# Chapter 2
# Data and Methods

## 2.1 Data

### *2.1.1 The Observation Data*

#### 2.1.1.1 The Observation Data of Southwestern Areas from China Meteorological Administration

The observation data of ground stations is the main data source of this study. The data about the daily mean temperature, daily minimum temperature, daily precipitation, daily wind speed and daily sunshine hours are from the meteorological observation database of national meteorological information center in China Meteorological Administration (http://www.nmic.gov.cn/). The time span of meteorological data is mainly set from January 1st, 1961 to December 31st, 2008 in order to ensure the length of all data uniform and stable. It's important to note that the wind speed data exist discontinuity in the record because of the replacement of the monitoring device in 1960s (Liu et al. 2004). For the sake of avoiding this problem, this study select the period from January 1st, 1969 to December 31st, 2008 to study base on the selection of Xu et al. (2006) about the study period of the wind speed change research in China. We gathered all ground observation data in the administrative range of five provinces in Southwestern China. There 27 stations are eliminated due to some reasons, such as, new stations, a longer break during observation, the problem in data records and quality and so on. The rest of the meteorological stations space distribute unevenly, especially there are few stations in the west of the Xizangan Plateau. We wipe one more off (Shiquan river station) in order to reduce the impact of sparse stations to climate change in the whole area. Finally, 110 meteorological stations are remained, which have the data of good quality, relatively even distribution and relatively continuous records and which are built earlier than 1961 (Fig. 1.1). The world meteorological organization (WMO) number, the name, longitude, latitude, altitude, etc. of stations selected in this



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chapter can be seem in Table 2.1. The elevation range of this 110 stations is between 285.7 and 4,700 m. Among them, there are 9 stations are above 4,000 m; the elevation range of 17 stations is between 3,000 and 4,000 m; the elevation range of 16 stations is between 2,000 and 3,000 m; there are 32 stations located in 1,000–2,000 m and there are 36 stations located in 1,000 m below. The related data of the East Asian monsoon index and South Asia monsoon index in 1961–2001 uses the research achievements of Guo et al. (2004) for references, and the data of plateau monsoon index is provided by China Meteorological Administration National Climate Center (http://ncc.cma.gov.cn/cn/). In addition, the population and energy consumption data in China are from the provincial statistical yearbook.

#### 2.1.1.2 The Data Quality Control of Stations

Most stations in China was established in the 1950s, and the station observation data is more steady after 1960s. However, stations' move, environment change around stations, the types of observation instrument and the change of observation time all will directly affect the comparativeness and continuity of the observation records, and have the different degrees of influence on the uniformity of annual climate data sequence (Wu 2005). In addition, there about 70 % of China's 731 standard ground observation stations have experienced relocation, of which about 31 % move once and about 41 % move more than two times, especially the stations located in the city, for example, the stations in Beijing, Shanghai and other major cities have moved to the district between suburbs and cities (Li et al. 2004a, b). So it is necessary to select qualified observation data by the data quality control before analysis in order to ensure the accuracy of the results of the study. The quality control of meteorological observation data in this study is to examine the date of the daily mean temperature, daily minimum temperature, daily maximum temperature and daily precipitation by using the international test method and software non-uniformity: RclimDex and RHtest, and to find out the station having data quality problems, then to delete them from the original data, finally to select the qualified observation stations and to make a statistics and analysis on the basis of this data. The control and inspection of data quality mainly includes three aspects: whether the recording date of data is consistent with reality; whether the daily precipitation is less than zero and whether the daily minimum temperature is greater than the maximum temperature; whether the relocation and the local environment changes caused the of the observation data records.

Data quality control mainly use RClimDex software and the text of data non-uniformity use RHtest software. The softwares above and their documentation can be downloaded in this website (http://cccma.seos.uvic.ca/ETCCDI/software.shtml) the reading file and writing file of softwares above have their specific formats. It is the first step of texting the quality control to prepare the data format as required. There are five requirements in the input of softwares above. Firstly, the data files should be ASCII text files. Secondly, the data sequence may be the annual, monthly and daily precipitation, the minimum temperature, the maximum temperature (the

**Table 2.1** The selected weather stations in Southwestern China

| WMO number | Name | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|
| 55279 | Bangor | 31°23′ | 90°01′ | 4,700 |
| 55299 | Naqu | 31°29′ | 92°04′ | 4,507 |
| 55472 | Xainza | 30°57′ | 88°38′ | 4,672 |
| 55578 | Shigatse | 29°15′ | 88°53′ | 3,836 |
| 55591 | Lhasa | 29°40′ | 91°08′ | 3,648.9 |
| 55598 | Tsetang | 29°15′ | 91°46′ | 3,551.7 |
| 55664 | Dingri | 28°38′ | 87°05′ | 4,300 |
| 55680 | Jiangzi | 28°55′ | 89°36′ | 4,040 |
| 55696 | Longzi | 28°25′ | 92°28′ | 3,860 |
| 55773 | Parry | 27°44′ | 89°05′ | 4,300 |
| 56312 | Nyingchi | 29°40′ | 94°20′ 2 | 991.8 |
| 56106 | Suoxian | 31°53′ | 93°47′ | 4,022.8 |
| 56116 | Dingqing | 31°25′ | 95°36′ | 3,873.1 |
| 56137 | Chamdo | 31°09′ | 97°10′ | 3,306 |
| 56227 | Bowo | 29°52′ | 95°46′ | 2,736 |
| 56038 | Shiqu | 32°59′ | 98°06′ | 4,200 |
| 56079 | Ruoergai | 33°35′ | 102°58′ | 3,439.6 |
| 56144 | Derge | 31°48′ | 98°35′ | 3,184 |
| 56146 | Ganzi | 31°37′ | 100°00′ | 3,393.5 |
| 56152 | Sertar | 32°17′ | 100°20′ | 3,893.9 |
| 56167 | Daohu | 30°59′ | 101°07′ | 2,957.2 |
| 56172 | Barkam | 31°54′ | 102°14′ | 2,664.4 |
| 56173 | Hongyuan | 32°48′ | 102°33′ | 3,491.6 |
| 56178 | Xiaojin | 31°00′ | 102°21′ | 2,369.2 |
| 56182 | Songpan | 32°39′ | 103°34′ | 2,850.7 |
| 56187 | Gaoping | 30°49′ | 106°15′ | 300 |
| 56188 | Dujiangyan | 31°00′ | 103°40′ | 698.5 |
| 56193 | Pingwu | 32°25′ | 104°31′ | 893.2 |
| 56196 | Mianyang | 31°27′ | 104°44′ | 522.7 |
| 56247 | Batang | 30°00′ | 99°06′ | 2,589.2 |
| 56251 | Xinlong | 30°56′ | 100°19′ | 3,000 |
| 56257 | Litang | 30°00′ | 100°16′ | 3,948.9 |
| 56287 | Ya'an | 29°59′ | 103°00′ | 627.6 |
| 56357 | Daocheng | 29°03′ | 100°18′ | 3,727.7 |
| 56374 | Kangting | 30°03′ | 101°58′ | 2,615.7 |
| 56385 | Emeishan | 29°31′ | 103°20′ | 3,047.4 |
| 56386 | Leshan | 29°34′ | 103°45′ | 424.2 |
| 56441 | Derong | 28°43′ | 99°17′ | 2,422.9 |
| 56459 | Muli | 27°56′ | 101°16′ | 2,426.5 |
| 56462 | Jiulong | 29°00′ | 101°30′ | 2,987.3 |

(continued)

**Table 2.1** (continued)

| WMO number | Name | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|
| 56475 | Yuexi | 28°39′ | 102°31′ | 1,659.5 |
| 56479 | Zhaojue | 28°00′ | 102°51′ | 2,132.4 |
| 56485 | Leibo | 28°16′ | 103°35′ | 1,255.8 |
| 56492 | Yibin | 28°48′ | 104°36′ | 340.8 |
| 56671 | Huili | 26°39′ | 102°15′ | 1,787.3 |
| 57206 | Guangyuan | 32°26′ | 105°51′ | 513.8 |
| 57237 | Wanyuan | 32°04′ | 108°02′ | 674 |
| 57306 | LangZhong | 31°35′ | 105°58′ | 382.6 |
| 57313 | Bazhong | 31°52′ | 106°46′ | 417.7 |
| 57328 | Daxian | 31°12′ | 107°30′ | 344.9 |
| 56565 | YanYuan | 27°26′ | 101°31′ | 2,545 |
| 57405 | Suining | 30°30′ | 105°33′ | 355 |
| 57608 | XuYong | 28°10′ | 105°26′ | 377.5 |
| 56571 | Xichang | 27°54′ | 102°16′ | 1,590.9 |
| 56586 | Zhaotong | 27°21′ | 103°43′ | 1,949.5 |
| 56651 | Lijing | 26°52′ | 100°13′ | 2,392.4 |
| 56664 | Huaping | 26°38′ | 101°16′ | 1,244.8 |
| 56444 | Deqin | 28°29′ | 98°55′ | 3,319 |
| 56684 | Huize | 26°25′ | 103°17′ | 2,110.5 |
| 56739 | Tengchong | 25°01′ | 98°30′ | 1,654.6 |
| 56748 | Baoshan | 25°07′ | 99°11′ | 1,652.2 |
| 56751 | Dali | 25°42′ | 100°11′ | 1,990.5 |
| 56763 | Yuanmou | 25°44′ | 101°52′ | 1,120.6 |
| 56533 | Gongshan | 27°45′ | 98°40′ | 1,583.3 |
| 56543 | Zhongdian | 27°50′ | 99°42′ | 3,276.7 |
| 56548 | Weixi | 27°10′ | 99°17′ | 2,326.1 |
| 56768 | Chuxiong | 25°02′ | 101°33′ | 1,824.1 |
| 56778 | Kunming | 25°00′ | 102°39′ | 1,886.5 |
| 56786 | Zhanyi | 25°35′ | 103°50′ | 1,898.7 |
| 56838 | Ruili | 24°01′ | 97°51′ | 776.6 |
| 56856 | Jingdong | 24°28′ | 100°52′ | 1,162.3 |
| 56875 | Yuxi | 24°20′ | 102°33′ | 1,716.9 |
| 56880 | Yiliang | 24°55′ | 103°10′ | 1,532.1 |
| 56886 | Luxi | 24°32′ | 103°46′ | 1,704.3 |
| 56951 | Lincang | 23°53′ | 100°05′ | 1,502.4 |
| 56954 | Lancang | 2°34′ | 99°56′ | 1,054.8 |
| 56959 | Jinghong | 22°00′ | 100°47′ | 582 |
| 56964 | Simao | 22°47′ | 100°58′ | 1,302.1 |
| 56966 | Yuanjiang | 23°36′ | 101°59′ | 400.9 |
| 56969 | Mengla | 21°29′ | 101°34′ | 631.9 |

(continued)

**Table 2.1** (continued)

| WMO number | Name | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|
| 56977 | Jiangcheng | 22°35′ | 101°51′ | 1,120.5 |
| 56985 | Mengzi | 23°23′ | 103°23′ | 1,300.7 |
| 56986 | Pingbian | 22°59′ | 103°41′ | 1,414.1 |
| 56994 | Wenshan | 23°23′ | 104°15′ | 1,271.6 |
| 59007 | Guangnan | 23°29′ | 104°31′ | 1,227.5 |
| 57348 | Fengjie | 31°01′ | 109°32′ | 299.8 |
| 57633 | Qiuyang | 28°50′ | 108°46′ | 664.1 |
| 57426 | Liangping | 30°41′ | 107°48′ | 454.5 |
| 57432 | Wanxian | 30°46′ | 108°24′ | 186.7 |
| 57516 | Shapingba | 29°35′ | 106°28′ | 259.1 |
| 57522 | Fuling | 29°45′ | 107°25′ | 273.5 |
| 57606 | Tongzi | 28°08′ | 106°50′ | 972 |
| 56691 | Xianning | 26°52′ | 104°17′ | 2,237.5 |
| 56793 | Panxian | 25°43′ | 104°28′ | 1,800 |
| 57614 | Xishui | 28°20′ | 106°13′ | 1,180.2 |
| 57707 | Bijie | 27°18′ | 105°17′ | 1,510.6 |
| 57713 | Zunyi | 27°42′ | 106°53′ | 843.9 |
| 57722 | Meitan | 27°46′ | 107°28′ | 792.2 |
| 57731 | Sinan | 27°57′ | 108°15′ | 416.3 |
| 57741 | Tongren | 27°43′ | 109°11′ | 279.7 |
| 57803 | Qianxi | 27°02′ | 106°01′ | 1,231.4 |
| 57806 | Anshun | 26°15′ | 105°54′ | 1,431.1 |
| 57816 | Guiyang | 26°35′ | 106°44′ | 1,223.8 |
| 57825 | Kaili | 26°36′ | 107°59′ | 720.3 |
| 57832 | Sanhui | 26°58′ | 108°40′ | 626.9 |
| 57902 | Xingren | 25°26′ | 105°11′ | 1,378.5 |
| 57906 | Wangmo | 25°11′ | 106°05′ | 566.8 |
| 57916 | Luodian | 25°26′ | 106°46′ | 440.3 |
| 57922 | Dushan | 25°50′ | 107°33′ | 1,013.3 |
| 57932 | Rongjiang | 25°58′ | 108°32′ | 285.7 |

unit of precipitation is mm, and the unit of temperature is °C). Thirdly, there should have spaces between the data columns. For example, each element is separated by one or more space. Fourthly, the lost or missing data in the records must be taken place by −99.9 coding. Fifthly, the data records must be ordered as the calendar date.

RClimDex software mainly includes three steps to do the quality control: (1) to modify all the missing values to the format which can be identified by software, for example, −99.9, after automatically identifying the error of the raw data and to replace all unreasonable value to NA (not available), for example, negative rainfall or less daily maximum temperature value than the daily minimum temperature. (2) To examine the potential outliers in the data sequence so that the researchers make a test, calibration and delete according to the actual data. The outliers refers to the values that the daily data records are more than user custom range. Meanwhile, the researchers themselves can set the threshold of outliers according to the actual situation of the selected data. Generally, the record range of the data is defined as a daily mean value pluses or minuses the n times standard deviation, that is (mean − n * std, mean + n * std). Among them, std presents the intraday standard deviation; n is the threshold of outliers inputted by users, for example, the daily maximum temperature is 30 °C. In this study, the threshold of outliers is set as the daily highest temperature is not more than 45 °C, the daily minimum temperature is no less than −35 °C, and the daily rainfall is not more than 180 mm. In this case of this, the study set three standard deviation to test the threshold of abnormal data so as to better determine the quality of the raw data. (3) The software will automatically generate time series diagrams rainfall and temperature in order to check whether there is any quality problem in the interannual and in-year change of data (Aguilar et al. 2005; New et al. 2006). For example, Fig. 2.1 is an example of quality control of precipitation data. Whether there is any quality problem in the precipitation data by the generating histogram and the Kernel filtering isodense, which is a kind of nonparametric test method (Aguilar et al. 2005). The precipitation data quality showed by this figure is good. Figure 2.2 is the trend diagram of in-year change of precipitation and temperature automatically generated by RClimDex. Through this figure the outliers of temperature or precipitation from a certain station can be monitored. Figure 2.3 is the inter-annual variation of DTR recorded by RClimDex, which is used to test the abnormal situation in its changing trend.

The uniformity test of data is relatively complicated and usually need to do with the aid of the detailed records of inspected stations and the records of the nearby

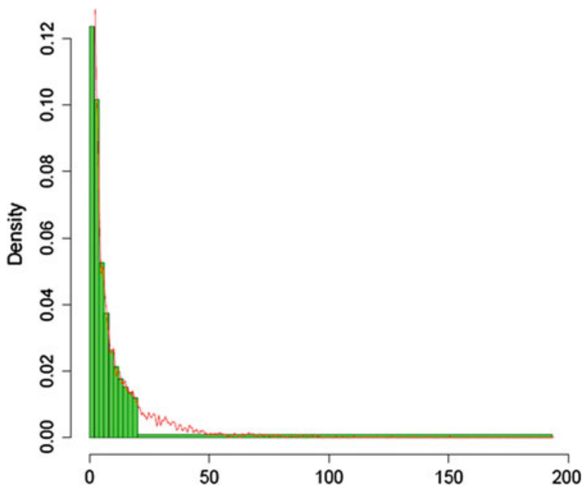


**Fig. 2.1** Example of daily precipitation successful quality control procedures using. RClimDex (Histogram (*vertical bars*) and Kernel-filtered density (*line*) showing the high density)

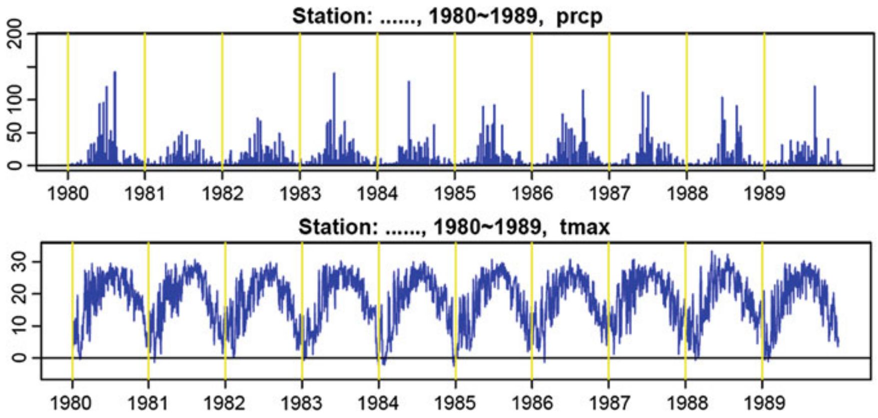


**Fig. 2.2** Annual variation of daily precipitation and the maximum temperature recorded by RclimDex during 1980–1989

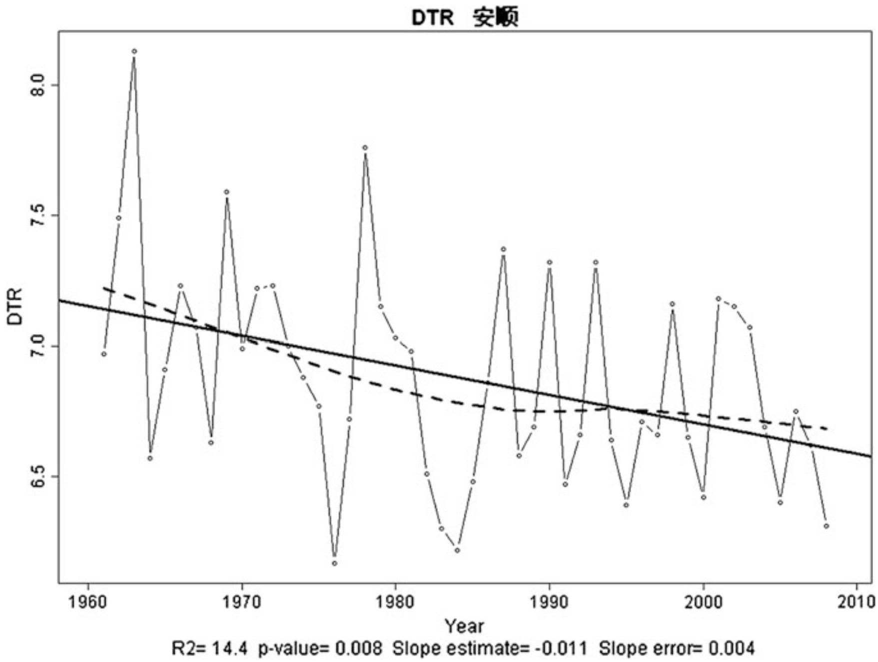


**Fig. 2.3** Inter-annual variation of DTRin Anshun station recorded by RClimDex

stations (Dyurgerov 2003). At present in China, there are non uniformity in the climate data sequence due to the historical evolution of the meteorological stations, especially relocation of the site. And the inspection work of non uniformity is still not enough. Many researchers lack enough awareness to the importance and application value of the information about historical evolution, and most of the research work by using the data of stations all lake the analysis and test of the annual data sequence (Wu 2005). In this study, we choose RHtest to evaluate the uniformity of observation data from meteorological stations, which estimate the multiple step change existing in the time series of data based on the two phase regression model (Wang 2001; Wang and Zhou 2005).

For the first time, Easterling and Peterson (1995) used RHtest to examine the non uniformity of the time series of data in the study of Canadian climate extreme. Lund and Reeves (2002), Wang (2003) made the further revision through their own researches. Zhang et al. (2004) examined the daily maximum temperature, daily minimum temperature and annual change trend of daily range by using the revised two phase regression model, identified the potential non uniformity of data and obtained good study effect. Thereafter, this method gets a great academic recognition as one of the important methods of testing non uniformity of data sequence, has eventually become a visualization software available for users and has brought great convenience for scientific research workers. The first step of this method is to test the annual sequence changes of the data by the analysis of regression model. The second step is to use regression model to find out the discontinuity in annual sequence changes. The third step is to apply F test to determine the statistical meaning of the regression model. Only when test results of the regression model in the first step would have reached the confidence level of 95 %, the results of the regression model in the second step was believed to be reliable. The fourth step is to identify whether the discontinuous points have statistical meaning and to finalize the uniformity of the data sequence. The data set selected in this study have eight stations existing potential discontinuity in the sequence of daily maximum temperature and four stations in a sequence of daily minimum temperature (Fig. 2.4).

Through seeking the original records of data and the historical documents of stations, we found that only one appears discontinuity of data because of site relocation among the 12 stations, the discontinuous data of the rest is caused by outliers. Hereby, we eliminate these outliers and remove a station with data non uniformity, in which the daily mean temperature, daily maximum temperature and daily minimum temperatures has the discontinuity around 1983 and the temperature variation characteristics is significantly consistent with that around the stations. We found the station site relocated in 1983 after checking the data records. Through a series of procedures, we finally select 110 eligible stations to be used in this study (Table 2.1).

### 2.1.2 The Data on Glacier Change

The data about the terminus fluctuation of glaciers, the change in areas and ice lake, material balance and so forth are mainly from previous works, the details of which can be shown in Chap. 7. Here we will focus on the source of data on the terminus fluctuation of eight glaciers, such as Hailuogou Glacier, Hailuogou No. 2 Glacier, Big

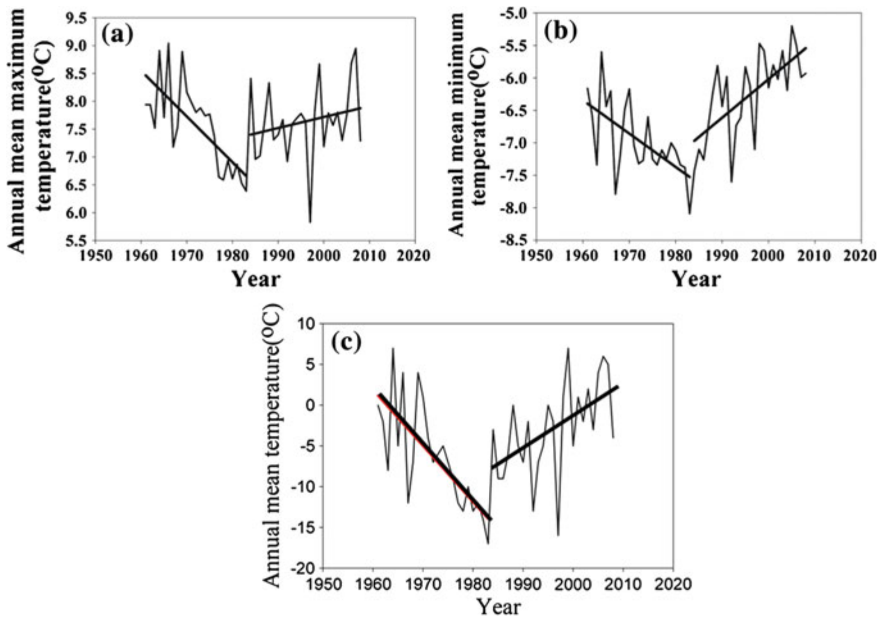


**Fig. 2.4** Homogeneity test of annual mean daily maximum temperature (**a**), minimum temperature (**b**), and mean temperature (**c**) for station Jiali (30°40′N, 93°17′E, 4,488.8 m a.s.l.). (The largest, statistically significant discontinuity around 1983 is verified by the original station data, which indicate that the station relocated in 1983)

Gongba Glacier, Small Gongba Glacier, Mingyong Glacier, Aza Glacier, Yanzigou Glacier and Baishui No. 1 Glacier. Before 1997, the data about the terminus fluctuation of these glaciers were from previous studies (Heim 1936; Su et al. 2002; Zhang et al. 2001; Pu 1994; Liu 2005; Li et al. 2008, 2009a, b, 2010a, b). The data of Hailuogou Glacier in 2006 and the data of Big Gongba Glacier and Small Gongba Glacier in 2007 are from author's on-the-spot investigation in 2006 and 2007; and since 1997, the data of Baishui No. 1 Glacier are from the field observations of Mount Yulong glacier and the environmental research station. The melting data of Hailuogou Glacier, Big Gongba Glacier and Baishui No. 1 Glacier in 1982 and 1983 come from a book named by "Glacier in Hengduan Mountains", while in 1990–1998 the melting data of Hailuogou Glacier is provided by Zhang wenjing in the Chengdu Mountain Office of Chinese Academy of Sciences. The meteorological and hydrological data of Hailuogou Glacier are offered by the observation station focusing on the alpine ecosystem of Mount Gongga. This station was built in 1988 and affiliated with the Chengdu Mountain Office of Chinese Academy of Sciences. The data on temperature variation in China and in Northern Hemisphere use the study of Wang et al. (1998) for reference. The data on material balance of Hailuogou Glacier from 1959/1960 to 1992/1993 are from the research result of water-material balance in the book named by "Chinese glacier and environment", and the data on material balance during 1993/1994–2003/2004 is calculated by author with water balance method based on the climate data and hydrological data in 1994–2004 from the observation station focusing on the alpine ecosystem of Mount Gongga. The hydrological data in 1979–2003 of Mujiaqiao hydrological station in Yanggongjiang valley are taken from Lijiang's hydrological bureau, and the climate data of Lijiang Basin are provided by Lijiang's Bureau of Meteorology.

### 2.1.3 The Reanalyzed Data

The atmospheric reanalysis data of National Center of Aatmospheric Research (NCAR) or National Centers for Environmental Prediction (NCEP) has two versions: the NCEP/NCAR global reanalysis products (NCEP-R1) and NCEP/DOE second set of reanalysis products (NCEP-R2). NCEP-R1 product has two main characteristics. One is the cover period of data is longer, from 1948 to now. The other is it integrate in a wide range of the observed data. NCEP-R2 is an upgrade or update version of NCEP-R1. It changes the known system error of NCEP-R1, and introduces the latest physical process. That is to say, it is the recalculation in the context of improving the system of NCEP-R1, therefore, they have the same input field, vertical and horizontal resolution. The improved reanalysis system correct the problems in using remote sensing technology to get snow parameters, for example, the area and the thickness of snow, and improve the forecast of winter precipitation, ground surface temperature and surface flux in high latitudes region (Kistler et al. 2001; Ma et al. 2008).

The reanalysis data sets of NCEP/NCAR-R1 contains the data from January 1948 to now, and its spatial resolution is 2.5° × 2.5° (Kalnay et al. 1996). It cover the whole earth (0–360°E; 90°S–90°N); the 17 isobaric surfaces in vertical direction from the ground are respectively 1,000, 925, 850, 700, 600, 500, 600, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa. In addition, there also is the surface mean sequence values. This study determines the impact of changes in atmospheric circulation system to climate change of Southwestern China by using the reanalysis data of NCEP/NCAR-R1 on monthly mean geopotential height, meridional and zonal wind, and relative humidity. Moreover, this study also make use of the reanalysis data on the net surface long-wave radiation, the net surface shortwave radiation, sea surface temperature, sea level pressure and others. The reanalysis data of the NCEP/NCAR on monthly mean temperature and air pressure also be used in this study to understand the change of the surface pressure gradient force and the change of wind speed (Kalnay et al. 1996). And in order to analyze the cause of sunshine time changes, the reanalysis data of the NCEP/NCAR on mean downward solar radiation flux, total area of cloud cover and water content of the cloud and so forth has been used.

## 2.2 Methods

### *2.2.1 The Linear Trend*

A reasonable linear denotes the relations between climate variables and time; $x_i$ denotes a contain climate variables; $t_i$ denotes corresponding time of $x_i$. Then unary linear regression equation is developed between $x_i$ and $t_i$.

$$\hat{x}_i = a + bt_i \tag{2.1}$$

In this formula, $a$ is the regression constant; $b$ is the regression coefficient. $a$ and $b$ can be estimated by the least squares.

The symbol of the regression coefficient $b$ refers to the inclination of climate variables $x$. When $b > 0$, it indicates that $x$ is on the rise with the increase of time $t$; when $b < 0$, it indicates that $x$ is on the decline with the increase of time $t$. The numerical size of $b$ reflects the rate of rise or fall, that is, the tendency of rising or falling. Generally, $b$ is called the tendency rate of climate (that is the change range).

$$\begin{cases} a = \bar{x} - b\bar{t} \\ b = \frac{\sum_{i=1}^{n} x_i t_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} t_i\right)}{\sum_{i=1}^{n} t_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2} \end{cases} \tag{2.2}$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i; \ \bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i \tag{2.3}$$

It is necessary to calculate the correlation coefficient $r$ in order to reflect the close degree of the linear relationship between the climate variables $x$ and time $t$. Generally, $r$ is called the climate trend coefficient.

$$r_{xt} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(t - \bar{t})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (t - \bar{t})^2}} \tag{2.4}$$

When the absolute value $r$ is the greater, it indicates the relation between climate variables $x$ and time $t$ is closer. If we want to judge whether the climate change trend is significant or not, significance text of the correlation coefficient $r$ is still necessary. $\alpha$ can be determined as the level of significance, if the absolute value $r > r_\alpha$, it indicates that climate variables $x$ change significantly with the change of time $t$, or it was not significant. The paper use $\rho$ to text. when $\alpha = 0.05$, if $r > 0.2818$, it suggests that the change trend is obvious; when $\alpha = 0.01$, if $r > 0.3649$, it means that the change trend is significant; When $\alpha = 0.001$, if $r > 0.4562$, it says that the trend is very significant. In this study, the linear correlation is 0.05 degree of confidence, and the straight line presents the linear trend.

### 2.2.2 Moving Mean

Moving mean is a basic method of trend fitting, which is equivalent to a low-pass filter used to determine the change trend of mean of the time sequence. For climate change sequence $x$ of the sample size $n$, the moving mean sequence is:

$$\hat{x}_i = \frac{1}{k}\sum_{i=1}^{k} x_{i+j-1} \tag{2.5}$$

In this formula, $k$ is for the sliding length, which is determined according to the specific matters and the size of the sample. Generally, $k$ take an odd number so that the mean can be added to each time coordinates in the time sequence; $j = 1, 2, \ldots, n - k + 1$.

The observed value is calculated with moving mean, and $n$ data can get $(n - k + 1)$ smoothed values. After smoothing, the great weakening of cycle which is shorter than the sliding length shows the change trend. Based on previous researches, the climate change sequence in study areas has the short cycle of 2, 2.5, 4, 7, 9, 11, 28 years. After considering again, the length of time sequence is 48 years. The sliding length take a value as 9, that means that the change of climate sequence is a sliding trend of 9 years, which has been marked with thicker curve in this paper.

### 2.2.3 The Calculation of Regional Trend

In order to avoid the effect of abnormally high or low values from individual stations or in individual years to emperature and precipitation sequence of the entire area, first of all, we make the mean value of climate data of stations, then calculate the change sequence of climate elements in the study area. Next the sequence of climate elements of stations in different periods, such as the monsoon and non-monsoon, are made as the period from December to following February is winter; the period from March to May is spring; the period from Jull to August is summer; the period from September to November is autumn; the period from May to October is monsoon and the period from November to following April is non-monsoon. Then we will calculate the annual, seasonal, monsoon and non-monsoon sequence of climate elements in different regions. The division between monsoon and non-monsoon use the conclusion of “Hengduan Mountain Glacier” written by Li and Su (1996). The calculation results of data in this study take the significance level of 0.05, if the statistical value is less than the significance level, the trend is thought significant. Finally, the spatial distribution diagram of tendency rate change of climate elements is drawn under the situation of ArcGIS to analyze the spatial variation.

The climate sequence in study area and the sub regional areas are calculated as the following formula:

$$x_{r,t} = \sum_{i=1}^{n_t} (x_{i,t} - \bar{x}_i)/n_t \tag{2.6}$$

In this formula, $x_{r,t}$ is the annual or seasonal means of the climate parameters of a region (e.g., temperature) in t years; $x_{i,t}$ is the value of a certain climate parameter of $i$ staion in $t$ year; $x_i$ is the mean value of a certain climate parameter of $i$ station in 1961–2008; $n_t$ is the number of eligible station of a certain climate parameter. $x_{i,t}$ and $x$ are standardized before calculation to avoid the influence of the abnormally high value.

### 2.2.4 The Definition of Urban Station and Rural Station and the Basis of Classification

Generally, the method to study the urban heat island effect is to compare the observations of meteorological stations in large cities with that in surrounding areas (the rural), and the difference between them will be defined as the contribution of city heat island (Jones et al. 2008; Ren et al. 2008). Due to the limitation of data, this study mainly analyzes the difference of change magnitude of each climate element between the rural station and the city station. A large number of climate researches defined population as an important basis of classifying urban stations and rural stations. This study use the research result of Easterling et al. (1997) as reference to define the meteorological station, of which administrative area has a population of more than 50,000 as urban station, otherwise, it is rural station. Based on this method, 110 stations in Southernwestern China are divided into 58 rural stations and 52 urban stations.

In order to determine whether the regional terrain where observation stations are located is influential to the observations, we set a specific distance as the radius to calculate the altitude difference between the observation stations (the center of a circle) and the surrounding eight directions with the use of GTOPO30 digital elevation model (http://eros.usgs.gov). Among at least five of eight directions, the elevation difference between them less than 100 m is defined as the plain station; less than 0 m is defined as peak stations; that in 100–300 m is defined as inter-mountain basin station; more than 300 m station is defined as the valley station. Then the geographic coordinates of meteorological stations are input in the digital terrain map to check the above calculation results and ultimately to determine terrain types of stations.

### 2.2.5 The Division of Sub-regions

In order to more systematically know the differences of regional climate change, this study make a factor analysis to the change trend of the annual mean temperature (standard value) of 110 stations and separate the areas with the same temperature trends. Factor analysis is a statistical method which can sort out several variables of which the correlation is quite close, and look each kind as a factor so as to distinguish factors with different changing trend, finally reach the purpose of classification. Southwestern China can be divides into three sub-regions by using the analysis results of changes factor of the annual mean temperature, that is to determine stations with the consistent temperature variation trends, and combining the latitude location and altitude. The first factor accounts for 42 % of the total variance and is Xizang Phateau and Hengduan Mountains. It includes: Shiquan River, Bangor, Naqu, Xainza, Shigatse, Lhasa, Zetang, Dingri, Jiangzi, Linzhi, Parry, Suoxian, Bowo, Longzi, Changdu, Dingqing, Shiqu, Ruoergai, sertar, Hongyuan, Dege, Ganzi, Barkam, Daofu, Xiaojin, Batang, Xinlong, Litang, Daocheng, Kangding, Muli, Jiulong, Yuexi, Songpan, Yanyuan, Xichang, Deqin, Gongshan, Shangri-la, Weixi, Lijiang, Huaping and Dali. The second factor accounts for the 33 % of the total variance and is Yunnan-Guizhou Plateau. It contains: Huize, Tengchong, Zhaotong, Baoshan, Yuanmou, Chuxiong, Kunming, Zhanyi, Ruili, Jingdong, Yuxi, Luxi, Wenshan, Yiliang, Lincang, Jinghong, Simao, Yuanjiang, Mongla, Jiangcheng, Mengzi, Pingbian, Guangnan, Xianning, Xishui, Panxian, Tongzi, Bijie, Zunyi,Meitan, Sinan, Tongren, Qianxi, Anshun, Guiyang, Kaili, Sanhui, Xingren, Wangmo, Luodian, Dushan, and Rongjiang. The third factor accounts for 9 % and is Sichuan Basin. It includes: Dujiangyan, Pingwu, Mianyang, Ya-an, Emeishan, Leshan, Zhaojue, Leibo, Yibin, Huili, Guangyuan, Wanyuan, Yanzhong, Bazhong, Daxian, Suining, Gaopingqu, Luzhou, Xuyong, Liangping, Wanxian, Peiling, Shapingba, Qiuyang and Fengjie.

### 2.2.6 The Changes of Atmospheric Circulation System in a Large Scale

On the basis of the reanalysis data on monthly mean meridional wind field, monthly zonal wind field, relative humidity, and geopotential height of 300 and 500 hPa in 1961–2008, this study analyzes the correlation between annual mean temperature and sea level pressure (SLP) of the studies areas in 1961–2008 by using the software of Grads. Based on this point, this study synthesizes the composite graph of atmospheric circulation of isobaric surface of 300 and 500 hPa in four seasons between 1961–1985 and 1986–2008. The variation can be got through former period minus latter one. Moreover, the study also analyzes the relationship between variation and temperature variations at the same period. In the same way, the composite graph of atmospheric circulation of extreme minimum and maximum temperatures in the isobaric surface of 300 and 500 hPa in summer (June–August) and winter (December–February) of 1961–2008 is synthesized, and the circulation of two periods is presented by that former minus the latter. The extreme high temperature in summer in Southwestern China occurred in 1961 and 2006, whereas, the extreme low temperature in summer happened in 1965, 1968,1974 and 1976; the extreme high temperature in winter occurred in 1987, 1999, 1987, 2003 and 2007, while the extreme low temperature in winter happened in 1968, 1976 and 1983.

Water vapor transport is the main factor of the atmospheric water cycle, and has an important influence on the regional climate change. In order to understand the change of water vapor transport in the study areas and its impact on regional precipitation variation under the background of climate change, this study makes use of the NCEP/NCAR reanalysis data on monthly mean meridional wind field, zonal wind field and relative humidity and the geopotential height to calculate the integral layer of atmospheric vapor transport flux, and analyzes the vapor flux change and its impact on regional precipitation variation under the background of climate warming in Southwestern China. The specific calculation formula is as follows:

$$Q = \frac{1}{g}\int_{p_t}^{p_0} (u, v) q dp \tag{2.7}$$

In this formula, $u$ and $v$ respectively is the east-west winds and south-north wind of air column per unit area in each layer of the atmosphere; $q$ is the specific humidity of air column per unit area in each layer of the atmosphere; $P_0$ is the sea level pressure; $P_t$ is pressure when it is assumed that there is no water vapour in the atmosphere. For simplicity sake, the study will take $P_0$ = 1,000 hPa and $P_t$ = 300 and 500 hPa. According to the principle proposed above, we calculate the mean water vapor flux of 500 and 300 hPa isobaric surface in summer and winter of 1961–2008 and the annual mean water vapor flux of 1986–2008 and 1961–1985 in study areas. The variation is presented through former minuses the latter. In addition, we also calculate the difference of water vapor flux of between more precipitation and less precipitation, and the former minuses the latter to present variation. In summer, the years with more precipitation are 1980, 1998 and 1999; the years with less precipitation are 1972, 1975, 1992 and 2006. In winter, the years with more precipitation are 1967, 1983, 1992, 1983 and 2004; the years with less precipitation are 1963, 1970 and 1974. In addition, in order to further verify the influence of the circulation system change on the climate parameters change in the study area, this study analyzes the annual and seasonal changes of meridional and zonal wind in the two periods of 1986–2008 and 1961–2008, and calculate the change of solar radiation flux, water content in cloud, relative humidity and so on in the different periods.

### 2.2.7 The Definition and Calculation of Extreme Event Index

The standard method to define and calculate the climate extreme index in this study is "the detection and index of climate change" of World Meteorological Organization (http://cccma.seos.uvic.ca/ETCCDI). This method has been widely used to research extreme weather events by scholars both at home and abroad. The research team of "the detection and index of climate change" finally identified 27 indexes of the climate events which consist of 16 temperature indexes and 11 precipitation indexes. These indexes are calculated with daily maximum temperature, daily minimum temperature and daily precipitation. The meaning of index and the basis of calculation will be shown in following parts. The above index can be classified into five types: (1) relative index based on percentage threshold; (2) absolute indicator presenting maximum or minimum in a season or a year; (3) threshold indicator; (4) continuous indicator; (5) other indicators, such as the annual total rainfall of rainy season, the temperature daily range (maximum minuses minimum), mean precipitation intensity in rainy days (precipitation divides rainfall days) etc. (Alexander et al. 2006).

Now the most common in the climate extreme change research on the international is using a percentile value as the threshold of extremum. The value more than the threshold value is considered as extreme value, which is considered to be the extreme events. The climate extreme threshold is determined by Bonsal non parametric solutions and the calculation steps are as follows:

It is assumed that a meteorological element has $N$ values which are arranged as the ascending order $x_1, x_2, \ldots, x_m, \ldots, x_n$. The probability of that a value is less than or equal to $x_m$:

$$\mathrm{P} = (\mathrm{m}\,0.31)/(\mathrm{n} + 0.38) \tag{2.8}$$

In this formula, m is serial number of $x_m$.

The statistics of extreme temperatures is to arrange the temperature data of a day in 1961–2008 as the ascending order and take the 10th and the 90th percentile value as the threshold of extreme temperature. When the temperature in a day is greater than the 90th percentile value, it is thought that the extreme high temperature event occurs in that day; when the lowest temperature is less than 10th percentile values, it is thought that the extreme low temperature event happens in that day. The statistics of the extreme precipitation events is to arrange the daily precipitation year by year from 1961 to 2008 as the ascending order and take the mean of 48 years of 99th percentile value as the threshold of extreme rainfall events. When rainfall in a day exceeds the threshold, it is thought that the extreme precipitation events occurs in that day. When the RClimDex software is calculating the index, not all index calculation base on the month due to the practical application. if the time of missing data is not more than three days of a month and not more than 15 days of a year, the monthly and annual extreme index will be calculated; if the data in a month is missing, extreme index of this years will calculate incorrectly. According to research needs, total 23 climate extreme indexes are chosen, of which calculation is completed with RclimDex. The calculation principle of the selected indexes is as follows:

1. The days of extreme low temperature during the day (TX10)
   $Tx_{ij}$ is the daily maximum temperature on the $i$th day during $j$; $Tx^{in}10$ is the 10th percentile threshold. The relative proportion of the index is expressed in the following formula: $Tx_{ij} < Tx_{in}10$, the unit is $d$.
2. The days of extreme low temperature at night (TN10)
   $Tn_{ij}$ is the daily minimum temperature on the $i$th day during $j$; $Tn_{in}10$ is the 10th percentile threshold. The relative proportion of the index is expressed in the following formula: $Tn_{ij} < Tn_{in}10$, the unit is $d$.
3. The low value of the daily maximum temperature (TXn)
   $TX_{kj}$ is the daily maximum temperature on the $k$th month during $j$; the smallest value of daily maximum temperature is expressed in the following formula: $TXn_{kj} = \min(Tx_{kj})$, the unit is °C.
4. The low value of the daily minimum temperature (TNn)
   $Tn_{kj}$ is the daily minimum temperature on the $k$th month during $j$; the smallest value of daily minimum temperature is expressed in the following formula: $TNn_{kj} = \min(Tn_{kj})$, the unit is °C.
5. The freezing days (ID)
   $Tx_{ij}$ is the daily maximum temperature on the $k$th month during $j$; the number of days is counted with the following formula: $Tx_{ij} < 0$ °C, the unit is $d$.
6. The frost days (FD)
   $Tn_{ij}$ is the daily minimum temperature on the $i$th day during $j$; the number of days is counted with the following formula: $Tn_{ij} < 0$ °C, the unit is $d$.
7. The daily range of temperature (DTR)
   $Tx_{ij}$ and $Tn_{ij}$ are the daily maximum and minimum temperature on the $i$th day during $j$; $I$ is the total number of days during $j$, counted with the following formula:

$$DTR_j = \frac{\sum_{i=1}^{I}\left(Tx_{ij} - Tn_{ij}\right)}{I} \text{the unit is } ^\circ\text{C}.$$

8. The days of extreme high temperature at night (TN90)
   $Tn_{ij}$ is the daily minimum temperature on the $i$th day during $j$; $Tn_{in}90$ is the 90th percentile threshold. The relative proportion of the index is expressed in the following formula: $Tn_{ij} > Tn_{in}90$, the unit is $d$.
9. The days of extreme high temperature during the day (TX90)
   $Tx_{ij}$ is the daily maximum temperature on the $i$th day during $j$; $Tx_{in}90$ is the 90th percentile threshold. The relative proportion of the index is expressed in the following formula: $Tx_{ij} > Tx_{in}90$, the unit is $d$.

10. The high value of daily maximum temperature in a year (TXx)
$TX_{kj}$ is the daily maximum temperature on the $k$th month during $j$; the maximum value of daily maximum temperature each month is counted with the following formula: $\mathrm{T}X_{xkj}$ = max($Tx_{kj}$), the unit is °C.
11. The high value of daily minimum temperature in a year (TNx)
$TN_{kj}$ is the daily minimum temperature on the $k$th month during $j$; the maximum value of daily minimum temperature each month is counted with the following formula: $TN_{xkj}$ = max($Tn_{kj}$), the unit is °C.
12. The growth day length (GSL)
$T_{ij}$ is the daily mean temperature on the $i$th day during $j$; when the statistics firstly appear, there are at least six consecutive day meeting the following formula: $T_{ij} > 5$ °C; when the statistics firstly appear after July 1st (Northern Hemisphere), there are at least six consecutive days meeting the following formula $T_{ij} < 5$ °C, the unit is day.
13. The total precipitation in the rain day (PRCPTOT)
$RR_{ij}$ is the daily precipitation on the $i$th day during $j$; $I$ is the number of days during $j$, which is counted with the following formula:

$$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}, \text{the unit is mm.}$$

14. The annual mean precipitation intensity in rainy days (SDII)
$RR_{wj}$ is the daily precipitation in rainy day $w$(RR ≥ 1 mm) during $j$; $W$ is the number of rainy days during $j$, which is counted with the following formular:

$$SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}, \text{ the unit is mm/d.}$$

15. Extreme precipitation (R95)
$RR_{wj}$ is the daily precipitation in rainy day $w$(RR ≥ 1 mm) during $j$; $RR_{wn95}$ is the 95th percentile threshold of precipitation in rainy day during 1961–1990; $W$ is the number of rainy days during $j$, which is counted with the following formular:

$$R_{95pj} = \sum_{\mathrm{w}=1}^{\mathrm{W}} RR_{wj} \text{ where } RR_{wj} > RR_{wn95} \text{ the unit is mm/d.}$$

16. Very extreme precipitation (R99)
$RR_{wj}$ is the daily precipitation in rainy day $w$(RR ≥ 1 mm) during $j$; $RR_{wn99}$ is the 99th percentile threshold of precipitation in rainy day during 1961–1990; $W$ is the number of rainy days during $j$, which is counted with the following formular:

$$R_{99pj} = \sum_{w=1}^{W} RR_{wj} \text{ where } RR_{wj} > RR_{wn99} \text{ the unit is mm/d.}$$

17. The maximum precipitation in odd days (RX1 day)
    $RR_{ij}$ is the daily precipitation on the $i$th day during $j$; the maximum precipitation in one day during $j$ is counted with the following formula: $Rx1day_j = \max(RR_{ij})$, the unit is mm.
18. Total precipitation in five consecutive days (R×5 day)
    $RR_{kj}$ is the precipitation in five consecutive days and end in $k$ day during $j$; the maximum precipitation in five day during $j$ is counted with the following formula:

$$Rx5day_j = \max(RR_{kj}), \text{the unit is mm.}$$

19. The maximum consecutive drought days (CDD)
    $RR^{ij}$ is the daily precipitation on the $i$th day during $j$; the maximum consecutive drought days is counted with the following formula: $RR_{ij} < 1$ mm, the unit is $d$.
20. The maximum consecutive rainy days (CWD)
    $RR_{ij}$ is the daily precipitation on the $i$th day during $j$; the maximum consecutive rainy days is counted with the following formula: $RR_{ij} \geq 1$ mm, the unit is $d$.
21. The number of days when the daily precipitation is more than 10 mm (R10 mm)
    $RR_{ij}$ is the daily precipitation on the $i$th day during $j$; the number of days is counted with the following formula: $RR_{ij} \geq 10$ mm, the unit is $d$.
22. The number of days when the daily precipitation is more than 20 mm (R20 mm)
    $RR_{ij}$ is the daily precipitation on the $i$th day during $j$; the number of days is counted with the following formula: $RR_{ij} \geq 20$ mm, the unit is $d$.
23. The number of days when the daily precipitation is more than 25 mm (R25 mm)
    $RR_{ij}$ is the daily precipitation on the $i$th day during $j$; $nn$ take 25 in this study, the number of days is counted with the following formula: $RR_{ij} \geq$ nnmm, the unit is $d$.

### *2.2.8 The Calculation of Glacier Length and Material Balance*

The data of terminus fluctuation of glaciers and the change in terminus elevation mainly are based on the previous researches (mostly before 2,000 year) and the observation of recent years (Table 2.2). Based on this point, the change in length of glacier is counted with the following formula:

$$L = L1 + D \tag{2.9}$$

In this formula, L is the glacier length; L1 is the glacier length in current year used as a reference, that is the length of 1982 or 1983 recorded; D is the fluctuating distance of glacier terminus. If the glacier advances prior to the current year, D is negative value; if the glacier advances after the current year, D is positive. The fluctuating speed of glacier terminus is the ratio of fluctuating distance to number of years.

The glacier mass balance is a combined action of result of climate factors like hydrotherm on the glacier, and is one of the most sensitive indicators reflecting climate change. Its dynamic change is the material basis of the change in the glacial scale and runoff. The observation and estimation of glacier material balance have received a wide of concern for a long time. In spite of the high precision, the traditional method given priority to with the measured still need to spend a lot of manpower, material resources and time, which limits to get observations of glacier mass balance in a larger scale. Within the scope of the river basin, the material balance changes have similar temporal and spatial variation characteristics. When Shen (2000) studied the distribution of Chinese glacial hydrology and climate, he found the precipitation and runoff distribution have a negative exponential relation with its area in the west plateau land. The region covered by glacier is the biggest distribution area of rainfall, runoff and runoff coefficient. Starting from the statistical mechanics and the maximum entropy principle, according to the characteristics of precipitation and runoff distribution, a set of equations used to calculate the glaciers mean material balance with hydrological and meteorological observation data have been deduced. On the basis of these formulas, we will be able to resume the year-to-year changing sequence of the mean material balance with the application of unoff and precipitation data recorded in hydrologic stations, which has a realistic meaning to systematically research the material balance of all the mountains and basins and to recover the understand the history of glacier mass balance and the influence of glacier change on runoff. This study calculates material balance of HaiLuoGou glacier during 1993/1994–2003/2004 with water balance method, and its principle is as follows:

$$Bn = (P - E - R)/K \tag{2.10}$$

In this formula, Bn is glacier mass balance, P is the basin rainfall, R is the runoff, E is evaporation, K is glacier coverage in the basin.

### 2.2.9 *The Calculation of Water Output in Snow and Ice at High Altitudes*

Mount Gongga (29°20′−30°20′N, 101°30′–102°15′E) and Mount Yulong (27°10′–27°40′N, 100°9′–100°20′E) are the typical Marine glacier areas. HaiLuoGou river basin is located in the east slope of Gongga mountain and finally falls into the Dadu River. There are eight glaciers with a total area of 29.66 $km^2$ (Pu 1994) in this basin, and the total area of HaiLuoGou river basin is 78.07 $km^2$. The whole river basin consists of mountains, of which minimum altitude is 2,920 m. The areas below 3,800 m are covered by vegetation, while the areas above 3,800 m are covered by ice and snow. The main water input in this river basin is from precipitation and ice and snow melting water. Gongga Mountain station in Chengdu land office began to observe the hydrological condition in 1994, which is located in the HaiLuoGou glacier terminus of 1 km. Yanggongjiang basin is located at the southern tip of Yulong snow mountain, within which the glacier area is 2.44 $km^2$ (Pu 1994). The melting water feeds into the Lijiang Basion and finally falls into Yanggongjiang. Lijiang-Yulong Snow Mountain region is mainly covered by limestones, and the rock dissolve physiognomy is relatively developed. So the precipitation and the melting water of Yanggongjiang basin can more easily infiltrate into underground and form underground water, then pour out surface in lower place of Lijiang basin forming many mouths to recharge the surface runoff. In 1979, hydrographic office of Lijiang county set up a hydrometric station in mainly controlling the Yangjiang river basin. The areas controlled is 436.8 $km^2$ and mainly is composed of Yulong snow mountain land and Lijiang Basin. Among these areas, snow and ice-snow region at high altitude which is more than 4,000 m is 13.8 $km^2$, and the other area is 423.0 $km^2$.

As calculating the water balance of rive basin, we just need to take the balance of non ice-snow region at low altitude into consideration, like Lijiang Basin, because there are not the observation data of precipitation and glacier melting water runoff at high altitude. At the same time, we approximately think ice-snow region at high altitude as one of input item of that region at low altitude, that is $P_{Glacier}$, without the distinction between the liquid precipitation and glacier melting water. In addition, the precipitation is another input item, that is P. And the output items include watershed runoff (D) and the actual evaporation (E). Therefore, the equation of water balance in the low altitude area can be presented as Eq. (2.11):

$$P_{Glacier} + P = D + E \tag{2.11}$$

Among them, the actual evaporation E can be calculated with potential evaporation $E_0$. According to the calculation of monthly evaporation $E_0$ in two river basins with Baney-Criddle model, Yang et al. (1994) showed that the actual evaporation calculated with this formula can present the actual evaporation of the entire basin.

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