Investigation of Rainfall Variability and Trends in the Indonesian Region (1900 – 2008)

Muhammad Yusuf Awaluddin, B.Sc.

A thesis submitted in fulfilment for the degree of Master of Science

School of the Environment
Faculty of Science and Engineering
Flinders University of South Australia

4th July, 2011
# Table of Contents

Abstract ................................................................................................................................. iv  

Declaration ............................................................................................................................ v  

Acknowledgements .............................................................................................................. vi  

List of figures ...................................................................................................................... vii  

Chapter 1: Introduction .......................................................................................................... 1  
  Chapter Summary ............................................................................................................. 1  
  1.1. Background ................................................................................................................ 1  
  1.2. General aims and research objectives ....................................................................... 3  
  1.3. Organisation of the thesis ......................................................................................... 4  

Chapter 2: Literature Review ............................................................................................... 5  
  Chapter Summary ............................................................................................................. 5  
  2.1. Geography of the Indonesian regions ........................................................................ 5  
  2.2. Climate of the study area ........................................................................................... 7  
  2.3. Indonesian sea surface temperature ......................................................................... 12  
  2.4. Modes of climate variability .................................................................................... 19  
  2.5. Gaps of knowledge .................................................................................................. 29  

Chapter 3: Data and Methods ............................................................................................. 31  
  Chapter summary ............................................................................................................ 31  
  3.1. Data .......................................................................................................................... 31  
    a. Rainfall ....................................................................................................................... 31  
    b. Sea surface temperature (SST) ................................................................................ 33  
    c. Climate indices: ENSO ............................................................................................ 34  
    d. Climate indices: Inter-decadal Pacific Oscillation (IPO) ........................................... 35  
    e. Climate indices: Dipole Mode Index (DMI) ............................................................... 35  
  3.2. Methods .................................................................................................................... 35
a. Correlation analysis ..................................................................................................... 35
b. Empirical orthogonal function (EOF) ......................................................................... 36
c. Wavelet analysis ......................................................................................................... 38

3.3. Tools used for data analysis ...................................................................................... 39

Chapter 4 : Results and Discussion .................................................................................... 40

Chapter summary ............................................................................................................ 40

4.1. Annual mean rainfall and recent trends ................................................................... 40
4.2. Intra-annual rainfall patterns and recent trends ....................................................... 44
4.3. Spatial characteristics analysis ................................................................................. 49
4.4. Periodicity of rainfall variations .............................................................................. 50
   a. Intra-annual periodicity ............................................................................................... 50
   b. Inter-annual periodicity ............................................................................................... 53
4.5. Influence of large scale climate drivers ................................................................... 53
   a. Entire Indonesia region ............................................................................................... 53
   b. Regional differences ................................................................................................... 56
   c. Relationship between SST anomalies and climate indices ........................................ 61
4.6. Further analysis of recent rainfall trends ................................................................. 64

Chapter 5 : Summary and Conclusion ................................................................................. 77

Appendix A: Miscellaneous Statistical Results ............................................................... 79
Appendix B: Wavelet Analysis of Climate Drivers ............................................................ 81
Appendix C: SST Trends in the Indonesian Region ........................................................... 84
References .......................................................................................................................... 85
Abstract

Characteristics of rainfall variability and trends in Indonesian region are investigated for the period 1900-2008 based on monthly gridded rainfall data. Standard statistical methods and multivariate statistical methods are used to examine rainfall variability and its trends. This study identified a significant decline in annual-mean rainfall in the entire region of more than 20% commencing in the late 1980s. There are only two dominant rainfall modes calculated from Empirical Orthogonal Function (EOF) that accounts for about 38% of variance occurring in the centre of the region. A smaller variance of about 9% appeared in the second EOF mode with the negative spatial loading concentrated in the southern part of the region.

Previous analyses of Indonesian rainfall data indicated a tight seasonal coupling between ENSO anomalies and rainfall anomalies during the dry season peaking in August. Nevertheless, rainfall anomalies tended not to persist from the dry season into the wet season. Indonesian rainfall variability has dramatically changed from the early 1970s onwards. Instead of being seasonally confined, ENSO events have switched into a mode in which they also control Indonesian rainfall anomalies outside the dry season.

This prolongation of ENSO influences and extended El-Nino episodes the early 1990s onwards explains the observed decline in annual-mean rainfall by ~20% in most of the Indonesian region and why this decline occurred spatially coherent and during most seasons of the year. Given the widespread impacts of ENSO events, we anticipate these findings to be an important clue in the understanding of climate-change impacts on changes in modes of climate variability. For instance, the sudden onset and persistence of intensified ENSO influences over the last 40 years, revealed here via an analysis of Indonesian rainfall anomalies, could point to a dramatic and permanent shift in ENSO-related climate variability influencing most areas across the tropical Pacific Ocean.
Declaration of Authenticity

‘I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text’.

Muhammad Yusuf Awaluddin, Adelaide, 4th July 2011
Acknowledgements

Firstly, I would like to thank to A/Prof Jochen Kaempf, for his enthusiasm, trust, encouragement and advice. I also wish to acknowledge Dr. Caecilia Ewenz for her co-supervision. Thank you for sharing your knowledge and time.

This thesis would not have been possible without the support of a scholarship from the Ministry of National Education (DIKTI) and Padjadjaran University (UNPAD) Indonesia, for which I am extremely grateful.

Data used in this study was provided by the University of Delaware, NOAA, HadISST, BoM, and KNMI Climate Explorer. I am thankful for the generosity extended by these organisations to facilitate this research project. In addition, I would like to acknowledge Dr. Edvin Aldrian, Dr. Geert Van Oldenborg, Dr. John Bennet, Dr. Agus Susanto, Dr. Iskhaq Iskandar, and Prof. Kenji Matsuura for constructive discussions and correspondence throughout the study.

I would also like to acknowledge and thank my colleagues at Flinders University in the School of Environment for their interest, support and company during the time I was there.

I dedicate this work to my parents, my wife Tiena Indra Pratami and my lovely son Muhammad Fathi Farrell Akbar (Babay) for their surrenders and sacrifices, patience and prayers all the time for me, I love you forever.
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Caption</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Map of the study area.</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Location of the inter-tropical convergence zone (ITCZ) and the South Pacific convergence zone (SPCZ) in the South Pacific region. From Trenberth (1991).</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Rainfall classification in the Indonesian region. From Aldrian &amp; Susanto (2003).</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Climatological average monthly rainfall for regions A, B, and C. The dotted lines refer to one standard deviation from the mean. From Aldrian &amp; Susanto (2003).</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>Monthly mean TRMM sea surface temperature (°C) superimposed with Quick Scatterometer (QuikSCAT) wind (m/s) in (a) August and (b) February. Data are averaged from December 1997 to June 2004 and from July 1999 to January 2005, respectively. From: Qu et al. (2005).</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Peak-to-peak SST variability in Indonesian seas. From Qu et al. (2005).</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>Monthly climatological mean of zonal wind stress derived from ERS1/2, NSCAT, and QSCAT scatterometers based on monthly mean data from January 1998 to December 2003. Seasonal monsoon winds are clearly seen. Stronger eastward zonal winds from the Australian continent affect the southern part of Indonesia during the SE monsoon (April–October). Conditions are reversed during the NW monsoon (October–April). Solid arrows in the months of February and August represent the general pattern of wind directions during the NW monsoon and SE monsoon, respectively. From: Susanto et al. (2006).</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>Indonesian Throughflow pathways and estimates of</td>
<td>19</td>
</tr>
</tbody>
</table>
total volume transport (in \( \text{Sv} = 10^6 \text{m}^3/\text{s} \)). From Gordon (2005).


11 The regions of Nino indices in Pacific Ocean

12 a) Time series of SOI. From: www.mfe.govt.nz. b) Seasonal SOI from 1990-2008 derived from BoM (2002). c) Seasonal NINO 3.4 from 1990-2008 obtained from HadISST 1.1 data.

13 Positive (a) and negative phase (b) of the IOD. Adopted from http://www.jamstec.go.jp/frsgc/research/d1/iod/


16 Definition of different rainfall regions used in this study.

17 SST regions (A*, B* and C*) considered in this study (dashed boxes).

18 Morlet wavelet basis. The left plot shows the real part (solid) and imaginary part (dashed) for the wavelets in the time domain. The right plot shows the corresponding wavelets in the frequency domain. From Torrence & Compo (1998).

19 a) Annual mean rainfall (cm/month) in Indonesia, and b) standard deviation of annual-mean rainfall (cm/month) from 1900-2008.

20 a) Annual-mean Indonesian rainfall from 1900 to 2008 (blue) with 5-year moving average (red line). b) Annual-mean percentages of rainfall values with reference to the long-term mean for the entire period. Shown is 11-year moving averages.

21 Annual-mean rainfall (mm/month) in regions A, B, C and D (see Fig. 12)

22 Climatological monthly mean precipitation (mm/month) in a) region A, b) region B, c) region C, and d) region D from 1900–2008 (solid lines). Dashed lines denote the mean value ±1 standard deviation. The horizontal axis
represents month while the vertical axis represents rainfall (mm/month).

23 Climatological monthly mean precipitation (mm/month) in a) regions A, b) region B, c) region C and d) region D from 1994–2008 (solid lines). Dashed lines denote values ±1 standard deviation. The horizontal axis represents month and the vertical axis represents rainfall (mm/month).

24 Differences in climatological monthly mean precipitation values in a) region A, b) region B, c) region C, and d) region D between 1900–2008 (blue) and 1994–2008 (red). The horizontal axis represents month (January – December) and the vertical axis represents rainfall (mm/month).


26 The first EOF for a) spatial loading and b) PC of Indonesian rainfall for 1900–2008 accounting for 38% of the observed variability.

27 The second EOF for a) spatial loading and b) PC of Indonesian rainfall for 1900–2008 accounting for 9% of the observed variability.

28 Wavelet analysis of rainfall in region A for 1900 – 2008. a) Monthly-mean rainfall (mm/month), b) wavelet power spectrum (line shows cone of influence; i.e. data points below this line are statistically insignificant), c) global wavelet spectrum (dashed line denotes the 95% significance level), and d) wavelet time series for the 0.5-1 year periodicity range.

29 Wavelet analysis. Same as Figure 28, but for region B.

30 Wavelet analysis. Same as Figure 28, but for region C.

31 Wavelet analysis. Same as Figure 28, but for region D.

32 Lag correlations between rainfall in the entire Indonesia region and climate indices (Niño 3.4, DMI, IPO), and SST anomalies in regions A*, B* and C*. X-axis represents lag (months), and y-axis gives the correlation coefficient. Note: lag positive, climate indices and SST
anomalies leading index.

33 Same as Figure 32, but for rainfall anomalies in region A.

34 Same as Fig. 32, but for rainfall anomalies in region B

35 Same as Fig. 32, but for rainfall anomalies in region C.

36 Same as Fig. 32, but for rainfall anomalies in region D

37 Lag correlations between SST anomalies in regions A*, B* and C* and climate indices (Niño 3.4, DMI and IPO).

38 Indonesian rainfall anomalies (cm/month) during 1900-2008. Shown are averages for DJF, MAM, JJA, SON, and the annual mean. Anomalies refer to the long-term mean value for the 1900-1979 period of 22.5 cm/month.

39 Schematic of seasonally ENSO-controlled annual-mean rainfall patterns.

40 Time series (1900-1969) of rainfall anomalies (annual mean) and JJA values of a) Niño 3.4 and b) DMI. The data are normalised by one standard deviation (units on the y-axis). The standard deviations for rainfall, Niño 3.4, and DMI anomalies are 1 cm/month, 0.6 °C, and 0.2 °C respectively.

41 Correlation value of the correlation between the combined index (5) and annual-mean rainfall anomalies. The best correlation of -0.77 is given for SON values of climatic indices and ε = 0.3.

42 Observed and reconstructed annual-mean rainfall anomalies based on ε = 0.3. a) JJA values of climate indices. b) SON values of climate indices. Dashed lines show differences between reconstructed and observed values. Y-axis values are in cm/month. Arrows indicate the period of calibration (1900-1979). Anomalies refer to the long-term rainfall average over the calibration period.

43 Sliding-window cross-correlation between JJA values of Niño 3.4 with seasonal rainfall anomalies in JJA, SON, DJF and MAM of the following year with visibility assistance in grey area.

44 Sliding-window cross-correlation between SON values of Niño 3.4 with seasonal rainfall anomalies in SON and DJF, and MAM and JJA of the following year with visibility assistance in grey area.
45 Same as Fig. 43, but using JJA values of DMI as a basis.

46 Same as Fig. 44, but using SON values of DMI as a basis.

47 11-year sliding-window correlations between JJA rainfall anomalies and rainfall anomalies in the following seasons with visibility assistance in grey area.

48 11-year sliding-window correlations between SON rainfall anomalies and rainfall anomalies in the following seasons with visibility assistance in grey area.

A1 Normal-probability plot of the rainfall distribution (1900 – 2008) for the Indonesian region.

A2 The first 24 EOF modes including variance explained.

B1 Wavelet analysis for monthly mean Indonesian rainfall anomalies for the period 1900-2008.

B2 Wavelet analysis for monthly mean values of Nino 3.4 for the period 1900-2008.

B3 Wavelet analysis for monthly mean values of SOI for the period 1900-2008.

B4 Wavelet analysis for monthly mean values of IOD for the period 1900-2008.

B5 Wavelet analysis for monthly mean values of IPO for the period 1900-2008.

C5 Time series of SST anomalies in a) region A*, B*, and C*. b) Global SST for the period from 1900 to 2008. Based on HadISST1 data.