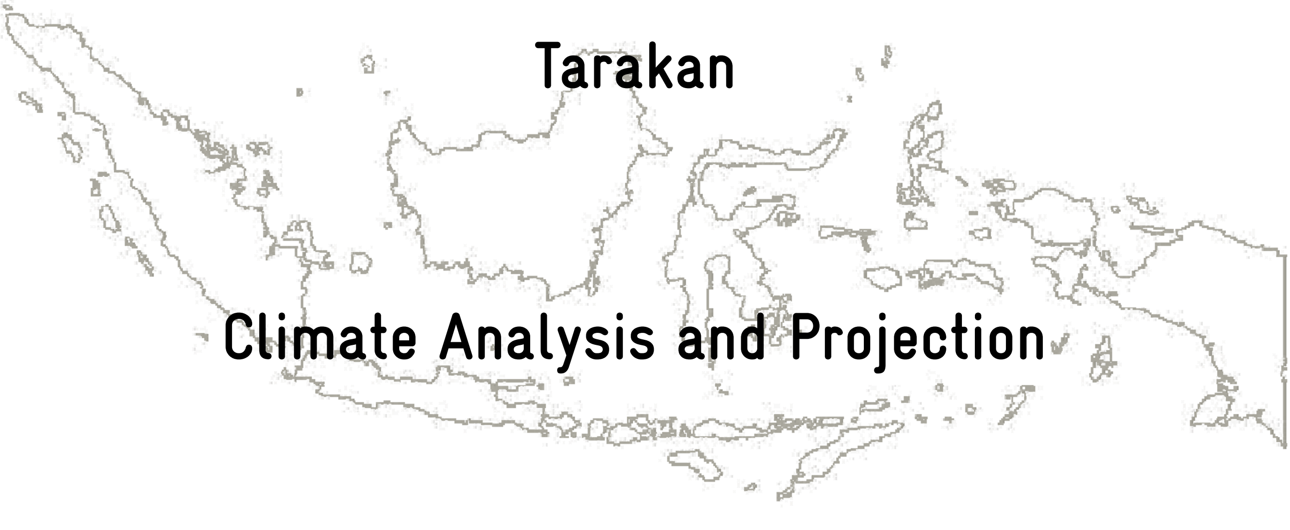
Climate Change Risk and Adaptation Assessment

Tarakan



Climate Analysis and Projection

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Climate Analysis and Projections – Tarakan

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Climate Analysis and Projection – Tarakan

Final Draft Report

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I. SCIENCE BASIS: CLIMATE ANALYSIS AND PROJECTION

1.1 Mean Annual Pattern of Rainfall and Temperature in Tarakan

Generally speaking, Tarakan belongs to humid tropical climate with relative humidity as high as 87% during the driest month. Tarakan also lies in the monsoon region where near surface winds generally reverse direction about every six months, preceding the onset of alternating drier and wetter seasons. Although affected by such annual variation of monsoon circulation, the rainfall in Tarakan is normally always higher than 240 mm for each month with an average value of about 310 mm (Figure 1.1). In Tarakan, the dry season does not well develop in normal years because rainfall amount in the "driest" month of February is still typically as high as about 250 mm. The rainfall in Tarakan is of equatorial-type, which can be identified from the two peaks around April (boreal spring) and November (the end of boreal fall).

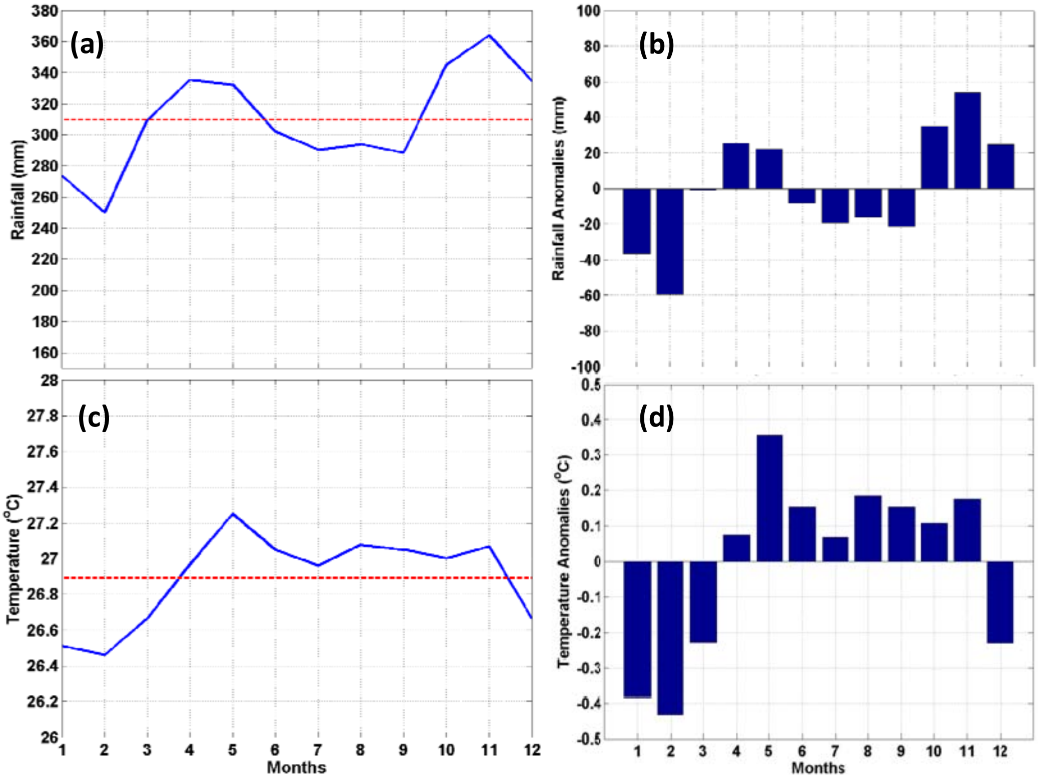

Figure 1.1. Mean annual variation of monthly (a)rainfall and (c)temperature, while (b) and (c) show the corresponding anomalies relative to long-term average as indicated by the red dashed lines.

From Figure 1.1, it can also be seen that the long-term mean temperature in Tarakan is around 26.9° C with less than 1° C variations between different months. Peaks in temperature data that are supposed to be corresponding to March and September equinoxes, are less clear probably due to the effects of cloud shading on surface temperature measurements. It is of interest to note that February is the "coldest" as well as "driest" month in Tarakan probably because there are predominant easterly winds that bring cooler air originated from the winter hemisphere.

1.2 Historical Climatic Hazards: Trend, Variabilites, and Extremes

Climatic change may be manifested by the changes in two main statistical parameters, namely *mean* and *variance*, of any weather/climate variables observed throughout at least two consecutive climatic periods. By WMO definition, a climatic period is defined as 30 years time span. In addition, secular change in surface temperature is always of interest to analyze in conjunction with global warming issue. Figure 1.2 shows long-term fluctuations in surface temperature observed over Tarakan with three trend lines calculated for the last 25, 50, and 100 years. During the last 25 years, there is a significant increase of about 0.63° C but for the last 50 and 100 years, the linear increase is only about 0.2° C/century.

Table 1.1 shows the trend of surface temperature change in Tarakan throughout the last century calculated for every month of the year. It can be seen that the trend of temperature change is different for each month with the highest value of about 0.35° C in March-April-May for 100-year period. The increasing trend of surface temperature is, in general, well defined for the months of February to June with values between 0.2 and 0.35 ° C/century. During these months, temperature measurements may be less affected by cloud shading because cloud formation is more dominated by local processes. Thus, temperature changes in March to May are likely influenced by the effect of urban heat island. During the other months (July-January), larger-scale cloud systems seem to more frequently develop due to stronger effect of the Asian monsoon.

Statistically speaking, across the climatic periods, the average trend of observed surface temperature change in Tarakan is around 0.2° C/century. For the last 25 years (less than one climatic period), trends of temperature increase are in the excess of 0.4° C for all months with the highest value of about 0.84° C in July and November. Linear extrapolation of the temperature trend to the future is subject to uncertainty because there was more than 1° C fluctuation in the past data. Moreover, there is only one single station in Tarakan that provides long-term record of temperature. Nevertheless, these data show that warming has possibly been intensified during the last several decades.

Different from temperature, trend analysis is not suitable for identifying the hazard of rainfall change because long-term fluctuation in rainfall data is much larger compared to the secular trend. In the case of Tarakan, the calculated trend is only about 10 mm/century, which is insignificant compared to the total variance of rainfall data. Therefore, the hazard of rainfall change is better analyzed in terms of inter-annual and inter-decadal variabilites as discussed below.

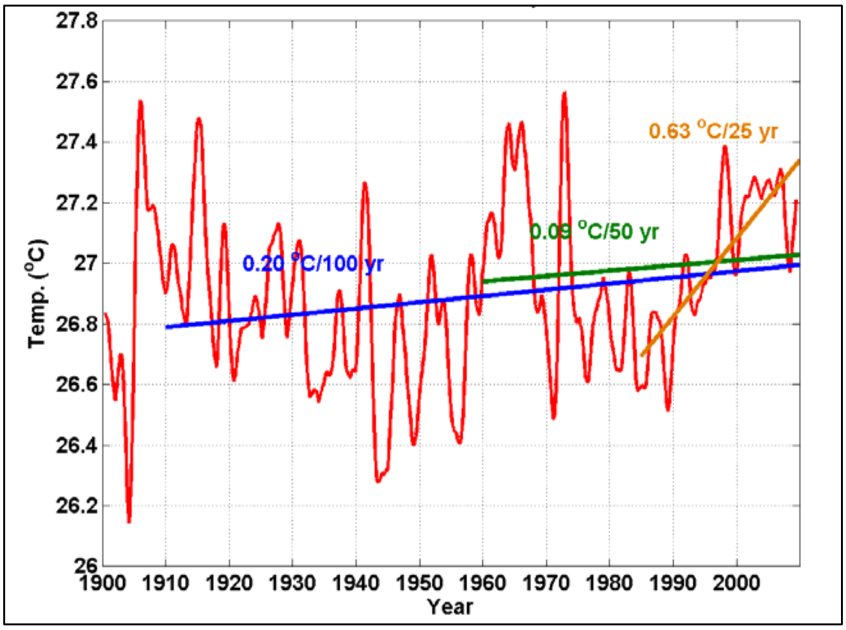

Figure 1.2. Trends in temperature changes in Tarakan over the past century. Red solid line is smoothed monthly temperature data, while blue, green, and orange lines indicate linear trends for the last 100, 50, and 25 years respectively.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trend (°C/100 yr)	0.17	0.15	0.33	0.35	0.37	0.24	0.11	-0.01	0.12	0.15	-0.06	0.10
Trend (°C/50 yr)	0.19	0.45	0.13	0.12	0.33	0.07	-0.08	-0.03	-0.33	0.01	-0.24	0.08
Trend	0.80	0.82	0.45	0.46	0.56	0.44	0.84	0.75	0.67	0.56	0.84	0.65

(°C/25 yr)												

Table 1.1 Trends of surface temperature change in Tarakan throughout the last century.

1.2.1 Inter-annual Rainfall Variabilities

In the tropics, rainfall variations at inter-annual time scale are known to be largely affected by global climatic phenomena known as *El Niño Southern Oscillation* (ENSO) and *Indian Ocean Dipole* (IOD). These phenomena are related to the dynamical behavior of the Pacific and Indian Ocean, which are manifested as temporal and spatial variations in Sea Surface Temperature (SST). Indices that represent the climatic events associated with ENSO and IOD have been developed based on SST measurements. Scatter plots in Figure 1.2 show the correlation between ENSO and IOD indices with Standard Precipitation Index (SPI) of Tarakan. SPI is one of the simplest indeces to represent drought level based on certain statistical distribution of rainfall observed at specific location. Thus, SPI signifies the deviation of rainfall amount during a period of time (one-, three-, six-, twelve-monthly, and so on) from its local long-term mean. In Figure 1.2, six-monthly SPI values are presented with more negative (less than -0.9) SPI means more severe drought event.

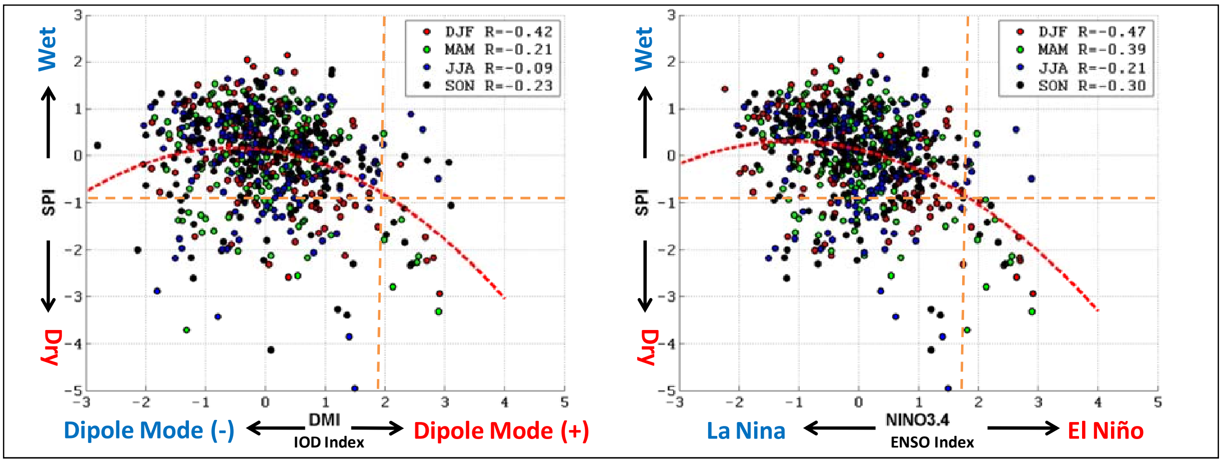

Figure 1.3. Correlation between 6-monthly Standardized Precipitation Index (SPI) calculated from rainfall of Tarakan and Dipole Mode Index (DMI)(left) as well as ENSO index (Nino3.4 sea surface anomaly)(right).

From the trend of SPI versus ENSO and IOD indices, it can be seen in Figure 1.2 that drought events at Tarakan are mostly attributed to strong El Niño, while correlation between

SPI and IOD is much weaker especially for the months of June-July-August. This result is consistent with the fact that Tarakan is close to the Western North Pacific Monsoon (WNPM) region so that effects of dynamic processes in the Pacific Ocean on the climate of Tarakan are naturally stronger compared to that of Indian Ocean. In this case, it is assumed that the strength of ENSO is represented by the absolute value of its index. However, it should be noted that stronger La Nina events are not necessarily associated with the wettest climate condition. When both ENSO and IOD are weak, the climatic state spreads between dry and wet condition indicating higher uncertainty. To summarize, strong El Niño event is one of the potential climatic hazards for Tarakan that are associated with the occurrence of drought. On the other hand, strong La Nina events do not clearly signify extreme “wetness” level. In addition, neutral (weak ENSO and IOD) events imply more uncertainties on rainfall.

ENSO is a quasi-periodic phenomenon, by which the state of the Pacific Ocean swings between cool (La Nina) and warm (El Niño) phases. El Niño may occur in every two to five years and recent investigations suggest that El Nino frequency tends to be higher. However, data of the past one and a half century indicate that strong El Niño events, which may cause severe, drought only reoccur about once in every 20 years. The impact of more frequent changes between El Nino and La Nina will be more likely associated with frequent occurrence of neutral state, in which rainfall condition of Tarakan maybe more unpredictable.

1.2.2 Inter-decadal Variations of Rainfall and Temperature

Rainfall variations at inter-decadal time scale are quite important because, as previously mentioned, climatological period is defined by WMO as a 30-year time window. Recent studies indicate that two oceanic variations known as Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO) may influence the climate in Asia and Australia at interdecadal time scale. Figure 1.4 shows the time series of smoothed monthly rainfall observed at Tarakan from 1911 to 2009. The interdecadal variation in Tarakan rainfall is quite pronounced during 1950 to 1980 period, which is marked by a significant decrease in decadal average rainfall during 1960 to 1970. This decreasing pattern of rainfall was not only found in Tarakan, but also appeared in most regions of East Kalimantan.

Scientific explanation for the decadal rainfall anomaly is beyond the objectives of this study but it is of interest to note that the decrease of rainfall during 1960 to 1970 only occurred in particular season. As it is shown in Figure 1.5, results of further analysis of rainfall and temperature data indicate that the decadal scale reduction of rainfall in Tarakan occurred most significantly in the months of June-July-August (JJA), while there were only relatively little changes in the rainfall of December-January-February (DJF). Figure 1.5 also indicates the correlation between temperature and rainfall data. When rainfall decreases, temperature tends to increase because there are less effects of cloud shading.

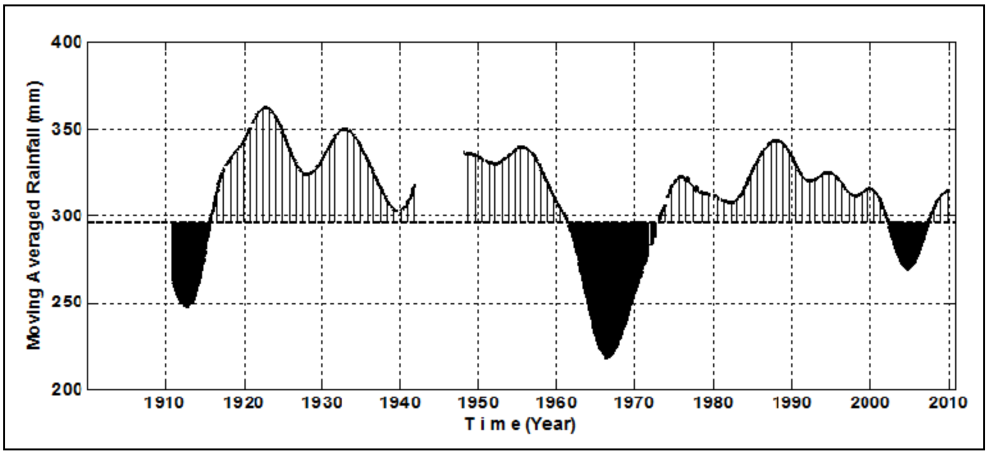

Figure 1.4. Smoothed time series of monthly rainfall observed in Tarakan from 1911 to 2009. Large gap between 1940 and 1950 indicates missing data.

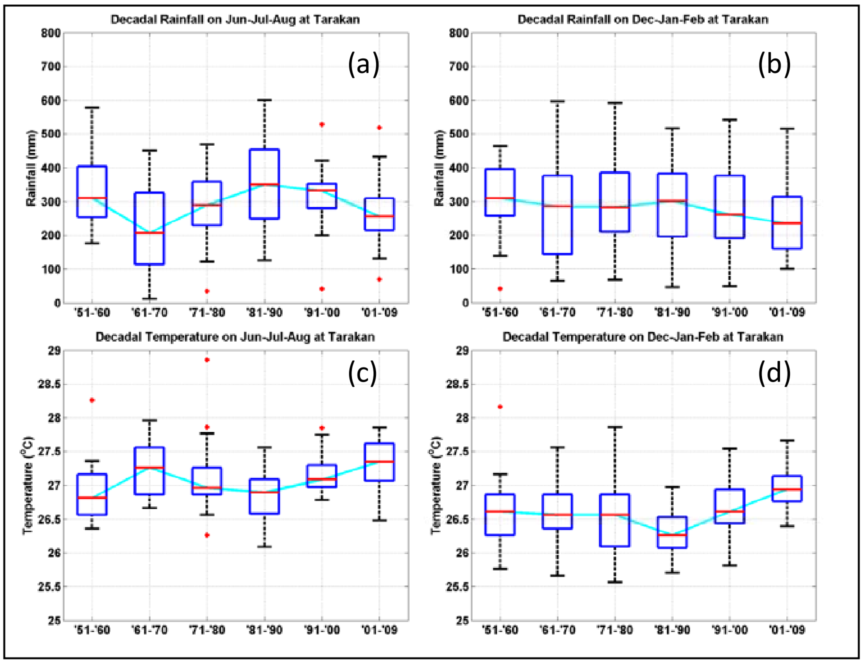

Figure 1.5. Box-plot diagrams showing statistics of monthly rainfall and temperature for June-July-August and December-January-February periods in every decades since 1951. Upper and lower ends of the boxes designate lower and upper quartiles,

while red lines indicate median values. In addition, dotted lines represent minima and maxima, whereas red dots indicate outliers.

1.3 Projection of Future Rainfall and Temperature Changes

Although there is a high degree of uncertainty, climate projection into several decades in the future is a fundamental element of climate change impact assessment. Two approaches may be used for climate projections : (i)projection based on empirical regression model, and (ii)projection based on the output of Global Circulation Models (GCMs). In this study, the former is only applied for rainfall projection, while the latter is used for both rainfall and temperature projection.

1.3.1 Empirical Projection of Interdecadal Rainfall Variations

As previously mentioned, interdecadal rainfall variability may be associated with global oceanic variations known as PDO and NAO. Thus, an empirical regression between PDO and NAO indices and smoothed (or low-pass filtered) rainfall model can be developed to predict the trend of rainfall changes in the next couple of decades. Result of the empirical regression is presented in Figure 1.6. The regression parameters were chosen so as to obtain the best fit the testing the observation during the testing period, although there may be large differences between model and observations during the training (development) period. The empirical projection is mainly for obtaining qualitative view of future trend in rainfall changes.

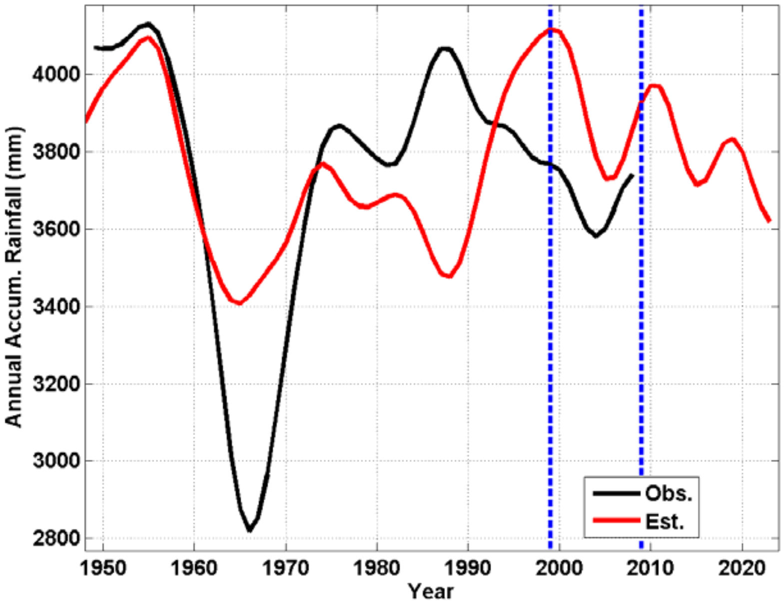

Figure 1.6. Result of empirical regression between PDO and NAO indices and smoothed annual rainfall observed over Tarakan (black line). Time window between blue dashed lines indicate "testing" period and red line shows projected rainfall 2010.

It can be seen from Figure 1.6 that there is a trend of decreasing rainfall from 2010 to 2020 with marked interannual variations. It should be noted that the correlation between rainfall and global climate indices may change phases so that the regression model fits well with observations during 1950s to 1960s but it shows large discrepancy for the 1970s to 1990s. However, the decreasing trend of rainfall is of primary interest and will be compared with the result of rainfall projection based on GCM outputs as described below.

1.3.2 Rainfall Projection Based on GCM Outputs

Global Circulation Models (GCMs) are the only tool that we can use to study the possible states of Earth's climate in the far future. Outputs of seven GCMs contributed for the IPCC AR-4 (the 4th Assessment Report) are used in this study to obtain projections of rainfall in Tarakan. Three carbon emission (SRES) scenarios i.e. B1 (low), A1B (moderate), and A2 (high) were chosen. The common problems with these GCM data for regional or local climate change risk assessment are the low horizontal grid resolution and the diverse results of rainfall estimation, especially in the tropical regions. In this study, a simple ensemble averaging and bias correction method have been applied to the GCM outputs to produce the rainfall projections as shown in Figure 1.7.

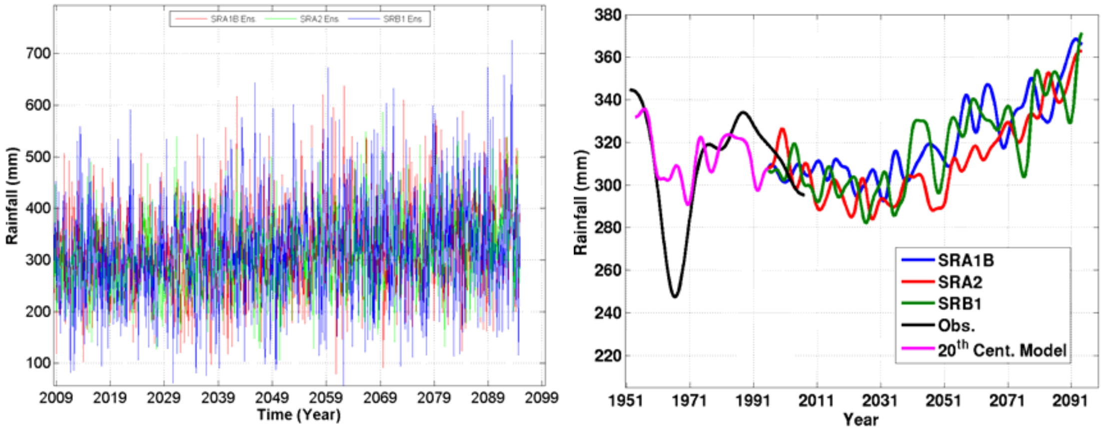

Figure 1.7. The GCM out based projected monthly rainfall of Tarakan for the 21st century (left) and the smoothed version with an extension back to 1951 (20th century) (right).

Although the models cannot perfectly match observations, Figure 1.7 shows that projected rainfall of Tarakan partially follows an observed interdecadal variations. More importantly, there is also a decreasing trend from 2010 to 2030, which is consistent with the result of empirical regression as discussed previously (Figure 1.6). It should also be noted that, although the long-term trend is quite similar, there are also significant differences in the year to year variations between different scenarios.

1.3.3 Temperature Projection

Temperature projection has been made based on GCM output similar to that of rainfall as discussed previously. As it is shown in Figure 1.8, the models show uniform increase of temperature from 1990s to 2030 for all scenarios. After 2030 the trend splits between B1 (low emission) and other (A1B and A2) scenarios. This result, is in general, agree with the global trend of temperature for the tropical region.

Note that, although models seem to fit the trend of temperature increase, they cannot actually follow observed interdecadal variations. This is one of the weaknesses of the GCMs contributing to the IPCC AR-4. Developments of better GCMs are on progress and the results are planned for contribution to IPCC AR-5 but published materials are still limited.

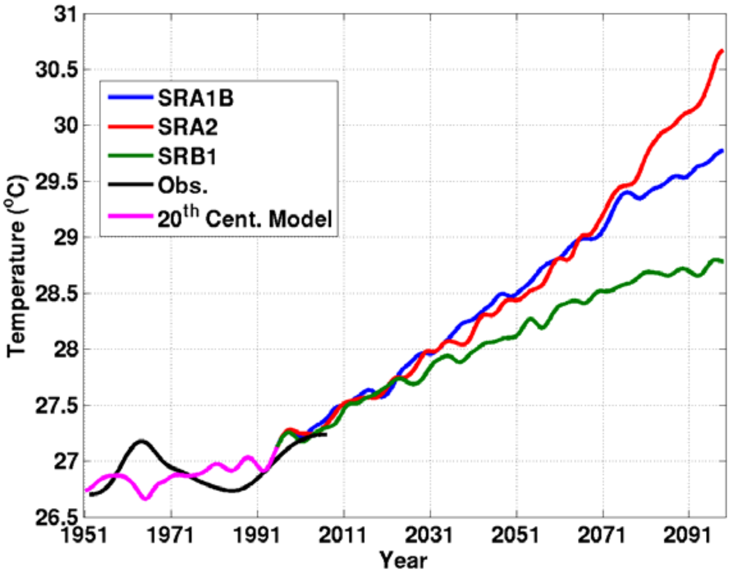

Figure 1.8. The GCM out based projected temperature of Tarakan for the 21st century with an extension back to 1951 (20th century). Data has been smoothed to show only the long-term trend.

1.4 Analysis of Extreme Events

Information of extreme events is important in climate change risk assessments. Analysis and projection of extreme events are, however, more difficult to perform because it requires more detailed and accurate data. Long records of observed daily temperature and rainfall are at least needed to analyze the extreme events, while GCM outputs with daily time resolution are also required for the projection. In tropical region, extreme temperature events such as heat wave are very rare events. Therefore, only several aspects of extreme rainfall events at Tarakan are briefly discussed below.

1.4.1 Historical Records of Extreme Rainfall

The best data for analysis of extreme events obtained in this study is probably daily rainfall data observed by BMKG station in Tarakan (Juwata). However, the record only spans from 2004 to 2009, which is not representative for climate analysis. Another data set show maximum daily rainfall in each year from 1984 to 2001. Figure 1.9 shows the yearly maximum rainfall data of 1984 to 2001 combined with those derived from more recent data up to 2009. This is incomplete information of extreme events because the data samples cannot be used to construct probability of exceedance (PoE), which is a measure of the probability of an extreme event to occur in certain period of time.

From Figure 1.9, it can be seen that 100 mm/day seems to be the minimum threshold for extreme rainfall event and the most extreme rainfall occurred on 7 August 1998 with a record of 295 mm/day. Correlation between the probability of extreme monthly and daily rainfall has been investigated in this study using daily rainfall data of Singapore, which is considered to be the most representative data that can be obtained. Figure 1.10(a) shows a three curves fitted to some pairs of probability of monthly rainfall data with a certain threshold (400 mm/month for Singapore) against that of daily rainfall (60, 80, and 100 mm/day). Data of Tarakan and Kenten (South Sumatra) are also plotted with adjusted threshold of monthly rainfall (433 mm/month in the case of Tarakan). It can be seen that data of all sites roughly follow the same trend. Hence, changes in the probability of monthly rainfall with certain threshold are an indicator for the probability of extreme daily rainfall.

As it is shown in Figure 10(b), the projected probability of monthly rainfall above 433 mm differs with the B1, A1B, and A2 scenarios. Although the magnitudes are also different from observations, A2 scenario gives quite similar trend with that of observations. It is inferred from this results that, until 2030s, the probability of occurrence of extreme daily will likely decrease or stay the same as present. However, it should be noted that after 2050s probability of extreme rainfall is projected to increase in all scenarios.

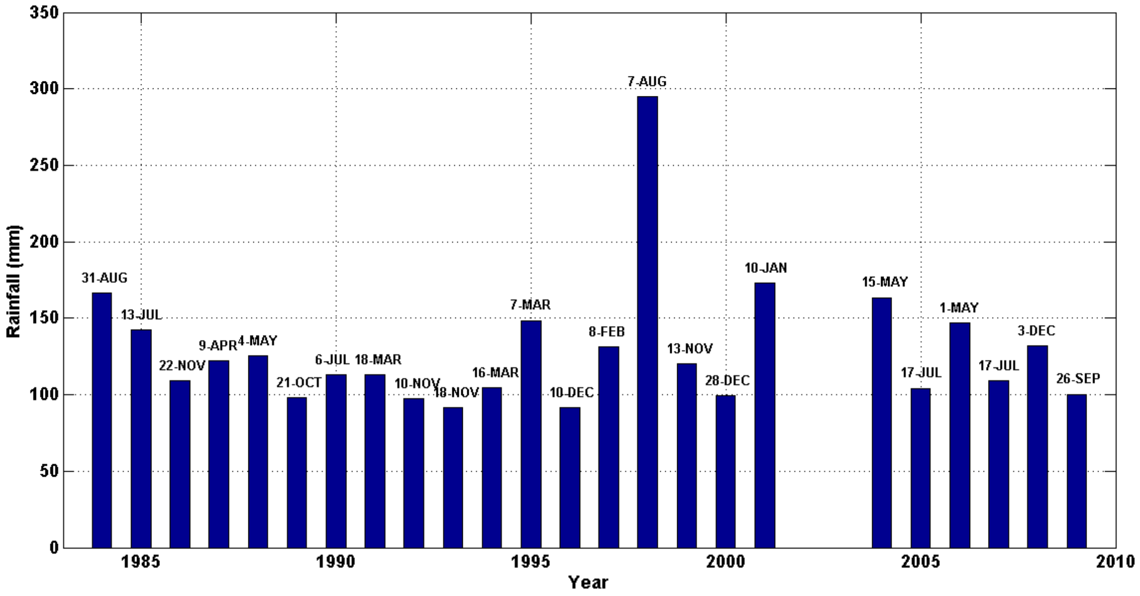

Figure 1.9. Records of maximum rainfall observed in Tarakan for each year from 1984 to 2009.

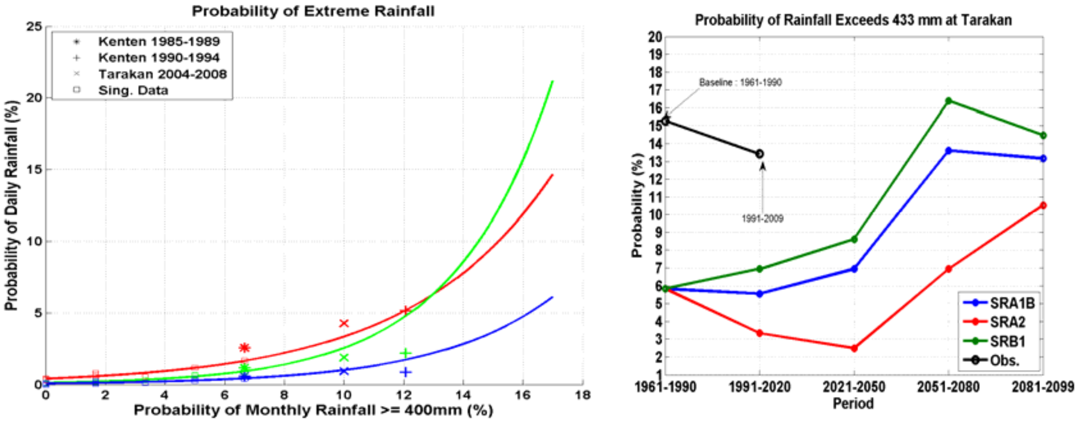

Figure 1.10. (a) Correlation between the probability of monthly rainfall exceeding certain threshold and the probability of daily rainfall exceeding 60 (blue), 80 (green) and 100 mm/day (red) with square symbol designates data of Singapore (threshold of monthly rainfall is 400 mm), while asterisk, cross, and plus symbols indicate data of Kenten (1985-1989), Kenten (1990 – 1994)

and Tarakan respectively (see text);m (b)projected trend of the probability of extreme events (rainfall exceeding 433 mm).