

AN E-SCIENCE APPROACH TO CLIMATE CHANGE ADAPTATION

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ABSTRACT

According to the Intergovernmental Panel on Climate Change's 4th assessment report (IPCC 2007), warming of the climate system is 'unequivocal' as indicated through a number of earth observations including temperature, melting snow and sea level rise. With climate change eminent there is a need to explore both adaptation and mitigation strategies. This paper focuses on the former, but adaptation strategies might also inform climate change mitigation strategies. Specifically, the aim of this research is to test a new approach to cross-organisational research collaboration to support policy makers, planners, and land managers in addressing climate change adaptation in south-west Victoria, Australia. The approach is based on the concept of virtual collaboration also known as e-Science. It comprises several core components including: (i) climate change data and models, (ii) land suitability analysis, (iii) geographical visualisation tools, and (iv) Virtual Organisation (VO) platform. A prototype e-Science VO platform known as the e-Resource Centre (e-RC) has been built for the study region to support data sharing, modelling and visualisation of climate change adaptation options for 2050. This paper reports on the current research in applying an e-Science approach, known as ecoinformatics, to enable better collaboration across organisations in addressing climate change adaptation. The next stage of the research is to evaluate the various components comprising the ecoinformatics platform, particularly from the point of view of end users.

Keywords: e-Science, ecoinformatics platform, climate change modelling, geo-visualisation, virtual organisations

INTRODUCTION

The development of an e-Science platform comprising: climate change data and models, land use change and impact (risk) models, geographical (geo)-visualisation and a supporting virtual organisation structure has been driven by the underlying research question: What are the climate change adaptation and mitigation options for south-west Victoria looking to 2050? In order to address such a question, the cooperation of research organisations across both government and university sectors is critical. In this paper an e-Science ecoinformatics platform is presented, which endeavours to support multidisciplinary and cross-agency research in dealing with the complex problem of climate change adaptation.

AN ECOINFORMATICS E-SCIENCE APPROACH TO COLLABORATION

E-Science

The term e-Science is used to encapsulate those activities based on the invention and exploitation of advanced information and communications technologies (ICT). In the words of one of the key champions of e-Science in the United Kingdom, Sir John Taylor (former Director General, UK Research Councils) its goals are:

- to generate, curate and analyse research data
- to develop and explore models and simulations
- to enable dynamic distributed virtual organisations.

E-Science is associated with a global approach to developing new ways of undertaking collaborative research. As such, it has been promoted under different labels in different contexts. In the United States e-Science mainly goes under the name of 'cyberinfrastructure', in Australia the term 'eResearch' is used, and the European effort tends to be labelled 'e-infrastructure'.

These combined efforts are relatively recent, emerging in the last five to ten years, but they are assuming an ever greater part of the agenda of research funding agencies and policy makers. Regardless of the different labels, the policy documents and guidelines for research are in agreement about promoting 'openness', collaboration and sharing. The latter can take place between research groups, between projects, between institutions, between disciplines and between different locations.

Ecoinformatics

Ecoinformatics is an approach to e-Science which focuses on the concept of virtual collaboration for managing and sharing environmental data and information products across organisations. The significance of ecoinformatics is it provides an integrated technology systems approach for supporting multidisciplinary research in addressing complex problems. Within the fields of ecology and environmental science, a number of ecoinformatic initiatives have developed software tools and products to address issues with data discovery, access, management, analysis, modelling and visualisation. The National Centre for Ecology and Synthesis (NCEAS) in partnership with the Long Term Ecological Research Network (LTER), San Diego Supercomputer Centre (SDSC) and Texan Tech University (TTU) are behind the Science Environment for Ecological Knowledge (SEEK) project which, in addition to promoting data access and

management, also produced Kepler, the scientific workflow system. This open source visual programming tool allows scientists to design and execute scientific workflows efficiently using emerging grid-based approaches to distributed computation.

The benefits achieved by harnessing computer resources for high-power grid computing are also being exploited for environmental modelling by Natural Environment Research Council (NERC) projects within the UK e-Science Program including Grid for Ocean Diagnostics, Interactive Visualisation and Analysis (GODIVA), Global Coastal Ocean Modelling (GCOM) and Grid ENabled Integrated Earth system modelling (GENIE). There is also a significant body of research exploring the application of the Semantic Web to ecoinformatics for improved data discovery and integration within projects such as SEEK, Semantic WildNet, Ecosystem Location Visualisation and Information System (ELVIS), Global Lake Ecological Observatory Network (GLEON), Coral Reef Observatory Network (CREON) and Long Term Ecological Research (LTER).

Ecoinformatics provides the broader context for which our research is a subset as illustrated in Fig. 1, with an initial focus on climate informatics. The ecoinformatics platform includes: socioeconomic, topographical, biophysical and climatic data which are necessary to derive a number of climate change and land use impact (risk) models. The outputs from these complex climate and risk models are then visualised using technologies such as digital globes (Google Earth) and collaborative virtual environments (Spatial Information Exploration Virtual Environment - SIEVE) (Stock et al., 2008). All data, models and visualisation outputs are accessible and can be shared via a collaboration platform where different levels of access and authorisation are given to a broad range of end users.

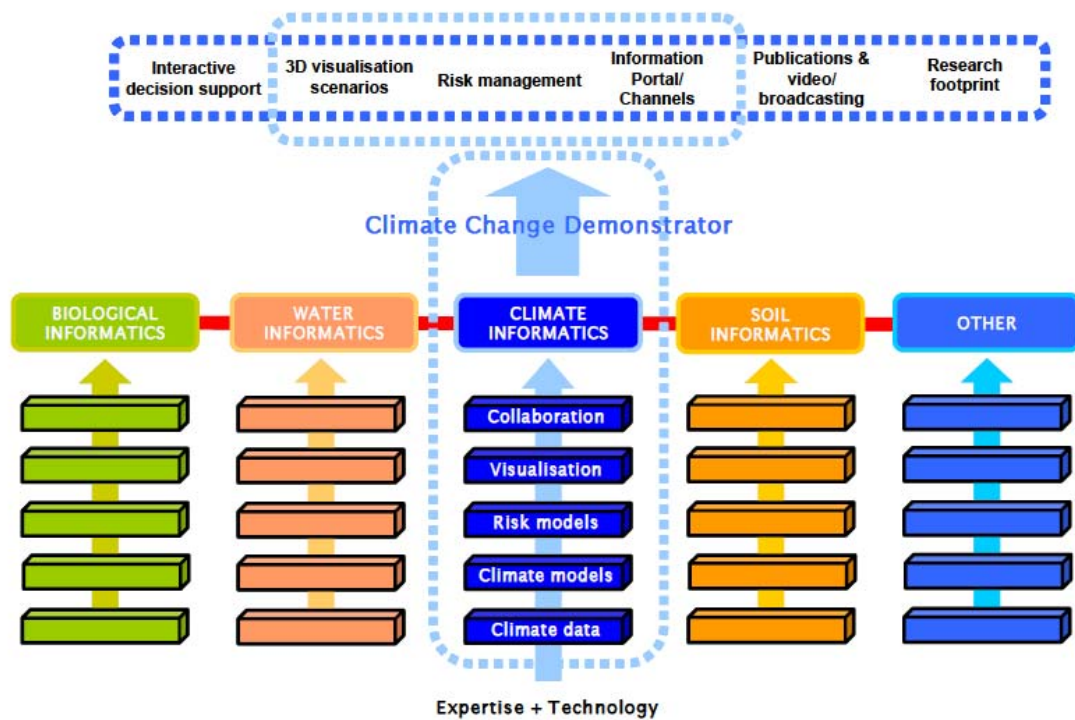


Fig. 1: Ecoinformatics platform focusing on climate informatics

This paper presents four components of the ecoinformatics platform, specifically: climate change models, land suitability (risk) models, geographical visualisation tools, and the virtual organisation e-Resource Centre (e-RC). The e-Science technology platform will be discussed in the context of the South West Victoria Case Study.

SOUTH-WEST VICTORIA A CASE STUDY IN CLIMATE CHANGE ADAPTATION

The south-west Victoria study area comprises the combined Glenelg Hopkins and Corangamite Catchment Management Authority areas. The total area is approximately 39,000 km² and is considered a high value agriculture region producing in excess of \$2 billion per year. There are a range of farming systems including dairy, grazing, beef, sheep, forestry and fisheries. Both irrigation and dryland farming is practiced and there is a rainfall gradient from north to south. Climate change is already impacting on enterprises and land use change and there is a motivated regional stakeholder group, known as the South West Climate Change forum.

Climate prediction models

Our understanding of regional climate change scenarios in south-west Victoria is underpinned by a regional climate model (RCM). Current climate prediction models have been developed from numerical weather prediction models. These atmospheric global circulation models (GCMs) are coupled with ocean and terrestrial models. Due to limited computational resources, GCMs generally have a spatial resolution of around 200 km, which is too coarse to provide detailed information on climate at regional and local levels. In dynamical downscaling, output of a GCM provides initial values and boundary conditions for a RCM having a high resolution (Fig. 2).

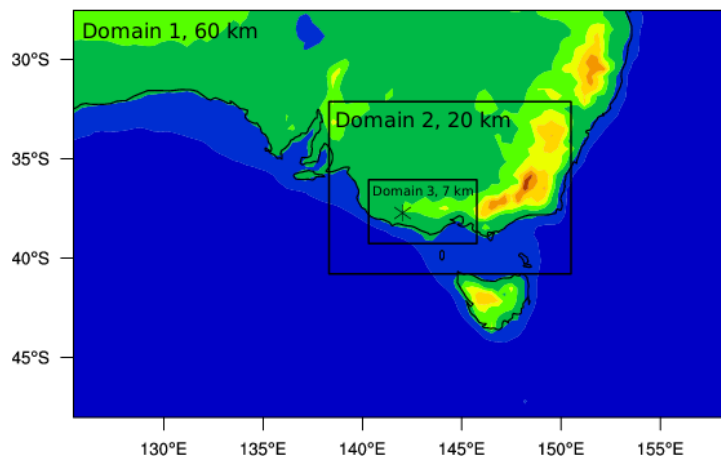


Fig. 2: Illustration of three nested RCM model domains: Domain 1 (60 km resolution), Domain 2 (20 km), and Domain 3 (6.667 km) applied to south-west Victoria. The location of the township of Hamilton is marked with the asterisk inside Domain 3.

The state-of-the-art North American Regional Climate Change Assessment Program (NARCCAP) protocol (see <http://www.narccap.ucar.edu/>) was applied in this study. The selected RCM was the Weather Research and Forecasting (WRF) model (Skamarock et al., 2005). The GCM data had a 6-hourly resolution to avoid aliasing of

the diurnal cycle. The GCM data (also used by NARCCAP) are CCSM model version 3.0 simulations from the National Centre for Atmospheric Research, USA. The CCSM model simulates the southern hemisphere circulation realistically (Uotila et al., 2007). The Monash high-performance computer facility was used for the RCM simulations. The WRF model was run on eight CPUs, where one day simulation took 75 minutes CPU time and 2.1 Gb RAM memory.

Two time periods of 1990–2000 and 2046–2055 were selected. The former time period represents the present climate with anthropogenic and natural forcing, while the latter time period represents climate conditions which already differ significantly from the present climate. Realisations based on three emission scenarios were used as input data for downscaling. The emission scenarios were IPCC SRES B1 (low, CO₂ concentration about 550 ppm by 2100), SRES A1B (middle) and SRES A2 (high, CO₂ concentration about 820 ppm by 2100). Downscaled climate data were validated by comparing annual means and variability at two weather station locations (Hamilton and Terang). The RCM was required to simulate annual and diurnal variability realistically.

Finally the data from RCM simulations were converted to interchangeable ASCII file formats and were uploaded on to the e-Resource Centre for the research team to access and download. The input files for land suitability models were converted to a format appropriate for ArcGIS and the input files for agricultural productivity models were converted to the Bureau of Meteorology's SILO file format.

Land suitability analysis

A number of land use (risk management) models are being applied to better understand the likely impact under various climate change scenarios in south-west Victoria to pastures, crops and commodities. One such category of land use models which uses the inputs from the climate modelling previously discussed is land suitability analysis (LSA). Land suitability can be defined as a measure of how well the qualities of a parcel of land match the requirements of a particular type of land use (FAO, 1976: see also Steiner, 2008). Identifying the suitable land for the growth of any agricultural commodity is a complex process. Each crop has specific growth requirements characterised by a combination of biophysical characteristics, or factors. There is usually not a single combination of those factors that will produce optimal plant growth; the presence of certain factors can nevertheless compensate for the absence of others.

A semi-quantitative approach has been developed by Sposito et al. (2008) to map/assess regional agricultural land suitability using a multi-criteria evaluation (MCE) methodology embedded in a GIS. MCE is a well-known methodology for dealing with complex decision making where several aspects are considered simultaneously (Kenney and Raiffa, 1993). Among the extensive array of MCE methods that apply a systematic analysis, the Analytic Hierarchy Process (AHP), developed by Saaty (2000), is one of the most widely used for LSA (e.g. Collins et al.; 2001; Hossain et al.; 2006; Thapa and Murayama, 2008). In this research, the primary concern was how to combine biophysical data with expert judgement to arrive at a single land suitability index of evaluation. Biophysical data (soil, landscape and climate characteristics) are often represented as criteria, which constitute the basis for a decision that can be measured and evaluated. Weights indicate the relative importance of the criteria in terms of their contribution to the overall evaluation index. Expert judgement is incorporated into the

process of selecting the criteria/factors to be included in the model and in assigning weights and ratings to each particular criterion.

The AHP method was applied to assess land suitability for eight agricultural commodities relevant to the study region given current and future climatic conditions. The crops belong to three groups: grains (barley, oats and winter wheat), pasture (lucerne, phalaris and ryegrass/sub-clover) and forestry (blue gum and radiata pine). An LSA model was developed for each of those crops using inputs from regional workshops with participation of growers, regional/local resource planners regional and experts in agronomy, soil science, climate science and geography.

After the LSA model is validated by the experts who participated in its construction, land suitability under future climatic conditions can be estimated using widely diverging climate change scenarios to cover a broad range of plausible futures. The set of resultant maps illustrate where and how much land suitability is likely to alter if future climate changes occur as predicted by the IPCC scenarios considered. Therefore, for each agricultural commodity analysed in the study region, four land suitability index maps were developed wherein one map is related to current suitability (year 2000) and three maps are related to future suitability based on the IPCC scenarios modelled by Monash University and explained in the previous section. As an example, Fig. 3 shows the winter wheat LSA for the IPCC A2 (high emissions) scenario 2050, which is stored on the Ecoinformatics map library as part of the e-RC.

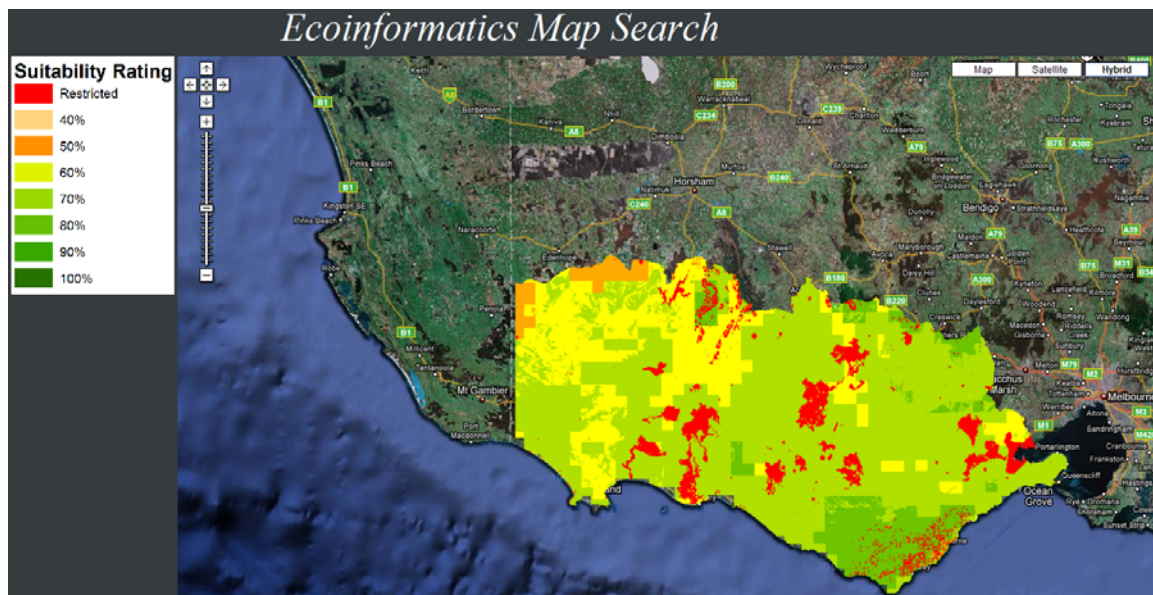


Fig. 3: Winter wheat LSA for IPCC A2 (high emissions) scenario in 2050

Geographical visualisation tools

The models supporting the development of climate change adaptation strategies come from an array of disciplines including climatology, agronomy, hydrology and pedology, for example. Effective communication and sharing of model outcomes between disciplines and with a broader public can be enhanced by the use of appropriate visualisation techniques. These have the potential to make the outputs more intuitively understood. Specifically, recent work (Stock et al., 2008) has focussed on semi-realistic

real-time three-dimensional representations in which people can develop and explore future scenarios (Fig. 4). When linked by the internet scientists, decision makers, farmers and others can collaborate within the virtual world. Within a collaborative virtual environment users can not only visit places of interest and review land management practices under different future scenarios, they can also potentially review tables and graphs setting out the model outcomes more traditionally, look underground at watertable or other effects, and share illustrative imagery.

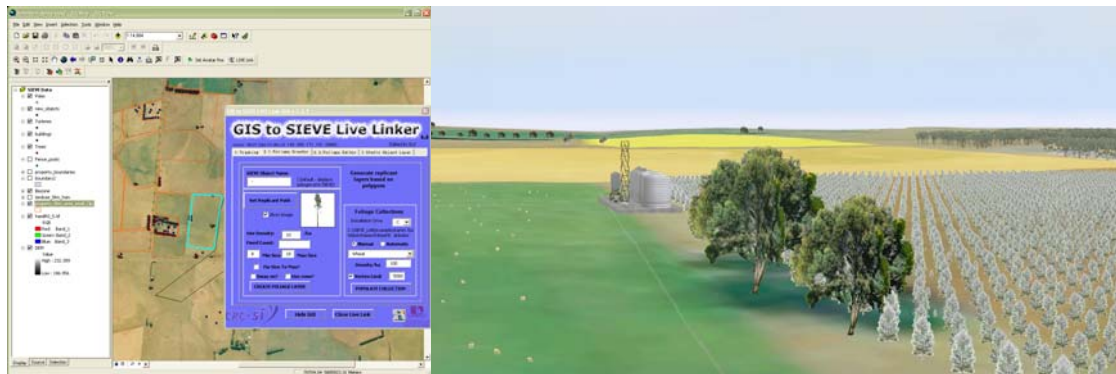


Fig. 4: An example of scenario development in the Hamilton (Victoria) study area. A polygon has been chosen within the GIS environment. Using a network connection to a computer running SIEVE, the chosen polygon has been filled with a blue gum plantation

The use of the internet for remote collaboration is one aspect of how this vision takes advantage of e-Science infrastructure. However, the vision for visualisation of outputs from development in ecoinformatics includes a range of other powerful capabilities. Examples include:

- Integration through systems architecture of multiple visualisation products—such as SIEVE to support real-time exploration and collaboration, Visual Nature Studio (VNS) to produce very high quality landscape renderings, and Google Earth to show an array of datasets in context (see Niño-Ruiz et al., 2009).
- An ability to draw on real-time data sources to include current events within the virtual environments in support of emergency response or training. Key sources might include: weather, property boundaries, fuel loads, animal tracking data etc., which may be delivered through online RSS, Atom or FTP feeds (Niño-Ruiz et al., 2009; Wang et al., 2009).
- Use of a comprehensive and powerful Object Library which makes surface objects available to the different visualisation components based on modelling outputs and without user intervention (Bishop et al., 2009).
- Support for remote image capture (from mobile phone) and spatially explicit presentation and sharing within the virtual world (Chen et al., 2009).

The scope for extension of this list extends rapidly as computer power and network bandwidths continue to increase. Augmented reality interfacing, streaming video textures and other features, perhaps not yet imaged, can integrate with the power of e-Science. A number of geo-visualisation products have been developed as front-ends to

the climate and land use models being developed. These geo-visualisation products are shared with other researchers within the project through the e-RC platform.

Climate Change Virtual Organisation platform

The e-RC has been developed as an online resource to support collaboration within the Victorian Climate Change Adaptation Program (VCCAP) as well as with partner research organisations including: University of Melbourne, Monash University, La Trobe University and the Victorian Department of Primary Industries and Department of Sustainability and Environment. The e-RC has been developed using the Confluence Open Source platform with support from the Victorian eResearch Strategic Initiative (VeRSI) program team. The e-RC is an evolving technology platform which provides secure and protected access to the members of the Climate Change Virtual Organisation (VO).

The e-RC architecture

The e-RC platform is a secure environment that uses a Shibboleth federated authentication system. The e-RC security framework ensures any communication between a user's web browser and an e-RC web application is encrypted. Secure access is initially via the VeRSI web portal that prompts the user for a username and password. If the user's credentials are accepted then they are forwarded to the e-RC, as illustrated in Fig. 5. When a user account is being created the VO administrator determines the level of access to different sections and resources of the e-RC each user should have. Resources will then be visible to a user only if their access has been authorised.

The e-RC platform implements layered software architecture to provide a robust and manageable system with a minimal effort required for maintenance. The e-RC platform is logically structured into four different tiers to facilitate a modular software development strategy:

- Client tier consists of the user's web browser on a desktop or laptop.
- Web Application tier consists of the VO applications and tools, supported by data bases providing secure access to the various ecoinformatics resources.
- Identity tier consists of the VO user identity registration system that is used for the authentication and authorisation of users. This is where fine-grained access control is set.
- Federation tier registers resources from the web application tier and the identity tier to establish a trust federation, ensuring that users have access to the appropriate resources.

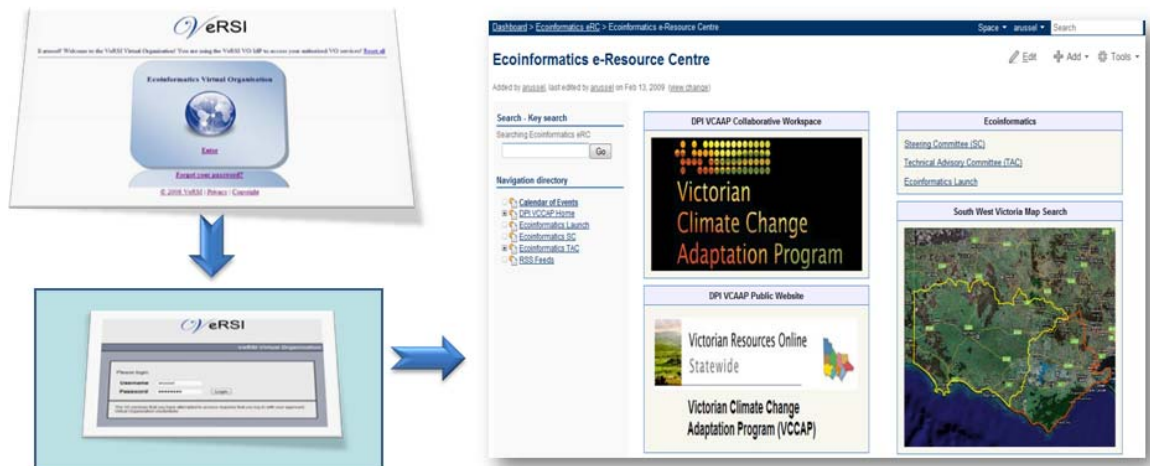


Fig. 5: Secure access to the e-RC platform front page

The e-RC functionality and contents

With 74 registered users spanning six organisations, the e-RC is proving to be an effective resource for collaborative climate change research. It provides a centralised workspace where information, data and knowledge can be exchanged between institutions, researchers and policy makers. Some of the key functionality of the e-RC includes:

- Homepage which provides links to recently updated sites (What's New?), the calendar of events, climate specific RSS feeds and customised VCCAP research workspaces.
- Key Word Search with advanced search options to restrict searches to workspaces, attachments or publishing date.
- Wiki functionality to create new pages, edit and format content, create and populate tables or add attachments.
- Calendar of Events where users can enter the details of workshops, conferences and events of interest to the whole VCCAP team.
- Virtual Library populated with articles and papers related to climate change research.
- Map Library populated with land use suitability models displayed using Google Maps (See Fig. 2).
- Users Guide and Instructional Videos to further assist users and introduce them to the functionality and tools available within the e-RC.
- Security features with the ability to restrict access to confidential files or data.
- Data Storage for storing working documents and data such as the Climate Change modelling outputs discussed previously.
- Visualisation Toolbox including Google Earth, SIEVE (See Fig. 3) and other geo-visualisation products for viewing climate change and land use models and adaptation scenarios.

- 3D Object Library includes three-dimensional models representing buildings, farm infrastructure, and vegetation found in south-west Victoria. Available for download in four formats (.skp, .kmz, .obj and .3ds) the models can be viewed with Google Earth or Google SketchUp (see Fig. 6).

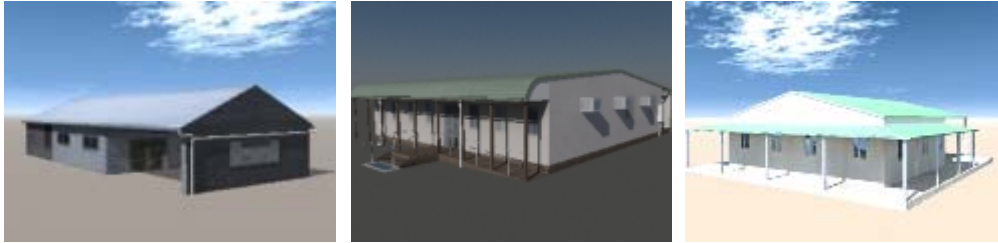


Fig. 6: 3D models of farm buildings located at Demo Dairy, Terang

CONCLUSIONS

E-Science offers a number of benefits to a wide range of stakeholders in dealing with complex problems such as climate change. E-Science supports a multidisciplinary research approach, connecting researchers across disciplines and organisations through the paradigm of a virtual organisation. In this paper we have presented an ecoinformatics platform for supporting climate change adaptation research across government and universities in Victoria. We have presented four key components of the ecoinformatics platform, these being: climate change modelling, land use risk modelling, geo-visualisation and an e-Resource Centre for sharing data models and visualisations. The next steps of the research will develop a metadata tool to better support search and discovery of data assets and models available via the e-RC, and develop workflows to dynamically connect datasets, models and geo-visualisation technologies. The evaluation and testing of the various components comprising the e-Science framework, particularly from the perspective of stakeholders, will also be considered.

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