Climate variations and New Zealand agriculture: The CLIMPACTS system and issues of spatial and temporal scale

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ABSTRACT

Internationally and nationally New Zealand has a growing requirement to assess and report on the possible effects of climate change. In association with this requirement, the science of climate change is rapidly evolving requiring a capacity for rapid re-assessment of effects to take account of scientific advances. Consequently past assessment methods, which have not been computationally efficient, nor easily repeated, are becoming outdated. To address this gap an integrated assessment model (IAM), the CLIMPACTS system, has been developed for New Zealand. The CLIMPACTS system has been developed to provide flexibility in application, to be easily updated to take account of scientific advances, and capable of providing information in a manner that is relevant to policy-makers. In order to be relevant in New Zealand, it has been necessary to account for different scales of assessment, nationally, at specific sites, and regionally. Nationally, the focus is on spatial applications (e.g. changes in areas of suitability), whereas at sites, the focus is on temporal applications (e.g. changes in risk). The regional capacity in the CLIMPACTS system has required an integration of spatial and temporal applications. This paper describes briefly the capability that has been developed at these different scales of assessment, with brief examples for each. The CLIMPACTS system has enhanced New Zealand's capability to examine environmental sensitivities to climate change, as a basis for informed policy decisions. Importantly, it is an evolving platform, that can be readily extended to other sectors and updated, for example, to account for the effects of internationally agreed greenhouse gas (GHG) emission targets.

INTRODUCTION

Modelling the effects of climate change has involved a significant research effort over the last decade. This effort has, in general, been computationally inefficient, involving the production of a set of results for a specified scenario, or set of scenarios, of climate change. Such assessments have not been easily repeated with different scenarios. This is largely because the required data and models are not linked in a manner that facilitates rapid, and repeated, assessments. These difficulties are compounded when attempts are made to conduct assessments that encompass different spatial and temporal scales (e.g. from sites to regions and from time series of daily weather to monthly climate averages), and different sectors or exposure units. In such cases it proves a significant challenge to provide some sense of coherence and consistency to analyses and interpretation of results. Nevertheless, a number of successful studies of this kind, the majority of which have focussed on agriculture, have been made (Parry *et al.*, 1988a,b; Kenny *et al.*, 1993, Rosenzweig and Iglesias, 1994). The demands for informed policy decisions, as required under the United Nations Framework Convention on Climate Change (UNFCCC), has increasingly required a re-evaluation of the approach to impact assessment. This has led to the emergence of integrated assessment models (IAMs).

IAMs have been characterised, in the climate change literature, as encompassing inter-linkages and feedbacks between global changes in climate, sectoral effects, socio-economic effects, and responses. Such models have tended to be global in scale, and focussed heavily on socio-economic effects and responses (see Weyant *et al.*, 1996). Often this precludes the requirements for integrated assessment at the nation scale, taking account of the issues described in the opening paragraph. In New Zealand, the CLIMPACTS programme was devised as a means to address the more immediate need for a more integrated approach to impact assessment. This directly built on work in Europe, in particular the ESCAPE model (CRU and ERL, 1992).

The CLIMPACTS Programme is a collaborative research effort between two Universities and five Crown Research Institutes (CRIs) in New Zealand that began in 1993. The focus of the Programme has been the development of an integrated assessment model, the CLIMPACTS system, which can address questions related to the impacts of climate variability and change on the New Zealand environment, in particular agriculture. The type of question, and approach to modelling, has been influenced strongly by the scale of assessment. In the first phase of development, the focus was on simple impact models, and spatial climate data to address questions at the ***national*** scale, such as "what changes in crop distribution might occur under climate change?" The second phase focussed at the ***site*** scale, with an emphasis on more detailed impact models, use of daily time series data and integration of impact models with weather generators and statistical tools for examining climatic risk. Thus, the type of question addressed at this scale is "how might frost risk for a particular crop vary or change at a given site?" The third phase, and most recent focus of CLIMPACTS, has involved development and implementation of models and tools for analysis at the ***regional*** scale within New Zealand. The purpose of this development has been to examine questions such as "how does the risk of frost vary within the region and how might this change in the future?" This paper describes, by way of examples, the development and application of the CLIMPACTS system at these different scales of assessment.

THE CLIMPACTS SYSTEM

The development of the CLIMPACTS system has had a very strong focus on system design, which has brought together a number of key requirements, including:

- User accessibility;
- Capability to handle spatial and non-spatial data;
- Integration of a flexible climate change scenario generator with data and sectoral impact models;
- Capacity to be readily updated with new models and data and to account for advances in climate change science.

The choice of hardware and software platforms was critical to addressing these requirements. The PC platform and Windows operating system were chosen, to provide accessibility for all of the CLIMPACTS programme collaborators and portability to other potential users. The system was developed in Borland Delphi, following a modular approach. Key developments were the graphic user interface (GUI), a customised geographic information system (GIS) for handling spatial data, and development of a data compression algorithm for the storage of the spatial data used in the CLIMPACTS system (Sims *et al.*, 1996, 1997). In parallel with these software developments was the design of the research capability of the CLIMPACTS system (Kenny *et al.*, 1995; Warrick *et al.*, 1996). The key system components (see Figure 1) are:

- A global climate model, known as MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change, Wigley, 1994);
- Patterns of climate change for New Zealand;
- Historical climate and land use data for New Zealand;
- Sectoral impact models;
- Weather generators and an extreme event analysis tool.

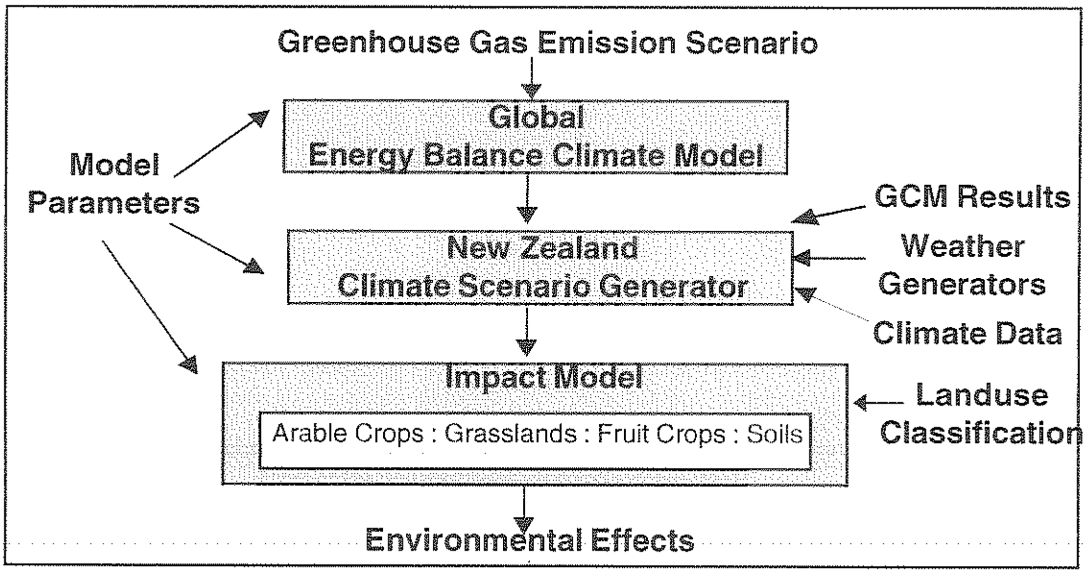

Figure 1: Conceptual structure of the CLIMPACTS system

The application of these components at different assessment scales is described in the following sections. A common feature at all scales of assessment, and an integral part of the research capability provided by the CLIMPACTS system, is the climate change scenario generator. This links together output from MAGICC, which provides time series (from 1990 to 2100) of global temperature changes for a wide range of greenhouse gas (GHG) emission scenarios, with patterns of climate change and historical climate data for New Zealand. The manner in which these components are combined is described in detail by Kenny *et al.* (1995) and Warrick *et al.* (1996). The most important characteristic is that the CLIMPACTS system provides flexibility to specify numerous combinations of GHG emissions scenarios, climate sensitivity, time horizon, and climate change patterns. Thus it is possible to explore environmental sensitivities to a wide range of scenarios (Kenny *et al.*, 1999).

THE NATIONAL-SCALE CAPACITY

The early development of the CLIMPACTS system focussed on the national scale (Kenny *et al.*, 1995, Warrick *et al.*, 1996) and was aimed at addressing broader questions related to relative changes in climate in different parts of New Zealand and the sensitivity of different agricultural crops to those changes. The principal system components for national-scale applications are:

- Interpolated monthly climate data, derived from the 1951-80 climate normals;
- Times series of monthly climate data, for selected sites;
- Land use capability (LUC) data, from the New Zealand Land Resources Inventory (LRI);
- Patterns of climate change, derived from general circulation models (GCMs);
- Models, for kiwifruit (Salinger and Kenny, 1995), grain maize, *Paspalum dilatatum* (Campbell and Mitchell, 1996), wheat, and barley.

The spatial data (climate, soils and GCM patterns) were all interpolated (or sampled in the case of the LUC data) to a 0.05° lat/long grid for North and South Islands. The LUC data are used in the CLIMPACTS system to identify arable and non-arable land classes, and thus reduce computation time for particular applications. For example, analyses for kiwifruit (*Actinidia deliciosa*) require data only for the arable classes (1 to 3).

The integration of these components within the CLIMPACTS system has provided the capability for detailed sensitivity analyses of the effects of climate change in New Zealand (Kenny *et al.*, 1999). One such analysis, for kiwifruit, identified a range of thresholds relating to biophysical responses, geographic changes, management responses, and changes in risk at different locations. In particular, results demonstrate a decline in suitability for kiwifruit in the Bay of Plenty (Figure 2). However the rate and amount of decline is influenced by the choice of scenario. A "best guess" scenario suggests that by the 2050s, management changes would increasingly be required in the Bay of Plenty, such as greater use of hydrogen cyanamide to manage the amount of flowering or introduction of new cultivars. By 2100, under the same scenario, the Bay of Plenty climate would no longer be suitable

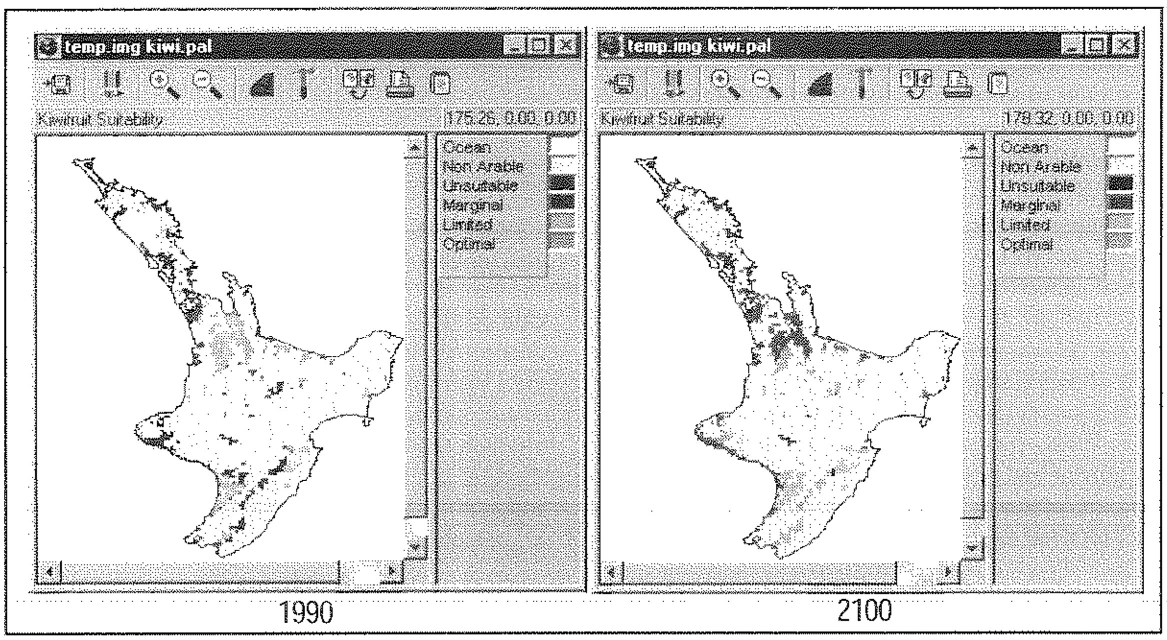

Figure 2: Changes in kiwifruit suitability in 2100 relative to 1990, for a "best guess" climate change scenario

for kiwifruit. However, other regions, such as Nelson/ Marlborough, would become increasingly suitable.

THE SITE-SCALE CAPACITY

The development of a site-scale capacity in the CLIMPACTS system formed the second stage of the research programme. This was designed to address more detailed questions related to effects of climate change on agricultural and climatological risk. The principal system components for site-scale applications are:

- Time series of daily weather data;
- Weather generators;
- A climate risk analysis tool;
- Simulation models for pasture production, wheat and maize yield, kiwifruit phenology, soil carbon.

A significant part of the site-capacity development was the development and incorporation of weather generators and a climate risk analysis tool, which are described in more detail by Ye *et al.* (1999). An important issue in climate change science is the matching of space and time scales between output from general circulation models (GCMs) and input requirements for impact assessments (Semenov and Barrow, 1997). GCM output is provided at a coarse spatial (tens of kilometres) and temporal (monthly or seasonal) resolution. On the other hand site assessments, such as risk analysis, require high-resolution data. This includes information on changes in both mean climate and its variability. The use of weather generators provides a means of realistically simulating changes in climate variability that may be associated with mean changes in climate (Barrow and Hulme, 1996; Barrow *et al.*, 1997; Semenov and Barrow, 1997). Four different weather generators were incorporated within CLIMPACTS to enable evaluation of differences in their performance under different conditions (Ye *et al.*, 1999).

In addition to the weather generators, an extreme event analysis tool was also incorporated. This tool can be applied to address a wide range of questions. For example, for kiwifruit, and many other crops, the timing and severity of frost at different stages of crop development can have significant negative effects on productivity. Under present conditions, at Te Puke, the return period for a -1°C frost after the date of bud break is 3.6 years (Figure 3). Under a future scenario (a mid-range warming scenario for 2100) the return period is 5.3 years. This change in return period for kiwifruit is influenced by the effect of climate change on the timing of bud break, which is delayed under warmer conditions, and frost risk, which is reduced under warmer conditions.

THE REGIONAL-SCALE CAPACITY

While the national capacity in the CLIMPACTS system focussed more on issues of spatial scale and the site capacity focussed more on issues of temporal scale, the requirements for the regional capacity were for both spatial and temporal-scale issues to be addressed. For this purpose a separate regional version of the CLIMPACTS system has been developed, focussing in the first instance on the Waikato and Canterbury regions. This incorporates the components described for both the national and site scale capacities, with several refinements including:

- Spatial data interpolated to the New Zealand map grid at a 1 km x 1 km resolution, with the addition of available water holding capacity (AWC) data;
- Time series of daily weather data for 21 sites in Waikato and for 20 sites in Canterbury;
- A water balance model, as the basis for developing a capacity for drought risk assessment.

The spatial climate data used for these two regions were developed by Leathwick and Stephens (1998). The use of finer resolution data at the regional scale allows for much closer examination of sensitivities to

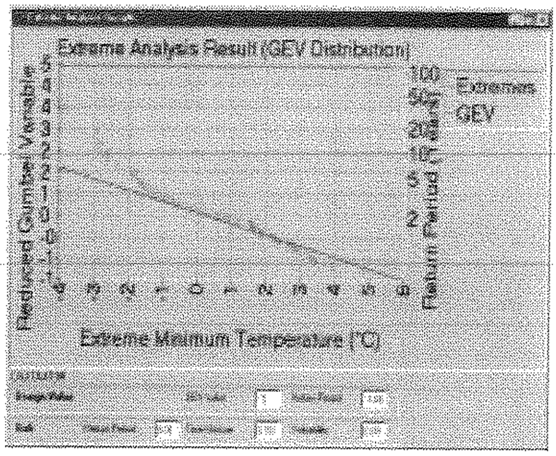

Figure 3: Extreme analysis tool, used to examine present frost risk after kiwifruit budbreak at Te Puke

change within regional boundaries (e.g. spatial changes in the regional water balance). Likewise, the addition of time series of daily weather data for a wider network of sites enables more detailed characterisation of within region changes (e.g. changes in drought risk at selected sites within the region). This capability has been extended by the development of methods for linking coarse resolution GCM output to the finer resolution required by a weather generator (Thompson and Mullan, 1999).

The regional water balance was characterised, in the first instance, by the balance between precipitation and potential evapotranspiration (PET). The latter was derived from the Priestley-Taylor method (Priestley and Taylor, 1972). The water balance can be evaluated on a monthly, seasonal, or annual basis. Under one scenario examined for the year 2100, conditions in the Waikato region become warmer and wetter on average. On balance this particular scenario leads to drier than average conditions in the summer months (December, January, February) and a greater extent of the region that experiences a deficit of 100 mm or more during this period (Figure 4).

SUMMARY AND CONCLUSIONS

The development of the CLIMPACTS system evolved from past experience in climate change impact assessment, which highlighted the need for a more integrated and computationally efficient approach for evaluating environmental sensitivities under different scenarios of climate change. This need for greater integration has been given impetus since New Zealand became a signatory to international agreements such as the UNFCCC.

A unique characteristic of the CLIMPACTS system is the combination of software and research design, which provides an accessible and powerful research tool. While system and research design have been an important part of this development, there has also been a significant research contribution through the development and refinement of appropriate models and tools for application within the system. This research effort has placed a strong emphasis on issues of scale, particularly over space and time. The capability has been developed for assessment at national, site and regional scales. National scale developments focussed primarily on spatial issues, whereas at the site scale the emphasis was on temporal issues. The more recent regional scale development has required a greater merging of space and time scales within the CLIMPACTS system. Taken together these developments provide the capability for detailed evaluation of the sensitivity of the New Zealand environment to climate variability and change, as briefly demonstrated in the examples provided.

A distinguishing characteristic of the CLIMPACTS research has been the focus on integration from the beginning, through development of an IAM for New Zealand. This has provided the capability for a comprehensive national assessment using the CLIMPACTS system, which will be the focus in the 1999/2000 period. While this capability only extends to agriculture at present, a platform has been developed which will now enable other sectors to be incorporated. Important issues for future consideration are human health, bio-security, and water resources. In addition to this research capability, the CLIMPACTS system serves as a valuable tool for educating and informing user groups (such as regional councils and industry) as to the possible effects of climate change in New Zealand. Thus, there is greater potential for climate change issues to be incorporated, in an informed manner, into planning. Finally, New Zealand now has the capability to respond rapidly to meet it international obligations, such as meeting its reporting requirements under the UNFCCC.

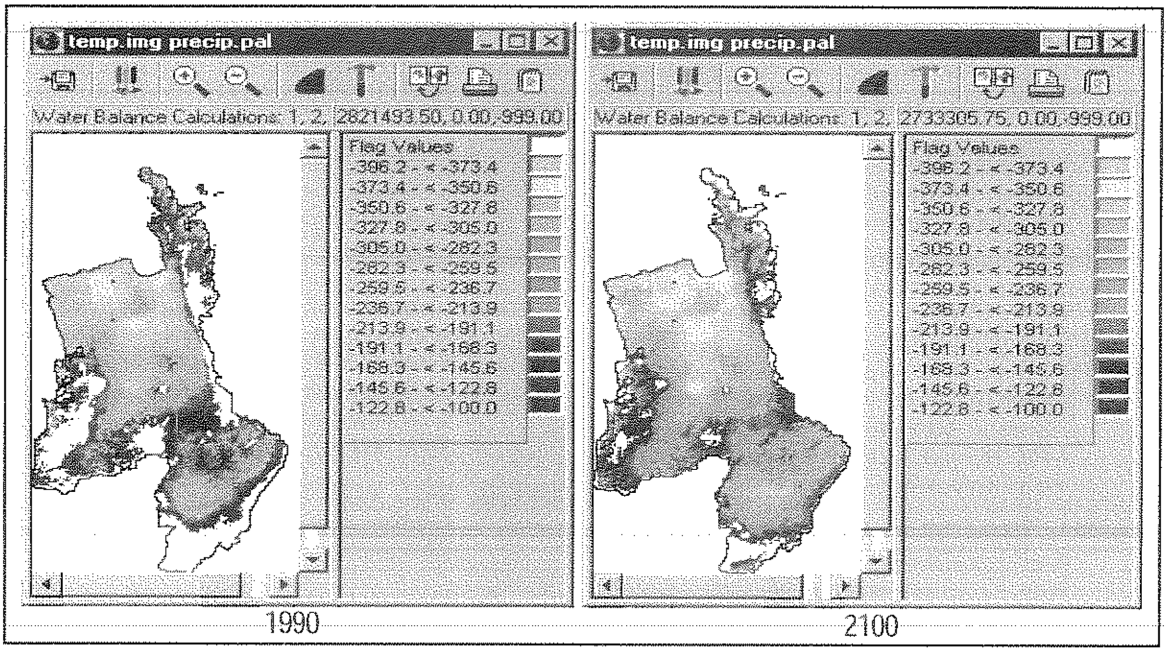

Figure 4: Change in the atmospheric water balance in the Waikato, 2100 relative to 1990, for a "best guess" climate change scenario

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