VISUALIZING CLIMATE CHANGE IMPACT WITH UBIQUITOUS SPATIAL TECHNOLOGIES

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ABSTRACT:

This paper further articulates the role of ubiquitous spatial technologies (e.g. Google Earth) as tools for analyzing, visualizing, and developing policy responses to predicted climate change impacts. Specifically, the efficiency and effectiveness of using the tools in the production of visualizations for the local level is studied. A brief background to climate change response reveals limited data and visualizations at the local level: ubiquitous spatial technologies can potentially fill the void. Case study data including temperature, rainfall and land suitability information from southwest Victoria (Australia) are used to test the hypothesis. The research team produced thirty short visualizations using minimal time, resources and a moderate skill base. The effectiveness of the visualizations was tested on a diverse group of stakeholders. It was found that the visuals provided contextual information and understandings of overarching climate change trends, however, integration with other datasets and higher levels of detail are required if the platform is to be used as a stand alone policy development tool. Moreover, the need to further develop design guidelines to guard against, or at least inform users about visual sensationalism is required.

1. INTRODUCTION

Over the last decade climate change science increasingly pervaded mainstream media and political discourse: debates and strategies relating to climate change permeated all levels of society. Mitigation and adaptation strategies were evident in the actions of governments, businesses and individuals: carbon footprints were assessed, emissions trading and reduction schemes developed, and the potential impacts of sea-level rises were analyzed.

The success of these strategies is a product of the data and models used for their justification. Increasingly, there is a need for these models to integrate data from a range of sources: the complex nature of climate change response requires this multi-disciplinary approach (Bell et al, 2003). Maps and graphic visualizations are a powerful tool for enabling integrated analysis: spatial coordinates can unite disparate datasets and represent them on a single platform. The ability of computers to perform this task has long been recognized (DiBase et al, 1992; Max et al, 1993). Animated weather maps provide prime examples (Gardner, 1985). However, until recently, the production and use of these maps belonged to specialized scientific communities: they remained out of the reach to local decision makers and citizens.

Ubiquitous mapping tools such as Google Earth radically democratized spatial analysis and visualization. These tools provide great utility in the realm of climate change response: amateur users from a range of disciplinary backgrounds can easily engage with climate change models and visualizations. This utility has received much attention in recent years; however, literature describing the development process is limited. Moreover, the limitations and risks associated with democratized visualization demand further research.

To this end, this paper aims to further articulate the role of Google Earth as a tool for analyzing, visualizing, and developing integrated responses to potential climate changes. Specifically, the efficiency and effectiveness of using the tool in the production of visualizations for the local level is studied. Case study data from the southwest region of Victoria (Australia) is utilized. First, a brief background to climate change response and visualization is provided. This leads to a discussion of the study’s methodology: the selected region, characteristics modelled, scenario development process, visualization design and testing procedure are articulated. Results are then discussed using imagery and preliminary user feedback. The paper concludes with a discussion of the utility of using Google Earth for localized climate change analysis, visualization and integrated policy development.

2. BACKGROUND

2.1 Contemporary responses to climate change

Contemporary responses to climate change occur at a range of scales: global, regional, national and local responses are evident. At the global level, the United Nations (UN) drives the most recognizable responses. In 1992, subsequent to the Earth Summit in Rio de Janeiro, the United Nations Framework Convention on Climate Change (UNFCCC or FCCC) was conceived. The international environmental treaty led to the creation of the Kyoto protocol, a tool for reducing the production of greenhouse gases in industrial countries. Additionally, the Special Report on Emissions Scenarios

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(SRES) prepared by the UN's Intergovernmental Panel on Climate Change (IPCC) in 2001 used future emission scenarios to describe potential changes to the climate. Forty scenarios divided into four families (A1, A2, B1, B2) were compiled, each based on different economic, social and environmental assumptions. The scenarios are intended to assist with climate change assessment, mitigation and adaptation strategies.

Regional and national responses are most evident through the European Union's (EU) European Climate Change Programme (ECCP) and the accompanying European Union Greenhouse Gas Emission Trading Scheme (EU ETS). Australia and New Zealand are in the process of implementing similar schemes and more recently the United States has begun development of a cap-and-trade system. Where national consensus is delayed, state based approaches emerge: Illinois (Emissions Reduction Market System) and New York State (Regional Greenhouse Gas Initiatives) provide examples in the United States, whilst New South Wales (NSW Greenhouse Gas Abatement Scheme) provides an example in Australia. These tools are largely directed at mitigation rather than adaptation.

Local level responses have been impeded previously by limited awareness, lack of specialized knowledge and minimal information at the local or landscape scale (Dockerty et al, 2005). While some visualization and analysis tools were evident during the 1990s and early 2000s (Gordin et al, 1994; Wilby et al, 2002), the pervasiveness of new ubiquitous spatial technologies and emergence of scenario building techniques (Dockerty et al. 2006; Carter, 2001) have enabled more local community engagement with respect to climate change analysis and response. These local responses are a focus of this research.

In addition to becoming more localized, contemporary climate change responses also exhibit 'integrated' natures. The complexity and scope of climate change requires such an approach: datasets, models, scientific communities, policy-making groups, and the public are incorporated into the decision-making process. Climate change literature confirms this diverse group of stakeholders (Sheppard, 2005; Gordin et al, 1994), whilst Bell et al (2003) articulate the overarching benefits and difficulties of these integrated approaches. Dockerty et al (2005) and Sheppard (2005) both highlight the need for design guidelines and caution when developing climate visualization tools for diverse audiences. For example, over-emphasis of visuals might lead to inappropriate policy responses. Integrated responses are also a focus of this research.

2.2 Modern tools for visualizing climate change

The power of computers to enable visualizations of climate systems has long been recognized (Gardner, 1985; Max et al, 1993). DiBase et al (1992) explain how animated visualizations combined with static maps, graphs, diagrams, images, and sound improve scientific expression. More recently interactive visualizations emerged enabling a range of users to undertake personal explorations of environments and scenarios. Gorden et al (1994), Wilby et al (2002), and Stock et al (2007) illustrate the advances in these tools over the last two decades: realism and available level-of-details have dramatically increased. These characteristics are worth exploring individually: they impact greatly on the design of climate visualizations.

Whilst static photo-realistic visualizations have been available for at least the last decade (c.f. Sheppard, 2005; Bishop and Miller, 2007), interactive visualizations exhibiting photo-realism emerged more recently through advances made in gaming engines. This interactively, potentially in real-time, is being rapidly translated to the scientific visualization community (Buhmann et al, 2005). In relation to climate change, studies are being undertaken to determine the utility of photo-realistic visualizations for climate change decision-making. Bishop and Miller (2007) demonstrate the utility in relation to determining the visual attractiveness of wind farms. Dockerty et al (2006) illustrate the potential in relation to changes to rural and agricultural landscapes brought about by climate change. Sheppard (2005) provides many more examples, however, like Dockerty (2005; 2006), he concedes the potential exists for sensationalism and audience manipulation through these visualizations. As such, guidelines and rules for ethical design are proposed (c.f. Sheppard, 2005).

In contrast to photo-realistic visualization, more abstract visualizations are still highly relevant. Such visualizations are borne out the weather mapping tradition where points, lines and polygons are used to represent environmental phenomena not visible to the human eye. The abstracted visualizations of Wong et al (2002) provide examples: superfluous data is purposely smoothed out of the visualization to enable better human conceptualization. Abstracted visualizations are particularly relevant to climate change where illustrative tools are required at regional, state, national and global levels. In this way, Google Earth is uniquely placed: it is a highly ubiquitous and interactive platform enabling visualization at multiple levels of detail and scale. This utility will only increase: more high-resolution imagery will be added to the platform and more users will emerge. Whilst the ubiquitous nature of Google Earth makes it an extremely useful tool for presenting climate visualization, the mass amateurism of web mapping does present some problems. Guidelines for articulating the authenticity of data and guarding against sensationalism are only now emerging (Sheppard and Cizek, 2009). At any rate, in a controlled environment, Google Earth appears to hold great potential for climate change visualization and presentation. This potential requires further exploration.

3. RESEARCH DESIGN

3.1 Overview

The specific aim of this research was to further articulate the role of Google Earth as a tool for analyzing, visualizing, and developing integrated responses to potential climate changes at the local level. To this end, a number of interactive climate change visualizations were developed using Google Earth for a case study area (southwest Victoria). The utility of the platform was tested quantitatively in terms of the time, cost and skill-base required to produce the visualizations. Additionally, qualitative feedback from a diverse set of end users was also captured. In this way, the project used a mixed methodology: qualitative and quantitative research outputs were combined.

3.2 Case study area and scenario design

The Victorian Climate Change Adaptation Program (VCCAP), a Victorian government initiative, has investigated climate change impacts and adaptation within Victoria since 2007. It aims to ensure that the Victorian farming industry is equipped with knowledge of climate change science, potential adaptation strategies, and tools for maximising economical, social and environmental outcomes. As part of this project, The Department of Primary Industry developed a pilot research program (DPI VCCAP) focusing on the southwest region of Victoria (Figure 1). This region was specifically chosen for the wide variety of agricultural commodities grown and for the high level of community engagement in regard to climate change.

Figure 1. The DPI VCCAP study area

DPI VCCAP was guided by four key questions:(1) what are the impacts of climate change on agriculture, (2) what climate change adaptation options are available, (3) what are appropriate government policies responses and (4) how can the information be most effectively communicated (DPI, 2009). It aimed to answer these questions through multiple themes including: farming systems, scenario development, impact modelling and land suitability analysis, an e-resource centre and visualisation, communications and utilisation, and institutional adaptation and policy research.

The visualisation products developed through this project linked a number of these themes. They used data produced by the impact modelling and land suitability analysis modules, and were made available internally via the e-resource centre and externally via the Victoria Resources Online VCCAP website (http://www.dpi.vic.gov.au/DPI/Vro/vrosite.nsf/pages/climate_vccap). More specifically, they were used to inform the scenario development and analysis workshops.

The scenarios development process is now briefly discussed. Scenarios were developed around drivers of change for agriculture over which local primary producers have little or no control. These included projections of climate change and non-climate drivers. The following SRES/IPCC climate projections were used: A1FI (high growth, high carbon), A2 (divided world), and B1 (green energy). Localized climate models from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) were also used. The non-climate drivers included the global economy, trade barriers, consumer preferences, declining terms of trade, energy requirements, government policy including carbon pollution reduction schemes, dramatic change such as war or disease, and developments in science and technology. Additionally, relevant issues from regional stakeholders such as competition for land and attitudes of the urban community towards farming were included. Plausible options for how these drivers might unfold to 2050 were then built into the three scenarios. The scenarios were then analysed by a technical working group of 20 experienced stakeholders from within the region. They utilized their specialist knowledge and local experience to integrate the formal analyses with their understandings of business and community operations to provide a holistic assessment of the likely impacts and adaptive responses to climate change. These outputs were synthesised and communicated through workshops to key regional agricultural industries, agencies and policy groups.

3.3 Data acquisition

The data used in the visualizations was developed in the land suitability research theme of DPI VCCAP. The potential implications of climate change on the agriculture and forestry industry in southwest Victoria were investigated. Sposito et al (2008) modelled how projected climate changes could impact the capacity of southwest Victoria to produce a range of agricultural commodities and forestry products. The analysis used a GIS based multi criteria evaluation method to assess regional agricultural land use suitability. The model used a combination of biophysical data (soil, climate and landscape parameters) and expert judgment. The method produced GIS data layers (ESRI shapefiles) of land use suitability across the 3 climate change emission scenarios for 8 commodities: perennial ryegrass, phalaris, lucerne, barley, oats, winter wheat, blue gum and radiata pine (Figure 2). Additionally, average annual temperature and annual cumulative rainfall datasets were acquired from CSIRO.

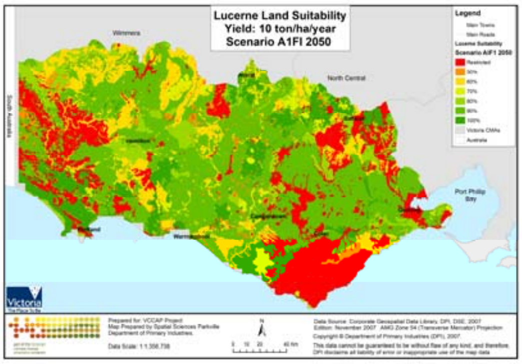

Figure 2. Example land-use suitability map (Sposito et al, 2008)

The multi-temporal datasets (2000 and 2050 epochs) produced were particularly difficult to communicate through standard paper reports and static maps: 3D visualisation techniques were therefore utilized.

3.4 Rainfall and temperature visualization development

First, data preparation was undertaken. This involved using ArcGIS to convert the temperature and rainfall features to raster for the 2000 and 2050 datasets. Second, a number of ArcGIS/Python scripts were developed to automate the frame production process. A script enabling the generation of 100 intermediate layers between the years 2000 to 2050 was developed. The visualization was intended to run for approximately 5 seconds: 100 was an appropriate number of layers. Linear interpolation was used: whilst less realistic than using individual datasets for each year, the smoothing better revealed the overarching trend. The intermediate layers produced by the script were converted to raster images. A KML file was then built: it located the raster images in space (extent) and time (span). A year counter, legend and view angle were included in the KML script. Finally, the visualization was composed in Google Earth. The KML file was opened and a tour was recorded. The collection of files was saved as a KMZ file to enable all elements to be contained in a single file, without external references.

3.5 Land-use suitability visualization development

First, the land-use data was prepared in ArcGIS. Feature classes were dissolved using a new column and a reclassification was undertaken. These were converted to raster and generalized by 'border cleaning': ascending order was used to privilege smaller areas. This generalization was then repeated. The resulting dataset was clipped to the relevant extent (as determined by the case study area) and was used to place symbols that represent areas effectively.

Second, the land-suitability data was prepared in ArcGIS. This was performed for each commodity variety (barley, oats, winter wheat, bluegum, lucerne, rye, pine, phalaris). The feature layers were converted to raster for the years 2000 and 2050. Reclassification occurred using percentages for non-negative values (10→100%; 9→90% etc.). Negative values were eliminated (→ NoData). Then datasets were clipped to the relevant extent. A feature point layer was created and roughly 15 symbols placed within the extent. Placement was determined by viewing the land-use layer and determining the areas aesthetically requiring symbols, and also by land-suitability values: symbol density was higher in high suitability regions.

Third, the symbols were prepared using Google Earth. Symbols for each crop were selected from various online libraries. Selection was based on semantics (how well the symbol illustrated the primary product e.g. milk bottles for cow pastures), 3D (for a more dynamic and appealing rendering), and performance (a low number of polygons was sought). The symbols were then scaled so that they were visible and appropriately proportioned compared to other symbols.

Fourth, a number of ArcGIS/Python scripts were developed to automate the layer production process. A script enabling the generation of 25 intermediate layers between the years 2000 to 2050 was developed. Linear interpolation of the land-suitability layers was used. Again, whilst less realistic than using individual datasets for each year, the smoothing better revealed the overarching trend. The intermediate layers produced by the script were converted to raster images. A KML file was then built. Again, it located the raster images in space (extent) and time (span). For each intermediate layer, the latitude and longitudes from the 'symbol location' layer were extracted along with the land-suitability value for that pixel(s). This information was used to place the symbol in the KML file, with height dimensions scaled in proportion to the land suitability value at the location. A year counter, legend and view angle were also included in the KML script.

Finally, the visualizations were composed using Google Earth. The KML files were loaded and a tour conducted. The complete set of files was then saved as a KMZ file without external references.

3.6 Testing the process and outputs

In order to test the efficiency of the process, indicators including total production hours, total costs ($AU), and required skills base were assessed. These were compared qualitatively against indicators for more traditional methods of production. Additionally, the effectiveness of the visualizations was tested using participants at a VCCAP workshop on July 22-23, 2009 at Warrnambool (Victoria, Australia). The quantitative outputs from the tests are not included here: these results are not the focus of this paper. Moreover, space does not permit their discussion. Instead, qualitative feedback from the session is used to inform the results.

4. RESULTS

4.1 The visualization products

In total, 30 individual animation sequences were produced: 8 commodities by 3 IPCC scenarios (A1FI, A2, B1); temperature by 3 IPCC scenarios; and rainfall by 3 IPCC scenarios. Each animation consists of 'x' raster data layers (between 2000 and 2050), a title, temporal labels, commodity symbols and a legend. Google Earth provides the remaining mapping infrastructure: orientation, scale, border, and underlying imagery source information. The animations run for approximately 5 seconds each. In addition to viewing the frames in sequence, the platform enables users to explore individual frames from each animation from multiple perspectives, scales and locations (Figures 3, 4, 5 and 6).

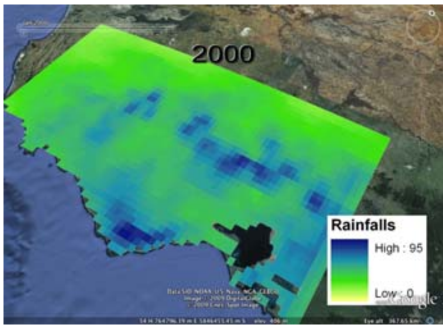

Figure 3. Rainfall animation: shades of blue and green are used to indicate rainfall amounts

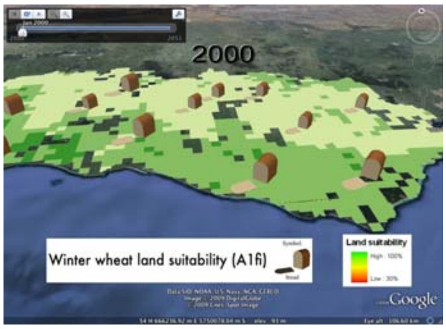

Figure 4. Winter wheat land suitability: shrinking/growing loaves of bread convey further meaning

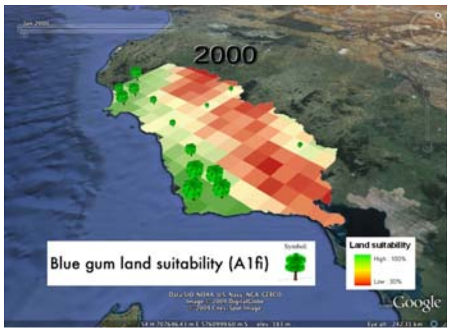

Figure 5. Blue gum land suitability for the A1FI scenario: growing symbols indicate increasing suitability

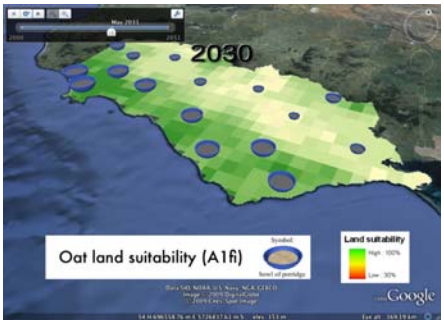

Figure 6. Oat land suitability animation: users can interact from various spatial and temporal perspectives e.g. 2030

4.2 Viewing and using the visualizations

The workshop provided access to an extremely diverse range of stakeholders including: farmers (dairy, sheep, cropping), environmental managers, social scientists, local community, emergency service workers, education workers, local government, state government, and planners. The group were exposed to the A1FI scenarios and allowed some guided interaction. Space limitations do not permit all qualitative comments to be reproduced here, however, Table 1 summarizes the overarching themes that emerged.

Theme	Description
1. An *overview* tool	The utility of the platform to provide an overarching context of potential changes occurring was recognized.
2. A *complimentary* tool	Alone, the visualizations were not enough to base decisions upon; however, they complemented tables and more specific data relating to the case study area.
3. A *collaboration* tool	The visuals provided a common language for the diverse range of stakeholders. The accessible visuals sparked discussions.
4. *Additional* data required	To be used for decision-making, more datasets would be required. Examples: social data (e.g. population, stress), environmental data (e.g. planning, sea-level rise, pests/diseases, fire/floods), economic (monthly household budgets, prices).
5. Higher *levels of detail* required	While visualizations could aid decision making at regional levels, higher resolution data would be required for the farm level.

Table 1. Themes from qualitative feedback

5. DISCUSSION

5.1 Ubiquitous spatial technologies: efficient and effective visualization platforms

Google Earth, a ubiquitous spatial technology, was found to be an efficient platform for developing climate change visualizations: good quality visualizations could be produced at low cost and within short timeframes. Coupled with ArcGIS, the tool enables fast production and accessible viewing of 3D visualizations. These characteristics have been lacking in other visualization platforms where specialized spatial knowledge was required to create and often interact with animations. However, while the overarching process can be seen as a success, a number of issues are worth further discussion.

5.2 Data and imagery: complementary in decision-making

Whilst images were found to be a useful tool for understanding overarching changes, some decision makers still desired more specific data in the form of tables or graphs. It is unclear whether this perceived limitation was a result of the user's limited exposure (or trust) to spatial technologies or whether the grid cells were too large and the legends unclear. At any rate, whilst this version of the visualizations did not provide data and graphs, Google Earth *can* be used to link text, data and graphs to geographic features. For example, upon clicking an individual land-suitability grid-cell a set of tables or graphs relating to the pixel could be displayed. More research is required to determine if visualization platforms can be used as the sole tool for landscape decision-making. It appears likely that both data and imagery will continue to complement one another in the medium term.

5.3 Abstraction vs. photo-realism: the debate continues

The grid-cell sizes and symbol scales used in the visualization pushed the visualization away from photo-realism towards a more abstracted environmental depiction. This was a conscious decision by designers: technological limitations in displaying vector graphics coupled with the low resolution of the raster datasets available guided the decision. Moreover, 'land-use suitability' cannot be perceived by the human-eye: some form of abstraction was therefore necessary. However, unconstrained resources would enable datasets at the parcel or paddock level to be produced. Additionally, technological advancements will improve the platform's ability to visualize large numbers of complex vector models simultaneously. Regardless, the 'abstraction' vs. 'reality' debate will continue to be an important design decision for any visualization project: the ability to produce photo-realistic products will not remove the issue.

5.4 Active vs. passive interaction: both are beneficial

The tool was found to promote engagement between users and the datasets. It is unclear whether tables of data would elicit a similar response from a diverse range of users, however, numerous respondent comments outlining the power of pictures and visuals suggest not. The demonstration was primarily moderator driver: respondents were able to dictate what was shown, however, they did not interact with the technology directly. Further testing of the individual interactions between the users, platform and data appears necessary. At any rate, the passive approach was found to maintain group focus and promote collaborative analysis. However, there appears to be great potential for more interactive approaches: enabling individual group members to move through the environment and express their ideas with points, lines, polygons or fuzzy zones could greatly enhance the collaborative utility of these visualizations. A parallel can be drawn with hands-on participatory tools such as touch tables or smart-boards and their ability to enable collaborative debate.

5.5 Utility in policy development: further work required

This paper focused on assessing the efficiency of using Google Earth for developing climate change visualizations: the potential of the visualizations to inform policy development and decision making was less thoroughly explored. Preliminary feedback suggests the tool has some utility in describing overarching trends. However, more detailed datasets, higher-resolution imagery, and integration with other forms of information such a tabular data and graphs would greatly enhance the application of ubiquitous spatial technologies as a participatory decision-making tool to inform planning and policy-making. The integration of additional datasets, functionality and trialling with stakeholders in an interactive session would be required to further test this hypothesis.

6. CONCLUSION

The utility of ubiquitous spatial technologies such as Google Earth to build community engagement and inform decision-making in relation to climate change holds great potential. While imagery detail and handling of complex vector graphics provide current challenges, these will be overcome in the near future. Longer-term challenges include the need to further develop and test design guidelines to guard against, or at least inform users about visual sensationalism. With the recent advent of Web 2.0 and collaborative visualization platforms there exists the research challenge to harness the enthusiasm of naïve cartographic users and visualisation producers. Whether this is through technology or educational means needs determination. At any rate, as the quality of freely available visualization products increases, ubiquitous visualization tools will play and important communicative and collaborative role in climate change policy responses.

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