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Temperature and Precipitation Variability in China – A gridded monthly time series from 1958 to 1988

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Approved by

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ABBREVIATIONS

AVEDEV	Average of the absolute deviations of data points from their mean
CAS	Chinese Academy of Sciences
CDIAC	Carbon Dioxide Information Analysis Center
CRA	W. Cramer climatic database created for the LUC project
CRU	Climate Research Unit
CV*	A Coefficient of Variation in percentage units, defined as: average absolute deviation from mean * 100 / mean
DEM	Digital Elevation Model
GIS	Geographic Information System
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LUC	‘Land Use and Change’ project at IIASA
SAS	Statistical Application Software
WMO	World Meteorological Organization

Abstract

Wide climatic variability is characteristic for large parts of China including events of extreme anomalies. This paper presents a time series covering the period 1958 to 1988 for monthly temperature and precipitation in China for a 5x5 km grid cell size. Monthly station histories (265 for temperature and 310 for rainfall), long-term averages of mean monthly temperature and rainfall on a 5 km grid, and a digital elevation model (DEM) are the input data used to build the grid time series data base. Individual station anomalies in terms of deviation from the 31-year average were calculated and interpolated throughout China using the Mollifier interpolation technique. It uses a statistical approach to non-parametric interpolation. As a result data is available for monthly anomaly surfaces for all the years. By linking these to the long-term average grid maps we derive a time series of temperature and rainfall for China.

Maps were produced for anomalies, and for absolute temperature and precipitation in each year between 1958 and 1988. Along with maps indicating variability at the stations, others have been completed based on the interpolated time series. Due to surface smoothing of the interpolation the variability of the interpolated time series is usually lower than the one based upon station observations.

Temperature variability is quite low during the summer half. Anomalies are mostly less than 2°C in nearly all of China. During the winter months the anomaly increases up to 6°C with the highest variability in northern China and on the plateau. The pattern of monthly anomalies is stable in that relatively large areas show the same trend of deviation.

Variability of rainfall shows large differences in spatial and temporal terms. Rainfall variability is highest during winter when rainfall is low. Especially the monthly data offer a comprehensive insight into seasonal differences in regional rainfall variability. In northern China's agricultural productive areas variability is high during the spring months, decreases in summer and increases as of September. In the middle and lower reaches of the Changjiang river basin variability is high in July and August amounting to as much as over 50%. Variability is relatively low in Southwest China, which includes the fertile Sichuan basin. Also in China's northeastern agricultural areas variability is relatively low during the growing season. From a policy point of view it is also of interest to aggregate the data for certain geographic regions. Results for provinces and major watersheds are presented.

The interpolated surfaces were validated by comparing them with the station observations available in this study. Anomaly surfaces validation is determined by the interpolation error. There is a good fit for temperature anomaly surfaces compared to observed station anomalies. Because of the high spatial variability of rainfall anomalies including the possibility of extreme events in selected stations, interpolated anomalies are usually reduced during the interpolation. The temperature and rainfall time series validation is, in addition by the interpolation error, influenced by the differences in the 31-year average observed at stations and the average represented in the long-term average grids to which the anomaly surfaces are linked.

Disclaimer

Acknowledgments

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About the Author

Sylvia Prieler is a Research Scholar and Geographic Information Systems (GIS) expert with the Land-Use Change (LUC) Project at IIASA. In 1994 she obtained her Master's degree in landscape planning and ecology at the University of Agricultural Sciences, Vienna. She studied at the University of Manchester for a year in 1993, where she wrote her dissertation on *Environmental Assessment - Assessing Impacts on Terrestrial Ecology and on the Landscape in the British context*.

In 1994 Ms. Prieler joined the IIASA project on "Regional Material Balance Approaches to Long-Term Environmental Policy Planning". In 1997 she joined the IIASA LUC project as a GIS expert. She maintains the large LUC Arc/Info GIS databases, and handles many requests for GIS-related services both from the LUC researchers and outside collaborators. In addition, Ms. Prieler is working on specific LUC research tasks with regard to climatic variability in China and its impact on agricultural production potential.

Temperature and Precipitation Variability in China – A gridded monthly time series from 1958 to 1988

Sylvia Prieler

1. Introduction

China's vast area with its variety of landforms shows equally diverse climates ranging from humid tropics in the South to continental temperate climates with extreme cold winters in the North and desert conditions in the West. Large parts of the country are influenced by high climatic variability including events that can be described as extreme anomalies. In some years, these anomalies can, and have resulted in major damage to parts of China that include important agricultural regions and densely populated areas. Such incidents include the recent 1998 flood, or the dry years of 1996 and 1997 which, combined with specific management practices, such as over pumping for irrigation purposes, caused the lower reaches of the Yellow River to dry out to an extent that it failed to reach the sea for a period of between 100-200 days. These significant events have attracted attention far beyond China's borders.

When making certain kinds of environmental assessments – such as the vulnerability of agricultural production, the availability of water resources, or when evaluating the risks related to flooding and droughts, it is important to carefully consider the variability of both temperature and precipitation. Such criteria are of particular importance, nationally and internationally, when considering a large country like China. Its population, still expanding at a rapid rate, relies on a relatively small area suited for agriculture. Per capita only 0.12 ha crop land is available. This represents less than half of the world average. Therefore any assessments of climatic variability including its spatial distribution, and any studies of extreme events take on a particular importance.

The IIASA project *Modeling Land Use and Land Cover changes in Europe and Northern Asia* (LUC) (http://www.iiasa.ac.at/Research/LUC) of which the study presented in this paper is a part, has been developing tools and methodologies as well as databases which enable agricultural production potential, agro-economic and hydrological questions to be assessed. Climatic time series data bases allow the impact of variability as well as extreme events on these issues to be explored and may thus enhance the assessments including discussion on future scenarios.

Although station measurement histories are both important and available for many sites, many studies require spatially interpolated climatic variables, as well as point data. The IPCC Data Distribution Center at the University of East Anglia, U.K., recently released a time series of global monthly climate data with a spatial resolution of 0.5 degree latitude by longitude (New et al, 1999). For China, a cell size of 0.5 degree translates into an area of about 50x50 km. Most of the biophysical assessment models employed in the LUC project apply to georeferenced databases of a 5x5 km grid cell size.

The aim of the study presented here was to develop a time series at monthly time-steps for temperature and precipitation in China with a high spatial resolution, and to describe the main features of their variability. According to the availability of data we have chosen a grid cell size of 5x5 km and a period of 31 years, covering 1958 to 1988. Such a period is considered to be sufficient to capture major characteristics of variability. Recently we have received data for the period 1989 to 1997 and were thus able to extend the time period of the data base to 1997. Results of these last nine years are not included in this paper.

Chapter 2 presents the data sources and the processing steps including the interpolation method used to derive gridded time series of climatic maps. Chapter 3 discusses temperature and Chapter 4 precipitation. Each of these contains four subsections. It starts with a brief introduction to the main characteristics of temperature or rainfall in China. Secondly they introduce the observed station histories by describing major variability characteristics in the country. Thirdly we present the interpolated monthly time series and their features of variability. This includes selected examples of further analysis using the time series data base with the aim to highlight China's variability in a spatially explicit way. Especially for temperature the focus is on the agricultural productive area. In the case of rainfall we also seek to identify regions that are prone to either drought and/or excessive rainfall. Finally the fourth subsection discusses validation and reliability of the interpolated surfaces. The section on conclusions includes potentials for further applications of the time series database.

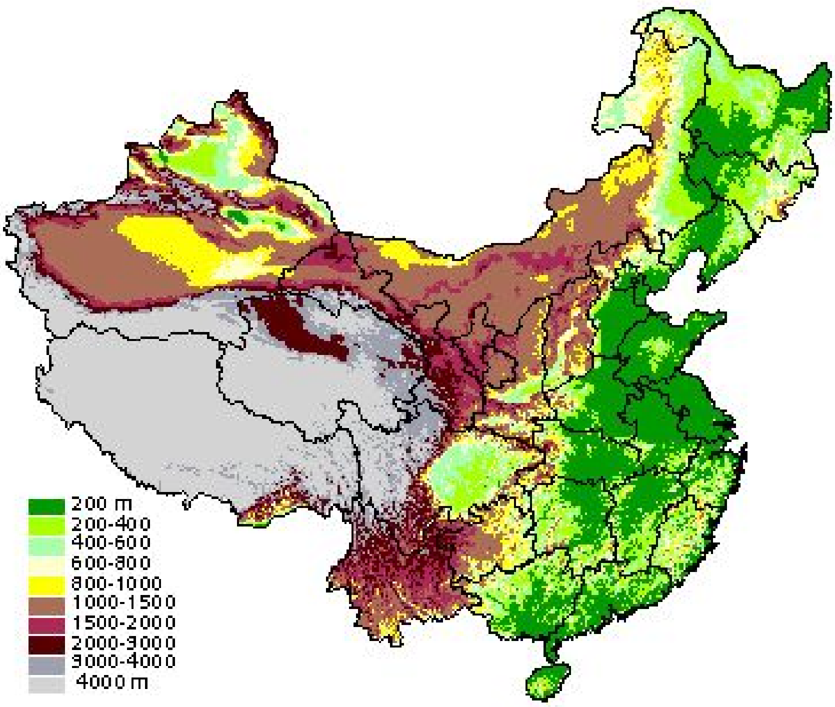
China extends from latitude 18º to 55º north. In the southern fringes climates are tropical and subtropical while small areas of cold polar-alpine climates reach into northeastern China. A detailed delineation of climatic regions in China is published in the Climatic Atlas of The People's Republic of China (Central Weather Bureau, 1979). Besides climatic indices the climatic regions are also determined by natural landscape features. They delineate nine first-order climatic areas from temperate over subtropical to tropical and a special region, the Tibetian Plateau. In describing climatic characteristics in this paper we often refer to geographic regions and administrative divisions which are shown in Figure 1.

The diversity in land cover reflects the wide range of climatic conditions in China. Large areas in the Northwest and Inner-Mongolia are desert, desert steppe, gobi or barren land. In the humid south in contrast, there are tropical rain forests on Hainan Island and in the south of Yunnan and mangrove swamps occur along the shores of the South China Sea. About a third of the country is covered by grassland ranging from sparsely vegetated to dense high-yielding meadows. Forest is concentrated in the mountainous areas in northeastern and southwestern China. Except for small areas in northwestern China, farmland generally only occurs in monsoon influenced eastern China and in northeastern China. The variety of agricultural production conditions is large, ranging from a single crop in the Northeast to three harvests a year in the South.

The whole pattern of climatic regions is closely related to physiography. High mountains and plateaus predominate the western part of China. The Qinghai-Tibet Plateau is well over 4000 m and the central part of this region, the North Tibetian Plateau, has an average height of about 5000 m. Towards the north and east, the mountains descend sharply to a lower level at 1000-2000 m and here basins are intermingled with plateaus including the Mongolian plateau, the Tarim basin, the Loess Plateau, the Sichuan basin and the Yunnan-Kweichow plateau. Most of the eastern part of China is below 400 m and composed of plains and hills (Fig. 2).

Figure 1. Provinces and major geographic regions of China.

Figure 2. Digital Elevation Model (DEM) of China.



2. Methodology

2.1 Overview

A major aim of the study reported here was to create a time series data base of monthly temperature and precipitation in China interpolated for a 5x5 km grid cell size. Box 1 provides a comprehensive summary of the methodology used to create the data base. To build the time series database we used two sets of input data. The first are historic monthly climatic station measurements covering the period 1958 to 1988. For temperature, 265 stations with mean monthly temperature time series are available. In the case of rainfall 310 stations feature monthly rainfall sums over the 31-year period. The second set consists of grid maps that detail long-term monthly average climatic data and a digital elevation model (DEM), both relative to a grid-cell size of 5 km. The grid maps are stored in a Geographic Information System (GIS).

Individual station anomalies in terms of deviation from the 31-year average were calculated and interpolated over a 10 km grid cell size throughout China. The Mollifier interpolation technique was used for this purpose. It uses a statistical approach to non-parametric interpolation (see Section 2.3). As a result monthly anomaly surfaces are available for all the years. The 10 km grid cell size was chosen to ensure reasonable file sizes and processing time. In a GIS the 10 km anomaly surfaces were resampled to 5 km anomaly surfaces using a simple nearest-neighbor assignment as interpolation method.

Box. 1 – Methodology Overview

Input data:

- Time series of monthly station data measurements from 1958 to 1988
  (310 stations for Precipitation, 295 stations for Temperature)
- Monthly rainfall and temperature long-term average grids on a 5x5 km grid cell size
- Digital Elevation Model (DEM), 5 km and 10 km grid cell size

Processing steps and *Results*:

a) Calculate anomalies* for each year and station
b) Interpolate anomalies over a 10 km grid cell-size throughout China
   using the Mollifier interpolation technique
   (predictors are: x, y coordinate and elevation of the grid cell)
c) Resample 10 km grid cell sizes anomaly surfaces into 5 km grid cell size using a GIS
   → *Time series (1958-1988) of anomaly surfaces*
d) Link the anomaly surfaces with the long-term average maps
   → *Time Series of rainfall and temperature*
e) Calculate Variability based on the interpolated time series
   → *Variability maps*

* Anomaly is for temperature the °C deviation and for rainfall the mm deviation in a particular year from the average over the period 1958 to 1988.

In addition to the anomaly surfaces we have subsequently created time series of monthly temperature and rainfall. This was done by linking the anomaly surfaces with temperature data from the LUC mean monthly climatic database. These data contain long-term averages (“normals”) for each month for a 5 km grid-cell size. For example, a cell which shows in the LUC average climatic database +15°C in July and records for a particular year from the interpolated July anomaly surface an anomaly of -2°C results in a temperature of +13°C in that cell and given year. We thus derive a spatially interpolated time series of monthly temperature and rainfall for China for the period 1958 to 1988.

The long-term average climatic databases are considered to be fairly accurate. Many more than 300 stations were used for their creation. In addition in areas with a difficult territory and where only few station data are available (e.g. in the western and southern parts of the Tibetan Plateau), manual corrections of obviously erroneous areas were introduced. By combining interpolated station data anomalies with long-term average maps, the possibility of creating unlikely climatic data has been eliminated. Furthermore, the Mollifier interpolation does not result in values higher or lower than the maximum or minimum of observed data in a particular set to be interpolated. A potential limitation of the approach to combine anomalies interpolated from station data with long-term average climatic maps is that the average calculated for a station based on the 31-year period may be different from the average presented in the long-term average maps.

In addition to variability based upon measured station time series, we then analyze the interpolated time series grids for their characteristics of variability. Thus for each point in China an estimate of variability characteristics is now available. This enables to highlight regional and temporal differences of China’s climatic variability.

2.2 Data sources

Climatic station time series

The majority of the climatic time series were obtained from the Carbon Dioxide Information Analysis Center (CDIAC), which provides “Climate Data Bases of the People’s Republic of China, 1841-1988” as public domain through Internet access (CDIAC, 1998). The United States Department of Energy (DOE) and the People’s Republic of China (PRC) Chinese Academy of Sciences (CAS) signed an agreement on August 19, 1987, to carry out a joint research program on possible CO2-induced climate changes. One subject in this agreement refers to the preparation of several PRC instrumental climate data sets. CAS’s Institute of Atmospheric Physics has provided records from 296 stations covering several monthly climatic variables including surface air temperature and precipitation. The time frame 1841-1988 describes only the maximum of recorded years, most stations provide data for between 25 to 60 years, gaps in time series are common. CDIAC has conducted a quality assurance review of the data, checking them for completeness, reasonableness, and accuracy. After resolving questions with the CAS where possible remaining questionable data were flagged. These data represent the most comprehensive, long-term instrumental Chinese climate data currently available outside China.

After reviewing this large data set for complete time series of monthly temperature and precipitation data, it was decided to use a time period of 31 years covering 1958 to 1988 for 265 stations for temperature and 294 stations for precipitation. The time series in these stations is nearly complete except for about 1% of the total data per month showing *no data* values. A considerable part of this 1% stems from one station in Western Tibet (WMO No. 55228) which has records only from 1961 to 1982 but was still included in the data set since it was the only available station in this part of China. For precipitation we use data of an additional 16 stations from a climatic database compiled by the LUC project derived from Chinese statistical yearbooks. In total we have thus a nearly complete monthly time series from 1958 to 1988 for 265 in the case of temperature and 310 stations for rainfall. Lately the time period could be extended throughout 1997. The CAS, Institute of Geography, a collaborator of the LUC project has provided for the period 1989 to 1997 monthly temperature and rainfall data for the 310 stations.

The station distribution is much denser in eastern China than in the western half. The average distance between stations used in this study in the eastern half of China is approximately 110 km. Therefore, the reliability of the interpolated time series is considered much higher in the eastern part of China. Especially on the Qinghai-Tibet plateau only few station histories exist. However, in these regions only few people live and crop production is either not possible or relatively unimportant. The map in Figure 3 details the 310 station network showing in the background the distribution of cultivated land.

Grid maps of long-term average mean monthly climatic data

In collaboration with Prof. Wolfgang Cramer from the Potsdam Institute for Climate Impact Research (PIK), the LUC project has created a climatic database for a grid cell-size of 5 km (henceforth CRA). It includes long-term averages of monthly mean temperature and monthly rainfall for the region of the Former Soviet Union, Mongolia and China. First, LUC provided W. Cramer with longitude, latitude and altitude of each 5 km grid-cell size, then he performed the interpolation using a methodology described in *Leemans and Cramer (1991)*. Due to availability of data, their approach has been to define “current climate” (or “normal climate”) as the average climate of the period 1931-1960. The number of station normals available for China was about 700 to 800. However also the information from stations in neighboring countries contributed to China’s 5 km normal grids.

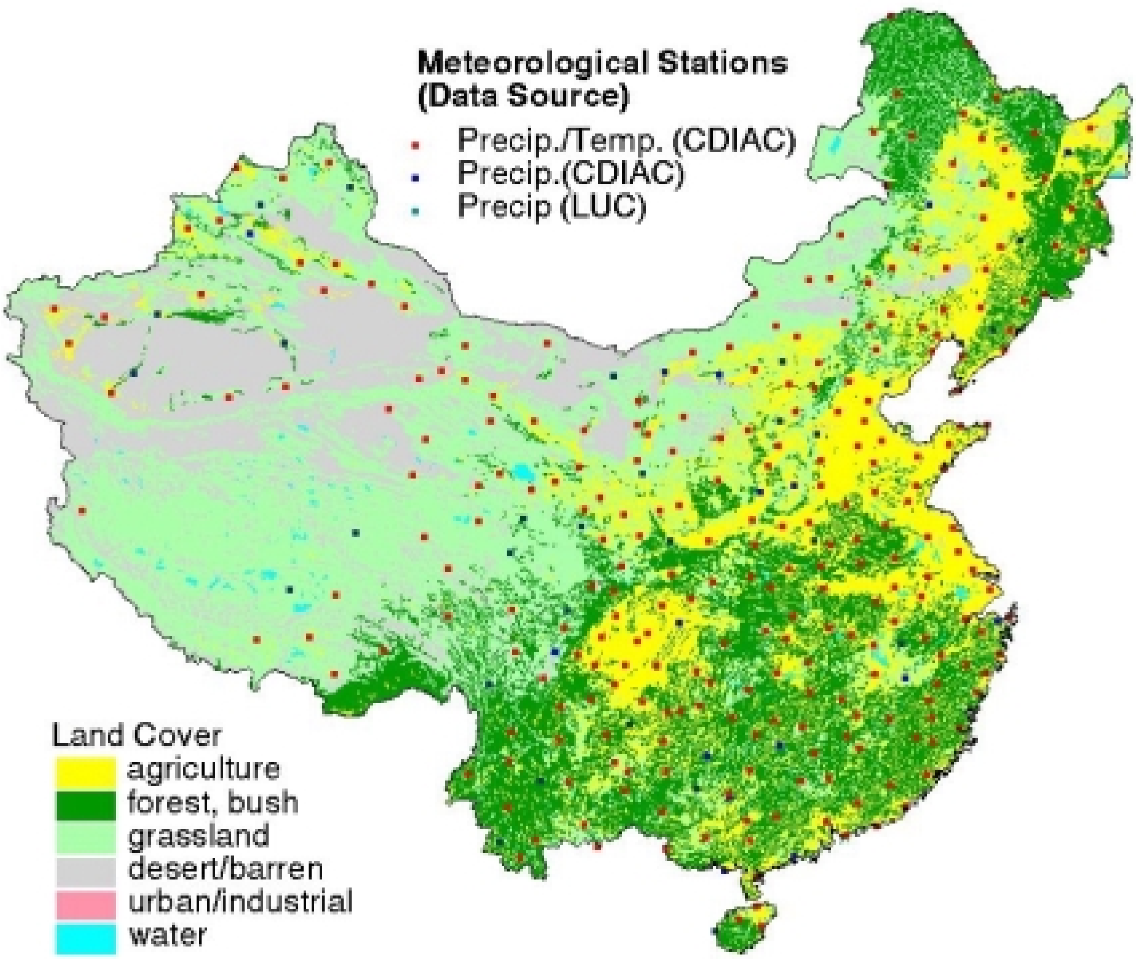
For China the CRA annual precipitation map appeared to deviate from information mapped in China (Inst. of Soil Science, 1986) in the difficult terrain of southwestern China and on the Tibetan plateau where only few station data are available. Therefore in this area apparent discrepancies in annual precipitation were manually corrected in a GIS environment using hardcopy atlases as information source. Any changes introduced to the annual precipitation levels were then translated into the monthly rainfall grid-cell data assuming the same distribution within the year as in the original data.

In addition we use climatologies developed at the Climatic Research Unit (CRU) at the University of East Anglia. In the frame of the *Climate Impacts LINK Project* they have created a 0.5° latitude by 0.5° longitude 1961-1990 mean monthly climatology for global land areas (New et al, 1999). It is available for public domain through the IPCC Data distribution center (IPCC, 1999). Temperature and rainfall for China from this database (henceforth LINK) are included in the validation exercise of this study.

Digital Elevation Model

The Digital Elevation Model (DEM) used in the LUC project originates from the public domain "GTOPO30 Global 30 Arc Second Elevation Data Set" available from EROS Data Center (EROS Data Center, 1998). GTOPO30 is a global DEM with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). Using a GIS we have projected the original DEM to an equal-area Lambert projection commonly used in the LUC project. The resulting cell size was 1039 m. Two additional DEMs, with a grid-cell size of 5 km and 10 km respectively, were created using the median of the particular grid-cells in the 1 km data set to derive the coarser resolution (Fig. 2).

Figure 3. Location of temperature and precipitation stations and major land use.



2.3 Interpolation using the Mollifier Program

A major task was to interpolate measured station data anomalies in order to create anomaly surfaces throughout China. The interpolation method employed is a non-parametric regression function, specified in the Mollifier program, which has been developed at the Center for World Food Studies, Amsterdam, The Netherlands (Albersen and Keyzer, 1998).

The Mollifier Program uses a statistical approach to non-parametric interpolation, i.e. interpolation is viewed as the calculation of an expected value in the statistical sense. The weighting function of the interpolation is then equal to the probability $P^s(x)$ of an observation y^s being the correct value of *y(x)* at an intermediate point *x*.

$$y(x) = \sum_{s=1}^{S} y^s \cdot P^s(x)$$

This system defines a non-parametric regression function, whose shape depends on the postulated form of the probability function. The software uses the normal distribution as the probability function. The regression curve lays a “soft blanket” on the observations such that it absorbs the peaks of the highest poles (upward outliers**)** and remains above the lowest ones. When emphasis is given to nearby points, the probability function is said to use a small bandwidth, or window size. It is possible to control the window size in order to meet a certain optimality criterion. The larger the window size, the tighter and smoother the blanket. Thus the Mollifier model allows for a manipulation of the observation point errors by the degree to which the surface is smoothed. The window size can be scaled by the user relative to the optimal window size defined by:

$$(4/n(d+2))^{(1/(d=4))},$$

with *n* being the number of observations and *d* being the number of explanatory variables.

The analytical form of the probability function $P^s(x)$ is obtained by applying a Mollifier mapping, which was first introduced by Sobolev (1988) and further developed at IIASA (see Ermoliev et al., 1995, Pflug, 1996). This mapping can be viewed as a special form of the joint density from the theory of kernel density regression (Parzen, 1962).

Compared to parametric methods such as spline regression or variogram estimation, the Mollifier-method has the important advantage that it gives a measure of statistical reliability at every point. It does not depend on the fit at other points. Indeed, for every point *x* the Mollifier method can calculate, besides the value *y(x)*, additional statistics such as higher-order derivatives and the (relative) likelihood $\Psi(x)$ of *x* being associated to any observation *y* in the sample, but also the probability of *y* falling within a given range around *y(x)*, thus measuring the quality of the fit at *x*.

For reasons of file size and processing time, the Mollifier interpolation was run using a 10 km grid covering all of China. The exogenous variables, i.e. *x*-coordinate, *y*-coordinate and altitude of each of the approximately 94000 10 km grid cells, as well as the dependent variable, i.e. temperature or precipitation anomaly at observation points were all transferred to a SAS[1] interface, which controls the Mollifier program. Since the exogenous variables involve geographical information, the influence of remote information points should not play a significant role. Thus after carrying out various tests, we selected a relatively small window size of 0.3. This means 30% of the optimal window size as defined above. For consistency, the same window size was kept for all interpolations. More than 800 interpolations were performed, calculating anomaly surfaces for each month and year from 1958 to 1988 with regard to both temperature and rainfall. For rainfall also seasonal and annual anomalies were interpolated.

3. Temperature

3.1 Main features of mean temperature distribution

In China a range of climatic zones occurs whose main characteristics are determined by physiography, latitude and the seasonal movement of air masses between the large continent of Asia and the Pacific Ocean. In general China is characterized by two different climates. In the Northwest, the continental climate type with severe winters and scorching summers. It covers Xinjiang, the Chaidam basin of Qinghai, western Tibet and the part of Inner Mongolia lying north of Helan and Yinshan mountains. The rest of China lies within the monsoon area.

"Monsoon" is defined as a climatological phenomenon manifesting itself by a marked change of wind directions between summer and winter. This change is due to the seasonal variation of the thermal structure of the underlying surfaces and involves different air masses, producing noticeable effects on the weather and climate of the areas concerned. During winter a strong cold anticyclone spreads over Mongolia (the Mongolian High), while at the same time there are two pronounced low-pressure zones, the Aleutian Low and the Equatorial Low, near New Guinea and Australia. Northeast and East China are in the path of the movement of cold air streaming from the Mongolian High to the Aleutian or Equatorial Low. Hence northwesterlies prevail in Northeast China and northerly and northeasterly flows prevail over the eastern half of China blowing cold and relatively dry air masses (winter monsoons) into most of China. In spring, when the sun returns to the Northern Hemisphere, the system of pressure zones reverses. Vast quantities of warm and moist air originating from the Pacific and Indian Ocean move northwestwards. The four distinctive seasons as well as the marked dry (in winter) and rainy (in summer) seasons in the eastern half of China stem from the monsoon effect.

A characteristic of the monsoon climate in China is a wide annual range of temperatures. Compared with temperatures in other parts of the world at the same latitude, China has a colder winter and a hotter summer. The degree of continentality expressed as average July minus January temperature increases from south to north (Fig. 4). It is less than 10°C on Hainan island and in southwestern Yunnan and increases to over 40°C annual temperature range in northwestern and northeastern China. Four stations in northern Mongolia and Heilongjiang show the largest temperature range of over 45°C with a maximum of 48°C.

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[1] The Mollifier software is controlled by SAS macros within a SAS job. SAS is a statistical package software.

In most of the country January is the coldest month and July the warmest. Maps with average temperature from January to December are shown in Figure 5. The coldest pole is in the northern fringes of Northeast China, where mean December and January temperature is between –25° and –30°C and can in some years even drop below –30°C. In contrast, during the winter months on southern Hainan island the average temperature is between 15° and 20°C. In July and August average temperatures rise above 20°C except in higher mountain regions.

Even in these regions temperature stay above 5°C in areas below 4000 m. In eastern and southeastern China July average temperatures exceed 25°C, and monthly averages are as high as 30°C in some locations in the southern Changjiang Valley. The hottest area is in northwestern China. Turfan, situated just to the south of the Tianshan Range, only 34 m above sea level and with bright sunny skies, records China's highest July average temperature of 33°C.

Figure 4. Degree of continentality – July minus January temperature (in °C).

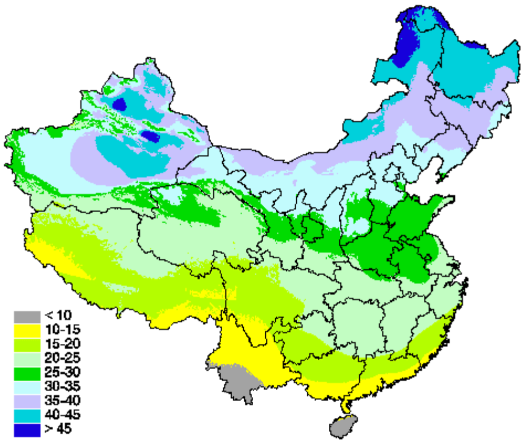
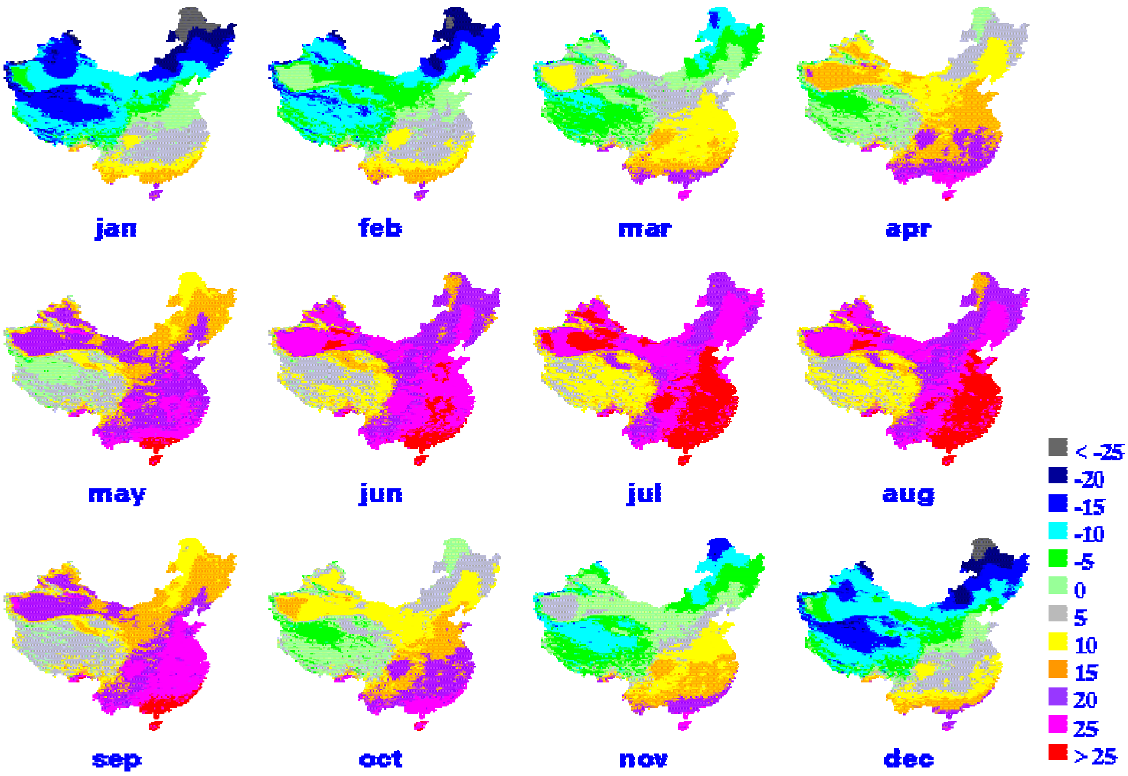


Figure 5. Average monthly mean temperature in China (in degree Celsius).

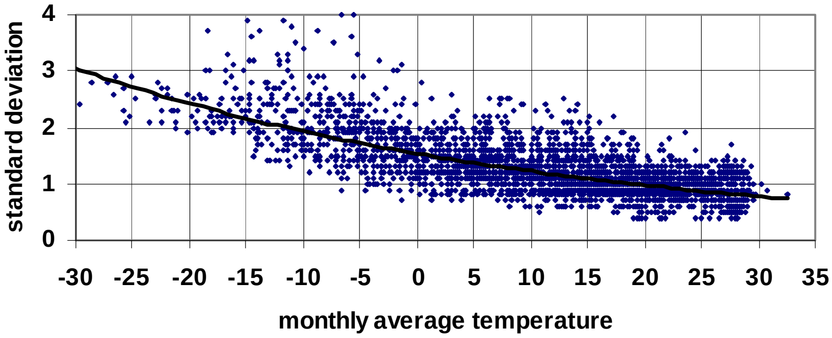


3.2 Variability of station histories

For 265 stations (see Fig. 2) histories of mean monthly temperature observations have been analyzed for their characteristics of variability. We speak of average monthly temperature to specify the average over the 31 years considered (1958 to 1988). Mean monthly temperature refers to the mean 24 hours temperature of all days in a particular month in a particular year. The analysis does not include temperature data of individual days. Extremes relate thus to minimum or maximum mean monthly temperatures. Anomalies in this paper are always expressed as deviation from the 31-year average.

Variability increases with decreasing monthly temperature. This becomes apparent in Figure 6 presenting a scatter diagram of monthly average temperature over the 31-year period against standard deviation for all stations in China. When monthly average temperatures are positive standard deviation is mostly between 1 and 2°C, in a few cases it goes up to 2.5°C. With negative average monthly temperatures standard deviations up to 4°C occur.

Figure 6. Monthly average temperature over the period 1958 to 1888 against standard deviation (in °C). (The chart shows all 265 stations and months.)



From maps showing absolute and relative standard deviations, we see that from April to October standard deviation is below 2°C for the whole of China (with five exceptions in April and May in the North). In relative terms between May and September this is a standard deviation of less than 4% of the 31-year average for nearly all the stations. Standard deviations of 2 to 3°C are measured at stations in northeastern and northwestern China from November to March. Only in February standard deviations of 2 to 3°C occur also in southern China, south of Changjiang river. The highest standard deviations are observed in northern China during the winter months when average temperature is below -15°C and standard deviation ranges from 2 to 4°C.

High humidity in the Monsoon season from April to October suppresses temperature fluctuations. This is reflected not only in the low standard deviations but also in a lack of extreme events. For each station we have calculated the difference between maximum and minimum mean monthly temperature over the 31 years considered. We call this difference monthly temperature range. Table 1 summarizes for all 265 stations the percentage of stations found in a particular range classes in a particular month. Between May and October for the majority of stations the difference between maximum and minimum mean temperature over the 31 years is less than 6°C. In June and July it is even less than 4°C for two thirds of the stations.

During the relatively dry winter period (low humidity) temperatures vary considerably. Standard deviations up to 4°C may seem low but looking into maximum and minimum mean temperatures over the 31 years considered reveals the possibility of extreme events in winter. The highest ranges over 10°C generally occur in northern continental China (Inner Mongolia, Xinjiang and on the Tibetan plateau). The maximum range was measured at a station on the border to Mongolia where in December 1967 -25°C mean monthly temperature was observed while the average is -11°C and the warmest year on record showed -7°C. Also southern China has higher temperature ranges in winter than in summer. South of the Changjiang river the provinces Guizhou, Guangxi, Hunan and Jiangxi experience high fluctuations in winter. In February ranges are over 8°C here compared to the summer months when they are less than 4°C.

Table 1. Distribution of monthly mean temperatures ranges (maximum minus minimum mean monthly temperature over the 31 year period 1958 to 1988).
(The table shows percentage of stations which fall in a particular range class based on the 265 station histories.)

Range Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<4°C	7	3	3	20	34	62	70	59	66	37	6	3
4 - 6°C	39	9	42	63	62	33	28	38	30	58	57	22
6 - 8°C	31	33	35	15	3	5	2	3	4	4	24	39
8 - 10°C	15	39	13	2	1	0	0	0	0	0	8	18
>10°C	7	16	7	0	0	0	0	0	0	0	5	17
max range [°C]	15	17	17	10	9	7	12	8	9	11	12	19

Station anomalies also point at a low variability during the summer months and the possibility of extreme events in winter. Anomalies here are expressed as degree Celsius deviation in a particular year from the 31-year average temperature over the period 1958 and 1988. Table 2 gives a comprehensive overview of the anomalies observed in a particular month. From May to October more than 90% of the anomalies are less than 2°C. In the rest of the year it is only 80% of all observations which measured such low anomalies. In winter some stations record deviations of more than 10°C in some years.

3.3 Time series of spatially interpolated monthly mean temperatures

As described in the methodology chapter, the spatially interpolated data base includes the following products: Two time series each from 1958 to 1988 of grid data for a 5x5 km cell size, first the temperature anomaly surfaces, second the mean monthly temperature. Based upon the latter we have also created maps featuring areas of high or low temperature variability in China.

Table 2. Anomalies for 265 station observations from 1958 to 1988. (Anomaly is expressed as degree Celsius deviation from average temperature of the 31 years considered.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percentage of Data* with anomaly below:												
<1°C	50	39	47	55	63	70	72	73	71	62	50	46
<2°C	81	69	79	89	93	96	96	96	97	93	83	76
< 3°C	93	86	93	98	99	100	100	100	100	100	95	91
<4°C	98	94	98	100	100	100	100	100	100	100	99	96
max anomaly[°C]	10	11	13	6	6	4	9	6	8	8	7	15
Mean [°C]	1.20	1.57	1.25	0.98	0.85	0.74	0.70	0.70	0.71	0.87	1.17	1.36

* The total number of data for each month is between 8172 and 8180 (265 stations times 31 years with some no data in certain years).

Appendix 1 shows examples of maps with time series of monthly anomalies. The color scheme is chosen to highlight anomalies of more than 2°C. Light gray, yellow and red tones symbolize areas which are warmer than average and dark gray, green and blue tones stand for areas colder than average.

From May to September the maps mainly highlight whether a region is warmer or colder than average because anomalies are less than 2°C in most of China. In some years only limited areas show anomalies up to 4°C. Among the highest deviations in August are the North China Plain in 1967 with 2-3°C above normal or the Changjiang valley in 1980 with 2-3°C below average. During the winter months anomalies increase all over the country and deviations of 2 to 4°C are more common. The highest deviations are found in North China and on the Tibetian plateau amounting up to over 6°C. These anomalies are quite high when we keep in mind that these are anomalies for monthly mean temperatures. Extreme daily events are not reflected in our data.

In general the pattern of monthly anomalies is stable in that relatively large areas show the same trend of deviation. Sometimes half or most of China is affected by warmer or colder temperatures than normal. Examples here are February of 1976, or 1987 when practically the whole country is warmer than average or February 1968 which was a cold month in nearly the whole country.

Based on the time series of mean monthly temperature we can estimate the probability that a certain anomaly occurs by simply counting the years above a threshold. Such calculations have been performed for cultivated areas using a mask derived from a 1 km cell-size land use (Liu, 1996) map. The mask was created in such a way that all 5 km pixels in which at least one 1 km pixel classify as cultivated land. The mask includes most of the eastern half of China and covers an area of 351 million ha. (The actual cultivated area in China amounts to 131 million ha). Figure 7 demonstrates for how many years (out of the total 31 years) what share of the cultivated area is affected by anomalies larger than 1°C throughout the year. For example, in May in two thirds of the cultivated area anomalies are larger than 1°C during 2 to 5 years. In another 30% of the cultivated area such anomalies occur between 5 to 10 years. Between June and September in 80% of the agricultural area anomalies over 1°C occur with a probability of less than 15% (less than 5 years out of 31 years).

From the temperature time series one can derive the variability of certain agroclimatic constraints such as frost occurrence. The first month in a year when mean monthly temperature is over 10°C, is an estimate for the start of the frost-free season. Fig. 13 displays the time series of the first months when the mean monthly temperature is above 10°C. In northern China there is little variability, May or April usually being the first frost-free month. In contrast, in southeastern China it is sometimes March and sometimes April marking the beginning of the frost-free period.

Figure 7. Number of years between 1958 to 1988 when the anomaly is larger than 1°C in China's cultivated area.

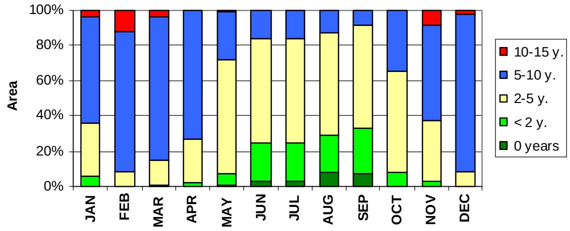
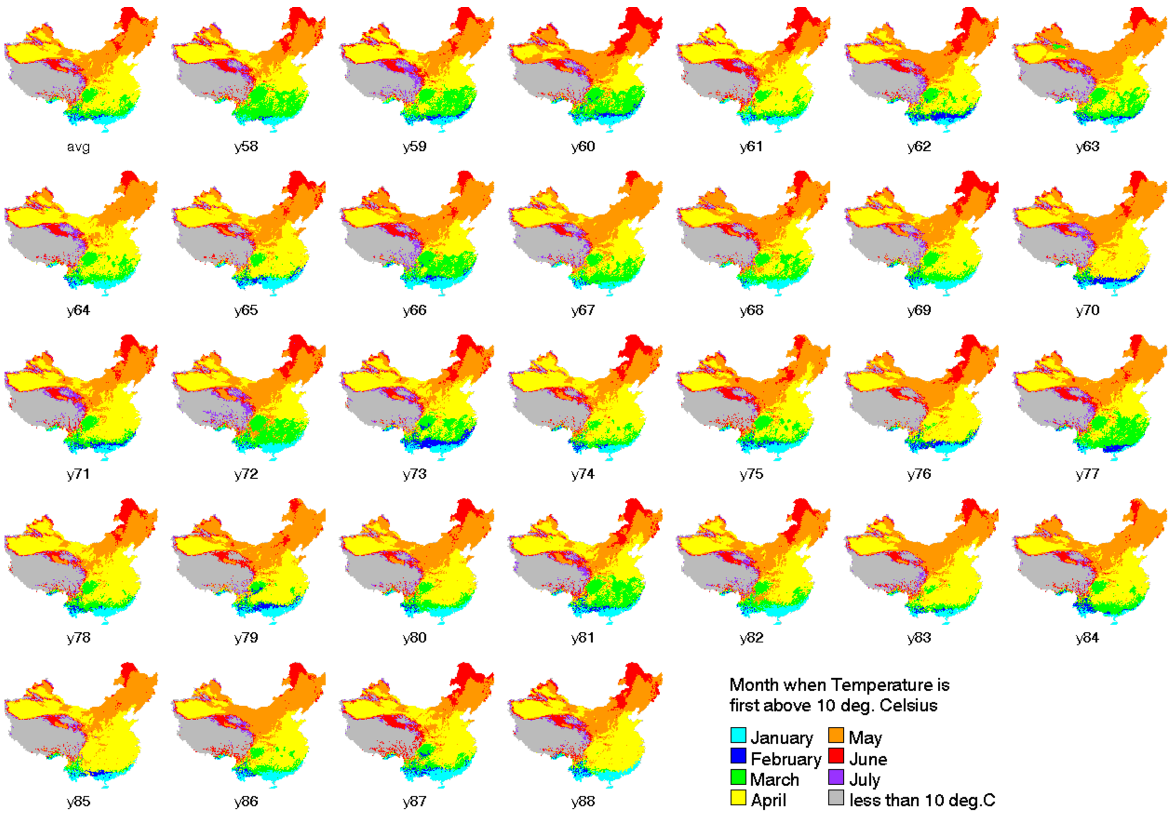


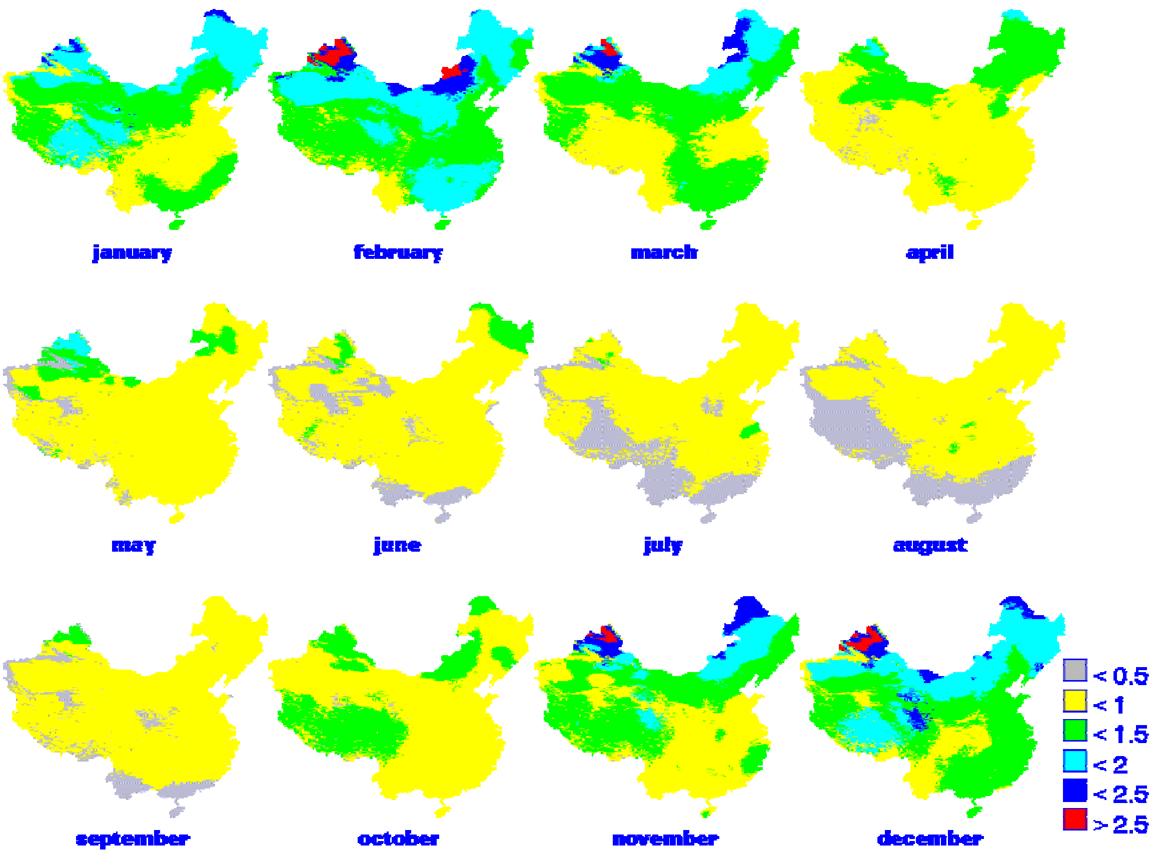
Figure 8. Time series from 1958 to 1988 of month when mean monthly temperature is first above 10°C. (First map is based on average climate.)



In addition to variability characteristics measured at stations we can now also analyze variability based on the interpolated temperature time series. Thus we obtain in addition to the point data variability characteristics for each grid cell in China. For temperature expressed in degrees Celsius with the scale ranging from less than -30°C to over +30°C, it is most useful to express variability in terms of average absolute deviation from normal (AVEDEV) calculated over the 31 years from 1958 to 1988 (Fig. 9).

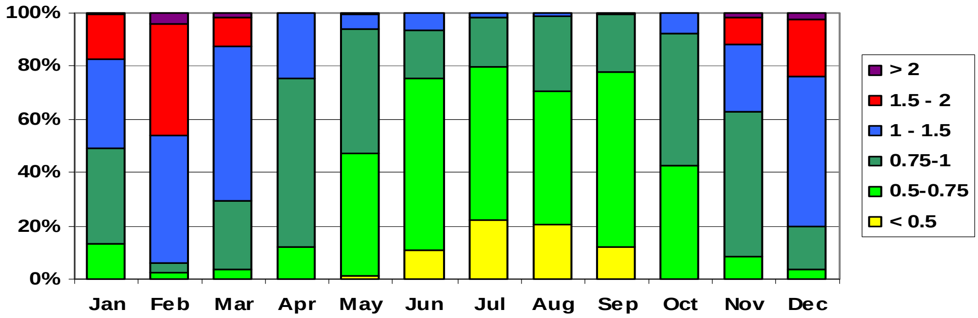
Again the stability of monthly mean temperatures during the summer half becomes apparent. Between June and September average deviation from normal is less than 1°C for nearly all of China. In April, May and October it is still below 1°C for most of the country, in the Northeast and Northwest and on the Plateau average deviation is up to 2°C. During the winter months temperature is less stable, in December and February average deviation is more than 1°C in most of the country and can even be over 2.5°C in northwestern Xinjiang.

Figure 9. Monthly average absolute deviation from normal (in °C).
(Based on the temperature time series 1958 to 1988.)



The spatial representation of the variability characteristics allows us to analyze the distribution of variability in certain land use categories. Figure 10 shows how much of China's cultivated area falls into certain temperature variability classes. The same agricultural mask as described above has been used. In summer we see that most of China's cultivated land is exposed to an average deviation from normal below 1°C, in winter this increases up to 2°C. In February a comparatively high variability is apparent.

Figure 10. Monthly average deviation from normal (in °C) for China's cultivated area.



3.4 Validation and reliability of interpolated fields

In this section we aim to assess the accuracy and reliability of the interpolated fields of the temperature time series climatology. The general approach is to compare the climatic variables of the 265 station observations with those at station location in the newly created interpolated climatology. In total we can assess three variables: 1) anomaly, 2) mean temperature and 3) variability. For each month and year from 1958 to 1988 we have interpolated the anomalies of the 265 stations over a 10 km grid for China. Anomalies are expressed as deviation in degree Celsius in a particular year from the average temperature of the 31 years concerned. Independent variables in the interpolation are the x, y coordinate and elevation of each 10 km grid cell. Variability is expressed as average deviation from normal (AVEDEV). Anomaly and AVEDEV are determined by the interpolation error. Because the mean monthly temperature time series have been created by linking the interpolated anomaly surfaces with 'normal' mean monthly temperature grids, the difference between the average temperature over the 31 years observed at station and the 'normal' mean grids is also important.

Anomaly validation

The error between anomalies observed at stations and derived from the interpolated surfaces is in general small, amounting to less than 0.5°C for the majority of cases and less than 0.25°C for more than two thirds of all cases (Table 3). Reflecting the higher variability during the winter months, larger errors occur in winter than in summer. During the summer months only 2% of a total of about 8180 (265 stations times 31 years) compared data pairs per month have errors larger than 0.5°C. In winter this increases to over

8%. Errors larger than 1°C are very rare even in winter when only in 1% of all comparisons such errors occur. The maximum error was 5.5°C in one station in December. There is no bias towards a positive or negative error. For all months the interpolation generates nearly the same amount of positive and negative deviations from observation points. The mean absolute error is 0.14°C between April and October and 0.2°C from December to February. In relative terms this amounts to approximately 15 to 20% of the average of all observed anomalies per month. A linear regression applied to the three months in each seasons calculates the following gradients and R-squares: Winter, 0.95, 0.97; Spring, 0.95, 0.97; Summer, 0.91, 0.95; Autumn, 0.94, 0.96.

Table 3. Comparison between observed and interpolated anomalies.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percentage distribution* of absolute error between observed and interpolated anomalies												
< 0.25°C	71	71	79	85	84	84	84	84	84	84	77	71
0.25 – 0.5°C	20	21	17	14	13	14	14	14	14	14	18	21
0.5 – 1°C	7.6	7.4	3.6	1.5	2.3	1.8	1.9	1.8	1.9	1.7	4.3	7.0
> 1°C	1.2	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.7	1.1
MAE**	0.20	0.20	0.16	0.14	0.14	0.14	0.14	0.14	0.13	0.14	0.17	0.20
MAX error[°C]	4.3	5.8	4.7	2.5	2.8	2.0	4.4	3.9	5.7	2.4	5.1	5.5

* The total number of compared data pairs per month is between 8172 and 8180 (31 years times 265 stations)
** Mean absolute error in °C

Temperature time series validation

Mean monthly temperature time series from 1958 to 1988 have been created by linking the interpolated anomaly surfaces with available mean monthly temperature grids. For each year the respective anomaly surface is added to the mean monthly grid. For the 265 observation points we can compare the temperature as it appears in the interpolated surfaces with the one observed at station. Besides the interpolation error of the anomalies (as described in the previous paragraphs), this includes an additional source of error, namely the difference between the 1958 to 1988 year average observed at a station and the average represented in the grid mean monthly climatologies.

For this study two mean monthly climatologies of China have been tested. The high resolution 5km grid-cell size database created by *W.Cramer* (henceforth CRA) interpolated especially for the LUC project, and the lower resolution 0.5 degree longitude, latitude public domain LINK database (henceforth LINK) (see Section 2.2 on data sources). Differences between the average observed at a station and temperatures represented in CRA and LINK in grid-cells containing the particular stations, and also a difference between CRA and LINK are due to several factors: different station networks; different interpolation schemes; differences in elevation originating from different resolution and DEMs; different underlying time period (for CRA 1941-1960, for LINK 1961-1990).

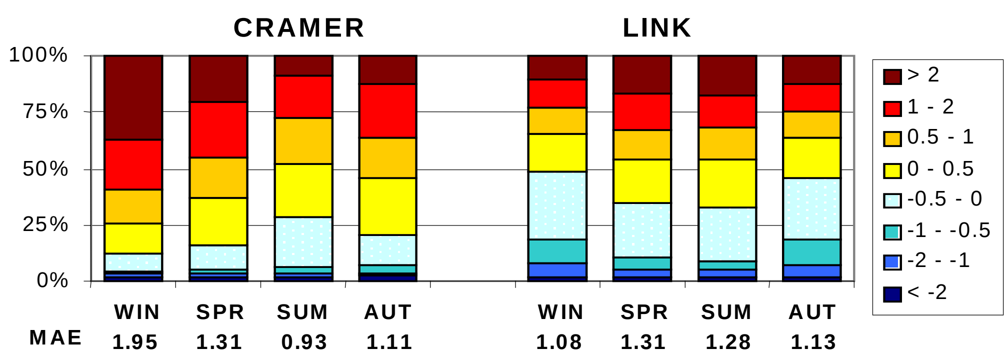
We compared all station observation averages over 1958 to 1988 with the averages represented in CRA and LINK mean climatologies of corresponding grid-cells. It is beyond the scope of this study to attempt an evaluation of the grid mean climatologies. Because of the underlying different assumptions especially with regard to grid-cell size and consequently elevation and time period, the comparisons hardly indicate the quality of the mean monthly climatologies.

Figure 11 provides a comprehensive summary of the differences. It shows for each season the distribution of differences (station observation minus CRA or LINK) for all compared data pairs. Thus per season there are 265 stations times three months, i.e. about 800 data pairs. The blue areas represent differences where 1958-1988 station observation averages are smaller than CRA or LINK, and for the yellow red colors vice versa.

In terms of mean absolute errors (lower row in x-axes in Figure 11) the difference in the winter season is clearly larger between 1958-1988 station observation averages and CRA (1.95°C) than the one with LINK (1.08°C). Furthermore, in the CRA database the winter temperature is obviously lower than in 1958-1988 station averages and lower than in LINK. In CRA winter (first bar in chart) more than 87% of all differences are positive thus indicating a larger 1958-1988 station observation average than CRA in contrast to LINK (fifth bar) where positive and negative differences are evenly distributed. Since CRA is based upon station observations from an early period (1941-1960) the question arises whether it was definitely colder during these decades. From the CDIAC data source we found 99 stations located throughout the country with more than ten years of temperature records between 1931 and 1960. For the majority of those records were available between 15 to 25 years. These data apparently do not confirm the period 1931 to 1960s being colder than the following 30 years. In contrast for the winter months averages over the two periods barely differ. A linear regression calculates a coefficient of 1.038 and a R-square of 0.995, the mean absolute error amounts to 0.6°C.

For the spring and autumn months mean absolute errors are about the same for CRA and LINK. In summer the difference between 1958-1988 station observation averages and CRA is slightly smaller than the one to LINK. There is a general bias of the grid temperatures being colder than in the station observation averages. For CRA this is true throughout the year, but especially in winter. In the case of LINK there is only a small bias in spring and summer.

Figure 11. Seasonal distribution of differences (former minus latter) [in °C] between station observation averages over 1958 to 1988 and the averages represented in CRA and LINK mean climatologies. (Difference calculated from monthly values, e.g. WIN (winter) includes all differences in December, January and February, thus, 265 stations times 3; MAE is mean absolute error [in °C] of all comparisons.)



Examining the spatial distribution we find that the large discrepancies mostly occur in areas of complicated terrain, e.g. in southwestern China and the fringes of the Tibetan plateau. These errors are closely related to differences in elevation represented in the mean climate surfaces and the recorded station altitudes. Such a disagreement is unavoidable in mountainous regions because of the grid structure. The larger the grid-cell size and the steeper the slopes, the more averaging of the original DEM is necessary. We have compared elevation represented in the grid with the real world altitude at the stations (Table 4). For CRA differences of more than 150 m were found for 10% of all stations. The majority of those was located in southwestern China, some on the plateau and its fringes in the Northwest. The highest disagreements in elevation was in Sichuan and Yunnan province where eight stations differ in over 500 m. However, at least three of those are considered to be incorrect in the original CDIAC station database in terms of location and/or elevation according to station descriptions in Zhang (1992). The coarser resolution of the five minute LINK DEM naturally causes much larger differences between elevation represented in the grid compared to real world station altitude. The average error in the different regions amounts to between 122 m in the relatively flat East or Northeast region to nearly 600 m on the plateau.

Table 4. Difference in elevation at WMO station and represented in CRA.

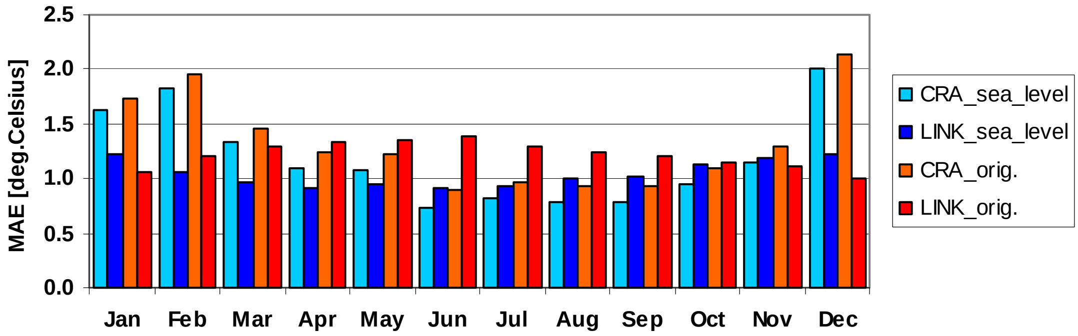
Region*	No.**	Average (abs)	Max
East	23	12 m	75
Central	27	23 m	29
Northeast	35	27 m	261
North	47	32 m	310
Northwest	73	42 m	423
South	22	54 m	526
Plateau	22	104 m	440
Southwest	61	203 m	1551

* as defined in Figure 1; ** Number of stations

Mean monthly temperature has also been compared including an adjustment for elevation. Temperature in general decreases with elevation. These altitudinal correction factors are called lapse rate. CRA has not used a fixe lapse rate, but the interpolation software he used accounts for elevation by a real 3d-interpolation. The only way for us however, to consider differences in elevation in the compared data sets, is to use a lapse rate. When we compare temperatures adjusted to sea-level the differences between temperature observed at station and represented in CRA does decrease, but not to a large extent. Figure 12 shows the mean absolute error (MAE) for each month based on all 265 station comparisons for both CRA and LINK featuring the original data and the temperature adjusted to sea level using a lapse rate of 0.6°C per 100 m.

To sum up, during the summer months there is a closer fit between averages observed at stations in the 1958 to 1988 time series with CRA than with LINK. The opposite is true for winter. There is a general bias of CRA towards being colder than station observation averages, but especially in winter. The largest inconsistencies are in the complicated terrain of southwestern China and the fringes of the Tibetan-Qinghai plateau.

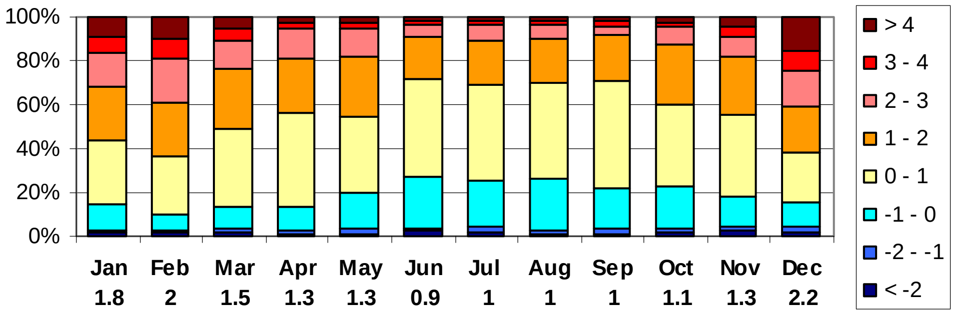
Figure 12. Mean absolute error (MAE) between mean monthly temperature at station observations and represented in the grid mean climatologies CRA and LINK (original temperature and adjusted to sea level).



For the reasons described above these differences are to a large extent unavoidable. They do of course have a direct influence when we add the interpolated anomaly surfaces to the mean climatologies of CRA or LINK. Depending on the direction of the difference they may exaggerate or understate the temperature deviation in a particular year. The analysis of the differences in averages in the foregoing paragraphs suggests that CRA being more suitable in summer to be linked with the anomaly surfaces while LINK apparently fits better in winter. Because of the higher resolution of CRA and the focus of the IIASA LUC project on agricultural production (for which the winter months are of less importance), we now further describe in this paper only the application of the anomaly surfaces to CRA.

Subsequently we can appraise the temperature time series by comparing temperature represented in the newly generated grid surfaces with those observed at stations. From the above analysis we expect larger differences in winter than in summer and a bias of station observation being warmer than grid surfaces. Figure 13 summarizes this comparison, for which about 8200 data pairs per month (265 stations times 31 years) were available. Blue colors indicate station temperature being colder than temperature in the calculated surfaces and vice versa for the yellow/red colors. During summer we find a mean absolute error (lower row in x-axes) of 1°C, in winter this increases to 2°C. For the months of the summer half the maximum error is 7° or 8°C, in winter it is 10° to 12°C. Applying a linear regression to the interpolated against the observed temperature we find a gradient of 1.02 for all the winter months, 0.93, 0.97 and 0.96 for spring, summer and autumn. R-squares are between 0.94 and 0.97 depending on the season.

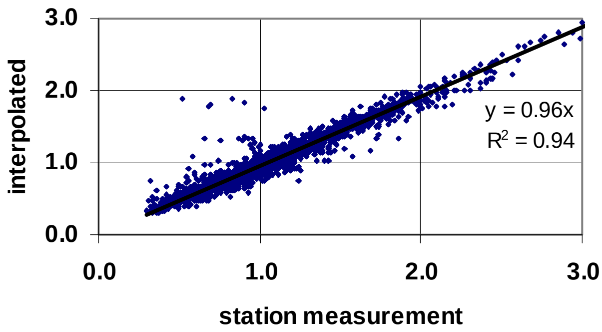
Figure 13. Monthly distribution of differences (former minus latter) [in °C] between temperature observed at station during 1958 to 1988 and the temperature represented in the interpolated temperature time series.
(Lower row in x-axes is the mean absolute error in °C.)



Variability validation

We use average absolute deviation from normal for describing temperature variability. The magnitude of differences between average deviation from normal measured at station and represented in the interpolated anomaly surfaces at station location is only influenced by the error introduced through the anomaly interpolations. As expected for interpolated databases there is a bias of the interpolated surfaces to underestimate variability. Average deviation measured at station is larger than those in the interpolated surfaces for nearly four fifth (78%) from the total of 3180 comparisons (265 stations times 12 months). Figure 14 plots the average deviation from normal measured at station against those derived from the interpolated anomaly surfaces for all months. The absolute difference between the two is quite small for most of the data amounting to less than 0.05°C in 57% of the comparisons. The remaining differences are: 0.05 to 0.1°C (24%); 0.1 to 0.2 (15%); 0.2 to 0.3°C (3%) and over 0.3°C (0.8%). In seven cases the differences is over 0.5°C (with the maximum being 1.4°C). These stem from three stations in southeastern Xizang and one station in western Sichuan, where interpolated surfaces overestimate variability. Scrutinizing the location of these stations we find that the DEM here is such that neighboring 5 km grid cell size pixels show differences of 1000 m and more. Because the interpolation uses elevation as a predictor neighboring grid cells can have very different results.

Figure 14. Monthly average deviation from normal (AVEDEV) [in °C] measured at station and derived from the interpolated anomaly surfaces.

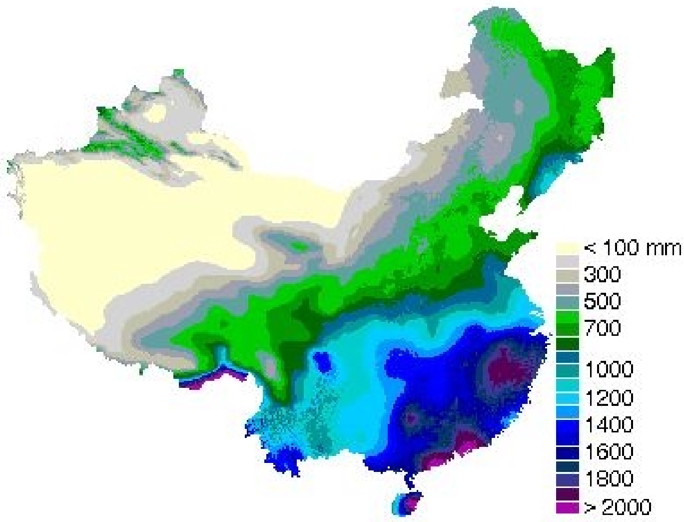


4. Precipitation

4.1 Distribution of Mean Rainfall and Seasonal Share

Amounts of rainfall vary greatly throughout China, generally decreasing from more than 1500 mm annually in the southeast to less than 100 mm in the northwest (Fig. 15). The main reason for this marked precipitation gradient is the direction of movement of the summer monsoons. The total amount of precipitation diminishes as the monsoon releases its moisture while it moves inland. The hinterland in Northeast China is beyond the reach of the pacific weather systems, while the Northwest is blocked by the Himalayas and the Tibetian plateau influencing the southwesterly monsoon weather systems of the Indian Ocean.

Figure 15. Annual Rainfall in China.

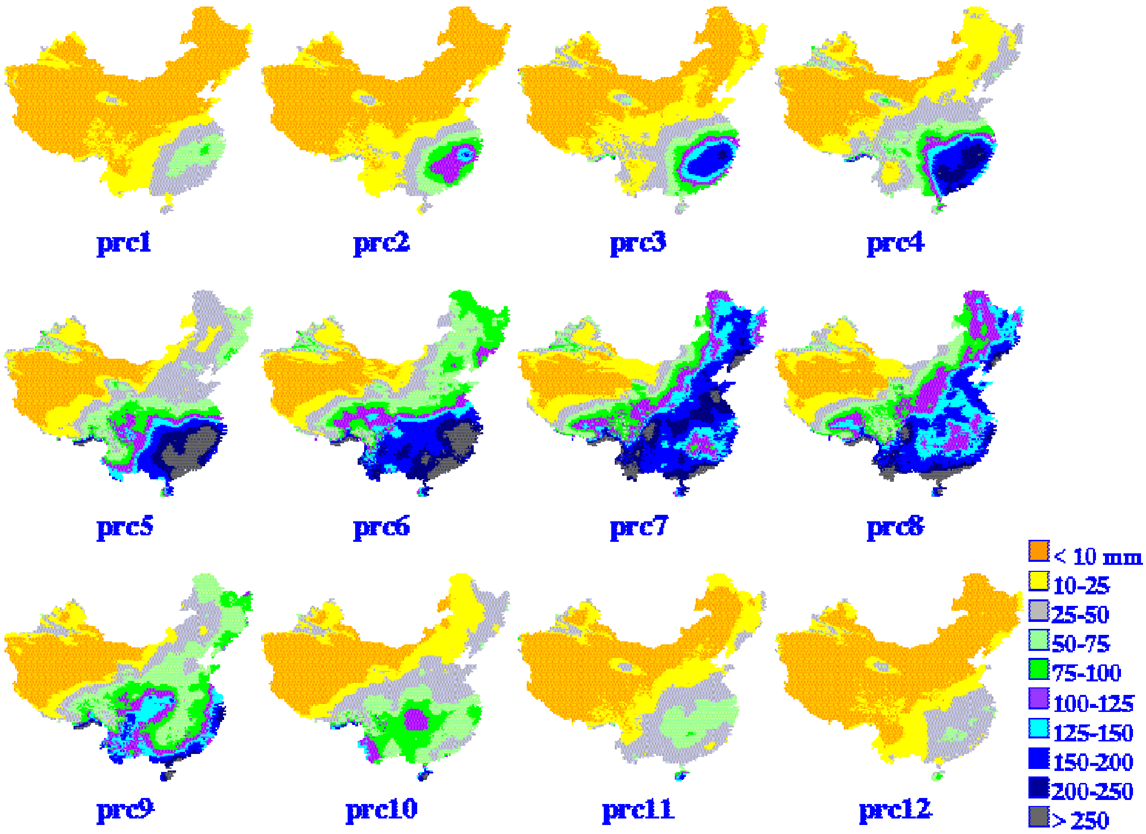


Northwest China is the most arid area with an annual precipitation in the range below 200 mm. This zone of hyper-arid and arid conditions includes the Gobi desert and semi-deserts in Xinjiang, the western parts of Inner-Mongolia and northern Gansu province, and the cold deserts at elevations over 2000 m on the northwestern Tibet-Qinghai plateau. In southeasterly direction rainfall increases on the plateau with a maximum on the southernmost fringes of the Himalayas, being on the windward side of the southwesterly monsoon with annual precipitation of over 4000 mm. In the dry northwestern Xinjiang autonomous region, the Tianshan mountains region form an exception with annual precipitation reaching up to 600 mm, providing sufficient water resources for crop and livestock production.

The North China Plain and Northeast China receive annual precipitation ranging from 400 to 800 mm, with exception of the southeast coast of Liaoning, where annual precipitation exceeds 1000 mm. The Southeast of China has dominantly sub-humid and humid climates with evergreen broadleaf forest and locally sub-tropical rainforest as climax vegetation. Annual precipitation is over 1000 mm and locally exceeds 2000 mm along the south coast of Guangdong Province and the east coast of Hainan Island.

China’s climate of intense monsoon (see also Section 3.1) and continental nature is marked by distinct difference of rainfall throughout the year. Figure 16 presents maps featuring average monthly rainfall. A dry polar continental air mass, originating in Siberia or Mongolia, dominates a large part of China in winter. In contrast during summer southerly winds from the low latitudes in the Pacific and Indian Oceans predominate and moist tropical pacific air mass exerts its influence. Along the front where the warm air collides and subsequently overflows the relatively dense cold air masses, a monsoon precipitation front is formed. The coming of the wind is characterized by sudden increase in rainfall and by progressive march towards the north.

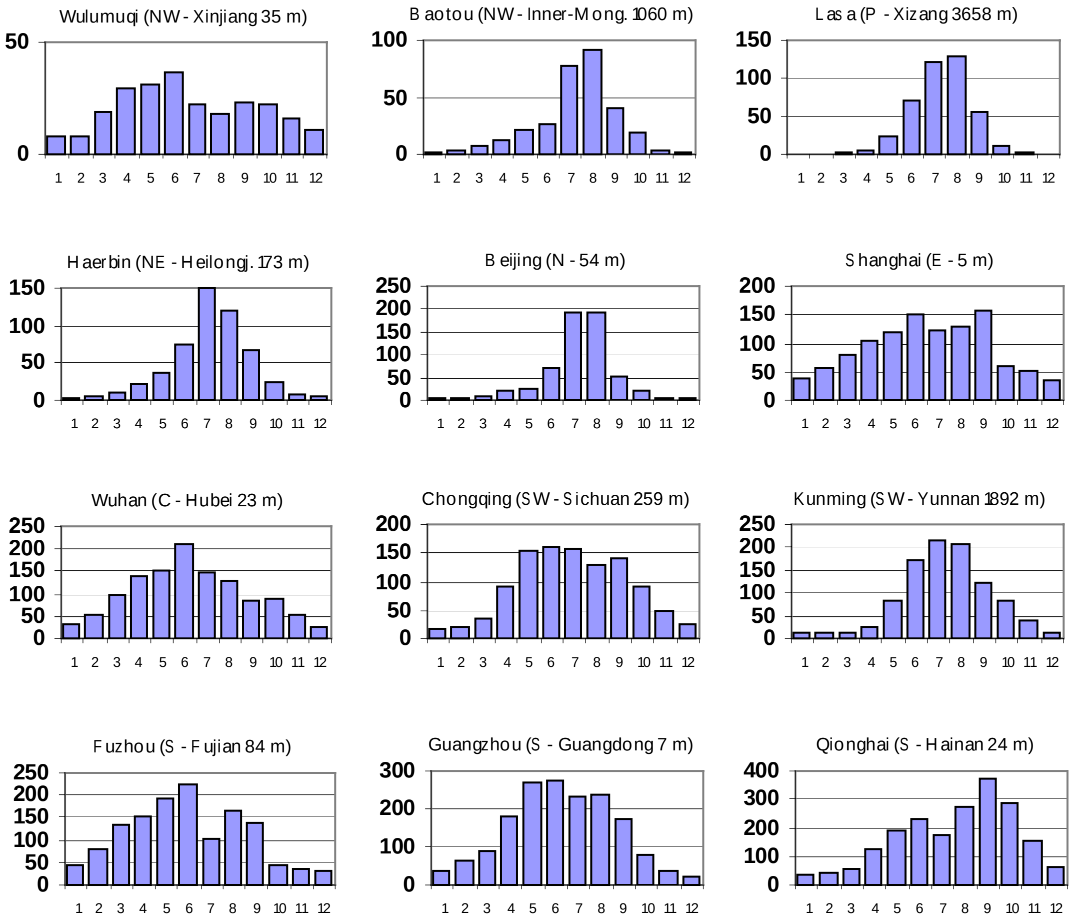
Figure 16. Monthly rainfall in China.



The distribution of rainfall over the year reveals the dominance of rainfall during summer in most of China, and in some regions the importance of the late spring or early autumn months. From the 310 station observation database Figure 17 shows observed monthly rainfall for selected stations throughout the country.

Winter, with its strong northerly monsoons, has the least precipitation amounting to only less than 10 or 20 mm monthly for most parts of the country. Higher winter rainfall is only found in the south banks of the lower reaches of the Changjiang river. Winter rains here stem mainly from the warm, moist southerly flows which get lifted by the cold bursts from the north.

Figure 17. Monthly rainfall for selected stations in China (in mm).
In brackets: geographic region as defined in Figure 1, province and elevation



In the spring months, with the rising temperature and moisture content of the air, precipitation increases steadily between March and May over almost the entire country. Over eastern China spring and summer is characterized by the gradual northward advance of the summer monsoon. Thus the rainy period in Southeast China is in May and June exceeding 200 mm. In June the monsoon rain belt reaches the Changjiang Valley, where it meets cold air flowing south to form the so called Meiyu or plum rain. This is a period of continuous, hot, muggy, rainy weather during June and July. It is unique to East Asia and so named for the time of the year when the plum ripens. A comparison of rainfall in May, June and July also reflects the movement of the summer monsoon. While in the rest of the country rainfall increases between May and June, the area south of the middle reaches of the Changjiang river (approximately Hunan and Jiangxi province) has more rainfall in May than in June. Summer monsoon then continues its northward journey to trigger off the rainy season of North and Northeast China. In contrast, the middle and lower Changjiang Valley enters into a dry and hot period as soon as the Meiyu terminates with the outbreak of the southeasterly winds. This is the famous summer drought. It greatly affects agricultural production and daily life in the vast area of southeast China (Zhang J., 1992, p.125).

From September onwards, rainfall decreases all over the country. The exception to this autumn decline is found in east Sichuan, around the middle reaches of the Changjiang River and along the east coast of Zhejiang province. Meteorological stations here show higher rainfall in October as compared to September. This is sometimes referred to as “unceasing autumn rains”. Also Hainan island receives high rainfall due to typhoon precipitation.

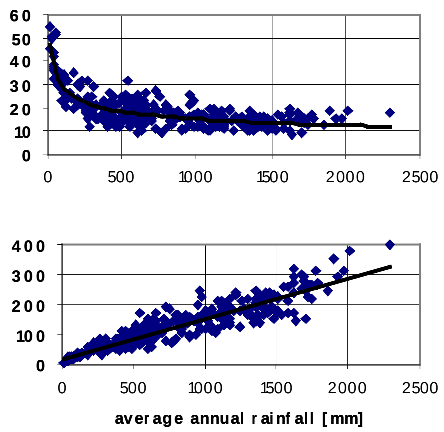
4.2 Rainfall variability of station histories

In this chapter we characterize rainfall variability by analyzing the 310 station histories available for this study. Besides standard deviation and extremes (minimum and maximum), the average of the absolute deviations (anomalies) from their 31-year mean (henceforth AVEDEV) and its relative figure, a coefficient of variation (CV*) is employed. For this study we define CV* as the percentage share of AVEDEV in mean (AVEDEV*100/mean) and call it henceforth CV*[1].

Variability and extremes of annual rainfall

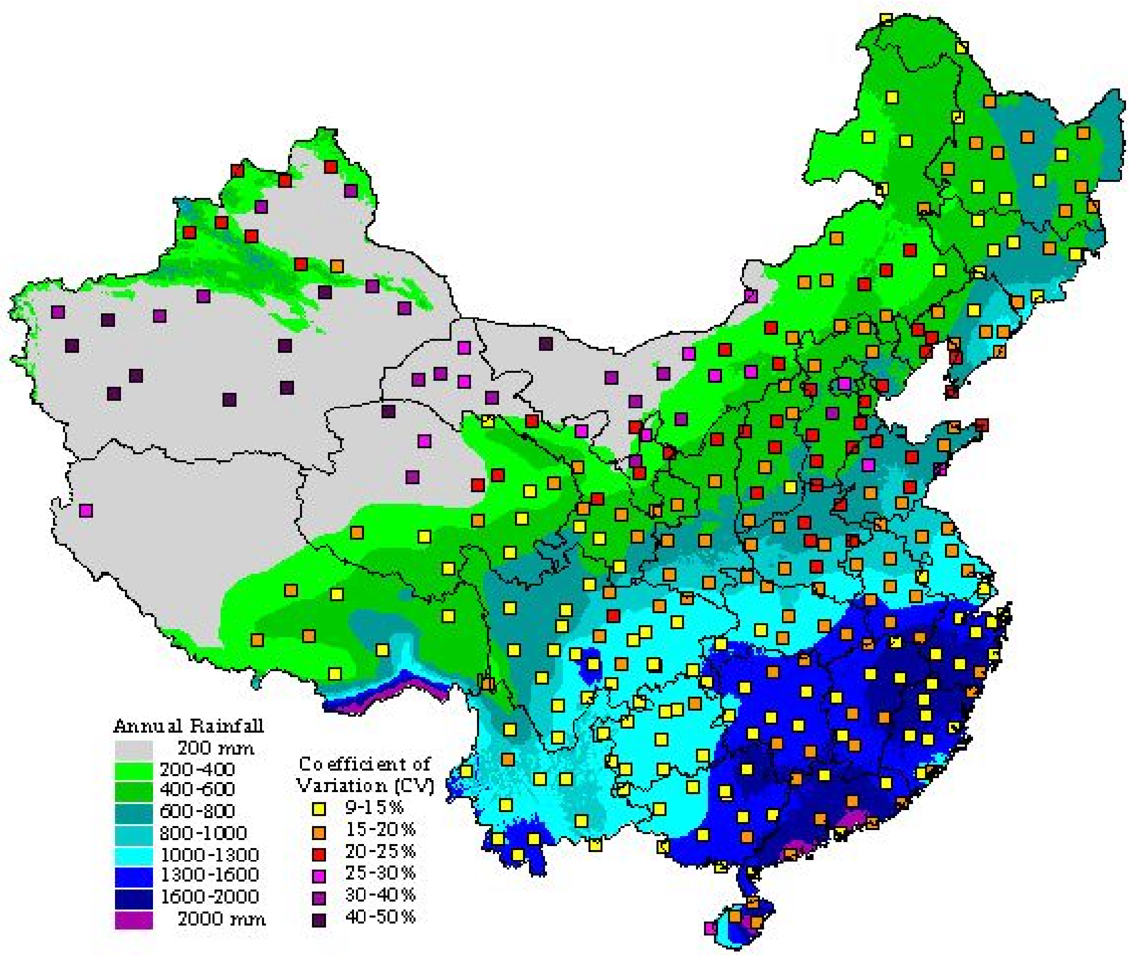
Except for the very dry areas with annual rainfall of less than 100 mm, the CV* of annual rainfall lies between 10% and 30% for most of China. Scatter diagrams of mean annual rainfall against AVEDEV and CV* give an overview of the range of variability for different amounts of annual rainfall (Fig. 18). Figure 19 highlights the geographic distribution of variability. Levels of maximum and minimum precipitation in the time series from 1958 to 1988 reveals the possibility of extreme events in large parts of the country. Annex 2 lists statistical measures of rainfall for each of the 310 stations including mean, minimum, maximum, standard deviation, AVEDEV and CV*.

Figure 18. CV* and AVEDEV of annual rainfall for the 310 stations.



[1] The asterisk is added to avoid a confusion with the more common definition of CV*, which is standard deviation divided by mean.

Figure 19. CV* at the 310 stations shown on the background of annual rainfall.



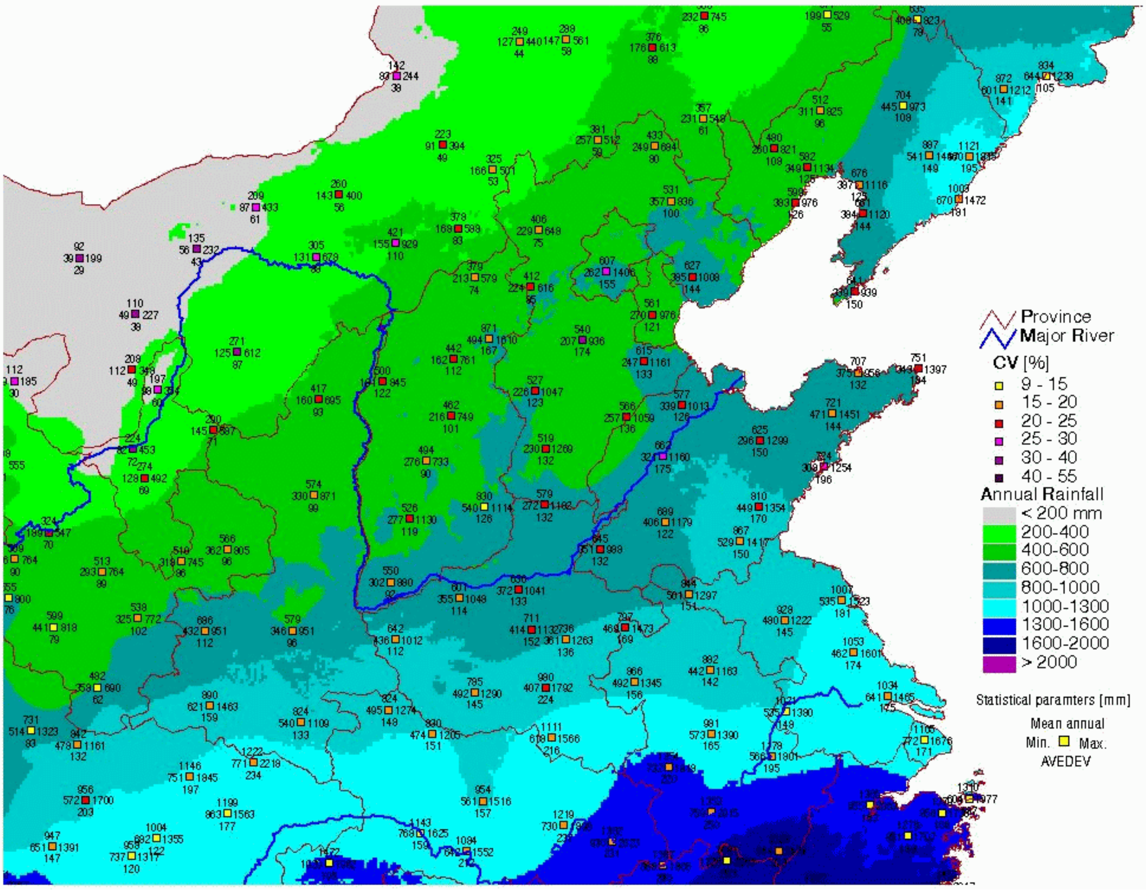
The large area of southeastern China, with its abundant annual precipitation of usually well over 1000 mm, has a low annual variability with a CV* ranging from 10% to less than 20%. A typical station in this region at the lower end of variability is station number 57655 in Hunan province with a mean annual rainfall of 1412 mm, a CV* of 12%, a standard deviation of 216 mm, a minimum of 1065 mm and maximum of 2005 mm. An example for a station at the higher end of variability in southeastern China is station number 59501 at the southern coast of Guangdong. It records a CV* of 19% at an annual rainfall of 1895 mm, a minimum and maximum of respectively 895 mm and 2958 mm during 1958 to 1988.

The same holds for Southwest China, comprising of Yunnan, Guizhou and Sichuan provinces, where average annual rainfall ranges between 500 to 1300 mm, and variability is low amounting to mostly less than 15%. An exception are the stations in the Red Basin in eastern Sichuan, where the CV* can go up to 21%. The Red Basin is an important crop and paddy production area with abundant rainfall of 800 to 1300 mm annually. The minimum annual rainfall here is over 600 mm. The maximum rainfall can be as high as 1500 mm or up to 2000 mm in some years. Bordering Southwest China, the eastern half of the Tibet-Qinghai plateau, over 3000 m above sea level, with annual rainfall between 300 and 600 mm, variability still is between 10%and 20%.

Another area of low variability is Northeast China where the CV* does not exceed 20% except for some stations in southern Liaoning and northeastern Inner Mongolia where the CV* increases up to 25%. A typical example is station no. 50953 in southern Heilongjiang with an annual mean of 526 mm and an AVEDEV of 80 mm (CV* is 15%); minimum and maximum are 354 mm and 747 mm.

In general, a CV* over 20% can only be found in areas with annual rainfall of less than 1000 mm (Fig. 18). In North China's belt with 400 to 800 mm annual, intensively used for agricultural production, variability mostly is between 19% and 27%. This region includes Beijing, Tianjin, Hebei, Shanxi and the northern halves of Shandong and Henan provinces. Figure 20 shows a map detailing some statistics for the stations in this region. Besides the CV*, it also minimum and maximum rainfall during the period 1958 to 1988, mean annual rainfall and AVEDEV.

Figure 20. Statistics of annual rainfall variability at stations in North China



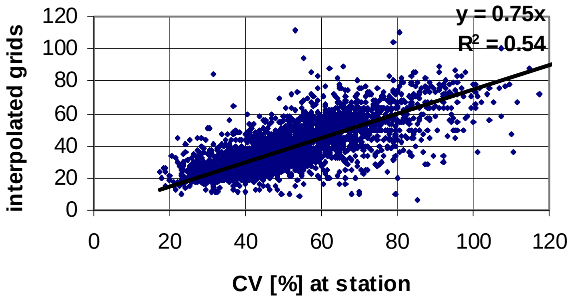
Baoding station (no. 54602) located south of Beijing, reports the highest variability amounting to 32% with an average rainfall of 540 mm. North China is characterized by the frequent occurrence of extreme events. Minimum rainfall at the stations is between 30% to 80% below average with the percentage being higher than 50% for about half of the stations in this regions. Such decreases cause significant draughts considering the annual average rainfall of 400 to 800 mm. In the case of wet years, maximum rainfall is reported to be 50% to over 100% above normal. Beijing station is an example for the occurrence of extreme events. While the mean rainfall is 607 mm, for instance in 1965 rainfall was as low as 262 mm and in 1959 as high as 1406 mm.

With one exception a CV* above 30% is found in the dry areas of less than 300 mm annual rainfall, mostly covering Northwest China (Xinjiang, northern Gansu and western Inner Mongolia) and the western part of the Qinghai-Tibet plateau. Most stations in this region report a minimum annual rainfall of less than 80 mm. The largest CV* observed is 55% in the very dry Tarim basin in southern Xinjiang.

Variability of seasonal and monthly rainfall

Variability of seasonal and monthly rainfall is generally much greater than that of annual rainfall owing to its small absolute value and short duration in which no counterbalance from drier to wetter spells can occur. Figure 21 provides an overview of the range of monthly variability in China in relation to average monthly rainfall. With very few exceptions variability for monthly rainfall over 100 mm is between 20% and 60 %. When rainfall is below 100 mm variability increases to 80 or 100% for the majority of cases, for less than 10 mm it can exceed 100 %.

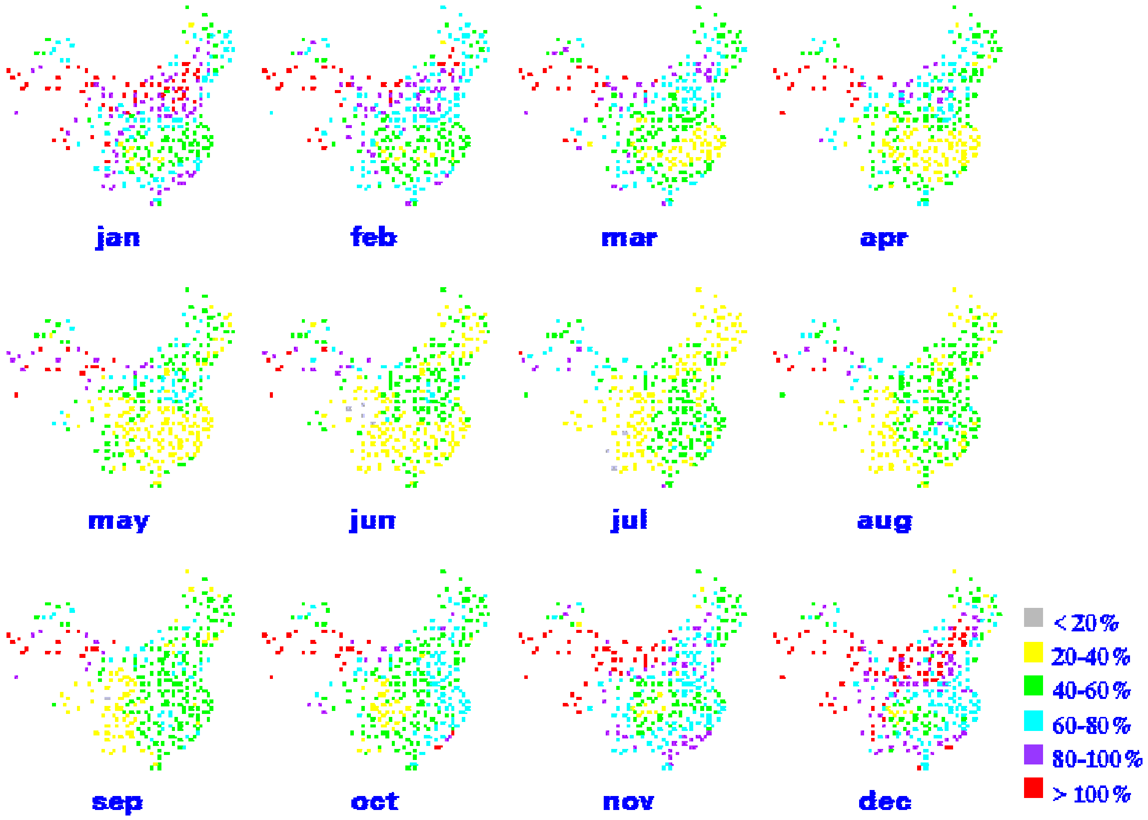
Figure 21. Scatter diagram of mean monthly rainfall and CV* at the 310 stations.



The geographic distribution of monthly variability is shown in Figure 22, which presents maps for each month displaying the CV* at the 310 stations. During the winter months with little rainfall, variability is between 40 to over 150% for most of the area with a lower variability in the wetter Southeast compared to the drier North and Northwest. Stations with the lowest variability in the winter months (less than 40%) are found in the middle reaches of the Changjiang river basin, in Sichuan, Henan and Guizhou province. In Northeast China, especially in Heilongjiang province and Northeast Inner Mongolia, variability during the winter months is rather low compared to other regions with monthly rainfall of less than 10 mm.

The general pattern of seasonal distribution of variability for most of China is that spring and autumn have a higher variability compared to winter. During summer variability is lowest amounting to between 20% and 60% except for the arid desert areas in the Northwest. This distribution is not surprising having in mind the seasonal rainfall distribution with the dominance of summer rainfall in large parts of the country. However, there are exceptions to this pattern. The most important is in the middle and lower reaches of the Changjiang river basin, where variability is lower in spring than in summer. High variability in summer exhibits a frequent alternation of summer drought and flood over the middle and lower Changjiang Valley.

Figure 22. Coefficient of variation (CV*) of monthly rainfall at the 310 Stations.



Anomalies at the 310 stations

For each of the 310 station anomalies for 1958 to 1988 were calculated in terms of mm deviation from the 31-year average. For the annual rainfall amounts about two thirds of more than 9000 observations (310 stations x 31 years) represent anomalies of less than 20%. However, there are also 56 cases with more than 100% deviation. Most of the latter are confined to northwestern China and the Tibet-Qinghai plateau, where low mean annual rainfall causes high percentage deviations. Seventeen cases, located in North and Northwest China, show high percentage deviations despite a relative high mean annual rainfall.

An example is Beijing in 1959, when annual rainfall was 800 mm higher than the average 607 mm. Table 5 presents some more examples for years with very high positive anomalies. During summer some extreme events are found besides North and Northwest China also in stations in the lower Changjiang valley. Compared to temperature, rainfall has a higher spatial variability. As a result anomalies may not only be high in some years but may also differ substantially for neighboring stations. The anomalies were interpolated over China creating a time series of interpolated anomalies and rainfall.

Table 5. Examples of extremely high rainfall.

Location and station number		rainfall [mm] in particular year	31-year average	CV* [%]
Anhui	58102	1474 (1963)	797	21
Beijing	54511	1406 (1959)	607	26
Hebei	53698	1047 (1963)	527	23
	53798	1269 (1963)	519	25
	54616	1160 (1964)	615	22
Henan	53898	1183 (1963)	579	23
	57290	1791 (1982)	980	23
Shandong	54776	1396 (1963)	751	25
	54714	1059 (1964)	566	24
	54843	1299 (1964)	625	24
	54852	1451 (1964)	721	20
Shanxi	53588	1610 (1959)	871	19
	53868	1130 (1983)	526	23
Liaoning	54337	1134 (1987)	582	22
Sichuan	57237	2218 (1983)	1222	19
	56182	1323 (1988)	731	11

* The tables presents all cases where percentage deviation from mean is larger than 80% and mean rainfall is larger than 100 mm, but stations in Northwest China and on the Plateau are excluded.

4.3 Time series of spatially interpolated anomalies and rainfall

For monthly, seasonal and annual rainfall a 5 km grid time series from 1958 to 1988 (respectively 1997 but not included in this paper) has been created describing both, rainfall anomaly and rainfall, in the particular year and month (season). Annex 3 presents examples from the time series of monthly anomalies[2]. For each month one sheet was prepared, which displays 31 maps representing anomalies from 1958 to 1988. There is a naming convention for each map as follows: y58m1 stands for year 1958, month 1, i.e. January, y80m10 means October of 1980, etc. A visual presentation requires a decision about a reclassification scheme, in which certain classes of anomalies are displayed in different colors. We have chosen twelve 20 mm classes. They show wet years (rainfall above average) in green and blue tones and dry years (rainfall below average) in yellow and red colors. Small anomalies (in absolute terms) of less than 20 mm are colored in white (above average) and gray (below average). Such a classification scheme allows a presentation of all months and for the whole of China. It tends however to draw our attention towards high absolute deviations, i.e. deviations during the summer months where rainfall is higher than in winter and deviations in the humid climate of southeastern China. Lower absolute deviations, which occur in winter in North China and during the whole year in the arid part of Northwest China, may however be high in relative terms.

[2] A hyperlink document presents maps for the whole time series database.

For annual and seasonal rainfall, not anomalies, but time series of rainfall are shown in Annex 4. Winter refers to the sum of rainfall from December to February, spring is the sum of March to May, etc. For comparison the first map shows average, then the time series starts with 1958 and runs through the year 1988. From this time series database one can derive a large amount of information regarding normal, dry or wet conditions between 1958 and 1988 in different parts of China. Here we will only hint once more towards the range of possible deviations and highlight a few cases of exceptional wet or dry years. For comparison some records of extreme events described in literature are presented.

China has been subject to severe drought or flooding throughout history. Based on the ‘Atlas of Drought and Flood in the Past 500 Years in China’, Zhang and Lin identified years of extraordinary drought and flooding (Zhang, 1992, p.289f.). They found that the number of years of extreme in North China is higher than in Central and South China. The number of dry years is much larger than the wet ones in Northern China while the reverse is true for South China and that severe drought seldom occurs in South China. In the past 500 years in Northern China (defined as higher than 35° N) 13 years of extraordinary drought and 11 years of excessive flooding have been recorded with 1965 being one of the drought years. In the same period for Central China (27° N–35° N) 1966 and 1978 were years among the seven recorded extraordinary droughts and 1954 was among six excessive flooding years. For southern China (south of 27° N) they identified only one year of strong drought and 6 years of heavy flooding, none of which in this century.

The seasonal distribution of drought differs over the country. Spring drought is most severe in North China, especially north of the Huanghe and Huaihe drainages and the western Liaohe reaches of Northeast China. It also occurs in the upper basins of the Changjiang River, Southwest and South China. Summer drought most often takes place in the Changjiang River basin, especially the southern parts of Jiangsu and Anhui, western Zhejiang, Hunan and Hubei. Autumn drought occurs in North China between September and October when rainfall sharply decreases or no precipitation happens at all. Winter drought takes place mainly in southern South China and southwestern China, where crops grow all the year round. In the second half of this century serious droughts have been recorded in 1959, 1960, 1961, 1966, 1972, and 1978 with the latter two being the most serious and extensive, which can be compared to the events in historical literature. In 1972, most of China was short of rain and 30 million ha of farmland was hit by drought, with 14 million ha visited upon by severe drought, and unprecedented low water level occurred in many rivers. In 1978, northern China was hit by spring drought while southern China by summer dryness, totaling in 40 million ha of farmland[3]. (Cheng, 1993, p.19,p.71,p.73).

Areas with frequent occurrence of flood damages are the mid and lower basins of the Changjiang River, the Huanghe-Huaihe-Haihe Plains in Northeast China and the southeastern coastal areas. In this century the most severe floods of the Changjiang and Huaihe rivers were in 1931, 1954, and 1980. They were results of anomalous general circulation patterns that led to an abnormally protracted duration of the Meiyu (Zhang, 1992, p.94). Cheng (1993, p.77) lists besides 1980 the years 1957, 1962, 1975, 1979, 1981 and 1983 with flooded areas between 7 and 12 million ha.

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[3] China’s total farmland is about 120 million ha.

Time series of rainfall for provinces and major watershed regions

Especially from the anomaly time series (Annex 3) one can already identify regions and years of high or low rainfall. However in order to be able to understand the variability of China's vast area and complex climate, it is very useful to aggregate the data for certain geographic regions. In particular for policy relevant studies, which may aim to link the precipitation time series with other information, two types of geographic aggregation seem beneficial. First an aggregation to administrative units and second to watersheds. Using a GIS environment we have calculated the average rainfall for each province and watershed for each year from 1958 to 1988, i.e. the average of all the 5 km grid cells in a particular province/watershed and year. Nine major watershed regions were delineated according to a water resource assessment report on China (U.N., 1997). In addition for each geographic unit conditions based on average ('normal') climate were identified.

Results for annual rainfall are summarized in Annex 5 for provinces and Annex 6 for the nine watershed regions. They also show the percentage deviation from 'normal' rainfall and highlight years which are especially dry or wet. In addition some statistical parameters of the time series are added (minimum, maximum, standard deviation, AVEDEV and CV*). Table 6 is an excerpt of Annex 5 and summarizes selected years and provinces with much drier or wetter conditions than normal. Due to smoothing from interpolation and spatial aggregation the extent of anomaly measured at stations is often larger than those reported for the provinces. Table 6 (or Annex 5) reports for example that in Ningxia the driest year (1982) had an annual rainfall of 35% below average. Exploring measurements of two stations located in this province we find that 1982 is the driest year, but the deviation is 53% and 63% below normal. Another example is Shanxi for which we have calculated a rainfall that was 37% lower than 'normal' for 1972. Exploring the nine station data in this province we find two stations in the south which report average rainfall in this year and seven stations with deviations between 30% and 63% below average. Some of the large provinces extend over different climatic zones, namely Inner-Mongolia, Xinjiang and Gansu in Northwest China and the two provinces on the Qinghai-Tibetian plateau. To some extent this also applies to Sichuan. Here the calculation of average rainfall per province may only of limited value.

In North China's provinces (Beijing, Tianjin, Hebei, Shanxi, Henan and Liaoning) annual mean is between 560 and 660 mm. The severe droughts of 1965 and 1972 are easily discernable in Table 6 (Annex 5). The drought in both years extended into the arid and semi-arid regions of Northwest China. The wettest year in North China including Liaoning apparently is 1964, when rainfall is between 35% and 60% above average. The same holds for the bordering provinces Gansu, Ningxia, Shaanxi and Hubei. Monthly data for 1964 demonstrate that in the whole region rainfall was above average between July and October. Only in the more central provinces Henan, Hubei and Shaanxi April and May also contributed to much higher rainfall than normal. In June it was only in Hubei province when rainfall was much above average. Thus 1964 is an example for a year when the late retreat of the Monsoon causes exceptional high rainfall in North China. In contrast, in 1959, in North and Northeast China it was July and/or August which raised yearly precipitation levels to unusual high values.

Shandong province, an important agricultural area with grain output amounting to nearly ten percent of the country's total, has an annual mean of 720 mm with a rather high standard deviation of 18% for the interpolated time series. During 1958 and 1988 there were five years with rainfall less than 600 mm and two years with less than 500 mm.

The driest years in the time series of annual rainfall aggregated over the Yellow River Basin are 1965, 1972 and 1986 (Annex 6). The same three years are the driest in the Hai He-Luan He Basin extending east of the Yellow River Basin to the coast. To the southeast of the Yellow River, in the Huai He Basin on the North China Plain the situation changes. The driest years here include 1966, 1978 and 1988. The year 1964 is the wettest in three watershed regions, the Yellow River, the Hai He-Luan He Basin and the Huai He Basin. In the Yellow River basin also 1961 and 1967 are 20% above average.

For North China it is interesting to note that we found in literature 1965 and 1972 among the years of drought mentioned, but so far no records of flood have been found recorded for the year 1964.

Central China is characterized by the vast area of the Changjiang river basin with a drainage area of 1.8 Mio. km^2 . From the source of the Changjiang river on the Tibetian plateau at an elevation of more than 4000 m the river drains after 6300 mm north of Shanghai into the Pacific Ocean. The river is well known for its disastrous flooding events but also years of severe drought are found especially in the middle reaches of the Changjiang basin and in East China

From both the province level as well as the Changjiang Basin time series it is evident that in 1978 the middle and lower reaches of the Changjiang Basin were hit by drought. East China's provinces Shanghai, Jiangsu, Anhui and Zhejiang show in the interpolated database a rainfall up to 37% below average. The drought lasted through the whole growing period from April to October and the severity becomes apparent by scrutinizing the station data in this year. Anhui and Jiangsu province show the highest anomalies. While on average annual rainfall here is between 800 and 1400 mm, in 1978 only between 450 and 900 mm were reported. With a smaller regional extension than the 1978 drought, also 1963 (Jiangxi, Hunan), 1966 (Jiangsu, Anhui, Hubei) and 1971 (Jiangxi, Hunan) were dry years. The 1963 drought reached into southern China's provinces Fujian, Guangdong, Hongkong and Guangxi. The drought of 1972 in northern China did not hit Central, East or South China except for Sichuan province.

Cheng (1993, p.77) lists flooded area and the area heavily damaged. Years with flooded area of more than 7 million ha are 1962, 1975, 1979, 1980, 1981 and 1983. Our monthly interpolated database reflects these large scale flooding in several provinces and/or months. There are of course other years where provinces show very high rainfall in certain months but no flooding is recorded in literature. This is not surprising considering that flood events are dependent not only on the extent and duration of rainfall but also on its intensity, which may not be very well reflected in an interpolated monthly database.

Table 6. Dry and wet years in China's provinces between 1958 and 1988.

The number in brackets show percentage deviation from mean rainfall. The table is an excerpt from Annex 5, which shows time series of rainfall for all provinces.)

DRY	REG.*	PROVINCE
1963	S Pl.	Guangdong (-31%), Guangxi (-20%), Hongkong (-34%), Fujian (-18%) Xinjiang (-14%)
1965	N, NE NW	Beijing (-30%), Tianjin (-39%), Hebei (-34%), Shanxi (-29%), Liaoning (-23%) Gansu (-19%), Inner-Mongolia (-27%), Ningxia (-28%)
1966	C, E SW	Henan (-26%), Shandong (-19%), Jiangsu (-24%), Anhui (-21%), Hubei (-24%) Guizhou (-20%), [Hunan (–11%), Jiangxi (-10%)]
1967	E, S	Shanghai (-29%), Zhejiang (-20%), Fujian (-21%), Zhejiang (-20%)
1968	N, NE S	Beijing (-24%), Tianjin (-42%), Shanxi (-21%), Shandong (-28%), Liaoning (-20%) Hainan (-26%)
1971	C, S	Hunan (-15%), Jiangxi (-24%), Fujian (-25%)
1972	N NW Pl, SW	Beijing (-26%), Tianjin (-31%), Hebei (-27%), Shanxi (-22%), Shaanxi (-19%), Gansu (-15%), Inner-Mongolia (-13%), Ningxia (-23%) Xizang (-16%), Sichuan (-11%)
1977	S	Hainan (-34%), Guangdong (-15%)
1978	E C, N NE	Shanghai (-31%), Jiangsu (-37%), Anhui (-37%), Zhejiang (-23%), Jiangxi (-18%), Hubei (-24%), Hunan (-12%), Henan (-23%) Jilin (-22%)
1979	NE Pl.	Heilongjiang (-20%), [Jilin (-14%)] Qinghai (-15%)
1986	N	Shandong (-33%), Henan (-25%), Hebei (-22%), Tianjin (-18%), Shanxi (-16%) Shaanxi (-24%), Ningxia (-22%), Gansu (-15%)
WET		
1959	N, NE NW S	Beijing (+52%), Tianjin (+39%), Shanxi (+26%), Liaoning(+25%), Heilongj.(+18%) Inner-Mongolia (+29%) Fujian (+20%), Guangdong (+29%), Guangxi (+20%), Hongkong (+24%)
1960	NE	Heilongjiang (+20%), Jilin (+30%)
1961	S, SW	Guangxi (+17%), Guangdong (+21%), Hunan (+14%), Jiangxi (+16%), Fujian (+21%)
1962	N, E	Shandong (+25%), Jiangsu (+20%)
1964	NW N, NE	Shaanxi (+34%), Gansu (+27%), Ningxia (+55%) Beijing (+39%), Tianjin (+62%), Hebei (+43%), Shanxi (+45%), Shandong (+54%), Henan (+24%), Liaoning (+39%)
1967	NW, Pl	Ningxia (+35%), Gansu (+25%), Qinghai (+18%)
1973	E, C, S	Zhejiang (+28%), Jiangxi (+22%), Fujian (+21%), Guangd. (+21%), Hainan (+24%)
1974	N, E	Shandong (+20%), Jiangsu (+16%)
1975	E, C, S	Jiangxi (+29%), Zhejiang (+24%), Anhui (+19%), Shanghai (+19%) Fujian (+31%), Guangdong (+25%), Hongkong (+27%)
1983	C, E S	Hubei (+33%), Anhui (+22%), [Zhejiang (+19%), Jiangxi (+17%)] Guangdong (+24%), Hongkong (+23%)
1987	NW, Pl	Xinjiang (+23%), Qinghai (+22%), Xizang (+19%)

* lists the regions to which the provinces in the third column belong. N=North, NE=Northeast, NW=Northwest, C=Central, E=East, S=South, SW=Southwest, Pl=Plateau

The 1980 flood of the Changjiang river is only reflected in the monthly time series. In the provinces of the middle and lower reaches (Hunan, Jiangxi, Hubei, Anhui, Zhejiang, Shanghai) in August rainfall averaged over the province raised from a normal of 130 to 170 mm to 250 to 310 mm in 1980, which are the highest in the period 1958 to 1988. Stations observations in these provinces show for August 1980 a rainfall between 200 and 500 mm, while the average is between 100 and 200 mm.

For the 1962 flood our database shows for Jiangsu in May and June 400 and 442 mm (average is 290 and 260 mm) and for Hunan for the same months 300 mm (average is 240 and 190 mm). In 1975 again in Jiangsu and Hunan there was very high rainfall but this time in April and May. From the annual rainfall time series one can see that 1975 is a year of large scale high rainfall on the eastern and southeastern coasts including Shanghai, Anhui, Zhejiang, Jiangxi, Fujian, Guangdong and Hongkong. In 1983 September and October rainfall in Anhui, Hubei and Jiangsu had exceptional high precipitation up to three times the average rainfall.

For annual data time series Sichuan and Hunan province have the lowest variability. Minimum and maximum rainfall are close together amounting to 808 and 1021 mm in Sichuan and 1200 and 1670 mm in Hunan. The other provinces in southwestern China (Yunnan, Guizhou and Guangxi) are also among those with the lowest variability.

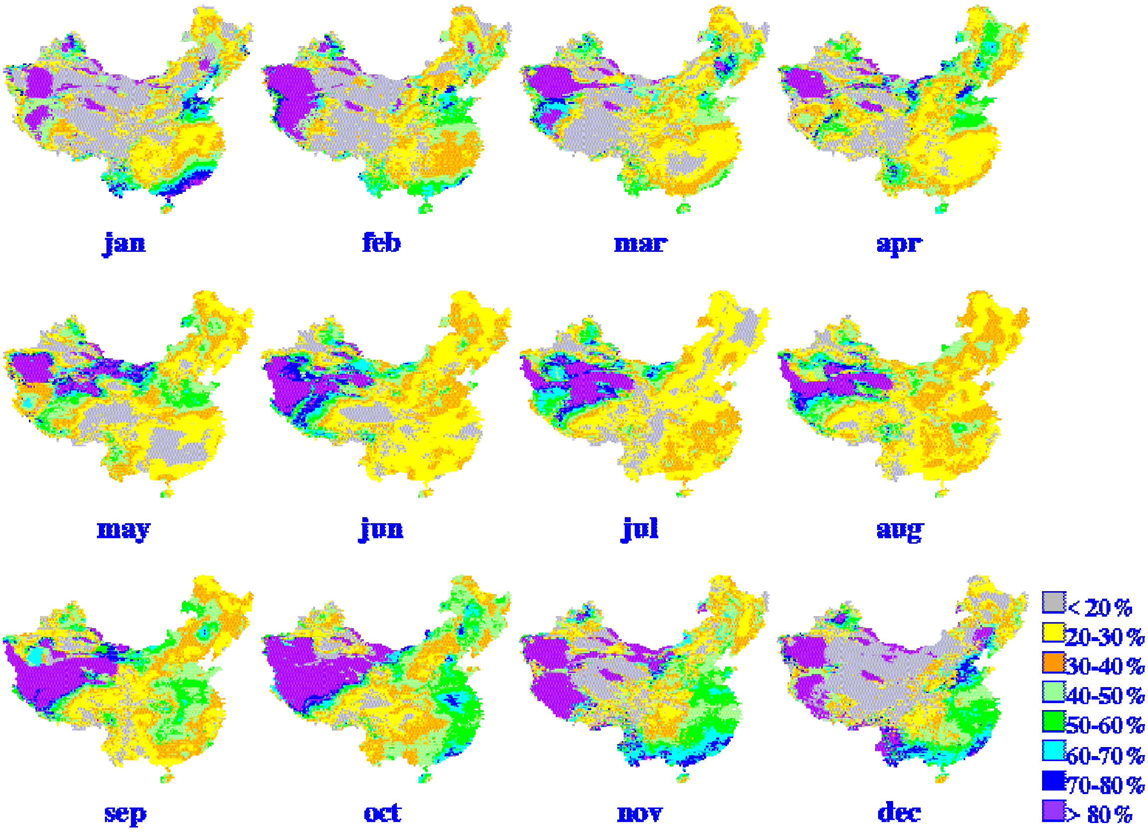
A map in Annex 5 shows the CV* derived from the interpolated averaged annual time series per province. Though the absolute numbers of variability are naturally too low compared to station measurements and average data for the large provinces Inner-Mongolia, Xinjiang and Xizang with a different climatic zones are only of limited value, the map indicates well the general pattern of variability in China. High variability in North China, lower in eastern China, very low in southwestern China including Sichuan. The comparatively high variability of Hainan, Ningxia, Beijing and Tianjin is due to the small area of these provinces where the averaging effect is not as big as in larger regions.

Variability of grid time series

Finally the interpolated 5 km grid time series was used to calculate once more variability over the period 1958 to 1988, now for each grid cell. The regional characteristics of precipitation variability in China are well reflected in variability maps, which have been prepared for monthly, seasonal and annual rainfall displaying CV* or AVEDEV. Especially the monthly data offer a comprehensive insight into seasonal differences in regional variability (Figure 23). For example the relative high variability in the middle and lower reaches of the Changjiang river basin in July and especially August attract attention. In contrast, in spring, it is the North China Plain and Northeastern China which fall into higher variability classes. As of September, when the Monsoon retreats, variability increases over all eastern China.

Figure 23. Variability maps for monthly rainfall.

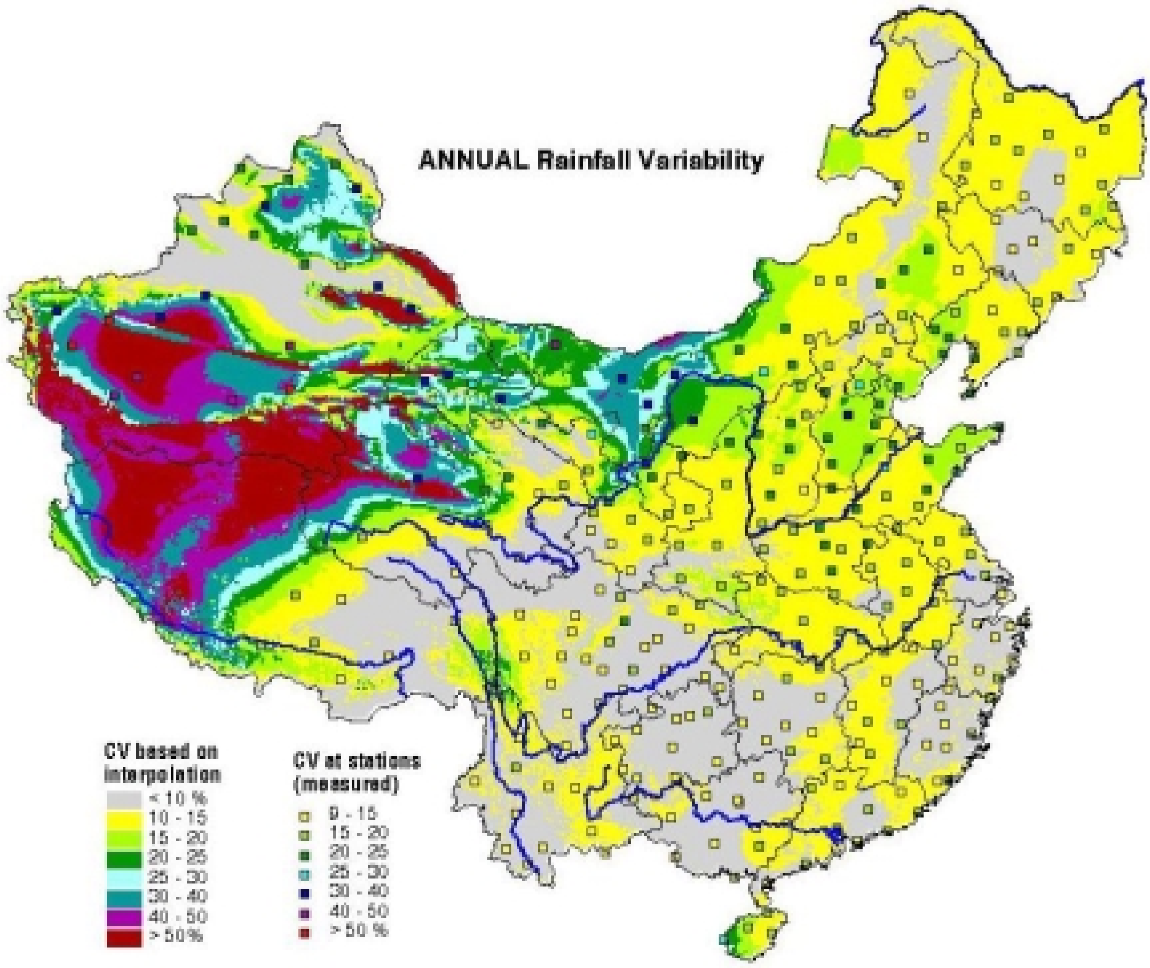
(The maps show CV* (AVEDEV*100/mean) based on the interpolated grid time series.)



In northwestern arid China there are general limitations in displaying variability for dry regions due to the high sensitivity of variability calculations for low amounts of rainfall. Here some unlikely patterns of variability may occur because both, CV* and AVEDEV are zero in some regions. Zero average (found in the 'normal' CRA climatology) had to be set to 0.1 mm to allow CV* calculation. Regions which include areas with zero deviation from normal may results in a pattern where very low variability may be next to very high variability. However, it is only variability which causes awkward patterns and not the underlying rainfall time series or AVEDEV.

Maps which show both variability from the interpolated grid time series as well as variability measured at meteorological stations reveal the extent to which variability decreases by calculating it from interpolated time series. Figure 24 shows this for annual rainfall. Variability based on the interpolated time series is mostly 5 to 10 units below the measured station variability. This difference increases for lower absolute rainfall levels, thus in the case of seasonal and monthly rainfall.

Figure 24. Annual rainfall variability – comparison of variability based on interpolated time series and on stations measurements.



4.4 Validation and reliability of interpolated fields

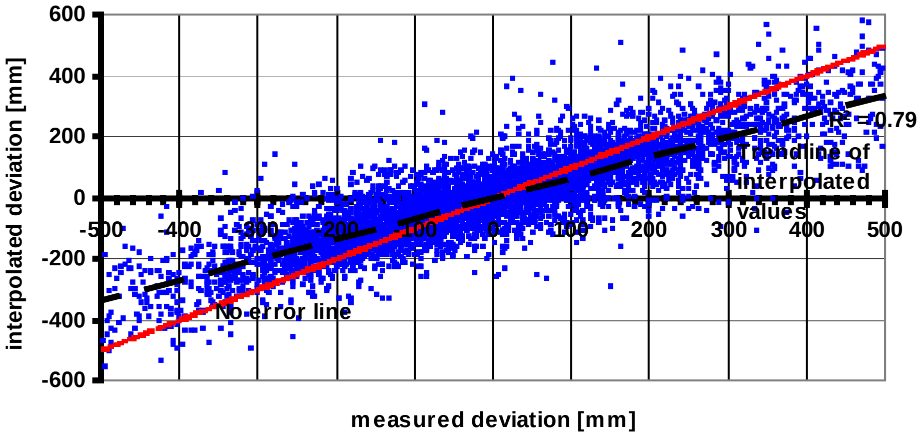
As for temperature two different data sets can be evaluated, the time series of anomaly surfaces and second the time series of monthly rainfall. The validation of the first is determined by the error introduced by the interpolation. In the case of the second an additional error is introduced by the difference in average rainfall for the period 1958 and 1988 observed at stations and represented in the grid mean rainfall CRA to which the interpolated anomaly surfaces are linked.

Anomaly validation

For each year from 1958 to 1988, anomalies observed at the 310 stations were interpolated throughout China for a 10 km grid cell size. In contrast to temperature, the spatial pattern of rainfall anomalies is more heterogeneous, i.e. neighboring stations often report large differences in their anomalies. In addition extreme anomalies are more common (see Section 4.2). Due to surface smoothing isolated located high anomalies get reduced. A constraint to the extent of errors imposed by the Mollifier technique is that the interpolated surface remains within the minimum and maximum of the observations from a particular set of 310 anomalies to be interpolated.

In total, for each time unit (year, season or month) an error can be determined for about 9500 data pairs of observed and interpolated rainfall anomaly (310 stations times 31 years with some stations reporting *no data* in particular years). Figure 25 shows a scatter diagram that relates observed and interpolated annual anomalies. In the anomaly chart there is besides a linear trendline (dotted line with a gradient of 0.68 and a R^2 of 0.79) for comparison also a so called 'no error' line (straight line). Eighty percent of the values have an error below 100 mm and 95% an error of less than 200 mm. On the whole deviations tend to be underestimated. In a few cases errors can be very large. Large errors reflect outliers in geographic terms, this is a deviation which is, at a particular station, very different from the deviations at the surrounding stations especially when they are at a similar elevation. In some cases observed negative anomalies representing drier conditions than normal become in the interpolated surface reversed to positive anomalies and vice versa. For annual rainfall the absolute difference between observed and interpolated anomaly amounts to less than 100 mm for 80% of all comparisons (Table 7).

Figure 25. Interpolation error for annual rainfall anomalies.



The correspondence between observed and interpolated data become much higher when we translate the anomalies into rainfall at a particular station and year. A linear trend line now yields a gradient of 0.99, indicating a strong vicinity to the line on which no errors occur. A measure of the scattering around the trend line is the R-square, which is 0.97. Looking closer into such a scatter plot and analyzing the different ranges of rainfall separately reveals a tendency to underestimate higher rainfalls and slightly overestimate lower rainfall.

Table 7 provides a comprehensive summary of anomaly errors for the interpolation of annual and seasonal data. The order of error is less than 100 mm for most of annual and summer rainfall, in spring and winter it is less than 50 mm for more than two thirds of the data. The regression indicates that interpolated anomalies are on average 20 to 30% below the observed ones. Again when we translate the anomalies into rainfall the fit between observed and interpolated increases considerably. A linear regression then results in gradients of 0.97, 0.98, 0.97 and 0.96 for winter, spring, summer and autumn and in a R^2 of 0.97, 0.97, 0.91 and 0.93. Regressions applied to the monthly data comparisons result in the same coefficients than those found for the seasonal data. A regression for all the data pairs from the months June, July and August gives a gradient of 0.63 and a R^2 of 0.76.

Table 7. Error between observed and interpolated seasonal and annual rainfall anomalies.

	Annual	Winter	Spring	Summer	Autumn
Absolute Error Percentage of total comparisons that fall into a certain class					
> 200 mm	5	0	0	2	0
100-200mm	14	0	3	11	3
50-100 mm	19	1	9	19	10
20-50 mm	23	7	18	25	23
0-20 mm	39	93	70	43	65
Linear Regression of observed and interpolated anomalies, intercept 0					
gradient	0.68	0.85	0.72	0.63	0.70
R-square	0.79	0.91	0.82	0.76	0.81

Finally two examples shall demonstrate how high error terms between observed and interpolated data may occur. Firstly uncommon high monthly rainfall (over 400 mm) may occur between April and October. During the interpolation procedure they may become strongly underestimated. An example here is a station on Hainan island with an average rainfall of 280 mm in September where in 1967 an observed monthly rainfall of 767 mm gets reduced to an interpolated 434 mm. The second example is a station that is located at the outer skirts of semi-arid regions, thus having stations in the vicinity with higher means and anomalies. A station (No. 52681) in Ningxia province records in September 1987 a monthly rainfall of 11 mm. This becomes interpolated to an unlikely 30 mm while average rainfall for this station and month is only 16 mm.

Rainfall time series validation

Using a GIS the interpolated 10 km anomaly grids were resampled (using nearest neighborhood method) to a 5 km cell size grid. These anomaly grids were linked to the mean 5 km monthly precipitation maps (created by Cramer, see Section 2.2) representing long-term average data (henceforth CRA). Thus we obtain time series of in addition to anomalies also precipitation for yearly, seasonal and monthly data. To connect interpolated anomalies with long-term average data ensures that no unlikely rainfall occurs. Not for the anomaly surfaces but for rainfall the linking may introduce additional distortions from real world conditions. Specifically when the 31-year mean measured at stations is much different from the mean of the long-term average 5 km grid at the particular station. Malformations may occur when the mean observed at stations (from which we derive our anomalies) is significantly higher than the mean in CRA at station location. In such a case, when there is a negative anomaly (dry condition), we exaggerate the dryness in this year. Then a high negative anomaly in relation to station mean will be much higher than the same anomaly added to the lower mean in CRA. In the other cases there is rather a tendency to underrate the extent of anomaly.

For rainfall we have only used the high resolution CRA long-term average database. The other available long-term average database is LINK with a resolution of more than 50 km, which is considered to small to describe monthly rainfall in China. Still, we have compared the 310 station averages over the period 1958 to 1988 with the average represented in both CRA and LINK at station location. Based on all 310 stations the correspondence between average represented in the station observations and in LINK seems to be better than those between station observations and CRA for winter. CRA in general is too wet in winter. A regression for all winter months between CRA and stations and LINK and stations calculates for CRA a slope of 1.08 and a R^2 of 0.94 while for LINK those values amount to 1.00 and 0.96. For the rest of the year LINK averages correspond slightly better with the station averages of this study except for July and August, when CRA is more closely related to the station averages.

Table 8 and Figure 26 provide a comprehensive overview of the extent of difference between the 31-year average derived from our observed station data and the long-term mean rainfall represented in the 5 km grid CRA surfaces. The difference is below 20% in half of the 310 stations in winter and more than two thirds in the rest of the year. In winter there is a bias of CRA being wetter than station observations.

Figure 26. Monthly mean rainfall – station observation and represented in CRA 5 km grid

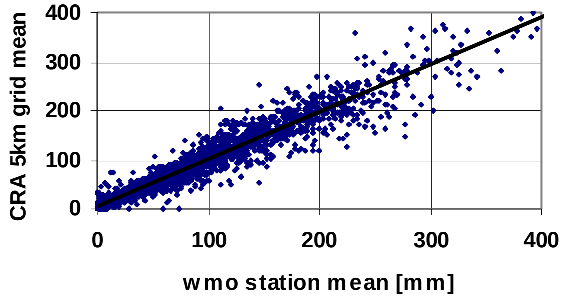


Table 8. Seasonal and annual rainfall difference between the 31-year mean 310 station observations and the mean represented in the 5 km grid CRA.

(The table shows percentage of data (total = 310 stations) in a season falling into a certain category of absolute or relative difference, calculated as station mean minus grid mean; MAE = mean absolute error.)

	Win	Spr	Sum	Aut	Year		Win	Spr	Sum	Aut	Year
< -20 mm	12	19	34	11	44	Relative difference					
–10 - –20	14	13	9	8	6	< 10 %	30	55	60	44	73
–10 - 0	51	25	15	25	9	10-20 %	21	24	20	30	16
0 - +10	18	23	12	18	12	20-50 %	26	12	18	22	9
+10 - +20	1	9	9	12	5	50-100 %	11	6	2	2	1
> 20 mm	3	11	21	25	25	> 100 %	12	3	0	2	1
max (abs)	91	207	330	202	677						
MAE[mm]	3.8	8.4	16.6	9.2	57						
MAE [%]	21	13	13	17	7						

To summarize there are two sources of errors that influence the accuracy of the interpolated grid time series rainfall compared to station observations. First, the error introduced from the interpolation exercise, i.e. the anomaly error. Secondly inaccuracies that stem from linking anomalies from station measurements with a long-term average grid for China. We can now compare rainfall observations with rainfall represented in the interpolated grid time series at the 310 station locations.

A linear regression for seasonal and annual data calculates the following gradients and R^2 values: Winter, 1.04, 0.93; Spring, 1.00, 0.94; Summer, 0.96, 0.83; Autumn, 0.89, 0.85 and Annual, 0.98, 0.93. Relative differences for spring, summer, autumn and annual data for those stations where rainfall is more than 50 mm are listed in table 9. Such a criteria applies to 95% of all annual rainfall comparisons. The error here is below 10% for more than half and below 20% for four fifth of the total comparisons.

Regression statistics for monthly data as well as the distribution of error found in all the comparisons are presented in Table 10. During winter there is apparently a tendency of the interpolated grids to overestimate rainfall. This is related to the long-term average grid which shows already higher rainfall than mean derived from stations (see Tab. 7). Between October and April for more than 60% of all comparisons the absolute difference is below 10 mm.

Table 9. Comparison of observed and interpolated rainfall for seasonal and annual rainfall over 50 mm.

	Spring	Summer	Autumn	Year
No.*	6823 (72%)	8623 (91%)	7394 (78%)	8997 (95%)
Percentage distribution of Relative Error				
<=10%	42	38	34	53
10-20%	30	27	28	27
20-30%	15	16	18	11
30-40%	7	8	10	5
>40%	7	10	10	4

* number of stations with rainfall below 50 mm, in brackets the percentage of the total 9478 comparisons

Variability validation

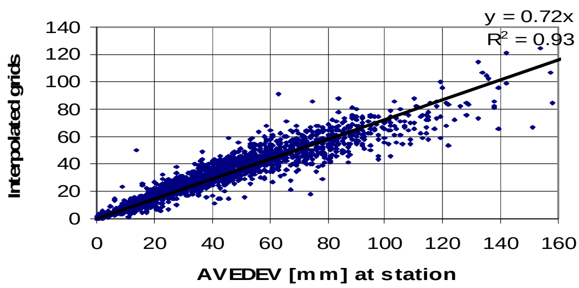
Using the interpolated anomaly time series we have calculated the average of the absolute deviations (anomalies) from their mean (henceforth AVEDEV) and its relative figure the coefficient of variation CV* (AVEDEV*100/mean). At the 310 station locations we can compare AVEDEV and CV* derived from the interpolated time series with those based upon the station observation time series. When we compare AVEDEV, it is the error introduced by the interpolation which determines the differences between them. In the case of CV*, the difference between the 31-year station average and average represented in the ‘long-term’ normal grid CRA becomes also relevant.

Table 10. Comparison of monthly observed rainfall and rainfall presented in the interpolated grid time series at station location.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percentage of comparisons* falling into a certain class of error [station – grid]												
< – 40 mm	0	1	2	2	8	11	16	15	6	1	0	0
–40 - –20	3	4	7	7	10	13	15	16	11	6	3	2
–20 - –10	8	8	9	10	12	11	9	9	11	9	7	7
–10 - 0	56	52	43	30	27	19	14	15	22	29	44	54
0 - +10	29	30	29	29	23	16	14	13	20	30	34	32
+10 - +20	3	3	5	9	8	9	8	8	9	10	6	3
+20 - +40	1	1	3	7	7	8	10	9	11	9	4	1
> +40 mm	0	1	1	5	6	12	14	14	12	5	1	0
Regression												
gradient	0.99	1.01	1.00	0.92	0.97	0.90	0.91	0.91	0.85	0.84	0.88	0.96
R-square	0.89	0.93	0.93	0.89	0.87	0.80	0.72	0.74	0.76	0.82	0.84	0.85

The total number of comparisons in each month is around 9500 (310 stations * 31 years).

Figure 27. Monthly AVEDEV observed at the 310 stations and derived from the interpolated grid surfaces at station location.



As presented in Figure 27 a comparison of AVEDEV for all months shows a high correlation between the interpolated and observed data sets. A linear trendline (with intercept 0) yields a slope of 0.72 indicating AVEDEV derived from the interpolated time series grids being on average about 30% below the one derived from station observations. The R^2 of such a regression is 0.93. The respective regression results for AVEDEV comparisons of observed annual and seasonal rainfall against their interpolated values are: Annual, slope = 0.73, R^2 = 0.89; Winter, 0.86, 0.97; Spring, 0.77, 0.92; Summer, 0.70, 0.84; Autumn, 0.73, 0.89.

The CV* is calculated as percentage and thus highly sensitive to low values of mean rainfall. The difference in average rainfall calculated from the station observation and the one represented in the interpolated grid time series has been discussed above (see Fig. 26). In Figure 28 we show CV* at stations plotted against the one derived from the interpolated grids for those data pairs where mean monthly rainfall is over 5 mm in both data sets. Such a criteria applies to 3051 data pairs, that are 82% of all possible comparisons for monthly CV*. A linear regression deter-mines a slope of 0.75 and a coefficient of determination R^2 of 0.54. When we increase the threshold of mean rainfall included in the regression to 15 mm (2523 data pairs) the slope amounts to 0.78 and R^2 increases to 0.63. More than four fifth of those 669 data pairs with mean rainfall below 5 mm occur between November and

March. More than one half is located in Northwest China, the remaining on the plateau, in Northeast and North China (all regions as defined in Figure 1).

When we use for seasonal data a lower limit of 20 mm for mean rainfall and apply a linear regression the gradient is 0.78 and R^2 amounts to 0.63. Such a threshold applies to 76% of all station data pairs in spring, 83% in summer, 75% in autumn and 51% in winter.

For annual rainfall the decrease of CV* derived from the interpolated grid time series compared to station observations has already been demonstrated in Figure 24. The mean absolute error of the difference between CV* from the two data sets amounts to 5 (the maximum error is 24, the average of all CV*s of station observation is 19%, those of the interpolated grid surfaces is 14%). The coefficient for the linear regression is 0.77 (R^2 is 0.75). Some of this misfit in the regression stems from the differences in averages at station observations and long-term mean grid CRA. When we remove this difference, i.e. relate AVEDEV from the interpolated grids not to the average in CRA but to the one from station observation, the regression would calculate a gradient of 0.82 and an R^2 of 0.89. To illustrate the impact of differences in average rainfall and AVEDEV on CV* Table 11 lists the top five percent of stations with the largest disagreement in CV*.

Figure 28. Comparison of monthly CV* between station observation and interpolated grid surfaces for all data pairs with a mean rainfall over 5 mm

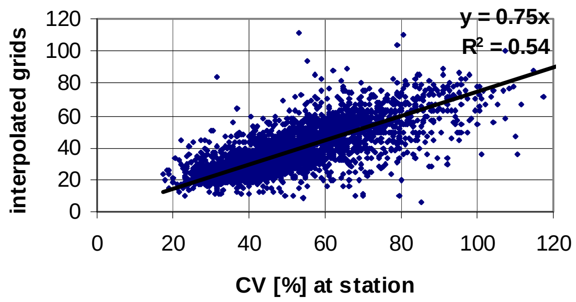


Table 11. Stations with the largest disagreement in CV* derived from annual rainfall station observations and derived from the interpolated grid time series.

wmo	province	region	elevation	Mean annual rainfall [mm]		AVEDEV [mm]		CV* [%]	
				station	grid	station	grid	station	grid
51765	Xinjiang	NW	847	36	72	15	13	42	18
52267	Inner-Mong.	NW	941	34	61	15	14	44	22
52424	Gansu	NW	1171	47	23	17	13	36	56
52602	Qinghai	P	2733	17	25	8	7	46	28
51495	Xinjiang	NW	873	36	65	14	14	38	21
51716	Xinjiang	NW	1117	50	58	26	21	52	36
51573	Xinjiang	NW	35	16	23	9	9	55	39
51334	Xinjiang	NW	320	100	308	24	26	23	8
54823	Shandong	N	52	662	647	175	95	27	14
54602	Hebei	N	17	540	536	174	109	32	20
53529	Inner-Mong.	NW	1380	271	314	87	65	32	20
52418	Gansu	NW	1139	38	47	15	13	39	27
52652	Gansu	NW	1483	128	211	26	20	21	9
57504	Sichuan	SW	347	1051	1106	184	72	18	6

They are all located in the western half of China. The first, fourth and seventh example demonstrates the strong impact of average rainfall divergence on CV*. Despite the average of interpolated anomaly surfaces corresponds very well with the one observed at station, because of the low value of average rainfall (and thus high relative error) CV* differences become large.

5. Conclusions

A gridded time series of monthly temperature and rainfall for China was produced to provide a tool to assess climatic variability and potential impacts in a spatially explicit way. According to data availability the grid cell size is 5 km, the period covered is between 1958 and 1988, and was recently extended to 1997[4].

First we calculated anomalies in terms of deviation from normal (that is the average over the 31-year period 1958 to 1988) for each of the 265 station observations for temperature, and 310 stations for precipitation. For each month and year, anomalies were interpolated throughout China using the Mollifier method. It uses a statistical approach to non-parametric interpolation. Predictors are the geographic coordinates and elevation of the 10-km grid surfaces. The Mollifier interpolation yields results that are between the minimum and maximum of observed data in a particular set to be interpolated. This ensures that no areas with 'unlikely' anomalies are created.

A comparison of observed anomalies and anomalies represented in the interpolated surfaces shows a good fit for temperature with regression coefficients being between 0.91 and 0.95 and R-squares between 0.95 and 0.97 for the different months. The spatial pattern of temperature anomalies is homogeneous in that relatively large areas show the same trend of deviation. In contrast, for monthly rainfall, anomalies of neighboring stations may be very different. This causes a higher interpolation error than in the case of temperature. Linear regression statistics of observed as opposed to interpolated rainfall anomalies yield gradients of between 0.72 in summer and 0.85 in winter. A coefficient below 1.0 reflects the smoothing effect of the interpolation. Accordingly anomalies in the interpolated grids tend to be lower than the one observed at station. The scatter around the 'no error' line is also larger for rainfall amounting to R-squares between 0.76 to 0.91. The interpolated anomaly surfaces made it possible to express variability characteristics, such as average deviation from normal or a coefficient of variation, for every grid cell in China.

Second we have linked the anomaly surfaces with available 5 km cell size grid maps representing 'normal' climate. The result is a grid time series of monthly temperature and rainfall. The advantage of this so-called 'anomaly' approach is twofold. Average climatic databases are considered to be fairly accurate because more station observations with normal climate are available than time series observations and secondly by combining interpolated anomalies with long-term average maps, the possibility of creating unlikely climatic data has been eliminated. A potential limitation of this approach is that the average calculated for the stations based on the period 1958 to 1988 may be different from the one presented

[4] Results for the period 1989 to 1997 are not included in this paper.

in the 'normal' grids. Such a comparison with the two 'normal' grids CRA and LINK[5] available for this study does not suggest a preference for one or the other. Depending on the time of year either CRA or LINK shows a closer fit with the averages of the station observations.

Mainly because of the much higher resolution of CRA compared to LINK, preference was given to the use of CRA. However, the use of CRA does introduce additional inaccuracies in creating the temperature/rainfall time series. The most important are: During the winter months there is a bias for temperature being colder and rainfall being higher in CRA compared to station observations. In the case of temperature we found the same direction of bias, but to a lesser extent, also during the rest of the year. For both temperature and rainfall, the largest inconsistencies are in China's mountainous regions in the Southwest and on the Tibetian plateau. This stems to a considerable extent from the differences in elevation between station records and elevation represented in a grid of a higher or lower resolution. A feature that is thus inherently unavoidable. The use of a 'normal' grid climate which corresponds to a higher degree with the station averages would certainly improve the quality of the created time series[6].

All this leads to the following characteristics of the created interpolated grid temperature and rainfall time series. There are no areas with unlikely climatic conditions. Local extreme events tend to get reduced due to the smoothing effect of the interpolation, but regional trends in deviations are well reflected. This is especially true for rainfall with its high spatial variability where locally errors may be large. However, the extent and direction of error is known and has been identified by a detailed comparison of observed station data with data represented in the interpolated grids at station location. The interpolated climatic surfaces are more reliable from spring to autumn than in winter, and in the eastern half of China than in the mountainous western and southwestern areas. There is a bias of the interpolated grids being colder than station observations, especially in winter.

Using the time series grids we finally calculated variability characteristics and thus received for the whole country (each 5 km grid cell) an estimate for variability. With few exceptions variability derived from the interpolated grids is lower than the one calculated from station observations. This effect is larger for rainfall than for temperature. The pattern of variability in the country and different months remains well reflected. For temperature average deviation from normal (AVEDEV) derived from the interpolated grids fits closely with AVEDEV recorded at stations. Four stations, all located in southwestern China, show larger differences. In the case of rainfall we have calculated in addition to AVEDEV, a coefficient of variation (CV*)[7], which we define as the percentage share of AVEDEV in mean rainfall. Because its calculation is highly sensitive to low mean rainfall, the pattern of CV* derived from the interpolated grids is in some dry regions unreliable. With very few excep-

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[5] see Section 2.2 for a detailed description of these grid data. CRA is a monthly climatic data base with a grid cell size of 5 km especially created for the LUC project by W.Cramer. LINK is a public domain global climatology on a 0.5 degree latitude by longitude resolution provided by CRU, Univ.of East Anglia.

[6] Recently the LUC project gained access to an additional 'normal' climatology of China, created by the Univ. of Oregon on a 4x4 km grid cell size.

[7] see 'Abbreviations' (page iii) for the type of CV* we use it in this paper.

tions CV* calculated for the interpolated rainfall data is generally below the one determined by station observations.

A monthly climate grid data base enables variability characteristics to be visualized in a comprehensive and understandable way. This is considered to be especially beneficial for China, a country with a wide range of biophysical conditions including a climate that is subject to a high variation and extreme events. From the interpolated grid data base we have produced a large number of maps. They include temperature and rainfall anomaly, temperature and rainfall for each month and year between 1958 to 1988. These maps can also be used for time series animations. Using the time series we also created variability maps that feature average deviation from normal and a coefficient of variability. Such maps or animations may provide additional insight into regional variability characteristics and allow to convey these in a straightforward and user-friendly way.

Applying techniques of 'Geographic Information Systems (GIS)' we can aggregate the grid data to certain geographic units or directly link them with other georeferenced information such as land use or soil type. This provides a wide field for further applications. It allows for example to incorporate variability into questions of climate change, agricultural production potential or water related assessments. In this paper we present an aggregation of annual rainfall to the administrative level of provinces. The aim here was just to provide another way of identifying regions and years when rainfall was normal, drier or wetter than normal. In addition they can be combined with socioeconomic variables from the LUC China databases. For instance, we can assess what share of China's population is affected by strong climatic variability.

One important reason for generating the gridded monthly time-series of temperature and rainfall was their input to the Agro-Ecological Zones (AEZ) methodology (Fischer et al., 1999). Time series are now available for attainable yields of different crops and grassland including underlying biophysical characteristics such as length of growing period, aridity index, crop water requirements and deficits, or a land suitability index. These results allow the variability of attainable production and the vulnerability of crops and grassland to agro-climatic constraints to be quantified, and to what extent and where climatic variability is significantly affecting their potential yields. Such an analysis is believed to be important for the purposes of regional planning and can contribute to the discussion on certain policy issues such as land use planning, development of irrigation schemes, or risk assessments for agricultural production.

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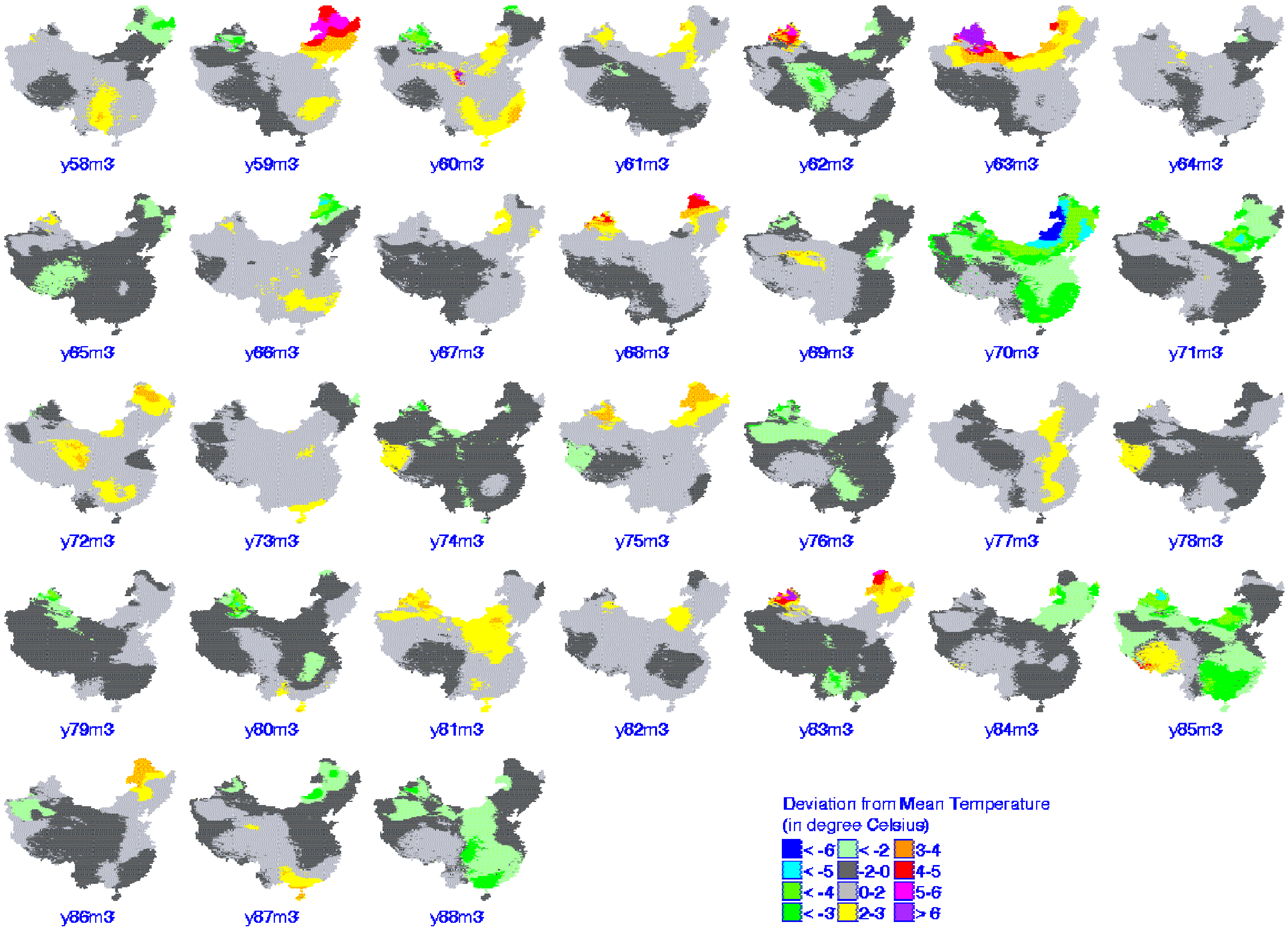
ANNEX 1 - MARCH temperature anomalies - Degree deviation from mean temperature between 1958 and 1988



Annex 2 : ANNUAL RAINFALL Statistics of the time series 1958 to 1988
for 310 stations in China*

LIAONING	54324	169	31	**480**	260	821	108	**23**	138
	54237	144	31	**512**	311	825	96	**19**	121
	54337	66	31	**582**	349	1134	125	**22**	166
	54455	9	31	**599**	383	976	126	**21**	158
	54662	93	31	**641**	339	939	150	**23**	176
	54476	20	31	**661**	384	1120	144	**22**	182
	54471	4	31	**676**	387	1116	125	**19**	167
	54342	42	31	**704**	445	973	108	**15**	129
	54483	235	25	**887**	541	1447	149	**17**	208
	54497	15	31	**1003**	670	1472	181	**18**	222
	54493	260	31	**1121**	660	1815	195	**17**	253
JILIN	50949	135	31	**433**	243	568	58	**13**	75
	54292	177	31	**511**	309	734	76	**15**	96
	54161	237	31	**576**	330	823	87	**15**	110
	54186	524	31	**624**	360	914	99	**16**	129
	54157	164	31	**635**	408	823	78	**12**	104
	54172	184	25	**641**	490	859	90	**14**	110
	54374	333	31	**834**	644	1238	105	**13**	137
	54363	403	31	**872**	601	1212	141	**16**	174
HEILONGJIANG	50136	296	29	**414**	274	635	64	**15**	87
	50745	147	31	**428**	284	672	78	**18**	98
	50854	149	31	**429**	272	681	61	**14**	85
	50353	177	31	**476**	338	797	68	**14**	93
	50557	224	31	**478**	339	707	71	**15**	90
	50658	237	31	**495**	253	686	82	**17**	102
	50953	173	31	**526**	354	747	80	**15**	102
	50788	64	31	**529**	339	825	104	**20**	126
	54094	241	31	**529**	339	748	82	**16**	104
	50873	0	31	**533**	341	742	80	**15**	106
	50978	233	31	**540**	314	819	95	**18**	122
	50564	235	31	**548**	359	754	89	**16**	106
	50756	239	31	**555**	347	867	100	**18**	119
	54096	497	31	**556**	304	906	108	**19**	136
	50963	109	31	**594**	369	869	89	**15**	115
	50774	231	31	**642**	455	987	103	**16**	127
BEIJING	54511	54	31	**607**	262	1406	155	**26**	215
TIANJIN	54527	3	31	**561**	270	976	121	**22**	161
HEBEI	54401	724	31	**406**	229	648	75	**19**	100
	53593	910	31	**412**	224	616	85	**21**	101
	54311	842	31	**433**	249	684	80	**19**	101
	53798	77	31	**519**	230	1269	132	**25**	194
	53698	82	31	**527**	226	1047	123	**23**	167
	54423	375	31	**531**	357	836	100	**19**	121
	54602	17	31	**540**	207	936	174	**32**	208
	54616	10	31	**615**	247	1161	133	**22**	196
	54534	27	25	**627**	385	1008	144	**23**	183
SHANXI	53487	1067	31	**379**	213	579	74	**19**	91
	53673	838	25	**442**	162	761	112	**25**	145
	53772	778	31	**462**	216	749	101	**22**	128
	53863	749	31	**494**	276	733	90	**18**	115
	53664	1013	31	**500**	181	845	122	**24**	151
	53868	0	31	**526**	277	1130	119	**23**	168
	53959	376	31	**550**	302	880	92	**17**	120
	53882	0	31	**830**	540	1114	126	**15**	150
	53588	2896	31	**871**	494	1610	167	**19**	226

* **wmo = station number**
elev. = elevation in meters
avgdev = average deviation from mean
avgvar = average variability (= avgdev / mean * 100)
stdv = Standard Deviation

Annex 2 : ANNUAL RAINFALL Statistics of the time series 1958 to 1988

SHANDONG	54714	21	31	**566**	257	1059	136	**24**	177
	54725	11	31	**577**	339	1013	126	**22**	170
	54843	44	31	**625**	296	1299	150	**24**	206
	54906	50	31	**645**	351	988	132	**21**	169
	54823	52	31	**662**	321	1160	175	**27**	217
	54916	52	31	**689**	406	1179	122	**18**	160
	54765	47	31	**707**	375	956	132	**19**	159
	54852	31	31	**721**	471	1451	144	**20**	197
	54857	76	31	**724**	308	1254	196	**27**	247
	54776	48	31	**751**	343	1397	184	**25**	241
	54936	107	31	**810**	449	1354	170	**21**	222
	54938	88	31	**867**	529	1417	150	**17**	198
HENAN	53898	76	31	**579**	272	1182	132	**23**	185
	57073	155	31	**601**	355	1048	114	**19**	151
	57083	110	31	**636**	372	1041	133	**21**	174
	57067	569	31	**642**	436	1012	112	**17**	149
	57089	71	31	**711**	414	1132	152	**21**	187
	57193	53	31	**736**	361	1263	136	**18**	189
	57178	129	31	**785**	492	1290	145	**18**	191
	57290	83	31	**980**	407	1792	224	**23**	288
	57297	115	31	**1111**	618	1566	216	**19**	254
SHANGHAI	58367	5	31	**1105**	772	1676	171	**15**	222
JIANGSU	58027	41	31	**844**	501	1297	151	**18**	184
	58144	15	31	**928**	480	1222	145	**16**	191
	58150	2	31	**1007**	535	1523	181	**18**	225
	58238	9	31	**1021**	535	1380	148	**14**	196
	58259	5	31	**1034**	641	1465	175	**17**	210
	58251	4	31	**1053**	462	1601	174	**17**	229
ZHEIJIANG	58556	104	31	**1276**	851	1707	189	**15**	231
	58477	36	31	**1310**	604	1977	187	**14**	262
	58457	42	31	**1365**	955	2063	163	**12**	226
	58562	0	31	**1370**	850	1730	166	**12**	206
	58646	61	31	**1378**	968	1956	197	**14**	241
	58665	1	31	**1455**	913	2047	221	**15**	274
	58633	67	30	**1627**	1106	2388	243	**15**	315
	58659	6	30	**1677**	1026	2402	297	**18**	367
ANHUI	58102	38	31	**797**	469	1473	169	**21**	220
	58203	31	31	**866**	492	1345	156	**18**	200
	58221	19	31	**882**	442	1163	142	**16**	177
	58321	28	31	**981**	573	1390	165	**17**	197
	58334	15	31	**1178**	566	1801	195	**17**	253
	58424	20	31	**1353**	759	2015	250	**18**	318
	58314	68	31	**1354**	732	1818	220	**16**	275
	58531	145	31	**1623**	914	2479	273	**17**	341
FUJIAN	59134	139	31	**1175**	840	1772	218	**19**	274
	58847	84	31	**1346**	776	1769	143	**11**	197
	59126	29	31	**1533**	1188	2067	164	**11**	231
	58921	206	31	**1580**	1043	2337	172	**11**	238
	58834	126	31	**1626**	921	2041	171	**11**	253
	58754	36	31	**1690**	1046	2484	277	**16**	338
	58731	277	31	**1704**	1108	2391	248	**15**	311
	58734	181	31	**1710**	1035	2151	155	**9**	218
	58931	1654	31	**1744**	1387	2405	217	**12**	269
JIANGXI	58502	33	31	**1367**	868	1865	239	**18**	282
	57896	126	31	**1413**	824	2071	215	**15**	293
	57993	124	31	**1429**	973	2184	238	**17**	300
	57799	76	31	**1478**	985	1966	232	**16**	266
	58606	47	31	**1504**	1046	2274	226	**15**	293
	57793	131	31	**1583**	1095	1995	211	**13**	252
	58527	48	31	**1681**	1126	2263	253	**15**	316
	58813	144	31	**1719**	1140	2336	267	**16**	326
	58626	0	31	**1786**	1056	2655	268	**15**	346

Annex 2 : ANNUAL RAINFALL Statistics of the time series 1958 to 1988

HUBEI	57253	202	31	**824**	495	1274	148	**18**	182
	57265	90	31	**830**	474	1205	151	**18**	185
	57378	66	31	**954**	561	1516	157	**17**	205
	57476	33	31	**1084**	642	1552	212	**20**	250
	57461	133	31	**1143**	768	1625	159	**14**	206
	57494	23	31	**1219**	730	1898	237	**19**	296
	58407	20	31	**1382**	930	2023	231	**17**	293
	57447	457	31	**1472**	1029	1962	195	**13**	248
HUNAN	57745	272	31	**1250**	790	1844	130	**10**	186
	57584	52	31	**1258**	787	1778	210	**17**	247
	57662	35	31	**1305**	927	1841	217	**17**	260
	57766	249	31	**1305**	923	1804	167	**13**	212
	57872	103	31	**1313**	956	1669	174	**13**	204
	57679	45	31	**1361**	1018	1955	147	**11**	203
	57865	0	31	**1375**	950	1938	217	**16**	261
	57853	341	31	**1388**	1067	1944	143	**10**	191
	57655	152	31	**1412**	1065	2005	166	**12**	216
	57972	185	31	**1447**	902	2248	239	**17**	305
GUANGDONG	59117	88	31	**1506**	1044	2355	224	**15**	302
	59082	69	31	**1511**	1005	2121	217	**14**	270
	59316	1	31	**1544**	942	2420	261	**17**	350
	59072	98	31	**1578**	929	2280	259	**16**	337
	59658	25	31	**1624**	1152	2411	241	**15**	318
	59287	7	31	**1694**	1243	2517	294	**17**	352
	59501	5	31	**1895**	895	2958	355	**19**	463
	59493	18	31	**1933**	913	2662	292	**15**	368
	59293	41	31	**1969**	928	3002	310	**16**	425
	59663	0	30	**2294**	1200	3342	416	**18**	536
GUANGXI	59007	1250	29	**1049**	725	1391	128	**12**	155
	59211	174	31	**1093**	730	1627	159	**15**	204
	59417	128	31	**1323**	950	1755	160	**12**	197
	59431	72	31	**1345**	1012	1797	162	**12**	200
	59046	98	31	**1411**	879	1968	187	**13**	254
	59044	0	31	**1440**	956	1968	173	**12**	234
	59265	119	31	**1502**	1038	1907	179	**12**	221
	59023	214	25	**1507**	1102	2044	171	**11**	216
	59453	82	31	**1624**	945	2513	321	**20**	393
	59644	0	31	**1724**	850	2213	229	**13**	301
	59254	42	31	**1725**	1193	2485	266	**15**	333
	57957	162	31	**1858**	1363	2679	244	**13**	301
HAINAN	59838	8	25	**958**	275	1529	248	**26**	315
	59758	14	31	**1625**	874	2343	295	**18**	361
	59845	169	31	**1772**	1103	2536	311	**18**	369
	59855	24	31	**2009**	1074	3162	378	**19**	481
GUIZHOU	57707	1511	31	**900**	645	1285	96	**11**	136
	56691	2238	31	**945**	656	1263	137	**15**	161
	57713	844	31	**1086**	798	1452	120	**11**	163
	57722	792	31	**1127**	763	1366	147	**13**	177
	57731	416	31	**1130**	721	1673	179	**16**	227
	57816	1071	31	**1134**	719	1422	133	**12**	171
	57916	440	31	**1142**	781	1623	176	**15**	216
	57932	0	31	**1178**	833	1469	151	**13**	182
	57902	1379	31	**1355**	960	1888	145	**11**	195
	56793	1527	31	**1404**	792	2106	193	**14**	256
YUNNAN	56768	1773	31	**820**	488	1093	122	**15**	149
	56985	1301	31	**842**	509	1190	122	**14**	152
	56651	2393	31	**934**	648	1213	102	**11**	128
	56778	1892	31	**1003**	658	1387	155	**15**	189
	56751	1191	31	**1048**	650	1411	175	**17**	214
	56951	1464	31	**1179**	896	1646	140	**12**	175
	56959	553	31	**1180**	927	1515	130	**11**	160
	56739	1648	31	**1474**	1127	1880	154	**10**	197
	56964	1302	31	**1527**	1120	1878	174	**11**	216
	56954	1055	25	**1639**	1307	2099	145	**9**	193
	56989	1367	22	**1783**	1325	2650	273	**15**	354

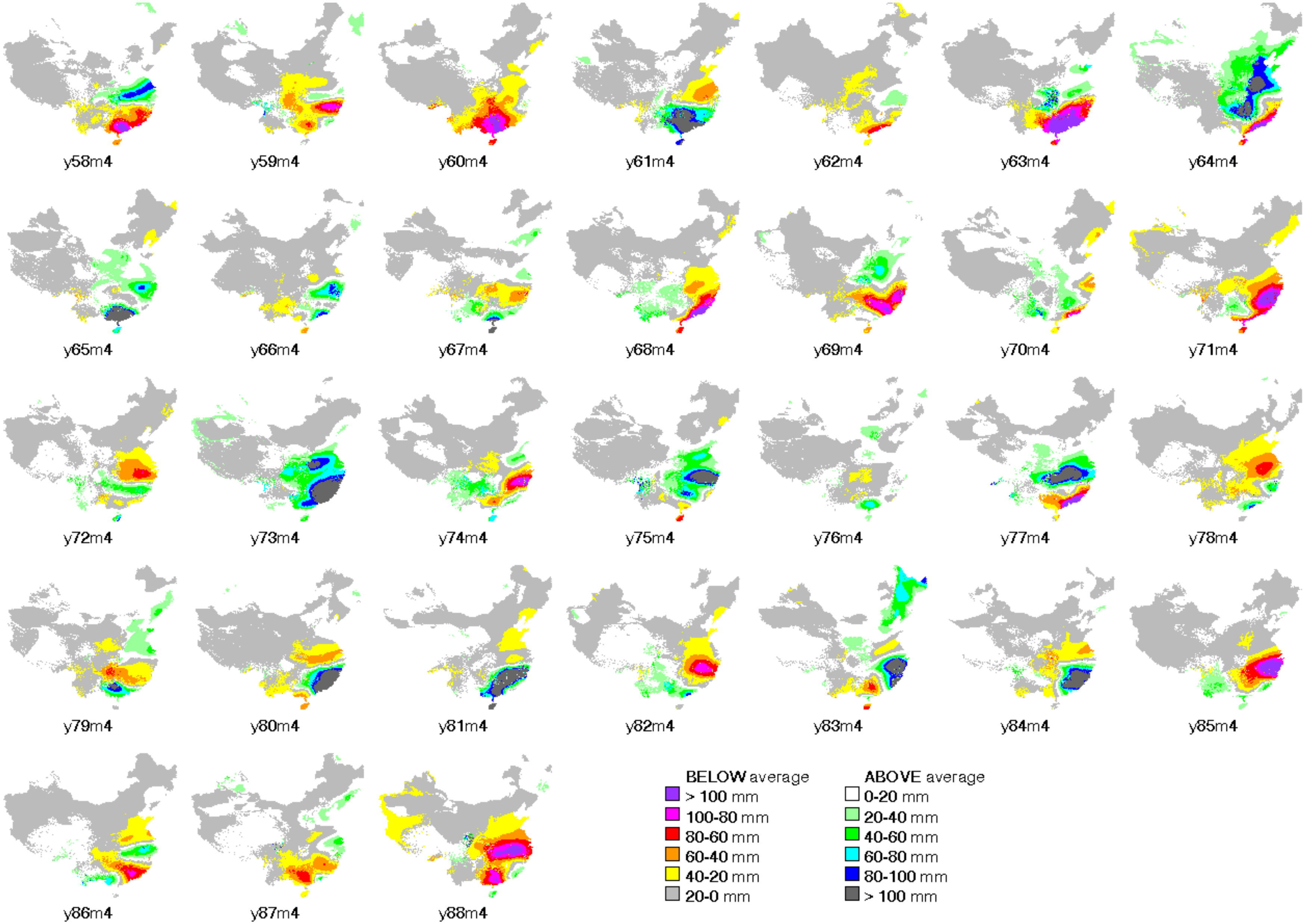
Annex 2 : ANNUAL RAINFALL Statistics of the time series 1958 to 1988

SICHUAN	56178	2369	31	**599**	462	714	56	**9**	69
	56444	3591	30	**626**	380	803	101	**16**	121
	56146	3394	31	**629**	489	815	63	**10**	78
	56257	3949	31	**702**	508	1096	105	**15**	137
	56182	2851	31	**731**	514	1323	83	**11**	141
	56172	2851	31	**766**	623	962	75	**10**	90
	56374	0	31	**791**	617	1022	85	**11**	103
	56485	1475	31	**839**	623	1235	108	**13**	140
	56193	877	31	**842**	478	1161	132	**16**	175
	56462	2987	31	**897**	678	1218	98	**11**	129
	56294	506	31	**947**	651	1391	147	**16**	185
	56196	471	31	**956**	572	1700	203	**21**	252
	57405	278	31	**958**	737	1317	120	**12**	150
	56571	1590	31	**979**	691	1471	119	**12**	159
	57411	298	31	**1004**	682	1355	122	**12**	158
	57504	347	31	**1051**	628	1622	184	**18**	239
	57606	972	31	**1052**	796	1528	116	**11**	155
	57516	259	31	**1080**	741	1385	109	**10**	144
	57515	261	31	**1095**	741	1354	117	**11**	148
	56671	1787	31	**1141**	728	1662	176	**15**	226
	57313	360	31	**1146**	751	1845	197	**17**	243
	56492	341	31	**1154**	727	1479	142	**12**	180
	57328	0	31	**1199**	863	1563	177	**15**	211
	57237	674	31	**1222**	771	2218	234	**19**	309
	57537	311	31	**1239**	916	1707	179	**14**	218
	56386	424	31	**1352**	914	1949	204	**15**	255
	57633	664	31	**1359**	851	1929	193	**14**	236
	56287	628	31	**1751**	1204	2367	268	**15**	320
SHAANXI	53646	1059	31	**417**	160	695	93	**22**	120
	53845	958	31	**574**	330	871	99	**17**	128
	57036	397	31	**579**	346	951	96	**17**	130
	57016	616	25	**686**	432	951	112	**16**	142
	57245	291	31	**824**	540	1109	133	**16**	154
	57127	508	31	**890**	621	1463	159	**18**	200
GANSU	52418	1139	31	**38**	8	106	15	**39**	20
	52424	1171	31	**47**	12	128	17	**36**	23
	52436	1526	31	**65**	25	143	19	**30**	25
	52323	1963	31	**79**	33	157	23	**29**	29
	52533	1478	31	**87**	41	166	29	**34**	34
	52681	1367	31	**112**	39	185	30	**26**	37
	52652	1483	31	**128**	70	214	26	**21**	34
	52889	1517	31	**324**	189	547	70	**22**	87
	52787	3045	31	**398**	231	555	71	**18**	88
	56096	1079	31	**482**	358	690	62	**13**	78
	52984	1917	31	**509**	326	764	90	**18**	110
	53915	1347	31	**510**	318	745	86	**17**	112
	52996	2451	31	**513**	293	764	89	**17**	115
	57006	1132	31	**538**	325	772	102	**19**	119
	56080	2937	31	**555**	374	800	76	**14**	100
	53923	1422	31	**566**	362	805	96	**17**	118
	56093	2315	31	**599**	441	818	79	**13**	95
NINGXIA	53614	1112	31	**197**	98	354	60	**30**	70
	53705	1183	31	**224**	82	453	72	**32**	90
	53810	1345	25	**274**	128	492	69	**25**	89
	53723	1348	31	**290**	145	587	71	**25**	97

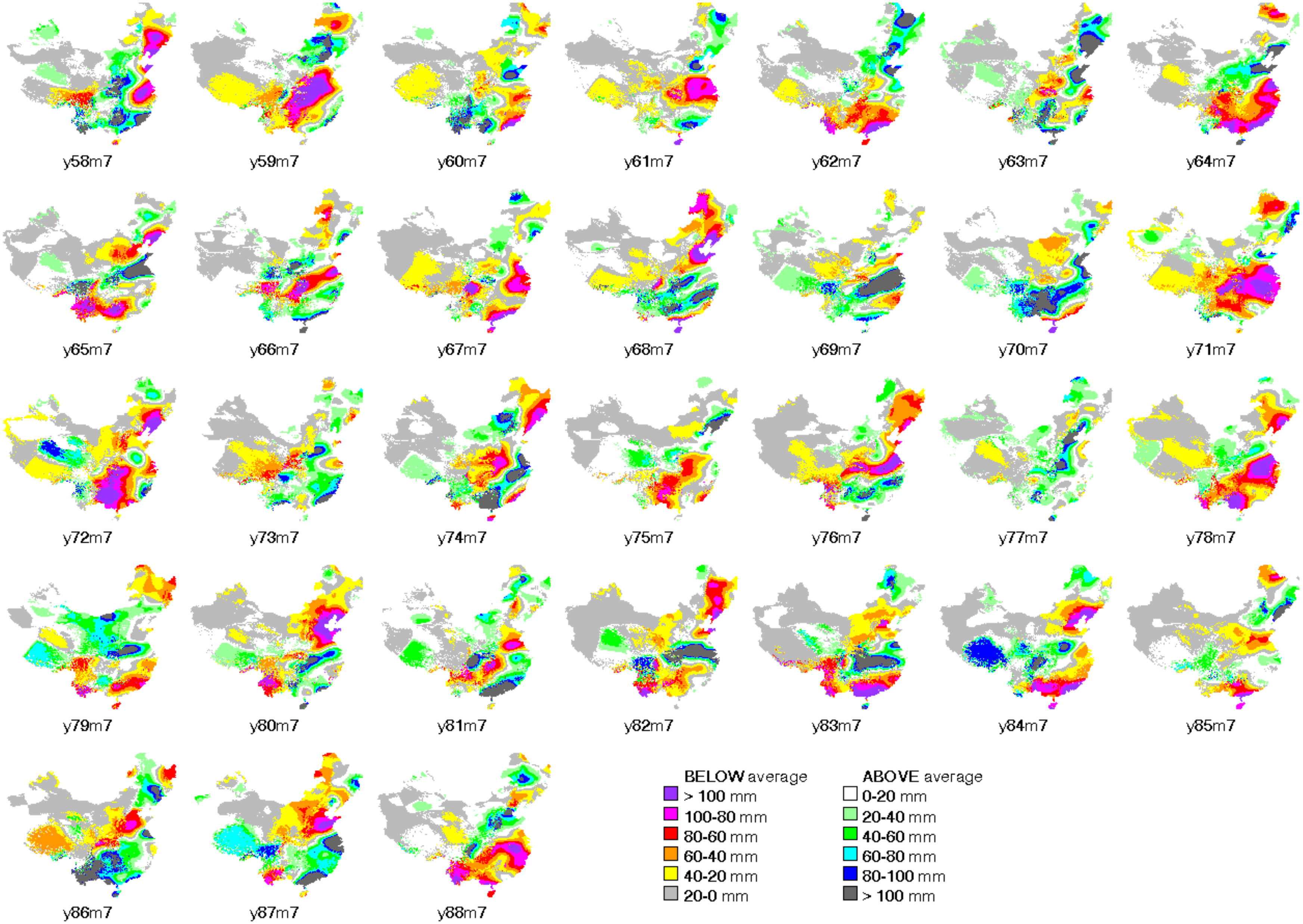
Annex 2 : ANNUAL RAINFALL Statistics of the time series 1958 to 1988

INNER-MONG.	52267	941	29	**34**	7	101	15	**44**	21
	52495	1329	31	**92**	39	199	29	**31**	39
	53502	1032	31	**110**	49	227	38	**34**	46
	53420	0	31	**135**	56	232	43	**32**	50
	53068	965	31	**142**	83	244	38	**26**	46
	53602	1561	31	**208**	112	348	49	**24**	59
	53336	1288	31	**209**	87	433	61	**29**	79
	53276	1151	31	**223**	91	394	49	**22**	67
	53192	1126	31	**249**	127	440	44	**18**	58
	50915	839	31	**249**	153	403	47	**19**	62
	53352	1376	31	**260**	143	400	56	**22**	70
	53529	1380	31	**271**	125	612	87	**32**	108
	54102	990	31	**288**	147	561	58	**20**	83
	53446	0	31	**305**	131	678	88	**29**	116
	53391	1483	31	**325**	166	501	53	**16**	70
	50527	614	31	**342**	121	547	51	**15**	77
	54218	571	31	**357**	231	548	61	**17**	81
	54115	779	31	**376**	176	613	88	**23**	108
	54135	179	31	**377**	199	529	55	**15**	75
	53480	1417	25	**378**	168	588	83	**22**	108
	54208	1245	31	**381**	257	512	59	**16**	74
	54027	484	31	**388**	232	745	86	**22**	113
	54026	265	31	**393**	238	551	81	**21**	94
	53463	1065	31	**421**	155	929	110	**26**	156
	50838	0	31	**421**	240	656	78	**19**	101
	50727	1027	31	**451**	317	681	55	**12**	73
	50434	733	31	**460**	339	623	60	**13**	74
	50632	739	31	**477**	313	636	61	**13**	75
QUINGHAI	52836	3191	31	**186**	107	323	38	**21**	50
	52842	3088	31	**207**	134	396	48	**23**	61
	56004	4534	24	**282**	181	389	47	**16**	55
	52633	3361	31	**285**	203	380	35	**12**	44
	56033	4272	31	**314**	184	510	61	**19**	78
	52856	2835	31	**319**	222	523	49	**15**	63
	52866	2261	31	**367**	196	541	62	**17**	81
	56021	4175	31	**404**	279	508	49	**12**	59
	52957	3290	24	**428**	317	558	61	**14**	73
	56029	3681	31	**484**	321	615	56	**12**	69
	56046	3969	31	**545**	417	702	64	**12**	76
XIZANG	55228	4728	22	**71**	34	137	21	**30**	27
	55696	3860	29	**271**	121	415	42	**15**	57
	55279	4701	23	**295**	171	469	56	**19**	70
	55299	4507	31	**416**	299	590	57	**14**	74
	55591	3658	30	**423**	219	797	73	**17**	105
	55578	3836	31	**430**	210	752	86	**20**	114
	56137	3306	31	**459**	307	652	70	**15**	89
	56312	3000	29	**656**	452	923	92	**14**	112
XINJIANG	52203	738	31	**36**	10	72	13	**36**	16
	51811	1231	31	**47**	11	125	24	**52**	31
	51716	1117	31	**50**	8	124	26	**52**	31
	51709	1289	31	**63**	17	146	22	**35**	30
	51628	1105	25	**67**	33	138	24	**36**	30
	51644	1099	31	**67**	33	195	22	**33**	33
	51334	320	31	**100**	45	164	24	**23**	30
	51243	426	31	**111**	59	260	35	**31**	47
	51156	1292	31	**141**	70	278	34	**24**	44
	51346	0	31	**164**	85	280	40	**24**	49
	51076	735	31	**178**	76	294	43	**24**	55
	51379	794	31	**179**	90	328	36	**20**	49
	51087	864	25	**180**	83	399	63	**35**	84
	51463	654	31	**244**	131	401	54	**22**	73
	51431	664	31	**263**	148	471	57	**21**	76
	51133	548	31	**285**	153	466	65	**23**	77

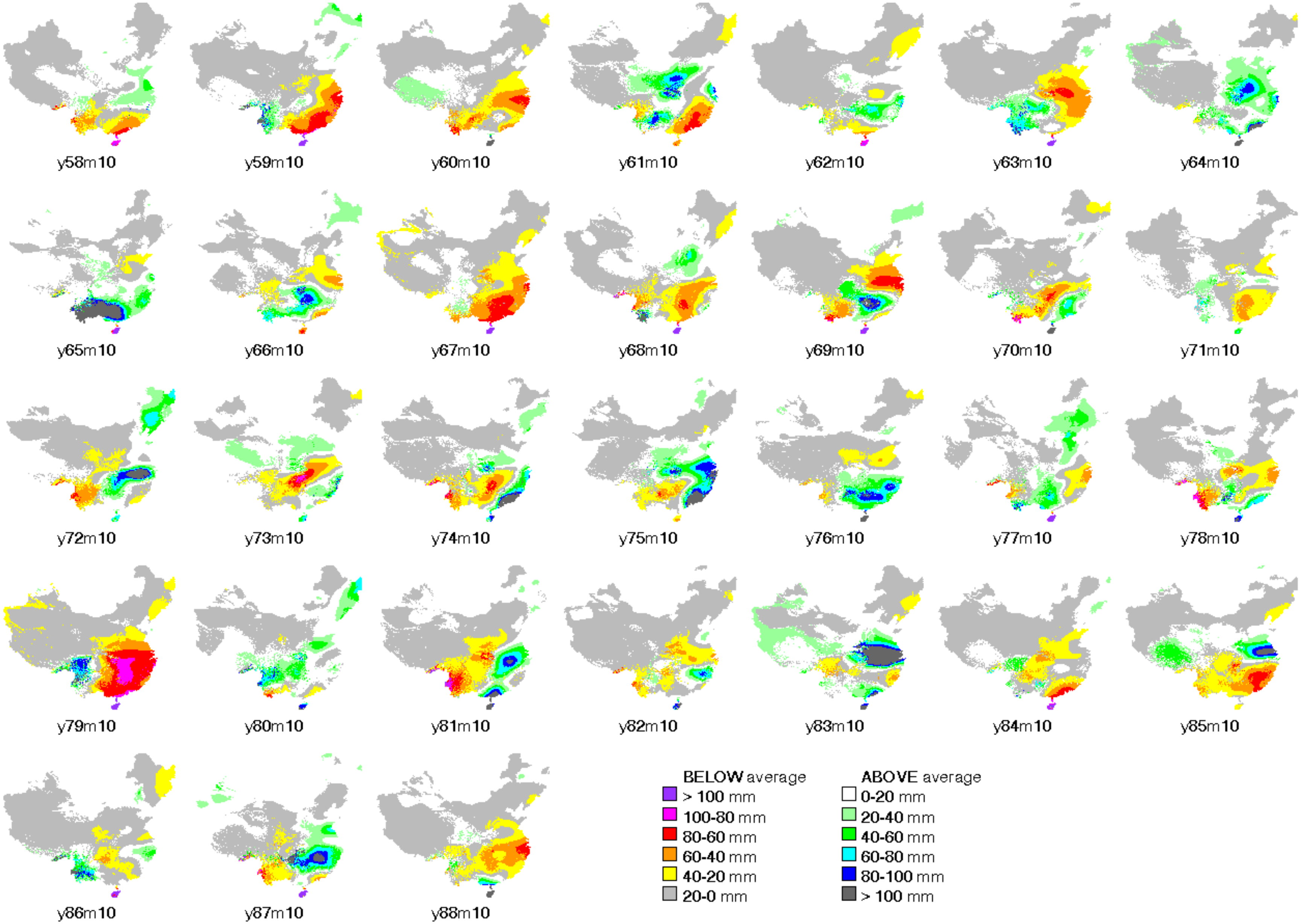
ANNEX 3 : APRIL – Precipitation anomalies from 1958 to 1988 - expressed as mm deviation from mean



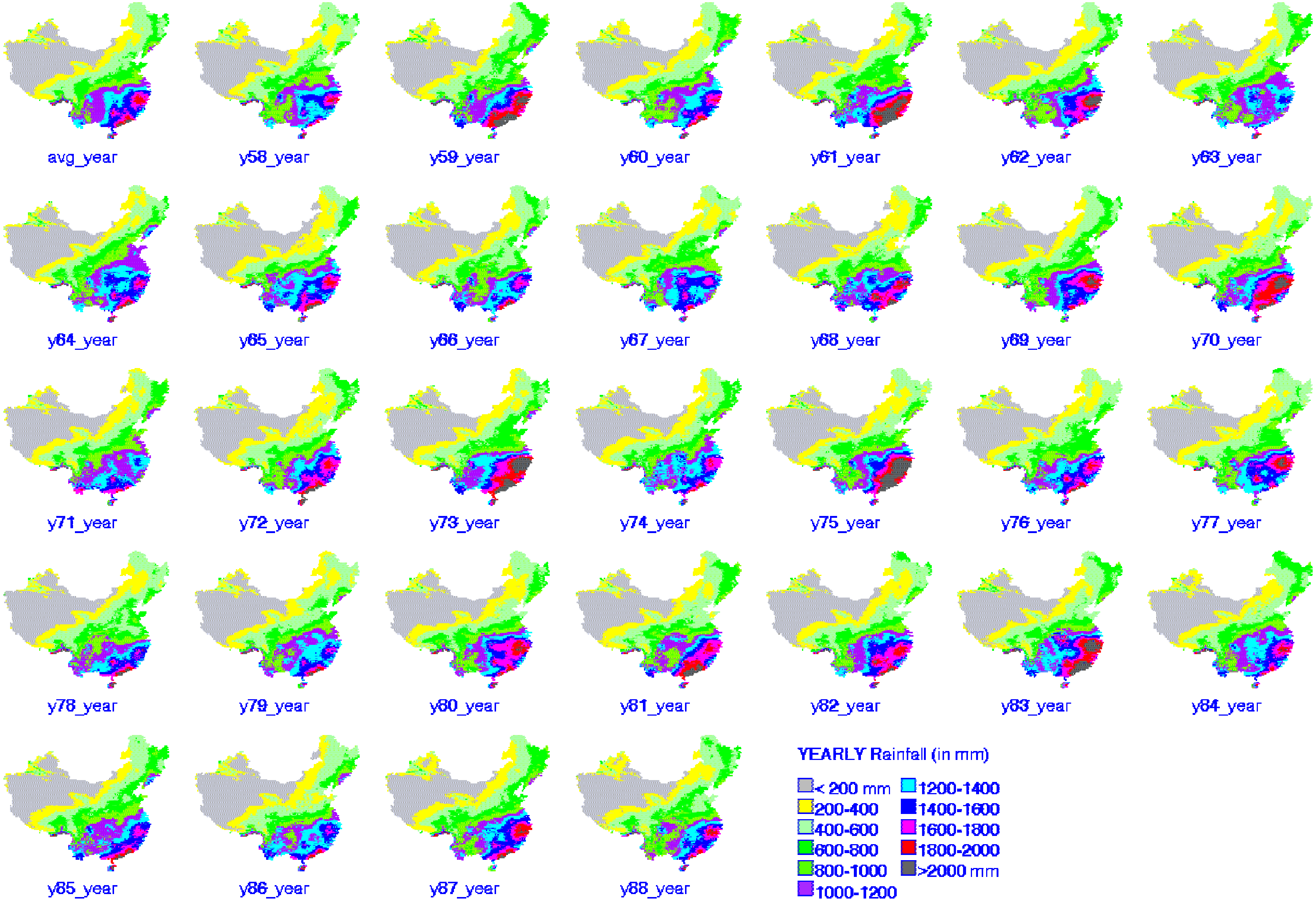
ANNEX 3: JULY – Precipitation anomalies from 1958 to 1988 - expressed as mm deviation from mean



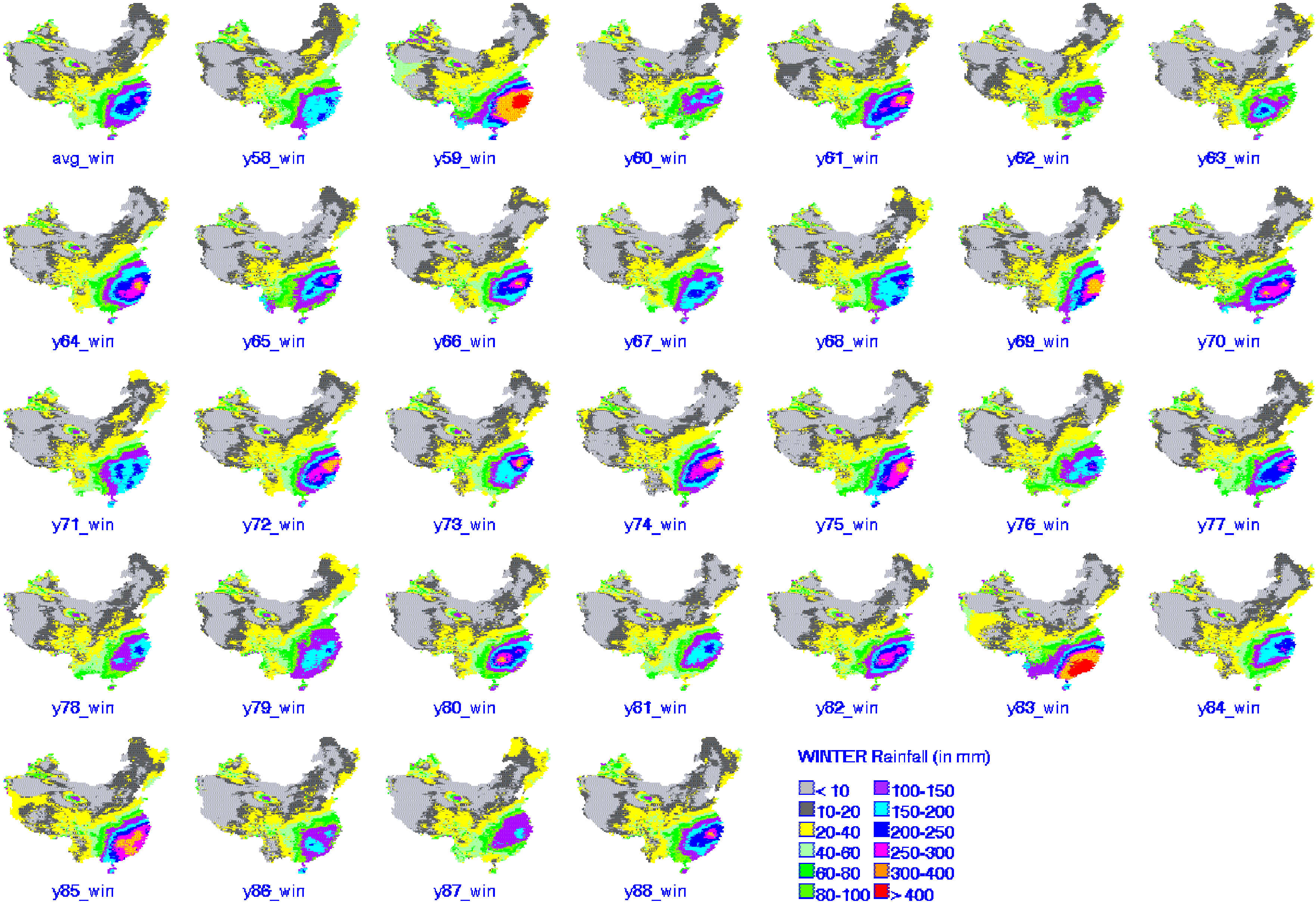
ANNEX 3: OCTOBER – Precipitation anomalies from 1958 to 1988 - expressed as mm deviation from mean



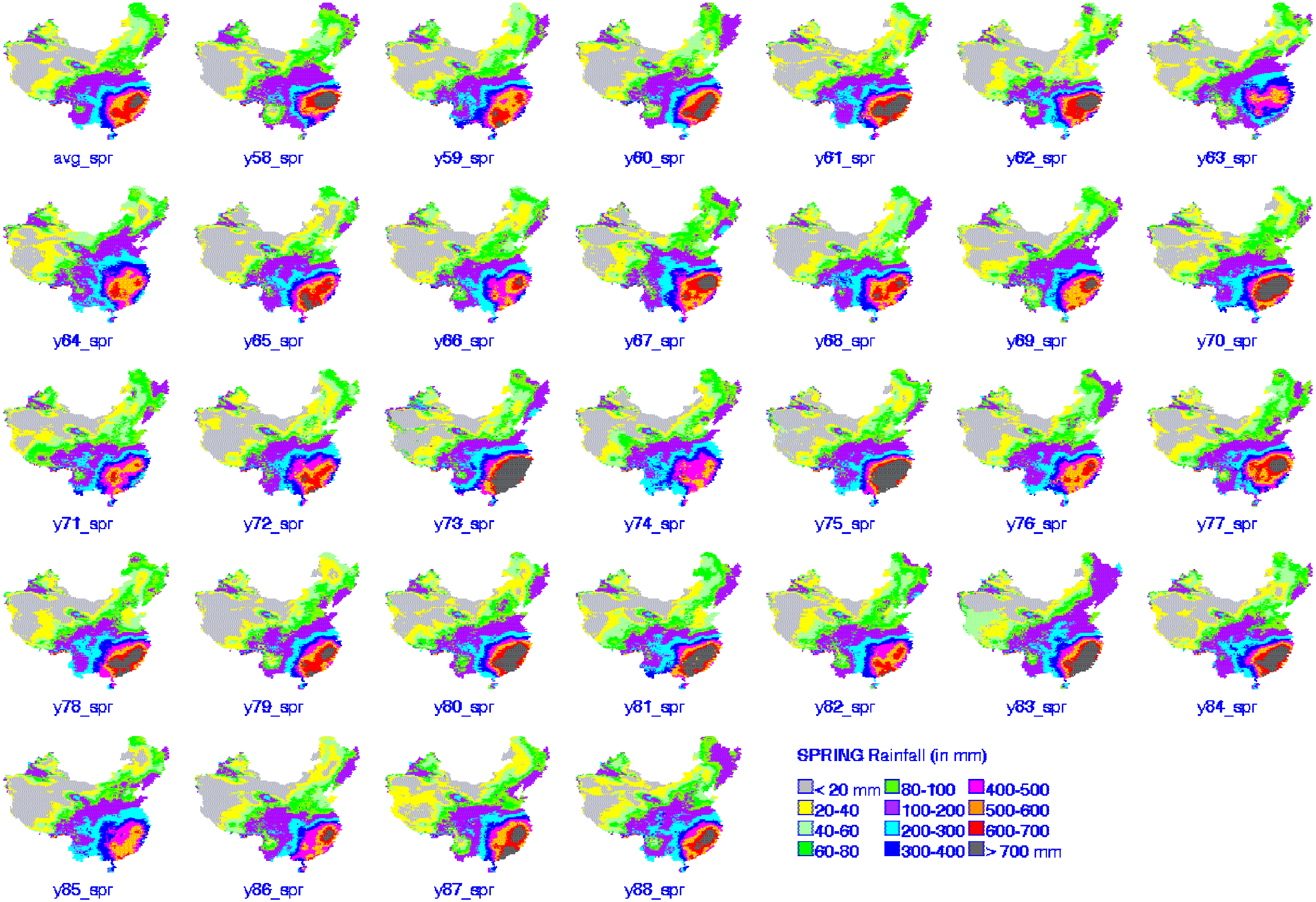
TIME SERIES of ANNUAL RAINFALL for 1958 to 1988 (first map shows annual average rainfall)



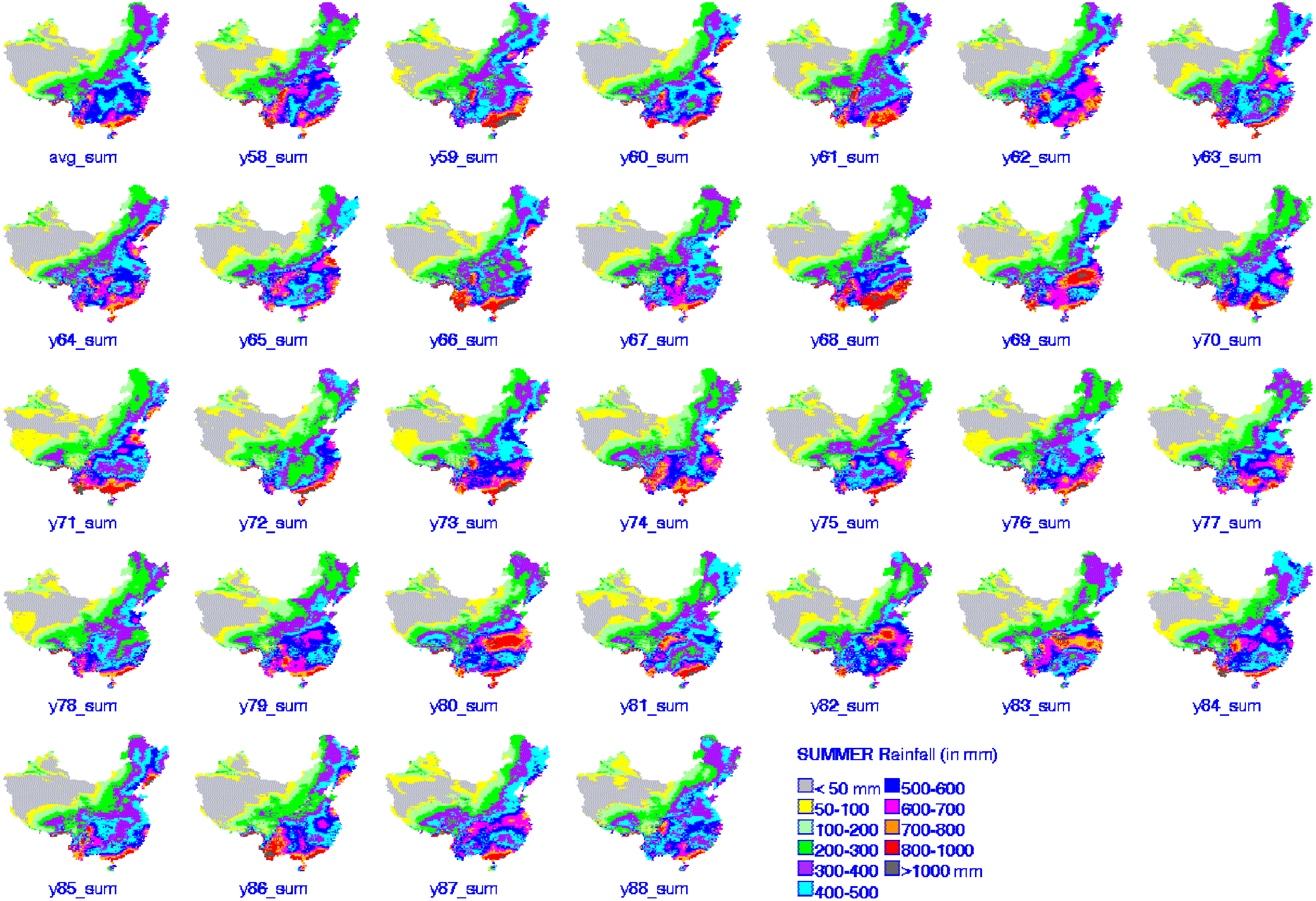
ANNEX 4: PRECIPITATION TIME SERIES from 1958 to 1988 for WINTER months (Sum of December, January, February)
(first map shows average precipitation)



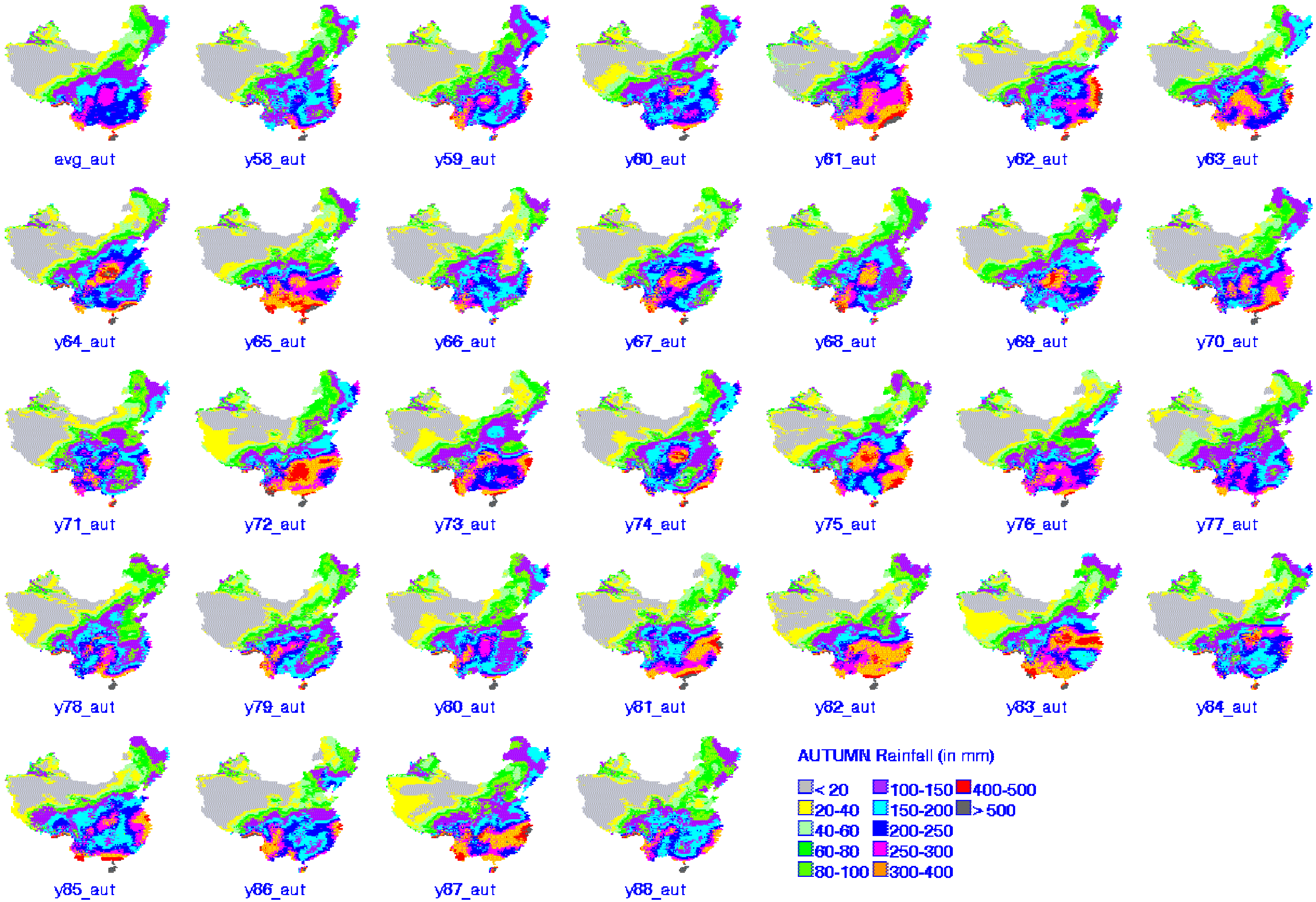
ANNEX 4: PRECIPITATION TIME SERIES from 1958 to 1988 for SPRING months (Sum of March, April and May)
(first map shows average precipitation)



ANNEX 4: PRECIPITATION TIME SERIES from 1958 to 1988 for SUMMER (Sum of June, July and August)
(first map shows average summer precipitation)



PRECIPITATION TIME SERIES from 1958 to 1988 for AUTUMN months (Sum of September, October, November)
(first map shows average autumn precipitation)



ANNEX 5

ANNUAL Rainfall [mm] per PROVINCE and deviation from normal [%]

Rainfall data stem from the interpolated 5km grid time series that were averaged per province.

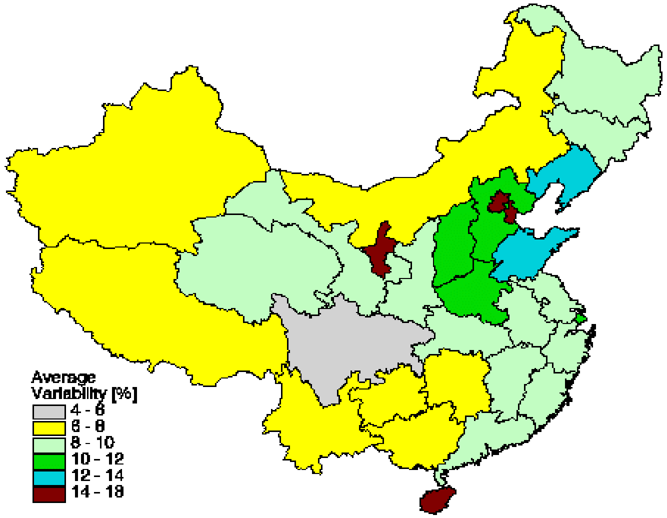
Region	North		North		North		North		North		North		NE		NE		NE		East		East		East		East	
Province	**Beijing**	**%**	**Tianjin**	**%**	**Hebei**	**%**	**Shanxi**	**%**	**Shand.**	**%**	**Henan**	**%**	**Liaon.**	**%**	**Jilin**	**%**	**Heilongj.**	**%**	**Shanghai**	**%**	**Jiangsu**	**%**	**Anhui**	**%**	**Zhejiang**	**%**
1958	578	-2	496	-15	665	19	583	5	729	2	946	14	573	-19	479	-23	530	-6	1171	-1	1094	5	1137	-4	1629	-1
1959	900	52	805	39	648	16	701	26	727	1	714	-14	887	25	694	11	661	18	1260	7	1041	0	1206	2	1878	15
1960	508	-14	503	-13	479	-14	489	-12	790	10	796	-4	816	15	813	30	676	20	1275	8	1184	14	1203	1	1622	-1
1961	627	6	683	18	667	19	630	13	813	13	740	-11	696	-2	654	5	583	4	1215	3	983	-5	1058	-11	1752	7
1962	512	-14	504	-13	494	-12	520	-6	895	25	817	-2	779	10	622	0	594	6	1258	7	1246	20	1260	6	1831	12
1963	578	-2	603	4	540	-3	640	15	888	24	1035	24	717	1	672	8	652	16	1148	-3	1148	11	1210	2	1366	-17
1964	823	39	940	62	799	43	805	45	1104	54	1124	35	984	39	693	11	511	-9	1031	-13	1081	4	1214	2	1486	-9
1965	415	-30	357	-39	368	-34	393	-29	660	-8	777	-7	545	-23	588	-6	562	0	1152	-2	1144	10	1181	0	1631	-1
1966	601	1	623	7	551	-1	530	-5	581	-19	615	-26	760	7	654	5	574	2	1091	-7	791	-24	934	-21	1517	-7
1967	653	10	615	6	684	22	595	7	710	-1	920	11	712	0	531	-15	479	-15	831	-29	888	-14	1064	-10	1319	-20
1968	448	-24	338	-42	546	-2	439	-21	517	-28	778	-7	567	-20	587	-6	545	-3	919	-22	852	-18	983	-17	1492	-9
1969	749	27	760	31	589	5	635	14	728	2	854	3	797	12	655	5	593	6	1161	-1	1125	8	1408	19	1738	6
1970	568	-4	550	-5	510	-9	517	-7	795	11	792	-5	672	-5	535	-14	462	-18	1248	6	1146	10	1293	9	1789	9
1971	544	-8	585	1	539	-4	565	2	879	23	875	5	748	5	710	14	577	3	993	-16	1015	-2	1122	-5	1298	-21
1972	439	-26	399	-31	409	-27	431	-22	703	-2	782	-6	598	-16	616	-1	605	8	1145	-3	1160	12	1279	8	1639	0
1973	724	22	709	22	630	13	675	21	762	6	841	1	811	14	638	2	528	-6	1344	14	994	-4	1288	9	2102	28
1974	578	-2	558	-4	456	-19	554	0	857	20	820	-1	754	6	640	2	562	0	1270	8	1202	16	1259	6	1671	2
1975	489	-17	467	-20	572	2	483	-13	764	7	869	4	692	-2	608	-3	476	-15	1403	19	1155	11	1418	19	2029	24
1976	606	2	593	2	588	5	582	5	681	-5	715	-14	639	-10	550	-12	454	-19	1199	2	896	-14	1012	-15	1607	-2
1977	742	25	870	50	581	4	658	18	651	-9	820	-1	732	3	579	-7	508	-10	1485	26	1054	2	1335	12	1818	11
1978	651	10	617	6	593	6	586	5	696	-3	643	-23	601	-15	489	-22	498	-11	810	-31	649	-37	744	-37	1263	-23
1979	667	13	601	3	527	-6	587	6	729	2	989	19	710	0	537	-14	448	-20	1014	-14	1050	1	1208	2	1362	-17
1980	461	-22	460	-21	486	-13	463	-17	648	-10	866	4	547	-23	620	-1	554	-1	1278	8	1078	4	1320	11	1711	4
1981	484	-18	466	-20	548	-2	467	-16	479	-33	746	-10	608	-14	648	4	629	12	1234	5	938	-10	1167	-2	1697	4
1982	519	-12	504	-13	510	-9	510	-8	641	-11	929	12	589	-17	517	-17	520	-8	1149	-3	979	-6	1199	1	1600	-2
1983	515	-13	460	-21	579	4	514	-8	594	-17	977	17	632	-11	633	1	613	9	1360	15	1104	6	1450	22	1955	19
1984	492	-17	534	-8	528	-6	503	-9	734	2	1038	25	690	-3	622	-1	632	12	1184	0	1055	2	1259	6	1647	0
1985	664	12	656	13	619	11	598	8	751	5	832	0	925	30	719	15	620	10	1369	16	1125	8	1166	-2	1526	-7
1986	572	-3	479	-18	435	-22	468	-16	483	-33	624	-25	820	16	767	23	537	-5	1119	-5	957	-8	1060	-11	1429	-13
1987	628	6	648	11	534	-4	577	4	696	-3	851	2	777	10	709	13	642	14	1420	20	1183	14	1358	14	1831	12
1988	623	5	645	11	655	17	552	-1	543	-24	678	-19	606	-14	584	-7	608	8	1020	-13	833	-20	1009	-15	1582	-3
AVERAGE	**592**		**581**		**559**		**556**		**717**		**832**		**709**		**625**		**562**		**1179**		**1037**		**1187**		**1639**	
min	415	-30	338	-42	368	-34	393	-29	479	-33	615	-26	545	-23	479	-23	448	-20	810	-31	649	-37	744	-37	1263	-23
max	900	52	940	62	799	43	805	45	1104	54	1124	35	984	39	813	30	676	20	1485	26	1246	20	1450	22	2102	28
range	484	82	602	104	431	77	413	74	625	87	509	61	439	62	334	54	228	41	675	57	597	58	706	59	839	51
stdv	114	19	139	24	88	16	88	16	132	18	123	15	112	16	78	12	64	11	163	14	137	13	154	13	210	13
AVEDEV	88		106		67		69		95		94		89		60		53		125		107		116		161	
CV*	15%		18%		12%		12%		13%		11%		13%		10%		9%		11%		10%		10%		10%	

* AVEDEV = average absolute deviation from mean rainfall; CV = AVEDEV*100/mean

ANNEX 5		**ANNUAL Rainfall [mm] per PROVINCE and deviation from normal [%]**																						
Region	Central		Central		Central		South		South		South		South		SW		SW		SW		SW	
Province	**Jiangxi**	**%**	**Hubei**	**%**	**Hunan**	**%**	**Fujian**	**%**	**Hainan**	**%**	**Guangdong**	**%**	**Hongkong**	**%**	**Guangxi**	**%**	**Sichuan**	**%**	**Guizhou**	**%**	**Yunnan**	**%**
1958	1500	-8	1251	5	1384	-3	1598	-2	1772	14	1510	-14	2054	-11	1233	-12	904	-1	1026	-10	967	-8
1959	1743	7	1115	-6	1449	2	1964	20	1263	-19	2261	29	2871	24	1682	20	860	-6	1141	0	1114	6
1960	1499	-8	1125	-6	1282	-10	1577	-4	1920	24	1711	-2	2399	4	1292	-8	922	1	1010	-11	968	-8
1961	1882	16	1098	-8	1619	14	1984	21	1410	-9	2125	21	2626	14	1646	17	922	1	1230	8	1129	8
1962	1793	11	1182	-1	1525	7	1811	11	1246	-20	1581	-10	2054	-11	1225	-13	922	1	1047	-8	983	-6
1963	1214	-25	1195	0	1231	-14	1342	-18	1780	15	1219	-31	1524	-34	1123	-20	937	3	1110	-3	1022	-3
1964	1513	-7	1366	15	1433	1	1603	-2	1842	19	1735	-1	2404	4	1304	-7	948	4	1203	6	1004	-4
1965	1556	-4	1149	-4	1420	0	1561	-5	1432	-8	1738	-1	2329	1	1507	7	1021	12	1291	13	1166	11
1966	1458	-10	908	-24	1272	-11	1469	-10	1345	-13	1627	-7	2313	0	1305	-7	876	-4	917	-20	1182	13
1967	1493	-8	1326	11	1494	5	1285	-21	1625	5	1544	-12	1898	-18	1476	5	931	2	1288	13	988	-6
1968	1607	-1	1149	-4	1463	3	1688	3	1149	-26	1782	2	2381	3	1553	10	983	8	1229	8	1177	12
1969	1740	7	1343	13	1524	7	1659	1	1081	-30	1577	-10	2038	-12	1323	-6	885	-3	1168	2	903	-14
1970	1948	20	1246	5	1669	17	1775	8	1806	16	1850	5	2405	4	1545	10	894	-2	1225	7	1130	8
1971	1228	-24	1079	-10	1213	-15	1225	-25	1364	-12	1528	-13	2032	-12	1485	6	834	-8	1164	2	1163	11
1972	1645	1	1088	-9	1420	0	1659	1	2197	42	1874	7	2436	5	1349	-4	808	-11	1140	0	967	-8
1973	1985	22	1346	13	1634	15	1981	21	1921	24	2118	21	2666	15	1606	14	946	4	1200	5	1162	11
1974	1491	-8	1139	-4	1284	-10	1505	-8	1673	8	1644	-6	2193	-5	1350	-4	1002	10	1200	5	1118	7
1975	2092	29	1338	12	1635	15	2137	31	1614	4	2185	25	2922	27	1441	2	909	0	1040	-9	993	-5
1976	1601	-1	988	-17	1391	-2	1587	-3	1565	1	1751	0	2346	2	1423	1	846	-7	1235	8	1049	0
1977	1703	5	1300	9	1533	8	1546	-6	1019	-34	1485	-15	2020	-12	1384	-2	879	-4	1313	15	959	-9
1978	1334	-18	911	-24	1249	-12	1546	-6	1838	19	1732	-1	2373	3	1459	4	878	-4	1124	-1	1087	4
1979	1473	-9	1218	2	1320	-7	1523	-7	1332	-14	1757	0	2313	0	1427	1	871	-4	1104	-3	1002	-5
1980	1769	9	1444	21	1592	12	1648	1	1819	17	1691	-4	2191	-5	1338	-5	945	4	1125	-1	944	-10
1981	1699	5	1108	-7	1406	-1	1603	-2	1675	8	1998	14	2402	4	1545	10	912	0	941	-18	1048	0
1982	1708	5	1329	12	1606	13	1635	0	1899	22	1772	1	2447	6	1482	5	931	2	1183	4	969	-8
1983	1904	17	1587	33	1489	5	1884	15	1383	-11	2184	24	2849	23	1521	8	960	5	1257	10	1124	7
1984	1628	0	1207	1	1364	-4	1605	-2	1301	-16	1631	-7	2071	-10	1219	-13	945	4	1139	0	1042	-1
1985	1512	-7	1079	-9	1239	-13	1608	-2	1566	1	1812	3	2313	0	1384	-2	938	3	1119	-2	1102	5
1986	1381	-15	1036	-13	1243	-13	1449	-12	1574	1	1590	-9	2248	-3	1345	-4	849	-7	1054	-8	1215	16
1987	1643	1	1270	7	1417	0	1668	2	1023	-34	1742	-1	2364	2	1396	-1	930	2	1122	-2	967	-8
1988	1542	-5	1035	-13	1331	-7	1616	-1	1645	6	1612	-8	2097	-9	1247	-11	864	-5	1004	-12	891	-15
AVERAGE	**1622**		**1192**		**1424**		**1637**		**1551**		**1754**		**2309**		**1407**		**911**		**1140**		**1049**	
min	1214	-25	908	-24	1213	-15	1225	-25	1019	-34	1219	-31	1524	-34	1123	-20	808	-11	917	-20	891	-15
max	2092	29	1587	33	1669	17	2137	31	2197	42	2261	29	2922	27	1682	20	1021	12	1313	15	1215	16
range	878	54	679	57	456	32	912	56	1177	76	1042	59	1398	61	559	40	212	23	397	35	325	31
stdv	210	13	153	13	137	10	202	12	296	19	235	13	293	13	134	10	49	5	100	9	91	9
AVEDEV	165		121		112		143		246		173		212		109		39		79		79	
CV	10%		10%		8%		9%		16%		10%		9%		8%		4%		7%		8%	

ANNEX 5 — ANNUAL Rainfall [mm] per PROVINCE and deviation from normal [%]

Region	Plateau		Plateau		NW		NW		NW		NW		NW	
Province	**Xizang**	**%**	**Qinghai**	**%**	**Shaanxi**	**%**	**Gansu**	**%**	**Inner-Mong.**	**%**	**Ningxia**	**%**	**Xinjiang**	**%**
1958	279	-15	303	10	770	16	346	10	342	13	385	15	165	19
1959	313	-5	243	-12	637	-4	318	1	391	29	375	13	163	17
1960	327	-1	244	-12	603	-9	290	-8	309	2	314	-6	145	4
1961	300	-9	306	11	778	17	357	13	327	8	445	34	139	0
1962	330	0	236	-14	598	-10	268	-15	277	-8	287	-14	124	-11
1963	359	9	278	1	670	1	293	-7	290	-4	284	-15	120	-14
1964	313	-5	277	0	891	34	399	27	329	9	515	55	146	5
1965	333	1	262	-5	569	-15	255	-19	220	-27	239	-28	125	-10
1966	290	-12	245	-11	636	-5	312	-1	275	-9	297	-11	133	-4
1967	297	-10	325	18	777	17	393	25	313	4	449	35	123	-12
1968	327	-1	263	-5	733	10	312	-1	270	-11	392	18	122	-12
1969	351	6	235	-15	598	-10	277	-12	330	9	272	-18	140	1
1970	318	-4	245	-11	653	-2	327	4	311	3	361	8	140	1
1971	343	4	302	10	587	-12	293	-7	272	-10	266	-20	144	4
1972	276	-16	276	0	539	-19	268	-15	263	-13	256	-23	147	6
1973	334	1	247	-10	698	5	340	8	316	5	387	16	153	10
1974	365	11	313	13	631	-5	289	-8	283	-6	278	-17	135	-3
1975	304	-8	315	14	729	9	337	7	279	-7	321	-4	133	-4
1976	319	-3	268	-3	632	-5	318	1	314	4	348	5	132	-5
1977	329	0	256	-7	611	-8	311	-1	318	5	350	5	132	-5
1978	325	-1	242	-12	660	-1	343	9	300	-1	413	24	122	-12
1979	314	-5	234	-15	604	-9	336	7	333	10	341	3	137	-2
1980	399	21	268	-3	651	-2	276	-13	260	-14	241	-28	128	-8
1981	321	-3	317	15	741	11	346	10	306	1	329	-1	150	8
1982	320	-3	295	7	596	-11	265	-16	272	-10	215	-35	131	-6
1983	341	3	296	7	830	25	336	7	309	2	347	4	154	11
1984	361	10	278	1	725	9	337	7	328	9	365	10	146	5
1985	387	17	307	11	695	4	330	5	327	8	369	11	131	-6
1986	286	-13	272	-1	508	-24	266	-15	277	-8	260	-22	123	-12
1987	393	19	338	22	611	-8	285	-10	295	-2	301	-10	171	23
1988	368	12	274	-1	689	3	331	5	317	5	335	0	153	10
AVERAGE	**330**		**276**		**666**		**315**		**302**		**333**		**139**	
min	276	-16	234	-15	508	-24	255	-19	220	-27	215	-35	120	-14
max	399	21	338	22	891	34	399	27	391	29	515	55	171	23
range	123	37	104	38	383	58	144	46	171	57	300	90	51	37
stdv	32	10	30	11	86	13	36	12	32	11	69	21	14	10
AVEDEV	24		25		69		30		25		54		11	
CV	7%		9%		10%		9%		8%		16%		8%	



Variability of provinces

calculated as the CV of the time series for the interpolated grid time series averages over the province

ANNEX 6 **ANNUAL Rainfall [mm] per watershed region***

	W1	%	W2	%	W4	%	W3	%	W5	%	W6	%	W7	%	W8	%	W9	%
1958	495	-8	588	7	571	16	926	5	1039	-2	1288	-11	1642	-1	613	-10	165	11
1959	634	18	702	28	508	4	851	-4	1043	-2	1710	18	1956	18	687	0	169	14
1960	631	18	472	-14	449	-8	957	8	1011	-5	1385	-5	1616	-3	656	-4	146	-2
1961	544	1	629	15	590	20	828	-6	1106	4	1702	17	1912	15	684	0	147	-1
1962	558	4	497	-9	438	-11	1012	14	1084	2	1280	-12	1861	12	687	0	124	-17
1963	581	8	600	10	485	-1	1071	21	1006	-5	1158	-20	1365	-18	719	5	136	-8
1964	550	3	787	44	662	35	1129	28	1093	3	1419	-2	1578	-5	667	-3	155	4
1965	485	-10	369	-33	379	-23	918	4	1096	3	1523	5	1617	-3	714	4	125	-16
1966	550	3	524	-4	456	-7	659	-25	949	-10	1339	-8	1513	-9	697	2	129	-13
1967	482	-10	607	11	590	20	870	-2	1078	2	1428	-2	1321	-20	638	-7	146	-2
1968	481	-10	448	-18	497	1	750	-15	1077	2	1519	5	1642	-1	724	6	131	-11
1969	584	9	618	13	451	-8	961	9	1088	3	1325	-9	1721	4	659	-4	150	2
1970	482	-10	507	-7	479	-2	935	6	1136	7	1570	8	1809	9	709	3	145	-2
1971	546	2	545	0	469	-4	956	8	946	-11	1422	-2	1262	-24	727	6	158	7
1972	529	-1	422	-23	404	-18	932	5	1008	-5	1491	3	1672	1	610	-11	141	-5
1973	528	-2	652	19	527	7	861	-3	1165	10	1689	16	2062	24	720	5	160	8
1974	538	0	517	-5	452	-8	993	12	1080	2	1412	-3	1590	-4	729	6	150	2
1975	487	-9	488	-11	519	6	966	9	1160	10	1582	9	2125	28	659	-4	142	-4
1976	473	-12	581	6	506	3	762	-14	995	-6	1484	2	1616	-3	673	-2	144	-3
1977	518	-3	631	15	474	-3	836	-6	1100	4	1341	-8	1674	1	659	-4	148	0
1978	475	-11	582	6	505	3	668	-25	928	-12	1491	3	1455	-12	685	0	134	-9
1979	477	-11	576	5	478	-3	992	12	1001	-5	1451	0	1475	-11	649	-5	154	4
1980	505	-6	460	-16	439	-10	889	0	1143	8	1399	-4	1693	2	721	5	139	-6
1981	547	2	475	-13	505	3	714	-19	1050	-1	1570	8	1658	0	676	-1	162	9
1982	491	-8	501	-8	424	-13	893	1	1109	5	1504	4	1643	-1	652	-5	139	-6
1983	560	4	512	-6	516	5	900	2	1199	13	1659	14	1926	16	700	2	163	10
1984	583	9	496	-9	523	7	983	11	1075	1	1310	-10	1646	-1	707	3	157	6
1985	616	15	592	8	530	8	920	4	1027	-3	1466	1	1584	-5	745	9	155	5
1986	557	4	454	-17	391	-20	705	-20	956	-10	1391	-4	1455	-12	688	0	132	-11
1987	585	9	557	2	466	-5	925	5	1096	3	1386	-5	1758	6	713	4	180	22
1988	550	3	567	4	499	2	674	-24	979	-8	1321	-9	1631	-2	673	-2	160	8
MIN	473	-12	369	-33	379	-23	659	-25	928	-12	1158	-20	1262	-24	610	-11	124	-17
MAX	634	18	787	44	662	35	1129	28	1199	13	1710	18	2125	28	745	9	180	22
avg	**536**		**547**		**490**		**885**		**1059**		**1452**		**1660**		**685**		**148**	
stdv	47		87		60		118		69		133		200		34		13	

* The 9 regions were taken from U.N. (1997): China: Water Resources and their use. ', where 9 regions for Water Resource Assessment were delineated.

W1 North-eastern
W2 Hai He-Luan He Basin
W3 Huai He Basin
W4 Huang He Basin (Yellow River)
W5 Chang Jiang Basin (Yanggtze)
W6 Southern
W7 South-eastern
W8 South-western
W9 Interior basins