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New developments in the ANUCLIM bioclimatic modelling package

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Abstract: ANUCLIM (Xu and Hutchinson, 2011) is a software package used to support the spatial modelling of environmental and natural resources. It enables users to readily obtain estimates, in point and grid form, of monthly, seasonal and annual mean climate variables from supplied elevation dependent monthly mean climate surfaces and an underlying digital elevation model. The climate surfaces are derived by the ANUSPLIN package (Hutchinson, 2004) and support interrogation at sub-kilometre scale. A key strength of the ANUCLIM package is its ability to generate bioclimatic profiles from known species locations to predict and map species distributions, in both current and projected future climates. It can also generate a comprehensive set of climate parameters and growth indices for the modelling growth of crops and plants. The package currently has four programs, MTHCLIM, BIOCLIM, BIOMAP and GROCLIM. MTHCLIM is used to obtain estimates of monthly mean climate variables from supplied climate surfaces at specified points or grids. BIOCLIM, in conjunction with BIOMAP, is a bioclimatic prediction system based on the bioclimatic envelope method devised by Nix (1986). GROCLIM is used to generate plant growth indices based on a simplified model of plant growth response to light, thermal and water regimes (Nix, 1981). ANUCLIM Version 6.1 incorporates substantial upgrades. In particular, the package now allows each of its four component programs to systematically incorporate the impacts of projected climate change. These projected climate changes can be provided either as simple constants, or more commonly, as grids of broad scale changes as obtained from General Circulation Model outputs under various emission scenarios. For Australia, such grids can be obtained from the OzClim website of CSIRO (2007). This enables the systematic investigation of the impacts of projected climate change on socio-environmental systems.

Keywords: bioclimatic modelling, bioclimatic envelope, bioclimatic parameters, BIOCLIM, ANUCLIM, ANUSPLIN, climate change, climate surfaces

1. INTRODUCTION

The ANUCLIM package has evolved from the BIOCLIM program conceived by Nix (1986) and first implemented by June McMahon. Busby (1991) provided an introduction to BIOCLIM that contributed to its early adoption in analyses of natural resources and the environment. BIOCLIM first became available for general use in 1984, after which it was expanded into four separate programs, ESOCCLIM, BIOCLIM, BIOMAP and GROCLIM. ANUCLIM Version 5.0, released in 1999, was equipped with a graphical user interface (GUI) by David Houlder to replace the command-line driven front end programs. The ESOCCLIM program has been renamed to MTHCLIM in ANUCLIM Version 6.1 to make the name more representative of its functionality.

A key factor in the widespread use of the ANUCLIM package is the acknowledged accuracy of the supporting elevation dependent monthly mean climate surfaces produced by the ANUSPLIN package (Hutchinson, 2004). ANUSPLIN has become

one of the leading technologies in the development of spatial climate models and has been applied in many regions around the world (e.g., New et al., 2002; Hijmans et al., 2005; Hutchinson et al., 2009; McKenney et al. 2011).

The ANUCLIM package has been used extensively by research organizations, universities and government departments for scientific research, teaching and informing policy across study areas at various spatial scales (Lindenmayer et al., 1991; Lindenmayer et al., 1996; Fischer et al., 2001; Beaumont and Hughes, 2002; Hugall et al., 2002; McKenney, 2004; Lesser and Parker, 2004; Beaumont et al., 2005; Manning et al., 2005; Yesson and Culham, 2006; Rissler et al., 2006; Sweeney et al., 2007; DEWHA, 2009; Manning et al., 2010; Cooke et al., 2011). BIOCLIM, in conjunction with BIOMAP, is the most popular module of the ANUCLIM package. It can be used to generate bioclimatic profiles from known species locations to predict and map potential species distributions. Although BIOCLIM was developed for the mapping of native species, the underlying concept of an environmental envelope is simple and applicable to a broad range of landuse and landscape planning activities (Bryan, 2003).

The ANUCLIM package has also provided a practical and efficient means of building climatic and bioclimatic data layers across a wide range of regional scales for various modelling purposes (ABARES, 2000; Lesslie, 2000; CSIRO, 2006; Kriticos et al., 2012). MTHCLIM, BIOCLIM and GROCLIM are able to generate comprehensive climatic, bioclimatic and plant growth index data layers, for both current and projected future climates.

2. CLIMATE CHANGE AND BIOCLIMATIC MODELLING

Climate change is one of the greatest challenges of the 21st Century. As elsewhere, the climate of the Australian continent has changed significantly over the last century, as indicated in Figure 1. One of the most direct impacts of climate change is on ecosystems and their constituent plant and animal species. It is now widely accepted that global climate change is affecting many ecosystems around the globe (Hughes, 2000; Williams et al., 2003).

Bioclimatic modelling remains one of the few methods able to rapidly assess potential broad scale changes in the distributions of multiple species in response to a changing climate (Beaumont and Hughes, 2002; McKenney et al., 2007). Earlier versions of BIOCLIM only permitted simple constant percentage modification of precipitation and a latitude dependent modification of temperature to account for projected climate change, in line with the lack of reliable region specific climate change scenarios from the early global climate models (c.f. Pittock and Nix, 1986). There was no similar functionality for other climate variables and these modifications could not be

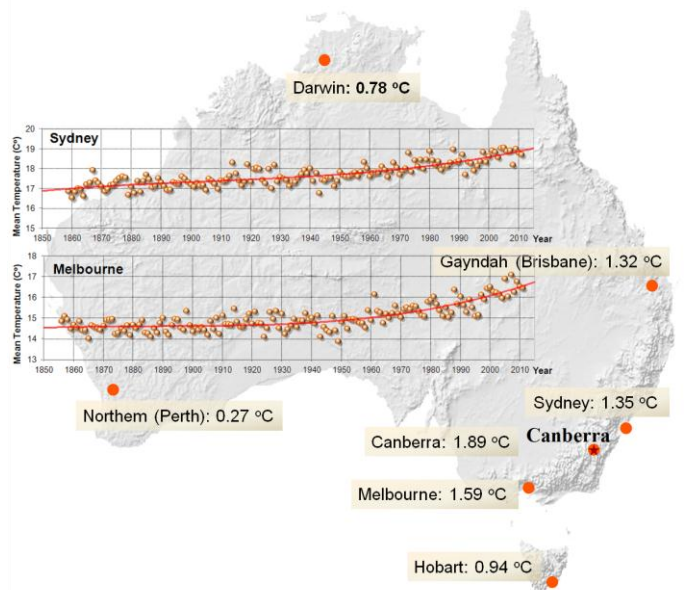


Figure 1. Temperature changes from 1900 to 2000 at major Australian capital cities

applied to either MTHCLIM or GROCLIM. Even so, BIOCLIM became one of the most widely used predictive models for estimating future changes in species distributions and guiding conservation decisions (Beaumont and Hughes, 2002; Pearson & Dawson, 2003; Téllez-Valdés and Dávila-Aranda, 2003; McKenney, 2004; Beaumont et al., 2005; Williams, 2007; Beebe et al., 2009).

There is an increasing need to support a wide range of applications in climate change and global warming research, and to take advantage of the region specific grid-based climate change fields now available. Although there remains uncertainty and some lack of consensus between recent climate scenarios (IPCC, 2007), the ability to apply region specific change scenarios provides more realistic spatial patterns of potential climate change, and expands the functionality of ANUCLIM in investigating the impacts of climate change on eco-systems. This will contribute to better solutions to mitigating impacts of climate change.

3. THE MAJOR REVISIONS ON ANUCLIM VERSION 6.1

ANUCLIM, and its GUI, have been extensively upgraded to Version 6.1 to permit a much more flexible grid-based climate modification procedure that can now be applied to all four components of the ANUCLIM package as illustrated in Figure 2.

ANUCLIM Version 6.1 does not supply climate change scenario grids. These must be supplied by the user. For Australia, climate change grids for a wide range of GCMs and greenhouse gas emission scenarios, relative to a baseline year of 1990, can be downloaded from the OzClim website of CSIRO Australia (CSIRO, 2007). The change grids must be supplied as additive changes for temperature, while for rainfall and all other naturally non-negative climate variables the change grids must be supplied as percentage changes. The climate change grids provided to ANUCLIM should be in the FLOATGRID or ASCIIGRID format of ESRI ArcGIS.

Climate change grids derived from the outputs of GCMs are usually of low (coarse) spatial resolution. Thus the grids provided by OzClim (CSIRO, 2007) have a spatial resolution of 0.25 degrees, and other data sources commonly have a resolution of 0.5 to 1.0 degree. These resolutions are much coarser than the resolution required in most applications. ANUCLIM Version 6.1 applies biquadratic spline interpolation (de Boor, 1978) to the supplied climate change grids to match the resolution of the input DEM data supplied to ANUCLIM.

ANUCLIM Version 6.1 retains the functionality to define climate change scenarios by providing a constant change from GUI. This can meet the needs for a small study area or for simple climate change scenarios. As for the climate change grids, constant changes are applied additively for temperature and as percentage changes for non-negative climate variables. This facility has also been extended to MTHCLIM and GROCLIM.

To apply the climate change grids relative to the baseline year of 1990, as supplied for Australia by the OzClim site, it is necessary to acquire monthly mean climate surfaces for a period centred on 1990. As noted above, the climate surfaces

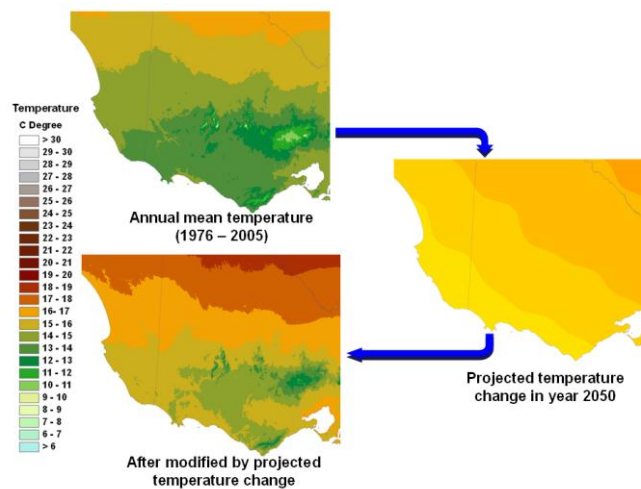


Figure 2. Modification of annual mean temperature based on climate change grids

supplied with the ANUCLIM package consist of coefficient files built from Australian Bureau of Meteorology data using ANUSPLIN (Hutchinson, 2004). The climate surfaces for earlier versions of ANUCLIM were derived from data for 1921 to 1995. For ANUCLIM Version 6.1 new monthly mean climate surfaces have been derived for the period 1976–2005. This period is centred on 1990, a standard baseline commonly used for climate change assessment.

Users have to build their own climate surfaces using the ANUSPLIN package if they wish to apply ANUCLIM outside Australia. Note however that monthly mean temperature and precipitation surfaces for Africa for the period 1920-1980, as documented in Hutchinson et al. (2011), are available from the authors.

There have also been many other minor improvements to ANUCLIM Version 6.1, including more coordinate system options for input data; more output files permitted in a single run; more accurate floating number calculations and more logical handling of extreme bioclimatic parameters (Xu and Hutchinson, 2011). The new version is also faster and more robust.

4. APPLICATIONS OF ANUCLIM VERSION 6.1

ANUCLIM Version 6.1 has been used in many applications. A recent example has been to generate downscaled climate scenarios for the Australian Capital Territory (ACT), to engage local communities in deliberating on climate change, as part of a Climate Change and the Public Sphere project (Hobson and Niemeyer, 2011). The ACT is located in the southeast of the Australian continent. It has an area of 2,358 square kilometres. Canberra, the urban centre of the ACT and Australia's largest inland city, has a population of 347,000. The territory has an abundance of natural vegetation with 53 per cent of the total area preserved as parks and reserves. There has also been over 20,000 years of human occupation in the surrounding region.

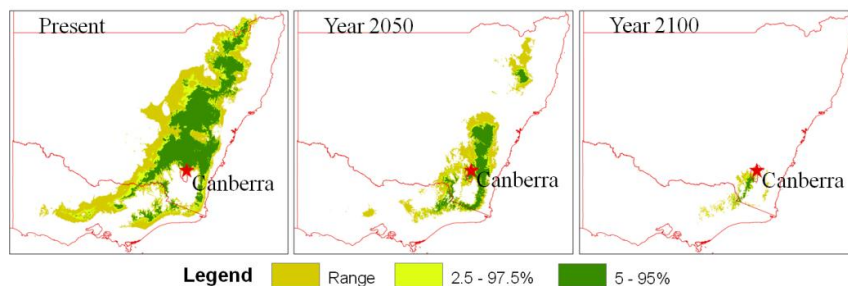


Figure 3. Projected distributions of *Eucalyptus Blakelyi* (Blakely's Red Gum) in southeast Australia under an A1FI climate change scenario

Figure 3 shows the potential shift and reduction in spatial extent of the suitable bioclimatic environment for *Eucalyptus Blakelyi* (Blakely's Red Gum) in southeast Australia under an A1FI greenhouse gas emission scenario. The distribution shifts to a limited area with higher elevation to the south west of Canberra. The climate change grids driving this scenario were obtained by OzClim (CSIRO, 2007) from output from the ECHAM5 General Circulation Model. This model has been identified by Smith and Chandler (2009) as having a good representation of observed Australian rainfall and a credible representation of ENSO (El Niño/La Niña-Southern Oscillation), but with some deficiencies in representing rainfall over the Murray Darling basin (Maximo et al., 2007). It has demonstrated the best overall rating in terms of matching observed temperature, rainfall and atmospheric pressure patterns (Suppiah et al., 2007). More comprehensive assessments would require using outputs from several climate models. Figures 4 and 5 show the areas whose current climate is bioclimatically similar to the climate of the Canberra urban region under an A1FI scenario, again as simulated by the ECHAM5 model. Thus, under this A1FI emission scenario, the temperature regime of the urban area of Canberra will be similar to current hotter inland areas of eastern Australia. The

rainfall regime will be similar to the drier conditions currently experienced by eastern inland Australia and a rainshadow area to the south.

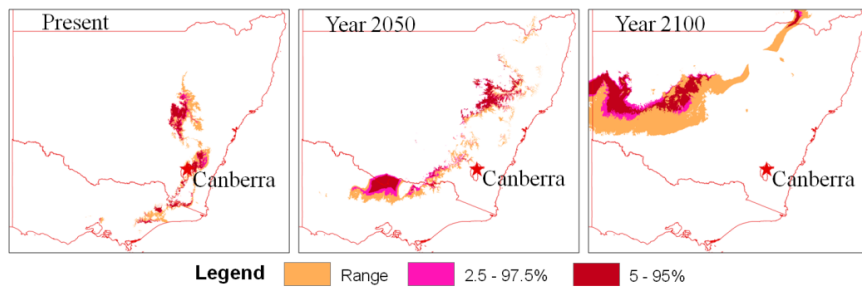


Figure 4. The current location of Canberra's future temperature regimes under an A1FI climate change scenario

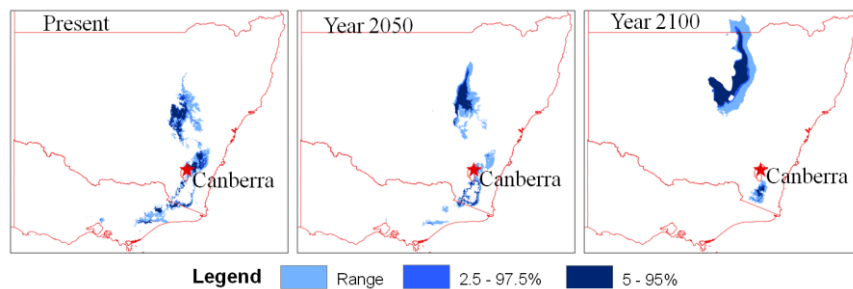


Figure 5. The current location of Canberra's future precipitation regimes under an A1FI climate change scenario

5. DISCUSSION AND FUTURE DEVELOPMENT

The latest Version 6.1 of ANUCLIM incorporates substantial upgrades. In particular, the package now permits each of its four component programs to systematically incorporate projected climate change scenarios. These projected changes can be provided either as simple constants or, more commonly, as grids of broad scale changes relative to current conditions. This enables the systematic investigation of the impacts of projected climate change on socio-environmental systems.

While bioclimatic envelope models, such as BIOCLIM, remain useful and efficient tools for species distribution and ecological environment investigation and mapping, they are known to have shortcomings. Fischer et al. (2001) found that bioclimatic modelling alone was not sufficient to determine taxonomic implications and further morphological studies and genetic analyses were required. Manning et al. (2005) noted that monthly mean climatic tolerances were not the only factors that influence the 'extent of occurrence' of species. This was particularly relevant to bird species that are highly mobile between different seasons. Climate envelope models also do not explicitly include the effects of biotic interactions between different species (Davis et al., 1998). However it is difficult to translate the results of detailed experiments under laboratory conditions to the natural environment.

Pearson and Dawson (2003) have concluded that at broader scales, bioclimatic factors are the key drivers of species distributions. However, at finer scales other factors can determine species occurrence at a particular location. These factors include soil properties, land cover and landscape morphological features. Ideally such could be integrated into bioclimatic models, particularly for the analysis of relatively small areas (Urban et al., 2000; Booth, 2004; Raynaud and Leadley, 2004; Coudun and Gegout, 2007; Titeux, 2009; Manning et al., 2010). It is increasingly acknowledged that bioclimatic models need to be applied with a careful understanding of their limitations in order to make them useful tools for decision-making (Titeux, 2009), particularly when human activity greatly reduces the distribution of a species (Manning et al., 2010).

It should also be noted that integrating fine scale landscape information, such as soil information, into a bioclimatic model is made difficult by the lack of complete and accessible soil datasets around the world (Mallavan et al., 2010). By contrast, monthly mean climate information is relatively complete for most parts of the world (New et al., 2002; Hijmans et al., 2005).

Despite acknowledged shortcomings, bioclimatic envelope models provide perhaps the best available guide for policy making at the current time (Pearson and Dawson, 2003). Bioclimatic models play a vital role in assessing potential distributions of species (Baker et al., 2000; Pearson and Dawson, 2003), and are useful 'first filters' for identifying locations and species that may be most at risk from a changing climate (Chilcott et al., 2003). Bioclimatic models often represent the most feasible method for examining potential distributions (Beaumont et al., 2005). They are also conceptually simple and transparent, making their results readily understandable by stakeholders, although as noted above, their limitations should always be taken into account. Bioclimatic modelling has become an essential tool for addressing many questions concerning conservation biology and invasion ecology in a rapidly changing global environment (Kriticos et al., 2011).

Future versions of ANUCLIM package will improve model performance by allowing more flexible percentile outputs, by incorporating measures of goodness of fit of bioclimatic models and by adding a facility to assist the selection of bioclimatic predictors, a key shortcoming in current bioclimatic models. Attention will also be given to the incorporation of time varying monthly climate information and soil regime information.

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