PAPER 10

GEOGRAPHIC INFORMATION SYSTEMS AS INTEGRATIVE PLATFORMS FOR CLIMATE CHANGE IMPACT AND ADAPTATION ANALYSIS

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ABSTRACT: Geographic Information Systems (GIS) allow for interdisciplinary efforts to foster collaborative science, spatial data interoperability, and knowledge sharing in climate change impacts and adaptation studies. The use of GIS has made data sets compatible, and created a bridge between the atmospheric sciences, geography, ecology, other more spatially-based sciences, and the natural resource management and planning communities. There is a need for better integration of datasets/models with GIS to address climate change issues, particularly for adaptation, mitigation and sustainable development at the practitioner level. In this paper, a framework of Web-GIS based Climate Change Impact and Adaptation Integrated Assessment Tool (CCIAT) is presented. This three-tier system framework is based on the J2EE technologies, and includes different web services linking climate model outputs to feed into impact models. A database server was setup to support various applications and online access to decision-support tools was provided. Overall, WEBGIS is the "great integrating technology" when used for climate change impacts and adaptation research.

Keywords: climate, climate change, geographic information systems, decision-support, decision support systems

1. Introduction

The climate change research community seeks to understand and project interactions between climate, environment and society, so as to inform attempts to maintain or improve societal welfare. This requires the representation of complex physical processes as weather forecast and climate system models, which are used to project future climatic conditions and their impact upon innumerable social and environmental processes. To accomplish this, tools, methods, and information provided by atmospheric science, must become accessible to a wider community of users, including researchers from various disciplines, educators, practitioners and policy-makers.

This paper provides an overview of Geographic Information Systems (GIS) as integrative platforms to facilitate climate change impact and adaptation analysis. We begin by describing examples of how GIS has been successfully employed in past research initiatives, and then explore how new, web-based technologies can be used to improve accessibility of integrated assessment models (IAM) to the larger research community. A framework of Web-GIS based Climate Change Impact and Adaptation Integrated Assessment Tool (CCIAT) is then presented.

We conclude with a short discussion of future implications for climate change research.

A Geographic Information System (GIS) is a computerized marriage between a graphic representation and a textual description of a geographic location (Anderson and Associates, 2007). A GIS provides the decision maker with a logical and graphic representation of geographically-referenced information. Over the past decade, Geographic Information Systems (GIS) have been used for data integration, analysis, and decision-making in many societal sectors and academic disciplines. GIS allows for interdisciplinary efforts to foster collaborative science, spatial data interoperability, and knowledge sharing on climate change impacts and adaptation studies. GIS can be used as both an analysis, and an infrastructure tool in climate change impacts and adaptation research. As technology, GIS also addresses issues of spatial data management, interoperability, and geoinformatics in climate change research.

Environment Canada's Adaptation and Impacts Research Division (AIRD) has extensive experience with projects utilising GIS in assessing climate change impacts: Canada-China Cooperation on Climate Change (C5) for crop production (Rong *et al.,* 2004; Fang *et al.*, 2004; Wang *et al.*, 2004); National Agri-Environmental Standards Initiative (NAESI) for water management (Koshida *et al.,* 2007); Climate Change and Okanagan Water Resources (Cohen and Neale, 2007); and Integrated Assessment of Vulnerabilities and Adaptation to Climate Variability and Change in the Western Region of China (AS25) for water management (Yin, 2004). In the Canada-China Cooperation on Climate Change (C5) project, AIRD and its Chinese partners have been working closely by applying a GIS-based approach to assess the impacts of climate change on Chinese agriculture. The project includes combined GIS/crop models, integration of both climatic (United Kingdom's Hadley Centre's Regional Climate Model known as PRECISE) and socio-economic scenario data, as well as a spatial/temporal analysis on crop yields (see Figure 1). C5 has demonstrated that GIS is a useful tool in climate impacts study by integrating regional–level information (bottom-up) and projected climatic and non-climatic data (top-down).

WEBGIS offers the possibility of extending this work by allowing for greater operability and accessibility. WEBGIS is a Geographic Information System (GIS) distributed across a computer network to integrate, disseminate, and communicate geographic information visually on the World Wide Web (Horanont *et al.*, 2007). In performing the GIS analysis tasks, this service is similar to the

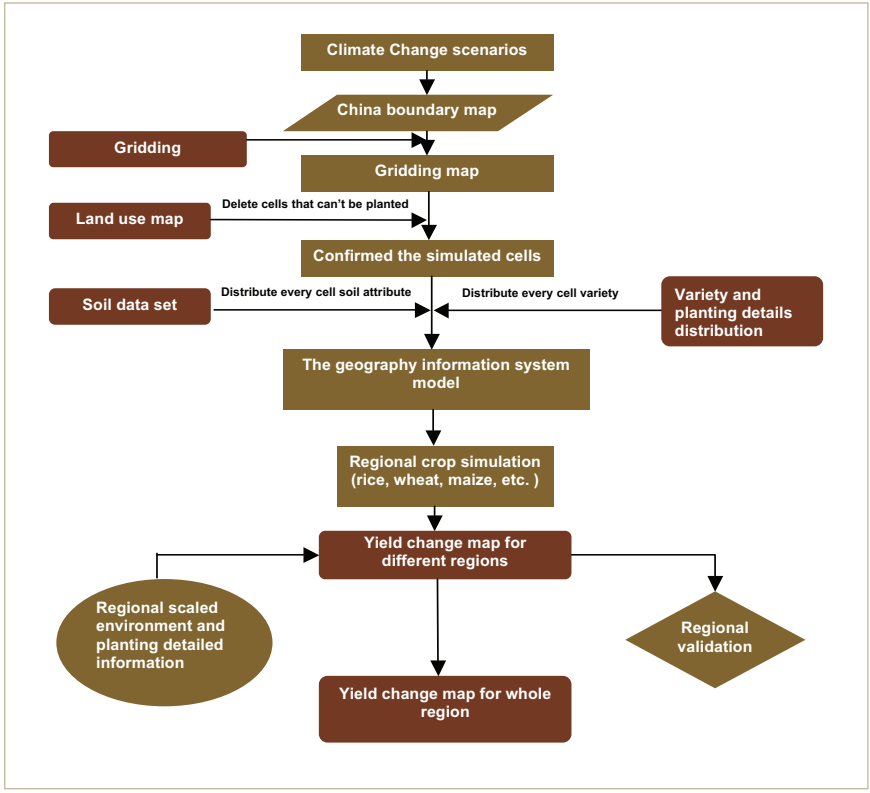

FIGURE 1
C5 I&A GIS modelling in Crop yields study

Client-Server architecture of the Web. The geo-processing breaks down into a server-side and client-side task that allows users to access, manipulate and retrieve GIS data from their browser without purchasing proprietary GIS software. A client typically is a Web browser and the server-side consists of a Web server that provides a WEBGIS software program. The client requests a map or some geo-processing over the Web to the remote server. The server translates the request into an internal code and invokes the GIS functions by passing on the request to the WEBGIS software. The software returns the result that is reformatted for interpretation by the client browser application itself or with additional functionality from a plug-in or Java applet. The server then returns the result to the client for display, or sends data and analysis tools to the client for use on the client-side (see Horanont *et al.*, 2007).

One advantage of this infrastructure is that it offers ready access to data and resulting maps via WEBGIS, (i.e., linking data to data). But it also offers the potential to link data to models for better exploration of new relations between observables, refinement of numerical simulations, and the quantitative evaluation of scientific hypotheses. For widespread data access, current applications of WEBGIS are therefore only a preliminary step. Better support for analysis, modeling and decision support within or connected to WEBGIS, should move users beyond the "data-to-data" mode towards "data-to-models" and eventually to the "data-to-interpretation" mode. Advances in web-enabled GIS servers and database engine technology are making such a transition possible.

2. Development of a Climate Change Impact and Adaptation Integrated Assessment Tool (CCIAT) in a WEBGIS Framework

To address questions of global climate change, especially those related to economic and environmental impacts, integrated assessment models (IAMS) are often applied. IAMs seek to combine knowledge from multiple disciplines in formal integrated representations that are used to inform policy-making, structure knowledge, and prioritize key uncertainties. IAMs have the advantage of identifying broad system linkages and feedbacks, particularly between socioeconomic and biophysical processes, but such analysis is dependant upon the provision of compatible information sources produced by atmospheric and geographic communities. GIS can play an important role in providing this compatibility, as well as a framework for planning and policy decision-making. A web-based GIS can provide online access to climate scenarios as well as socio-economic information creating a one-stop solution that integrates data, impacts models and adaptation options.

The Climate Change Impact and Adaptation Integrated Assessment Tool (CCIAT) has been developed as a WEBGIS. It utilises generic outputs from Climate Models (GCMs/RCMs) and applies them to assess specific responses required by different sectors, to adapt to, and capitalise on the opportunities presented by climate change and increased climate variability. MapServer from the University of Minnesota (UMN) was chosen to work as the backbone for CCIAT. MapServer is an Open Source development environment for building spatially-enabled internet applications which excels at rendering spatial data (maps, images, and vector data) for the web. To better support the open source community, a Linux/Java coding environment was established.

CCIAT's WEBGIS infrastructure is illustrated in Figure 2, showing four web services as provided by a GIS tool and associated databases. In the sections that

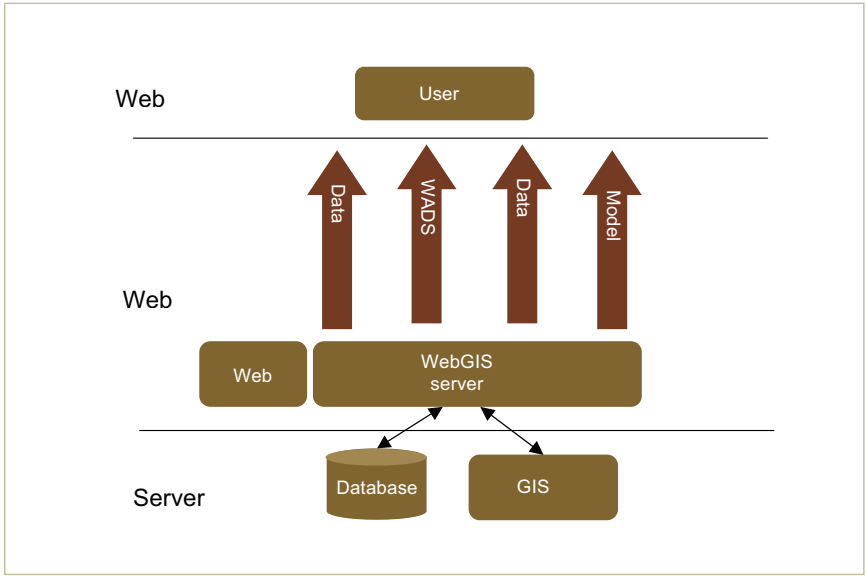

FIGURE 2
WEBGIS-based framework for CCIAT

follow the components of CCIAT are described. These include a data translator, a spatially enabled data access interface, as well as a data visualization tool in Section 3. In Section 4 we present an agriculture impact model and in Section 5 we describe the decision support systems in development for CCIAT. We conclude with a brief discussion of the implications such a tool may have upon research in climate change impacts and adaptation analysis.

3. From Scenarios to Adaptation - GIS data translator

Currently, climate change scenarios data reside in the atmospheric science domain (binary or spreadsheet format). There is a need for better integration of datasets to address climate change issues, particularly for adaptation, mitigation and sustainable development at the practitioner level. The Climate Change Scenarios Network (CCSN) is an Environment Canada initiative to disseminate climate scenarios data to Canadian users. In 2007, the CCSN will extend to regional nodes to improve system robustness, but also to highlight regionally specific research initiatives. A node for the Pacific Region (West Coast) of

Canada will provide access to the following GIS tools that are currently under development:

- **A Data Translator:** translates climate model simulation outputs into GIS data format (e.g. Environmental Systems Research Initiative (ESRI) shapefile) for British Columbia, pre-processed maps available for download (British Columbia or sub-regions with different variables); Global and Regional Climate Model (GCM/RCM) outputs in a GIS format will allow for easy integration of climate predictions with environmental and socio-economic datasets.
- **Spatially enabled data access interface (with map navigation):** a web-based spatial search tool and enable a full suite web-mapping service (WMS), users can preview and explore data online;
- **Data Visualization tool: pre-processed maps (ready–to-use GIS layers)** can be overlaid and analyzed with other data layers (predefined or added from other WMS sources) according to users' interest (see Figure 3).

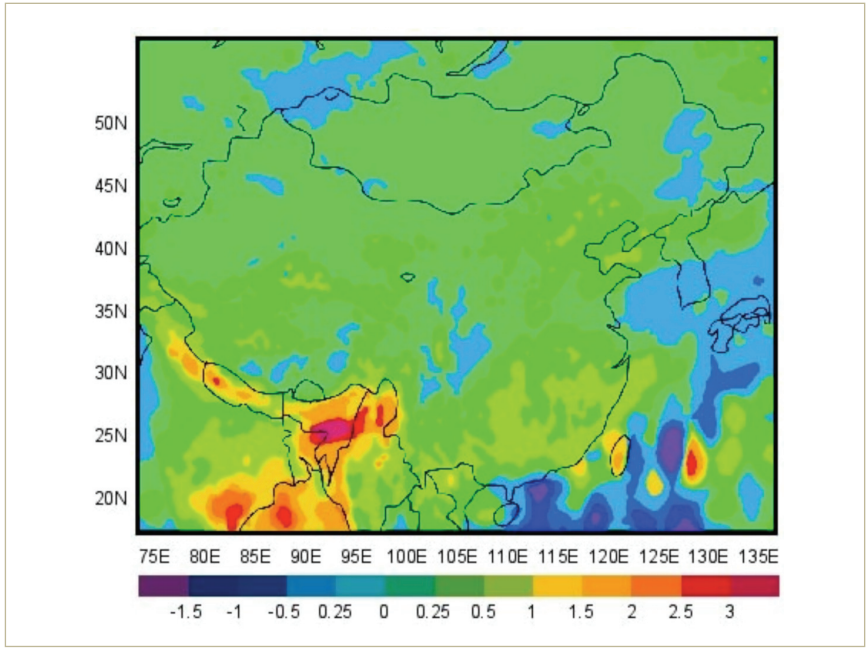

FIGURE 3
UK PRECIS RCM Simulation run in C5 project (Xu *et al.*, 2006).

The above tools help convert atmospheric data into a plain usable format. This bridges communities of atmospheric scientists, geography, ecology, other more spatially-based sciences, and the natural resource management and planning communities at large. It provides another possibility in coupling climate projections with traditional environmental, socioeconomic, and demographic GIS data. Open access will be provided for viewing and analyzing model simulations in a more interdisciplinary way through GIS.

4. Model Builder through GIS Server: CERS agricultural impacts model

Analysis of climate impacts, adaptation, and vulnerability involves a set of activities designed to identify the effects of climate variability and change, to evaluate and communicate uncertainties, and to examine possible adaptive responses. Methods for analysis of impacts, adaptation, and vulnerability have evolved over the past decade, and a large array of methods and tools are now available for use in specific sectors, at different scales of analysis, and in contrasting environmental and socio-economic contexts. Most assessments of the impacts of future climate change are based on the results of impact models. Two Crop Simulation Models (CERS- wheat and corn) developed by CAAS (Chinese Academy of Agricultural Science) were both packed with web service and XML technology. Since the three-tier architecture enable any web client to access a full function GIS server (e.g. ESRI ARCGIS), models can be further tuned via the model builder modules available in commercial GIS packages. All model parameters and inputs can be managed centrally via a database interface.

5. Web-based adaptation decision support system (WADSS)

Decision tools that are typically applied to climate-change adaptation are cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and risk-benefit analysis (UNFCCC, 1997). Multi-criteria options evaluation (MCOE) of adaptation measures has long been adopted as the major approach to identify desirable adaptation measures by which decision makers can alleviate the vulnerabilities associated with climate change. In the adaptation policy evaluation process, multi-stakeholder consultation (MSC) and multi-criteria options evaluation (MCOE) can provide mechanisms to relate impact information to decision making requiring subjective judgment and interpretation.

A Web-based adaptation decision support system (WADSS) is being developed based on multi-stakeholder consultation (MSC) and multi-criteria options evaluation (MCOE). WADSS is a simple tool providing an effective means of

measuring the effects of a given adaptation option against a number of sustainability indicators. This adaptation tool will be useful for regional planners to select effective adaptation options to reduce climate risks. In particular, the WADSS tool can assist users to identify desirable adaptation options or policies that can be incorporated into a regional management strategy while supporting regional sustainable development. Such a tool will improve the integrated assessment capacity of regional managers or planners to identify the economic and environmental impacts of adaptation decisions that may reduce climate vulnerability. A user friendly interface was designed for the adaptation tool to facilitate data transfer between users, a set of models, and the GIS.

6. Results/Discussion

This preliminary paper proposes that the integration of climate scenarios data and impact models with WEBGIS can provide/an easy-to-use tool to assess and disseminate atmospheric sciences, models and outputs. This work will contribute to the development of spatial decision support tools that can generate useful information for policy-makers and resources management in light of potential climate impacts. This one-stop solution has the advantage of moving climate change researchers towards a "data-to-interpretation" mode that will speed up the decision process, as well as facilitate integration across sectors and disciplines.

A distinct advantage of this work is that it will provide researchers with a standardized framework for analyzing the effects of climate change. By making such an approach seamless and accessible, researchers from various disciplines, decision makers, and stakeholders will be able to undertake comparable analysis. Not only with this provide insight into the effects of climate change for locally specific circumstances, but it will provide the basis for comparative studies including vulnerability assessments. By up-scaling the results of numerous cases, standard or generalized relationships between climatic change and social and environmental processes may be uncovered. The development of such *formula*, may one day provide policy makers with a quantifiable means of evaluating and prioritizing options.

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