GCM-derived Climate Change Scenarios and their Impacts on New Zealand Water Resources

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Abstract

The derivation of local scale climate information from experiments of coarse-resolution general climate models (GCM) can be addressed with variety of 'downscaling' techniques. 'Downscaling' refers to attempts to address the scale mismatch between information from the GCMs and that at which impacts occur. Methods for downscaling range from simple interpolation of climate model outputs to the use of regional climate models nested within larger-scale simulations. Some methods use statistical representations and interpolations; some use dynamic approaches. All of these methods depend on the quality of the initial simulation. Downscaling models fitted to present climatological records are generally referred to as empirical approaches. In a semi-dynamical approach, regional free atmospheric circulation indices simulated by a GCM were employed in this study to derive local climate variables from cross-scale relationships. The relationships were captured from historical records of simultaneously observed local variables and regional-scale circulation indices. Subsequent climate change scenarios were used in impact case studies of two New Zealand catchments' response and water resources.

The assessment of climate change impacts requires data at the spatial and temporal resolution at which impacts occur. The outputs of the current GCMs cannot be used directly in the development of specific climate change scenarios due to their coarse resolution although semi-empirical downscaling of GCM outputs to desired scales may offer an immediate solution by relating GCM outputs to single-site climate elements. Artificial neural network (ANN) and multivariate statistics (MST) models were adapted to derive the changes to a number of New Zealand site precipitation and temperature characteristics from free atmosphere circulation indices in a comparative study of their potential in downscaling outputs of GCM transient experiments. Both downscaling models capture similar general patterns from free atmosphere circulation indices.

Subsequently the ANN model was used to derive changes of mean monthly precipitation and temperature characteristics from circulation variables projected in a transient climate change experiment performed by the Hadley Centre coupled ocean-atmosphere global climate model (HadCM2). HadCM2 validated well with respect to

the National Centers for Environment Prediction reanalysis for its 'present climate' simulation. The predicted changes in seasonal mean sea level pressure fields over the 'New Zealand' region include an intensified anticyclonic belt coupled with negative pressure tendencies to the southwest, which is expected to squeeze stronger westerly winds over southern and central New Zealand.

Monthly mean precipitation and temperature time series for 18 points on a 0.25°latitude x 0.25°longitude grid over New Zealand were derived from the circulation indices. The indices were defined by anomalies (with respect to 1961-1990) of mean sea level pressure, zonal and meridional mean sea-level pressure gradients, atmospheric geopotential thickness between 850-700 hPa pressure surfaces, and wind speeds at 10 m above the surface over New Zealand for the period 1980-2099. Temperature and precipitation characteristics were examined for four tri-decades (1980-2009, 2010-2039, 2040-2069 and 2070-2099), and changes projected with respect to the pseudo-present tri-decade (1980-2009). An average temperature increase of 0.3-0.4°C per tri-decade is projected. Precipitation distribution was modelled using the Gamma probability function and the precipitation characteristics determined by the 'scale' and 'shape' parameters of the Gamma function. Precipitation is predicted to decrease over the north of North Island while marked precipitation increases are projected over the western, central and southwestern areas of the country. Changes in coefficients of variation of monthly precipitation exhibited both increases and decreases in interannual variability of precipitation over the region. Interannual variability in monthly precipitation increases to 1.2-2.2 and decreases to 0.5-0.9 times the pseudo-present coefficients of variations of monthly precipitation by 2070-2099 are projected. The tri-decade to tri-decade changes however, show no trend and this may be attributed to high frequency variations in monthly precipitation.

A water balance model was adapted to assess the impacts of changes in precipitation and temperature in two case studies of catchment response. Time series of monthly flows were simulated for each tri-decade. Data for each tri-decade were modelled using a lognormal distribution to generate a 3000-year data set, which was used in a risk analysis to determine the reliability, resiliency and vulnerability of the two water resource systems (hydro power and irrigation schemes). For both of these water resource systems, the changes in operational risk-descriptors with respect to the pseudo-present tri-decade, are within limits in which adjustments can be made, taking into account that traditional design criteria incorporate considerable buffering capacity for extreme events.

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I dedicate this thesis to our daughter Amy for whom all this seems worthwhile.

Table of Contents

List of Figures

List of Tables

List of abreviations and symbols

A_i	Snow accumulation in month i
alb	Albedo (short-wave radiation reflection coefficient)
ANN	Artificial neural networks model
CFC	chlorofluorocarbons
CH_4	Methane
CLIMPACTS	Climate change, variability and environment effects programme
CO_2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organization
°C	Degrees Celsius
C_p	Specific heat at constant temperature
Cv	Coefficient of variation
DJF	December, January and February
dp_m'	Anomalies of meridional mean sea level pressure gradient
dp_z'	Anomalies of zonal mean sea level pressure gradient
E	Evaporation estimate
E_a	Evaporation estimate which assumes an unlimited availability of energy
E_r	Evaporation estimate that assumes the ability of the system to remove moist air is not limiting
E_{rc}	Reference crop evapotranspiration
E[x]	Expected value
e_d	Vapour pressure
ENSO	El Niño South Oslillation
ETa	Actual evapotranspiration
ETp	Potential evapotranspiration
f	Cloudiness factor
G	Soil heat flux
GCM	Global circulation model
GG	Greenhouse gases
gpm	Geopotential meter

HadCM2	Hadley Centre coupled ocean-atmosphere global climate model
hPa	Hekta pascal
IISA	The International Institute for Applied Systems Analysis database
IPCC	Intergovernmental panel for climate change
IPO	Inter-decadal Pacific oscillations
IR	Infrared radiation
J	Joules
JJA	June, July and August
K_w	Diffusivity
l	Mixing length
LAM	June, July and August
LPIS	Level plains irrigation scheme
m	Meter
mf_i	Snow melt factor in month i
mm	millimeter
Mslp'	Anomalies of mean sea level pressure anomalies
MST	Multivariate Statistics model
µm	Micrometer
N	Total day length
n	Bright sunshine hours per day
NCEP	National centers for environmental prediction
NIWA	National Institute for water and atmospheric research limited
NOAA	National oceanic and atmospheric administration
N_2O	Nitrous oxide
NREBP	Artificial neural networks software package
PgC	Petagram of carbon
O_3	Ozone
P_{eff}	Effective precipitation
P_{effi}	Effective precipitation in month i
Pm_i	Observed precipitation in month i
ppbv	Parts per billion by volume
ppmv	Parts per million by volume
Prin	Principal component

Prob	Probability
Q_o	Observed monthly discharge
Q_p	Modelled monthly discharge
R_a	Extraterrestrial radiation
R_b	Baseflow
R_d	Direct runoff
R_n	Net radiation
R_s	Surface runoff
R_{ss}	Sub-surface runoff
R_t	Total runoff
RMSE	Root mean square error
S_{max}	Maximum storage capacity (depth)
SAS	Statistical analysis software
Sp	Degree of distribution spread
T	Mean air temperature
t	Time
thk'	Anomalies of atmospheric thickness between 700 and 850 hPa pressure surfaces
UK	United Kingdom
UV	Ultraviolet radiation
WBM	Water balance model
Wm^{-2}	Watts per square meter
WMO	World Meteorological Organization
wsp'	Anomalies of wind speed at 10m above surface
$\bar{x}$	Mean
z	Relative storage ($0 \leq z \leq 1$)
α	Reliability; sub-surface runoff proportionality coefficient; relative humidity index
β	Gamma function scale parameter; direct runoff coefficient
γ	Gamma function shape parameter; resiliency; sub-surface runoff exponential coefficient; psychometric constant
Γ	Gamma probability function
ν	Vulnerability

ε	Surface runoff coefficient
Δ	Slope of the saturated vapour pressure curve
σ	Stefan-Boltzmann constant