Drought Predictions: Applications in Australia

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Abstract

Drought is a global and recurrent natural phenomenon, the inevitable consequence of meteorological variability. This natural hazard brings about devastating effects because water is one of the most fundamental commodities for human survival, and a lack of water can result in varying consequences, from mere inconvenience to life threatening instances. Drought cannot be prevented but its effects can be mitigated through the design of appropriate water resource infrastructure and management strategies. The goal of this thesis is to model the spatial and temporal characteristics of drought occurrence in Australia, the driest continent. In doing so predictions can be made, levels of risk can be evaluated and conditional estimates of drought can be based on climatic state variables.

For insight into the nature of drought in Australia, multivariate models of drought characteristics are developed. Preliminary analysis demonstrates high correlations between several drought characteristics, these are the drought severity, intensity and duration. This thesis applies the copula concept, which is a versatile means of modelling their dependence structure. Copulas are multivariate uniform distributions, which allow the joint behaviour of variables to be modelled independently from their marginal distributions. This research extends the application of copulas by investigating the effect of climate variability on copula models and subsequent drought characteristics. Two different copula families are fitted to the drought characteristics to demonstrate the importance of tail dependence when modelling extreme climatic events. An important application of these models is the calculation of return periods of extreme drought events exceeding certain thresholds, taking account of variability in climatic indices.

A second objective is to forecast drought at various spatial resolutions. The most straightforward method are regression and ARMA models that incorporate global climatic indicators. The effect of climatic variation on Australia's precipitation is examined by investigating the association between climatic indices and the multivariate distribution of drought at numerous sites across Australia. Two classification strategies for forecasting rainfall are compared using significance testing based on multiple comparison techniques. Further to this, rainfall forecasting relationships are explored using global sea-surface temperature anomalies.

The versatility of copula models is demonstrated through short-term rainfall predictions for neighbouring rainfall districts, using separate copulas conditioned on antecedent climate conditions. This technique is shown to improve rainfall predictions in neighbouring districts and improve estimates of drought probability.

Contents

Publications Arising from this Thesis

G. Wong, A. Osti, M. F. Lambert and A. V. Metcalfe. Drought Forecasting using adaptive stochastic models in New South Wales. In *Proceedings of the 30th Hydrology and Water Resources Symposium*, Hobart, Tasmania, 2006.

G. Wong, S. Need, P. Adamson, M. F. Lambert and A. V. Metcalfe. Modelling Multivariate Extreme Flood Events. In *Proceedings of the 30th Hydrology and Water Resources Symposium*, Hobart, Tasmania, 2006.

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G. Wong, M. Leonard, A. V. Metcalfe and M. F. Lambert. Drought analysis using trivariate copulas conditional on climatic states. *Journal of Hydrologic Engineering (Accepted for Publication)*, 2009.

Declaration

I hereby declare this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Acknowledgments

"Trust in the LORD with all your heart and lean not on your own understanding; in all your ways acknowledge Him, and He will make your paths straight."

Proverbs 3:5-6

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Glossary of Technical Terms and Abbreviations

Climate terminology

ENSO	El-Niño Southern Oscillation
IOD	Indian Ocean Dipole
IPO	Inter-decadal Pacific Oscillation
MEI	Multivariate ENSO Index
PDO	Pacific Decadal Oscillation
SLP	Sea Level Pressure
SST	Sea-surface temperature
SOI	Southern Oscillation Index

Drought terminology

PDHI	Palmer Drought Hydrololgical Index
PDSI	Palmer Drought Severity Index
SPI	Standardized Precipitation Index
S_t	SPI at time t

Statistical terminology

AIC	Akaike's Information Criterion
AEP	Annual Exceedance Probability
ARMA	Auto-regressive Moving Average

ARIMA	Auto-regressive Integrated Moving Average
R^2	Coefficient of determination
$\varphi(t)$	Copula generator
θ	Copula parameter
cdf	Cumulative Distribution Function
IFM	Inference Function of Margins
λ_L	Lower tail dependence
MLE	Maximum Likelihood Estimation
$C(u_1, \ldots, u_n)$	n-dimensional copula
pdf	Probability Density Function
λ_U	Upper tail dependence