A CORRELATION STUDY BETWEEN CLIMATE INDEXES AND HIGH RUNOFF EVENTS IN THE LANJIANG RIVER BASIN, CHINA

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A correlation study between climate indexes and high runoff events in the Lanjiang River Basin, China.

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University of Twente
Water Engineering and Management

Zhejiang University
Civil Engineering
Institute of Hydrology and Water Resources

Bas Christiaan Krewinkel
S1229974

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Supervisors:
Dr. Ir. M. J. Booij, University of Twente
Dr. Y. Xu, Zhejiang University

Foreword

After eleven weeks this thesis is the outcome of a study about the relationship between three climate indexes, namely the PDO, SOI and EASMI, and the high runoff events in the Lanjiang River Basin. This river basin has an outlet point which is connected to the Qiantang River; the main river through the city of Hangzhou.

The topic of the study was a proposal by the Zhejiang University situated in Hangzhou, specifically by Dr. Yue-ping Xu of the institute of Hydrology and Water Resources who has also been my supervisor abroad. During my time at the Zhejiang University Dr. Yue-ping Xu and I have had our conversations about the topic, which sometimes took hours trying to explain things to each other and getting me up the track when my train was once again derailed in a landscape of strange graphs and new information about the climate system. I therefore want to thank her gratefully for her time and patience guiding me through this research process. This research has improved my skills in how to handle a research like this significantly, to stay in statistical terms. Besides that my Matlab skills are once again up to date and improved, which I think will prove to be very useful for the next stage in my educational career. Besides Yue-ping Xu, I also want to thank my other supervisor in the Netherlands, Dr. Ir. Martijn Booij, for getting me in contact in first instance with Yue-ping Xu, and helping me setting up the research besides being a second advisor when needed via the mail. Thirdly I want to thank Frank Bijleveld for taking the time to read through my report and giving comments on it.

Although the official supervisors have been the main help, I also want to thank the whole office with all the PhD students in the Anzhong Building; they made the time a lot more pleasant than it would have been without them (and besides that, I would not have had my laptop anymore without them…). Last but certainly not the least I want to thank my parents for supporting me making this trip. I really enjoyed my time in China, and besides the research time I really feel that I saw a lot of it during my stay. I can therefore recommend any other student to, when the chance is there, do his or her Bsc. assignment abroad, or even better; at the Zhejiang University!

Bas Christiaan Krewinkel, 10^{the} of July
Zhejiang University, Hangzhou, China

Abbreviations

EASM	=	East Asian Summer Monsoon
EASMI	=	East Asian Summer Monsoon Index
ENSO	=	El Niño–Southern Oscillation
EOF	=	Empirical Orthogonal Function
P	=	Precipitation
PDO	=	Pacific Decal Oscillation
POT	=	Peak over Threshold
SLP	=	Sea Level Pressure
SOI	=	Southern Oscillation Index
SST	=	Sea Surface Temperature
Q	=	Runoff
Q3	=	Three day average runoff

SUMMARY

Flood forecasting is becoming more important for the Lanjiang River Basin according to recent literatures about climate change. A way to forecast more precisely is by looking to climate indexes. In this research finding the relationship between three climate indexes that are thought to be of influence according to the literature, and high runoff events for the Lanjiang River Basin was the main aim. The indexes are the PDO, the SOI and the EASMI. The Lanjiang River basin was split up in two smaller basins, namely the Jinhua and the Quzhou River basin. This choice was made since there were precipitation and runoff data available via the China Meteorological Administration and the Bureau of Hydrology of the Zhejiang Province. Besides that, it covers a great part of the total area of the Lanjiang river basin. To accomplish the aim a number of steps were carried out, including researching the relationship between runoff and precipitation, precipitation and climate indexes and runoff and climate indexes. Using the knowledge of the first two relationships it could be easier to understand the results for the relationship between climate indexes and runoff directly. To perform these correlation studies Pearson and a multiple regression analysis were applied. Besides looking to daily runoff values for high runoffs, also three day average runoff values were looked into, since this may deliver stronger relationships and would tell something about the relation with the volume of the runoff.

Firstly the indexes were interpolated to daily values, since high runoffs mainly occur for just a few days. After interpolating the index data, the peak over threshold method was selected instead of annual maximum runoff values since this delivered a larger number of runoff samples. With this method, both for the maximum daily runoff values and three day average runoff values sufficient values were found for the period used for the PDO and SOI. A little less, but still enough samples, were found for the shorter period used for the EASMI. The PDO was investigated for the long term relationship since it is a long term index with an average cycle period of 50 years. The SOI was investigated for the long and short term, since both types of relationships were already found in earlier studies between ENSO and precipitation/runoff in other regions. The EASMI was only investigated for short term relations, since it is a yearly returning event. For both the PDO and SOI there are significant correlations found when looking to the precipitation, runoff and three day average runoff; positive for the PDO, and negative for the SOI. For the SOI Jinhua had a large decline in the correlation value when comparing precipitation with runoff and three day average runoff. This result is according to the results of the runoff - precipitation relationship which is weaker for Jinhua compared to Quzhou. For the short term SOI and EASMI the relationship was also investigated by looking at the different PDO phases, since this could matter for the correlation. Indeed this showed some differences for the SOI index, but they could not be explained. For the EASMI it also showed differences which in contrast were explainable mainly for the Quzhou area. For Quzhou there is a pattern of a strong correlation between precipitation and (three day) runoff with the EASMI during a positive PDO phase, and a weaker correlation during a negative PDO phase, which is understandable. In general the correlation for the EASMI turned out to be the highest (negative direction) of the three indexes, especially for the Quzhou area. Comparing the results between the combinations of runoff – precipitation and precipitation – climate index with the direct runoff – climate index only showed comparable correlations for the SOI index for the Quzhou area. Finally the multiple regression showed that this is a valuable addition, especially in general for the PDO/SOI combination and the EASMI combinations for the Jinhua area since these correlations were higher.

Further research is mainly interesting for the EASM and ENSO (SOI index) phenomenon. Especially the EASMI gave a significant correlation in generally. Advisable though is using the whole year instead of the current two months of the data to have even more certainty. Lastly the PDO should always be considered when splitting up the data in different periods, since it seems it has an influence for this area on the other climate phenomena (indexes).

Contents

1 INTRODUCTION

1.1 Motive

The past has proven that floods can be seen as one of the most destructive natural events in terms of economic damage and human losses. Examples of these economic damages are losses of crops and blocking of transportation. Other indirect consequences of floods that could be dangerous are events like land-and mudslides, which could be devastating as well (Xie et al. 2014). Therefore, it is important that these floods can be forecasted.

Floods themselves are often caused by heavy precipitation which last for a relatively long period. As shown in previous studies for certain regions around the world, possible predictors of precipitation are the different climate indexes since there is a relationship between these two for the regions investigated (Chiewn et al., 1998; Jin, et al., 2005; Zhang et al., 2007; Kamruzzaman et al, 2011; Lü, et al., 2011; Zhang et all, 2013). Therefore researching the relationship between high runoff and climate indexes becomes interesting for other regions as well.
For the Yangtze River Basin in China this sort of study has already been done, for example by Tong et al (2006) and Zhang et al. (2007). These studies concluded that there is an influence of different climate phenomena on precipitation and floods. The first of these phenomena is the El Niño Southern Oscillation (ENSO) which influences the whole Yangtze River Basin. Secondly the Indian summer monsoon is indicated, and thirdly the East Asian summer monsoon (EASM). The upper part of the Yangzte River basin was mainly influenced by the Indian Summer Monsoon, and the lower part of the Yangtze River basin by the East Asian Summer monsoon.

This study will focus on a part of the Qiantang River Basin, a river basin in the east of China. This basin lies approximately 200 kilometre south of the lower part of the Yangtze River basin. For the Qiantang River Basin less studies have been carried out compared to other major river basins in China. Previous studies for the Qiantang River Basin include an investigation on future extreme precipitation events due to climate change (Xu et al., 2012), and the consequences of climate change on precipitation in a sub basin within the Qiantang River Basin (Xu et al., 2013), namely the Lanjiang river basin (yellow in Figure 1). The Lanjiang river basin is also the part of the Qiantang River Basin that will be the focus in this study. Xu et al. (2012) and Xu et al. (2013) concluded that there is a significant chance that because of climate change precipitation in the Qiantang River basin would be more extreme in the future.
Since there is a possible relationship between climate indexes and precipitation like mentioned in the beginning, and since the precipitation could become more intense in this area, it could be interesting to study this relationship for the Lanjiang River Basin. The climate phenomena that are interesting in this specific region are the earlier mentioned ENSO and EASM phenomena since they have a high potential to be of influence, and the pacific decadal oscillation (PDO) as will be described below.

The ENSO phenomenon which could be measured by the Southern Oscillation Index (SOI) is of influence in the lower part of the Yangtze basin (Zhang Q. et al., 2007), which lies only 200 kilometre north of the Lanjiang river basin. Since this is fairly close to the Lanjiang river basin, it is hypothesised that it might be of influence on this basin as well. The ENSO phenomenon occurs every 2-7 years (Jin et al., 2005), in which there is an El Niño and La Niña phase which normally last for 6-18 months (Brabets & Walvoord, 2009; Mantua N. , 2000).
The second phenomenon that could be of influence is the EASM, since it does influence the lower part of the Yangtze River Basin as well. The EASM has a lot of index methods to measure it, and Wang et al. (2008) reviewed 25 of them. The dynamical normalized seasonality (DNS) (Li & Zeng, 2002) turned out to be the best available index for Lanjiang River Basin which measures the EASM in this specific area. This DNS is a general index method for all monsoons, which can be specified for a certain region. For the region between 10-40 °north and 110-140° east Li (2014) found the East Asian Summer Monsoon Index (EASMI), which is an implementation of the DNS. The EASM phenomenon is in contrast to the ENSO phenomenon a yearly returning event.

The third phenomenon that could be interesting is the PDO phenomenon, which is measured by the PDO index (Mantua et all, 1997). This index looks into the sea surface temperature (SST) of the North Atlantic Ocean. The PDO has been proven to be of influence in the Eastern part of China (Shen et al., 2006), and according to Mantua et all. (1997) it is of influence for region's lying higher than 20° North next to the North Pacific Ocean. Since the Lanjiang River Basin lies at 30° north, it is worth testing the correlation for this index as well. A PDO phase (warm or cold) normally last for 2-3 decades and a full cycle takes about 50 years, so it is important to note that so far only two full PDO cycles occurred in the past century (Brabets & Walvoord, 2009; Mantua N. , 2000).

The relationship between these climate indexes and the runoff has not been yet investigated for the Lanjiang River Basin, let alone the relationship between climate indexes and high runoff. Therefore this could be an addition in more precise flood forecasting for the region, which is relevant since this region may experience more high floods in the future (Xu et al, 2013; Xu et al, 2012). Whereas other studies often investigate only one climate phenomenon, this study will focus on more than one climate phenomena to gain a general overview of the influences of multiple climate phenomena and their indexes in this area. In this way it could be a starting point of further research to the indexes that according to this study have a significant relationship with precipitation or runoff for the Lanjiang River Basin. The study will differentiate itself from other related studies (Chiew et all; 1998; Lü, et al., 2011; Zhang Q et al., 2007) as it will not only look to the high river runoff relation with the climate indexes directly, but also by looking to the relationship between the runoff and the precipitation that caused these high runoff events and these precipitation events and the climate indexes as comparison material for the direct method. Therefore it is possible to compare the direct correlation between the runoff and the climate index with the indirect method (combination of correlations between runoff and precipitation, and precipitation and climate indexes). Since these high river runoff events occur mostly in the plum (Mei-Yu) and typhoon season (summer rainfall), this will also be the period that is investigated. The plum rains occur mainly in May, June and sometimes July (June and July for the Lanjiang Basin), and the Typhoon rains in August.

1.2 Research objective:

The goal of the research is to determine what the relationship is (if there is one) between the SOI, PDO and EASMI climate indexes and the high runoff events within the Lanjiang River Basin by doing a correlation study. For this correlation study different lag times and temporal resolutions will be used in order to find the highest correlation possible.

1.3 Research questions:

1. What is the relation between precipitation and high runoff events in the Lanjiang River Basin, and what sort of precipitation events caused floods in this river basin in the past?
2. What is the relationship between the three climate indexes (SOI, PDO and EASMI) and 'heavy' precipitation events in the Lanjiang River Basin?
3. What is the relationship between the three climate indexes (SOI, PDO and EASMI) and high runoff events in the Lanjiang River Basin and does this change when applying a three day average runoff value?

1.4 Report outline

Firstly in Chapter 2 the study area is described together with information about the data that is used. Chapter 3 is about the methodology. In this Chapter some choices made involved in the methodology are further explained and the different methods like Pearson and Multiple regression are described. Chapter 4 is about the results from the four different correlation assessments; runoff – precipitation, precipitation – climate indexes, runoff – climate indexes and three day average runoff - climate indexes. Chapter 5 includes the discussion and the conclusions.

2 STUDY AREA AND DATA

2.1 Study area

The study area is the Lanjiang River Basin (Figure 1), which lies in the Zhejiang province (118°-121°N, 28°-30°E), China. The Lanjiang River Basin is part of the Qiantang River Basin, which lies mainly in the Zhejiang province and for a smaller part in the Anhui province as well. This basin has a drainage area of 55,600 km^2 and a total river length of 668 km. This basin is divided in three smaller basins, namely Lanjiang (yellow), Xin'anjiang (green) and Fuchunjiang (purple). The first basin, Lanjiang, will be included in this research. The Xin'anjiang basin will not be incorporated due to the reservoir that is part of the basin which makes finding a direct correlation between climate indexes and runoff less meaningful. The last basin, the Fuchinjiang, doesn't have many discharge measurement stations, which makes it difficult to find correlations as well.

The main river that flows through the Lanjiang River Basin is the Lanjiang. This river arises from the Jinhuajiang in the south and the Qujiang in the west. The Jinhuajiang arises from two other streams in the east; the Dongyangjiang and the Wuyijiang. The Qujiang arises from the Changshangang, the Jiangshangang and the Waxijiang. The specific areas that will be looked at in this research are the catchment areas above the Jinhua and the Quzhou station (Figure 1). The Jinhua station has a catchment area of 5990 km^2, and the Quzhou station a catchment area of 5690 km^2. These areas are the most important in the relationship between precipitation and runoff, since the other main stream (the Wuxijiang) has a large reservoir which makes the relationship more complex for that area, and not comparable to the other two areas.

The Lanjiang River Basin has a humid sub-tropical climate according to the most updated Köppen climate classification (Kottek et all., 2006). The annual average mean temperature is 17°C. The annual average minimum and maximum temperatures are respectively 12.9°C and 21.3°C. The precipitation on annual basis is approximately 1200-2200 mm, depending on the location (Xu, Zhang, & Tian, 2012). The land use in the Lanjiang River Basin is mainly agriculture (Xia & Yang, 2007).

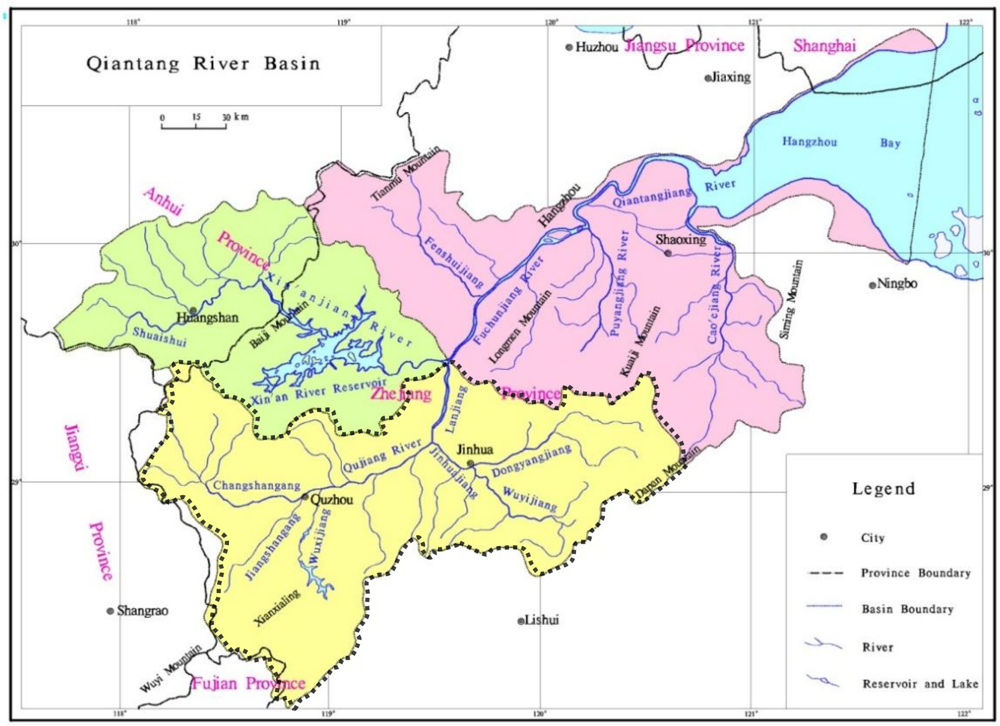


FIGURE 1: STUDY AREA; QIANTANG RIVER BASIN. IN YELLOW THE LANJIANG RIVER BASIN IS INDICATED.

2.2 Data

It is important to examine which data are available for usage, since this determines which methods can be applied for the research. For example the length of the data series determines whether a yearly maximum or a peak over threshold (POT) method would be better when selecting the high runoff values. A short overview of the data and the data source that will be used is given in Table 1.

TABLE 1: OVERVIEW OF THE USED DATA AND THEIR SOURCES

Type of data		Time scale	Period available each year	Period available total	Spatial availability	Source
Index data	SOI	Monthly	All months	1876-2014	The entire Lanjiang River Basin	Australian Government; Bureau of Meteorology (BOM)
	PDO	Monthly	All months	1900-2014	The entire Lanjiang River Basin	College of the Environment; University of Washington
	EASMI	Monthly	June/July/August	1948-2012	The entire Lanjiang River Basin	Dr. Jianping Li's personal website
Precipitation data	Quzhou	Daily	All days	1963-2008	Area lying above the Quzhou station	China Meteorological Administration (CMA)
	Jinhua	Daily	All days	1962-2011	Area lying above the Jinhua station	China Meteorological Administration (CMA)
Runoff data	Quzhou	Daily	All days	1960-2006	Runoff at the Quzhou station	Bureau of Hydrology, Zhejiang Province
	Jinhua	Daily	All days	1961-2000	Runoff at the Jinhua station	Bureau of Hydrology, Zhejiang Province

2.2.1 Data limitations

Climate Index limitations

The three climate indexes as mentioned above that will be taken into consideration are the South Oscillation Index (SOI), the Pacific Decadal Oscillation (PDO) and the East Asian Summer Monson Index (EASMI). This means that each of the climate phenomena will only have one index for the correlation study, and not multiple like ENSO has in for example Lü et al (2011). The index data used is given in Appendix I, Figure 19.

Temporal limitations

The length of the available datasets will determine how many years from the past can be included in this correlation study. The limitation for the temporal aspect is different for Jinhua and Quzhou, still the same period will be used to minimize the error due to a difference in dataset lengths when comparing both areas. For Jinhua data are available from 1962 (precipitation limitation) till 2000 (runoff limitation). For the Quzhou the data are available from 1963 (precipitation data) till 2006 (runoff data). The final temporal range that can be used for the areas is the period from January 1963 till January 2001 (38 years). The period per year that is investigated for high runoff events is 5 months for the SOI and PDO, and 2 months for the EASMI. This is indicated in Figure 2. For the EASMI this is due to data limitations, and for the PDO and SOI the 5 months are chosen since these are the months that are the most important for summer precipitation.

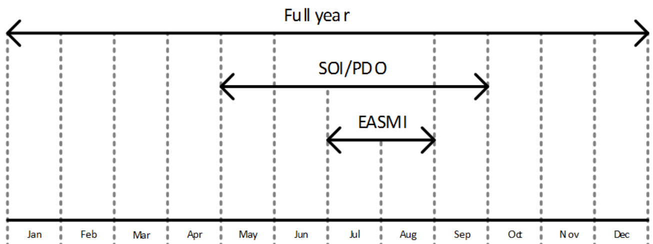


FIGURE 2: TIME PERIOD FOR EACH INDEX IN WHICH THE RUNOFF EVENTS ARE SELECTED.

3 METHODOLOGY

3.1 General overview

In the methodology the most important issues are discussed with respect to how the research was carried out. The first part of the methodology includes an introduction of the correlation assessments that are used in this study. But firstly a short outline of the methodology; further on in the methodology the climate indexes will be discussed with their specific features, after that the specific techniques are shown that will be used to carry out the data preparation, like the interpolation of the climate indexes and the method to determine the maximum runoff values. Besides that Pearson and multiple regression are introduced as possible methods to determine the correlation, and it is explained how they work. Finally also the terms 'lag' and 'temporal resolution' are explained.

But first an overview about the different correlation assessments that are distinguished, and the type of model that is used in this study. Performing a study like this, a few model types can be used. Hereby three model types are generally distinguished; namely mechanistic models (white box), parametric models (grey box) and metric models (black box) in decreasing order of preciseness of the modelled hydrological processes within the area of interest (Wagener et al., 2004). Whereas deterministic models describe exactly all the process inside the area, the black box models often only have a few inputs and an output. It is therefore logical that this study uses a black box model in the form of a correlation assessment.

This research is about finding possible relationships between the PDO, SOI and EASMI climate indexes and high runoff events as explained in the introduction and the research objective. Therefore a global overview can be given like Figure 3, though it is still not in detailed level. In this figure multiple relationships are shown, that correspond with the different research questions. Research Question one is coupled to Relation one, Research Question two to relation two and Question three to Relation three.

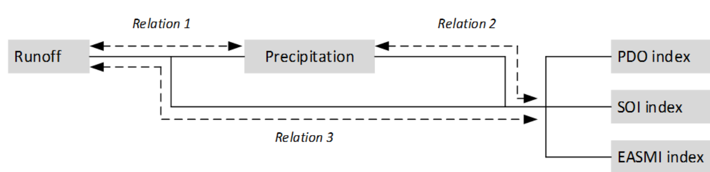


FIGURE 3: GENERAL OVERVIEW RELATIONSHIPS TO BE INVESTIGATED

Relation One can be further specified by distinguishing the runoff values in two parts: the daily maximum values, and the three day average maximum values. This difference, and why the three days average is also taken into account, is explained in Chapter 3.6. Also the precipitation and runoff part can be distinguished further by looking to the PDO/SOI period, the EASMI period and the full year. Figure 4 gives relationship one in detail. This gives in total six different relations within relation one. Relation Two can also be further specified by using the three precipitation periods specified in relation one. This way Figure 4 is constructed. Relation Two can also be given for a multiple regression analyses, where two climate indexes are combined and coupled to the

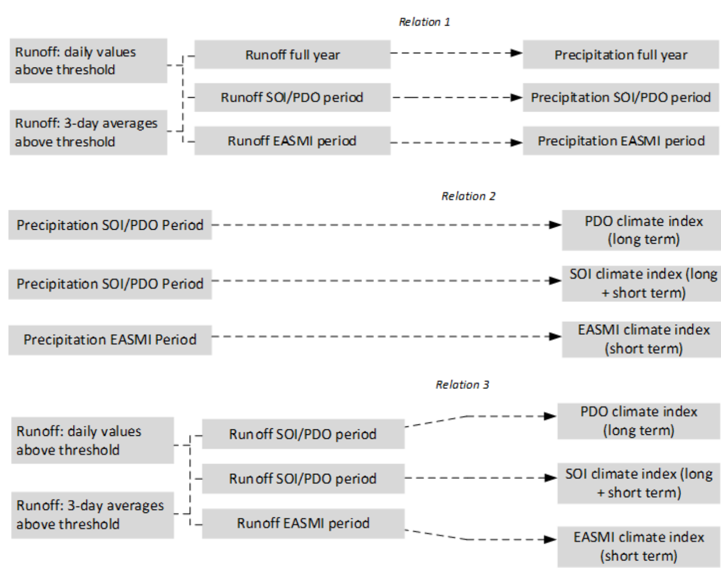


FIGURE 4: DETAILED LEVEL OF EACH RELATIONSHIP TO BE INVESTIGATED

period of the climate index that is the shortest, to see whether this makes a difference for the optimal correlation height. Finally Relation Three can be specified by using the details mentioned in Relation One and Two and combine these. This way Figure 4 is created. Like Relation Two, also the Third can be used for a multiple regression between two climate indexes and the runoff for the period of the climate index with the shortest period of infuence. This period of influence is explained in the intorduction and in Chapter 2.2.1. The schemes like Figure 4 for the multiple regression for relation two and three are given in Appendix II, Figure 23.

As can be understood Relation One and Two are not independently of one another. The outcome of Relation One can be used as an input for Relation Two. Consequently Relation Two is not just about heavy precipitation, but about heavy precipitation causing the high runoff events found at research question (relation) one.

Finally it is also shown in Figure 4 for Relation Two and Three that the climate indexes have different periods for the correlation assesment. The PDO only a long term, the SOI both long and short term and the EASMI only short term. For the PDO this choice was made since it is a very long term index, and therefore it is estimated that it needs high temporal resolutions. For the SOI this is partly the same since Zhang et al. (2007) found a more long term relationship between ENSO and Yangtze river runoff already, so it is expected that this region may show similar results. Besides that ENSO may also show short term correlations, like what Jin et al. (2005) found for Japan and Korea. The EASMI is due to the shortage of data only investigated on short term since it is a yearly returning event (EASM).

3.2 Climate index information

3.2.1 Principles of ENSO and the SOI

The ENSO Phenomenon is a term for the El Niño and La Niña events. These events are caused by the interaction between the ocean and the atmosphere. Changes in one of them, for instance the atmosphere, thus effects the other as well. ENSO has three phases. The 'neutral' phase, El Niño and La Niña (Australian Bureau of Meteorology, 2012) . Normally the trade winds over the Ocean go from east to west, warmed up by the air in the west. This causes humid air to rise and causes precipitation in the west. The dry air then returns to the east, where the cycle begins again. With these conditions the air pressure in Tahiti is relatively low, and in Darwin relatively high. During an El Niño event this circulation is interpreted by local distortions due to weakening of the trade winds, which causes warm trade winds flow to the east instead of the west. This causes precipitation in the east, and relative dry conditions in the western part of the Pacific Ocean (National Oceanic and Atmospheric Administration, 2014). With these conditions the difference between the air pressure measured at Tahiti and Darwin is less. La Niña

$$SOI = \frac{(Standarized\ Tahiti - standarized\ Darwin)}{MSD} \qquad \textit{Eq 1.}$$

$$Standarized\ Tahiti = \frac{(actual\ Tahiti\ SLP - mean\ Tahiti\ SLP)}{Standard\ deviation\ Tahiti} \qquad \textit{Eq 2.}$$

$$Standarized\ Darwin = \frac{(actual\ Darwin\ SLP - mean\ Darwin\ SLP)}{Standard\ deviation\ Darwin} \qquad \textit{Eq 3.}$$

$$MSD = \sqrt{\sum \frac{Standarized\ Tahiti^2 - standarized\ Darwin^2}{N}} \qquad \textit{Eq 4.}$$

events in contrary are caused by stronger trade winds, which causes the values at Darwin and Tahiti to differ even more from each other than in normal situations. The ENSO phenomenon has the largest influence on heavy precipitation around June, July and August for the Yangtze in China (Lü, et al., 2011). This period, including May and September (as a buffer zone), can be used for the Lanjiang River Basin. The SOI index uses the differences in air pressure to calculate a value for ENSO's 'strength'. Values higher than 8 indicates a la Niña event, values below minus 8 are defined as an El Niño event (Australian Bureau of Meteorology, 2012). The basic formulas for the SOI index are given in Equation 1, 2, 3 and 4. The 'SLP' in these formulas stand for the sea level pressure.

3.2.2 **Principles of the PDO and the PDO index**

The PDO describes the climate phenomenon based on the sea surface temperature (SST) and the sea level pressure (SLP) in the North Pacific Ocean, and is of influence on areas lying northward of 20°N. (Mantua et al., 1997). The PDO is measured by the SST based PDO index, which has a positive (negative) and warm (cold) value if the SST is anomalously cold(warm) in the Western Pacific and warm(cold) in the Eastern Pacific ocean. For China in general this means that the northern and southern parts experience relatively dry periods during a warm period, and wet periods during cool periods. The area surrounding the middle and lower Yangtze Basin in contrast shows the opposite pattern: wet periods during the positive phases, and dry periods during the negative phases. The Lanjiang River Basin lies in a more complex area between a small positive correlation to the north (like the Yangtze Basin), and a more negative correlation to the south (Shen et al., 2006). The PDO index was found for the first time when doing an EOF (empirical orthogonal function) analysis performed by Zhang et al. (1997) to the anomalies of the SST values northward of 20°N, where it turned out that there was a leading mode. This leading mode that was found is called the PDO, which has a PDO index (Mantua et al, 1997). This PDO index is calculated by spatially averaging the monthly SST values northward of 20°N (so not just two locations like the SOI). To exclude possible long term climate changes, the global average anomalies are extracted from these values (since it is a relatively long term index compared to the SOI and EASMI. These EOF analysis like described above are done to compress the number of variables that are of influence on for example in this case anomalies of the SST values. When for example 100 variables are of influence, it could be that 6 variables describe 95% of the phenomenon. The period that the PDO has the most significant influence on the precipitation is not mentioned in earlier literature as far as known for the Eastern part of China.

3.2.3 **Principles of the EASM and the EASMI**

The EASM describes a component of the Asian climate system that is partly caused by the thermal contrast between the Eurasia continent and the Pacific Ocean. This thermal contrast is influenced by the Tibetan plateau, the world's highest land plateau (Wang, et al., 2008). One of the main features is the concentration of a precipitation band in an east west direction. The period that the EASM will affect the Lanjiang River Basin with the precipitation is mainly during the months June, July and August (Zhou, Gong, Li, & Li, 2009; Li J. , 2014). Due to the complexity of the EASM it is difficult to measure the phenomenon, and there is no general accepted index yet for this climate event (Zhou et al., 2009; Wang, et al., 2008). Yet, like describe earlier, research has been carried out to find the best suited index for different regions. The EASMI could be a correct index to use in the Lanjiang River Basin, since the index is developed for the region between 10°–40°N and 110°–140°E; the eastern part of China (Li J. , 2014; Wang, et al., 2008). The EASMI is based on wind vectors in this specific region, as it is a DNS based index (Li & Zeng, 2002). The DNS formula uses the wind vectors (speed and direction) at a certain point to calculate the DNS value. The general formula for the DNS is given in Equation 5 (Li & Zeng, 2002).

$$\delta = \frac{\left\|\overline{V_1} - V_i\right\|}{\left\|\overline{V}\right\|} \qquad \textit{Eq 5.}$$

In which V_1 'stripe' are the January climatological and V_i the monthly wind vectors. V 'stripe' is the mean of the January and July climatological wind vectors (Li & Zeng, 2002).

3.2.4 **Combination of the indexes**

The three indexes are not fully independent of each other. There is an interaction between the PDO, ENSO (SOI) and EASM (EASMI) by which the PDO has an influence on the EASM as already explained by many previous studies (Feng et al., 2013). When the PDO has a negative phase, it stimulates ENSO's positive phase, i.e.: it weakens the El Niño phase and makes the process of turning the El Niño into a La Niña faster (Feng et al., 2013). This since a negative PDO phase has the same anomalies for the SST as the positive phase for the SOI: cooler in the Eastern part, and warmer in the Western part of the Pacific. In contrast, a positive PDO strengthens a negative SOI phase (El Niño) since it has higher SST values for the Eastern part and lower values for the Western part of the Pacific. Therefore the relation between the PDO and SOI is negative in general (Mantua et al., 1997). When the negative phase of ENSO, El Niño, is strengthened by the positive PDO, the EASM has less spatial influence compared to the situation where the PDO is in a negative phase and the EASM has more spatial influence. The El Niño in the case of a positive PDO has a strong influence in the North Indian Ocean, which is the place the EASM anomalies originate (Feng et al., 2013). A weaker EASM, caused by a positive PDO phase, results in less precipitation in Northern China (Yellow River area), and more precipitation in and around the Yangtze River basin during the summer as described by Li et al. (2008), Ronghui et al. (2012) and Feng et al. (2013) using multiple previous studies. This theory is illustrated in Figure 5 for the period that is important for the research as mentioned in Chapter 2.2.1. Many studies in addition already found that during the period 1980-2000 the precipitation in the Northern part of China was anomaly low, and in the Yangtze River Basin and Eastern china anomaly high as shown by Li et al. (2008).

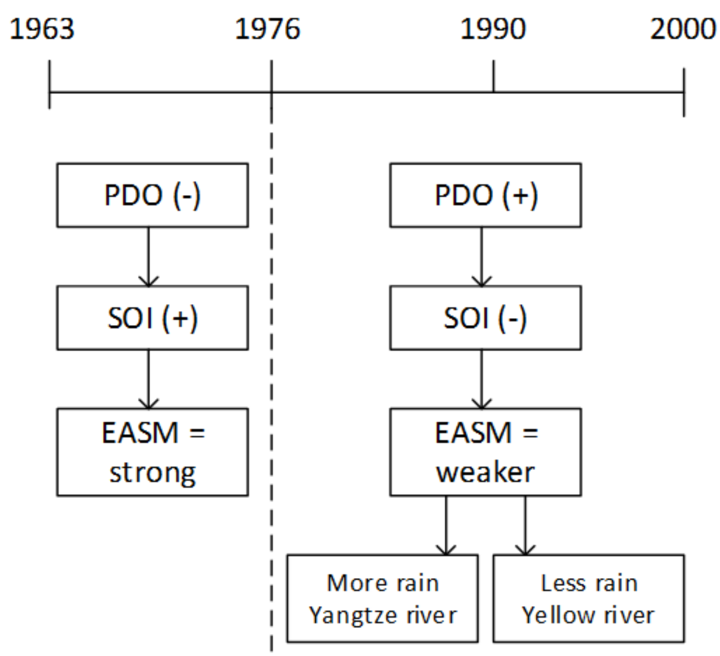


FIGURE 5: COMBINATION OF THE INDEXES; INTERACTION SHOWN BY TIMELINE.

3.3 Data Usage

3.3.1 Data split up: calibration and validation

For the validation there is a distinction made between the First Research Question and the Second and Third Research Questions. The validation for the First Research Question will be executed by using a classical split-sample validation (Klemeš, 1986) test. Only in this study there is no real calibration process, since it is more comparing two periods than a real calibration and validation process. The Second and Third Research Questions are validated by comparing the two areas to see if they show the same trend (Quzhou and Jinhua area). This choice is made since the climate indexes, especially the SOI and PDO, have relatively long cycle times (2-7 years and 50 years). This may cause large errors when choosing to do a split sample test where the validation period is only a short period compared to the cycle period of the indexes. Besides these two validation methods, the Second and Third Research Questions are also investigated for the positive, negative and 'combined' PDO phase separately (in Figure 6 'A1', 'A2' and B) for the SOI and EASMI (short term), since this could make a difference as readable in Chapter 3.2.4. Whenever in this report the terms 'three smaller periods' are used for the short term relationship, it is linked to the periods mentioned here. For the split sample validation of the First Research Question the dataset is split up in two continuous parts. The parts are divided by the ratio 70 and 30 percent, according to what Klemeš (1986) advises when it is not clear if the dataset is large enough for a fifty-fifty partition. The 70 percent belongs to the first 'calibration' period, and the 30 precent to the second 'validation' period. This means that the length for the first 'calibration' period for both the Jinhua and Quzhou area is 27 years between January 1963 and January 1990, and the length of the 'validation' period 11 years between January 1990 and January 2001. The periods are still named by calibration and validation to not cause mistakes with the three periods used for Question Two and Three, but like mentioned there is no real calibration process since it is correlation assessment without calibrating any parameters. In Figure 6 the first period is indicated with an 'A' and the second 'validation' period with a 'B'.

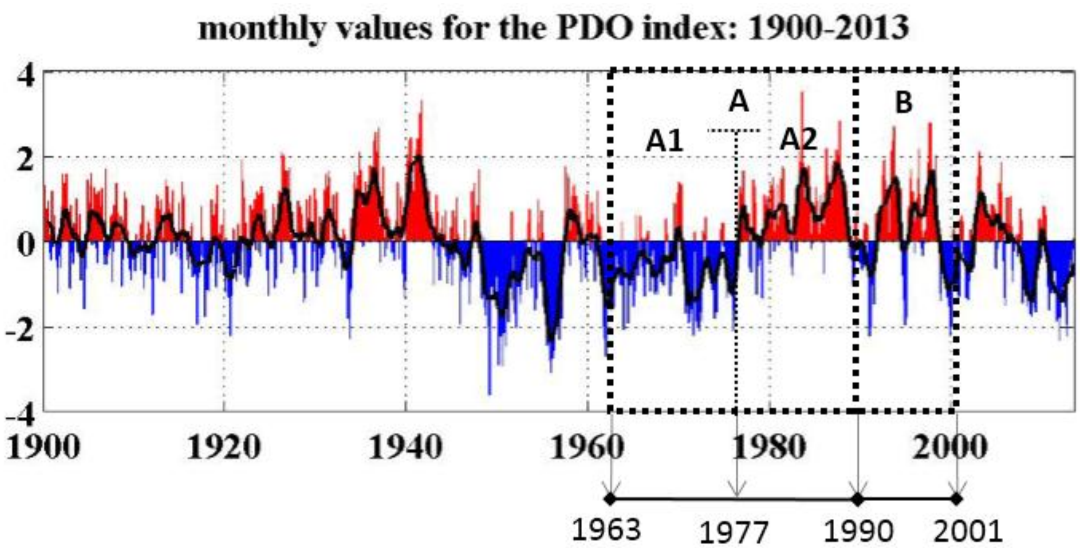


FIGURE 6: SEPERATION OF THE TOTAL PERIOD THAT THE DATA IS AVAILABLE, TO SMALLER SUB PERIODS BASED ON THE PDO VALUE.

3.3.2 **Interpolating the PDO, SOI and EASMI data**

The data that are used for the interpolation are the 'raw' index data. It is possible to interpolate the data using different methods such as linear and spline interpolation. The interpolation method that is being used to interpolate the monthly data to daily values is the spline interpolation method, since the index values are averages which means they could potentially be higher. When the linear method would have been chosen, the averages would be sometime peak values, which is a bit strange if they are monthly averages. The spline interpolation method in contrast is able to create higher peak values than the monthly averages while making the line smooth (Wilks, 2006). Appendix I (Figure 20) gives an example of the output of the spline interpolation compared to the 'raw' monthly data points and a linear interpolation.

3.3.3 **Peak over threshold method for runoff data**

The values for the runoff that will be used to find a possible relation with the precipitation and climate indexes can be determined by an annual maximum flood (AMF) method or by a so called peak over threshold (POT) method, sometimes referred as partial duration series (PDS) (Madsen et al, 1997; Lang et al, 1999). The AMF selects the highest value per year, while the POT selects all the values above a certain level (threshold). Because the AMF only selects one value per year, al lot of useful data are 'lost'. This for example because there are multiple high runoff values in a certain year, while the next year the runoff values are generally lower than the previous year. Therefore the POT method is selected to determine the high runoff values in this research.

The first step is to find the peaks that can be used as an input for the next step: determining the threshold value. These peaks need to be independent, and therefore for example the peaks need to have a certain distance between them. For this research the conditions for independency are used that also have been used in a recent research to the Lanjiang River Basin (Zhang, Xu, & Booij, 2014), who use the conditions described by the USGS (1982). These conditions are given in Equations 6 and 7.

$$D_p = 5 + log(A_i) \qquad \text{Eq. 6}$$

$$G_p = 0.75 * P_m \qquad \text{Eq. 7}$$

In which D_p is the distance between the peaks in days, and A_i is the area of interest in square miles. Furthermore G_P is the minimum value of the distance (D_P) between two peaks, and P_m is the value of the lowest peak.

The next objective is to choose the correct threshold value for the peaks. To determine the threshold value, two approaches can be used. The first one is a physical based value, using a value by which the river starts for example with overflowing. The second one is based on mathematical and statistical reasoning (Lang, Ouarda, & Bobee, 1999). Since there is no information available about the water level in the rivers, and how this corresponds to potential flood risk, the second method should be applied. Bezak et all (2013) showed in a recent study that this is still a very doubtful and subjective process, since every situation (area) is different, and in the past a lot of studies have been done with different recommendations. For this study the threshold value will be chosen by looking to the number of peaks that will be higher than the threshold value, since there need to be sufficient data for the correlation assessments. Besides this, two methods will be used to give an indication what could be a useful region to seek for a threshold value in order to not randomly seek for a correct value. The first is by looking at the frequency graphs for the percentage of the peaks that are below a certain threshold value. Therefore the formula given in Eq. 8 is used, with a minimum value for the peaks to exclude the low values that are no real peaks. Besides this method, a mean excess plot (Davison & Smith, 1990; Gilli & Kaellezi, 2006) is made for both

Jinhua and Quzhou. This plot gives an insight in how the mean excess changes when the threshold value changes. For very high threshold values it will be visible that there are not enough values since the graph will be very capricious, and for values that are too low the graph has a very steep slope. The value that is correct according to these plots, is the value when the graph is more or less horizontal linear. The formula to create this graph is the same as used by Gilli and Kaellezi (2006), and is given in Eq. 9. When applying this formula for multiple threshold values 'u', the graph can be plotted.

$$P = (\frac{N_b}{N_t}) * 100$$ *Eq. 8*

In which P is the percentage of peaks below the threshold, N_b the number of peaks below the threshold value and N_t the total number of peaks.

$$e_n(u) = \frac{\sum_{i=k}^{n} (x_i{}^n - u)}{n - k + 1} \rightarrow k = min\,\{i \mid x_i{}^n > u\}$$ *Eq. 9*

In which 'e_n' is the mean excess value for a certain threshold u for the number 'n' of values that are above threshold u. 'x_i^n' Is the value of the peak 'i' that is bigger than the threshold value. 'k' Is the value for the peak that is closest to the threshold value.

3.4 Regression methods

Pearson (Pearson, 1896) is the linear regression method that will be used in this study. Besides that also the multiple regression is applied. Below both methods are further explained. Lastly the significance test is explained.

3.4.1 Pearson

When using Pearson, the formula given in Eq. 10 is used. Pearson compares two data series to find a correlation on a non-ranked base. The two main drawbacks of Pearson's formula however are that it is not robust and not resistant (Wilks, 2006, p. 51). It is not robust since it only recognizes linear relationships, and no other strong relationships such as exponential and quadratic. It is not resistant since extreme values could be of large influence. The first of these two drawbacks, the robustness, could be included by applying for example Spearman (1904) since this is a rank based method. Although this method was carried out for this research, it is not further described in this report since it did not have any real additional value when comparing the results. The second downside does not necessarily have to be a downside in this study, since this research is mainly about the high runoff values (including the outliers).

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2 \sum_{i=1}^{n}(Y_i - \overline{Y})^2}}$$ *Eq. 10*

In which X_i and Y_i are values of the 'i' ^{the} position of two data series X and Y, and X 'stripe' and Y 'stripe' are the average values of the data series of X and Y. The outcome r is the correlation coefficient.

3.4.2 **Multiple regression**

For the correlation assessments involving the climate index data, it can also be interesting to see if a combination of more climate indexes delivers higher correlation scores comparing to linear regression (Pearson). Therefore the indexes are combined for a multiple regression analysis. The combinations investigated are the PDO-SOI, SOI-EASMI and EASMI-PDO. The formula that will be used for the multiple regression is given in Eq. 12 (Kutner et al., 2005; Wilks, 2006). Important to note is that the assumption is made that the variables 'x', in this case the climate indexes, are independent from each other. In reality they are not, since they are partly dependent from each other in a complex way.

$$\widehat{y} = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_k x_k \qquad \textit{Eq. 12}$$

Using this formula, it is possible to get estimated values 'ŷ' based on the climate indexes. When comparing these estimated values with the real observation 'y' a correlation coefficient can be determined, only this time by combining two climate indexes.

3.4.3 **Testing significance**

To determine the significance the formula given by Kutner et al. (2005) is used for a significance of 95%, one sided, which is given in Eq. 13. The corresponding table can be found in Kutner et all (2005) p. 1317. To test the significance a null hypothesis is determined which states that the correlation is not significant against an alternative which says that is significant. When the null hypothesis is true it is accpeted, when this is not the case the alternative hypothesis is accepted and there is a significant correlation. Eq. 14 gives the null hypothesis and Eq. 15 the alternative hypothesis. Note that the value that determines the outcome of the significance test is different for each correlation assesment, as it depends on the number of samples available for the correlation assessment . The used significancies for the different correlation assessments are given in Appendix IV.

$$t^* = \frac{r_{\sqrt{n-2}}}{\sqrt{1-r_2}} \qquad \textit{Eq. 13}$$

$$H_0 : \beta = 0 \qquad \textit{Eq. 14}$$

$$H_A : \beta \neq 0 \qquad \textit{Eq. 15}$$

In which t^* is the value that needs to be compared to the value in the table, when determining the significance. 'r' Is the correlation found by using Pearson and 'n-2' the amount of 'degrees of freedom'.

Another test, which is more subjective, is whether the outcome is realistic and logical. When a correlation is just significant, it can still be a sort of coincidence. Therefore it is necessary to check whether it is physically logical that there is a relationship between to variables. Therefore it is always tried in this study to find a logical explanation for the results, and it is discussed in some correlation assessments how literally the coefficient must be taken, or that it only gives an indication of a higher chance instead of a real relation.

3.5 **Lag and temporal resolution**

To find the highest correlation the lag and temporal resolution can be adjusted. This is for example done by Demirel et al. (2013) for low flow indicators at the Rhine Basin and by Lü, et al. (2011) for ENSO indices influencing general runoff values at the Yellow River Basin. Each of the correlation assessments has a certain optimal lag and temporal resolution for the correlation. The lag means that there is a delay in influence of for example variable X regarding to Y. When an optimal lag of one day is valid for the optimal correlation between X and Y it means that X has the most significant relation to Y one day after variable X happened compared to Y (The best correlation is found when variable Y is measured one day after X, and these values are compared to each other). The temporal resolution of variable X refers to the broadness in for example time for which X is measured. A temporal resolution of for example seven days means that variable X is not a measurement of just one day, but an average of seven days that shifts when parameter Y shift as well. The example of X and Y is illustrated in Figure 7, for the case of the correlation between a certain precipitation event X and runoff event Y. These two aspects, the lag and the temporal resolution are taken into account when searching the optimal correlation between the relations. These lags and temporal resolutions are calculated by including them in the Matlab code. This is done by creating a loop in a loop within the code that calculates the correlation by using Pearson.

When changing the lag and temporal resolution, it is important to have a clear boundary for the maximum lag and temporal resolution that will be applied for the analysis (Figure 8). For the EASMI this boundary (range) is equal to a maximum of 32 days combining the lag and temporal resolution (summation of these two) due to the data limitation of three months each year (two months for selecting high runoffs as seen in Chapter 2.2.1 (Figure 2), and one month for changing the lag and temporal resolution). Therefore the EASMI (short term) is tested for a temporal resolution and lag time that have summed up a maximum of 32 days. All these combinations are tested, but the one with the highest correlation is given. For the SOI (short term) this range is set on one year for the lag and 90 days for the temporal resolution, since other studies investigating the relationship between the SOI and the precipitation found mainly high correlations within one year of the ENSO event (Jin et al., 2005; Lü, et al., 2011). Lastly, for the PDO and SOI (long term) a temporal resolution of 20 years has been chosen since Zhang et al. (2007) found a relationship between ENSO and the annual maximum runoff for the Yangtze River Basin within this range. The temporal resolution will be increased each time in steps of 100 days. The lag will be set on zero

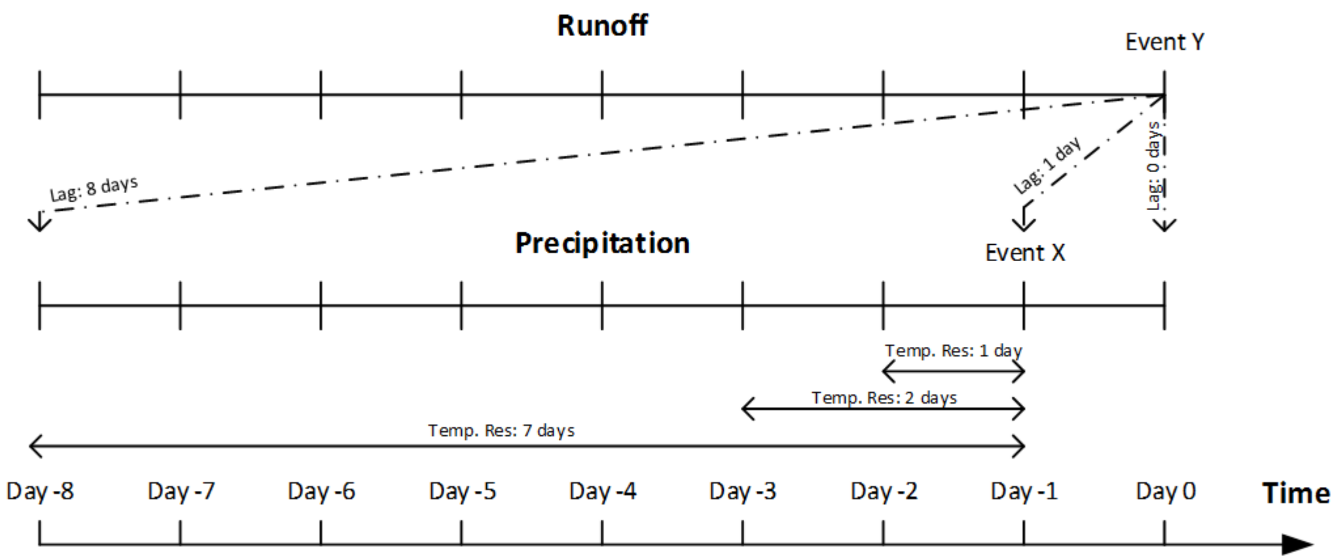


FIGURE 7: FIGURE OF THE EXAMPLE ABOUT THE LAG AND THE TEMPORAL RESOLUTION EXPLAINED IN THE TEXT.

days in this report since a lag time is not very realistic for a time period that is estimated for more then 8 years (Zhang et al., 2007), and the correlations height do not differ much when adjusting the lag time as found after calculating them. Therefore these results are not shown in this report, and will not be further discussed in this report since it would only make the methodology unnecessary complicated. In this report for the long term the lag time is thus equal to zero days. Also for the multiple regression anaylis only the temporal resolution will be adjusted for the SOI and PDO. For the EASMI the lag and the temporal resolution will be adjusted, depending on which one of them causes the most variation in correlation height. The other one is set on the number of days found in the linear regression analysis.

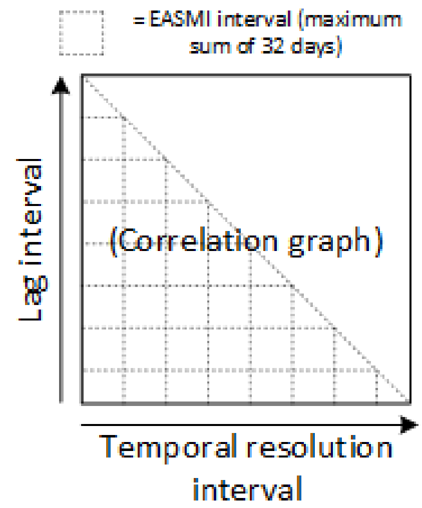


FIGURE 8: EXAMPLE CORRELATION GRAPH.

3.6 Using a three day average runoff instead of daily runoff values

In addition to the daily runoff relations with the precipitation and the climate index, it is interesting to see whether the correlation between the runoff and the precipitation and the runoff and the climate indexes (Relation One and Three in Chapter 3.1, Figure 3) will change when averages are used for the runoff values instead of the daily maximum values. Therefore three day average (day before and after original daily runoff event included) values are used instead of the daily maximum values, as also used by Demirel et al. (2013) and Southard (1993). This would also give more information about the relation between precipitation/climate indexes and the volume of the peak runoff, since a flood has a duration of more than one day in most situations as shown by for example Nadarajah and Shiau (2005). They investigated a fairly bigger drainage area, and showed that a three day duration of a high runoff is a relatively short period (floods often have a longer duration). Another study (Wang et al., 2012) about a smaller drainage area showed that three days was exactly the average of the duration of flood peaks. For this study three days has been chosen, though it might be a little short period. The reason behind this choice is that it is necessary to have sufficient measurement points, which would decline in number when taking more days for the average (for example five or seven days).

The hypothesis is that when using a three day average the correlation increases, especially for high flows that last for multiple days. On the other hand using the average is also less precise compared to the daily runoff values, since the relation tells something about a three day average, and therefore leaves more room for fluctuations (it will not be clear when the peak of the three day average will be achieved within these three days when people want to use these kind of results it for this purpose). To find out whether it makes a difference, the correlations for Questions One and Three (direct correlations between runoff and climate indexes) are also given for the three day average runoff. These runoff values may have different peak values compared to the daily runoff series, since all the values of the time series are averaged before seeking the peaks above the threshold value. This means that also the number of samples per index is different compared to the daily runoff values. This further discussed in Chapter 4.1.

4 RESULTS

In this chapter the results are given from the research carried out as described in the methodology (Chapter 3). The first subject discussed is the threshold value. After this the results for the different relationships are given. Depending on the correlation assessment a graph is given that shows the correlation value for a certain lag with a certain temporal resolution. Besides these graphs, each assessment also has a table with the value for the maximum correlation and if it is significant, together with the related lag and temporal resolution. A last important general note: when a correlation is underlined in this report, it means it is significant.

4.1 Threshold value and correlation method determination

The threshold is determined by using two methods like explained in the methodology in Chapter 3.3.3. For the Jinhua area that means a threshold value of 250 m^3/s is appropriate, since the graph is horizontal and linear for the mean excess plot, and the frequency lies above the 50 percent (Appendix I, Figure 21). For the Quzhou area this value is 500 m^3/s. For this value the frequency lies above the 60 percent, and the mean excess plot is approximately horizontal and linear (Appendix I, Figure 22). For both the areas this threshold value cannot be any higher, although it may seem possible when looking at the mean excess and frequency plots. This is due to the number of peaks over the threshold value for the EASMI period (that needs to be sufficient) as shown in Table 2. Using these POT values the number of data points are obtained for each of the indexes for Jinhua and Quzhou (Table 2) (number of times a peak is higher than the threshold value). These data points will be used for the calibration and the validation. For the three day average runoff they are also given in Table 2.

TABLE 2: NUMBER OF SAMPLES PER INDEX PER AREA.

	Jinhua threshold: 250 m^3/s			Quzhou threshold: 500 m^3/s		
	Full year	*SOI/PDO*	*EASMI*	*Full year*	*SOI/PDO*	*EASMI*
	Calibration					
Q	212	114	32	174	97	18
Q3	179	103	28	146	87	16
	Validation					
Q	83	43	16	63	30	11
Q3	76	38	13	54	27	9
	Total					
Q	295	157	48	237	127	29
Q3	255	141	41	200	114	25

4.2 Relation high runoff values (Q and Q3) – precipitation (P)

For the relation between the runoff values and the precipitation the graphs are given for Jinhua and Quzhou for three periods in Figure 9 and Figure 10. The periods are the full year, 5 months for the SOI and PDO and 2 months for the EASMI. The whole year is added to compare the results with Zhang et al. (2014) who also investigated this relation. The maximum value is indicated by a white cross, but for the chosen correlations the appropriate values are used which sometimes have another temporal resolution compared to the maximum.

4.2.1 Using daily peak values for runoff

Jinhua

For the Jinhua area the correlation reaches an appropriate value at a lag of zero days and a temporal resolution of three days for the three different periods for the first ‘calibration’ period. The second ‘validation’ period shows the same numbers for the lag, and almost the same for the temporal resolution. The difference is that the validation period is still a bit increasing after three days until four days, although it is not a lot. The calibration period in contrast shows a lower correlation for the EASMI when comparing four days with three days of temporal resolution. The value of an appropriate correlation is in average higher for the validation, with the maximum difference visible at the EASMI period. Furthermore the correlation for the EASMI period is relatively low compared to the SOI/PDO period and the 'full year' period coefficient.

Quzhou

The Quzhou area has equally to the Jinhua area only lags of zero days for the highest values, both for the 'calibration' and the 'validation' period. This seems reasonable for heavy precipitation events, since one should expect that these events react quickly to the runoff. For the calibration the highest correlation value is obtained after three days for the temporal resolution for all the periods. According to the validation this should be two days. Still the difference is not that much, and a temporal resolution of three days seems reasonable. The value for the calibration is in general for the three periods higher for the calibration than the validation, especially when looking to the EASMI. Secondly it can be seen that the EASMI coefficient is, in contrast to the Jinhua area, relatively high compared to the SOI/PDO and 'full year' period. A final remarkable finding is that the correlation for the Quzhou area in general is higher than the Jinhua area. This is in accordance to what Zhang et al. (2014) found for the length of a full year. The average correlation (Quzhou and Jinhua) of about 0.85 is comparable to other studies, like Chen et al. (2014) for the Yangtze basin, who found a correlation of 0.89 for the precipitation-runoff relation.

4.2.2 Using three day averages peak values for runoff

Jinhua

For the Jinhua area the three day runoff does not differ much from the daily values in general, it is even a bit lower for a relatively small temporal resolution. The lag for each period is zero days as can be seen in Table 3, and the temporal resolution in achieved for the SOI/PDO and 'full year' period after approximately three days. The only big difference is visible at the EASMI period. For this period the optimal correlation is reached after 6 days for the temporal resolution. The results for the 'validation' period for the three day average are given in Appendix III.

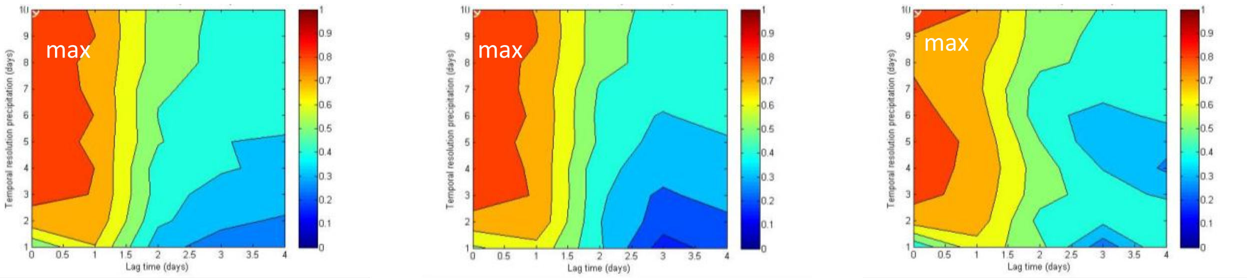
Quzhou

The optimal lag for the Quzhou area is zero days (Table 3), which is the same lag as for the daily runoff peak values. The temporal resolution is also equal to the daily runoff values with a length of 3 days. The correlations that are appropriate for the three day average runoff values for the Quzhou area are generally a bit higher for all three periods compared to the correlation for the Quzhou area for the daily runoff values.

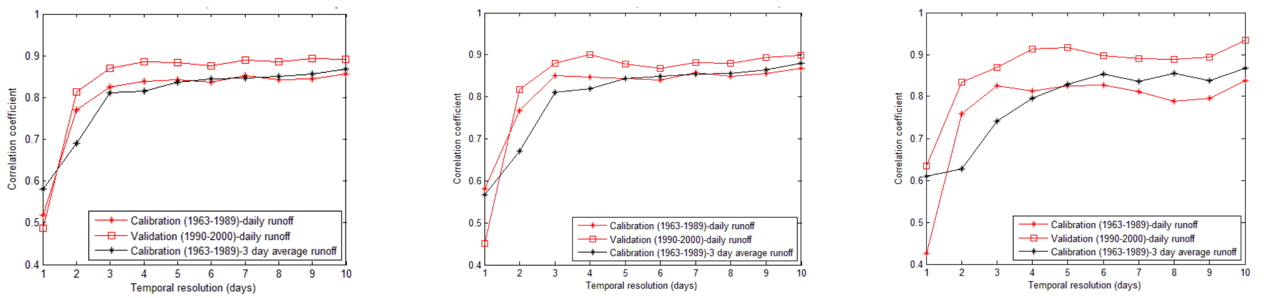
TABLE 3: CORRELATION VALUES RUNOFF – PRECIPITATION RELATION. SIGNIFICANT VALUES ARE UNDERLINED.

Index Period	Correlation Period One 'calibration' daily runoff	Lag (days)	Temporal resolution (days)	Correlation Period Two 'validation' daily runoff	Lag (days)	Temporal resolution (days)	Correlation Period One 'calibration' three day average runoff	Lag (days)	Temporal resolution (days)
				Jinhua					
Full year	0.824	0	3	0.871	0	3	0.811	0	3
SOI/PDO	0.850	0	3	0.880	0	3	0.810	0	3
EASMI	0.825	0	3	0.869	0	4	0.829	0	4
				Quzhou					
Full year	0.891	0	3	0.794	0	2	0.925	0	2
SOI/PDO	0.895	0	3	0.769	0	2	0.925	0	2
EASMI	0.928	0	3	0.883	0	2	0.953	0	2

Jinhua



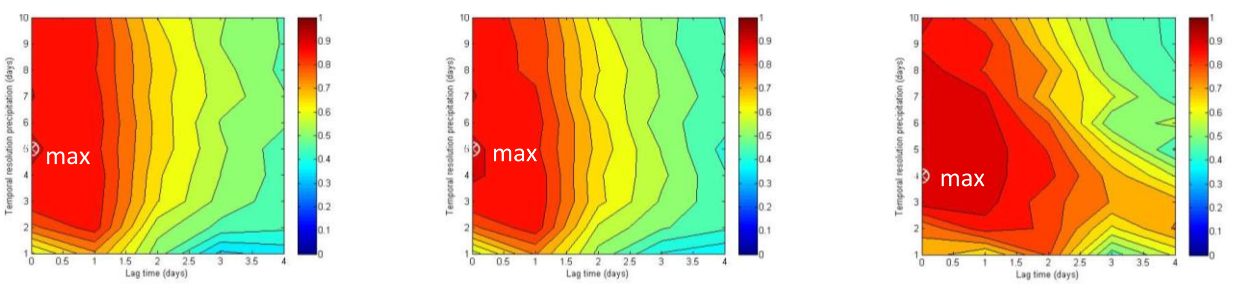
(A) full year for 'calibration' period (1963-2000) (B) SOI/PDO period for 'calibration' period (1963-2000) (C) EASMI period for 'calibration' period (1963-2000)



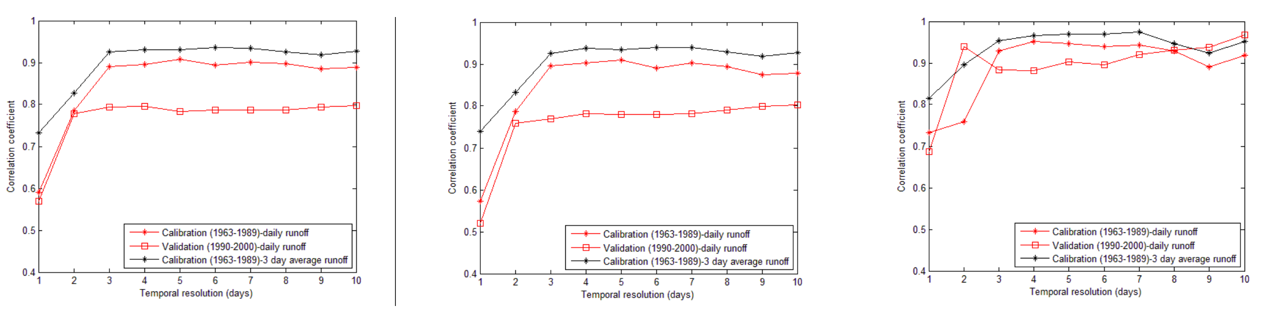
(D) full year, for 'calibration' and 'validation' period (E) SOI/PDO period, for 'calibration' and 'validation' period (F) EASMI period, for 'calibration' and 'validation' period

FIGURE 9: CORRELATION COEFFICIENTS BETWEEN RUNOFF AND PRECIPITATION FOR JINHUA FOR DIFFERENT LAG AND TEMPORAL RESOLUTIONS FOR PRECIPITATION FOR DIFFERENT PERIODS GIVEN IN 'A, B AND C'. THE CORRELATION FOR A LAG TIME OF ZERO DAYS IS GIVEN IN GRAPHS 'D, E AND F', INCLUDING THE DAILY AND THREE DAY RUNOFF CORRELATION. THE MAXIMUM CORRELATION VALUES ARE INDICATED WITH A WHITE CROSS.

Quzhou



(A) full year for 'calibration' period (1963-2000) (B) SOI/PDO period for 'calibration' period (1963-2000) (C) EASMI period for 'calibration' period (1963-2000)



(D) full year, for 'calibration' and 'validation' period (E) SOI/PDO period, for 'calibration' and 'validation' period (F) EASMI period, for 'calibration' and 'validation' period

FIGURE 10: CORRELATION COEFFICIENTS BETWEEN RUNOFF AND PRECIPITATION FOR QUZHOU FOR DIFFERENT LAG AND TEMPORAL RESOLUTIONS FOR PRECIPITATION FOR DIFFERENT PERIODS GIVEN IN 'A, B AND C'. THE CORRELATION FOR A LAG TIME OF ZERO DAYS IS GIVEN IN GRAPHS 'D, E AND F', INCLUDING THE DAILY AND THREE DAY RUNOFF CORRELATION. THE MAXIMUM CORRELATION VALUES ARE INDICATED WITH A WHITE CROSS.

4.3 Relation precipitation (P) – climate indexes

After the relation between runoff and precipitation, the second step is to determine the relation between precipitation and the climate indexes. This relationship is investigated by Pearson using a linear regression analysis. Besides the standard linear regression, also a multiple regression is applied like mentioned in the methodology since there are more than one climate indexes involved in this research. The results are discussed per climate index for both the Jinhua and Quzhou area. The PDO like mentioned in the methodology (Chapter 3.1) is only investigated for long term periods (high temporal resolution), since it is a long term index. The SOI is investigated both for long and short term periods (high and low temporal resolution), and the EASMI only for a short term period since this is a yearly returning event.

4.3.1 Using linear regression

PDO

The method applied for the PDO for the long term can be found in Chapter 3.5. Figure 12 shows the graphs with the highest correlation points when applying a lag of zero days, therefore it is just a line with different values for different temporal resolutions. The appropriate correlation values are summarized together with the temporal resolution in days in Table 4.

For Jinhua there is a temporal resolution for which the correlation is significant. For the Quzhou in contrast the correlation is not significant, although it comes very close. The final temporal resolutions for the PDO that are found for the optimal combinations are given extracted from Figure 12, and given in Figure 13. When there are two clear peaks for the temporal resolution in the graphs in Figure 12, there are also two bars in Figure 13. The time in years in this table is rounded to the nearest half for a global impression. As seen, the correlation is only significant for the Jinhua area. The positive direction of the correlation is in line with the theory explained in the background information and what Shen et al. (2006) shows for the Lanjiang area. The PDO has influence on the EASM in such a way that it stimulates the precipitation during the summer when it is in a positive phase, what is the same as a positive relationship as seen in Figure 13. For the temporal resolution the PDO has the highest (stable) correlation around 8 - 18 years for Jinhua (and 15 – 18 years for Quzhou, but not significant). These numbers are based on Figure 12, in which they are the appropriate correlation in the graphs (only in days instead of years). These temporal resolutions seems reasonable since the PDO is a long term index.

TABLE 4: CORRELATION VALUES, LAG TIMES AND TEMPORAL RESOLUTIONS FOR PDO AND SOI LONG TERM RELATIONSHIP BETWEEN PRECIPITATION AND CLIMATE INDEXES (SOI AND PDO). SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index	Temporal resolution (days)	Correlation
Jinhua	PDO	3000-6500	0.19
	SOI	2500-5500	-0.21
Quzhou	PDO	5500-6500	0.14
	SOI	2400-3000/3900-4200	-0.17

SOI

For the SOI both short and long term relationships are explored. The maximum temporal resolutions and lag values are for the short term 1 year for the lag, and 3 months for the temporal resolution with and interval of 1 day. For the long term the lag and temporal resolution for the maximum correlation are the same as for the PDO. First the results for the short term are discussed, and after that the results for the long term correlations.

The short term results show that the SOI correlations, for which the graphs are given in Figure 11 for the full period and Appendix V (Figure 25) for the three small periods, are very fluctuating (every 50-100 days another correlation direction). It is not clear why some periods are specifically positive and other negative for this region (within a small lag and temporal time). There is however the presumption that the different positive and negative phases are caused by the different stages of ENSO; El Niño and La Niña. Both these phases could react differently and have different lag times as shown by Lau and Weng (2001) and Jin et al. (2005). According to these researches even the strength of the El Niño or La Niña matters for the lag time on a short term. In this research the focus will not be on this separation, but it may be interesting to further investigate this since there is a significant value for Quzhou for the full period as shown in Table 6. Also, when dividing the full period in three smaller periods like discussed in Chapter 3.3.1, there are a few significant peak values mainly in the positive (First Period, 1963-1976) and negative (Second Period, 1977-1989) periods as seen in Appendix V, (Table 22). Furthermore it seems that the very small peaks that only occur for temporal resolutions smaller than one month are a result of the fluctuating SOI index (changes every month, although it has a trend on the long term), since they disappear when the temporal resolution gets higher. Besides that it is remarkable that the SOI has very positive correlations for the second period (significant for P - SOI and Q3 – SOI relation), and very negative correlations for the First Period (significant for P – SOI relation). This does not mean that the correlation changes during the shift from a negative to a positive PDO, since it seems that the positive or negative correlation is just more highlighted for the different PDO phases. During the negative PDO phase the SOI has clearly stronger negative correlations, and during the positive PDO phase stronger positive correlations. For the Third Period this is more a combination. Therefore there is the presumption that the PDO has influence on the SOI, like also mentioned in Chapter 3.2.4. However, since it is not clear how the relation with the different stages of ENSO is, there could be no further conclusion drawn from these results other than that it seems like interesting information for further research.

For the long term the same procedure is used as for the PDO. The values for optimal temporal resolution that are used for the appropriate correlation are given in Table 4, based on the graphs in Figure 12. It is visible that the SOI has a significant relationship for both the Jinhua and Quzhou area. The temporal resolution for the Jinhua is 7 - 15 years, and for the Quzhou area 6.5 - 8 or 10.5 - 11.5 years for the optimal negative correlation. Zhang et al. (2007) found a positive relationship between the annual maximum runoff and ENSO for the lower reaches of the Yangtze River basin (which is relatively close to the Lanjiang River Basin), but in that research the NINO 3 index was used, which is calculated in another way than the SOI by using the SST values between 150° - 90°W and 5°S - 5°N (Ocean Observations Panel for Climate, 2014). The NINO 3 in contrast to the SOI gives positive values to El Niño events, and negative values to La Niña events. Therefore the negative relationship seems in accordance to what Zhang et al.(2007) found, tough it was of course between the runoff and the climate indexes, and not the precipitation (but when looking to the correlation between runoff and precipitation, it is highly certain that the correlation direction is the same). Finally, compared to the PDO findings, it seems that for the precipitation – climate index relation the Quzhou area has a more specific period that needs to be taken into account in comparison to the Jinhua area, both for the PDO and the SOI. A general overview is given in Figure 13.

EASMI

The EASMI has relatively the strongest correlation of the three indexes and is significant for both the regions for the maximum negative correlation as seen in Figure 11 and Table 6. This maximum is located for Jinhua at the combination of 18 days lag time and 2 days temporal resolution, and for the Quzhou area for 13 days temporal resolution and zero days lag time.

This difference in reaction time is possibly explainable since the EASM has a North-East advancing direction (Yihui & Chan, 2005), and the Quzhou is situated more westward compared to Jinhua. The high significant correlation is most easily explainable since it is a regional indicator in contrast to the SOI and the PDO. Furthermore the Quzhou area has clearly a higher correlation with the EASMI than the Jinhua region, which may be caused by the geographical position of the areas. Quzhou lies more land inwards compared to Jinhua and is therefore less affected by other influences from the sea, still both regions show a negative correlation which corresponds with the findings of Li (2014) about the EASMI index.

To analyze the figure even more, since the values are significant, it is split into three periods. Again these periods are divided by looking to the PDO index; the same periods that are also used for the PDO and SOI analysis since some studies indicate that the PDO has influence on ENSO and the EASM (Chapter 3.2.4). The correlations values are given in Table 5, based on the graphs shown in Appendix V (Figure 25). Although most of the correlations are not significant (mainly due to the low number of samples), it does show a trend. When looking at these graphs carefully it becomes clear that in the First Period, between 1963 and 1976, the EASMI has a lower correlation with the precipitation in comparison to 1977-1989 (and for Quzhou also 1990-2000). This is understandable when applying the theory in Chapter 3.2.4. This theory concludes that the PDO in a positive (negative) phase is a cause for a weaker (stronger) EASM, which is again a cause for more (less) precipitation in the Yangtze River Basin and the surroundings. This explains why the correlation is higher for both areas in the Second and Third Period compared to the First Period; since there is more precipitation in these periods combined with a weaker EASM, it seems logical that the correlation with the EASMI, which normally is negative as mentioned earlier, is stronger (more negative) because of the heavier precipitation. This is also in line with what Li (2014) notes; the EASM is weak in years of flooding, and strong in years of droughts in the area that is meaningful for the EASMI. The difference between the areas in correlation height is thus not clearly explainable (although the presumption is that it is due to the influences from the sea). The difference in reaction time (lag versus temporal resolution) seems less obvious than the graph of the total period indicated when looking to the three different periods in Table 5. Especially the Quzhou area is not reacting the same in the three periods (with the highest correlation for a certain lag time or temporal resolution), whereas the Jinhua area seems a little bit more stable with lag times. Of course the significant periods are of most interest. For the Jinhua area this is only Period Two, which corresponds to the theory mentioned above about the positive and negative PDO phases. The lag time for the maximum negative correlation for the Jinhua area during Period Two is equal to 25 days, combined with a temporal resolution of 2 days. For the Quzhou area only Period Three is significant, though it has to be mentioned that Period Two is also close to be significant. The lag time for Period Three is 9 days combined with zero days of temporal resolution. For Period Two this is approximately 30 days of temporal resolution combined with zero days of lag time. Important to note is that it is not really one highest value, but more a range that has a high correlation value as seen in Appendix V (Figure 25) .This range however seems to be within the 25-30 days for both the areas.

TABLE 5: CORRELATIONS VALUES FOR RELATION EASMI WITH PRECIPITATION FOR THREE SHORT PERIODS. SIGNIFICANT VALUES ARE UNDERLINED

Period	Correlation (minimum)	Lag (days)	Temporal resolution (days)	Correlation (minimum)	Lag (days)	Temporal resolution (days)
	Jinhua			Quzhou		
1963-1976	-0.128	26+	5+	-0.134	6	17+
1977-1989	-0.407	25	2	-0.546	0	28+
1989-2000	-0.129	14	15	-0.567	9	1

TABLE 6: CORRELATION VALUES FOR SOI AND EASMI WITH THE PRECIPITATION FOR SHORT PERIOD RELATIONS. SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index	Correlation max	Correlation min	Index	Correlation min
Jinhua	SOI	0.11	-0.038	EASMI	-0.116
Quzhou	SOI	0.0529	<u>-0.205</u>	EASMI	<u>-0.402</u>

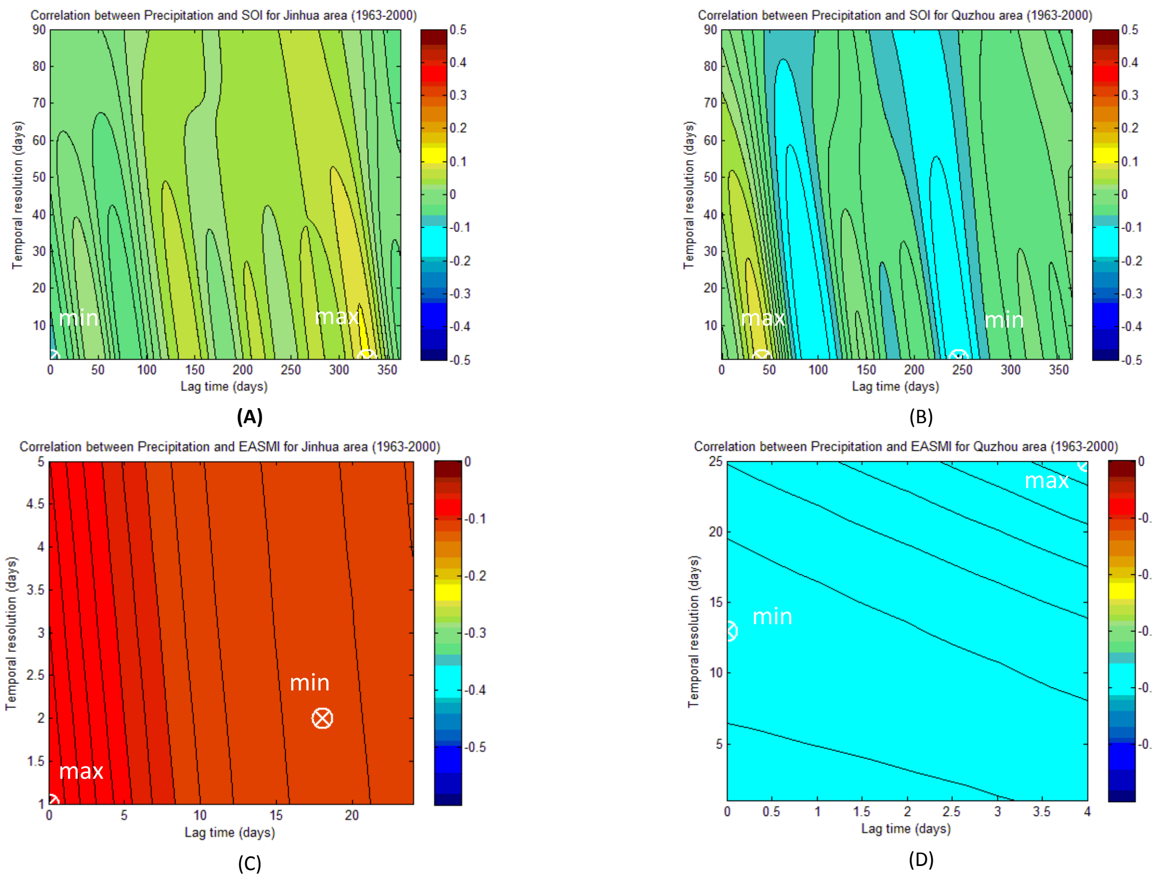


FIGURE 11: GRAPHS OF THE CORRELATION BETWEEN THE SOI AND THE EASMI, AND THE PRECIPITATION FOR DIFFERENT LAG EN TEMPORAL TIMES. USED PERIOD IS 1963-2000. 'A' IS JINHUA SOI, 'B' QUZHOU SOI, 'C' JINHUA EASMI AND 'D'QUZHOU EASMI. THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWED WITH A WHITE CROSS.

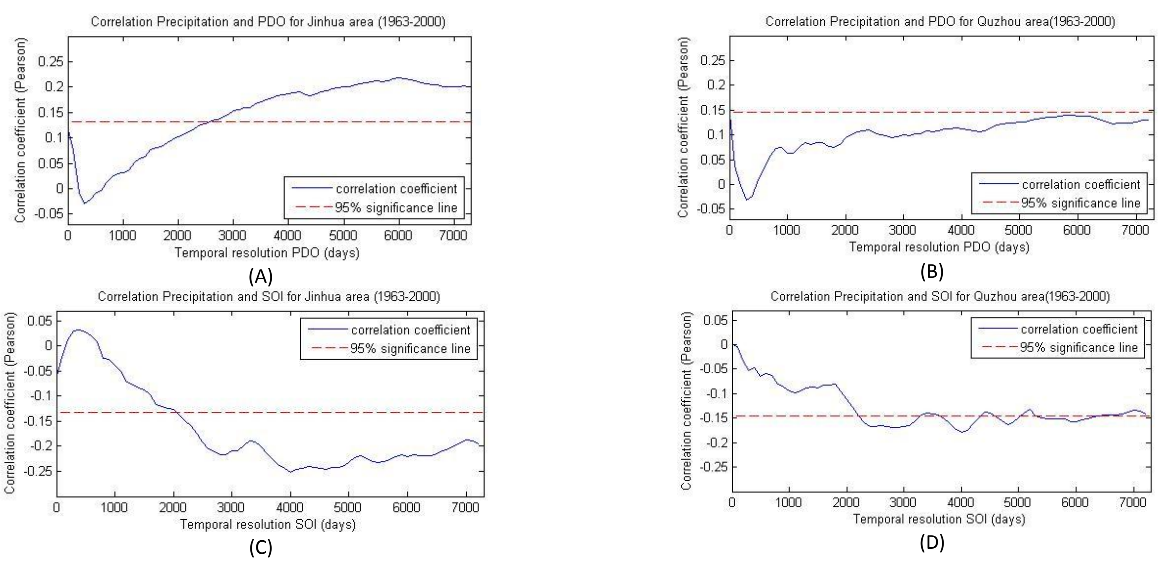


FIGURE 12: CORRELATION GRAPHS BETWEEN THE PRECIPITATION AND THE CLIMATE INDEXES FOR JINHUA PDO (A), QUZHOU PDO (B), JINHUA SOI (C) AND QUZHOU SOI (D) FOR DIFFERENT TEMPORAL RESOLUTIONS.

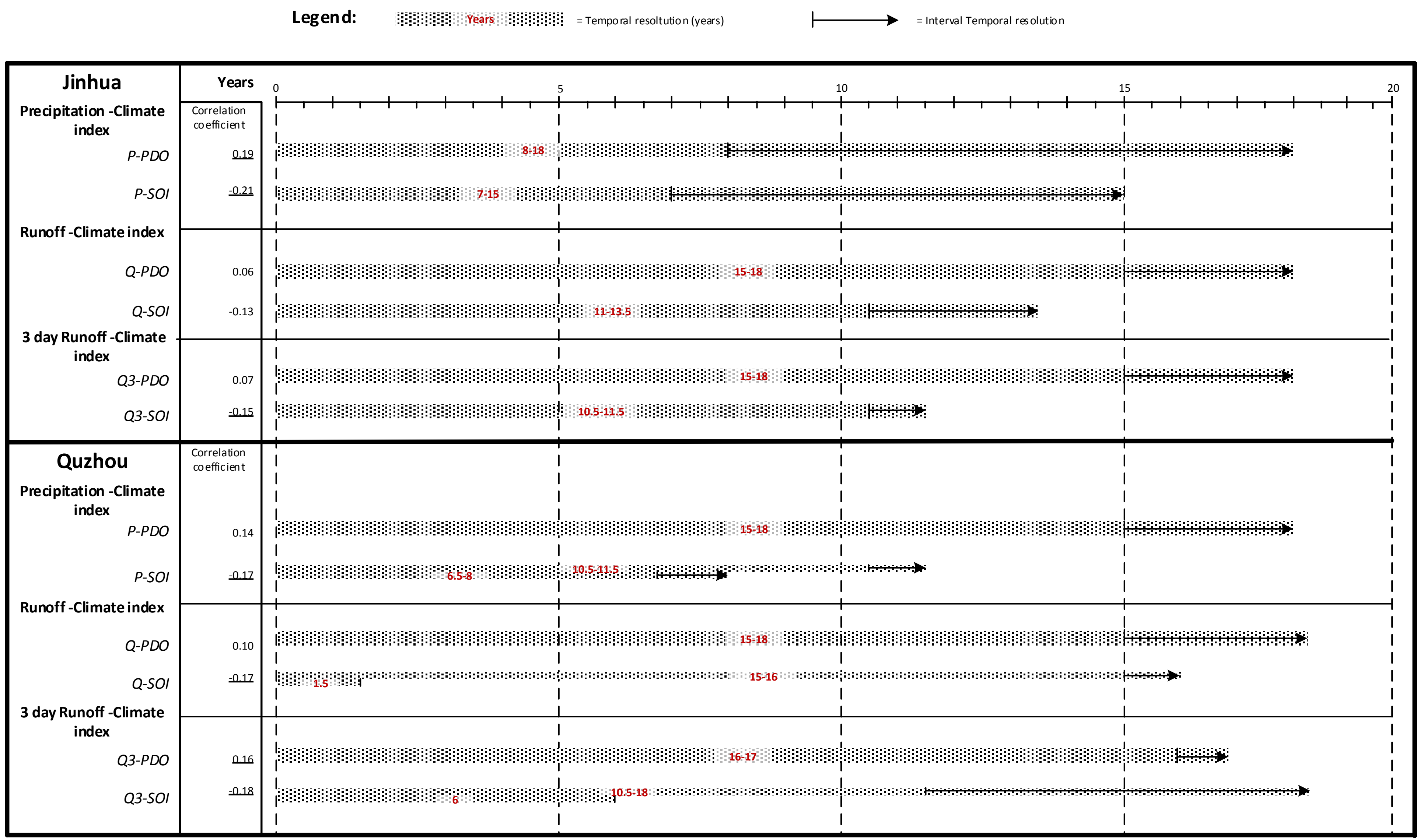


FIGURE 13: OVERVIEW TABLE WITH TEMPORAL RESOLUTION AND CORRELATION VALUES FOR THE LONG TERM RELATIONSHIP BETWEEN THE PRECIPITATION, HIGH RUNOFF AND THREE DAY AVERAGE HIGH RUNOFF WITH THE CLIMATE INDEXES FOR JINHUA AND QUZHOU

4.3.2 **Using multiple regression**

Other than linear regression, the multiple regression approach combines two of the three indexes to see if this will give a higher correlation compared to the linear regression and if there are different lag and temporal times. This is done for the SOI – PDO, the SOI – EASMI and the PDO – EASMI. For the multiple regression the temporal resolution for the PDO and SOI (long term) is adjusted in steps of 100 days. For the EASMI the lag is adjusted for both the Jinhua and Quzhou area, since when looking to the graphs (Chapter 4.3.1, Figure 11) this is more sensitive than adjusting the temporal resolution. The lag for the EASMI increases in steps of one day. The graphs of the outcomes are given in Figure 14 and calculated by using the method described in Chapter 3.4.2. Table 7 shows the correlation values when looking to the range that is given in this table, the values within this range are approximately all above this correlation value. Important therefore to note is that these correlation values do not correspond with the highest values indicated in Figure 14 with a white cross!

Most important firstly is that all the correlations, except for the EASMI combinations for Jinhua, are significant. Furthermore the PDO – SOI correlation value is higher compared to the correlation for the individual correlations for both Jinhua and Quzhou; 0.19(PDO) and -0.21(SOI) versus 0.29(PDO/SOI) for Jinhua, and 0.14(PDO) and -0.17(SOI) versus 0.22(PDO/SOI) for Quzhou. The temporal resolution for the SOI is a little different for the multiple regression, but not strange. For Quzhou it is 4000 days, which lies in the range of the linear regression's temporal resolution (Chapter 4.3.1, Table 4), and for Jinhua it is the average value of the linear regression's temporal resolutions range. For the PDO for Quzhou it is a little lower since it begin at 1200 days (less number of days), but since it is a range it falls partly in the range for the temporal resolution for the linear regression. For Jinhua the temporal resolution is fairly comparable. It seems therefore that the multiple regression is a useful tool to get a higher correlation when applying the PDO and SOI in it. For the EASMI combinations it only increases for the Jinhua area a lot; 0.23(EASMI/ PDO) and 0.24(EASMI/ SOI) versus -0.116(EASMI). Despite this major increase in correlation height the correlations are still not significant according to the used criteria. The absence of the negative sign for the EASMI combinations is explainable since the beta coefficient for the EASMI and SOI in the formula is negative, and for the PDO positive. For Quzhou it is more or less comparable to the linear regression. The lag times for the EAMSI are also not really different. A last thing to mention is the temporal resolution for the PDO for Quzhou area, this does not seem to be important. However this is in line with the correlation that is not really increasing when applying the multiple regression for the Quzhou area (-0.402 for EASMI linear regression versus 0.41 for EASMI/PDO multiple regression).

TABLE 7: CORRELATION VALUES FOR MULTIPLE REGRESSION ANALYSIS BETWEEN PRECIPITATION AND THE CLIMATE INDEXES WITH OPTIMAL LAG AND TEMPORAL RESOLUTIONS FOR THE COMBINATION OF TWO CLIMATE INDEXES. SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index combination	Correlation	Temp PDO (days)	Temp SOI (days)	Temp EASMI (days)	Lag EASMI (days)
Jinhua	PDO-SOI	<u>0.29</u>	1200-4000	4000-4600	-	-
	EASMI-PDO	0.23	3900-4500	-	2	17
	EASMI-SOI	0.24	-	2700-4200	2	22
Quzhou	PDO-SOI	<u>0.22</u>	4200	4000	-	-
	EASMI-PDO	<u>0.41</u>	2200	-	13	0
	EASMI-SOI	<u>0.44</u>	-	2600	13	1

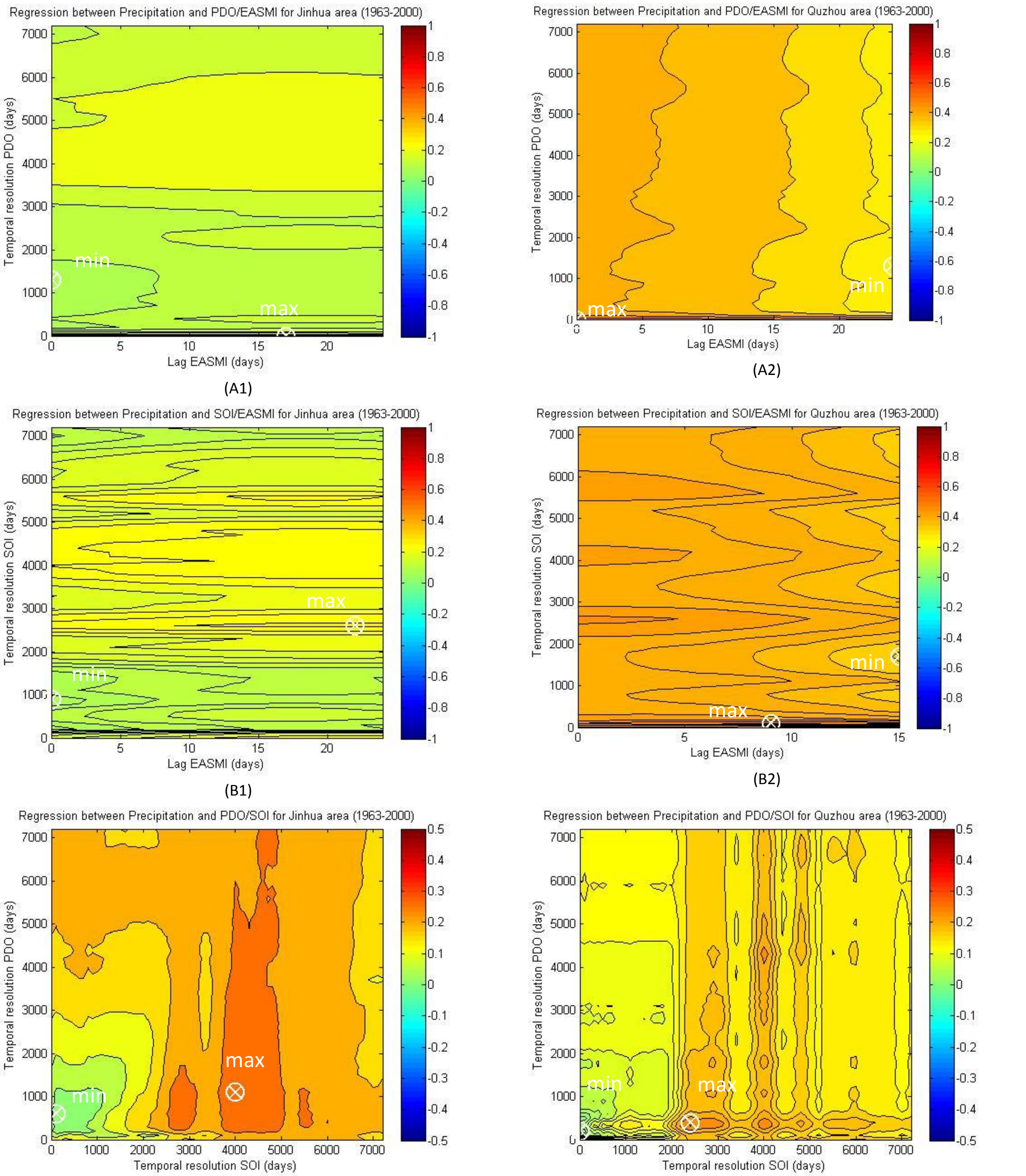


FIGURE 14: CORRELATION GRAPHS FOR MULTIPLE REGRESSION ANALYSIS BETWEEN PRECIPITATION AND CLIMATE INDEXES FOR PDO/EASMI (A), SOI/EASMI (B) AND PDO/SOI (C) FOR JINHUA (1) AND QUZHOU (2). THE MAXIMUM (NEGATIVE = MIN AND POSITIVE = MAX) VALUES ARE SHOWED WITH A WHITE CROSS.

4.4 Relation high runoff values (Q and Q3) – climate indexes

4.4.1 Using daily peak values – linear regression

PDO

The optimal temporal resolutions for the appropriate correlations are given in Table 8 based on the graphs in Figure 16, just like the correlation height. For the PDO it is obvious that the correlation for the runoff-PDO relation is lower than the relation between the precipitation-PDO; it is even not significant anymore. However this is more the case for the Jinhua area than for the Quzhou area (-0.19 and -0.06 for Jinhua versus 0.14 and 0.10 for Quzhou, Figure 13). Therefore it seems the Jinhua area somehow is more influenced by the relation between precipitation and runoff than the Quzhou region. Furthermore the temporal resolution for the optimal correlation is for both regions almost the same as for the precipitation-PDO relation, only the interval (temporal resolution length) given in Figure 13 for the temporal resolution for Jinhua is a bit lower (15-18 years for the runoff compared to 8-18 years for the precipitation).

TABLE 8: CORRELATION VALUES AND TEMPORAL RESOLUTIONS FOR PDO AND SOI LONG TERM RELATIONSHIP BETWEEN HIGH RUNOFF EVENTS AND CLIMATE INDEXES (SOI AND PDO). SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index	Temporal resolution (days)	Correlation
Jinhua	PDO	5500-6500	0.06
	SOI	4000-500	-0.13
Quzhou	PDO	5500-6500	0.10
	SOI	500 / 5500-6800	-0.17

SOI

The short term relationship is as expected very similar to the SOI – precipitation relationship. The explanation for the different correlation peaks for different lag times when applying different (PDO based) periods is again unknown. Also for this relationship, like for the precipitation-SOI, the runoff shows for the first period a negative, and for the second period a positive correlation trend. Though only Quzhou has significant values as seen In Appendix V (Figure 29 and Table 22). The total period between 1963 and 2000 shows no significant correlation values (Table 11).

For the long term relationship of the SOI the same counts as for the PDO for how the results were calculated. Figure 13 show the optimal temporal resolution in years based on Table 8 and the graphs in Figure 16. The general trend for the SOI is the same as for the PDO when looking to the correlation; the correlation is equal or even lower for the runoff-SOI than for the precipitation-SOI. For the Jinhua area it is lower, and for the Quzhou area it is equal (-0.21 and -0.13 versus -0.17 and -0.17, Figure 13). The temporal resolutions are in contrast to the PDO higher for the runoff-SOI compared to the precipitation-SOI, although the SOI for the Quzhou area also has a relatively high value for a low temporal resolution (1.5 year). It is not clear if this is correct, or that it is a coincidence. The temporal resolutions are higher but fairly comparable to what Zhang et al. (2007) found for the relationship between the annual maximum runoff and ENSO for the lower reaches of the Yangtze River Basin. According to the research of Zhang et al. (2007) the bands between 2 and 8 years (using a continuous wavelet transform analyses) were dominant for this relationship. Using the lowest possible temporal resolution it would be 11 for the Jinhua and 15 (or 1.5) years for the Quzhou area (lag and temporal resolution combined).This may be a little lower when applying a more specific lag time, but this is excluded in the results of this study like described in Chapter 3.5. Besides that Zhang et al. (2007) also found the same direction, negative (positive), for the relationship between the SOI (NINO 3) and the precipitation as mentioned earlier.

EASMI

The graph for the whole period (1963-2000) is shown in Figure 15. It shows that also for the runoff – EASMI relation the Jinhua area has a higher lag, and the Quzhou area a higher temporal resolution. This is the same as for the precipitation – EASMI relation. The temporal resolution for Jinhua is also a little higher than for the precipitation – EASMI relation, which is expected regarding the precipitation-runoff relation with a temporal resolution of 3 days to reach the optimal correlation. It must be noted that this relationship is not significant. The lag time for the Quzhou area does not differ much from the precipitation – EASMI relationship. Besides that the correlation for the Quzhou area is clearly higher than the Jinhua area (Table 9). Strange is the general height of the correlation for the runoff in contrast to the correlation for the precipitation – EASMI relationship; for the runoff it is higher. Again also the three different PDO periods are looked in to, since for the precipitation – EASMI relationship there was an indication that the first period was lower compared to the second period due to the different PDO phases (Chapter 4.3.1). These results are shown in Table 9, based on Appendix V (Figure 26). In general the results show that the correlations are lower than the correlations between the precipitation and EASMI, which is fairly logical. For the Runoff – EASMI relationship the Jinhua area has no significant relations, but the correlations that the (not) significant correlations indicate does not show a real difference between Period One and Two. For the Quzhou area the correlation in Period Two is significant, and higher than Period One. The trend explained including the PDO phases is thus visible for the Quzhou area.

TABLE 9: CORRELATIONS VALUES FOR RELATION EASMI WITH PRECIPITATION FOR THREE SHORT PERIODS. SIGNIFICANT VALUES ARE <u>UNDERLINED</u>

Period	Correlation (minimum)	Lag (days)	Temporal resolution (days)	Correlation (minimum)	Lag (days)	Temporal resolution (days)
	Jinhua			Quzhou		
1963-1976	-0.320	27+	4	-0.333	3	25+
1977-1989	-0.340	0	1	-0.719	0	25
1989-2000	-0.221	7	1	<u>-0.678</u>	0	15

4.4.2 Using daily peak values – multiple regression

Table 10 gives the correlation results and Appendix VI (Figure 31) gives the graphs. Again the PDO-SOI combination is higher compared to linear regression. Also the EASMI combinations are mostly higher compared to the linear regression. Only the EASMI/PDO for Quzhou is more or less equal to the linear regression. The only not significant value is for the Jinhua area with the EASMI-SOI combination. What is more remarkable is that the correlations for all combinations are higher compared to the precipitation correlation using a multiple regression for Quzhou. For the EASMI this was already visible for the linear regression, but for the PDO and SOI it was not. The temporal resolutions for the SOI are not really strange, only the PDO has relatively low values compared to the linear regression for the Jinhua area (same as for the multiple regression for the precipitation – PDO/SOI relation for the Jinhua area, mentioned in Chapter 4.3.2). For the EASMI there are no remarkable lag times or temporal resolutions.

TABLE 10: CORRELATION VALUES FOR MULTIPLE REGRESSION ANALYSIS BETWEEN HIGH RUNOFF AND THE CLIMATE INDEXES WITH OPTIMAL LAG AND TEMPORAL RESOLUTION FOR THE COMBINATION OF TWO CLIMATE INDEXES. SIGNIFICANT VALUES ARE <u>UNDERLINED</u>.

Area	Index combination	Correlation	Temp PDO (days)	Temp SOI (days)	Temp EASMI (days)	Lag EASMI (days)
Jinhua	PDO-SOI	<u>0.26</u>	1200-3500	4300	-	-
	EASMI-PDO	<u>0.25</u>	500/1200	-	2	25
	EASMI-SOI	0.19	-	600/4200	2	25
Quzhou	PDO-SOI	<u>0.27</u>	4500	4800	-	-
	EASMI-PDO	<u>0.50</u>	4200	-	12	2
	EASMI-SOI	<u>0.53</u>	-	2500/5800	12	2

TABLE 11: CORRELATION VALUES FOR SOI AND EASMI WITH THE HIGH RUNOFF FOR SHORT PERIOD RELATIONS. SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index	Correlation max	Correlation min	Index	Correlation min
Jinhua	SOI	0.103	-0.066	EASMI	-0.157
Quzhou	SOI	0.091	-0.120	EASMI	<u>-0.494</u>

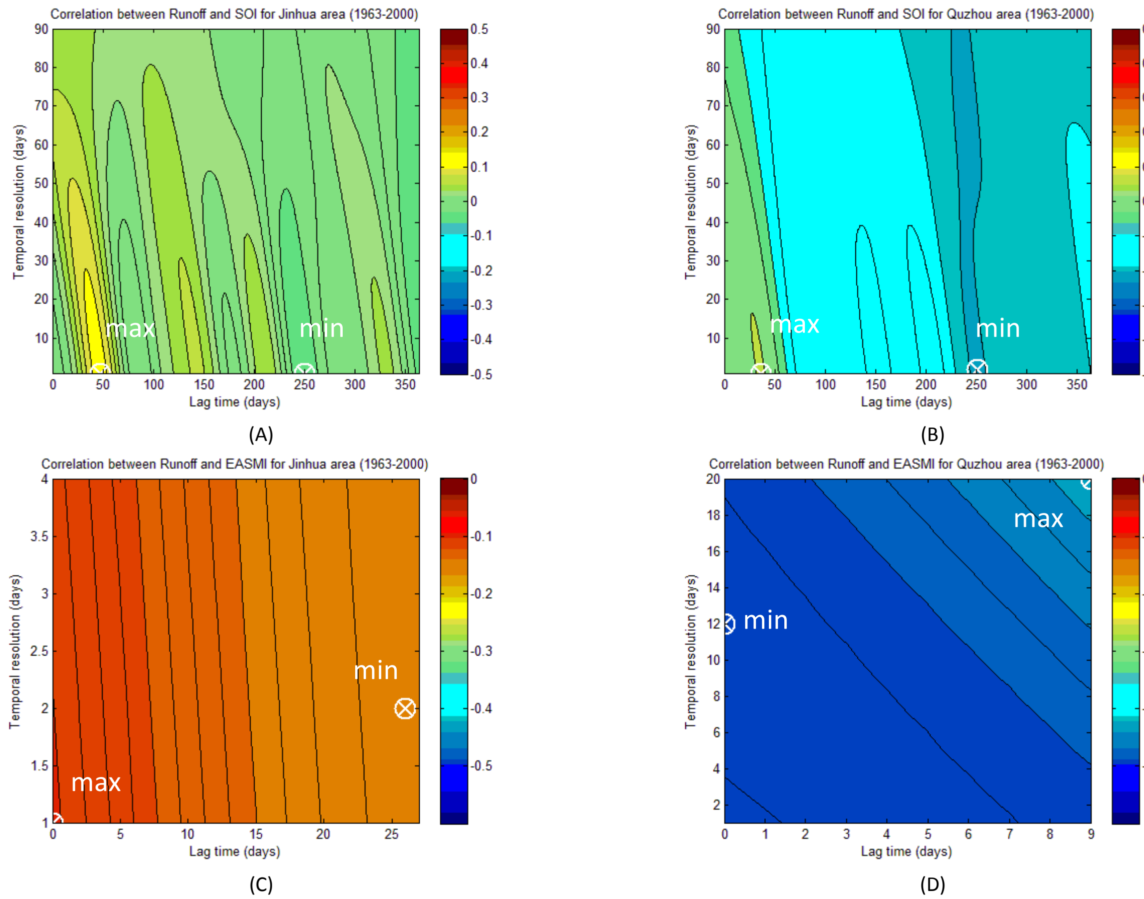


FIGURE 15: GRAPHS OF THE CORRELATION BETWEEN THE SOI AND THE EASMI, AND THE HIGH RUNOFF FOR DIFFERENT LAG EN TEMPORAL TIMES. USED PERIOD IS 1963-2000. 'A' IS JINHUA SOI, 'B' QUZHOU SOI, 'C' JINHUA EASMI AND 'D'QUZHOU EASMI. THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWED WITH A WHITE CROSS.

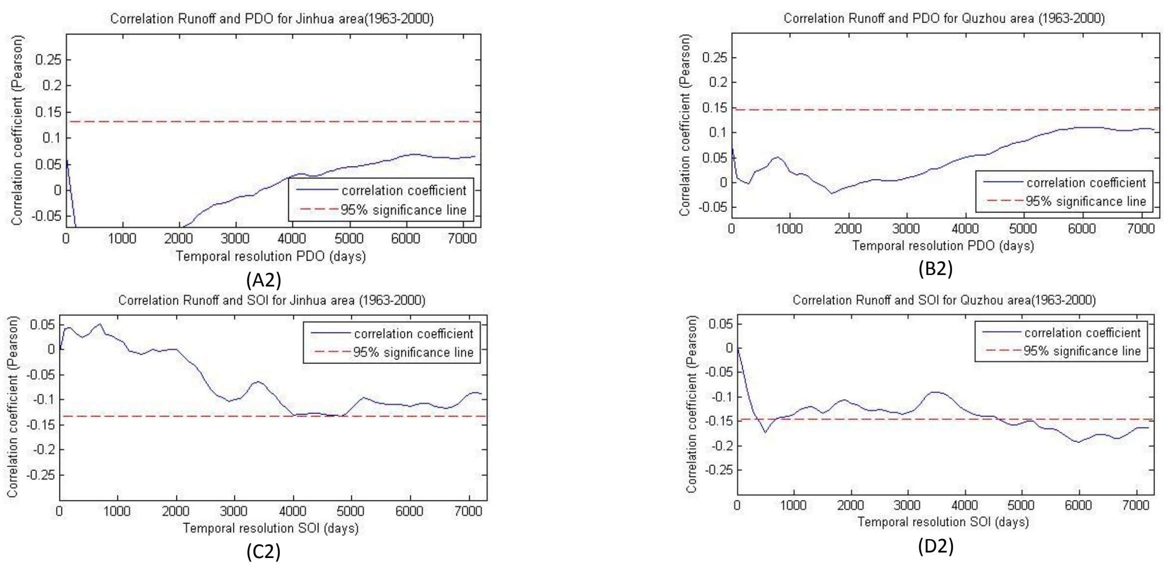


FIGURE 16: CORRELATION GRAPHS BETWEEN DAILY RUNOFF AND THE CLIMATE INDEXES FOR JINHUA PDO (A), QUZHOU PDO (B), JINHUA SOI (C) AND QUZHOU SOI (D) FOR DIFFERENT TEMPORAL RESOLUTIONS.

4.4.3 **Using three day average peak values – linear regression**

PDO

The values for the temporal resolution can just like the correlation values be found in Table 12 and the graphs are shown in Figure 18. For the PDO the correlation increases for both the Jinhua and Quzhou area compared to the daily runoff – PDO relation (0.06 to 0.07 and 0.10 to 0.16, Figure 13).For the Quzhou area this causes the correlation to be significant again, and for the Jinhua area the correlation stays insignificant. The temporal resolutions for both the areas are comparable to the resolution for the daily runoff – PDO relation.

TABLE 12: CORRELATION VALUES AND TEMPORAL RESOLUTIONS FOR PDO AND SOI LONG TERM RELATIONSHIP BETWEEN HIGH RUNOFF EVENTS (THREE DAY AVERAGES) AND CLIMATE INDEXES (SOI AND PDO). SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index	Temporal resolution (days)	Correlation
Jinhua	PDO	5500-6500	0.07
	SOI	3900-4200	-0.15
Quzhou	PDO	5800-6200	0.16
	SOI	2200/3900-6600	-0.18

SOI

For the short term relationship, as seen in Table 15, based on the graphs in Appendix V (Figure 30), the same counts as for the relationship between the SOI and the runoff. Especially the first period has again significant negative values for both Quzhou and Jinhua, the other periods are not significant. The whole period (1963-2000) shows only one significant correlation peak, which is for the Quzhou area and is negative; the same direction as the long term SOI relation with the precipitation as seen in Table 15.
The values for the temporal resolution and the correlation for the long term can be found in Table 11, which are based on Figure 15. The correlations for the SOI show the same trend as for the Quzhou area; they increase when applying a three day average for the runoff instead of a daily runoff value (-0.13 to -0.15 for Jinhua and -0.17 to -0.18 for Quzhou, Figure 13). The temporal resolutions are comparable to the daily runoff value relation with the SOI, only the Quzhou area has slightly different values (a little lower).

EASMI

For the three day average runoff relation with the EASMI the same counts as for the runoff and precipitation; the full period (1963-2000) is investigated and the three smaller periods based on the different stages of the PDO. The full period graphs can be found in Figure 17, and the correlation values in Table 15. The full period shows higher correlations for both the Jinhua and Quzhou area compared to the daily runoff – EASMI relation for both the Jinhua and Quzhou area. Again the Quzhou area is higher in comparison to the Jinhua area for the temporal resolution for again approximately 12-14 days. It is as mentioned before a range; as seen approximately this correlation height can also be reached for 6-8 days of lag with zero days of temporal resolution. For the Jinhua however it is different, since the lag and temporal resolution are getting higher than then the 32 days summarized. Therefore it is only clear that the total number of days (lag and temporal resolution) is over the 32 days for the Jinhua area. The graphs and correlation values for the smaller periods are given in Table 13, based on Appendix V (Figure 27). For the three day runoff the correlations for only Period Two are significant, and higher than Period One. This indicates that the PDO has also influence on the relationship between the three day average runoff and the EASM. The lag time and temporal resolution for the different periods are very variable for the different periods. Comparing them to the runoff/precipitation – EASMI relation it shows that the different periods do show similar trends; only the different periods differ a lot from each other. This indicates that is wise for the EASMI to take different periods, for example based on the PDO, in consideration when doing further research since this does matter for the lag and temporal time.

TABLE 13: CORRELATIONS VALUES FOR RELATION EASMI WITH PRECIPITATION FOR THREE SHORT PERIODS. SIGNIFICANT VALUES ARE UNDERLINED.

Period	Correlation (minimum)	Lag (days)	Temporal resolution (days)	Correlation (minimum)	Lag (days)	Temporal resolution (days)
	Jinhua			Quzhou		
1963-1976	-0.401	24+	5	-0.410	4	25+
1977-1989	<u>-0.564</u>	14+	15+	<u>-0.834</u>	0	24+
1989-2000	-0.279	0	1	<u>-0.743</u>	6	2

4.4.4 **Using three day average peak values – multiple regression**

The multiple regression part works the same as for the precipitation and runoff relation with the climate indexes. The table with the outcomes is shown below in Table 14, and the graphs can be found in Appendix VI (Figure 32).

Compared to the linear regression the correlations are all higher. The PDO and SOI are going from approximately 0.07(PDO) and -0.15(SOI) to 0.30(PDO/SOI) for Jinhua and 0.16(PDO) and -0.18(SOI) to 0.29(PDO/SOI) for Quzhou. For the EASMI the correlations increase with 0.16 to 0.31 for Jinhua and 0.5 to 0.58 for Quzhou. The PDO/SOI combinations are both not a lot higher compared to the daily runoff multiple regression PDO/SOI combinations. The combinations with the EASMI included are in contrast a lot higher compared to the daily runoff combinations with the EASMI included (multiple regression). These EASMI combinations are also higher compared to the linear regression correlations. The lag times for the EASMI are comparable to the linear regression. This is also the case for the PDO/SOI combinations for both areas, although again it seems that the temporal resolution for the PDO, when choosing a certain high SOI temporal resolution, does not matter a lot anymore.

TABLE 14: CORRELATION VALUES FOR MULTIPLE REGRESSION ANALYSIS BETWEEN THREE DAILY AVERAGE HIGH RUNOFF AND THE CLIMATE INDEXES WITH OPTIMAL LAG AND TEMPROAL RESOLUTION TIMES FOR THE COMBINATION OF TWO CLIMATE INDEXES. SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index combination	Correlation	Temp PDO (days)	Temp SOI (days)	Temp EASMI (days)	Lag EASMI (days)
Jinhua	PDO-SOI	<u>0.30</u>	4300	4500	-	-
	EASMI-PDO	<u>0.33</u>	1200	-	14	15
	EASMI-SOI	<u>0.31</u>	-	4200	14	15
Quzhou	PDO-SOI	<u>0.29</u>	2800	4400	-	-
	EASMI-PDO	<u>0.58</u>	2100	-	14	1
	EASMI-SOI	<u>0.58</u>	-	2500/4100	14	1

TABLE 15: CORRELATION VALUES FOR SOI AND EASMI WITH THREE DAY AVERAGE RUNOFF FOR SHORT PERIOD. SIGNIFICANT VALUES ARE UNDERLINED.

Area	Index	Correlation max	Correlation min	Index	Correlation min
Jinhua	SOI	0.098	-0.055	EASMI	<u>-0.278</u>
Quzhou	SOI	0.034	<u>-0.218</u>	EASMI	<u>-0.564</u>

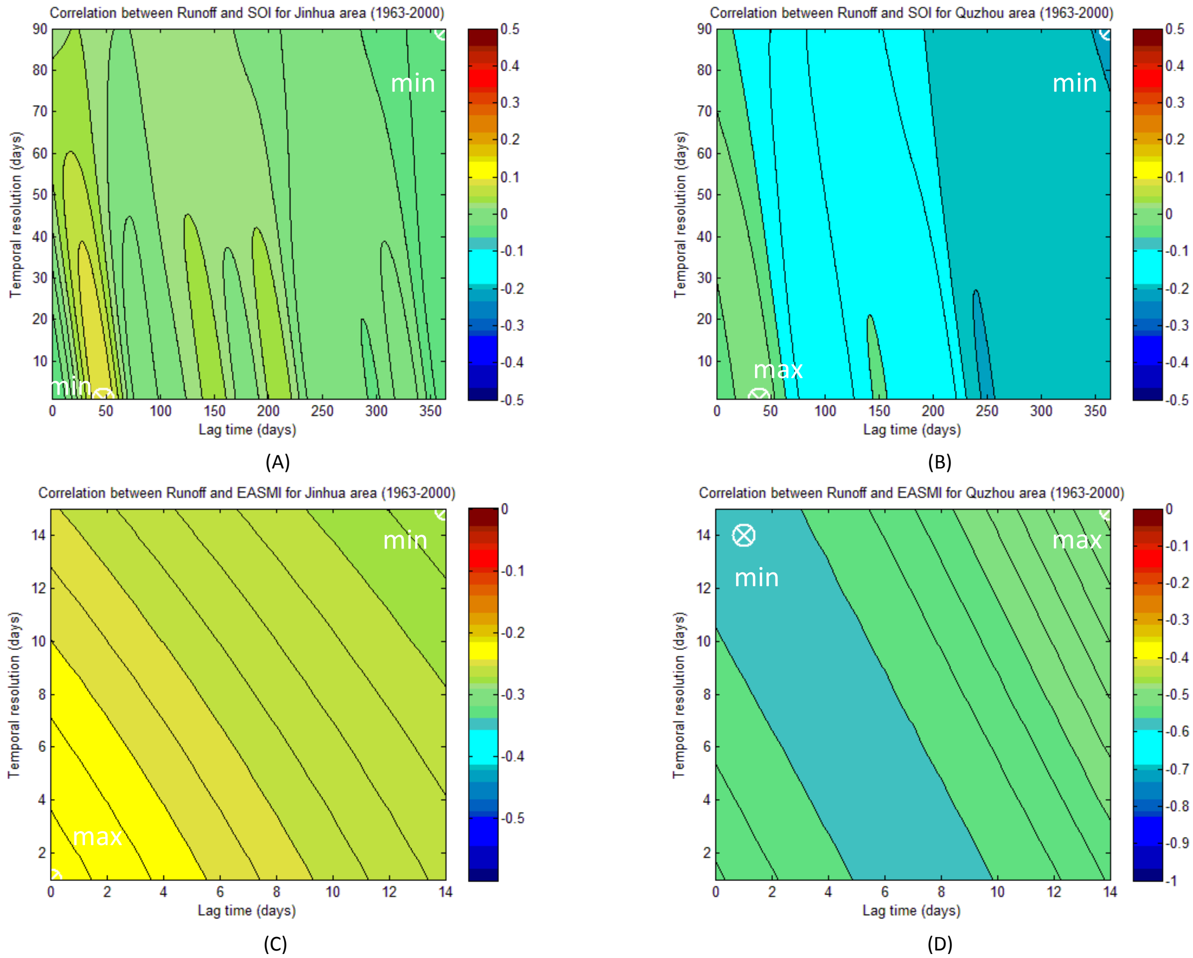


FIGURE 17: GRAPHS OF THE CORRELATION BETWEEN THE SOI AND THE EASMI, AND THREE DAY AVERAGE RUNOFF FOR DIFFERENT LAGS AND TEMPORAL RESOLUTIONS. USED PERIOD IS 1963-2000. 'A' IS JINHUA SOI, 'B' QUZHOU SOI, 'C' JINHUA EASMI AND 'D'QUZHOU EASMI. THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWED WITH A WHITE CROSS.

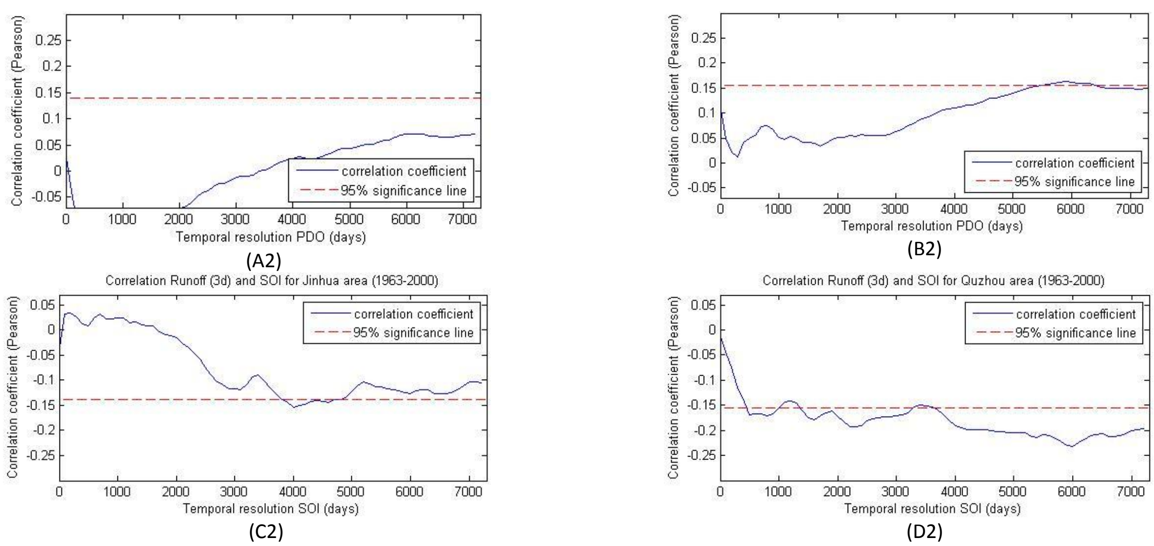


FIGURE 18: CORRELATION GRAPHS BETWEEN THREE DAY AVERAGE RUNOFF AND THE CLIMATE INDEXES FOR JINHUA PDO (A), QUZHOU PDO (B), JINHUA SOI (C) AND QUZHOU SOI (D) FOR DIFFERENT TEMPORAL RESOLUTIONS.

4.5 Comparing direct and indirect Runoff – climate index

The relation for the indirect (combined) relation between runoff and climate indexes is not calculated, but only described by using the relation between precipitation and runoff, and precipitation and climate indexes. These two relations can be compared to the direct correlation between runoff and climate indexes, to see where the main uncertainty is, and what the cause may be. Since the relations between precipitation and climate indexes, and runoff and climate indexes showed different lag and temporal times, it is already impossible to suggest that the relation found by the direct correlation assessment between runoff and climate indexes is the same as the relation found by the combination of runoff and precipitation, and precipitation and climate indexes.

Still the correlations are given in Table 16 for the different climate indexes. The SOI and PDO show that the correlation is indeed, as one should expect, decreasing when comparing the precipitation – index relation with the runoff – index relation correlation. For the EASMI this is not the case. Therefore when comparing the runoff – precipitation relation in combination with the precipitation – EASMI relation with the direct runoff – EASMI relation, it can be said that the combination and the direct relation outcome are not the same. For the SOI for Jinhua and the PDO for Jinhua and Quzhou they already show more similarities, although the difference between the runoff – climate index and the precipitation – climate index looks fairly bigger than the correlation between the runoff and precipitation. This difference can therefore not only be caused by the runoff-precipitation correlation. For the SOI for the Quzhou area it looks most similar when comparing the direct runoff – climate index relation with the combination of runoff – precipitation and precipitation – climate index. To summarize it can therefore not be said if the relations are the same, although it is estimated that only for the SOI for the Quzhou area the combination shows more or less the same correlation as the direct runoff-climate index relation.

When wanting to really compare these relations, one should use the same lag and temporal times for the precipitation – climate index relation as the ones found for the runoff – climate index. In this research this was not done since the main goal was finding the highest correlations for the runoff – climate indexes and therefore as well the precipitation – climate indexes, including their lag and temporal times. When using the same lag and temporal times for the precipitation – climate index relation as for the runoff – climate index relation, the mediator technique (Cohen and Cohen, 1983) could be applied to know if the so called 'mediator' variable, in this case the precipitation, explains all or maybe a significant part of the runoff values regarding to the climate indexes. However it is not expected, using the results from this research, that the relation between the climate indexes and the precipitation would be the same as between the runoff and the climate indexes. Therefore the relation between the climate indexes and the precipitation could only be a significant predictor for the relationship between the climate indexes and the runoff, but like mentioned, this is not included in this research.

TABLE 16: CORRELATION VALUES FOR RELATIONSHIPS BETWEEN RUNOFF – PRECIPITATION – CLIMATE INDEXES. SIGNIFICANT CORRELATION VALUES ARE UNDERLINED.

Area	Q-P	P-PDO	Q-PDO (direct)
Jinhua	0.850	0.19	0.06
Quzhou	0.891	0.14	-0.07

Area	Q-P	P-SOI	Q-SOI (direct)
Jinhua	0.850	-0.21	0.13
Quzhou	0.891	-0.17	-0.17

Area	Q-P	P-EASMI	Q-EASMI (direct)
Jinhua	0.825	-0.116	-0.157
Quzhou	0.928	-0.402	-0.494

5 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

Below the main issues are discussed that where not taken into account in this study, or where the results are somehow strange and could be improved.

Firstly it is important to note that in this research the relations between the precipitation and the climate indexes are not about the most heavy precipitation events but the most high runoff events. The precipitation events are thus based on the high runoff events like explained in Chapter 3.1. The relation between the maximum precipitation and the climate indexes could therefore be stronger, but is not included in this research.

Another point of discussion is the ENSO – precipitation/runoff relation. For the short term it is not clear what causes the different peaks, and why there is a difference between the PDO negative and positive phase in the strength of the correlation between the precipitation/runoff and the SOI. This may become clear when investigating ENSO for the different stages (El Nino and La Nina) and different strengths within these stages. This was already done for Japan and Korea before (Jin et al., 2005), and in that area it showed significant differences between the different stages for the short term relationship. Also for this area this could be an interesting subject for a further study. As mentioned, when investigating these relationships, it is important to link it with the PDO positive and negative phase, since the relationship is different within these stages of the PDO.

The EASMI showed the highest correlation coefficient for the relation with the precipitation and the runoff. Only since there were just three months of data available, the first part of the first month (June) and last part of the third month (August) each year where set equal to the monthly average value that was available. Besides that the number of samples for the EASMI was relatively low compared to the PDO and SOI (although naturally it is mentioned when the correlation is statistically significant). This may have caused some error, but since the relationship shows very strong negative correlations for especially the Quzhou area, and a little less strong for the Jinhua area, this should not matter very much. Still it is advisable to maybe even create an index, based on the 'DNS' method (Li & Zeng, 2002), for the Qiantang river basin for the whole year when really wanting to have a reliable temporal resolution and lag time for the EASMI that is more precise.

As mentioned in the results, the lag time and temporal resolution for the different relationships, especially for the relationships including the EASMI, are discussable. Sometimes there are just more options for the highest correlation, and for the EASMI this meant that taking a high temporal resolution with a zero lag time or a little lower lag time combined with one day of temporal resolution gives approximately the same correlation height.
For the relation between the SOI and PDO the correlation with the precipitation and runoff is sometimes not the highest. This due to the temporal resolution (range) that was chosen for a certain range, and not the highest correlation. This is done since an exact temporal resolution of a number of years is presumably not realistic when searching for relationships on a time scale like 10 to 20 years.

These correlations of the long term relationships (PDO and SOI) are sometimes found to be significant, and sometimes not. Important however is to mention that these correlations that are significant are most of the time not a lot higher than 0.2. This is still a little low, and therefore it is hard to tell if there is really a relation between the SOI/PDO and the precipitation, runoff and three day average runoff. Therefore, like mentioned in the methodology Chapter 3.5, it is better to regard it as a chance that for example the precipitation will be higher/lower when there is a positive relationship between the PDO and the precipitation. This is due to the very long term (for example 15-18 years) temporal resolutions that are found in this study.

For the multiple regression it was assumed that the indexes are all independent. Like already described in this report this is not the reality, and these indexes have some interaction. This is however not included in this research. This may have caused some error in the results for the multiple regression. But since these indexes mainly stimulate each other in their strong phases, it is expected that the correlations would only get higher.

Another remarkable result is the correlation for the runoff with the climate indexes, especially for the EASMI. For the linear regression and the multiple regression it showed this correlation was higher compared to the correlation between this EASMI and the precipitation. For the linear regression these differences are -0.11(P) versus -0.16(Q) for Jinhua and -0.4(P) to -0.49(Q) for Quzhou. Normally one should expect the correlation between the precipitation and the climate index to be higher. It is not clear what the cause is for this difference. Of course there are more relations between the climate indexes and the runoff, like the evapotranspiration and how the local communities react to the forecasted weather. Besides that also the precipitation is influenced by more factors than the climate index, like local meteorological circumstances. It is therefore hard to tell whether it is an error in the calculation or a cause of other influences as described above. A similar thing is notable for the SOI. Remarkable here is that the 3 day average runoff has a higher correlation with the SOI than the precipitation.

A last relatively small error may be made by interpolating the climate indexes by using a spline interpolation. Still this was necessary since the research was originally set up to investigate in days and not in months as it is not about monthly average runoff events, but the high runoff events that may only take a few days.

5.2 Conclusion

For this study the goal was to determine the relationship between the SOI, PDO and EASMI climate indexes and high runoff events in the Lanjiang River Basin. Therefore the climate indexes combined with precipitation, runoff and three day average runoff with different lag times and temporal resolutions were tested on their correlation strength, just like the relationship between the runoff and the precipitation.

The first research question was about the the relationship between the precipitation and runoff. This was investigated already by another study for this area, but not for the periods that are used in this research, respectively 5 months (May-Sep) for the PDO and SOI, and 2 months (Jul-Aug) for the EASMI. The previous study was therefore used to compare the results (validate) for the full year period. Similar to this study, it is shown that atboth Jinhua and Quzhou have a positive relationship (95 % significant, one sided) between the runoff and the precipitation. Furthermore the correlation for the Quzhou basin was slightly higher compared to the Jinhua basin; approximately 0.83 (Jinhua) versus 0.9 (Quzhou). The three different periods, including the full year, the SOI and PDO period and the EAMSI period did show a little difference in optimal temporal resolutions and lag times, but generally a precipitation event with lag time of zero days and a temporal resolution of three days was sufficient to gain an optimal correlation value for the relation between the precipitation and the high runoff events.

The second and third research questions included the relationship between the climate indexes, and precipitation and runoff. The relationship between the PDO and precipitation was found to be positive significant for both areas. The positive relation between the PDO and precipitation is explainable as the PDO stimulates the EASM to become weaker, which generates more precipitation over the Yangtze Basin and its surroundings (including the Lanjiang River Basin). For the runoff and three day average runoff the relationship is lower with 0.19(P) versus 0.06(Q) and

0.07(Q3) for Jinhua. The relations between the PDO and the (three day) runoff events (0.06 and 0.07) are not significant anymore. For Quzhou the three day average is the highest with 0.14(P), 0.10(Q) and 0.16(Q3). It therefore seems, and this is confirmed by the precipitation-runoff relation, that for Jinhua the relationship is weaker between precipitation and runoff than for Quzhou. The optimal temporal resolution for Jinhua starts at 8 years, and for Quzhou at 15 years for the precipitation – PDO relation. The temporal resolution does not differ much between precipitation, daily runoff and three day average runoff.

The SOI was tested for long and short term relations. It seems that the SOI is influenced by the PDO, since the correlation strength was different when looking to three separated periods (PDO positive, negative and combined/neutral). The reason for this is presumed to be lying in the different stages of ENSO, but this research did not look further into this. For the long term the SOI has a negative relationship with the precipitation, runoff and three day-average runoff, with the correlations being -0.21(P), -0.13(Q) and -0.15(Q3) for Jinhua and -0.17(P), -0.17(Q) and -0.18(Q3) for Quzhou. Like discussed these correlations for the long term (SOI and PDO) have to be seen as chances that there will be more or less precipitation or runoff, since it is a relative long term temporal resolution.

The relationship between the precipitation and the EASMI, which is negative, turned out to be significant for the Quzhou area, and not for the Jinhua area. This negative relationship is similar to what other researches note about the EASM for Eastern China. Furthermore it shows that the Jinhua area has mainly high lag values and the Quzhou area mainly high temporal resolutions, which both get higher (with the exclusion for the Quzhou runoff – EASMI relation) when comparing the precipitation with the runoff, and the runoff with the three day runoff. It must be noted though that it is more a range than 'one' value. Jinhua goes when comparing precipitation-EASMI with the three day-EASMI relation runoff from 18 to 25+ days (temporal resolution), and Quzhou from 12 to 14 days (lag). (When looking to the three periods that were chosen based on the PDO index, it is visible that the three periods are not showing the same trend in correlation height and temporal resolution or lag time. This counts for the precipitation, high runoff and tree day average high runoff. The difference comes down to a lower correlation of the first period compared to the second and third period. Using other literatures it is assumed that this is because of the relation between the PDO with the SOI and thus the EASM. This relationship is, as mentioned above, negative. A positive PDO therefore is a cause for a weaker EASM, which means more rain for Eastern China since the relation between the EASM and the precipitation in negative. Finally the relation is stronger for the Quzhou area compared to Jinhua, which may be caused by the geographical position since this is not only for the (three day) runoff the case, but also for the precipitation. Comparing the results between the runoff - precipitation and precipitation climate index relations with the runoff – climate index relations is not fully possible since the lag and temporal times show differences. Still, when comparing them, the only relationships that show similarities are the PDO and SOI index for the Jinhua area.

The multiple regression showed that for most combinations the correlation increases when applying multiple regression instead of linear regression. Only for Quzhou for the EASMI combination relations with the precipitation and runoff it does not increase a lot, probably because the EASMI already has a great influence compared to the PDO and SOI in the Quzhou area. Besides that it is remarkable that when comparing the precipitation correlation with the runoff correlation for the multiple regression it shows that the correlations for the runoff with the combinations of the climate indexes is higher than the precipitation with these indexes for Quzhou. The three day average runoff is for the combinations with the EASMI included again higher than the daily runoff multiple regression correlations, just like for the linear regressions. Finally the lag and temporal times are not showing very strange patterns; in general they are comparable to the linear regression assessments.

5.3 Recommendations

Further research could be interesting in the EASM relation with the runoff, only than for a more precise index (for example by using the 'DNS method' more locally, Chapter 3.2.3.) or at least the full year index of the EASMI. This is especially the case for the Quzhou area since it has a relatively stronger correlation compared to the Jinhua area. Also the ENSO phenomenon seems interesting to analyze for the different stages of ENSO as the correlation direction may be different during these stages. Also testing more different indexes than only the SOI can be an interesting addition when wanting to investigate the ENSO in particular. Lastly the PDO seems to be of most importance to keep in mind when analyzing the EASM and ENSO for different periods, since it has influence on both indexes and their relations with the precipitation and/or runoff. When wanting to do more research in specific protection measures for the Lanjiang area, or for local authorities who may be more interested in volumes of the high runoffs, it is advisable to go further with the longer, in this research three day average, runoff values. These correlations were in general higher compared to the daily runoff relation correlations. Of course the number of days for the average runoff can be higher, although it is not known how the correlation will change in that case.

Applications of the results of this research could be for example flood frequency analysis. Further research could therefore be found in the linkage between the meteorological and hydrological systems, by combining the correlation of the high runoff events and the climate indexes with the flood frequency curves calculation methodology (especially for the EASM since this turns out to have a strong relationship).

For other areas where a similar research as performed in this study could be interesting, the same steps could be taken. Important tough is that the climate indexes that will be investigated for that area should always have a connection with that area. Therefore the three indexes investigated in this area are not always the three best indexes for every area. The results for this area are therefore only for this area and not for areas lying elsewhere applicable.

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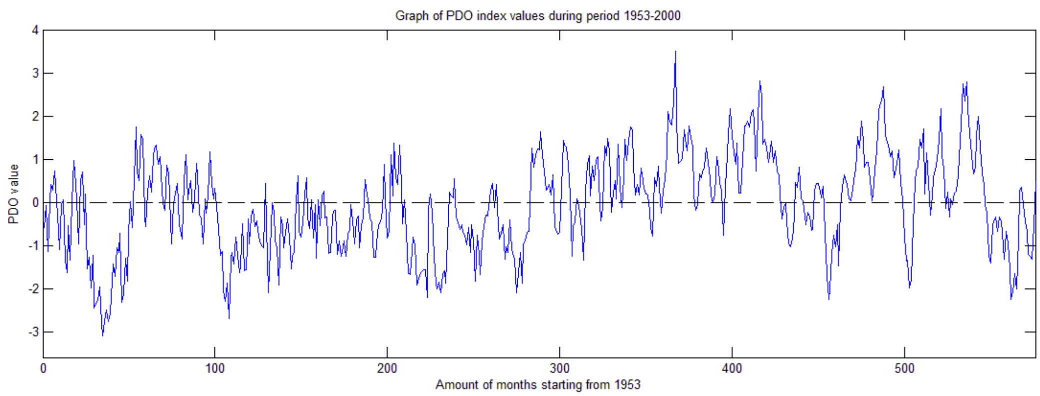
APPENDIXES

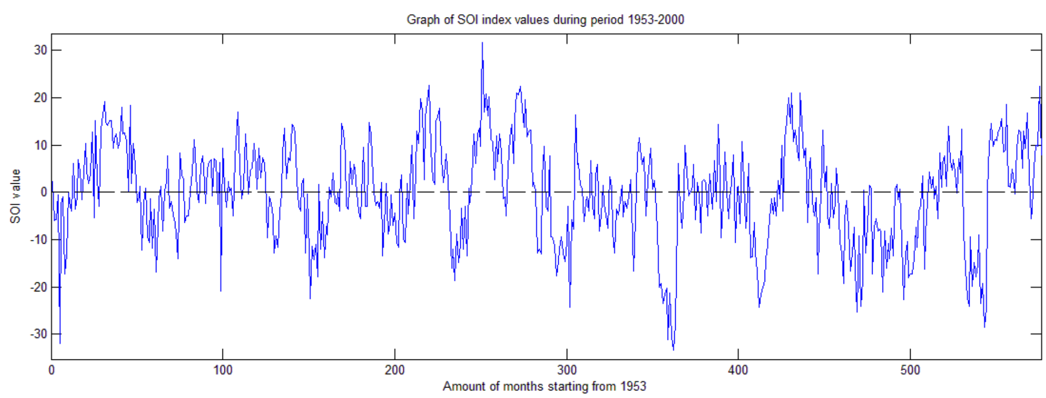
Appendix I: Data preparation

Data PDO, SOI and EASMI (visually)

PDO



SOI



EASMI

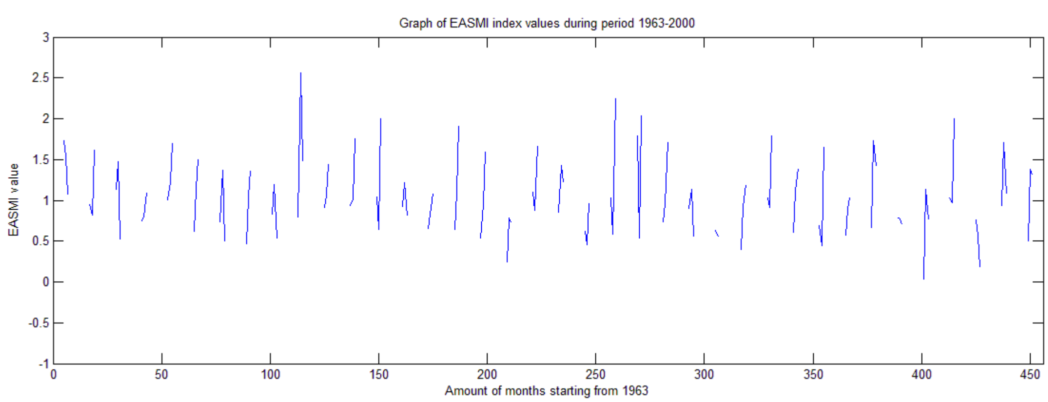


FIGURE 19: INDEX DATA USED

Spline interpolation versus linear interpolation

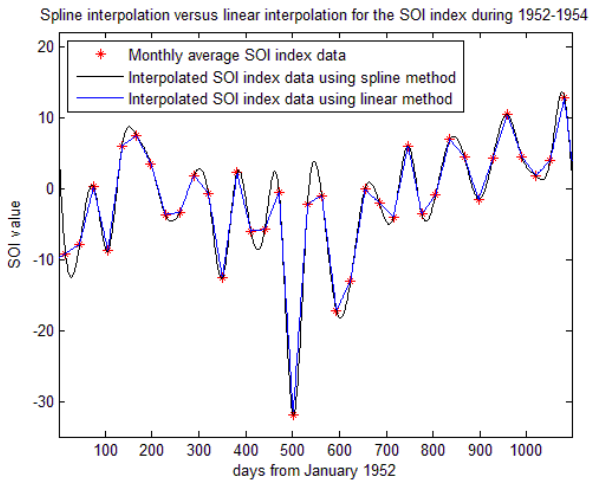


FIGURE 20: SPLINE VERSUS LINEAR INTERPOLATION. THE DATASET USED FOR THIS EXAMPLE IS THE SOI INDEX DURING THE PERIOD JANUARY 1952 TILL JANUARY 1955.

Graphs of helping tools to determine POT values

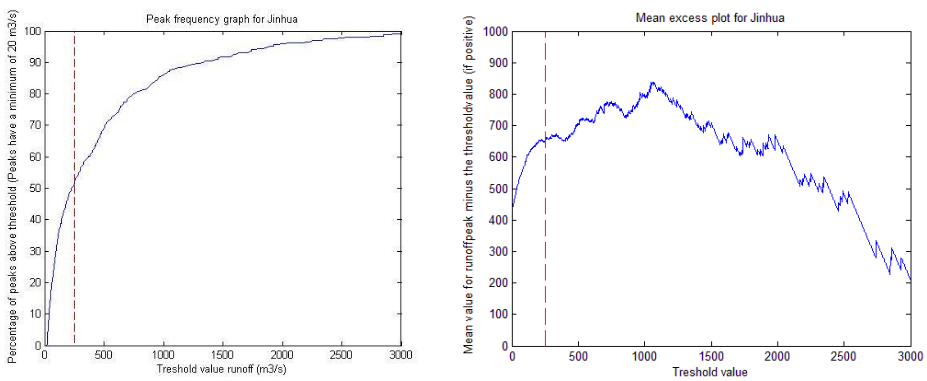


FIGURE 21: FREQUENCY PLOT (LEFT) AND MEAN EXCEEDANCE PLOT (RIGHT) OF JINHUA AREA. RED LINE IS THE CHOSEN THRESHOLD VALUE

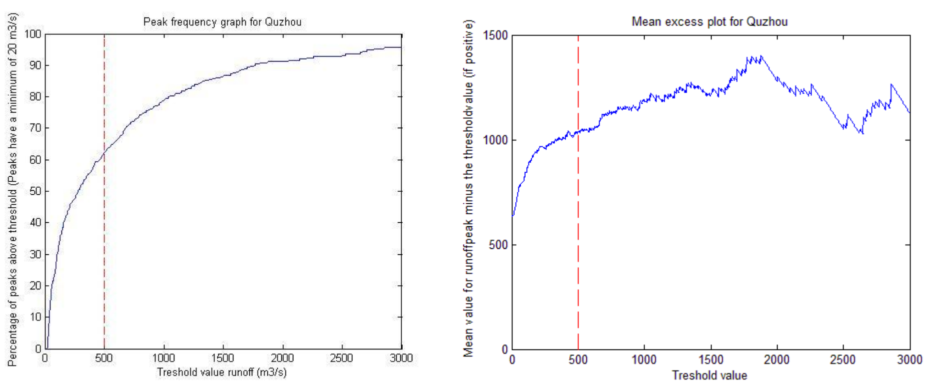


FIGURE 22: FREQUENCY PLOT (LEFT) AND MEAN EXCEEDANCE PLOT (RIGHT) OF QUZHOU AREA. RED LINE IS THE CHOSEN THRESHOLD VALUE

Appendix II: Schemes for multiple regression

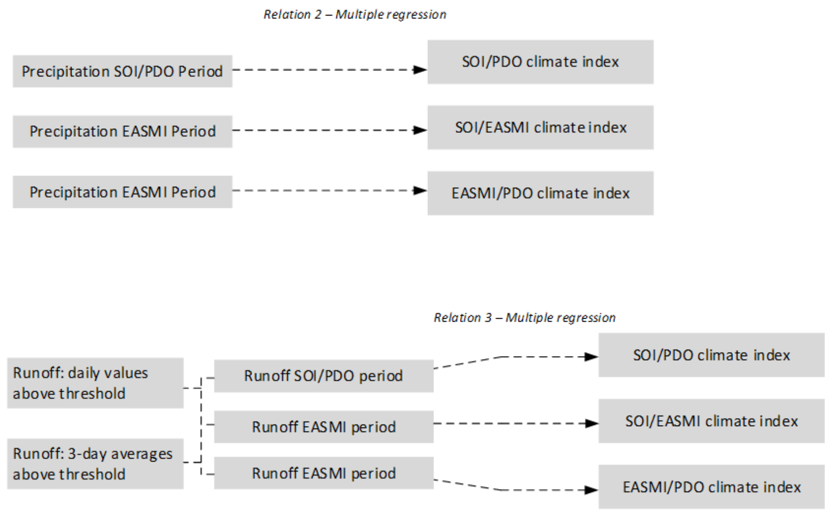


FIGURE 23: SCHEMES FOR MULTIPLE REGRESSION METHODS FOR RELATION TWO AND THREE

Appendix III: Graphs for validation Q3-P relationship

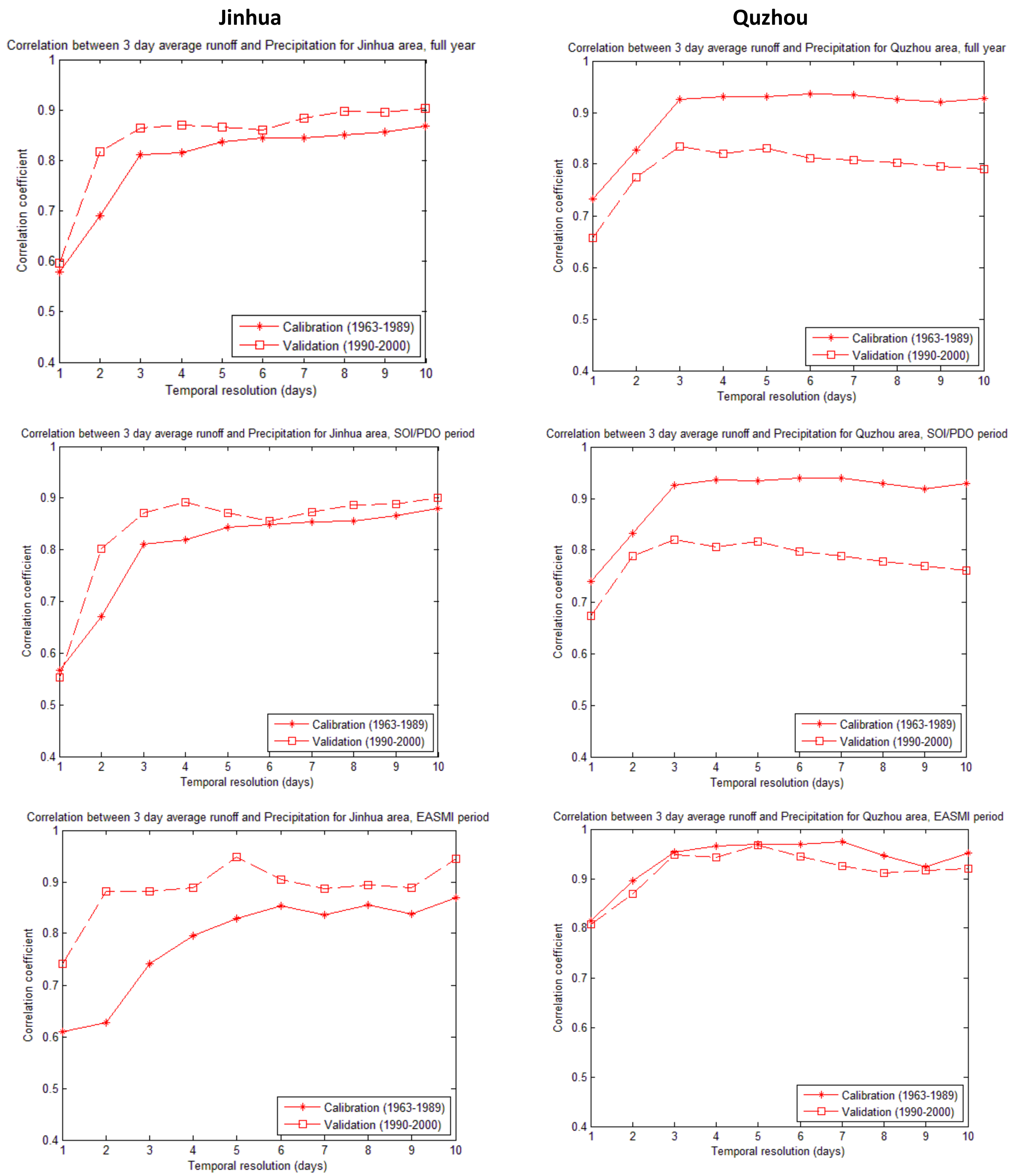


FIGURE 24: VALIDATION GRAPHS FOR THE CORRELATION BETWEEN THE THREE DAY AVERAGE RUNOFF AND THE PRECIPITATION FOR JINHUA AND QUZHOU FOR THE THREE PERIODS; FULL YEAR, PDO/SOI AND EASMI.

Appendix IV: Significant correlation values

In this Appendix both the significant correlation values are given for the daily runoff and precipitation, and for the three day average runoff. These are calculated using the method described in Chapter 3.1.2.

TABLE 17: SIGNIFCANT VALUES FOR THE HIGH RUNOFF AND PRECIPITATION CORRELATION ASSESMENTS

Daily runoff values / precipitation							
EASM				**PDO/SOI**			
Period 1 (1963-1976)	*Period 2 (1977-1989)*	*Period 3 (1990-2000)*	*Total (1963-2000)*	*Period 1 (1963-1976)*	*Period 2 (1977-1989)*	*Period 3 (1990-2000)*	*Total (1963-2000)*
Jinhua							
0.521	0.378	0.426	0.241	0.230	0.216	0.254	0.132
Quzhou							
0.521	0.729	0.521	0.311	0.228	0.258	0.306	0.146

TABLE 18: SIGNIFCANT VALUES FOR THE THREE DAY AVERAGE HIGH RUNOFF CORRELATION ASSESMENTS

Three day runoff values							
EASM				**PDO/SOI**			
Period 1 (1963-1976)	*Period 2 (1977-1989)*	*Period 3 (1990-2000)*	*Total (1963-2000)*	*Period 1 (1963-1976)*	*Period 2 (1977-1989)*	*Period 3 (1990-2000)*	*Total (1963-2000)*
Jinhua							
0.521	0.426	0.476	0.262	0.241	0.228	0.272	0.139
Quzhou							
0.550	0.805	0.582	0.337	0.244	0.269	0.323	0.156

Appendix V: Relation P/Q – EASMI/SOI short term

EASMI -Precipitation

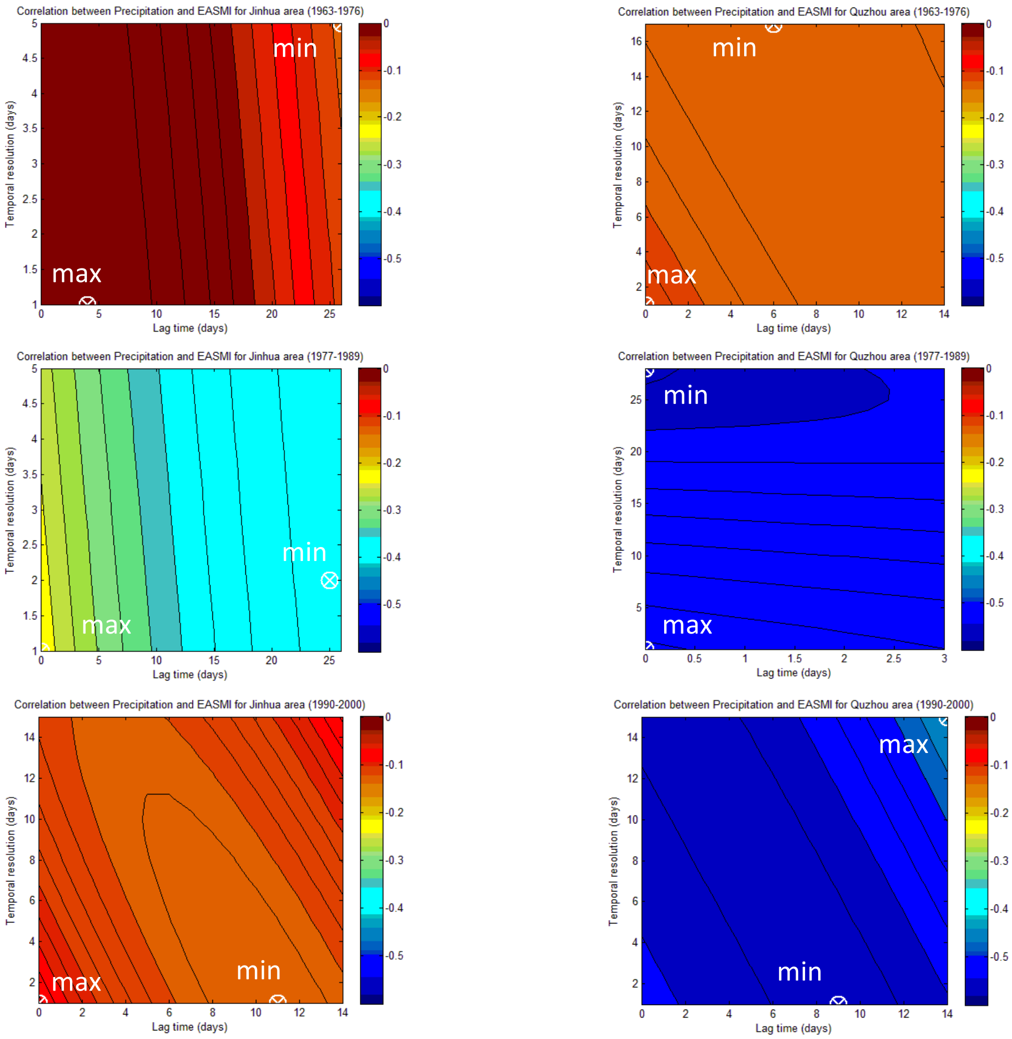


FIGURE 25: CORRELATION GRAPHS BETWEEN EASMI AND PRECIPITATION FOR THREE DIFFERENT SHORT PERIODS. THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWN WITH A WHITE CROSS.

TABLE 19: CORRELATIONS VALUES FOR RELATION EASMI WITH PRECIPITATION FOR THREE SHORT PERIODS. SIGNIFICANT VALUES ARE UNDERLINED

Period	Correlation (minimum)	Lag (days)	Temporal resolution (days)	Correlation (minimum)	Lag (days)	Temporal resolution (days)
	Jinhua			Quzhou		
1963-1976	-0.128	26+	5+	-0.134	6	17+
1977-1989	-0.407	25	2	-0.546	0	28+
1989-2000	-0.129	14	15	-0.567	9	1

EASMI – Runoff

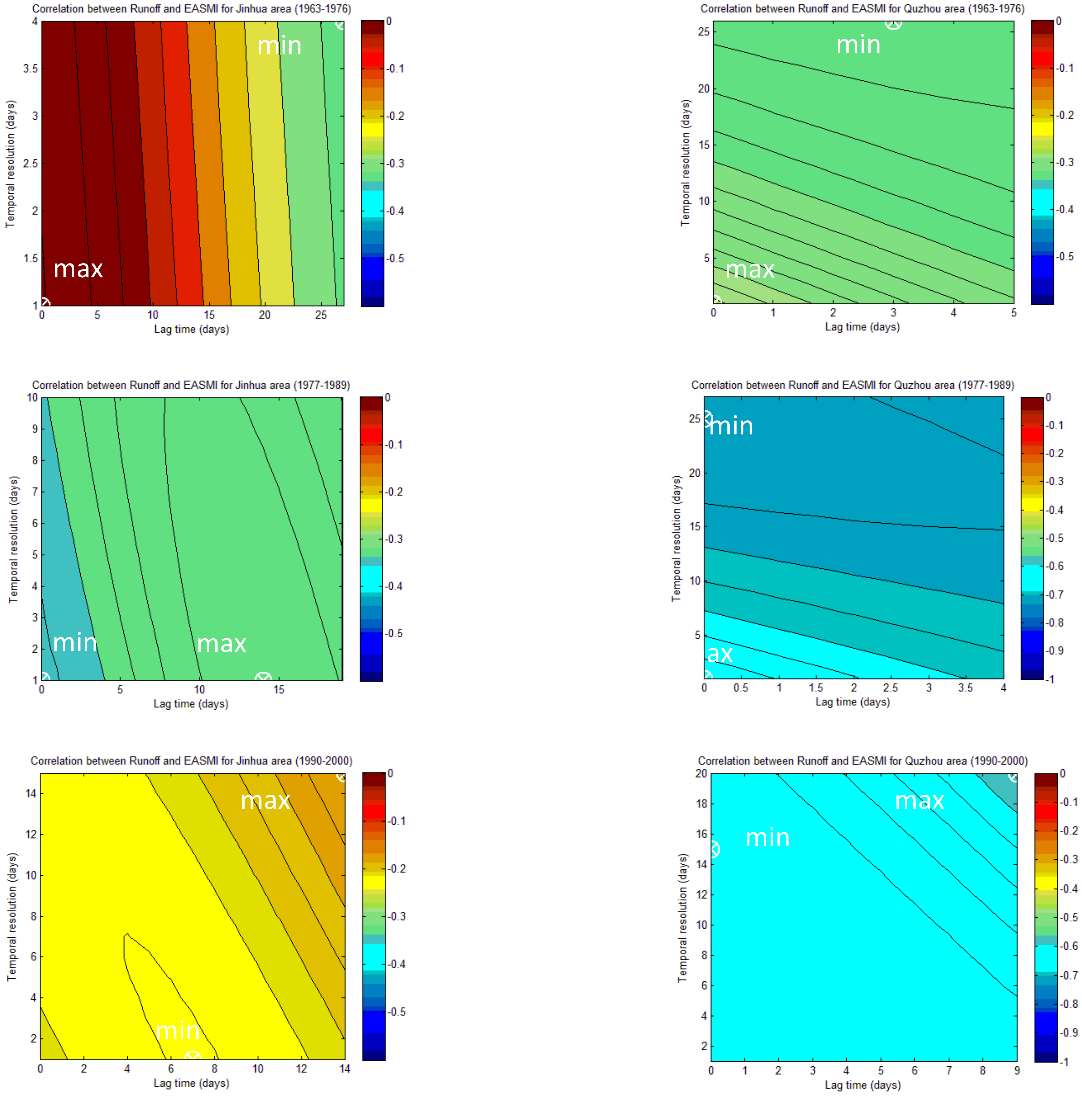


FIGURE 26: CORRELATION GRAPHS BETWEEN EASMI AND HIGH RUNOFF FOR THREE DIFFERENT SHORT PERIODS. THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWN WITH A WHITE CROSS.

TABLE 20: CORRELATIONS VALUES FOR RELATION EASMI WITH PRECIPITATION FOR THREE SHORT PERIODS. SIGNIFICANT VALUES ARE UNDERLINED

Period	Correlation (minimum)	Lag (days)	Temporal resolution (days)	Correlation (minimum)	Lag (days)	Temporal resolution (days)
	Jinhua			Quzhou		
1963-1976	-0.320	27+	4	-0.333	3	25+
1977-1989	-0.340	0	1	-0.719	0	25
1989-2000	-0.221	7	1	<u>-0.678</u>	0	15

EASMI – Three day average runoff

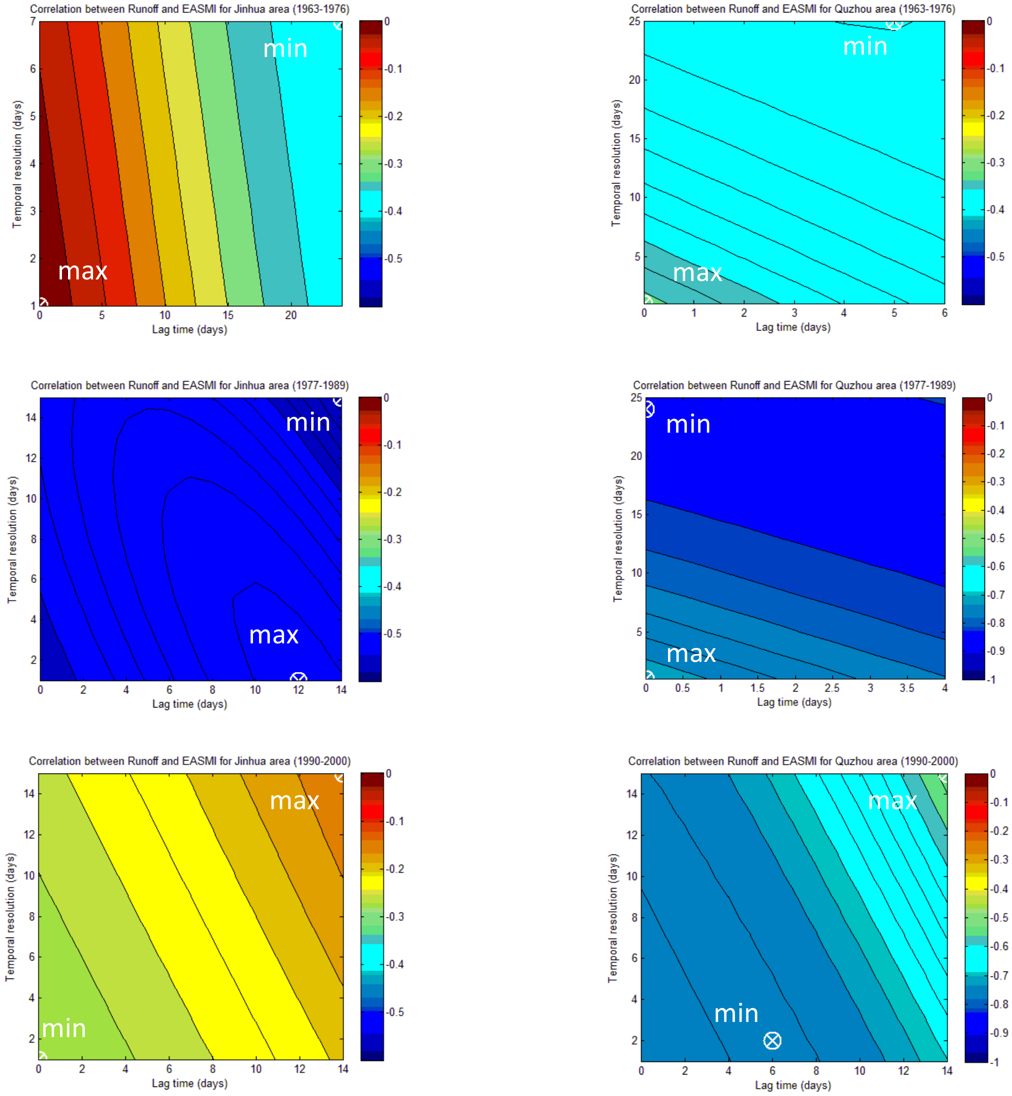


FIGURE 27: CORRELATION GRAPHS BETWEEN EASMI AND THREE DAY AVERAGE HIGH RUNOFF FOR THREE DIFFERENT SHORT PERIODS. THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWN WITH A WHITE CROSS.

TABLE 21: CORRELATIONS VALUES FOR RELATION EASMI WITH PRECIPITATION FOR THREE SHORT PERIODS. SIGNIFICANT VALUES ARE UNDERLINED

Period	Correlation (minimum)	Lag (days)	Temporal resolution (days)	Correlation (minimum)	Lag (days)	Temporal resolution (days)
	Jinhua			Quzhou		
1963-1976	-0.401	24+	5	-0.410	4	25+
1977-1989	<u>-0.564</u>	14+	15+	<u>-0.834</u>	0	24+
1989-2000	-0.279	0	1	<u>-0.743</u>	6	2

SOI – Precipitation

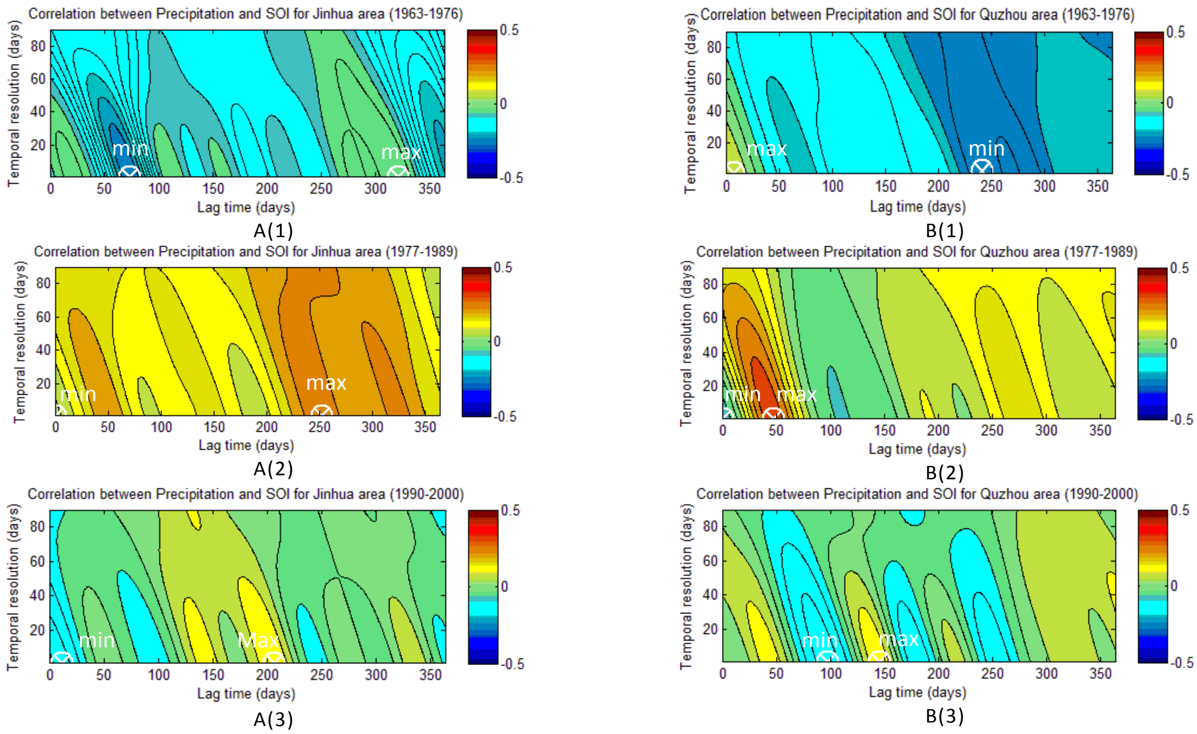


FIGURE 28: CORRELATION VALUES FOR THE RELATIONSHIP BETWEEN PRECIPITATION AND THE SOI DURING THREE DIFFERENT PERIODS.

SOI – Runoff

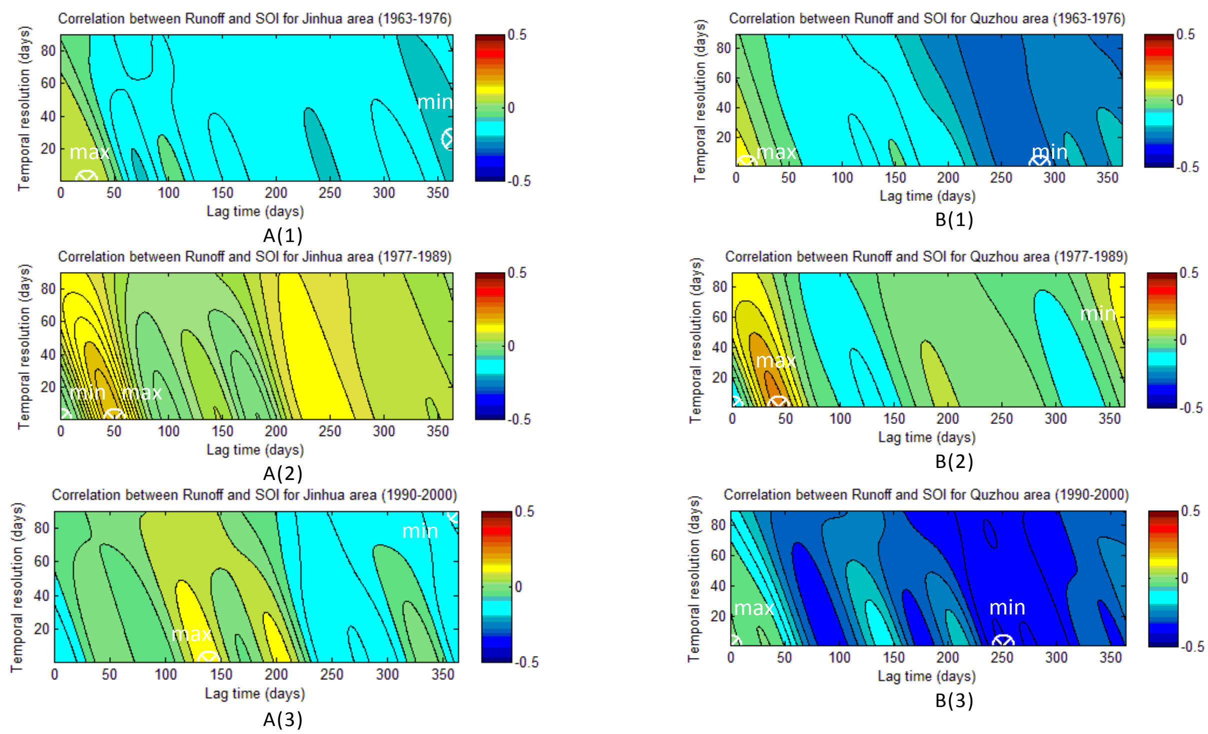


FIGURE 29: CORRELATION VALUES FOR THE RELATIONSHIP BETWEEN HIGH RUNOFF AND THE SOI DURING THREE DIFFERENT PERIODS.

SOI – Three day average runoff

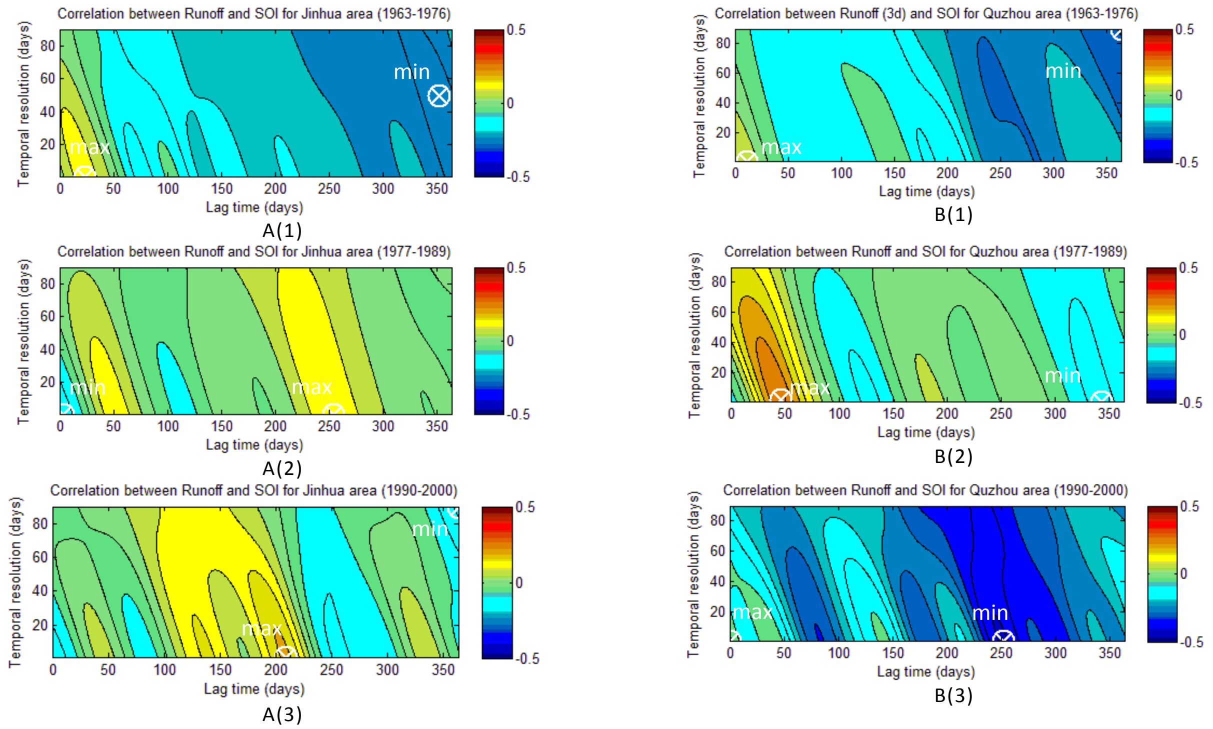


FIGURE 30: CORRELATION VALUES FOR THE RELATIONSHIP BETWEEN THREE DAY AVERAGE HIGH RUNOFF AND THE SOI DURING THREE DIFFERENT PERIODS.

Correlation table SOI (maximum correlation)

TABLE 22: CORRELATION VALUES FOR THE RELATIONSHIP BETWEEN THE SOI AND THE PRECIPITATION, HIGH RUNOFF AND THREE DAY AVERAGE HIGH RUNOFF FOR THE DIFFERENT SHORT PERIODS (BASED ON THE DIFFERENT PHASES OF THE PDO). SIGNIFICANT VALUES ARE UNDERLINED.

Area	Relationship (+/- is positive/negative)	Correlation 1963-1976 (PDO -)	Correlation 1977-1989 (PDO +)	Correlation 1990-2000 (PDO +/-)
Jinhua	SOI-P +	0.146	0.278	0.148
	SOI-P -	-0.240	0.031	-0.163
Quzhou	SOI-P +	0.085	0.334	0.137
	SOI-P -	-0.279	-0.078	-0.171
Jinhua	SOI-Q +	0.096	0.196	0.140
	SOI-Q -	-0.188	-0.021	-0.156
Quzhou	SOI-Q +	0.111	0.267	0.035
	SOI-Q -	-0.285	-0.112	-0.405
Jinhua	SOI-Q3 +	0.118	0.149	0.209
	SOI-Q3 -	-0.270	-0.114	-0.162
Quzhou	SOI-Q3 +	0.080	0.285	0.018
	SOI-Q3 -	-0.306	-0.113	-0.407

Appendix VI: Multiple regression graphs

Runoff – climate indexes

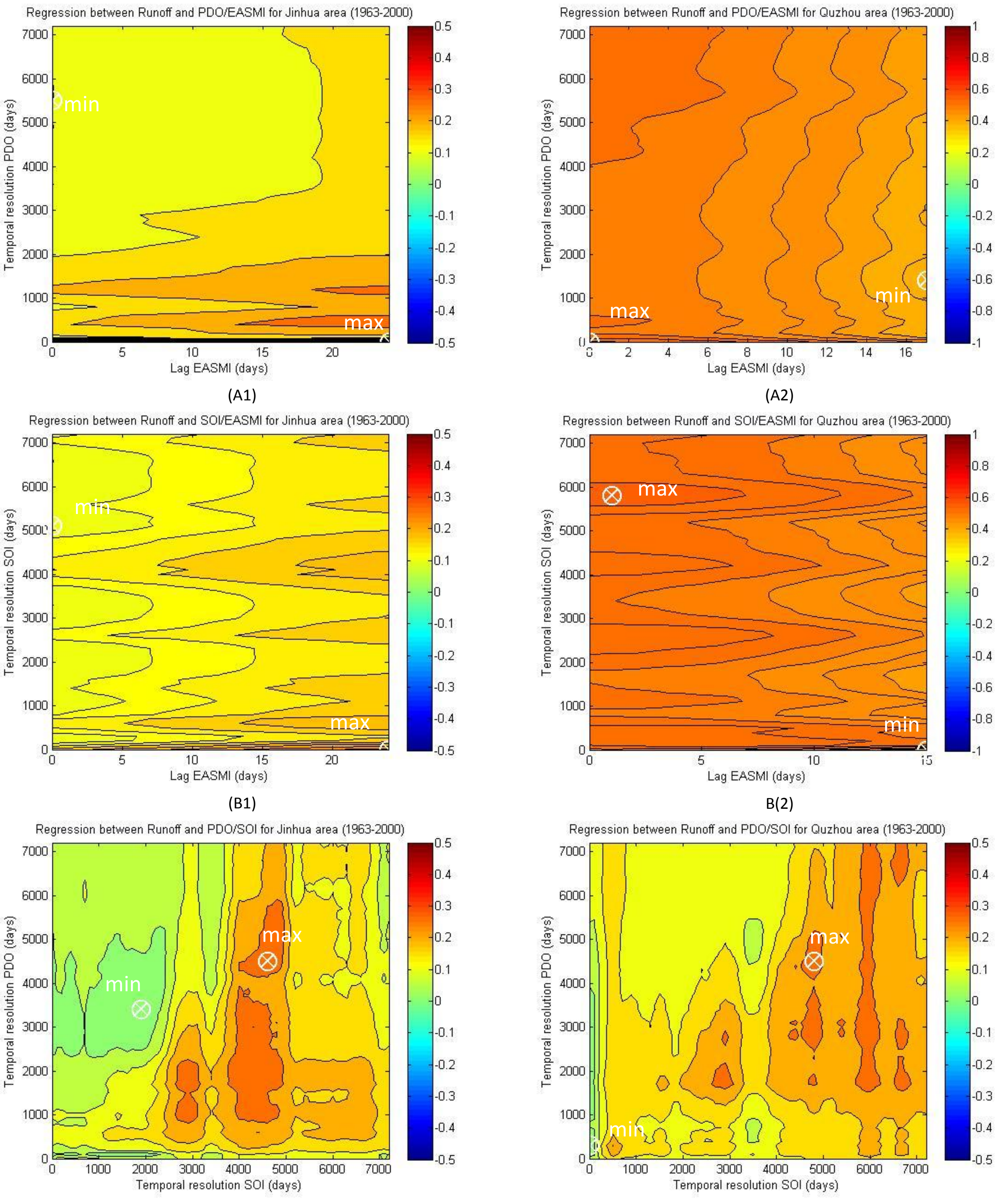
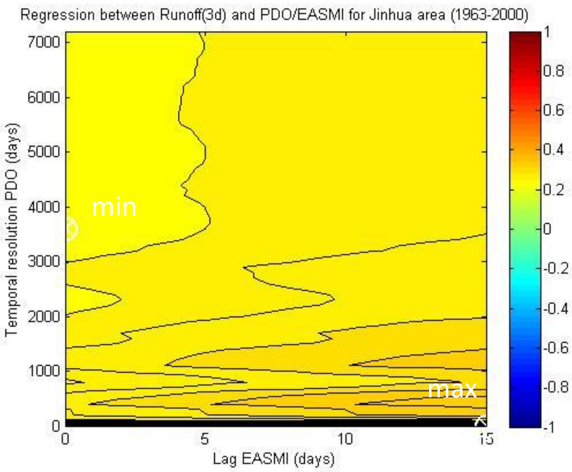
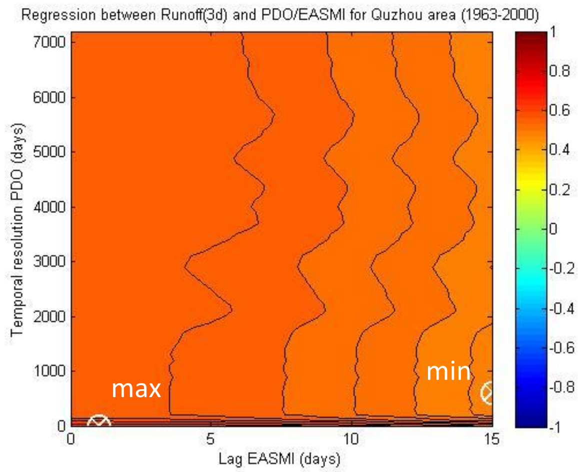


FIGURE 31: CORRELATION GRAPHS FOR MULTIPLE REGRESSION ANALYSIS BETWEEN HIGH RUNOFF AND CLIMATE INDEXES FOR PDO/EASMI (A), SOI/EASMI (B) AND PDO/SOI (C) FOR JINHUA (1) AND QUZHOU (2). THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWN WITH A WHITE CROSS.

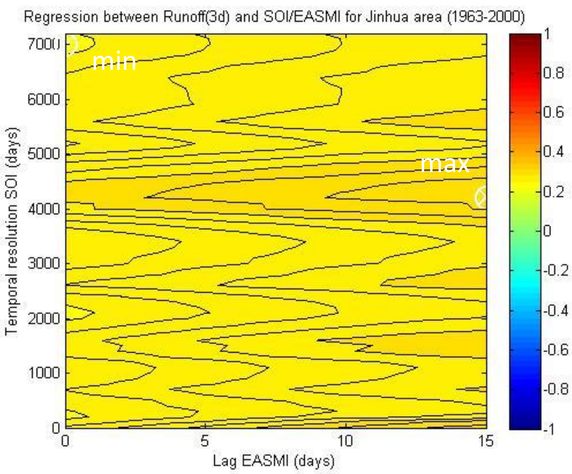
Three day average runoff – climate indexes



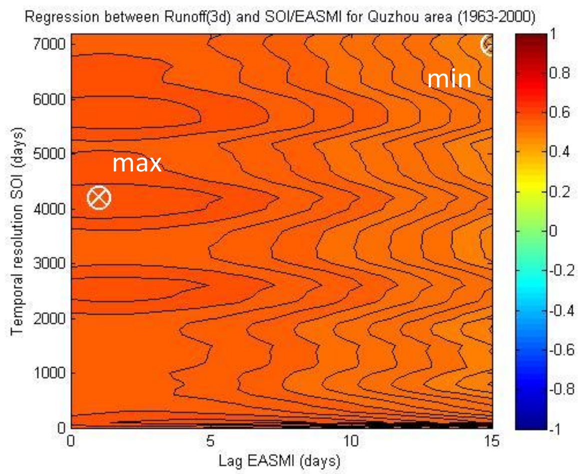
(A1)



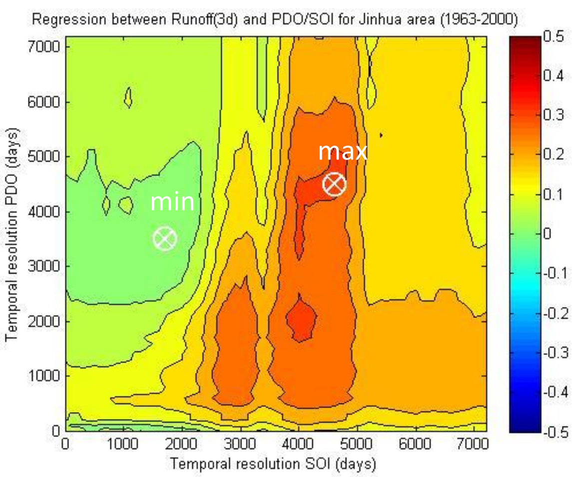
(A2)



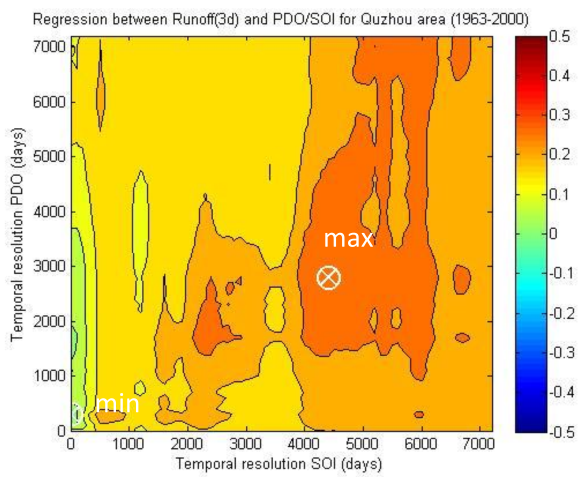
(B1)



B(2)



(C1)



(C2)

FIGURE 32: CORRELATION GRAPHS FOR MULTIPLE REGRESSION ANALYSIS BETWEEN THREE DAY AVERAGE HIGH RUNOFF AND CLIMATE INDEXES FOR PDO/EASMI (A), SOI/EASMI (B) AND PDO/SOI (C) FOR JINHUA (1) AND QUZHOU (2). THE MAXIMUM (NEG. = MIN AND POS. = MAX) VALUES ARE SHOWN WITH A WHITE CROSS.