Climate Change Risk and Adaptation Assessment

Greater Malang

Climate Analysis and Projection

June 2012

Ministry of Environment

Climate Analysis and Projection – Greater Malang

FINAL DRAFT

Published by:

Ministry of Environment

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The development of this document was supported by:

Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung

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Climate Analysis and Projections – Greater Malang

Draft Final Report

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I. SCIENCE BASIS : CLIMATE ANALYSIS AND PROJECTION

1.1 Mean Annual Pattern of Rainfall and Temparature in Malang

The Greater Malang Region, which is situated in the East Java Province of Indonesia, now consists of three administrative regions i.e. Malang and Batu municipalities (kota), and the districts (kabupaten) of Malang. Because of its unique climate, there have been centers for agricultural activities in Malang since the Dutch colonial era. However, past climate studies specific to the area are difficult to find. Nevertheless, information about the climate of Malang may be found in more recent studies of Brantas catchment area.

The climate of Malang, as part of Java Island, is basically governed by the Asia-Australian monsoon. The west monsoon occurs during Asian winter (December-January-February) normally brings rain, while the east monsoon that occurs during Australian winter (June-July-August) is usually dry. We used both long-term globally gridded data (1900-2008) provided by GPCC and local observational data provided by PUSAIR-PU of the ministry of public work (1980-2009) to calculate the mean annual rainfall of Malang area. As shown in Figure 1.1, the rainfall of Malang is predominantly monsoonal type with one single peak around January. This result is consistent with other studies such as that reported by Aldrian and Djamil (2006). Although there are some discrepancies, both global data and local observations clearly show similar annual pattern (Figure 1.1 (a)). Results of further analysis of global data from 1951 to 2008 (Figure 1.1 (b)) indicate that there have been relatively large inter-decadal variations in the rainfall of each month, especially in March. These variations may affect the onset and length of rainy season, which occurs around October, and also the length of dry season in each individual year.

Long-term temperature record for Malang area only available in the form of globally gridded temperature data provided by the University of Delaware (UDEL). Similar to that of Figure 1.1 (b), the annual variations of monthly mean temperature analyzed from UDEL data are depicted in Figure 1.2. It can be seen that temperature has two peaks corresponding to the equinoxes with “coldest” temperature occurs in July during Australian winter. The annual temperature variations are also characterized inter-decadal changes with long-term average of around 25° C as Malang has relatively high elevation. It should also be noted that the highest mean temperatures have been observed during the last decade (data of 2001-2008), which will be discussed further in the next sections.

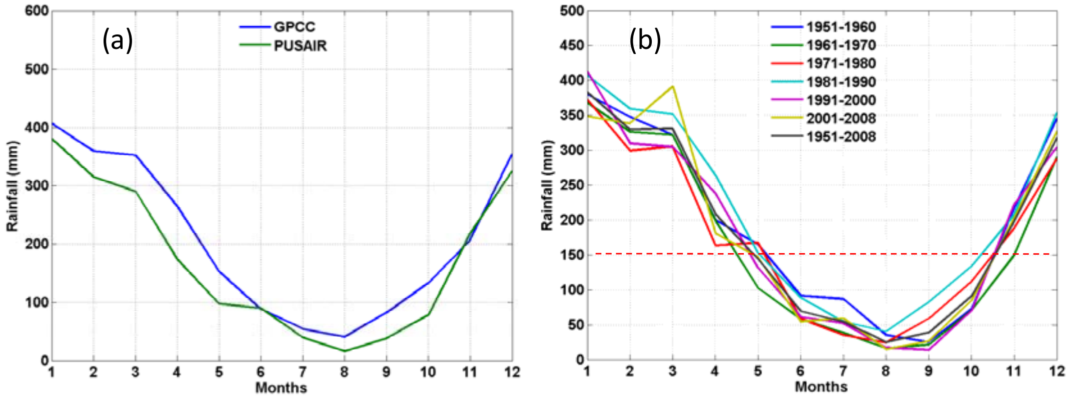

Figure 1.1. Mean annual variation of monthly rainfall in Malang : (a)comparison between global data (GPCC) and local observations (PUSAIR) during 1981-2008 period and (b)mean decadal pattern since 1951 analyzed from the global data. Red dashed line indicates the rainfall of 150 mm, which can be used as a threshold for defining dry season.

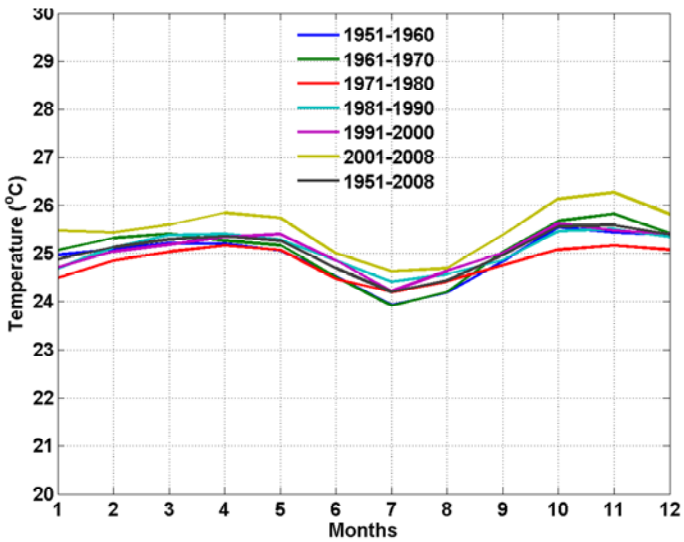

Figure 1.2. Mean annual variation of monthly mean temperature in Malang analyzed from globally gridded temperature data provided by the University of Delaware (UDEL).

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. Secular change in surface temperature is always of interest to analyze in conjunction with global warming issue. Figure 1.3 shows long-term fluctuations in surface temperature analyzed for Malang from the UDEL temperature data. It can be seen that the three linear trend lines calculated for the last 25, 50, and 100 years all show increasing pattern with the largest increase of 0.69° C during the last 25 years. The temperature trends of Surabaya and Pasuruan have been analyzed by Harger (1995) with inferred positive trends of 1.4 and 1.0 per century. We also analyzed temperature trend of other regions from the same data set and our results indicate that the increase of temperature during the last 25 years is of regional scale and may have been affected by global warming. It should be noted that large changes in temperature trend occurred after the mid 1970s, which marked the "Climate Shift" phenomenon. The origin of the phenomenon is still a matter of debate but IPCC scientists suspect the anthropogenic global warming was the main cause. It seems to differ from previous decades, which are marked by larger inter-decadal fluctuations in surface temperature.

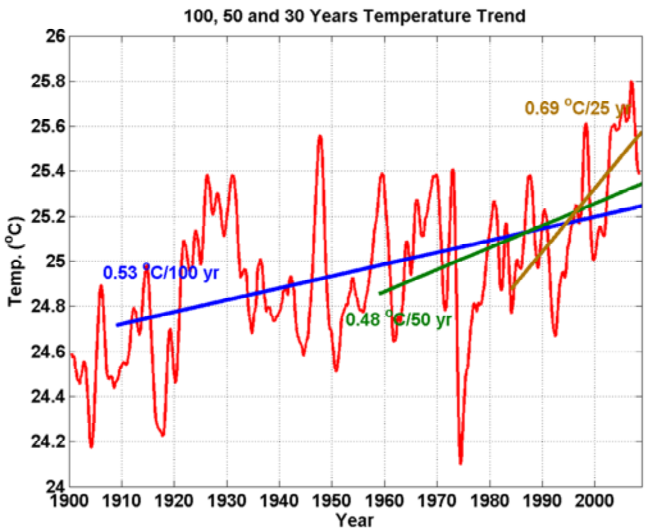

Figure 1.3. Temperature fluctuations and linear trends calculated from UDEL temperature data for Malang. Blue, green, and orange lines indicate the linear trends of the last 100, 50, and 25 years. Running mean smoothing was applied to monthly temperature data before plotting.

1.2.1 Inter-annual Rainfall Variabilities

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. Therefore, the hazard of rainfall change is better analyzed in terms of inter-annual and inter-decadal variabilites.

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 1.4 show the correlation between ENSO and IOD indices with Standard Precipitation Index (SPI) of Malang. SPI is one of the simplest indices 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 1.4, six-monthly SPI values are presented with more negative (less than -0.9) SPI means more severe drought event.

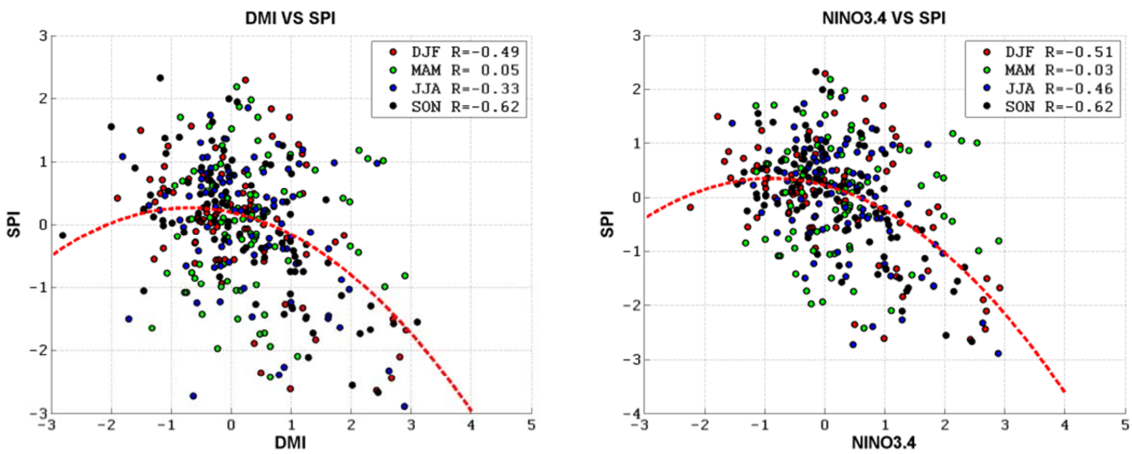

Figure 1.4. Correlation between 6-monthly Standardized Precipitation Index (SPI) calculated from rainfall of Malang (from GPCC data) and Dipole Mode Index (DMI)(left) as well as ENSO index (Nino3.4 sea surface anomaly)(right).

From Figure 1.4, it can be seen that drought events in Malang are correlated with strong El Niño and Dipole Mode (+) events. Correlation between El Nino and SPI is somewhat higher but same correlation is found for September-October-November, when the impacts of both El Nino and Dipole Mode(+) are strongest. In this case, it is assumed that the strength of ENSO/Dipole Mode is represented by the absolute value of the indices. However, it should be noted that negative events (La Nina/Dipole Mode (-)) events can be associated with wet climate condition in average but not extreme ones. As indicated in Figure 1.4, the most extreme "wetness" level occurred during neutral (weak ENSO and IOD) events but with large spread in the SPI data. This implies that neutral ENSO-IOD state imposes uncertainty in the rainfall of Malang. We found similar and consistent results for the correlations between SPI in Indonesia with ENSO/IOD events.

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 Malang maybe more unpredictable.

1.2.2 Inter-decadal Variations of Rainfall and Temperature

Rainfall variations at inter-decadal time scale are quite important in the analysis of climate change. As previously mentioned, climatological period is defined by WMO as a 30-year time window so that inter-decadal variations may have significant contribution to a component of detected climate change. 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 inter-decadal time scale.

Figure 1.5 shows box plots of inter-decadal rainfall time series (each box represents statistics of ten-year rainfall data) at Malang during the period of 1951 to 2009. It can be seen that during 1960s the dry season (June-July-August) was relatively dryer compared to other decades. In contrast to that, the dry season was relatively wetter during 1980s. Similar variations can be found for September-October-November period but with the leading phase. These results may indicate that the inter-decadal rainfall variations were caused by the gradual changes in the strength of the monsoon. In this case, the changes first affected the dry-to-wet transition period before they caused stronger dry monsoon to occur.

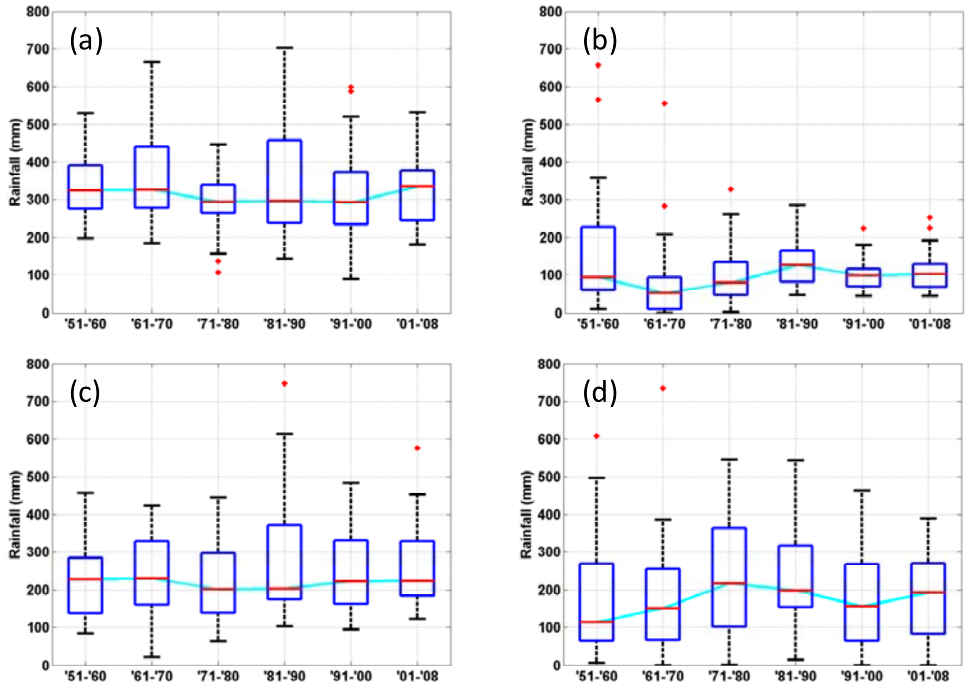

Figure 1.5. Box-plot of inter-decadal rainfall time series of Malang (calculated from GPCC data) for (a) December-January-February, (b)June-July-August, (c)March-April-May, and (d)September-October-November. Each box represents the statistics of ten-year rainfall with cyan-colored lines connects the median values.

We also analyzed rainfall data of Tarakan and East Kalimantan, and found similar pattern of "dryer" dry season during 1960s. We have not investigated the cause of the phenomenon but it is of interest to note that our results are consistent with that of D'Arrigo et al. (2006) who analyzed the variations of Palmer Drought Severity Index (PDSI) as shown in Figure 1.6. It can be seen that, for the past sixty years or so, the climate of Java was relatively dryer during 1950s to 1960s. It should be clear that inter-decadal changes in rainfall could cause long-term negative rainfall anomaly. The effects of such negative rainfall anomalies will be more severe if combined with higher temperature due to global warming. Therefore, meteorological drought is one of the climatic hazards that must be seriously considered and anticipated in Malang, with or without global climate change.

Inter-decadal variations in temperature do not show specific climatic phenomena but Figure 1.7 clearly shows the increasing trend of surface temperature. This result confirms that the large changes, as previously mentioned, occurred during 1970s to 1980s due to the climate shift.

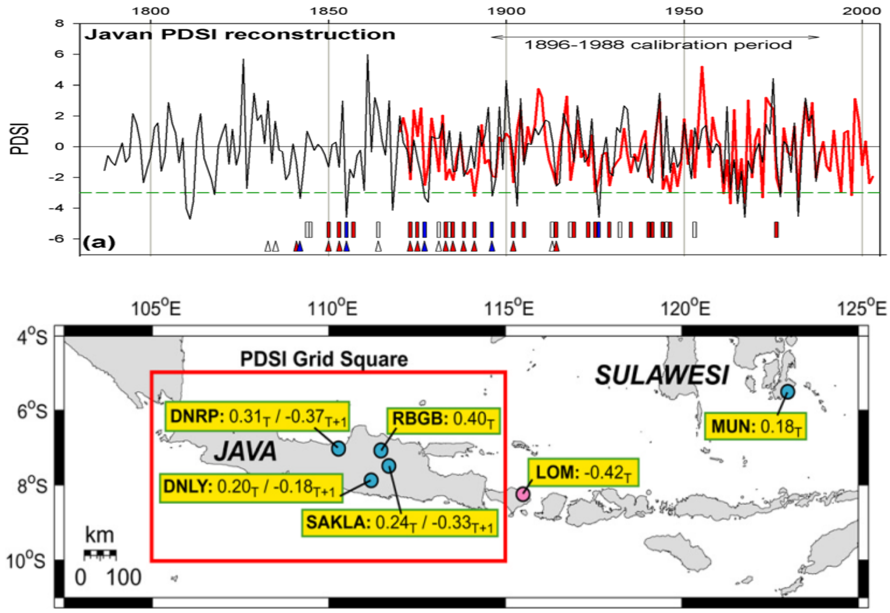

Figure 1.6. Results of historical drought in Java Island analysis that has been reported by D'Arrigo et al. (2006). Upper panel : calculated (red line) and reconstructed Palmer Drought Severity Index (PDSI; black line) over Java Island. Lower panel : locations of tree-ring samples.

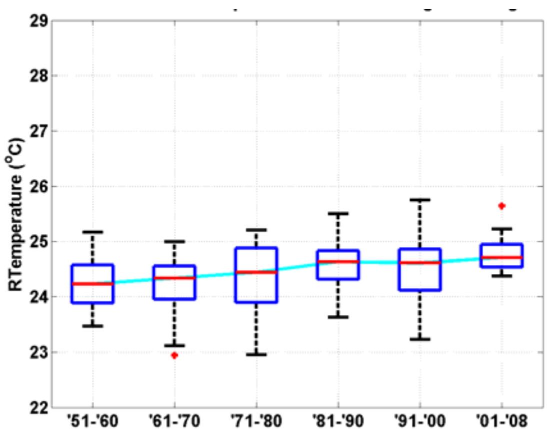

Figure 1.7. Decadal plots of temperature variations. Similar to Figure 1.5 except for temperature in June-July-September.

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 1.8. The regression parameters were chosen so as to obtain the best fit the the observation during the testing period i.e. the period in which observational data were not included in the calculation of regression parameters.

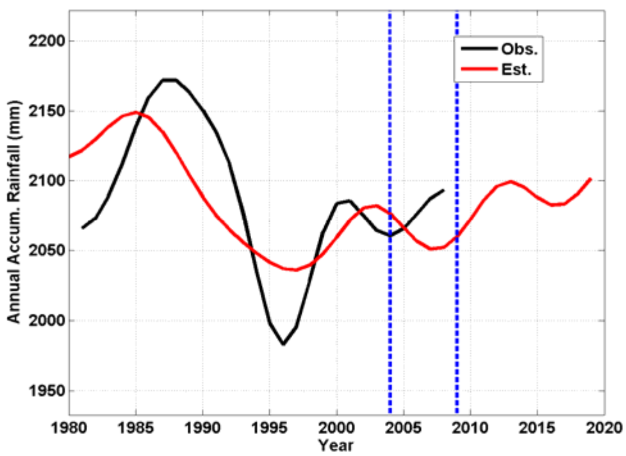

Figure 1.8. Result of empirical regression between PDO and NAO indices and smoothed annual rainfall observed over Malang (black line). Time window between blue dashed lines indicate "testing" period and red line shows projected rainfall until 2019.

Despite the differences in phase and amplitude, the projected rainfall shown in Figure 1.8 depicts similar inter-decadal rainfall variations with observations. Moreover, the empirical projection is mainly used for obtaining qualitative view of future trend in the rainge of rainfall changes. This result indicates that, until the end of this decade, there will be only modest inter-annual rainfall variations, probably due to ENSO or Dipole Mode events.

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 Malang. 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 1.9. It is found that almost all of the seven IPCC models that we have selected failed to produce rainfall variations. In Figure 1.9, the best model was obtained by using correlation coefficient against observational data as weights for each model in the ensemble averaging process.

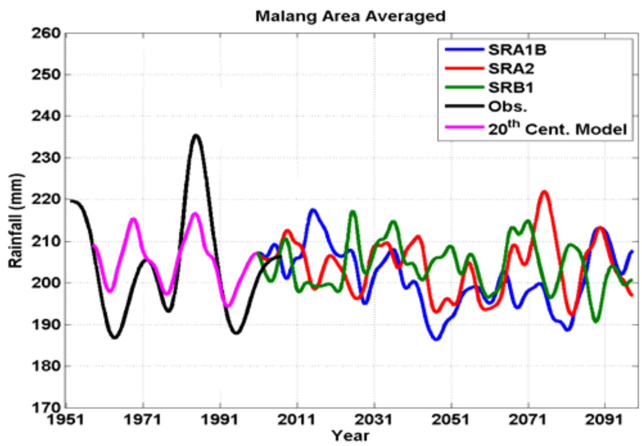

Figure 1.9 The projected rainfall variations of Malang in the 21st century based on GCM output. Blue, green, and red lines respectively represent the results of B1, A1B, and A2 SRES scenarios with extension back to 1951 (20th century; magenta line). Smoothing by moving average was applied to the monthly time series before plotting.

Although the models shows large discrepancy from observations, the future rainfall variations projected using A1B scenario is consistent with that of empirical results. Accordingly, it is important to note that drought hazard is projected to occur around 1950s. This result agrees with previous study by Naylor et al. (2007), who analyzed projected rainfall changes in 1950 (only). They concluded that in East Java, the dry season will be longer and the onset of monsoon will be delayed by about 30 days. Our results show that the trend of decreasing rainfall around 1950 is consistently shown by all scenarios.

It should be noted that rainfall projection is produced for spatial grids over Greater Malang region. In order to provide more detailed spatial variations, we have developed a different method of rainfall projection based on "analogue" technique. In this case, we have used high quality rainfall observations provided by PUSAIR, although the data are only available for less than 30 years. Analogue technique normally requires longer database to implement.

1.3.3 Temperature Projection

Temperature projection has also been made based on GCM output using methods similar to that of rainfall, and the results are presented in Figure 1.10. It can be seen that the model matched the temperature trend during the last 25 years, which signifies the effect of global warming. All scenarios projected almost similar temperature trend until 2030 with an increase of about 1 C compared to the 1961-1990 baseline period. Based on IPCC model, the temperature will further increase by about 2 C until the end of the 21st century with A1B and A2 scenarios.

As with rainfall, we produced temperature projections on spatial grids but it is found that the data do not show consistent variations with topography. Therefore we have made corrections based on simple adiabatic lapse rate by which temperature decreases with height by about 1 C every 100 m. It should be noted that we also used the temperature observed at Karang Ploso climatological station of BMKG to make gross bias correction before applying adiabatic correction.

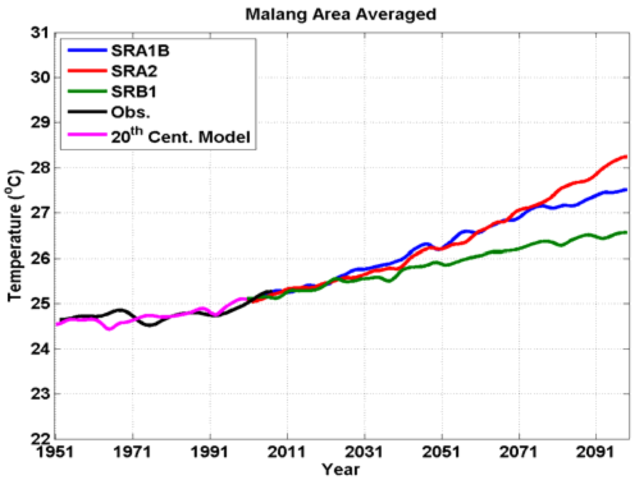

Figure 1.10. The GCM out based projected temperature of Malang for the 21st century with an extension back to 1951 (20th century). Data has been smoothed to show only the long-term trend.

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 in Malang are briefly discussed below.

1.4.1 Historical Records of Extreme Rainfall

Extreme rainfall events can be analyzed in various ways but data with high temporal resolution are always needed. In this case, daily rainfall data provided by PUSAIR are quite useful to analyze the distribution of extreme rainfall events, although the time span (most stations recorded data less then 30 years) is still quite limited for climate change studies. In order to analyze the probability of extreme events, we propose the use of "probability of exceedence" curve as shown in Figure 1.11. It can be seen that, for example, 150 mm rainfall/day has a probability of about 40% to occur once in 10 year. For comparison, results of "return periods" calculated by Nippon Koei Co. Ltd. (Hidayat et al., 2008) show that over Madiun Basin, rainfall with 141 mm/day has a return period of 100 years.

According to the definition of BMKG, 100 mm/day is considered as very heavy rainfall event. In Figure 1.11, it can be seen that the probability of 100 mm/day rainfall is 80% to occur in 5 years and 60% to occur in 2 years. If 100 mm rainfall is to cause flooding in Malang, then all drainage system should be designed at least to withstand this rainfall amount. We leave to the water sector experts to do further analysis of these data.

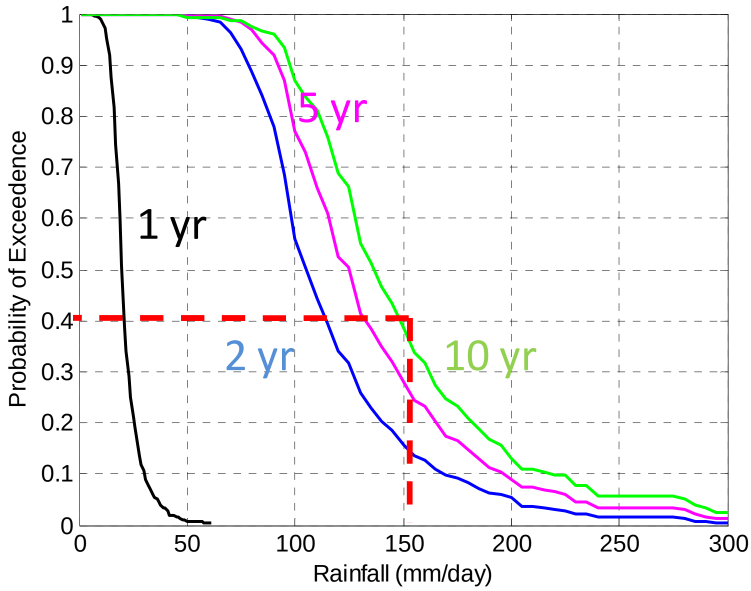

Figure 1.11. Probability of exceedence calculated from daily rainfall observations over more than 40 stations provided by PUSAIR-PU with a time span from 1981 to 2009.

1.4.2 Correlation Between Monthly Rainfall and Extreme Daily Rainfall

One of the challenging problems in our work is how to find useful relationships between distribution of monthly and daily rainfall data. Extreme events can be statistically represented by the data falling into the uppermost percentiles of the distribution. From available daily rainfall data of Malang, we calculated the probability of occurrence of daily rainfall larger than the threshold of 90^{th}, 95^{th}, and 98^{th} percentiles in each month corresponding to classes of monthly rainfall. The results are presented in Figure 1.12. It can be seen that extreme rainfall events in Malang mostly occurred when monthly rainfall is in the range of 250-450 mm. Similar results have been found for South Sumatra region, indicating that such pattern of relationship is quite robust.

We suspect that this class of monthly rainfall mainly occurs during transition months of March-April-May (MAM) and September-October-November (SON) periods. More importantly, with these results we may identify changes of the probability of extreme rainfall events if we could analyze the changes of probability of occurrence of monthly rainfall in previously mentioned range.

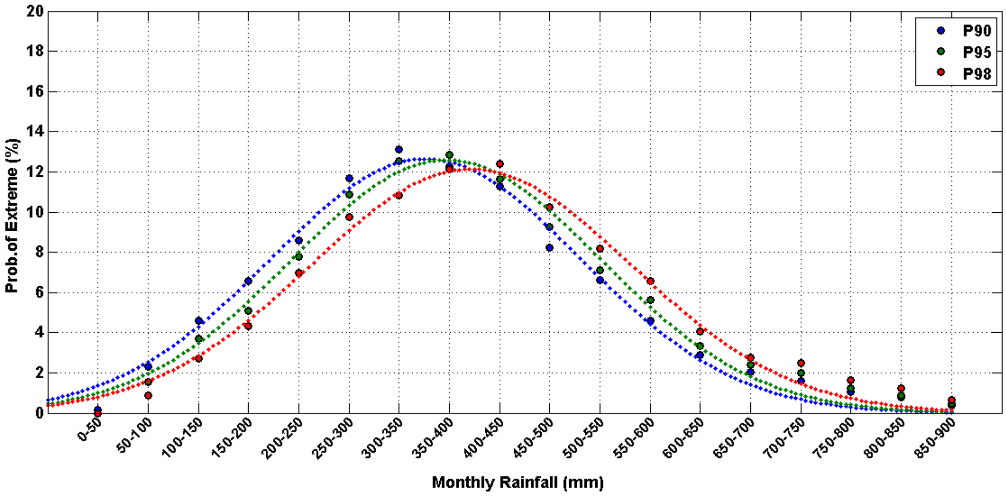

Figure 1.12. Curves that represents the relationships between the probability of occurrence of extreme rainfall (values exceeding the threshold of 90th percentile) as a function of classes of monthly rainfall.

1.4.3 Changes in the Probability of Extreme Rainfall

We attempted to analyze the changes of the probability of occurrence in projected monthly rainfall and found the results as depicted in Figure 1.13. It can be clearly seen that the model (with A1B scenario) projected an increase in the probability of extreme rainfall indicator (monthly rainfall of 300-351 mm) by about 3 % after 2010s compared to present. Only rainfall in the range of 401 - 450 mm is projected to decrease in the probability of occurrence. It should be noted, however, that models tend to produce more moderate monthly rainfall compared to observations. Therefore, this result is subject to further validation and should be used cautiously when analyzing the projected extreme rainfall events. Nevertheless, the increase of extreme rainfall probability over Malang area may be expected to increase during the next two decades.

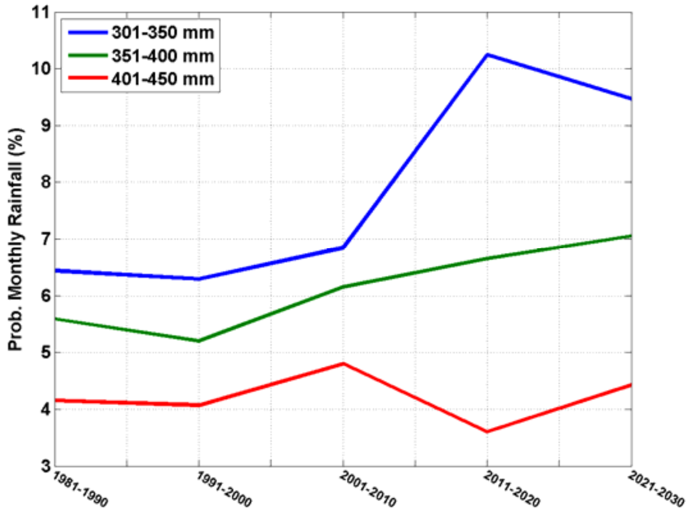

Figure 1.13. Changes in projected probability of monthly rainfall in the range of strongest correlation with extreme daily rainfall in Malang region, based on A1B scenario.