Proceedings of Spatial Knowledge and Information - Canada (SKI-Canada) 2011, March 3-6 in Fernie BC, Canada.

**Volume 2**

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We invite you to read the proceedings of the 2011 conference of Spatial Knowledge and Information Canada, the 3rd SKI conference. It will be held March 3-6 in Fernie BC, Canada. The intent of Spatial Knowledge and Information Canada is to bring together (digital) Geographic Information researchers and their students from across Canada. We define Geographic Information research broadly as any geographic research in which computation is its main focus. The prime computational platform is Geographic Information Systems although we include Geographic Information Science, geomatics, remote sensing, geospatial web 2.0 (Geoweb) and volunteered geographic information (VGI), and spatial statistics and computational modeling. We encourage theory and practice and we invite research on the widest range of applications from GIS-transportation and health to GIS in education and business. We also stress work-in-progress, our reasoning being that the conference will stimulate additional avenues of exploration.

The 2011 conference is being held in partnership with the GEOIDE Network Center of Excellence, who this year gave us a very generous award to fund ALL student presenters and create student awards. Over 70 researchers, university faculty, students and interested parties from across Canada are registered and plan to attend. The conference is composed of 48 scientific papers. We are delighted to have as our keynote with David Mark (expat Canadian), who presents on *Cultural Differences in Geographic Information: Why Geographic Categories Matter for GIS*.

SKI also will hold its first workshop, Hands-on with Neogeography: a VGI/Open Street Map (OSM)/Application Programming Interface (API) Participant Activity where participants will not only get acquainted with the concepts but will conduct a mapping party to expand the geographic information for Fernie. This workshop was conceived and conducted by students. The conference concludes with a planning meeting on the final day, where we will plan our conference in 2012, our first venture towards the eastern side of the country, near Quebec City.

A substantial focus of the conference continues to be the promotion of Canadian student research on Geographic Information. We greatly expanded our student presentations: this year, we're excited to have 35 presentations by undergraduate, Master's, PhD students and postdoctoral fellows. We plan to award seven outstanding students substantial awards for their research and presentation quality. These will be listed on the website, http://rose.geog.mcgill.ca/ski/. We extend our congratulations to the prizewinners and to all our student presenters!

Please enjoy the extended abstracts of student and faculty in these two volumes, visit the SKI-Canada site, http://rose.geog.mcgill.ca/ski/ and attend the 2012 conference.

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# Volume 2

# Evaluating Potential Spatial Access to Trauma Centres in Canada using Geographic Information Systems


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**Abstract**

The purpose of this research is to evaluate the potential spatial access of severely injured patients to trauma centres in Canada. The availability of unique datasets allowed these biases and limitations to be overcome and provided insight into how well Canada's trauma care needs and resources are spatially aligned. Ultimately, this research will identify potential gaps in access where needs are high and resources few.


## Background and Relevance

The purpose of this research is to evaluate the potential spatial access of severely injured patients to trauma centres in Canada. Specifically, this study will determine what proportion of severe injuries occur within one hour transport time of the closest trauma centre. Designated trauma centres are acute care hospitals that have a trauma team immediately available to assess patients, and all resources required to provide definitive care to the severely injured (1,2). The proximity of the site of injury to the nearest trauma centre might significantly affect timely access to trauma centre care (3;4). Assuring that access needs are met through strategic distribution of trauma centres is important in reducing injury-related mortality (1). While need is typically estimated through an assessment of the number and distribution of severely injured patients admitted to hospital, this information provides a biased evaluation (2). Focusing on this cohort alone results in the exclusion of patients who die in the field or emergency department, whose location of death might reflect an unmet need for trauma centre care. Others have focused on the relationship between population distribution and the spatial location of trauma centres as a measure of "access", but this is a poor surrogate of need given that not all populations have a similar risk of severe injury (3). The availability of unique datasets allowed these biases and limitations to be overcome and provided insight into how well Canada's trauma care needs and resources are spatially aligned. Ultimately, this research will identify potential gaps in access where needs are high and resources few.

## Methods and Data

Various datasets and methods were utilized in this research. The spatial distribution of Level 1 and 2 trauma centres in Canada was provided by the Public Health Agency of Canada. Level 1 and 2 trauma centres are almost always the acute care hospitals which have the largest capacity to treat severely injured patients in every region of the country.

The spatial distribution of severely injured patients was derived from two sources. First, those surviving to hospital admission were identified through the Hospital Morbidity Database (HMDB) using ICD-10 diagnoses codes. Deaths occurring outside the hospital were identified through the Canadian Mortality Database (CMDB) using external cause of injury coding. The six-digit postal codes of the patients' residences, which were used as a proxy for the site of injury, were translated into geographic coordinates using Statistics Canada Postal Code Conversion File Plus software. Using postal code of residence, rather than the precise geographic coordinates of the site of injury, is appropriate since several lines of evidence suggest that nearly half of all individuals spend their time within 10km of their home (the remainder stay within 50km) and, consistent with these data, 85% of injuries occur within this distance of home (5; 6; 7). Trauma centre catchment areas were created using a well-established travel-time catchment method developed by Schuurman *et al.* (8). First, travel times were calculated for each road segment in Canada using travel impedance values (e.g., speed limits) and impactors (e.g., stop signs, traffic lights, etc.) provided as attributes in the road access data from DMTI (Desktop Mapping Technologies Inc.) Spatial Canada. This allowed catchments to be delineated within a GIS by selecting road segments within 1 hour road travel time of each trauma centre. One hour is widely recognized as the 'golden hour': the time within which patients should receive emergency care at a hospital in order to minimize the risk of serious health outcomes (9;10). The postal code conversion file was used to link the spatial distribution of severely injured patients with road segments, which allowed the proportion of severely injured patients living within one hour of a trauma centre to be calculated.

## Results

The catchment areas served to highlight the regions of Canada that are considered to be out of practical service range for trauma care based on a travel time of one hour. Numerous regional clusters were identified that had high numbers of severe injuries and very distant trauma centres. A clear urban/rural divide was also evident, which supports recent research in this area (11).

## Conclusions

Results of this research suggest serious inadequacies exist in the spatial distribution of trauma care services in Canada. Access to trauma care in rural and remote regions of the country is particularly sparse or in many cases so distant as to be non-existent. The creation of strategically located trauma centres based on the findings of this study could help to improve geographic inequities in service provision. The methods employed in this study could be easily translated to other health research in which resolving inequities in geographic access and improving resource allocation are the objectives.

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# The use of geovisualization to public health, in the context of open source applications and digital earths: an effective representation?

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### Abstract

The use of geographic visualization (geovisualization) has increased over recent years with the prevalence of digital earths (e.g., Google Earth). We investigate how well applications of digital earths employ geovisualization principles using the example of health data. We utilized trauma data from Cape Town, South Africa. We created a number of geovisualizations at both the coarse level and fine grained level of resolution. These utilized various application programming interfaces (APIs), Google Earth, and scripting languages. We based our applications on evaluation of geovisualization design principles and extant examples in health and epidemiology.

## Background and Relevance

The use of geographic visualization (geovisualization) has increased over recent years with the emergence of digital earths, especially the Google Earth (GE) platform (Dykes & Wood, 2007; Schultz et al., 2008; Butler, 2006). As their popularity increases, so do new ways of representing data from various fields. Applications such as mashups are starting to emerge in the health field (Chang et al., 2009; Zhang et al., 2009; Auchincloss & Roux, 2008; Sui & Holt, 2008; Janies et al., 2007). However, the investigation of how well health applications of digital earths employ geovisualization principles is relatively new.

According to MacEachren and others, the goal of geovisualization is to reveal the unknown and non-obvious and communicate it in an effective manner through end user interaction (MacEachren & Taylor, 1994; Kraak & MacEachren, 2001). There is some question whether these new platforms are sufficiently advanced in their capacity to adhere to these and other principles (e.g., in Cartwright et al. 2001) and certainly whether the digital earths are superior to more traditional GIS (Elwood 2009). Conversely, digital earths as part of the “read-write” web of bottom-up non-expert contributions, is compatible with MacEachren and Taylor’s (1994) vision, as opposed to the expert-driven nature of GIS. These have allowed us to discover ways of interacting with spatial data in a way that has not been implemented before.

This paper investigates geovisualization in digital earths as it pertains to trauma data. These data are useful as they are binary (one is either injured or not) and provide an example of spatial data clustering – which in turn permit analysis of risk associated with specific geographic areas like neighbourhoods. In addition, the Cape Town injury data set incorporated data from informal townships that are not included in the official census. This is a common phenomenon in low resource settings and often results in undercounting of the most vulnerable populations. These data – though not a complete population – cover three years and thus allow for temporal aggregation resulting in a better overview of patterns. For the purposes of this study, injury data support both spatial pattern recognition and the basis for higher resolution investigation of on-the-ground conditions based on vulnerability of specific neighbourhoods.

We primarily focus our attention on the ease of use of these new platforms for the developer and researcher. Our research question aims to answer the reasons for choosing specific geovisualization techniques such as two dimensional versus three dimensional, static images versus animation, coarse and fine resolution visualization, and repurposing of application add-ons to digital earths. We also evaluate domain-specific issues in the application of digital earths to the health field, such as confidentiality of data.

## Data and Methods

The data sets utilized in this research all derived from Cape Town, South Africa: aggregate trauma injuries, suburbs and population (raw population and population density maps). The data is monthly and covers 6,644 injuries, out of which 4,269 (64%) can be used. The data is based on one of the two health catchment areas, which cover 174 suburbs in the city. To make the data compatible with the applications, extensive refinement of the data was required. This is typical of health data (Sack et al. 2009; Le, 2005). The research took place over sixteen months, (July 2007 to October 2008) and builds on prior work (Cinnamon and Schurmann, 2010).

To evaluate applications to be used in our research, we created a matrix of existing health and digital earth applications to better understand the relationships between geovisualization and health. Matrix criteria were formed from the geovisualization literature, including ease of modifiability and collaborative work, cost and other resource requirements, ability to integrate multimedia, quality of application user interfaces, and interactivity. We focused on the developer side of geovisualization so, for instance, we looked at interactivity in terms of the ease of the user's movement about the data as well as the interoperability of applications. Based on these criteria we developed a number of applications, which included a variety of multimedia, dimensional visualizations, and multiple geographic resolutions.

## Results

We evaluated numerous digital earth applications for trauma data against those geovisualization design criteria. Certain applications, such as Jamstec (developed for the field of geology) were free but difficult to modify. Google Earth (GE) Graph was extensively used in creating many of the geovisualizations due to its high level of interoperability with GE. It also rated highly in its interoperability among different programs (e.g., GE, GE Graph, Google Docs, and Google Charts). Figure 1a, shows a 3D bar graph model of aggregate suburb injuries, using GE Graph.

Figure 1b shows data that was visualized within the GE 'information balloon'. The graph is generated "on the fly" from data in Google Spreadsheets (i.e., the chart is automatically updated in GE when it is changed in Google Charts). This relied on Google Charts's embedded application programming interface (API). Use of an application of Google Charts also offered opportunities for collaboration because multiple people can log in to modify the data in "the cloud". One way we chose to represent time or 4D was to use two bars per suburb and two graphs in an information balloon (not shown).

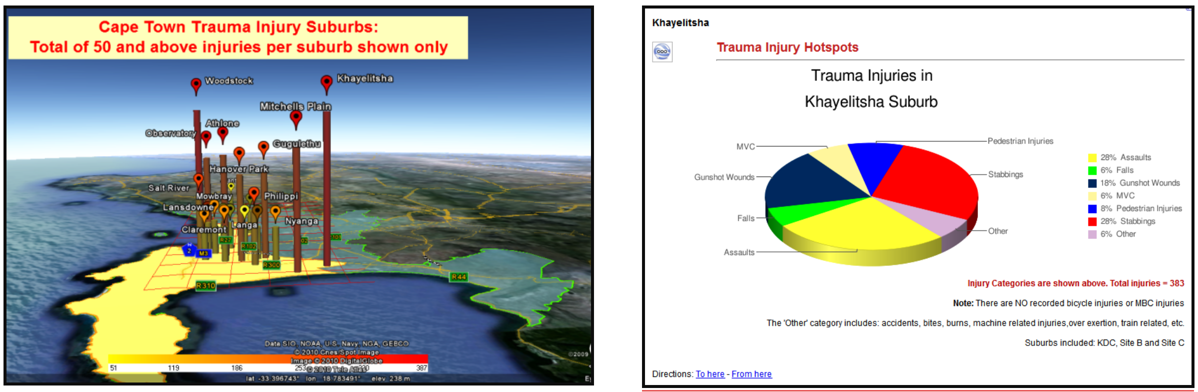


Figure 1.a. GE Graph model of Cape Town's top ten injury prone suburbs, and municipal catchment (green and yellow) areas, represented in Google Earth. 1.b Google Earth visibility balloon created with Google Charts API, representing trauma injury categories in Khayelitsha, Cape Town.

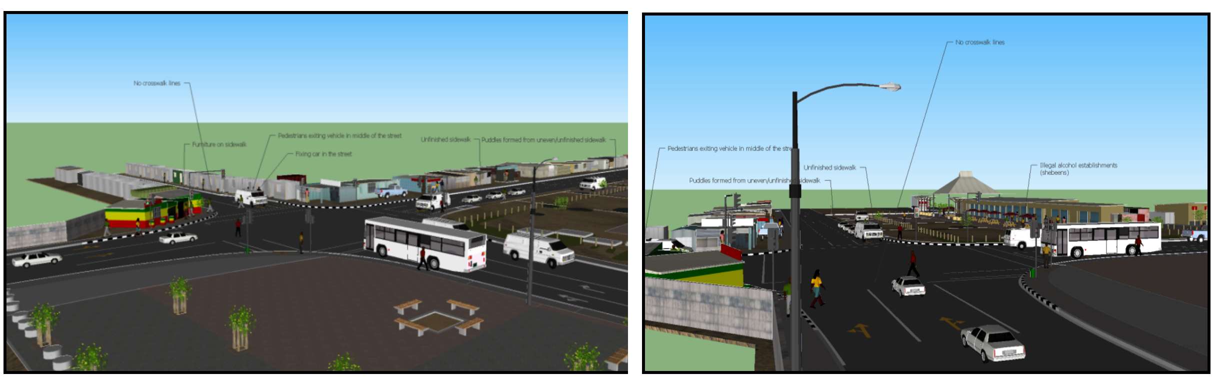


Figure 2.a Google Sketchup of a street intersection that causes numerous cases of trauma. 2.b Same Sketchup model but at a different angle.

Figure 2 shows our use of Google SketchUp to model a street intersection in Cape Town. The Sketch up model was used to visualize possible connections between environmental form and traumas. This includes places where the sidewalk is degraded allowing cars to come up on the pavement or forcing pedestrians into oncoming vehicles. The above views represent approximately 300 objects, which allowed for great visual depth but which frequently crashed laptops.

We have numerous findings. These applications, through incorporation of multimedia, dimensionality, and ability to pan, zoom and "walk" through the landscape, appear provide rich information for users who wish to explore and learn more about domain processes. The geovisualizations offered via the interfaces appear to assist in complex tasks. They can easily be customized; they need not be a one-size fits all approach (Dykes and Wood 2007). We argue that the difficulty in using traditional interfaces like those in ArcGIS, gave rise to digital earths and generated both lively interest in and a disdain for traditional geography found in the neogeography entrepreneurs who developed products like Keyhole, which became Google Earth (Crampton 2009).

Another finding relates to data accuracy. Regardless of data quality, geovisualization gives the impression of greater data accuracy, digital earths chiefly because of the ability to zoom into the particular and navigate the well-defined edges (resolutions) of objects (indeed, we looked for textures to blur edges). Accuracy is not necessarily important; instead, what is essential is confidence in the data. We may not need to know where the trauma occurred especially if it is difficult to obtain higher resolution data than suburban centroid. However, these platforms can misrepresent how much we know.

From a developer's standpoint, these applications are well-suited for resource-poor environments, which is very important when comparing the cost of digital earth applications to other geovisualization packages. The developer need not have to buy the software nor his/her own hardware. Another potential resource cost concerns the learning curve for developers, which compared to traditional GIS can be considerably less steep. However, if developers need to go beyond simple representations and interoperability then knowledge of more traditional computer programming is vital.

With these applications, development time is reduced, particularly when existing applications can be repurposed. The data can be uploaded quickly and visualized collaboratively. Time may be critical to public health where it concerns the spread of vector borne diseases or a mass trauma event. Conducting health-related work in the cloud has advantages but it exposes data to a proprietary based interface and confidentiality issues. For resource reasons, a psychiatrist may wish to keep all his/her records on Google Docs but governments or businesses can more easily harvest/mine that data. Digital earths may reduce uncertainties in understanding the data but expose one to uncertainties in development.

## Conclusions

Many variables affect the visualizations outcomes and many questions arise from our research. Digital earths are rapidly innovating and their future remains difficult to predict but there is a high probability that over time they will better conform to geovisualization principles.

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# GIS and evidence based decision-making: a knowledge translation story

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**Abstract**

The transfer of research findings from the academic realm to stakeholders is a critical process for facilitating social change. Knowledge translation (KT) tools derived from theoretical development in a discipline are required to foster the engagement of practitioners and community groups on important societal issues. This paper describes how the visualization power of GIS, and the accessibility of research findings resulted in an inadvertent collaboration between a research team and a community advocacy group on an important public health issue. Users of GIS may be in strong position to transfer knowledge and contribute to decision-making and stakeholder engagement. For GIS practitioners, KT principles derived largely from the health and medical literature can provide some guidance on how to accomplish these aims; however, what is needed is broader theoretical development from within the GIS community regarding this important instrument of social change.

## Background and Relevance

This abstract describes an inadvertent collaboration between a team of academic researchers and an advocacy group on an important public health issue. This collaboration was catalyzed as a result of the knowledge translation (KT) and communicative powers of GIS, combined with open-access publishing. Evidence-based decision-making (EBDM) – essential in public health - "requires that the right people have the right information at the right time and in the right formats" (Kiefer *et al.*, 2005, pp. I-2) Many decisions affecting public health (and other concerns) are still made, however, without adequate evidence of need or effectiveness (MacKay & Vincenten, 2009; Mallonee *et al.*, 2006). Bridging the divide between research and decision-making requires 1) *collaboration*, 2) *communication*, and 3) *knowledge translation* (Mallonee *et al.*, 2006). GIS, in particular, is highly touted for its ability to bring disparate groups together (Benigeri, 2007), including researchers, administrators, policy makers, and advocacy groups. As GIS is particularly suited to communication and knowledge transfer, researchers working with these media should take advantage of collaboration opportunities with these groups to not only translate their research findings into results, but also to harness the knowledge and expertise of collaboration partners.

## Methods and Data

An academic study designed to examine associations between the built-environment and pedestrian injury was carried out. Maps of pedestrian injury were created, which visualized 'hotspot' locations throughout the City of Vancouver. Hotspot locations were surveyed for potential roadway design and land-use features that are associated with pedestrian injury. Certain land-use and environmental correlates of pedestrian injury were observed at the hotspots, however, a primary result ended up simply being the disproportionate burden of pedestrian injury centred in the downtown eastside (DTES) area of Vancouver – a place infamous for poverty, drug abuse and homelessness, but also well-known for community and political capital. The results were published in *BMC Public Health*, an online open access journal. Due to the findings of the study – which provided evidence of a hidden public health problem – combined with the accessibility of the article (freely accessible, easy to interpret visualized results), the press picked it up immediately. Increased awareness of this issue instigated the creation of the City-funded DTES Pedestrian Safety Project. Project coordinators invited DTES stakeholders, City engineering, public health, and transportation departments, and our research team from UBC and SFU to form an advisory group to steer the project. The aim of the Pedestrian Safety Project was to harness the knowledge of the advisory group to understand the reasons for the problem, and deliver feasible recommendations for improving pedestrian safety in this community.

## Results

At the end of the eight-month Pedestrian Safety Project, a report was produced that provided evidence regarding the unique pedestrian injury problem in the DTES, and proposals for its redress. Based on the knowledge of the advisory group, proposed interventions included the implementation of a reduced speed zone in the area, and engineering solutions designed to reduce pedestrian-vehicle conflicts. Soon after the release of the report, some of the safety measures were implemented, with more planned for the short term. In addition to this direct result, a further benefit of the collaboration between our team and the advisory group was the mutual involvement on a subsequent study of human behaviour and pedestrian injury. Our team provided GIS data analysis and study design expertise, and the project coordinators provided volunteer hours and knowledge translation expertise. In addition, we were presented with an opportunity during the meetings to harness the expertise of the advisory group to fine-tune the design of our pedestrian behaviour study.

## Conclusions

Greater focus on the ‘healthy communities’ model has helped to highlight the need for collaborative, localized, and evidence-based decision-making (Gudes *et al.*, 2010). Although involvement with the community advocacy group required commitments beyond the proposed scope of the project, participation was mutually beneficial. This case study in community collaboration and knowledge translation is a successful example of research leading to results. As EBDM becomes paramount in many sectors, community collaboration and effective methods of KT will be required in order to ensure research findings are understood and utilized. Visualization of spatial data was a key driver in communicating and translating the study results. Those of us who are involved with GIS and data visualization in health and other domains may be in a unique position to participate in and influence the decision-making process.

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# Obesity and the Built Environment: a cluster analysis of urban and peri-urban communities in the Greater Vancouver Regional District

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**Abstract**

The purpose of this research is to examine spatial clustering of obesity and physical activity and their relationship to specific aspects of the built environment.

## Background and Relevance

The purpose of this research is to examine spatial clustering of obesity and physical activity and their relationship to specific aspects of the built environment. The prevalence of obesity in Canada has increased since the 1980's to the point that nearly 60% of adults are obese and overweight, and over a quarter is obese (Tjepkema, 2006). In order to understand the increase, researchers have attempted to construct linkages between obesity trends and the built environment (Papas et al., 2007). Several environmental variables have been cited as potential determinants of physical activity and obesity such as: presence of sidewalks, neighbourhood aesthetics, mixed land-use, street connectivity, access to recreational facilities, access to food, etc. (Frank, 2008). Assuming that the built physical environment does affect physical activity and obesity, then it would be expected that individual occurrences of high or low physical activity and obesity will be clustered. (Schuurman *et al.,* 2009). However, a remaining challenge is to determine the optimal methods for detecting clusters of both obesity and high/low physical activity.

## Methods and Data

The data used were derived from the Prospective Urban-Rural Epidemiologic study, an international investigation set to identify the social and environmental determinants of obesity, diabetes, and cardiovascular disease. The cross-sectional data used in this analysis represent the built environment phase of the investigation with the objective of measuring the perceived and objective environmental determinants of health anthropometric measures, obesity, and related metabolic risk factors. 2000 men and women in 13 urban and peri-urban communities of the Greater Vancouver Regional District were recruited in 2008 and individual data were collected in 2009 . Measures of individual physical activity –recorded based on the International Physical Activity Questionnaire (short format) categories - were reported as total physical activity and converted into ordinal measurements. Obesity was determined by individual body mass index (BMI) derived from objectively measured height and weight with an intraclass correlation of .125. Participants' postal codes were geocoded using Geographic Information Systems. The challenge then was to test clustering measures. We used test data from another study to determine pros and cons of each of several clustering methods. These included Morans I test statistic for global spatial-autocorrelation, Anselin's Local Moran statistic for local spatial-autocorrelation, and Geographic Weighted Regression (GWR). In each case, tests were conducted to detect potential clusters of point-based physical activity and BMI measurements. For the local test a row standardized, inverse-distance weighted spatial weights matrix was used based on manhattan distance. A bivariate version of Anselins's Local Moran statistic was also conducted to detect spatial dependency among participants' BMI and total physical activity.

## Results

Preliminary results indicate that higher BMI and lower physical activity are somewhat correlated at the local level, however not correlated to the degree that was hypothesized (Schuurman *et al.*, 2009). Generally, the local clustering measures were more efficient – given the resolution of neighbourhoods. Higher incidences of obesity and their relationship to physical activity may be linked to specific environmental variables that will be addressed in subsequent research. We expect that when we run these tests for each of the cities, we will find similar results.

## Conclusions

Results from this research show that physical activity and obesity are clustered but further examination is required to extract the finer relationships between them. In addition, it indicates that local clustering measures may be more suitable for teasing out possible relationships between physical activity, obesity and the built environment. The relationship from this experiment begs us to consider other methods of analysis for more specific elements of the physical built environment. Elements such as land-use mixture, pedestrian connectivity, accessibility to recreational facilities, and accessibility to food outlets should be considered for the influence on physical activity and obesity. Other variables such as gender, age, deprivation measure, and primary mode of travel could also be used to elicit a more finite factor in trends of obesity.

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# Mass Casualty: a Spatial Model to Support Triage Decision Making


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## Abstract

The survival or recovery of persons critically injured in incidents involving mass casualties is directly related to their access to timely and appropriate treatment. The management of mass casualty evacuation priorities has been underexplored from a spatial perspective. We have created a model for decision-making for evacuation and definitive care priorities. Using a web based GIS, the model incorporates driving time to hospital, hospital capacity in addition to injury type and severity as the basis for decisions about which patients are sent to which facilities. The model produces rapid result and the hope is that it will be used to assist emergency service personnel to optimize decision-making processes during critical stages of evacuation.


## Background and Relevance

During a mass casualty incident, evacuation of patients to the appropriate health care facility is critical to survival. Despite this, no existing system provides the evidence required to make informed evacuation decisions from the scene of the incident. To mitigate this absence and enable more informed decision making, a web based spatial decision support system (SDSS) has been developed. This system supports decision making through the provision of data regarding hospital proximity, capacity, and treatment specializations to decision makers at the scene of the incident.

## Methods and Data

The proposed web based SDSS uses pre calculated driving times to analyze the driving time to each hospital within the metro Vancouver region of British Columbia. In calculating and displaying its results, the model incorporates both road network and hospital data (e.g. capacity, treatment specialties, etc.). The model will also enable hospital personal to update hospital capacity in real time while producing results in a matter of seconds, as is required within an MCI situation.

## Conclusions

The use of SDSS in the prioritization of MCI evacuation decision making has been demonstrably successful. Key to this success is the utilization of pre-calculated driving times from each hospital in the region to each point on the road network. The incorporation of real-time traffic and hospital capacity data would further improve this model.

# Spatial Epidemiology and GIS/ABM: a case study looking at the Red Colobus monkey

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## Abstract

The purpose of this talk is to examine the use of GIS and agent-based modeling in the emerging field of spatial epidemiology. A case study will be presented examining the effects that logging has on disease transmission in a population of red colobus monkeys. In this study, we use an agent-based model coupled with GIS to simulate population level disease dynamics. With this framework we are able to alter the simulation landscape, in this case the effects of logging on the distribution of red colobus resources, to determine disease related impacts. We find that there is an optimal distribution of resources on the landscape which facilitate the spread of disease within the simulated population. The characteristics of this distribution are similar to logged areas within our study site. The use of these highly spatial simulation models will be discussed for more general use in spatial epidemiology.

## Background and Relevance

The recent emergence and spread of novel zoonotic diseases, such as AIDS, SARS, Swine Flu, Bird flu, Ebola and Lyme Disease underscores our need to understand the ecology of infectious diseases. Recent surveys indicate that 75% of all newly emerging diseases are zoonotic (i.e. human disease originating in wildlife) (Taylor 2001), and the increasingly dominant role that humans are playing in changing their environment is a leading cause for this rapid emergence (Daszak 2001). The field of spatial epidemiology advocates the study of the spatial variation in disease risk or incident and the ecological process driving these spatial patterns (Ostfeld 2005). This offers an ideal approach to investigating how anthropocentric activity can alter ecological process and how it might relate to host-parasite interactions in wildlife communities. The goal of this research is to inform public health as well as conservationists in dealing with disease in wildlife.

## Methods and Data

We focus on red colobus living inside Kibale National Park, Uganda. Landscape estimates of resource distribution in a logged and unlogged forest were used to develop a simulated resource landscape. Past observational studies with detailed behavioural data were used to develop the foraging and movement algorithms for simulated red colobus agents. Individual red colobus agents then forage on this resource landscape. Through combined individual decisions, group movement patterns are produced. Inverse modeling techniques were then used to test and parameterize this movement model to observed group movement behavior in the field. The introduction of a parasitic agent enables the simulation to estimate population level transmission dynamics. Infected red colobus hosts pass through stages of infection based on a traditional epidemiological SEIR model (Susceptible, Exposed/latent period, Infectious and Recovered), where spread of the parasitic agents from one host to anther is determined by proximity and is effected by within and between group contact.

## Results

By varying forest composition and hence the distribution of resources within the simulation, we were able to test how changes in resource distribution could affect transmission rates in red colobus populations. We found that the distribution of resources affects within group transmission (spread of group individuals) as well as transmission between groups (inter-group encounters) affecting population level disease outcomes.

Highly homogeneous landscapes had relatively lower contact rates, with the rate of contact between groups increasing with increasing resource heterogeneity. As heterogeneity was further increased the probability of contact between groups decreased, resulting in an optimum transmission rates occurring at a mid-level of heterogeneity. Our model therefore predicts that the density of high resource sites influences the probability of contacting other groups.

The virulence of the parasitic agent, modeled here as the chance of the host dying during infection, was found to affect overall population mortality rates. We find that the distribution of resources which facilitates overall contact rates within the population enables more virulent strains to have a greater impact on the population as well as to spread over larger areas.

## Conclusions

Red colobus group movements and foraging patterns are closely associated with environmental characteristics (Snaith and Chapman, 2008). This creates an opportunity to simulate how changes to environmental characteristics can affect aspects of host parasite interactions within a population. A similar approach, using detailed environmental data along with behavioural data, should also be applicable to other host-parasite systems in which environmental factors play a strong role in influencing either host, parasite or vector populations. Examples of systems that would benefit from these highly spatial approaches include: directly transmittable parasites reliant on a mobile host for transmission, where habitat connectivity amongst the host population is determined from landscape properties (e.g., rabies); parasites who have a life stage in the external environment, where overlap and range use of the definitive host would be important (e.g., gastro-intestinal parasites). Predictions from such models should be useful in constructing informed management plans for endangered species that account for the transmission of infectious disease across real landscapes (depicted with remote sensing data), as well as for predicting the disease-related effects of a changing climate, habitat fragmentation, logging, or other similar anthropogenic changes to wildlife habitat.

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# Linking a land-use cellular automata and a hydrological model to investigate the impact of land-use changes on the hydrological processes in the Elbow River watershed in southern Alberta, Canada

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### Abstract

This paper describes the linkage of a land-use cellular automata (CA) model with a spatially explicit, physically-based hydrological model (MIKE SHE/MIKE 11) to simulate the impact of land-use changes on the hydrological processes in the Elbow River watershed in southern Alberta. Prior to the linkage, the two models were tested for the sensitivity of different parameters and configurations. They were then calibrated and validated for the Elbow River watershed, after which simulations were carried out up to the year 2031 with an interval of five years. The results of the overall study demonstrated that land-use changes affect the hydrological processes significantly in the watershed which are caused mainly by the increased urbanization and decreased forested areas.

## Background and Relevance

The Elbow River is the source of the Glenmore reservoir, which provides drinking water to the City of Calgary. Due to the rapid population growth and urbanization in the City of Calgary, the Elbow River watershed is under considerable pressure for development (City of Calgary 2005). The watershed lies in the rain shadow of the Rocky Mountains, and as a result, is among the driest regions of southern Canada. It is predicted that along with the effects of climate change and the rapidly increasing human activities, water availability will become a critical issue in the near future (Schindler and Donahue 2006). Therefore, investigating the future possible land-use changes in the Elbow River watershed and their impact on the hydrological processes and water availability is becoming a crucial issue. To simulate land-use changes and the land phase of the hydrological cycle in the Elbow River watershed, two dynamic models were chosen: 1) a cellular automata (CA) to simulate land-use changes (Hasbani *et al.*, 2010), and 2) a hydrological model, MIKE-SHE/MIKE-11, to simulate the hydrologic cycle within the study area.

Cellular automata (CA) are dynamic, spatially explicit models composed of a regular discrete lattice of cells having a finite set of possible states. Each cell state is updated at regular temporal steps through a set of transition rules that take into account the value of the cells in its local or extended neighborhood. Despite their simplicity, they are remarkably effective at generating realistic simulations of land-use patterns and other spatial structures and are increasingly used to test what-if scenarios in spatial planning (White and Engelen 2000). The MIKE-SHE/MIKE-11 model is a comprehensive, deterministic, distributed, and physically-based modeling system capable of simulating all major processes in the land phase of the hydrologic cycle (Sahoo *et al.*, 2006). This study was initiated in collaboration with Alberta Environment and the Hydrological Danish Institute (DHI) to investigate the possible impact of land-use changes on the hydrology of the watershed and the availability of water resources.

## Methods and Data

Historical land-use maps of 1985, 1992, 1996, 2001, 2006, and 2010 were classified into nine land uses (water, road, rock, evergreen forest, deciduous forest, agriculture, rangeland/parkland, built-up, and clear-cut areas) using Landsat TM imagery at the spatial resolution of 30 m. Maps showing the distance to a main river, the distance to downtown Calgary, the distance to a main road, and ground slope were prepared and used to represent the influence of external driving factors on land use. Analyses were first conducted to assess the sensitivity of the CA model to different parameters, including the cell size, neighborhood configuration, and selection of external driving factors (Hasbani et *al*., 2010). The land-use CA model was then calibrated at the scale of 60 m using a semi-interactive calibration procedure using historical land-use maps of the years 1985, 1992, 1996, 2001, and validated against the reference land-use maps of 2006 and 2010. Simulations of land-use changes were then performed from 2006 to 2031 at a five year interval.

A suitable conceptual model was prepared using the MIKE-SHE/MIKE-11 modeling environment to carry out hydrological modeling based on the data availability and the focus of the study. A sensitivity analysis was conducted for the parameters: saturated hydraulic conductivity, evapotranspiration (ET) surface depth, degree day coefficient, detention storage, surface roughness, and time constants for interflow and baseflow. The model calibration was then carried out based on the goodness-of-fit calculated between observed and simulated flow data measured at three hydro-metric stations (using Nash-Sutcliffe coefficient of efficiency criteria). MIKE-SHE/MIKE-11 was calibrated using data for the period 1985-1990 and validated for the period 2000-2005. Land-use based watershed characteristics such as spatial vegetation properties (leaf area index, root depth), spatially-distributed hydraulic conductivity, and spatially-distributed surface roughness, were extracted from the simulated land-use maps and transferred to MIKE-SHE/MIKE-11 to assess the impact of land-use changes on the hydrological processes in the watershed. Simulations with

MIKE-SHE/MIKE-11 were carried out for five years using different values of land-use based characteristics based on each land-use change in 2001, 2006, 2011, 2016, 2021, 2026, and 2031. After each simulation, the total water balance error, total overland flow, baseflow, infiltration, and evapotranspiration were calculated and tabulated. The simulated river hydrograph at the end of the Elbow River after each simulation was also obtained.

## Results

Based on the sensitivity analysis of MIKE-SHE/MIKE-11, the two main parameters that were adjusted during the calibration were the saturated hydraulic conductivity (1e-012 m/s for urban and clear-cut, 8e-008 m/s for the remaining area) and the surface roughness for the river bed (Manning's M: 15). The remaining parameters were assigned the default values and physical values appropriate to the Elbow River watershed. The Nash and Sutcliffe coefficient of efficiency values calculated for the calibration period (1985-1990) and for the validation period (2000-2005) were 0.56, 0.52, 0.79, and 0.75 using monthly data based on different hydrometric stations. The total water balance error during all model runs of MIKE-SHE was less than 1%. These values indicate an adequate performance of MIKE-SHE/MIKE-11.

Simulations carried out between 2001 and 2031 based on a 'business as usual' scenario showed a 65% increase in urbanization and 36% decrease in total forest areas in the watershed, which resulted in a reduction of 1%, 13%, 2% in total evapotranspiration, baseflow and infiltration respectively, 7% increase in total overland flow, and 4% reduction of total annual river flow.

## Conclusions

This study demonstrates that land-use changes affect the hydrological processes significantly in the watershed and that these effects are mainly caused by the increase of urban development and the diminution of forested areas. The model shows a decreased water retention capacity in the watershed which increases the total overland flow to the main river. This can increase the occurrences of flash flood in the area in a rainfall event of high magnitude. With the reduced infiltration, the ground water storage can decrease. The results also show that due to the reduced baseflow to the main river as a consequence of the above, the total annual river flow is reduced in the Elbow River. This might have a negative impact on the total water supply to the Glenmore reservoir with the reduction of total supply of drinking water to the city of Calgary from the reservoir. The reduction of total annual flow of the river and reduced ground water will further affect the existing and new surface water and groundwater extractions, respectively.

Further work is in progress to improve the setup of the two models. Additional constraints and transition rules could be implemented in the CA model to better capture certain aspects of the dynamics of the watershed, such as the deforestation. Work is being carried out to integrate a physically-based comprehensive groundwater model and improve the calibration of the MIKE-SHE/MIKE-11 model. It is expected that this will lead to a better representation of the surface-groundwater interactions in the watershed.

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# Literature Review: Linking Climate Change Scenarios to Biodiversity Species Data in Order to Protect Future Distributions

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## Abstract

Growing interest in the link between climate change and biodiversity has lead to many studies in the past decade. We evaluate a variety of biodiversity and climate modeling studies to understand methodogies used. Our goal is to review studies linking biodiversity and climate at the regional and continental scale. We conclude by suggesting common themes and opportunities for future geomatics based investigations of biodiversity and climate change. A synthesized view of the works completed in this field will aid in the convergence of ideas for future research.

## Background and Relevance

The Intergovernmental Panel on Climate Change (IPCC) states that "[p]rojected impacts on biodiversity are significant and of key relevance, since global losses in biodiversity are irreversible" (IPCC, 2007). Many facets of society are concerned about the future of biodiversity because it provides a foundation of goods and services to allow for a healthy functional biosphere (IPCC 2007, Gayton, 2008). In order to protect species diversity, Canada became a member of the Convention on Biodiversity in 1992 and is committed to protecting and managing biodiversity. Canada is therefore required to address any threats to biodiversity such as climate change (Duro et al., 2007).

The use of climate models to predict future biodiversity is a relatively new field of research. Previously scientists did not have the capacity to accurately model climate and its impact on ecosystems but advances in technology have allowed researchers to accurately map future scenarios of biodiversity and climate change (Duro et al., 2007; Nagendra, 2001; Kerr and Ostrovsky, 2003). Methods to research climate and biodiversity vary depending on the scale of the research, landscape structure, time, resources, and desired detail (Kerr and Ostrovsky, 2003). Remote sensing and field data are commonly used as inputs along with climate models to predict long term forecasts of future biodiversity (Xiaoyang et al., 2004). Reviewing the range of research in the field of biodiversity and climate change will consolidate information and aid in the improvement of future research methodologies. In this paper, we provide a literature review of large area, spatially explicit studies that investigate the link between species distributions or biodiversity and climate change.

## Methods and Data

Our interests are in large area biodiversity which requires a great amount of species spatial data. Most spatial biodiversity research falls into three categories: field based data, remote sensing based data, or a combination of the both (Nagendra, 2001).

Field plot data are used by many researches such as Iverson, Thuiller, and Hamman and Wang (Iverson and Prasad, 1998; Iverson et al., 2008; Thuiller, 2003; Guisan and Thiller, 2005; Hamman and Wang, 2006). Field data requires a massive amount of input data that involves physically sampling the vegetation structure of tens of thousands of plots (Hamman and Wang, 2006; Iverson and Prasad, 1998). The spatial and species data are then put through a number of statistical models. Common models include: regression tree analysis (RTA), random forests, bagging, linear models, generalized boosting models (GBM), multivariate adaptive regression splines, and artificial neural networks (Moisen and Frescino, 2002; Prasad et al., 2006; Iverson et al., 2008; Thuiller, 2003; Thuiller and Morin, 2009). There is no one model that prevails at this time. RTA is the most widely used, but even this model has literature that conflicts with its dominance as the best species distribution modeling technique (Moisen and Frescino, 2002). RTA has a non additive behavior because it separates predictor variables making RTA a valuable model in large diverse environments (Iverson and Prasad, 1998). Researchers commonly use a variety of statistical models and or hybrid / ensemble of models. Thuiller and Morin chose the GBM niche based model and the Phenofit process based model, but also suggest that a hybrid model would better reflect reality and therefore improve the accuracy of the results (Thuiller and Morin, 2009). Field plot data provides a detailed and ground truthed look at species interactions and diversity. The drawback to this type of data gathering is that it dates itself in the short to medium term which will require re-sampling every few years (Condes and Milan, 2010). Furthermore, this is an intensive and costly way to research biodiversity (Condes and Millan, 2010; Guisan and Thuiller, 2005). The field plots must represent all bioregions since the data will need to be interpolated; this is difficult in diverse and remote study areas. Field data research is recommended for limited uniform landscapes at the regional to sub regional level with adequate resources (Nagendra, 2001).

Remote sensing is used by biogeographers such as Foody, Duro, and Xiaoyang; to quickly and cheaply research biodiversity (Foody, 2008; Gillispie et al., 2008; Duro et al., 2007; Xiaoyang et al., 2004). Remotely sensed data can be gathered by a number of passive sensor satellites such as the moderate-resolution imaging spectroradiometer (MODIS), Landsat, and SPOT; as well as active sensor satellites such as Radarsat, SRTM, and ASAR (Gillespie et al., 2008; Turner et al., 2003). This satellite data can provide massive amounts of data such as the fraction of light absorbed by vegetation values (fPAR values), digital elevation models, disturbance, land cover, and fragmentation (Ritters et al., 2002, Running et al., 2004; ). This data are provided in a continuous raster format and can cover all scales of research from local to global scales (Duro et al., 2007). Species richness and diversity can be found using the normalized difference vegetation index (NDVI) which is gathered using passive satellite data (Xiaoyang et al., 2004). Although a large amount of information about biodiversity can be gathered quickly, this type of input data can have limited resolution and currently has limited utility at the species level (Gillespie et al., 2008). At this time only a generalized view of biodiversity is attained from these data sets (e.g., Hamann and Wang, 2006). Innovative research is now being conducted that will refine methods for using remote sensing data. Researchers are using derivatives of satellite data such as fragmentation, land cover, disturbance, productivity, and topography to enhance the accuracy and scope of biodiversity research (Foody, 2008; Hamman and Wang, 2006). Future work will use higher resolution data, integrate a variety of biodiversity data sets, and link field data to ground truth results. Remote sensing is currently recommended for regional to global biodiversity analysis that requires repeatable quantitative analysis (Turner et al., 2003). Although field data are being overtaken by remote sensing as a data source, it is important to sustain both types of research to continuously improve and calibrate methodologies (Gillespie et al., 2008).

Climate models and emission scenarios are constantly being updated. Most research is being conducted on IPCC approved models and emission scenarios that give a variety of outcomes from worst case to best case. Common models include the Hadley CM3, GCM, CGCM, and PCM (Iverson et al., 2008; IPCC, 2007; Flato et al., 2000). Emission scenarios are used in climate models to compare possible future CO2 levels in the atmosphere. The most common emission scenarios used are the A series (high $Co^2$), B series (low $Co^2$) and an averaged scenario. Most researchers use a variety of models and scenarios to allow individual interpretation of the data since no one model or scenario can accurately predict the future of these complex systems (Thuiller, 2007; Iverson and Prasad, 1998; Iverson et al., 2008).

Some common goals for biodiversity and climate change forecasting is to find conservation gaps, species niches, invasive species movements, modeling species distributions, and habitat analysis (Hamann et al., 2005; Guisan and Thuiller, 2005; Hannah et al., 2005). There are many applications for this research that will help resource managers make informative decisions; for example: Hamann et al. used geographic information systems to layer biodiversity models with protected areas data to find conservation gaps for particular forest types (Hamann et al., 2005). The fates of many species can be determined by analyzing future species distribution, the climactic stresses put on them, and the amount of conservation efforts existing for those species (Willis et al., 2008; Foody, 2008). Although the methods to create future biodiversity models differ the value of the data are the same.

## Results and Discussion

GIS is an excellent tool to research shifting biodiversity due to climate change in large complex environments (Duro et al., 2007; McDermid et al., 2005). Field plot data are valuable for species specific relationships, but is not practical for large diverse environments. Remote sensing is valuable for regional to global analysis, but until recently has not been applicable to research at the species level.

Biodiversity and climate research has a number of common opportunities and challenges. For instance, the assumption that climate is the main variable for species survival may be problematic (Currie, 2001; Turner et al., 2003). All researchers used climate scenario models and species distribution data in a GIS to predict future biodiversity. There is a consensus that temperature and precipitation are the most important factors in climate models and biodiversity; however, other variables may be important as well (Hamann and Wang 2006; Turner et al., 2003; Negendra, 2001; Iverson et al., 2008; Hannah et al., 2002). Nagendra stated in 2001 that species diversity research in remote sensing was confusing and contradictory. Current literature shows a more directed approach to this type of research (Nagendra, 2001; Hannah et al., 2002, Barnard and Thuiller, 2008). Output data can be linked with parks and protected areas. Studies use biodiversity models to make suggestions about migration corridors, non climactic stressors to ecosystems, and ecosystems where protected areas should be placed (Ritters et al., 2002; Turner et al., 2003; Lemieux and Scott, 2005; Willis et al., 2008). Although biodiversity research has shown to be useful, there are many opportunities that are not being explored. Within the literature there seems to be a lack of integration between data sets, traditional knowledge, and policies perspective that would help synergize conservation efforts into the future.

## Conclusions

We looked at common biodiversity and climate research to find the methodologies used to map biodiversity, choose climate models, and address conservation gaps. Biodiversity research can be done using field data, remote sensing, or both. Given the spatial nature of predicting future geographical distribution of biodiversity, GIS and remote sensing are important technologies to employ in addressing research questions. Biodiversity and climate mapping has limitations but it provides valuable data to make informed decisions about the impact climate change will have on the biosphere.

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# Using the Geospatial Web 2.0 to Improve Climate Model Accessibility

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## Abstract

In this paper, we introduce our initiative to use the Geospatial Web 2.0 (Geoweb) to improve the accessibility of climate models developed by NASA/GISS. This initiative aims to increase the general public's literacy of climate change to promote their participation in climate change issues. Three groups of Geoweb applications that wrapped around the climate models are presented. The first is a web-based user-friendly and well-guided interface for setting up climate model simulations. The second is an OpenLayers application that enables users to create their own boundary conditions for designing simulations. The third is a group of geovisualization applications for analyzing and visualizing model outputs as well as for comparing model outputs data to observational data. Some of these applications have already been publicized. However, by the end of this project, it is necessary to wrap up all the applications and to present them to EdGCM users group for feedback.

## Background and Relevance

The majority of scientists recognize that climate change is an urgent concern for society. However, the same consensus is not built among the general public. These divergences are due, in part, to the inherent complexity of climate change. It happens in a global scale and has long-term and gradual effects. Dilling et al. (2007) raised eight points to explain why climate change is not perceived as urgent and identified five common pitfalls for communicating climate change.

One obstacle for climate change communication lies in the complexity of the primary tools used for climate change research: the climate models. Climate models are simplifications of the real world with attempts to provide useful projections of future climates (IPCC Third Assessment Report 2001). Scientific predictions, for example, the extensive use of fossil fuels will induce further global warming in the 21st century, are mainly based on climate model experiments.

Until now, however, they have been little more than a "black box" to most people. Take the coupled atmosphere-ocean model (AOM) developed at NASA Goddard Institute for Space Studies (GISS) for example. The model runs on UNIX workstations and is programmed using Fortran-90 and Open-MP parallelization statements. The Fortran source code and input files for the 2004 version of the AOM are downloadable in their website (AOM, NASA/GISS 2007). However, a significant level of computer skills, scientific knowledge, and computer resources is expected to use it in a "scientifically useful manner". Another example can be drawn from PRECIS Regional Climate Modeling System. It was developed at the UK Met Office Hadley Centre to help climate change study mainly in UNFCCC classes Annex I nations. It was ported to run on a Linux based PC, however, it takes 4.5 months to complete a 30-year simulation for a typical experiment runs on a 2.8GHz machine (PRECIS, Hadley Centre 2010). Unfortunately, this unfamiliarity and lack of access often engender public's distrust of scientific findings based on climate models (EdGCM 2010).

To increase comprehension, we propose the need to allow the public to interact with actual climate models. We argue that there is value in walking users through the same process a climate scientist would use, which includes designing and running simulations, analyzing and visualizing climate model outputs. EdGCM, the Educational Global Climate Model, was developed with the goal of helping high school students learn about climate change and climate modeling by giving them the ability to run a genuine NASA global climate model (GCM) on a desktop computer (EdGCM 2010). Although EdGCM gives users a clear view of some of the complexities involved in using a climate model, it can be daunting for the general public. Nonetheless, EdGCM sheds light on the possibility to improve public's access to climate models. Actually, we have research efforts going on to bring realistic global climate modeling experience to a broader audience (Sohl et al. 2010).

Furthermore, we propose the use of Geoweb technologies (e.g., earth browsers like Google Earth and OpenLayers) for engaging a broader audience. Earth browsers are interactive virtual templates of our planet. They enable easy and straight global research and allow users to conveniently collaborate and share their projects and results (Chen et al. 2009). Via an easy-to-use and intuitive earth browser interface, it is possible to build an attractive interaction between the public and climate models.

We are trying to answer the question: How to use Geoweb concepts, technologies for the design and development of our applications to improve climate model accessibility?

## Methods

Our research is an initiative to use Geoweb technologies to improve the accessibility of climate models. We plan to use the Geoweb in three ways, to 1) develop a web-based interface for setting up climate simulations, 2) develop Geoweb applications for designing and controlling simulations, and 3) develop geovisualization applications for analyzing and visualizing climate data (model output data and observational data).

The web-based interface for setting up simulations allows users to choose the initial conditions and input files for GCM runs. We look to build a graphical user interface (GUI) that is user-friendly and well-guided for setting up simulations. It could be one webpage containing different components and forms (similar to EdGCM setup simulations interface) or several webpages that guide the users to set up simulations step-by-step. The web-based interface will have an advantage over the EdGCM by enabling the users to perform GCM controls across a network.

The Geoweb applications for designing and controlling simulations will be an OpenLayers application that allows users to create/modify boundary conditions (e.g., vegetation file). By taking advantage of the panning and zooming abilities of OpenLayers, the application could offer attractive and efficient ways for users to design simulations. EdGCM didn't include the components for modifying boundary conditions, however, several other applications (e.g., MapProjector) could be used as scientific reference to make sure the modified boundary conditions work compatibly with GCM runs.

Geovisualization applications with attracting features (e.g., 3D representation, animations, and interaction) will be developed for analyzing and visualizing climate data. One application will integrate existed climate data analysis software, Ferret (2010), with the common earth browser data format, KML. Another application will be a multiple Google Earths platform. By taking advantages of Google Earth and KML, the Ferret application allows users to dynamically visualize climate data in three dimensional spaces, and the platform offers one way for comparing model output data to observational data because multiple earths can be rendered and controlled asynchronously or synchronized.

## Results

At this point, our results include a web-based interface for setting up and running simulations, an OpenLayers application for designing vegetation boundary conditions, and the geovisualization applications mentioned above (see Figure 1).

The interface is accessible at http://edgcm.columbia.edu/~jianzhou/web/. To lower the access threshold of setting up simulations, it allows users to import pre-setup simulations (e.g., Global warming and Doubled CO2). Users can design their own simulations by modifying the parameters for components like 'Ocean Model', or 'Greenhouse Gases Trends'. The parameters are error checked and then sent to the server for building up model simulations (run folders). The interface was implemented as a web-based version of EdGCM setup simulation interface, thus still it could be daunting for the general public because of so many entries. Further efforts are expected to build a dynamic interface according to different users' interests and expertise.

The OpenLayers application is available at http://rose.geog.mcgill.ca/~jian/veg/. Extensive cooperation between climate scientists, GIS experts, and computer scientists makes it possible to implement the integration of Geoweb (e.g., OpenLayers API and Google Chart API) and climate model input. Instead of manually type vegetation percentages for each grid cell in climate model, this application provides an intuitive and interesting interface for designing, creating, and modifying vegetation boundary. It supports visually selection and manipulation of multiple cells. Similar applications are expected to be implemented for working with other climate model inputs (e.g., topography boundary condition).

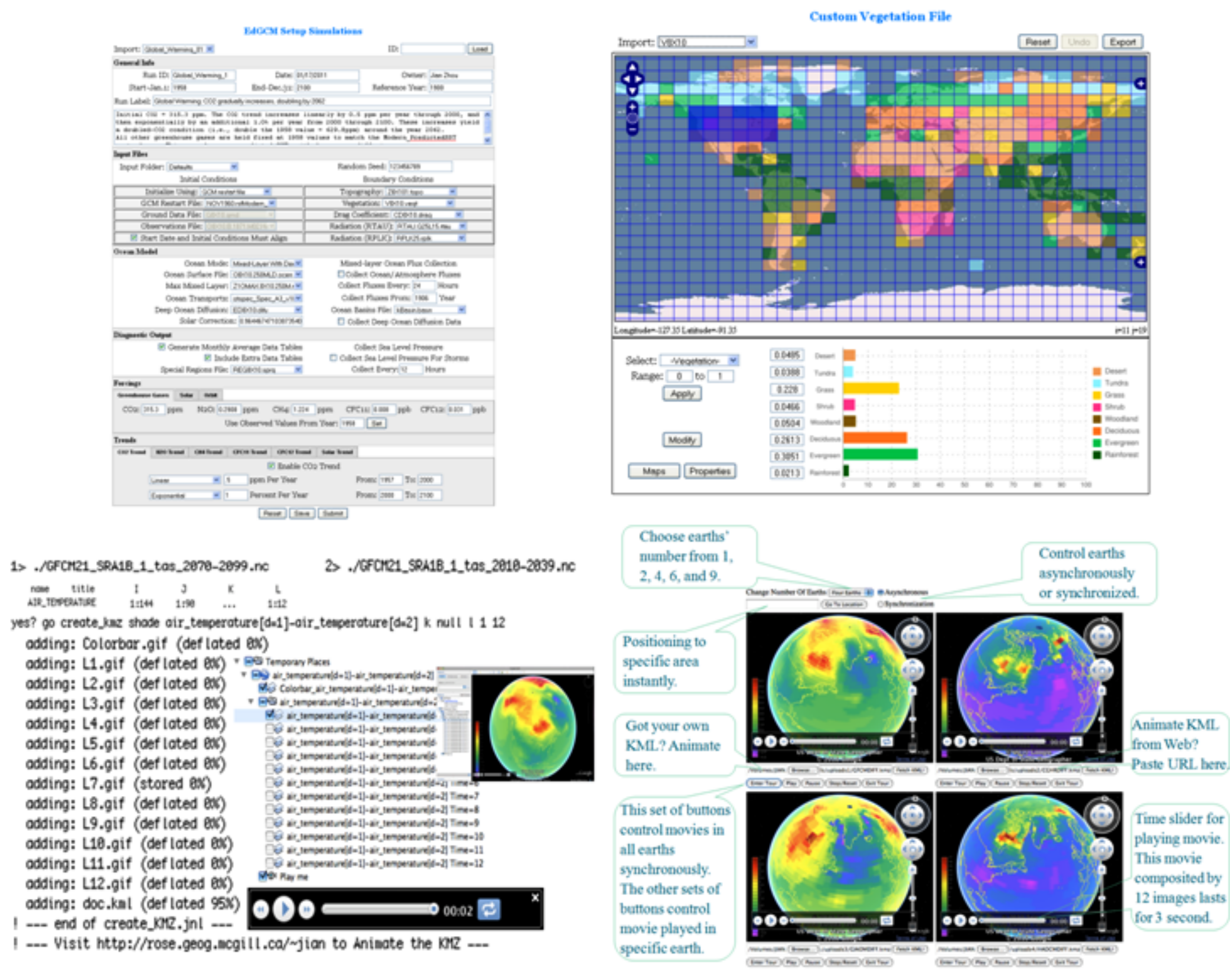


**Figure 1. Collage of Geoweb applications. (clockwise from top left) Web-based interface for setup simulations; OpenLayers application for designing vegetation boundary conditions; multiple Google Earths platform for visualizing and comparing model outputs; and Ferret scripts for integrating Ferret with KML.**

The Ferret scripts were implemented to integrate Ferret with KML. They contain many enhancements for climate data. Firstly, they are capable of generating multiple images along either spatial or temporal dimensions from a standard NetCDF data set at one time (executed with a single Ferret command). Secondly, the scripts support KMZ (zip KML files with supporting images) as the output format. They extend Ferret's features and have been publicized together with the newest version of Ferret V6.6.4.

The multiple Google Earths platform supports displaying of 1, 2, 4, 6, or 9 earths at one webpage according to the user's need. What is more, the multiple earths could be controlled asynchronously or synchronized. For example, if four earths are displayed with each earth fetched its own KMZ file outputted from the scripts, in the synchronized mode, the platform could show you four movies (touring) synchronously. The platform is available at http://rose.geog.mcgill.ca/~jian. One critical limitation for using the platform is that it requires Google Earth API (not available for Linux machine) installed in the client machine.

Our further work is to wrap up all the applications and to present them to EdGCM users group for feedback. Two issues have already been identified. The first was about the extensibility of our applications. The web-based interface and OpenLayers applications are designed and implemented for the same GCM (Model II from NASA/GISS) used in EdGCM. How can we extend our applications to work with other GCMs (e.g., Model E) from NASA/GISS or even GCMs developed by other institutes (e.g., Hadley Center and NCAR)? The second issue was raised from the social concern perspective. As mentioned, climate models require significant scientific knowledge to design simulations as well as to understand model outputs. Our applications enable users to design and to run simulations. However, how can they also help with understanding model outputs? Climate change deniers may also use our applications to run simulations to prove that climate change is not happening. Since all models are "wrong", those deniers (most of whom are non-expert in climate science) may not be able to understand different model simulations scientifically. This is not only a social concern for our project, but also a problem for the whole climate modeling community.

## Conclusions

An initiative to use Geoweb technologies to improve the accessibility of climate models has been introduced. By attempting to bring a realistic global climate modeling experience to the public, hopefully it will promote public's interests and capability to participate in climate change communication.

Continued efforts are expected to improve our applications as well as to encourage others to develop applications to facilitate climate change communication. It will be interesting to look at how online social networks and collaborative work could promote public's awareness of climate change.

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# Visualizing Climate Change in Canadian Newsprint Media

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### Abstract

Climate change issues have gained substantial ground on the world stage over the past decade. Especially Canada has gained a pivotal global position, making its domestic climate change discourse a key issue. Newsprint media are a wide-reaching form of public communication that is readily available in digital archives. Growing volumes of information create a need to develop more effective techniques to mine and display discourse-relevant patterns. Thirty environmental keywords were searched through major newspapers in 15 Canadian cities for the period of 1999 – 2009 for a general coverage of key climate change debates. A subset of nine keywords was chosen for this paper to present the core findings in problem identification, renewable energy, and carbon based solution discourses. The cartographic techniques open the discussion on the communicative interface of mapping and 'meaning' in visualized media discourses. The research contributes to a concept development for utilizing visualization techniques to enhance understanding of spatial and thematic discourse dynamics across the media.

## Background and Relevance

Science is reconstructed in the media; it is in this way that public knowledge and opinions are influenced by the media (Carvalho, 2007; Speth, 2008; Zehr, 2000). Ideology in journalism often leads to polemic coverage of scientific news. Science is supposed to be a mirror of the physical entity that it is examining but this is often not the case when science is interpreted, generalized and simplified by the media. Values and worldviews are integrated into news media stories that affect public opinion and understanding of the issues being covered (Carvalho, 2007).

Foucault already noted that social position and political change are channeled through knowledge (Foucault, 1972). Statements "must be viewed within the context of power as objects and weapons of political struggle" (Kennedy, 1979, pp. 286). The agendas pushed by media conglomerates are very important to the way climate change is presented to the public. The recent acceptance of anthropogenic climate change (ACC) into popular culture (in part by Al Gore) has helped facilitate a shift away from skeptical journalism (Carvalho, 2007). Journalist coverage of scientific news can insinuate that there is disagreement in the academic community when there is none. Foucault identifies a need to develop knowledge without reductionist tendencies toward political, economic, and social interests of the stakeholders (Foucault, 1972). There is also a need to understand what role discourse plays in the transformation of social norms (Kennedy, 1979). The media does not necessarily convey the ideology of environmental actors but does integrate points of view and ideological standpoints that affect how the issue is digested by the public (Carvalho, 2007).

Spatialization is a geographic visualization of non-spatial data used to enhance cognitive understanding of phenomena (Fabrikant, 2008). It typically relies on dimension reducing techniques and layout algorithms to project similarity in non-spatial data into distance (Börner *et al.,* 2002). Spatialization conforms to Tobler's first law of geography that all objects are related but closer objects are more related to each other than distant objects (Tobler, 1970). A visualization of similarity in geographic data can be created by transforming geographic space into synthetic (metaphorical) space (Spielman & Thill, 2007). Tobler's first law of geography has been adapted by Montello *et al.* (2003) for spatialization by asserting people believe closer things are more related. The purpose behind creating a physical visualization in any discipline is that it is easier to understand and learn by expert and non-expert users (Fabrikant & Buttenfield, 2001). One of the key directions today for visualization of the spatial metaphor is data mining large volume databases to further the ease of access and understanding for all users (Skupin & Fabrikant, 2003; Spielman & Thill, 2007; Wise, 1999). Spatio-temporal data pose many interesting and unsolved problems that geographers are applying cartographic techniques to better understand (Fabrikant, 2008).

## Methods and Data

### Keyword Development

Mainstream media reporting on climate change is less likely to use technical terminology than would a peer review publication. A variety of keywords were chosen in order to generalize the problem identification discourse into something tangible that can be captured in a news archive. The keywords were selected in such a way as to minimize ambiguity and retain climate change context. It is also important that the keyword terminology is likely to be used in newsprint language. General, but specific terms were selected that represent the core issues of problem identification, renewable energy, and carbon focused solutions.
The keywords selected for this paper were:

| **Problem Identification** | **Renewable Energy** | **Carbon Focused Solutions** |
|---|---|---|
| Climate Change | Hydro Power | Carbon Capture |
| Greenhouse Gas | Solar Power | Green Economics |
| Emissions | Wind Power | Carbon Trade |

These keywords capture the essence of the emerging struggles over climate change over the past decade as it has become a major issue both nationally and globally.

## Data Collection

Newsprint is a widely accessible means of media communication around the world. In recent years, in terms of newspaper history, most newspapers have publicly accessible archives. The search engine accommodates Boolean search expressions which enables precise archive data mining. Canadian Newsstand contains 300 newspapers from Canadian publishers with coverage from 1977 to present. The database is hosted by ProQuest, a major international information service provider of such trademarks as RefWorks, CSA, eLibrary, and Chadwyck-Healey. Other forms of media, although important, were excluded for a number of problems with each. Radio and television transcripts, magazines, and NGO news releases were initially included in the research design. By specifically using Canadian Newsstand, search techniques were standardized and consistent for recording keywords. Since the other forms of media are unstandardized and in many cases unavailable, it was decided not to include them at this phase of the research.

By hosting all of the newspapers used for this study in a single database it allowed for systematic and consistent search results that would otherwise be encountered by using multiple data hosts. Cross comparability was a key objective of compiling the keyword dataset. Database queries count the number of articles that the keywords appear in, not the absolute number of times the keyword was used. By counting keywords this way, each article is a separate entity with which an idea regarding climate change is presented.

Geographic visualizations, spatializations, and graphs were utilized to examine the collected data for trends and anomalies. Connections to place and time were able to be uncovered in the data and presented by using the fore mentioned toolsets.

## Results

From the problem identification phase of this research, it look as if "climate change" and "emissions" are the favored topics in the climate change discourse. These keywords are subject to a common temporal trend of a peak in 2002, a valley between 2003 and 2005, followed by another peak in 2007.

The data collected here indicates that much of the development in media coverage of the carbon debate has occurred over the latter portion of the decade with relatively little coverage of most of the issues in the early part of the decade. Alberta has consistently appeared as the more active region for carbon related keywords throughout the study period.

Wind Energy was the most prevailing form of renewable energy according to the data collected. In terms of the media relevance, these keywords are indicative as a snapshot of the holistic discourse which suggests that the media had a higher than normal focus on wind power.

The data indicates that there has been steadily increasing diffusion of carbon sequestration in the media over the study period. Studies (primarily Sharpe *et al.* 2009) suggest that the public is in favor of solutions that remove carbon from the atmosphere despite it being catastrophically expensive to undertake in its current phase of development.

## Conclusions

The variety of visualization techniques used in this research was useful for exploring and offering meaningful explanation of otherwise invisible patterns in the media.
The current capitalism market is relying on economic incentives to promote a green shift in society. The hopefuls want to encourage renewable energy and sustainable development while simultaneously discouraging consumption and pollution. Since most environmental reform policies have been fought based on economic interests, Canada has been slow to react to climate change. The data used in this study presents solid evidence of the widespread media coverage of problem identification. While most of the data has created a whirlwind artificial peak in 2002, the mid-decade span was comparably less prevalent until 2007. More research is needed to hypothesize the cause for this valley. A societal transition is needed to unite development and environmental regulation. By exploring the messages in Canadian media, policy makers and environmental researchers are better able to adjust their actor roles for the public good. Cultural norms have changed radically over the last hundred years for the better so it is possible to look beyond short term economic gain for long term environmental loss; there needs to be a widespread willingness at all levels.

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# Maps and Memes


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### Abstract

In this paper I examine the question of whether or not the meme represents an advance on Discourse/Power (D/P) theoretical frameworks for analyzing imperial and/or indigenous maps. Memes are posited to represent an advance over many aspects of D/P analyses, supplying explanations for phenomena that the latter framework is simply not able to provide. Two sources of data are used in order to compare the 'Meme's Eye View' against D/P: Landscape Maps entered in an art contest in an Eastern James Bay village; and Cartographic Utterances, spoken during a youth public speaking event in the same location, the following day. The Meme's Eye View was found to give a very different, but complementary, analytic outcome, when compared to D/P. The meme is able to theorize maps as vehicles for cultural transmission. Mapping was found to be the primary mechanism for transfer between generations.


## Background and Relevance

### *Memes*

The meme is a unit of cultural transmission, similar to a gene, but applicable in the realm of culture. Dawkins (1976 and 1982) invented the term 'meme' as an analog to the gene. Distin (2005 and 2011) demonstrated that memetics and genetics are simply two instances of a general evolutionary process; they are not analogous to each other. Much has been made of the meme and whether or not it is appropriate, correct, or useful to use memes to explain cultural transmission (Blackmore, 1999; Dennett, 1995; Brodie, 1996; Aunger, 2002; Shennan, 2002; Cavalli-Sforza and Feldman, 1982; Cavalli-Sforza, 2000).

Distin (2005) dispels previous hesitations and confusions about where memes reside (both in minds and in the world), about their viral nature (memes go viral when transmission is horizontal), and about the implications of the particulate and distributed nature of the meme. Memes, like genes, are discrete entities; but unlike genes, individuals do not have a fixed set of memes upon birth. Individuals may interact with and create enormous numbers of ever changing meme-complexes, in the form of ideas, diagrams, skills, survival techniques, and most importantly for our purposes, maps.

### *Critical Cartography*

Cartography is the art and science of making maps. Thus defined, cartography would seem to be a value-neutral activity or undertaking. Critical cartographers are map makers who challenge the alleged neutrality of maps, pointing out that maps always serve interests. When the interests of states, governments, corporations or other powerful institutions are served by maps, the maps themselves are posited by critical cartographers to embed or infuse the power inherent to the interests they serve.

Critical cartographers (Crampton, 2003 and 2010; Pickles, 2004; Curry, 1998; Harley, 1989; Wood, 1992) do not confine themselves to maps for their insights. Critical cartographers are heavily invested in theoretical frameworks developed outside of the discipline of geography. Like critical pedagogy (Freire, 1970), critical cartography makes maps into co-productions that break down user/producer dichotomies. Thus conceived, the map becomes a device for the assertion of power as much as for the empowerment of the user.

But some maps, by their design, preclude empowerment because of the erasures, silences and gaps inherent to that design. In response to such lacunae, indigenous groups have developed counter-mapping, a method for putting back the peoples formerly excluded from maps (Peluso, 1995).

Maps as assertions of power, and the analyses of such maps, have relied upon postmodern theorists, especially Foucault (1990, 2005). According to Foucault (2005), discourses of power are arranged in formations or groupings that mask their power through the naturalization of statements that always occur in the context of other statements. Statements include verbal utterances, diagrams, art, and maps. In a later work, Foucault (1990) describes power as diffuse and with many handles upon which it is leveraged. Maps are one such handle.

Combining early (discourse focused) and late (power focused) Foucauldian theoretical frameworks, I name my hybrid critical cartographic theoretical framework 'Discourse/Power,' deliberately invoking Foucauldian terminology, but upsetting sedimented and dogmatic Power/Knowledge frameworks already established by critical cartographers (cf. Foucault, 1980; Akerman, 2009; Edney, 2009; Wood, 1992; Burnett, 2009; Hostetler, 2009; Kivelson, 2009; Hefferman, 2009; Crampton, 2003 and 2010; Abrams and Hall, 2006; Pickles, 2004).

According to Foucault's writings on Discourse/Power, the formations of power implicate a whole order of geospatial technologies inside and outside of bodies, machines and territories. In this paper I examine the question of whether or not the meme represents an advance on Discourse/Power theoretical frameworks for analyzing imperial and/or indigenous maps

## Methods and Data

Two types of data, 'cartographic utterances' and 'landscape maps' are each examined (and cross-examined) from two different perspectives: 'Discourse/Power' and 'the meme's eye view.'

Cartographic utterances consist of six statements made by six individuals during a public speaking contest held in Wemindji, Québec on March 25, 2010. These statements were chosen for their illumination of cartographic and spatial issues facing the youth of Wemindji today.

Cartographic utterances are examined from both Discourse/Power and meme's eye view perspectives in order to evaluate the strengths and challenges of each toward answering the primary research question. The primary research question is: what is the role of maps in the transfer of intergenerational indigenous knowledge? Does a memetic framework offer anything to a Foucauldian framework for analyzing the power of maps for enabling or disabling the transfer of intergenerational indigenous knowledge?

The six cartographic utterances are derived from the following youth speeches: “Matuuskach,” “Camping/Blackstone Bay,” “Going for a Walk,” “Digital Devices/1,” “Time in the Bush,” and “Digital Devices/2.” Four of the participants were females, including three in high school and one in elementary school; while two were young (primary/elementary) boys.

Landscape maps consists of six works of art from each of six categories (children 0-12, youth 13-34, youth/adult, adult 35-64, adult/elder, and elder 65+) of art entered into an art contest held in Wemindji, Québec on March 24, 2010. The principles guiding my examination of these maps include the presence or absence of cartographic symbols or perspectives; the depiction of landscapes ‘from above’ (whether oblique or perpendicular to the depicted surface); and the artistic composition of the maps. Other principles guiding my analysis include examination of the maps for the inclusion of discrete representations (or memes) of traditional activity on the land.

In addition to the six works of art from local contestants, I examine a map entered into the same art contest by the primary author of this paper. This 1:50,000 map, entitled ‘Kaachiiwaapechuu’ depicts the course of a three day walk in which I participated alongside children, youth, adults and elders from March 8-11, 2010. It provides a contrast to the locally produced art in terms of examining different kinds of oblique and normal (perpendicular) view maps from both Discourse/Power and meme’s eye perspectives. It also verifies intergenerational knowledge occurrence ‘on the ground’ through commemorative activity on the land.

The inclusion of my own map in the art contest is justified in two ways. First, I was solicited by the manager of the art contest to enter my map into the contest. Second, my map depicts traditional activity inscribed by GPS and superimposed upon a Google Earth image. As such, it represents a contemporary ‘geoweb’ map, allowing for contrast and juxtaposition with the other maps entered into the contest (Scharl and Tochtermann, 2007).

Lastly, a website developed by the primary author serves as a repository and public display of locally produced works of art and youth public speeches. Entitled “Indigenous Technology and Science, James Bay” the website shows compatibility with memes due to the ability to bundle together a wide range of place-based materials. The materials so bundled are available to contemporary and future generations interested in their own heritage and in the effects of rapid cultural change.

The website is also part of the ‘geoweb’ in two senses: a web of indigenous knowledge both traditional and local that has existed, in part, for hundreds of years; and a web of device-enabled geospatial information that is coming to inform and overlay the older, traditional and already established web of indigenous knowledge (Eades, 2010; Carlson, 2008; Borgmann, 1984).

## Results

Cartographic utterances and landscape maps perpetuate the idea of the land, of being and dwelling ‘there’ (the place depicted) in ways reminiscent of the artist’s ancestors. In this way, cartographic representations come to be a primary vehicle for the vertical downward transmission of discrete representations of (maps/memes of) cultural knowledge.

The utterances of young public speakers similarly emphasize the land, but in a more questioning mode, challenging the status quo and in effect producing vertical *upwards* transmission, in which elders and adults in the audience learn of the aspirations, challenges, hopes, dreams, and knowledge of youth.

Horizontally transmitted memes are revealed through utterances related to teaching and learning by playing with friends and siblings (as in a young boy's learning to hunt by playing with his friend at Matuuskach; or by another boy walking around town teaching his little brother about local places). Horizontal transmission in this case is revealed in an act of upward vertical transmission represented by youth public speaking (to elders).

Thus there is a double representation, or meta-representation evident in the (cartographic) utterances of the very young (children). The ability to meta-represent is posited as an innate ability of the mind, which is an extension of, and is loosely coupled with, the gene-defined brain (Distin, 2005; Blackmore, 1999).

I would take this further: in the present cases of art and public speaking, it is the ability to *map* (somewhat like imitating, but not the same) between generations (vertical transmission) and between individuals of the same generation (horizontal transmission), that is at the heart of the meta-representing, memetic, human mind. Distinct and different from mimesis (cf. Blackmore, 1999), mapping is more appropriate ground for discussing the meme and cultural transmission.

Both literally and as metaphor, the map, and more precisely, the act of *mapping*, is both performed and inscribed in bodies and brains. This strong assertion is true in the sense that bodies perform maps through not only physical, but also through mental, activity. Physical and mental map performances are not easily separated; indeed both maps and memes exist internal and external to the human body. Furthermore, the brain is structured like a set of stacked maps (Edelman, 1989; Searle, 1997).

This positing of maps as memes and of memes as mappings itself maps onto the concept of the geoweb, in which the geoweb is distributed and user-controlled, and includes old and new elements (Eades, 2010; Scharl and Tochtermann, 2007; Carlson, 2008).

## Conclusions

As noted by Johnson (2007), the meme is an improvement over Discourse/Power in a number of ways. It should be used alongside Discourse/Power to strengthen the field of critical cartography. Not only power, but empowerment, would thus enter the purview of cartographers interested in challenging the status quo. As demonstrated in this paper, the people of Wemindji are using maps, mappings, art, and public speaking for the purposes of empowerment, local discourse and decision making, and communication.

As the analysis of data in the form of cartographic utterances and landscape maps have shown, these two forms of representation are being used locally for the enhancement and enablement of knowledge transmission in horizontal, oblique, and vertical directions. The latter (vertical) was shown to occur in both downward and upward directions, implying that elders are teaching youth and that youth are teaching elders. This bi-directional movement of memes was facilitated by multiple technological contexts such as broadcasting (the use of the microphone), posting (art on walls in an art contest), and the geoweb (posting multi-media components on the ITS site).

The geoweb component of this research is intended as both supplement to, and additional support for local knowledge production and transmission. In this regard it has been deemed successful. However, only through the continued use and development of geoweb technologies and features, such as tagging, posting, blogging, 'texting' and many other features, will the full potential of the geoweb be realized. Whether or not this comes to fruition, only time will tell.

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# Territorial representations and collective participation in the planning process: A case study in suburban Dakar


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### Abstract

In order to support community involvement in the planning process of its living environment, the research uses a participatory process to elicit inhabitants' territorial representations as the groundwork for a participatory geographic information system (PGIS). It is conducted in a poor Senegalese neighborhood located in the immediate vicinity of Dakar's rubbish dump, which is undergoing foreclosure as a part of important infrastructure projects that will change the territorial dynamics of the area. The research aims to show that the process will transform the citizens' territorial representations of and relationships to their environment, as well as, stimulate the collective will to be a part of the ongoing planning process of which they are presently excluded.


## Background and Relevance

PGIS research has focused on access to information. It has often been used to value local knowledge of the territory (see for example community-integrated GIS in Harris et Weiner, 2002; Elmes and al, 2005; Koti et Weiner, 2006) or to provide a better community access to spatial information (Elwood, 2008; Kyem, 2009). There is also room for using GIS to elicit conversations on place perceptions. This research stresses the process of sharing, reflecting on and discussing place and space representations as a means to awaken a community's involvement in planning its environment. It is interested in the way citizens describe their environment, or *space description* (Mondada, 2000); their travels and daily activities, or *living space* (Di Méo, 1996); their feelings associated with their surroundings, or *lived space* (Di Méo, 1996) and *place attachment* (Altman and Low, 1992; Breux, 2007). GIS can contribute to the process by integrating this information, as well as by superposing it with more usual territorial information integrated in GIS. The purpose of the research is to provide citizens with a basis for discussions on the future of their territory and to encourage planners and decision makers to take into consideration the citizens' territorial representations.

Part of a wider ongoing action-research project in planning and architecture, this presentation bears on two stages of the research: 1. a participatory process aimed at reflecting on place representations and the future of the neighbourhood; 2. the integration of the qualitative material thus generated into a GIS equally accessible to citizens and planners. The transfer of the GIS to the community will be studied in a future stage of the research.

## Methods and Data

The first participatory meetings with the community were held during the summer of 2009. The views expressed at this first stage serve as a reference for assessing community change during the whole action research project. At stage two in the summer of 2010, a structured interactive process was carried out in order to study the inhabitants' representations and their transformation both at the individual and the collective levels.

Four groups of five inhabitants – segregated by age and gender – were involved in participatory workshops that focused on their representations of their living space. In the first workshop, held at the community health center, each group drew a mental map. The second workshop consisted of a neighborhood walk, where participants commented, took pictures, and interviewed people on their way through. Data thus collected about important places were integrated in a GIS to produce static maps. The four groups were then brought together to evaluate the maps, which were thereafter presented and analyzed during a community meeting. All the material generated through the workshops and the community meetings was analyzed further in the fall, with an exploration of ways to integrate this type of qualitative material in the GIS. Several important elements, as well as, comments and pictures taken by participants during workshops and walks were integrated into the GIS. The regroupment of this data facilitated the analysis of the differences and similarities in territorial representations expressed by the four groups.

To measure the participants' *awakening to* the planning process, two concepts were used. These two concepts depict the participants' sense of engagement in a situation. The researchers may then measure the change in the participants' mindset concerning the control or the impact they have on the planning process. The first concept is the «locus of control» developed by Julin B. Rotter in 1954 (Smith and all, 1995). An individual's locus of control can be internal (the person thinks he controls his life and the events that affect him), or external (the person believes that external forces, or a higher power, control events that happen in their life and their environment). The second is Perry's «scale of cognitive and intellectual development» (1981). In a first stage of «dualism», the person considers only binary viewpoints concerning a situation. In a second one of «multiplicism», the person understands that different perspectives co-exist. In a third of «relativism», the person qualifies his own thoughts. In a final «engaged relativism», the person feels he has to do something about a situation. A person or group with a dualist understanding of the urban planning process and an external locus of control would tend to be reluctant to engage in discussions concerning the future of his/its neighborhood. Conversely, a person or group with an engaged relativistic mind frame and an internal locus of control would more readily participate in debates and actions aimed at improving his/its living environment.

Individual open-ended interviews before and after the participatory workshops were used to measure change in locus of control and cognitive and intellectual development. At the community scale, using the same concepts, the content of a community meeting held in the summer of 2009 around aerial photographs of the neighborhood and its surroundings was compared with the content of the one held in the summer of 2010 after the workshops around the resulting maps.

## Results

The results show that participants advanced in terms of locus of control and scale of cognitive development. For example, when asked what they could do to improve the neighborhood, some of the young women replied, before the workshops, that the men – the heads of the households – should be responsible for the community. When asked the same question after the workshops, they had changed their discourse to include themselves as agents of change and they pointed at the necessity of community meetings and collective actions, hence, showing a shift from an external to an internal locus of control and an *engaged relativistic* position concerning this topic. Participants also argued that their capacities and skills were improved due to their participation in the workshops.

The analysis of the issues discussed during the community meetings point to the emergence of a common discourse about the future of the neighborhood and the prioritization of needs and actions for territorial planning. In 2009, the residents had a tendency to rely on researchers to delineate further action for their neighborhood. They then listed their needs without prioritization in the form of a wish list. According to age and gender, they expressed different viewpoints concerning future actions and solutions. Overall, during this meeting, the community expressed a predisposition to count on an external locus of control and a *dualistic* understanding of neighborhood issues. During the 2010 meeting, there was a real conversation between all participants and land development emerged as a major issue over which the community should have control. Contrasting with the minimal internal locus of control expressed in 2009, at this meeting, a community leader, and his supporters, emphasized the necessity to create a plan for future development. There was a consensus at the end of this meeting to further the discussion by engaging the neighborhood chief and the mayor in the process.

## Conclusions

As in all research-action processes planned over many years, there are many uncontrolled factors may have influenced these research results. Indeed, during this research, other participatory activities were held in the neighborhood and, over a year, many events may have contributed to the observed changes. However, the change observed in individuals happened over a relatively short period, under relatively controlled circumstances. As to the community, although change over a year cannot be controlled, the comparison between the meetings held in 2009 and 2010 underlines the importance of relying on the situation as defined by the community to really engage the inhabitants in the planning process. It remains to be seen whether change will be sustained over the years to come and how the community will appropriate further development in the PSIG.

Despite its limits, this research shows the way towards a promising role for PGIS in transforming the representations people have of their territory and in raising their interest in neighborhood and urban planning. In conclusion, next stages in this research will be discussed.

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# Digital Networks and the Geoweb

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**Abstract**

The geoweb is usually conceptualized as a blending of GIS (or broadly: geospatial data and techniques) with Web 2.0 (an umbrella term encompassing online interconnected software patterns and social practices of sharing and creating of data). In addition, many geographers who have undertaken geoweb research, either exploring ways to harness user-generated data or to structure their own participatory projects, have drawn primarily from the literature of Public Participation GIS (PPGIS). However, the definition of the geoweb remains amorphous and the intersection of geodata and social software bears further examination. In this presentation I offer a literature review of geographers' engagements with Web 2.0 discourses both inside and outside academic scholarship. I outline the major themes of this engagement and identify elements of overlap and difference, proposing potential avenues for further geoweb research.

## Background and Relevance

The geoweb exists somewhere in the intersection of several rapidly moving processes congruent with the development of new mapping and communication technologies: the increasing spatialization of information online, the emergence of relatively free and user-friendly web mapping software, the growing availability of mobile computing platforms and sensors (such as smartphones), and a paradigmatic shift toward collaborative creation and distribution of spatial data on the internet. Yet, in the years since “map hacks” and “mashups” first entered geography's vocabulary (Crampton and Krygier 2005) heralding the start of what would become an influx of geoweb mapping tools and map-making populations, geographers have still not agreed on a consistent name for these phenomena (Crampton 2009; Elwood 2009). The emergence of “neogeography” (Turner 2006) shares many features with the geoweb, and has amplified this state of confusion about how to understand the operations and implications of geoweb practices within the discipline of geography (Rana and Joliveau 2009).

Some geographers have suggested that the multivocal and mutable traits of the geoweb make it an extension or successor to the field of Public Participation GIS (Miller 2006; Rouse et al. 2007; Flanagin and Metzger 2008; Tulloch 2008). Another thread of research uses the concept of Volunteered Geographic Information (VGI) (Goodchild 2007) as an analytic to understand user-generated online geodata, frequently from the perspective of research on Spatial Data Infrastructures. Out of all the numerous terms and concepts for aspects of these emerging phenomena, VGI and the geoweb appear to be the two terms that have received the widest adoption within the discipline.

Geographers have also turned outside the discipline to technology and media discourses surrounding Web 2.0 (O'Reilly 2005) in attempts to understand the dynamics of user activity on the geoweb. Like the geoweb, Web 2.0 is a problematic signifier (Beer and Burrows 2007), and has been critiqued as a meaningless corporate branding strategy (Bassett 2008; Scholz 2008). While other terms have been suggested, such as the Social Web, by Scholz (2008), or Social Software, preferred by Shirky (2008), Web 2.0 is the most commonly used name. Monmonier (2007), however, observes that the "Web" itself may cease to be a meaningful term—at least for understanding the breadth of digitally networked geospatial information—as telecommunication increasingly incorporates mobile platforms and further permeates the environment in the form of embedded computing. From this perspective, the constellation of practices and technologies usually called the geoweb bears further analysis in light of research on cybercartography and ubiquitous computing.

There is more at stake here than arguments over terminology. Through a more systematic study of overlaps and differences between the geoweb and similar fields, I hope to make observations that not only help situate the geoweb as an object of study, but also suggest new avenues of research and identify gaps in current scholarship.

## Methods and Data

This presentation looks at the relationship between the geoweb (as formulated by scholars working in the field of Geography) and the concept of Web 2.0 through a series of discursive engagements. As Geographers have turned to Web 2.0 literatures to explore individual participants' experiences on the geoweb, certain recurrent questions form three broad categories: 1) the study and classification of geoweb users 2) the examination of collaboration and participation on the geoweb and 3) the exploration of crowdsourcing and collective intelligence. These three themes represent an upscaling of the analysis, from the level of the individual user, to groups of individuals, to and then, at the third level, the dynamics of larger "crowds" of people. Each level is also mediated in different ways by the machine intelligence of the online environment and of "smart" everyday objects in the physical realm.

For each of these categories, I approach the literature through a series of questions: How have the theories and analyses of Geographers and Web 2.0 commentators been informed by the social and technical affordances of their respective digital environments? What are the challenges in translating theories and frameworks developed in one context to another? In particular, how might the peculiar qualities of the geospatial digital environment cause aspects of Web 2.0 theories to amplify, mutate, or break down?

## Results and Conclusions

For each of the three themes described above (classification of users, collaboration, and collective intelligence) I focus on one observation from Web 2.0 research that has yet to be applied to the geoweb. Drawing on these expanded connections between the two fields, I argue that the geoweb is not simply a combination of geospatial information and digital communications networks, but that it is the interface between spatial and *social* networks online. Instead of crowds (Surowiecki 2005; Brabham 2008) composed of individual user/mappers generating apparently autonomous information, most geoweb spaces include groups of users that are interconnected to various degrees and via a variety of mediating digital artifacts and communications channels. Thus, user-generated geodata frequently bears marks revealing the social contexts of its origin, an observation that suggests new opportunities for academic research as well as new privacy concerns that must be understood and addressed.

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# Harnessing chaos: using the Geoweb as a tool to support social change

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## Abstract

The Okanagan community is increasingly under threat from forest fires due to climate change and expanding development in fire interface zones. The effects of forest fires are not always quantifiable "hard" impacts. The fluid and chaotic "soft" impacts can have a profound effect on the collective consciousness of the people living close to the fires. To make sense of these impacts and understand where and when these forest fires have taken place, we have employed a Geweb tool to support citizen-to-citizen dialogue and tell the stories of these impacts. Governments are looking for ways to encourage citizen-government interaction; the Geoweb is increasingly used to facilitate the flow of data between the two. This presentation argues that the Geoweb offers greater opportunity for citizen-citizen interaction and combines many types of dissimilar data into a unified whole. To support fundamental social change there must first be clear understanding of the problems at hand followed by informal communication between members of a community. This presentation will explore the interlinked 'chaos' that exists between forest fires, governmental GIS and citizen contributed geographic information, as well as theorize about the role that the Geoweb plays in the transformation of chaotic individual sets of data into identifiable social change.

## Background and Relevance

The Okanagan Valley is increasingly under threat from forest fires due to two inter-related issues, firstly the expanding development in forest fire interface zones and secondly climate change within the valley causing hotter and drier forest fire seasons. Severe forest fires in 2003 and 2009 led to thousands of evacuations and cost millions of dollars to combat. Forest fires are a yearly concern, yet the public awareness surrounding forest fires varies with the severity of the human impact. Forest fire modeling and prediction are currently the main areas of research in this field, leaving many human impacts ignored. The social construction of forest fires has been dominated by public awareness cycles and established information mediums. Citizen-citizen and many-to-many streams of information are lacking. Forest fire patterns, government information on forest fires and public opinion are all disaggregated and chaotic. This tool attempts to clear the confusion and the media maelstrom that often surrounds the annual forest fires in the Okanagan Valley through heightened discourse.

Quantitative attempts to predict or prevent forest fires using a variety of geographic information system (GIS) based tools are common (Castro & Chuvieco, 1998; Chuvieco & Congalton, 1989; Erten, Kurgun, & Musaoglu, 2002). For these studies the validity of the outcomes are contingent upon the technology and epistemology used, weighing several quantifiable variables to produce a final prediction or action planning. The attempt is to turn chaotic natural systems into clearly ordered, predictable GIS models. Despite nature and natural events being fundamentally chaotic, with a myriad of small changes and movements leading to massive changes elsewhere, science attempts to control the chaos (Worster, 1994). For example, decades of fire suppression can ultimately yield an explosion in instances of wildfire when natural ecology's chaos can no longer be contained (Stephens & Ruth, 2005). Humanity's chaos mirrors that of ecology and fires in unpredictability and interaction. In studying natural events, or anything with a high level of unpredictability, it may be beneficial to refuse system simplification and organization and instead allow for randomness and multiple perspectives. Studies that integrate the views, perspectives and experiences of citizens through technology that is not confined to an 'expert-only' realm are needed to examine the impact of forest fires on human populations.

With the emergence of Geospatial Web (Geoweb), defined as "the use of the Internet to deliver geographic information and maps" (Haklay, Singleton, & Parker, 2008, p. 2011), geographic information and GIS are no longer usable solely by experts. Volunteered geographic information (VGI), whereby information is contributed by the public and verified and validated by other users (Goodchild, 2007a), is supported using Geoweb applications which allow the multi-directional flow of knowledge, including the knowledge, values and experiences of the general public (Turner, 2006). Connected populations are able to collectively construct geographical knowledge; the merits of VGI lie in the applications of citizens as sensors and citizen science (Goodchild, 2007b). This enables the production of Geoweb applications that can harvest and communicate information that is representative of community opinions and values "on a scale never before achieved" (Elwood, 2008, p. 174). GIS's attempted simplification of the world into data "points", "lines" and "polygons", working in absolute, positivist perspectives, represents an attempted control of the natural order of chaos. The attempt to overcome GIS's failings at representing fuzzy information and poorly represented data through tools like the Geoweb could be viewed as a failure of representing the chaotic nature of life.

While GIS and geographic information science (GIScience) attempt to apply rigid models to nature, VGI can allow for difference, and incorporate many opinions and ideas. Through use of the Geoweb and VGI, chaos can be embraced rather than barely contained. By utilizing the participatory potential of the Geoweb, public involvement can be supported and can utilize multiple forms of media and data. Furthermore, government data can be demystified, public opinion can be codified and random forest fire events can be visualized. Individually, all of this information is chaotic and incomprehensible or non-representative. The Geoweb is uniquely poised to take advantage of the intersecting chaotic systems of human interaction, forest fire behaviour and governmental data presentation. The result is a clearer picture of forest fire events than any individual source as well as a presentation system favouring the natural chaotic outcomes of the systems described above. However, on the flip side, due to a lack of expert accredited quality control, issues have been raised over VGI's credibility. However, in the case of our Firemapping research project, we argue that when the aim is to organize and gather qualitative, personal accounts, credibility becomes less of an issue than in the technocracy (Flanagin & Metzger, 2008).

## Methods and Data

While other research has examined forest fires through the lens of ecology, physical geography and GIS, this project seeks to provide new insight on the human impacts of forest fires in the Okanagan by providing a Geoweb portal (www.firehistory.ok.ubc.ca) upon which to facilitate the contribution of VGI. This portal revolves around a Google-based map of the Okanagan that displays polygons for forest fire burn areas at different periods of time (since 1984). The polygons are clickable, providing a page of statistics about the fire (date, total area burnt, probable cause) as well as news articles and other online information about the fires. To this, users are able to volunteer their own personal stories, experiences or photographs related to the forest fires. Through a mixed method (qualitative and quantitative) research methodology, this research explores the potential of the Geoweb to make chaotic data more understandable to the general public.

This presentation will report on the Geoweb's ability to harness the chaotic and foster citizen-citizen dialogue within the Okanagan related to the issue of forest fires and their human impacts. Distilling chaotic systems of governance, climate, forest fires, and human ecology into an easily understood and presentable format is a fundamental challenge of GIScience, but often remains unstated, and is usually difficult and reductionist in nature. We will re-examine the results of the first summer of usage of this tool, resolving issues from creation to launch and exploring the deeper meaning behind this notion of 'control' over the Internet and 'controlling chaotic information', chaos being inherent in the contributions, users themselves and official data all combined into this tool. Ultimately, it is an issue of controlling participation.

## Results

Initial results regarding the reception of the Geoweb portal indicate a high level of interest, particularly from the media. To date, the project has been featured in articles in the Canadian Geographic, the Globe and Mail, interviews on CBC Radio and Global TV Okanagan. This interest level helps us gain more users, particularly during the summer, when forest fire risk is highest. Traffic to the website has noticeably increased, with new members and contributed data. In addition, a partnership with the Kelowna Fire Museum provides direction in terms of evaluating the website and helping to tell the "millions of stories" experienced by Okanagan community members. Using results from user surveys conducted last year the website is being updated and improved. The next step will be to evaluate the use of the website over the summer and conclude on its usability and public discussion potential during an active fire season.

## Conclusions

The Okanagan Valley is increasingly under threat from forest fires due to two inter-related issues: the expanding development in forest fire interface zones and climate change within the valley resulting in hotter and drier forest fire seasons. This presentation reports on the ability for Geoweb applications to harness chaotic location-based experiences and foster citizen-citizen dialogue within the Okanagan on the issue of forest fires and their human impacts. By making use of the chaotic elements of data, rather than resisting, structuring or oversimplifying, the Geoweb and VGI can comprehensibly merge several forms of data to increase dialogue and understanding on an extremely important issue. This coalescing of data can aid in the creation and strengthening of community bonds and support social change.

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# "I don't come from anywhere." Using maps to rediscover a sense of place.


## Jon Corbett

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### Abstract

This presentation reports on a community-based research project that investigates the role of participatory mapping in rediscovering a sense of place within a geographically dispersed aboriginal community, the Tlowitsis Nation from Northern Vancouver Island. The research investigates how participatory mapping can be used to understand and reconnect with Tlowitsis land-related knowledge and examine the ways in which these technologies serve to re-present place-based memories and facilitate dialogue amongst community members located in different geographic settings.


## Background and Relevance

The territory of the Tlowitsis Nation spans the coastal area of Northern Vancouver Island, British Columbia. Seasonal travel routes, food processing spots, burial and cultural sites and other named places extend across the entire territory. Karlukwees, located on remote Turnour Island, became a central settlement for the Tlowitsis Nation since the turn of the 20th century. In the early 1960s, the provincial government halted essential services to the island. With little prospect of schooling and access to health care, the Tlowitsis community began to leave the island. In the ensuing diaspora, community members have become culturally, as well as physically, removed from their traditional territories. A rising urban population with little attachment to these lands has reduced the opportunity and ability, for members to take an active and informed role in their community. Furthermore, many Tlowitsis members lack a deep sense of their national identity and are most often poorly acquainted with their relatives and other members of the Nation. One member expressed these feelings in a small group discussion during a Tlowitsis Nation meeting in 2006:

> *"It's kind of hard to say where I come from because I don't come from anywhere. To say that, being First Nations is important, but to say that I'm Tlowitsis doesn't really have any significance for my family … I went there as a child - but for me to pass anything on to my children, its really hard to explain to them where our extended family came from because there's nothing, there's no land, there's nothing to go to."*

Furthermore, the Nation's governing body has had difficulty in maintaining communication and participation of its members in Tlowitsis activities. Despite these issues there remains a core group of elders in the community with knowledge of the lands, resource use and language, as well as a number of community leaders and youth with a yearning to participate in planning and decision-making activities.

## Methods and Data

The need to overcome these constraints became more urgent when the Tlowitsis' Statement of Intent to negotiate a treaty was accepted by the BC Treaty Commission in June 2006. The Nation is currently engaged in substantive negotiations and is positioned at stage four of a six-stage treaty process. Identification and acquisition of community settlement lands is a key priority of those negotiations and a major focus for the Nation. However, in order to inform the decision-making process, the Nation's leaders have identified the need to increase the participation of community members. The challenge is to develop information collection and presentation tools not only for engaging in dialogue with decision-makers, but also for assisting dispersed members to better understand their connection to the land and its memories and thus support an informed community input into the process.

In 2010 a core group of ten Tlowitsis members have begun crafting of a land selection and resource management plan. Corbett is working directly with this group using a range of cartographic tools to facilitate their engagement in this process. The research component of this project explores the role of the participatory mapping in developing greater literacy of the land and territory – a place that the group's members have never physically visited while simultaneously forming a core component of the sense of themselves. A place rich in personal and collective memories that they hope can act as a catalyst in recreating a sense of community, identity and belonging.

The investigation employed qualitative research techniques including focus group discussions, semi structured interviews and participant observation to investigate how participatory mapping might lead to the rediscovery of a sense of place.

## Results and conclusions

The research project is ongoing, definitive results remain forthcoming. This presentation will report on the initial findings from two community workshops. Using, wherever possible, the voices of the Tlowitsis members and Corbett's, the talk will intertwine digital media, field note observations and photo collage as a way of articulating to the SKI audience the richness of qualitative inquiry and the varied, and at times subtle, role(s) of participatory mapping in rediscovering a sense of place.

# Land Use Consultation Services for First Nations, Dreamcatcher Geomatics Beta Service Development

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### Abstract
We present a functioning web-based system called Dreamcatcher Informatics that provides specific knowledge on First Nation community cultural mapping implementation and the use of such data for the purposes of consultation.

## Background and Relevance

A new paradigm in geographic information science has emerged since the late 1990's often referred to as "cybercartography" (Taylor and Pyne, 2009) which emphasizes that "we must move away from the narrow 'technological' normative and formalistic approaches to cartography to a more holistic approach where both mapping as a process and the map are expanded". This new approach or paradigm in geographic information science has led to more holistic, integrated and interactive forms of mapping such as public participation geographic information systems (PPGIS) and collaborative geomatics. There are other similar terms used to convey concepts comparable to PPGIS including "participatory GIS (PGIS)", Collaborative GIS, Critical GIS, or Collaborative GIS (Elwood, 2006; Sieber, 2006; Dunn, 2007). However, many PPGIS systems only allow users to display content rather than being truly interactive, allowing for volunteered geographic information (VGI) (Haklay et al., 2008).

In contrast, we have defined collaborative geomatics is "a participatory approach to both the development and use of online, distributed-authority, geomatics applications" (McCarthy et al. Submitted). What makes collaborative geomatics truly unique is the declarative application engine upon which it is based, referred to as the Web Informatics Development Environment (WIDE). The Computer Systems Group of the University of Waterloo developed the WIDE toolkit to begin to remove "gate keepers" such as programmers, allowing domain experts in the social sciences to build low cost applications that enable citizens to take control of some of their own data, information and knowledge, collection, processing and management.

This project brings together the Computer Systems Group of the University of Waterloo and the Centre for Community Mapping (COMAP), a not-for-profit provider of software as a service, and two Ontario aboriginal communities, the

Mississaugas of the New Credit First Nation and Fort Albany First Nation. The goal is to build a functioning web-based system called Dreamcatcher Informatics (DI) that will provide specific knowledge on First Nation community cultural mapping implementation and the use of such data for the purposes of consultation.

DI will support community-based mapping services that empower aboriginal community cultural mapping and planning and support remote land use consultation between community, agency and development proponents, with a premise of sustainable community economic development. The DI beta implementation is funded by the Ontario Ministry of Culture, Ministry of Aboriginal Affairs and SSHRC.

## Methods and Data

This project is part of an on-going series of collaborative, participatory research projects between the Fort Albany First Nation and the University of Waterloo that have ranged from toxicology, nutrition, food security, environmental policy and land use planning. As with all of these collaborative projects, members of both the Fort Albany and Mississauga's of the New Credit First Nations were part of the research team, helping to develop the project proposal and seeing it through implementation. Both communities expressed a need for set of tools to enable the collection of community-based, cultural mapping information. This project will pilot the preparation of cultural content for and by the Mississaugas of the New Credit First Nation and the development and implementation of a cultural resources plan with constraint mapping. Both processes will ensure the proper interpretation and application of Traditional Knowledge (TK) and western science in cultural preservation in the face of resource developmental pressures. Specifically, this project will:

1. Develop and implement a suite of collaborative geomatics tools including:
    - multi-media narrative services with WIKI tools and archival metadata,
    - modular map-based pop-ups or mapups
    - mediated community network services with roll-based access controls, and
    - real-time, repayable collaborative mapping negotiation services that employ AJAX and COMET technologies

   for undertaking community-based, cultural asset mapping, constraint mapping and consultation; and
2. Provide adequate training and support: for the development of cultural asset mapping process by the Mississaugas of the New Credit First Nation;

## Results and Conclusions

The project is expected to generate an alpha system by February 28th 2011; that will be introduced to and tested by the Mississaugas of the New Credit and Fort Albany First Nations. The resulting beta system will be further modified for pilot community operations and other aboriginal communities. The project will be presented, discussed and demonstrated live at the SKI Canada conference.

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# Intra-Urban Heat Vulnerability Assessment for Toronto: Lessons from a Community-University Partnership

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### Abstract

This contribution reviews an ongoing project aimed at supporting Toronto Public Health with a neighbourhood-level assessment of heat vulnerability. Heat-related illness and mortality are increasing with the frequency of extreme hot weather due to climate change. This work started out as a consulting project but made its way into the scholarly GIScience literature as well as the Geography classroom. The paper reflects on the synergistic nature of research, teaching, and practice of GIS that was experienced in this partnership with municipal government and community stakeholders.

## Background and Relevance

Global environmental change brings with it an increased frequency of extreme heat events (Easterling et al. 2000). Hot summer weather threatens human health, in particular in higher latitudes where people are not prepared for oppressive heat (e.g. Luber & McGeehin 2008). Pengelly et al. (2007) estimate that in both, Toronto and Montreal, 120 persons die prematurely on average each year from heat-related illness such as heat stroke. In the United States, heat/drought is the deadliest natural hazard (Borden & Cutter 2008). As a consequence of striking events such as the 1995 Chicago heat wave with 700 deaths (Semenza et al. 1996) and the 2003 European heat wave with nearly 40,000 deaths (Sardon 2007), researchers became interested in the population-level and place-based risk factors that made some people more susceptible to heat-related illness than others. Heat vulnerability assessments at intra-urban geographic levels include studies by Wilhelmi et al. (2008), Johnson & Wilson (2009), Wolf et al. (2009), and Loughnan et al (2010).

## Methods and Data

In a six-month pilot project in 2008/09, recommendations for a Toronto-specific, geographically explicit heat vulnerability assessment were developed (full report at http://www.toronto.ca/health/hphe/air_quality/pdf/finalreport.pdf), some of which are summarized in Rinner et al. (2010). The article focuses on the role of maps to support the visual analysis of social, environmental, and health-related indicators of heat exposure and heat sensitivity in the population. Indicator selection was based on a literature review, and includes surface temperature, lack of green spaces, concentrations of renter households in older high-rise buildings, low-income seniors living alone, young children in low-income families, and lack of educational attainment to name a few. In the article (Rinner et al. 2010), we discuss a number of recommendations pertaining to the geographic level of detail, the use of cross-tabulated Census data rather than Census profile variables, and the options for creating composite indices of heat vulnerability by urban neighbourhoods.

In contrast, in the present paper I am taking a step back to report on this consulting project as a personal learning experience in applied GIS research, and as an opportunity to enrich the undergraduate Geography curriculum at Ryerson University.

## Results

This collaboration started with an invitation to bid on a formal request for proposals issued by the City of Toronto. The invitation was received because the RfP cited a previous publication of mine in the context of multi-criteria analysis of public health data (Rinner & Taranu 2006). Although Ryerson's Geography Department is well-known for its applied, career-relevant orientation, this consulting project was my first significant experience in this direction. With clear deadlines and deliverables that were critiqued in client meetings, and with our maps being subject to stakeholder feedback, I faced exam situations for the first time in years!

The staff at Toronto Public Health turned out to be experienced with, and interested in, academic publishing, which resulted in a collaborative effort on the above-mentioned article in a special issue of CaGIS on "New Directions in Hazards and Disaster Research" (Rinner et al. 2010). Another academic outcome of the pilot project is the participation of several members of the project team as international collaborators in a NASA project on developing a "System for Integrated Modeling of Metropolitan Extreme Heat Risk".

Closer to home, first-year Geographic Analysis students were given a series of GIS lab assignments that mimicked parts of the project and resulted in a mini-atlas of heat vulnerability. The assignments combined raster data handling (e.g. for surface temperature from thermal remote sensing imagery) with vector data from the Census, and required students to understand spatial patterns and clustering of environmental and socio-economic indicators. The labs also introduced the students to GIS use in the City of Toronto administration and to the City's open data initiative (http://www.toronto.ca/open/).

## Conclusions

This paper tells the story of a successful partnership between University researchers and municipal government analysts and decision-makers. If anything, I want to encourage colleagues and graduate students to participate in knowledge exchange with their communities, and reap the benefits of such collaborations for their academic progress.

Phase II of the consulting project is ongoing under the title "Implementation of a Map-Based Heat Vulnerability Assessment and Decision Support System", and substantial results may be reported in the scholarly literature in the near future.

## Acknowledgements

This paper reflects on a project with significant contributions from Dianne Patychuk, Stephanie Gower, Monica Campbell, Kate Bassil, Suzanne Briggs, Carol Mee, Cheryl Dow, Shiraz Nasr, and Dan Jakubek. Funding of this research received from Toronto Public Health and from Natural Resources Canada through the Ontario Regional Adaptation Collaborative (ONADAPT) is gratefully acknowledged.


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# What happened to Overlay Engines: A Story of Technological Shifts

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**Abstract**

At a certain point in the history of GIS, the polygon overlay tool was seen as the essential marker of a “real” GIS. Benchmarks were built around performance, and reputations made or lost on this criterion. In the current functionality of web mapping, there is next to no emphasis on such analytical tools. There are complex operations (such as shortest path) performed, often in blindingly fast real-time (on huge networks).

Overlay engines have become a minor issue, pursued by a few fanatics in computational geometry. Major software packages include radically improved geometrical processing, but do not provide any user interface to control the process. Important issues do not get taught, so the next generation may have little background in the technical subtlties.

This paper will be a reflection on how technological shifts not only influence performance, but they change expectations totally. The written paper will make connections to science and technology studies as a way to understand the interactions between technology and society.

# VGI in the Geoweb: an Experiment to Test Data Reliability

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**Abstract**

This paper presents an experiment to test the quality, validity and lay monitoring of data in the Geoweb using such sites as Wikimapia. This experiment is set in the context of opposing arguments on the quality and reliability of data in the Geoweb, particularly those data that are provided by ordinary citizens.

## Background and Relevance

A theoretical tension exists between the view that data in the Geoweb is championed by citizen sensors (Goodchild, 2007) versus the 'cult of the amateur' (Keen, 2007). The former sees the opportunity for the Geoweb to facilitate self provision, quality monitoring and map making while the latter refutes the 'wisdom of the crowd'.

## Methods and Data

Publicly provided data, including geographic place names, geographies and metadata were systematically modified and tracked for update and corrections in Spring 2010. A timeline of corrections (or further changes) was traced over a four week period. Baseline and change data trace the extent to which all types of VGI are corrected. All data changes introduced in the study that remained at the end of the observation period were returned to their original values/formats.

### Results

This case study shows that there is a high degree of community monitoring and protection of publicly provided data, geographic information and metadata. This is true of public- and private-sector sites in a number of Canadian cities. At least in this case we see that the citizen sensor has validity for generating, updating and maintaining high quality public domain data. The citizen sensor sometimes vehemently protected data but there is no support in this case study for the view that the Geoweb suffers unwise or amateur data provision.

### Conclusions

At least in this case we see that the citizen sensor has validity for generating, updating and maintaining high quality public domain data. The citizen sensor sometimes vehemently protected data but there is no support in this case study for the view that the Geoweb suffers unwise or amateur data provision.

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# HEAT – Home Energy Assessment Technologies:
## Geomatics Solutions to Improve Urban Energy Efficiency Through Residential Waste Heat Monitoring

**Geoffrey J. Hay, Bharani Hemachandran, Christopher D. Kyle, Gang Chen, Sulakshmi Das and Mustafiz Rahman**

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### Abstract

The HEAT pilot project is a FREE GeoWeb mapping service, designed to help residents visually evaluate the amount and location of waste heat leaving their homes and communities as easily as clicking on their house in Google Maps. HEAT incorporates Geomatics solutions for residential waste heat monitoring using GEOBIA (*Geographic Object Based Image Analysis*), the GeoWeb and Canadian built *TABI (Thermal Airborne Broadband Imager)* technologies to provide users with timely, in-depth, easy to use, location-specific waste-heat information, as well as opportunities to save their money and reduce their green-house-gas (GHG) emissions.

### Background and Relevance

HEAT is a FREE GeoWeb mapping service [1], designed to help residents visually evaluate the amount and location of waste heat leaving their homes and communities as easily as clicking on their house in Google Maps. HEAT incorporates Geomatics solutions for residential waste heat monitoring using GEOBIA [2], Canadian built TABI technology and a GeoWeb delivery system using Google Maps as the front-end. A back-end geospatial information system provides users with timely, in-depth, easy to use, location-specific waste-heat information; as well as opportunities to save their money and reduce their *green-house-gas* (GHG) emissions. We suggest that with this new geointelligence (i.e., tailored geospatial knowledge), home owners can better participate [3] in government grant and tax incentive programs to carry out energy saving renovations at identified waste heat locations, by certified service providers**.**

### Methods and Data

The (2010) *Phase I pilot* is located in the Brentwood community of Calgary, Alberta Canada where it includes 358 residential buildings (built 1961 -1965), suggesting that they are good candidates for potential energy saving renovations. A corresponding 600 x 2000 pixel TABI-320 geometrically corrected mosaic was provided by ITRES Research Limited. The TABI-320 is a pushbroom thermal infrared sensor that produces an image 320 pixels wide. The sensor is sensitive to the 8□m - 12□m range of the electromagnetic spectrum, and contains flight information that is later used to geo- and ortho-correction the imagery. The image was delivered with a spatial resolution of 1.0 m and a radiometric resolution of 0.1°C. During the *Phase II pilot*, a new larger area (24 x 35 km full city) dataset will be acquired by the TABI-1800 [4] during the winter (Feb – March) of 2011. This new sensor is capable of collecting 1800 pixels per swath, effectively 5+ times the capabilities of the TABI-320, and will be evaluated with cadastral data for over 110,000 homes provided by The City of Calgary. During 2012, *Phase III* will be developed for 300,000+ homes over the entire city (25 x 35 km).

HEAT Web 2.0 architecture is based on OGC (*Open Geospatial Consortium*) standards [5] and includes (i) a geospatial database, (ii) an image processing pipeline, (iii) a web server platform capable of running server side scripting languages, and (iv) an Ajax supported web browser. A combination of PostgreSQL and PostGIS provide the geospatial database backend to the HEAT web service. Open source geospatial libraries such as GDAL/OGR for raster and vector file handling, and PROJ.4 for coordinate system conversion are used within the thermal image processing pipeline and by the geospatial database itself. Google Maps is used as the front end, and Python is used for rapid program development. Image processing is conducted using ENVI and IDL, with feature extraction based on a combination of in-house and commercial GEOBIA software and cadastral data

## Results and Discussion

HEAT incorporates (i) *volunteered geospatial information,* (ii) defines the 6 hottest locations on each home (i.e., 3 along the roof edge, and 3 within the roof envelope), (iii) locates the hottest (3+) homes in a neighborhood, and (iv) incorporates multiscale monitoring ranging from individual homes to neighborhoods and cities. This may be used to provide evidence of successful energy incentive retrofit programs, along with opportunities to promote national and international intra- and inter-city waste heat competitions. Potential City Savings ($) and reductions in $CO_2$e (Carbon Dioxide equivalent) are also calculated based on *fuel-type* and *temperature models*. Users can mouse-over the list of communities, highlighting each community HEAT map. Statistics such as number of homes, total heated area and approximate cost to heat all homes in a community are shown.

Clicking on an area will zoom into the *Residential HEAT Map*, which displays individual homes classified into 10 temperature classes based on their *average roof top temperature*. Clicking on a classified house polygon will show a detailed TABI waste heat *signature* for a specific home, with the top 6 hotspots automatically illustrated (as colored circles) (Figure 1). The cost of heating the home per day, along with estimated $CO_2$e for different fuel types is also modeled. Clicking on a fuel type will bring up the *$avings tab*, which provides information on the cost of heating the home and $CO_2$e generation for specific fuel types. It also shows the *potential savings* and *reduced* $CO_2$e when the average roof temperature is reduced to the minimum roof temperature. Ideally, the roof temperature should equal the ambient atmospheric temperature. Anything above this is *waste-heat*.

Users can also click a button that links their thermal perspective with Google Streetview. In many cases, this immediately provides visual evidence linking the ‘edge’ hotspots, with doors and windows located directly beneath them. Thus, providing additional evidence of locations where waste-heat solutions could be applied. As a result of this new geointelligence, value-added services related to low $CO_2$e fuel sources (i.e., wind, solar etc), energy efficiency and waste-heat reduction could be promoted from the web service (i.e., installing thermal windows, doors, siding, roofing, insulation etc).

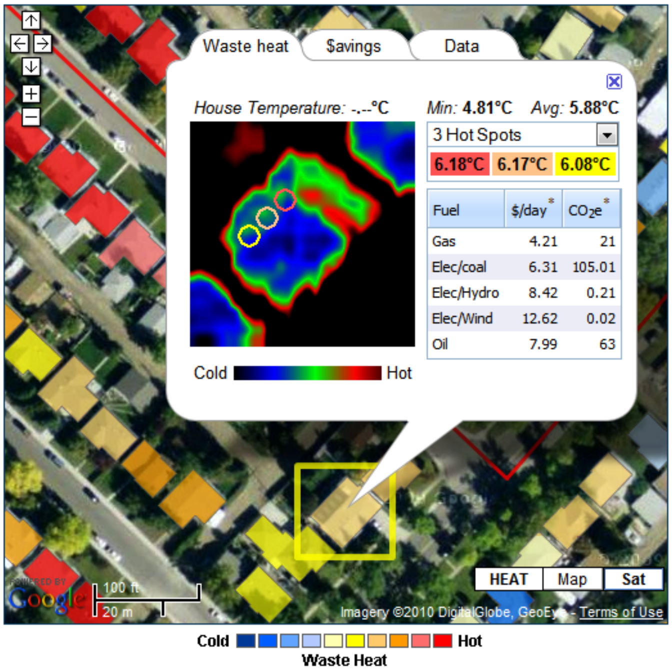


***Fig 1:*** Three circles (inset) automatically define the 3 hottest locations on a home – which in this case fall above 4 sky-lights (inside yellow box). Individual homes (i.e., colored polygons) are designated one of 10 colour classes based on their average *roof top temperature*.

## Conclusions

Based on location-aware web services and high resolution airborne thermal imagery, the HEAT pilot project presents free Geomatics solutions with a high potential for commercialization and advanced spatial decision making, that are applicable through a range of scales from the individual home owner, the neighborhood, the community, to an entire city. Tools have been developed that allow a resident to examine the 100+ hottest homes in a community, as well as the top 6+ hottest waste heat locations (and their temperatures) leaving their home. $CO_2e$ estimates, based on different fuel sources (i.e. gas, oil, wind and hydro electricity, etc) are also provided. An *annual home energy use model* also provides estimates of the money saved and the $CO_2e$ reduction if a home owner is able to take action to reduce the temperature leaving their home (as waste heat), from the average to the minimum roof temperature defined by the TABI sensor. Ideally these free tools will help residents reduce the amount of waste heat and green house gases leaving their home, as well as provide them with opportunities to save their money through energy efficiency. They may also provide agencies evidence of successfully implementing energy retrofit programs, along with opportunities to promote national and international intra- and inter-city waste heat competitions. Renovation contractors may also find these tools useful for identifying neighbourhoods where upgrades are required for marketing purposes; residential construction companies may be able to verify the (waste heat) quality of their homes, and police agencies may be able to use this geointelligence for identifying grow-ops. Additional uses may be found by municipal planners looking to identify the 'best' communities to focus energy efficiency incentives upon, and organizations mapping urban ecological footprints [6].

To evaluate the current GeoWeb version of HEAT, please login to (http://www.wasteheat.ca) as *beta*, with the password *beta* (no italics).

## Acknowledgements

Dr Hay acknowledges support from ISEEE (www.iseee.ca), ITRES Research Limited (www.itres.com), the City of Calgary (www.calgary.ca), the Urban Alliance (www.urban-alliance.ca), Enmax Energy (www.enmax.com), the UofC Foothills Facility for Remote Sensing and GIScience (www.ucalgary.ca/f3gisci), and NSERC (www.nserc.ca). The opinions expressed here are those of the authors, and may not reflect the views of their funding agencies

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# Estimating Crop Yields from Remote Sensing Data

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## Abstract

Reliable estimates of crop yields are important planning tools, not only for individual farmers, but also for regional and national agronomists. Yield forecasts have been traditionally made at the field level by noting that there is a strong correlation between mid-season green leaf area index (LAI) and harvest production. This paper examines the LAI-yield relationship by estimating LAI from multispectral remote sensing data. Additional relationships between vegetation indices both measured on the ground and estimated from satellite imagery are explored.

## Background and Relevance

The production of food, feed, and fibre is fundamental to continued human existence. Remote sensing of croplands can provide important information for crop management decisions to improve water and nutrient use efficiency and enhance crop performance (Hatfield et al. 2004). The application of remote sensing for quantifying crop biomass, leaf area, ground cover, and yield is generally dependent on how they affect the quantity and quality of electromagnetic radiation reflected and/or emitted by the vegetation (Pinter Jr. et al. 2003, Ferencz et al. 2004). However, soil reflectance through an incomplete crop canopy cover complicates the remote sensing of the crop.

Reliable estimates of crop yields are important planning tools (Doraiswamy et al. 2003). The earlier in a growing season that an accurate yield prediction can be made, the more useful the analysis will be. Important crop parameters for yield estimation are the green leaf area index (LAI) and the normalized difference vegetation index (NDVI) (Best and Harlan 1985, Thenkabail 2003).

This paper reports on the application of remote sensing observations to estimate harvest yield for small grain crops near Indian Head, Saskatchewan. The objective was to assess the efficacy of estimating yields from and leaf area index (LAI) measurements derived from multispectral imagery acquired by a spaceborne sensor at some time prior to harvest.

## Data

The study site is located near the town of Indian Head, Saskatchewan (50°30'N 103°40'W) and approximately 70 km east of Regina. Canola, spring wheat and field peas are considered the most essential and vital cereal, oilseed, and pulse crops of the region (C. Holzapfel pers. comm. 2009). The area is located in the Aspen Parkland ecoregion and is characterized by a semi-arid continental climate with extreme seasonal temperatures (average daily temperatures are -16°C in January to 18°C in July) and limited precipitation (approximately 250 mm of rain falls throughout the growing season) (Environment Canada 2010).

Field measurements were collected from 16 fields associated with the Agriculture and Agri-Food Canada (AAFC) research centre at Indian Head at approximately 2 week intervals from June 1 through August 31, 2009. The fields were planted in barley, canola, field pea, flax, oat, and spring wheat. Field data included *in situ* NDVI, LAI, crop growth stage, soil moisture, row spacing and orientation, and grain yield at harvest.

Multispectral remote sensing imagery was collected by the RapidEye constellation on June 2, July 17, July 27, August 10, August 25, and September 5. The RapidEye system consists of 5 identical satellites that were launched in 2008. The RapidEye sensors collect reflected radiation in 5 spectral bands from the visible blue (440-510 nm) to the near infrared (760-880 nm), including a unique red-edge band at 690-730 nm). The images are acquired at 12-bit precision with a ground sampling distance of 6.5 m (RapidEye AG 2010).

## Analysis Methods

The *in situ* data were averaged to the field level and then divided into 2 groups: one for calibrating the yield model and the other for an independent validation of its effectiveness.

The analyses were completed in 2 parallel procedures: one for NDVI-based estimation and the other for LAI-based estimation. Each procedure followed a 3-step process:

i. Establish the statistical relationship between crop yields and *in situ* measurements.
ii. Establish the statistical relationship between *in situ* and spaceborne measurements.
iii. Establish the statistical relationship between crop yields and spaceborne measurements.

At each step, the coefficient of determination was calculated though linear correlation to estimate the amount of yield variability that could be accounted for with the NDVI or LAI data. The statistical significance of the results was assessed using a *t*-test.

## Results and Discussion

A strong correlation ($r^2 = 0.7$; significant at the 95% level) was found between *in situ* LAI and the RapidEye vegetation index. When the calibrated model was applied to the validation data, the results were also found to be statistically significant ($r^2 = 0.7$; significant at the 95% level). However, consistent with other studies (Weiss and Baret 1999), it was found that high levels of pixel heterogeneity affected the LAI estimates. In addition, areas of high LAI values (2–4) had weaker correlations because of high solar attenuation by dense plant canopies (Carlson and Ripley 1997, Asrar et al. 1985). Additional results are still being assessed.

A major challenge to the analysis of the data was the reliability of the RapidEye imagery. No images were available from the critical growth period between June 2 and July 17. In addition the imagery acquired at peak growth stage (July 17 and July 27) had significant cloud contamination.

## Conclusions

The methods presented here address the potential of multispectral satellite imagery for estimating crop yield. Future work will include an assessment of non-linear modeling. The analyses will be further extended to calculate net primary productivity.

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# Impacts of sensor noise on land cover classifications: sensitivity analysis using simulated noise

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## Abstract

Land cover maps are typically derived through classification of remotely-sensed data, usually relying on a multispectral set of views from satellite-borne sensors. A number of corrections can be applied to improve the geometric and radiometric quality of the data. We have been assessing the importance of radiometric quality using a factorial design to assess the impacts of various levels of sensor noise, and spatial autocorrelation of that noise on classified land cover maps. We compare simulated noise-affected maps to a control with no noise addition. The objective is a sensitivity analysis to quantify the effects of noisy data on image classification, both on the overall accuracy statistics and the spatial configurations of error maps. We have tested a series of noise models, and our first results show that most classifications are relatively robust except in conditions of noise with high spatial autocorrelation. We are continuing to refine our noise models to better represent typical combinations of sensor and atmospheric conditions.

## Background and Relevance

Accurate land cover maps from classified multispectral images require high signal-to-noise ratios, which are affected by signal-dependent noise (Rangayyan *et al.*, 1998), atmospheric influences (Song *et al.*, 2001), and systematic sensor errors, such as striping (Pan and Chang, 1992; Torres and Infante, 2001). Much work has gone into attempts to understand and correct for these sources of noise, but there is very little research on quantifying the impact of these potential errors on classification of the data into land cover categories. Therefore, we aimed to study the stability of common classification regimes in the presence of a range of likely noise treatments. Initial experiments using this approach (Remmel and Mitchell, 2010) employed regression trees for the classification and only 4 classes, and found very little difference between treatments, likely due to the high thematic aggregation. We have moved to more detailed classes, and are examining alternative error models. This presentation demonstrates the first findings from this process. The full results of this analysis will guide methods selection for further land cover products, and justifications of the effort used to correct imagery for given applications.

## Methods and Data

We selected a boreal forest study site in north-western Ontario, centred around 418054 m N, 5958262 m E UTM zone 16. The choice was based on access to an existing land-cover classification along with the multi-spectral IKONOS imagery used to develop the classified map (Remmel and Perera 2009). We used a 1024x1024 pixel sub-scene for our work, which at 4m spatial resolution results in a 1678 ha area of boreal forest for our analysis. Land cover classes in the original product were distributed between Bedrock, Complete Burn, Partial Burn, Dense Conifer, Sparse Conifer, Alder Shrub Woodland and Low Shrub, Wetland, and Water.

Using training sites based on the original classification, we developed new classified maps, using supervised maximum-likelihood (ML) and sequential maximum *a posteriori* (SMAP) approaches. Mimicking the process used to produce the original map, we classified based on the IKONOS input bands (blue, green, red, near infra-red and panchromatic), plus a texture image based on the panchromatic band, targeting the same classes listed above. This lead to new versions of the land cover map, used as the reference data for the rest of the study. The purpose of the re-classification was to provide class signatures that could be used for all further classifications with noisy data.

Noise was generated across a spectrum of intensity and spatial autocorrelation using an isotropic conditionally autoregressive model (Cressie, 1993, algorithm presented in Remmel and Csillag, 2003). Outputs from the model were divided into seven categories of intensity, and autocorrelation corresponding to Moran's I ranging from 0 to 0.99999. The modelled noise was thresholded so that our treatments were based on frequency of pixels with noise, rather than the absolute levels. In other words, low noise images had a few relatively high noise values, whereas high noise images had greater frequency of noise pixels, covering a wider distribution of intensity.

The resulting images were scaled to correspond to between 1% and 6% error in each original band, and added to the original multi-spectral bands (blue, green, red and near-infrared, but not panchromatic) across 30 replicates, to provide 1470 alternative input images across the 49 treatments. New classified maps were generated for each realization, using the training generated above. Map comparisons were made using contingency tables and distributions of overall agreement were analyzed.

## Results

In the absence of spatial autocorrelation, overall agreement dropped small but statistically significant amounts with increasing frequency of noisy pixels (Figure 1). Agreements were consistently higher using SMAP classification: overall agreements under increasing noise went from over 89% to about 87% agreement using SMAP, and from about 82.5% to 79% agreement using ML.

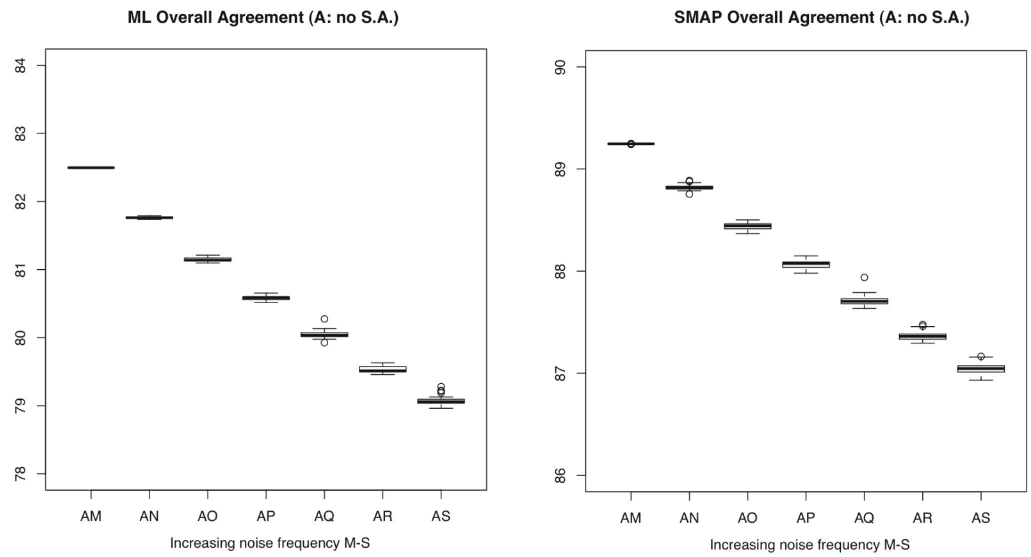


Figure 1 – Impact of noise frequency (treatment codes AM increasing through AS on the x-axis) on overall agreements between treatment land cover map and reference map with no spatial autocorrelation (treatment code A) in the error models.

Increasing spatial autocorrelation of noise increased the variance of agreement between realizations, overwhelming the effect of noise frequency at higher levels of autocorrelation. These results are summarized in Figures 2 and 3.

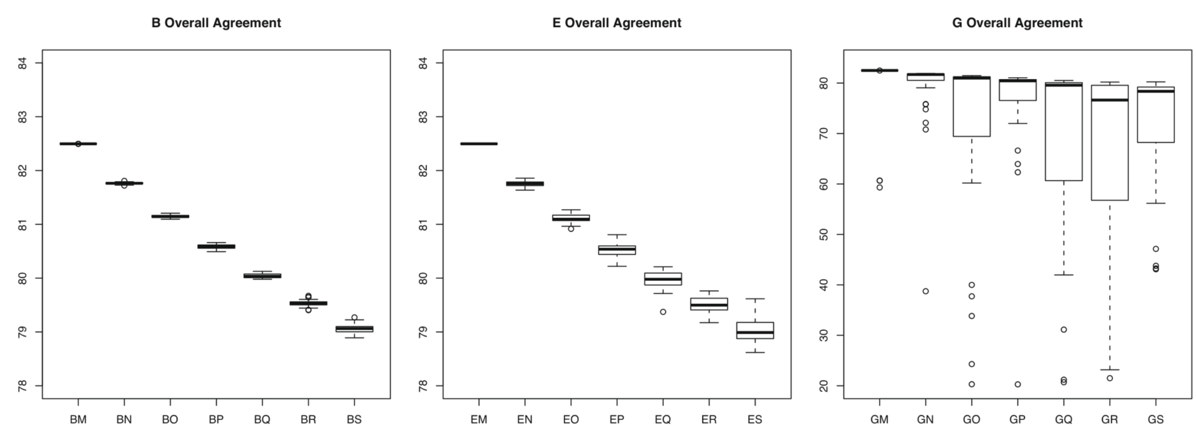


Figure 2 – Impact of noise frequency (x-axis treatment codes xM through xS, where x is the spatial autocorrelation treatment) on overall agreement between reference maps and error treatments with low (B), medium (E), and high (G) spatial autocorrelation, using maximum likelihood (**ML**) classifications. Note change in overall agreement (y) axis range in the right-most graph.

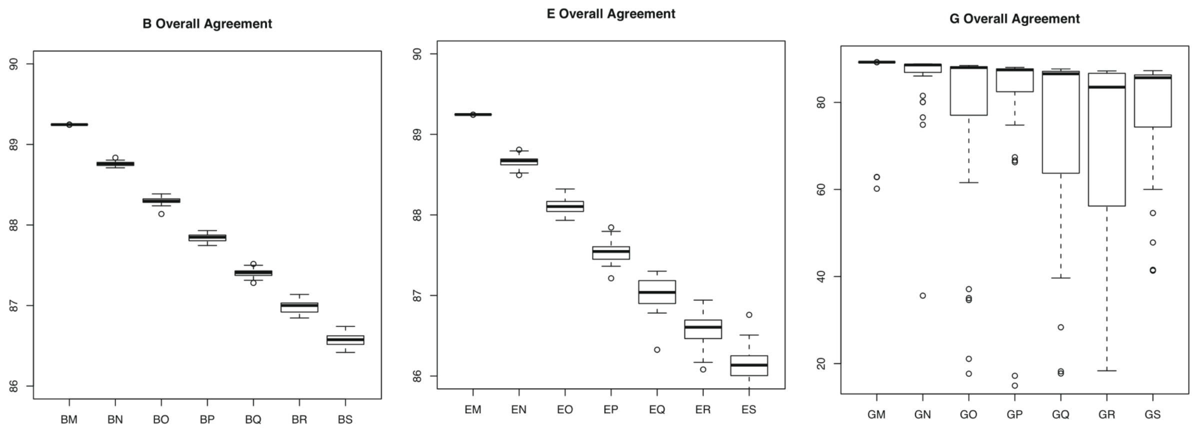


Figure 3 – Impact of noise frequency (x-axis treatment codes xM through xS, where x is the spatial autocorrelation treatment) on overall agreement between reference maps and error treatments with low (B), medium (E), and high (G) spatial autocorrelation, using sequential maximum *a posteriori* (**SMAP**) classifications. Note change in overall agreement (y) axis range in the right-most graph.

## Conclusions

As expected, at low levels of noise, the likelihood-based classification methods are fairly resistant to misclassification, even with classes that have high possibility of confusion. The SMAP classification algorithm performed better than maximum likelihood in all cases, remaining higher than the 85% agreement threshold commonly used in classification error assessments, in all but the highest spatial autocorrelation error treatment. At the highest levels of spatial autocorrelation of errors, classification accuracy dropped dramatically, likely due to threshold effects in the relationship between the error-infused multi-spectral bands and the texture of the unaffected panchromatic band.

We continue to research error properties of actual remote sensing platforms, and are working on new noise models with multiplicative rather than additive noise, and based on sensor characteristics rather than arbitrary distributions. We will combine these findings with results from atmospheric correction research to create the desired sensitivity analyses.

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# Ten Years of Geospatial Research for Alberta Grizzly Bear Conservation


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### Abstract

We provide a brief overview of ten years' worth of geospatial research in the FRIGBRP, including strategies, progress, lessons learned, and current activities. In particular, we will focus on latest geospatial products used to map the 228,000 km$^2$ of Alberta grizzly-bear range, and their transformation to habitat maps and grizzly-bear conservation areas.


## Background and Relevance

Contemporary strategies for to research and conservation of grizzly bears (*Ursus arctos*) rely strongly on a *spatial-information approach* to knowledge formulation that links animal data sets – observations related to grizzly bear location, abundance, health, and genetics, for example – to spatially explicit environmental variables derived from GIS and remote sensing. However, the approach depends in part on the availability of accurate, spatially-explicit information on vegetation, land cover, and other physical habitat elements, and is often limited by our capability to assemble such data layers over large, fast-changing landscapes. The Foothills Research Institute Grizzly Bear Research Program (FRIGBRP) has relied on remote sensing as its primary source of land and vegetation information since its inception in 1999. In this paper, we provide a brief overview of ten years' worth of geospatial research in the FRIGBRP, including strategies, progress, lessons learned, and current activities. In particular, we will focus on latest geospatial products used to map the 228,000 km$^2$ of Alberta grizzly-bear range, and their transformation to habitat maps and grizzly-bear conservation areas.

## Methods and Data

We used a combination of 3890 field plots, 30 Landsat TM and ETM+ satellite images, and MODIS scenes (MOD-13Q1 data products) to create wall-to-wall models of land cover, crown closure, tree-species composition, and phenology. The baseline mapping strategy begins with an image selection process designed to favour clean, cloud-free imagery from the summer growing season of the target year of interest. If no high-quality scenes were available for the target year of interest, then we used alternative summertime scenes from previous years in the archive. Once assembled, the base map was updated to the target year of interest by identifying change features – roads, well sites, cut blocks, mine expansion, urban development, and forest fires – that represent the bulk of disturbance events occurring on the landscape. We followed a design III approach (Thomas and Taylor, 1990) to RSF modeling to represent grizzly bear habitat selection, with available resources defined for each animal using a minimum convex polygon home range and habitat use defined from radio-telemetry locations (Manly et al., 2002). We modeled mortality risk mortality using the spatial patterns of 297 human-caused mortality (kill) locations from the Central Rockies Ecosystem (Benn and Herrero, 2002) and landscape characteristics at human-caused mortality locations compared to random and telemetry locations.

## Results and Summary

The major value of the geospatial products developed in this work lies in their capacity to characterize the spatial arrangement of key structural and phenological habitat over an enormous area of the province, at relatively high spatial and temporal detail and in a manner that is consistent across multiple management jurisdictions. Habitat selection and mortality models provided indices of attractive sink (sink-like habitats) and safe harbor (source-like habitats), and contributed to the identification of grizzly bear conservation areas in the province, following the Alberta Grizzly Bear Recovery Team (2008) guidelines. The research highlights the value of geospatial products in grizzly bear conservation, and provides a template for other wildlife-conservation priorities in western Canada.

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# Dealing with noise in multi-temporal NDVI datasets for the study of vegetation phenology: Is noise reduction always beneficial?

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## Abstract

The prevalent, limiting effects of noise on the application of remotely-sensed VI time series in the remote sensing of vegetation phenology is well-recognized. A multitude of noise-reduction approaches exist in the literature, but rarely are the benefits of such techniques in the study of vegetation growth and development ever questioned. We present a two-part statistical analysis examining when and where the application of noise-reduction algorithms to a multi-temporal NDVI dataset are beneficial. Both a root mean square error (RMSE) analysis and a phenological metric analysis were conducted, examining noise reduction under a variety of conditions. Results showed that although statistically significant benefit was seen under particular conditions, under many conditions it was not observed. The complex interplay of multiple factors (e.g. level of noise, biogeographical region) on the effects of noise reduction was also clearly demonstrated through statistical interaction effects. Our work raises questions regarding the wide-spread application of noise reduction in the remote sensing of vegetation phenology.

## Background and Relevance

Satellite remote sensing has become an important and widely-used tool in the study of vegetation phenology. Application of these datasets typically involves the per-pixel analysis of multi-temporal vegetation indices (VIs), which are frequently subject to high-frequency fluctuations (i.e. noise) caused by changing atmospheric conditions and varying sun-sensor-surface geometries (Duggin, 1985). A broad range of time series noise-reduction strategies are found in the literature, (e.g. Moody & Johnson, 2001; Van Dijk, Callis, Sakamoto, and Decker, 1987; Beck, Atzberger, Hogda, Johansen, & Skidmore, 2007; Sellers et al., 1994). However, rarely are the benefits of applying such techniques to remotely-sensed VI datasets questioned. In light of this, we set out to enhance current understandings of noise reduction in the remote sensing of vegetation phenology, by conducting a rigorous statistical analysis designed to: 1) investigate whether a series of noise-reduction strategies is indeed beneficial to maintaining signal integrity, and to the subsequent extraction of phenological metrics; 2) examine the circumstances under which benefits may or may not be observed; and 3) explore the factors that might influence this benefit (e.g. annual variations, noise-reduction strategy).

## Methods and Data

To avoid the large constraints imposed on effective evaluation by the difficulties of acquiring suitable reference data for satellite datasets, we adopted the analytical framework described by Hird and McDermid (2009). Their model environment employs simulated, idealized NDVI time series containing varying levels of introduced noise to test the benefit of noise reduction. The data consisted of a multi-temporal 16-day 250 m NDVI dataset collected by Terra's MODIS sensor, and covering the front ranges of the Rocky Mountains in west-central Alberta, Canada, for 2003 through 2005. Six common noise-reduction techniques were used, on the basis of their successful applications within the literature, and accessibility to researchers. These were: Beck et al.'s (2006) double logistic function-fitting, Jönsson and Eklundh's (2002) asymmetric Gaussian function-fitting, Chen et al.'s (2004) modified Savitzky-Golay filter, Ma and Veroustraete's (2006) MVI filter, Velleman's (1980) 4253H, Twice filter, and Filipova-Racheva and Hall-Beyer's (2000) autoregressive combination ARMD3-ARMA5 filter. Our analysis comprised two components: 1) root mean square error (RMSE) calculations, to provide a measure of mean difference (Willmott, 1982) between noise-reduced and the original, ideal NDVI time series; and 2) phenological metric calculations, to examine the effects of noise reduction on these estimations. We focused on a start of spring growing season metric (SOS) and a maximum NDVI metric (maxNDVI), as these are two of the most widely-used metrics found in the literature (e.g. Pettorelli et al., 2005; Schwartz, Reed, & White, 2002). Statistical analysis of the RMSE and metric results involved a series of two-way repeated measure ANOVAs (analysis of variance), as well as simple effects pair-wise comparisons involving Bonferroni correction – to account for multiple combinations effects. Noise-reduction approach, including the no noise reduction option, provided our within-subject factor, , while between-subject factors included level of noise, biogeographical region, and (for metric results only) year. Significance was observed for the 0.05 level.

## Results

Two, two-way repeated measures ANOVAs of RMSE values showed that the selection of a noise-reduction approach was a significant within-subject effect ($F = 12.404$, $p < 0.001$; $F = 7.471$, $p < 0.001$). Biogeographical region did not have a significant effect on RSME ($F = 1.380$, $p = 0.299$), but an interaction effect between biogeographical region and noise-reduction technique was observed ($F = 3.611$, $p < 0.001$). The amount of noise (e.g. 10%, 40%, or 70%) did produce a significant effect on RMSE results ($F = 7.724$, $p = 0.005$). No interaction effect was observed between level of noise and noise-reduction technique ($F = 1.551$, $p = 0.121$). Main effects testing showed that each noise-reduction technique provided a significantly better RSME than applying no noise reduction, indicating that it was indeed beneficial overall.

Three, two-way repeated measures ANOVAs analyzing the effects of noise reduction with biogeographical region, level of noise, and year on each set of metric calculations revealed that noise-reduction showed a significant effect on both SOS values ($F = 14.995$, $p =< 0.001$; $F = 14.310$, $p < 0.001$ ; $F = 13.170$, $p < 0.001$), and maxNDVI ($F = 75.567$, $p < 0.001$; $F = 84.797$, $p < 0.001$; $F = 69.306$, $p < 0.001$). Biogeographical region was a statistically significant factor in SOS estimations ($F = 3.580$, $p = 0.008$), and this effect varied with noise-reduction technique. In addition, the effect of noise-reduction technique varied significantly with biogeographical region and percent noise, as demonstrated by the interaction effects. Closer examination in the form of simple effects pair-wise comparisons showed that significant improvement in SOS estimates by the application of noise reduction was only seen in the Alpine time series, and only at the 70% noise level. Neither level of noise, nor annual variation, was a significant factor on its own.

With regard to maxNDVI. biogeographical region also produced a significant effect, but again, neither level of noise, nor year, had a significant effect on this metric. However, all three of these factors did demonstrate significant interaction effects with noise-reduction approach ($F = 2.343$, $p < 0.001$; $F = 8.004$, $p < 0.001$; $F = 1.842$, $p = 0.041$)). Simple effects testing showed more significant effects from the application of noise reduction on the extraction of maxNDVI than for SOS. However, the data show that these were significant degradations (i.e. lowering) of maxNDVI metric values, rather than improvements. In other words, in the majority of cases, noise reduction produced a less accurate result when compared to a lack of noise reduction.

## Conclusions

We found that while NDVI time series noise reduction did offer a statistically significant benefit both in the general removal of spurious, high-frequency fluctuations in the data, and in the subsequent extraction of more accurate phenological metrics, this benefit occurred much less often than might be assumed given the current plethora of noise-reduction strategies. We suggest that noise reduction is not universally beneficial, and can, in fact, be detrimental in some situations. In particular, careful consideration must be taken when the extraction of phenological is the ultimate goal.

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