

JCU ePrints

This file is part of the following reference:

Flay, Shaun Alexander (2006) *Climatology of Queensland landfalling tropical cyclones: evaluating instrumental, historical and prehistorical records*. PhD thesis, James Cook University.

Access to this file is available from:

<http://eprints.jcu.edu.au/17525>



**Climatology of Queensland Landfalling Tropical Cyclones:
Evaluating Instrumental, Historical and Prehistorical
Records**

**Thesis submitted by
Shaun Alexander FLAY
in February 2006**

**for the degree of Doctor of Philosophy
in the School of Tropical Environmental Studies and Geography
James Cook University**

STATEMENT OF SOURCES

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree of diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

Signature

1 November 2006

Date

STATEMENT OF ACCESS

I, the undersigned, author of this work, understand that James Cook University will make this thesis available for use within the University Library and, via the Australian Digital Theses network, for use elsewhere.

I understand that, as an unpublished work, a thesis has significant protection under the Copyright Act and;

I do not wish to place any further restrictions on access to this work.

Signature

1 November 2006
Date

ELECTRONIC COPY

I, the undersigned, the author of this work, declare that the electronic copy of this thesis provided to the James Cook University Library is an accurate copy of the print thesis submitted, within the limits of the technology available.

Signature

1 November 2006

Date

ABSTRACT

Knowledge of the probability of occurrence of major tropical cyclone events forms an integral part of developing hazard mitigation strategies in regions prone to their impact. Queensland landfalling tropical cyclones are analysed in this study in order to provide a climatology of event frequency and magnitude. The adopted modelling approach differs from previous studies in the region in that it focuses specifically on the incorporation of historical and prehistorical information. The availability of such records offers a means to test whether the satellite-based instrumental record, which encompasses only the last few decades, provides a representative sample with which to characterise extremes of the process.

A methodology based on Bayesian statistical techniques is presented and applied to facilitate the incorporation of historical information. Through this approach, historical observations are specified as prior information for models of seasonal activity and intensity. When combined with reliable information from the instrumental record, subsequent inferences on the landfall climatology can be made with greater precision and confidence. Among the statistical models considered is a Poisson distribution for seasonal counts, a Generalised Linear Model that incorporates an index of ENSO as a predictor for seasonal activity, and a Generalised Pareto Distribution for tropical cyclone minimum central pressures.

The inclusion of historical information is shown to lead to increased certainty in parameter estimates for these models. Furthermore, the incorporation of historical information on storm intensities leads to predictions of the frequency of major

landfall events that are higher than what would be expected from an analysis using only the instrumental record. A further outcome of implementing a Bayesian strategy is the development of predictive distributions showing the probability of specific levels being reached in future periods.

A trend analysis identified the presence of decadal to multi-decadal variability in seasonal storm numbers and in the strength of the relationship between ENSO and tropical cyclone activity. A statistically significant downward trend in landfalling storm intensities over the 20th century was also detected. For Coral Sea region tropical cyclones, there is also evidence of decadal variability in storm numbers. Interestingly, a marginally significant upward trend in peak intensities is found for the Coral Sea region over the period 1960/61-2004/05, which is in contrast to the general downward trend in landfall intensities. No evidence is found to suggest that ENSO has a direct effect on either regional or landfall storm intensities.

A simulation model was then derived from the Coral Sea region satellite record and subsequently applied to generate a series of landfall events. Comparison of the observed landfall record with this simulated series showed close agreement. A further comparison of observed and simulated records with prehistoric data, previously reconstructed from storm ridge sequences found throughout the Great Barrier Reef region, showed some discrepancy. In particular, estimates based on observed and simulated data were tending to underestimate the frequency of major events. Uncertainties inherent in reconstructing storm intensities from the geological record complicate the utility of this comparison, however, suggesting further work is needed to address the use of prehistoric records as an independent data source.

ACKNOWLEDGEMENTS

Foremost I would like to thank my supervisor Professor Jonathan Nott for his continued support during the course this research. Jon provided the catalyst for the project and his invaluable contribution through ongoing discussions on the topic has provided the encouragement necessary to complete this thesis.

I am also indebted to the assistance of Greame Hubbert and Steve Oliver from Global Environmental Modelling Systems (GEMS) for providing several of the physical models used in Chapter 7 as well as technical support on their application.

TABLE OF CONTENTS

ABSTRACT	i
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	ix
LIST OF FIGURES	x
CHAPTER 1: INTRODUCTION	1
CHAPTER 2: QUEENSLAND PERSPECTIVE	8
2.1 Introduction	8
2.2 Queensland Tropical Cyclones	8
2.3 Tropical Cyclone Hazards	14
2.3.1 Severe Winds	15
2.3.2 Coastal Flooding	16
2.4 Available Data Sources	18
2.4.1 Best-Track Database	18
2.4.2 Prehistorical Records	23
2.5 Summary	24
CHAPTER 3: LITERATURE REVIEW	26
3.1 Introduction	26
3.2 Risk Prediction Concepts	28

3.3 A Review of Sampling Strategies	30
3.3.1 Fixed Subregion Approach	31
3.3.2 Basin-Wide Approach	32
3.4 The Issue of Representativeness	34
3.4.1 Representation of Uncertainty	35
3.4.2 Temporal Variability	37
3.5 Incorporation of Historical Information	40
3.5.1 Bayesian Approach	41
3.5.2 Other Approaches	43
3.6 Summary	44
CHAPTER 4: QUEENSLAND LANDFALLING TROPICAL CYCLONES: COUNTS	46
4.1 Introduction	46
4.2 Data	47
4.3 Model for Seasonal Activity	49
4.3.1 Combining Historical and Instrumental Counts	51
4.4 Relationship to ENSO	55
4.4.1 Regression Analysis	55
4.5 Trend Analysis	62
4.5.1 Trends in Storm Counts	63
4.5.2 Temporal Variability in the ENSO Relationship	68
4.6 Summary	70

CHAPTER 5: QUEENSLAND LANDFALLING TROPICAL CYCLONES: INTENSITIES	72
5.1 Introduction	72
5.2 Data	73
5.3 Distribution of Storm Intensity	75
5.3.1 Extreme Value Analysis	75
5.3.2 Incorporation of Historical Information	82
5.3.3 Validation	88
5.4 Trends and the Effect of ENSO	92
5.4.1 Time Trends	93
5.4.2 ENSO Effects	95
5.5 Summary	97
CHAPTER 6: A SIMULATION MODEL DERIVED FROM CORAL SEA REGION TROPICAL CYCLONES	100
6.1 Introduction	100
6.2 Data	101
6.3 Trends and Climate	103
6.3.1 Counts	103
6.3.2 Intensities	107
6.4 Simulation Scheme	110
6.4.1 Track Generation	111
6.4.2 Simulated Intensities	115
6.4.2.1 Pressure Minimum	115
6.4.2.2 Timing of Pressure Minimum	122
6.5 Summary	125

CHAPTER 7: GEOLOGICAL RECORDS OF PAST STORM	
ACTIVITY	128
7.1 Introduction	128
7.2 Palaeotempestology	129
7.2.1 Overwash Deposits	129
7.2.2 Storm Ridge Deposits	132
7.3 Regional Sequences	134
7.3.1 Lady Elliot Island	136
7.3.2 Curacoa Island	137
7.3.3 Princess Charlotte Bay	138
7.4 Reconstructing Palaeostorm Intensity	139
7.4.1 Site Description	140
7.4.2 Tropical Cyclones Dinah and David	143
7.4.3 Modelling Water Levels	146
7.4.4 Results	151
7.5 Summary and Discussion	154
CHAPTER 8: COMPARATIVE ANALYSIS OF INSTRUMENTAL,	
HISTORICAL AND PREHISTORICAL RECORDS	158
8.1 Introduction	158
8.2 Comparison of Simulated and Observed Records	159
8.2.1 Analysis of Simulated Series	159
8.2.2 Quantile Comparisons	163
8.3 Uncertainty Analysis	165
8.3.1 Bootstrap Confidence Intervals	166
8.3.2 Simulated versus Observed	170

8.4 Comparisons with Prehistorical Record	172
8.5 Summary	176
CHAPTER 9: SUMMARY, DISCUSSION AND CONCLUSIONS	178
9.1 Introduction	178
9.2 Summary of Findings	179
9.3 Discussion	183
9.3.1 Comparison with Previous Studies	183
9.3.2 Implications for Risk Modelling	186
9.3.3 Trends	188
9.4 Future Research	191
9.4.1 Statistical Approaches	191
9.4.2 Incorporation of Prehistorical Records	194
9.5 Conclusions	195
REFERENCES	197

LIST OF TABLES

2.1	Australian scale for ranking tropical cyclone intensity.	12
2.2	Accuracy of key Australian region tropical cyclone parameters.	21
4.1	Summary statistics for landfalling tropical cyclone counts.	49
4.2	Summary of Poisson hypothesis test for seasonal counts.	50
6.1	GEV distribution fit to Coral Sea tropical cyclone minimum central pressures with covariates for time and space.	118

LIST OF FIGURES

2.1	Histogram of Coral Sea tropical cyclone day of occurrence.	9
2.2	Tracks of Queensland landfalling tropical cyclones over the period 1960/61-2004/05.	10
4.1	Time series of Queensland landfalling numbers over the period 1910/11-2004/05.	48
4.2	Posterior distributions of Poisson rate parameter and predictive distribution of future activity.	54
4.3	SOI time series for the period 1910/11-2004/05.	57
4.4	Posterior distributions of GLM regression parameters for seasonal activity conditional of ENSO.	60
4.5	Predictive distribution showing expected tropical cyclone numbers under extremes of ENSO.	62
4.6	Autocorrelation functions for seasonal counts.	64
4.7	Trend in Poisson rate parameter over period 1910/11-2004/05.	67
4.8	Temporal variability in the ENSO-tropical cyclone relationship.	69
5.1	Time series of minimum central pressures for Queensland landfalling tropical cyclones.	74
5.2	Plots of Generalised Pareto Distribution fit to landfall intensities.	81
5.3	Bootstrap sampling distributions of GPD parameters.	84
5.4	Posterior distributions of GPD parameters.	86
5.5	Posterior distributions of 50-year and 100-year return periods.	87
5.6	Predictive distributions showing probability of tropical cyclones reaching certain levels in 5 and 10-year periods.	88
5.7	Outline of type I censoring approach.	89

5.8	Comparison of return period estimates based of fitting GPD to tropical cyclone minimum central pressures.	91
5.9	Autocorrelation functions for seasonal intensities.	93
5.10	Estimate of median of the fitted GPD for storm intensities incorporating linear trend in scale parameter for time and SOI.	96
6.1	Time series of Coral Sea tropical cyclone counts and intensities.	102
6.2	Autocorrelation functions for Coral Sea seasonal counts.	105
6.3	Trends in seasonal arrival rate over time and for ENSO.	106
6.4	Autocorrelation functions for Coral Sea minimum central pressures.	108
6.5	Linear trends in median central pressures over time and for ENSO.	109
6.6	Selection of Coral Sea tropical cyclone tracks over the period 1960/61-2004/05.	112
6.7	Histograms comparing track characteristics of observed landfall events against simulated landfall events.	114
6.8	Plots showing minimum central pressures versus latitude, longitude and time of occurrence.	117
6.9	Trend in median of GEV distribution for minimum central pressures incorporating covariates for time and latitude.	120
6.10	Residual probability and quantile plots for GEV distribution fit to minimum central pressures.	122
6.11	Empirical density of ratio of time to maximum intensity versus time to landfall for Coral Sea landfalling events.	123
7.1	Locations of geological indicators of past tropical cyclone activity identified along the Queensland coast.	135
7.2	Storm ridge sequences at Curacoa Island and Princess Charlotte Bay.	138
7.3	Lady Elliot Island and surrounding platform reef.	141
7.4	Tracks of tropical cyclones Dinah and David.	144

7.5	Synoptic maps of tropical cyclones Dinah and David.	145
7.6	Outline of wave processes on coral reefs.	148
7.7	Modelled water and wave set-up levels at Lady Elliot Island for tropical cyclones Dinah and David.	152
8.1	Series of landfall central pressures generated from regional simulation model.	160
8.2	Diagnostic plots of GPD fit to simulated central pressures.	162
8.3	Threshold stability plots for GPD shape parameter.	163
8.4	Return period curves based on Poisson-GPD model fit to observed and simulated landfall central pressures.	164
8.5	Bootstrap 95% confidence limits for quantiles of output simulated series and subset of output series.	169
8.6	Comparison of uncertainty measures in parameter estimates of simulated and observed record.	171
8.7	Comparison of return period curves for observed and simulated landfall intensities, adjusted to the at-site level, and plotted against empirical estimates of ridge forming events at Princess Charlotte Bay and Curacoa Island.	175
9.1	Interdecadal Pacific Oscillation (IPO) time series.	190