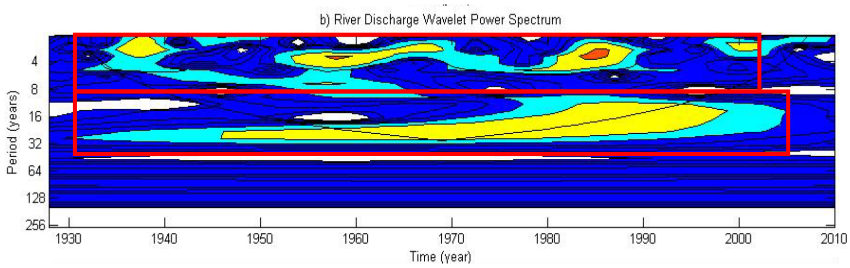


Figure 66 Station 59 – Autumn – Red group

* Blue group, shows a cohesive pattern going from a 16-year period in the beginning of the time series towards a 32-year period in the end of the time series. It also has a dot in 1975-1985 and a clear 8-years pattern in between 1980-2010 (Figure 67).

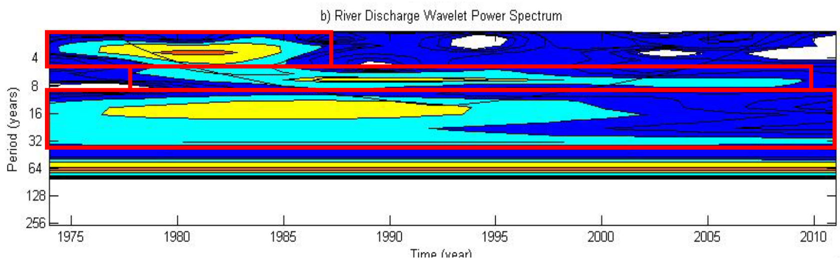


Figure 67 Station 65 – Autumn – Blue group

Climate Indices

The typical patterns in the different groups are below described in more detail and also their potential connection to the climate indices.

Red group

1. The 32- towards 8-year pattern, visible in the river discharge wavelet figure is shown also in the wavelet for **winter PDO**. Also the 4-8 years pattern in between 1930 to 1965 suits (Figure 68).

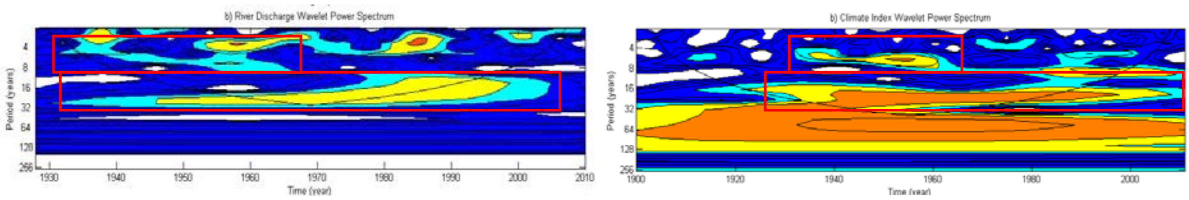


Figure 68 Station 59 (left) and wintertime PDO (right)

2. The 32years pattern, visible in the river discharge wavelet figure is shown also in the wavelet for **summer PNA** (Figure 69).

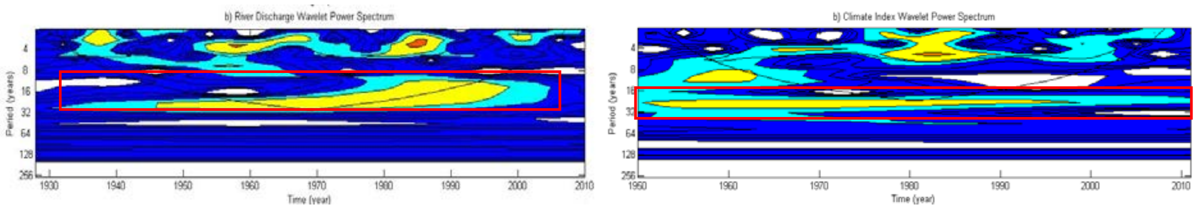


Figure 69 Station 59 (left) and summertime PNA (right)

3. The 32- towards 8-year pattern, visible in the river discharge wavelet figure is shown also in the wavelet for **winter NAO** (Figure 70).

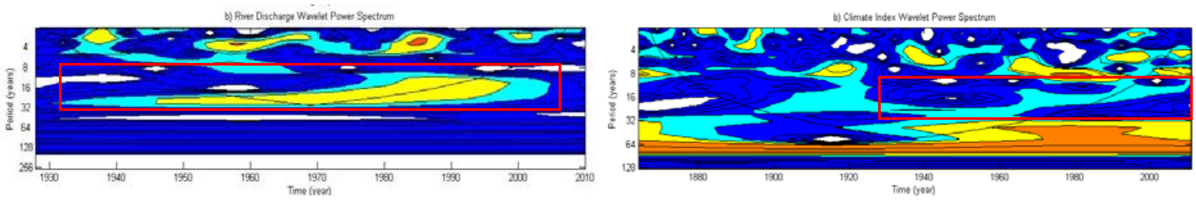


Figure 70 Station 59 (left) and wintertime NAO (right)

4. Winter EA/WR shows both the 2-4-year pattern but also the 32- towards 8-year pattern, visible in the river discharge wavelet figure (Figure 71).

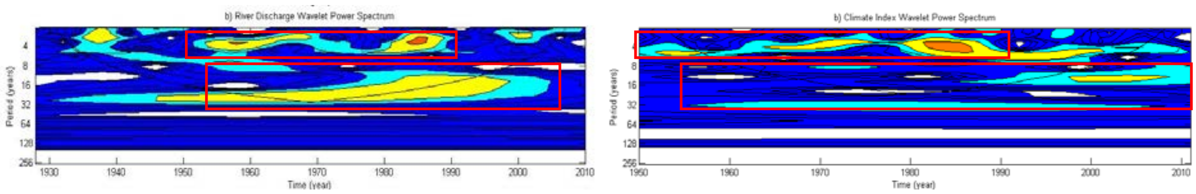


Figure 71 Station 59 (left) and wintertime EA/WR (right)

Blue group

1. Winter PDO shows similar features in the same period in between 1975 to 2010 as this river discharge wavelet does, both with the eight years period and the 16-year period (Figure 72).

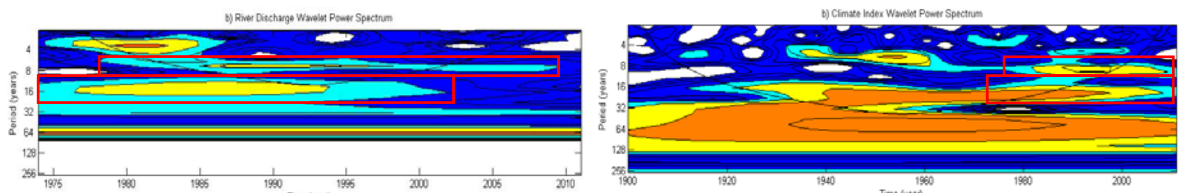


Figure 72 Station 65 (left) wintertime PDO (right)

4.3 Northern Sweden

The results for "northern" Sweden are presented below, starting with the spring division and ending with the autumn division. The map right below (Figure 73) shows the number and situation of the stations in "northern" Sweden.

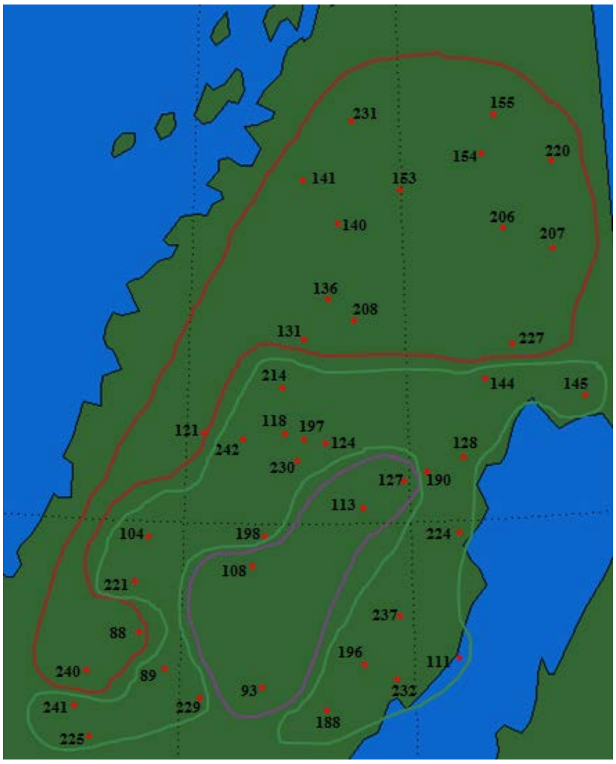


Figure 73 Grouping according to the spring wavelet spectra in northern Sweden

4.3.1 Spring

Spring river discharge in northern Scandinavian rivers consists predominantly of melt water from ice and snow accumulated during the winter. Consequently, the flow rate during the melting period is primarily an indicator of the precipitation during the winter immediately prior to it. Hence, the result from the wavelet analysis of the spring river discharge can logically be related to the climate during the winter, but for a complete analysis the summer climate has also been compared with the result.

Coloured groups

A short explanation of the coloured groups will follow.

Studying the wavelet power spectra for spring in northern Sweden, there are two main patterns of which either one or both reoccur in all of the graphs.

The red pattern is found in the top part of the spectrum graph (red rectangle). It is characterised by short but clearly significant periods (four to eight-year, often less frequent than the one in Figure 74) at two occasions; one around 1950 (usually ca. 1945-1955) and another one in 1990's; sometimes stretching into the new millennium or is sometimes missing. This pattern is found in almost all of the wavelet spectrum except for four stations located inland, east of the mountains (the purple area in Figure 73, including e.g. station number 93). Stations located furthest north and a few located in the mountains shows only this pattern (the red area in Figure 73).

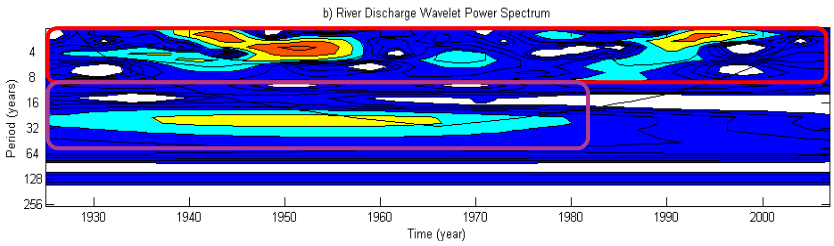


Figure 74 Station 221 – Spring – Red and purple pattern

Purple pattern that is seen in the middle part of Figure 74, outstretched between 1930 to the end of 1970's with a period somewhere between 16- and 32-year. For some of the stations that have been identified as belonging to the two groups with this pattern, the appearance is not as significant nor is it as long. However, it always include 1950, with varying starting and ending years and the period is at least 16 years or larger (but never larger than 32 years).

* Red group includes time series that show proof of the red pattern on the wavelet power spectrum but is missing the purple pattern (Figure 75). These stations are mainly located in the far north or on the west side i.e. in the mountainous area (see Figure 73).

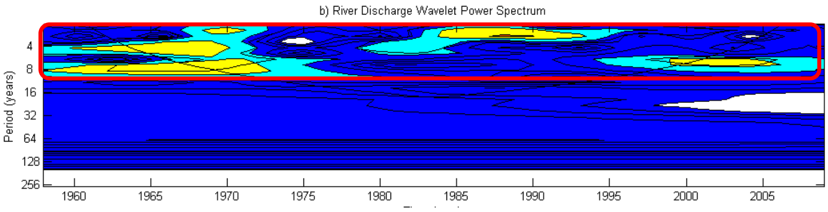


Figure 75 Station 154 - Spring - Red group

* Purple group consist of the few time series that miss the red pattern, but all containing the purple pattern (Figure 76). These are found in the south part in Figure 73, inland but to the east of the mountains.

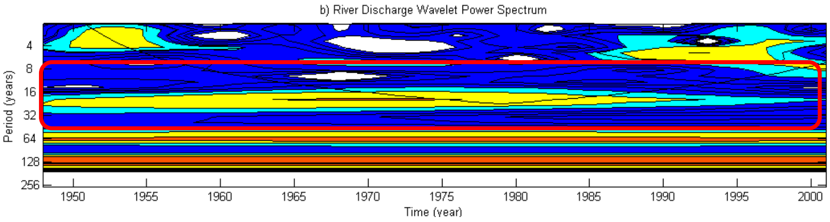


Figure 76 Station 127 - Spring - Purple group

* Green group is hence the remaining stations (green area in Figure 73). These stations, which have indications of both patterns, are located in the "southern" mountains and along the east coast (Figure 77).

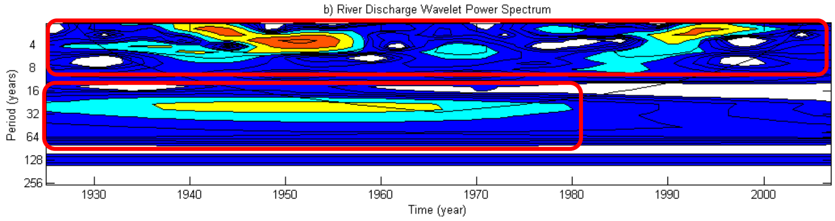


Figure 77 Station 225 - Spring - Green group

Climate Indices

The typical patterns in the different groups are below described in more detail and also their potential connection to the climate indices.

Red group

1 Similarities to the river discharge wavelet power spectra can be found in most of the spectra for the climate indices, although they are more or less striking. In the spectrum for **winter SCA** short and relatively high frequent variations appear, which is sought as a match for the red pattern. In **Error! Not a valid bookmark self-reference.** below, two similar points between the climate index and one of the stations with the red pattern are marked with rectangles. The first of these, occurring around 1960, is close in time and period. On the other hand, the second one occurs later although the shape and period is about the same. In **Error! Not a valid bookmark self-reference.**, which show **winter**

SCA, a significant indication of a period in the 1950's is circled. This could be related to the highly significant period occurring around 1950 in most river power spectra with the red pattern.

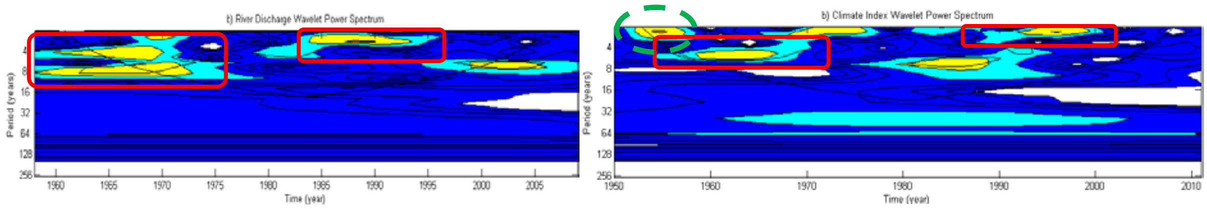


Figure 78 Station 154 (left) and wintertime SCA (right)

2. Winter WP also has some indication of the significant 4-8-year period of around 1950. It is marked in the Figure 79 which can be compared with 206 in which it appears.

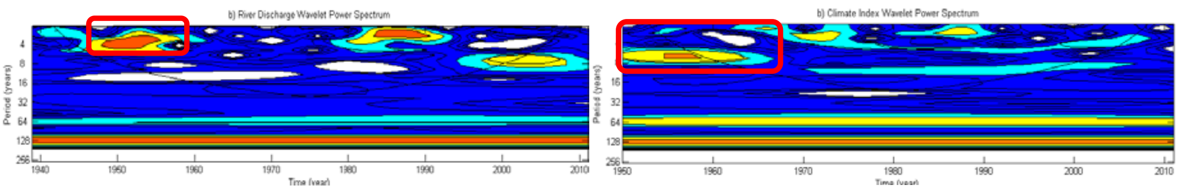


Figure 79 Station 206 (left) and wintertime WP (right)

3. Winter EA/WR has some resemblance to a few of the stations located in the far north of which one is found in Figure 80. Same time span has been marked, in both Figure 80, from the end of the 1970's and forward, during which similar patterns is found.

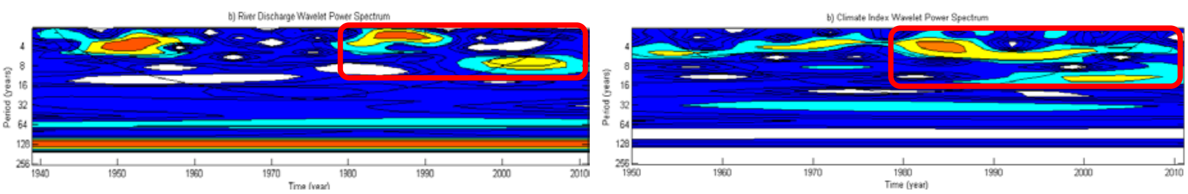


Figure 80 Station 206 (left) and wintertime EA/WR (right)

Purple group

1. Wavelet power spectrum for **winter PNA**, found in Figure 81, have a semblance to both patterns. However, it shows a clear period of somewhere between 16-32 years which could be related to very similar patterns in the river discharge spectra. Figure 81 illustrate a river discharge time series for which this period is very evident. Similarities to the red pattern exist in the 1950's and around 1980, but not very significant.

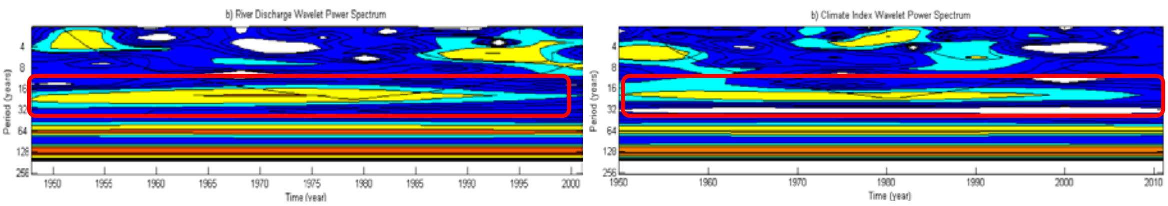


Figure 81 Station 127 (left) and wintertime PNA (right)

2. Winter PDO also has indications of a connection to the purple pattern. As can be seen in Figure 82 **winter PDO** had a significant period of 16-32 years during a major part of the last century which is the same pattern found in the purple (and green) group.

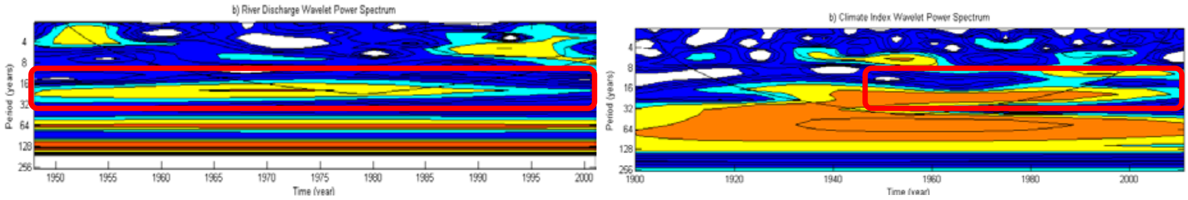


Figure 82 Station 127 (left) and wintertime PDO (right)

3. It is remarkable that similarities have been found between the river discharge in northern Sweden and all of the studied wintertime climate indices in this report except for NAO. NAO, as mentioned above, is one of the most studied teleconnection patterns and is thought to be connected to the climate in Scandinavia. Instead it is the **summer NAO** that show any resemblance to the northern spring river discharge. In Figure 83 the 16-32-year period is found once again with a likeness to the purple pattern.

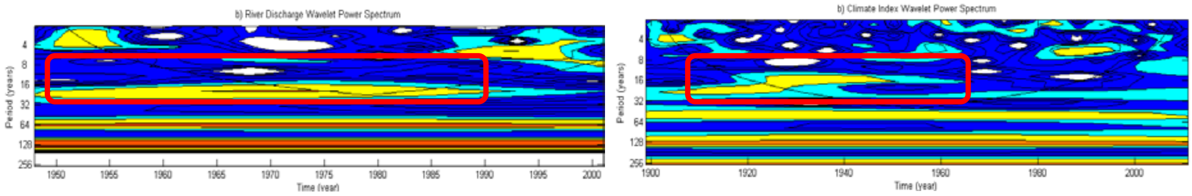


Figure 83 Station 127 (left) and summertime NAO (right)

4. Few of the indices show any patterns at all during the summertime but **summer WP** is one of them that do. The pattern found has some likeness to the purple pattern and there seems to be an indication of the same pattern in Figure 84. Note that the periods are different and it is more an indication of the same pattern than an identical match.

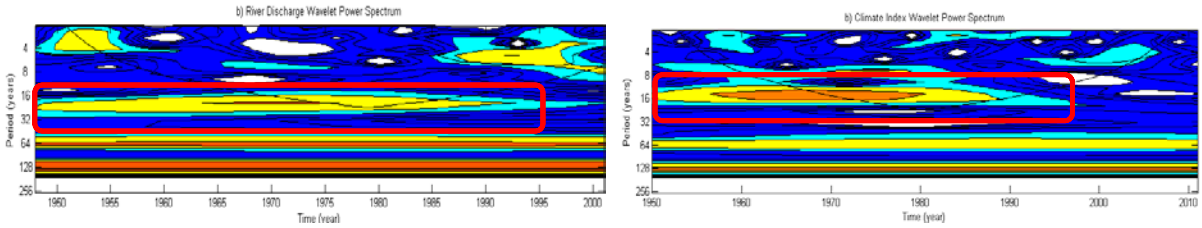


Figure 84 Station 127 (left) and summertime WP

Green group

1. Otherwise, in the wavelet power spectrum for the indices during the summer has in general few occurrences. **Summer PDO** is another exception (Figure 85) which shows similarities to the spring river discharge spectra during summer too. The 16-32-year period is once again significant during the mid of 20th century. Resemblance between the river discharge spectra with the red pattern is marked in Figure 85, occurring both in the mid of the century and in the new millennium.

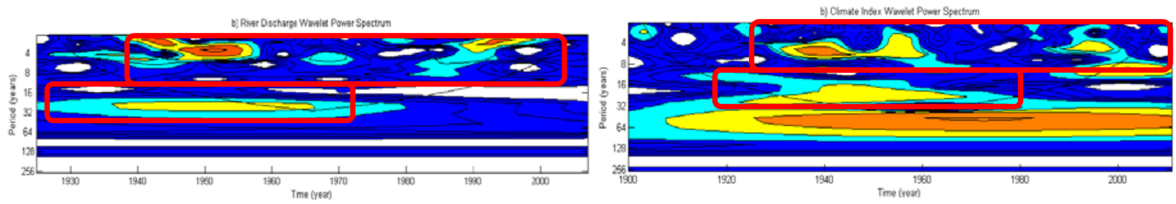


Figure 85 Station 221 (left) and summertime PDO (right)

2. Likewise in **winter EA** a similarity to both patterns is found. It is marked in Figure 86 showing a period of around 16 years during the time span when it appears in the river discharge spectra. During the last decades there is also a pattern that could be connected to the red pattern.

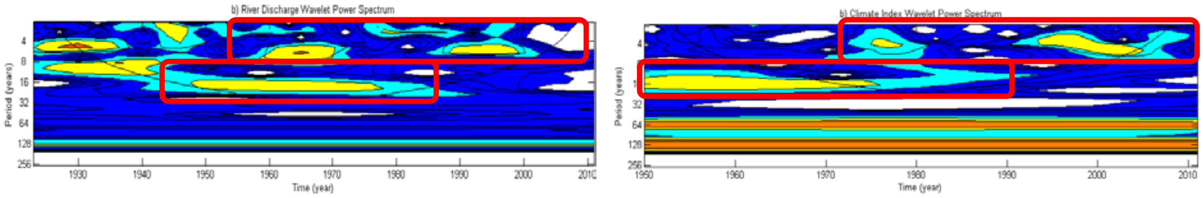


Figure 86 Station 188 (left) and wintertime EA (right)

4.3.2 Autumn

For the autumn river discharge in northern Sweden, it is a hard task to divide it into zones based on the river discharge wavelet power spectrum. The three areas presented here have a few common characteristics and in this case it is to a wide extent based on the geographical location of the stations. For instance, some of the stations furthest to the north are not very unlike the ones furthest to the south in Figure 87. However, there are of course other similarities with the stations in the immediate surrounding too which have been chosen as the basis of the division of the stations.

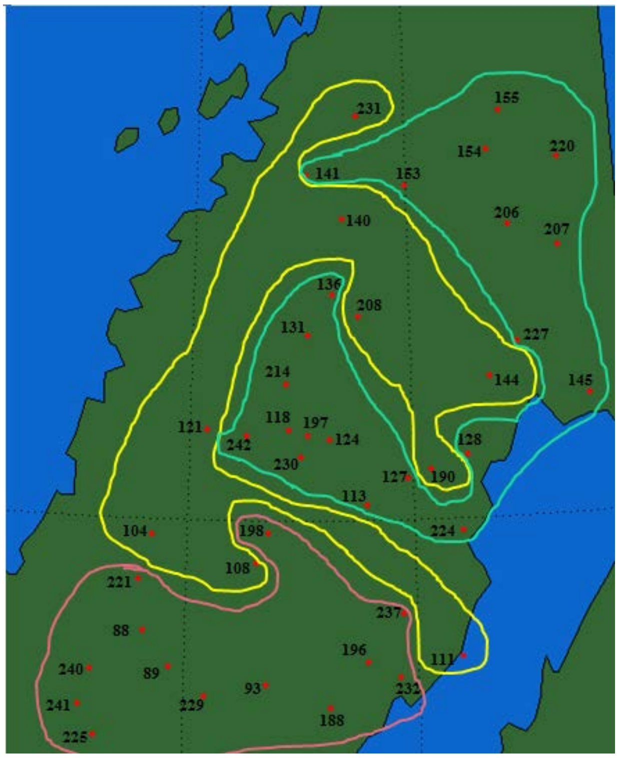


Figure 87 Grouping according to the autumn wavelet spectra in northern Sweden

Coloured groups

A short explanation of the coloured groups will follow.

The pink and turquoise groups are in general very much alike, and if not divided by a distance and other stations, the stations could have been matched differently with a few stations in the turquoise group being more like the majority in the pink group and vice versa. Nevertheless, there are some main characteristics for each of these groups.

* Pink group, the river discharge time series all have a period of 16 to 32 years in the second half of the century, most time series looks like Figure 88 (showing the spectrum graph for station number 225), covering the whole second half of 20th century but sometimes not as significant and other times stops around 1990. Many of the river discharge time series in the

groups also have a significant period of around 8 years around 1950 to 1970 and other relatively high frequent periods in the later years.

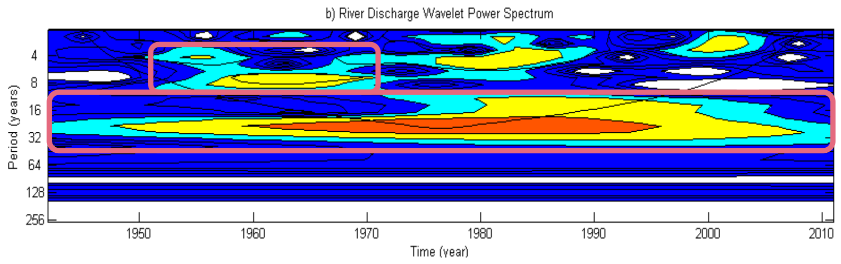


Figure 88 Station 225 – Autumn – Pink group

* Turquoise group, river discharge time series all have the same significant period of 16 to 32 years during almost the same time span as the pink group. In addition, a significant period of 8 to 16 years is found for many of the time series in this group, this is pointed out in Figure 89, which is station number 131. For almost all stations in northern Sweden there is a significant period in the time series of four to eight years around 1980 and then again in the early 21st century and these points are quite prominent in Figure 89.

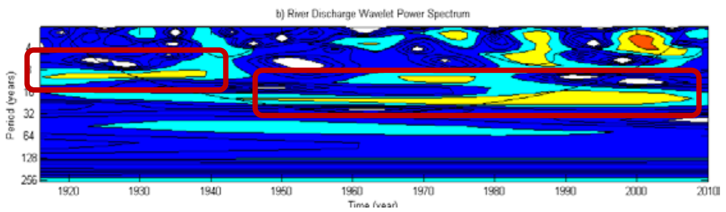


Figure 89 Station 131 – Autumn – Turquoise group

* Yellow group, has time series that are distinguished from the rest since they lack the 16 to 32 year period in the second half of the century. For a few of them this could be due to a too short time series that end around the 1960's. The characteristics of the group are illustrated in Figure 90 (station number 104) that shows no indication of this period, but a shorter one of between 8 and 16 years. For stations in the yellow group that have a time series that start earlier than this one usually it is possible to find a similar period but earlier, starting as early as in the 1910's.

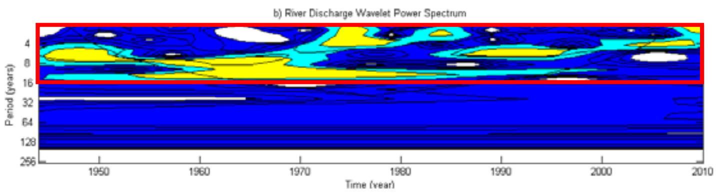


Figure 90 Station 104 – Autumn – Yellow group

Climate indices

Pink group

1. Summer NAO show some patterns that could be matched with the autumn river discharge spectra. In Figure 91 this is illustrated by the marked area, however this seem to match the stations that have this kind of pattern in the spectrum, it seems to be the most obvious likeness between the **summer NAO** and the stations.

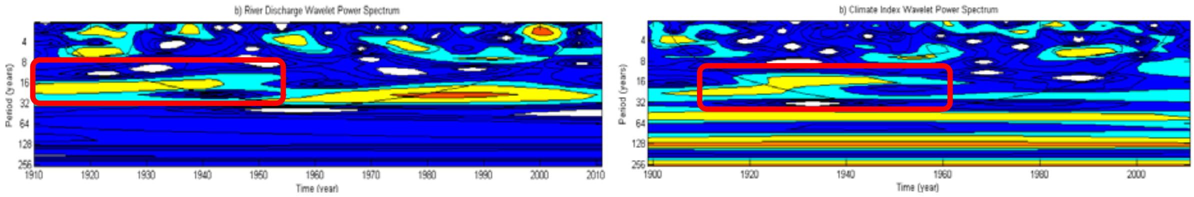


Figure 91 Station 232 (left) and summertime NAO (right)

2. The pattern in **summer PDO** was pointed out for the spring river discharge and should not be forgotten when discussing the autumn discharge. As mentioned in the previous chapter, the 16 to 32 years period is clear in this spectrum too (see Figure 92). It resembles more than one pattern, either the marked pattern in Figure 91 or maybe the long 16 years period in Figure 88 or it could be both.

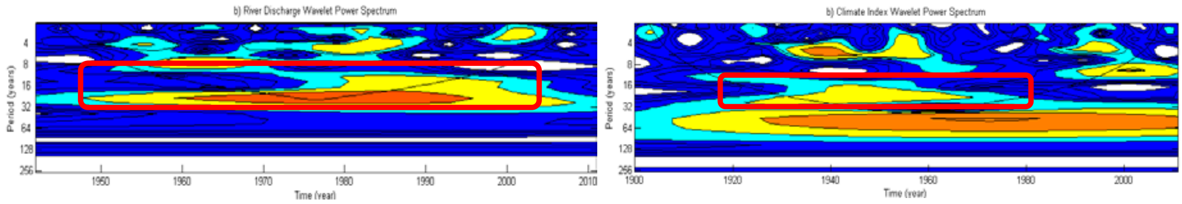


Figure 92 Station 225 (left) and summertime PDO (right)

3. This period is also found in the spectrum for **summer WP**, see Figure 93, but the pattern in the pink group covers a larger part of the second half of the century.

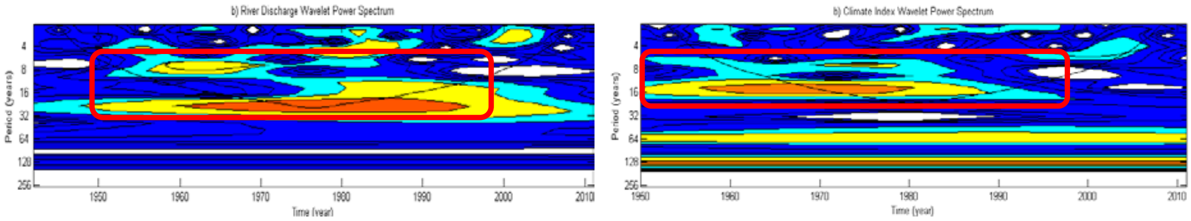


Figure 93 Station 225 (left) and summertime WP (right)

4. The very significant period of about 16 to 32 years in **winter PDO** must not be neglected when comparing the indices and discharge spectra. For the pink group the significance is about the same as for the **winter PDO**, and the size of the period and the time span is very much alike (see Figure 94).

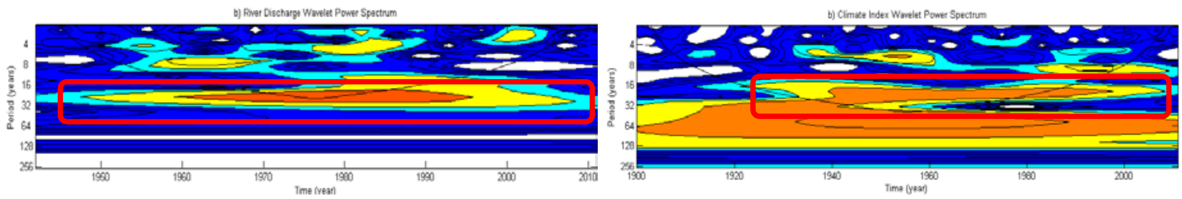


Figure 94 Station 225 (left) and wintertime PDO (right)

5. For **winter PNA**, the period and time span show a striking similarity to this station from the pink group (Figure 95). Note that the data for the station start almost ten years before **winter PNA** data. **Winter PNA** has both a significant period of about 16 years as well as other point of smaller periods that is found in the pink group.

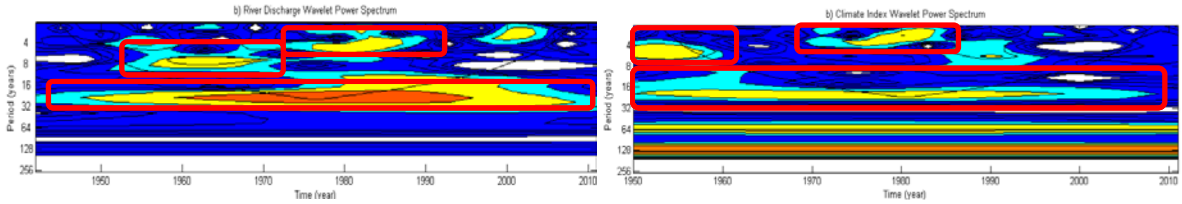


Figure 95 Station 225 (left) and wintertime PNA (right)

Turquoise group

1. Summer NAO, since the turquoise in many aspects has similar properties to the pink group, the indices that match this group are about the same as for the pink group. Illustrated in Figure 96.

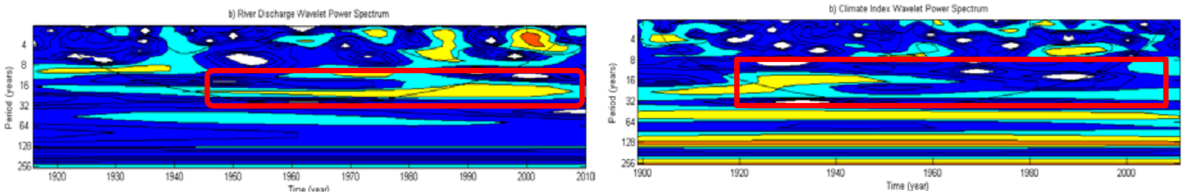


Figure 96 Station 131 (left) and summertime NAO (right)

2. Winter PNA again resembles the river discharge spectrum. The match is not as evident as for the pink group, but the period of 16 years is found in both of Figure 97.

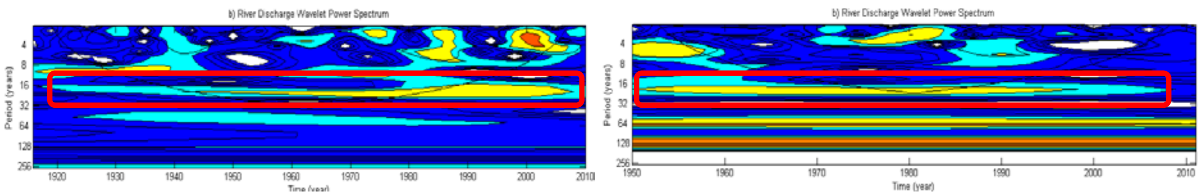


Figure 97 Station 131 (left) and wintertime PNA (right)

3. Winter PDO should not be forgotten for the turquoise group either. The match is not as significant as for the pink group, but there is some resemblance for the size of the period and the time span (see Figure 98).

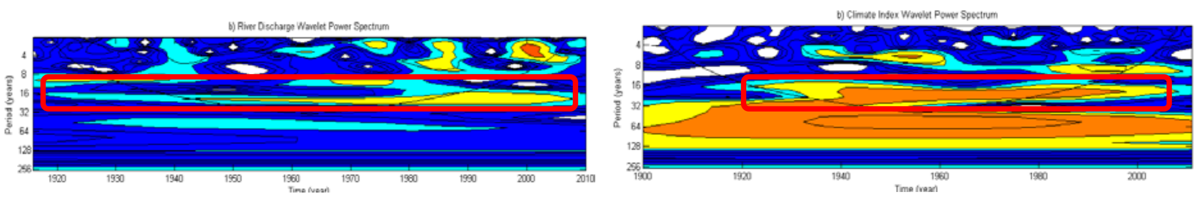


Figure 98 Station 131 (left) and wintertime PDO (right)

4. The pattern found in **summer WP** has been illustrated previously and it has been pointed out to match patterns like the one found in the turquoise group. Still, it occurs mainly in the beginning for its data period presented in this report i.e. during 1950 to late 1980 or early 1990 when it gets weaker. In the turquoise group the pattern gets more significant in the 1980's and therefore it is questionable to consider this relation a match.

Yellow group

1. The resemblance between the **summer NAO** and the yellow group is very small, but there is a pattern that is a good match in the 1990's with the same size of the period. Another similarity is found in 1970 – 1985 with a period of 4 or even smaller. However, as can be seen for the marked patterns in Figure 99, the time spans are not identical.

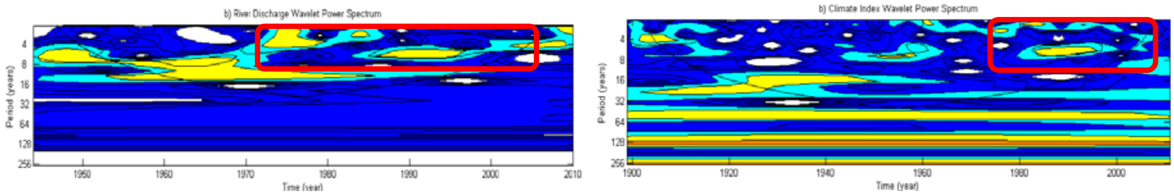


Figure 99 Station 104 (left) and summertime NAO (right)

2. Wintertime average for some of the indices show some similarities to the autumn river discharge spectra. **Winter EA** in Figure 100 has a very similar pattern with a period of around 16 years for the same size and time span as the yellow group.

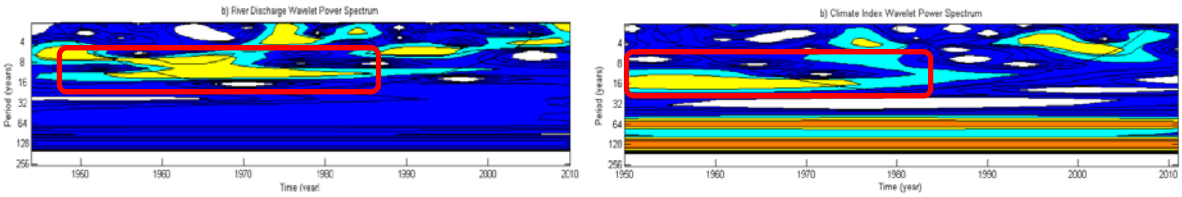


Figure 100 Station 104 (left) and wintertime EA (right)

4.4 Map 64 years period

The following two maps (Figure 101 and Figure 102) show a picture on whole Sweden (autumn and spring) and on how many stations that has a multidecadal 64 years period visible in the river discharge wavelets, almost throughout the whole time period (black ring around them). As more then half of the total stations show this pattern, an interpretation to this, could be that, there is a very strong 64 years pattern that occurs in many of the climate indices, which all contributes to a very clear pattern, where all of Sweden is affected. Both PDO and another teleconnection pattern Atlantic Multidecadal Oscillation (AMO), which are not discussed in this thesis, could have strong influences in a longer perspective, as they are both decadal/multidecadal oscillations.

An issue with this 64-years pattern seen in the wavelet power spectra is that the period is situated outside the black line i.e. it is affected by the padded zeros, explained before. Therefore even though many stations had this period, it is of importance to understand, that it could also mean nothing.

What can also be seen in many of these 64 years pattern stations is a clear tendency towards an increased river discharge. In the normalised river discharge over time (see example station 218) it is possible to see a slight increase going from left to right in the figure. A possible interpretation to this 64 years pattern could then also be the climate change factor. As described above (in Theory part), Sweden have faced, is facing and will be facing an increase in precipitation as the climate change more and more. This could naturally have a direct effect on the total river discharge.

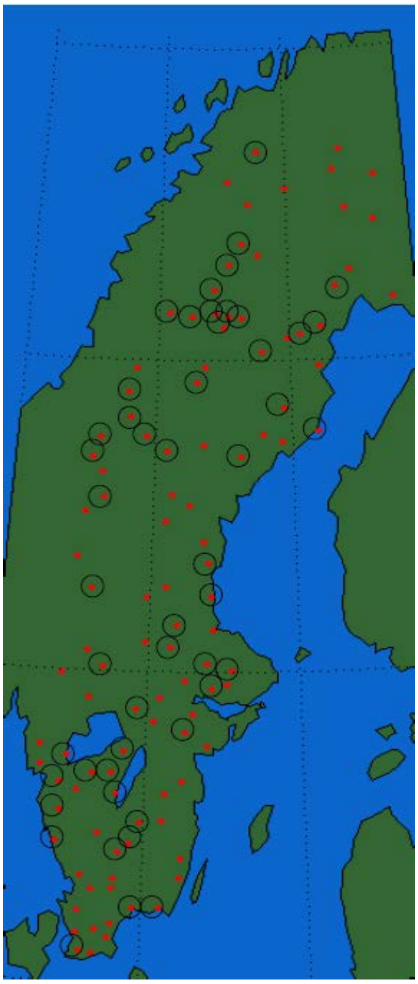


Figure 102 Stations with a 64 year period for its autumn spectrum

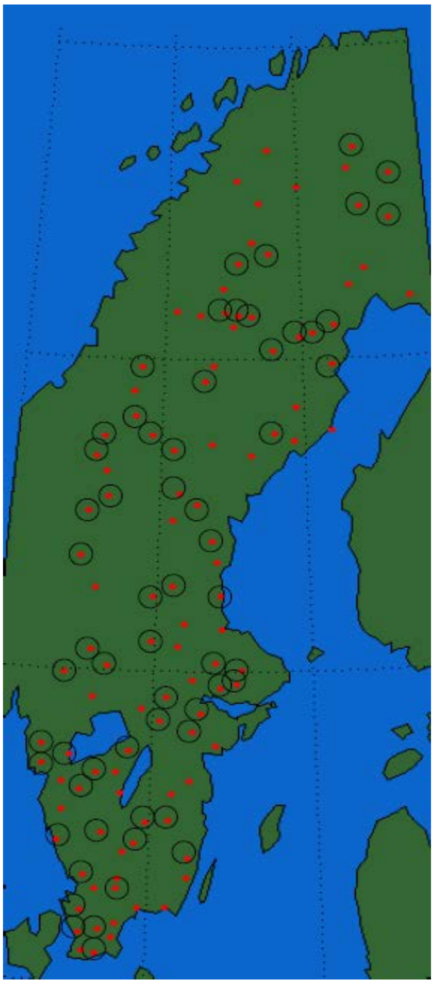


Figure 101 Stations with a 64 year period for its spring spectrum

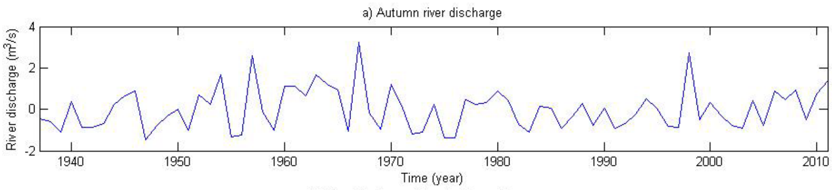


Figure 103 Normalised autumn river discharge for station 218, showing a slight increase towards later years.

5. Discussion

Considering all the presented graphs in the previous chapter, the results of this thesis may seem a bit overwhelming. However, summarising what they say together as a group, the facts behind them can be narrowed down to more understandable reasoning. In the graphs, the decadal oscillations have been marked by colourful rectangles in the spectra to point out that there actually is a plausible low frequent oscillation of the seasonal climate in Sweden. However, comparing the appearances between the river discharge wavelet power spectra and the ones from the teleconnection patterns, is in this case mainly a qualitatively evaluation of possible relations.

Evidently the teleconnection patterns affect the climate in Scandinavia to varying extents. According to the result presented in this thesis it is possible to distinguish two teleconnection patterns as plausible causes for the decadal and multi-decadal variations. They are PNA and PDO; two patterns that have centres located mainly in the northern Pacific Ocean and over the North American continent. Remaining teleconnection patterns encompassed in this thesis seem to have possible effect on the climate in Sweden, although it is of lower impact on the low-frequency variations. Other teleconnection patterns with centres closer to northern Europe have some indications of a possible connection to the decadal oscillations, such as NAO and EA. In turn, SCA seem to have less relation to the long-term variability of river discharge in Sweden due to a lack of decadal oscillations on SCA.

PDO is the pattern that is attributed with the most obvious multidecadal oscillations, which the name itself implies, and it is foremost the wintertime PDO that reoccurs frequently in the analysis in previous chapter. PDO is compared to a large number of the groups of stations in the result since it resembles the river discharge spectra in many aspects. In the spectrum for wintertime PDO, the period of 32 years is very significant. Periods of 4 – 8 years also occur in the PDO spectrum, as well as a clear 16 years period. PDO may hence be related to many different lengths of oscillations in the Scandinavian climate. In this thesis, longer periods than of 32 years where chosen not to be included in the comparison between the river discharge and teleconnection patterns. See later discussion.

NAO is already known to impact the winter climate in Sweden, since the strong centres affect most of Europe and parts of the Middle East. NAO seem to have a more frequent variability and is companied by PNA that show the same tendencies. This difference from PDO, whose longer periods are more significant, raise the question whether the teleconnection patterns contributes to oscillations of different periods. In addition, it is very plausible that from the variability of the teleconnection patterns, speculate that there might be some connection between their low frequency oscillations. A pattern of 16 years that appear in almost all river discharge spectra in southern and middle Sweden and in some of the autumn river discharge in northern Sweden is one example. Some of the teleconnection pattern spectra include a similar pattern; NAO, PDO, PNA, summer WP, summer SCA and autumn EA, which could indicate that these are connected somehow.

Except for PDO the teleconnection patterns are all strongest during winter (PDO is defined as an oscillation of decadal magnitude and thus varying over long time periods). This is a good explanation to why a few of the teleconnection patterns in this thesis do not show any significant variability during the summer. Nevertheless, both WP and NAO show tendencies to oscillate during summer and more relations are found between their summertime spectra and the river discharge spectra than for their wintertime spectra. The results does not give any reason for this behaviour, but it seem to indicate that there are possible oscillations for these teleconnection patterns during summer as well and they might be strong enough to affect the climate during other times of the year than the winter months.

In this thesis, spring river discharge is not only compared to wintertime variations of the teleconnection pattern, but also the summertime ones. The autumn river discharge was compared to both as well. There are resemblances between the spectra in all cases, i.e. spring discharge – winter climate, spring discharge – summer climate, autumn discharge – winter climate and autumn discharge – summer climate. Thus, there is a possibility that variations of the teleconnection patterns could result in weather events at unsuspected locations or with so far unknown lag times.

Although stations were divided by geographical borders, this division does not seem to apply in reality regarding reoccurrence of patterns as groups from the different areas tend to look alike. An example of this is the autumn red group in middle Sweden, which is very similar to the autumn yellow group in southern Sweden. These two groups are geographically connected to each other, and it is not impossible that a correlation also exists. Since this is a qualitative analysis the fact that the months for which the average spring and autumn river discharge is calculated vary – a spectrum from one geographical area is not entirely comparable with one from another area – can be disregarded. Another example of the same equally looking river discharge wavelets in different parts of the country is the autumn red group in middle Sweden that looks fairly alike the autumn pink group in northern Sweden. They both have a 32 years pattern that moves more and more towards a 16- to 8-years pattern around year 2000. As can be seen on the maps created of northern and middle Sweden (see Figure 59, Figure 65, Figure 73 & Figure 87), these groups border to each other. From the climate zone map (see Figure 1) it is plausible that the stations in these two groups are located within the same zone which could verify that these two groups are in fact related.

A further comparison between the groups in the different areas of Sweden, the stations in the middle and northern areas are divided into fewer groups and the difference in variability of the river discharge seem less in these two areas than in the southern area. Nonetheless, this is entirely in accordance with the division of Sweden in climate zones (see Figure 1) in which the zones are smallest in southern Sweden and is increasing in size further north. Comparing this map to the ones with the grouped stations (Figure 20, Figure 39, Figure 59, Figure 65, Figure 73 & Figure 87) the areas seem to coincide to some extent. In the north, one area has been identified in the furthest north and including some stations in the mountains (Figure 73 & Figure 87) which is similar to one of the zones in Figure 1. In the rest of the country there are similarities between many of the groups and the climate zones. Thus, these already acknowledge climate zones of Sweden give some validation to the results in this thesis since the long term variations seem to be affected in somewhat the same manner as the climate generally is.

Furthermore, the climate in spring, in comparison with the autumn river discharge, seems to be less varied over the geographical areas. Patterns reoccur in the spring wavelet power spectra which created less difficulty when sorting the stations into groups. This could be due to that many of the teleconnection patterns are stronger in the wintertime, and if these are the cause for the types of oscillations of the climate found in this thesis, the winter precipitation could be more affected by these oscillations. In a global perspective, the rivers in Sweden are short and hence the lag time between rain events upstream and outflow into a recipient (generally the Baltic Sea) is short. Hence, the main lag time that should be taken into account is the one caused by the cold climate. This is also a big difference between northern and southern Sweden; the rivers in northern Sweden is affected by the wintertime storage of precipitation as ice and snow every year while in southern Sweden some years are too warm. This means that the spring river discharge may be more related to the direct effect of current weather some years and no longer reflect the one occurring during the winter.

As opposed to the spring river discharge, the one occurring in the autumn is mainly a result of recent hydrological conditions. Since the rivers flow from the mountains in the west to the Baltic Sea in the east, a delay of a few days of travelling time is expected but no large scale lag times. Hence, prevailing climate and weather have a more direct effect on the flow rates than during the spring, and the investigated months for the climate indices should be closer in time to have a plausible effect on the river discharge. A further comparison between the autumn river discharge and the teleconnection patterns, with data chosen for the latter closer in time to the autumn, might give a further understanding of the effect these teleconnection patterns have on the Scandinavian climate all year round.

For some stations, of which the major part is located in southern Sweden, the time series were much shorter than the rest. Stations with flow rate measurements of only 30 to 40 years were included to cover most areas of Sweden. The shorter time series makes the qualitative evaluation of the graphs more difficult, since the patterns are elongated compared to matching patterns in spectra of longer time series. In addition, the shorter time series mean that the wavelet analysis will not be able to compare the river discharge to as large periods as for longer ones. In most case the periods were of enough size, but in a few cases, the periods could not be as large as desired. Moreover, the padded zeros may affect the wavelet power spectra for the short time series to a wider extent, and especially affect the power for long periods that continues outside of the actual time series. Hence the division of these stations into groups should be considered arbitrary in some cases. Since the available data for these stations were limited, patterns that in other power spectra would have been considered too small had to be taken into account to be able to match these stations with others.

Several of the patterns considered in this thesis are partly or in a few cases entirely outside of the cone of influence. Since the patterns (e.g. the ones of 32 years period) that are used as a basis for the grouping of the stations are chosen for the very reason that they exist in many spectra, they can be considered to verify each other.

Another issue with the cone of influence are the projected 64-year map. Here, as said before, the pattern is within the cone of influence. It is still part of the result considering that there were such a large amount of the stations that showed this pattern and therefore worthy of discussing.

6. Conclusion

Decadal oscillations were found for almost every station examined in this thesis. It was possible to divide stations into groups according to similar features in the river discharge wavelet power spectra and the location of the stations. Common decadal oscillations were found not only between stations close by but also between stations situated further away from each other. These potential relations could be useful to predict weather events that could occur within certain areas. The group division is fairly comparable to the generally used climate zones in Sweden. This fact proposes that the decadal oscillations found depend not only on the large scale movement of the atmosphere but also on the local climatic conditions. The majority of the northern hemisphere teleconnection patterns also showed these decadal oscillations, which indicates a possible relation between the river discharges and the climate indices. PDO and PNA were found to be the two teleconnection patterns that had the most resembling decadal oscillations to the river discharge wavelet power spectra. SCA teleconnection pattern showed least similar features and is probably not the cause for the long-term variability in Swedish rivers.

To conclude the result part, the most similarly looking climate index wavelet and river discharge time series wavelet are summarized below. Notice that these are just the clearest examples on possible connection but all others are discussed in the result part.

- Southern Sweden - Spring;
  - Yellow group – Summer WP
  - White group – Winter PNA
  - Green group – Winter PDO
  - Red group – Winter PDO
  - Blue group – Summer PNA
- Southern Sweden – Autumn;
  - Yellow group – Winter EA/WR
  - Green group – Summer PNA
  - Red group – Winter EA/WR
  - Black group – Winter NAO
  - Blue group – Winter EA/WR
- Middle Sweden – Spring;
  - Red group – Winter PNA
  - Blue group – Summer NAO
- Middle Sweden – Autumn;
  - Red group – Winter PDO
  - Blue group – Winter PDO
- Northern Sweden – Spring;
  - Red group – Winter SCA
  - Purple group – Winter PNA
  - Green group – Winter EA
- Northern Sweden – Autumn;
  - Pink group – Winter PDO
  - Turquoise group – Winter PNA
  - Yellow group – Winter EA

This result is foremost of qualitative basis and to be able to produce a more scientifically proven result, further investigations are needed. A possibility could be to use another wavelet analyse called cross-wavelet analysis. This analysis aims to compare different time series by applying them on top of each other and compare their features. This could possibly prove the results even further.

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Figure 11. Climate Prediction Center, 2012. *PNA* [online]: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/pna_loading.htm [Accessed 10 February 2012]

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Figure A4-2. SMHI, 2012. *Sommar* [online]: http://www.smhi.se/kunskapsbanken/meteorologi/sommar-1.1084 [Accessed 2 March 2012]

Figure A4-3. SMHI, 2012. *Höst* [online]: http://www.smhi.se/kunskapsbanken/host-1.1257 [Accessed 2 March 2012]

Figure A4-4. SMHI, 2012. *Vinter* [online]: http://www.smhi.se/kunskapsbanken/meteorologi/vinter-1.1480 [Accessed 2 March 2012]

9. Appendices

Appendix 1. Matlab codes

1. Creating the map of Sweden

```
%made by Karin Persson and Angelica Lidén, 2011-11-28
coor=zeros(2,242); % a matrix for the coordinates for the 242 stations,
containing only zeros from start

ind=[1:1:242]; % a matrix for the sprintf to use to go through the files
figure
for i=1:1:242
    file=sprintf('st%d.xlsx', ind(1,i)); % all the files are named stX
where X is a number between 1-155, sprintf replaces "%d" with a number, one
at a time for each for-loop
    coor(1,i)=xlsread(file,'I7:I7'); % reads the latitude in the excel-file
that is in degrees with decimals in WGS84 (no min or sec)
    coor(2,i)=xlsread(file,'H7:H7'); % reads the longitude in the excel-
file
    %printing the current number in the for-loop to keep track of the how
    %far it has gone:
    i
end

m=axesm('MapProjection','eqdconic','Frame','off','Grid','on','MapLatLimit',
[55 70.2],'MapLonLimit',[10 25]); %creates the map, a equal distance conic
projection 55N-70.2N and 10E-25E.
set(m,'color',[0.05 0.4 0.8]) % sets the background color to the same as
the lakes'

geoshow('landareas.shp', 'FaceColor', [0.2 0.4 0.2]); % makes the land
visible in the map
geoshow('worldlakes.shp', 'FaceColor', [0.05 0.4 0.8]); % makes the lakes
visible in the map
%colormap([.45 .60 .30; 0 0 0; 0 0.5 1; 0 0 1]);
setm(m,'MLineLocation',5); % add grid-lines (more fine, 5 degrees apart)
setm(m,'PLineLocation',5); % add grid-lines

setm(m,'MeridianLabel','on');
setm(m,'ParallelLabel','on');

title('Locations of the Stations');



plotm(coor(1,3:4),coor(2,3:4),'LineStyle','none','Marker','.','MarkerEdgeCo
lor','r','MarkerFaceColor','r','MarkerSize',5) % displays the locations of
the stations
plotm(coor(1,7:8),coor(2,7:8),'LineStyle','none','Marker','.','MarkerEdgeCo
lor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,12),coor(2,12),'LineStyle','none','Marker','.','MarkerEdgeColo
r','r','MarkerFaceColor','r','MarkerSize',5)
```

```
plotm(coor(1,14),coor(2,14),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,25),coor(2,25),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,29:31),coor(2,29:31),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,33),coor(2,33),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,38),coor(2,38),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,41),coor(2,41),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,45:46),coor(2,45:46),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,54),coor(2,54),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,57),coor(2,57),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,59),coor(2,59),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,61:65),coor(2,61:65),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,68),coor(2,68),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,70),coor(2,70),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,72),coor(2,72),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,74:75),coor(2,74:75),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,88:89),coor(2,88:89),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,93),coor(2,93),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,104),coor(2,104),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,108),coor(2,108),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,111),coor(2,111),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,113),coor(2,113),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,118),coor(2,118),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,121),coor(2,121),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,124),coor(2,124),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,127:128),coor(2,127:128),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,131),coor(2,131),'LineStyle','none','Marker','.','MarkerEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
```

```
plotm(coor(1,136),coor(2,136),'LineStyle','none','Marker','.','MarkerEdgeCo
lor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,140:141),coor(2,140:141),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,144:145),coor(2,144:145),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,153:155),coor(2,153:155),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,159),coor(2,159),'LineStyle','none','Marker','.','MarkerEdgeCo
lor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,161:162),coor(2,161:162),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,165:166),coor(2,165:166),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,168:170),coor(2,168:170),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,173:178),coor(2,173:178),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,180:181),coor(2,180:181),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,186:188),coor(2,186:188),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,190:191),coor(2,190:191),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,196:198),coor(2,196:198),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,201:202),coor(2,201:202),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,206:209),coor(2,206:209),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,211),coor(2,211),'LineStyle','none','Marker','.','MarkerEdgeCo
lor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,213:214),coor(2,213:214),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,216:218),coor(2,216:218),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,220:225),coor(2,220:225),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
plotm(coor(1,227:242),coor(2,227:242),'LineStyle','none','Marker','.','Mark
erEdgeColor','r','MarkerFaceColor','r','MarkerSize',5)
```

2. Creating the wavelet figures

```
%WAVETEST Example Matlab script for WAVELET, using NINO3 SST dataset
%
% See "http://paos.colorado.edu/research/wavelets/"
% Written January 1998 by C. Torrence
%
% Modified Oct 1999, changed Global Wavelet Spectrum (GWS) to be sideways,
%   changed all "log" to "log2", changed logarithmic axis on GWS to
%   a normal axis.
%
%Modified and changed Jan 2012, by Karin Persson and Angelica Lidén
```

```
load monthflow1.mat   % input flow series
monthflowAvg = monthflow;

%------------------------------------------------------ Computation

% normalize by standard deviation (not necessary, but makes it easier
% to compare with plot on Interactive Wavelet page, at
% "http://paos.colorado.edu/research/wavelets/plot/"
variance = std(monthflowAvg)^2;
monthflowAvg = (monthflowAvg - mean(monthflowAvg))/sqrt(variance) ;

n = length(monthflowAvg);
dt = 1/12;
time = (0:length(monthflowAvg)-1)*dt + 1912.0 ;  % construct time array
xlim = [1912,2011];  % plotting range
pad = 1;      % pad the time series with zeroes (recommended)
dj = 0.25;    % this will do 4 sub-octaves per octave
s0 = 2*dt;    % this says start at a scale of 6 months
j1 = 7/dj;    % this says do 7 powers-of-two with dj sub-octaves each
lag1 = 0.72;  % lag-1 autocorrelation for red noise background
mother = 'Morlet';

% Wavelet transform:
[wave,period,scale,coi] = wavelet(monthflowAvg,dt,pad,dj,s0,j1,mother);
power = (abs(wave)).^2 ;        % compute wavelet power spectrum

% Significance levels: (variance=1 for the normalized river discharge)
[signif,fft_theor] = wave_signif(1.0,dt,scale,0,lag1,-1,-1,mother);
sig95 = (signif')*(ones(1,n));  % expand signif --> (J+1)x(N) array
sig95 = power ./ sig95;         % where ratio > 1, power is significant

% Global wavelet spectrum & significance levels:
global_ws = variance*(sum(power')/n);   % time-average over all times
dof = n - scale;  % the -scale corrects for padding at edges
global_signif = wave_signif(variance,dt,scale,1,lag1,-1,dof,mother);

% Scale-average between El Nino periods of 2--8 years
avg = find((scale >= 2) & (scale < 8));
Cdelta = 0.776;   % this is for the MORLET wavelet
scale_avg = (scale')*(ones(1,n));  % expand scale --> (J+1)x(N) array
scale_avg = power ./ scale_avg;   % [Eqn(24)]
scale_avg = variance*dj*dt/Cdelta*sum(scale_avg(avg,:));   % [Eqn(24)]
scaleavg_signif = wave_signif(variance,dt,scale,2,lag1,-1,[2,7.9],mother);

whos

%------------------------------------------------------ Plotting

%--- Plot time series
subplot('position',[0.1 0.75 0.65 0.2])
plot(time,monthflowAvg)
set(gca,'XLim',xlim(:))
```

```
xlabel('Time (years)')
ylabel('River discharge (m^3/s)')
title('a) River discharge (m^3/s) over time')
hold off

%--- Contour plot wavelet power spectrum
subplot('position',[0.1 0.37 0.65 0.28])
levels = [0.0625,0.125,0.25,0.5,1,2,4,8,16] ;
Yticks = 2.^(fix(log2(min(period))):fix(log2(max(period))));
contourf(time,log2(period),log2(power),log2(levels));  %*** or use
'contourfill'
caxis([-1 +2]);
colormap(jet(6))
%colorbar('location','southoutside')
c=colorbar('XtickLabelMode','Manual','XTickLabel', ...
     {'0.5','0.7','1','1.4','2','2.8','4>'},'fontname',...
 'arial','fontsize',10,'location','southoutside');
x=get(c,'Position');
x(2)=0.29;
set(c,'Position',x)
set(gca,'position',[0.1 0.37 0.65 0.28])
set(gca,'Ylim',[0,0.1])
%imagesc(time,log2(period),log2(power));  %*** uncomment for 'image' plot

xlabel('Time (year)')
ylabel('Period (years)')
title('b) River Discharge Wavelet Power Spectrum')
set(gca,'XLim',xlim(:))
set(gca,'YLim',log2([min(period),max(period)]), ...
    'YDir','reverse', ...
    'YTick',log2(Yticks(:)), ...
    'YTickLabel',Yticks)
% 95% significance contour, levels at -99 (fake) and 1 (95% signif)
hold on
contour(time,log2(period),sig95,[-99,1],'k');
hold on
% cone-of-influence, anything "below" is dubious
plot(time,log2(coi),'k')
hold off

%--- Plot global wavelet spectrum
subplot('position',[0.77 0.37 0.2 0.28])
plot(global_ws,log2(period))
hold on
plot(global_signif,log2(period),'--')
hold off
xlabel('Power ((m^3/s)^2)')
title('c) Global Wavelet Spectrum')
set(gca,'YLim',log2([min(period),max(period)]), ...
    'YDir','reverse', ...
    'YTick',log2(Yticks(:)), ...
    'YTickLabel','')
set(gca,'XLim',[0,1.25*max(global_ws)])
```

```
%--- Plot 2--8 yr scale-average time series
subplot('position',[0.1 0.07 0.65 0.2])
plot(time,scale_avg)
set(gca,'XLim',xlim(:))
xlabel('Time (year)')
ylabel('Avg variance (m^3/s)')
title('d) 2-8 yr Scale-average Time Series')
hold on
plot(xlim,scaleavg_signif+[0,0],'--')
hold off

% end of code
```

3. Creating the river discharge figures

```
%made by Karin Persson and Angelica Lidén, 2011-10-27
number = (1:1:242);  %gör en nummervektor som säger att man ska börja på
den första siffran och sen ska man ta ett steg emellan och sen gå tills
sista siffran

for k = 1:1:242                             %for-sats innebär att matlab
kör detta nedan tills slutet är nöjd
  myfilename = sprintf('st%d.xlsx', number(1,k));    %sprintf är en
funktion som gör att man byter fil vid varje genomgång av for-satsen
  B = xlsread(myfilename,'G:G');                    %xlsread är en funktion
som gör att matlab kan läsa excel-filer, G:G betyder att man tar hela raden
  [C,text1] = xlsread(myfilename,'C2:C2');    %text1 betyder att den ska
läsa de här värdena som en textrad och inte ett numeriskt värde (det är
okej för text att innehålla mellanrum)
  [A,text2] = xlsread(myfilename,'D2:D2');
  [D,text3] = xlsread(myfilename,'H2:H2');
  [E,text4] = xlsread(myfilename,'I2:I2');
  F = xlsread(myfilename,'E2:E4');
  G = xlsread(myfilename,'F2:F4');
  H = xlsread(myfilename,'A2:A2');

  startDate = datenum(F');    %datenum ger startdatumet ett värde som kan
läsas med matlab och ' betyder att man konverterar startvärdet till läsbart
för matlab
  endDate = datenum(G');
  time = linspace(startDate,endDate,length(B));    %för att skapa en längd
på datumen på x-axeln med ett linjärt förhållande används linspace
  figure
  plot(time,B)   %plot är funktion som gör plotten av xData och flödet=B
  xData = [startDate:fix((endDate-startDate)/10):endDate];
  set(gca,'XTick',xData);
  datetick(gca,'x','yyyy/mm/dd','keepticks');   %datetick är en funktion
som gör om datumvärdena till den formen man vill
  axis tight;    %betyder att man drar samman x- och y-axlarna till till
där värdena slutar
  xlabel('Date (days)');   %ger namn till x-axeln
  ylabel('Flow rate (m^3/s)');  %ger namn till y-axeln
```

```
  title([H,' ',text1,' ',text2]);   %titlen på grafen


 %  nedan är en while-sats som definierar att man måste trycka på en
tangent för att byta figur och det går inte att trycka på musen
  c=0;
  while c==0;
      h=waitforbuttonpress;
      if h==1;
          c=1;
      end

  end


end
```

4. Creating the river discharge figures for month values

```
%made by Karin Persson and Angelica Lidén, 2011-11-27
number = (1:1:242);  %gör en nummervektor som säger att man ska börja på
den första siffran och sen ska man ta ett steg emellan och sen gå tills
sista siffran

for k = 169:1:169                             %for-sats innebär att matlab
kör detta nedan tills slutet är nöjd
  myfilename = sprintf('st%d.xlsx', number(1,k));    %sprintf är en
funktion som gör att man byter fil vid varje genomgång av for-satsen
  B = xlsread(myfilename,'G:G');                     %xlsread är en funktion
som gör att matlab kan läsa excel-filer, G:G betyder att man tar hela raden
  [C,text1] = xlsread(myfilename,'C2:C2');    %text1 betyder att den ska
läsa de här värdena som en textrad och inte ett numeriskt värde (det är
okej för text att innehålla mellanrum)
  [A,text2] = xlsread(myfilename,'D2:D2');
  [D,text3] = xlsread(myfilename,'H2:H2');
  [E,text4] = xlsread(myfilename,'I2:I2');
  F = xlsread(myfilename,'E2:E4');
  G = xlsread(myfilename,'F2:F4');
  H = xlsread(myfilename,'A2:A2');

  Years = (length(B)/(365*3+366))*4;            % - antal år borttagna,
närsom i tiden
  Month = round(Years*12+0.5);
  ValuesPerMonth = round(length(B)/Month);

  monthflow=zeros(Month,1);
  index=1;                              %+365.25*antal år borttagna, om i
början av perioden
  for j=1:1:Month
    monthflow(j,1)=nanmean(B(round(index):round(index+28.9375)));
    index=index+ 29.9375;
  end
```

```
  startDate = datenum(F');    %datenum ger startdatumet ett värde som kan
läsas med matlab och ' betyder att man konverterar startvärdet till läsbart
för matlab
  endDate = datenum(G');
  xData = linspace(startDate,endDate,Month);    %för att skapa en längd på
datumen på x-axeln med ett linjärt förhållande används linspace
  figure
  plot(xData,monthflow,'-')   %plot är funktion som gör plotten av xData
och flödet=B
  datetick(gca,'x','mmmyyyy');   %datetick är en funktion som gör om
datumvärdena till den formen man vill
  axis tight;    %betyder att man drar samman x- och y-axlarna till till
där värdena slutar
  xlabel('Date (months)');   %ger namn till x-axeln
  ylabel('Flow rate (m^3/s)');  %ger namn till y-axeln
  title([H,' ',text1,' ',text2]);   %titlen på grafen

 %  nedan är en while-sats som definierar att man måste trycka på en
tangent för att byta figur och det går inte att trycka på musen
  c=0;
  while c==0;
      h=waitforbuttonpress;
      if h==1;
          c=1;
      end

  end


 end
```

Appendix 2. Station selection with motivation

Number	Keep	Reject	Motivation
1		X	Not needed due to that station nr 2 is missing less data and lies in the same area.
2		X	Use this due to that it is missing less data then nr 1 and lies in the same area. This is compared to new station 209, which is a 50000 station and therefore 209 is used instead of 2
3	X		Keep, as it is situated a long way enough from the rest
4	X		This is situated more convenient towards the other stations on the map, when comparing to nr 5, and has more years of data then nr 183. Therefore nr 4 is chosen.
5		X	As described in nr 4, this is not chosen above nr 4 and nr 183
6		X	Very low flows and is closely situated to nr 7, less time of data then nr 7 also
7	X		Choose this one since even though it is slightly regulated, it has higher flows and a lot more time of data then nr 6
8	X		Keep, as it is situated a long way enough from the rest
9		X	Not needed as there are many other stations in the same area
10		X	Compared to nr 222 which has more data and is a 50000 station
11		X	Compared to nr 213 which has more data and is a 50000 station
12	X		Keep, as it is situated a long way enough from the rest
13		X	If needed this is useable, but as it is close to other stations and has some strange patterns, it is for now rejected
14	X		Keep, as it is situated a long way enough from the rest
15		X	Compared to nr 238 which has more data and is a 50000 station
16		X	Compared to nr 228 which has more data and is a 50000 station
17		X	Lower flows then nr16
18		X	Same place as 239, therefore not chosen
19		X	Compared to nr 239 which has more data and is a 50000 station
20		X	Not so good, possible to get another one here
21		X	Not so good, possible to get another one here
22		X	Compared to nr 236 which has more data and is a 50000 station
23		X	Compared to nr 236 which has more data and is a 50000 station
24		X	Compared to nr 223 which has more data and is a 50000 station
25	X		Keep, as it is situated a long way enough from the rest
26		X	Do not use this as it miss a lot of data and is very regulated.
27		X	Is the same as nr 13, refer to note on nr 13
28		X	Do not use this as it is very regulated and have strange patterns
29	X		Keep, as it is situated a long way enough from the rest
30	X		Keep, as it is situated a long way enough from the rest
31	X		Keep, though it has around the same time of data as nr 32 but nr 32 has some years of missing data
32		X	Reject due to that it is missing quite a lot of data and when comparing with nr 31, which is close by, nr 31 feels better as it does not lack any years of data (Can be of use if something happens)
33	X		Keep, as it is situated a long way enough from the rest
34		X	Very regulated and in the late 70´s something happens, which makes

			the flow more non-natural (dam?) but as this is compared with nr 35, which is close by, same thing seem to happen for nr 35 but not so severe changes
35		X	Comparing with nr 34, which is close by, nr 35 is chosen as it seems to be less affected by the regulation but then comparing to nr 235, which is a 50000 and has longer time period, this is chosen
36		X	Extremely regulated, not usable
37		X	Extremely regulated, not usable
38	X		Keep, as it is situated a long way enough from the rest
39		X	Extremely regulated, not usable
40		X	Extremely regulated, not usable
41	X		Keep, as it is situated a long way enough from the rest
42		X	Compared with 43 and 44, though all of them seem regulated, but maybe nr 43 is the one which has the best "chances" anyway, and also it has longest time period of data
43		X	Look at nr 42 plus compared to 216, which is a 50000 and used
44		X	Look at nr 42
45	X		Keep, as it is situated a long way enough from the rest
46	X		Keep, as it is situated a long way enough from the rest
47		X	Keep, as it is situated a long way enough from the rest
48		X	Keep, as it is situated a long way enough from the rest
49		X	Quite regulated when compared to nr 50 and missing some data
50		X	This is chosen instead of nr 49 as they are very closely situated and this has more years of data and seems less regulated, 50 is though not chosen against 211 which is a 50000 station
51		X	Not useful as it has almost no data
52		X	It is better then nr 53, regulated towards the end period but not used over 191 as that is a 50000 station
53		X	Very regulated, not useful and besides very closely situated to nr 52
54	X		This is chosen over nr 55, due to that it has a longer amount data time
55		X	This is rejected over nr 54, due to less time
56		X	Almost no data
57	X		Chosen over nr 58 due to that they are so closely situated
58		X	Not chosen as it is so close to nr 57
59	X		Has more data time then nr 60
60		X	Has less data time then nr 59
61	X		Keep, as it is situated a long way enough from the rest
62	X		Keep, as it is situated a long way enough from the rest
63	X		Keep, as it is situated a long way enough from the rest
64	X		Keep, as it is situated a long way enough from the rest
65	X		Keep, as it is situated a long way enough from the rest
66		X	Not needed, even if it is good, but nr 68, which is very close, has a higher flow and also some more data
67		X	Not needed, even if it is good, but nr 68, which is very close, has a higher flow and also some more data
68	X		Chosen before nr 66 and nr 67, due to above statements and also chosen above 193 and 215, as it has longer time period and higher flows

69		X	Compared to nr 202 which is a 50000 station
70	X		Keep, as it is situated a long way enough from the rest
71		X	Extremely regulated, not usable
72	X		Keep, as it is situated a long way enough from the rest
73		X	Extremely regulated, not usable
74	X		Keep, as it is situated a long way enough from the rest
75	X		Keep, as it is situated a long way enough from the rest
76		X	Not chosen as it is very regulated, need to find another station in this area
77		X	Not chosen as it is very regulated, need to find another station in this area
78		X	To regulated and there are stations in the near
79		X	Compared to nr 229 which has more data and is a 50000 station
80		X	Very regulated under a long time
81		X	In the same place as nr 82 and low flow
82		X	Close to nr 81 and 83, plus low flow and less data available
83		X	Close to nr 82 and 81, plus low flow and less data available
84		X	Good data during long time but compared to 241 it has not enough data and nr 241 is a 50000 station
85		X	Good data during long time but compared to nr 225, it has less data time and 225 is a 50000 station
86		X	Heavily regulated, not used
87		X	Clearly regulated and more later years, so not used, neither nr 80 is used that lies very closely to this
88	X		Good and only small regulations
89	X		Good, with not much regulations, maybe not necessary when having nr 88
90		X	Heavily regulated, not used
91		X	Heavily regulated after 1950 and lies on almost exact the same place as nr 92
92		X	Heavily regulated after 1950 and lies on almost exact the same place as nr 92
93	X		Is regulated more after year 2000 but good otherwise, compared with nr 94
94		X	Way to regulated and close to nr 93
95		X	Do not need to use this as there are others in the area
96		X	Do not need to use this as there are others in the area
97		X	Regulated after around 40 years non regulated, not good enough
98		X	Heavily regulated, not used
99		X	Early data is good, but more regulated after some time, not used
100		X	Close to nr 99 and does not have a lot of data
101		X	Already decided not to use this
102		X	Missing years of data and is regulated
103		X	Already decided not to use this
104	X		Good data and compared to nr 102 and nr 105, it is not regulated
105		X	Is not needed as it is close to nr 104, and heavily regulated
106		X	Good geographically but maybe not so good data
107		X	Do not need to use this as there are others in the area

108	X		Keep, as it is situated a long way enough from the rest
109		X	Do not need to use this as there are others in the area
110		X	Compared to nr 237 which has more data and is a 50000 station
111	X		Heavily regulated last 50 years but otherwise good
112		X	Very bad, not useful
113	X		Keep, as it is situated a long way enough from the rest
114		X	Heavily regulated, not useful
115		X	Good data but in the same area as nr 117 and 118
116		X	Short period of data, but is not needed as it close to other stations
117		X	Good data but in the same area as nr 115 and 118
118	X		Good data but in the same area as nr 115 and 117
119		X	Short period of data, but is not needed as it close to other stations (nr 120 and nr 121)
120		X	Heavily regulated, but close to nr 121, so not needed
121	X		Long time period and no visual regulation
122		X	Regulated but not needed as it is close to nr 123 and nr 131
123		X	Regulated but not needed as it is close to nr 122 and nr 131
124	X		Keep, as it is situated a long way enough from the rest
125		X	Chosen instead of nr 126 as it has higher flows and is closely situated to nr 126, but comparing to 224 it has less data time and 224 is a 50000
126		X	Not chosen instead of nr 125 and 224, as it has lower flows
127	X		Keep, as it is situated a long way enough from the rest
128	X		Missing data in the early 00´s but otherwise good
129		X	Shorter time then nr 128 and also missing data in the middle
130		X	Keep, as it is situated a long way enough from the rest
131	X		Good and long time and not clear regulation
132		X	Short time and missing data, not needed as there are others in the area
133		X	Not needed as there are others in the area
134		X	Already decided not to use this
135		X	Lower flows then nr 136 and under a shorter time
136	X		Good and under long time
137		X	Heavily regulated and is close to nr 136, therefore not usable
138		X	Keep, as it is situated a long way enough from the rest
139		X	Reject as it is not any good data, find another in the area?
140	X		Keep, as it is situated a long way enough from the rest
141	X		Keep, as it is situated a long way enough from the rest
142		X	Heavily regulated and miss a lot of data
143		X	Missing data under long periods, nr 144 is close and better
144	X		Continuous measurements and looks better then nr 143
145	X		Good but missing some data by the 00´s
146		X	Missing a long time of data and is situated close to nr 145 and nr 147, therefore not needed
147		X	Good, but compared to 145 it is not good enough, has to few data
148		X	Compared to nr 227 which has more data and is a 50000 station
149		X	Not as long time period as nr 150, therefore not used
150		X	It has more years of data then the closely lying nr 149, but it is not as natural and not a 50000 station as nr 207
151		X	Not used as nr 206 already contains this data

152		X	Compared to nr 206 which has more data and is a 50000 station
153	X		Keep, as it is situated a long way enough from the rest
154	X		Keep, as it is situated a long way enough from the rest
155	X		Keep, as it is situated a long way enough from the rest
156		X	Pretty regulated, not so good to use
157		X	This has less data then nr 188
158		X	Pretty regulated, not so good to use
159	X		Good data and good position
160		X	A part of station number 188
161	X		Good data and good position
162	X		Good data and good position
163		X	Pretty regulated, not so good to use
164		X	Pretty regulated, not so good to use
165	X		Good data and good position
166	X		Good data and good position
167		X	Pretty regulated, not so good to use
168	X		Good data and good position
169	X		Good data and good position
170	X		Good data and good position
171		X	18 is better with less regulation and more time
172		X	19 is better with less regulation and more time
173	X		Good data and good position
174	X		Good data and good position
175	X		Good data and good position
176	X		Good data and good position
177	X		Good data and good position
178	X		Good data and good position
179		X	Pretty regulated, not so good to use
180	X		Good data and good position
181	X		Good data and good position
182		X	Pretty regulated, not so good to use
183		X	Nr 4 has much longer time period
184		X	Nr 223 is a 50000 station
185		X	Extremely regulated
186	X		Good data and good position
187	X		Good data and good position
188	X		Chosen above 157 as 157 miss some years of data
189		X	Nr 236 has more time period
190	X		Good data and good position
191	X		Keep this over 52 as it is a 50000 station
192		X	Keep this over 169, as it is less regulated and has higher flows but as it is the same station as nr 57, do not use it
193		X	Nr 68 has higher flows and longer time period
194		X	Nr 57 has higher flows, is less regulated and has longer time period
195		X	Compared with 225 which is a 50000 and has more time
196	X		Good data and good position
197	X		Good data and good position

198	X		Good data and good position
199		X	Nr 228 has longer time and is a 50000 station
200		X	Nr 216 is a 50000 station
201	X		Good data and good position
202	X		Compared to 69 this is chosen as it is a 50000 station
203		X	Nr 7 has longer time and higher flows
204		X	Nr 59 has longer time period
205		X	Nr 206 has longer time and is a 50000 station
206	X		See 205
207	X		Compared to 150 and 206 this is chosen as it is a 50000 station and is more natural
208	X		Good data and good position
209	X		Compared to 2 this is chosen as it is a 50000 station
210		X	Nr 145 has longer time and is less regulated
211	X		This has more data then nr 50
212		X	Nr 224 has longer time and is a 50000 station
213	X		This station has longer time and is a 50000 station
214	X		This station is a 50000 station and therefore “better” then 117
215		X	See nr 68
216	X		Good data and good position
217	X		Good data and good position
218	X		Good data and good position
219		X	Nr 241 has more time, is a 50000 and less regulated
220	X		Good data and good position
221	X		Good data and good position
222	X		This station has longer time and is a 50000 station, then 10
223	X		This station is a 50000 station and therefore “better” then 24 and 184
224	X		This station has longer time and is a 50000 station, then 212 and 125
225	X		Good data and good position
226		X	Nr 207 is more natural and a 50000 station
227	X		Good data and good position
228	X		Good data and good position
229	X		This station has longer time and is a 50000 station, then 79
230	X		This station has longer time and is a 50000 station, then 115
231	X		Good data and good position
232	X		Good data and good position
233	X		Good data and good position
234	X		This station has longer time and is a 50000 station, then 47
235	X		This station has longer time and is a 50000 station, then 35
236	X		This station has longer time and is a 50000 station, then 23
237	X		This station has longer time and is a 50000 station, then 110
238	X		This station has longer time and is a 50000 station, then 15
239	X		Good data and good position
240	X		Good data and good position
241	X		This station has longer time and is a 50000 station, then 219 and 84
242	X		Good data and good position

Appendix 3. Station selection with number and name

Number in Matlab	Station number and name	Water course number and name
3	1953 ÄNGABÄCKENS KRV	98 LAGAN
4	2191 TORSEBRO KRV	88 HELGE Å
7	186 MÖRRUM	86 MÖRRUMSÅN
8	1069 MÖCKELN	88 HELGE Å
12	855 GETEBRO	75 ALSTERÅN
14	200 RÖRVIK	98 LAGAN
25	1622 BRUSAFORS	74 EMÅN
29	1623 VRÅNGEBÄCKEN	108 GÖTA ÄLV
30	257 MUNKEDAL 2	110 ÖREKILSÄLVEN
31	1375 FLÖTEMARKEN	112 ENNINGDALSÄLV
33	1639 TÖRNESTORP	108 GÖTA ÄLV
38	1243 HALVORSBYN	108 GÖTA ÄLV
41	2420 BRATTFORSENS KRV	108 GÖTA ÄLV
45	138 ÖVRE HYNDEVAD	61 NORRSTRÖM
46	1742 STABBY	61 NORRSTRÖM
54	1643 LÅNGHAG	53 DALÄLVEN
57	654 ERSBO	53 DALÄLVEN
59	1171 GRÖTSJÖN	53 DALÄLVEN
61	1567 SKATTUNGEN	53 DALÄLVEN
62	2407 SVÄRDSJÖ	53 DALÄLVEN
63	1940 TOLVFORS KRV	52 GAVLEÅN
64	2257 LJUSNE STRÖMMAR KRV	48 LJUSNAN
65	740 NYBRO	48 LJUSNAN
68	1169 LJUSNEDAL ÖVRE	48 LJUSNAN
70	1159 ROLFSTA	45 DELÅNGERSÅN
72	1874 BJÖRNHÅN	42 LJUNGAN
74	20036 ÖSTAVALLSELET	42 LJUNGAN
75	97 GIMDALSBY	42 LJUNGAN
88	1341 RENGEN	40 INDALSÄLVEN
89	1909 HOTAGSSTRÖMMEN	40 INDALSÄLVEN
93	1378 RÅÖN	38 ÅNGERMANÄLVEN
104	1537 ANKARVATTNET	38 ÅNGERMANÄLVEN
108	2369 MALGOMAJS KRV	38 ÅNGERMANÄLVEN
111	1734 STORNORRFORS KRV	28 UMEÄLVEN
113	1609 STRÖMFORS	20 SKELLEFTEÄLVEN
118	2275 SKIRKNÄS	28 UMEÄLVEN
121	436 SOLBERG	28 UMEÄLVEN
124	20061 STORAVAN	20 SKELLEFTEÄLVEN
127	1480 KÅTASELET	18 BYSKEÄLVEN
128	1788 SIKFORS KRV	13 PITEÄLVEN
131	37 STENUDDEN	13 PITEÄLVEN
136	591 NIAVVE	9 LULEÄLVEN
140	20019 VIETAS (SATISDELEN)	9 LULEÄLVEN
141	2298 RITSEM KRV	9 LULEÄLVEN
144	1123 YTTERHOLMEN	7 RÅNEÄLVEN

145	16722 KUKKOLANKOSKI ÖVRE	1 TORNEÄLVEN
153	1456 KAALASJÄRVI	4 KALIXÄLVEN
154	5 LANNAVAARA	1 TORNEÄLVEN
155	1780 MERTAJÄRVI	1 TORNEÄLVEN
159	1910 STORSILLRET	42 LJUNGAN
161	2251 BJURSTORP	65 NYKÖPINGSÅN
162	2231 ALMBRO	61 NORRSTRÖM
165	2299 TÄRNSJÖ	54 TÄMNARÅN
166	2248 HÄRNEVI	61 NORRSTRÖM
168	2310 KVARNTORP	108 GÖTA ÄLV
169	2309 GREA	108 GÖTA ÄLV
170	2203 MOCKFJÄRD KRV	53 DALÄLVEN
173	2213 EGGVENA	108 GÖTA ÄLV
174	2359 SVED	67 MOTALASTRÖMMEN
175	2330 NYTTORP	67 MOTALASTRÖMMEN
176	2332 GULLRINGSVATTNET	70 STORÅN
177	1879 SVEDALA	90 SEGE Å
178	2129 TÅNEMÖLLA	89/90 SKIVARPSÅN
180	2146 HALLAMÖLLA	88/89 VERKAÅN
181	2171 HÖGSMÖLLA	92 KÄVLINGEÅN
186	2128 HEÅKRA	96 RÖNNE Å
187	2256 NYMÖLLA	88 HELGE Å
188	50027 ANUNDSJÖN	36 MOÄLVEN
190	50013 BJÖRKLIDEN	1 TORNEÄLV
191	50103 EDEBÄCK	108 GÖTA ÄLV
196	50025 FÄLLFORS	27 TAVLEÅN
197	50024 GRANSELET	9 LULEÄLVEN
198	1574 GRÅTANBÄCKEN	38 ÅNGERMANÄLVEN
201	50115 HAMMARBY	61 NORRSTRÖM
202	50109 HASSELASJÖN	44 HARMÅNGERSÅN
206	50003 JUNOSUANDO TÄRENDÖGR.	4 KALIXÄLVEN
207	50148 KALLIO	1 TORNEÄLVEN
208	1403 KARATS	9 LULEÄLVEN
209	50093 KLIPPAN	96 RÖNNE Å
211	50108 KÅFALLA	61 NORRSTRÖM
213	50019 KÄLLSTORP	77 LJUNGBYÅN
214	50149 LAISAN	28 UMEÄLVEN
216	50083 LÅNGHALSEN	65 NYKÖPINGSÅN
217	10016 MAGNOR	108 GÖTA ÄLV
218	50150 MARUM	108 GÖTA ÄLV
220	10007 MUONIO	1TORNEÄLVEN/MUONIOÄLVEN
221	10012 MURUSJÖN	38ÅNGERMANÄLVEN/MURUÅN
222	50121 NÄTTRABY	NÄTTRABYÅN
223	50090 NÖMMEN	SOLGENÅN
224	50027 OSTTRÄSKET	STORBÄCKEN
225	50060 OTTSJÖN	STORBODSTRÖMMEN

227	50005 RÖDUP	KALIXÄLVEN
228	50097 SIMLÅNGEN	100 FYLLEÅN
229	50068 SOLBERGSVATTNET	AMMERÅN
230	50131 SORSELE	VINDELÄLVEN
231	50145 TORNETRÄSK	1 TORNEÄLVEN
232	50107 TORRBÖLE	ÖREÄLVEN
233	50142 TVÄRSJÖN	KULLAÅN
234	50110 VATTHOLMA	FYRISÅN
235	50084 VELEN	MOSSÅN
236	50098 VIKARESJÖN	NISSAN
237	50023 VINDELN	VINDELÄLVEN
238	50095 VÄRMESHULT	SKÅLÅN
239	50102 ÅS	VISKAN
240	1309 ÄCKLINGEN	40 INDALSÄLVEN/YCKLAN
241	50058 ÖSTER-NOREN	INDALSÄLVEN
242	50130 ÖVERSTJUKTAN	SJUKTA/JUKTÅN

Appendix 4. Seasons in Sweden

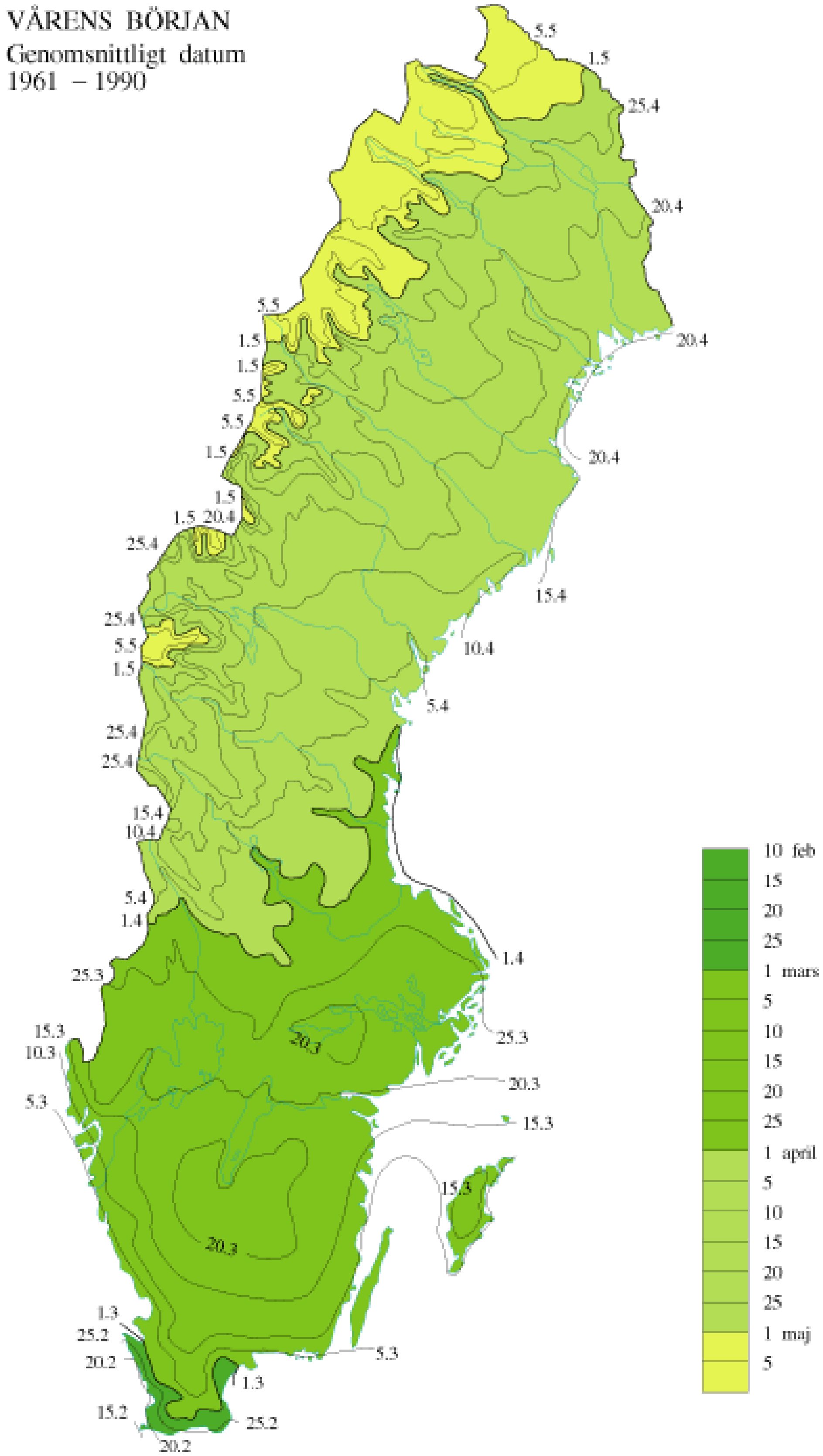


Figure A4-1 Arrival of spring in Sweden (SMHI, 2012)

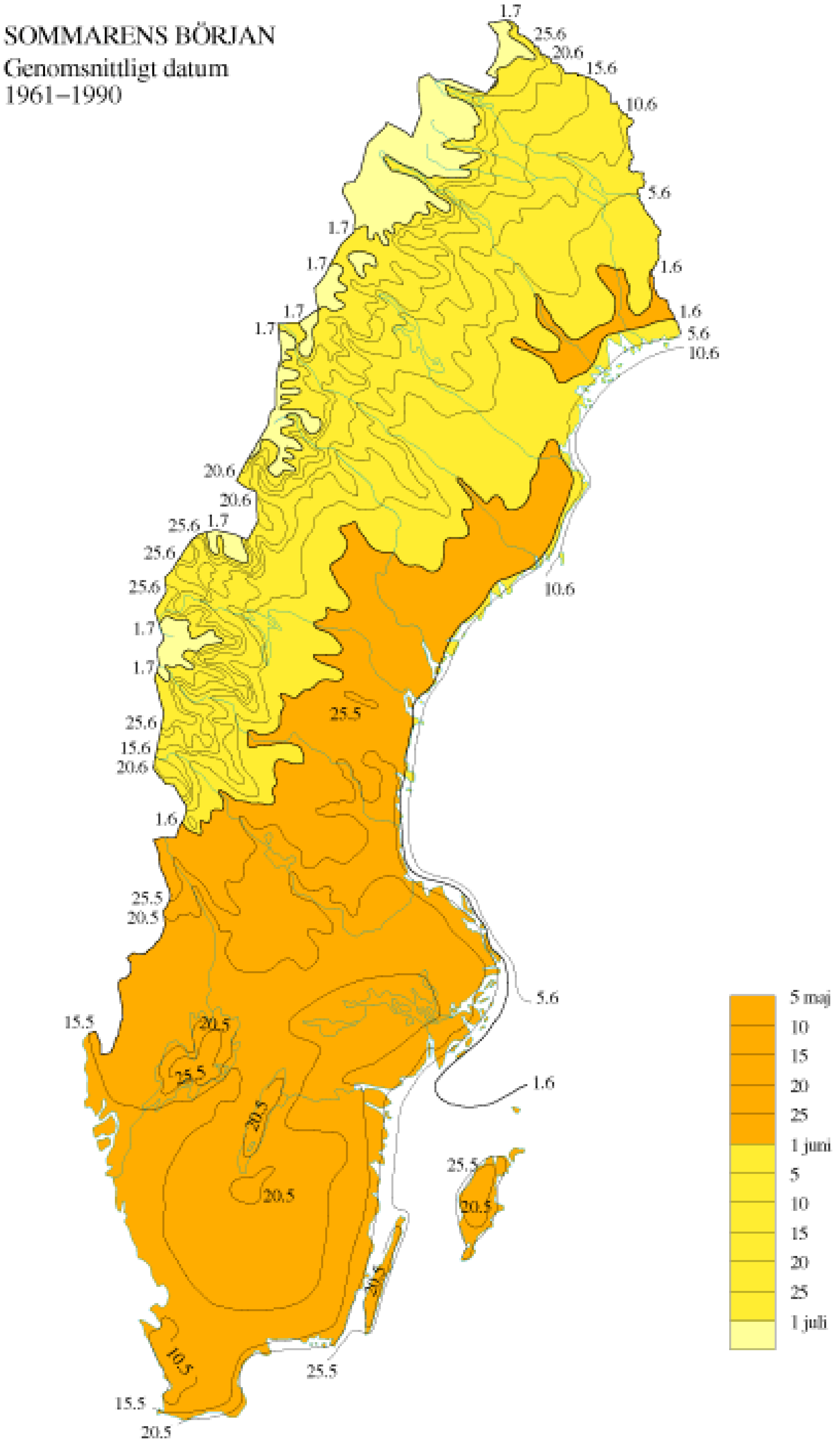


Figure A4-2 Arrival of summer in Sweden (SMHI, 2012)

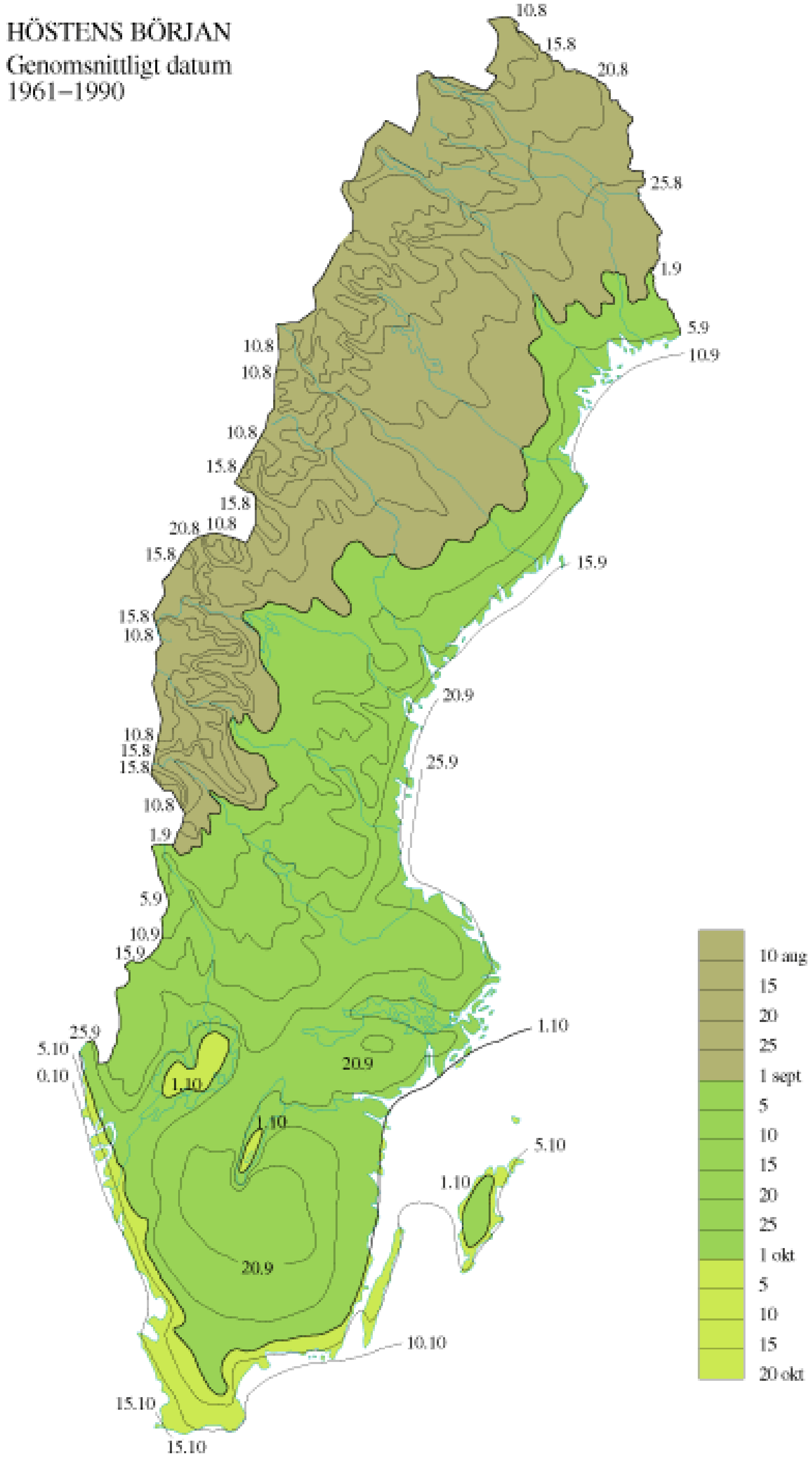


Figure A4-3 Arrival of autumn in Sweden (SMHI, 2012)

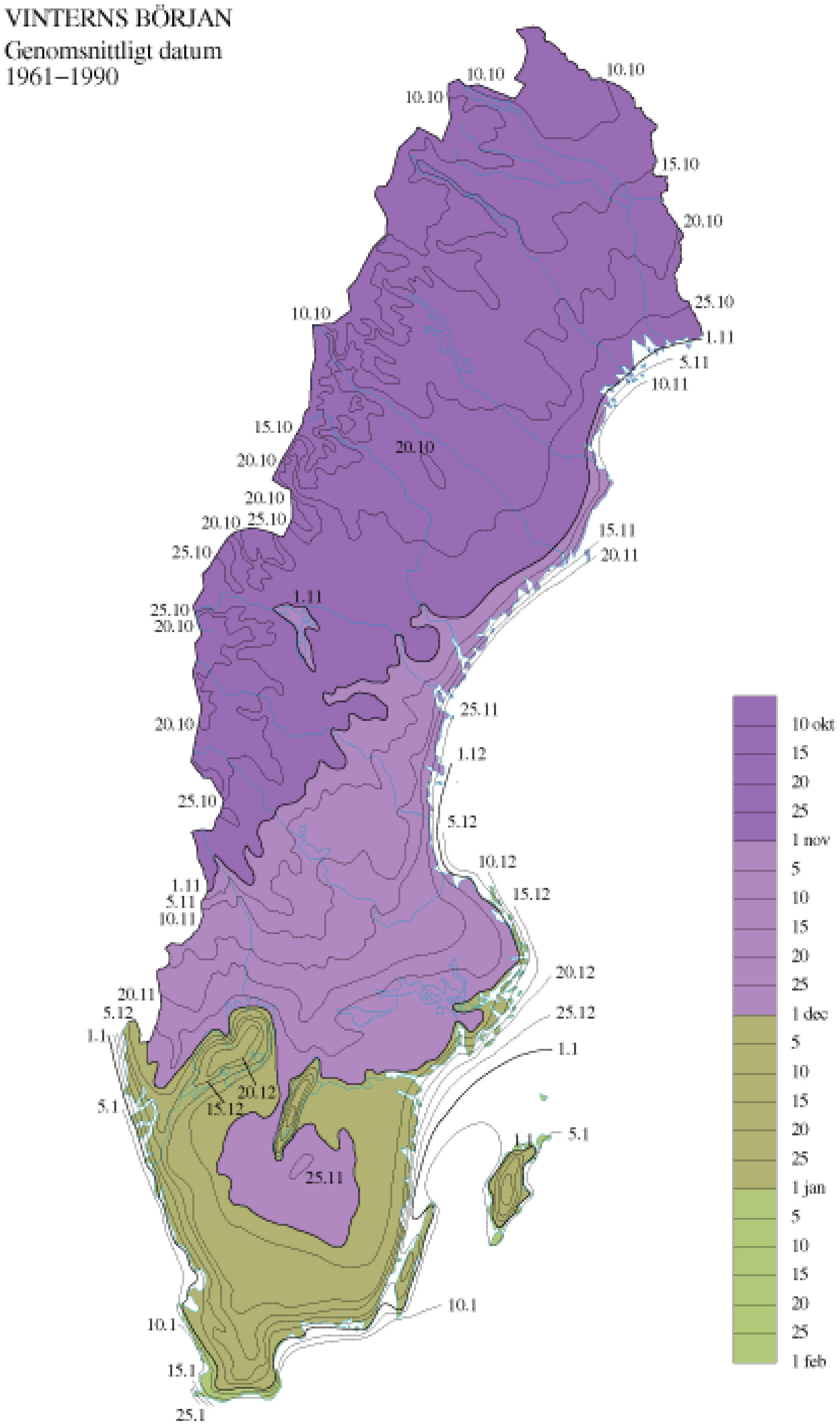
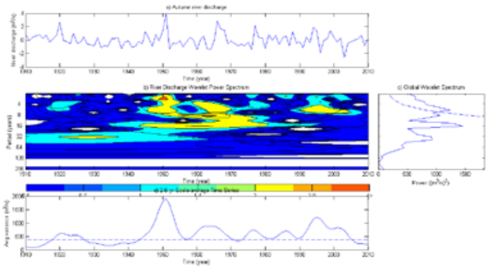


Figure A4-4 Arrival of winter in Sweden (SMHI, 2012)

Appendix 5. Group division

Group division – South – Spring – Yellow, green, turquiose, blue and violet group

3.



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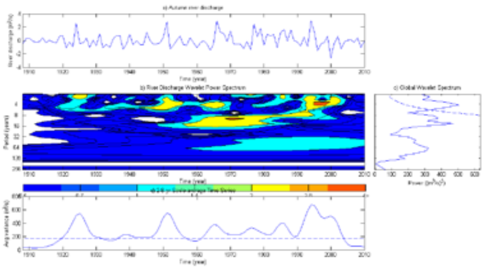

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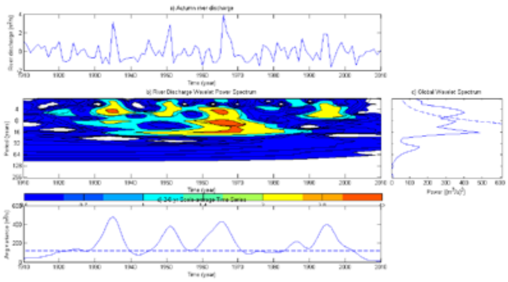

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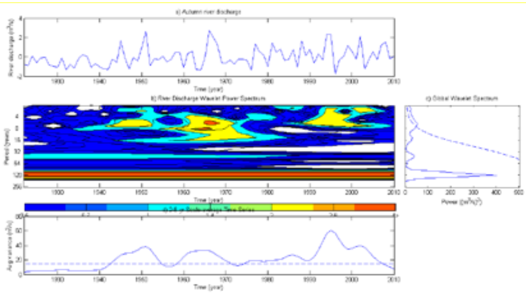

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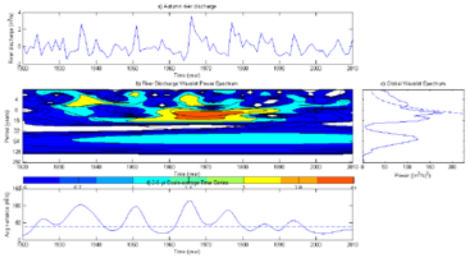

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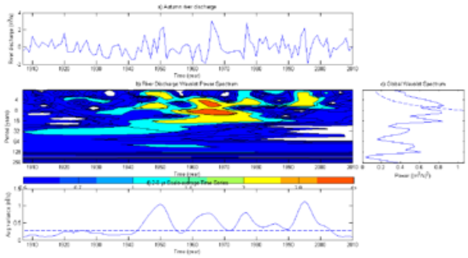

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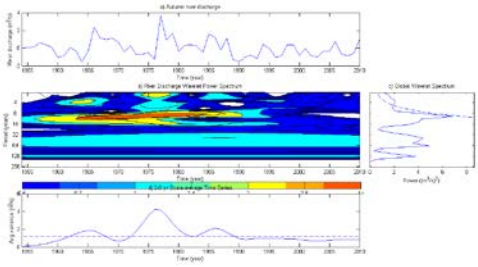

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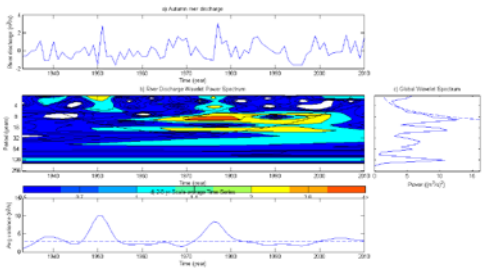

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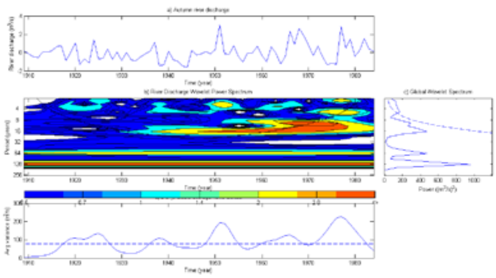

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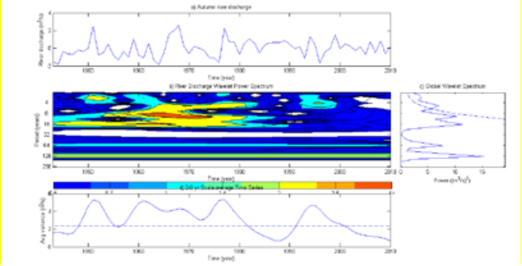

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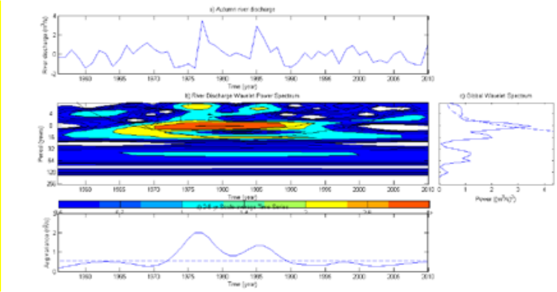

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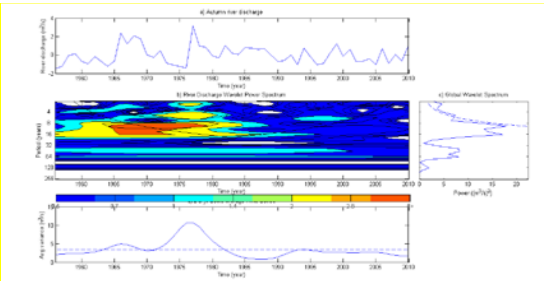

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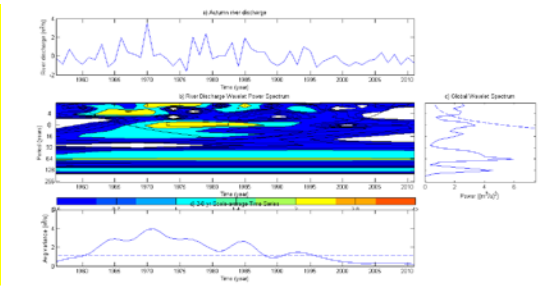

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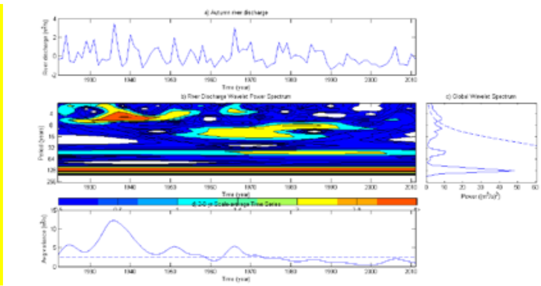
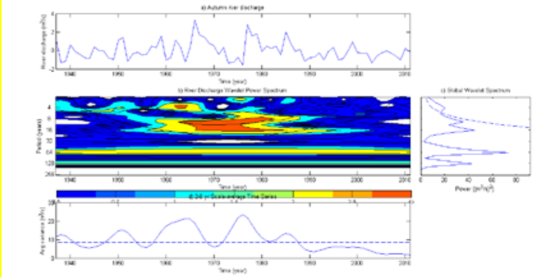


218.



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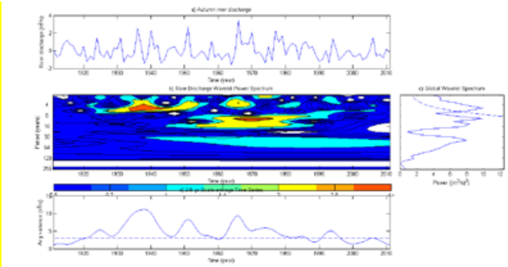

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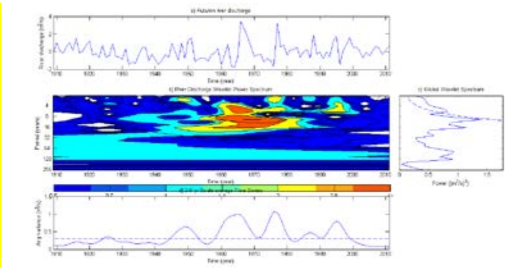

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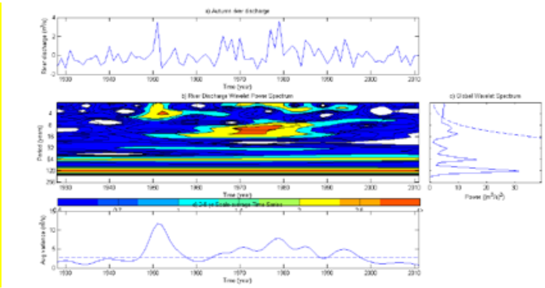

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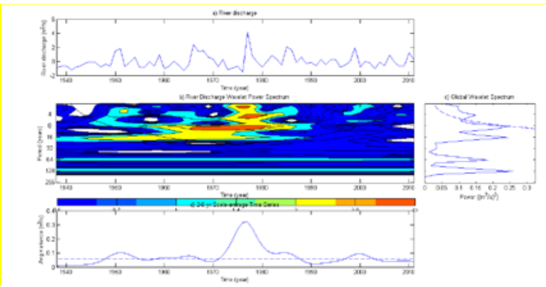

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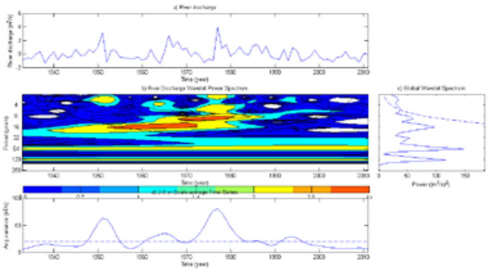

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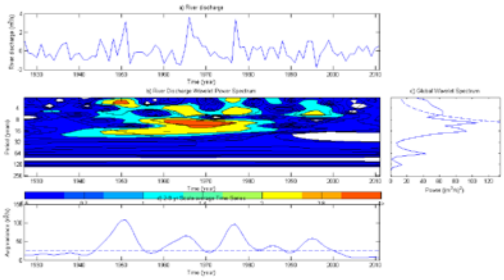

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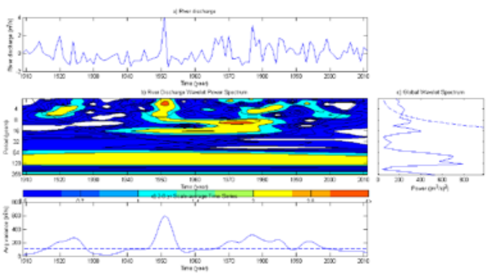

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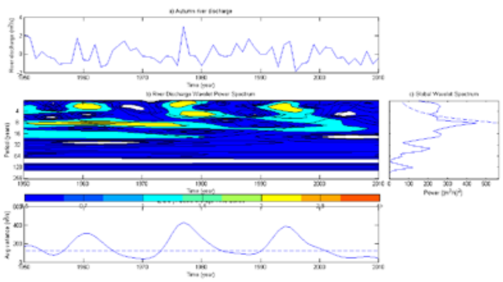

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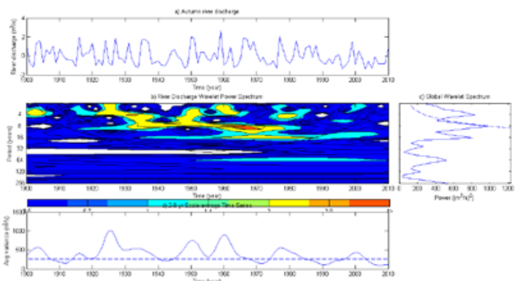

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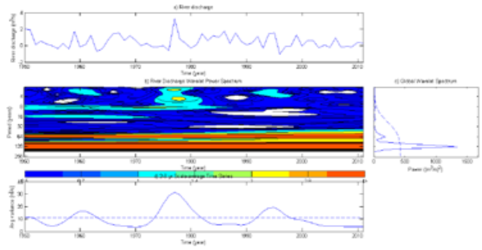

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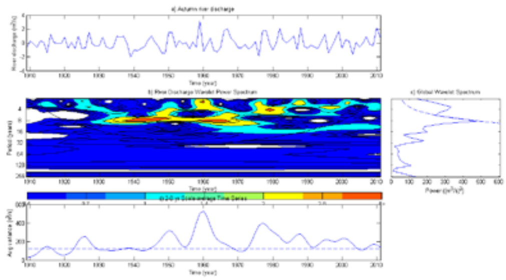

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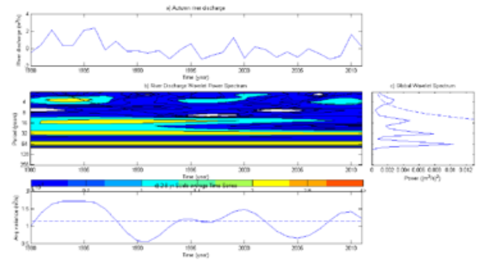

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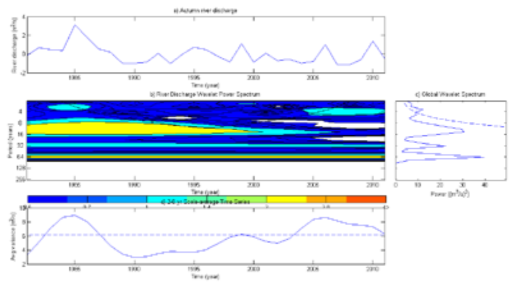

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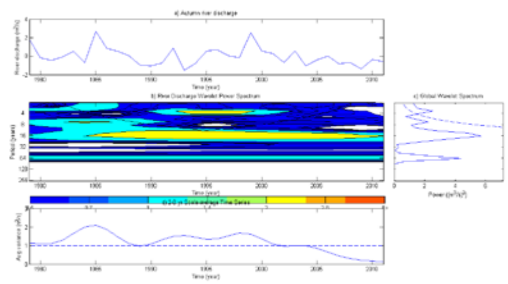

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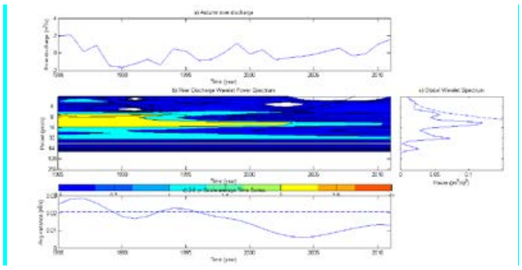

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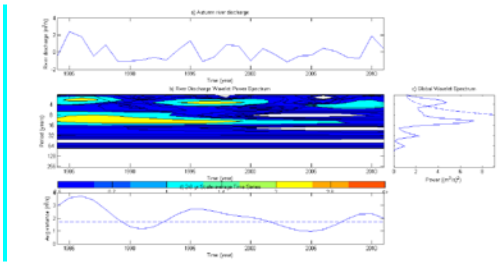

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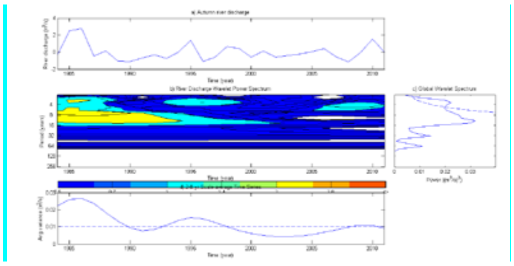

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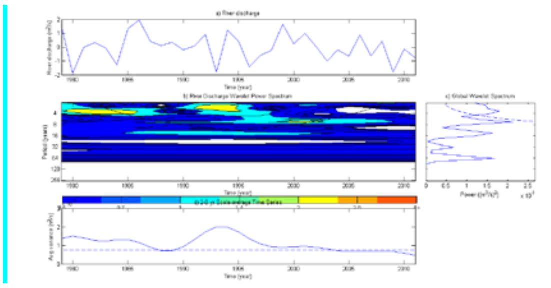

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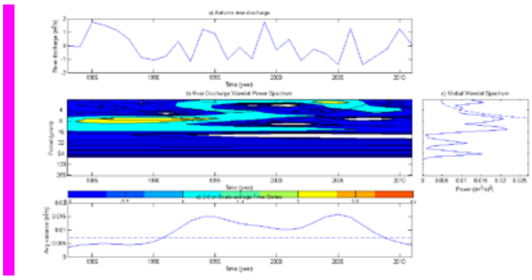

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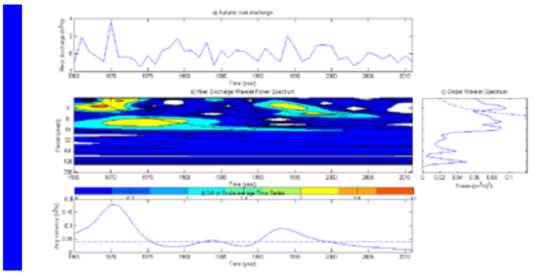

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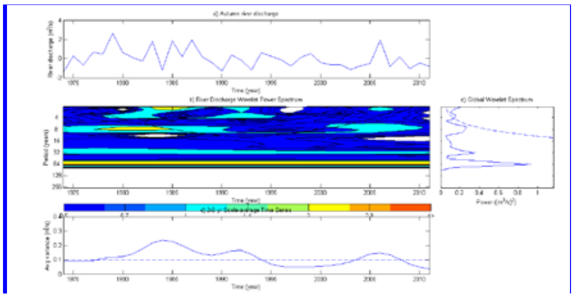

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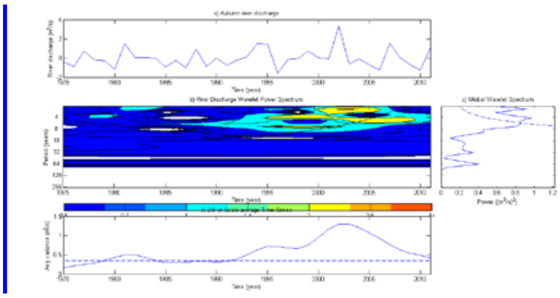

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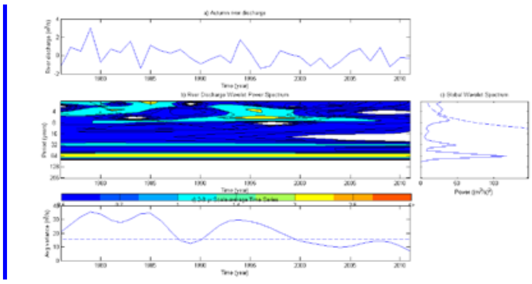

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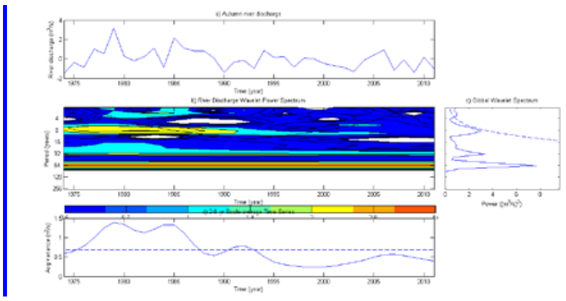

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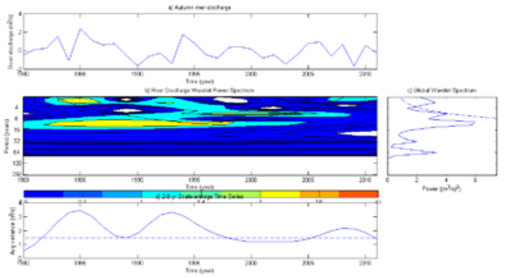
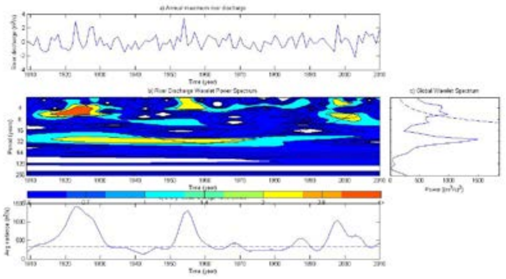


Group division – South – Autumn – Yellow, green, turquioise, blue and violet group

3.



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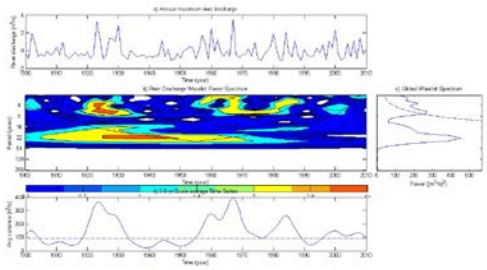

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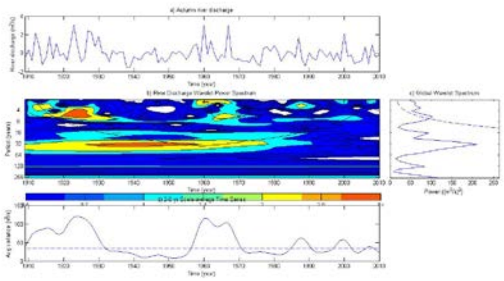

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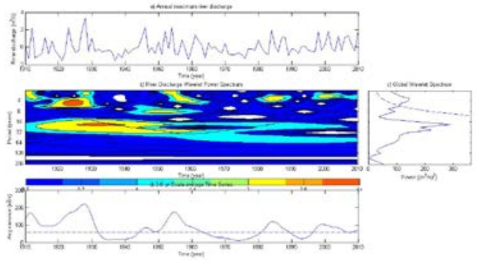

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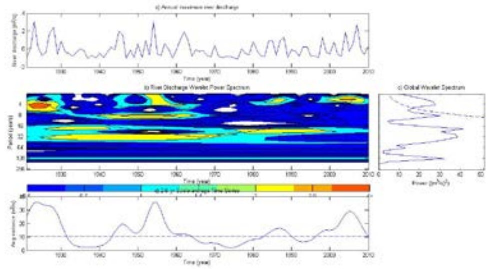

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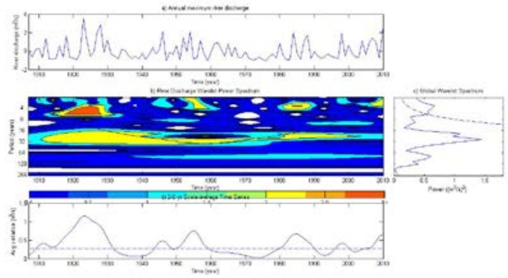

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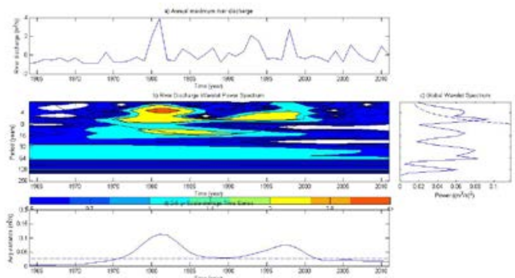

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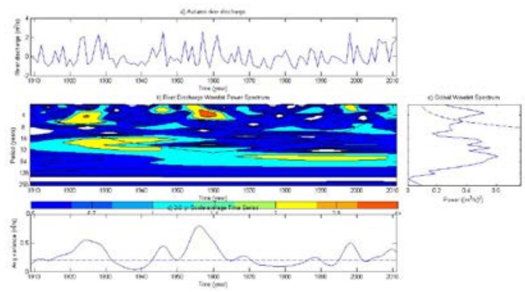

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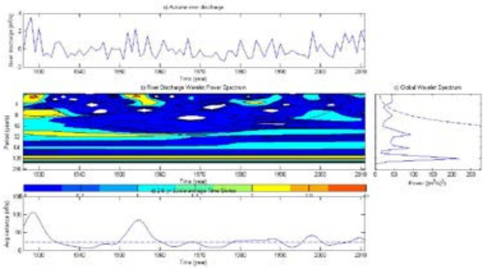

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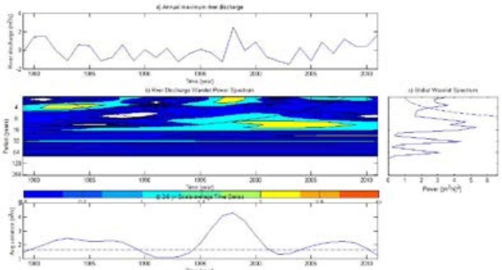

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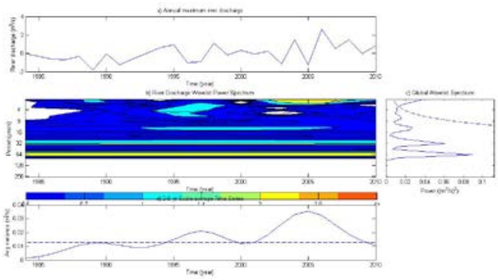

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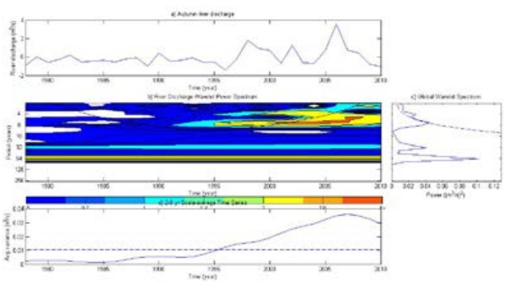

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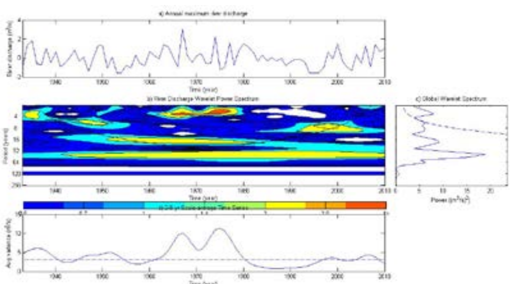

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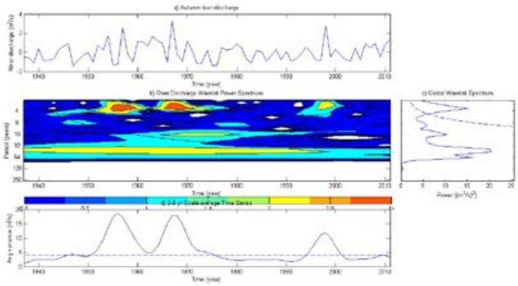

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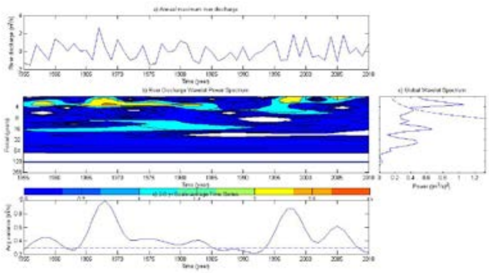

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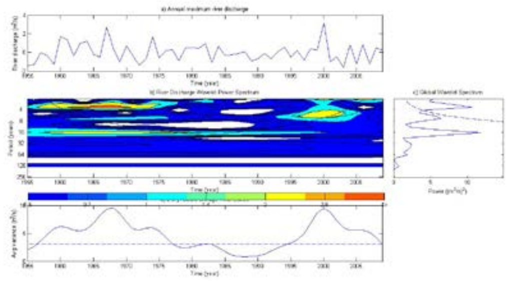

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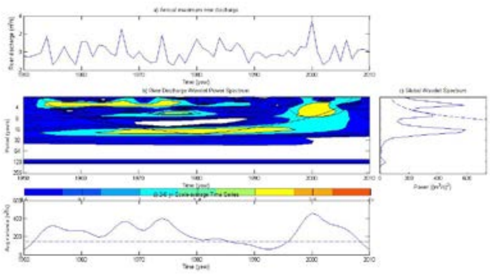

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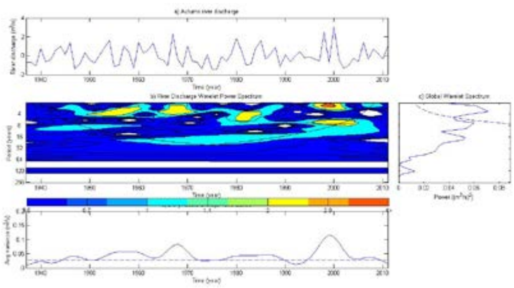

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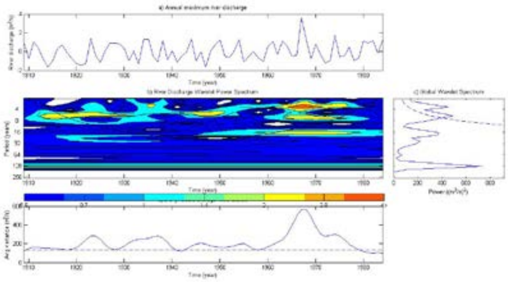

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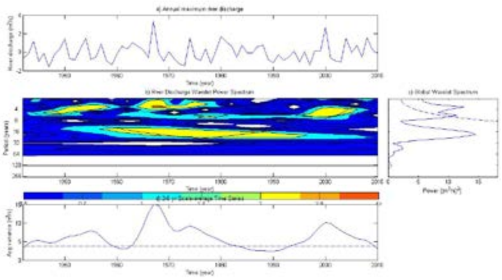

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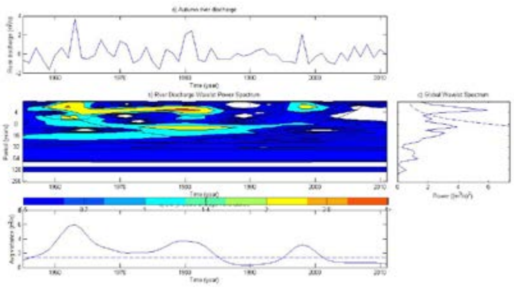

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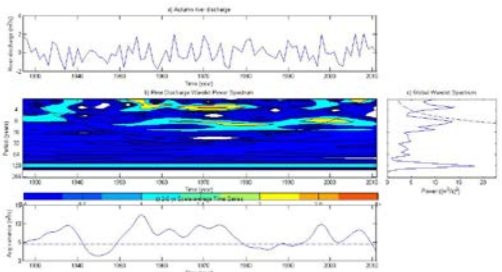

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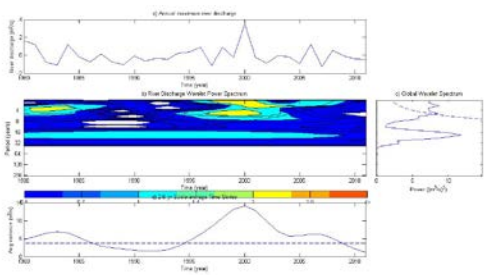

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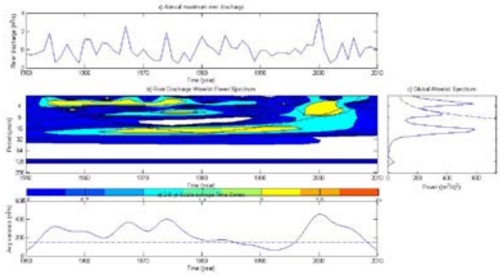

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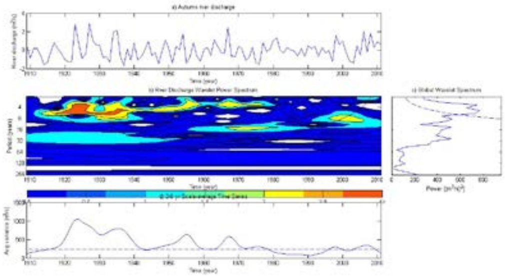

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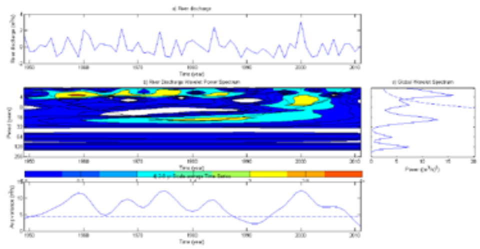

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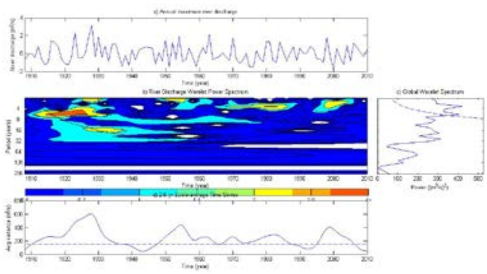

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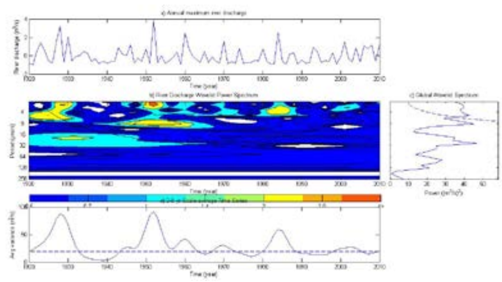

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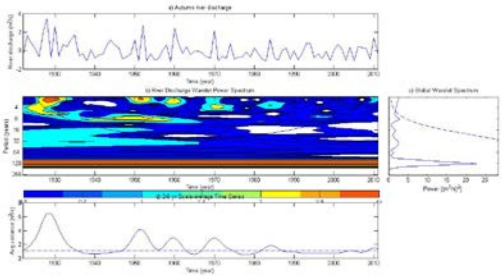

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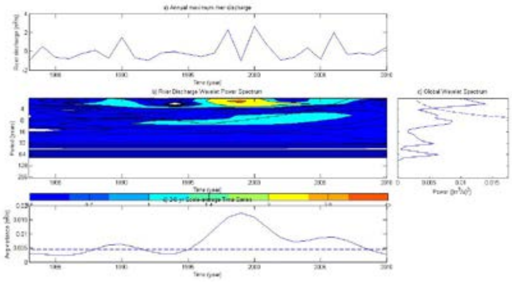

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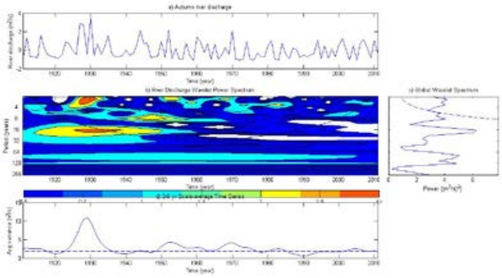

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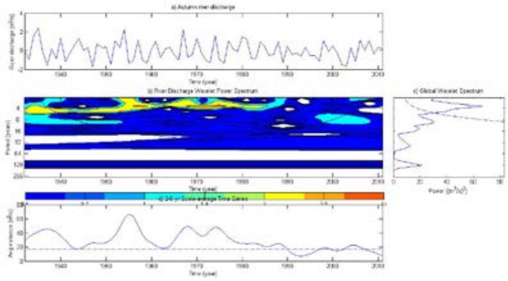

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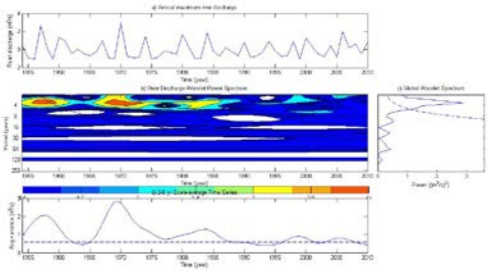

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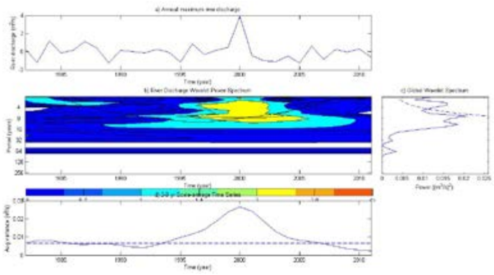

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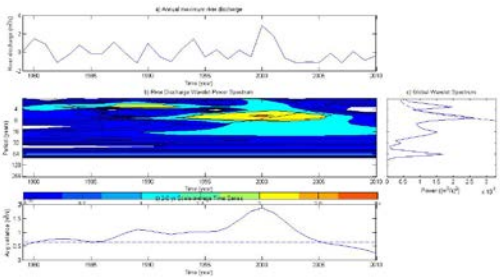

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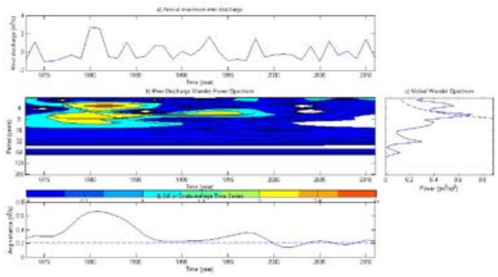

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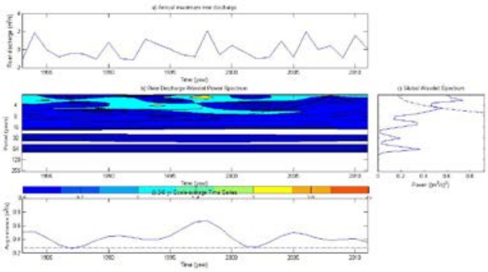

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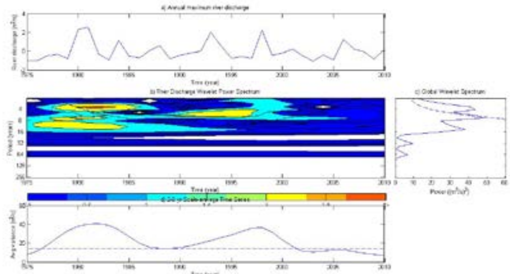

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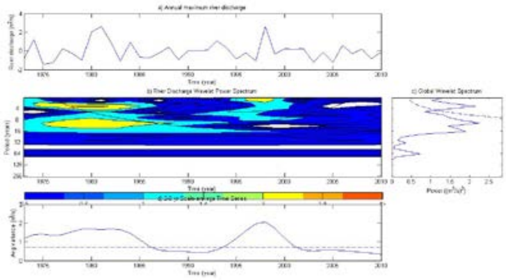

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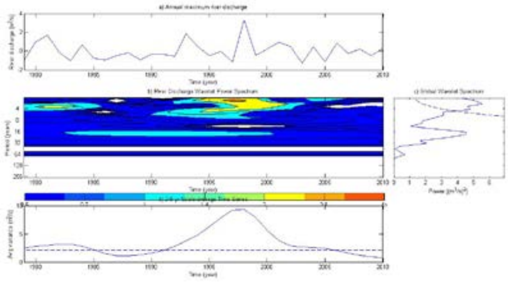

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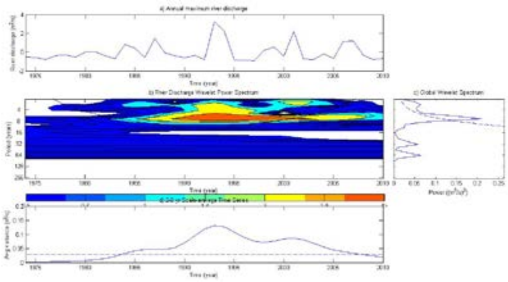
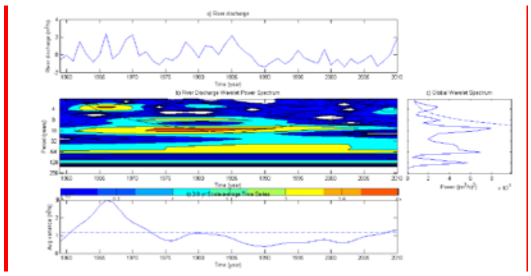


Group division – Middle – Spring - Red and blue group

46.



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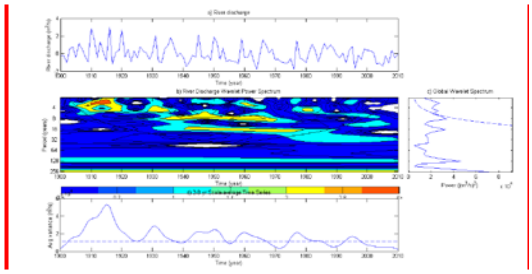

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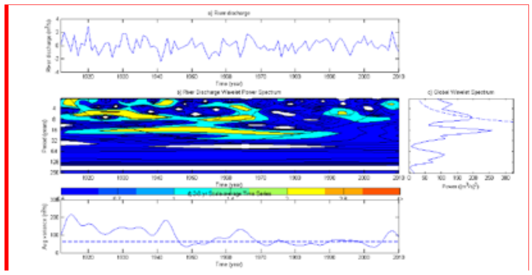

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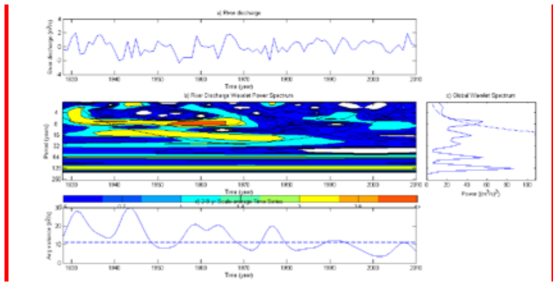

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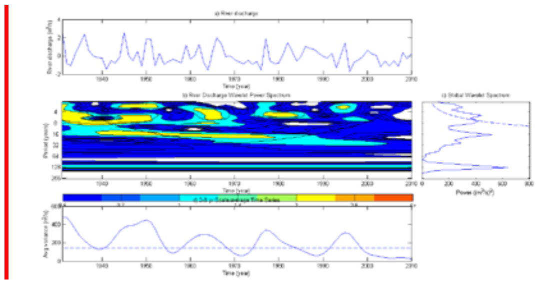

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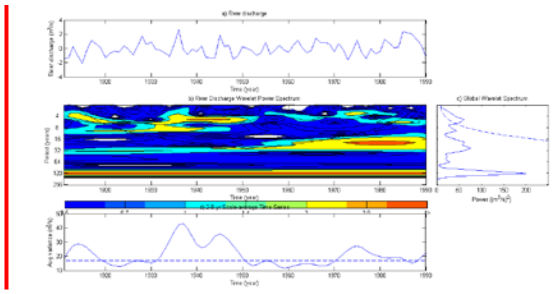

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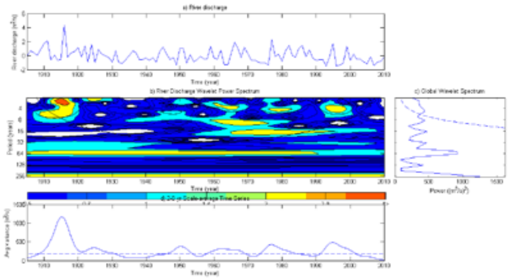
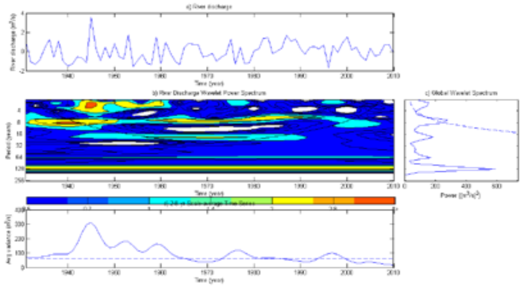


75.



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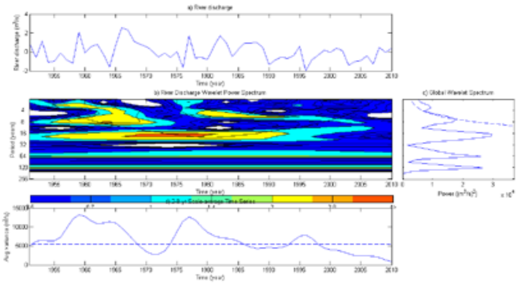
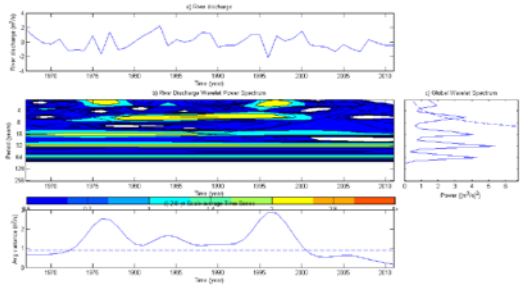


159.



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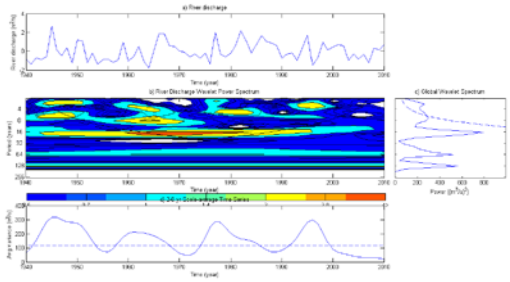

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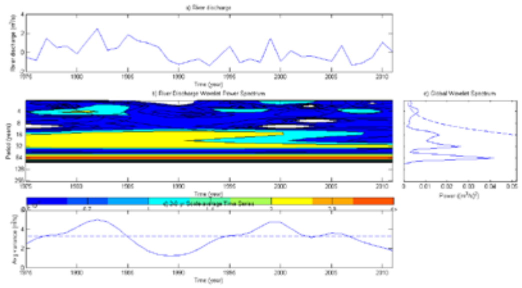

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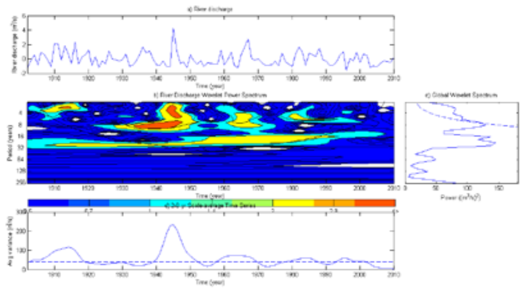

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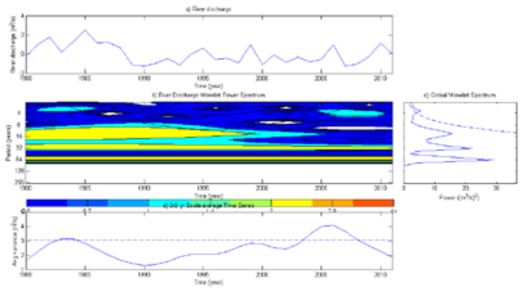

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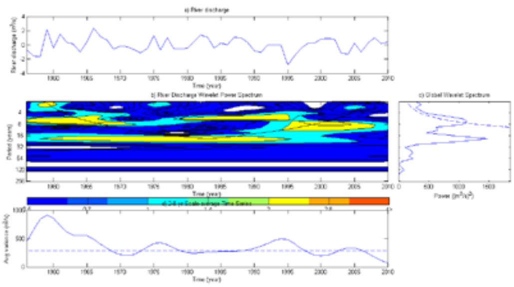

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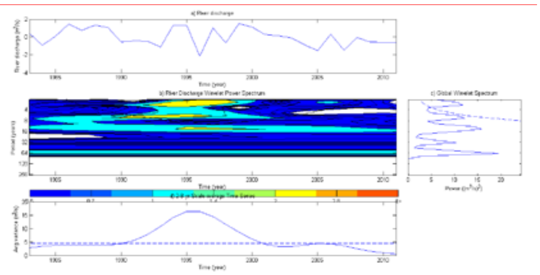

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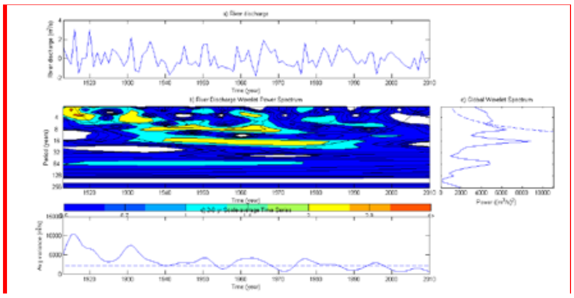

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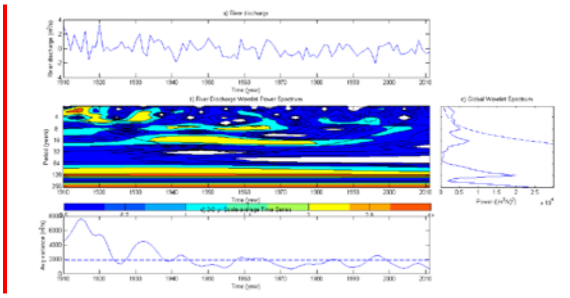

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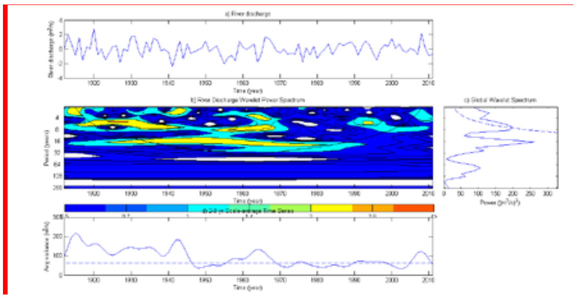

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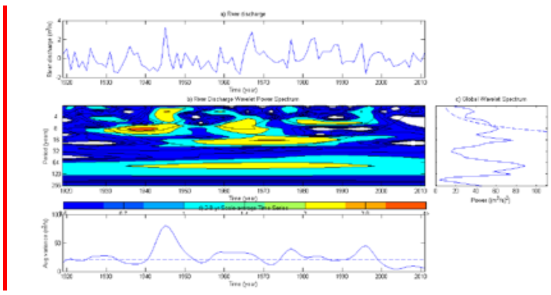

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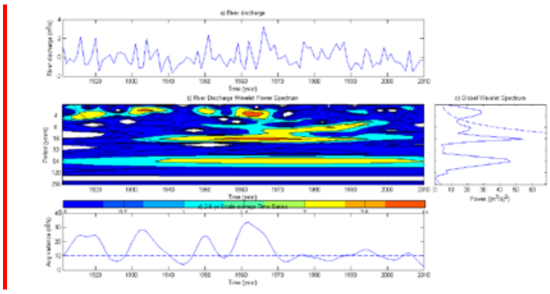

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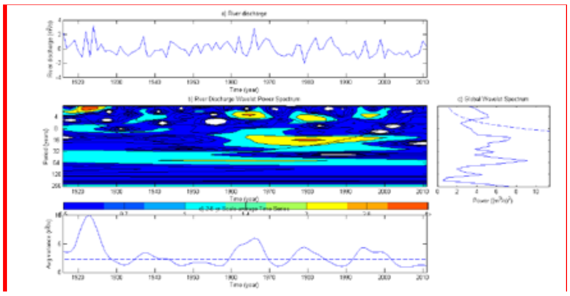

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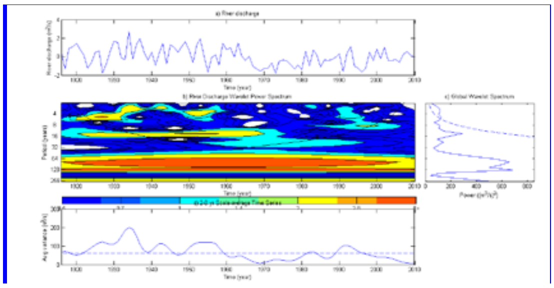

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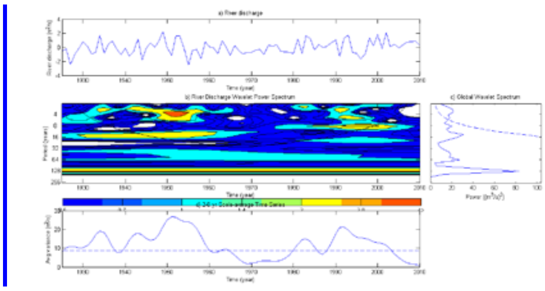
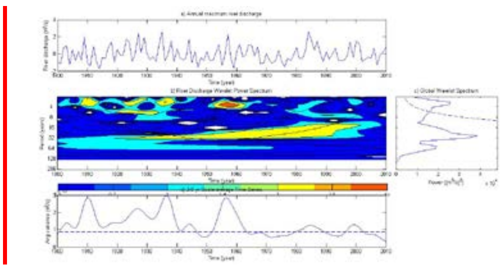


Group division – Middle – Autumn – Red and blue group

54.



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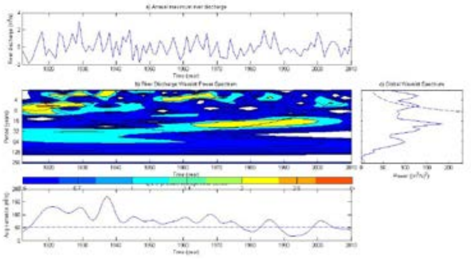

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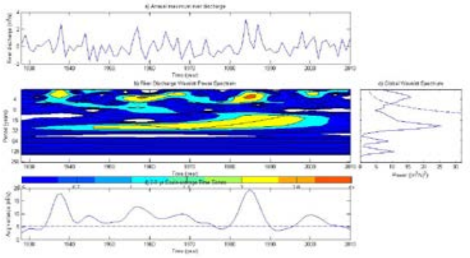

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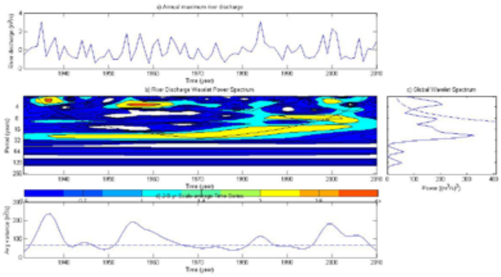
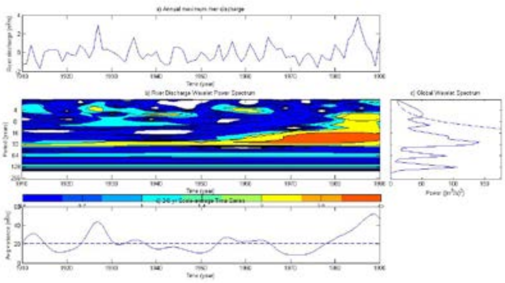


62.



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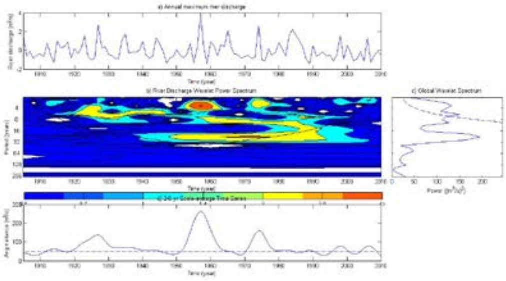

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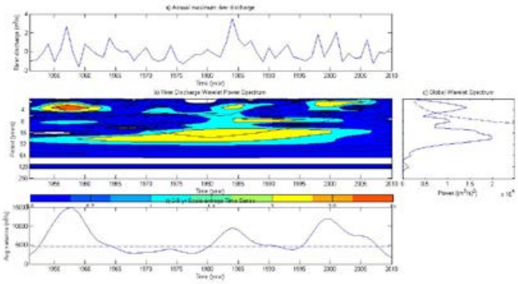

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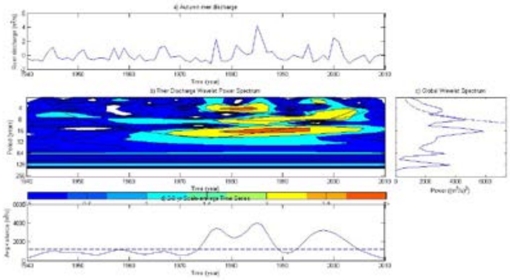

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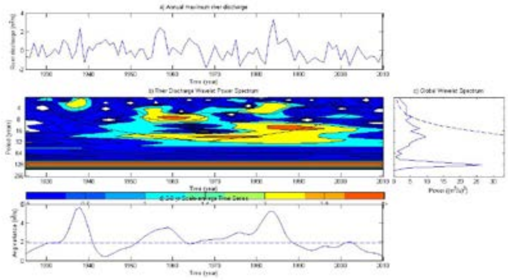

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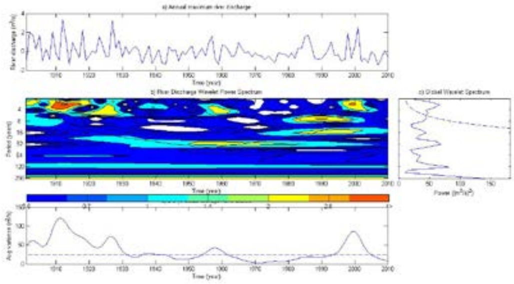

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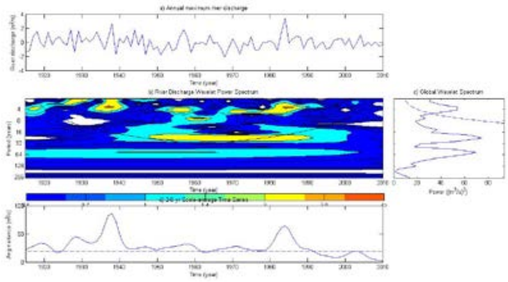

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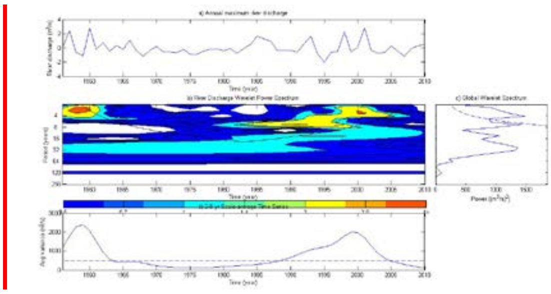

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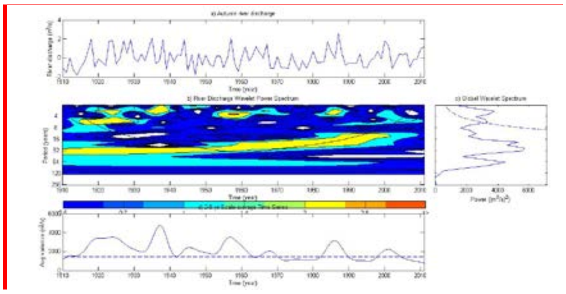

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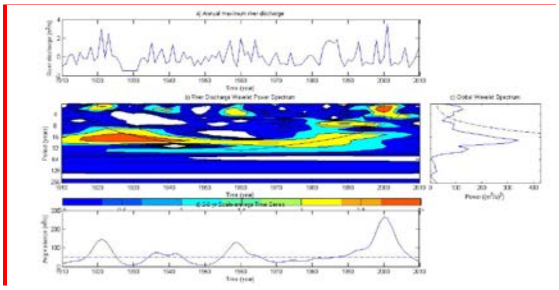

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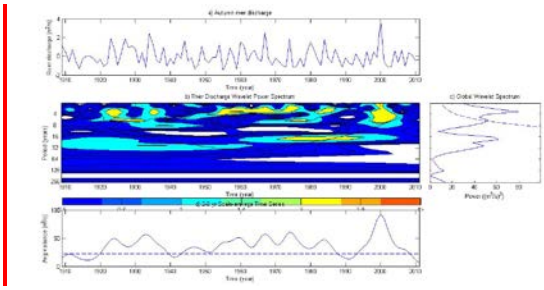

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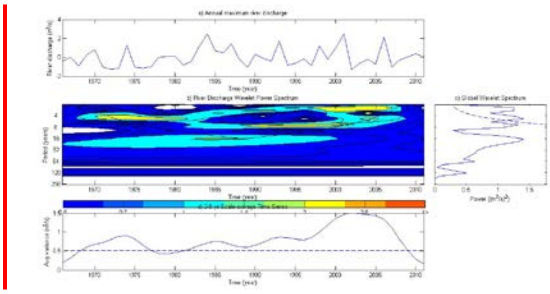

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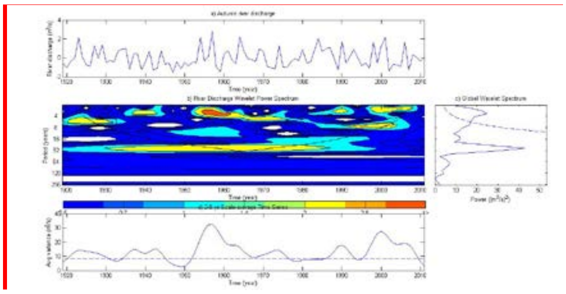

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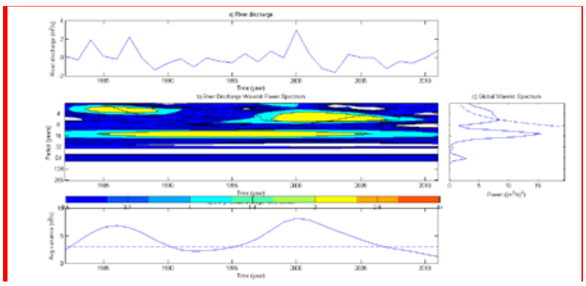

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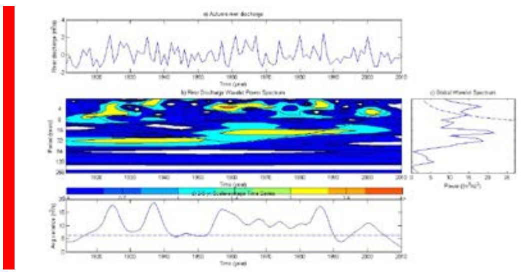

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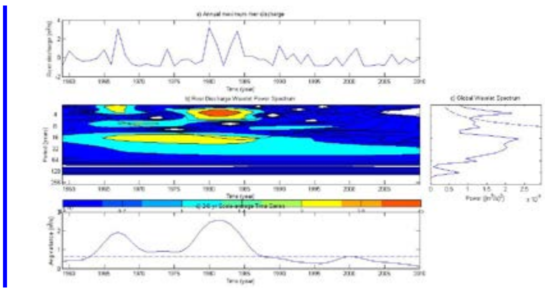

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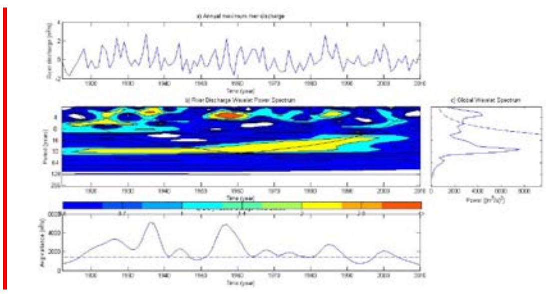

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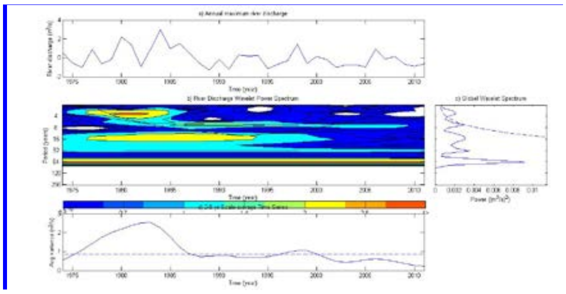

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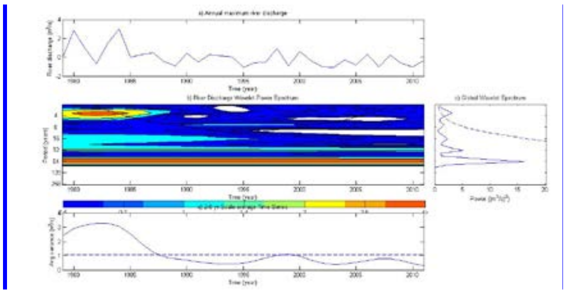

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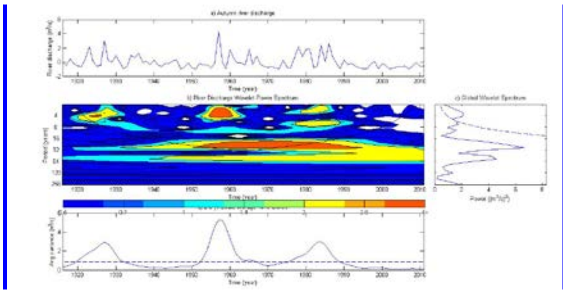
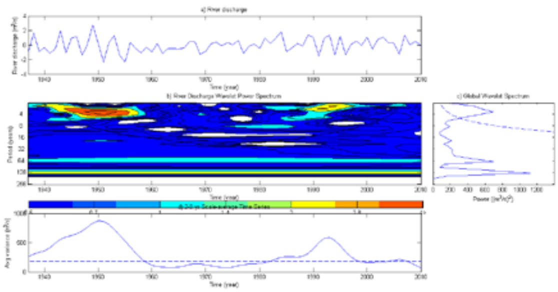


Group division – North – Spring – Red, green and purple group

88:



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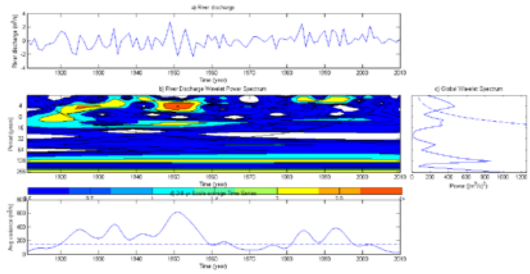

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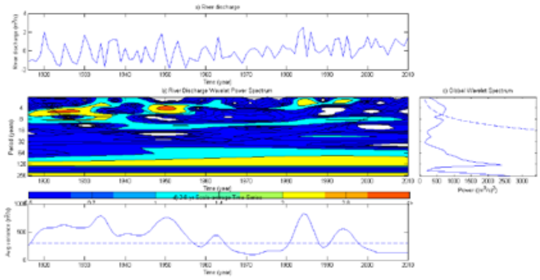

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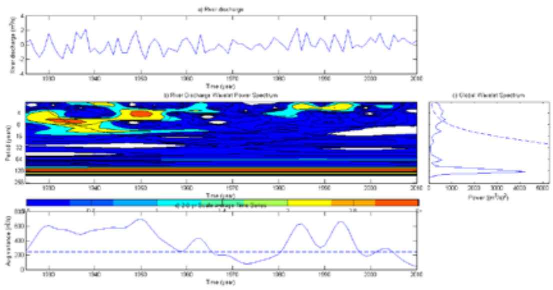

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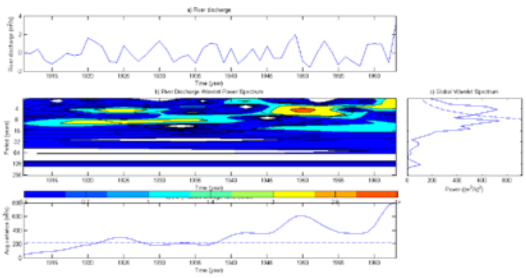

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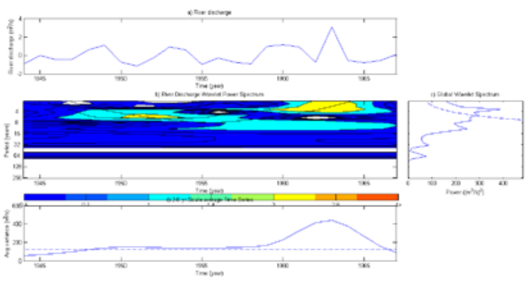

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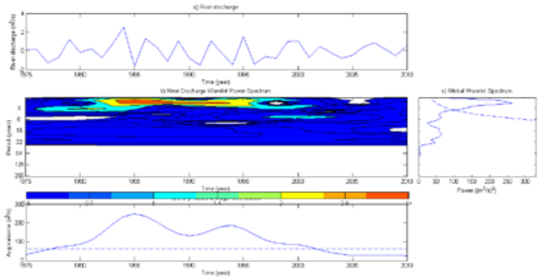

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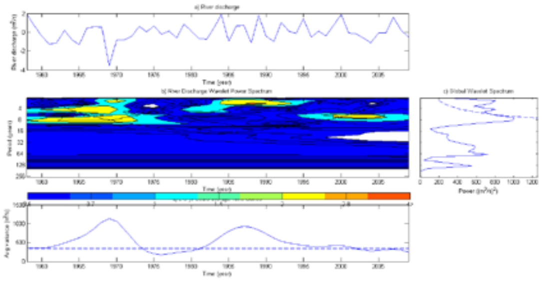

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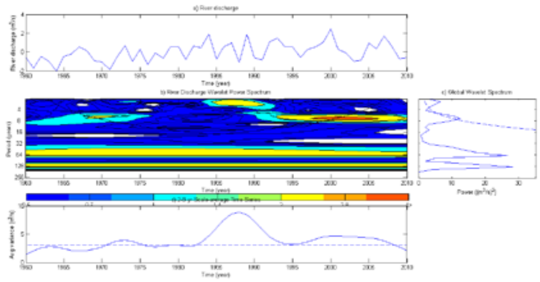

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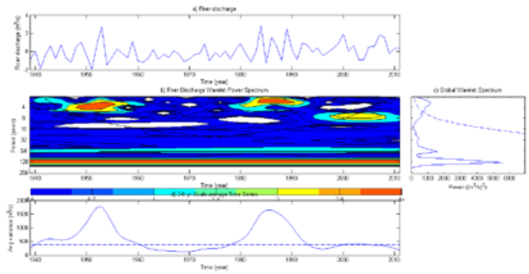

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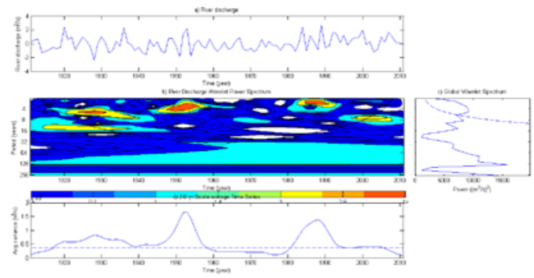

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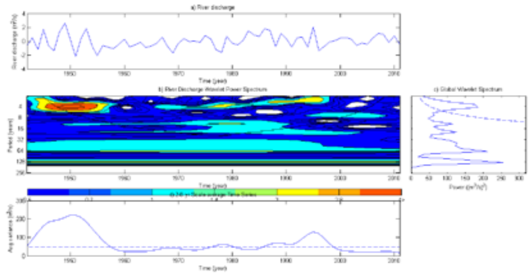

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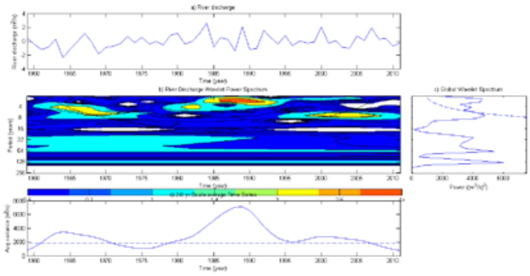

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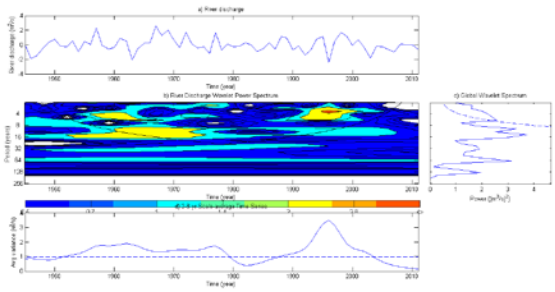

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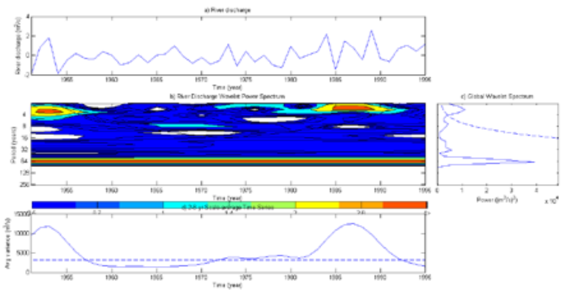

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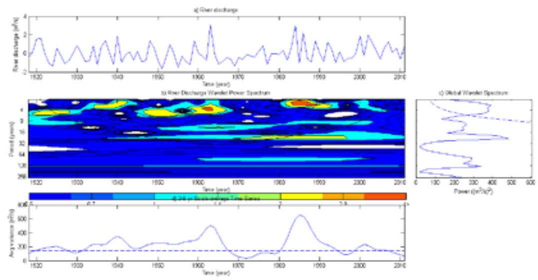

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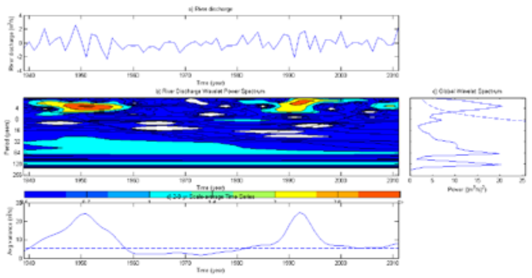

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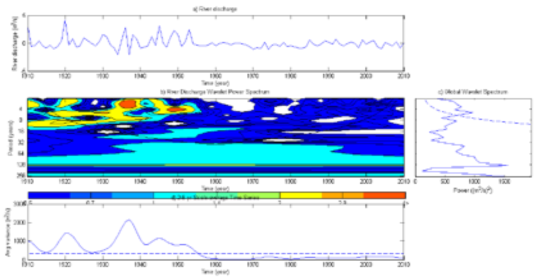

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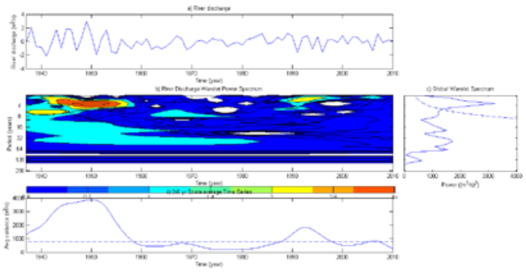
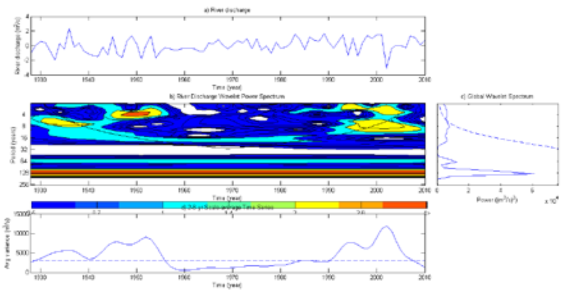


128:



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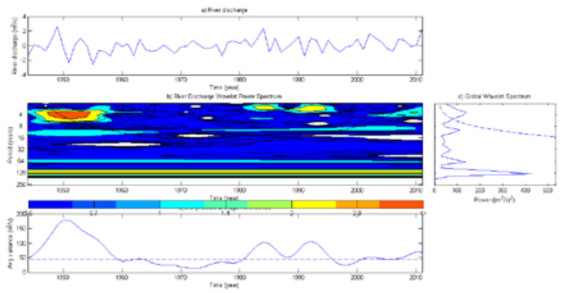

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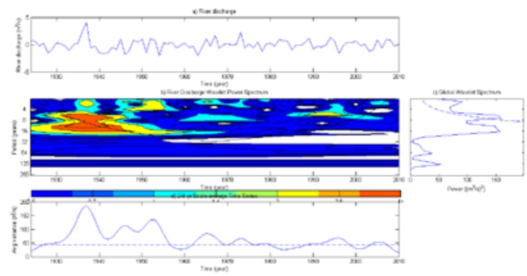

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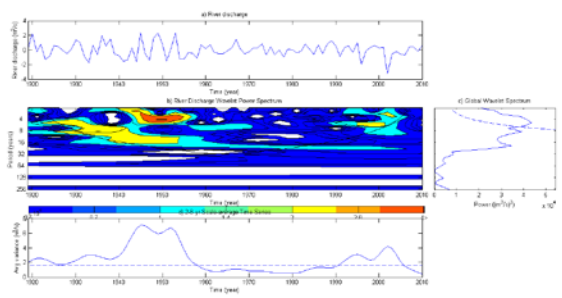

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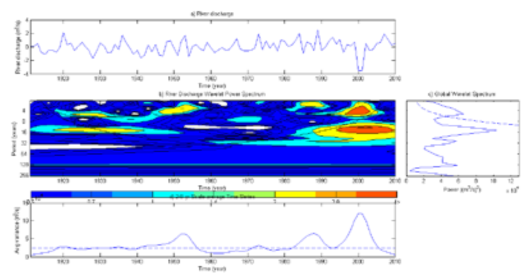

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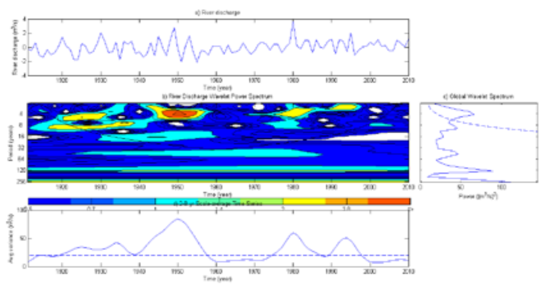

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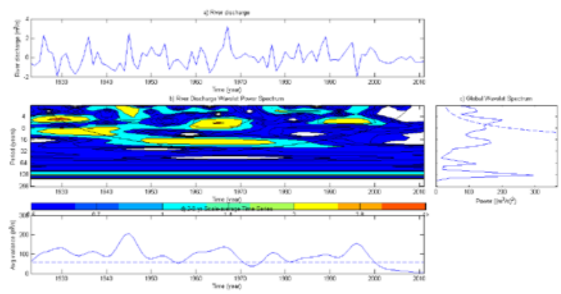

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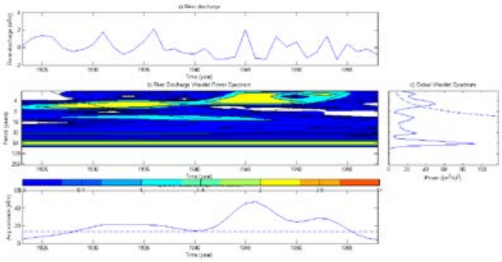

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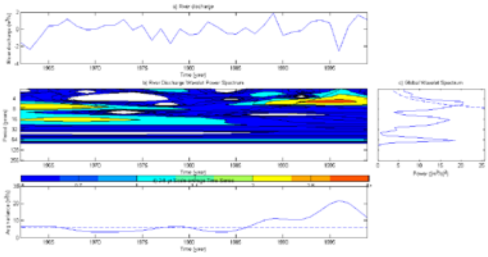

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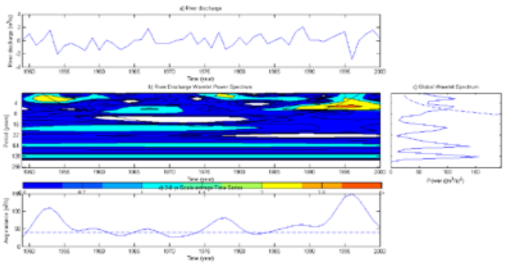

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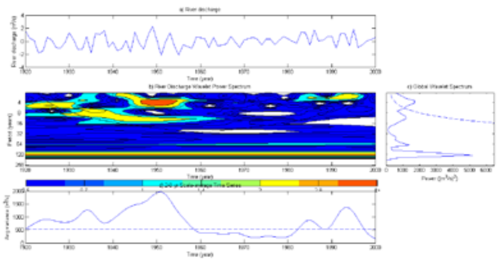

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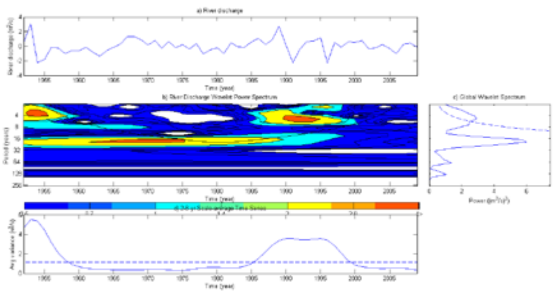

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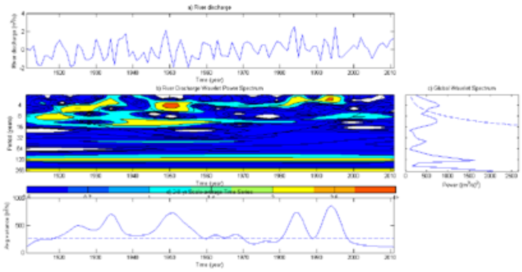

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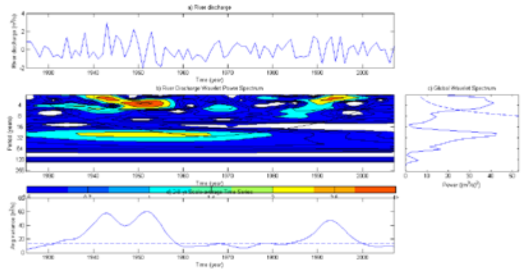

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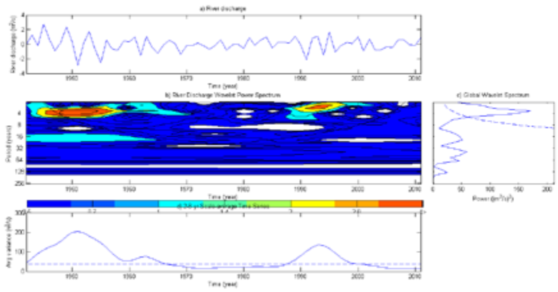

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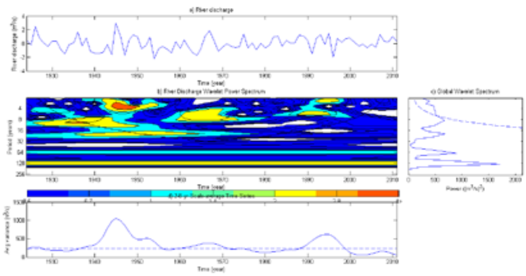

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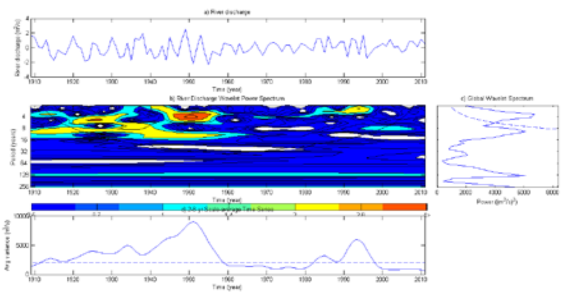

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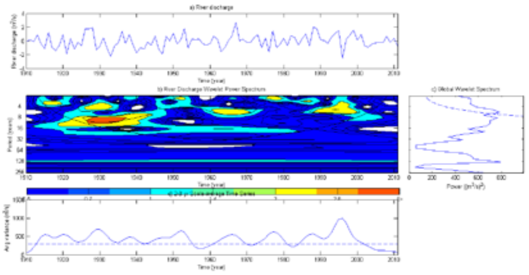

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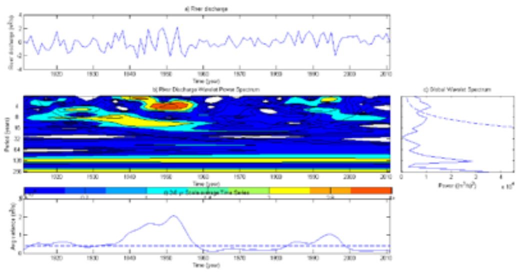

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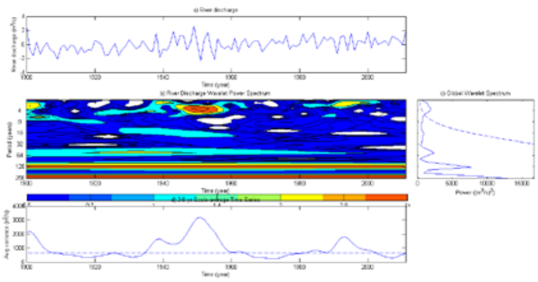

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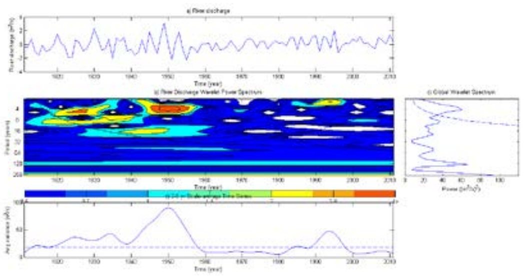

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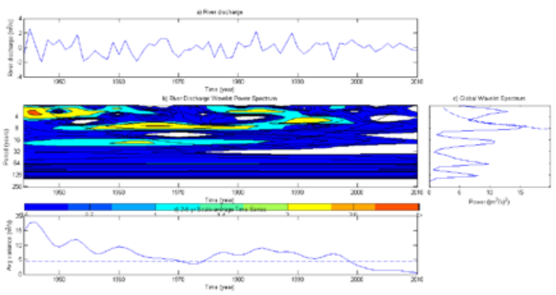

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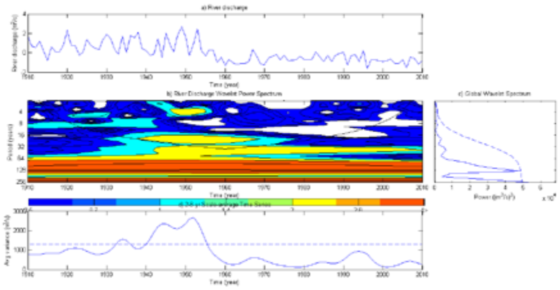

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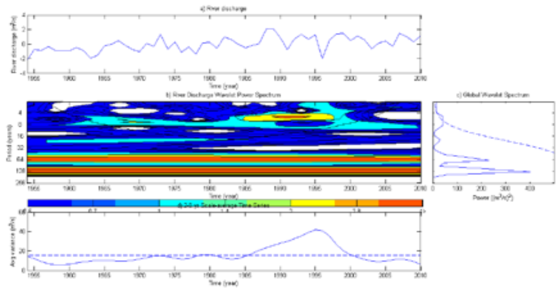

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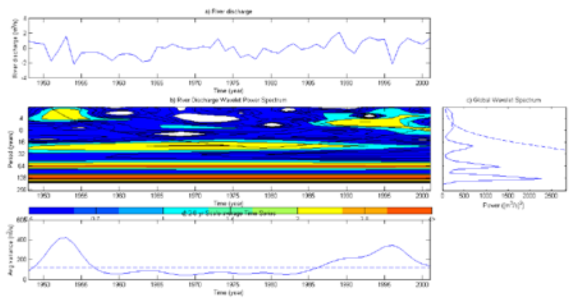
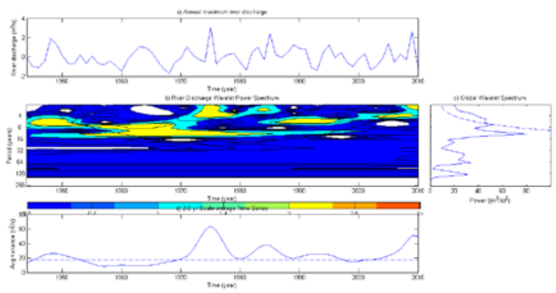


Group division – North – Autumn – Yellow, green, turquiose and pink group

104:



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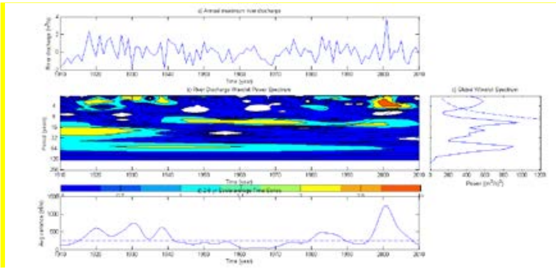

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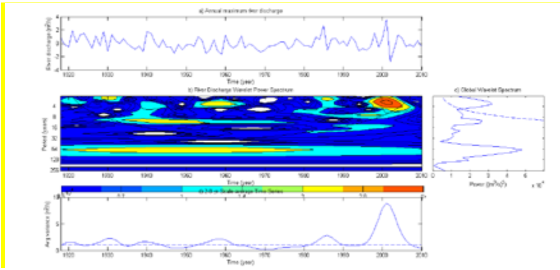

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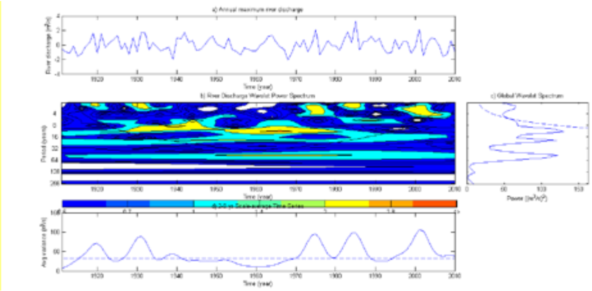

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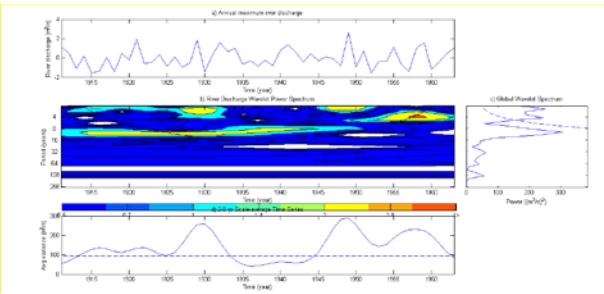

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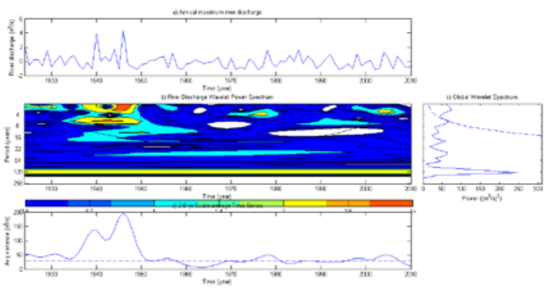

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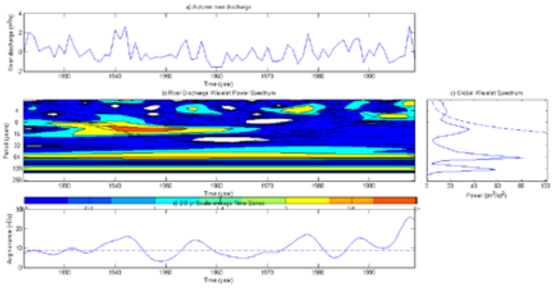

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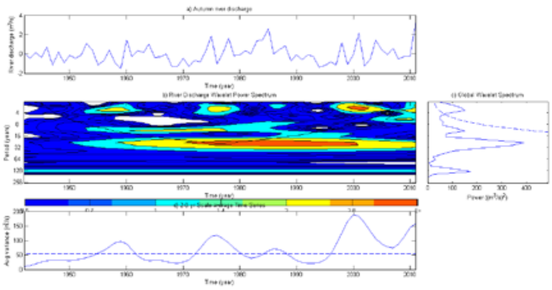

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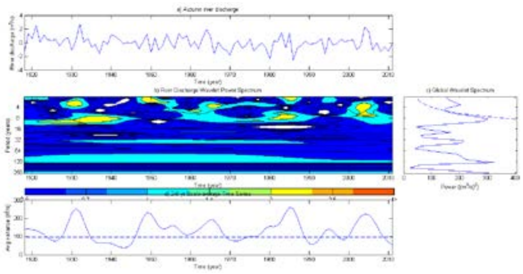

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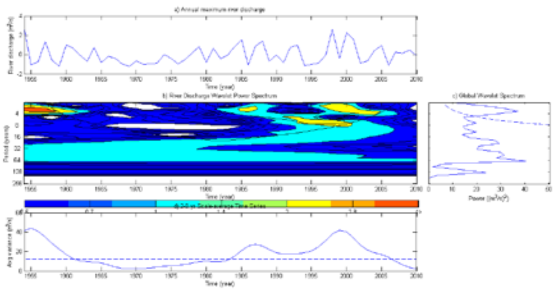

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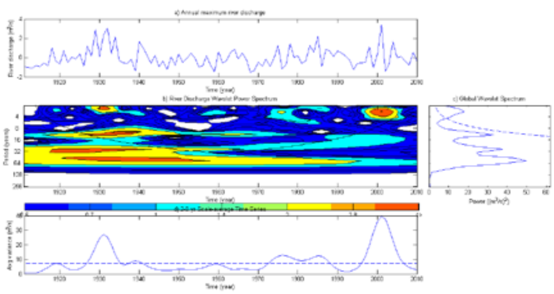

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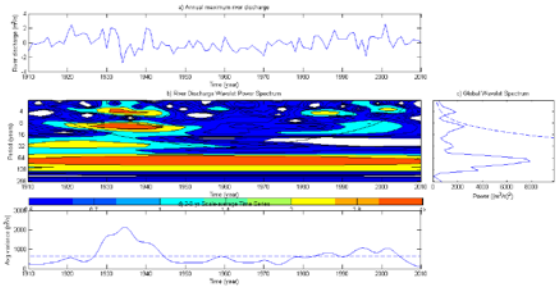

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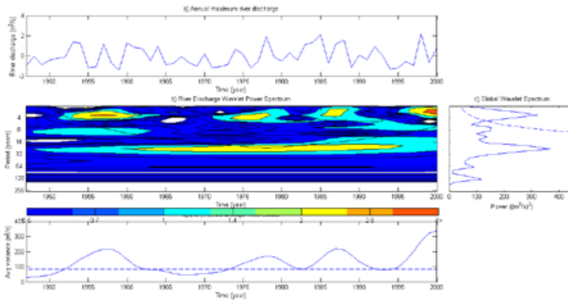

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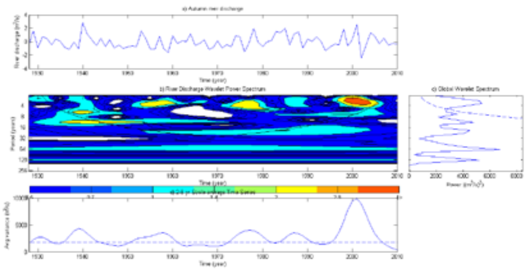

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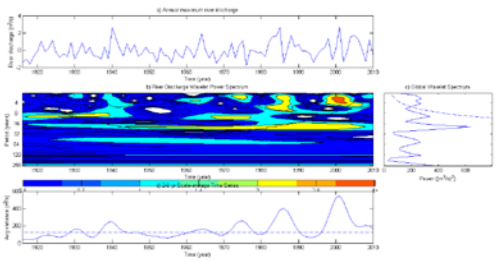

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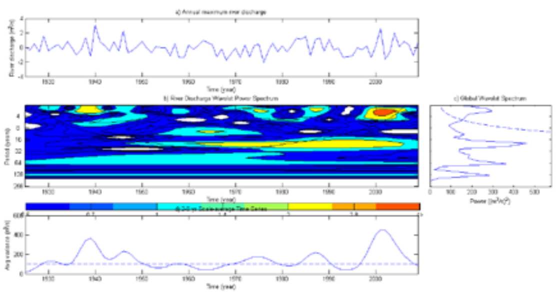

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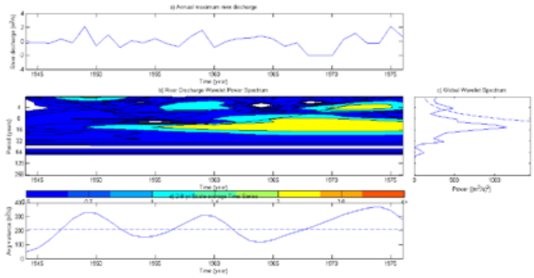

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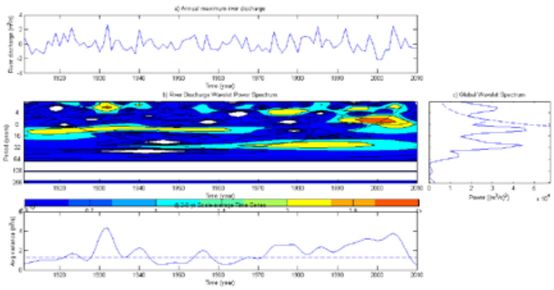

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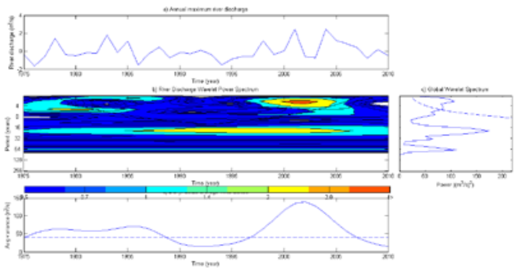

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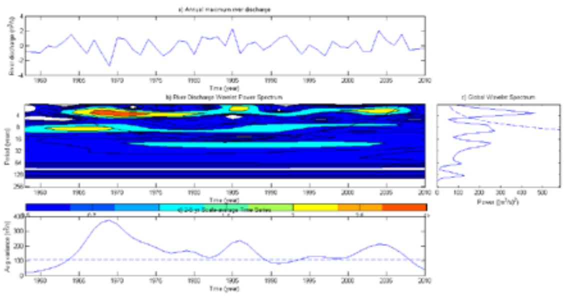

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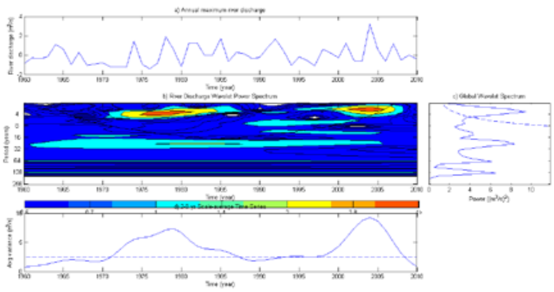

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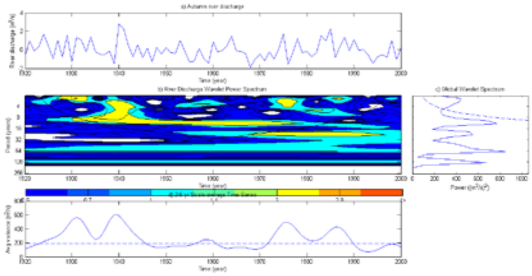

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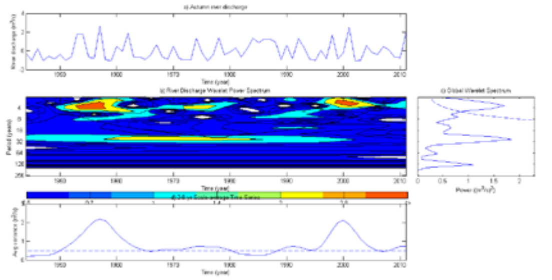

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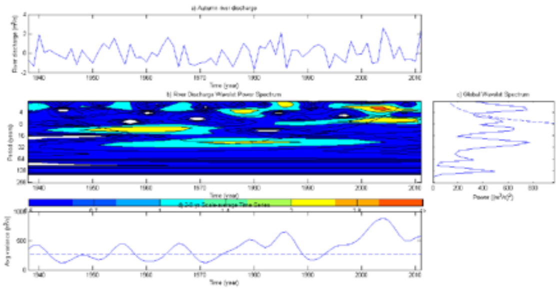

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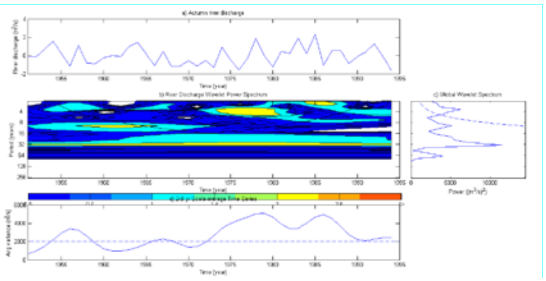

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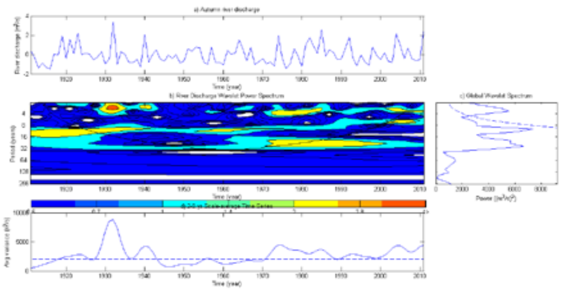

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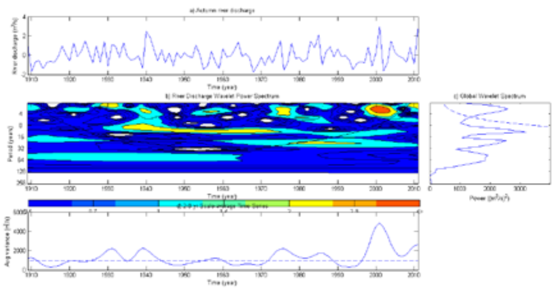

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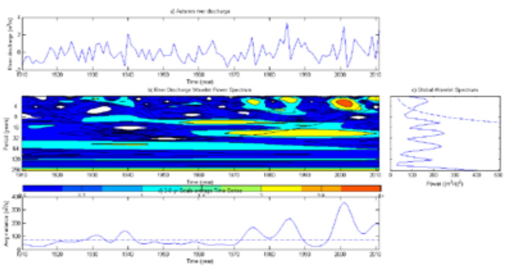

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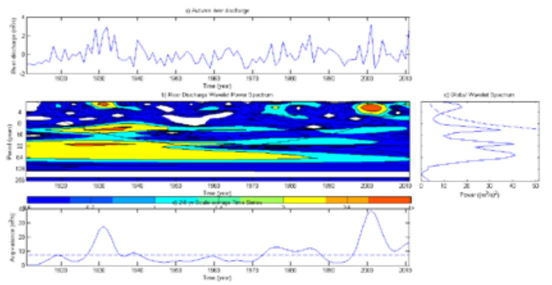

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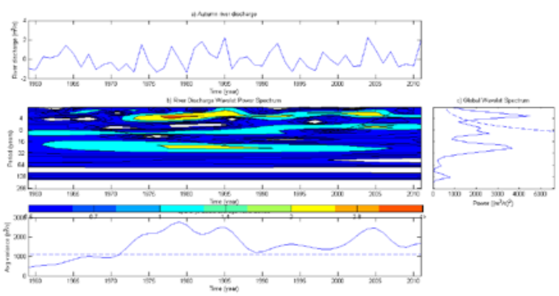

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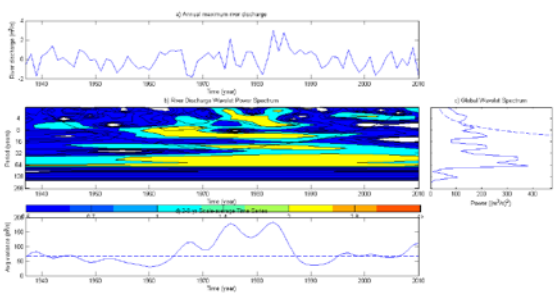

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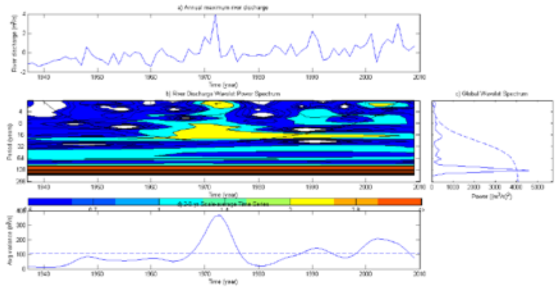

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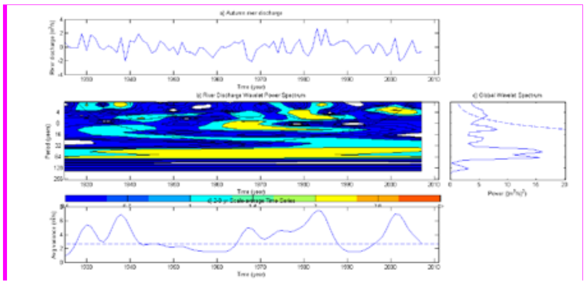

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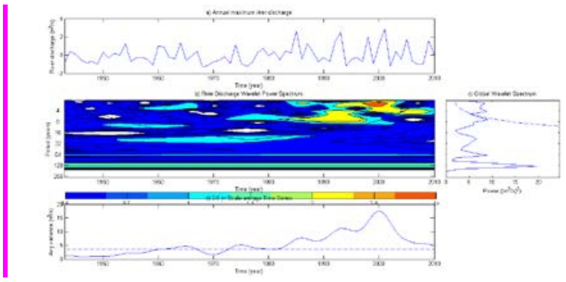

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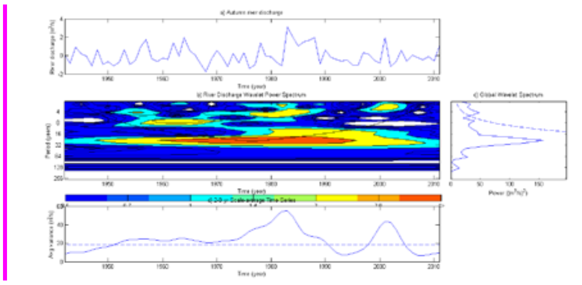

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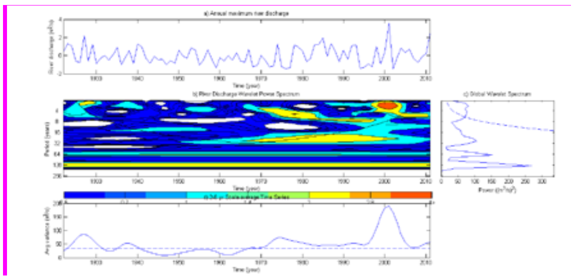

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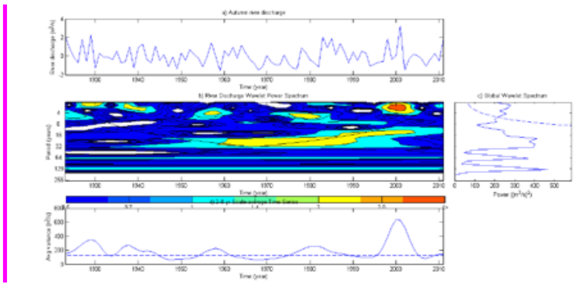

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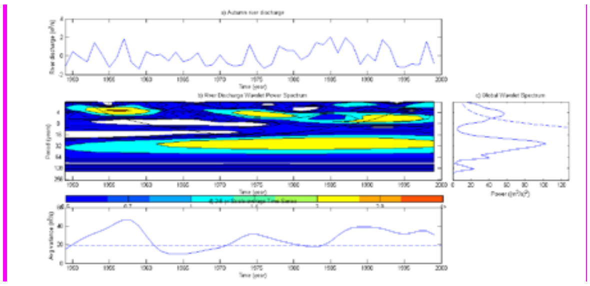

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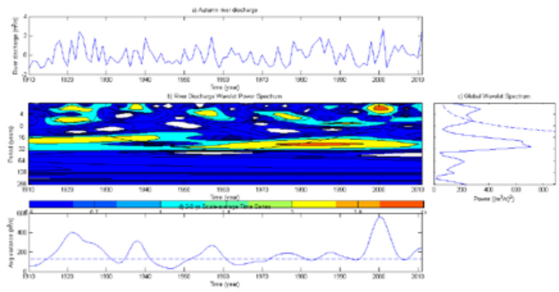

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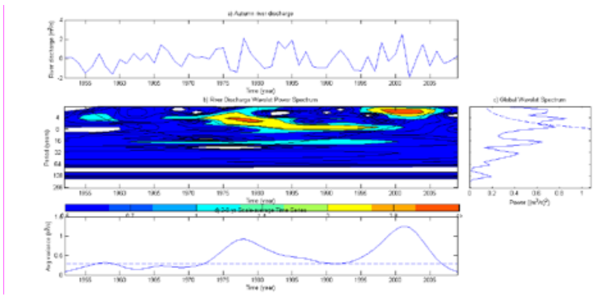

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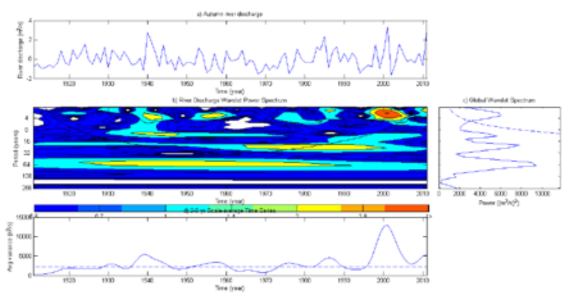

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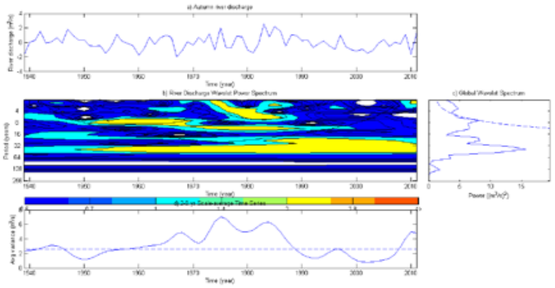

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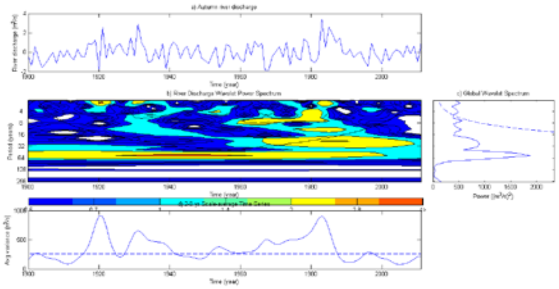
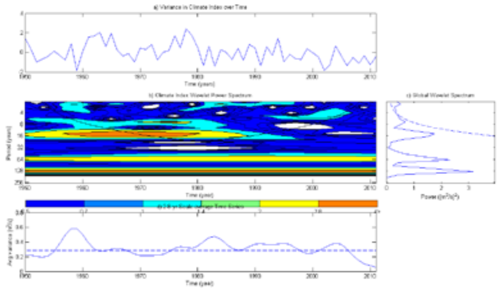


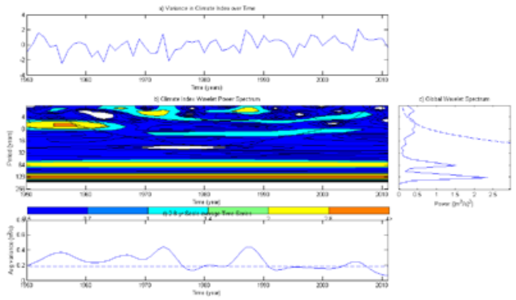
Appendix 6. Climate Indices, wavelets

WP

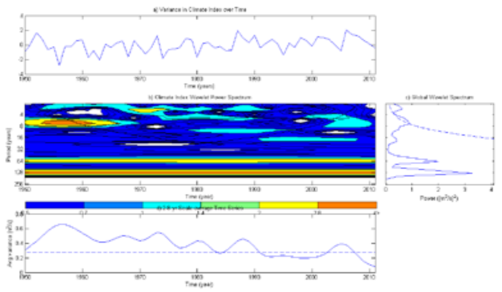
Summer (JJA)



Winter (DJFM)

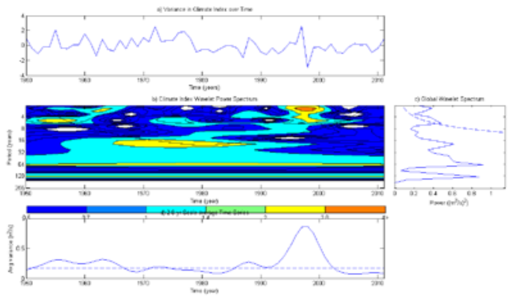


Winter (DJF)



SCAND

Summer (JJA)



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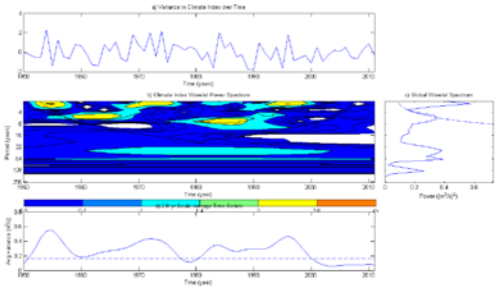

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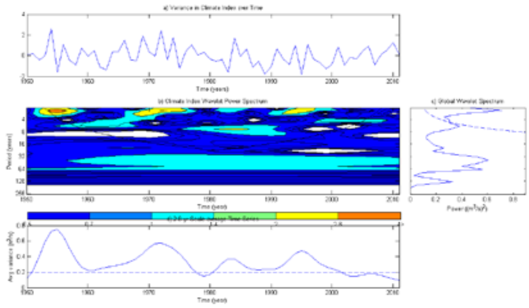
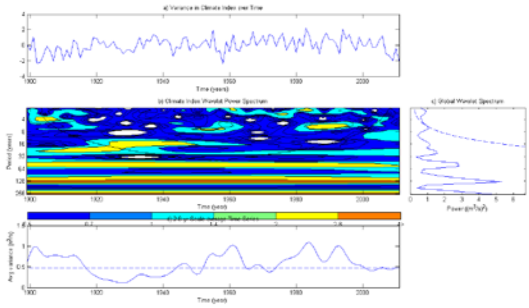
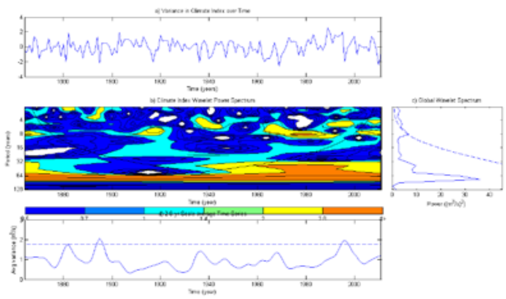


NAO

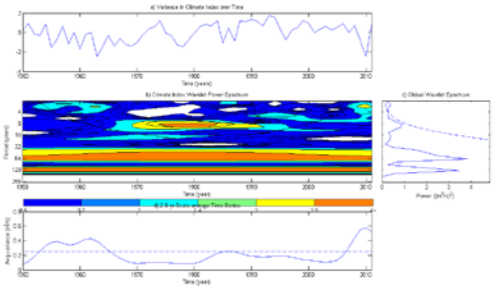
Summer (JJA)



Winter (DJFM)

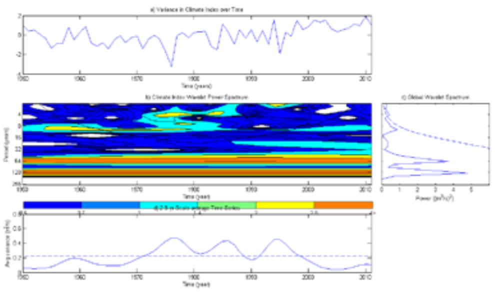


Winter (DJF)

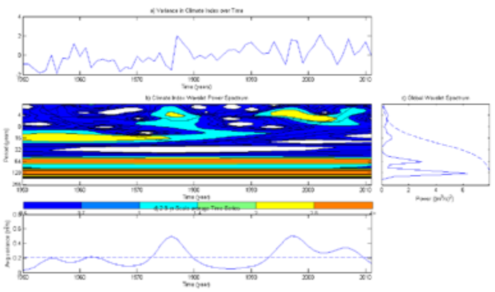


EA

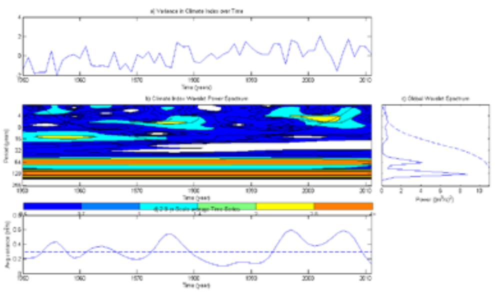
Summer (JJA)



Winter (DJFM)

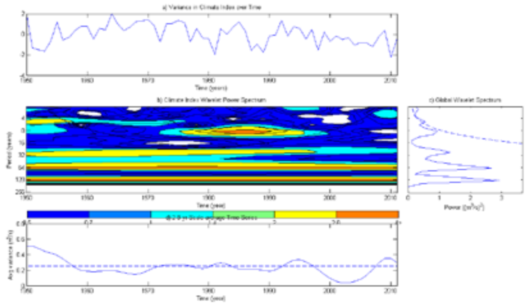


Winter (DJF)

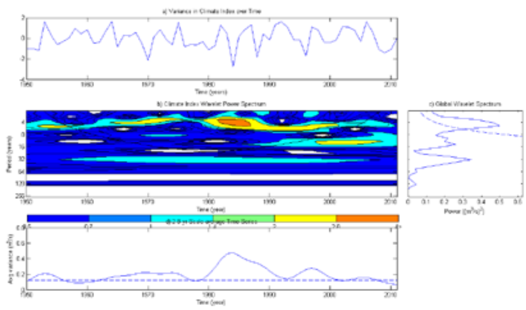


EA/WR

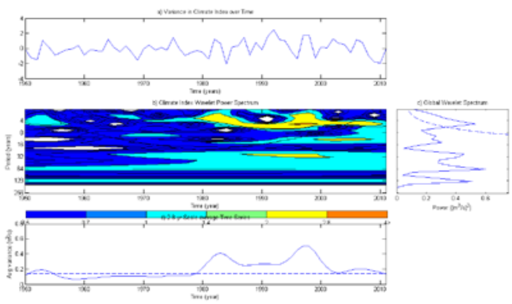
Summer (JJA)



Winter (DJFM)

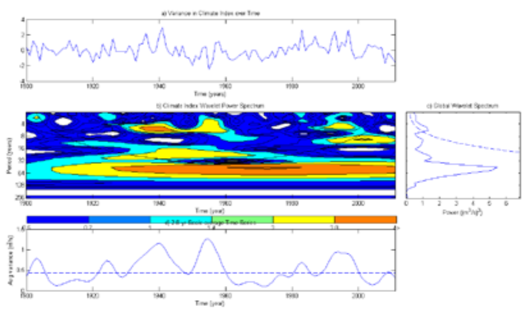


Winter (DJF)

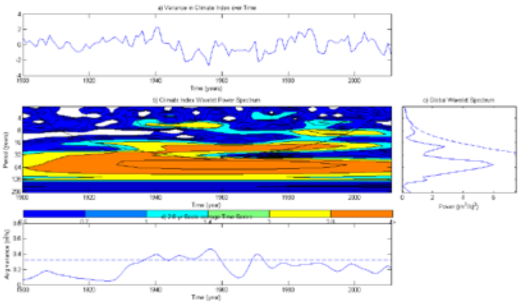


PDO

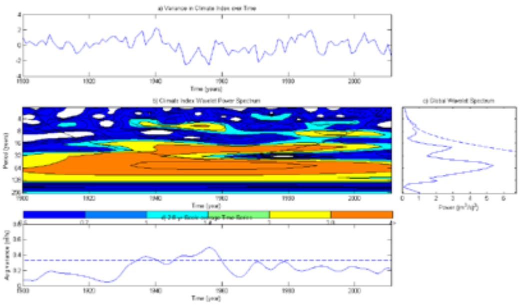
Summer (JJA)



Winter (DJFM)

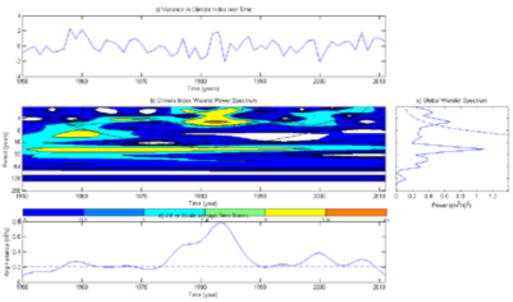


Winter (DJF)

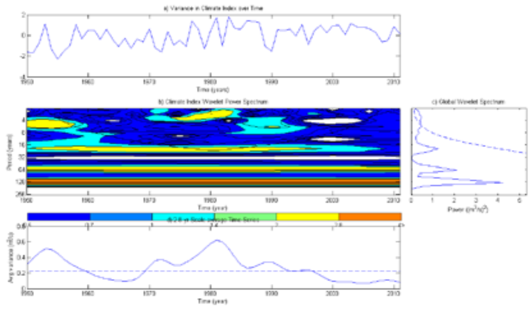


PNA

Summer (JJA)



Winter (DJFM)



Winter (DJF)