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SUMMARY OF DOCTORAL THESIS

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Title: Study on rainfall time series in Malawi, an analysis of the temporal and spatial fluctuation, linkage with global sea surface temperature
（マラウイにおける降雨量時系列に関する研究．時間的空間的変動、全球海水面温度とのリンクの解析）

This research work focuses on three studies that can be summarized as follows;

The first part covers a study on rainfall seasonality and spectral analysis on the inter annual fluctuation of rainfall time series in Malawi that was conducted using a 31 year time series from nine selected rain gauge stations with the aim of analyzing the spatial and temporal characteristics of rainfall in Malawi. The rainfall data were first screened to make sure they were consistent, homogenous and stationary. Rainfall seasonality was assessed using the Seasonal Index, developed by Walsh and Lawler (1981) while the seasonality of rainfall regime and heterogeneity of rainfall amounts was evaluated by using the Precipitation Concentration Index described by Oliver (1980). Spectral analysis was carried out to evaluate the periodicity of the rainfall time series. The Maximum Entropy Method was used in this study. The study found strong inter-annual fluctuation of rainfall, with topography and location playing major roles in the annual rainfall distribution. The seasonal index and precipitation concentration index showed that rainfall is highly seasonal and highly concentrated with most stations receiving rainfall in three months, except for Nkhatabay which has seasonal rainfall. The intra annual rainfall distribution was highly variable in time and space. Cross correlations among the stations suggested two distinct zones, zone 1 composed of Karonga and Nkhatabay and zone 2 composed of Bolero, Kasungu, Salima, Dedza, Mangochi, Makoka and Ngabu. Spectral analysis of the rainfall time series revealed cycles at five to eight years, suggesting links with the El Nino Southern Oscillation and double the period of the Quasi Biennial Oscillation.　Apart from the common cycles, the rainfall time series of the two zones showed periods of 13.64 and 10.06 years, respectively, which suggests links with the solar cycle. These cycles are consistent with those found in other southern Africa countries.

Secondly, the evaluation of the teleconnection between Malawi rainfall and sea surface temperature was conducted. Correlation between rainfall in Malawi and sea surface temperature (SST) were studied to elucidate the linkage between SST and rainfall. The study used SSTs for the period 1979–2011 and rainfall data for 1981–2012 from nine stations, which were grouped into two zones on the basis of inter-station rainfall correlations. The Pearson correlation coefficient was used to test the hypothesis that the main influence on summer rainfall in Malawi was the Indian Ocean SST rather than the Pacific or Atlantic SST. We found that summer rainfall was more strongly correlated with the Indian Ocean SST compared to the Atlantic and Pacific Ocean SSTs. The correlations were more significant for northern stations than for central and southern stations. These results agree with other findings, the suggestion being that different climatic drivers influence the climate of different parts of Malawi. Northern areas are strongly influenced by the SST Indian Ocean dipole, whereas central and southern areas are strongly linked to the SST in the subtropical Indian Ocean. The

results reveal that SST in the Atlantic Ocean off South Africa also affects Malawi rainfall. Further analysis of Zone 1 rainfall showed that November to January rainfall for Zone 1 has a significant inverse relationship with SST in Indian Ocean and East, South China Sea while the February to April rainfall for Zone 1 showed significant negative relationship with equatorial Pacific SST in the Nino region and significant positive correlation with SST in the Australasia region suggesting that ENSO events in the region affect rainfall in Malawi. December to February rainfall for Zone 2 showed significant positive correlations with SST in the Australasia region also suggesting linkage with ENSO events in the Pacific Ocean. At Lags 5 and 6 months of February to April rainfall of Zone 1, significant positive and negative correlations were found between SST and rainfall. Differentiating the positive and negative SST at Lags 5 and 6 months and correlating the result with February to April rainfall significantly increased the resulting correlations. For example at Lag 6 months, the correlation between February to April rainfall and negative SST time series was ($r<-0.45$) was -0.506 while the correlation between February to April rainfall and positive SST time series ($r>0.45$) was 0.469. However, the correlation increased to 0.562 after correlating the SST differenced time series and February to April rainfall. Similar observations were noted for Lag 6 months where the correlation between February to March rainfall and SST increased to 0.550after using the SST differenced time series. We conclude that the Indian Ocean SST, including in particular the SST dipole strongly influences Malawi rainfall and that ENSO event in the Nino region and Australasia region significantly influence rainfall in Malawi.

Lastly prediction of Malawi summer rainfall from global sea surface temperature was studied. This study deals with a way of predicting Malawi rainfall from global sea surface temperature (SST) using a simple multiple regression model. Using links between Malawi rainfall and SST based on statistical correlations that were evaluated from our previous study, the regions with significant positive and negative correlation between SST and Malawi rainfall were selected as predictors for use in rainfall regression modeling. The student t test was used to evaluate the significance of the predictors as to whether they should be used in rainfall modeling. Monthly rainfall data from nine stations in Malawi grouped into two zones on the basis of inter-station rainfall correlations were used in the study. The predictors for Zone 1 model were identified from the Atlantic, Indian and Pacific oceans while those for Zone 2 were identified from the Indian and Pacific Oceans. Regression models were developed from Lag 0 to 11 months for all the two Zones. The models were then evaluated by looking at the correlation between observed and predicted rainfall, root mean square error and BIAS. The models that gave satisfactory results were then selected as the prediction models. The correlation between the fit of predicted and observed rainfall values of the models were satisfactory with $r = 0.81$ and 0.54 for Zone 1 and 2 respectively (significant at less than 99.99%). The results of the models are in agreement with other findings that suggest that SST anomalies in the Atlantic, Indian and Pacific oceans have an influence on the rainfall patterns of Southern Africa. We conclude that SST in the Atlantic, Indian and Pacific Oceans is correlated with Malawi rainfall and can be used to predict rainfall values.