

Realising an eScience platform to support climate change adaptation in Victoria

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Abstract — Our research is focused on developing an ecoinformatics platform to support climate change adaptation in Victoria. A multidisciplinary, cross-organisational approach is taken in developing adaptation strategies to deal with the ‘diabolical’ policy problem of climate change.

The platform comprises a number of components including: (i) a metadata discovery tool to support modelling, (ii) a workflow engine for connecting climate change models, (iii) geographical visualisation tools for communicating landscape and farm impacts, (iv) a landscape object library for storing and sharing digital models, and (v) a landscape constructor tool to support participatory decision-making, and (vi) a virtual organisation for collaboration and sharing information.

In this paper we will discuss the platform as it has been developed to support collaborative research and to inform stakeholders of the likely impacts of climate change in South West Victoria, Australia. We will discuss some of the drivers for research in developing the ecoinformatics platform and its components. The paper concludes by identifying some future research directions in better connecting researchers and communicating science outcomes associated with climate change impact and adaptation.

Keywords – climate change; geographical visualization; workflows; models; virtual organisations

I. INTRODUCTION

Our research has focused on the development of a demonstrator of eScience capabilities to support climate change adaptation in Victoria, Australia. Specifically we have developed a case study approach focused on the impacts of climate change and adaptation options in South West Victoria. An ecoinformatics platform has been developed to support multi-disciplinary, cross-organisational collaboration in dealing with the complex multifaceted problem of climate change.

II. BACKGROUND

Ecoinformatics is an eScience approach and focuses on the concept of virtual collaboration for managing and sharing environmental data and information products across organisations. Ecoinformatics provides an integrated technology systems approach for supporting multidisciplinary research in addressing complex problems. Within the broad

field of environmental science, a number of ecoinformatics initiatives have developed software tools and products to support data discovery, access, management, analysis, modelling and visualization.

The ecoinformatics platform can be characterised as a virtual research environment (VRE). A VRE can be described as a set of web applications, online tools, systems and processes interoperating to facilitate or enhance the research process within and without institutional boundaries; it enables collaborative research activities beyond geographical barriers. Several other terms can be used instead of VRE, such as CVE (Collaborative Virtual Environment), Cyberinfrastructure/e-Infrastructure, Collaborative eResearch Communities, VRC (Virtual Research Community), and VO (Virtual Organisation).

Despite the range of terms, there are, however, understandings converging on a set of characteristic features: an electronic web-based infrastructure for i) access to data, tools, resources, and other researchers; ii) co-operation or collaboration with other researchers at the same or different institutions; iii) co-operation at the intra- and inter-institutional levels; and iv) preserving or taking care of data and other digital outputs.

There are a number of ecoinformatics initiatives being undertaken internationally. Some of the key activities in this space include: the National Centre for Ecology and Synthesis (NCEAS) [17], the Long Term Ecological Research Network (LTER) [15], the Science Environment for Ecological Knowledge (SEEK) project [19], Global Lake Ecological Observatory Network (GLEON) [11], the Coral Reef Observatory Network (CREON) [8] and Natural Environment Research Council (NERC) [16] projects within the UK e-Science Program: Global Coastal Ocean Modelling (GCOM) and Grid ENabled Integrated Earth system modelling (GENIE). Some Australian National Collaborative Research Infrastructure Strategy (NCRIS) related initiatives include: the Integrated Marine Observing System (IMOS) electronic Marine Information Infrastructure (eMII) [12], AuScope Spatial Information Service Stack (SISS) [20] and Terrestrial Ecosystem Research Network (TERN) [22].

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 geographical locations.

III. METHODS

In our research we have developed an eScience platform which is focused on climate informatics as a subset of ecoinformatics—see Figure 1. Underpinning this platform is a data infrastructure which supports climate and risk modelling. These climate change impact (risk) models need to be communicated to practical end users (land managers and policy-makers) and hence information visualisation provided an important component to the proposed technology stack.

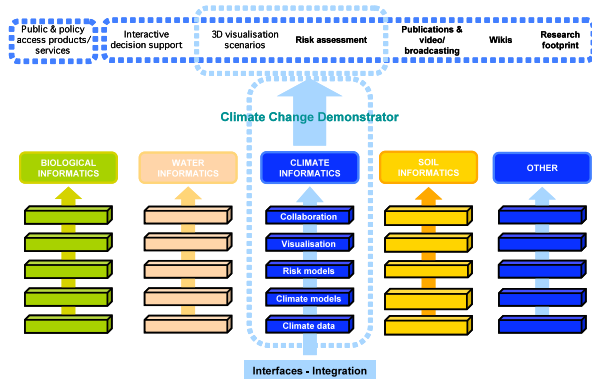


Figure 1. Platform for Online Collaboration focusing on climate change data information, models and communication [4]

A number of technologies have been developed and coupled together to create the ecoinformatics platform for modeling and communicating the likely impact of climate change and adaptation options in South West Victoria. These include:

- A model metadata tool: The Model Information Knowledge Environment (MIKE) has been developed to record and discover model instances.
- A model workflow engine: The Workflow supports the dynamic link of simulation models.
- Geographical visualisation tools: A suite of visualisation tools to communicate localised climate change scenarios — Google Earth and the Spatial Information Exploration Visualisation Environment (SIEVE).
- Landscape Object library: An online database for storing, sharing and managing digital objects used to create visualisation products.
- Landscape Constructor tool: A participatory decision making tool for supporting end users in creating and exploring climate change adaptation scenarios.

- An online collaboration space: A confluence wiki tool to store documents, data, models and support program management and information exchange.

In this paper we introduce these technology components and discuss the drivers of research in developing them.

A. Model Information Knowledge Environment

Since 2007 there has been a body of climate change adaptation research undertaken in South West Victoria, Australia, under the Victorian Climate Change Adaptation Program (VCCAP) [24]. This has involved the running of downscale climate change models and using these model inputs into a range of computer simulation models. Primary data inputs into these models include: climate and weather data, soil, land use, hydrological, and socio-economic data. Primary and derived data such as processed imagery have been used to drive a number of biophysical, socio-economic and three-dimensional (3D) landscape models. Metadata tools are critically important in supporting search and discovery of primary and derived data. Conventional metadata search and discovery tools enable researchers to understand what data has been collected previously in a study area. In contrast the Model Information and Knowledge Environment (MIKE) also supports storage of metadata for computer based models that have previously been run in a study area and describes how this digital information can be accessed.

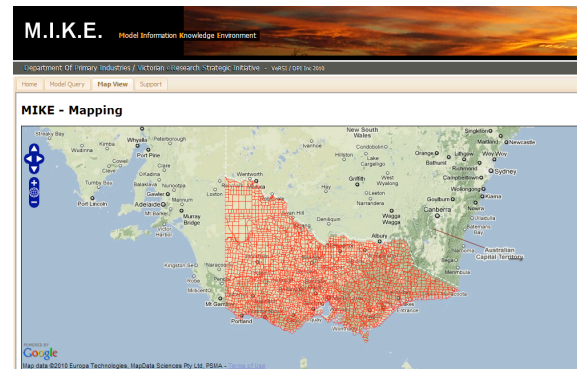


Figure 2. Model Information Knowledge Environment (MIKE) enabling the search and discovery of environmental models using spatial and attribute queries.

The MIKE [18] is an online search and discovery tool. It holds over 100 climate model instances run for South West Victoria. Metadata search and discovery tools such as MIKE are a critical part of the eScience infrastructure supporting climate change research in Victoria (<http://mike.versi.edu.au/mike/>).

The MIKE database is designed to store model metadata against core model, model versions and model instances. The metadata recorded encompasses model description, purpose and methodology and also includes the details of data inputs and outputs together with spatial details of model instances. An online spatial and aspatial viewer allows a user to query and discover modelling activity. Spatial referencing is supported via the integration of the model metadata to a spatial

registration grid. The spatial referencing of model instances appears to be unique to the MIKE [18] and enables model activity discovery based on spatial location and extent. Practical support for this function required online user-friendly and efficient approaches to the spatial registration of model instances together with a unique approach to database and spatial technology integration. The MIKE application was developed using open source software (Geoserver and Postgres/PostGIS) and platform independent programming technologies (HTML, Ext & Java).

In the context of the ecoinformatics platform, MIKE provides metadata tools to support the discovery of climate and environmental models. From an eScience perspective it enables researchers/modellers to explore what other modellers have produced. This may reduce duplication in modelling efforts and also better connect researchers and facilitate collaboration. Research investors can also understand where previous investment in model based research has occurred and this may influence future investment decisions. Policy-makers can search a system such as MIKE to identify domain experts to ask more domain specific questions. Metadata tools such as MIKE are a critical underpinning technology to the ecoinformatics platform and have broad application for data and model search and discovery.

B. Model Workflow Engine

An extensive array of environmental models is available to simulate the likely impact and adaptation options to climate change in South West Victoria. These computer models include forecasts of temperature, and rainfall, land suitability analysis, likely land use change, crop simulation, pasture simulation, and adaptive capacity. These models assist policy-makers and planners in understanding and communicating the potential risks climate change poses to South West Victoria.

Each of these models require digital data inputs in order to generate model simulations of land suitability, possible land use change, biological and socio-economic responses. Within our problem domain there are a number of custodians for these input datasets and models including state government departments (Department of Primary Industries and of Sustainability and Environment), Universities (Melbourne University and Monash University) and Federal government research agencies (Australia's Commonwealth Scientific Industrial Research Organisation). One of the eScience challenges is being able to deal with multiple custodians. Technically, streaming data feeds from different organisations into the simulation models is not a significant challenge in comparison to organisational barriers to information sharing. In this research, working across government and universities at the data and modelling level raised many organisational issues including: conflicting security policies, intellectual property management and a cultural shift in researchers sharing data.

The technical challenge we addressed was to pass modelling parameters from one model to another to create scientific workflows. For example, in order to run land use change scenarios for South West Victoria no less than three different simulation models are run in sequence. Firstly, the climate model must generate parameters required by the land

suitability analysis models, the land suitability surfaces are then used to guide the outcomes for the land use optimisation model. Scientific workflow tools such as the open source application Kepler [14] can assist in streamlining model flows. Figure 3 illustrates a workflow exemplar that has been developed to link various modelling components within the scope of this project.

Land suitability analysis and crop optimisation workflow

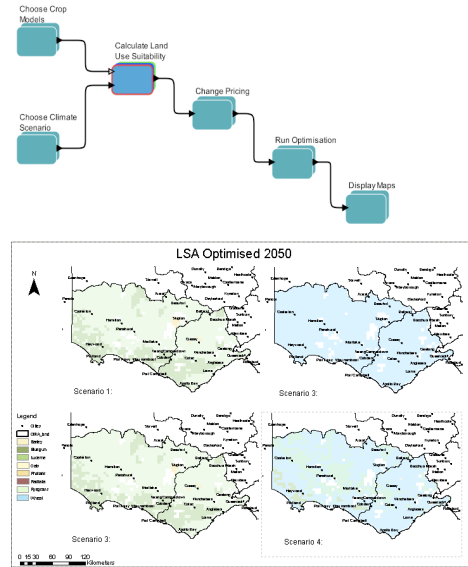


Figure 3. Model Workflow Engine connecting crops models, climate change scenarios with land suitability and optimisation models.

Another technical challenge was to create a climate change model workflow that combined different domain datasets using an integrated graphical workflow execution environment. The workflow integrated climate scenarios with land suitability scenarios based on eight agricultural commodities. The climate datasets for the year 2050 were based on the IPCC A1FI CSIRO MK3 model and were pre-generated. The output of the integration process were maps which identify which crops are more suitable for South-West Victoria, and these are used in the optimisation program.

In computer science, a workflow system allows multiple programs to connect together to create a larger, automated task. Kepler [14] is a workflow engine written in Java that provides a user-friendly graphical environment to define such applications. Nimrod/K [7] is an extension to Kepler that provides two new tools to perform experiments at a much larger scale. These are: data exploration tools and tools to scale a workflow to do more detailed simulations. The data exploration tools (used in this workflow) adjusted input parameters to the land allocation model. This allowed multiple simulations to be performed and then analysed. As each of these simulations can run independently of each other (that is, the results of one simulation do not affect the results of another simulation) we can run many of them simultaneously using additional compute resources to produce results quickly.

ArcGIS [1] is used for designing the Analytic Hierarchical Process (AHP) model [21] and for combining Land Suitability Analysis (LSA) crop datasets with climate scenarios. The ArcGIS parameters are exported as Python scripts. In this proof-of-concept prototype, eight crops have been considered for optimisation against CSIRO's A1FI MK3 model for the year 2050 climate datasets. The crops were: wheat, barley, oats, pina radiata, blue gum, ryegrass, phalaris and lucerne. Eight GIS models were designed to identify land-use suitability for a set of agricultural commodities in South West Victoria as part of the Victorian Climate Change Adaptation Program (VCCAP).

These models were constructed based on an AHP in which the influence of parameters such as soil attributes, landscape and climate are weighted against each others based on expert knowledge and information available in the literature. Models relevant to each of the eight commodities were initially developed in the ESRI ArcView 3.3 Model builder environment [23]. The input data for each model corresponded to climate data (current or future), was provided in raster format, and soil information data (pH, depth to bedrock, slope, electric conductivity, soil depth), and was provided in the ESRI shapefile format.

Computing instructions corresponding to each model were translated into the Python environment (making use of ESRI ArcObjects). The use of Python scripts allows automated runs of land-use suitability models outside the ArcGIS user environment and enabled easy application of the models to different regions of interest or investigations of the implications of various climate change scenarios. Runs from each model produced an ASCII text file whose values (ranging between 0 and 9) were indicative of the how suitable a specific area was for the growth of a chosen commodity, under a chosen climate scenario.

The optimisation program was written in Visual Basic (VB) language. The input consisted of ASCII files - one for each crop in the region being covered. The program read the number of columns and the number of rows of grid cells across the region and then it read the position of the region's top left corner. It then recorded the market price, the yield, the total hectares and the total tonnes produced for that crop. The soil suitability for that crop, ranged between +1 and -1, where -1 indicated that the cell is out of bounds for cropping. The program assumed the market demand is equal to current tonnes produced. Optimisation is performed on current land suitability scores plus revenue generated from growing crops by using the iterative "probabilistic improvement" method.

The workflow has implemented the following actors (actors in Kepler are Java classes to do specific task(s)):

- (i) Choose Crop Models: to specify which AHP crop files to pass.
- (ii) Select Climate Scenario: to specify which climate datasets to pass.
- (iii) Calculate Land-use Suitability: to execute Python scripts to combine LSA models with climate datasets.

- (iv) Change Pricing and Yield: to specify different values to construct scenarios for optimisation.
- (v) Run Optimisation: to execute optimisation codes based on user-defined scenarios in the previous actor.

The climate change model workflow component provided an exemplar on how different models can be connected and run in near-real-time. This is an important driver for eScience as a challenge for modelling is being able to provide timely advice to practical end users, in this case being regional planners and policy makers. By streamlining the modelling process where multiple models and custodians exist, end users will ultimately be able to access climate change impact information in a timelier manner.

C. Geographical Visualisation Tools

The communication of complex climate change science can be enhanced through information visualisation approaches. Visualisation enables the outcomes of social, economic and environmental analysis to be brought together using visual media to convey meaning to land managers, communities, industry, regional planners and policy-makers. Visualisation provides a powerful front-end for displaying the output of sophisticated models and land use change scenarios.

In this research, we have developed automated scripts and GIS geoprocessing routines to convert data surfaces of past and future climates into Google Earth KML features such as temporal animations, and clickable balloons displaying graphical or tabular information (at a 5 km grid cell) perspective (Figure 4 & 5). The combination of these products created an environment allowing the exploration of datasets from a broad perspective at a landscape scale down to detailed analysis for a specific location of interest. Specifically, Figure 4 displays spatial-temporal climate change temperature projections for the IPCC A1FI scenario. Figure 5 depicts monthly temperature and rainfall variations averaged over two historical periods (1961-1990, 1998-2007) and two future climate snapshot years (2020, 2050). There are approximately 11,000 complex spatial-temporal climate change data points at 5km grid interval that users can interrogate through this visual interface of digital globe technology.

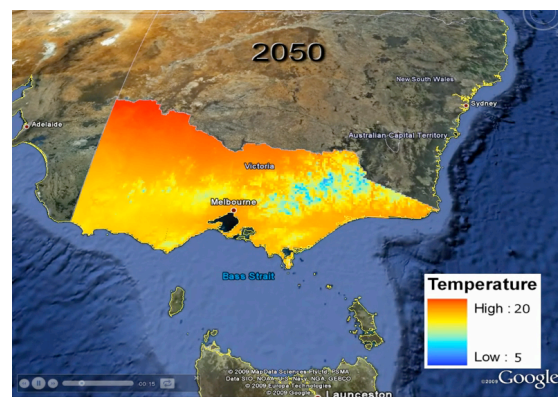


Figure 4. Landscape Scale Google Earth Visualisation – Temp. 2050 [5]

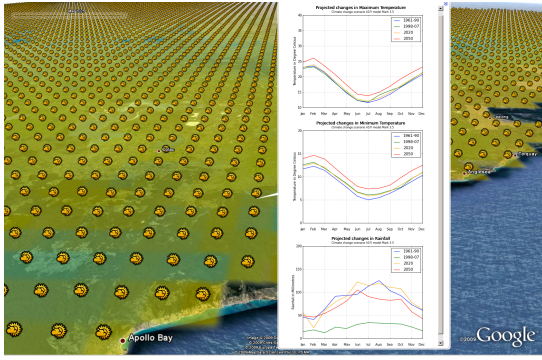


Figure 5. Point scale Balloon in Google Earth Displaying Graphic Information.

This data exploration environment was complemented by on the ground farm scale visualisations, illustrating the potential implications projected climate changes on rural landscapes. To this purpose, we used realistic visualisation software, such as 3D NatureVisual Nature Studio, to combine landscape aspects, vegetation structure (derived from land-use suitability models), photographic vegetation objects and objects of human made structures, into realistic representations of local environments.

Farm scale visualisations for current and projected climate conditions were then integrated at specific locations in the Google Earth environment as 360 degree interactive virtual panoramas (Figure 6). These products allowed users to move back and forth between scenarios and observe how their environment may be affected by projected changes in climates.



Figure 6. Panorama for present (top) and future (bottom) conditions in South West Victoria.

Computer game engine technologies provide another category of visualisation products which enable end users to interactively explore landscape and farm scale information. As

part of this research the direct linkage of GIS and game engine technologies as been explored. Stock et al. [7] describe the SIEVE suite of programs for export of GIS (ArcGIS) data into game engine (Torque) format, for live linkage to allow data editing and landscape scenario development in either the 2D or 3D world and the potential for linkage of realistic visualisations to scientific process models (such as ground water models as represented in Figure 7). The automated linkage of a GIS to a computer game engine enables data and modelling products to be created more efficiently and provides an environment for end users to interact with complex climate change models. There is a significant eScience challenge in providing better access to datasets and models. The geographical visualisation products developed and described above are an important step in making complex scientific information more accessible to practical end users.

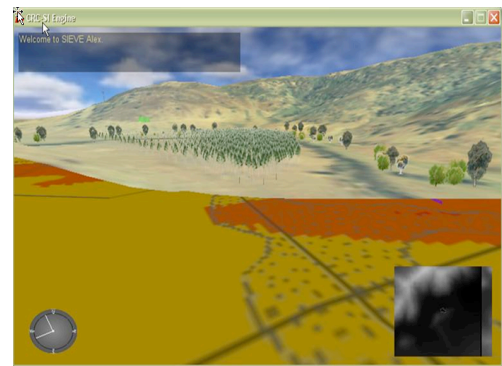


Figure 7. Farm scale SIEVE Visualisation including cropping of the foreground to reveal the outcome of ground water modelling.

D. Landscape Object Library

To support the development of visualisation products a digital landscape object library has been developed (<http://objectlibrary.versi.edu.au/Objects/>). Digital objects representing vegetation, animals, farm equipment and built infrastructure can be used to create photo-realistic three-dimensional representations of past, present and future landscapes. These landscape objects are stored in an online database environment where applications can consume objects from the database to create virtual worlds, such as illustrated in Figure 7.

The landscape object library has been developed using a data model which supports object acquisition, management and distribution. The features of the data model support multiple roles such as user, image creator, custodian and administrator. In addition, the data model supports custodianship that manage the objects in: categorising versioning, reviewing, editing and publication through the application web interface.

The objects stored in an oracle database are geotagged and include associated metadata. The application provided easy retrieval of objects through the deployment of a keyword search engine facility. The objects can be distributed to users through an object ordering system available through the web interface and also web services embedded in the application.

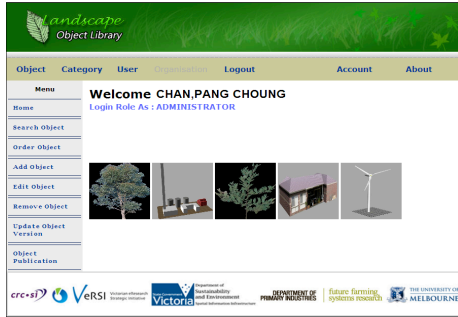


Figure 8. Landscape Object Library.

The research driver behind the creation of the landscape object library is the exploration of the benefits in providing a database where a number of custodians can store and share landscape objects from across multiple organisations. In this case the end users are researchers who can download landscape objects and through using their own visualisation tools can create their own geographical visualisation products. The object library also provides a step towards a 3D spatial data infrastructure to support the near real-time visualisation of climate change futures.

E. Landscape constructor tool

In order to facilitate a participatory decision making approach to climate change adaptation we have developed an interactive tool known as the landscape constructor tool. The landscape constructor tool is a .NET standalone application that uses ESRI's ArcObjects, windows libraries and remote connectivity with the object library oracle database (discussed above) to build past, present and future landscapes on the fly.



Figure 9. Landscape Constructor Tool with workflow user interface to enable climate change futures to be created and explored.

The tool enables users to interact in a group decision-making environment through a touch table interface that connects to the SIEVE game engine (discussed above), ArcGIS software with the object library database accessed remotely. Practical users to the tool choose an area of interest and can create and collaboratively explore climate change adaptation scenarios. For example, biolinks (large biodiversity corridors) can be created through the user selected appropriate vegetation from the object library and then digitising polygons directly onto the touch table. Using the landscape constructor workflow interface (Figure 9) a virtual representation of this future landscape scenario can be visualised and explored by the decision-making group. The landscape constructor tool

provides a powerful collaborative decision making environment to enable the creation and exploration of climate change adaptation scenarios.

F. Online Collaborative Space

With the advent of web 2.0 there has been a shift from the internet as a vehicle for solely disseminating information to a platform that can support collaboration and facilitate bi-directional flow of information. One of the drivers of eScience is to better connect researchers in being able to tackle complex problems such as how to respond to climate change. To facilitate information sharing cross government and university and access to a number of the technology components described above an online collaborative space has been developed as part of the ecoinformatics platform to support a multidisciplinary research effort.

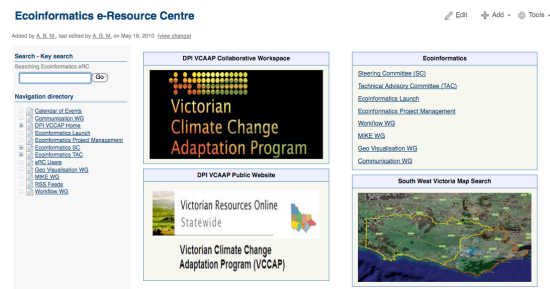


Figure 10. e-Resource Centre – Virtual Organisation for Climate Change Research in Victoria.



Figure 11. e-Resource Centre – Virtual Organisation for VCCAP [24].

The online collaboration space known as the e-Resource Centre (Figure 10) has been developed on top of an open-source confluence Wiki platform to facilitate collaboration capabilities such as content sharing, messaging, calendar, library, project management and model storage etc. Specific virtual work areas have been established to support the various research groups comprising the project team. The e-RC platform is using shibboleth for authentication, authorisation and access control. This is a federated identity framework to allow cross-organisational collaboration. The e-RC has been governed by the policies and procedures defined by the Australian Access Federation (AAF) [1]. The e-RC utilised fine grained access controls such as content level read/write access. Hence, access to specific data, models and visualisation outputs can be restricted or the information can be made available to all registered users.

The structure of the e-RC is shown in Figure 12. The collaboration space includes a Wiki and repository for discussion, RSS feeds to related climate change sites, map search facility for data products created and a host of other services. The e-RC creates a neutral research space, implementing a strong security and access framework to enable protection of data and integration of services. Overall there is enhanced accessibility for government and universities researchers. There are presently 90+ registered users who have access to more than 1,000 digital artifacts including documents, maps, models, landscape objects and other digital content.

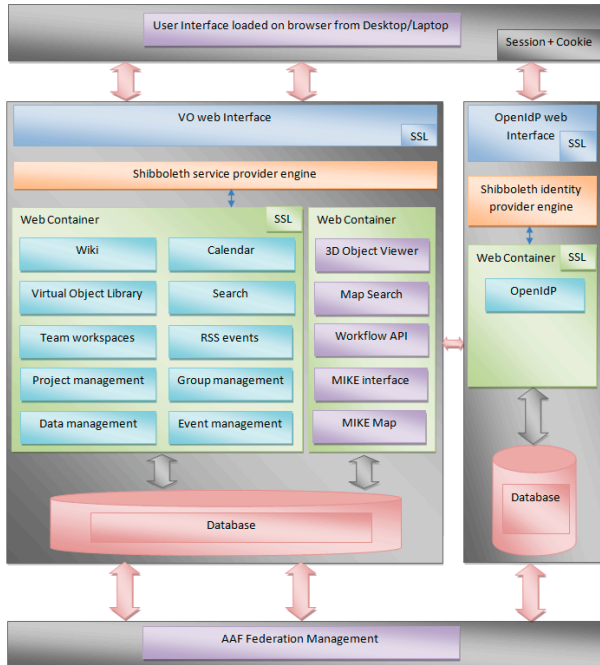


Figure 12. Structure of the e-RC hosting different tools and project management collaborative spaces.

It is important to point out that the e-RC does not only connect researchers and provide an environment to support project archiving but it also provides a powerful project management tool. As a project management tool, the e-RC provides a secure and efficient means of sharing project information, documents and related digital artefacts. Until recently, email has been the only electronic means available to support collaboration and sharing of project information across organisational firewalls. As an externally hosted online web enabled repository, use of the e-RC by project staff reduced much of the burden that this type of project would have had on corporate email systems. The e-RC provided the means for project teams across government departments and universities to collaborate in a way that was not previously possible. The e-RC addressed many of the issues associated with access across organisational boundaries and network computing constraints that were otherwise difficult or time consuming to resolve.

For each project component, a collaboration workspace was created to support project activities. The e-RC currently supports 20 project team members, 20 subject matter experts

and 15 representatives from each of the partner organisations who as members of the project steering committee provide project governance, support and direction to the project team. Online collaborative spaces such as the ecoinformatics e-RC provide a critical eScience component in supporting multidisciplinary and cross organisational research. Such technologies offer exciting potential to a joined up government approach to dealing with complex problems such as climate change

IV. RESULTS

This research has successfully demonstrated that primarily open source technologies can be coupled to facilitate the exchange of data, models and information across organisations. The value in using an open source approach is that it promotes sharing of software and code, which can extend the lifetime of an application. The inherent value in coupling data, models, visualisation interfaces and collaboration tools together is that scientific expertise both in soft (people) and hard (technology) systems can be better harnesses to deal with complex real world problems, such as climate change.

In this research we have successfully deployed a number of technology components which comprise the ecoinformatics platform (see Figure 1). Each of these components addressed one or more drivers of eScience as discussed through-out the paper. However, by linking these components through a common ecoinformatics platform we can begin to realise and explore the benefit of an integrated holistic systems approach where the whole of the system is greater than the sum of the parts.

Whilst we believe the ecoinformatics platform developed is a significant step forward there are components which the platform does not yet incorporate. These components include (i) a metadata repository for all datasets, to complement the metadata register (MIKE) developed for models; (ii) a data catalogue to support back end access to datasets through a metadata repository; (iii) a visualisation toolbox (visual analytics) to support researchers in interrogating complex scientific datasets.

In dealing with complex policy problems such as climate change a systems approach [10] is required. In this research we have endeavoured to develop an integrated technology platform which will enable a systems approach to dealing with complex societal problems such as climate change.

Initial feedback on the eScience approach has provided positive responses from a range of end-users including: regional planners, catchment manager and policy-makers [13]. However, there lie significant challenges in being able to make the outputs of eScience more accessible and user-friendly. Bridging the communication gap between experts (scientists) and practical end users (land managers and policy-makers) is a critical next step. This will involve further research into (i) communication theory, (ii) participatory research to better understand how to connect different stakeholder groups, and (iii) usability research into information systems, models and visual interfaces to ensure eScience outputs are end-user designed and tested.

V. CONCLUSIONS

In this research we have introduced a VRE - the ecoinformatics platform for supporting climate change adaptation research in Victoria, Australia. Through undertaking this research and development we have found there are a number of benefits in developing such a VRE including: scholarly collaboration over a distance, exchange of information among scholars, access to skills, knowledge, research data and computational resources situated in remote locations and cooperative writing of research material.

Some of the main challenges for the development and success of VREs we see are: space, time, funding, isolation, poor motivation, trust, commitment, workflow variations, ownership, data access, software and technology that is difficult to learn, lack of appropriate skills and extensive training needs.

There are of course a number of technical challenges facing eScience. We believe further research is required to develop the technical standards and interoperability to support the automated workflow of data into and between the suite of climate and environmental models. It is essential that both datasets and models are searchable and discoverable and that information can seamlessly flow across organization and geographies. This is a critical next step and challenge for eScience in enabling land managers and policy-makers to make the best possible decisions based on the best available information in dealing with complex societal problems such as climate change.

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