A User Friendly Interface to Provide Point Specific Climate Change Projections

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Keywords: *Downscaling; Climate change; Climate impacts; Graphical User Interface*

1. EXTENDED ABSTRACT

The climate change information required for many impact studies is of a spatial scale much finer than that provided by climate models. For impact applications point specific climate projections are required. Therefore a gap exists between what climate models can predict about future climate change and the information relevant to our daily life. Statistical downscaling models are commonly used to fill this gap. Statistical downscaling models are based on the view that the regional climate is conditioned by two factors: the large scale climatic state, and local physiographic features. The analogue approach developed in the Bureau of Meteorology is one example of a more general type of statistical downscaling method based on weather classification methods in which predictands are chosen by matching previous (i.e., analogous) situations to the current weather-state.

Individual statistical downscaling models were optimised for six regions covering the southern half of the Australian continent (five on the mainland and one for Tasmania) and for the four calendar seasons. Three surface predictands for which high quality climatic records are available were modelled: T_{max}, T_{min} and rainfall. Each individual model was optimised in two steps: first the best combination of large-scale atmospheric predictors was determined and then three additional parameters were tuned. The development and validation of the models was done using the NCEP/NCAR reanalyses from 1958 to 2003. Once all parameters were chosen and optimized, the statistical downscaling models were applied to a selection of global climate models which contributed to the 4th assessment made by the Intergovernmental Panel on Climate Change (IPCC) released in 2007. Up to 23 GCMs contributed to the assembled dataset, however as the statistical models rely on daily outputs for the predictors, only a subset of 11 models could be used. The experiments available include a simulation of the 20th century with external forcings and projections for the 21st century under two emissions scenarios: the A2 scenario (one of the highest emission scenario available) and the B1 scenario (one of the lowest emission scenarios available). In all cases time slices of either 40 years (at the end of the 20th century) or 20 years at the middle or the end of the 21st century are available.

A graphical user-friendly interface has been developed to facilitate dissemination of the statistical downscaling model results. The graphical user-friendly interface covers the southern half of the Australian continent, and provides a range of options for users to obtain tailored information. The user may choose the emission scenario, the global climate models (one or several), the season, the region and the type of predictands. Once these choices are made, all available stations are displayed and the user can choose to display graphical outputs or download ASCII files containing the data. Point-specific future projections are available for the locations included in the high-quality climate data network, maintained by the National Climate Centre of the Bureau of Meteorology. This network forms the basis of our current understanding of the Australian climate.

This new tool will enable users to access tailored climate change projections for their particular application and to investigate a range of uncertainties: emission scenario, climate model sensitivity, inter-annual variability and the spatial heterogeneity. The tool is currently only available internally within the Bureau of Meteorology but is expected to be made available to the public in 2008.

2. INTRODUCTION

Global climate models (GCMs) have resolutions of hundreds of kilometres whilst regional climate models (RCMs) may be as fine as tens of kilometres. However impact assessment applications may require point specific climate projections. Point specific climate projections are highly sensitive to fine-scale climate variations, in particular for regions of complex topography, coastal or island locations, and in regions of highly heterogeneous land-cover, but these are parameterized in coarse-scale models. Therefore a gap exists between what climate models can predict about future climate change and the information relevant to our daily life. Statistical Downscaling Models (SDMs) are commonly used to fill this gap. SDMs are based on the premise that the regional climate is conditioned by two factors: the large scale climatic state, and local physiographic features. From this perspective, regional or local climate information is derived by first determining a statistical model which relates large-scale climate variables (or "predictors") to regional and local variables (or "predictands"). Then the large-scale output of a GCM simulation is fed into this statistical model to estimate the corresponding local and regional climate characteristics.

The Australian Bureau of Meteorology has developed a SDM using the idea of meteorological analogue. This is one example of a more general type of SDM based on weather classification methods in which predictands are chosen by matching previous (i.e., analogous situations) to the current weather-state. The method was originally designed for weather forecasting applications but was abandoned due to its limited success and lack of suitable analogues for systems with large degrees of freedom. The popularity of the method has recently increased with the availability of longer time-series datasets following the completion of reanalysis project and the recognition that the size of the search space must be suitably restricted when identifying analogues. Even so, the analogue method still performs poorly when the pool of training observations is limited and/or the number of classifying predictors is large.

The Graphical User Interface (GUI) presented here has been developed to facilitate access to downscaled climate change projections across the southern half of the Australian continent. The GUI is a Web-based tool using a mix of static HTML pages using Java script and dynamically generated pages using CGI and Perl. It provides users with access to projections for a series of surface predictands at point specific locations. The locations correspond to the stations included in the high-quality climate data network, maintained by the National Climate Centre of the Bureau of Meteorology. This network forms the basis of our current understanding of long-term trends and variability of the Australian climate.

3. THE STATISTICAL DOWNSCALING MODEL

The Bureau of Meteorology SDM was first developed for daily temperature extremes (T_{min} and T_{max}) across the Murray-Darling Basin (MDB) (Timbal and McAvaney, 2001). It was then extended to rainfall occurrences (Timbal et al., 2003) and amount (Timbal, 2004). During these applications, the technique was tested on other geographical areas in mid-latitude climatic zones in both Australia and Europe. More recently, the technique was extended to the entire non-Tropical half of the Australian continent, generally south of 33ºS, and applied to the latest round of GCM projections for the 21st century, which were assembled as part of 4th assessment of the Intergovernmental Panel on Climate Change (IPCC). The southern half of the continent was separated into six distinct climate entities:

1. The Southwest of Western Australia (**SWA**): south west of a north boundary from Geraldton to Kalgoorlie and West of a line from Kalgoorlie to Esperance;
2. The Nullarbor (**NUL**) region: a vast region from the SWA in the West and the Peninsulas in South Australia in the East and from the coast to 33ºS. This area has very few high quality observations and therefore its optimisations are likely to be the least successful;
3. The Southwest of Eastern Australia (**SEA**): southwest of a line from Melbourne to Port Augusta, this area was identified as the centre of the early winter rainfall decline (Timbal and Jones, 2007);

4. The Southern half of the Murray-Darling Basin (**SMD**) limited to about 33ºS in the north, limited in the West by the line described earlier and separating the region from SEA and limited in the East by the Great Dividing Range (GDR);
5. The South-East Coast (**SEC**): the coastal band East of the GDR from Wilson Promontory in Victoria in the South all the way along the NSW coast up to the Queensland Border; and
6. The island of Tasmania (**TAS**) including all Bass Strait islands.

The development and validation of the SDM was performed using the best possible surface predictands and large-scale predictors. Global re-analyses of the atmosphere were used for the large-scale predictors. Both the NCEP/NCAR re-analysis datasets (NNR) (available from 1948 to current) (Kalnay et al., 1996) and the European Centre ERA40 re-analysis datasets (available from 1957 to 2003) (Kallberg *et al.*, 2005) were tested. The impact of data quality on the SDM performance was carefully assessed. It was found that NNR from 1958 to 2005 (i.e. not using the earlier decade from 1948 to 1957) provided the best results and are therefore used as the basis to search for analogues from the global climate models used in the GUI. The optimum combination of predictors varies across regions, seasons and predictands (Table 1). The predictors in Table 1 are labelled as follow (subscript numbers indicates the atmospheric level for the variable in hPa):

- MSLP is the Mean Sea Level Pressure;
- T_{max} and T_{min} are the surface min and max temperature;
- PRCP is the total rainfall;
- Q is the specific humidity;
- T is the temperature; and
- U and V are the zonal and meridional wind components.

	Season	**SWA**	**NUL**	**SEA**
T_{max}	Summer	MSLP & T_{850} & V_{850}	MSLP & T_{850} & V_{850}	MSLP & T_{850}
	Autumn	MSLP & T_{850} & V_{850}	MSLP & T_{850} & V_{850}	MSLP & T_{max}
	Winter	MSLP & T_{850} & V_{850}	MSLP & T_{850} & U_{850}	MSLP & T_{850} & T_{max} & U_{850}
	Spring	MSLP & T_{850} & V_{850}	MSLP & T_{850} & V_{850}	MSLP & T_{850}
T_{min}	Summer	MSLP & T_{850} & Q_{850} & U_{850}	MSLP & T_{850} & Q_{850}	MSLP & T_{850}
	Autumn	MSLP & T_{850} & Q_{850} & U_{850}	T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}
	Winter	MSLP & T_{850} & Q_{850}	MSLP & T_{850} & Q_{850} & U_{850}	MSLP & T_{850} & Q_{850}
	Spring	MSLP & T_{850} & Q_{850}	T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}
Rain	Summer	MSLP & PRCP & Q_{850} & U_{850}	MSLP & PRCP & Q_{850} & U_{850}	MSLP & PRCP & T_{850}
	Autumn	MSLP & PRCP & Q_{850} & U_{850}	MSLP & T_{850}& Q_{850} & U_{850}	MSLP & T_{max} & Q_{850} & U_{850}
	Winter	MSLP & Q_{850} & U_{850}	MSLP & T_{850}& Q_{850} & U_{850}	MSLP & PRCP & V_{850}
	Spring	MSLP & Q_{850} & U_{850}	MSLP & Q_{850} & T_{850}	MSLP & PRCP
	Season	**SMD**	**SEC**	**TAS**
T_{max}	Summer	MSLP & T_{max}	MSLP & T_{max}	MSLP & T_{850} & T_{max} & U_{850}
	Autumn	MSLP & T_{max}	MSLP & T_{max}	MSLP & T_{850} & T_{max} & U_{850}
	Winter	MSLP & T_{850} & T_{max} & U_{850}	MSLP & T_{max}	MSLP & T_{850} & Q_{850} & U_{850}
	Spring	MSLP & T_{850} & U_{850}	MSLP & T_{850} & T_{max} & U_{850}	MSLP & T_{850} & T_{max} & U_{850}
T_{min}	Summer	T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}
	Autumn	T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}
	Winter	MSLP & T_{850} & Q_{850}	MSLP & T_{850} & T_{min} & U_{850}	MSLP & T_{850} & T_{min} & U_{850}
	Spring	MSLP & T_{850} & Q_{850}	MSLP & T_{850} & Q_{850}	MSLP & T_{850} & T_{min} & U_{850}
Rain	Summer	MSLP & PRCP & V_{850}	MSLP & T_{max} & Q_{850} & U_{850}	MSLP & Q_{850} & V_{850}
	Autumn	MSLP & PRCP & V_{850}	MSLP & PRCP & Q_{850} & U_{850}	MSLP & Q_{850} & V_{850}
	Winter	MSLP & PRCP & V_{850}	MSLP & PRCP & U_{850}	MSLP & PRCP & Q_{850} & U_{850}
	Spring	MSLP & PRCP & V_{850}	MSLP & PRCP & Q_{850} & U_{850}	MSLP & PRCP & Q_{850} & U_{850}

Table 1: Optimum combination of parameters for each calendar season and predictand available in the GUI

Each individual SDM (72 in total: 3 predictands * 4 seasons * 6 regions) was optimised using a range of statistics, covering the ability of the SDM to reproduce the observed characteristics of the series (mean and variance), the skill to reproduce day-to-day variability (RMS and Pearson correlation between daily observed and reconstructed time series) and inter-annual variability as well as for long-term trends. The optimisation methodology was based on a subjective analysis of these various metrics. No attempt was made to develop an objective approach in order to allow for expert knowledge of the importance of the different predictors and their inter-dependence. Furthermore, it is generally not the case that a single combination of predictors gives superior results for all metrics used and hence a trade-off exists between the importance of the various predictors and their role. The optimisation was performed in two steps, first the best combination of predictors was determined; and then three additional parameters were optimized in a second step:

1. The size of the geographical domain used for the predictors (latitude and longitude): two domain sizes were tested; the size of each domain depends on the region;
2. The calendar period from which analogues were searched for; three periods were tested; 15, 30 and 60 days prior to and after the model date; and
3. The way the daily anomalies were calculated: using either a month-to-month averages or a seasonal averages.

For surface predictands, the best possible stations available for long-term climate purposes are the High Quality dataset assembled by the National Climate Centre (NCC) from the Bureau of Meteorology. Variables used were daily HQ temperatures extremes (Trewin, 2001) and daily HQ rainfall amount (Lavery et al., 1992 and 1997). Both records were extended to 2005 by the NCC. Consequently, downscaled projections for three surface predictands can be obtained through the GUI: rainfall, T_{max} and T_{min}.

Originating Group	Country	Acronym	Grid size (km)
Canadian Climate Centre	Canada	CCM	~300
Meteo-France	France	CNRM	~200
CSIRO	Australia	CSIRO	~200
Geophysical Fluid Dynamics Lab	U.S.A.	GFDL 1	~300
Geophysical Fluid Dynamics Lab	U.S.A.	GFDL 2	~300
NASA/Goddard Institute for Space Studies	U.S.A.	GISS-R	~400
Institut Pierre Simon Laplace	France	IPSL	~300
Centre for Climate Research	Japan	MIROC	~300
Max Planck Institute for meteorology DKRZ	Germany	MPI	~200
Meteorological Research Institute	Japan	MRI	~300

Table 2: Global Climate Models from the CMIP3 database accessible through the GUI. The grid size represents each models approximate horizontal resolution.

As part of the Intergovernmental Panel on Climate Change (IPCC) 4th assessment of climate change science released in 2007 a new set of systematic coupled GCM experiments has been organised. This represents a major advance both for the evaluation of models, and for the generation of climate projections. The open nature of output availability has resulted in this set of experiments being subjected to unprecedented levels of evaluation and analysis: the Couple Model Intercomparison Project Nº3 (CMIP3). The models represent the current state-of-the-art in climate modelling, with advances in sophistication in the physical parameterisations used; a greater number of components included and increased resolution in both ocean and atmosphere. Model outputs were obtained from the IPCC Model Output website at http://www-pcmdi.llnl.gov/ipcc/info_for_analysts.php.

Up to 23 GCMs contributed to the CMIP3 dataset, however because the SDM relies on daily outputs for the predictors only a subset of this database could be used (Table 2). These include GCMs which provided daily data for both the simulation of the 20th century and simulations of the 21st century under different emissions scenarios. Approximately 6 of these scenarios were used by GCMs contributing to the CMIP3 database and this lead to different projected global warmings. In order to reduce the amount of data used, only two scenarios for the 21st century were used: A2 and B1. The A2 scenario is based on a very heterogeneous world with continuously increasing population and a technologically fragmented economic development leading to one of the highest emission scenario available. On the contrary, B1 is based on a convergent world with the same global population that peaks in mid-century and declines thereafter, with a rapid change in economic structure toward a service and information economy, and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability. Therefore B1 is one of the lowest emission scenarios available.

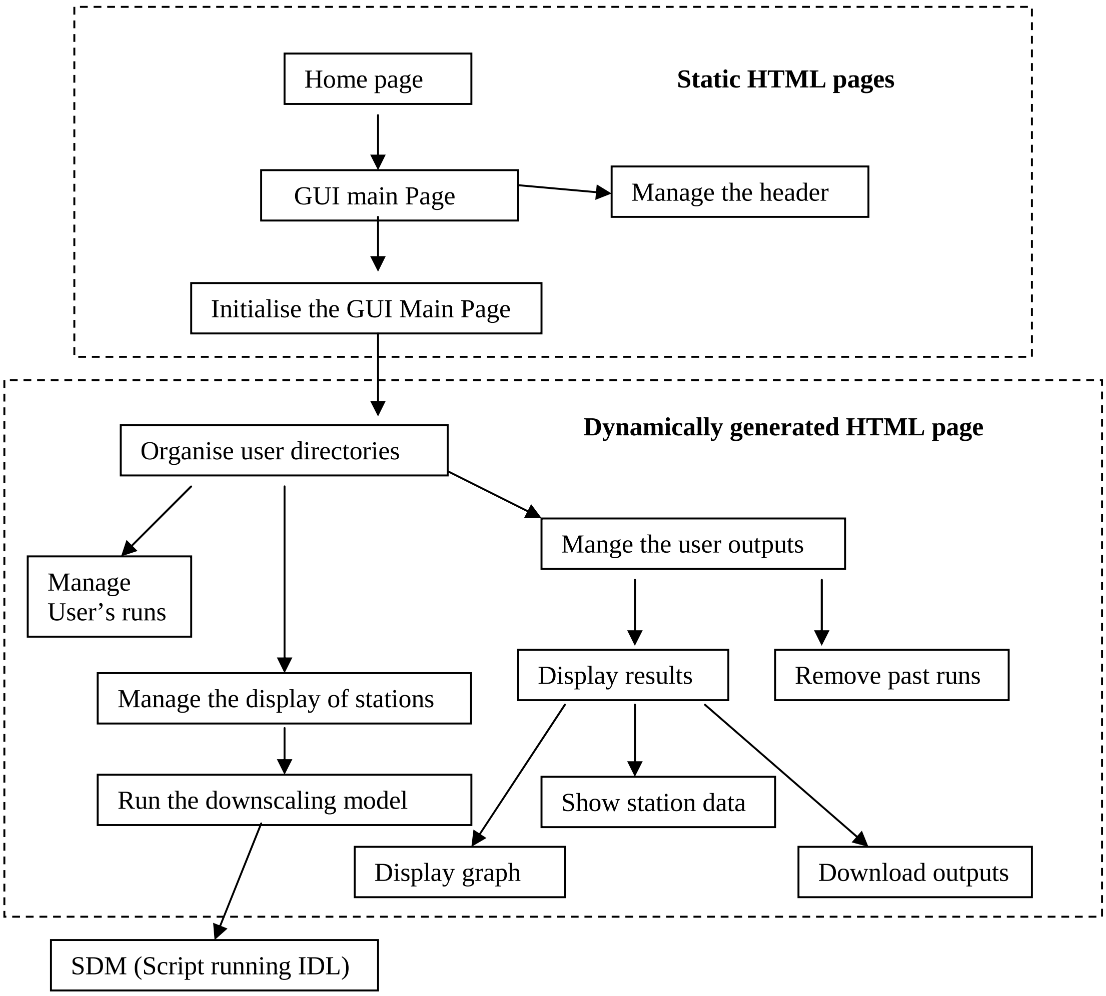

Figure 1: Architecture of the GUI for the Bureau of Meteorology SDM.

The daily data available from the GUI cover three time-slices for which daily Direct Model Outputs (DMOs) were available and used by the GUI:

1. 40 years from 1961 to 2000 from the 20C3M experiment;
2. 20 years from 2046 to 2065 in the middle of the 21st experiments for both the A2 and B1 scenarios; and
3. 20 years from 2081 to 2100 at the end of the 21st experiments for both the A2 and B1 scenarios.

4. THE SOFTWARE STRUCTURE

The GUI interface is constructed using four static HTML pages (Fig. 1). Additional pages are generated dynamically using Perl and output the datasets in response to user input.

The last component of the GUI is an Interactive Data Language (IDL) script which starts the calculation of the SDM itself. The entire SDM (data inputs, statistical calculation and visual outputs) is written in IDL. Beside the GUI, the SDM code can be run interactively in research mode; however, no access is given to the SDM code to the user through the GUI.

5. THE GRAPHICAL INTERFACE

The starting point of the GUI (Fig. 2) displays a large region around the Australian continent using MapData © powered by Google. It provides an option to choose the background between physical maps, satellite pictures or a combination of both (using buttons displayed at the top right). The user has a series of four steps to follow in order to carry out the downscaling process:

Step 1: Choose the predictand and season

- Select a predictand: Rainfall, T_{max} or T_{min};
- Select a calendar season: summer, autumn, winter or spring.

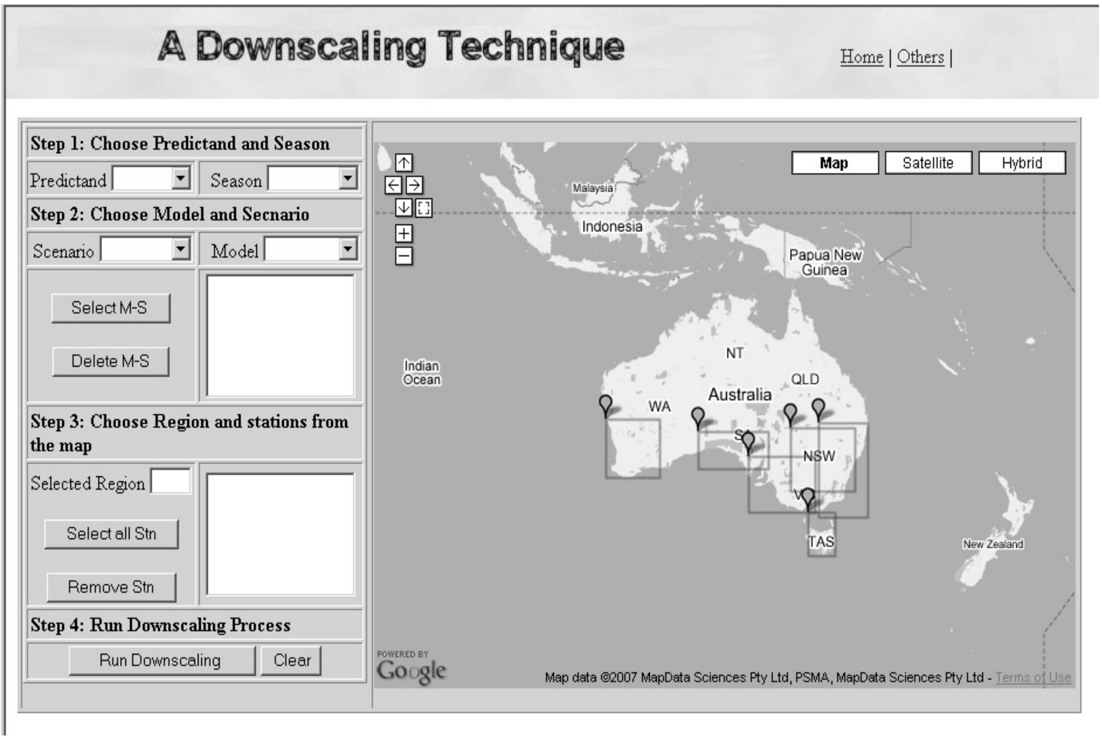

Figure 2: The default page of the GUI as it appears to the user before any action is taken by the user.

Step 2: Choose the model(s) and a scenario

- Select the climate scenario: available scenarios are a simulation of the 20th Century (20C3M) providing daily data from 1961 to 2000 and future emissions scenarios A2 and B1 for the 21st century providing daily data for 20-years time slices: 2046-2065 and 2081-2100.
- Select climate model: the user can choose all available models or select individual CMIP3 model.

Step 3: Select a region and the station(s)

- Select one of the six regions of interest from the map.
- Select the stations: the user can select stations one by one using the geographical display or choose to select all stations from the region of interest.

Step 4: Run the downscaling process

Following submission the user will be presented with an html page providing access to the outputs of the run either in a graphical format or as ASCII files. Both types of output can be visualised or downloaded for subsequent use in impact modelling applications.

6. CONCLUSIONS

A SDM developed within the Bureau of Meteorology over several years has now been extended to provide a tool for a large community of users to access downscaled climate change projections based on IPCC 4AR datasets. It provides the user with state-of-the-art tailored projections available at a selection of sites for integrated assessments. In particular the tool allows researchers dealing with climate change impact studies to explore local scale impacts of a range of uncertainties (scenarios, models, inter-annual variability).

7. ACKNOWLEDGEMENTS

The authors would like to thank the Australian Greenhouse Office (AGO) for their support during the development of the GUI as part of the Australian Climate Change Science Program (ACCSP). We acknowledge the international modelling groups for providing their data for analysis, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and Climate Simulation Panel for organizing the model data analysis activity, and the IPCC WG1 TSU for technical support. The IPCC Data Archive at Lawrence Livermore National Laboratory is supported by the Office of Science, U.S. Department of Energy. Thanks are due to Aurel Moise and Lawson Mawson from the Bureau of Meteorology for transferring the CMIP3 database to Australia.

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