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## Projected Changes of Future Climate Extremes in Malaysia (Unjuran Perubahan Iklim Ekstrim Masa Depan di Malaysia)

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### ABSTRACT

*Mitigating and adapting to the impacts of climate change at regional level require downscaled projection of future climate states. This paper examined the possible changes of future climate extremes over Malaysia based on the IPCC SRES A1B emission scenario. The projected changes at 17 stations were produced by bias correcting the UKMO PRECIS downscaling simulation output. The simulation expected higher probability of rainfall extreme occurrences over the west coast of Peninsular Malaysia during the autumn transitional monsoon period. In addition, possible early monsoon rainfall was projected for certain stations located over East Malaysia. The simulation also projected larger increase of warm temperature extremes but smaller decrease of cold extremes, suggesting asymmetric expansion of the temperature distribution. The impact of the elevated green house gases (GHG) is higher in the night time temperature extremes as compared to the day time temperature extremes. The larger increment of warm night frequencies as compared to the warm day suggests smaller diurnal temperature ranges under the influence of higher greenhouse gases. Stations located in East Malaysia were projected to experience the largest increase of warm night occurrence.*

*Keywords: Bias correction; climate extremes; Malaysia; PRECIS; SRES A1B*

### ABSTRAK

*Tebatan dan adaptasi kepada impak perubahan iklim pada aras rantauan memerlukan penurunan skala unjuran keadaan iklim masa depan. Kertas ini mengkaji kemungkinan perubahan iklim ekstrim masa depan sekitar Malaysia berasaskan senario pancaran IPCC SRES A1B. Unjuran perubahan pada 17 stesen dihasilkan dengan membetul pincang output simulasi penurunan skala UKMO PRECIS. Simulasi menjangka kebarangkalian kejadian hujan ekstrim yang lebih tinggi di sekitar pantai barat semenanjung Malaysia semasa musim peralihan luruh. Perawalan musim monsun turut diunjur bagi sesetengah stesen di Malaysia timur. Simulasi turut mengunjur penambahan tinggi ekstrim suhu panas tetapi pengurangan rendah ekstrim sejuk. Ini mencadangkan kembangan taburan suhu secara tak bersimetri. Impak peningkatan gas rumah hijau lebih tinggi kepada suhu ekstrim waktu malam berbanding dengan suhu ekstrim waktu siang. Penambahan kekerapan malam panas yang lebih tinggi berbanding dengan siang panas mencadangkan pengurangan julat suhu harian bawah aruhan gas rumah hijau yang tinggi. Stesen-stesen di Malaysia timur diunjur akan mengalami penambahan paling tinggi bagi kejadian malam panas.*

*Kata kunci: Iklim ekstrim; Malaysia; pembetulan pincang; PRECIS; SRES A1B*

### INTRODUCTION

The Global Circulation Models (GCMs) are used to model the responses of the climate system to different scenarios of greenhouse gas and aerosol concentrations or some other hypothetical forcings. Although the GCMs generally simulate well the large and planetary scale climate (Houghton et al. 2001; McCarthy et al. 2001; McGuffie & Henderson-Sellers 1997), their applications to regional studies are restricted by their coarse resolutions and constrained capability in resolving the local and regional scales dynamics. On the other hand, assessment of climate change at regional and local scale, which is required at national level, relies on detail climate projection information (Robinson & Finkelstein 1991) in order to capture the fine scale climate variations. This is particularly crucial in the regions with complex topography, coastal or island locations and in areas with highly heterogeneous

land surface cover (Wilby et al. 2004) such as the Southeast Asia maritime continent.

A commonly used approach to resolve the scale gaps is by downscaling the GCM projection output, with either dynamical or statistical/empirical methods (Giorgi & Mearns 1991; Karl et al. 1990; Zorita & von Storch 1999). The empirical approaches map the large scale climatic field (usually called predictor) to the local climate variables via empirical mapping functions (Benestad et al. 2008). On the other hand, dynamical approaches required the use of a regional climate model (RCM) conditioned at the boundaries by the GCM output (Giorgi & Hewitson 2001; Jones et al. 2004). At the cost of higher computational resources, dynamical downscaling provides local climate information taking into account the physical interaction between various local features and is more favorable over areas without observational data. However, the

systematic biases in the dynamical model often requires post simulation treatment before the output can be used for further analysis.

In the present study, changes in the projected temperature and rainfall extremes represented by 6 different indices (2 for rainfall and 4 for temperature) were examined based on the SRES A1B emission assumption. The Hadley Centre regional climate model, PRECIS (Providing Regional Climate for Impacts Studies) nested within the UKMO HadCM3 were used to produce the rainfall projection at a higher resolution of  $0.22^{\circ} \times 0.22^{\circ}$ . This rainfall output was then corrected at the location of the 17 observational stations to remove the systematic biases before the analysis of changes.

## MATERIALS AND METHODS

### THE NUMERICAL SIMULATIONS

The RCM used in current study is the HadRM3P. It is the component model of PRECIS (Providing Regional Climates for Impacts Studies), developed by the Hadley Centre. It is a land-atmosphere coupled model similar to the HadRM3H described by Hudson and Jones (2002). The model was configured with a horizontal grid resolution of  $0.22^{\circ} \times 0.22^{\circ}$  (a coarser resolution of  $0.44^{\circ} \times 0.44^{\circ}$  is also available) and a 19 levels of hybrid vertical coordinate from ground up to 0.5 hPa (Simon et al. 2004). The model domain extended from  $95^{\circ}\text{E}$  to  $123^{\circ}\text{E}$  and  $7.5^{\circ}\text{S}$  to  $14^{\circ}\text{N}$ , covering both Peninsular Malaysia and East Malaysia. The land-surface was modeled with the Met office surface exchange scheme (MOSES) (Cox et al. 1999). A detail description of the model is given in Jones et al. (2004).

For the current study, the HadRM3P is driven by the Hadley Centre Coupled Model version 3, HadCM3 running for the IPCC SRES A1B emission scenario. The simulation was integrated for 141 years from 1960-2100 with every 6 h update of boundary conditions. However, for the climate change analysis, the baseline climate is calculated from the 30 years period of 1970-1999. The

end of 21<sup>st</sup> century climate was defined from a 30 years period from 2070-2099.

### STATION DATA AND BIAS CORRECTION

The station (Figure 1) data used in current study was obtained from Malaysia Meteorological Department (MMD). The parameters used in the study are temperature and rainfall available at daily resolution. The rainfall data is the daily accumulated amount. The temperature data used include the daily mean, daily maximum and daily minimum.

Two rainfall indices namely the extreme rainfall frequency (R99) and wet spell length (CWD) are defined as indicators for the extreme rainfall condition. The R99 is the frequency of days exceeding the mean of the annual 99<sup>th</sup> of the rainfall percentile. The CWD is the number of consecutive rain days. In this study, a day is considered raining if the daily accumulated rainfall amount exceeded 1 mm. Four different temperature indices were defined to represent the extreme temperature climate over a station. These include the cold days (TX01P), warm days (TX99P), cold nights (TN01P) and warm nights (TN99P). The cold days and warm days were defined as the percentage of days when the daily maximum values is less than the first percentile and more than the 99<sup>th</sup> percentile, respectively. The cold night and warm nights were defined as the percentage of days when the daily minimum values is less than the first percentile and more than the 99<sup>th</sup> percentile, respectively. The detail of the definition of these extreme temperature indices are given in Islam (2009).

The PRECIS simulation produces output at  $0.22^{\circ} \times 0.22^{\circ}$  grid resolution. The value on a grid is representative of an area averaged value within the grid and is known to contain systematic biases. To evaluate the extreme climate changes at the 17 selected stations, the gridded values from the model were then spatially interpolated to the stations locations using a bilinear interpolation technique. It is noted that interpolating the grid values to a single station do not generate extra information and at the same time inherited retain the systematic biases. Figure 2 shows an

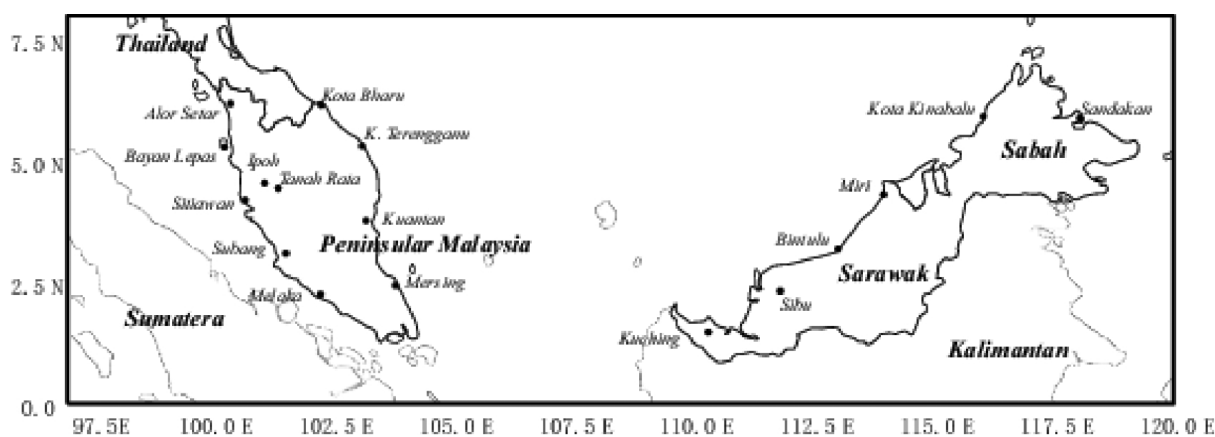


FIGURE 1. The locations of the 17 monitoring stations used in current study

example of the rainfall quantile-quantile plot (Q-Q plot) of the daily total rainfall. It indicates the simulated rainfall is systematically lower than the observed values for every high rainfall occurrences whilst for the low rainfall days (< 10mm), the model produces more rainfall amount. This suggests the model always under predicted the severe rainfall event during the wet seasons but over predict the dry season rainfall events. This discrepancy affects certain climate statistics calculated from the daily values, such as the extreme climate indices used in the current study. Hence, a bias correction algorithm is designed to remove the discrepancy of the simulated output before any subsequence analysis.

The bias correction algorithm employed in the study is based on the quantiles mapping algorithm (Boè et al. 2007). The mapping functions were defined separately for each of the climatological months. The data for each of the climatological months was first collected for both the observations and the PRECIS raw output values during the baseline period. The quantiles for each of the data set was then determined and compared with each other. The conventional quantile mapping methods first fit a suitable parametric distribution to the data. The comparison is then done on the fitted space. However, determination of the most appropriate distribution for certain meteorological elements such as daily rainfall is somewhat subtle and requires rigorous research and testing. In the current study, the quantiles were computed from empirical distribution instead, removing the need to pre-fit a parametric equation to the data sets. At each of the quantiles, the baseline value was adjusted to match that of the observed. For the rainfall value, the quantiles adjustment was based on multiplicative factors determined from the differences between the observation and the baseline. For the temperature, additive factors were used. Figure 2 shows

an example of the quantiles comparison between the observation and the raw PRECIS output as well as the bias corrected daily rainfall value at station Kota Bharu (Figure 1) for the baseline years. The same correction factors were then used to correct the future (2070-2099) projected values of rainfall and temperature. Readers are referred to Boè et al. (2007) for further mathematical treatment of the quantile mapping method.

## RESULTS AND DISCUSSION

### CHANGES OF FUTURE EXTREME RAINFALL CHARACTERISTICS

The extreme rainfall frequency was calculated from the bias corrected rainfall for both the baseline (1970-1999) and the future period (2070-2099). The differences over the climatological cycle are shown in Figure 3. The most notable projected changes appear to be the increasing frequency of high rainfall events during the autumn transitional – early winter monsoon period in the month of September to November. These stations located largely along the western coast of the Peninsular Malaysia (Alor Setar, Bayan Lepas, Ipoh, Melaka, Subang and Tanah Rata). During the transitional monsoon period, the meteorology of the western coastal regions is dominated by late afternoon thunderstorm mostly driven by local convection and land-sea breezes. The warmer climate in the future may enhance the local convective activities and strengthens the land-sea thermal contrast and modulate higher rainfall intensity during this time of the year. This hypothesis requires further numerical experiment testing which is not cover in this study.

Stations located over the eastern coast of Peninsular Malaysia appear to be less affected by the warming. The

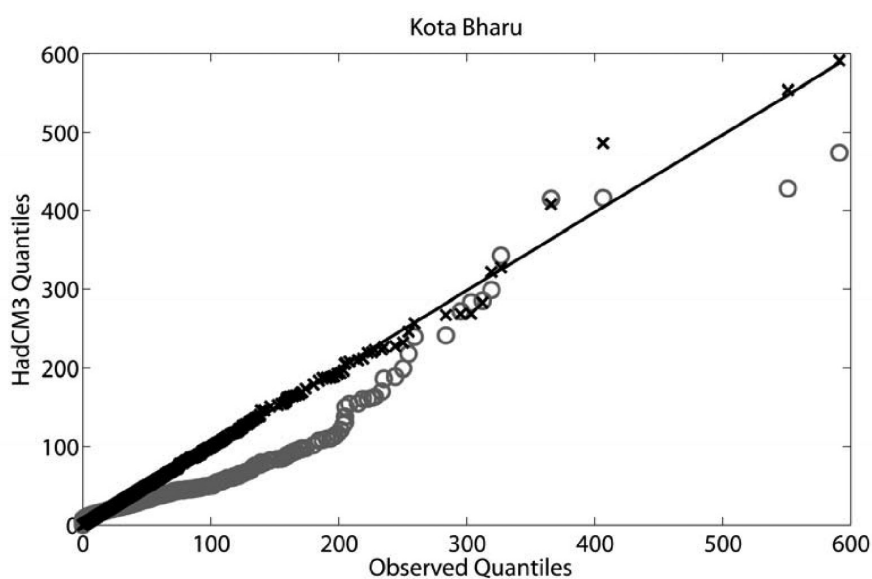


FIGURE 2. Quantile-quantile plot of the observed daily rainfall versus the raw PRECIS output (circles) and the bias corrected daily rainfall (crosses)

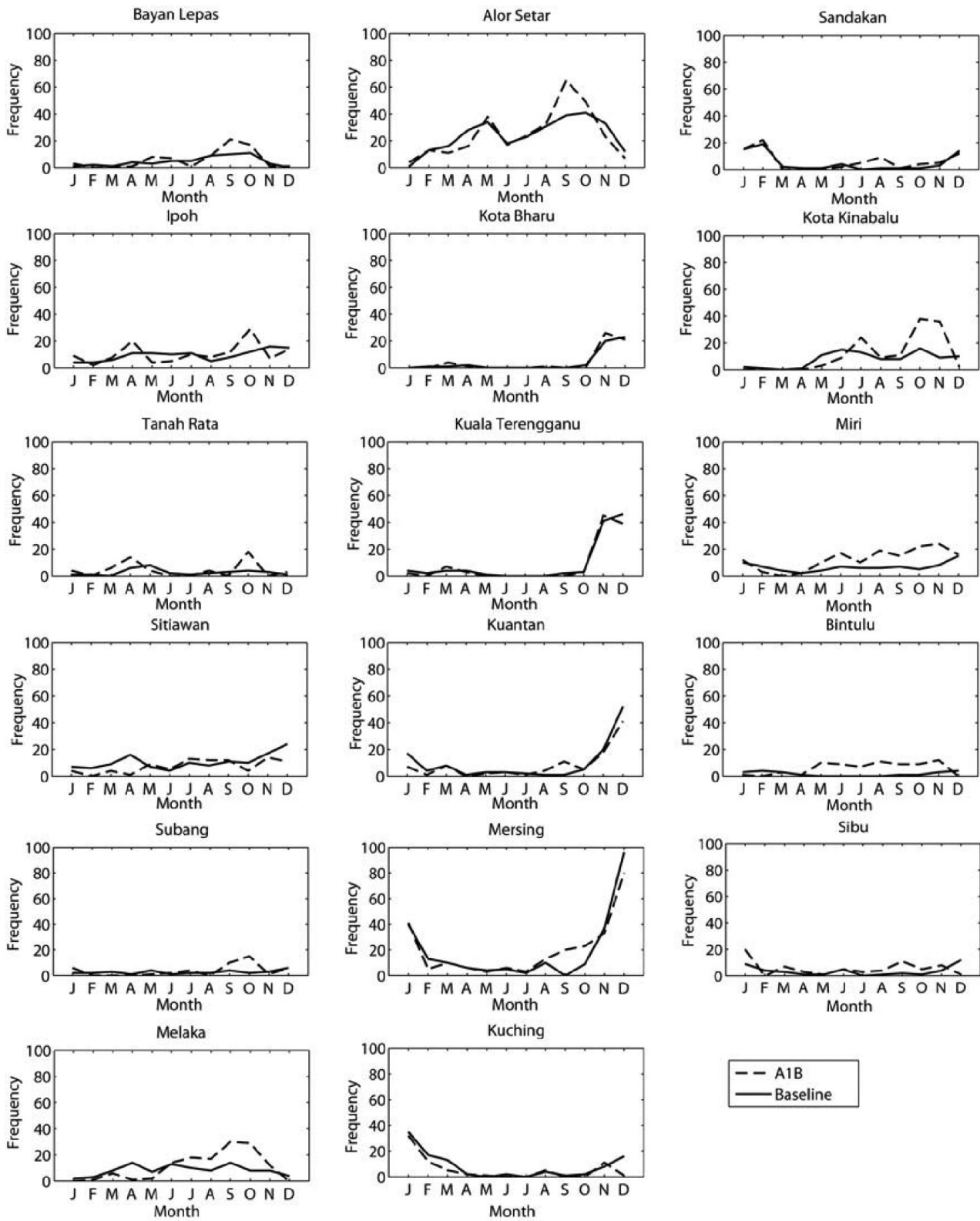


FIGURE 3. The frequency of days with rainfall amount exceeding the mean annual 99<sup>th</sup> percentile calculated from the PRECIS modeled baseline (solid) and the future period (dashed)

experiment suggests marginal decrease of extreme rainfall frequencies during the late winter monsoon season. Some stations located at the central east coast (Mersing and Kuantan) show signature of antecedent onset of raining season in the future with increasing pre-monsoon rainfall intensity. On the other hand, stations located over the northern coast of East Malaysia (i.e. Bintulu, Miri and Kota Kinabalu) show increasing frequency of extreme rainfall occurrence in the later half of the climatological months. Previous studies (both numerical and observational) have indicated the potential changes of the synoptic meteorology over the South China Sea to the warmer global climate (Hori & Ueda 2006; Juneng & Tangang 2010). However, how the projected increase of rainfall intensity is associated with the changes is currently unknown.

Figure 4 shows the semi-log diagram of the wet spell occurrence probabilities. The simulation projected increasing probabilities of wet spell with longer CWD. However, the changes of short CWD are not clear. The increment probability of longer wet spell is most remarkable at stations located over East Malaysia. These stations show increasing probabilities for longer wet spell as well as increasing CWD as compare to the baseline. The projected wet spell changes however are smaller for stations located over the east coast of Peninsular Malaysia. The increasing of consecutive raining days coupled with increasing high frequencies of extreme rainfall occurrence may render higher adaptation to climate change challenges for west coast regions of Peninsular Malaysia.

#### CHANGE OF FUTURE EXTREME TEMPERATURE CHARACTERISTICS

Changes in extreme temperature was examined based on four different indices, indicating the percentage of cold days, warm days, cold nights and warm nights. In general, the projected local mean temperature showed monotonic increment with averaged increment of  $\sim 1-4^{\circ}$  towards the end of the 21<sup>st</sup> century following the SRES A1B emission scenario (figure not shown).

Table 1 shows the percentage differences between the future and baseline extreme temperature. The extreme definition used here is based on the values from the corrected temperature. It is expected that as the world continue to warm, there are higher chances of the occurrence of warm extremes and lower occurrence probability for cold extremes. The result from the experiment generally is in agreement to this expectation. However the increment of the warm extreme occurrence is much larger than the decrement of the cold extreme. This indicates warmer shift of the temperature distribution coupled with an expansion of the warm tail. These characteristic changes were estimated in the experiment for both the day and the night time temperature extremes.

The results also showed larger changes in the night time temperature extremes compared to the day time temperature extremes. The cold night decrease percentages range from about -1.4% to -15.4% whilst the

cold days only decrease by about -0.3% to -1.7% across the nation. For the warm day occurrence, the projected increase range from about 28% to 75%. For the warm night occurrence, the projected percentage increase range from about 46% to 95%. This implies that some stations were projected to have almost all their future night time temperature exceeding those extremely hot night recorded during the baseline period. This suggests that elevated green house gases in the atmosphere may impose a larger impact on the night temperature variability as compare to the day time temperature. In addition, the greater percentage changes for warm night occurrence as compared to warm day occurrence indicate smaller diurnal temperature ranges in the future climate.

The projected changes of the warm night occurrences showed considerable spatial variations with the largest change over the stations located in the East Malaysia, particularly over the northern coast of the Borneo Island. The warm nights over the region are expected to increase to about 90% of the total future night. Over the Peninsular Malaysia, the increment of warm night occurrences were projected to be higher at the stations located along the eastern coast as compare with the stations over the western coast. In addition slightly higher increment chances of warm days were also projected for stations located over the northwest of Peninsular Malaysia. In general, there is no distinctive pattern of spatial variation of the characteristic change for both the cold days and cold nights occurrences.

#### CONCLUSION

The current study analyzed and projected the future changes of climate extremes by mean of numerical simulations and subsequent empirical bias correction treatment. Two indices that represent the rainfall extremes and four indices for the temperature extremes were examined. The projection estimated increase of probability of rainfall extreme occurrences during the autumn transitional period over the west coast of Peninsular Malaysia. Increase of rainfall extremes were also projected for the stations located over the East Malaysia, particularly during the later halve of the year. There is also an indication of earlier shift of monsoon onset at certain regions over the East Malaysia.

The projection estimated a large increase of temperature warm extreme but a smaller decrease of cold extremes, suggesting asymmetric expansion of the temperature distribution towards the warmer tail. The results also indicated higher impact of the elevated GHG to the night time temperature extremes as compare to the day time temperature extremes. The higher increment percentages of warm night as compared to the warm day suggest decreasing diurnal temperature ranges. The warm night frequencies were projected to increase the most at stations located over the East Malaysia and over the western coast of Peninsular Malaysia.

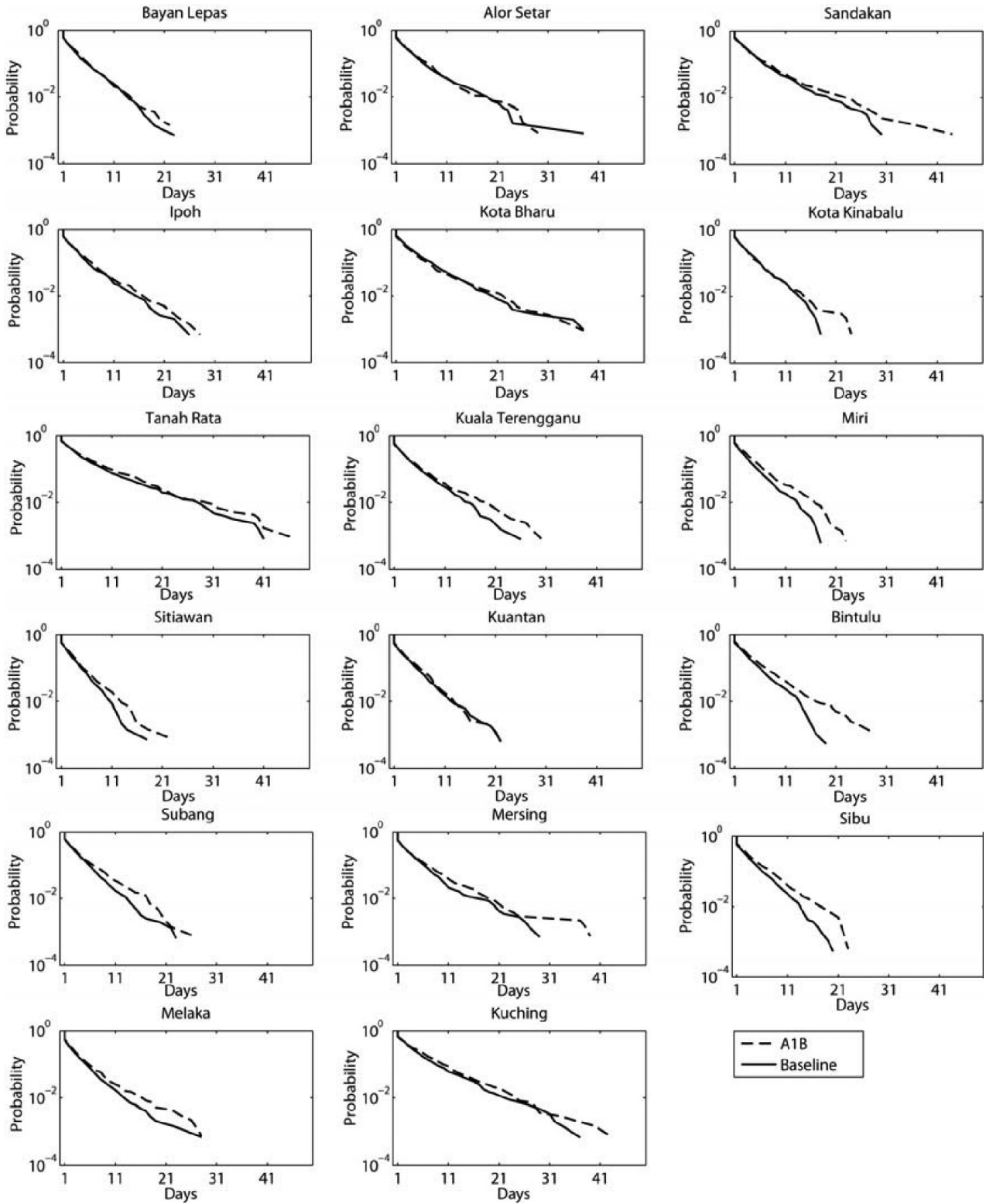


FIGURE 4. The distribution of wet spell lengths for each of the 17 stations in the study

TABLE 1. The computed changes (future minus baseline) of day time and night time temperature extremes

Station	Cold Days % Change	Warm Days % Change	Cold Night % Change	Warm Night % Change
Bayan Lepas	-1.38	73.97	-7.76	83.92
Alor Setar	-0.34	44.38	-1.37	87.83
Kota Bharu	-1.01	58.89	-7.48	66.60
Kuala Terengganu	-1.28	51.92	-6.27	62.01
Sitiawan	-0.99	67.21	-1.99	90.81
Ipoh	-0.56	69.02	-13.37	69.23
Tanah Rata	-0.66	56.45	-1.93	71.07
Subang	-0.90	58.23	-15.43	66.92
Kuantan	-1.66	62.36	-12.87	70.76
Melaka	-2.05	50.21	-10.44	95.44
Mersing	-0.50	45.30	-6.46	45.85
Kuching	-1.26	51.05	-1.62	87.74
Sibu	-1.54	50.04	-11.66	81.90
Bintulu	-0.40	27.96	-6.27	91.12
Miri	-0.74	48.98	-12.21	95.07
Kota Kinabalu	-1.68	56.37	-13.37	90.22
Sandakan	-0.50	50.03	-12.34	52.89

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